The mystery of proto-planetary disk and planet evolution.

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From molecular clouds to planets

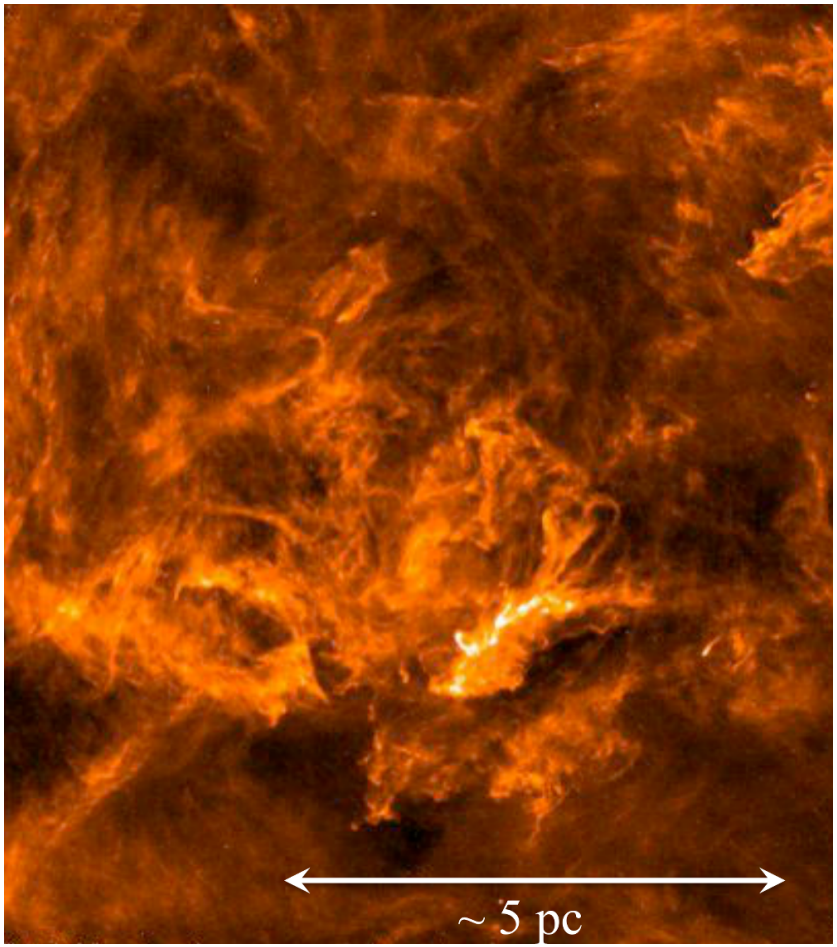
Overview

Formation and evolution of the disk and planets

The role of turbulence

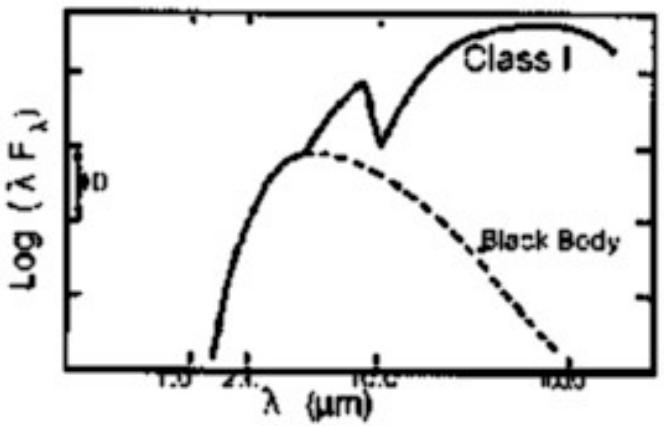
Summary

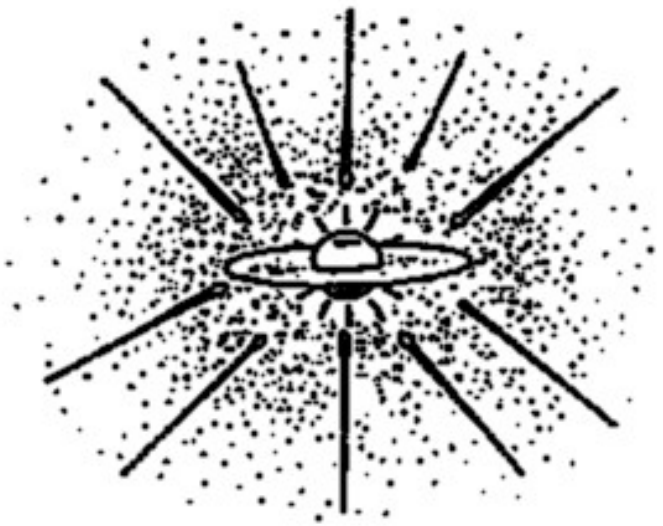
From molecular clouds to planets



Polaris, Herschel/SPIRE 250 μm, André et al. 2014

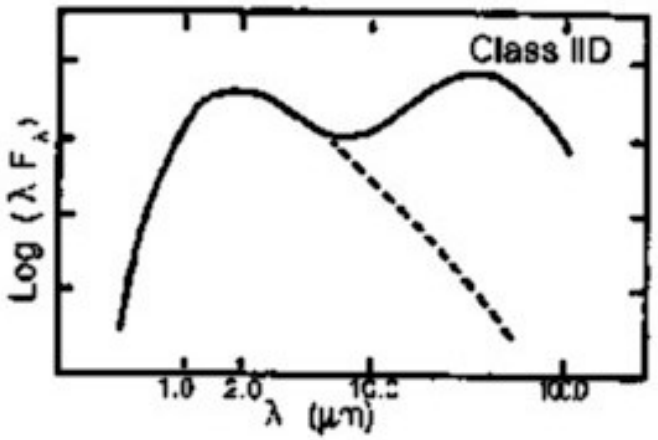
From molecular clouds to planets (Shu 1987)

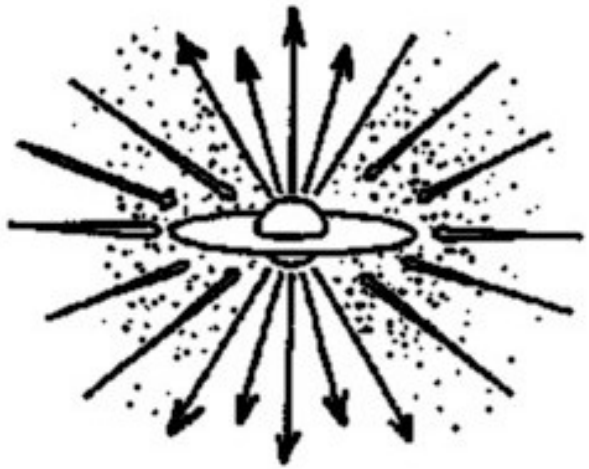




	composition	mass fraction	radiation
core	gas	medium	optical(UV)
disk	gas+dust	medium	IR
envelope	gas+dust	large	FIR,MM

From molecular clouds to planets (Shu 1987)





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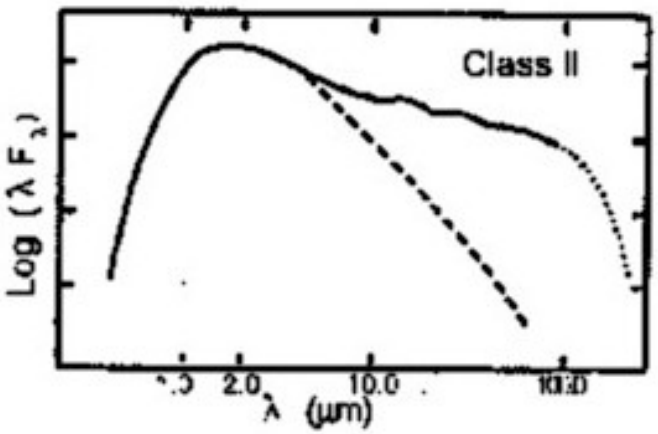
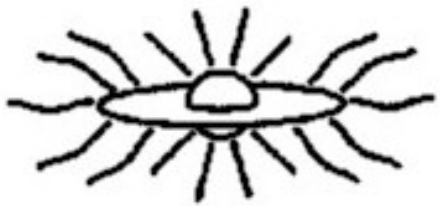
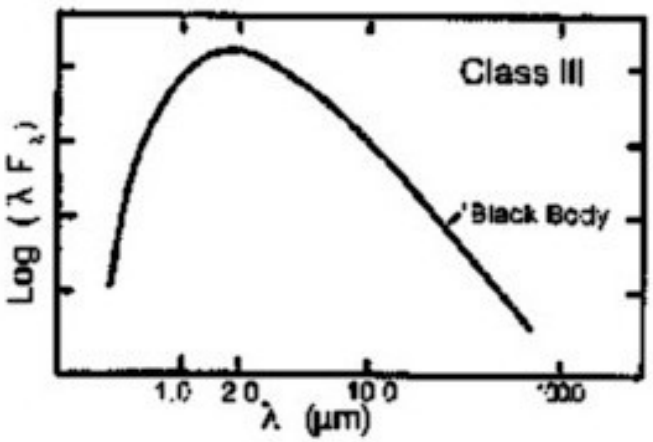




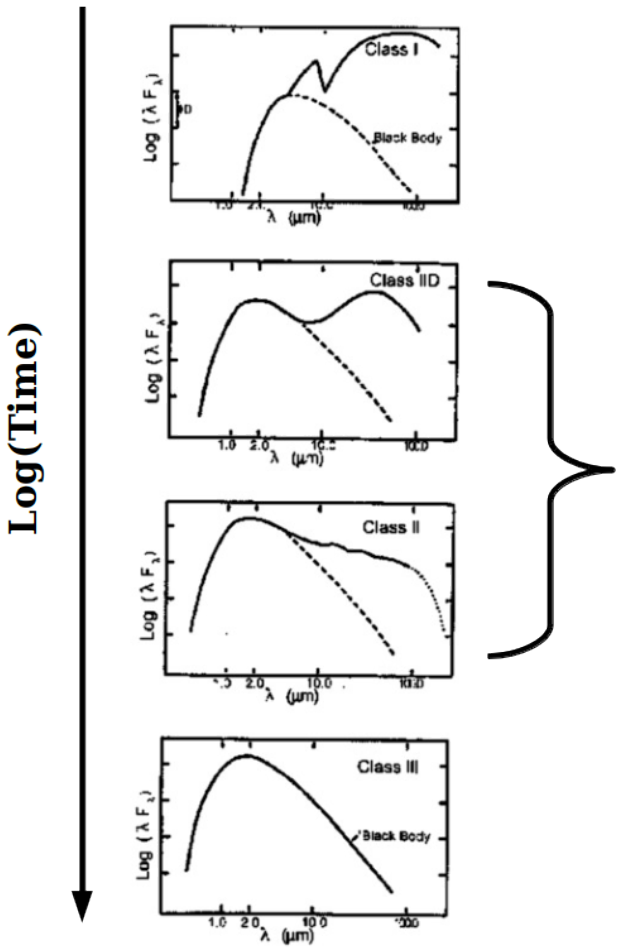
	composition	mass fraction	radiation
core	gas	large	optical(UV)
disk	gas+dust	medium	IR,MM
envelope	gas+dust	tiny	-

From molecular clouds to planets (Shu 1987)



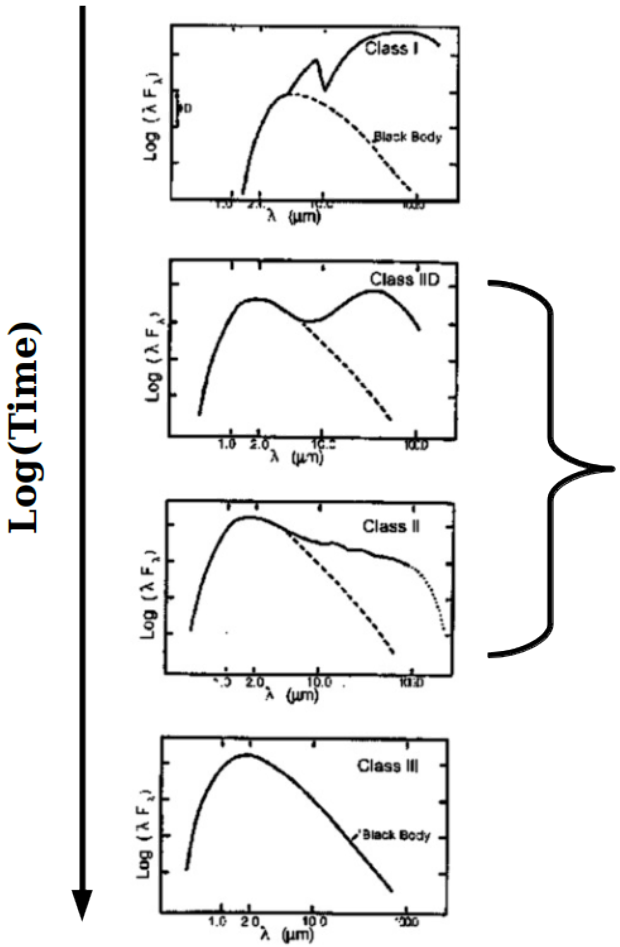
	composition	mass fraction	radiation
core	gas	large	optical
disk	dust	tiny	-
envelope	-	-	-

From molecular clouds to planets



Lifetimes of protoplanetary disk around $10^6 - 10^7$ years.

From molecular clouds to planets



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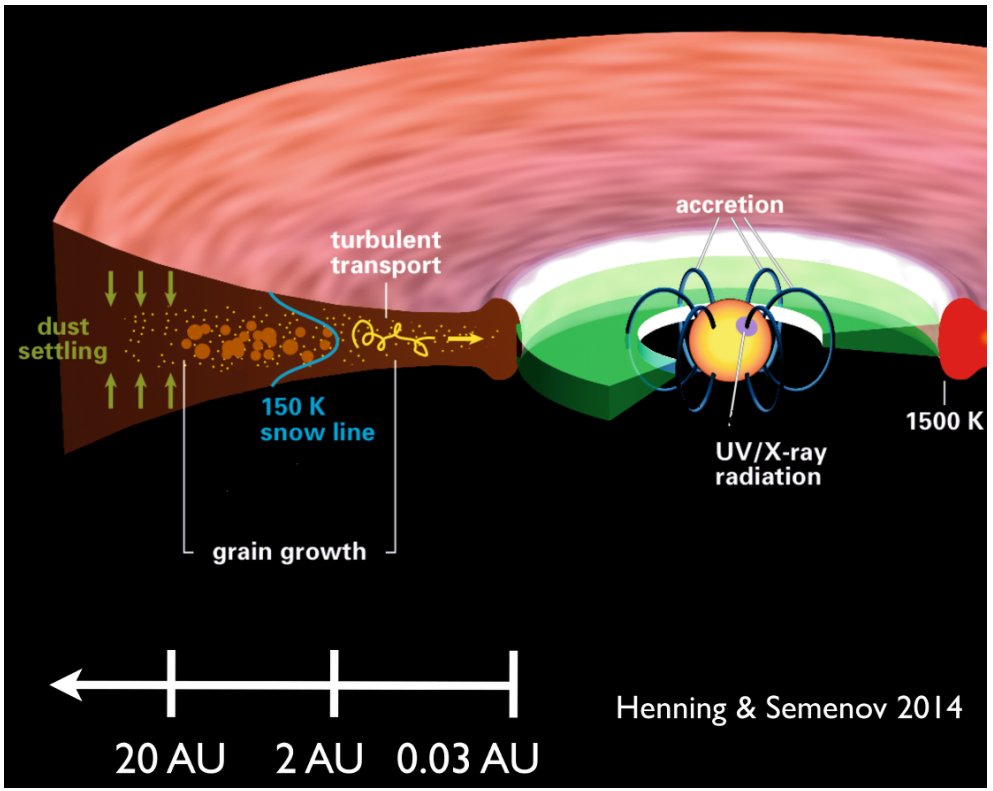
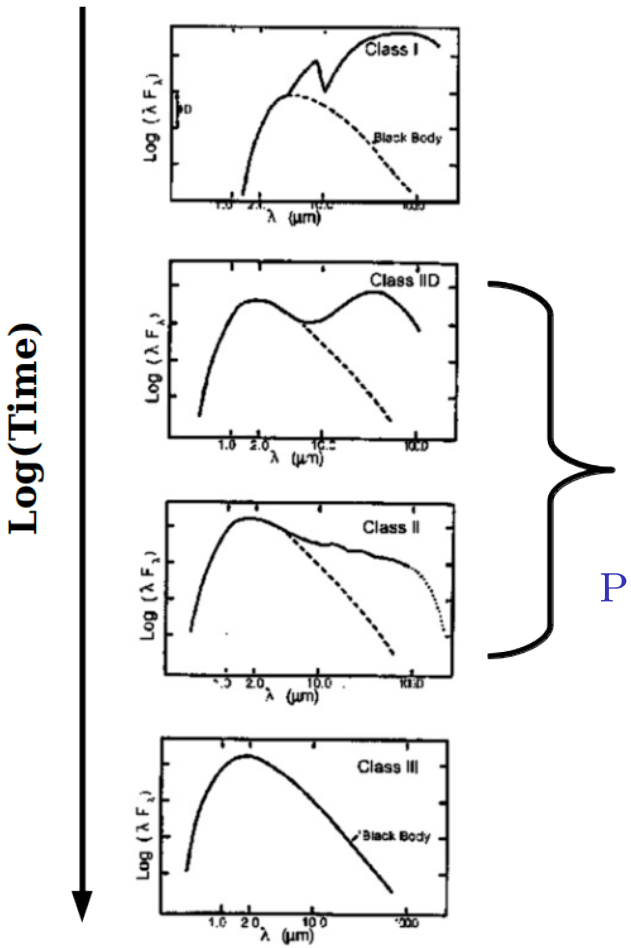


From molecular clouds to planets



Lifetimes of protoplanetary disk around $10^6 - 10^7$ years.

We have to understand the

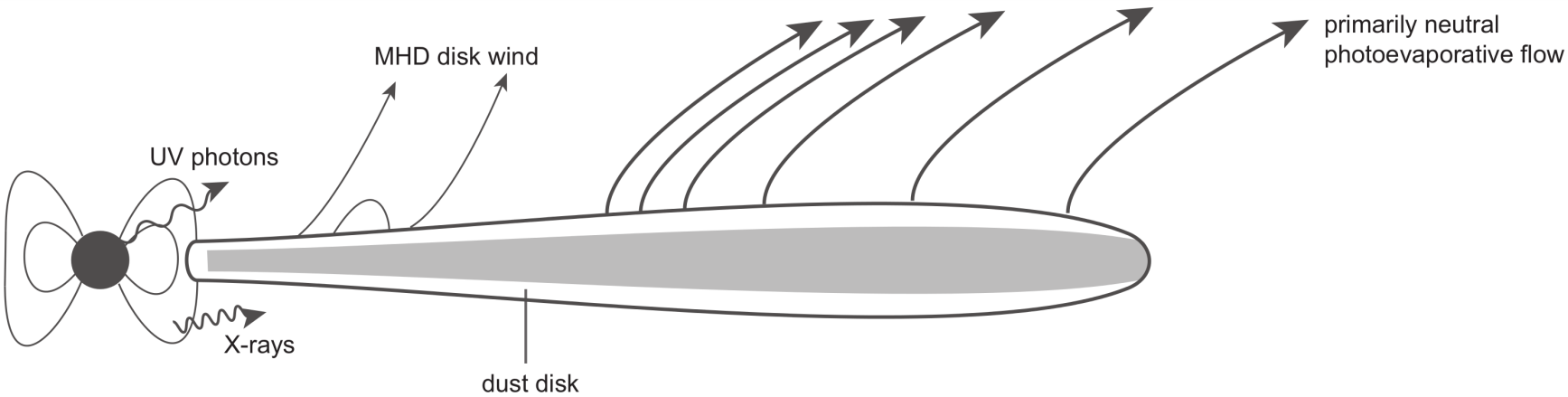
GAS accretion and dispersal in the disk ?

DUST growth and evolution ?

PLANET migration and growth ?

Gas accretion and dispersal ? (Armitage 2011)

early stage outflows, effective viscosity by turbulence (Shakura & Sunyaev 1973)
driven by the Magneto-rotational instability (Balbus & Hawley 1991)



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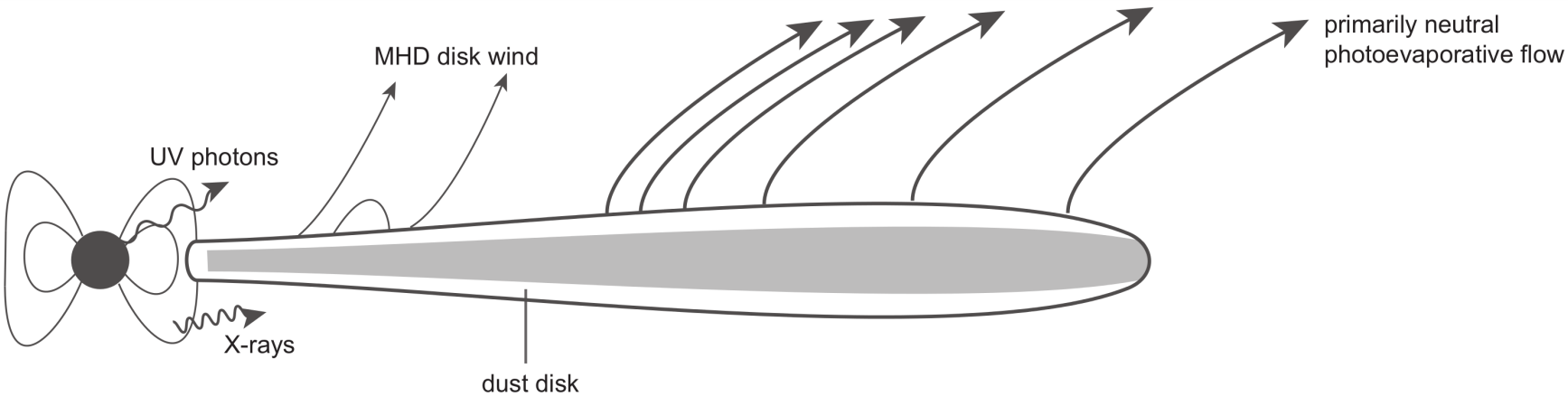
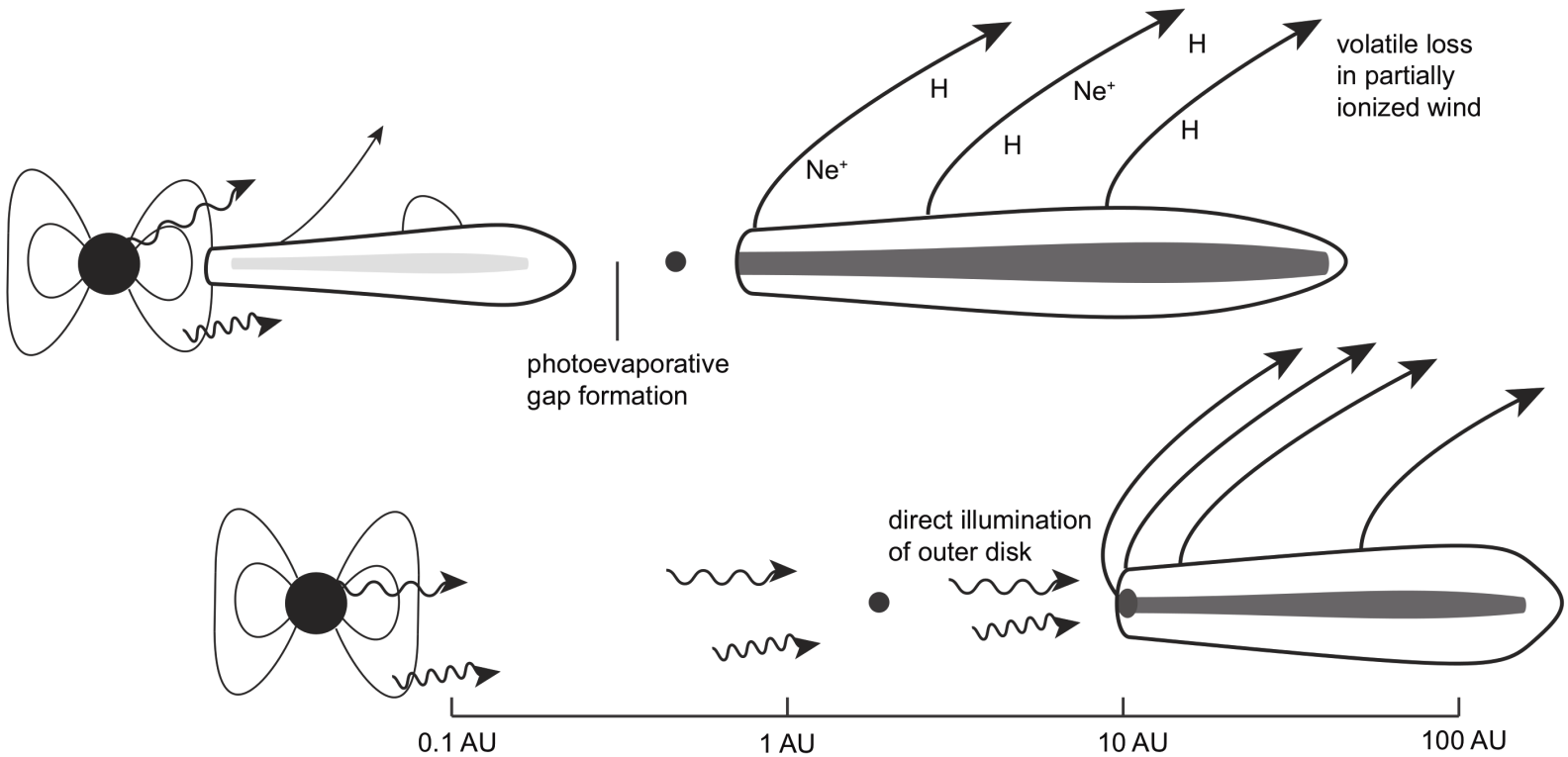


1. mystery
What causes the accretion in the low magnetic coupling regime ?

Gas accretion and dispersal ? (Armitage 2011)

late stage photoevaporation by radiation from the central star



Dust growth and evolution ?

early stage coagulation, fragmentation, radial drift (Movie by T. Birnstiel)

Dust growth and evolution ?

EARLY STAGE coagulation, fragmentation, radial drift (Movie by T. Birnstiel)

2. mystery
How do particles overcome the fragmentation barrier/radial drift ?

How to observe the disk ? Dullemond et al. 2010

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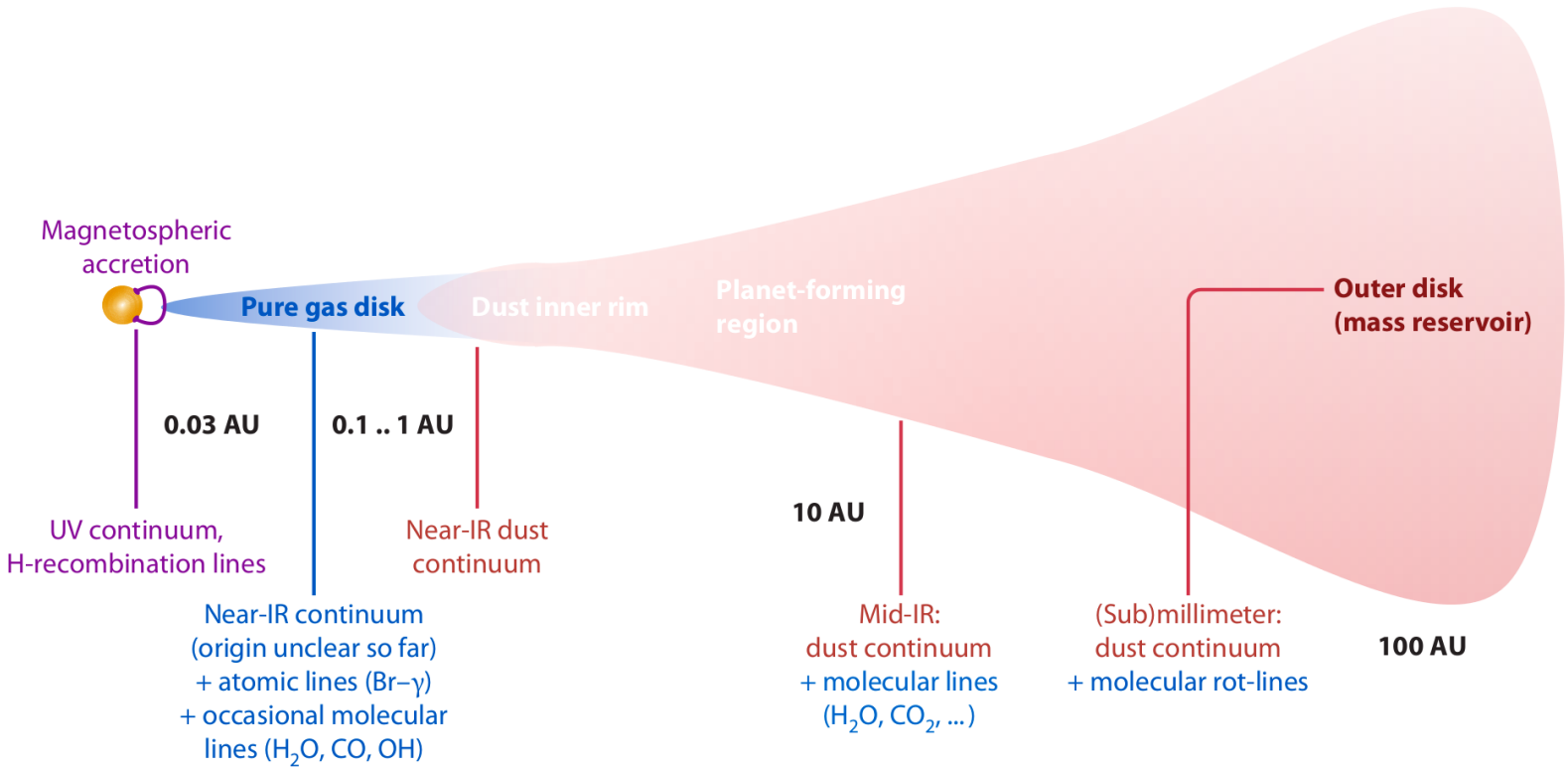
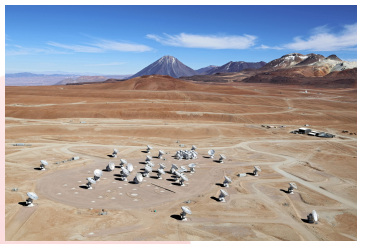
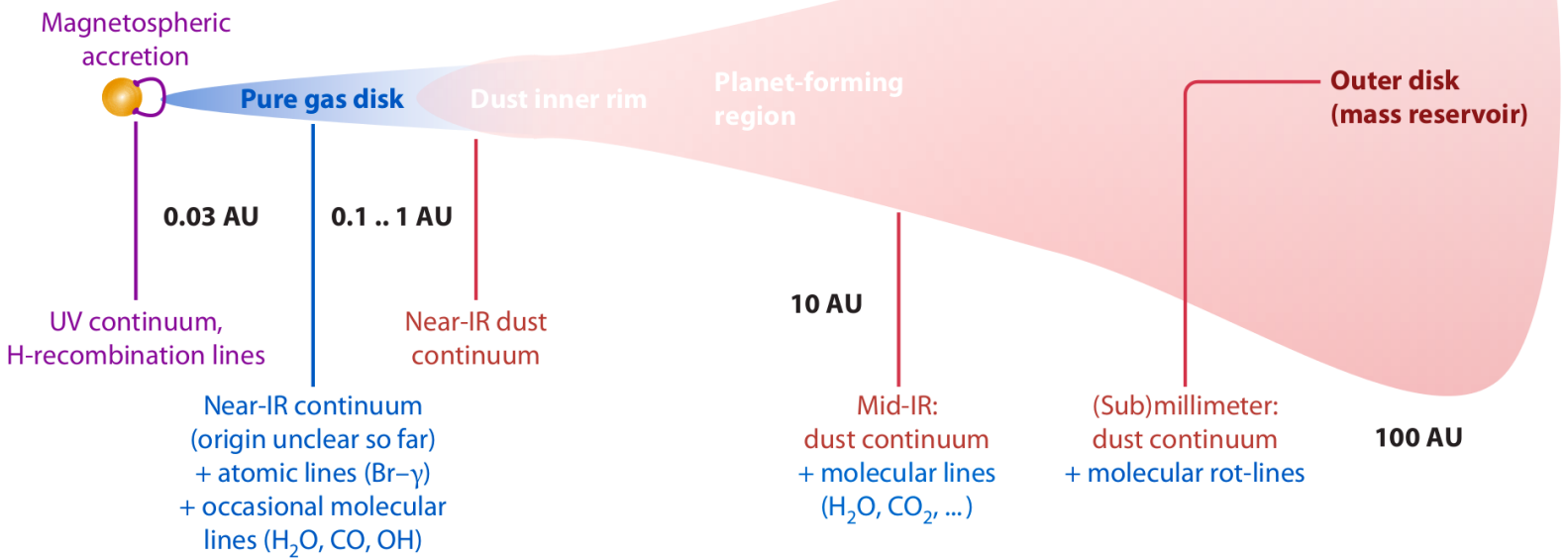


How to observe the disk ? Dullemond et al. 2010

Atacama Large Millimeter/submillimeter Array (ALMA)
12-m antennas, 400 μm to 3 mm
exp. cost 1000 million Ref: ESO





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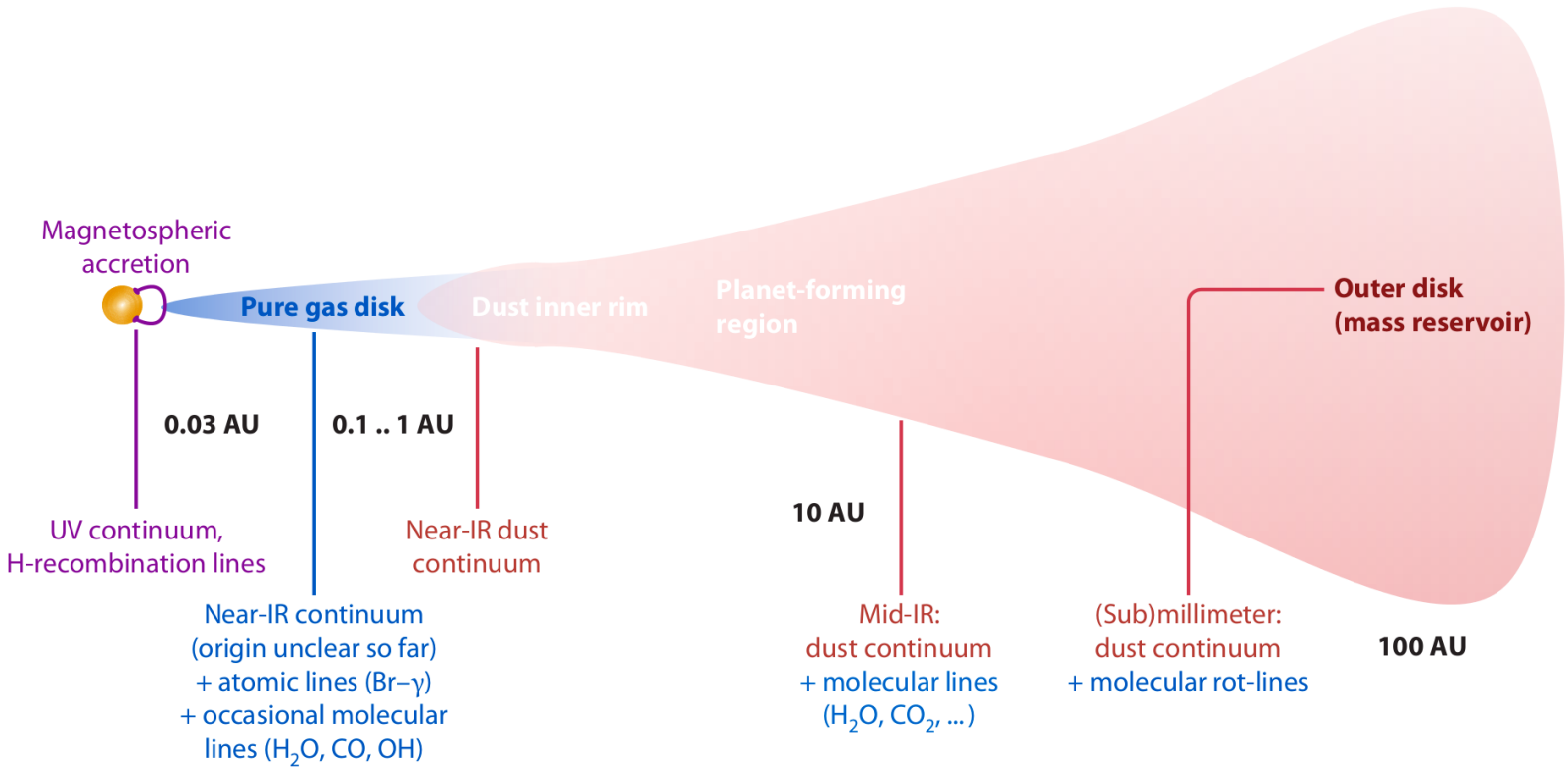
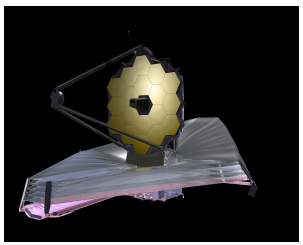
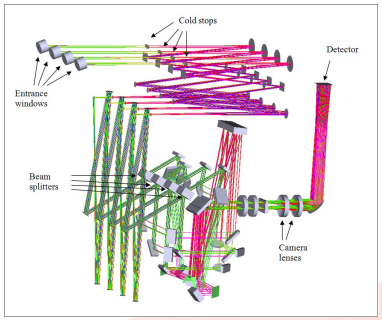




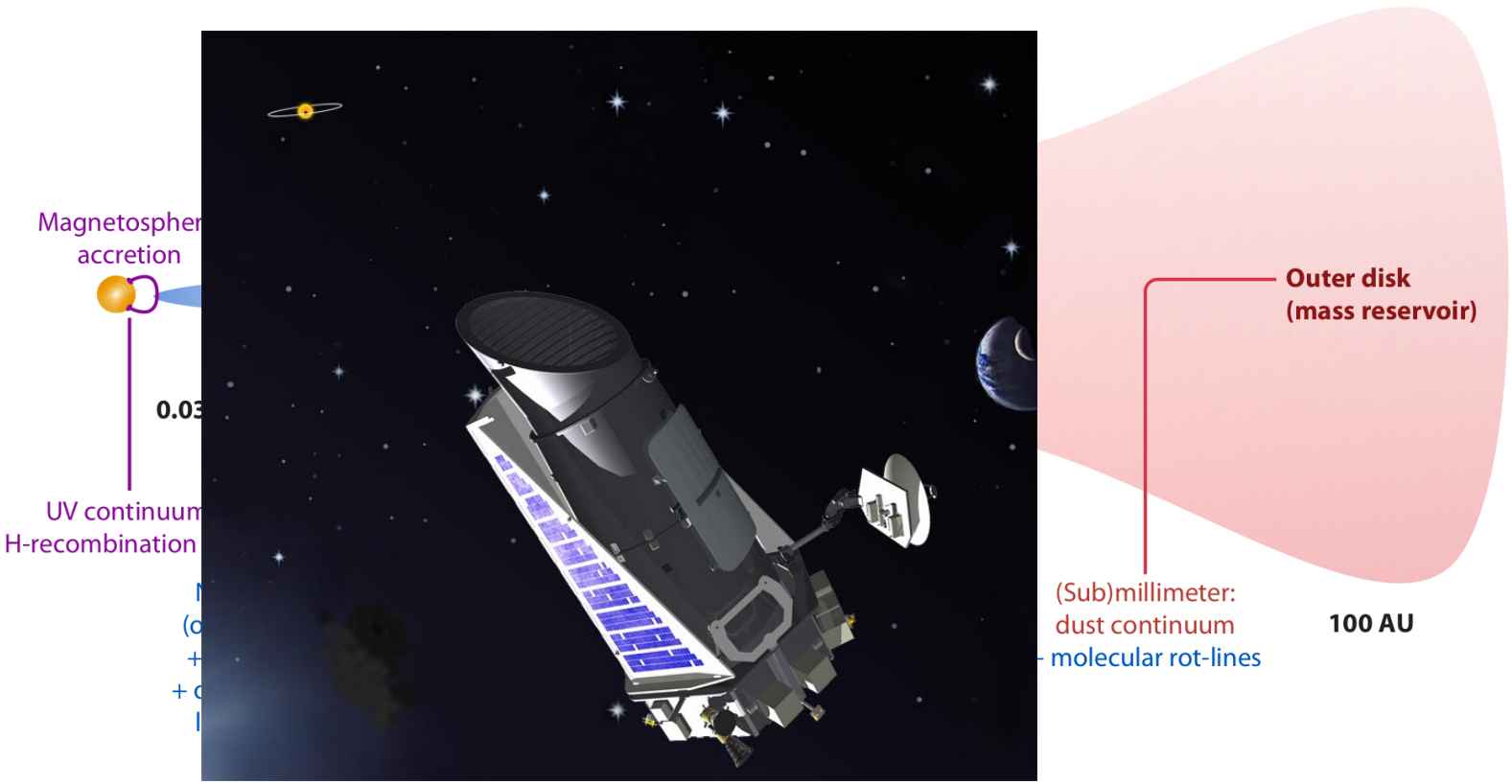
James Webb Space Telescope (JWST) (2018)
6.5m primary mirror, 0.6 - 28 microns
est. total cost 8835 million Ref: NASA

How to observe the disk ? Dullemond et al. 2010



Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) (2018)
MIR (L/N/M) Band, est. cost 3.1 million

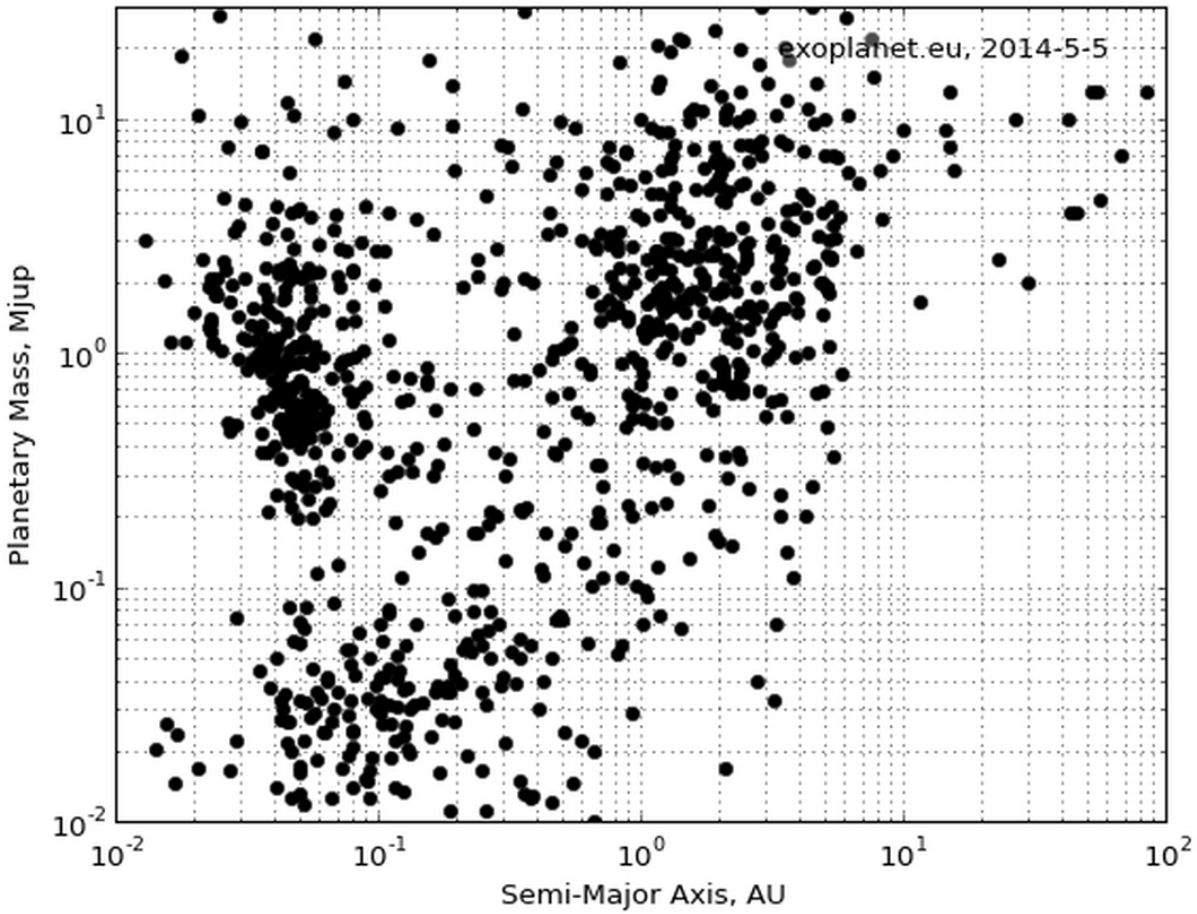
How to observe the disk ? Dullemond et al. 2010



Kepler (spacecraft) (2009-2013)
1.4m mirror, single photometer, search for planet transits, cost 600 million

Planet migration and growth ?

LATE STAGE Type I,II migration (Movie by C. Mordasini)



Planet migration and growth ?

late stage

Type I,II migration (Movie by C. Mordasini)

Planet migration and growth ?

LATE STAGE Type I,II migration (Movie by C. Mordasini)

3. mystery
What explains the planet void between 0.1 and 1 AU ?
Planets $\leq$ 0.1 AU ?

The role of turbulence

The role of turbulence

1. Controls gas accretion (turbulent viscosity)
2. Controls dust growth (fragmentation, radial drift)

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Global 3D simulations

- Take PLUTO code (Mignone et al. 2012)
- Setup initial conditions
  - Radial and vertical density profile
  - Keplerian Rotation
  - Weak toroidal magnetic field
- Tweak the numerics: Second order time and space, HLLD Riemann solver, recently also with radiation transfer (Flock et al. 2013)

The mystery of proto-planetary disk and planet evolution.

- Does the MRI drive the gas accretion ? Low coupling problem ?
- How do the particles overcome the fragmentation/radial drift barrier ?
- What explains the observed planet distribution ?