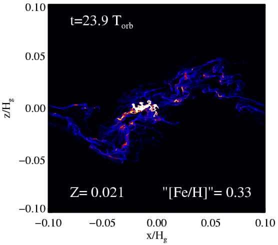
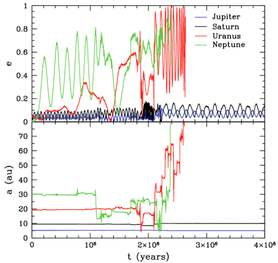
# Terrestrial planet formation in the PLATO era




**Anders Johansen and Melvyn B. Davies**
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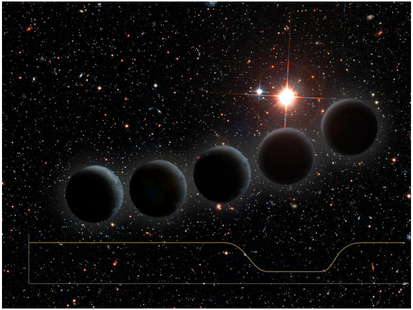
Lund planet researchers: AJ, MBD, Ross Church, David Hobbs, Michiel Lambrechts, Kalle Jansson, Katrin Ros

# PLATO and terrestrial planets

**PLATO**
**Next-generation planet finder**

*... to detect and characterize transiting exoplanetary systems of all kinds, in particular small, telluric planets in their habitable zones*

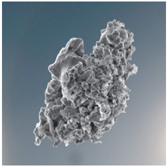


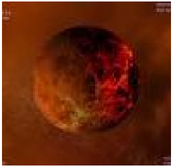
⇒ PLATO will test our *fundamental* understanding of how systems of terrestrial planets form and evolve

# Classical picture of terrestrial planet formation

**Terrestrial planets form in protoplanetary discs around young stars from dust grains that collide and stick together**

1. Dust to planetesimals
   μm → km: contact forces during collision lead to sticking
2. Planetesimals to protoplanets
   km → 1,000 km: run-away accretion
3. Protoplanets to terrestrial planets
   Giant impacts ($10^7$–$10^8$ years)






# An emerging new picture

1. Dust to pebbles

   μm → cm: contact forces during collision lead to sticking

   *(Dullemond & Dominik 2005; Brauer et al. 2008)*

2. Pebbles and rocks to protoplanets

   km → 1,000 km: spontaneous clumping and self-gravity

   *(Johansen et al. 2007, 2009; Lyra et al. 2008)*

3. Protoplanets to terrestrial planets

   Giant impacts or pebble accretion

   *(Raymond et al. 2006; Johansen & Lacerda 2010)*

4. Migration and scattering

   Migration due to torques from gas disc

   *(Nelson & Papaloizou 2005; Paardekooper & Mellema 2006)*

   Planet-planet and planet-planetesimal scattering

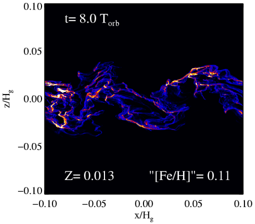
   *(Gomes et al. 2005; Tsiganis et al. 2005; Juric & Tremaine 2008)*

   Perturbations by passing stars or binary companions

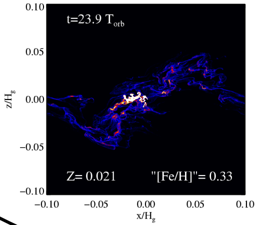
   *(Malmberg et al. 2007; Malmberg, Davies, & Heggie 2011)*

# Metallicity trigger

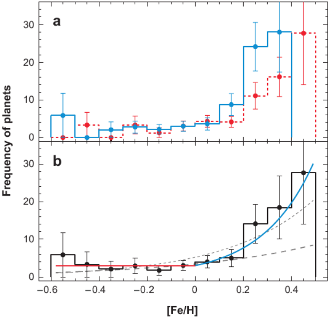
Solar metallicity or lower: no clumping

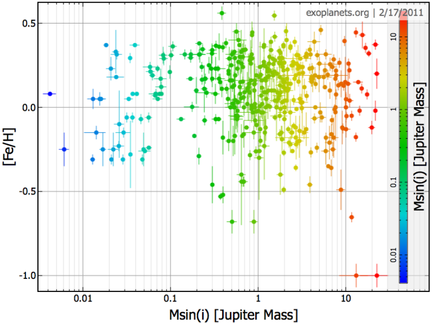



Higher metallicity: *streaming instabilities* cause particle clumping and collapse of rocks into planetesimals *(Johansen et al. 2009)*



# Metallicity correlation of exoplanets




- Exoplanet frequency rises steeply with metallicity
- Correlation less pronounced for low mass planets?

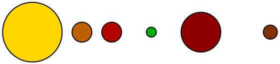
⇒ Planetesimal formation triggered by photoevaporation

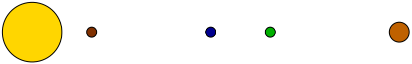
*(Johansen et al. 2009)*

- Photoevaporation-triggered planet formation may also explain Jupiter's overabundance of noble gases

*(Guillot & Hueso 2006)*

# Low and high metallicity systems





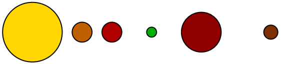
High metallicity systems

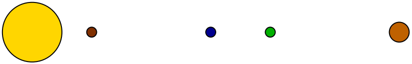
- Planet formation is rapid
- Lots of time to accrete gas
- Moderate mass planets migrate and become hot Jupiters

Solar (or lower) metallicity systems

- Planet formation triggered by photoevaporation
  *(Throop & Bally 2005; Alexander & Armitage 2007)*
- Little gas when planets form, so no strong migration

# Low and high metallicity systems





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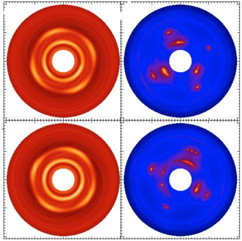
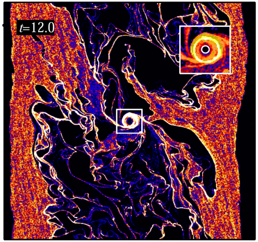
⇒ Predict that the solar system formed after the solar nebula had accreted or evaporated half of its $H_2$ and He gas

⇒ Predict that low-metallicity systems may preferably produce terrestrial planets and super-Earths

# Planetesimals or protoplanets?

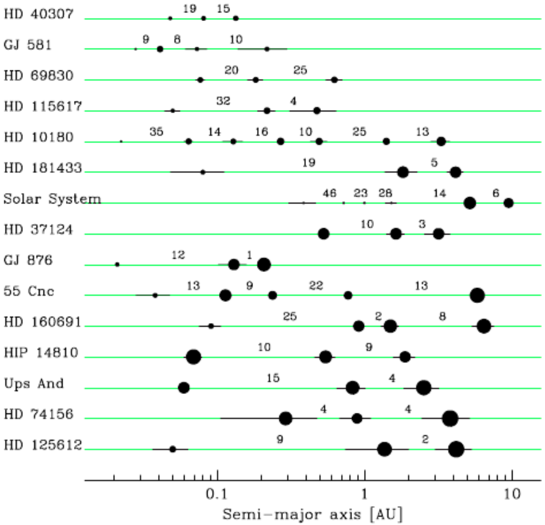
- Hydrodynamical simulations show that rocks and boulders concentrate strongly in turbulent gas flow
  *(Johansen et al. 2006, 2007; Lyra et al. 2008, 2009)*
- Overdense regions of rocks and boulders contract under their own weight into planetesimals
- Planetesimals accrete remaining rocks and boulders rapidly
  *(Johansen & Lacerda 2010)*






⇒ Rapid growth from protoplanets to terrestrial planets

# Observed planetary systems




(Lovis et al. 2010)

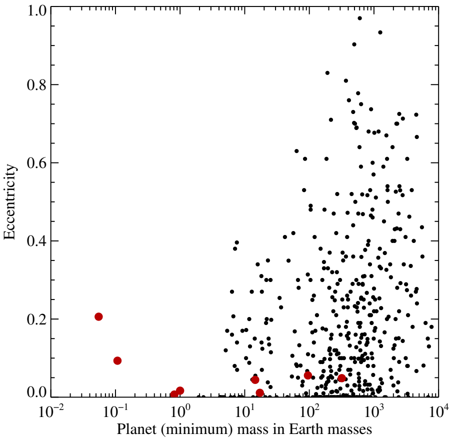
# How to make eccentric planetary systems

## Unstable planetary systems as:

1. Planets are born too close to each other
   *(Weidenschilling 1996)*
2. Planetary systems are perturbed by passing stars
   *(Malmberg & Davies 2008)*
3. Planetary systems are perturbed by Kozai resonance with distant binary
   *(Malmberg et al. 2007)*

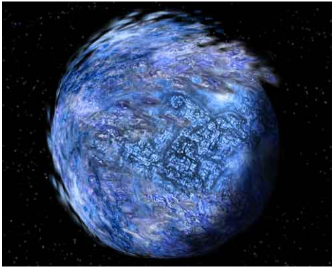
⇒ What about terrestrial planets?

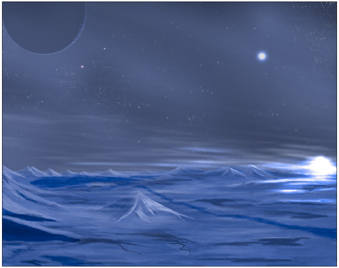
*(data from Extrasolar Planets Encyclopedia)*



# Eccentricity and habitability

- Studying the observed eccentricity distribution of terrestrial planets can teach us about planet formation and about external perturbations
- Eccentricity also has implications for habitability





# Planet formation theorists wish list for PLATO

$\Rightarrow$ PLATO could allow us to answer fundamental questions about e.g. how the terrestrial planet formation efficiency depends on metallicity and on how stable systems of terrestrial planets are

Planetary systems:

- Masses (RV follow-up)
- Radii (transits)
- Semi-major axes (transits)
- Eccentricities (RV)

Stars:

- Ages and radii (seismology)
- Metallicities
- Well-understood observational bias