Chapter 16: Star Formation

- What force makes stars? **Gravity!** Out of what? Interstellar gas and dust
- But this stuff is VERY low density… a dense area may have ~100 atoms / cm^3. Compare that the air you're breathing… $\sim 10^{20}$ atoms/cm^3!
- Dense, cold areas are also where atoms are most likely to collide and form molecules – Stars usually form within **giant molecular clouds**

Environments Suitable for Star Formation…

- Requires **high density**, and **low temperatures** to initiate gravitational collapse
- High Density? – to amplify self-gravity
- Low Temperature? – to insure pressure, which fights gravity, is low. A hot gas will expand, right?
- **And dust helps too**, Dust? – to shield out high energy photons, especially UV photons, which would heat the gas

And… Molecules Needed Too

- Why? Because molecules have lots of ways that they can absorb collisional energy and radiate away that energy as infrared light, which can escape through the dust
- So, the **<u>molecules enable the cloud to cool efficiently</u>** – molecules are coolants, in this environment
- And cooler clouds will collapse quicker under gravity, as we already explained.

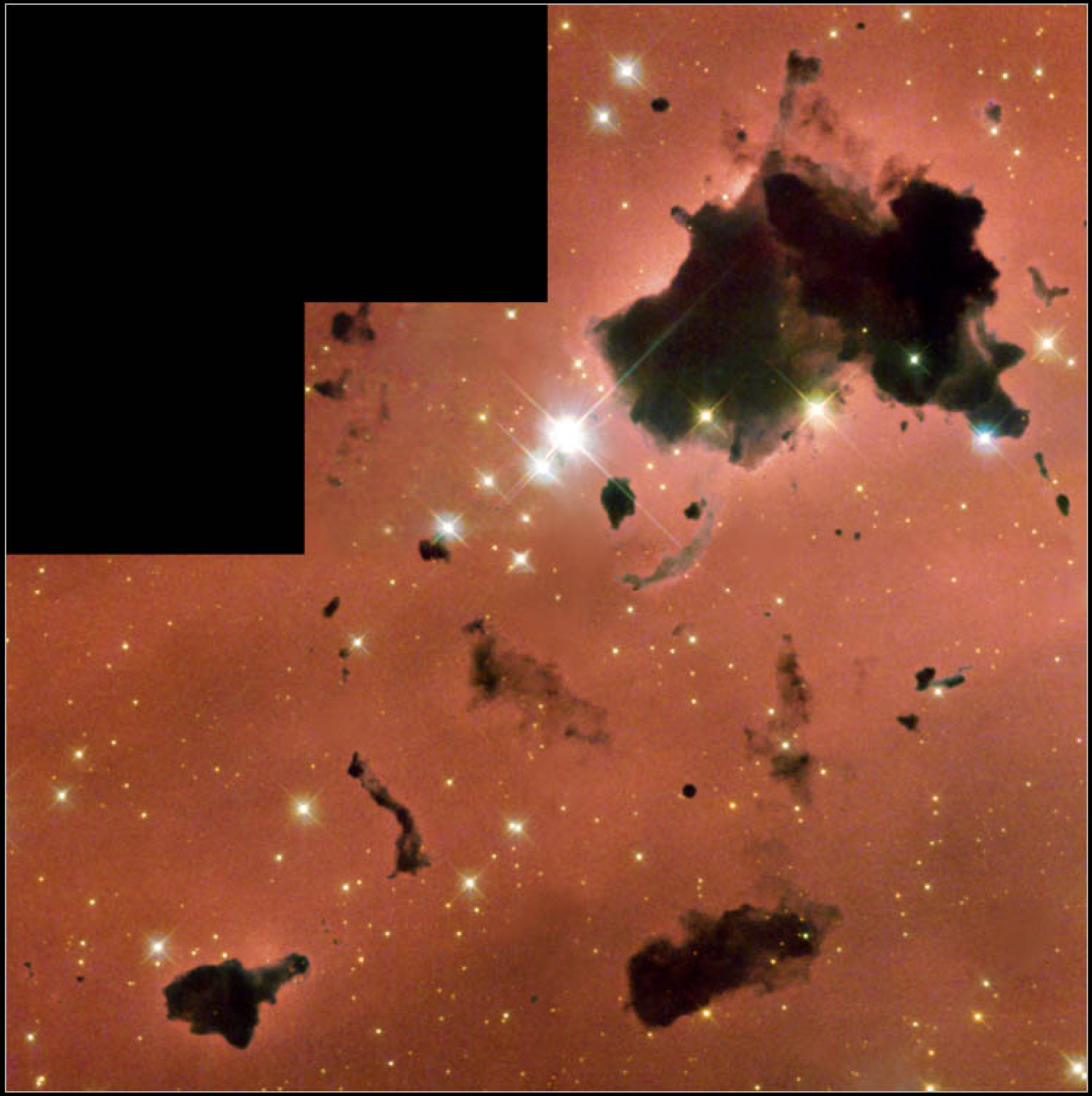
The Star Formation Sequence…

- Shock wave (from nearby Supernova, or spiral density wave, or massive stellar winds from outside the cloud perhaps) piles up gas/dust to high density
- Molecules help it cool
- Gravity pulls it together to a proto-star
- Center is opaque, trapping the heat and light which can escape only slowly
- …Raising temperature in the core until…
- Hydrogen fusion begins at temperature of ~10 million Kelvin
- Fusion creates light, whose pressure fights against gravity, stabilizing the star against further collapse
- A star is born!

Dark Globules in Emission Nebulae – are Where Stars Are Forming Today

- Stars only form in the DENSE, DARK places on the following slides.
- THIS is where it is cool enough for gravity to pull things together
- The outer edge of these dark globules is sharp because UV light from nearby stars is eroding away the dust from the surface inwards

Thackeray's Globules in IC 2944



Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC02-01

Keyhole Nebula

Hubble Heritage

NASA and The Hubble Heritage Team (STScI) • Hubble Space Telescope WFPC2 • STScI-PRC00-06

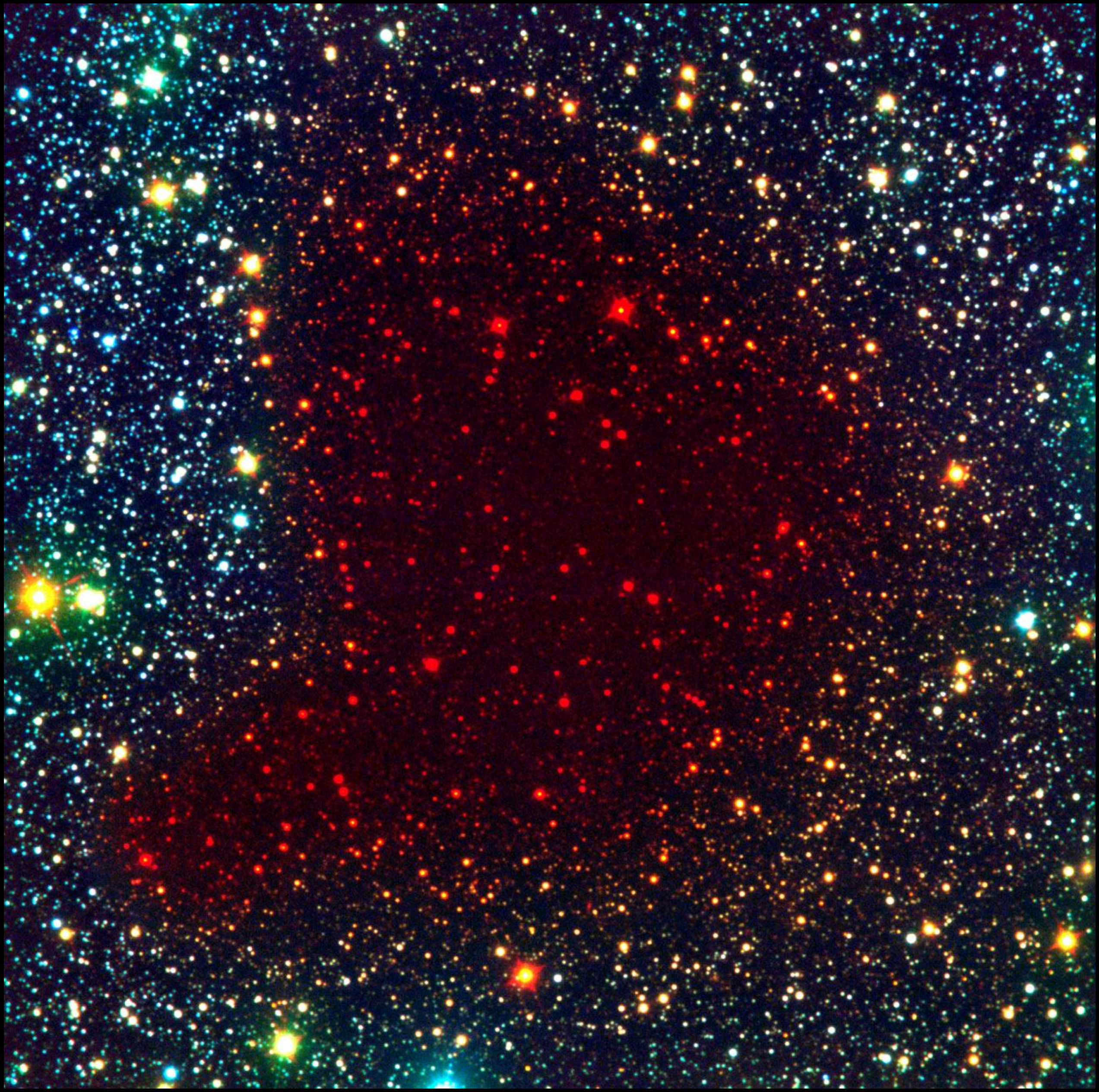
Horsehead Nebula

Hubble Heritage

Interstellar Reddening

- Starlight passing through a dust cloud will preferentially have the shorter (bluer) wavelengths scattered out, leaving the redder light to pass through for you to see
- You see the same thing every day, as the setting sun is reddened by dust in our own atmosphere
- Not to be confused with redSHIFT, which is a CHANGE in wavelength for all wavelengths in an objects spectrum, due to motion

Interstellar Reddening of Stars Behind this Dusty Cloud



Stars: Nearly Always Born in Star Clusters

- Achieving low temperature requires shielding from the radiation of other stars;
- This requires dust, which blocks all wavelengths, not just those few causing absorption, as a gas does.
- But that means you need a MASSIVE interstellar cloud which requires a lot of mass, since dust is only a few percent at most of any interstellar cloud
- Star clusters forming in today's environment are called "open star clusters", dozens to hundreds of stars

UV from the Star Cluster at Left, Plowing a Shock Wave into the Hydrogen to the Right. Compression Might Later Enable Star Formation in the Newly Dense Gas/Dust

Same Story here

N11B in the Large Magellanic Cloud

Hubble Heritage

Eagle Nebula
M16

Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-12b

The "Pillars of Creation" Dense dust where stars are still forming, but being eroded by UV light from already formed stars above

Dust/gas disks around newly forming stars: Proto-solar systems in Orion

Open *vs.* Globular Star Clusters

- **Open clusters**: few hundred scattered stars. Young, because they usually evaporate within a few hundred million years. Made out of the current interstellar material – about 3% heavy elements (rest is H and He)
- **Globulars:** few hundred THOUSAND stars. OLD; oldest date-able objects in the Galaxy, made of almost pure H and He.

Messier 80 – A Globular Cluster in Scorpius

But Globular Clusters are WAY more massive, and older

- Massive! Require entire galaxies to collide to produce these.
- A few hundred thousand to a million stars!
- So our Milky Way’s globulars are all ancient, dating back to the birth of the Galaxy shortly after the Big Bang
- At that time the universe was made of only H and He, essentially no heavy elements

What do the colors of Nebulae Mean?

- Dense, opaque dust will be black; can't see through it and it doesn't reflect light well, just absorbs it
- Thin dust is about the same size as cigarette smoke, about the same as the wavelengths of visible light. Will scatter bluer light better than redder light, so **thin dust lit up from the side will glow blue**
- **Red clouds are virtually always hydrogen** – H-alpha emission

Green?

- Twice ionized oxygen has a strong emission line in the green part of the spectrum, excited by light from hot objects like new stars. If there's significant oxygen around, you may see some green nebulosity as well

Hot young stars clear bubble in core of Rosette Nebula

Hubble

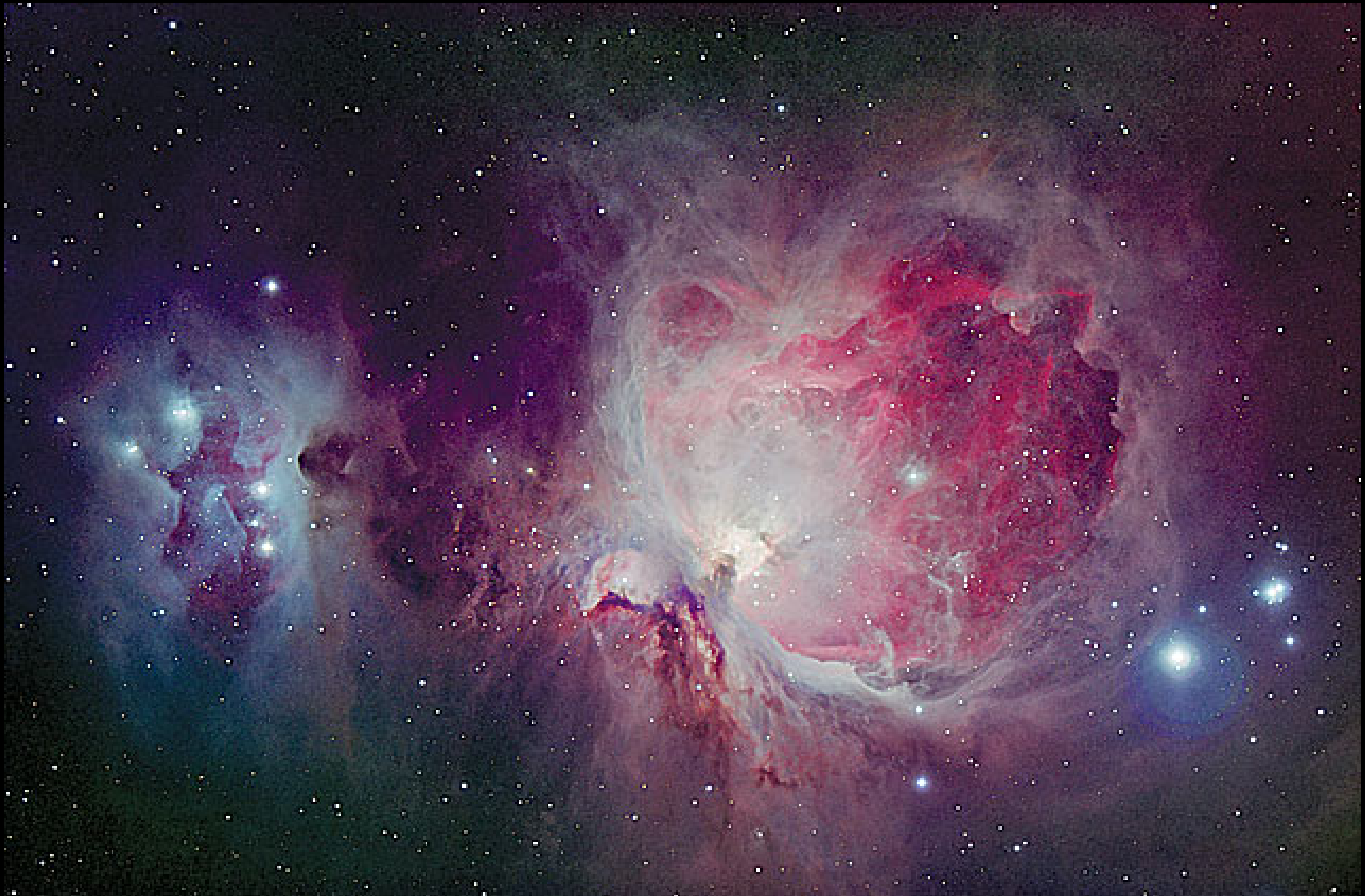
new star cluster, stellar winds clear hydrogen away

Small cluster blows bubble in larger dust cloud.
Background galaxy on left

Dust scatters blue light from hot stars above picture frame, hydrogen gas (red) already blown and piled up farther down

Small cluster creates bubble in gas/dust cloud

The Orion Nebula. Red H-alpha emissions, dust nebula scatters blue light



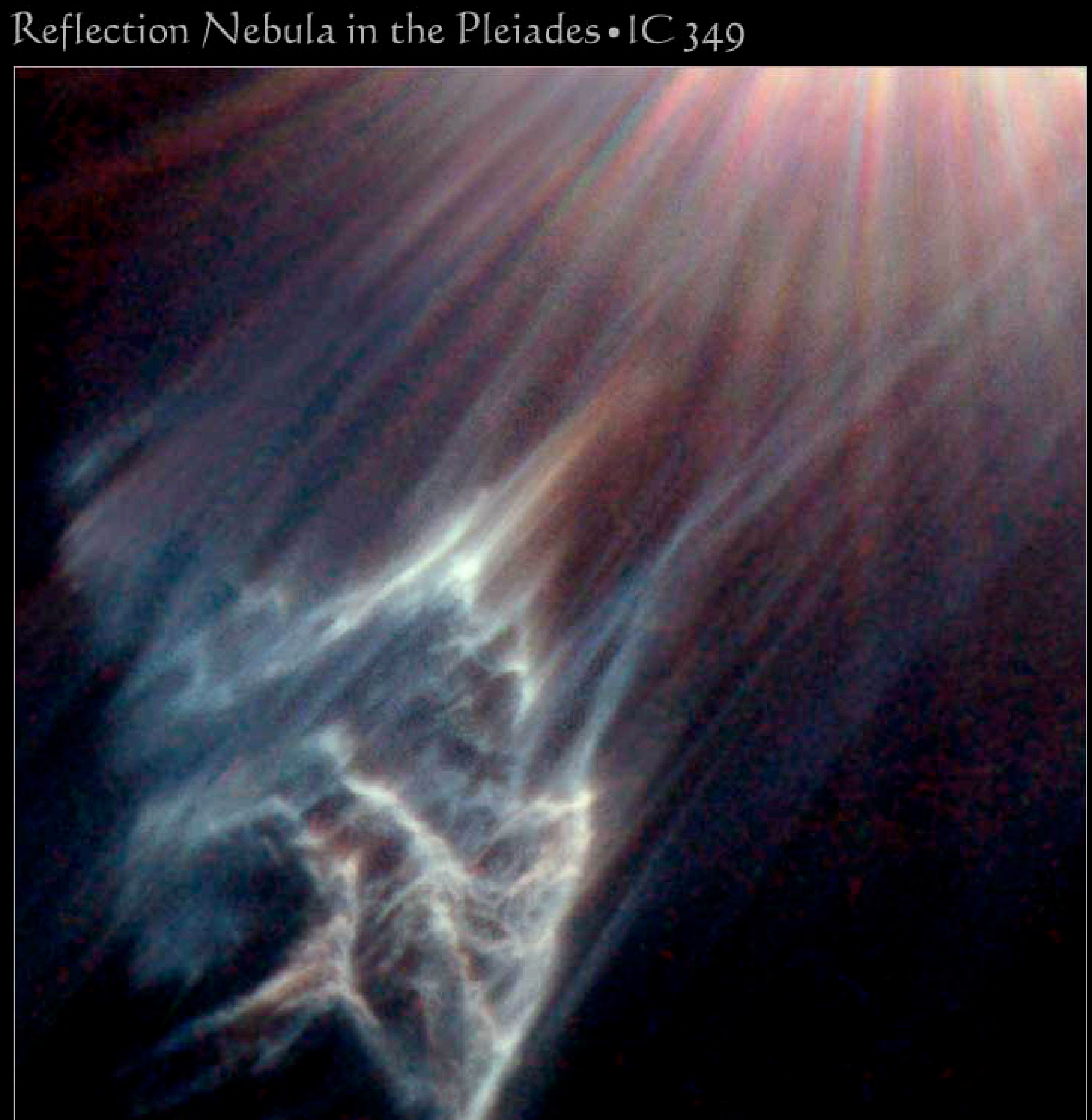
How do nebulae respond to light?

- Photons of light have momentum, they impact atoms and push them away. Atoms are easy to move as they're very low mass
- Photons will also push on dust, but a dust grain is millions of atoms, like a massive boulder compared to atoms, and much harder to push around.
- Therefore, as star clusters age, they push away the "after birth" of gas quickly, and only later the heavier dust. So you see blue glow surrounding open star clusters when the gas is gone but dust is still there
- Later, even the dust is gone – then just an open cluster is left

So the Full Sequence of Star Birth to Adulthood Looks Something Like This…

- Giant Molecular Cloud, to
- Emission Nebula as stars form and shine on hydrogen gas
- To Dust Reflection Nebula as hydrogen and other gas blown away early on by stellar winds
- To Open Star Cluster with no gas **or** dust left over
- To Stellar Association as cluster stars drift apart
- To individual stars scattered widely and not clustered any longer (like the sun today)

The Plieades, a Cluster and Reflection (dust) Nebula. About 100 million years old. Hydrogen gas blown away by now



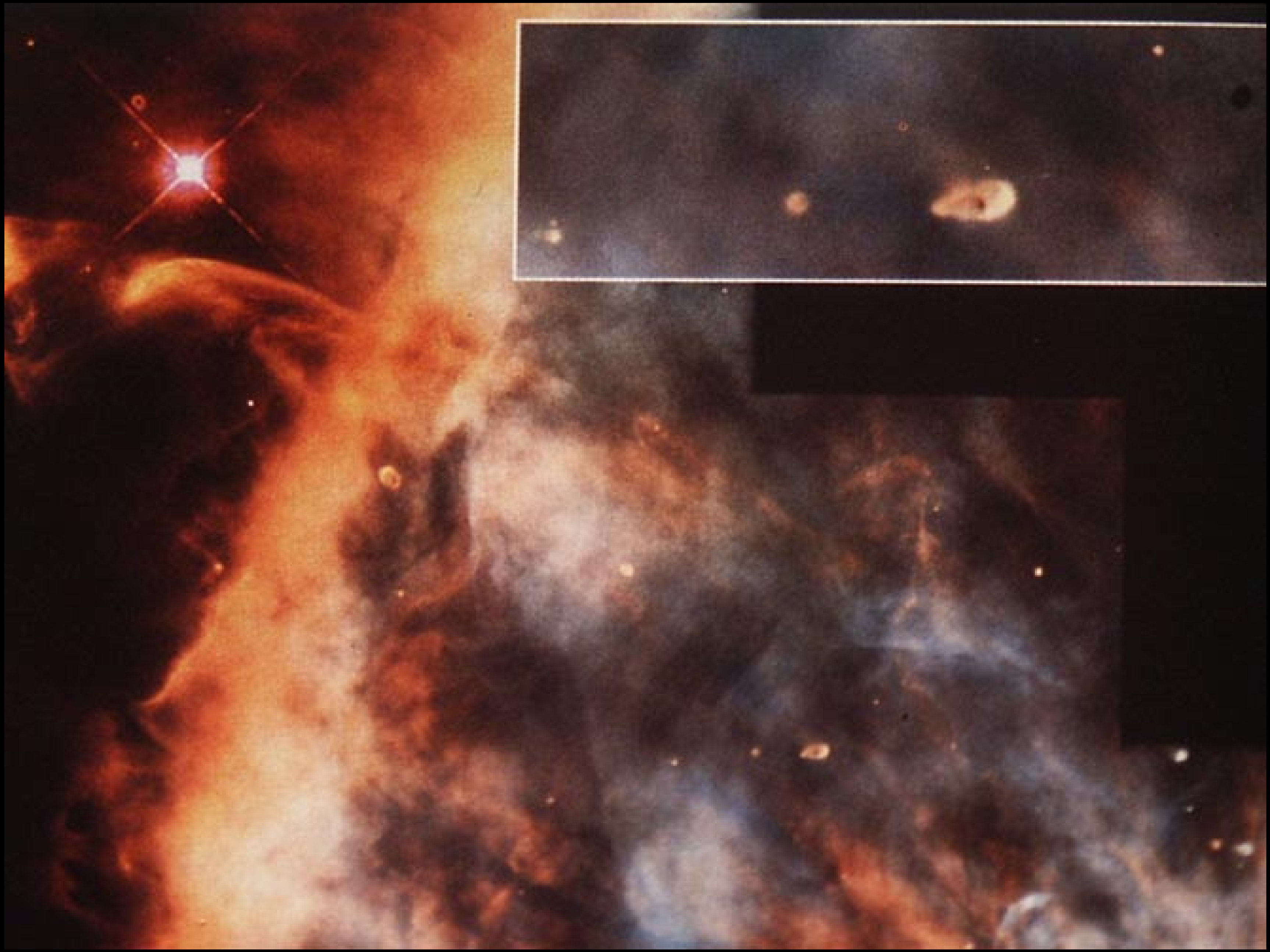
Close-up of a spooky dust cloud in the Plieades

The Witches Head Nebula; Dust Being Lit by Orion's Brilliant Star Rigel

New Open Cluster, Just a bit of Dust Left


© Anglo-Australian Observatory

Dusty proto-planetary disks in Orion



Bow Shock Around LL Orionis

Bipolar flows: common from new stars / solar systems in formation

Our Solar System Apparently Formed After a Blast Wave from a Supernova Compressed a Giant Molecular Cloud

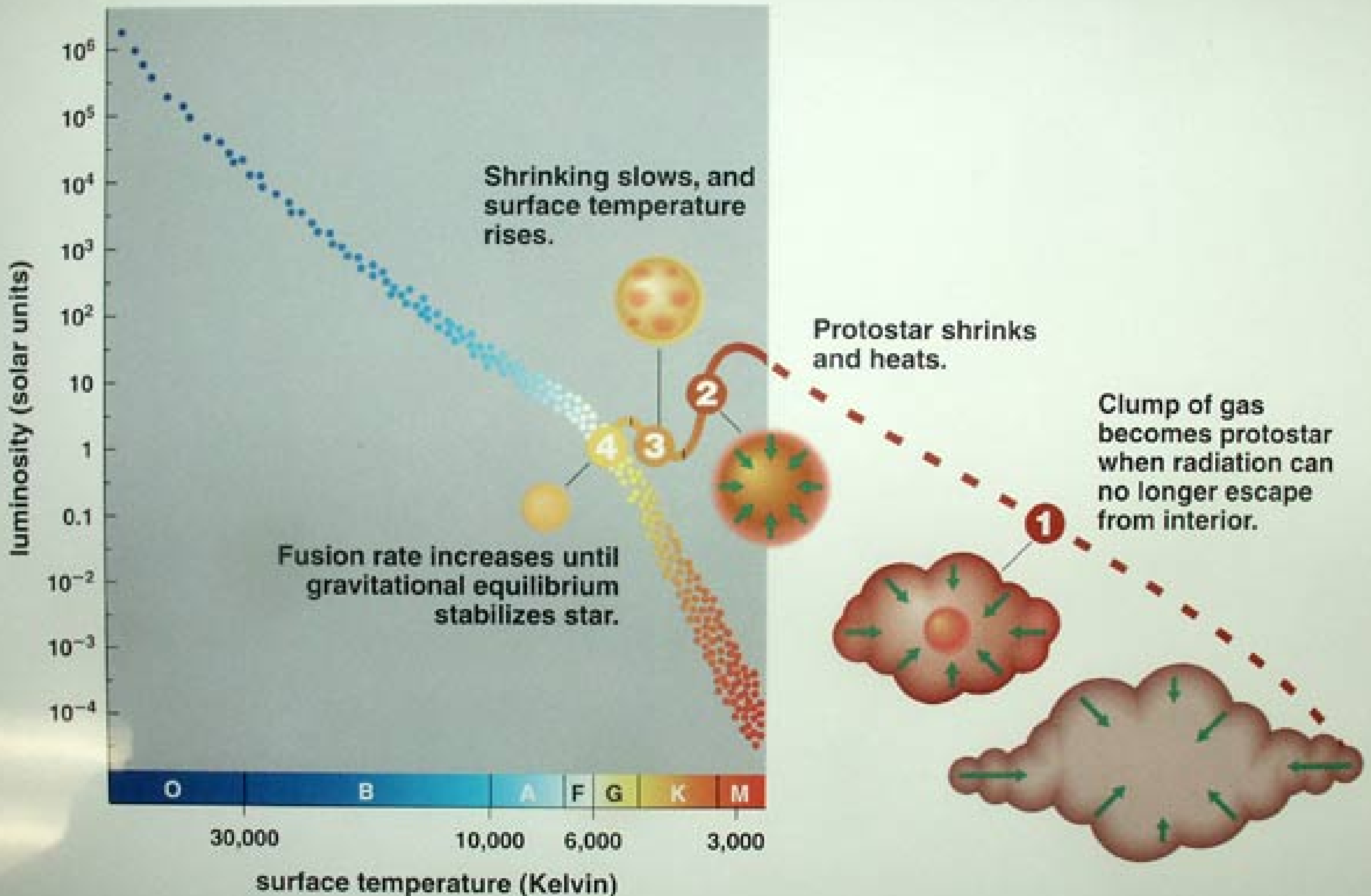
- **Evidence**: Mg ^{26} far above standard levels, within the body of meteorites. Mg ^{26} is the daughter product of Al ^{26}, a radioactive element created in supernova explosions.
- **Indicates:** A supernova went off nearby, seeding the solar system with Al ^{26} while the material which makes meteorites was still molten or at least not a solid – indicating it was at the birth of the solar system. This Al ^{26} decayed within a few million years to Mg ^{26} which we see today.
- Iron and a few other elemental isotopes also tell a similar story

- That’s just a tease… if you want the BIG story of solar system formation, and ours in particular, then take **Astro 3**, in the Fall

How Does a Star Stabilize?

- Stars heat up as gravity compresses and heats their gas, which continues until the core gets hot enough to produce nuclear fusion.
- By then, the core is very dense, far denser than water, and the heat can't get out easily or quickly, so collapse by now is very slow.
- This new energy source provides pressure which stabilizes (after some wiggling around) the star against further collapse for the time being

Figure 14.5 The life track of a $1M_{Sun}$ star from protostar to main-sequence star

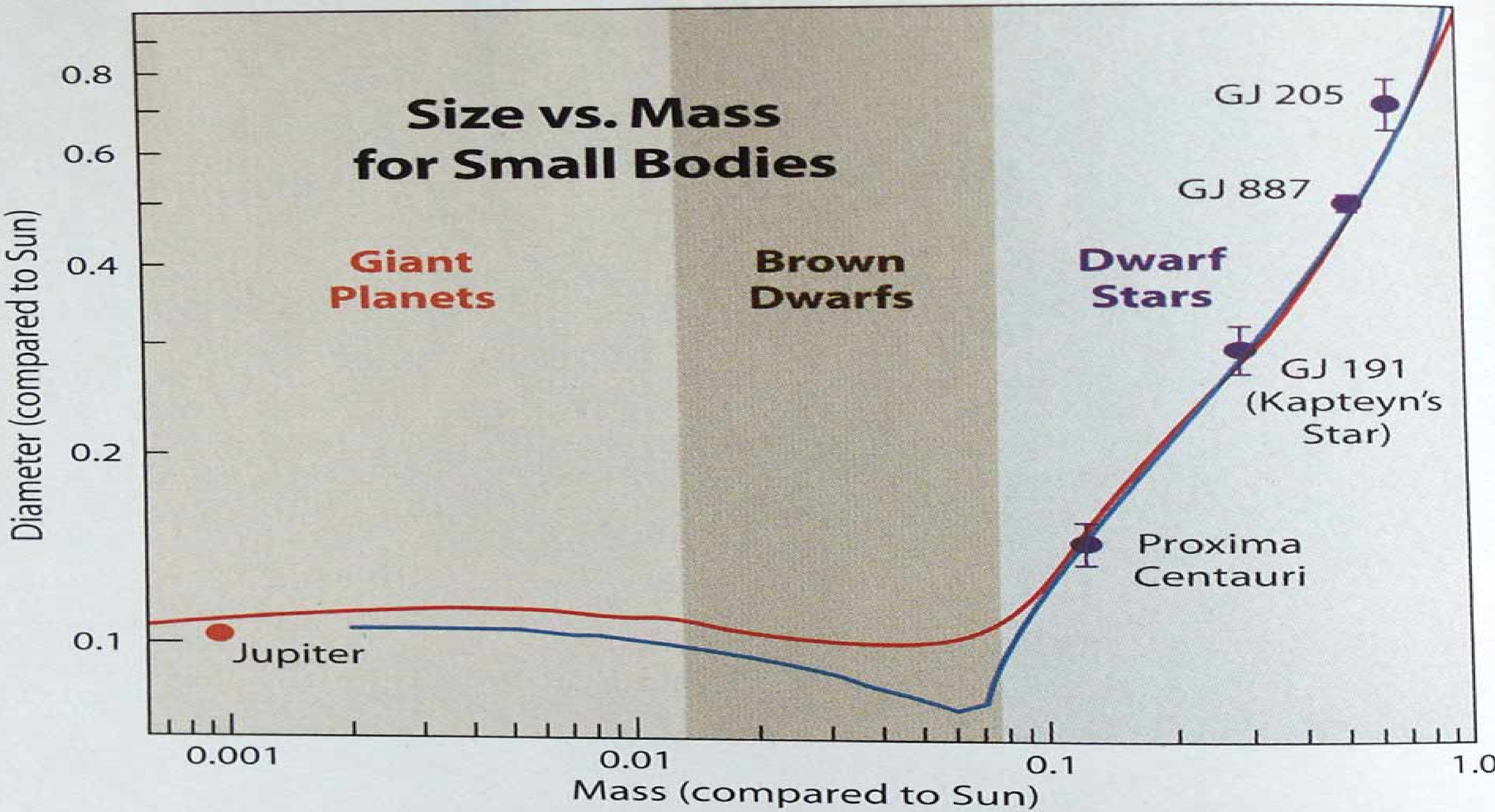


What are the Limits of a Star's Mass?

- Stars below 0.08 solar masses don't have enough gravity to heat their core hot enough to fuse Hydrogen
- Stars above about 150 solar masses have such vast luminosities that the pressure of their own light will drive off their outer atmosphere and also prevent any infall from outside.
- So stars are all 0.08 to roughly ~150 solar masses

Brown Dwarfs

- …Are "failed stars". Not massive enough to fuse hydrogen, but still shining dimly in the visible and more in the infrared by tapping their gravitational potential energy
- It's not clear how common Brown Dwarfs are (too faint to see except VERY nearby), but Red Dwarfs (true stars, and a little more massive) are the most common stars in the Galaxy. Most of the stars in a given volume of the Galaxy will be Red Dwarfs, the evidence suggests



Theory predicts that red-dwarf stars, brown dwarfs, and giant planets will have very specific sizes depending on their masses. The curves show the predicted size-mass relation for objects 400 million years old (red line) and 5 billion years old (blue line). The four red dwarfs with sizes measured by the VLT Interferometer fall on or near these lines. Objects ranging from 1 to 100 Jupiter masses should all

Key Points: Star Formation

- Star formation requires: High density and LOW temperature plus Dust, and Molecules
- 2-3 stars are born per year, in our Milky Way Galaxy
- Molecules are coolants, helping lower pressure and aiding gravity in collapse
- Dust needed for shielding out hot UV light from nearby stars
- Requires hundreds of solar masses to insure enough dust to accomplish shielding, so star formation nearly always results in an **Open Star Cluster**
- Supernova blast waves near clouds can initiate star formation (happened for our own sun, from SNe produced radioactive daughter products in meteorites)
- Collapse raises density, core cannot radiate away heat gravitational collapse heat fast enough, and temp rises, until H fusion begins at 10 million K
- Fusion provides pressure, balancing gravity, stabilizing star.
- Star clusters lose much of their mass in stellar winds, losing gravity, and cluster stars drift apart, becoming "stellar associations", and then just individual stars
- Globular clusters ~100x more massive than open clusters, and made during formation of the Galaxy. More on them in the chapter on the Milky Way Galaxy