Giornate INAF 2019 *27 Mar - 28 Mar*

Stellar Evolution

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Con Santi Cassisi, Sergio Cristallo, Marcella Di Criscienzo, Leo Girardi, Marco Limongi, Ilaria Musella, Grazia Umana, Paolo Ventura et al.

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The study of stellar evolution is a key astrophysical goal ← Visible Universe made of stars

- for our understanding of resolved stellar populations in Galactic and extragalactic environments
- for the definition of standard candles to be used in the cosmic distance ladder
- for robustly measuring stellar ages
- for providing **reliable and accurate information about the SFH** of both simple and complex stellar systems; a crucial step for **understanding the process(es) of formation and evolution of the Galaxy and the Local Group**
- for our understanding of the chemical evolution of the galaxies and, in turn, of the Universe

Leading role of the Italian community with important reference stellar model databases available to the whole scientific community, and a huge number of milestone papers on all the relevant evolutionary phases

Many open problems but ...

*A unique **big** question*

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Taking stellar models to the next power

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Several physical mechanisms (**rotation** and related rotational induced mixings, **magnetic fields**, thermohaline mixings, internal **gravity waves**, and **mass loss**) still poorly known in stellar evolutionary computations

↑

complexity of their inclusion
their impact controlled by
several free parameters

Other ingredients, such as the C12(α,γ)O16 cross section are still uncertain→ link with nuclear physics

It is no longer possible to ignore their efficiency if we wish to properly understand the huge amount of high-accuracy spectroscopic data and seismic information that on-going and next-future surveys are planned to provide

3D stellar models

- very ambitious project
- only a few international teams that are already working in this direction
- *The Italian community, that boats a longtime worldwide recognized leadership in the field of stellar evolution, should definitely avoid to miss this chance*

The results based on 3D simulations can also be used as guidelines to update the treatment of non-canonical physical processes in traditional 1D codes (as implemented for the first time by the italian stellar evolution community)

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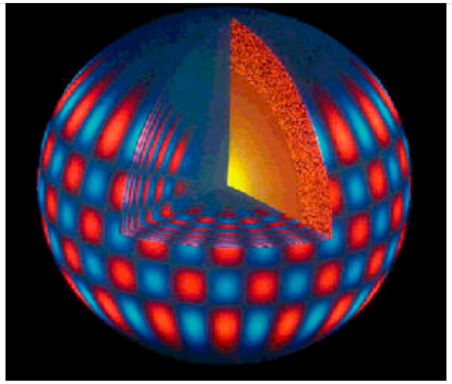

The power of asterosismology

Past, present and future space facilities (e.g. Kepler, PLATO and TESS) are in progress and planned for the coming decade.

→ accurate observations of stellar oscillations for stars in different evolutionary stages

→ unique benchmark for testing and improving stellar evolution models

Asteroseismology → present **stellar mass**, **radius** and **HR position** for thousands of stars within some tens of kpc.

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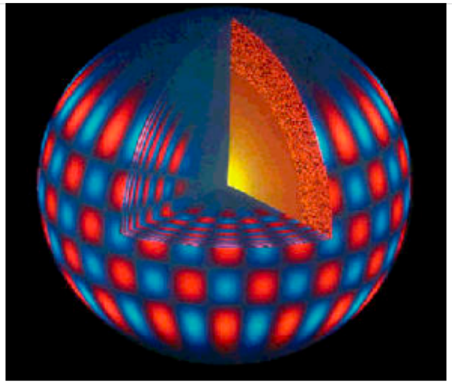

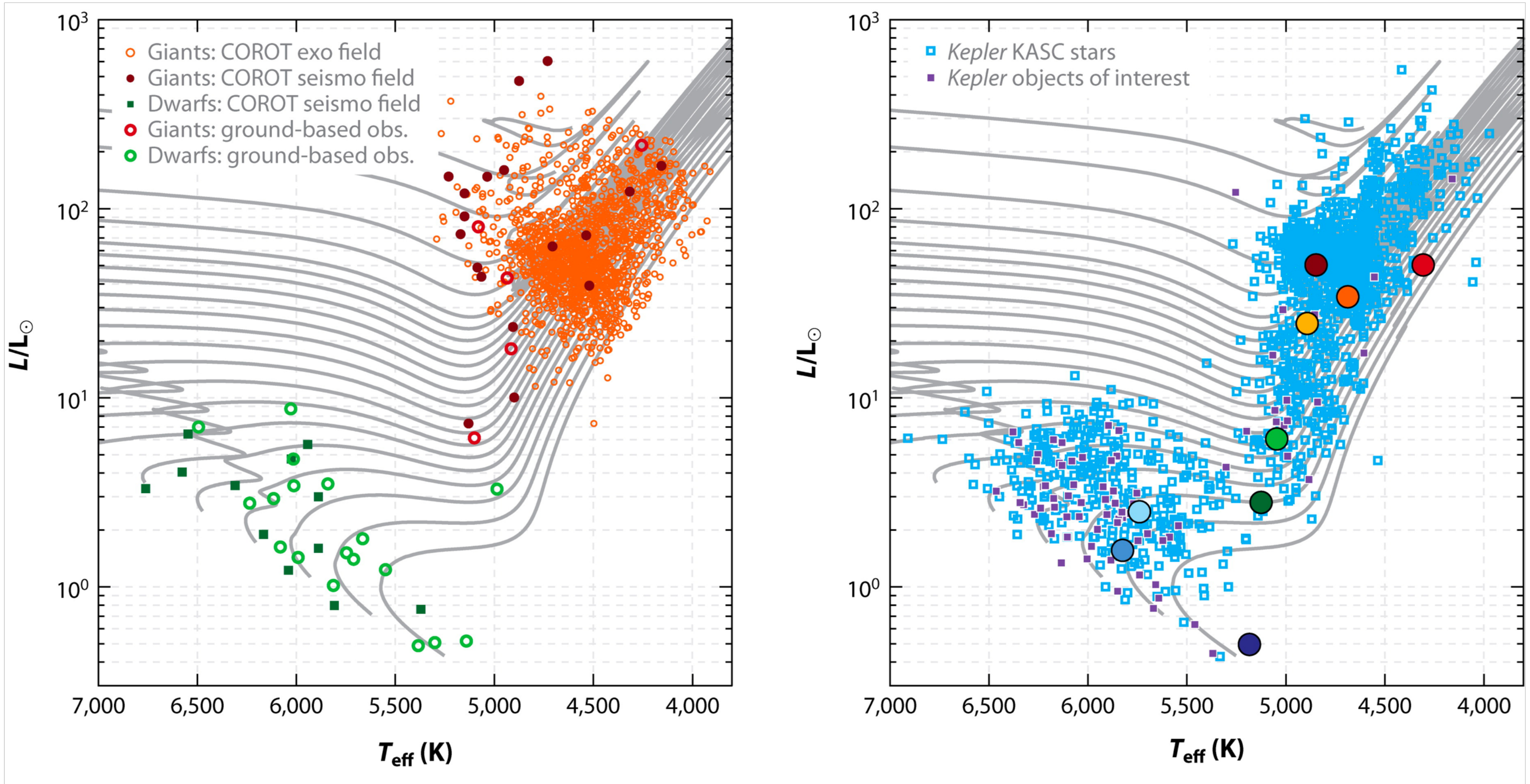

Chaplin WJ, Miglio A. 2013.
Annu. Rev. Astron. Astrophys. 51:353–92

The role of PLATO

PLATO will detect and characterize planets around bright solar-like stars and provide accurate seismology for 85000 stars → **stellar radii and masses at a ~2% level of precision**

The characterization - via accurate stellar models - of the planet-host stars is a pivotal step in order to understand the process of formation and evolution of the planet and its atmosphere. This would require a strong synergy between the stellar astrophysics community and the exoplanets one. → ages at ~10%.

The role of Gaia (and LSST)

Individual distances --> HR diagrams, distance scale

Test of evolutionary and pulsation models

Independent constraints on Mass-Luminosity relations, Helium abundance, extinction law

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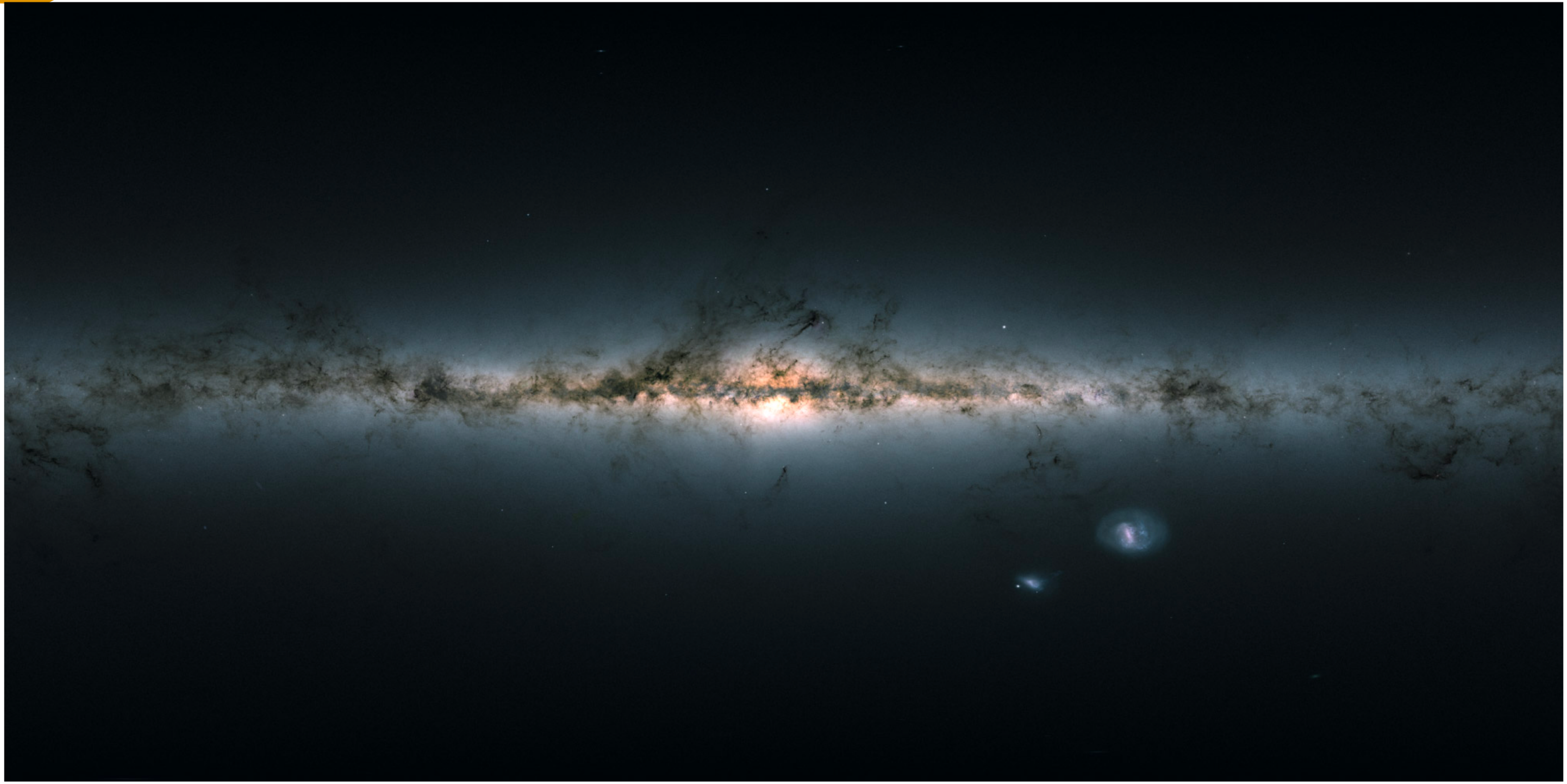
Gaia DR2



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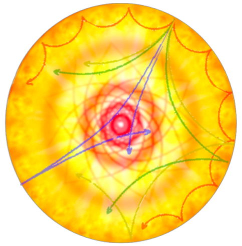
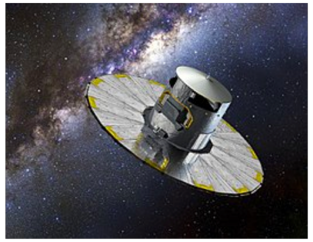
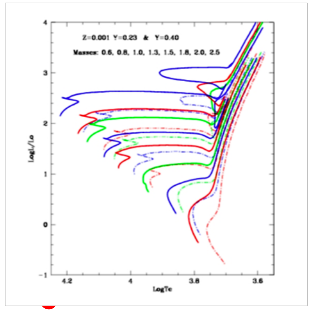
 +  + 

Asterosismology + Gaia parallaxes + stellar evolution models

⬇

Accurate stellar ages, star formation histories, Galactic Astronomy (see Antonella's talk)

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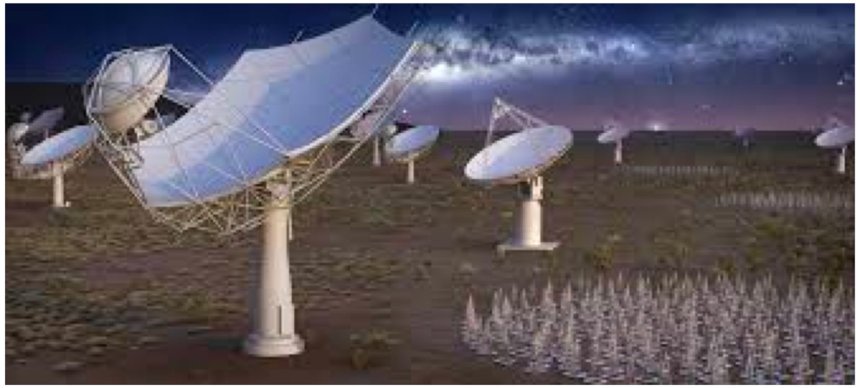


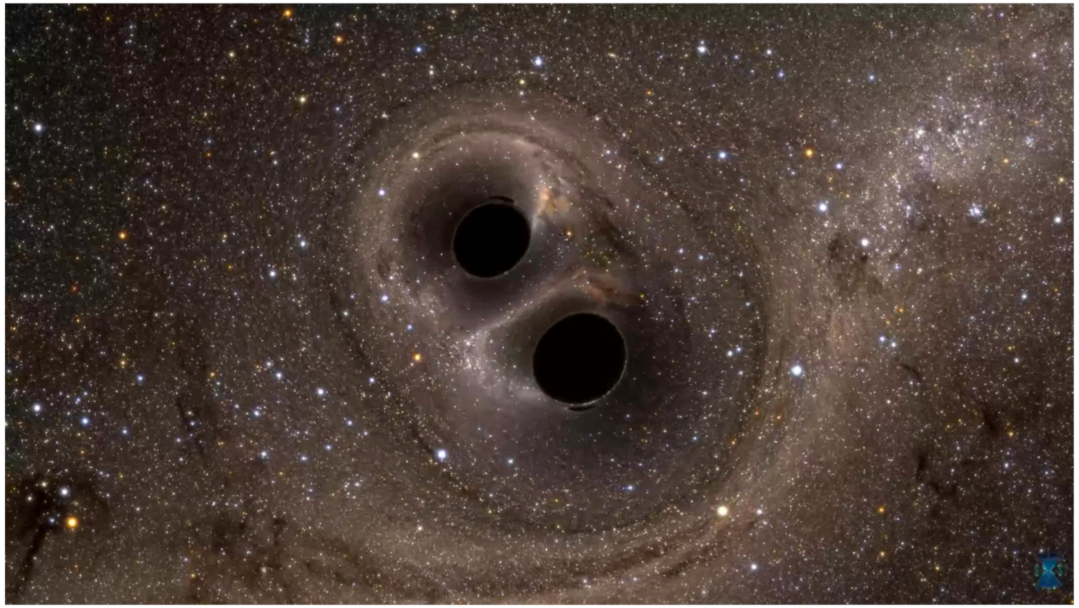
Role of SKA

SQUARE KILOMETRE ARRAY

Magnetic field measurements for stars in different evolutionary phases

From massive stars evolution to GW research

The first two gravitational-wave sources, GW150914 and GW151226 have been associated with the merger of two massive black holes



10 out of 11 subsequent events involve a BH/BH merging

- *Which is the evolutionary path leading to the formation of a neutron star or a black hole?*
- *How the nature of the remnants and its mass depend on the initial stellar parameters, i.e., mass, metallicity and rotation velocity?*
- *What is the expected frequency of NS/NS, NS/BH, BH/BH binaries and with which mass ratio?*

What is the mechanism to produce the high mass compact objects observed in GW events?

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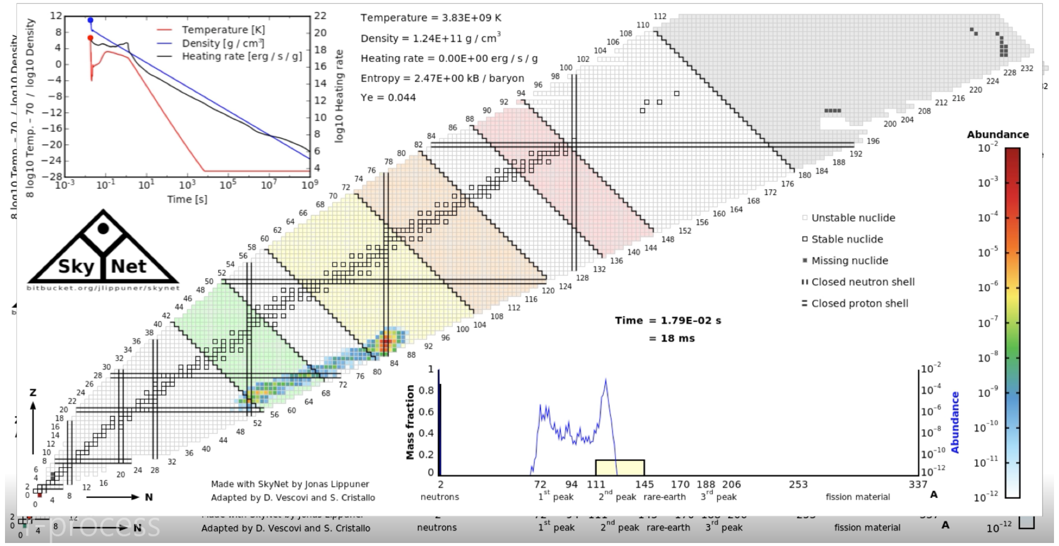
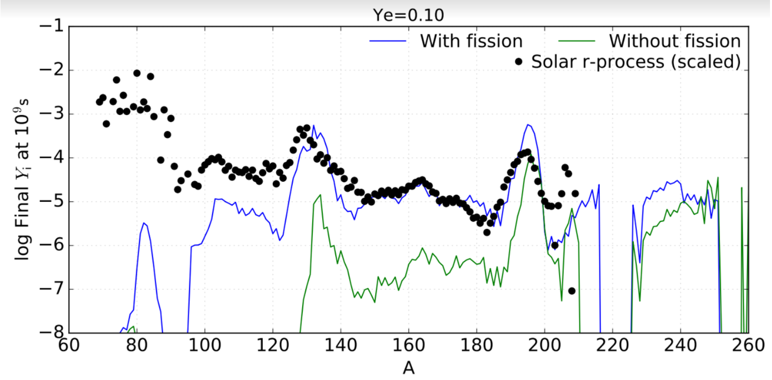
From massive stars evolution to GW research: r-process heavy element nucleosynthesis

A detailed chemical characterization, including n-capture elements, for a sample of 2.5M stars in the Galactic halo and disk(s) will be delivered by WEAVE (INAF is a founding partner):

- *Are NSMs the sole responsible of the chemical enrichment in our Nearby Universe?*
- *Which are the rate and timescale of r-process event(s) necessary to explain the enrichment in the Galactic halo?*
- *How does a kilonova light-curve depend on the on-going r-process nucleosynthesis?*





- **Important sinergies with INFN not only for GW detection, but also from a nuclear astrophysics point of view (neutron capture and fission processes).**
- **Detailed s-process nucleosynthesis needed (see next slides on AGB stars).**

Mass loss is one of the key ingredients that determine the final remnant mass and the role of stars as polluters of surrounding interstellar medium

→ *Need to carry out a census and a close monitoring of the final phases of massive stars, the so called hyper- giants which populate the brightest part of the HR diagram.*

Most of the massive stars evolve during the so called **Luminous Blue Variable (LBV) phase**, where they experience strong episodes of dynamical mass ejection.

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The role of LSST for LBV research

The multiband high performance monitoring capabilities of LSST will allow us to significantly increase the number of confirmed LBV stars.

→ more accurate determinations of the length of the LBV phase

→ properties and mass loss (in total and per eruption) of the stars during this unstable stage

→ initial mass-remnant mass relation for massive stars.

LSST Italian project also devoted to LBVs

Other future developments

→ digital scanning of all plates available in the archives of the Italian telescopes, even the smaller ones to create an incremental public database with light curves and spectra of these extreme stars.

→ study of circumstellar envelopes around massive stars of the Milky Way and Local Group thanks to the high spatial resolution of the next generation instruments in the optical (E-ELT) and in the radio (SKA)

The AGB phase

→ AGB phase critical for the interpretation of the infrared observations of the evolved populations (e.g. Magellanic Clouds and dwarf galaxies of the Local Group) and to study extinction properties.

→ In INAF long tradition in the modeling of the thermal pulse phase of AGB stars and significant progress in the international context

→ AGB stars could have played a fundamental role in the appearance of the Multiple Stellar Population Phenomenon in Galactic Globular Clusters

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The AGB phase: heavy elements nucleosynthesis

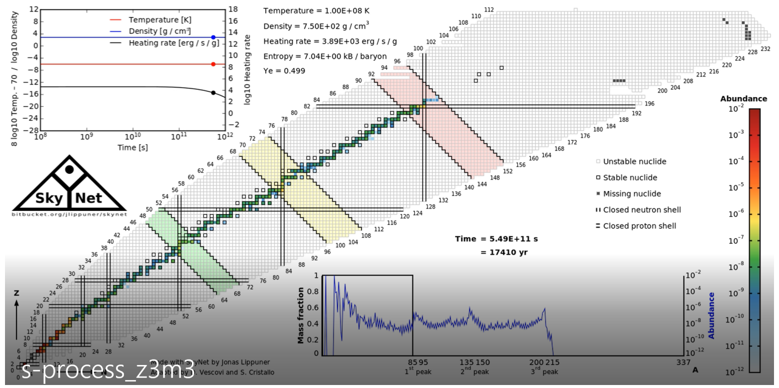
→ accurate nucleosynthesis predictions - in particular for s-elements - require a detailed modeling of the AGB stage

Theory

Models
Nuclear inputs
Spectroscopy

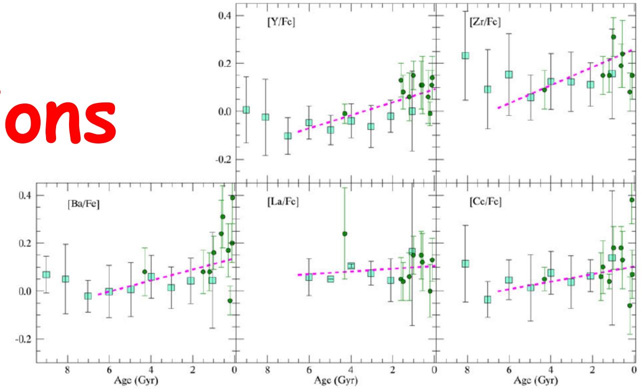
Observations

GALACTIC CHEMICAL EVOLUTION



Fix the physics of the process at the origin of the formation of the ^{13}C-pocket (the main neutron source in AGB stars):

- Treatment of convective/radiative borders;
- Evaluation of rotation-induced mixing;
- Evaluation of mixing triggered by magnetic fields;
- Determination of solar r-process residuals as a reference curve.



Magrini+ 2018

GAIA-ESO, the only spectroscopic survey on a 8 m class telescope (PI: S. Randich), provides a large sample of heavy elements, both for s-process-dominated (Y-Zr-Ba-La-Ce), r-process-dominated (Sm-Eu), and mixed s&r (Pr-Nd) elements:

- Enlarge the current sample with open clusters and extended to field stars (with distances and age estimates thanks to Gaia) to better trace disk and enrichment in young populations;
- Determine the relations between heavy elements ratios, metallicity and position.

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The role of Alma for AGB stars

Recent observations at high spatial resolution and high signal-to-noise ratio, obtained using tools such as ALMA have stimulated within INAF a new research aimed at the investigation of the dust formation process in the stellar wind, with the modeling of this process as based on a self-consistent description of the AGB phase.

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The role of Alma for AGB stars

→ AGB + dust models **successfully tested against IR Spitzer data** for the evolved stellar populations of the Magellanic Clouds and **used to derive the dust production rate** of some dwarf galaxies (e.g. IC1613, IC10, SextantA etc..)

The SCORPIO project:

A first glimpse on the Galactic Plane with ASKAP

Early science phase of ASKAP *(Australian Square Kilometre Array Pathfinder)*

In the framework of the EMU survey

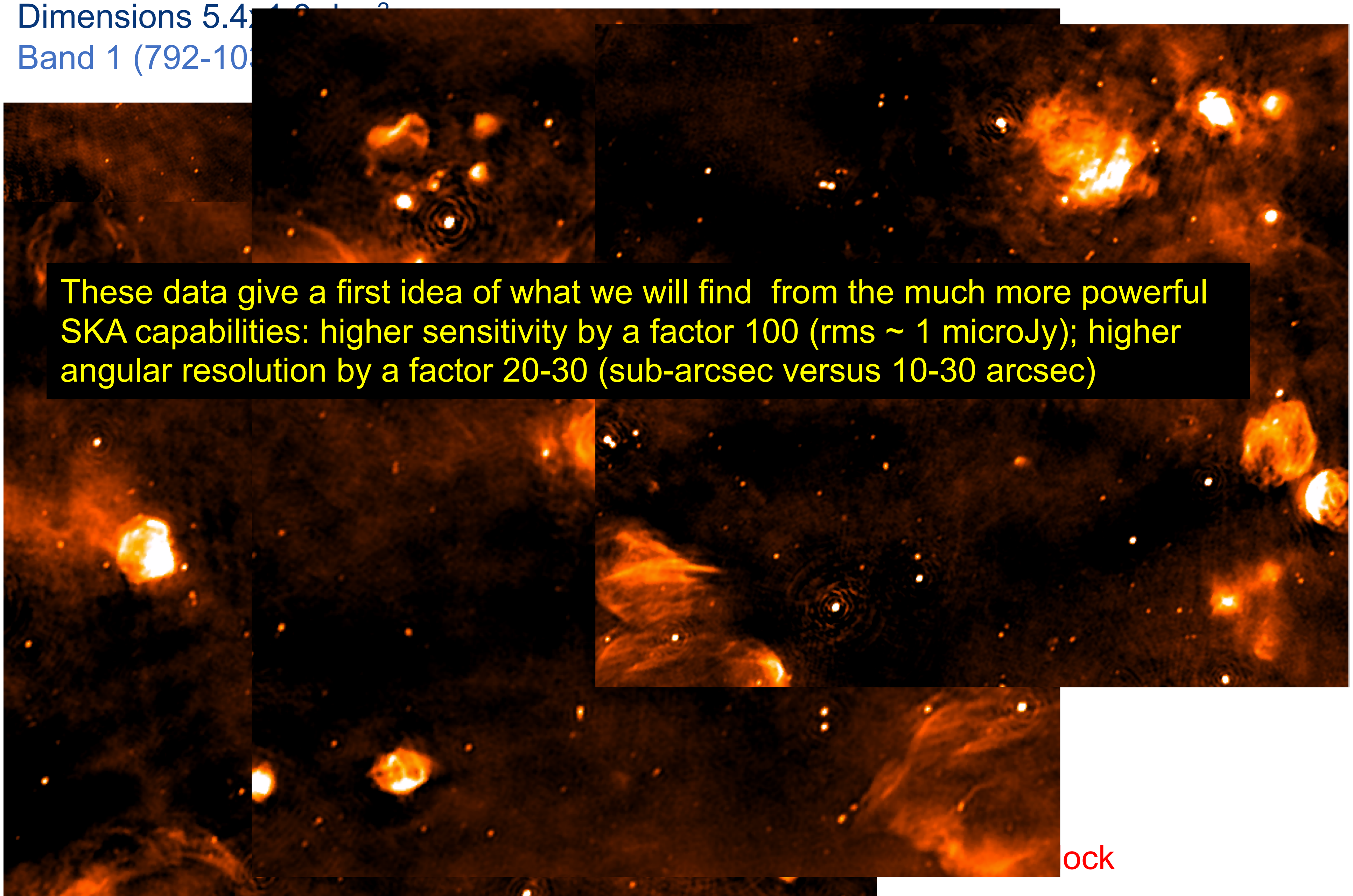
ASKAP EMU Evolutionary Map of the Universe

P.I. G. Umana, INAF-OACt

Field center 343.8 -0.2

Dimensions 5.4

Band 1 (792-10



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The role of JWST, ELT and LSST for AGB stars

→ **The upcoming JWST and ELT** instruments, which will enormously increase the number of galaxies where AGB stars will be resolved and studied

→ **LSST will open important possibilities on still poorly known aspects** of the AGB evolution: e.g. pulsation and its impact on dust formation

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Summary

Key Question	Method	Project
Taking stellar models to the next power	Comparison with astrometric information, and accurate asteroseismic data; Developing of suitable numerical algorithms to implement multidimensional physical phenomena in 1D stellar evolutionary codes based on 3D simulations; Developing of 3D stellar models; Refining dust formation codes through the comparison with observations at high spatial resolution and high signal-to-noise ratio or via observational tools that will enormously increase the numbers of galaxies where AGB stars will be resolved. Developing of hydro-dynamical codes for investigating the impact/efficiency of non canonical mixing processes; Comparison with updated magnetic fields measurements.	Kepler, Gaia, TESS, PLATO, JWST, ALMA.Hershel, LBT,VLT, SKA, LSST, E-ELT