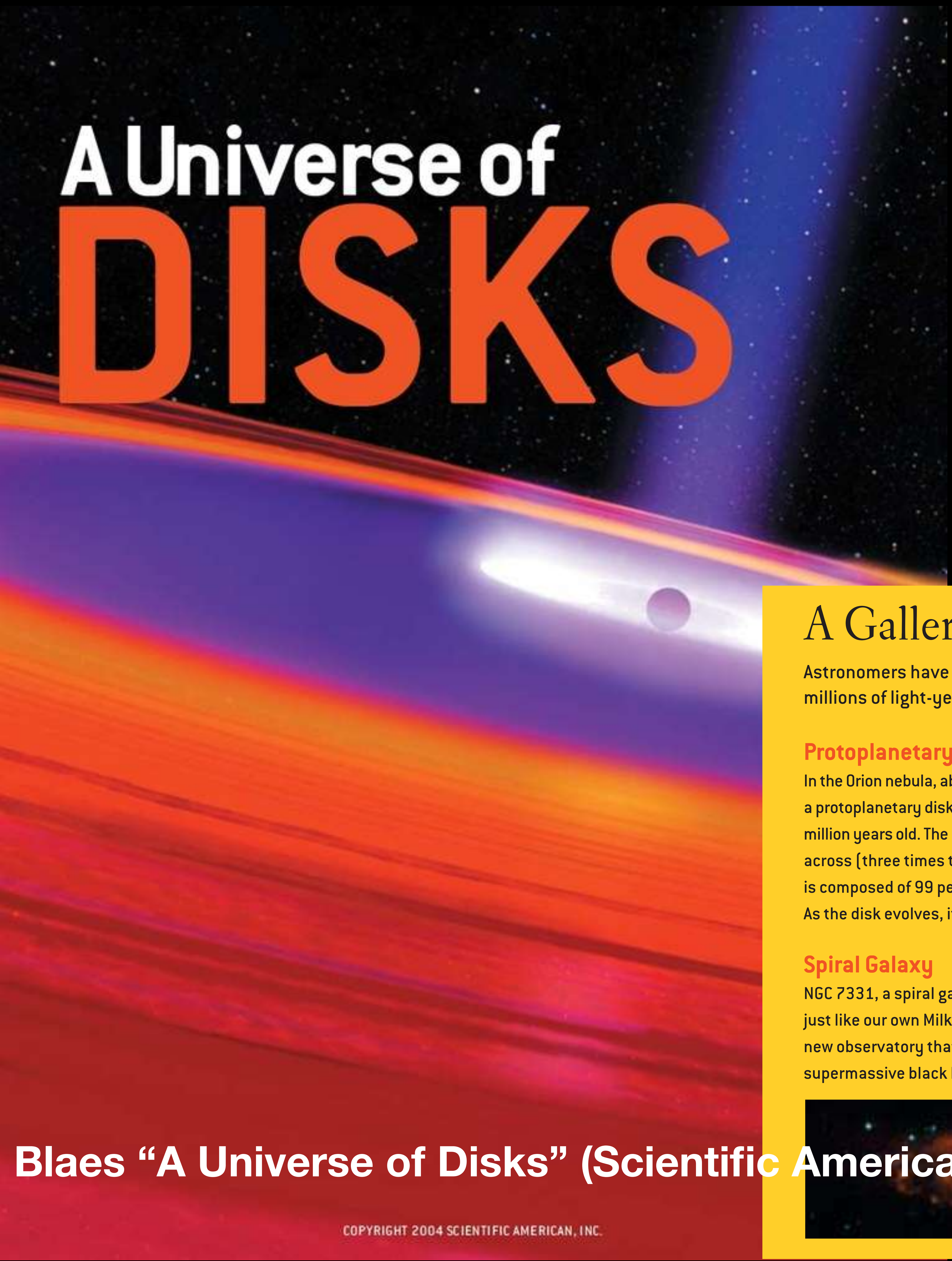
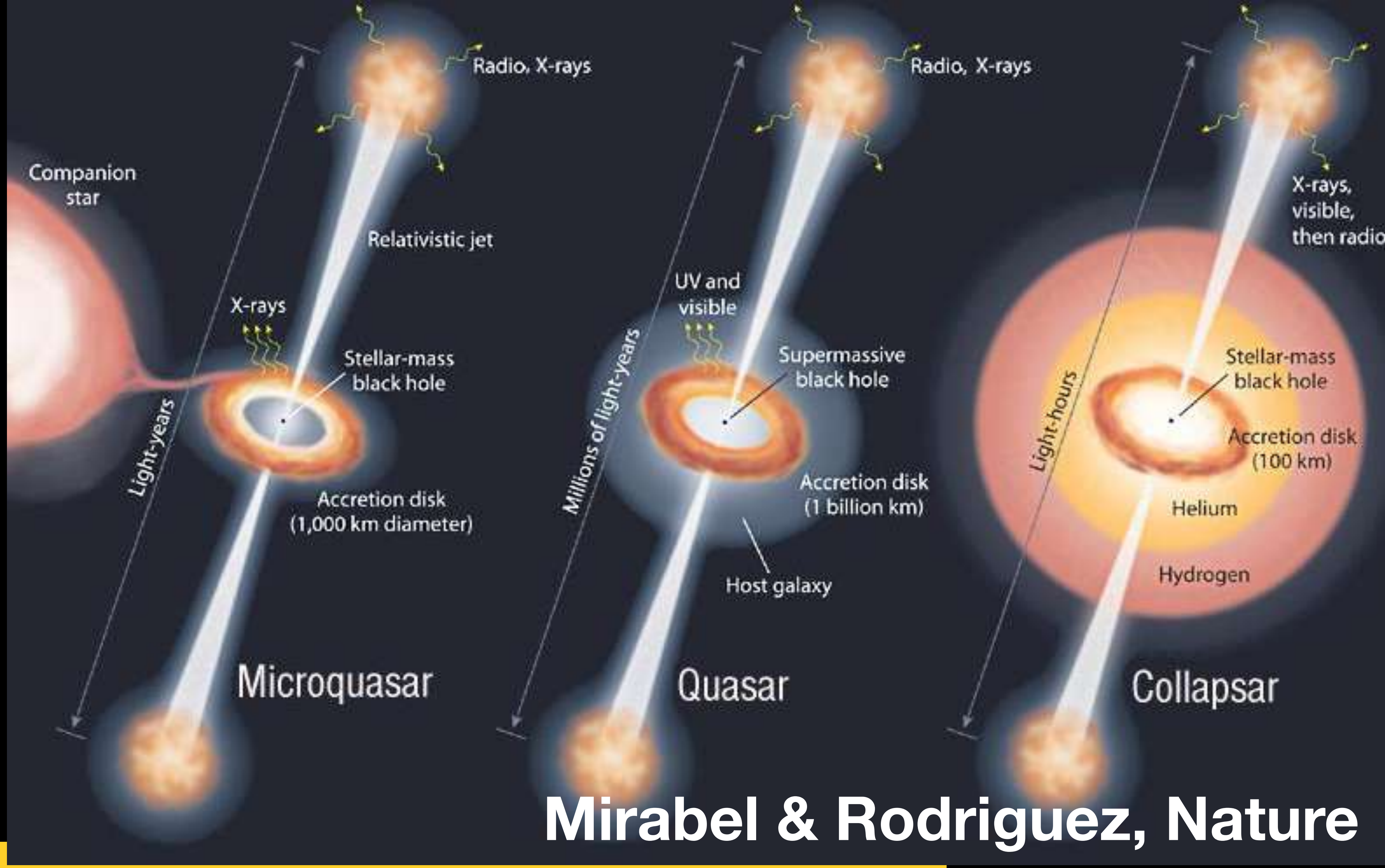
Estructura de Discos Protoplanetarios 2

a.k.a black holes and planets



Blaes “A Universe of Disks” (Scientific American)



Mirabel & Rodriguez, Nature

A Gallery of Disks and Jets

Astronomers have observed disks across the universe—around young stars in nebulas in our own galaxy and at the centers of galaxies millions of light-years away. Many of the disks emit long jets of particles in a process that is still not well understood.

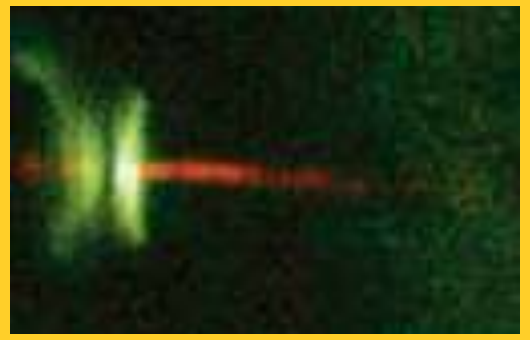
Protoplanetary Disk

In the Orion nebula, about 1,500 light-years from Earth, a protoplanetary disk surrounds a star that is only one million years old. The disk is about 40 billion kilometers across (three times the size of our solar system) and is composed of 99 percent gas and 1 percent dust. As the disk evolves, it may form a planetary system like our own.

Spiral Galaxy

NGC 7331, a spiral galaxy about 50 million light-years from Earth, is a disk just like our own Milky Way galaxy. Data from the Spitzer Space Telescope, a new observatory that looks at infrared radiation, indicate the presence of a supermassive black hole in the galaxy's core.

Jet from a Nascent Star



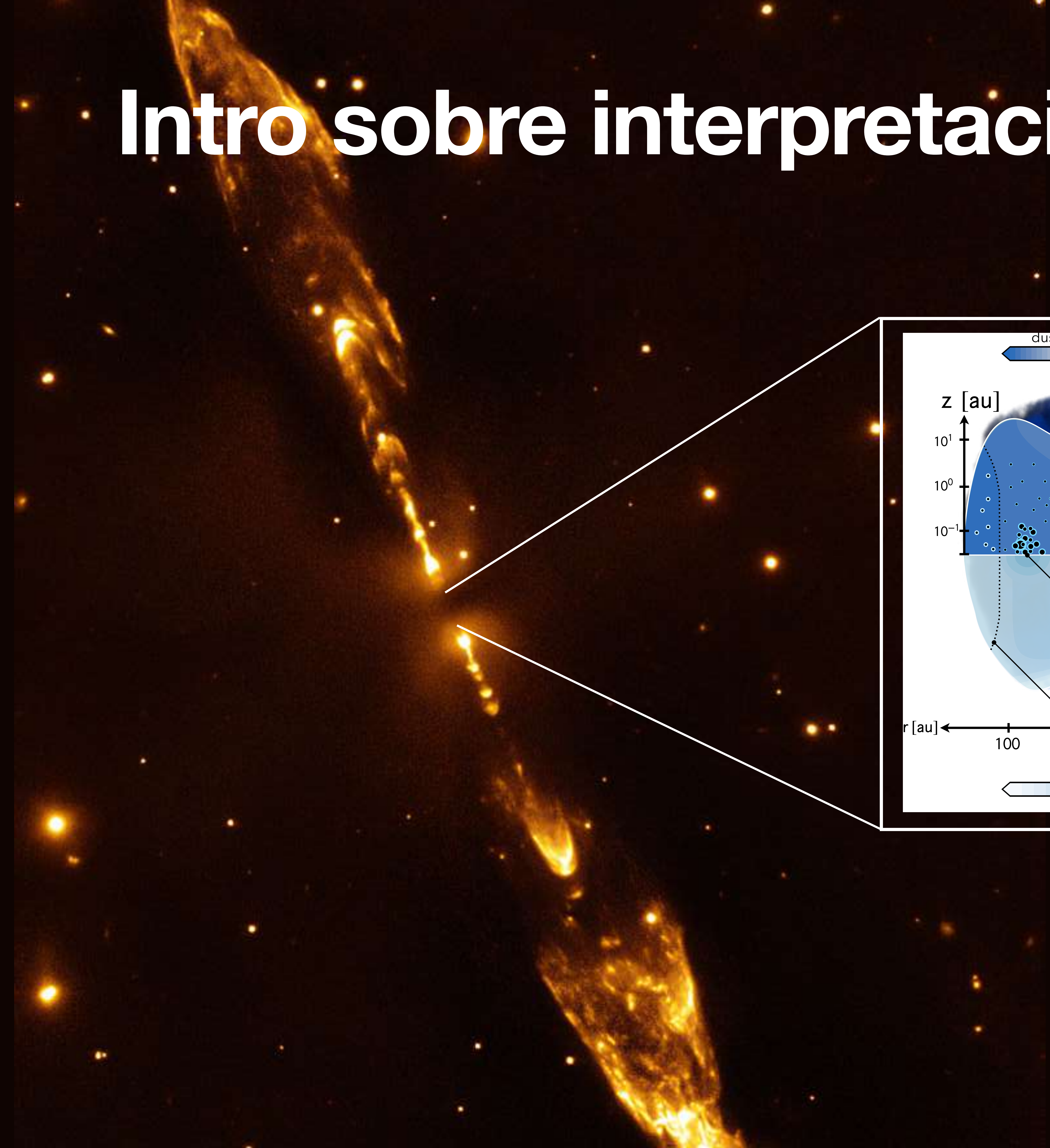
HH-30, a newborn star about 450 light-years from Earth, is embedded in a protoplanetary disk (*viewed edge-on at left*). Two jets of gas stream in opposite directions from the center of the disk, moving as fast as 960,000 kilometers per hour. The star's magnetic field may be channeling the gas.

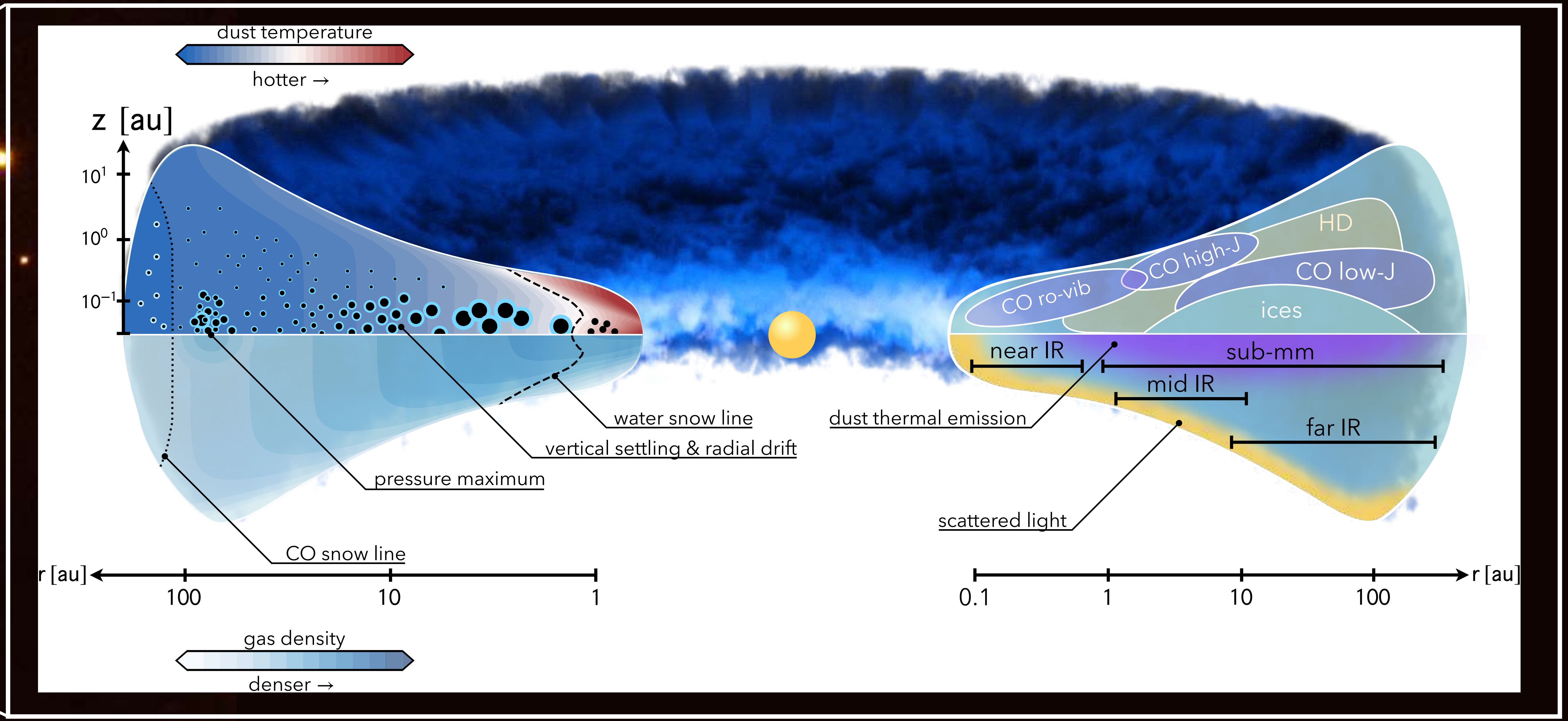
Jet from an Active Galaxy

The active nucleus of M87, a giant elliptical galaxy about 50 million light-years from Earth, is emitting a jet of high-speed electrons that stretches 6,500 light-years from the galaxy's core. An accretion disk spinning around a supermassive black hole is putting most of its power into the jet.

¿Cuáles son las diferencias entre los discos de acreció en torno a agujeros negros estelares, supermasivos, y protoestrellas?

Intro sobre interpretación de observaciones

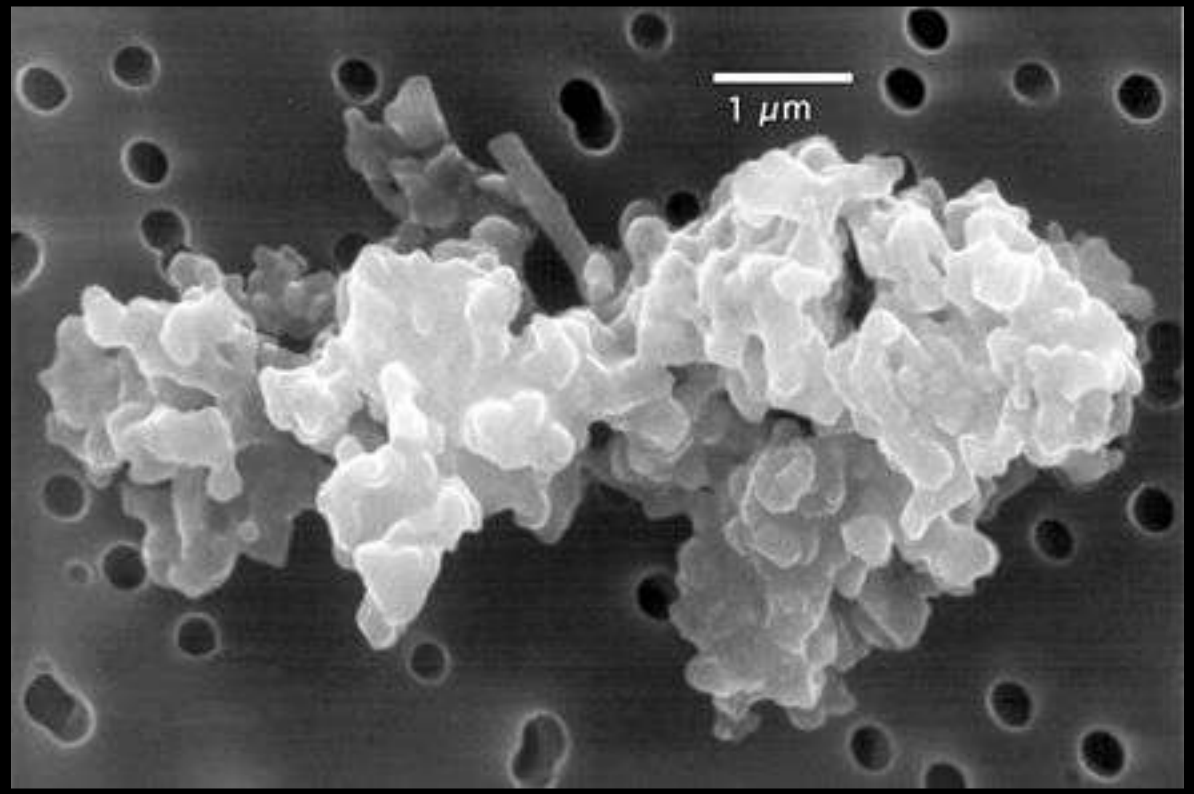


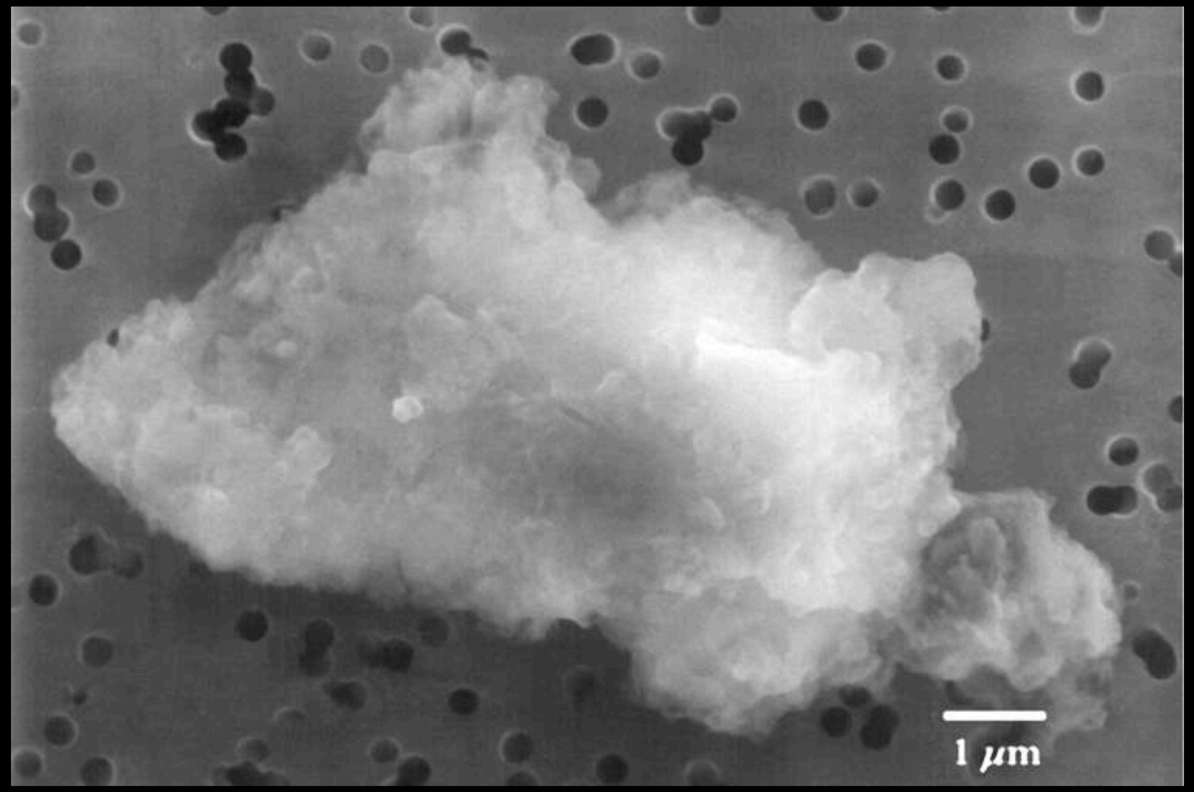



dust temperature
hotter →
z [au]
10^1
10^0
10^{-1}
water snow line
vertical settling & radial drift
pressure maximum
CO snow line
r [au]
100
10
1
gas density
denser →
HD
CO high-J
CO low-J
CO ro-vib
ices
near IR
sub-mm
mid IR
far IR
dust thermal emission
scattered light
0.1
1
10
100
r [au]

Continuo de polvo

- Los discos protoplanetarios tienen temperaturas de 100 a 1500K más o menos. Eso significa que son lugares ideales para encontrar “polvo”. Qué significa esto?
- A partir de observaciones en longitudes de onda opticamente delgadas podemos determinar las propiedades del polvo. Qué significa esto?





Necesitamos transferencia radiativa

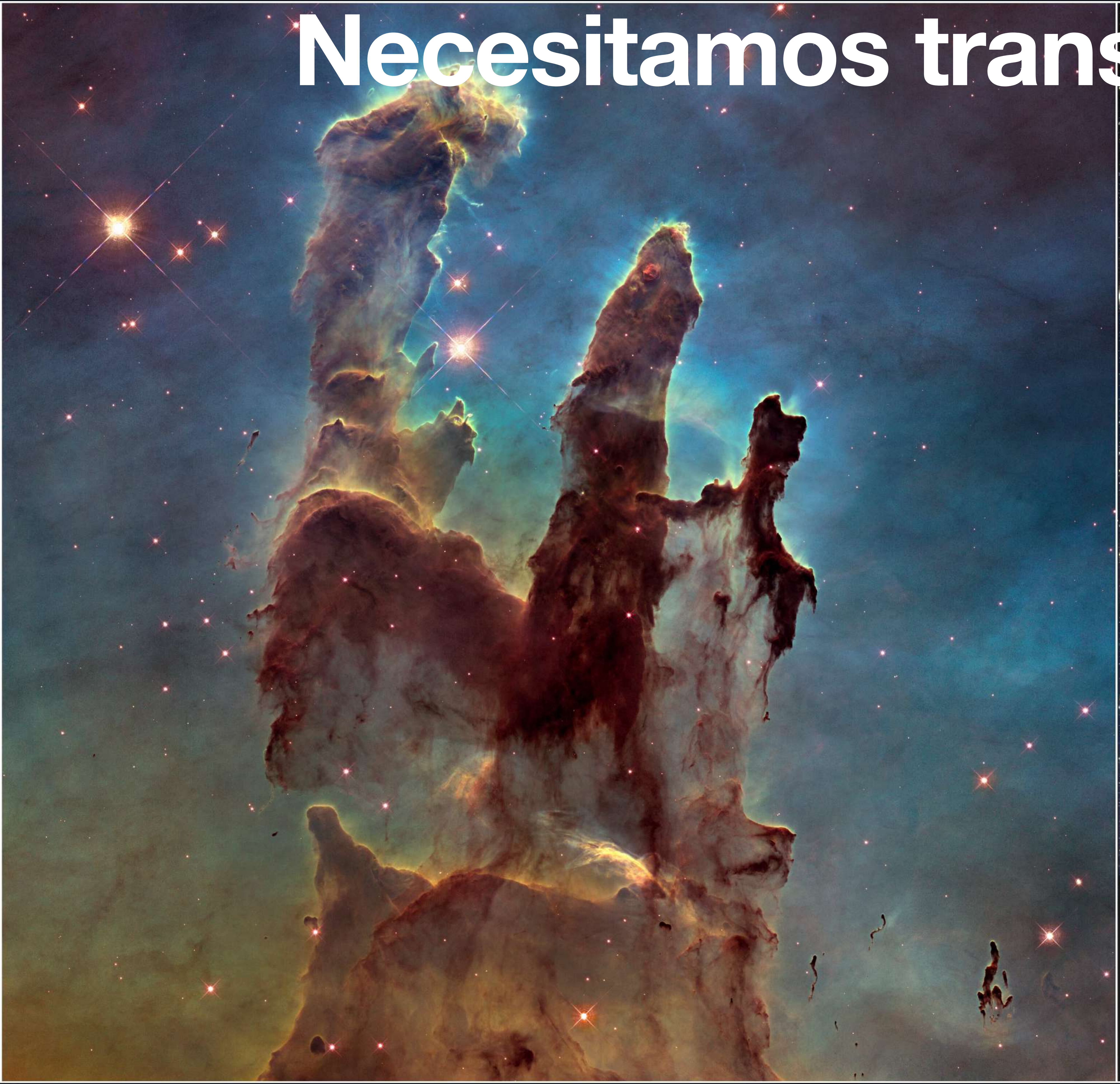


Image Credit: NASA, ESA, CSA, STScI

What is radiative transfer?

A discipline? A process? A theory? A phenomenon? A tool?

- Radiative transfer is essentially a theory, allows you to study how radiation travels and interacts with a medium.

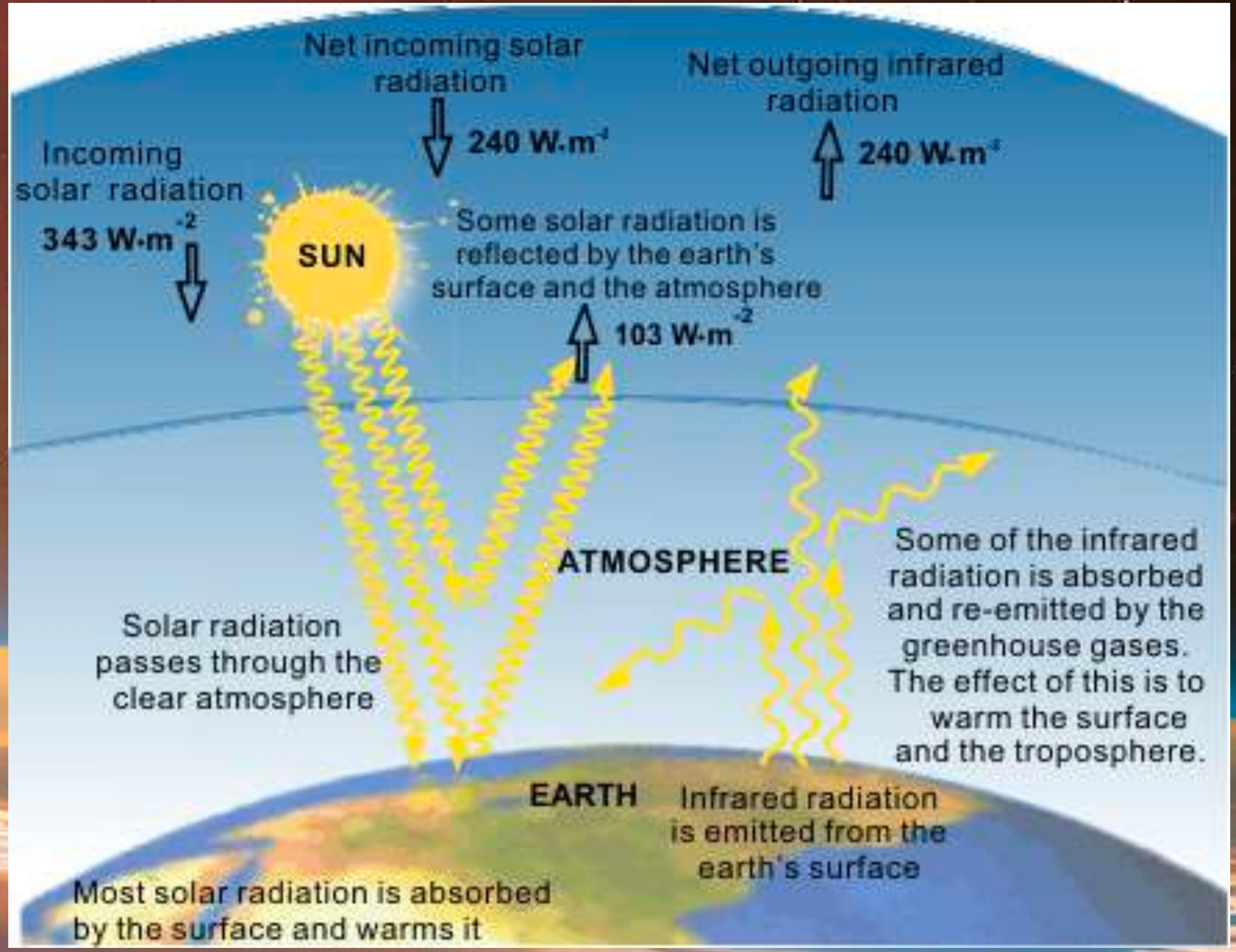
- It's a **macroscopic description** of the interaction between light and matter. Pre-dates quantum mechanics.

- Complex interplay between absorption, emission and scattering of photons.

Solar Radiation and Earth's Atmosphere

Climate Science

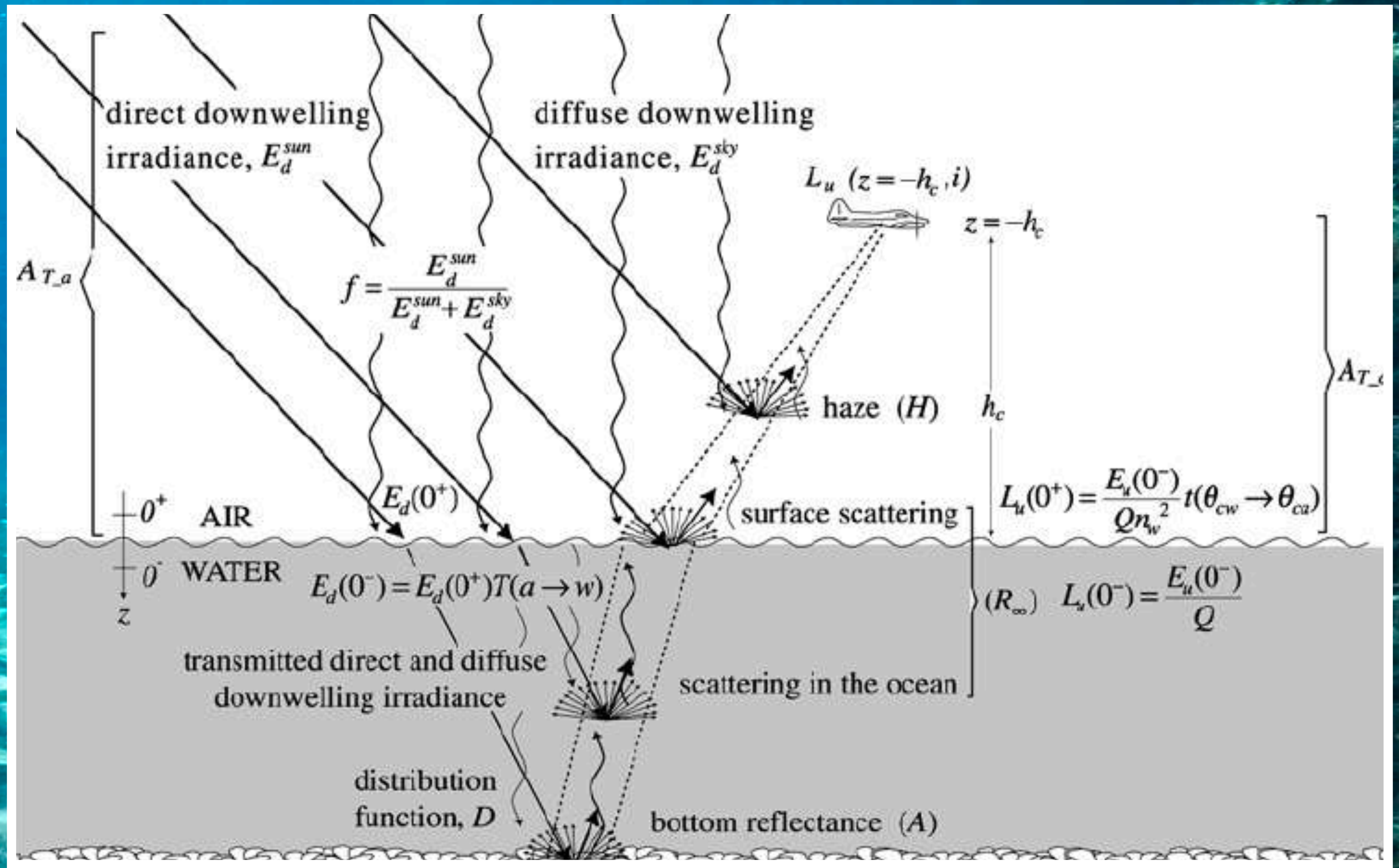
- Radiative transfer is fundamental in understanding how solar radiation is absorbed and re-emitted by the Earth's surface and atmosphere, crucial in climate models and studies of global warming and the climate crisis.



Light absorption and scattering in ocean waters.

Oceanography

- Radiative transfer is used to study how light penetrates ocean layers, which is important for understanding oceanic heat content, plant life distribution, and underwater visibility.



“Atmospheric perspective” in paintings

Art

- Atmospheric perspective, a concept often used in art, is the effect where objects at a distance appear less distinct and usually “colder” than objects close by. This phenomenon is a direct consequence of the radiative transfer of light as it travels through the Earth's atmosphere.

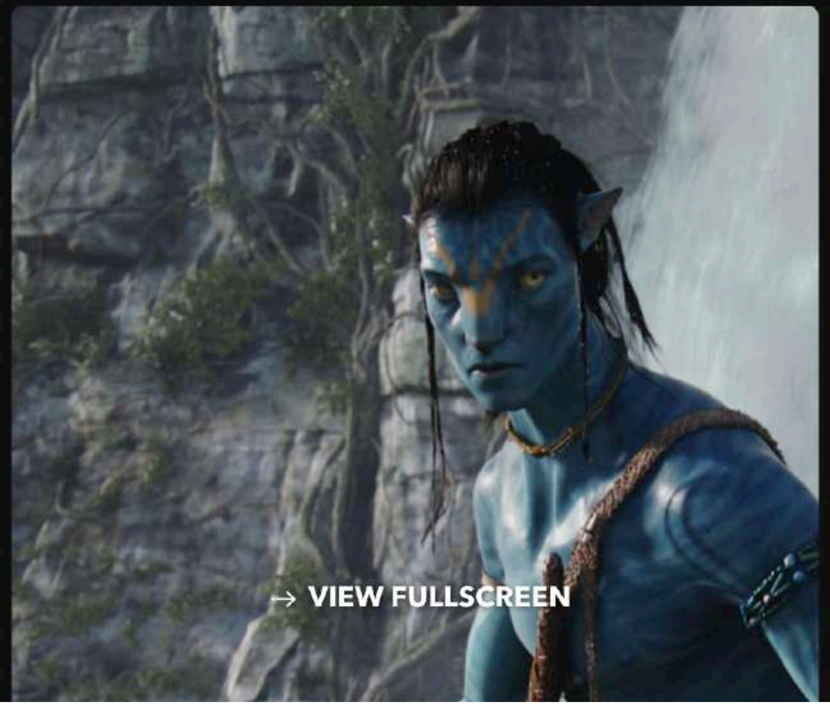
Special FX in movies

Tech & Innovation

PHYSICALLY-BASED SHADING

SHADING IS THE PROCESS OF CALCULATING HOW LIGHT INTERACTS WITH SURFACES: WHAT THE OBJECT ACTUALLY LOOKS LIKE WHEN LIGHT SHINES ON (OR THROUGH) IT.

This is incredibly complex, especially for things like hair or skin – where the light is partially shining through the surface. Weta's approach to shading is to look to real-world physics. The shading models for different surfaces are based on the actual physical properties of those surfaces. Our in-house renderers, Manuka and Gazebo, use real-world physics to calculate how light interacts with each surface – down to the level of calculating wavelengths of light separately.

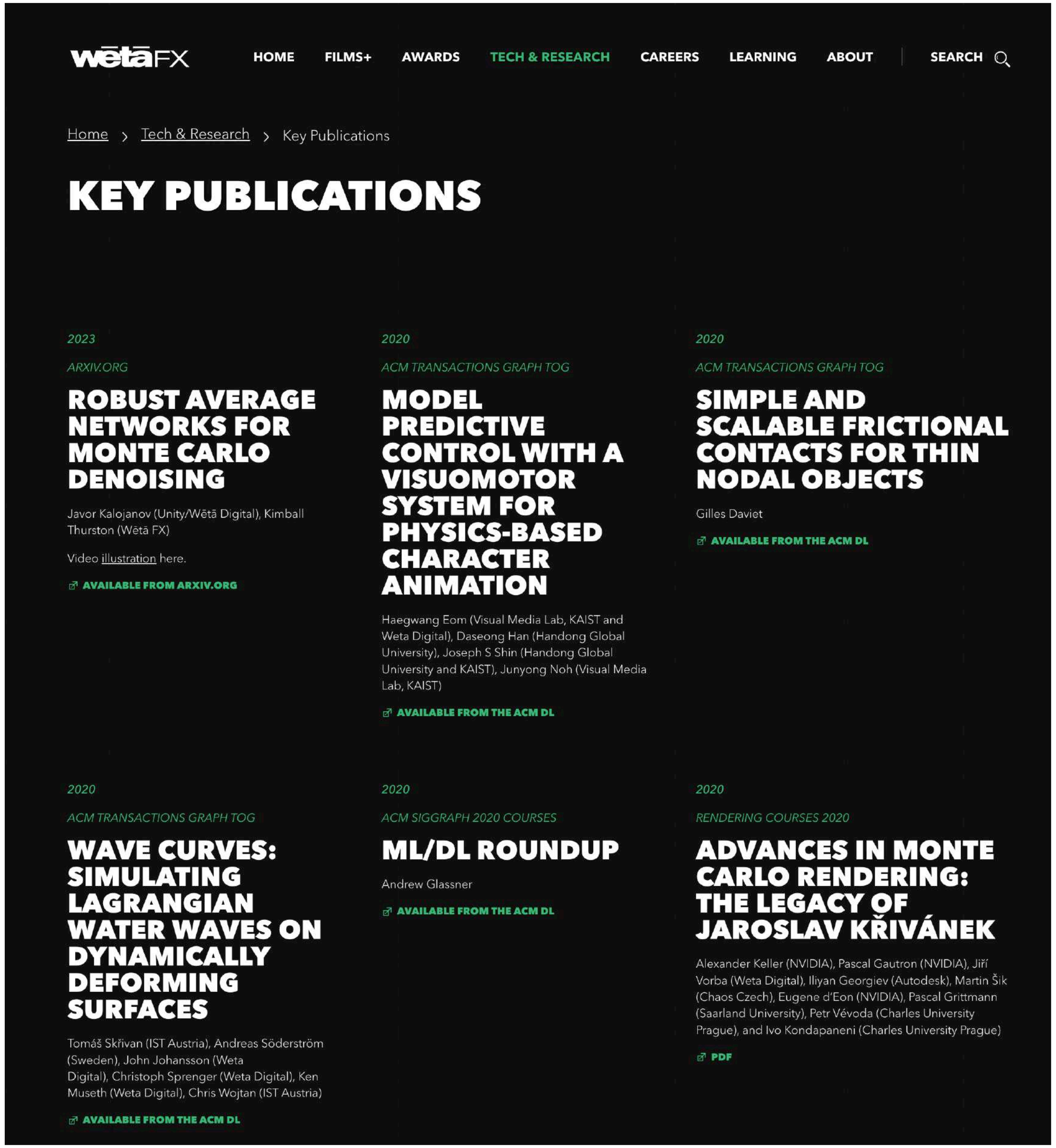


Special FX in movies

Tech & Innovation

PHYSICALLY-BASED SHADING

SHARE



KEY PUBLICATIONS

2023

ARXIV.ORG

ROBUST AVERAGE NETWORKS FOR MONTE CARLO DENOISING

Javor Kalojanov (Unity/Wētā Digital), Kimball Thurston (Wētā FX)

Video illustration here.

AVAILABLE FROM ARXIV.ORG

2020

ACM TRANSACTIONS GRAPH TOG

MODEL PREDICTIVE CONTROL WITH A VISUOMOTOR SYSTEM FOR PHYSICS-BASED CHARACTER ANIMATION

Haegwang Eom (Visual Media Lab, KAIST and Weta Digital), Daseong Han (Handong Global University), Joseph S Shin (Handong Global University and KAIST), Junyong Noh (Visual Media Lab, KAIST)

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2020

ACM TRANSACTIONS GRAPH TOG

SIMPLE AND SCALABLE FRICTIONAL CONTACTS FOR THIN NODAL OBJECTS

Gilles Daviet

AVAILABLE FROM THE ACM DL

2020

ACM TRANSACTIONS GRAPH TOG

WAVE CURVES: SIMULATING LAGRANGIAN WATER WAVES ON DYNAMICALLY DEFORMING SURFACES

Tomáš Skřivan (IST Austria), Andreas Söderström (Sweden), John Johansson (Weta Digital), Christoph Sprenger (Weta Digital), Ken Museth (Weta Digital), Chris Wojtan (IST Austria)

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2020

ACM SIGGRAPH 2020 COURSES

ML/DL ROUNDUP

Andrew Glassner

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2020

RENDERING COURSES 2020

ADVANCES IN MONTE CARLO RENDERING: THE LEGACY OF JAROSLAV KŘIVÁNEK

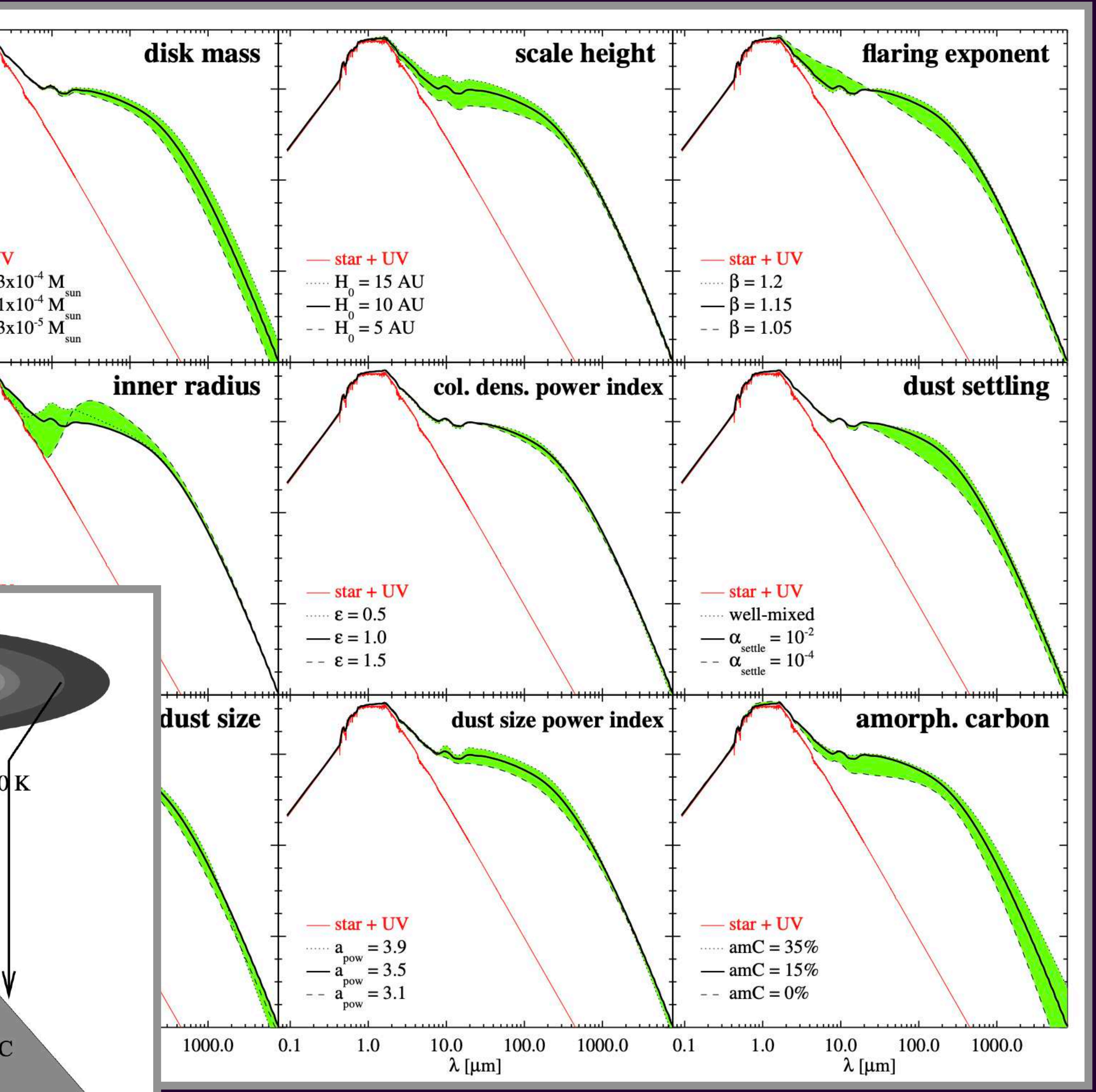
Alexander Keller (NVIDIA), Pascal Gautron (NVIDIA), Jiří Vorba (Weta Digital), Iliyan Georgiev (Autodesk), Martin Šik (Chaos Czech), Eugene d'Eon (NVIDIA), Pascal Grittmann (Saarland University), Petr Vévoda (Charles University Prague), and Ivo Kondapaneni (Charles University Prague)

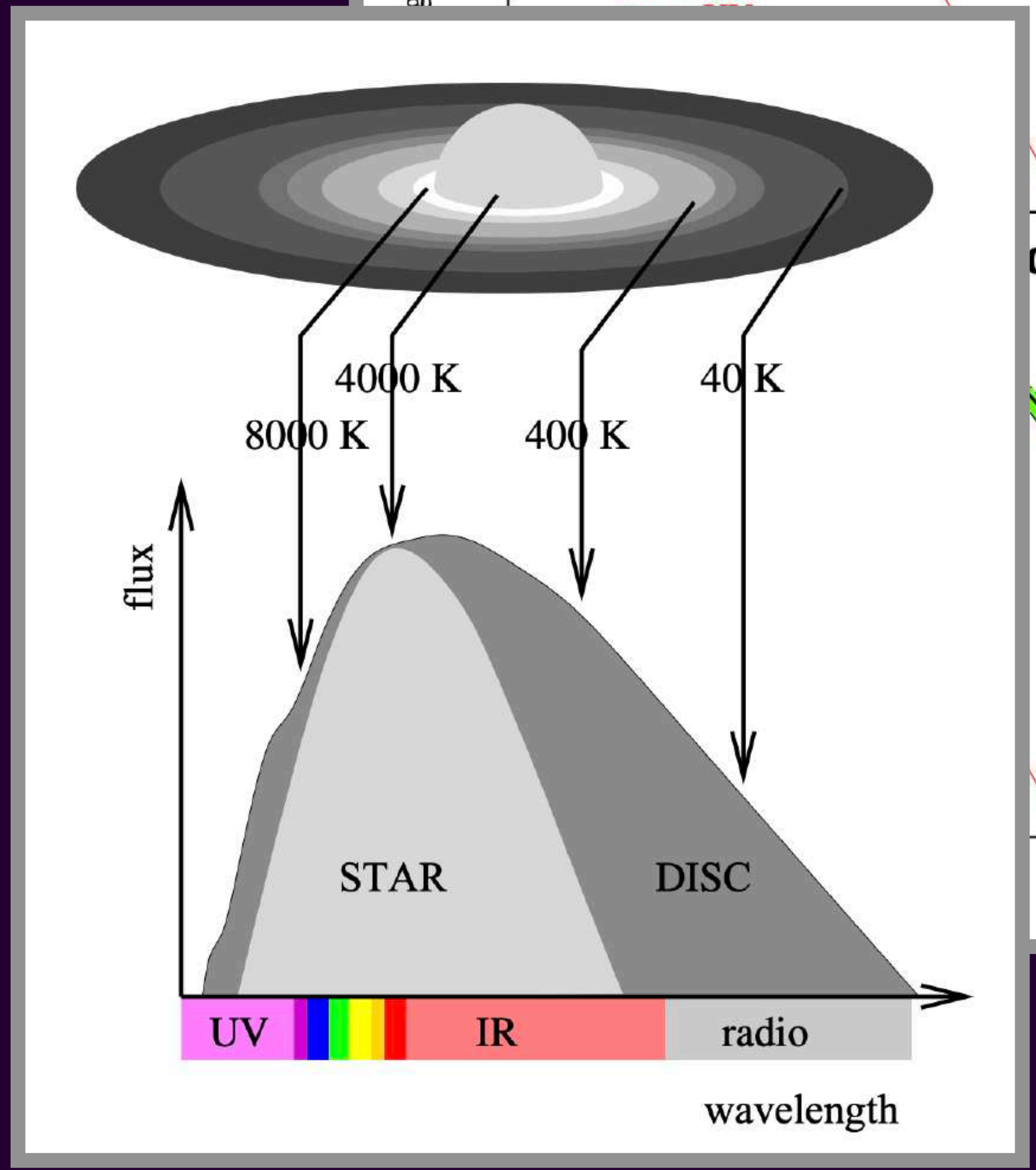
PDF

Radiation Transfer

Key issue in astrophysics

- Involves the main cooling processes and also heating processes
- A lot of the chemistry is driven by radiation
- **Link between theory and observations (diagnostic RT).**





Pinte 2014

Woitke 2014

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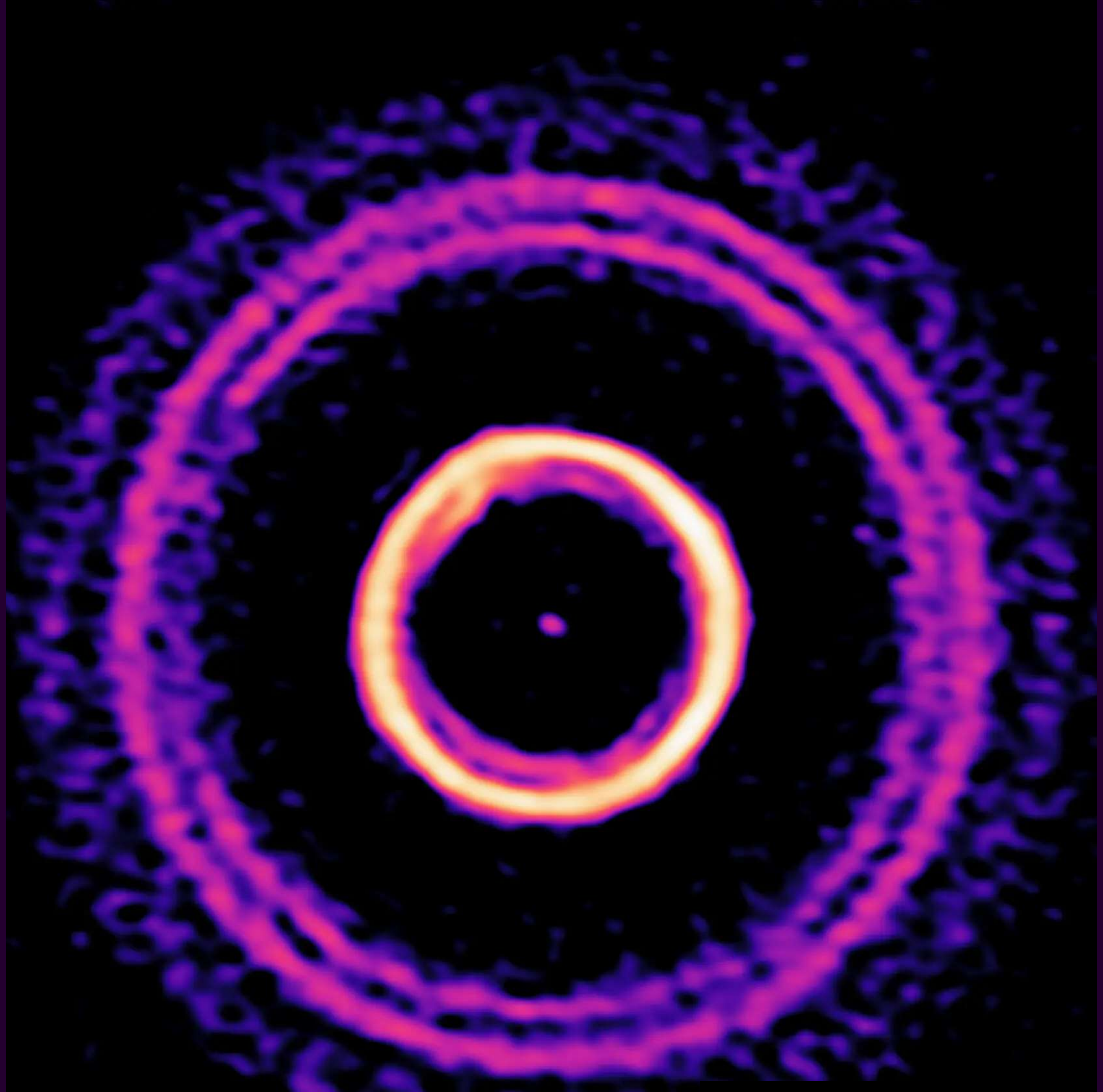

Real observation

HD169142, Pérez et al. (2019)

Radiation Transfer

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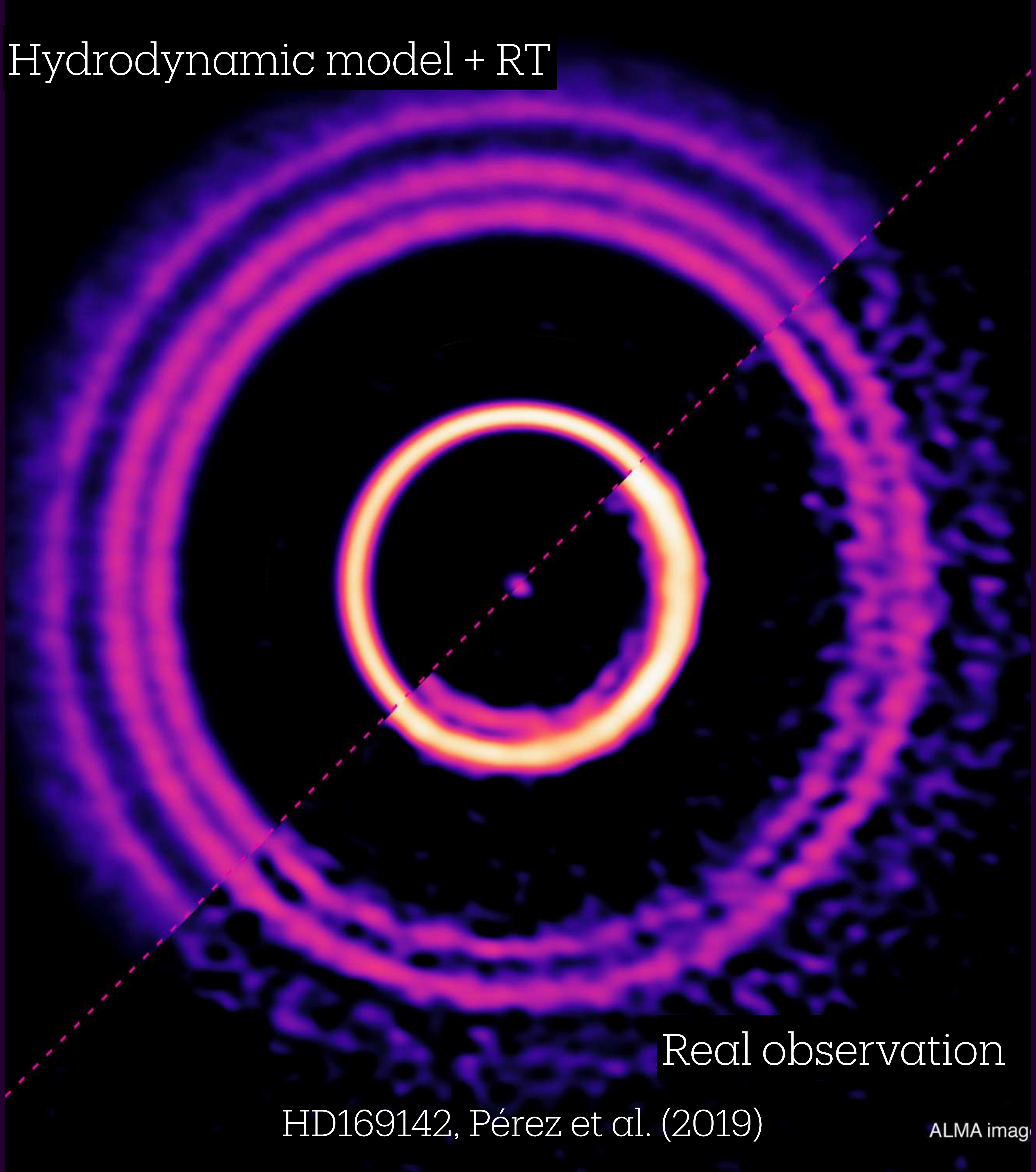


HD169142, Pérez et al. (2019)

Radiation transfer approximation

- good news: we do not need to solve Maxwell's equations
- the laws of geometric optics apply sometimes.
- we can use the particle description of electromagnetic radiation and ignore diffraction (except…)
- For a diluted medium (like nebulae or some parts of protoplanetary disks)
  - Index of refraction is set to 1. —> Light travels strictly in straight lines
  - In case of scattering, light travels in straight lines between two events

Imagine a beam of light (I)

Source terms (j)
(add to the emission)

Absorption $(-\alpha I)$
(dust/planets/rebel scum)

Δs

$$\Delta I = -\text{absorption} + \text{emission}$$

$$\Delta I = -\alpha I \Delta s + j \Delta s$$

$$\frac{dI}{ds} = -\alpha I + j$$

Radiation transfer equation

The radiative transfer equation is nothing more than injecting photons into a ray, and removing photons from that same ray.

$$I = I(\nu, x, y, z, \mathbf{n})$$

$$\frac{dI}{ds} = -\underbrace{\alpha}_{\text{opacity}} I + j + \text{scattering}$$

Radiation transfer equation

The radiative transfer equation is nothing more than injecting photons into a ray, and removing photons from that same ray.

$$I_\nu(s_1) = I_\nu(s_0)\, e^{-\tau_\nu}$$

$$\frac{dI_\nu}{ds} = -\rho\kappa_\nu I_\nu$$

$$\tau_\nu(s_0, s_1) = \int_{s_0}^{s_1} \rho\kappa_\nu ds$$

mass weighted opacity

$$\alpha_\nu = \rho\kappa_\nu$$

Radiation transfer equation

Case of a medium in thermal equilibrium

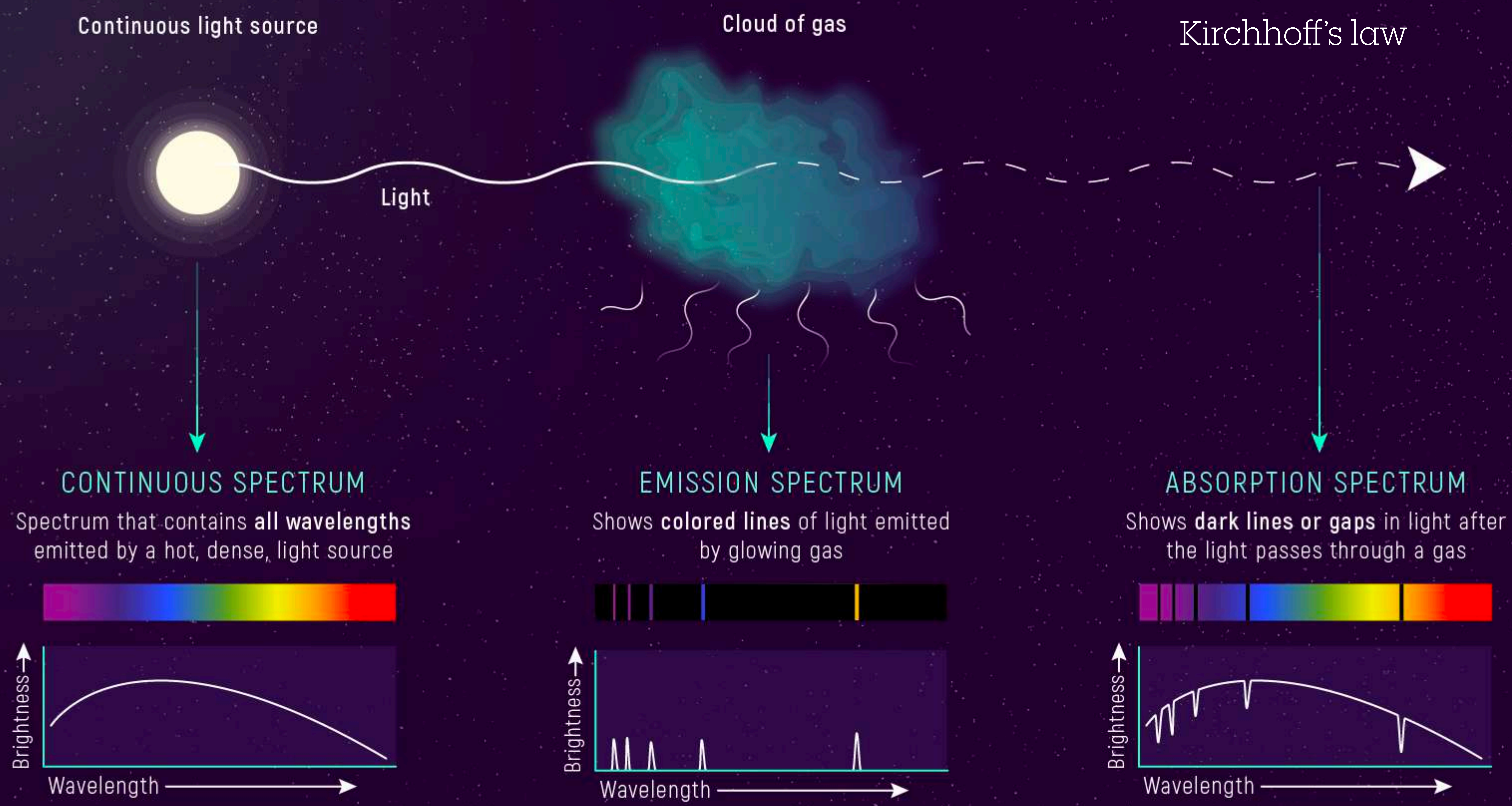
$$I_\nu = B_\nu(T)$$

$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu = -\alpha_\nu B_\nu(T) + j_\nu = 0$$

$$\frac{j_\nu}{\alpha_\nu} = B_\nu(T)$$

Kirchhoff's law

Kirchhoff's law



NASA, ESA, Leah Hustak (STScI)

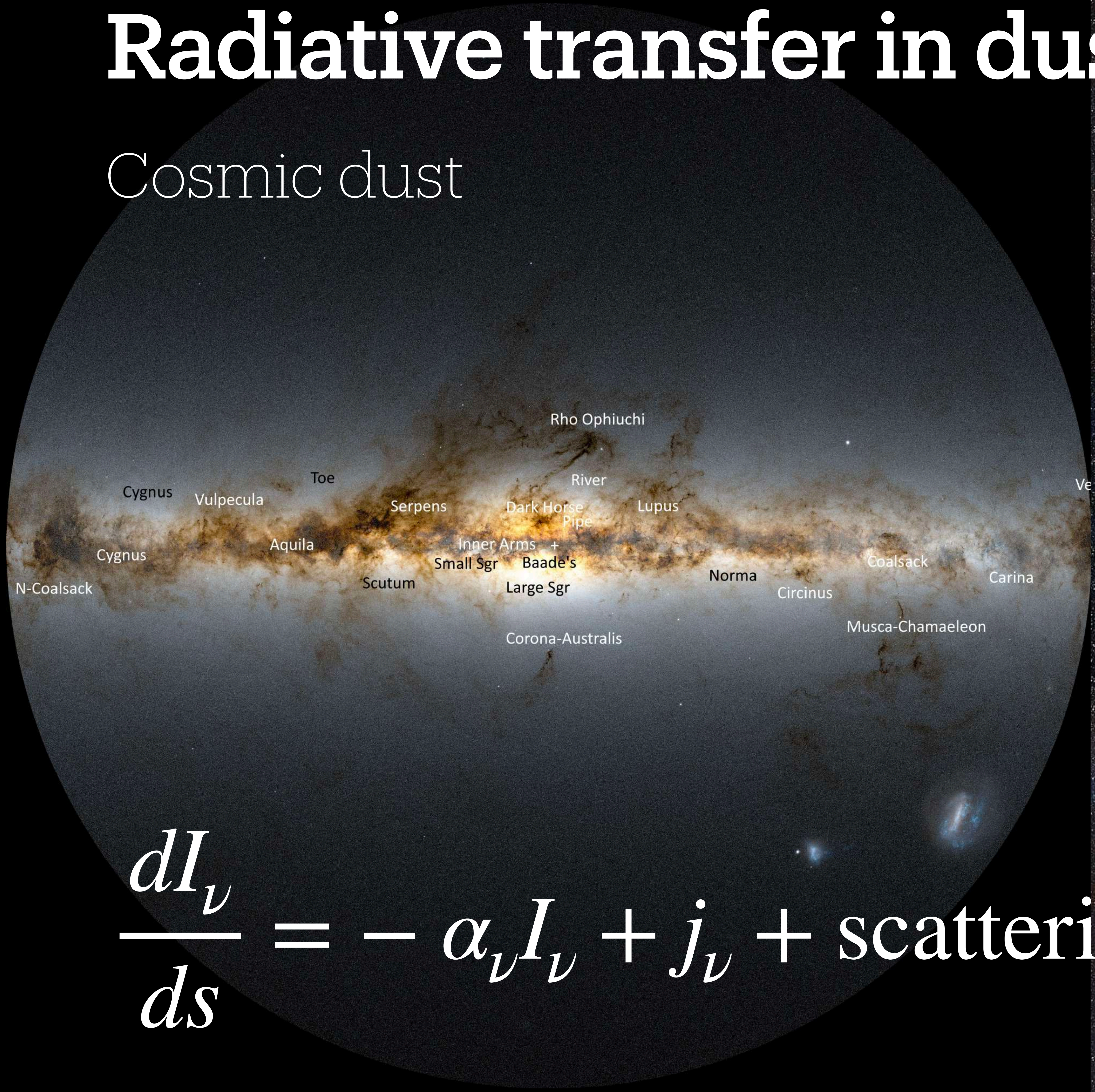
Radiation transfer equation in LTE

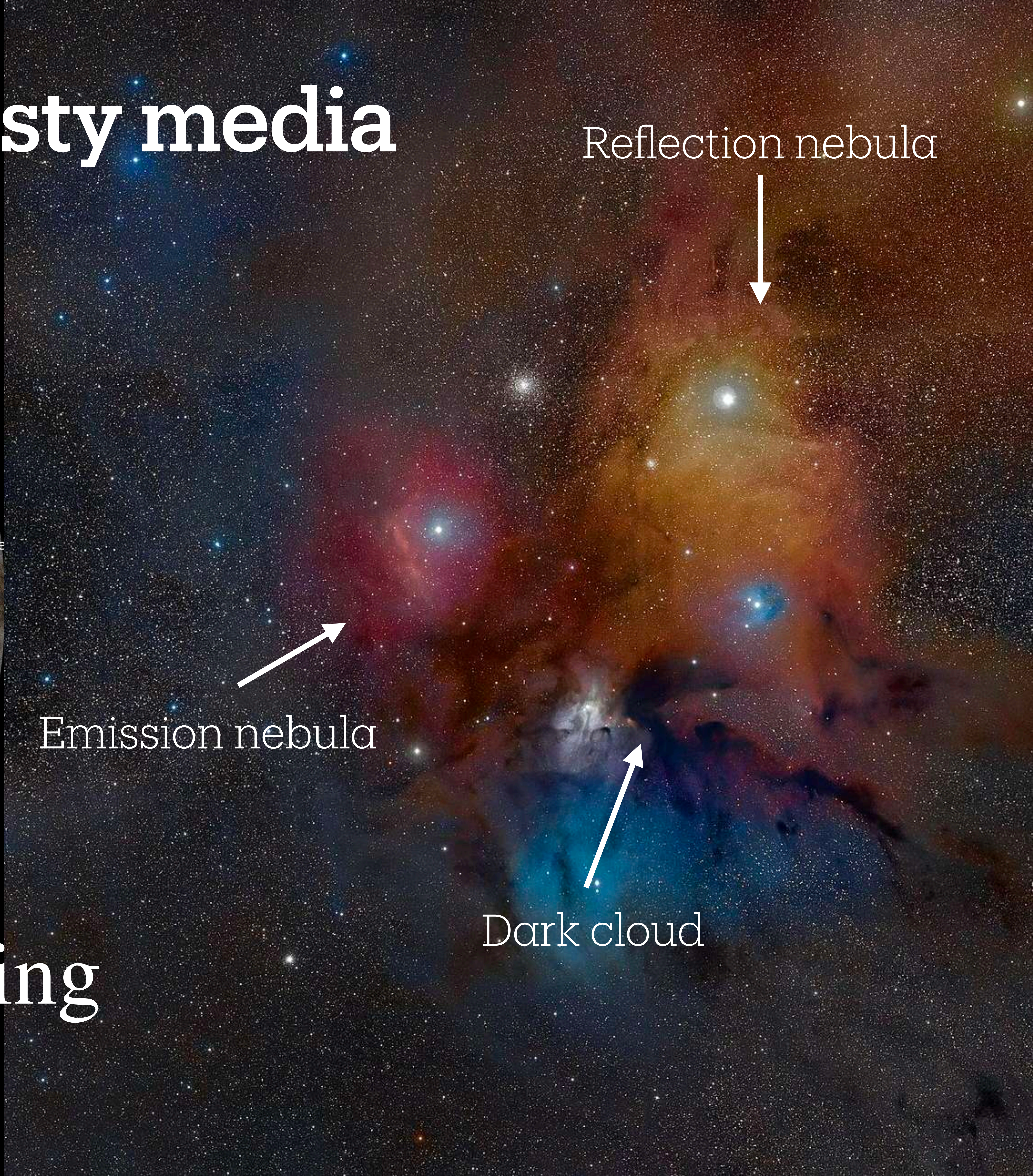
$$\frac{dI_\nu}{ds} = \rho\kappa_\nu[B_\nu(T) - I_\nu]$$

- To solve the RT for a given medium, we need to put the problem on a grid.
- Choose the right spatial resolution.
- Use a stable numerical integration scheme.
- Use all the appropriate approximations.

Radiative transfer in dusty media

Cosmic dust



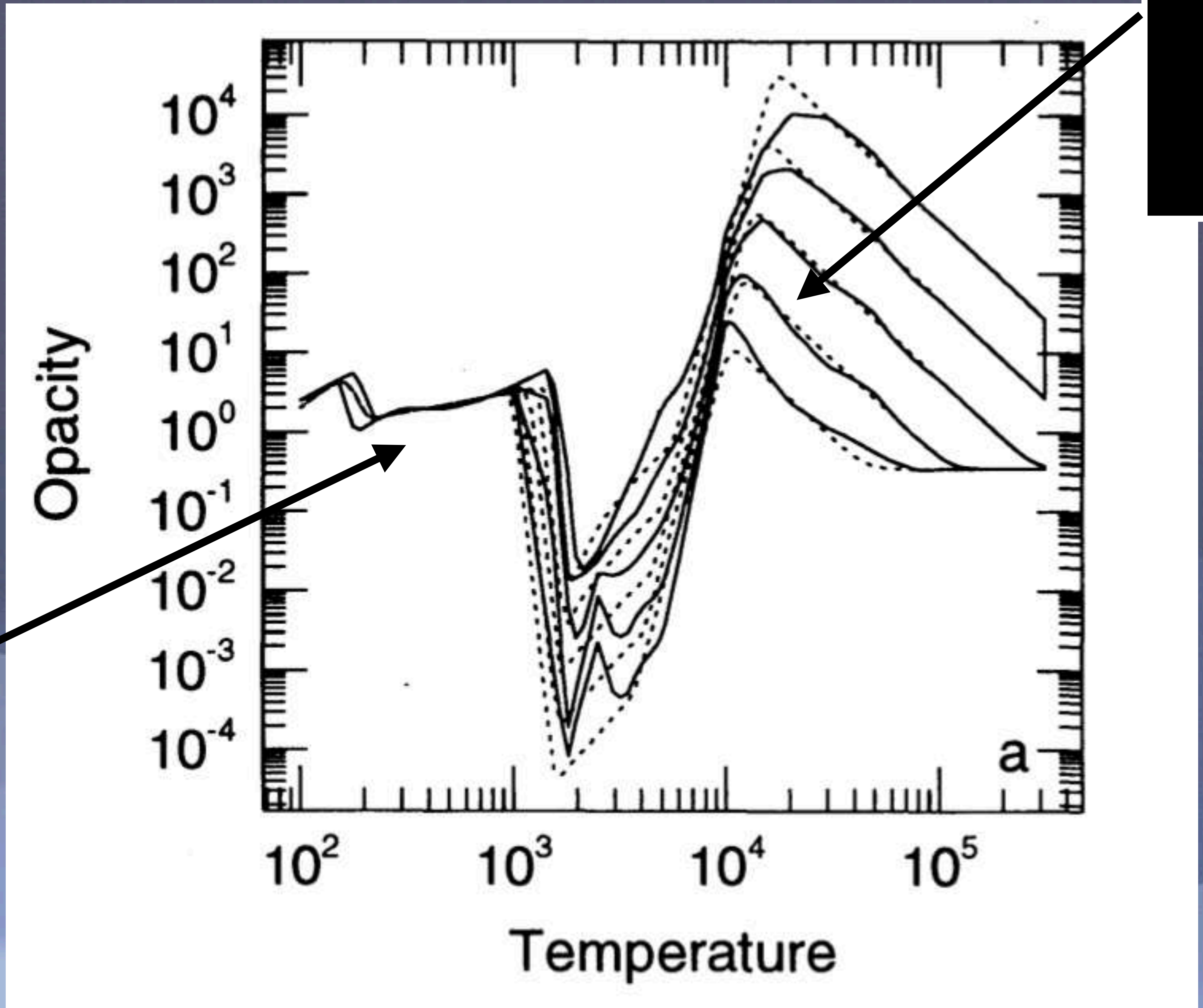


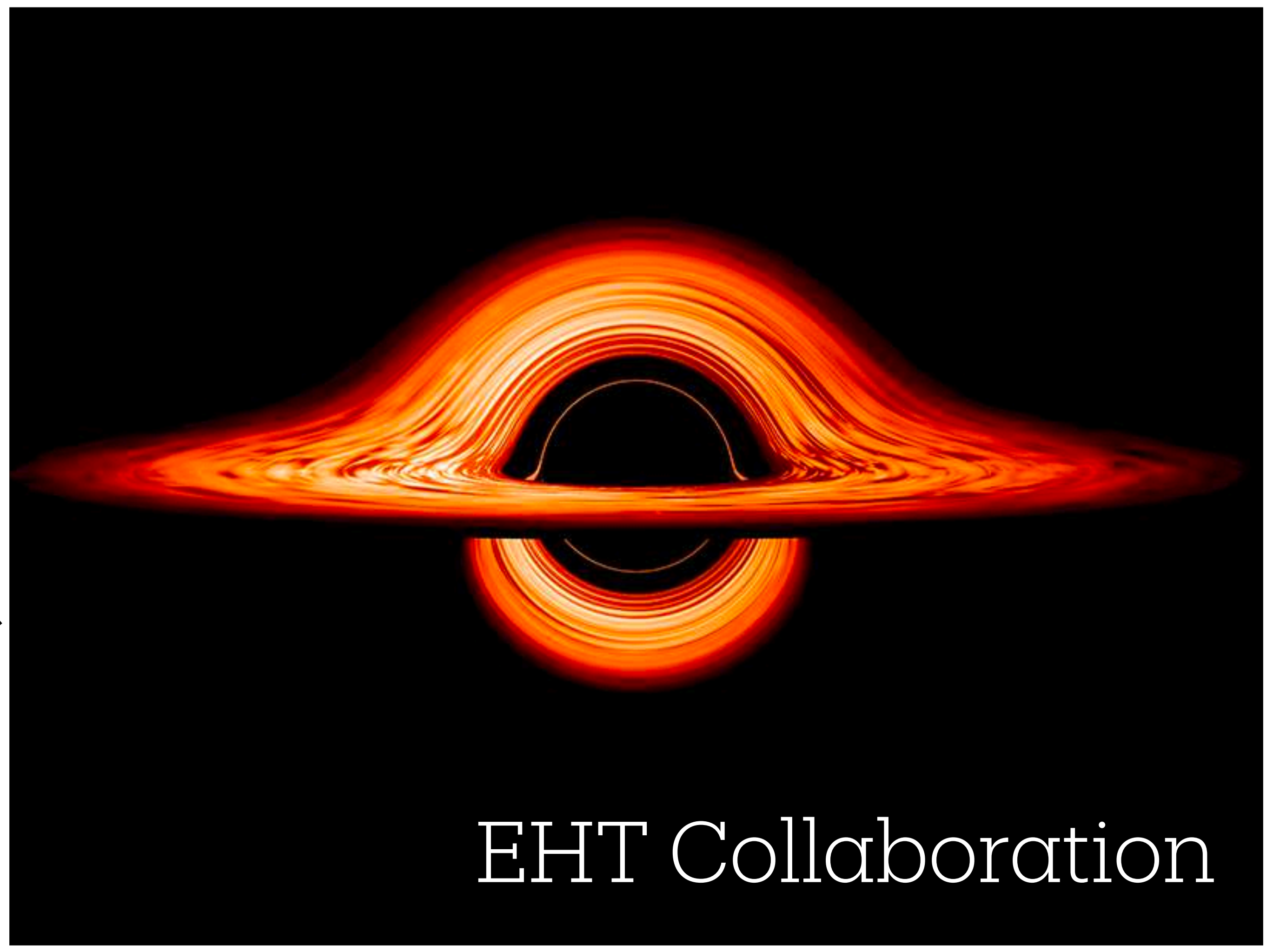
$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu + \text{scattering}$$

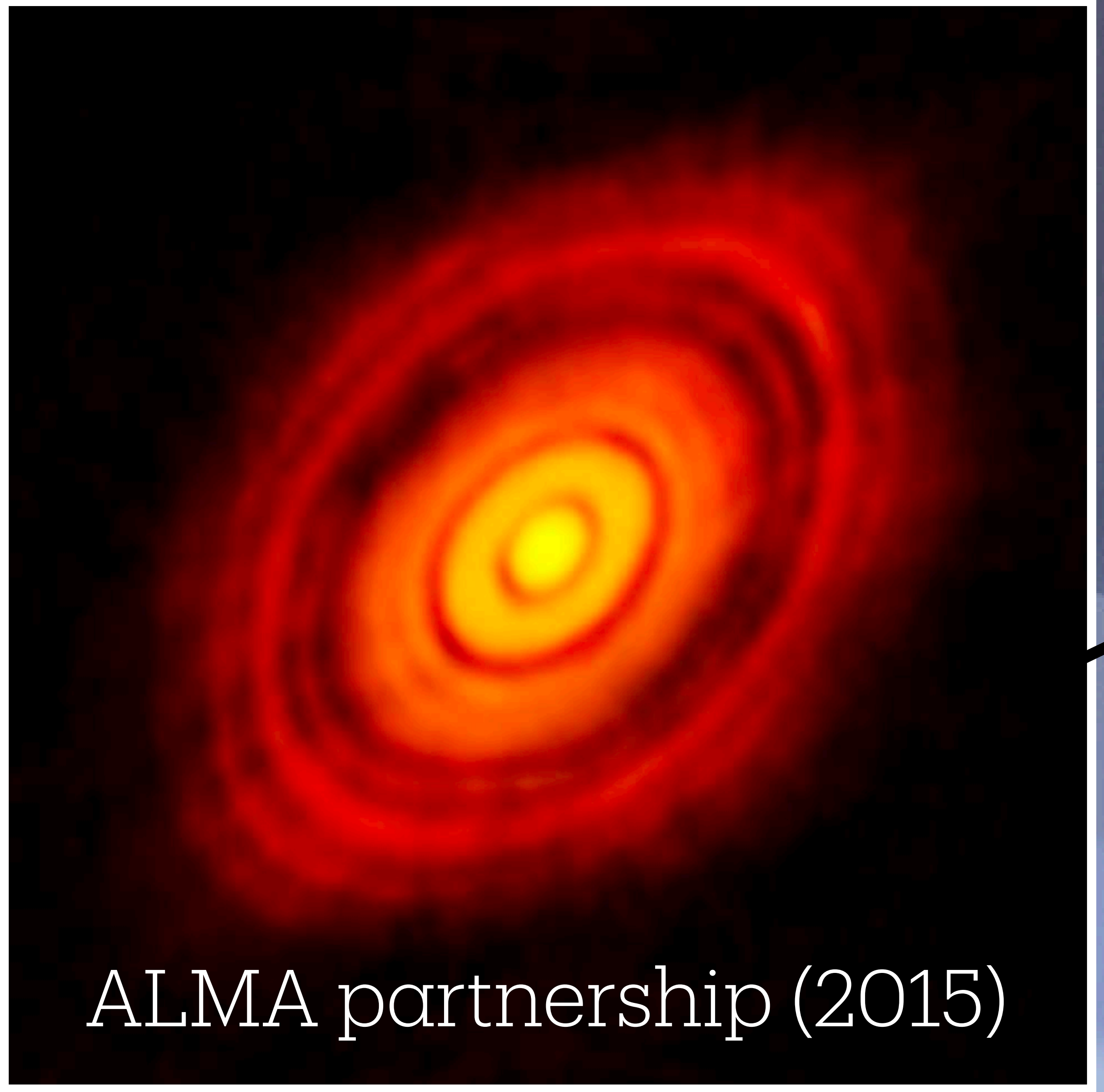
What dictates what we see?

It has to do with opacities κ_ν

Bell & Lin (1994)



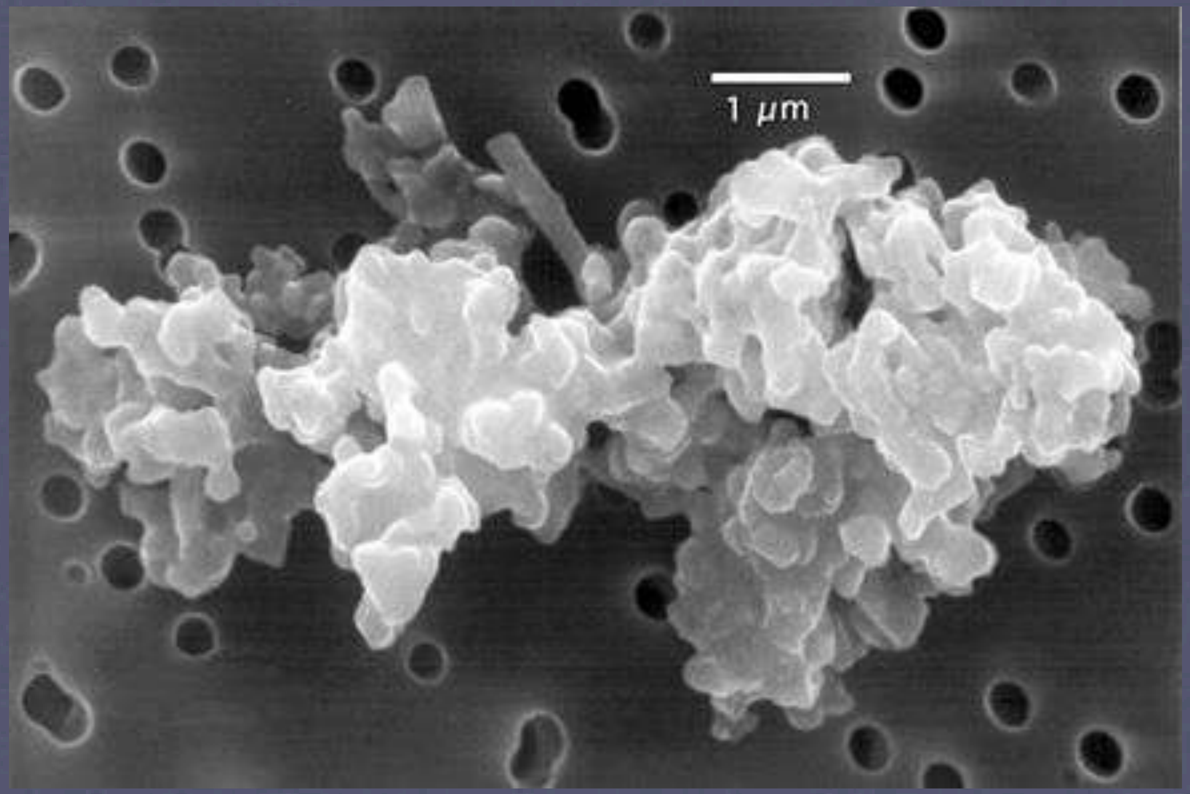




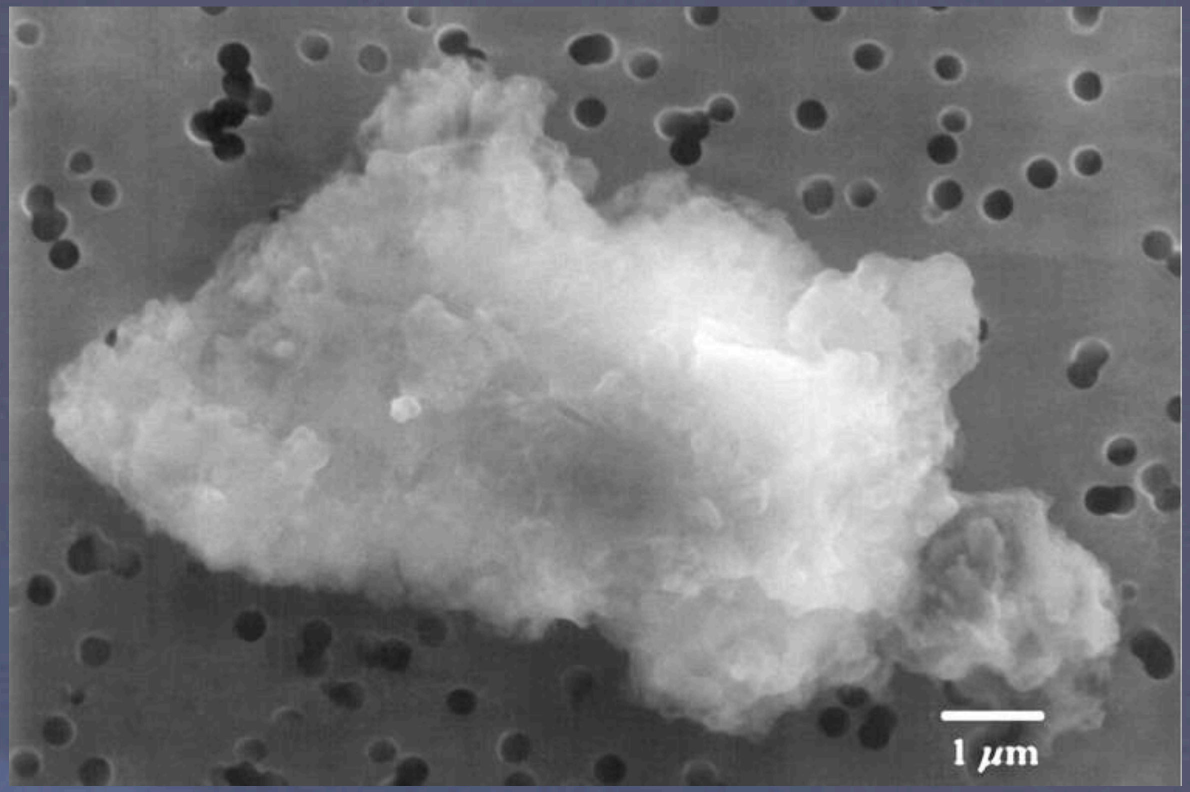
Opacities

How are they calculated?

- The value of kappa will depend on many variables:
    - Composition (most common are silicates, carbonaceous materials, and ices (water, CO, etc) - is it a mix?
    - Shape - are they really spherical?
    - Porosity - fractal structures?
    - Use of correct optical constants (people are trying to measure this here in labs)



Chondrites



Simulation by Alexander Seizinger