Ongoing work in RSN4 on Gravitational Wave sources

Giulia Stratta (INAF-OAS)

Giornate RSN4 Napoli 28-30 gennaio 2026

RSN4 activity on gravitational wave sources

This talk is heavily based on the information gained in the shared doc where members of RSN4 were free to add their activity in the GW astronomy field:

https://docs.google.com/document/d/1wfbcNv6uKBEQlrAtcTpbatuFn-9frcOuGIXAnju9RjA/edit?tab=t.0

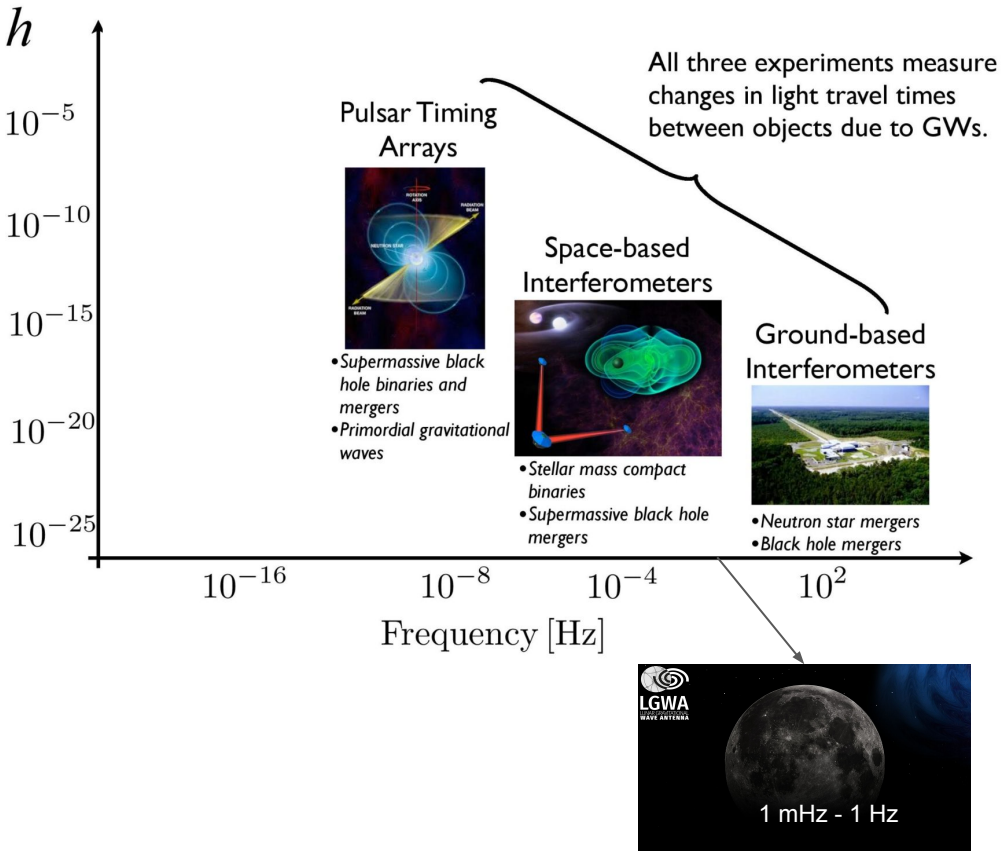
(thank you!)

>50 people in RSN4 is working on GW -> >30% of RSN4

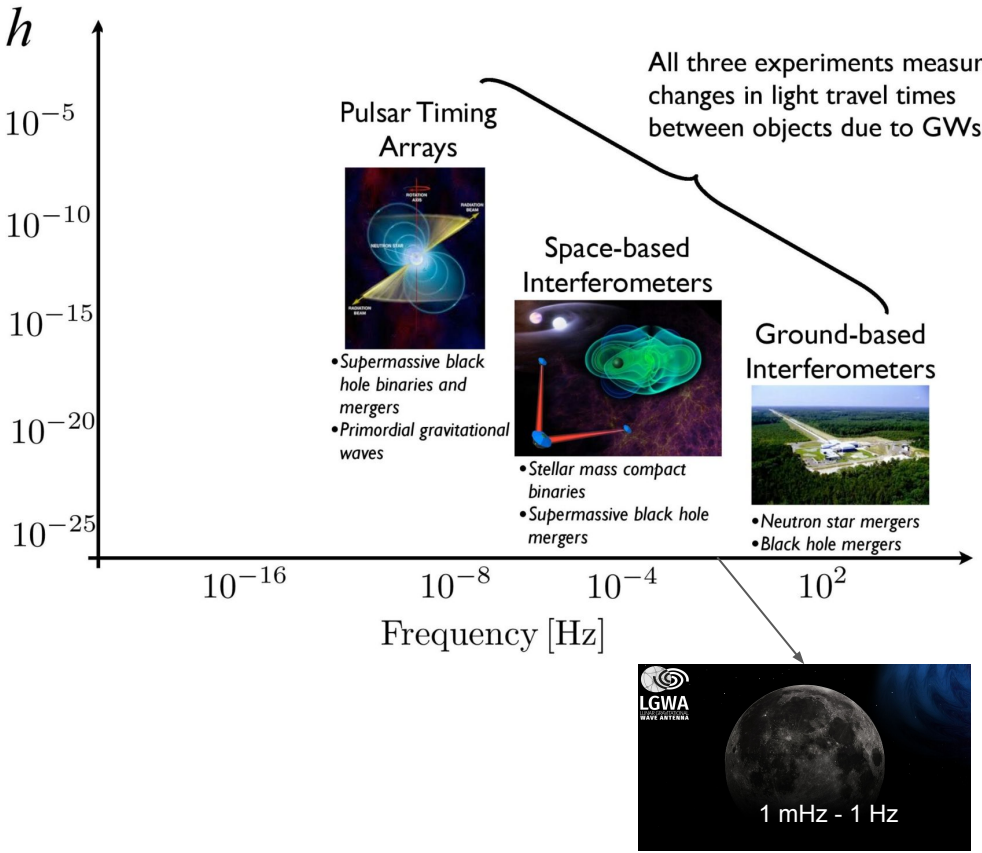
Nome e cognome	email	Istituto	Breve descrizione dell'attività di ricerca in corso	link utili	Altro
Andrea Possenti	andrea.possenti @inaf.it	OA Cagliari	PTA science at 360°, including multi-messenger for SMBH binaries		in EPTA and IPTA context
Caterina Tiburzi	caterina.tiburzi@inaf.it	OA Brera	PTA science at 360°, including multi-messenger for SMBH binaries. Modeling of noise caused by the ionised interstellar medium and Solar wind. Studies of plasma effects using pulsar data taken at low radio-frequencies with the European interferometers LOFAR and NenuFAR. 2 PhD students on PTAs: Francesco Iraci (University of Cagliari) and Danilo Zecca (University of Salento) 1 postdoc on low-frequency pulsar data: Mark Bitsome		in EPTA and IPTA context
Delphine Perrodin	delphine.perrodin @inaf.it	OA Cagliari	PTA science at 360°, including multi-messenger for SMBH binaries. Cosmological backgrounds of GW. Contribution to ET Blue Book OSB Div 5 (synergies between GW detectors): cosmological backgrounds from PTAs to ground-based detectors. GW searches with PTAs in alternative theories of gravity. 2 postdocs (Large Grant INAF 2023 "Gravitational wave detection using Pulsar Timing Arrays": Pratik Tarafdar & Jyotjwal Debnath 1 postdoc (Amodio Carleo) funded by PRIN MUR 2022 "Gravity tests in the Ultraviolet and the Infrared with Pulsar Timing"		in EPTA and IPTA context; ET collaboration
Marta Burgay	marta.burgay@inaf.it	OA Cagliari	PTA science at 360°, including multi-messenger for SMBH binaries		in EPTA and IPTA context
Om Sharan Salafia	om.salafia@inaf.it	OA Brera	Modelling and interpretation of the multi-messenger emission of binary neutron star and black hole - neutron star mergers, at both the single-event and the population level, for the double purpose of enabling the extraction of information from the available data (to shed light on a wide range of open questions in physics, including the equation of state of matter beyond the nuclear saturation density; the origin of heavy elements; the central engine of relativistic jets; the expansion history of the Universe; the mass of the graviton; ...) and to guide the development of observing strategies and of new instruments		
Alessandra De Rosa	alessandra.derosa@inaf.it	IAPS	dual AGN and binary SMBHs in MW and MM with LISA		in LISA context (there will be a talk)
Cristiana Spingola	cristiana.spingola @inaf.it	IRA Bologna	search and characterization of strongly lensed binary SMBHs at high-z as precursors of LISA sources		in LISA context
Matteo Bachetti	Matteo Bachetti	OA Cagliari	Population studies for super-Eddington sources as GW progenitors, contribution to ET blue book		ET
Antonio Stamerra (with other INAF members)	antonio.stamerra @inaf.it	OA Roma	Prospects for joint detection of gamma-ray counterparts, specifically from Cherenkov telescopes (MAGIC, ASTRI, LST, CTAO). Computation of joint probabilities and constraints on physical parameters driving the afterglow emission. Optimization of observing strategies.		ET
GRAWITA		OAB, OAS, IRA, OAPd, OAR, OA	Follow-up of GW triggers with the main INAF facilities: VLT Survey Telescope, Large Binocular Telescope, Telescopio Nazionale Galileo, Rapid	https://grawita.inaf.it/grawita/	LVK

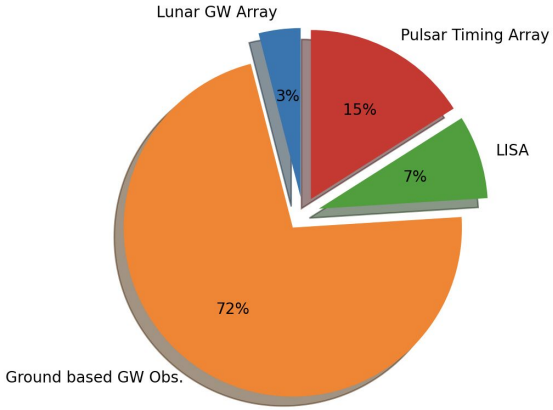
shared document with RSN4 activity on GW

The spectrum of gravitational wave astronomy



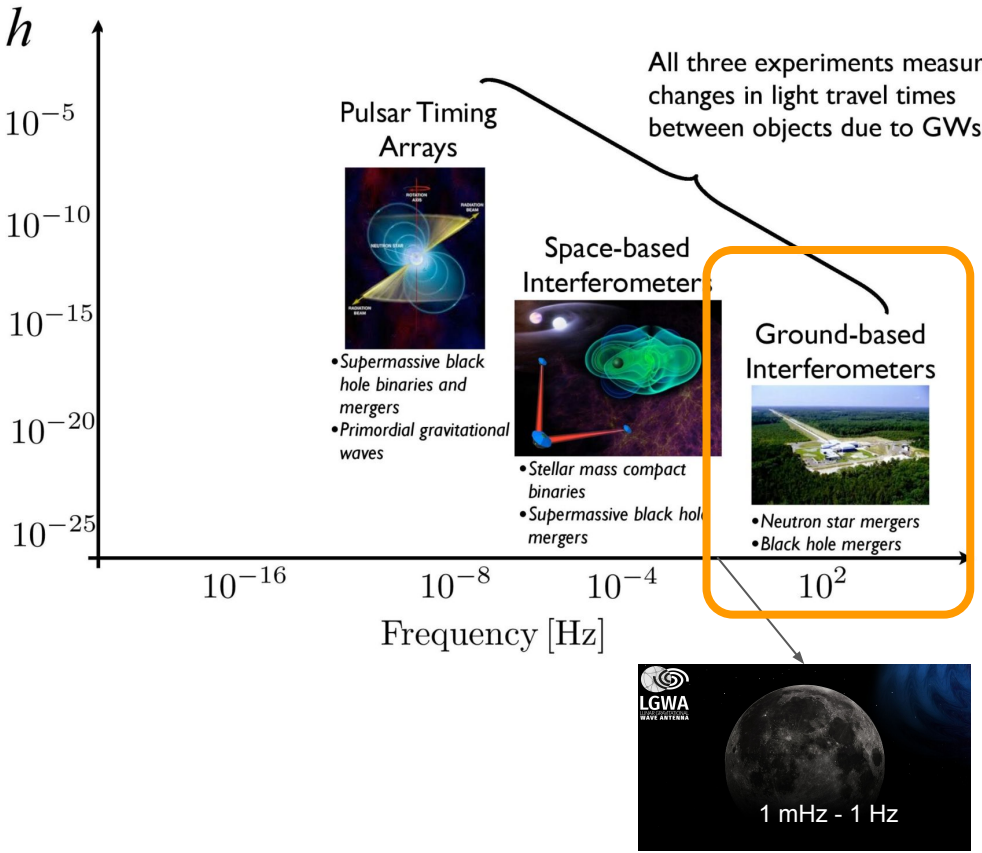
The spectrum of gravitational wave astronomy

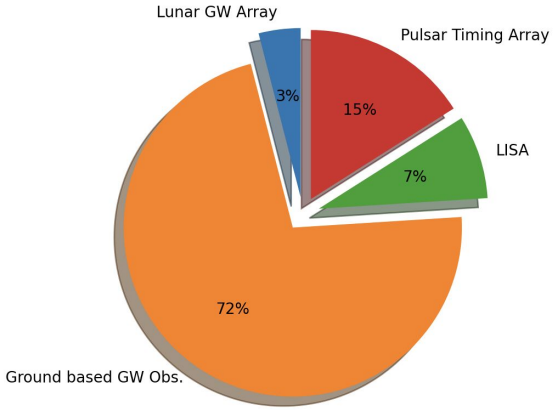




RSN4 activities with different types of GW sources

The spectrum of gravitational wave astronomy

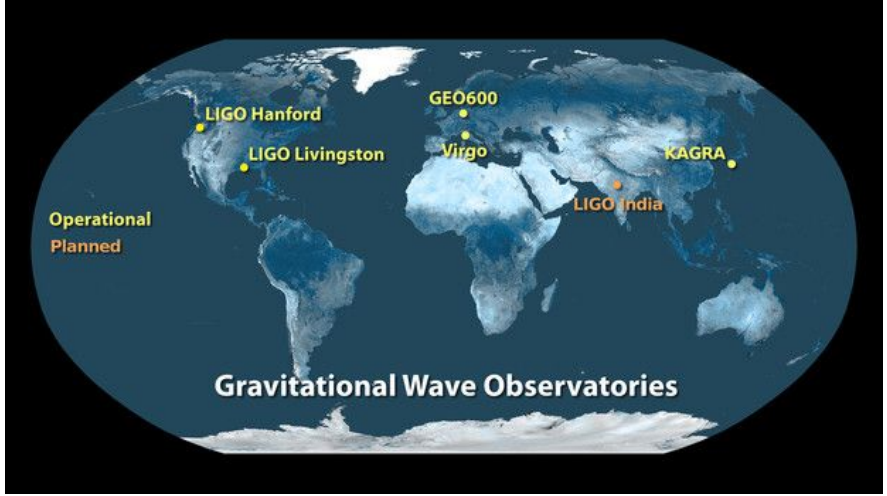


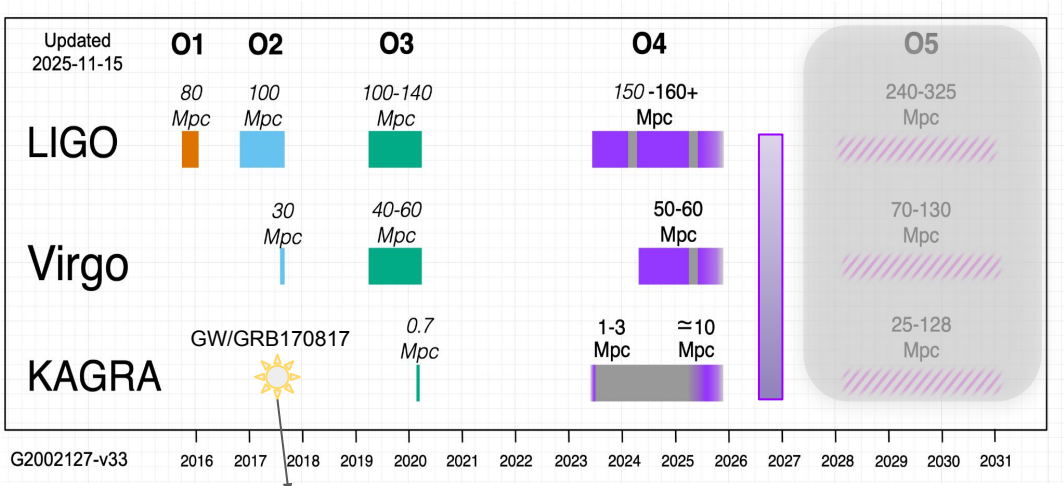


RSN4 activities with different types of GW sources

LIGO-Virgo-Kagra

- “Second generation” Interferometer network for high-frequency GW (~10-1000 Hz) detections
  - Expected sources are: BH-BH, NS-NS, NS-BH, ccSN, magnetars
- 4 Observing runs
  - Hundreds of BBH, 2 NSBH, 2 BNS
- Future:
  - **O4c: 6 months from fall 2026**
  - Planned upgrades for 2030s: Virgo_nEXT, A#, Voyager, ET





The only GW source with EM counterpart so far

LIGO-Virgo-Kagra -> **RSN 4 activities**

- **Observations: LVK GW source follow-up campaigns**

- **Theory: EM counterpart modelling**

- **Future perspectives**

LIGO-Virgo-Kagra -> **RSN 4 activities**

- **Observations: LVK GW source follow-up campaigns**
- **Theory: EM counterpart modelling**
- **Future perspectives**

- **MW** (L. Piro, G. Gianfagna, A. Thakur, **IAPS;** S. Piranomonte, A. Melandri, **OA Roma;** E. Maiorano, E. Pian, A. Rossi, G. Stratta **OAS,** M.G. Bernardini, P. D'Avanzo, S. Covino, **OA Brera**)
- **radio** (G. Bruni, **IAPS,** M. Giroletti**, IRA**)
- **High-energy** (e.g. AGILE, Swift, etc., Campana, Bernardini, D'Avanzo, Sbarrato, Sbarufatti, Covino, Tagliaferri, **OA Brera,** F. Verrecchia, **OA Roma**; C. Casentini, **IAPS**)
- **VHE with Cherenkov telescopes** (MAGIC, ASTRI, LST, CTAO, A. Stamerra, **OA Roma**)
- **GRB (jet), kilonova radiation, mechanisms and source population studies** (O. Salafia, G. Ghirlanda,**OA Brera,** R. Salvaterra **IASF Milano**)
- **GW+afterglow modelling** (G. Gianfagna, L. Piro, **IAPS**)
- **GRB afterglow+kilonova modelling** (G. Stratta, A. Rossi, R. Farinelli, E. Maiorano **OAS**)
- **NS-NS GW+jet+kilonova formation and emission** (R. Ciolfi, **OA Padova**)
- **Future GRB missions as THESEUS, eXTP, newAthena** (L. Amati, G. Stratta, **OAS,** G. Ghirlanda, i **OA Brera,** R. Salvaterra, S. Mereghetti **IASF Milano;** R. Ciolfi, **OA Padova;** L. Piro, **IAPS**)
- **Future GW observatories - Einstein Telescope** (M. Bachetti, D. Perrodin, **OA Cagliari**; S. Piranomonte, F. Verrecchia, A. Stamerra, **OA Roma**; C. Casentini, **IAPS**; R. Ciolfi, **OA Padova**, G. Ghirlanda, **OA Brera**

LIGO-Virgo-Kagra -> **RSN 4 activities**

- **Observations: LVK GW source follow-up campaigns**
- **Theory: EM counterpart modelling**
- **Future perspectives**

- **MW** (L. Piro, G. Gianfagna, A. Thakur, **IAPS;** S. Piranomonte, A. Melandri, **OA Roma;** E. Maiorano, E. Pian, A. Rossi, G. Stratta **OAS,** M.G. Bernardini, P. D'Avanzo, S. Covino, **OA Brera**)
- **radio** (G. Bruni, **IAPS,** M. Giroletti**, IRA**)
- **High-energy** (e.g. AGILE, Swift, etc., Campana, Bernardini, D'Avanzo, Sbarrato, Sbarufatti, Covino, Tagliaferri, **OA Brera,** F. Verrecchia, **OA Roma**; C. Casentini, **IAPS**)
- **VHE with Cherenkov telescopes** (MAGIC, ASTRI, LST, CTAO, A. Stamerra, **OA Roma, A.Bulgarelli, OAS**)
- **GRB (jet), kilonova radiation, mechanisms and source population studies** (O. Salafia, G. Ghirlanda,**OA Brera,** R. Salvaterra **IASF Milano**)
- **GW+afterglow modelling** (G. Gianfagna, L. Piro, **IAPS**)
- **GRB afterglow+kilonova modelling** (G. Stratta, A. Rossi, R. Farinelli, E. Maiorano **OAS**)
- **NS-NS GW+jet+kilonova formation and emission**(R. Ciolfi, **OA Padova**)

- **Future GRB missions as THESEUS, eXTP, newAthena** (L. Amati, G. Stratta, **OAS,** G. Ghirlanda, i **OA Brera,** R. Salvaterra, S. Mereghetti **IASF Milano;** R. Ciolfi, **OA Padova;** L. Piro, **IAPS**)
- **Future GW observatories - Einstein Telescope** (M. Bachetti, D. Perrodin, **OA Cagliari**; S. Piranomonte, F. Verrecchia, A. Stamerra, **OA Roma**; C. Casentini, **IAPS**; R. Ciolfi, **OA Padova**, G. Ghirlanda, **OA Brera**

LIGO-Virgo-Kagra -> **RSN 4 activities**

- **Observations: LVK GW source follow-up campaigns**
- **Theory: EM counterpart modelling**
- **Future perspectives**

- **MW** (L. Piro, G. Gianfagna, A. Thakur, **IAPS;** S. Piranomonte, A. Melandri, **OA Roma;** E. Maiorano, E. Pian, A. Rossi, G. Stratta **OAS,** M.G. Bernardini, P. D'Avanzo, S. Covino, **OA Brera**)
- **radio** (G. Bruni, **IAPS,** M. Giroletti**, IRA**)
- **High-energy** (e.g. AGILE, Swift, etc., Campana, P[illegible] Sbarrato, Sbarufatti, Covino, Tagliaferri, **OA Brera**[illegible] Casentini, **IAPS**)
- **VHE with Cherenkov**[illegible]erra, **OA Roma, A. Bu**[illegible]
- **GRB**[illegible]ies (O. S[illegible]
- **GW+a**[illegible]
- **GRB a**[illegible]nelli, E. Maioran[illegible]
- **NS-NS G**[illegible]sion(R. Ciolfi, **OA Padova**)
- **Future GR**[illegible]SEUS, eXTP, newAthena** (L. Amati, G. Stratta, **OAS,** G. Gh[illegible]**A Brera,** R. Salvaterra, S. Mereghetti **IASF Milano;** R. Ciolfi, **OA Padova;** L. Piro, **IAPS**)
- **Future GW observatories - Einstein Telescope** (M. Bachetti, D. Perrodin, **OA Cagliari**; S. Piranomonte, F. Verrecchia, A. Stamerra, **OA Roma**; C. Casentini, **IAPS**; R. Ciolfi, **OA Padova**, G. Ghirlanda, **OA Brera**

…and many other researchers/institutes from different INAF RSN !!

LIGO-Virgo-Kagra -> **RSN 4 activities**

RSN4 people in the GRAWITA collaboration ~40

- **Observations: LVK GW source follow-up campaigns**
- **Theory: EM counterpart modelling**
- **Future perspectives**

- **MW** (L. Piro, G. Gianfagna, A. Thakur, **IAPS;** S. Piranomonte, A. Melandri, **OA Roma;** E. Maiorano, E. Pian, A. Rossi, G. Stratta **OAS,** M.G. Bernardini, P. D'Avanzo, S. Covino, **OA Brera**)
- **radio** (G. Bruni, **IAPS,** M. Giroletti**, IRA**)
- **High-energy** (e.g. AGILE, Swift, etc., Campana, Bernardini, D'Avanzo, Sbarrato, Sbarufatti, Covino, Tagliaferri, **OA Brera,** F. Verrecchia, **OA Roma**; C. Casentini, **IAPS**)
- **VHE with Cherenkov telescopes** (MAGIC, ASTRI, LST, CTAO, A. Stamerra, **OA Roma, A. Bulgarelli OAS**)
- **GRB (jet), kilonova radiation, mechanisms and source population studies** (O. Salafia, G. Ghirlanda,**OA Brera,** R. Salvaterra **IASF Milano**)
- **GW+afterglow modelling** (G. Gianfagna, L. Piro, **IAPS**)
- **GRB afterglow+kilonova modelling** (G. Stratta, A. Rossi, R. Farinelli, E. Maiorano **OAS**)
- **NS-NS GW+jet+kilonova formation and emission(**R. Ciolfi, **OA Padova**)

- **Future GRB missions as THESEUS, eXTP, newAthena** (L. Amati, G. Stratta, **OAS,** G. Ghirlanda, i **OA Brera,** R. Salvaterra, S. Mereghetti **IASF Milano;** R. Ciolfi, **OA Padova;** L. Piro, **IAPS**)
- **Future GW observatories - Einstein Telescope** (M. Bachetti, D. Perrodin, **OA Cagliari**; S. Piranomonte, F. Verrecchia, A. Stamerra, **OA Roma**; C. Casentini, **IAPS**; R. Ciolfi, **OA Padova**, G. Ghirlanda, **OA Brera**

credit: P D'Avanzo

GRAvitational Wave Inaf TeAm

Science Board
M.G. Bernardini (PI), M. Branchesi, E. Cappellaro, A. Grado, E. Palazzi, A. Possenti
P.D'Avanzo

WG1 24h/7d OPERATIONS — **P. D'Avanzo**

WG2 WIDE FIELD SEARCH — **F. Getman**

WG3 CHARACTERISATION AND FOLLOW-UP (Opt & NIR) — **Andrea Melandri**

WG4 RADIO FOLLOW-UP — **M. Giroletti**

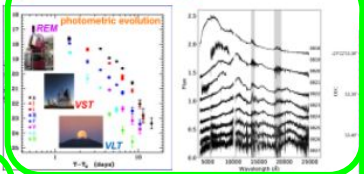
WG5 HIGH ENERGY PROMPT & FOLLOW-UP — **A. Bulgarelli**

WG6 THEORY — **R. Ciolfi**

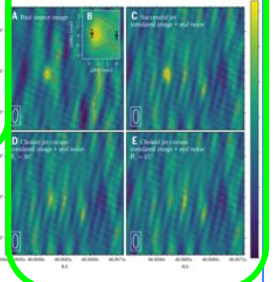
WG7 ARCHIVING & WEB — **L. Nicastro**

- born on 2015
- PI: M.G. Bernardini
- 7 Working Groups, from observations to data analysis, archiving and modelling

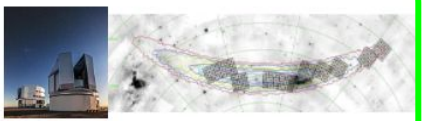
Pian et al. 2017

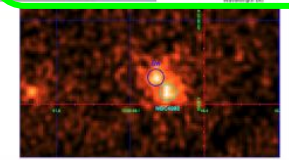


Ghirlanda et al. 2019



Brocato et al. 2017





Follow-up of GW triggers with main INAF facilities:

Wide field:
- **VLT Survey Telescope,**
- **Asiago Observatory,**
- **Campo Imperatore Observatory,**

Narrow Field:
- **Large Binocular Telescope,**
- **Telescopio Nazionale Galileo,**
- **Rapid Eye Mount Telescope,**
- **Loiano Observatory,**
- **SRT**

\+ other facilities (e.g. Swift, SVOM, VLBI, etc.)

Contribution to ENGRAVE EU collaboration

RSN4 in GRAWITA ~40 INAF researches:

- OA Brera
- OAS Bologna
- IRA Bologna
- OA Padova,
- OAR Roma
- OA Capodimonte,
- OA Cagliari
- OA Teramo (+GSSI)

ACME
Astrophysics Centre for Multimessenger studies in Europe

https://www.acme-astro.eu

The Astrophysics Centre for Multi-messenger studies in Europe (ACME) consortium gathers 40 institutes, 15 countries, over 30 research infrastructures from Astronomy and Astroparticle domains, covering GW, Gamma & X-rays, neutrinos, CR, radio, optical.
One common objective: to provide enhanced access to infrastructure and services for the European multi- messenger and time-domain research communities.

The project has been funded by the European Union (call: HORIZON-INFRA-2023-SERV-01, grant no. 101131928) for 4 years (Sept 24, Aug 28), for a total cost of 14.5 MEuro.

INAF@ACME

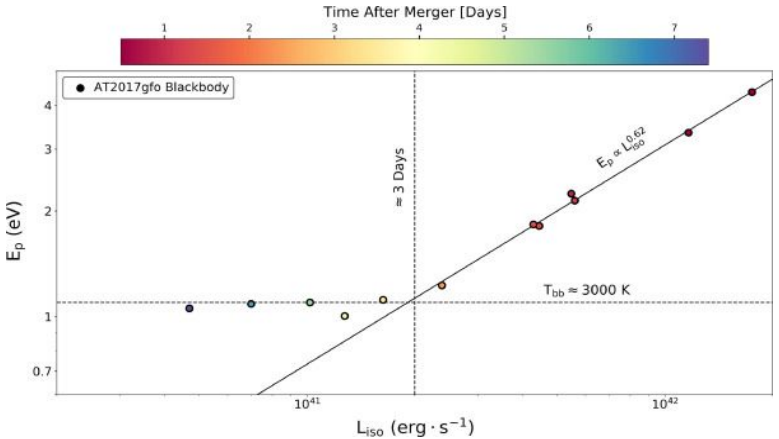
Project co-Coordinator: Paolo D'Avanzo
INAF reference person: Silvia Piranomonte
21 INAF researchers (> 60% from RSN4) from 8 structures

Contribution to:
WP1: Coordination and Management
WP3: TA3/VA3 Provision of scientific expertise for multi-messenger observations
WP4: Provision of improved access to near-real time and archival multi- messenger data.
WP6: Training for scientists and engineers.

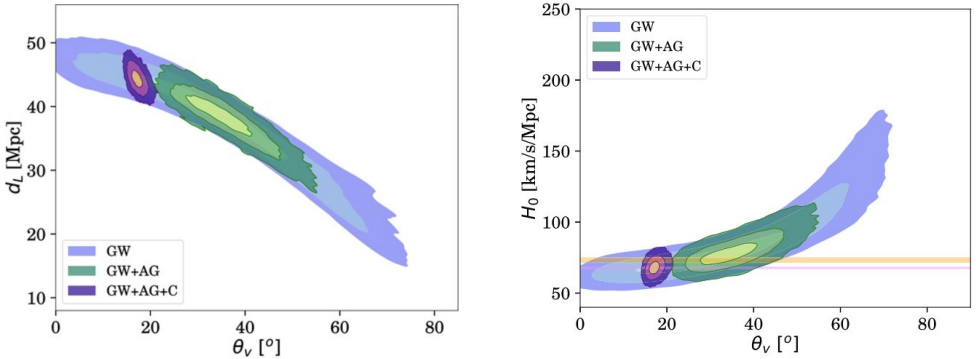
LIGO-Virgo-Kagra -> **RSN 4 activities**

Examples of studies on the famous GW170817/GRB170817/AT2017gfo

Using AT2017gfo X-Shooter spectra -> spectral evolution with time show a characteristic path in the Ep-Liso reminiscent of GRB prompt emission, that can be used to test kilonova models (Farinelli et al. 2026)



Accurate GW170817 + GRB170817afterglow modelling to disentangle DL vs inclination degeneracy from GW-only analysis, allowing for more precise H0 measures (Gianfagna et al. 2024)

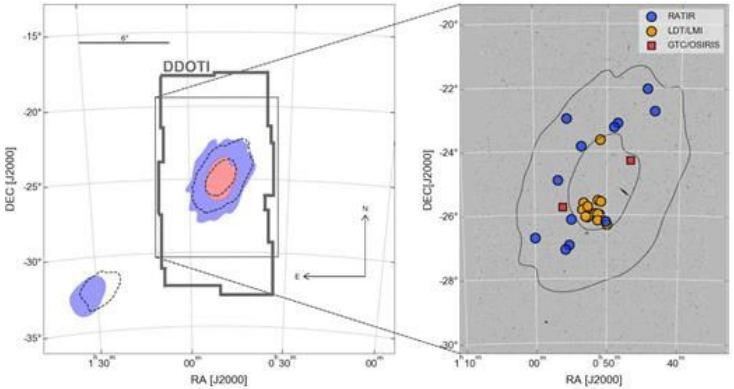


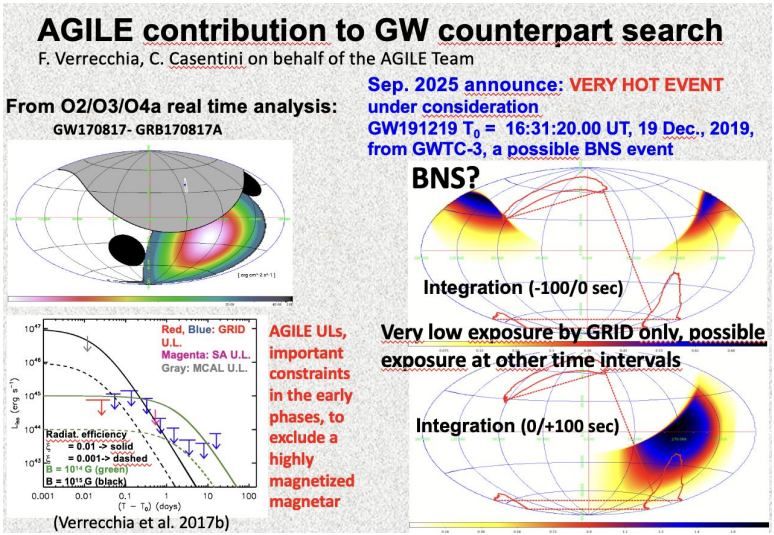
LIGO-Virgo-Kagra -> **RSN 4 activities**

Examples of GW sources follow-up

Opt/NIR: GW190814, a potential NS-BH with 18.5 deg^2 sky localization (90%) at 240 Mpc -> deep searches and model comparison (Thakur et al. 2020)

Thakur et al. 2020



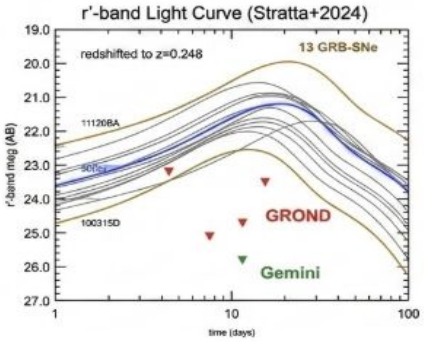


High-energies: AGILE / GRID follow-up of the NS-NS merger GW170817 -> upper limits vs expected magnetar emission (Verrecchia et al. 2017)

AGILE archival data covering the sky at the time of GW191219, a NS-NS or NS-BH candidate -> data sill under investigation

LIGO-Virgo-Kagra -> **RSN 4 activities**

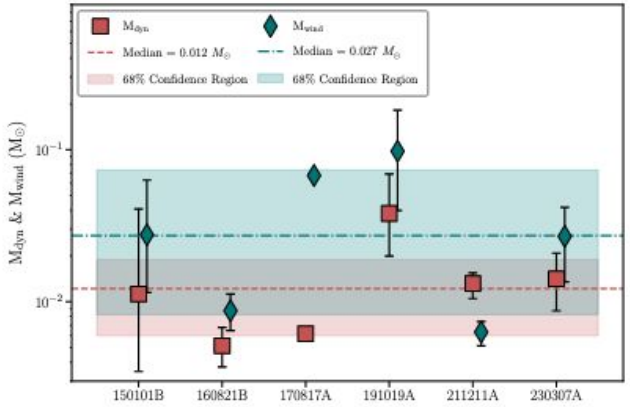
Examples of KN studies from merger-driven GRBs



long GRB 191019A
- no SN
- old host
- Evidence of **kilonova** signature

(Stratta et al. 2025)

INAF Mini Grants RSN4 (ID: 1.05.24.07.04) PI: Andrea Rossi
Titolo: The GRB-KN connection

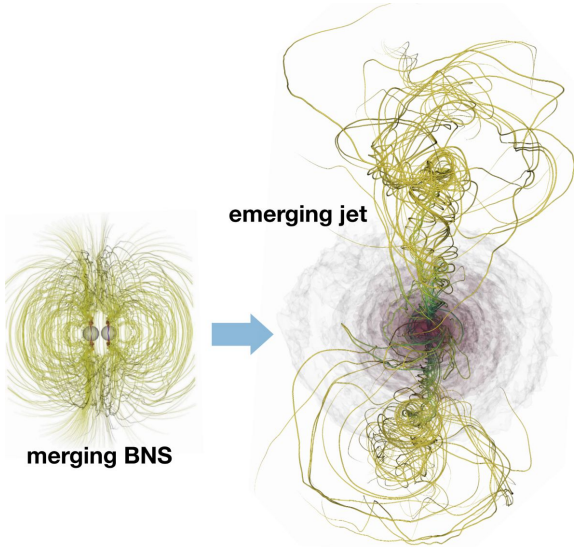


Joint afterglow+kilonova fit for a sample of GRBs with evidence of KN (Singh et al. 2025)

LIGO-Virgo-Kagra -> **RSN 4 activities ->** *THEORY*

- **Modelling and interpretation of MM emission of NS-NS and NS-BH,** at both **single-event** and **population level** (O. Salafia, G. Ghirlanda, **OA Brera,** R. Salvaterra **IASF Milano**)
  - equation of state of NS
  - origin of heavy elements
  - central engine of relativistic jets
  - expansion history of the Universe
  - observing strategies and of new instruments

- **BNS merger simulations** (R. Ciolfi, **OA Padova**)
  - GRMHD simulations to study how kilonovae and GRB jets form, along with the GW emission before and after merger
  - Relativistic MHD simulations of jets from BNS mergers, covering up to the much larger scales relevant for shaping the GRB prompt and afterglow emission



LIGO-Virgo-Kagra -> **RSN 4 activities ->** *near future*

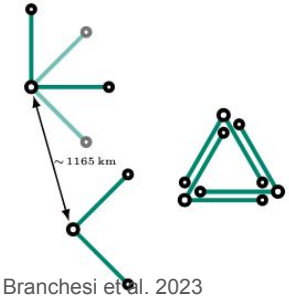
- **Vera Rubin Observatory** -> Kilonovae observational campaigns (S. Piranomonte, A. Melandri, E. Loffredo, F. Onori, OA Roma,...)
  - contribution to Vera Rubin Target Of Opportunity program (Andreoni et al. 2024, arxiv: 2411.04793)

- **Square Kilometer Array Observatory (SKAO)** -> prospects of EM counterpart identification and characterization
  - contribution to SKAO Science Book (M. Giroletti, IRA et al.)

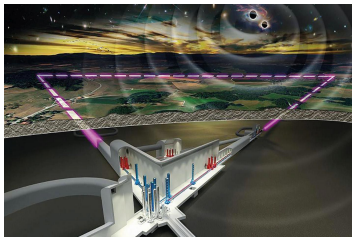
- **CTAO** -> follow-up campaigns at very high energies with (A. Stamerra, OA Roma et al.)

- **ELT** -> Kilonovae characterisation with (MORFEO-ELT, GW Science Case: E. Maiorano, A. Rossi, G. Stratta, E. Palazzi, OAS, et al.)

LIGO-Virgo-Kagra -> **RSN 4 activities ->** *Far future*



Branchesi et al. 2023



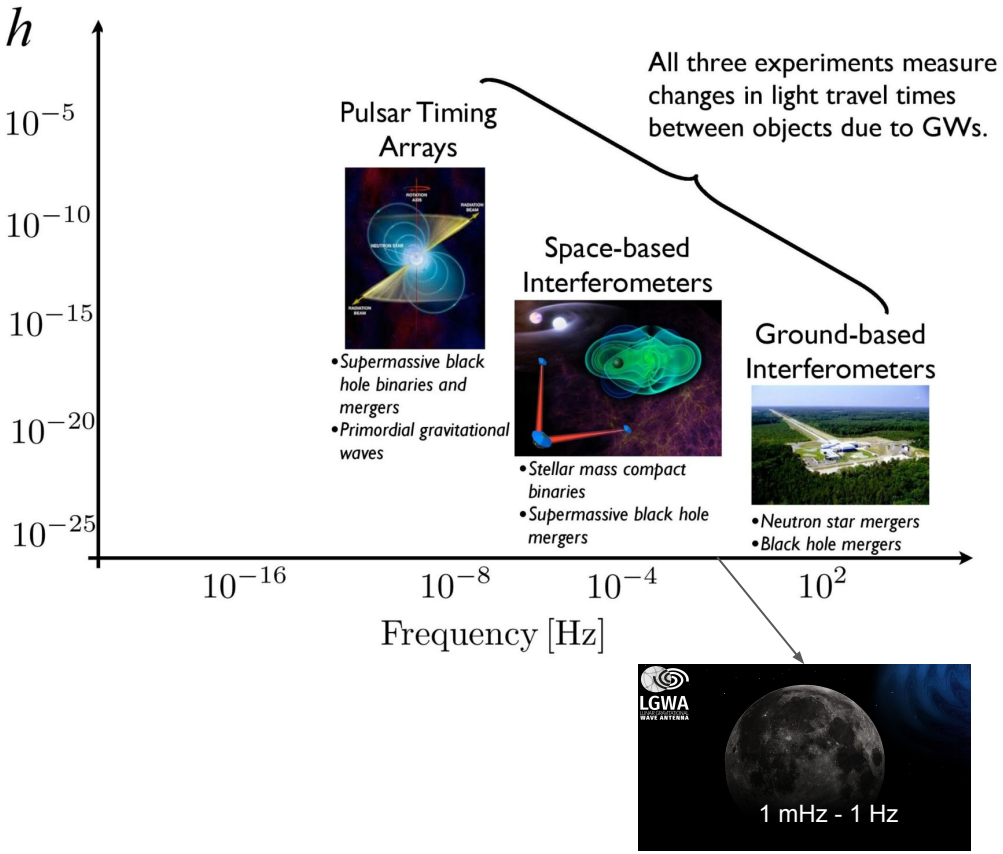
- **Einstein Telescope** is the next generation EU GW ground-based observatory (>2035)
- **Large RSN4 participation to the Einstein Telescope "blue book"** (e.g. D. Perrodin, M. Bachetti, OA Cagliari; G. Ghirlanda, O. Salafia, OA Brera; A. Stamerra, S. Piranomonte, F. Verrecchia, OA Roma; C. Casentini, IAPS, and many others….)

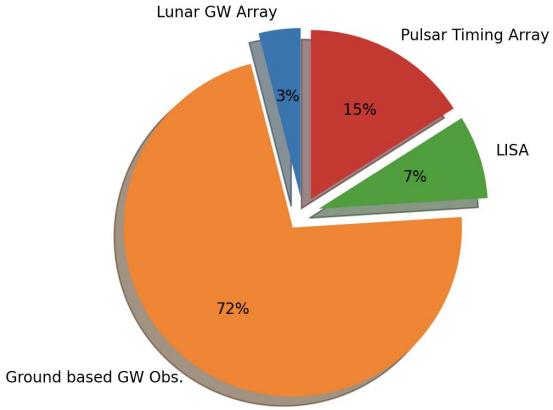
The Science of the Einstein Telescope

Einstein Telescope collaboration

Adrian Abac[1] Raul Abramo[2] Simone Albanesi[3,4] Angelica Albertini[5,6] Alessandro Agapito[7,8,9] Michalis Agathos[10,11] Conrado Albertus[12] Nils Andersson[13] Tomás Andrade[14] Igor Andreoni[15,16] Federico Angeloni[7,17,8,18] Marco Antonelli[19] John Antoniadis[20,21] Fabio Antonini[22] Manuel Arca Sedda[23,24,25,26] M. Celeste Artale[27,28] Stefano Ascenzi[23] Pierre Auclair[29] Matteo Bachetti[30] Charles Badger[31] Biswajit Banerjee[23] David Barba-González[12] Dániel Barta[32] Nicola Bartolo[26,33,34] Andreas Bauswein[35] Andrea Begnoni[26,33] Freija Beirnaert[36] Michał Bejger[37,38] Enis Belgacem[39,40] Nicola Bellomo[26,33,34] Laura Bernard[41] Maria Grazia Bernardini[42] Sebastiano Bernuzzi[3] Christopher P. L. Berry[43] Emanuele Berti[44] Gianfranco Bertone[45] Dario Bettoni[46,12] Miguel Bezares[47,48] Swetha Bhagwat[49] Sofia Bisero[50] Marie Anne Bizouard[51] Jose J. Blanco-Pillado[52,53,54] Simone Blasi[55,56] Alice Bonino[49] Alice Borghese[18] Nicola Borghi[57,58] Ssohrab Borhanian[3,59,60] Elisa Bortolas[34,59,60] Maria Teresa Botticella[61] Marica Branchesi[23,24] Matteo Breschi[3] Richard Brito[62] Enzo Brocato[25,18] Floor S. Broekgaarden[63] Tomasz Bulik[64] Alessandra Buonanno[1,65] Fiorella Burgio[66] Adam Burrows[67] Gianluca Calcagni[68] Sofia Canevarolo[69] Enrico Cappellaro[34] Giulia Capurri[70,71] Carmelita Carbone[72] Roberto Casadio[57,73] Ramiro Cayuso[74,75] Pablo Cerdá-Durán[76,77] Prasanta Char[12] Sylvain Chaty[78] Tommaso Chiarusi[73] Martyna Chruslinska[79,80] Francesco Cireddu[81,82,70] Philippa Cole[59,60] Alberto Colombo[42,60] Monica Colpi[59] Geoffrey Compère[83] Carlo Contaldi[84] Maxence Corman[1] Francesco Crescimbeni[7,8] Sergio Cristallo[25] Elena Cuoco[57,73] Giulia Cusin[85,39] Tito Dal Canton[86] Gergely Dálya[87] Paolo D'Avanzo[42] Nazanin Davari[18] Valerio De Luca[88] Viola De Renzis[9] Massimo Della Valle[61] Walter Del Pozzo[70,71] Federico De Santi[70,71] Alessio Ludovico De Santis[23,24] Tim

The spectrum of gravitational wave astronomy



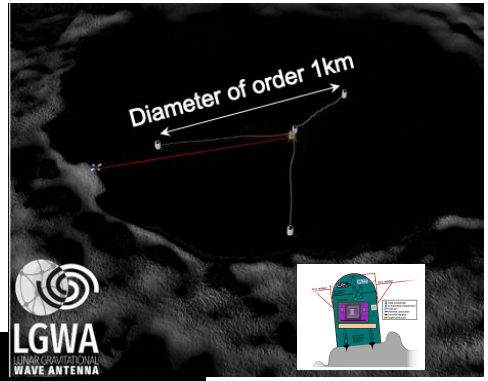


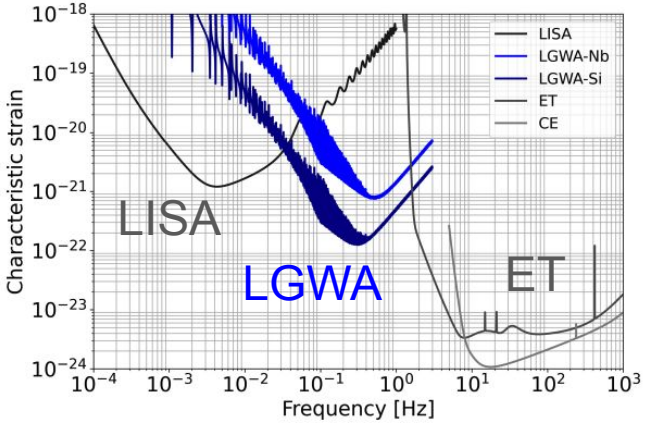
RSN4 activities with different types of GW sources

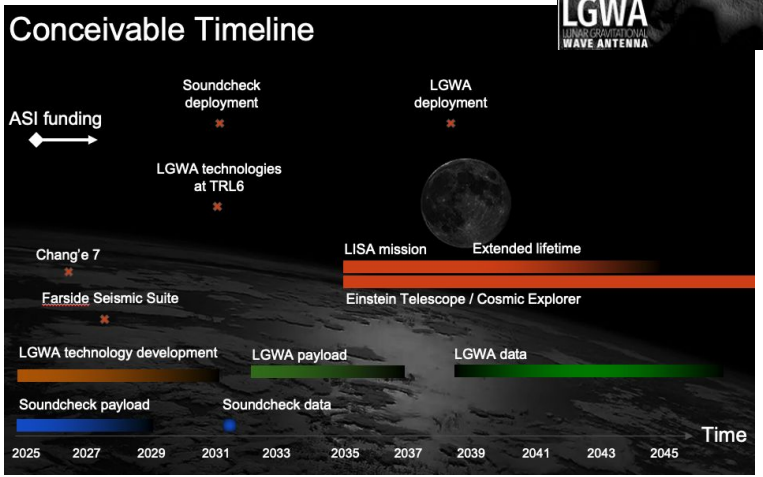
Lunar GW Antenna (LGWA) -> **RSN 4 activities**

Mission concept:

Sensor array inside a **permanently shadowed lunar region** (low T and stable) to measure Moon oscillations due to **dHz GWs**





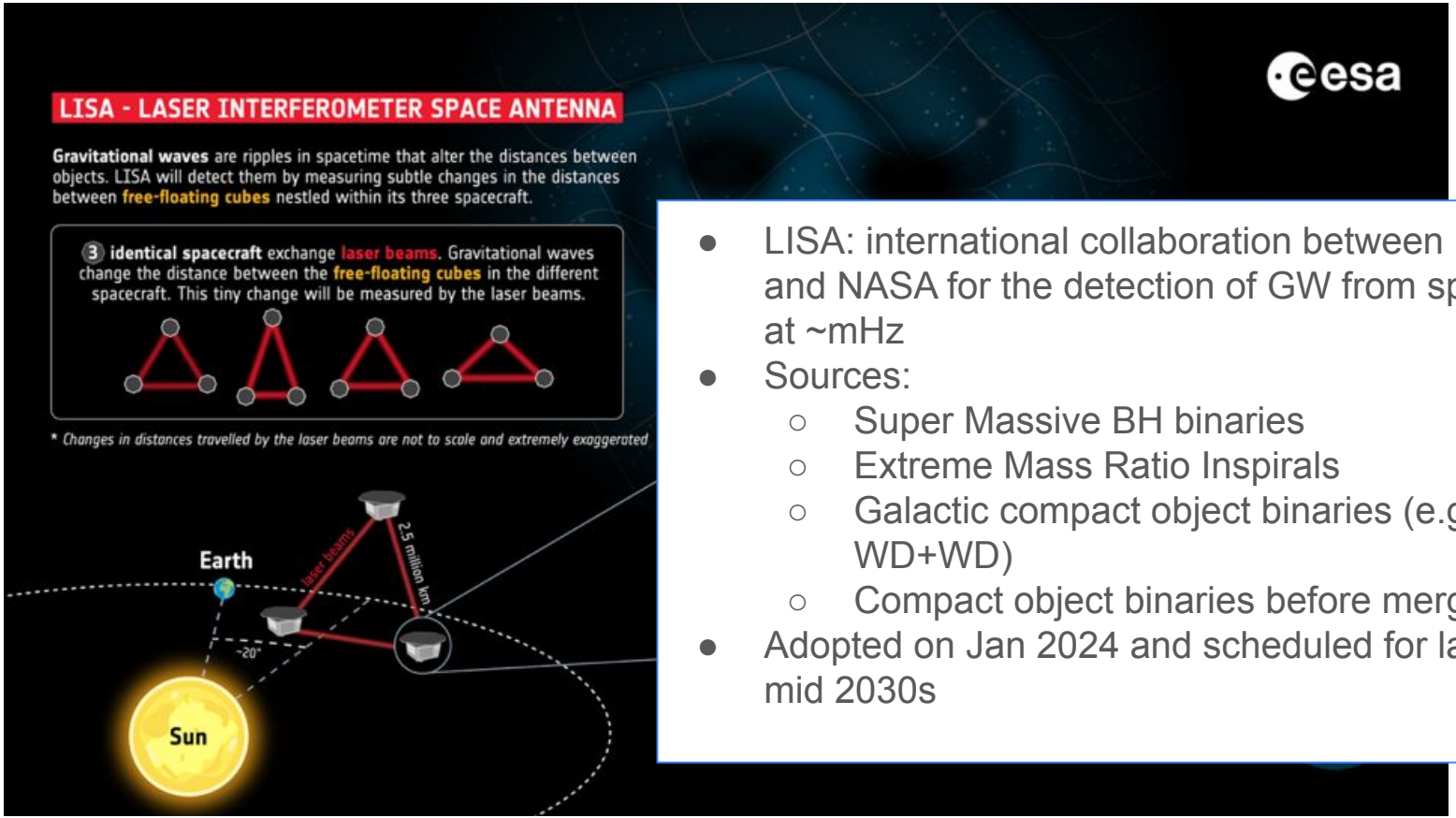


Scientific cases (some examples): Early warnings (week/month) and localization of NS-NS, AGN, TDE, SNIa progenitors (e.g. WD+WD)

RSN4 activities: study of scientific cases, contribution to "LGWA mission studies and scientific cases" -> **JCAP01, 2025, 108 (**P. Severgnini, OA Brera, S. Piranomonte, OA Roma, and many others….)

Credit: J. Harms (GSSI)

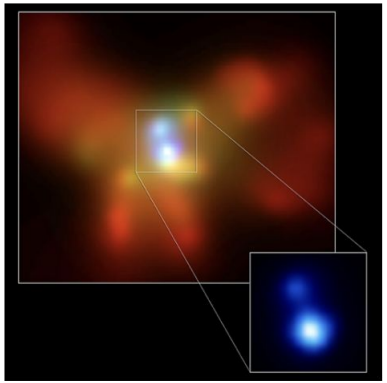
Laser Interferometer Space Antenna



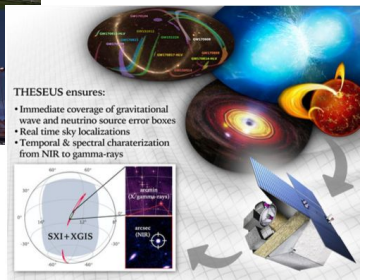
- LISA: international collaboration between ESA and NASA for the detection of GW from space at ~mHz
- Sources:
  - Super Massive BH binaries
  - Extreme Mass Ratio Inspirals
  - Galactic compact object binaries (e.g. WD+WD)
  - Compact object binaries before merger
- Adopted on Jan 2024 and scheduled for launch mid 2030s

Laser Interferometer Space Antenna -> **RSN 4 activities**

- MW and MM study of dual AGN and SMBH and their identification methods (A. De Rosa, **IAPS**)
- Search and characterization of strongly **lensed binary SMBHs** at high-z as precursors of LISA sources (C. Spingola, **IRA**)
- Study of the synergies between newAthena, THESEUS, and other future facilities with LISA (w.g. Piro, **IAPS,** Amati **OAS,** etc.)

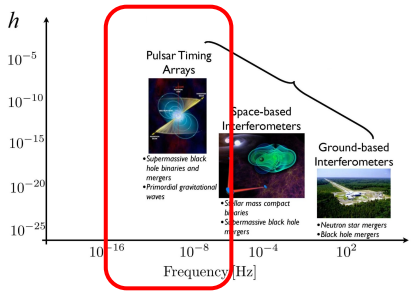


Chandra image of NGC 6240 and its pair of accreting SMBHs (De Rosa et al. 2017)



Pulsar Timing Array -> **RSN 4 activities**

- PTA allows for detection of **GWs at nHz frequencies** with variations in the pulsar signal arrival time due to GW crossing
- GW sources:
  - SMBH binaries
  - stochastic gravitational wave background (SGWB) sources in early Universe



- RSN4 activity:
  - **multi-messenger emission from SMBH binaries** (A. Possenti, OA Cagliari; C. Tiburzi OA Brera + 1 postdoc M. Brionne + 1 PhD F. Iraci, Univ. of Cagliari + PhD D. Zecca, Univ. of Salento)
  - **Cosmological backgrounds of GWs** (C. Tiburzi, M. Brionne, OA Brera)
  - **Modeling of noise by the ionised ISM and Solar wind** on PSR timing (C. Tiburzi, M. Brionne, OA Brera)
  - **Studies of plasma effects using pulsar data taken at low radio-frequencies with the European interferometers LOFAR and NenuFAR** (C. Tiburzi, M. Brionne, OA Brera)

Some of the key open questions we will address in the coming years

- EM emission from NS-BH?
- central engine of GRB jets (NS vs BH)
- Are kilonovae the dominant cosmic sites for r-process nucleosynthesis?
- EoS of NS?
- EM emission from SMBH mergers?
- GWs from Early Universe?
- SNIa progenitors?
- ….

Some of the key open questions we will address in the coming years

- EM emission from NS-BH?
- central engine of GRB jets (NS vs BH)
- Are kilonovae the dominant cosmic sites for r-process nucleosynthesis?
- EoS of NS?
- EM emission from SMBH mergers?
- GWs from Early Universe?
- SNIa progenitors?
- ….

To answer many of these questions:

- large samples of GW sources -> ET (Meanwile, study of EM sources that are connected to GW emitters, such as GRBs, KNe, SNe,)
- go down in GW frequencies -> LGWA/LISA/PTA

Summary and Conclusions

- GW source studies represent roughly ~30% of the whole RSN4 network activities

- ~ 70% of the RSN4-GW activities are focussed on high frequency GW sources as NS-NS and NS-BH detected with ground based GW observatories, and their EM counterparts, ~30% on PTA, LISA and LGWA projects

- Good fraction of RSN4-GW activities devoted to GW source science with future missions like newAthena, THESEUS, and telescopes as CTA, ELT, etc. -> mandatory to answer many open questions in synergies with next ground-based GW detectors and low GW frequency detections