Solid H_2 : Interstellar Dust

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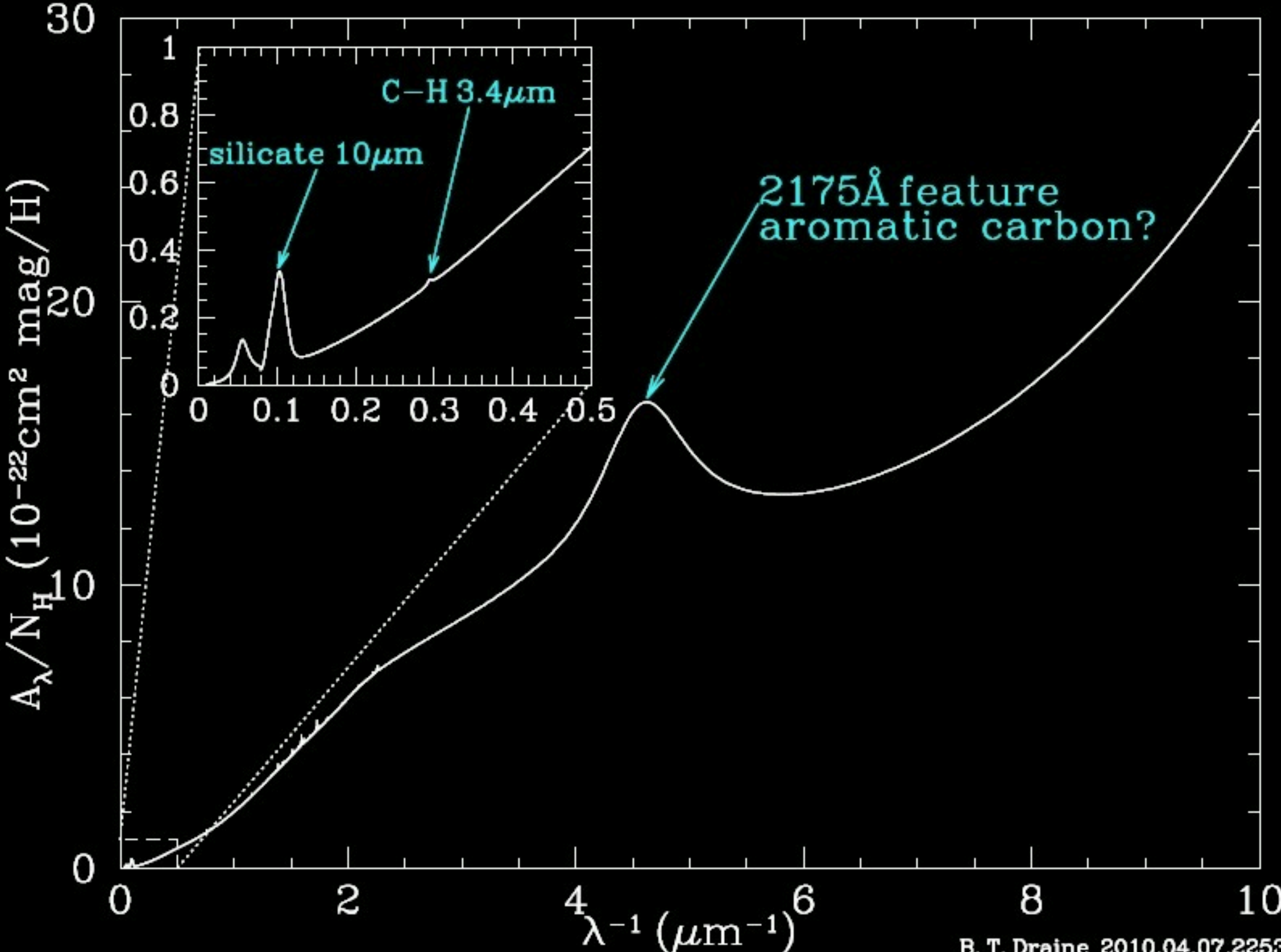
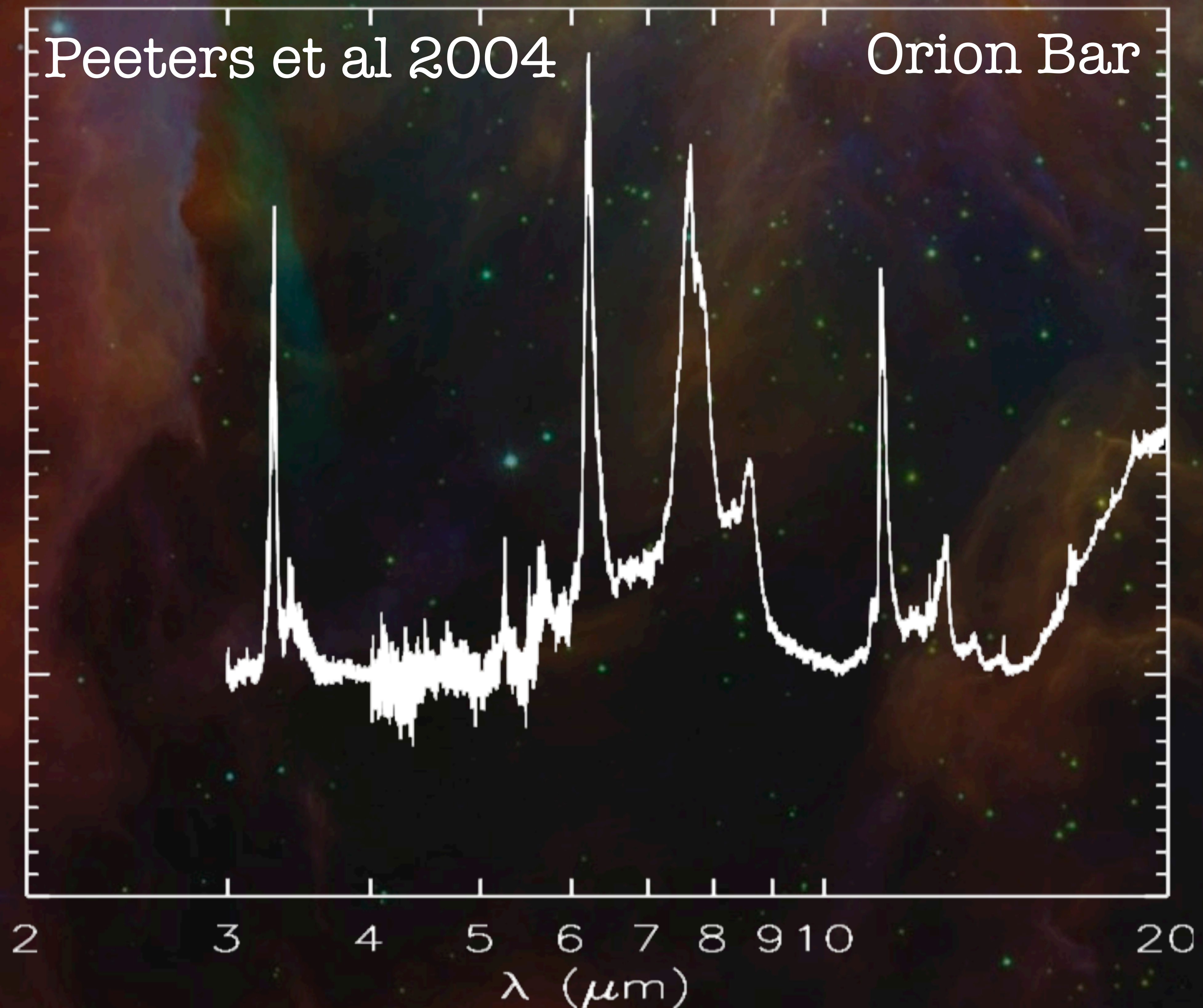
(Manly Astrophysics)

Overview

- What is interstellar dust?
  - Observations ↔ Silicate/Graphite Model
- Solar System observations of interstellar dust
  - Direct test of S/G Model → Problem
- Solution : interstellar dust made of solid H_2
  - Origin in cold, dense gas : dark matter
- Survival of H_2 grains : charging is critical
- Ionisation chemistry of solid H_2 → H_6^+
  - Mid-IR vibrational signatures
    - Comparison with ISM bands



C−H 3.4μm
silicate 10μm
2175Å feature
aromatic carbon?
A_λ/N_H (10^{-22}cm^2 mag/H)
λ^{-1} (μm^{-1})
B. T. Draine 2010.04.07.2253



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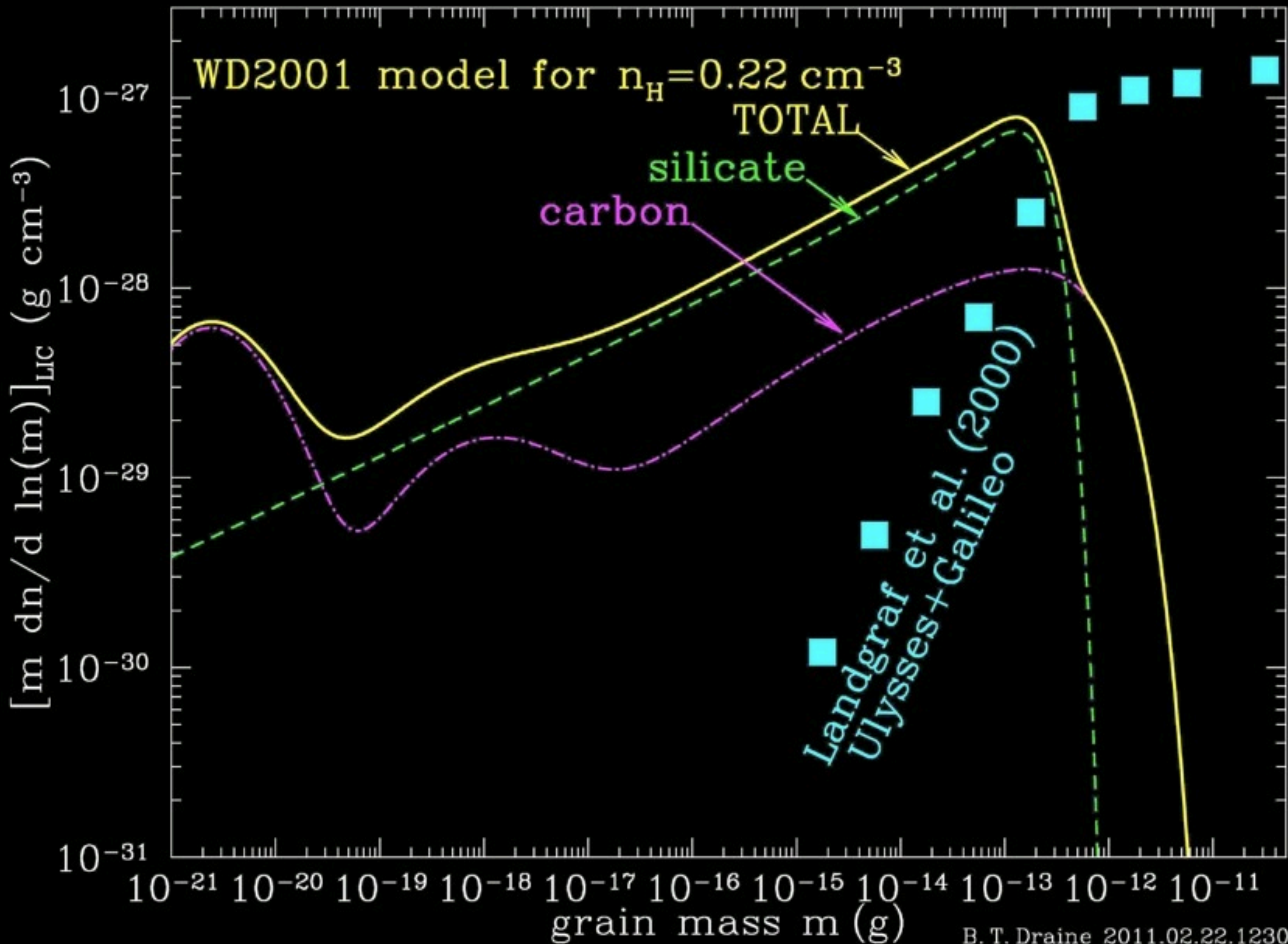
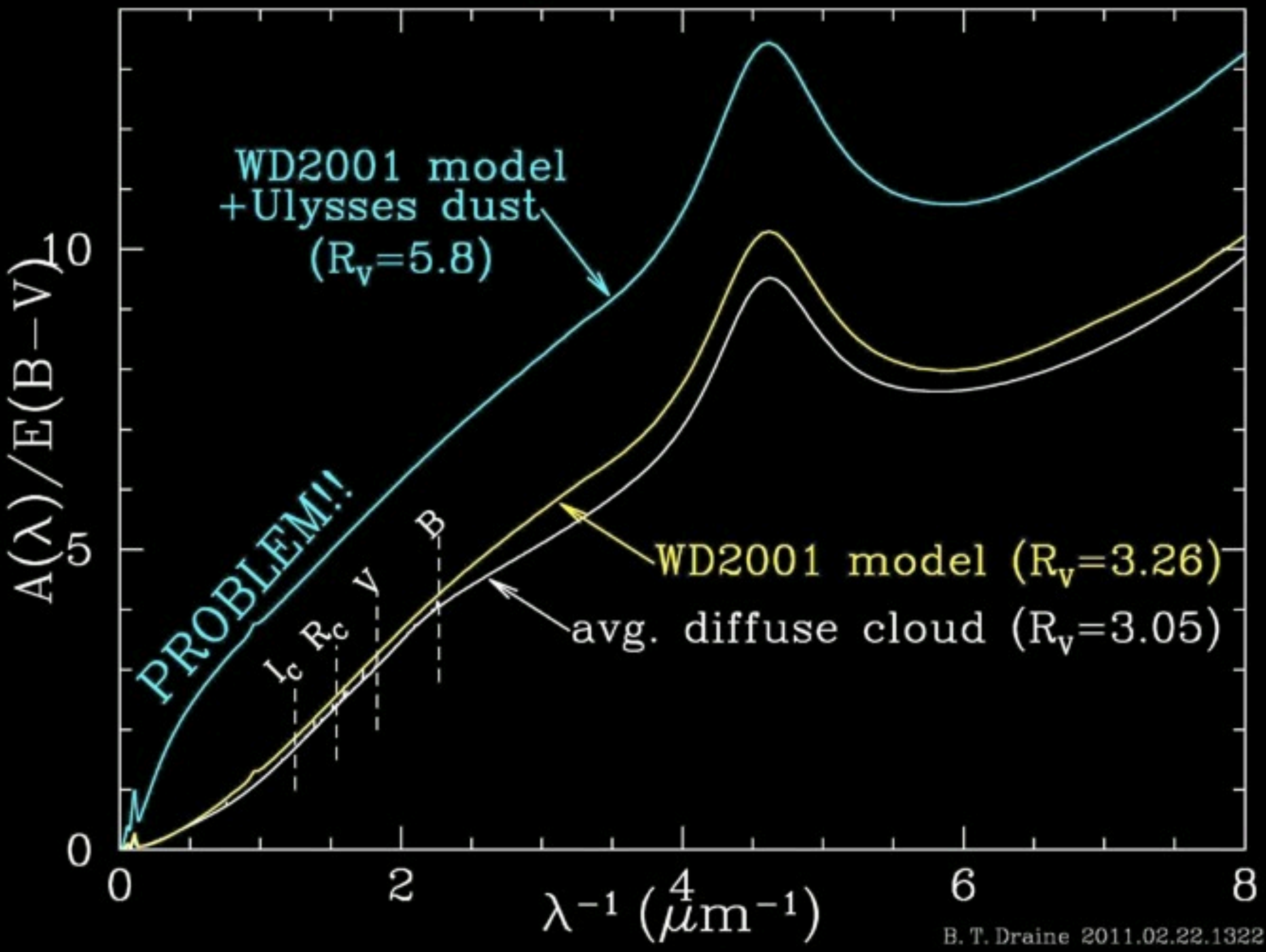
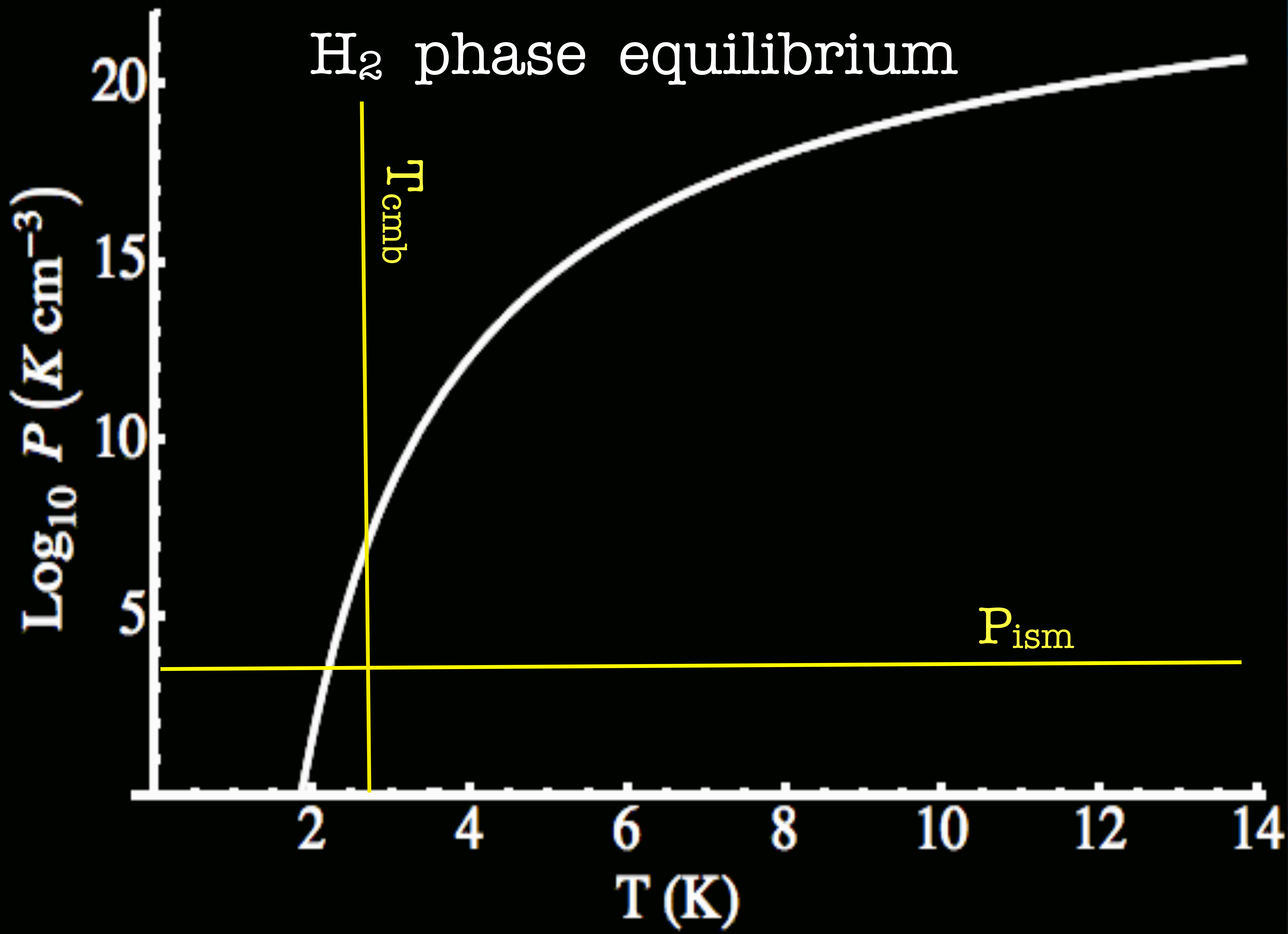

WD2001 model for n_H=0.22 cm^{-3}
TOTAL
silicate
carbon
Landgraf et al. (2000)
Ulysses+Galileo
$[m\ dn/d\ \ln(m)]_{LIC}$ (g cm^{-3})
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-21} 10^{-20} 10^{-19} 10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14} 10^{-13} 10^{-12} 10^{-11}
grain mass m (g)
B. T. Draine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

Extinction Law for "Ulysses" Grain Size Distribution



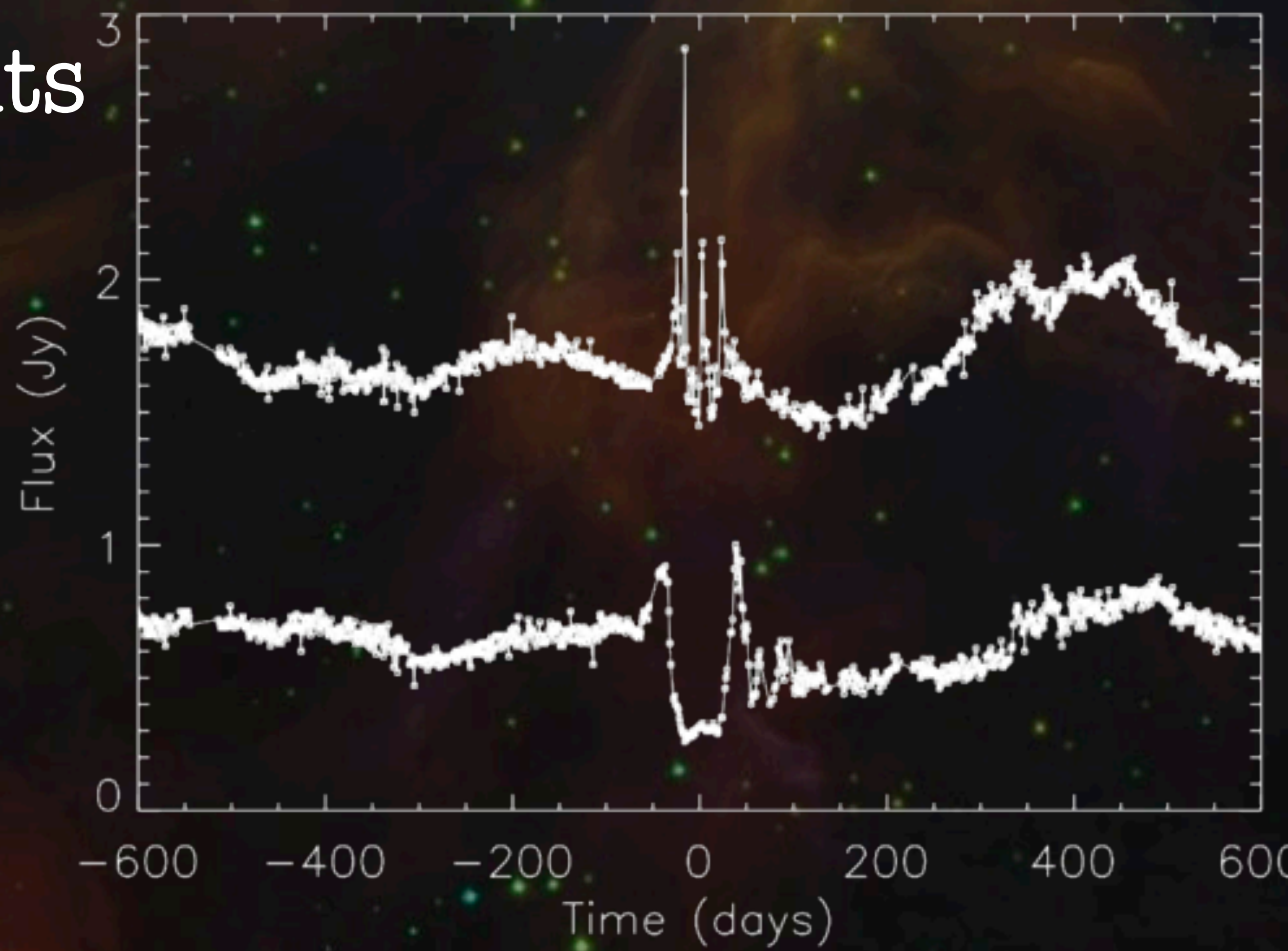
- "Ulysses" size distribution would have $R_V = A_V/E(B-V) \approx 5.8$ whereas we observe $R_V \approx 3.1$ for the (average) diffuse ISM.
- "Ulysses" size distribution *cannot* be characteristic of the diffuse ISM, based on reddening alone.



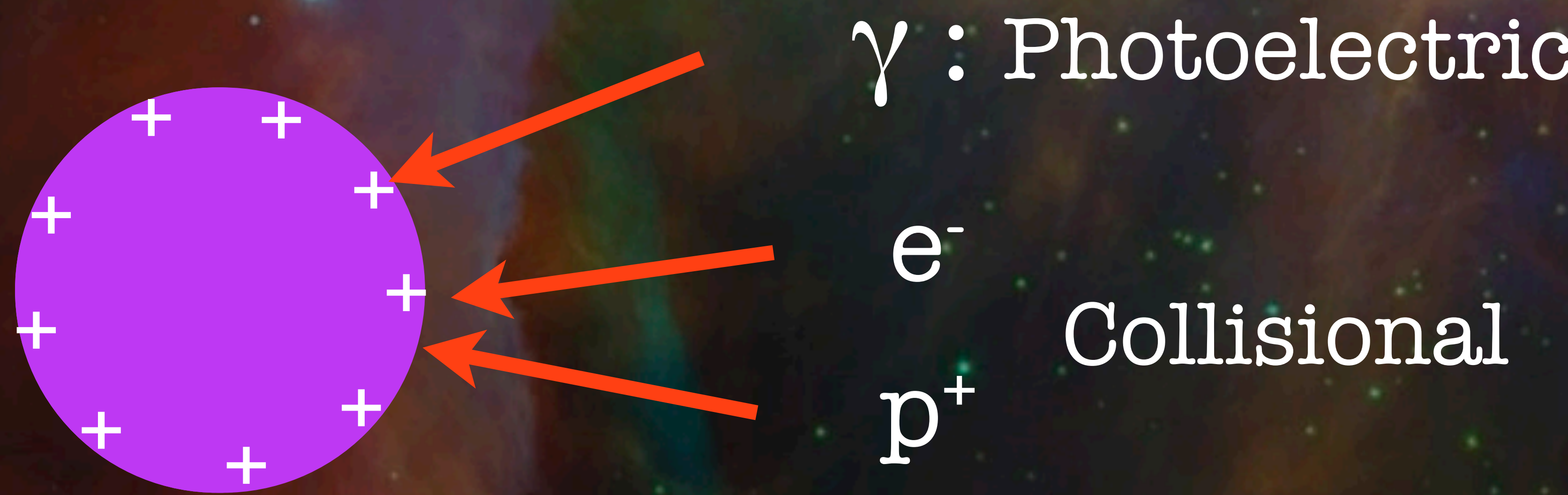
H2 phase equilibrium
Tcmb
Pism
Log10 P (K cm-3)
20
15
10
5
2
4
6
8
10
12
14
T (K)

How could H_2 grains form?

- Need gas clouds with $P \sim P_{sat} \gg P_{ism}$
  ∴ not part of the diffuse ISM
  - Self-gravitating
- But denser than any known clouds
  - New population : baryonic dark matter (Pfenniger & Combes 1994)
- Extreme Scattering Events (Fiedler et al 1987) support this idea
  - Cloud radii ~ 1 AU, Masses ~ planetary



Charging of dust grains

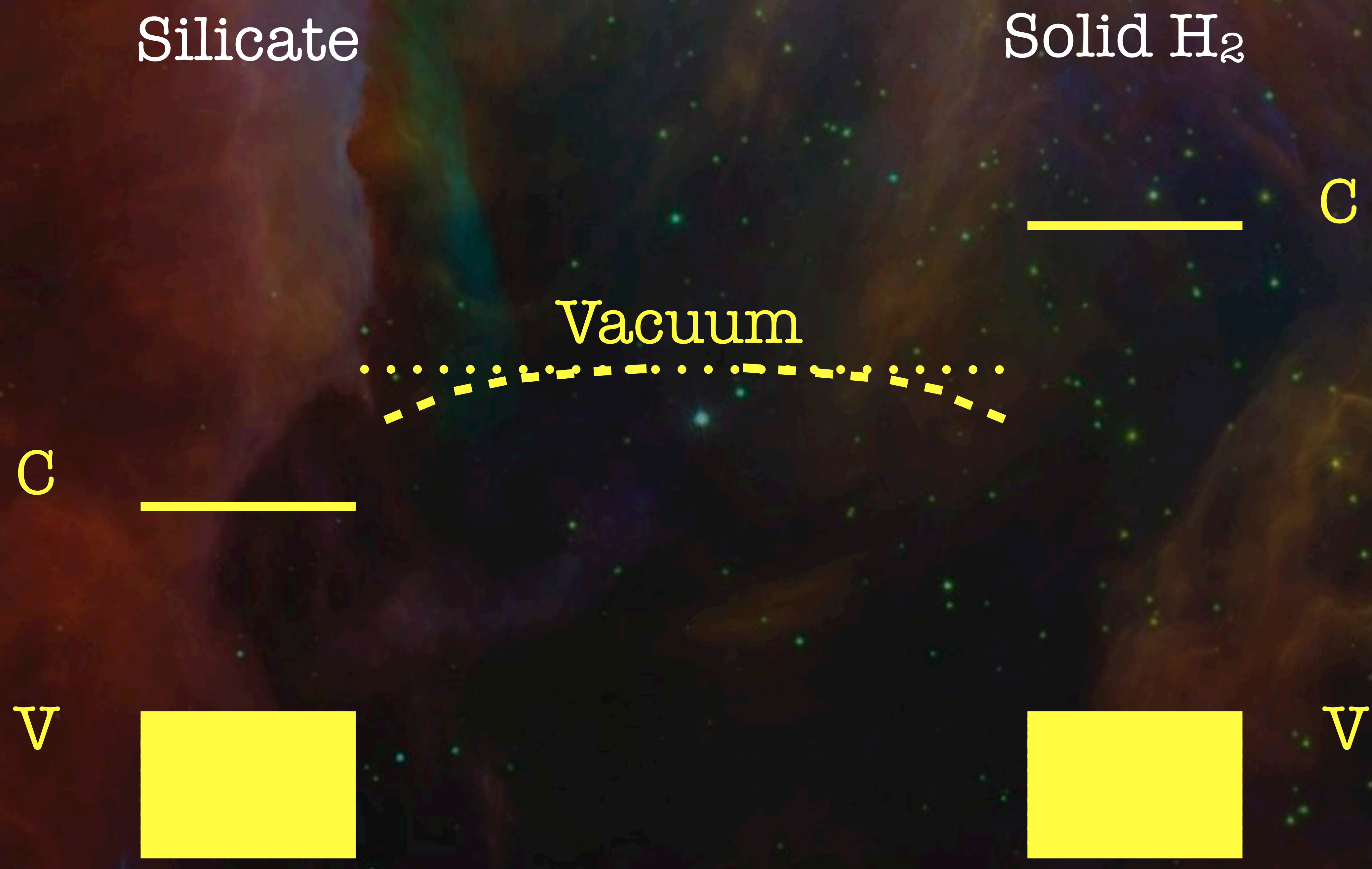


$\Phi \sim$ few V

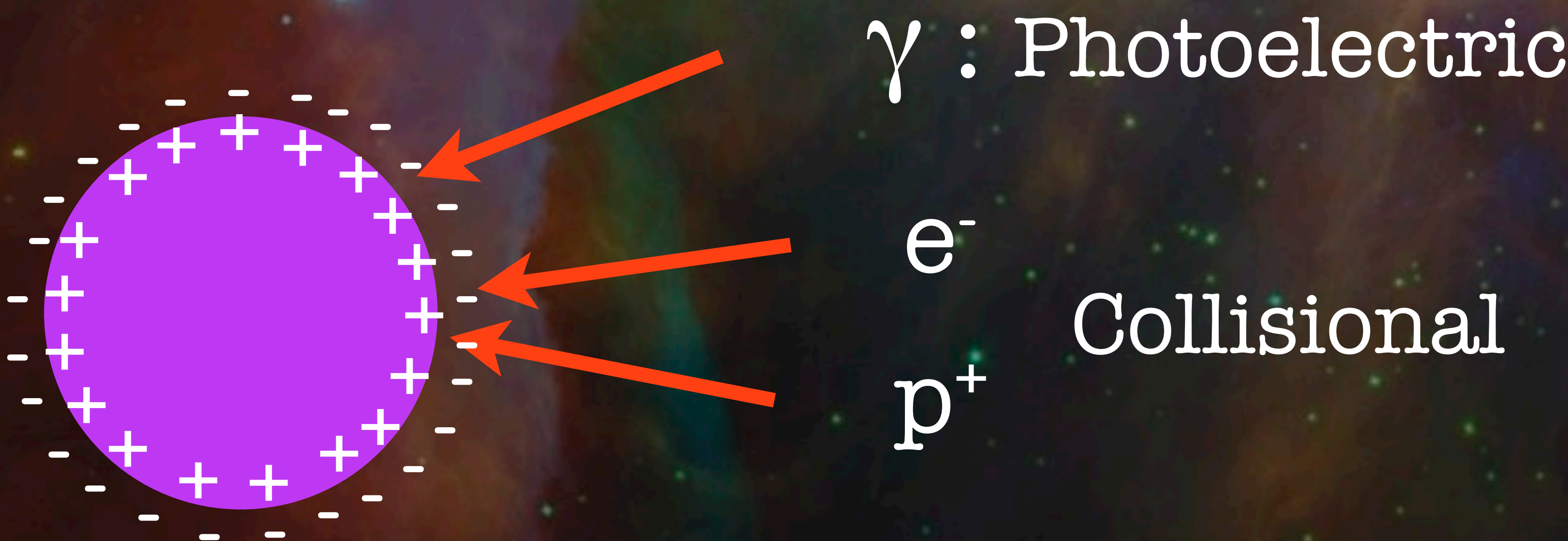
$L \sim$ few μm $\quad \therefore \quad E \sim 10^6$ V m^{-1}

$U_{pol} = \alpha E^2 / 2 \sim 10\ \mu K$

Electronic band structure



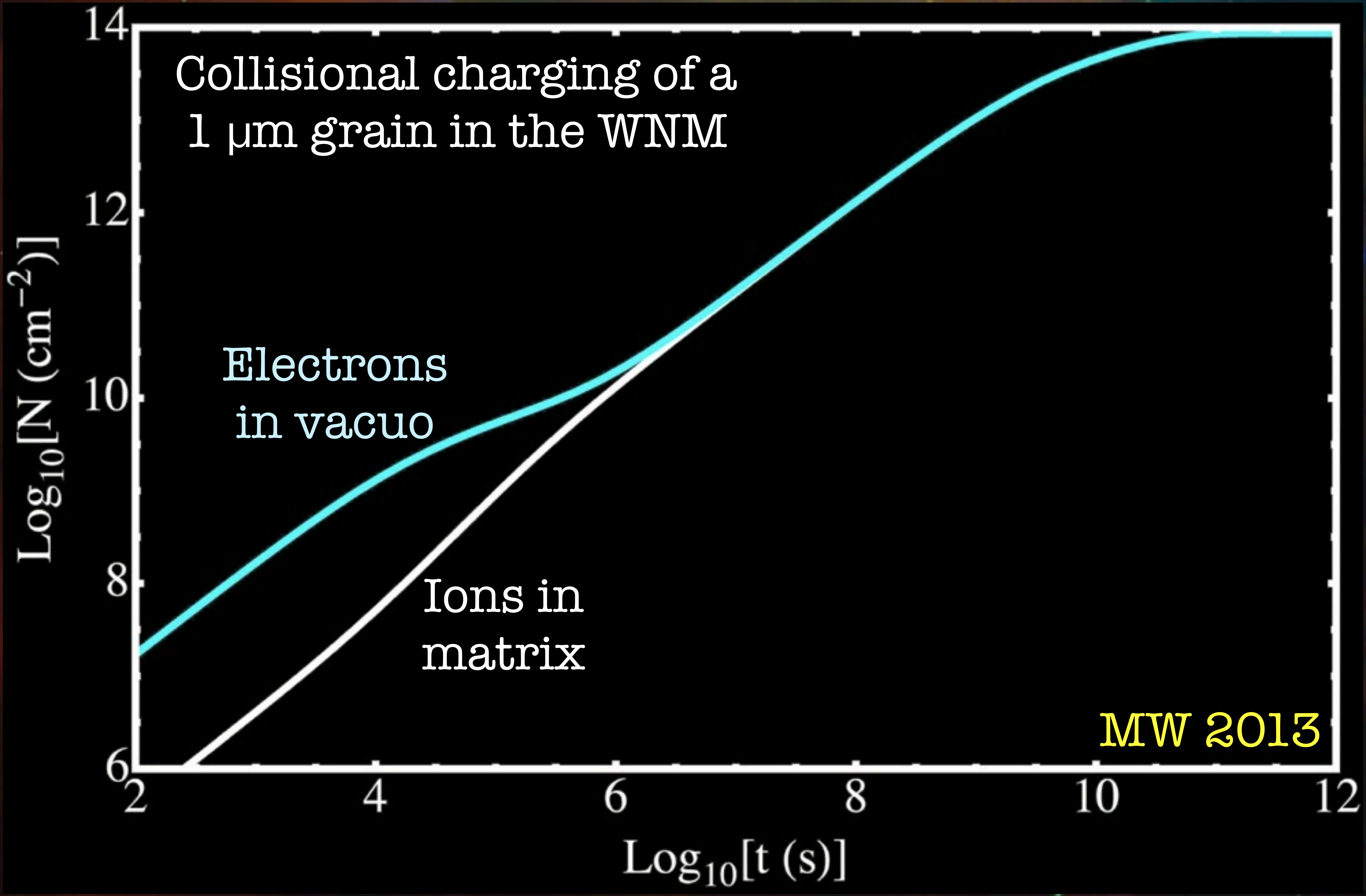
Charging of H_2 grains



$\Phi \sim$ few V

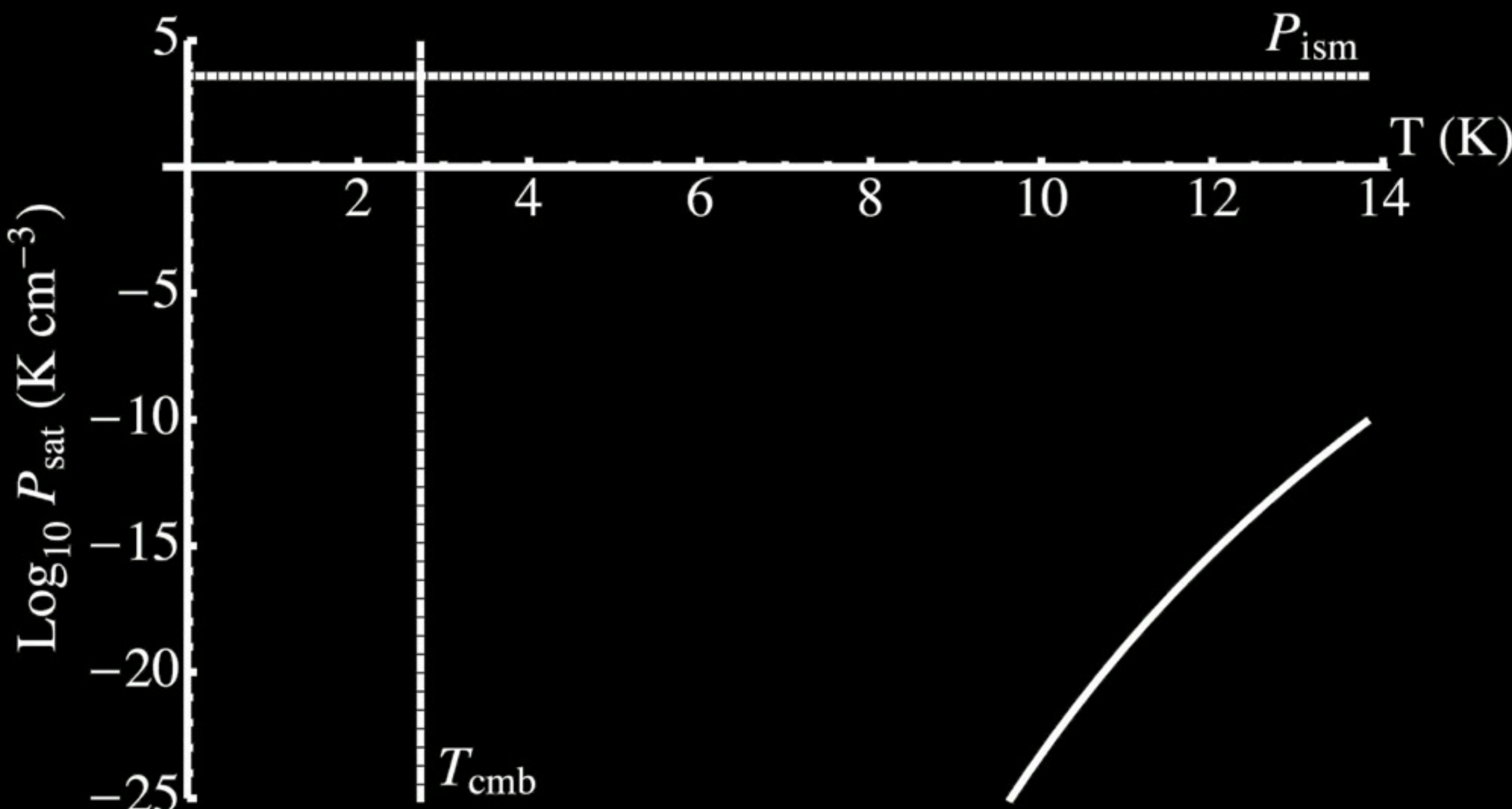
$L \sim$ few Å $\quad \therefore \quad E \sim 10^{10}\ \mathrm{V\,m^{-1}}$

$U_{pol} = \alpha E^2 / 2 \sim 1000\ \mathrm{K}$



Collisional charging of a 1 μm grain in the WNM
Electrons in vacuo
Ions in matrix
MW 2013
14
12
10
8
6
2
4
6
8
10
12
Log10[N (cm−2)]
Log10[t (s)]

Charged - H_2 phase equilibrium



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H_2 ionisation chemistry

Gas phase: $H_2^+ + H_2 \rightarrow H_3^+ + H$

Solid phase: $H_2^+ + 2\,H_2 \rightarrow H_6^+$

ESR : Miyazaki, Kumada, Kumagai, Shimizu

Theory : Kurosaki & Takayanagi

No lab spectroscopy yet

Ab Initio model of H_6^+ vibrations

CCSD + cc-pVTZ

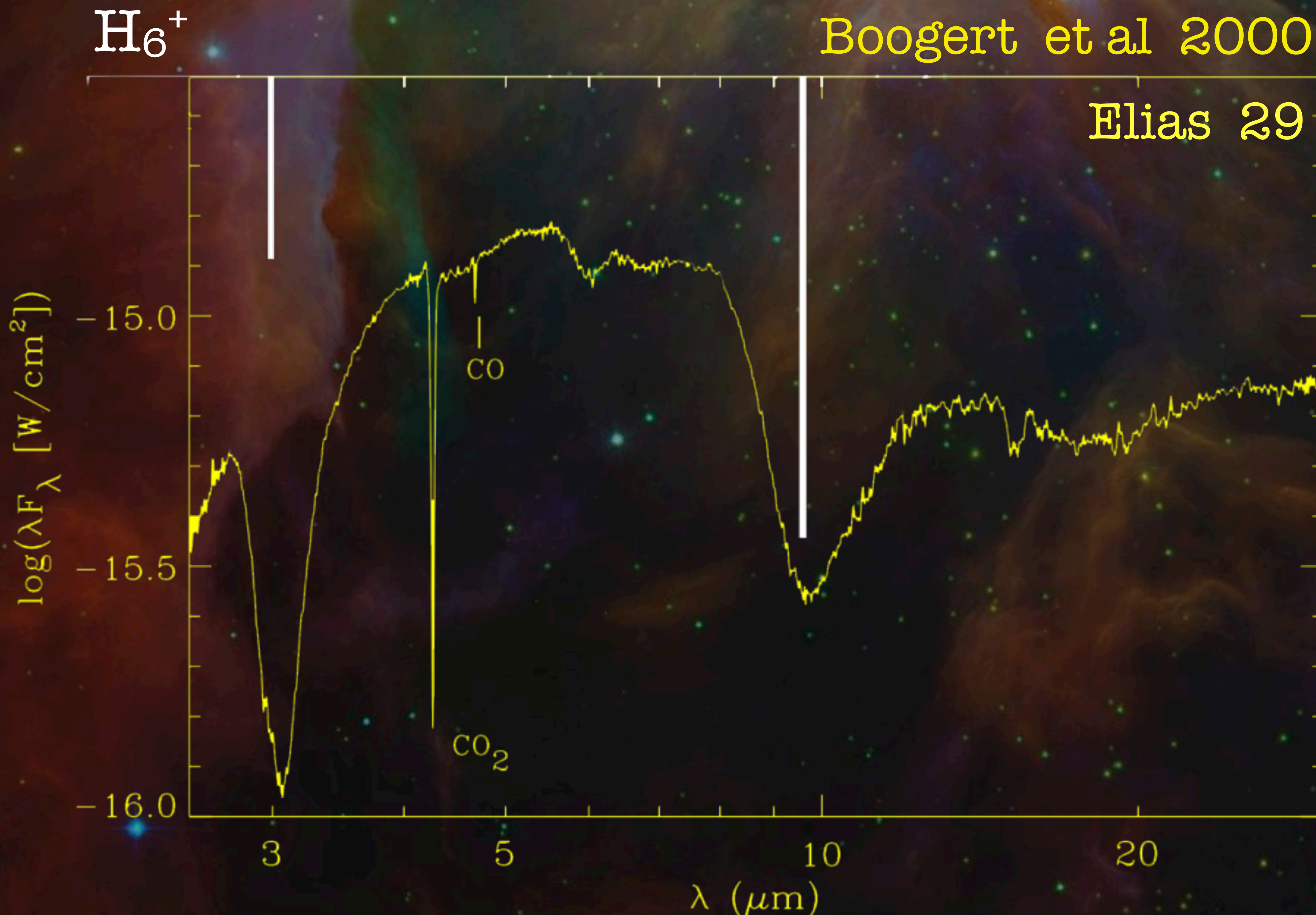
Highly anharmonic :
Include cubic & quartic
Use VCI method

Can only model 5 modes

H_6^+ and $(HD)_3^+$
Isotopomers

Leaf Lin,
Andrew Gilbert,
& MW 2011

Mid-IR Absorption



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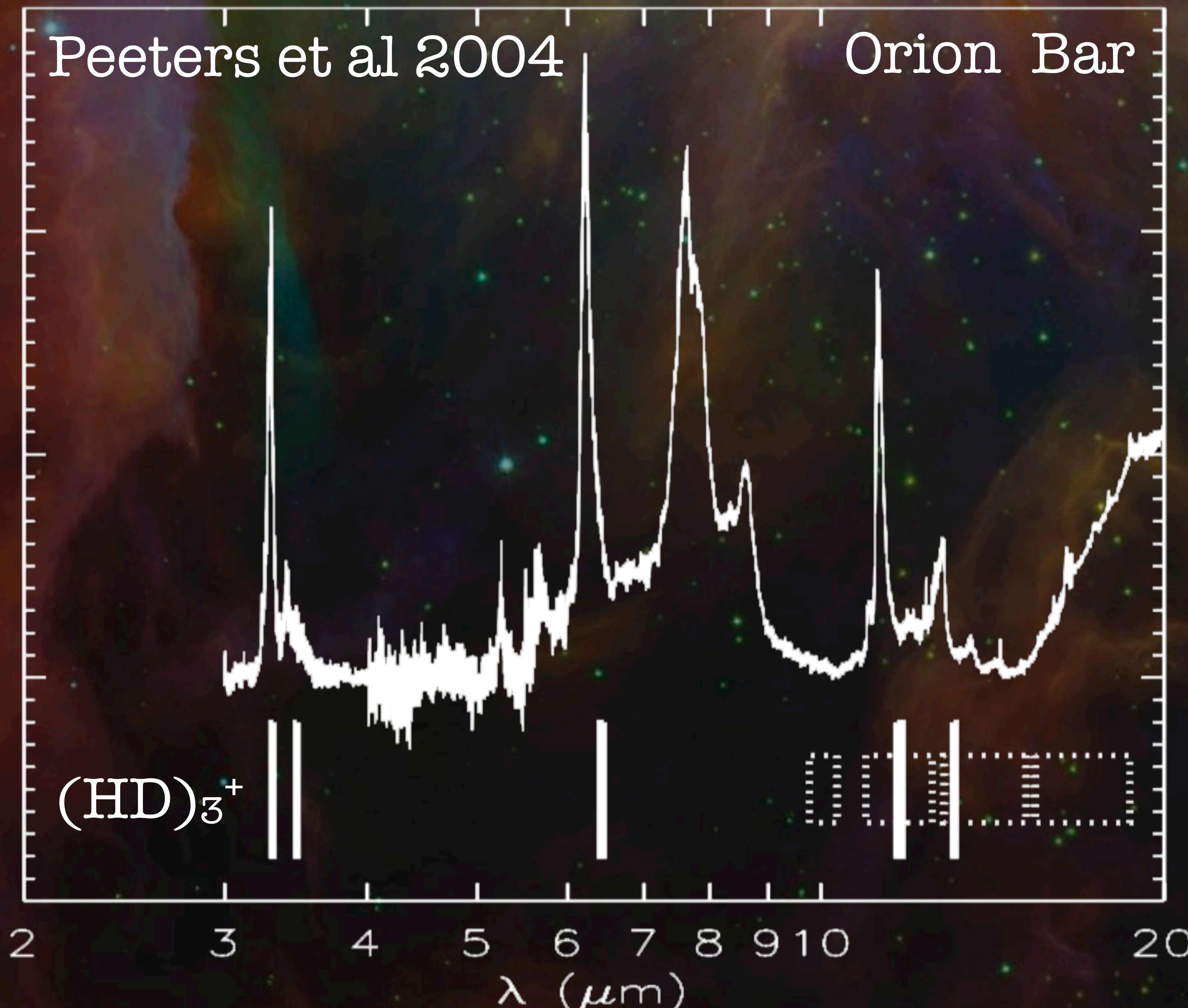
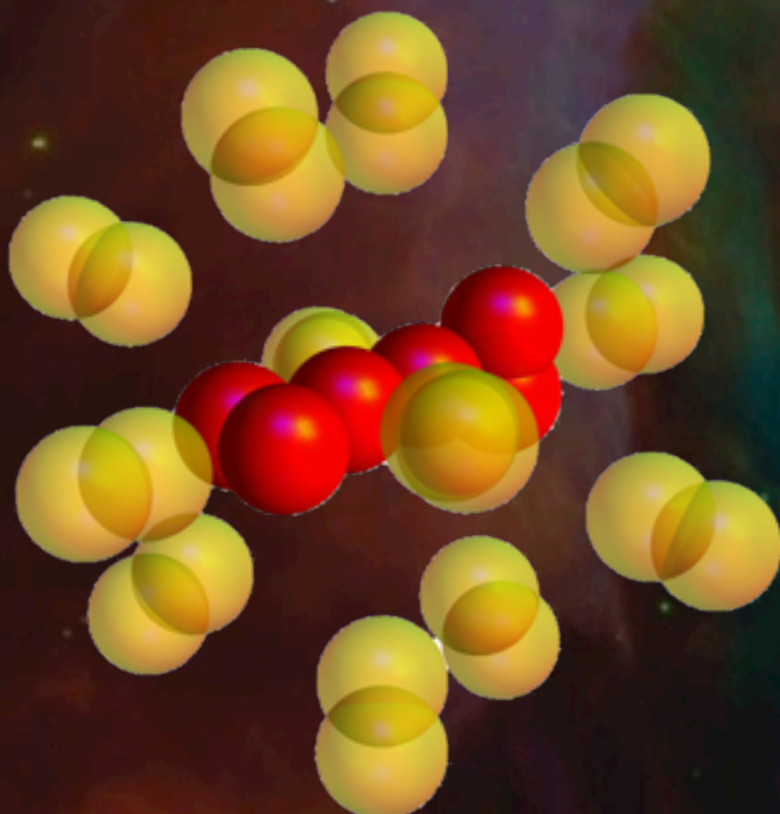


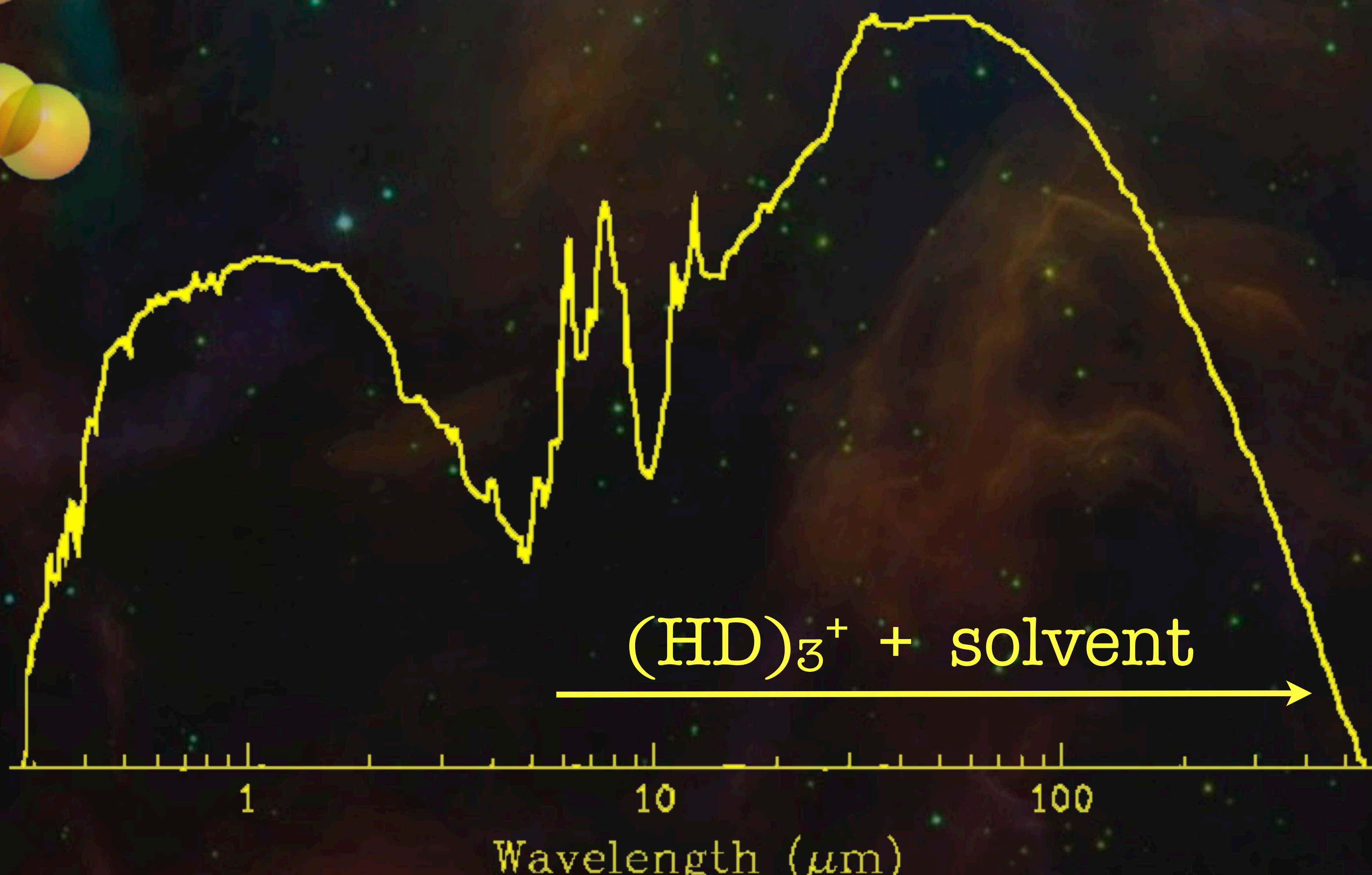
Peeters et al 2004
Orion Bar
(HD)3+
2
3
4
5
6
7
8
9
10
20
λ (μm)

FIR from cluster modes.

Many modes :

quasi - continuum FIR.





Current focus of H_2 dust studies

- Attempt to model extinction curve
  - H_2 matrix + impurities + surface electrons
- Influence on radio-wave propagation
  - Metallic character of surface electrons
  - Large volume fraction possible
  - No contribution to fluid pressure
    - Maybe relevant to Intra-Day Variability and pulsar parabolic arcs
- Individual surface electrons bound to individual sub-surface ions
  - A new one-electron atom : Halfium
    - Characteristic energy levels

Summary

- Dark gas clouds seed the Galaxy with H_2 grains
- Solid H_2 conduction band above vacuum level
  - Charging leads to "double-layer" surface charge distribution : strong E-fields
    - Heat of H_2 sublimation increased 10×
  - Hydrogen dust may persist in diffuse ISM
- Ionisation chemistry in solid differs from gas
  - H_6^+ is favoured product (new molecule!)
    - Isotopic condensation to $(HD)_3^+$
  - Vibrational lines of H_6^+ and $(HD)_3^+$ match strong mid-IR bands of ISM
    - Suggests that solid H_2 is ubiquitous