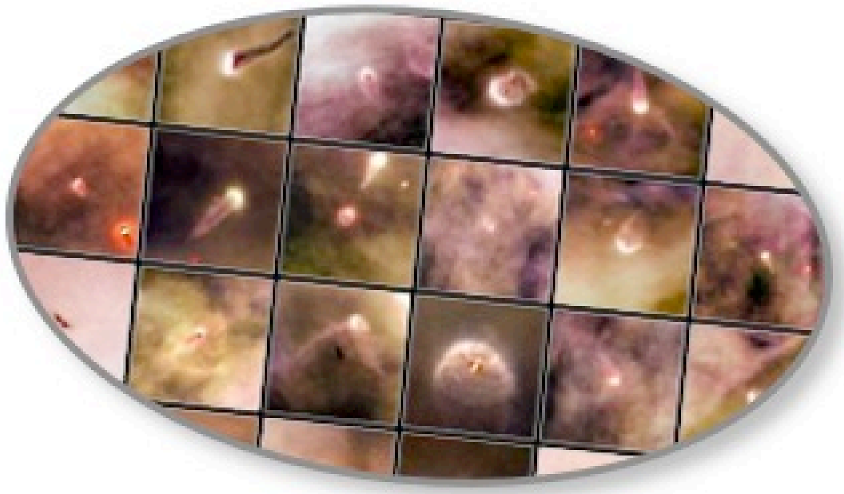
Chemical evolution of the protosolar disk



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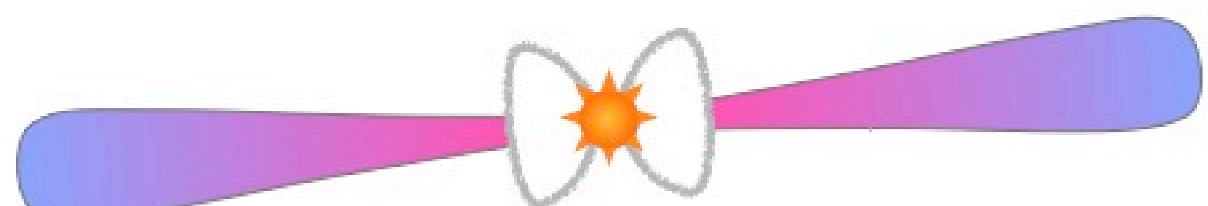
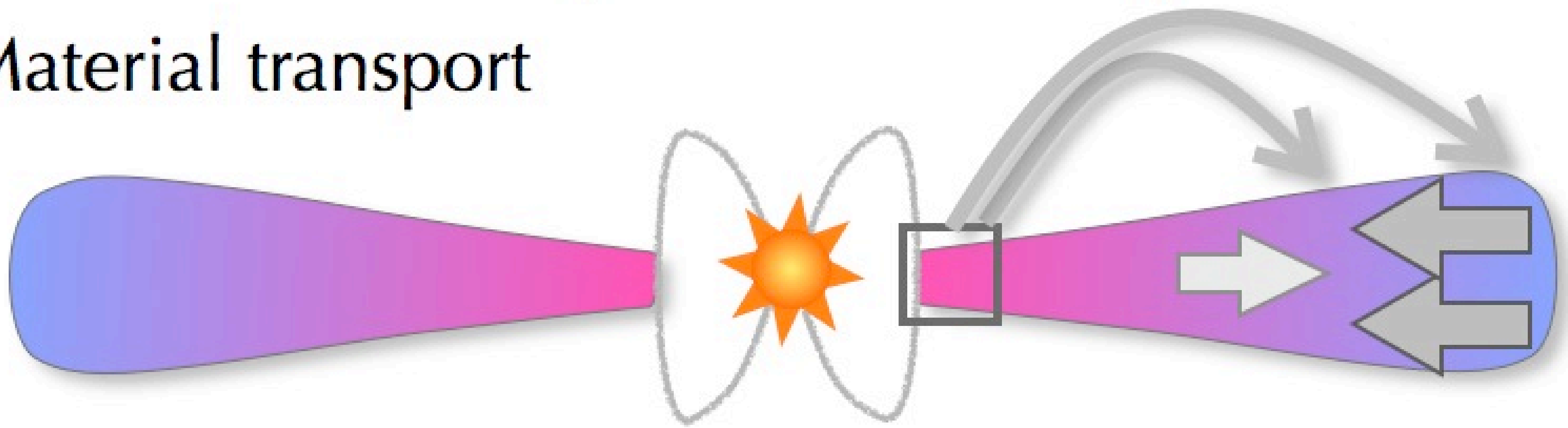


Inner rim of a protosolar disk

- Condensation / evaporation all through disk evolution
- Material transport



- Combined chemical and physical model needed
  - Condensation / evaporation at the high-T rim
  - Cooling by transport outward
  - Accretion of low temperature component from outside

Condensation

- Kinteic process : condition and time dependent
- Controlling factor : cooling time of the gas
- Departure from equilibrium : kinetic barrier for nucleation and growth

  condensation coefficient (sticking coefficient)

  Experimental determination of the coefficients

  $Al2O3$ (Takigawa et al., 2010)
  forsterite (Nagahara et al., 2008; Tachibana et al., 2010)
  Fe metal (Tachibana et al., 2011)

- Mode of condensation : homogeneous or heterogeneous

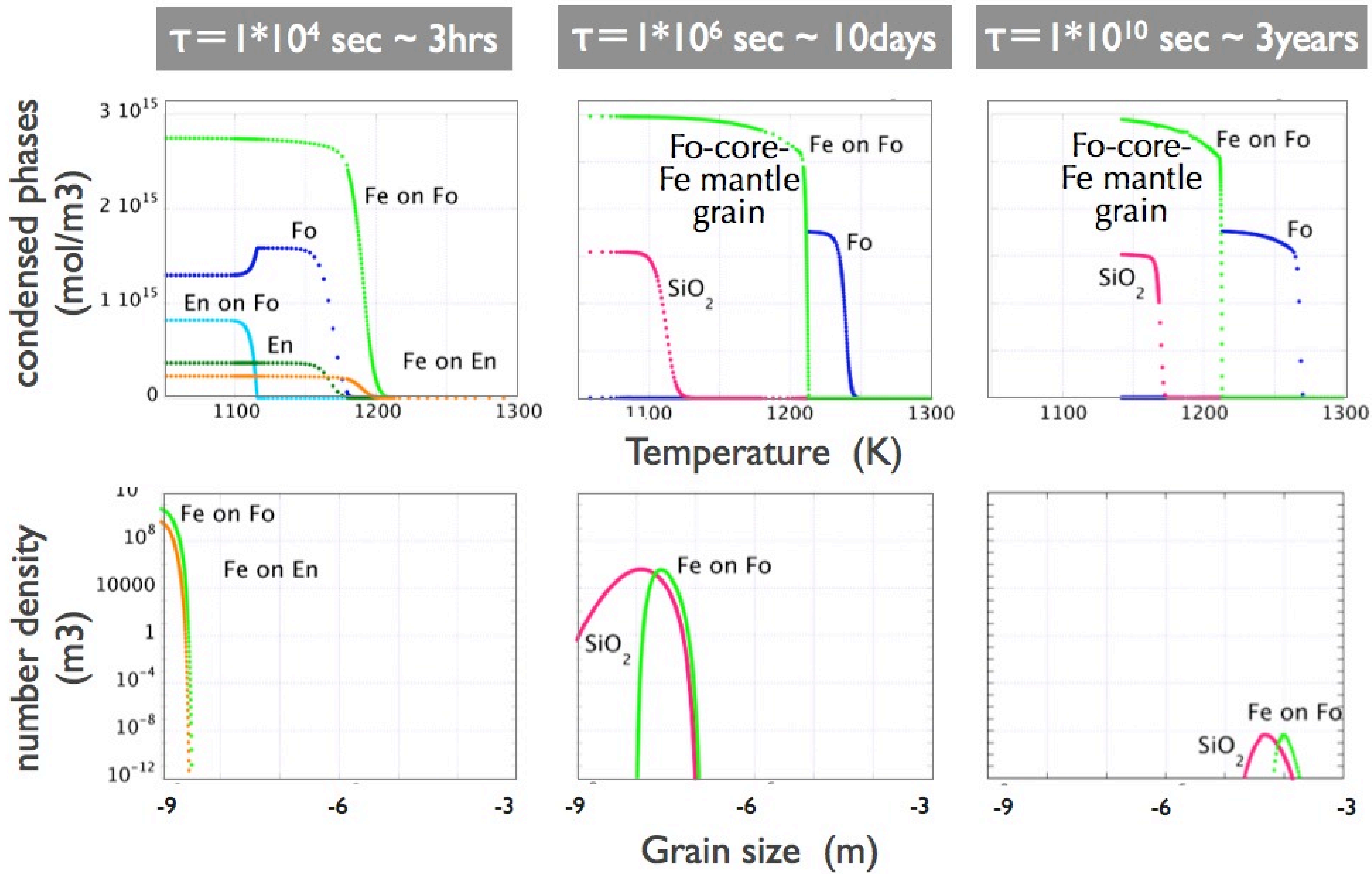
  Experimental determination of wetness

Kinetic condensation model

- Condensation in a cooling gas
- Free parameters : cooling time scale, total pressure
- Kinetic parameters (condensation coefficient and wetness of metal on silicate) : our experimental data
- System : H-He-C-N-O-Mg-Si-Fe
  Condensed phases : Fo, En, SiO_2, Fe^0
- Gas/dust separation : present/absent (system open/closed)

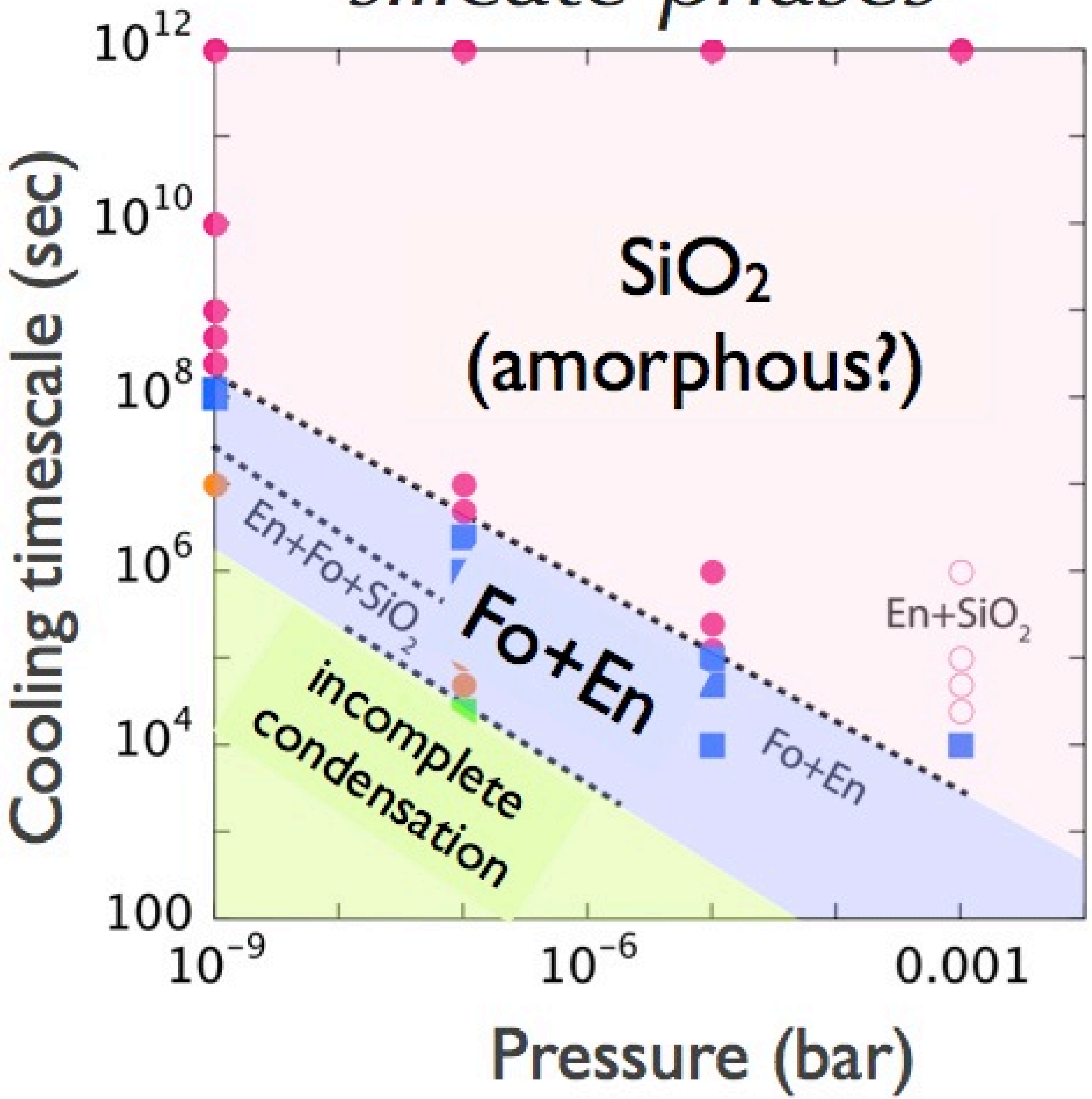
- Condensation temperature of phases
- Size change, number density and structure of grains

Results [1] dust growth w/o d/g separation

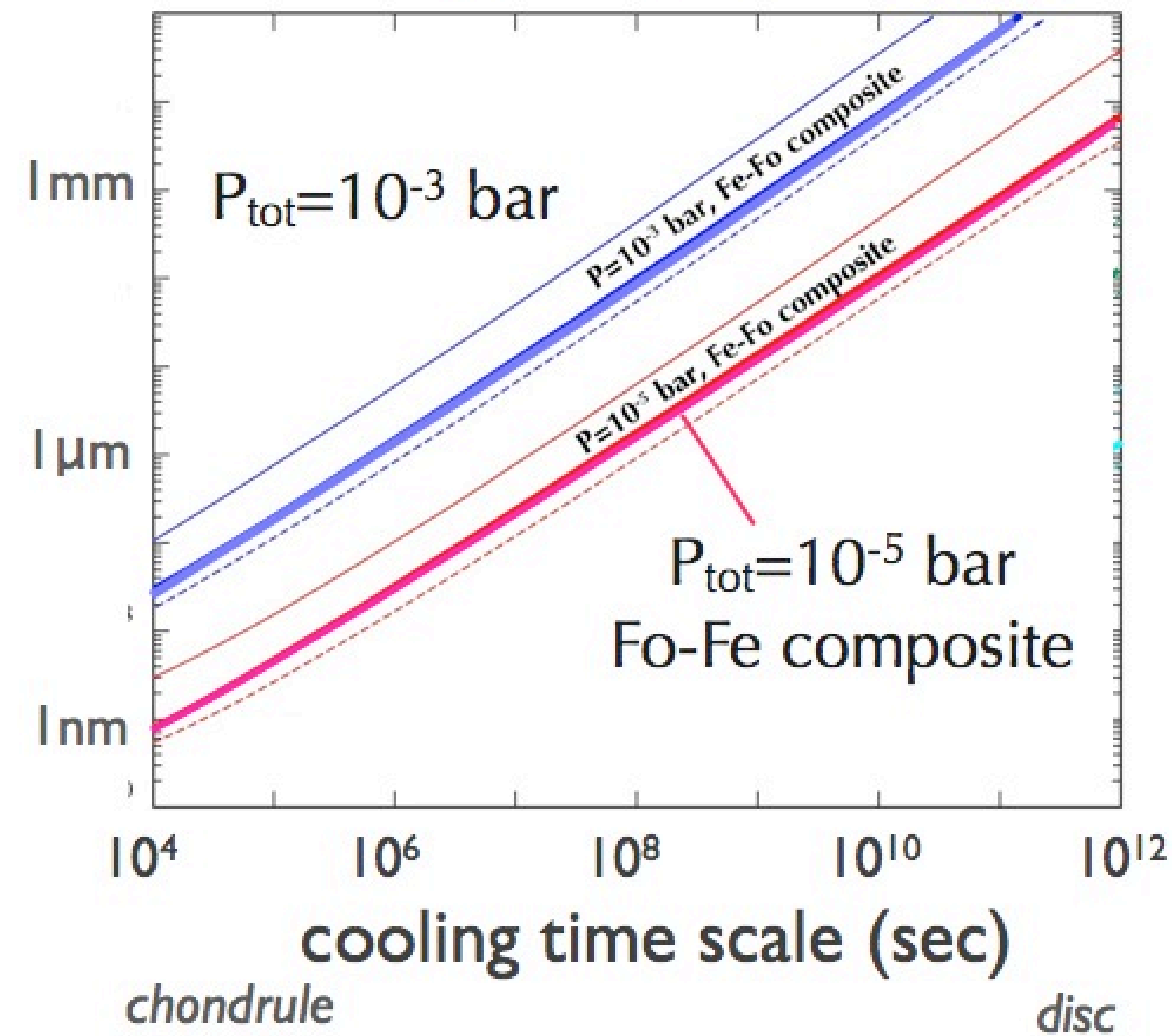


Results [1] dust growth w/o d/g separation

silicate phases



grain size



appearance of SiO_2, which does not appear in equilibrium, but thought to be present by observation

growth to mm size in a disc evolution time scale without physical coagulation

Results [2] dust growth with d/g separation

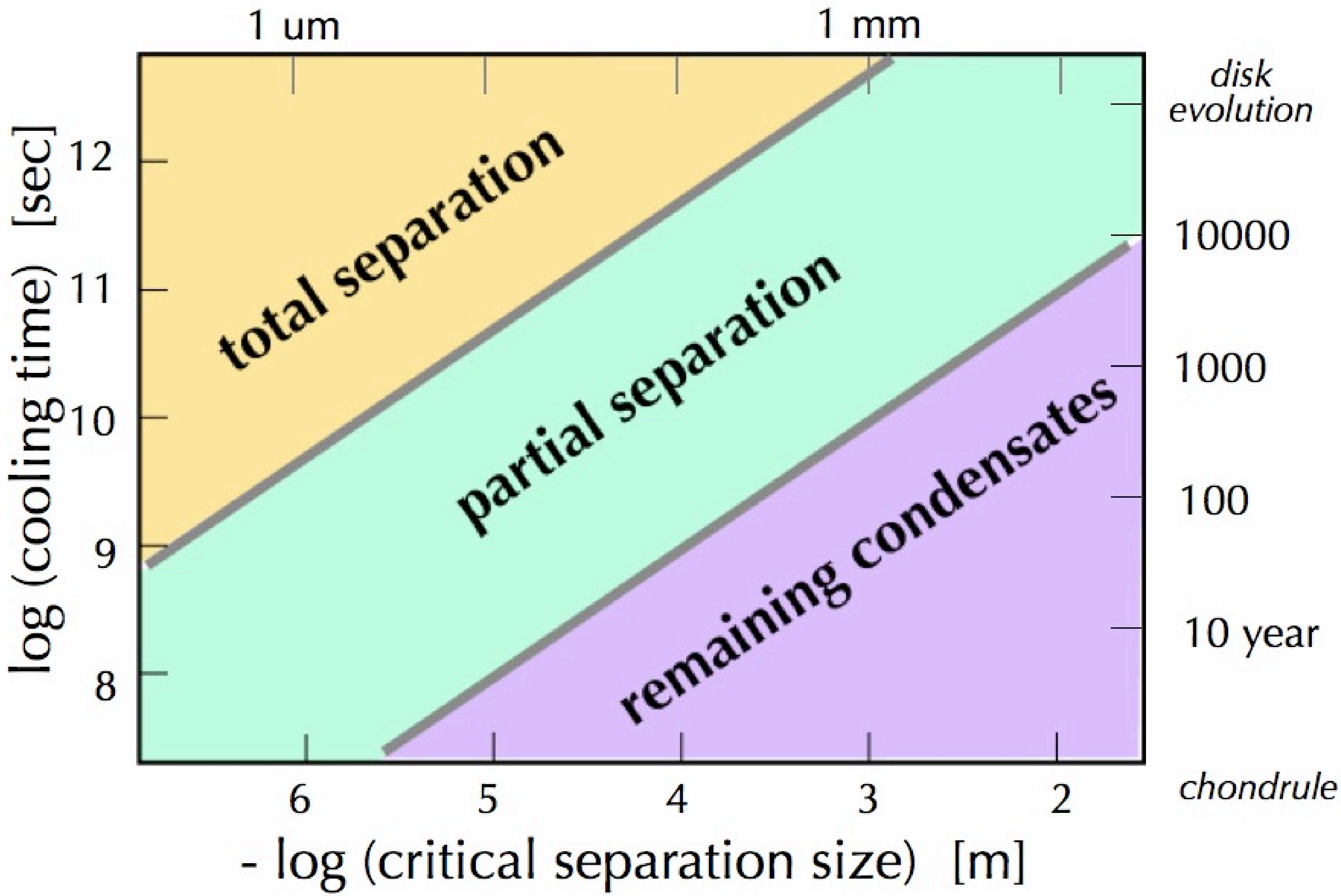
- Competition between gas comp change vs. condensation
- Critical parameter : size of separating dust

⇓

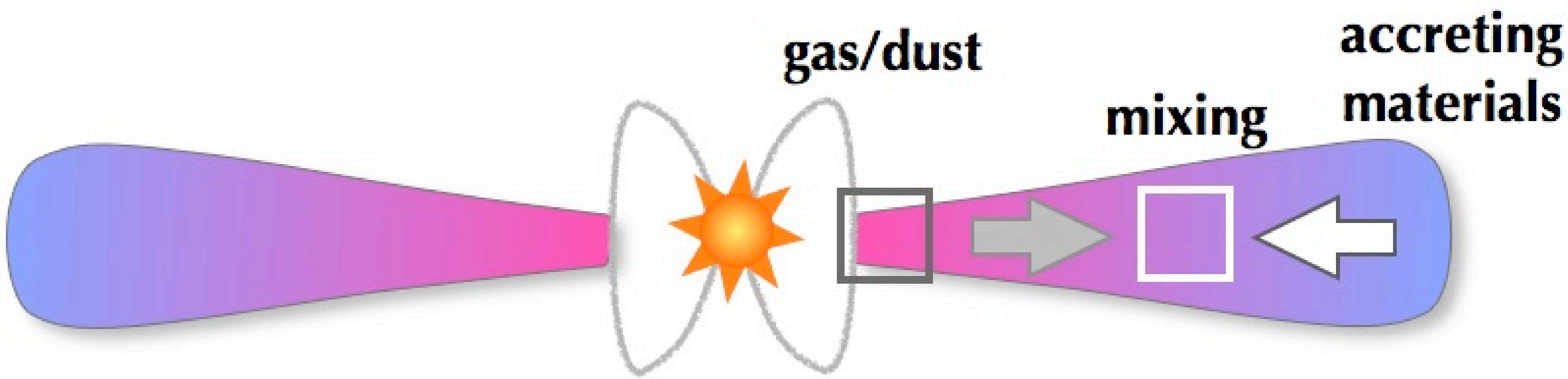
- **Repeated nucleation and growth**
- **Complicated appearance of phases**
- **Dust size controlled by the critical separation size**
- **Chemical fractionation from the solar comp in terms of major elements**

Results [2] dust growth with d/g separation

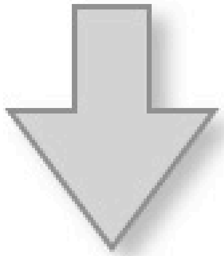
H-He-C-N-O-Mg-Si-Fe, 10^{-5} bar



Protosolar disk



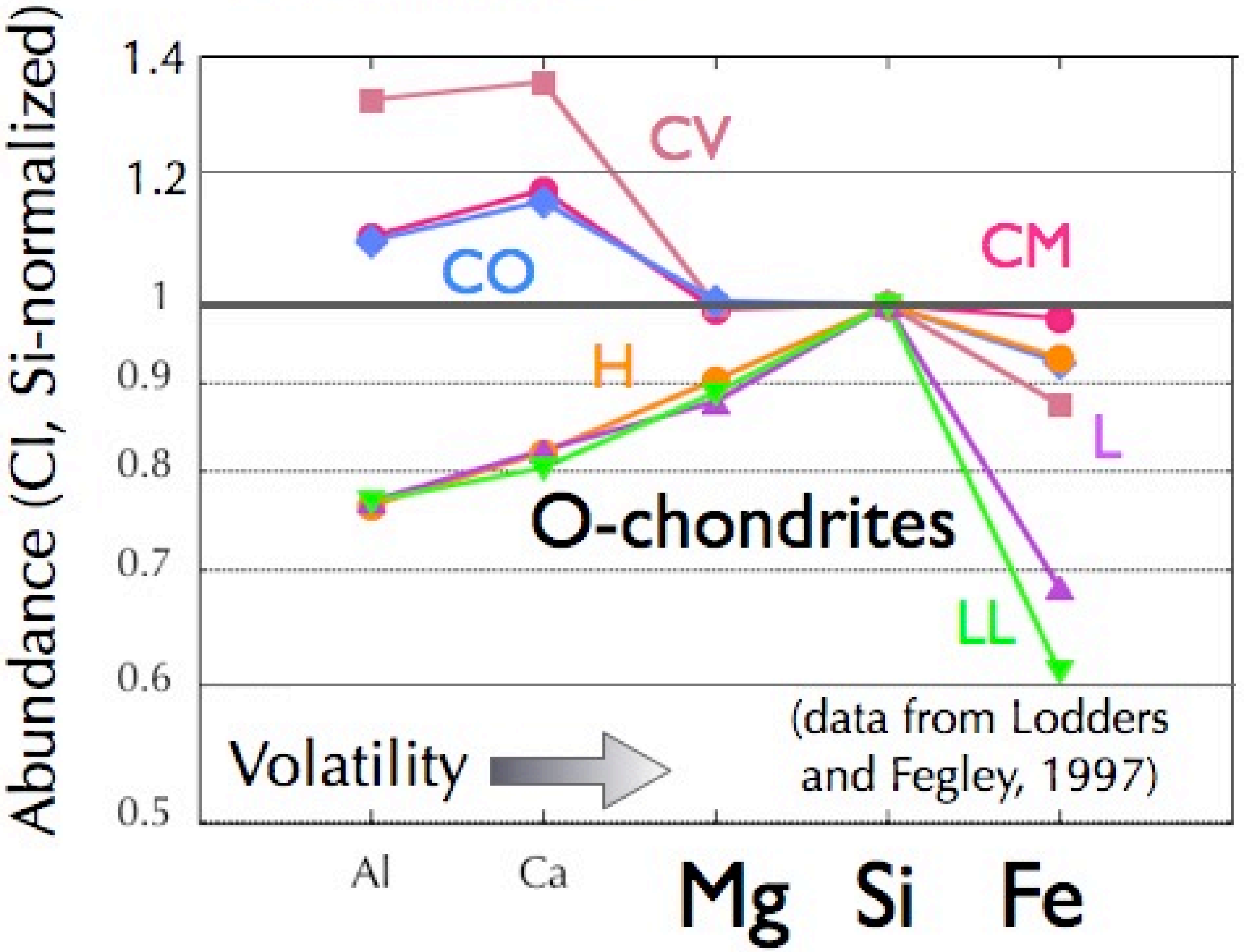
- Cooling rate : gas/dust outward transport rate or accretion rate of the inner edge
- Dust/gas separation : dust settling rate onto the midplane



- Mg/Si/Fe chemical fractionation in chondrites (and planets)
- astrophysical observation of disk surface dust

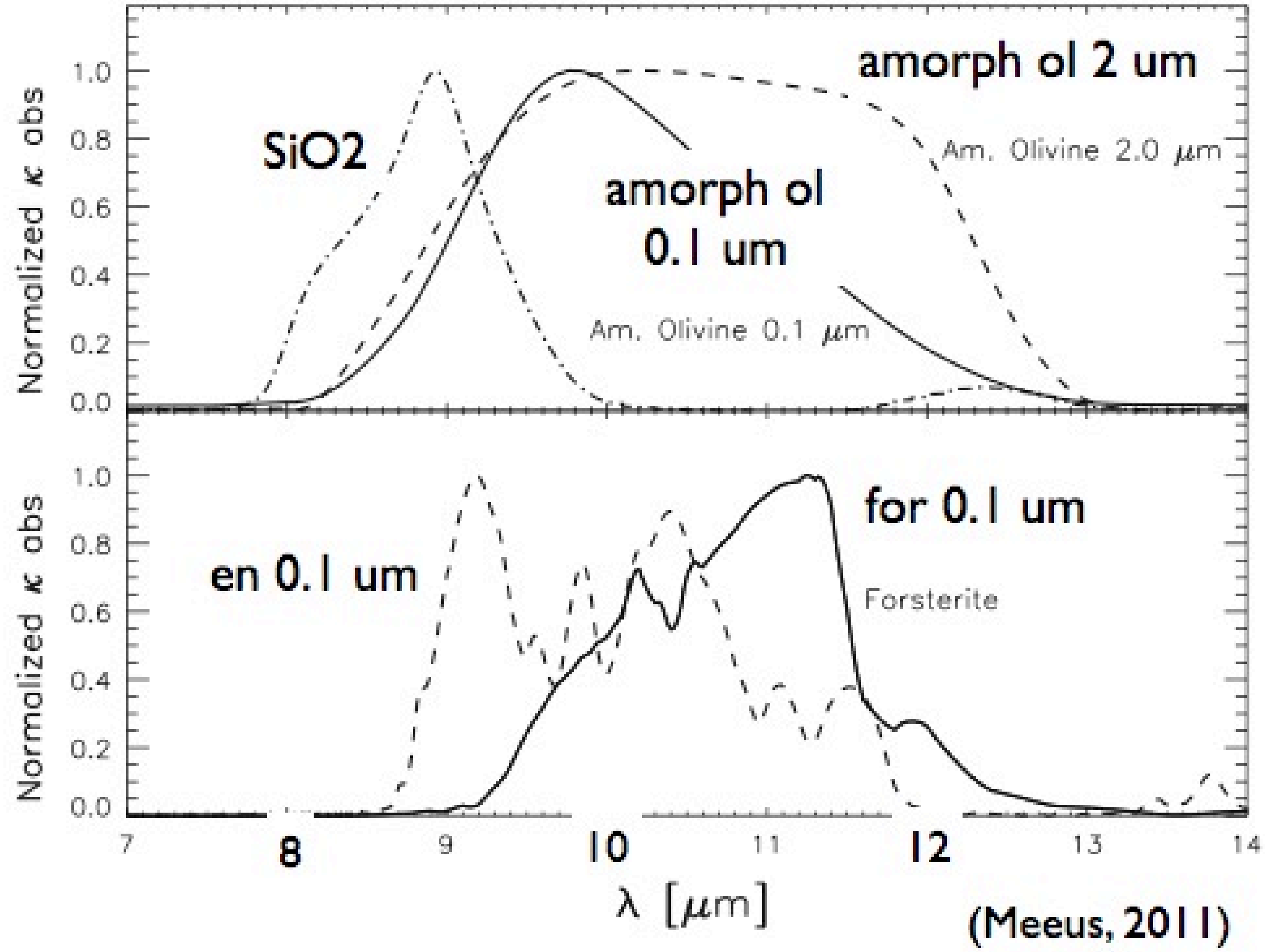
Protosolar disk

- Mg/Si/Fe chemical fractionation in ordinary chondrites



Mg and Fe depletion relative to Si in O-chondrites : due to composite grain separation

- astrophysical observation of disk surface dust



possible coexistence of ~0.1 um SiO_2 grains with olivine at the surface of protoplanetary discs

Conclusions

- Condensation in a cooling gas : formation of phases not appear in equilibrium, Fo/Fe composite and SiO_2 (amorphous)

- Dust size : strongly dependent on cooling time scale of the gas, which can reach mm in size without physical coagulation in the disc evolution

- Kinetic condensation causes chemical fractionation : chondrites' (Mg and Fe)/Si < solar the Earth's Mg/Si > solar and and astrophysical observation of SiO_2 well understood by kinetic condensation and dust/gas separation near the inner edge and large scale material transport in the protosolar disc