Gravità e Fisica Fondamentale

Elena Pian (Bologna, Pisa) & Luigi Stella (Roma)

A nome della comunità astrofisica italiana

Contributors: L. Amati, E. Amato, M. Bachetti, R. Bandiera, S. Bianchi, P. Blasi, M. Branchesi, M. Busso, S. Campana, P. Casella, M. Colpi, E. Costa, M.T. Crosta, D. De Martino, A. Drago, M. Feroci, F. Fiore, G. Ghisellini, G. Giovannini, F. Govoni, L. Gualtieri, G. L. Israel, M. Mapelli, G. Matt, P. Mazzali, S. Mereghetti, A. Pastorello+ PD SN Team, R. Peron, M. Persic, L. Piro, P. Soffitta, A. Possenti, M. Punturo, G. Tagliaferri, A. Tornambè, C. Travaglio, R. Turolla, P. Ubertini, L. Zampieri

What are we up to?

4.1 Come si comporta la Gravità in regime forte?

4.2 Rivelazione delle onde gravitazionali e l'individuazione delle controparti elettromagnetiche delle sorgenti di GW

4.3 Gravità e meccanica quantistica

4.4 Quali sono i meccanismi di accelerazione cosmici per le particelle e la materia? Quale è il ruolo del campo magnetico?

4.5 Esplosioni cosmiche e fisica nucleare

4.1
Come si comporta la Gravità in regime forte?

Strong Field Gravity

Relativistic Binary pulsars
with at least 1 post-newtonian parameter measured

- periastron advance,
- orbital decay,
- time-dilation and gravitational red-shift parameter,
- sin of the inclination of the orbit (equal, in GR, to the shape parameter of the Shapiro delay)
- mass of the companion star (equal, in GR, to the range parameter of the Shapiro delay)
- relativistic precession

* Accurate test of gravity; several GR effects confirmed with very good accuracy

* BUT: direct measurements only at large radii ($R \sim 10^6$ Schwarzschild radii)

PSR
J0024-7204H*
J0024-7204J*
J0045-7319
J0437-4715**
J0514-4002A*
J0621+1002
J0737-3039A
J0737-3039B
J0751+1807
J0823+0159
J1022+1001
J1023+0038**
J1141-6545
J1518+4904**
J1537+1155
J1600-3053
J1603-7202
J1614-2230
J1623-2631*,**
J1640+2224
J1713+0747
J1740-3052
J1748-2021B*
J1750-3703A*
J1750-3703B*
J1756-2251
J1802-2124
J1804-0735*
J1811-1736
J1823-1115
J1829+2456
J1857+0943
J1903+0327
J1906+0746
J1909-3744**
J1915+1606
J1959+2048**
J2019+2425
J2051-0827
J2129+1210C
J2145-0750**
J2305+4707

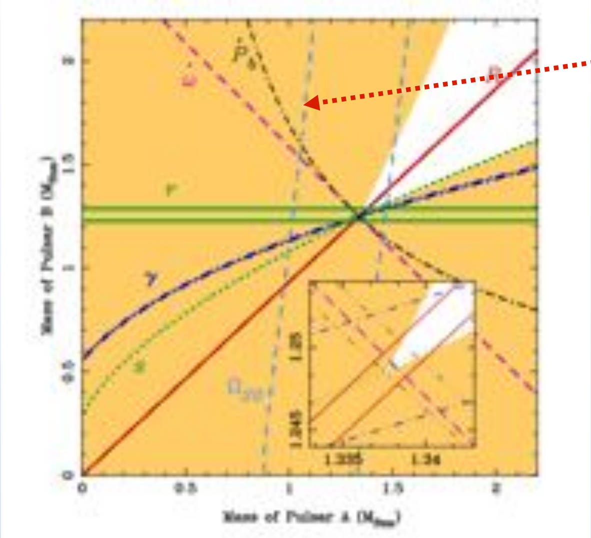
Constraining GR…

The Double Pulsar J0737-3039A/B [Burgay et al. 2003, Lyne et al 2004] remains the best laboratory for precision measurements, e.g.:

Spin period (ms) = 22.699378846809636 ± 0. 0000000000003 (measured to 30 atto-seconds)

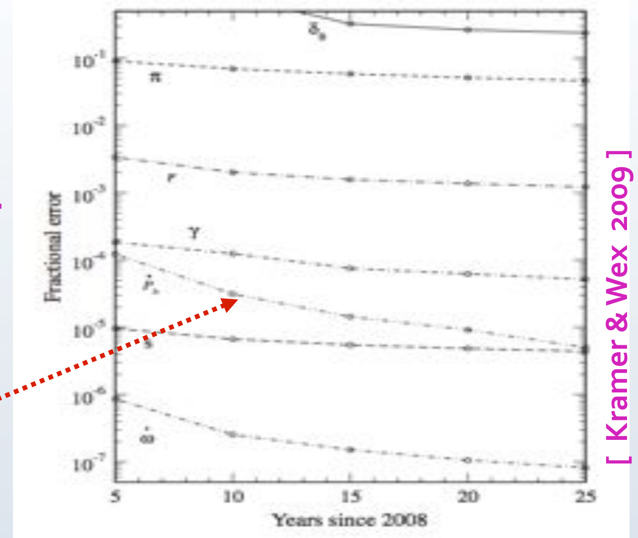
Orbital period (d) = 0.102251562465 ± 0.000000000002 (i.e. 2.45h measured to 173 nano-seconds)

[Kramer et al 2015 (in prep.)]



Already a factor ≈6-7 better than the PSR 1913+16 in constraining the RADIATIVE predictions of GR [Kramer et al. 2015 in prep]

Moreover the fractional error for all the relativistic parameters will improve with time

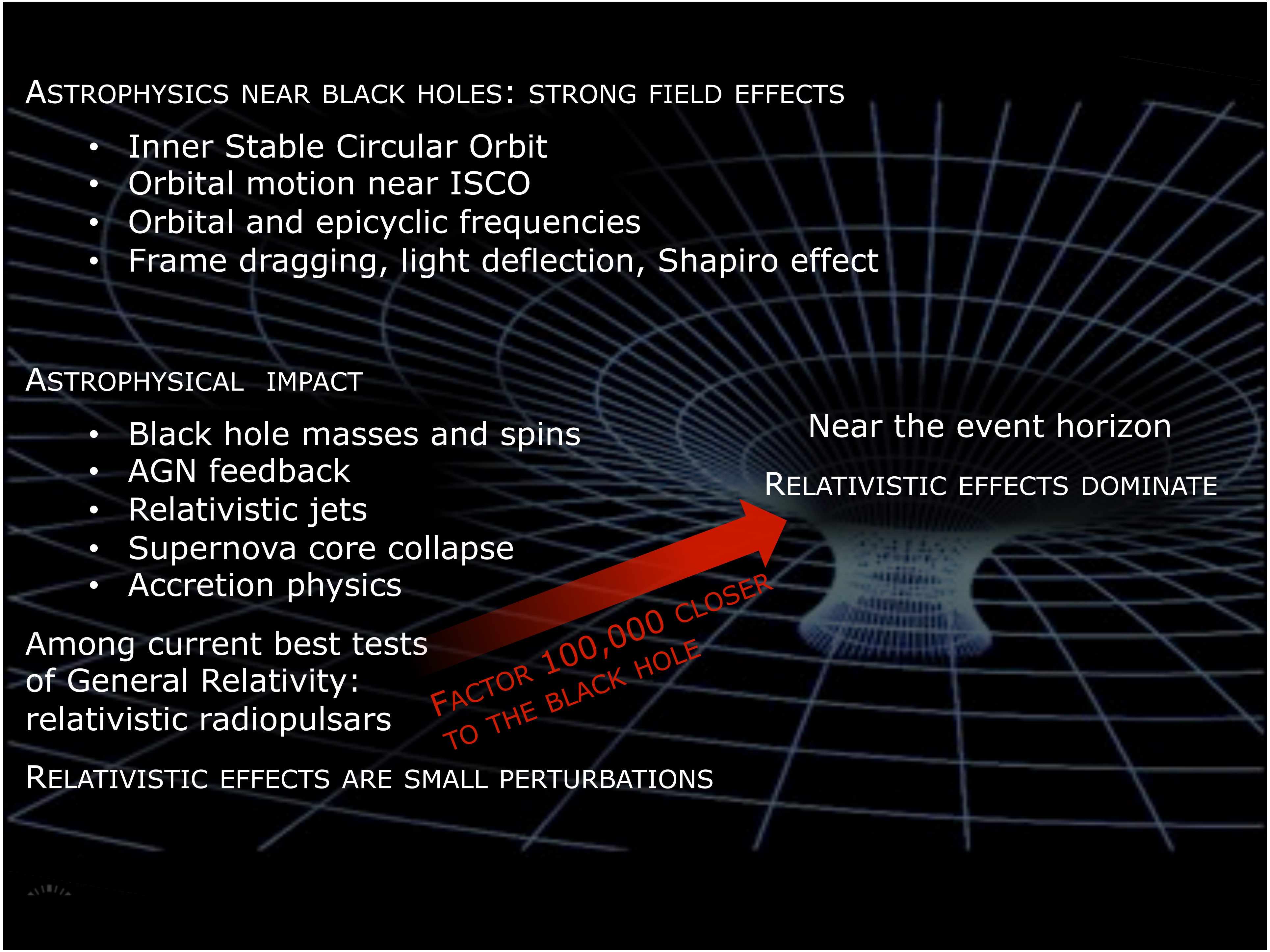


[Kramer & Wex 2009]

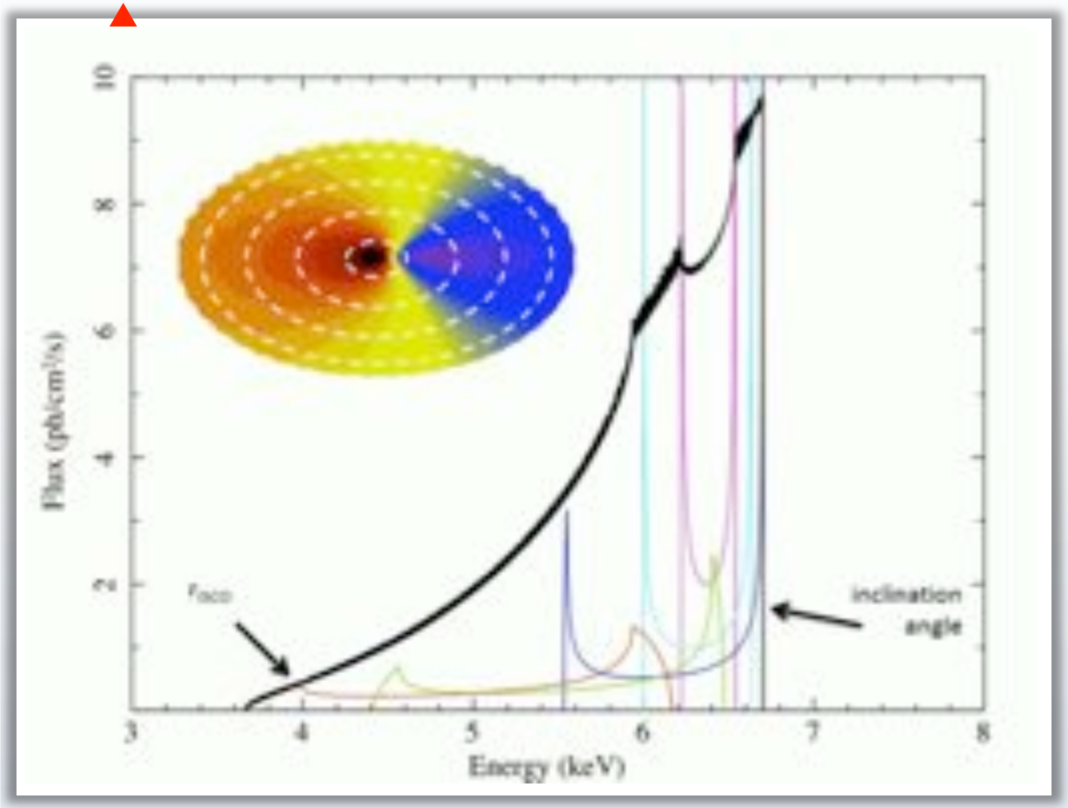
The timing precision of SKA1 and, even more, SKA2, will lead to measure relativistic effects in J0737-3039A/B beyond the first-order PN approx, i.e. the relativistic effects from pulsar spin

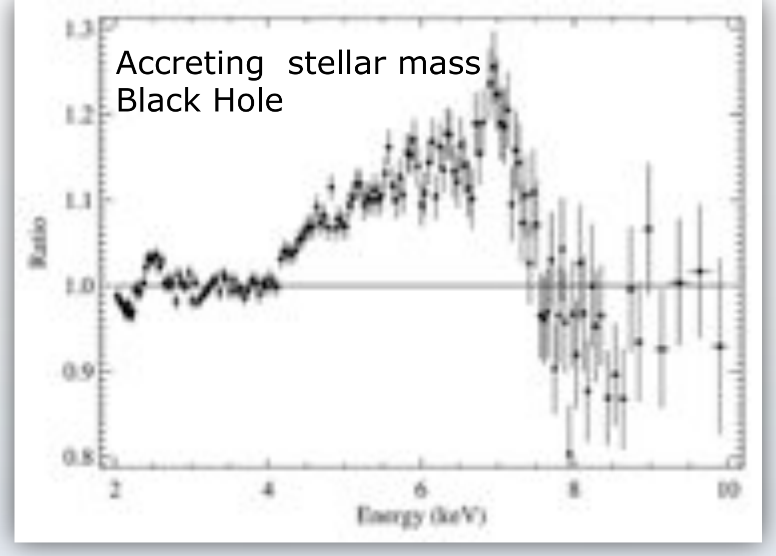
Additional ≈200 of relativistic NS+NS systems will be discovered with SKA1 and SKA2, some of which with the suitable orientation and orbital parameters to directly measure the Lense-Thirring effect (from which the EoS for nuclear matter), the relativistic precession of the spin axis, the relativistic deformation of the orbit, the time-variation of eccentricity, etc…

A radio pulsar in close orbit around Sgr A* would provide even more GR tests !


ASTROPHYSICS NEAR BLACK HOLES: STRONG FIELD EFFECTS
• Inner Stable Circular Orbit
• Orbital motion near ISCO
• Orbital and epicyclic frequencies
• Frame dragging, light deflection, Shapiro effect
ASTROPHYSICAL IMPACT
• Black hole masses and spins
• AGN feedback
• Relativistic jets
• Supernova core collapse
• Accretion physics
Among current best tests
of General Relativity:
relativistic radiopulsars
RELATIVISTIC EFFECTS ARE SMALL PERTURBATIONS
FACTOR 100,000 CLOSER
TO THE BLACK HOLE
Near the event horizon
RELATIVISTIC EFFECTS DOMINATE

Fe-line diagnostic





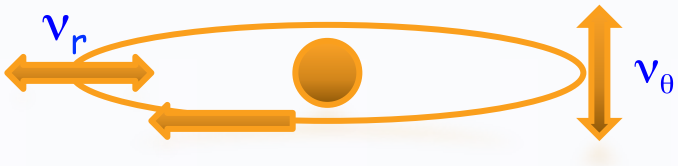
Line profile integrated over entire flow encodes:

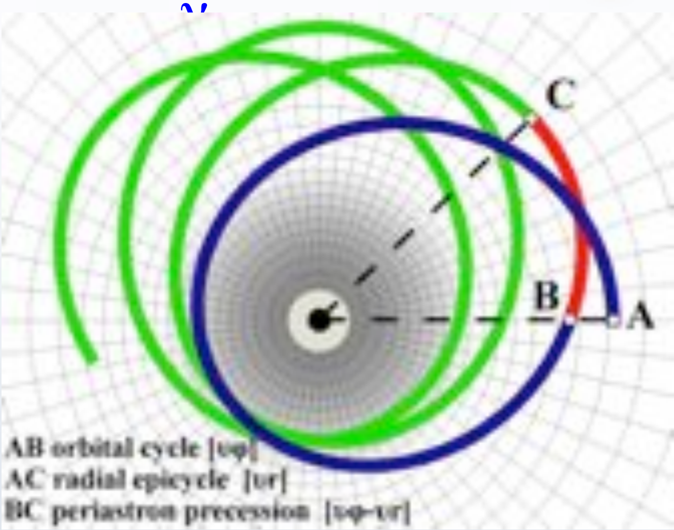
- Strong field relativistic effect: Doppler shifts and boosting, gravitational redshift, strong field lensing

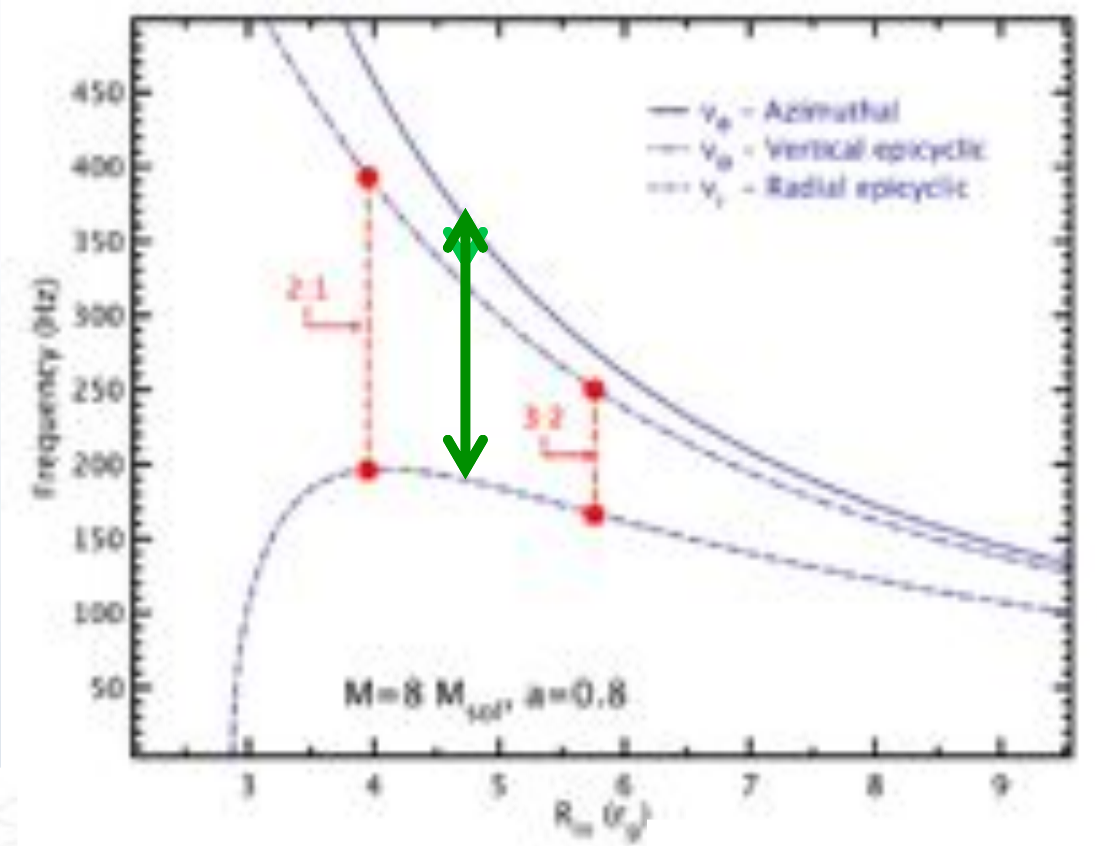
- Observed in Active Galactic Nuclei and X-ray binaries

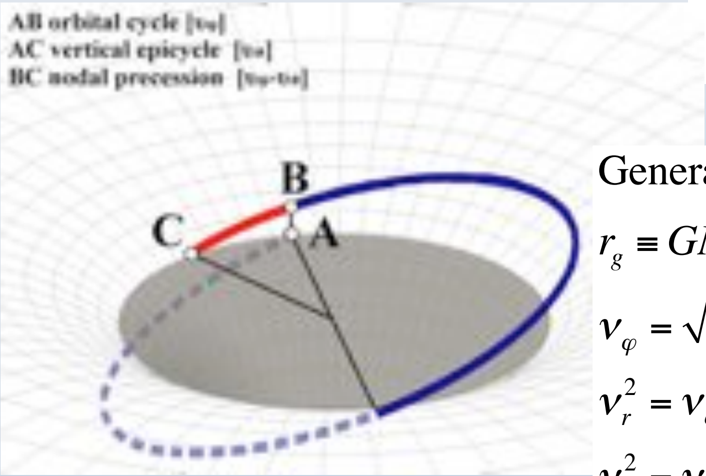
Variability Diagnostic

- Epicyclic Resonance (fixed r)
- Relativistic Precession: nodal and periastron (variable r)









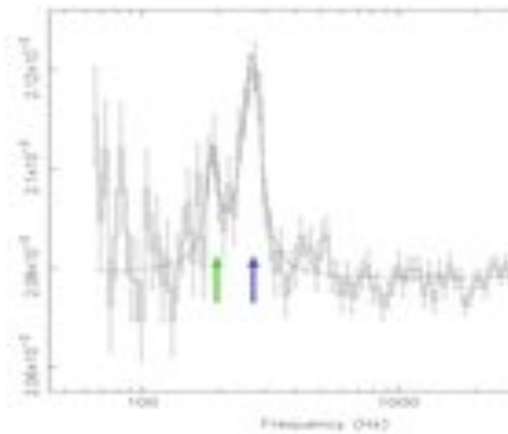
General relativity:

$$r_g \equiv GM / c^2 \qquad j \equiv Jc / GM^2$$

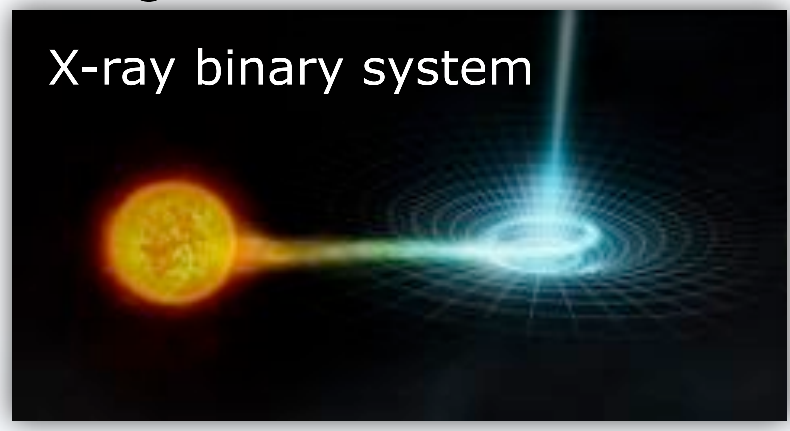
$$\nu_\varphi = \sqrt{GM / r^3} / 2\pi (1 + j(r_g / r)^{3/2})$$

$$\nu_r^2 = \nu_\varphi^2 (1 - 6(r_g / r) + 8j(r_g / r)^{3/2} - 3j^2 (r_g / r)^2)$$

$$\nu_\theta^2 = \nu_\varphi^2 (1 - 4j(r_g / r)^{3/2} + 3j^2 (r_g / r)^2)$$



Strong field GR with stellar mass and supermassive black holes



Athena (mainly bright and relatively faint AGN): Fe-line
1. Measure spin distribution of AGN, relationship with AGN evolution, accretion/ejection history

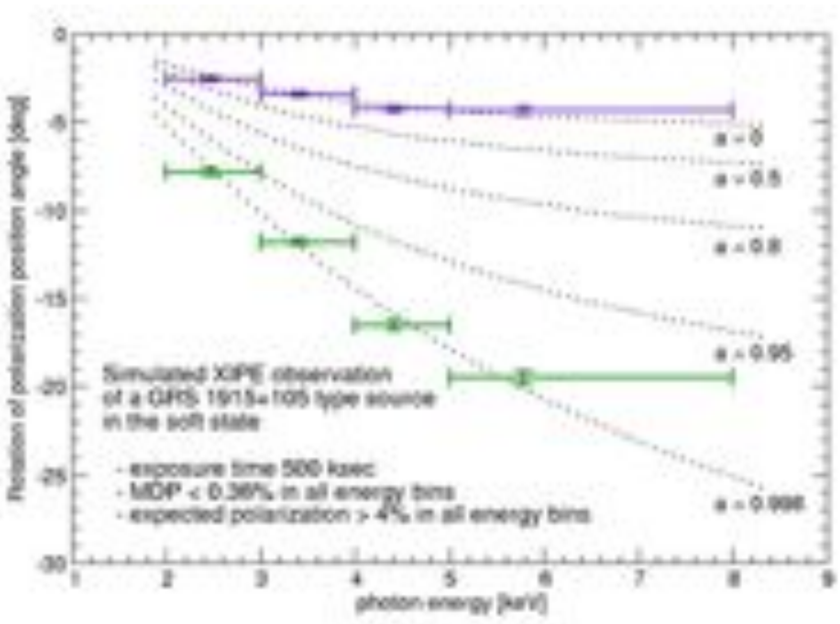
LOFT (X-ray binaries and bright AGN): combined spectral (Fe-line) and timing (QPOs etc) on dynamical timescales
1. Precisely measure orbital and epicyclic frequencies at each radius
2. Obtain strong field velocities and relativistic effects, such as light bending, as a function of absolute radius
3. Compare to GR predictions in strong field regime
4. Measure black hole mass and spin: 0.1% precision in X-ray binaries

Event Horizon Telescope (mm VLBI): black hole "shadow" in SGR A* and M87; strong field light bending

X-ray polarimetry diagnostic

- **X-ray emission is generally produced by physical mechanisms with intrinsic polarized emission (synchrotron, cyclotron, non-thermal bremsstrahlung).**

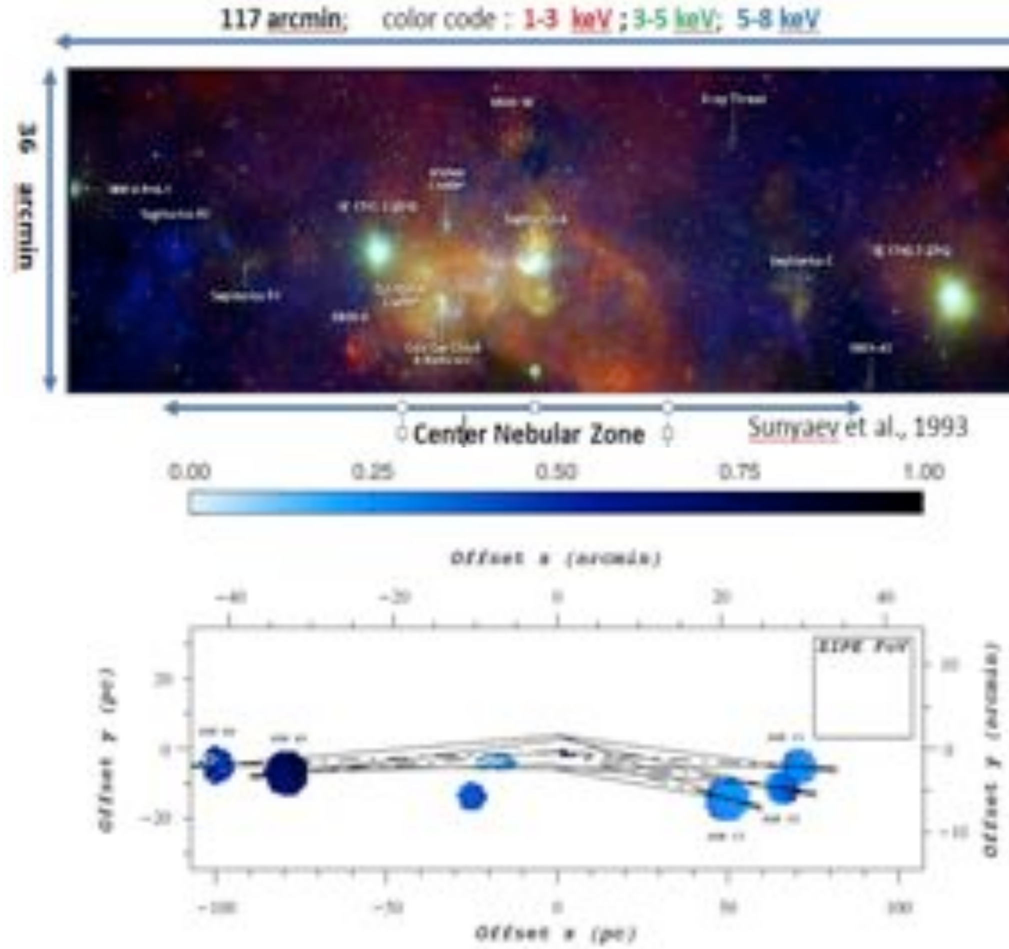
- **Thermal (non-polarized) emission can be polarized by :**
  (1) scattering in non-spherical structures common in X-ray emitting sources
  (molecular clouds around the Galactic Center, disks around BHs, ionization-cones and torus in AGNs).
  (2) propagation in highly magnetized plasma in X-ray binaries, pulsar and magnetars;



XIPE (X-rays):
- Polarization -angle dependence of thermally emitted X-rays in strong-gravity regime: an alternative way to measure the spin of stellar mass black holes (based on photoelectric X-ray polarimeter);
- Birefringence effects and search for axion-like particles.

Astrogam (gamma-rays): GRB polarization.

Was Sgr A* a faint AGN in the past ?



By scattering from cold molecular clouds (Sgr B complex, Sgr C complex) around the galactic center, the radiation becomes polarized. The angle of polarization pinpoints the emitting X-ray source (possibly SgrA*) and the degree of polarization locates their real distance). There measurements are afforded by XIPE.

4.3
Gravità: teorie alternative e meccanica quantistica

Constraining alternate theories...

Tensor-scalar theories predict the emission of a large amount of DIPOLAR scalar waves (as opposed to the dominant QUADRUPOLAR radiation predicted by GR) in binaries with a high asymmetry in the degree of compactness ε (i.e. in the self-gravity) of the two bodies

$$\varepsilon_{NS} = \left|\frac{E_{grav}}{E_{rest}}\right| = \frac{GM_{NS}}{c^2 R_{NS}} \cong 0.2 \qquad \varepsilon_{WD} = \left|\frac{E_{grav}}{E_{rest}}\right| = \frac{GM_{WD}}{c^2 R_{WD}} \cong 10^{-4}$$

In fact, NS+WD binaries (like J1738+0333 and J0348+0432) for which one can measure or constrain the orbital decay and the masses are the best available systems for constraining the coupling constant α_0 in tensor-scalar theories [Esposito-Farese 2005; Freire et al 2012]

$g_{\mu\nu}$ = metric

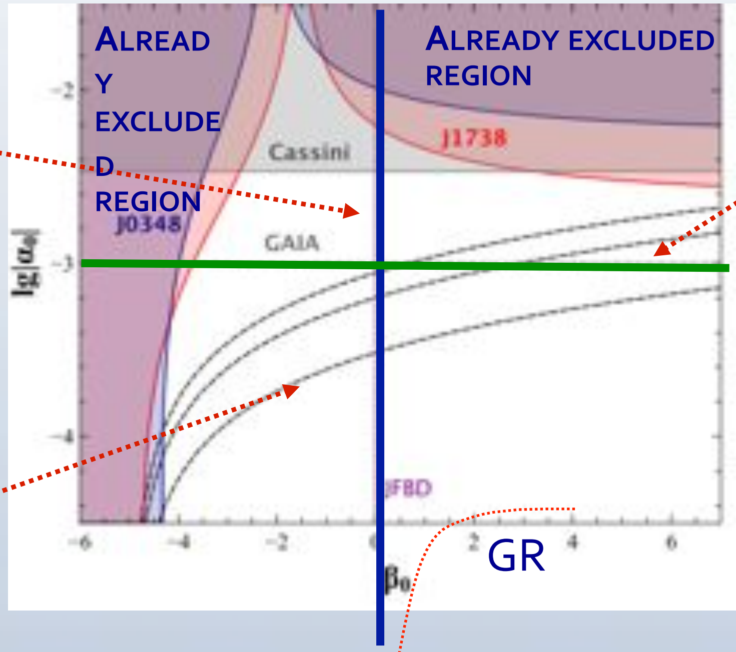
$$a(\varphi) = \alpha_0\varphi + \frac{1}{2}\beta_0\varphi^2$$

φ scalar field

$a(\varphi)$ coupling field-matter

α_0, β_0 coupling parameters

Brans-Dicke



Expected upper bound from GAIA

Upper bound from discovery of a MSP+BH binary

[Shao et al. 2015]

Constraining principles and constants…

[© Hessels 2014]

The **Strong equivalence principle (SEP)** can be tested by precisely measuring the orbital motion of the inner NS+WD binary in the strong gravitational field of the outer orbiting WD in the triple system J0337+1715

Few **tens of such systems** expected to be in the Galaxy and discovered in the future with SKA and SEP tested with exquisite precision

Einstein equivalence principle (EEP), namely the local Lorentz invariance **(LLI)** of gravity and the local position invariance **(LPI)** of gravity, are nowadays best constrained with pulsar timing experiments. These constraints will improve a factor 10-50 with next generations SKA experiments

The constraints on **time-variation of the gravitational constant** G [Freire et al. 2012], from observations (both VLBI [Deller et al. 2008] and timing [Verbiest et al. 2008]) of the pulsars J0437−4715 and J1738+0333, are already comparable to the best constraints from the Solar System experiments [Will 2014]. Pulsar-derived limits will improve significantly, and pulsar tests are sensitive also to strong-field effects on $\dot{G}$ [Wex 2014]

The exciting perspectives of a PSR+BH…

FINDING AND TIMING A PSR-BH BINARY (AND MAYBE A PSR-MSP BINARY IN A GLOBULAR CLUSTER [Clausen et al. 2014])

From the ordinary PK parameters — ***BH mass with precision < 0.1%***

From precessional effects on semi-major axis and longitude of periastron — ***BH spin S with precision < 1%***

From M & S $\chi \equiv \frac{c}{G}\frac{S}{M^2}$ — $\chi \leq 1$ ***Test of*** Cosmic Censorship Conjecture" [Penrose 1969]

FINDING AND TIMING A PSR CLOSELY ORBITING SGR A*

From only 1 PK parameter — ***BH mass with precision < 0.001%***

From BH oblateness — ***BH quadrupole moment Q with precision ~ 1%***

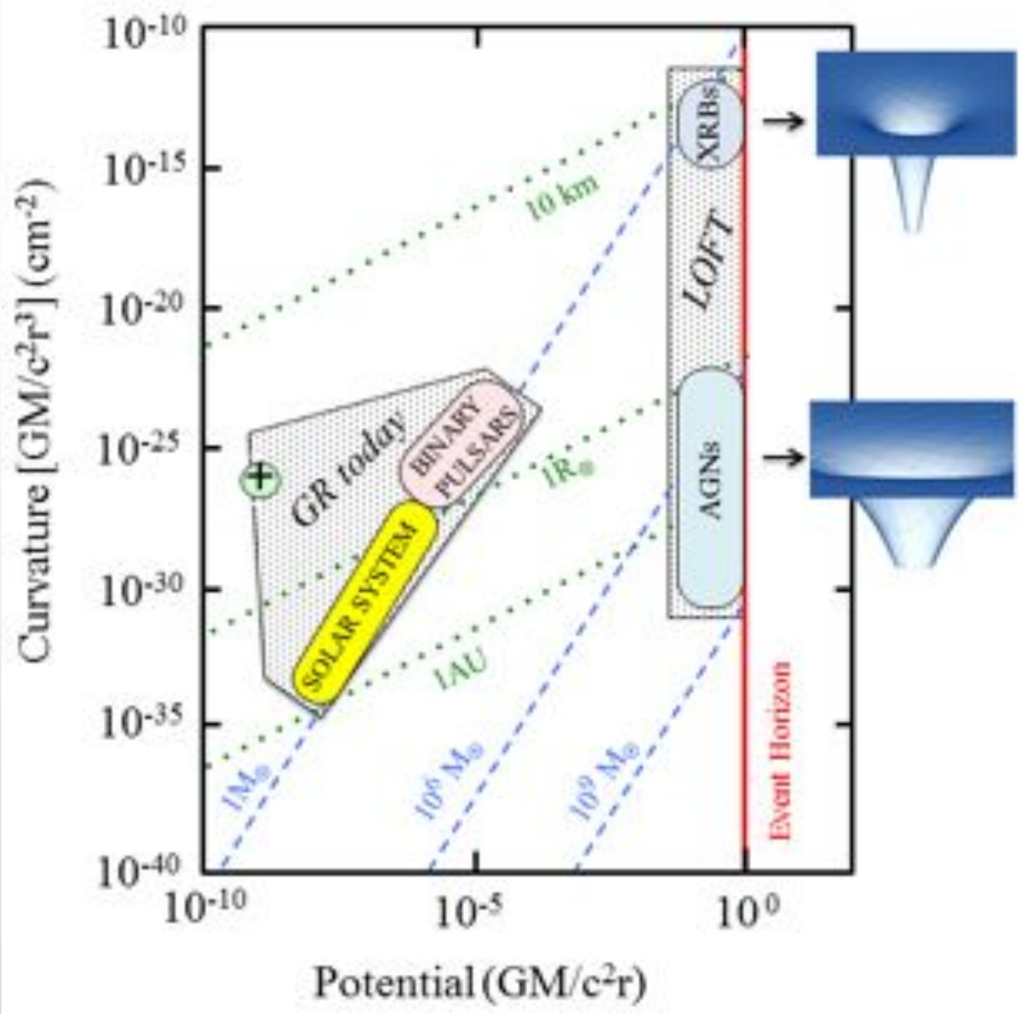
From M & Q $q \equiv \frac{c^4}{G^2}\frac{Q}{M^3}$ — $q = -\chi^2$ ***Test of*** No Hair theorem"

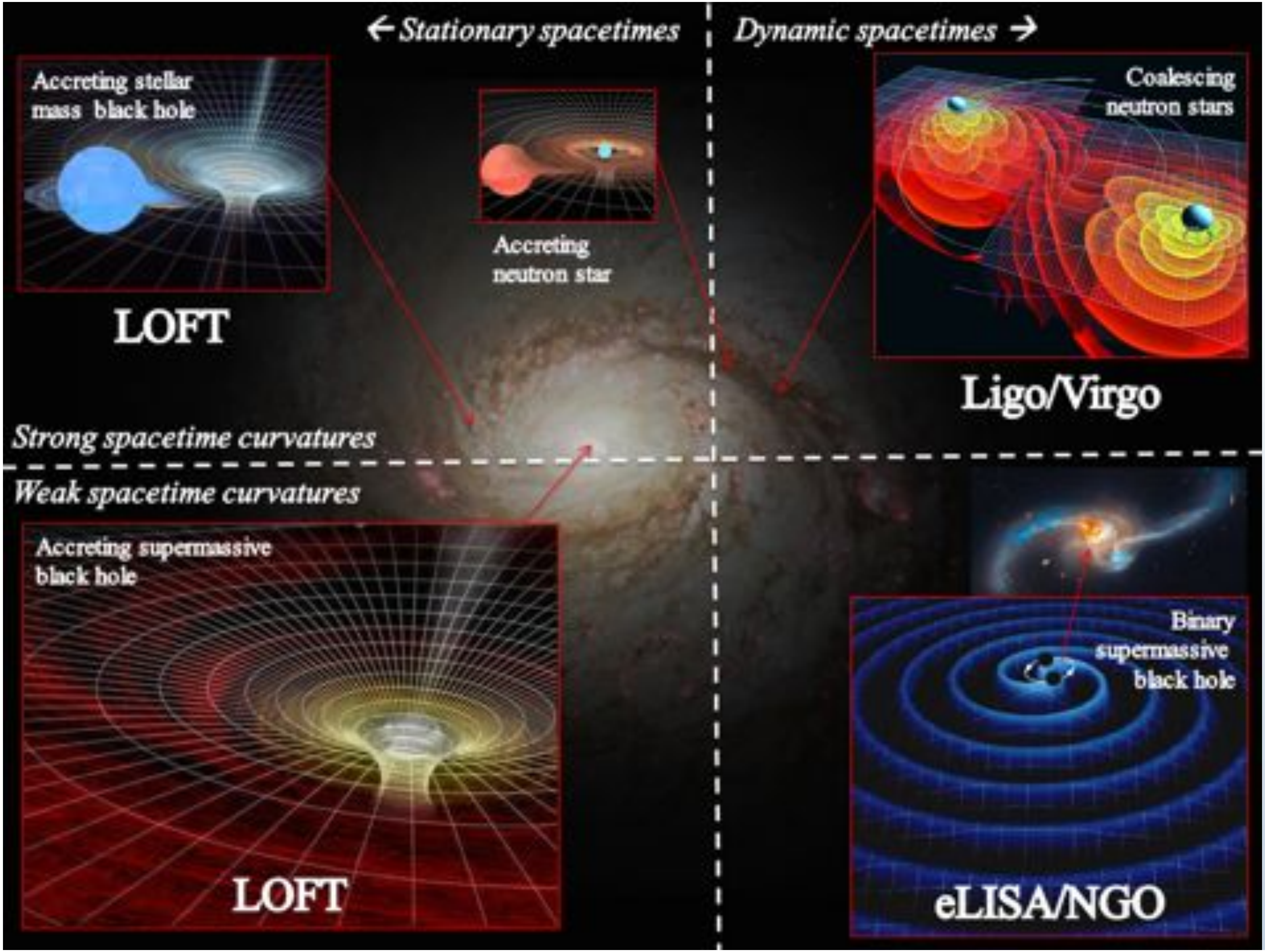
Probing gravity with X-ray Diagnostics (Fe-line & QPOs)

* Strong fields and both:
- weak curvatures (AGN)
- strong curvature (XRB, BH & NS)

- Complementary to gravitational wave experiments: LOFT probes *static* spacetimes

- Testing/constraining alternative gravity theories that differ from GR only in the strong field regime (e.g. Einstein-Dilaton-Gauss-Bonnet)





← Stationary spacetimes
Dynamic spacetimes →
Accreting stellar mass black hole
Accreting neutron star
Coalescing neutron stars
LOFT
Ligo/Virgo
Strong spacetime curvatures
Weak spacetime curvatures
Accreting supermassive black hole
Binary supermassive black hole
LOFT
eLISA/NGO

L'Astrometria Relativistica&Fisica Fondamentale:
L'Astrometria Gravitazionale

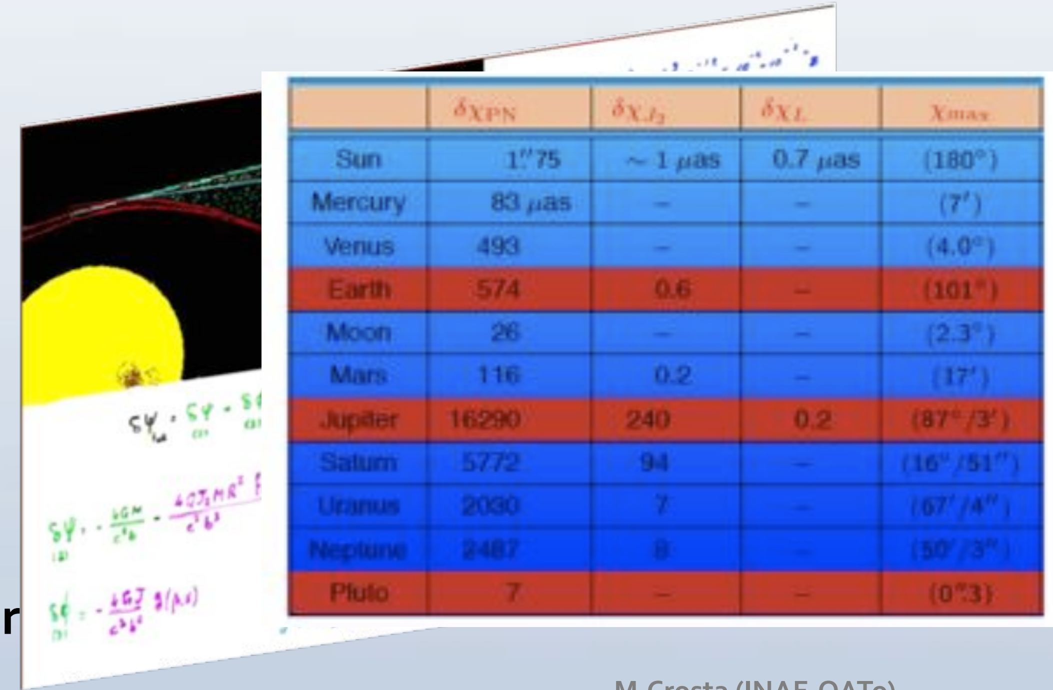
Con Gaia accuratezza del micro-arcosecondo (μas) -> deflessioni relativistiche della luce per tutte le direzioni di arrivo nei campi gravitazionali del sistema solare:

<u>necessità di una trattazione completamente relativistica della propagazione della luce stellare.</u>

<u>Goals:</u>

<u>1) Riformulazione di tutte le grandezze fisiche inerenti alle misure nello spazio-tempo del nostro laboratorio,</u> ovvero nel Sistema Solare.

2) Correzioni delle misure di PSR per Potenziale della Galassia

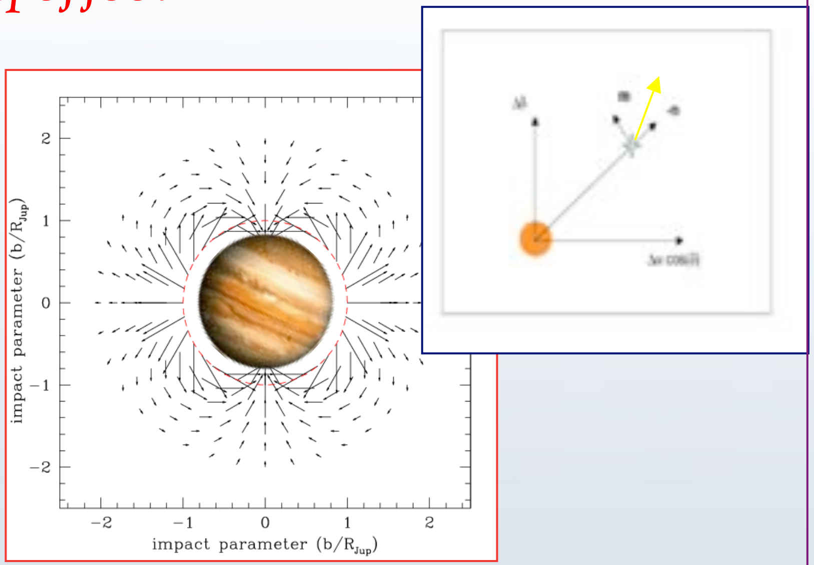


	$\delta\chi_{PN}$	$\delta\chi_{J_2}$	$\delta\chi_{L}$	χ_{max}
Sun	1''75	~ 1 μas	0.7 μas	(180°)
Mercury	83 μas	–	–	(7')
Venus	493	–	–	(4.0°)
Earth	574	0.6	–	(101°)
Moon	26	–	–	(2.3°)
Mars	116	0.2	–	(17')
Jupiter	16290	240	0.2	(87°/3')
Saturn	5772	94	–	(16°/51'')
Uranus	2030	7	–	(67'/4'')
Neptune	2487	8	–	(50'/3'')
Pluto	7	–	–	(0''3)

esperimenti della RG in bassa gravità con Gaia: caso "locale"

- **Misura della deflessione della luce prodotta dal quadrupolo di Giove: predetto dalla RG e mai misurato!!**

"q-effect"



campo vettoriale delle posizioni stellari deflesse attorno Giove, misurabili da Gaia o VLTI

(Crosta & Mignard, QCG, 2006)

IMPORTANTI RICADUTE

1. ulteriore conferma della RG di Einstein-> eliminazione di alcune teorie alternative
2. estrapolazione della misura ai cluster di galassie -> valutazione del contributo di quadrupolo al lensing nella determinazione della materia oscura
3. Effetti gravitomagnetici e post-newtoniani sia di ordine superiore sia legati alla velocità di Giove
4. Effetti relativistici con le Quasars (Kopeikin et al.,) e link tra sistemi di riferimento dinamici e ICRF (Souchay et al.)
5. prima applicazione di soluzione esatte tipo Erez-Rosen (Bini, Crosta, de Felice, Geralico and Vecchiato 2013 Class. Quantum Grav. 30 045009)
6. Estensione alle misure di Euclid

Tests astrometrici della RG&Local Cosmology

esperimenti della RG in bassa gravità con Gaia: caso "globale"

misurare $|1 - \gamma| = 3\times10^{-7}$ ⇒ deviazione 3σ dalla RG!

•in RG γ=1;

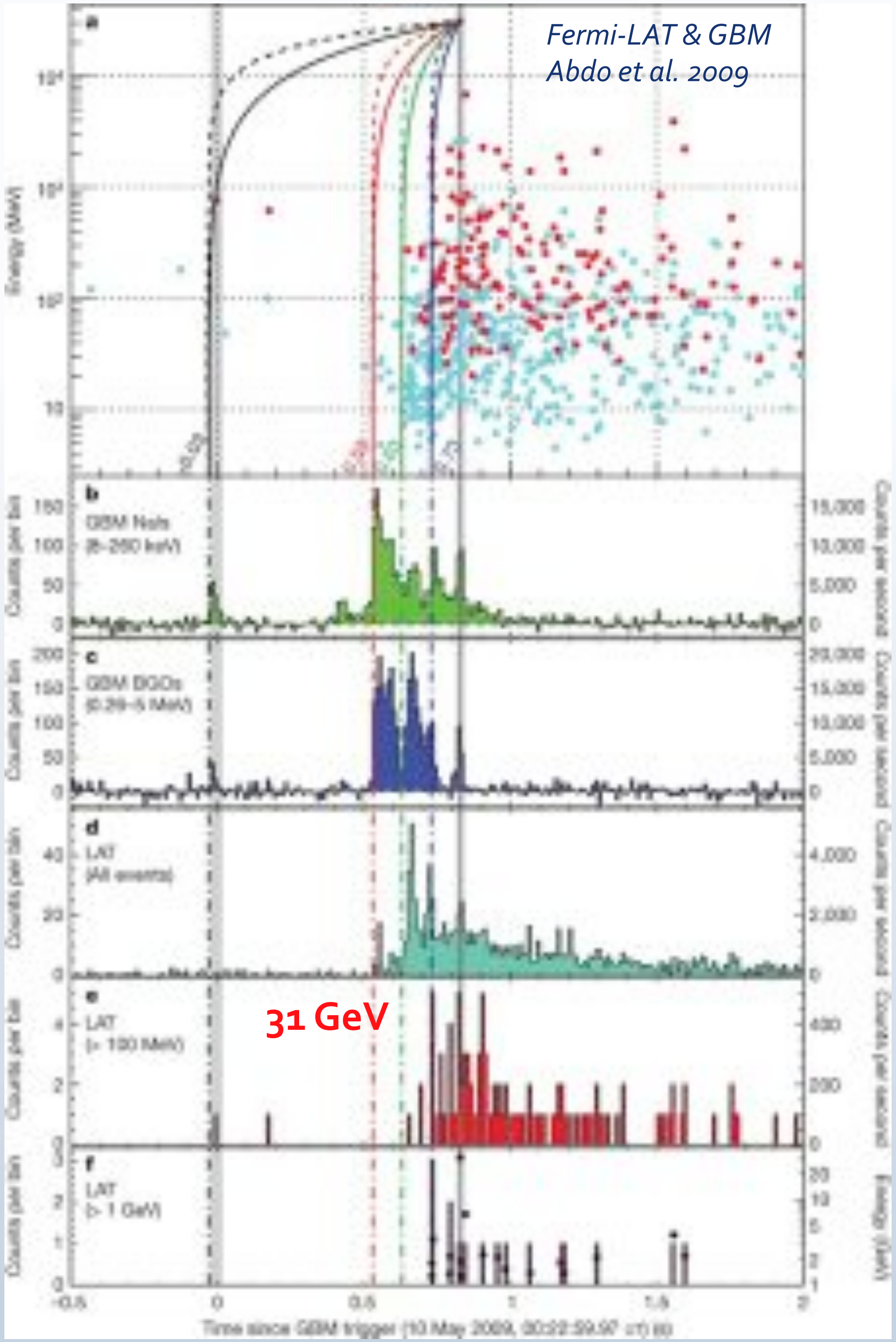
• le teorie alternative, es. le *scalari-tensoriali*, predicono la RG come attrattore cosmologico e deviazioni residue da 1 entro un intervallo $|\gamma - 1| \approx 10^{-5} - 10^{-7}$

La misura di tali deviazioni dipende dalla teoria scalare-tensoriale adottata

=> "quantizzazione" della gravità, verifica dei modelli inflazionari, f(R) gravity e problema della *dark matter* e *dark energy* , violazione del principio di equivalenza, non costanza delle costanti fisiche, etc..

Altre attivita' di Gravitazione Sperimentale (IAPS)

- accelerometro ISA per BepiColombo,
- esperimento LARASE per verifiche della gravitazione in campo terrestre
- misura di G e verifica del Principio di Equivalenza.



A Multidisciplinary laboratory: short GRBs

Goals:

1) Progenitors of binary compact star mergers
2) Acceleration and emission mechanisms
3) Relevance to quantum physics and gravity: “granularity” of spacetime on Planck scales
4) Nucleosynthesis
5) GWs

Example: Short GRB090510 (z = 0.9, Duration: 2 seconds) AGILE, FERMI LAT + GBM

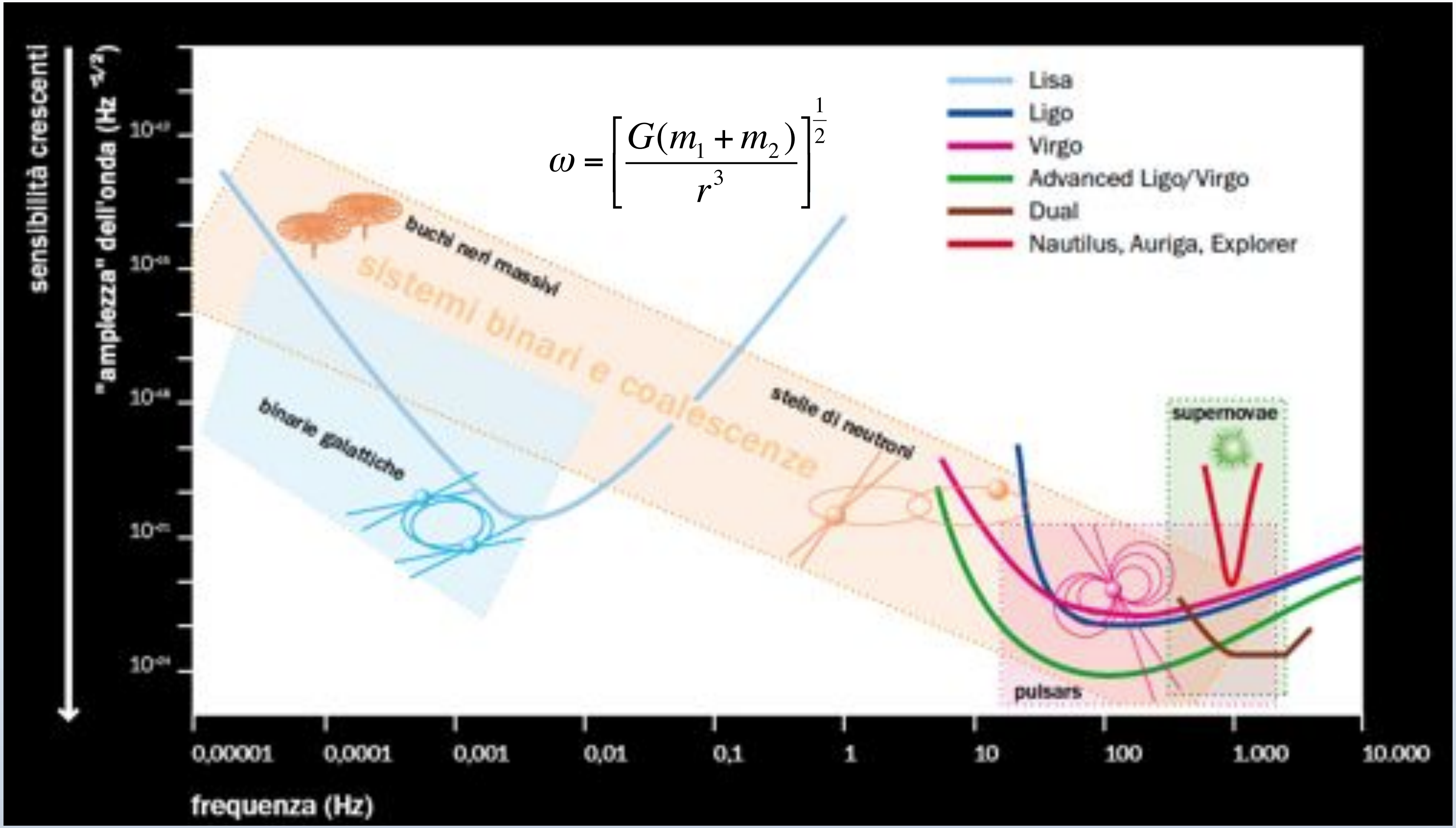
The detection of multi-GeV photons at intervals < 1 s puts tight constraints on **Lorentz Invariance Violation**

Uniqueness of interpretation is debated; see for example negative results of HST imaging of SN1994D (Ragazzoni et al. 2003), and various studies of G. Amelino-Camelia, F. Fiore

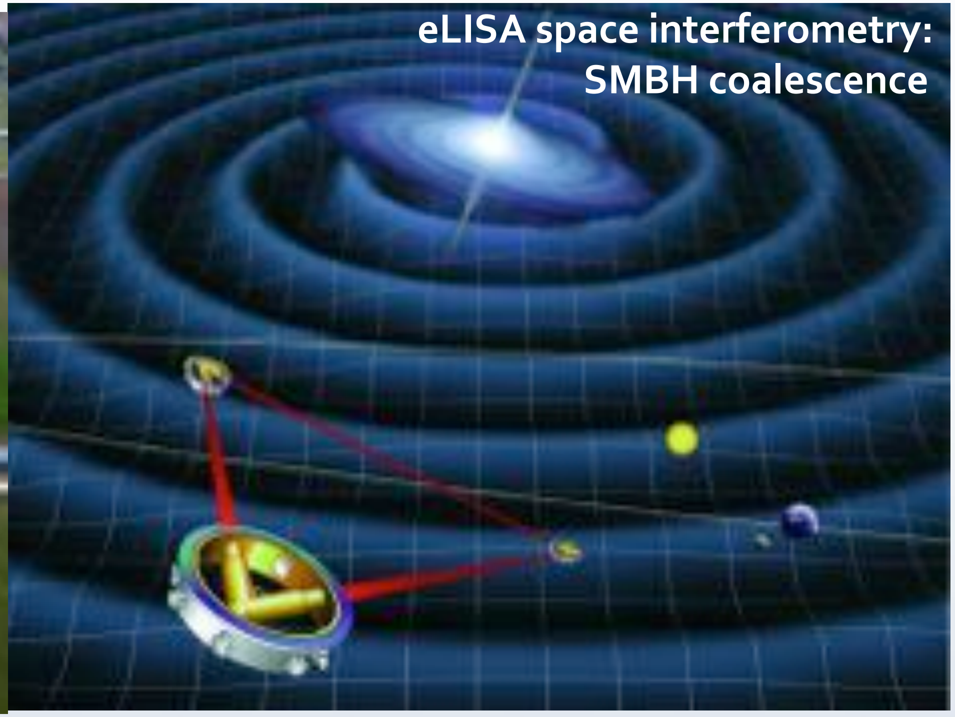
4.2
Rivelazione delle onde gravitazionali e individuazione delle controparti elettromagnetiche delle sorgenti di GW

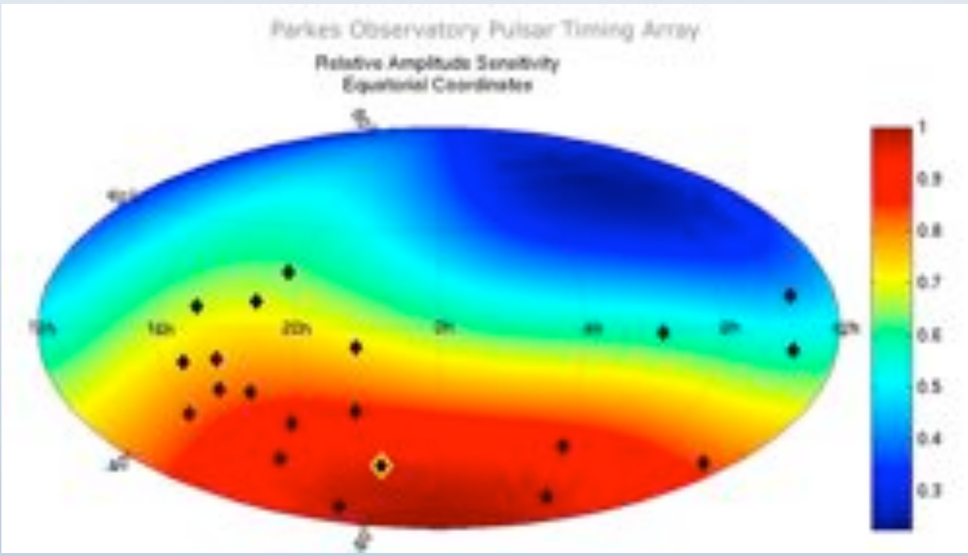
FRONTIER: detection of Gravitational Waves

INAF has a role in the EM follow-up (see MoU with Ligo-Virgo!)



Gravitational Waves





Pulsar Timing Array: use PSRs to detect relic GWs

Goals:

1) look into heart of explosions/ mergers (including big bang)
2) Nature of compact stars
3) Determine standard "sirenes"

Summary of plausible observing scenario

LSC & Virgo collaboration arXiv:1304.0670

		aLIGO/Virgo Range				Rate	Localization	
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within $5\,\mathrm{deg}^2$	$20\,\mathrm{deg}^2$
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

INAF has decided to participate in the EM follow-up program <u>as an Institution</u> by providing observational resources and the expertise in time domain astronomy

Wide-field telescope

Reference images
Observational strategy

Image Analysis Server Software to select a sample of candidate counterparts

- **GPU** for rapid and precise photometry
- **Machine learning** to identify and classify transients: **thousands to a few**

Candidate characterization the candidates

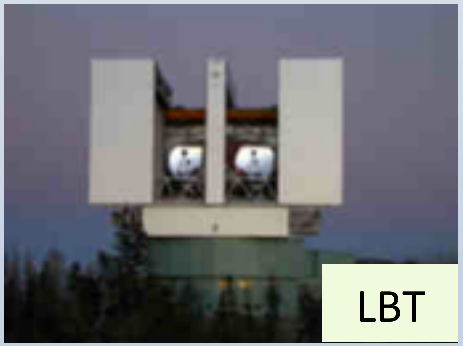
- Light curve
- Spectra
- Multiwave-length

The EM Counterpart!

Approved observing programs at VST, TNG, NOT, LBT

STEPS for an efficient EM-follow up

VST



STEP 1

Search & Detect

Transients in the error box provided by LVC have to be discovered and measured *as soon as possible*

Telescopes to find transients in the LVC error box

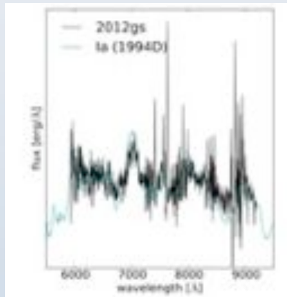
Distributed at different latitudes/longitudes

STEP2

Observe & Characterize

The detected transients have to be observed to infer their nature

Telescopes to obtain spectral features of transients



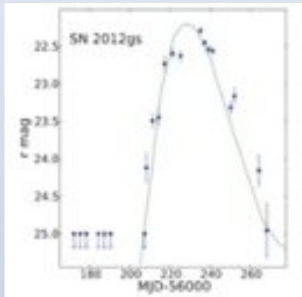
λ

STEP 3

Follow & Study

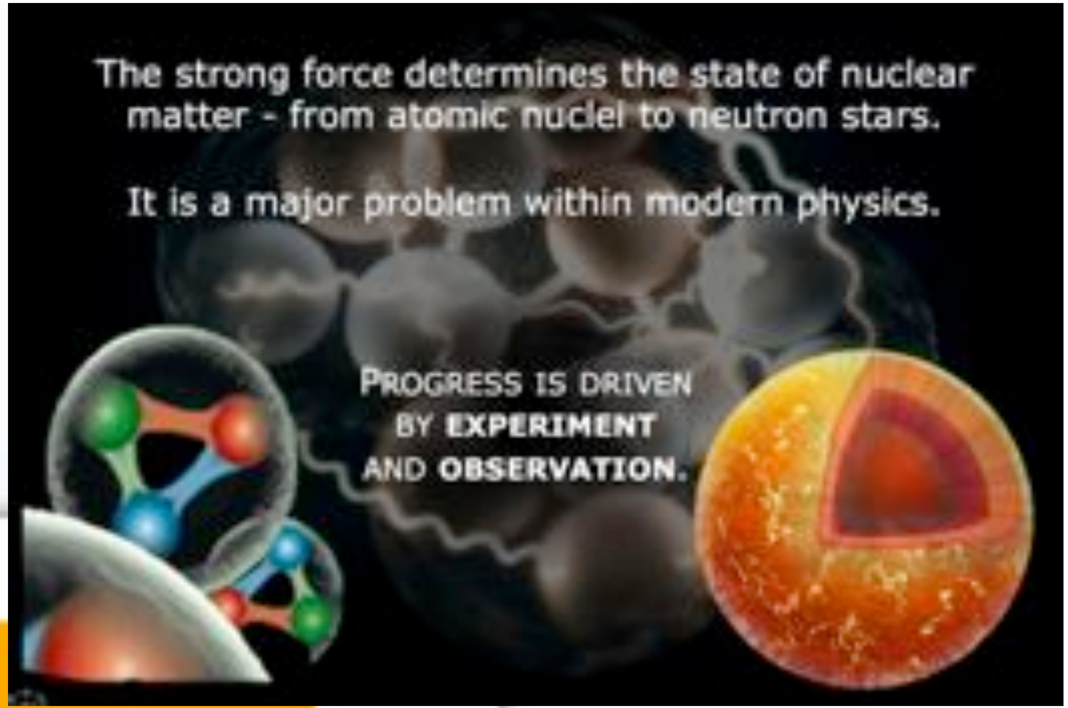
Follow-up at all observable λ for an adequate time to study the physical properties of

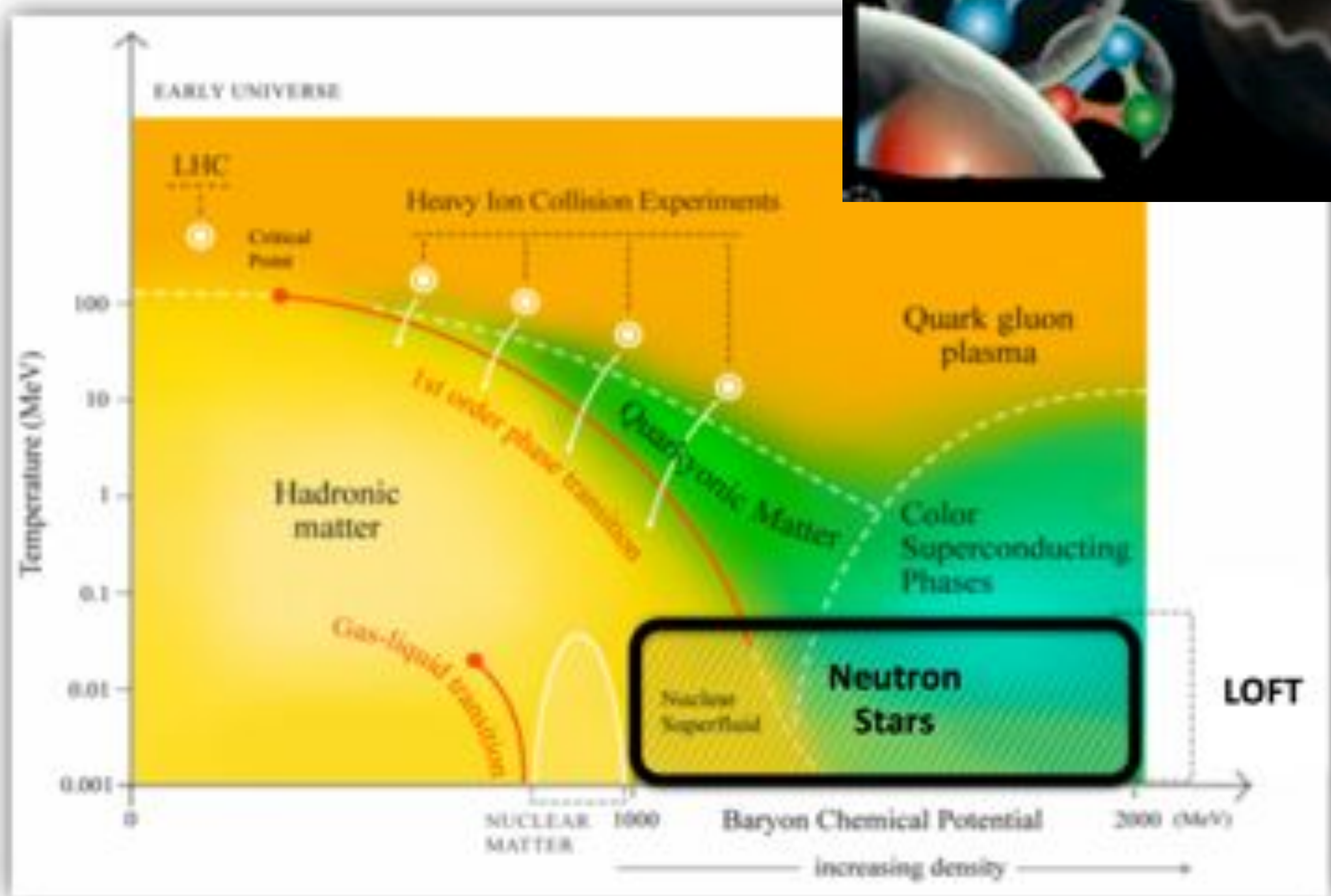
the EM counterparts of GW



time

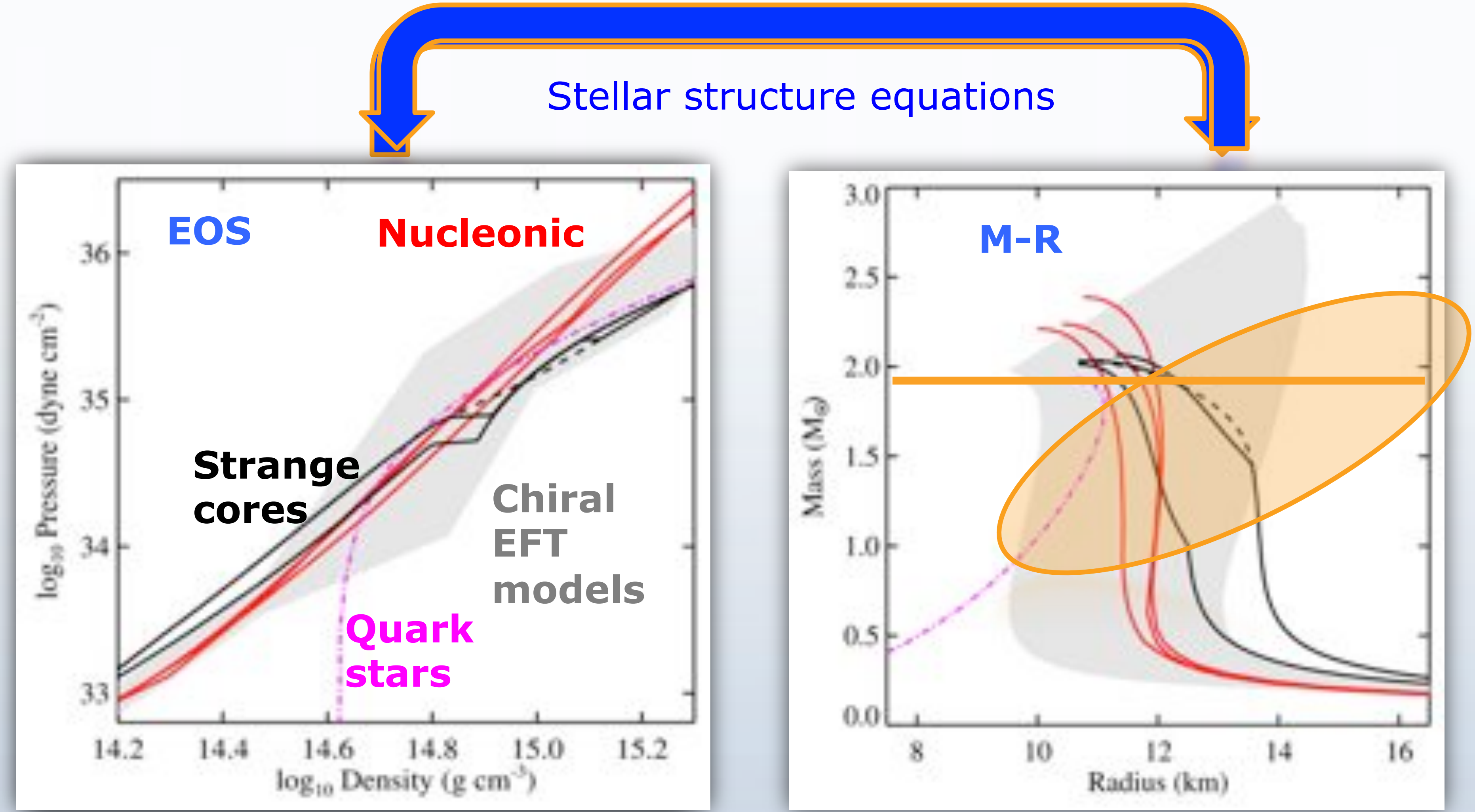
Materia ultradensa,
Interazione forte,
Campi magnetici estremi





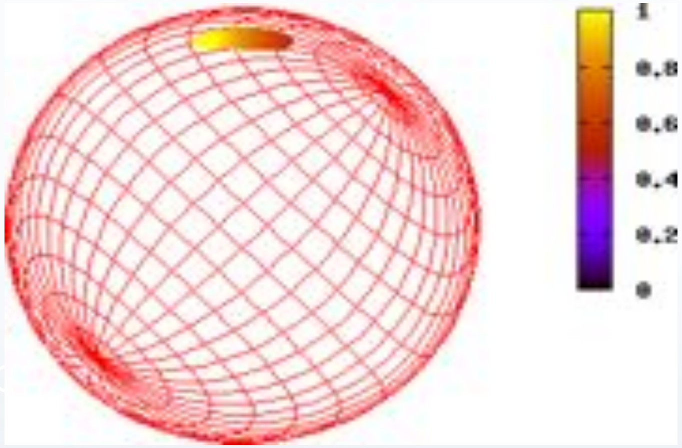
Neutron stars contain the **densest** and most **neutron-rich** matter **in the Universe**.

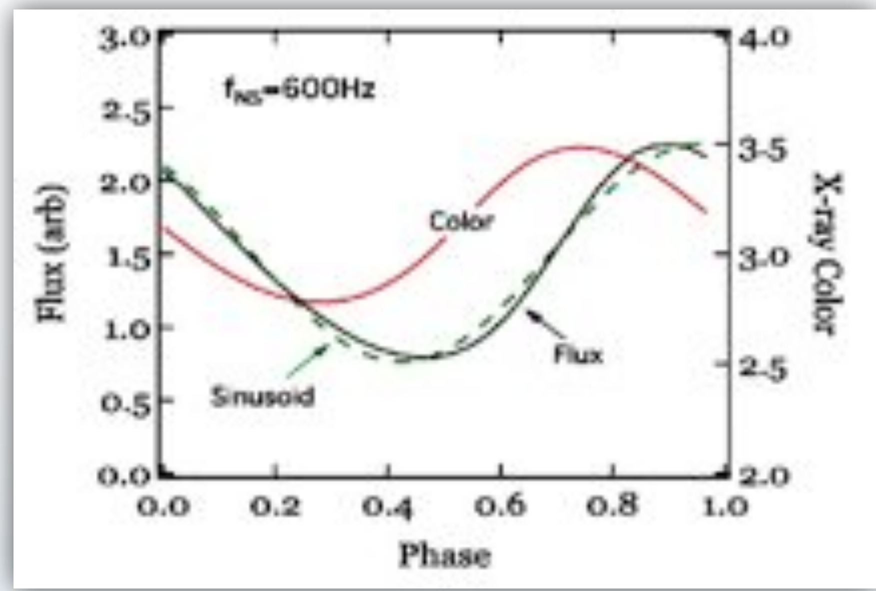
The strong force determines the 'stiffness' of neutron star matter.
This is encoded in the **Equation of State**.



Must measure **both M and R** to **high precision**
(low statistical and systematic errors) for a **range of M**.

Determining Mass and Radius of Neutron Stars



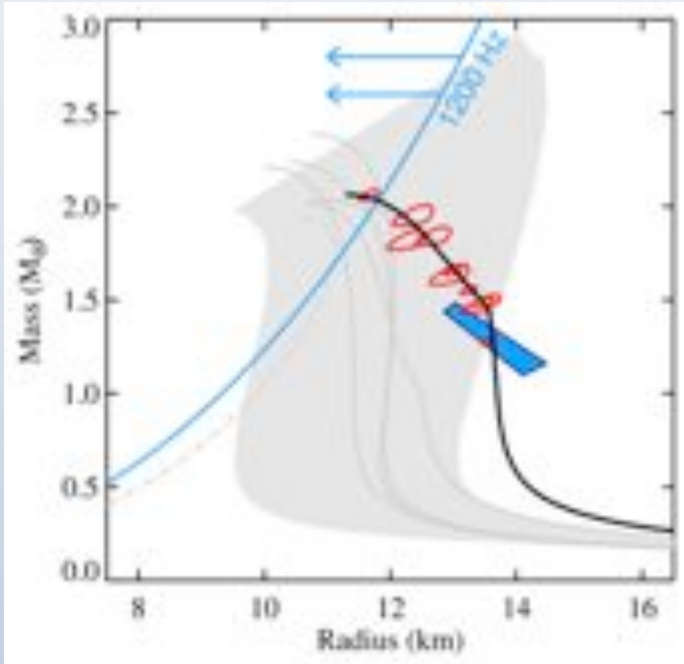


X-rays: LOFT (~10 N; methods 1,2,3; ~ 3-4 % errors on M and R)
NICER, Athena (few NSs; method 1; 10% error on M),

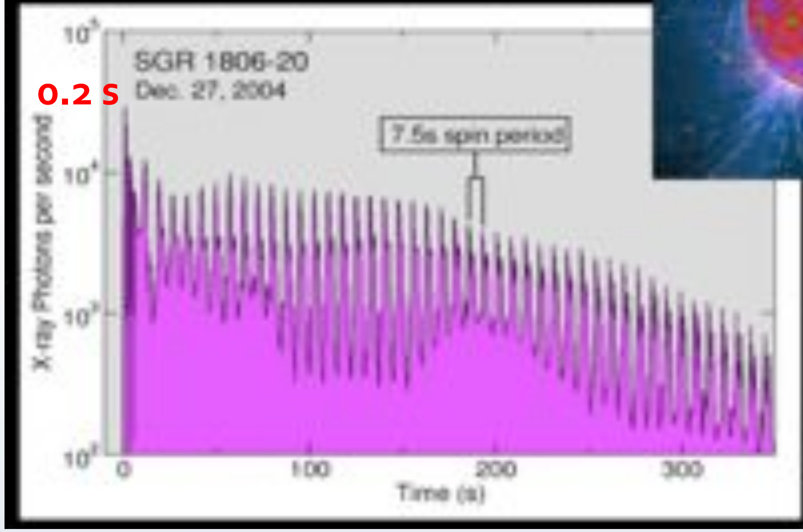
1. Hotspots on neutron stars generate pulsations
2. Fastest spin period
3. Seismic oscillations during Magnetar Flares

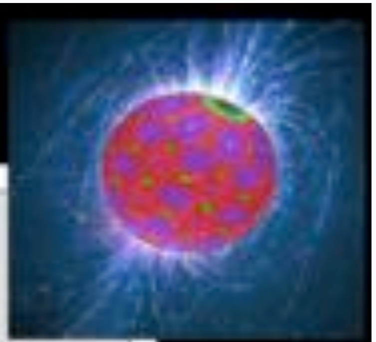
RADIO: SKA (~10% errors ?)
4. Measuring M and I (moment of inertia)
in some binary pulsars

GWs: aVirgo/aLIGO (errors TBD but large)
5. Signal from coalescing binary neutron stars



Magnetars: B-field Power





SGR1806-20 (15 kpc) L_γ = 10^{47} erg/s

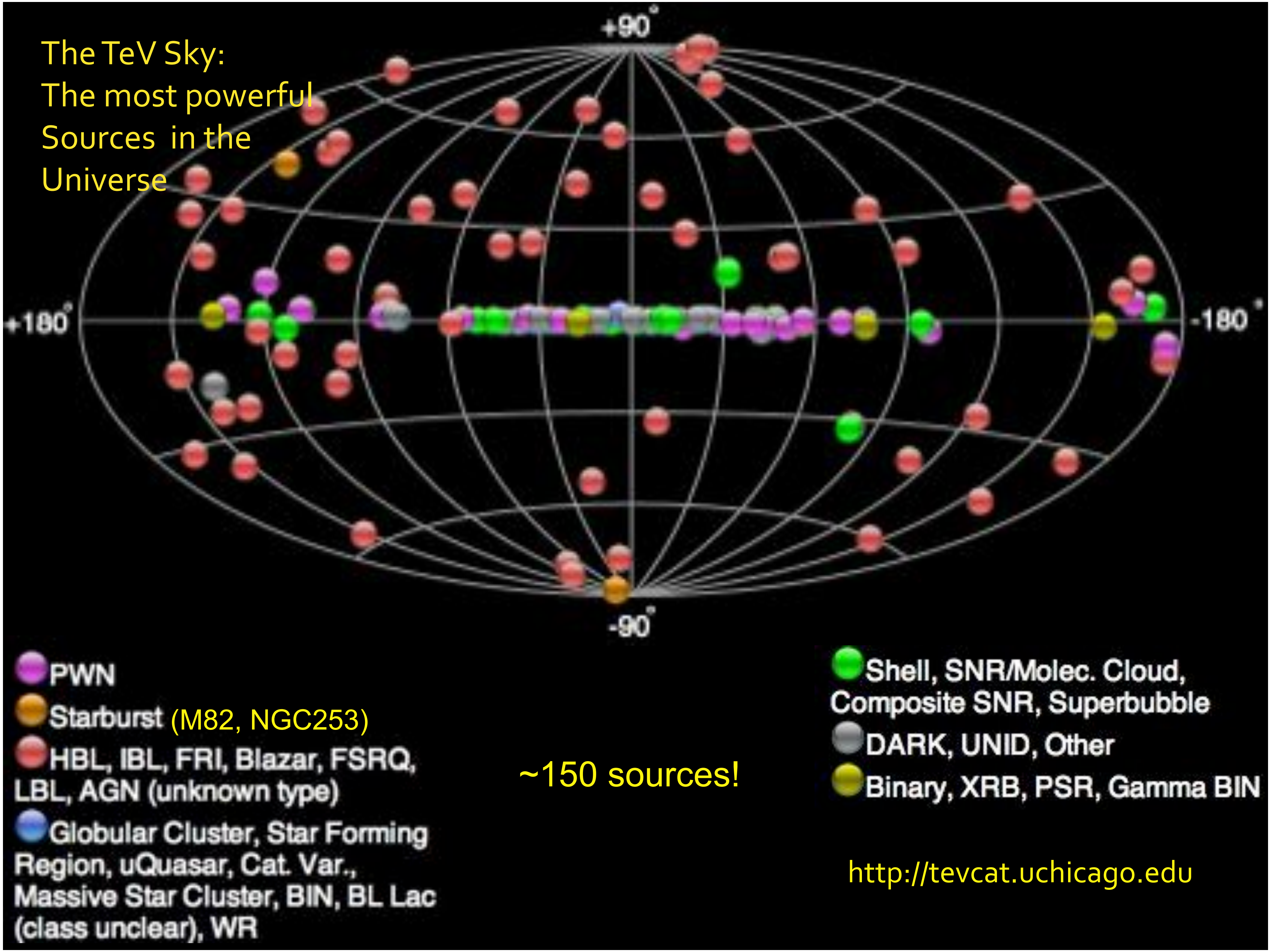
- stellar quake on magnetars, young isolated neutron stars with B ~ 10^{14} – 10^{16} G
- about 20 magnetars known
- many NSs born as magnetars

Magnetar-related goals and subjects:

- Physics of supercritical B-fields
- NS seismology -> NS structure, M & R
- Newborn magnetars to power:
  GRBs (short and/or long) ? GW emission ? Super-luminous SNe ?
- Magnetars as sources of Cosmic Rays ? Fast Radio Bursts ?

4.4
Quali sono i meccanismi di accelerazione cosmici per le particelle e la materia? Quale è il ruolo del campo magnetico?

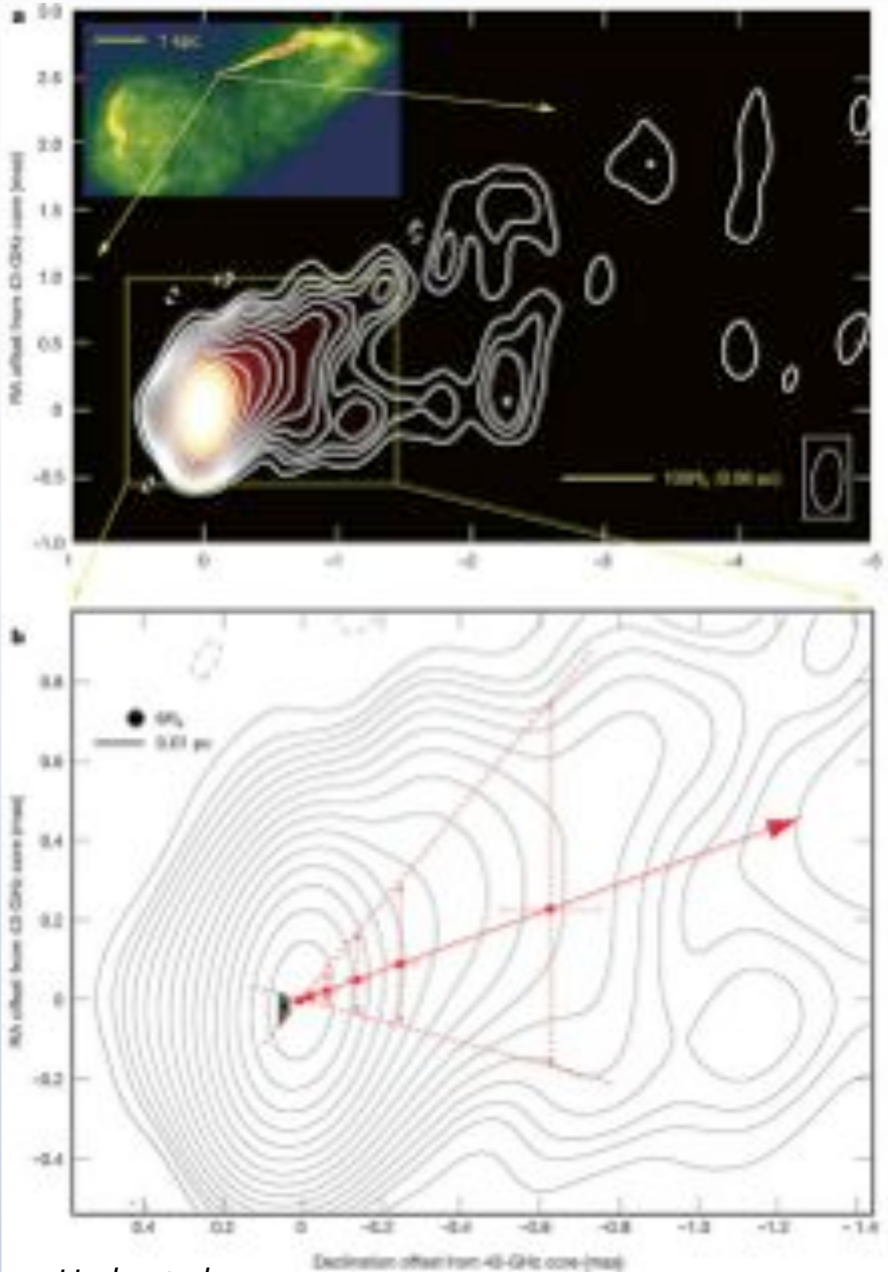
The TeV Sky:
The most powerful
Sources in the
Universe



~150 sources!

http://tevcat.uchicago.edu

Extragalactic jets: Radio VLBI observations of the jet of M87

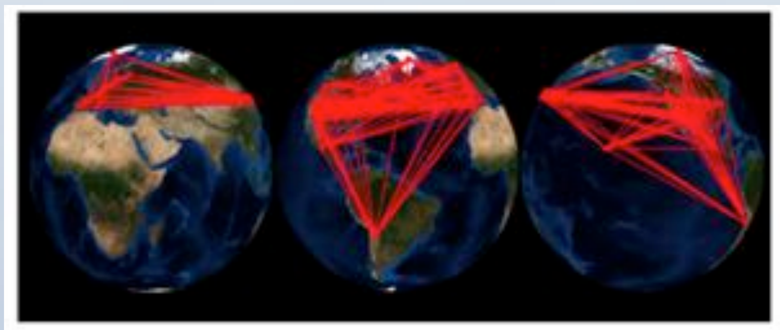


Hada et al. 2011

Goals:

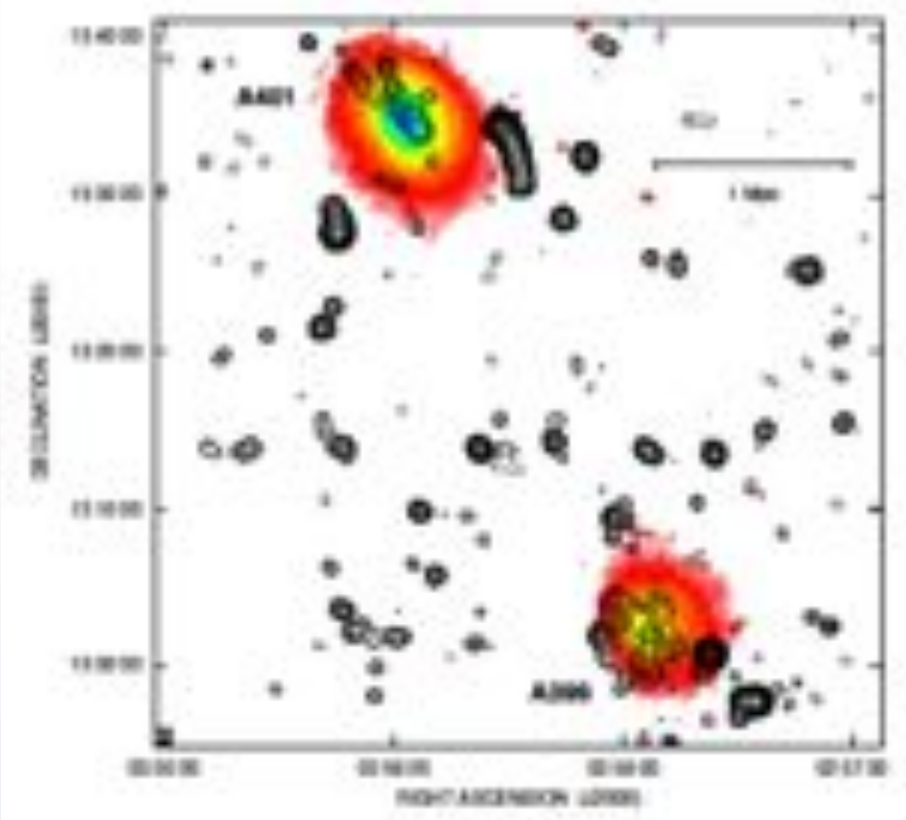
1) How is energy extracted from central BH? Interplay BH, accretion disk and jet
2) What are the scales relevant for acceleration?
3) How is the jet influenced by the intergalactic medium?
4) How is the jet influenced by the magnetic field?
5) More in general, how do magnetic fields develop from initial seeds?

A new investigation tool: mmVLBI (86 GHz)



Cosmic Magnetism

VLA+XMM

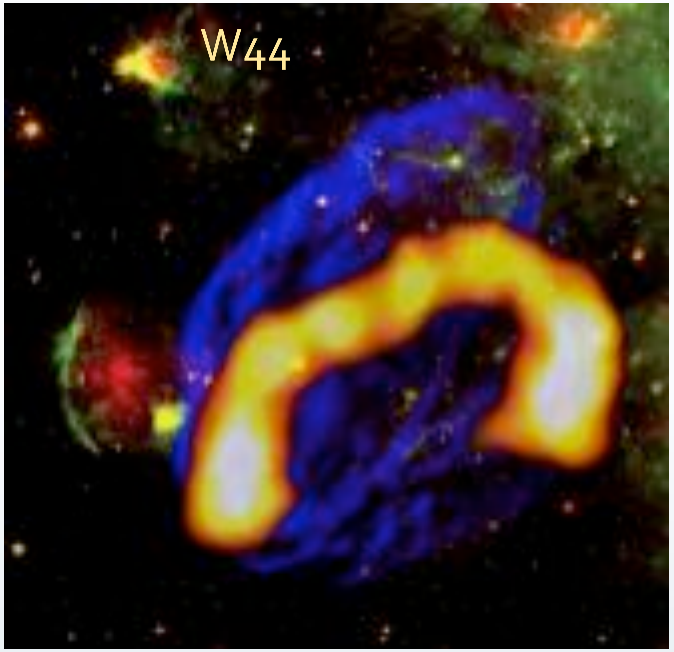


Planck

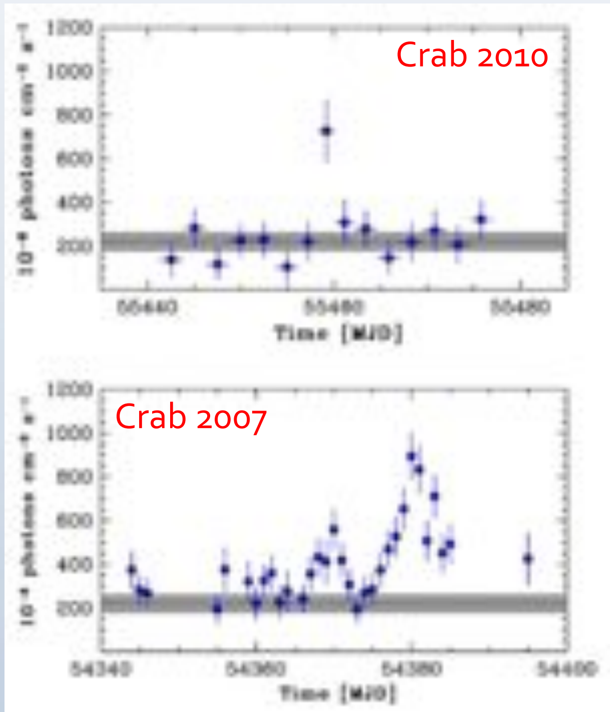
Double-halo in A399-A401: synchrotron radiation (1.4GHz) and Sunyaev-Zeldovich emission

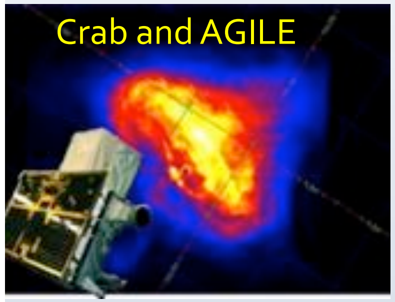
Goals:
Identify origin and evolution of magnetic fields in the Universe and understand their diagnostic power (see also **polarization** at radio, optical and **X-ray** frequencies)

AGILE detected MeV-GeV emission from SNR W44 that pointed to cosmic rays interaction and role of SNRs as CR accelerators (see Also Fermi-LAT). **But can they reach PeV energies**?
The only **confirmed PeVatron, Crab, is in itself a mystery** (see 2012 Rossi Prize to M. Tavani and AGILE Team)
CTA perspective



Goals: what are the primary accelerators in the Universe and how do they work





Flares detected by AGILE-GRID in 2007 and 2010

4.5
Esplosioni cosmiche e fisica nucleare

Cosmic explosions and nuclear physics

- Open issues on Type Ia and core-collapse supernovae
- New types of stellar explosions from the synoptic surveys
- Constraining the stellar SN precursors
- Searching supernovae outside the optical domain

Supernovae and stellar transients are a multi-disciplinary subject, and give the opportunity to study phenomena related to stellar explosions in different time domains and multiple wavelength regions. An ideal laboratory for the new generation of instruments.

Cosmic explosions and nuclear physics

SNe Ia

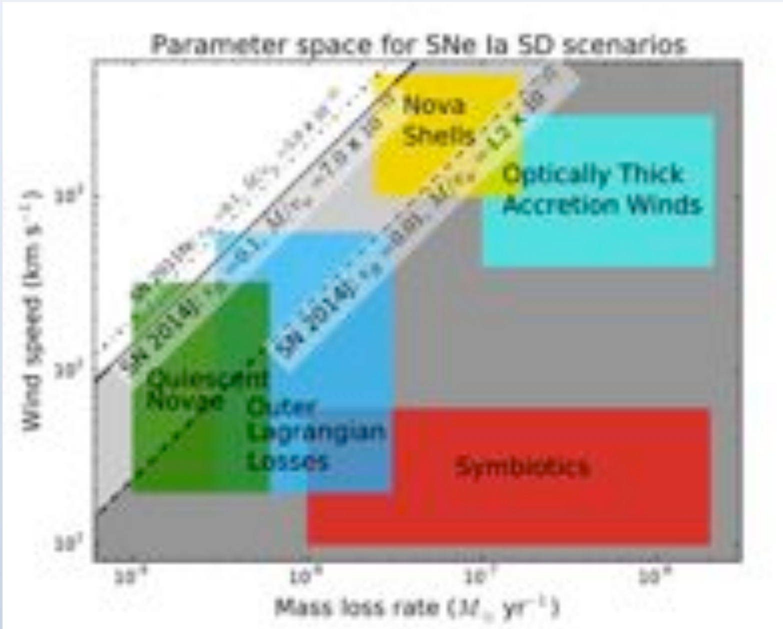
Status

1. Well-studied in optical and NIR; robust standardizable candles.
2. Major improvements in the knowledge of the explosion dynamics: 3D hydro & radiative transfer models

Still to address:

1. Characterization of type Ia SN diversity (e.g. some sub-types violate the Chandrasekhar-mass explosion postulate)
2. Discrimination between progenitor scenarios (double or single degenerate) through signatures of SN ejecta and circum-stellar gas interaction

- Observations in the Millimeter and Radio (e.g. LOFAR, SKA)
- Observations in the high-energy domain (Swift, MAXI, Fermi)
- Large optical telescopes for deep and/or high spatial resolution imaging to detect surviving companions in the Milky Way and Local Group Galaxies (E-ELT; VLTI)



Pérez-Torres et al. (2014)

Cosmic explosions and nuclear physics

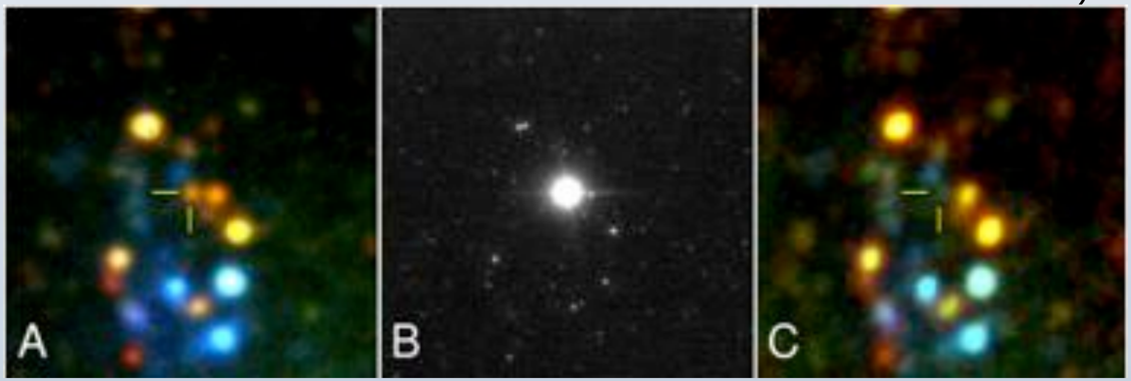
Core-Collapse SNe

Status

1. well-studied in UV to NIR; modeled to constrain progenitor and explosion parameters
2. Recovered Progenitors of a few core-collapse SNe (~30) in pre-explosion archival images; pre-SN variability observed
3. Highly asymmetric explosions in CCSNe: evidence of jets; connection with GRBs and XRFs

Still to address:

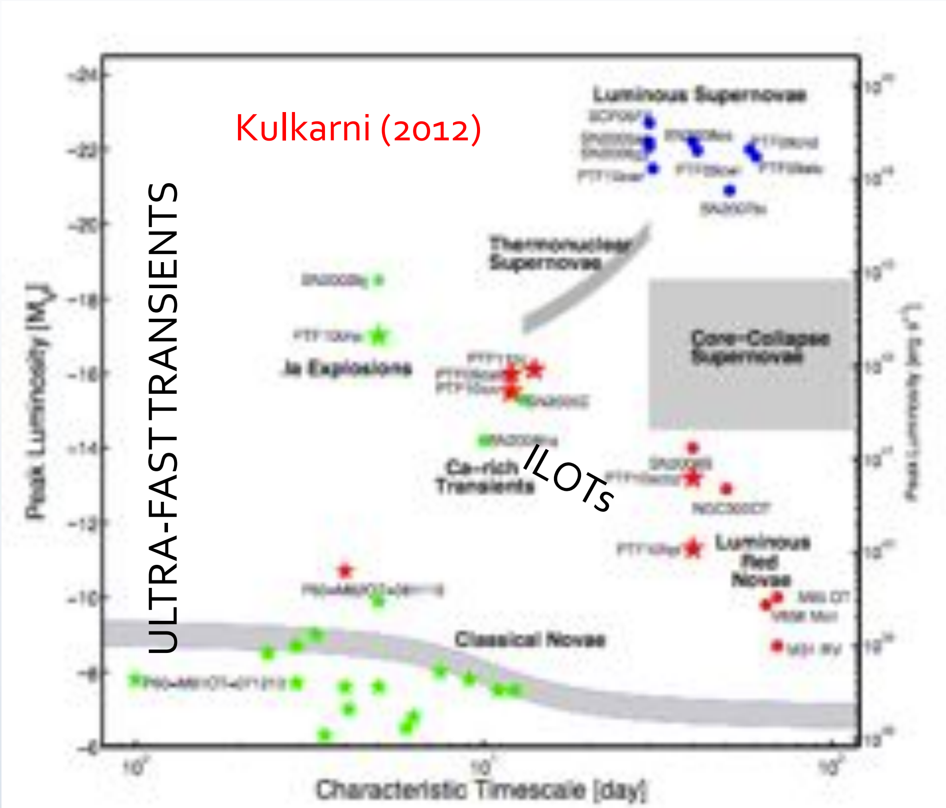
1. Monitoring in other domains to unveil
   - stellar mass-loss history (radio, X-ray);
   - hidden CC SN population (far-IR, mm, radio)
   - detect fleeting early evolutionary phases, e.g. shock break-out signatures (gamma-ray, X-ray, UV).
2. Deep, high spatial resol. imaging => archival images of nearby galaxies to increase the number of SNe with detected progenitors; constraining pre-explosion variability.
3. Linking progenitor types with SN types (e.g. deep mid-res spec. to study the CSM in interacting SNe)



Mattila et al. (2010)
Progenitor (A); SN (B); Remnant (C)

Cosmic explosions and nuclear physics

New types



A new era for the transient sky not only in the optical domain!

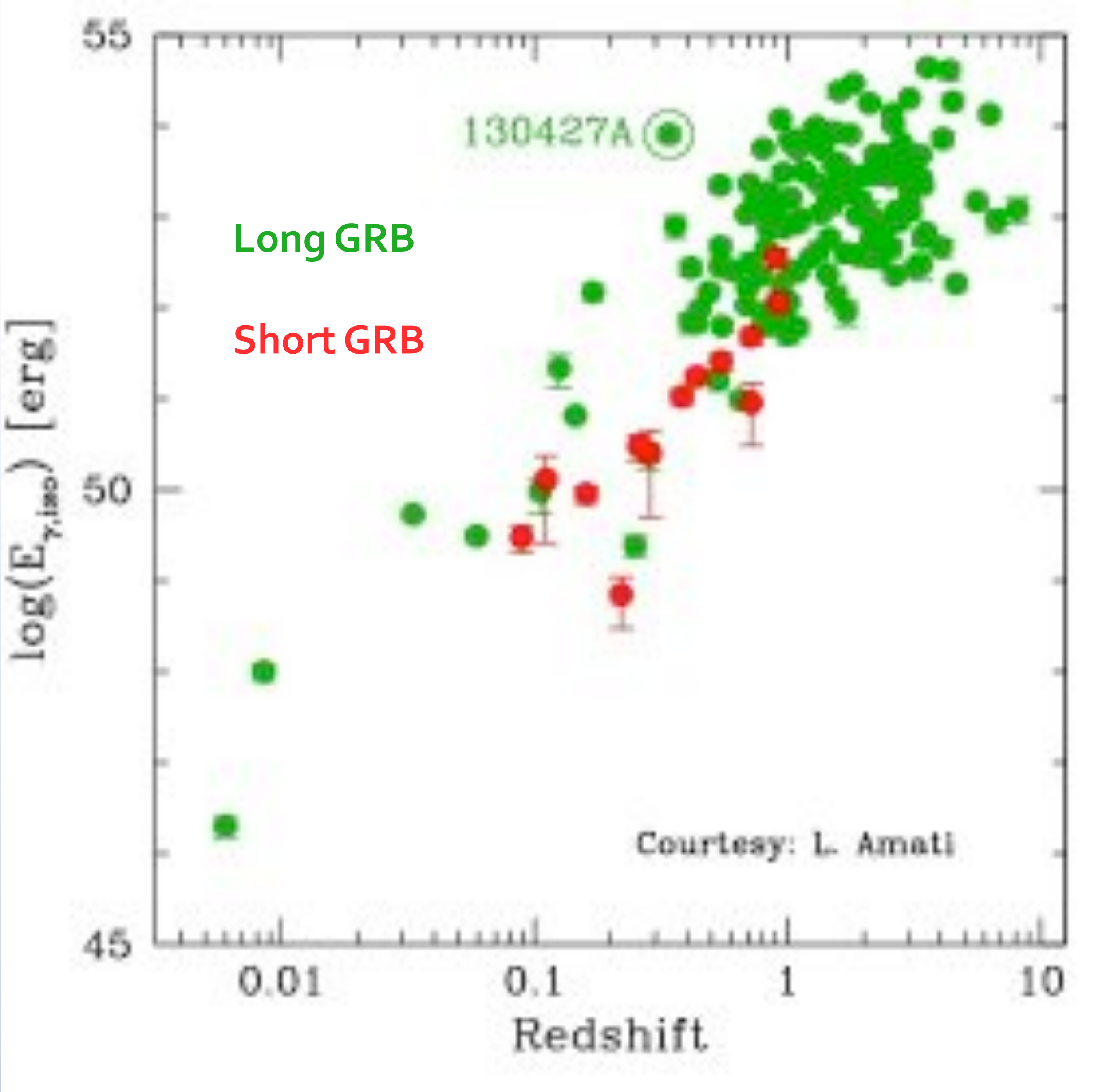
Exploring sky variability in ultra-fast time domains (GRBs, shock break-out, stellar flares)

Fast-evolving intermediate luminosity transients (ILOTs) - Type .Ia SNe, Ca-rich transients, fall-back and electron-capture CC-SNe, SN impostors, luminous red novae => request of high-cadence monitoring, and medium resolution spectroscopy (e.g. SOXS)

Super-luminous SNe – Interacting SNe, ultra-bright stripped-envelope SNe (e.g. magnetar-powered), pair-instability events.

Fast radio transients; high-energy bursts (GRBs, X-ray binaries, magnetar flares, tidal disruption events…. the unknown)

Isotropic irradiated γ–ray energy vs redshift



GRBs are unparalleled probes of the whole Universe, from local to edge.

Goals:

1) Progenitors

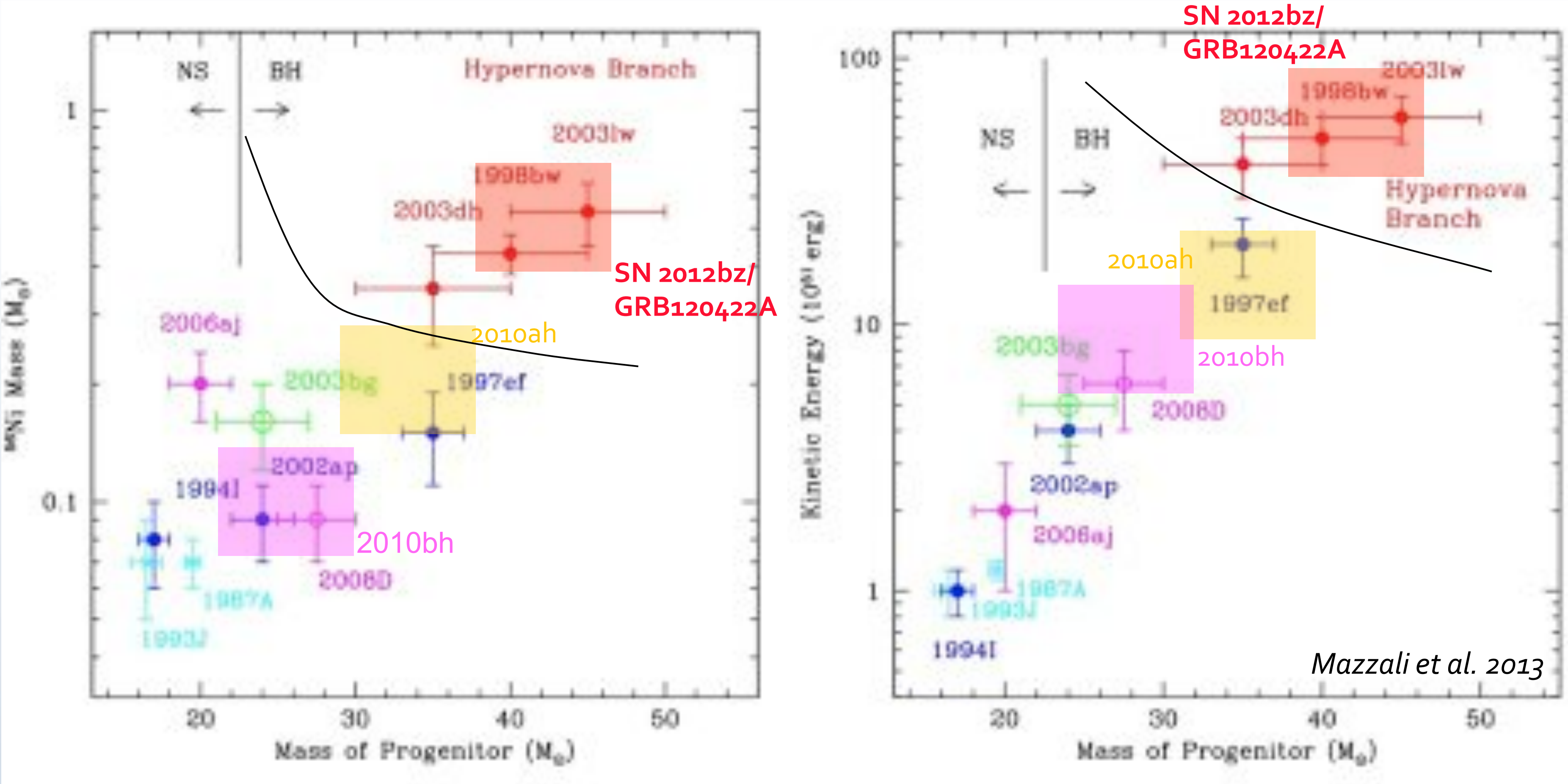
2) Explosion physics

3) Ultra-relativistic jets

4) Very high-redshift cosmology (e.g. first stars and supernovae)

Future is uncertain: no <u>firm</u> plan on a dedicated mission

Properties of SNe Ibc as $f(M_{prog})$



GRB-Sne: Collapsar or magnetar?

A minimum mass and energy seem to be required for GRBs: so, what is ***special*** about Long GRB supernovae?

A Multidisciplinary Laboratory: short GRBs

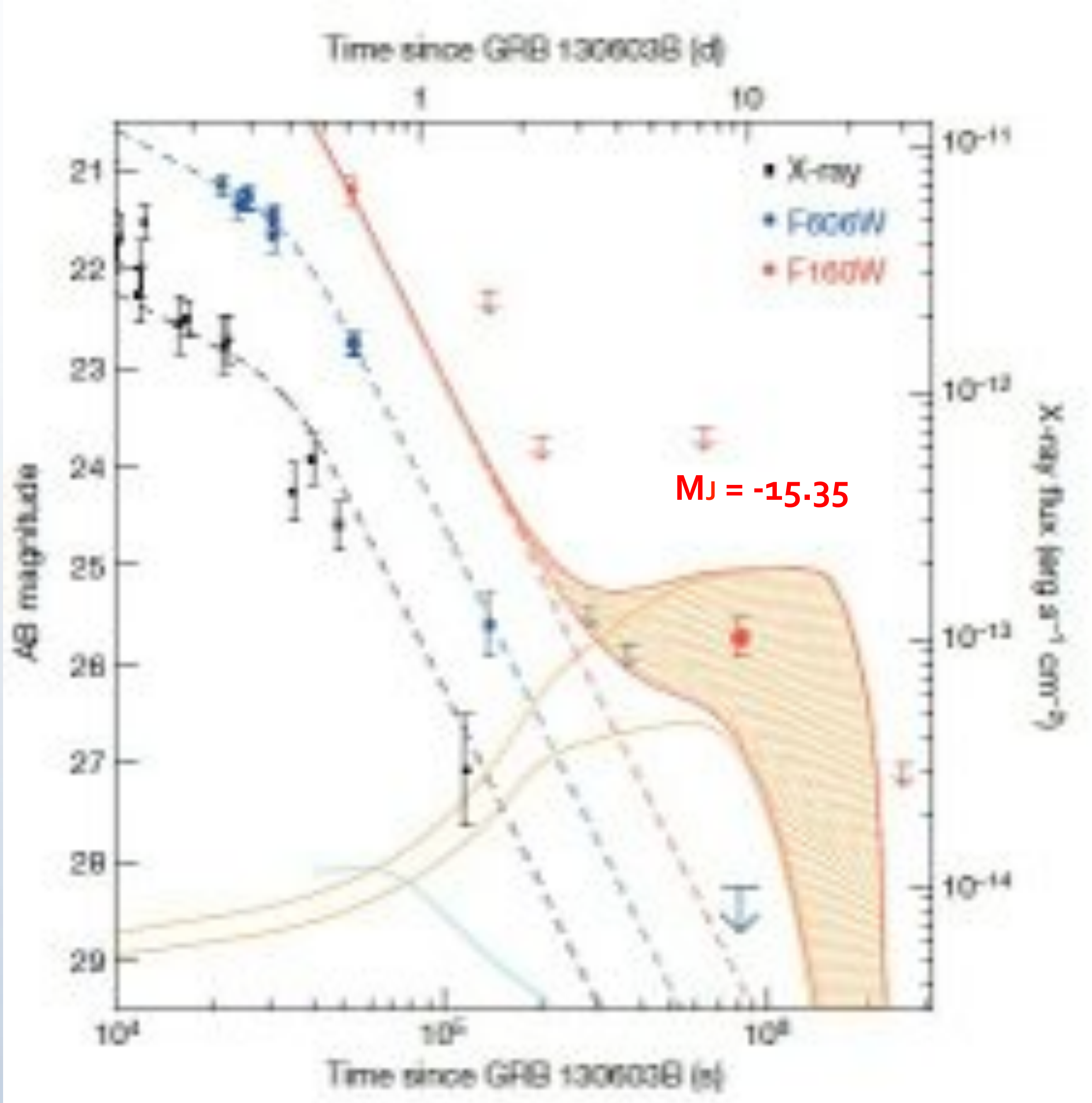
Short GRB130603B
(z = 0.356)

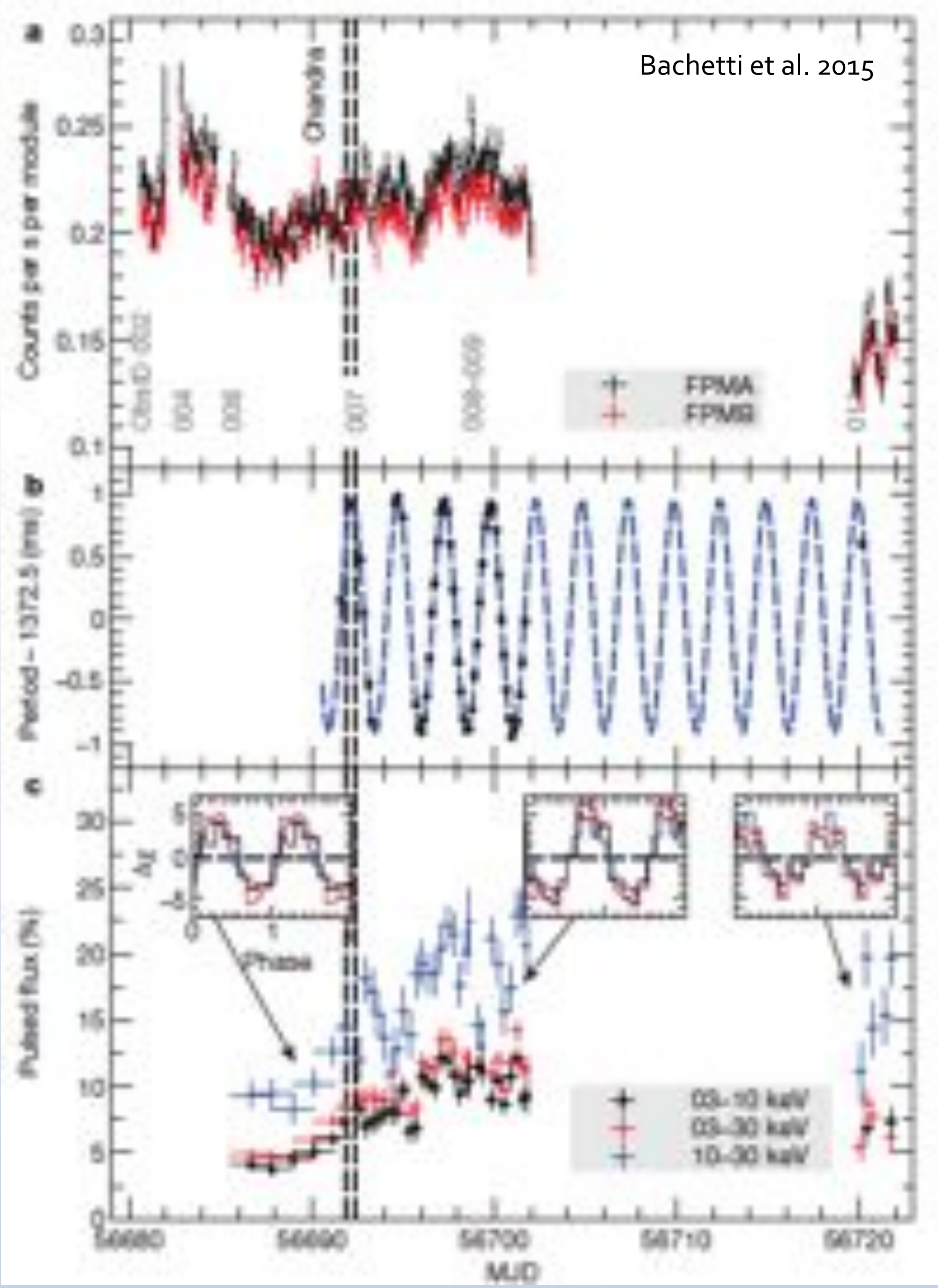
<u>Kilonova nucleosynthesis</u>:
Ejection of r-process material from a NS merger (0.01-0.1 $M_\odot$)
(Barnes & Kasen 2013)

$M_H \approx -15$

$M_R \approx -13$

Tanvir et al. 2013;
Berger et al. 2013





NuSTAR observation of J05551+6940.8:

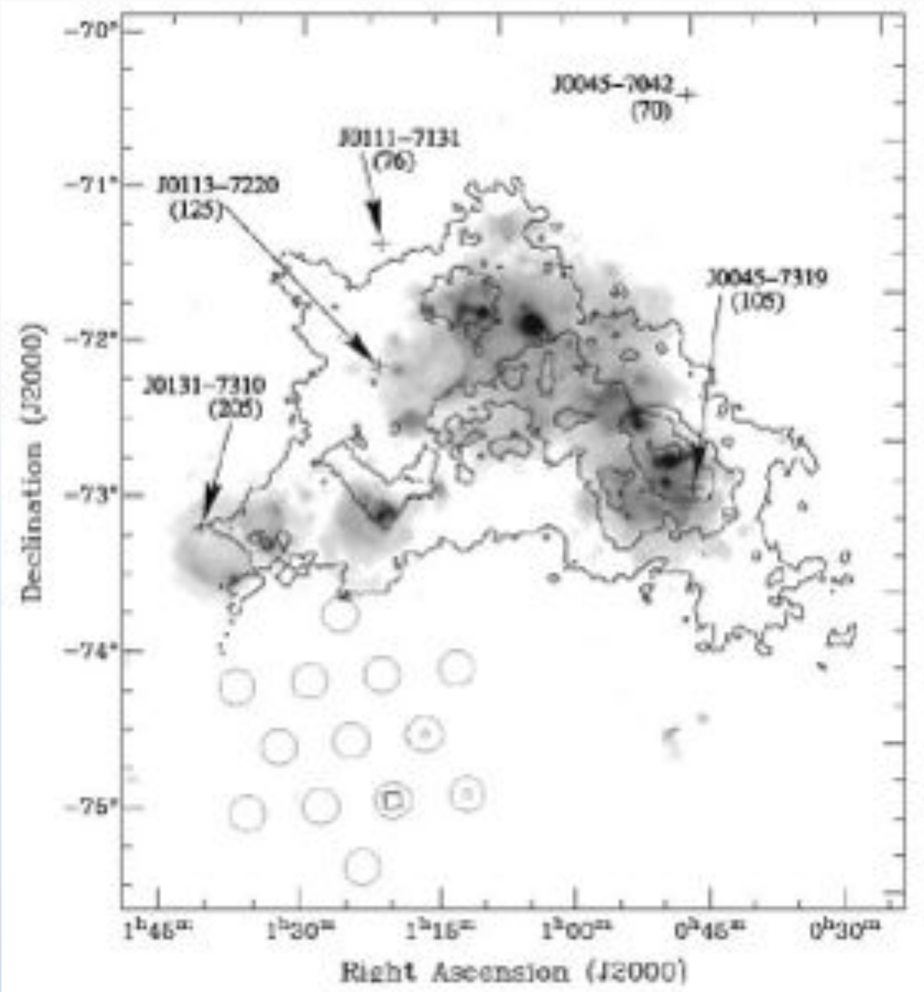
Luminosity a factor 100 in excess of Eddington limit for 1 solar mass, period of 1.37 seconds modulated by 2.5 days

Black holes may not be always the culprits: NS with "extreme" EoS? Strange stars?

Goals in nuclear physics:

1) Measurement of NS radius, equation of state of matter
2) Are excited states of nucleons produced at high densities?
3) Is it possible to deconfine quarks?
4) Distributions of masses of NS (see SKA)

FRONTIER: Fast Radio Bursts

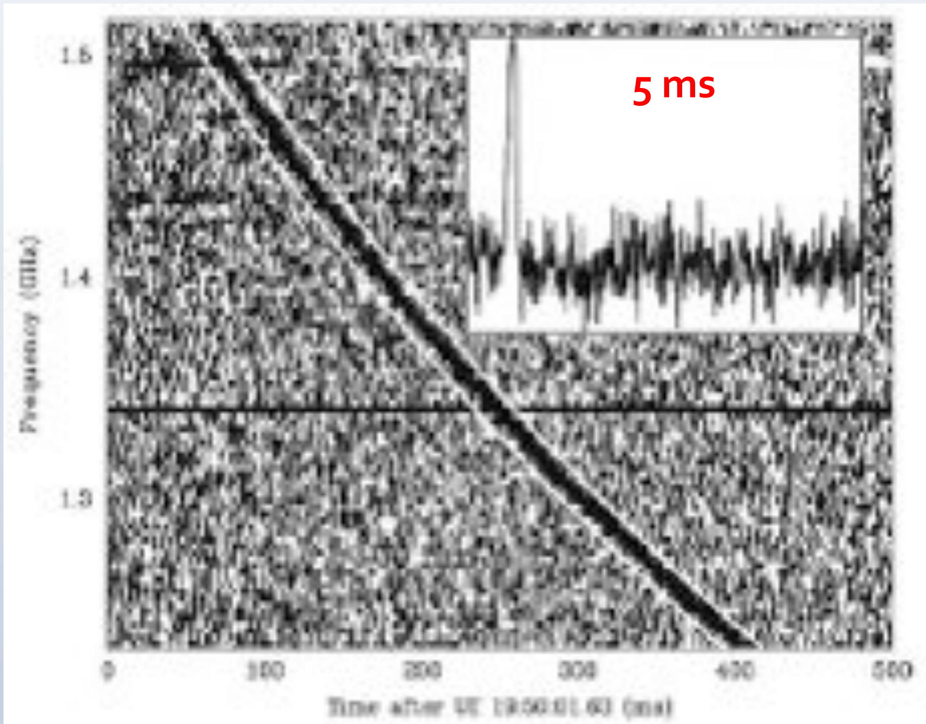


1.4 GHz Parkes survey of the Magellanic Clouds (Aug 2001)

Lorimer et al. 2007

F(1,4 GHz) = 30 Jy
D < 1 Gpc
L ≈ e43 erg
Monstruous brightness temperatures: e27 K!

Goal: what are the progenitors of these transients? What is the coherence mechanism?



The way forward

Matter tells spacetime how to curve, spacetime tells matter how to move

BHs, NSs, GW sources, jets, SNRs are responsible for acceleration to the highest energies, but the mechanisms are still unknown, because not all ingredients have been taken into account yet.

Current observational and theoretical investigation in GFF aims at understanding behavior of sources in various gravity regimes (strong gravity, weak gravity, quantum gravity) and various scales (quantum "foam" on Planck scales to Mpc jets) to have detailed mapping of spacetime.

<u>Investigation tools 1</u>

The X- and gamma-ray sky is highly variable!   -> Time Domain Astronomy
Good theoretical background and correct observational approach thru big surveys with intensive cadence, but need to intensify ***coordinated*** MWL observational effort.

Acceleration mechanisms and powering sources are relevant on all scales, and intertwined with magnetic field strength and orientation

New window: MWL polarimetry

Theoretical work on physics of matters at nuclear densities and nucleosynthesis; need IR and gamma-ray instruments. *LOFT* for high precision studies of EoS.

Gravity on various scales and regimes: good observational (GAIA, SKA) and theoretical prospects; *Fermi-LAT, Athena, LOFT*
Investigation of strong GR regime is perceived as a priority wrt weak GR regime (already better explored)

Investigation tools 2

Electromagnetic (not complete):

Optical: robots to 8m tels, LSST, "giant tels", GAIA, HST, JWST, SOXS on NTT
Radio: SRT, LOFAR, SKA, VLBI, mmVLBI
X-rays: Swift, INTEGRAL, XMM, NuSTAR, Athena, LOFT, eROSITA, NICER, XIPE
Gamma-rays: Fermi, MAGIC, HESS, ASTRI, CTA, THESEUS? ASTROGAM?
GW: aLigo-aVIRGO, eLISA, KAGRA, ET…
Neutrinos: ANTARES, Km3NeT, ICECUBE
Gravitation: GAIA, SKA, BepiColombo-ISA

Big news: Multi-messenger approach

Good CRs and commitment on GWs, no observational work on neutrinos, only theoretical

Three new commissions are currently under evaluation by the IAU Executive Committee for Division D: SNe, GW, SMBHs

Domande 3 – 5

Domanda 3: Quante persone, e in che misura, sono disposte a impegnarsi sia a livello di lavoro scientifico che a concorrere per posizioni di responsabilità, affinché le infrastrutture e la strumentazione di punta in preparazione siano costruite ed organizzate così da massimizzarne il ritorno scientifico per la comunità italiana?

Poche risposte: Non lo so (o domanda mal posta): 7
Risposte sul presente e/o generali: 13
Riposte in chiave personale: 3

Onde Gravitazionali:
- aVirgo/aLIGO ~30 ricercatori in INAF per programma follow-up; 5-6 disponibili per ruoli di responsabilità'.
- Comunita' di GWs, indipendentemente dalla "frequenza", si trovi e costruisca strategie.
- Rafforzare il link con quella parte di INAF che si occupa di strong-field gravity

Strong Field Gravity :
- comunita' italiana e' tra quelle leader a livello internazionale.
- molte decine di persone per SKA, Athena e LOFT.
- gli utilizzatori scientifici dentro INAF sono invece centinaia.

Equazione di Stato:
~ 20 ricercatori in INFN (esteso documento di Drago in ambito WhatNext)
~ 20 in INAF tra SKA, Athena e LOFT.

Domanda 3: continua …

CTA/Very High Energy:
- Forte comunità INAF interessata ed esperta in problemi di astrofisica delle alte energie.
Se messa nelle condizioni giuste questa comunità può dare molto (5 a Fi , ~ 10 in tutto INAF)
- "Mi pare che INAF in quanto tale dia a CTA un contributo che finora è soprattutto tecnico".

Jets/SKA:
- 1 posizione di responsabilita' nel Board, 2 chair-position in 2 degli 8 key projects.
Formare giovani pronti ad occupare posti di responsabilita' nella fase operativa di SKA1.
- La comunità in varie sedi, con maggiore concentrazione a Bologna (IRA, IASF) e nell'area milanese e romana, oltre simulazioni numeriche localizzata a Torino.

Domanda 4: Quali dovrebbero essere le strategie di INAF per supportare tale impegno della comunità e massimizzarne il ritorno scientifico?

GW:

- competenze INAF utilissime, parzialmente mancanti e complementari a quelle INFN.
- stretta collaborazione con INFN in analisi dati ed electromagnetic, follow-up
- coinvolgimento in programmi internazionali di follow-up
- tema delle GW nella "cultura INAF", attraverso scuole, corsi e progetti di ricerca
- prospettiva di lungo termine con eLISA

Strong field Gravity/Gravity/EoS/Campi Magnetici

- supporto per R&D per strumentazione, team scientifici internazionali, analisi dati
- supporto a progetti innovativi e di alto valore conoscitivo e/o tecnologico, anche se non "grandi"
- favorire anche studi teorici e promuovere formazione specifica post-laurea

Altissime Energie/ Raggi Cosmici

- ok grandi progetti, ma puntare un po' di piu' sulla formazione e su strutture intermedie
- investimenti specifici in alcuni settori
- Programmi postdoc mirati

Domanda 4: continua ….

Jets/SKA

- Continuare supporto alla strumentazione esistente e futura (radio e alte energie)
- Inclusione di long baselines in SKA
- Partecipazione a VLBI mm

Generale su Formazione e Personale TD ed AdR

Molti giovani nelle attivita', incarichi di responsabilità aTD e AdR,

- non 'in formazione', ma con anni di carriera sottoinquadrata
- con competenze spesso in balia di fondi esterni, e quindi a rischio

Investire di piu' sul personale giovane

Prevedere contratti appetibili anche per ricercatori di altri paesi

Per le grandi strutture a cui partecipa (SKA, CTA, etc) INAF dovrebbe riservare un budget per indire borse o tenure track quinquennali e di prestigio per attirare/formare ricercatori top-level legati a tali progetti.

Incentivare formazione universitaria e post-universitaria su diversi dei temi dell'area 4

Generale su Progetti e Facilities

"Percorsi" con scale temporali piu' brevi per arrivare alle grandi facilities del futuro.

- ASTRI come ponte verso CTA: una scelta strategica
- ATHENA distante nel futuro: si riuscira' a colmare il "gap" generazionale senza missioni intermedie su scala piu' piccola?

Parte della ricerca INAF deve comunque essere dedicata a progetti piu' piccoli ma che possono poi fungere da semi a nuove e importanti linee di ricerca (sia a livello scientifico, di R&D tecnologico e mission concept)

I grandi progetti INAF devono essere percepiti come piu' aperti:

- de-personalizzare i grandi progetti, farli davvero sentire di tutti.
- stimolare l'ingresso dei ricercatori non originalmente coinvolti.

Non si puo' fare tutto: INAF si chieda di quante persone ha bisogno per le varie strumentazi
Se non ci sono I numeri o si aumenta il personale o si rinuncia alla strumentazione

Programmare con anni in anticipo l'assunzione di personale che conosca la potenzialita' scientifica della strumentazione

Generale aree da sviluppare

High Performance Computing (HPC): facility "trasversale" per temi quali nucleare, jets,MRI, dinamica sistemi (Torino, Firenze, Padova); ma INAF presta scarsa attenzione a HPC.

Supportare piu' efficacemente la Time Domain Astronomy, anche attraverso LSST.

Generale su Gestione

- Altre nazioni sono molto più abili di noi nel creare sinergie fra I vari gruppi di ricerca: è tempo che anche da noi questa sinergia sia potenziata.

- Creare strutture con piu' "massa critica", laboratori d'eccellenza interstruttura e altri tipi di coordinamento federale tra membri di strutture

- Collaborazioni inter-ente con:
  - INFN: grandi temi e progetti da sviluppare (gravita', raggi cosmici, fisica nucleare, neutrini etc.)
  - Universita', ASI (ASDC e Centro Geodesia Spaziale), CNR

- Maggiore investimento nella ricerca di base (non solo grandi progetti, satelliti o laboratori).

- Bandi, call for ideas, trasparenza

- Verifica comparativa del ritorno scientifico dei progetti finanziati (verifiche attuali spesso non complete, non tempestive, non binding).

Bottom up vs. Top Down

Coinvolgimento INAF in grandi progetti: spesso processo “inverso”:

- poche persone decidono autonomamente che è strategico entrare in un grande progetto
- poi si cercano o si convogliano le risorse necessarie,
- infine si cerca interesse al progetto tra i ricercatori INAF.

Questo processo ha spesso come conseguenze :

- si aderisce a linee strategiche preesistenti, non si sceglie
- si entra ad un livello scientificamente e programmaticamente subordinato
- il personale INAF che entra sul progetto è poco stimolato, difficilmente può aspirare a posizioni di coordinamento, se non acquisendolo con il contributo finanziario italiano.

La nascita di un progetto di ricerca deve essere bottom-up, non top-down.

- la ricerca sarebbe automaticamente radicata e supportata dalla comunità INAF.
- è necessario permettere e stimolare lo sviluppo di (molte) nuove idee dalle quali attingere: quindi investire di più’ su PRIN e TECNO.

Le nuove risorse (personale e fondi per infrastrutture) devono essere dedicate non solo ai "grandi progetti”.

Il processo bottom-up può essere incentivato e coordinato attraverso una reale attivazione delle commissioni di macro-area ed una loro stretta e strutturata interazione con i ricercatori dell'ente.

Generale su Gestione: continua …

Criteri di selezione:

- la capacita' di acquisire risultati che risolvano problemi fondamentali
- Il ruolo di ricercatori INAF nei progetti (PI, Co-PI, … etc.)
- la rilevanza e, possibilmente la unicita' dell'hardware contribuito da ricercatori INAF

Definire processo che porta alla selezione di progetti e finanziamenti:

- comitati di macro-area INAF (attualmente sottoutilizzati): possono funzionare come le commissioni INFN, con ruolo di coordinamento ed indirizzamento ?
- decisione finale, trasparente, tenendo anche conto del contesto internazionale, da parte di:
  * struttura agile ed autorevole per i grandi progetti a cui INAF partecipa
  * I comitati di macroarea per PRIN e TECNO ?

INAF vs INFN

Differenze: in INFN rispetto ad INAF

- meno progetti, mediamente piu' grandi
- piu' "esperimenti" che "osservatori"
- piu' forte legame con universita'
- grandi laboratori nazionali

INAF ha storia recente e lontana diversa da INFN:

- desiderio di "assomigliare" di piu' ad INFN
- statuto INAF alquanto simile a statuto INFN
- forti differenze di cultura della gestione