Supernovae : H_2 snowflake factories

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(Manly Astrophysics)

Why consider solid H_2 dust?

- More durable than you thought
- Good match to mid-IR ISM bands
- Easy to make with supernovae

H_2 phase equilibrium

T_{cmb}

P_{ism}

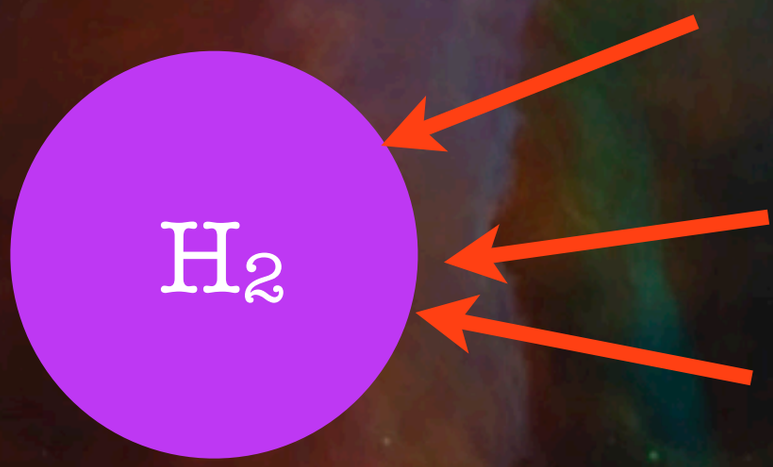
$\mathrm{Log_{10}}\ P\ (K\,\mathrm{cm^{-3}})$

20
15
10
5

2 4 6 8 10 12 14

T (K)

Charging of H_2 grains

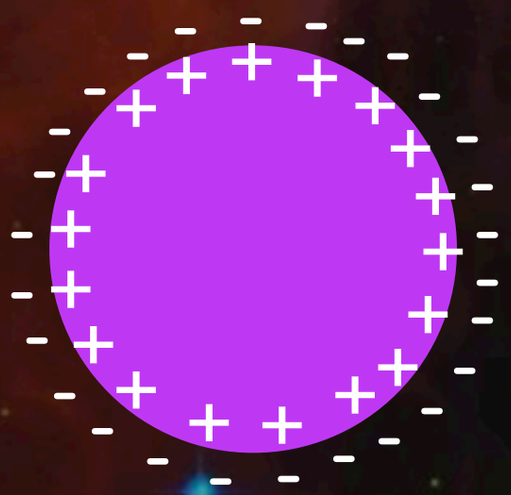


γ : Photoelectric

e^-

p^+

Collisional



Conduction

Vacuum

Valence

H_2 phase equilibrium

T_{cmb}

Charged surface

P_{ism}

$\mathrm{Log_{10}}\ P\ (K\,\mathrm{cm^{-3}})$

20
15
10
5

2 4 6 8 10 12 14

T (K)

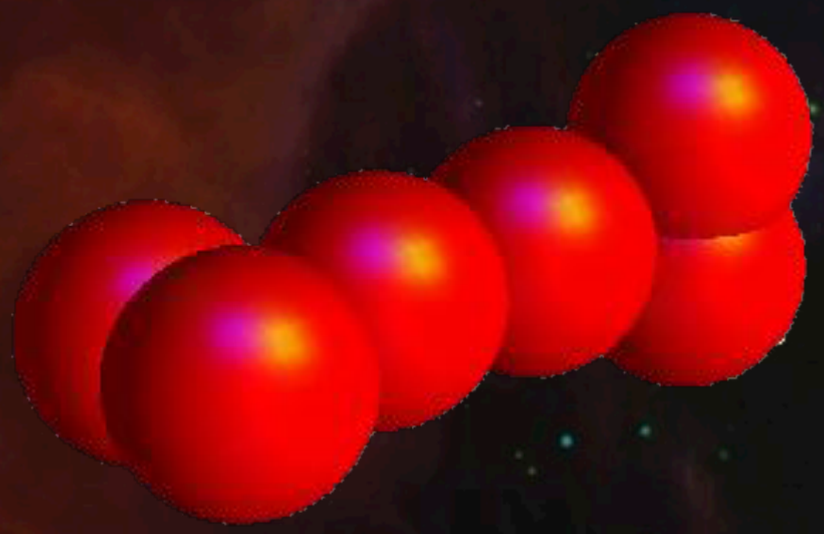
Ionisation of solid H_2

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

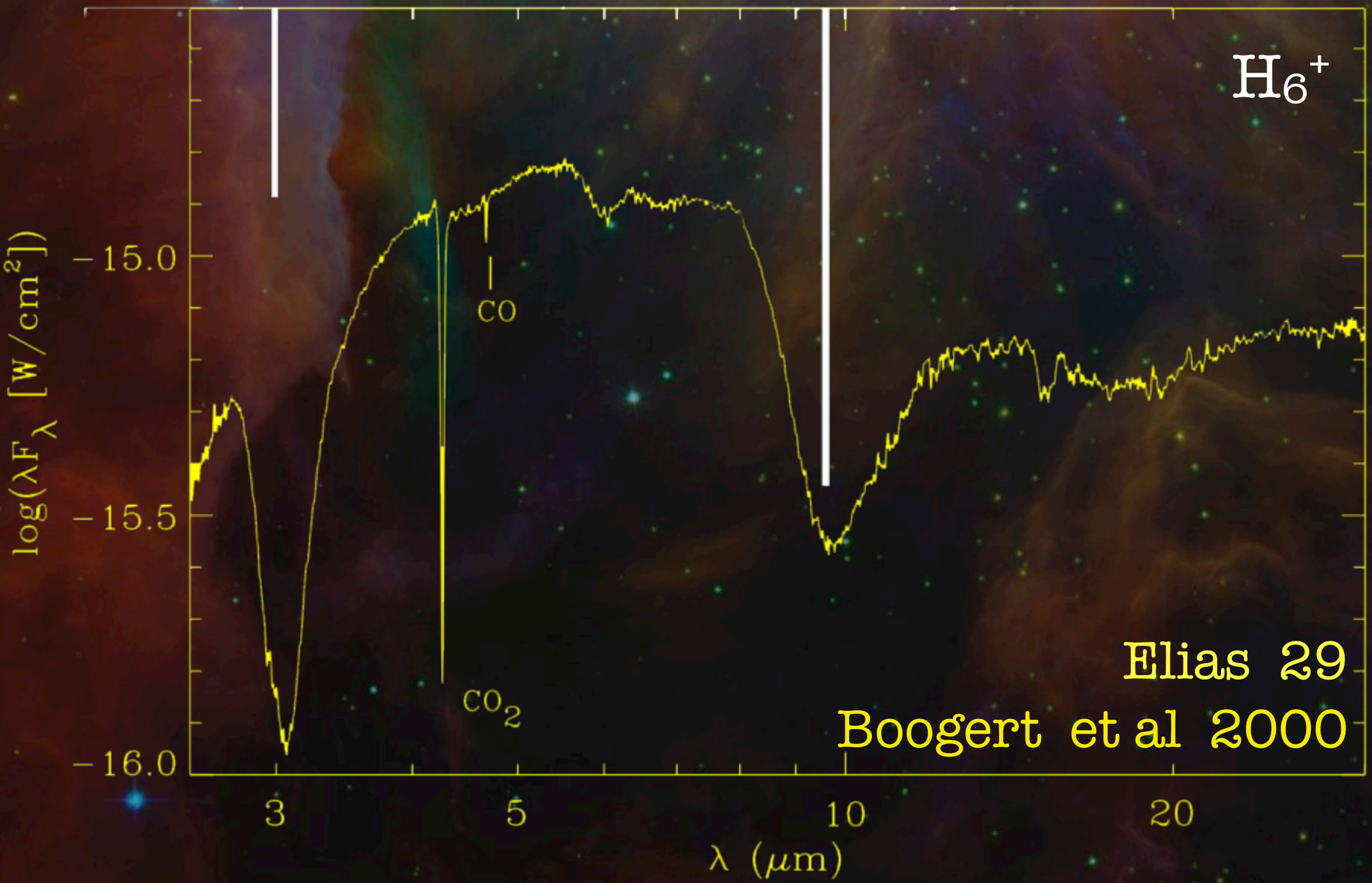
Highly anharmonic :
Include cubic & quartic
Use VCI method

Can only model 5 modes

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

Leaf Lin,
Andrew Gilbert,
& MW

IR Absorption



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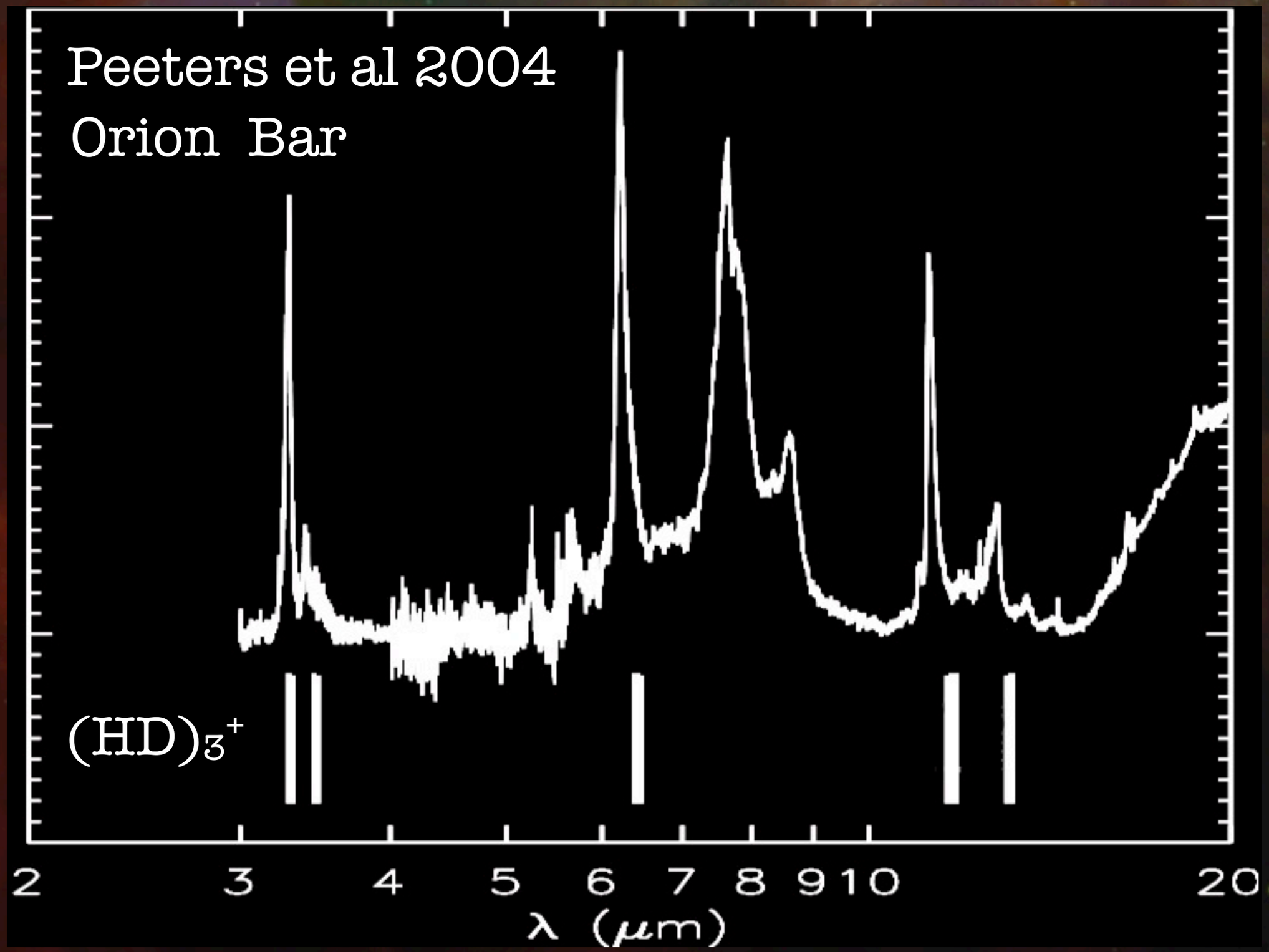
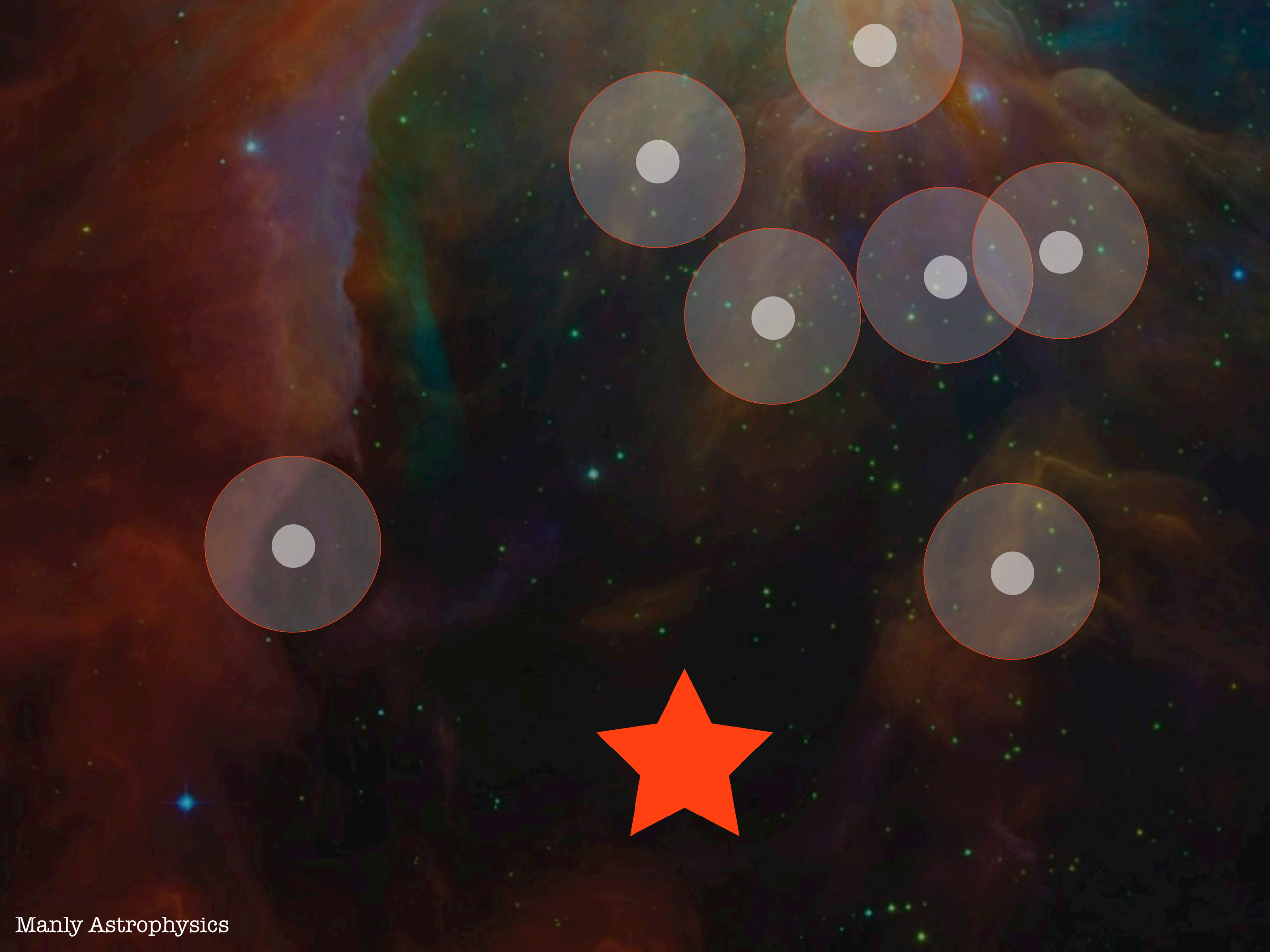
IR Emission



Recipe for making solid H_2

- Need cold, dense gas
  - $P_{sat} \gg P_{ism}$ $\therefore$ self-gravitating clouds
  - Difficult to detect : dark matter
    Pfenniger & Combes 1994
- Preferred model :
  - Spherical clouds, R ~ 1 AU
    Indicated by "Extreme Scattering Events"
  - Average column $\langle \Sigma \rangle \sim 100$ g cm^{-2}
- Just add heat !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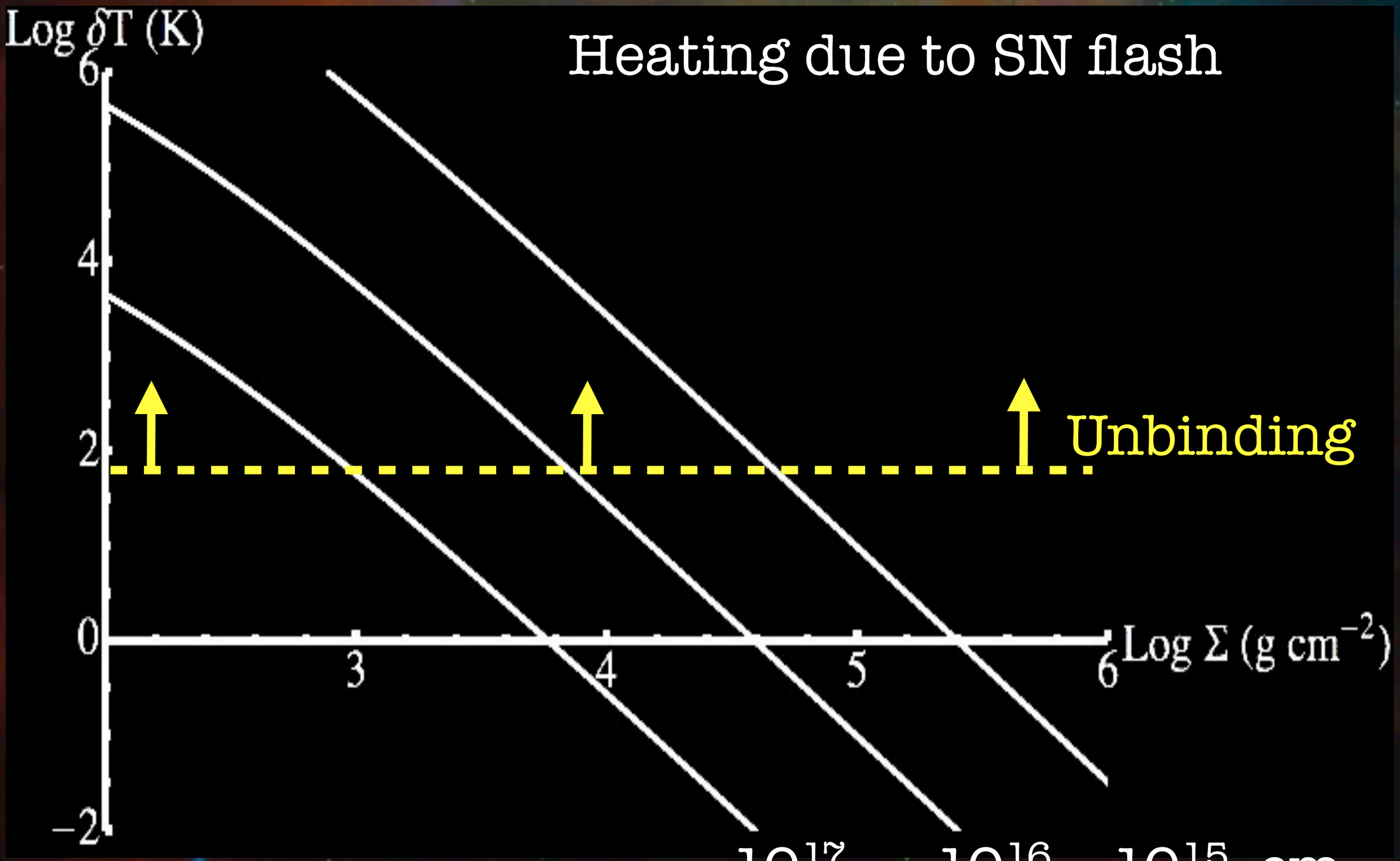
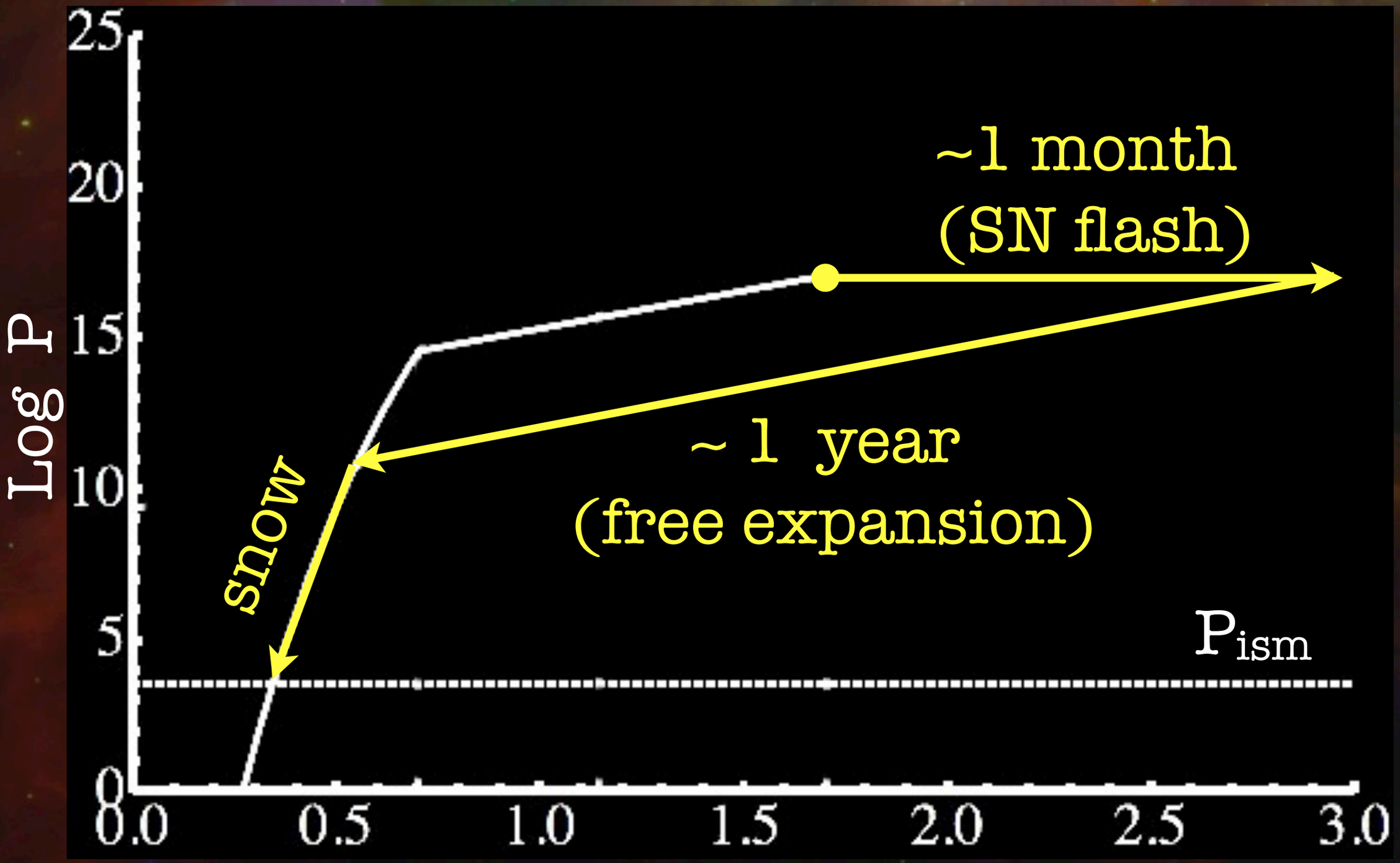
Heating due to SN flash



Response to flash heating



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Helix (planetary) Nebula

Summary

- Solid H_2 might be abundant in the ISM :
  - Charged H_2 grains may be long-lived
  - Mid-IR signatures from H_6^+ and $(HD)_3^+$ show a good match to strong ISM bands
- Cold, self-gravitating clouds make H_2 dust when heated
- Supernovae flash-heat any local clouds
  - Some clouds unbind completely
  - High yields of H_2 dust