Measuring stellar ages from light curves

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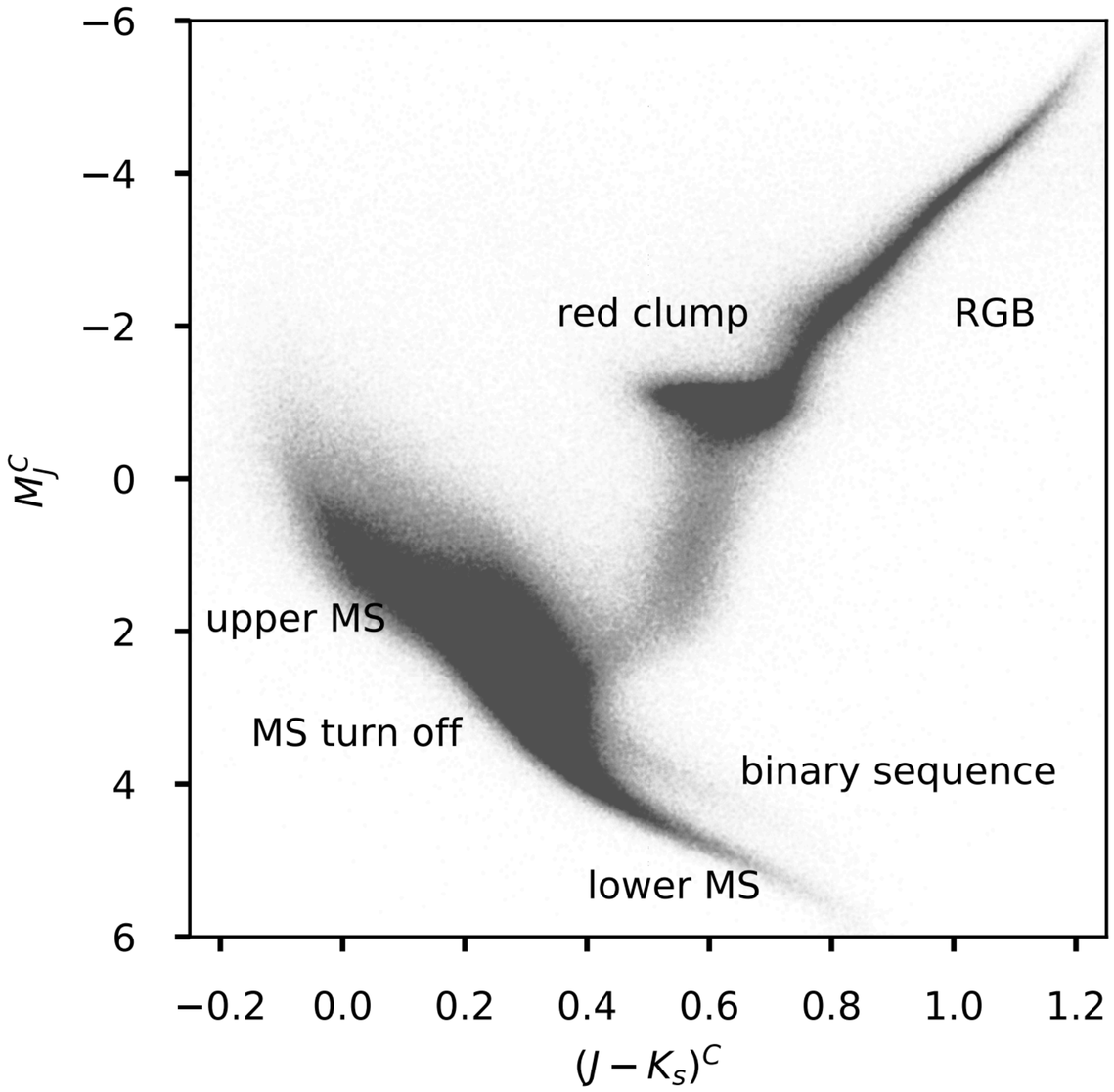
The Gaia color-magnitude diagram



Anderson et al. (2017)
ArXiv: 1706.05055

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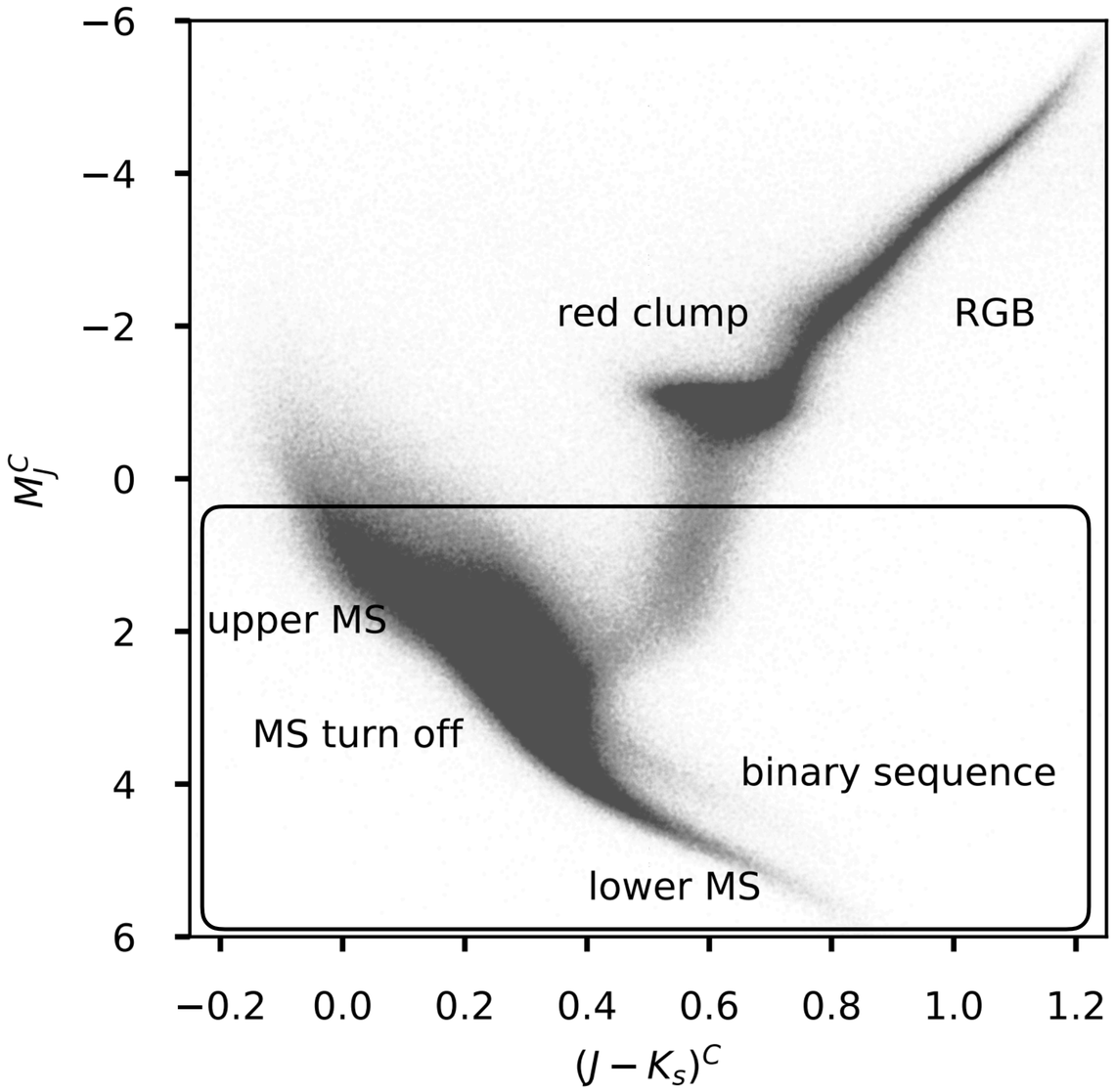

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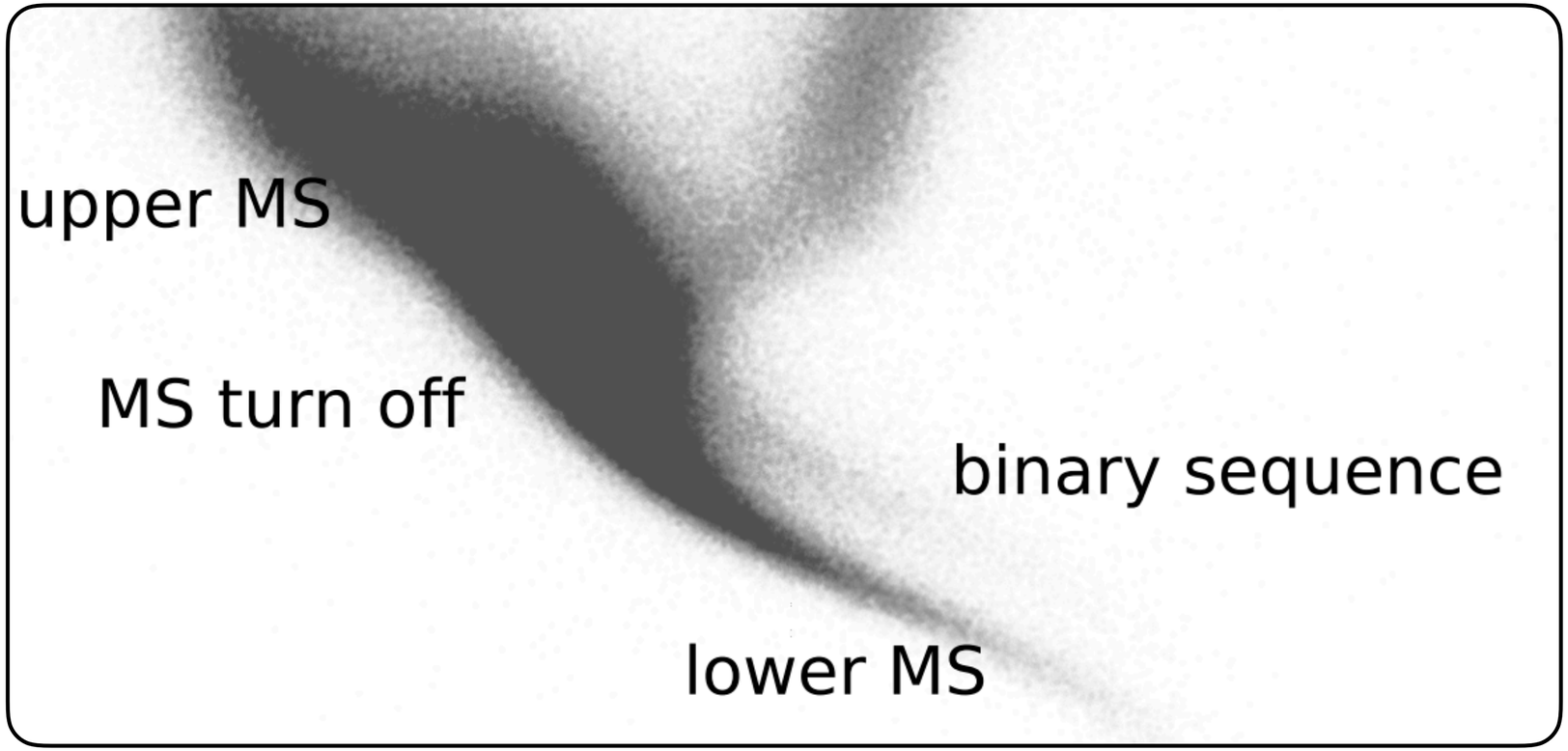
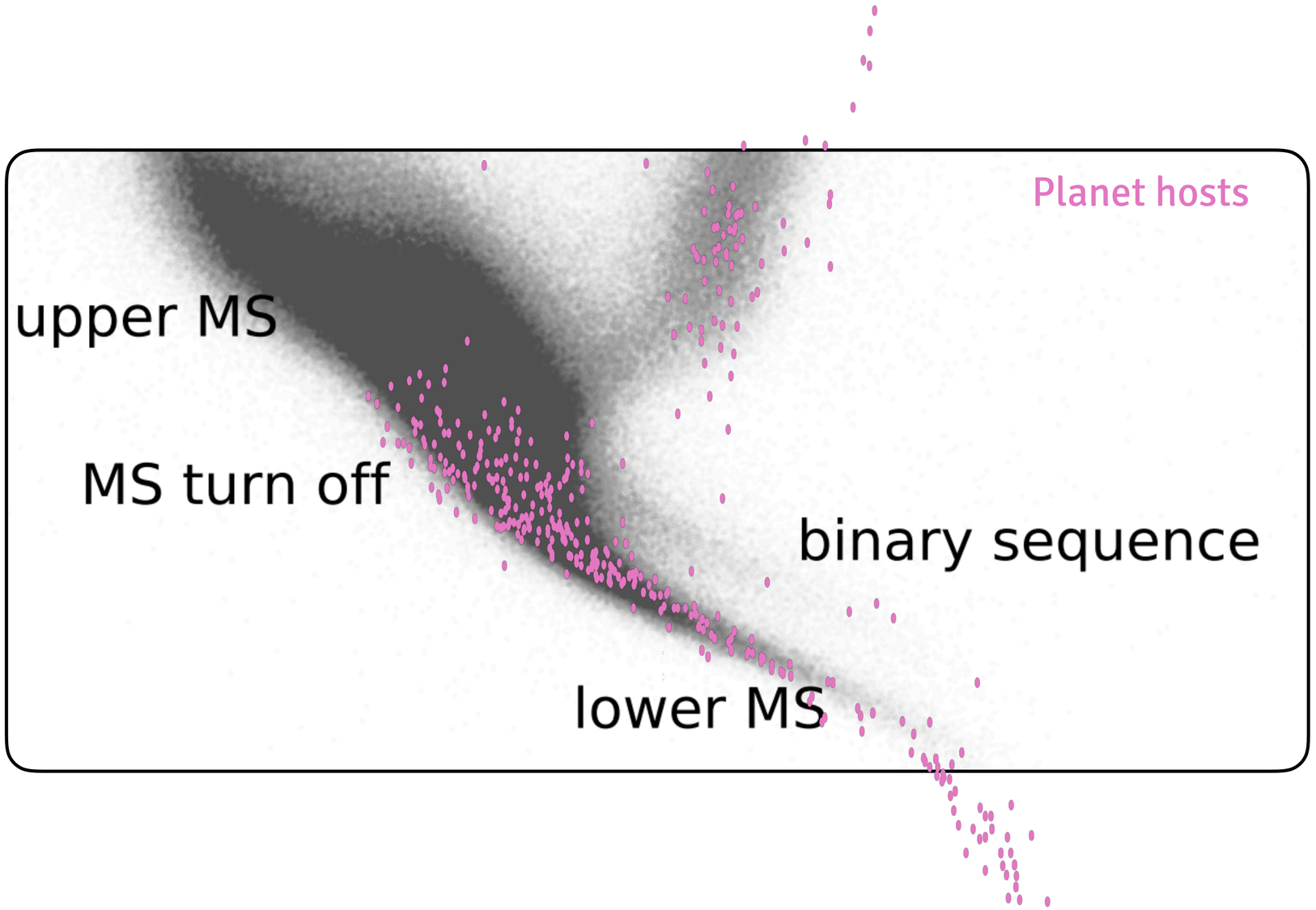
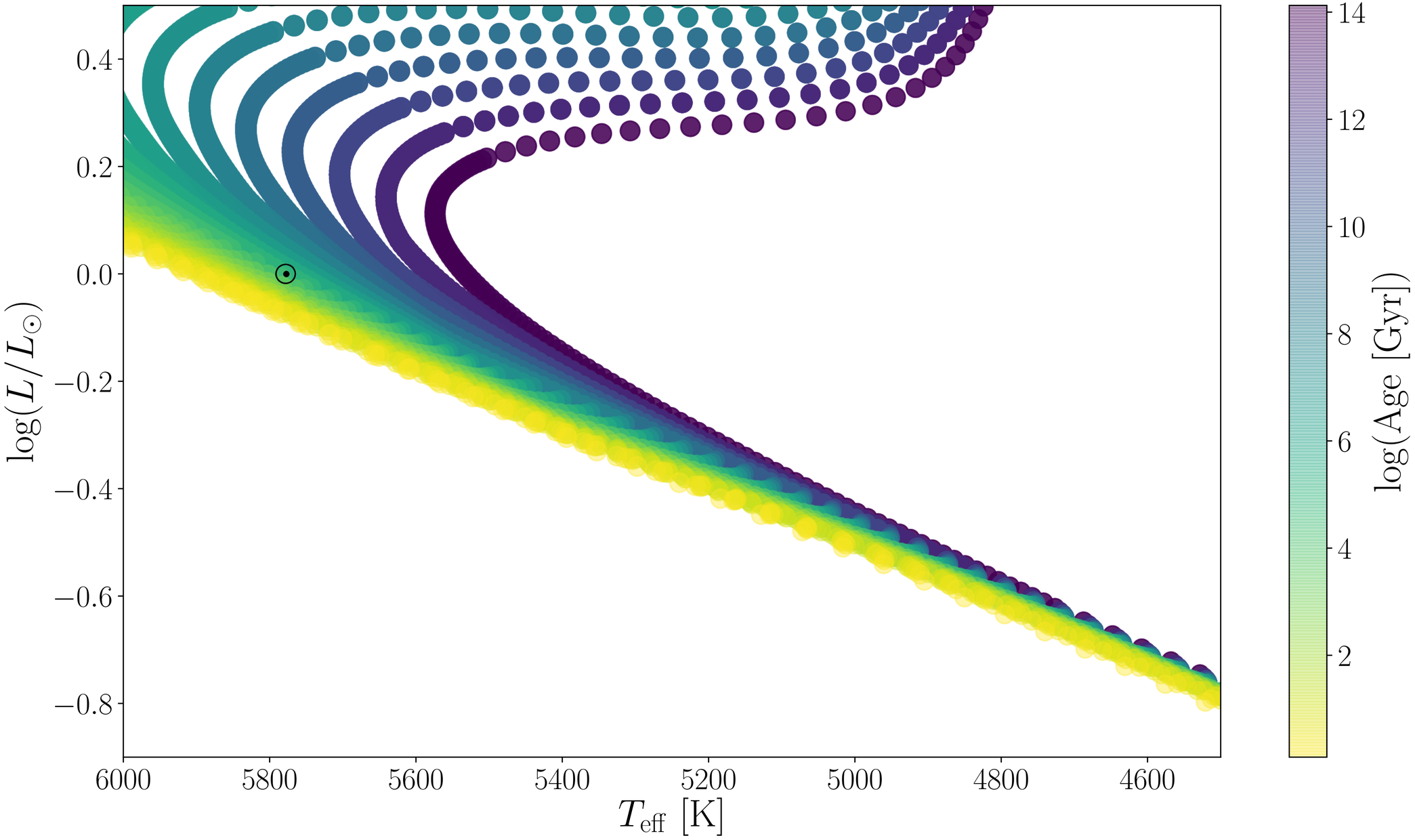


The Gaia color-magnitude diagram



Ages from isochrone fitting



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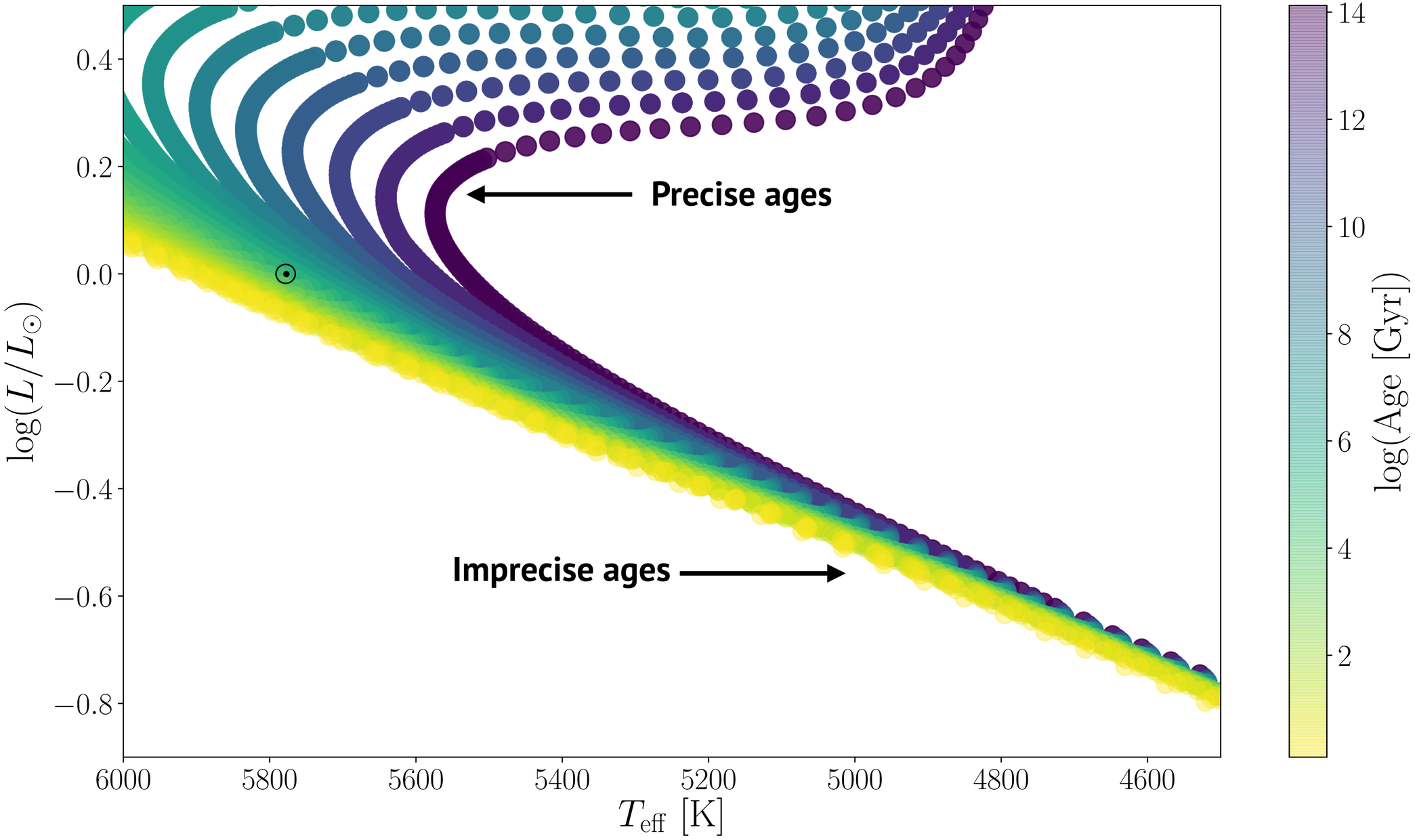
Ages from isochrone fitting



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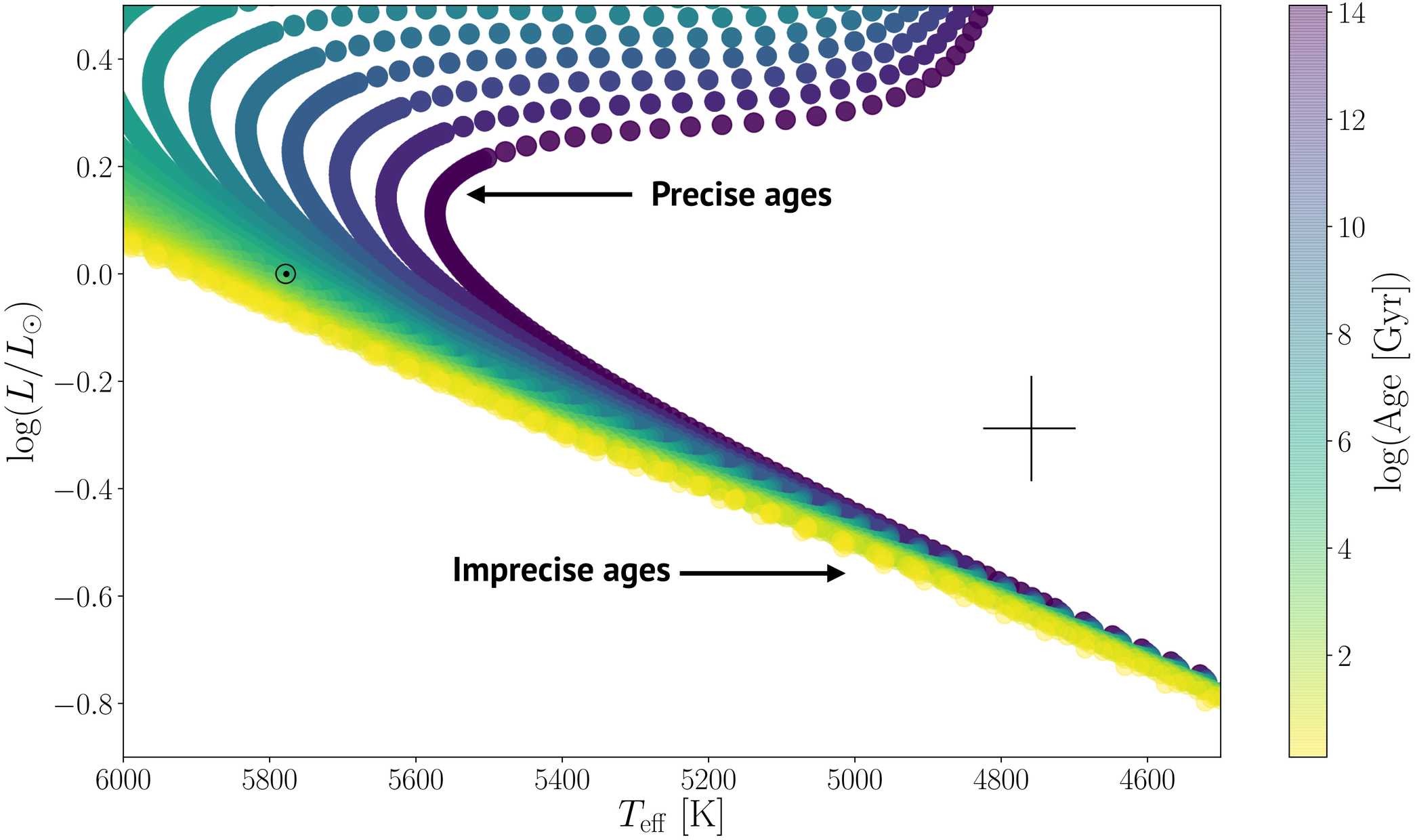
Ages from isochrone fitting



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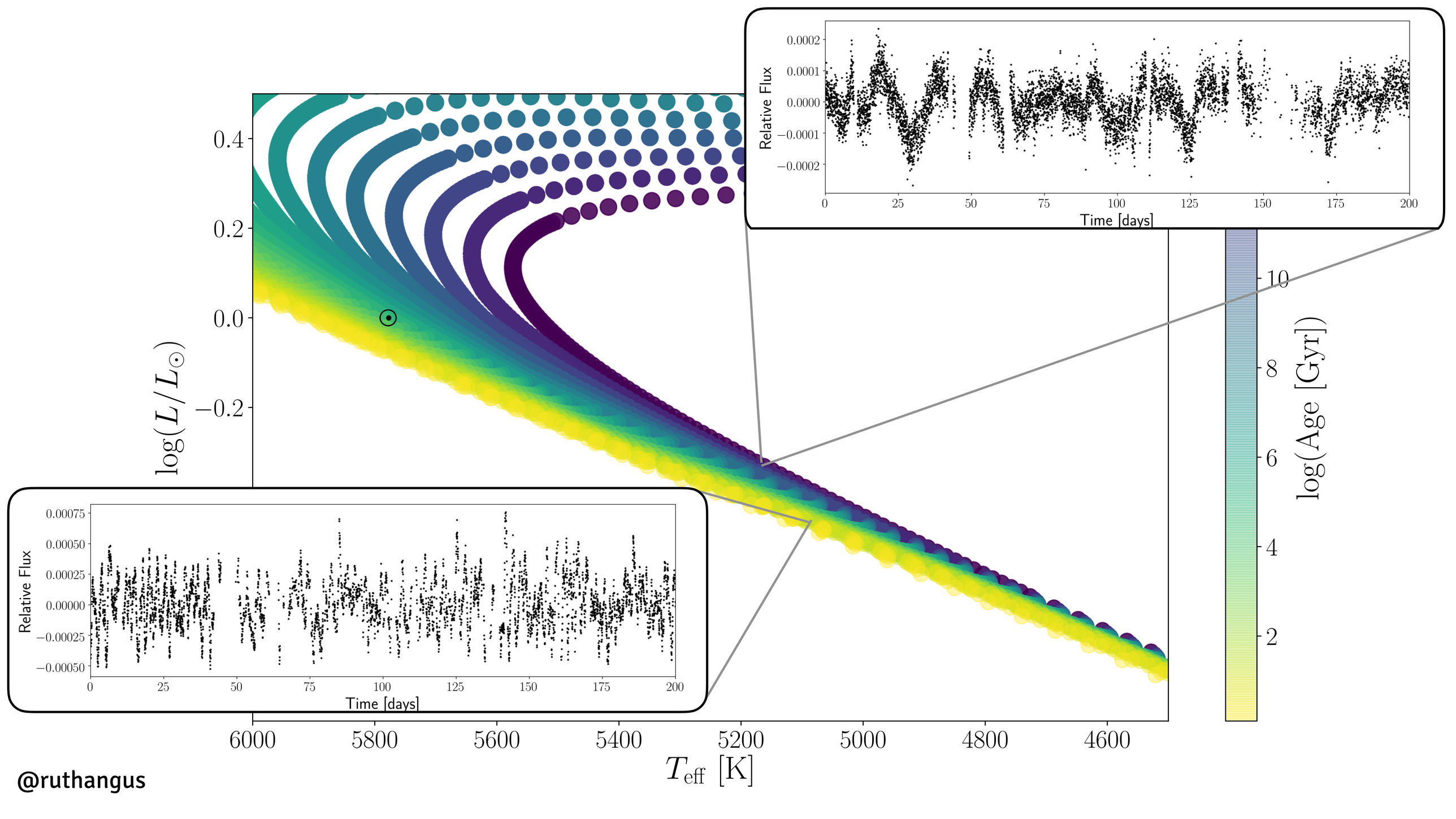
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0.0001
0.0000
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−0.0002
Relative Flux
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25
50
75
100
125
150
175
200
Time [days]
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0.00050
0.00025
0.00000
−0.00025
−0.00050
Relative Flux
0
25
50
75
100
125
150
175
200
Time [days]
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0.2
0.0
−0.2
$\log(L/L_\odot)$
6000
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5600
5400
5200
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$T_{\rm eff}$ [K]
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$\log(\mathrm{Age\ [Gyr]})$
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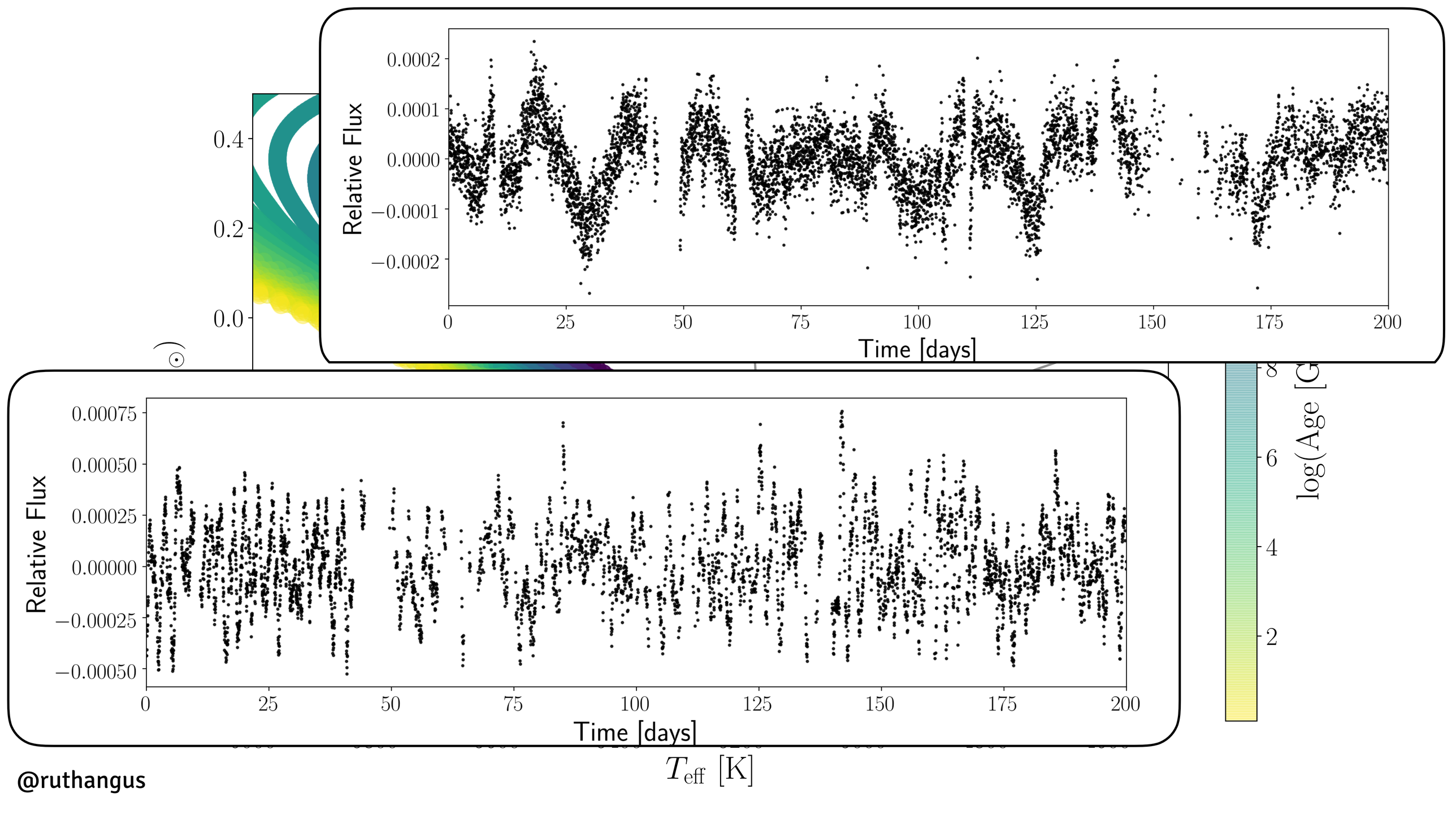
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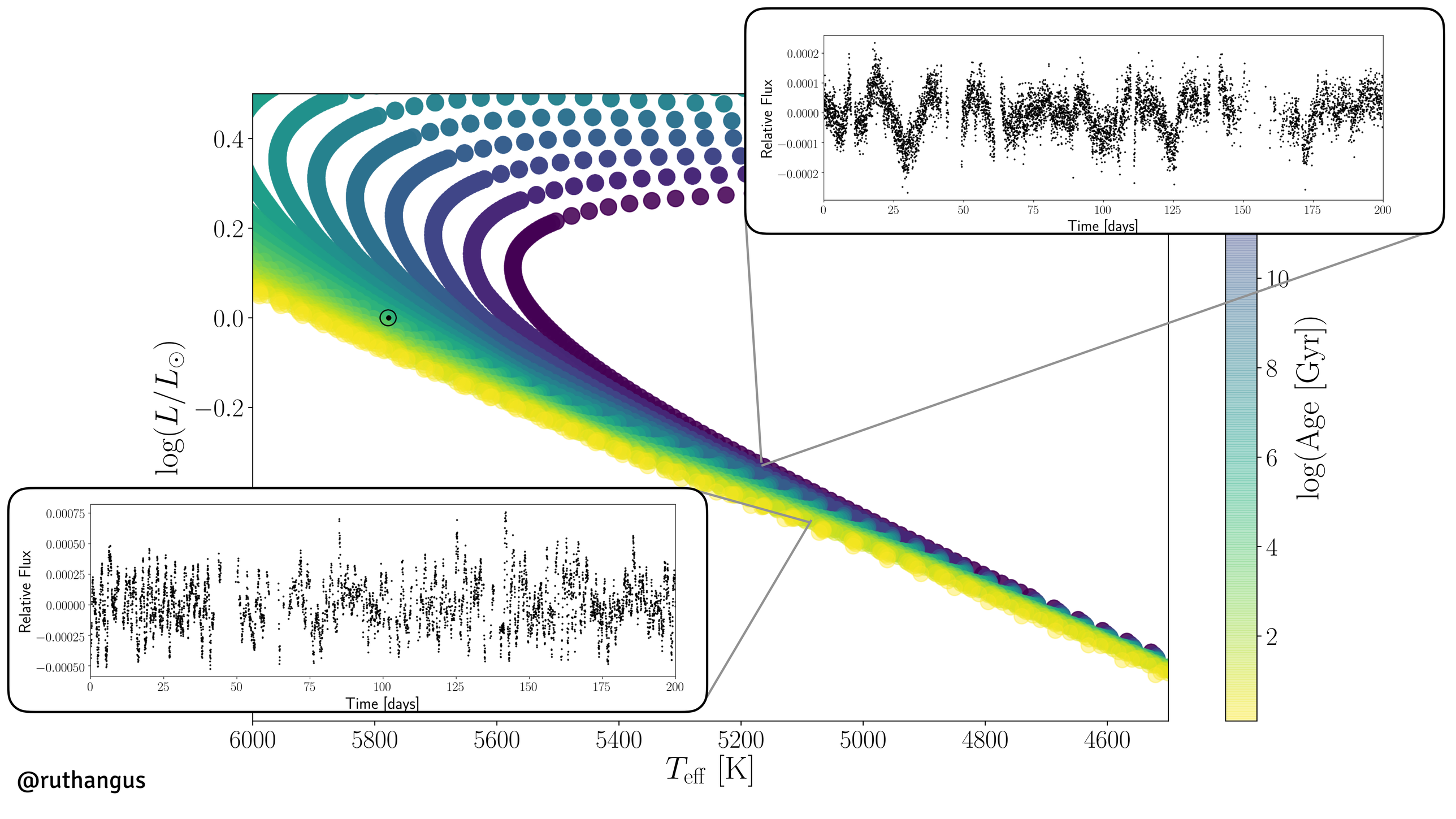
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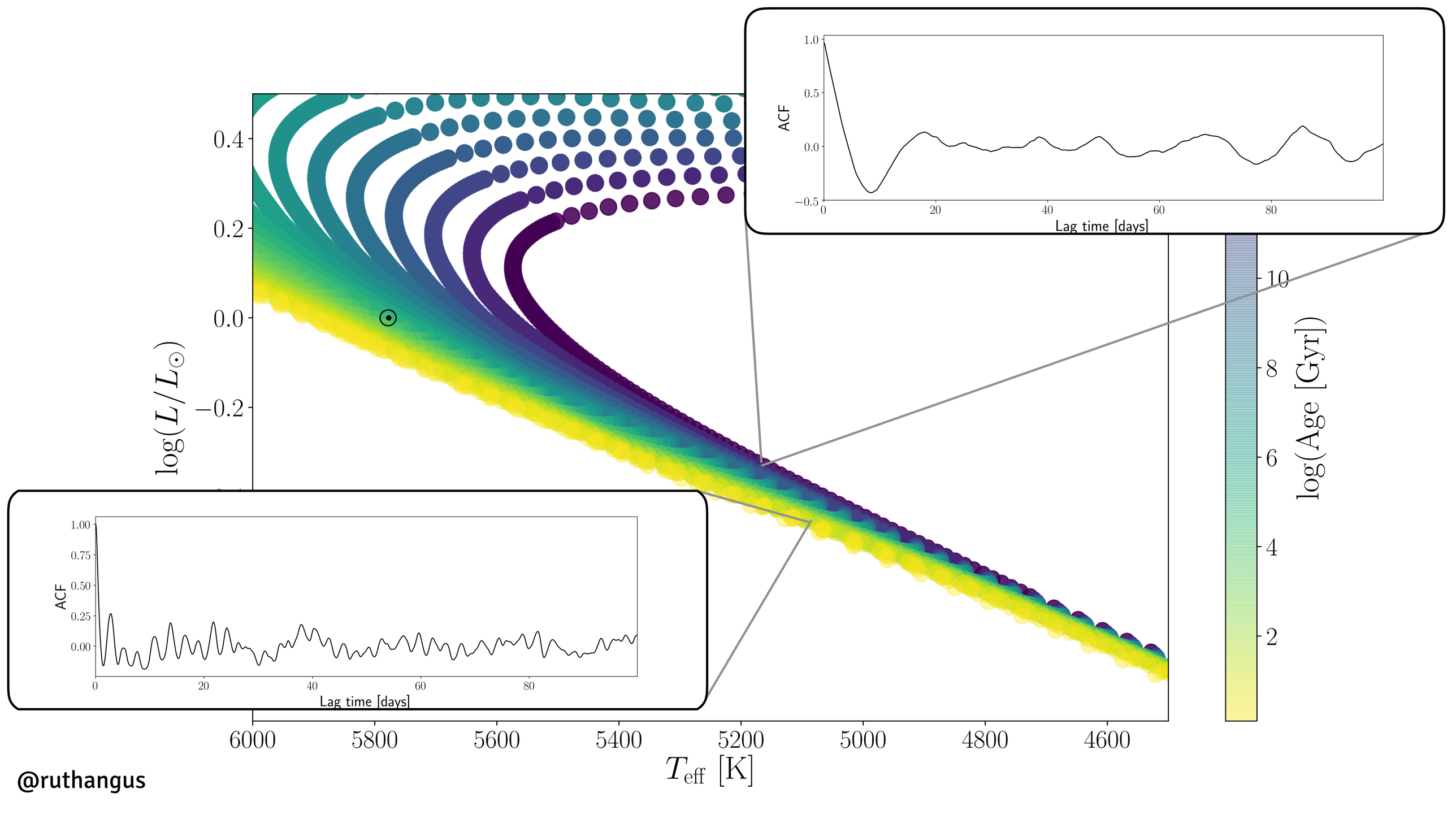
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$T_{\rm eff}$ [K]
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−0.5
0
20
40
60
80
Lag time [days]
ACF
1.00
0.75
0.50
0.25
0.00
0
20
40
60
80
Lag time [days]
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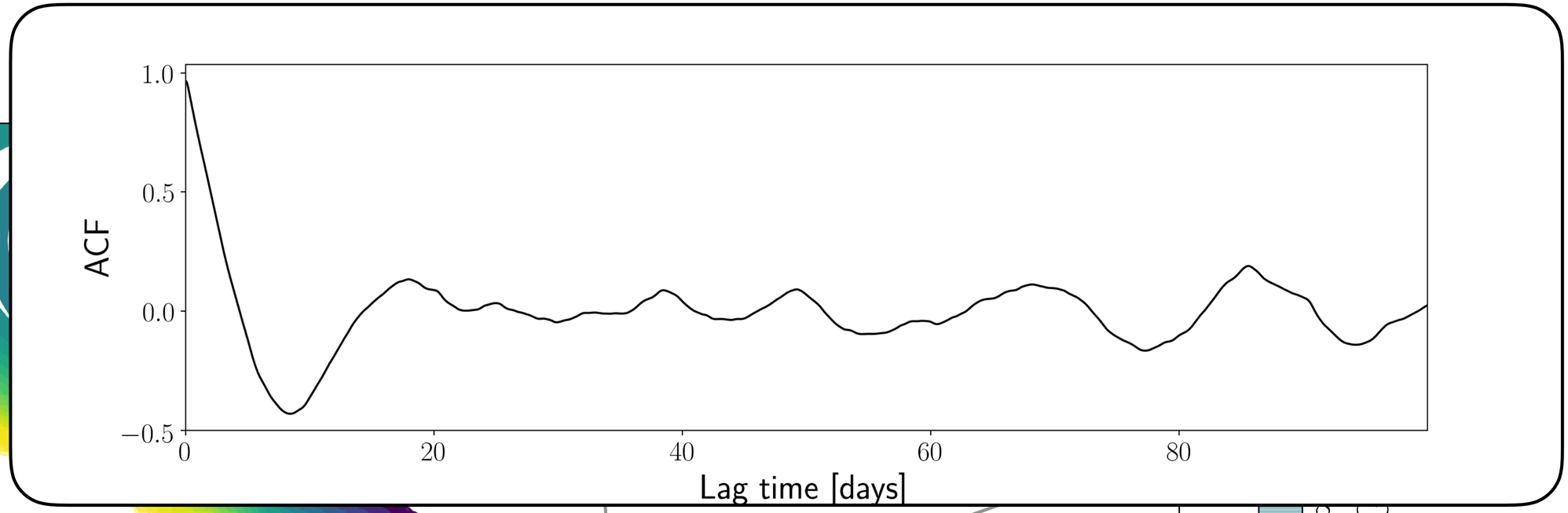
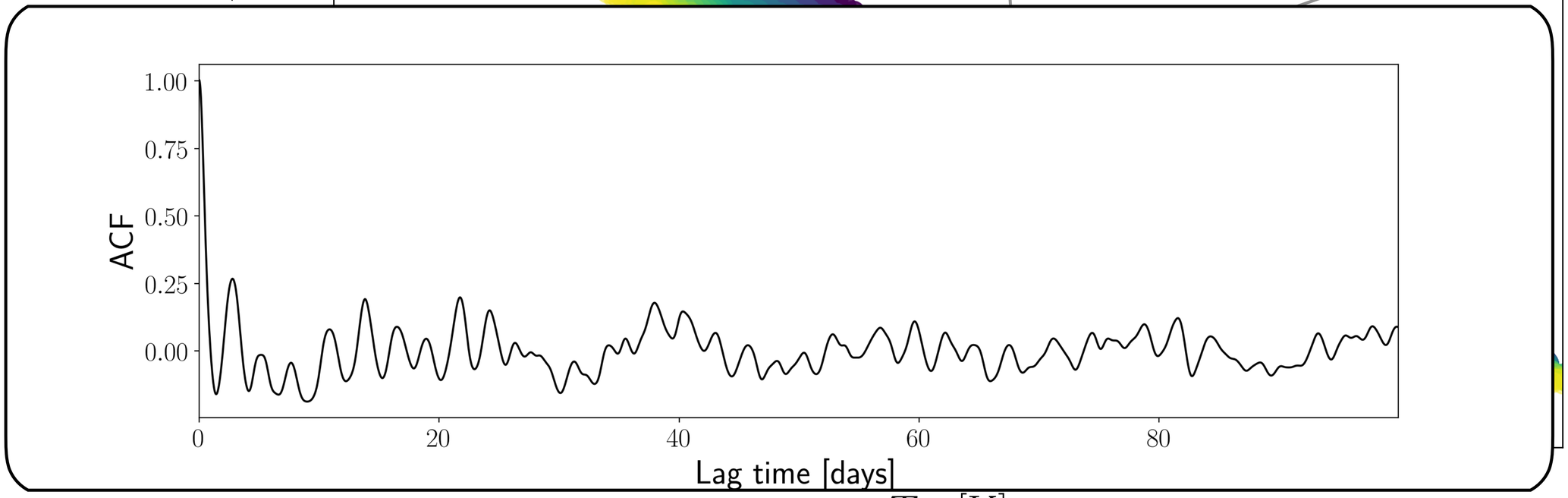
The light curve Cannon (Ness et al., 2018)





$T_{\rm eff}$ [K]

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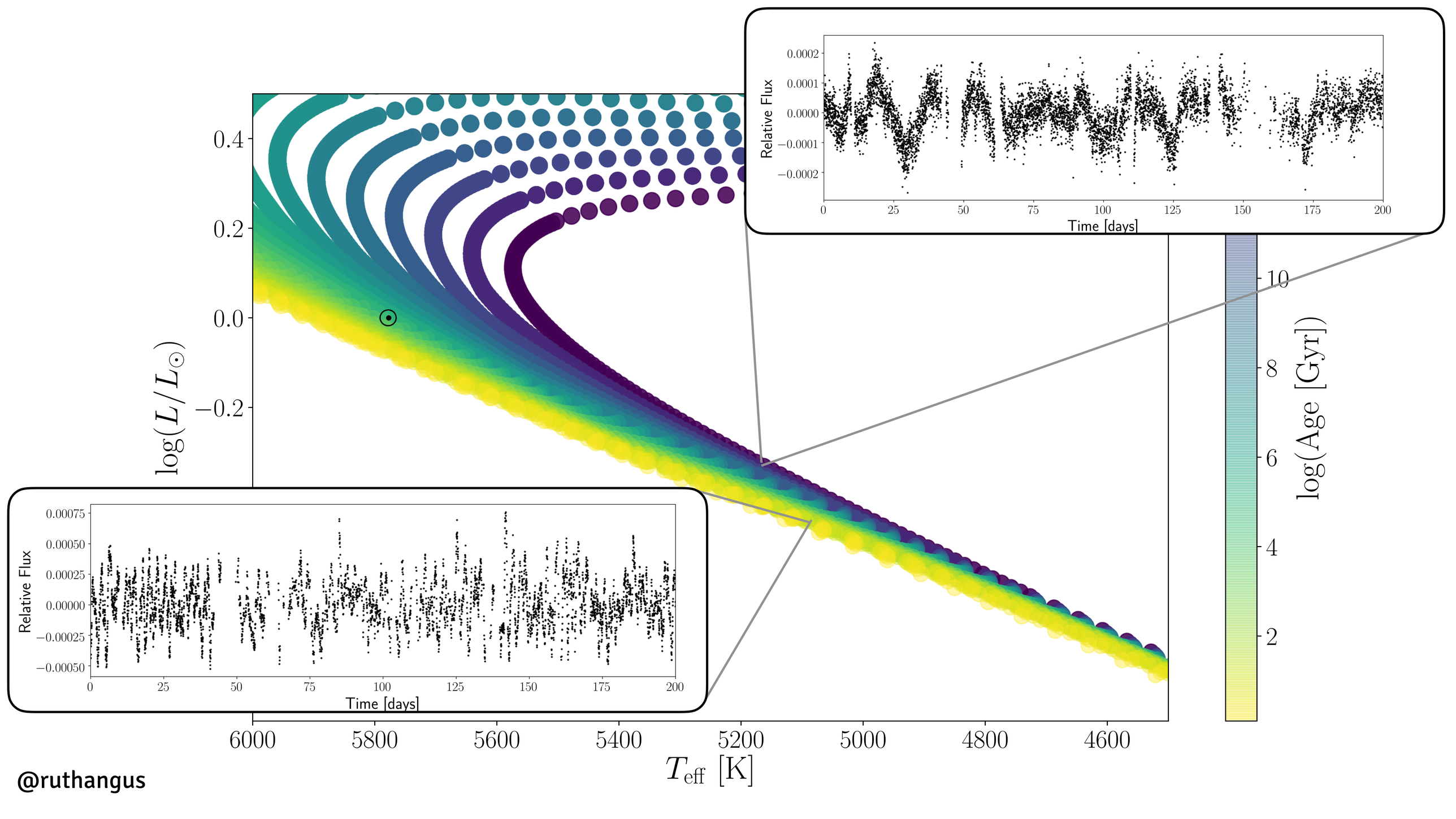
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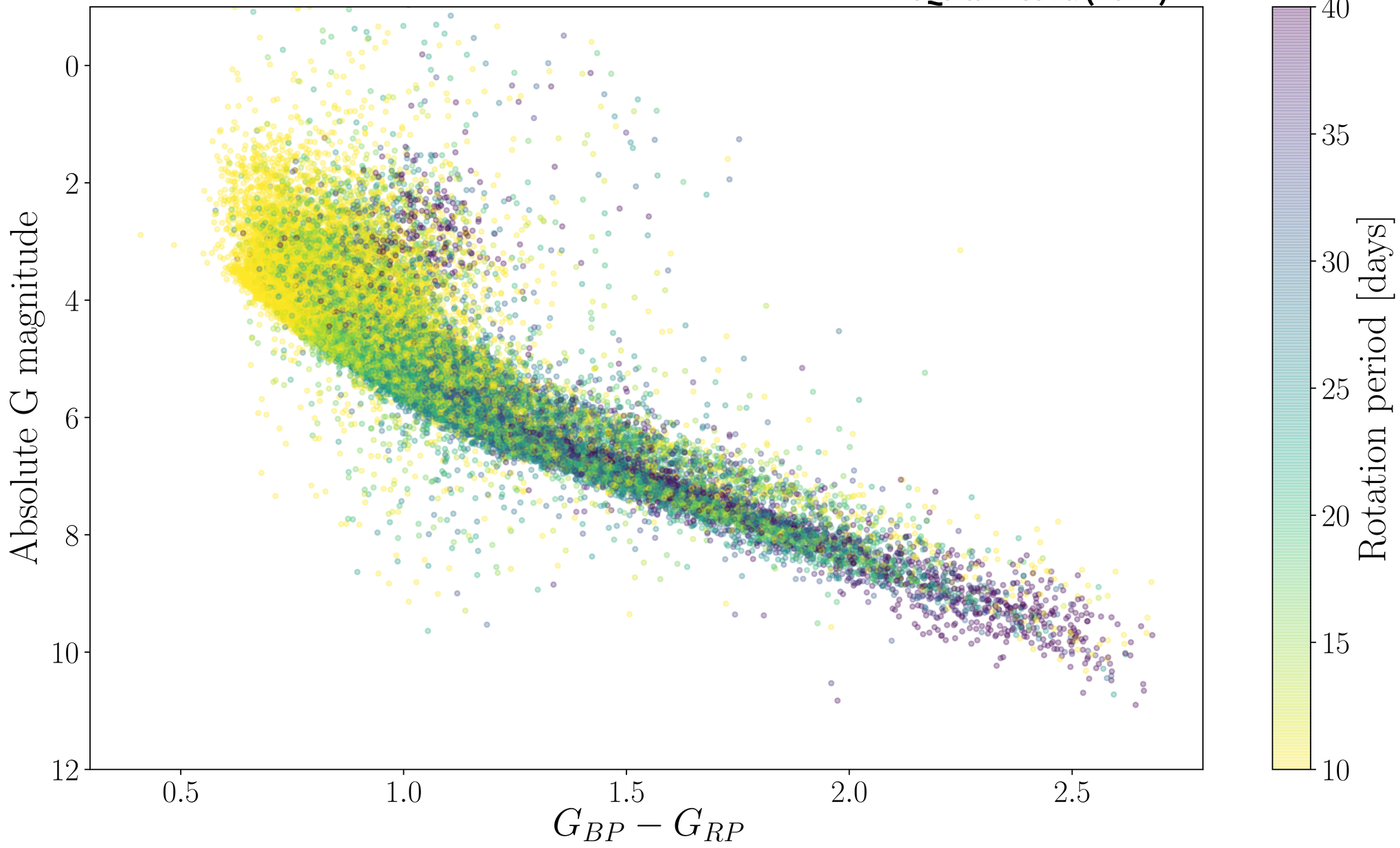
Stellar rotation on the CMD

McQuillan et al. (2014)



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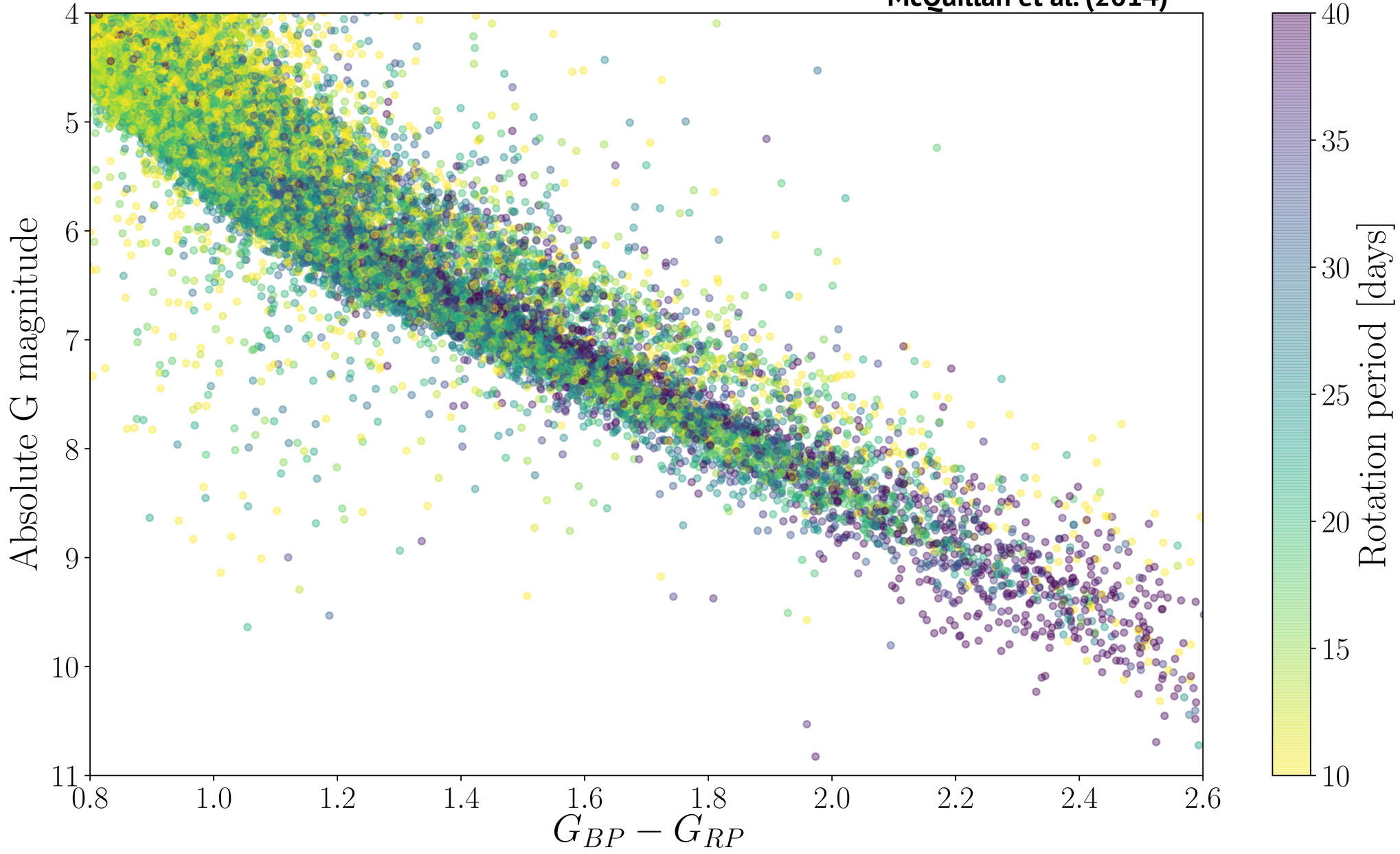

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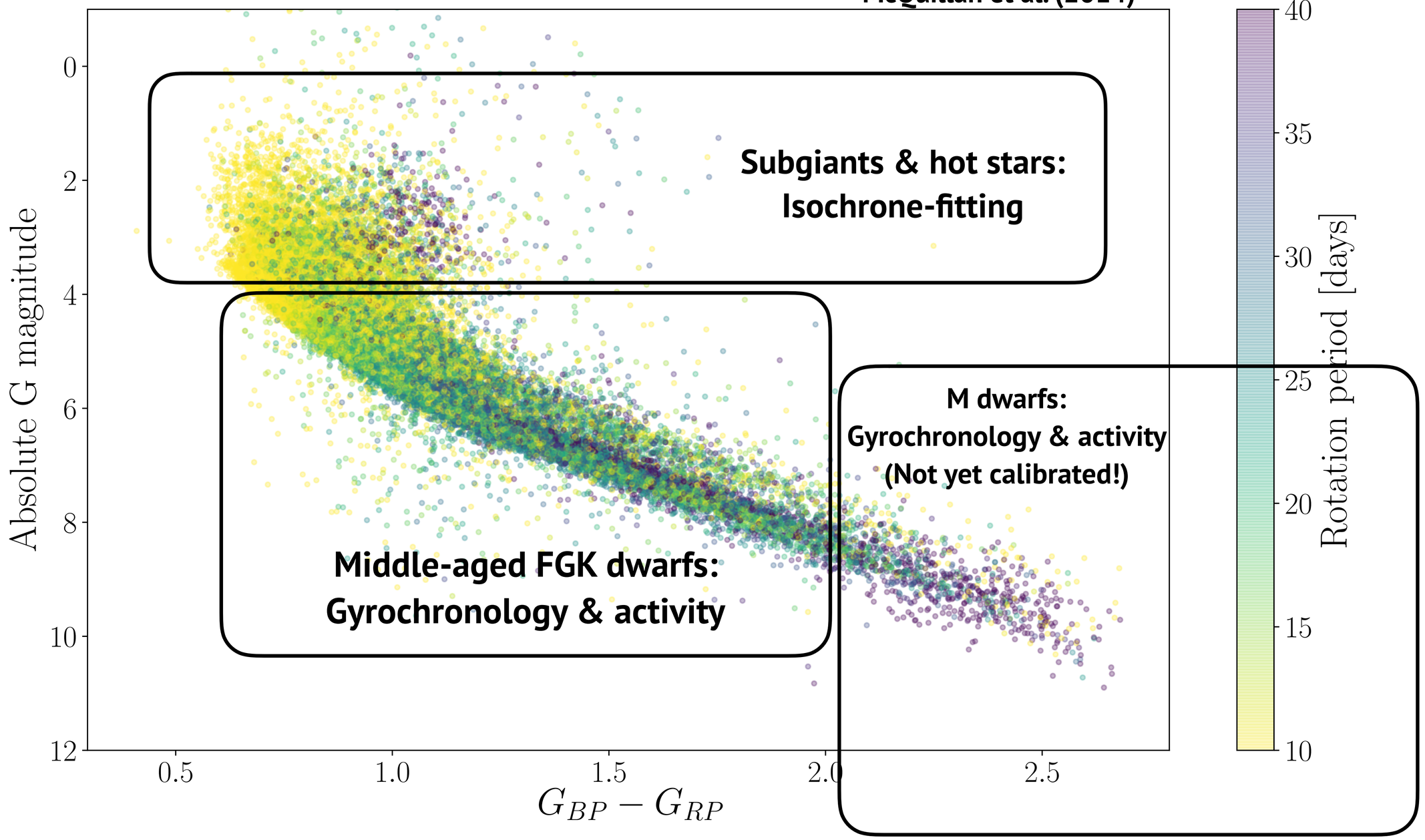

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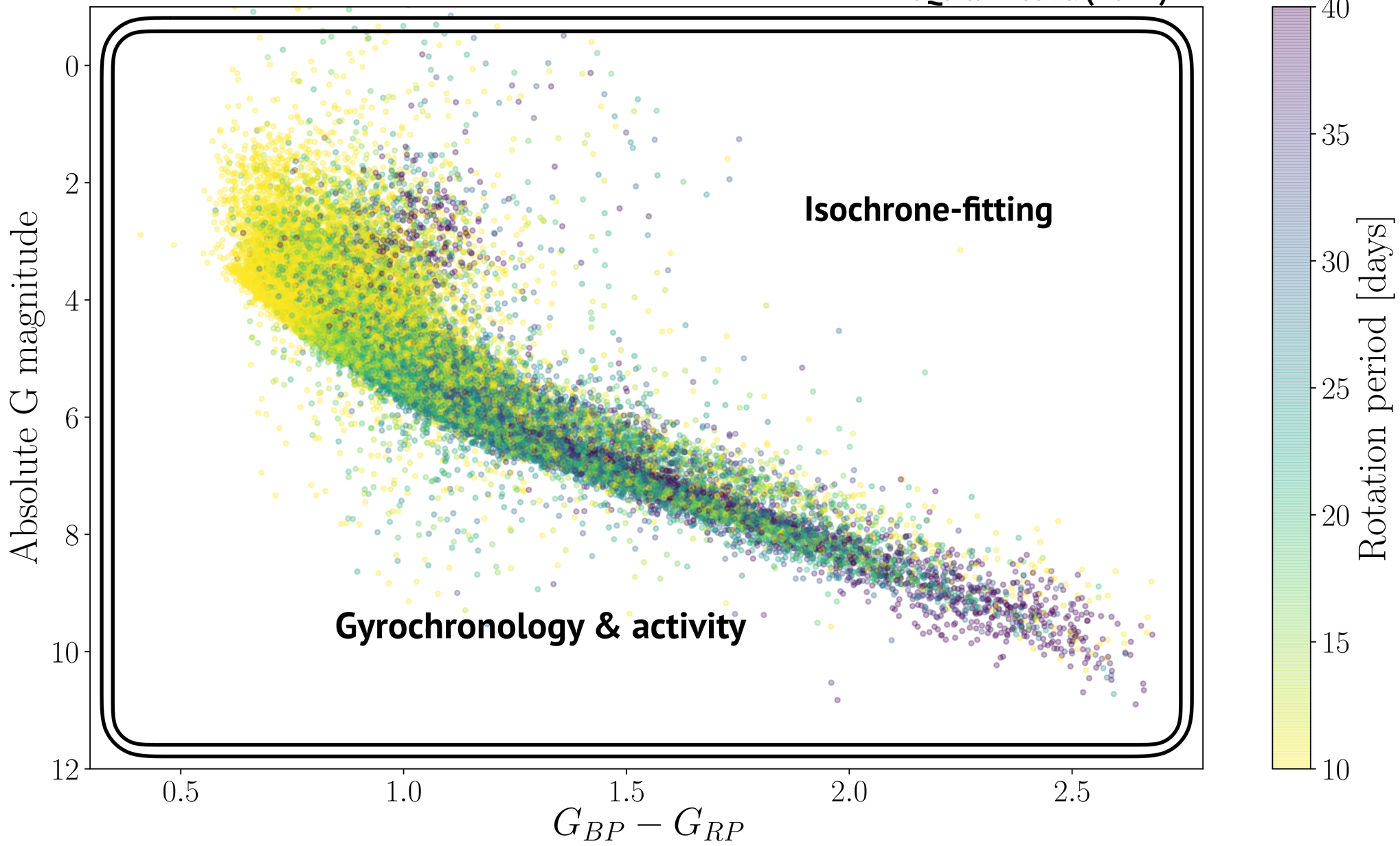

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stardate

stardate.readthedocs.io
github/ruthangus/stardate

1. Combines **multiple** age indicators/dating methods

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2 Selects **best dating method** in each region of parameter space

stardate

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3 Rotation period is a **function of all stellar parameters**

stardate

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4 **Empirical** equivalent of isochrones/tracks with rotation

stardate

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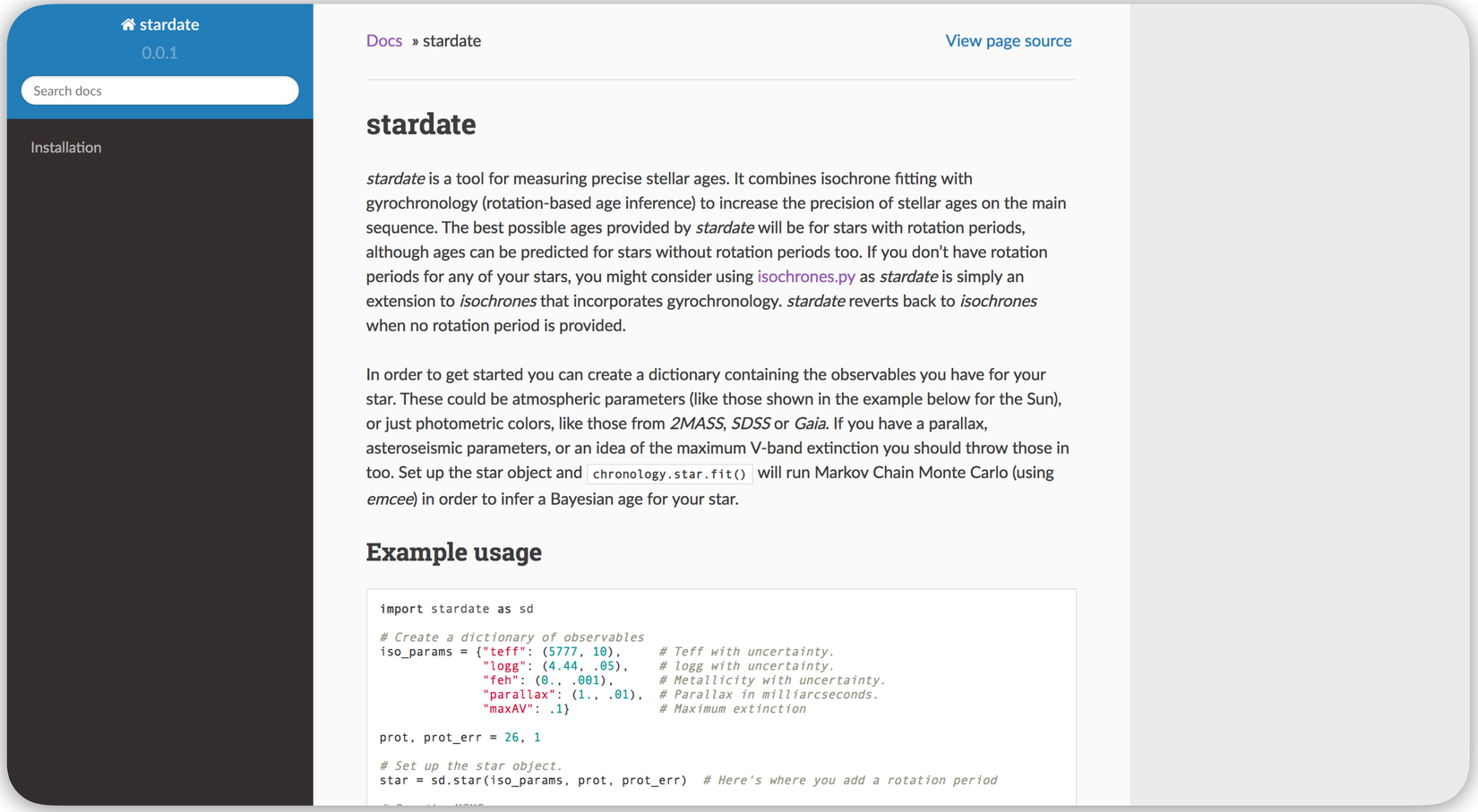
5 Built on top of ***isochrones*** (github.com/timothydmorton/isochrones)

stardate (Cross-submitted to AJ and JOSS)

Ruth Angus, Tim Morton, Dan Foreman-Mackey, Jen van Saders,
Stephen Kane, Rocio Kiman, Jason Curtis, John Brewer, David Hogg

stardate.readthedocs.io
github/ruthangus/stardate



stardate
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Installation

Docs » stardate

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stardate

stardate is a tool for measuring precise stellar ages. It combines isochrone fitting with gyrochronology (rotation-based age inference) to increase the precision of stellar ages on the main sequence. The best possible ages provided by *stardate* will be for stars with rotation periods, although ages can be predicted for stars without rotation periods too. If you don't have rotation periods for any of your stars, you might consider using isochrones.py as *stardate* is simply an extension to *isochrones* that incorporates gyrochronology. *stardate* reverts back to *isochrones* when no rotation period is provided.

In order to get started you can create a dictionary containing the observables you have for your star. These could be atmospheric parameters (like those shown in the example below for the Sun), or just photometric colors, like those from *2MASS*, *SDSS* or *Gaia*. If you have a parallax, asteroseismic parameters, or an idea of the maximum V-band extinction you should throw those in too. Set up the star object and `chronology.star.fit()` will run Markov Chain Monte Carlo (using *emcee*) in order to infer a Bayesian age for your star.

Example usage

```
import stardate as sd

# Create a dictionary of observables
iso_params = {"teff": (5777, 10),      # Teff with uncertainty.
              "logg": (4.44, .05),     # logg with uncertainty.
              "feh": (0., .001),       # Metallicity with uncertainty.
              "parallax": (1., .01),   # Parallax in milliarcseconds.
              "maxAV": .1}             # Maximum extinction

prot, prot_err = 26, 1

# Set up the star object.
star = sd.star(iso_params, prot, prot_err)  # Here's where you add a rotation period
```

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stardate.readthedocs.io
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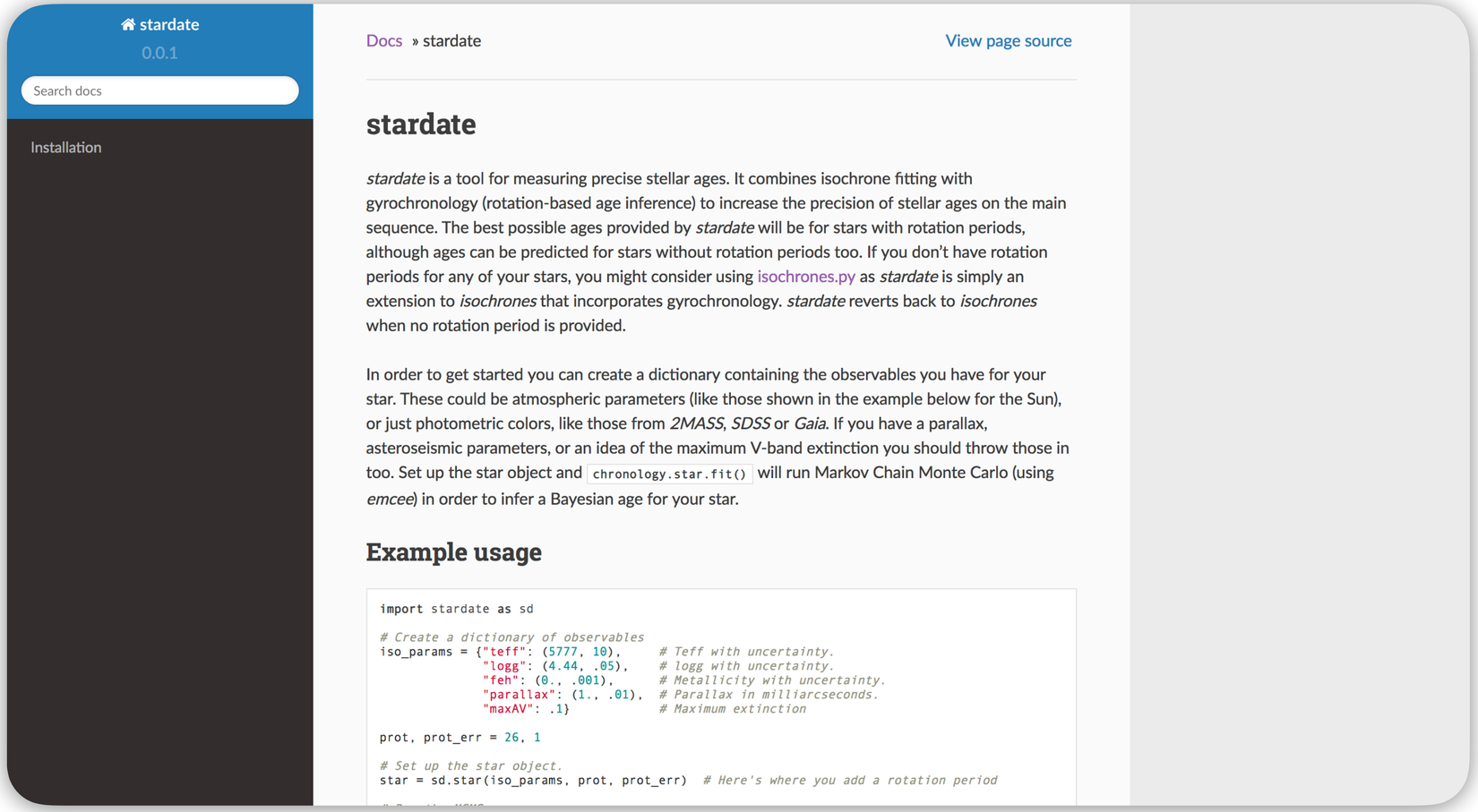

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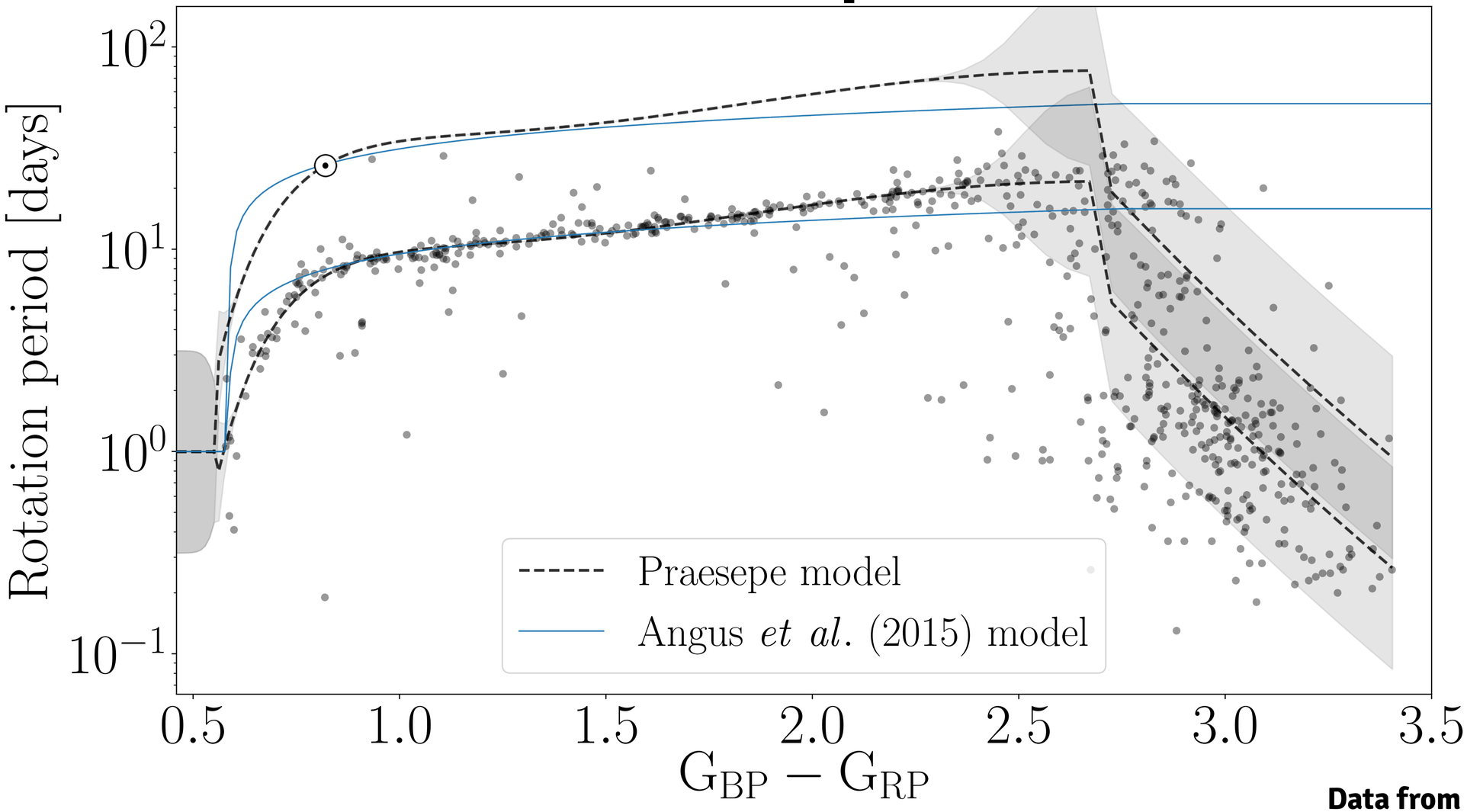
Calibrating to Praesepe & the Sun

~650 Myrs



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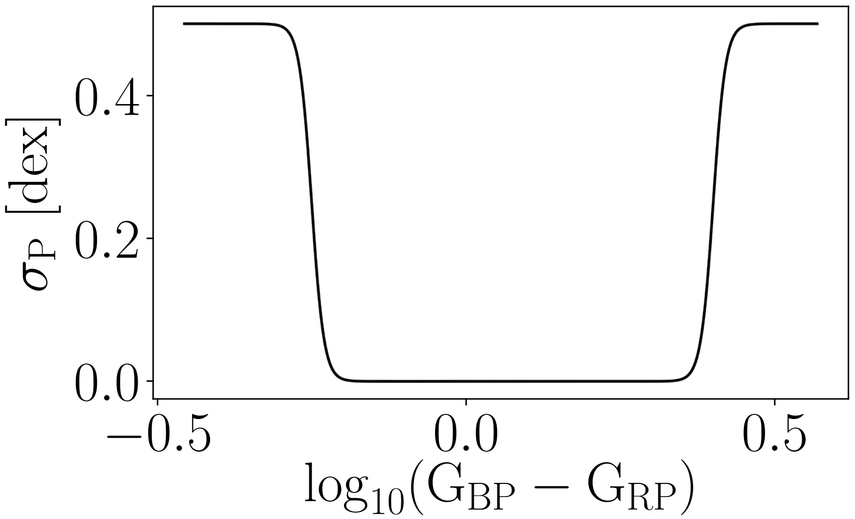
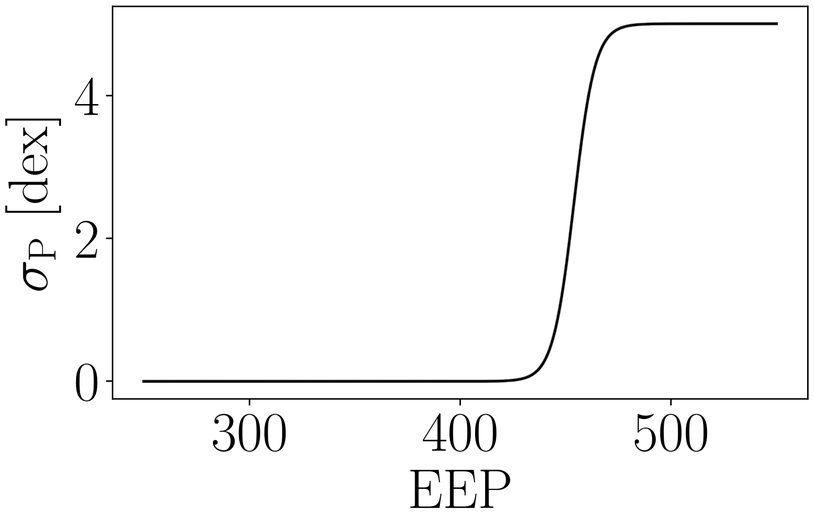
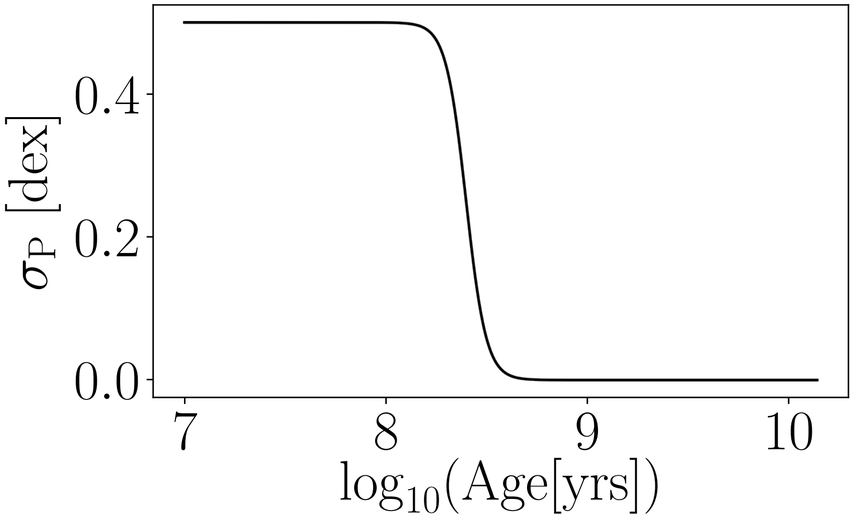
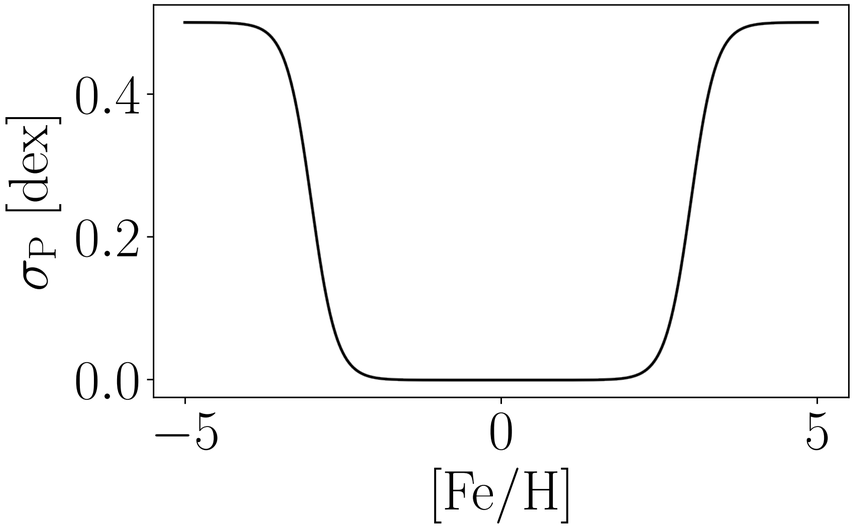
Data from Douglas et al. (2017)
See also Douglas et al. (2019)
ArXiv: 1905.06736

Inflating the variance where gyro doesn't apply (or is poorly calibrated)









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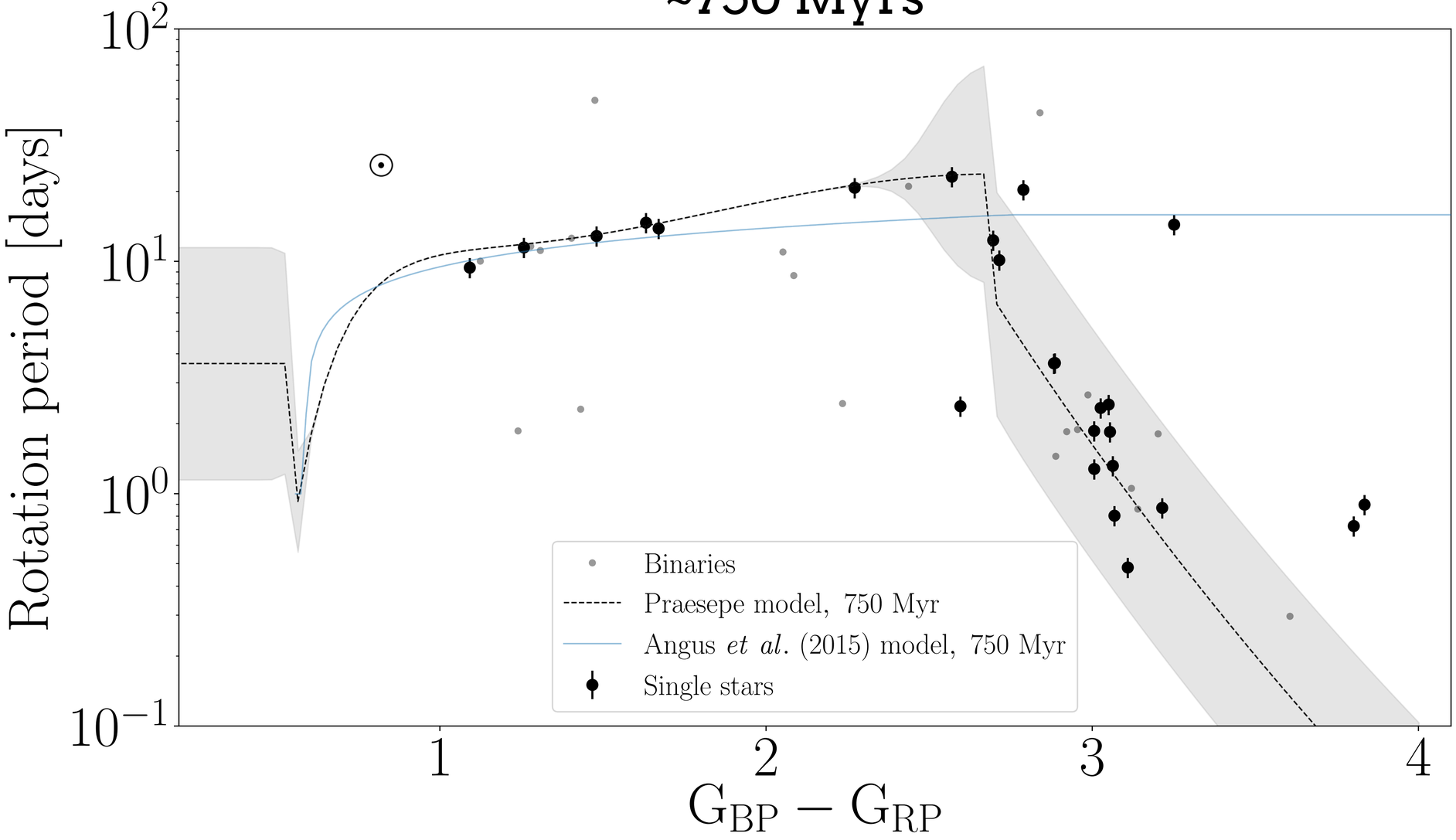
The Hyades

~750 Myrs



Data from Douglas et al. (2016)

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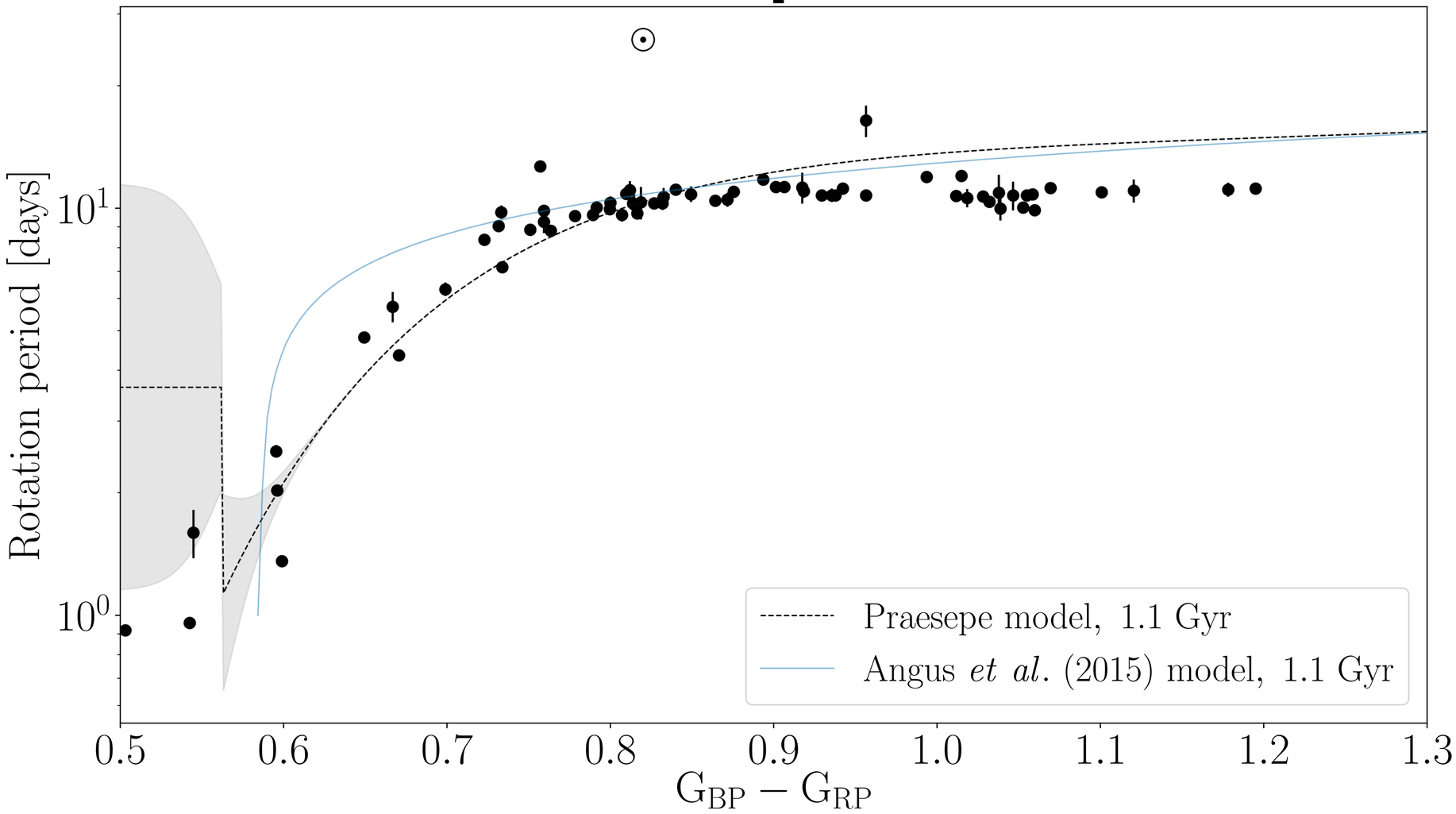
NGC 6811

1.1 Gyrs

See Curtis et al. (2019)
ArXiv: 1905.06869



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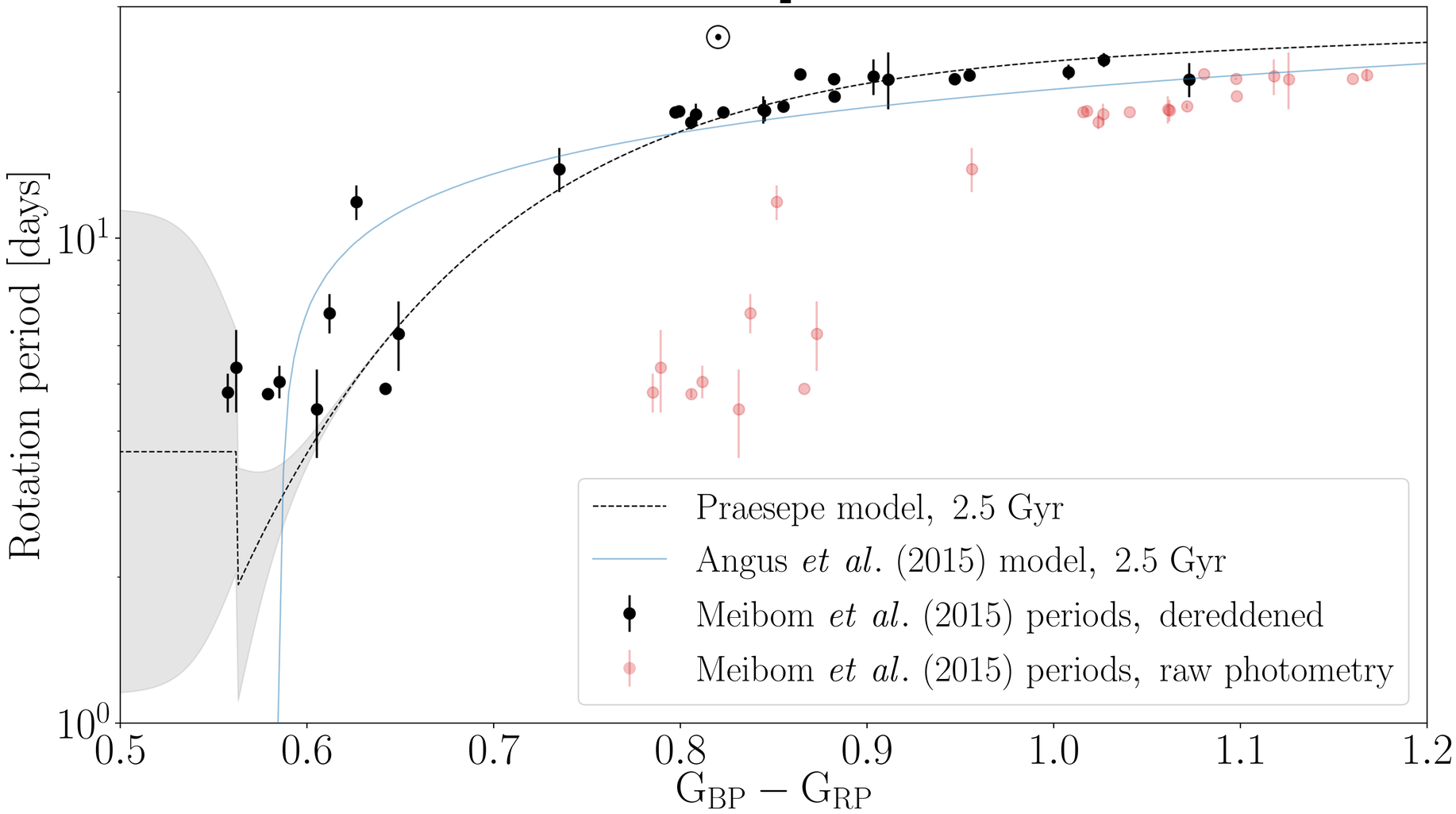
Data from Meibom et al. (2011)

NGC 6819

2.5 Gyrs



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Data from Meibom et al. (2015)

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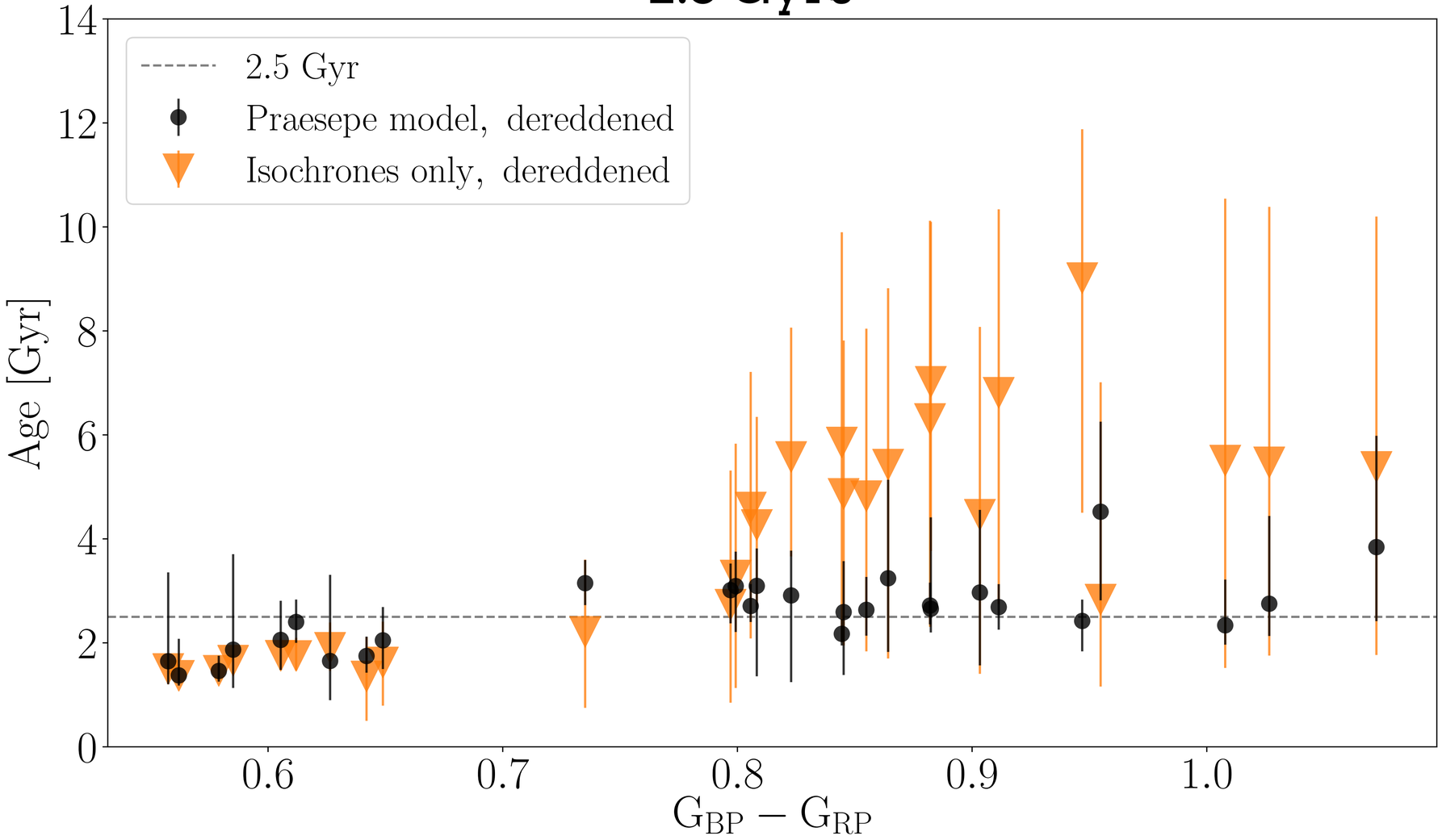

F

G

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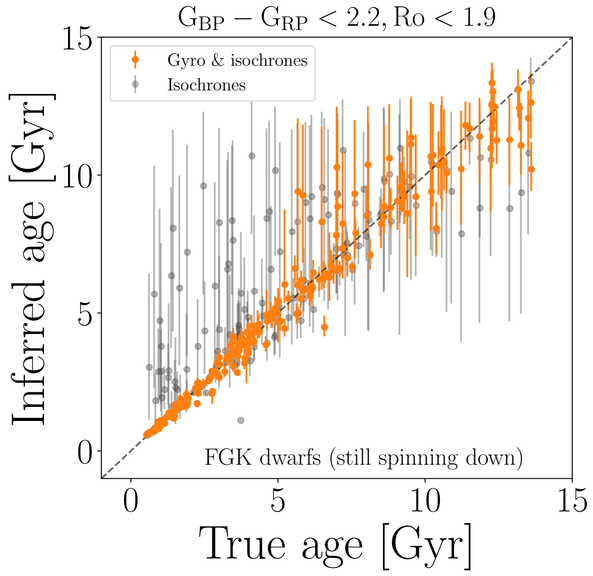
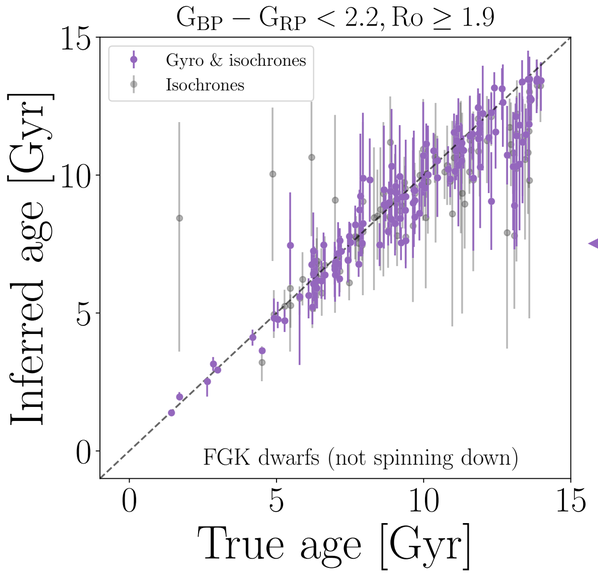
Combining gyrochronology & isochrones

Angus et al. (submitted)

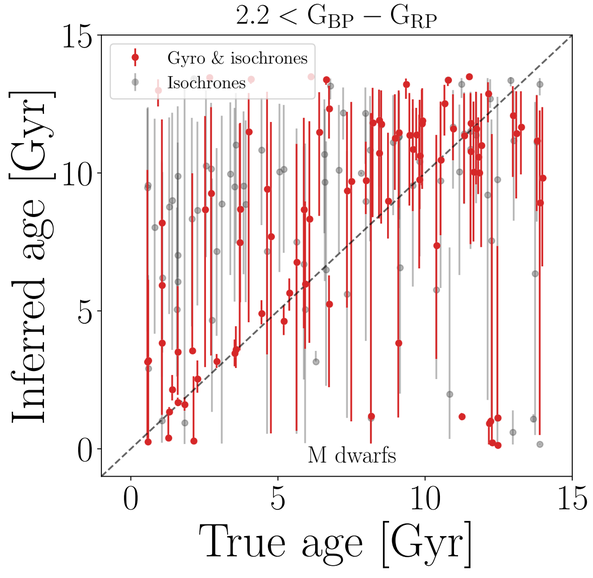
FGK dwarfs →

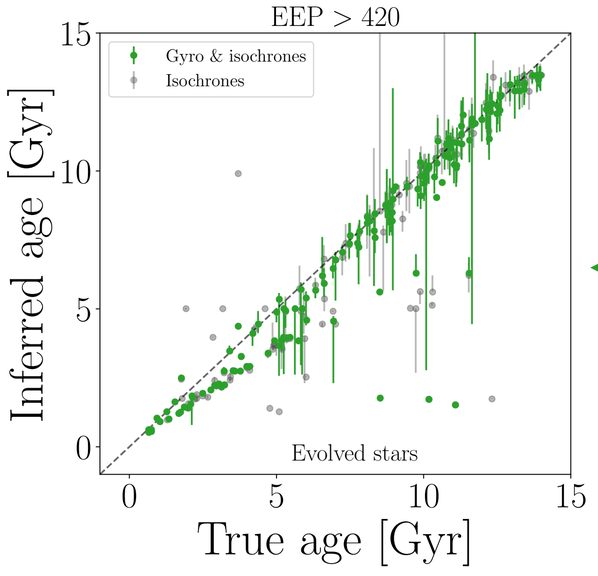




← Old FGK dwarfs

M dwarfs →





← Subgiants

Combining gyrochronology & isochrones

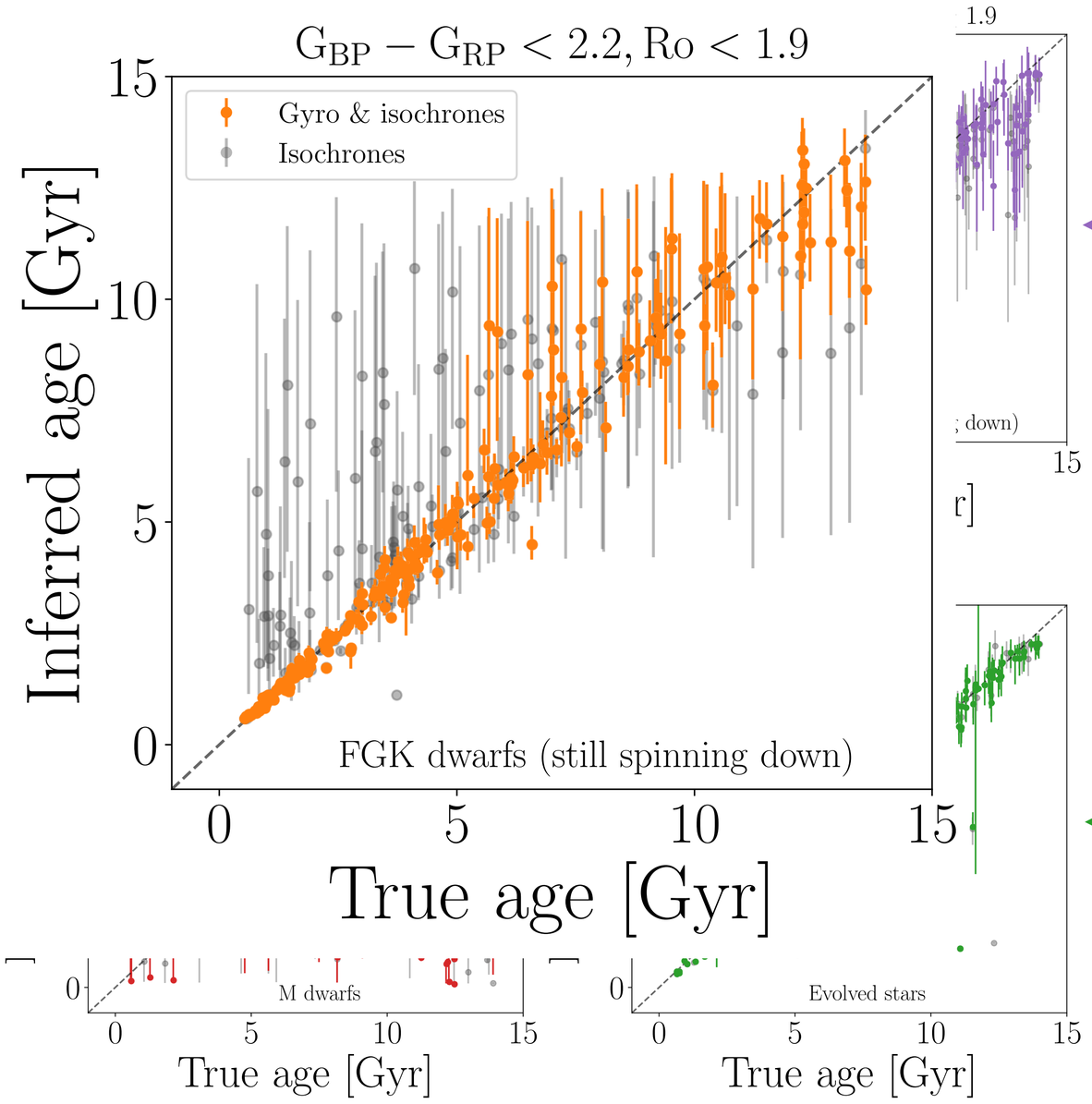
Angus et al. (submitted)

FGK dwarfs →

← Old FGK dwarfs

M dwarfs →

← Subgiants



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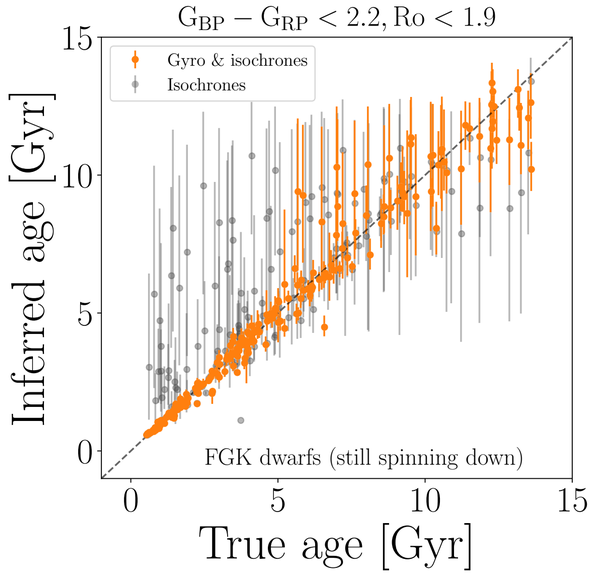

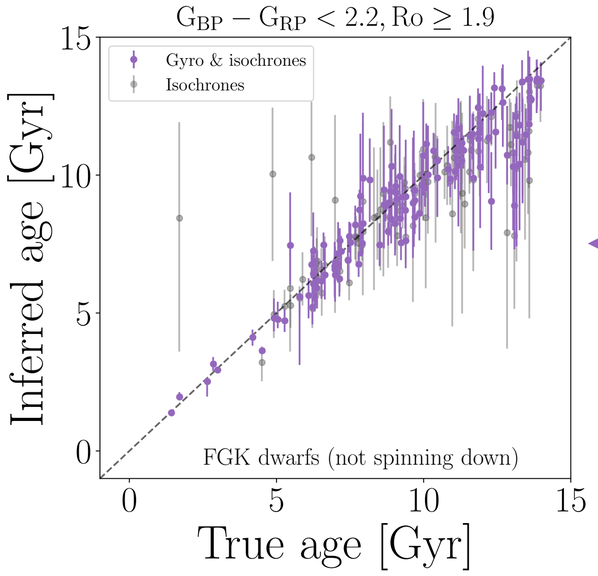

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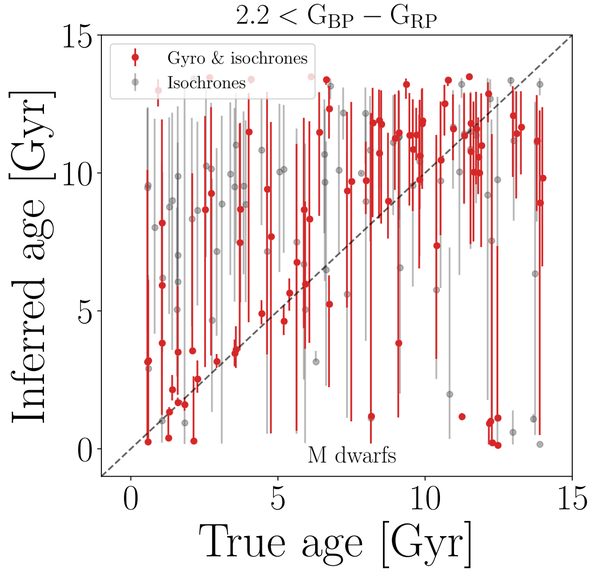

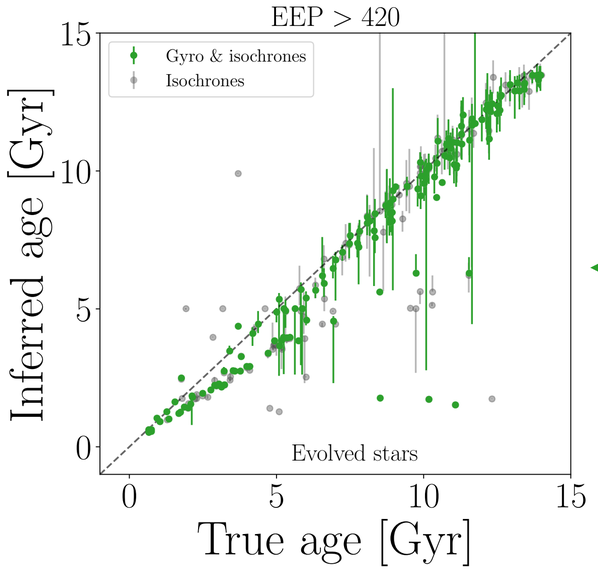

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Combining gyrochronology & isochrones

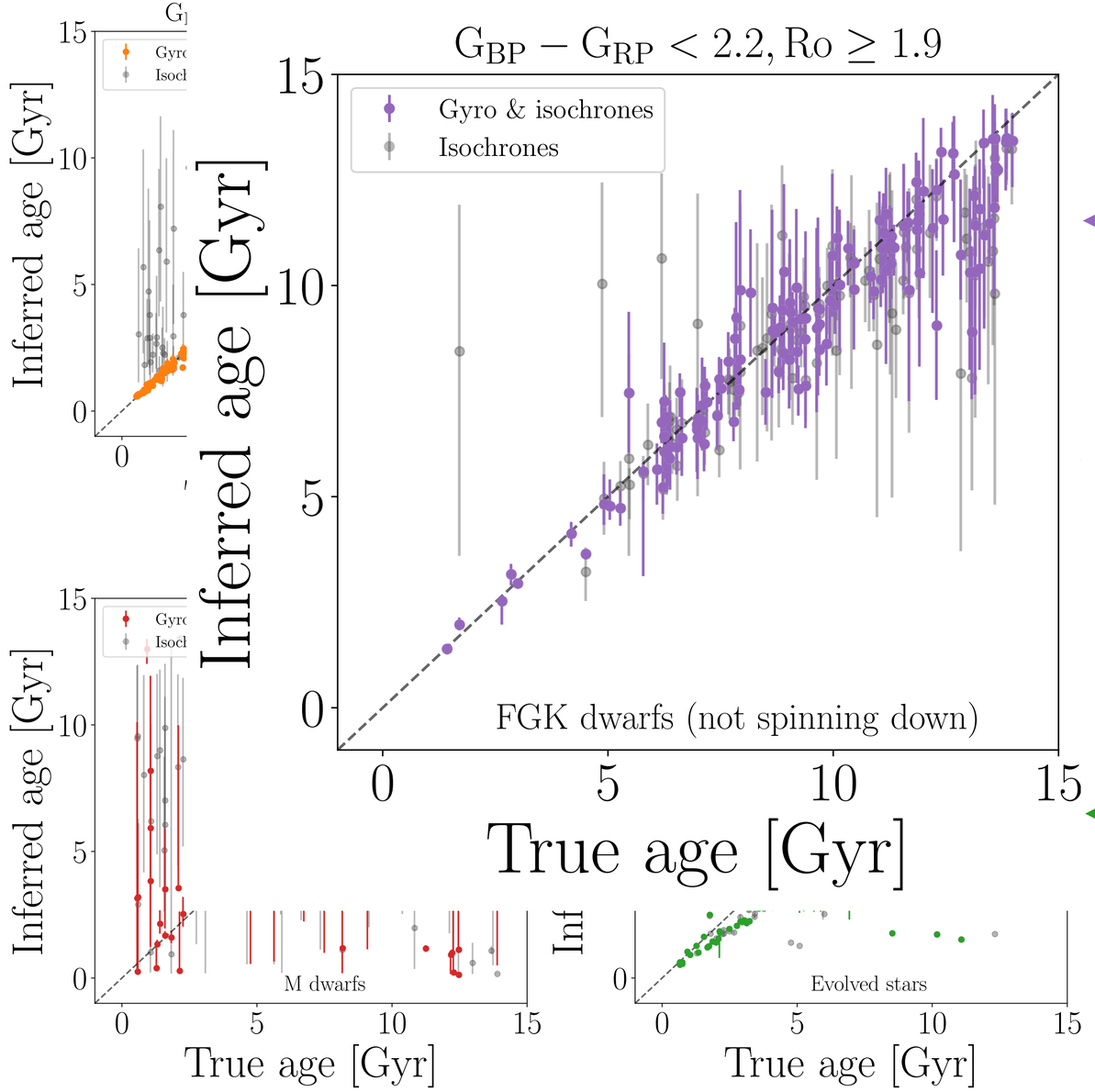
Angus et al. (submitted)

FGK dwarfs →

← Old FGK dwarfs

M dwarfs →

← Subgiants



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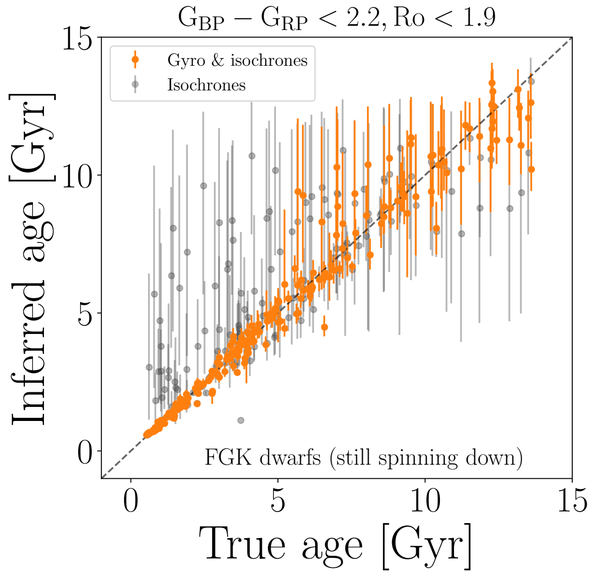

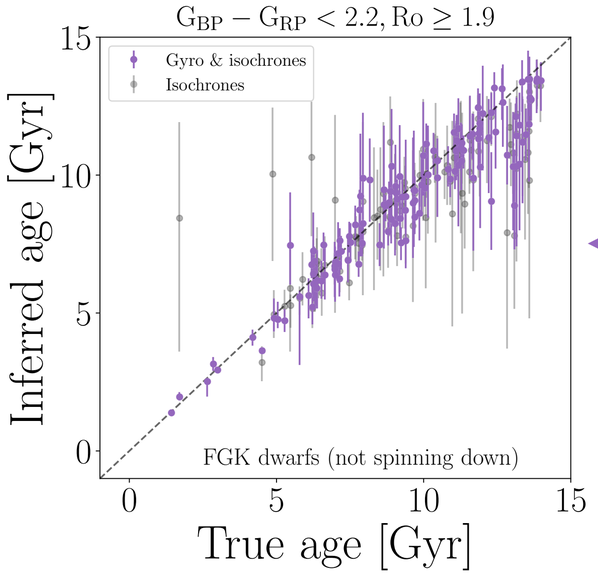

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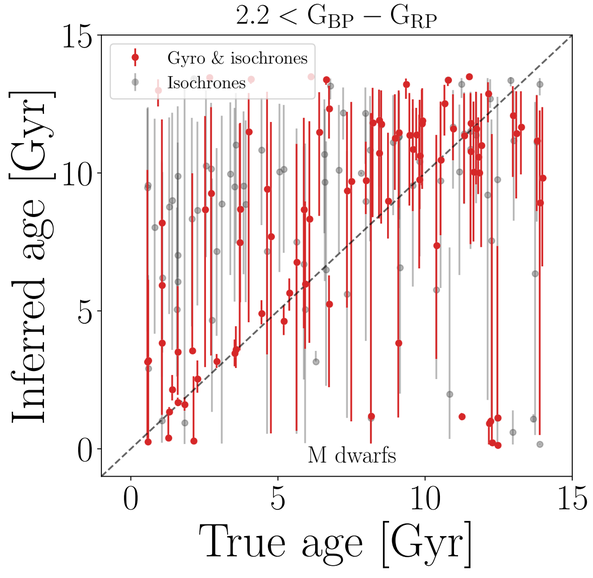
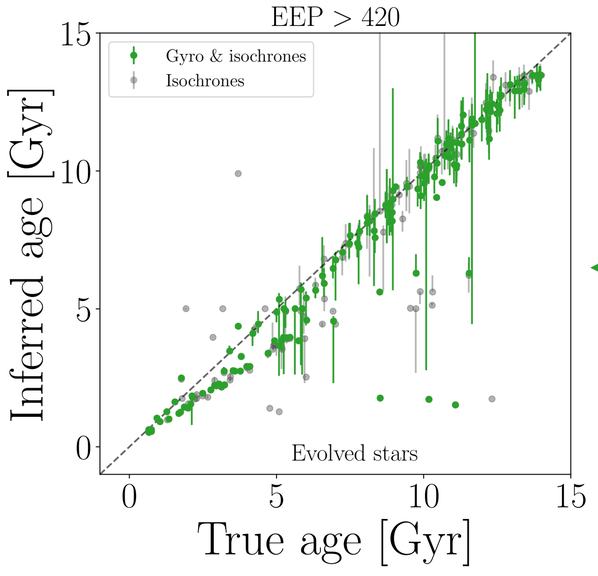
M dwarfs →

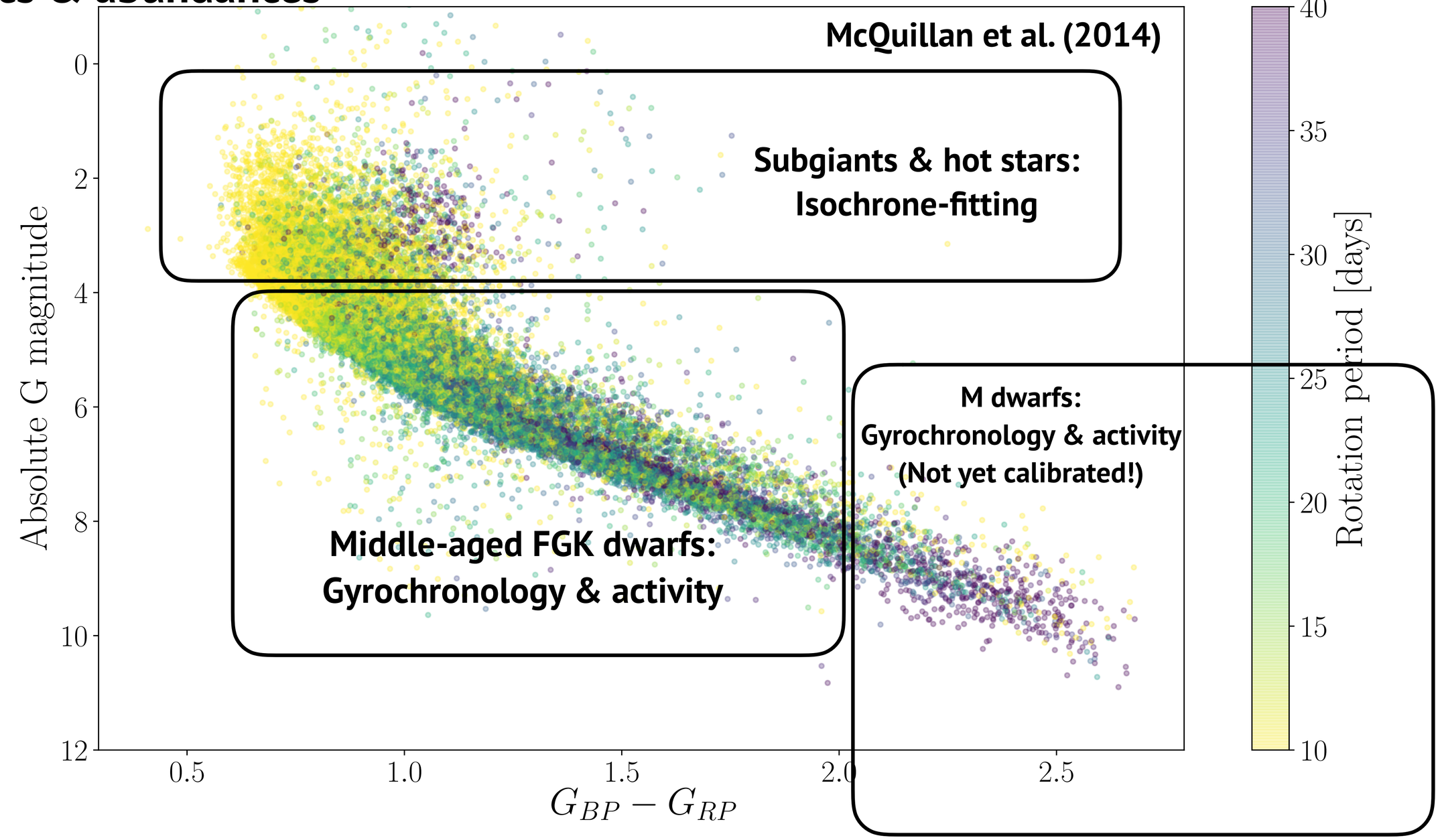




← Subgiants

Stellar rotation on the CMD

All stars:
Kinematics & abundances



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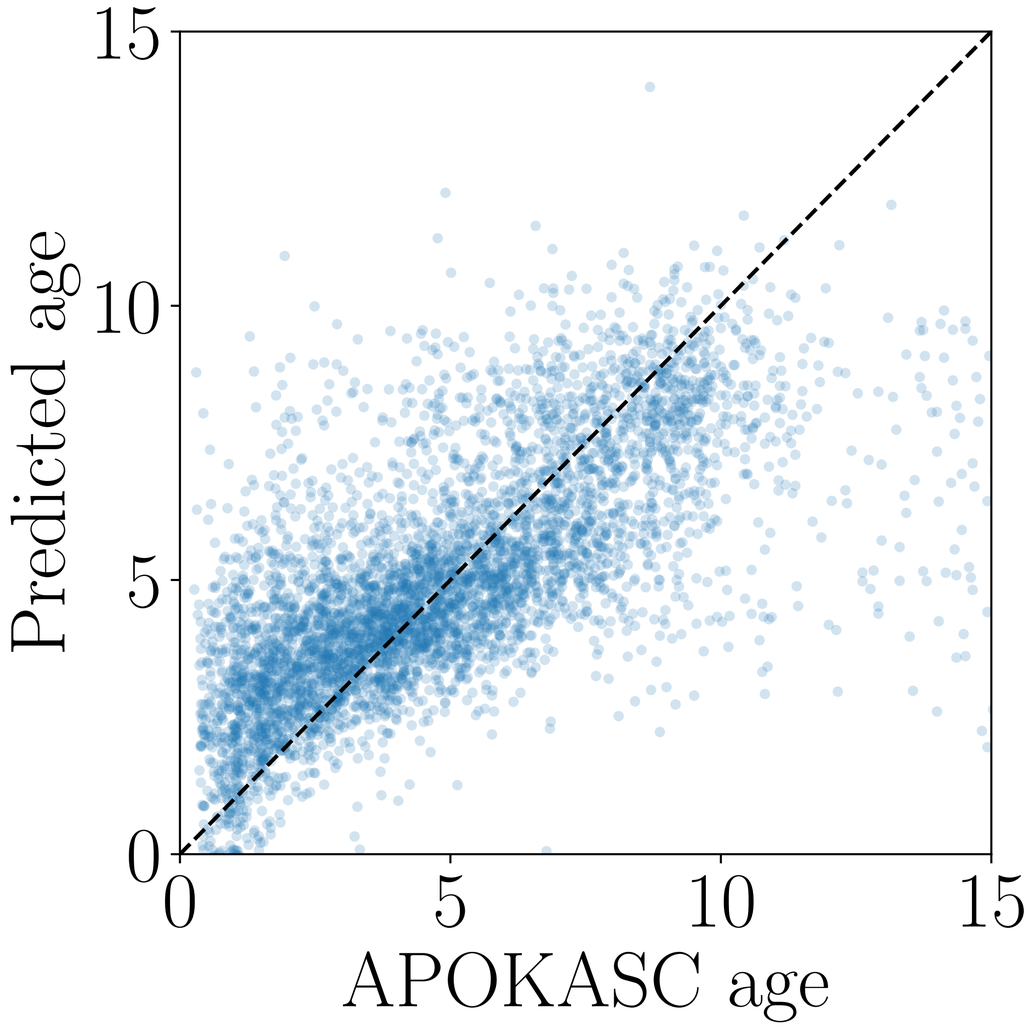
Stellar ages from **abundances**

Made at KITP with Phil Muirhead, Jamie Tayar & Melissa Ness



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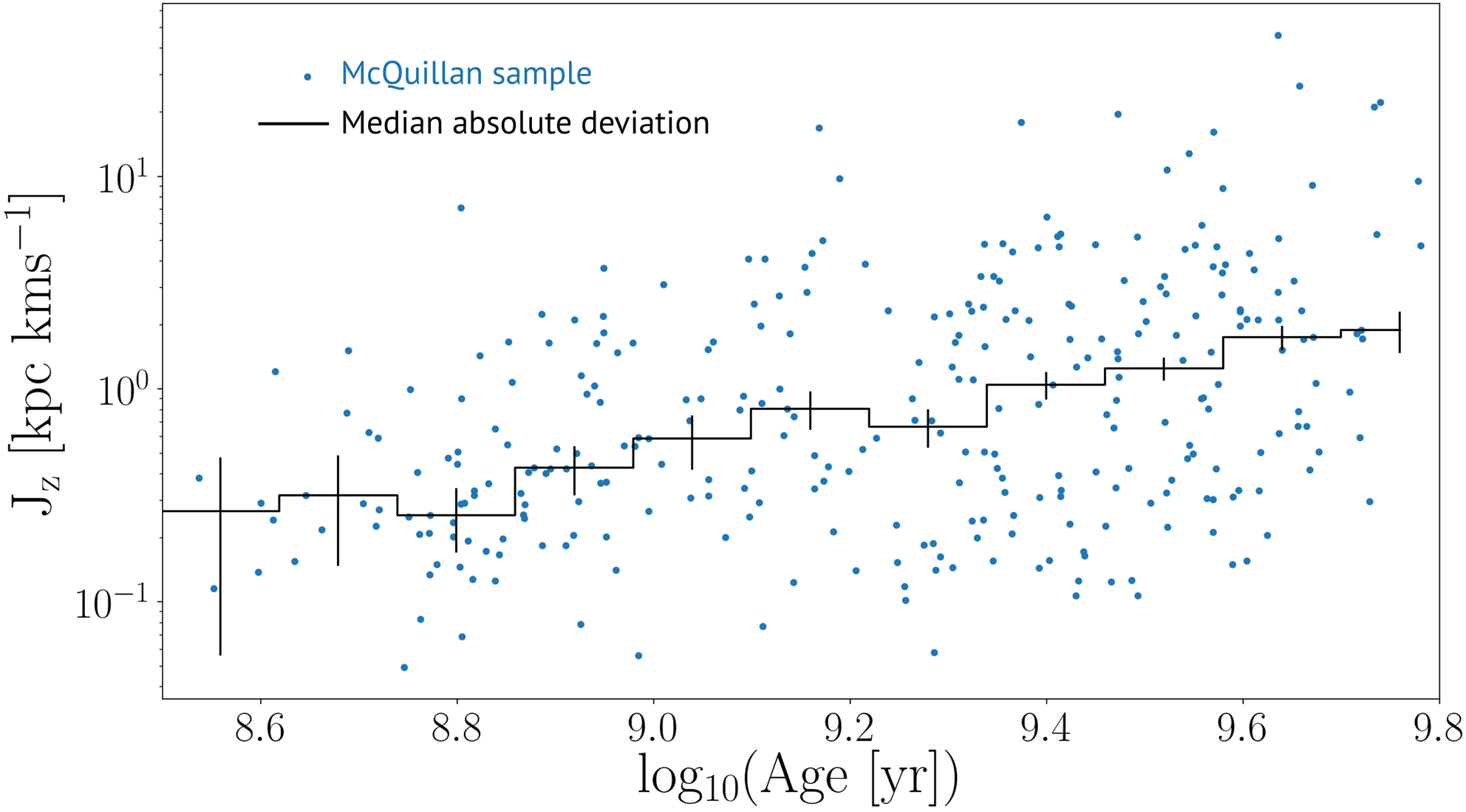
Stellar ages from **kinematics**

Made at KITP



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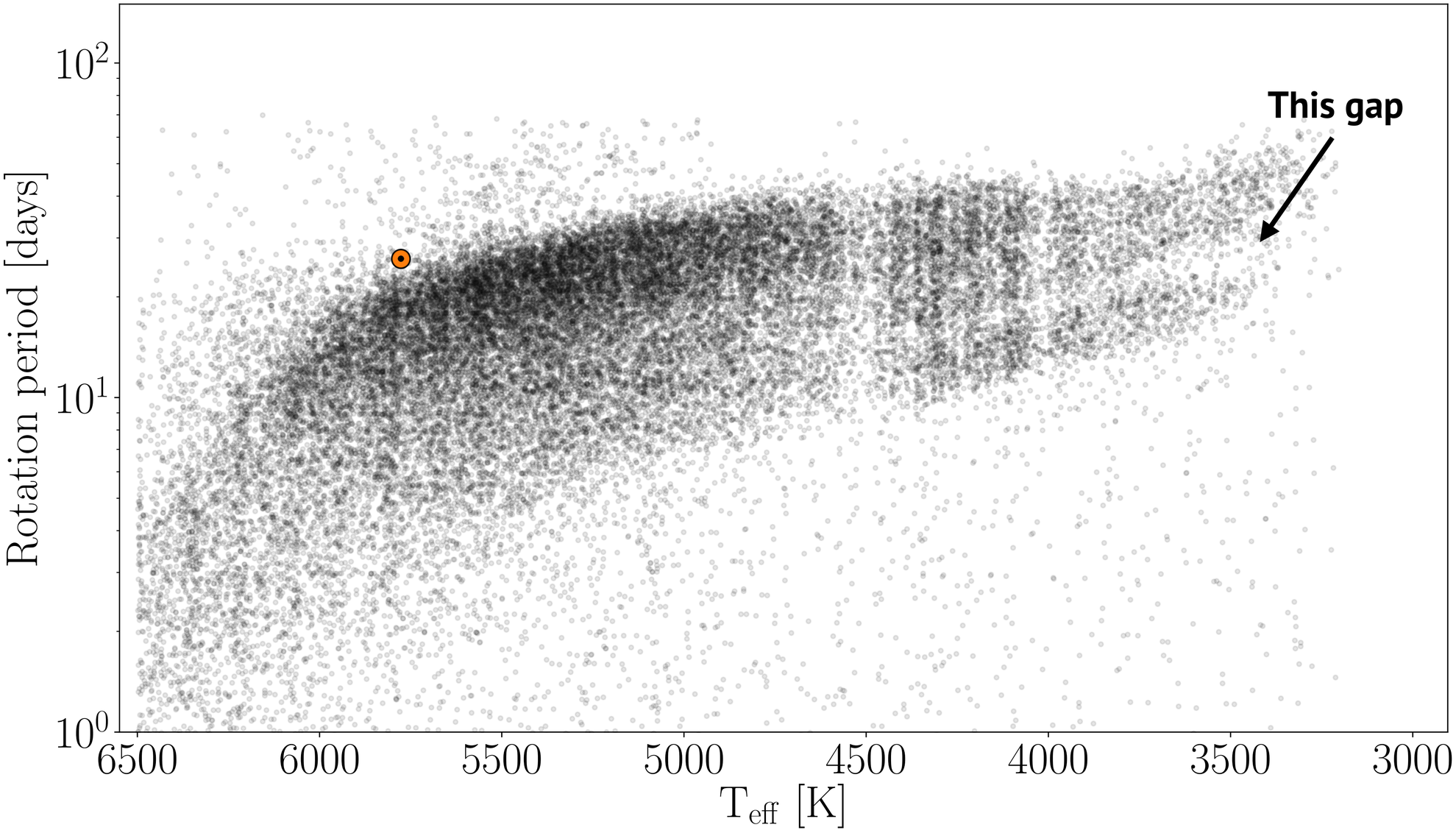
Rotation vs Temperature

McQuillan et al. (2014)



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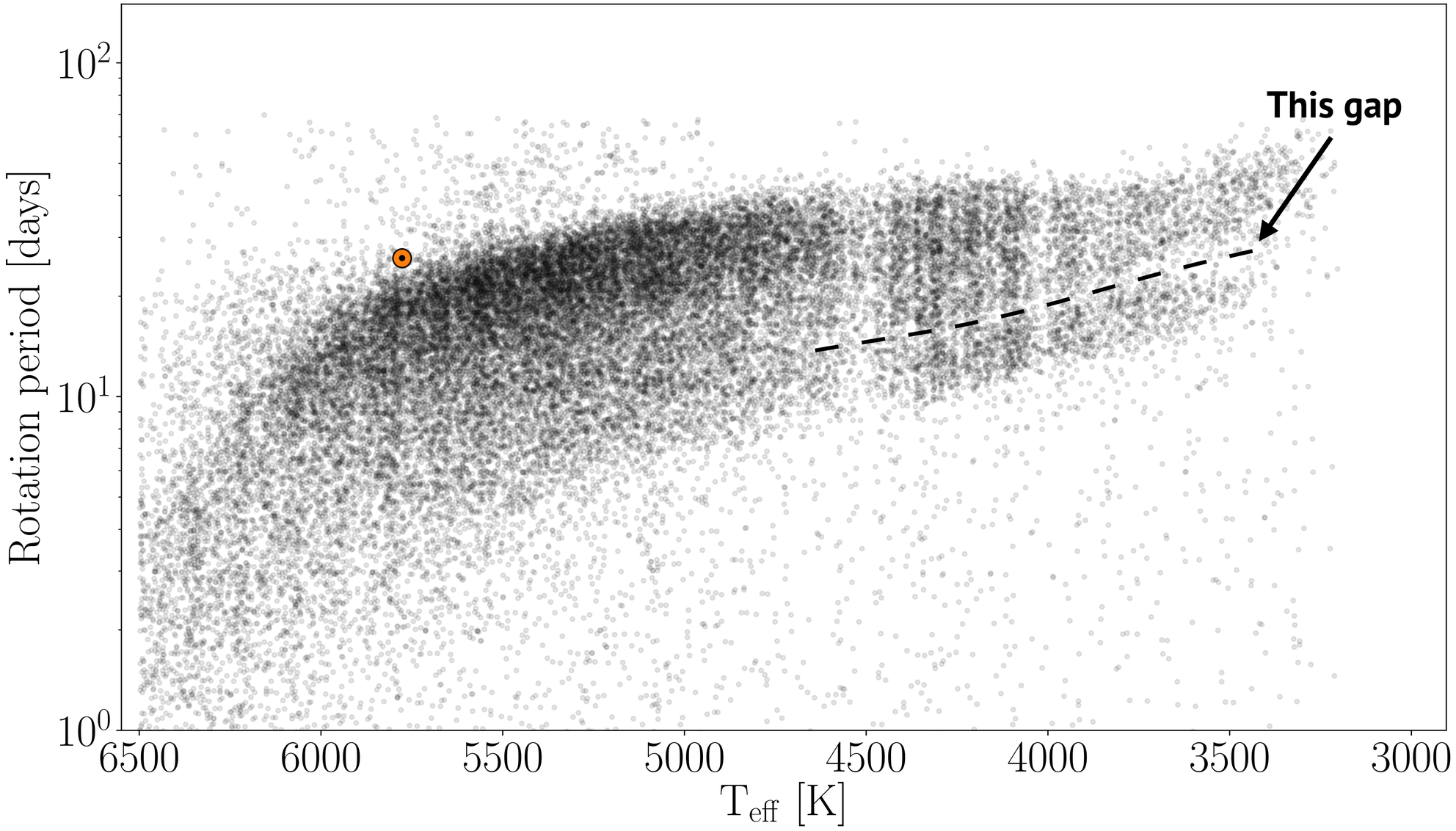
Rotation vs Temperature

McQuillan et al. (2014)



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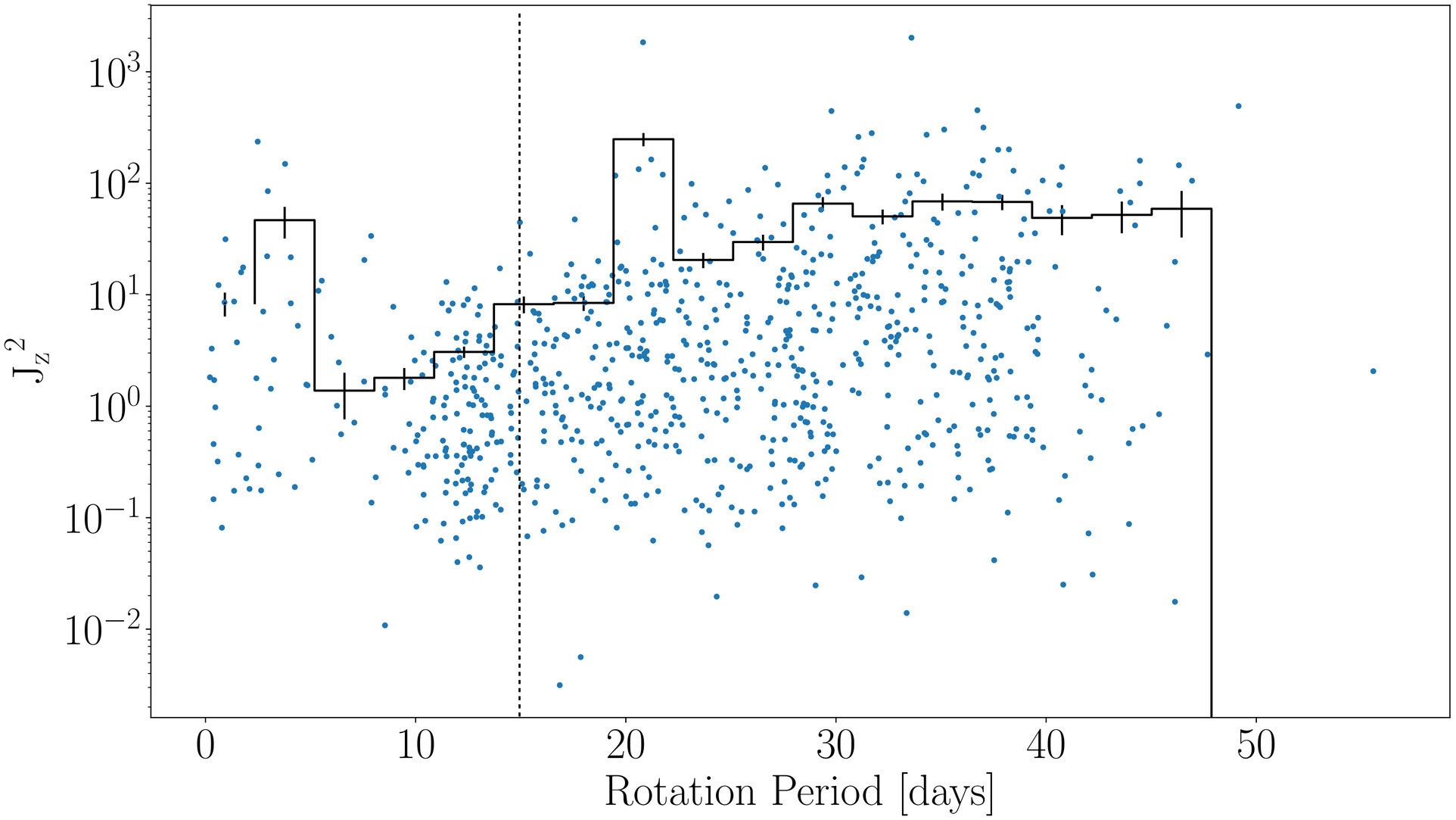
Stellar ages from **kinematics**

Made at KITP



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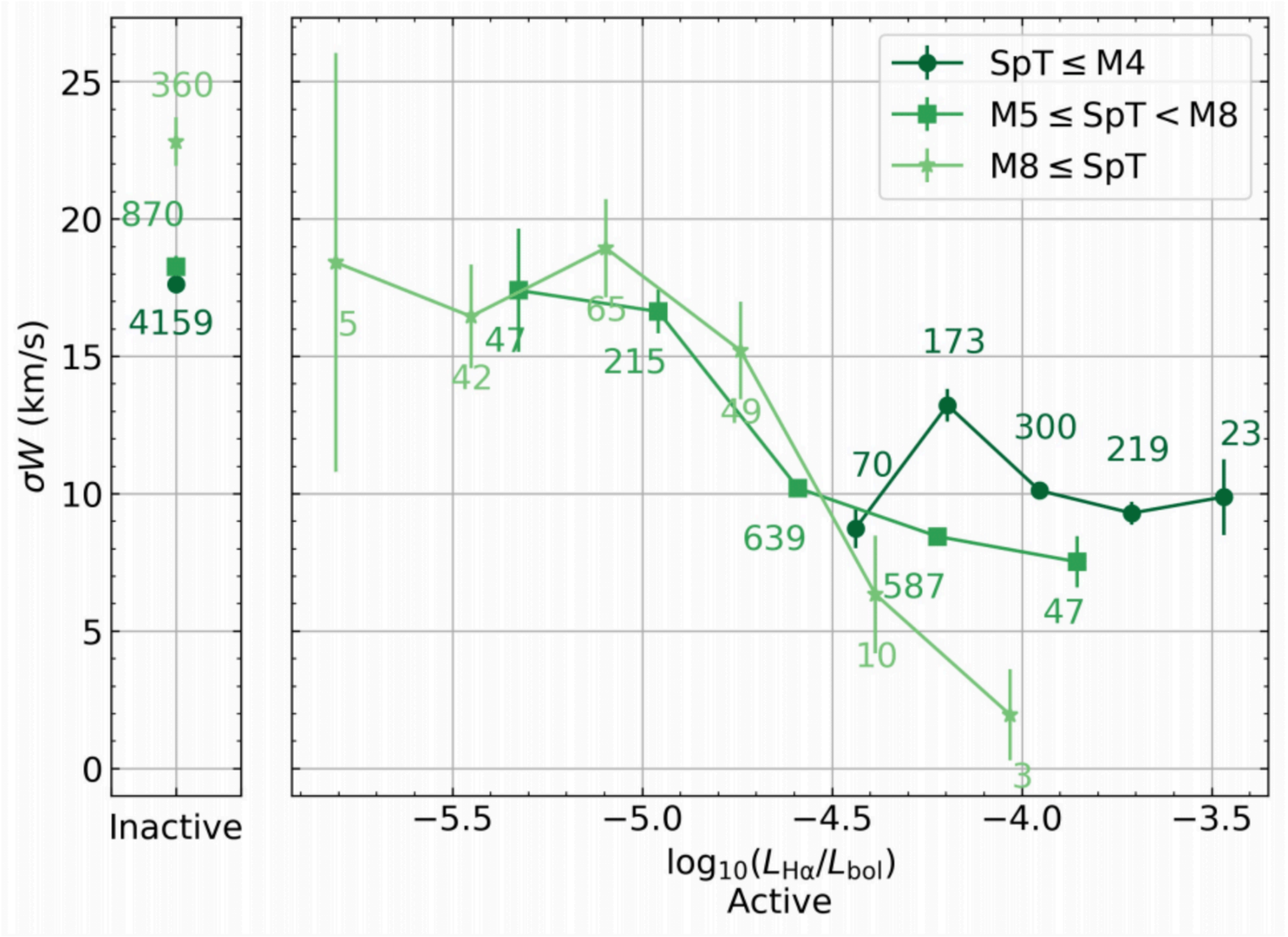
Ages of M dwarfs from magnetic activity & Kinematics

Rocio Kiman (CUNY) Kiman *et al.*, (2019) arXiv:1904.05911



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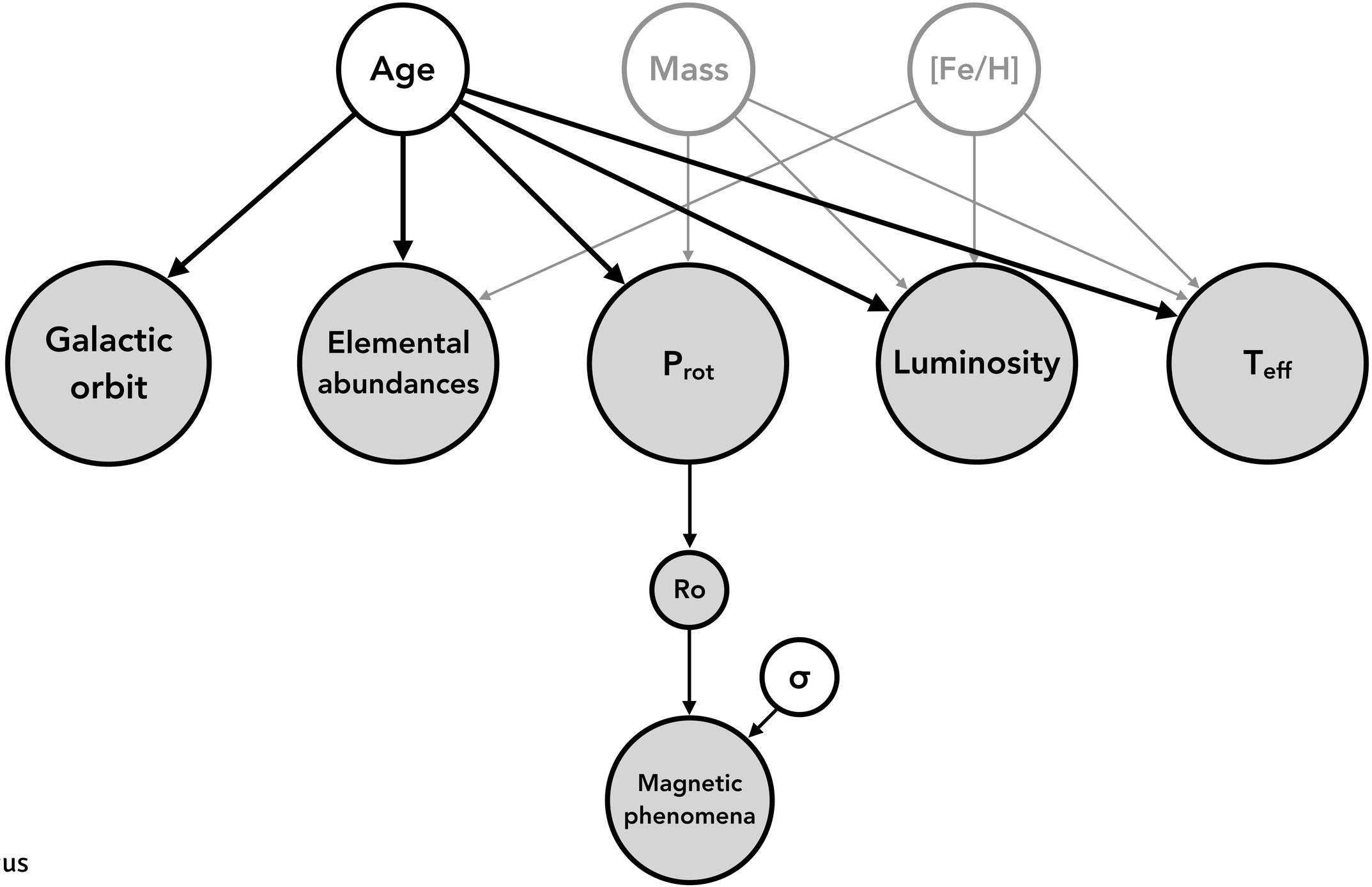
Age
Mass
[Fe/H]
Galactic orbit
Elemental abundances
P_{rot}
Luminosity
T_{eff}
Ro
σ
Magnetic phenomena

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Measuring stellar ages from light curves

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