Radial velocity planet searches

Andrzej Niedzielski
Toruń Center for Astronomy, UMK

The first planetary system

Nicolaus Copernicus Thorunensis (1473-1543).

Terrae motor, Solis Caelique stator.

The first extrasolar planetary system

PSR 1257+12

Wolszczan & Frail (1992)

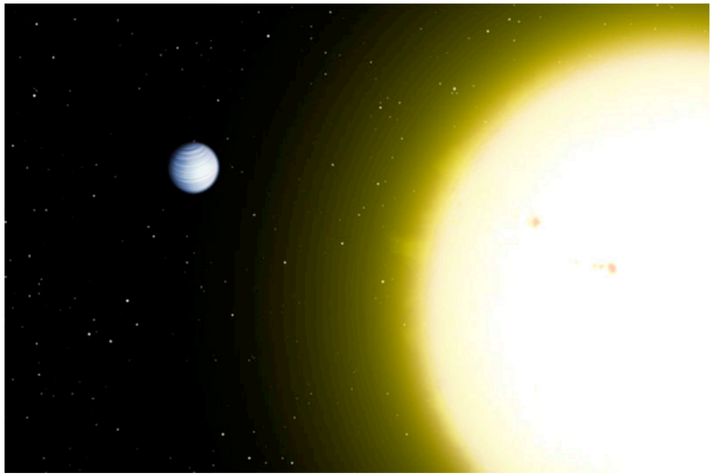
Aleksander Wolszczan

The first extrasolar planetary system around a solar type star

51 Pegasi

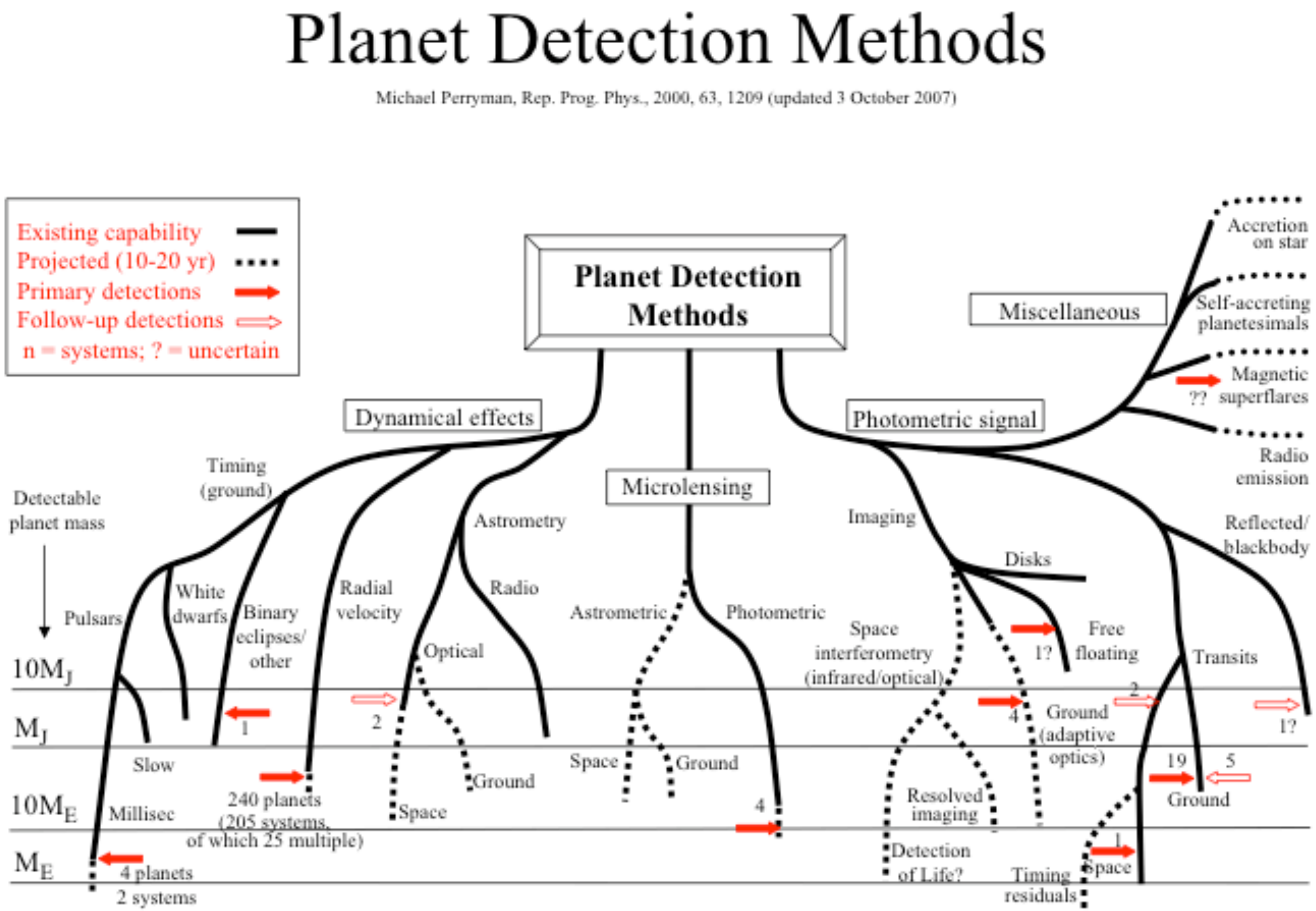
Mayor & Queloz (1995)

Michel Mayor & Didier Queloz



Hot jupiter

The methods …

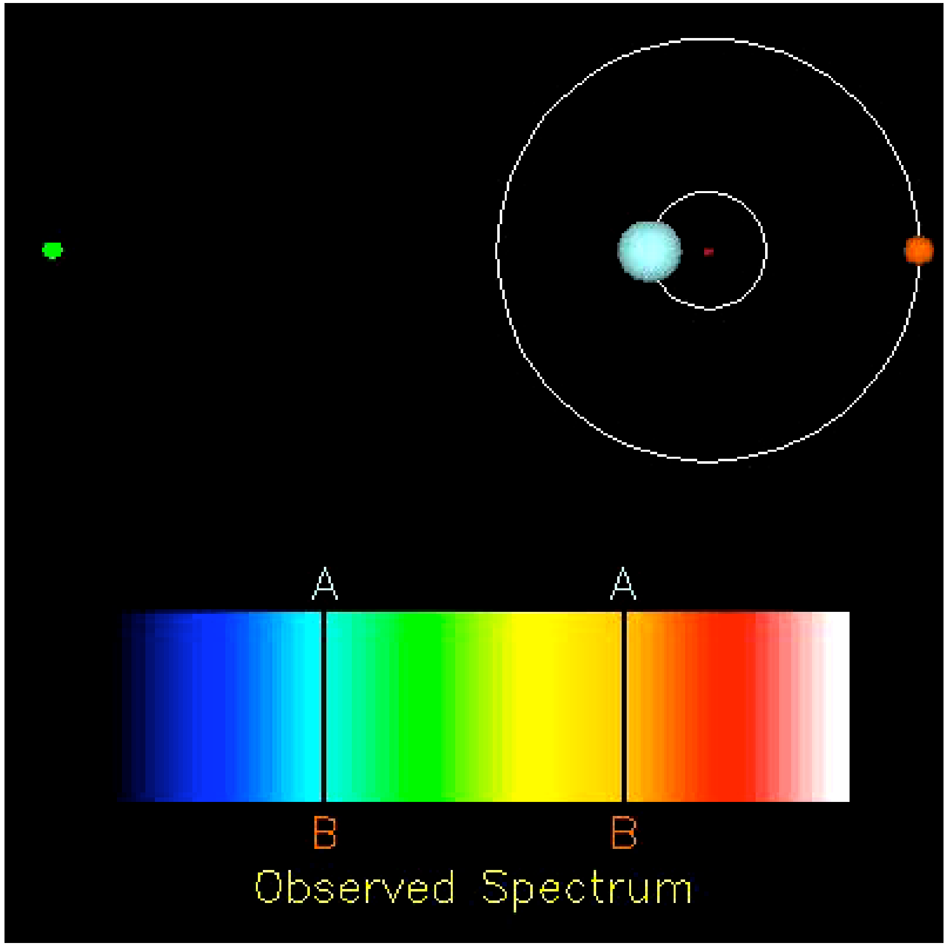

Planet Detection Methods
Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated 3 October 2007)
Existing capability
Projected (10-20 yr)
Primary detections
Follow-up detections
n = systems; ? = uncertain
Planet Detection Methods
Dynamical effects
Microlensing
Photometric signal
Miscellaneous
Accretion on star
Self-accreting planetesimals
Magnetic superflares
??
Radio emission
Reflected/ blackbody
Detectable planet mass
Timing (ground)
Pulsars
White dwarfs
Binary eclipses/ other
Radial velocity
Astrometry
Radio
Optical
Astrometric
Photometric
Imaging
Disks
Space interferometry (infrared/optical)
Free floating
1?
Transits
10MJ
MJ
10ME
ME
Slow
Millisec
1
2
240 planets (205 systems, of which 25 multiple)
Space
Ground
Space
Ground
4
Ground (adaptive optics)
4
2
1?
19
5
Ground
Resolved imaging
Detection of Life?
Timing residuals
1
Space
4 planets
2 systems

… and their efficiency

All Catalogs
update : **13 November 2010**

All Candidates detected	**497 planets**
Candidates detected by radial velocity or astrometry *update : 13 November 2010*	392 planetary systems 463 planets 45 multiple planet systems
Transiting planets *update : 12 November 2010*	105 planetary systems 106 planets 7 multiple planet systems
Candidates detected by microlensing *update : 12 October 2010*	10 planetary systems 11 planets 1 multiple planet systems
Candidates detected by imaging *update : 11 November 2010*	11 planetary systems 13 planets 1 multiple planet systems
Candidates detected by timing *update : 13 October 2010*	6 planetary systems 10 planets 3 multiple planet systems

Radial velocities



$$K = 28.4 \left(\frac{P}{1\ \mathrm{year}}\right)^{-1/3} \left(\frac{M_p \sin i}{M_\mathrm{J}}\right) \left(\frac{M_*}{M_\odot}\right)^{-2/3} \ \mathrm{m\,s^{-1}}$$

Radial velocities

How to increase RV precision?

Number of lines and their width:

Echelle spectra,

solar type or cooler stars, slow rotators.

Wavelength scale precision:

ThAr, gas cells, laser comb.

Spectrograph stability (physical, optical, thermal):

fibers,

controlled environment,

monitoring & model.

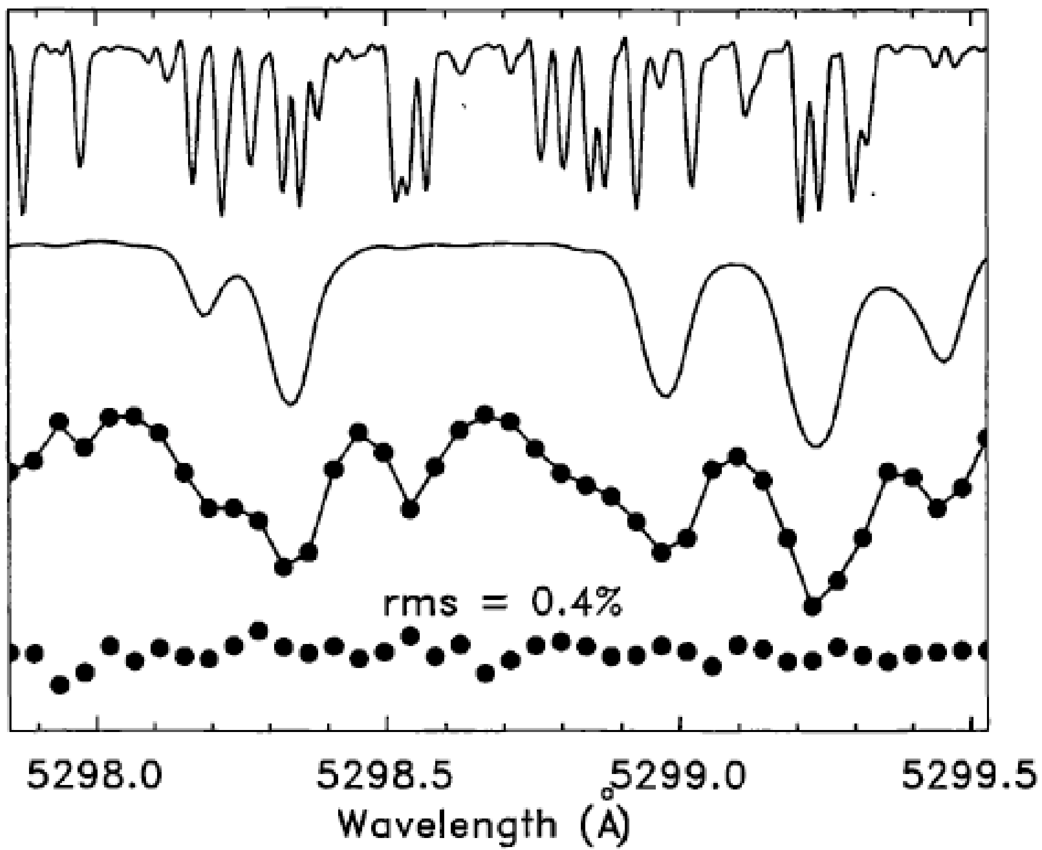
Efficiency:

what SNR (EXPTIME) to reach given precision?

Targets:

avoid or trace activity.

Gas cell (I2) technique

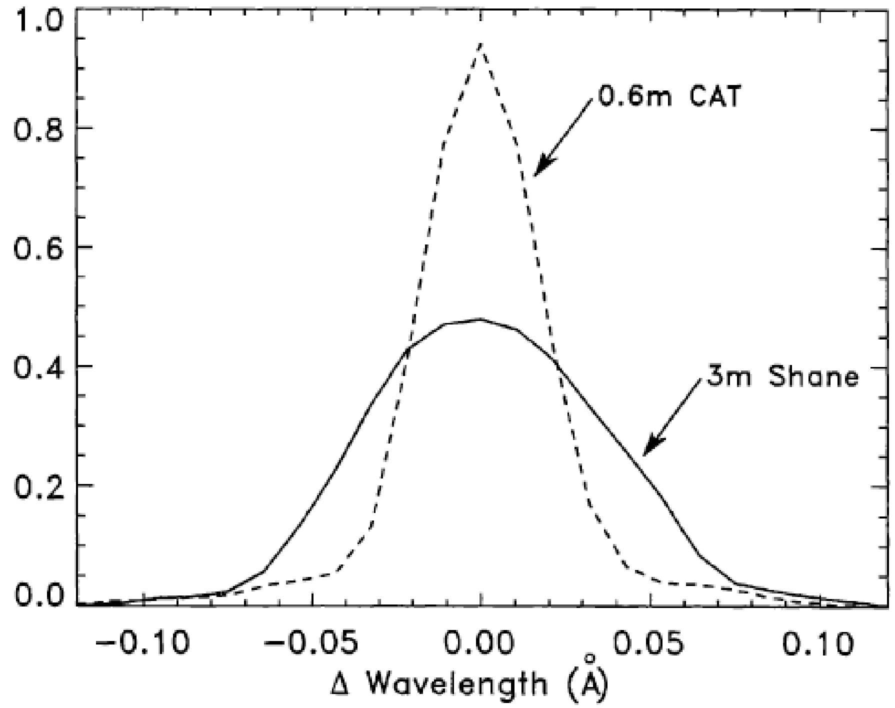


Marcy & Butler (1992)
Valenti et al. (1995)
Butler et al. (1996)

SNR =200 for 3 m/s

$$I_{\mathrm{obs}}(\lambda) = k[T_{I2}(\lambda) I_s(\lambda + \Delta\lambda)] * \mathrm{PSF},$$

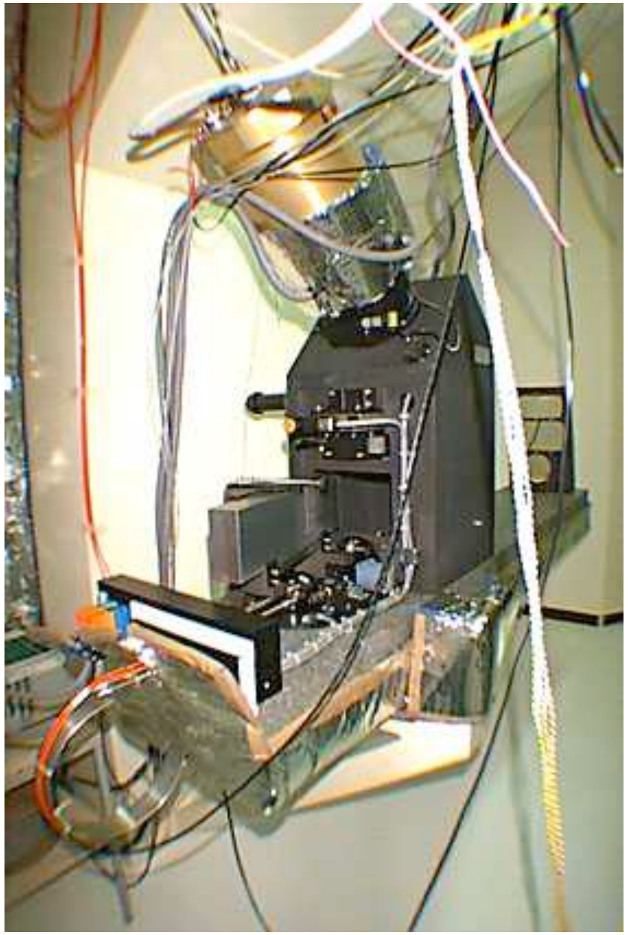
Gas cell (I2) technique



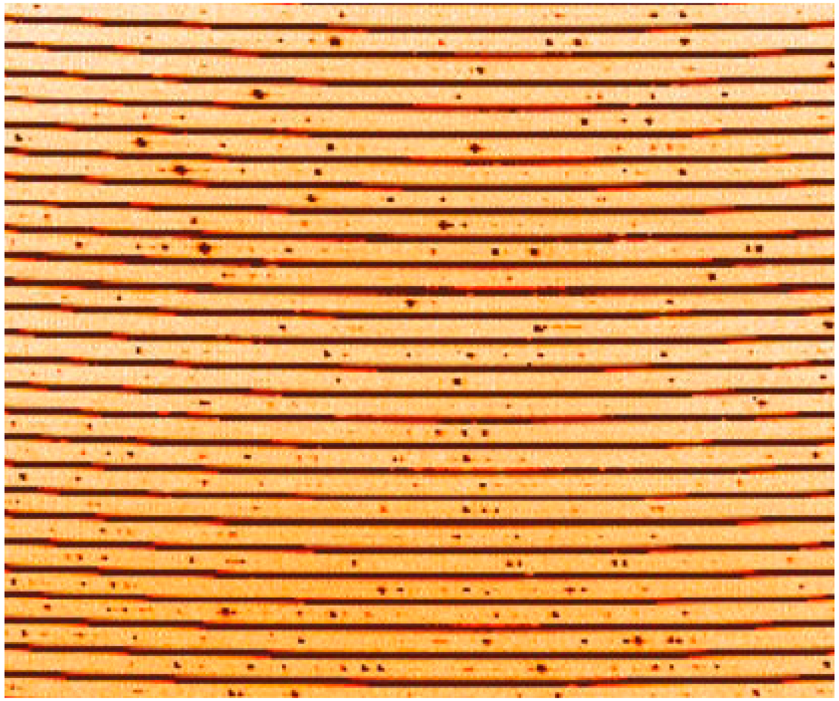
PSF model & monitoring is the key

The technique can be applied at <u>any</u> spectrograph

Simultaneous ThAr reference



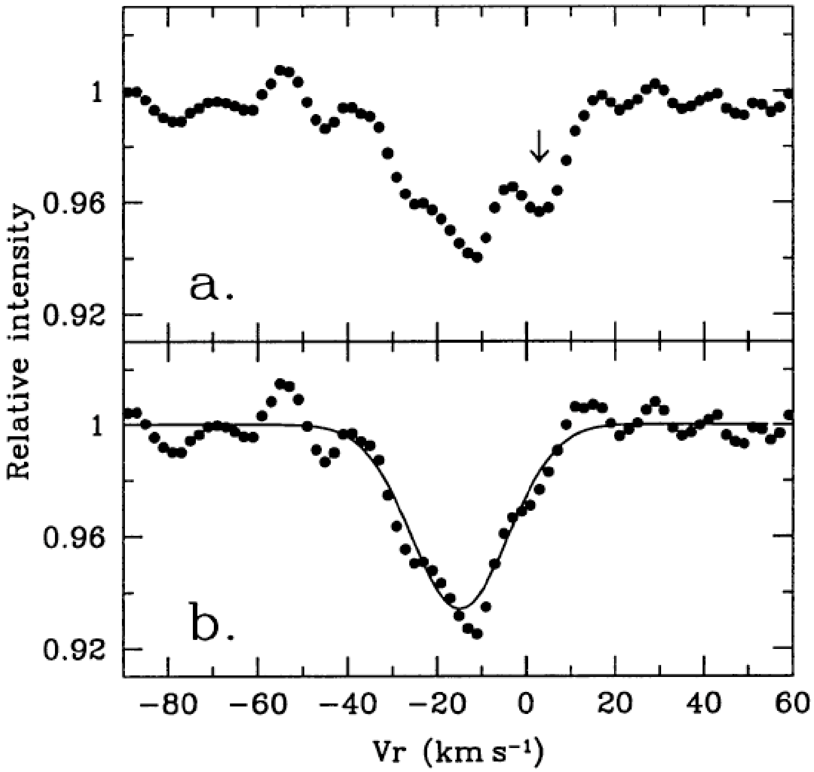
Baranne A. et al. (1996)



ELODIE (1996)

Stellar + ThAr spectrum

Simultaneous ThAr reference



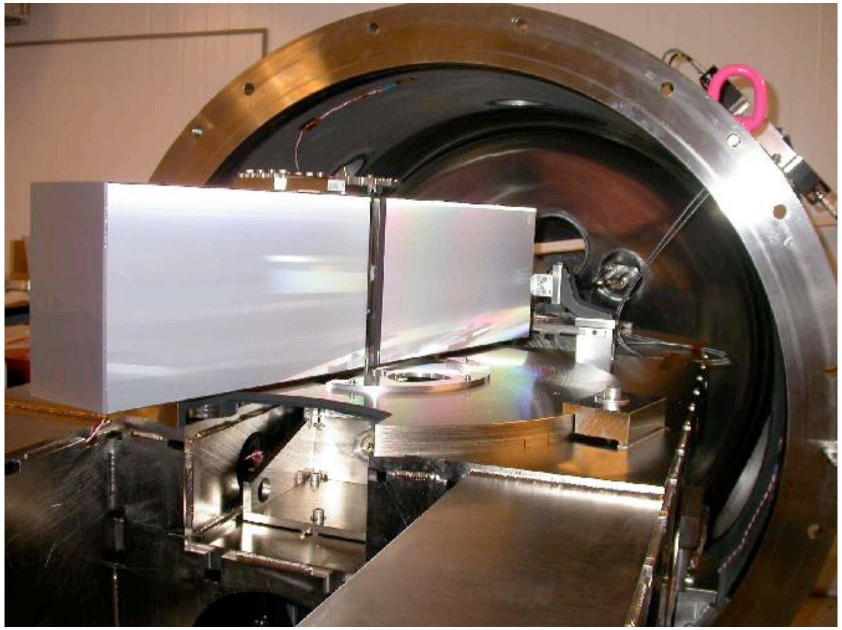
CORALIE (1998)

Cross-correlation with a **mask**

$$C(v) = \sum_{l} \sum_{x,o} p_{l,x,o}(v)\, f_{x,o},$$

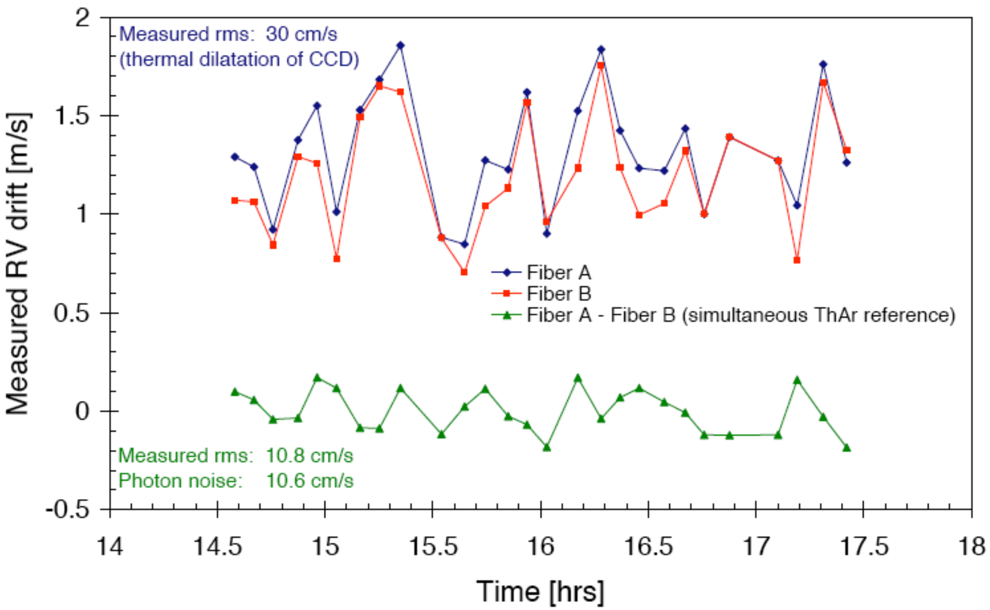
SNR =150 for 6 m/s

Simultaneous ThAr reference



HARPS (2004)

Stability is the key!
Need a dedicated spectrograph?



ΔRV =1 m/s =1/1000 pixel

<u>Requires:</u>

ΔT =0.01 K

Δp=0.01 mBar

SNR =500 for 0.51 m/s rms

Radial velocities. The choice.

Simultaneous reference	Gas absorption cell
Requires stable IP: fiber feed only. Spectral range: all available. Efficiency: entire spectral information available. SNR = 60 required for 1 m/s. Need a dedicated spectrograph.	Suitable also for slit spectrographs Spectral range: limited by gas cell Efficiency: cell absorption photon-consuming deconvolution SNR = 250 required for 1 m/s Only need a gas cell.

RV planet searches.

Ongoing Simultaneous ThAr reference:

High Accuracy Radial velocity Planetary Search
HARPS (ESO, La Silla)
(several planets found)

Coralie at Leonard Euler Telescope (La Silla)
(several planets found)

Sophie (OHP)
Several planets found

Elodie (OHP & Geneva)
(several planets found)

Under development

HARPS-N HARPS North

Absolute Astronomical Accelerometry
(Emilie Spectrograph)

Ongoing gas cell searches:

California & Carnegie Planet Search
(several planets found)

N2K Consortium
(several planets found)

AFOE
(several planets found)

Anglo-Australian Planet Search Program
(several planets found)

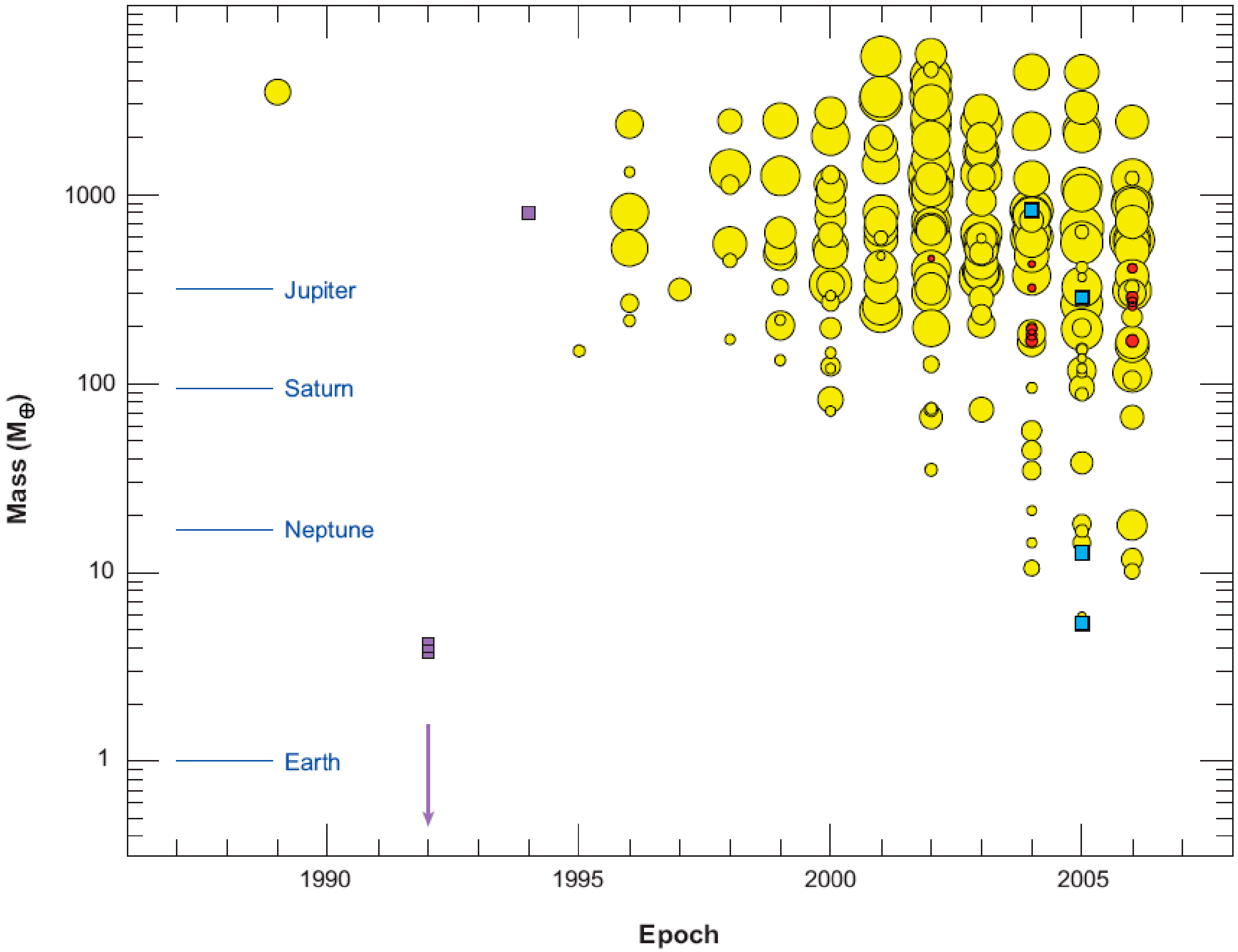
Tautenberg Planet Survey
(several planets found)

Hobby-Eberly Telescope
(several planets found)

Mc Donald Observatory
(several planets found)

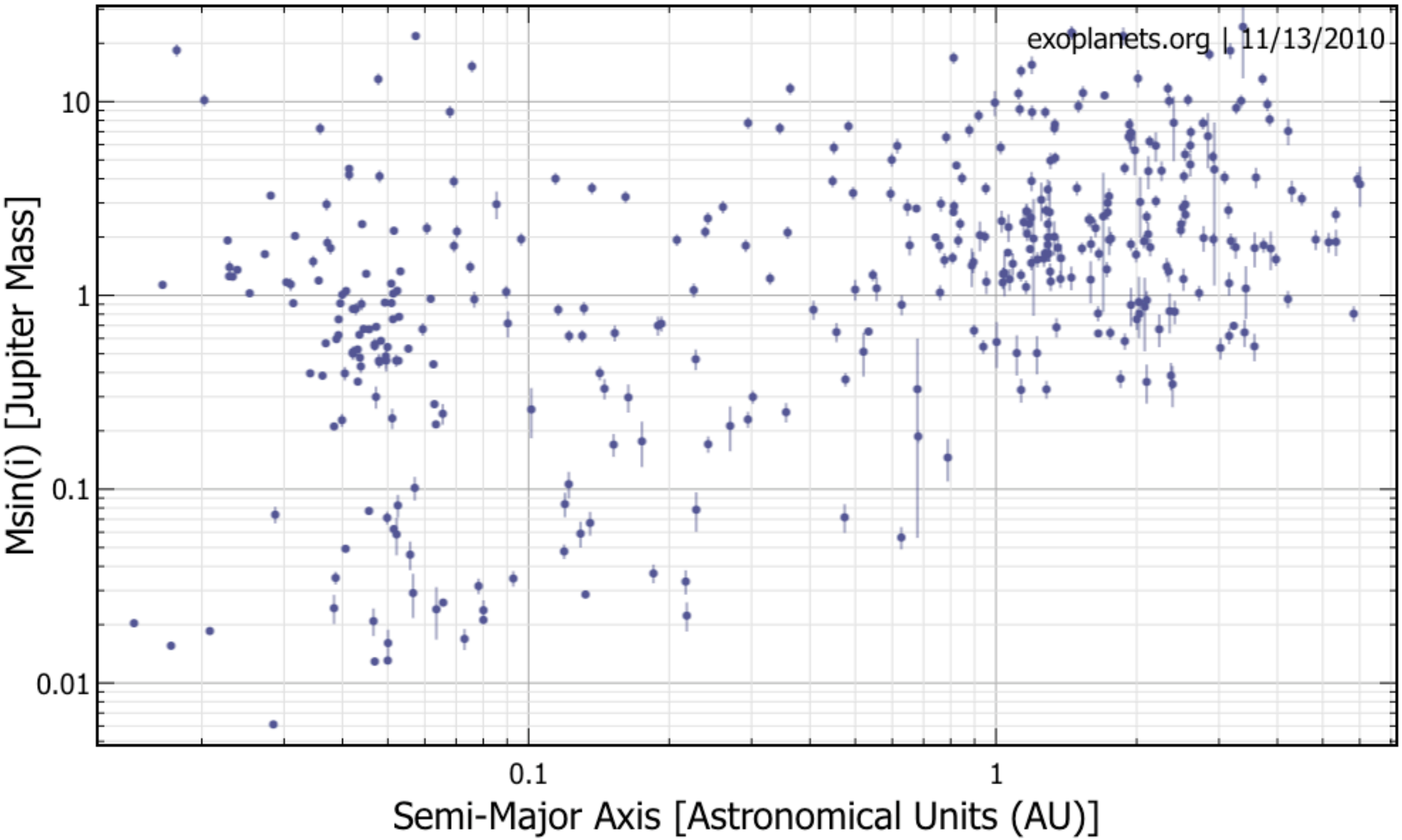
Exoplanet Tracker
(one planet detected)
Spectrashift.com Amateur radial velocity search
(1 planet confirmed)

RV planet searches. Results.

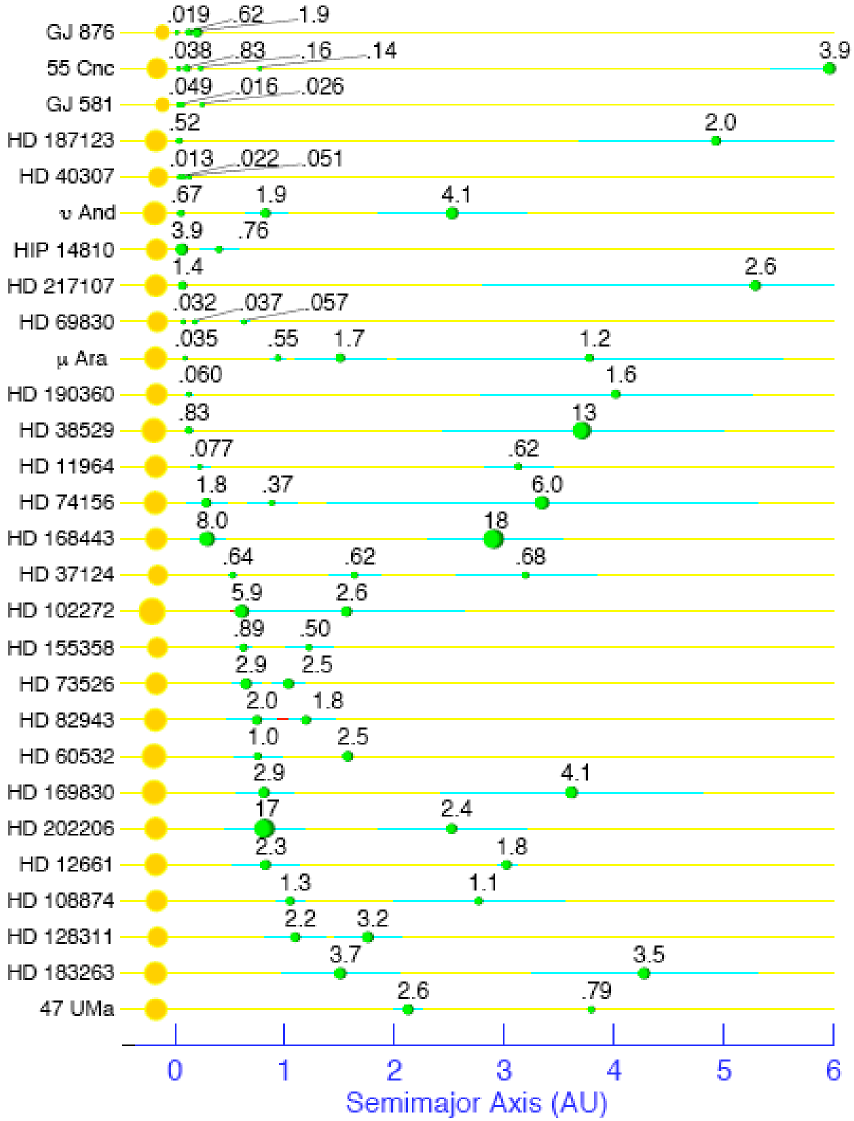


Udry & Santos (2007)

RV planet searches. Results.



RV planet searches. Results.



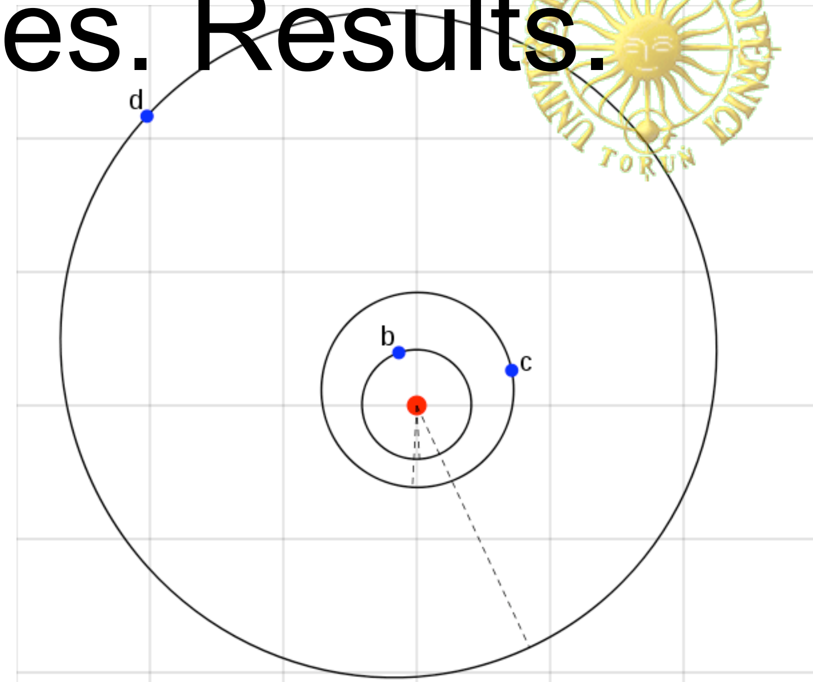
Wright (2009). 28 multi-planet systems

Today:

497 planets known,

(50 multi-planet systems).

RV planet searches. Results.



Gl 581

M3V, V=10.55

Distance: 6.26 pc

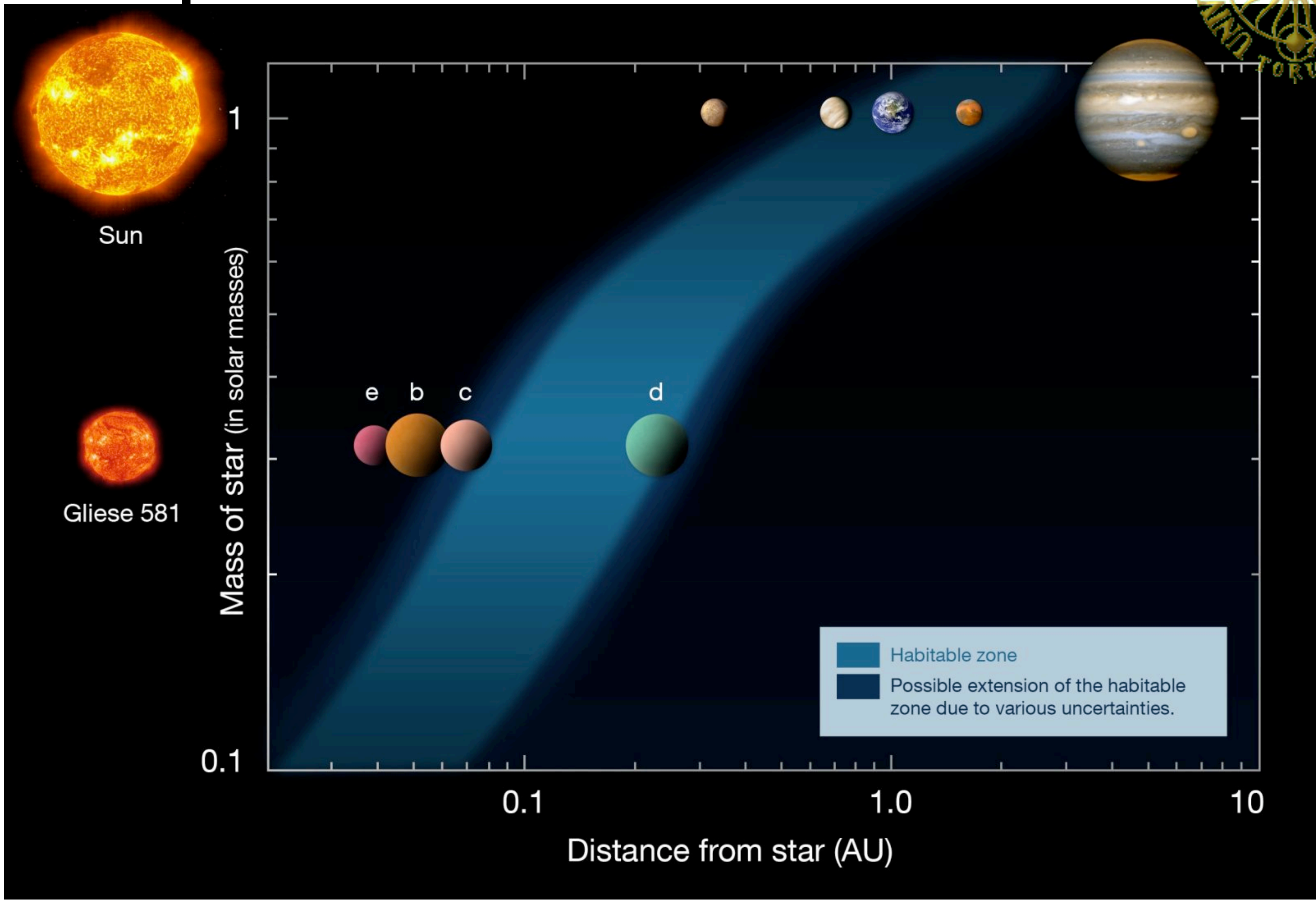
Stellar mass: 0.31 $M_{\odot}$

Stellar radius: 0.38 $R_{\odot}$

Age: >2 Gy

planet	mass [M_J]	a [AU]	P [d]	e	mass [$M_{\oplus}$]
b (2005)	0.049	0.041	5.37	0	15.6
c (2007)	0.017	0.07	12.92	0.17	5.4
d (2007)	**0.022**	**0.22**	**66.8**	**0.38**	**7.0**
e (2009)	0.006	0.03	3.15	0	**1.9**

RV planet searches. Results.

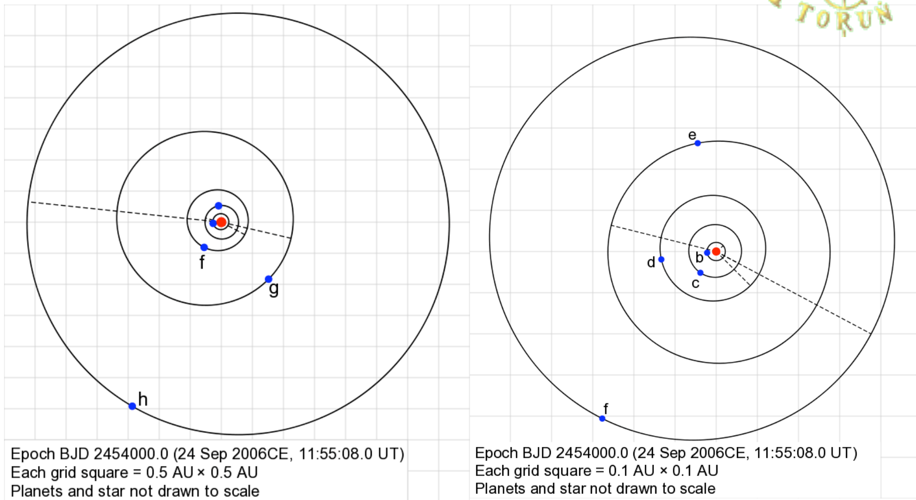


Habitable Zone in Gl 581 system.

RV planet searches. Results.

HD 10180

G1V, V=7.33
Distance: 40 pc
Stellar mass: 1.06 $M_\odot$
Eff. Temperature: 5911 K
Age: 4.3 Gy



planet	Mass [M_J]	a [AU]	P [d]	e	mass [$M_\oplus$]
b (2010)	0.004247	0.022	1.18	0.0	**1.40**
c (2010)	0.041217	0.064	5.76	0.077	13.16
d (2010)	0.036969	0.128	16.36	0.142	11.91
e (2010)	0.078973	0.269	49.75	0.061	25.3
f (2010)	0.075197	0.492	122.72	0.127	23.5
g (2010)	0.067331	1.422	602	0.0	21.3
h (2010)	0.202624	3.40	2229	0.145	65.2

RV planet searches.

Limitations:

SpType and V_{rot} limited.

Stellar masses needed.

Minimum planetary mass only $M_p \sin i$.

Stellar activity to be considered.

RV planet searches.

Conclusions

RV - very efficient way to find and characterize (multiple) extrasolar planetary systems.

Current precision ~ $3ms^{-1}$

Can reach Earth-mass planets in HZ soon.

In transiting systems delivers masses and densities.