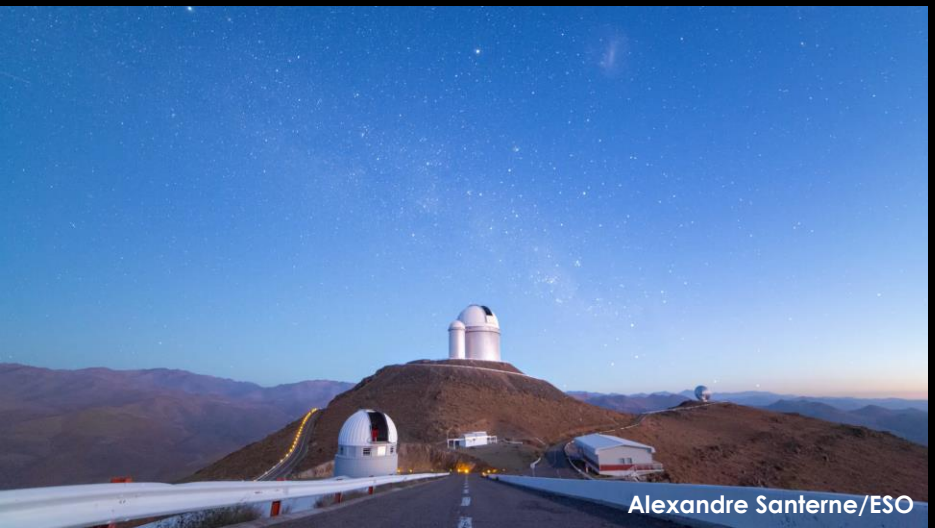
Red dwarfs and the nearest terrestrial planets

Guillem Anglada-Escudé
Queen Mary University of London

Queen Mary University of London

Abel Mendez/PHL



Alexandre Santerne/ESO

Alexandre Santerne/ESO

FANTASTIC PLANETS
AND WHERE TO FIND THEM

Guillem Anglada-Escudé
Queen Mary University of London

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University of London

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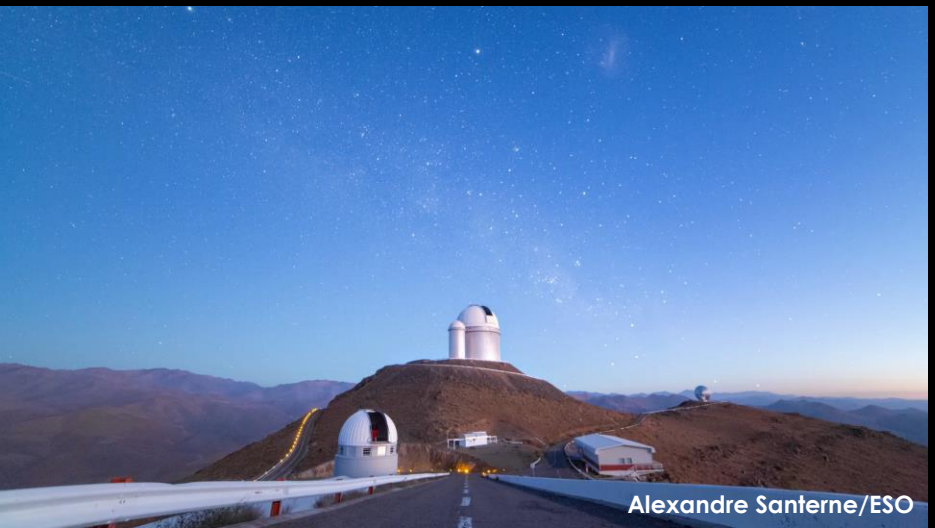


Alexandre Santerne/ESO

Alexandre Santerne/ESO

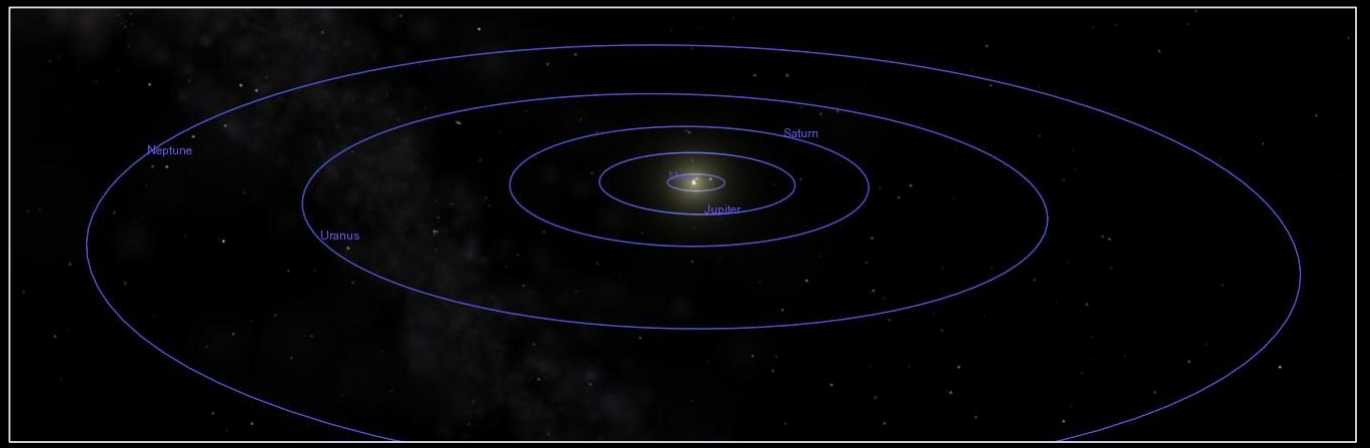
Outline of the talk

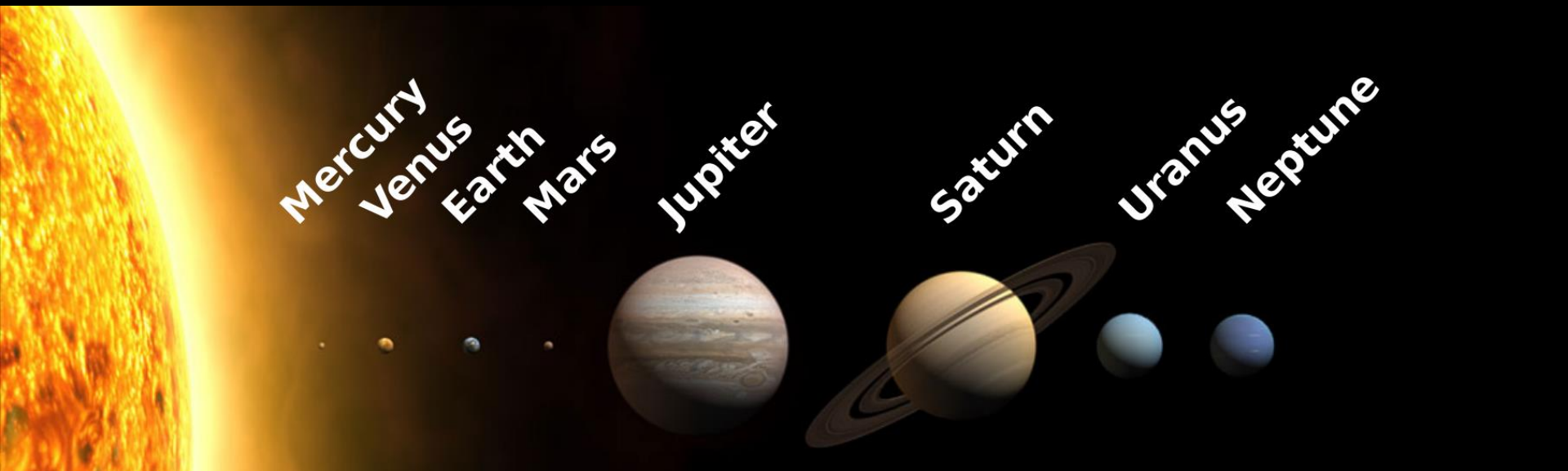
Red dwarf planets : why?

Very nearby stars

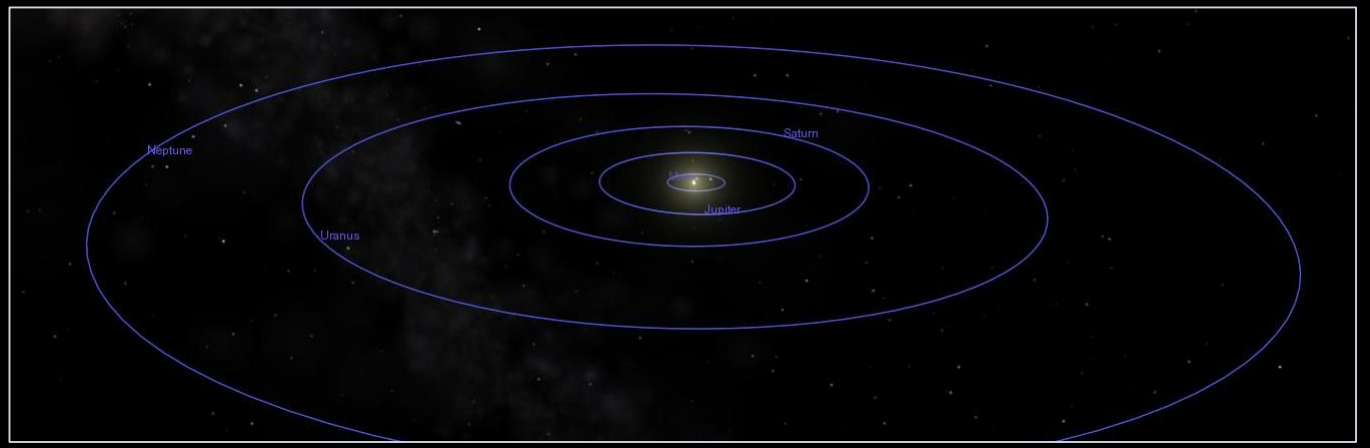
Characterization prospects

Exterior


Neptune
Saturn
Jupiter
Uranus

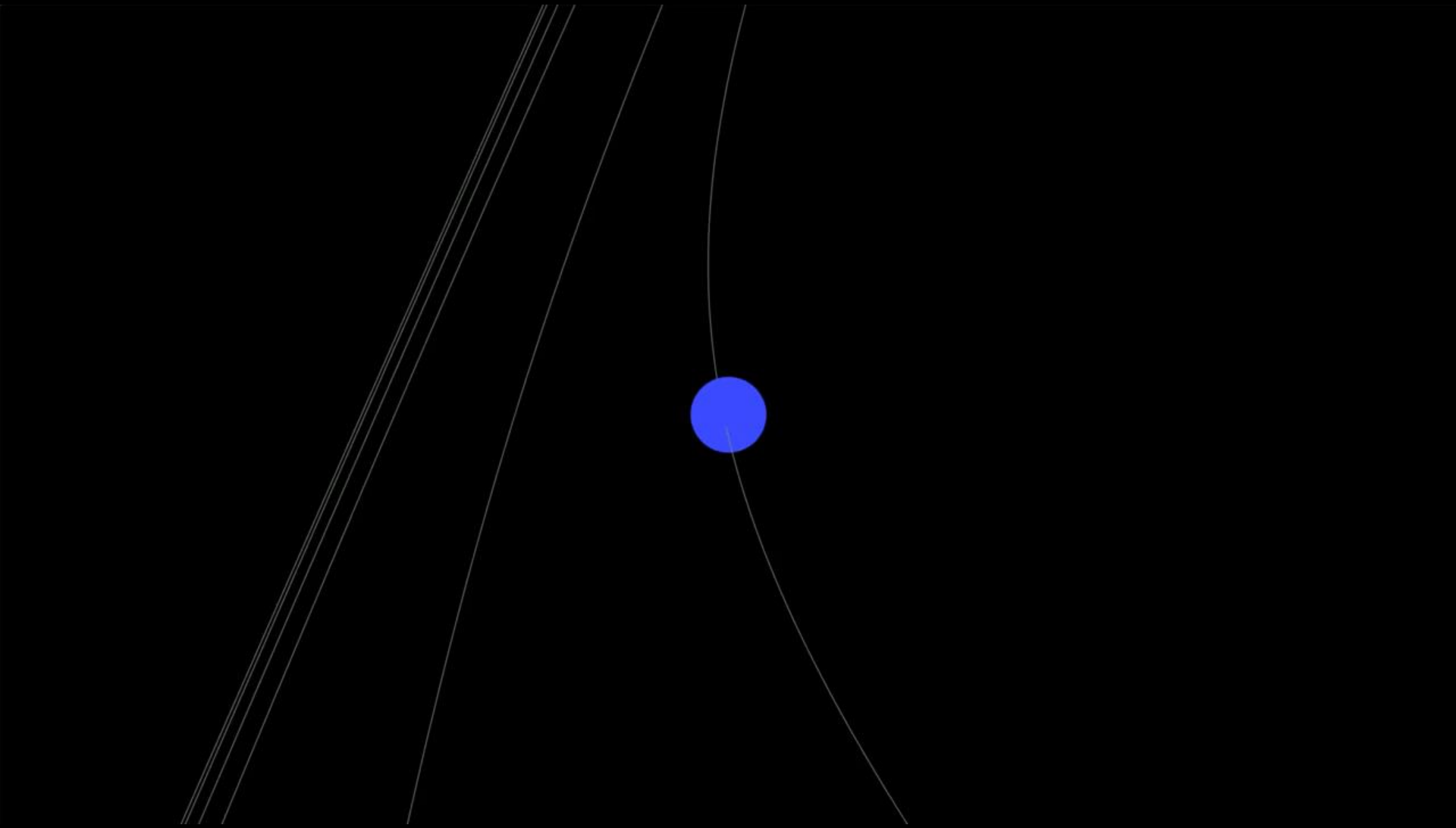

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune

Exterior



Nearest stars

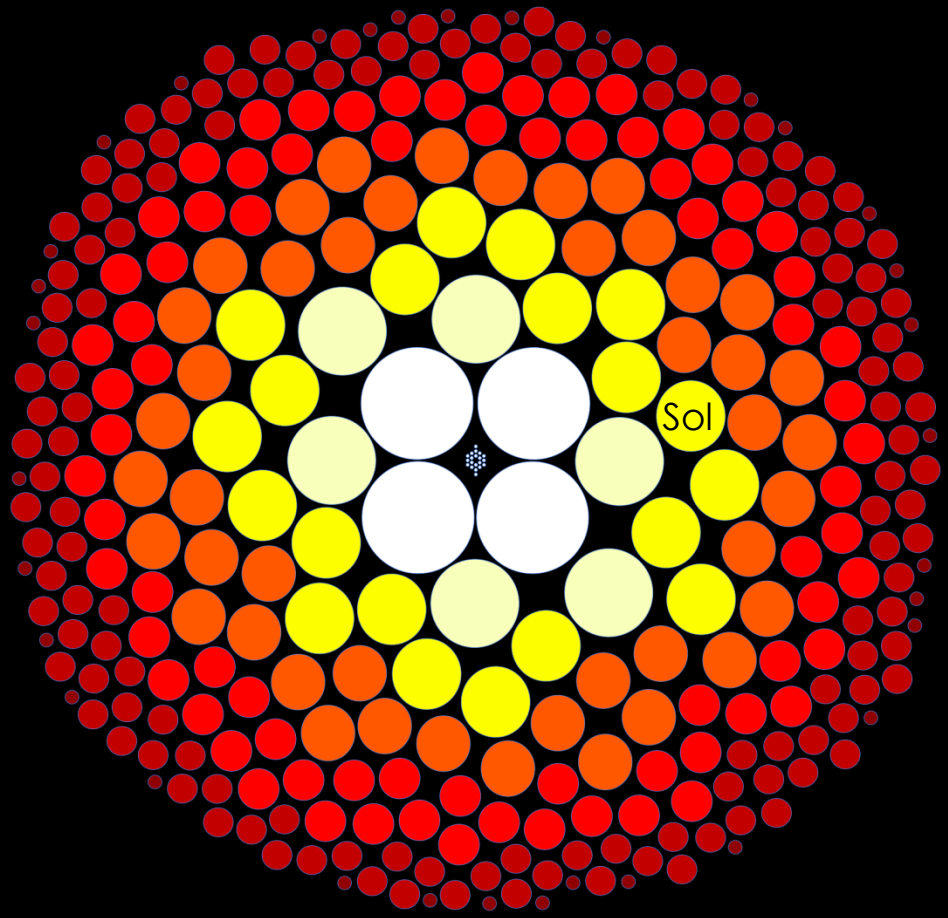
Nearest stars



Visuals - Adric Riedel, Music - Clarence Yapp
RECONS Group
www.recons.org

Nearest stars

10 pc sample



Credits : Todd Henry, RECONS group
www.recons.org

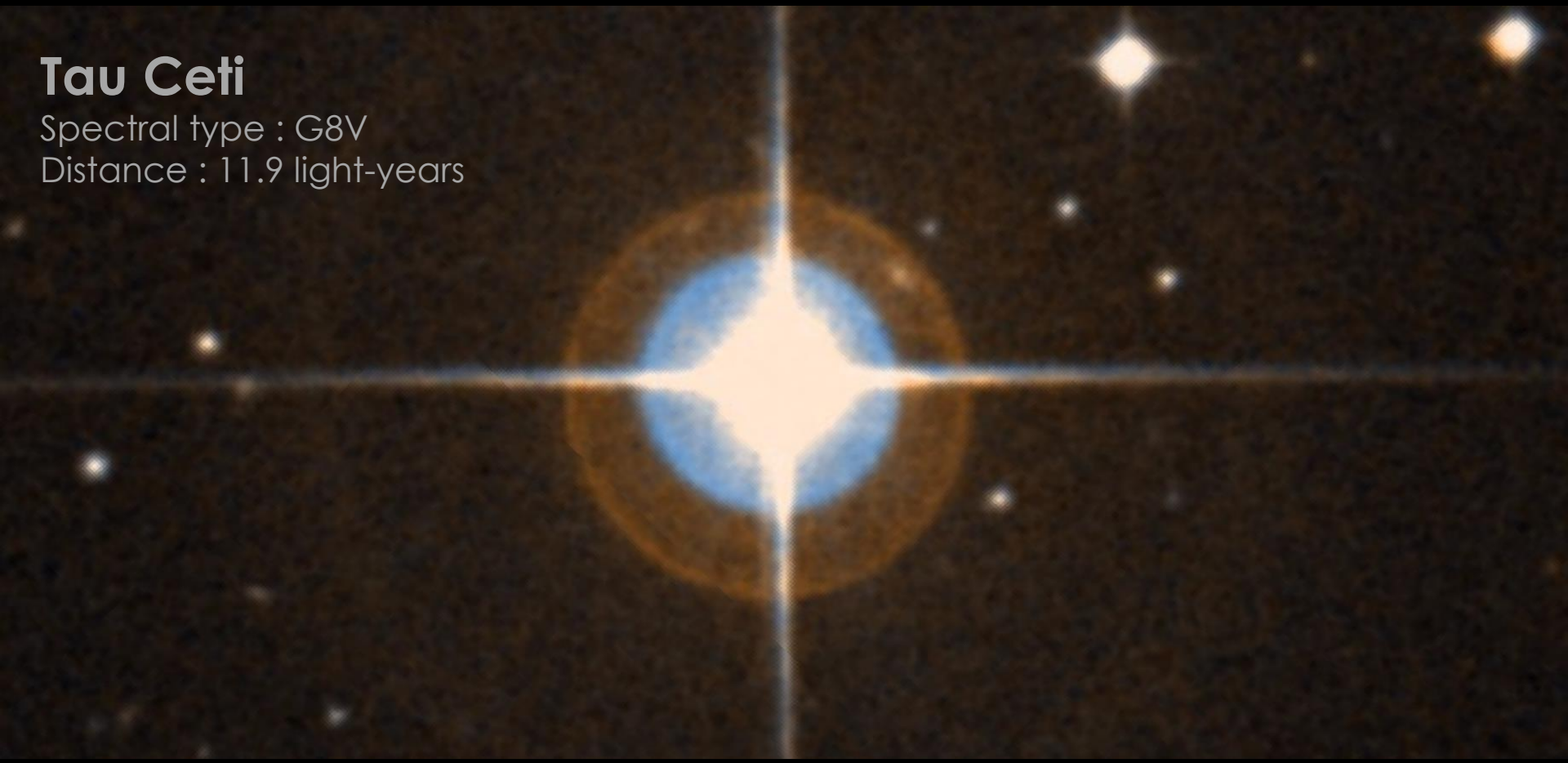
Take home message 1

Most stars are red dwarfs

It’s complicated…

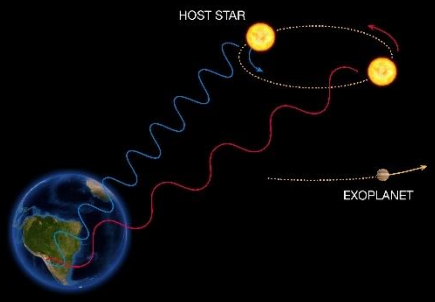
Tau Ceti
Spectral type : G8V
Distance : 11.9 light-years

It’s complicated…

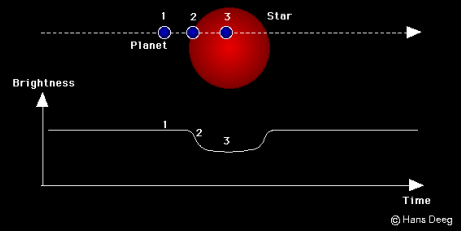


1 / 10 000 000 000

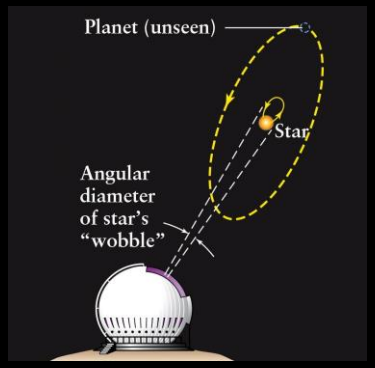
How we find exoplanets?



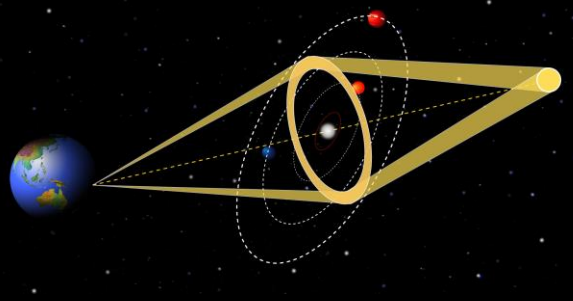
Radial velocity



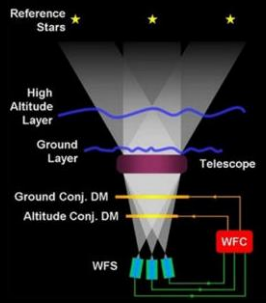
Transits



Astrometry

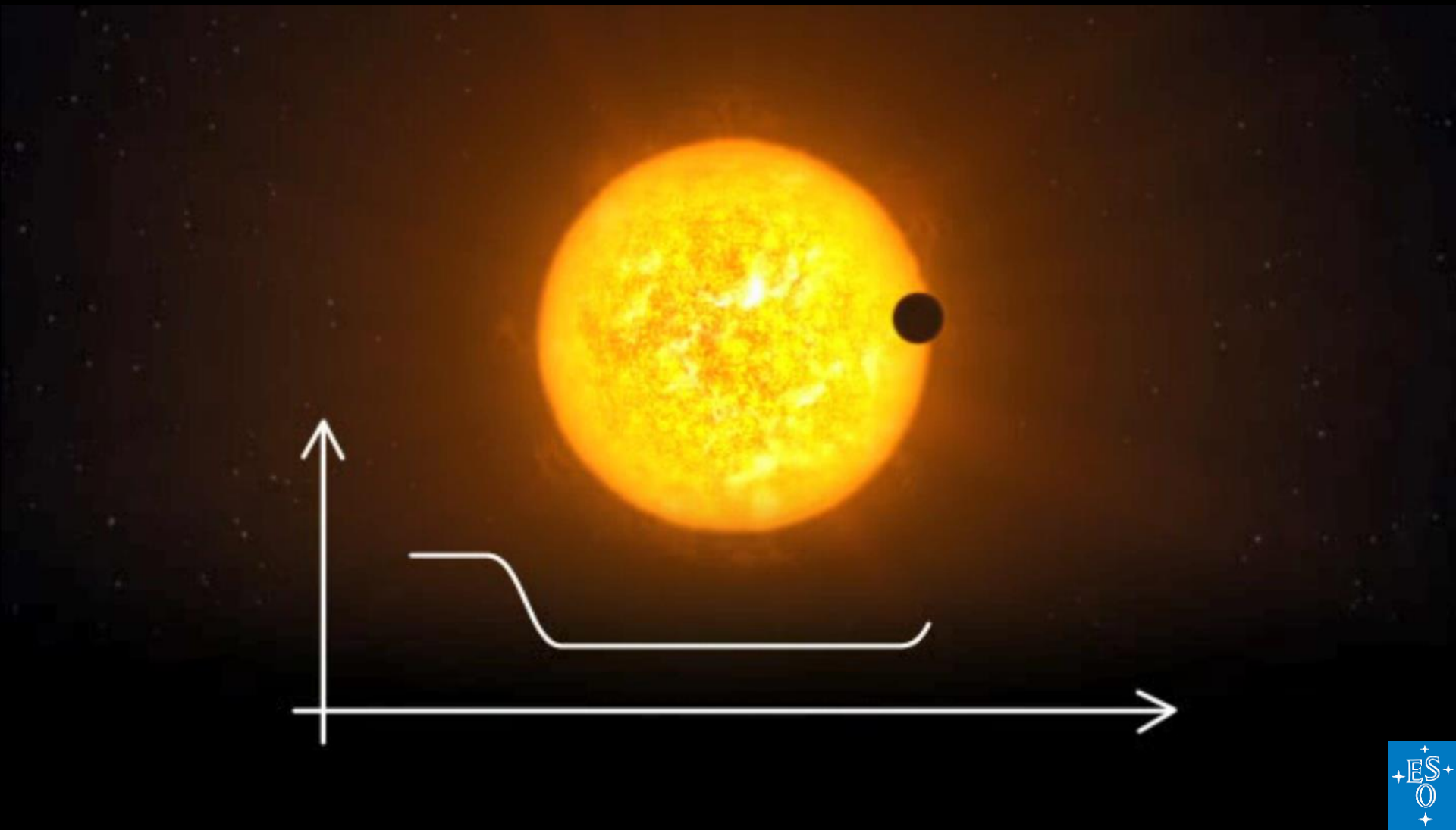


Microlensing

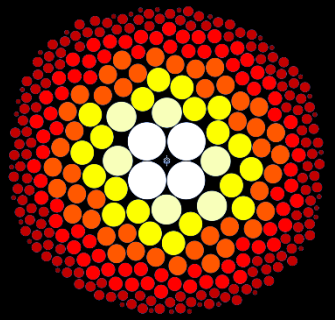


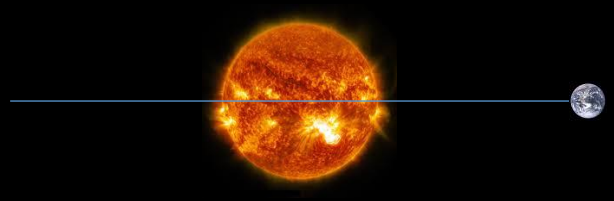
Direct imaging

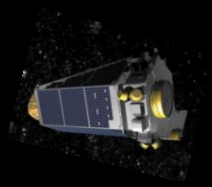
Transit photometry

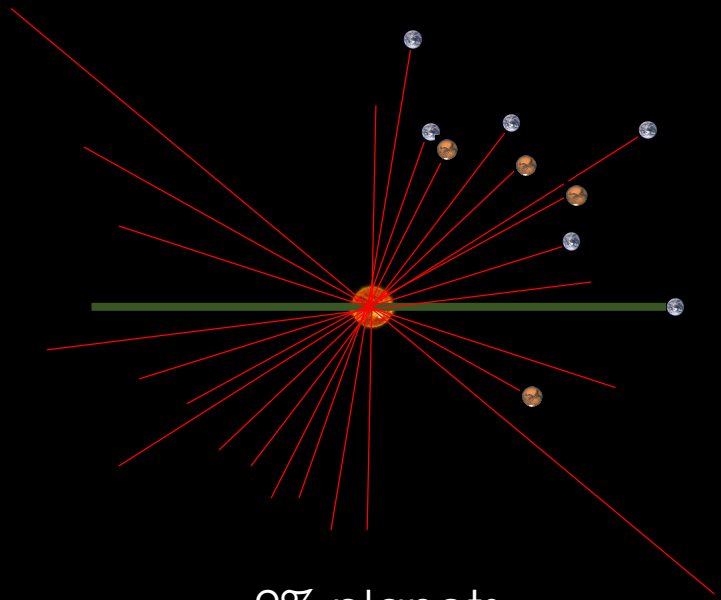


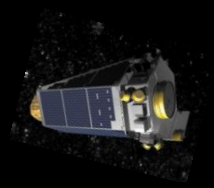
Transit photometry







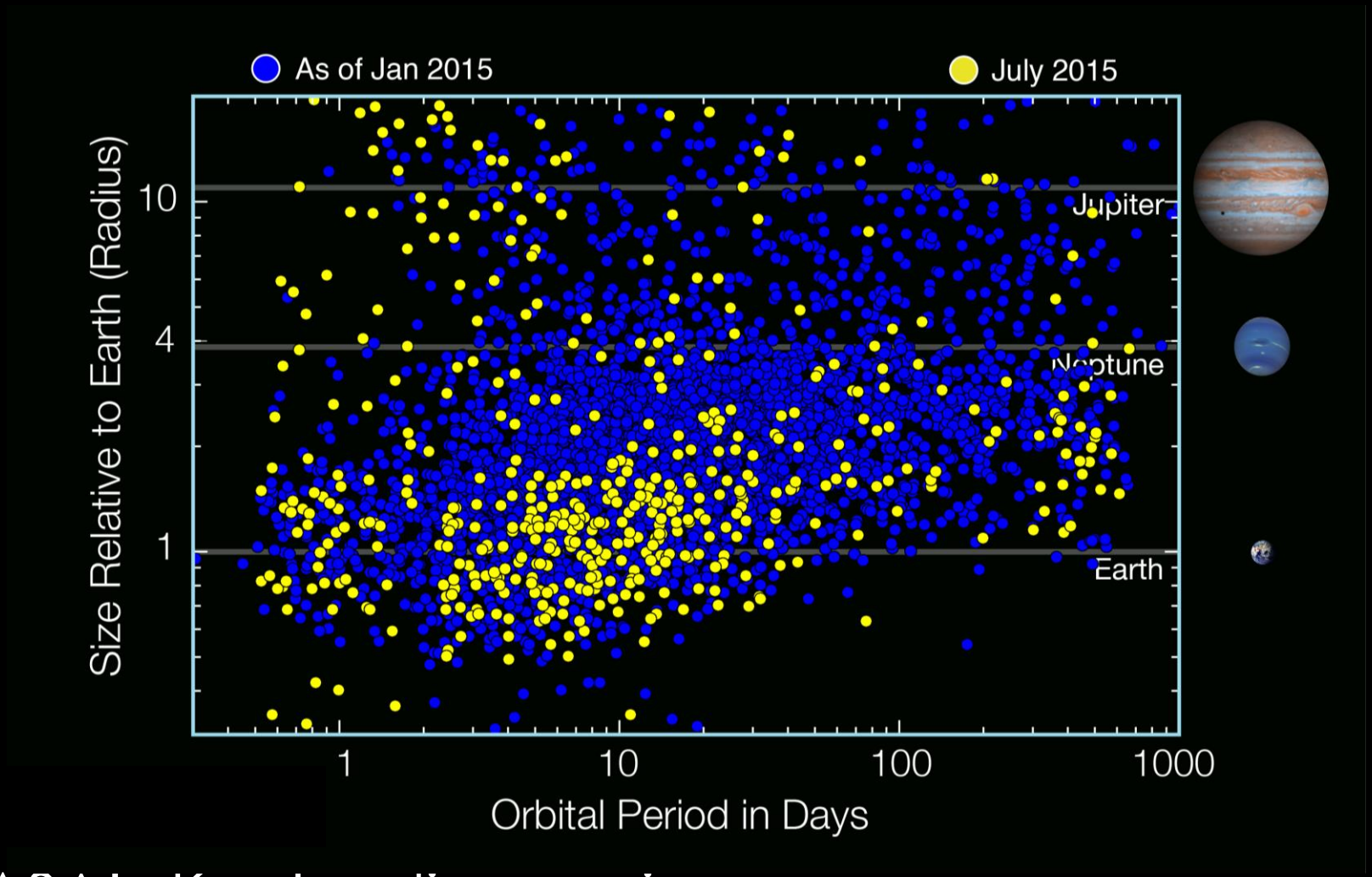




110 000 stars

~2% planets transit → ~2200 planets

Transit photometry



NASA's Kepler discoveries

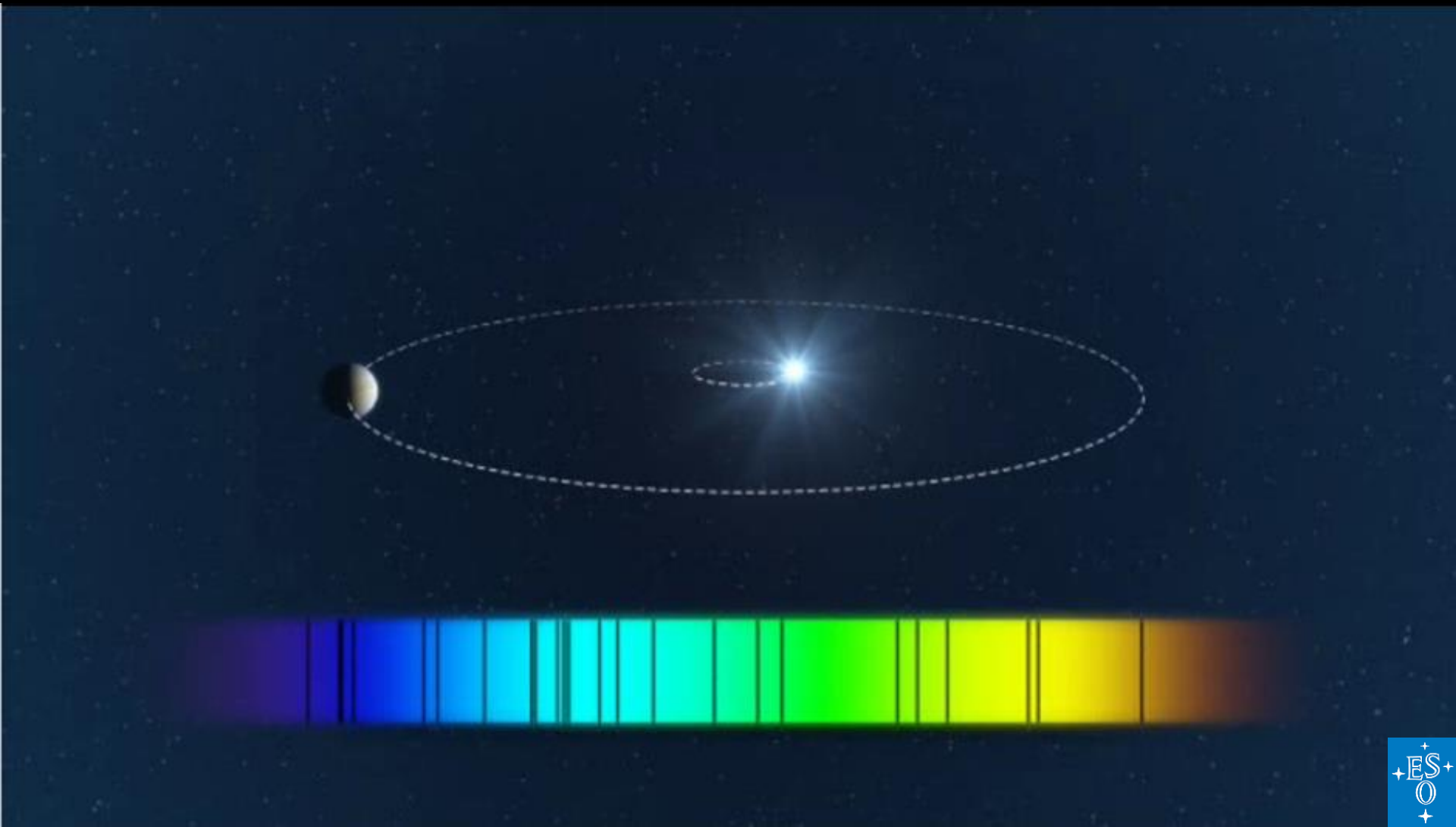
Take home message 1

Most stars are red dwarfs

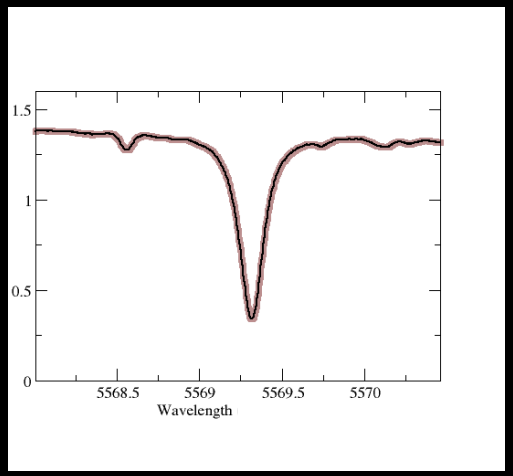
Take home message 2

Most stars have small planets in short period orbits

The Doppler method

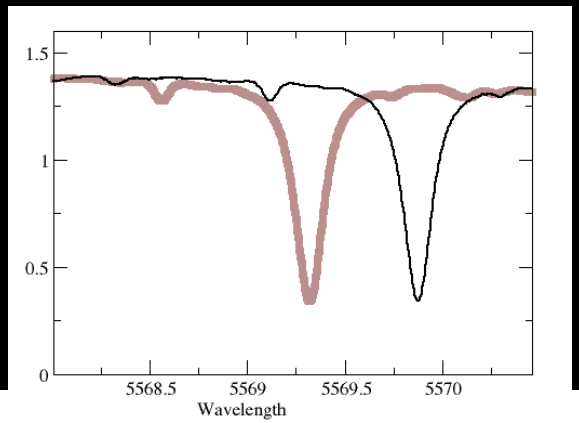


The Doppler method

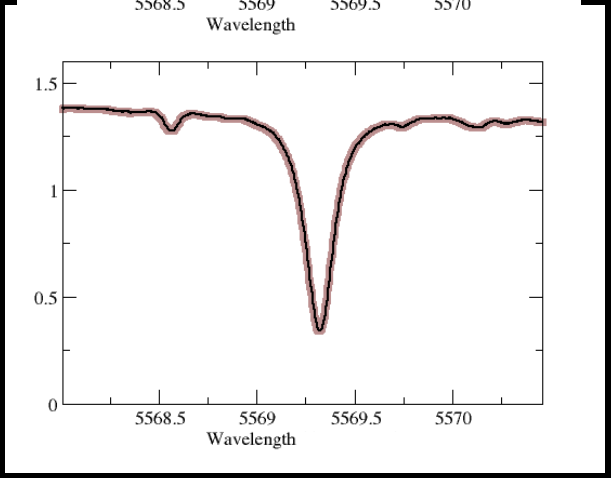


Solar line is 15 km/s

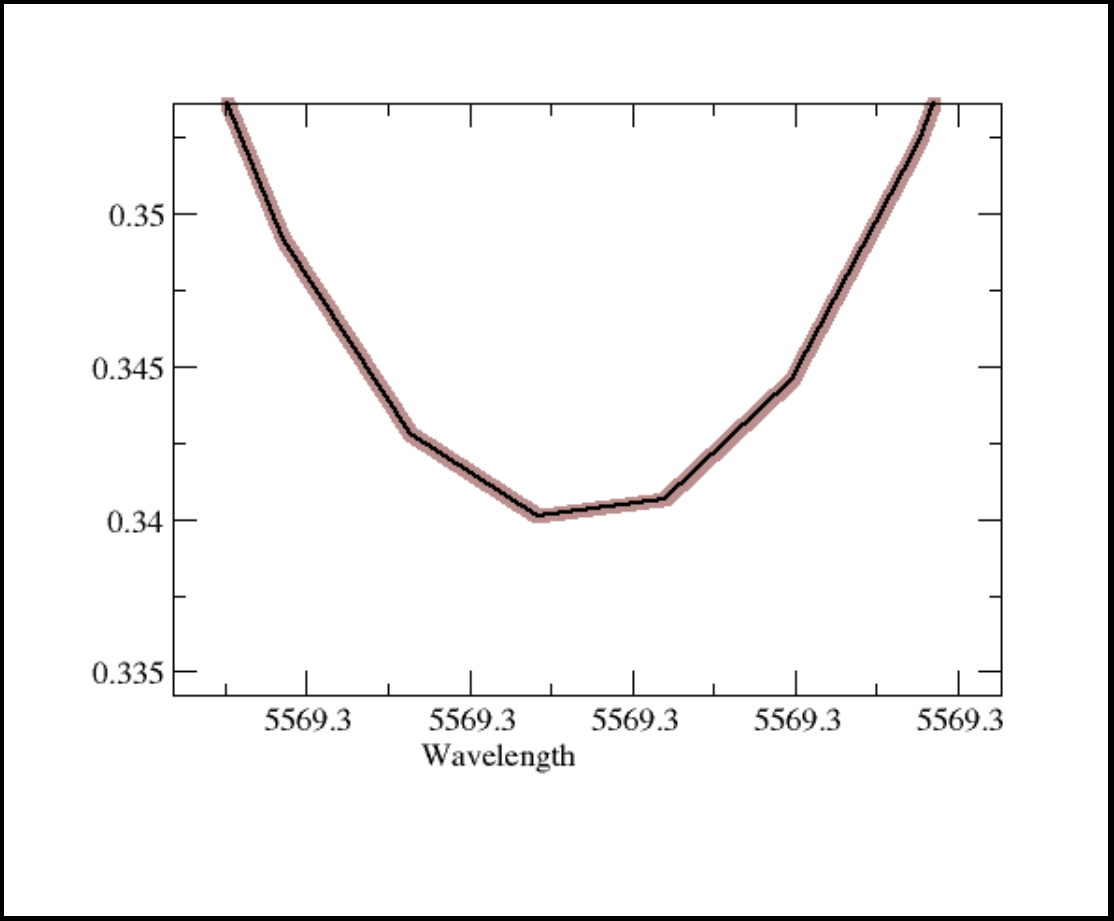
Spectroscopic binary K=30 km/s



Hot jupiter K=300 m/s

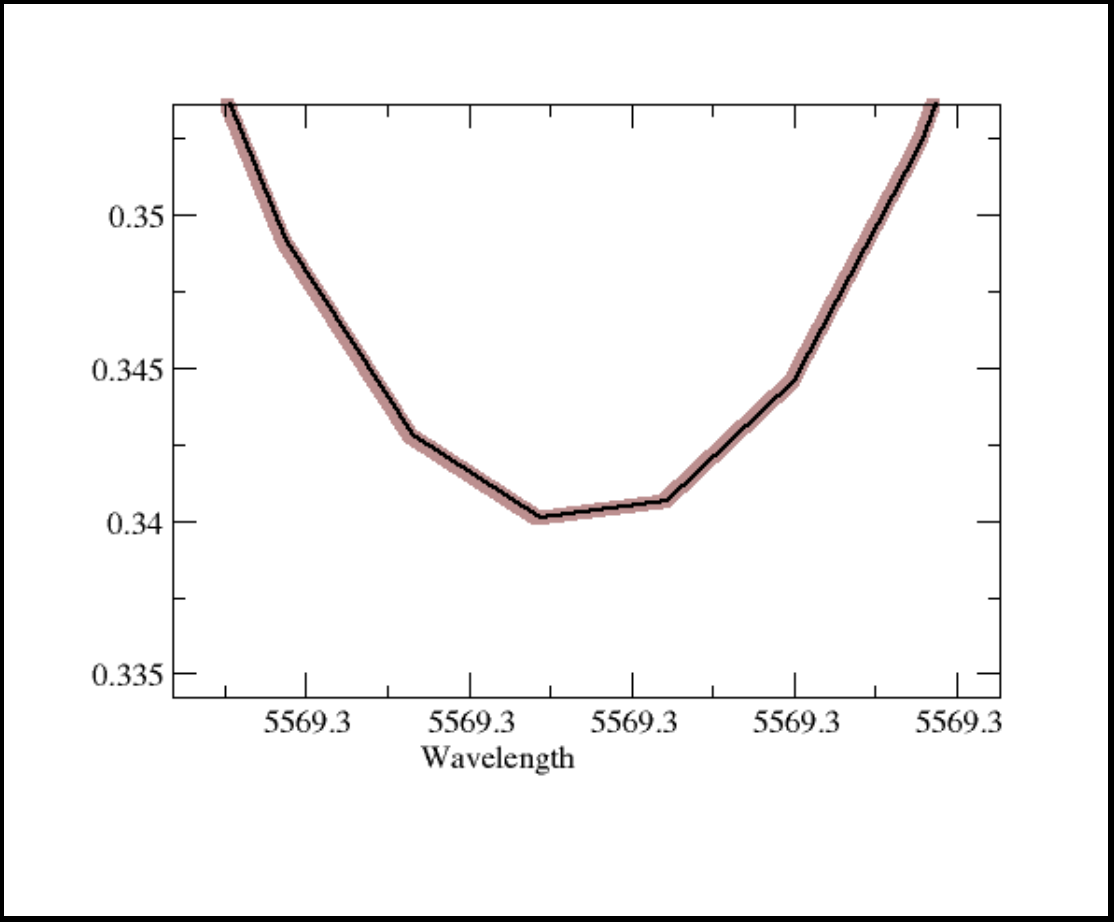


The Doppler method



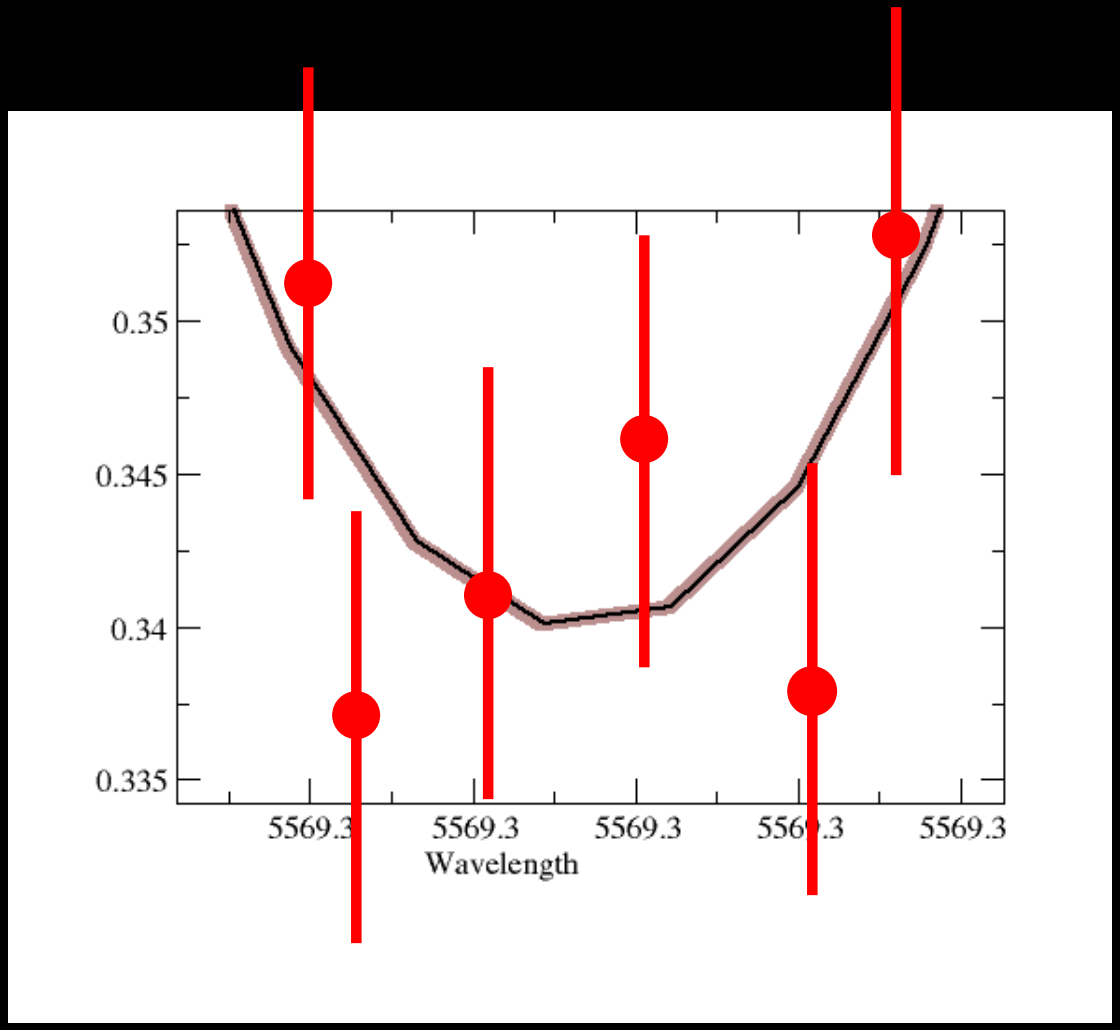
0 m/s

The Doppler method

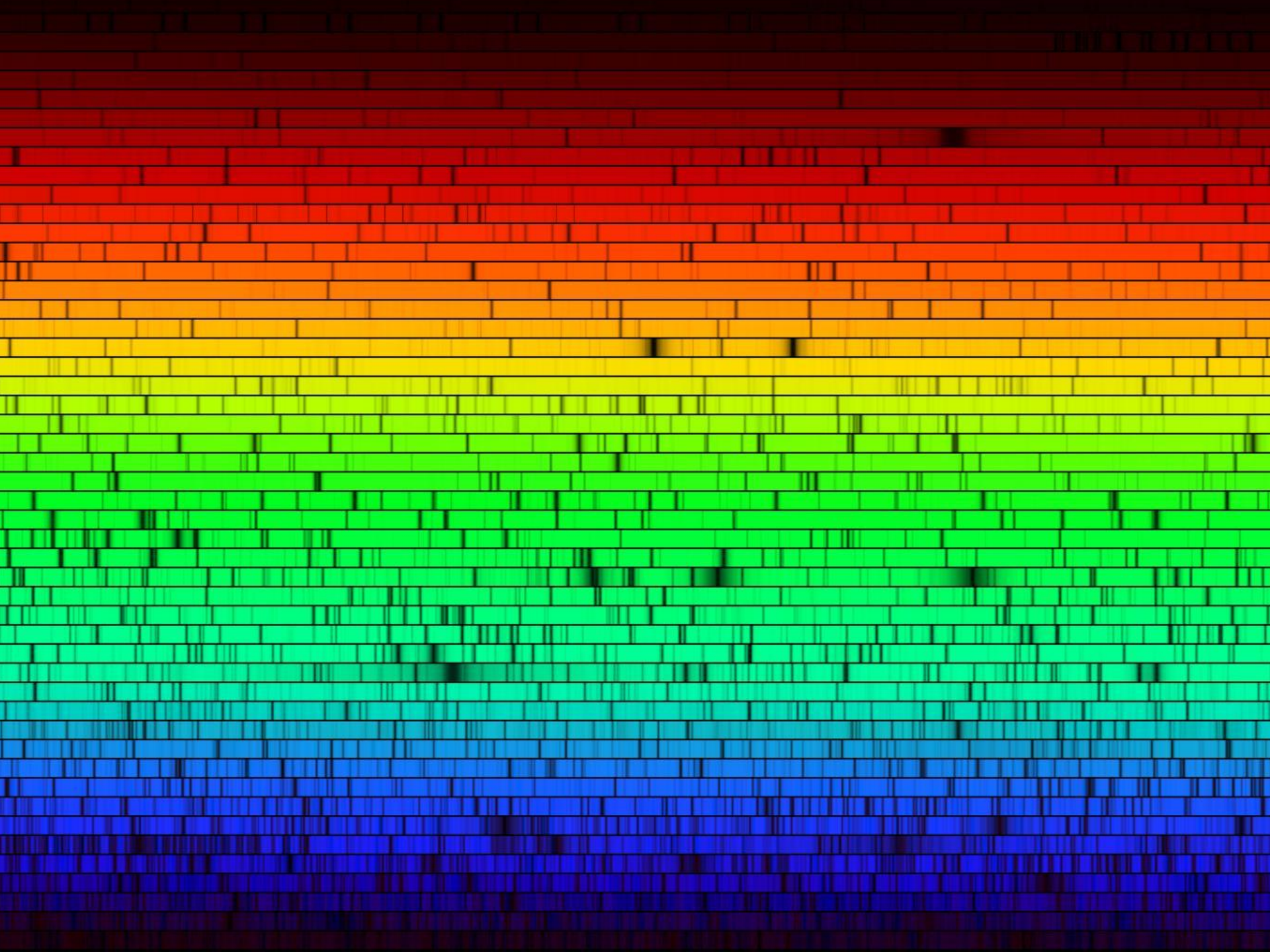


+ 3 m/s

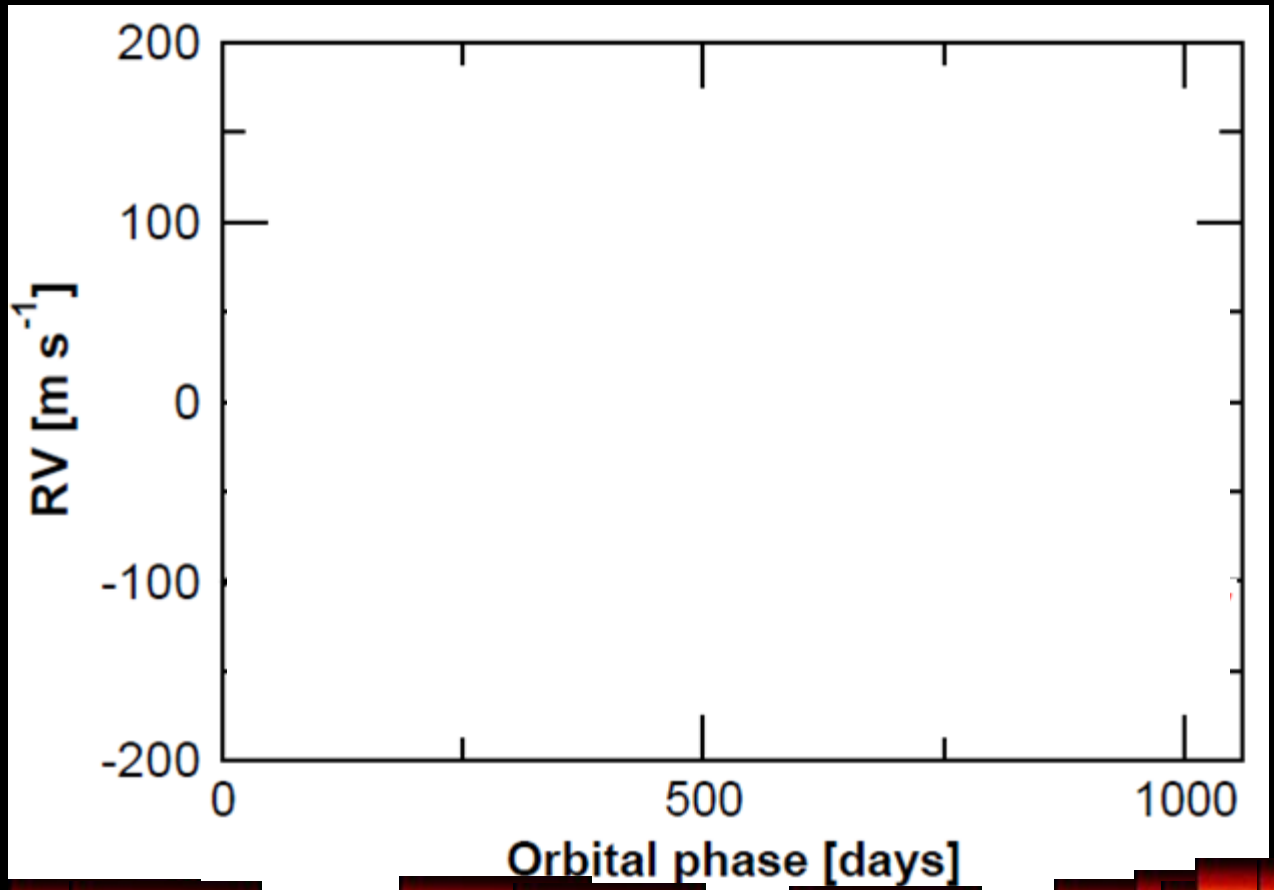
The Doppler method



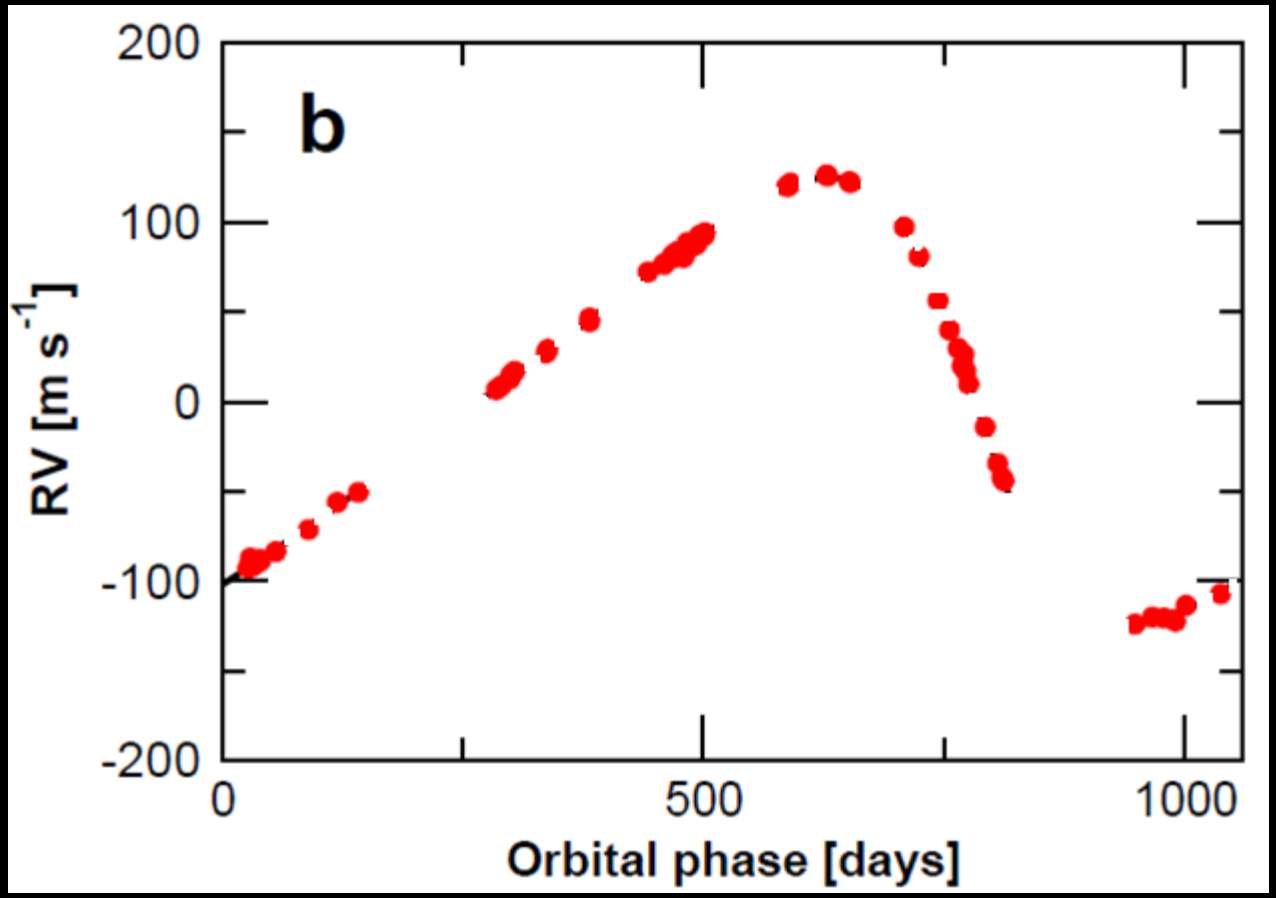
+ 3 m/s



The Doppler method

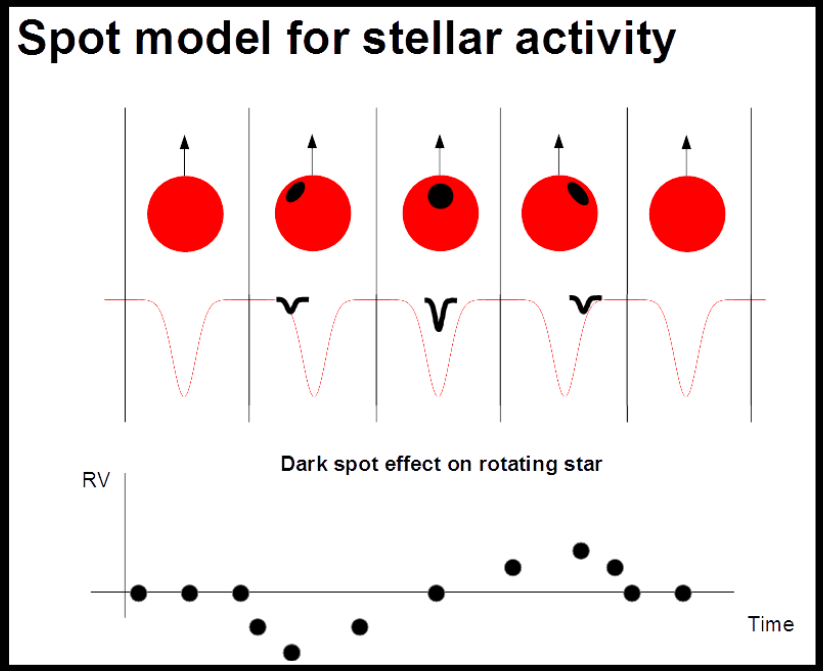


The Doppler method



The Doppler method

Detecting a planet in the presence of stellar noise



Parameter space exploration

Multiparametric fit to the data

Model comparison

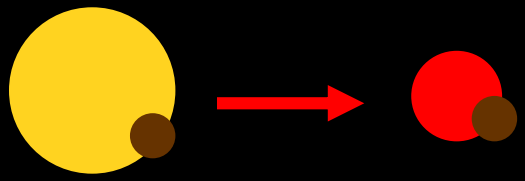
Astrophysics

Additional observables

The red-dwarf advantage

50 ppm
0.1 m/s

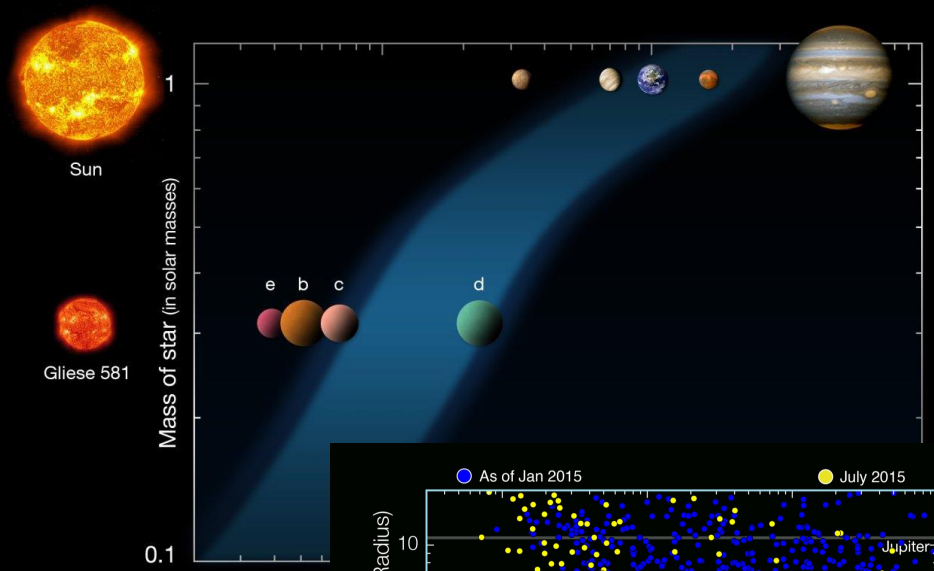
>1000 ppm
1.5 m/s

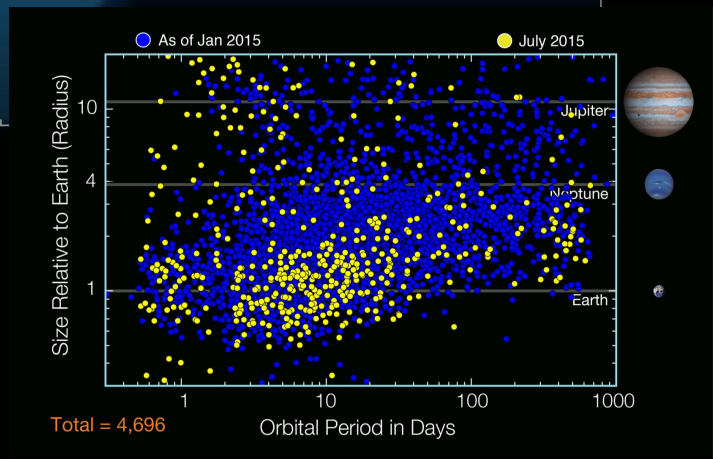


G2V **M5.5V**

Transit x30-100
Doppler > x15
Nperiods >x30

> X50-200 easier





Take home message 1

Most stars are red dwarfs

Take home message 2

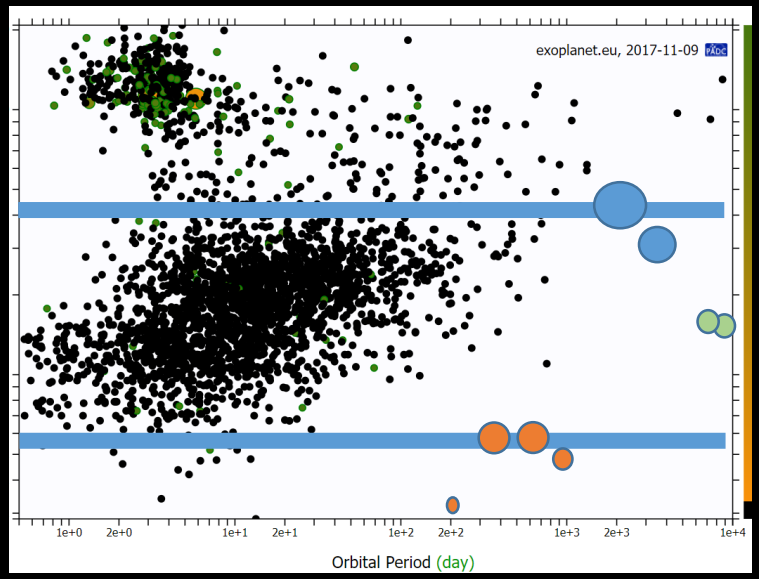
Most stars have small planets
in short period orbits

Take home message 3

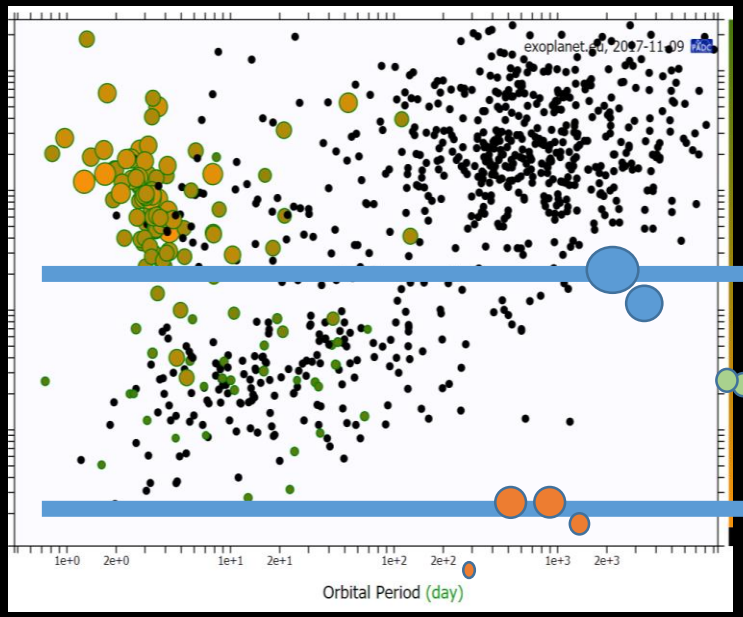
Planets around red dwarfs are
(way) easier to detect

FANTASTIC
PLANETS
AND WHERE TO FIND THEM

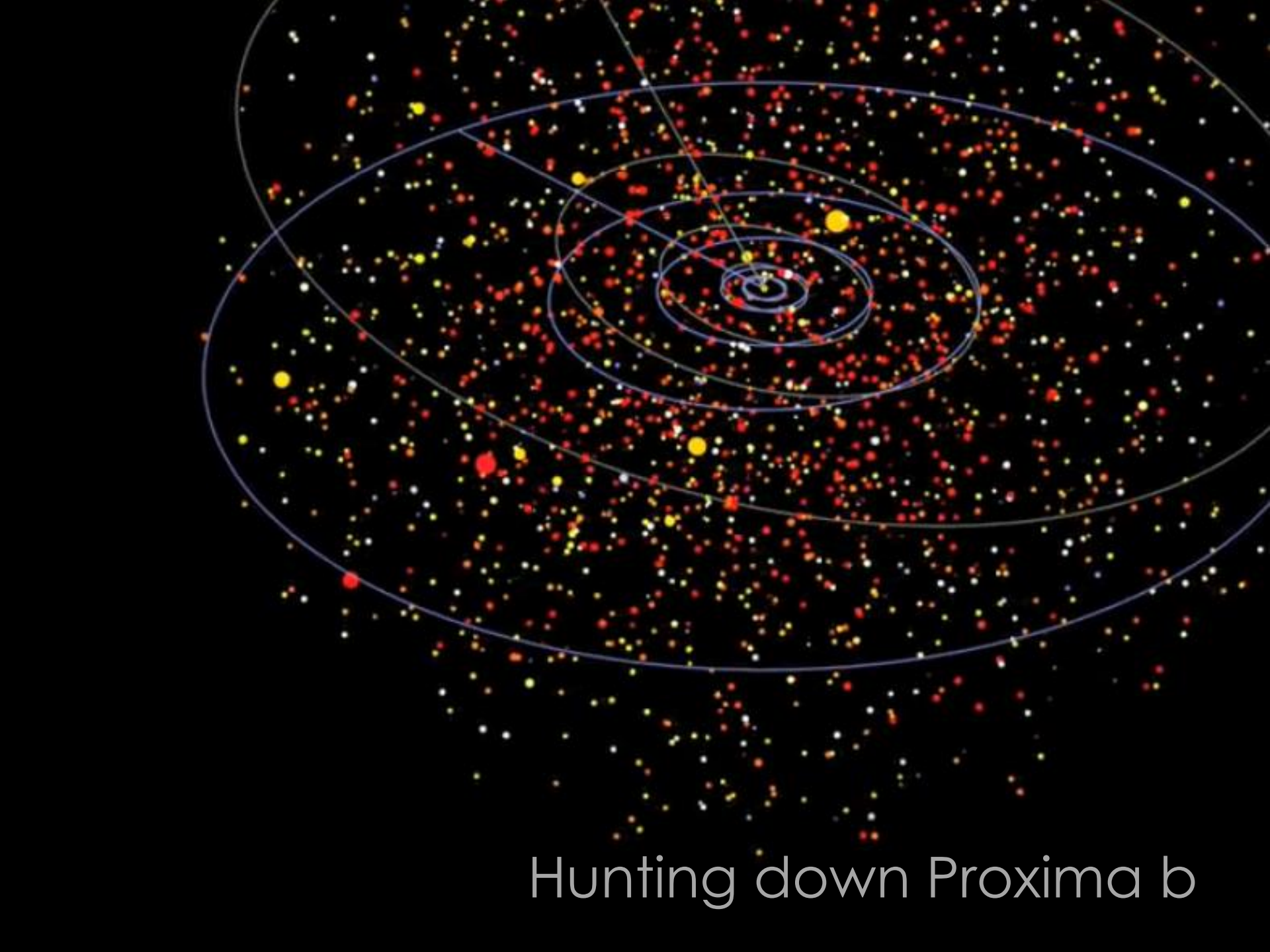
The exoplanet zoo today



Transit method
Radius



Radial velocity method
Mass

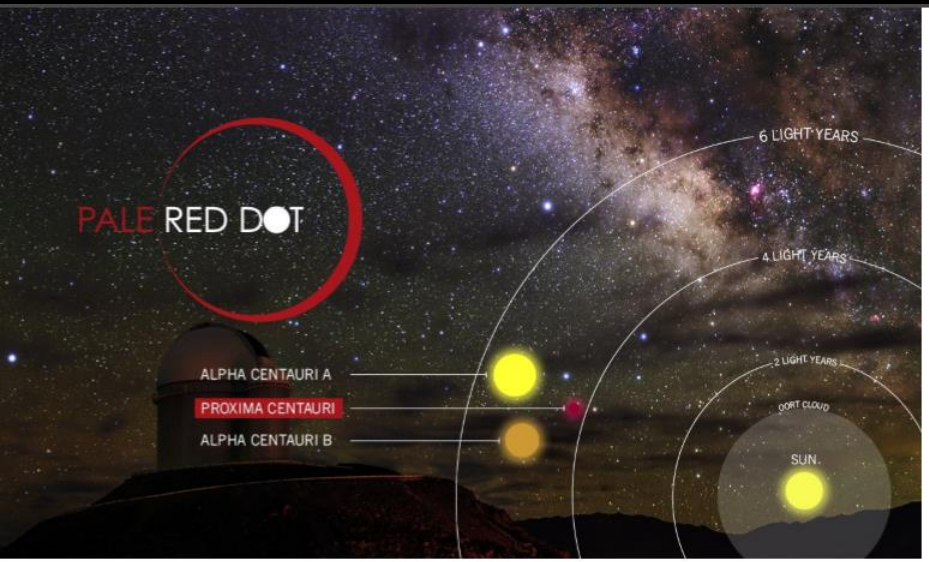


Hunting down Proxima b

Planets around Proxima Centauri?

2000-2008 : UVES planet search	232
2002-2012 : HARPS- various teams	70
2013-2014 : HARPS – our data	194
Pre 2016	**496**
2016 : HARPS – Pale Red Dot	**54**

Pale Red Dot



Doppler Spectroscopy (HARPS) Guillem Anglada-Escude, Mathias Zechmeister

Doppler Spectroscopy (UVES) R. Paul Butler, Martin Kuerster, Michael Endl

Data analysis Mikko Tuomi, James Jenkins, Hugh R. A. Jones

Spectroscopic Analyses John Barnes, Zaira M. Berdinas, John P. Strachan

Photometry Cristina Rodriguez-Lopez, Eloy Rodriguez, Nicolas Morales, Jose Ortiz, Ignacio de la Cueva, Maria J. Lopez Gonzalez(ASH2), Yiannis Tsappras (lcogt.net), Aviv Ofir, Marcin Kiraga

Stellar physics and activity Ansgar Reiners, Pedro Amado, Sandra V. Jeffers, Julien Morin

Planet formation and Dynamics Richard P. Nelson, Gavin Coleman, Sijme-Jan Paardekooper, Stefan Dreizler, Benjamin Giesers

Observers Christopher Marvin, Luis F. Sarmiento

HARPS, La Silla/ESO, Doppler RV

LCOGT.net, Photometry

ASH2-SpaceObs, Photometry

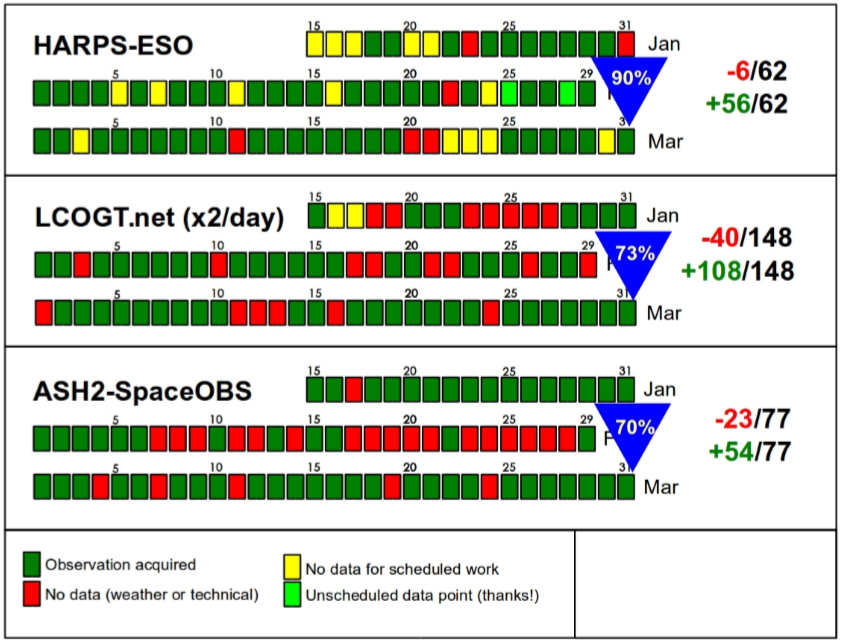
Outreach website
www.palereddot.org

Twitter
@Pale_red_dot
#palereddot

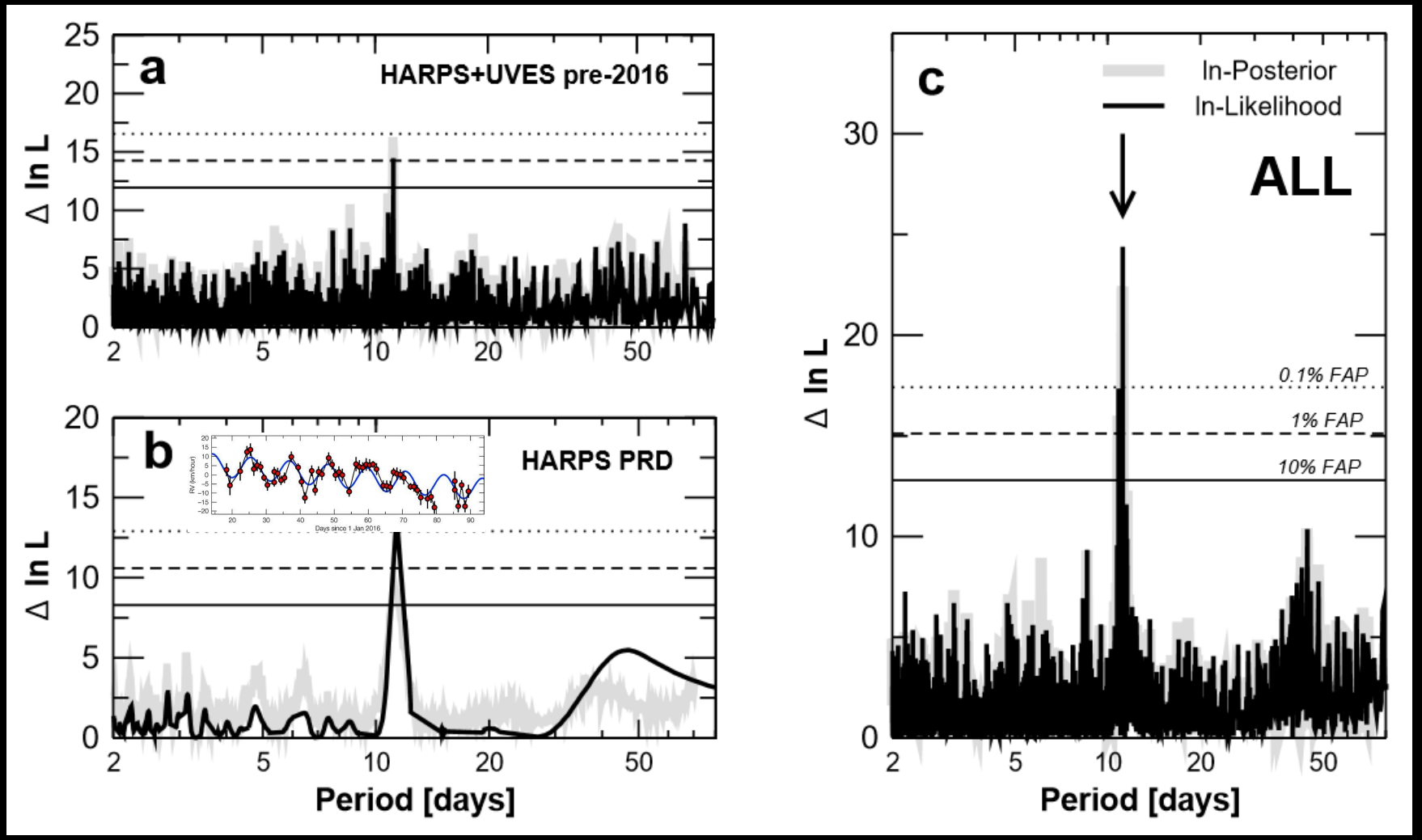
Facebook page
Pale Red Dot

Pale Red Dot

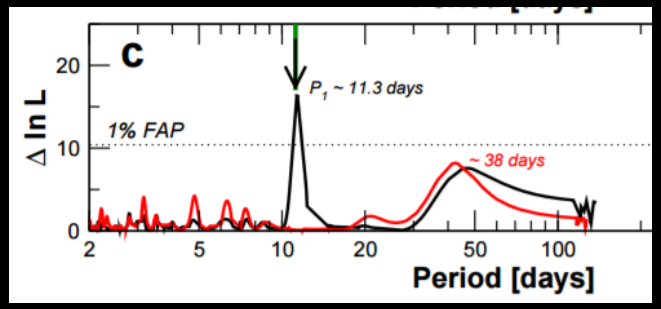
- Signal between 1-2 m/s
- Cover 3-6 orbital periods
- At least 45 Rvs for statisical significance
- Optimized regular sampling
- Simult. photometric follow-up *easy*
- Outreach project in col. ESO epod



Pale Red Dot

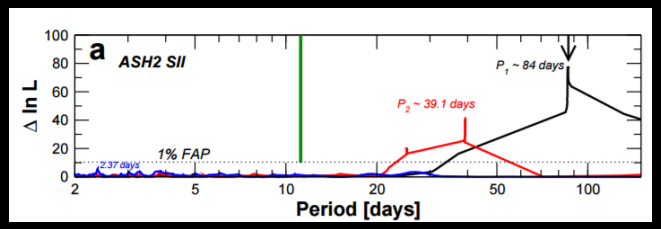

a
HARPS+UVES pre-2016
b
HARPS PRD
RV (cm/s)
Days since 1 Jan 2016
Δ ln L
Period [days]
c
ln-Posterior
ln-Likelihood
ALL
0.1% FAP
1% FAP
10% FAP
Δ ln L
Period [days]

RV



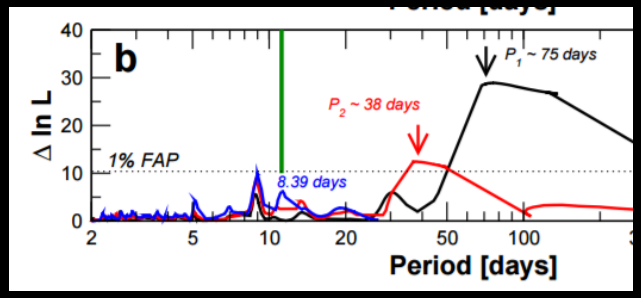
~40 days?

Photometry

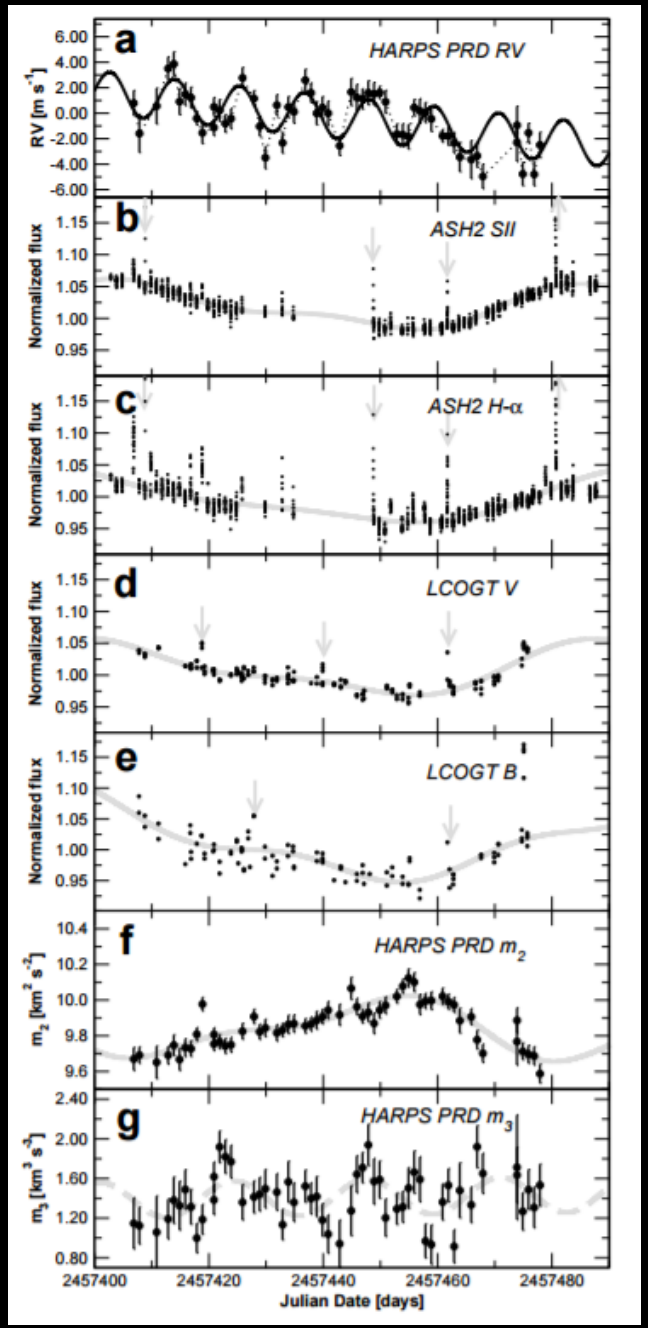


~80 days &
40 days

Width of the spectral lines



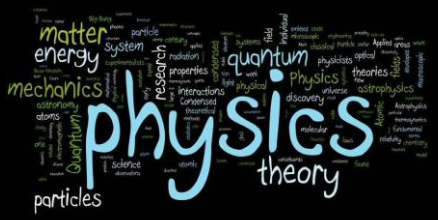
~80 days &
40 days



Pale Red Dot

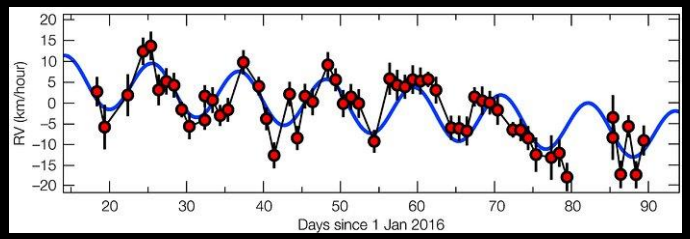
Signal

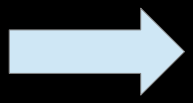
Amplitude : **1.4 m/s**
Orbital period : **11.2 days**



Proxima b

Min. mass : **1.3 Mearth**
Orb. distance : **5% of an AU**
Irradiance : **65% of Earth's**
Eq. temperature : **~235 K (-40 C)**





Follow-up on Proxima Cen

ACA + ALMA observations – Disk? No, superflares

Transit searches

- MOST photometry (no convincing transits)
- Ground based – Several attempts, some tentative transit-like features but not entirely consistent
- SPITZER 4.5 microns (in prep)

Other observations are coming...

Climate and atmospheric circulation models

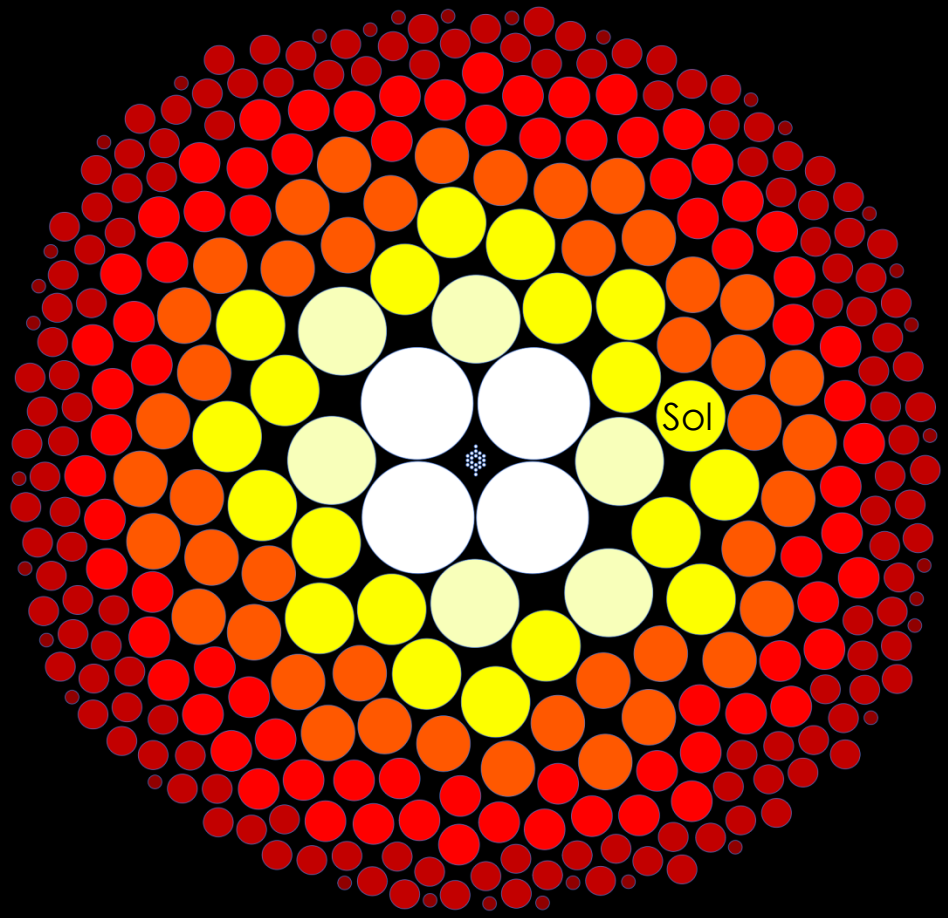
Atmospheric loss of red dwarf planets (megaflares & solar wind)

Evidence for volatile rich worlds (>5% water content)

Nearby star sample

Nearest stars

10 pc sample



Credits : Todd Henry, RECONS group
www.recons.org

The 5pc sample

1 A 7 K 5 wd
1 F 46 M
3 G 6 BD

#	Name	ID		Sp.type	Radius	Teff	L/L_{Sun}	Center HZ [AU]	Distance [pc]	$Mass/M_{Sun}$
0	**Sol**	**Sun**		**G2.0V**	**1.00**	**5800**	**1.000000**	1.225	**0.000**	**1.00**
1	Proxima Centauri	GJ 551	C	M5.5V	0.17	2700	0.001328	0.046	1.301	0.11
1	Alpha Centauri A	GJ 559	A	G2.0V	0.88	6700	1.411351	1.491	1.339	1.14
	Alpha Centauri B		B	K0.0V	0.77	5400	0.456550	0.848	1.339	0.92
2	Barnard's Star	GJ 699		M4.0V	0.20	3100	0.003245	0.072	1.833	0.16
3	Luhmann 16 A	WISE 1049		L7.5V	0.05	1350	0.000006	0.003	1.998	0.05
	Luhmann 16 B			T0.5	0.04	1250	0.000003	0.002	1.998	0.05
4	Wolf 359	GJ 406		M6.0V	0.16	2500	0.000919	0.038	2.386	0.09
5	Lalande 21185	GJ 411		M2.0V	0.34	3700	0.019190	0.174	2.543	0.46
6	Sirius	GJ 244	A	A1.0V	1.65	10000	24.252863	6.181	2.632	1.99
	Sirius B		B	WD/DA2	0.01	20000	0.014340	0.002	2.632	1.00
7	BL Ceti	GJ 65	A	M5.5V	0.25	2600	0.002519	0.063	2.674	0.11
	UV Ceti		B	M6.0V	0.23	2700	0.002411	0.062	2.674	0.10
8	Ross 154	GJ 729		M3.5V	0.21	3100	0.003791	0.077	2.965	0.17
8	Ross 248	GJ 905		M5.5V	0.22	2700	0.002222	0.059	3.161	0.12
9	epsilon Eridani	GJ 144		K2.0V	0.63	5400	0.302474	0.690	3.213	0.85
10	Lacaille 9352	GJ 887		M1.5V	0.41	3800	0.032031	0.225	3.278	0.53
11	Ross 128	GJ 447		M4.0V	0.21	3000	0.003294	0.072	3.354	0.16
12	EZ Aquarii A	GJ 886	A	M5V	0.16	3000	0.001858		3.454	
	EZ Aquarii C		C	M6V	0.15	2700	0.001072		3.454	
	EZ Aquarii B		B	M5V	0.22	2700	0.002202	0.059	3.448	0.08
13	61 Cygni A	GJ 820	A	K5.0V	0.71	4000	0.115336	0.427	3.497	0.70
	61 Cygni B		B	K7.0V	0.53	4300	0.086071	0.369	3.497	0.63
14	Procyon	GJ 280	A	F5.0IV-V	1.91	6700	6.561093	3.215	3.509	1.57
	Procyon B		B	WD/DQZ					3.507	0.50
15	LHS 58	GJ 725	A	M3.0V	0.34	3400	0.014173	0.150	3.521	0.35
	LHS 59		B	M3.5V	0.28	3300	0.008038	0.113	3.521	0.26
16	GX Andromedae	GJ 15	A	M1.5V	0.32	3800	0.019497	0.176	3.571	0.49
	GQ Andromedae		B	M3.5V	0.20	3200	0.003647	0.076	3.571	0.16
17	Epsilon Indi A	GJ 845	A	K5.0V	0.61	4900	0.190995	0.549	3.623	0.77
	Epsilon Indi B		B	T1.0V	0.08	1300	0.000016	0.005	3.623	0.07
	Epsilon Indi C		C	T6.0V	0.08	900	0.000004	0.002	3.623	0.05
18	DX Cancri	GJ 1111		M6.0V	0.16	2400	0.000780	0.035	3.626	0.09
19	Tau Ceti	GJ 71		G8.0V	0.70	5700	0.463582	0.855	3.650	0.92
20	GJ 1061	GJ 1061		M5.0V	0.18	2700	0.001509	0.049	3.676	0.11

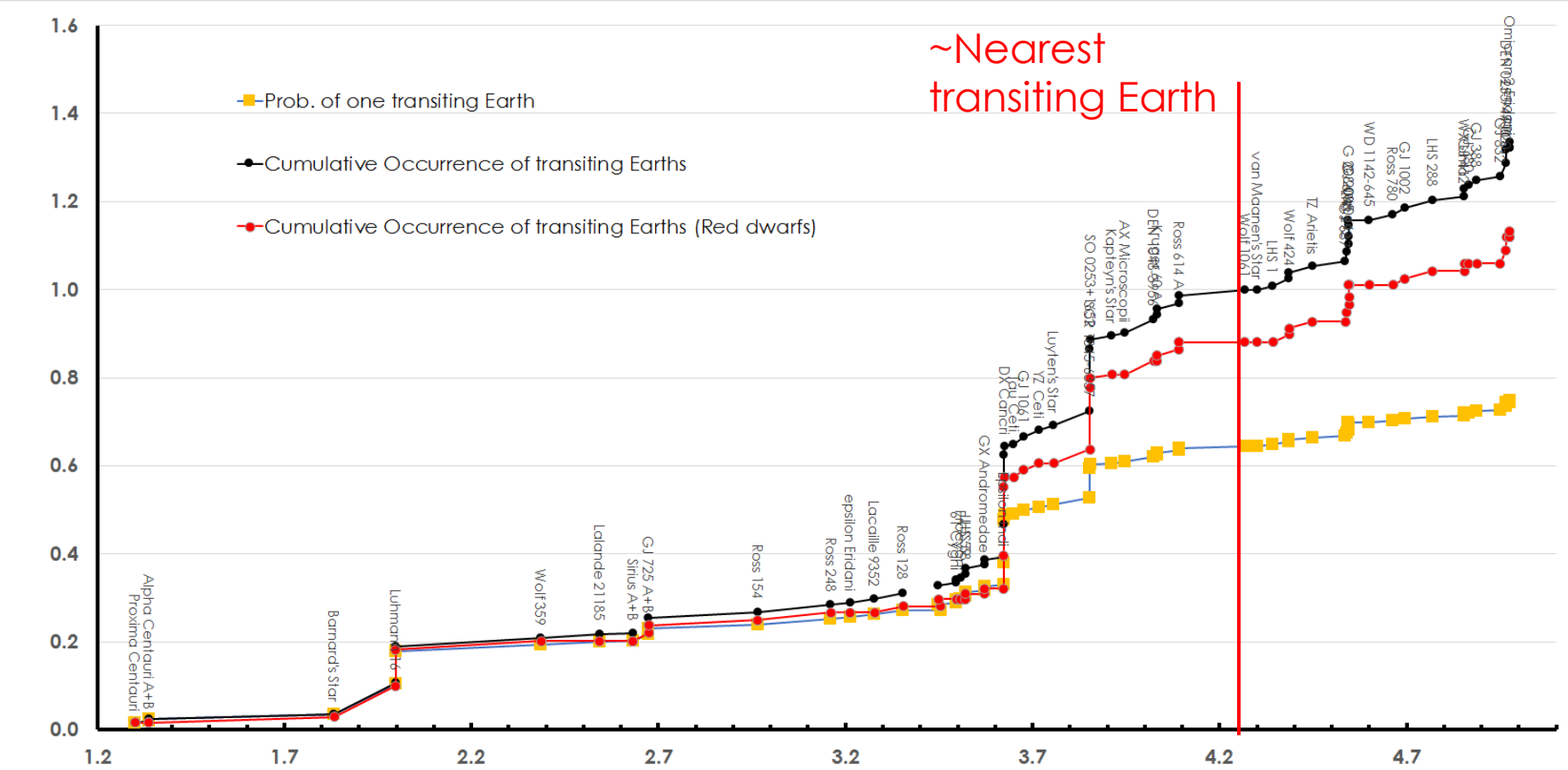
#	Name	ID		Sp.type	Radius	Teff	L/L_{Sun}	Center HZ [AU]	Distance [pc]	$Mass/M_{Sun}$
21	YZ Ceti	GJ 54.1		M4.5V	0.18	2900	0.002077	0.057	3.716	0.13
22	Luyten's Star	GJ 273		M3.5V	0.32	3200	0.009384	0.121	3.756	0.26
23	SCR 1845-6357 A	SCR 1845	A	M8.5V	0.13	2000	0.000239	0.019	3.854	0.07
	SCR 1845-6357 B	SCR 1845	B	T5V	0.08	950	0.000005	0.003	3.854	0.03
24	SO 0253+1652	SO 0253		M7.0V	0.16	2400	0.000724	0.034	3.855	0.08
25	Kapteyn's Star	GJ 191		M1.5VI	0.24	3800	0.010764	0.130	3.911	0.39
26	AX Microscopii	GJ 825		M0.0V	0.52	4100	0.067432	0.326	3.946	0.60
27	DEN 1048-3956	DEN 1048		M8.5V	0.13	2000	0.000257	0.020	4.024	0.07
28	Kruger 60 A	GJ 860	A	M3.0V	0.33	3300	0.011435	0.134	4.032	0.28
	Kruger 60 B		B	M4.0V	0.19	3200	0.003537	0.075	4.032	0.16
29	Ross 614 A	GJ 234	A	M4.0V	0.29	3000	0.005980	0.097	4.092	0.17
	Ross 614 B		B	M5.5V	0.16	2700	0.001144	0.043	4.092	0.10
30	Wolf 1061	GJ 628		M3.0V	0.32	3200	0.009684	0.124	4.267	0.26
31	van Maanen's Star	GJ 35		WD/DZ7.5	0.01					0.50
32	LHS 1	GJ 1		M1.5V	0.35	3700	0.020459	0.179	4.342	0.48
33	Wolf 424	GJ 473	A	M5.0V	0.21	2700	0.002141	0.058	4.386	0.12
	Wolf 424		B	M7.0V	0.18	2900	0.001986	0.056	4.386	0.12
34	TZ Arietis	GJ 83.1		M4.5V	0.20	2900	0.002410	0.062	4.448	0.14
35	GJ 687	GJ 687		M3.0V	0.41	3400	0.019742	0.176	4.536	0.39
36	LHS 292	LHS 292		M6.5V	0.15	2400	0.000634	0.032	4.539	0.08
37	G 208-044	GJ 1245	A	M5.5V	0.19	2700	0.001793	0.053	4.545	0.11
			B	M6.0V	0.15	2700	0.001072	0.041	4.545	0.07
	G 208-045		C	M7.0V	0.17	2100	0.000510	0.029	4.545	0.10
38	GJ 674	GJ 674		M2.5V	0.36	3400	0.015094	0.154	4.543	0.36
39	WD 1142-645	GJ440		WD/DQ D						0.50
40	Ross 780	GJ 876		M4.0V	0.39	3100	0.012589	0.141	4.663	0.27
41	GJ 1002	GJ 1002		M5.0V	0.14	2900	0.001278	0.045	4.695	0.11
42	LHS 288	LHS 288		M5.5V	0.15	2700	0.001072	0.041	4.769	0.11
43	GJ 412	GJ 412	A	M1.0V	0.35	3700	0.020931	0.182	4.854	0.48
	WX Uma		B	M5.5V	0.15	2600	0.000946	0.039	4.854	0.10
44	GJ 380	GJ 380		K7.0V	0.65	4100	0.106345	0.410	4.865	0.64
45	GJ 388	GJ 388		M3.0V	0.45	3300	0.021715	0.185	4.888	0.39
46	GJ 832	GJ 832		M1.5V	0.42	3600	0.026935	0.206	4.950	0.50
47	LP 944-020	LP 944-020		M9.0V	0.09	2000	0.000119	0.014	4.965	0.07
48	DEN 0255-4700	DEN 0255		L7.5V	0.09	1300	0.000021		4.966	0.05
49	Omicron 2 Eridani	GJ 166	A	K0.5V	0.74	5200	0.354013	0.747	4.975	0.89
			B	WD/DA4					4.975	0.50
			C	M4.5V	0.25	3200	0.005827	0.096	4.975	

RECONS : list of nearest stars
+ a few more

1 Earth-size planet in the HZ of the star

The 5 pc sample by transits

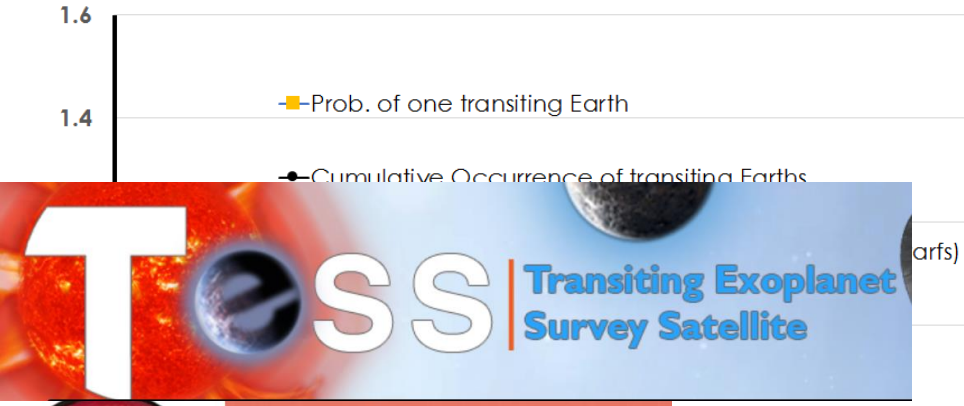
Chance of one transiting : ~75%
Expected number ~1.2



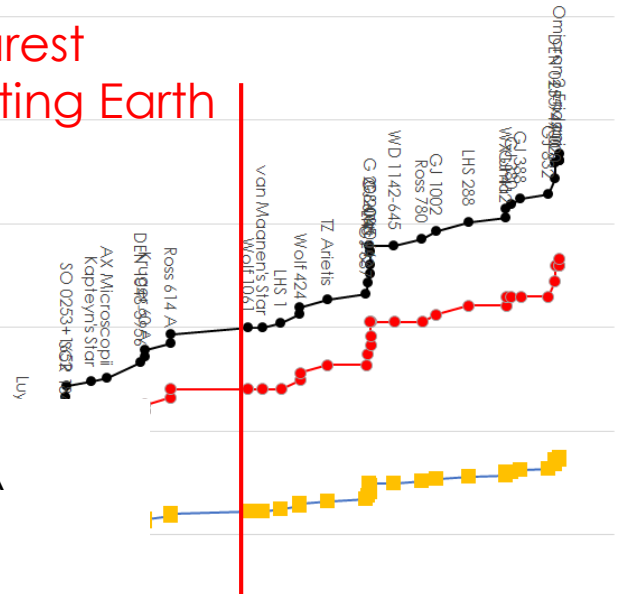
1 Earth-size planet in the HZ of the star

The 5 pc sample by transits

Chance of one transiting : ~75%
Expected number : 1.1 & 1.3



~Nearest transiting Earth



Charbonneau et al. CfA
LHS 1140b @11pc

SPECULOOS

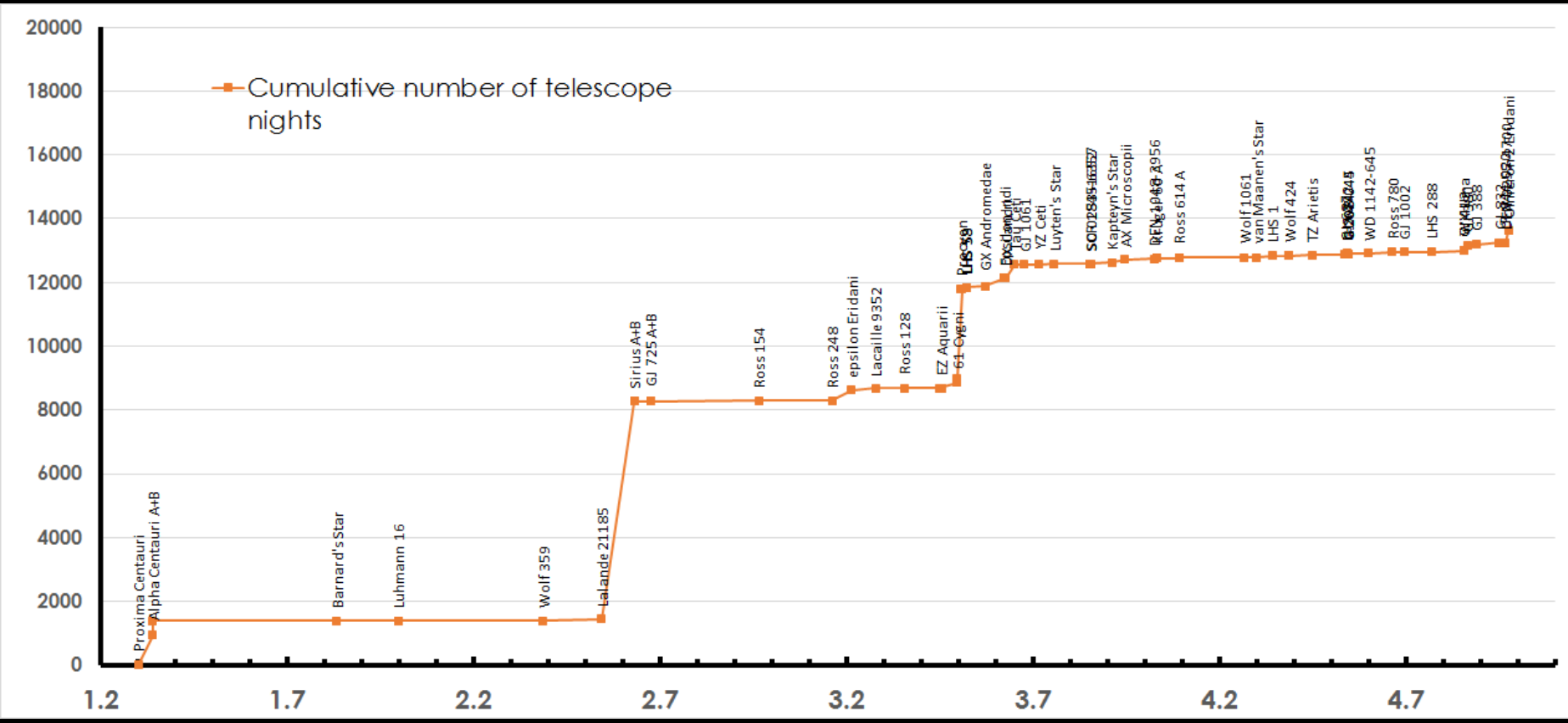
Search for habitable Planets EClipsing ULtra-cOOl Stars

M. Gillon et al,
TRAPPIST-1 @11pc

The 5 pc sample by Doppler

1 Earth-sized planet in the HZ of the star

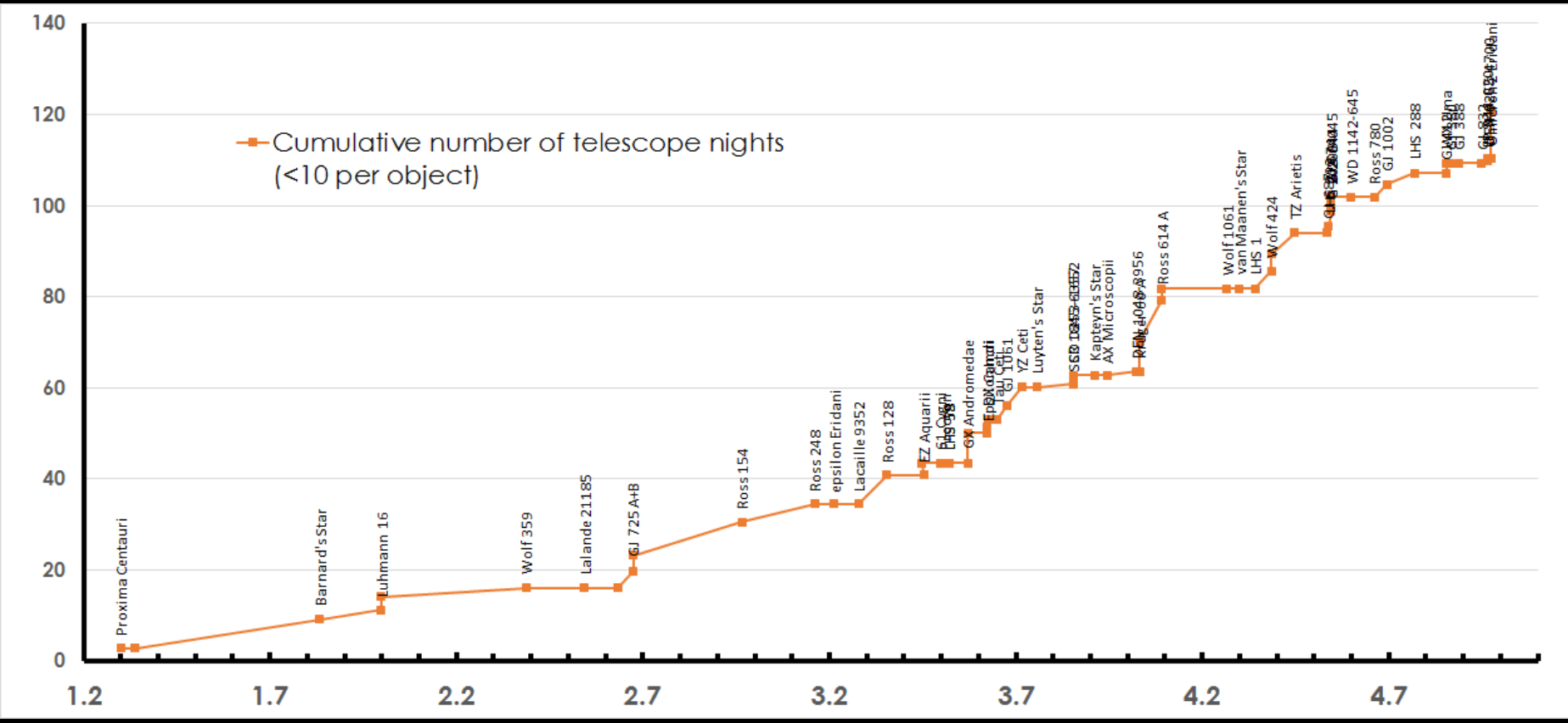
One epoch precision of 1 m/s
S/N > 5



1 Earth-size planet in the HZ of the star

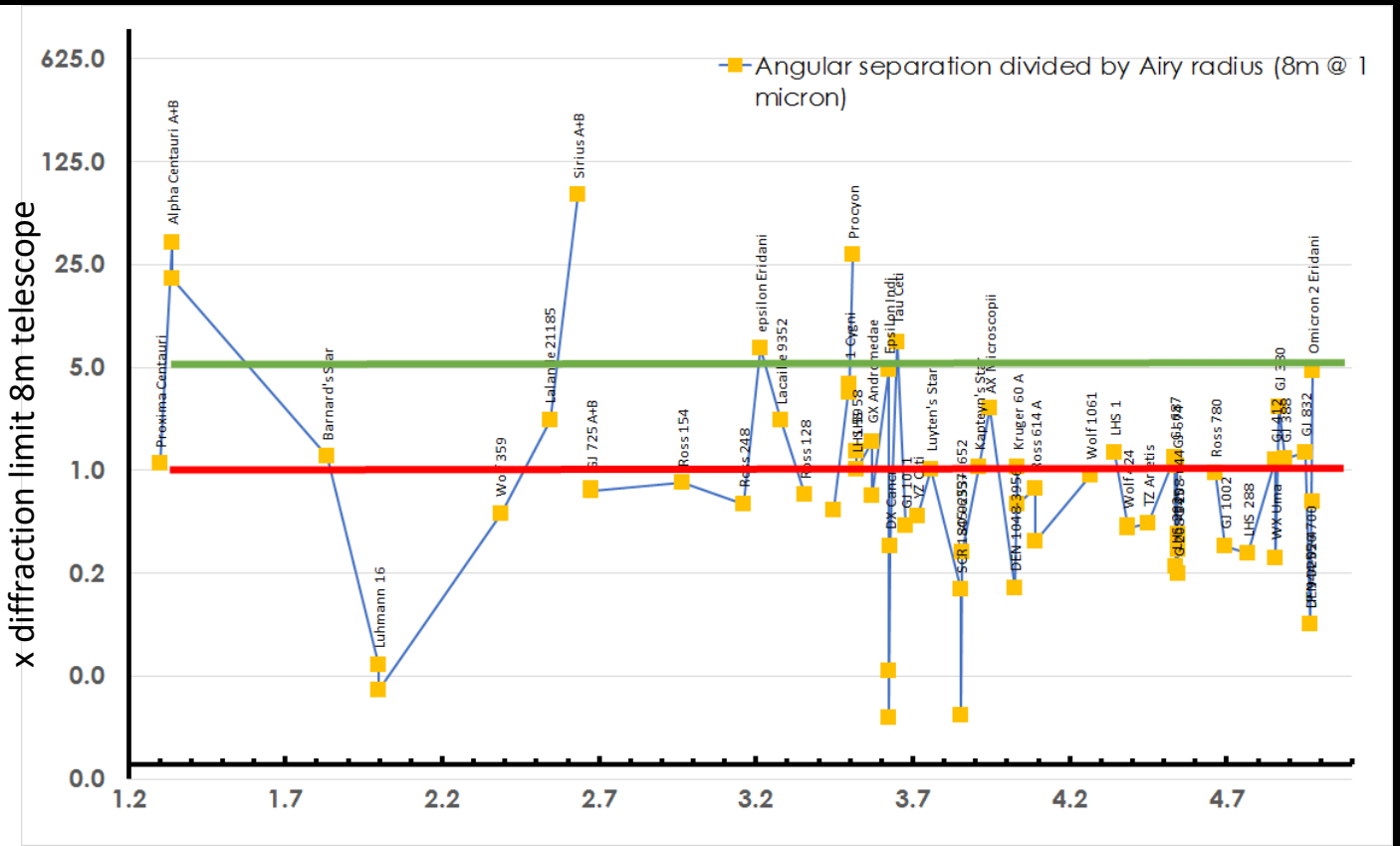
The 5 pc sample by Doppler

Easy ones : less than 1 year
37 systems (~60%)



1 Earth-size planet in the HZ of the star

The 5 pc sample by Imaging



High contrast **8**

High contrast + Spectral Enhancement **19**

Spectral methods

(Phase curves with JWST?)

Proxima (GJ 551, #1)

Proxima b
Orbital period ~ 11.2 days
Mass >1.3 M_{earth}

Anglada-Escude et al. 2016, Nature

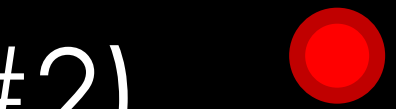
[Red Dots #1 : Possible second planet?] (in prep)

Alpha Cen A+B (#1)

- Lots of RV data. Sun-like stable, meaning stellar jitter at >2 m/s level & not fully understood.
- Transits hard and not reported. Too bright?
- LOTS of unshared data exist. No point in starting yet another SQRT(N) programme.

Source :Youtube, https://www.youtube.com/watch?v=vzzVsOdumqg
Visit http://www.avatarmovie.com for more

Barnard star (GJ 699, #2)



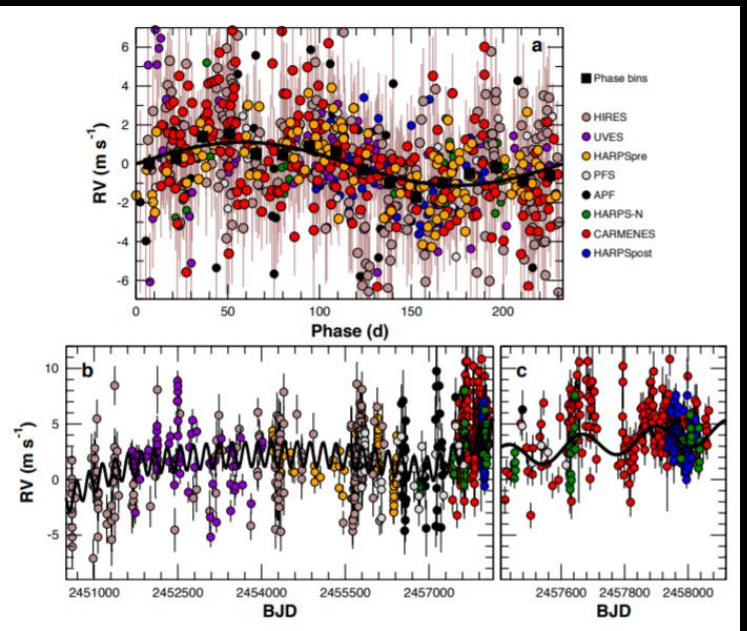
IN PREP

Barnard star (GJ 699, #2)

Barnard's star b
Orbital period ~ 230 d
Mass >3.3 M_{earth}

[Red Dots #2 & many more incl. CARMENES]

Ribas et al. 2018, Nature



Luhmann 16A+B #3

- Brown dwarfs. Not enough Doppler precission (yet). Fast rotation

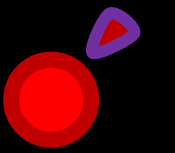
- Excellent for transits (nothing reported so far, with SPITZER, TRAPPIST, etc.)

Wolf 359 (GJ 406, #4)

- CARMENES, HARPS, HIRES
- Transits searched but not found
- Lot of data, very active (in a chaotic way). Still in 'probe' stage.
- Future Red Dots target

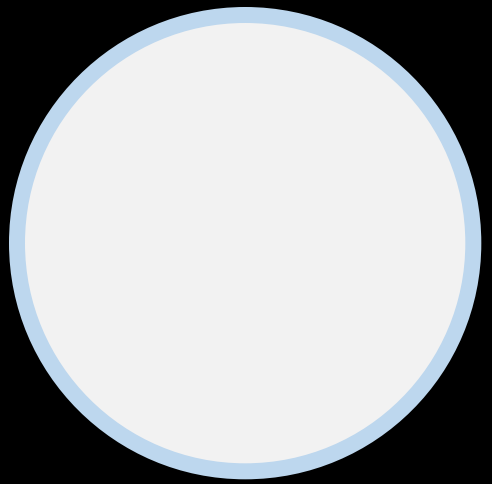
Source : Youtube https://www.youtube.com/watch?v=4-0Jg6_zHu0

Lalande 21185 (GJ 411, #5)



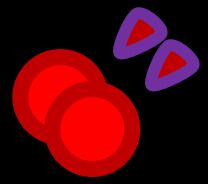
- CARMENES, HARPS, HIRES, others
- Substantial data. Some unconfirmed signals
- Future Red Dots 3

Sirius (#6)



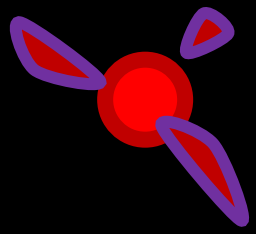
- Too hot for precision RV
- Transits unlikely (not found so far). Difficult photometry (too bright!)
- White dwarf companion at few AU (unstable orbits)
- Either direct imaging (or astrometry)

BL Ceti + UV Ceti (#7)



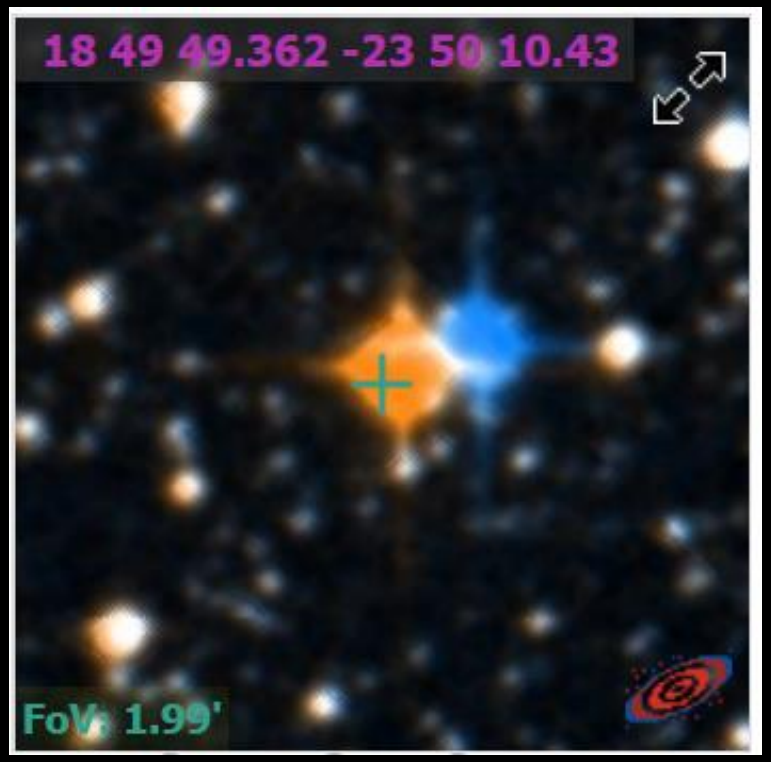
- Hard to measure precision RV (yet), Binary with 2" separation.
- Transit search possible (nothing reported)
- Stability of HZ orbits unclear

Ross 154 (GJ 729, #8)



- Fast rotation, frequent flares.
  Moderate RV data from before.
- Transits possible (none reported).
- Photometry shows clear rotation period at 2.8 days
- RED DOTS #2 target

GJ 729 (Ross 154, #8)

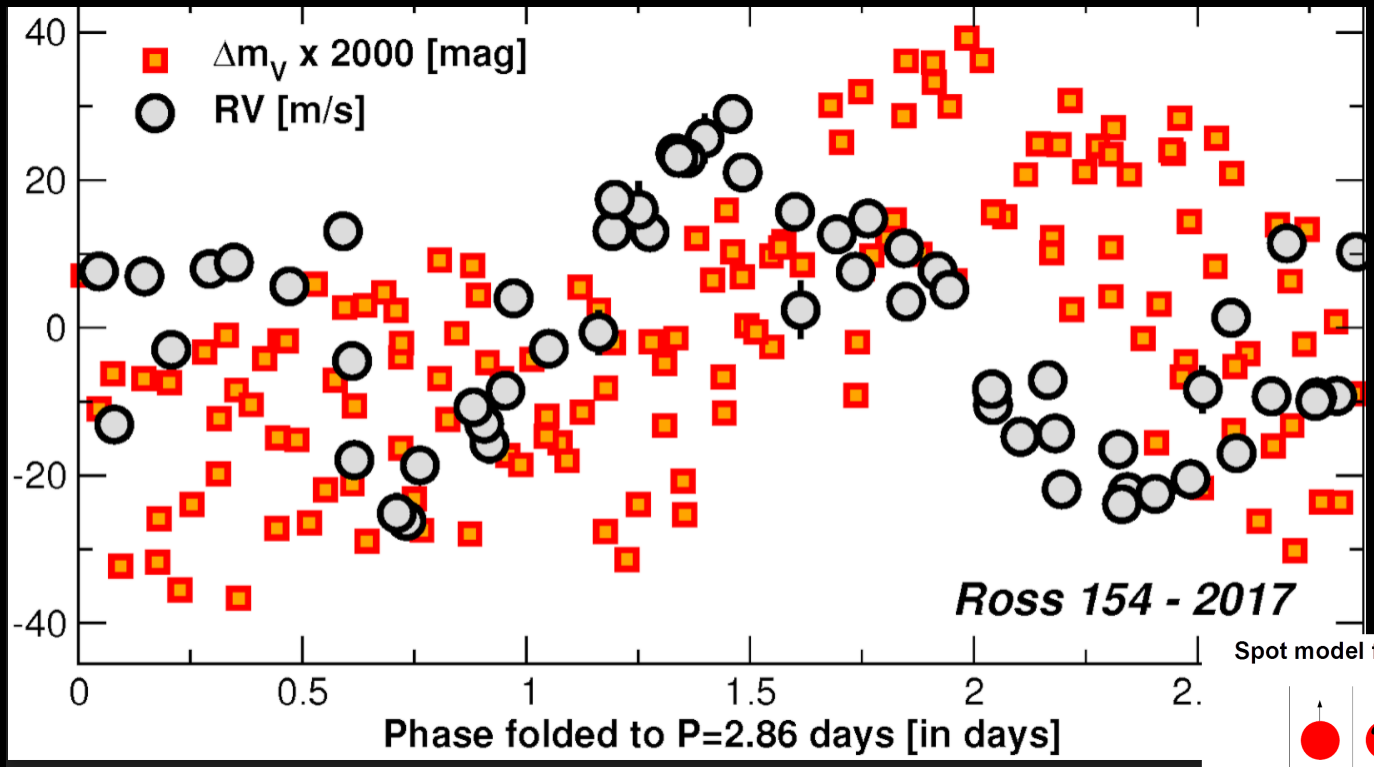


Astrometry	
Radial velocity (R_v)	−10.7[5] km/s
Proper motion (μ)	RA: +637.02[1] mas/yr Dec.: −191.64[1] mas/yr
Parallax (π)	339.59 ± 1.63[6] mas
Distance	9.60 ± 0.05 ly (2.94 ± 0.01 pc)
Absolute magnitude (M_V)	13.07[2]
Details	
Mass	0.17[2] $M_\odot$
Radius	0.24[7] $R_\odot$
Luminosity	0.0038[8] $L_\odot$
Surface gravity (log *g*)	5.00 ± 0.05[9] cgs
Temperature	3,340 ± 10[9] K
Metallicity [Fe/H]	-0.25[10] dex
Rotational velocity (*v* sin *i*)	3.5 ± 1.5[10] km/s
Age	under 1[10] Gyr

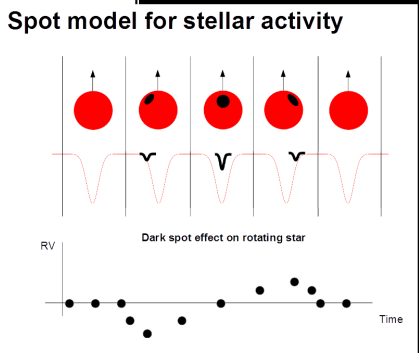
GJ 729 (Ross 154, #8)

John Strachan,
PhD candidate
@ QMUL

RV [m/s]



Simultaneous photometry and RV



John Strachan,
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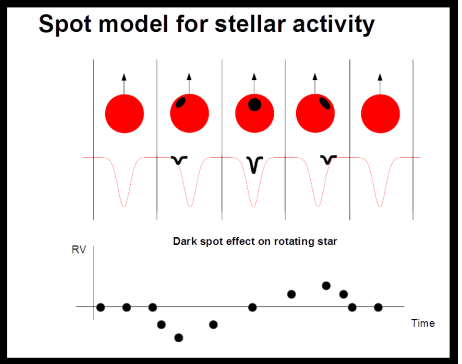
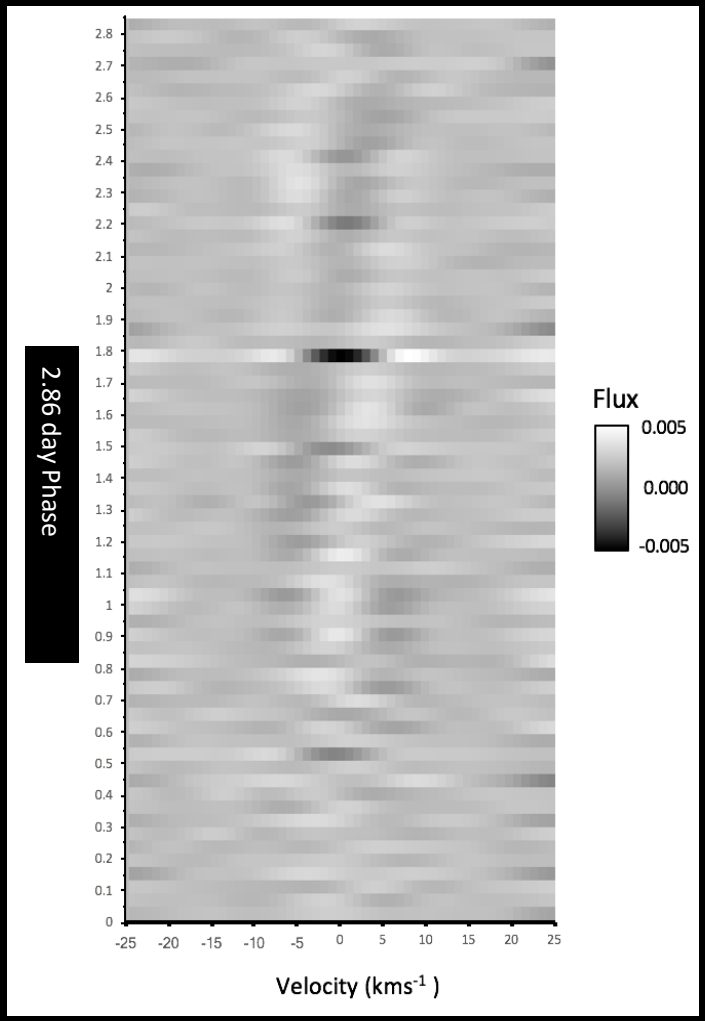
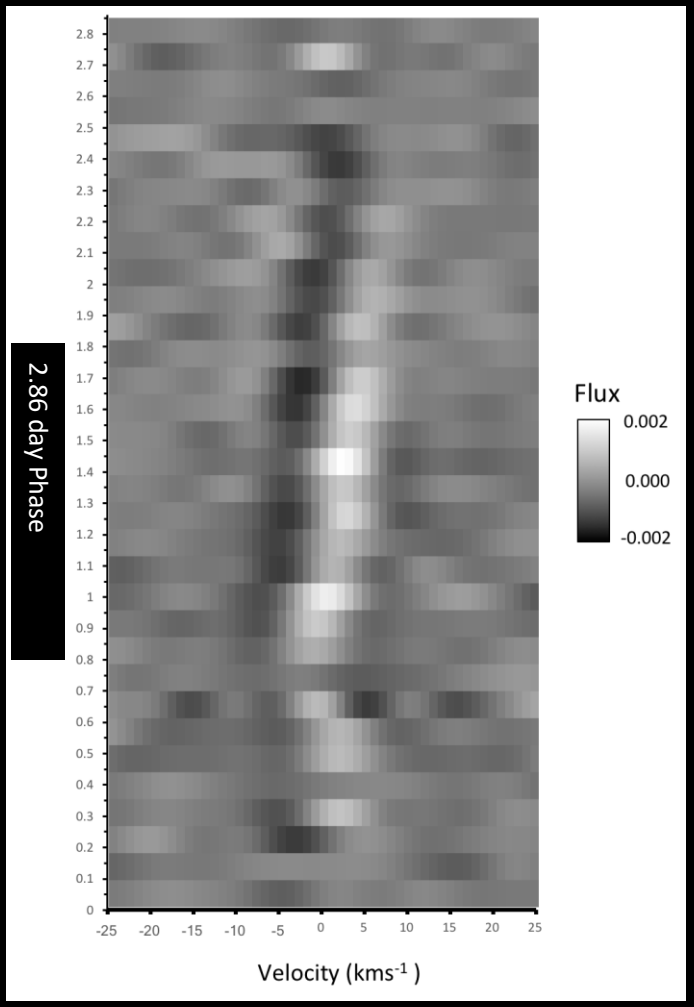
@ QMUL

GJ 729 (Ross 154, #8)





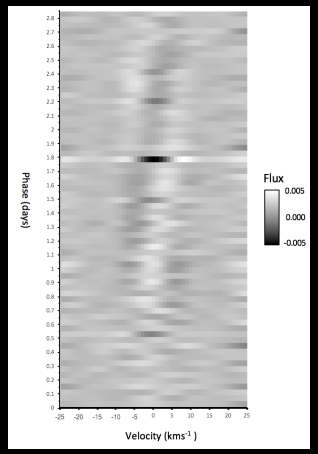
dLSD with HARPS spectra

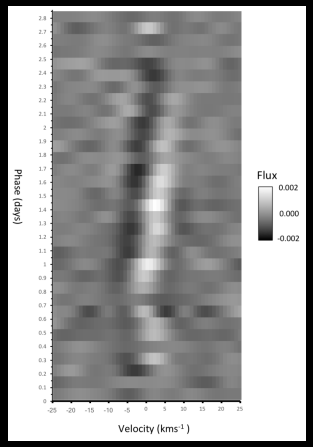


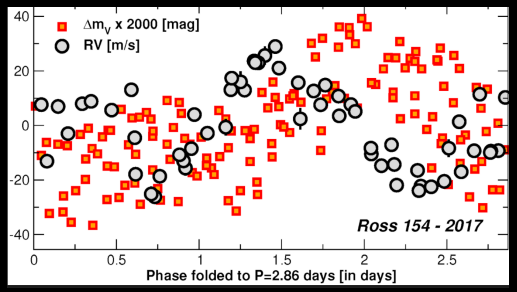
dLSD with CARMENES spectra

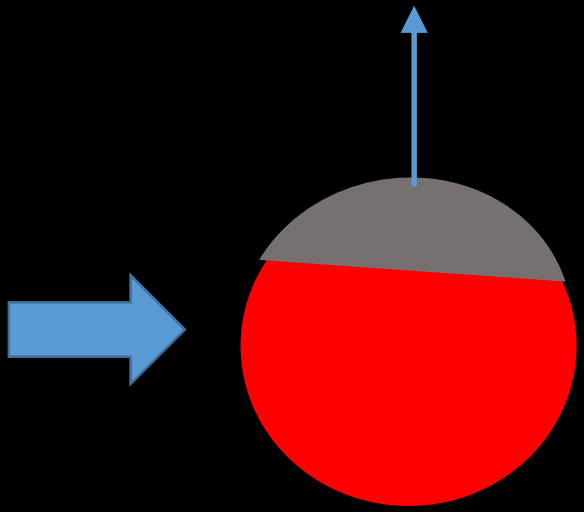
John Strachan,
PhD candidate
@ QMUL

GJ 729 (Ross 154, #8)









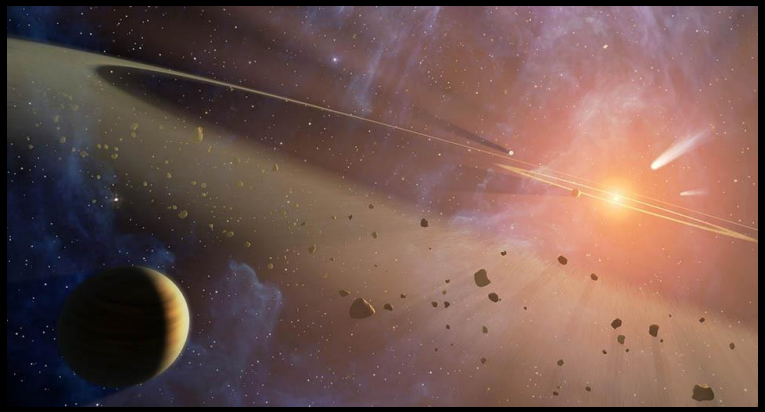
Rapid rotator
Large magnetic/polar spot…

Some additional Doppler (planet?)… may be
Paper in prep.

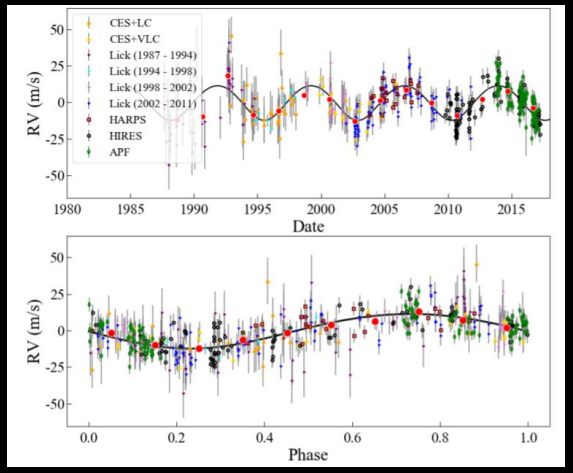
Epsilon Eridani (#9)

- RV : Gas giant planet? Strong magnetic activity. RV jitter NOT understood
- Transits : nothing reported. Too bright? Activity
- Future Orange dots target? (in prep)

Epsilon Eridani b
Orbital period ~ 7 years
Mass >0.7 M_{Jup}



Hatzes et al. 2000, ApJ



Confirmed (2 weeks ago!)
Mawet et al. 2018, AJ

Lacaille 9235 (GJ 887 #10)

- RV : One of the brightest M-dwarfs. No evidence for strong activity. Moderate to slow rotation
- Transits. A bit bright but doable. Nothing reported
- RED DOTS #2 target

TESS now getting data!!! Is this the one with the transits within 5pc?!

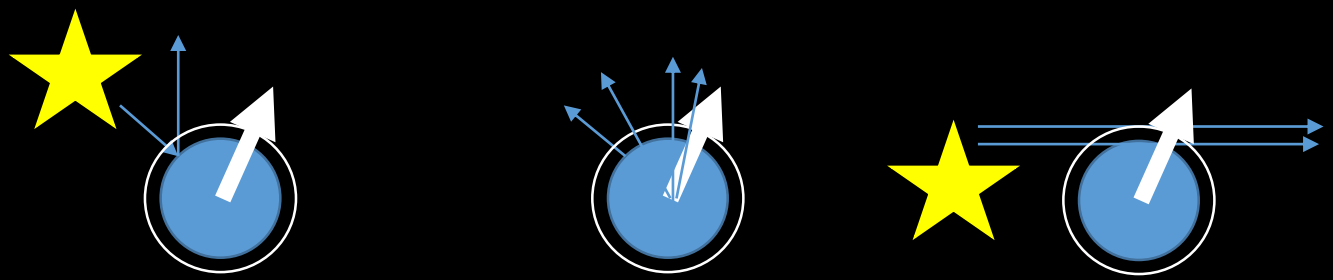
Very nearby stars

#1 Proxima (planet), Alpha Cen A+B
#2 Barnard's star (planet)
#3 Luhmann 16A+B
#4 Wolf 359 (?)
#5 Ross 248 (?)
#6 Sirius
#7 BL Ceti + UV Ceti
#8 Ross 154 (in prep, planets unlikely)
#9 Epsilon Eridani (gas giant & ?)
#10 Lacaille 9235 (in prep, !!!)
#11 Ross 128 (planet)
…

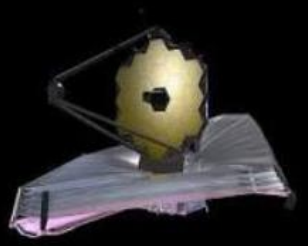
Characterization

(Evidence for life)

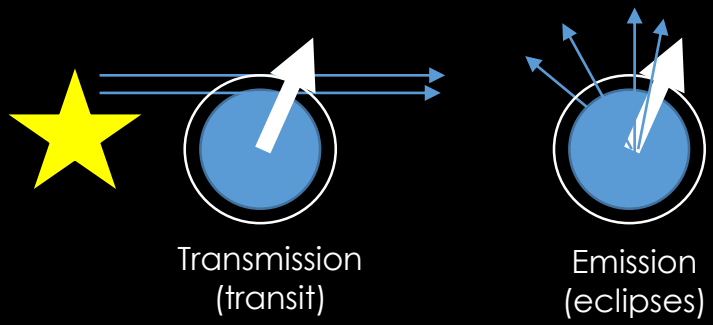
Characterization

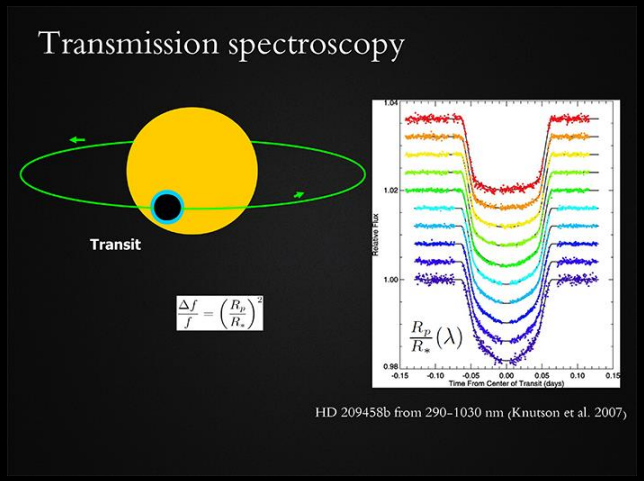


Characterization

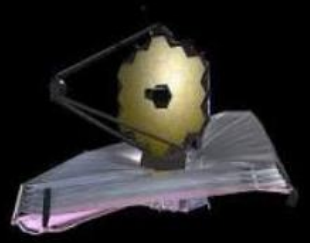


Transit spectroscopy

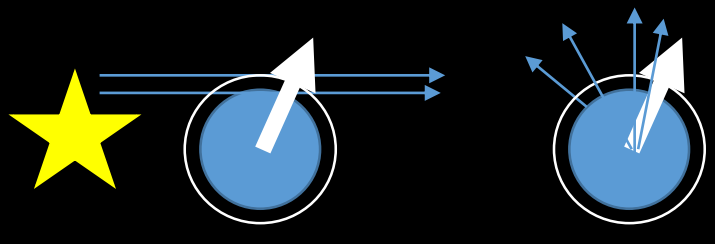


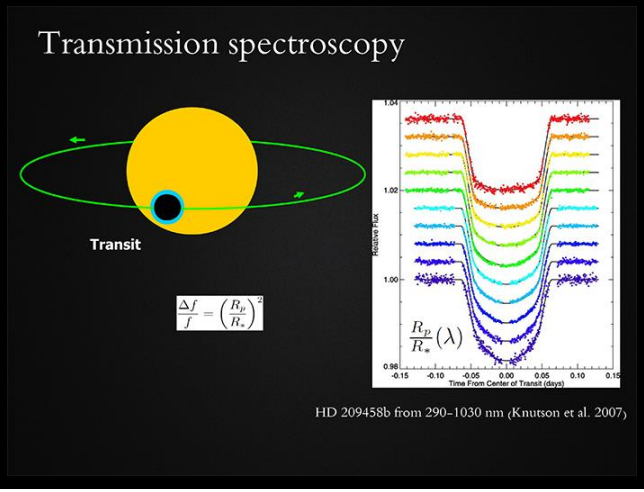


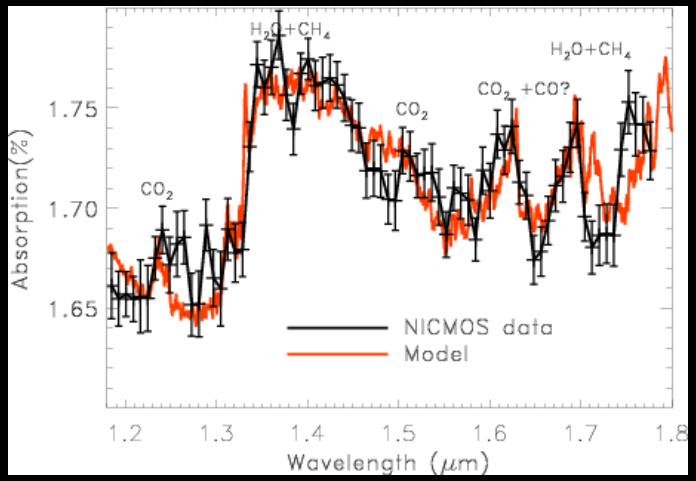
Characterization



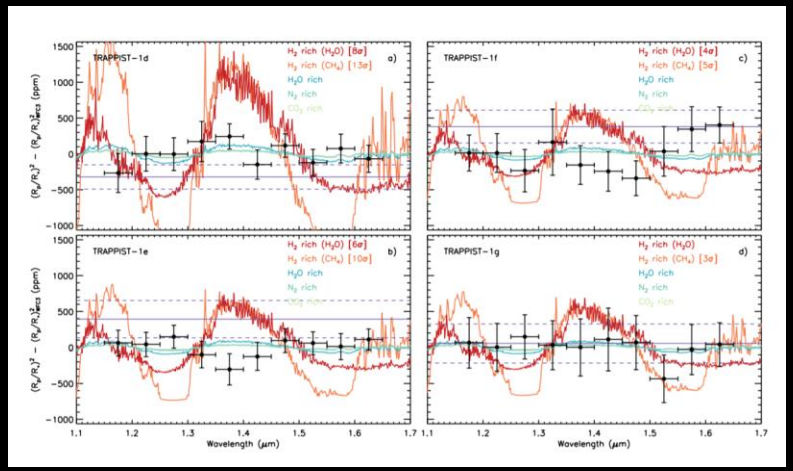
Transit spectroscopy







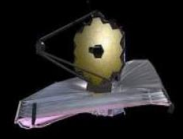
Tinnetti et al. 2010 ApJ
XO-1

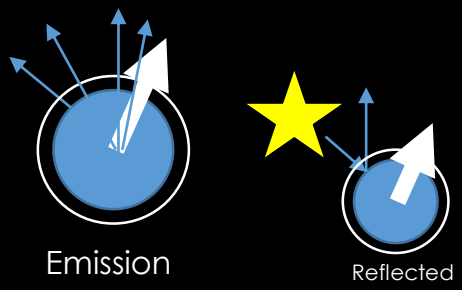


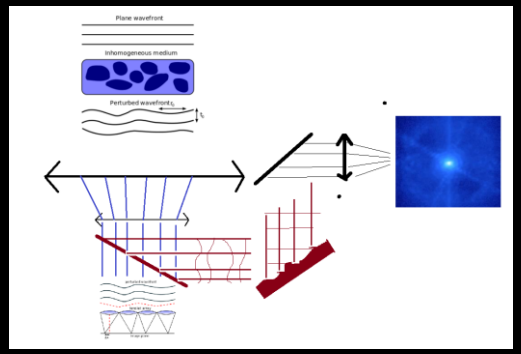
De Wit et al. 2018, Nature
TRAPPIST-1

Characterization

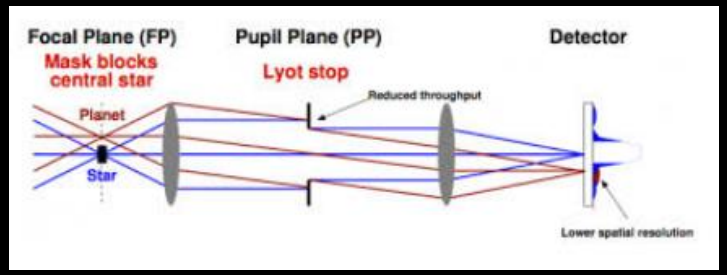
Direct imaging







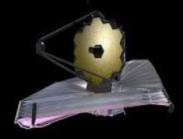
Adaptive Optics

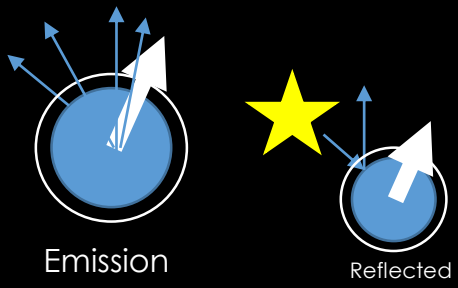


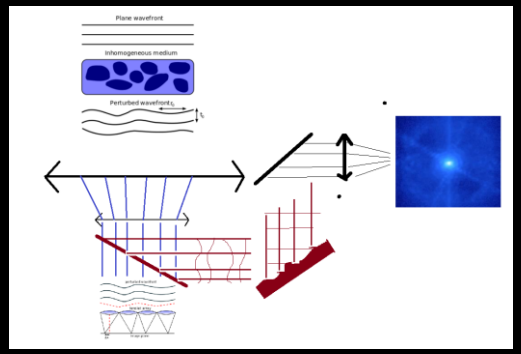
Coronograph

Characterization

Direct imaging







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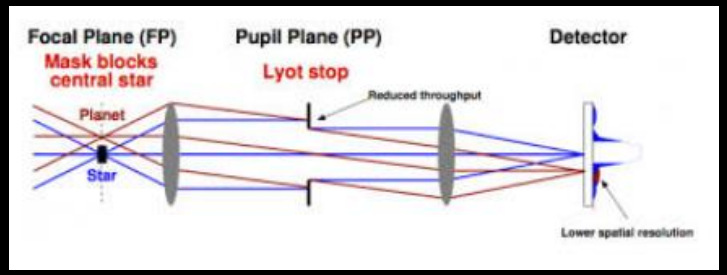

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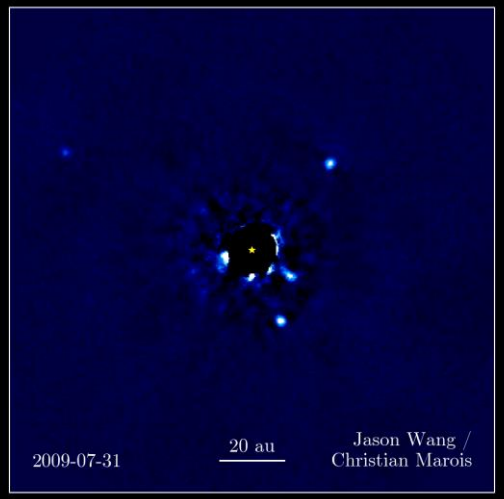
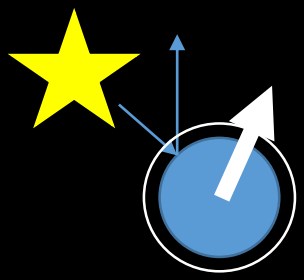
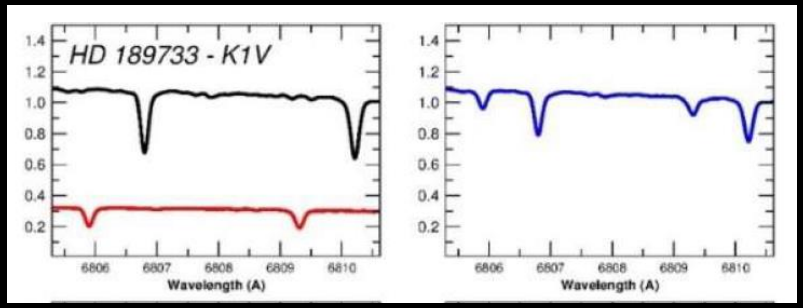


HR 8799 (~30 pc, young A type)
Marois et al. 2008, Science (3p)
Marois et al. 2010, Nature (+1p)

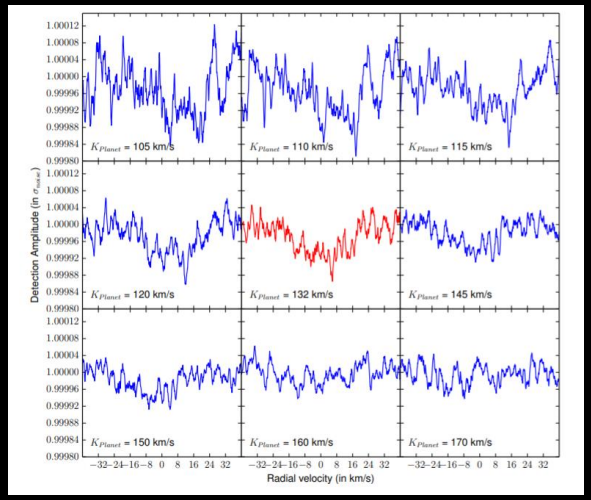
Characterization

High spectral resolution : Reflected star-light





10^3 -10^4 gain

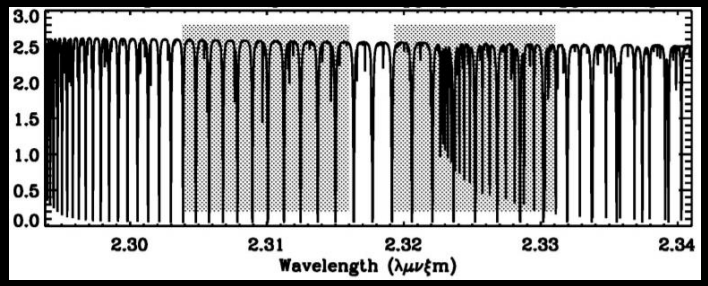


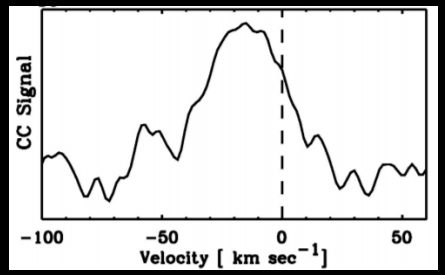
Martins et al. 2015 A&A
51 Peg b (controversial)

Characterization

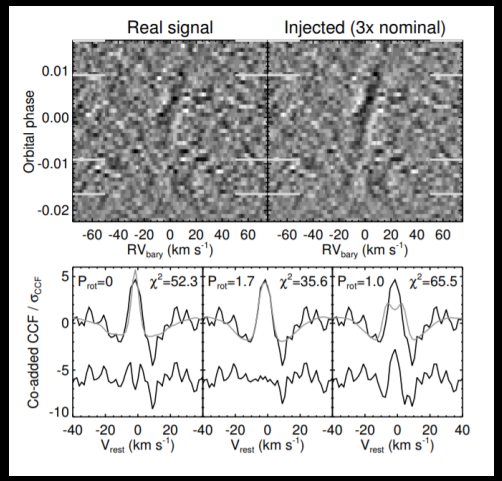
High spectral resolution : planet unique features

Snellen et al. 2014, Nature

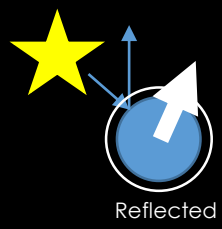


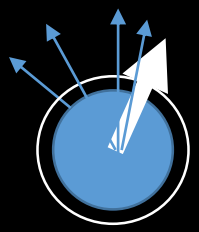


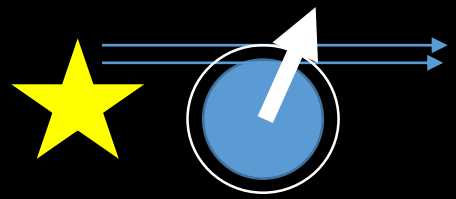
HD 189733 – during transit



Brogi et al. 2016, ApJ
(nIR spectrometers : CRIRES/VLT, CARMENES, etc.)

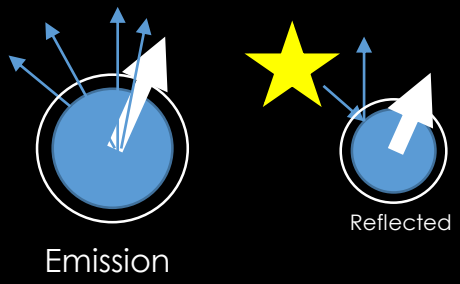


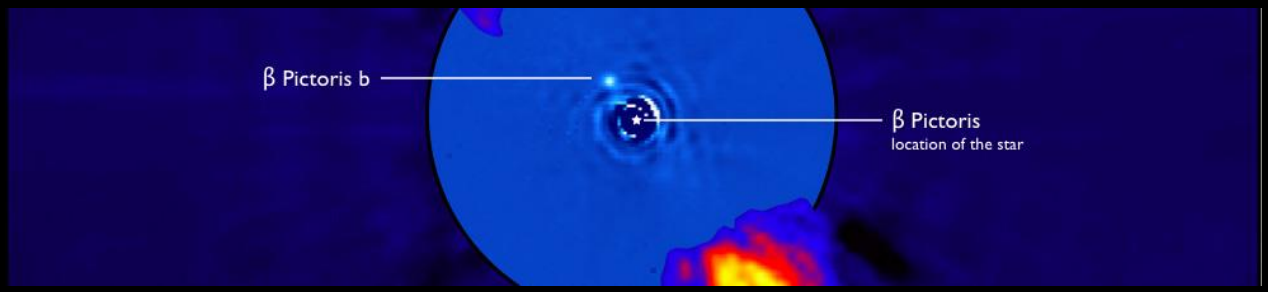




Characterization

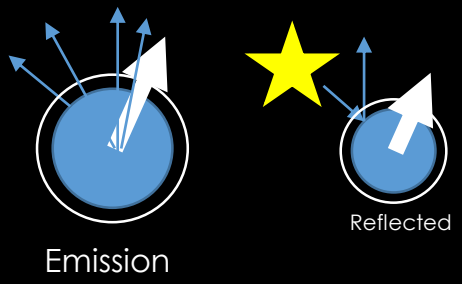
Direct imaging + high-resolution spectroscopy

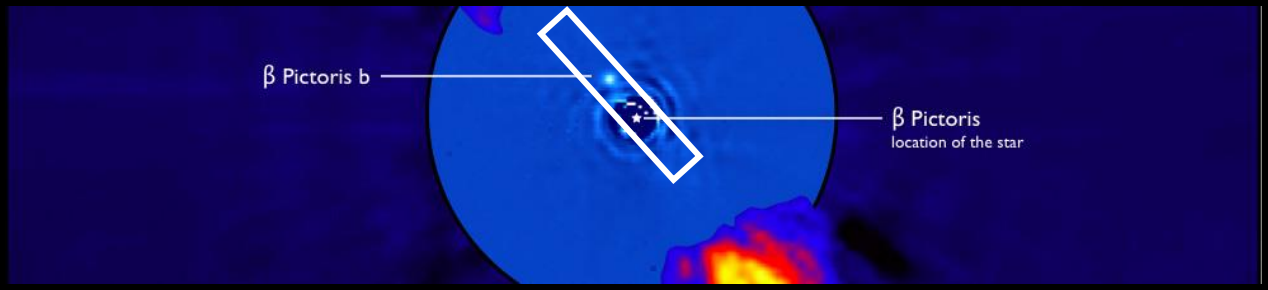


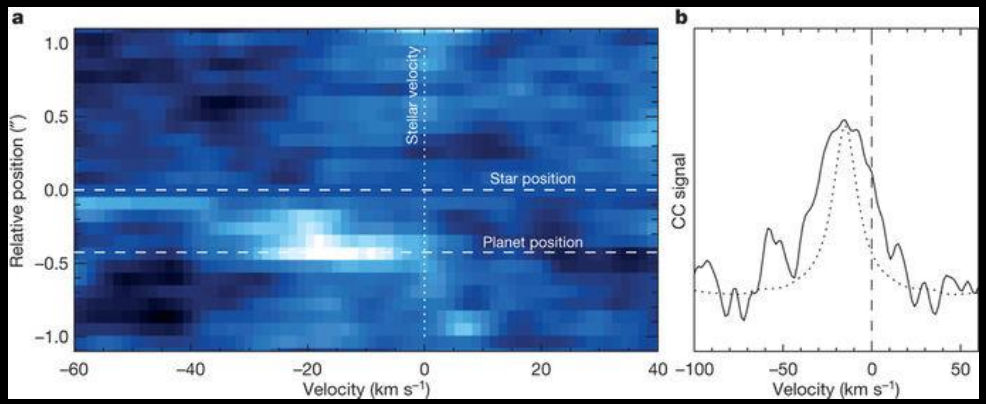


Characterization

Direct imaging + high-resolution spectroscopy







Snellen et al. 2014, Nature
CRIRES, CO bands at 2.3 microns

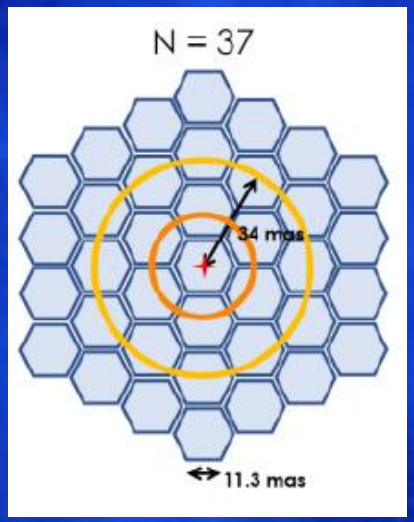
Characterization

Direct imaging + high-resolution spectroscopy

Characterization

Direct imaging + high-resolution spectroscopy

Based on Snellen et al. 2015 A&A



Obtained with VLT/SPHERE @800nm

http://www.onera.fr/en/news/saxo-the-adaptive-optics-of-sphere-vlt

Credits : ESO/SPHERE consortium

Characterization

Direct imaging + high-resolution spectroscopy

Snellen et al. 2015 A&A
E-ELT simulation on Proxima Cen (no planet yet detected)

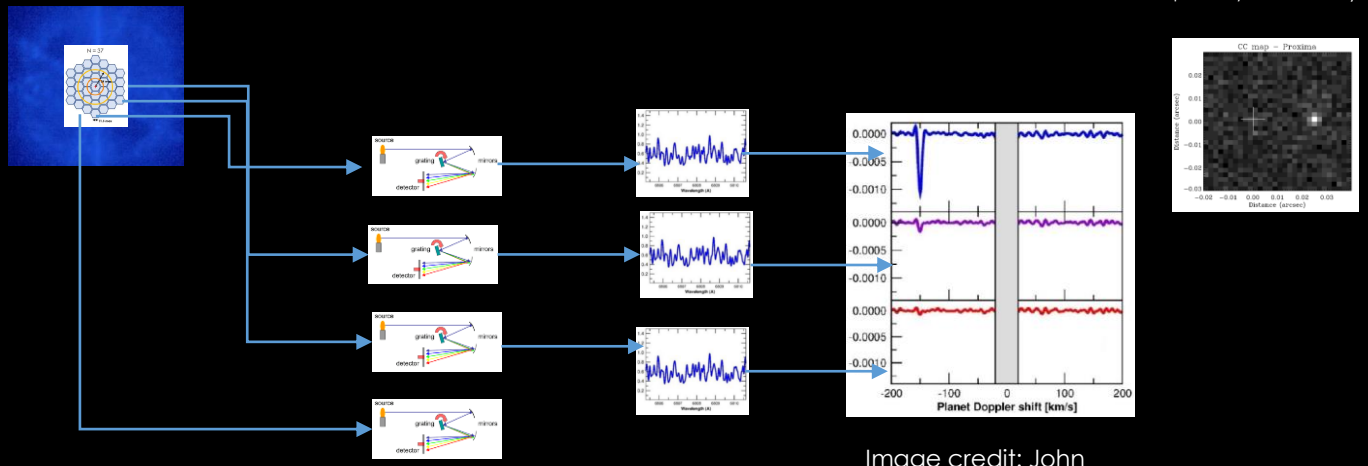
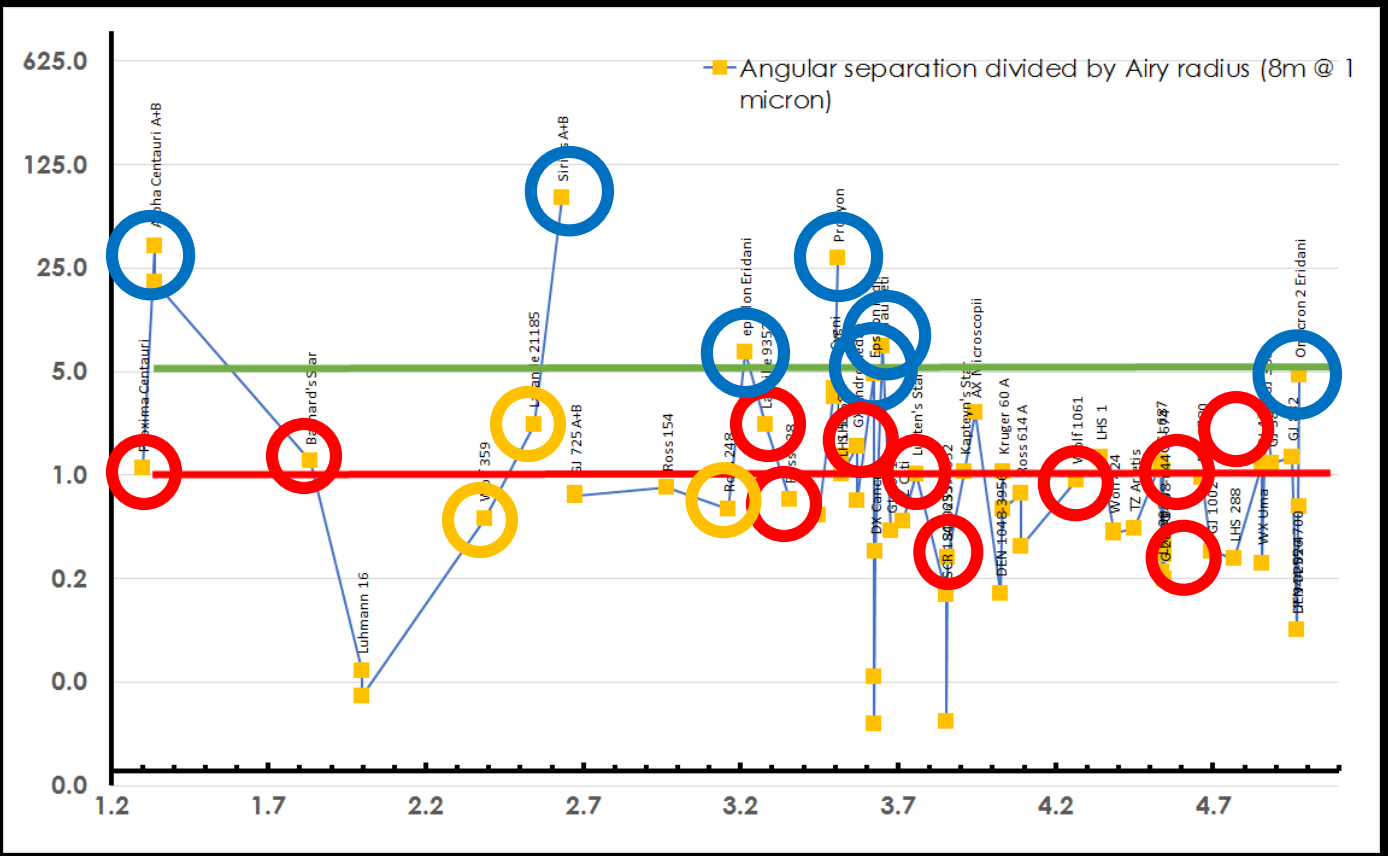


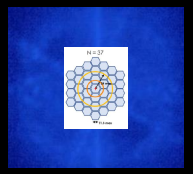
Image credit: John Strachan/ QMUL

Detection in 'search' mode
(it also works on sun-like stars)

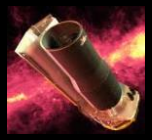
Characterization

Direct imaging + high-resolution spectroscopy



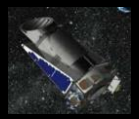


HST
2.5m class
NASA/ESA



SPITZER
1m, infrared, NASA

Kepler
NASA, 1m



Space

Gaia
1m, astrometry,
ESA

NOW **2020** **2030**

Ground-based

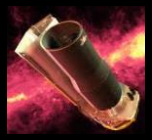
Doppler spec.
2m class telescopes
HARPS (ESO)
CARMENES
HARPS-N
APF, PFS

Transit searches
10cm-1.5m telescopes
NGTS, Mearth,
SPECULOOS, QATAR

Direct imaging
10m class telescopes
SPHERE/ESO
GPI/Gemini

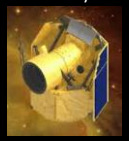
Microlensing
0.5m class telescope
OGLE, LCOGT

HST
2.5m class
NASA/ESA

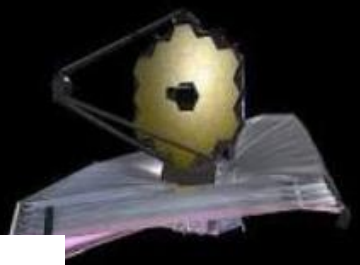


SPITZER
1m, infrared, NASA

CHEOPS
(30cm, ESA)

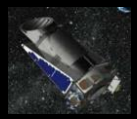


JWST
6.5m, NASA/ESA



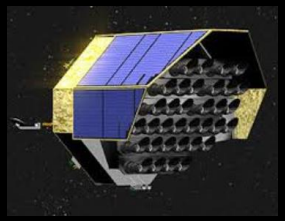
Project BLUE?
1m class telescope

Kepler
NASA, 1m

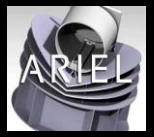


TESS
10x20 cm, NASA)

PLATO
ESA, 50x10 cm



ARIEL
ESA, 1m, spectra



Space

Gaia
1m, astrometry,
ESA

gaia

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Direct imaging
ELF concept, Mutil 8m
class telescope

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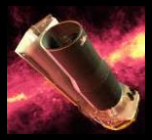
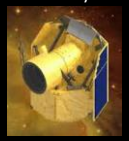
0.5m class telescope
OGLE, LCOGT

HST
2.5m class
NASA/ESA

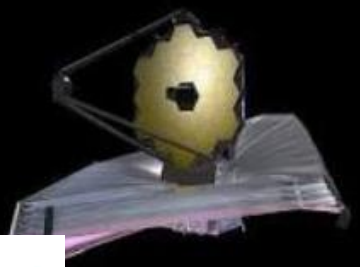


SPITZER
1m, infrared, NASA

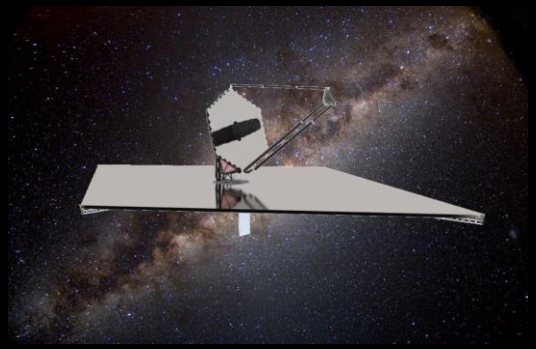
CHEOPS
(30cm, ESA)



JWST
6.5m, NASA/ESA

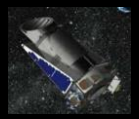


Project BLUE?
1m class telescope



LUVOIR/HabEx?
16m, NASA

Kepler
NASA, 1m



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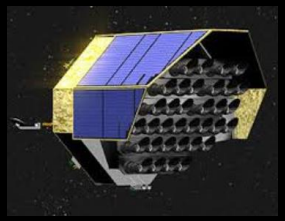

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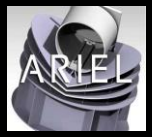
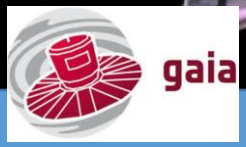
ESA, 1m, spectra



Space

Gaia
1m, astrometry,
ESA



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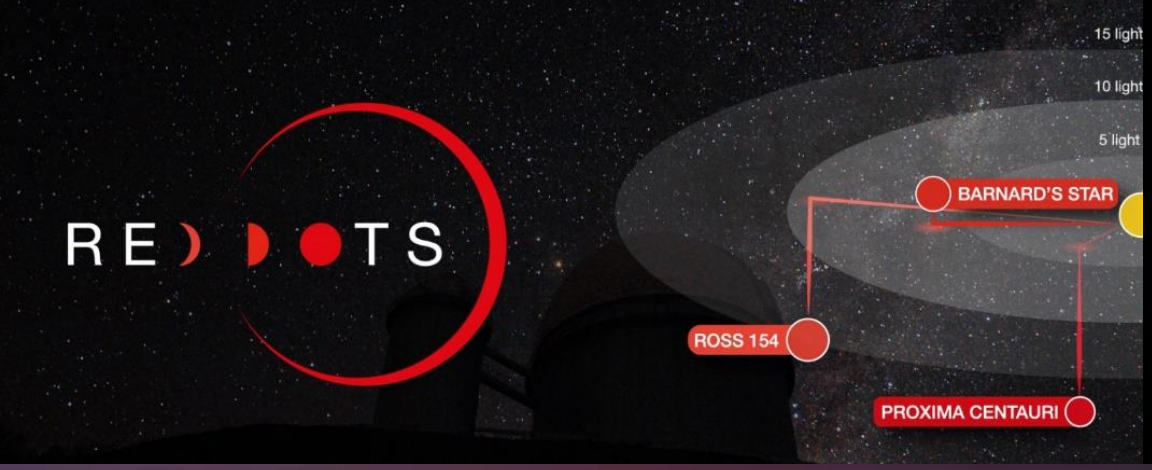
OGLE, LCOGT

2050+

2050+



http://reddots.space

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Thanks!

Proxima b
@PaleRedDot

Barnard's Star b
@BarnardsStarb