Planets: From observations to formation

Wilhelm Kley
Institut für Astronomie & Astrophysik
& Kepler Center for Astro and Particle Physics Tübingen

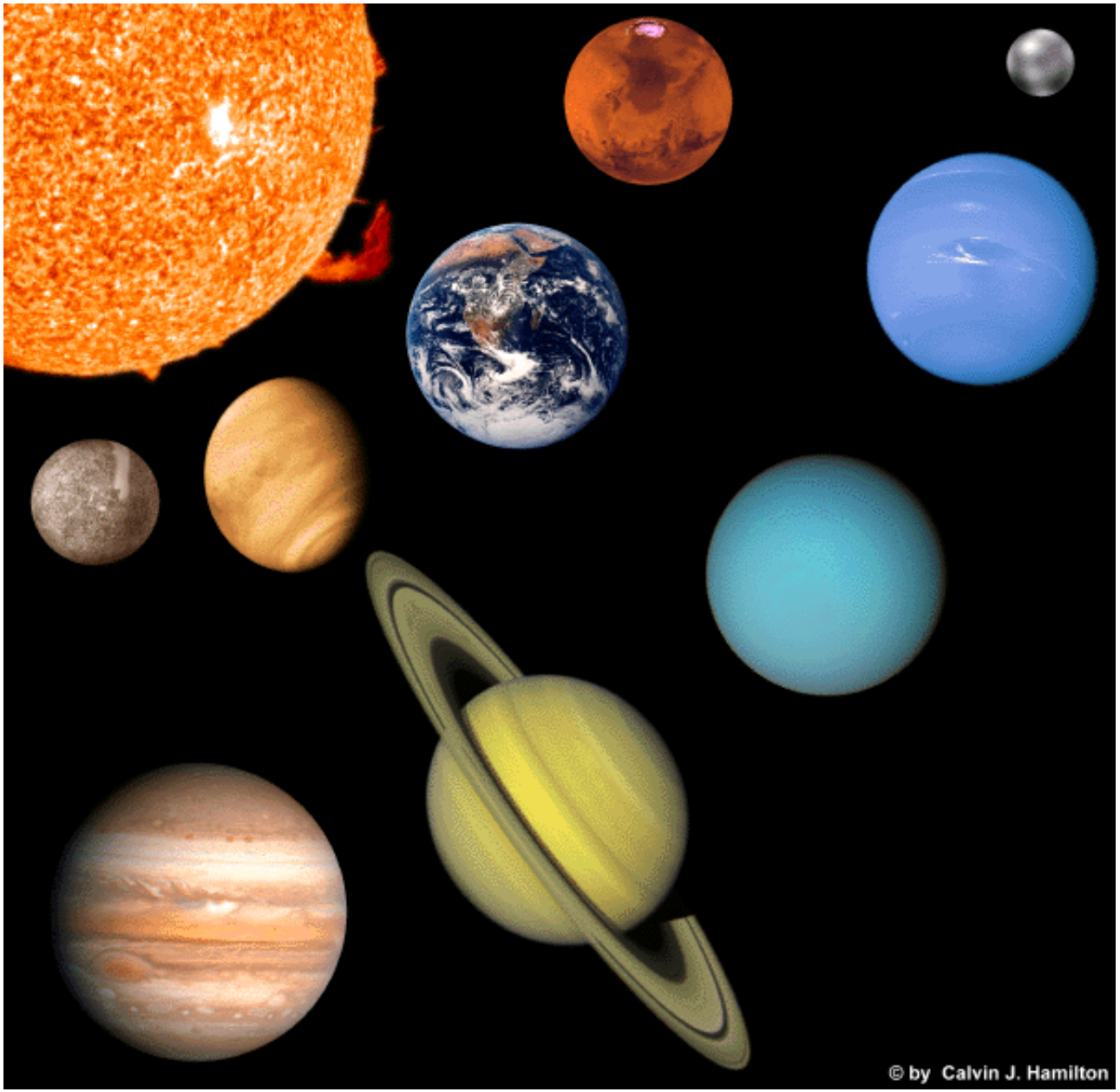
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

March 2015

0. Observations to Models: Organisation

- The Solar System
- Exoplanets
- Formation

0.1 Solar System: The inventory



Sun

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptun

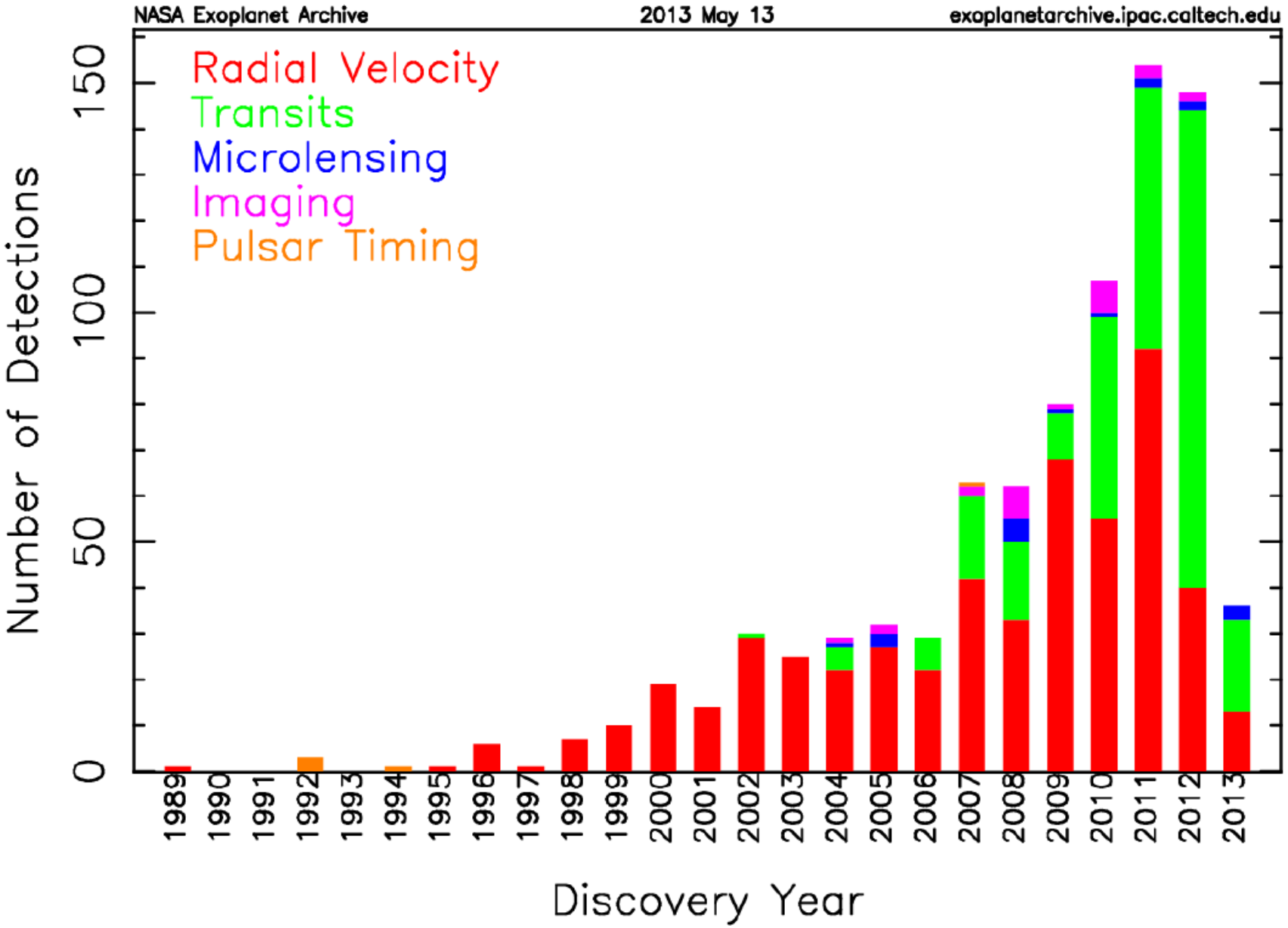
(Pluto)

0.1 Solar System: Summary of properties

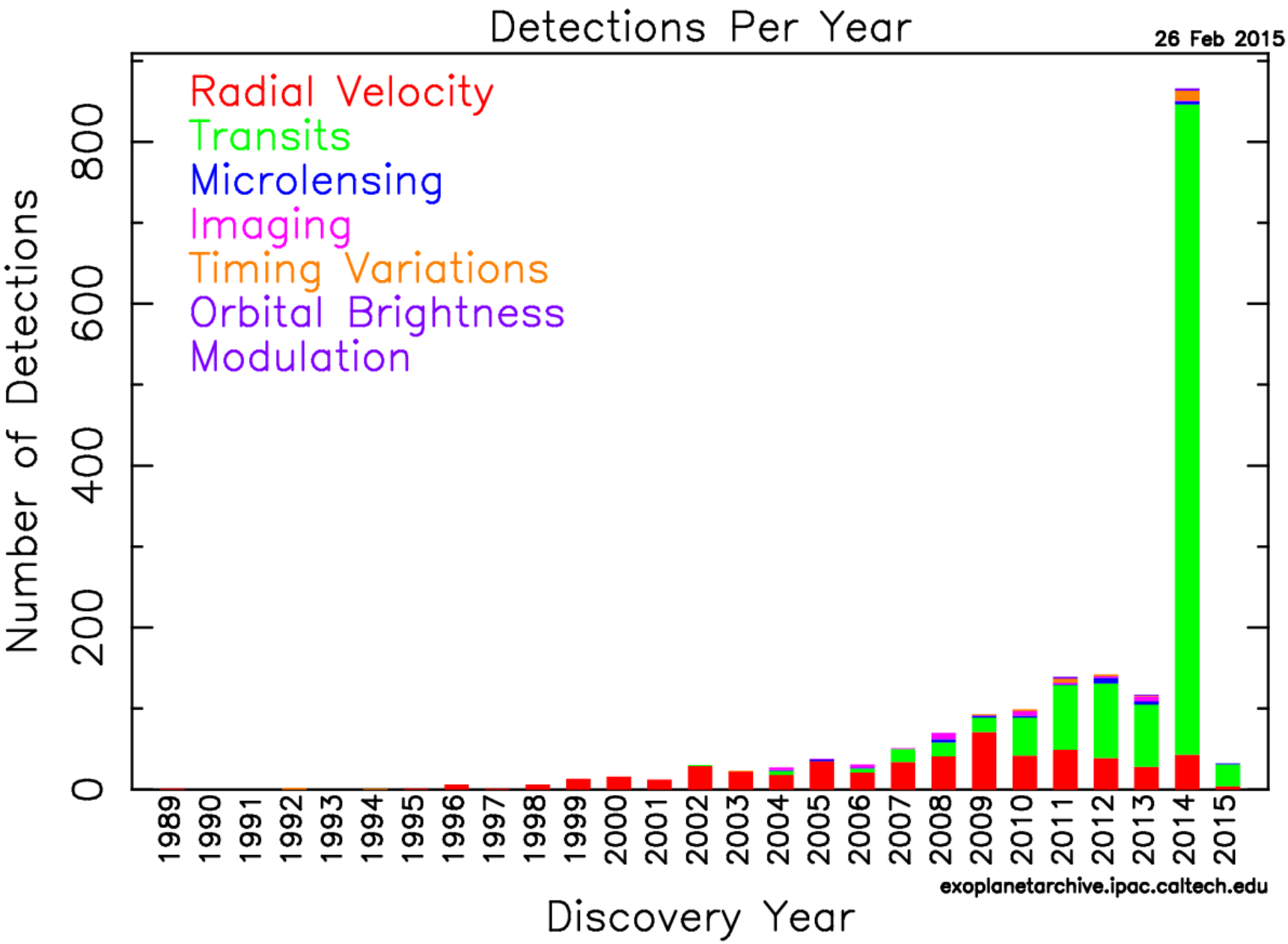
8 Planets:	Mercury to Neptune
5 Dwarf Planets:	Ceres, Pluto, Eris, Makemake, Haumea
Minor bodies:	TNO, asteroids, comets
Tiny bodies:	meteorites, dust

- coplanar, circular, uniform orbits (cp. Kepler candidates)
- Solid and gaseous planets (with Cores)
- prograde rotation (with exceptions)
- 99% of mass in Sun
- 99% of angular momentum in planets
- Age: about 4.5 billion years

0.2 Exoplanets: Numbers: May 2013



0.2 Exoplanets: Numbers: February 2015



0.2 Exoplanets: Overview of detections

Planet candidates around: Solar type stars

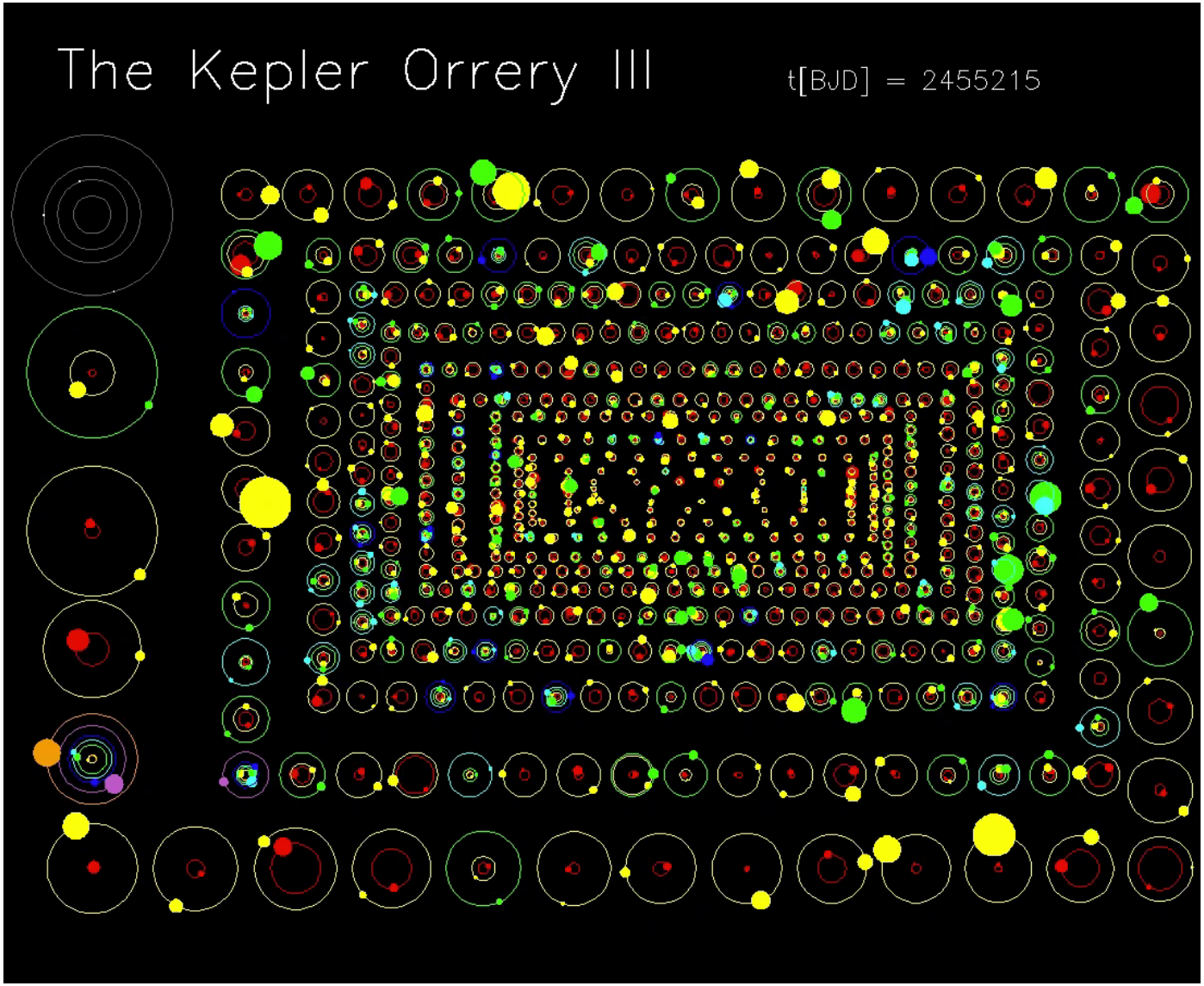
as of March 2015 (exoplanet.eu)

- Total 1896
- eclipsing systems (Transits) $\approx$ 1195
- planetary systems $\approx$ 1194
- systems with 2 or more planets $\approx$ 478
- planetary systems in binary stars $\approx$ 80

Online-Catalogues:
`http://exoplanet.eu/`
`http://exoplanets.org`
`http://www.openexoplanetcatalogue.com/`

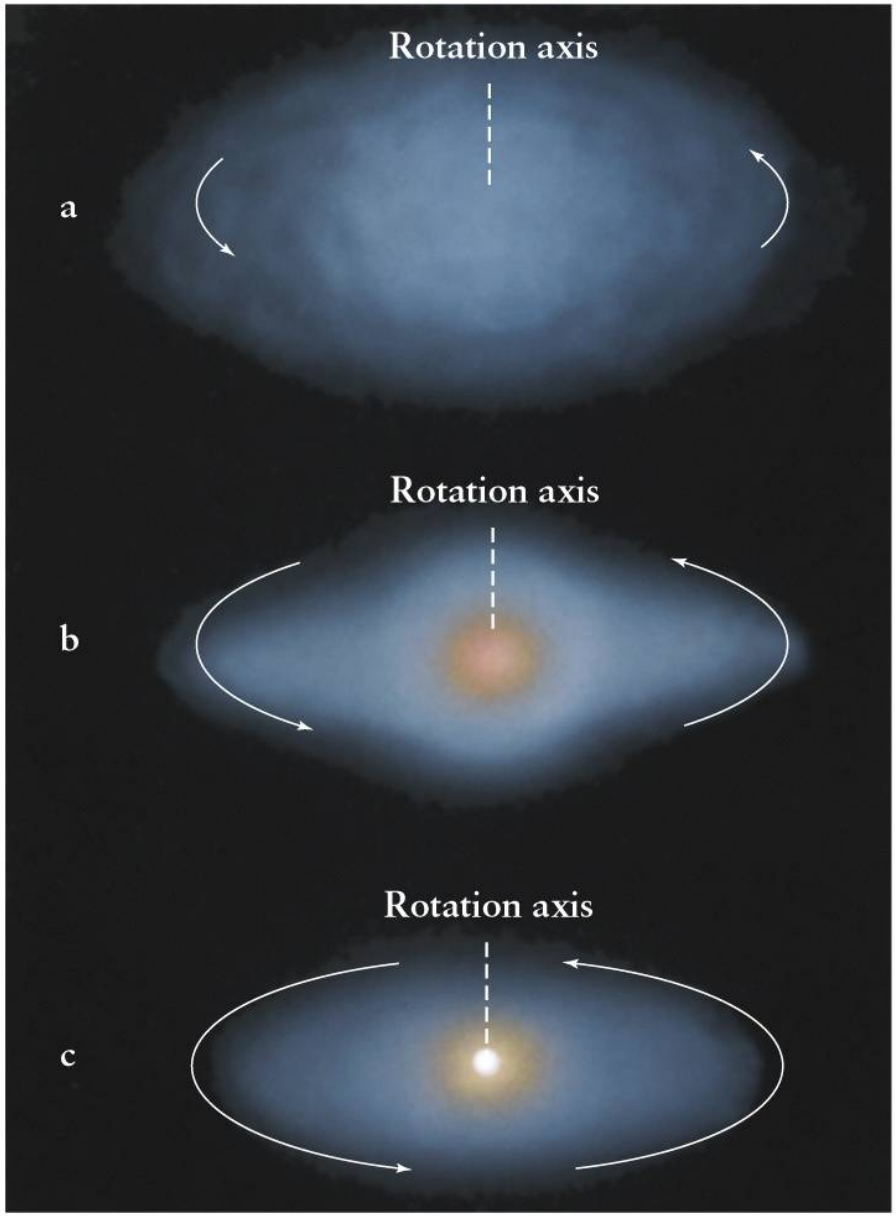
(Image: `http://oklo.org/`)
(by Greg Laughlin)

0.2 Exoplanets: The Kepler-Orrery



(by Daniel Frabrycky, On Youtube)

0.3 Formation: The overview



Historic View:
(Leukippos, 480-420 BC)
“The worlds form in such a way, that the bodies sink into the empty space and connect to each other.”

Modern View:
Collapse of an interstellar molecular cloud
Slight rotation $\Rightarrow$ Flattening
Protosun in center / disk formation
(based on Kant & Laplace, 1750s)

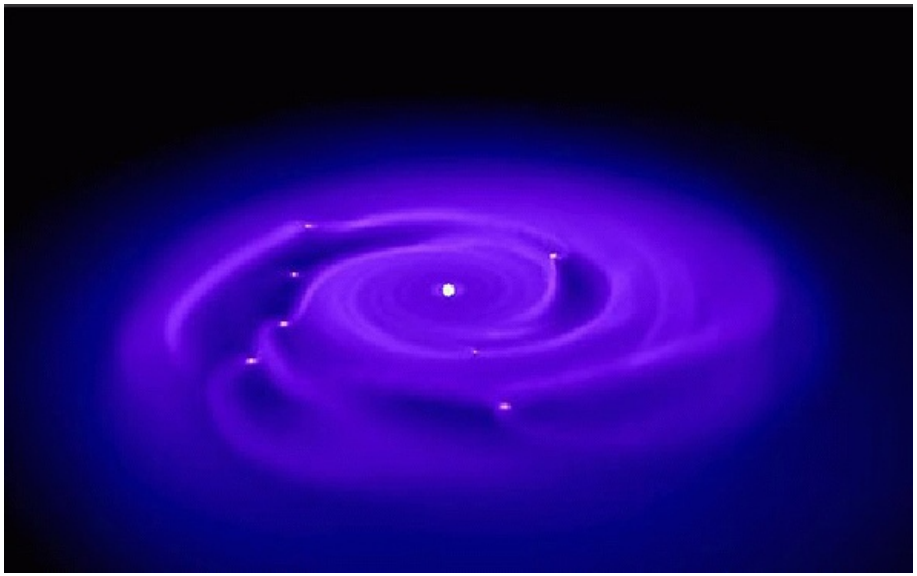
Planets form in protoplanetary disks $\equiv$ Accretion Disks (99% Gas, 1% Dust)

$\Longrightarrow$

Flat system, uniform rotation, circular orbits
As in Solar System & Kepler Systems

0.3 Formation: Two main scenarios

Gravitational-Instability (top-down)



(L. Mayer)

Self-gravitating disk

Density-Fluctuations grow

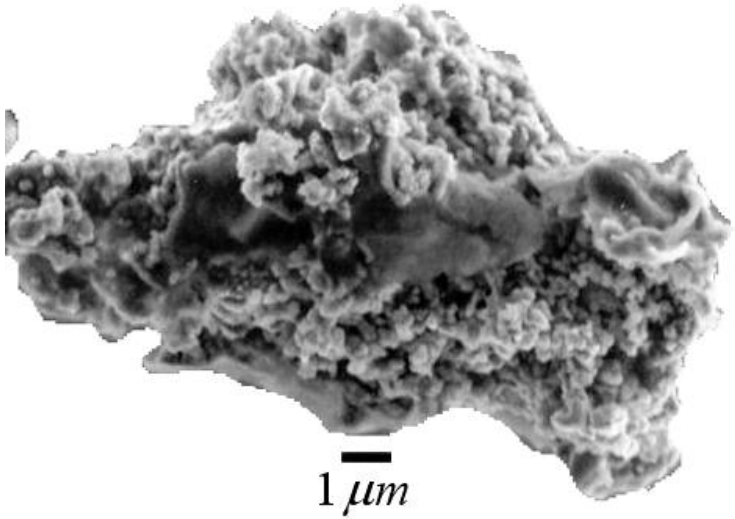
Spiral arms $\Rightarrow$ planets

Fast formation (10^3 years)

No cores

(Good for distant planets?)

Sequential Accretion (bottom-up)



(NASA, U2)

From small to large particles

Slow formation (10^6 Years)

Need: High sticking probability

(Comets, asteroids, solid planets, cores of planets)

(Preferred for Solar System)

0. Overview of lectures:

Planet formation and disk-planet interactions

1) From dust to planetesimals
2) Terrestrial planet formation
3) Formation of massive planets
4) Planet-disk interaction
5) Population synthesis
6) Multi-body systems
7) Planet formation by self-gravity
8) The dynamical structure of the solar system

0. Literature:

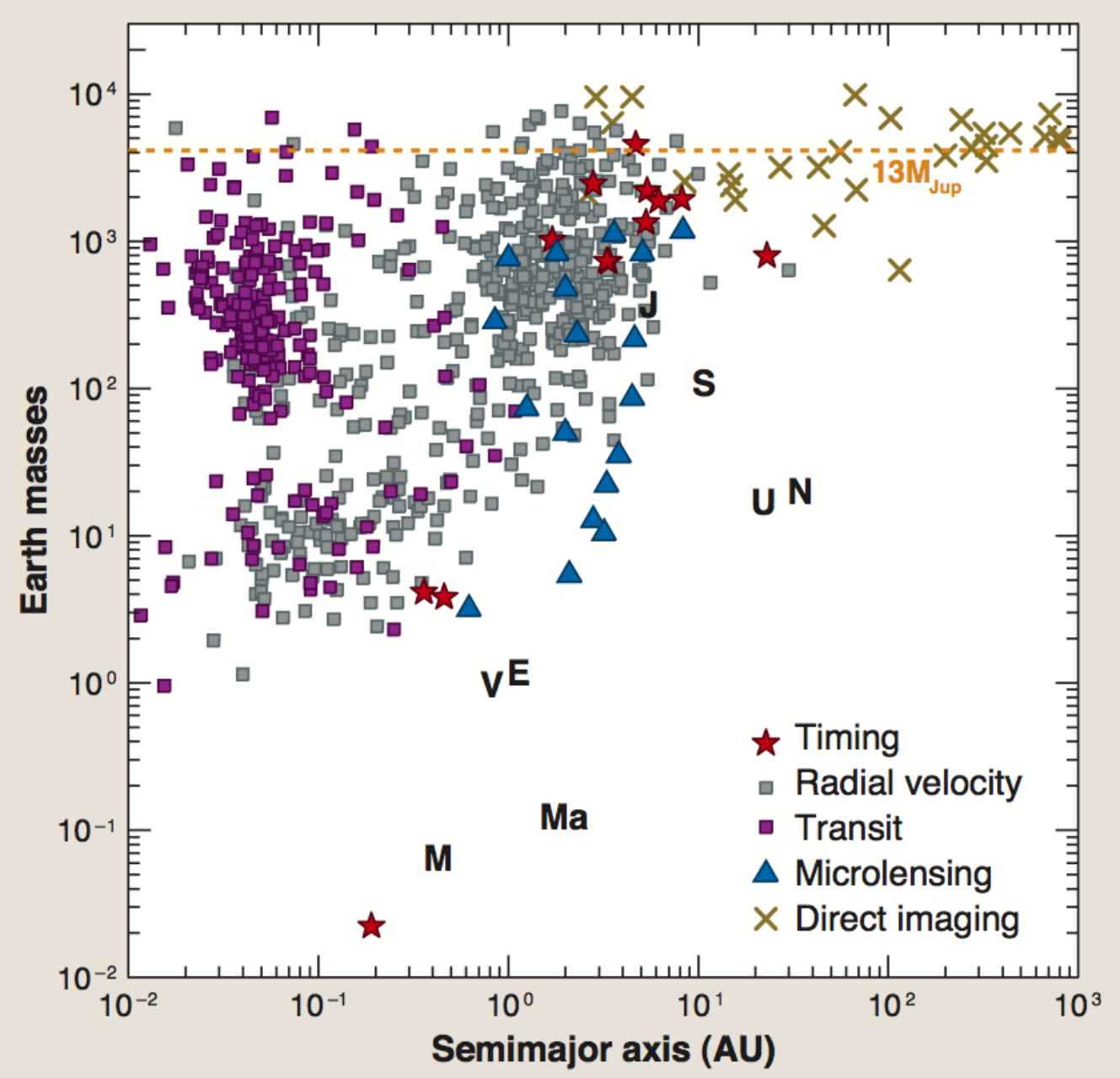
Overview texts in Planet Formation

- Phil Armitage
  The astrophysics of planet formation, Cambridge University Press
  Also available on astro-ph
- Protostars & Planets Series
  Chapters of PPIV (2000): here
  Chapters of PPV (2006): here
  Slides of PPVI (2013): here

0. Appendix: Additional Slides

Not seen in the Presentation

0. Appendix: Mass vs. distance



As of today:
1894 planets
in 1194 systems

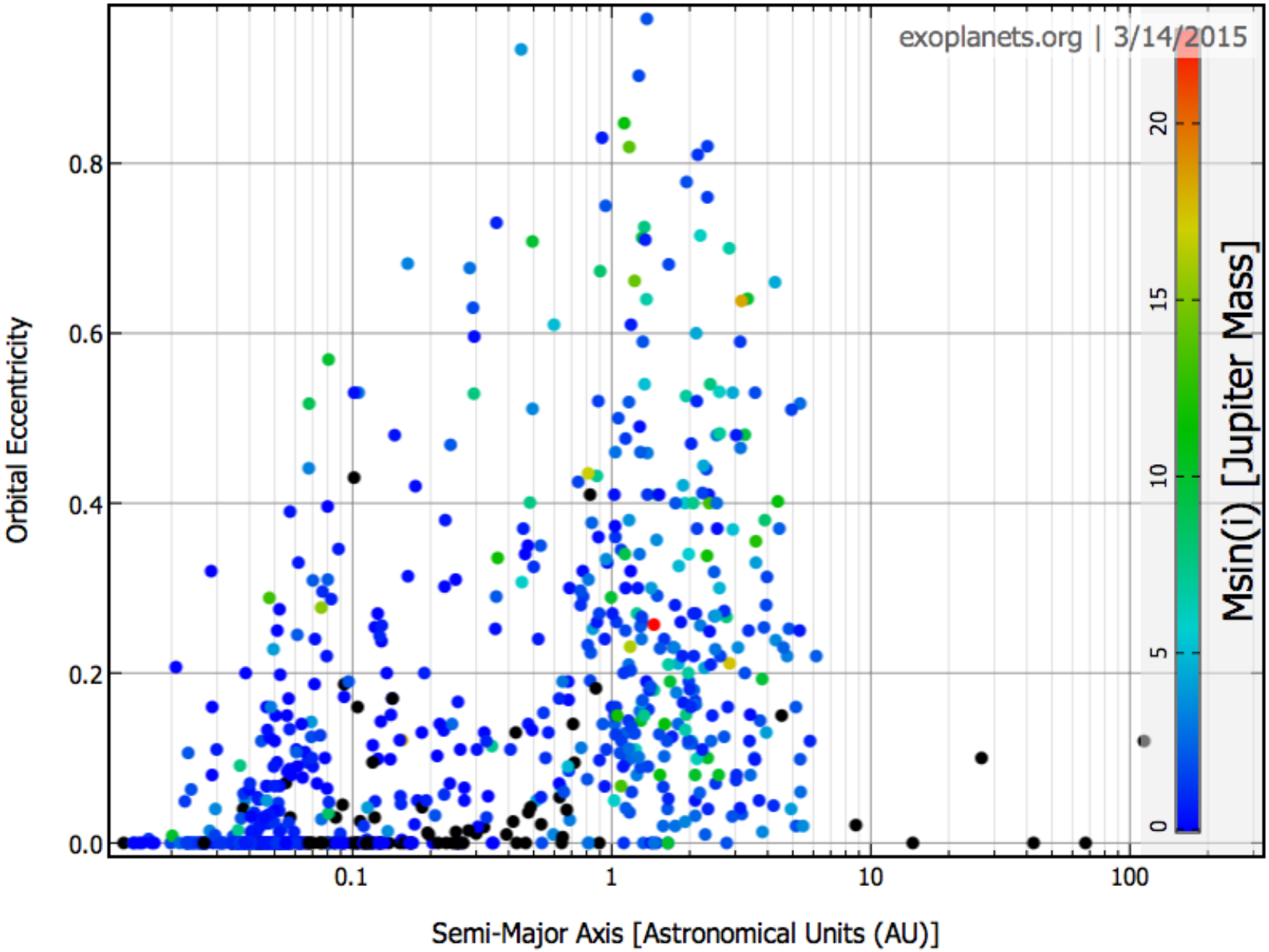
Color-Coding:
detection methods

Distances:
- orbital period
- direct imaging

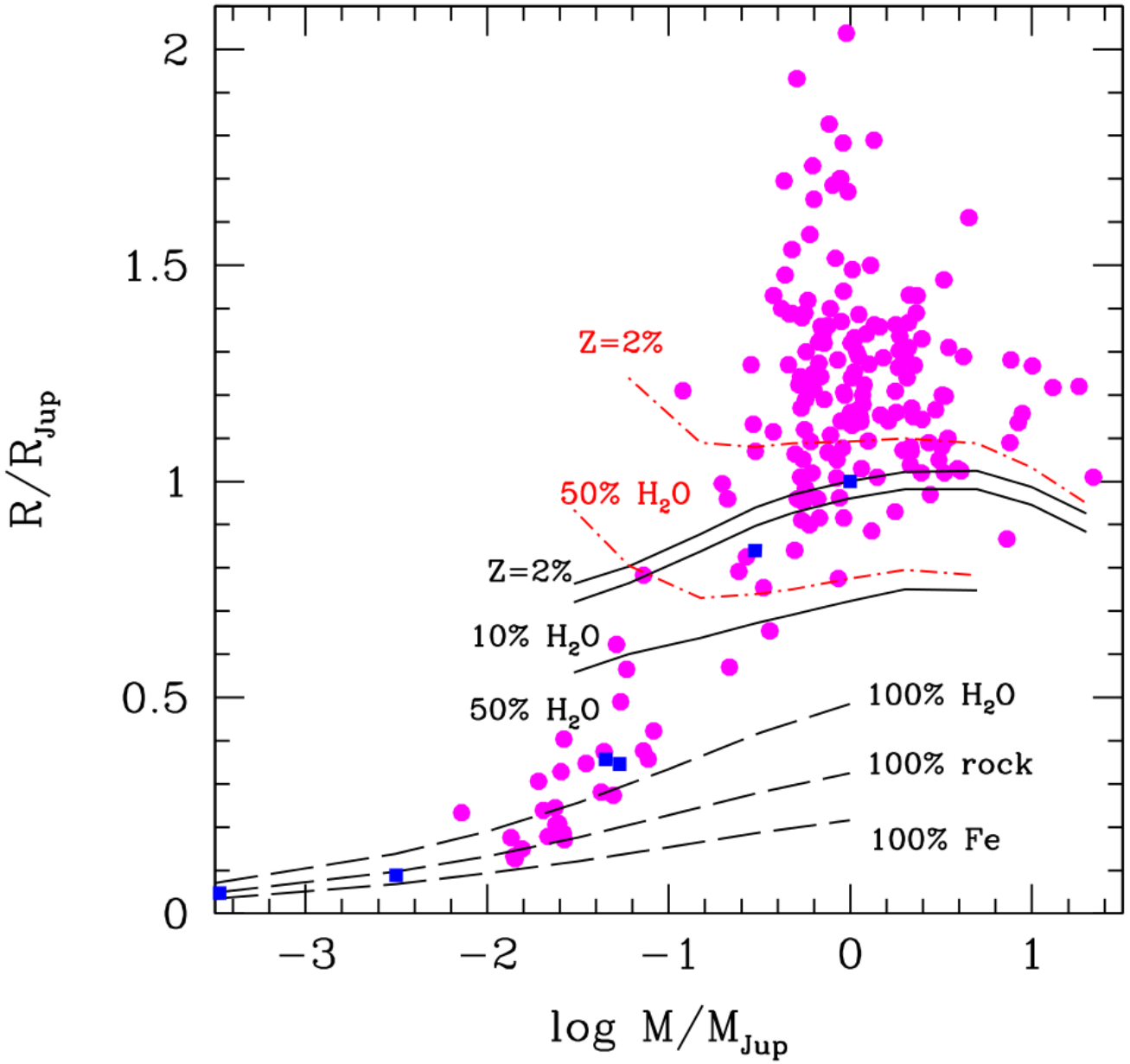
Masses:
- RV (sin *i*)
- spectra (uncertain)

(Seager, 2013)

0. Appendix: Eccentricity vs. distance (RV-data)



0. Appendix: Mass-Radius relation



Observations:

Solar Planets

- Mars to Neptune

Exoplanets

- cleaned sample

Models:

dashed lines:

- pure systems

solid lines:

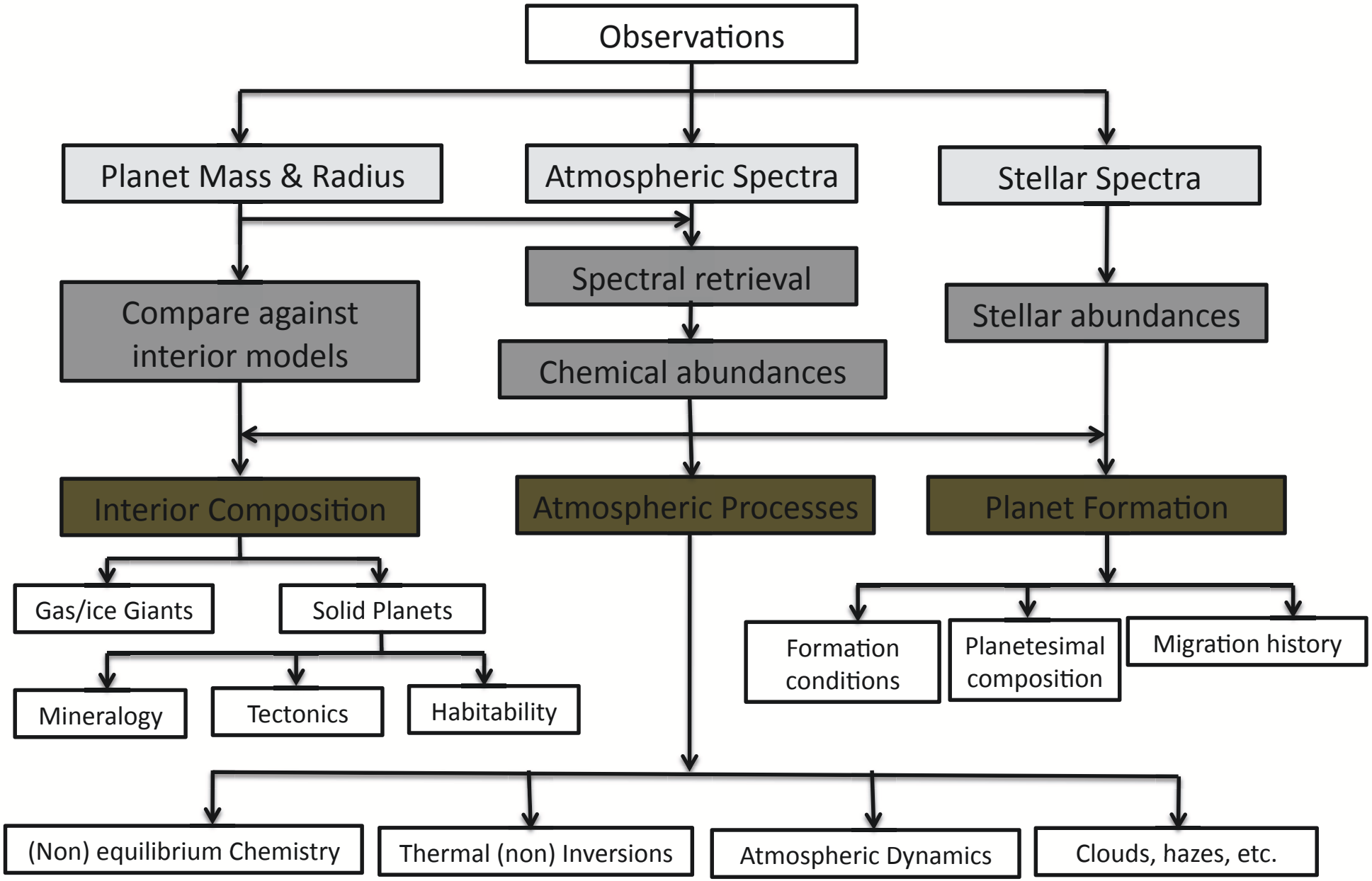
- mixtures

in red:

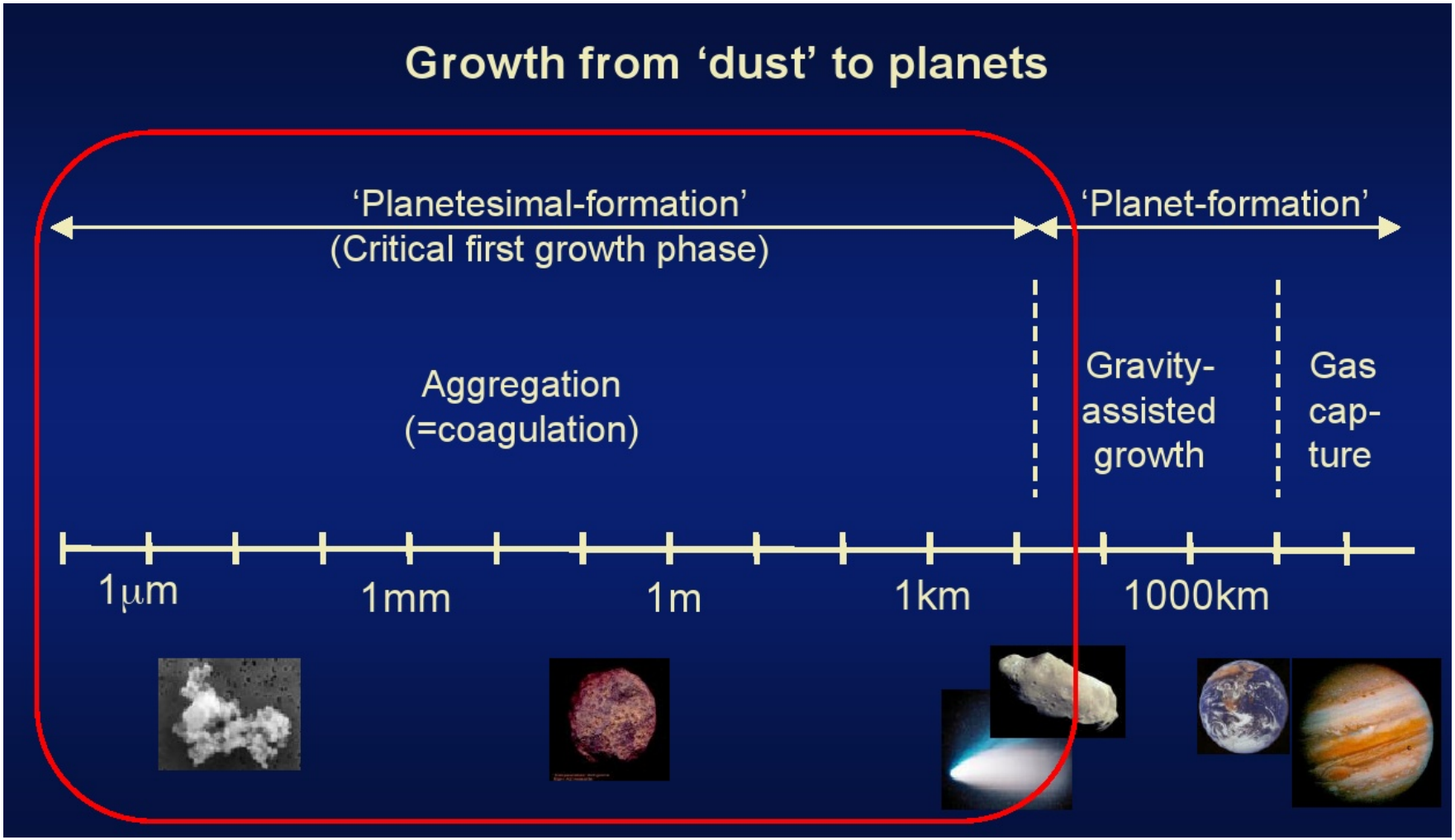
- irradiated planets

(Baraffe, 2014)

0. Appendix: Observations → Physics (Madhusudhan, ea 2014)



0. Appendix: Overview of Formation Process



(C. Dullemond)

Dust $\Rightarrow$ Planetesimals (μm $\Rightarrow$ 1-10km, through Collisions)

Massive Planets: gravitation & gas accretion