Resolved stellar populations: from now to the next decades

From large spectroscopic surveys to the next generation of instruments for the study of resolved stellar populations

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Galactic Archaeology: stellar populations in the MW

Credit AMNH

Our Galaxy is representative of spiral galaxies (but still unique...)

The only one we can study in detail

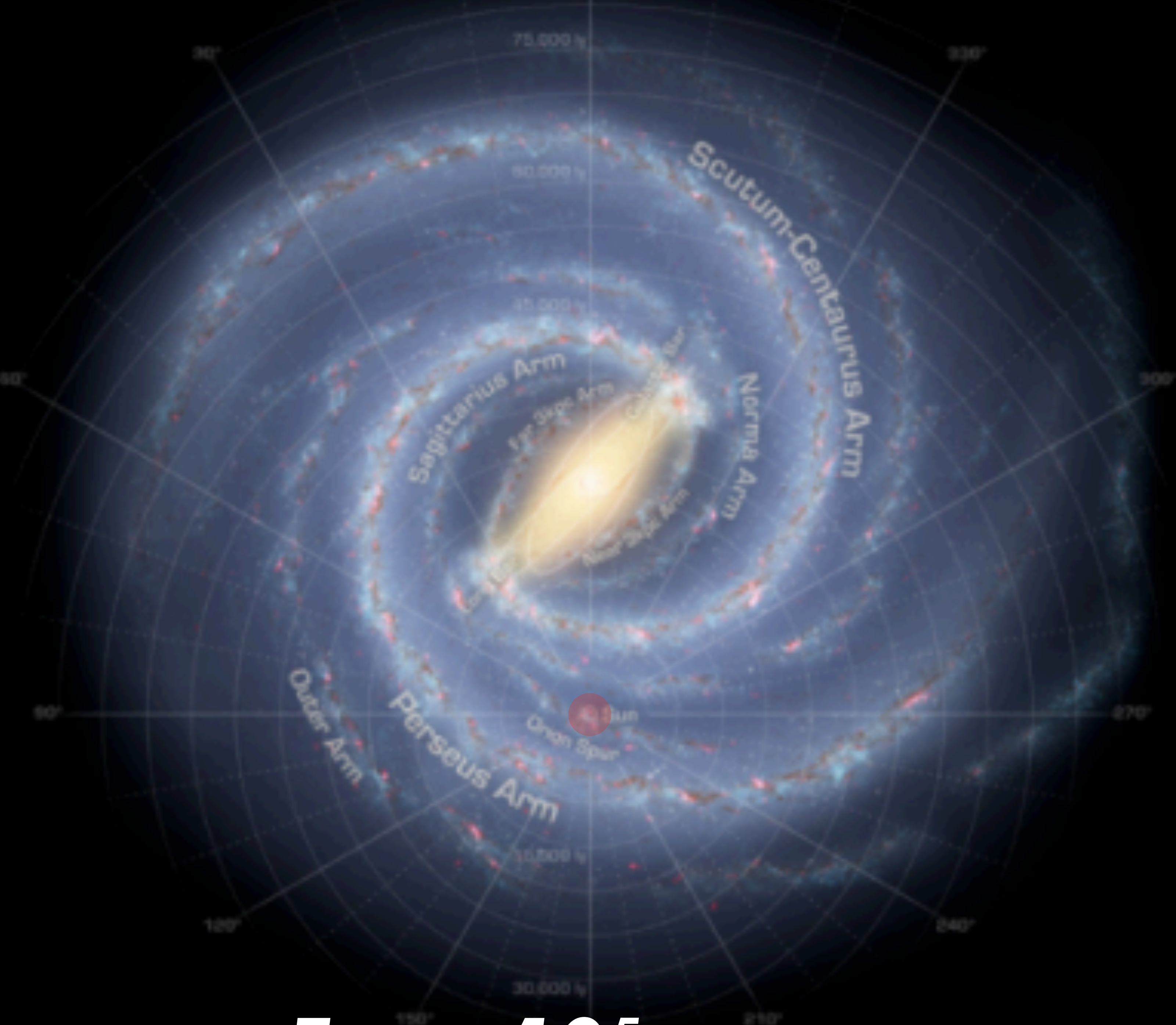
Inspired from the Y-S. Ting's presentation

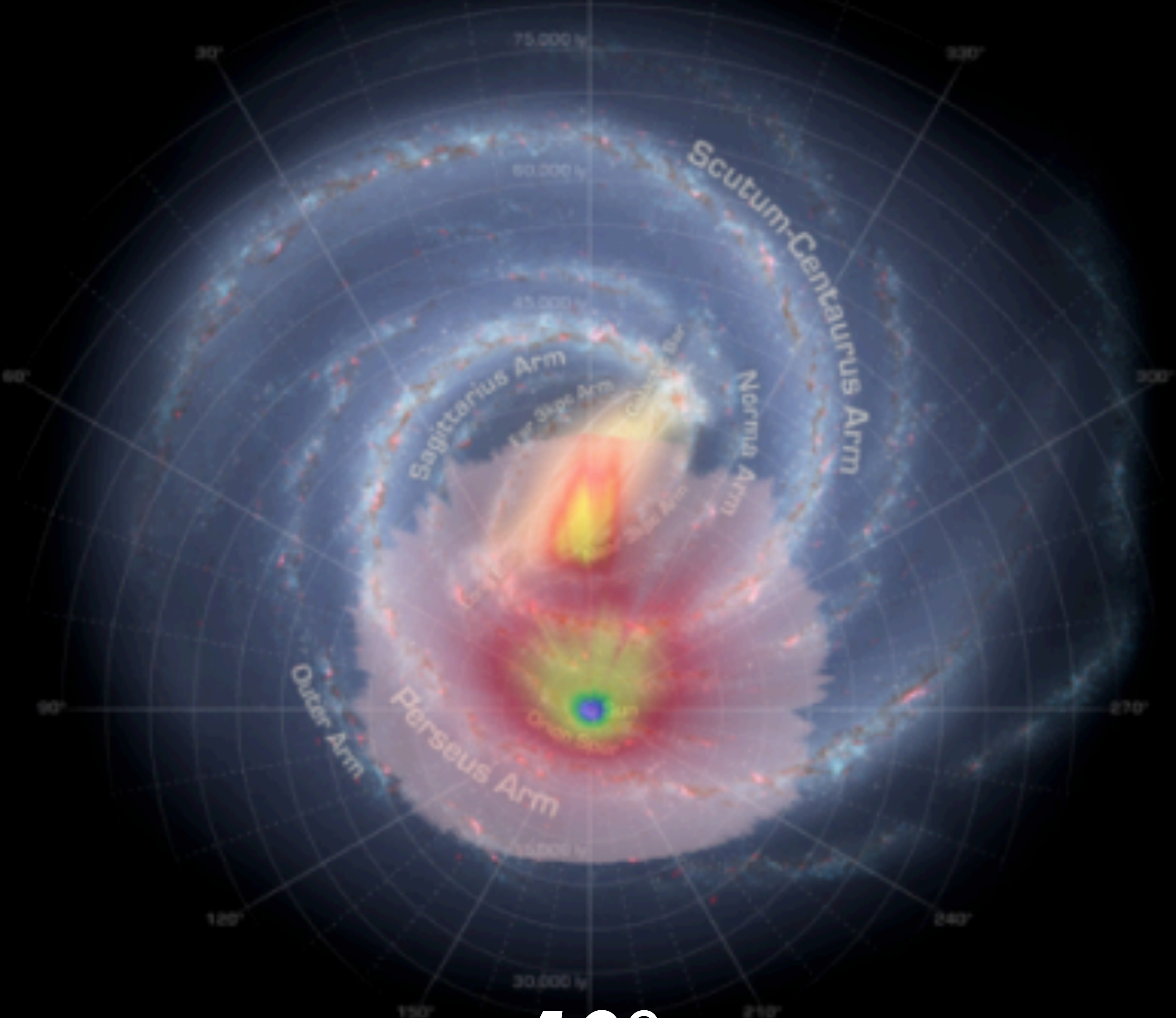
Galactic Archaeology: stellar populations in the MW

- *Observations from old low mass stars to the younger ones*
- *To reconstruct the whole Galactic evolution*
- *Combining Chemistry and Dynamics + Ages*

The Gaia revolution: opening a new era for Galactic archaeology

From Hipparcos ......*to Gaia*



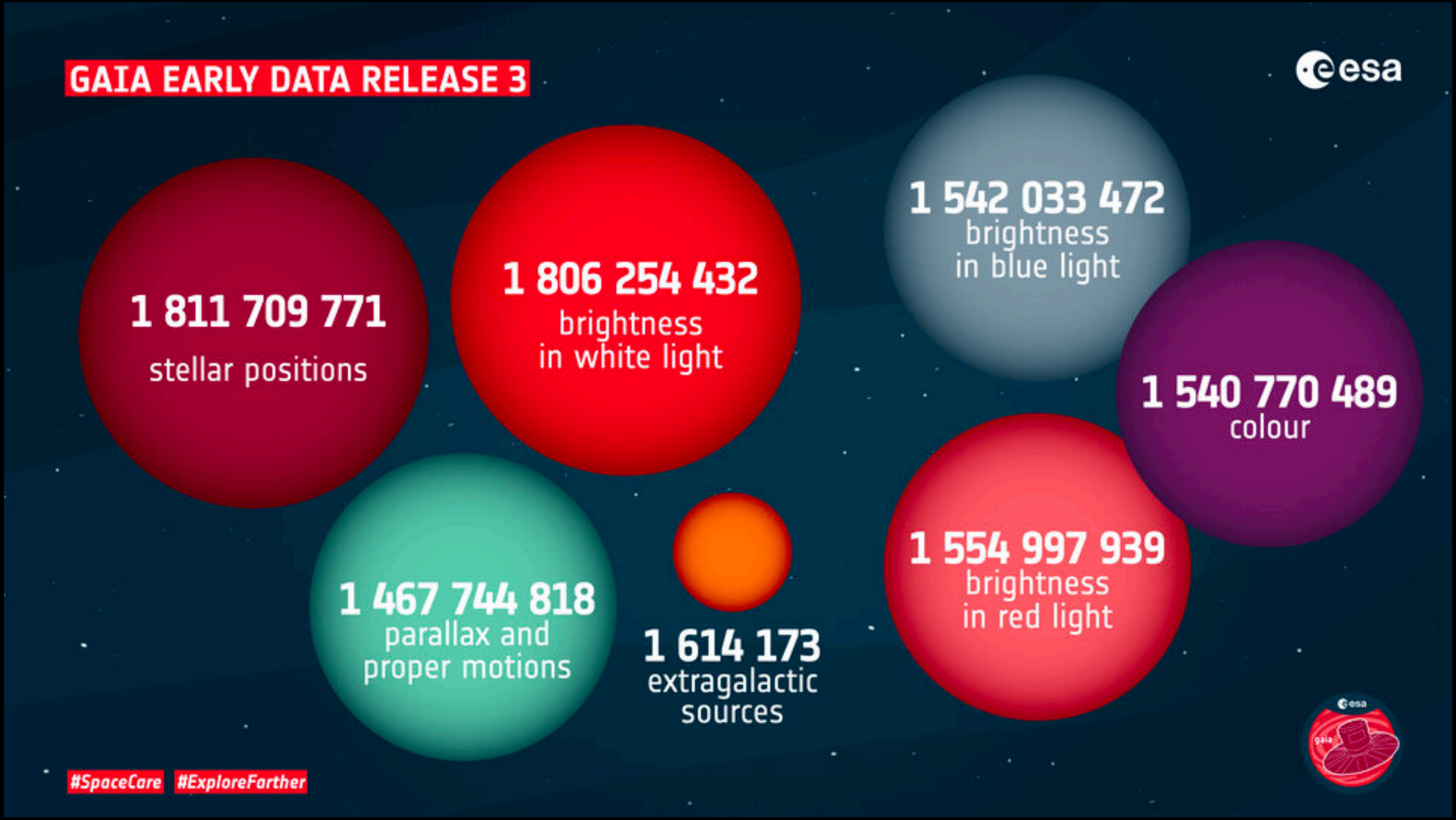


From 10^5 stars ...... *to 10^9 stars.*

Positions, parallaxes, proper motions, magnitudes for about 1.8 billion stars

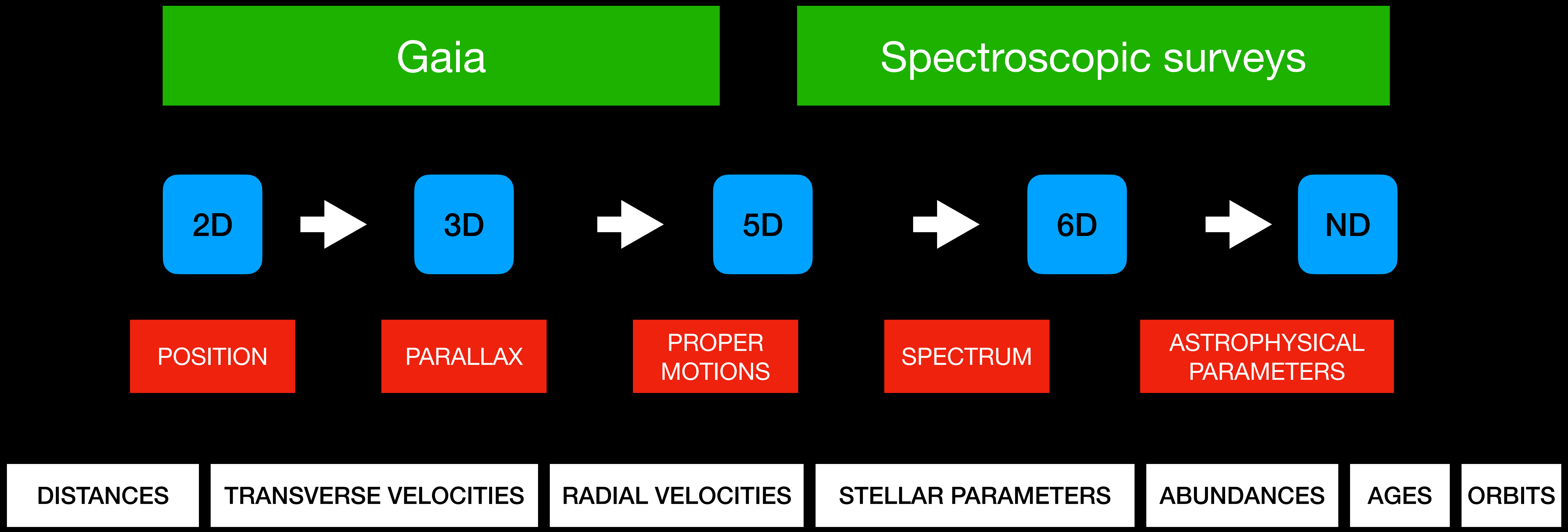
Credit Image: X. Luri & the DPAC-CU2

The Gaia revolution: opening a new era for Galactic archaeology



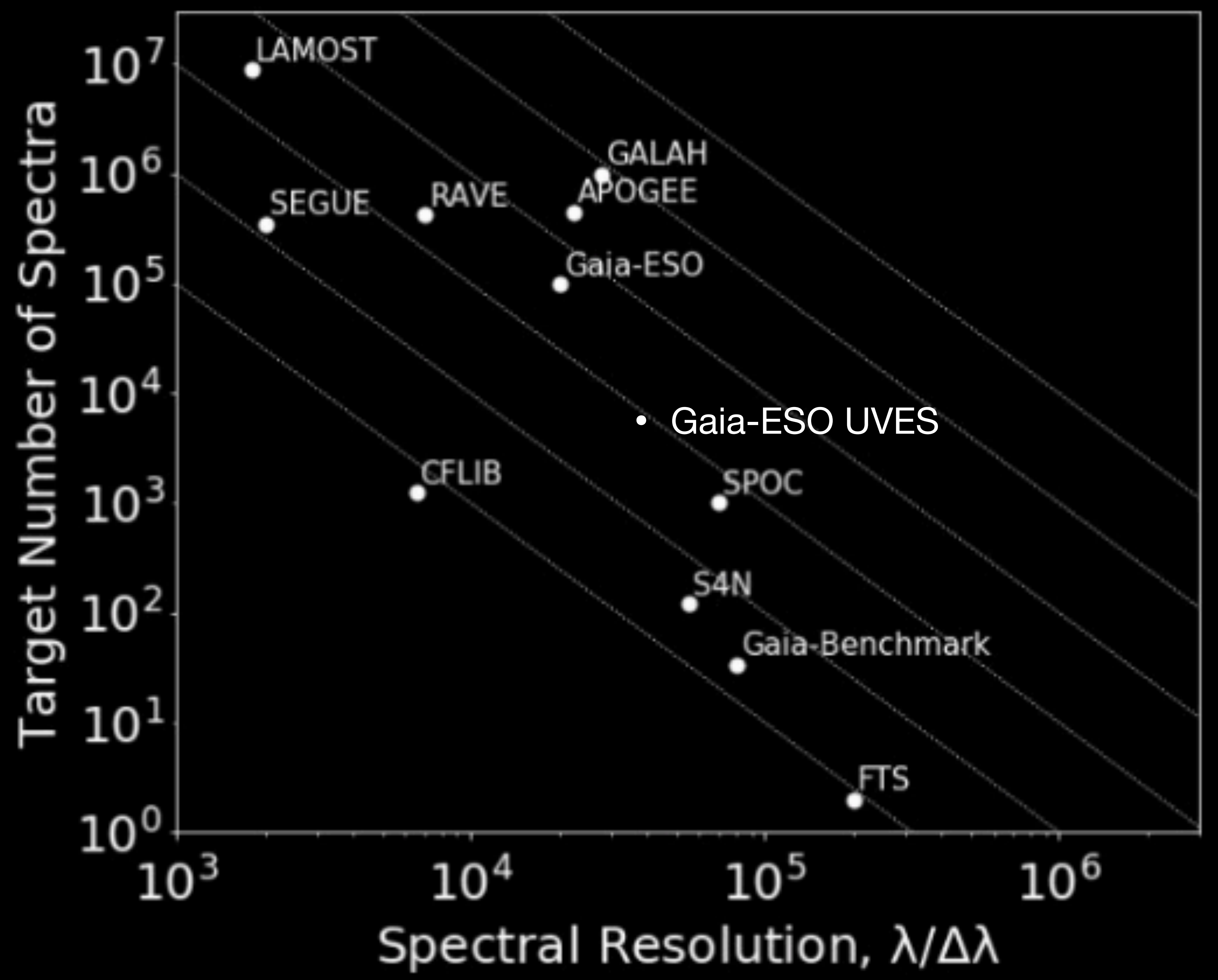
Complementing Gaia with spectroscopic surveys

Adding dimensions to Galactic Archeology



Adapted from Gilmore et al. (2012)

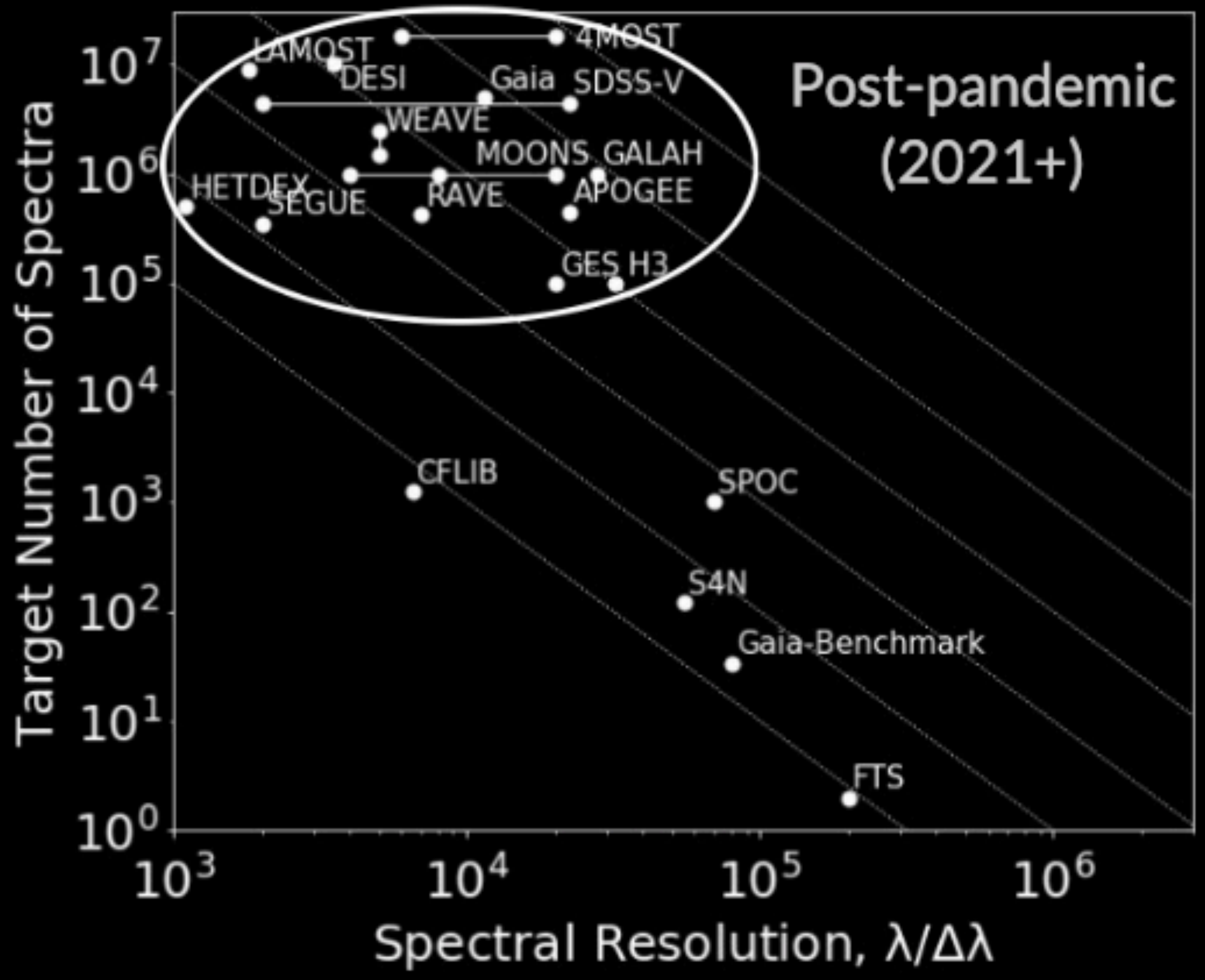
Complementing Gaia with spectroscopic surveys



Until now

Inspired from the Y-S. Ting's presentation

Complementing Gaia with spectroscopic survey

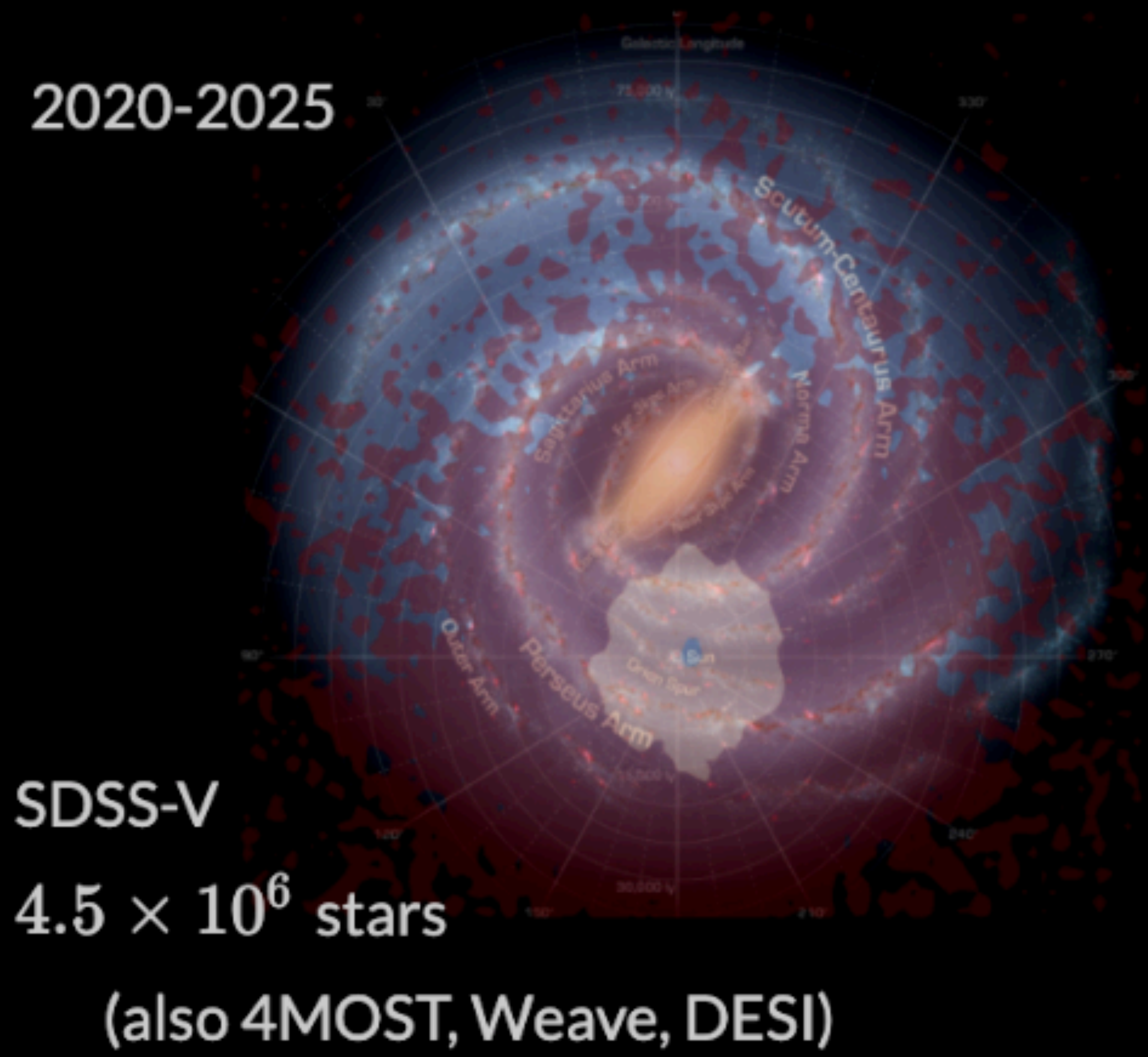


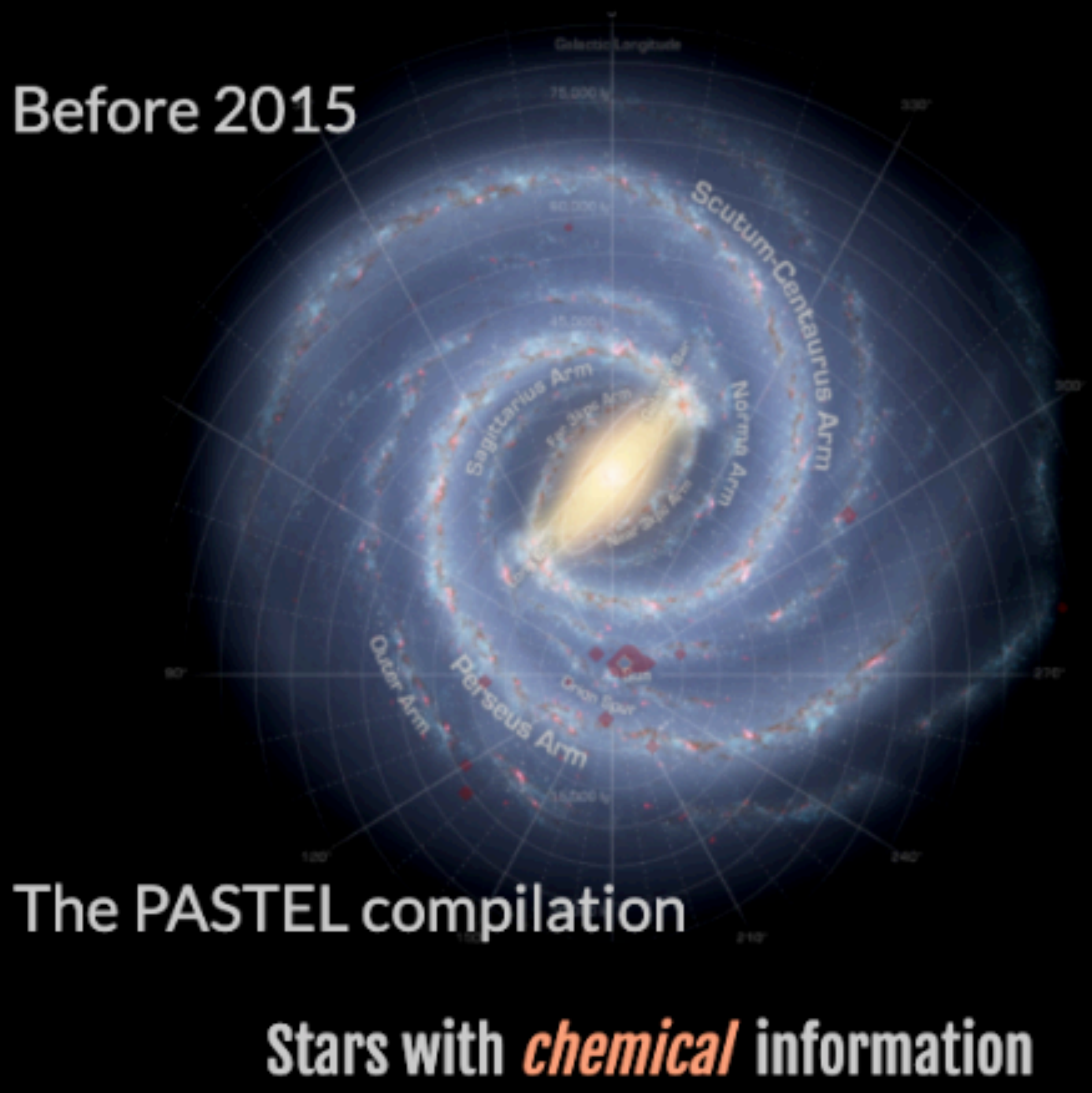
Next future

Larger samples, observed with medium resolution spectrographs R~20000

Inspired from the Y-S. Ting's presentation

Complementing Gaia with spectroscopic survey





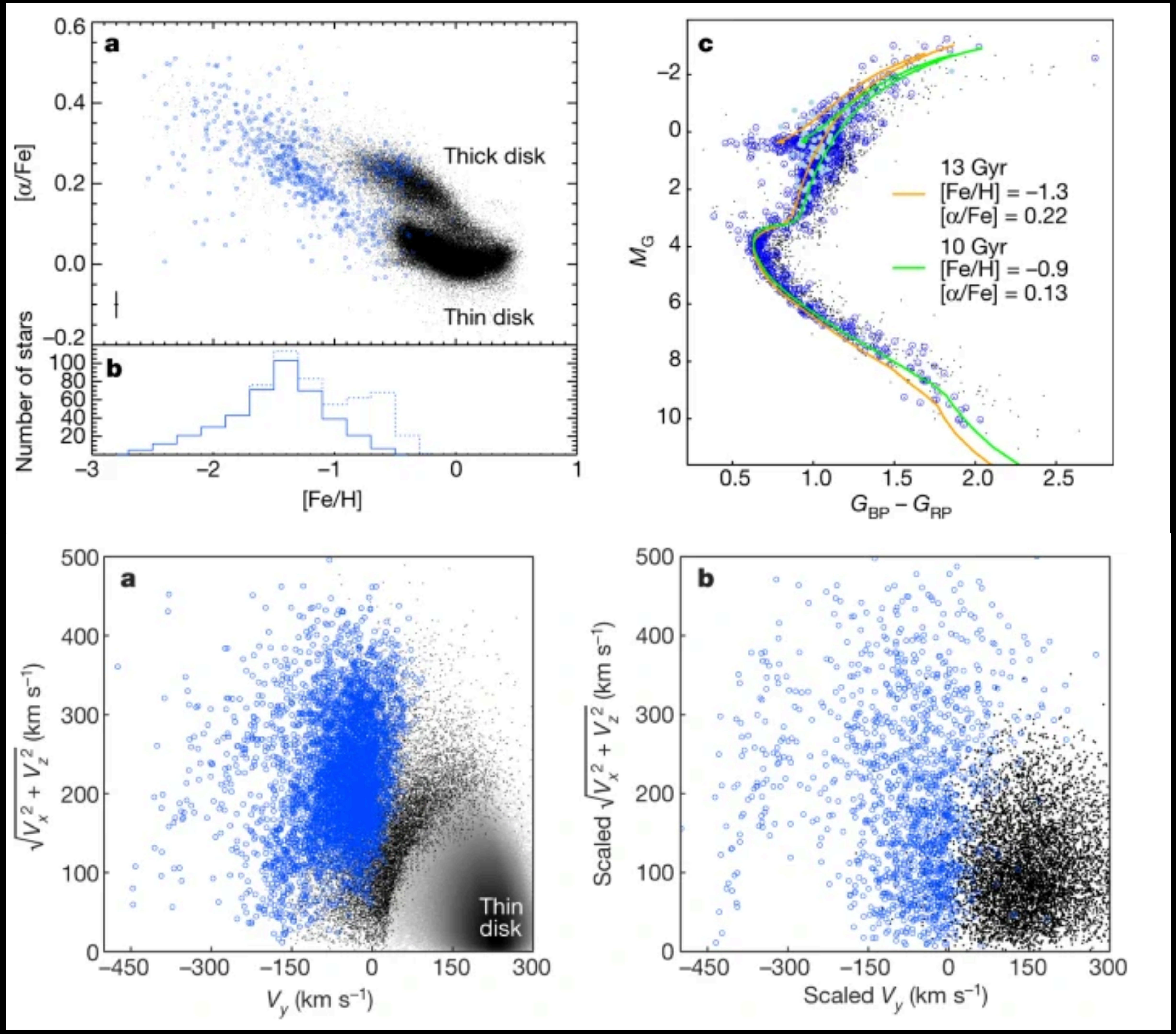
Larger samples, observed with medium resolution spectrographs R~20000

Inspired from the Y-S. Ting's presentation

Some key-results

The merger that led to the formation of the Milky Way's inner stellar halo and thick disk

Helmi et al. (2018)

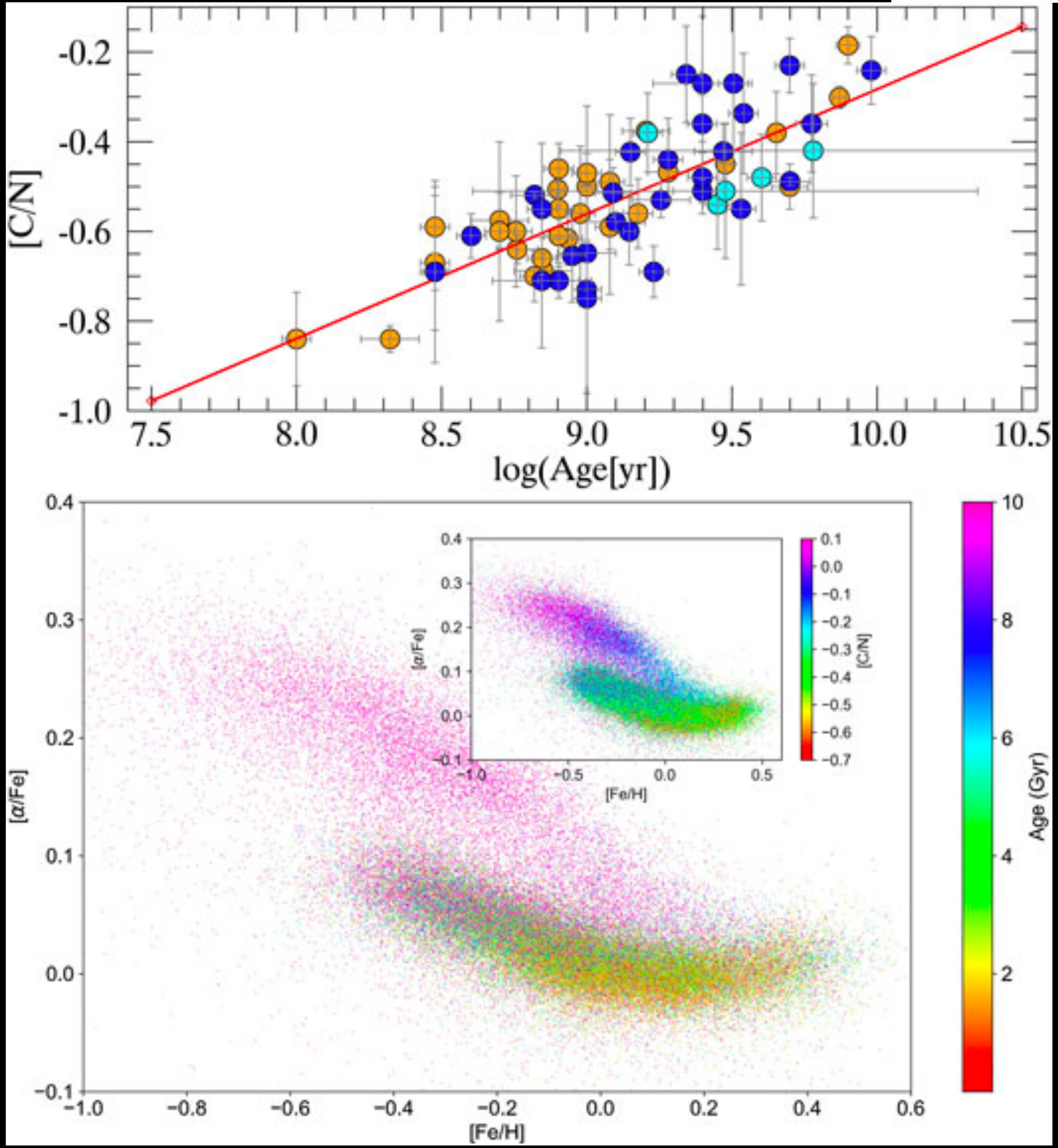


- *Gaia and APOGEE*
- *Discovery of a retrograde kinematic structure in the halo near the Sun, which may trace an important accretion event experienced by the Galaxy*
- *Gaia–Enceladus must have led to the dynamical heating of the precursor of the Galactic thick disk, thus contributing to the formation of this component approximately ten billion years ago*

Some key-results

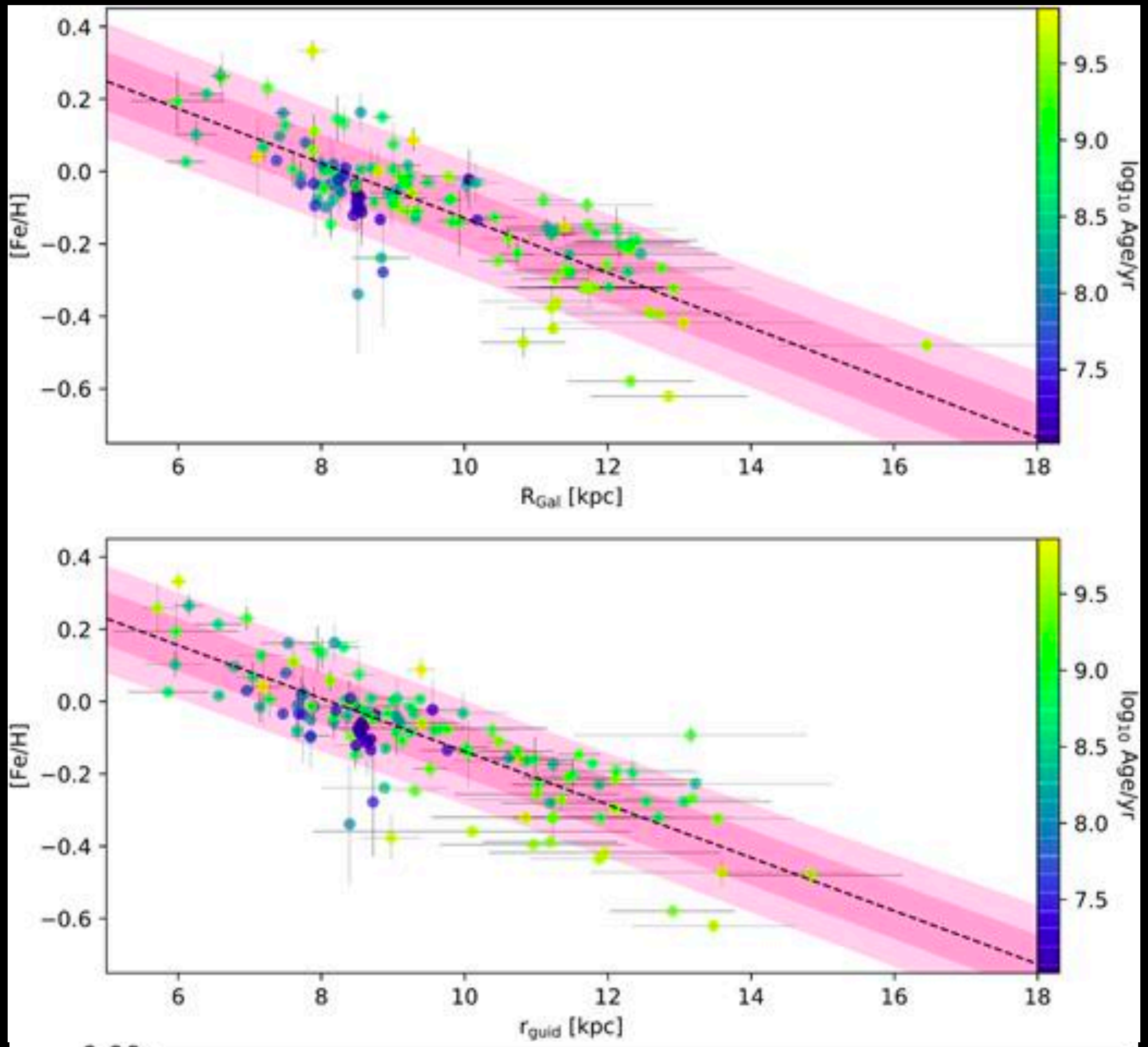
The Gaia-ESO survey: Calibrating a relationship between age and the [C/N] abundance ratio with open clusters

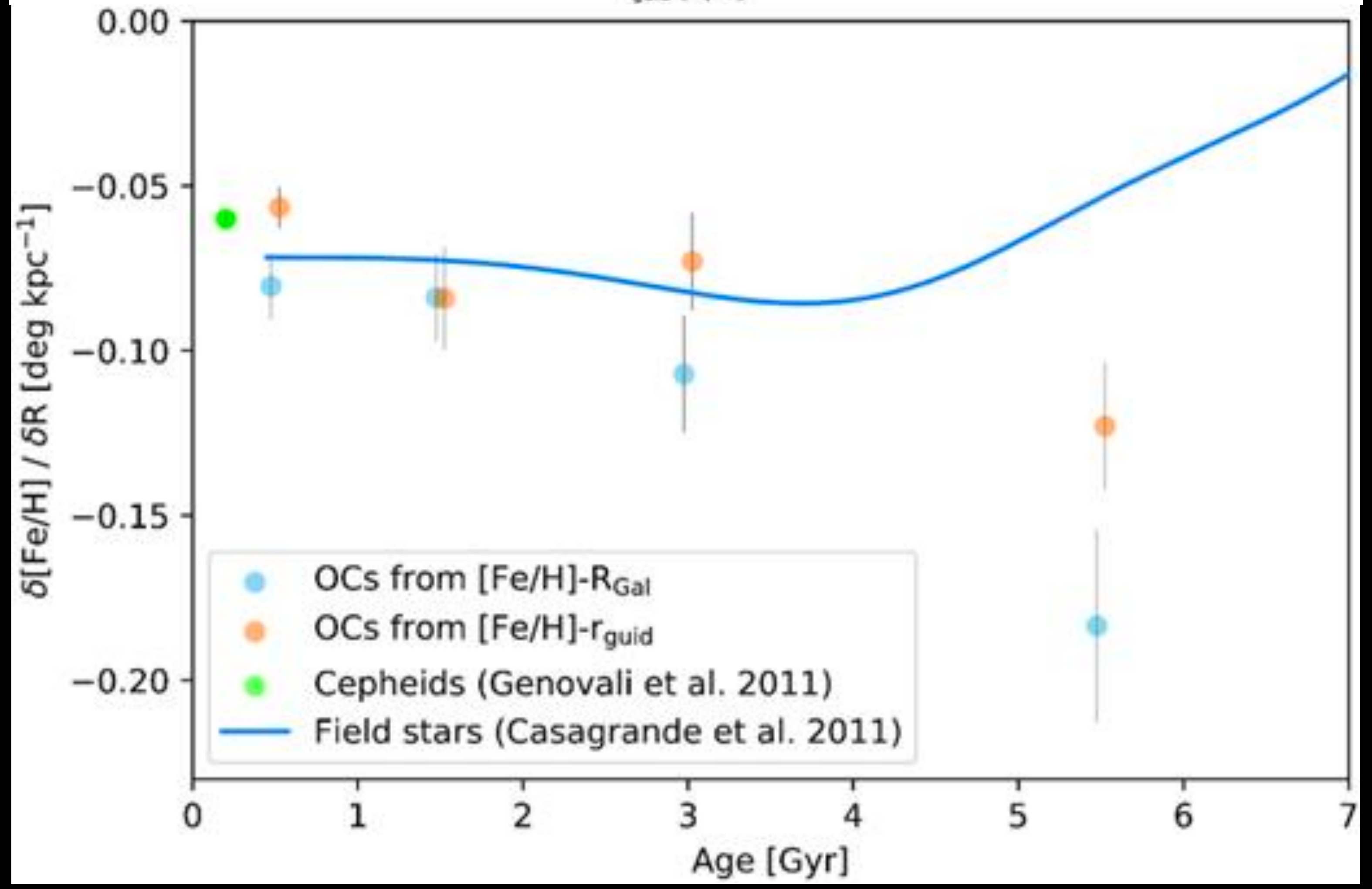
Casali et al. (2019)



- *Gaia-ESO and APOGEE*
- *[C/N] used as an excellent indicators of stellar ages*
- *Star clusters to calibrate the relation, used to measure the ages of selected giant field stars in the Gaia-ESO and APOGEE surveys*
- *Age separation between thin- and thick-disc stars and age trends within their populations, with an increasing age towards lower metallicity populations.*

Some key-results





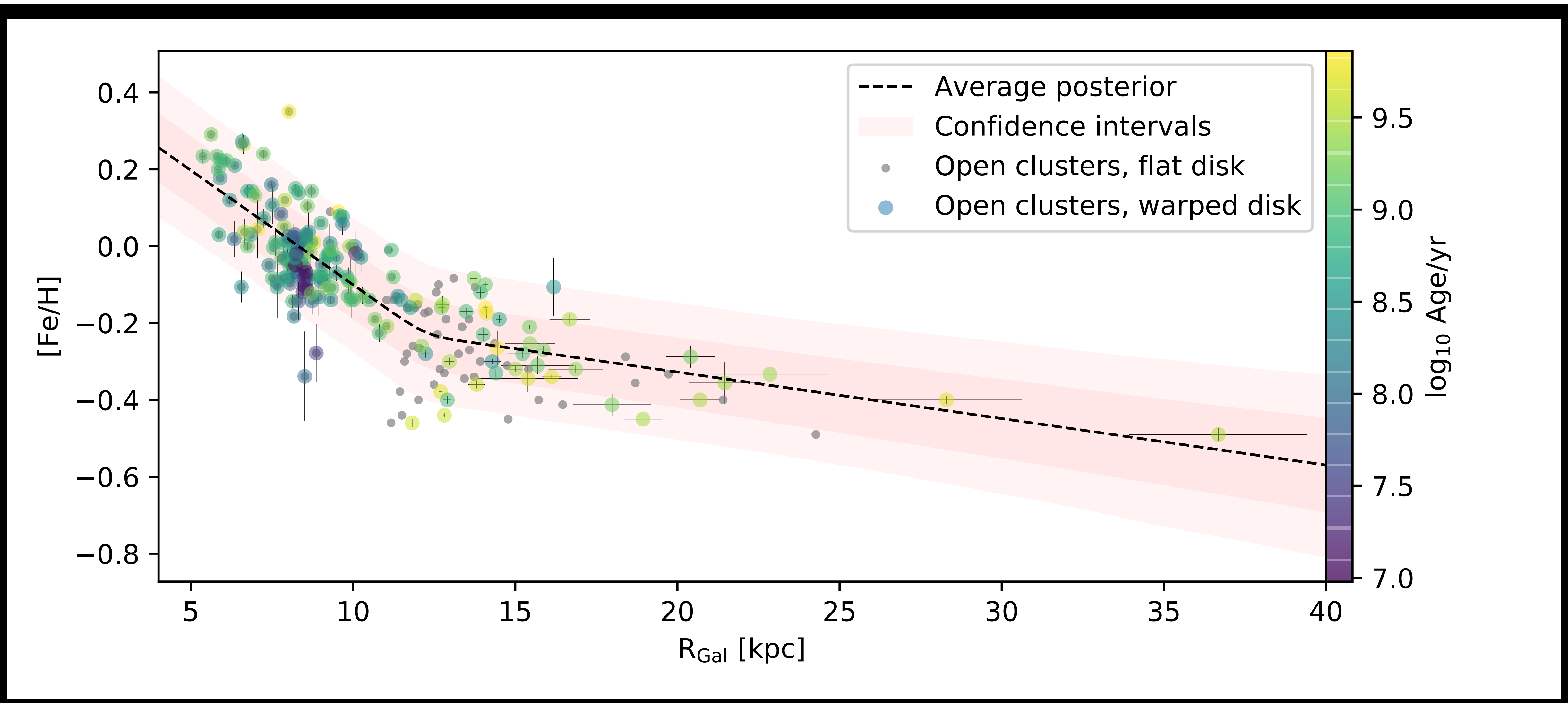
The GALAH survey: tracing the Galactic disc with open clusters

Spina et al. (2021)

- *Gaia, GALAH and APOGEE*
- *Tracing the radial gradient, both with the present time Galactocentric radii and with Guiding radii*
- *Time-evolution of the gradient*

Mapping the Galactic metallicity gradient with open clusters: results from large spectroscopic surveys
Spina, LM al. (in prep.)

Adding Gaia-ESO



Two ways to go forward

Going beyond

MAVIS

https://mavis-ao.org/mavis/

Going deeper

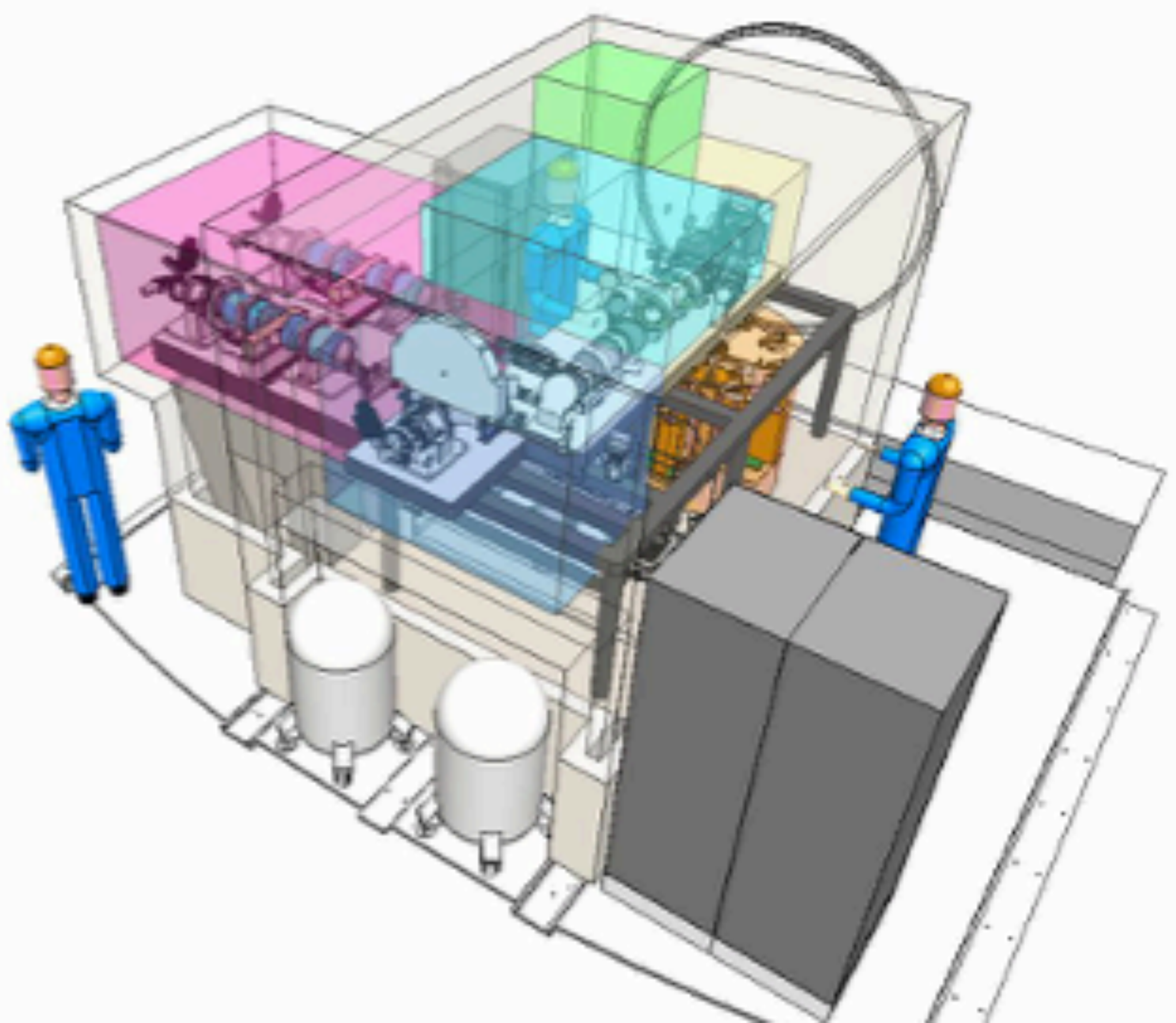
HRMOS

https://indico.ict.inaf.it/event/1547/page/621-online-material

Strong collaboration between Italian and Australian Institutes

MAVIS in one slide

- **Multi-conjugate Adaptive Optics** system for correction in the **visible**
  - complete with an **4kX4k imager** @ 7.3mas pixels
  - and an **IFU w/ 4 spectral resolution modes** (4-12k), ¼ number of MUSE spaxels
- Expecting > **10% Strehl** (goal 15%) **at V band** over **30”x30”**
- Consortium **Australia** (**AAO Consortium**, lead) / **INAF / LAM / ESO**
- Passed phase A 06/2020, **first light expected Sem 2 2027**
- For the ESO VLT AOF (UT4)
  - 4x2 Laser Guide Stars;
  - 3 Near-IR NGS Wavefront Sensors (using SAPHIRA);
  - 3 Deformable mirrors (DSM + 2 post focal DMs);
- A **brilliant science case** for a **facility instrument** (publicly available on arXiv), with themes:
  - Emergence of Hubble sequence
  - Resolving galaxy contents
  - Star clusters as tracers of galaxy evolution
  - Birth, life, death of stars and planets



Courtesy F. Rigaut

HRMOS in one slide

The High Resolution Multi-Object Spectrograph (HRMOS) is a proposed facility instrument for the ESO's VLT, following the initial presentation at the VLT 2030 workshop.

HRMOS provides a combination of capabilities essential to carry out breakthrough science across a broad range of active research areas from Galactic and Local Group Archaeology to Stellar Astrophysics and Exoplanet studies.

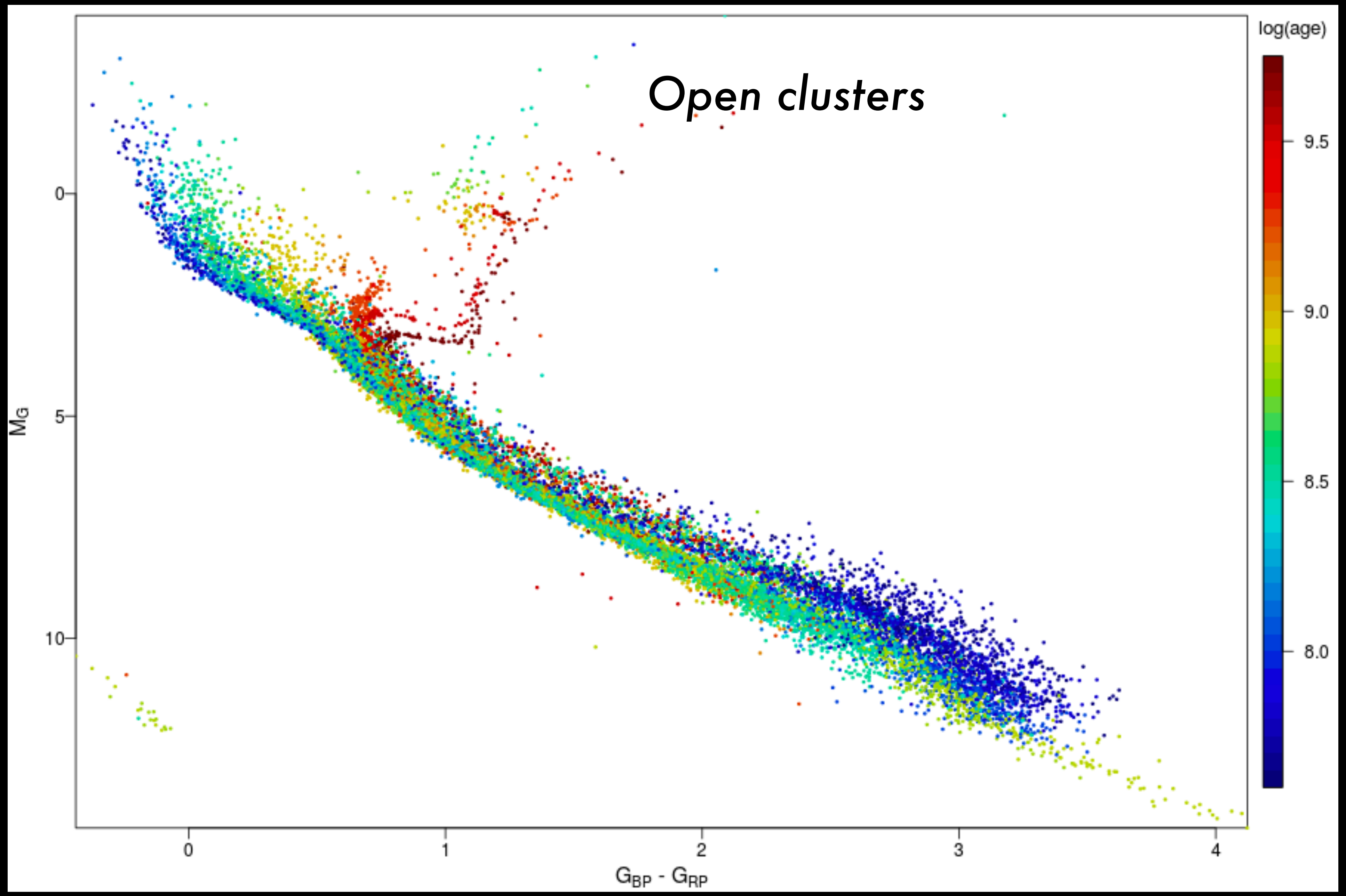
HRMOS fills a gap in capabilities amongst the landscape of future instrumentation planned for the next decade.

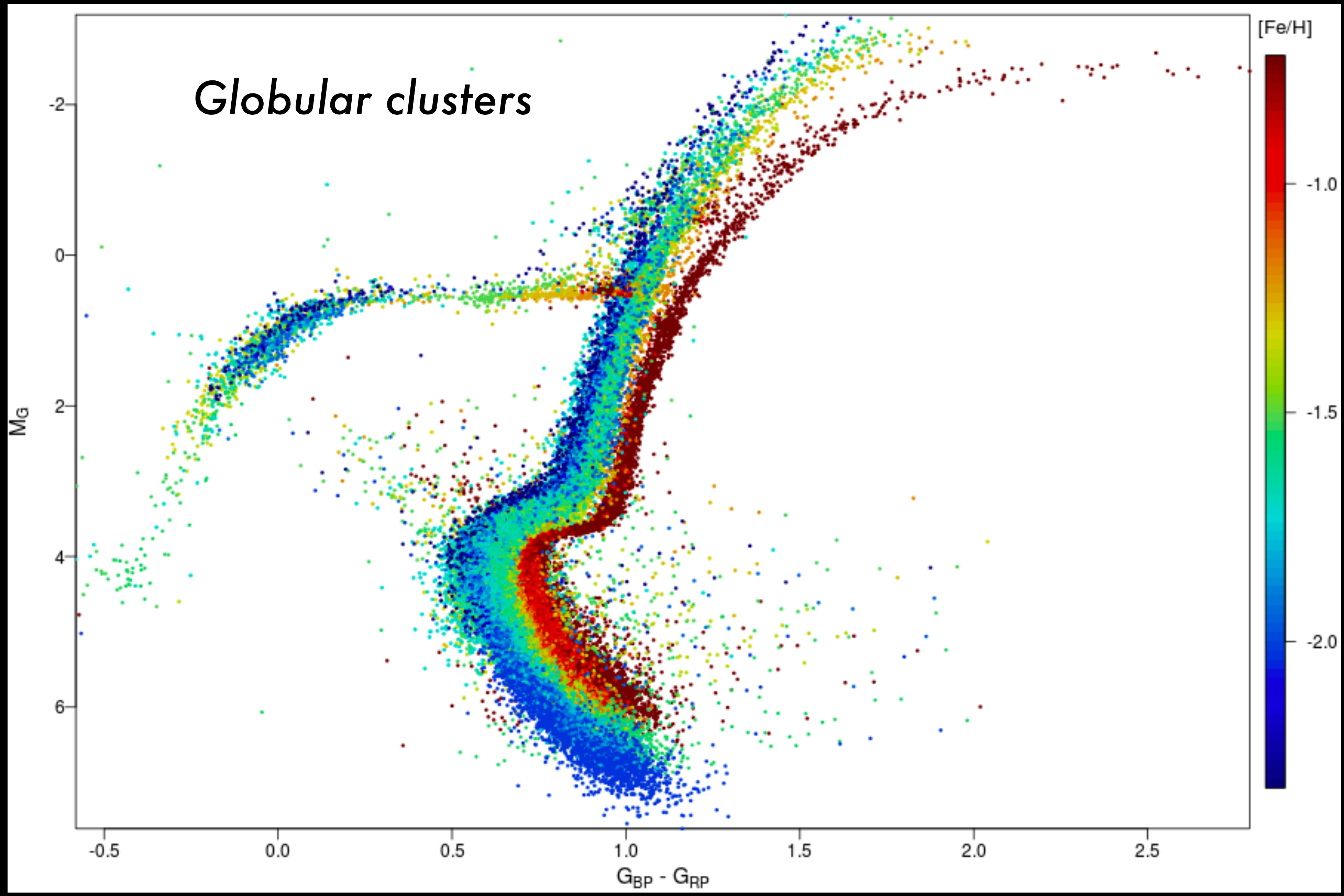
The key capability of HRMOS is high spectral resolution (R = 60,000 - 80,000) with multi-object (50-100) capabilities and stability that provides radial velocity precision (~10m/s).

Initial designs predict a SNR=30 is achievable within 1hr for mag(AB) = 17-18 depending on resolution.

The combination of high resolution and multiplex going to relatively bluer wavelengths (from 380nm), is truly a spectrograph that will push the boundaries of our knowledge and is envisioned as a workhorse instrument in the future.

Key-Science cases: a look at nearby and distant star clusters





Credit: ESA/Gaia/DPAC/Babusiaux, C., van Leeuwen, F., Barstow, M.A.et al.

- *Simple stellar populations, with well-determined age, distance, reddening*
- *Tracers of different epochs and Galactic populations*
- *Chemically homogenous (open clusters) or with multiple populations (globular clusters)*

Going beyond with MAVIS

- *Star clusters in nearby galaxies*
  - *Diversity in cluster populations in Local Group galaxies*
  - *No clear dichotomy between old (globular) and young (open) clusters in other galaxies*
  - *Massive and young clusters in interacting galaxies (as the Magellanic Clouds)*

From the Local Volume.....to our Galaxy

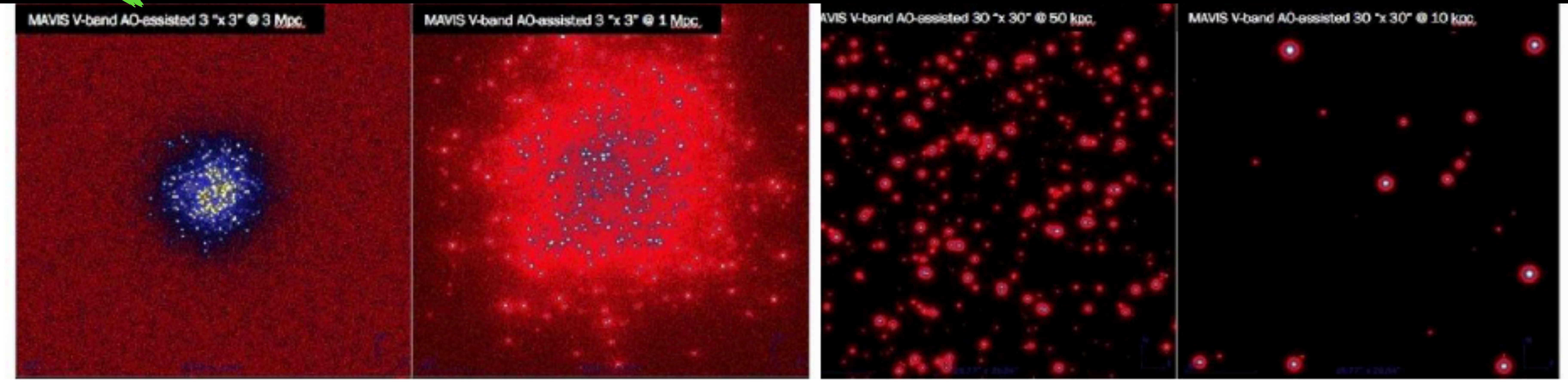


Figure 4.10: *Simulated V-band images of an old star cluster (1,000 $M_{\odot}$, half-light radius of 5 pc, texp=1 hr) at the distance of 3 Mpc, 1 Mpc, 50 kpc, 10 kpc.*

Going beyond with MAVIS

- *Star clusters in the Magellanic Clouds*

- *IMF at low metallicity: going down to 0.1 M ⊙ to detect metallicity effects*
- *Star formation history of SMC and LMC*
- *Chemical composition and characterisation of the high- and low-mass member stars*
- *Multiple populations in young massive clusters*

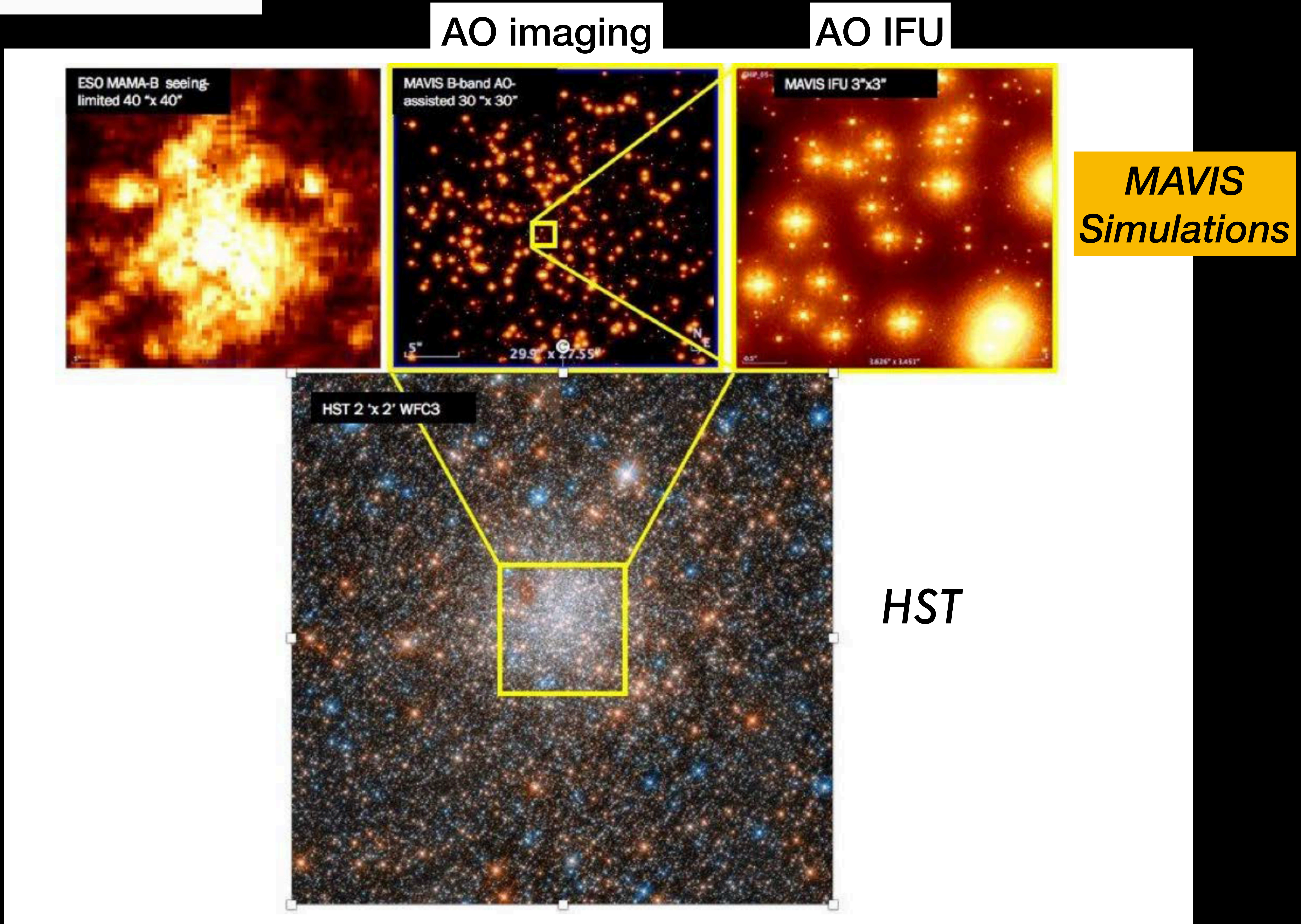


***Figure 4.12**: ESO archive image (from Aladin, MAMA-B), simulated B band MAVIS image, with t=3600 s in a FoV 30"x30", zoom on the central 3"x3" field for NGC1898, in the Large Magellanic Cloud. Bottom image from WFC3 HST, FoV 2'x2'.*

Going beyond with MAVIS

AO imaging

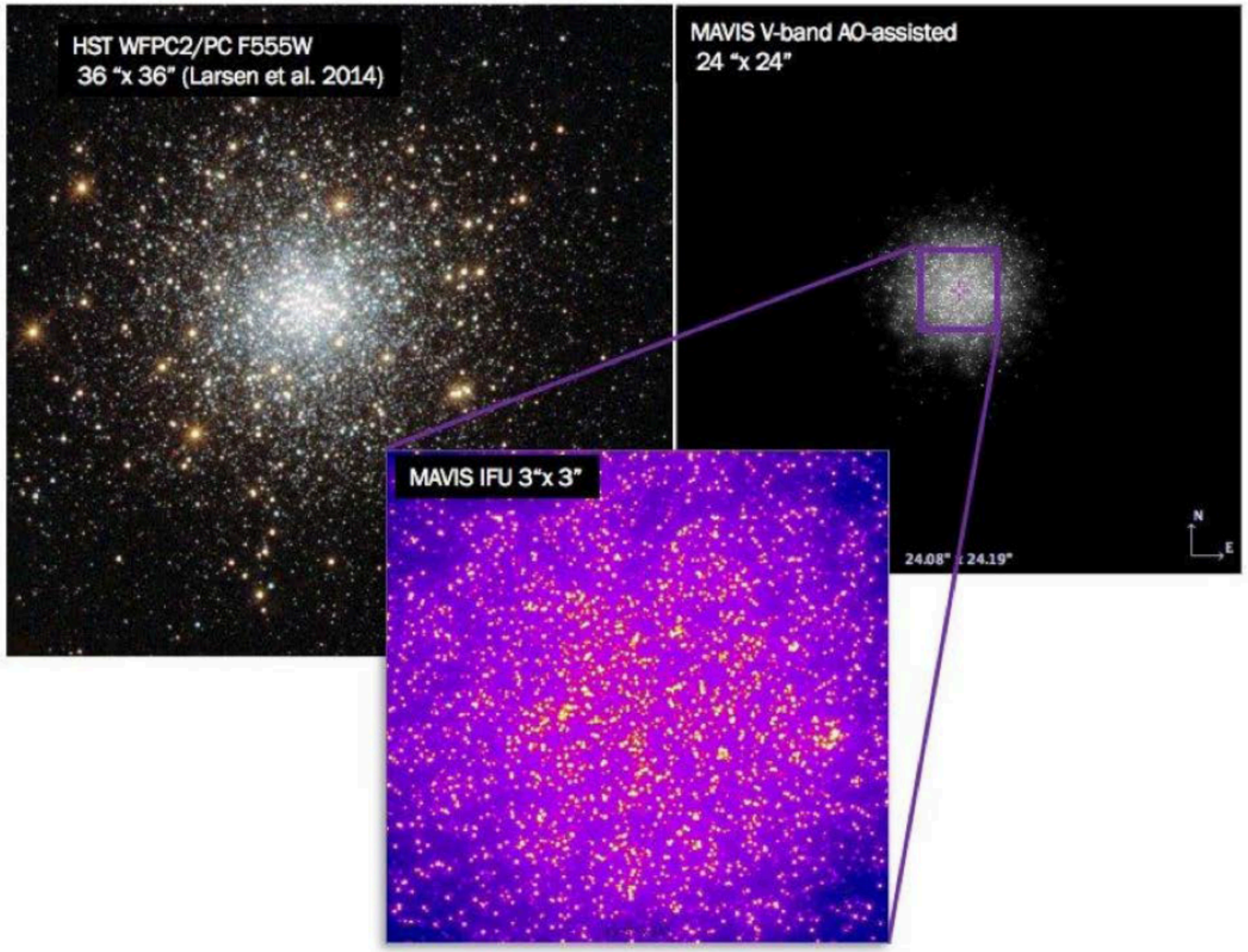


Figure 4.11: *HST observations of a globular cluster in the Fornax dwarf spheroidal galaxy, compared with simulated observations of MAVIS V-band, with a zoom on the central regions (FoV 3"x3", corresponding to the MAVIS spectroscopic mode).*

MAVIS Simulations

- *Star clusters in nearby dwarf galaxies*
  - *Full chemical characterisation*
  - *Comparison between field and cluster populations*
  - *Stacking of spectra with similar parameters*

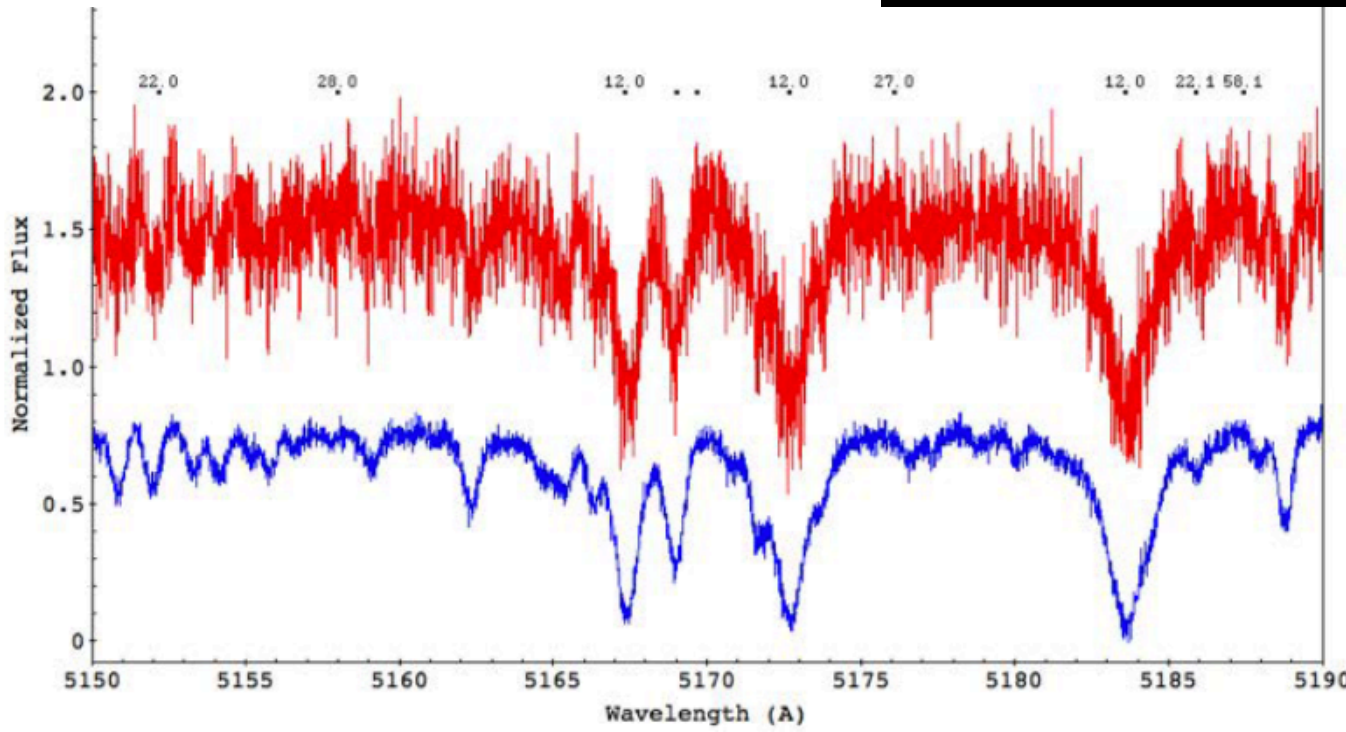
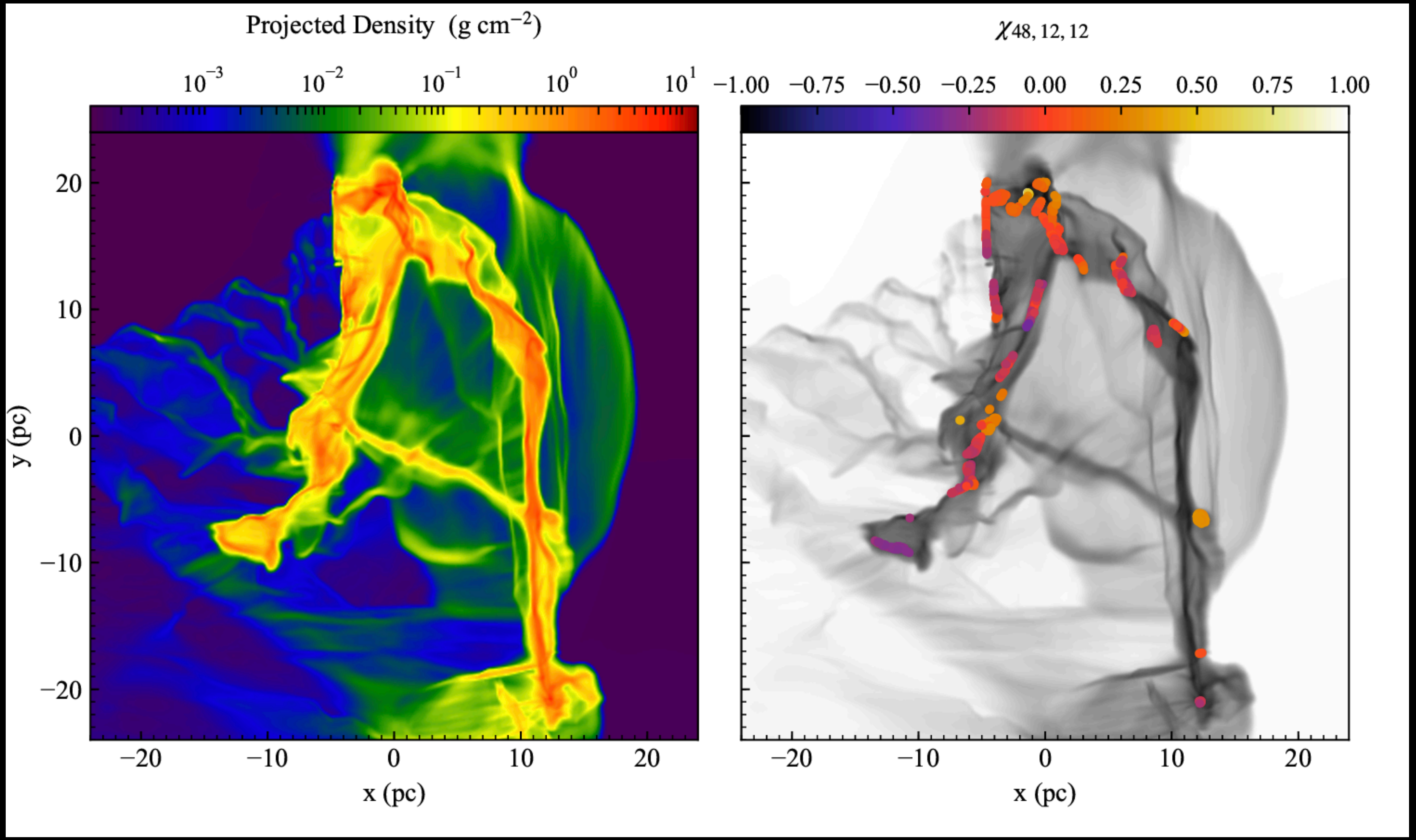


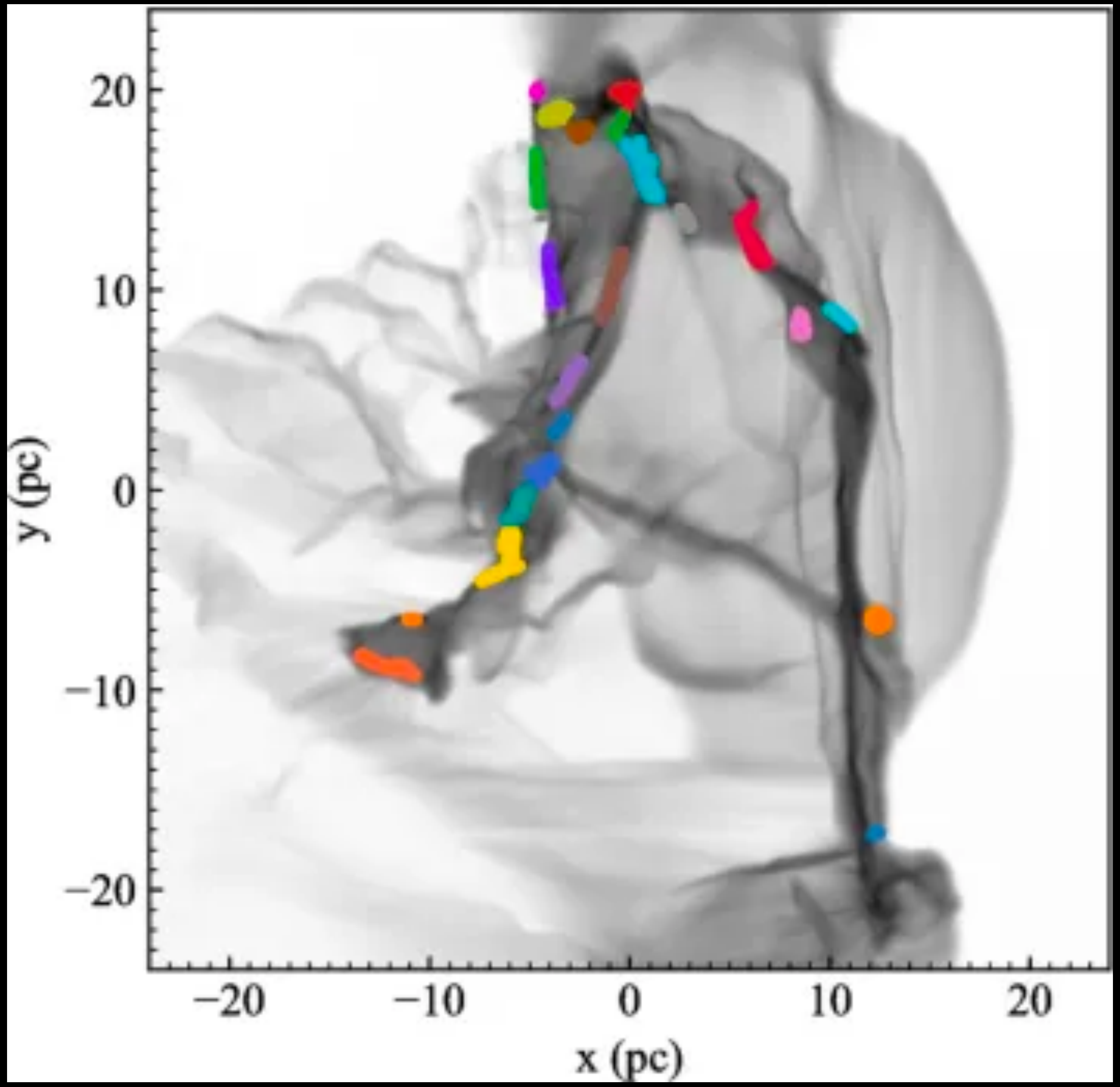
Figure 4.15*: Simulated spectra at R=15000 of a G-type star at SNR~10 (red spectrum) and SNR~35 (blue spectrum). Some absorption lines are marked and labelled with the atomic number of the corresponding element.*

Going deeper with HRMOS

- *Galactic star clusters*
  - *Investigating the level of homogeneity of open clusters*
  - *Putting constraints to the chemical tagging*



Formation of star clusters within a giant molecular cloud



Armillotta et al. 2018

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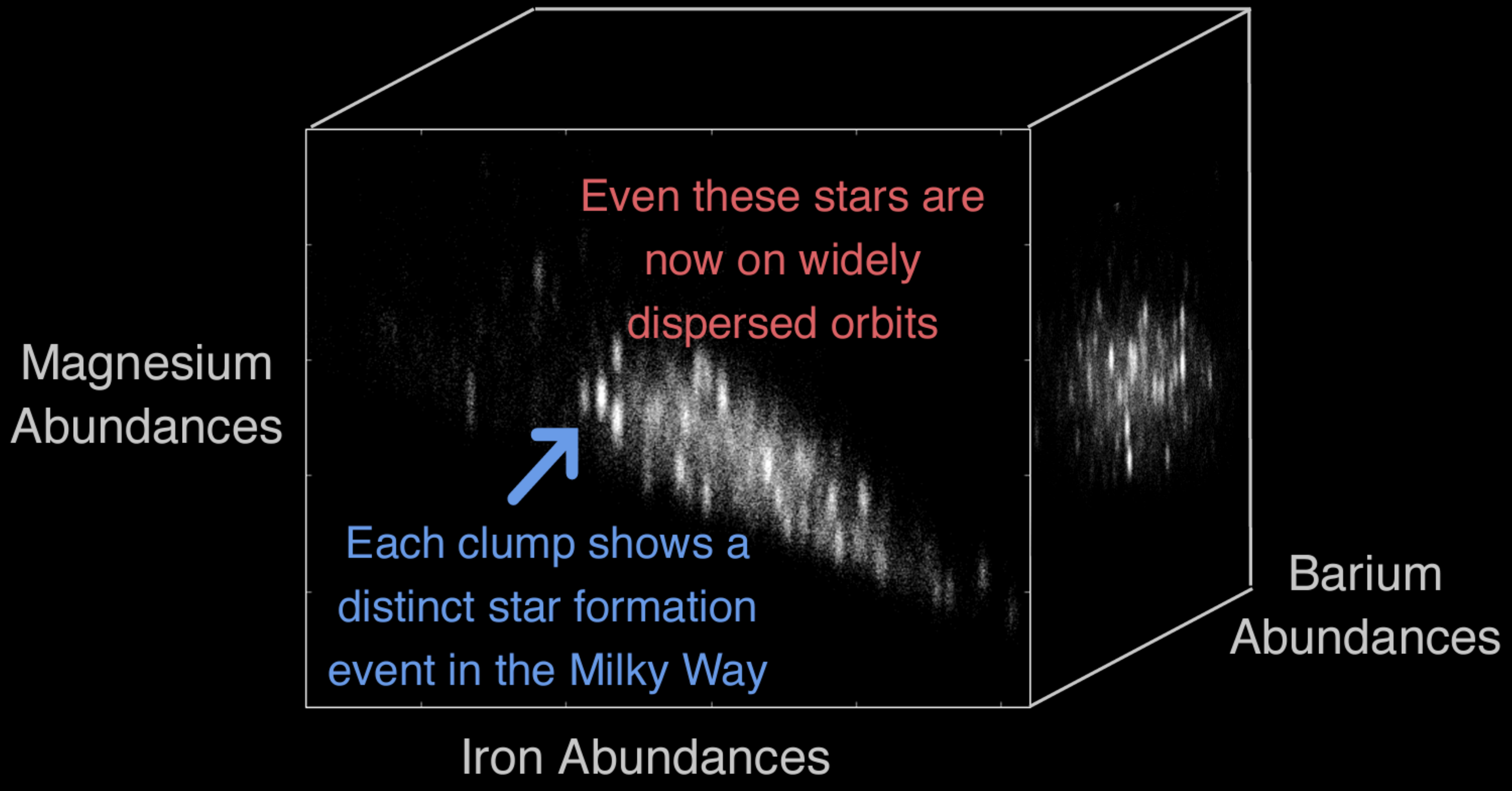

Credit: Y-S Ting

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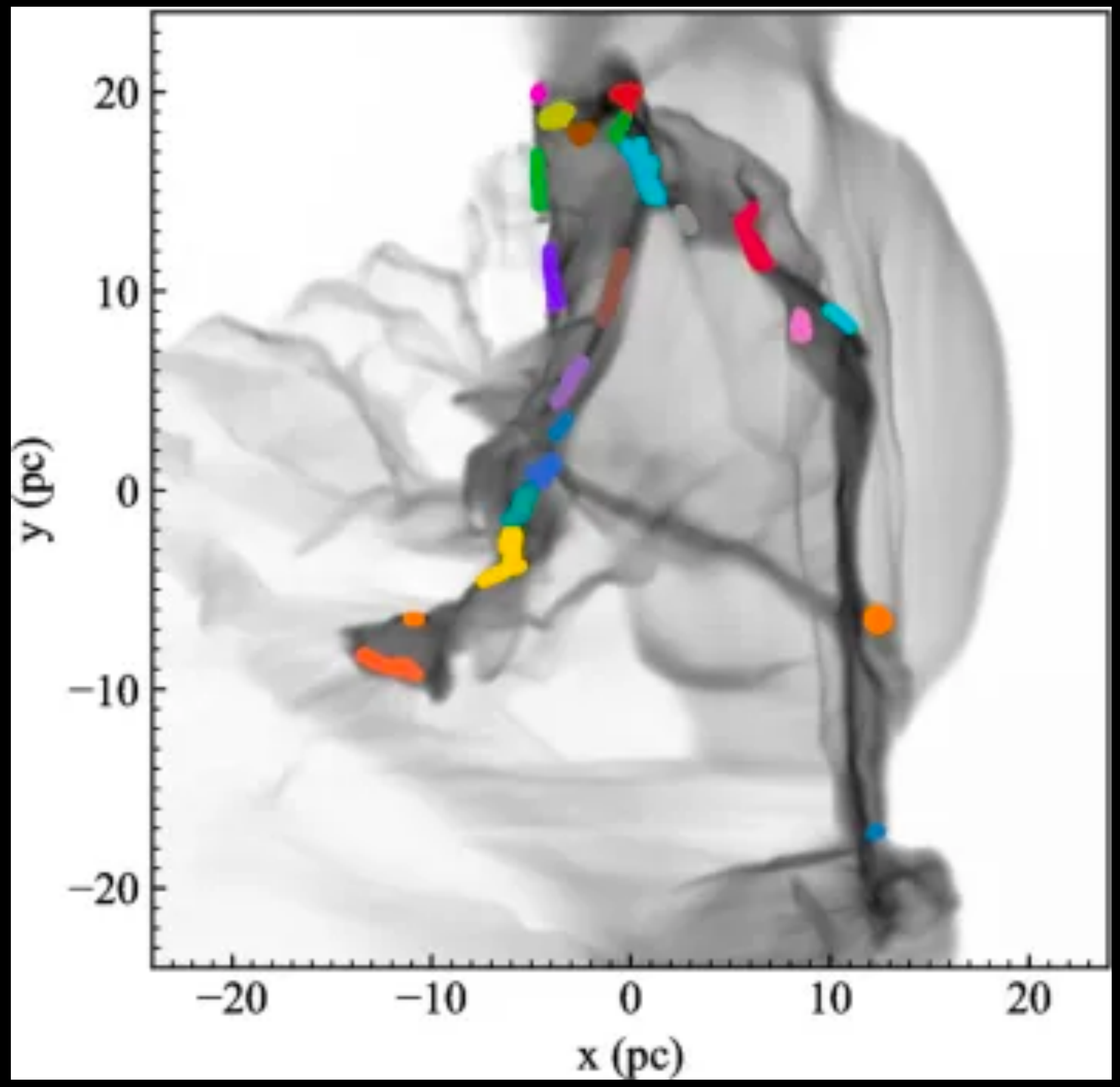
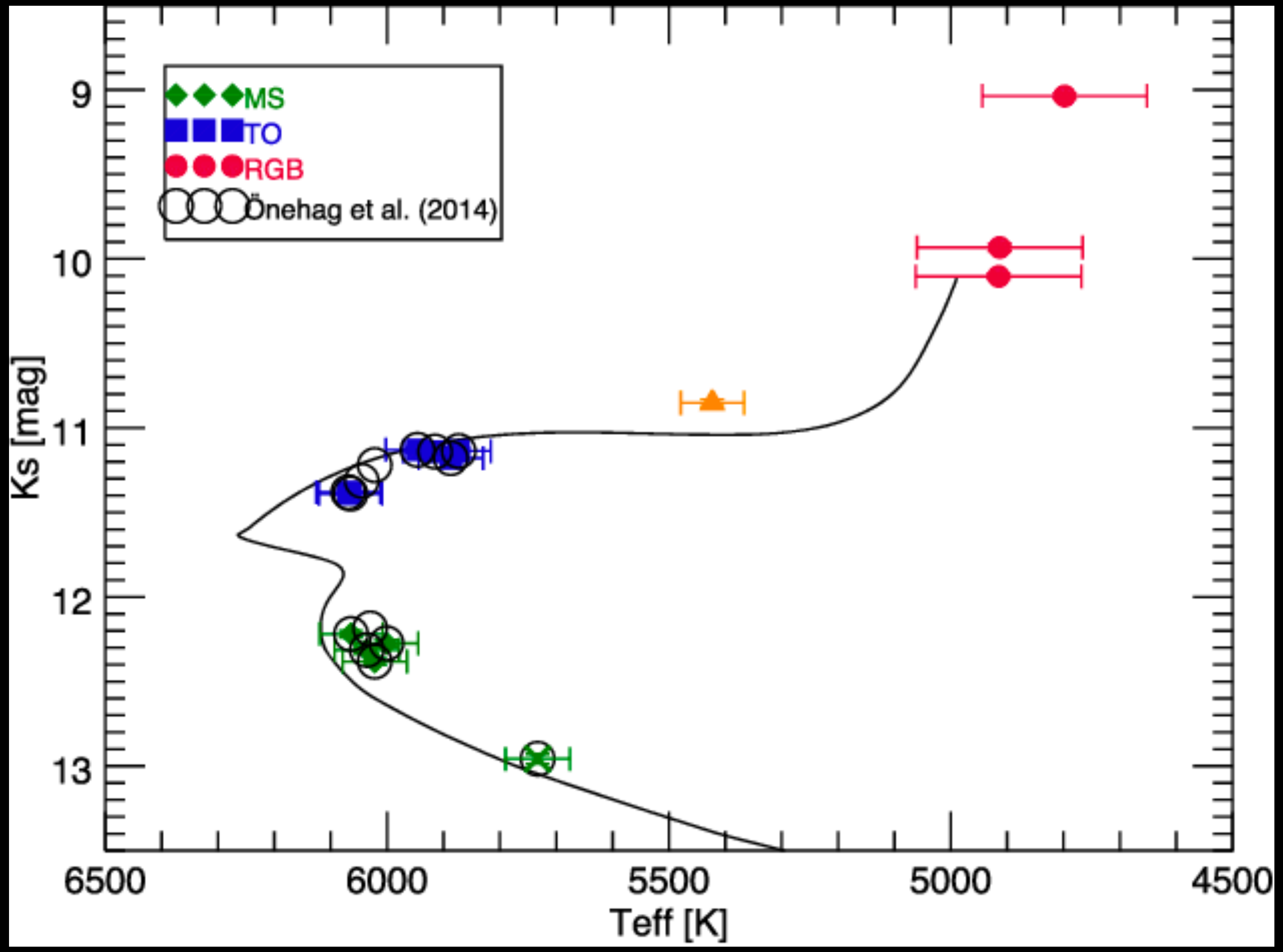


Armillotta et al. 2018

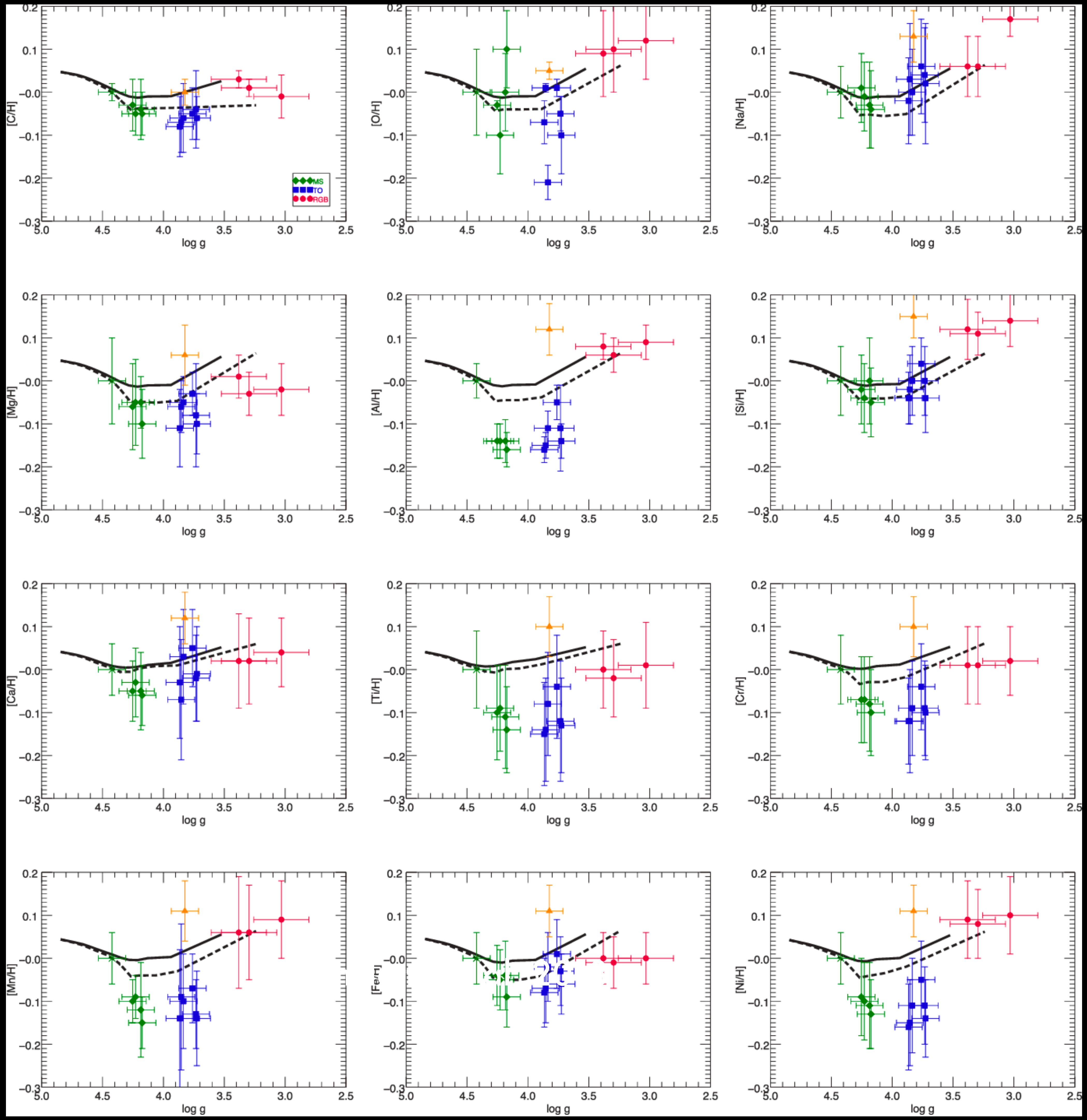
Going deeper with HRMOS

- *Galactic star clusters*
  - *Studying the effect of stellar evolution: diffusion, mixing and deep mixing*
  - *Isotopic abundances: constraints for nucleosynthesis and for stellar evolution*



Bertelli-Motta et al. 2018

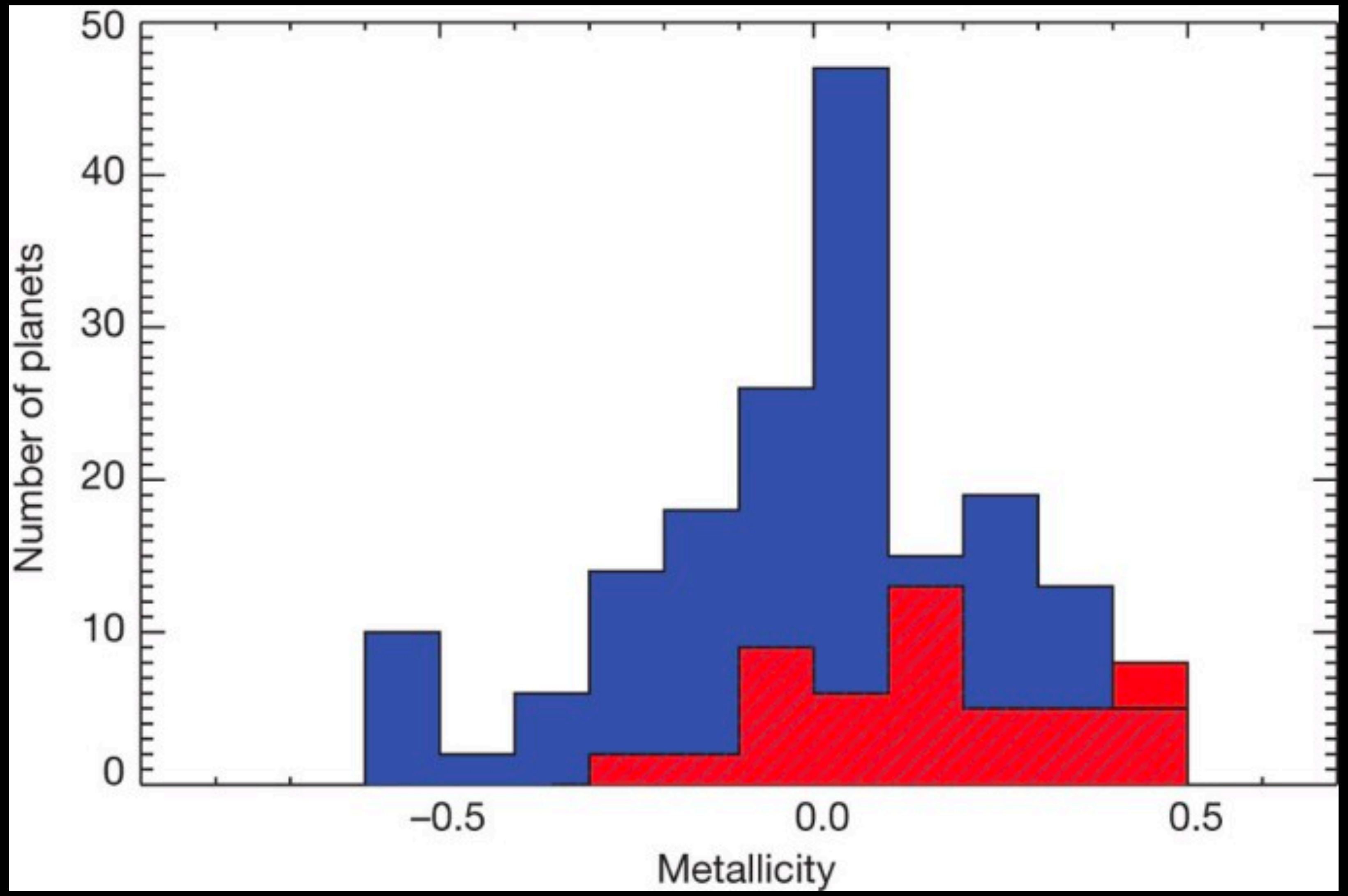
Effect of diffusion in the open clusters M67



Going deeper with HRMOS

- *Planet populations in open clusters*
  - *Correlations between stellar properties and presence/type/architecture of planetary systems*
  - *Signature of planet engulfment (see Spina et al. 2021)*

Buchhave et al. 2012



In blue small planet (R<4 R Earth) distribution, in red giant planets (R>4 R Earth)

- *HRMOS –> planet hunting (hot Jupiters)*
  - *Information on the presence/absence of hot Jupiters*
  - *Information on the presence/absence of chemical enrichment*
- *In group of co-eval and chemical homogeneous stars*

Conclusions

- Entering in the era of extremely large Galactic spectroscopic surveys at medium resolution
- New instruments will allow us to follow parallel paths in the study of resolved stellar populations:
    - Going beyond with MAVIS
    - Going deeper with HRMOS
- Well consolidated collaboration between Italy and Australia