ASTR 511

Galactic Astronomy

Lecture 09

Star Formation History

Prof. James Davenport (UW)

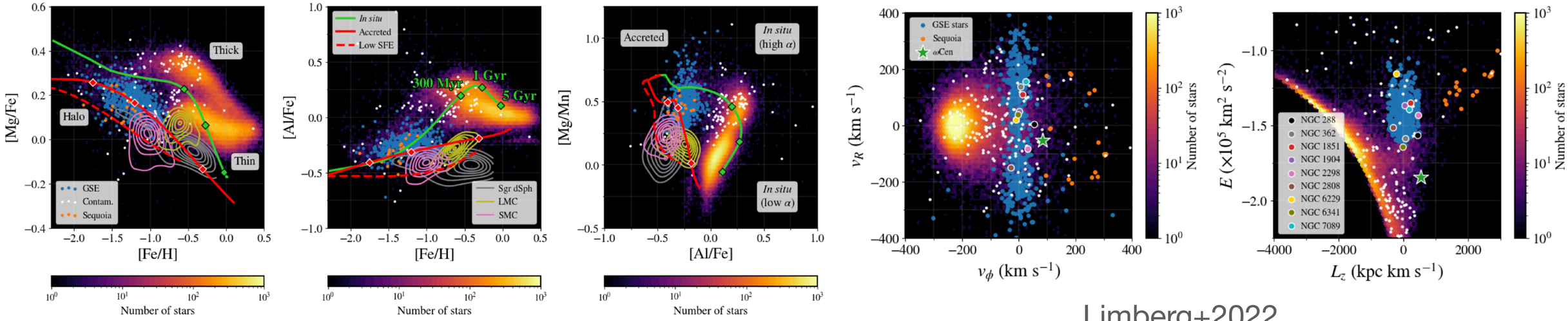
Winter 2023

What is a “Star Formation History”?

- Classically – assuming stars form in a relatively “closed-box” model (i.e. within the Milky Way)
  - **measure the age distribution of stars** (or some proxy or age)
  - Using knowledge (assumptions) of e.g. the IMF, from age distribution of stars you see extrapolate the total # of stars formed over time
- The SFH is tracing star formation rate, and periods of high or low star formation activity over ~13 Gyr
  - i.e. to first order, how efficient is the disk/arms at forming stars over time?

What is a “Star Formation History”?

- But we KNOW the Milky Way is *not* a closed box…



Limberg+2022

- So is SFH of the MWY really just mapping the *accretion* history, or does it trace the in-situ formation?

- **Answer: Both**

Today: Ages of Stars & SFH

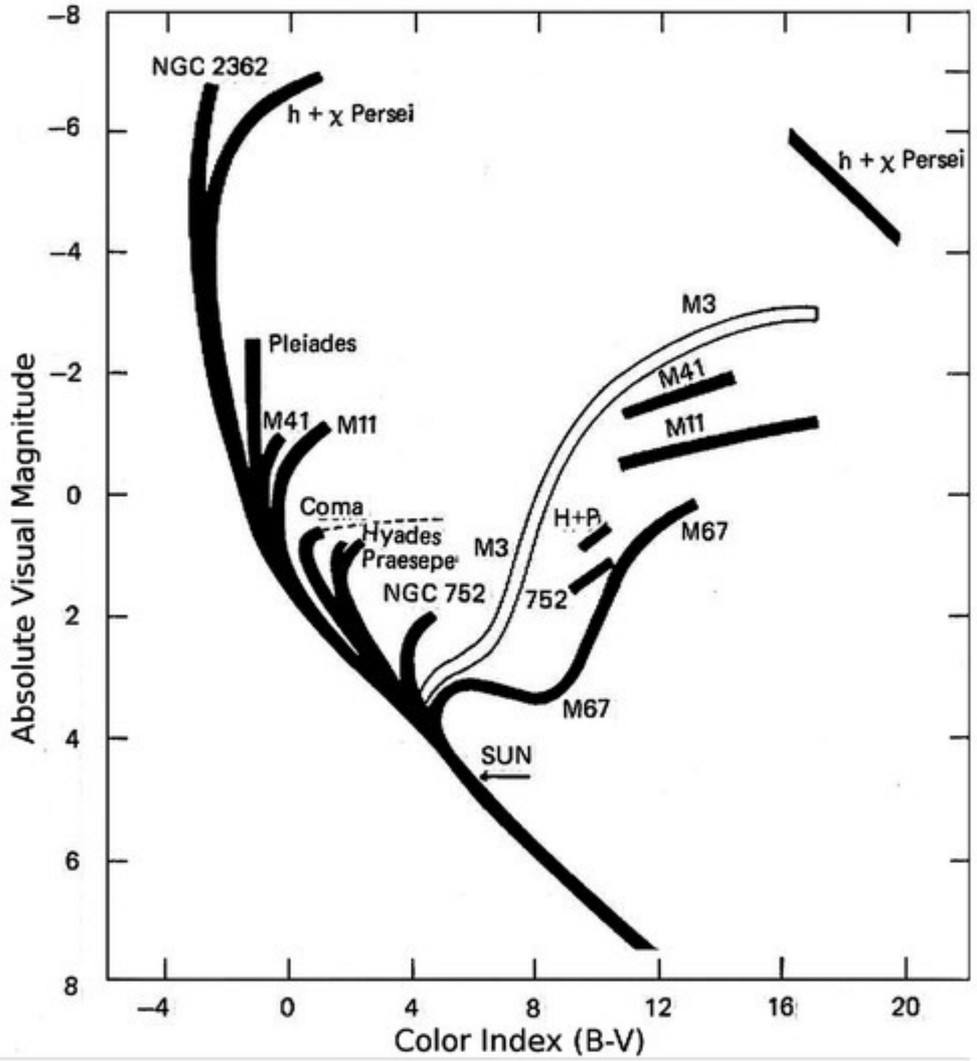
- How do we measure the age of individual stars in MWY?

- How do we statistically estimate the age distribution (i.e. SFH)?

Ages of Stars

- SFH should be simple enough if we can just measure the ages of all the stars… right?
- This is a notoriously ~~hopeless~~ difficult problem.
- Uncertainties of 10-50% are considered good, probably impossible to do better for some stars (Soderblom 2010)
- Clusters are the only “good” ages
- Ages are fairly easy for some stellar masses at certain phases of their evolution… but very hard for *most* stars over *most* of their lives

Ages of Stars

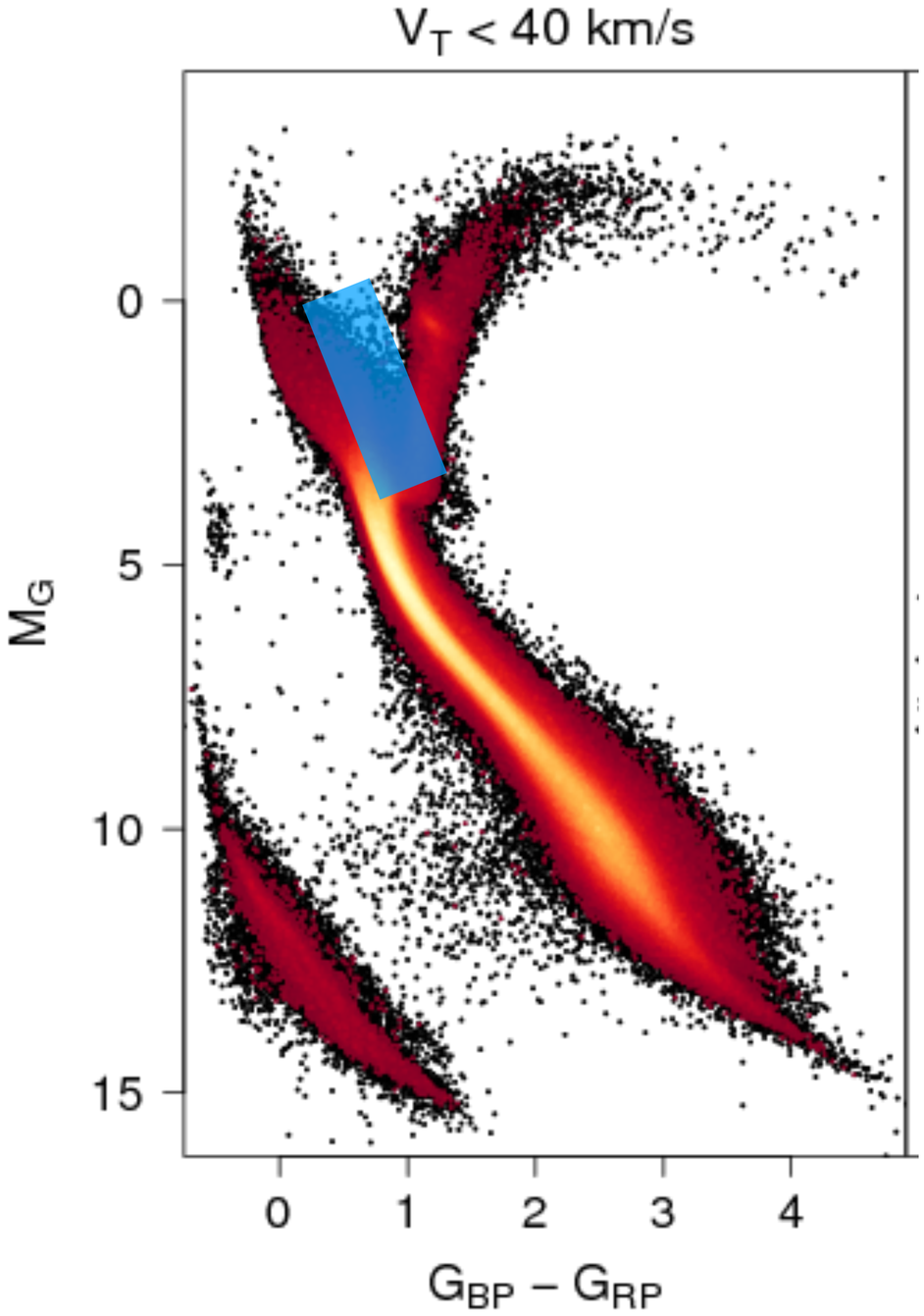


Sandage (1957)

- Clusters are the best age indicators
  - finding clusters/groups/associations with Gaia VERY helpful for measuring age distribution of disk
- For clusters: turn-off is the most age-sensitive feature (see HW 2)
- Can’t easily identify “turn-off” stars in the field/disk…
  - But the related sub-giant phase is easier!

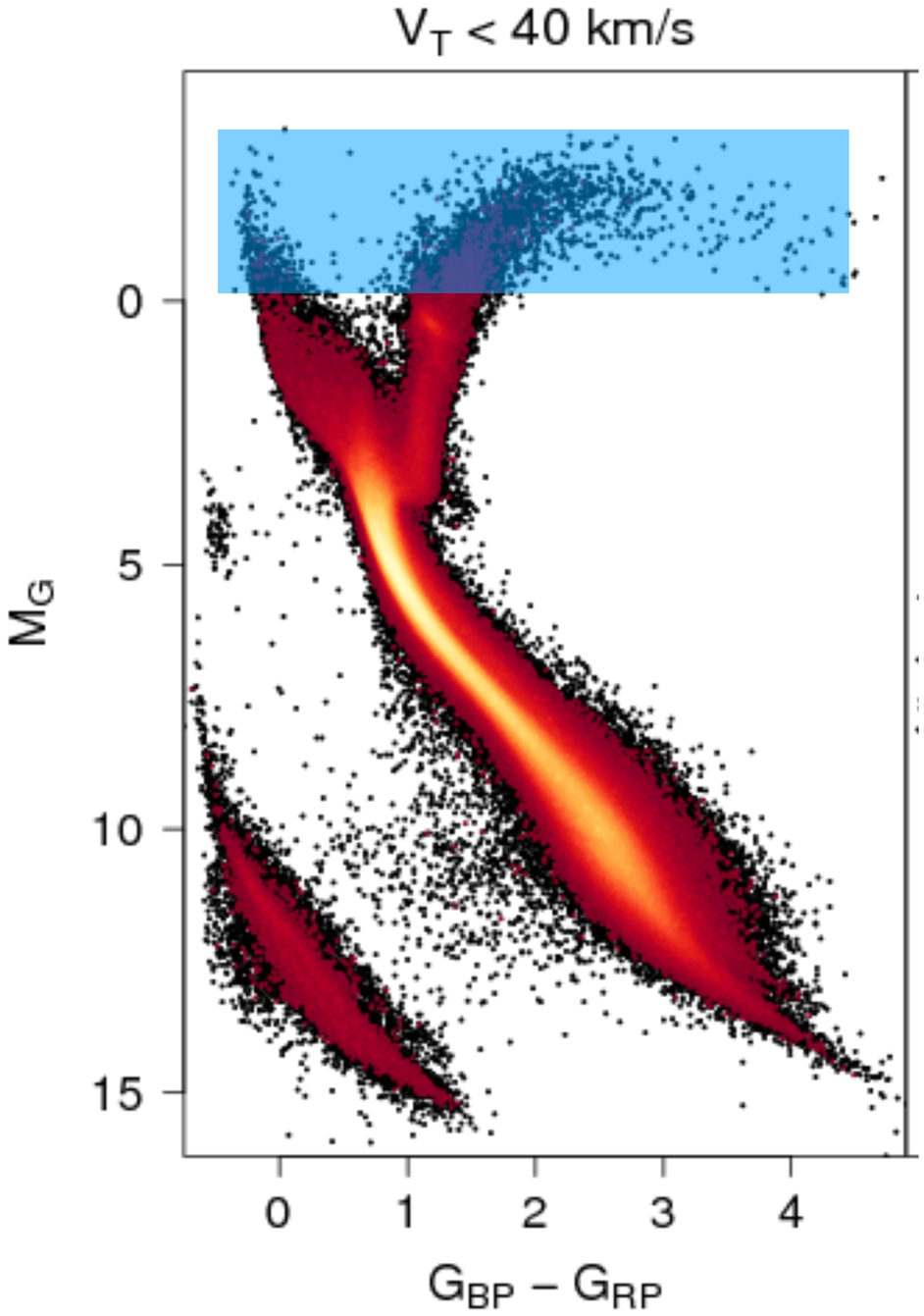
Ages of Stars

- Sub-giant stars… verrrry interesting!
- Short-lived phase of star's life
  - Unfortunately quite *late*
- Position on CMD relatively deterministic based on mass



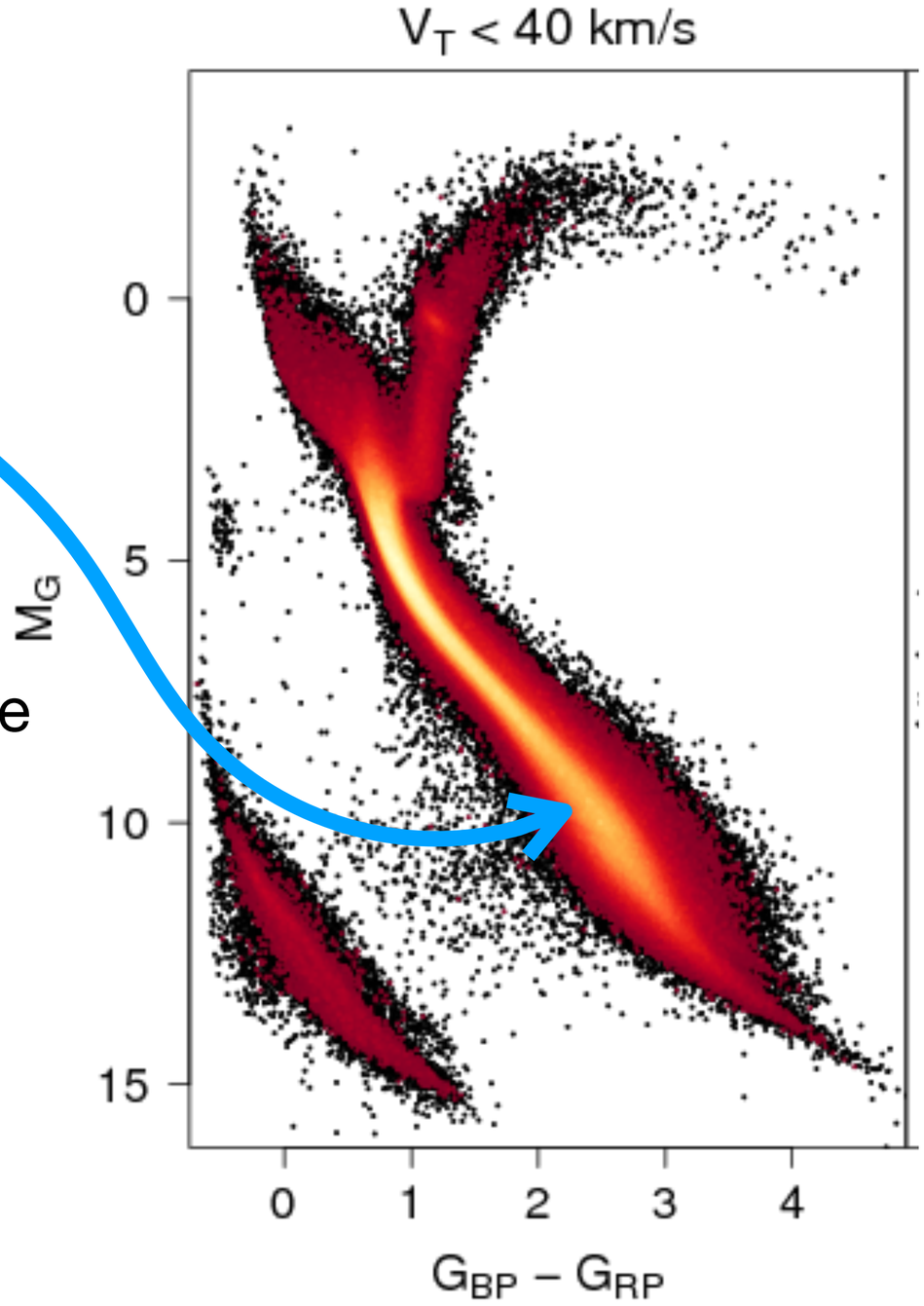
Ages of Stars

- How old are these stars?
- Massive stars don’t live long… that’s very helpful age anchor here!
- Not *too hard* to get a rough age constraint here, evolutionary tracks are very dramatic



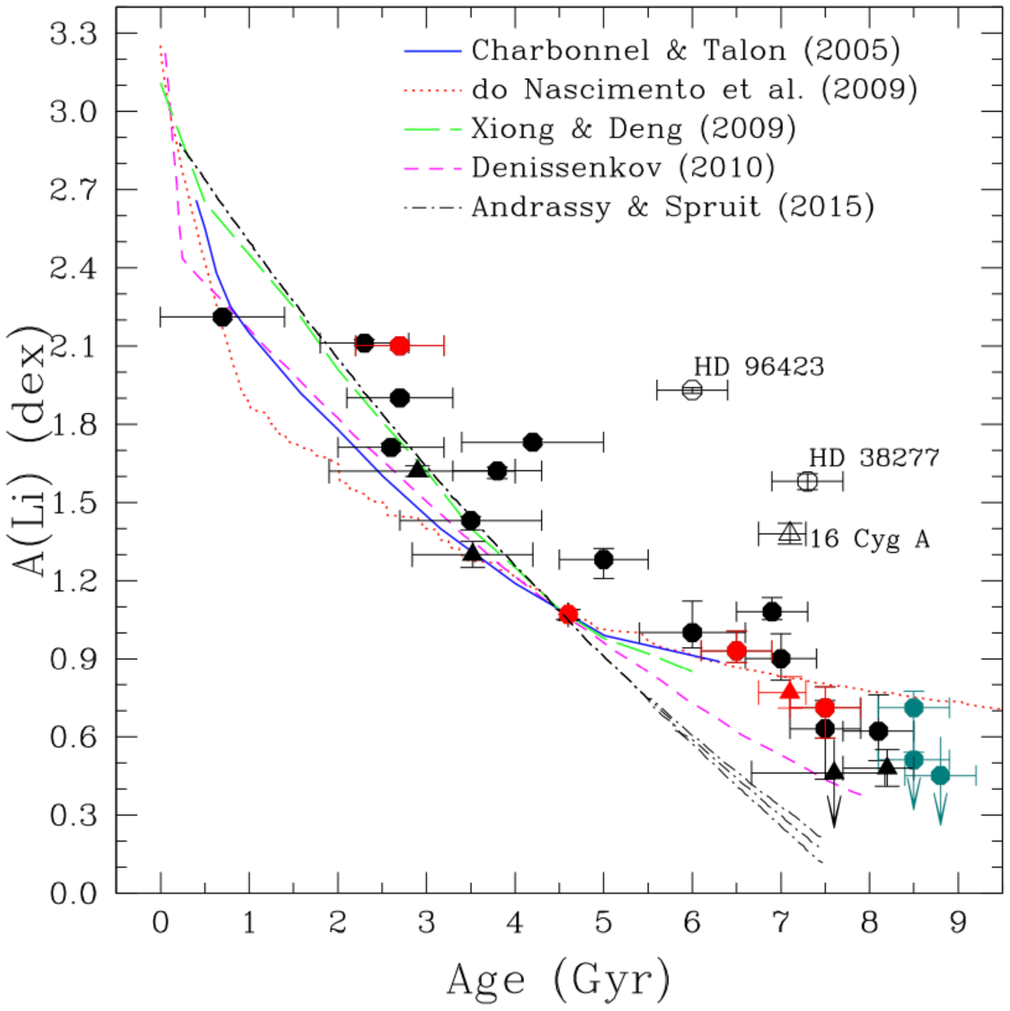
Ages of Stars

- How old is this star?
- Low mass main seq. stars don't change much over their lives…
  - Majority of stars in the galaxy,
  - they live "forever" (i.e. should be more pristine or direct tracers of SFH)
  - **Almost impossible to age date**



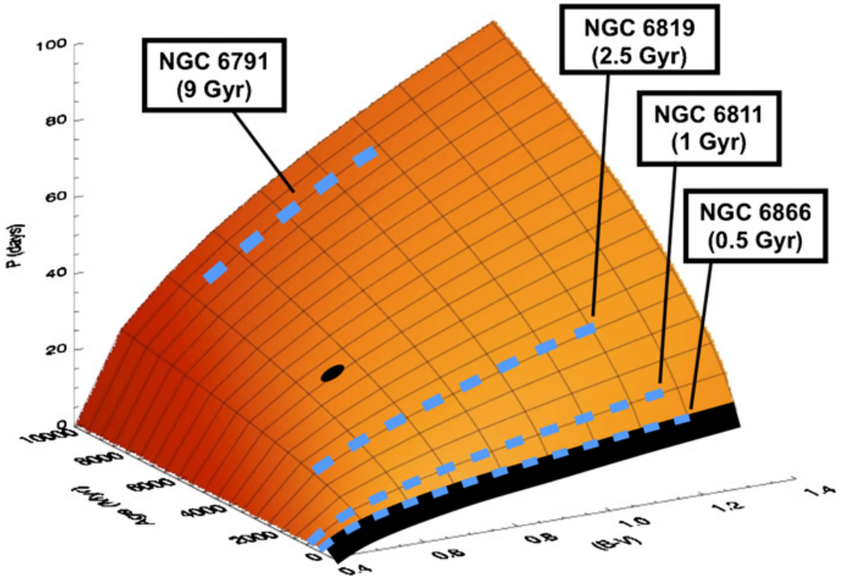
Ages of Low-Mass Stars

- **Some chemical indicators of age**
  - Lithium is easily destroyed in stars, abundance declines strongly with time (e.g. Carlos+2016)
  - But is hard to measure



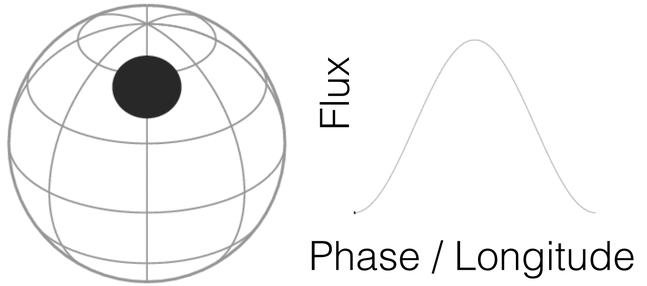
Ages of Low-Mass Stars

- **Rotation of stars**
- Stars lose angular momentum over time, this “spin-down” is maybe useful as a clock
  - Gyrochronology (Barnes 2003)
- Idea established over 50 years ago! Skumanich (1972)
- How good is this clock?
  - Depends on what the initial rotation is, how constant the angular momentum loss (wind) is, how well you can measure rotation, tidal disturbance

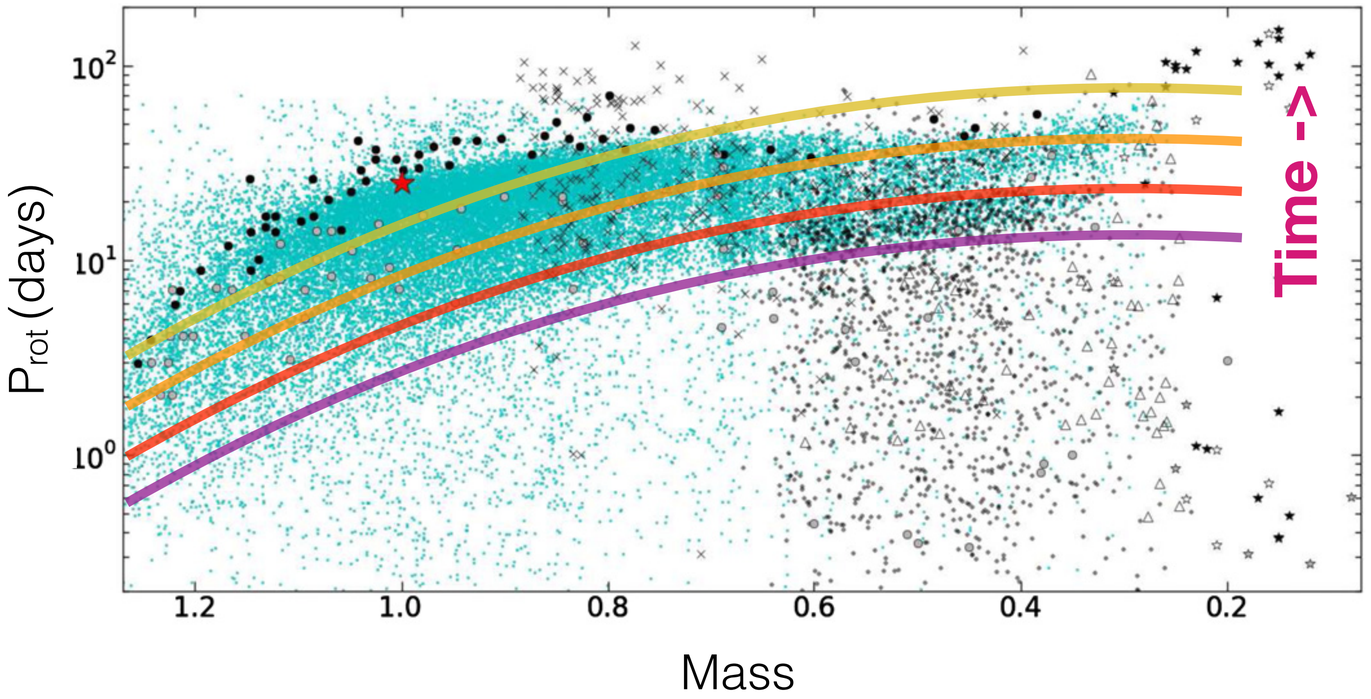


Meibom+2011

Ages of Low-Mass Stars

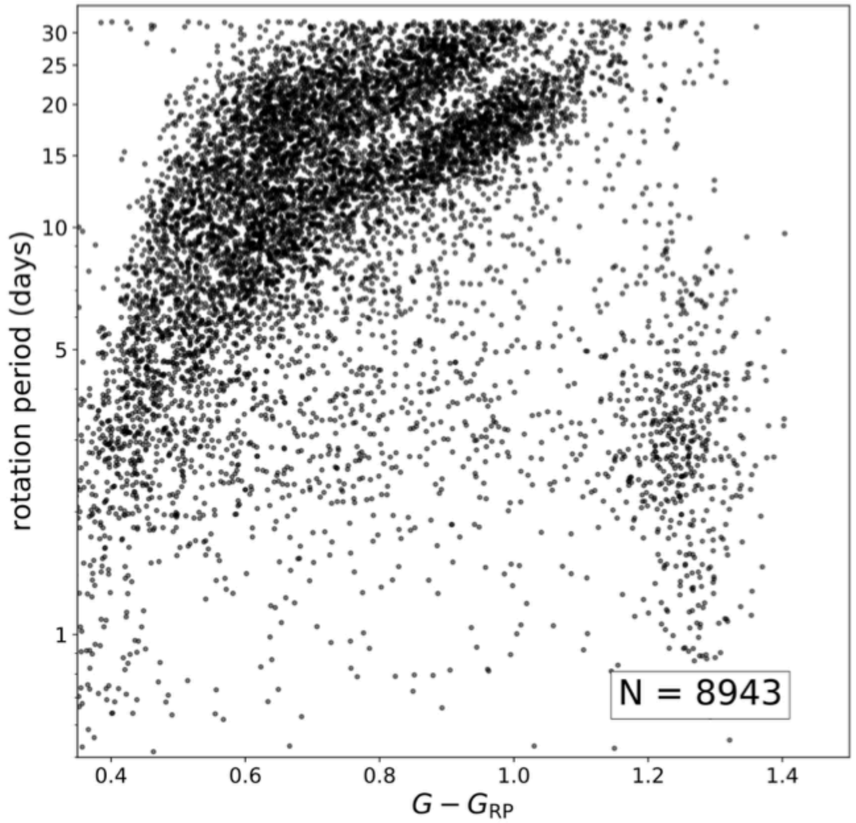


- **Rotation of stars**
- Field has exploded since ~2013, thanks to rotation periods from e.g. Kepler
- pre-Kepler: rotation for a few thousand stars, mostly from spectra
- Now: tens of thousands!



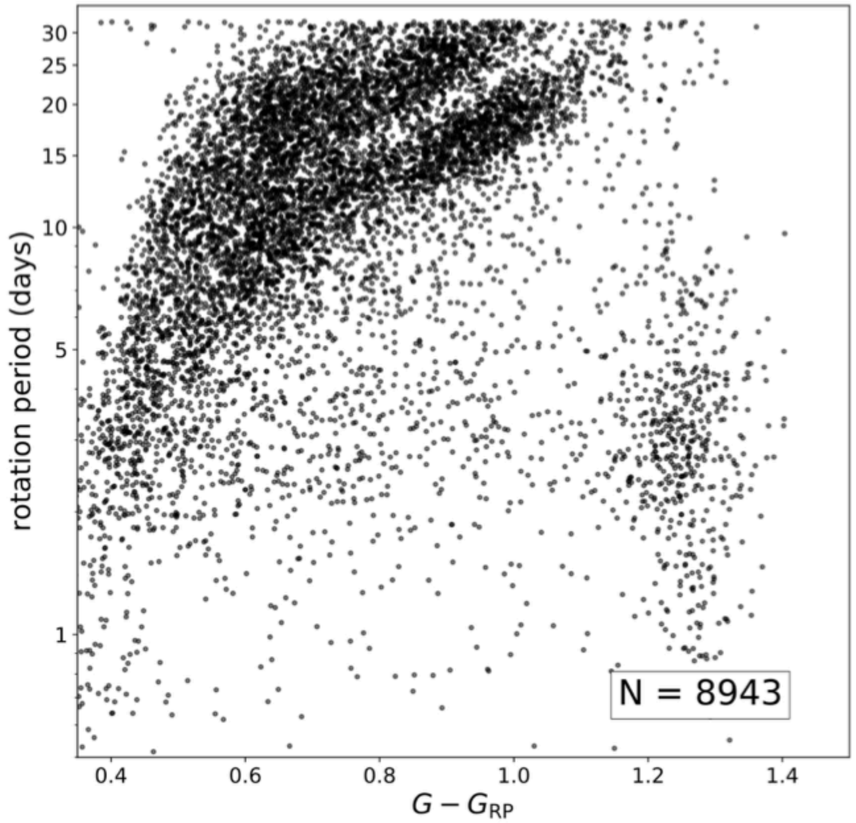
Ages of Low-Mass Stars

- **Rotation of stars**
- Many more surveys now making “industrial scale” rotation periods possible (spot amplitudes ~1%)
- e.g. K2 (**Gordon+2021**), TESS, and Gaia
  - Possibly a million stars will have rotation from Gaia DR4
- Some stars will have rotation from LSST, but its harder



Ages of Low-Mass Stars

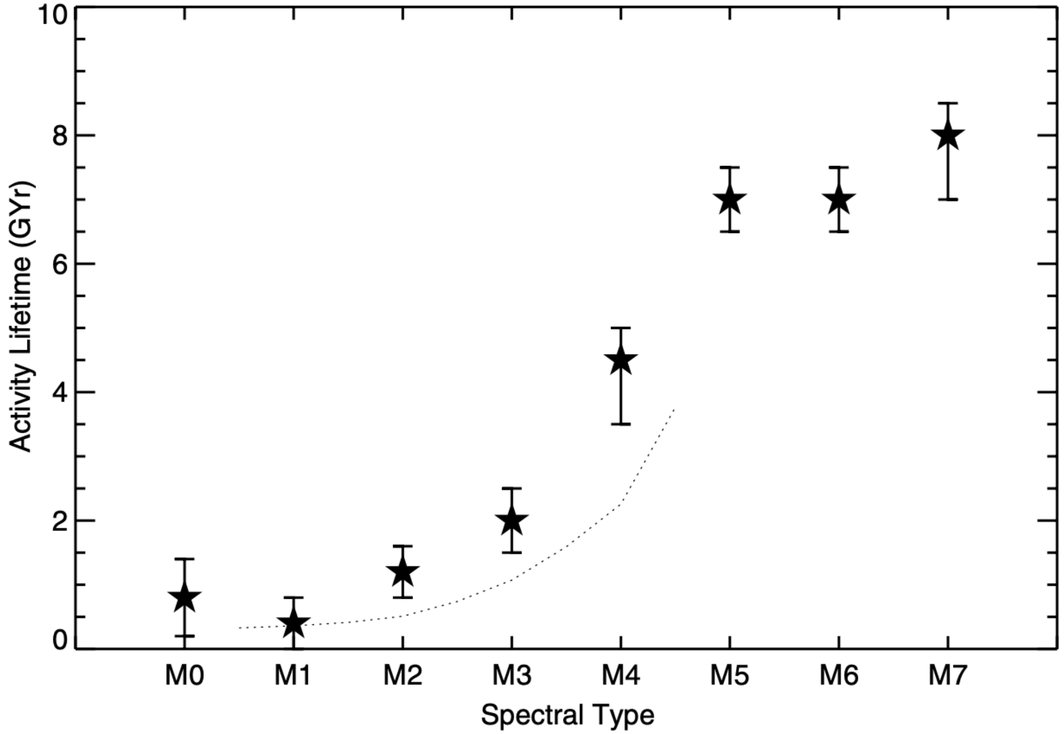
- **Rotation of stars**
- This clock is broken in multiple places
  - Range of initial Periods
  - Stalled spin-down at middle (Myr-Gyr) ages
  - Halted spin-down at late (few Gyr) ages



- **Good area to work in, but NOT my go-to for inverting into SFH currently**

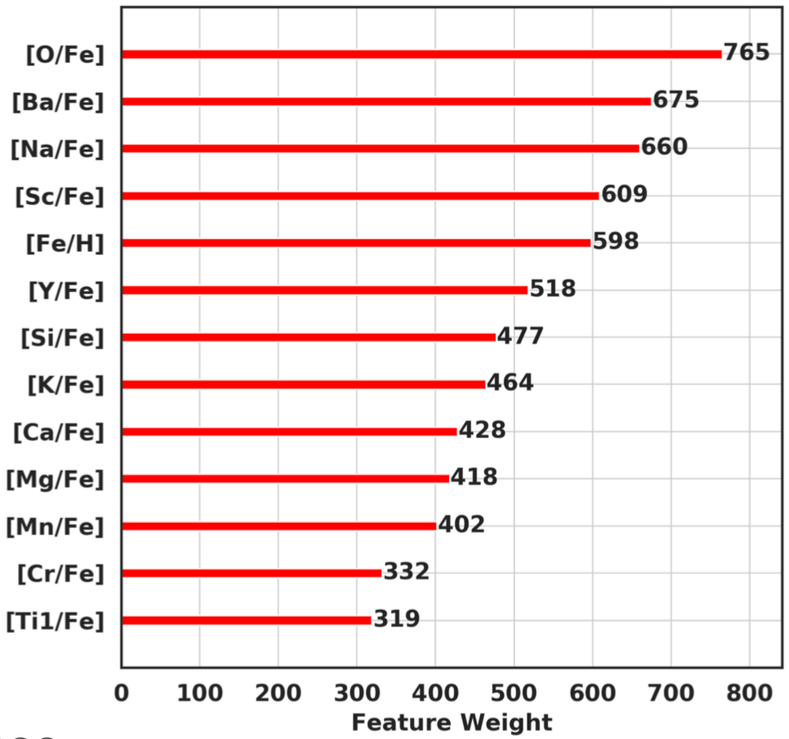
Ages of Low-Mass Stars

- Angular momentum loss: quieting the stellar dynamo
- Lower magnetic field strength over time, smaller spots, fewer flares, lower chromospheric emission
  - Probably good for biology/life!
- Magnetic Activity (esp. $H\alpha$ emission) a statistical age indicator
  - Activity Lifetime

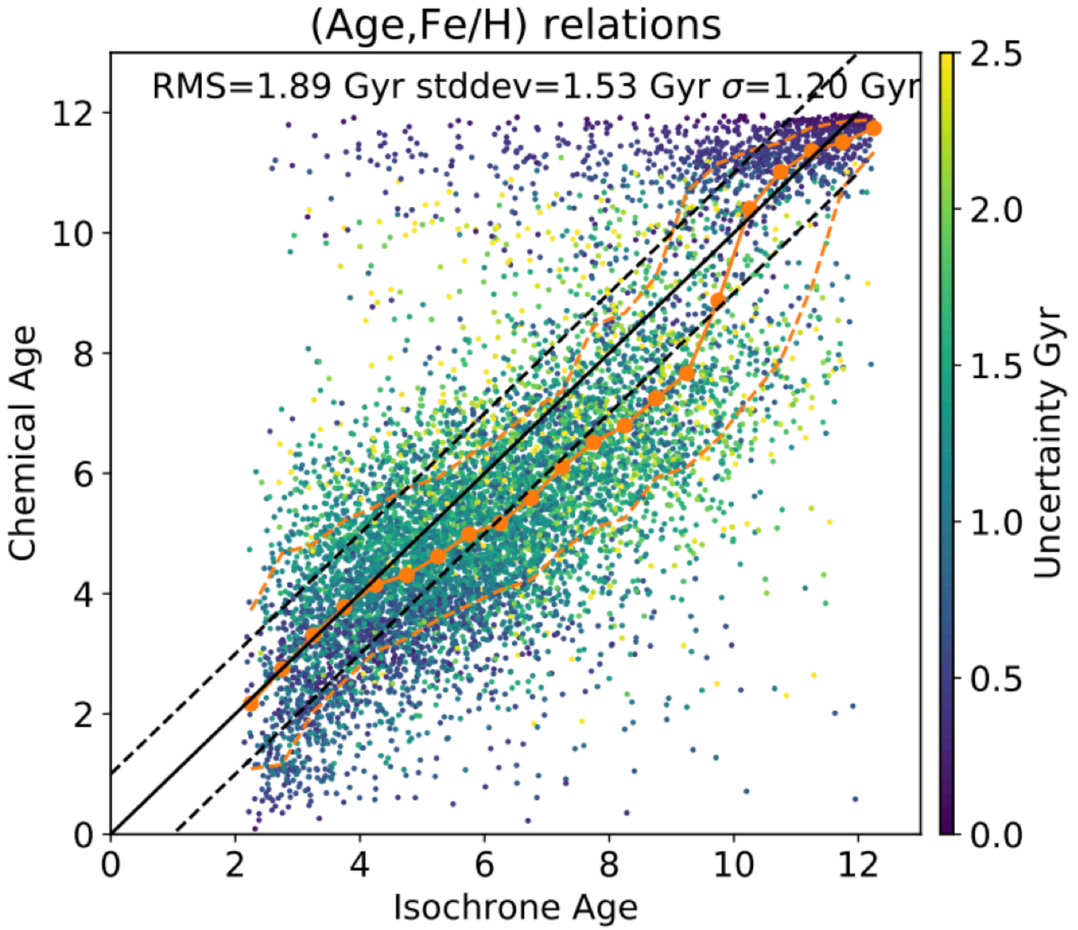


Ages of Stars

- **Chemical Clocks**
- Beyond simply [Fe/H]



Hayden+2020



- Not so great for precise age-dating of individual stars
- Very neat for statistics…

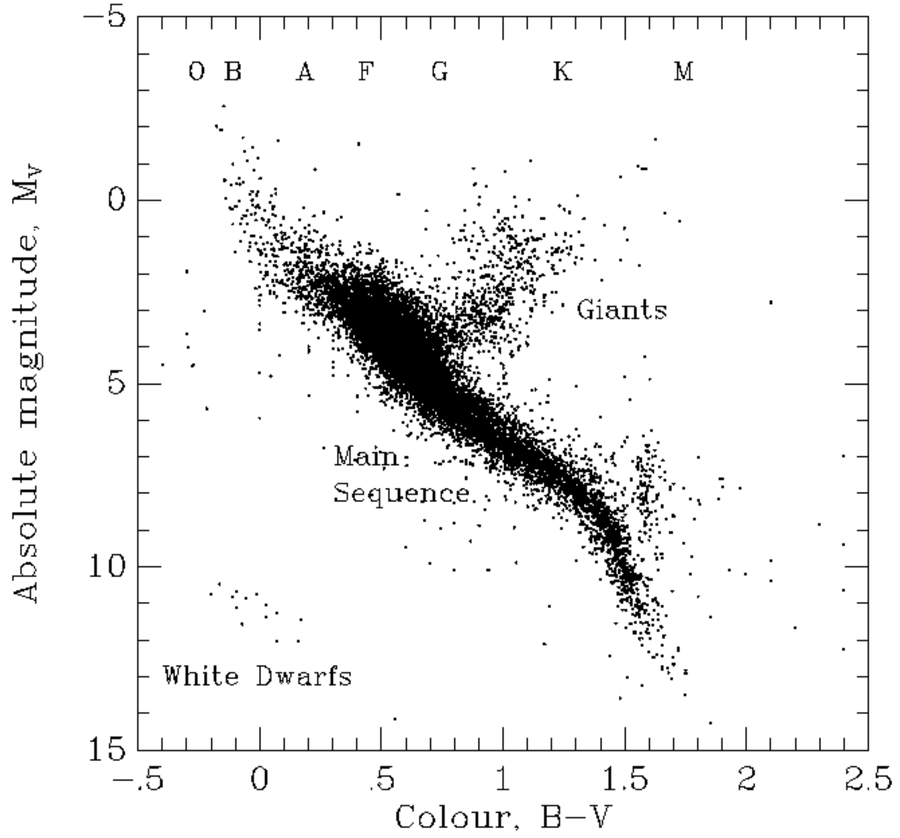
And that’s kind of it…

- Obviously there’s other ways to estimate individual star ages
  (e.g. asteroseismology, kinematics, careful CMD fitting, other chemical clocks, specific phases of stellar evolution that pin-point age)
- Most ALL stellar ages only good to 10-50%…
- **So we need statistics to back out the “truth”!**

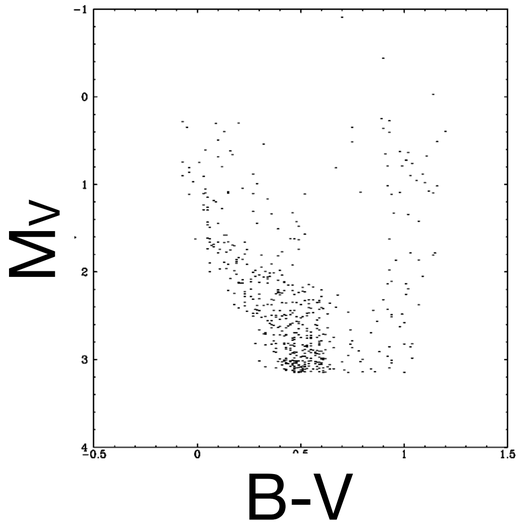
- **Let’s switch to Star Formation History then**

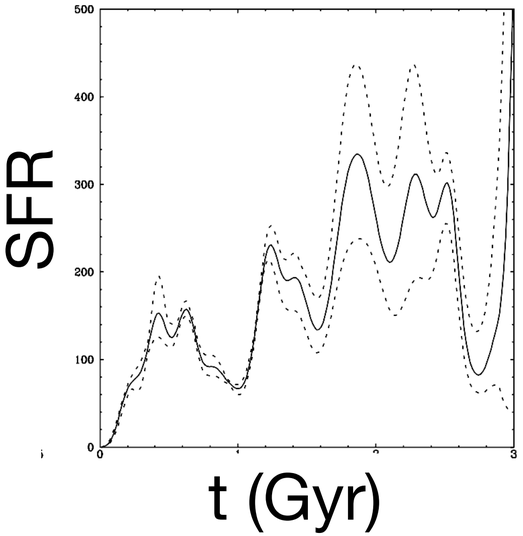
SFH: Modeling the CMD

- Hipparcos (~120k stars)



- Need volume limited sample (<100pc)
- Small sample size (~450 stars)
- Claim 50 Myr time resolution back to 3 Gyr!

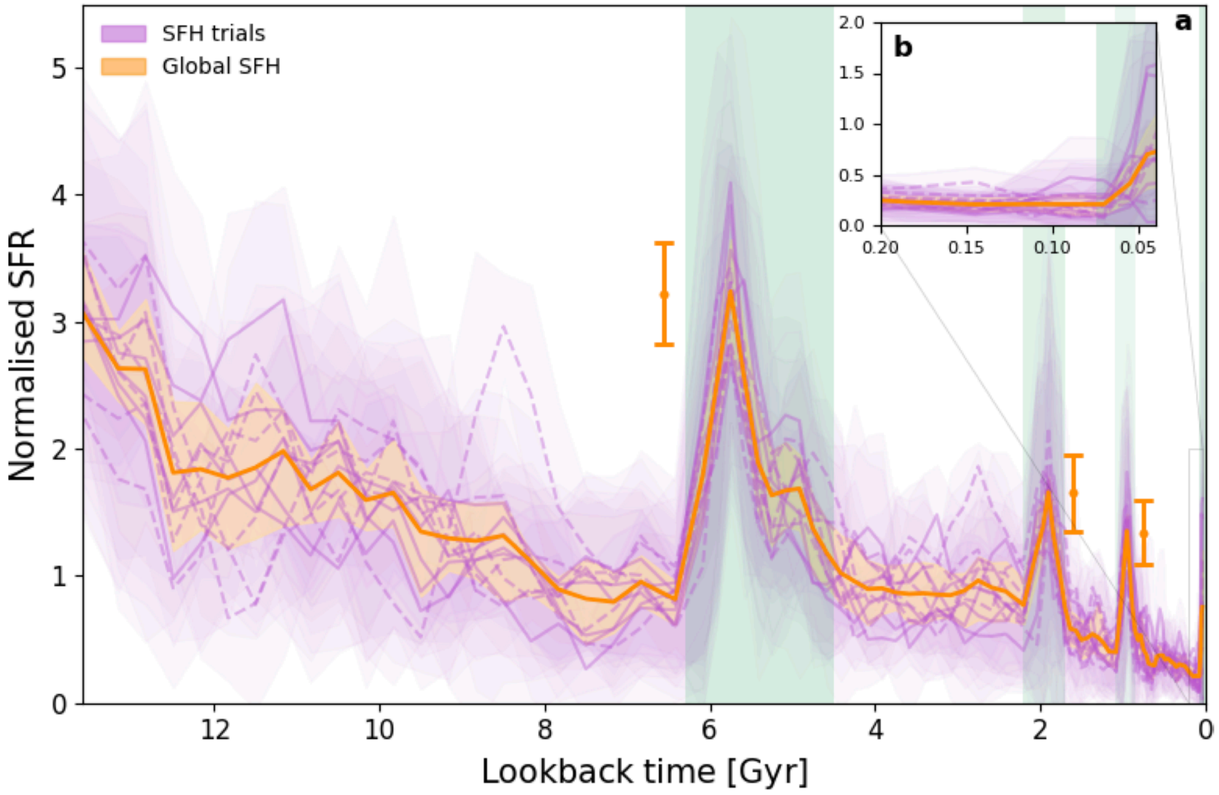


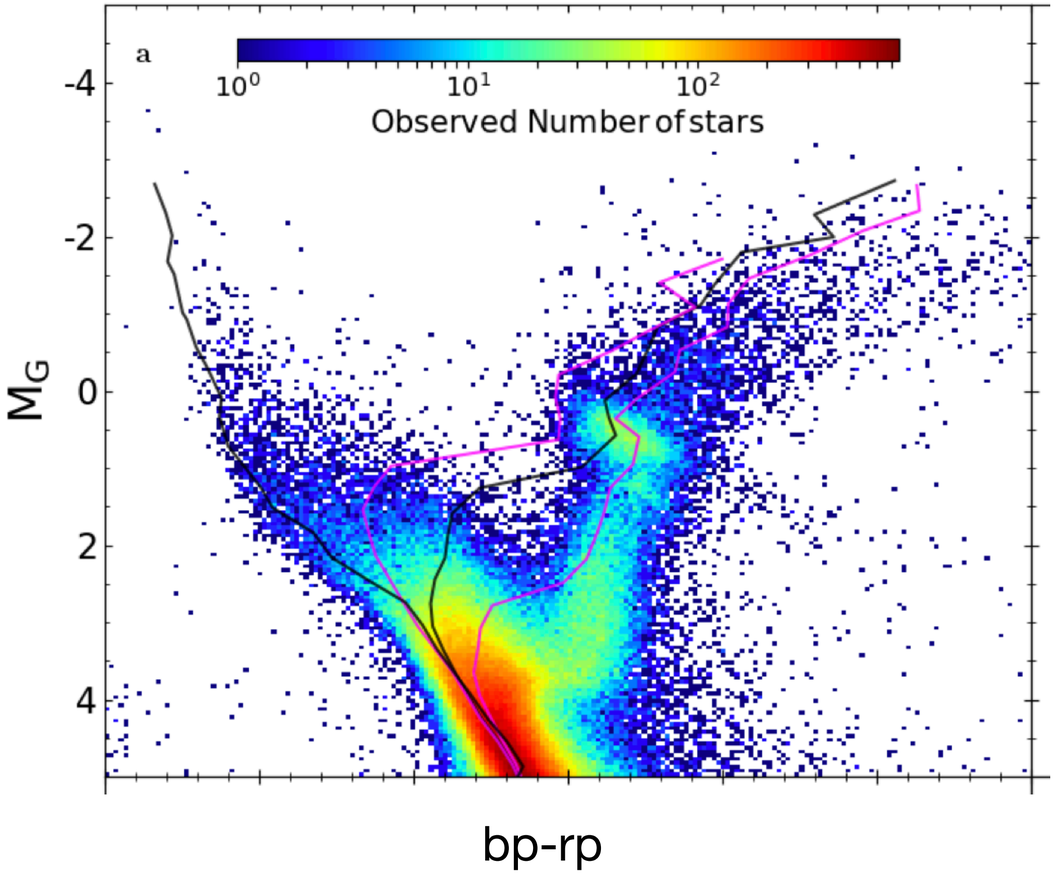


Hernandez+2000

SFH: Modeling the CMD

- **Gaia**! (80 million stars, out to 2 kpc)



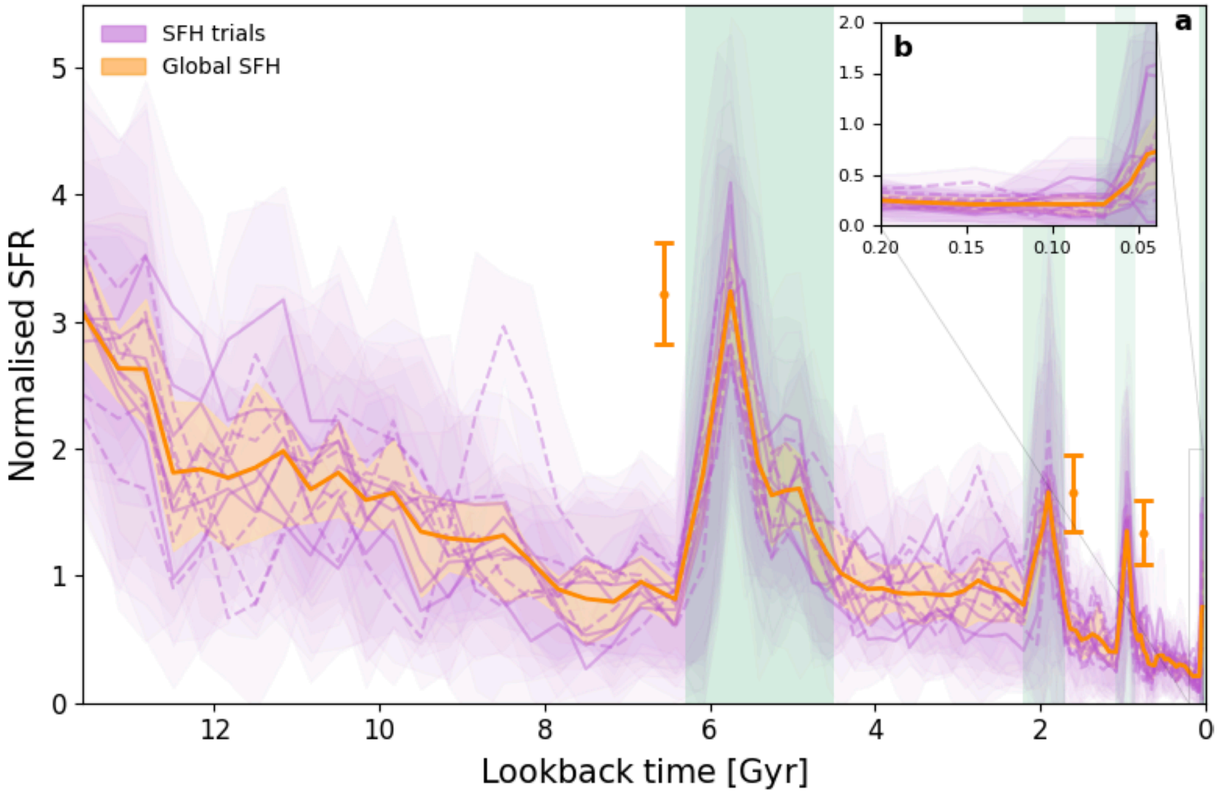


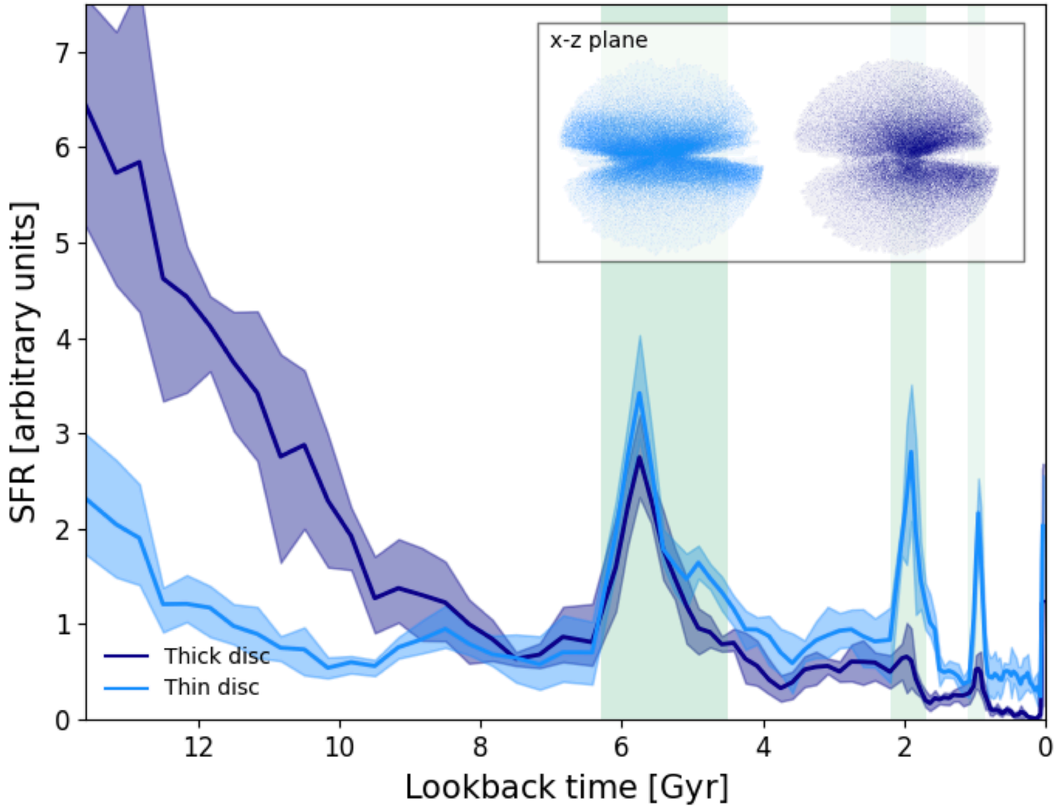
- Forward modeling the CMD (or Hess diagram)

Ruiz-Lara+2020

SFH: Modeling the CMD

- **Gaia**! (80 million stars, out to 2 kpc)



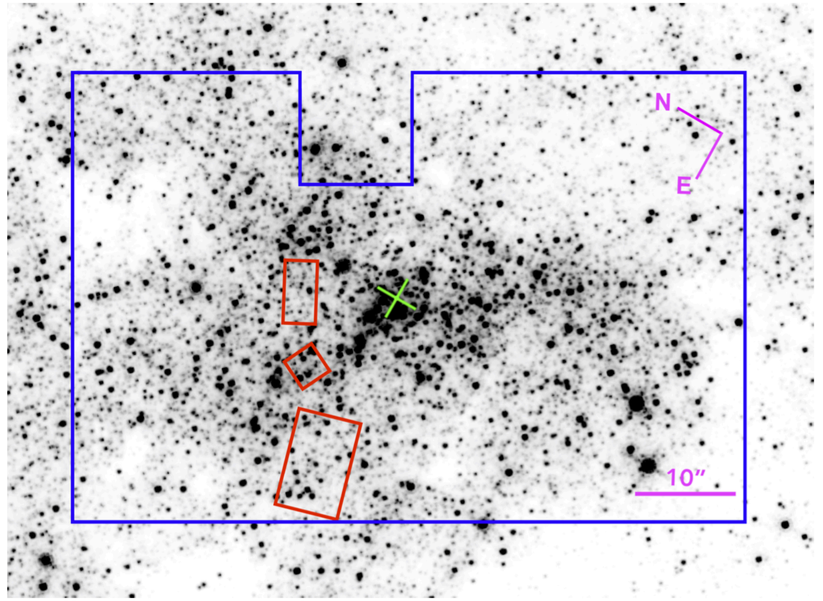


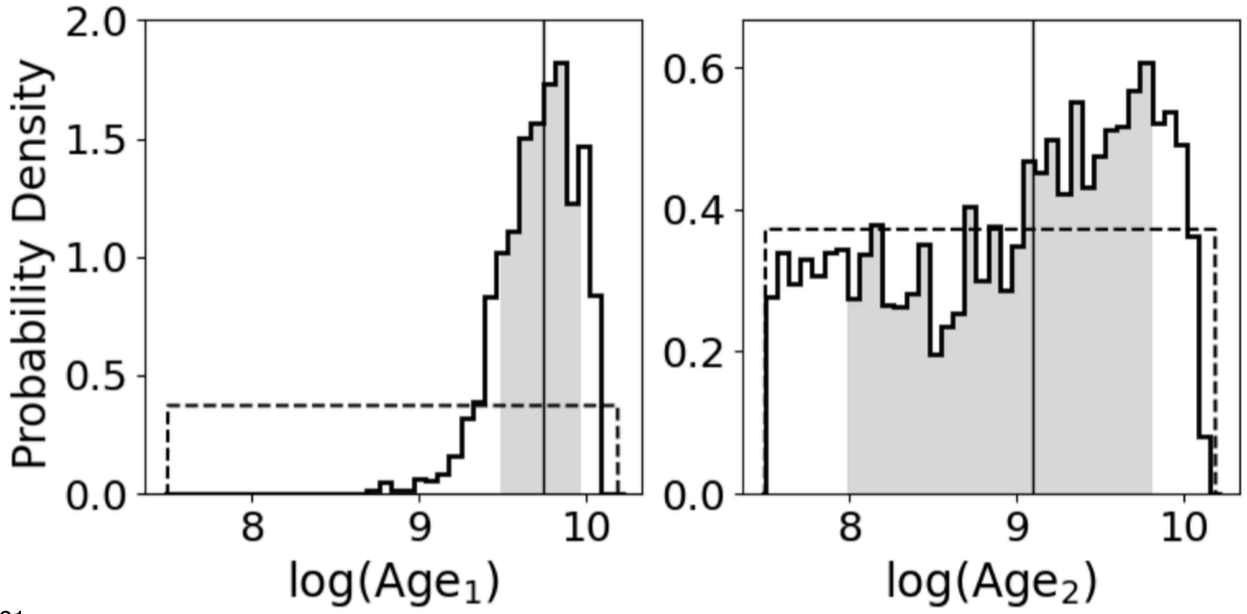
- **Can study individual components**

Ruiz-Lara+2020

SFH of Specific Components

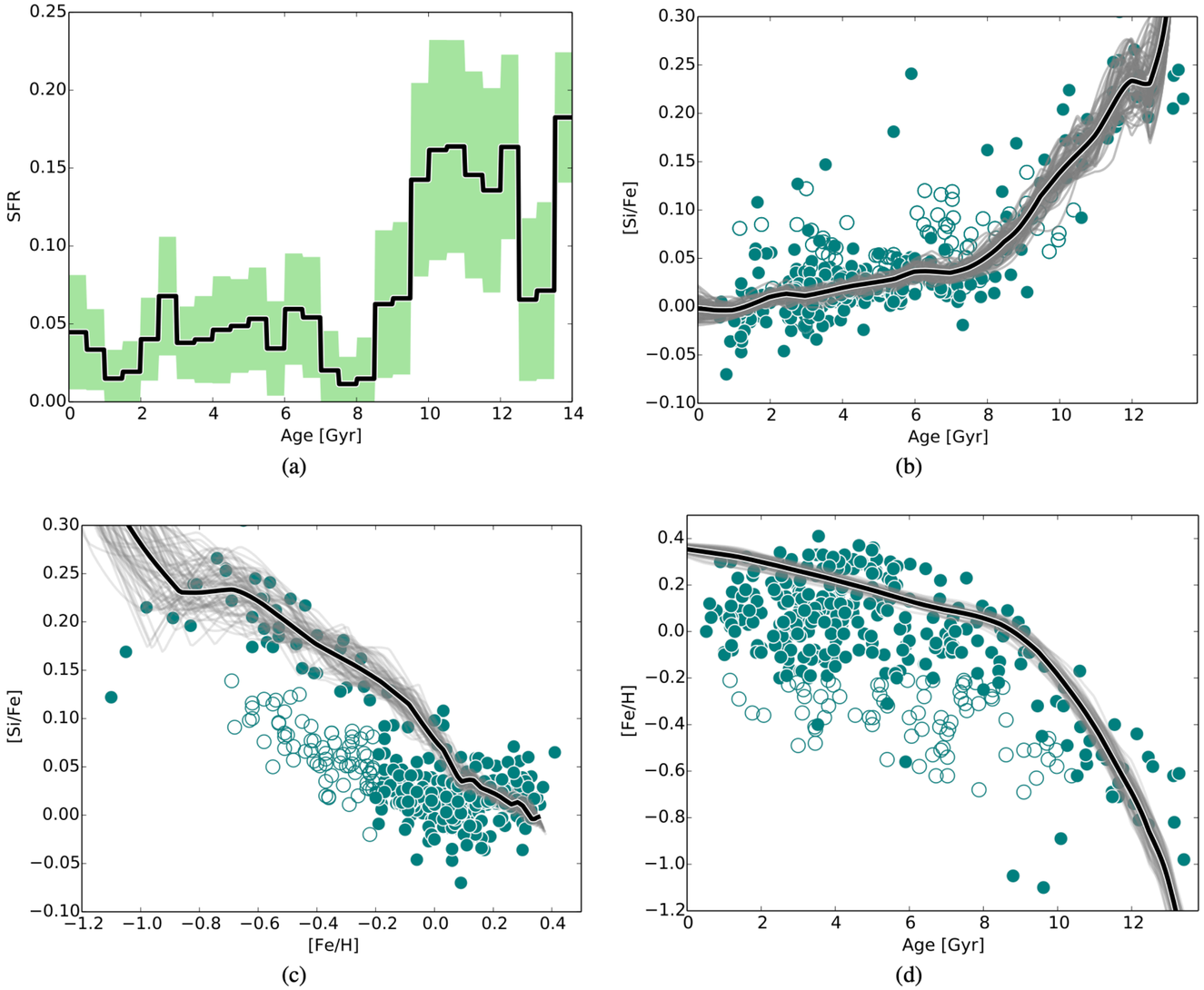
- Go beyond the Disk(s) & Halo:
  - SFH of nuclear cluster starting to be studied, with photometry & spectra
  - A young population of stars there!
  - Helps the “missing pulsar problem”





Chen+2022

SFH from Chemical Evolution Modeling

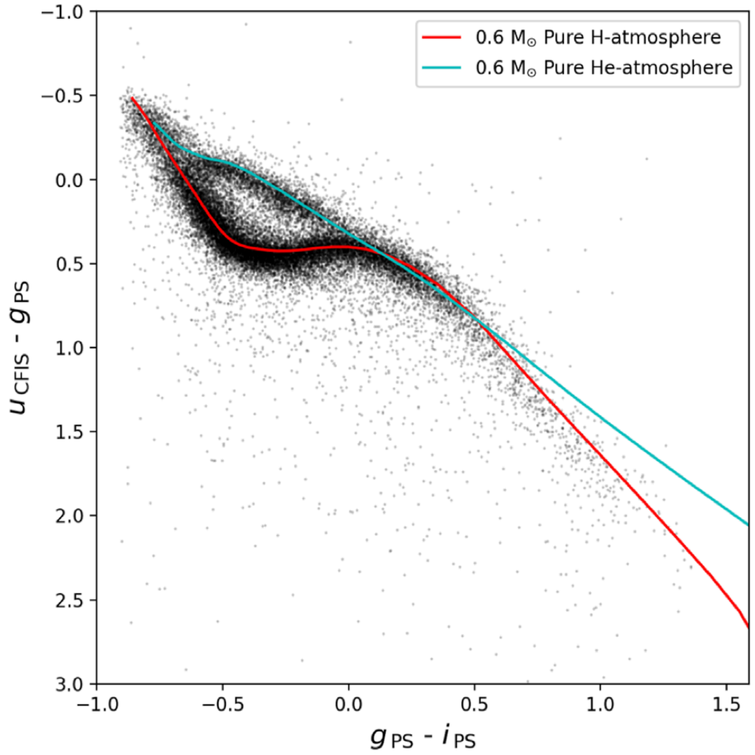


- Lots of assumptions about gas accretion/merger history (see Lecture 8)
- Also about recycling timescales and efficiencies
- BUT, pretty compelling approach!

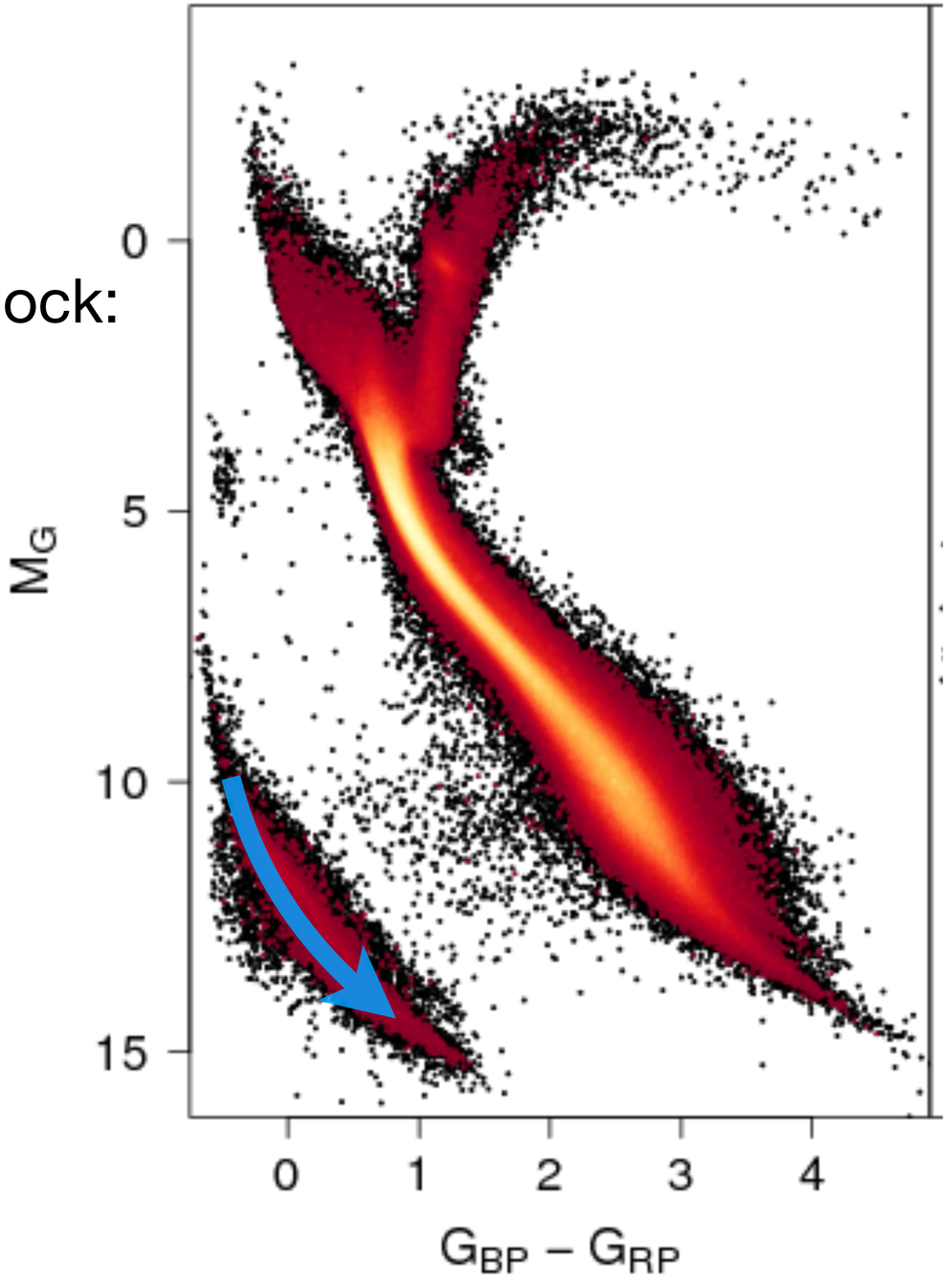
Snaith+2015

SFH from White Dwarfs!

- White Dwarfs cool over time, can be used as a clock: “cosmochronology”
- Neat physics involved in cooling curves

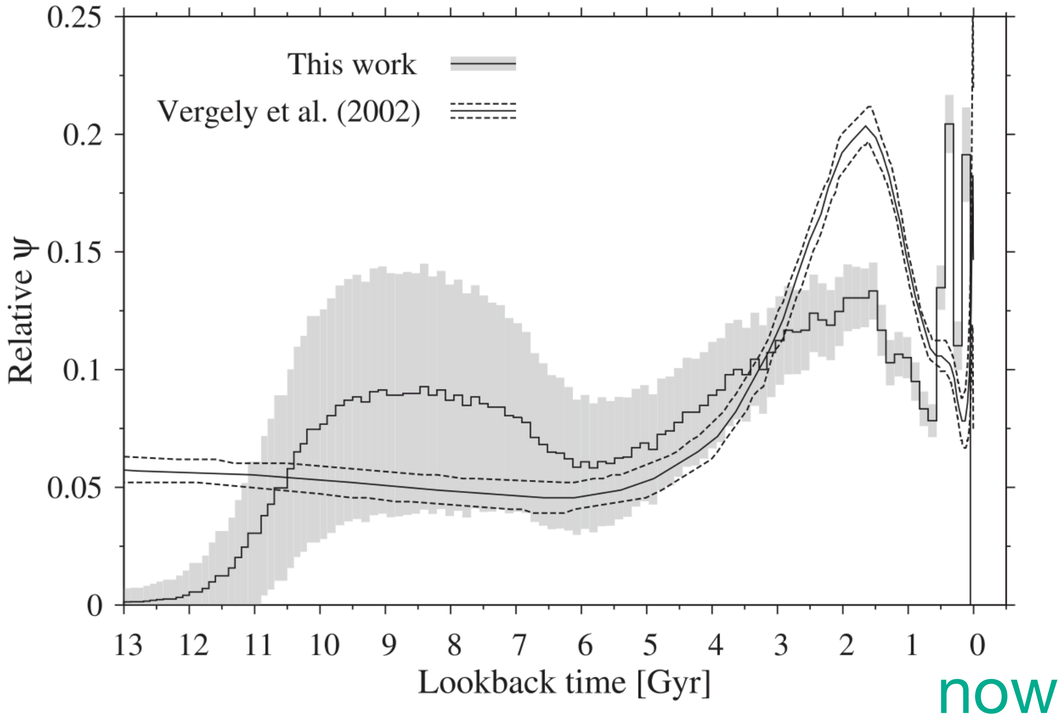


Fantin+2019



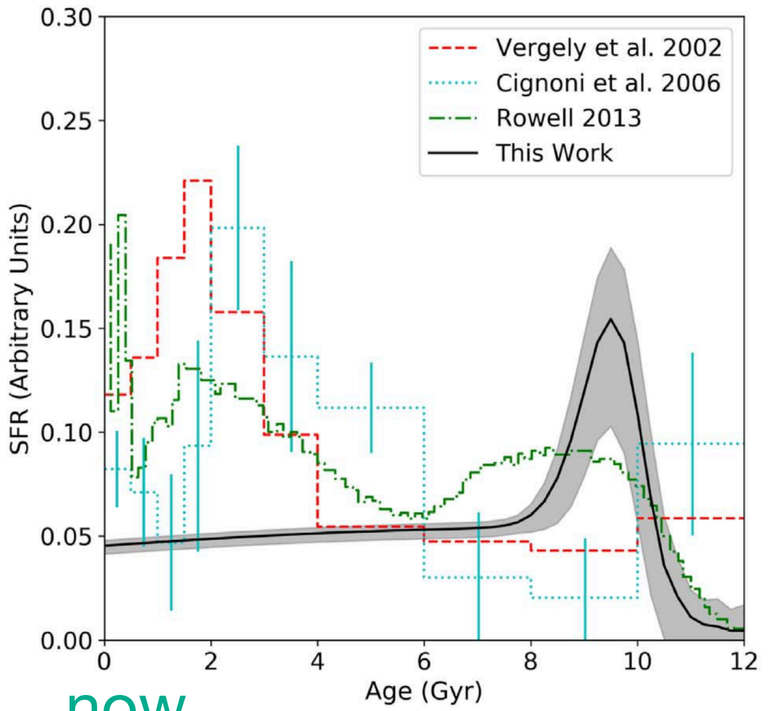
SFH from White Dwarfs!

- Recent results show… tension (IMO) about what age ranges WD's are sensitive to for SFH reconstruction…
- Still, a promising approach nearby!



now

Rowell 2013



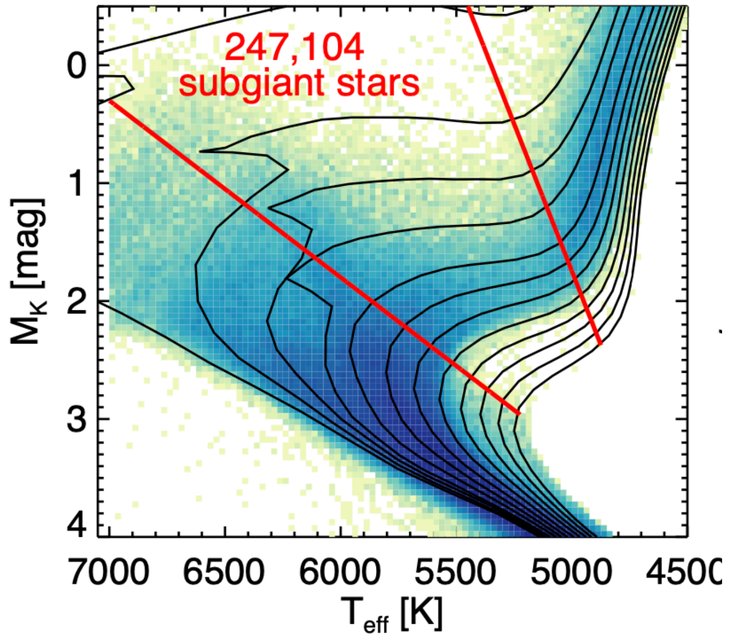
now

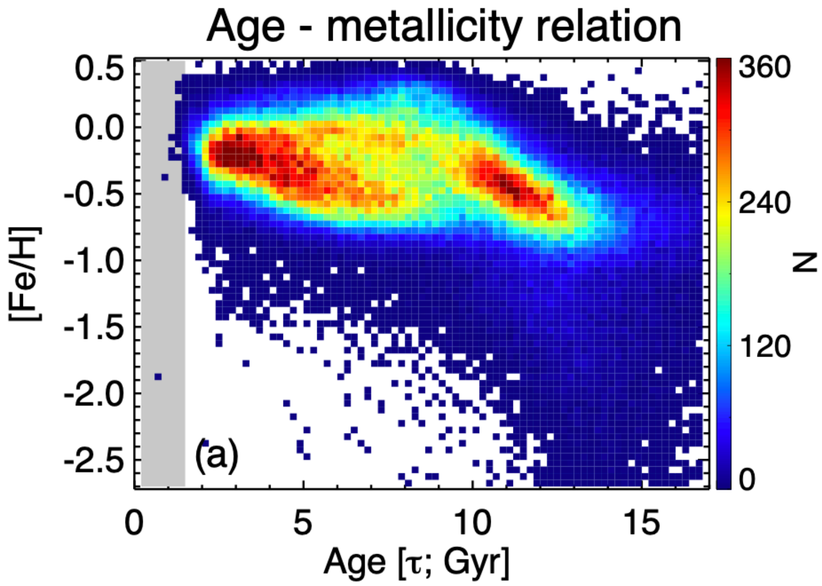
Fantin+2019

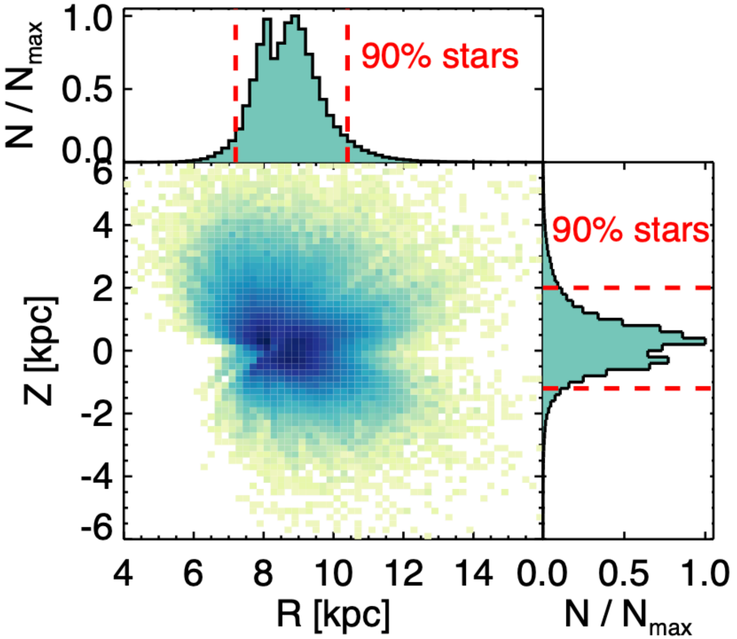
- **Looks like star formation "burst" 8-10Gyr ago**

SFH from TO & Sub Giants

- Helpful tracer in stellar evolution
- Get lots of spectra & 6D locations (positions & velocities)
- New Age -> [Fe/H] distributions



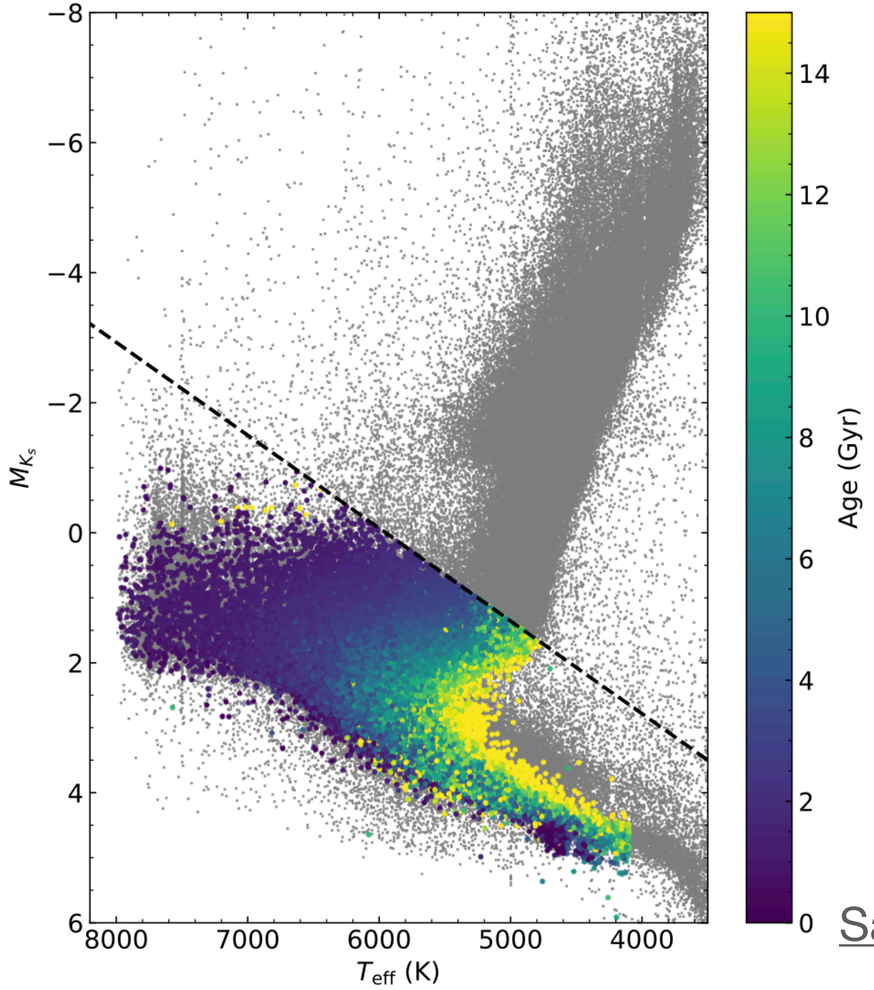


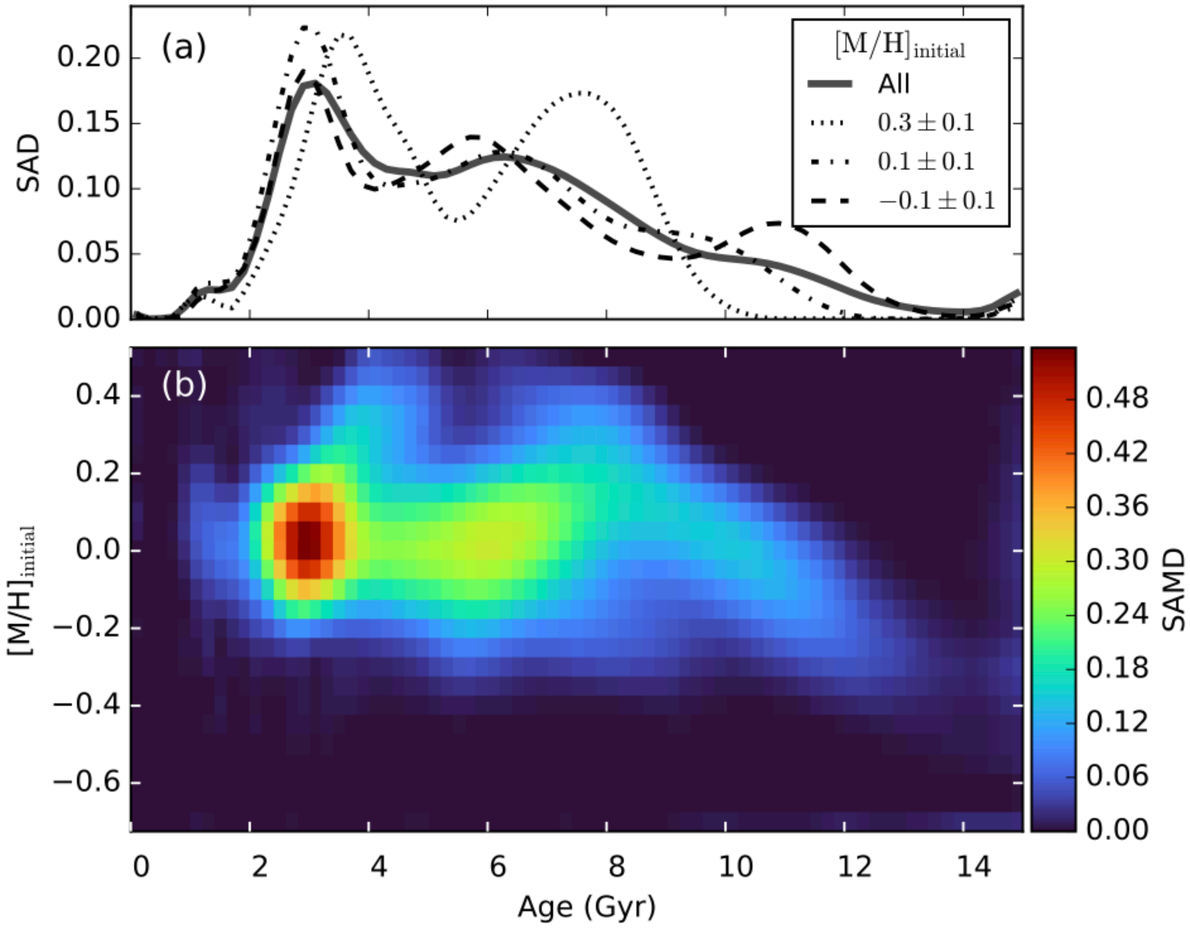


Xiang & Rix (2022)

SFH from TO & Sub Giants

- Recent paper using Gaia + GALAH!

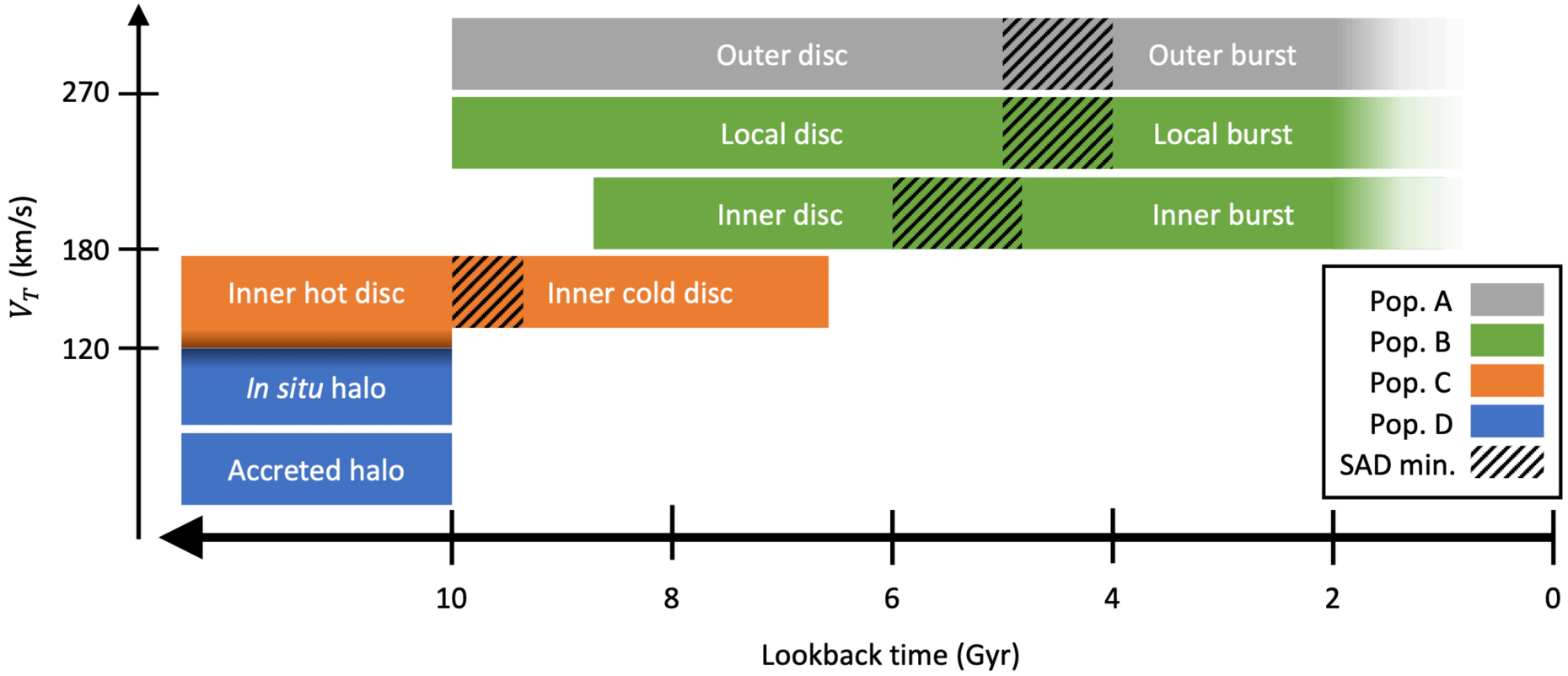




Sahlholdt+2022

SFH from TO & Sub Giants

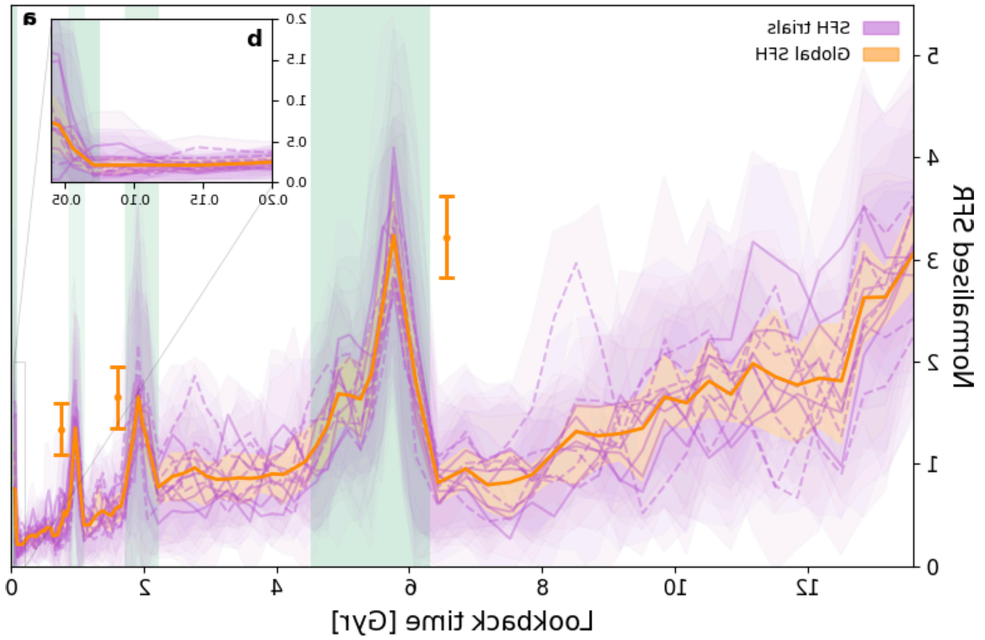
- Recent paper using Gaia + GALAH!



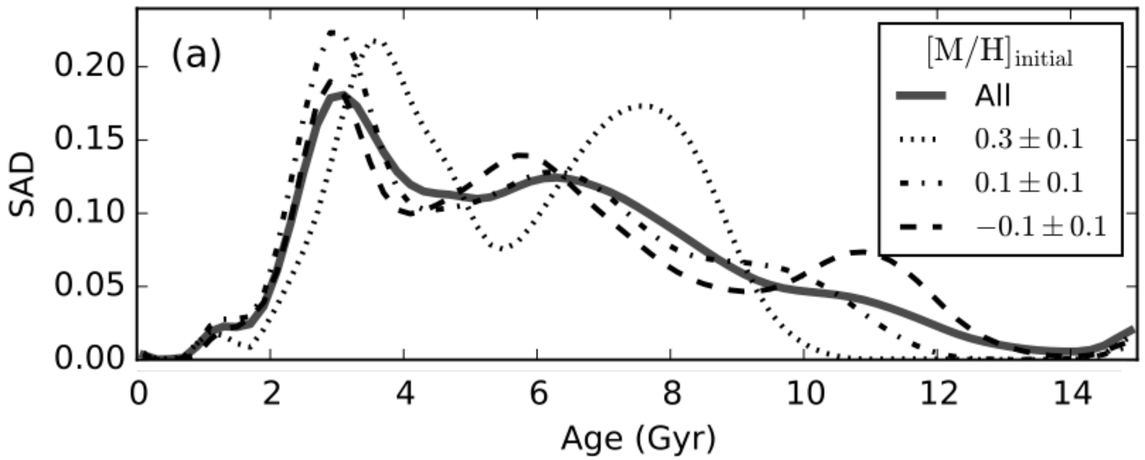
Sahlholdt+2022

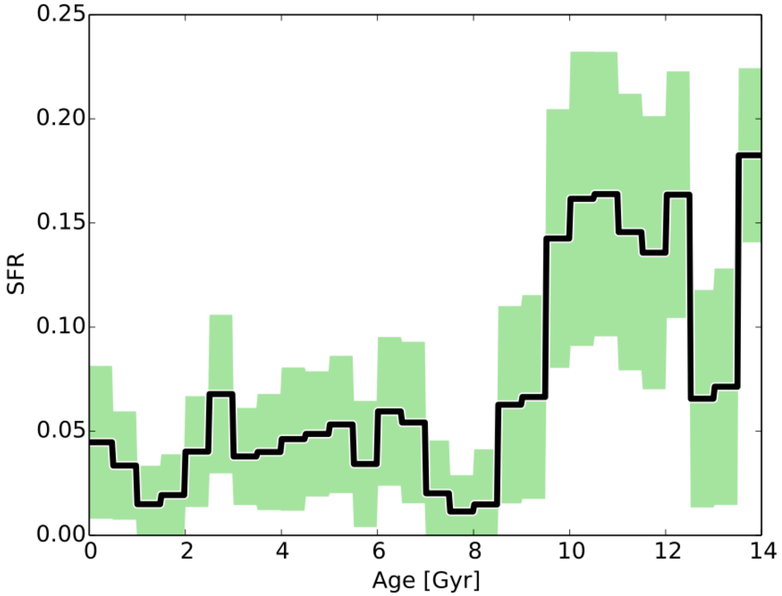
How does it compare?

Ruiz-Lara+2020

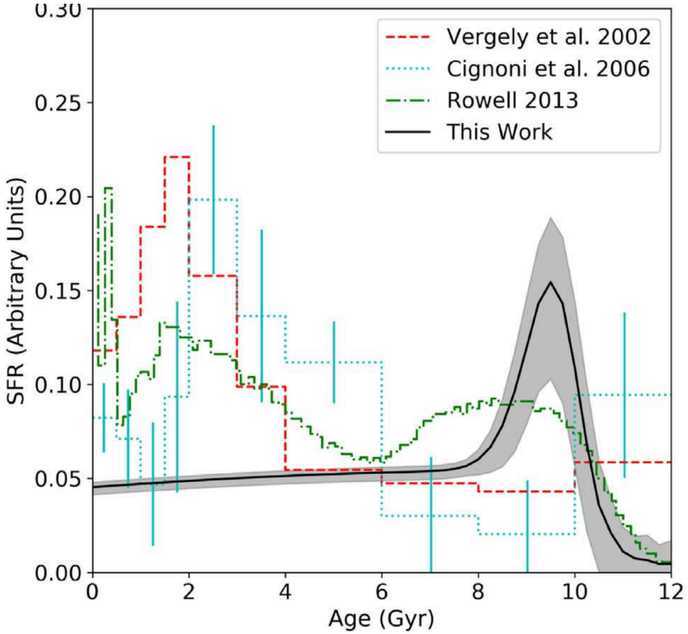


Sahlholdt+2022





Snaith+2015



Fantin+2019

How does it compare?

- Lots of *internal* consistency checks done (e.g. fitting mock data)
- Each SFH method is *so different*, VERY hard to cross-calibrate
- Probing different regions of Galaxy

- **We still have not coalesced on a single detailed SFH picture for the MWY**

Next time:

- Kinematics, Rotation,
  and the “Oort Constants”
- Nothing on the schedule for
  Next Thursday… YET.
  - Maybe try and connect Kinematics -> dynamics lectures?
  - Or do a homework / discussion day?