CENTRO DE ASTROBIOLOGÍA

CSIC Consejo Superior de Investigaciones Científicas

INTA Instituto Nacional de Técnica Aeroespacial

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CHRONOS: TOWARDS A HOMOGENEOUS AGE SCALE

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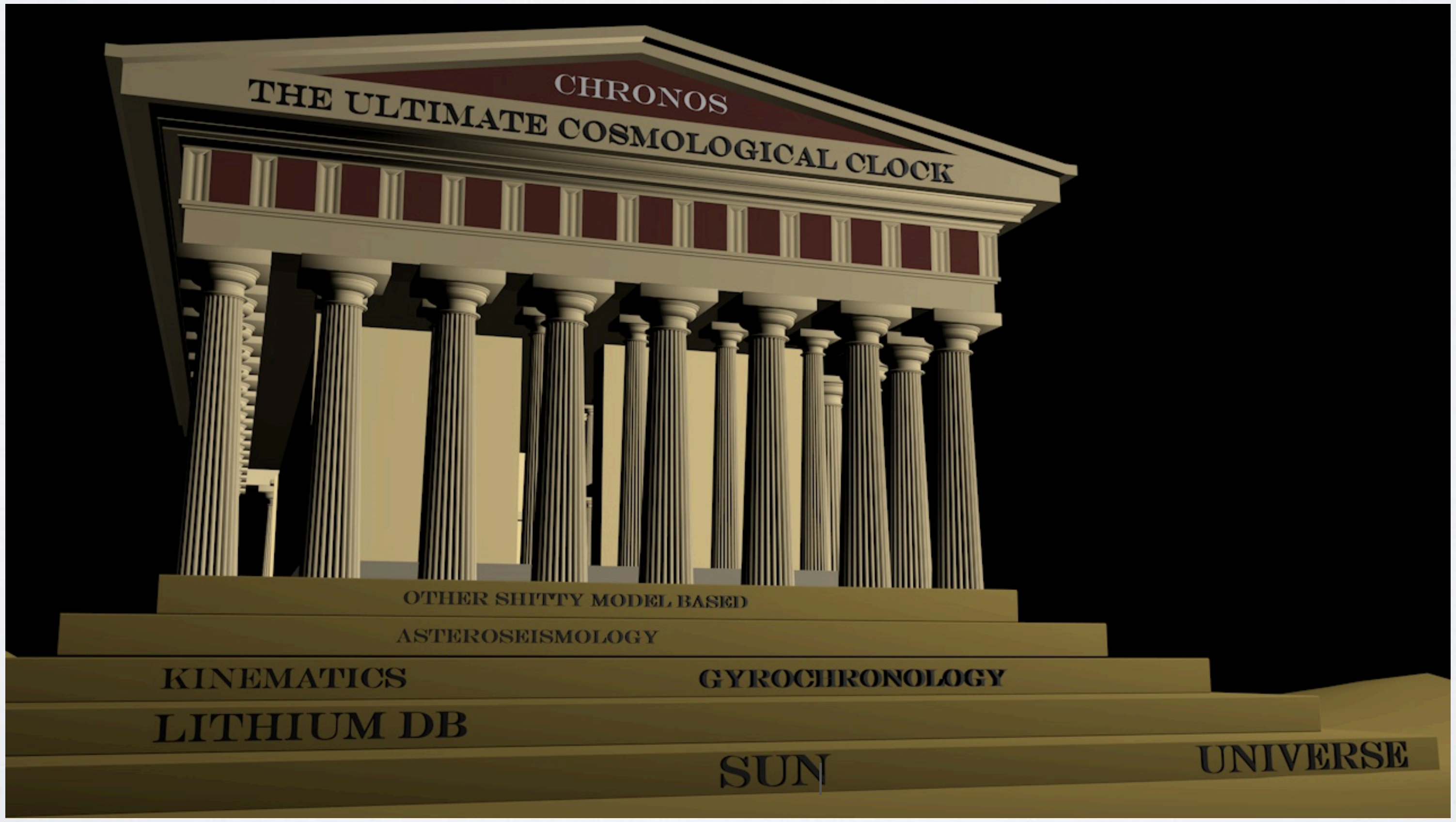
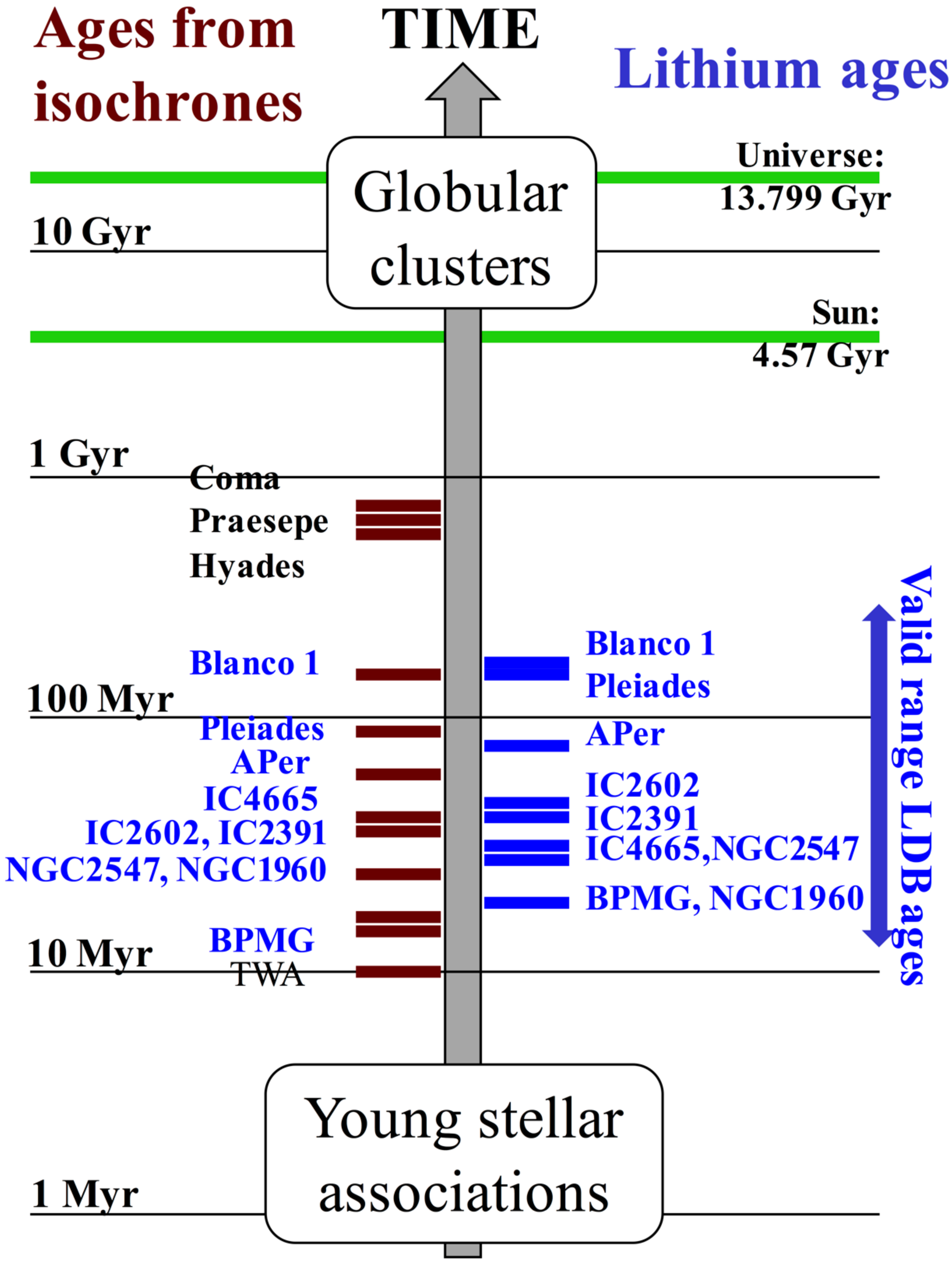




Anchors

- •**13.799±0.021 billion years** within the Lambda-CDM concordance **model**
- •The Sun and its age of **4.57 Gyr**.
  - i) Computer **models** of stellar evolution and through nucleocosmochronology
  - ii) A **radiometric date** of the oldest Solar System material, at 4.567 billion years ago

The puzzle

Different age scales produce a diversity of values, with **differences up to 50%**

Methods

Methods: classification

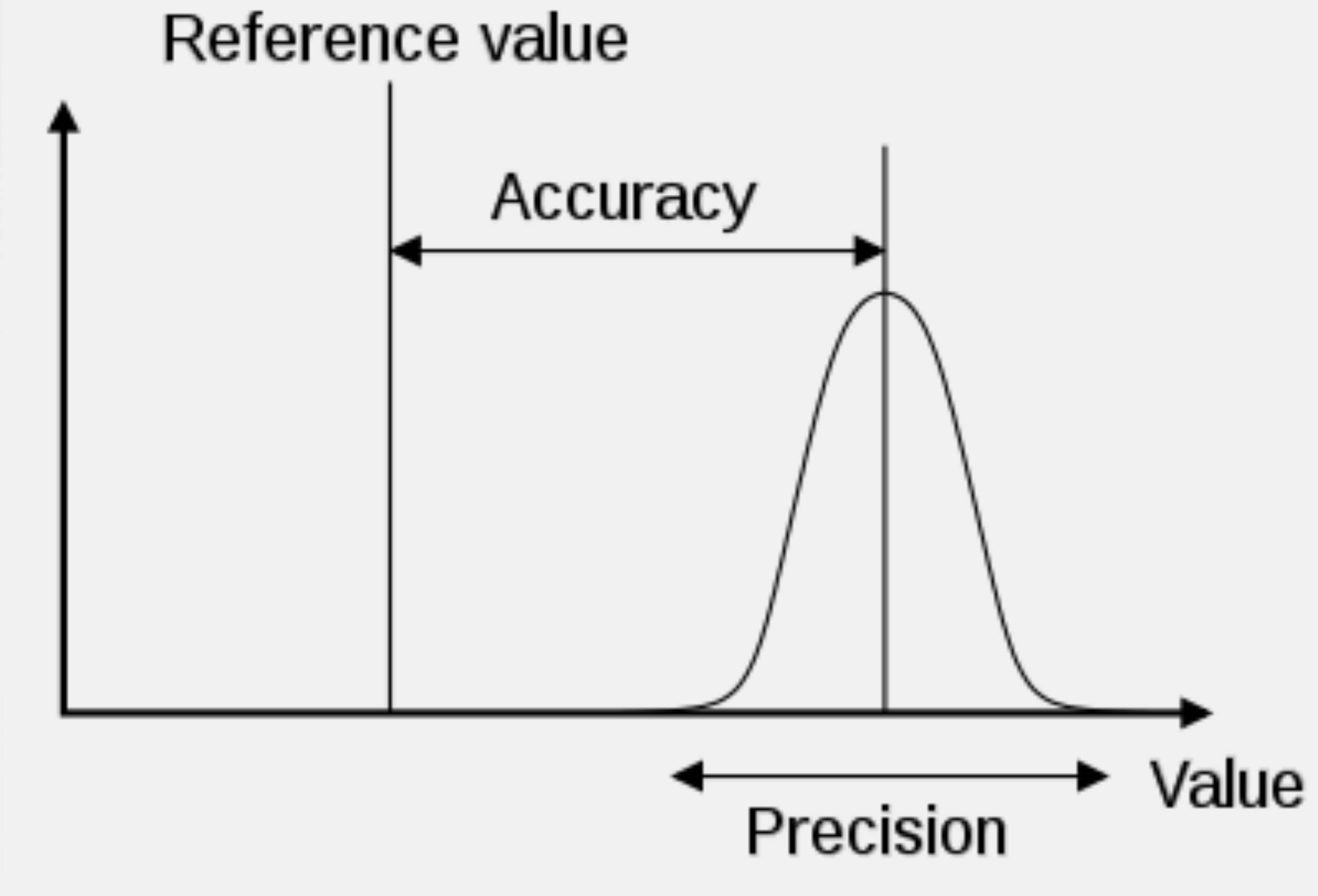
Soderblom (2010); Soderblom et al. (2013)
See also Mermilliod (2000)

I) Fundamental

II) Semi-fundamental

III) Model dependent

IV) Empirical
(isolated stars, planets)



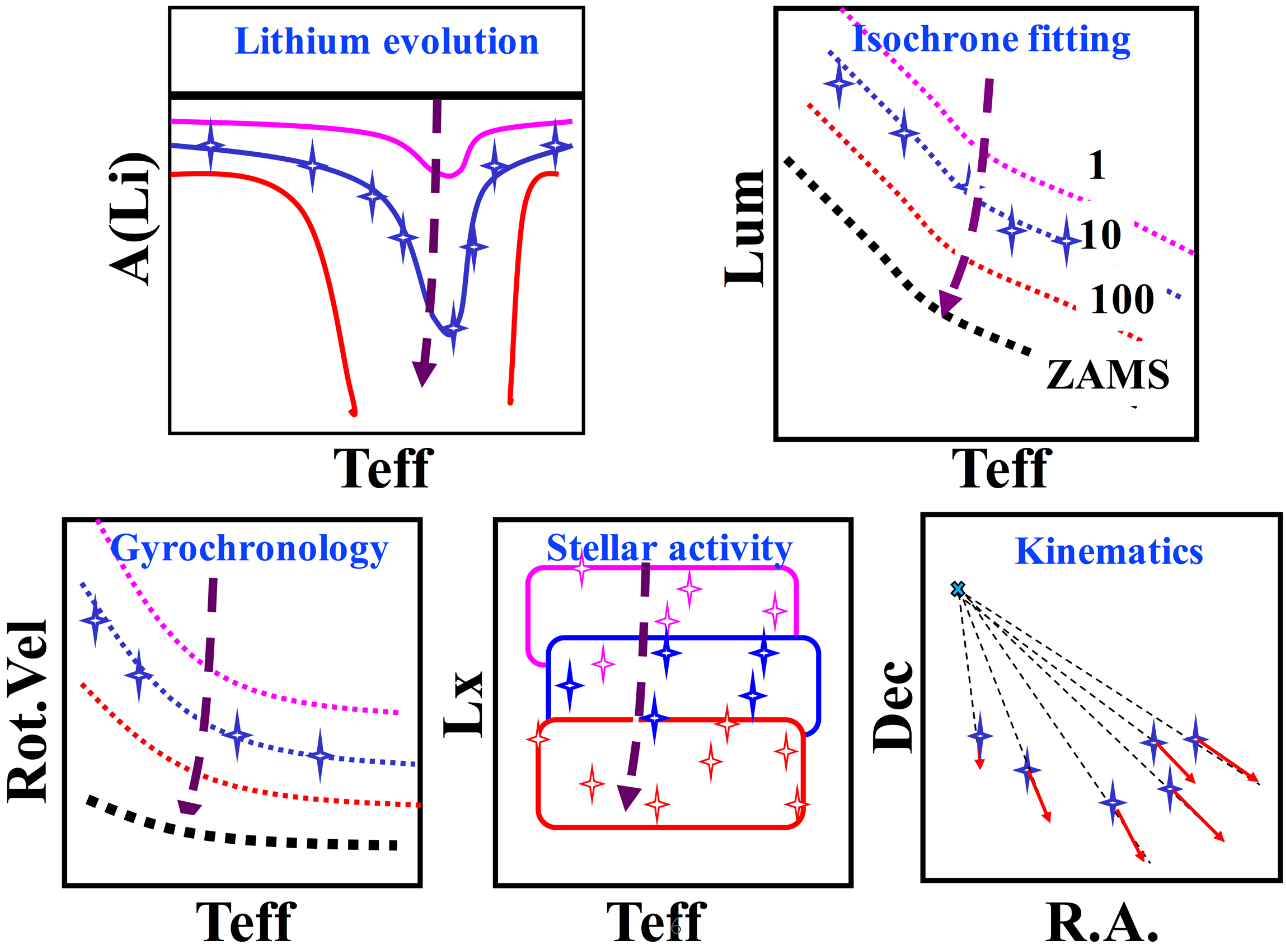
Many times only intrinsic errors are taken in to account.

Some historical perspective: the meter and the size of Earth

- After the French revolution, the directory ask the Academy of Science to provide a **standard distance measurement**: the meter.
- P. F. Méchain and J.-B. Delambre measured by triangulation the meridian from Dunkirk (Dunquerque) to Barcelona during several years
- The computations were tied to the determination of the latitudes of the extremes. Several stars were used and a very **precise** new instrument, the circle of repetition invented by J.-C. de Borda.
- Unfortunately the methodology itself was **not so accurate**.
- Méchain knew there was a problem (essentially in his several measurements of the latitude of Barcelona), but was unable to understand the origin and to correct it. He struggled for years and tried not to publish his data.
- The result: the total length of the meridian (1/4 Earth perimeter) is **10.002.290 meter**, not 10.000.000.

As a curiosity, **France and Spain were at war** then, but both governments agreed to continue with the **scientific cooperation**

Some methods to estimate stellar ages (+asteroseismology)

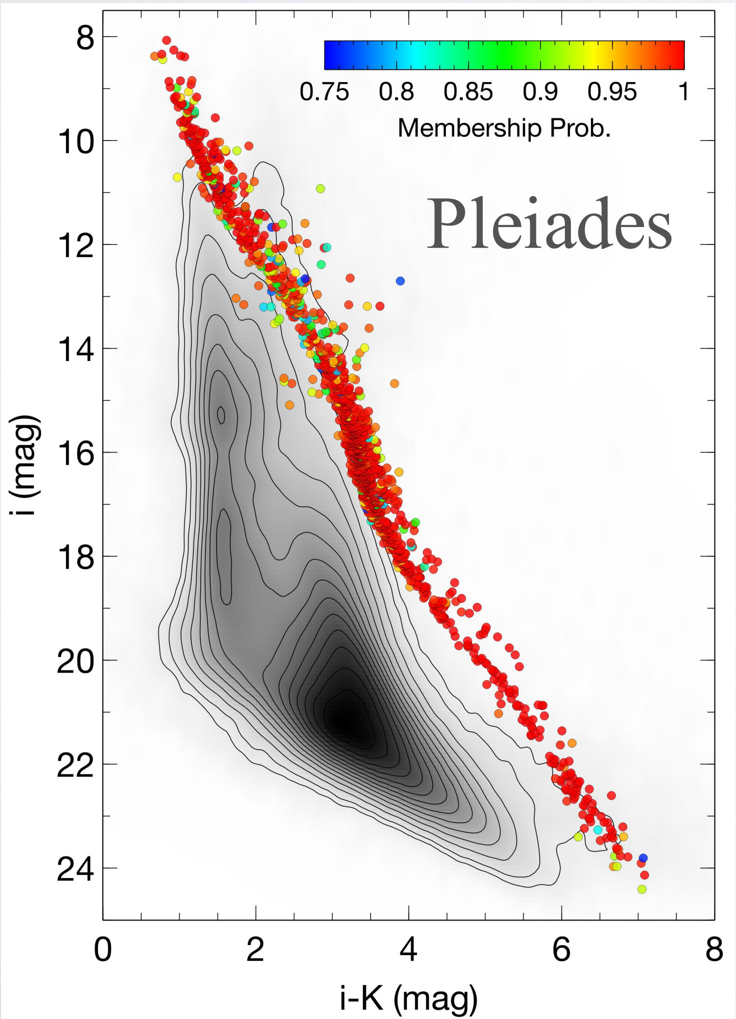


CHRONOS:

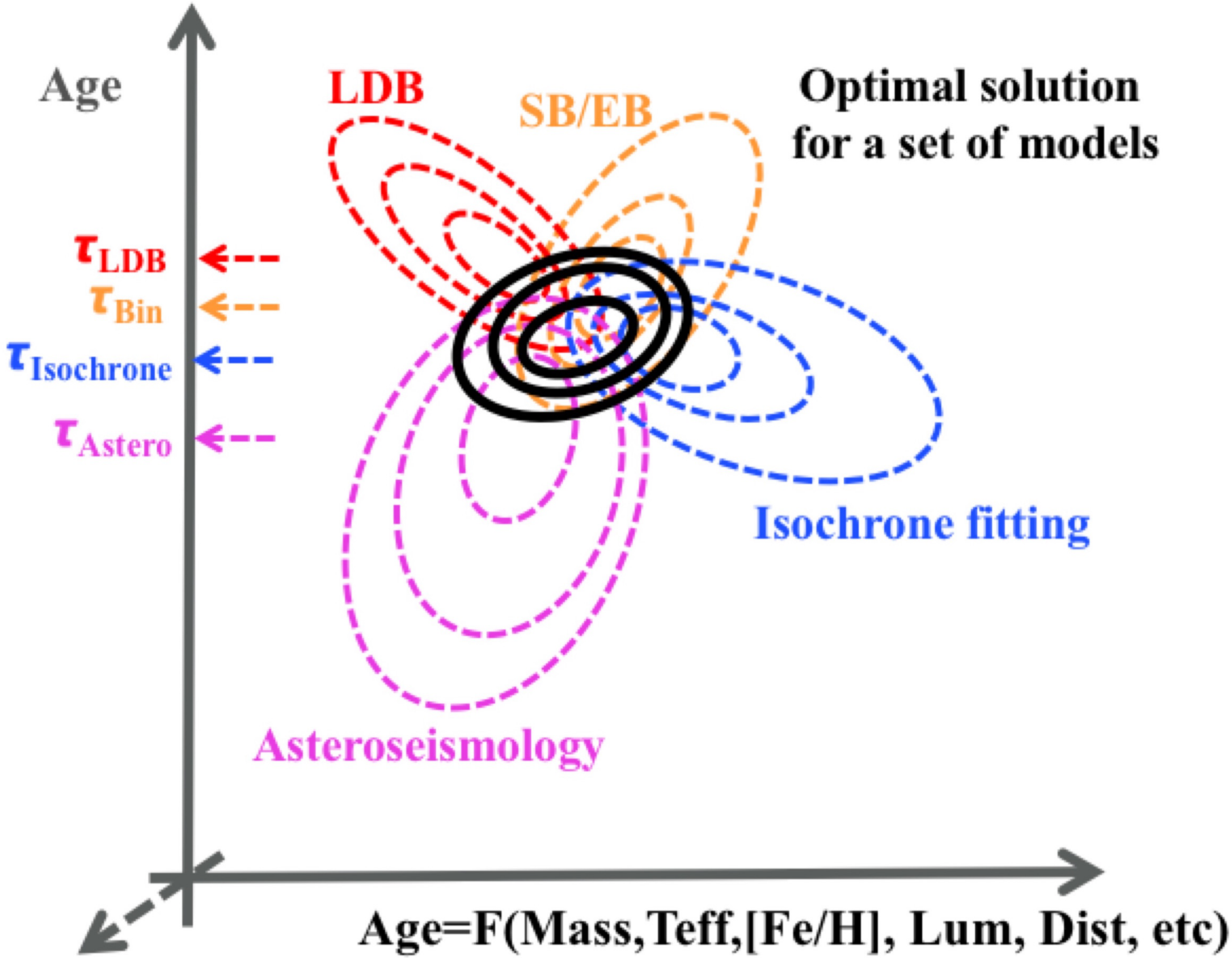
Towards an auto-consistent, universal and absolute age scale

CHRONOS is built upon:

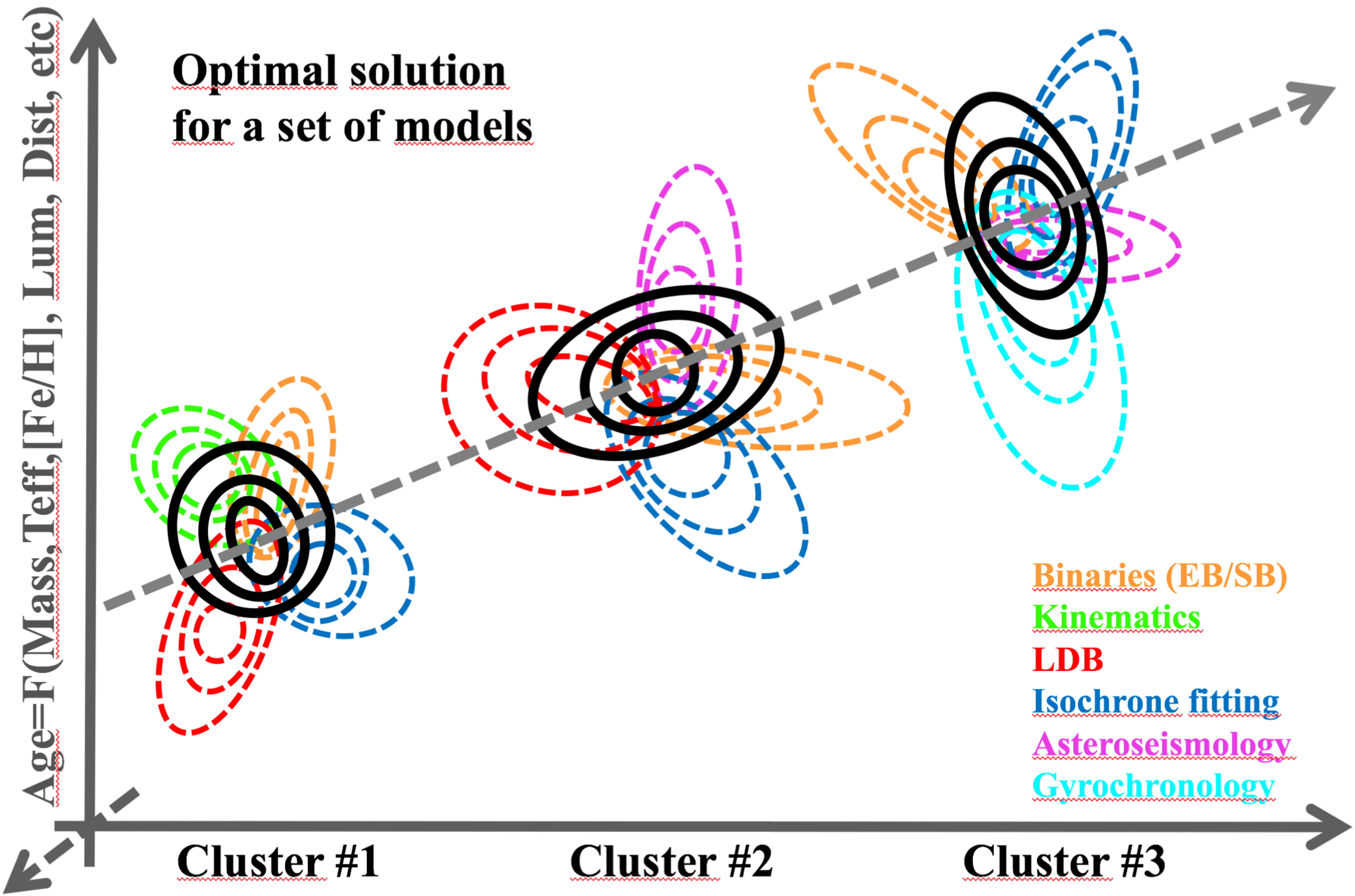
- A large number of public spectroscopic and photometric surveys (**Gaia**, etc)
- **Cosmic-DANCe** is providing deep data in young (reddened) stellar associations

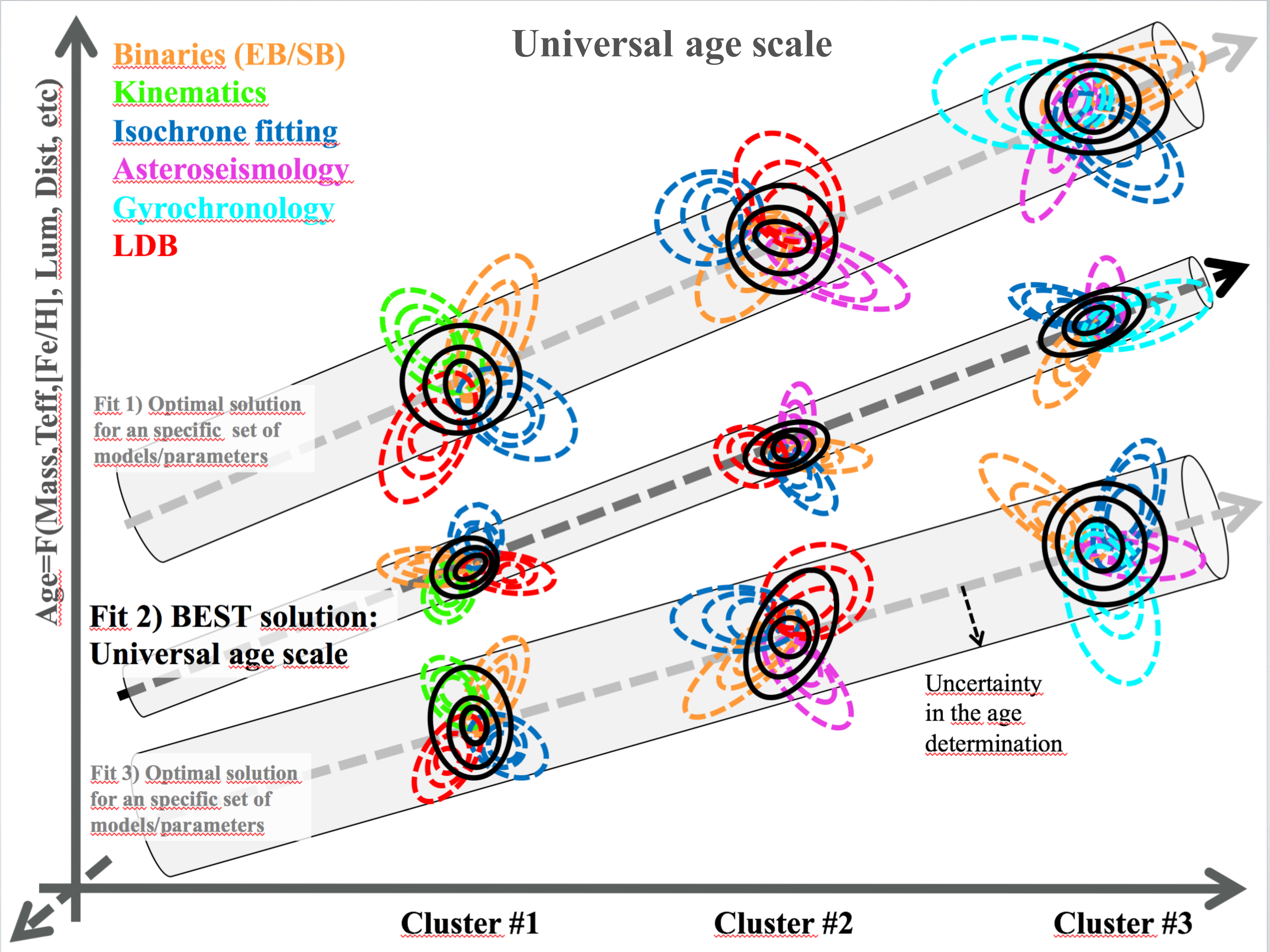


An optimal age of a cluster based on several methods



Universal age scale





Universal age scale
Binaries (EB/SB)
Kinematics
Isochrone fitting
Asteroseismology
Gyrochronology
LDB
Age=F(Mass,Teff,[Fe/H], Lum, Dist, etc)
Fit 1) Optimal solution for an specific set of models/parameters
Fit 2) BEST solution: Universal age scale
Fit 3) Optimal solution for an specific set of models/parameters
Uncertainty in the age determination
Cluster #1
Cluster #2
Cluster #3

How to achieve the goal

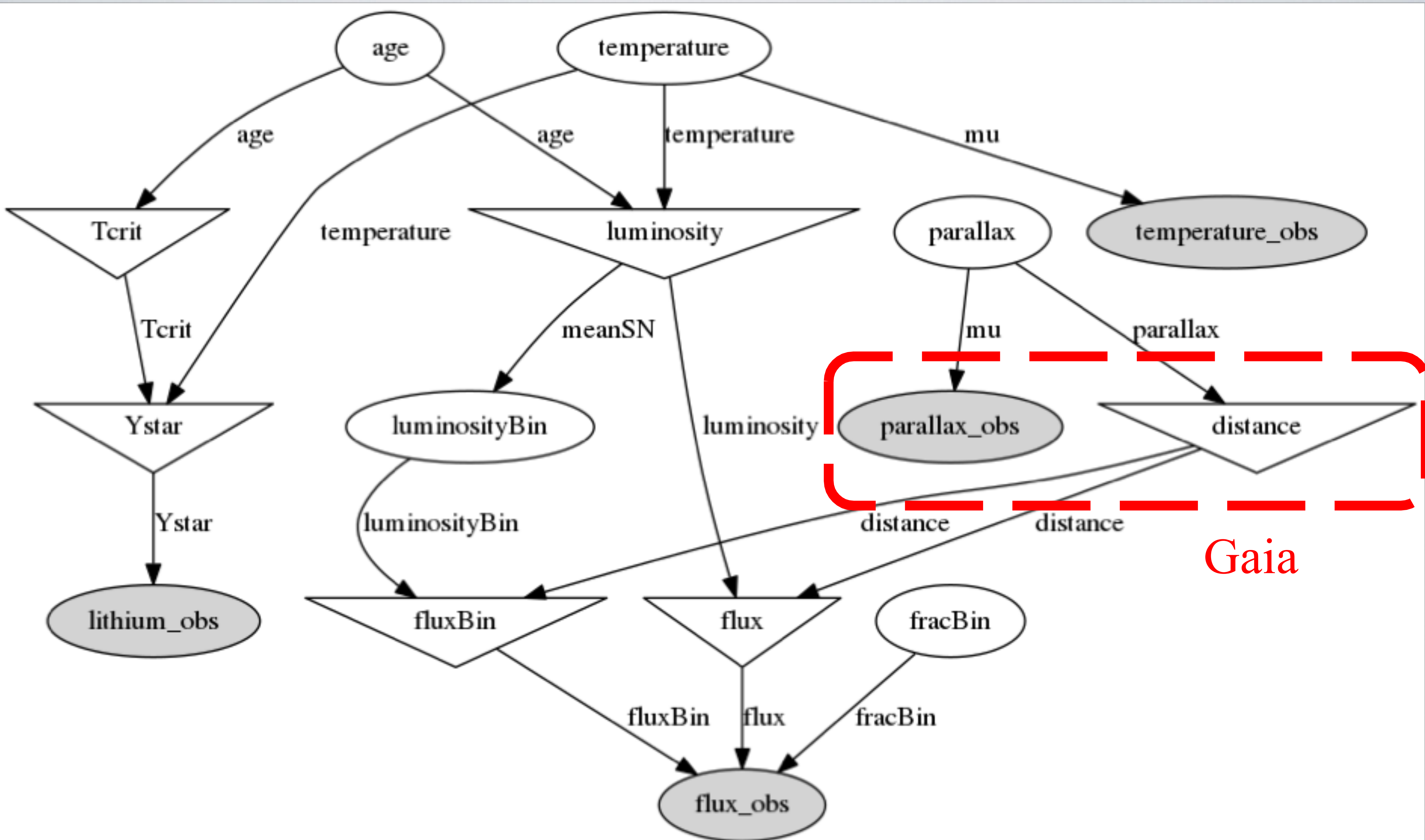
We will apply probabilistic modeling to do inference on the parameters of interest exploring the parameter space and error propagation by using **Bayesian framework** (MCMC and/or Variational Inference).

The final aim is to be able **to judge the ability of an age scale to produce a robust posterior probability distribution of the ages**.

Bayesian techniques produce posterior distributions for very large number of initial parameters given the observations, and allow to assign proper credible intervals based on the sampling of the posterior distribution of the different parameters involved, as well as performing **proper model comparison and selection.**

Impact: age is a key parameter in order to understand the properties of the planet/s. We do need a reliable age scale.

A proper treatment of the LDB



Lalande et al. 2020, in prepr

DATA

PHOTOMETRY/PROPER MOTION

Gaia data.

Cosmic-DANCe: Bouy et al. 2013, multi-wavelength and multi-epoch archival imaging with large field-of-view in order to derive **very accurate proper motions** for very faint cluster members. It is the perfect complement to Gaia since it also probes young embedded stellar associations where Gaia is blind due to extinction. Key for the LDB age-dating.

Kepler/K2: Howell et al. 2014, very **accurate photometric time series** (gyrochronology and asteroseismology), especially for stellar associations and open clusters with ages from 1 Myr to 4 Gyr, as well as several globular clusters.

TESS: a similar but smaller and **quasi-All sky LC**, which will play a similar role.

SPECTRA

Gaia-ESO: tens of stellar associations and is collecting several hundred thousands spectra. Stellar parameters (**lithium, metallicity, radial velocity, temperatures**, equatorial velocity, etc) are derived in a *homogeneous way*.

Archives: From **high resolution spectrographs**: ESO, CAHA, OHP, LP, Keck

New spectra: LS/FEROS, CAHA/CAFE, OHP/SOPHIE, GTC/OSIRIS&MEGARA

The culprits

Beta Pic MG

PscEri/MFA1 MG

Pleiades

M39

M35

Hyades

…

20 Myr

AGE

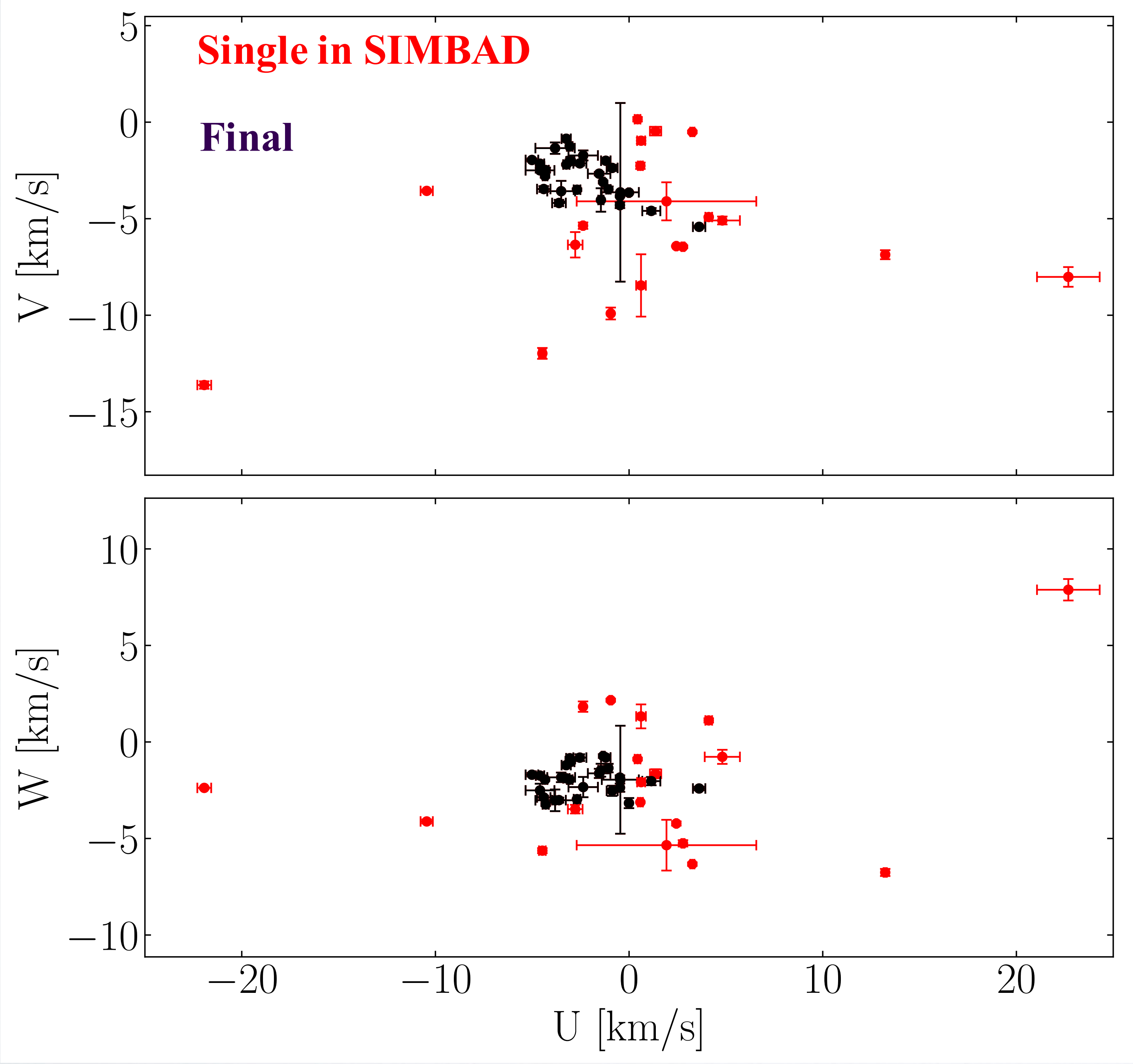
600 Myr

KINEMATIC AGES

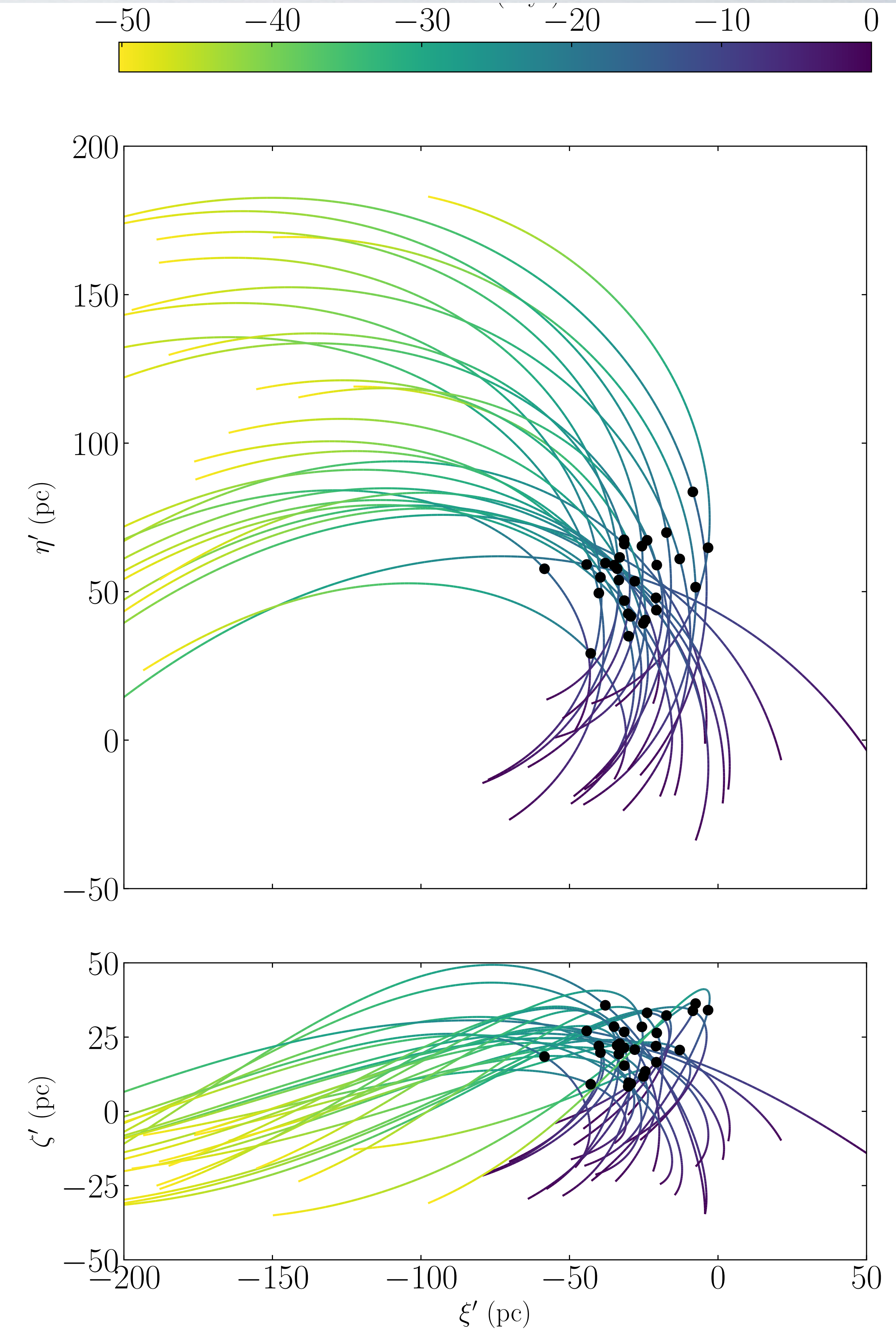
Dynamical Age of β Pic MG

Miret-Roig et al. (2020), in prepr

Kinematic selection of members

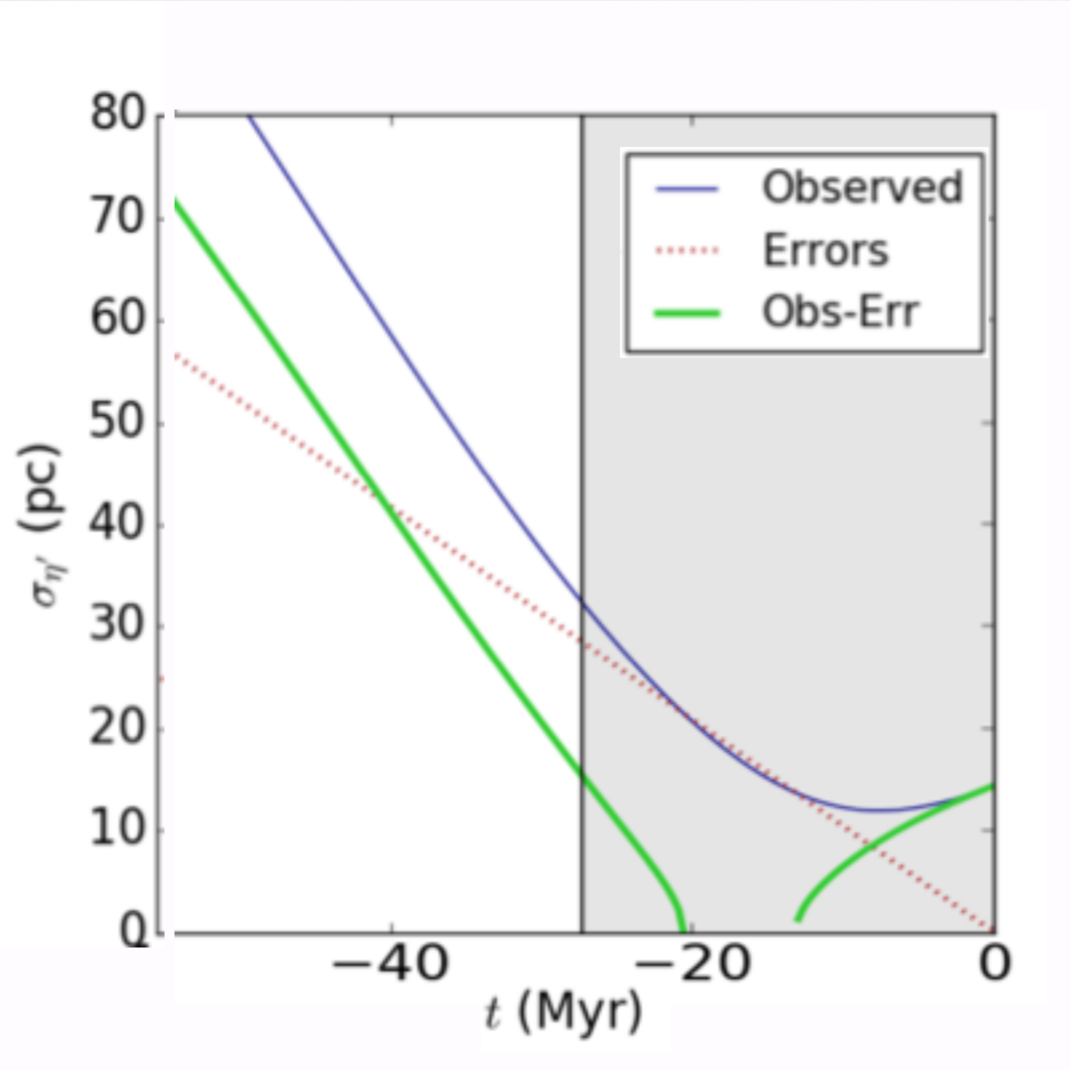


Orbital integration using a Galactic potential



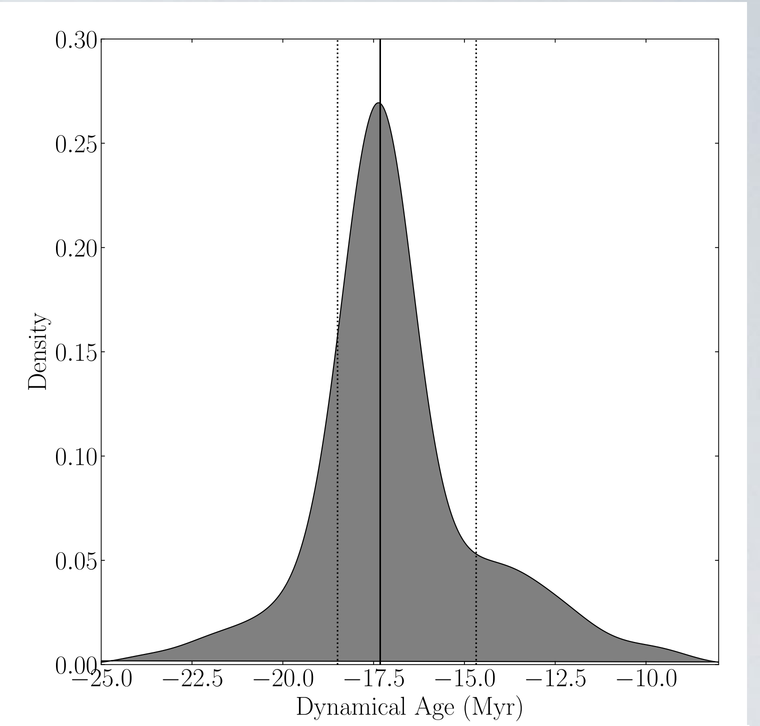
Orbital projection in the Galactic plane (top) and the vertical plane (bottom) of our sample of 29 members of β Pic.
M minimum dispersion at **−17.3 ± 2.6 Myr.**

Dynamical Age of β Pic MG



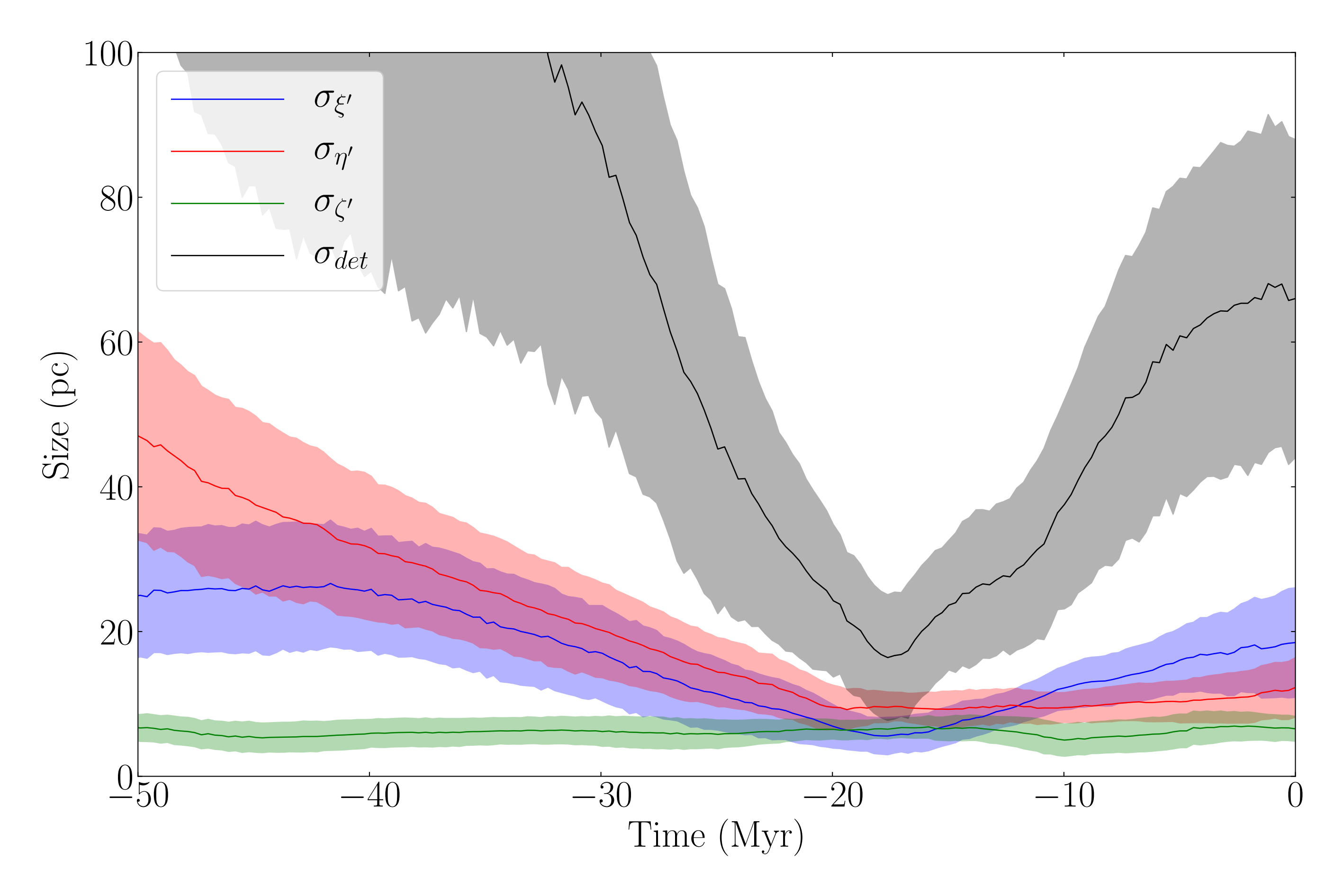
Miret-Roig 2018

- 21 members
- *Gaia* DR1 + RV literature
- *Analytical error propagation*



Miret-Roig et al. 2020, in prepr

- *Gaia* DR2 + RV consistently measured
- we started with over 80 targets, and rejected many because they were: rejected as non members or SB1/SB2 binaries
- 29 members
- *Bootstrap uncertainties*

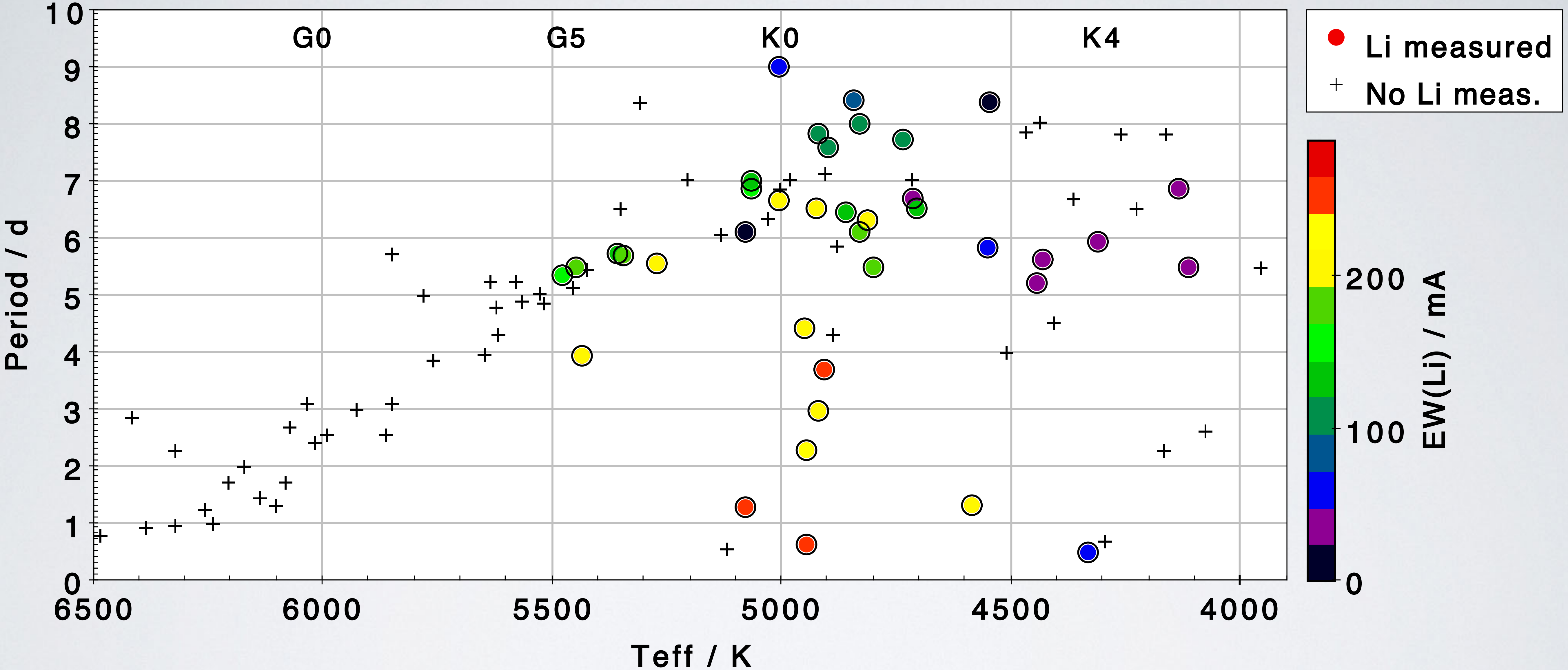


Size of β Pic as a function of backwards time. Represented in different colours are the size in the ξ′ (blue), η′ (red), ζ′ (green), and the determinant of the covariance matrix (black). The solid lines represent the median size with 500 bootstrap repetitions and the shaded areas represent the 1 − σ uncertainties.

Lithium Depletion in FGK dwarfs

PSc Eri / MFA1 MG: Lithium and rotation

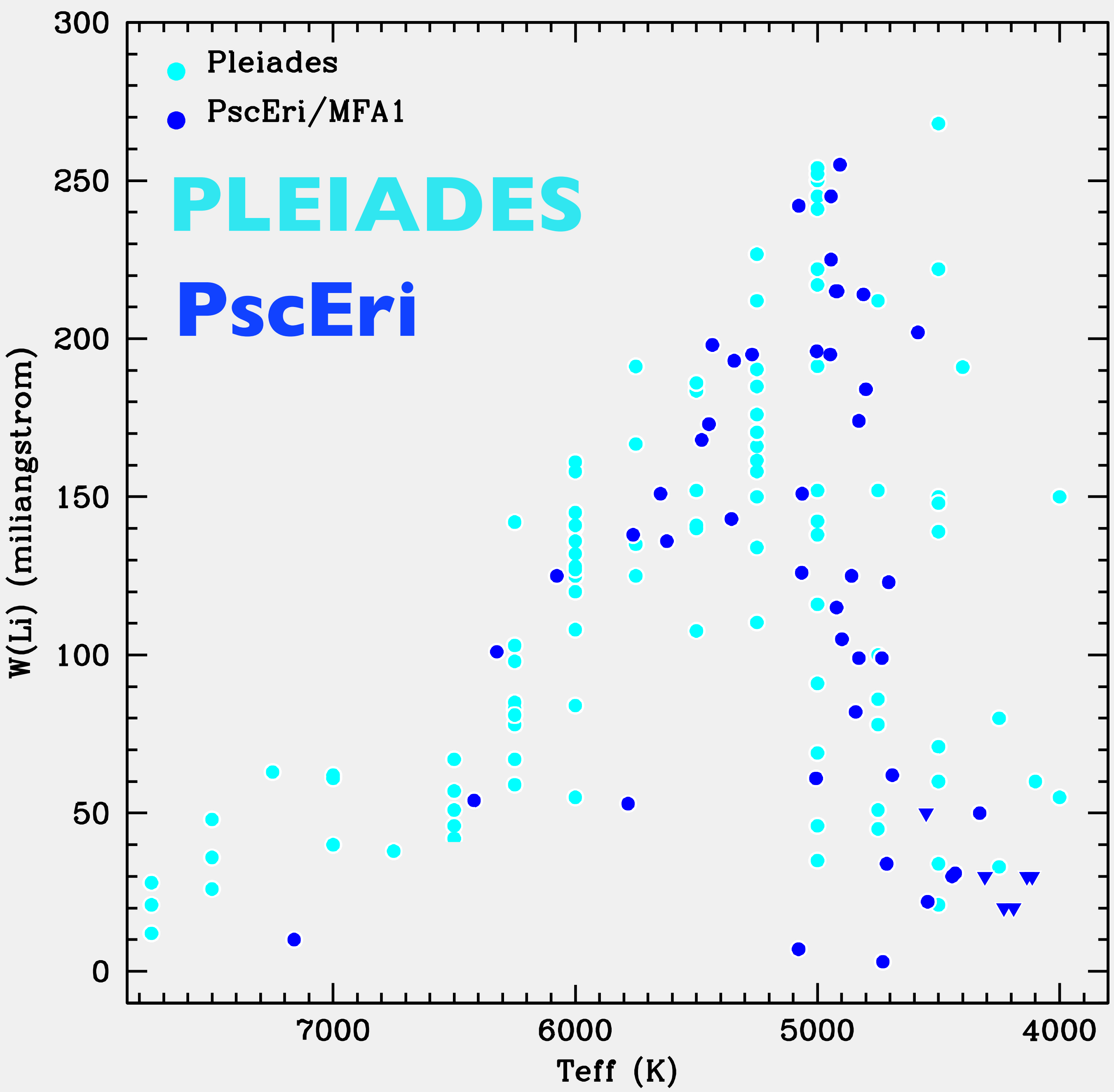
Same behavior as the Pleiades (*Bouvier et al. 2017, Barrado et al. 2016*):
The faster the rotation, the larger the W(Li)

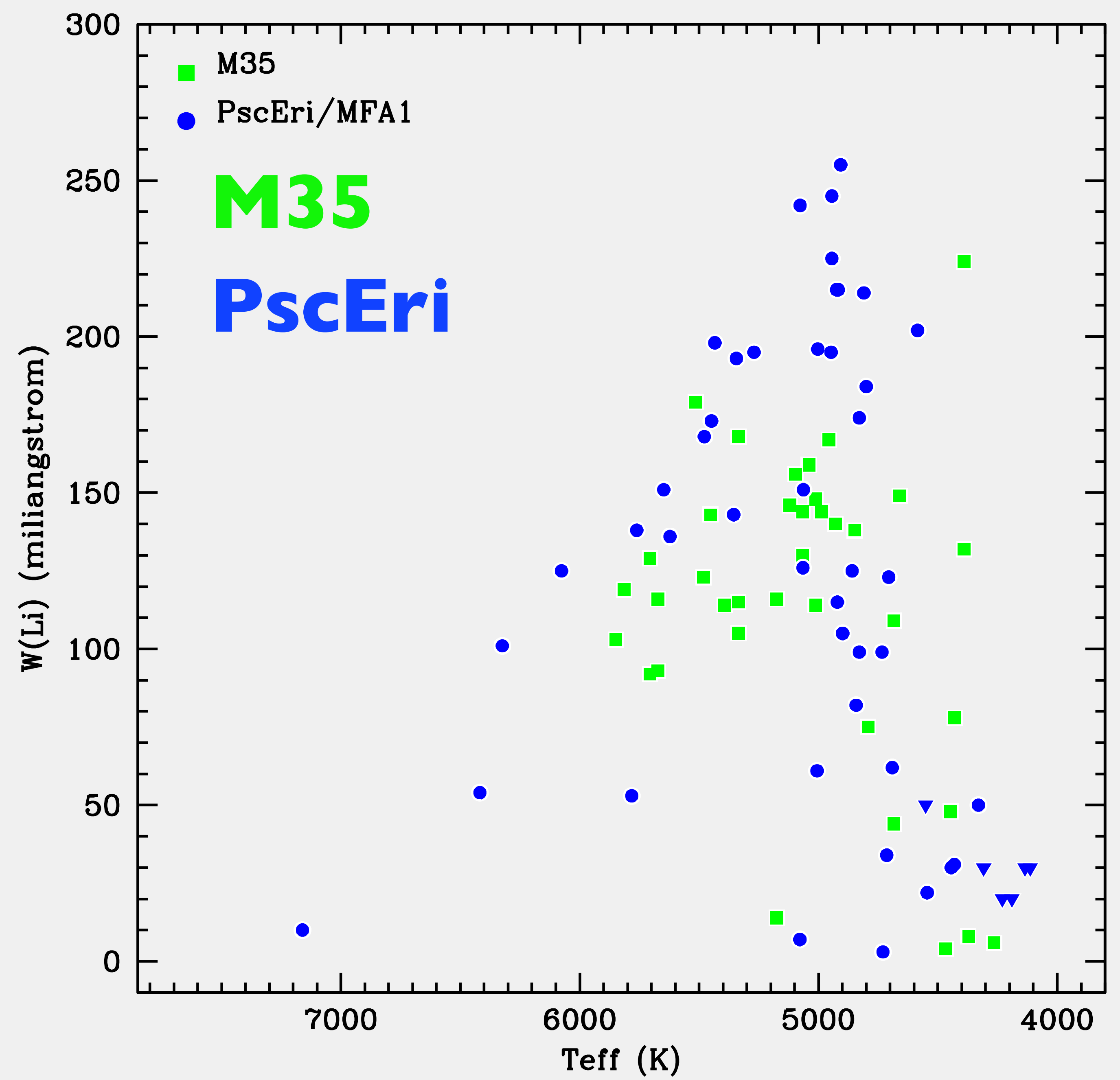


The rotational period distribution of low-mass members of the Psc-Eri stream is plotted as a function of effective temperature. *Filled circles:* stars with lithium equivalent width measurements. The color code scales with EW(LiI). *Crosses:* Stars without lithium measurement. A clear trend appears with the fast rotators being systematically more lithium rich than the slow rotators over the *T*eff range 4500-5100 K

Arancibia et al. 2020, submitted

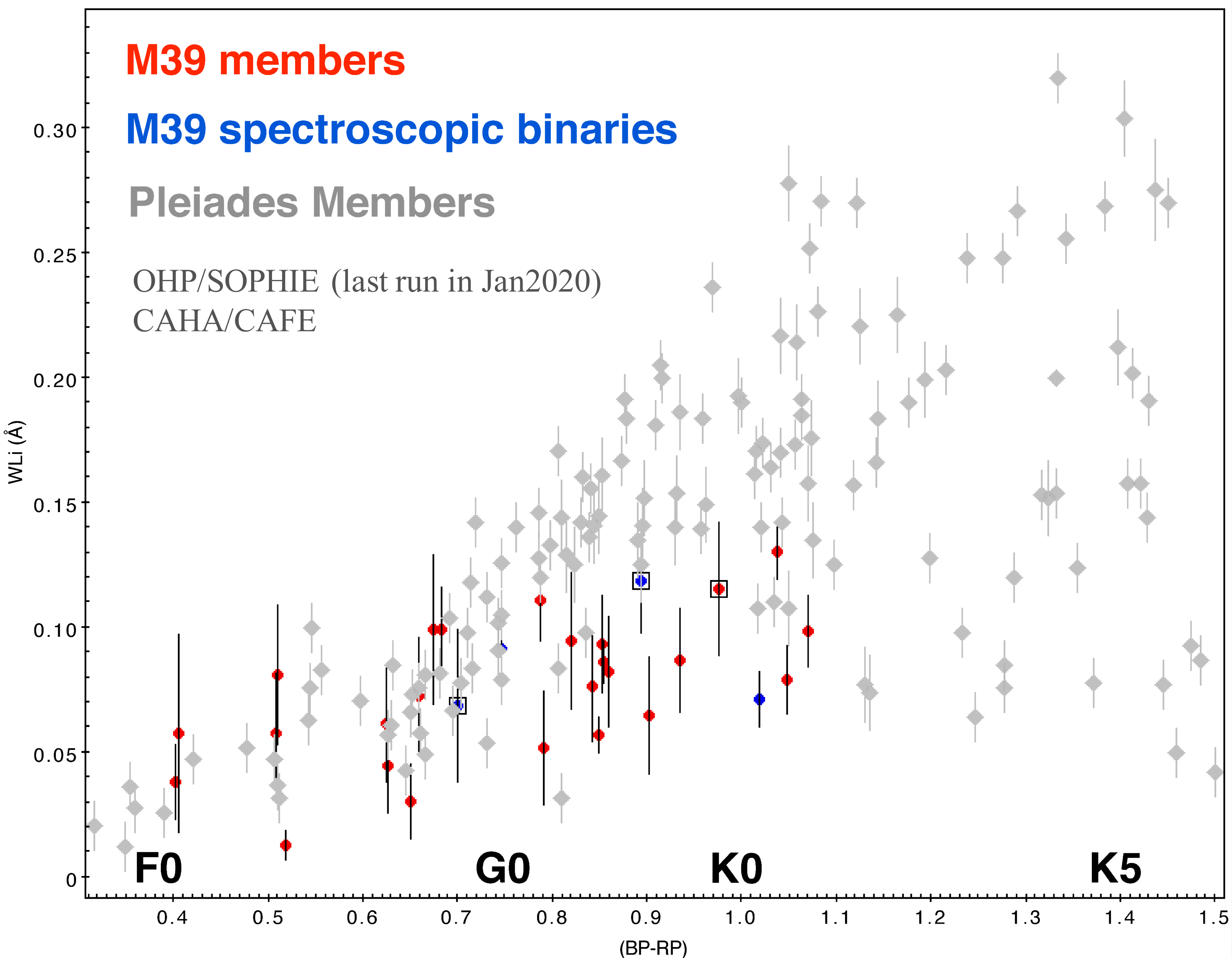
PSc Eri / MFA1 MG: Lithium and age





Empirical age: between 125 and 175 Myr

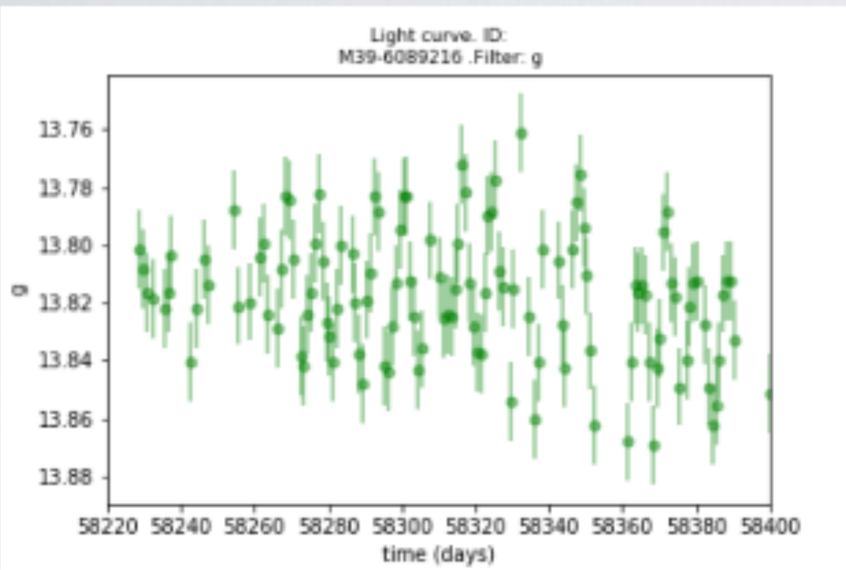
Lithium in M39

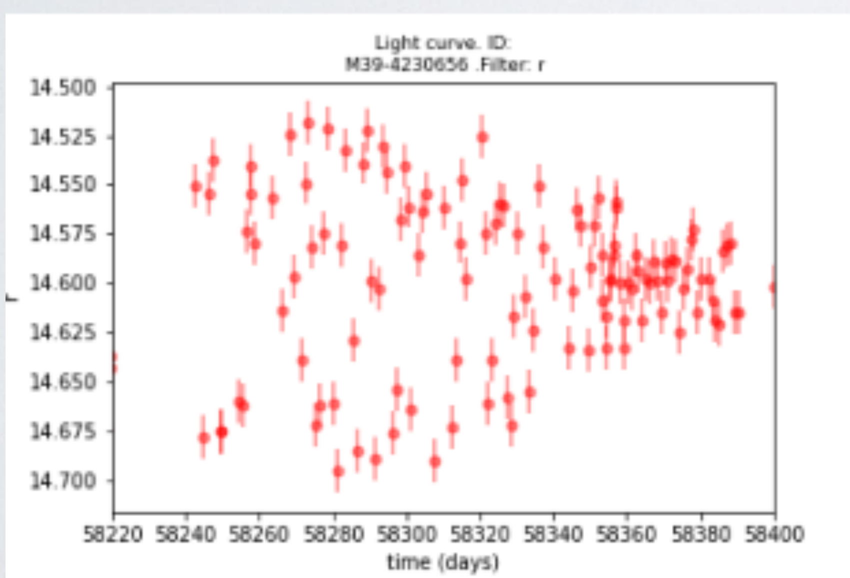


Rotation in M39

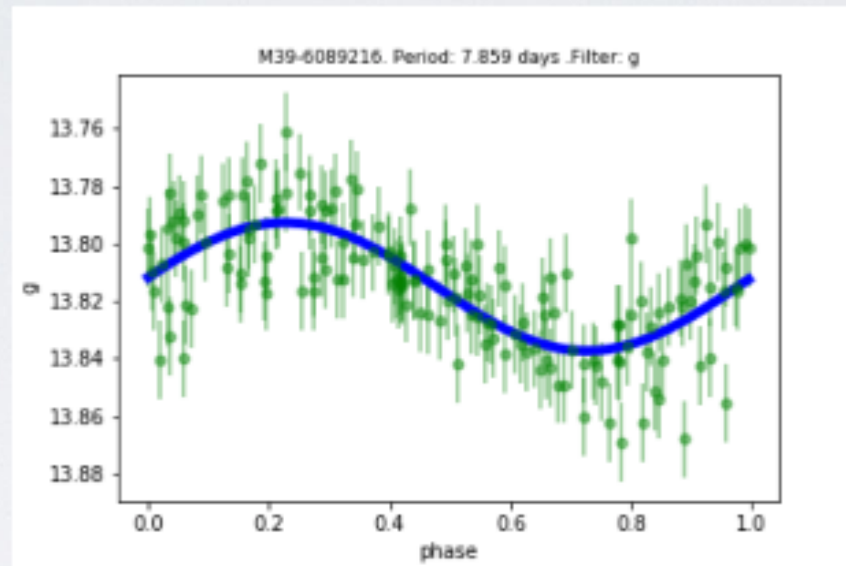
Data from Zwicky Transient Facility (ZTF)

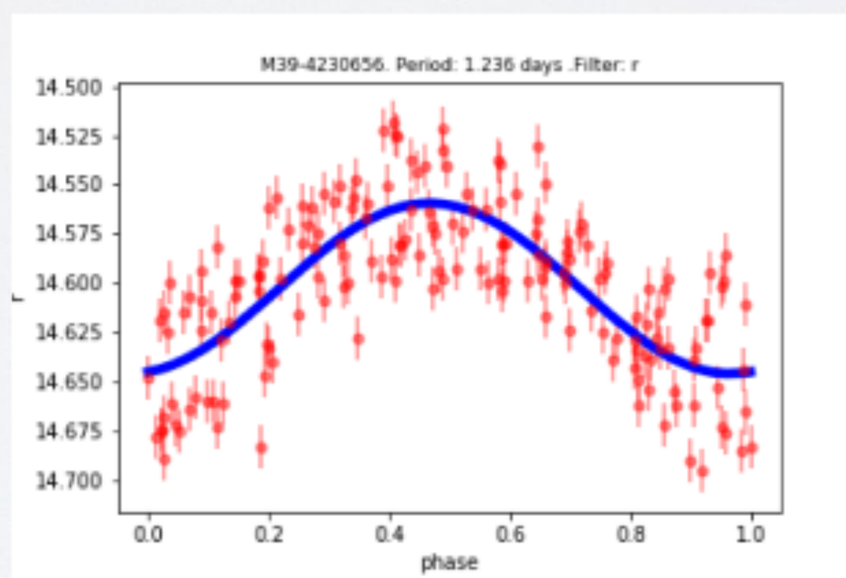
Light-curve:



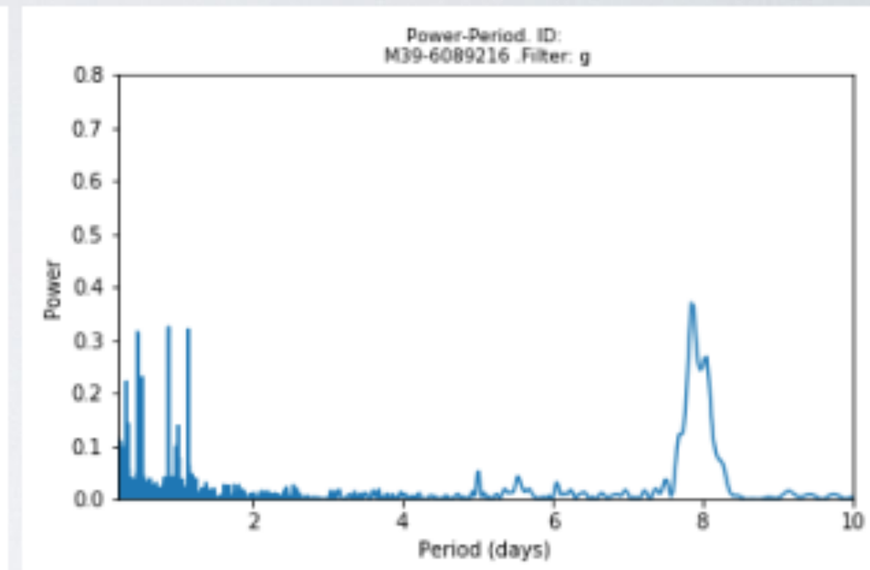


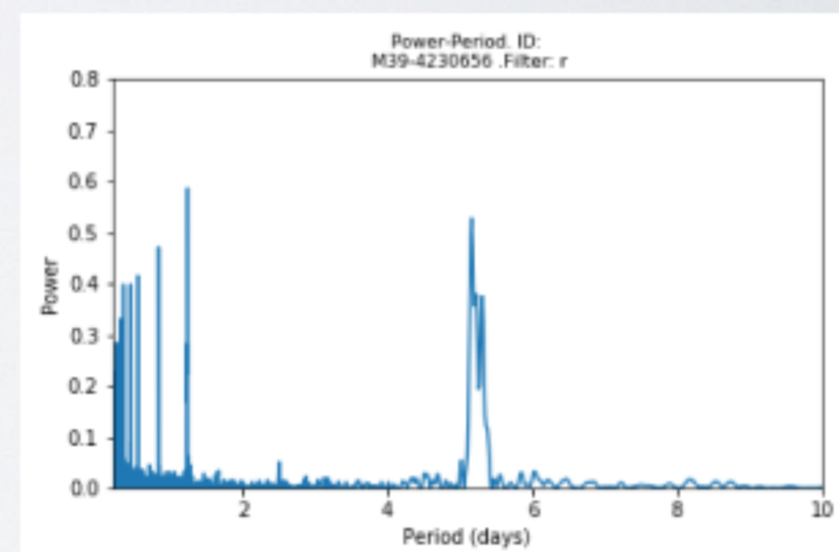
Phase-folded light curve:





Power-Period Diagram

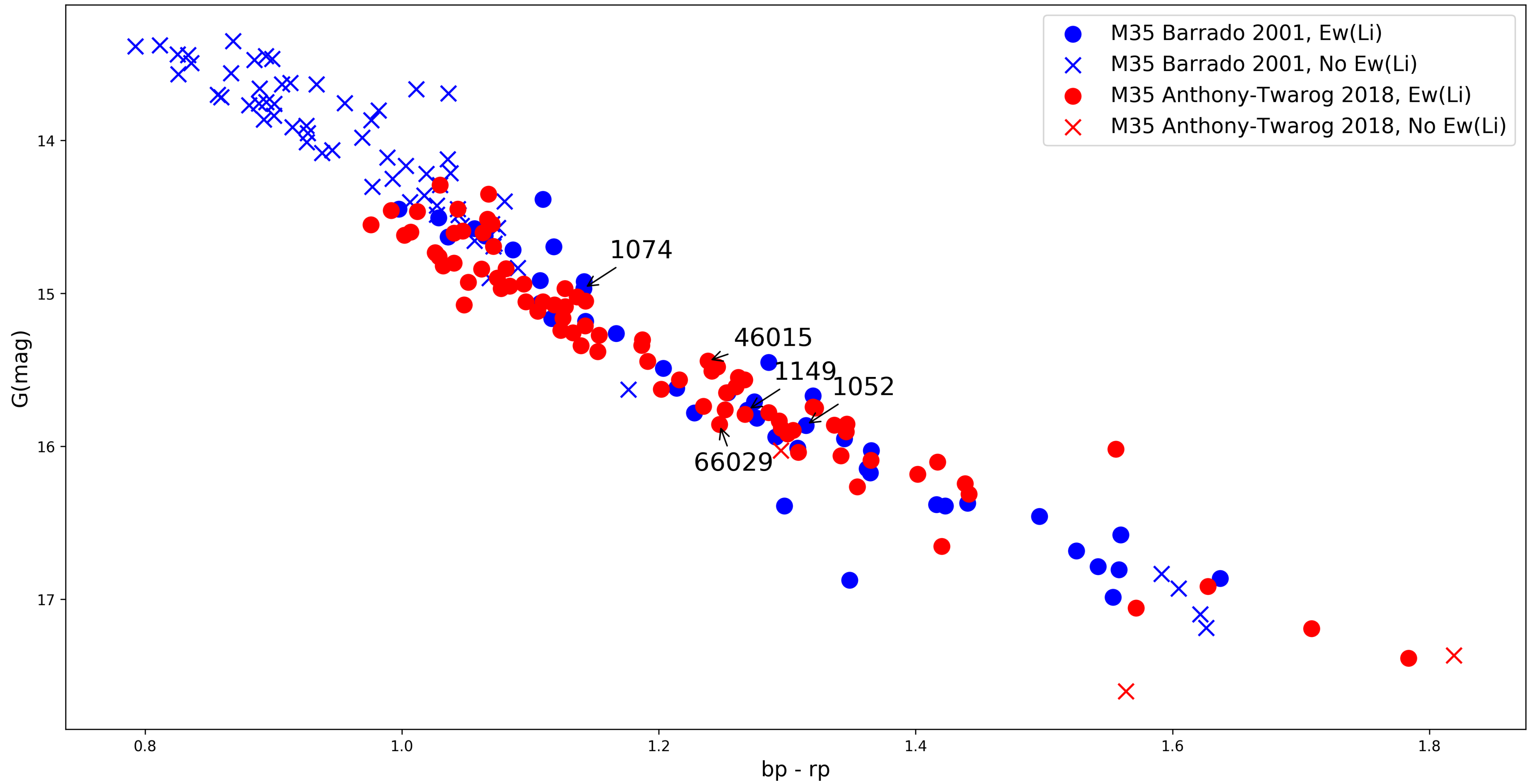


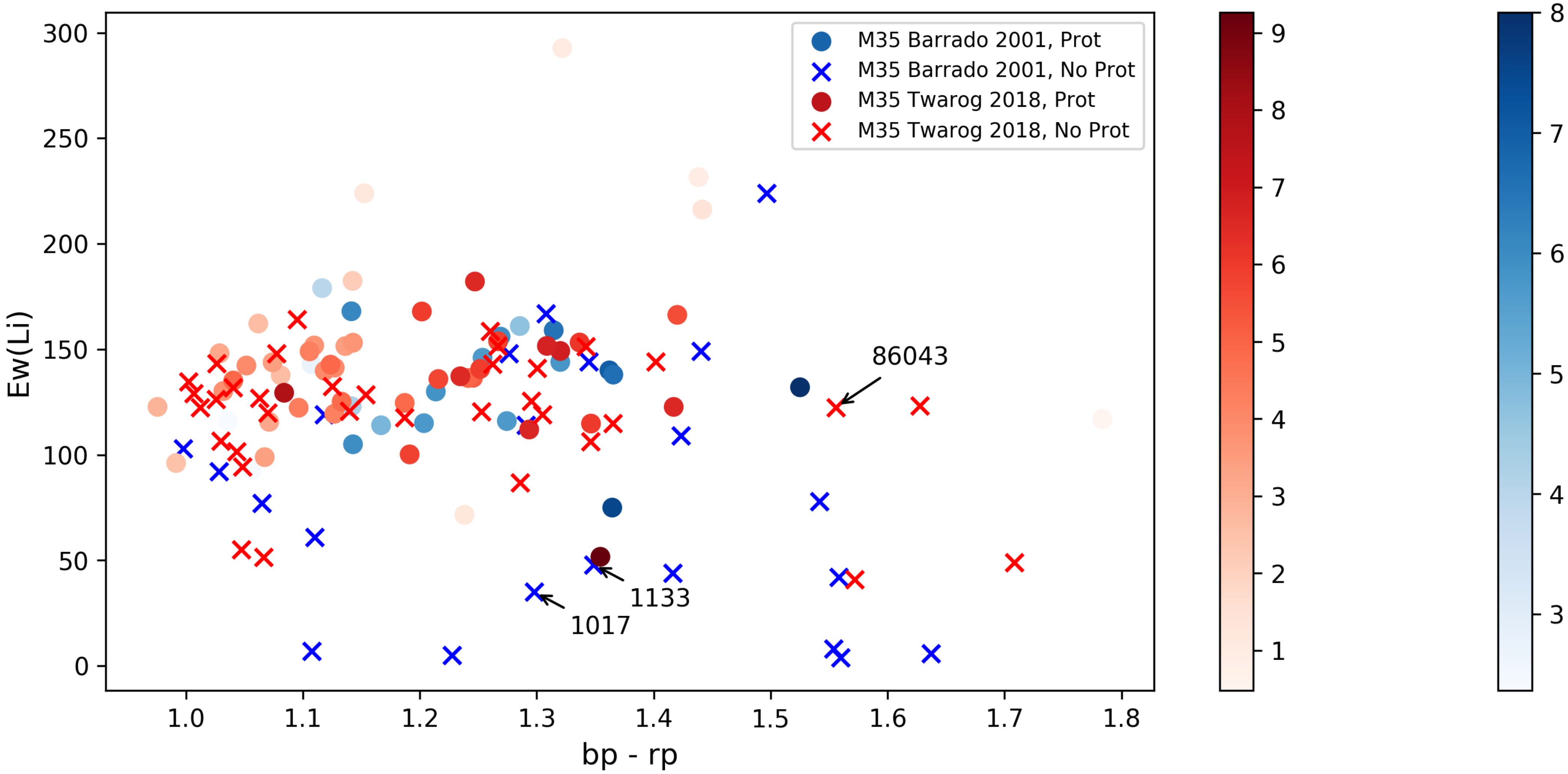


Alvaréz-Saavedra et al. 2020, in prep.

Lithium in M35

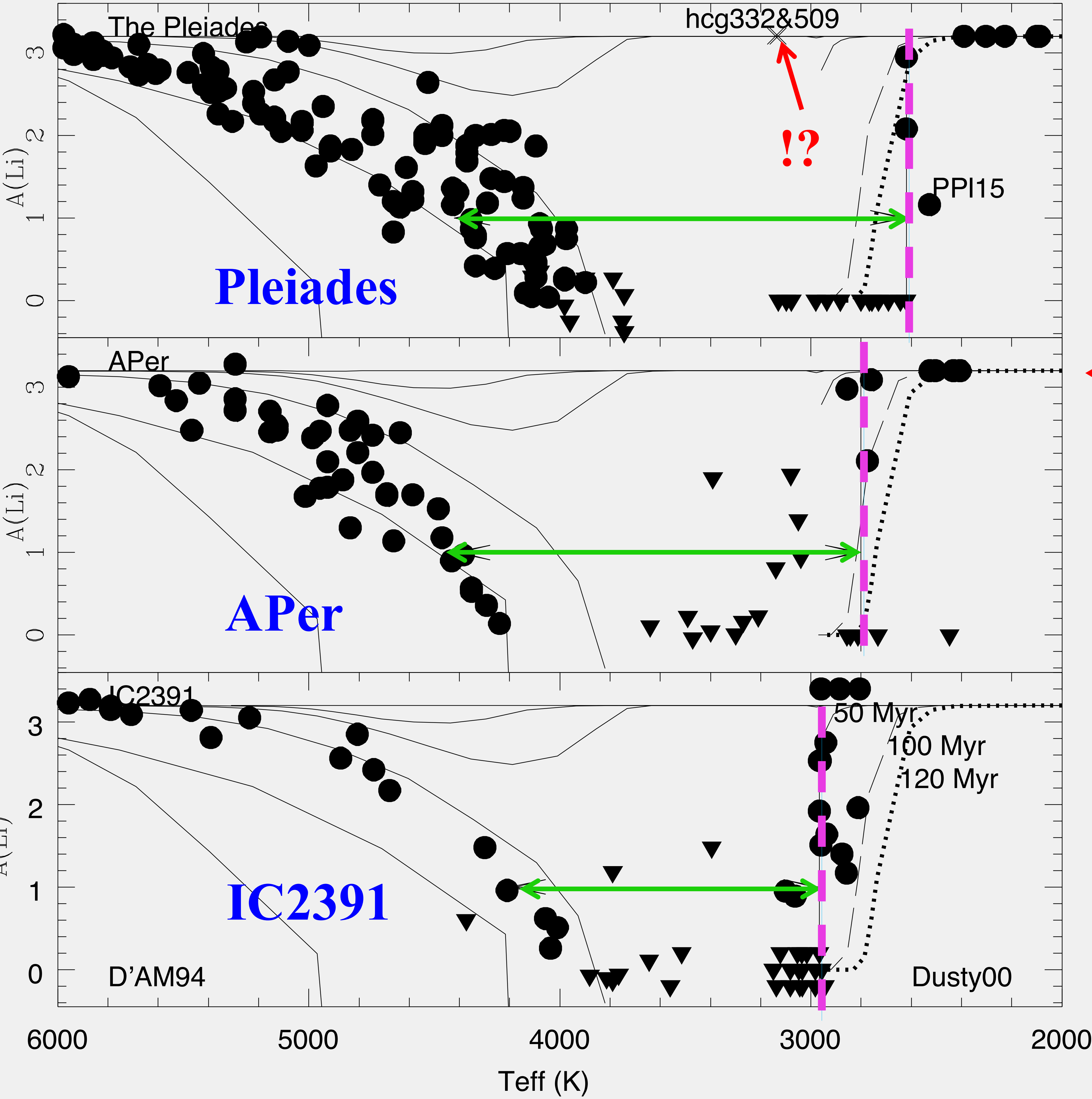
Cuenda et al. 2020, in prep.





Lithium Depletion Boundary in mid M

Lithium evolution: dependence on mass and age



A(Li)=3.1-3.2, the meteoritic Abundance

The lithium abyss increases its width with age

Barrado et al. (2004)

LBD in the Pleiades

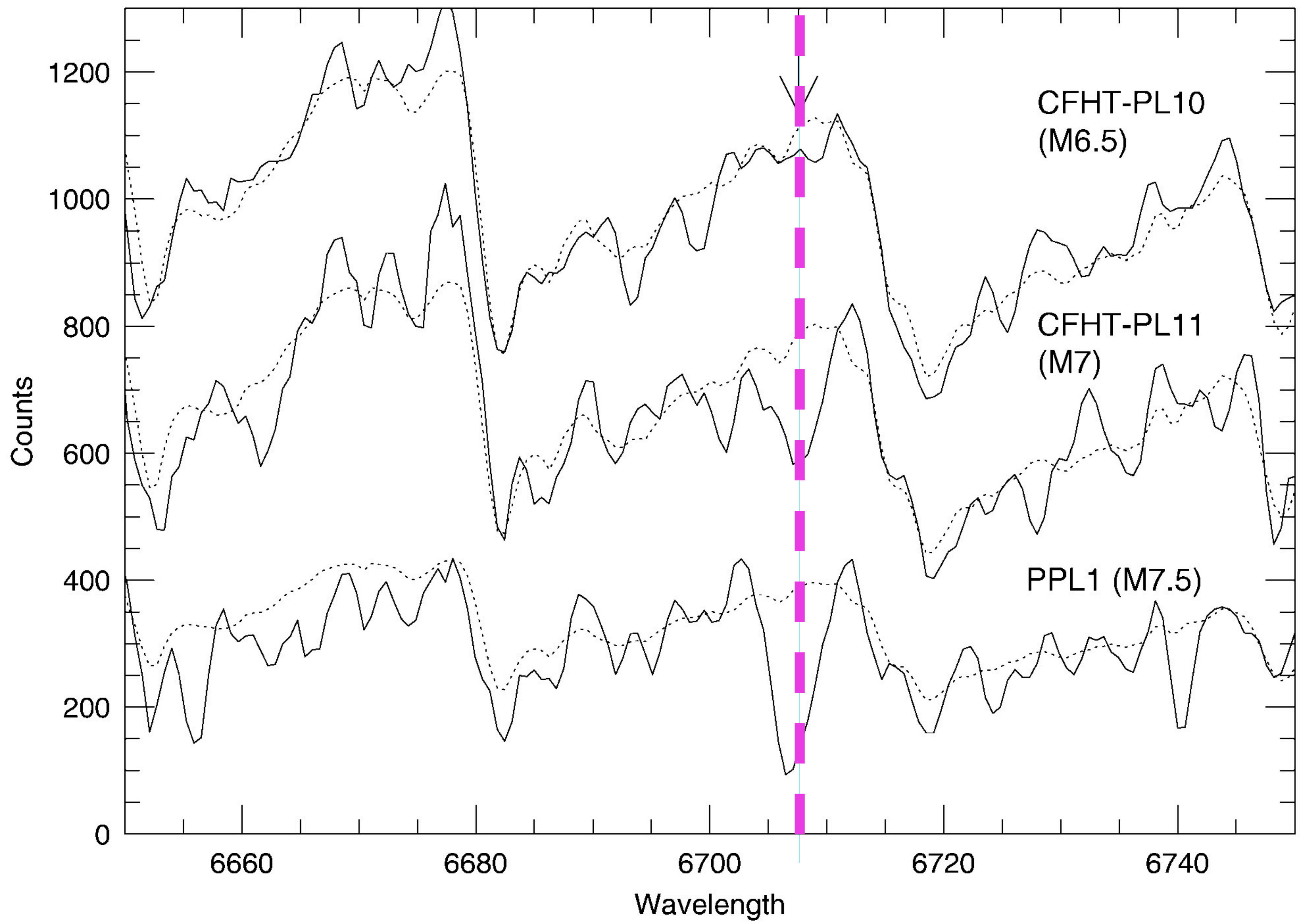
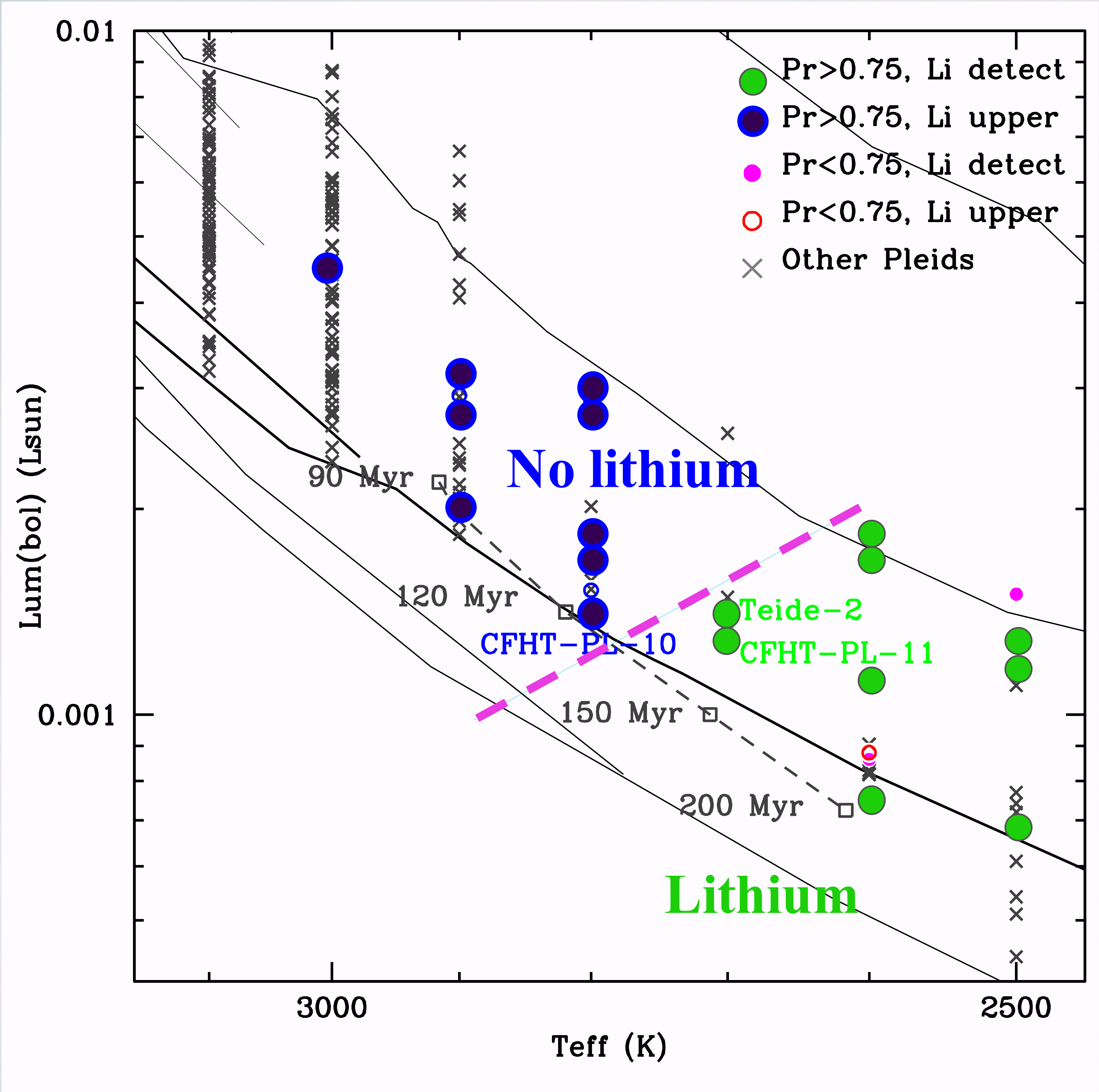
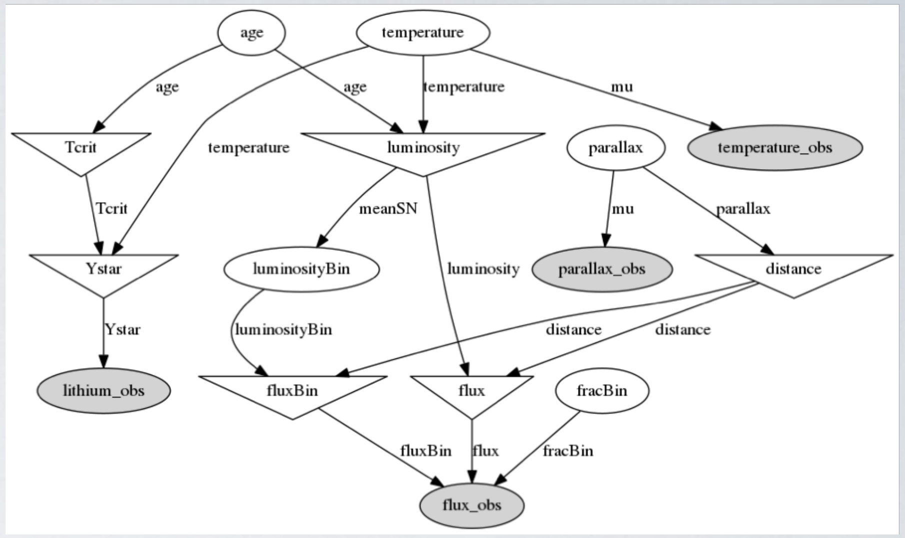


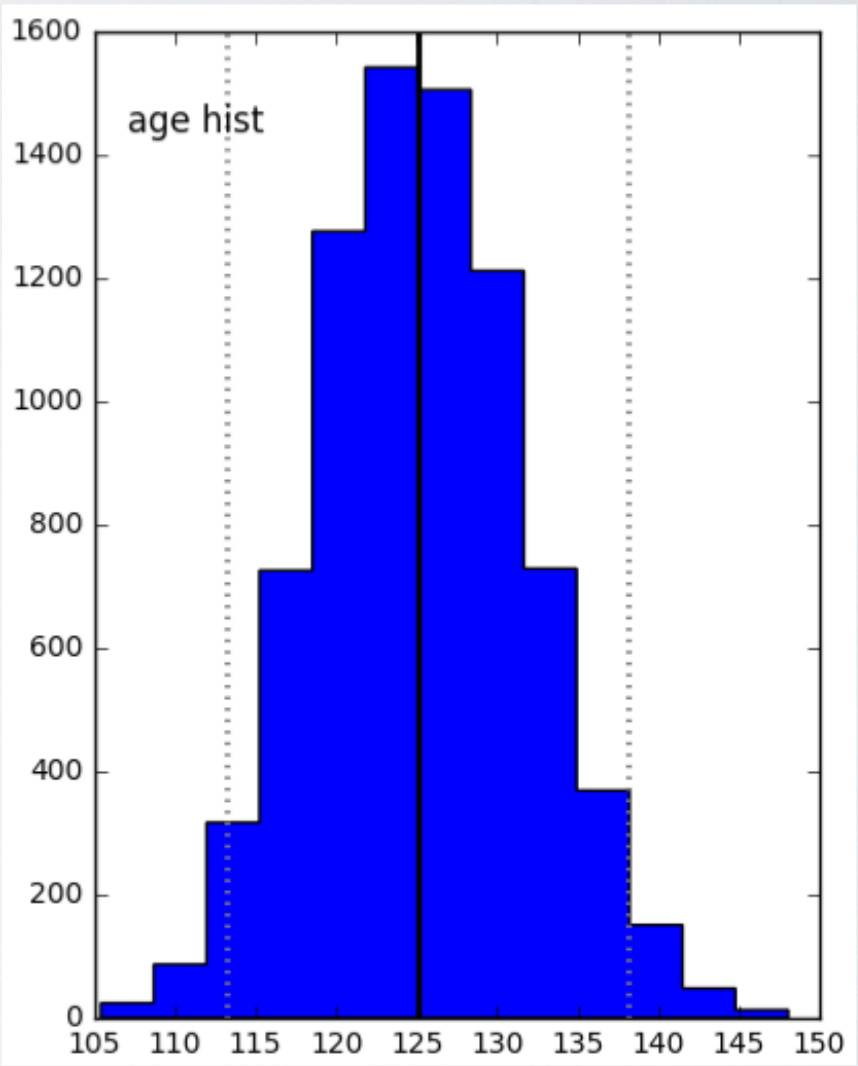
FIG. 1.—Sample spectra of Pleiades brown dwarf candidates obtained with the Keck II LRIS. The displayed wavelength region is only a small portion of the full spectrum, selected in order to highlight the lithium 6708 Å region. The *y*-axis is correct for CFHT PL 10, while the spectra of the other two stars are offset relative to CFHT PL 10 to avoid having the spectra overlap. The dashed line is a spectrum of GL 65AB, a field M6–M6.5 binary, assumed to have entirely depleted its initial lithium.

Stauffer et al. (1998)

DANCE: LBD in the Pleiades

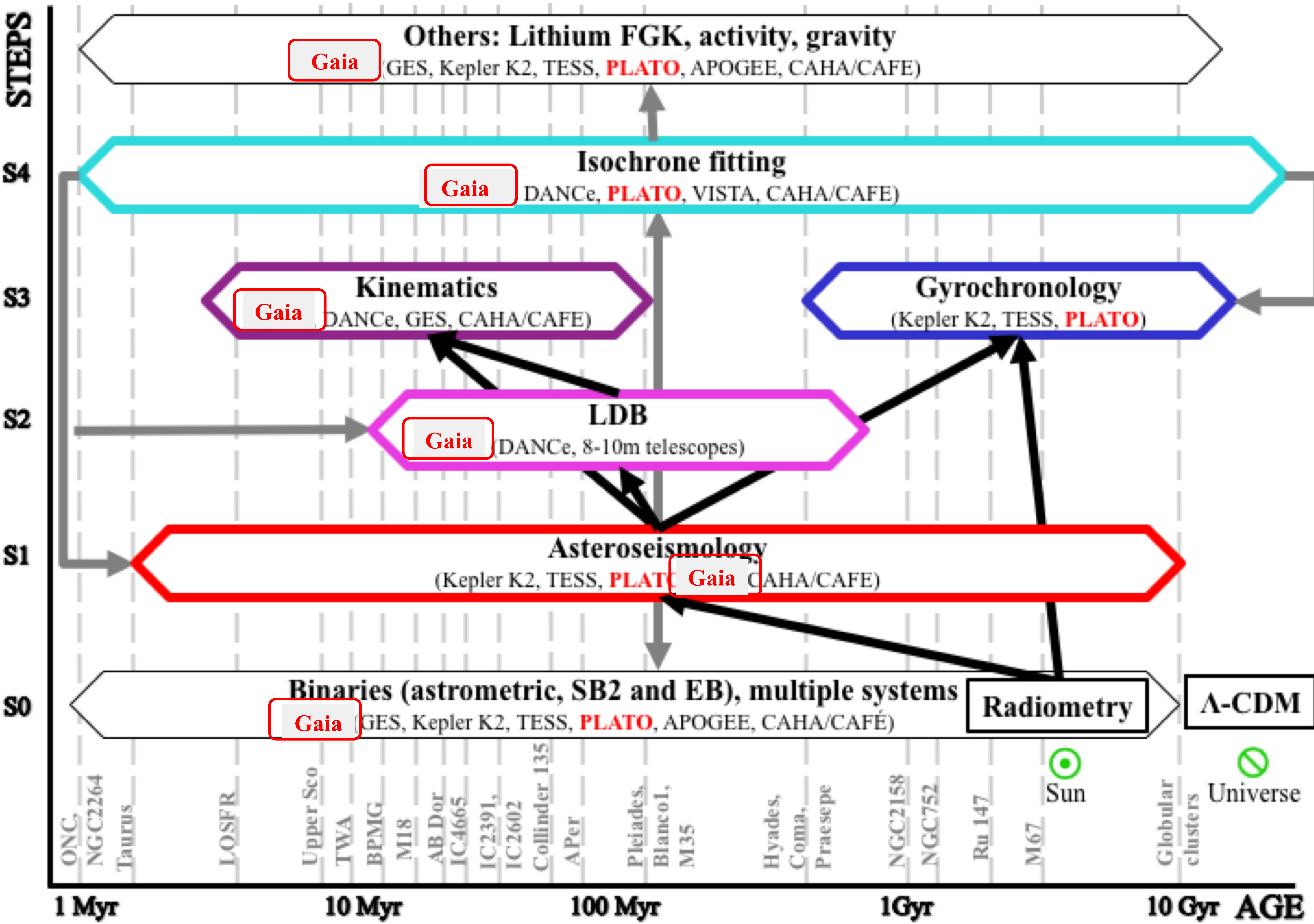






Sarro et al. (2014), Bouy et al. (2015), Lalande et al. (2020), Barrado et al. (2020), in prep

PLATO and Gaia impact



Questions?

Moltes gràcies!