TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Area – *Astrophysics and Space Science*

Programmazione Ricerca del Dipartimento di Fisica

Birth of the Astrophysics and Space Physics group

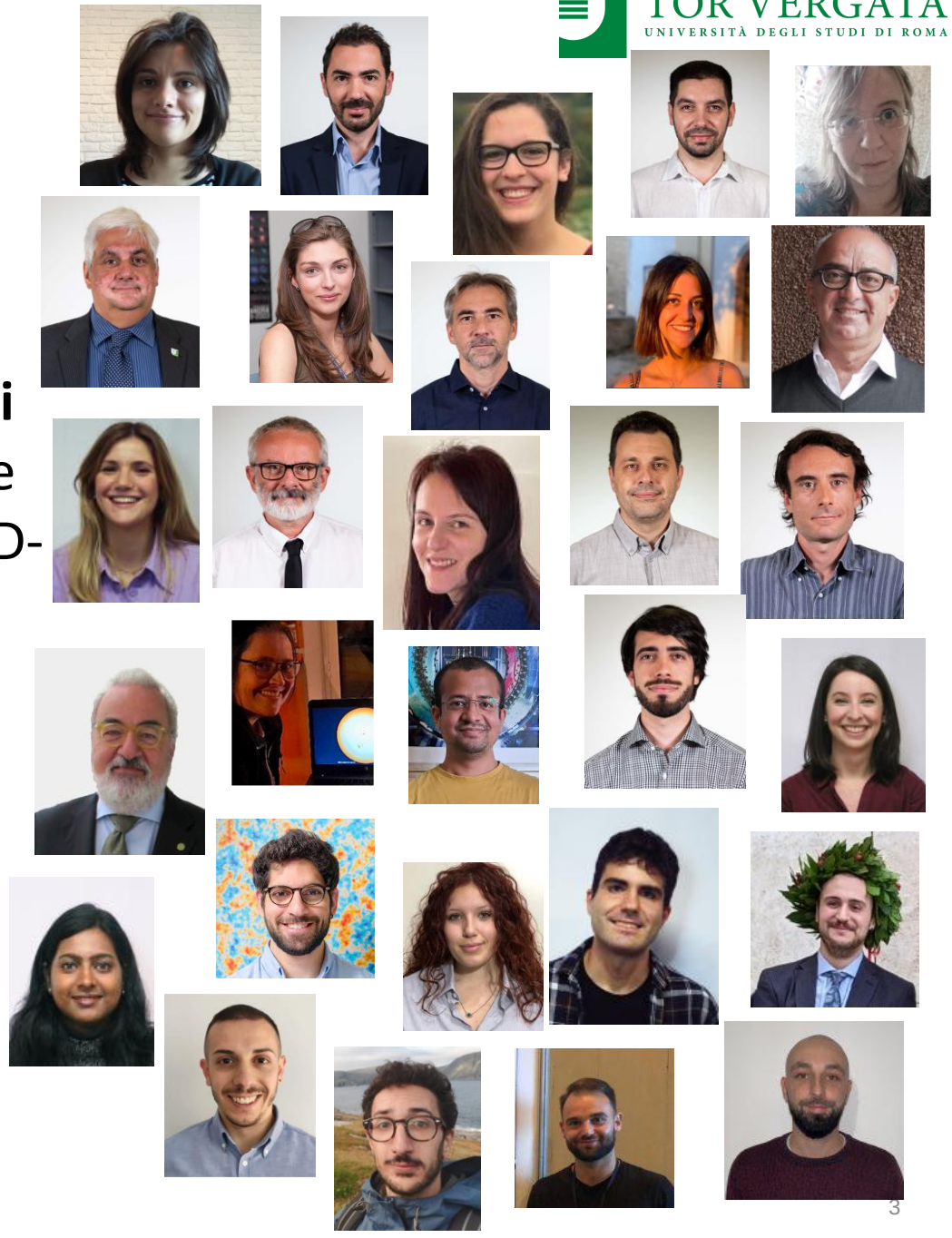
- The **Astrophysics and Space Physics** group at the University of Rome Tor Vergata was established as part of the initial development of the Physics Department, which started its teaching activities when the university was founded in 1982.
- The **astrophysics** unit began with **Alfonso Cavaliere**, who focuses on Galaxy Clusters and Hot Gas Physics, Cluster-Galaxy Relationships, Active Galactic Nuclei (AGN), and Diffuse Baryonic Matter.
- The **space physics** unit originated as a continuation of the Fundamental Physics Group, which was founded by **Edoardo Amaldi**, particularly in GCR research, which included Francesca Bachelet, **Franco Mariani**, Anna Maria Conforto, **Alberto Egidi**, **Sergio Cantarano**, and **Guido Pizzella** (GW).





People

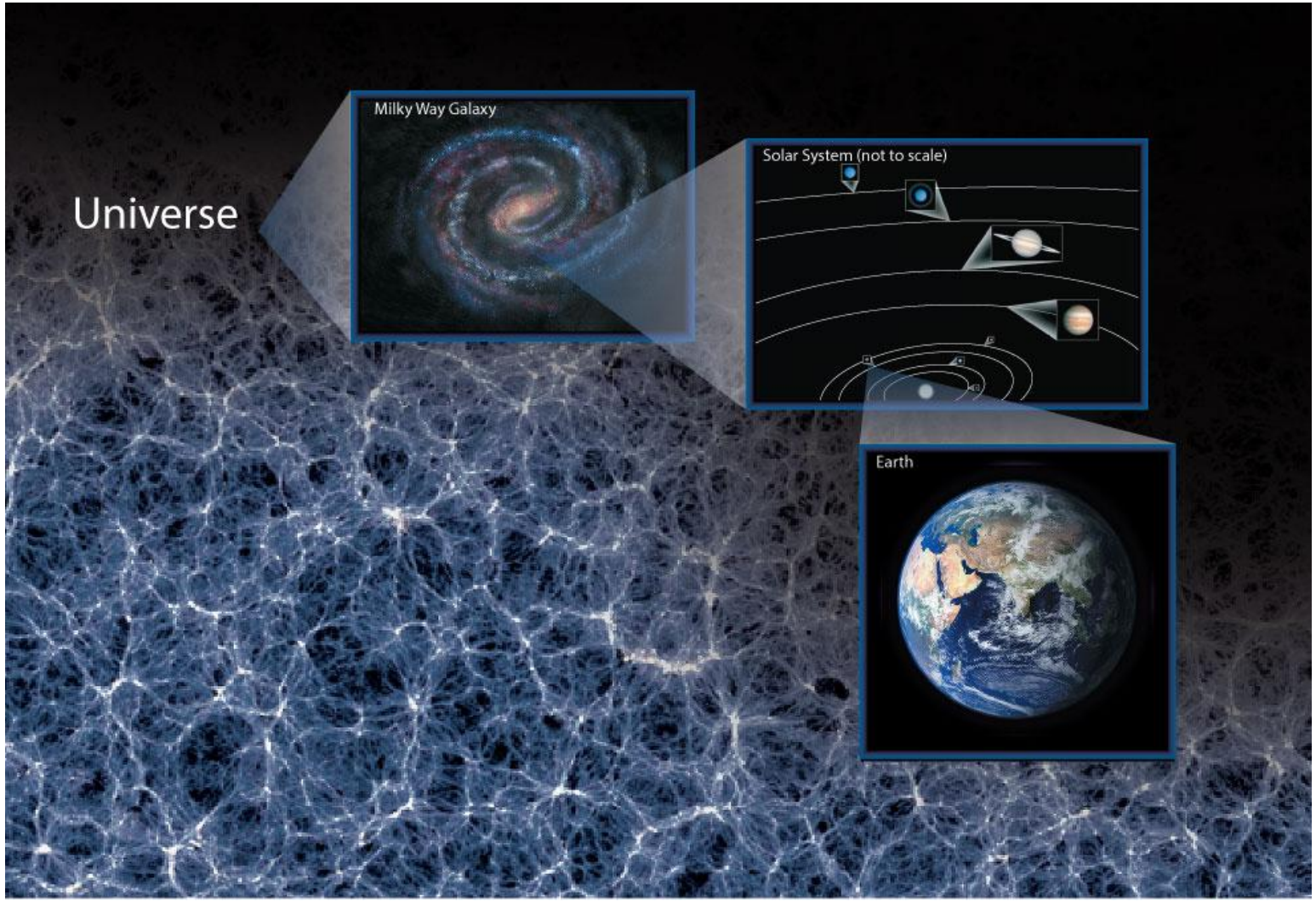
- Core Faculty: **Balbi** Amedeo (PA), **Berrilli** Francesco (PO), **Bono** Giuseppe (PO), **Bourdin** Hervé (PA), **Del Moro** Dario (PA), **D'Orazi** Valentina (PA), **Giovannelli** Luca (RTD-B), **Mancini** Luigi (PA), **Mazzotta** Pasquale (PO), **Migliaccio** Marina (PO), **Nigro** Giuseppina (RTD-A), **Tombesi** Francesco (PA), **Troja** Eleonora (PA), **Vittorio** Nicola (PE)
- AdR/Postdocs (last 5 y): **26**
- PhD student (last 5 y): **43**
- Support: 2 Technologists
- External Collaborators: INFN, INAF, ASI, ESA, ESO, CNR, ….



Evolution of the Astrophysics and Space Physics group

The Astrophysics and Space Physics group at Tor Vergata has developed around five broad research meta-themes, creating a critical mass of researchers, both inside and outside the Department of Physics.

- ***Cosmology***
- ***Extragalactic Astrophysics***
- ***Stellar Astrophysics***
- ***Exoplanets***
- ***Solar and Space Physics***

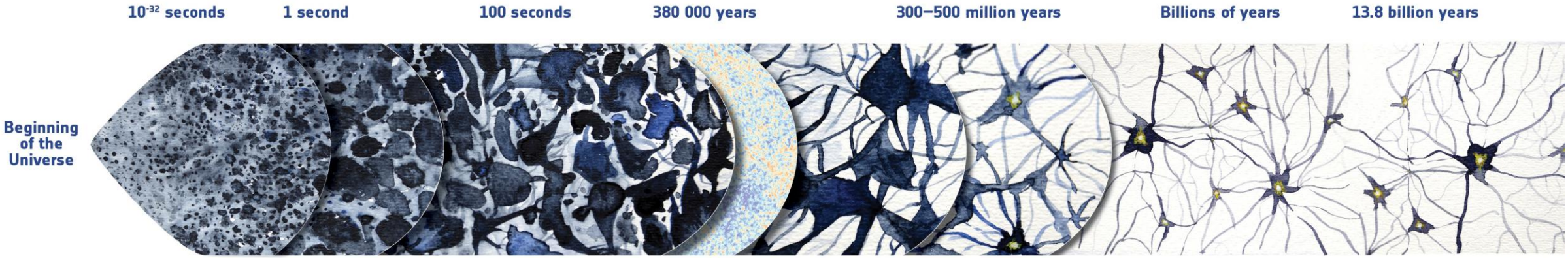


TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

COSMOLOGY

Marina Migliaccio (PO), Nicola Vittorio (PE)

Brief Description of the Scientific Activity 1



Cosmic Inflation

- Observational constraints on physical phenomena at energies not reproducible in any terrestrial laboratory
- Primordial non-Gaussianity of density perturbations
- Primordial B-modes in Cosmic Microwave Background polarization

Late-time accelerating expansion of the Universe

- Dark Energy and Modified Gravity models
- Tensions in measurements of the Hubble Constant
  (Type 1a supernovae yield a higher H_0 (around 73-76 km/s/Mpc), while early-universe measurements from the CMB predict a lower H_0 (around 67-68 km/s/Mpc).

Dark Matter

- Constraints from large-scale structures and the Cosmic Web
- Gravitational lensing

Cosmic Reionization

- Study the epoch in which first cosmic structures formed

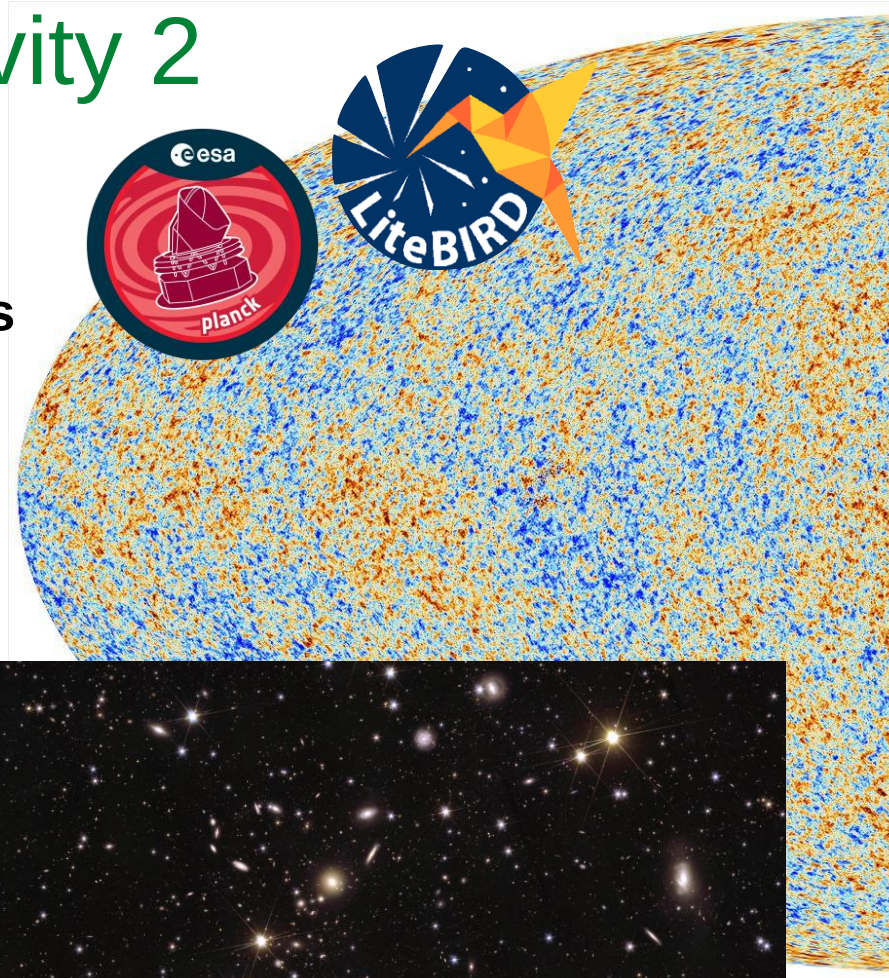
Neutrino properties

- N_{eff} , $\sum m_{\upsilon}$

Brief Description of the Scientific Activity 2

Cosmic Microwave Background Radiation

- We work on **Theory**, **Numerical Simulations** and **Data Analysis**
- Past: BOOMERanG, **Planck**
- Future: **LiteBIRD**, a space-mission to measure CMB polarization and search for primordial B-modes from cosmic inflation.



Large-scale structure

- Characterization of galaxy distribution and shear
- Active Galactic Nuclei distribution
- Radio Continuum
- **Euclid**, **Square Kilometre Array**

Impact of Activities on the National/International Research

- Strong **Legacy** from the **ESA Planck mission**, in which we played key roles.
- Leading the definition of an **Italian roadmap for CMB experiments** (ground-, balloon- and space-borne) of the next decade supported by ASI.
- Leading the **Italian participation to the Phase A of the LiteBIRD mission** supported by ASI.
- Appointed by ASI among 22 experts in the Astrophysics Roadmap Working Group tasked with defining the **roadmap and frontier challenges to guide the Italian space science community** over the next decade.
- Co-lead of the **CMBX Science Working Group** within ESA ***Euclid*** mission.
- Lead of the **Cross-Correlation Science Project Study Group** for the **LiteBIRD** mission.

Short- and Medium-Term Planned Activities

- **Physics of Cosmic Inflation and the quest for CMB primordial B-modes**
  - Novel approaches to test for non-standard inflationary scenarios.
  - Advanced data analysis techniques and simulations to control instrumental and astrophysical systematic effects.
  - Planning the next-generation JAXA-led space mission LiteBIRD (> 2033).
- **Tensions in the Hubble constant H_0**
  - Model-independent approaches (e.g. machine learning based) to assess the role of methodological systematics and approximations in data interpretation.
  - Theoretical extensions beyond the standard model of cosmology.
  - Role of emerging cosmological probes, e.g. gamma-ray bursts, cosmic chronometers and quasars.
- **CMB and Large-Scale Structure Cross-Correlations for new physics**
  - Optimally combine the unprecedented amount of data from ongoing and next generation surveys.
  - Maximize the scientific return and minimize the impact of uncorrected systematics in each probe.
  - Develop novel tests of the cosmological model.
  - The cosmology group is at the forefront of this effort, leading dedicated initiatives in the ESA Euclid mission (2023 - ongoing) and SKA (> 2029).

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

EXTRAGALACTIC ASTROPHYSICS

Pasquale Mazzotta (PO), Francesco Tombesi (PA), Eleonora Troja (PA),
Hervé Bourdin (PA)

Brief Description of the Scientific Activity – I

Black Hole Astrophysics & Active Galactic Nuclei (Tombesi):

- Physics of accretion and ultra-fast outflows from black holes; co-evolution between galaxies and black holes
- Cutting-edge X-ray spectroscopy and polarimetry from space missions (XRISM, IXPE, NICER team membership)
- Multi-Messenger synergy between electromagnetic radiation and gravitational waves, neutrinos, astroparticles

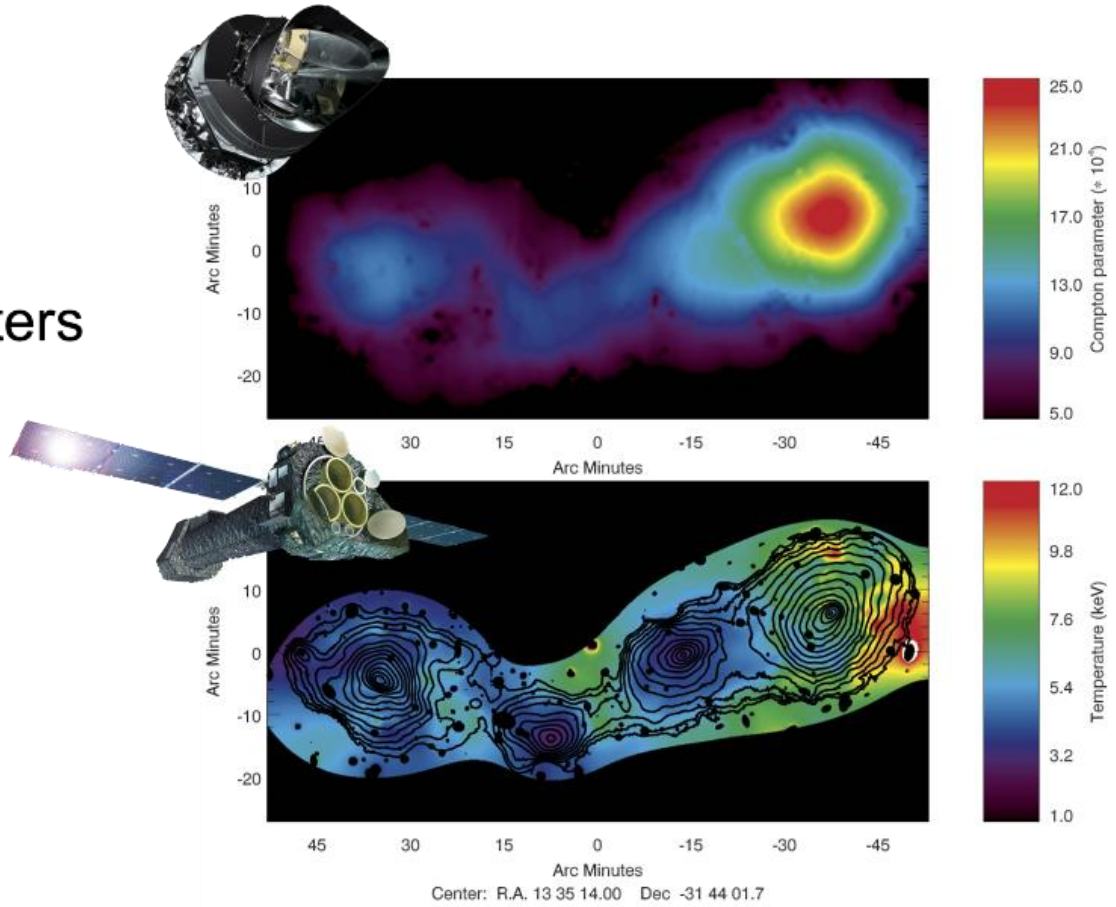
Cosmic Explosions & Transients (Troja):

- Gamma-ray bursts, kilonovae and counterparts to gravitational-wave events
- Cutting-edge X-ray timing and spectroscopy (NewAathena, Einstein Probe team membership)

Brief Description of the Scientific Activity – II

Galaxy Clusters & Large-Scale Structures (Mazzotta, Bourdin):

- Physics of the Intra-Cluster Medium (ICM)
- Cutting-Edge Spectral-Imaging of Galaxy Clusters in X-ray and Millimetre Bands
- Luminous and dark matter content of galaxy clusters
- New Cosmological Constraints and Hubble Constant Estimates from Galaxy Clusters



Impact of Activities on National/International Research

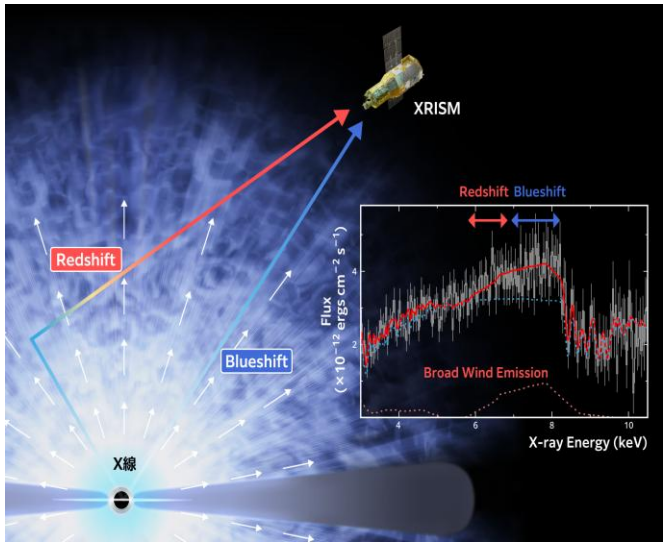
nature

Explore content · About the journal

nature › articles › article

Article | Published: 14 May 2025

Structured ionized winds shooting out from a quasar at relativistic speeds



(Tombesi)

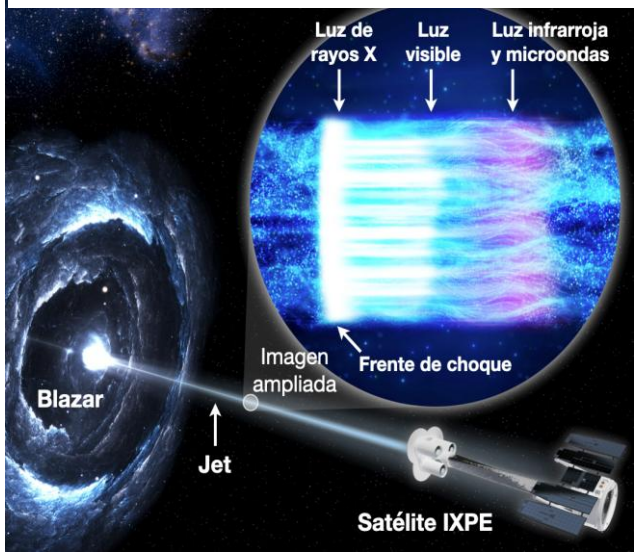
nature

Explore content · About the journal

nature › articles › article

Article | Open access | Published: 23 November 2022

Polarized blazar X-rays imply particle acceleration in shocks



(Tombesi)

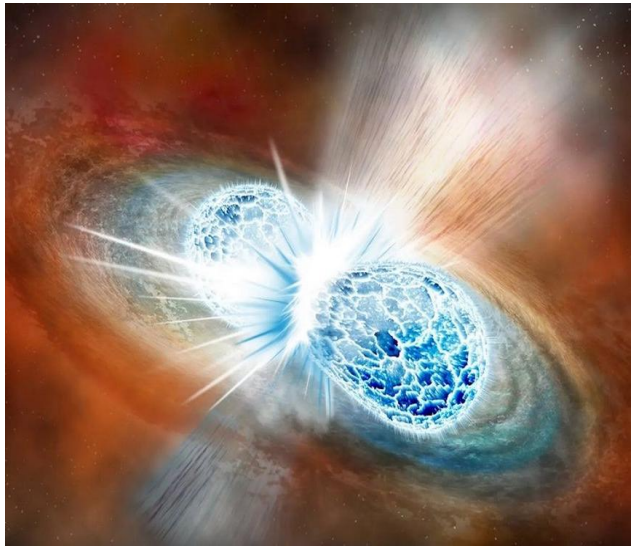
nature

Explore content · About the journal · Publish with us

nature › articles › article

Article | Open access | Published: 07 December 2022

A nearby long gamma-ray burst from a merger of compact objects



(Troja)

Short- and Medium-Term Planned Activities

Strategic Participation in Flagship Missions:

- Rubin Observatory - LSST for variable extragalactic sources (Tombesi)
- ESA's LISA gravitational-wave observatory (Tombesi)
- Cerenkov Telescope Array Observatory, very-high energy gamma-ray observations (Tombesi)
- ESA's NewAthena X-ray space observatory (Tombesi, Troja, Mazzotta, Bourdin)
- NIKA2 (New IRAM KID Arrays 2) (Mazzotta, Bourdin)
- AtLAST (Atacama Large Aperture Submillimeter Telescope) (Mazzotta, Bourdin)

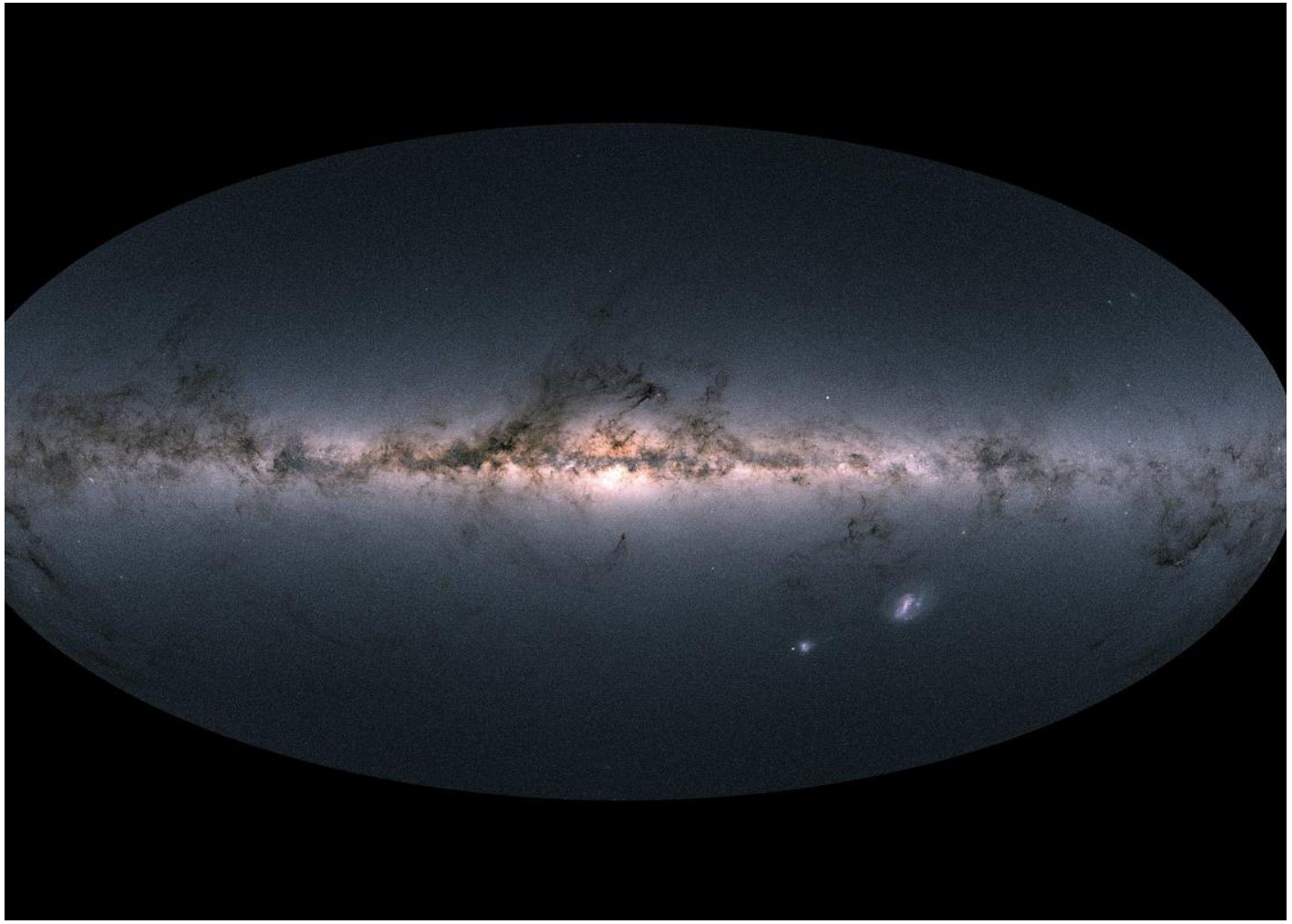
Rubin LSST

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

STELLAR ASTROPHYSICS

Giuseppe Bono (PO), Valentina D'Orazi (PA)

Brief Description of the Scientific Activity



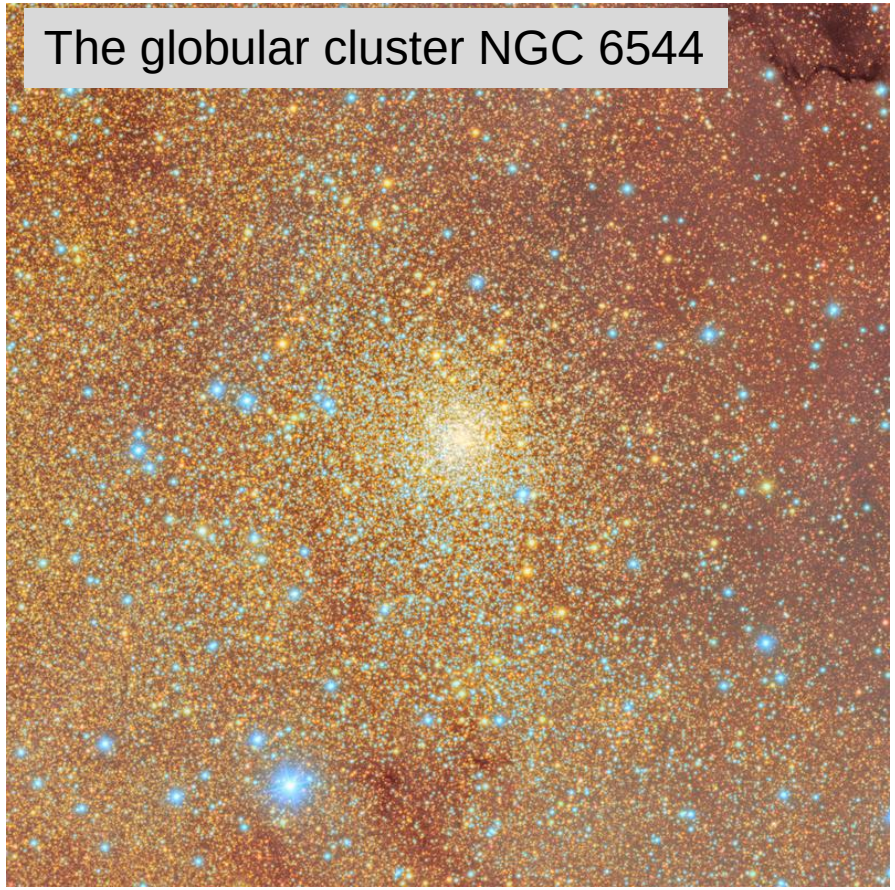
The Milky Way view from the Gaia satellite (Credits: ESO)

- Understanding the formation of the Milky Way and our neighbours (including e.g., the Magellanic Clouds and M31) by means of photometric and spectroscopic large-scale stellar survey
- How galaxies form and evolve through their stellar populations (clusters, variable stars)
- Multiple populations in globulars, radial and azimuthal gradients in the MW and beyond
- Stellar structure and evolution

Impact of Activities on the National/International Research

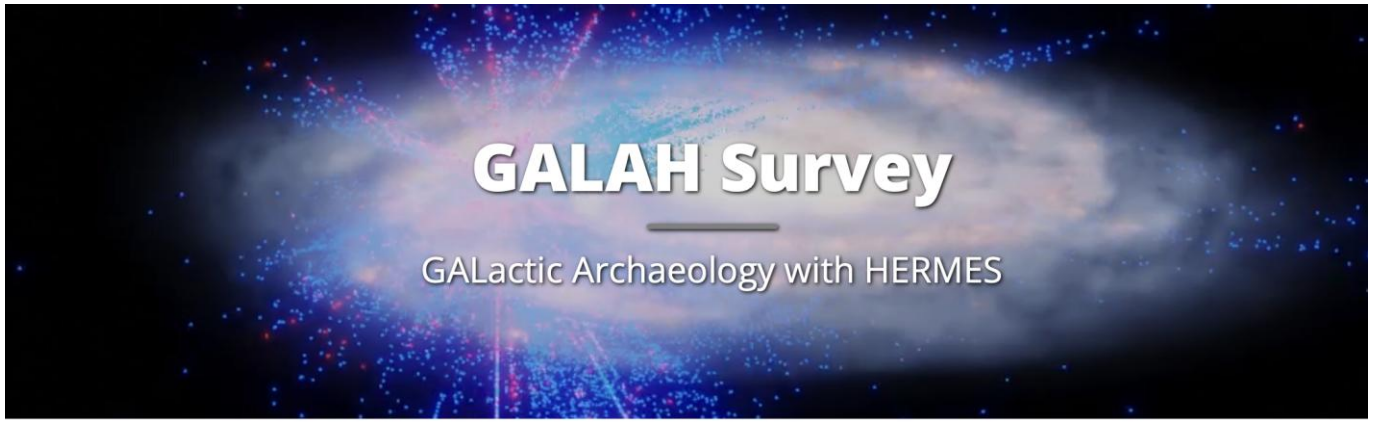
Large international collaborations include (but not limited to):

Large Synoptic Survey Telescope



Medium resolution spectra for million of stars!

Impact of Activities on the National/International Research

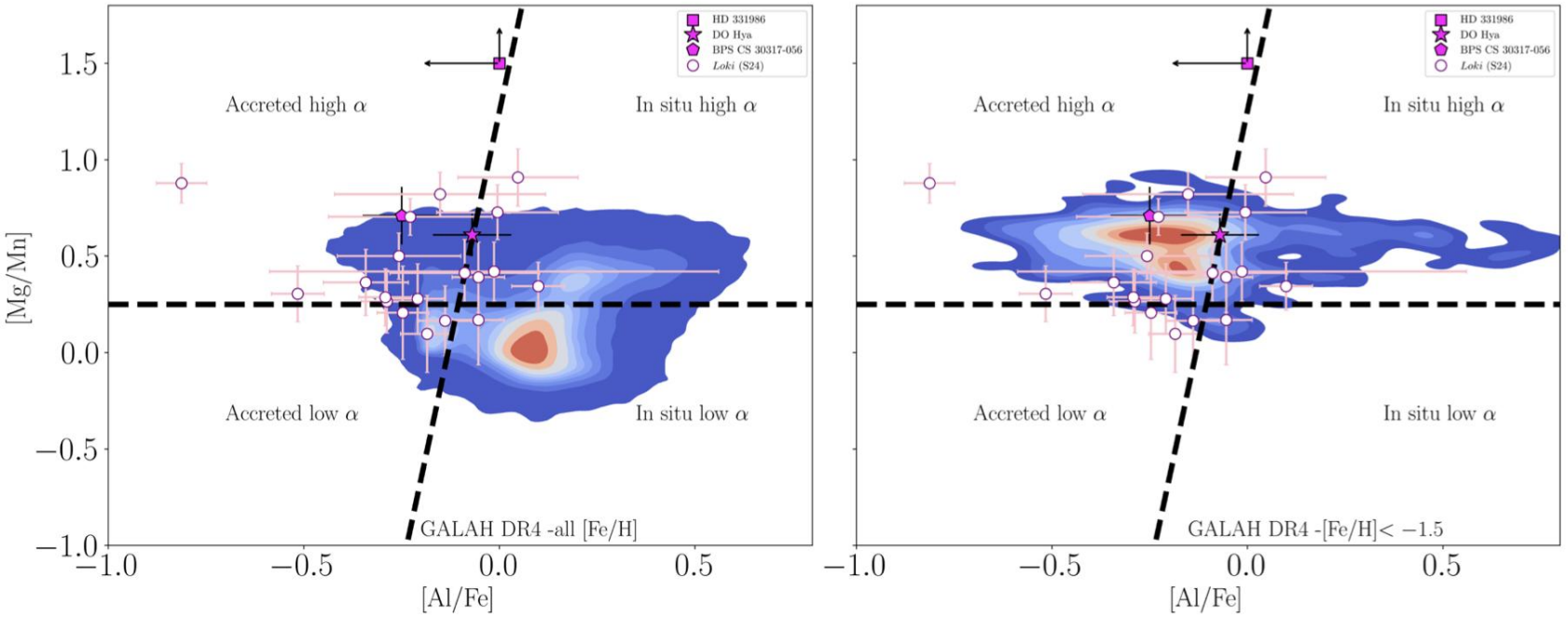


WEAVE

Getting spectra for million of stars to infer their **chemical composition**. This is fundamental to get information on the origin and evolution of stars in our Galaxy.

Short- and Medium-Term Planned Activities

- Non-LTE spectral analysis and advanced statistical methods on high-resolution spectra
- Low resolution spectra for kinematics of clusters and variable stars (Cepheids, RR Lyrae)
- Photometric analysis to get fundamental parameters of resolved stellar populations (e.g., age)



D'Orazi, Braga, Bono+ 2025

Using the chemical abundance ratios, we can disentangle if stars were accreted or formed *in situ*

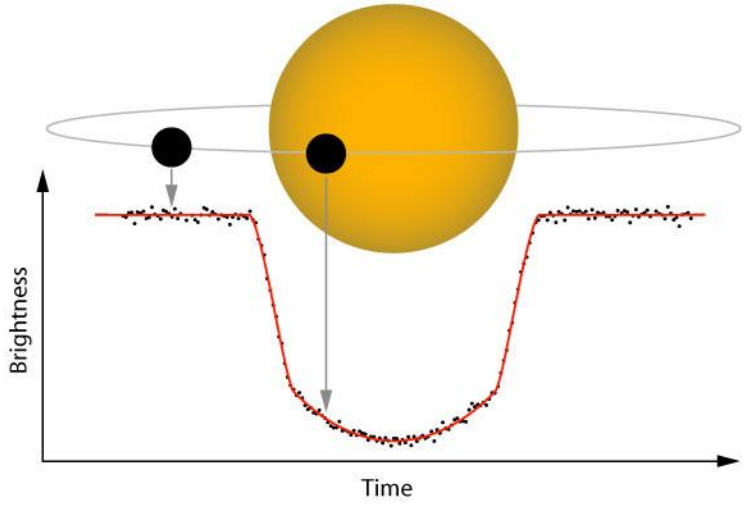
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

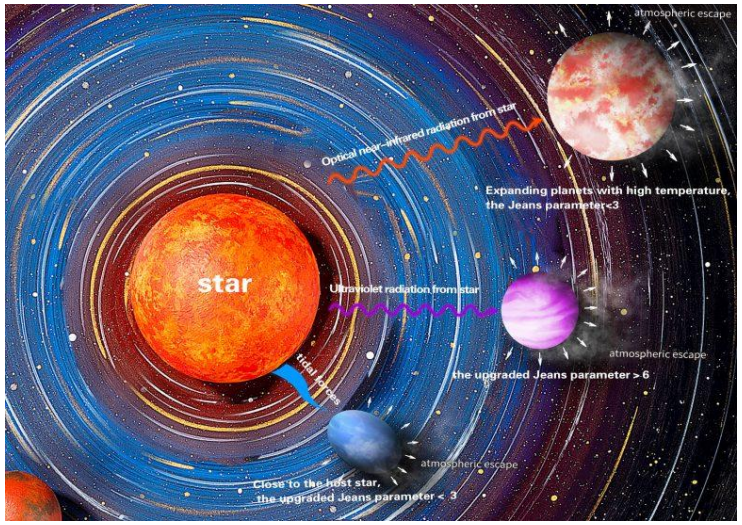
EXOPLANETS

Luigi Mancini (PA)

Brief Description of the Scientific Activity 1

- The research activity is mainly focused on the
  - detection of Exoplanets
  - physical, atmospherical and orbital characterization of exoplanets (including the characterization of their parent stars and their environment).
  - For these purposes, we use both ground-based and space-borne observatories and instrumentations across a wide range of wavelengths
- Among the various activities undertaken for the dissemination of scientific knowledge, L. Mancini is the creator and main organizer of the “Advanced School on Exoplanetary Science”, whose first five editions took place in Vietri sul Mare (Italy) in May 2015, 2017, 2019, 2023 and 2025.





Brief Description of the Scientific Activity 2

- LM has been the **discoverer and co-discoverer of more than 100 extra-solar planets** with the Transit technique and more than 20 planets with the Radial-Velocity (including Teegarden's Star b, which has the higher Earth Similarity Index) the Microlensing and the Astrometry techniques;
- LM is running a **long-term observational program that has led to accurately measure the physical, orbital and atmospheric properties of more than 450 planetary systems and validated more than 100 planets**, not to mention binary systems and brown dwarfs;
- LM had a primary role in **HATSouth, one of the most important and successful ground-based surveys with robotic telescopes for transiting exoplanets**; he also collaborated with other ground-based-survey teams (WASP, KELT, QES);
- LM participated in several **observational programs to confirm the planetary nature of the space-telescope Kepler and K2 candidates via radial-velocity measurements**. He and his group are currently working on TESS planetary candidates;
- LM pioneered **different observational techniques and strategies to improve the precision of the measurements of the exoplanetary-system parameters**, like (i) telescope defocussing, (ii) transmission photometry, (iii) the use of multi-band cameras in the observations of planetary transits, and (iv) the two-site observational strategy;

Impact of Activities on the National/International Research

- LM was **PI and Co-PI of over fifty observational programs with ESO telescopes** (VLT, ESO-3.6m, ESO-2.2m, DK 1.5m) and others (Keck, Subaru, LBT, TNG, NOT, INT, CAHA-2.2m, CAHA-1.2m, Copernico 1.8m, Cassini 1.5m) **for the follow-up of exoplanetary systems**;
- LM was **member of the CARMENES team, which carried out a survey of 300 late-type stars with the aim of detecting low-mass planets in their habitable zones**;
- LM had a **primary role in the EDEN survey, which provided the most sensitive volume-complete photometric monitoring of late-M dwarf stars** to date and upper limits on the short-period planet population;
- LM is **co-founder and active member of the GAPS (Global Architecture of Planetary Systems) team**. This is a national project that has been investigating open questions in exoplanetary science for over 12 years;
- LM was a **member of the Transiting Exoplanet Community Early Release Science program of the James Webb Space Telescope (JWST)**, whose goal was to understand the limitations and capabilities of the JWST instruments and provide the scientific community with the technical skills to analyse JWST data.

Short- and Medium-Term Planned Activities

- Confirmation and characterization of new exoplanets via accurate ground-based radial-velocity measurements and space-based photometric time-series observations, which are currently performed by TESS and in the future by PLATO.
- Determining the occurrence rate of planetary systems with a mass and orbital separation hierarchy similar to that of the Solar System (the so-called “ordered systems”).
- Probing the atmosphere of rocky planets with the JWST.
- NASA Great Observatory Maturation Program (GOMAP) Habitable Worlds Observatory (HWO) START Living Worlds Working Group. HWO is a concept for a NASA flagship mission, as recommended by the 2020 Astrophysics Decadal Survey, that would pursue a breadth of astrophysics goals, including searching for and characterizing potentially habitable planets beyond our solar system.

Transiting Exoplanet Survey Satellite

Plato - Terrestrial planet hunter

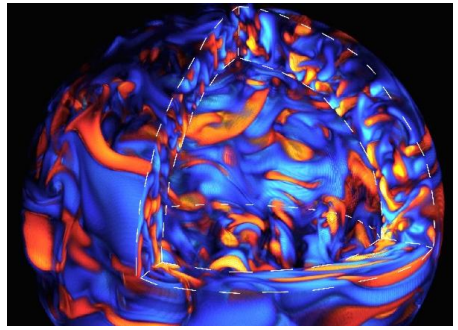
TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

HELIOPHYSICS AND SPACE SCIENCE

Francesco Berrilli (PO), Dario Del Moro (PA), Amedeo Balbi (PA), Luca Giovannelli (RTDb),
Giuseppina Nigro (RTDa)

Brief Description of the Scientific Activity 1

- How likely is a superflare to occur, and what is the impact of such powerful space weather events on the habitability of exoplanets?
- What fundamental physical processes determine a planet's ability to support life? Does the activity of Sagittarius A BH affect the habitability of Earth-like planets in the Milky Way?
- How do stars, like our Sun, generate and regulate their magnetic fields, and what part does turbulent convection play in this process?
- What are the key physical mechanisms that heat the Sun's atmosphere to millions of degrees, creating the solar corona?
- What physical processes cause sudden, intense bursts of electromagnetic radiation and accelerate particles during solar flares and CME, and what instabilities trigger space weather events?



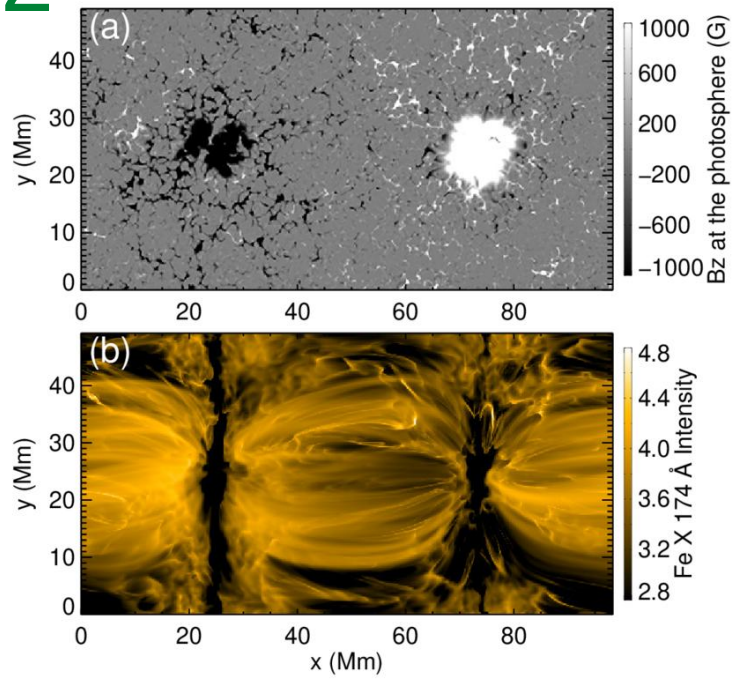
Numerical simulation of high-Rayleigh-number rotating turbulent convection

Did a Supermassive Black Hole Influence the Evolution of Life on Earth?

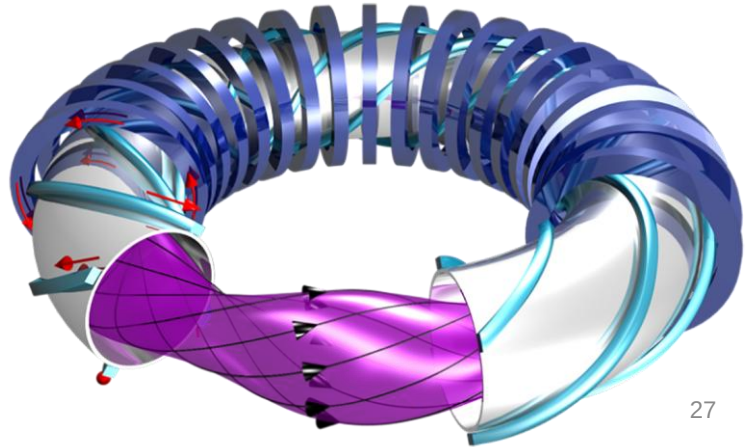
Solar flare

Brief Description of the Scientific Activity 2

- **Physics of the Sun's magnetic field in the photosphere**: CHs and forecasting (ML, Topology, ..) of solar flares and CMEs.
- **Space Weather and Climate:** forecasting of thermosphere density and reconstruction of TSI and Earth's climatic response during solar grand minima.
- **Numerical Modeling:** Numerical models of dynamos and magnetic structures describing plasma dynamics in both solar magnetic loops and laboratory plasmas like tokamaks (G. Nigro).
- **Instrument Development:**
  - Development of synoptic telescopes for solar magnetism study, like the Robotic TSST synoptic telescope.
  - Development of solar CubeSats.
  - Development of spectropolarimetric instrumentation for next-generation solar telescopes.

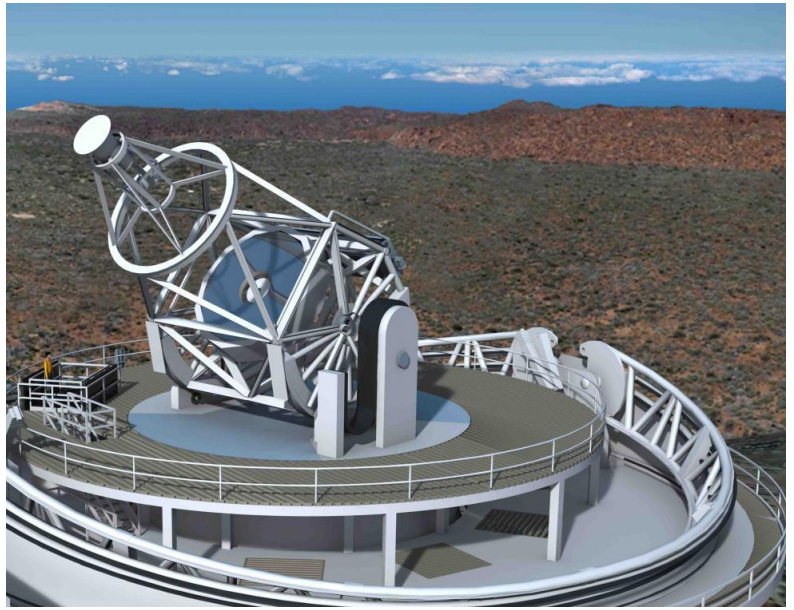


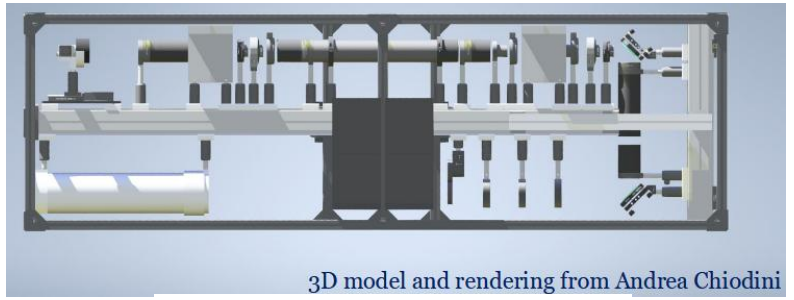
(a) Bz magnetic field and (b) intensity map Fe X 17.4nm line solar AR model. Chen+, 2021b



Impact of Activities on the National/International Research

- **European Solar Telescope (EST):** Our group leads the JRU EST-IT, a collaboration to manage Italian participation in EST. EST, a next-generation 4.2-meter solar telescope on the ESFRI roadmap since 2016.
- **TSST/GATES:** Our two-decade collaboration with the Univ. of Hawaii and GSU on MOF telescopes led to the Global Automatic Telescopes for Exploring the Sun (GATES) network.
- **Sun CubE OnE (SEE):** ASI's Board has approved funding for Phases C/D/E1 of the 12U CubeSat SEE. Our group retains the scientific PI-ship (PI: F. Berrilli) and P/L control (System Engineer: L. Giovannelli).
- **IBIS2.0:** The IBIS interferometric spectrometer is being upgraded. The enhanced instrument, with D. Del Moro serving as Instrument Scientist, will be moved to the Teide Observatory in Tenerife.
- **ASI Space Weather (SWE):** ASI aims to establish a National Space Weather Center for real-time analysis, nowcasting, and forecasting.

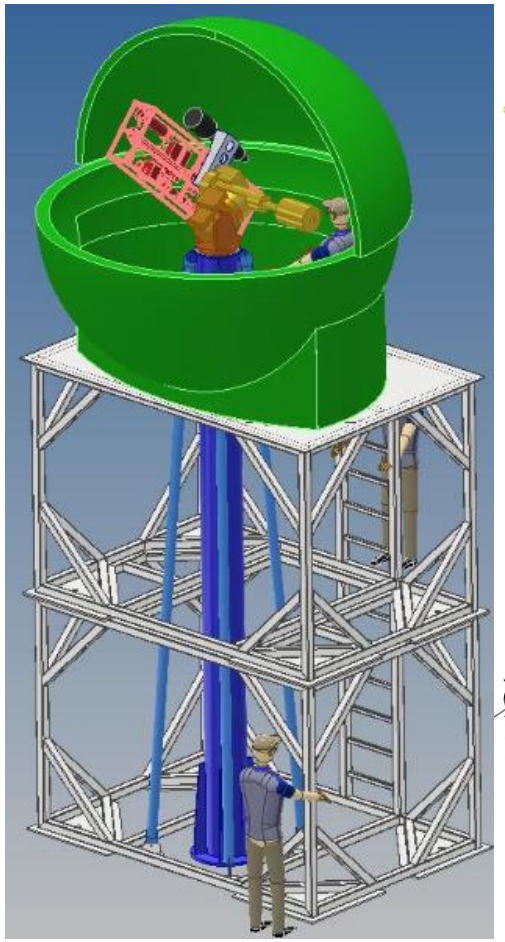


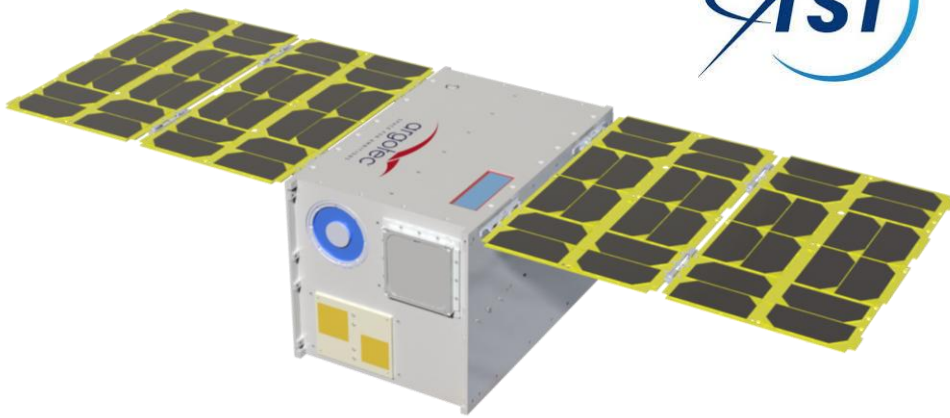


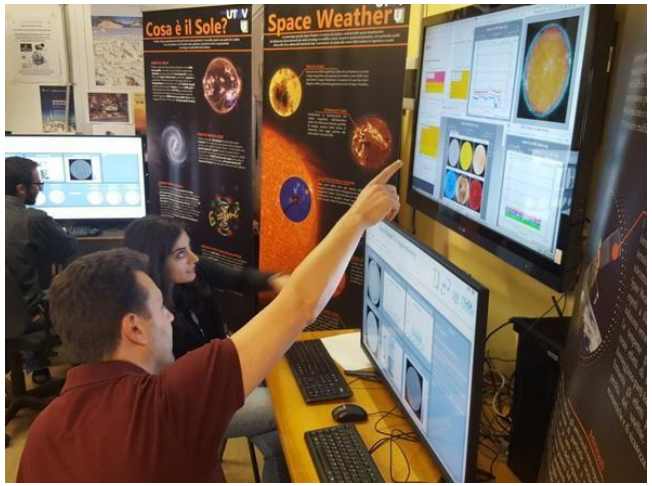
3D model and rendering from Andrea Chiodini

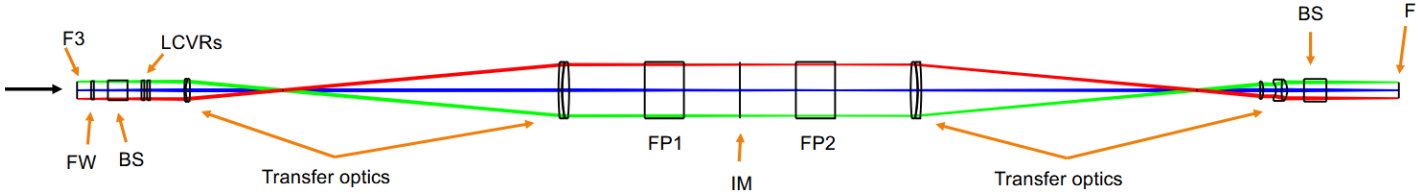
Short- and Medium-Term Planned Activities

- SEE-Cubesat (C/D/E1) UV telescope +X/ detectors (INFN UNITOV coll.)
- TSST/GATES: Robotic dome and telescope (GSU and INAF TNG coll.)
- EST: Tunable Imaging Spectropolarimeters (IAA-CSIC coll.)
- Servizio di Space Weather in ASI (A/B)
- SWERTO: Space-Weather at the University of Rome Tor Vergata









Scientific Output – Last 5 Years

Indicator	Cumulative Value
Peer-reviewed publications	> 700 in top international journals (Nature, ApJ, MNRAS, A&A, JCAP, JSWSC, etc.)
Research funding obtained	> **14M€ from ERC, ASI, H2020, Marie Skłodowska-Curie Actions, PNRR, PRIN, INFN**
Bachelor's theses supervised	> 30
Master's theses supervised	> 40
PhD theses supervised	> 40
Conference presentations	> 70 invited

Specialist and General Teaching Activities

Faculty and researchers in the area play a major role in both undergraduate and graduate teaching, particularly within:

- The BSc in Physics (L-30)
- The MSc in Physics (LM-17) and Astrophysics and Space Science (LM-58)
- The inter-university Erasmus Mundus Master MASS
- UNIVERSEH (European Space University of Earth and Humanity)
- The PhD program in Astronomy, Astrophysics and Space Science (AASS)
- The II Level Master – Space Science and Technology
- MSCA ITN and DN PhD networks (SWATnet, TALES)
- Dottorato di Interesse Nazionale in Space Science And Technology - SST