Cosmic-ray powered FIR from H_2 snowflakes

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(Manly Astrophysics)

Why consider solid H_2 dust?
1. Origin: cold, dense gas

- Proposed by Pfenniger & Combes (1994)
  - Close to H_2 sublimation curve
    - Would form H_2 “snowflakes”
      - Inject snowflakes into diffuse ISM
- Growing evidence for presence of dark gas
  - Gamma-ray (Greiner + 2005)
  - Microwave (Planck Collaboration 2011)

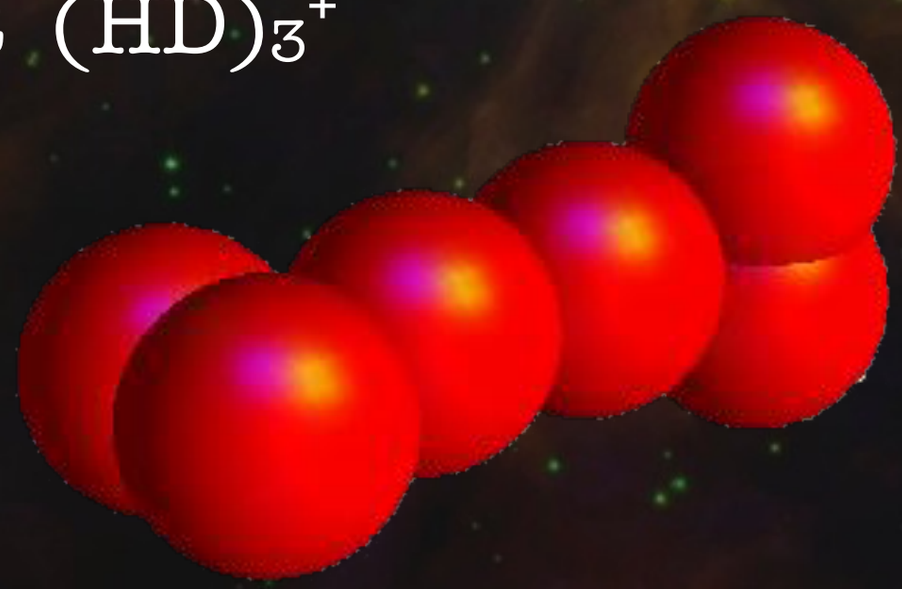
Why consider solid H_2 dust?
2. Survival

- 1968: Wickramasinghe + proposed H_2 dust
- 1969: Rapid sublimation in diffuse ISM conditions (Greenberg & de Jong; Field)
  - Subsequently ignored

- 2013: Charging lowers sublimation rate (MW)
  - Surface electric field → electrostatic binding
    - Strong Field → Large Effect
      - Rate lower by ~ 10^{-85} @ T = 5 K
      - Snowflakes survive in diffuse ISM

Why consider solid H_2 dust?
3. Spectral Features

- Solid H_2 itself almost featureless in optical-IR
  - But impurities contribute
  - Ionisation chemistry differs from gas phase
    - "New" molecule : H_6^+ (Kumada + 2005)
    - And isotopic variant $(HD)_3^+$

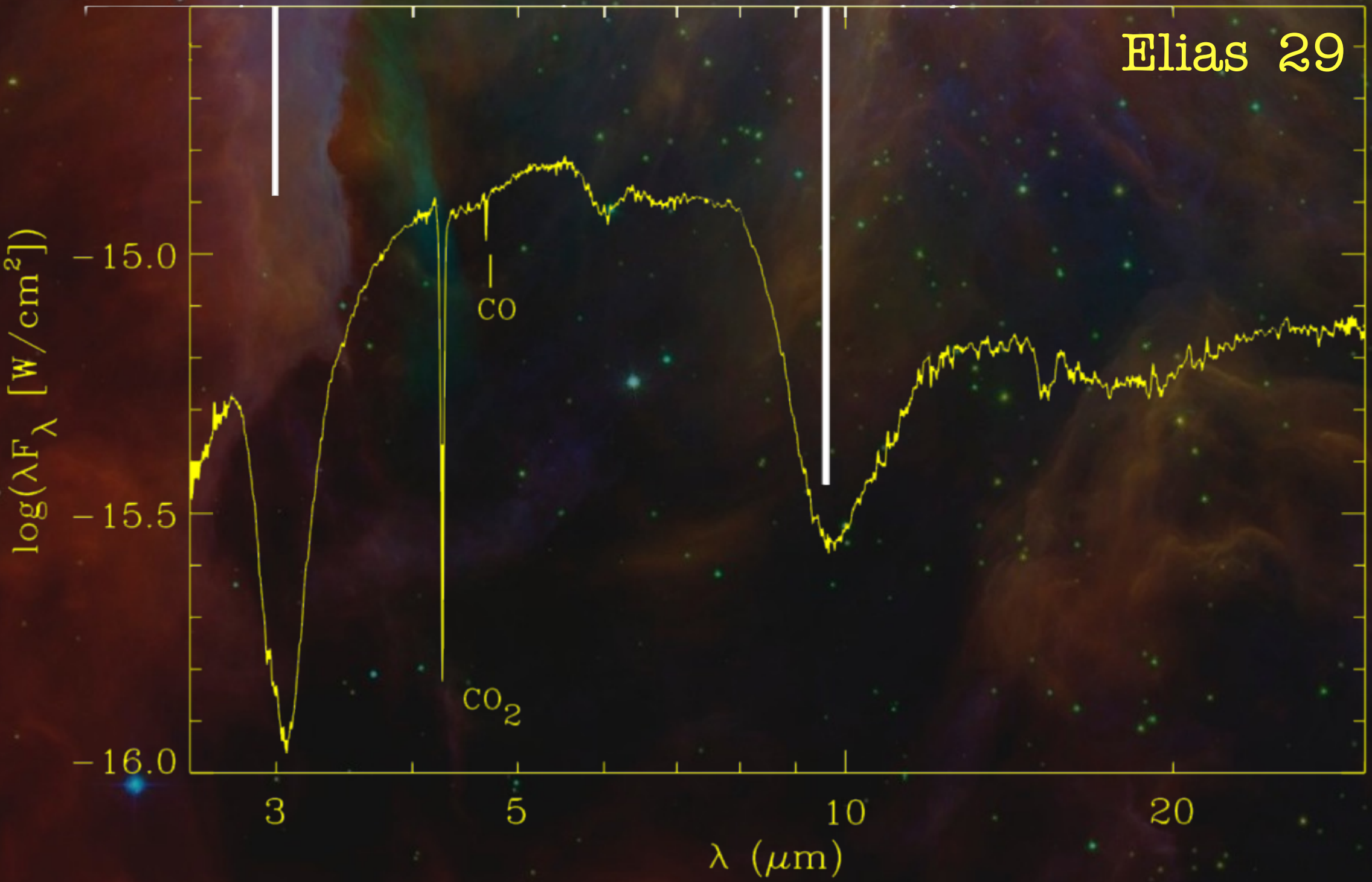


Mid-IR Absorption

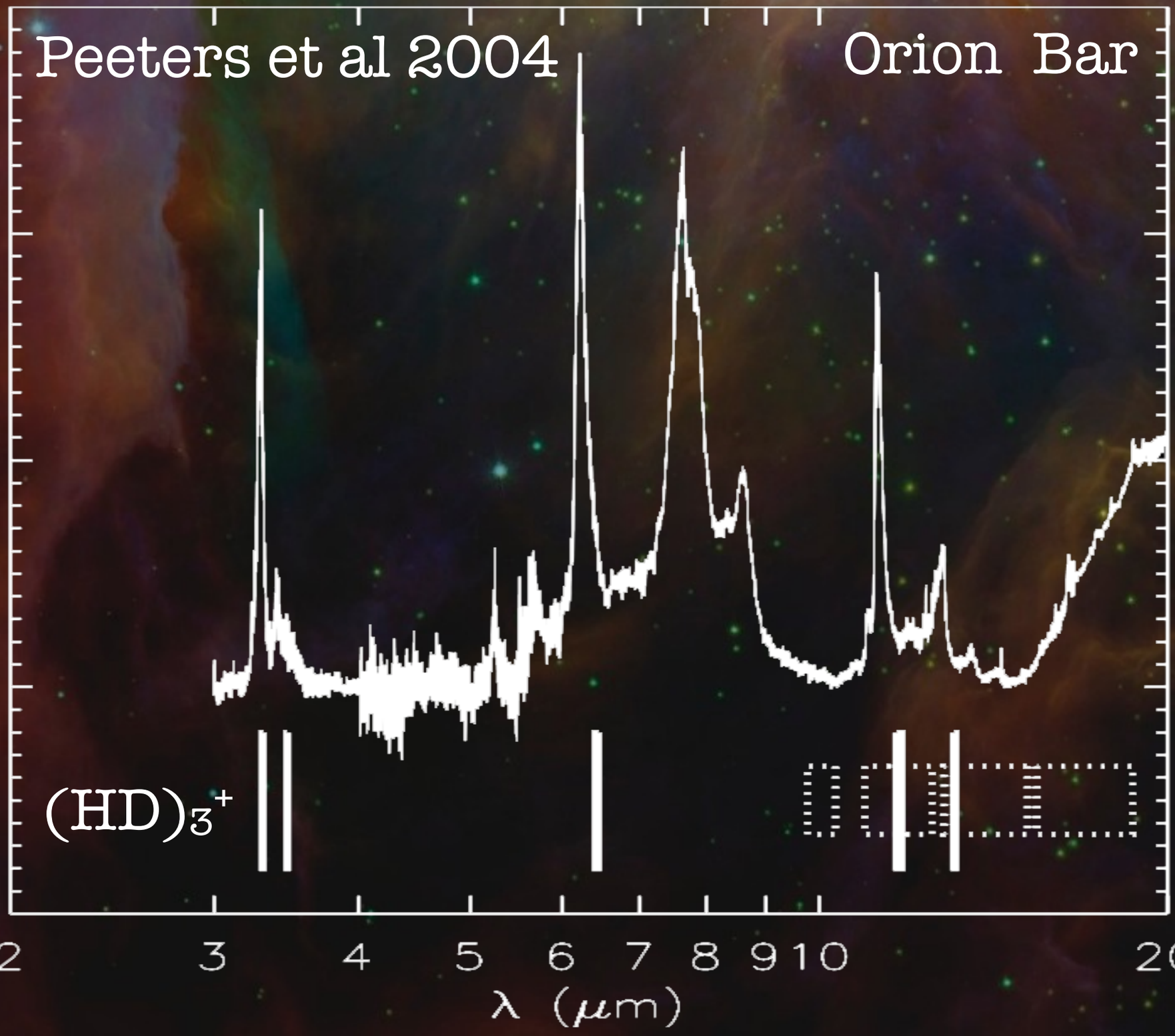
H_6^+ (Lin + 2011)

Boogert et al 2000

Elias 29



Mid-IR Emission



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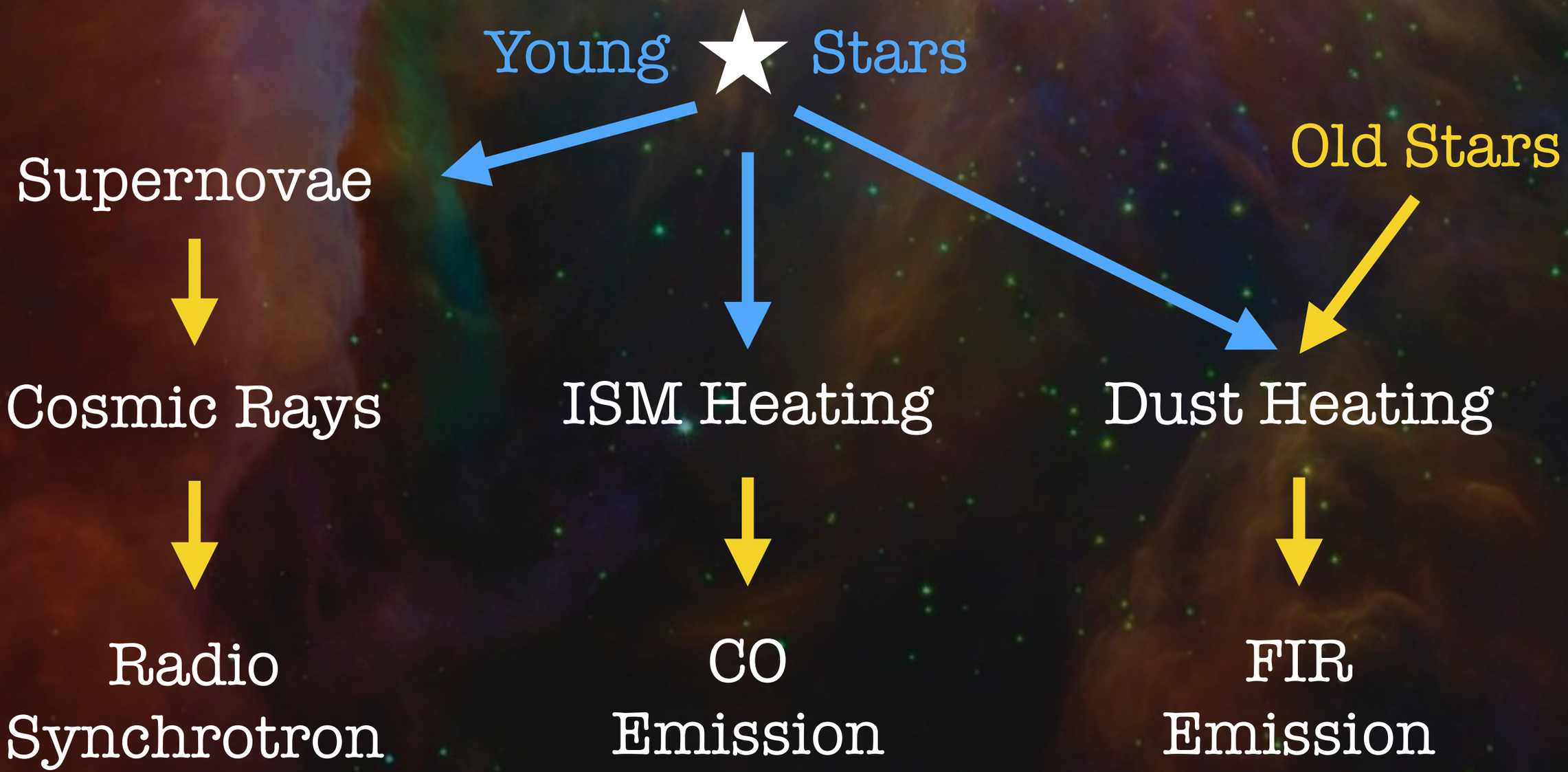
FIR & Radio: current picture



FIR & Radio: desirable picture ?

Young ★ Stars

Supernovae

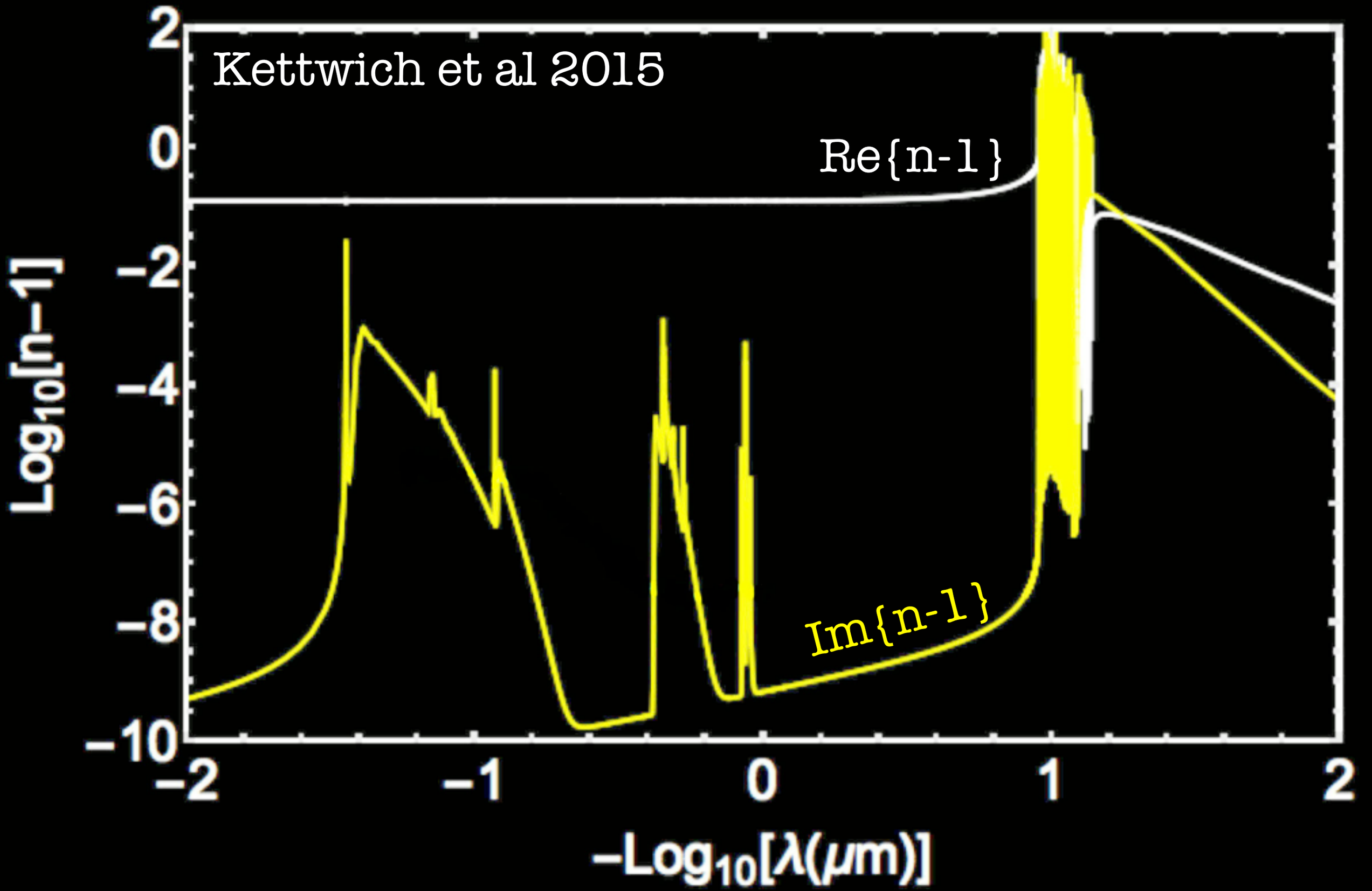
Cosmic Rays → ISM Heating → Dust Heating

Radio Synchrotron

CO Emission

FIR Emission

Optical constants of solid H_2



FIR emission from H_2 snowflakes

- FIR emission primarily from surface-state electrons
  - But not much optical absorption (?)
- Strong heating of surface e^- by thermal ions in ISM
  - Distant Coulomb collisions dominate
  - Enough to explain observed Galactic FIR power
- But what heats the ions?
  - Unsolved problem (heating of WIM)
  - Cosmic-rays a possibility
    - Heating dominated by low energy particles
      - Low-energy spectrum poorly understood

FIR & Radio: snowflake picture

Young ★ Stars

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FIR & Radio: snowflake picture

Problem with Milky Way power budget

Young ★ Stars

Supernovae

Up to ~ 10^{42} erg/s

Cosmic Rays → ISM Heating → Dust Heating

Radio Synchrotron

CO Emission

FIR Emission

Observe ~ 10^{43} erg/s

Summary

- Charged hydrogen snow is an alternative to silicate+graphite dust models:
  - Most abundant element, robust grains, many mid-IR bands coincident with H_6^+
- H_2 snowflakes only scatter starlight
- FIR emission not powered by UV/Optical
- FIR emission from surface-state electrons
  - Heated by thermal ions in ISM
    - Ionised gas heated by cosmic-rays (?)
- Both Radio and FIR driven by cosmic-rays
  - Good correlation likely
- Main problem is energetics: In our Galaxy SNe mechanical power < 10% FIR Power