INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

How to discover the secrets of nature up to the largest scales

Paolo D'Avanzo
(with significant contribution from Andrea Bianco)

INAF – Osservatorio Astronomico di Brera

TECH-FPA PhD Retreat 2025 – Feb 17, 2025, LNGS

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

- July 23, 1999: INAF date of birth.
- The National Institute of Astrophysics is the principal Italian Research Entity for the study of the Universe.
- It promotes, realizes, and coordinates research activities in **the fields of astronomy and astrophysics**, both in collaboration with universities and with other public and private entities, nationally and internationally. This includes participation in programs of the European Union and international organizations.
- It designs and develops **innovative technologies** and cutting-edge instruments for the study and exploration of the Cosmos.
- It fosters the **dissemination of scientific culture** through educational projects and the popularization of Astronomy aimed at schools and society."

Headquarter in Rome – Monte Mario

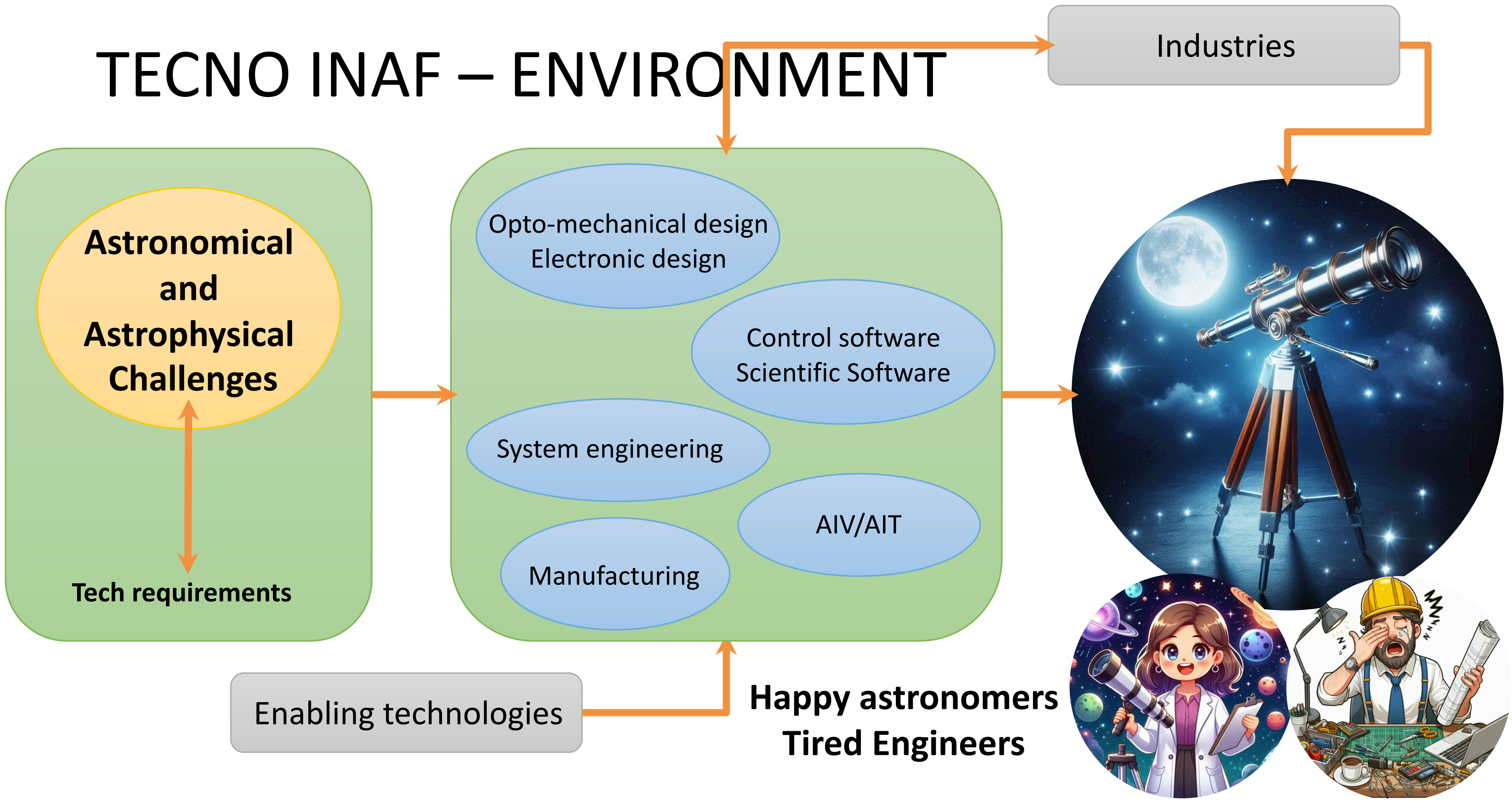
Science @ INAF

- Galaxies and Cosmology
- Stars, Interstellar Medium and Exoplanets
- Sun and Solar System
- Relativistic Astrophysics and Astroparticles
- Advanced Technology and Instrumentation

INAF – some numbers

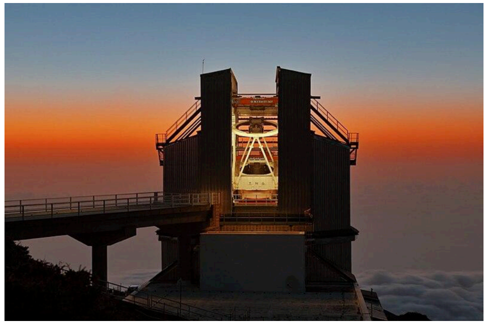
- **More than 1,400: the number of people that work for INAF**, composed of researchers (including research students and post-docs), technicians and administrative staff
- **19: the number of national research institutes**, and one in the Canary Islands which operates the Telescopio Nazionale Galileo - TNG.
- **200**: the number of international research institutes that collaborate with INAF.
- **Between 3,000 and 4,000:** the scientific publications written by INAF researchers each year.
- **Different optical telescopes: TNG, Copernico, REM, Cassini, LBT.**
- **4 radio facilities in Italy: SRT, Medicina, Noto, Croce del Nord.**
- **Cherenkov telescopes: ASTRI.**
- **125,000**: the number of ancient volumes on physics and astronomy in INAF's historic libraries.

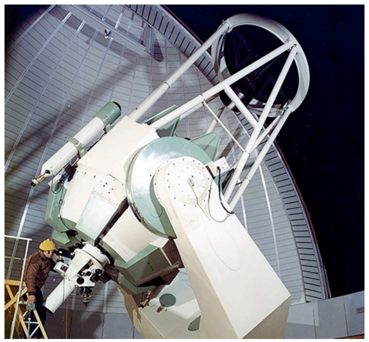
Canary Islands


TECNO INAF – ENVIRONMENT
Industries
Astronomical and Astrophysical Challenges
Tech requirements
Opto-mechanical design
Electronic design
Control software
Scientific Software
System engineering
AIV/AIT
Manufacturing
Enabling technologies
Happy astronomers
Tired Engineers

INAF – Optical telescopes

- **TNG** – La Palma (Spain): 3.6 m telescope.
  Set of instruments:
  - HARPS-North: Radial velocity Planet Searcher in North hemisphere;
  - GIANO: near IR high resolution echelle spectrograph
  - DOLORES: low res multiobject spectrograph in the visible
  - SiFAP (Silicon Fast Astronomical Photometer) to detect optical pulses from transitional millisecond pulsars and from other slower neutron stars.
- **REM** – La Silla (Chile): 0.6 m fast robotic telescope
  - REMIR, infrared (zJHK') camera;
  - ROSS2, multi-channel visible imaging camera.
- **Copernico** – Asiago: 1.8 m telescope. Instruments:
  - AFOSC: low res multiobject spectrograph in the visible;
  - Reosc Echelle Spectrograph for the visible;
  - Coudé focus: general purpose optical bench.

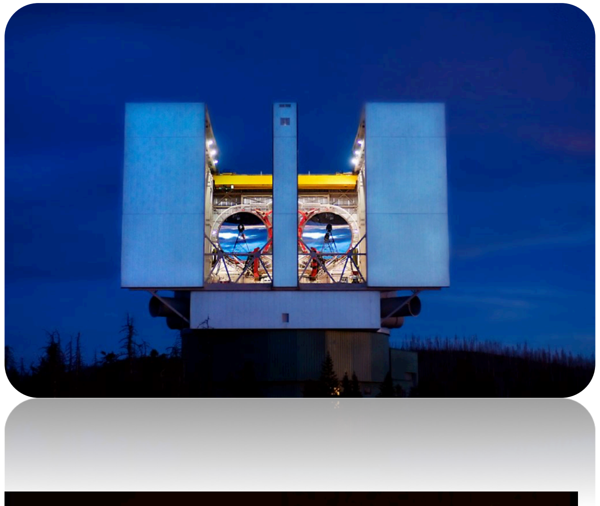


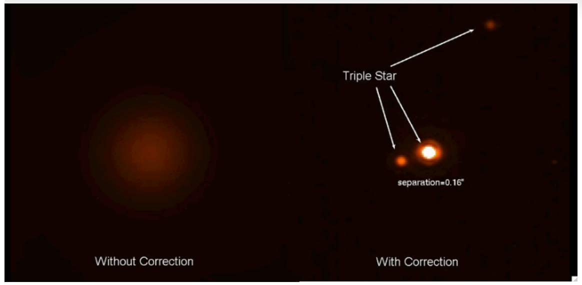


INAF – Optical telescopes

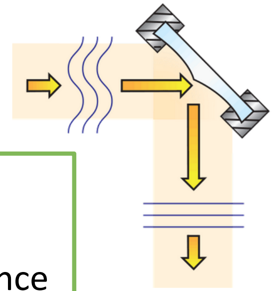
- **LBT** – Mount Graham, Arizona, 2 x 8.4 m mirrors:
    - **25% INAF** (+ Arizona + Ohio + Germany)
    - Adaptive optics fully implemented;
    - Interferometric mode (almost unique feature);
    - Large suite of instruments from VIS to NIR/MIR:

	Instrument	Type	Wavelength	AO
VIS	LBC-B (Left)	Wide Field Imager	350 – 650 nm	
	LBC-R (Right)	Wide Field Imager	550 – 1000 nm	
	MODS 1 (Left)	Imager / Spectrograph	320 – 1100 nm	
	MODS 2 (Right)	Imager / Spectrograph	320 – 1100 nm	
	PEPSI	Spectrograph / Polarimeter	383 – 907 nm	
	SHARK-VIS	Broad/Narrow band Imager, Spectral Differential Imaging, Coronagraph	400 – 900 nm	✓
NIR/MIR	LUCI1 (Left)	Imager / Spectrograph	890 – 2440 nm	✓
	LUCI2 (Right)	Imager / Spectrograph	960 – 2440 nm	✓
	LMIRCAM	Imager / Coronagraph	3-5 µm	✓
	NOMIC	Imager	8-13 µm	✓
	SHARK-NIR	Imager / Spectrograph / Coronagraph	0.95-1.7 µm	✓





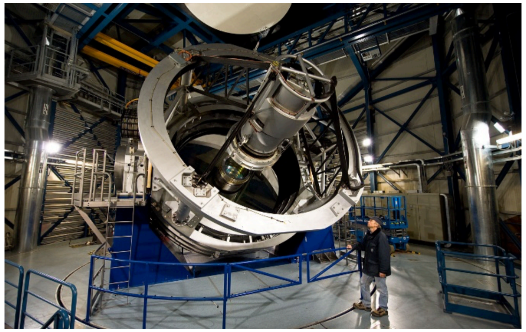
Adaptive optics



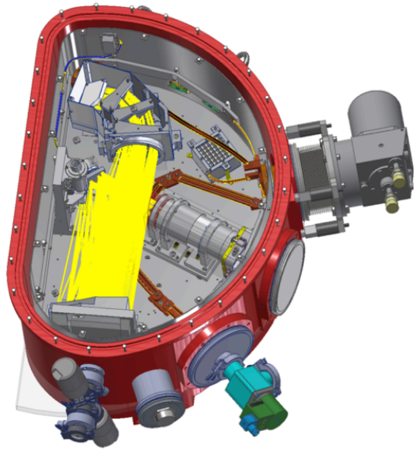
SHARK-NIR and SHARK-VIS two coronographic INAF cameras for exoplanet science

INAF – ESO

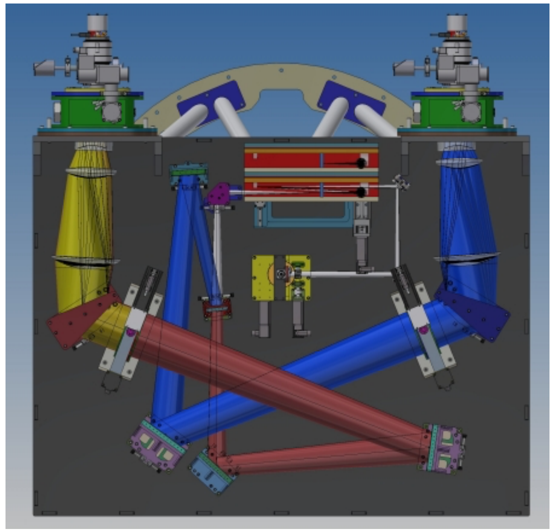
- **ESO – European Southern Observatory,** Italy is part of it since 1982. INAF is leading the participation in some instrumentations for the different telescopes;
- **ESO leads very large observing facilities:**
  - 4 Very large telescopes – VLTs (8m class telescope with a huge set of instruments from UV to MIR, img/spec);
  - VISTA, VST (4 m size telescopes for surveys);
  - NTT (4 m size telescope).



INAF – ESO instruments



- **SOXS (Son of X-Shooter)**: spectroscopic facility for the ESO-NTT 3.6-m covering the optical/NIR band (350-2000 nm) + Vis imaging for studying transient sources;
  - INAF (PI Sergio Campana) responsible of the NIR arm, system engineering, AIV/AIT, commissioning, operations;



- **CUBES:** (Cassegrain U-Band Efficient Spectrograph), VLT spectrograph covering with a high efficiency the UV ground-based region (300 - 400 nm) with intermediate resolution (about 20K);
  - INAF (PI Stefano Covino) large contribution, with System engineering, AIV/AIT.

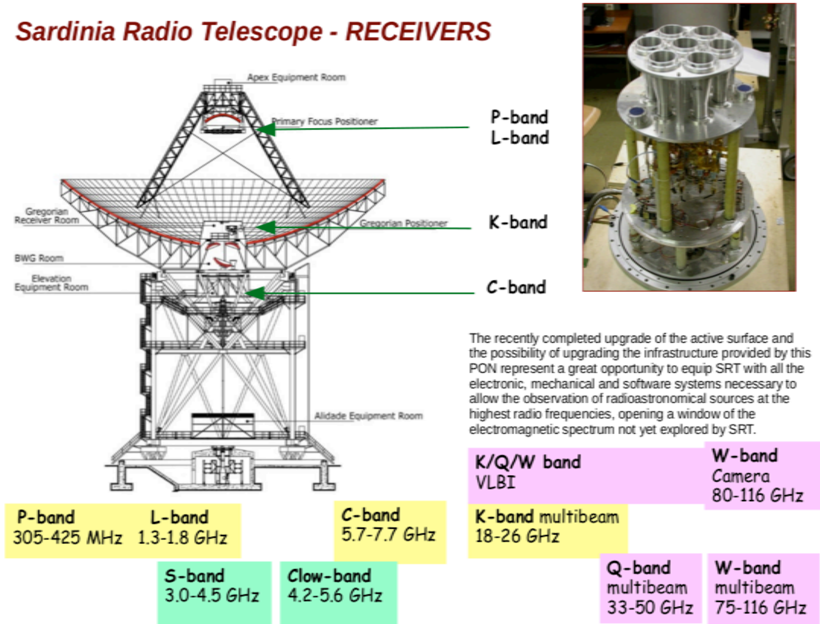

SOXS #14
SOXS #14
SOXS
#17
FRAGILE
FIAT

SOXS #6

INAF – Radio Facilities

Single dish antennas:

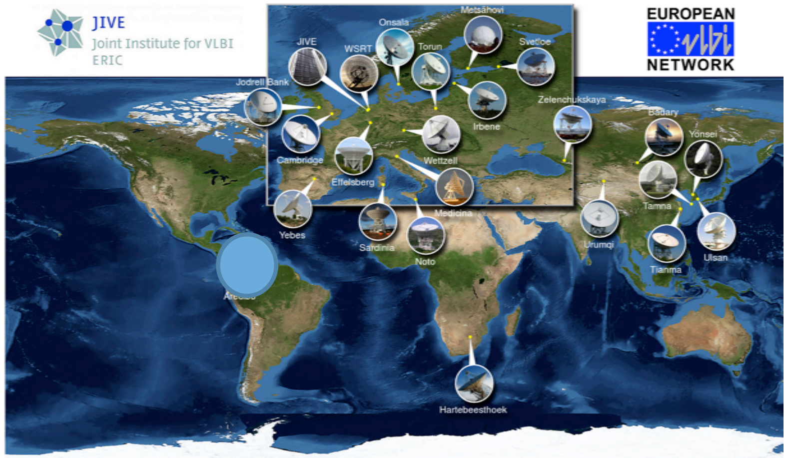
- **Medicina (BO):** 32 m dish operating in the 1.4 – 26.5 GHz band; backends: Spectrometers (XARCOS, Arcos, MSpec0) and Continuum (Analog large-bandwidth backend, Mark IV);
- **Noto (SR):** 32 m dish operating in the 2.2 – 43.5 GHz band through 5 receivers;
- **SRT (CA):** 64 m dish operating from in the 0.3 – 26.5 GHz band. L-P, C and K bands (7-pixel multi-feed configuration). Different Backends (SARDARA, SKARAB, total power).
- New receivers able to collect signals up to 110 GHz are/will be mounted on the three antennas, thanks to the triband K/Q/W.



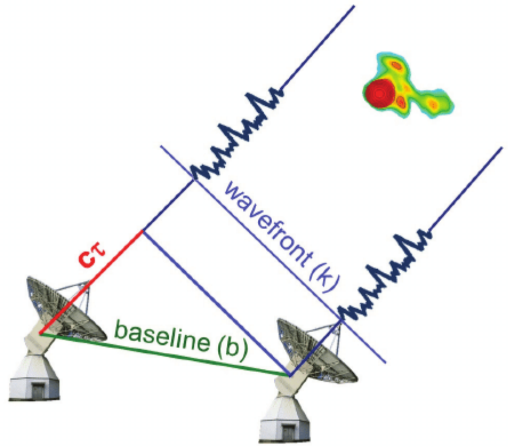
INAF – Radio Facilities: EVN

The **European VLBI Network (EVN)**: network of 19 radio telescopes in Europe and Asia, with additional antennas in South Africa, which performs very high angular resolution observations of cosmic radio sources.

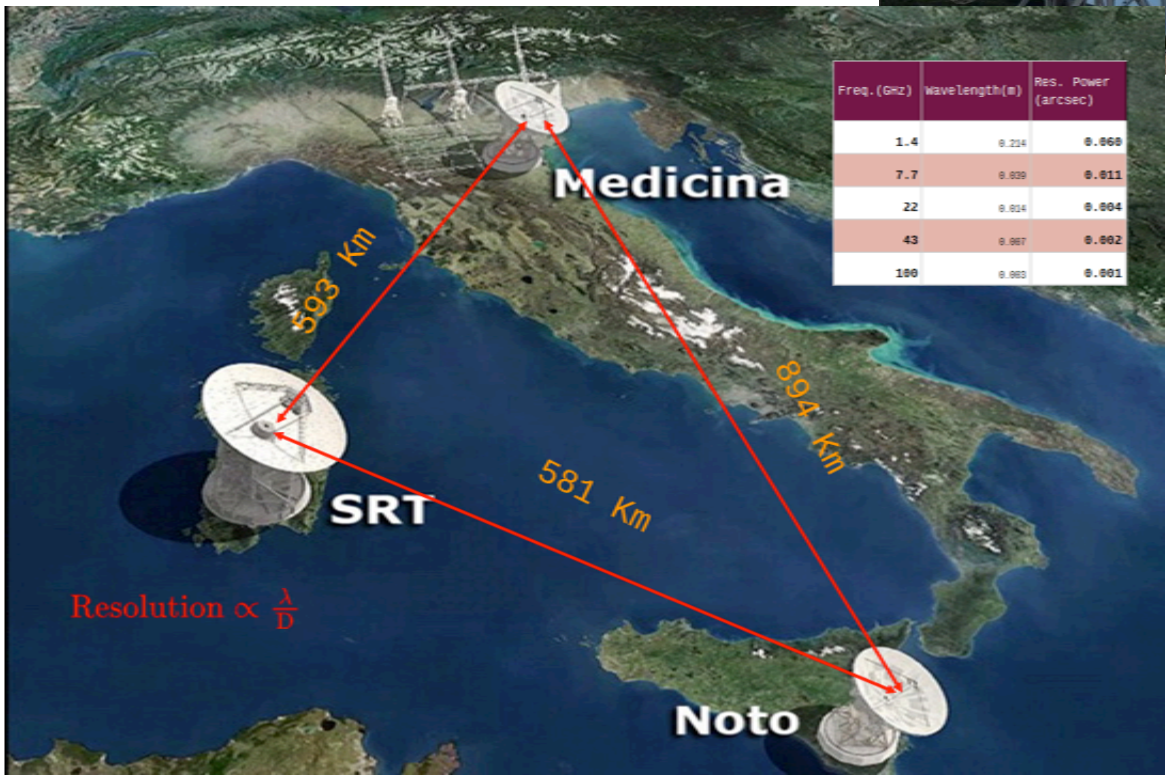
The EVN is the most sensitive VLBI (Very Large Baseline Interferometry) array in the world, and the only one capable of real-time observations.



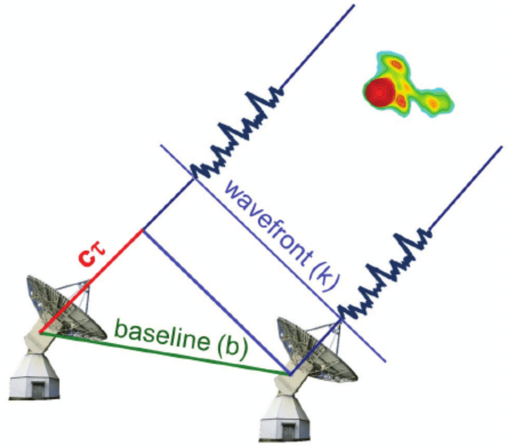
Rete Evn e Jive di radiotelescopi. Crediti: Poul Boven/Nasa



INAF – Radio Facilities



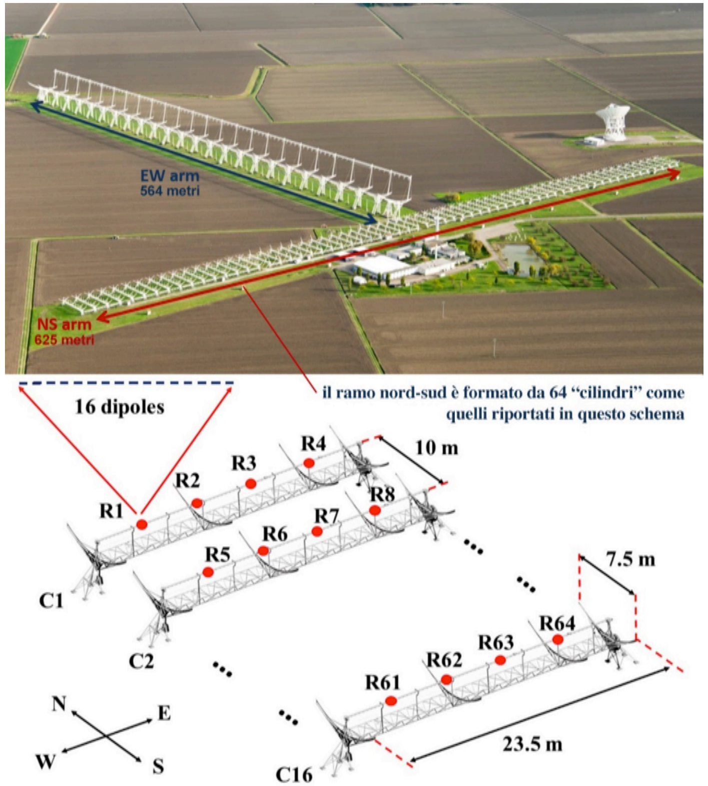
Freq.(GHz)	Wavelength(m)	Res. Power (arcsec)
1.4	0.214	0.060
7.7	0.039	0.011
22	0.014	0.004
43	0.007	0.002
100	0.003	0.001



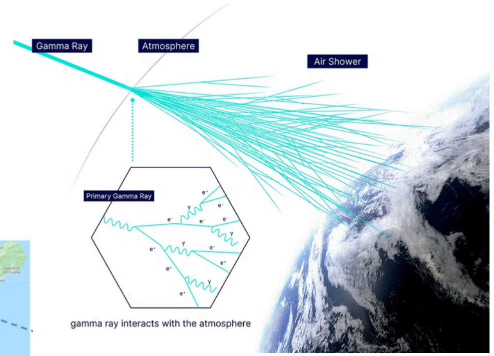
INAF – Radio Facilities

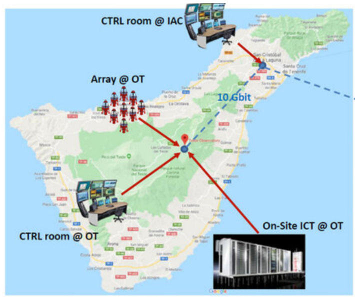
Croce del Nord: The Northern Cross has two perpendicular arms of antennas, respectively 564 m (East/West) and 640 m (North/South), with a total collecting area of over 30,000 m working on the 408 MHz frequency (16 MHz bandwidth);

PNRR project (NextGeneration Croce del Nord) for its upgrade together with the improvement of the performance of the other antennas, monitoring of space debris, new data center.

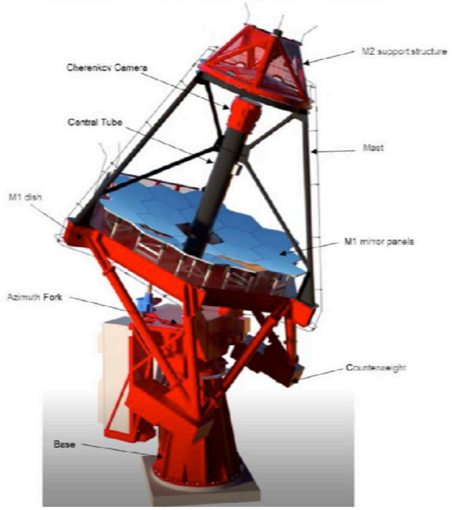


INAF – ASTRI & ASTRI Miniarray





- ASTRI (Astrofisica con Specchi a Tecnologia replicante Italiana) aimed at developing the next generation of IACT telescopes (Atmospheric Cherenkov Telescope Imaging) for astronomy in gamma rays from the ground;
- ASTRI is the first Cherenkov telescope with the Schwarzschild-Coude optical configuration;
- Detection of particle showers released by cosmic gamma rays (energies between 30 GeV and 100 TeV). The gamma rays interact with the atmosphere and produce cascades of charged particles, which emit Cherenkov radiation that the telescopes can detect.
- The ASTRI Mini-Array will consist of 9 telescopes at Teide surpass the current Cherenkov telescope array differential sensitivity above a few tera-electronvolt (TeV), extending the energy band well above hundreds of TeV.

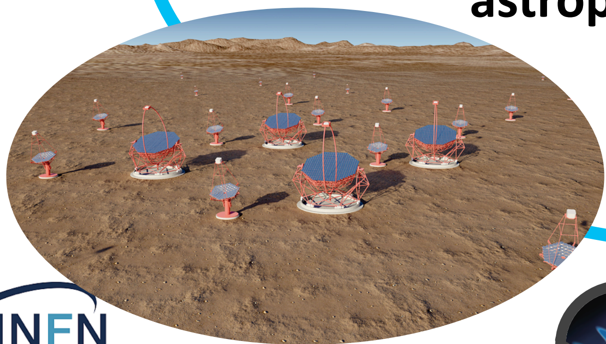


INAF – GROUND BASED LARGE PROJECTS

Extreme Large Telescope

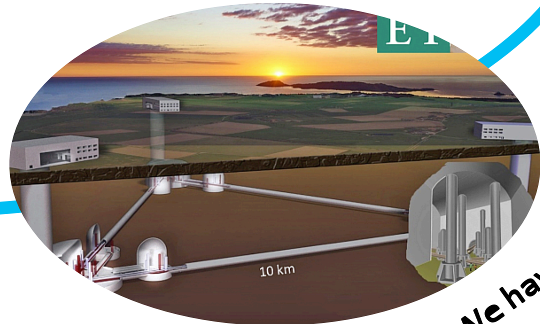
Square Kilometre Array

Key roles in main future large size international facilities that will change astrophysics in the next decade



Istituto Nazionale di Fisica Nucleare

Cherenkov Telescope Array

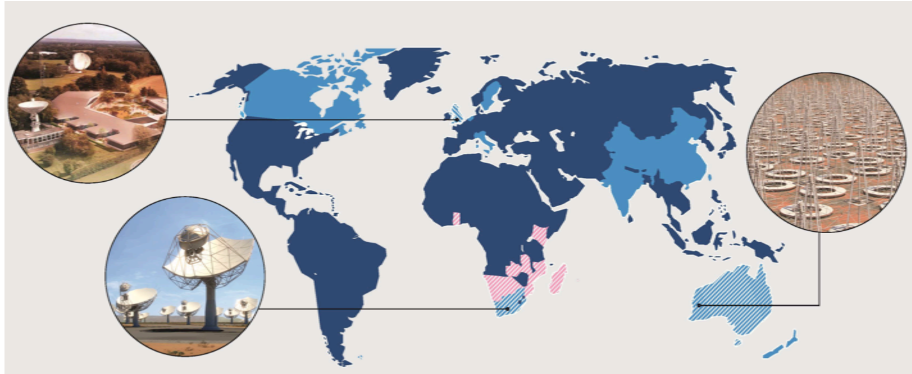


Istituto Nazionale di Fisica Nucleare

We have to wait more!

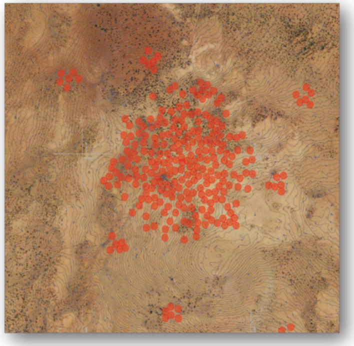
Einstein Telescope

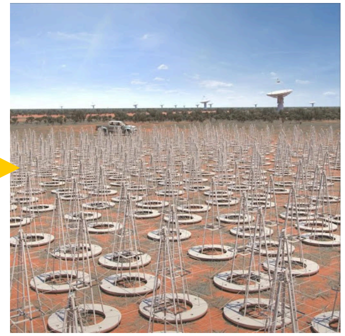
INAF – SKAO

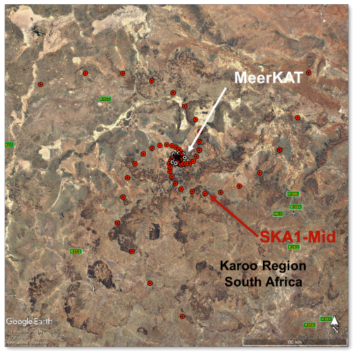


Square Kilometer Array: the most sensitive Radio observatory worldwide.

- **SKA1-Low**:log-periodic dipole antennas distributed across 512 aperture array stations of 256 antennas each.
- **SKA1-Mid**: 133 15 m SKA dishes and 64 13.5 m Meerkat dishes at the Karoo site in South Africa. The core will be composed of around 50% of the dishes, randomly distributed within 2 km. There are 3 logarithmic spiral arms with a maximum baseline extending out to 150 km.







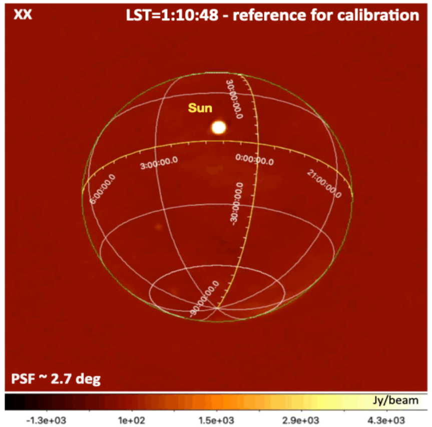
https://youtu.be/nXcsFWw2qd8?si=ckPEFapwtHjIIN1Y

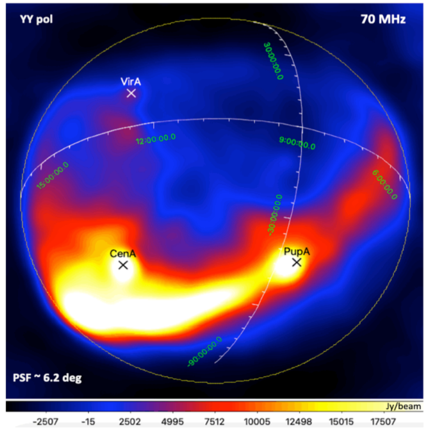
INAF – SKAO

AAVS2 (end of 2019)
256 **SKALA 4.1** log-periodic
LNA optimized for
full **50-350 MHz**
38 m diameter

Square Kilometer Array: the most sensitive Radio observatory worldwide.

- **SKA1-Low**:log-periodic dipole antennas distributed across 512 aperture array stations of 256 antennas each.
- INAF: designed and built both the antennas and the receiving chain including digital signal acquisition and processing system. Innovative algorithms have been developed. It has installed Aperture Array System 2 prototype.
- Nowadays INAF collaborates with SKAO to fine tune the designs and helps Italian industries for manufacturing the different parts.





INAF – ELT

Extreme Large Telescope: it will be the largest optical telescope in the world with a primary mirror of 39 m diameter, composed by 798 hexagonal mirrors;

- 5 mirror design **with embedded Adaptive Optics** to exploit the potential spatial resolution;
- First generation:
    - MICADO (Multi-AO Imaging Camera for Deep Observations),
    - HARMONI (high Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph)
    - METIS (Mid-infrared ELT Imager and Spectrograph) first generation instruments
    - MORFEO (MCAO module);
- INAF deeply involved in MORFEO and ANDES;
- First light 2027/2028.

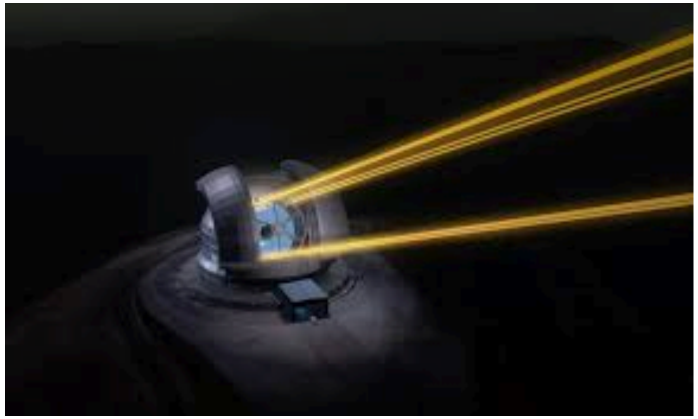
Cerro Armazones (Chile)

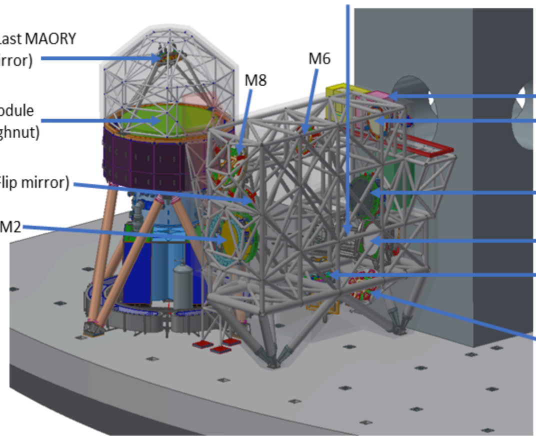
https://youtu.be/xJADOkZshUk?si=egLwVqkT0C2gQpt4

INAF – ELT

Multiconjugate adaptive Optics Relay For ELT Observations

- MORFEO is the Multiconjugate adaptive Optics Relay For ELT providing a corrected FoV of 2 arcmin;
- It feeds MICADO and a second generation instrument and it works with 3 deformable mirrors, 6 LGS and 3 NGS;
- “INAF” instrument:
  - Optomechanical design;
  - System engineer;
  - Adaptive optics system;
  - AIV AIT.

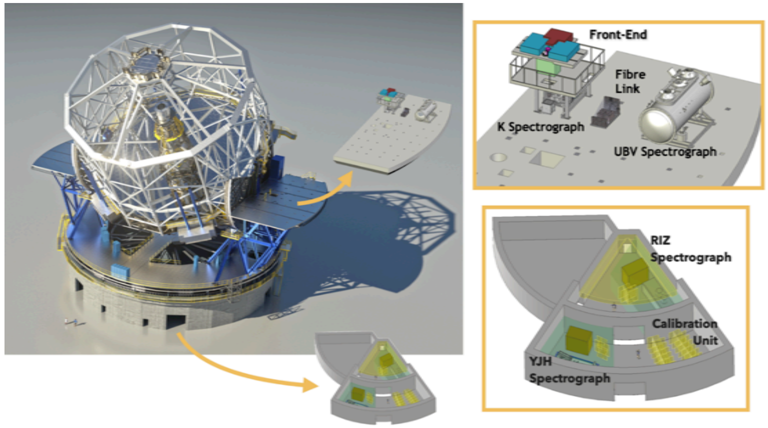


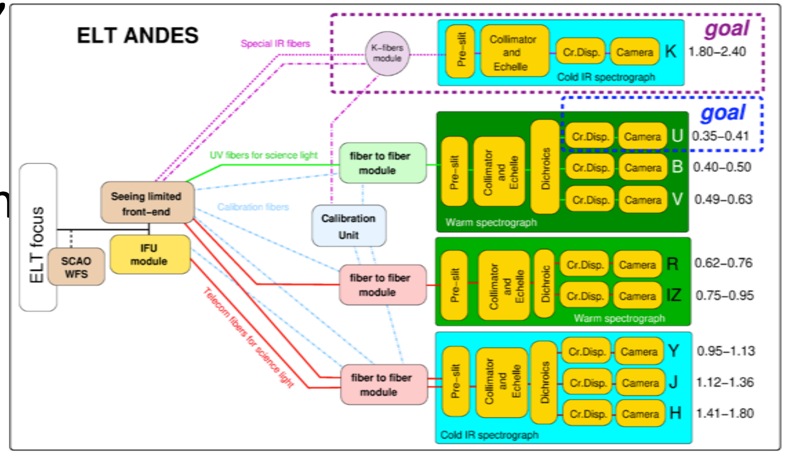


PI: Paolo Ciliegi, INAF

INAF – ELT

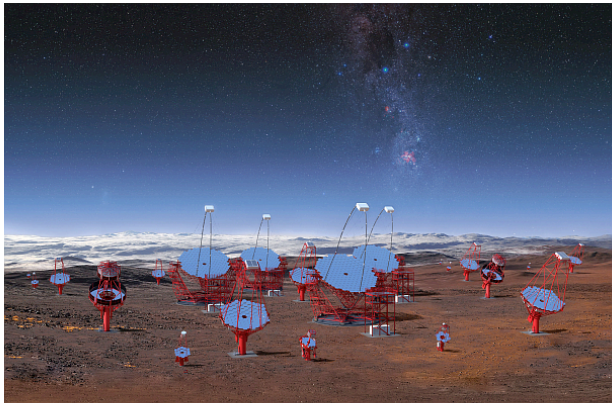
- the ArmazoNes high Dispersion Echelle Spectrograph for the ELT;
- ANDES baseline: modular fiber-fed cross dispersed echelle spectrograph composed by four ultra-stable modules capable of providing a simultaneous spectral coverage of 0.35 -2.4 nm at a resolution of 100,000 with, interchangeable, observing modes.
- Science characterization of atmospheres in Earth-like planets in other solar systems; detection of the first generation of stars, through their chemical fingerprint in the primordial Universe.



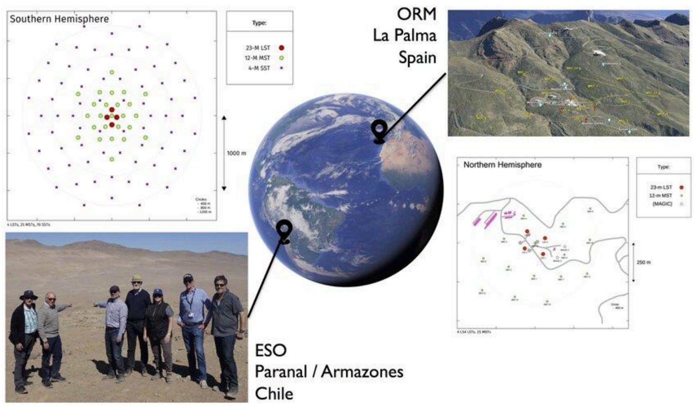


PI: A. Marconi, Univ. Florence

INAF – cta



- Cherenkov Telescope Array observatory is a set of telescopes that collect the Cherenkov light;
- Two sites: Canary Islands (North), Chile (South);
- CTA consists of more than 100 telescopes concentric positioning:
  - The **Large Size** Telescopes (LST) with a diameter of 23m (central);
  - The **Medium Size** Telescopes (MST) with a diameter of 12m;
  - The **Small Size** Telescopes (SST) with a diameter of 5m;
- Different size for different energies;
- Many telescopes to collect more of the shower;
- Large INAF contribution…Software development, SST development through ASTRI;
- CTA+ (PNRR) project for building of 2 LST and 5 SST.



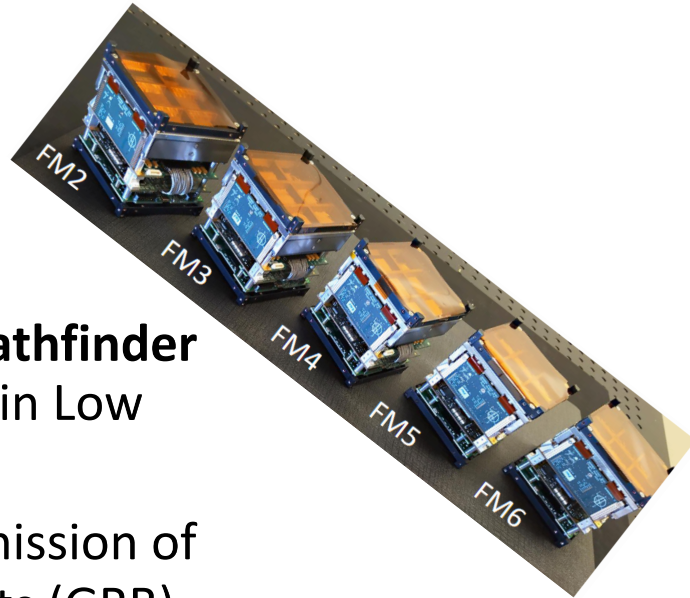
https://youtu.be/0QgnKA5AUDY

INAF – SPACE PROJECTS

- Currently there are 40 space projects in progress within ASI, all with INAF as prime, in the following thematic/functional areas:
    - Astrophysics and Cosmology;
    - Heliophysics and Physics of the Solar System;
    - Technology;
    - Support activities;
    - Fundamental Physics.

Credits: Gabriele Minervini

INAF – HERMES Scientific Pathfinder

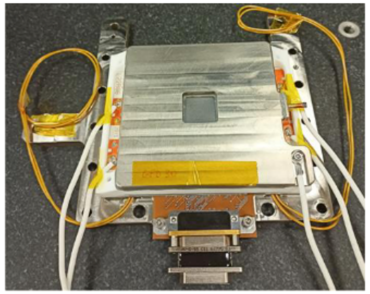


- **High Energy Rapid Modular Ensemble of Satellites** - **Pathfinder** is a mission based on a constellation of nano-satellites in Low Earth Orbit (LEO);
- **Miniaturized detectors** to probe the X-ray temporal emission of bright high-energy transients such as Gamma-Ray Bursts (GRB) and the electromagnetic counterparts of Gravitational Wave Events (GWE);
- **Objective:** to demonstrate the feasibility of an innovative and cheap space system based on distributed nano-platforms;
- The first HERMES Pathfinder payload has been launched on Dec. 1st 2023 onboard the Australian mission SpIRIT.

Credits: Gabriele Minervini, PI: Fabrizio Fiore

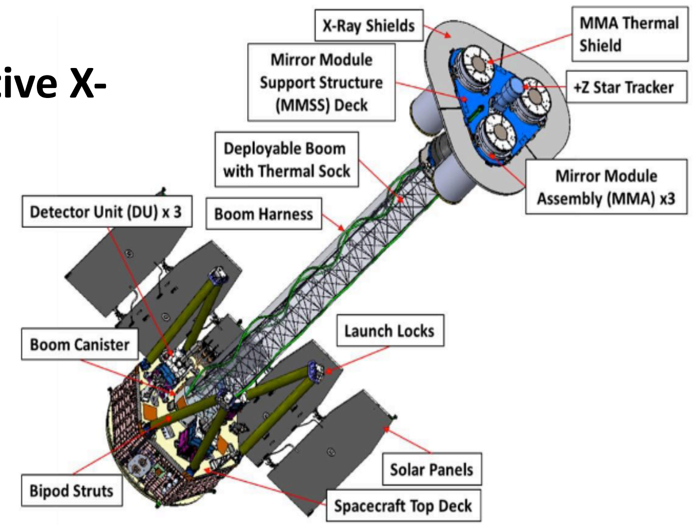
Yuri Evangelista (Payload responsible)
Riccardo Campana (Integration and calibration)

INAF –



Gas Pixel Detector (with INFN)

- IXPE is a NASA-ASI mission. It has been launched in the end of 2021.
- The payload consist in a set of three identical telescope systems co-aligned to the pointing axis of the spacecraft and with the Star-Trackers.
- Italy has designed, built and tested the three **polarization sensitive X-ray detectors** of the telescope system.
- INAF Hardware contribution:
  - Polarization sensitive detector (Co-development with INFN)
  - On-board calibration system (Polarized & unpolarized sources)
  - Construction & operation of three calibration facilities
- Payload activities held @ INAF
  - Acceptance test of all the polarization sensitive detectors
  - Full calibration of 4 Detector Units (DU) system
  - Electrical AIV&T of the Instrument
  - Thermal-Vacuum Tests of DU.

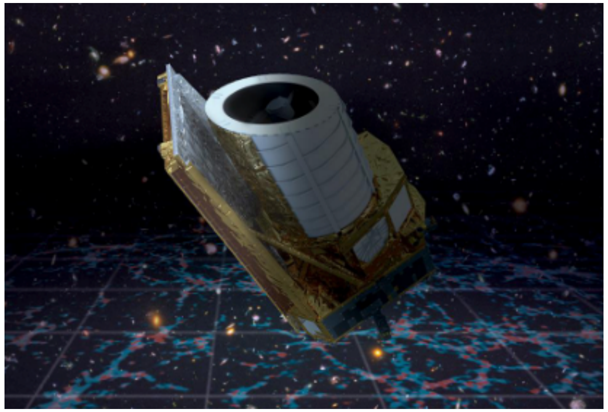


Credits: Gabriele Minervini, PI Italy: Paolo Soffitta

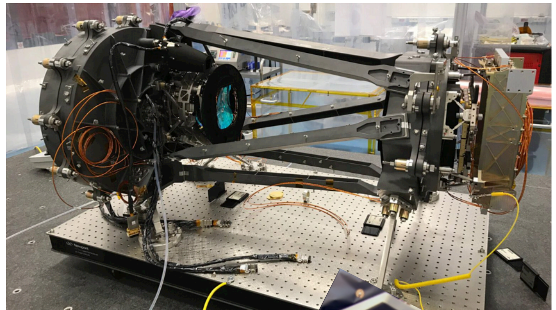
2024, Bruno Rossi Prize of American Astronomical Society

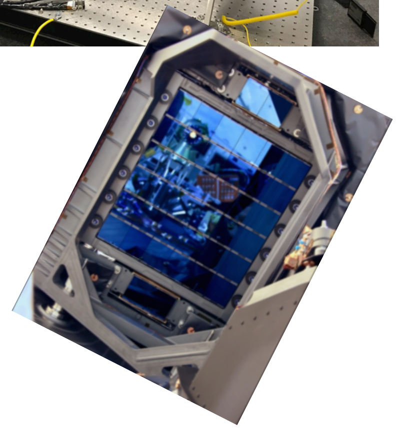
INAF –

- Euclid (ESA+NASA) mission: explore the composition and evolution of the dark Universe. It will create a great map of the large-scale structure of the Universe across space and time by observing billions of galaxies out to 10 billion light-years;
- Payload: 1.2-m-diameter telescope +two scientific instruments: a vis camera (the VISible instrument, VIS) and a near-infrared camera/spectrometer (NISP);
- INAF: VIS - NISP On board control and data processing SW. Important industrial and scientific contribution.



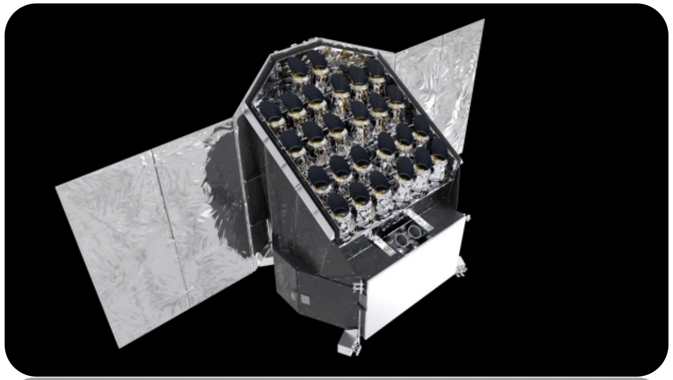
July 1, 2023



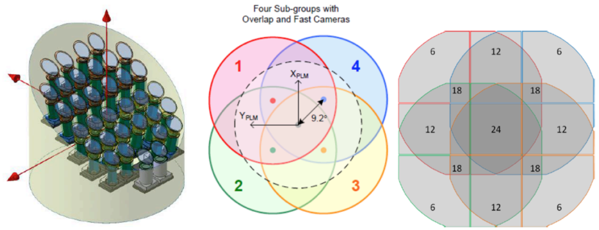


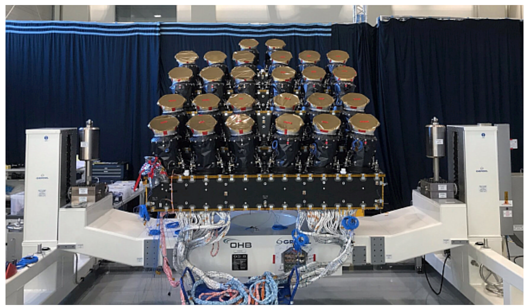
INAF –

- Detection of terrestrial exoplanets up to the habitable zone of solar-type stars through ultra–high precision, long photometric monitoring in the visible band of very large samples of bright ($V \leq 11$-13) stars.
- Requirements: very large field of view (FoV) + sensitivity of a 1 m-class telescope,the concept is based on a multi-telescope approach: **Set of 24 normal 20cm cameras organised in 4 groups** resulting in many wide-field co-aligned telescopes, each telescope with its own CCD-based focal plane array;
- INAF contribution : Instrument Control Unit (ICU), Telescope Optical Units (TOU).



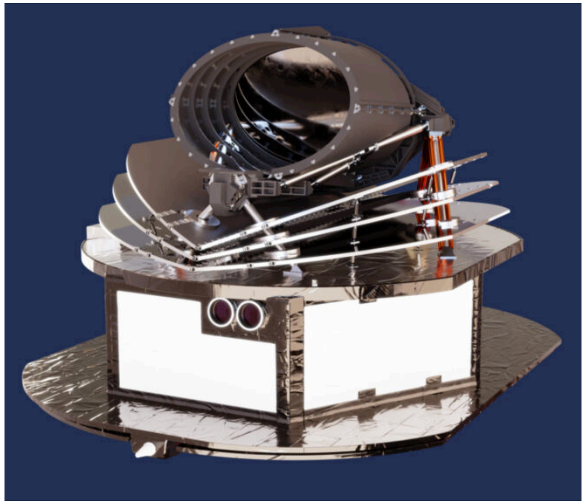
Lunch 2026 in L2



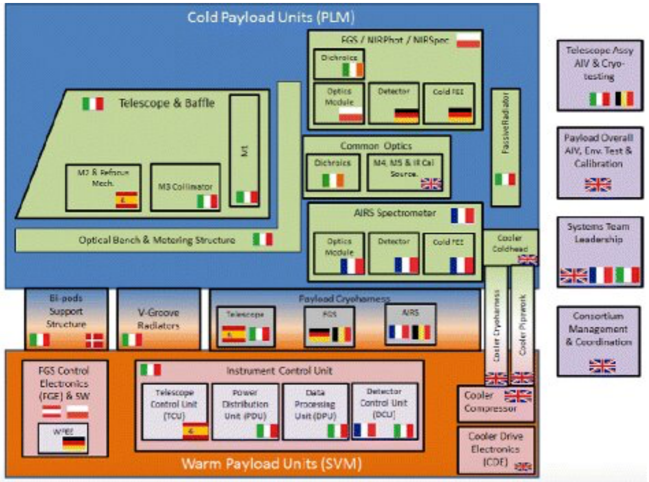


PI Italy: Isabella Pagano, payload concept: Roberto Ragazzoni

INAF – Ariel



- **Ariel** measurement of the chemical composition and thermal structures of exoplanets, enabling planetary science far beyond the boundaries of the Solar System. Orbit around the Lagrange 2 point (L2);
- **Elliptical primary mirror:** 1.1 x 0.7 m;
- **Instrumentation:** 3 photometric channels and 3 spectrometers from 0.5 to 7.8 μm in wavelength;
- Activities: Payload Electronic lead and Instrument Control Unit, FGS Detector Control Unit, Project and realization of the Telescope Assembly, Payload thermal and performances analysis.



Credits: Gabriele Minervini, PI Italy: G. Malaguti, G. Micela

Burst Alert Telescope (BAT)

- New CdZnTe detectors
- Detect >100 GRBs per year depending on logN-logS
- Most sensitive gamma-ray imager ever

X-Ray Telescope (XRT)

- Arcsecond GRB positions
- CCD spectroscopy
- Photometry in the range 10^{-7}-10^{-15} erg cm^{-2} s^{-1}

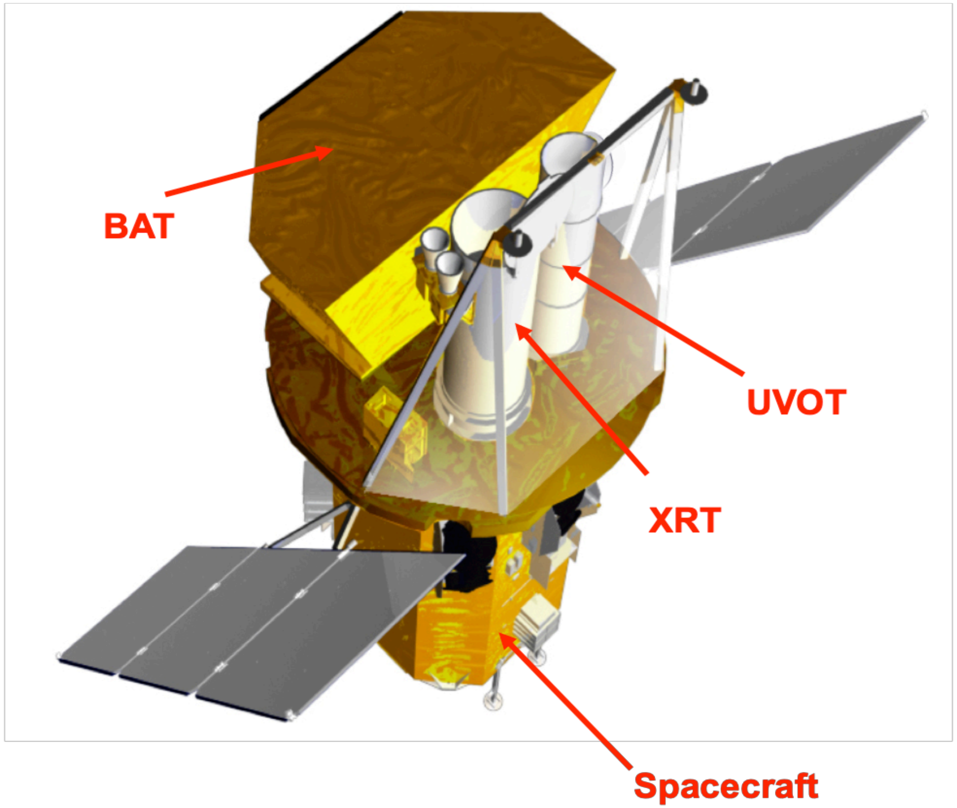
(UVOT) UV/Optical Telescope

- Sub-arcsec imaging
- Grism spectroscopy
- 24^{th} mag sensitivity (1000 s)
- Finding chart for other observers

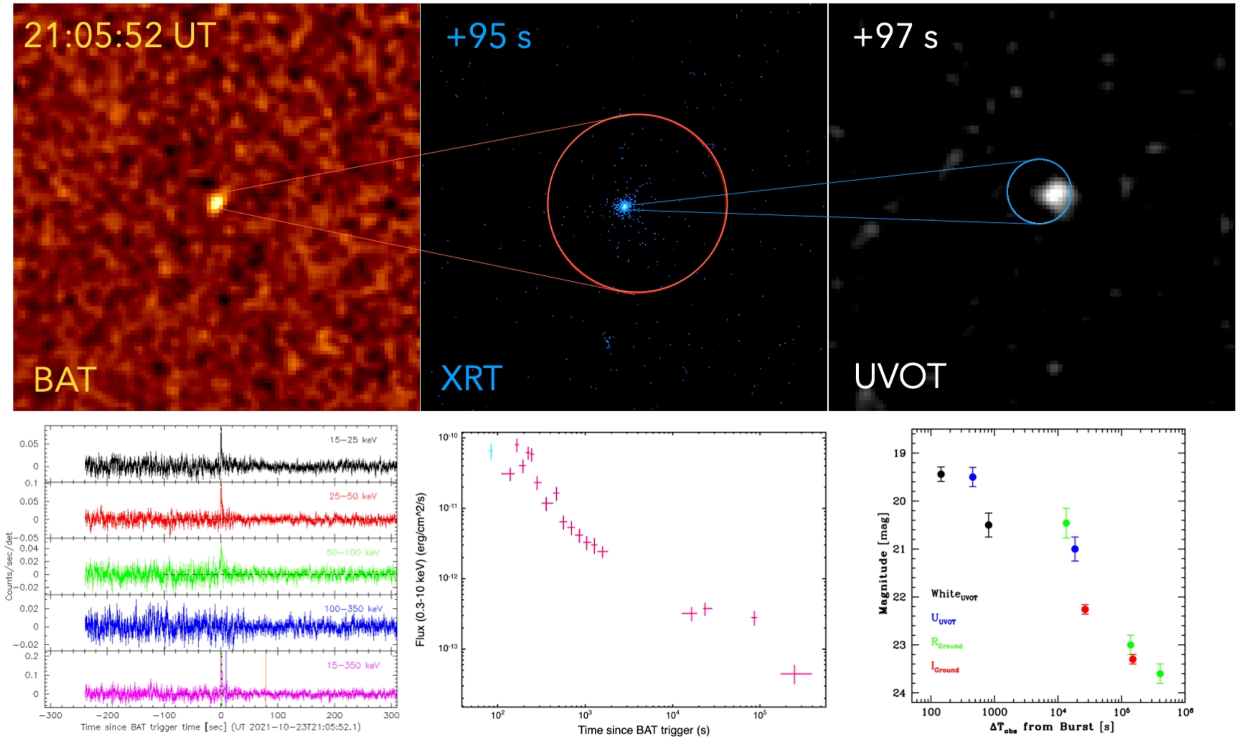
Spacecraft

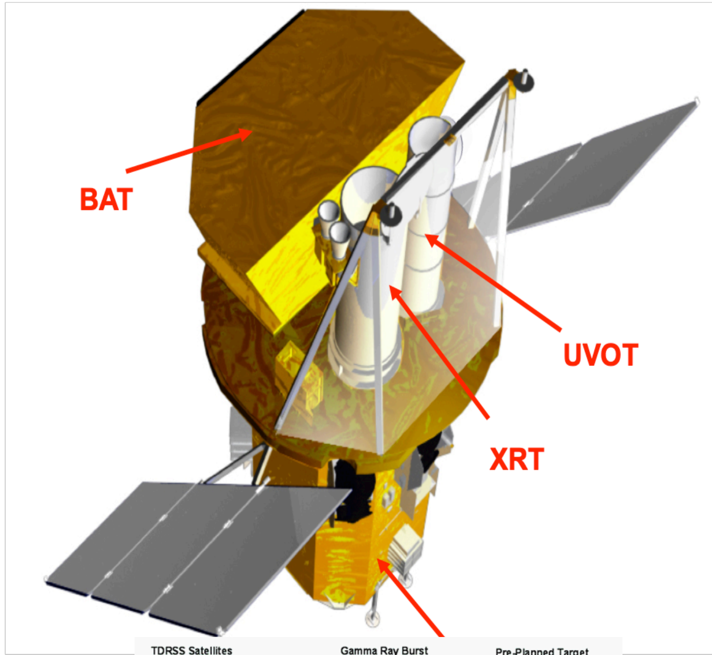
Autonomous re-pointing, 20 - 100 s

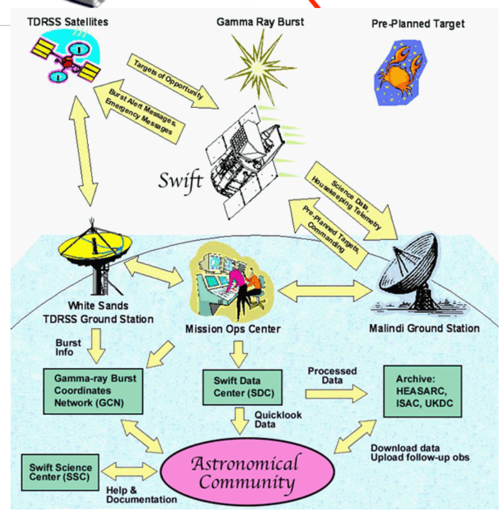
Onboard and ground triggers



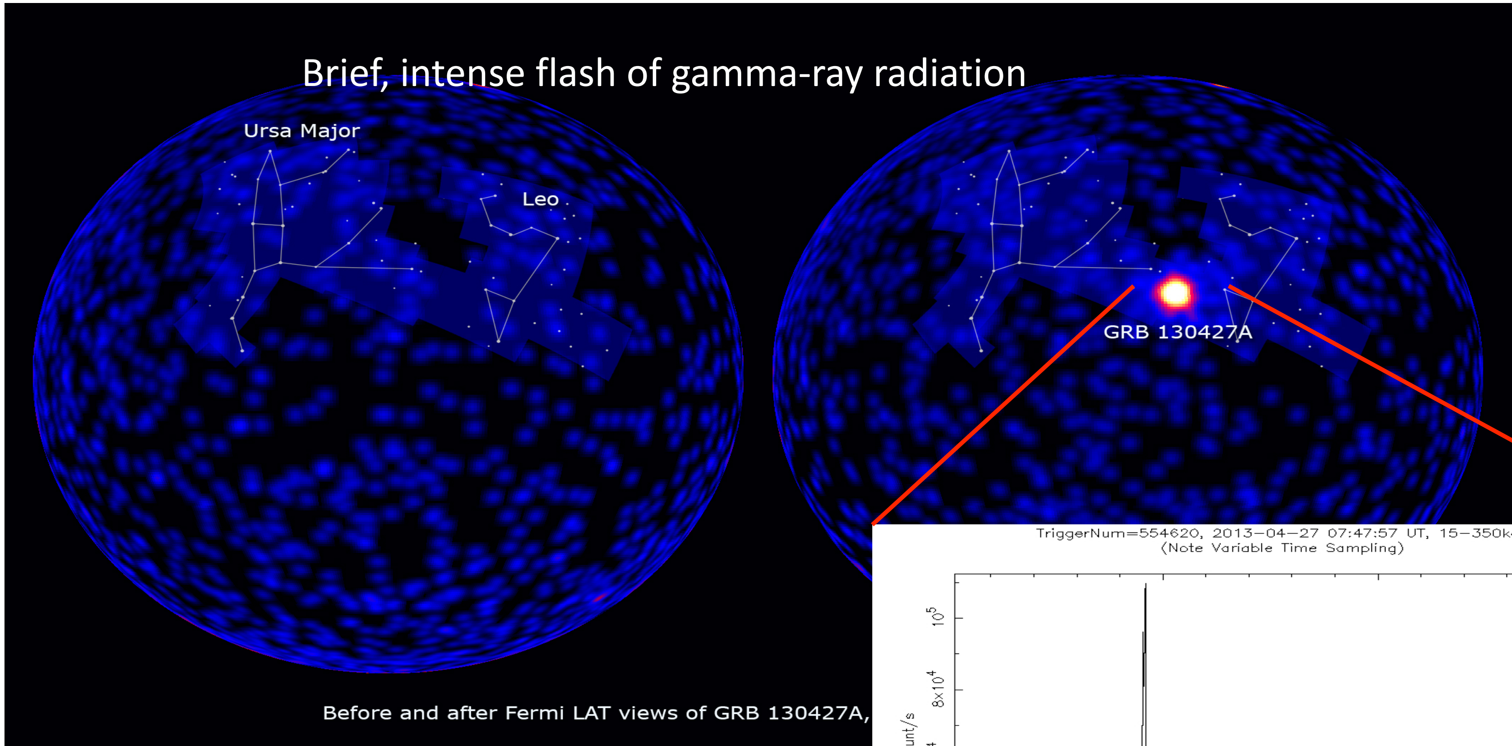
GRB 211023B: *Swift*'s 1500th GRB

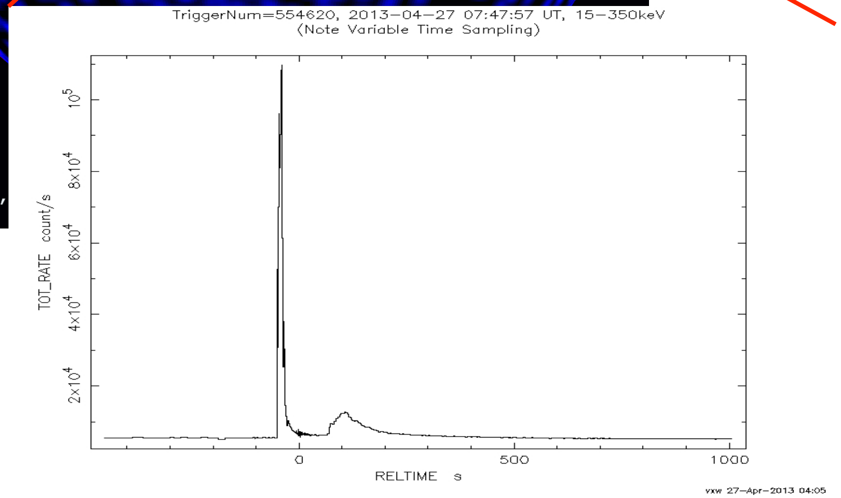






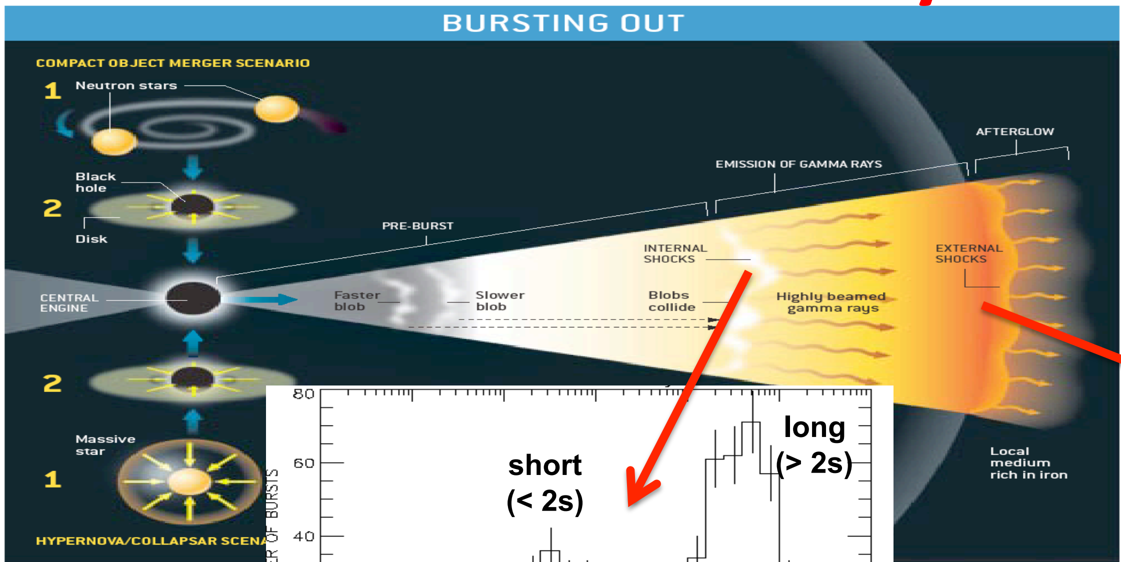
Gamma-ray bursts (GRBs)



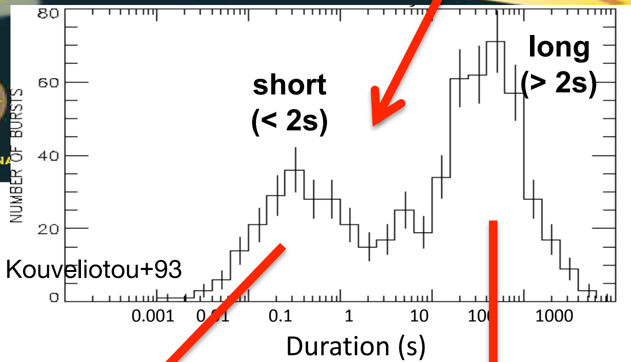


Fast: from few ms to hundreds of s
Energetic: 10^{-7} - 10^{-3} erg cm^{-2}
Bright: 10^{-8} - 10^{-4} erg cm^{-2} s^{-1}

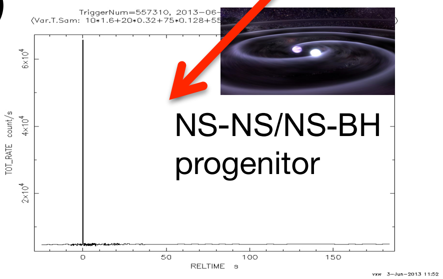
Gamma-ray bursts (GRBs)

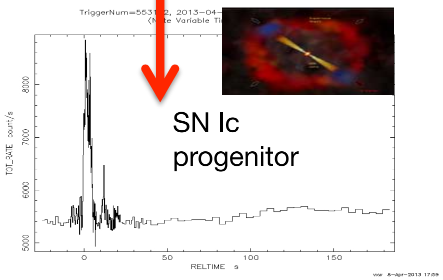


Brief, intense, flash of gamma-ray radiation:
($\langle z\rangle \sim 2.1$, $E \sim 10^{52}$ erg)

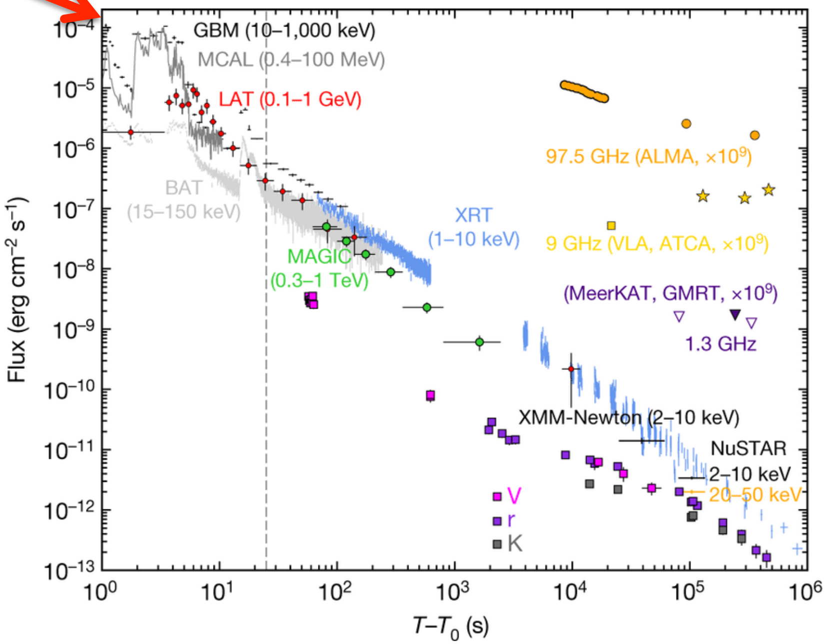


Prompt emission (gamma)



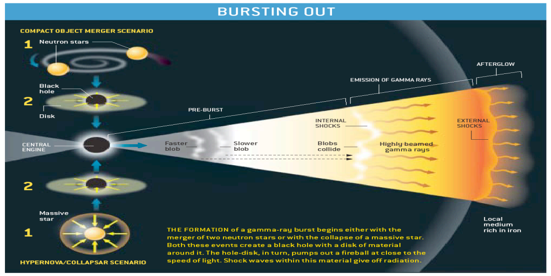


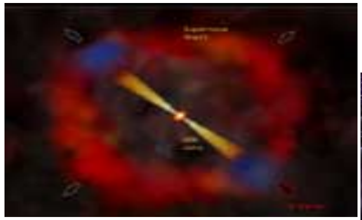
Afterglow emission
Long lasting, fading, multiwavelength
(from radio to TeV)

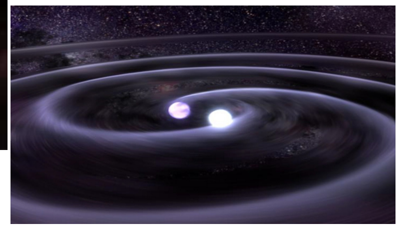


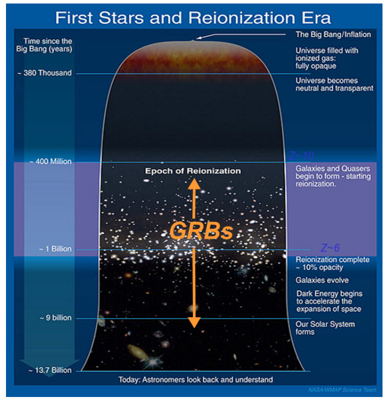
Science with GRBs

- GRB physics
  - Shocks
  - Role of magnetic fields
  - Jets
  - Accretion/ejection: extreme regimes
- Progenitors
  - Long GRBs: GRB-SN connection
  - Short GRBs: compact objects merging (GW, multi-messenger)
- GRB redshifts
  - From the local Universe to the re-ionization era
- GRB environment
  - Circumburst environment
  - IGM
  - Chemical history of the Universe





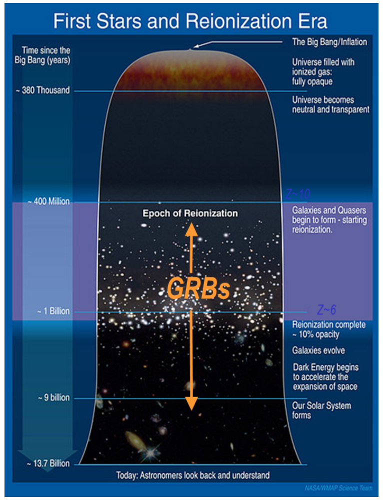


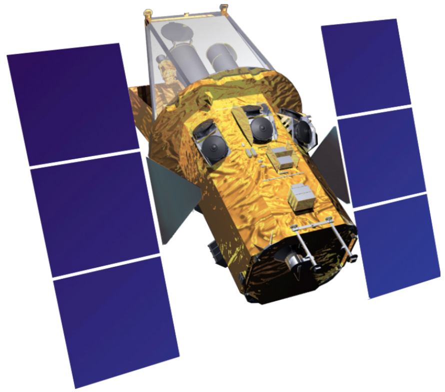


GRBs as cosmic probes

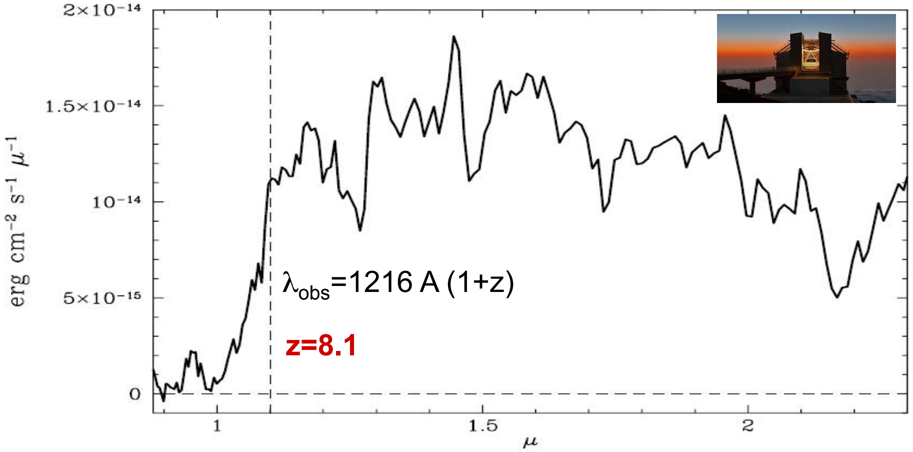
Thanks to their brightness, long GRBs are detectable from the local Universe to very high redshift. A unique tool to study:

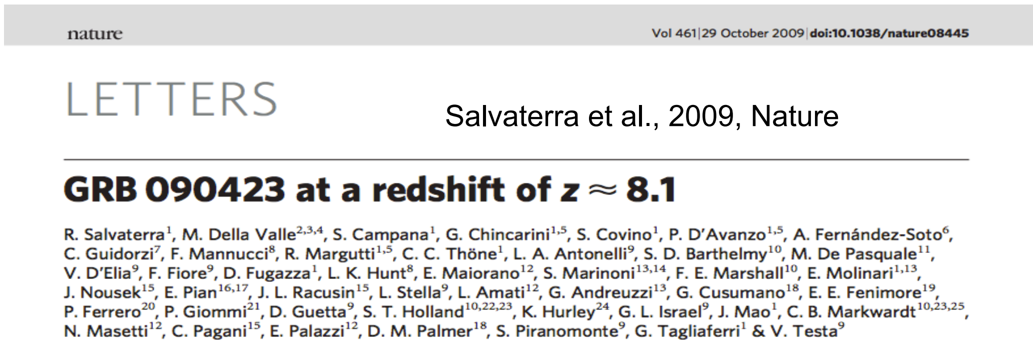
- cosmic star formation history
- metallicity & dust evolution
- the properties of faint galaxies that would be missed by 'traditional' surveys





TNG Amici prism spectrum





nature Vol 461|29 October 2009|doi:10.1038/nature08445

LETTERS

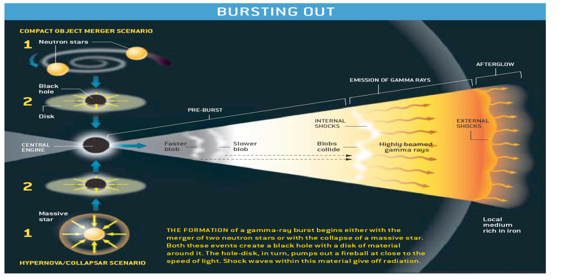
Salvaterra et al., 2009, Nature

GRB 090423 at a redshift of $z \approx 8.1$

R. Salvaterra[1], M. Della Valle[2,3,4], S. Campana[1], G. Chincarini[1,5], S. Covino[1], P. D'Avanzo[1,5], A. Fernández-Soto[6], C. Guidorzi[7], F. Mannucci[8], R. Margutti[1,5], C. C. Thöne[1], L. A. Antonelli[9], S. D. Barthelmy[10], M. De Pasquale[11], V. D'Elia[9], F. Fiore[9], D. Fugazza[1], L. K. Hunt[8], E. Maiorano[12], S. Marinoni[13,14], F. E. Marshall[10], E. Molinari[1,13], J. Nousek[15], E. Pian[16,17], J. L. Racusin[15], L. Stella[9], L. Amati[12], G. Andreuzzi[13], G. Cusumano[18], E. E. Fenimore[19], P. Ferrero[20], P. Giommi[21], D. Guetta[9], S. T. Holland[10,22,23], K. Hurley[24], G. L. Israel[9], J. Mao[1], C. B. Markwardt[10,23,25], N. Masetti[12], C. Pagani[15], E. Palazzi[12], D. M. Palmer[18], S. Piranomonte[9], G. Tagliaferri[1] & V. Testa[9]

LumDist = 84.7 Gpc,
AgeUniv = 0.6329 Gyr

Science with GRBs



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  - Shocks
  - Role of magnetic fields
  - Jets
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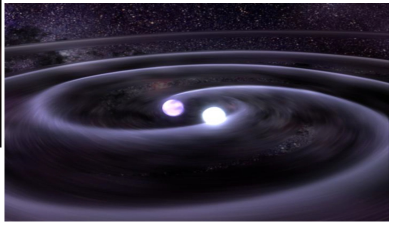

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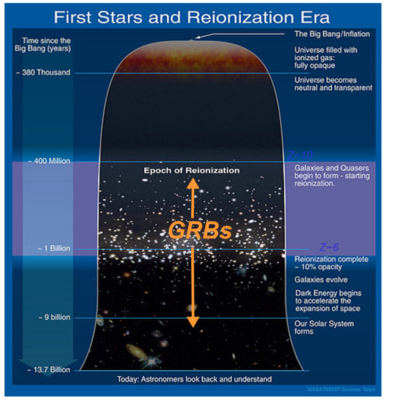
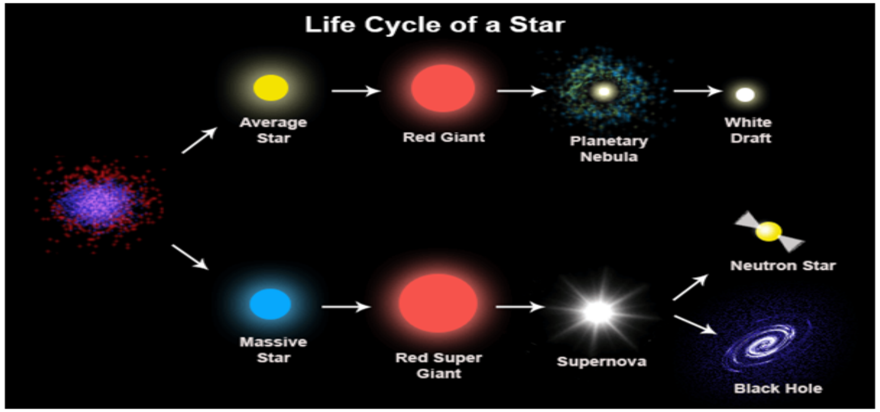
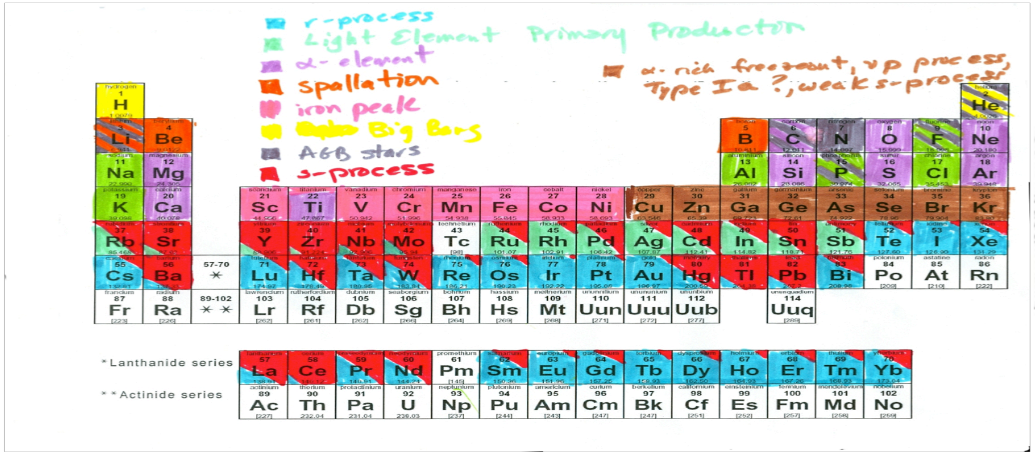


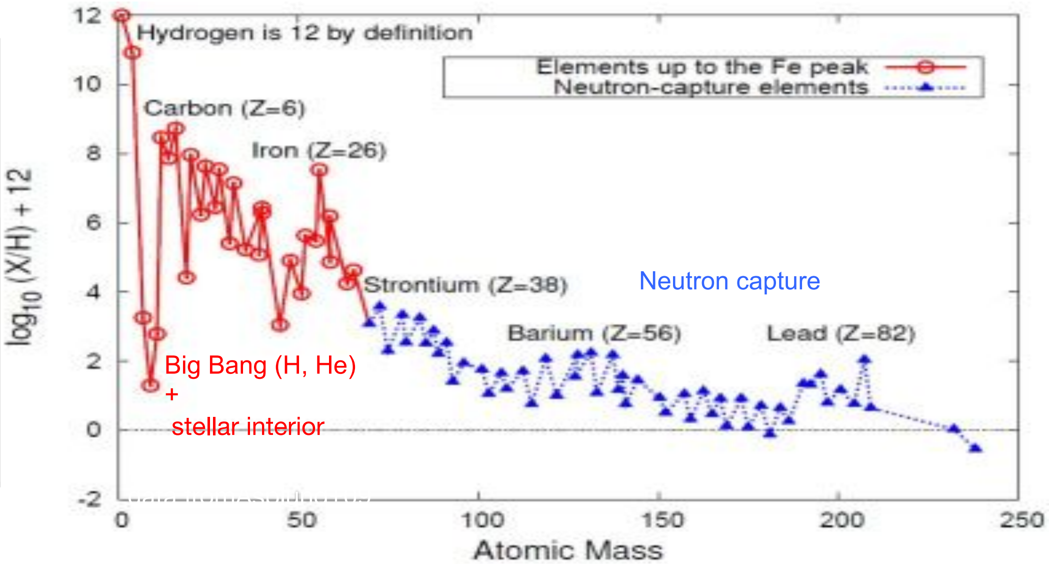
Elements nucleosynthesis



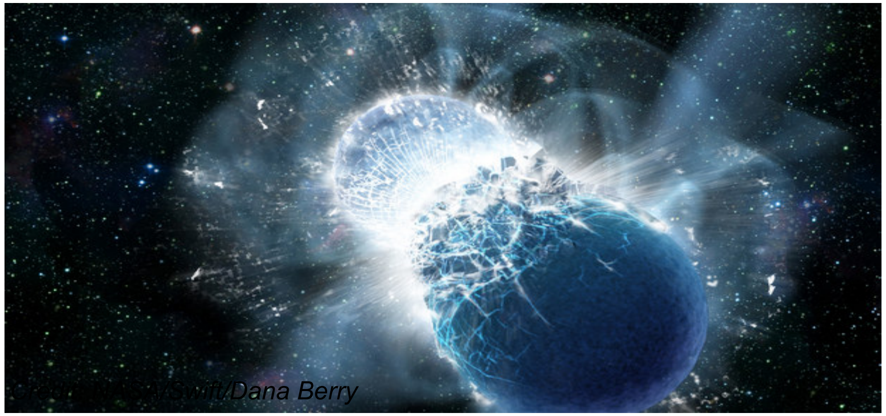
About 50% of the elements heavier than iron are synthetised via rapid neutron capture process (r-process): capture of neutrons in a dense neutron-rich environment on a timescale shorter than the β-decay one.

Proposed r-process sources:
- Core collapse SNe (tradition)
- merger of compact stars (BH-NS, NS-NS)





R-process nucleosynthesis



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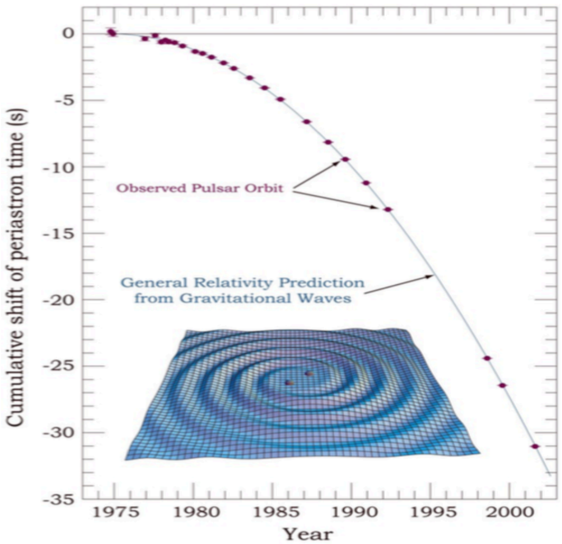
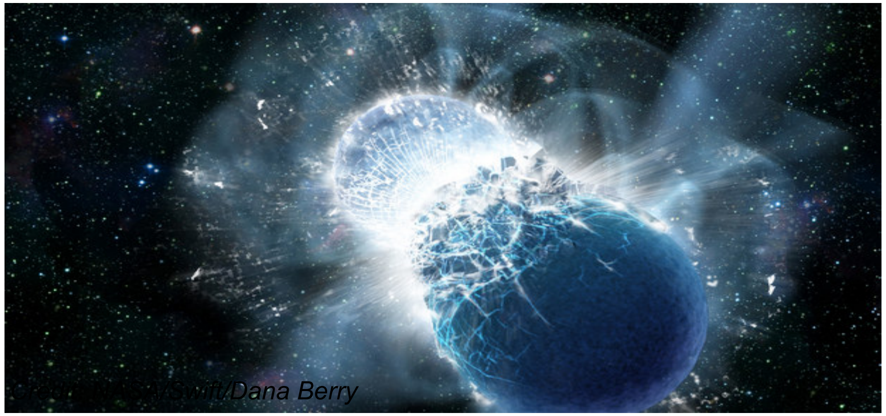


- BH-NS proposed as r-process sites by decompression of neutron-rich ejecta (Lattimer & Schramm 1974, 1976)
- Discovery of the first binary pulsar (Hulse & Taylor 1975); indirect evidence of GW emission

R-process nucleosynthesis



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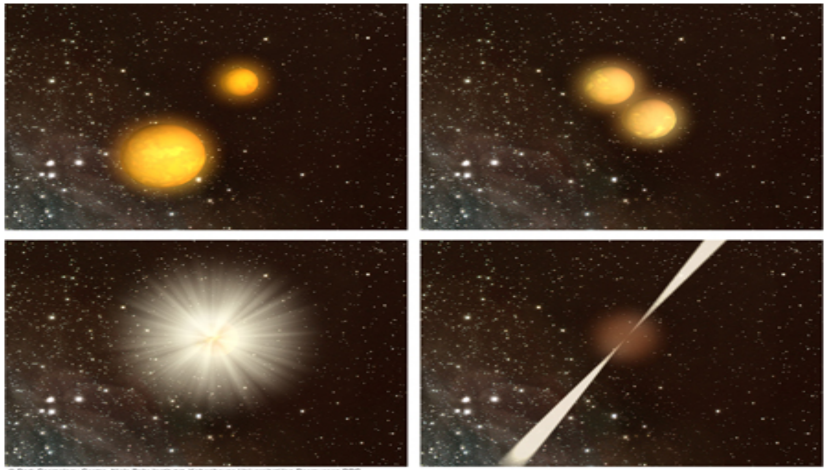

The Neutron Stars Merging Scenario

ESO PR Photo 32c/05 (October 6, 2005) © ESO

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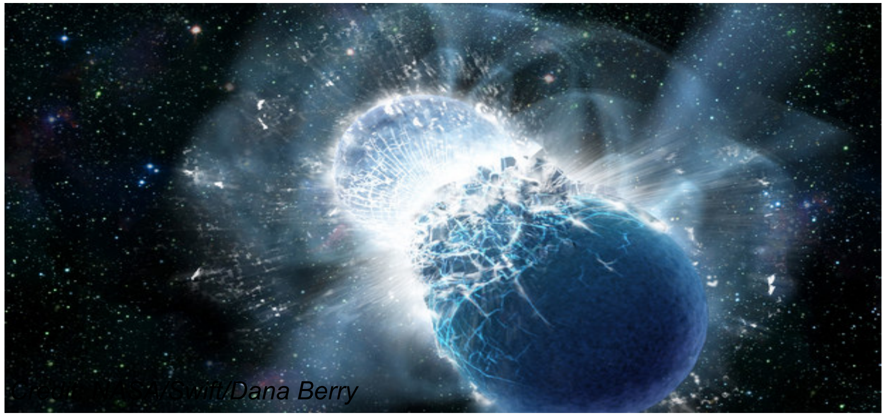

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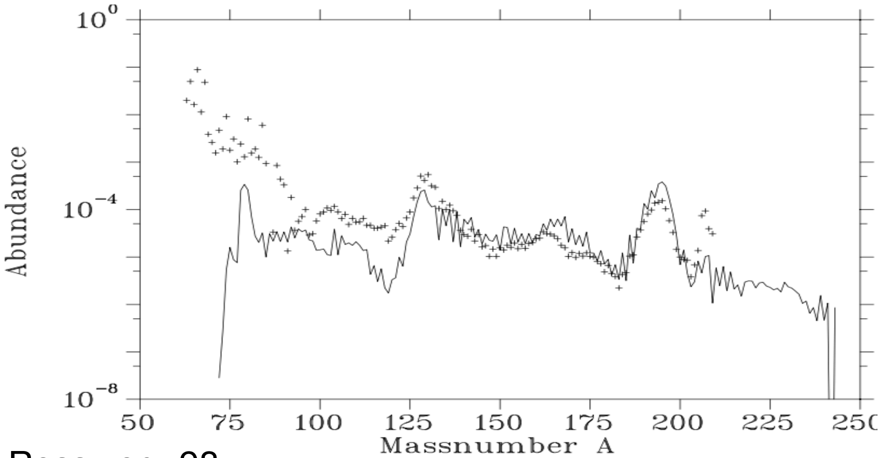

Rosswog+98

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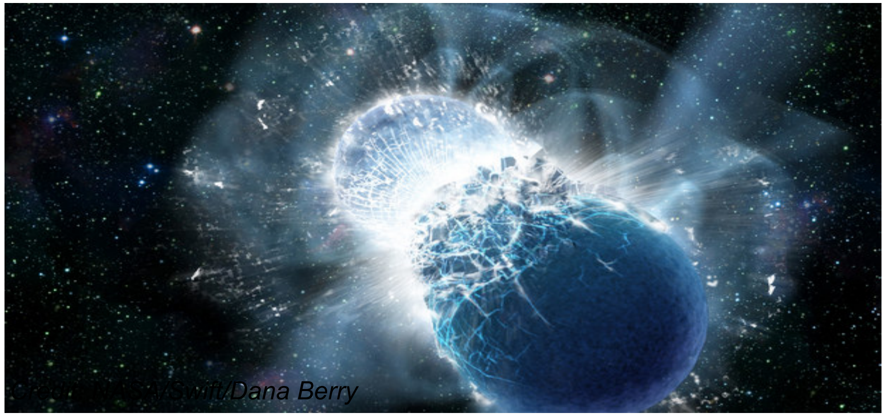
R-process nucleosynthesis



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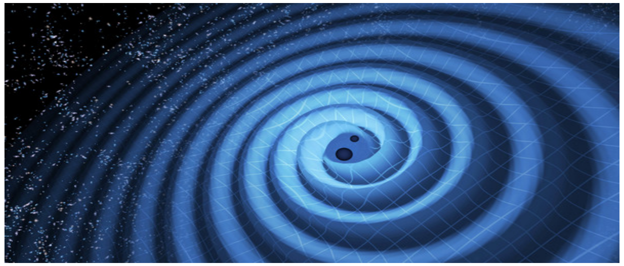
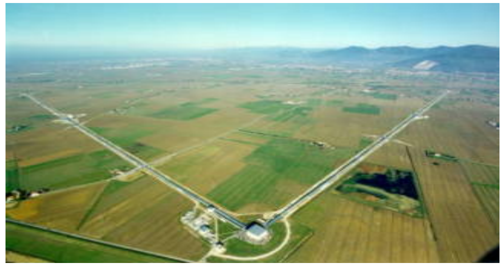
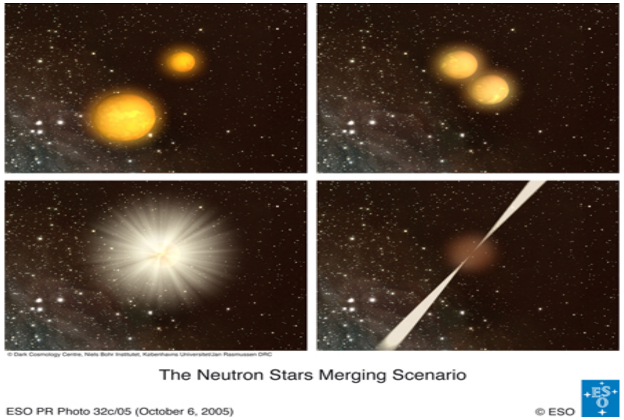
-Radioactive ejecta from NS-NS, BH-NS merger power optical/NIR EM transient (Li & Paczynsky 1998) -> “kilonova” (Metzger 2010)

So, what do we expect for a NS-NS merger?

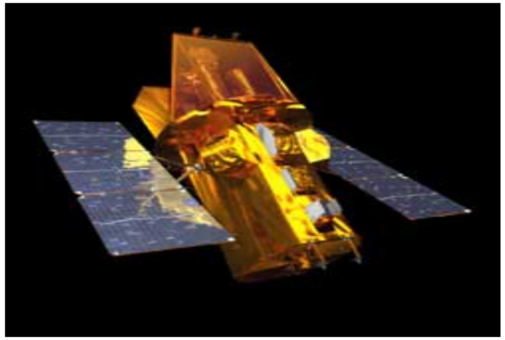


Gravitational waves



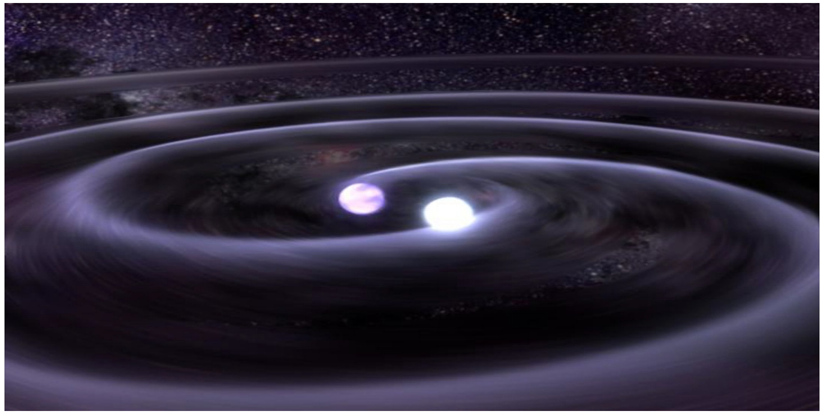


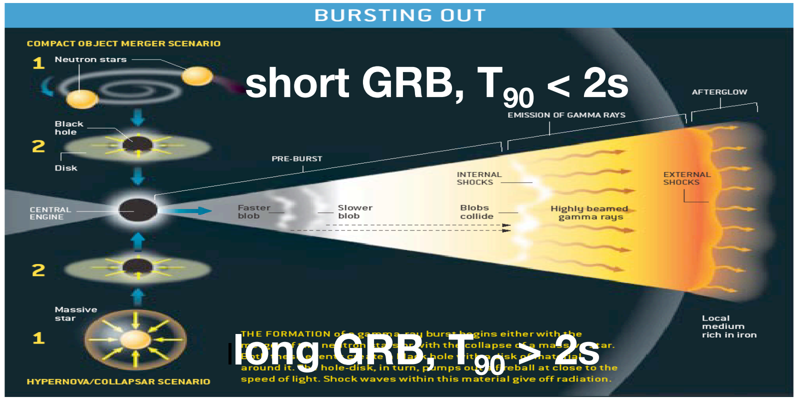
(short) gamma-ray burst

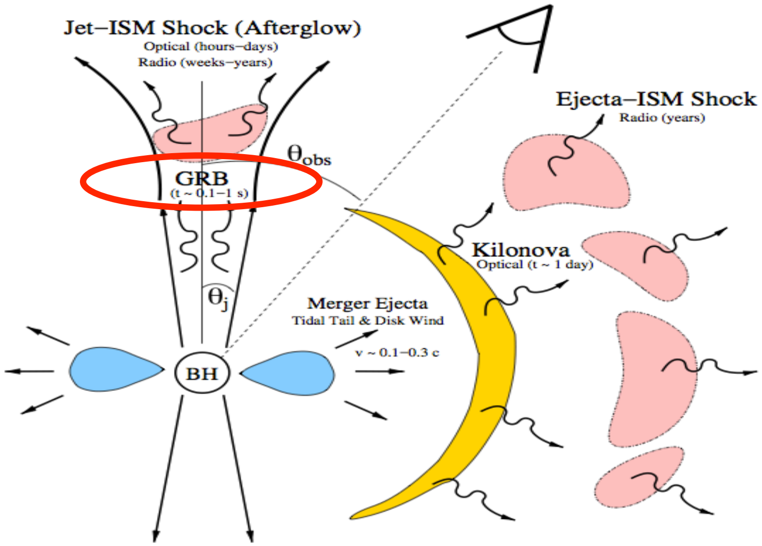


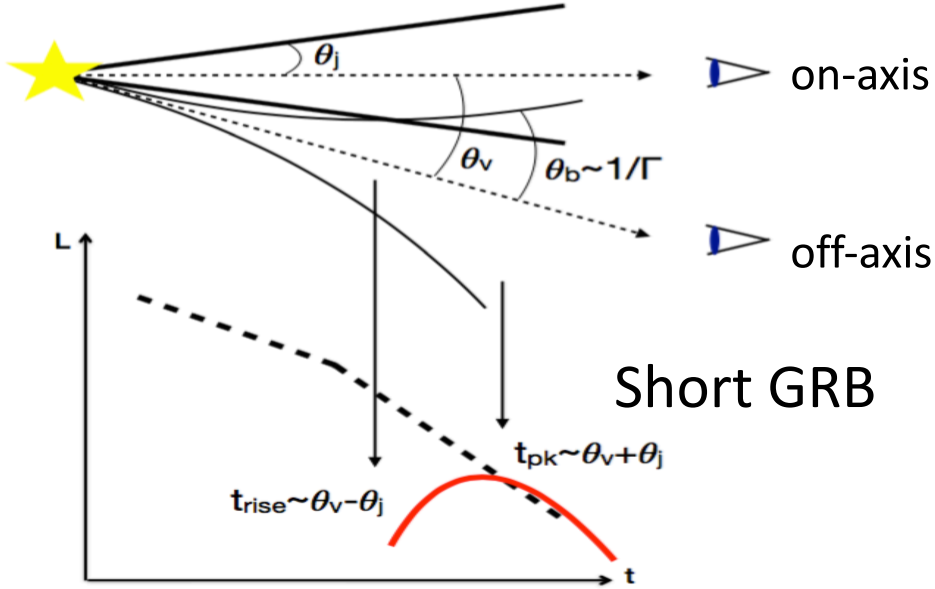
kilonova

NS-NS / NS-BH electromagnetic counterparts

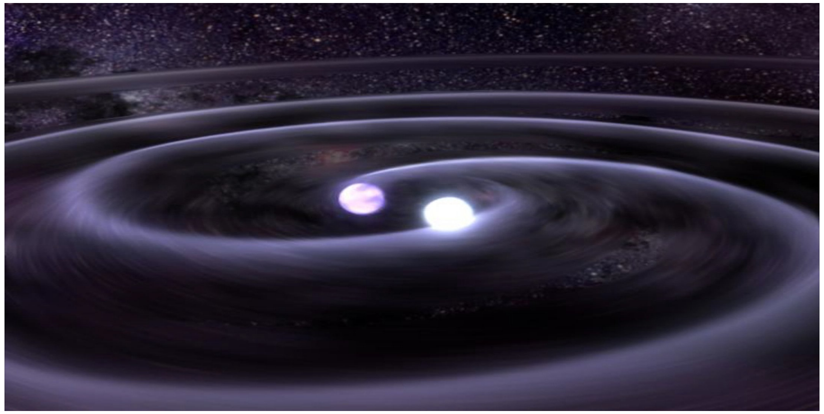


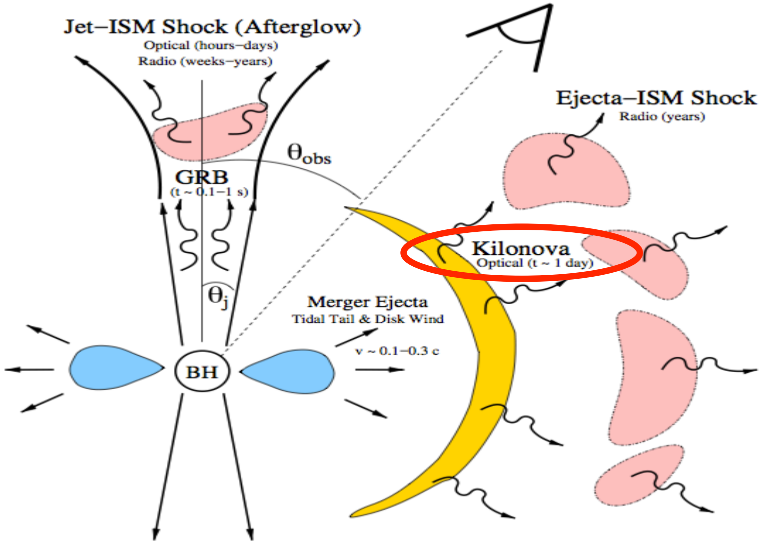


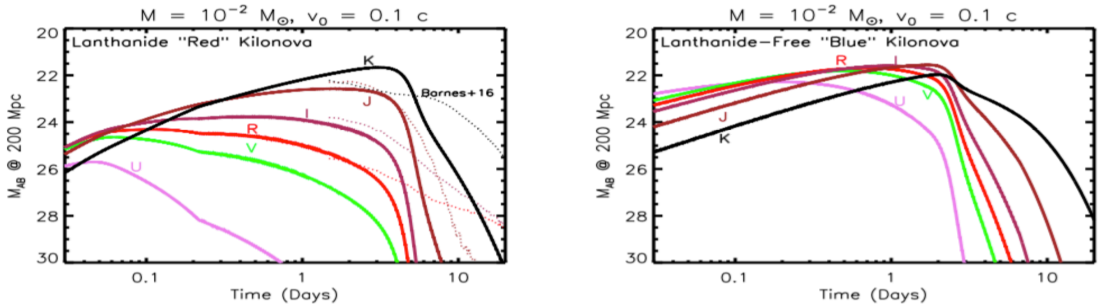




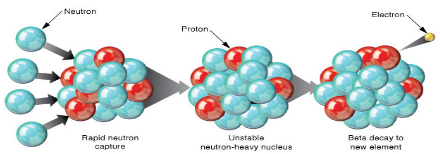
NS-NS / NS-BH electromagnetic counterparts

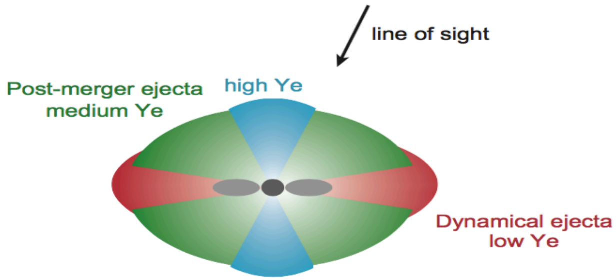






A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "kilonova" (aka "macronova") due to the decay of heavy radioactive species produced by the *r*-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog, 2005; Metzger et al., 2010).



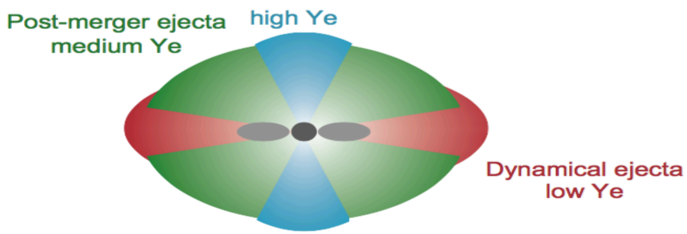


Tanaka et al. (2017)

NS-NS mergers: ejecta types

Ye = e^- fraction = #protons/#nucleons = #electrons/#nucleons

Tanaka et al. (2017)

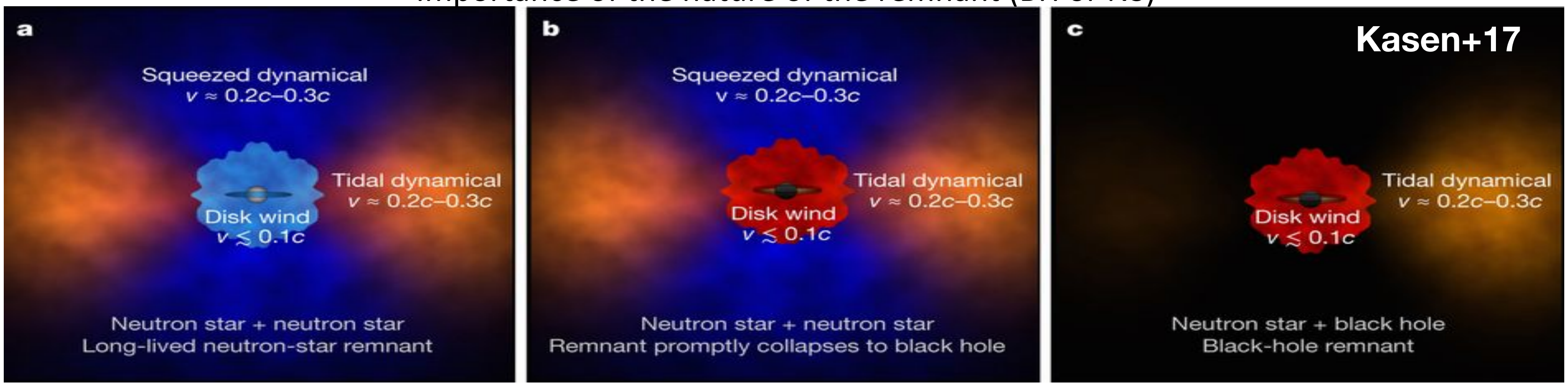


Dynamical ejecta (10^{-4}-10^{-2} M_{SUN}, v~(0.2-0.3)c)

- **tidal** -> equatorial, low Ye~0.1
- **contact** -> polar, high Ye > 0.1

Disc (ν-driven) wind -> polar/isotropic, broad Ye, 10^{-2}-10^{-1} M_{SUN}, v~(0.05-0.1)c

Importance of the nature of the remnant (BH or NS)



EM emission: observable quantities

Ejecta with mass M, expanding at a constant v such as its radius R = vt at a given time

Metzger 2017

- optical depth: $\tau \simeq \rho\kappa R = \frac{3M\kappa}{4\pi R^2}$

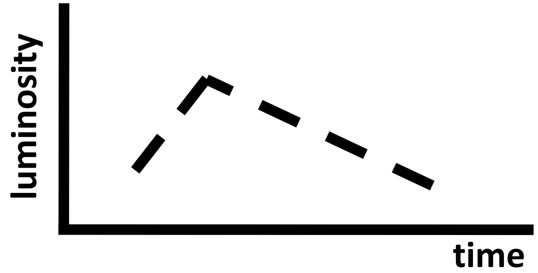
- diffusion time: $t_{\rm diff} \simeq \frac{R}{c}\tau = \frac{3M\kappa}{4\pi c R} = \frac{3M\kappa}{4\pi c v t}$

- peak emission: $t_{\rm peak} \equiv \left(\frac{3M\kappa}{4\pi\beta v c}\right)^{1/2}$

(when $t_{diff} = t_{expansion}$; Arnett 1980)

- peak luminosity: $L_{\rm peak} \approx \dot{Q}(t_{\rm peak})$

radioactive heating rate



Opacity *κ*:

- Iron (SN-like) -> ~0.1 cm^2/g

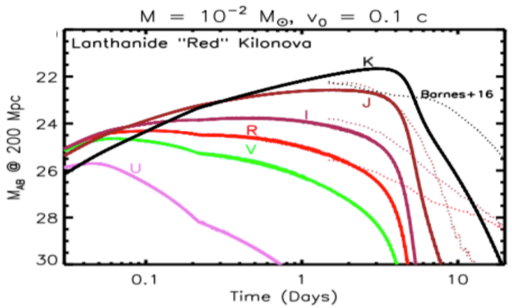
- lanthanides (heavy r-process)-> ~10 cm^2/g

Expectations:

M_{ej}~ 10^{-3}-10^{-1} M_{SUN}, v_{ej}~(0.1-0.3)c

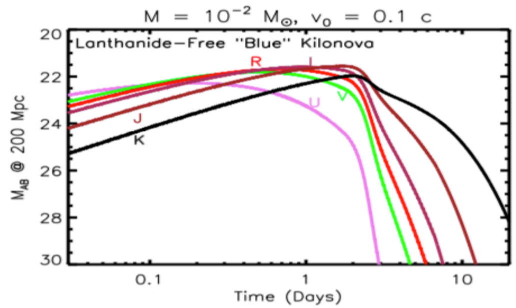
Depending on the opacity:

t_{peak} ~ 1-10 d, L_{peak} ~ 10^{40}-10^{41} erg/s, UV/NIR emission



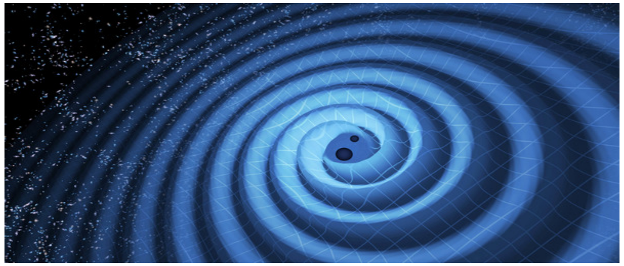
Neutron-rich ejecta
(low e⁻ fraction Y_e)
Strong r-process
Very heavy elements (A>140)
Lanthanide rich
Higher opacity
Red KN, peak time~ 1 week

Metzger 2017

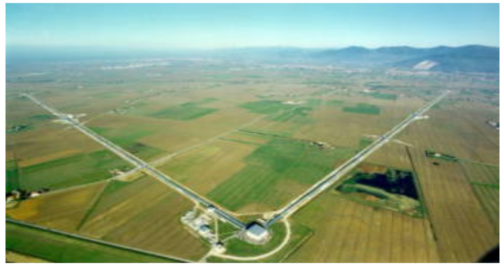


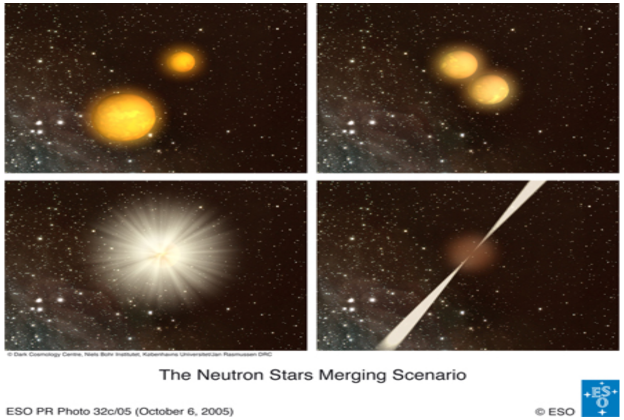
Neutron-poor ejecta
(high e⁻ fraction Y_e)
r-process
heavy elements (A<140)
Lanthanide poor
Lower opacity
Blue KN, peak time~ 1 day

So, what do we expect for a NS-NS merger?

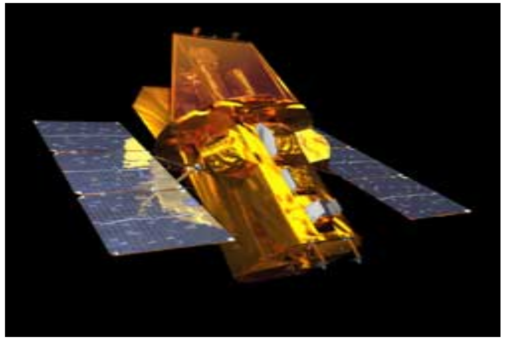


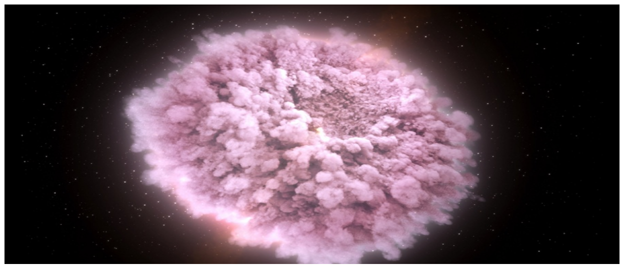
Gravitational waves



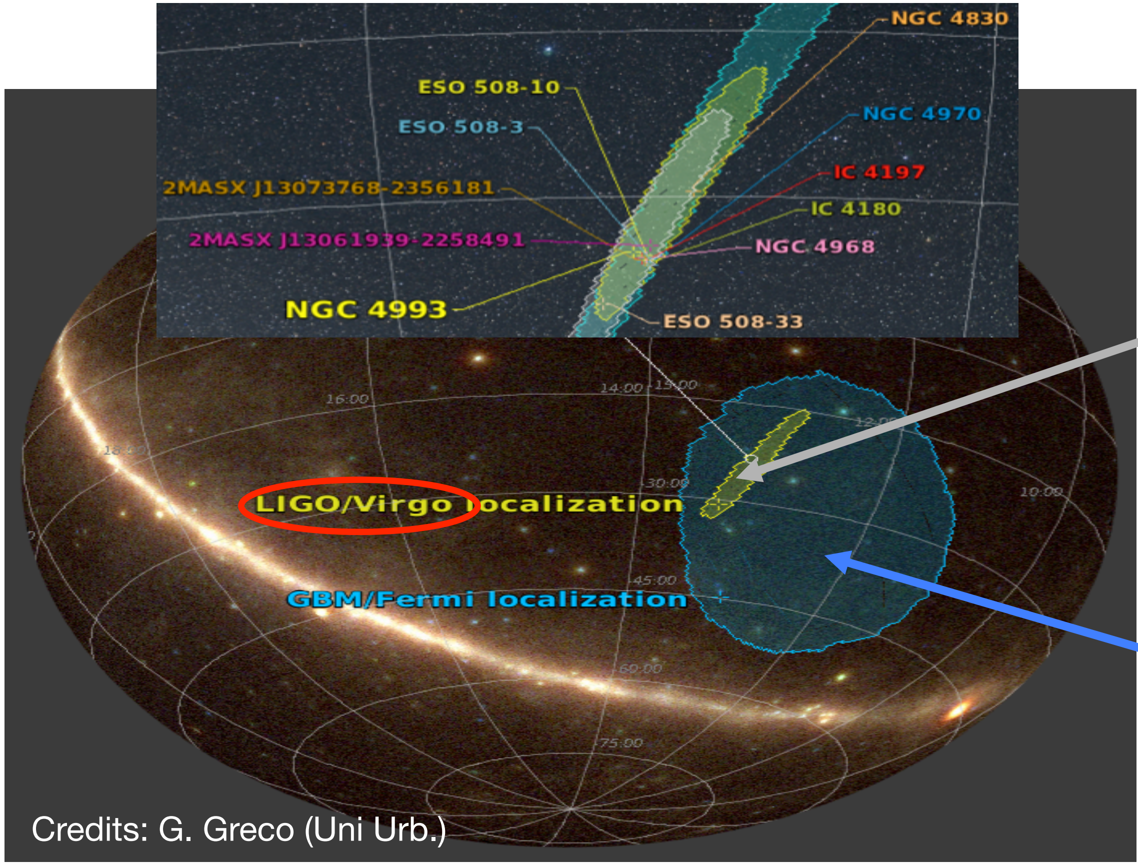


(short) gamma-ray burst

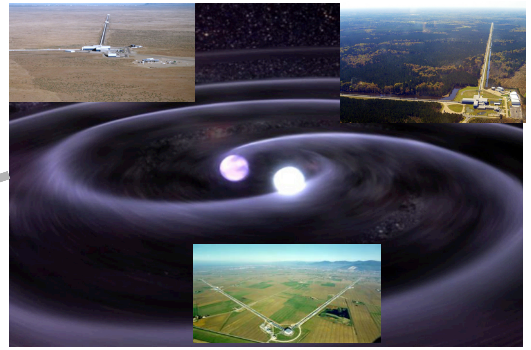




kilonova



2017, August 17
12:41:04 UTC



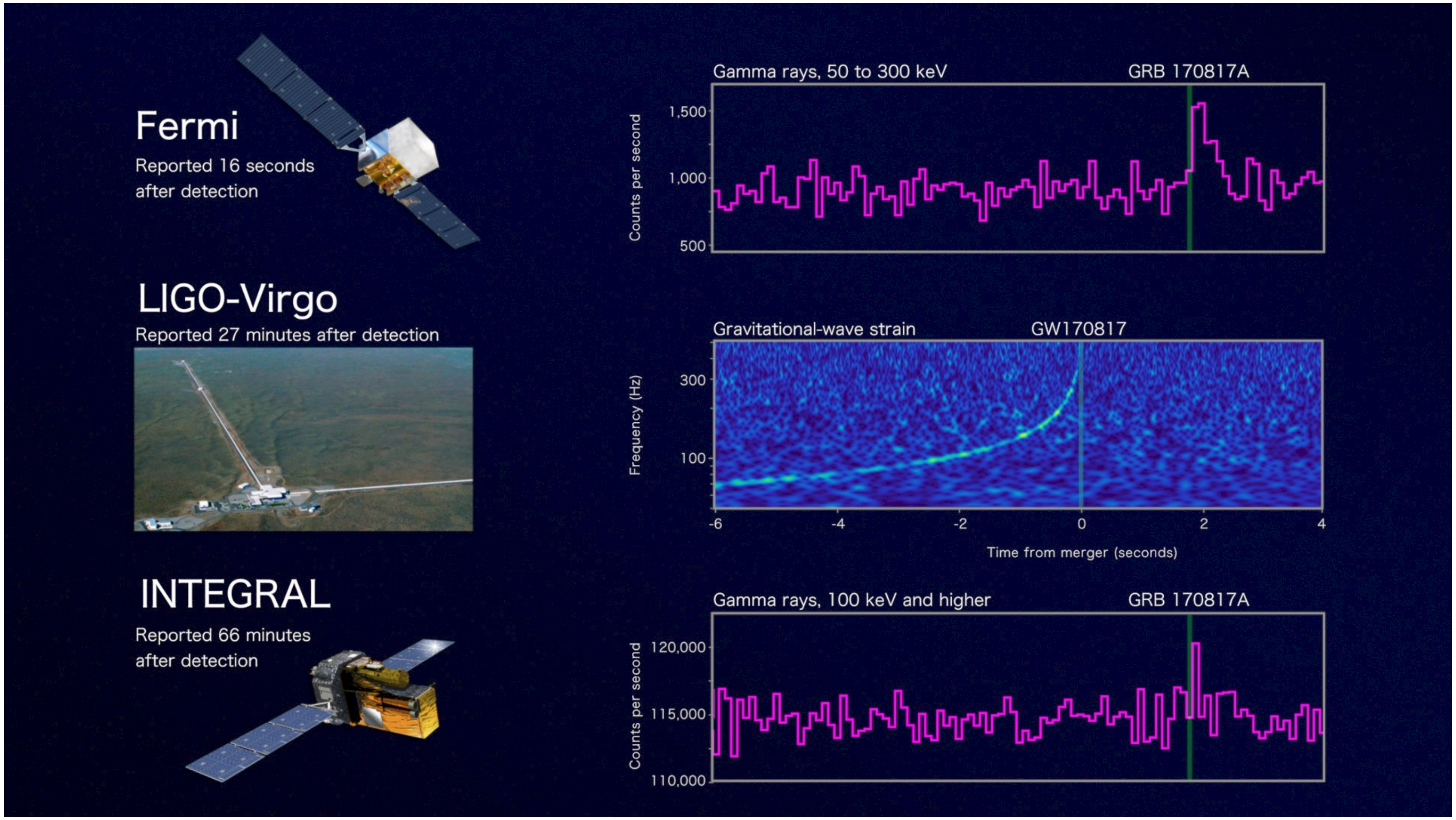
Selected for a Viewpoint in *Physics*
PRL **119,** 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

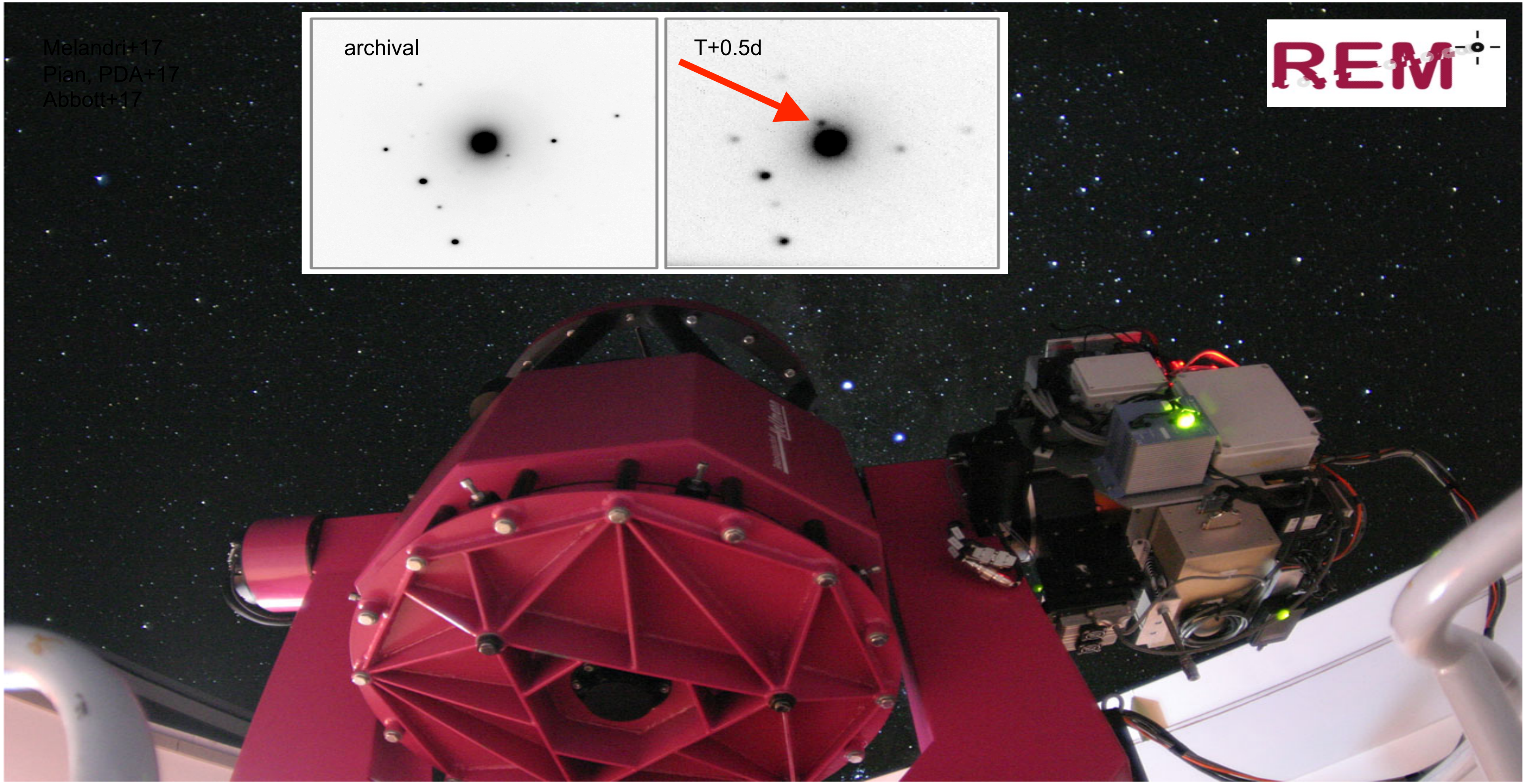
B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

	Low-spin priors ($|\chi| \leq 0.05$)	High-spin priors ($|\chi| \leq 0.89$)
Primary mass m_1	1.36–1.60 $M_\odot$	1.36–2.26 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$	0.86–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass m_{tot}	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy E_{rad}	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc

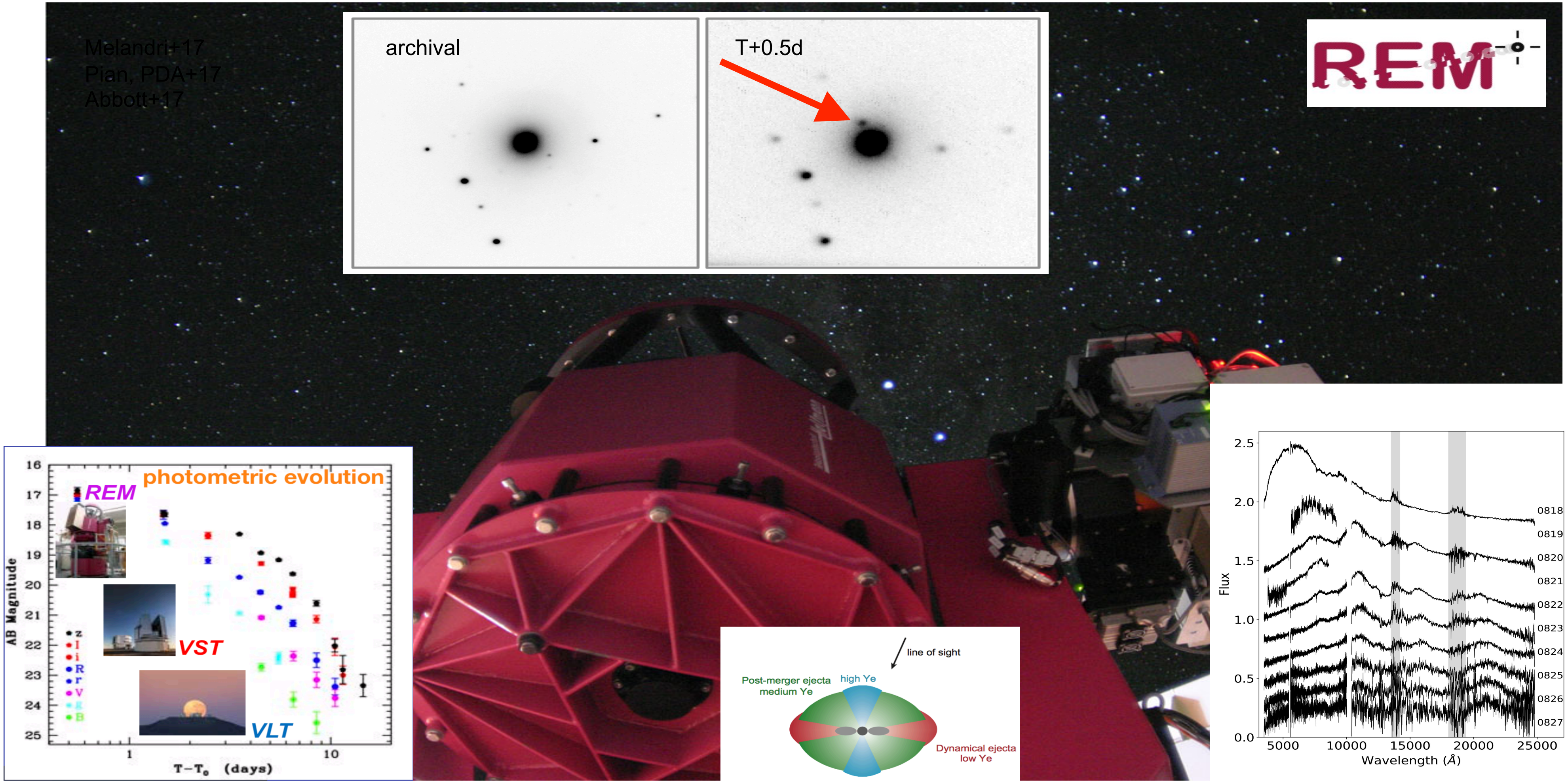
GW 170817 / GRB 170817A



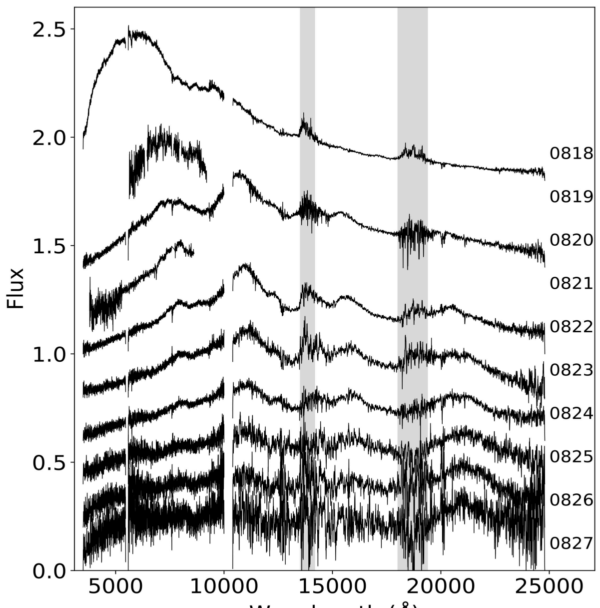
GW 170817 / GRB 170817A / AT2017gfo



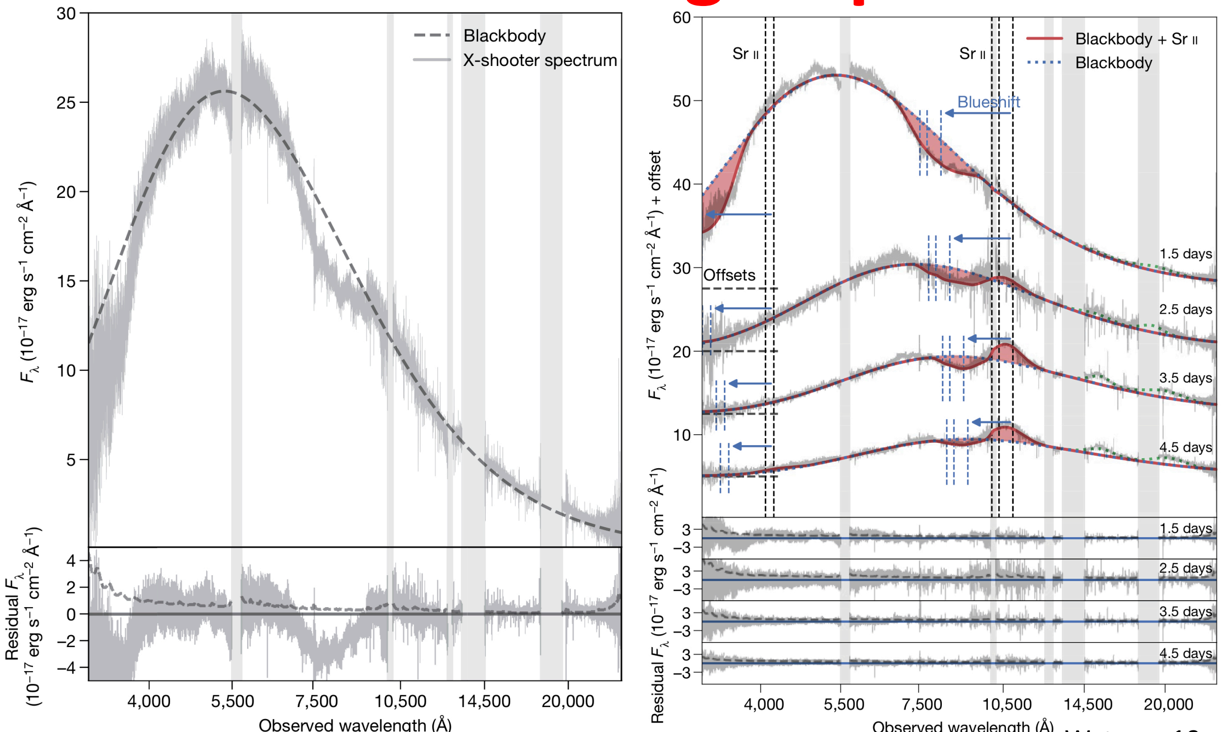
GW 170817 / GRB 170817A / AT2017gfo



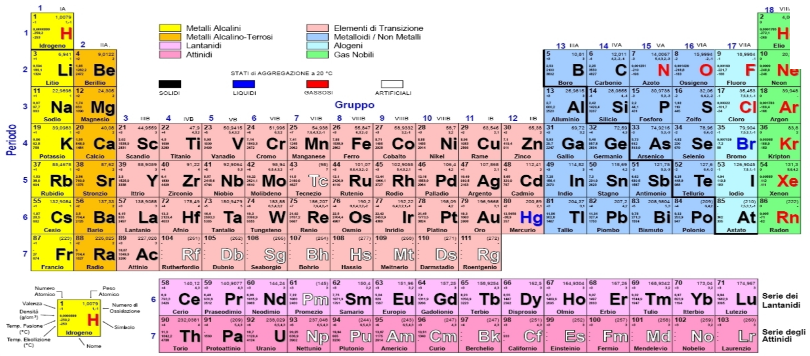
Heavy element signatures in the AT2017gfo spectrum

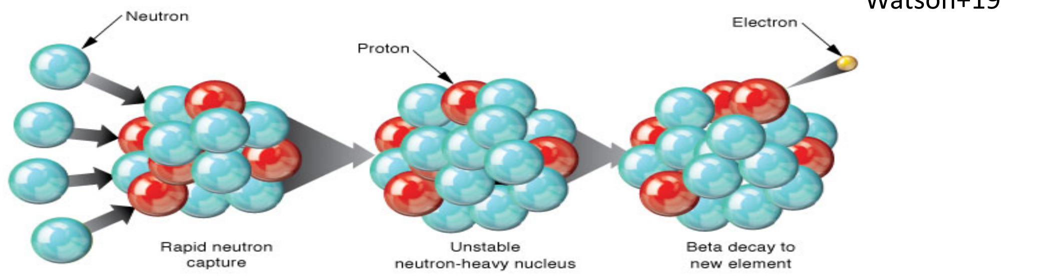


Pian, PDA+17

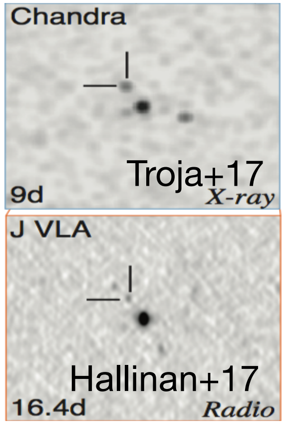


Watson+19

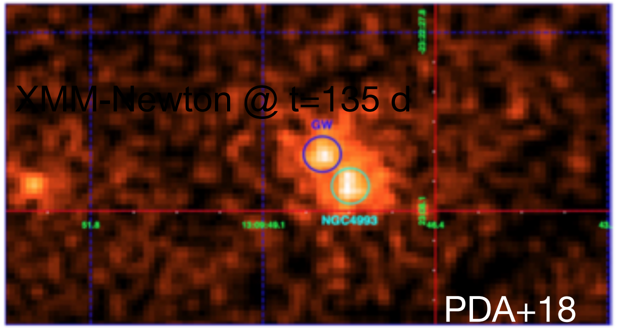




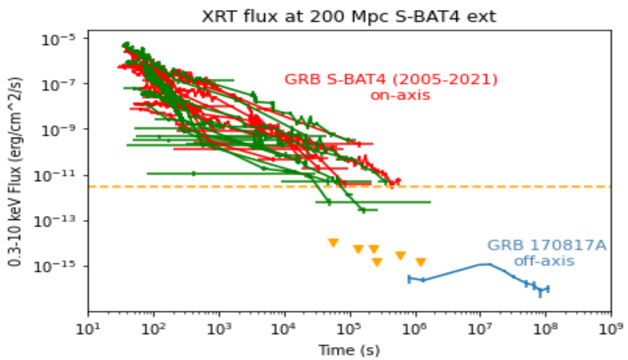
GW 170817 / GRB 170817A / AT2017gfo



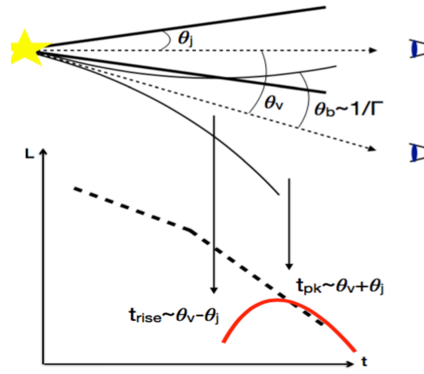
1st detection of the afterglow

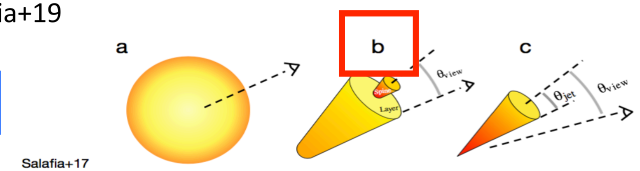


detection of the afterglow at the **peak**

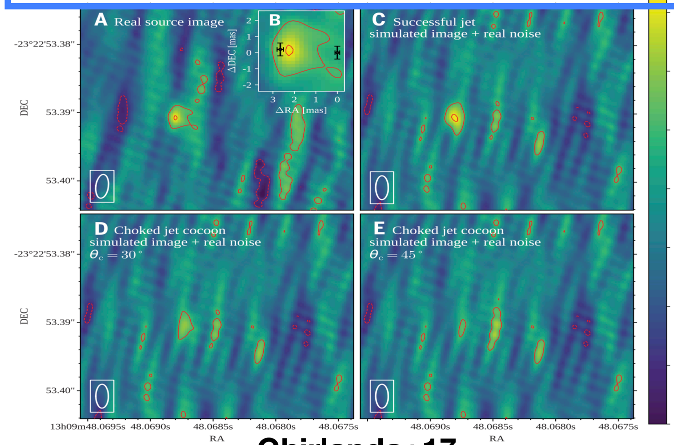


Michela Di Natolo (Bachelor Thesis)
see also Duan+19; Salafia+19





Full characterization of the GRB properties: evidence for a structured jet

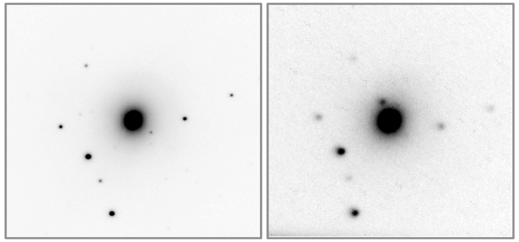


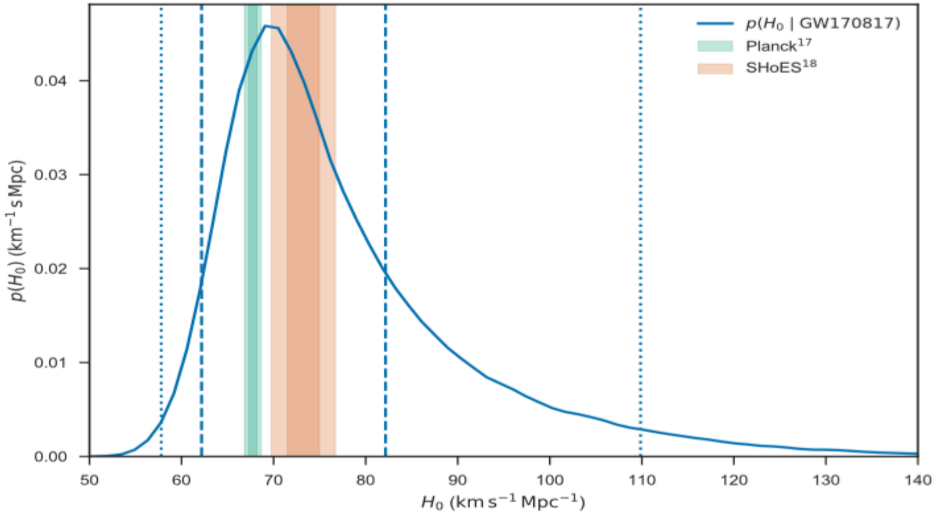
Ghirlanda+17

The radio afterglow is detected with an angular size < 2 mas in VLBI data obtained ~ 207 d after the merger. Evidence for superluminal motion is also found measuring an angular offset between T+75 d and T+235 d.
These findings, together with the afterglow light curve modelling, support the structured jet model. Fit to the data and numerical simulations are in agreement with the scenario of a structured jet with a relativistic core with θ_{jet} < 5 deg and θ_{view} ~ 20 deg.

Alexander+17,18; PDA+18; Dobie+18; Fong+19; Haggard+17; Hallinan+17; Hajela+19; Margutti+17,18; Mooley+18a,b; Resmi+18; Ruan+18; Troja+18a,b,19,20; Ghirlanda+19; Piro+19; Margutti & Chornock 21 and many others

Measuring the Universe



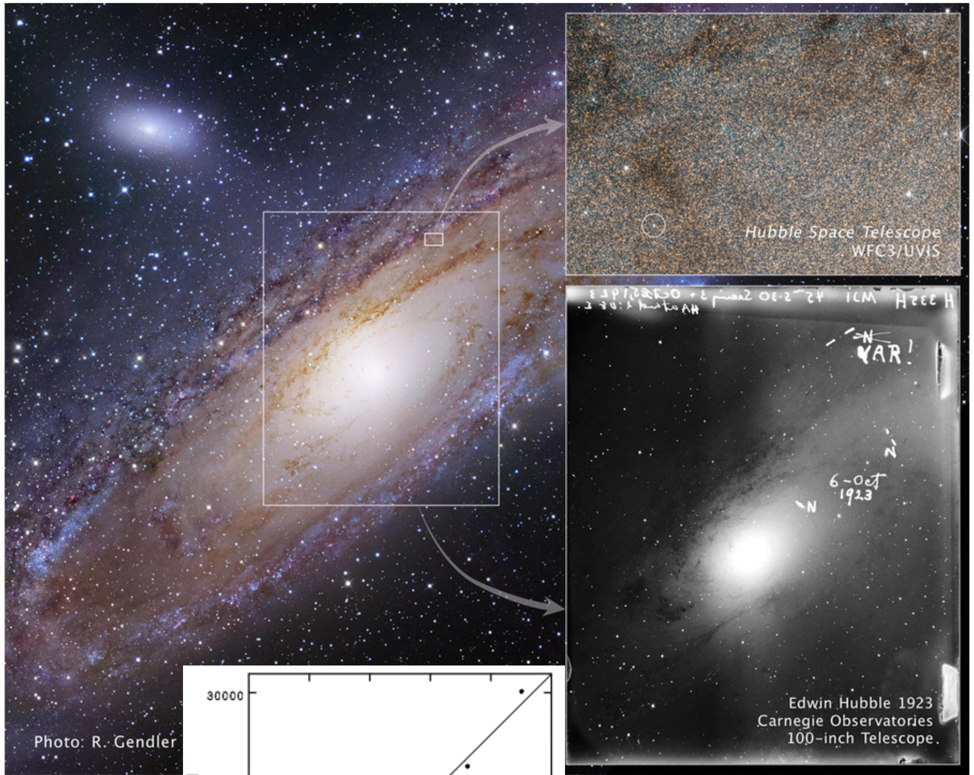


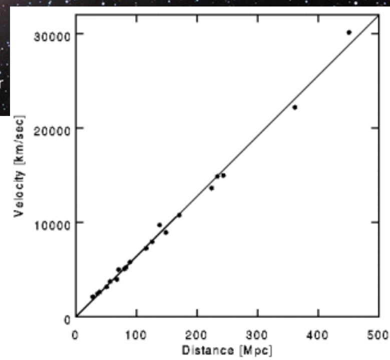
NGC 4993 redshift & luminosity distance (GW)

Independent measure of the Hubble constant

-> H_0 = 70 [+12, -8]

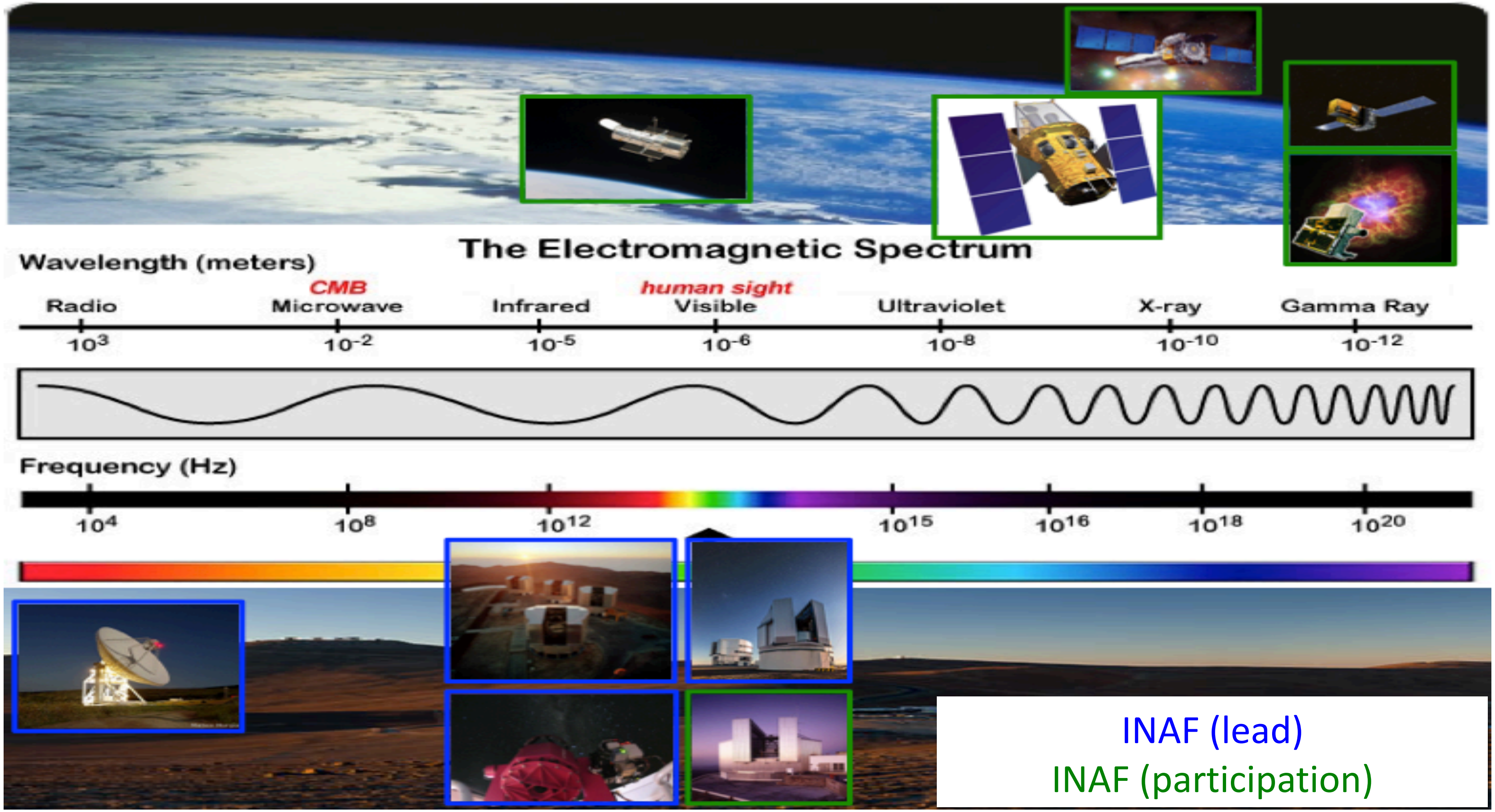
LVC (2017)





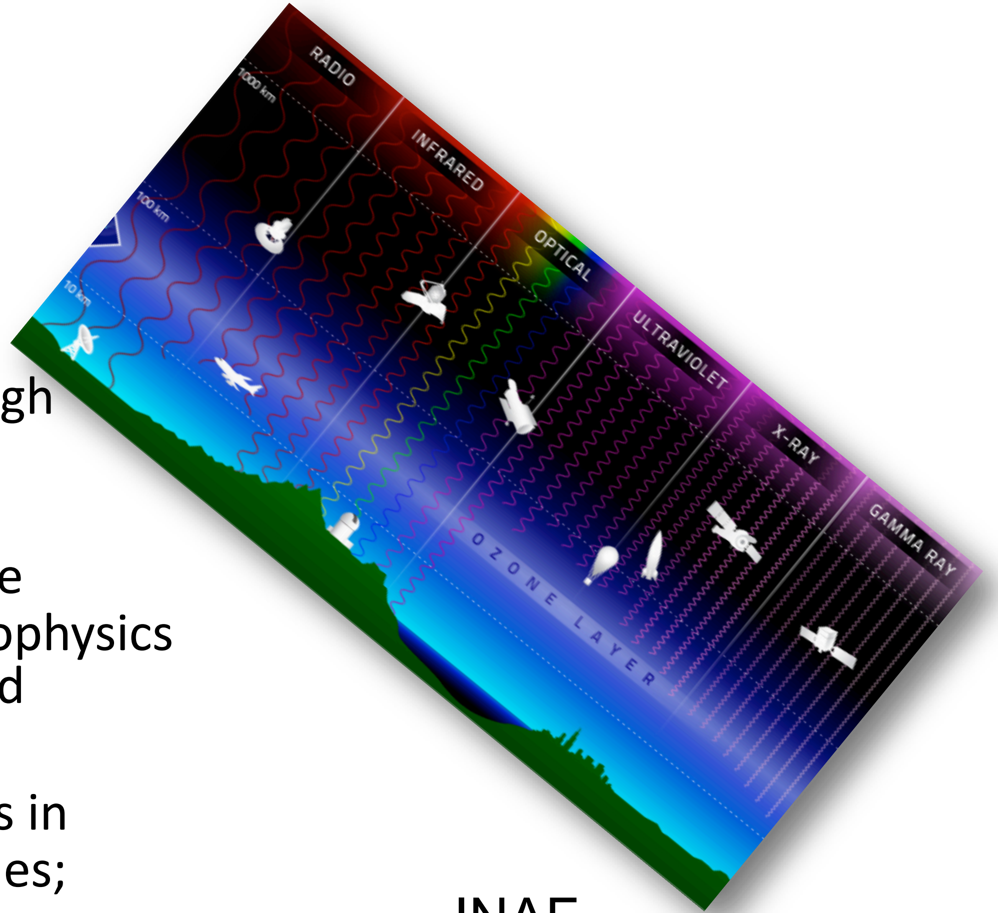
$v = H_0 \times D$

An impressive observational campaign



CONCLUSIONS

- INAF has observing facilities from radio to high energies going through the optical (Vis-NIR). Quite unique feature!
- INAF is involved in the most important future ground-based facilities that will change astrophysics in the next decade working with national and international agencies (INFN, ESO);
- INAF has an important role in space missions in collaboration with ASI, ESA and other agencies;
- INAF shows widespread technological competences, often stemming from the heritage of individual observatories.



INAF
MULTIWAVELENGTH
& MULTIMESSENGER
environment