Astrophysical Polarimetry in the Time-Domain Era

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Politecnico di Milano - Polo territoriale di Lecco

Book of Abstracts

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Spectropolarimetric Mapping of the 3D Wind Structures of WR+O Binaries

Massive stars in WR+O systems are in a unique phase of their evolution; their strong and dense winds are thought to significantly affect their future evolution into GRBs, SNe, and ultimately inspiraling compact objects. Our team is carrying out an observational spectropolarimetric study of southern, WR+O star, colliding wind binaries to characterize their shock and wind structures using the RSS instrument on SALT. I will present our preliminary analysis of systems for which we have good orbital coverage. With these observations, we are able to fully map out their 3D wind structures. In particular, I will focus on how their polarized line profiles vary with phase and how information derived from those line profiles relates to wind signatures seen at other wavelengths.

Polarization and surveys, etc. / **65**

Magnetic Polarization in the Dense Interstellar Medium

Our understanding of star formation has been revolutionized by the insight that star-forming cores and hubs are embedded in complex filamentary networks. Fragmentation as well as level of star formation within these filaments differ greatly. Still, the exact role of filaments in star formation remains unclear. In particular, magnetic fields might play an important role, as indicated by well-ordered polarized dust emission that imply strong magnetic fields on large scales probed by the Planck mission. Testing whether star formation in our Galaxy proceeds in the strong or the weak magnetic field regime however requires more than an order of magnitude resolution than was possible with Planck. Far-infrared polarimetry using the HAWC+ instrument on SOFIA has become a powerful tool to image the magnetic field structure on much finer scales relevant for star formation. SIMPLIFI is a SOFIA HAWC+ Legacy program that is carrying out a systematic high resolution large-scale study of the magnetic polarization of filaments. In this talk, I will provide a brief review of insights gained from polarimetry in the dense ISM with recent facilities and present some of the first results of SIMPLIFI.

Polarization and supernovae, novae and kilonovae / **70**

Probing the Shapes of Thermonuclear Explosions through Early to Late-Time Polarimetry

Thanks to the rapid detections of supernovae by modern high-cadence wide-field transient surveys, the geometry properties of supernovae can be probed at unprecedented phases early as the first few days after the explosion. The geometry through the outer to inner layers can be inferred observationally through tomographic dissection, for example, with time-resolved spectropolarimetry that is sensitive to three-dimensional geometrical and chemical structures. I will provide a brief overview of the lessons we learned from the polarimetric observations of thermonuclear supernovae, as well as the main challenges and potential future efforts that need to be considered to better understand thermonuclear explosions.

Polarization and AGN and blazars / **71**

X-ray polarimetry of radio quiet AGN in the IXPE era

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X-ray polarimetry is expected to contribute to our understanding
of Radio Quiet AGN in at least two ways: by constraining the geometry of the hot corona in unobscured sources, thereby providing clues to its nature; by measuring the geometrical parameters of circumnuclear matter, especially in heavily obscured sources.

In this talk, first IXPE (Imaging X-ray Polarimetry Explorer) results on Radio Quiet AGN will be presented and discussed.

Polarization and gamma-ray bursts / **76**

Gamma-Ray Burst Prompt Emission Polarimetry: an Overview

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One of the main targets of astrophysical X- and gamma-ray polarimetry has been the prompt emission of Gamma-Ray Bursts (GRBs). This polarization is theorized to hold a wealth of information on the nature of these extreme events prompting a range of attempts at measuring it over the last 20 years. Initial attempts to measure it using non-dedicated instruments, such as BATSE, RHESSI and INTEGRAL SPI and IBIS, were followed in the last decade by the first attempts using instrumentation fully dedicated to this purpose like GAP and POLAR. Although close to 50 GRB polarization measurements have been reported thus far and great progress has been made regarding instrumentation and analysis techniques, no clear picture of the GRB prompt polarization properties exists to date. This is due, in part, to the extreme difficulties in performing such measurements as well as potentially due to the complex nature of the polarization. During this talk I will present the various measurements performed over the last two decades along with the various encountered issues and problems. In addition, I will present the progress made in recent years within the field which can lead to the first conclusive measurements to be performed during the coming decade.

Polarization and gamma-ray bursts / **77**

Measuring Gamma-Ray Transients Polarization with the POLAR-2 Compton polarimeter

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Gamma-Ray Bursts (GRBs) are among the most powerful and violent events in the Universe. Despite half a century of observations of these transient sources, many open questions remain about their nature and the physical emission mechanisms at play. Polarization measurements of the GRB prompt emission have long been theorized to be able to answer most of these questions.

With the aim of characterizing the polarization of these prompt emissions, a compact Gamma-Ray polarimeter has been sent to space as part of the Tiangong-2 Chinese space lab for 6 months of operations starting September 2016. Developed by a Swiss, Chinese, and Polish collaboration, the

instrument detected 55 GRBs as well as several pulsars. Time integrated polarization analysis of the POLAR GRB catalog shown that the prompt emission is lowly polarized or fully unpolarized. However, time resolved analysis depicted strong hints of an evolving polarization angle within single pulses, washing out the polarization degree in time integrated analyses.

Based on the success of the POLAR mission, a larger scale instrument, approved for launch to the China Space Station (CSS) in 2024, is currently developed by a Swiss, Chinese, Polish, and German collaboration. Thanks to its large sensitivity, POLAR-2 will produce polarization measurements of at least 50 GRBs per year with a precision equal or higher than the best results published by POLAR, allowing for good quality time and energy resolved analysis. Furthermore, thanks to its large effective area which exceeds 2000 cm^2 at 100 keV, POLAR-2 will be able to observe faint GRBs such as 170817A and will be capable of sending alerts of such transients, including localization information to ground within seconds to minutes. POLAR-2 thereby not only aims to make the prompt polarization a standard observable, it will additionally play an important role in multi-messenger observations.

Polarization and gamma-ray bursts / **79**

Time-resolved and Time-integrated Spectro-polarimetry Predictions of Gamma Ray Bursts

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A major question surrounding the study of Gamma Ray Bursts (GRBs) is the origin of the high energy prompt emission detected in the first few tens of seconds of the event. This question can be answered with time-resolved and time-integrated polarimetry observations across the electromagnetic spectrum. Recently, we used the MCRaT radiative transfer code to make robust optical to gamma-ray spectropolarimetry predictions for GRB prompt emission. The MCRaT code follows photons as they scatter in a hydrodynamically simulated GRB jet, taking cyclo-synchrotron emission and absorption processes and the full Klein-Nishina cross section into account. Using these simulations we present our constructed mock observations and associated correlations which can then be compared against future observations. We also show how our simulations allow us to infer GRB jet properties from future detected spectropolarimetric measurements, something that was not possible before. This study shows the importance and the utility of conducting global radiative transfer simulations of realistic GRB jet structures.

Polarization and AGN and blazars / **80**

Jets, Blobs, and Circular Polarization: Using PLUTO & RADMC-3D to Model Time Domain Variability in Blazars

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Blazars are an extreme subclass of active galactic nuclei (AGN), in which an accreting supermassive black hole launches a powerful relativistic jet of magnetized plasma that is closely aligned to our line-of-sight. Blazar jets: (i) shine across the entire electromagnetic spectrum (from low-frequency radio waves to high-energy gamma-rays), (ii) exhibit dramatic flares (on time scales ranging from days to minutes), and (iii) dominate the high-energy extragalactic sky. Very long baseline interferometric (VLBI) arrays (such as phased ALMA & The Event Horizon Telescope) are capable of imaging

the polarized synchrotron emission emanating from the innermost regions of relativistic blazar jets with unprecedented angular resolution and sensitivity. In particular, the linearly and circularly polarized synchrotron emission from blazar jets carry imprints of both the strength and orientation of the collimating magnetic field as well as the plasma content of the jet environment. In parallel to these advances in VLBI imaging, modern computational resources now support the execution of increasingly sophisticated 3D numerical jet simulations, from shock-in-jet/turbulence models, to relativistic magneto-hydrodynamic (RMHD) and particle-in-cell (PIC) plasma simulations. In this talk, I will present a new suite of relativistic jet simulations which study the variability in the circular polarization produced by a blob of relativistic plasma passing through a standing recollimation shock within a jet. This is accomplished through the use of the PLUTO code in concert with polarized radiative transfer ray-tracing calculations computed using the RADMC-3D code. The physical implications of this polarization variability will be discussed and direct comparisons will be made to full-Stokes light curves obtained with the Polarimetric Monitoring of AGN at mm-Wavelengths (POLAMI) Program.

Polarization and X-ray binaries / **84**

Black hole spin–orbit misalignment in the X-ray binary MAXI J1820+070

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The observational signatures of black holes in X-ray binary systems depend on their masses, spins, accretion rate, and the misalignment angle between the black hole spin and the orbital angular momentum. We present optical polarimetric observations of the black hole X-ray binary MAXI J1820+070 with high-precision polarimeter DIPol-UF at the Nordic Optical Telescope, from which we constrain the position angle of the binary orbital axis. Combining this with previous determinations of the relativistic jet orientation, which traces the black hole spin, and the inclination of the orbit, we determine a lower limit of 40 deg on the black hole spin-orbital angular momentum misalignment angle. The misalignment must originate from either the binary evolution or black hole formation stages. If other X-ray binaries have similarly large misalignments, these would bias measurements of black hole masses and spins from X-ray observations. A high misalignment adds complexity to the models of the X-ray and optical quasi-periodic oscillations observed from black hole X-ray binaries in their hard state. We will also discuss the prospect of measuring misalignment using the polarimetric data from the Imaging X-ray Polarimetry Explorer.

Polarization and AGN and blazars / **85**

Mapping the 3D magnetic field of AGN jets through spectropolarimetry study

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Here, I overview one of the available techniques for the analysis of broad-band spectropolarimetric data, the Stokes QU-fitting. Since broad-band receivers have been installed at most radio facilities, the collection of radio data, both the total intensity and the linear polarization, is revealing interesting features in their spectra. The polarized light, and therefore its properties, i.e. the fractional polarization and the polarized angle, are now finally well sampled in wide wavelength ranges. The new complex behaviors revealed by the data can be studied using the Stokes QU-fitting, which consists of modeling the Stokes parameters Q and U using wavelength-dependent analytical models, available in the literature. This technique provides a very good diagnostic of the nature and structure of the magnetized plasma, with the possibility to identify complex structures, internal or external, of

the source of study. A summary of the available and most used models describing the polarization behavior, is presented. Moreover, some of the most significant observational works which use this technique are also summarized.

Polarization and supernovae, novae and kilonovae / 86

Spectropolarimetry of core collapse supernovae: 35 years and counting

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I will give a brief of overview of what spectropolarimetry has taught us about core collapse supernovae and stripped envelope supernovae, as well as highlight what I see as being the main challenges/issues that now need to be addressed to take us to the next level.

Polarization and stars / 87

Optical polarimetry of cataclysmic variables

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This talk presents a revision of the literature relative to optical polarimetric measurements of cataclysmic variables (CVs). It is briefly introduced this kind of objects and the historical relevance of the detection of circular polarization in magnetic CVs. It is then discussed how polarization can be used to estimate important properties of those objects as the white-dwarf magnetic field, mass accretion rate, and white-dwarf mass. Some available instruments for this research are enumerated.

Polarization and stars / 88

Modeling Polarimetric Variability from Thomson Scattering in Colliding Wind Binaries

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Massive star binaries are important for measuring stellar masses and stellar wind mass-loss rates. One obstacle is inferring viewing inclination and extracting information about the colliding wind interaction (CWI) region. Polarimetric variability from electron scattering in the winds and CWIs of massive stars provides information about system inclination and the geometry of the colliding wind bow shock. Using the semi-analytic solution for bow shock properties from Canto et al (1996), we calculate the polarimetric properties of CWI systems. We conduct an parameter study to explore scenarios involving nearly equal winds (e.g., O+O), strongly unequal winds (e.g., WR+OB), and wavelength-dependent effects (UV, optical, and IR).

Poster Session / 89

Design and Development of Spectro-polarimeters for PRL Mt. Abu Telescopes

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Physical Research Laboratory (PRL), India, has been operating a 1.2m optical-near infrared (NIR) telescope at Gurushikhar peak, Mt. Abu, India, since the mid-1990s and is establishing another 2.5m telescope at the same site, which will be operational by the end of 2022. Optical and NIR spectroscopy studies of transients (novae, supernovae etc.) have been a forte of the observatory's science programs. The larger aperture of the upcoming 2.5m telescope has opened an exciting window to probe such events (and related objects) with the technique of spectro-polarimetry as well. We have been designing a multi-mode, two-channel instrument named - Mt. Abu Faint Object Spectrograph and Camera-Echelle Polarimeter (M-FOSC-EP) for the 2.5m telescope. M-FOSC-EP would provide the capabilities of intermediate resolution spectro-polarimetry (resolutions ~ 15000), grism based low-resolution spectroscopy (R~700-800), and seeing limited imaging in the visible wavelength range (3900-9900 angstroms). The optical design of the instrument has been completed recently, and currently, the mechanical design is being optimized. Another instrument, named - ProtoPol, is also being developed using off-the-shelf optical components as a precursor prototype of the M-FOSC-EP. ProtoPol can be used on the existing 1.2m telescope as well as on the upcoming 2.5m telescope. M-FOSC-EP and ProtoPol offer novel designs and approach to develop the capabilities of spectro-polarimetry on small aperture telescopes. Here we shall present the designs and the simulated performance of these instruments.

Polarization and TDE / 90

Polarized light from tidal disruption events: observations and modelling

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Polarimetric observations of tidal disruption events (TDEs) have been very scarce until now, with most measurements conducted for relativistic (jetted), or otherwise extraordinary, TDEs. I will present the first results from a program at the VLT, focusing on spectral polarimetry of optical (thermal) TDEs. After appropriate corrections, the continuum polarization appears constant with wavelength. The core of broad emission lines are depolarized, but polarization peaks are sometimes present at the wings of the lines. Our observations suggest that the origin of polarization in optical TDEs is electron scattering. Contribution from synchrotron is ruled out, while dust polarization is unlikely. Polarization decreases with time and the system becomes closer to axial symmetry, which we suggest is evidence for rapid disk formation. We model the polarization properties for a unification model for TDEs, based on a super-Eddington accretion disk and the radiative transfer code POSSIS, and find polarization levels that are consistent with the observations. The same methodology is also applied to the collision-induced outflow model. Spectral polarimetry of TDEs combined with adequate modelling can therefore shed light on the nature of optical emission from these transients.

Polarization and supernovae, novae and kilonovae / 91

Shedding light on the geometry of neutron star mergers with kilonova polarimetry

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The detection of an electromagnetic counterpart to the gravitational-wave source GW170817 marked year zero of the multi-messenger gravitational-wave era. This event was generated by the merger of two neutron stars and gave rise to an electromagnetic transient, dubbed a "kilonova", which was intensively monitored with all the main ground-based and space-borne facilities. The general agreement between existing models and data is remarkable. However, critical parameters like the inclination of the system and the distribution and composition of the ejecta components are still uncertain despite their being crucial to e.g. calculate kilonova rates, compare yields to cosmic abundances and estimate the Hubble constant. In this talk, I will show how linear polarimetry can unveil some of these properties, which are not easily constrained through the analysis of light curves and spectra alone. I will focus on a detailed analysis of the linear polarization expected from kilonovae resulting from both binary neutron star and neutron star - black hole mergers. I will highlight how the detection of a signal in future events will place constraints on the system inclination, unambiguously reveal the ejecta composition and unveil its spatial and angular distribution.

Polarization and supernovae, novae and kilonovae / 92

Are peculiar extinction and polarization properties along the sightlines toward Type Ia Supernovae produced by circumstellar or interstellar matter?

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Polarimetry offers an independent method to the study inter/circum-stellar dust properties by observing the continuum polarization. Some highly reddened Type Ia Supernovae (SNe Ia) display peculiar extinction curves with low R_V values and polarization curves steeply rising towards blue wavelengths, different from typical Serkowski-like polarization curves observed towards normal Milky Way stars.

We acquired imaging polarimetry of a statistical sample of 68 SNe Ia in host galaxies of different morphological types, and found that the source of the peculiar polarization curves steeply rising towards blue wavelengths (and the peculiar extinction curves with low R_V values) observed towards some reddened SNe Ia is likely the result of interstellar material as opposed to circumstellar material. Thus, the peculiar polarization and extinction properties observed toward some SNe Ia may be explained by the radiative torque disruption mechanism induced by the SN or the interstellar radiation field (Chu et al. 2022).

Polarization and AGN and blazars / 93

Blazars in the discovery era of X-ray polarimetry

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High-energy polarization is an important probe of emission processes in astrophysical systems. This is particularly true for blazars where it allows us to investigate the physical conditions experienced by the most energetic particles. Until now, polarization observations have been limited to the radio-to-optical range. However, the X-ray polarization window is finally open with the recently launched Imaging X-ray Polarimetry Explorer – IXPE, offering radically new ways of studying particle acceleration and high-energy emission processes in relativistic jets. I will discuss the multiwavelength polarization observations and first results from the first year of IXPE-blazar observations. Our results demonstrate the importance of X-ray polarization, and IXPE, in understanding high-energy processes in the Universe.

Polarization and AGN and blazars / 94

Multi-wavelength polarization signatures as a probe for blazar flaring mechanism

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Blazars are among the most powerful cosmic particle accelerators. They exhibit highly variable emission across the entire electromagnetic spectrum. It is often believed that the blazar flares are driven by dissipating magnetic energy in the blazar jet. Current theories suggest that both turbulence and magnetic reconnection can lead to blazar flares. This talk aims to understand the time-dependent multi-wavelength polarization signatures from magnetic reconnection and turbulence in the blazar flaring region. We combine particle-in-cell and polarized radiation transfer simulations to study temporal behaviors of multi-wavelength radiation and polarization signatures under first principles. Our results suggest that simultaneous optical and X-ray polarization evolution can distinguish turbulence and magnetic reconnection for high-frequency-peaked BL Lac objects. Specifically, reconnection predicts flashes of highly polarized emission in the X-ray band without optical counterpart, while turbulence generally predicts similar optical and X-ray polarization.

Polarization and supernovae, novae and kilonovae / 95

Hydrogen-poor superluminous supernova with aspherical circumstellar material

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Superluminous supernovae (SLSNe) are a fascinating population of stellar explosions. They are too luminous ($M < -21$) to be powered by the decay of radioactive ^{56}Ni, the canonical power source of normal Type Ia and Ib/c SNe, but numerous studies based mostly on conventional photometry and spectroscopy have not yet been conclusive on the nature of the physical mechanism. Here I show that the spectroscopic and polarimetric properties of the most nearby hydrogen-poor superluminous supernova (SLSN-I), SN2018bsz at $z = 0.027$, are highly unusual for its class. While its spectroscopic evolution closely resembles SLSNe-I, the multi-component Hα profile appearing at ~ 25 d post-peak is the most atypical. The Hα is at first characterised by two emission components, one at $\sim +3000$ km/s and a second at ~ -7500 km/s, with a third, near-zero velocity component appearing after a delay. Spectropolarimetry obtained before (10.2 d) and after (38.4 d) the appearance of the H lines show a large shift on the Stokes Q - U plane consistent with SN2018bsz undergoing

radical changes in its projected geometry. Assuming the SN is almost unpolarised at 10.2 d, the continuum polarisation at 38.4 d reaches $P \sim 1.8\%$ implying an aspherical configuration. The observed evolution of SN2018bsz can be explained by a disk-like circumstellar material (CSM) with several emitting regions. After the SN explosion the CSM is quickly overtaken by the ejecta, but as the photosphere starts to recede, the different CSM regions re-emerge producing the peculiar line profiles. The emerging CSM also affects the shape of the photosphere explaining the drastic change in the polarisation properties. The presence of CSM has been inferred previously for other SLSNe-I, both directly and indirectly. However, it is not clear if the rare properties of SN2018bsz can be generalised for SLSNe-I, for example in the context of pulsational pair instability of the progenitor star, or if they are the result of an uncommon evolutionary path possibly involving a binary companion.

Polarization and stars / **96**

Time-resolved UV Circular Polarimetry of Massive Star Magnetospheres

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Massive stars are characterized by their intense luminosities and powerful, radiatively driven stellar winds. About 7% of massive stars also host strong (~1 kG), global magnetic fields, with stable, nearly dipolar magnetic topologies. These fields channel the stellar wind into a complex magnetosphere which has a significant impact on the star's evolution. It is therefore critical to measure these fields in order to determine how magnetic massive stars live, die, and influence their environment. This is typically accomplished with optical spectropolarimetry, by measuring the circular polarization caused by Zeeman splitting in optical photospheric lines. Additionally, the amplitude of the circular polarization (Stokes V) signatures is modulated with the stellar rotation period, as the observer's view of the magnetosphere changes. We explore here the possibility of detecting Stokes V signatures in the wind-sensitive UV resonance lines formed in magnetically confined winds. High-resolution UV spectropolarimetry can provide a technique for direct measurement of the field in the magnetosphere, which to date has only been estimated from theoretical calculations. We use the "UV-ADM code"to calculate synthetic Stokes V signatures at multiple viewing angles of the magnetosphere, to trace the rotational modulation and estimate the field strength. Our parameter study provides important observational constraints for the next generation of high-sensitivity, spaceborne UV spectropolarimeters, such as the Polstar mission.

Polarization and X-ray binaries / **97**

Low mass X-ray binaries: a polarimetric view

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Low mass X-ray binaries are binary systems hosting a compact object (a stellar mass black hole or a neutron star) which accretes mass from a low-mass companion star through an accretion disc.
These systems are perfect laboratories to study accretion mechanisms, and how these are coupled with ejections in the form of jets and/or winds. Optical and near-infrared (NIR) observations are of great importance, since at these frequencies, the companion star, accretion disc, the jet, the hot spot, the accretion disc wind and the hot accretion flow could be detected.
Carefully modeling the broad band spectral energy distribution of these systems can reveal sources

of emission such as the disc and jet, but sometimes this is insufficient to disentangle all the components involved in the emission. Spectroscopic observations are an important tool in order to unambiguously detect the presence of discs or winds, thanks to the observation of specific features in the spectrum, like double-peaked emission lines and P-Cygni profiles. A very powerful tool is also offered by polarimetric observations, which, especially if combined with photometry or spectroscopy, can help to unveil unambiguously what physical processes are at play in the system, and can give important information about the geometry of the source.
Only a few physical processes are capable of producing polarized radiation in X-ray binaries. Jets emit synchrotron radiation, that is known to be intrinsically linearly polarized. Their synchrotron spectra are optically thick from the radio up to the synchrotron break frequency, which typically falls in the infrared when compact jets are produced in the hard state. Above this frequency, the spectrum turns optically thin. The polarization level is therefore expected to be high (up to tens of %) in the near infrared, depending on the level of ordering of the magnetic field lines in the jet. Observations have shown that this ordering is however quite low in the majority of cases, near the jet base. At optical wavelengths, despite the spectrum of the jet being optically thin, the expected level of polarization due to the jet will be low (a few per cent), because the jet contribution is low compared to other sources of emission, such as the accretion disc.
A few per cent linear polarization in the optical could also arise from Thomson scattering with free electrons in the accretion disc; in this case the polarization spectrum will typically rise towards higher frequencies. In addition, a possible variability of the polarization level with the orbital phase of the system can be observed. Similarly, scattering of the accretion disk's radiation in the hot accretion flow located close to the inner radius of the disk can give rise to linear polarization.
In this talk I will present a review of the most recent and significant polarimetric measurements of Low Mass X-ray binaries. I will first focus on the polarization measurements aimed at detecting the emission of jets, showing how these can be crucial to probe the accretion/ejection coupling scenario proposed for these sources. I will also review how polarimetric observations can give important information on the geometry of the systems, and I will show how the contribution of jets and hot flows to the emission of X-ray binaries can be constrained thanks to polarimetric observations.

Polarization and gamma-ray bursts / **98**

GRB 080928 AFTERGLOW POLARISATION ANALYSIS AND GAMMA-RAY BURSTS SPECTRO-POLARIMETRY

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In the context of modern astrophysics, transient phenomena are among the most fascinating and challenging to observe and analyse, usually arising from physically extreme conditions. Gamma-ray bursts (GRBs), the most energetic phenomena in the whole Universe, fall into this category, being produced after the collapse of a massive star or a compact binary merger. Their main emission, lasting from a fraction to hundreds of seconds, peaks in the gamma-rays and it is followed by an afterglow, covering the whole electromagnetic spectrum at different timescales. Despite several years of observations and the large number of GRBs analysed to date, a unique, general picture describing GRBs physics is still missing: further observations and additional, independent techniques are needed to reconcile observations with theoretical models and predictions. Polarimetry constitutes a really powerful tool since it allows us to investigate some features of the source that are difficult to determine with different techniques, such as the geometry of the emitting region and the local magnetic field configuration. Time-resolved polarimetric analysis of GRB afterglows would allow us to compare observed light curves and polarisation curves with theoretical expectations, possibly inferring some features of the burst emitting region and of the physics behind the event.
A not so diffused - yet extremely efficient - technique is spectro-polarimetry, which can allow us to investigate the spectral dependence of the polarised radiation and to identify possible contributions given to the total polarisation by different sources. Indeed, the total detected polarisation could be the combination of intrinsically-polarised radiation emitted from the burst and interstellar polarisation induced by the dust aligned along the line of sight, both in the host galaxy and in the Milky Way. Spectro-polarimetric analysis can tell us if the observed polarisation is due to a standard afterglow (i.e. constant behaviour with lambda) or if it comes from a dominant dust-induced contribution,

which is wavelength dependent. However, despite its importance in this context, only a handful of bursts detected by space telescopes were accompanied by ground-based spectro-polarimetric follow-up to date.
In the talk I will present (spectro-)polarimetric analysis of GRB 080928, an event not yet properly analysed, for which multi-epoch polarimetric observations were obtained, both in the imaging polarimetry and spectro-polarimetry modes. The analysis revealed the detection of a polarisation degree $P \sim 4\%$ after 1.70 days from the trigger at 4σ confidence level, and the comparison with theoretical models suggested the presence of a homogenous jet observed inside the cone. More in general, I will discuss the role of spectro-polarimetry in GRBs afterglow analysis, also showing how it was applied to the other very few bursts analysed with this technique, i.e. GRB 020813, GRB 021004, GRB 030329, GRB 191221B.

Polarization and surveys, etc. / **99**

Everything Everywhere All At Once: Widefield Broadband Time-Domain Spectropolarimetry of the Radio Sky

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Radio astronomy has begun to explore an exciting frontier, in which we can not only probe polarimetry in the time domain, but are doing so across enormous fields of view and with extremely broad instantaneous wavelength coverage. This has led to the discovery of new populations of magnetised objects that are extremely rare or that have very unusual properties. I will present some of the highlights from the new radio telescopes that offer these powerful capabilities, with particular focus on the wide-field polarisation capabilities of the Australian Square Kilometre Array Pathfinder (ASKAP) and on the enormous number of fast radio bursts detected by the Canadian Hydrogen Intensity Mapping Experiment (CHIME).

Poster Session / **100**

Study of the alignment between local magnetic field and galactic plane in low latitude molecular clouds

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The formation of stars in our galaxy is a result of collapse and fragmentation in giant molecular clouds. Bok globules and Lynd's clouds, being the simplest, isolated molecular clouds (dark clouds) in our galaxy, are considered as the ideal sites for low-mass star formation. In this work, we study the magnetic field morphology traced via optical polarimetry of selected Bok globules and Lynd's clouds situated at low latitude within the galactic latitude (⊠) range of −10 degrees to 10 degrees. The polarimetric observations of three clouds CB27, CB24 and CB188, were conducted using the 104-cm Sampurnanand Telescope (ST) located at ARIES, Manora Peak, Nainital, India, during 22-23

Dec. 2017 and 8th May 2019. The results obtained from the observed data are combined with 14 more low latitude clouds (viz., CB3, CB4, CB17, CB25, CB26, CB34, CB39, CB56, CB60, CB69, CB130, CB246, L1014, and L1415) available in literature. From the polarimetric analysis of 17 clouds, we find that the alignment between the envelope magnetic field and galactic plane of the low latitude clouds varies with their galactic position (⊠, b). We also observe a strong correlation between the longitude and the offset between the orientation of envelope magnetic field and galactic plane. We have also made use of the stellar polarization data available in the Heiles catalog (Heiles 2000) to observe the consistency of our results.

Polarization and AGN and blazars / **101**

Prospects for multi-wavelength polarimetry of blazars

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This talks provides a review of prospects for multi-wavelength polarimetry of blazars. This includes inferences from optical spectropolarimetry as well as high-energy polarimetry, with special emphasis on first results from and expectations for IXPE.

Polarization and neutron stars and pulsars / **102**

X/γ Ray Polarimetry of the Crab pulsar/nebula Observed by POLAR and IXPE

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The X/γ ray polarization properties of the Crab pulsar and nebula are widely recognized as a unique probe into their emission models. Several missions have shown evidence of polarized emission from the Crab but all have been limited in statistics. Dedicated instruments and new measurements are therefore required.
POLAR was a wide field of view Compton-scattering polarimeter (50-500 keV), which took data from September 2016 to April 2017 onboard the Chinese spacelab Tiangong-2. A novel polarimetric analysis method for the Crab pulsar observed by POLAR was recently developed. When applied to the Crab pulsar the method found that: 1) averaged phase interval, Polarization Degree (PD)=14^{+15}_{-10}\%, Polarization Angle (PA)=$108^{+33\circ}_{-54}$; 2) Peak 1, PD=17^{+18}_{-12}\%, PA=$174^{+39\circ}_{-36}$; 3) Peak 2, PD=16^{+16}_{-11}\%, PA=$78^{+39\circ}_{-30}$. To illustrate the capabilities of this method, a two-year observation of the Crab pulsar with POLAR-2 (the successor of POLAR) has been simulated. The simulation shows that POLAR-2 will be able to confirm the emission to be polarized with 5σ or 4σ confidence level if the Crab pulsar is polarized at 20% or 10% respectively.
The Imaging X-ray Polarimetry Explorer (IXPE) is a focusing Photoelectron-track polarimeters (2-10 keV). It is exploring the jet-torus morphology of the Crab nebula and the phase-resolved polarimetry of the Crab pulsar with unprecedented precision. Such results will put more stringent constrains on the models. In this talk, we will study the IXPE measurements of the Crab pulsar/nebula and compare it with that of POLAR and of other instruments at different energies. Based on that, we will also discuss the future prospects of multiple missions for the polarimetry of the Crab pulsar/nebula.

Polarization and instruments / 103

The New Robotic Telescope's Polarimetry Plan

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The New Robotic Telescope (NRT) is a 4-metre class, fully autonomous, robotic optical facility due to join the Liverpool Telescope on Roque de los Muchachos on the Canary Island of La Palma, Spain in 2026. With a time-to-target requirement of 30 seconds, the NRT will be one of the earliest-responding ground-based facilities to provide optical spectroscopic, polarimetric and photometric observations of explosive and energetic targets identified by survey and satellite telescopes. One of the main science foci of the NRT is the exploitation of facility's polarimetric capabilities; particularly in the context of synchrotron-emitting objects such as gamma-ray bursts and blazars, along with dusty environments.

I will present the Liverpool Telescope's polarimetric successes over the past 18 years, and show how these shape the NRT's science and instrumentation requirements. I will then discuss the NRT's capabilities in the context of polarimetric science over the coming years and invite the community to contribute and comment on key NRT scheduling and instrumentation requirements.

Polarization and X-ray binaries / 104

High-precision optical polarimetry of black hole X-ray binaries

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Stellar-mass black holes in low-mass X-ray binaries are natural laboratories for studying the interaction of matter and radiation under extreme physical conditions. These systems spend most of their lifecycle residing in the inactive (quiescent) state, sometimes suddenly bursting out, increasing their brightness by several orders of magnitude over the entire spectrum. Their optical and infrared emission is a product of a complex interplay between the jet, wind, accretion disc, and hot accretion flow components.

The study of the contributions of various components and their properties to the observed spectrum is crucial for the understanding of the mechanisms leading to outbursts. One of the effective, and often overlooked, ways of such study is optical polarimetry since the polarization carries information about the geometrical properties of the emitting/scattering media, which may otherwise be inaccessible to an observer.

We present the results of multiwavelength (BVR) polarimetric studies of a sample of eight black hole X-ray binaries during outbursts and those residing in the quiescent (or near-quiescent) state. We surveyed both long- and short-period systems located at different Galactic latitudes. Careful analysis of the interstellar polarization in the direction of the sources allowed us to estimate the intrinsic polarization of all binaries. Intrinsic polarization is found to be small (<0.2%) for sources in bright soft states. It was found to be significant in the rising hard state of MAXI J1820+070 at the level of 0.5% and negligible in the decaying hard state. Four out of five sources observed during quiescence show no evidence of significant intrinsic polarization. The only exception is MAXI J1820+070, which showed substantial (>5%) intrinsic quiescent state polarization with a blue spectrum. The absence

of intrinsic polarization at the optical wavelengths puts constraints on the potential contribution of non-stellar (jet, hot flow, accretion disc) components to the total spectra of quiescent black hole X-ray binaries.

Polarization and surveys, etc. / **105**

Polarization patterns in the sky

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Polarimetry is a powerful technique that reveals details of astronomical objects that otherwise would be concealed in standard imaging or spectroscopic observations.
However, reliable measurement of the polarization requires a good understanding of all contamination sources in our system. As the main source of light in our nocturne sky, the Moon and its patterns of polarization in the sky are our focus in this study. We performed multi-wavelength observations with the FORS2 instrument at the VLT on blank fields during the full Moon to analyze these patterns and their influences on polarimetric measurements.
We present and discuss our results of the moonlight polarization patterns, comparing them to known analytical models of single and multiple scattering and our proposed corrections.

Polarization and AGN and blazars / **106**

Do Narrow-Line Seyfert 1 galaxies have smaller BH masses? Spectropolarimetry to the rescue

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Black hole mass measurements for Narrow Line Seyfert 1 (NLSy1) galaxies are based on *unexpectedly* short time lags seen in the reverberation mapping (RM) of the Broad Line Region (BLR) campaigns. Black hole masses are estimated under the assumption of the virial factor, which depends on the geometry of BLR and the viewing angle of the source. Spectropolarimetric observations of BLR would allow us to explore the full Keplerian velocity profiles due to the scattering of the line photons

- via the polarized spectrum. This can then allow us to estimate the viewing angle for each source using the information from both polarized and unpolarized spectra and help improve the BH mass estimates.

We used Very Large Telescope - FORS2 spectropolarimetric observations of 3 NLSy1 galaxies to measure their inclination and black hole mass from the wavelength-dependent polarization spectra around the Halpha region. For all three sources, we estimated the viewing angle and the black hole mass. For the viewing angles, we obtained an almost face-on (IRAS 04416+1215, $\approx 4^o$), to an intermediate (SDSS J080101.41+184840.7, $\approx 31^o$), to the most inclined (Mrk 1044, $\approx 54^o$) source.
Moreover, we estimated the black hole mass for each source: $10^{6.97}$ solar masses (IRAS 04416+1215), $10^{6.40}$ solar masses (SDSS J080101.41+184840.7), and $10^{6.05}$ solar masses (Mrk 1044). Our measurements are consistent with the estimation from RM.

To infer the geometry and composition of the scattering media around the SMBH, we modelled the STOKES parameters using the polarization radiative transfer code STOKES. We then compare the modelled estimates with our observed spectral properties and find good agreement for the presence of polar scatterers in addition to regular equatorial scatterers.

We also performed a Principal Component Analysis (PCA) using the spectral parameters for our and other archival FORS2-VLT sources to check for potential drivers for existing correlations.

Polarization and AGN and blazars / **107**

Probing particle acceleration in jets through X-ray polarimetry

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X-ray polarimetry allows us an unprecedented look at the structure of magnetic fields and on the processes at the base of acceleration of particles up to ultrarelativistic energies in relativistic jets. Crucial pieces of information are expected from observations of blazars of the subclass defined by a synchrotron emission extending to the X-ray band (so-called high synchrotron peak blazars, HSP). I will present some of the models and numerical simulations developed to predict the polarimetric properties of HSP at high energy, contrasting them with the recent measurements of the IXPE satellite.

Poster Session / **108**

Hard X-ray polarisation measurement capability of proposed Indian high-energy transient mission –Daksha

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Daksha, a proposed Indian mission, will be the most sensitive all-sky high-energy time domain telescope in the world. Daksha will detect and characterise about ten electromagnetic counterparts of the gravitational wave (EMGW) events per year and about thousand classical GRBs (especially high redshift GRBs) per year. For bright transients, Daksha will be able to measure hard X-ray polarisation, a key to understanding the geometry and physical process of the emission mechanism. The mission will consist of two identical satellites monitoring the entire sky in the energy range of 1 –

1000 keV and with all-sky median effective area of ~1300 cm^2 for a single satellite and an effective fluence sensitivity of 4×10^{-8} erg/cm^2 (for a 1 second duration transient). Daksha will have 340 pixelated Cadmium Zinc Telluride (CZT) detectors on each satellite arranged in a quasi-hemispherical configuration and without any field of view collimation (open detectors). These CZT detectors form an excellent polarimeter capable of measuring photon polarisation in the energy range 100 –400 keV. The CZTI instrument aboard AstroSat has successfully measured the polarisation of the Crab pulsar and 11 GRBs using these detectors. In this talk, I will introduce the Daksha mission concept, discuss details of the polarisation measurement method using the CZT detectors, and show results of simulations carried out using the mass model to estimate polarisation measurement sensitivity of the Daksha mission.

Poster Session / **109**

Synchrotron Polarization of Gamma-Ray Burst Afterglow Shocks with Hydrodynamic-scale Turbulent Magnetic Field

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The afterglows of gamma-ray bursts (GRBs) are non-thermal electron synchrotron emissions from relativistic shocks. The amplification mechanism of magnetic field at the shocks is one of the major problems in high-energy astrophysics, which could be solved by polarimetric observations. Two field amplification mechanisms, Weibel instability and magnetohydrodynamic instability, have been proposed so far, and the former one produces field on plasma skin depth scale, smaller than that of the latter one by 7-10 orders of magnitudes. Polarimetric properties of the plasma-scale field model have been well studied (e.g., Rossi et al. 2004; Shimoda & Toma 2021). In this work, we focus on the latter mechanism and build a semi-analytic model of the synchrotron polarization with magnetohydrodynamic turbulence for the first time. We perform numerical calculations and find that for the isotropic turbulence and the zero viewing angle, the observed level of late-phase optical afterglow polarization degrees (~1-3 %) can be reproduced when the field coherence length scale in the fluid comoving frame is comparable to the thickness of the shocked regions. Our model also shows that the radio polarization degrees are comparable to the optical ones on average but can be higher than the optical ones at some time intervals. The polarization angles are shown to vary randomly and continuously. These polarimetric properties are clearly different from the plasma-scale field model. Simultaneous polarimetric observations of GRB afterglows in the radio and optical bands have recently started, which will help us constrain the magnetic field amplification mechanism.

Polarization and instruments / **110**

Time-domain polarimetry with RoboPol

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The Robotic Polarimeter (RoboPol) is a unique optical polarimeter that operates for almost ten years at Skinkas observatory, Crete, Greece. It has no rotating parts and can measure the linear Stokes parameters with a single exposure.
Built primarily to monitor blazars, it has studied their polarization overtime, and has offered valuable insights on the connection of polarization degree and angle variability to gamma-ray flares.

RoboPol instrument also has the capability to respond to targets of opportunity. It has been used to follow-up with optopolarimetric observations the optical afterglow of gamma-ray bursts (GRBs), including the recent, and exceptionally bright, GRB210619B.
I am going to present a brief overview of the RoboPol contribution to time-domain optical polarimetry, highlighting important results and discussing future plans.

Poster Session / **111**

Interstellar polarization in imaging polarimetry of supernovae

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Imaging polarimetry evolution of supernovae can provide invaluable information on the explosion asymmetries and the circumstellar material ejected by the progenitor. However, constraining the insterstellar polarization (ISP) from the Milky Way and the host galaxy are necessary ingredients to obtain the intrinsic polarization of any transient. Traditionally, the ISP has been estimated through spectral polarimetric techniques that make use of e.g. P-Cygni profiles. We present here the methods to obtain both the ISP of the Milky Way, using multi-band linear imaging polarimetry of the field stars, together with the ISP in the SN host for nearby galaxies obtained from direct imaging polarimetric analysis of the environment. We apply our methodology for dedicated host galaxy imaging polarimetry of nearby supernova hosts with FORS2-VLT and for direct supernova imaging polarimetry with CAFOS-CAHA.

Poster Session / **112**

ComPol - A Compton polarimeter in a Nanosat

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The CubeSat mission ComPol will investigate the black hole binary system Cygnus X-1. The goal is to improve its physical model by measuring the polarization of the hard X-ray spectrum (20 –300 keV). The information about the polarization can be extracted from the kinematics of the Compton scattering. A Silicon Drift Detector (SDD) is used as a scatterer. The SDD is stacked onto a CeBr3 calorimeter to be able to measure the full kinematics. The talk gives a basic overview of the scientific motivation, the detector setup, the performance of the system and the sensitivity study carried out for this purpose.

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Poster Session / 113

Type II Supernova Imaging Polarization with CAFOS

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In the last years great progress has been achieved on our understanding of supernovae (SNe). However, there are still many unknowns on the nature of the progenitor systems, their environment, and the physics behind the explosions. An important approach in this context is to use polarimetric data, which are scarce compared to spectrophotometry and can reveal essential information on the geometry of the explosions and the dust along the line of sight. In this talk, I will introduce the efforts conducted by a team from the University of Cadiz, the Center for Astrophysics and Gravitation (Lisboa) and the Institute of Space Sciences (Barcelona) to increase the number of imaging polarimetry data of SNe using the Calar Alto Faint Object Spectrograph (CAFOS). Specifically, I will present BVRI polarimetry of a few type II SNe, and discuss the possible mechanisms giving rise to the measured polarization. For example, SN 2017eaw shows a polarization degree above 1% throughout its evolution and after correcting for the Milky Way interstellar polarization. The measurements are also above the maximum polarization degree expected from the SN's host galaxy, showing that the object is intrinsically polarized. I will expose possible interpretations for our observations involving asymmetries in the explosion and/or the properties of the dust grains in the path of the light of SN 2017eaw.

Poster Session / 114

GRB prompt emission polarimetry with proposed Indian high-energy transient monitor –Daksha

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Daksha is an ambitious mission, expected to be the most sensitive high energy time-domain telescope. It will detect the highest number of GRBs and other high energy transients than any other mission. In addition to the interesting science with fainter and more distant sources, Daksha will also significantly impact the study of bright transients by measuring rapid spectral and temporal variations. A key feature is Daksha's ability to measure X-ray polarisation by utilizing multi-pixel events caused by Compton scattering of incoming photons. The large effective area, open CZT detectors, and the all-sky coverage make Daksha at least an order of magnitude more sensitive than

the current generation satellites measuring GRB polarisation. The spectral and temporal analysis of GRB data allows us to identify models that are consistent with data; however, there are degeneracies among the various models. Different models give rise to a different degree of polarisation. A statistical analysis of GRBs' polarisation properties can help us constrain the models. In this work, we will present how Daksha and its capability of polarisation measurement will help us probe the physical processes related to GRBs and put constraints on the existing models related to GRBs.

Polarization and neutron stars and pulsars / **115**

The origins of radio pulsar polarization: a broad-band view

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For the past half-century, pulsars have been used to push the boundaries of our understanding of the Universe, yet our understanding of pulsar radio emission is still limited by many unanswered questions. Polarimetry provides important information about pulsar emission geometry and magnetic field processes, but the pulsar population exhibits considerable variety in its polarimetric behaviour that is not well captured by the canonical descriptions of pulsar emission. In recent years however, new and upgraded telescopes have given us a broad-band time- and frequency-resolved perspective of pulsar radio polarization, enabling us to study the origins of radio pulsar polarization in detail.

In this talk I will present results from a broad-band survey of radio pulsars made with the Parkes Ultra-Wideband receiver and describe how these new observations update the picture of radio polarization in the pulsar population. I will discuss the magnetospheric origins of the polarization features observed, particularly the origins of circular polarization, and explain how they can be captured in a simple three-parameter model. By modelling broad-band time-resolved pulsar observations in this way, we will be able to improve our understanding of pulsar geometry by properly accounting for the impact of the magnetosphere. This work demonstrates the importance of modern time-resolved and frequency-resolved polarimetry for understanding transient radio emission.

Polarization and neutron stars and pulsars / **116**

The Imaging X-ray Polarimetry Explorer observing neutron stars binary systems

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The Imaging X-ray Polarimetry Explorer is a joint NASA-ASI Small Explorer mission launched on December 9th 2021 and dedicated to angular-, time- and energy-resolved X-ray polarimetry in the 2-8 keV energy range. The observatory features three identical telescopes, with grazing-incidence mirrors built at NASA-MSFC and focal plane polarimeters based on the Gas Pixel Detector design provided by Italy. Currenlty, IXPE is in Science Observation phase: in this talk, I will present the mission, its science objectives and avaiable preliminary results.

Polarization and neutron stars and pulsars / **117**

Modelling the non-thermal emission and polarisation from the white dwarf pulsar AR Sco.

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AR Sco is a binary system that contains both a white and red dwarf. Optical emission from this system is observed to be highly linearly polarised. The spin rate of the white dwarf has been observed to slow down with time, analogous to rotation-powered radio pulsars; it has thus been dubbed a "white dwarf pulsar", also given the lack of evidence for accretion activity in the system. We previously fit the traditional radio pulsar rotating vector model to linearly polarized optical data from this source, constraining the system geometry and white dwarf mass. Next, using a much more extensive dataset from the South African Astronomical Observatory (SAAO) HIPPO Polarimeter on their 1.9-m telescope, we also explored the application of the same geometric model to the orbitally phase-resolved optical polarimetric data. The optical emission is thought to be the result of non-thermal synchrotron radiation. We constrained the magnetic inclination angle and the observer angle at different orbital phases finding evolution of these parameters over the orbital period. This could indicate precession of the WD, an asymmetric emission source, a non-uniform distribution of injected particle pitch angles or complicated time-dependent particle injection. Now we have constructed a much more sophisticated emission model, solving the particle dynamics from first principles, including a generalized radiation reaction force, and implementing similar techniques to what were used in a pulsar emission code developed by A.K. Harding and collaborators to produce emission maps, light curves and spectra. We present some of our results from the geometric model as well as how we intend to calculate the polarisation of the particles in our new model to create polarisation emission maps. With spectral, light curve, and polarisation predictions in hand we will be able to constrain the emission mechanism and magnetic-field structure more robustly of this novel source.

Polarization and surveys, etc. / **118**

Unveiling the Magnetic Fields around Galactic Center

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We present new magnetic field measurement around the Galactic Center regions, including the 20km/s cloud, 50 km/s cloud, Sgr A*, and the Brick. Our data are obtained through the James Clerk Maxwell Telescope (JCMT) B-Fields In Star-forming Region Observations (BISTRO) survey with the POL-2 instrument. We decouple the complicated velocity structure in the Galactic center regions to estimate the velocity dispersion needed for the magnetic field strength estimates with the Davis-Chandrasekhar–Fermi method. We analysis the energy budget and access the relative importance of the magnetic fields and the turbulence for star formation.

Polarization and neutron stars and pulsars / **119**

IXPE Observations of the Pulsar 4U 1626-67

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We report on new X-ray spectropolarimetric observations from the recently launched Imaging X-ray Polarimetry Explorer (IXPE) of the ultracompact low-mass X-ray binary system 4U 1626-67. We also report on supplementary observations taken by NICER and Chandra/HETGS around the IXPE observation window. We will present time-resolved spectropolarimetric 2-8 keV IXPE observations of 4U 1626-67 and discuss implications for our understanding of accretion geometries in accreting pulsars; we will also present results from intensity-resolved spectropolarimetric analysis. 4U 1626-67 is an interesting system as it hosts a slowly spinning accretion-powered pulsar (~7.7 s) with a strong magnetic field (B ~ 10^12 G) in a ~42 minute ultracompact orbit around a very low mass hydrogen-depleted companion. It has exhibited two episodes of long-term torque reversals in 1990 and 2008, and it is currently in the spin-up state. The quiescent emission in the spin-up state is also occasionally punctured by >100 s-long flaring episodes, which we will discuss in context of the new polarization measurements. The pulse profiles also exhibit strong energy dependence, and the system hosts a highly collisionally-ionized plasma in the accretion disk and complex emission line phenomena around 1 keV (attributed to Ne X and O VIII).

Poster Session / **120**

The importance of high cadence observations for blazar polarimetry

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Blazars are highly variable sources that emit light across the entire electromagnetic spectrum. The period of their variability can range from intra-night minute/hour long timescales, day/week timescales, and have even been known to vary over the course of years. This makes high cadence observations key to understanding the processes producing the observed radiation. This is no more apparent than with polarimetric data. Large gaps between subsequent data points allow for multiwavelength flares to go unobserved, as well as linear polarisation flares and position angle rotations. Data taken in the middle or at the end of an event does not provide the timescale or magnitude of the rapidly changing variability.

I will present data from the long-term photo-polarimetric blazar monitoring program using the RINGO3 and MOPTOP polarimeters on the Liverpool Telescope. We have conducted correlation analysis between the different photo-polarimetric components and Fermi data, and I will discuss the issues presented by interrupted monitoring and poorly sampled data over various timescales. I will also present the application of machine learning techniques for interpreting activity phases in blazars giving us the potential to understand the source behaviour during periods where they cannot be observed with ground-based optical telescopes.

Polarization and gamma-ray bursts / **121**

Temporal Evolution of Prompt GRB Polarization

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The dominant radiation mechanism that produces the prompt emission in gamma-ray bursts (GRBs) remains a major open question. Spectral information alone has proven insufficient in elucidating its nature. Time-resolved linear polarization has the potential to distinguish between popular emission mechanisms, e.g. synchrotron radiation from electrons with a power-law energy distribution or inverse Compton scattering of soft seed thermal photons, which can yield the typical GRB spectrum but produce different levels of polarization. Furthermore, it can be used to learn about the outflow's composition (i.e. whether it is kinetic-energy-dominated or Poynting-flux-dominated) and angular structure. For synchrotron emission, it is a powerful probe of the magnetic field geometry. In this talk, I will discuss synchrotron emission from a thin ultrarelativistic outflow and use a phenomenological pulse model to construct the energy-dependent temporal evolution of polarization for both coasting and accelerating flows. I will present results for a top-hat jet with sharp and smooth edges with observers having different viewing angles. I will then use the single pulse model to construct the polarization evolution for multiple overlapping pulses that arise due to episodic internal dissipation in the outflow. In the end, I will discuss how energy dependent polarization can be used to distinguish between different particle acceleration/heating scenarios in a magnetized outflow.

Poster Session / **122**

POLIX simulation results

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POLIX is an X-ray polarimeter working in the energy range of 8-30 keV and the main scientific payload onboard the upcoming Indian astronomy mission XPoSat (X-ray Polarimeter Satellite) dedicated to study of polarization of cosmic X-ray sources. The polarisation measurements will be performed using anisotropic Thomson scattering of polarised X-rays and this will be enabled by spinning the satellite around the viewing axis of the instrument. Being a dedicated X-ray polarisation mission in this unexplored energy band, POLIX will allow many in-depth investigations of astrophysical processes in neutron star and black hole sources. Along with a description of the instrument, results from simulation of POLIX response to polarised X-ray photons and background will be presented here.

Polarization and AGN and blazars / **123**

Polarization variability in a sample of gamma-ray blazars

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The low energy emission of AGN, from radio to optical wavelengths, is liked to the magnetic field of the jet and its synchrotron emission. Specifically, blazars show an extraordinarily high optical polarization with respect to other AGN types, with values that can reach a fraction of ~50%. As for the total emission, the polarization degree also exhibits strong variability in different time scales.

Therefore, studying the variability and properties of the polarized emission can shed light into the features and evolution of the magnetic field, its role in the particle acceleration and in the jet dynamics, and the connection between the polarized and total emission.
In this talk I will present the results of the analysis of 10 years of polarimetric data from a large sample of gamma-ray bright blazars regularly monitored by the Steward Observatory. This 10-year monitoring provides an excellent data sample to carry out an extensive study of the behaviour and evolution of the degree and angle of the polarization, their variations, as well as possible rotations related to the global emission properties. We have analyzed the long-term variability and evolution of the polarized emission for this sample of blazars, studying possible similarities/differences between the different blazar types that can reveal the behaviour of the magnetic field and the polarization degree.

Polarization and AGN and blazars / **124**

Polarimetry of GSN 069: the source of the quasi-periodic eruptions

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GSN 069 is a high Eddington-ratio Seyfert galaxy that exhibits an unabsorbed highly variable X-ray spectrum typical of a Seyfert 1, but it does not show broad emission lines in its optical spectrum, which leads to a Seyfert 2 classification. It could be then considered as a true Seyfert 2 candidate. Those candidates are thought to accrete at low Eddington rates, unable to sustain the broad line region (BLR). Nevertheless, GSN 069 exceeds the theoretical accretion rate at which a BLR is formed. On the other hand, since December 2018 and during 54 days, GSN 069 has exhibited a new X-ray variability pattern characterized by high-amplitude quasi-periodic X-ray bursts over a rather stable quiescent flux level. This new phenomenon has been dubbed X-ray quasi-periodic eruptions (QPEs) (Miniutti et al. 2019, Nature, 573, 318). Since its discovery with GSN 069, QPEs have been identified in a very few sources and their driving mechanism remains unknown. In the specific case of GSN 069, some models point to a possible tidal disruption event (TDE) as possible origin of the exhibited QPEs, but more observational efforts are needed for a better understanding.
Polarimetry is the only technique capable of demonstrating the existence of hidden-BLRs. It has also been demonstrated that the degree of polarization is sensitive to TDEs (Wiersema et al. 2020, MNRAS, 491, 1771). Thus, in this work we report imaging polarimetry and spectropolarimetry of GSN 069 with FORS2@VLT to explore both scenarios, the true Seyfert 2 candidacy and the possibility of a TDE in GSN 069.

Poster Session / **125**

Performance of the calorimeter prototype for the ComPol In-Orbit Verification mission

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Polarimetry has become one of the latest potential tools to be used in the study of high energy astrophysical phenomena. Following INTEGRAL polarisation measurements in the gamma ray range and subsequent studies done by AstroSAT and POLAR, polarisation capability has become an important design parameter for future x/gamma ray instruments like Astrogam, Polix, COSI. The scientific communities interest in polarimetry can also be confirmed by the multiple instrument proposals.
Unfortunately, there are currently no confirmed big observatories with polarimetric capabilities in the soft gamma ray range. As a consequence, we are studying the possibility of long-term observation of persistent sources with compact polarimeters flown on nano-satellites. Our proposed mission, ComPol, has been selected by the ORIGINS Excellence Cluster for long-term observation of Cygnus X-1. It should fly by the end of 2025, which opens up the exciting prospect of concurrent observation with NASA's SMEX mission, COSI. ComPol will be capable of detecting a 20% Minimum Detectable Polarisation(MDP) up to 1MeV during its 1 year mission.
An in-orbit verification prototype is currently being prepared to be flown on the ISS in 2023. This prototype will use the same technology as the nano-sat mission albeit in a smaller form-factor. The payload is a Compton Polarimeter consisting of a pixelized SDD scatterer and a CeBr3 calorimeter built by MPP/TUM/Polimi and CEA Saclay respectively; in collaboration with LRSM Munich.
In this talk we will present the calibration campaign of the ISS ComPol polarimeter prototype and its performance.

Polarization and stars / **126**

Detection of Magnetospheric Interaction in Magnetic Hot Binary

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Although > 6% of isolated massive stars are magnetic, a magnetic field is rarely observed (<1.5%) in the case of close hot binaries. Among them, ϵ Lupi A is the only close hot binary where both the components are magnetic. The stars have anti-aligned dipoles pointing to interacting magnetic fields, and orbit close enough that their magnetospheres are predicted to overlap, leading to speculation that ϵ Lupi may exhibit magnetospheric interactions. Although several studies are going on to understand the nature of radio emission from single massive magnetic stars, only a few observations have been performed to study the stars in binary. In this work, we shall report the discovery of radio emission from ϵ Lupi observed with the upgraded Giant Metrewave Radio Telescope (uGMRT) and the MeerKAT radio telescope. The light curve shows a variable nature with the presence of strong, sharp, linearly polarized pulses near the periastron. This behavior makes ϵ Lupi the first-ever main-sequence binary to show direct evidence of magnetospheric interaction. We also witness some out-of-periastron spikes in the light curve that we try to explain by considering different phenomena: electron cyclotron maser emission, multi-polar interaction, or magnetic reconnection due to the relative motion of the magnetospheres of the components. We also observe a possible periodic variability of timescale much smaller than the orbital period in the light curve that might indicate the yet-unknown rotational period of one or both contributing stars. This complex system serves as a test-bed for different exotic physical processes that may arise in other magnetically interacting systems like star-star, planet-star, and moon-planet. We anticipate our work to be a starting point for a more detailed variability study.

Polarization and AGN and blazars / 127

Modeling the Multi-wavelength Polarization and Spectral Energy Distributions of Blazars

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In the radio through optical-UV/X-ray regime, blazars emit highly polarized (nonthermal) synchrotron emission. Emission from the dusty torus, broad line region, accretion disk and host galaxy is of thermal origin and unpolarized. In some cases, their contribution is visible in spectropolarimetry wherein the unpolarized thermal emission dilutes the synchrotron polarization. However, partially ordered magnetic fields decreasing with distance along the jet from a shock also yield a decrease of polarization towards longer wavelengths in some sources. The Large Science Program "Observing the Transient Universe" using the *Southern African Large Telescope* provides target-of-opportunity spectropolarimetry observations of gamma-ray bright blazars, indicating a decrease in the total degree of polarization towards shorter or longer wavelengths in many sources. The program includes co-ordinated multi-wavelength observations from the *Las Cumbres Observatory*, the *Swift*-XRT and the *Fermi*-LAT. A shock acceleration model including the effects of magnetic-field compression and gradual restoration of the original magnetic-field configuration behind the shock is implemented to study the multi-wavelength spectral energy distributions and spectropolarimetry of blazars observed in steady states. In this presentation, the model is discussed in application to 3C 273, 3C 279 and 4C+01.02. Spectropolarimetry contributes to our understanding of the high-energy polarization, most notably the IXPE observations of 3C 273 and 3C 279.

Polarization and stars / 128

Tracking the Short Timescale Evolution of the Linearly Polarized Jets from V404 Cygni's 2015 Outburst

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Accretion-powered relativistic jets are a ubiquitous element of systems with accreting black holes. Despite the ubiquity of these jets, we have yet to construct a complete picture of the underlying mechanisms that control their evolution. In these jets, synchrotron emission leads to partial linear polarization, with fractional polarization levels and polarization angles that depend on the local magnetic conditions. Thus, we can use polarimetry to probe the magnetic field directly and better constrain the evolution of jets.

Black hole X-ray binaries (BHXBs; i.e., accreting stellar-mass black holes) effectively probe the temporal evolution of accretion-powered relativistic jets, typically on timescales of minutes to weeks. In 2015 the BHXB V404 Cygni was detected as it entered an extremely luminous outbursting state. Follow-up radio observations taken with the Very Large Array (VLA) uncovered multiple bright flaring events. Additional simultaneous observations with the Very Long Baseline Array (VLBA) conclusively revealed that the jet axis was precessing and that the emission originated from both resolvable jet ejecta and an unresolved compact core. In this work, we build on the previous analyses of V404 Cygni to include a time-resolved investigation of the linear polarization VLA data, constituting one of the most rapid cadence studies of radio polarimetry in BHXBs to date. Here, I will present how the short timescale polarized variability (~15 minutes) that we detect evolves in frequency and

time. We observe an offset in time between the fractional polarization peaks and the total intensity. Moreover, the intrinsic electron vector polarization angle evolves rapidly. These observations are characteristic of a rapid evolution of both the jet morphology and the structure of its internal magnetic fields.

Polarization and stars / **129**

Magnetospheres around High Mass Stars revealed by Polarimetry

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About 10% of the known massive stars have strong, dipolar magnetic fields. Magnetohydrodinamical simulations show that the combination of strong magnetic fields and fast rotation can lead to the formation of co-rotating magnetospheres around these objects.
A theoretical model (the Ridigly Rotating Magnetosphere model, RRM) is available for the case of very strong magnetic fields. This model was applied, with some success, to the archetype star σ Ori E. However, more recent results based on high-precision polarimetric data showed that the RRM falls short in explaining the polarization modulation, which indicates that the model cannot reproduce correctly the geometry of the σ Ori E's magnetosphere. An alternative, parametric model (dubbed the Dumbbel plus Disk model, D+D) was proposed, that allows for a good fit of the data and the successful determination of several fundamental parameters of the magnetosphere. In this work we show the results for HD35502, for which unambiguous modulation was found and a well-contrained model was developed. We also present results for HR 5907 and HR7355, the two magnetic massive stars with shortest rotation period known to date. For them the modulation detection was marginal, at best. Finally, we report an ongoing polarimetric survey made in Observatorio Pico dos Dias (OPD) for another 15 magnetic massive stars and the preliminary results for modelling 6 of them. The results are based on a novel approach to the D+D model that incorporates Bayesian statistics to fit the model to the data.
It is expected that both the increased sample and our new modelling approach will bring further light to help us understand what are the shortcomings of the RRM model, and possibly reveal the ways upon which this model can be improved.

Poster Session / **130**

The unique Be star binary HD 92406 - two stellar eclipses and two disk occultations per orbit

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About 20% of the B-type stars rotates very rapidly. Among these are the classical Be stars, which eject material and build up gaseous circumstellar 'decretion'disks. Rotation plays a significant role in the structure and evolution of massive stars, yet in many aspects is poorly understood. One viable evolutionary pathway to acquire near-critical rotation is through binary interaction - namely mass and angular momentum transfer, during which the remaining core of the mass donor becomes a hot stripped star and the mass gainer spins up to become the Be star. Some models suggest the binary

channel is dominant in creating rapid rotators, yet only about 15 rapidly rotating Be + stripped star binaries are known.

HD 92406 is the first late-type Be + stripped star binary, occupying a unique niche in the rapidly rotating binary population. HD 92406 is exceptionally valuable as there are two stellar eclipses and two disk occulations per binary orbit - this is the only known eclipsing binary that hosts a Be star. As flux from the stripped star passes through the disk, the local disk properties are encoded in the observed spectrum. This offers the unique possibility of probing the disk conditions with exquisite details.

Ongoing analysis of this system allowed us to determine some of its parameters with great precision. HD 92406 is composed of a 4.8 ± 0.3 $\mathrm{M}_{\odot}$ primary Be star with temperature ranging from 12000 K (equator) to 18000 K (pole) and polar radius of 3.5 $\mathrm{R}_{\odot}$, confirming it as a late type Be star. The parameters of the secondary remains to be better constrained, but it is confirmed as a 0.7 ± 0.2 $\mathrm{M}_{\odot}$ hot subdwarf with temperatures around 20000 – 30000 K and radius $\mathrm{R} < 0.7$ $\mathrm{R}_{\odot}$. From TESS photometry and NRES spectra, we were able to determine the orbital parameters as $\mathrm{P} = 32.1854$ d, $\mathrm{i} = 88 \pm 1^{\circ}$, $\mathrm{K}_1 = 15 \pm 3$ km/s and $\mathrm{K}_2 = 100 \pm 5$ km/s.

For this contribution, we present the results of a imaging polarimetric campaign for HD 92406. The rich field of this star allowed us to determine the interstellar polarization as 0.71 ± 0.02 % @ 128.2 degrees. The intrinsic polarization is very low (average polarization of ≈ 0.085 %), consistent we the fact that late type Be stars possess tenuous disks. Despite these low levels, we were able to detect polarimetric modulations as a function of orbital phase. A weak modulation was observed during the disks occulations and a strong, fast variation was observed during the primary stellar eclipse, consistent with the expectation that, during the eclipse, the unpolarized flux is reduced, thus boosting the polarization level. The diagnostic potential of this data to constrain the disk parameters cannot be underestimated. Disk models calculated with the HDUST code will be presented.

Polarization and AGN and blazars / **131**

Jets in Blazars as seen by POLAMI: Polarization Monitoring of AGN at Millimeter Wavelengths with the IRAM 30m Telescope

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A Large Program at the IRAM 30m Telescope called POLAMI observes since 2007, with a time sampling of ~2 weeks, the four Stokes parameters of the 3.5 and 1.3 mm emission of a sample of ~40 of the brighter sources in the northern sky. This contribution outlines the most salient scientific results obtained from the first detailed analysis of the data on which regards to the structure and magnetic field of the innermos blazar jet regions. In particular, the analysis of the variability of our data implies that shorter mm emission should come from smaller regions with progressively better magnetic field order, one-zone models are de finitely excluded by the general properties of mm polarization of blazars, blazar jets are not compatible with axisimmetric geometries in general on which regards to their polarization emission. Moreover, variable circular polarization emission seems to be present in most blazars at mm wavelengths at levels of ~2% or larger.

Polarization and instruments / **132**

A polarized view on how to design astronomical instrumentation

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Ideally, our astronomical instruments measure a complete five-dimensional phase space: intensity and polarization (1) as a function of sky coordinates (2,3), wavelength (4), and time (5). Inclusion of polarimetric capabilities almost always provides unique scientific benefits, but also almost always leads to tensions within the optimization of the optical system design. All optical components for image formation and spectroscopic analysis induce instrumental polarization effects at some level, and polarization modulation optics necessarily compromise temporal, spatial and/or spectral range/resolution.

I will provide an overview of the implementation of polarization measurement techniques within astronomical instruments, and discuss their system-level trade-offs. I will discuss polarization modulation in the temporal, spatial, and spectral domains, and combinations thereof, to maximize the measurement efficiency, and to minimize the susceptibility to systematic (differential) effects and obtain the best possible polarimetric sensitivity. Moreover, I will discuss calibration techniques to mitigate a myriad of instrumental polarization effects with the goal to obtain the best possible polarimetric accuracy. I will provide examples from existing instruments at e.g. the VLT, and from more experimental concepts that we are developing in Leiden.

Finally, I will provide a sneak preview of our design for a polarimetric upgrade of the VLT Survey Telescope, that would enable unique deep and wide-field polarimetric survey capabilities, and rapid follow-up of transient events.

Poster Session / **134**

Polarimetry with small and medium-size telescopes

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In my talk, I will briefly present the results of polarimetric studies of various types of astronomical objects with small and medium-size telescopes, i.e. pulsars, pulsar wind nebula, white dwarfs and high mass X-ray binaries with Be stars as well as multiband polarimetry of Kepler filed stars. I will describe several different polarimeters, to name a few: the high-time resolution photopolarimeter OPTIMA, a fast-readout optical imaging multiwavelength polarimeter RINGO3 mounted on the 2-m fully robotic Liverpool Telescope, located at the Observatorio del Roque de Los Muchachos on La Palma and the double Wollaston RoboPOL polarimeter mounted on the 1.3-m telescope at the Skinakas Observatory, as well as the double-wedged Wollaston-type polarimeter on the 1.5-m RTT150 telescope at the TÜBİTAK National Observatory. Last but not least, I will describe our recent results obtained with the Polish2 polarimeter at the 3-m Shane telescope. I will also show and discuss polarization standard stars, including their high-accuracy measurements with the Polish2 polarimeter.

Polarization and TDE / **135**

Shocking news - a polarizing study of a tidal disruption event

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I.Liodakis, K. Koljonen, D.Blinov, E. Lindfors et al.
(Presenter: E. Lindfors)

Supermassive black holes have been known to disrupt passing stars producing outbursts called tidal disruption events (TDEs) offering a unique view on the early stages of the accretion disk and jet formation. The advent of large-scale optical time-domain surveys has significantly increased the number of known events and challenged our understanding of their dynamics and emission processes. Especially, the so-called optical TDEs have shown late-time X-ray and radio emission years after the optical peak emission indicating delayed accretion disk formation and long timescales for the circularization process. In this talk, I will present our study on the most polarized TDE up-to-date without any indication of contribution from a jet to the emission. Our observations demonstrate that optical TDE emission can be powered by tidal stream shocks.

Polarization and neutron stars and pulsars / **136**

Circular polarization in radio pulsar PSR B1451-68: a close look at coherent mode transitions

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The radio signal of pulsar PSR B1451-68 contains two polarization modes
of comparable strength, which are observed as two flux patches that rotate
meridionally on the Poincare sphere. Whenever they pass through the Stokes V poles, a transition between the orthogonal polarization modes (OPMs) is observed on a polarisation angle diagram. The circular polarization can be interpreted as a result of a coherent OPM transition (COMT), ie. a coherent superposition of orthogonal modes with their relative strength undergoing inversion.
COMTs may be ubiquitous and difficult to detect in radio pulsar data, because, unlike the usual OPM jumps, COMTs can leave no trace in polarized fractions, and their polarization angle follows an equation similar to the rotating vector model.
The meridional circularization in PSR B1451-68 requires that the oscillation phase in radiation that is forming consecutive pulse components must increase in steps of 90 degrees per component. A physical mechanism for such case will be presented.

Polarization and instruments / **137**

Polarimetry at the Liverpool Telescope with the RINGO and MOPTOP instruments

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Following the start of science operations in 2004, it was quickly realised that the full robotic nature of the 2.0m Liverpool Telescope (La Palma) was ideally suited to follow up observations of Gamma Ray Bursts (GRBs) and that polarimetry could be a key tool in diagnosing the structure and order of the magnetic fields in these spatially unresolved objects.

The rapid time variability of GRB light curves meant that conventional polarimeters designs with sequential observations being obtained with an analyser effectively working at different angles could not be used. Instead the RINGO series of polarimeters was developed using a continuously rotating polaroid to record the polarisation signal either spatially (RINGO1) or via fast readout cameras (RINGO2 and 3).

In this presentation I will summarise the evolving design of the RINGO polarimeters and the observations that have been made with them of GRB afterglows. I will then conclude by presenting some initial results from our latest polarimeter design (MOPTOP) that uses a dual beam, dual camera concept to reduce systematics and increase sensitivity over our previous design.

Polarization and gamma-ray bursts / **138**

Gamma-Ray Burst Polarization: Status and Perspectives

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This talk will review the important and unique role of polarization in the study of GRBs. The afterglow polarization provides unique and valuable information on the GRB jet's angular structure as well as the magnetic field structure produced in relativistic collisionless shocks. It may also probe dense clumps or a weak large-scale magnetic field in the circum-burst medium. The magnetic field structure within the GRB outflow can be studied through the reverse shock emission: the "optical flash" during its initial passage or the later "radio flare" after hours to days, which probes a larger part of the ejecta shell that becomes visible as it decelerates. In the prompt GRB it is challenging to measure the polarization as the emission is primarily in hard X-rays to soft gamma rays, but such measurements can be very rewarding as they may probe its elusive dominant emission mechanism as well as the composition and angular structure of the GRB outflow. An overview of these different phases will be provided along with some recent polarization results and their possible implications, as well as a brief outlook for the future.

Polarization and neutron stars and pulsars / **139**

X-ray Polarization in neutron stars and magnetars

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Over the recent years the scientific interest around Xray polarimetry has blossomed, thanks to the advent of the first instruments conceived to perform systematically these measurements in celestial sources.

The Imaging X-ray Polarimetry Explorer (IXPE, NASA), launched in December 2021, is opening a new window in Astronomy, adding for the first time polarimetry to the array of techniques to investigate systematically the X-ray sky. Looking beyond, we also expect to see in orbit the enhanced X-ray Timing and Polarimetry (eXTP) mission, which is a mission concept developed by an international Consortium led by the Institute of High Energy Physics of the Chinese Academy of Science, and expected to be launched in the next decade. The eXTP mission will also host on board an X-ray polarimetry, continuing and consolidating the path opened by IXPE, but this instrument will also be complemented to a powerful array of instruments capable to perform simultaneously high resolution X-ray timing and spectroscopic observations.

Highly magnetized sources, which are at the same time characterised by transient outburst and burst activity emission therefore represent key targets for these missions. In this talk I will show a few examples of the science potential of polarimetry data for studies of the physics and astrophysics of strongly magnetized objects, namely magnetars, accreting X-ray pulsars, and other classes of neutron stars, and for QED studies. I will present the very first X-ray spectro-polarimetry observation for a magnetar (4U 0142+61, as observed by IXPE), and possible interpretation(s).

Polarization and surveys, etc. / **140**

Interstellar polarization in imaging polarimetry of supernovae

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Imaging polarimetry evolution of supernovae can provide invaluable information on the explosion asymmetries and the circumstellar material ejected by the progenitor. However, constraining the insterstellar polarization (ISP) from the Milky Way and the host galaxy are necessary ingredients to obtain the intrinsic polarization of any transient. Traditionally, the ISP has been estimated through spectral polarimetric techniques that make use of e.g. P-Cygni profiles. We present here the methods to obtain both the ISP of the Milky Way, using multi-band linear imaging polarimetry of the field stars, together with the ISP in the SN host for nearby galaxies obtained from direct imaging polarimetric analysis of the environment. We apply our methodology for dedicated host galaxy imaging polarimetry of nearby supernova hosts with FORS2-VLT and for direct supernova imaging polarimetry with CAFOS-CAHA.

Polarization and fundamental physics / **141**

LIV constraints derived from INTEGRAL observations of polarized GRB

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In complement to spectro-imaging and timing observations, polarimetry provides a unique in-sight into the geometry and magnetic configuration of compact gamma-ray sources, such as neutron stars or black holes. Thanks to the Integral coded mask imaging technics which efficiently suppresses most of the background contribution, we have measured linearly polarized emission from the brightest

cosmic high energy sources, such as Gamma-Ray Bursts (GRB). These observations have enabled us to put strong constraints on the physical process at work in these sources. Models of Lorentz Invariance Violation (LIV) predict a energy-dependant rotation of the polarization angle along the photon path from the GRB site to Earth. Integral observation of polarized GRB have enable us to put strong constraints on these models. After a short review of Integral as a Compton polarimeter, I will describe these Integral results and their implication.

Poster Session / **142**

SPARC4 - Simultaneous Polarimeter And Rapida Camera in 4 bands

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We present the development status of a new instrument for the 1.6m telescope of Observatório do Pico dos Dias/Brazil: SPARC4 - Simultaneous Polarimeter And Rapid Camera in 4 bands. This instrument will use four frame-transfer EMCCDs to acquire simultaneously four images in optical broad bands similar to the g, r, i, and z bands of the SDSS photometric system. SPARC4 can be used as a polarimeter or as a standard imaging camera and is tailored to produce rapid time series of variable objects. All optical and mechanical subsystems are already tested and the instrument is being integrated. The Graphical Unit Interface (GUI) is being developed under the LabView environment: a preliminary version was already tested in real observations using other observatory instruments. Python routines for data reduction are being developed and are already tested using data obtained using another polarimeter. SPARC4 first light is planned to occur in 2022.

Polarization and gamma-ray bursts / **143**

Radio Polarimetry of GRB Afterglows

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As the most energetic explosions in the Universe, relativistic astrophysical transients such as Gamma-ray Bursts (GRBs) provide a unique opportunity to explore physics at extreme energy scales that are otherwise impossible to investigate in Earth-bound laboratories. I will demonstrate the power of radio polarimetric observations, combined with theoretical modeling, in teasing apart the physics of these energetic explosions. I will review the status of radio polarimetric observations of GRB afterglows, and present the first discovery of polarized radio emission with the radio afterglow of GRB 190114C. I will describe how ALMA's unparalleled sensitivity for photometric and polarimetric observations is leading to new insights into the structure, composition, and magnetization of GRB jets. I will conclude by highlighting the current and future role of mm-band polarimetry in the ongoing multi-messenger revolution in extragalactic time-domain astrophysics.

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Fast-follow up Optical Polarimetry of GRBs afterglows

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Gamma-ray Bursts (GRBs) are the most powerful explosions in the Universe. After the collapse of a massive star or the merger of a compact object binary, material is accelerated to relativistic speeds along the narrow beam of a jet. As this jet continues to travel outwards, it collides with the external material surrounding the dying star, producing a long-lasting afterglow that can be seen across the entire electromagnetic spectrum, from the most energetic gamma-rays to radio wavelengths. But how can such material be accelerated and focused into narrow beams? The internal shock model proposes that repeated collisions between material blasted out during the explosion can produce the gamma-ray flash. The competing magnetic model credits primordial large-scale ordered magnetic fields that collimate and accelerate the relativistic outflows.

To distinguish between these models and ultimately determine the power source for these energetic explosions, our team studies the polarization of the light during the first minutes after the explosion. Using novel instruments on fully autonomous telescopes around the globe, we directly probe the magnetic field properties in these extragalactic jets. In this talk, I will review the recent developments that have been made using this technology. Those include some insights on GRB progenitors/remnants, the first detection of highly polarized optical light and confirmation of mildly magnetized jets with large-scale primordial magnetic fields (GRB 120308A), and the early-time polarimetric observations of the first GRB detected at very high TeV energies (GRB 190114C). This suggests some jets can be launched highly magnetized and that the collapse and destruction of ordered magnetic fields at very early times may have powered the explosion itself. Fast-follow up polarimetry opens a new frontier of GRB magnetic field studies in the multimessenger era.

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First study of Vela PWN polarization in X-ray band

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Imaging X-ray Polarimetry Explorer (IXPE) is the first observatory fully dedicated to study the polarization of X-ray sources, it works in the 2-8 keV energy band and thanks to imaging capabilities allows to study polarimetry spatially resolved for the first time. During the first year of observations, Vela Pulsar Wind Nebula (PWN) has been observed for the first time allowing to detect a significant surprising high polarization degree and an angle in agreement with radio observations. PWNe are among the brightest non-thermal X-ray sources in the sky. Many PWNe show axisymmetric equatorial torus/polar jet structures radiating synchrotron X-rays from accelerated electron/positron pairs. The organized magnetic fields in these structures should allow synchrotron polarization in the X-rays. X-ray polarimetric results allow to improve the knowledge on accelerations models in PWNe.

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Polarimetry of neutron stars

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Neutron stars are the strongest magnetised stellar objects in the Universe. Therefore, it is natural to assume that their radiation, either from the magnetosphere or the surface, is strongly polarised. In this review I will summarise the multi-wavelength polarisation properties of isolated neutron stars, mainly rotation-powered pulsars, both time averaged and time resolved and outline observational perspectives for the near future.

Polarization and fundamental physics / **147**

Polarimetric observation to hunt axion dark matter

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Identification of dark matter has been an outstanding problem in physics and astronomy for decades. We found that the polarimetric observations of protoplanetary disks provides a one of the most sensitive probes of a well-motivated candidate for dark matter, axion. Since axion dark matter causes the rotation of the linear polarization plane of photon (i.e. birefringence), it should deform the concentric polarized pattern of protoplanetary disks. Using a polarimetry observation data taken in 2011, we put the best constraint on axion dark matter. We will shortly improve it with our own new observations.

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New capabilities of AGN optical polarimetry with small telescopes: instrumentation & methods

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Recently, our group has discovered new possibilities for studying AGN in polarized light, which has been a “reboot” for some branches of optical research. First, it was shown that all-night monitoring of BL Lac type objects with high accuracy and temporal resolution in polarized light allows us to estimate the size of an optical jet, and the intraday variability is consistent with a simple geometric model of the jet. Second, the technique of AGN reverberation mapping in polarized light was reinterpreted and it was shown that in the case of Sy 1 galaxies with equatorial scattering, the delay of the polarized signal in a broad emission line allows us to estimate the size of the scattering region, which is closely related to the radius of dust sublimation. These approaches have already been successfully applied to several well-known AGNs and have produced quantitative results presented in the report. At the same time, these methods are suitable not only for large instruments, as in the case of AGN

spectropolarimetry, but also for small telescopes. Such an example is the 1-m telescope of the SAO RAS, for which our team developed and launched a new polarimeter in January 2020. This device makes it possible to conduct polarimetric observations in narrow and broad bands and allows us to achieve accuracy of up to 0.1% due to the use of a double Wollaston prism.

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Modeling of magnetic stars

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Magnetic fields can be found at the surface of non-degenerate stars all over the HR diagram. Their nature is split between those contemporaneously generated by dynamo mechanism (e.g. low mass MS stars) and those of fossil origins (e.g. high mass MS stars). This means that there are fundamental differences in their observed properties —for example, while magnetic fields of low-mass stars are ubiquitous and variables on many time scales, magnetic fields are only found in 10% of high-mass stars and their topologies are generally simple and stable.

This said, the way we use polarization to detect these fields, and the way we model this polarization to infer magnetic fields characteristics is very similar for all stars. I will discuss how the modeling of time-domain spectropolarimetry to can be used to recover the field topology.

While the time variation of the polarization signal is necessary for studying field topologies, it can also make the search for fossil fields difficult as they are not present in all massive stars —thus in the context of surveys, it might be ambigous whether a non-detection implies the absence of a field or is a result of a badly-timed observation. I will discuss spectropolarimeric surveys efforts that, when combined with an understanding of detection biases, have been very successful in establishing the properties of fossil fields.

However, these blind survey tactics require too much observing time to efficiently increasing the number of known magnetic massive stars, which would be essential to establish the origin of these fossil fields. I will also discuss targeted survey efforts that leverage other proxies for the presence of fossil fields, such as chemical peculiarities and magnetospheric emission. Finally, I will briefly discuss the impact of fossil field on stellar evolution and on the ultimate demise of massive stars.