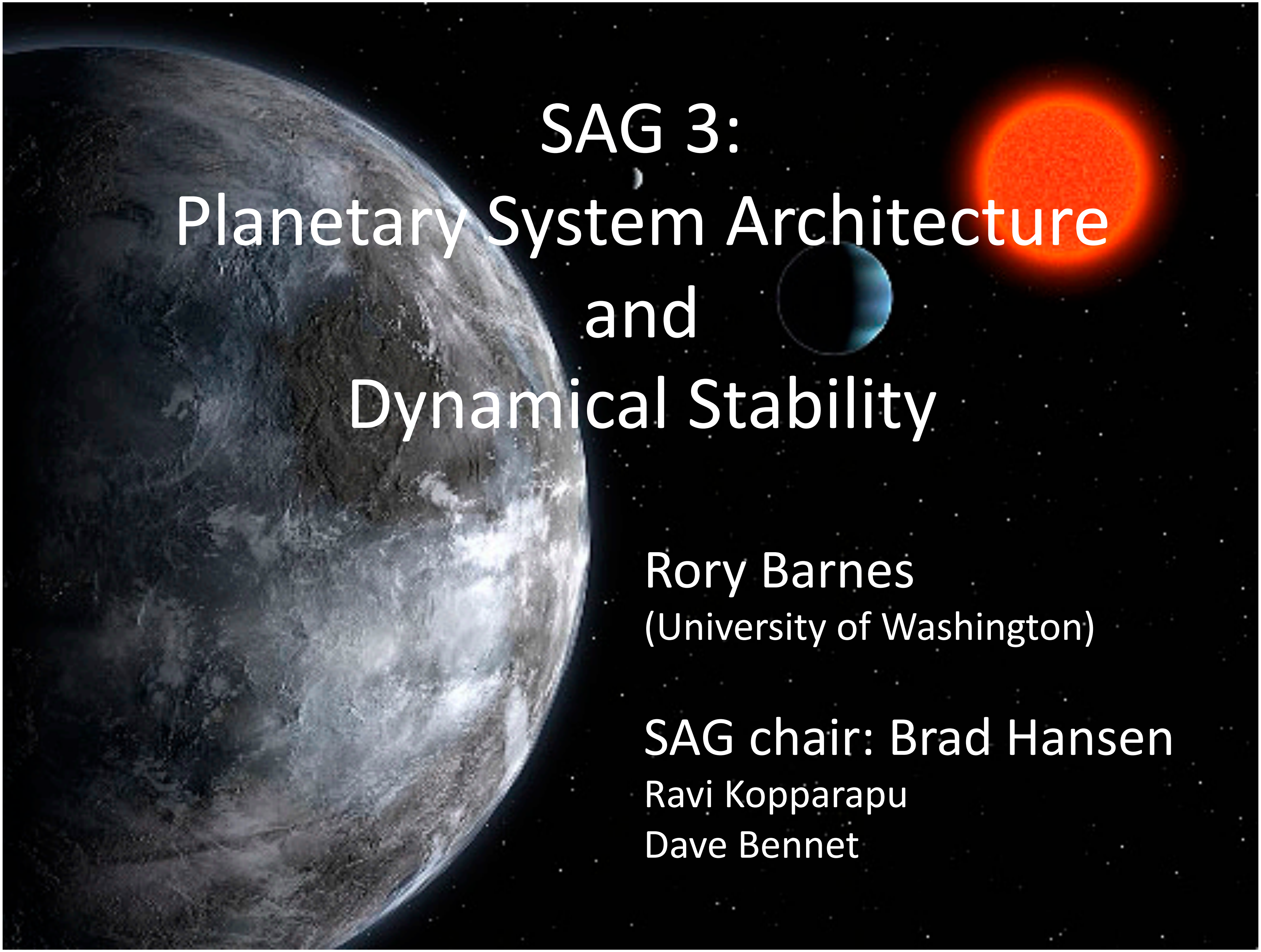


SAG 3: Planetary System Architecture and Dynamical Stability

Rory Barnes
(University of Washington)

SAG chair: Brad Hansen
Ravi Kopparapu
Dave Bennet

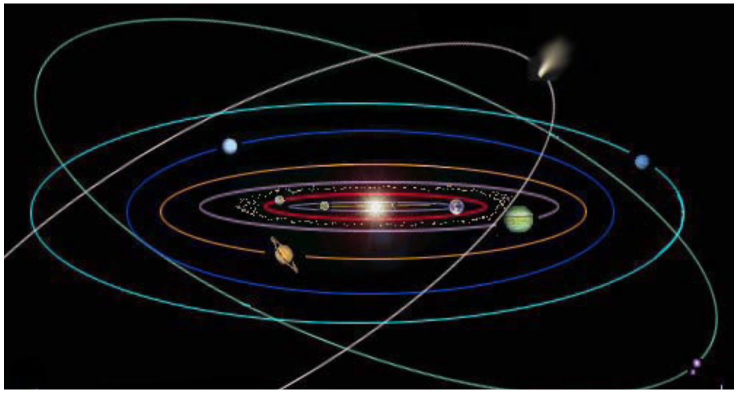
From the DC meeting

How well does one need to characterize planetary architecture to properly understand exoplanet habitability?

Can we use the statistical properties of planetary systems gleaned from a Galactic census to inform the study of nearby planetary systems?

From the DC meeting

Would it be possible or prudent to exclude some nearby systems from a direct imaging target list based on prior dynamical information that their habitable zones are unstable? Alternatively, is it advisable to prioritize a target list based on such dynamical considerations?



What is “architecture”?

Stellar and planetary masses

Orbital elements

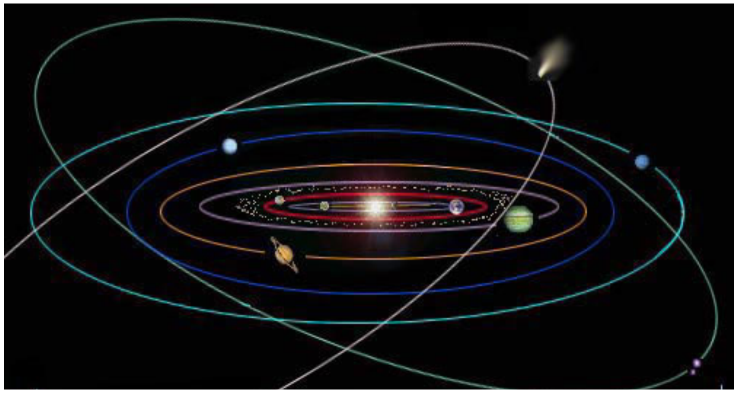
“Minor exoplanets”

Exo-moons

Planet-planet interactions

e.g. mean motion resonances

Obliquities



Architecture helps…

Assess planetary habitability

- How do orbits change with time?

Determine stability

- Where should we NOT look?

Constrain origins scenarios

- Does that super-Earth have water?

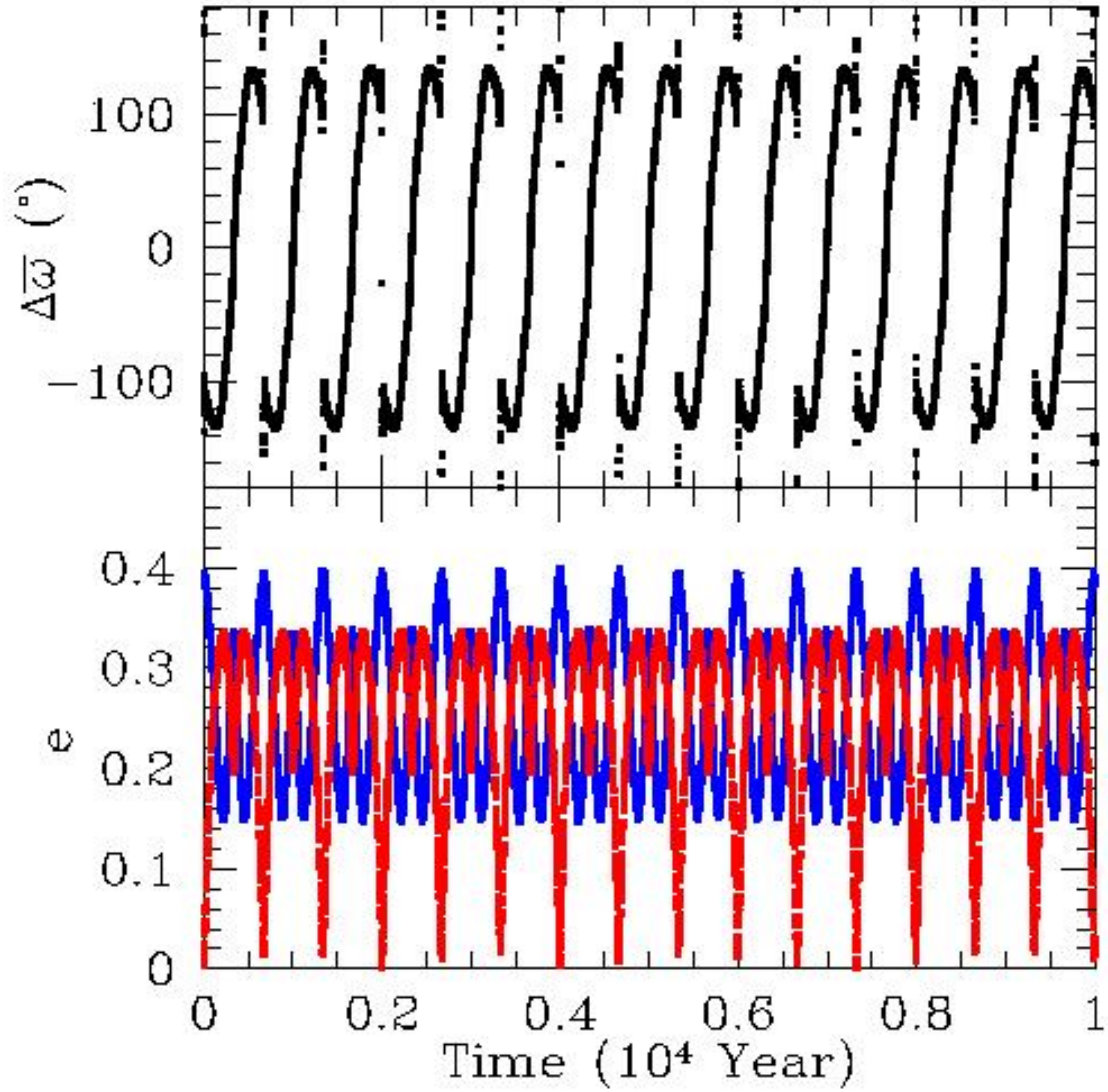
Search for planets

- Fomalhaut b
- T*V

Planetary Habitability

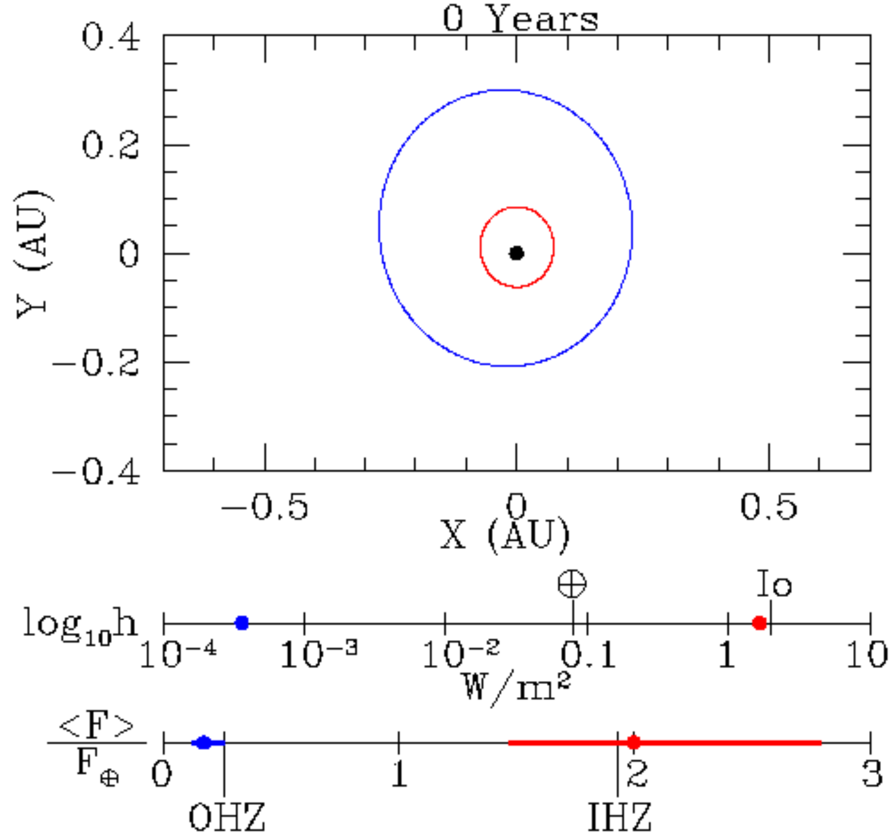
Perturbations from other planets change
- orbits with time
- obliquities with time
- insolation with time
- tidal effects (mainly for M stars)

HD 82943



Barnes &
Greenberg
2006

Planetary Habitability



Gl 581 w/extra 1 M_J planet at 0.75 AU with e = 0.3

red is planet c

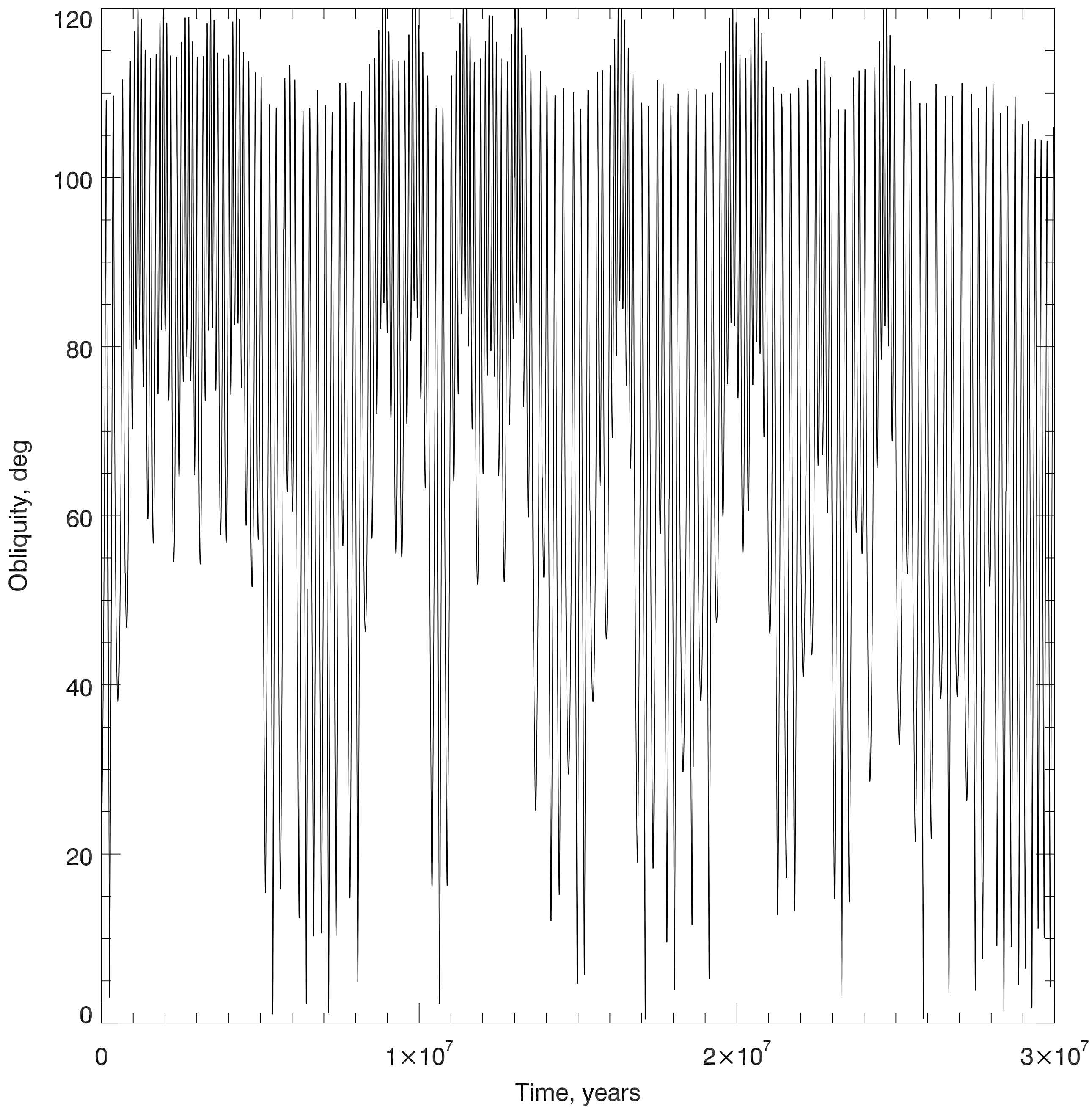
blue is planet d

Planetary Habitability

Mutual inclinations -> fast, large obliquity variations on terrestrial planets

υ And c and d have relative inclination of 30^{o} (McArthur *et al*. 2010)

Moons can stabilize obliquities, but are they detectable?



An Earth sandwiched between two super-Earths with mutual inclination 30^o

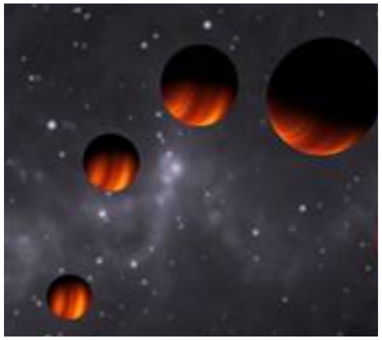
Figure courtesy John Armstrong

Dynamical Stability

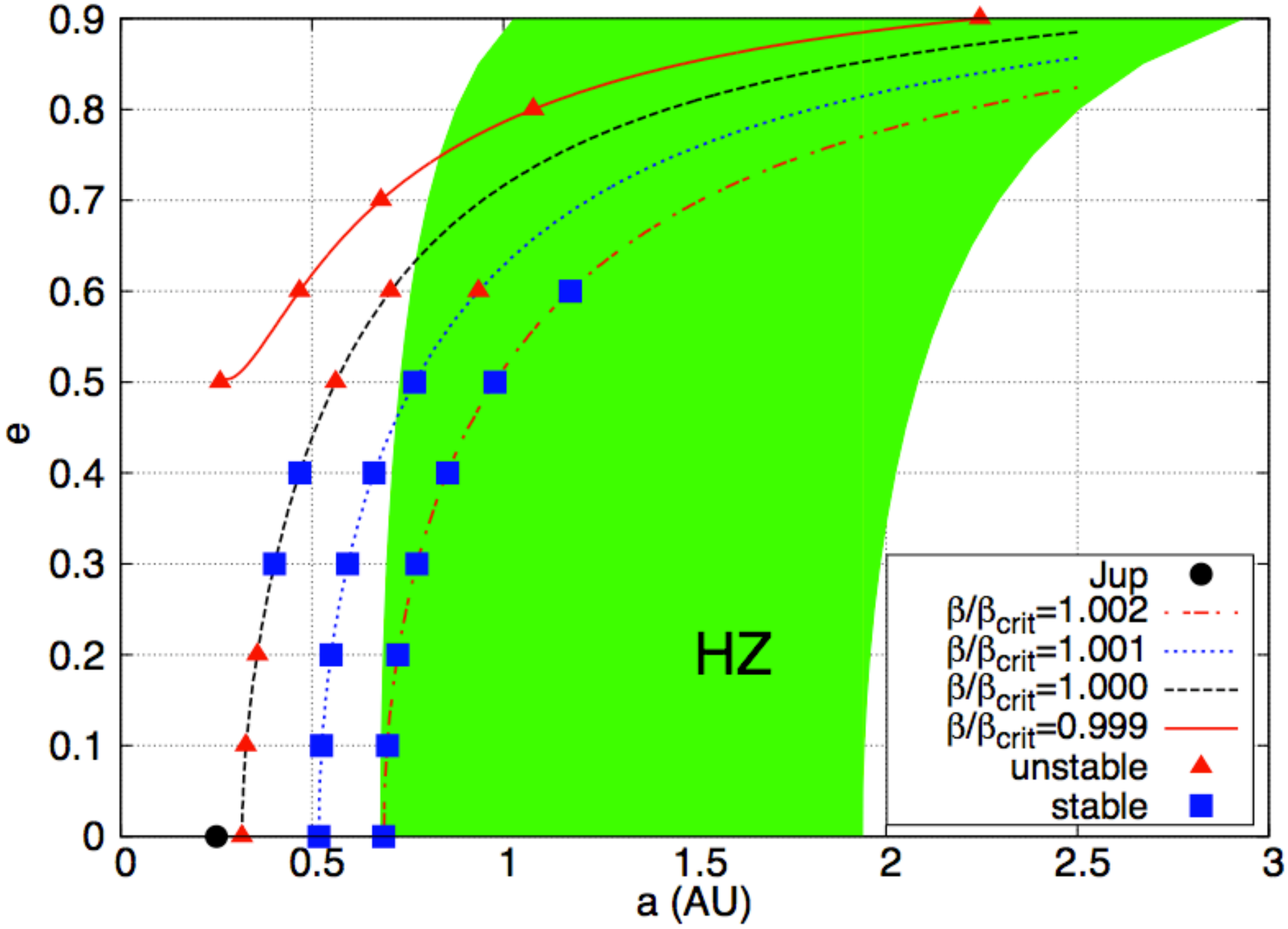
Detecting terrestrial planets is hard

Can we narrow our search by excluding some habitable zone as unstable?

Several studies: Jones *et al*. (2001); Menou & Tabachnik (2003); Sandor *et al.* (2005); Kopparapu & Barnes (2010)

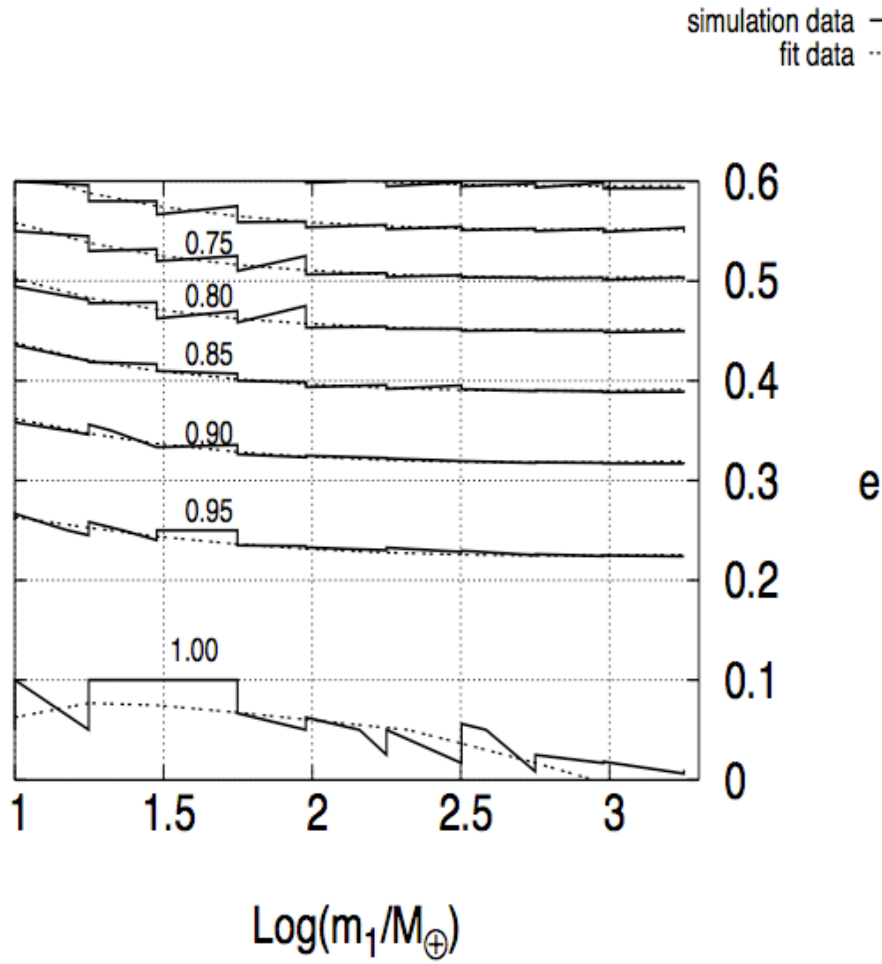


Dynamical Stability



Kopparapu & Barnes 2010

Dynamical Stability



Kopparapu & Barnes 2010

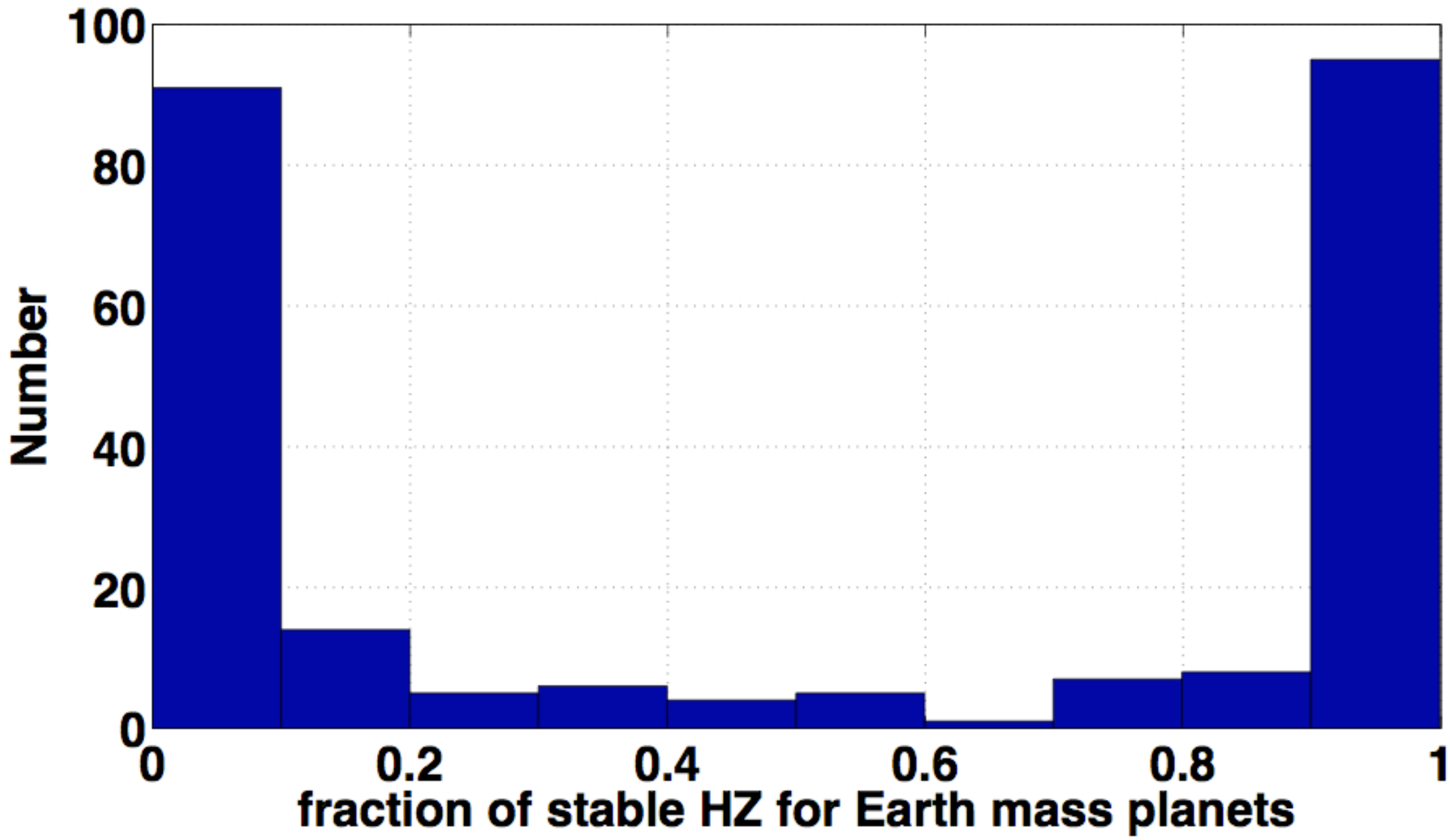
Dynamical Stability

http://gravity.psu.edu/~ravi/planets/tab4.txt

#System	m_{1}(Mjup)	a(AU)	e	tau_s (1 ME)	tau_u (1 ME)	FHZ (1 ME)	tau_s (10 ME)	tau_u (10 ME)	FHZ (10 ME)
HD142b	1.3057	1.04292	0.26	0.9347	0.9323	0.000	0.9552	0.9320	0.000
HD1237b	3.3748	0.49467	0.51	0.7407	0.7401	0.213	0.7549	0.7450	0.000
HD1461b	0.0240	0.06352	0.14	0.9920	0.9780	0.976	1.0200	0.9200	0.959
WASP-1b	0.9101	0.03957	0.00	1.0022	0.9990	0.990	1.0200	0.9980	0.991
HIP2247b	5.1232	1.33884	0.54	0.7138	0.7111	0.000	0.7490	0.7387	0.000
HD2638b	0.4773	0.04357	0.00	1.0027	0.9993	0.973	1.0200	0.9868	0.974
HD3651b	0.2290	0.29472	0.60	0.6514	0.6451	0.591	0.7243	0.7043	0.656
HD4208b	0.8075	1.65355	0.05	1.0006	0.9966	0.000	0.9984	0.9970	0.366
HD4308b	0.0477	0.11919	0.00	1.0050	0.9950	0.937	1.0200	0.9602	0.919
HD4203b	2.0821	1.16537	0.52	0.7332	0.7316	0.000	0.7727	0.7554	0.000
HD4313b	2.3479	1.17834	0.04	0.9985	0.9978	0.000	1.0024	0.9946	0.000
HD5319b	1.9377	1.74656	0.12	0.9860	0.9849	0.026	0.9919	0.9842	0.000
HD5388b	1.9651	1.76349	0.40	0.8427	0.8400	0.000	0.8423	0.8414	0.416
HD6434b	0.3972	0.14206	0.17	0.9750	0.9698	0.874	1.0095	0.9685	0.866
HD7924b	0.0291	0.05664	0.17	0.9840	0.9710	0.964	1.0200	0.9120	0.945
HD8574b	1.8060	0.75714	0.30	0.9120	0.9105	0.015	0.9114	0.9108	0.621
HD10647b	0.9250	2.02175	0.16	0.9766	0.9734	0.000	0.9910	0.9694	0.000
HD10697b	6.2351	2.13177	0.10	0.9906	0.9900	0.000	0.9904	0.9901	0.194
HD11506b	4.7347	2.60488	0.30	0.9110	0.9103	0.000	0.9111	0.9105	0.197
HD11977b	6.5199	1.93643	0.40	0.8410	0.8402	0.000	0.8416	0.8410	0.003
GJ86b	4.0010	0.11422	0.04	0.9988	0.9980	0.857	1.0057	0.9981	0.806
HD13931b	1.8812	5.14931	0.02	0.9995	0.9987	0.742	1.0032	0.9947	0.668
HD16141b	0.2497	0.35566	0.25	0.9422	0.9394	0.752	0.9464	0.9388	0.811
30AriBb	9.8779	0.99475	0.29	0.9163	0.9155	0.000	0.9215	0.9164	0.000
HD16417b	0.0670	0.13543	0.20	0.9735	0.9600	0.936	0.9686	0.9600	0.932
HD16175b	4.3795	2.11850	0.60	0.6446	0.6427	0.000	0.7096	0.6913	0.000
81Cetb	5.3409	2.53876	0.21	0.9562	0.9557	0.018	0.9622	0.9578	0.000
iotaHorb	2.0468	0.92376	0.14	0.9815	0.9800	0.057	0.9993	0.9819	0.000
HD17092b	4.9621	1.30798	0.17	0.9711	0.9707	0.074	0.9785	0.9718	0.000
WASP-11b	0.5262	0.04309	0.00	1.0029	0.9991	0.939	1.0200	0.9887	0.943
HD19994b	1.3268	1.30567	0.27	0.9291	0.9268	0.000	0.9503	0.9240	0.000
epsilonErib	1.0851	3.42426	0.25	0.9408	0.9379	0.265	0.9399	0.9380	0.718
HD23127b	1.4049	2.31864	0.44	0.8100	0.8081	0.000	0.8404	0.8257	0.000
HD23079b	2.4433	1.59509	0.10	0.9913	0.9901	0.000	0.9908	0.9899	0.074
HD23596b	7.7427	2.77219	0.27	0.9274	0.9269	0.000	0.9353	0.9299	0.000

Kopparapu & Barnes 2010

Dynamical Stability



Kopparapu & Barnes 2010

Dynamical Stability

But…

Mean motion resonances can stabilize

Earth-mass planets can masquerade as
eccentricity (Anglada-Escude *et al*. 2010)

Stability analyses should be used cautiously

Planet Formation

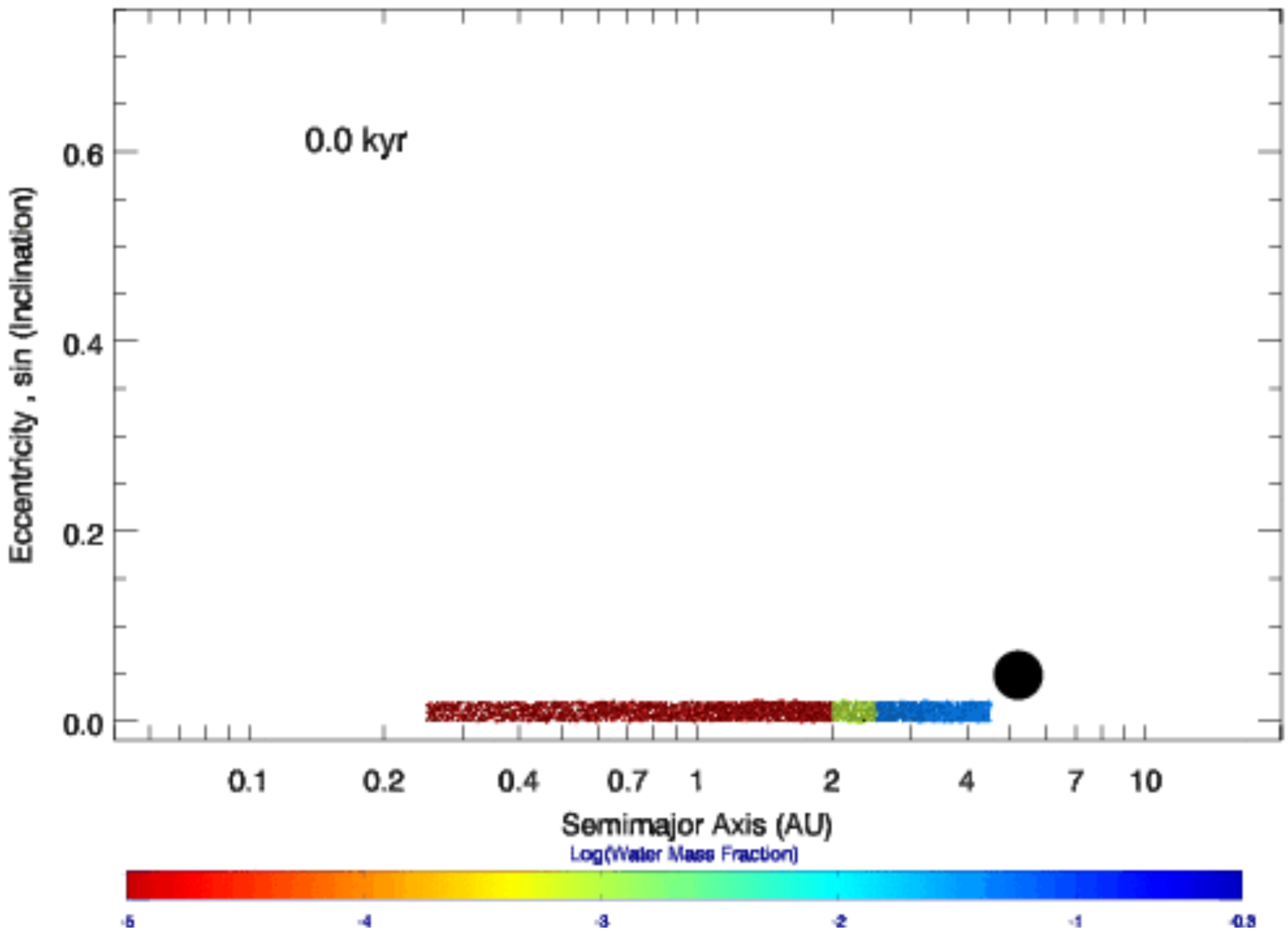
Can the layout of a planetary system reveal its history?

Large eccentricities => planet-planet scattering

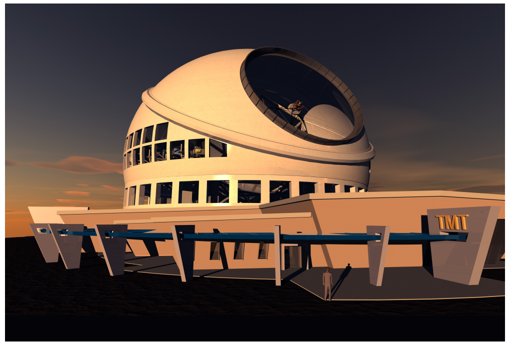
Mean motion resonances => migration

Can we constrain composition?

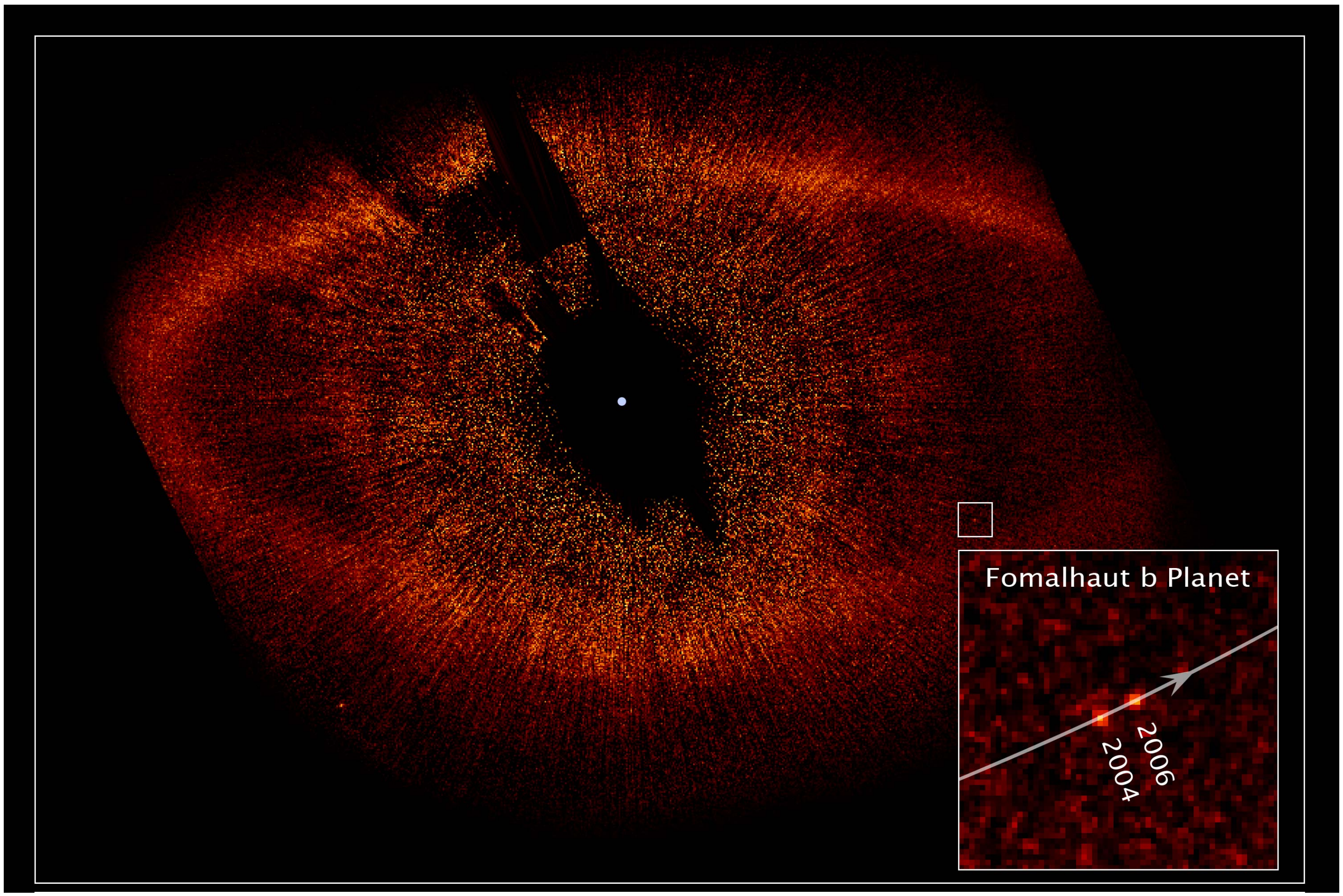
Planet Formation



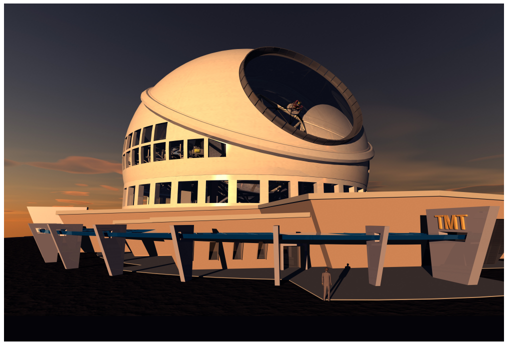
Raymond, Mandell & Sigurdsson (2006)



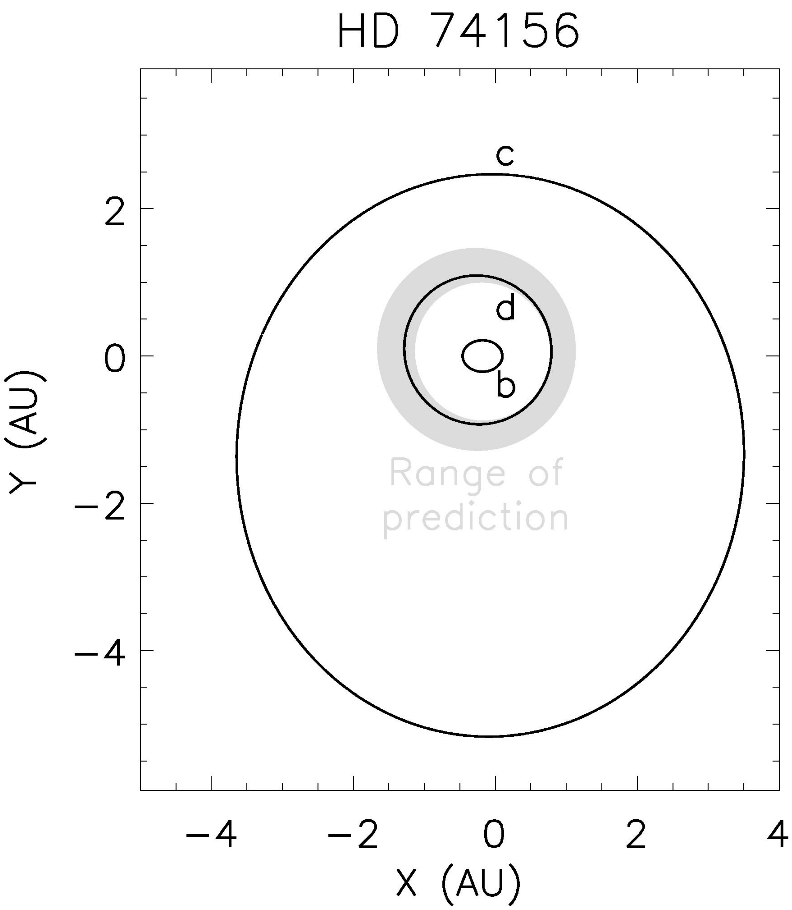
Detection



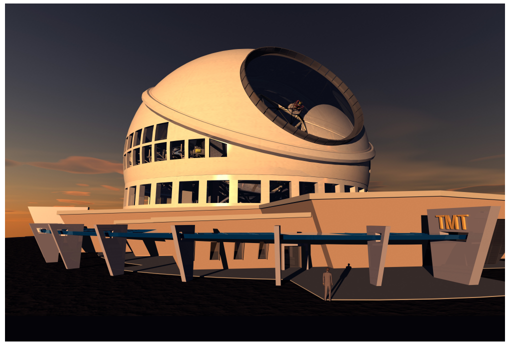
Kalas *et al.* (2008)



Detection



Barnes *et al.* (2008)



Detection

Transit Timing Variations

Search Program	Telescope	Object	V Mag	Precision (approx)	Ref.
APOSTLE	ARC 3.5m (Ground)	WASP-2b	11.98	5 sec	Becker et al. (in prep)
APOSTLE	"	TrES-3b	12.4	11 sec	Kundurthy et al. (in prep)
Kepler	0.95m (Space)	Kepler-7b	13(?)	12 sec	Latham (2010)
Kepler	"	Kepler-8b	13.9	25 sec	Jenkins et al (2010)
CoRoT	0.27m (Space)	CoRoT-2b	12.57	12 sec	Alonso et al (2008)
CoRoT	"	CoRoT-7b	11.7	120 sec	Queloz et al (2009)
MOST	0.15m (Space)	HD 189733	7.67	20-50 sec	Miller-Ricci et al (2008a)
MOST	"	HD 209458	7.65	40-70 sec	Miller-Ricci et al (2008b)
EPOXI	0.30m (Space)	HAT-P-7	10.5	85 sec	Christiansen (2010)
Spitzer	0.85m (Space)	HD 149026b	8.15	40 sec	Nutzman et al (2009)
HST	2.4m (Space)	HD 209458b	7.65	10-40 sec	Agol & Steffen (2007)
VLT	8.2m (Ground)	OGLE-TR-111b	16.9	25 sec	Diaz et al (2008)

Table courtesy
Praveen Kundurthy

Discussion