Benchmark targets for studying Rotation and Activity of Sun-like stars and its evolution

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In collaboration with* F. Baudin, A. Lanza, S. Barnes, E. Nunes, L. Almeida, F. Anthony, J. Bouvier, A. Brun, R. Garcia, S.Meibom, S. Saar, M. Castro, J. Marques, P. Boumier, J. Melendez, K. G. Strassmeier

(*) PLATO 2.0 – WP120 Meeting 2016 Paris Observatory–Meudon, May23-24

Outline

1. Benchmark stars for Plato?

2. Stellar Rotation and Activity (stellar ages)

3. Kepler Legacy for Rotation and Activity
   Gaia DR2 impact

4. Conclusions

Benchmark stars for PLATO

Activity and Rotation

Motivation

Test methods to measure
- Rotation
- & Differential Rot.
- Photometry_0 Teff,
- Evolutionary status,
- Metallicity
- Activity
- Cycles
- ....

Accuracy for PLATO

(Mass, Radius and age)

The Benchmark stars should Present the test for PLATO nominal Level of Accuracy

Calibrators

σR~1-2%, σM~5%, σAge~10%

Benchmark stars for PLATO

Activity and Rotation

Calibration of the rotation-activity and rotation-age

(e.g.. van Saders et al. 2016, Nature 529, 181; Barnes et al. 2016, ApJ, 823, 16);

Accuracy for PLATO

(Mass, Radius and age)

Connection between photospheric variability and higher energy emissions (chromospheres and coronae);

Activity cycles on short (months) and long (years) timescales;

Benchmark stars for PLATO

Benchmark categories

Single, Binaries
Single Interferometric
Binaries Interferometric
Eclipsing Binaries
Eclipsing +SB2 binaries
Solar Twins and analogs
Subgiants
Giants

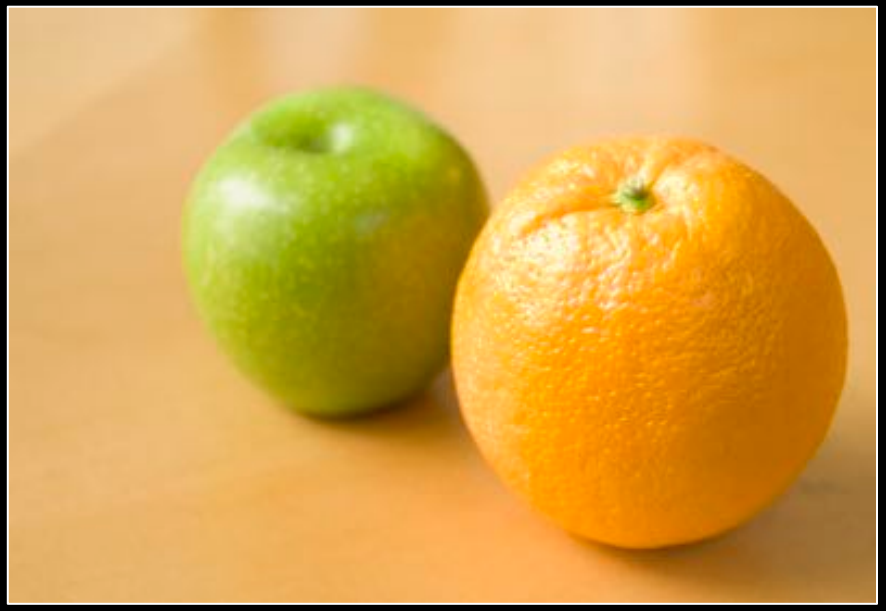
Accuracy for PLATO

(Mass, Radius and age)

Calibrators

Track data problems
Pipeline tests
Limits of detection
Long Duration stability
Short Duration stability

Which Properties for the Benchmark stars?



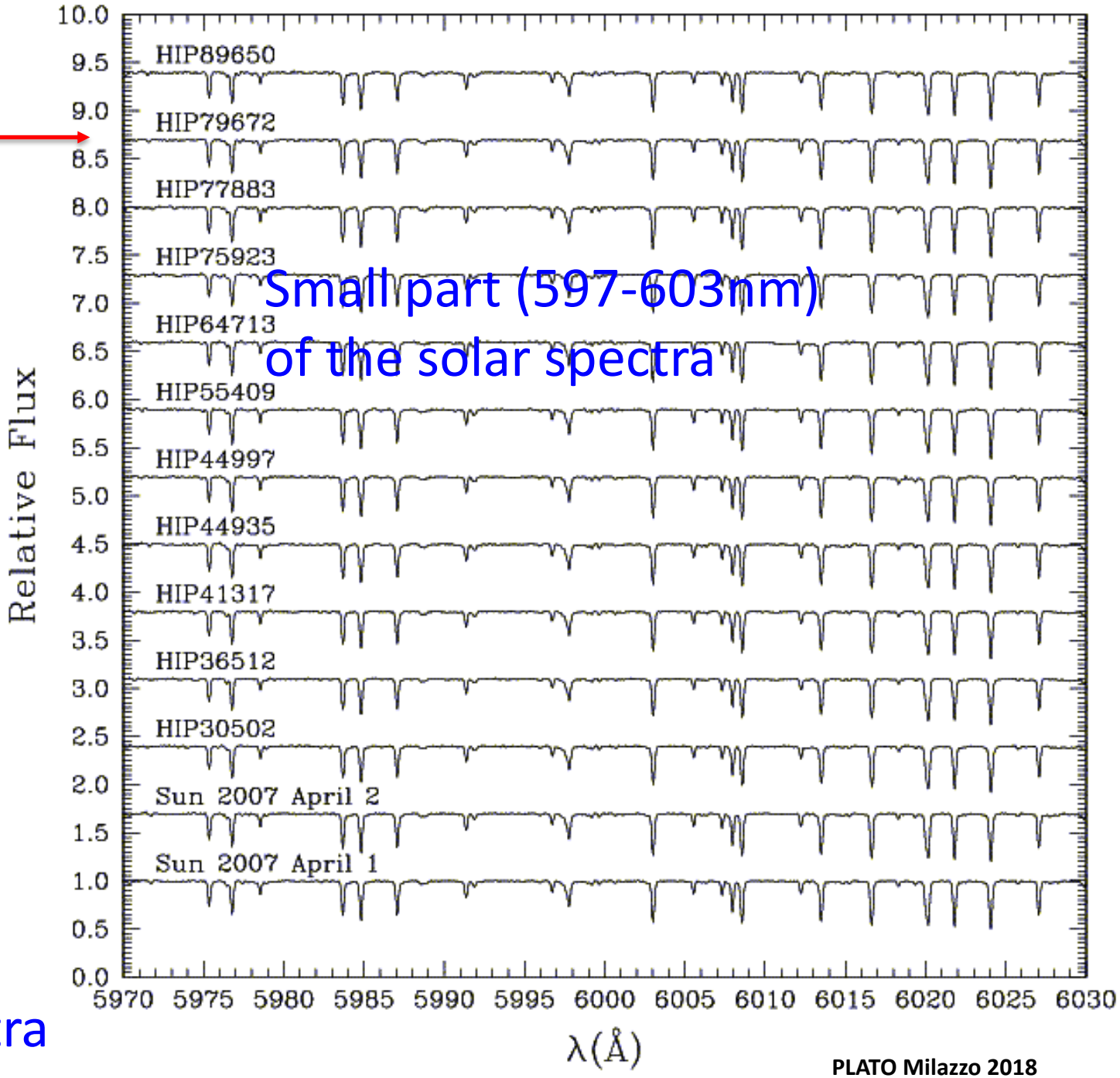
Solar Twins defined

- Solar type stars – late F, G, early K
- Solar analogs – about G2V and factor of 2 dex in composition
- Solar twins – very rare – stars with indistinguishable temperature (within 100 K), gravity and composition (0.1 dex) to the Sun's values.

Can also be defined as 1 solar mass stars with composition indistinguishable to the Sun

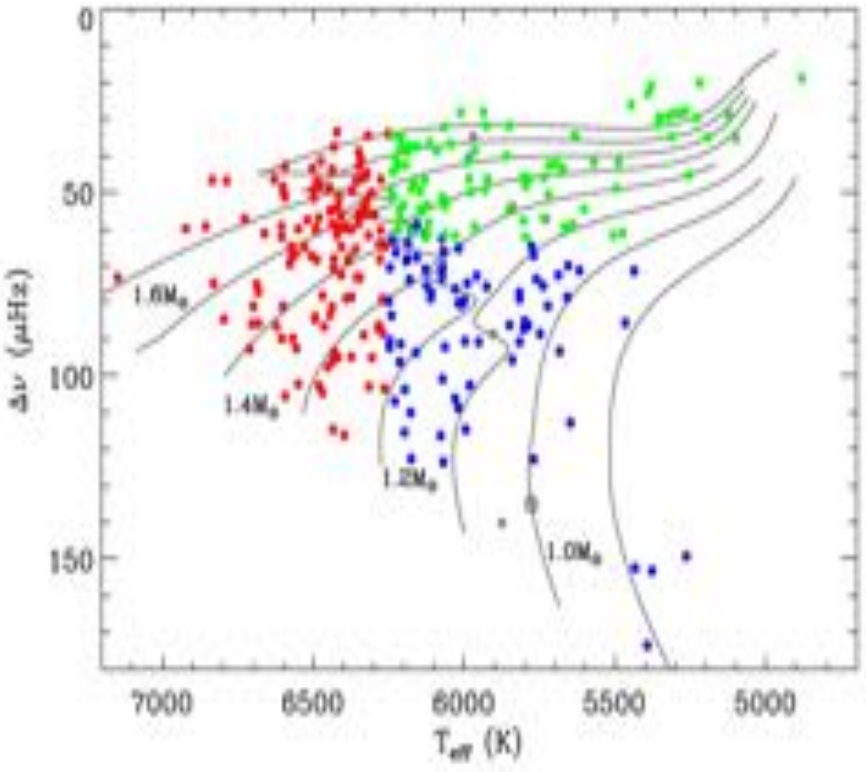
- Solar sibling – would be a star born from same natal cloud as the Sun. Could be any spectral type.

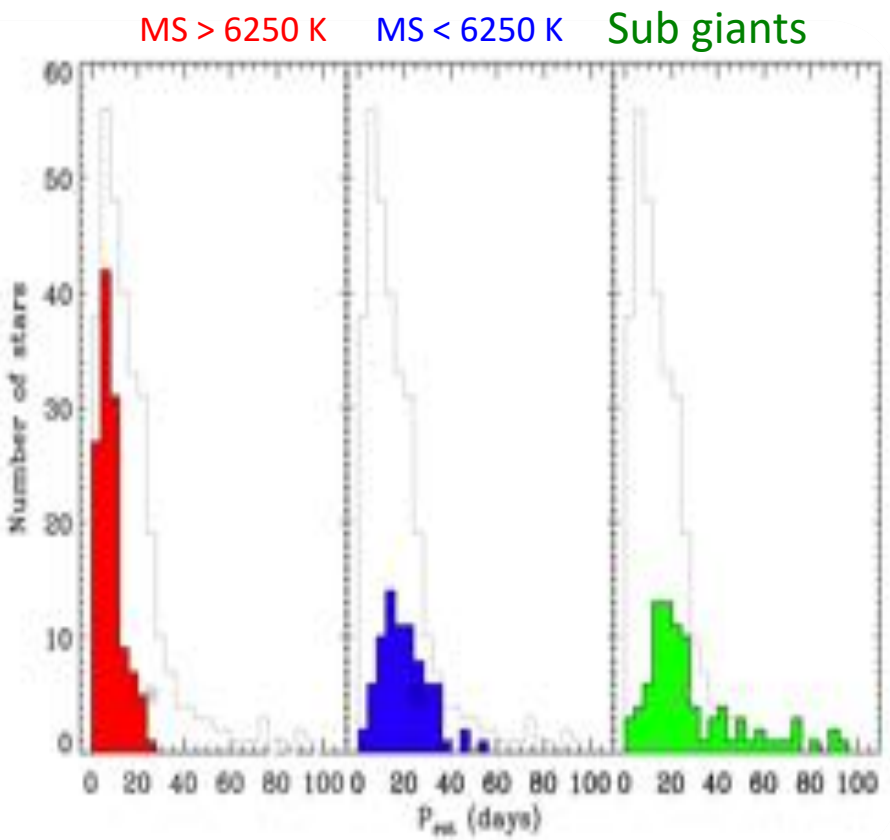
18 Sco T_{eff} = 5822 ± 20 K, log g = 4.45 ± 0.02 [Fe/H] = 0.05±0.02



Small part (597-603nm) of solar twin & Sun's spectra

Rotation periods for seismic solar analogs





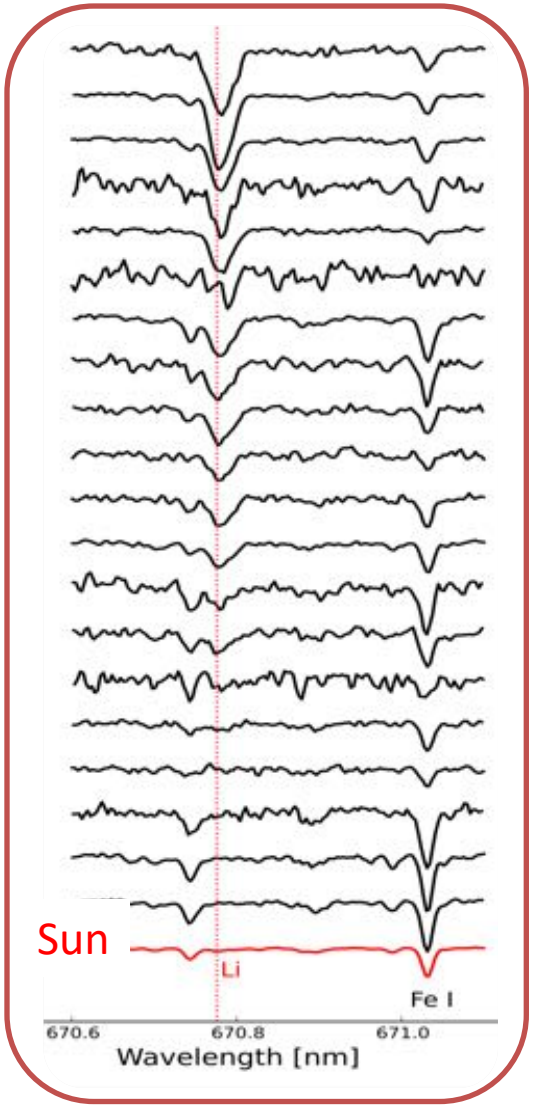
For ~300 stars:

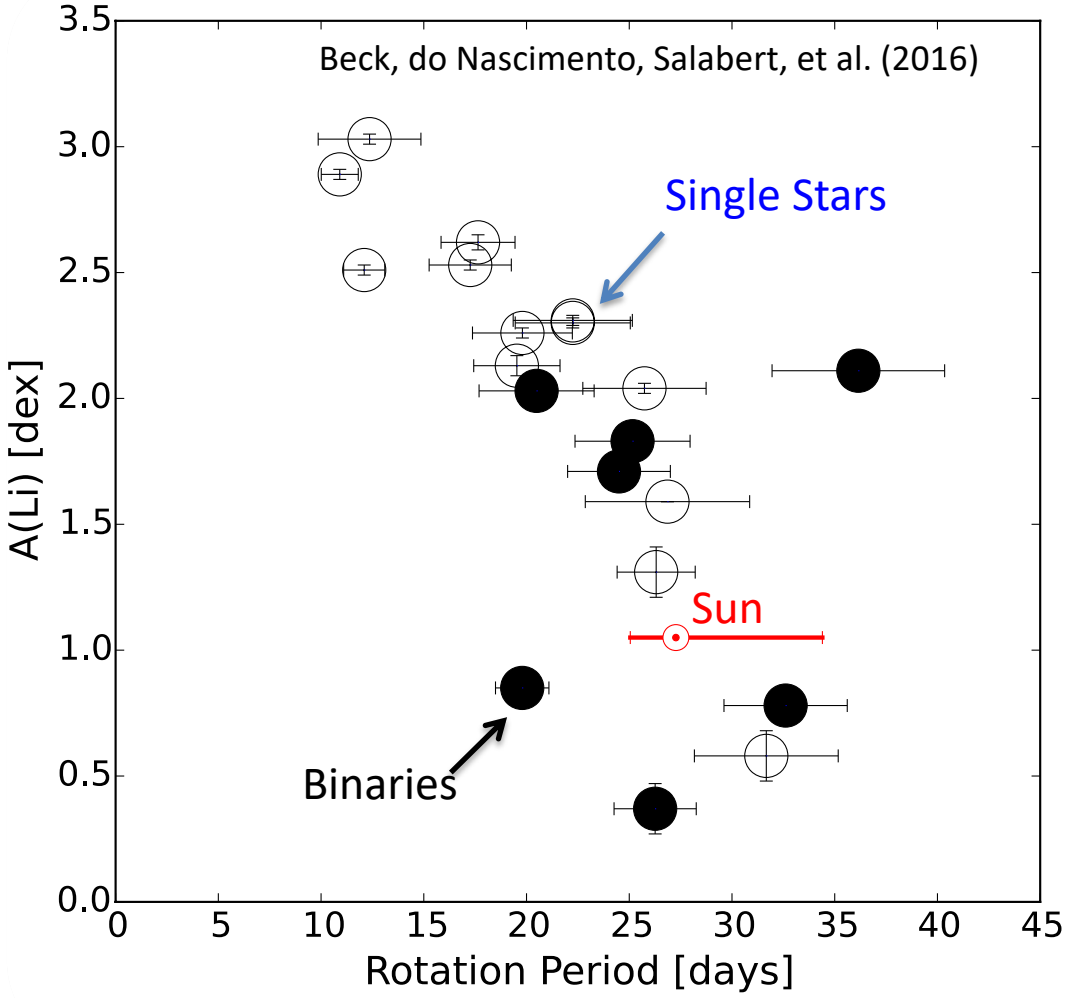
- Rotation periods → hotter stars rotate faster (1-100 days)
- Activity levels → ~60% solar activity, ~25% super, 15% sub solar

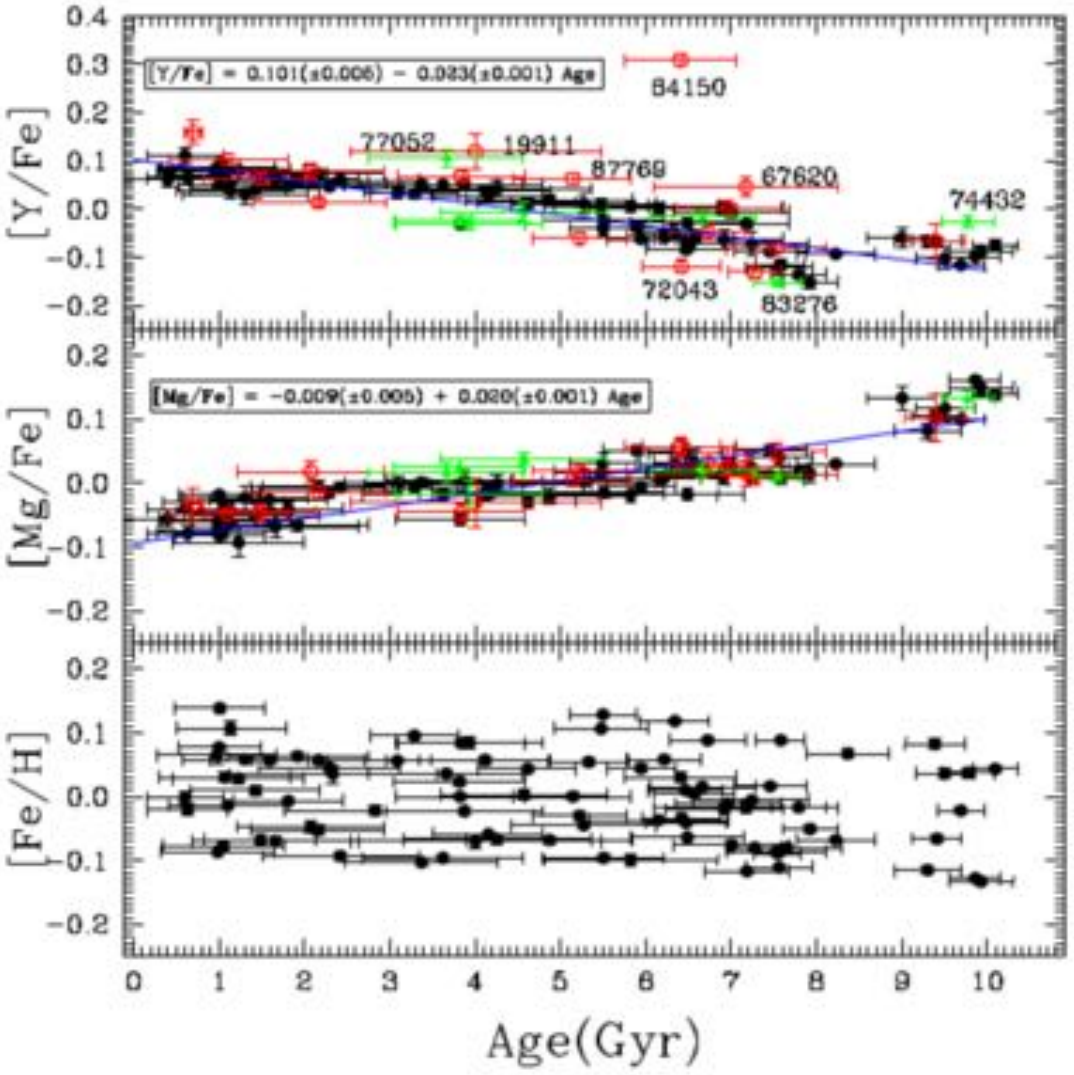
(cf. Talk by Rafael Garcia)

Garcia, Ceillier, Salabert, et al. (2014, A&A 572A 34)

Lithium for seismic solar analogs







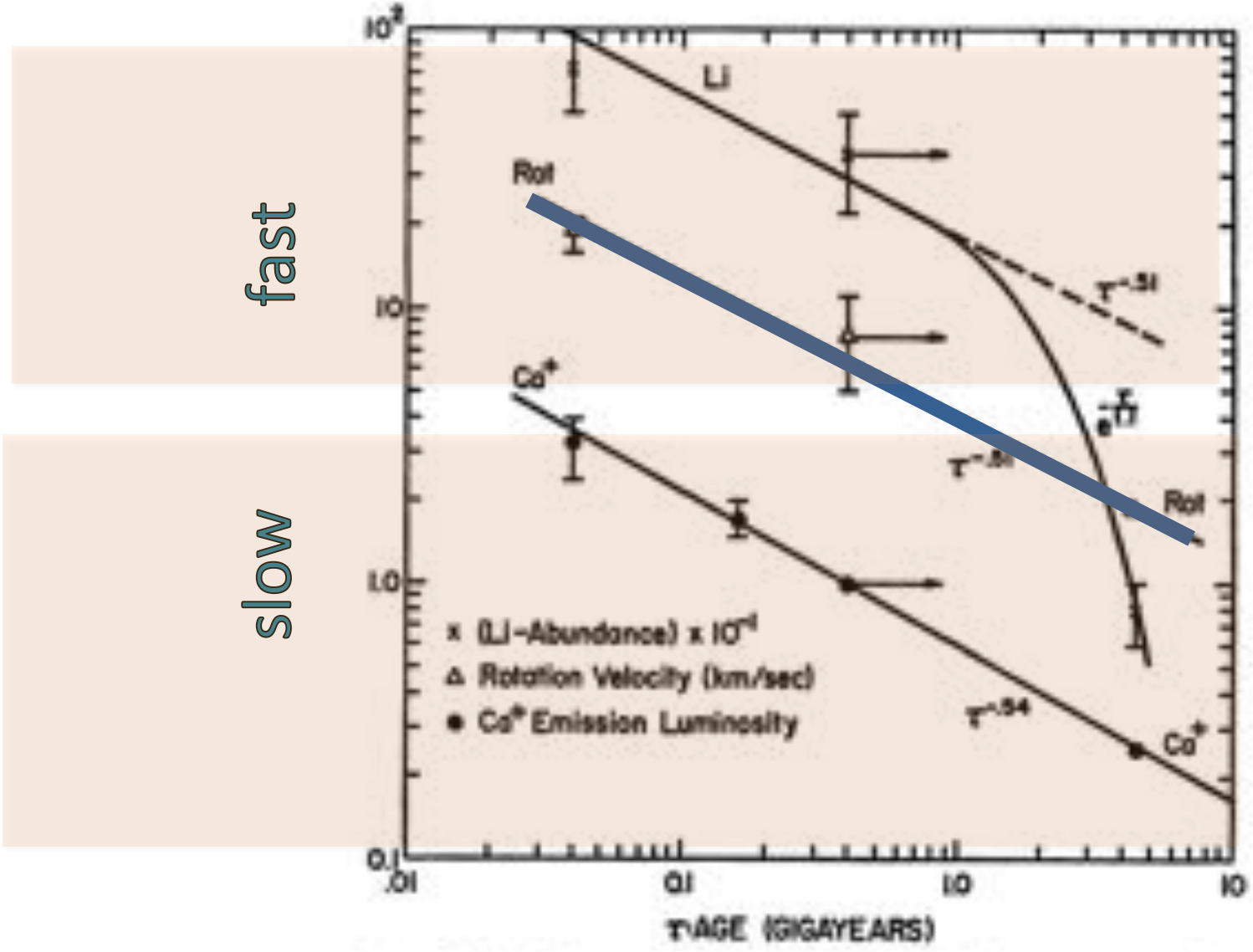
See also Nissen et al. (2015, 2016, 2017); Spina et al. (2016) Tucci Maia et al. (2016); Adibekyan et al. (2016, 2017).

[Y/Fe] (upper panel), [Mg/Fe] (middle panel) and [Fe/H] (lower panel) as function of age. The red open circles are spectroscopic binary stars and the green triangles are visual binaries. [Fe/H] vs. age do not show any correlation with age. We also present the linear fit for [Y/Fe] and [Mg/Fe] versus age on their respective panels. From Tucci Maia et al. 2016

Stellar Rotation and Activity (stellar ages)

Basis for gyrochronology

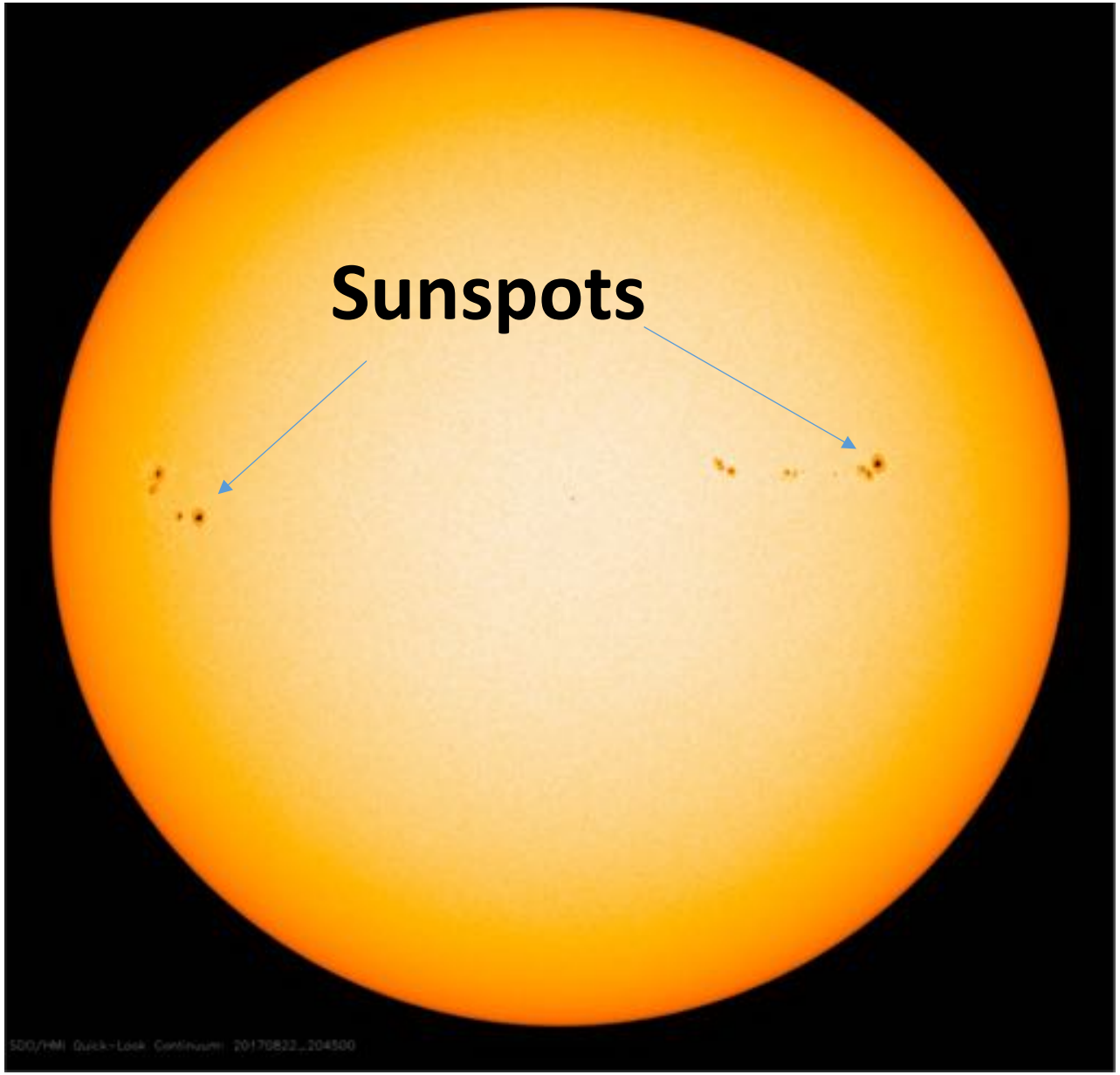
Skumanich 1972



$$v_{rot} \propto t^{-\frac{1}{2}}$$

(Barnes 2007)

Sun-like stars Rotation Period: 15 – 49 days



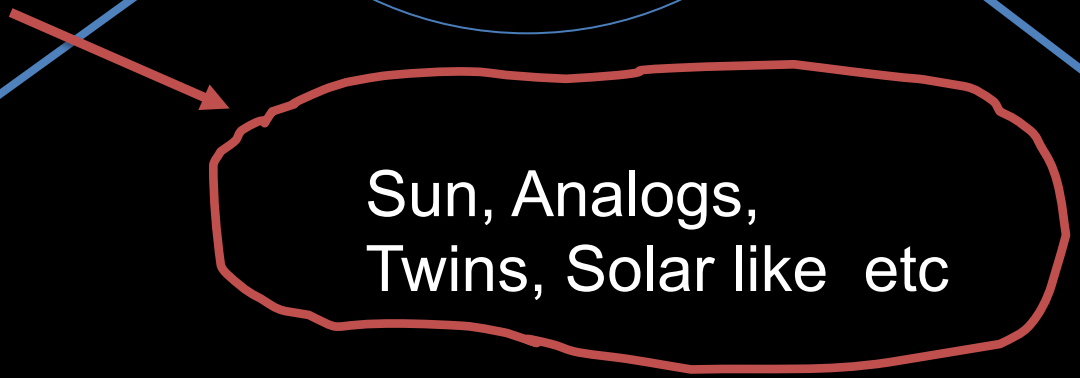
Stellar Rotation

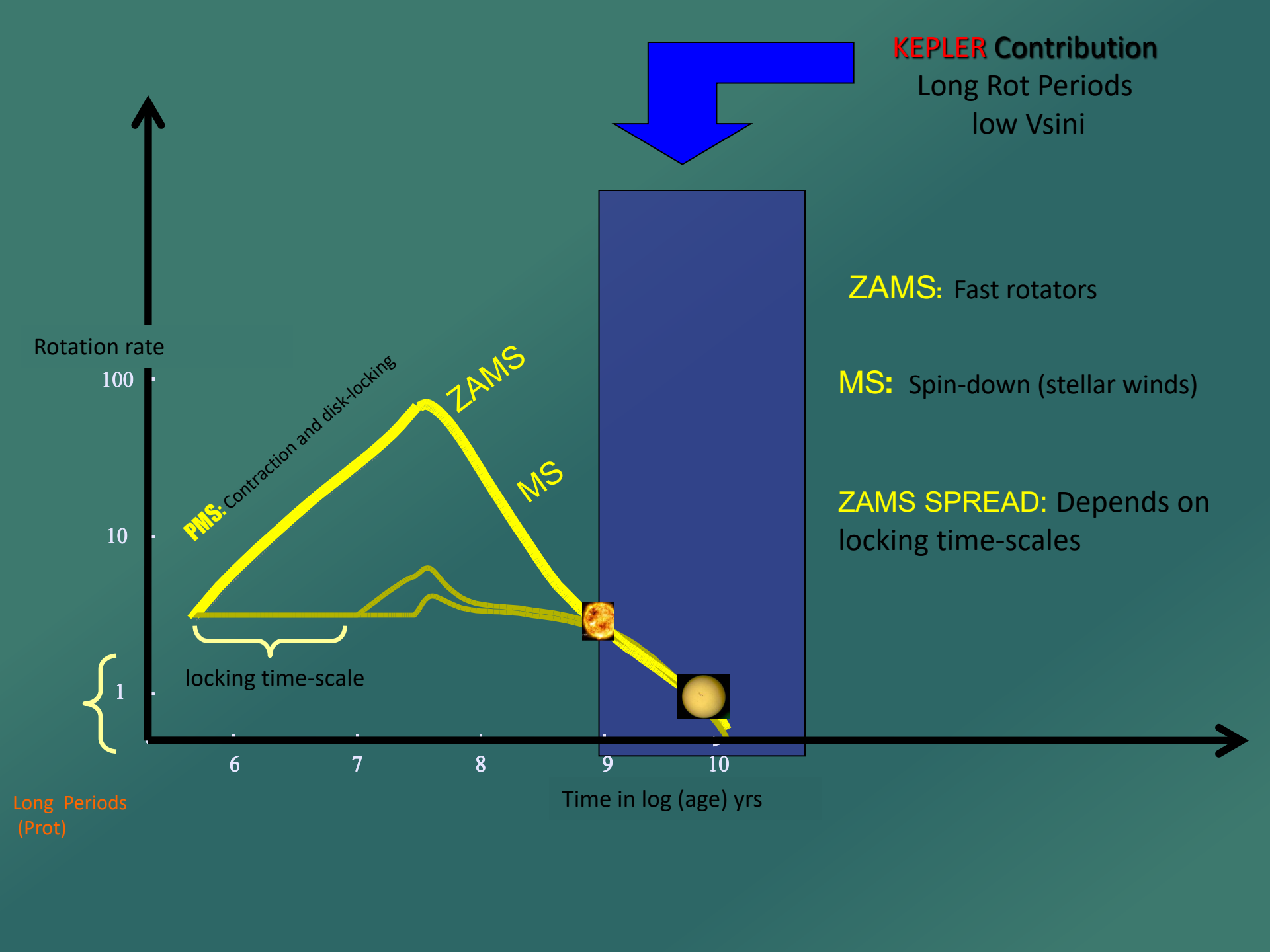
Fundamental stellar property (M, Fe/H, etc)

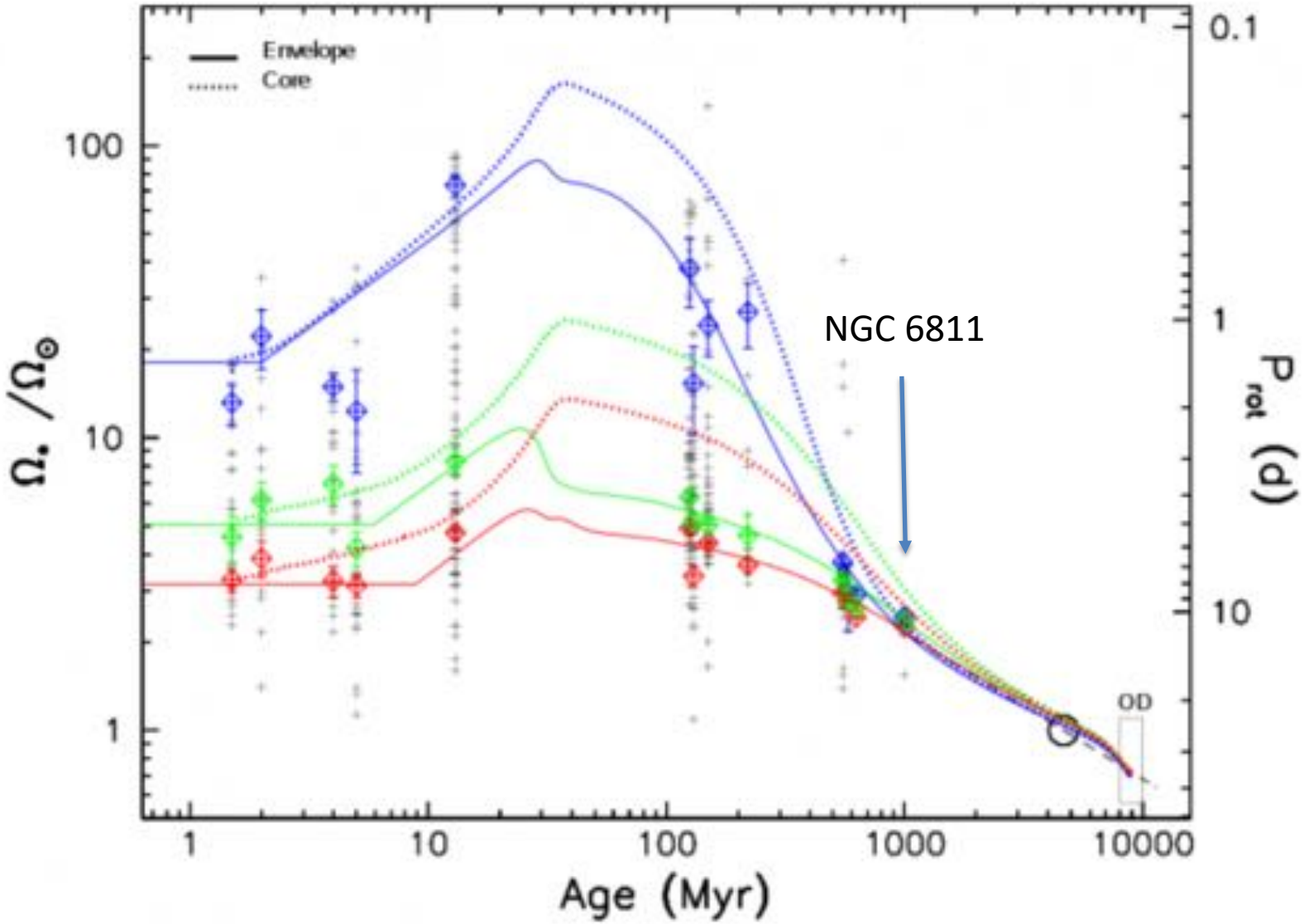
Prot and Vsini techniques

Meibon et al (2011); Gallet, F. & Bouvier, (2015)

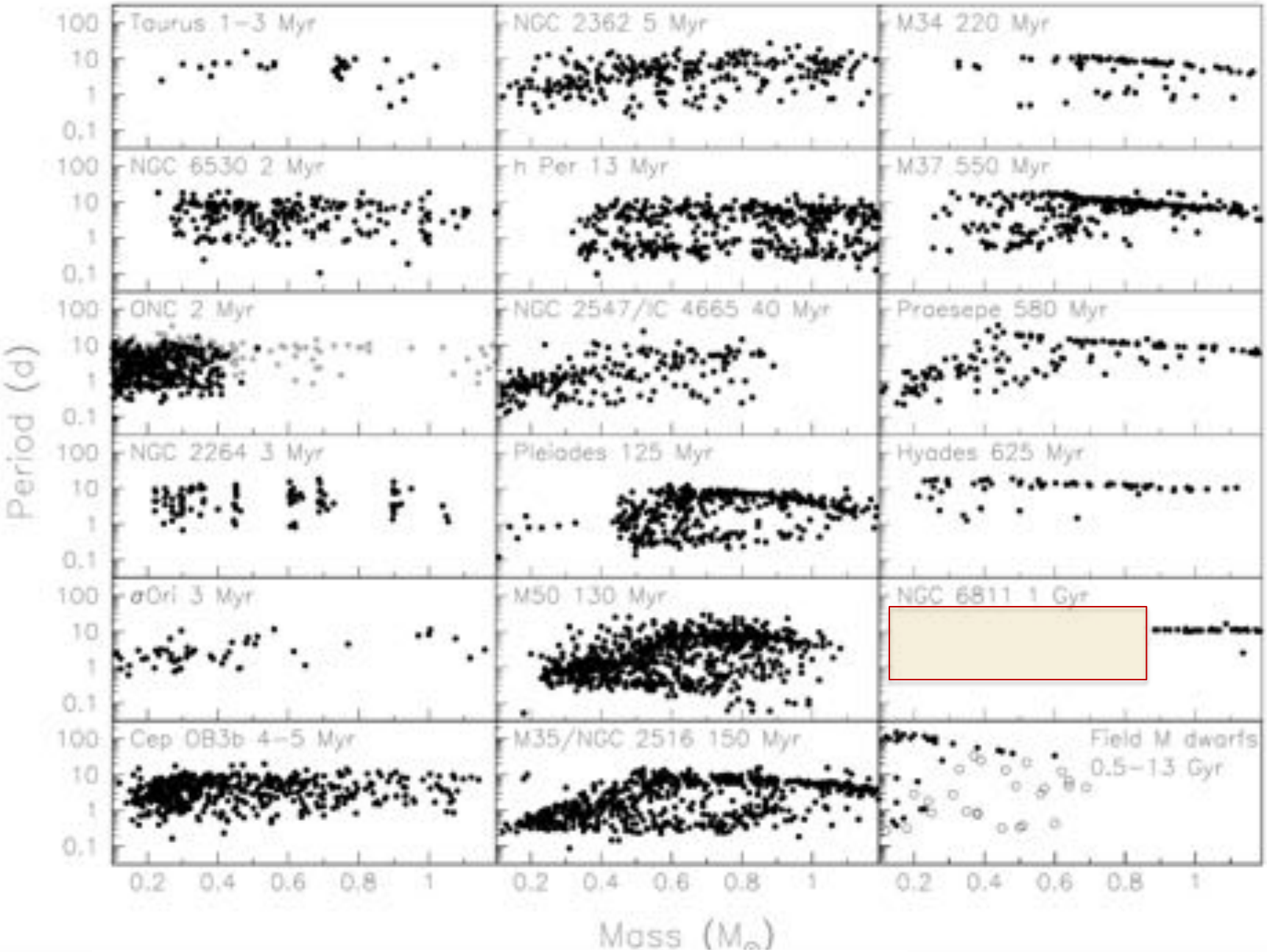
Intimately related with generation of magnetic field and magnetic activity, Mass loss, interior structure, mixing , chemical evolution…




KEPLER Contribution
Long Rot Periods
low Vsini
ZAMS: Fast rotators
MS: Spin-down (stellar winds)
ZAMS SPREAD: Depends on locking time-scales
Rotation rate
100
10
1
PMS: Contraction and disk-locking
ZAMS
MS
locking time-scale
6
7
8
9
10
Time in log (age) yrs
Long Periods (Prot)

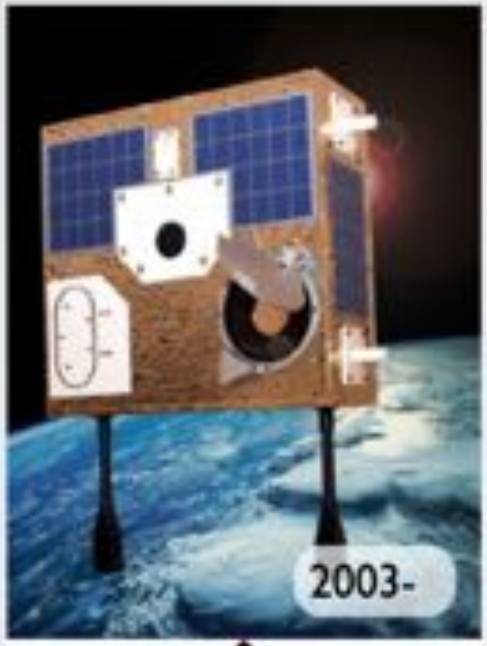


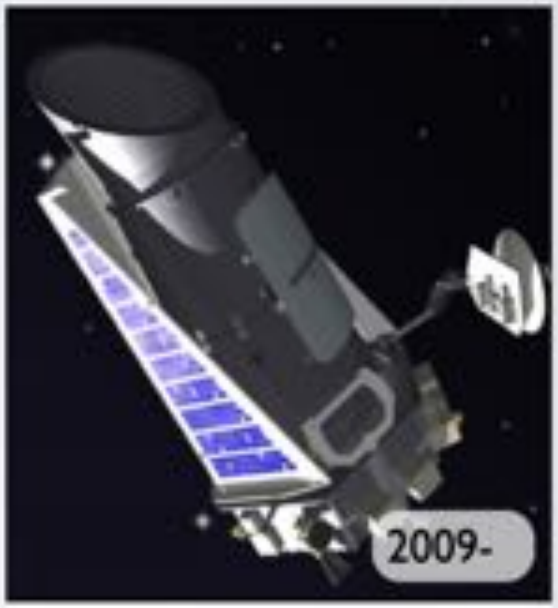
Angular momentum evolution for solar-type stars
Gallet, F. & Bouvier, J. 2015, A&A

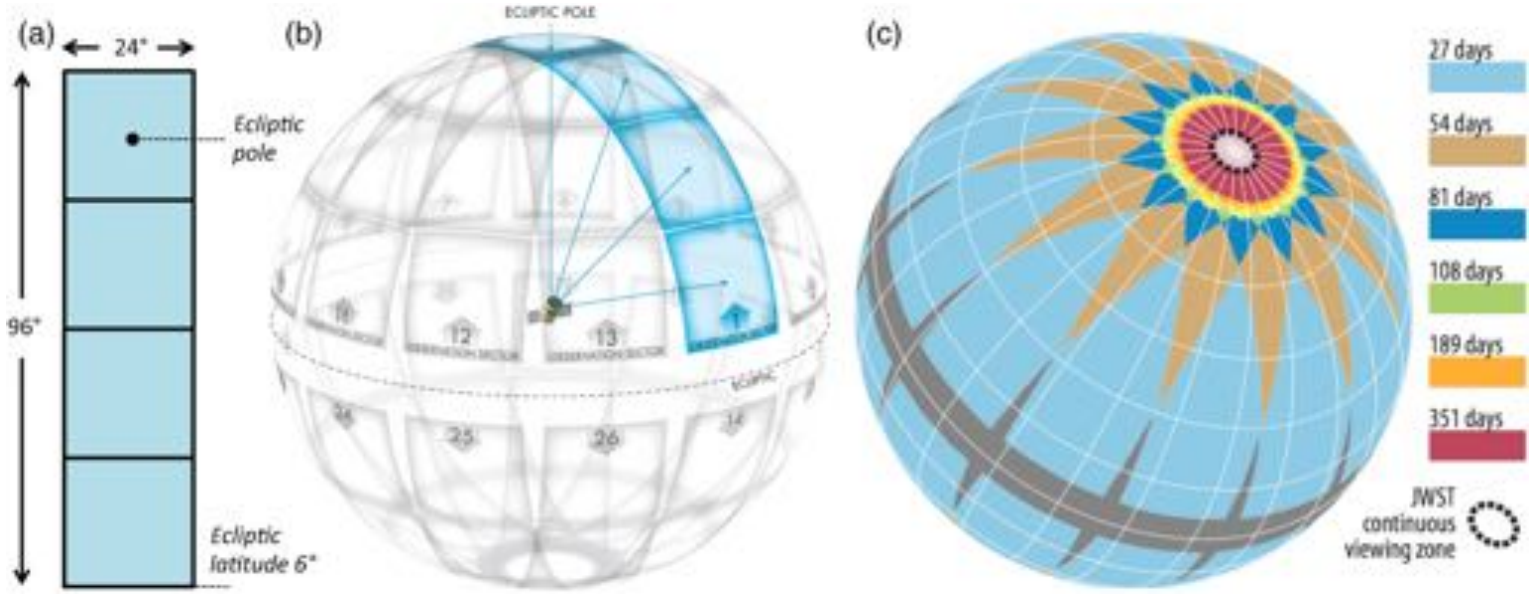


Gallet, F. & Bouvier, J. 2015, A&A; Meibon et al. (2011)

NEW OPPORTUNITIES IN THE ERA OF SPACE-BASED PRECISION PHOTOMETRY

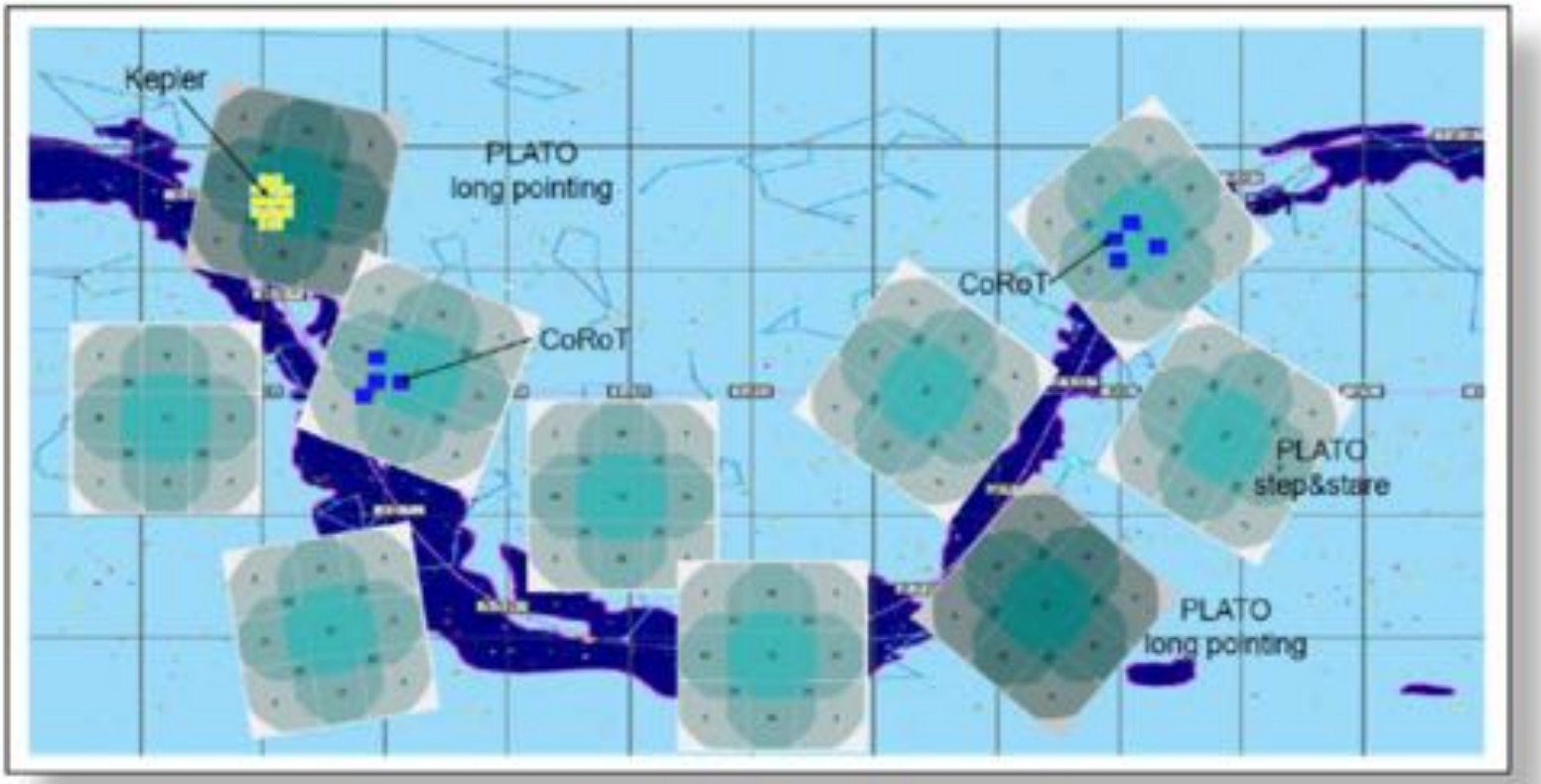






The Transiting Exoplanet Survey Satellite (TESS) will discover thousands of exoplanets in orbit around the brightest stars in the sky. In a two-year survey of the solar neighborhood, TESS will monitor more than 200,000 stars for temporary drops in brightness caused by planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances

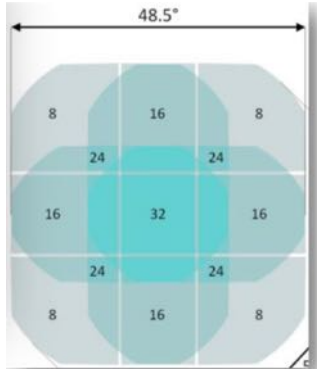
PLATO 2.0 instrument (2025/2026)



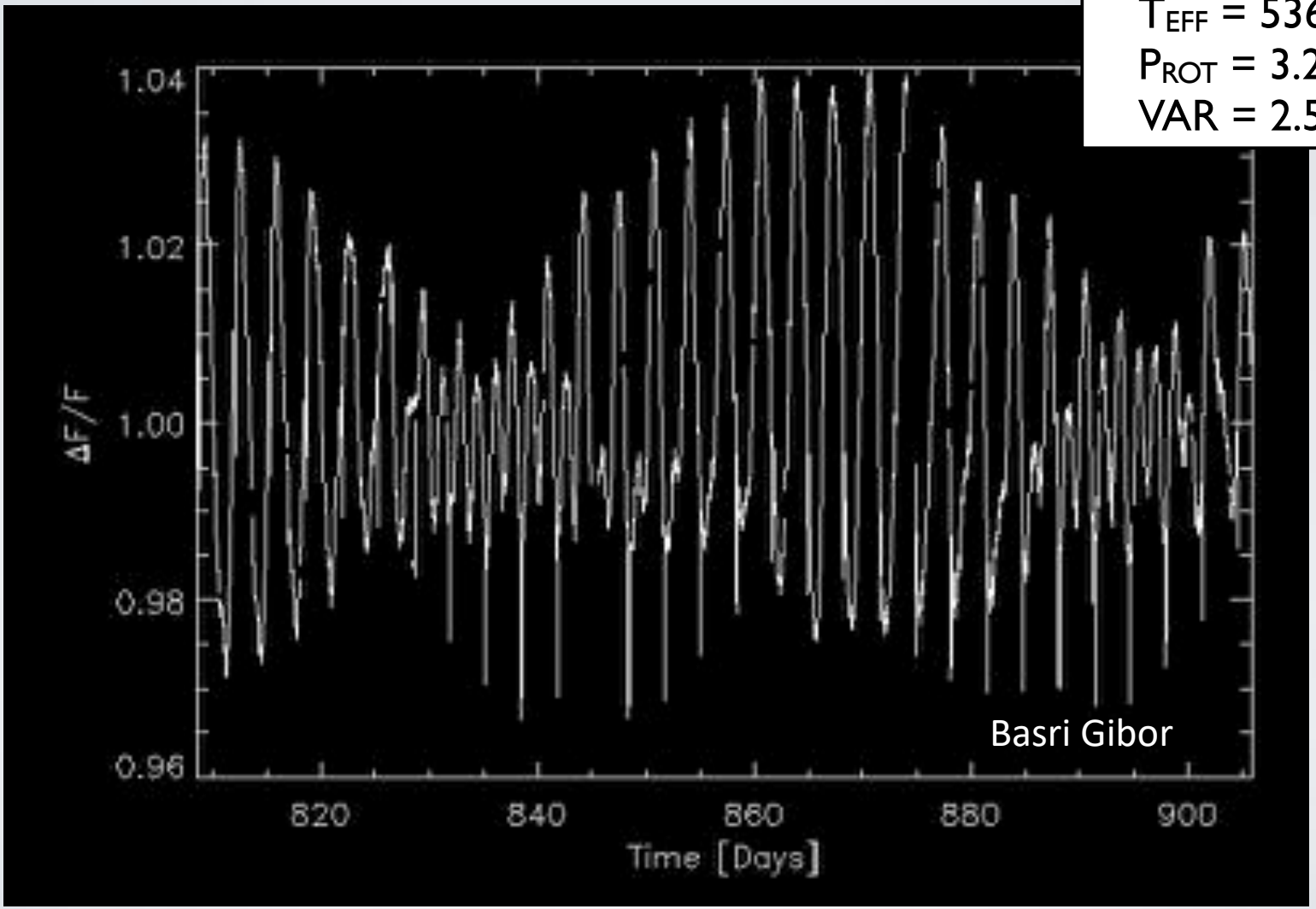
→ covers ~50% of the sky

6 years nominal science operation:

- **2 long pointings of 2-3 years**
- **step-and-stare phase (2-5 months per pointing)**



ROTATIONAL VARIABILITY AT A RANGE OF PERIODS



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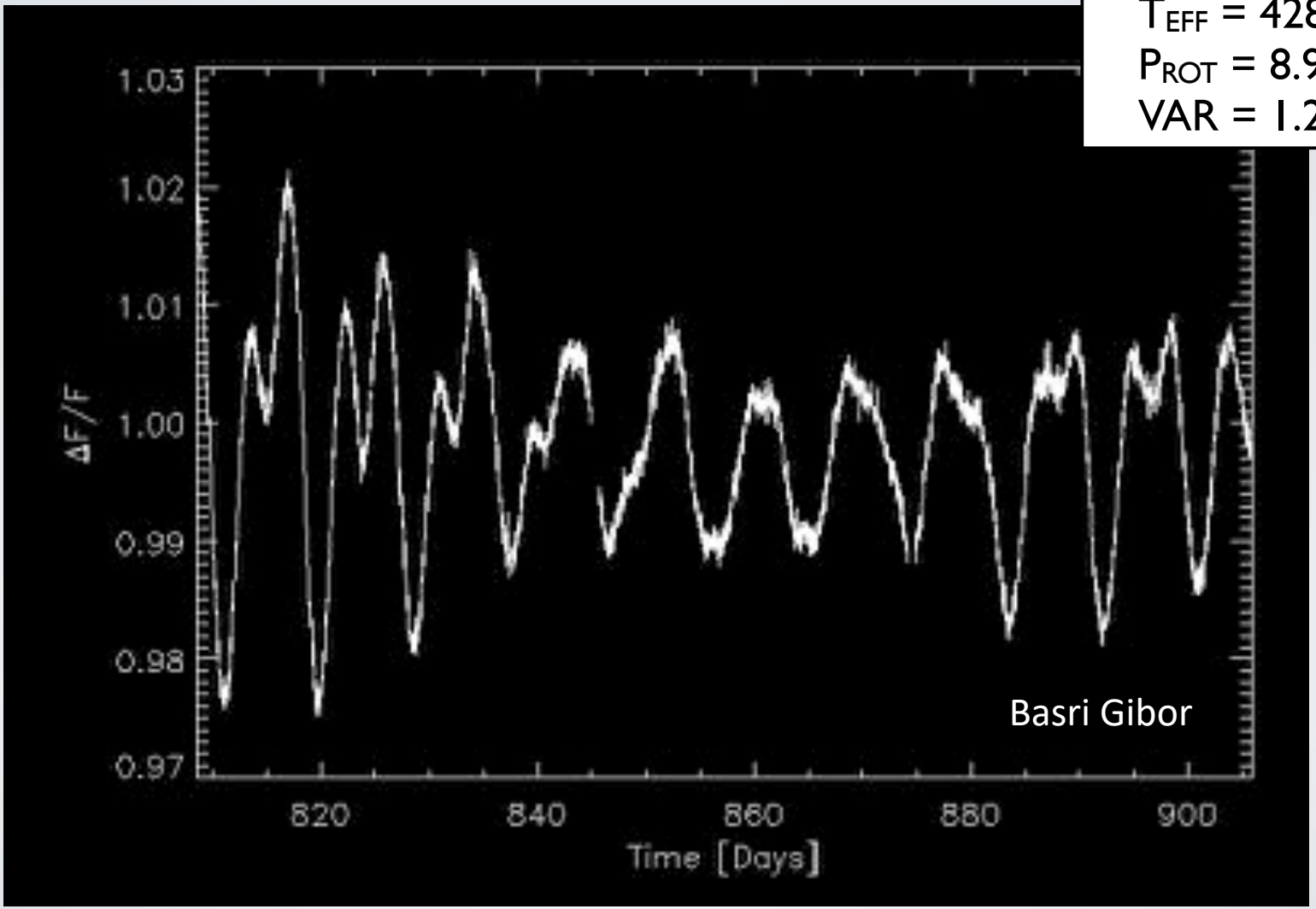
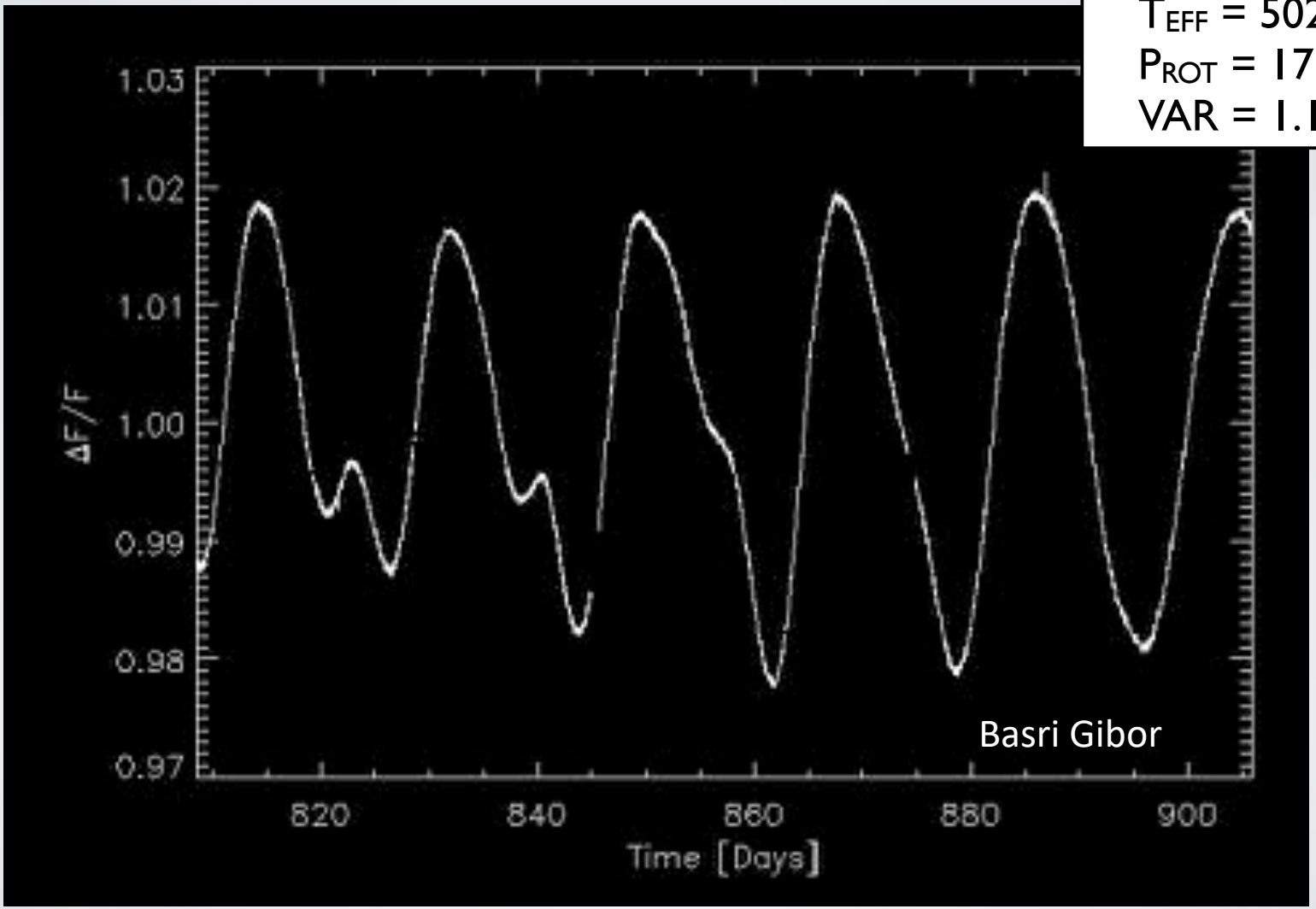


Double-Dipping: A New Relation between Stellar Rotation and Starspot Activity
"Combination of spot coverage and lifetime" Gibor Basri, Hieu T. Nguyen (May 2018)



Stellar Rotation measurements

The rotation period can be determined via

1. Lomb-Scargle periodograms:

Lomb (1976), Scargle (1982) and Zechmeister & Kurster (2009).

Most activity-induced signals will show some quasi-periodicity with a recurrence timescale related to the stellar rotation period, Prot and/or its harmonics.

Generalized LS

We can fit a sinusoid to our dataset:

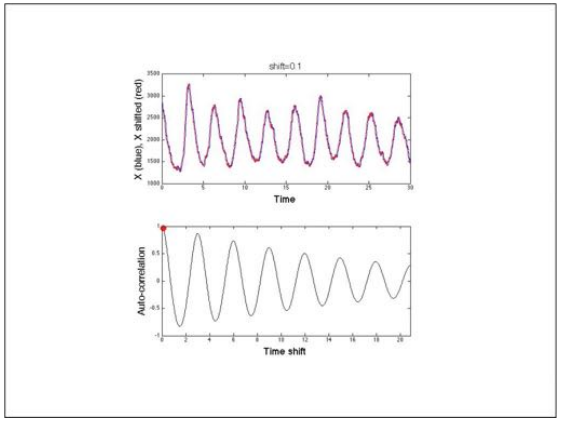
$m_i = A \cos(\omega t_i) + B \sin(\omega t_i) + C,$

2. Autocorrelation functions

Edelson & Krolik, 1988.

Star's activity identity card:

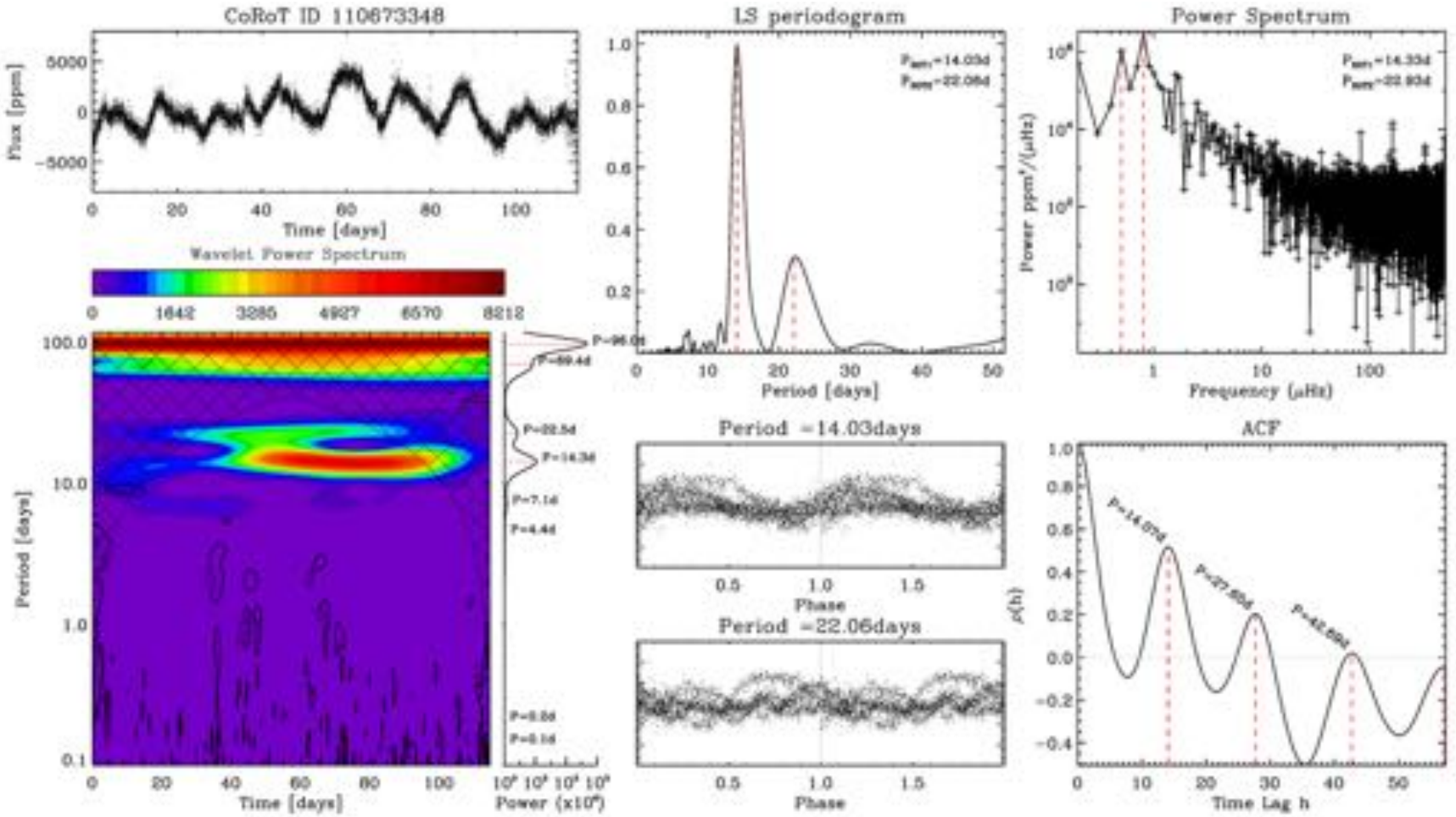
$$K_{ij} = \frac{(yi - \boldsymbol{y})(y_j - \boldsymbol{y})}{(\sigma_i \sigma_j)^{\wedge 1/2}}$$



3. Power Spectrum, Wavelet, Slide Lomb Scargle, GP, …

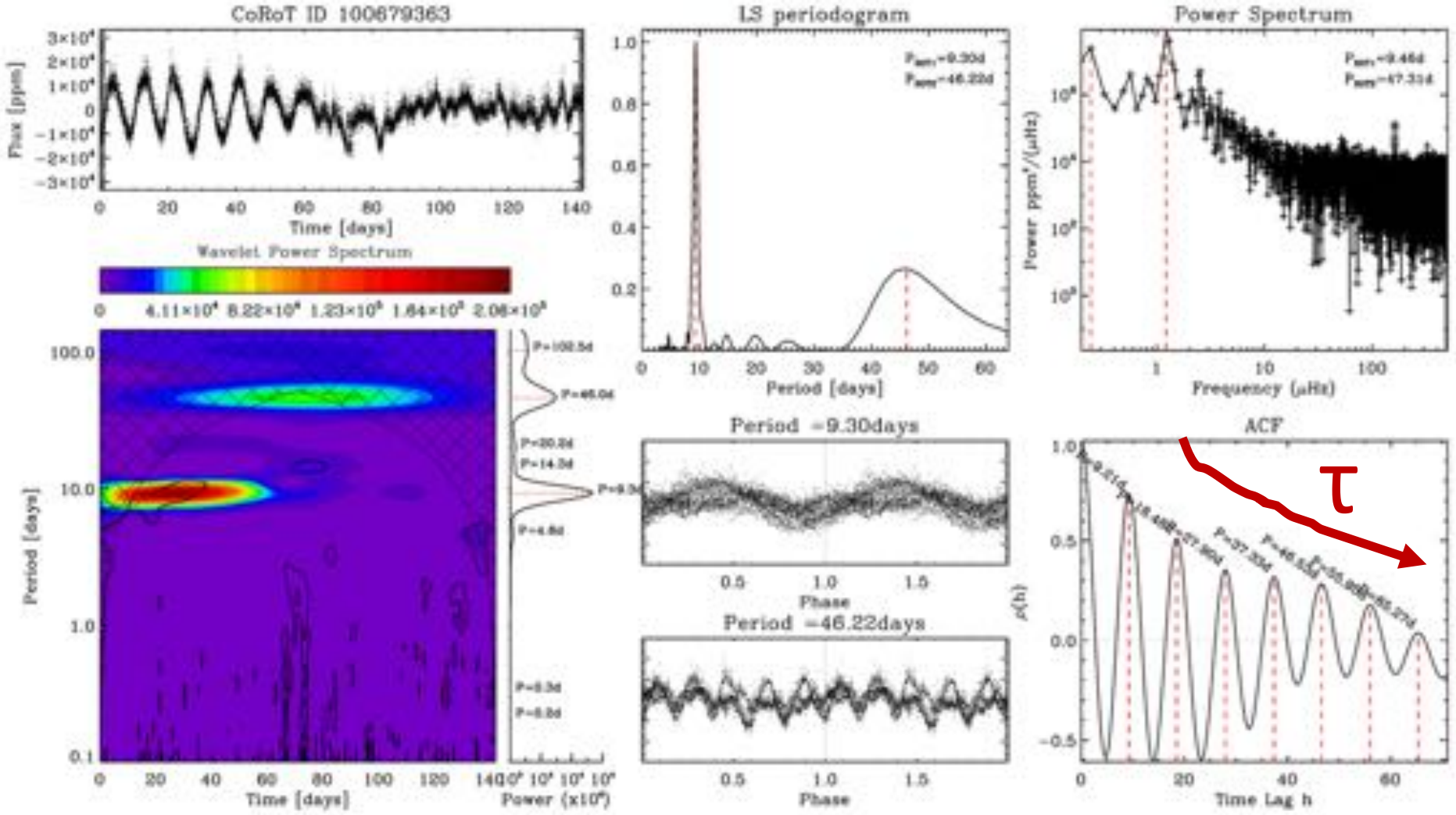
CoRoT 110673348

Anthony, F. PhD's Thesis



CoRoT 100679363

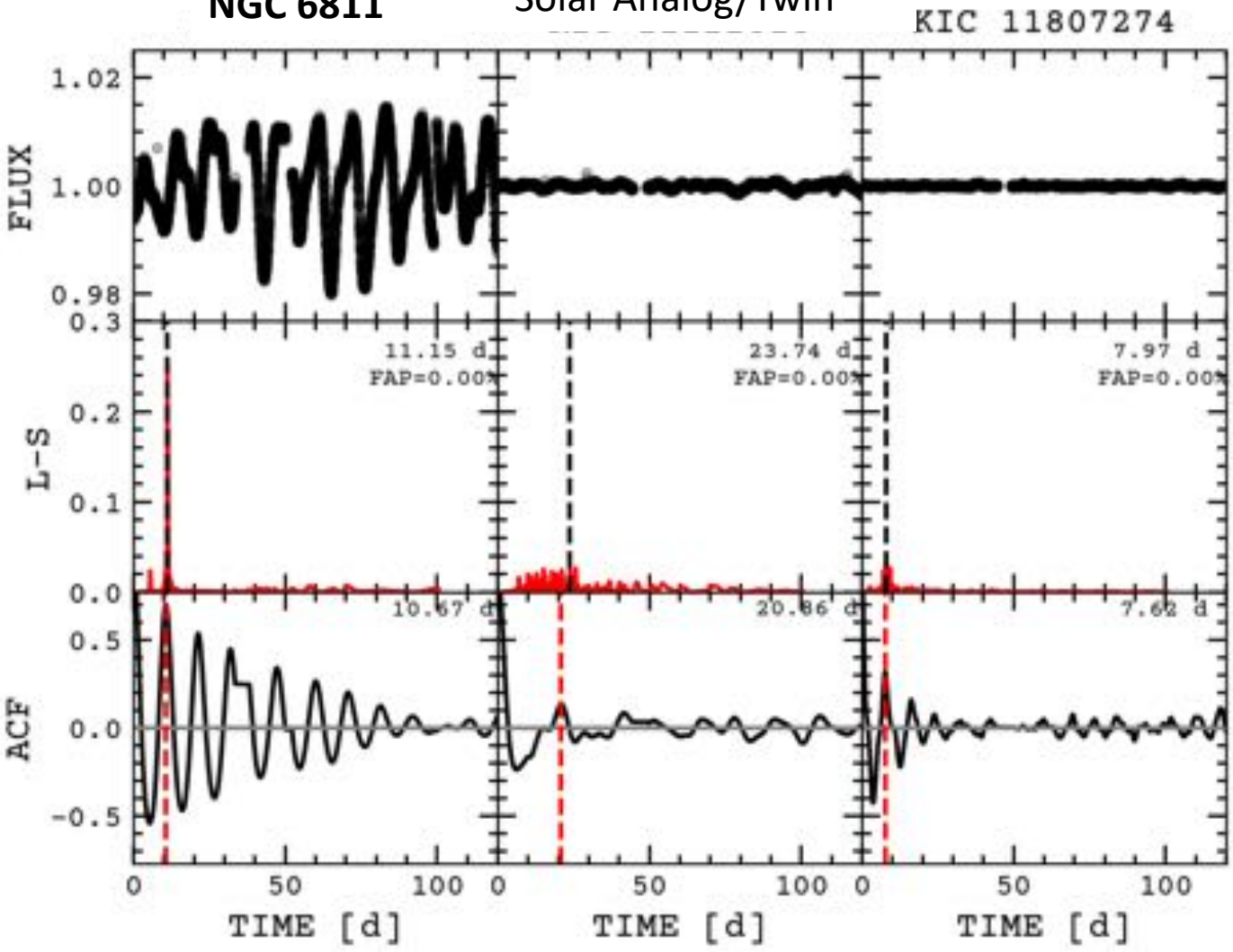
Anthony, F. PhD's Thesis



1 sola mass
NGC 6811

Solar Analog/Twin

kepler-50, F star

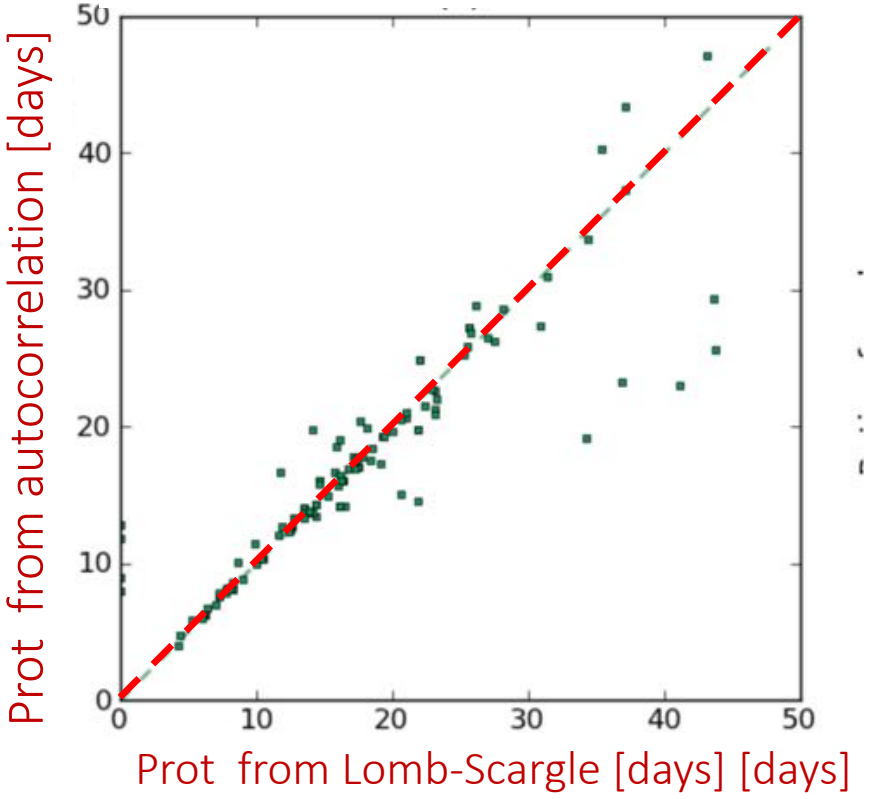


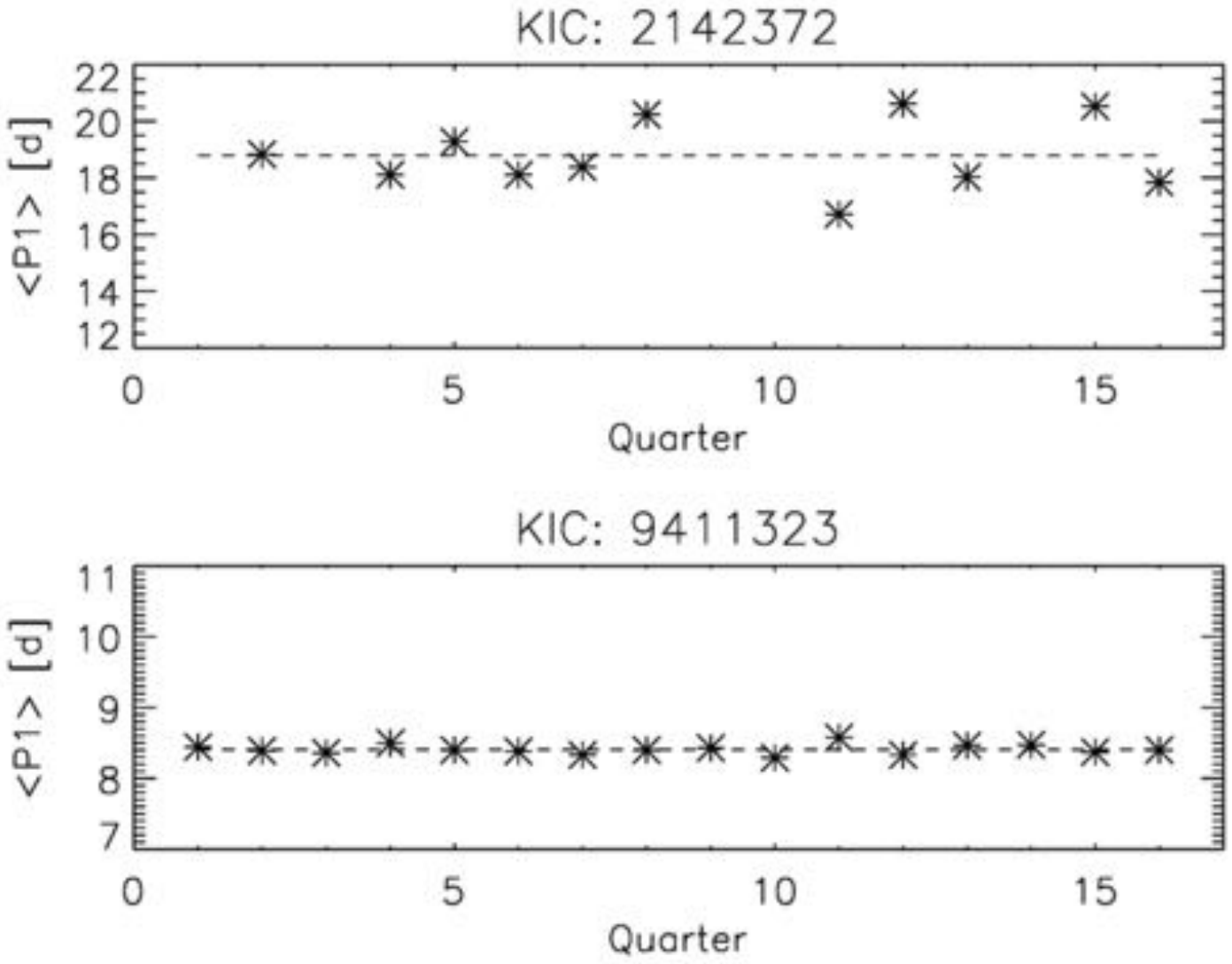
KEPLER Targets

Stellar rotation periods

- Good agreement overall for short period (active stars)
- Few cases, especially at long periods, the period identified via Lomb-Scargle is twice as long as that of the autocorrelation
- Use stellar rotation period obtained when both agrees (not perfect).
- The majority of the old stars in our sample show very little photometric variations. 0.01 parts per thousand
- Difficult to measure the rotation period for old stars

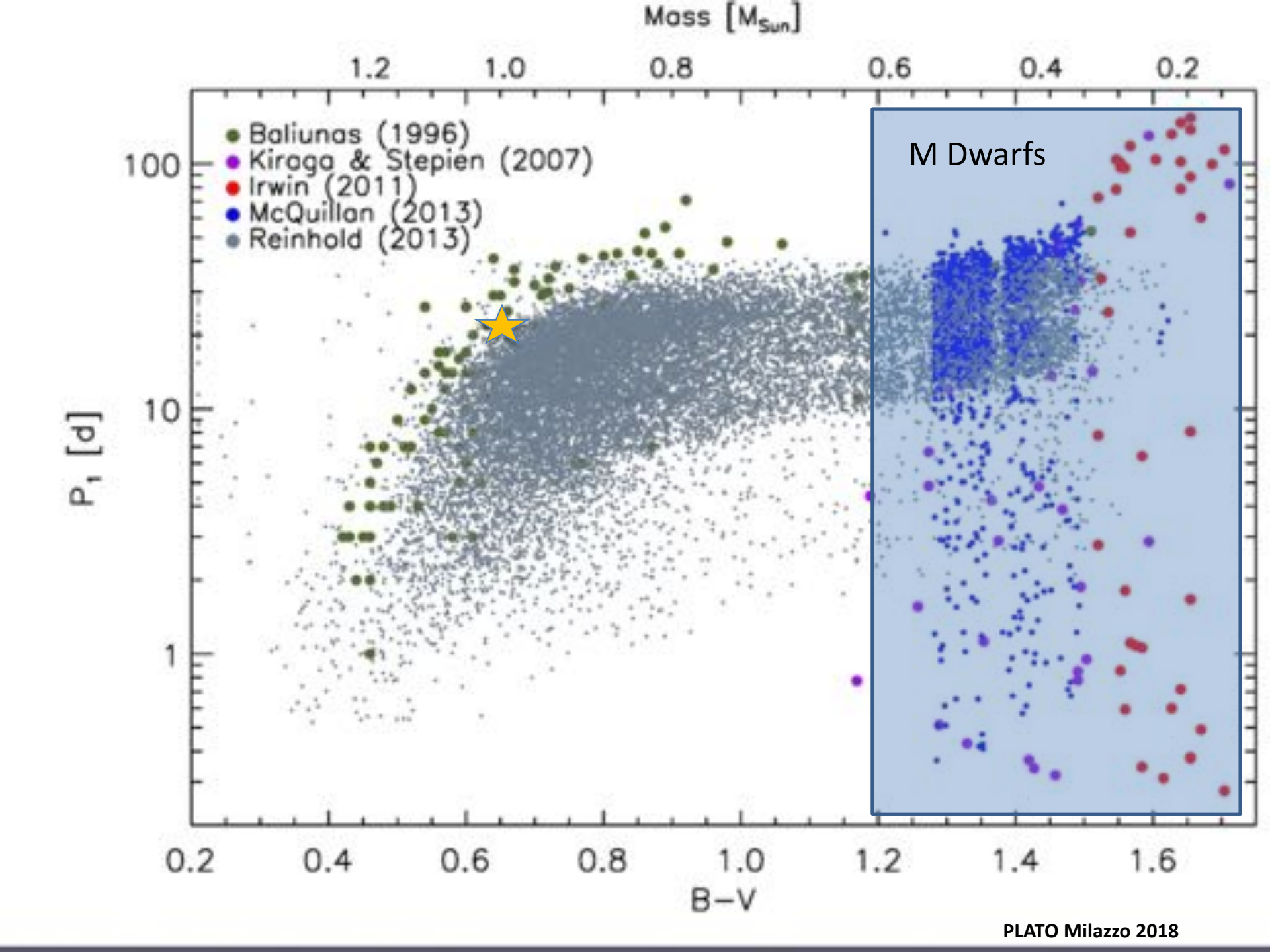
Both methods plotted




KIC: 2142372
<P1> [d]
22
20
18
16
14
12
0
5
10
15
Quarter
KIC: 9411323
<P1> [d]
11
10
9
8
7
0
5
10
15
Quarter

Kepler Mission and Rotation period Measurements

- McQuillan et al. (2013) 1,570 (M dwarfs)
- Nielsen et al. (2013) 12,151 stars
- McQuillan et al. (2013) 737 (KOI)
- Walkowicz & Basri (2013) 950 (KOI)
- Reinhold et al. (2013): 24,124 star
- McQuillant et al. (2014): 34,030 stars


Mass [M_Sun]
1.2
1.0
0.8
0.6
0.4
0.2
Baliunas (1996)
Kiraga & Stepien (2007)
Irwin (2011)
McQuillan (2013)
Reinhold (2013)
M Dwarfs
100
10
1
P_1 [d]
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
B−V

GAIA to improve the measurements of stellar fundamental parameters

III - Gaia DR2 impact on Benchmark targets for studying Rotation and Activity of Sun-like stars and its evolution

Submitted to ApJL. Manuscript LET00000
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ROTATIONS OF SOLAR ANALOGS CROSS-MATCHING KEPLER AND GAIA DR2

J.-D. do Nascimento, Jr.[1,2], L. de Almeida[1], E. N. Velloso[1], F. Anthony[1], S. Meibom[2], S. Barnes[3], F. Baudin[6], et al.

Submitted to ApJL. Manuscript LET00000

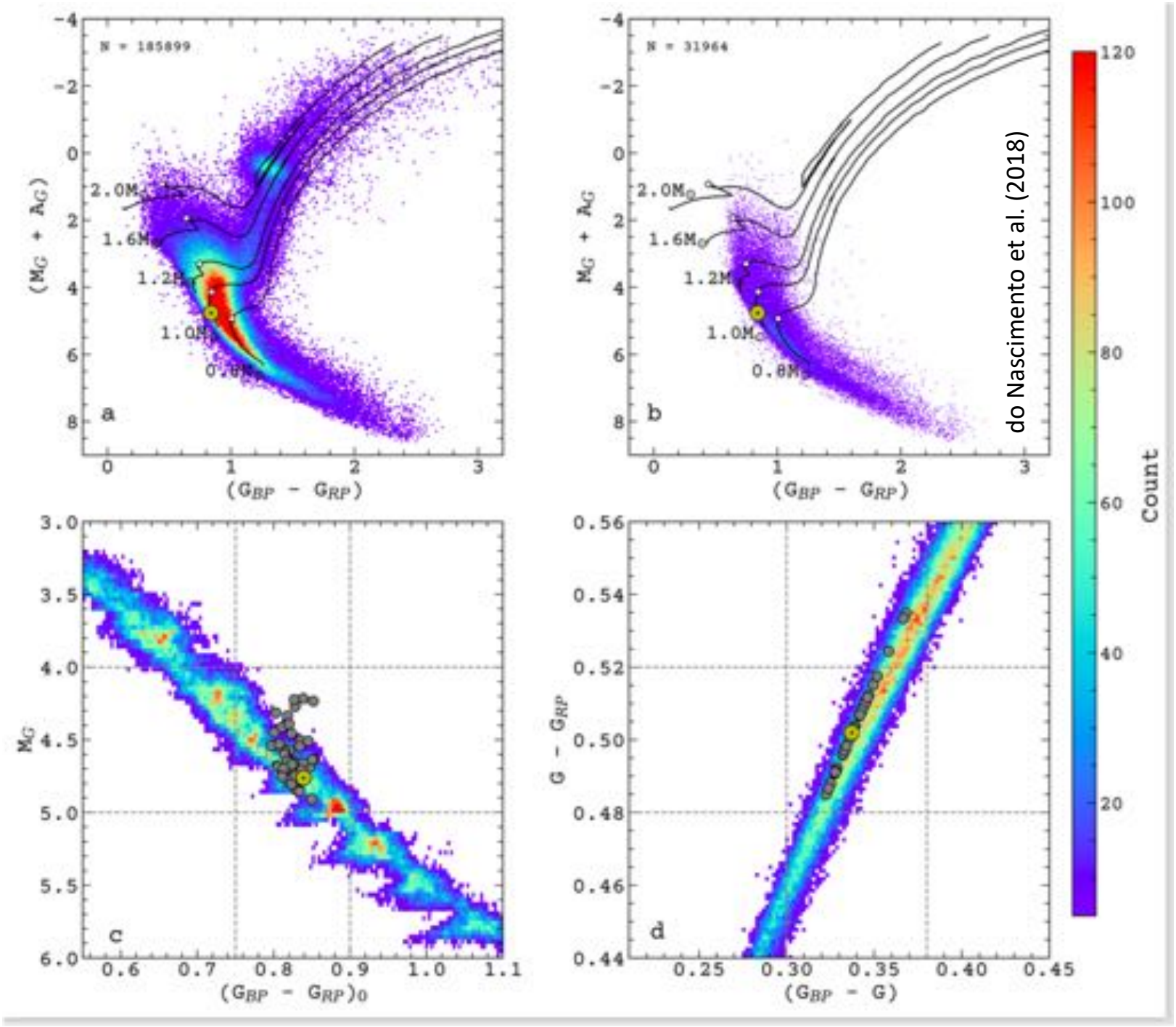
ABSTRACT

A major issue to interpret the rotation period distribution for main sequence stars by using *Kepler* mission data has been the lack of precise evolutionary status for those objects. We present here evolutionary status based on Gaia Data Release 2 parallaxes and photometry for 2,573 s... state. Our results... like the Sun. Those... rotation values from... not the root cause... d with astrometric... s. This new sampl...

K

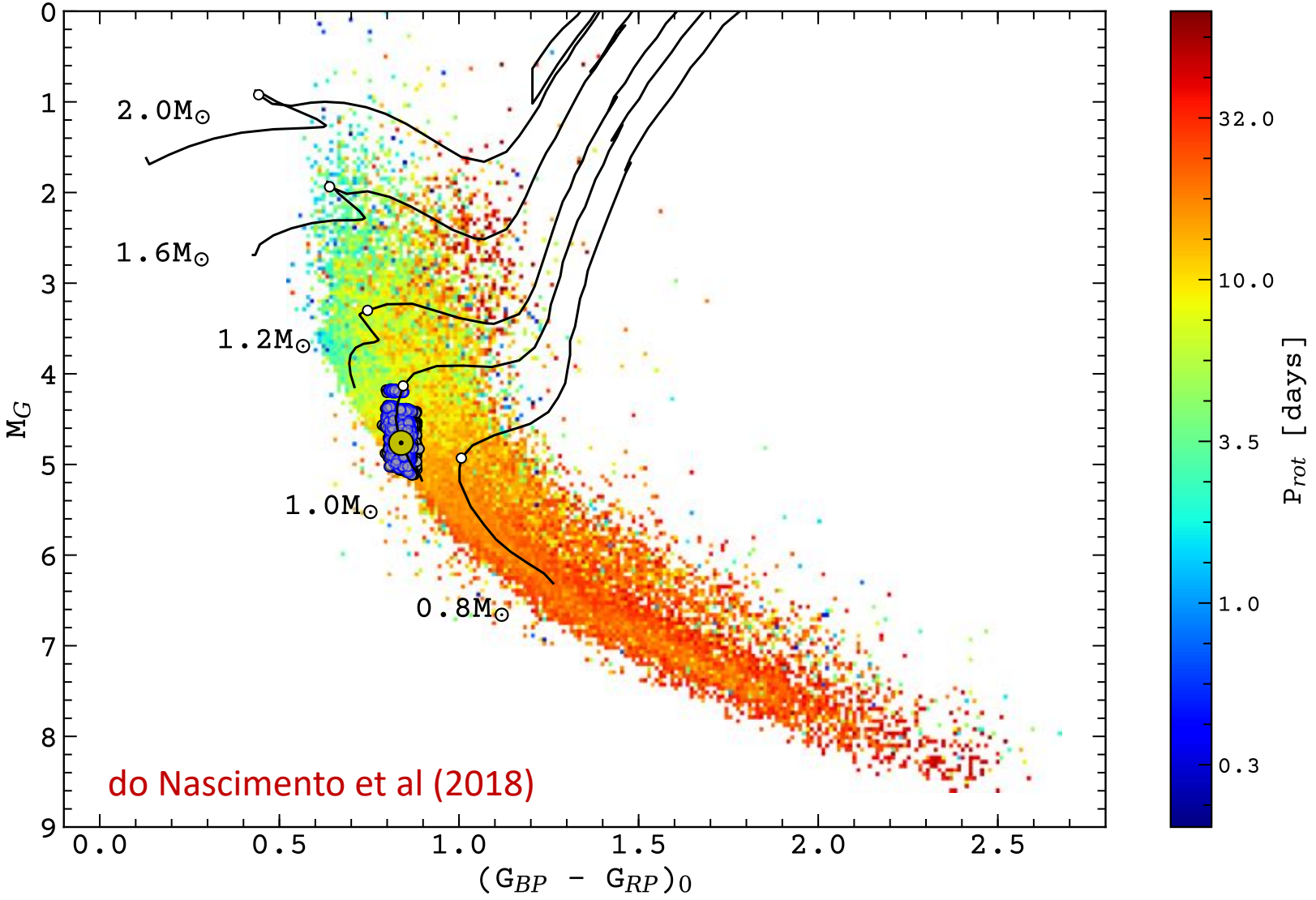
"A major issue to interpret the rotation period and activity behavior for main sequence stars by using Kepler mission data has been the lack of precise evolutionary status for those objects and the understand of selections criteria."

Gaia DR2 + Kepler Cross matching Sample



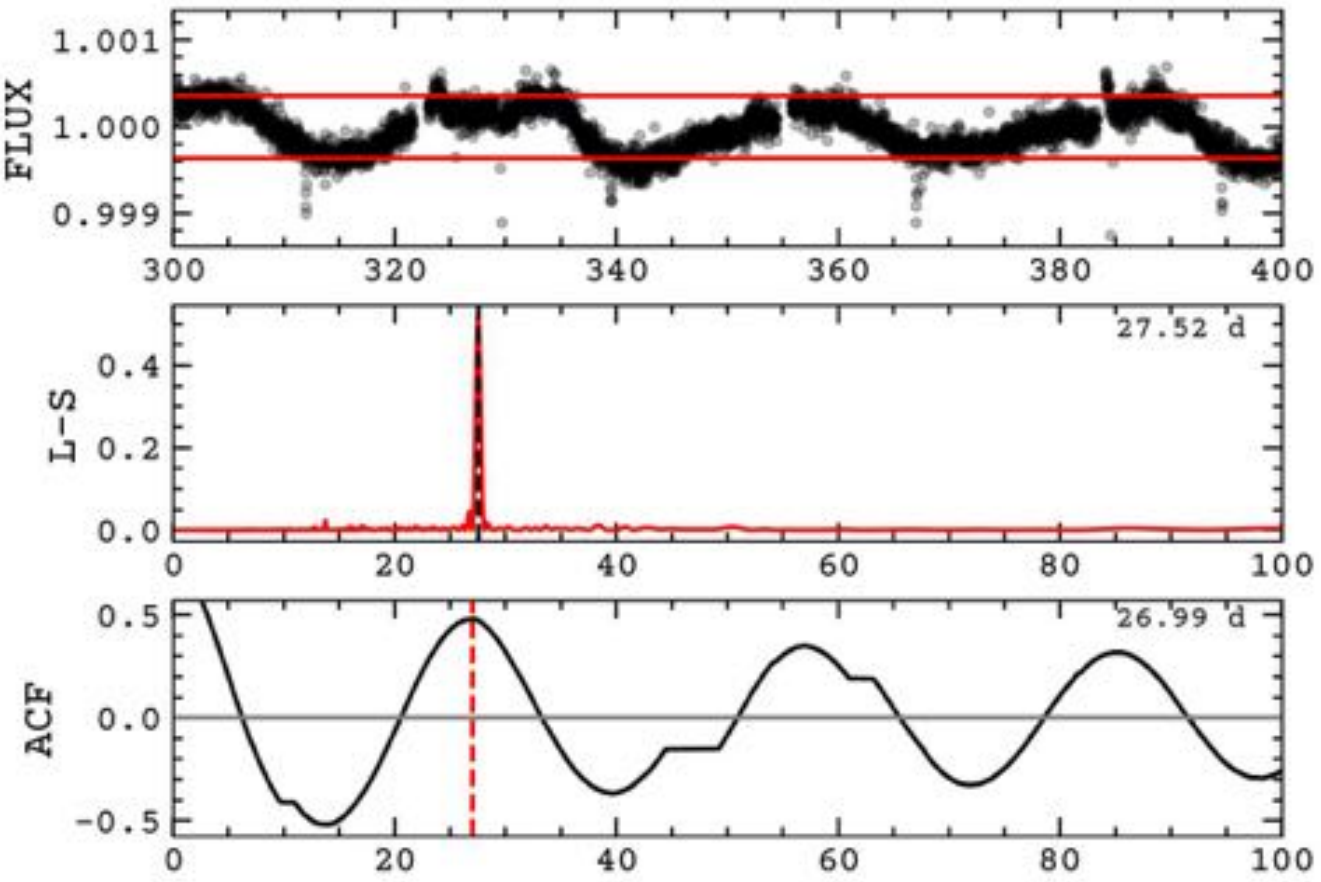
Rotation Period measurements from 34K stars

+ GAIA DR2 + Girardi et al (2000) tracks

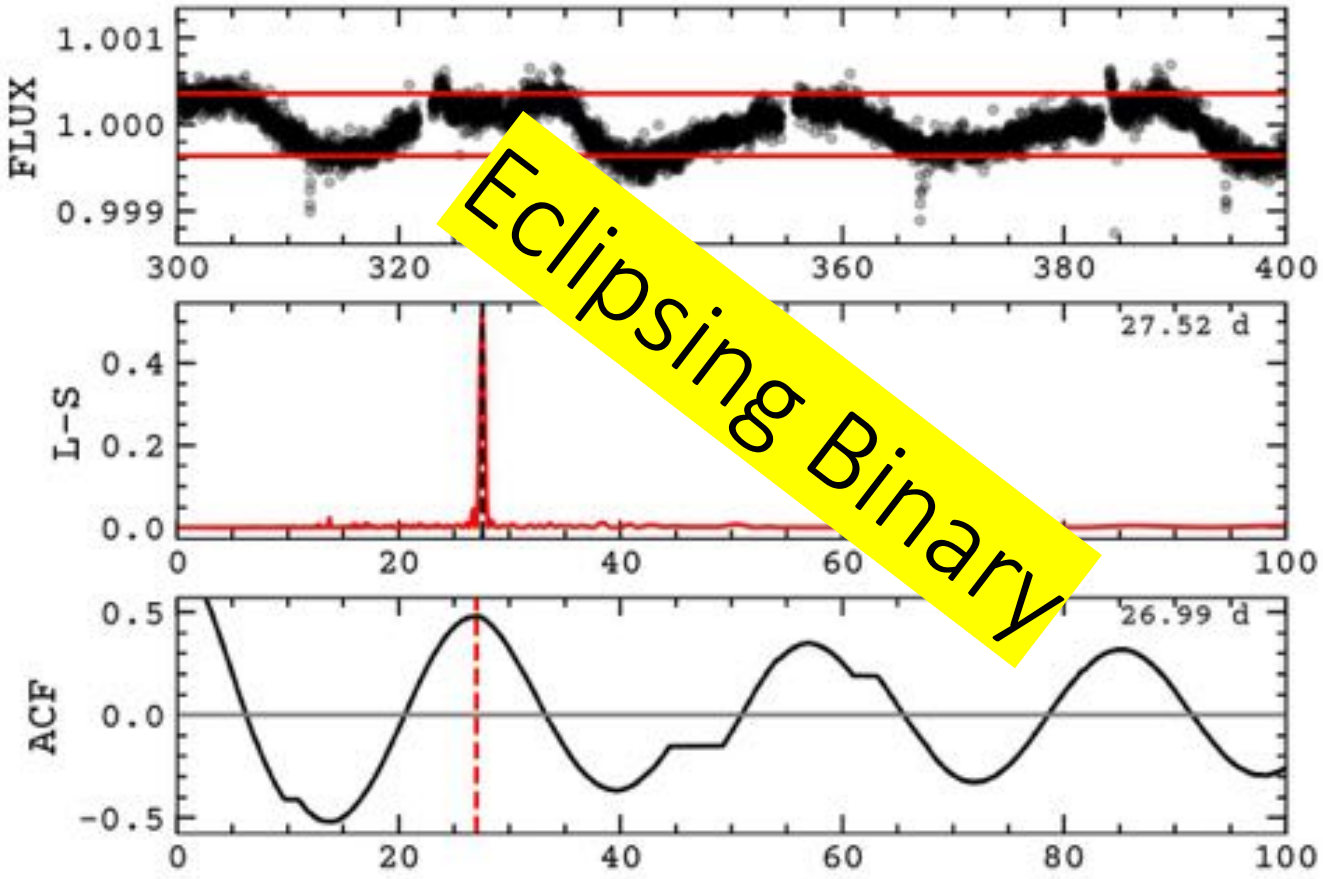


do Nascimento et al (2018)

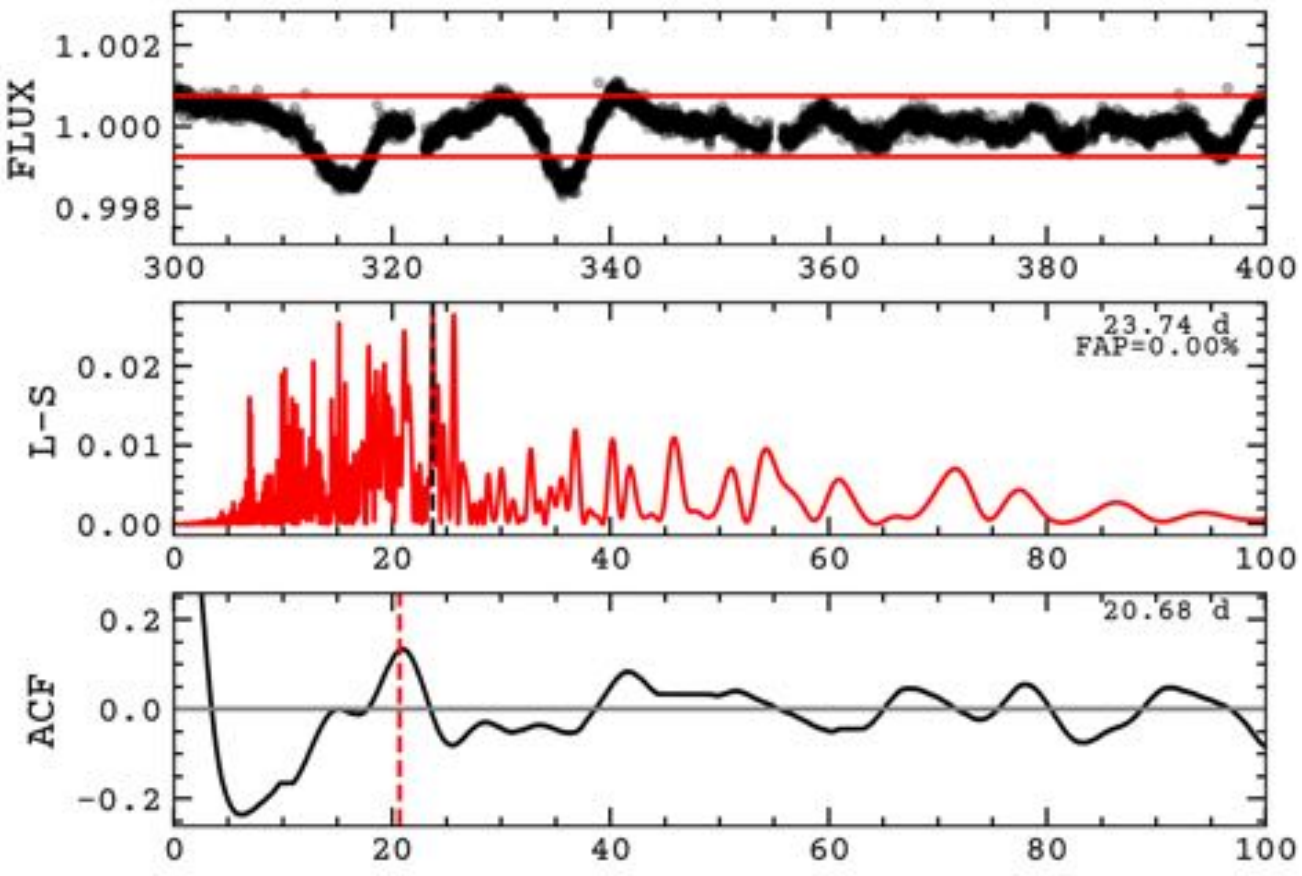
A typical Solar Twin candidate ?



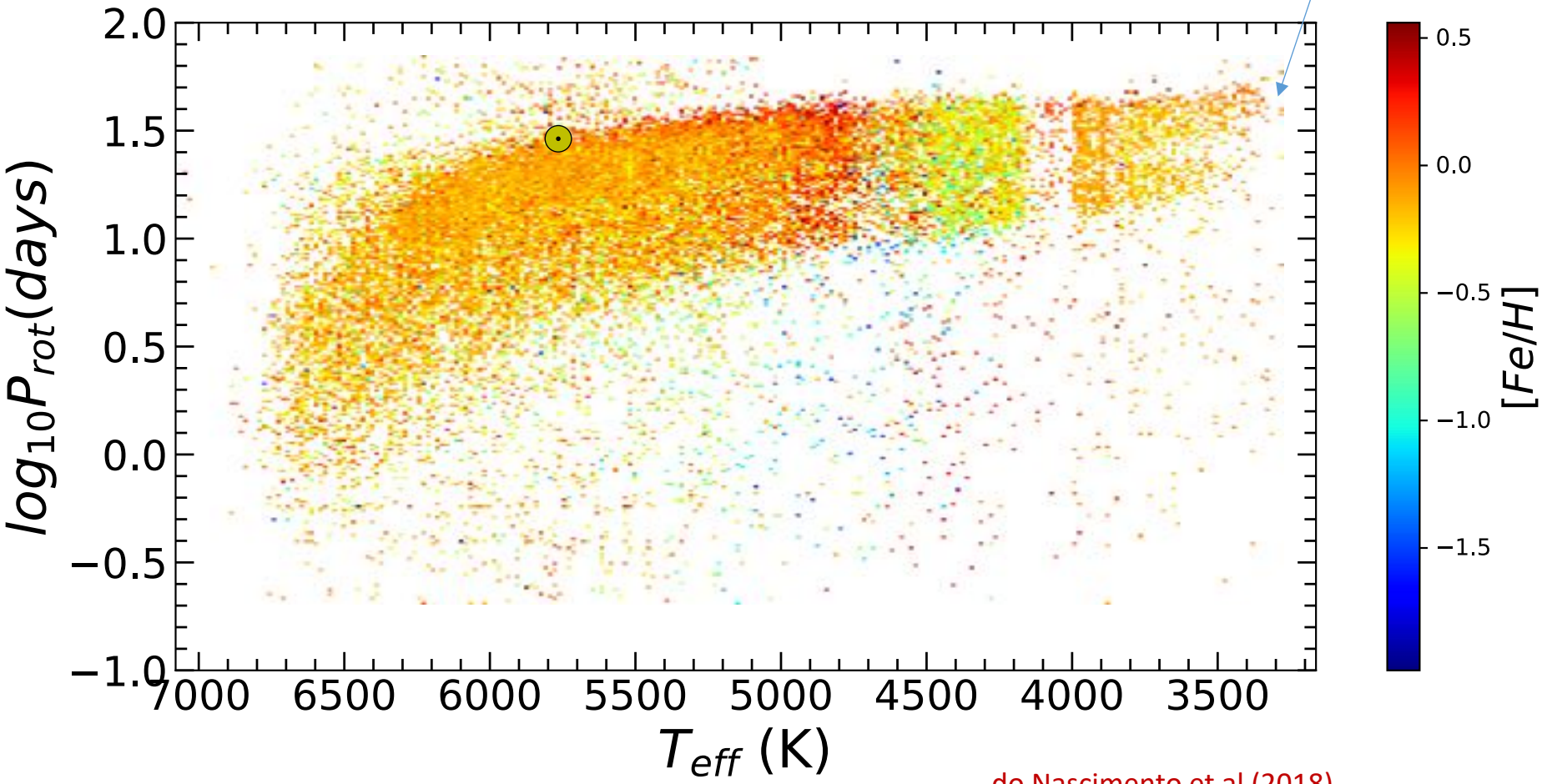
A typical Solar Twin candidate ?



A typical Solar Twin candidate from our sample to the benchmark Target list

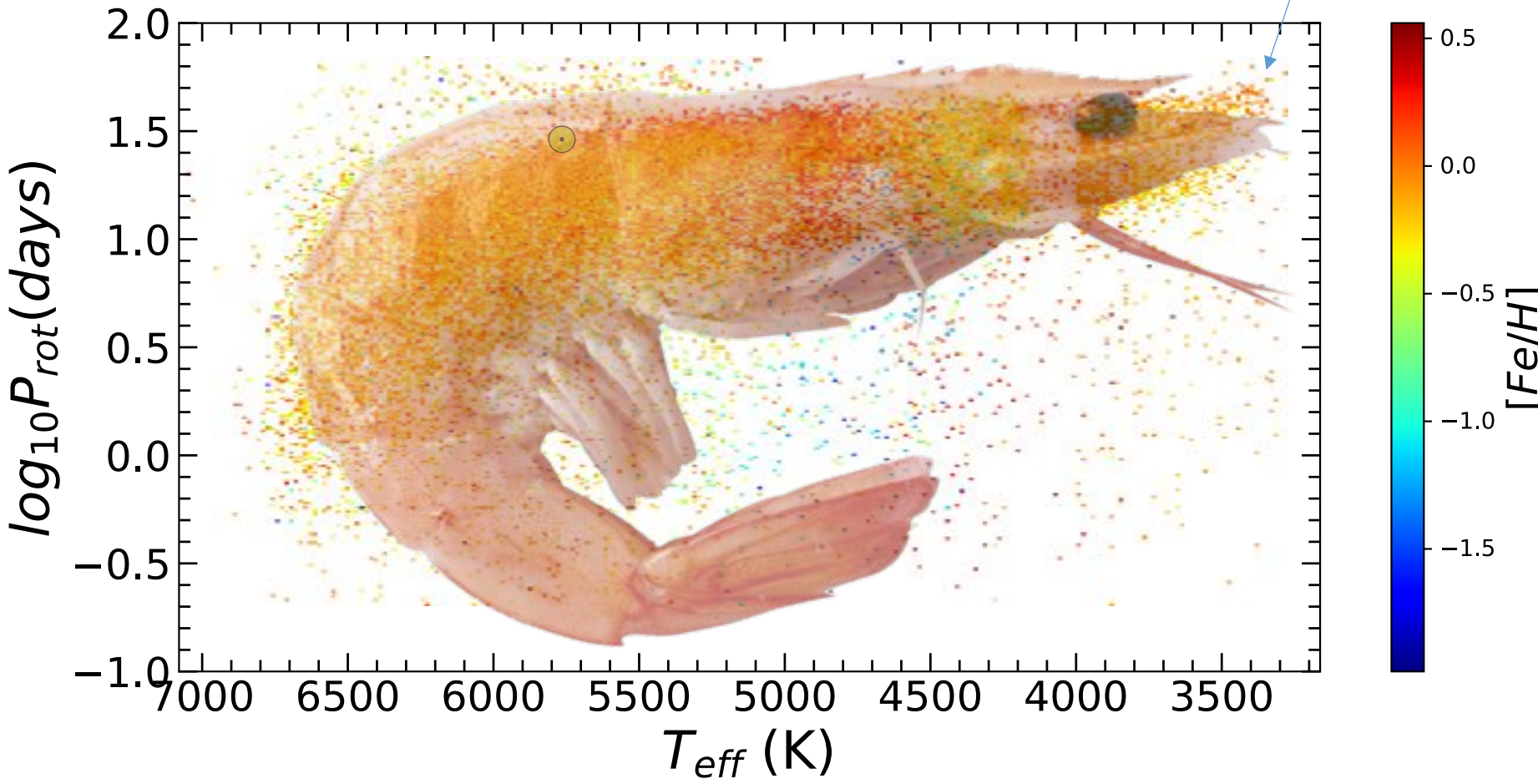


Bimodal?
Davenport et al. (2016)



do Nascimento et al (2018)

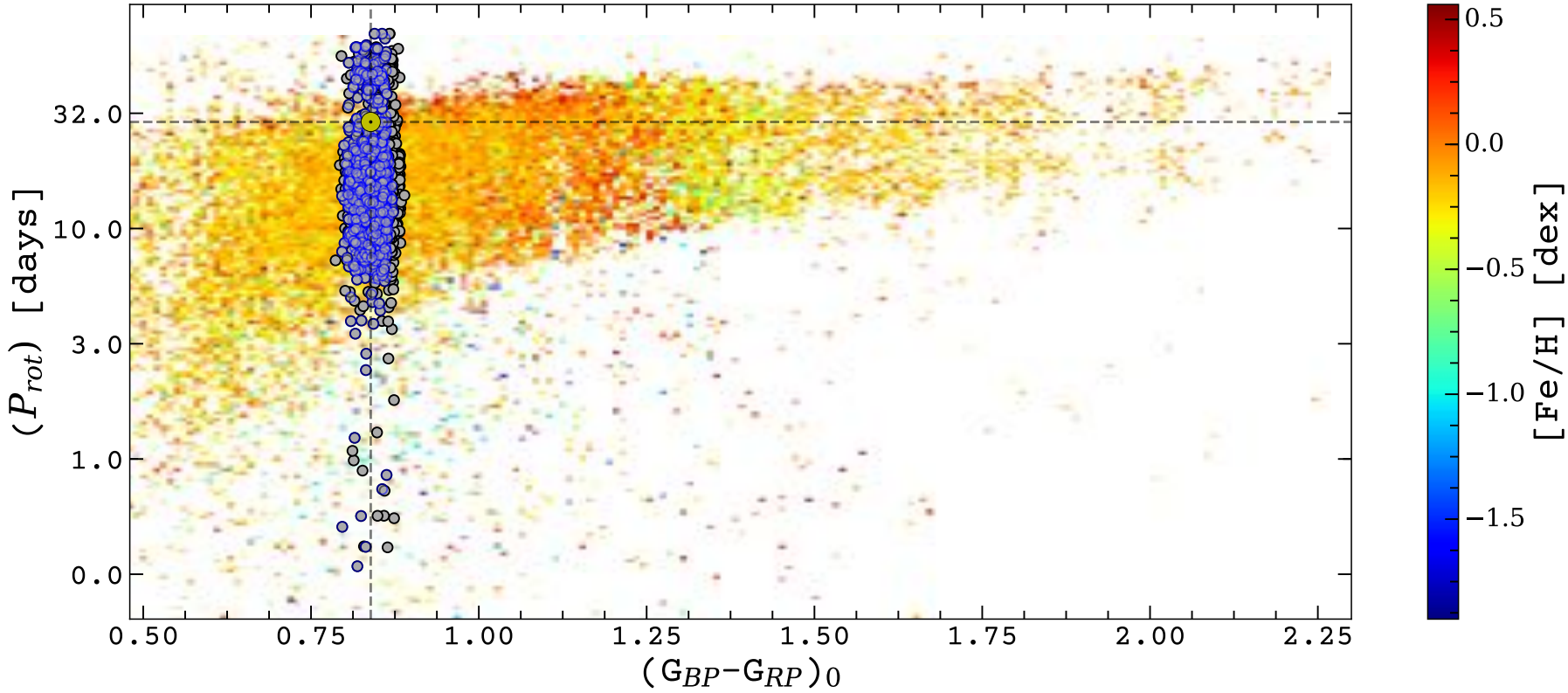
Shrimp Diagram



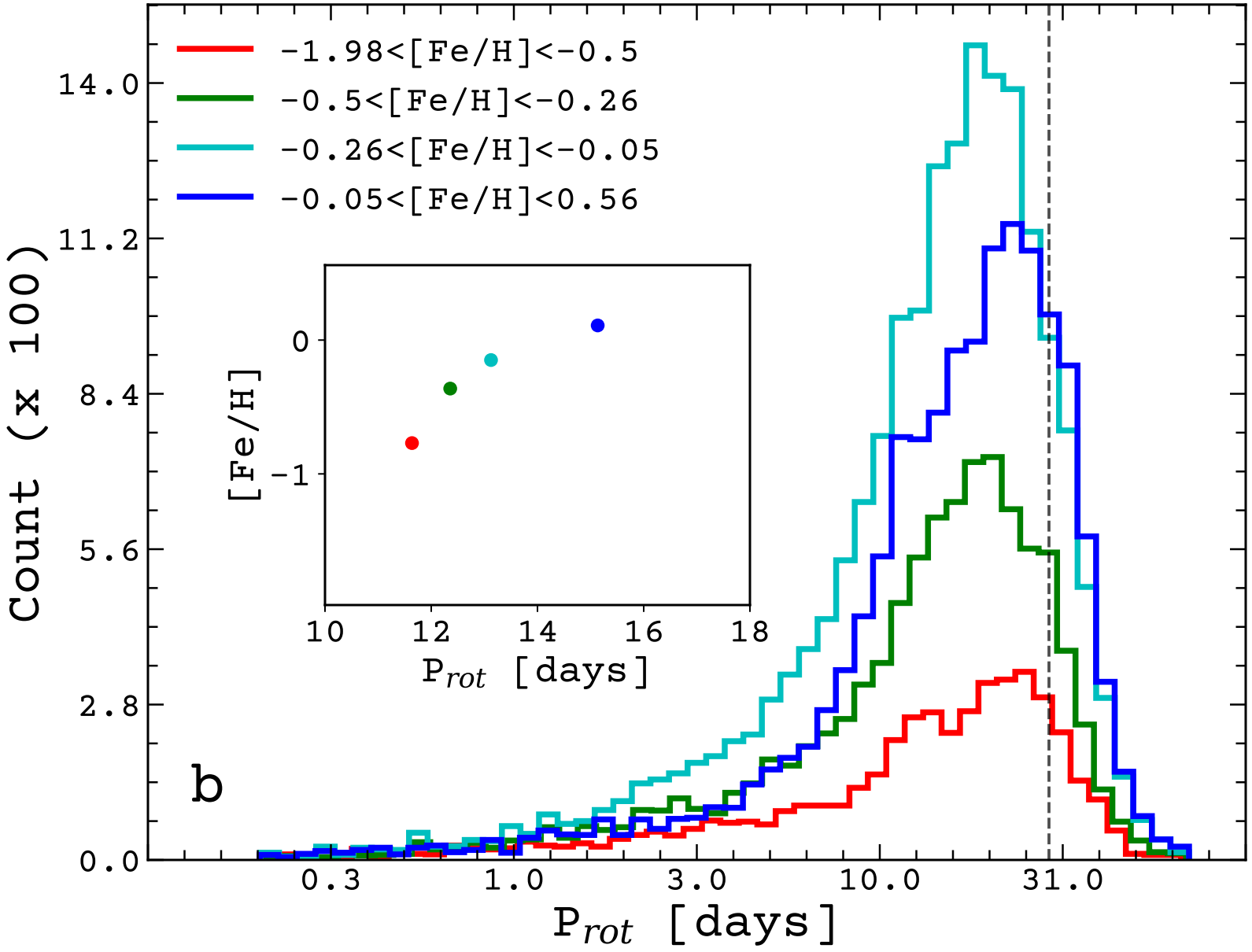
Rotation Period measurements and metallicity from 34K stars

+ GAIA DR2 + Girardi et al. tracks + Huber et al. (Metallicties)

do Nascimento et al (2018)

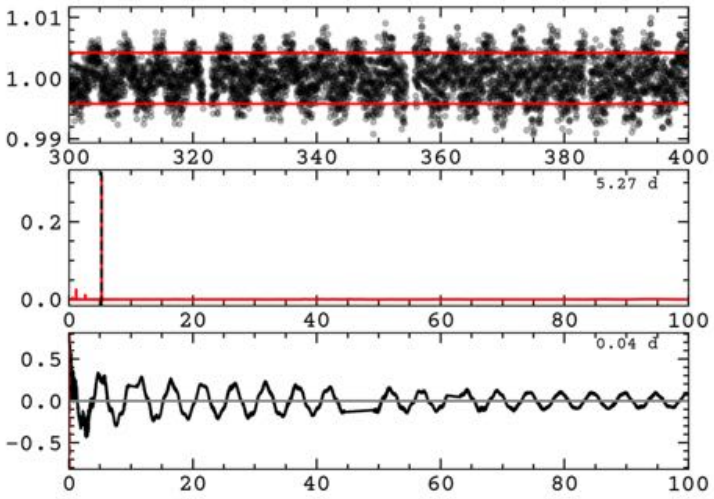


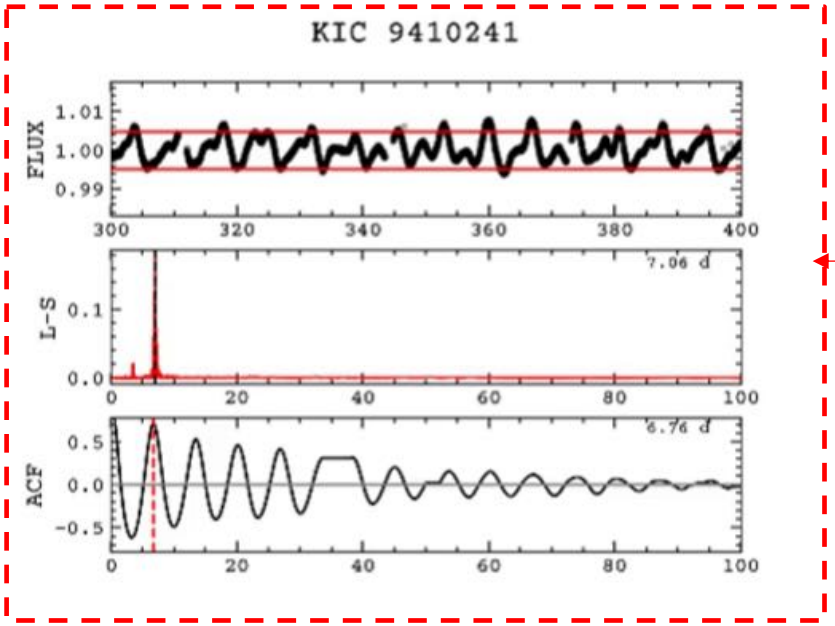
Reliable stellar rotational periods for a large sample of old stars (as old as the Sun) it is possible.



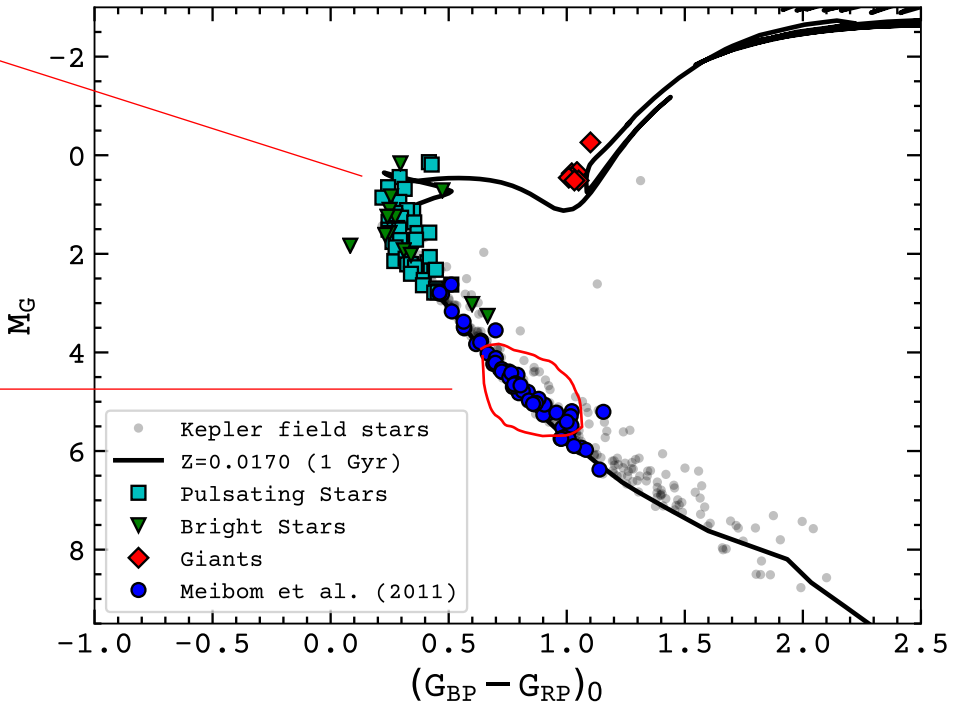
do Nascimento et al (2018)

NGC 6811 and Kepler + GAIA DR2





Nunes, do Nascimento et al. (2018)



Conclusions

- **We need a selection criteria for benchmark stars.**

Ex: rotation – activity – Age

Pre-Main-Sequence (PMS)
Main-sequence stars (MS)
Subgiants (SgB) > 35 days
Giants (?)

- Rotation Periods from 0.5 to 150 days;
- Covering a range of parameters
- KEPLER photometry activity proxy?
- Distinguishing main sequence / subgiants

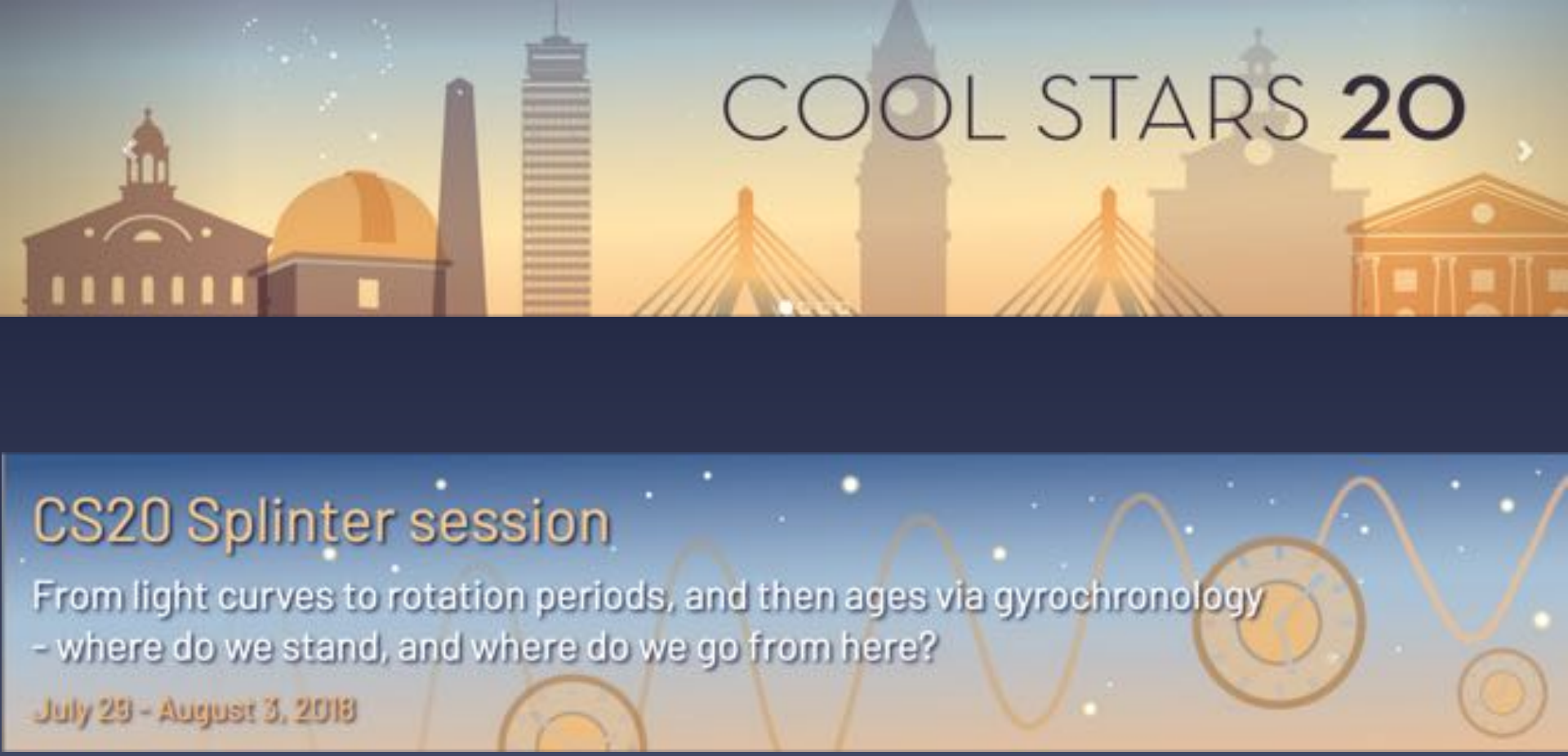
Reliable stellar rotational periods for a large sample of old stars (as old as the Sun).
it is possible?

Conclusion

- Benchmark stars according the scientific purposes and datasets possibilities
- Pick up some “golden” stars to be follow-up intensively
- Better understand physical processes on those targets (facula, spots dynamics)
- Optimize It is mandatory , as a well a connection between other PLATO Work packages
- Benchmark stars from Clusters [like NGC 6811 (1 Gyr) and M67 (4 Gyr): homogeneous population]: Gaia perspectives

Possible samples of benchmark stars

Individual targets full characterized (e.g., solar twins, e.g., 18 Sco, ν_1 Cet; CoRoT, KEPLER Asteroseismic targets, Kepler. Mount Wilson sample (HK stars) …



July 29- Aug 3 2018, Boston / Cambridge, USA

Thank you!