From snowflakes to planets

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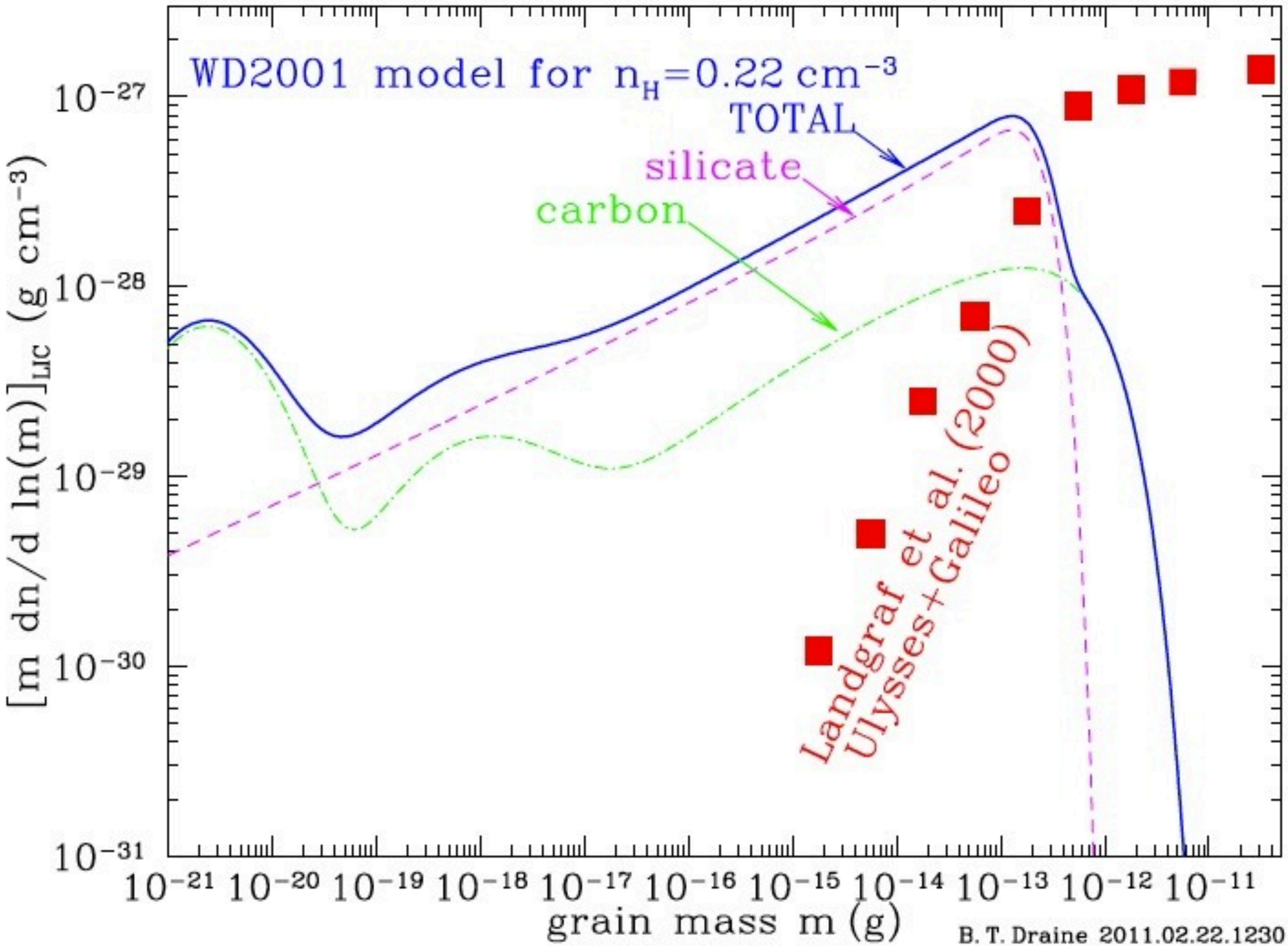
Why consider solid H_2 ? : #1

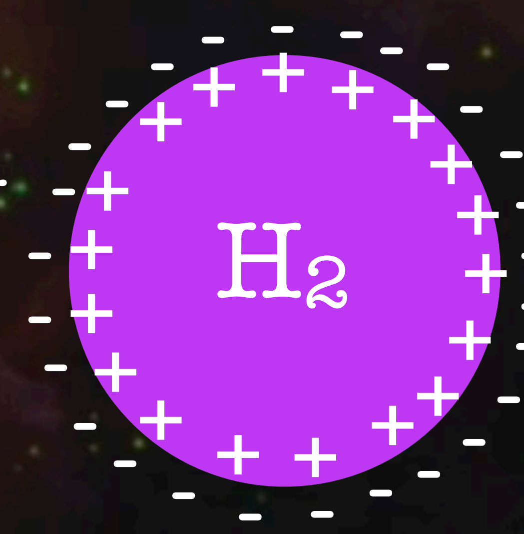
- ISM dust models constrained by abundances
  - Need grain size distribution cutoff at ~ 0.3 μm
  - Still use 100% of Si, Mg, Fe, and 50% of C
- But large ISM grains found in Solar System
  - Ulysses & Galileo impact detectors (Grun et al 1993, Landgraf et al 2000)
  - Radar detection of micrometeors
    Arecibo (Meisel et al 2002)
    AMOR (Baggaley+)
  - 50× more mass than available in metals



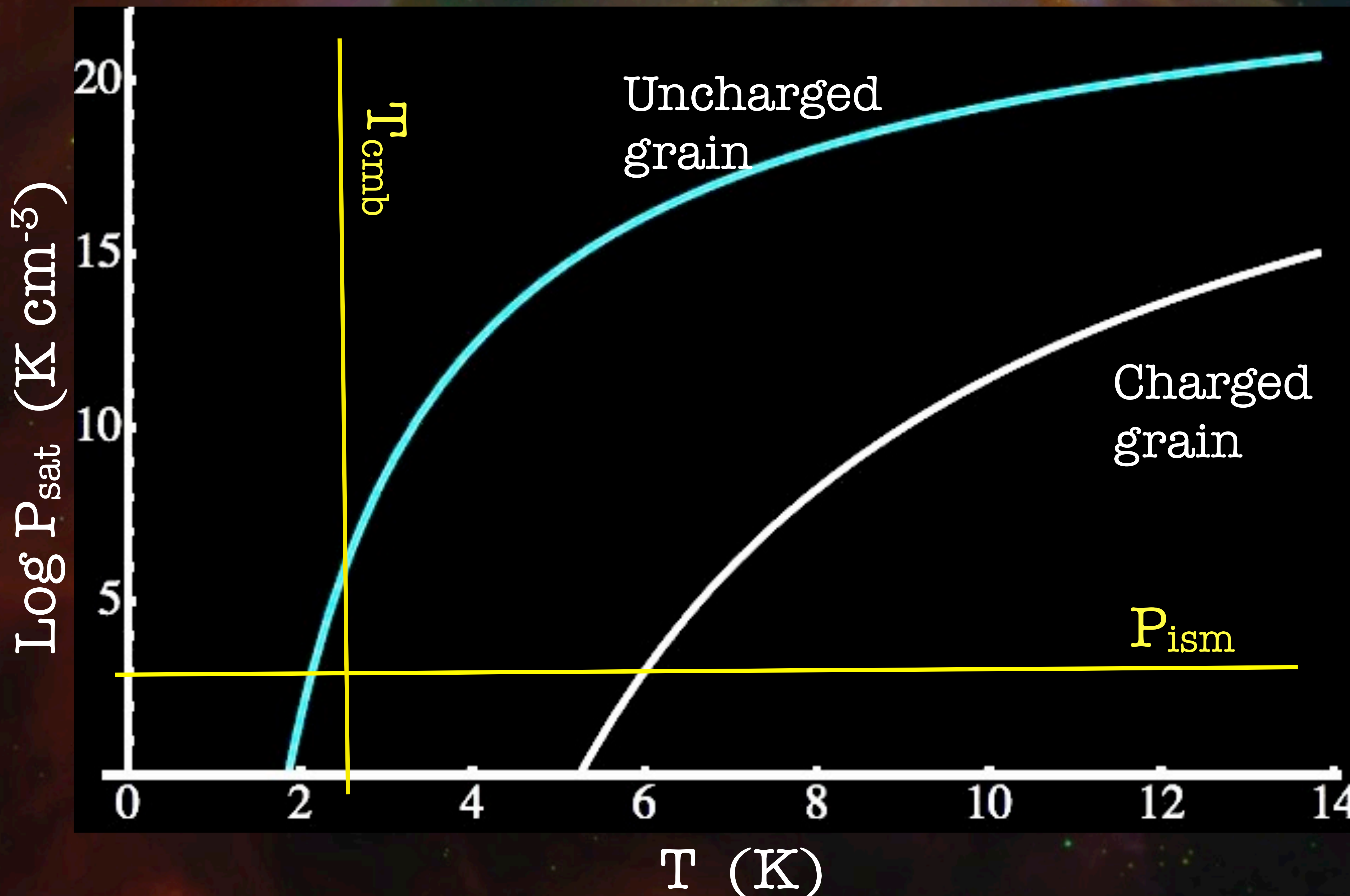
WD2001 model for $n_H = 0.22\ cm^{-3}$
TOTAL
silicate
carbon
Landgraf et al. (2000)
Ulysses+Galileo
$[m\ dn/d\ ln(m)]_{LIC}$ (g cm^{-3})
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-21} 10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14} 10^{-13} 10^{-12} 10^{-11}
grain mass m (g)
B. T. Draine 2011.02.22.1230

Why consider solid H_2 ? : #2

- Solid H_2 suggested in 1960's (Wickramasinghe+)
  - Based on erroneous P_{sat}
  - Pure solid H_2 too volatile to survive in ISM (Field, and Greenberg & de Jong)
- But thermodynamics of <u>pure</u> solid is misleading
- Surface ionisation from ambient UV
  - Cations remain in solid, e- bound in vacuum
  - Large electric fields at surface
  - Sublimation energy of H_2 ~ quadrupled
  - Cold grains can survive indefinitely



Phase equilibrium : effect of charging



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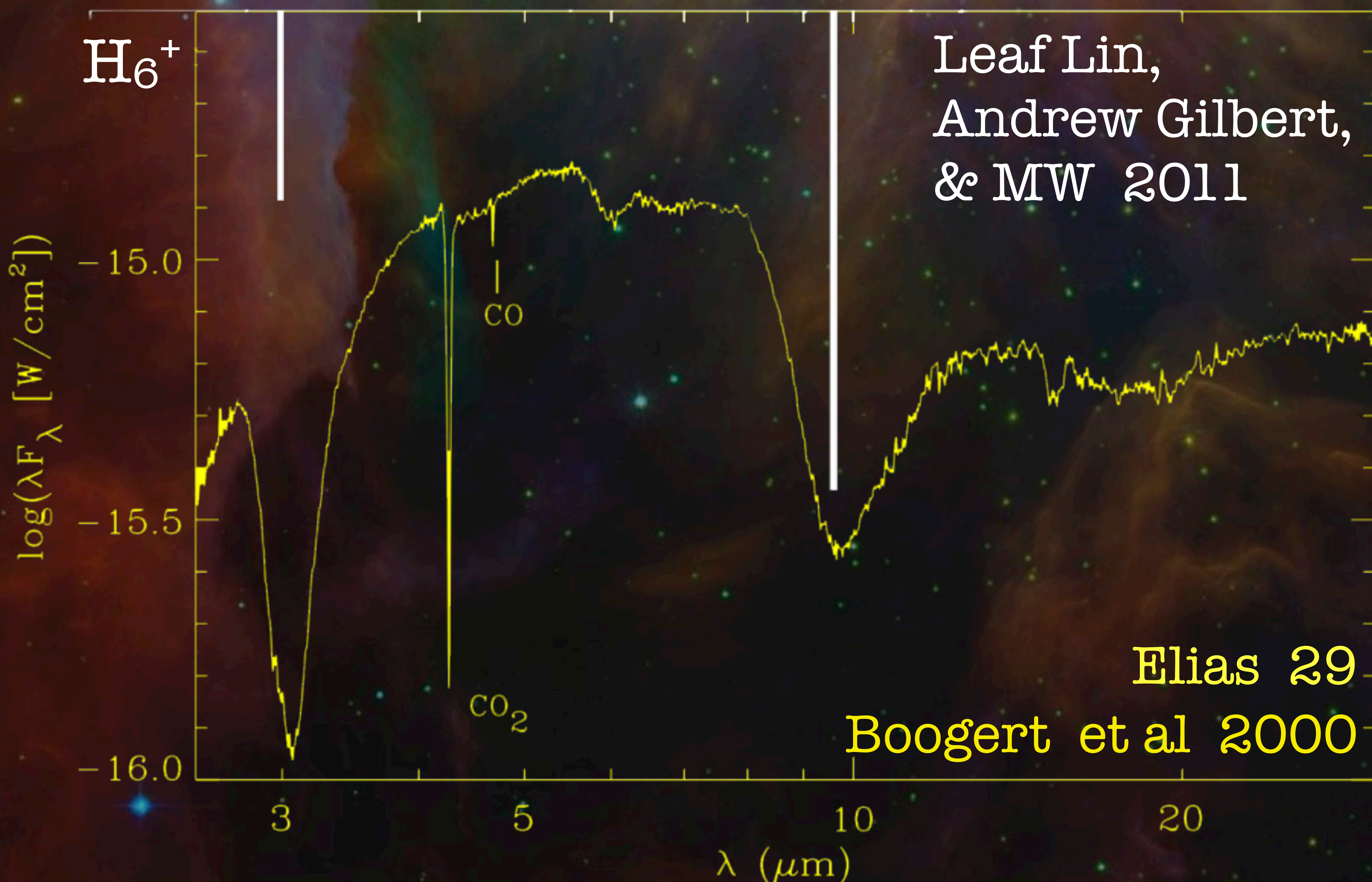
Why consider solid H_2 ? : #3

- Mid-IR spectra support conventional model :
  - 9.6 µm absorption : astronomical silicate
  - Various emission lines : PAH's
- But features are broad : hard to identify securely
- Pure solid H_2 has feeble mid-IR transitions
- Dominant bands from cations: H_6^+ and $(HD)_3^+$
  - Recently discovered; only form in solid H_2
  - No IR lab spectroscopy
  - Calculated transitions match ISM bands

IR Absorption



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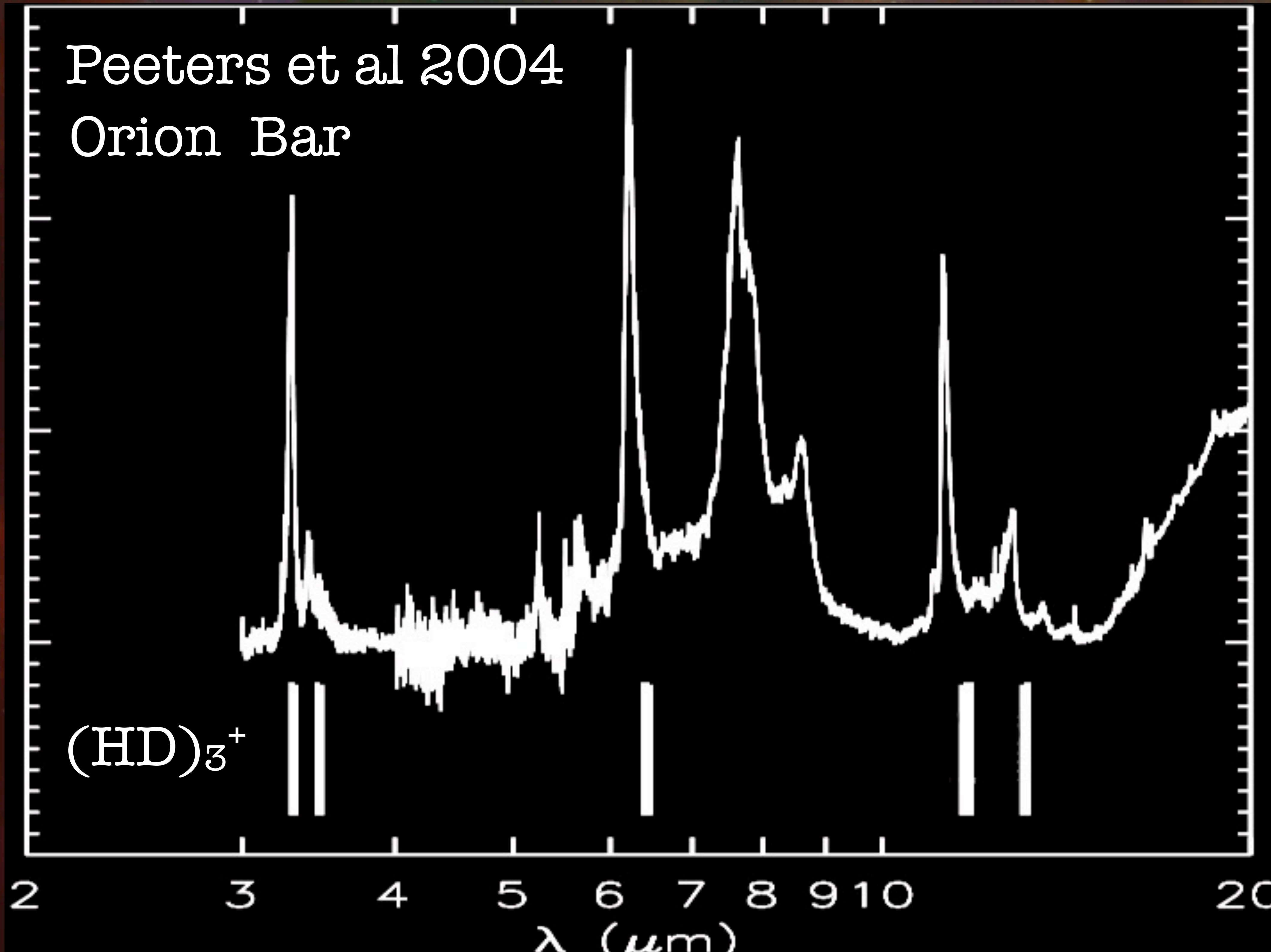
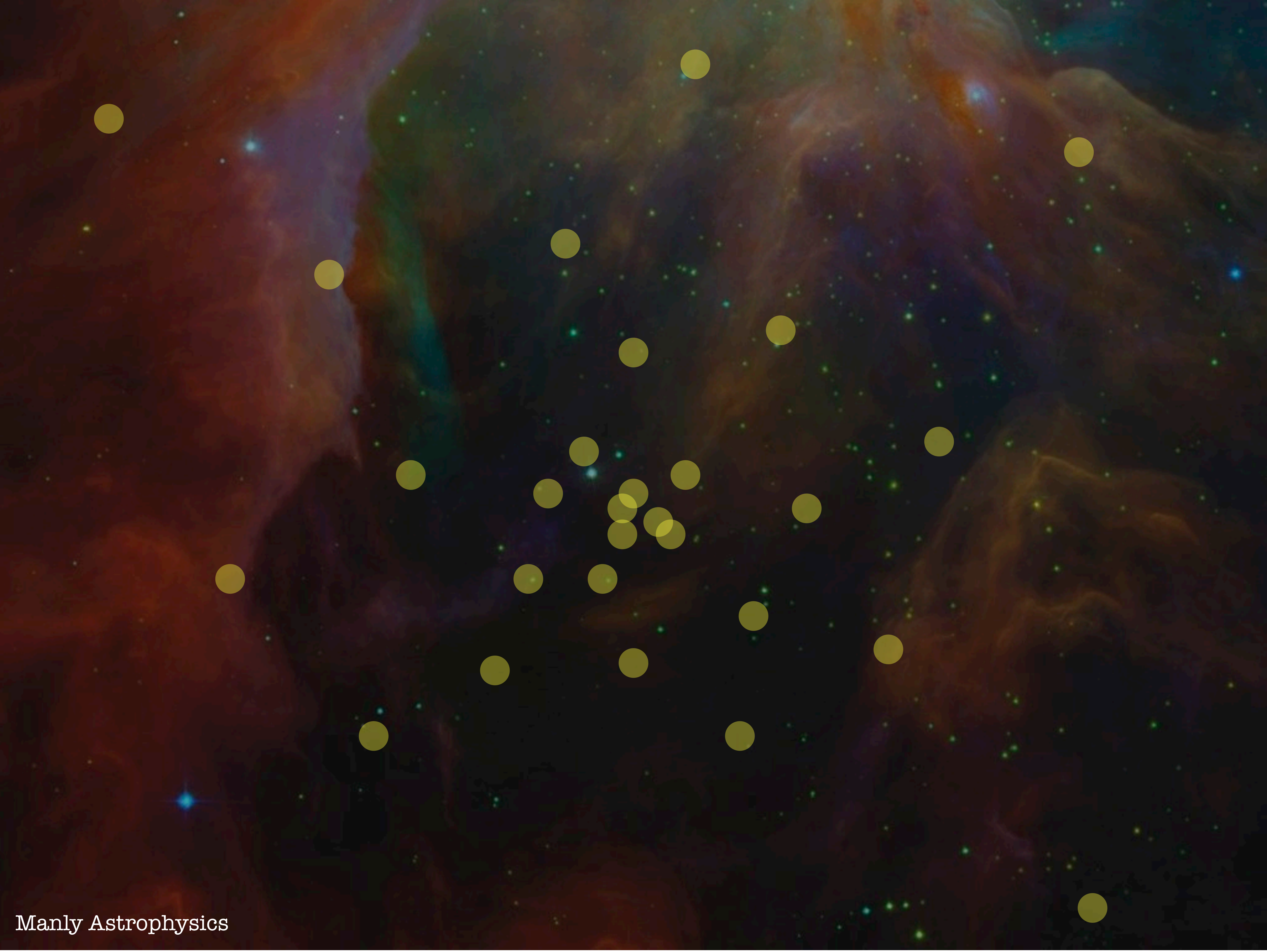
IR Emission



Star & planet formation with solid H_2

- Need cold, dense gas to make H_2 snow
- Self-gravitating clouds with
  - Radius ~ AU
  - Mass ~ $M_\oplus$ (?)
- Start with clusters of, e.g., $\sim 10^7$ snowclouds
- Collisions : merging & disruption of snowclouds
  - Disruption causes precipitation of H_2
  - Central agglomerate → Star
  - Remaining debris → Planets
  - Snowclouds at large radii remain intact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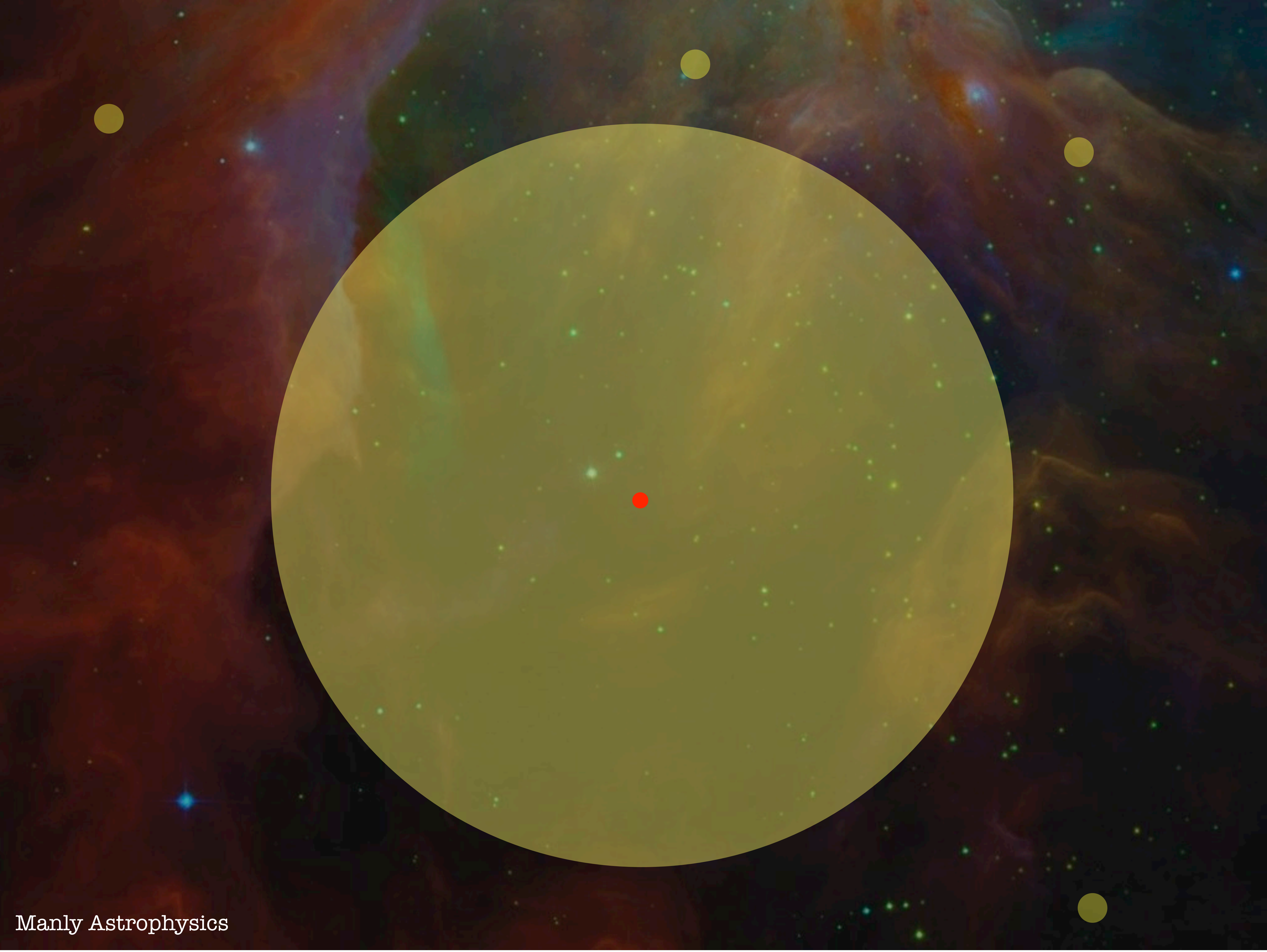
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Intact snowclouds observed in death throes

Intact snowclouds observed in death throes

Possibilities for planet formation

- Protoplanetary disk mass could be dominated by solid H_2
- Solid H_2 has a low density (0.087 g cm^{-3})
  - Snowballs would have much lower density
    - Could have rapid growth:
      - Snowflakes → snowballs → "gas" giants
- Silicates etc. already aggregated into lumps at centres of pre-disruption snowclouds
  - Prefabricated metallic objects:
    - Asteroids, comets (moons? dwarf planets?)
      - Gravitational nucleation sites

Summary

- Interstellar dust could be mainly solid H_2
  - Large ISM grains observed in solar system
  - Charging makes solid H_2 durable
  - H_6^+ and $(HD)_3^+$ vibrational spectra match ISM
- Need cold, dense gas-clouds to make H_2 snow
  - Dark snowclouds: radii ~ AU, masses ~ $M_\oplus$ (?)
- Clusters of snowclouds evolve to yield stars and protoplanetary disks
  - Prefabricated metallic lumps + H_2 snowflakes
  - Rapid growth of planets