Chemodynamical insights with TGAS-APOGEE

The science of Gaia and future challenges

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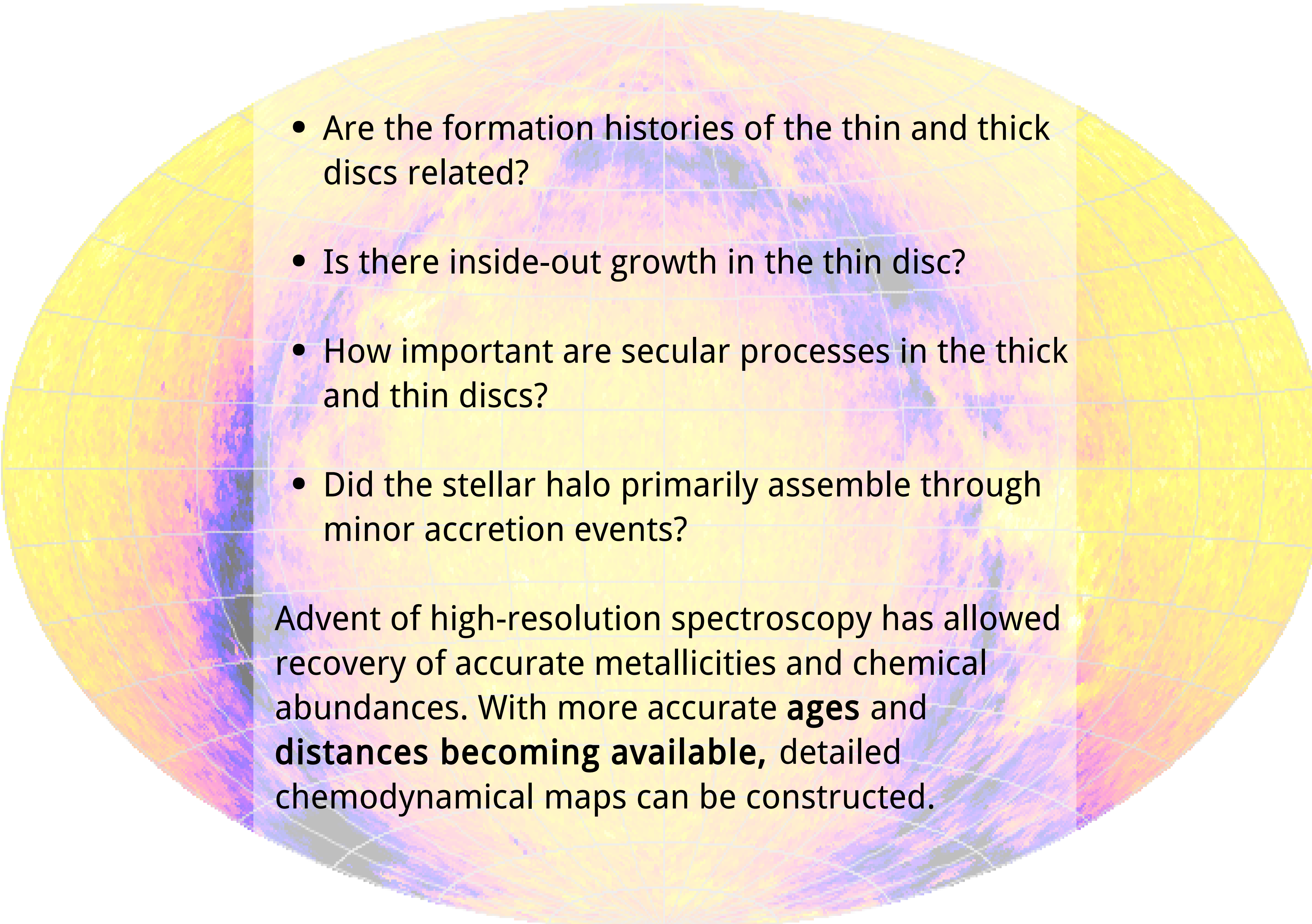
Credit: Mark Gee

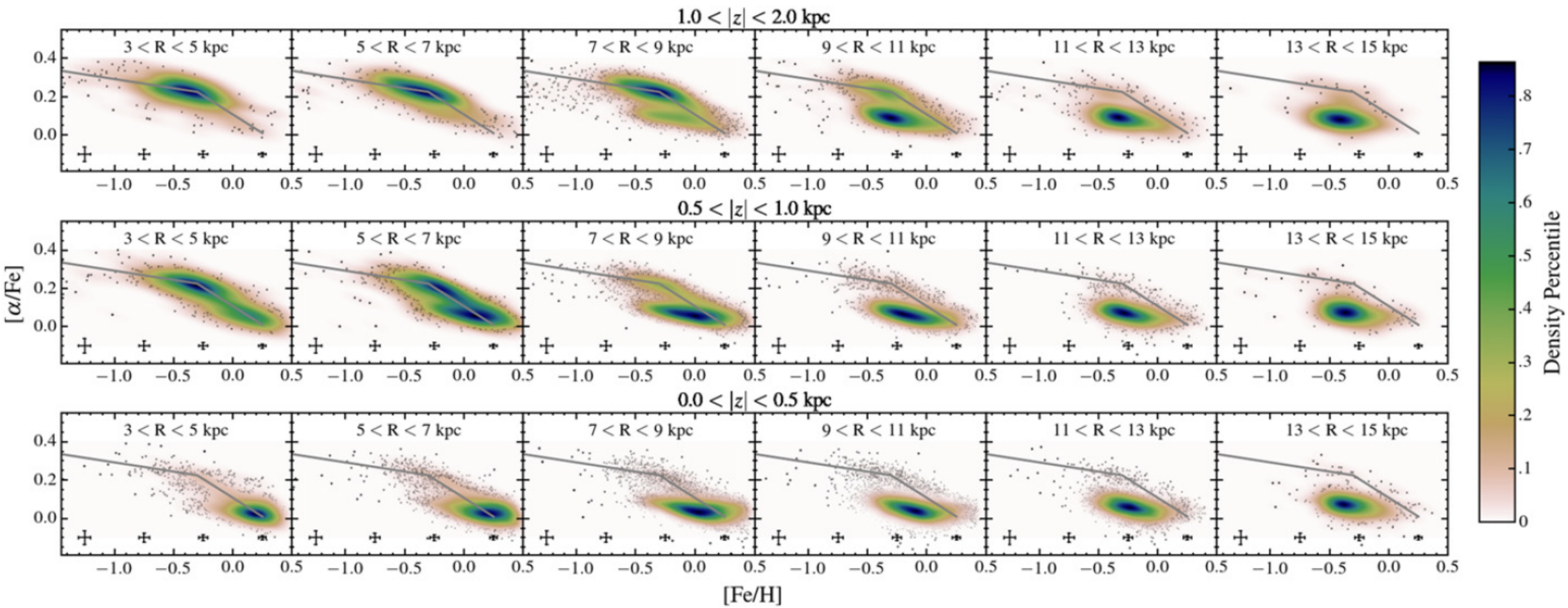
Outstanding questions



- Are the formation histories of the thin and thick discs related?
- Is there inside-out growth in the thin disc?
- How important are secular processes in the thick and thin discs?
- Did the stellar halo primarily assemble through minor accretion events?

Advent of high-resolution spectroscopy has allowed recovery of accurate metallicities and chemical abundances. With more accurate **ages** and **distances becoming available,** detailed chemodynamical maps can be constructed.

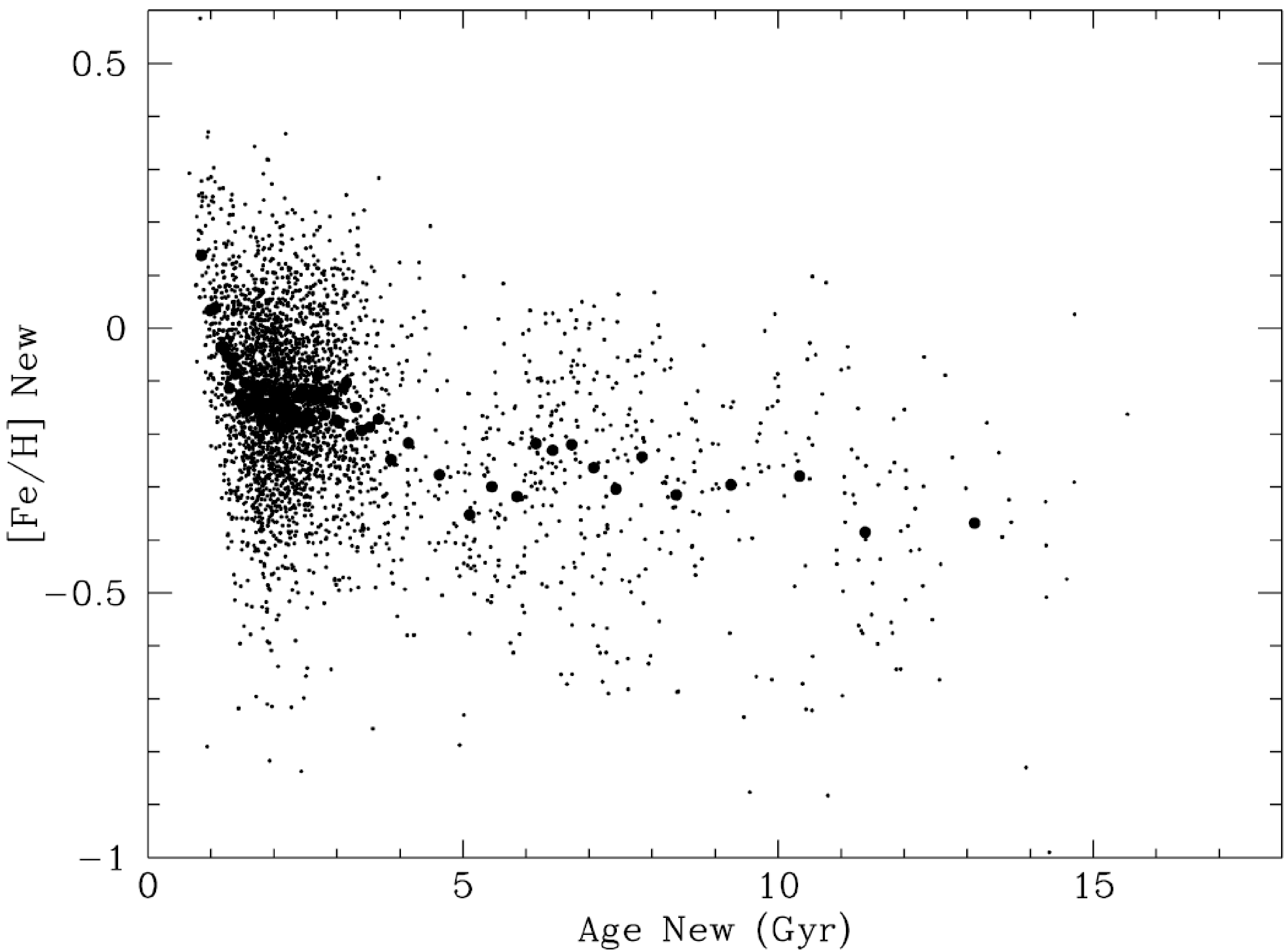
Era of chemodynamical mapping



Two components in [α/Fe]-[Fe/H] relation at solar neighbourhood.

Hayden et al. 2015

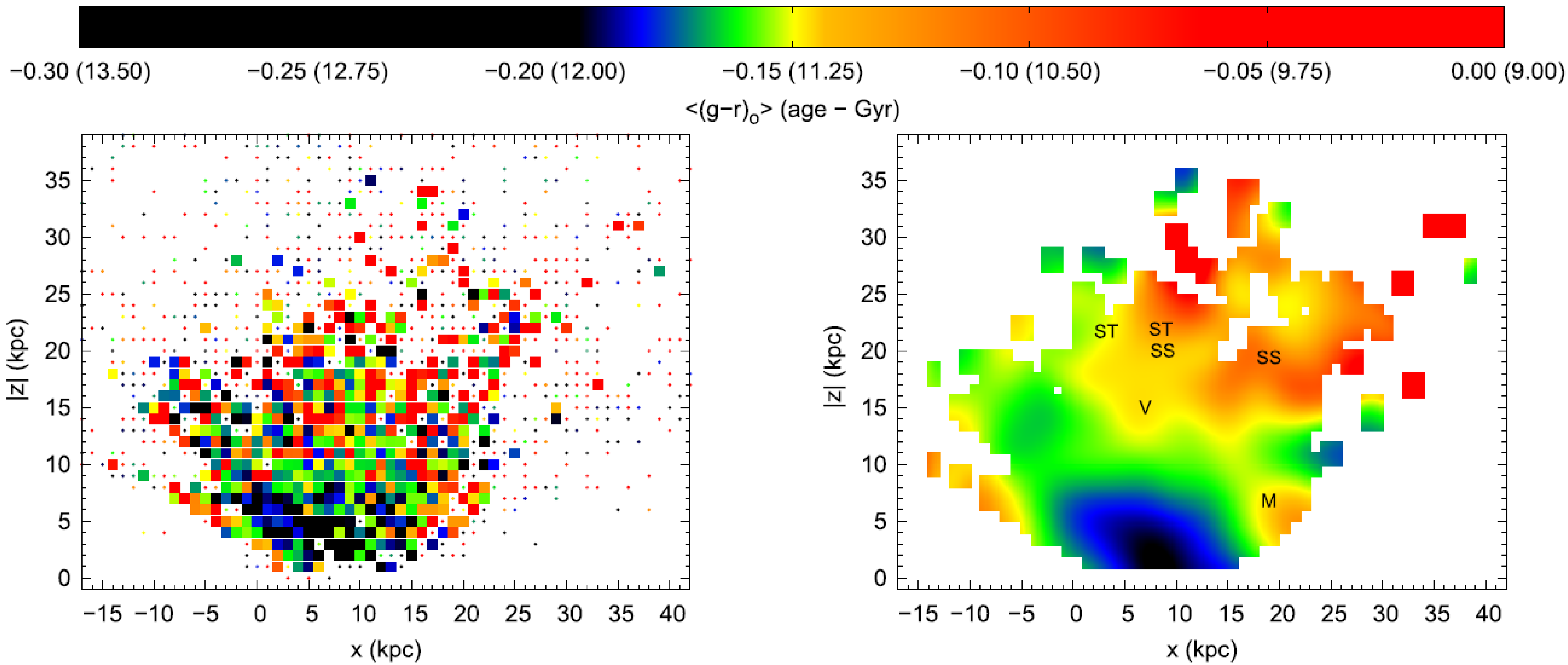
Era of chemodynamical mapping



High dispersion in age-metallicity relation in solar neighbourhood.

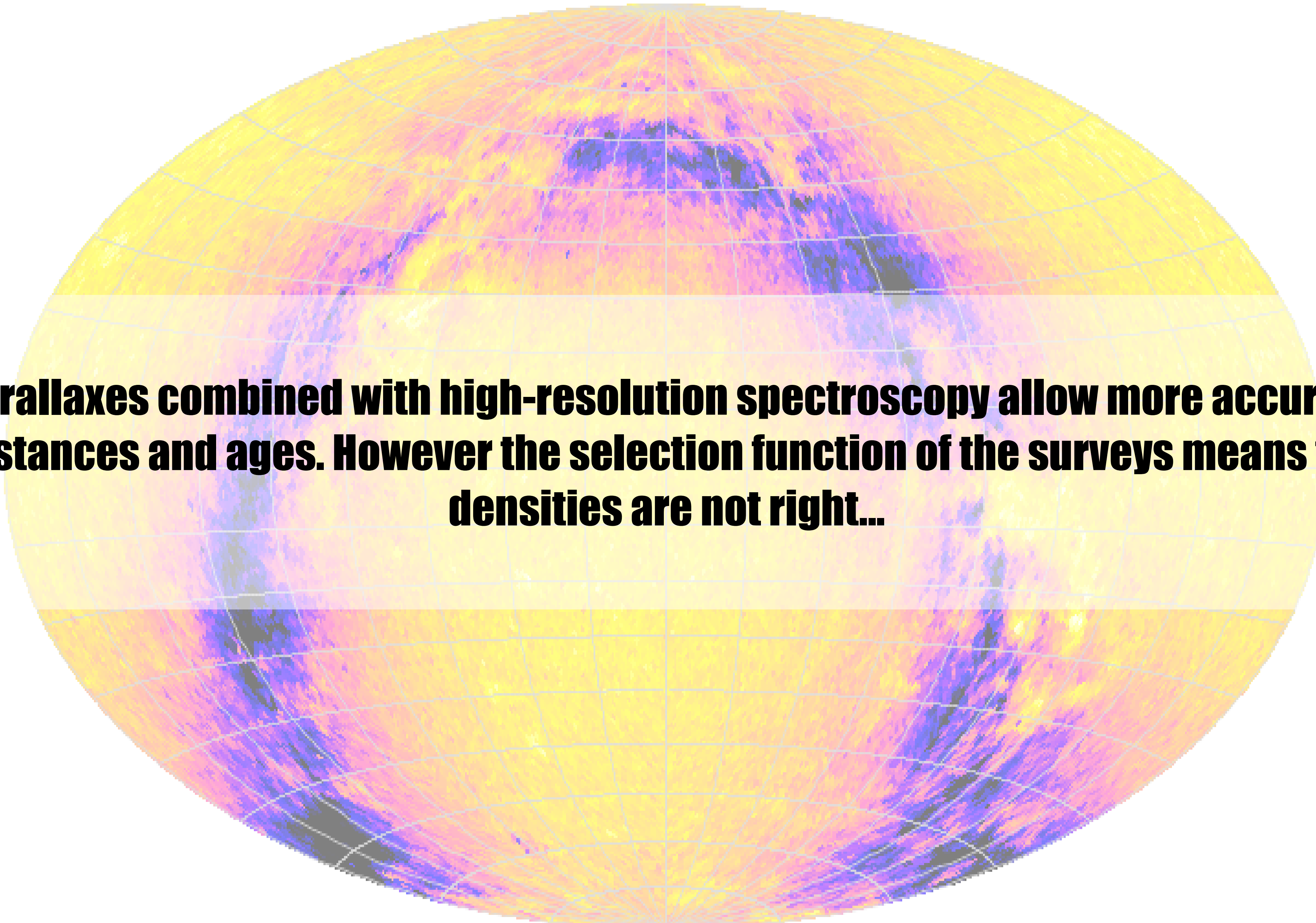
Holmberg et al. 2007

Era of chemodynamical mapping

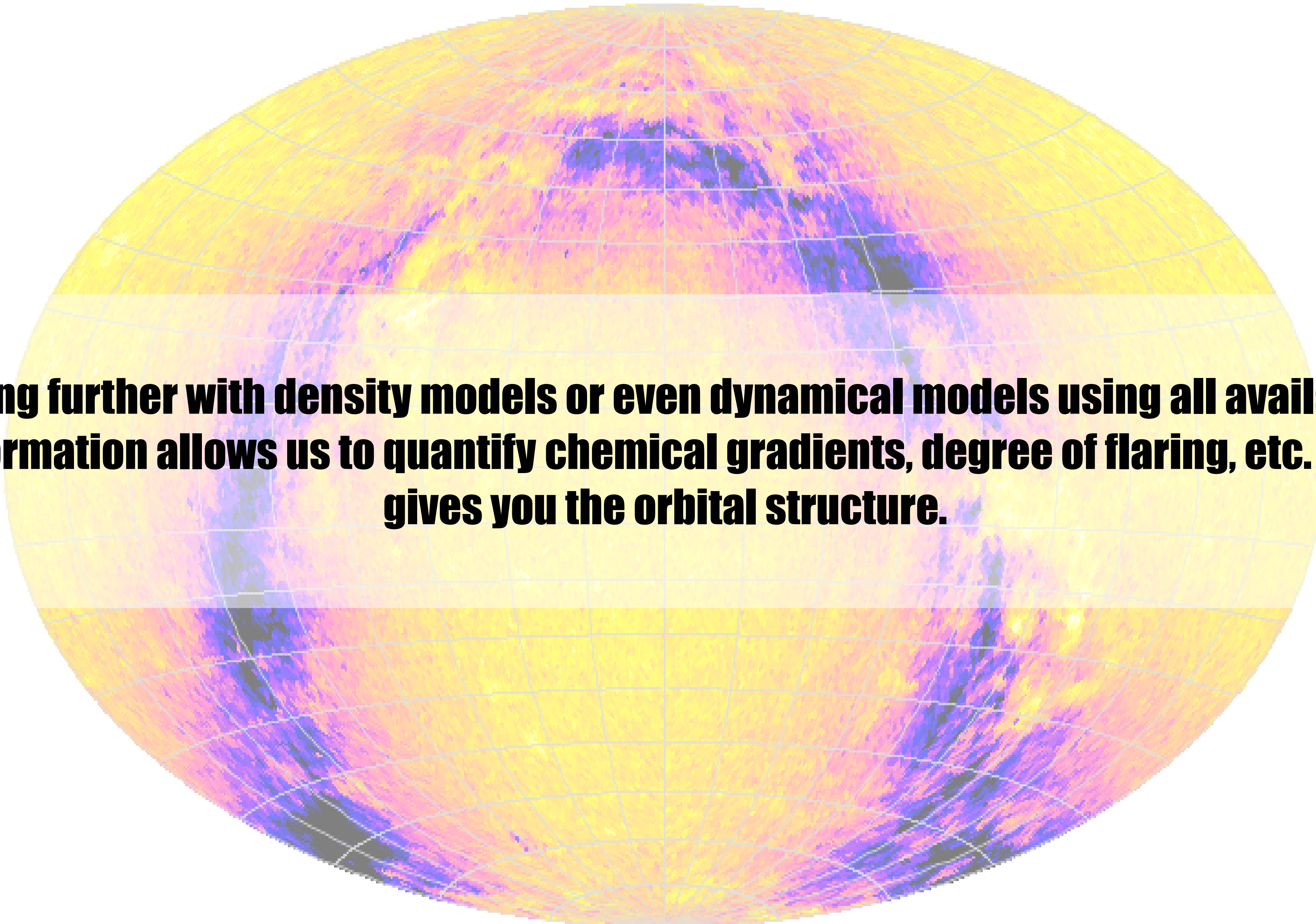


Modest age gradient in the stellar halo.

Santucci et al. 2016



Parallaxes combined with high-resolution spectroscopy allow more accurate distances and ages. However the selection function of the surveys means the densities are not right...

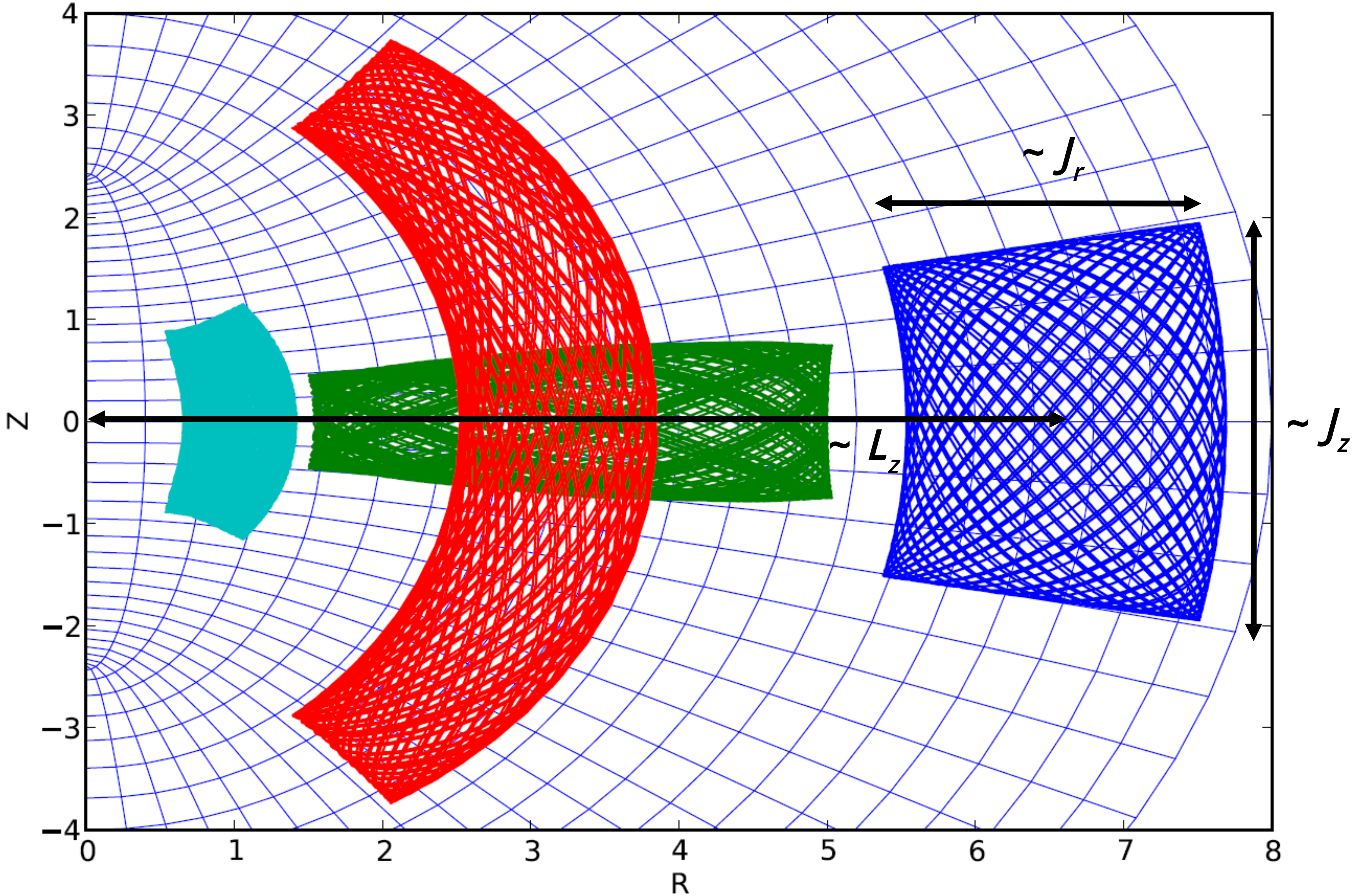


Going further with density models or even dynamical models using all available information allows us to quantify chemical gradients, degree of flaring, etc. Also gives you the orbital structure.

Outline

- **TGAS-APOGEE dataset**
- **Ages and distances** using a Bayesian photo-spectroscopic-astrometric method
- **Selection function** in age, distance, and metallicity space
- **A chemodynamical model for the** thin disc, thick disc, and stellar halo
- **Summary and future work**

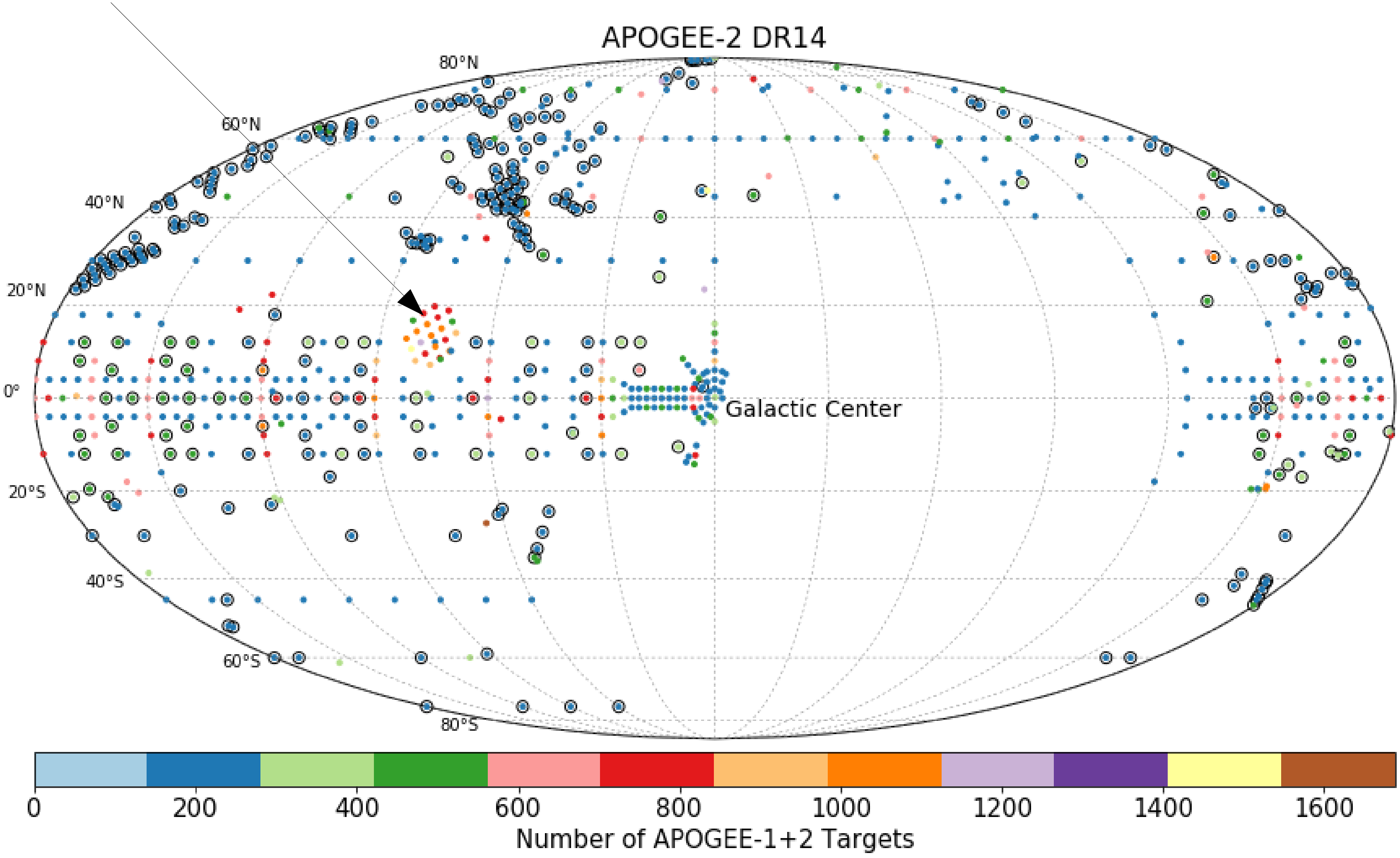
A quick reminder of actions in an axisymmetric system



Credit: Eugene Vasiliev

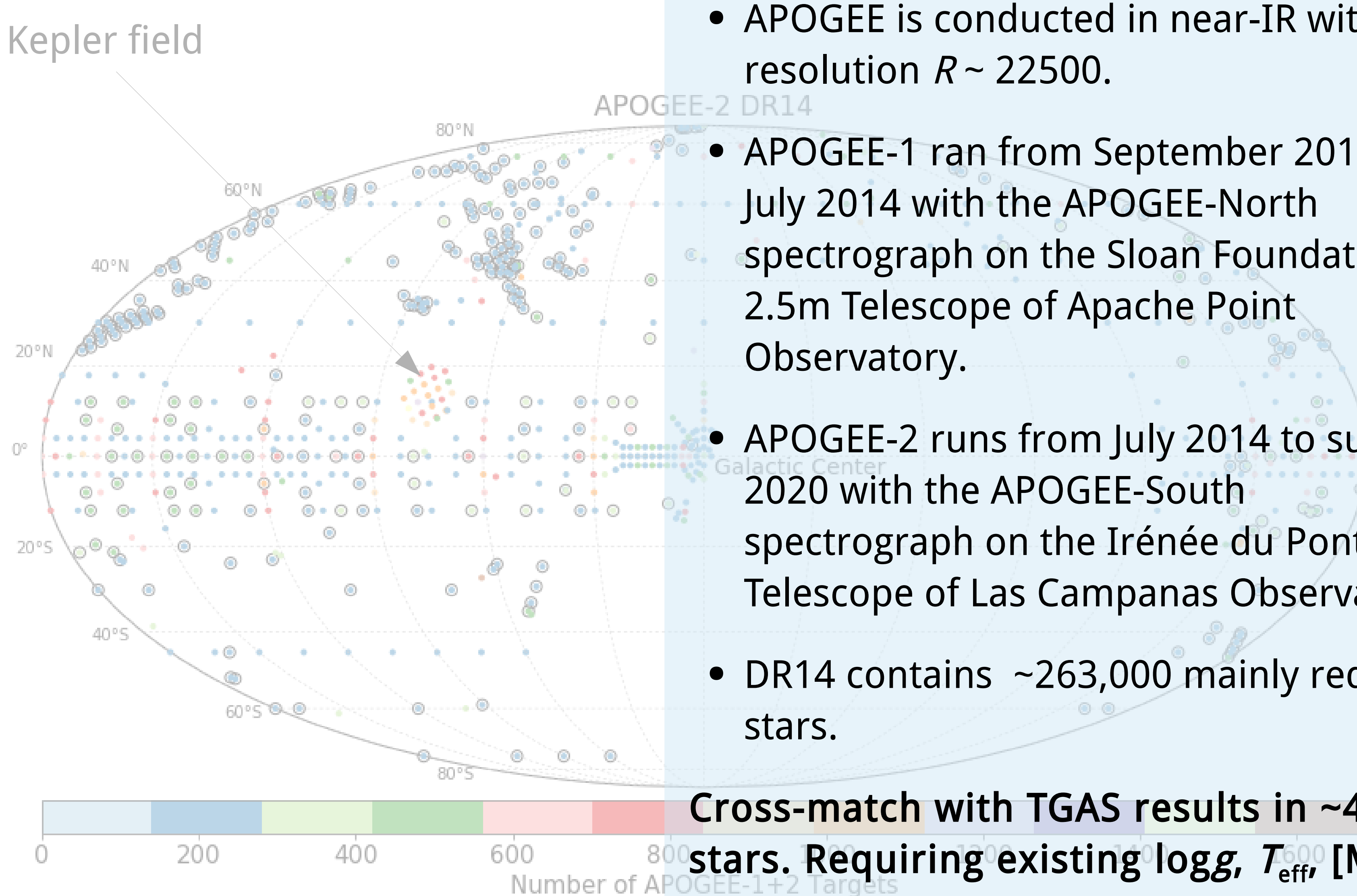
Photo-spectroscopic variables from APOGEE DR14

Kepler field



Fields new to DR14 are encircled in black.

Photo-spectroscopic variables from APOGEE DR14

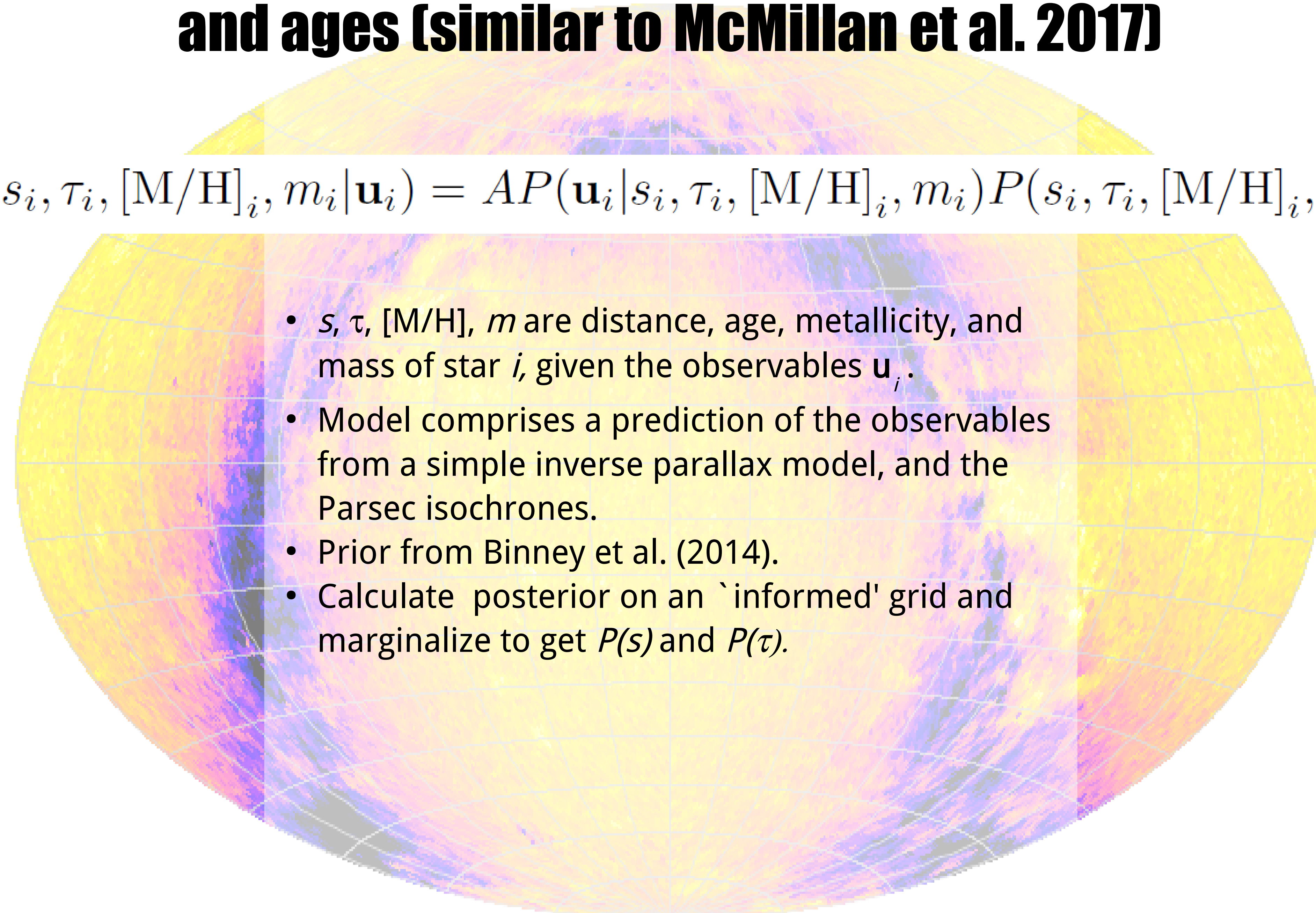


Fields new to DR14

- APOGEE is conducted in near-IR with resolution $R \sim 22500$.
- APOGEE-1 ran from September 2011 to July 2014 with the APOGEE-North spectrograph on the Sloan Foundation 2.5m Telescope of Apache Point Observatory.
- APOGEE-2 runs from July 2014 to summer 2020 with the APOGEE-South spectrograph on the Irénée du Pont 2.5m Telescope of Las Campanas Observatory.
- DR14 contains ~263,000 mainly red giant stars.

Cross-match with TGAS results in ~46,000 stars. Requiring existing log$g$, $T_{\rm eff}$, [M/H], [α/M] results in ~14,000 stars with α, δ, ϖ, μ_α, μ_δ, J, H, K_s, $v_{\rm los}$, log$g$, $T_{\rm eff}$, [M/H], [α/M].

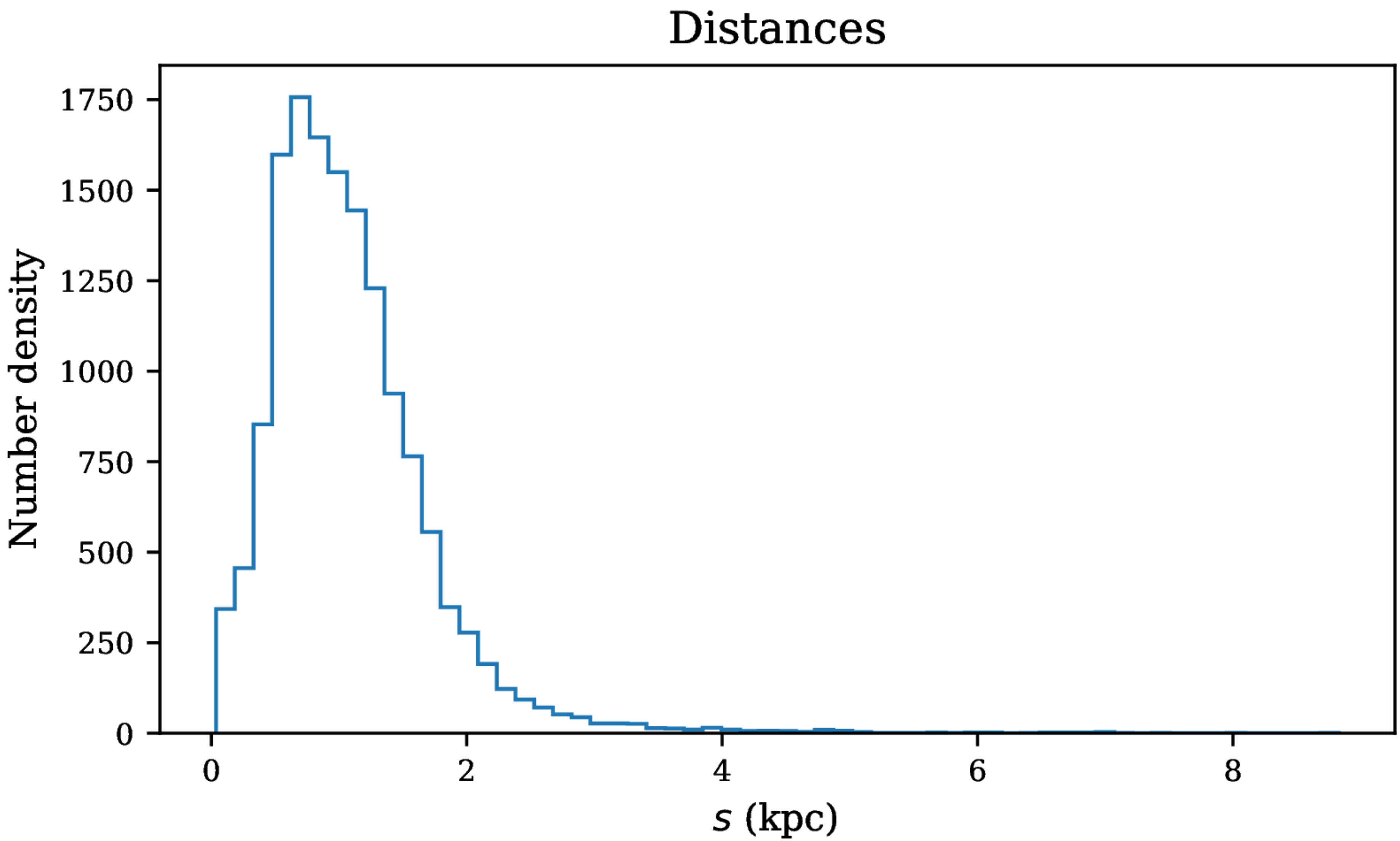
TGAS-APOGEE photo-spectroscopic-astrometric distances and ages (similar to McMillan et al. 2017)



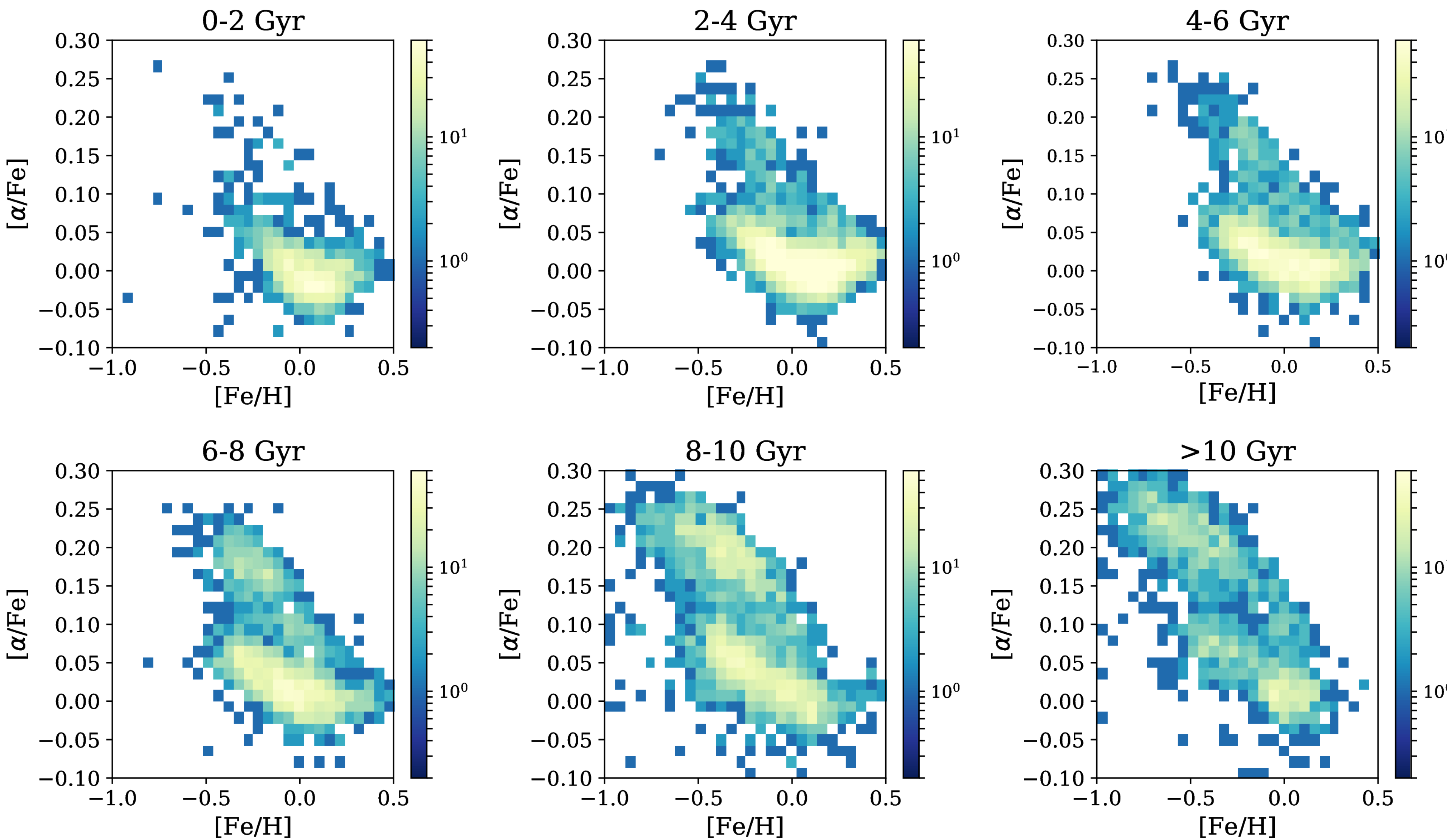
$$P(s_i, \tau_i, [\mathrm{M/H}]_i, m_i | \mathbf{u}_i) = AP(\mathbf{u}_i | s_i, \tau_i, [\mathrm{M/H}]_i, m_i) P(s_i, \tau_i, [\mathrm{M/H}]_i, m_i)$$

- s, τ, [M/H], m are distance, age, metallicity, and mass of star *i,* given the observables $\mathbf{u}_i$.
- Model comprises a prediction of the observables from a simple inverse parallax model, and the Parsec isochrones.
- Prior from Binney et al. (2014).
- Calculate posterior on an `informed' grid and marginalize to get $P(s)$ and $P(\tau)$.

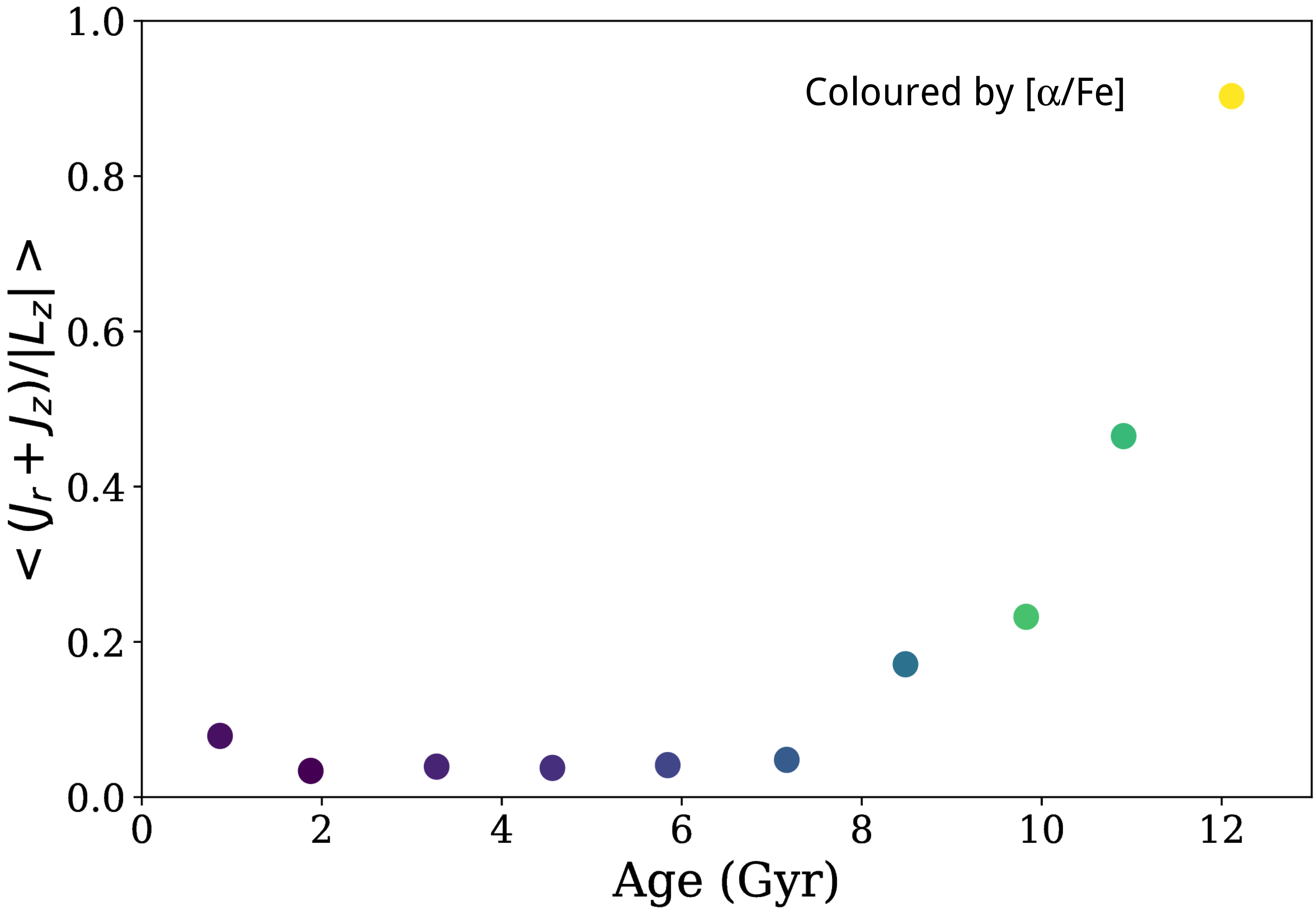
TGAS-APOGEE distances and ages



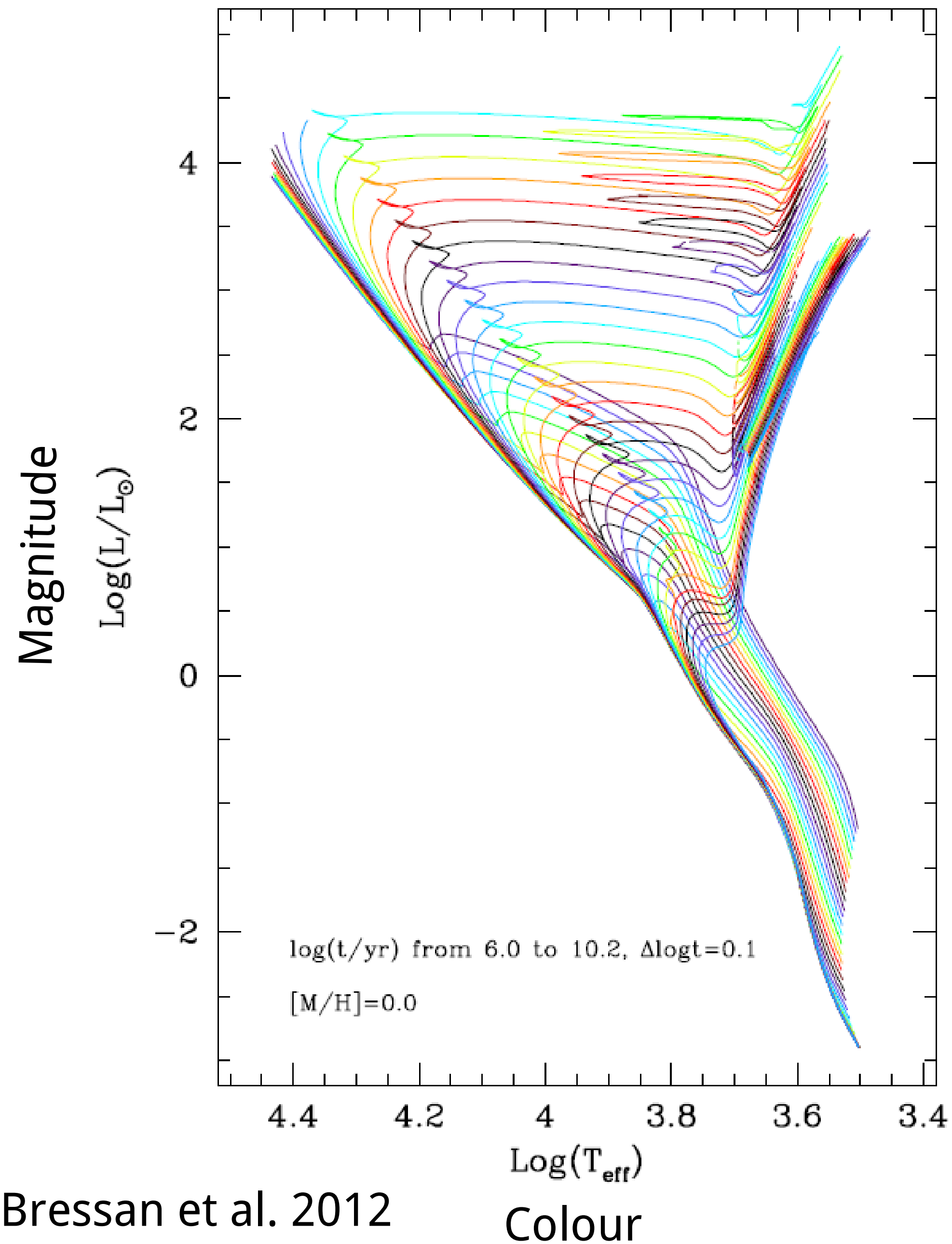
TGAS-APOGEE distances and ages



TGAS-APOGEE chemodynamical map



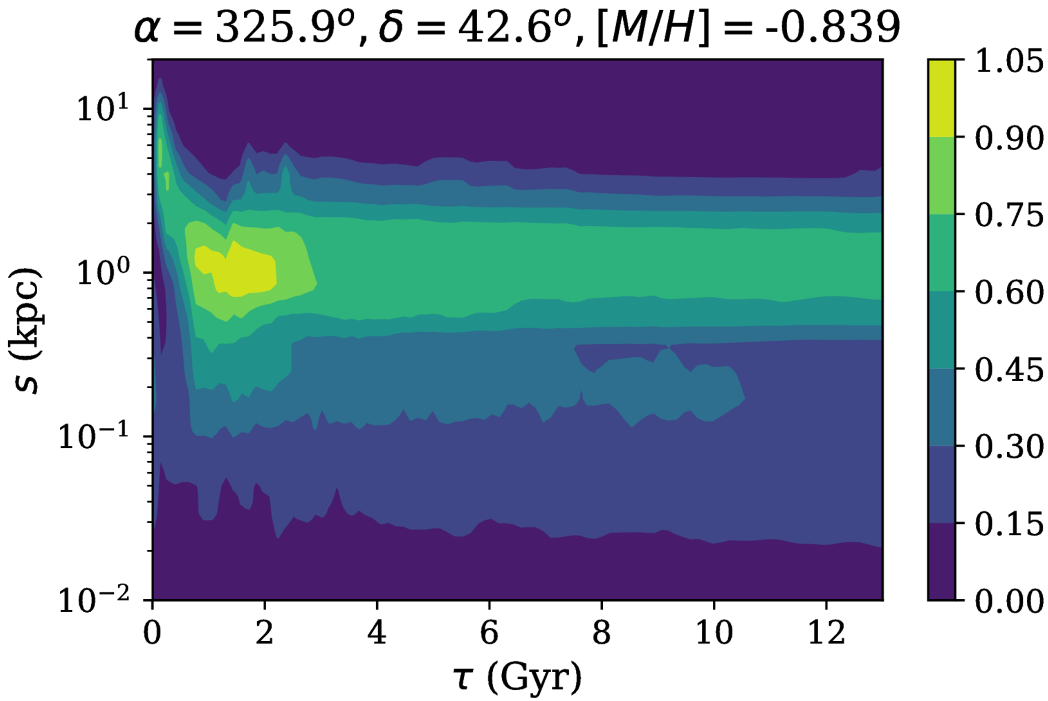
TGAS-APOGEE selection function



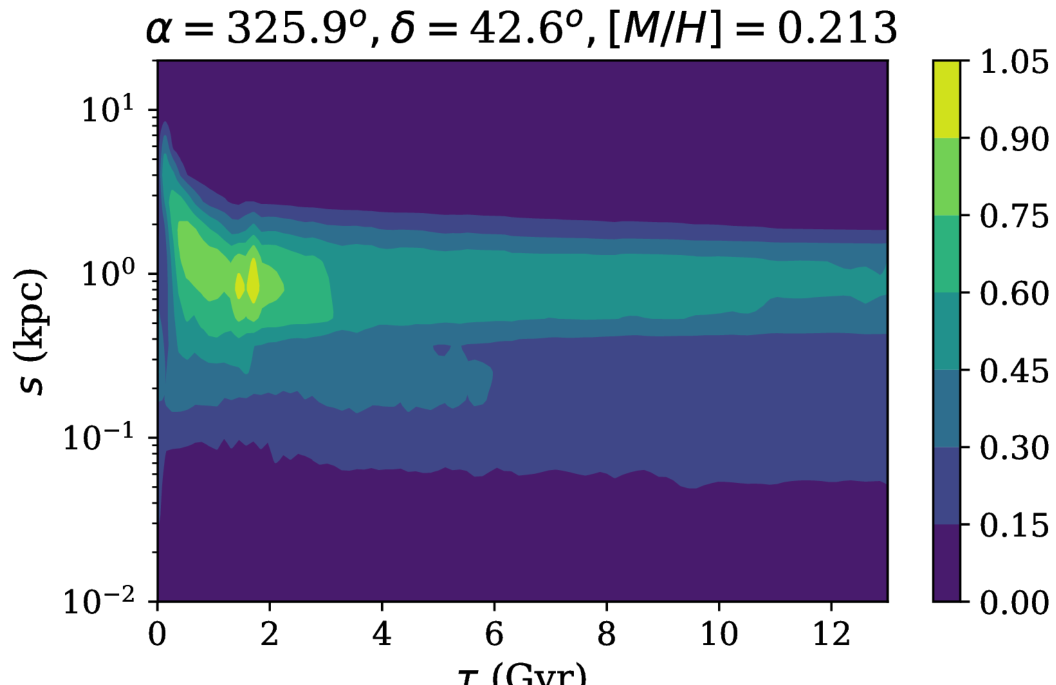
Bressan et al. 2012

Bovy et al. 2016 and 2017 derive APOGEE selection function as a function of sky positions and magnitude, and TGAS selection function as a function of sky positions, magnitude, and colour. Convert to selection function as a function of sky positions, distance, metallicity, and age using Parsec isochrones.

TGAS-APOGEE selection function



For a few hundred fields and
10 metallicities.



Chemodynamical models with action-based extended distribution functions (EDFs)

- Distribution function DF($\mathbf{J}$) gives probability of finding a star with actions $\mathbf{J}$.

- Can be extended to EDF($\mathbf{J},\chi$) (Sanders and Binney, 2015) to give probability of finding a star with phase-space and chemistry coordinates ($\mathbf{J},\chi$).

- Using actions has the following advantages:
  - They are integrals of motion (IoM), i.e. are constant along orbits.
  - Steady-state DFs depend only on IoM (Jean 1916).
  - Can simply add DFs($\mathbf{J}$) to obtain a composite galaxy model (Piffl et al. 2015).
  - Actions are invariant to slow evolution of potential (Piffl and Binney 2015).

Proposed EDF for the Milky Way f(J,[M/H],[α/H],τ)

- Discs are superpositions of mono-age populations whose velocity dispersions grow with time. Also allow scale lengths and scale heights that depend on τ .

- Star formation history gives distribution in τ.

- Stellar [M/H] and [α/H] as a function of present L_z and τ are dispersed from values at the birth radii in chemical evolution models of Schönrich et al. (2017), where dispersions depend on age.

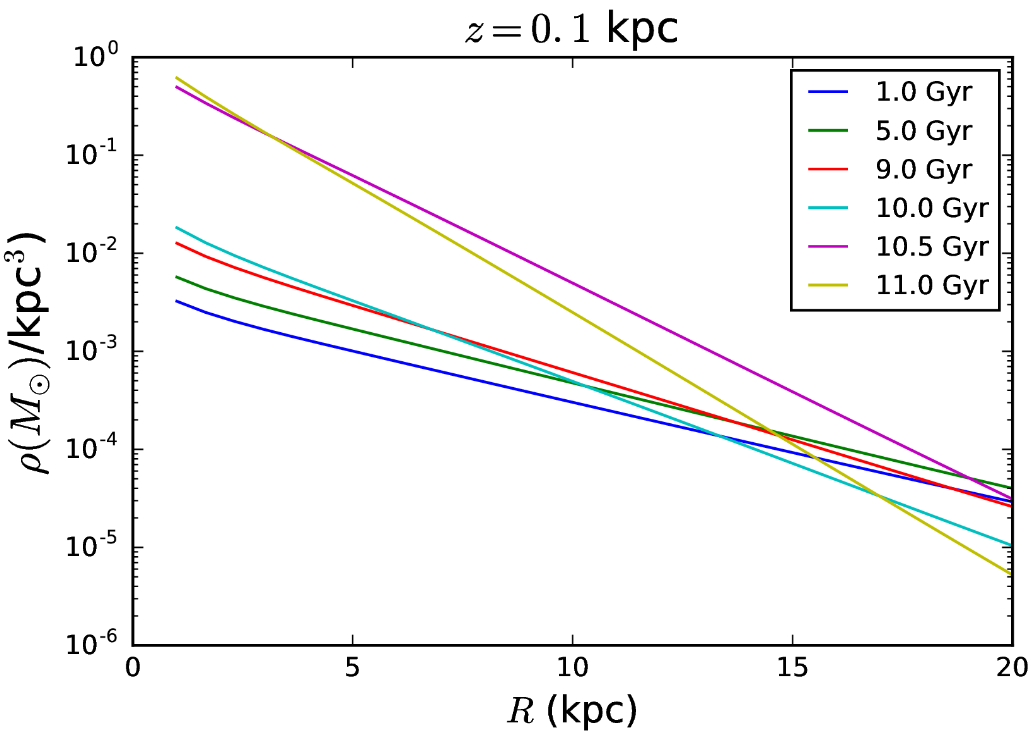
Hope to constrain **the level of inside-out growth, dependence of v_ϕ gradient on metallicity, heating, degree of flaring, chemical, and age gradients.**

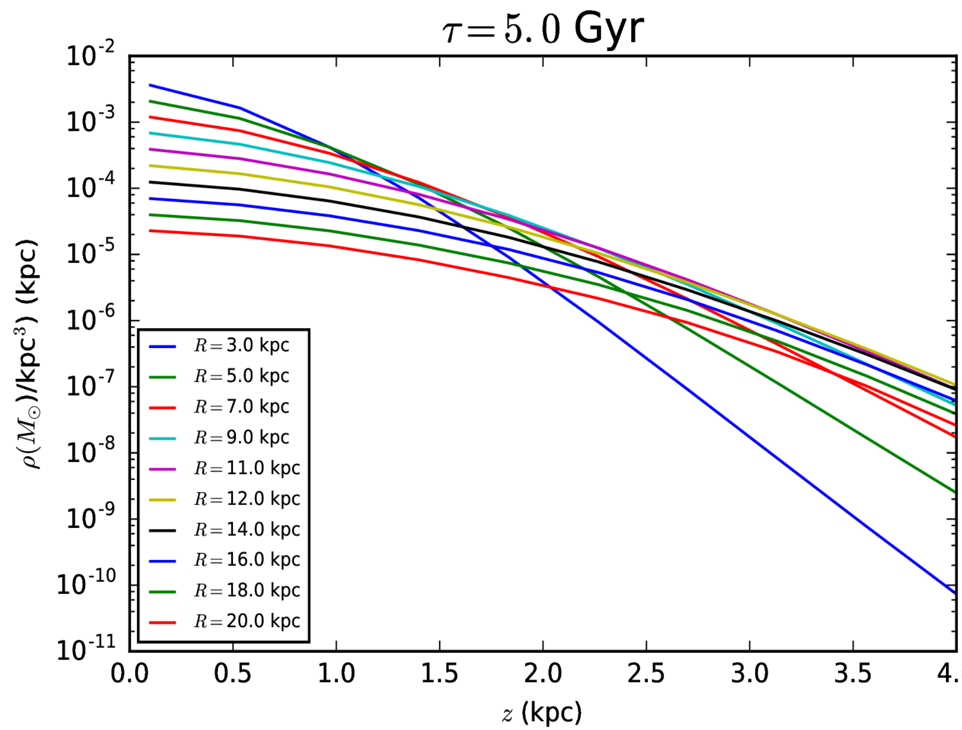
- Stellar halo is a superposition of accreted systems that follow a steepening density profile and changing anisotropy profile.

- Each system (i.e. set of actions) is associated with a narrow band of [M/H], [α/H], and τ.

Hope to assess **`dual-halo' scenario, and imprint of the halo's accreted systems on chemical and age gradients.**

Proposed EDF for the Milky Way: disc

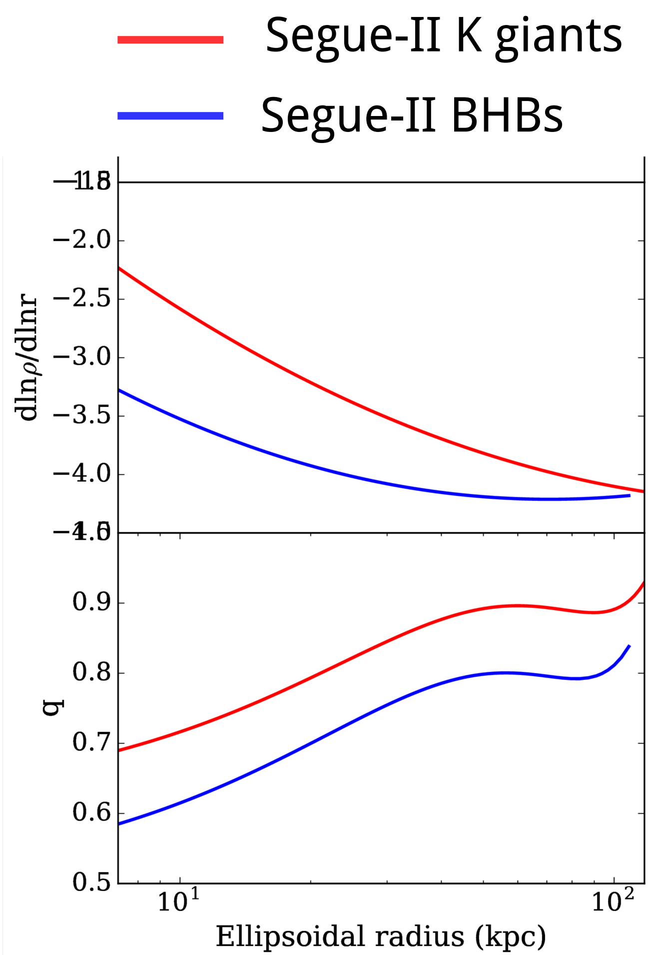




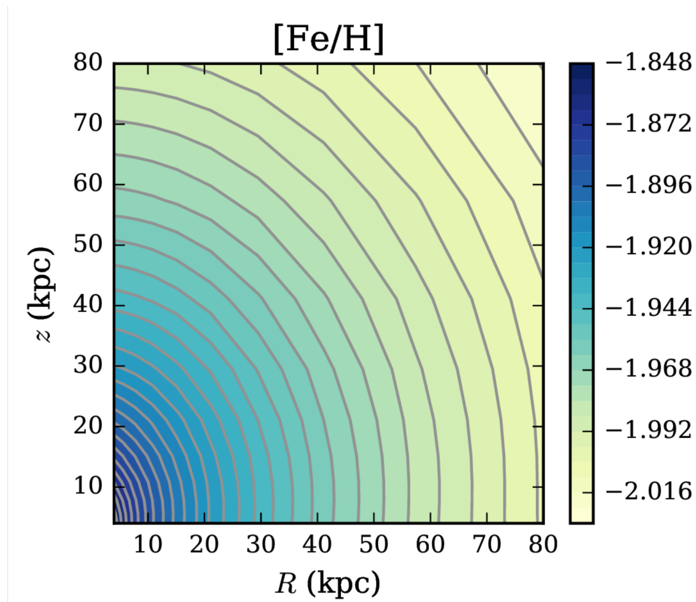
Radial profile: Inside-out growth

Vertical profile: Flaring and radial migration

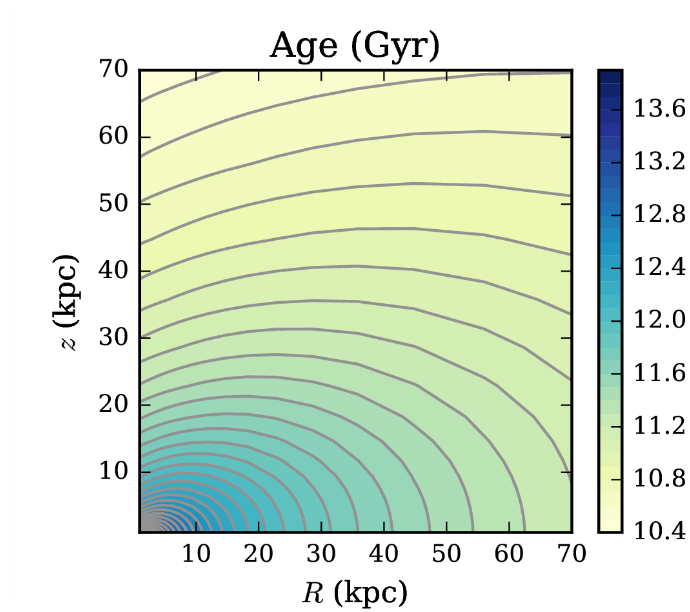
Proposed EDF for the Milky Way: stellar halo



Steepening profile, flattened system.



Very weak metallicity gradient.



Weak but significant age gradient.

Das et al. (2016a,b)

Finding the best-fit parameters

$$\mathcal{L} = \prod_{k=i}^{n_*} \frac{P(S|\mathbf{u}_i)P(\mathbf{u}_i|M(\mathbf{J},\chi))}{P(S|M(\mathbf{J},\chi))}$$

where $n*$ is the number of stars, $\mathbf{u}_i$ are the observables of star i, and $\chi \equiv$ ([M/H],[α/H], τ).

Assume gravitational potential consisting of a bulge, thick disc, and thin disc. Contributions for stellar halo are accounted for in the bulge potential.

Summary and future work

- TGAS-APOGEE distances peak at around ~1kpc.
- TGAS-APOGEE selection function peaks at ~1 kpc and ages < 2 Gyr. Similar between fields and range of metallicities.
- Propose a chemodynamical model that will quantify inside-out growth, flaring, gradients.
- Have ~1700 stars with masses in the newest Kepler-2 data. Will derive photo-spectroscopic-astrometric-asteroseismological ages.
- Gaia DR2 will have too much data! Designing an optimal binning scheme that will preferentially bin where there is less information for the EDF.

Credit: Mark Gee