Diagnostic radiative transfer in Astrophysics with RADMC-3D

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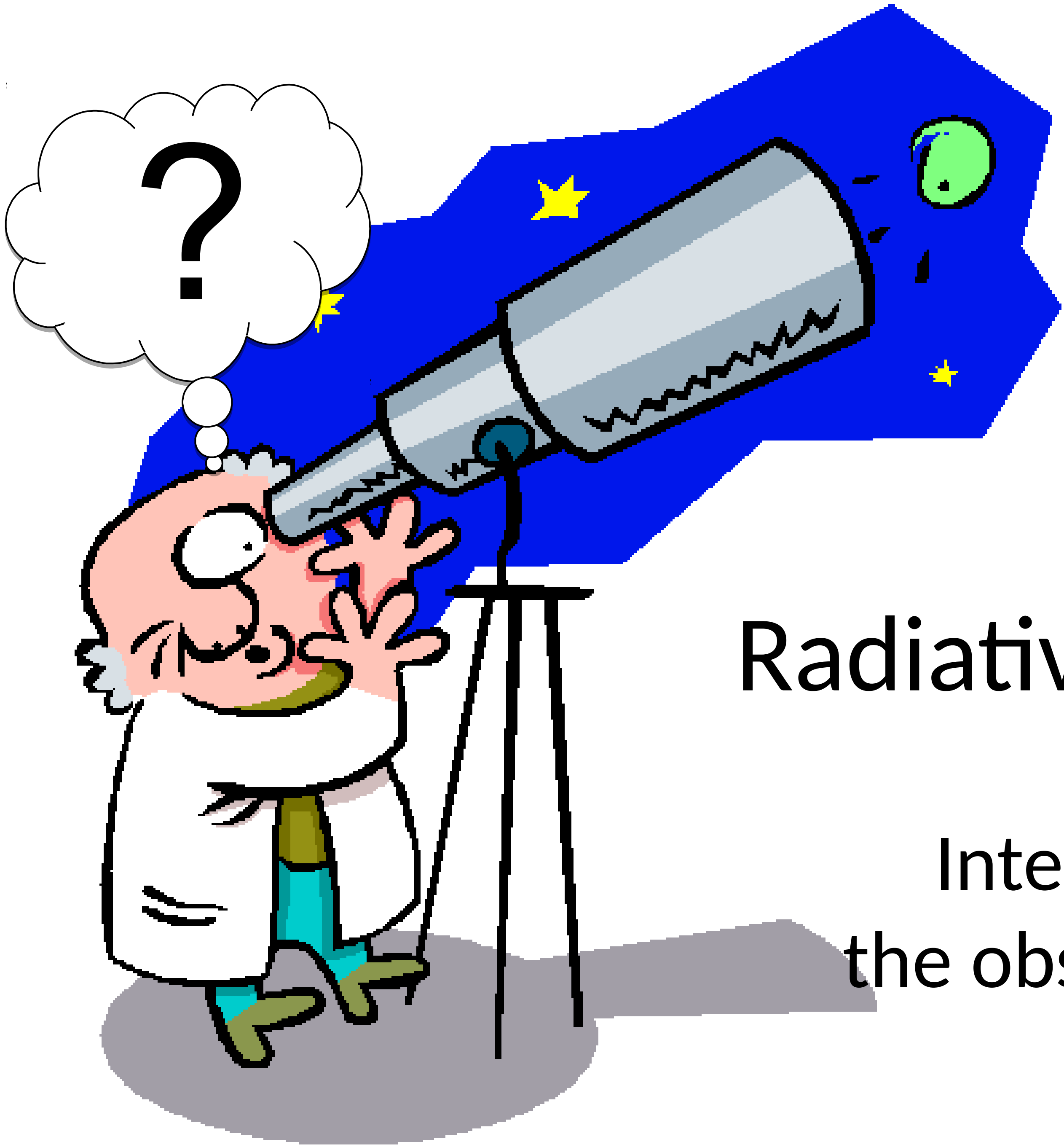


Radiative Transfer:

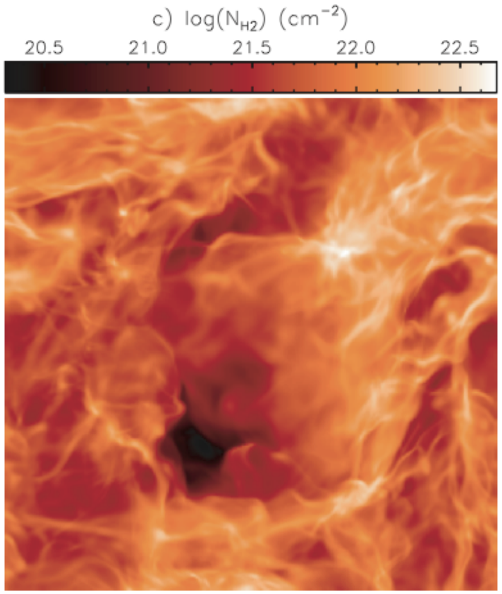
Interpreting
the observed light

Radiative transfer: Diagnostic tool

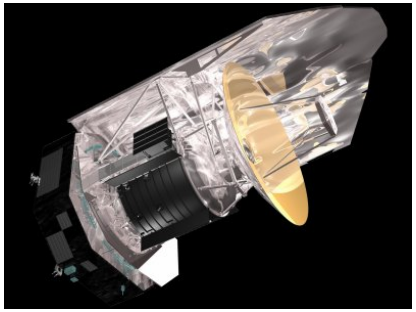
Model

Diagnostic radiative transfer

Observation

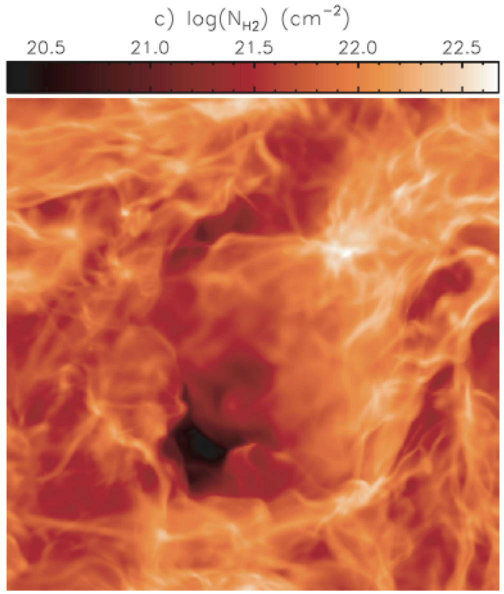


Forward modeling



Radiative transfer: Diagnostic tool

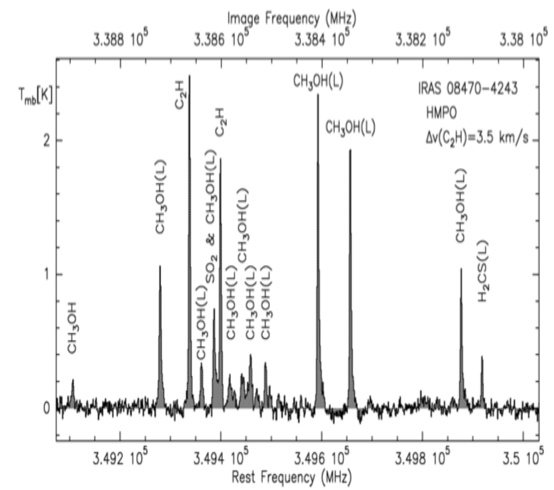
Model



Diagnostic
radiative transfer

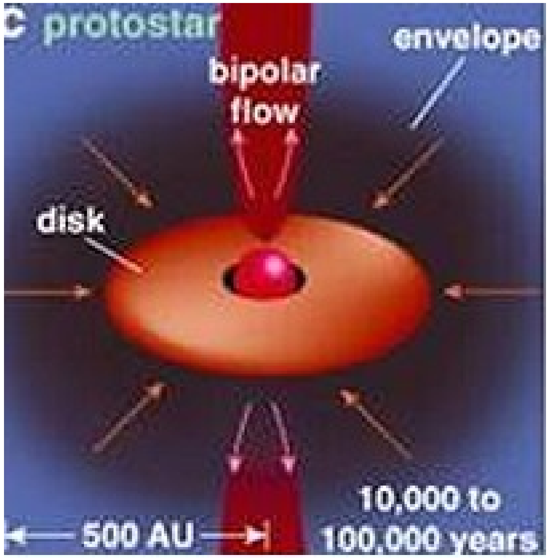
Forward modeling

Observation

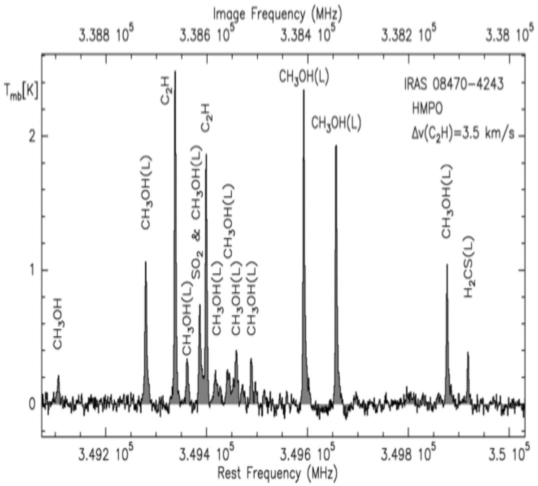


Radiative transfer: Diagnostic tool

Model	Diagnostic radiative transfer	Observation



Forward modeling →

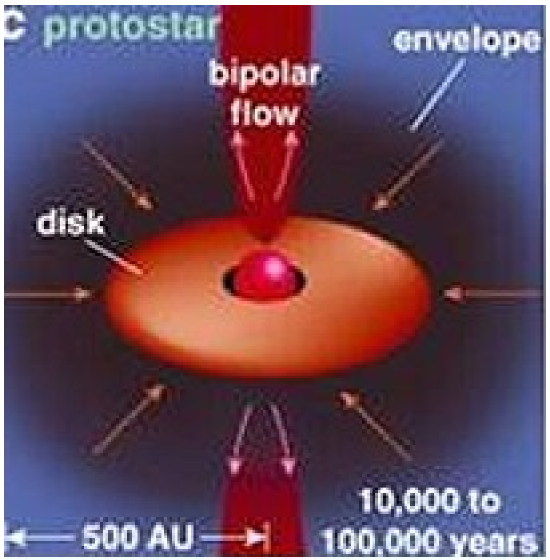


Radiative transfer: Diagnostic tool

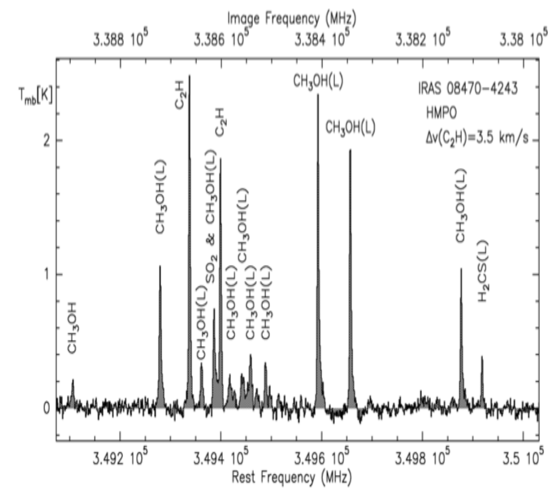
Model

Diagnostic radiative transfer

Observation



Forward modeling



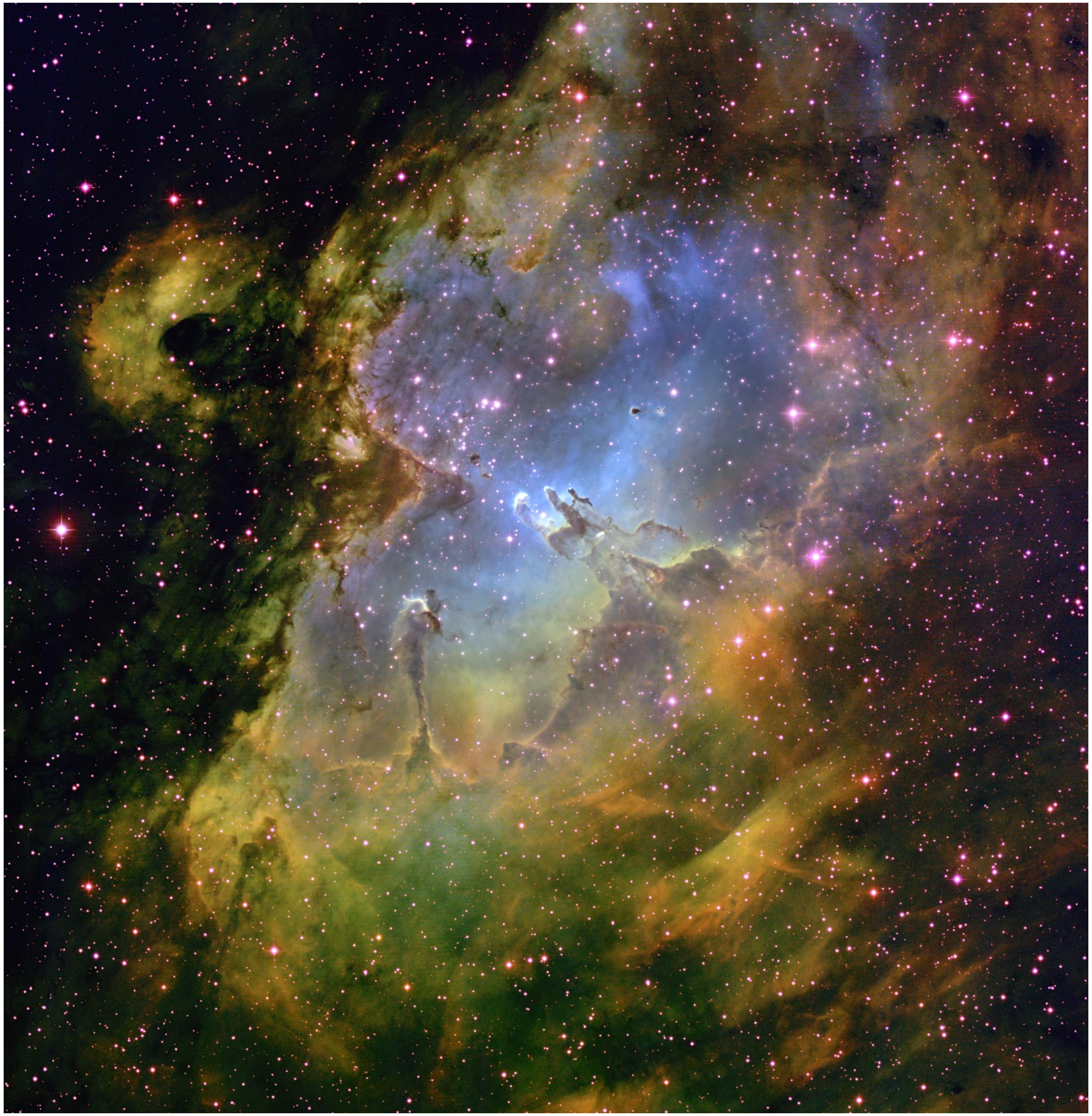
Radiative transfer:
Heating, cooling and energy transport

- Astrophysical objects cool by emitting radiation
- That same radiation is the radiation we observe with our telescopes
- Inside the object: Radiation can transport energy from one place to another
- Often linked to hydrodynamics: „Radiation hydrodynamics“

Radiative transfer: Driving photochemistry

- Energetic photons can:
  - photoionize atoms, molecules
  - photodissociate molecules
  - charge dust grains
- This powers a complex photochemical network

Photon-Dominated Regions (PDR)



Eagle Nebula

Example of object with PDRs where photochemistry and photo-ionization play a major role

In summary:

- Radiative transfer is BOTH about:
  - How radiation affects the object *and*
  - how we can interpret our observations
- In many cases these two are *linked*, so that we cannot interpret our observations without computing how the radiation affects the object.

This Lecture

This lecture:

- Emphasis:
  - …on *diagnostic* radiative transfer

- We will discuss:
  - Physics of dust and line radiative processes
  - Equations of radiative transfer
  - Monte Carlo method for dust continuum RT
  - LTE and non-LTE line transfer
  - Hands-on experimentation with RADMC-3D

This lecture:

- Radiative processes:
  - Dust continuum:
    - Dust thermal emission, local radiative equilibrium
    - Scattering off dust particles, polarization
    - Dust opacities, Mie theory, DDA theory
    - Quantum-heated grains, Polycyclic Aromatic Hydrocarbons (PAHs)
  - Gas lines:
    - Atomic lines, recomb. lines, forbidden lines, incl. examples (H, O, O^{2+}, Ne^{+}, ...)
    - Molecular lines: rotational, rovibrational, incl. examples (H_2, CO, NH_3, H_2O, ...)

This lecture:

- Radiative processes (cont.):
  - Gas continuum:
    - Bound-free
    - Two-photon
  - Photoionization
  - Photodissociation of molecules
  - Thompson & Compton scattering

This lecture:

- Applications in Astrophysics:
  - Interstellar medium, molecular clouds, star formation
  - Protoplanetary disks
  - Stellar atmospheres
  - Planetary atmospheres
  - Hot gas around compact objects

- Visualization of 3-D model data

Literature:

- A standard book on radiative processes in astrophysics is: Rybicki & Lightman "Radiative Processes in Astrophysics" Wiley-Interscience
- For radiative transfer in particular there are some excellent lecture notes on-line by Rob Rutten "Radiative transfer in stellar atmospheres" http://www.staff.science.uu.nl/~rutte101/
- For stellar atmospheres: pleasantly written book by Böhm-Vitense „Stellar Astrophysics Vol. 2: Stellar atmospheres"

Literature:

- In-depth reference work by Mihalas „Stellar atmospheres“
- Allround bible on radiation hydrodynamics by Mihalas & Mihalas „Radiation Hydrodynamics“
- Book on Exoplanetary atmospheres by Seager „Exoplanet Atmospheres“
- Book on radiative transfer in Earth‘s atmosphere (application to e.g. climate research): Wendisch & Yang „Theory of Atmospheric Radiative Transfer“

Literature:

- My own set of lecture notes:
  http://www.ita.uni-heidelberg.de/~dullemond/teaching.shtml