Nordita Winter School 2017

Physics of Planets

Do Stars Care About Planets?

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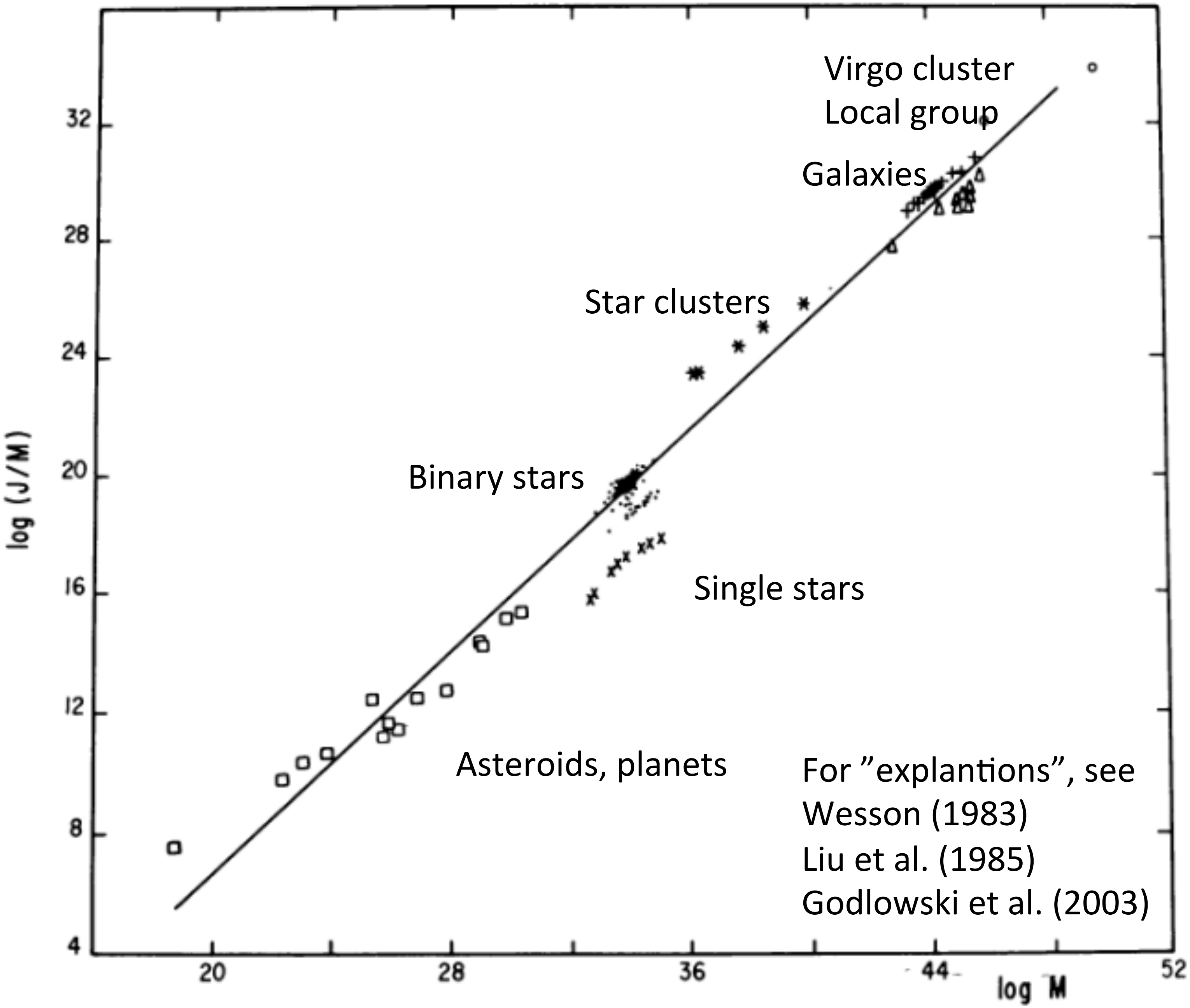
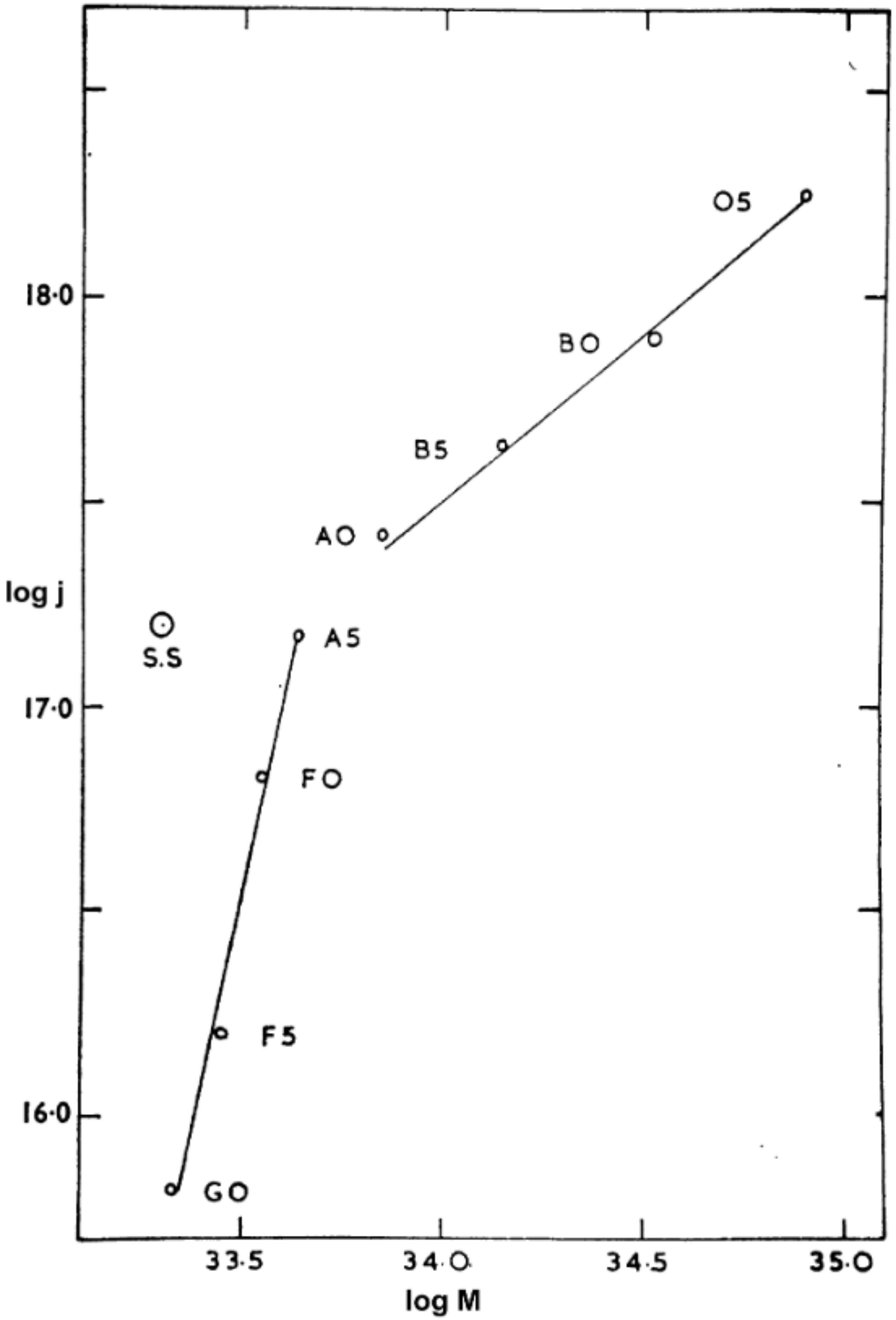
$$\textbf{Stars} \quad \underset{?}{\overset{!}{\rightleftarrows}} \quad \textbf{Planets}$$

Stars $\underset{?}{\overset{!}{\rightleftarrows}}$ Planets

- Angular momentum?
- Tidal effects?
- Chemical composition:
  - by fractionation in pp disk?
  - by engulfing of planets?

Brosche (1963, 1989), Carrasco et al. (1982)





”Break” around 2 Msun;
~ where surface convection sets in.

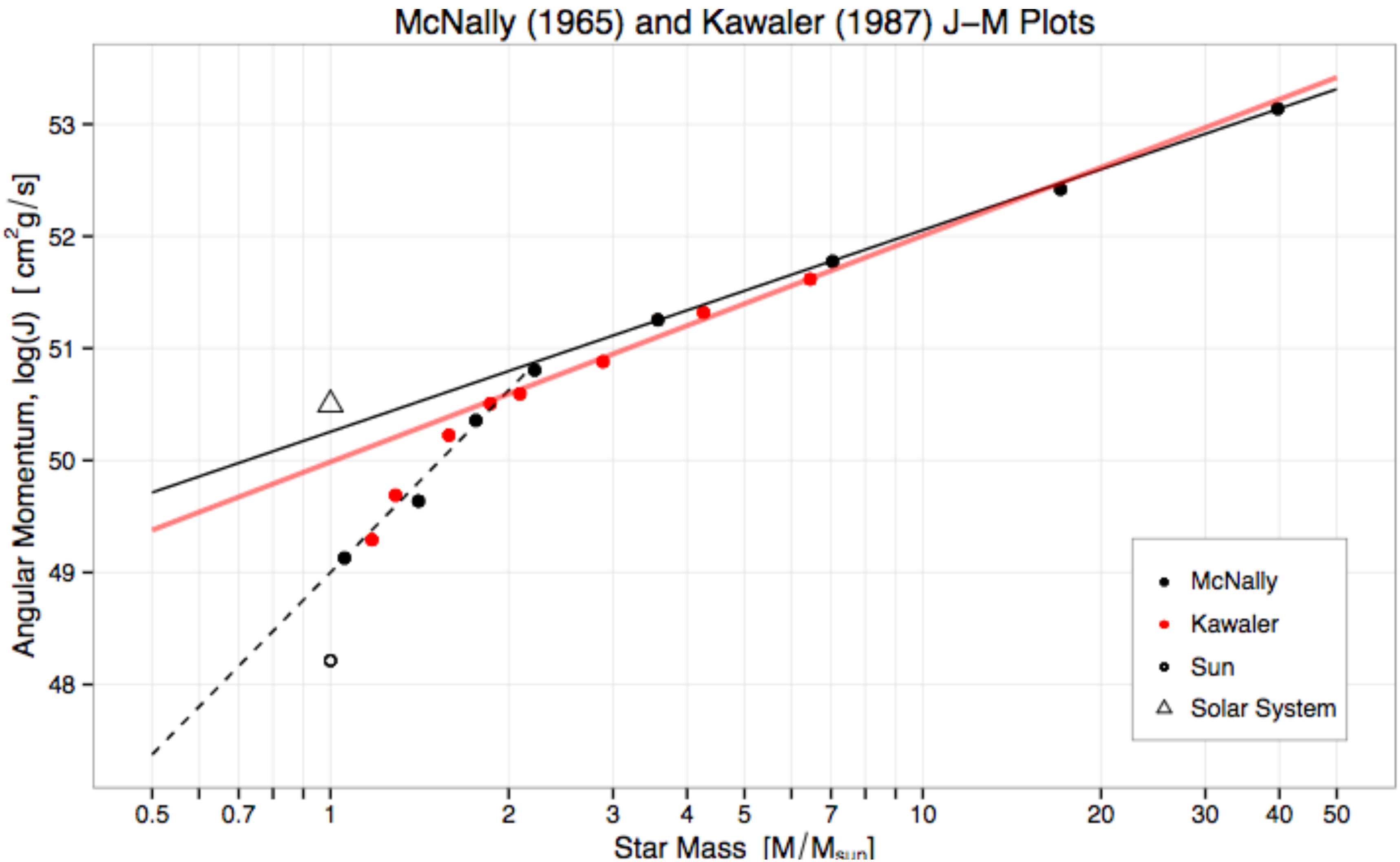
Angular momentum lost by
– magnetic braking/stellar winds

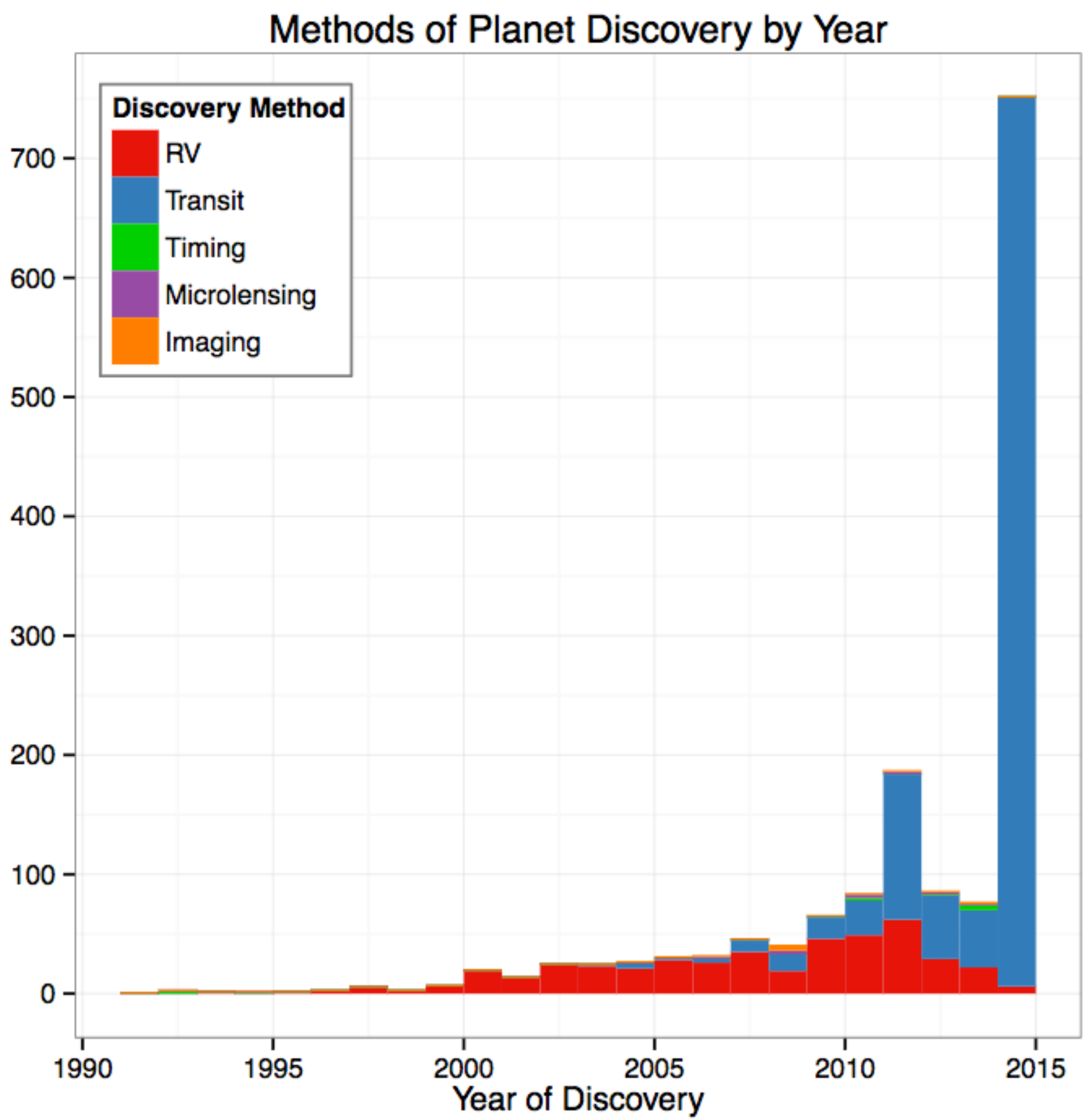
McNally (1965): coupled to planetary formation?

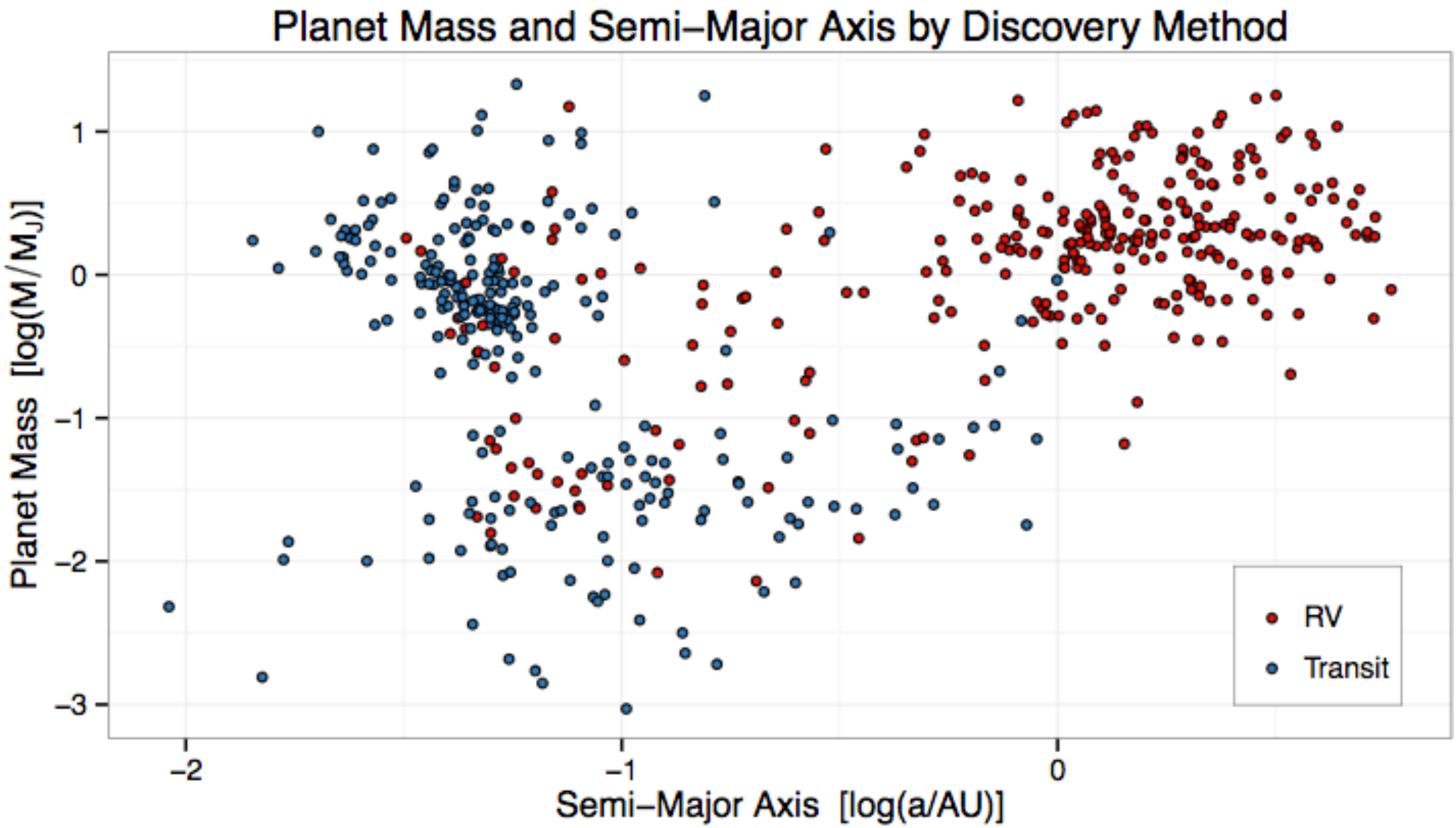
Table 1.1. Angular Momentum Distribution of the Solar System

Body	Mass [10^{27}g]	a [AU]	e	$J_{\rm body}$ [g cm^2/s]	$J_{\rm body}/J_{\rm total}$
Sun	1989100	—	—	$1.69{\cdot}10^{48}$	0.005
Mercury	0.3302	0.3871	0.2056	$8.96{\cdot}10^{45}$	<0.001
Venus	4.8685	0.7233	0.0068	$1.85{\cdot}10^{47}$	<0.001
Earth	5.9736	1.0000	0.0167	$2.66{\cdot}10^{47}$	<0.001
Mars	0.64185	1.5237	0.0934	$3.52{\cdot}10^{46}$	<0.001
Jupiter	1898.6	5.2028	0.0485	$1.93{\cdot}10^{50}$	0.612
Saturn	568.46	9.5428	0.0555	$7.81{\cdot}10^{49}$	0.248
Uranus	86.832	19.1921	0.0463	$1.69{\cdot}10^{49}$	0.054
Neptune	102.43	30.0689	0.0090	$2.50{\cdot}10^{49}$	0.079
Planets total	2668.1			$3.13{\cdot}10^{50}$	0.995
System total	1991800			$3.15{\cdot}10^{50}$	1.000

This and most of the following 11 frames are adopted from S. A. Irwin, thesis 2015,
https://repository.lib.fit.edu/bitstream/handle/11141/684/IRWIN-DISSERTATION.pdf?sequence=1


McNally (1965) and Kawaler (1987) J–M Plots
Angular Momentum, log(J) [cm²g/s]
53
52
51
50
49
48
0.5
0.7
1
2
3
4
5
7
10
20
30
40
50
Star Mass [M/Msun]
McNally
Kawaler
Sun
Solar System


Methods of Planet Discovery by Year
Discovery Method
RV
Transit
Timing
Microlensing
Imaging
700
600
500
400
300
200
100
0
1990
1995
2000
2005
2010
2015
Year of Discovery



Note: Biases!

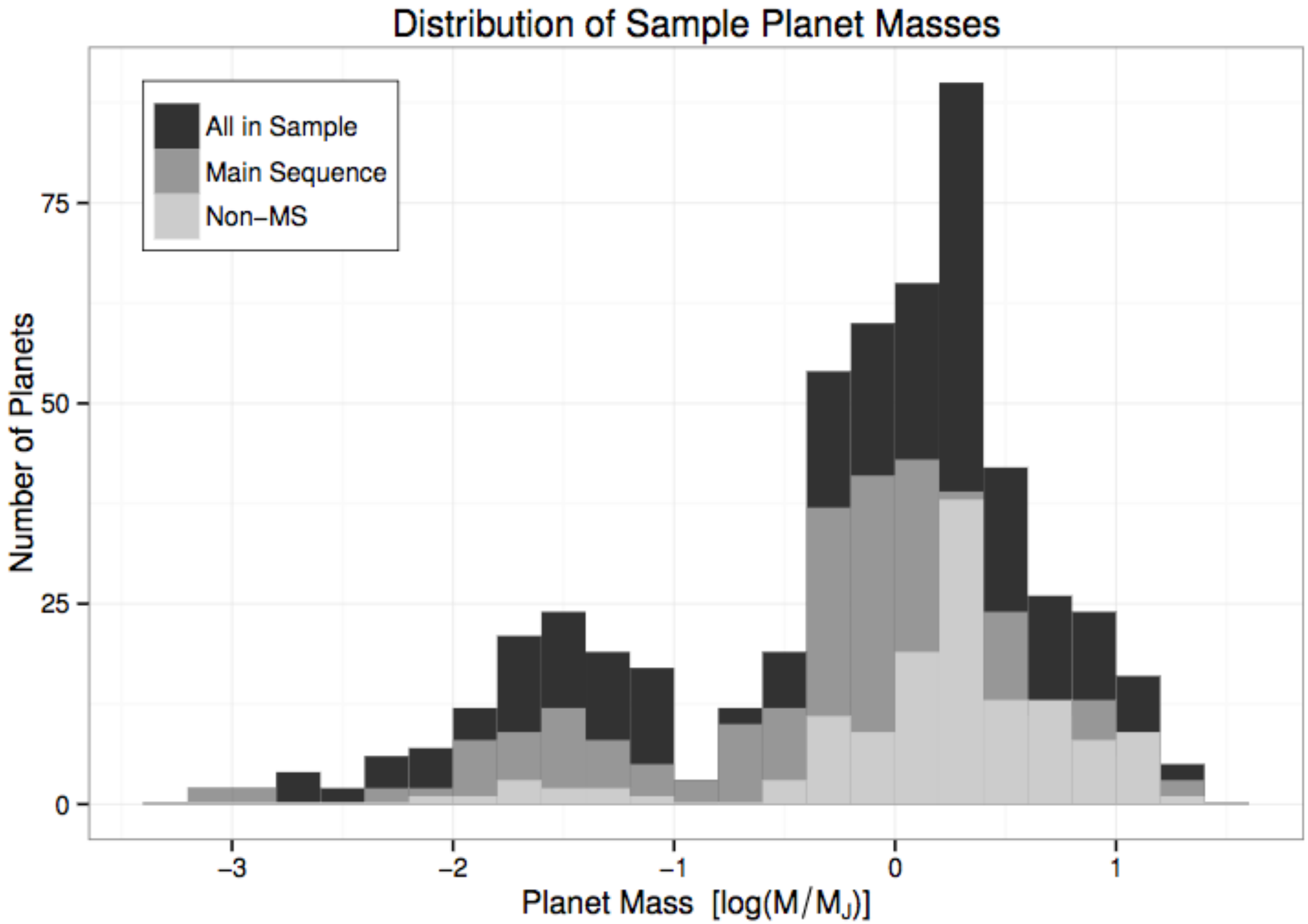
In discovery, in rotation data for stars, in orbital elements for planets, …

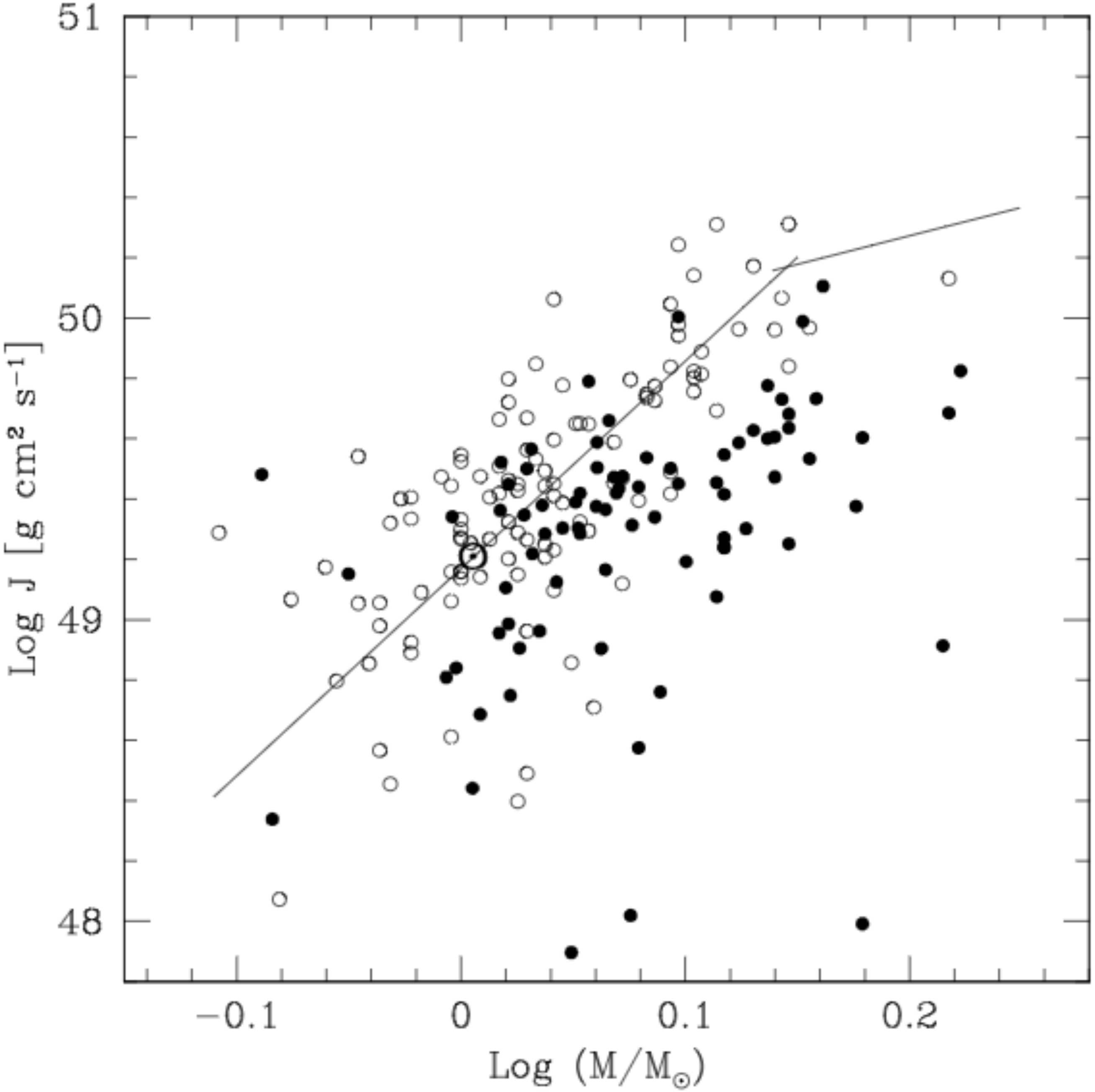
Uncertainties in converting $v\,\sin i$ *and* R *to* J*:*

M*, moment of inertia, interior rotation*

Study by S. A. Irwin (2015)

Sample of 426 host stars, 532 planets



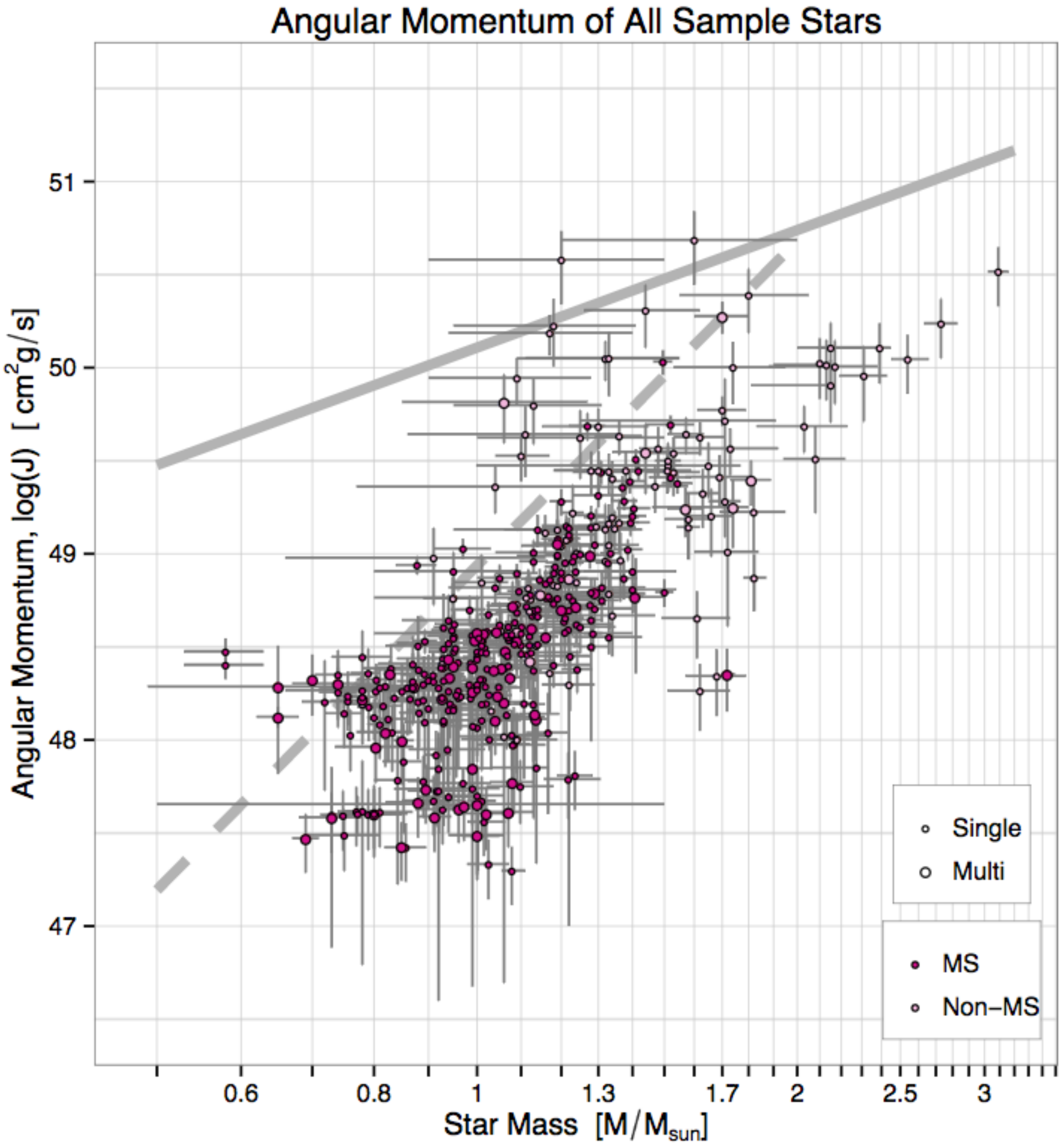


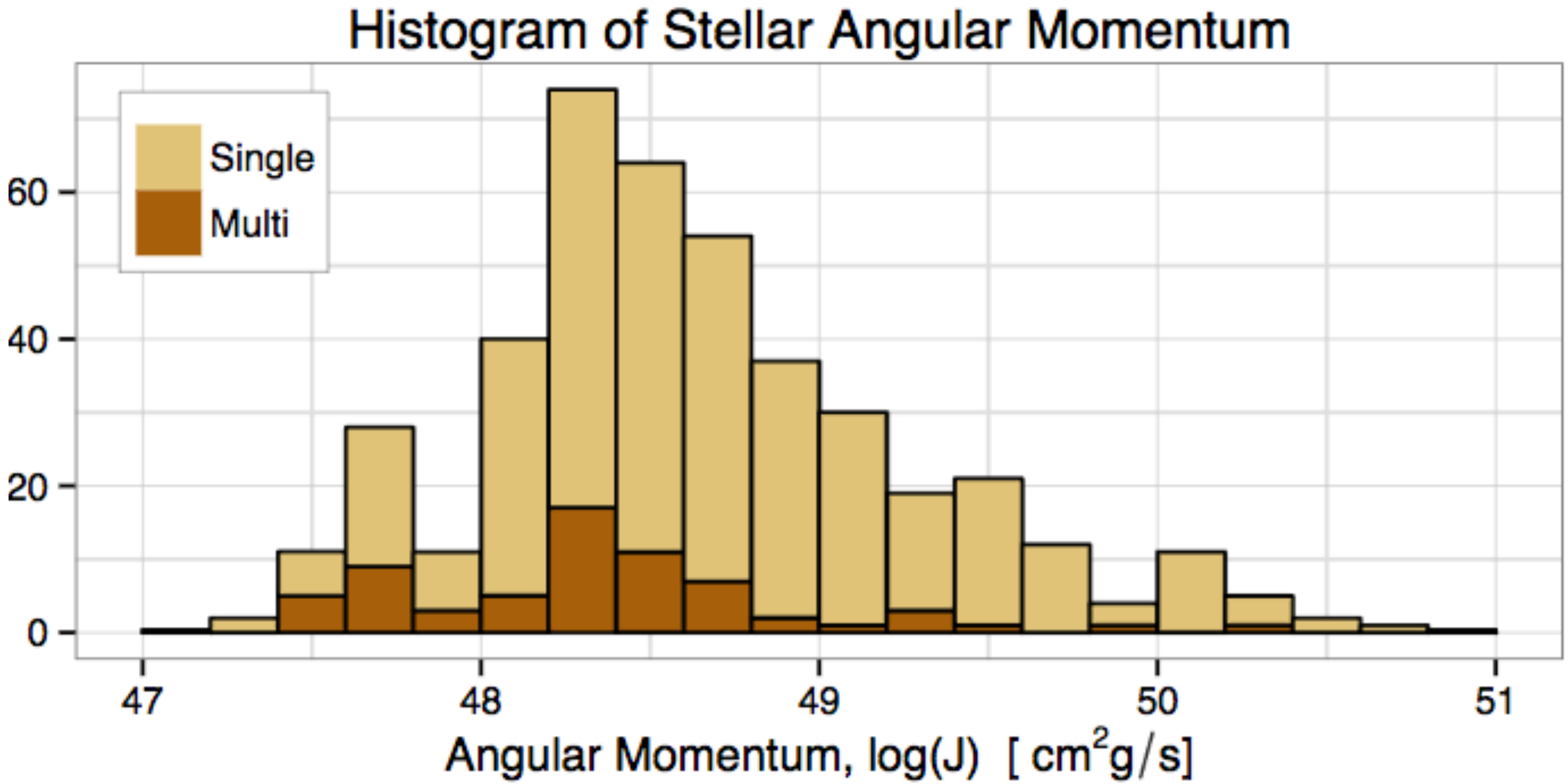
Alves (2010):

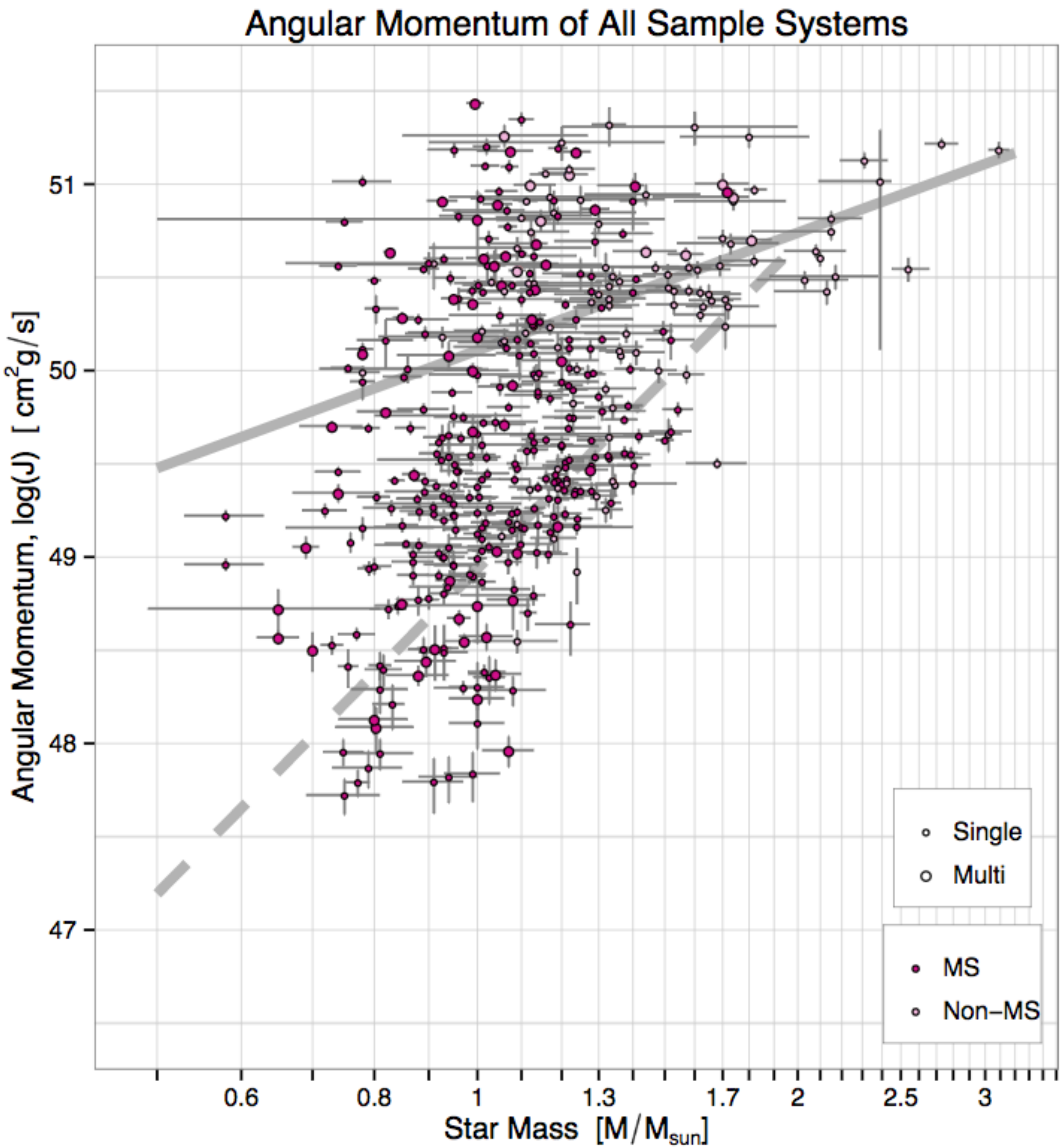
Open: stars with planets (RV-methpd)

Filled: stars with no detected planets

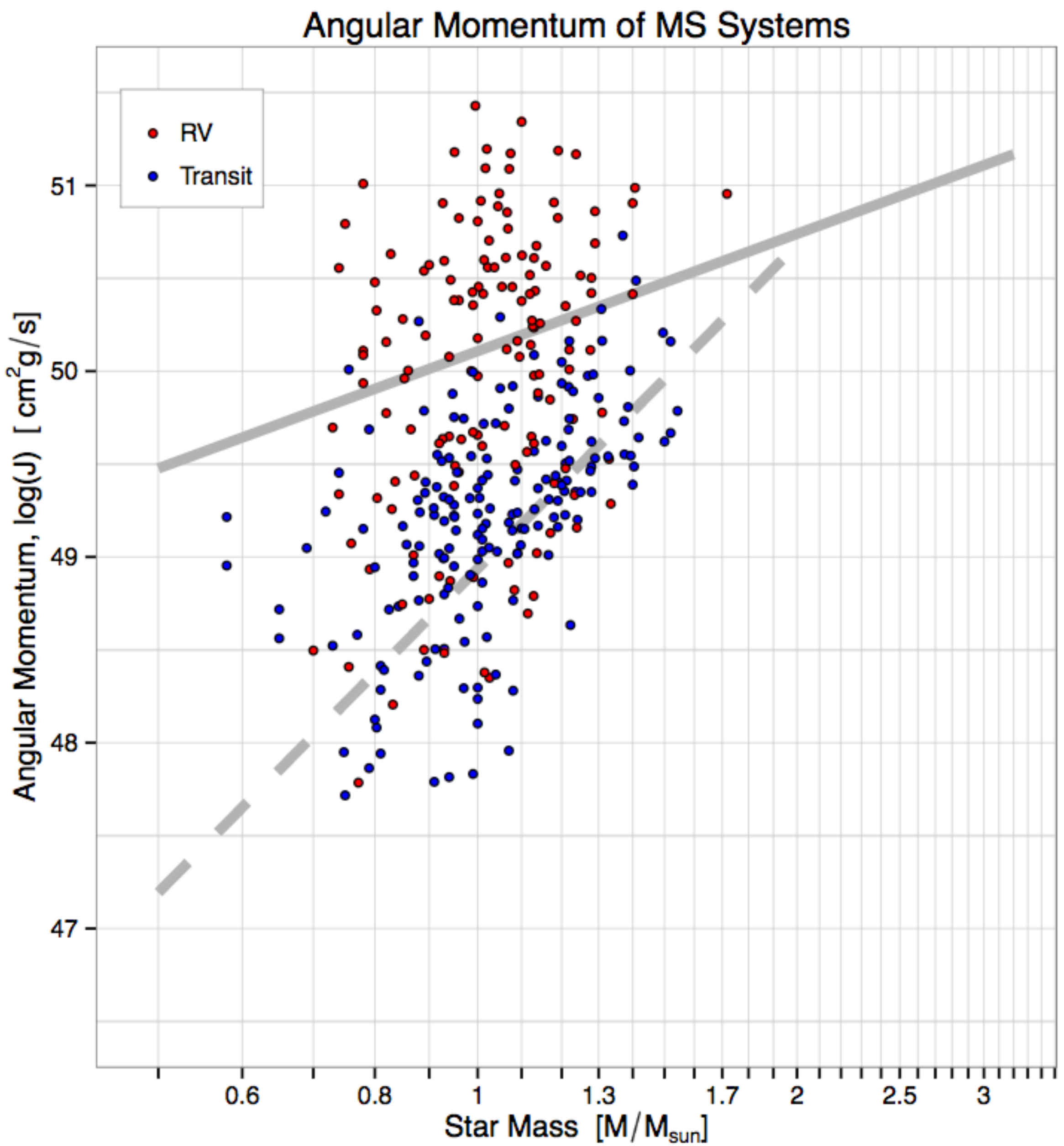
See also Paz-Chinchón et al. (2015), (transit method)


Angular Momentum of All Sample Stars
Angular Momentum, log(J) [cm2g/s]
Star Mass [M/Msun]
51
50
49
48
47
0.6
0.8
1
1.3
1.7
2
2.5
3
Single
Multi
MS
Non−MS


Histogram of Stellar Angular Momentum
Single
Multi
60
40
20
0
47
48
49
50
51
Angular Momentum, log(J) [cm^{2}g/s]

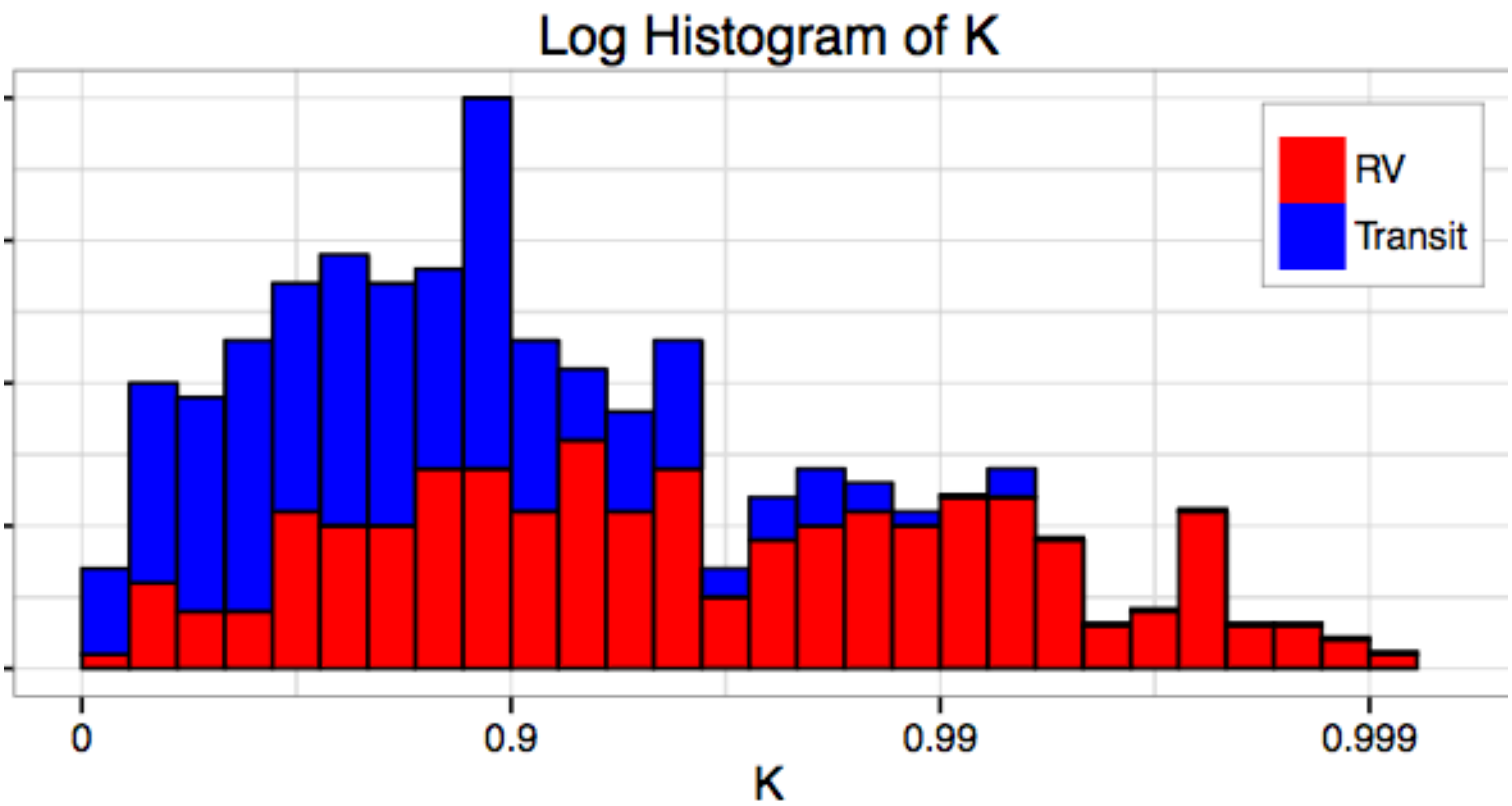


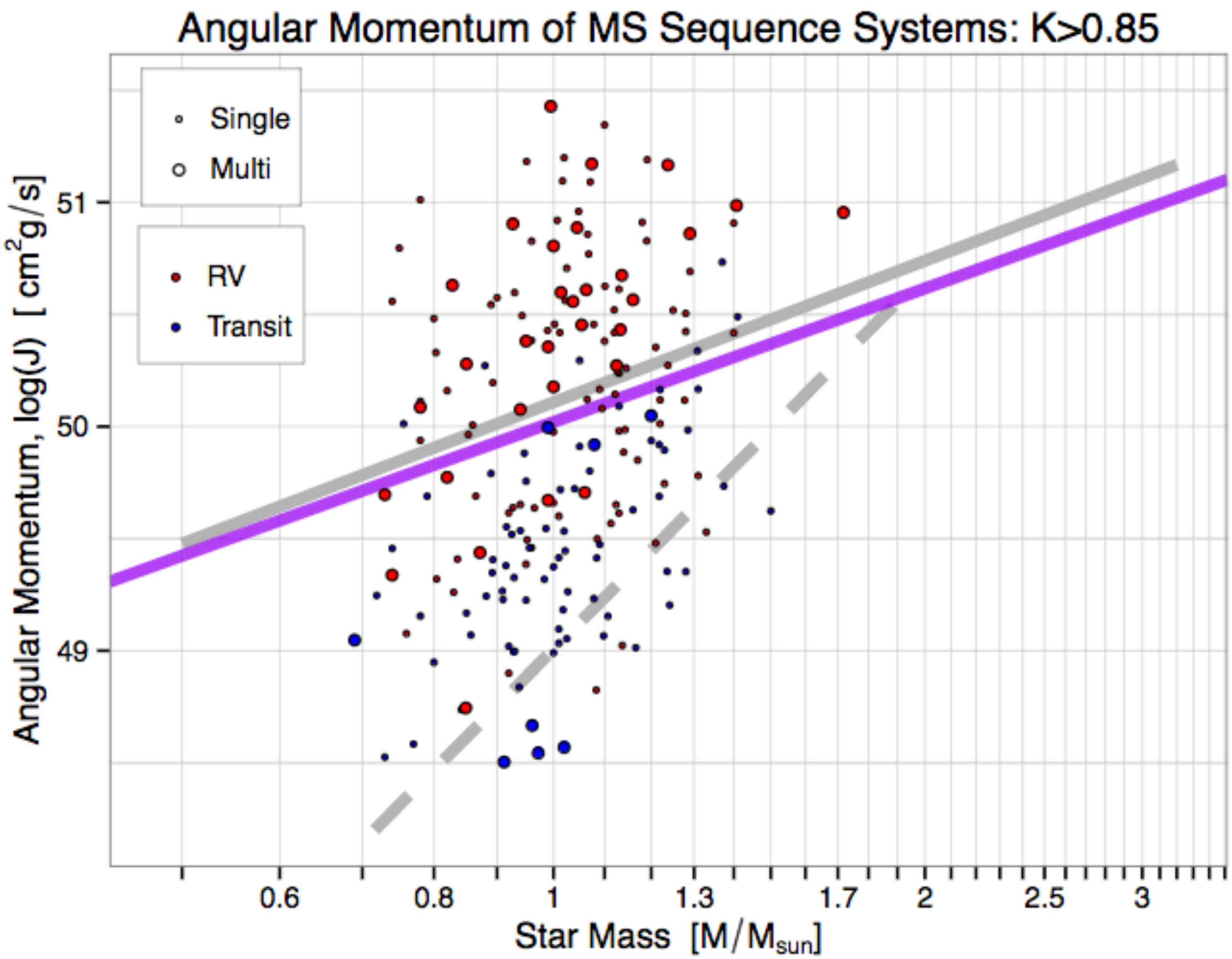
Angular Momentum of All Sample Systems
Angular Momentum, log(J) [cm^{2}g/s]
51
50
49
48
47
Star Mass [M/M$_{sun}$]
0.6
0.8
1
1.3
1.7
2
2.5
3
Single
Multi
MS
Non−MS



Angular Momentum of MS Systems
RV
Transit
Angular Momentum, log(J) [cm^{2}g/s]
51
50
49
48
47
0.6
0.8
1
1.3
1.7
2
2.5
3
Star Mass [M/M$_{sun}$]

K: fraction of J_{syst} in planet orbits




Angular Momentum of MS Sequence Systems: K>0.85
Single
Multi
RV
Transit
Angular Momentum, log(J) [cm2g/s]
51
50
49
0.6
0.8
1
1.3
1.7
2
2.5
3
Star Mass [M/Msun]

Conclusions on angular momentum

- No clear evidence that planetary hosts are more braked than stars with no (known) planets
- No clear evidence that stars with multiple planetary systems are more braked than stars with only one (known) planet
- Some tendencies (in many but not all cases) that planets with a great fraction of the total angular momentum of the system may have taken up much of the original momentum (?)
- Much remains to do!

Tidal effects?

- Tidal acceleration: $a_t = 2\ GmR/r^3 = 4\ 10^{-10}$ m s^{-2}
- Centrifugal acc: a_c(equator) = $M\ \omega^2\ R = 6\ 10^{-3}$ m s^{-2}

  (i.e. $2\ 10^{-5}$ of surface gravity on the Sun)

  a_t(Jupiter) / a_c = $4\ 10^{-10}$ m s^{-2} / $6\ 10^{-3}$ m s^{-2} ~ 10^{-7}.

Yet, Grandpierre (1996): Planetary tides -> 11 year cycle! See also Seker (2013): no empirical evidence for sunspot birth "under planets", although time delay from tachocline to surface.

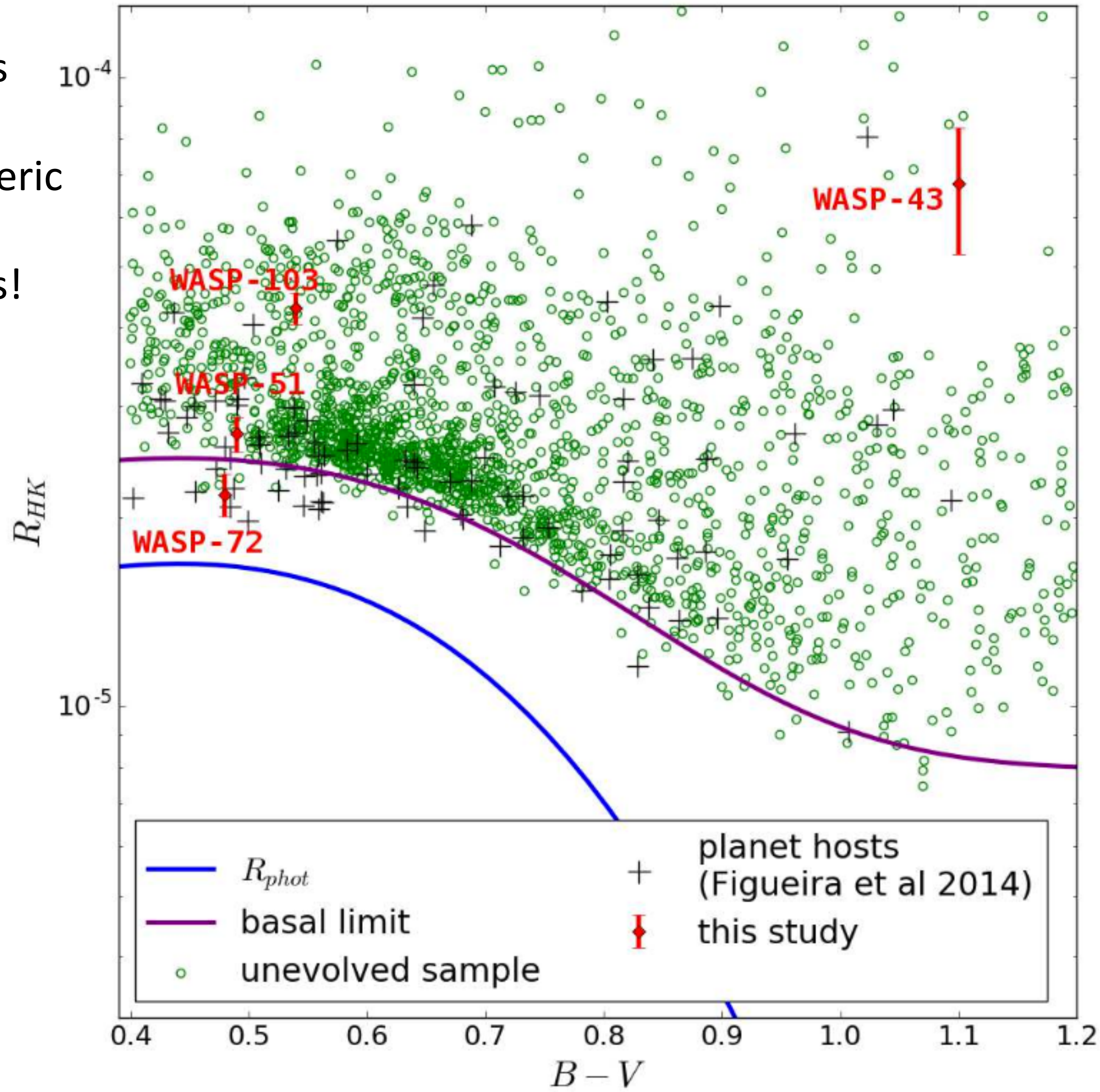
But, for hot Jupiters, e.g. 51 Peg, $M_{planet} = 0.52\ M_J$, a = 0.052; a_t = $5\ 10^{-3}$ m s^{-2}. Study activity of such systems.

Staab et al. (2016), arXiv:1612.01739

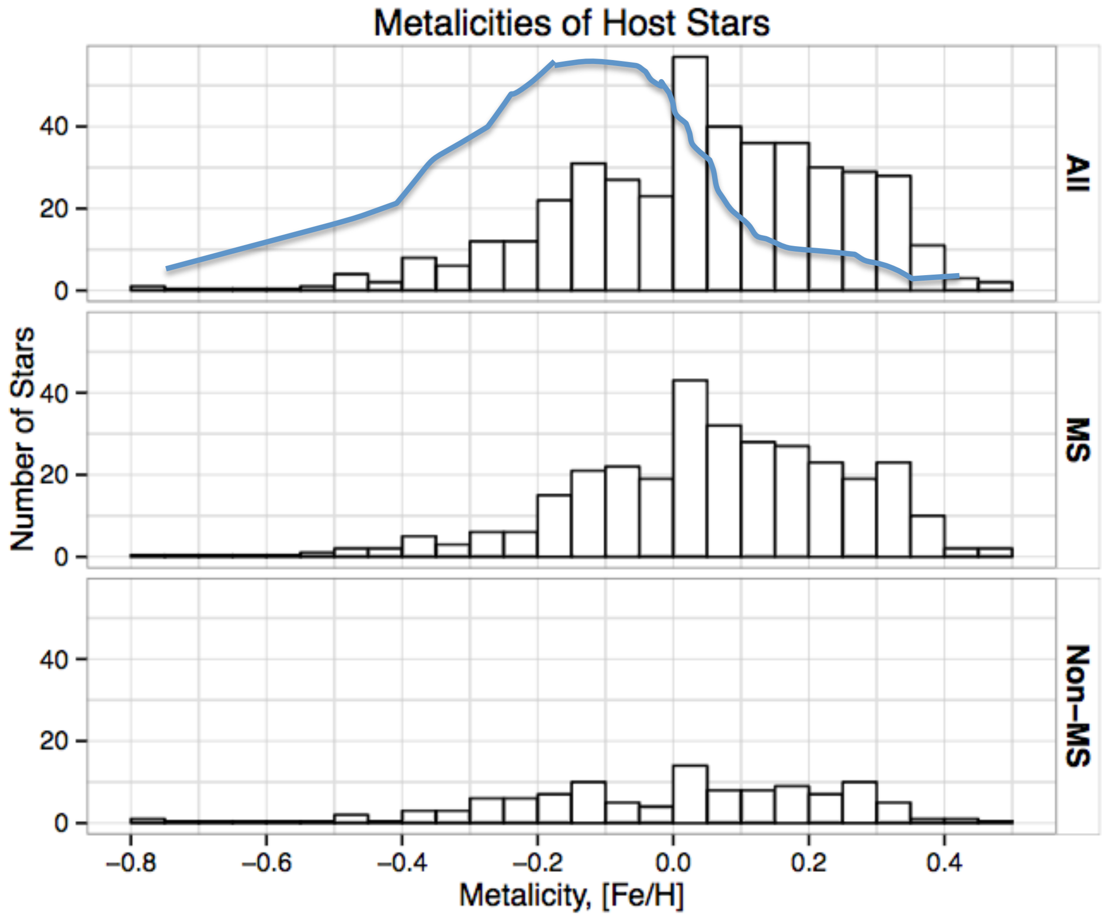
4 systems with hot jupiters

RHK measures chromospheric activity.
Strong and weak measures!

Activity *and* veiling due to planet evaporation?



Chemical composition



Metalicity matters
Gonzalez (1997),
Fischer & Valenti (2005),
Santos (2004)
for nearby "jupiters".

Smaller effects for"neptunes",
Sousa (2008)
Wang & Fischer (2015), …

From application for observing time by Meléndez et al. (2007) at Magellan telescopes

ustralian Gemini Office
vww.ausgo.anu.edu.au

ATAC Reference:
Date Stamp:

Names and Institutions of Applicants — **Possible Observer?**

Name	Possible Observer?
Jorge Meléndez, ANU	Yes
Martin Asplund, ANU	No
David Yong, ANU	Yes
Bengt Gustafsson, Uppsala	No

Principal Contact: Jorge Meléndez
Telephone: +61 (02) 61250253
Email: jorge@mso.anu.edu.au

Postal Address:
Mt Stromlo Observatory, Cotter Road, Weston Creek, ACT 2611, Australia

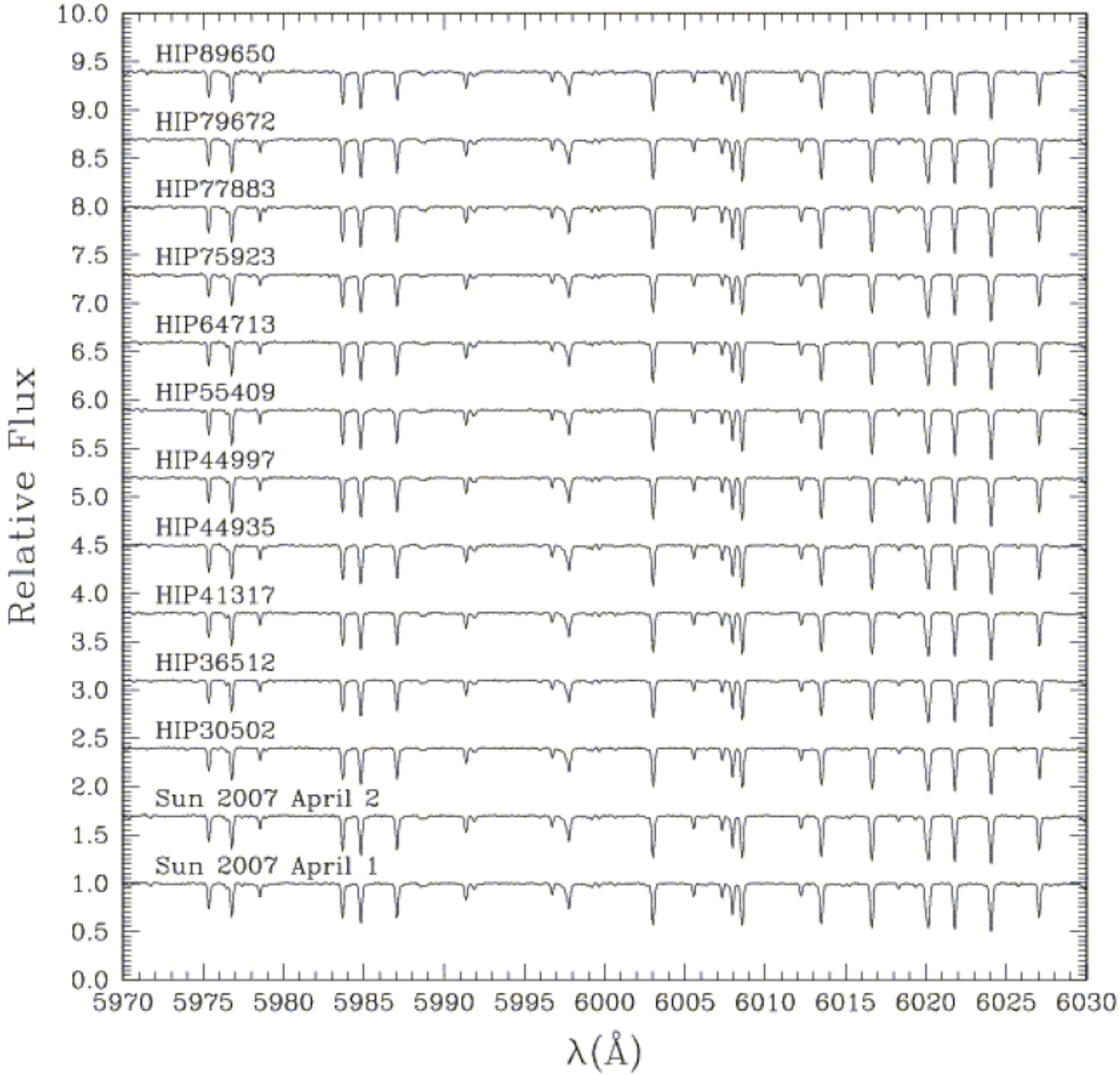
Are the observations required for the completion of a student's thesis? No
Name of Student(s):
Name of Supervisor(s):

Project Title: The Fundamental Blocks of Life in Solar Twins and Planet-hosting Stars

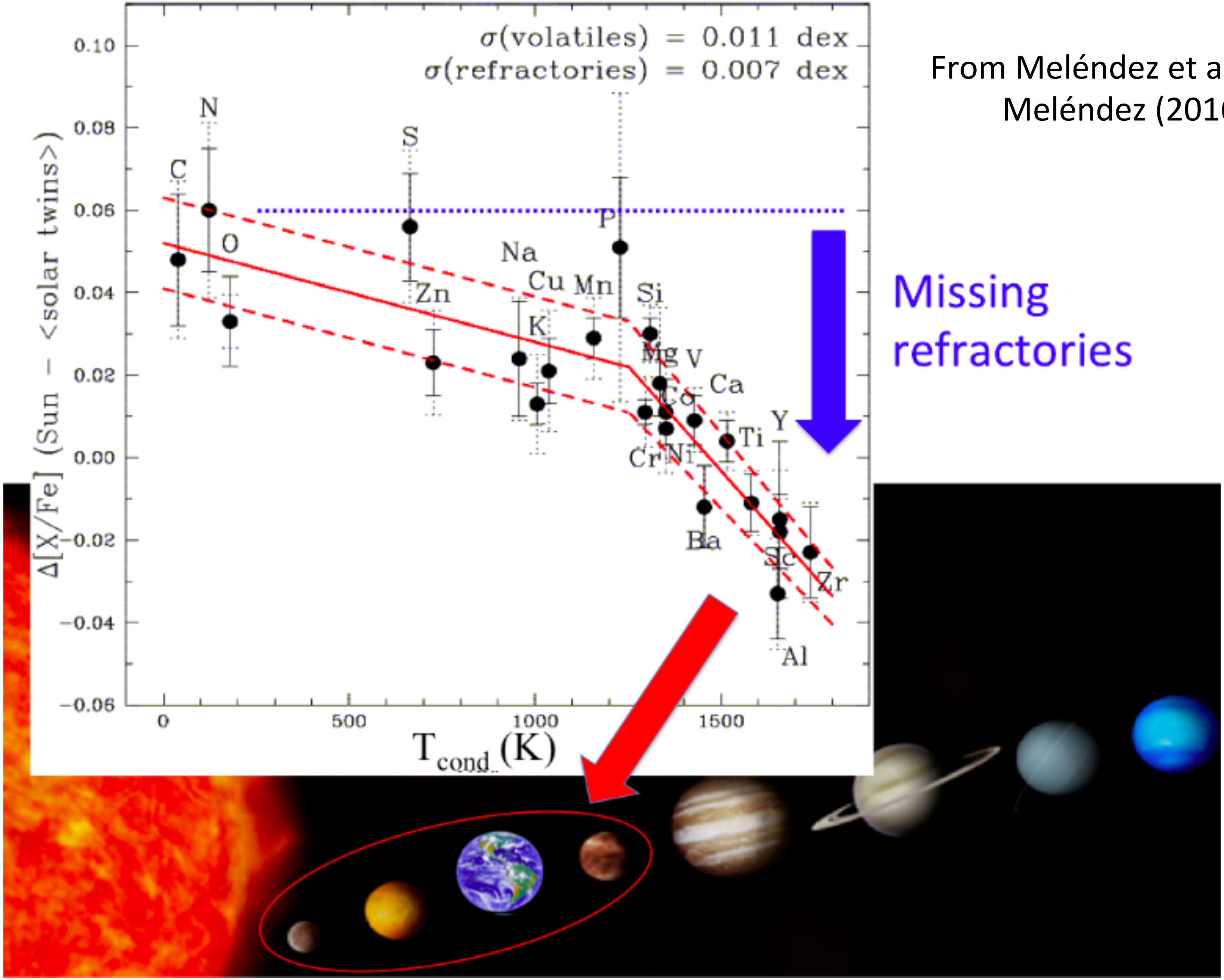
Summary of Scientific Objectives:

The biogenic elements H, C, N, O, S, and P are the essential ingredients for life as we know it. We pro
to undertake the first observational survey of biogenic elements in solar twins and in stars with planets employing
MIKE spectrograph at the Clay telescope. Clay+MIKE are the ideal combination providing high S/N and high spe

Note: The motivation was not related to the existence to planets but to the existence of life.
An example of how interesting science may emerge from very questionable initialmotivations.



From Meléndez, Asplund, Gustafsson & Young (2009)



From Meléndez et al. (2009), Meléndez (2016)

”Planet formation fractionation” but

- Convection zone deep until about 30 Myr
- Life time for ppn gas disks < 10 Myr

  - *Episodic accretion (Baraffe & Chabrier 2009) would shorten this considerably*

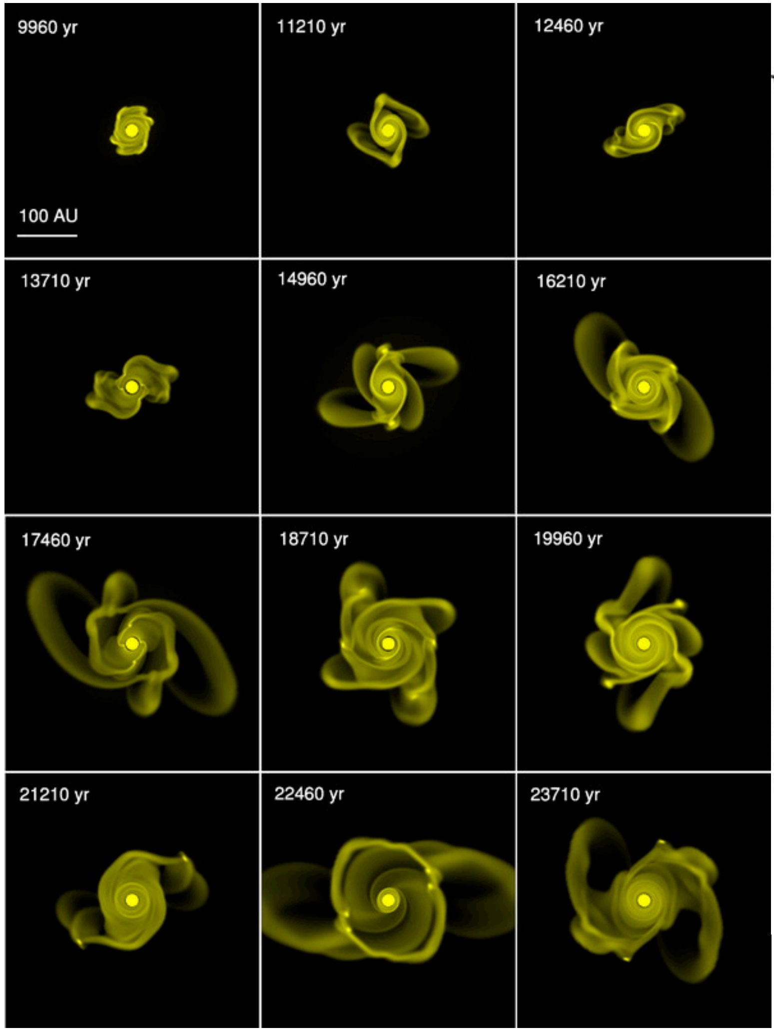
  - *Selection effects (Pfaltzner et al. 2014, Ribas et al. 2015) may prolong this*

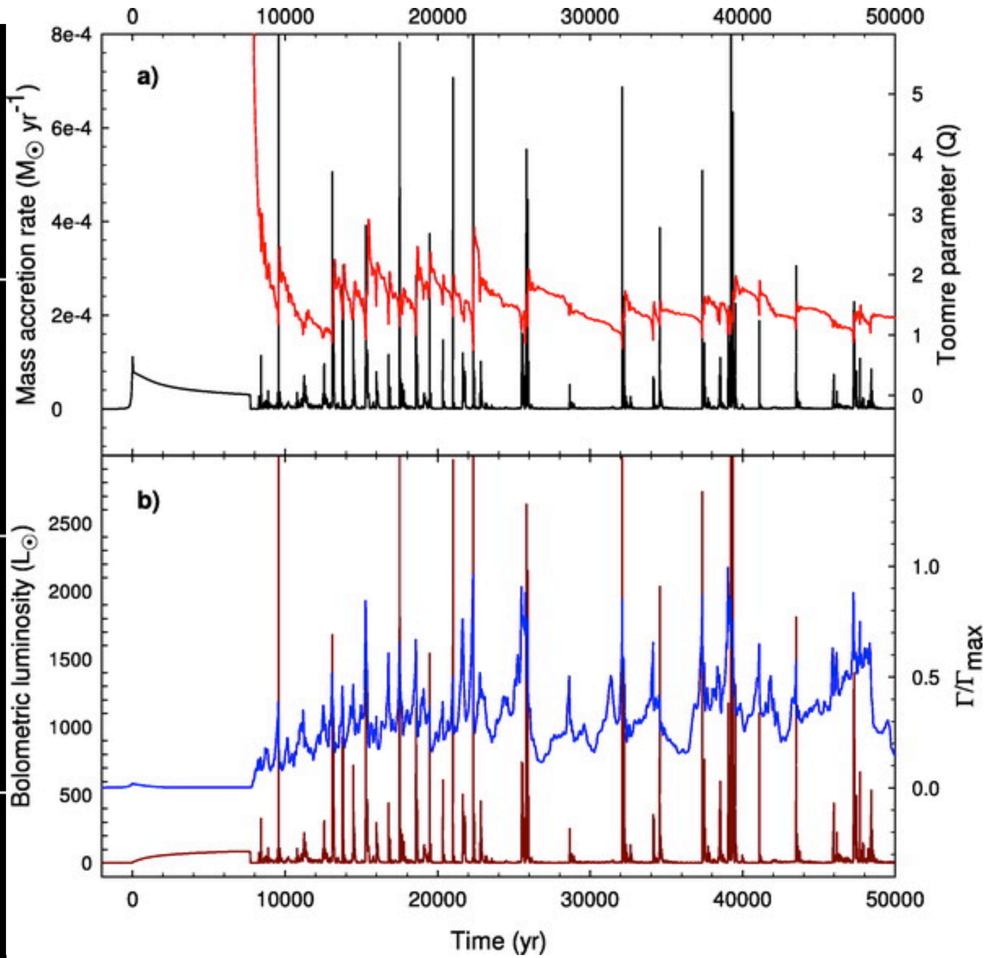
Alternatives:

- Galactic chemical evolution + solar orbital diffusion
- Dust cleansing of pre-solar cloud by bright stars

Maybe shallow convection due to episodic accretion?

Vorobyov & Basu (2005, 2015): Episodic accretion bursts





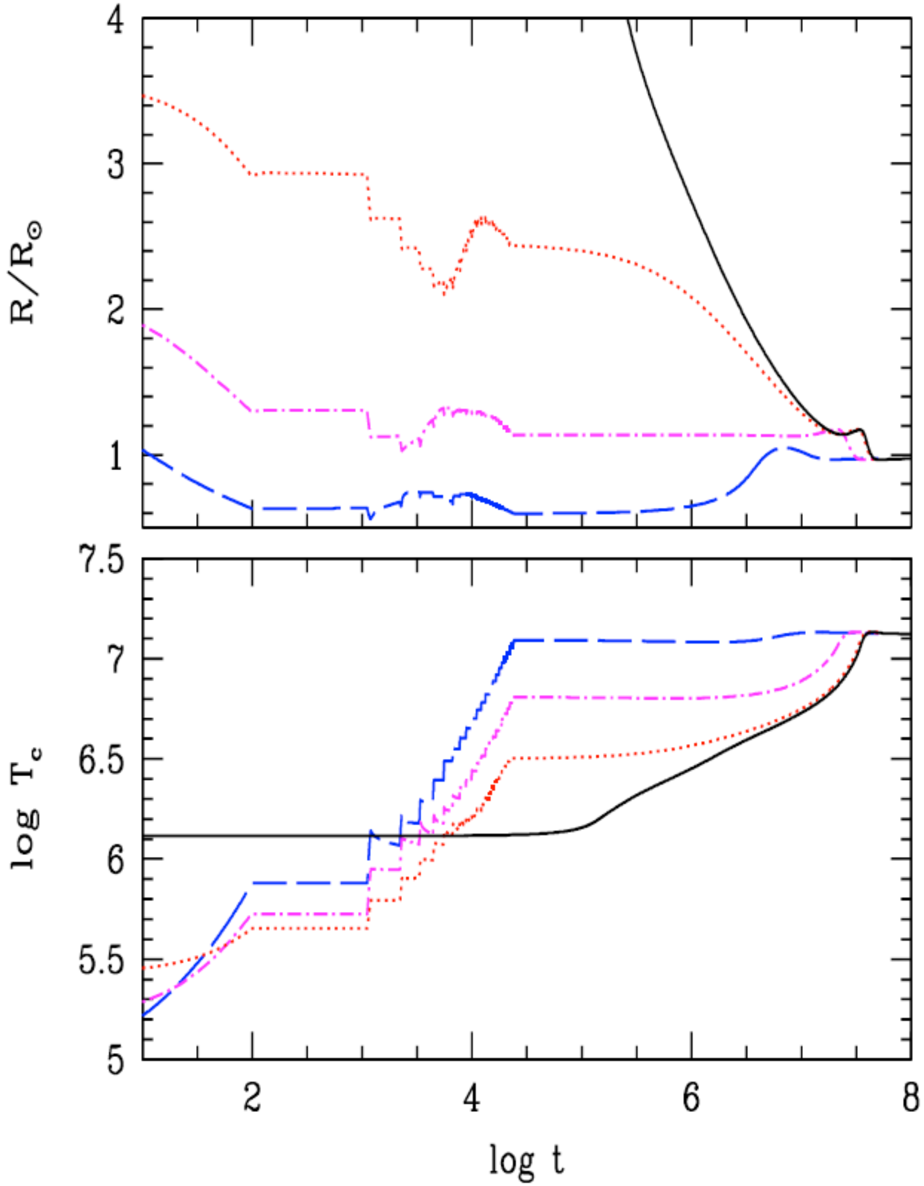
From Baraffe & Chabrier (2010)

cf. FU Orionis objects

Baraffe & Chabrier (2010)

Spherical symmetric PMS models with accretion episodes

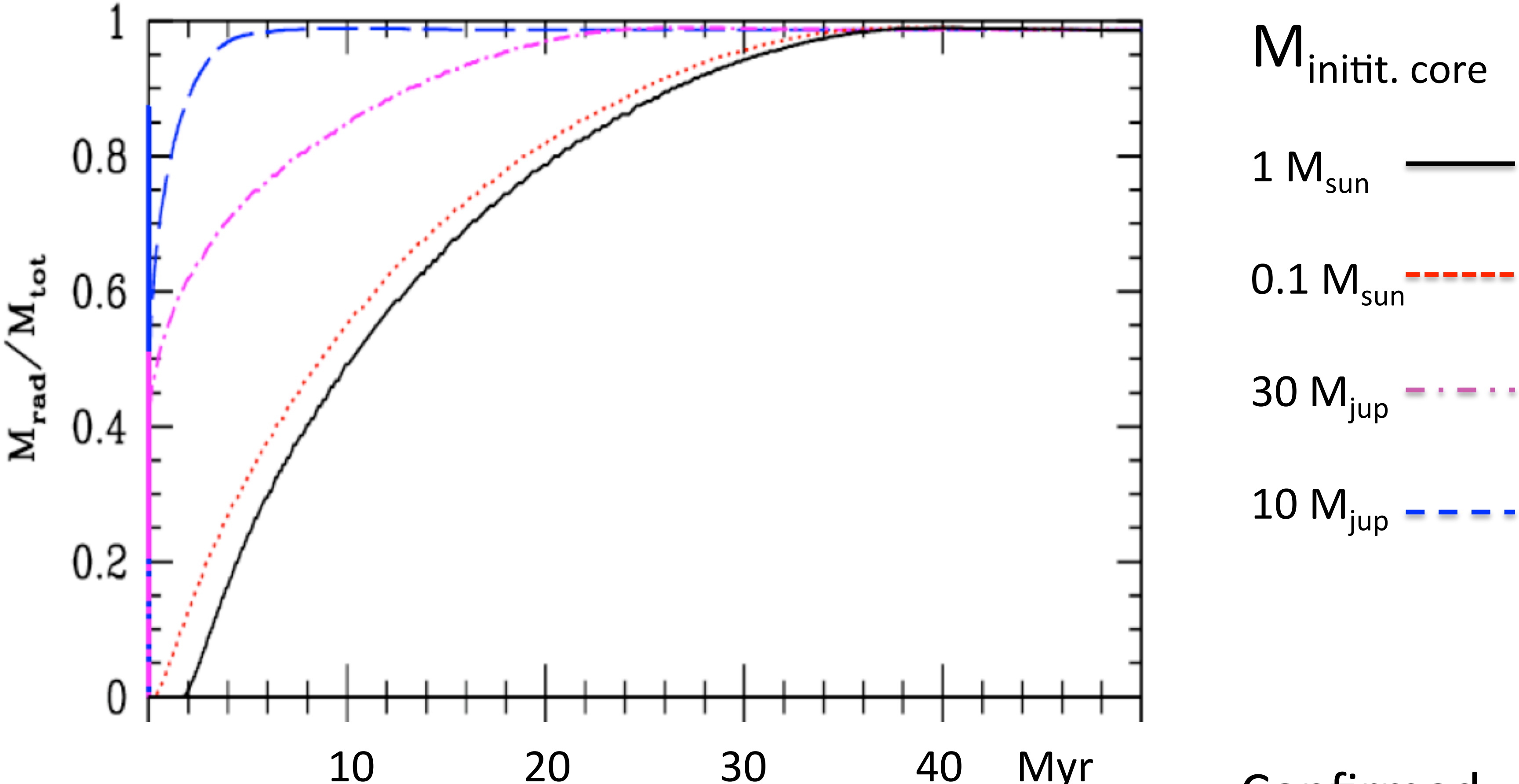
M_{core} = 1 M_{sun}
0.1
30 M_{Jup}
10



Result: rapid episodes in fast sequence =>

Very rapid evolution to MS, small radius and …

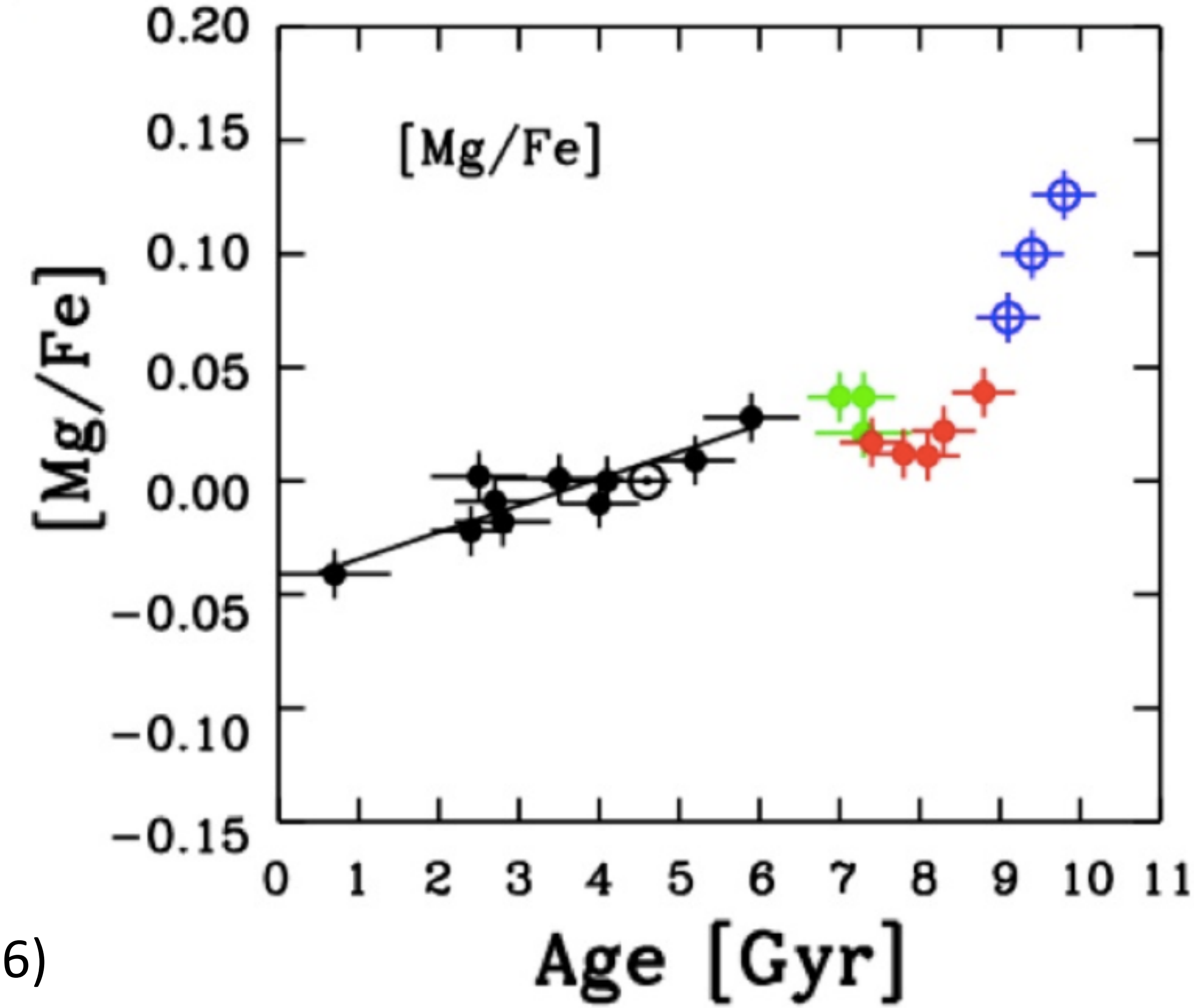
… much more shallow convection



from Baraffe & Chabrier (2010)

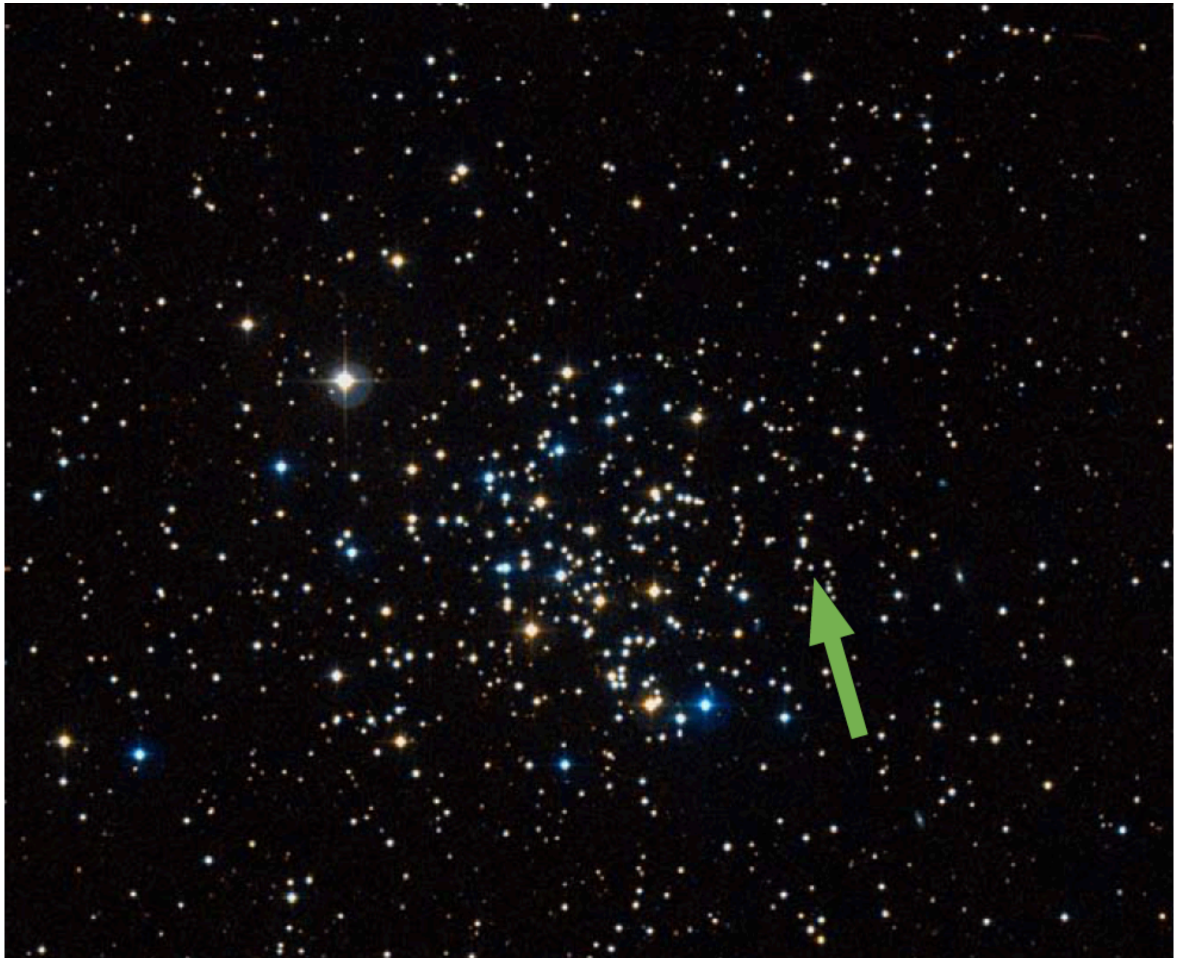
Confirmed.

Galactic evolution matters! One example:



from Nissen (2016)

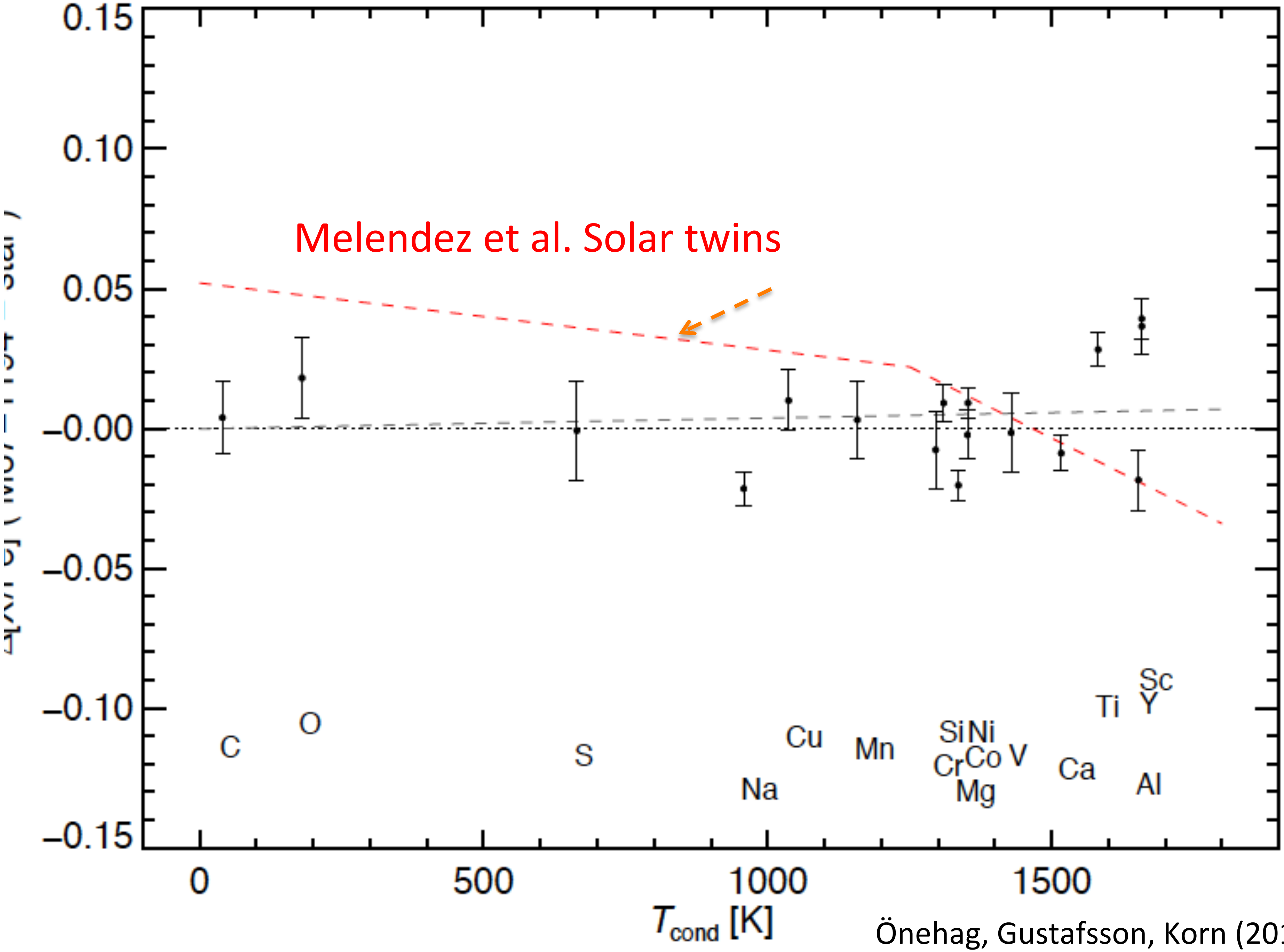
To test dust cleansing hypothesis:



M67, solar metallicity and approximate age

Önehag et al. (2011, 2014)

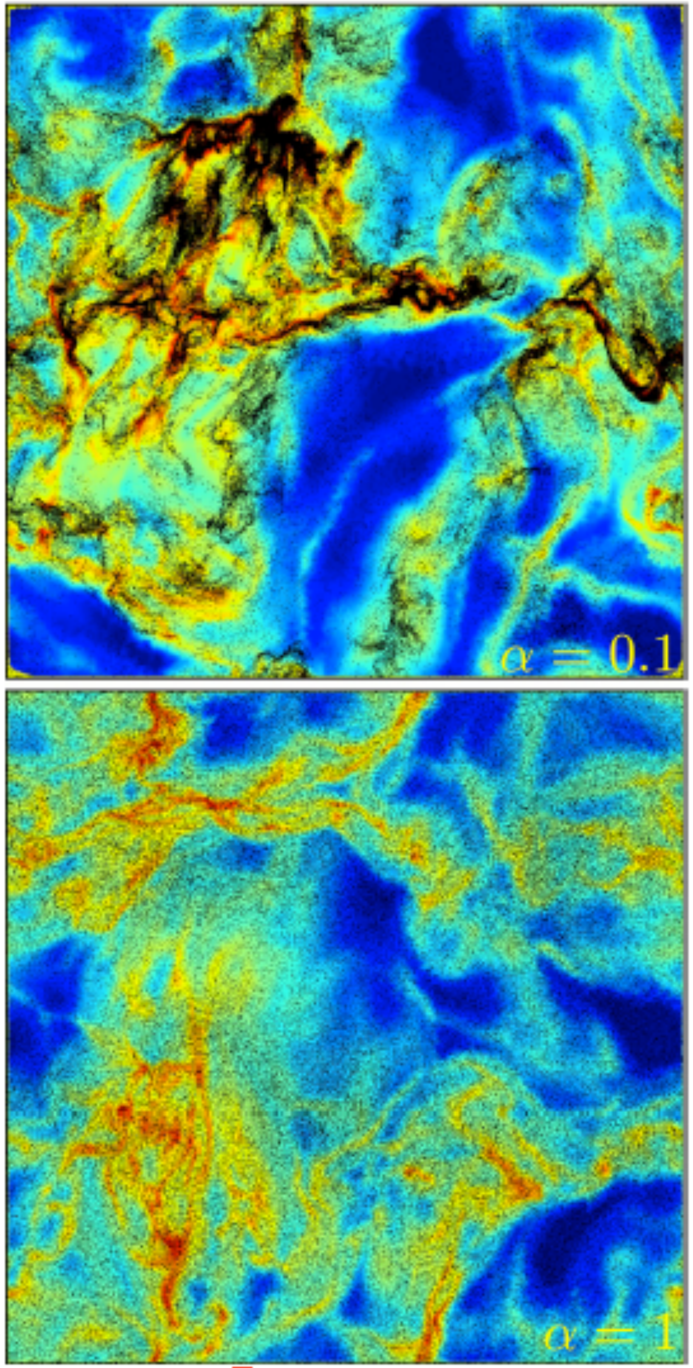
M67-1194 very solarlike!



Önehag, Gustafsson, Korn (2014)

NASA/ESA, F. Paresce

Gustafsson (2017): Very difficult for this cleansning to work, before photo-ionization takes over. Possible for individual stars, hardly for clusters



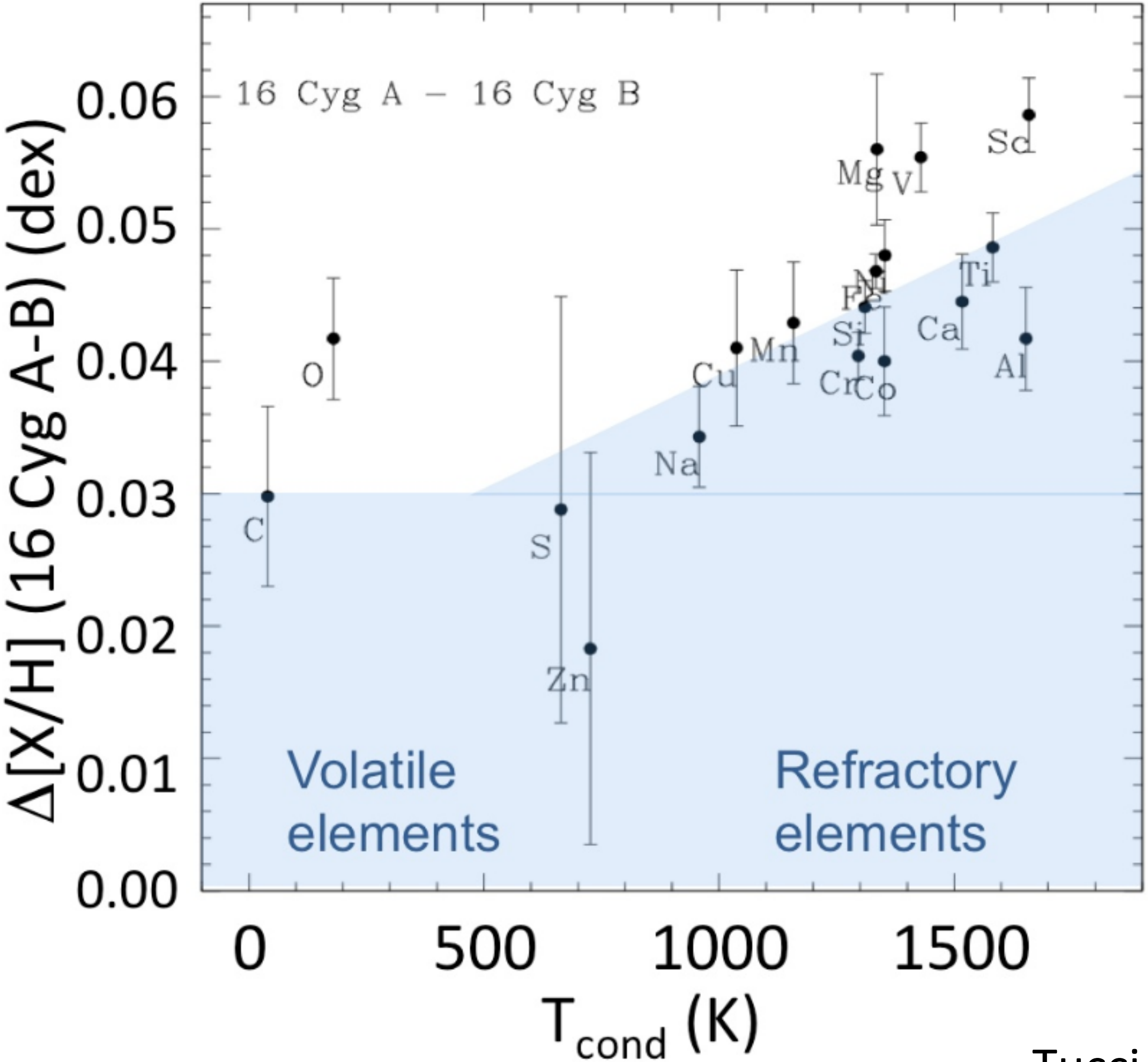
Small grains

Big grains

Hopkins & Lee (2015), arXiv 1510.02477v2

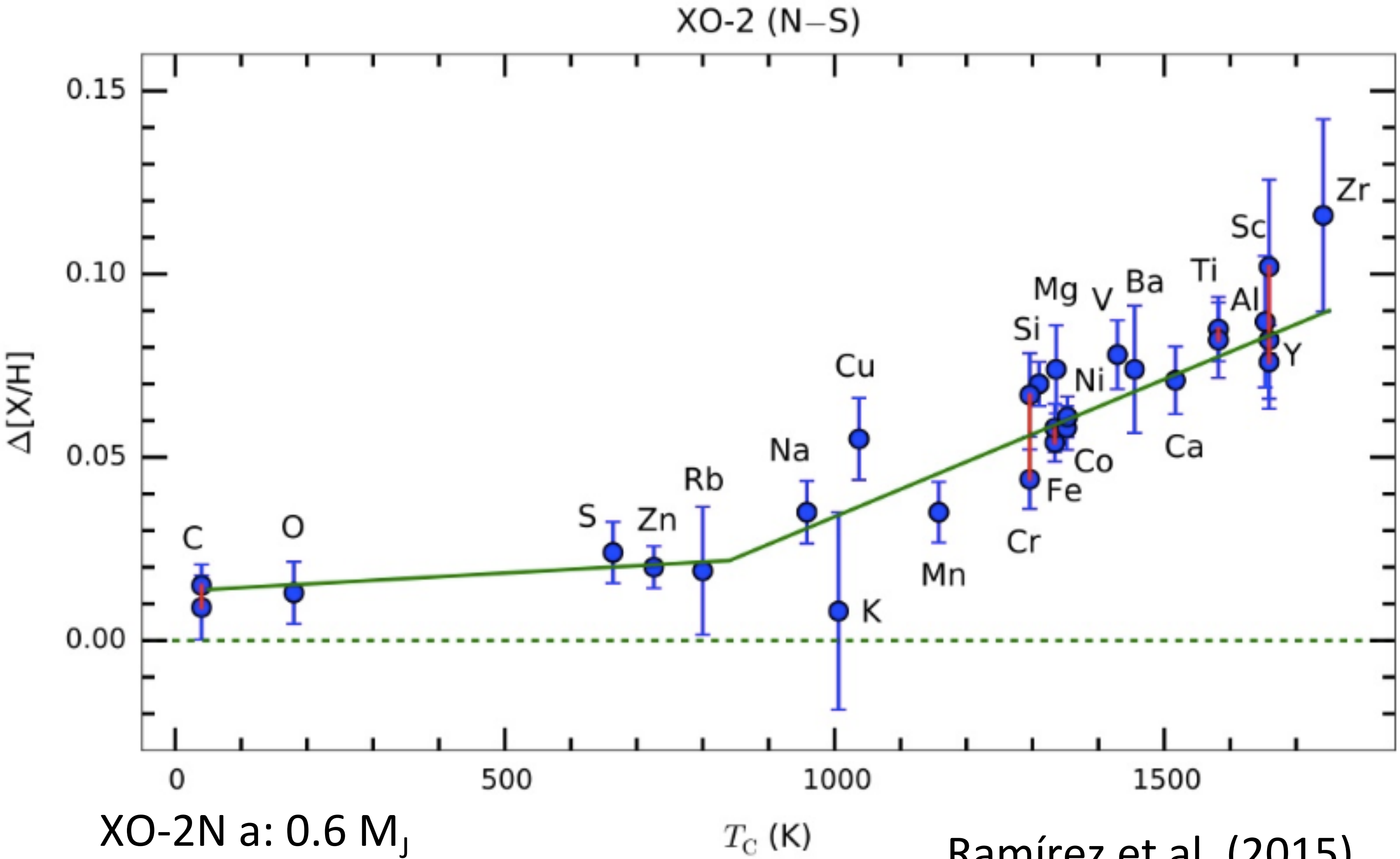
Other tests of planetary hypothesis for the Meléndez effect:

- Binary stars: 5 found to have abundance differences between planetary hosts and components with no known planets. Negative results in a few cases.



16 Cyg B
has a
1.5 M_J planet

Tucci Maia et al. (2014)



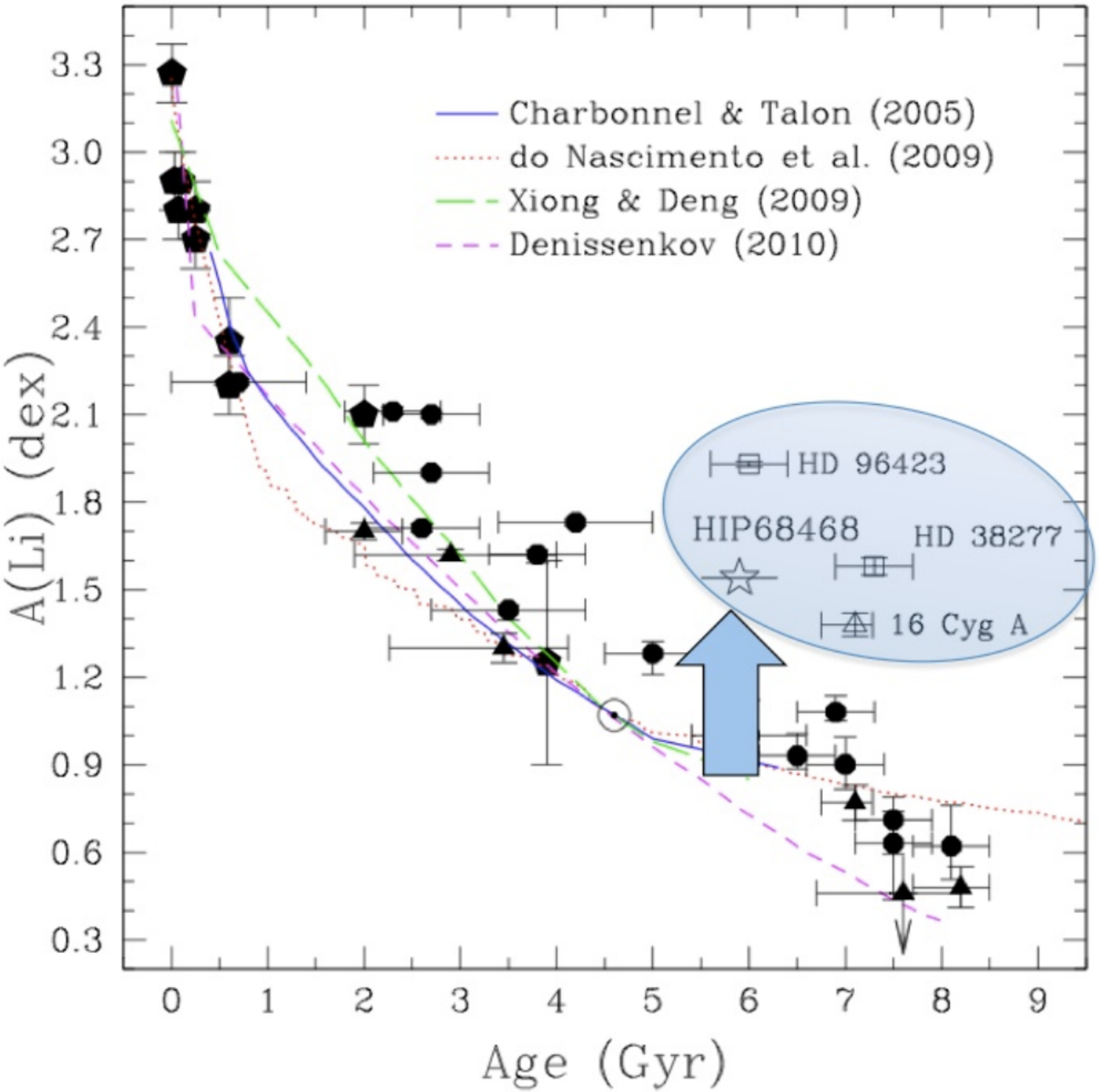
XO-2N a: 0.6 M_J

XO2S a+b: > 1.6 M_J

Ramírez et al. (2015)

Planet accretion?

- Test by studying Li as a function of age for solar twins.



From Meléndez (2016)

Do planets affect their host stars?

- Angular momentum. Questionable
- Tidal effects?? Questionable
- Chemical composition
  - by planet-formation fractionation in pp disk?
    Perhaps, or even probably for stars with episodic accretion.
  - by engulfing of planets?
    Yes, probably.

Thus, be careful when taking the composition of a solar-type star as representative for its birth cloud!

In other respects??