Constraining planet structure from stellar chemistry

Nuno C. Santos
Instituto de Astrofísica e Ciências do Espaço, Portugal
Departamento de Física e Astronomia, Fac. Ciências, University of Porto, Portugal

With: V. Adibekyan, C. Mordasini, C. Dorn, L. Noack, S. Barros,
E. Delgado-Mena, O. Demangeon, S. Sousa, et al.

The Daily Planet

06 SEP 2017

Dry law for distracted astronomers!

By ANONYMOUS

An independent but anonymous source reports rumours that astronomers in a PLATO conference will have no access to wine in the conference dinner if they do not pay attention to late afternoon talks.

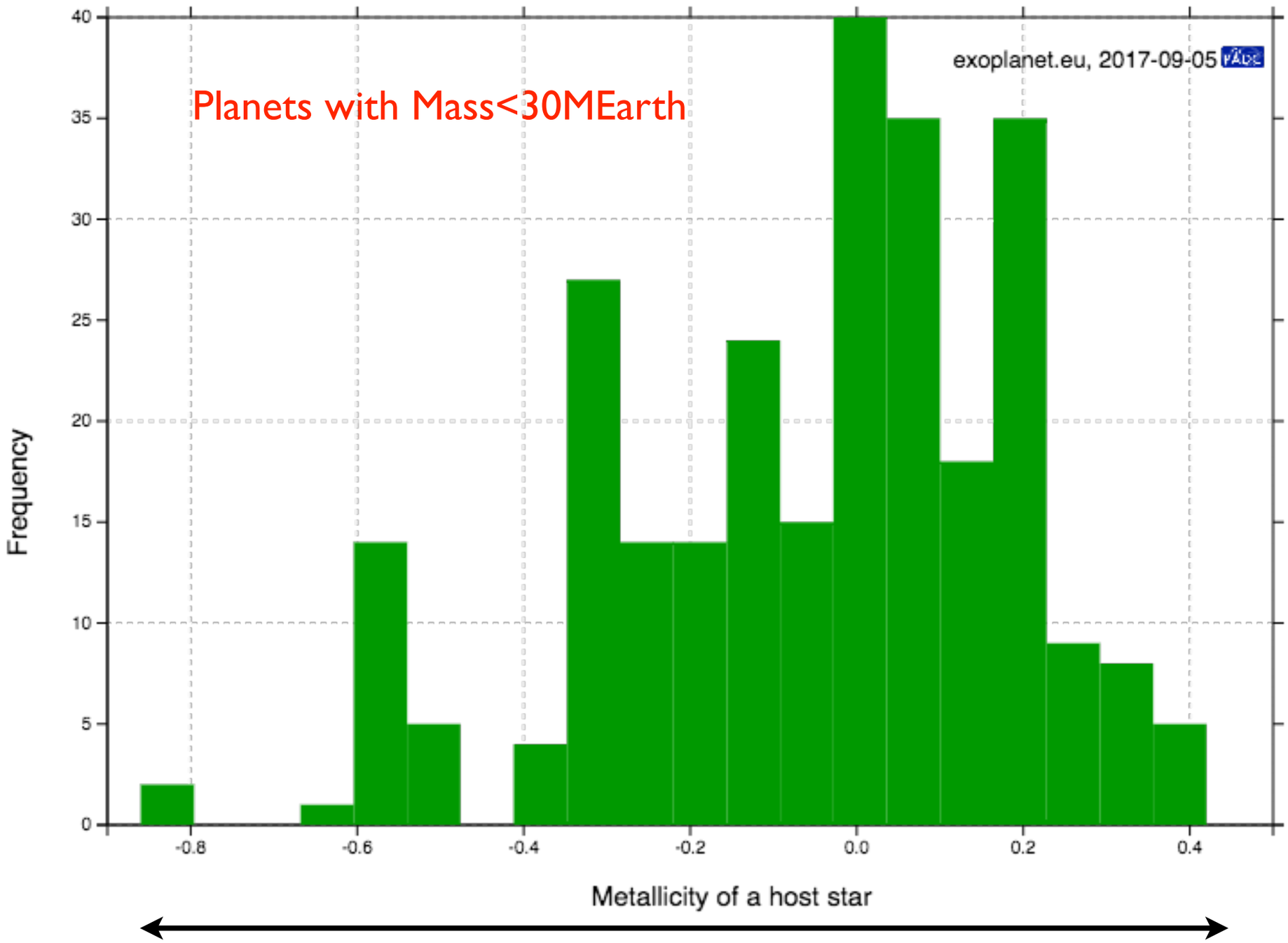
Reuters

to make gains. The largest percentagege increase in moose will likely come from China'', says McRobson, The Chinese government has invested heavily in moose infrastructure over the past decade, and their committment to macrofauna is beginning to pay dividends''. Since 2004 China has expanded moose pasture from 1.5% of arable land to nearly 3.648% and moose numbers are expected to rise to 60,000 making China a net moose exporter for the first time. This is good news for neighbouring Mongolia, a barren moose-wasteland whose inhabitents nonetheless have an insatiable desire for the creatures. The increase in Beijing-Ulanbataar trade is anticipated to relieve pressure on the relatively strained Russian suppliers, but increase Mongolia's imbalance of trade with its larger neighbour.

Historically the only competitor to China in the far eastern moose markets has been Singapore but the ity controls are holding back the development of the eastern european populations compared to last year when they contributed significantly to europe's strong growth figures. Norway, which is not an EU member but has observer status, strengthed in numbers relative to the Euro area with numbers of Norweigian moose, known locally as elk'' expected to rise for the tenth consecutive year, particularly thanks to a strong showing in the last quarter.

As moose season reaches its close, researchers world wide are turning to science in an attempt to boost next year's figures. NASA stunned the scientific community today with the announcment of their discovery that the moon is significantly smaller than previously believed. This conclusion, which is the conclusion of a ten-year collaborative project, will have profound implications for the moose community as the gravitational field

Planet host stars spread a large metallicity range

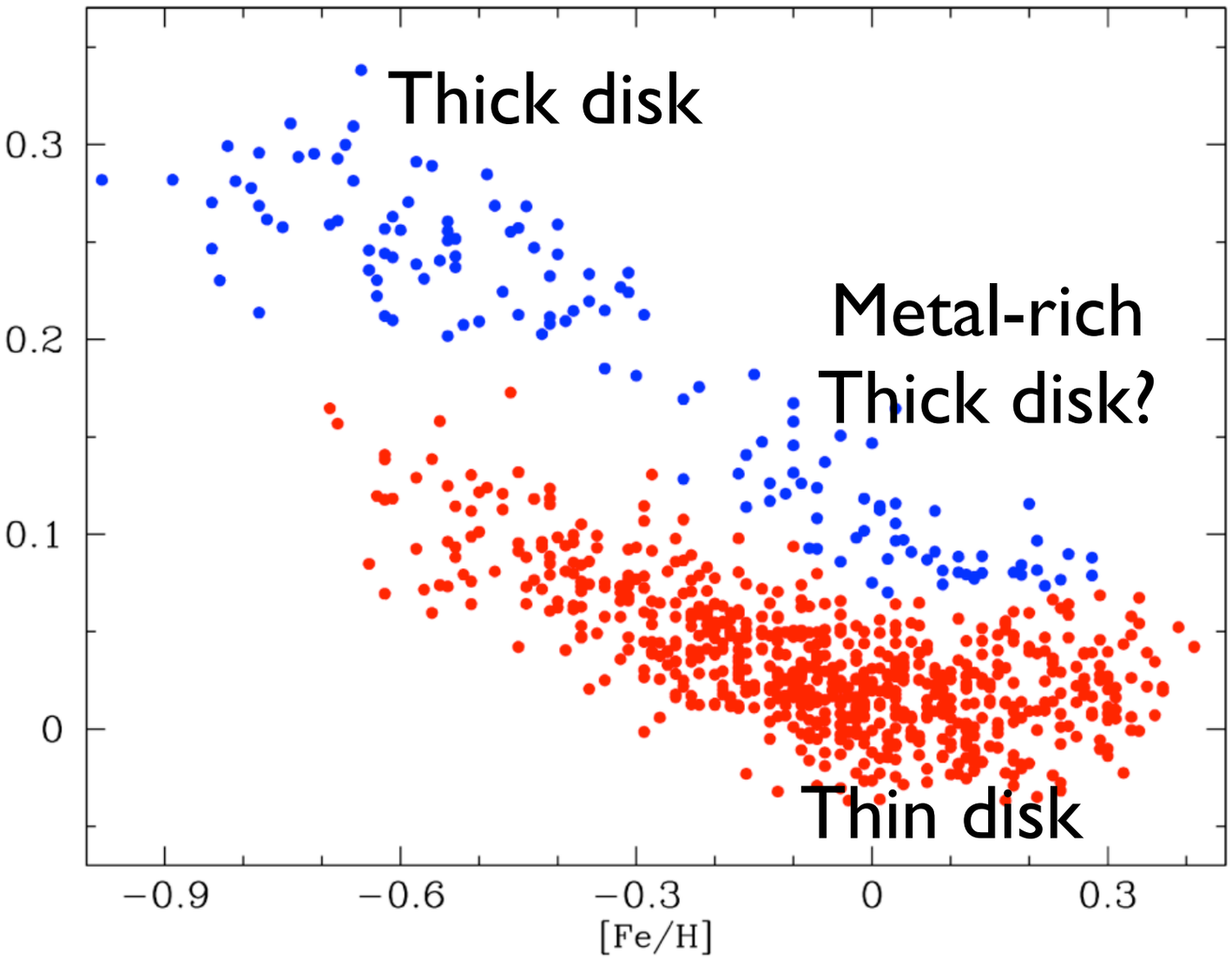


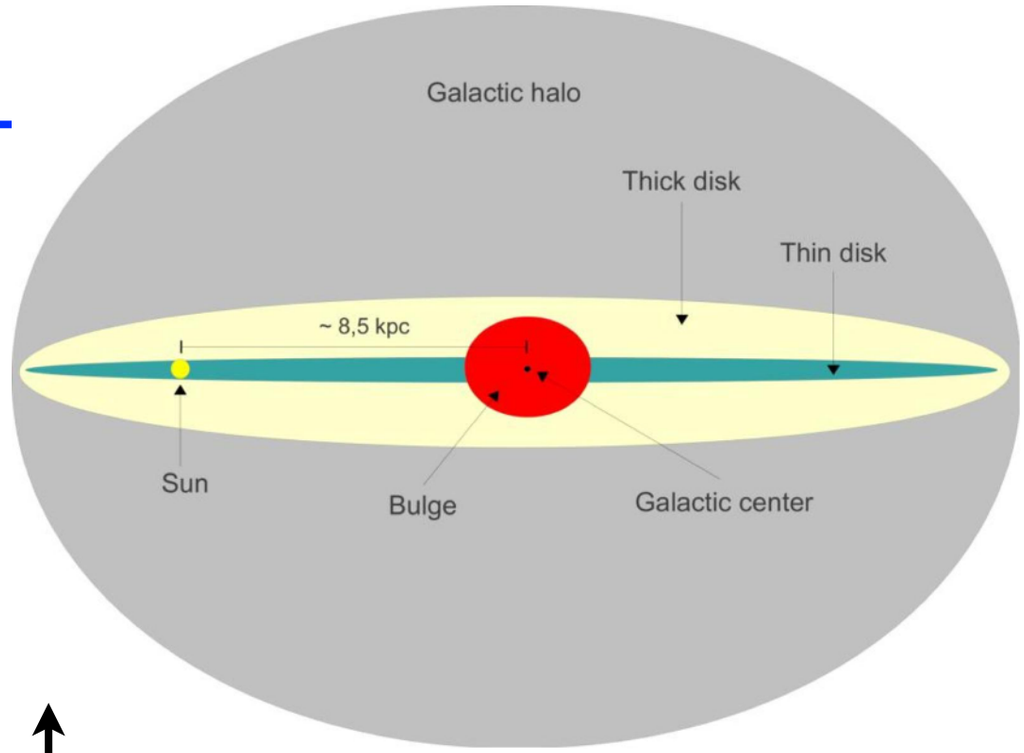
[Fe/H] varies by a factor of 16!

Nuno C. Santos
nuno.santos@astro.up.pt

Stellar composition in the Galaxy

- Different stars present different abundance ratios





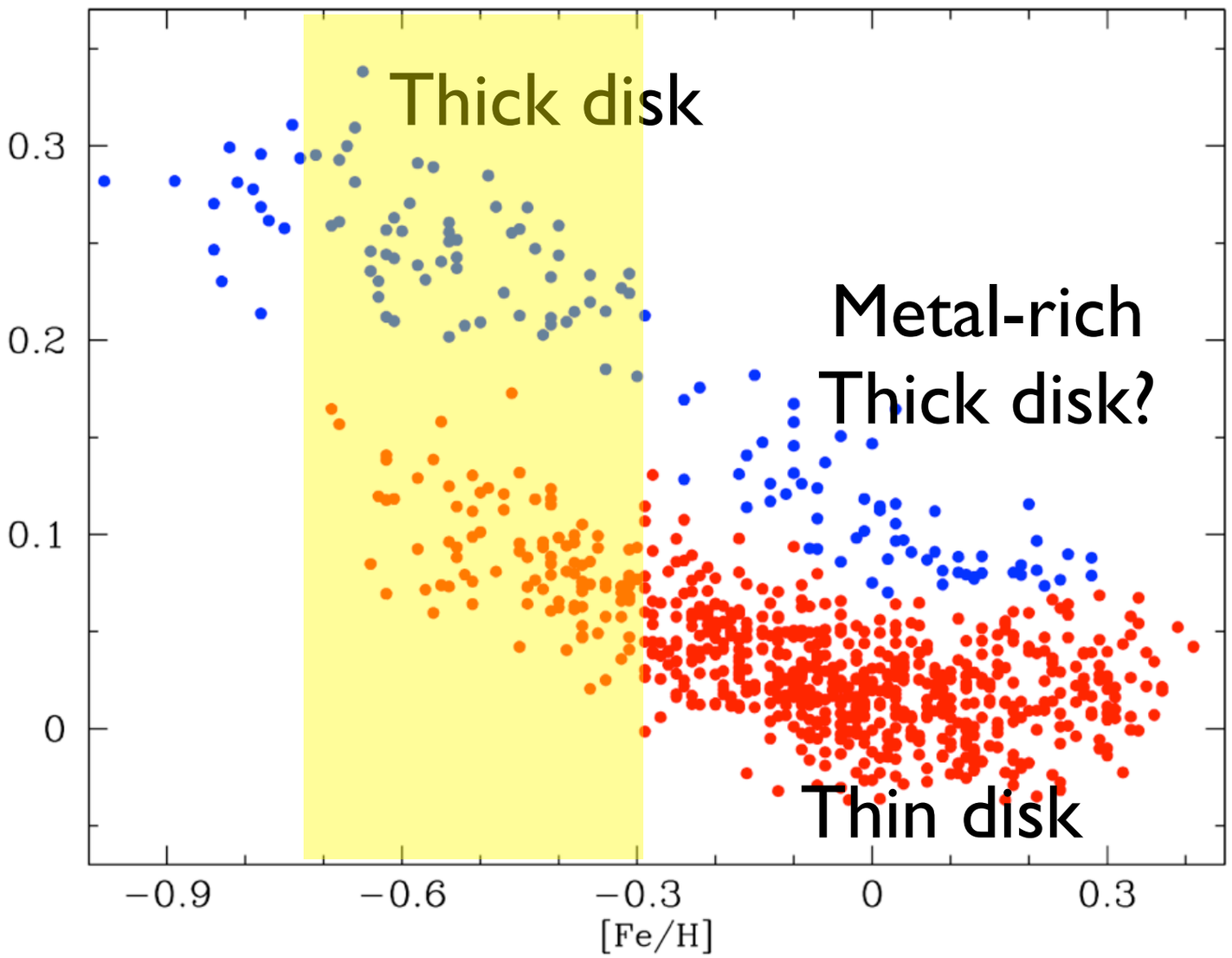
Abundance ratios vary factor of ~2!

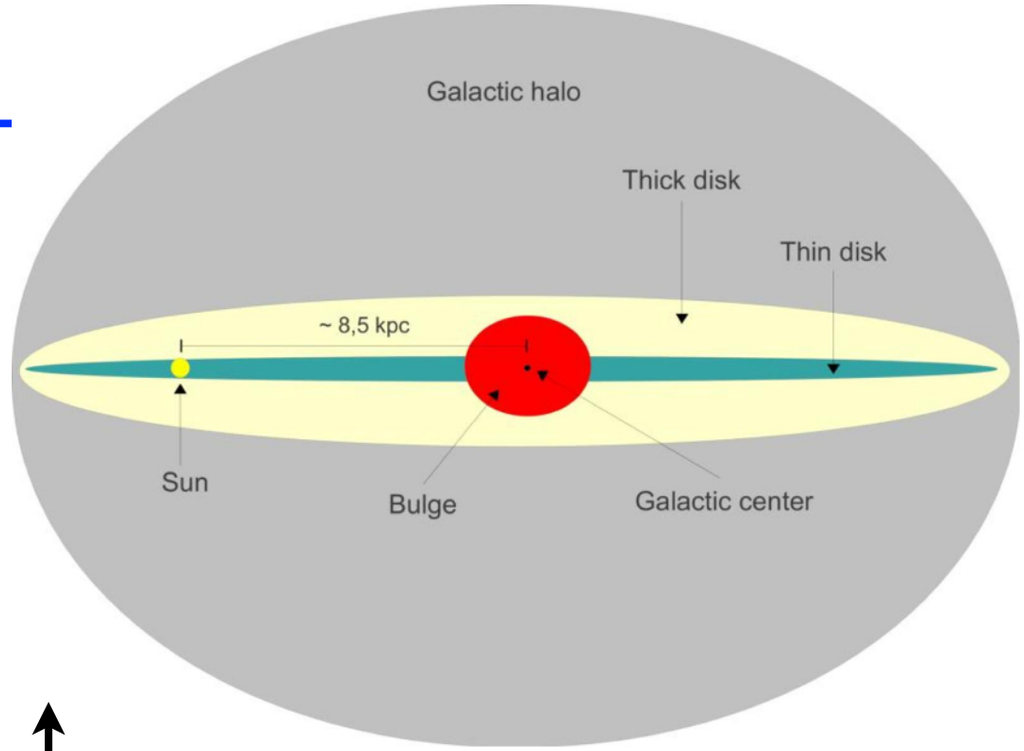
Adibekyan+ (2012)

Nuno C. Santos
nuno.santos@astro.up.pt

Stellar composition in the Galaxy

- Different stars present different abundance ratios





Abundance ratios vary factor of ~2!

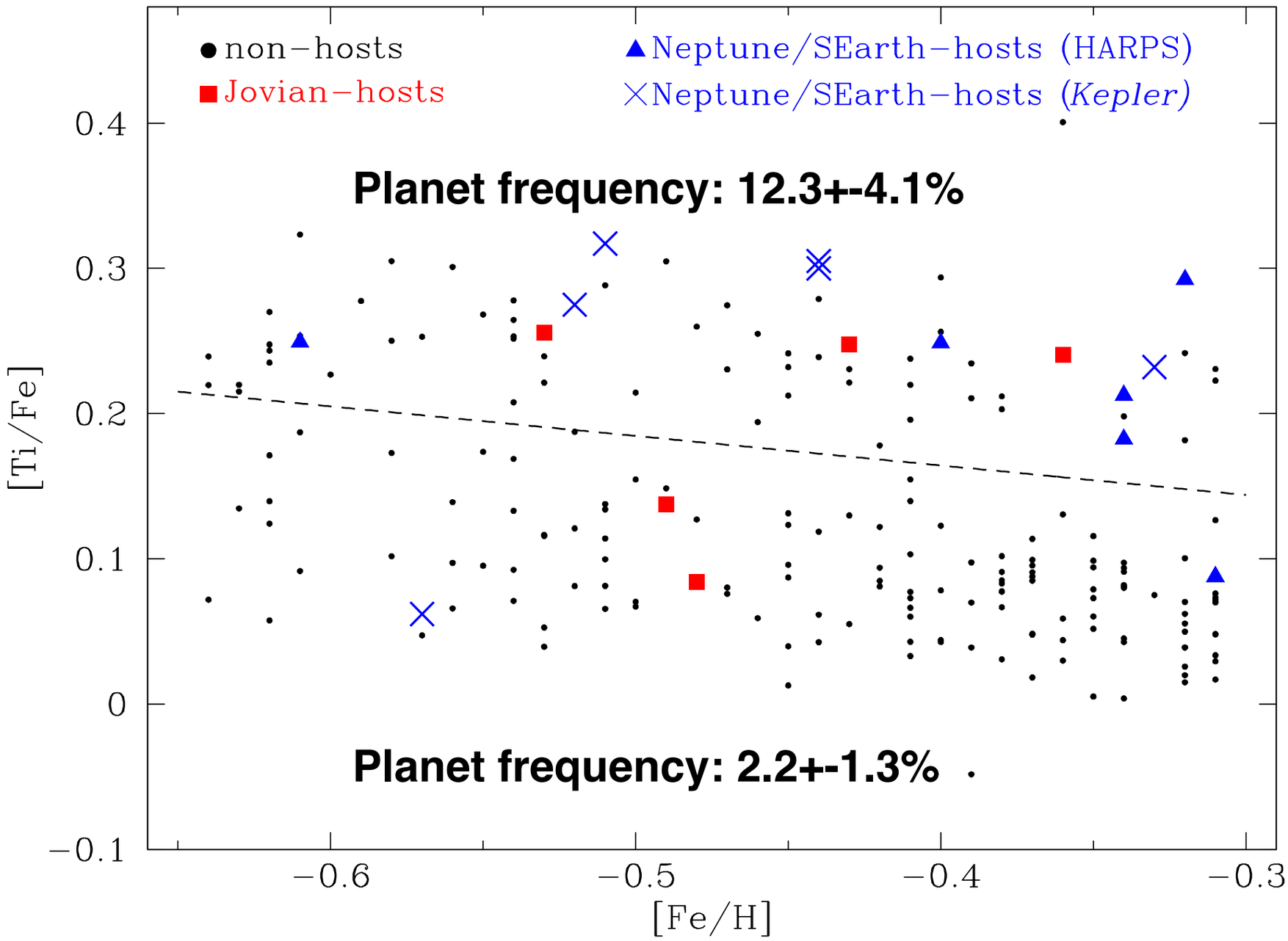
Adibekyan+ (2012)

ia instituto de astrofísica e ciências do espaço

U.PORTO

Nuno C. Santos
nuno.santos@astro.up.pt

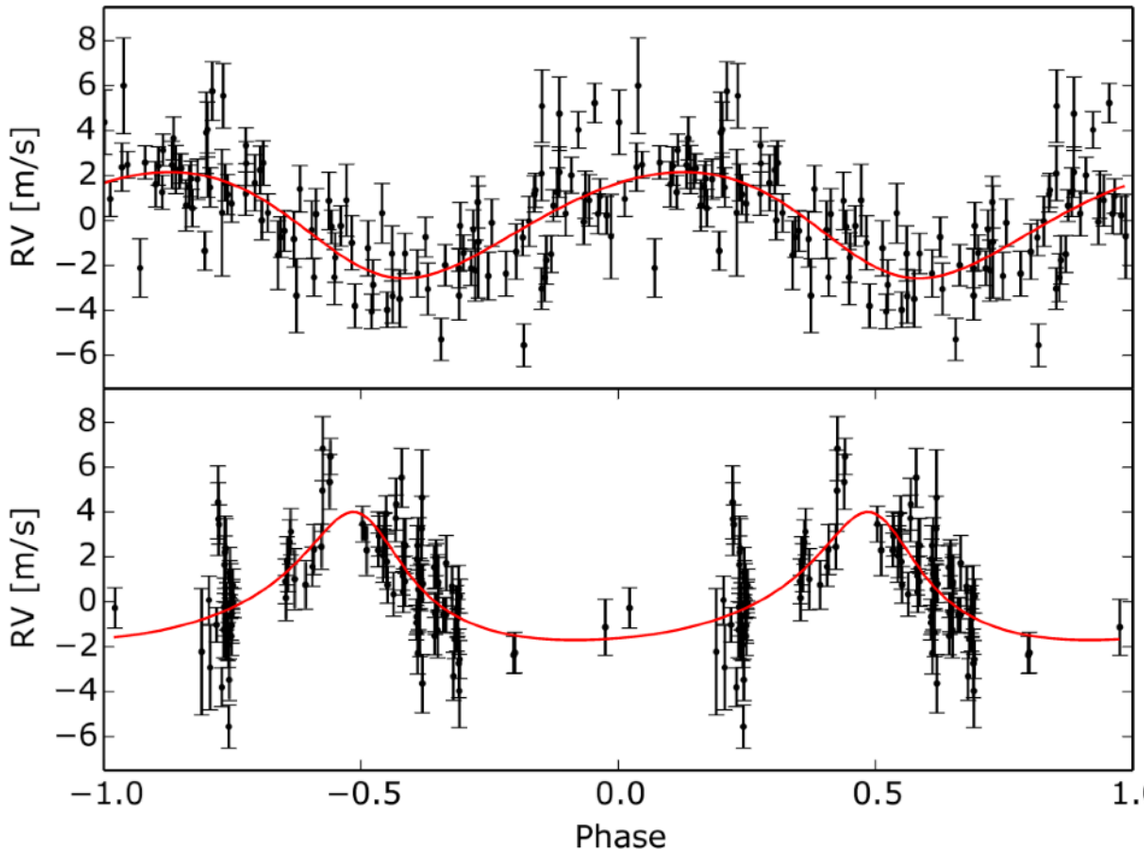
Metal-poor planet hosts: a preference for thick disk



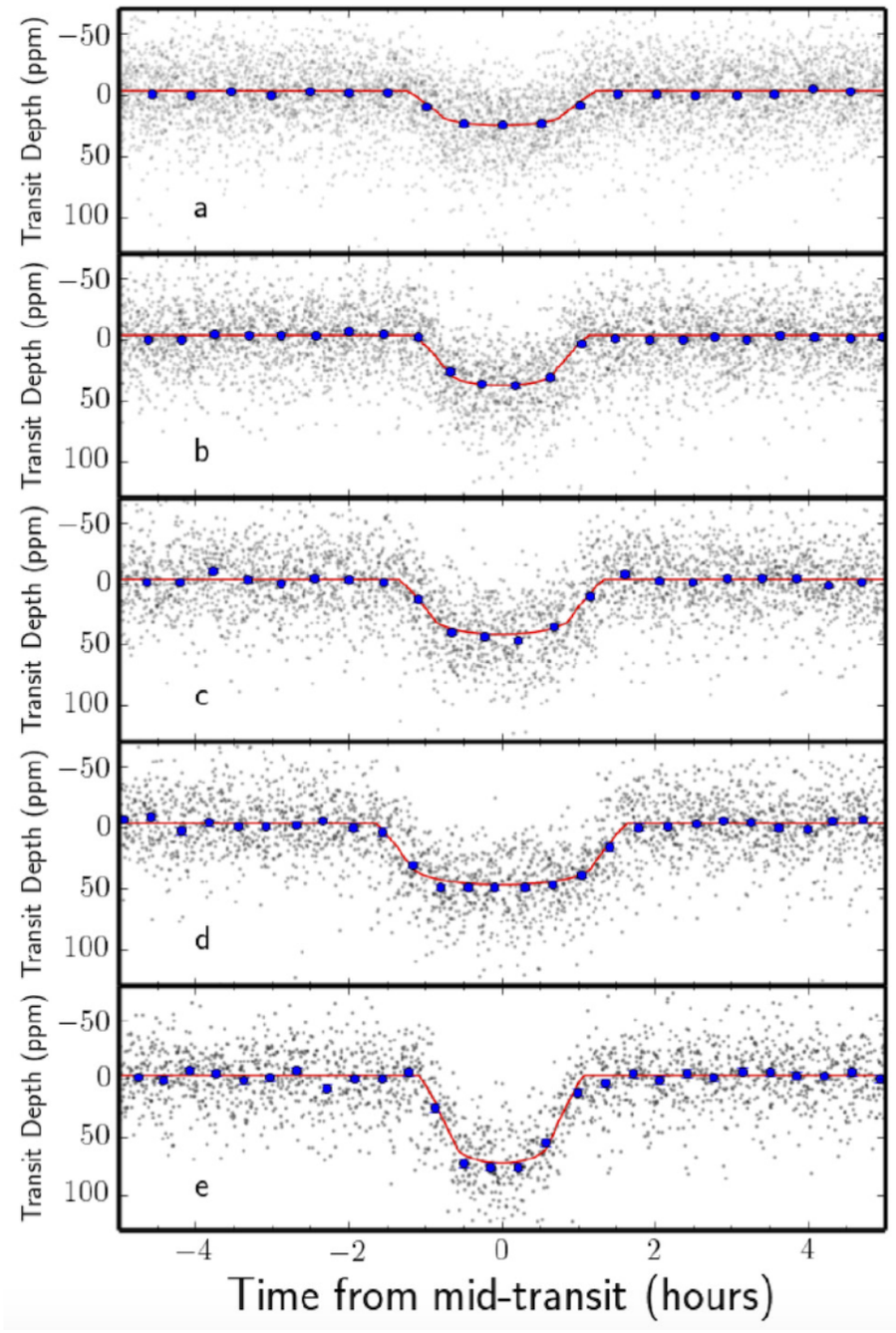
(Adibekyan et al. 2012; see also Haywood 2008)

Nuno C. Santos
nuno.santos@astro.up.pt

Planets around a variety of Galactic "populations"



(HD175607, [Fe/H]=-0.62, thick disk - Mortier et al. 2016)

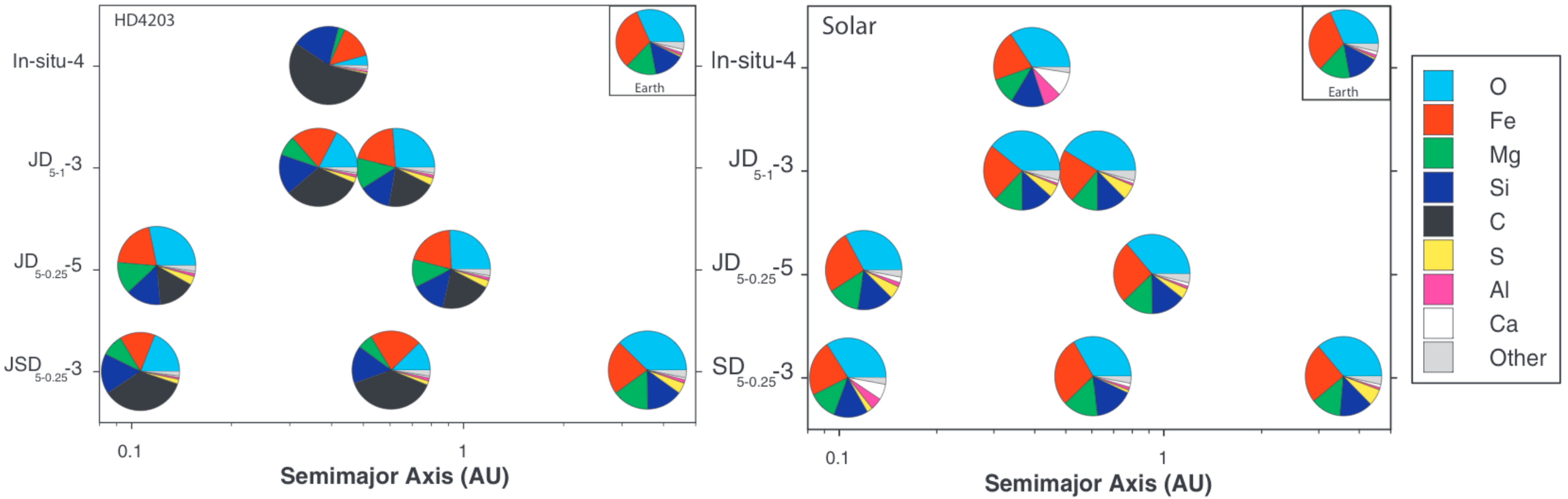


(Kepler-444, Age=11.2 Gyr!!! - Campante et al. 2015)

Nuno C. Santos
nuno.santos@astro.up.pt

Different stellar abundances => different planets?

- Simulated planets considering different C/O ratios



See also: Delgado-Mena et al. (2010), Carter-Bond et al. (2013), Alibert et al. (2015), Thiabaud et al. (2015), Dorn et al. (2015, 2017), Santos et al. (2015), Adibekyan et al. (2016)

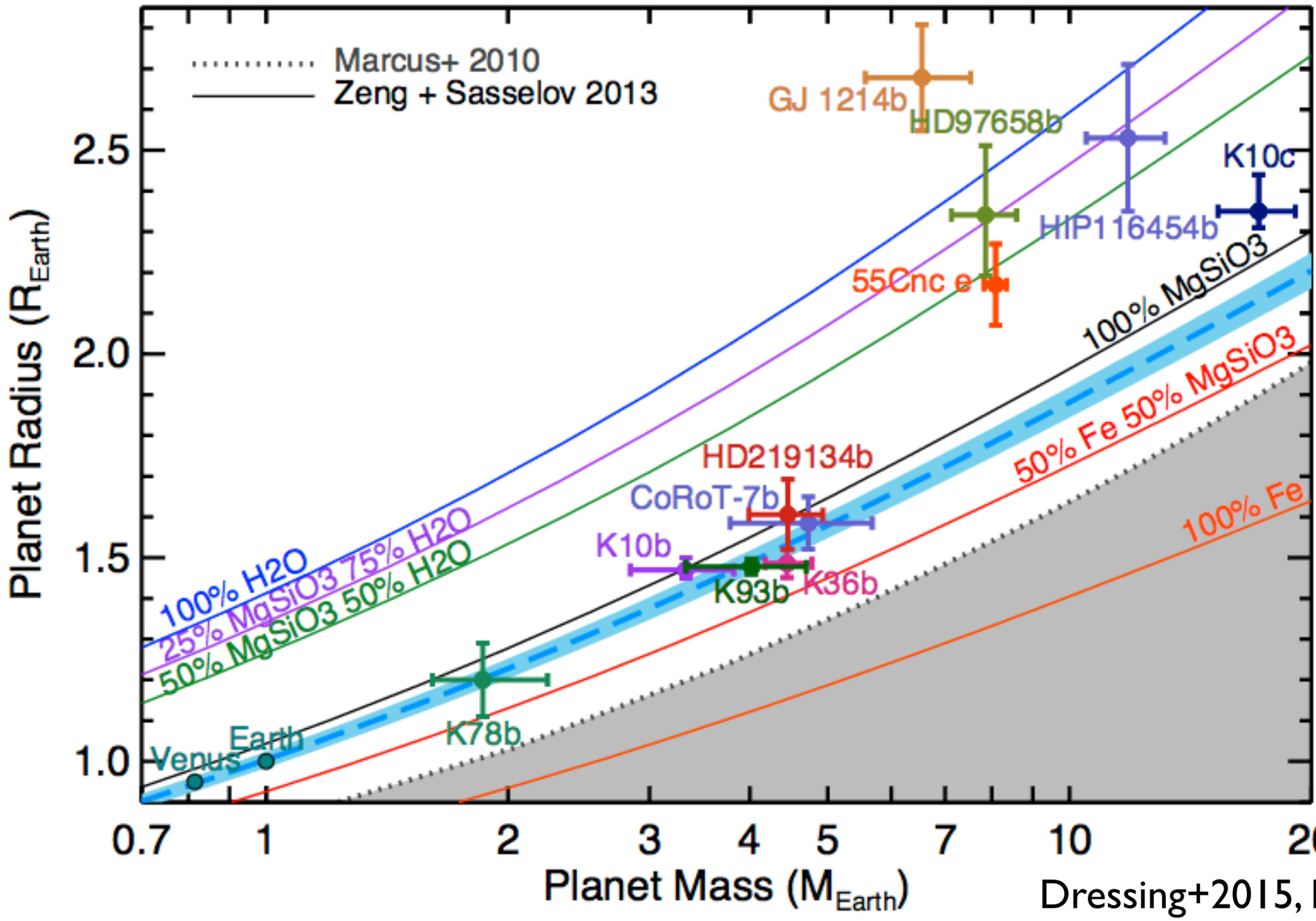
Nuno C. Santos
nuno.santos@astro.up.pt

What do we know from our Solar System?

- Solar system planets:
  - Earth, Venus, Mars, and meteorites all have "solar" relative abundances of Fe, Mg, and Si - e.g. Sanloup et al. 1999
  - Can we use stellar Fe, C, O, Mg, Si to predict the composition of rocky exoplanets? (e.g. Dorn et al. 2015, 2017)

Nuno C. Santos
nuno.santos@astro.up.pt

Rocky exoplanets: same composition?

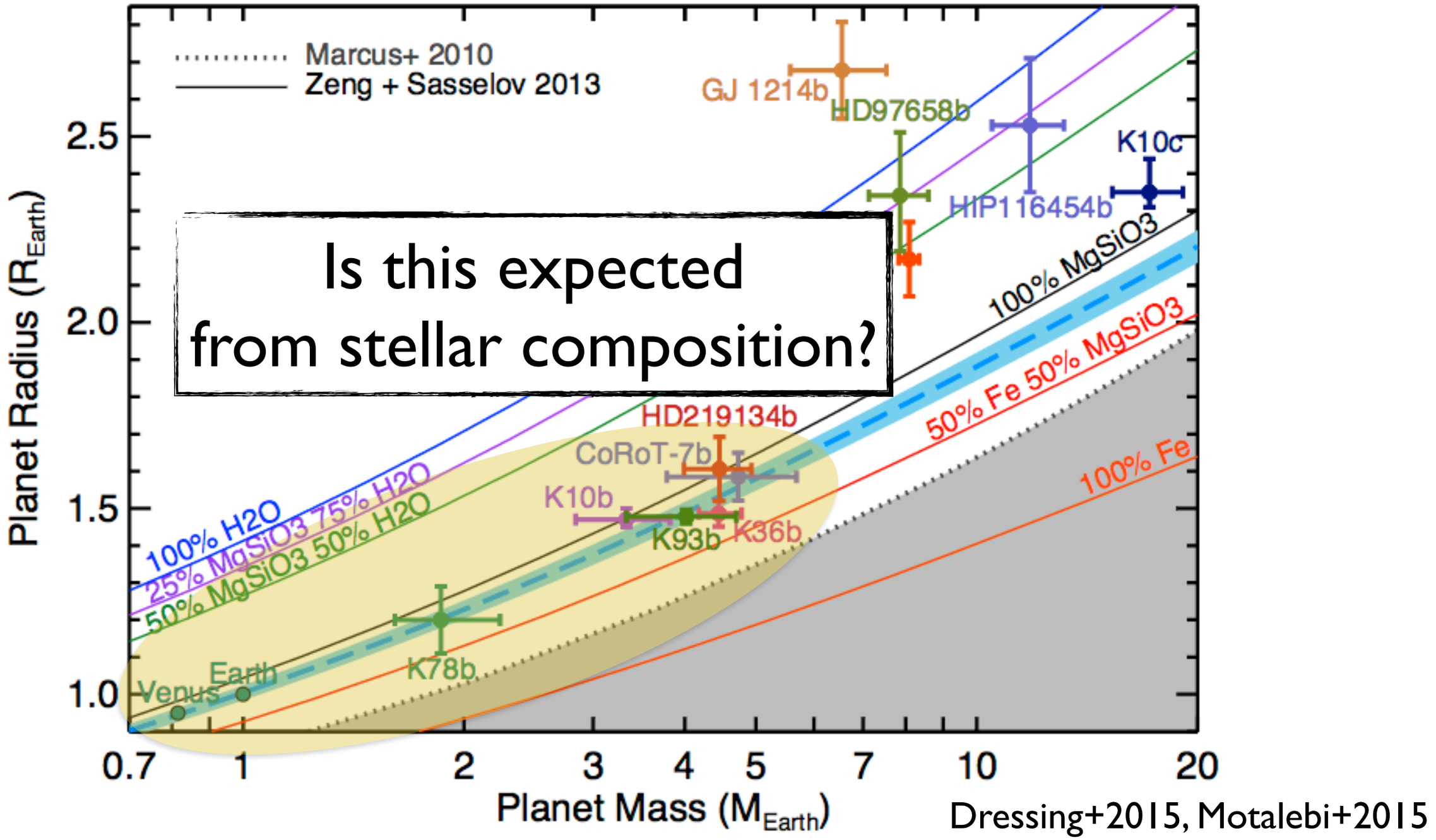


Dressing+2015, Motalebi+2015

Nuno C. Santos
nuno.santos@astro.up.pt

Rocky exoplanets: same composition?

- Rocky planets: follow the Earth composition line!



Dressing+2015, Motalebi+2015

Nuno C. Santos
nuno.santos@astro.up.pt

Rocky exoplanet composition: a simple model

$$
\begin{aligned}
N_{\mathrm{O}} &= N_{\mathrm{H_2O}} + 3N_{\mathrm{MgSiO_3}} + 4N_{\mathrm{Mg_2SiO_4}} \\
N_{\mathrm{Mg}} &= N_{\mathrm{MgSiO_3}} + 2N_{\mathrm{Mg_2SiO_4}} \\
N_{\mathrm{Si}} &= N_{\mathrm{MgSiO_3}} + N_{\mathrm{Mg_2SiO_4}}
\end{aligned}
$$

Iron mass fraction $f_{\mathrm{iron}} = m_{\mathrm{Fe}}/(m_{\mathrm{Fe}} + m_{\mathrm{MgSiO3}} + m_{\mathrm{Mg2SiO4}} + m_{\mathrm{SiO2}})$

Water mass fraction $w_f = m_{\mathrm{H2O}}/(m_{\mathrm{Fe}} + m_{\mathrm{MgSiO3}} + m_{\mathrm{Mg2SiO4}} + m_{\mathrm{SiO2}})$

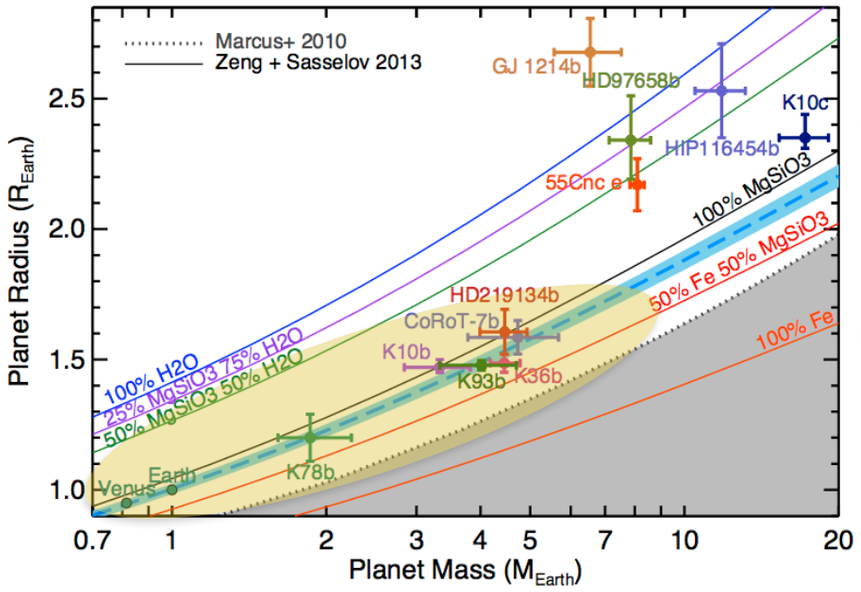
Santos+2015

ia instituto de astrofísica e ciências do espaço
U.PORTO
Nuno C. Santos
nuno.santos@astro.up.pt

Rocky exoplanets: same composition!

$$
\begin{aligned}
N_{\mathrm{O}} &= N_{\mathrm{H_2O}} + 3N_{\mathrm{MgSiO_3}} + 4N_{\mathrm{Mg_2SiO_4}} \\
N_{\mathrm{Mg}} &= N_{\mathrm{MgSiO_3}} + 2N_{\mathrm{Mg_2SiO_4}} \\
N_{\mathrm{Si}} &= N_{\mathrm{MgSiO_3}} + N_{\mathrm{Mg_2SiO_4}}
\end{aligned}
$$

Input measured stellar C, O, Si, Fe



. Mass fractions of heav ement, total fraction of heavy ele-
nd iron mass fraction among refractory species (values in %).

tity	C-7	K-93	K-10	Sun	Sun[f]
	0.75±0.31	0.54±0.22	0.98±0.20	0.50	0.51
	0.32±0.05	0.35±0.13	0.36±0.04	0.37	0.29
	0.14±0.01	0.09±0.01	0.10±0.00	0.13	0.17[d]
O_3[a]	0.25±0.08	0.10±0.06	0.11±0.05	0.19	0.27[e]
Mg_2SiO_4[a]	0.05±0.06	0.08±0.06	0.14±0.06	0.08	
Z[b]	1.50±0.31	1.17±0.25	1.69±0.21	1.26	1.32
f_{iron}[c]	31.6±2.6	34.7±3.7	27.5±1.7	33.2	38.0

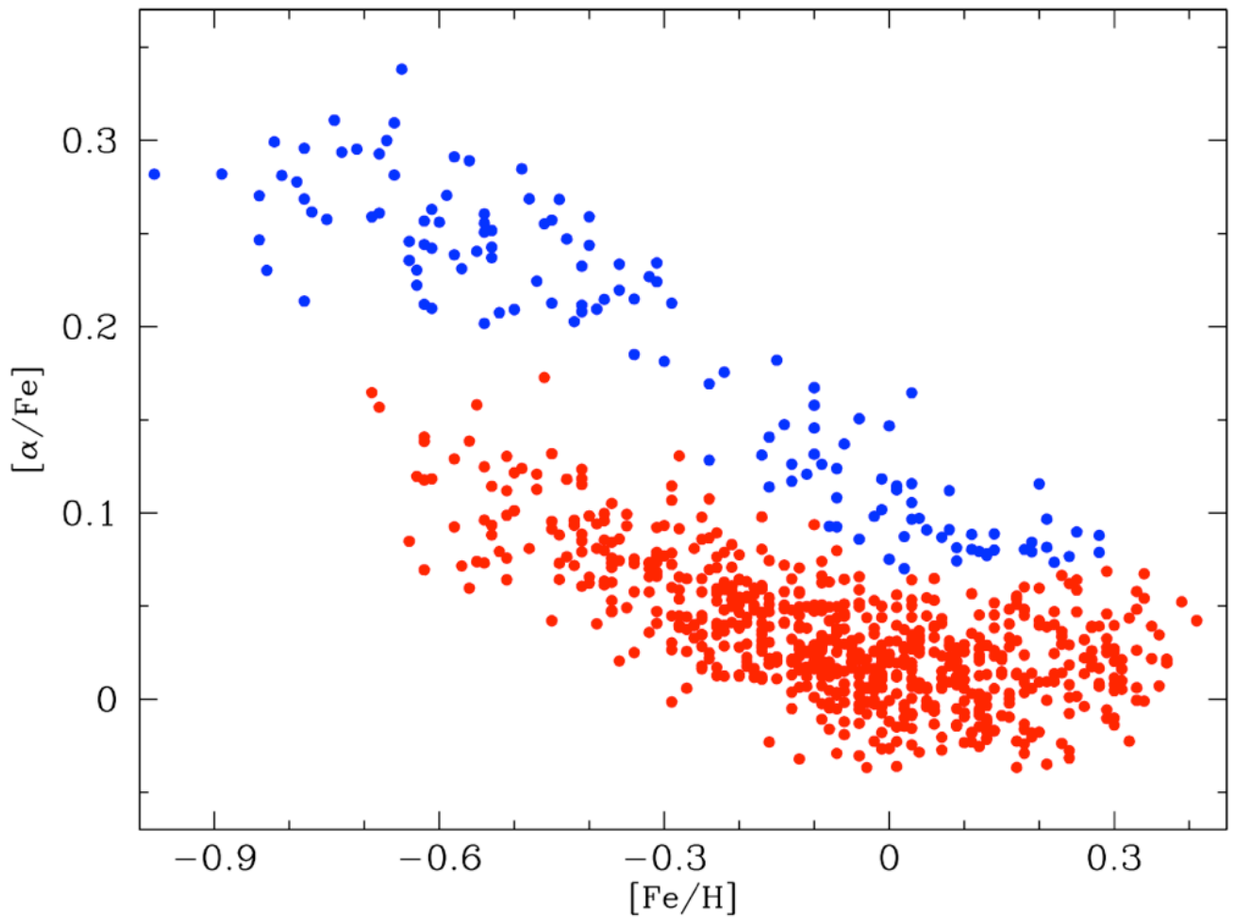
[(a)] The m_{H2} and m_{He} are between 74.7-75.1% and 23.6-23.7%, respectively. [(b)] Summed mass percent of all heavy elements. [(c)] $m_{Fe}/(m_{Fe} + m_{MgSiO3} + m_{Mg2SiO4})$. [(d)] Includes all metal species and FeS. [(e)] Includes all silicates and oxides. [(f)] Lodders (2003).

Santos+2015

ia instituto de astrofísica e ciências do espaço
U.PORTO
Nuno C. Santos
nuno.santos@astro.up.pt

Predicting rocky planet composition in the Galaxy

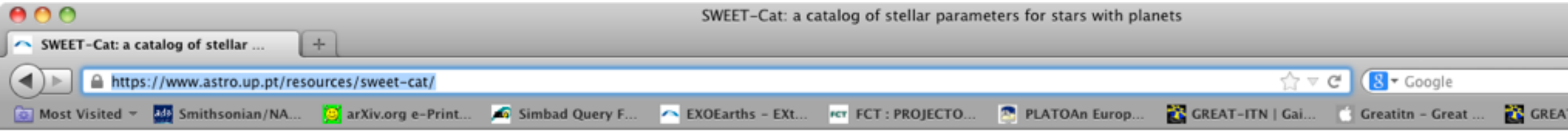
- Sample of solar neighbourhood stars (HARPS sample, Adibekyan et al. 2012)
- 371 stars with well determined and very reliable values of C, O, Mg, Si, Fe
- All stellar parameters are homogeneous (SWEET-Cat)



Santos+2017, subm.

Nuno C. Santos
nuno.santos@astro.up.pt

SWEET-Cat (http://www.astro.up.pt/resources/sweet-cat)



Centro de Astrofísica da Universidade do Porto

SWEET-Cat: a catalog of stellar parameters for stars with planets

SWEET-Cat is a catalogue of stellar parameters for stars with planets listed in the Extrasolar Planets Encyclopaedia. It compiles sets of atmospheric parameters previously published in the literature (including Teff, logg, and [Fe/H]) and, whenever possible, derived using the same uniform methodology (see e.g. Santos et al. 2004; Sousa et al. 2008).

The catalog is described in Santos et al. 2013. However, it is continuously being updated as new planets are announced and new stellar parameters derived. If major changes occur concerning the structure of the catalog they will be described here or in a subsequent paper.

SWEET-Cat is built from literature data, either published or to be published soon. Although we do not encourage, we understand that for simplicity the user may wish to cite only the catalog presentation paper if using it in a statistical way. However, we strongly encourage the user to give the propper credit to the original source of stellar parameters.

(click on any specific header to sort, a detailed description of each field can be found here)

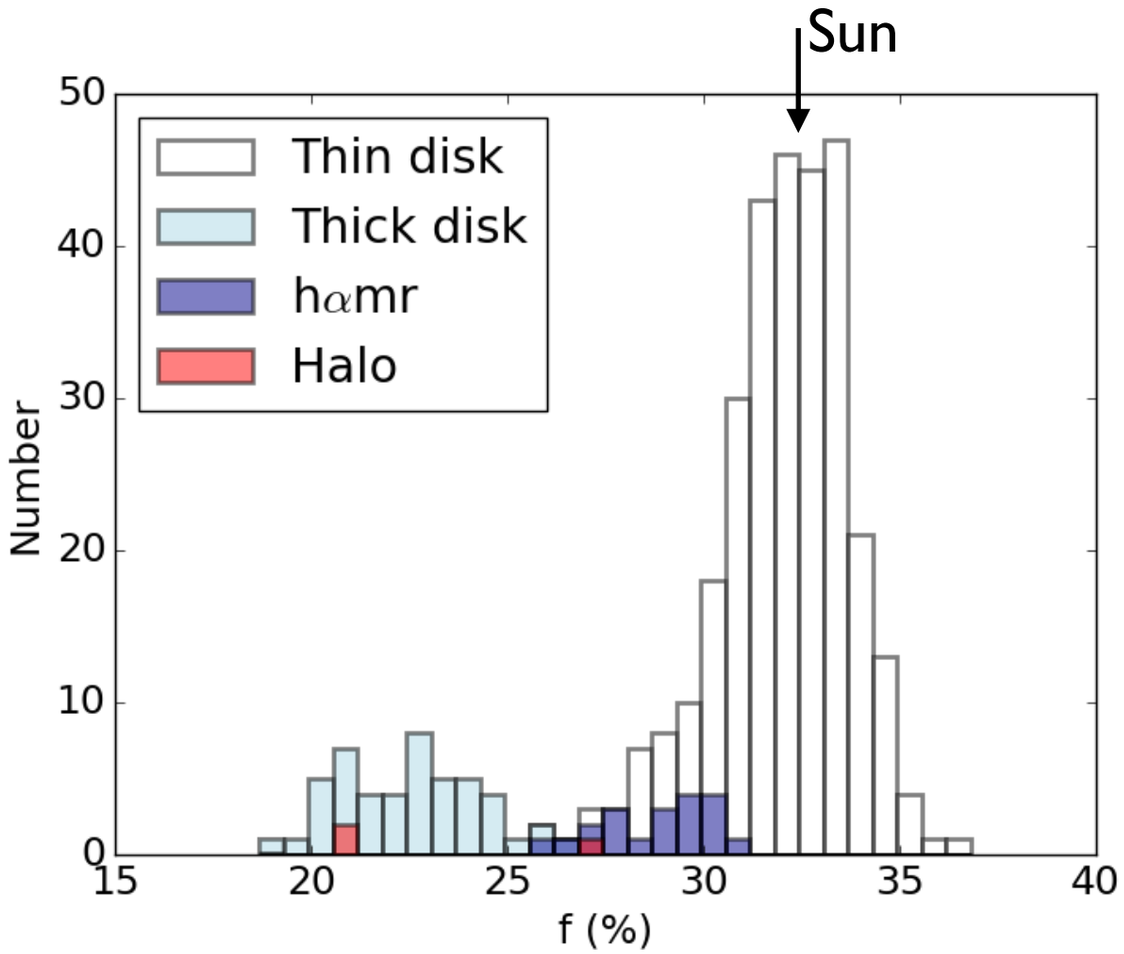
(Santos+ 2013; Andreasen+ 2017)

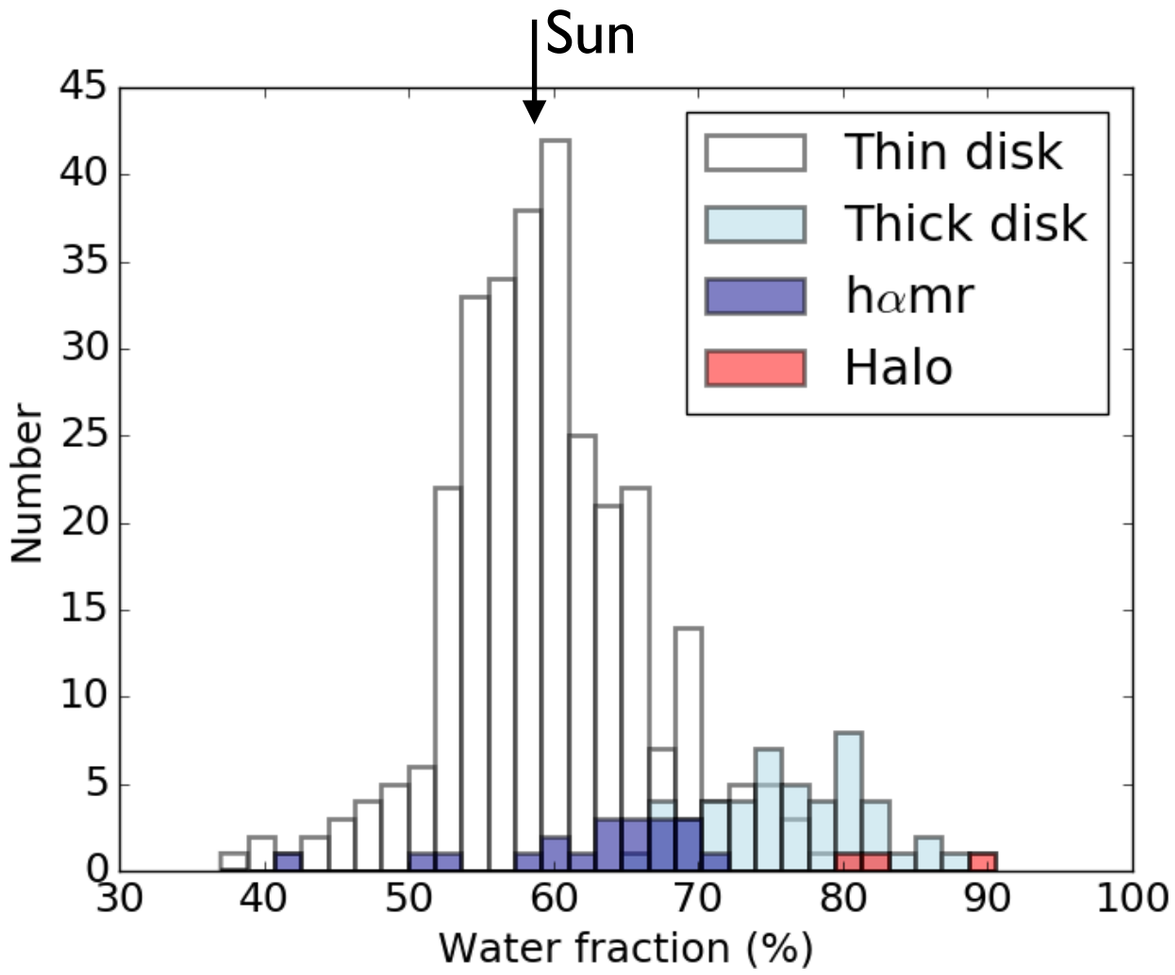
Download Data

Name	HD number	RA	Dec	Vmag	σ(Vmag)	π	σ(π)	Source of π	Teff	σ(Teff)	logg	σ(logg)	LC logg	σ(LC logg)	Vt	σ(Vt)	[Fe/H]	σ([Fe/H])	Mass	σ(Mass)	Reference
11 Com	107383	12 20 43.02	+17 47 34.33	4.74	0.02	11.25	0.22	Simbad	4830	79	2.61	0.13	-	-	1.70	0.10	-0.34	0.06	2.00	0.29	Mortier et al. 2013b
11 UMi	136726	15 17 05.88	+71 49 26.04	5.02	-	8.19	0.19	Simbad	4340	70	1.60	0.15	-	-	1.60	0.80	0.04	0.04	1.80	0.25	Dollinger et al. 2009
14 And	221345	23 31 17.41	+39 14 10.30	5.22	-	12.63	0.27	Simbad	4773	100	2.53	0.10	-	-	1.64	0.30	-0.26	0.11	1.45	-	Luck & Heiter 2007
14 Her	145675	16 10 24.31	+43 49 03.52	6.67	-	56.91	0.34	Simbad	5311	87	4.42	0.18	-	-	0.92	0.10	0.43	0.08	0.95	0.09	Santos et al. 2004
16 Cyg B	186427	19 41 51.97	+50 31 03.08	6.20	-	47.14	0.27	Simbad	5772	25	4.40	0.07	-	-	1.07	0.04	0.08	0.04	1.00	0.07	Santos et al. 2004
18 Del	199665	20 58 25.93	+10 50 21.42	5.52	-	13.28	0.31	Simbad	5076	38	3.08	0.10	-	-	1.32	0.04	0.00	0.03	2.33	0.05	Mortier et al. 2013b
24 Sex	90043	10 23 28.37	-00 54 08.09	6.44	0.01	12.91	0.38	Simbad	5069	62	3.40	0.13	-	-	1.27	0.07	-0.01	0.05	1.81	0.08	Mortier et al. 2013b
30 Ari B	16232	02 36 57.74	+24 38 53.02	7.09	-	24.52	0.68	Simbad	6377	170	4.49	0.05	-	-	-	-	0.14	0.18	1.16	0.04	Guenther et al. 2009
4 Uma	73108	08 40 12.81	+64 19 40.57	4.60	-	12.74	0.26	Simbad	4564	100	2.28	0.10	-	-	1.69	0.30	-0.16	0.13	1.48	-	Luck & Heiter 2007
42 Dra	170693	18 25 59.13	+65 33 48.52	4.83	-	10.36	0.20	Simbad	4513	100	2.24	0.10	-	-	1.59	0.30	-0.39	0.12	1.74	-	Luck & Heiter 2007
47 Uma	95128	10 59 27.97	+40 25 48.92	5.04	0.05	71.11	0.25	Simbad	5954	25	4.44	0.10	-	-	1.30	0.04	0.06	0.03	1.04	0.08	Santos et al. 2004
51 Peg	217014	22 57 27.98	+20 46 07.79	5.46	0.05	64.07	0.38	Simbad	5804	36	4.42	0.07	-	-	1.20	0.05	0.20	0.05	1.04	0.08	Santos et al. 2004

Predicting rocky planet composition in the Galaxy

- Thin disk stars (like the Sun): planets should be mostly "Earth like"
- Thick disk: lower iron-to-silicate ratios => bigger mantles?
- Thick disk planets should have more water!





Santos+2017, subm.

ia instituto de astrofísica e ciências do espaço

U.PORTO

Nuno C. Santos
nuno.santos@astro.up.pt

In brief…

- Stellar chemistry is providing important clues for planet composition and structure!
  - Planets formed in different galactic regions/populations/ages may have different composition
  - We may be able to predict (at least statistically) planet composition from stellar chemistry
  - Constraints for models of planets detected by PLATO (also CHEOPS/TESS)
  - Implications for plate tectonics? and life?

Nuno C. Santos
nuno.santos@astro.up.pt

Thank you!

Questions?

Acknowledgements:

ia instituto de astrofísica e ciências do espaço

U.PORTO

Nuno C. Santos
nuno.santos@astro.up.pt