Searching for young exoplanets in dispersed clusters guided by gyrochronology

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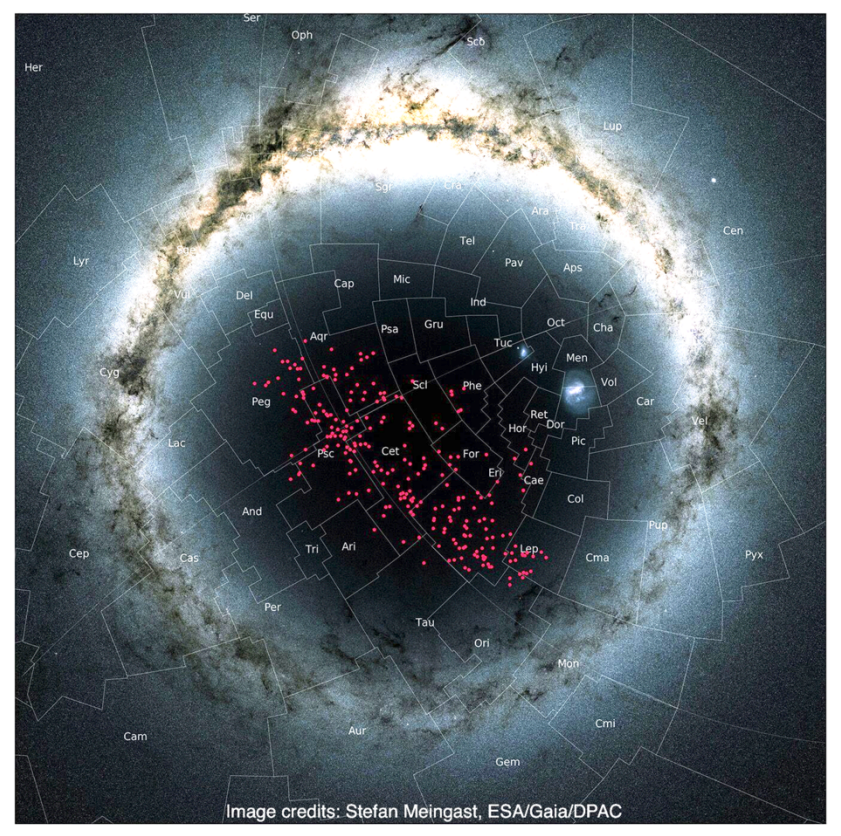
with

Marcel Agüeros
Eric Mamajek
Jason Wright
Jeffrey Cummings
Aaron Rizzuto
Elisabeth Newton
Andrew Mann
and the THYME collaboration

Pisces–Eridanus: a river of stars



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The Astronomical Journal, 158:77 (11pp), 2019 August https://doi.org/10.3847/1538-3881/ab2899

TESS Reveals that the Nearby Pisces–Eridanus Stellar Stream is only 120 Myr Old

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Abstract

Pisces–Eridanus (Psc–Eri), a nearby ($d \simeq 80$–226 pc) stellar stream stretching across $\approx 120^\circ$ of the sky, was recently discovered with *Gaia* data. The stream was claimed to be ≈ 1 Gyr old, which would make it an exceptional discovery for stellar astrophysics, as star clusters of that age are rare and tend to be distant, limiting their utility as benchmark samples. We test this old age for Psc–Eri in two ways. First, we compare the rotation periods for 101 low-mass members (measured using time-series photometry from the *Transiting Exoplanet Survey Satellite*) to those of well-studied open clusters. Second, we identify 34 new high-mass candidate members, including the notable stars λ Tauri (an Algol-type eclipsing binary) and HD 1160 (host to a directly imaged object near the hydrogen-burning limit). We conduct an isochronal analysis of the color–magnitude data for these highest-mass members, again comparing our results to those for open clusters. Both analyses show that the stream has an age consistent with that of the Pleiades, i.e., ≈ 120 Myr. This makes the Psc–Eri stream an exciting source of young benchmarkable stars and, potentially, exoplanets located in a more diffuse environment that is distinct from that of the Pleiades and of other dense star clusters.

Key words: open clusters and associations: individual (Pisces–Eridanus Stream, Pleiades, Praesepe, NGC 6811) – stars: evolution – stars: individual (HD 1160 B, TOI 451) – stars: rotation

Supporting material: figure set, machine-readable tables

Why young planets? Study formation/evolution

The Astrophysical Journal, 847:29 (14pp), 2017 September 20 https://doi.org/10.3847/1538-4357/aa890a

The Evaporation Valley in the Kepler Planets

James E. Owen[1,3] and Yanqin Wu[2]
[1] Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540, USA; jowen@ias.edu
[2] Department of Astronomy and Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada; wu@astro.utoronto.ca
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Photoevaporation model

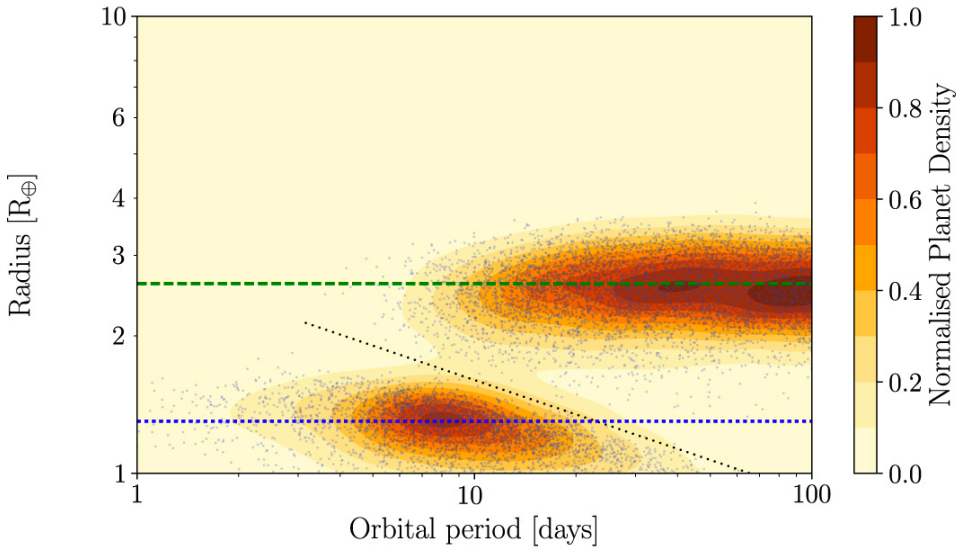

Figure from Owen & Wu (2017)

Observed *Kepler* distribution

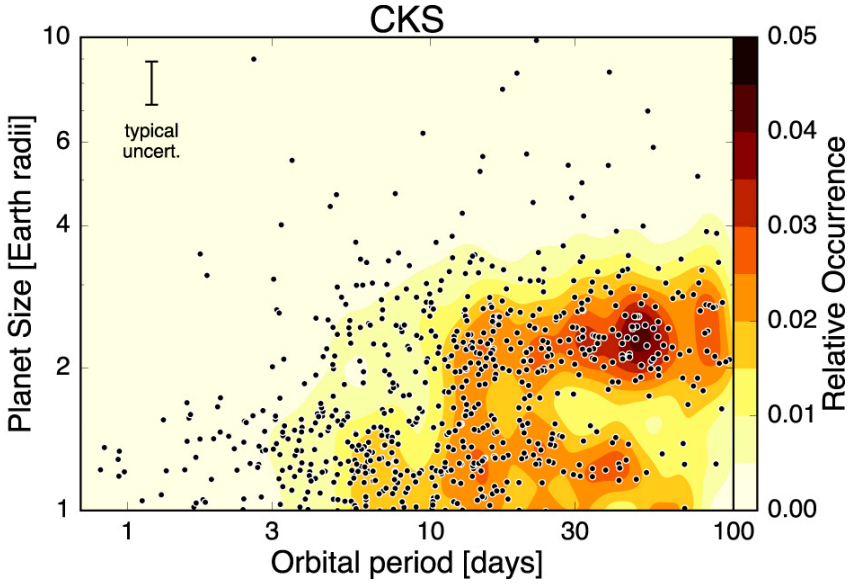

Figure from Fulton et al. (2017)
(reproduced in Owen & Wu)

Inferring precise stellar ages is challenging, so let's instead focus on star clusters

Age-Dating young coeval populations:

Isochrones, lithium depletion boundary, white dwarf cooling and Tim Bedding said yesterday delta Scuti pulsators!

Transiting planets found in:

10 Myr: Upper Sco
40 Myr: Tuc-Hor (Elisabeth Newton tomorrow)
700 Myr: Hyades, Praesepe
1000 Myr: NGC 6811
2700 Myr: Ruprecht 147

No transiting cluster planets found in the Pleiades (120 Myr)

We need more Pleiades-aged stars

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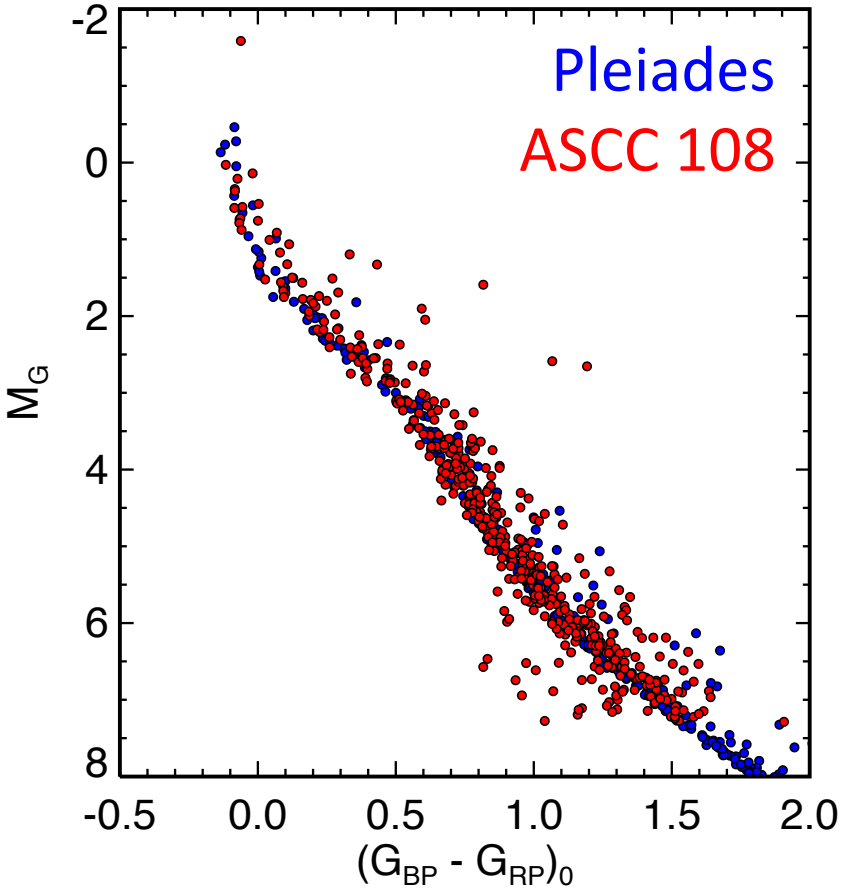
The *TESS* era is different than Kepler/K2 in two critical ways: *Gaia* and 30-min FFI data

ASCC 108: A Pleiades-aged cluster in the ***Kepler*** field



Kepler observed only
35 of 487 *Gaia* members
(list from Cantat-Gaudin et al. 2018)

24 rotation periods are consistent,
but not much to do with so few stars

TESS data will be waiting on MAST
for any interesting star or population
found in the future

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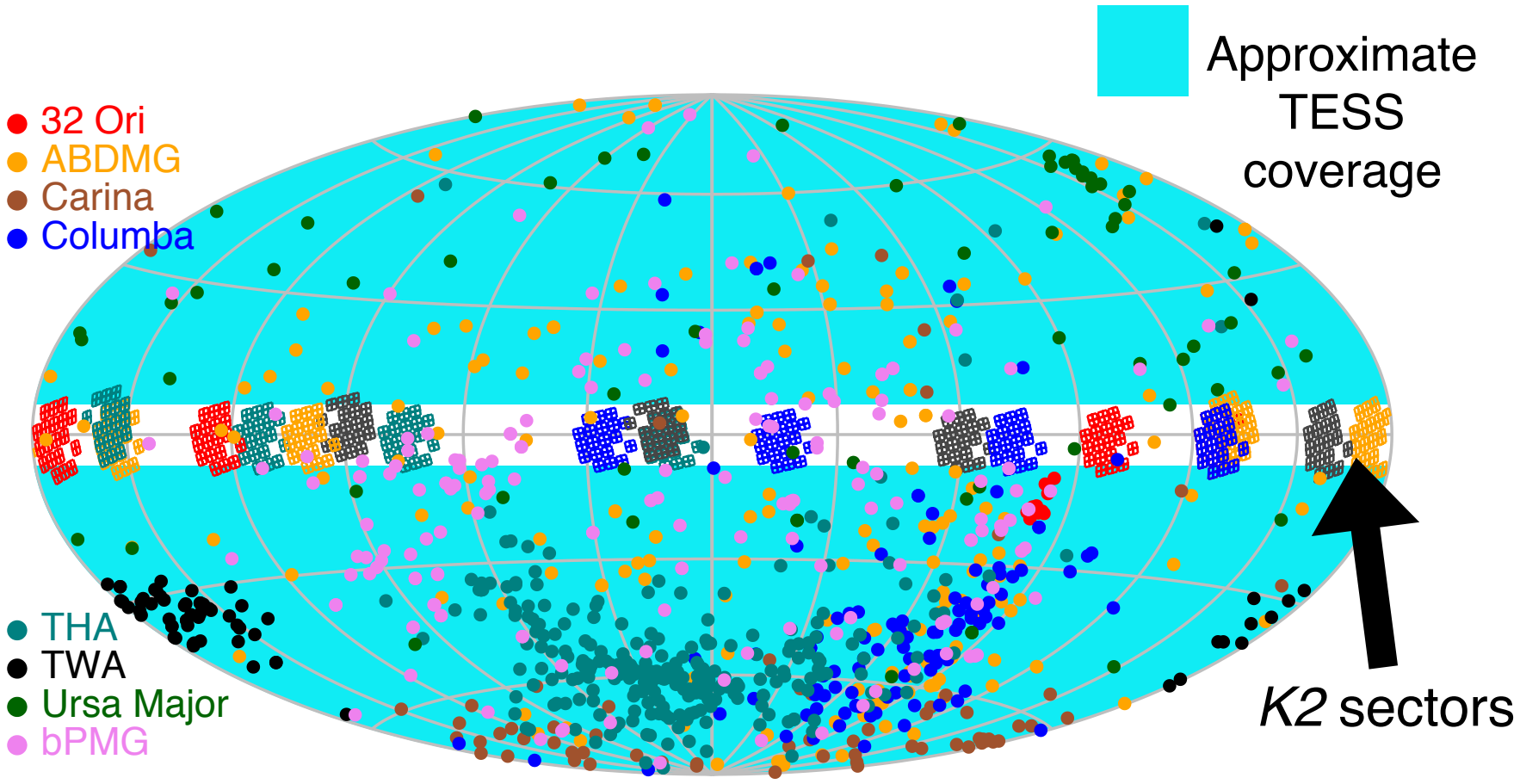
TESS covers thousands of young stars in the Solar Neighborhood



This slide is from Andrew Mann's talk at the Kepler & K2 Science Conference in March, 2019
The full set of slides is available on the conference website.

A&A 622, L13 (2019)
https://doi.org/10.1051/0004-6361/201834950

Astronomy & Astrophysics

LETTER TO THE EDITOR

Extended stellar systems in the solar neighborhood

II. Discovery of a nearby 120° stellar stream in *Gaia* DR2

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e-mail: stefan.meingast@univie.ac.at
[2] Radcliffe Institute for Advanced Study, Harvard University, 10 Garden Street, Cambridge, MA 02138, USA
[3] Data Science at Uni Vienna, Faculty of Earth Sciences Geography and Astronomy, University of Vienna, Austria

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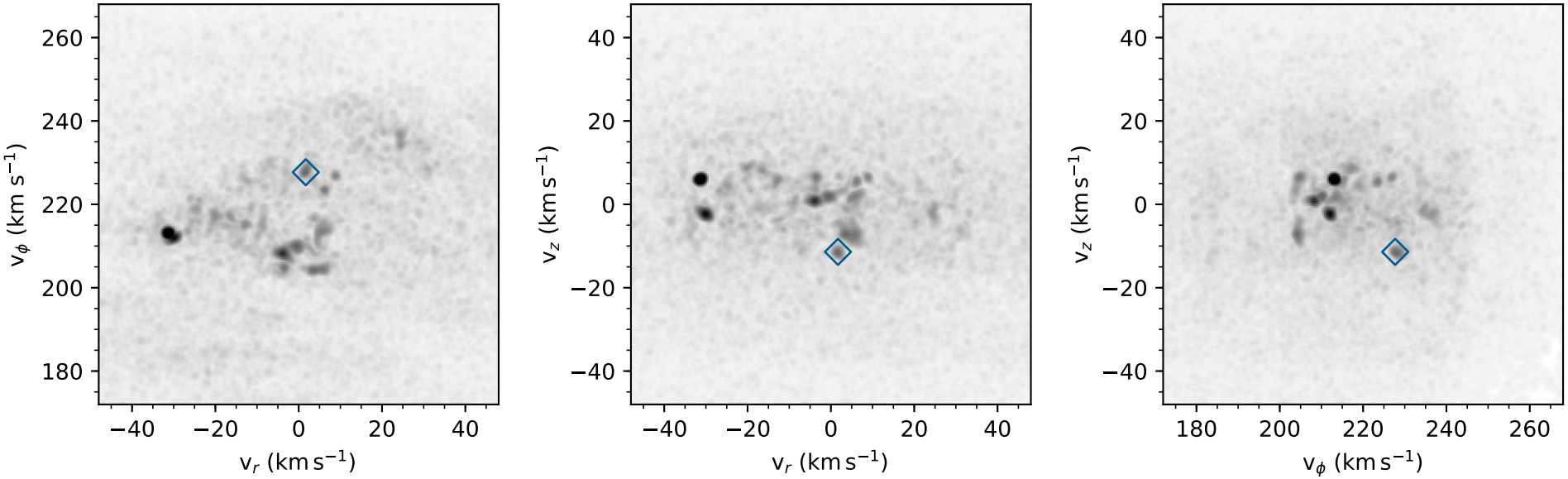
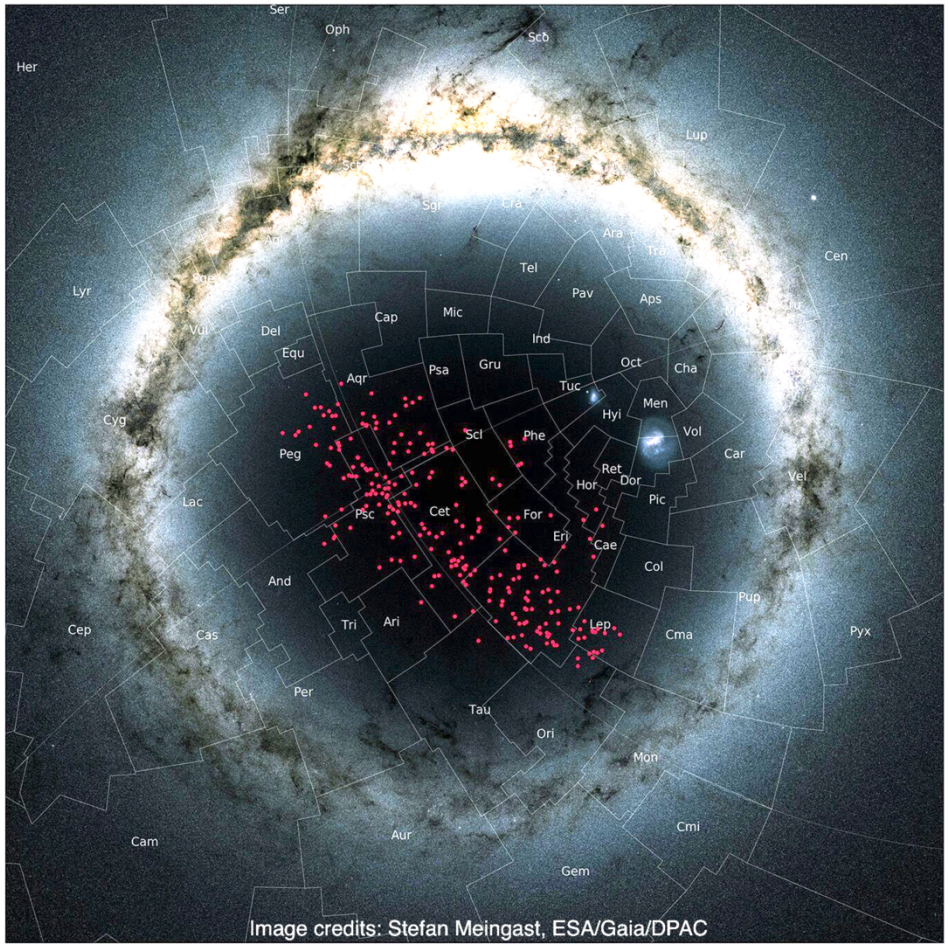
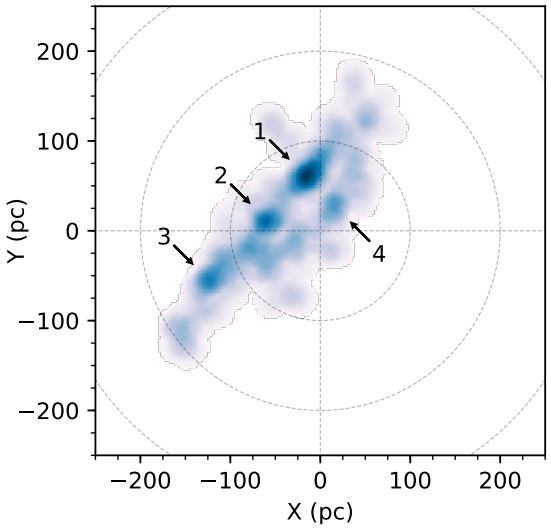


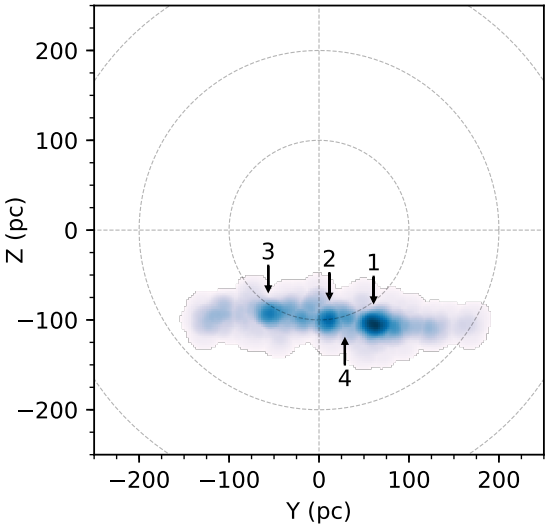
The Pisces–Eridanus stream (Psc–Eri): 400 pc long, 80-226 pc away, spans 1/3 of the sky

"A River of Stars"





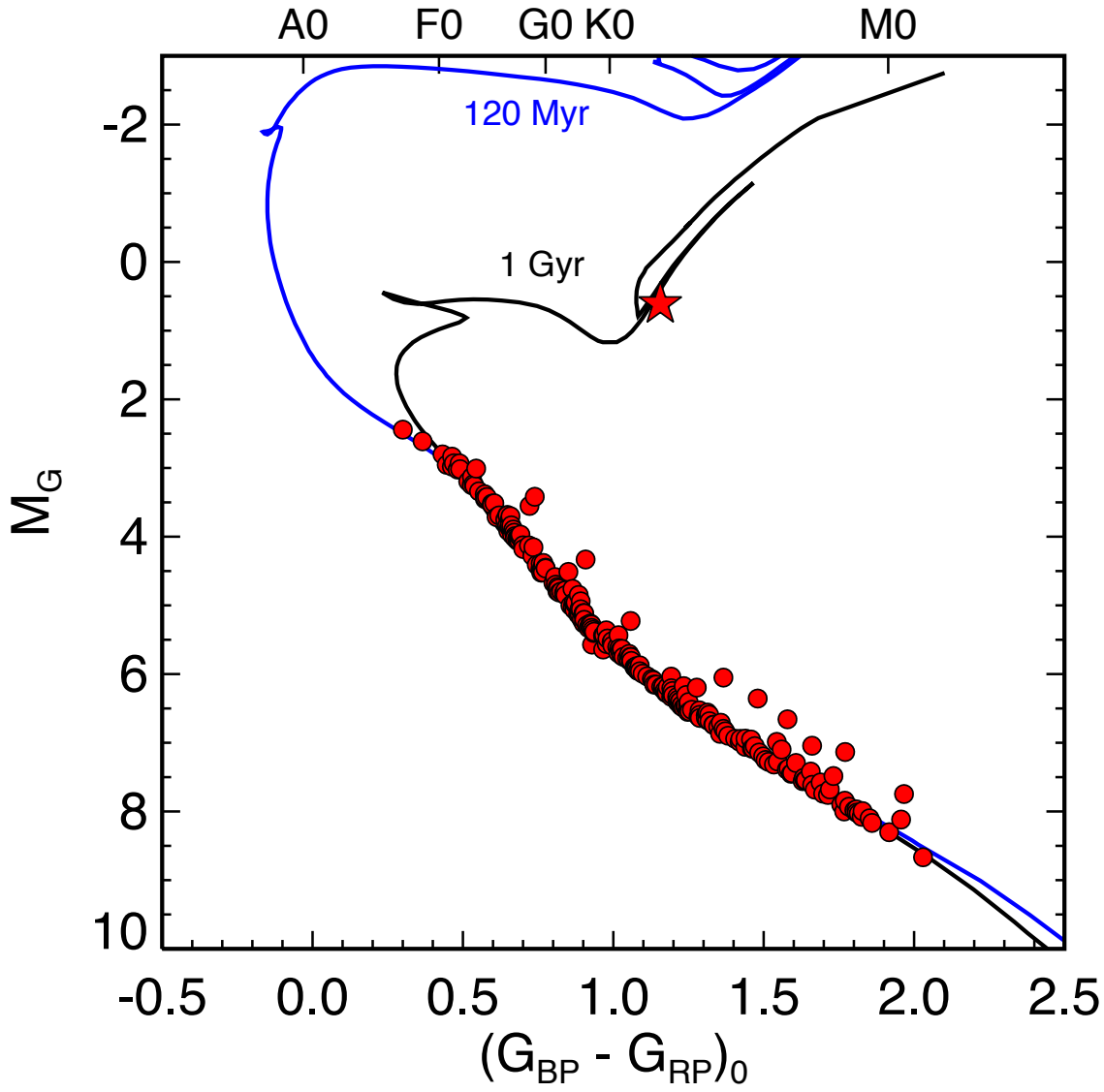
X vs Y



Y vs Z

Figures from Meingast et al. (2019)

Meingast estimated the age of Psc-Eri to be 1 Gyr based on the sole giant, 42 Ceti



Red:

Meingast et al. (2019) members of Psc-Eri

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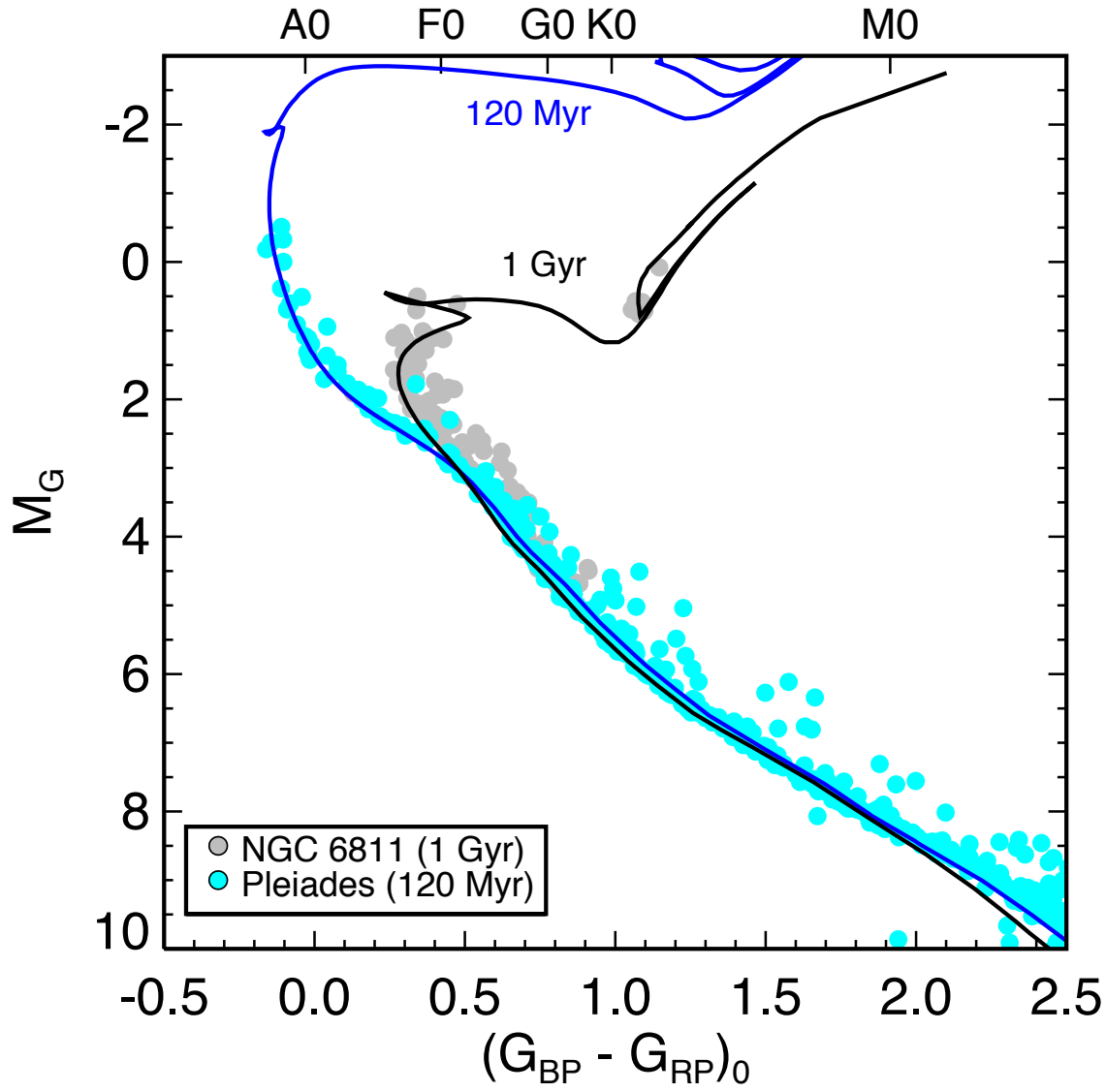
The apparent absence of a main-sequence turnoff is a problem



Light Blue:

Pleiades members

Gray:

NGC 6811 members

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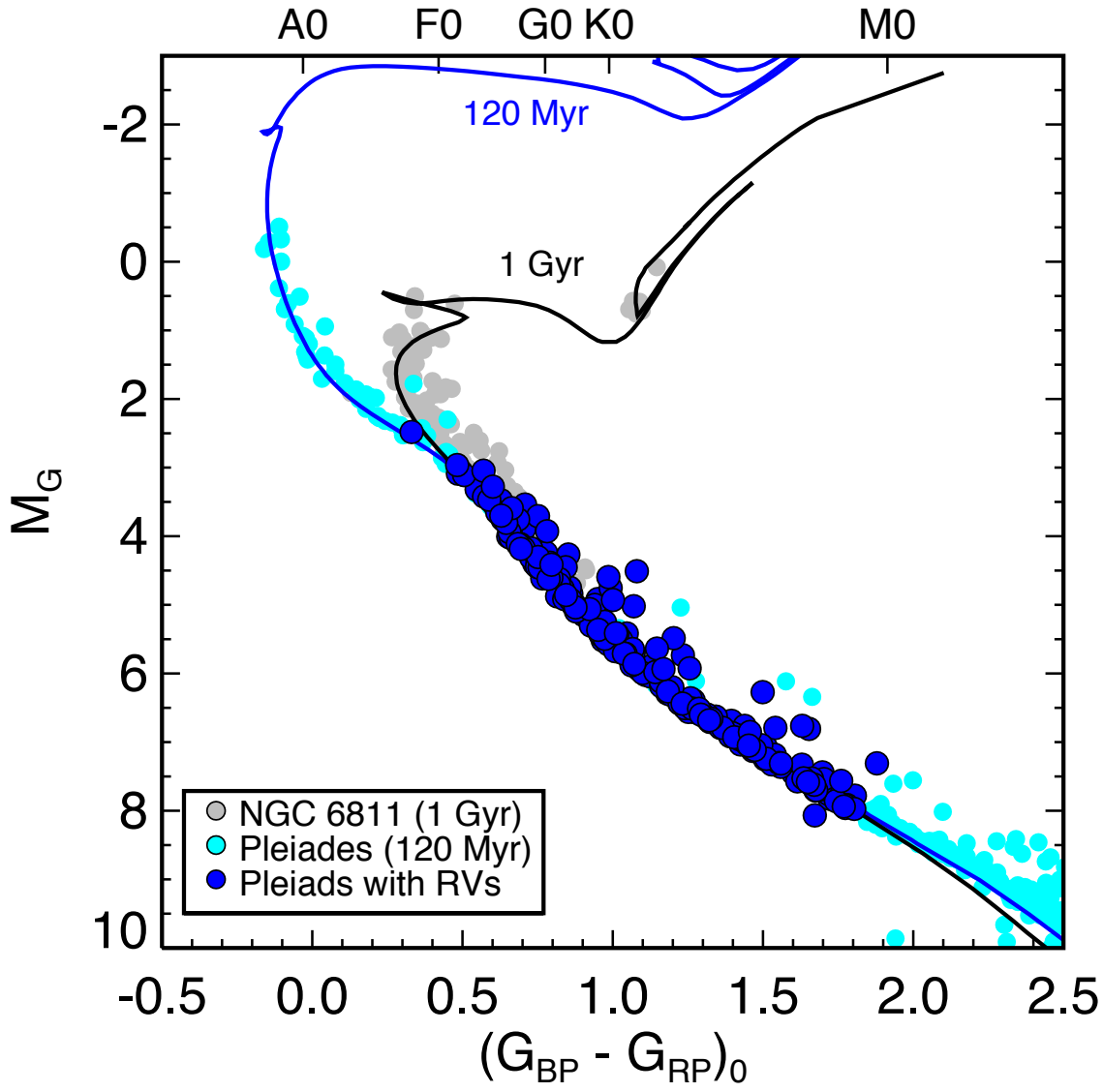
Gaia DR2 only provides radial velocities between $3500 < T_{eff} < 7000$ K



Light Blue:

Pleiades members

Dark Blue:

Pleiades members with *Gaia* RVs

Gray:

NGC 6811 members

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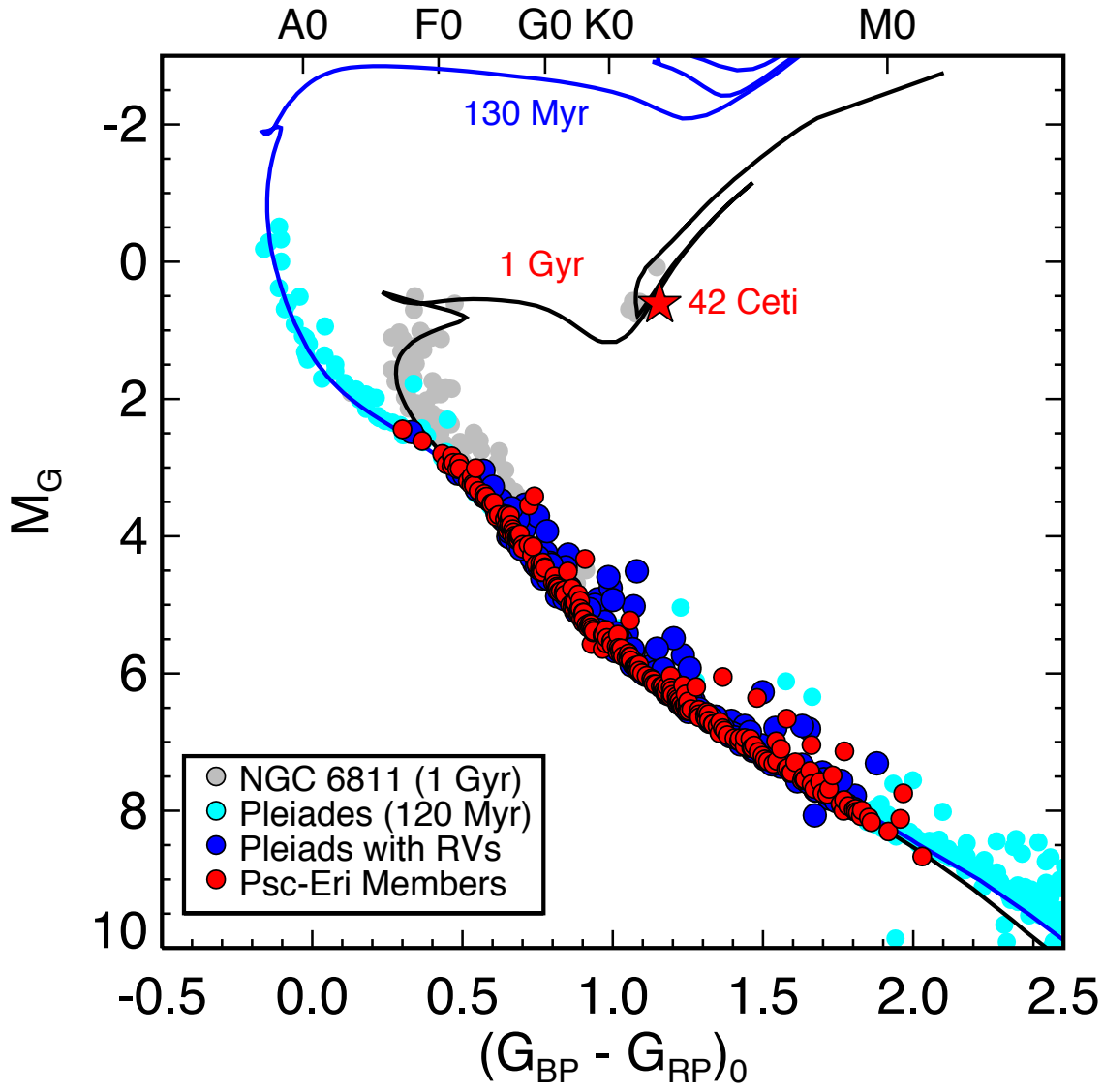
There are a similar number of *Gaia* RV members of the Pleiades cluster and Psc-Eri stream



Red:

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Light Blue:

Pleiades members

Dark Blue:

Pleiades members with *Gaia* RVs

Gray:

NGC 6811 members

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TESS Reveals that the Nearby Pisces–Eridanus Stellar Stream is only 120 Myr Old

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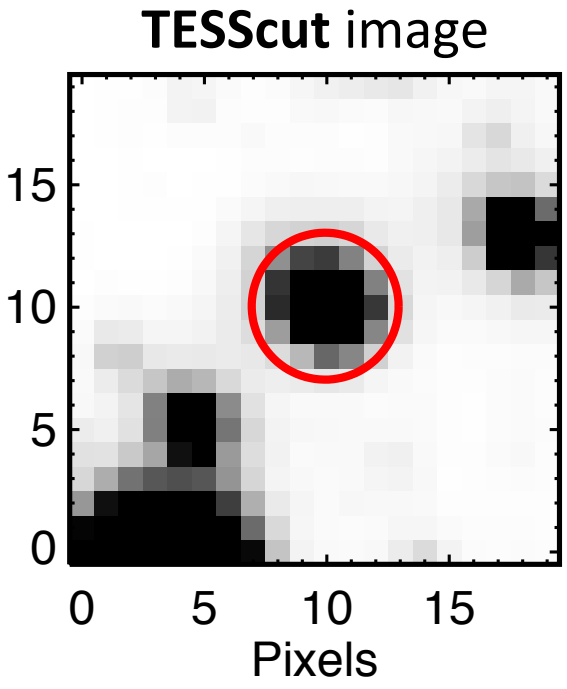
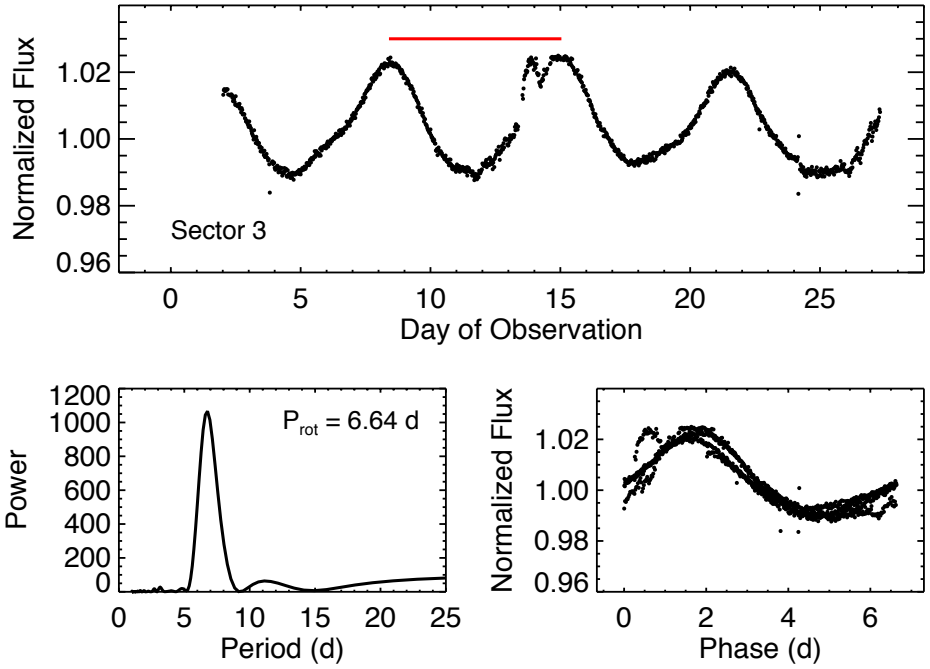
Rotation periods can be measured from light curves extracted with simple aperture photometry





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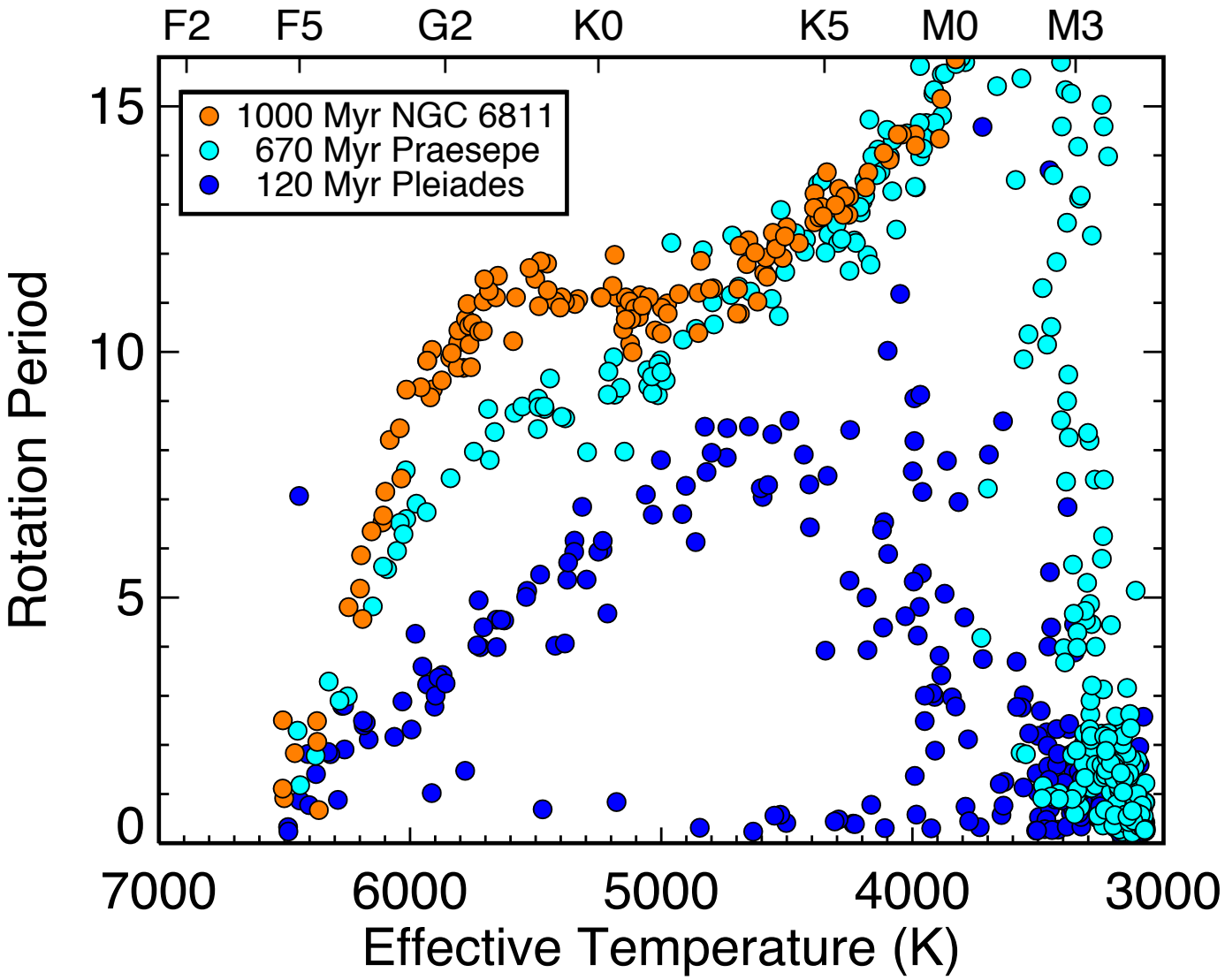
Gyrochronology: age-dating stars by how fast they spin



NGC 6811 (1 Gyr):
Curtis et al. (2019a)

Praesepe (670 Myr):
Douglas et al. (2019)
and references therein

Pleiades (120 Myr):
Rebull et al. (2016);
…also check out
Stauffer et al. (2016)

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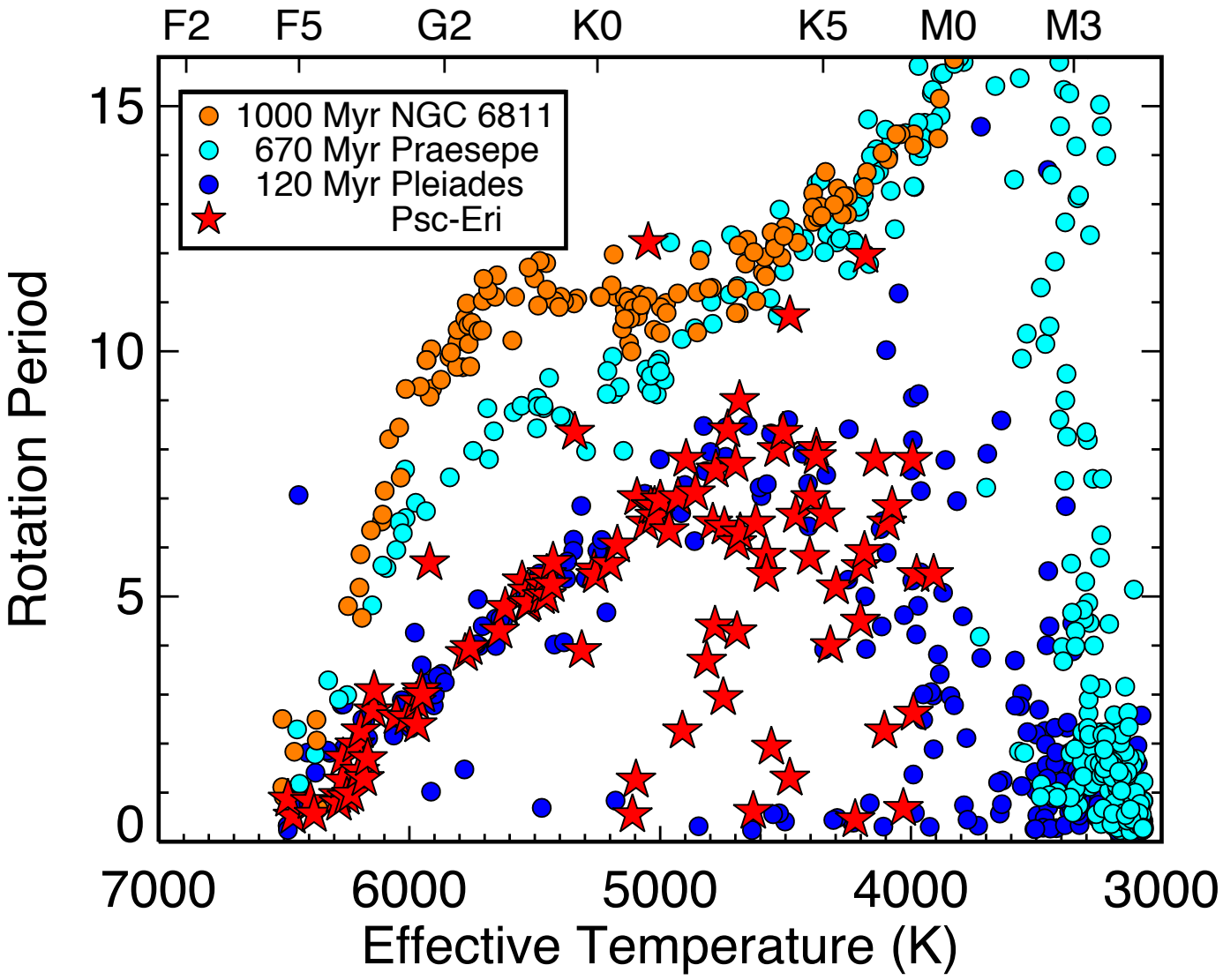
Psc–Eri periods precisely overlap the Pleiades distribution



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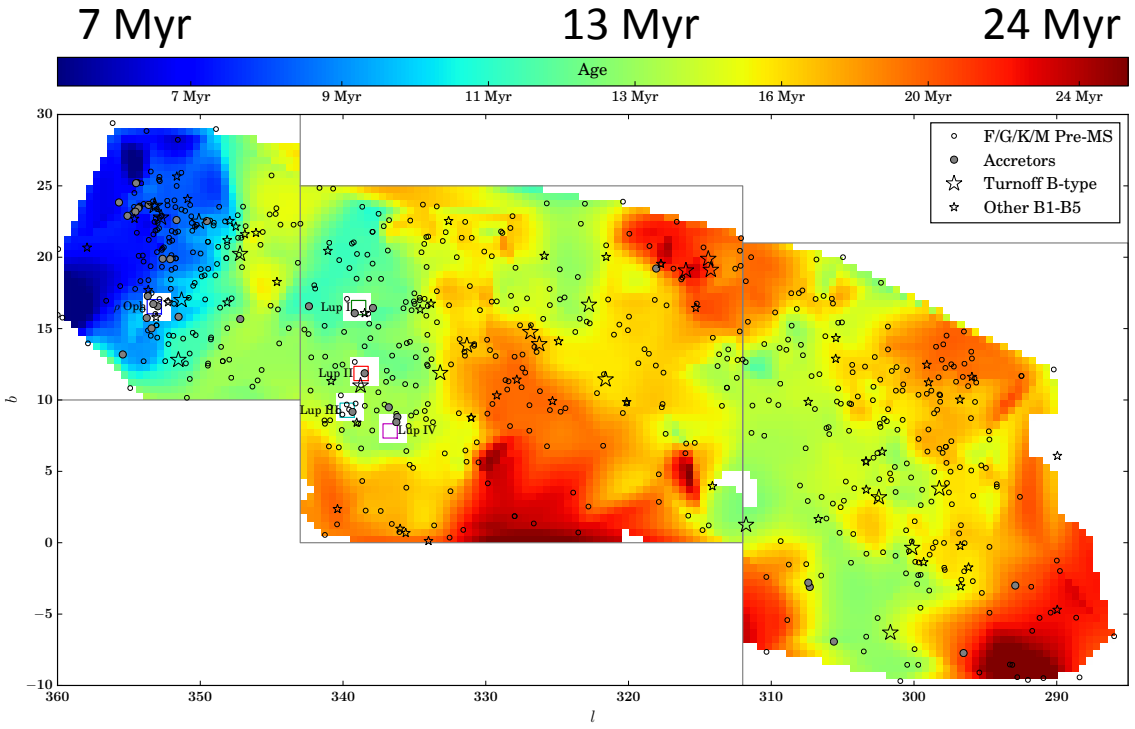
How could a 120 Myr old cluster disperse its stars across 400 pc with such a low velocity dispersion?

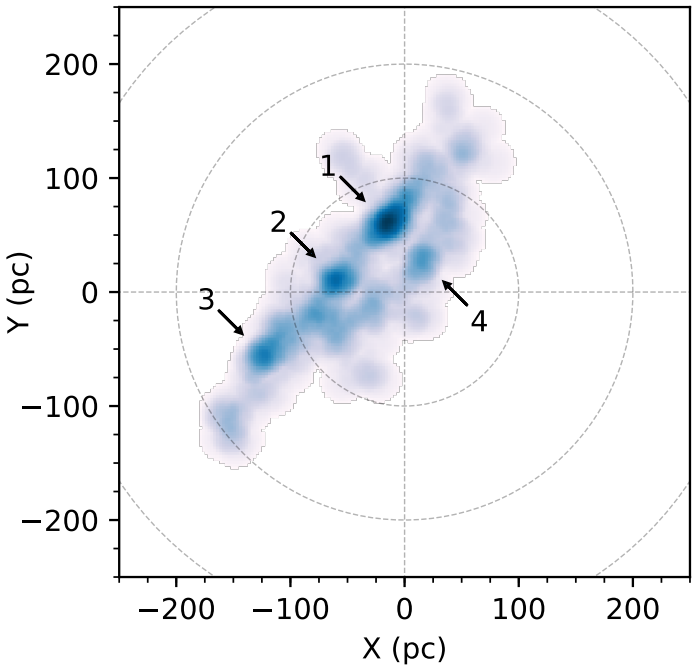
Perhaps, decentralized star formation, not a dispersed Pleiades-like cluster

Sco–Cen age map



Pecaut & Mamajek (2016)

The Psc-Eri stream Galactic Cartesian X vs Y



Meingast et al. (2019)

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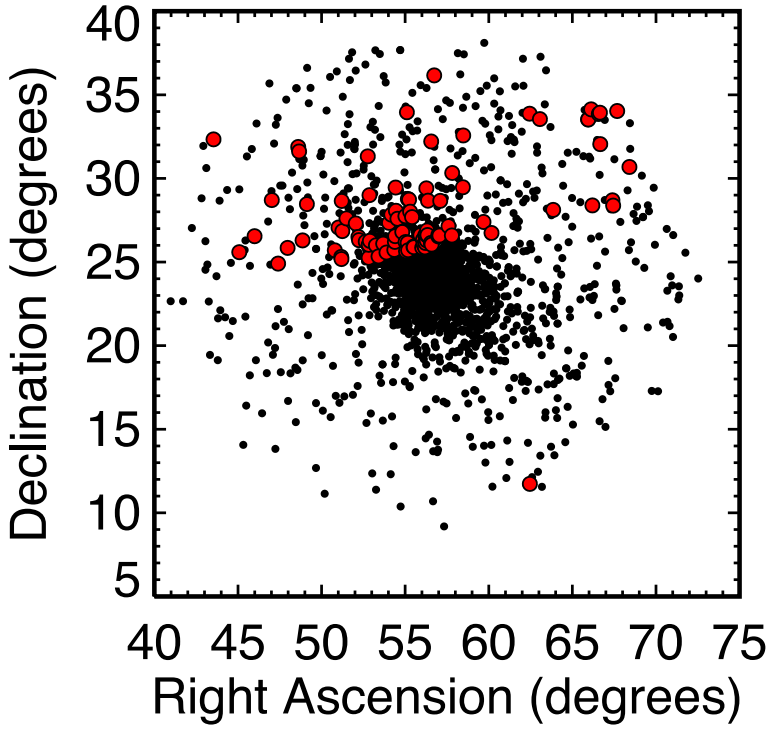
An expanded census with *Gaia* + *TESS*:

We want more planet targets, and would need a thorough census for estimating planet occurrence

How many stars are there in Psc-Eri?

Lodieu et al. (2019) found **2281** stars in the **Pleiades**:
(red: *G*<15 in *TESS* Cycles 1 & 2)



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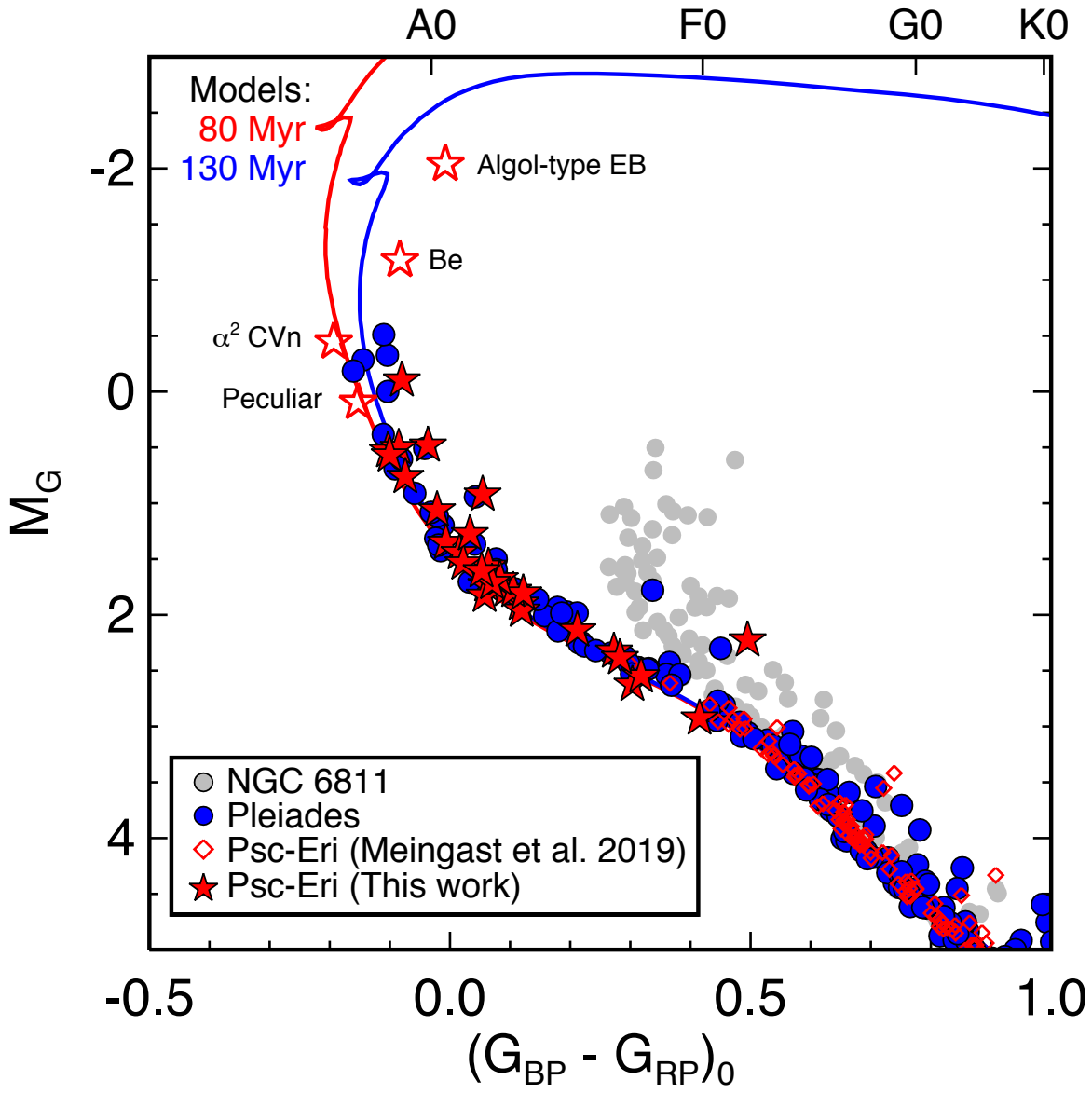
New massive comoving stars support a young age



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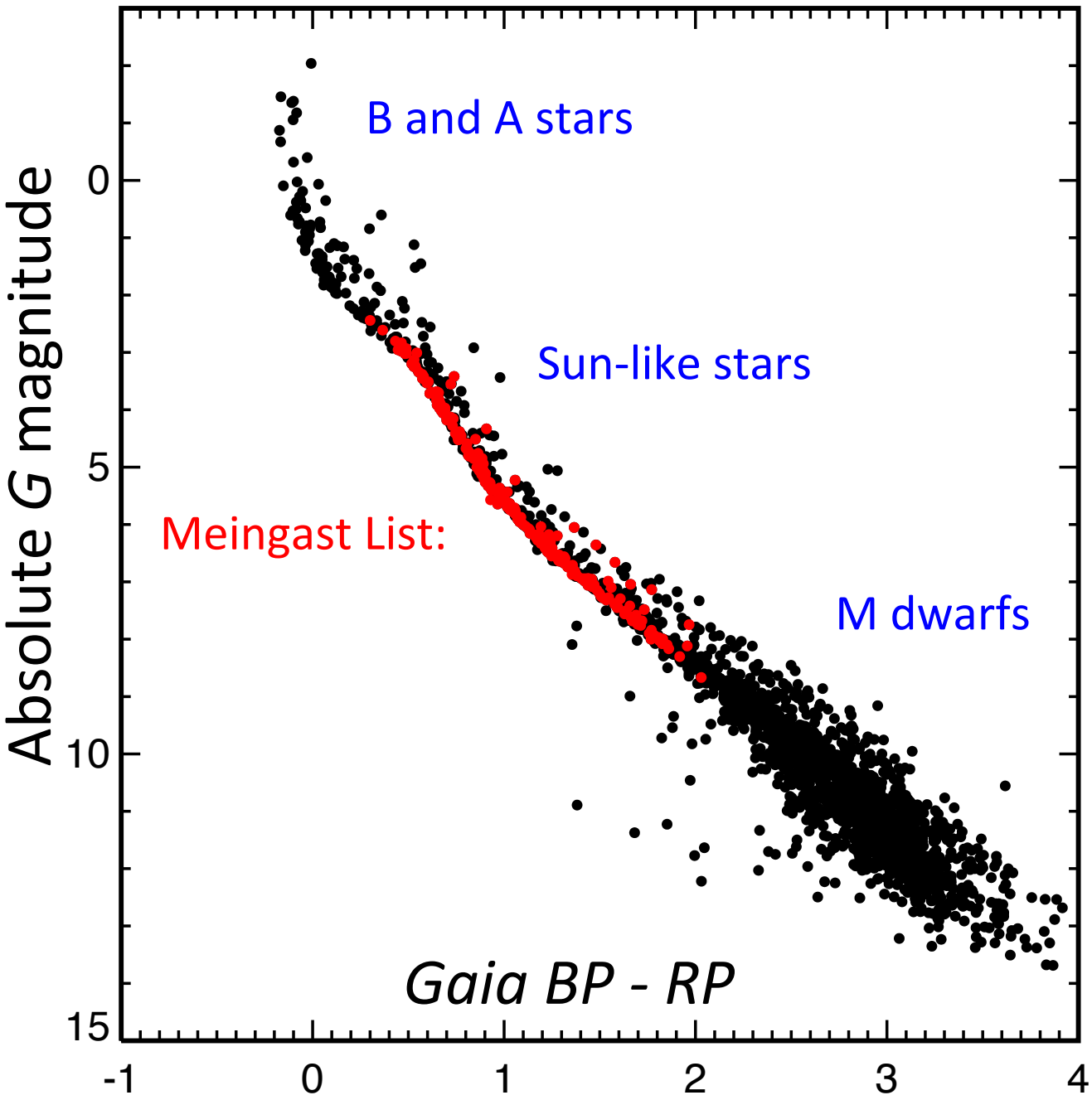
Aaron Rizzuto's Candidate List for Psc-Eri



5800 candidates

2500 displayed
(with quality cuts)

40% will eventually have *Gaia* RVs

TESS can validate many now via P_{rot}:

P_{rot} good for 550!
(preliminary)

No P_{rot} for ~400
(Blending, crowded, interlopers?)

HD 1160 B:

a directly imaged object in Psc-Eri Near the hydrogen-burning limit

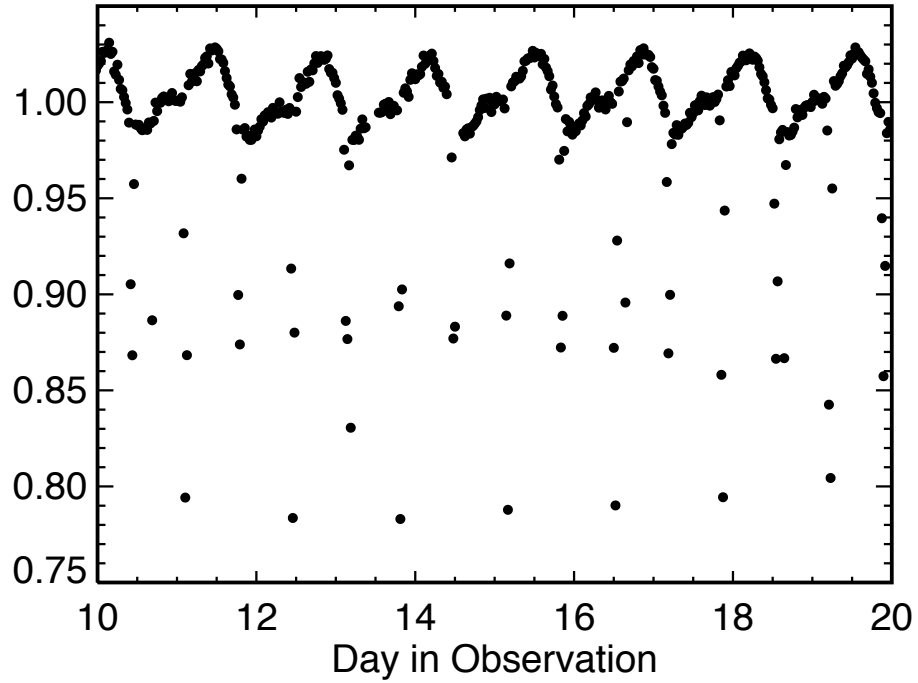
"While the *UVW* motion of the system does not match any known moving group, the small magnitude of the space velocity is consistent with youth." − Nielsen et al. (2012)

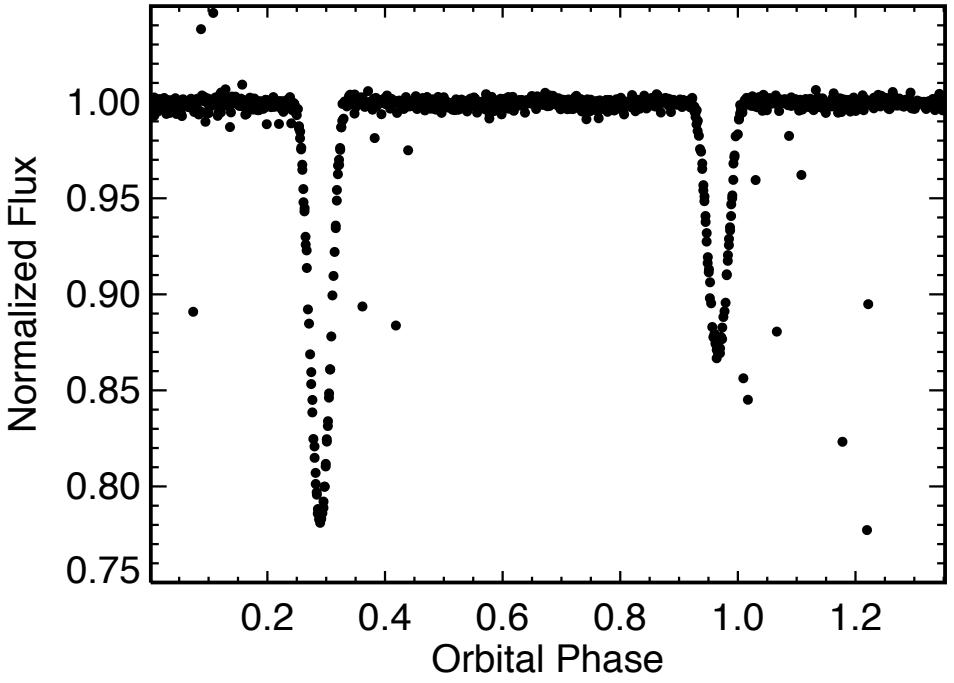
(see also Maire et al. 2016, Garcia et al. 2017)

Figure: Nielsen et al. (2012)

Eclipsing Binaries in Psc-Eri with *TESS* FFI data

This early-M dwarf binary
has a 1.4 day orbital period





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TOI 451 a Psc-Eri G dwarf with two planet candidates

Star:

T_{eff} = 5530 K

G = 10.75

P_{rot} = 5 days

Single star member

Planet b:

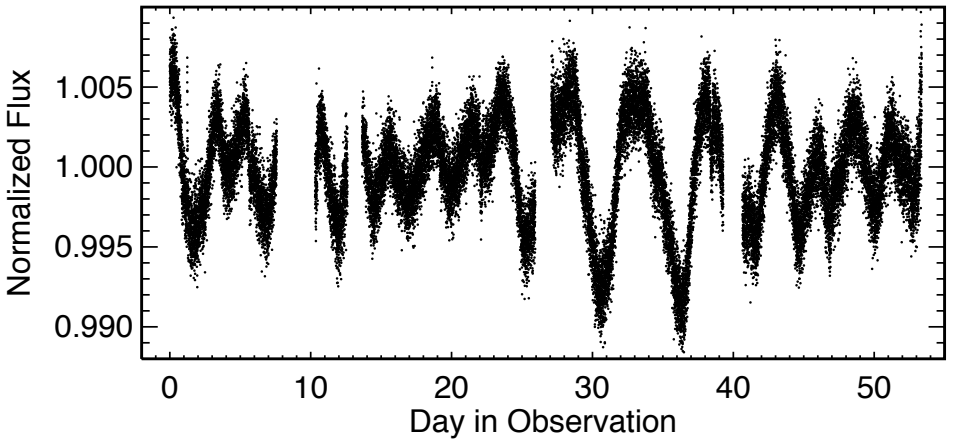
P_{orb} = 9.2 days

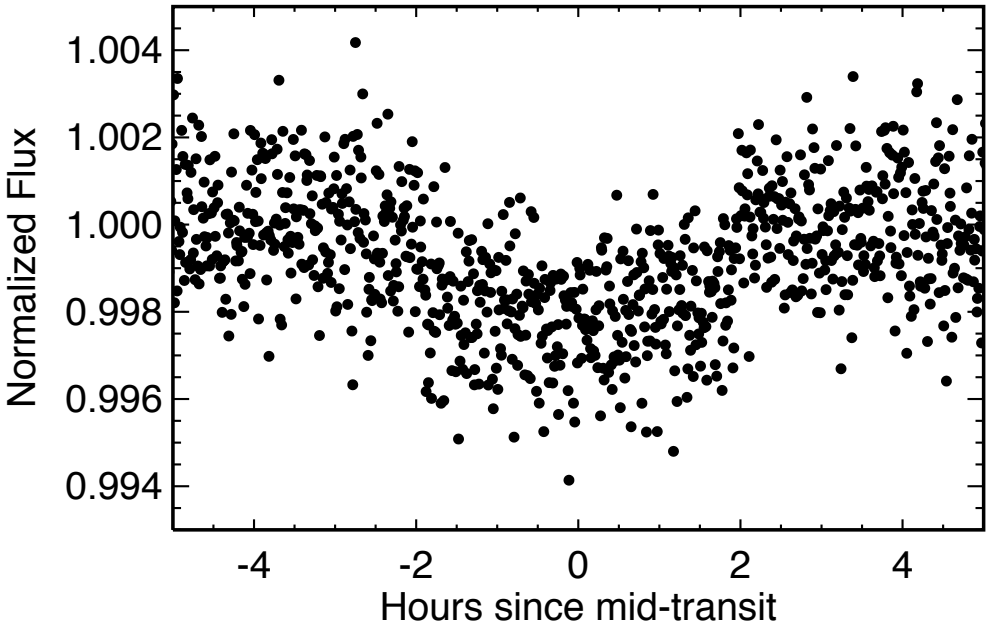
Planet c (at right):

P_{orb} = 16.4 days

R_p ~ 4 R_E

Elisabeth Newton is leading THYME follow-up





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Conclusions

The Pisces−Eridanus stellar stream is an exciting new source of Pleiades-aged stars in a more diffuse environment distinct from that of the Pleiades

TESS sees many young stars in groups & clusters

Candidates from *Gaia* can be vetted with *TESS* gyrochronology

Gyrochronology also validates group ages

THYME will search improved lists for planets (see Elisabeth Newton's talk)

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Thanks to

Stefan Meingast for sharing their list ahead of publication

My co-authors:
Marcel Agüeros, Eric Mamajek, Jason Wright, Jeffrey Cummings

The THYME collaboration:
Aaron Rizzuto, Elisabeth Newton, Andrew Mann,
Andrew Vanderburg, Adam Kraus, Ben Tofflemire

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