Reading: OpenStax, Chapter 20; Sections 20.1-20.3
Chapter 21; Section 21.1

NOTE: The Oct 13 and 15th lectures will be delivered synchronously (while still being recorded for anyone who cannot attend) — *we will talk about black holes!!!*

Brief review of last time: **Stellar Families, Masses and Luminosities**

- M-L relation tells us that massive stars 'die' sooner
- Stellar lifetimes are very long. But what happens when they 'die?'
- Star clusters reveal what happens to stars as they age and die

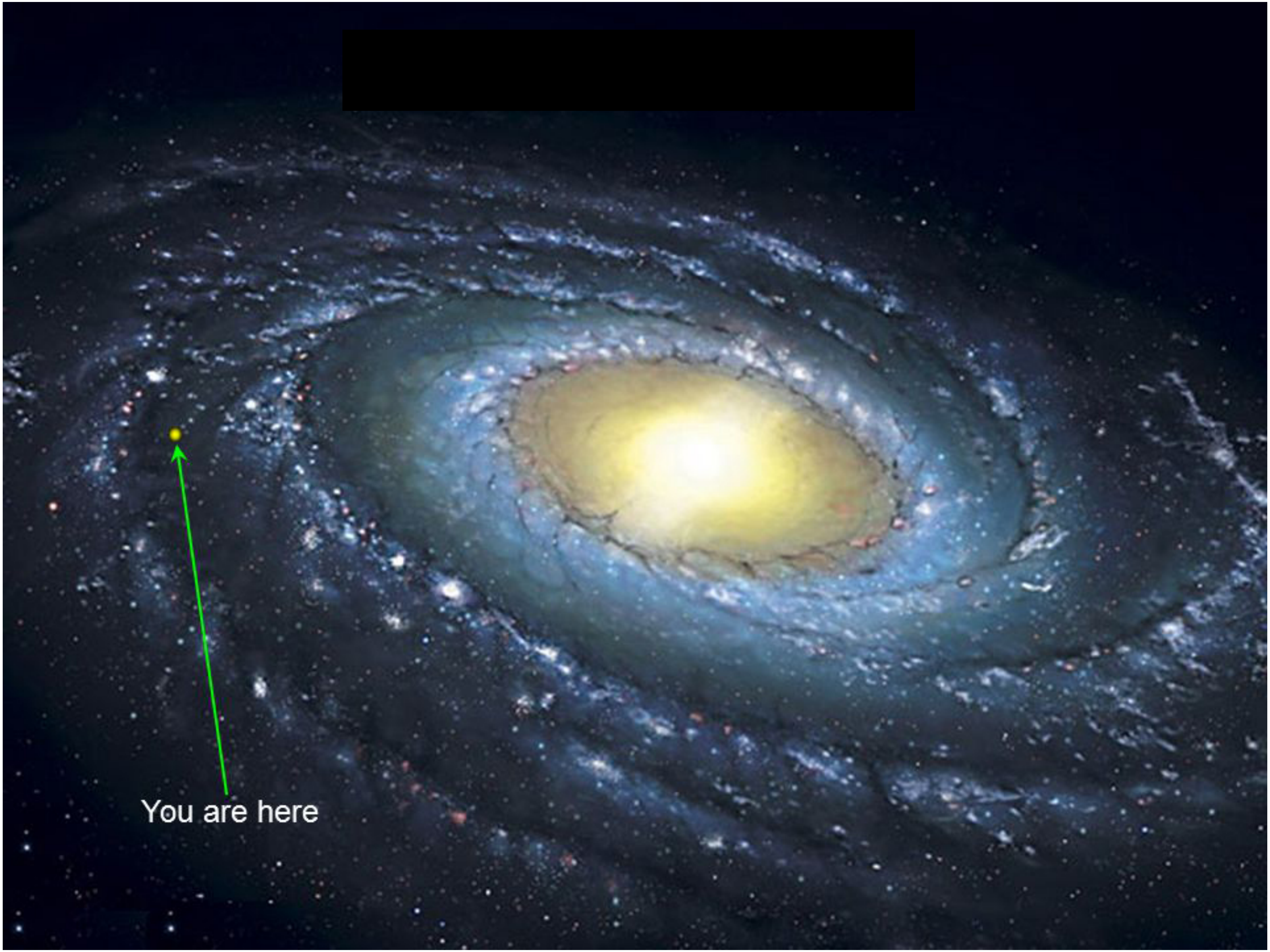
Today: **Star Formation: the Interstellar Medium and Cloud Collapse**

- The interstellar medium is not uniform; different types of gas clouds
- Dust makes up only 1% of the material but has a very large impact on what we can observe.
- Gas in giant molecular clouds collapse to form stars

Interstellar Medium (ISM)

- What is it?
  - All of the stuff between the stars!
  - Not uniform!
  - Some of it turns into stars

[redacted]



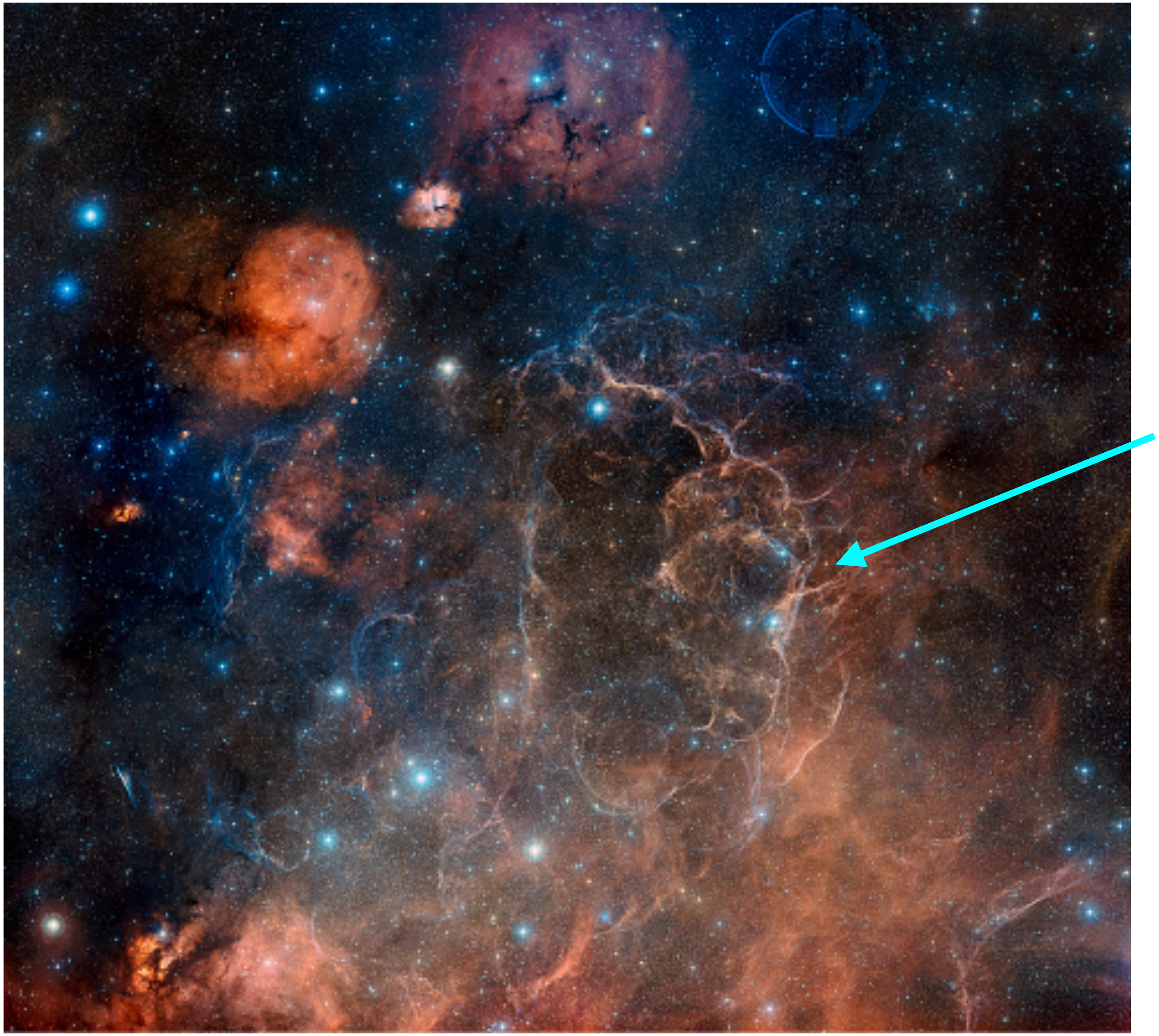
Interstellar Medium (ISM)

- What is it?
  - All of the stuff between the stars!
  - Not uniform!
  - Some of it turns into stars

- What is it made out of?
  - Mostly gas (99%) but some dust too (1%)
  - Average density: a few atoms per cc (air: 10^{18} atoms/cc)
  - BUT not uniform — very clumpy! (think clouds on Earth)
    - Nebulas — more general term for gas and dust clouds
    - Ultra-hot interstellar gas
    - HII regions (i.e., large bubbles of ionized gas)
    - HI gas (neutral hydrogen clouds)
    - Molecular clouds

Analogous to clouds on Earth

Ultra-hot Interstellar Gas



Produced by exploding stars (will talk about in Lecture 16)

Can see remnants of the exploded star

This explosion rapidly heated the nearby gas to millions of K

$T = 10^6$-10^7 K (X-rays!)

HII ("H-two") Regions

Orion Nebula!

Massive stars heat gas to the point where Hydrogen is ionized*

Leads to a bubble of hot ionized gas

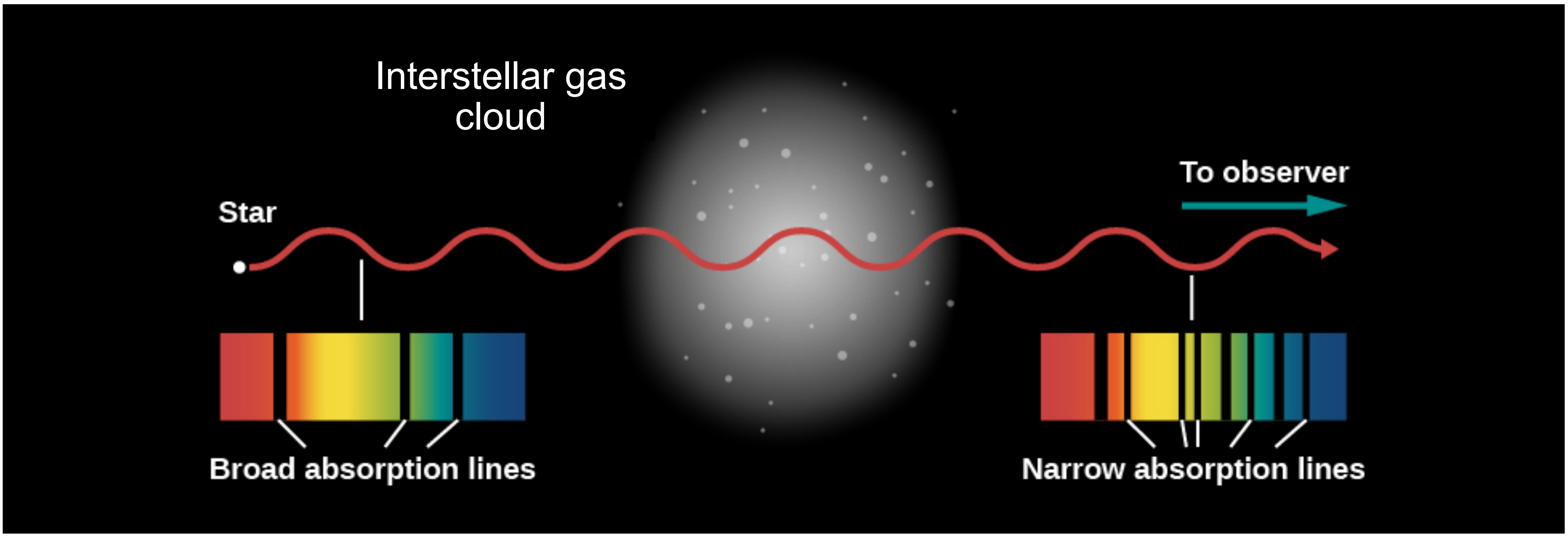
* II - means once ionized
* I - means neutral

T = 10,000K

electrons recombine and cascade to produce visible light

HI (“H-one”) Clouds

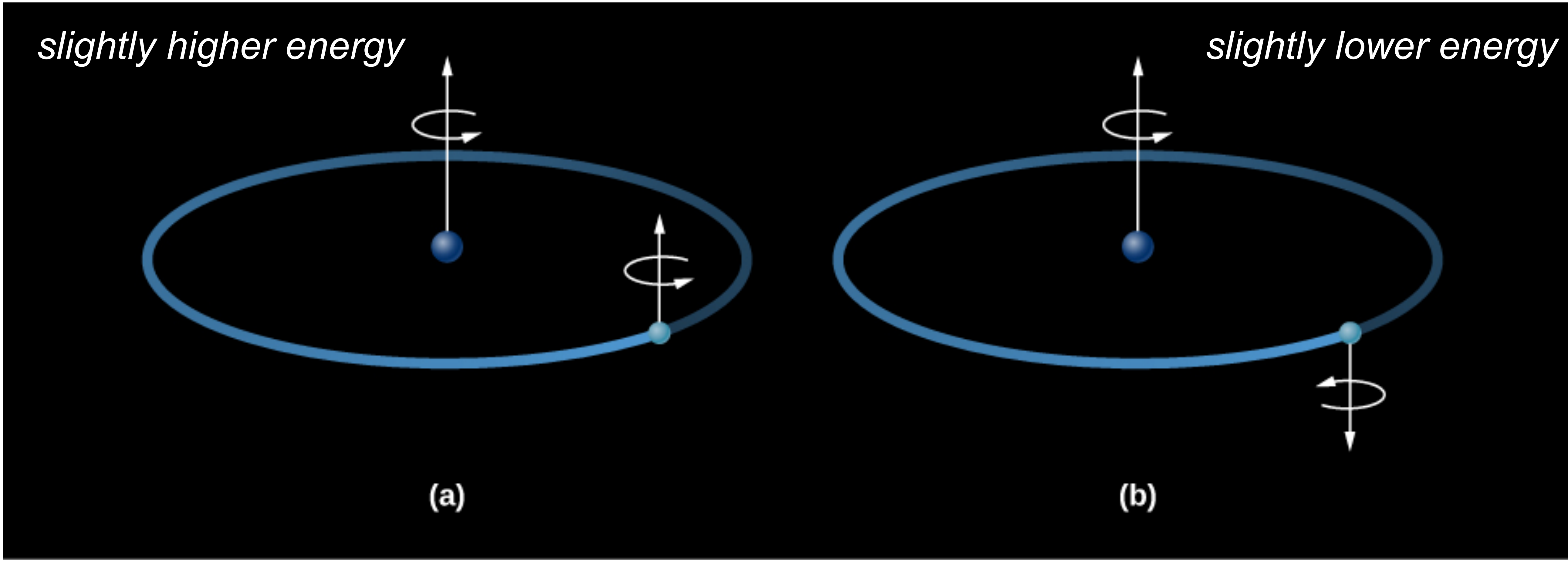
- Neutral Hydrogen*
- Takes up most of the volume!
- Hard to detect directly — mostly need trace elements



T = 100-8,000K

* II - means once ionized
* I - means neutral

Can also directly detect HI with the "spin-flip" transition

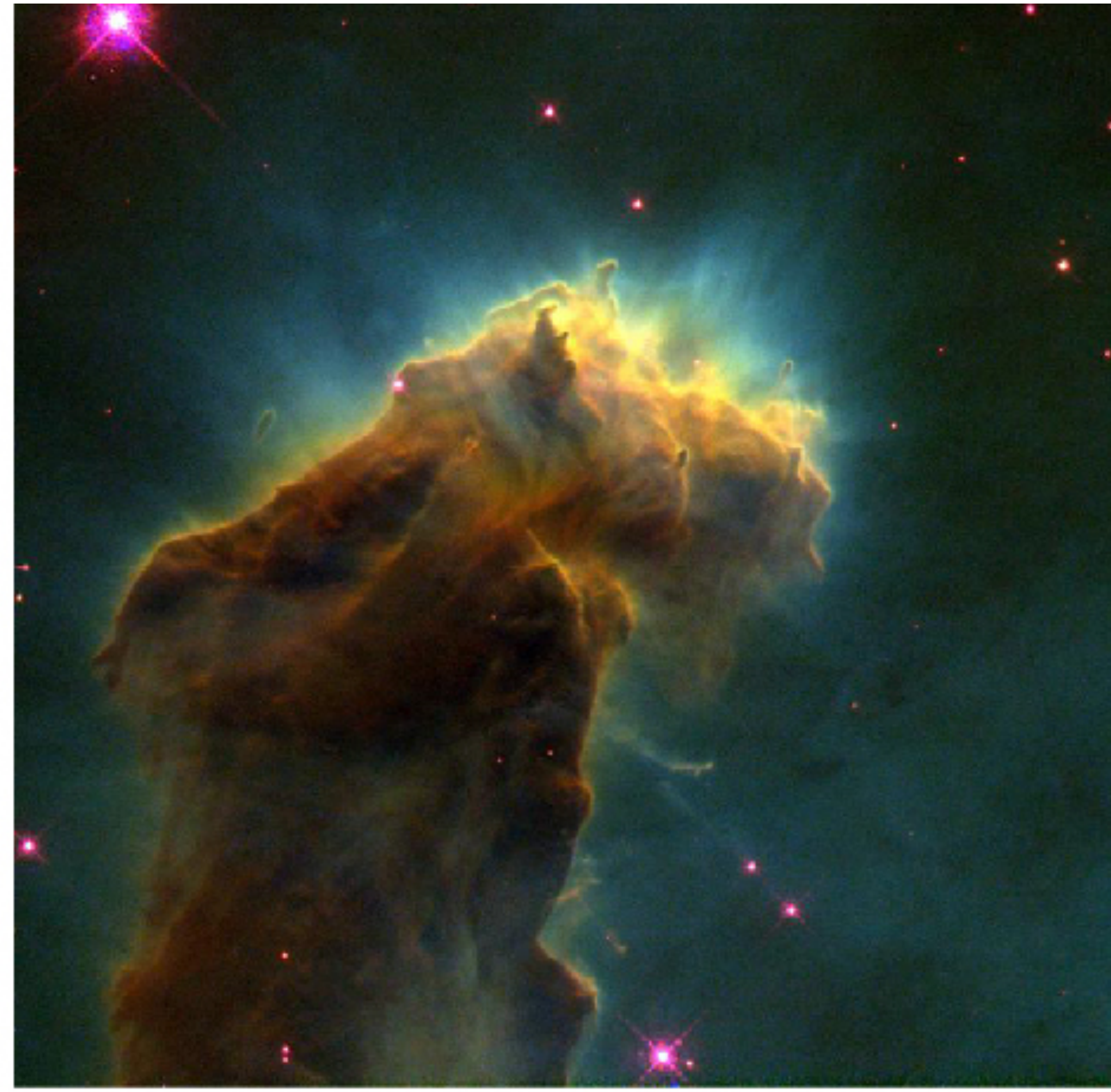


Electron will eventually flip its spin, emitting light with a wavelength of 21 cm (need radio telescopes to see them)

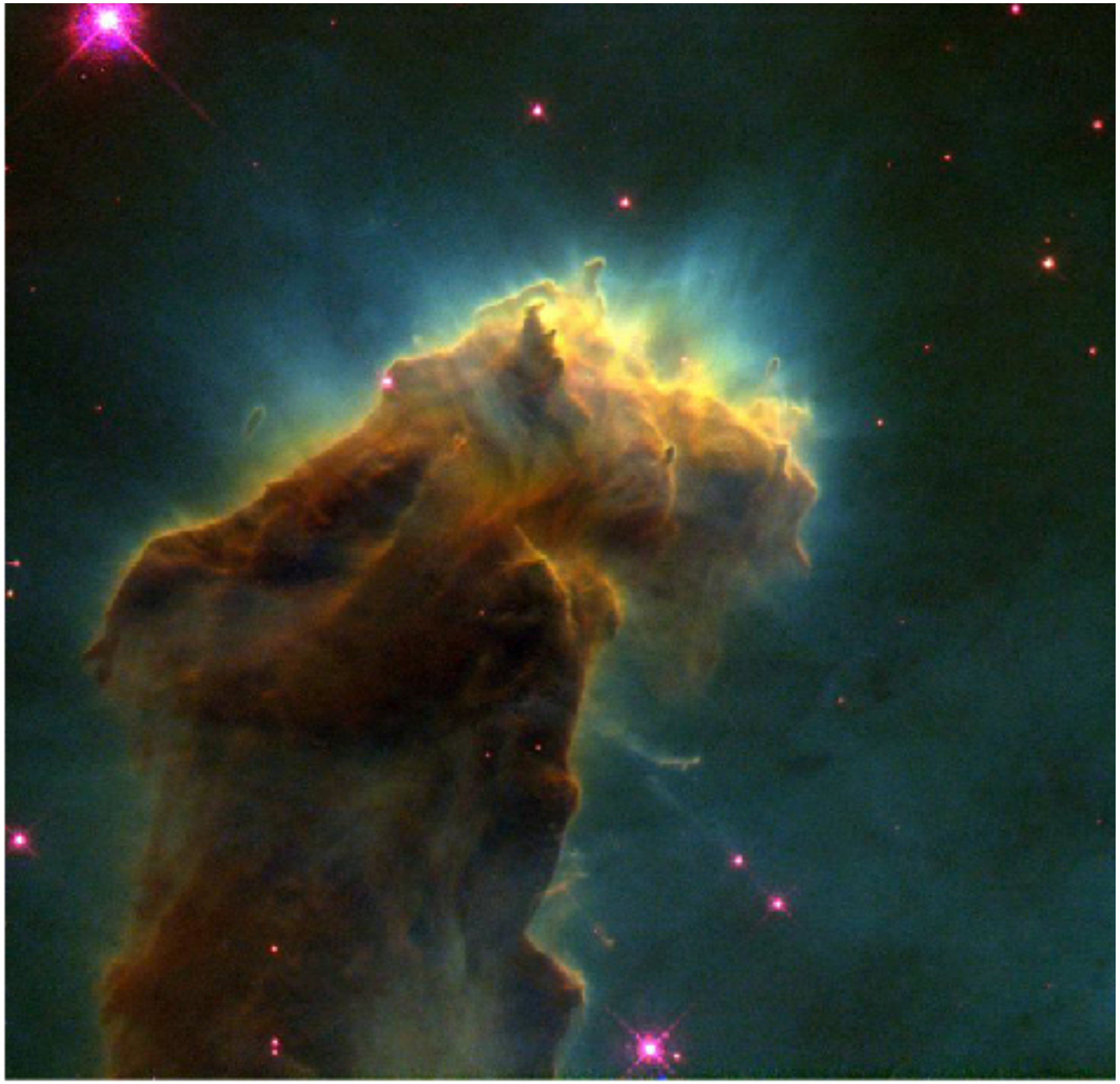
This is a *VERY* rare event (takes 10 million years for one atom to flip the spin!)

But there is SO MUCH Hydrogen that we can still see these clouds

Giant Molecular Clouds



Giant Molecular Clouds



T = 10K

Very cold

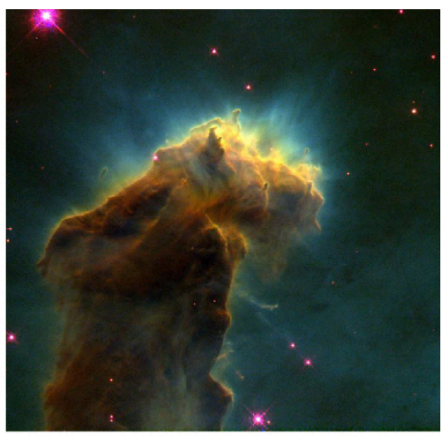
- Very cold (T = 10 K)
- Birthplaces for stars
- As massive as million times the mass of the Sun (these are held together by gravity)
- Very dense (very small fraction of volume of ISM but 20-30% of the mass!!!): 10^4 atoms/cc
- Hydrogen is in H_2 — can't see very easily
- Seen by (other) molecular lines (remember that molecules can emit/absorb light too!)

Some “common” chemicals have been found in these clouds

Some Interesting Interstellar Molecules		
Name	**Chemical Formula**	**Use on Earth**
Ammonia	NH_3	Household cleansers
Formaldehyde	H_2CO	Embalming fluid
Acetylene	HC_2H	Fuel for a welding torch
Acetic acid	$C_2H_2O_4$	The essence of vinegar
Ethyl alcohol	CH_3CH_2OH	End-of-semester parties
Ethylene glycol	$HOCH_2CH_2OH$	Antifreeze ingredient
Benzene	C_6H_6	Carbon ring, ingredient in varnishes and dyes

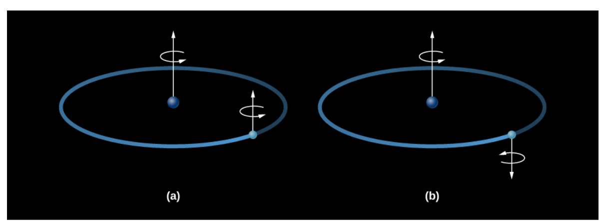
ISM: Summary of different clouds

Giant Molecular Clouds



T = 10K

HI Clouds



T = 100-8,000K

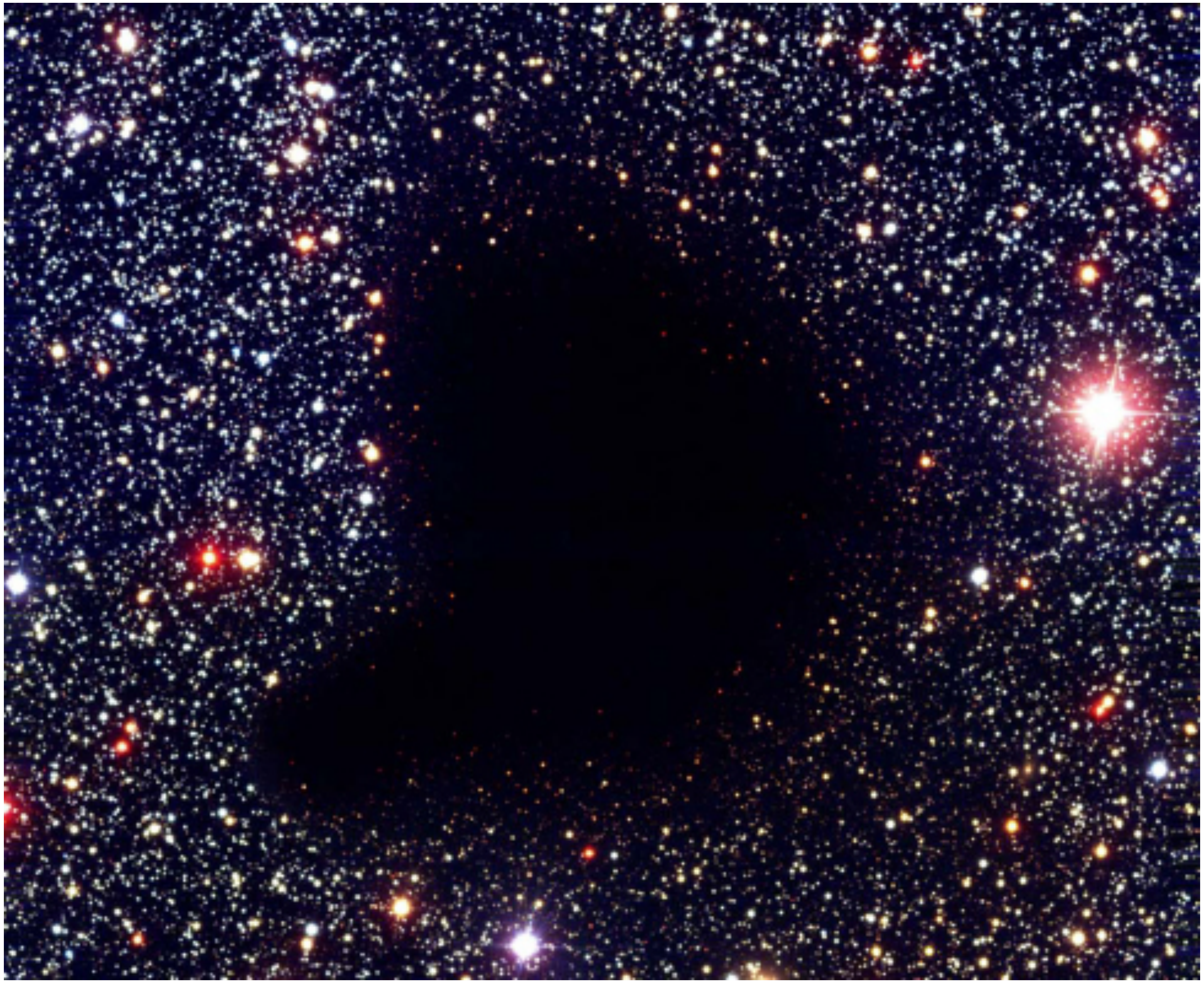
HII Regions

T = 10,000K

Ultra-hot ISM

T = 10^6-10^7 K

Another component to the ISM: Dust!

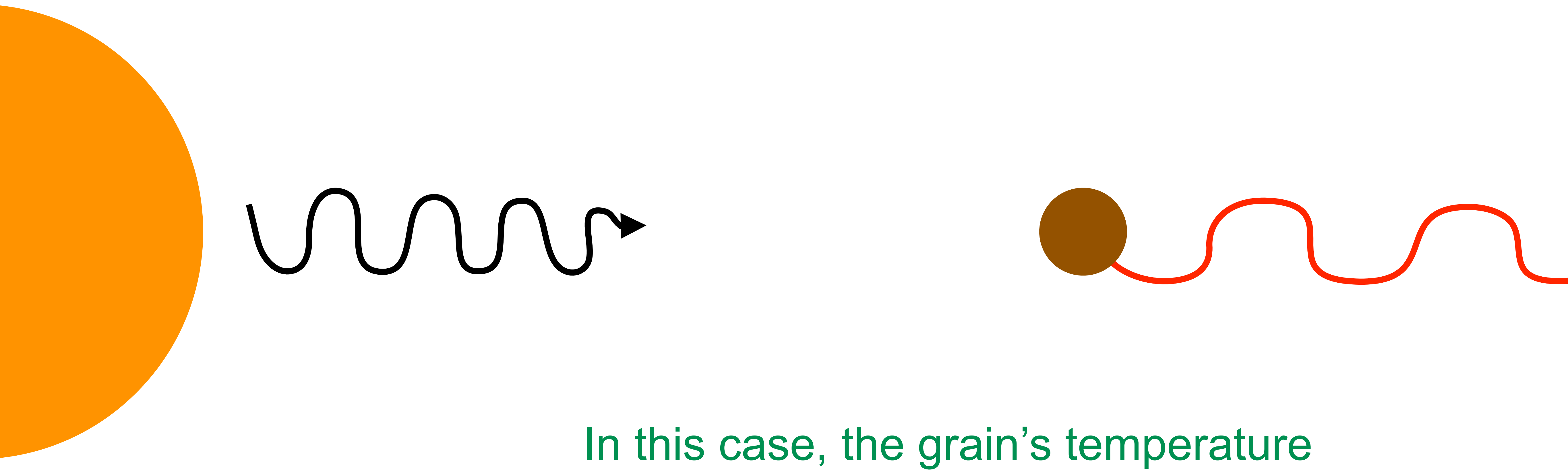


ESO

Another component to the ISM: Dust!

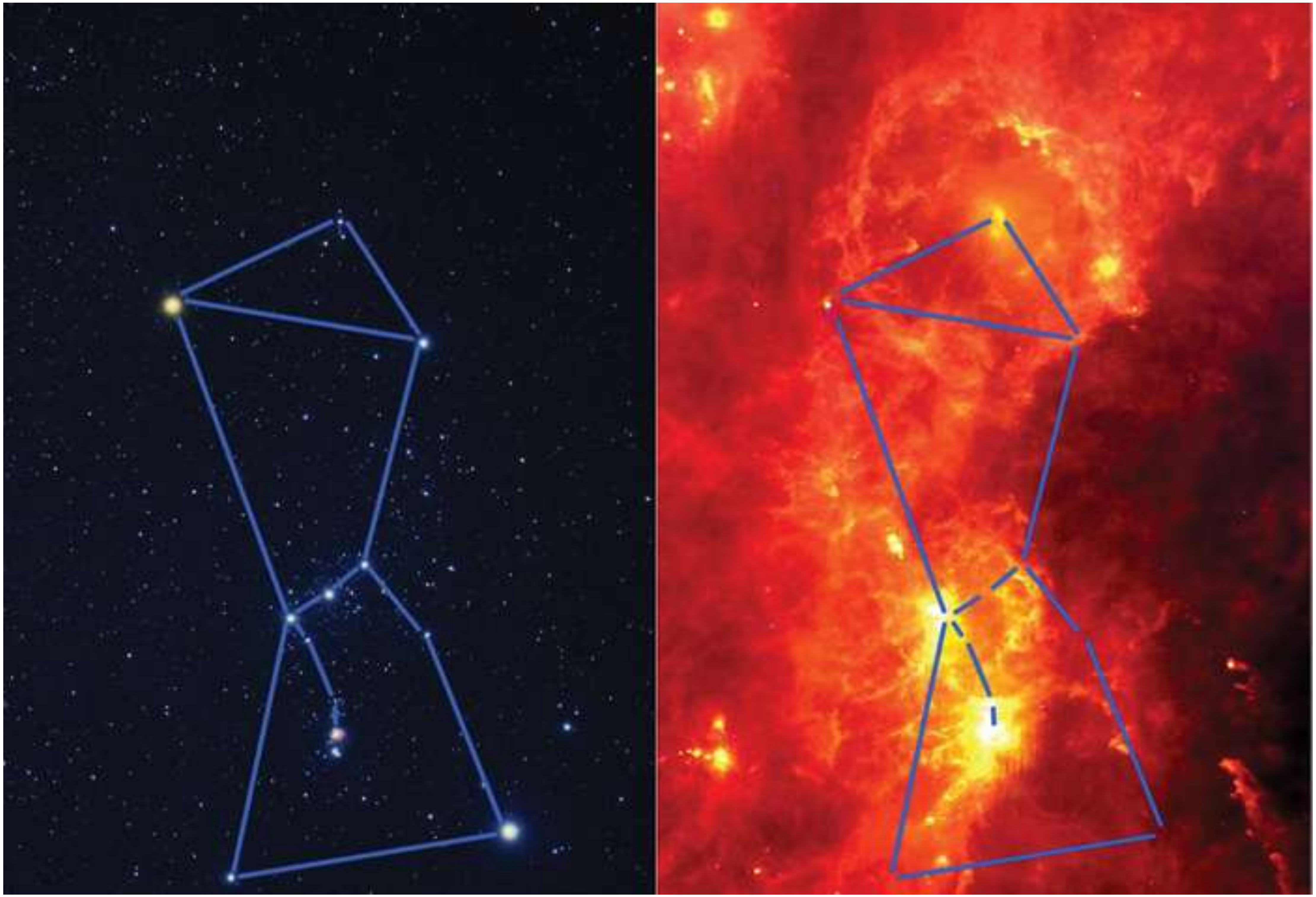
Dust affects light in several ways

1. Dust grains can absorb some of the light from a star



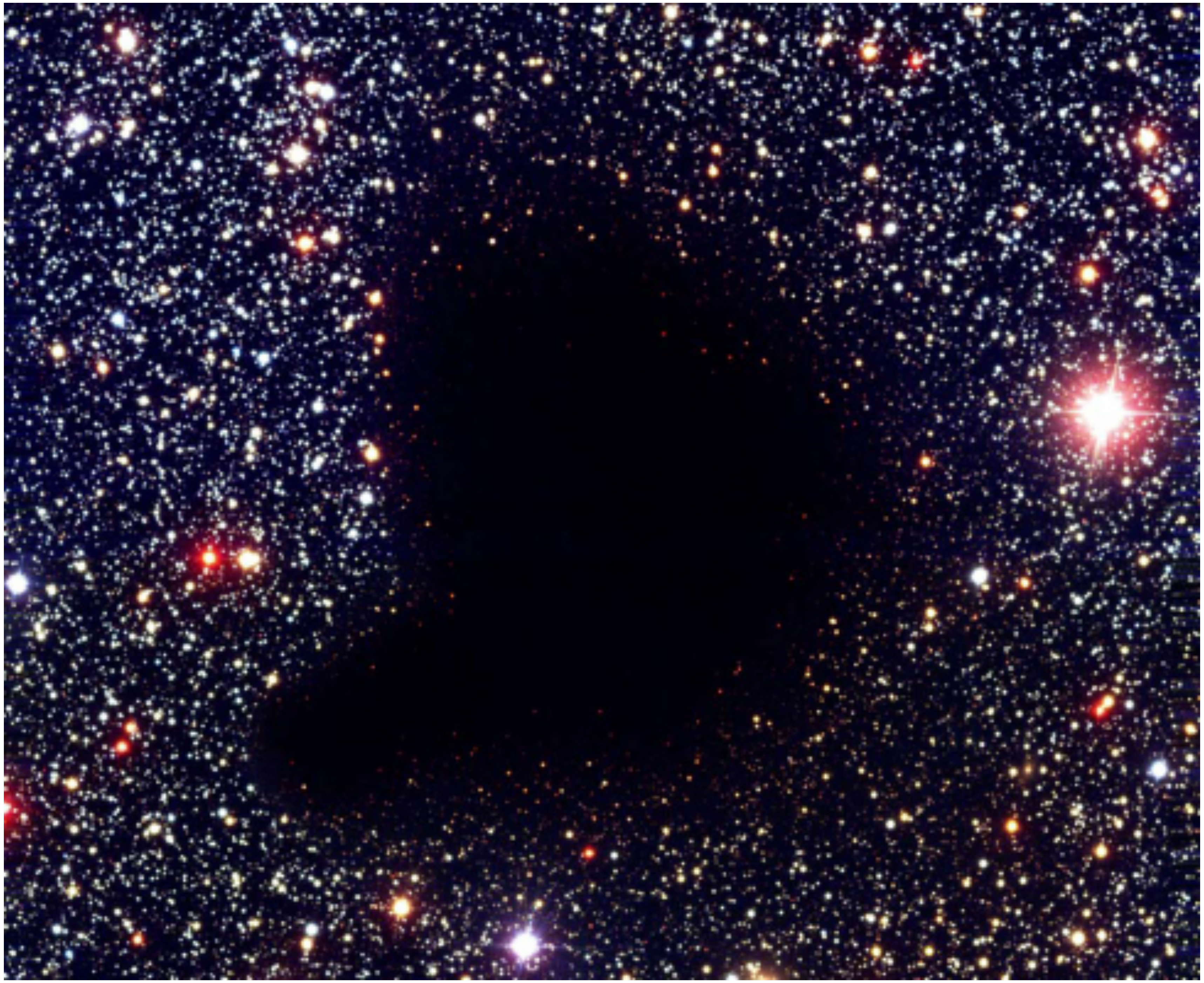
In this case, the grain's temperature increases as it absorbs light and it emits as a blackbody at longer wavelengths (e.g., infrared, sub-mm)

Absorption and reemission



Visible light image, left, Akira Fujii; Infrared image, right, Infrared Astronomical Satellite/NASA

Interstellar Extinction



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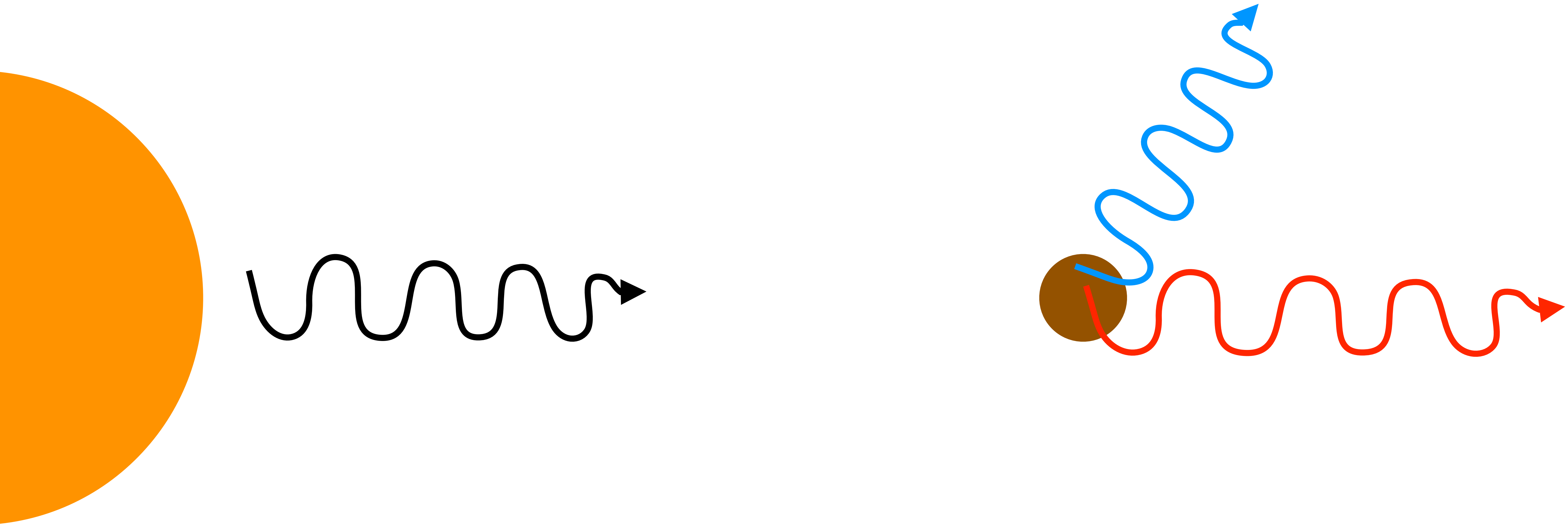
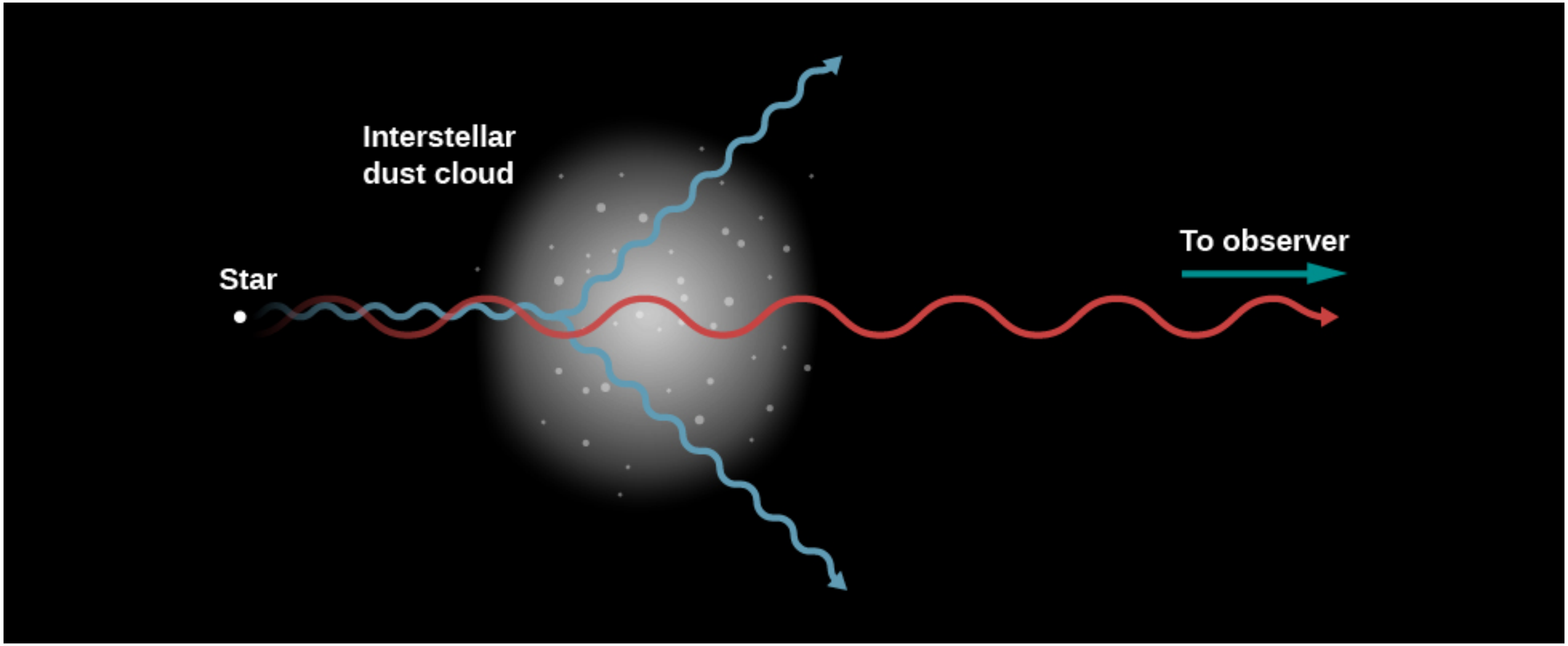
Dust affects light in several ways

2. Dust grains will scatter what is not absorbed



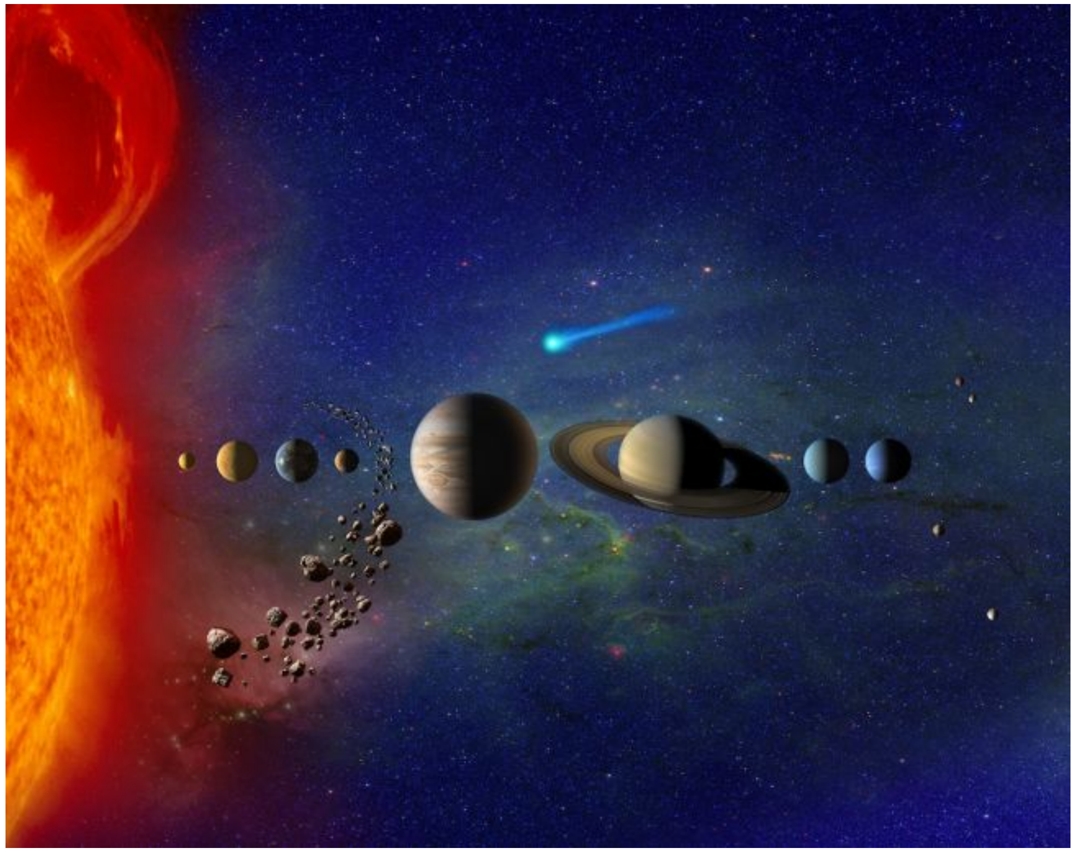
And actually, blue light is preferentially scattered compared to red light

Interstellar Reddening



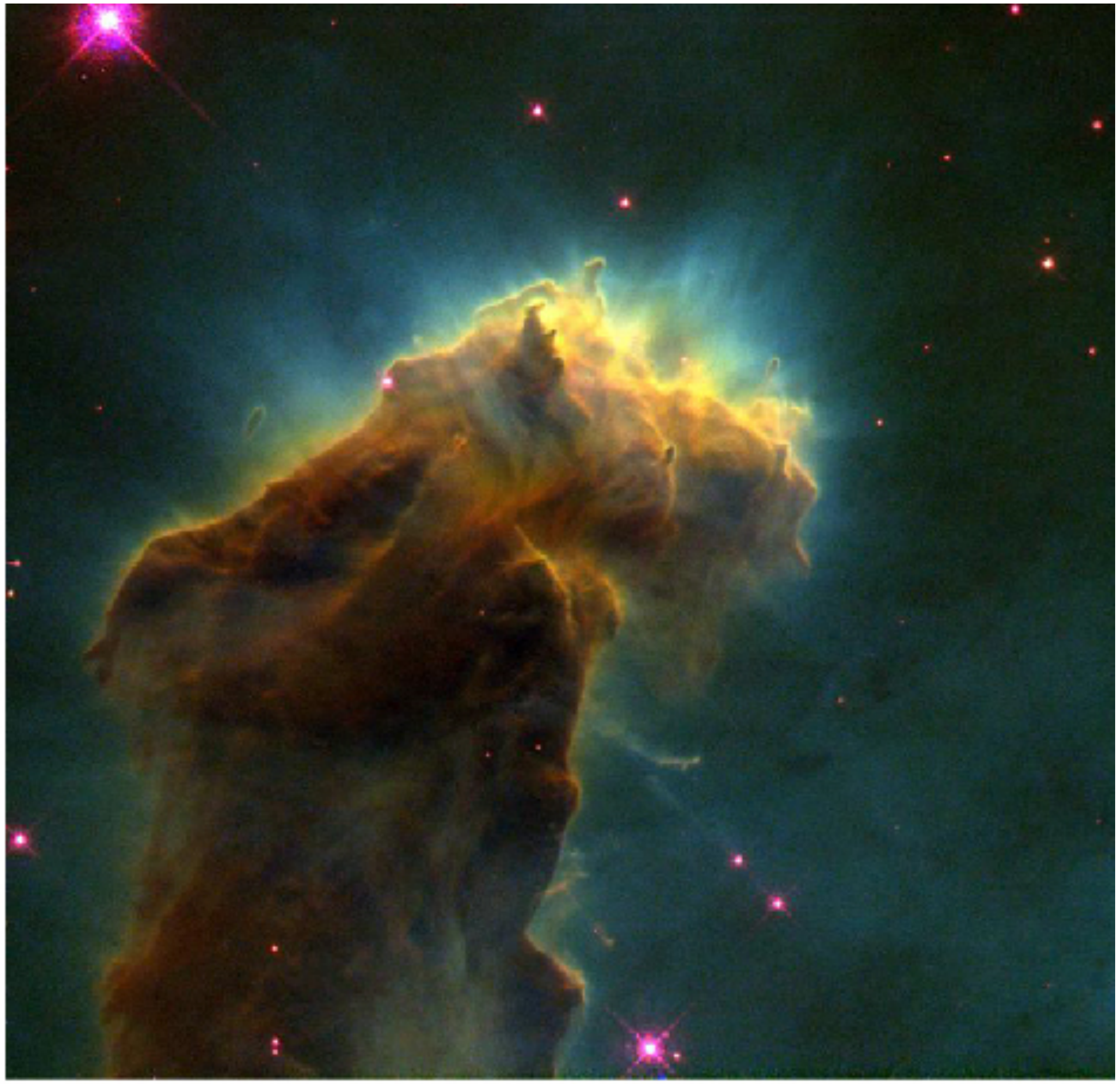
Brief aside: why the sky is blue and sunsets are red

Brief aside #2: Dust grains are very small, but will ultimately end up as gigantic planets!



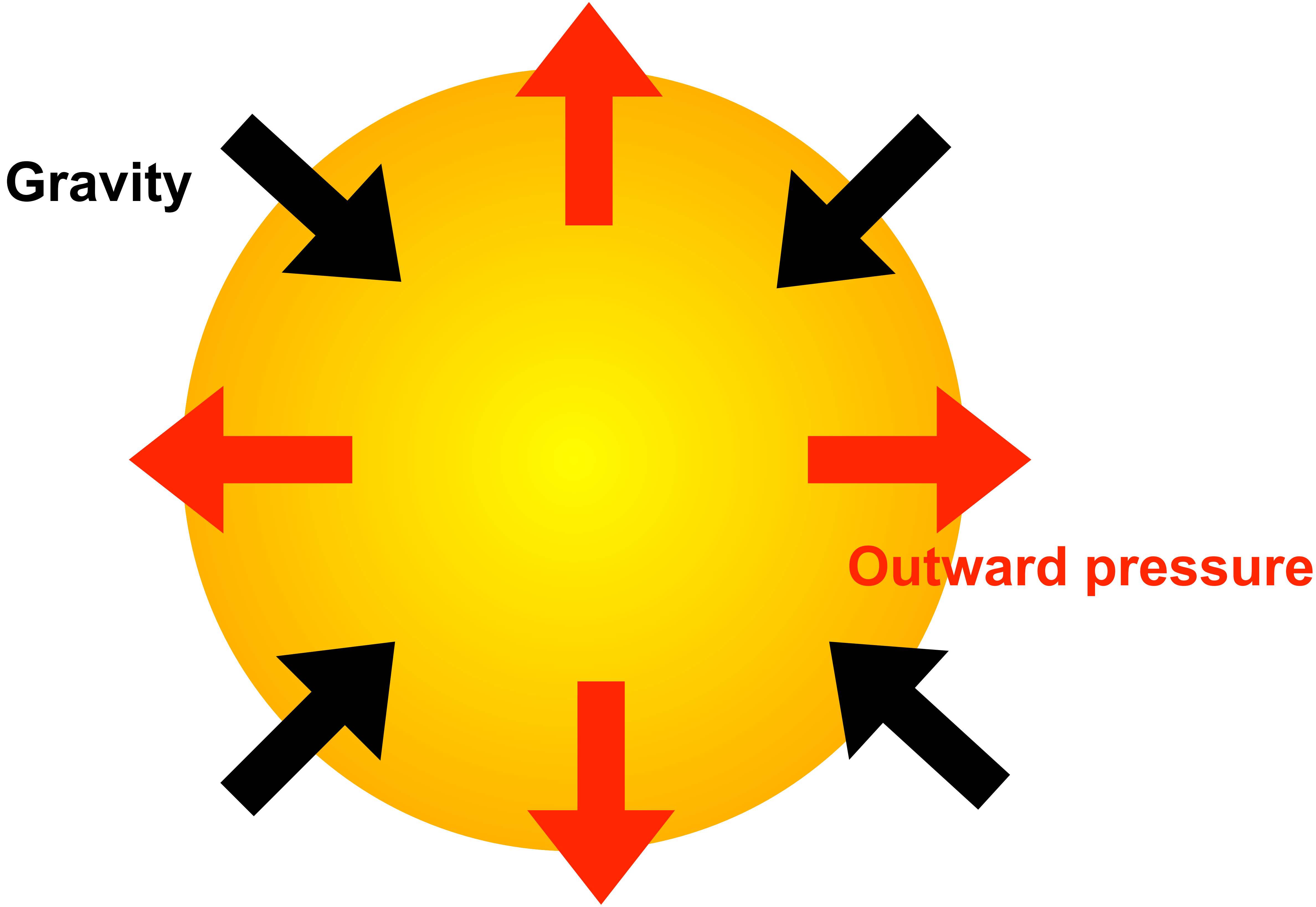
NASA/JPL-Caltech

Onto star formation!



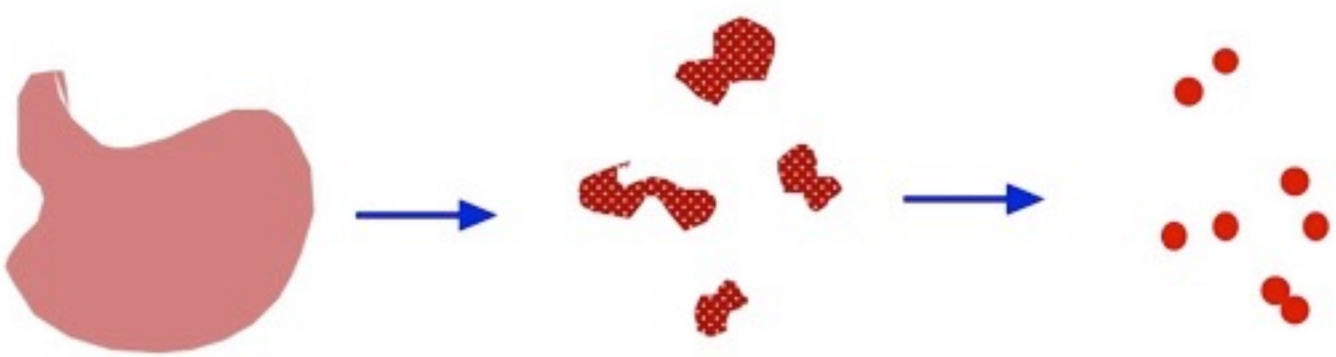
Giant molecular clouds have filamentary structures (kind of like Cirrus clouds on Earth): denser parts are called clumps and even denser parts are cores

Star formation occurs within the densest regions: *cores*

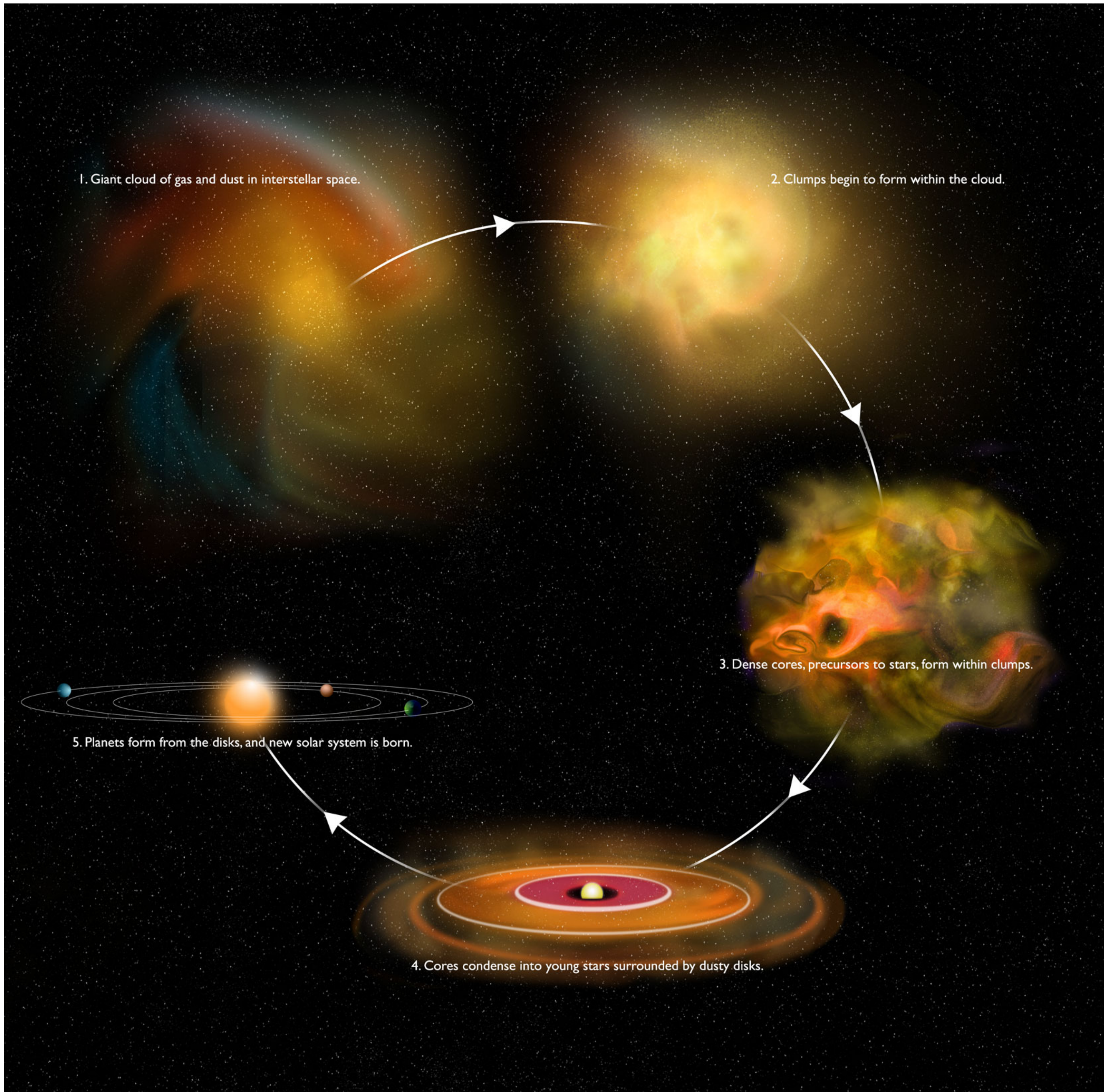


Gravitational collapse

- How do you initiate the collapse?
  - **increase density** (kick the cloud)
    - **cloud collisions**
    - **stellar wind sweeping**
    - **nearby supernovae**
    - **turbulence within the cloud (like a super bumpy airplane ride)**
  - **fragmentation**
    - **initial collapse of large cloud (M>300 Msun)**
    - **density increases**
    - **smaller fragments begin their own collapse**
    - **a star cluster?**

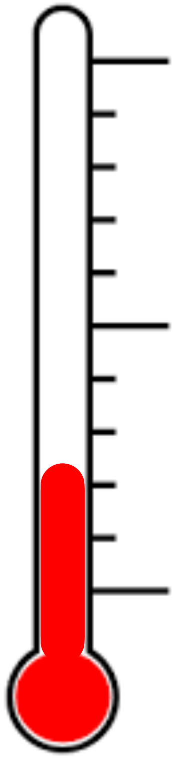


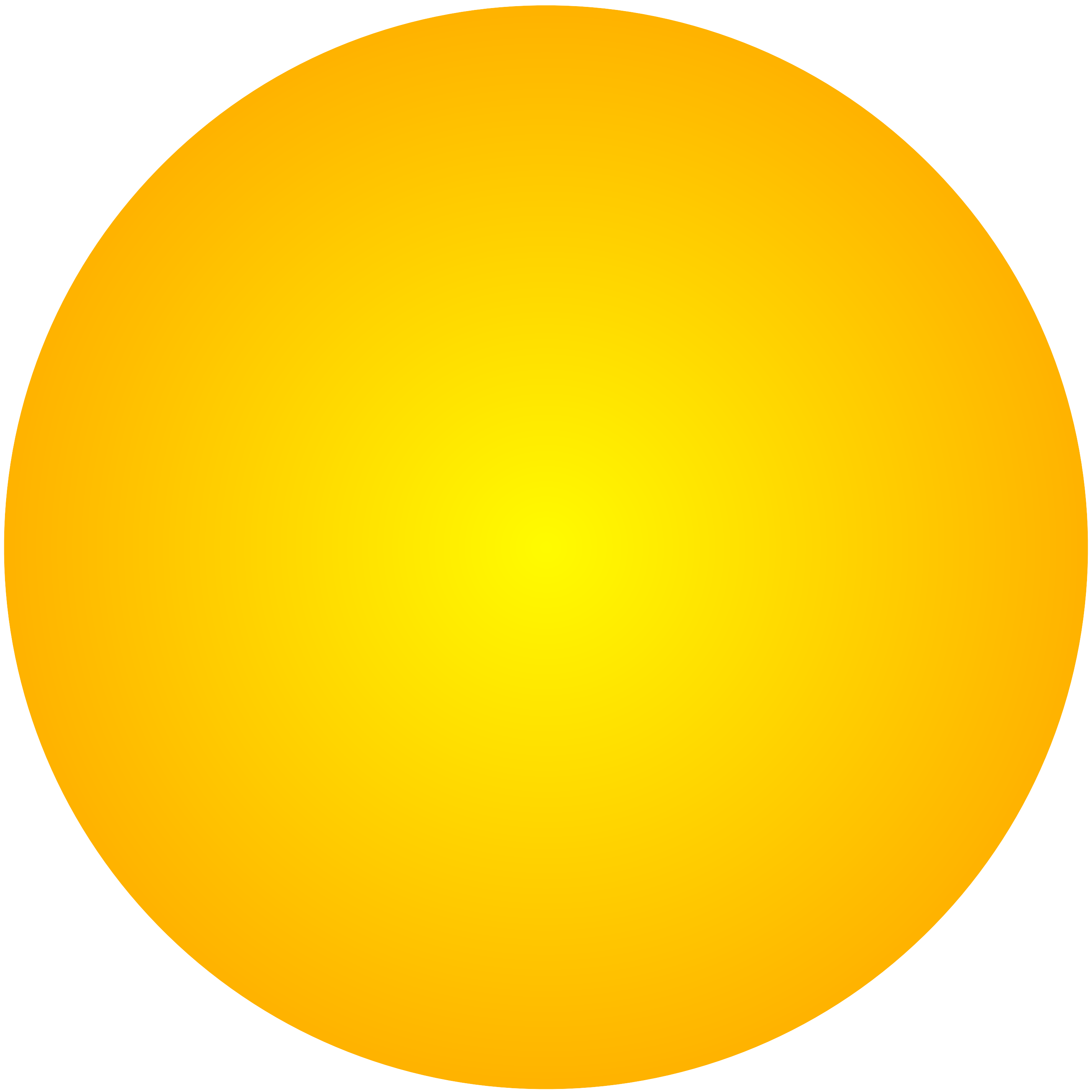
After collapse: protostar surrounded by a disk



Bill Saxton, NRAO/AUI/NSF

Protostar shines not from nuclear fusion but from gravitational contraction!





Many details still to be understood