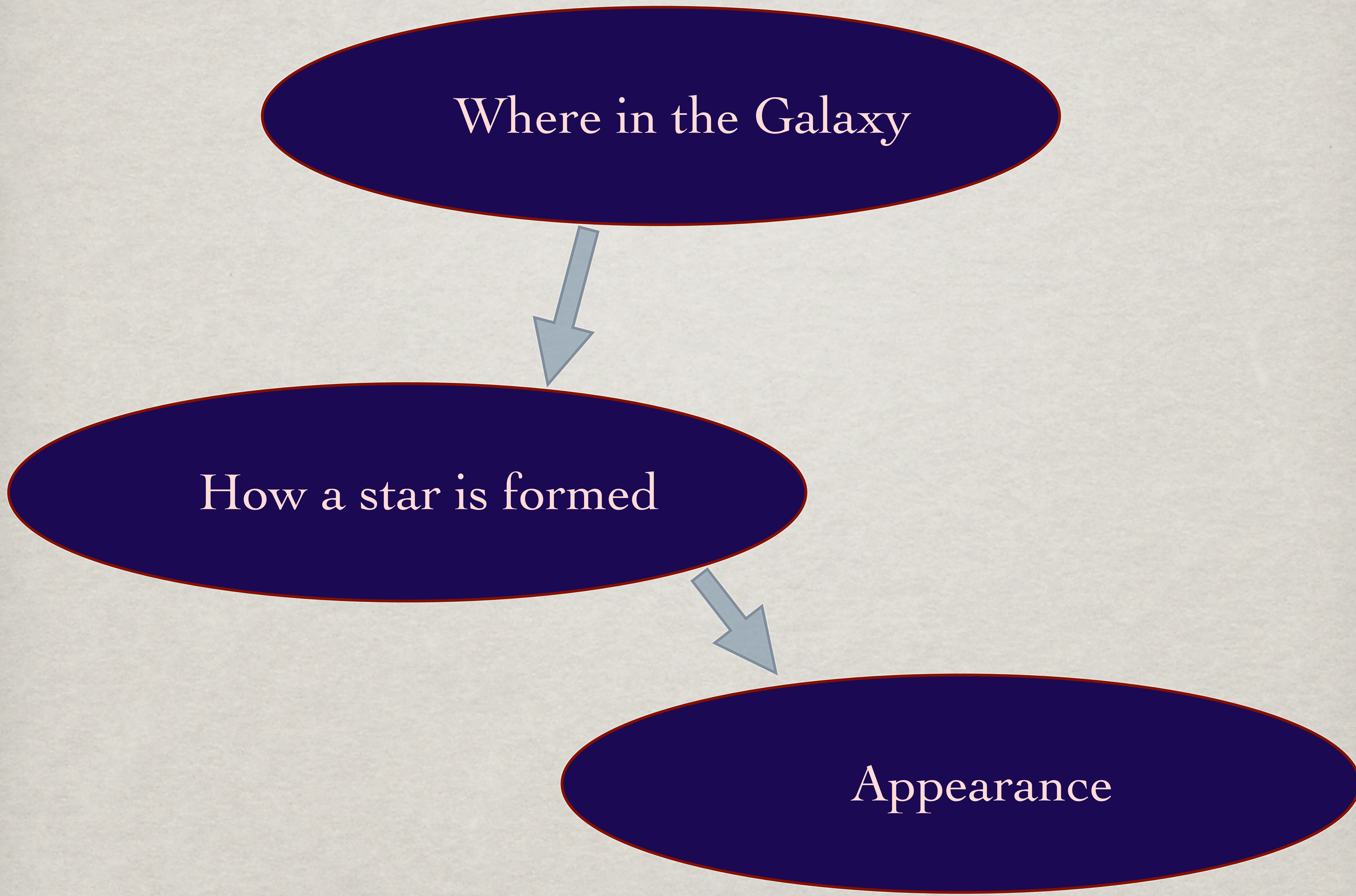
Formation of Stars


Where in the Galaxy
How a star is formed
Appearance

Where in the Galaxy


Where in the Galaxy


Where in the Galaxy


Where in the Galaxy

Where in the Galaxy


Where in the Galaxy

Where in the Galaxy

Where in the Galaxy

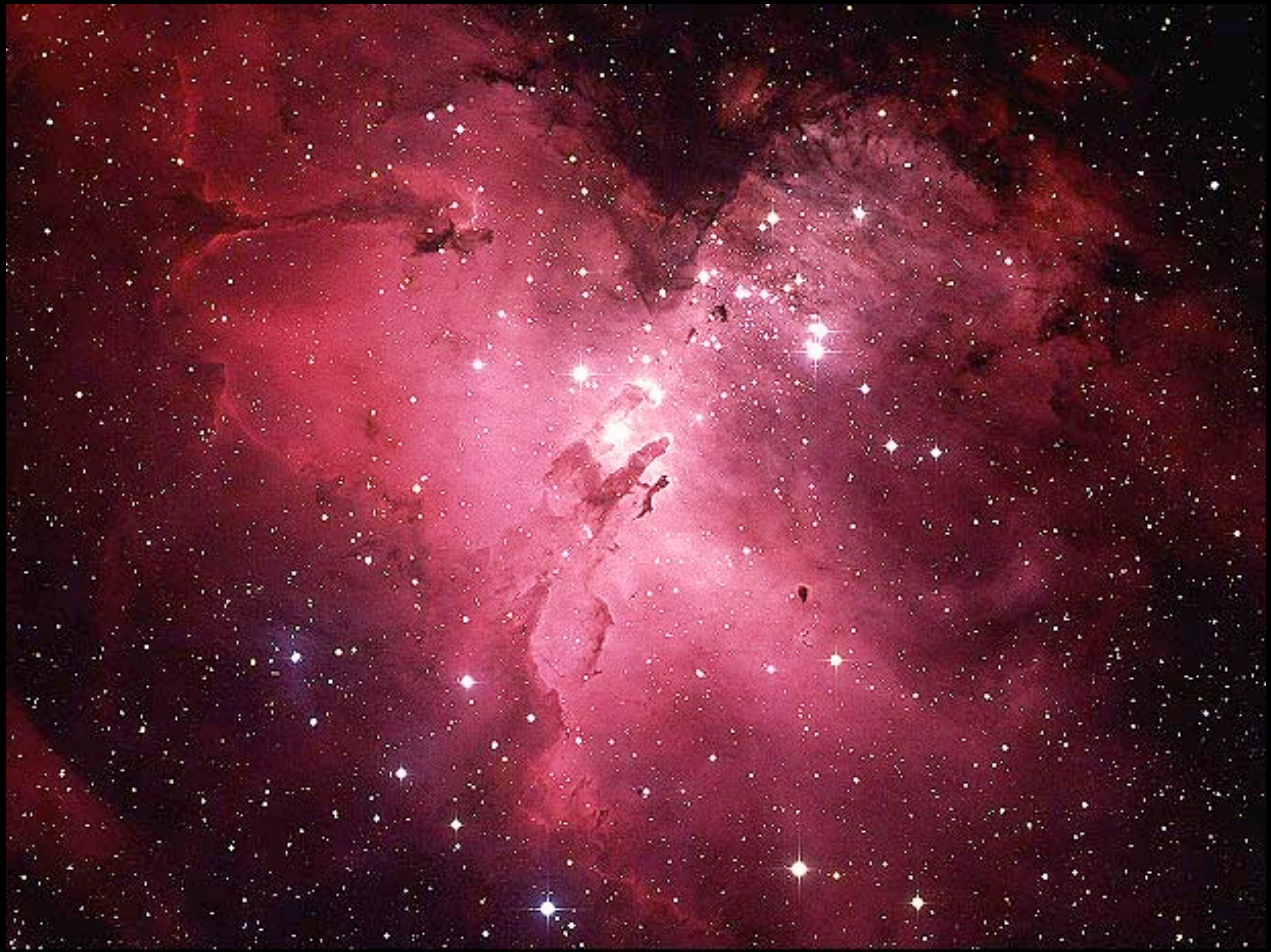
Where in the Galaxy: Giant Molecular Clouds

Carina Nebula

Hubble Heritage

NASA, ESA, N. Smith (University of California, Berkeley), and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope ACS/WFC • STScI-PRC07-16a

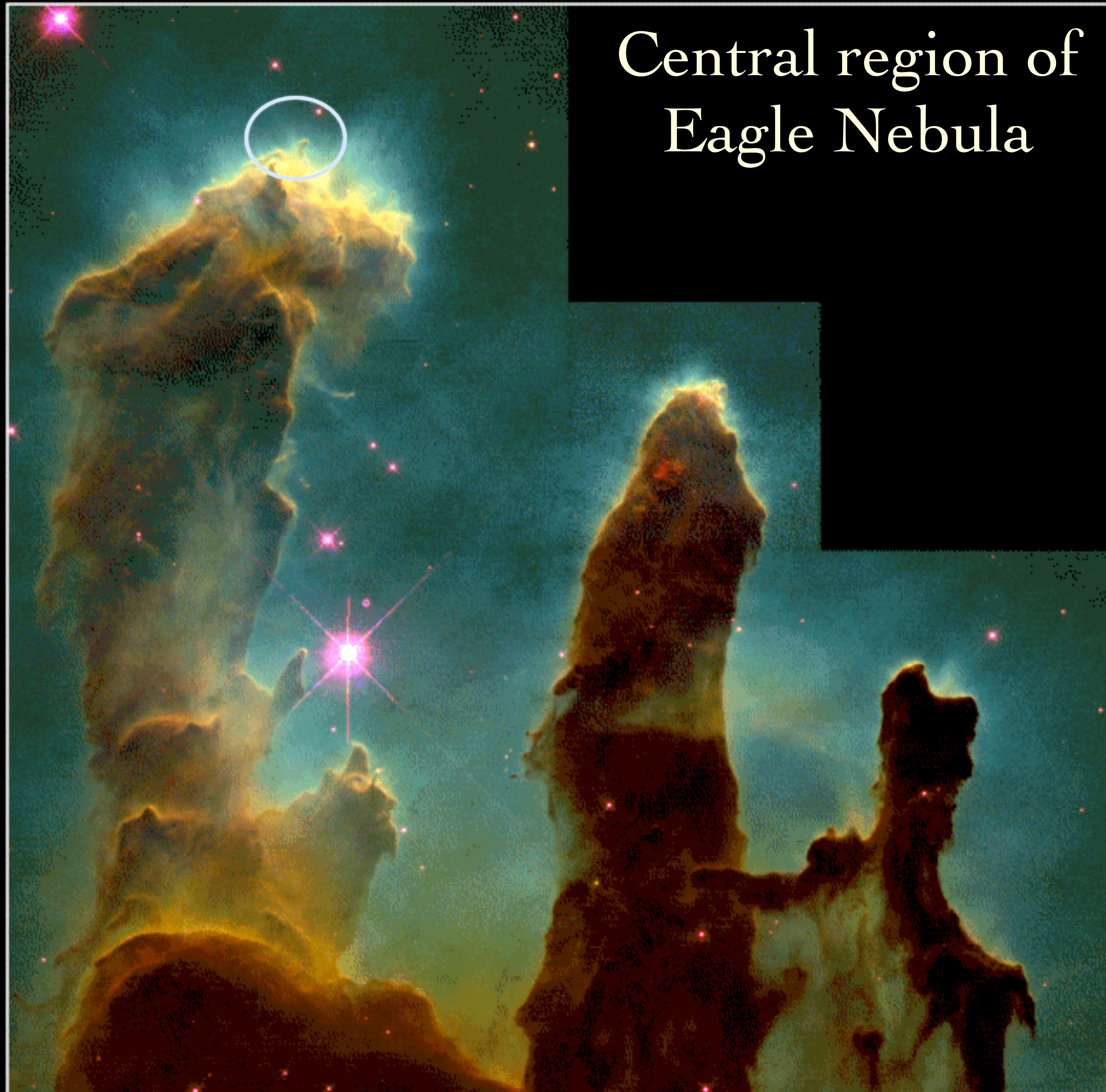
Eagle Nebula



M16 © Anglo-Australian Observatory Photo by David Malin

Gaseous Pillars · M16 HST · WFPC2

PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



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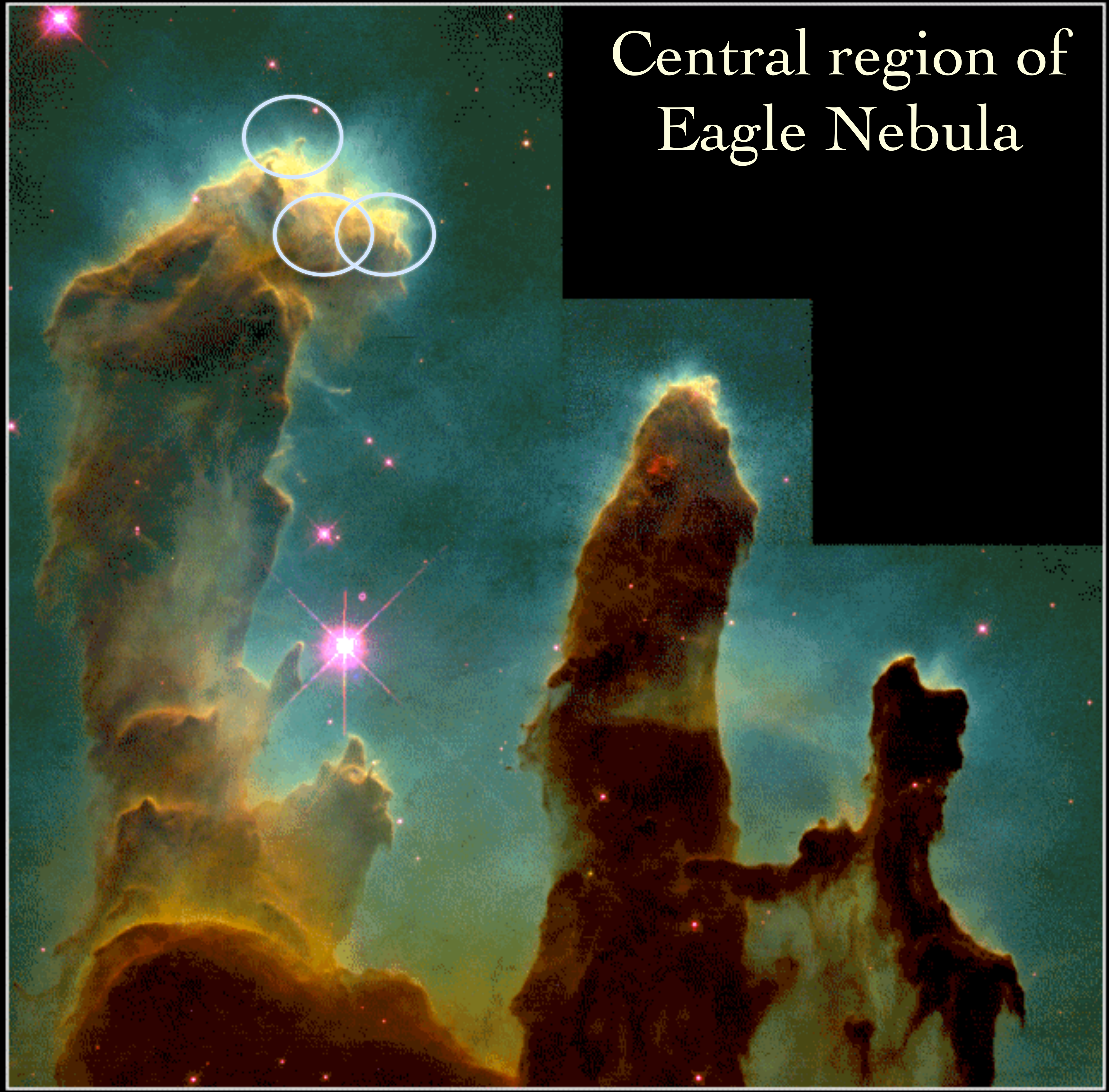

Gaseous Pillars · M16

HST · WFPC2

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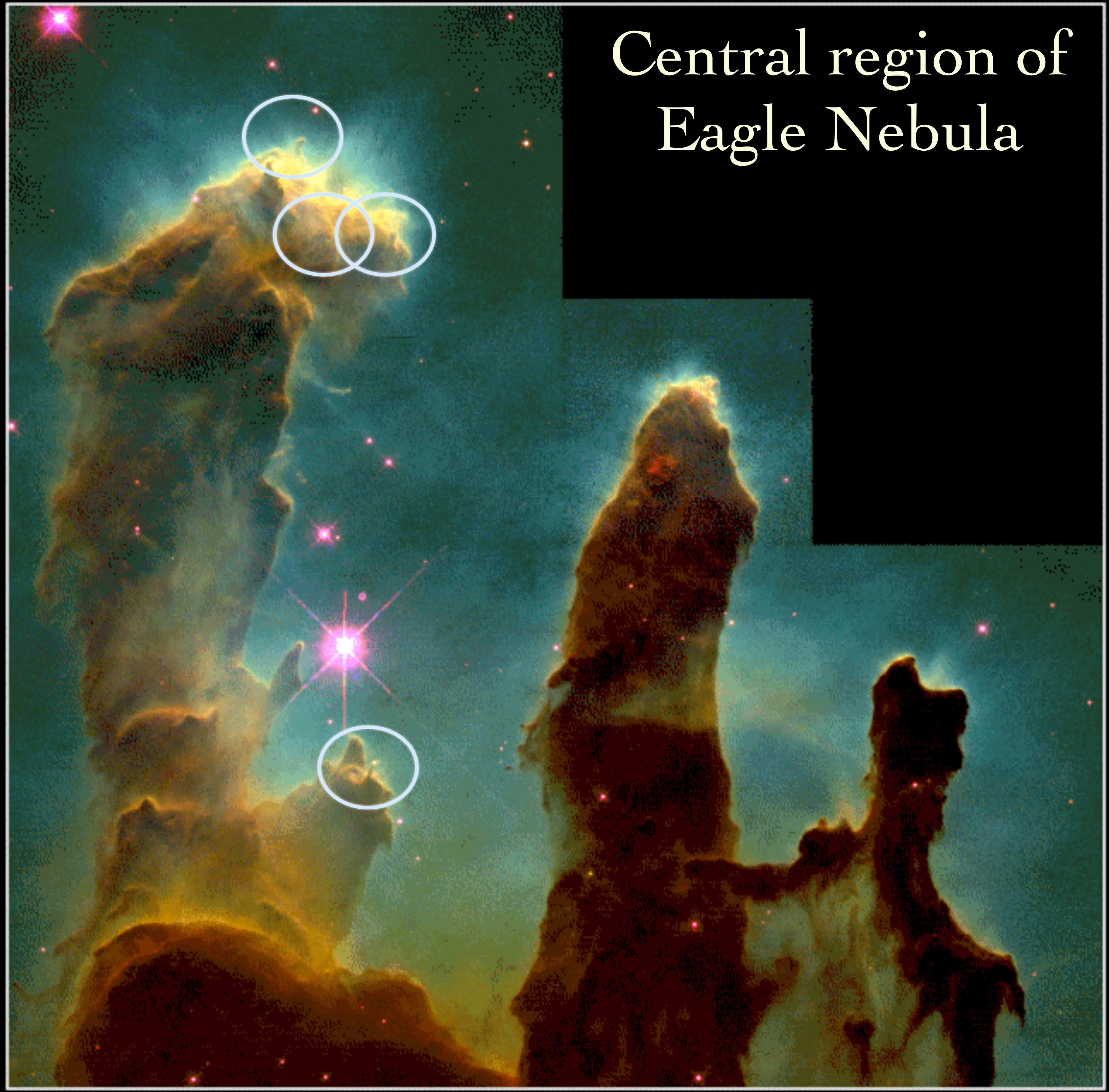
Central region of Eagle Nebula



Gaseous Pillars · M16 HST · WFPC2

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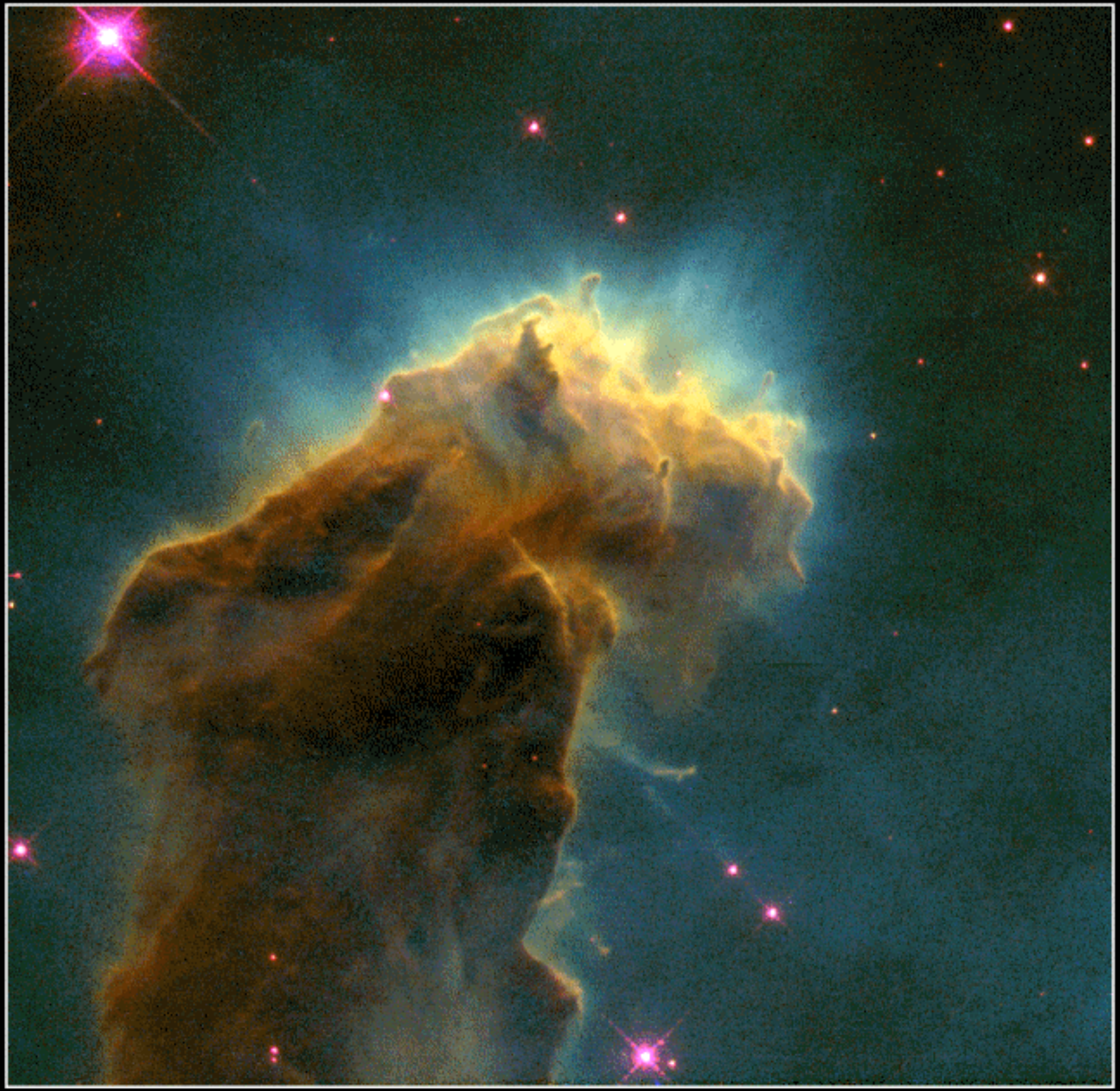

Star-Birth Clouds · M16 HST · WFPC2

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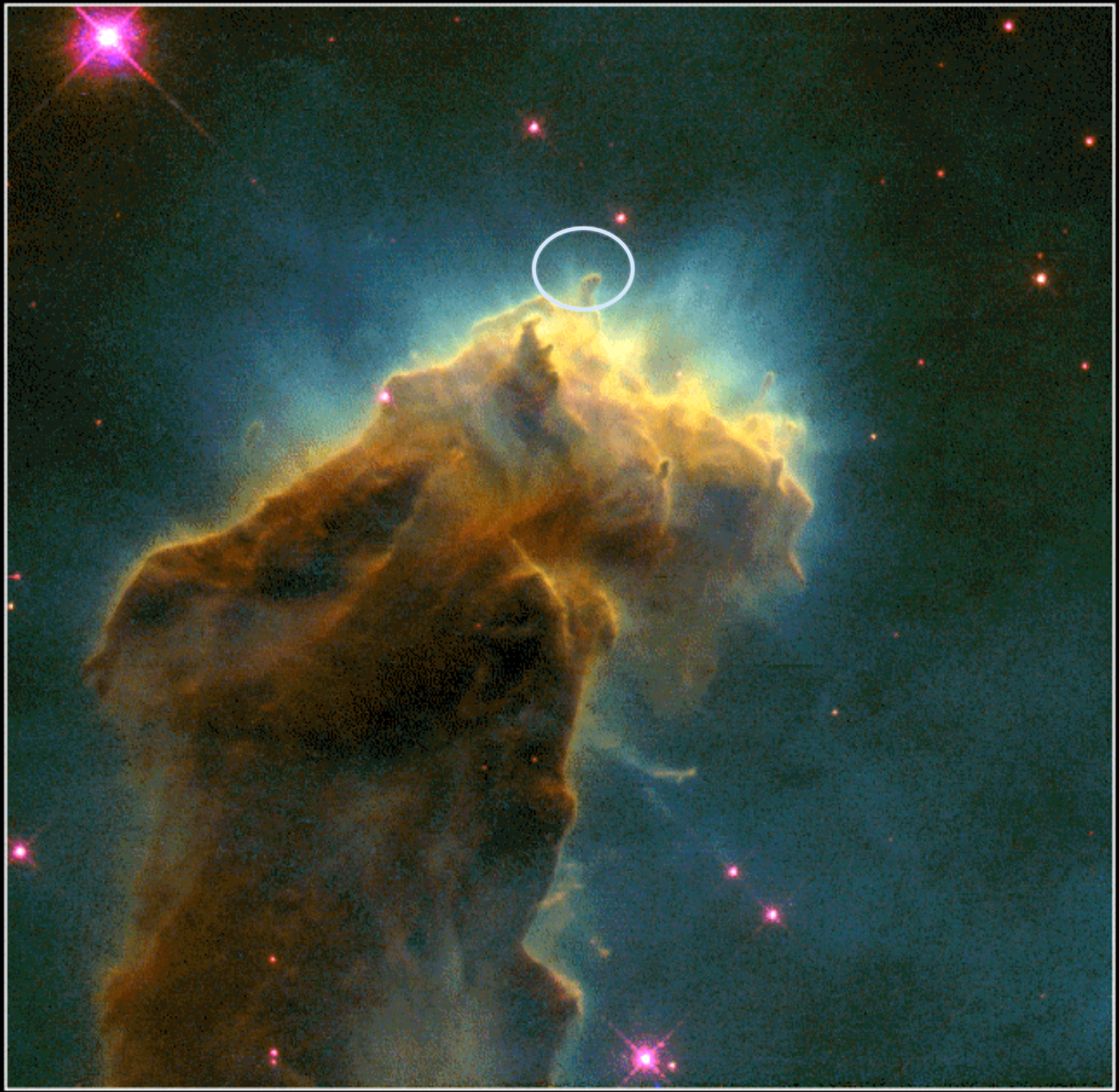
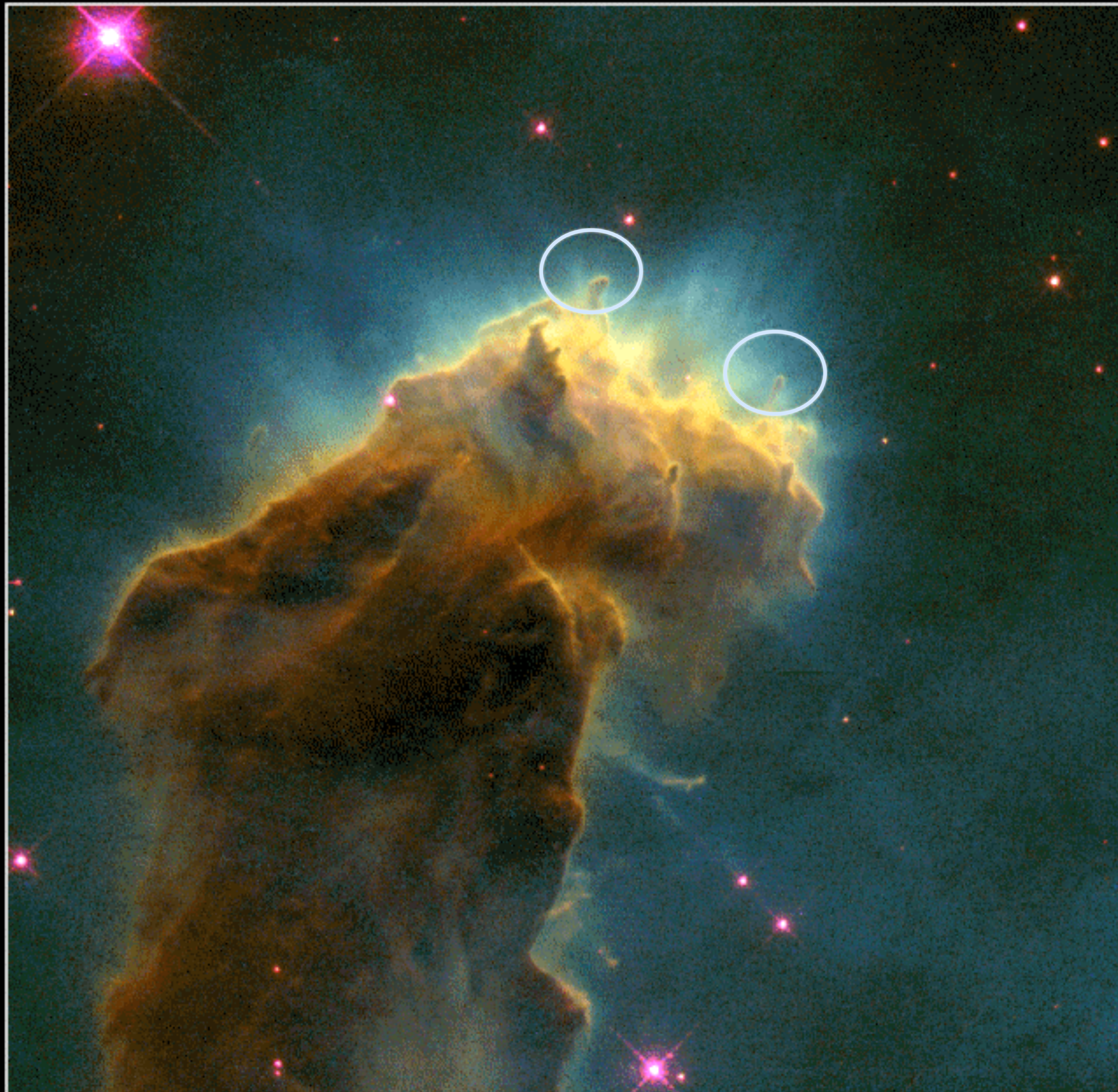


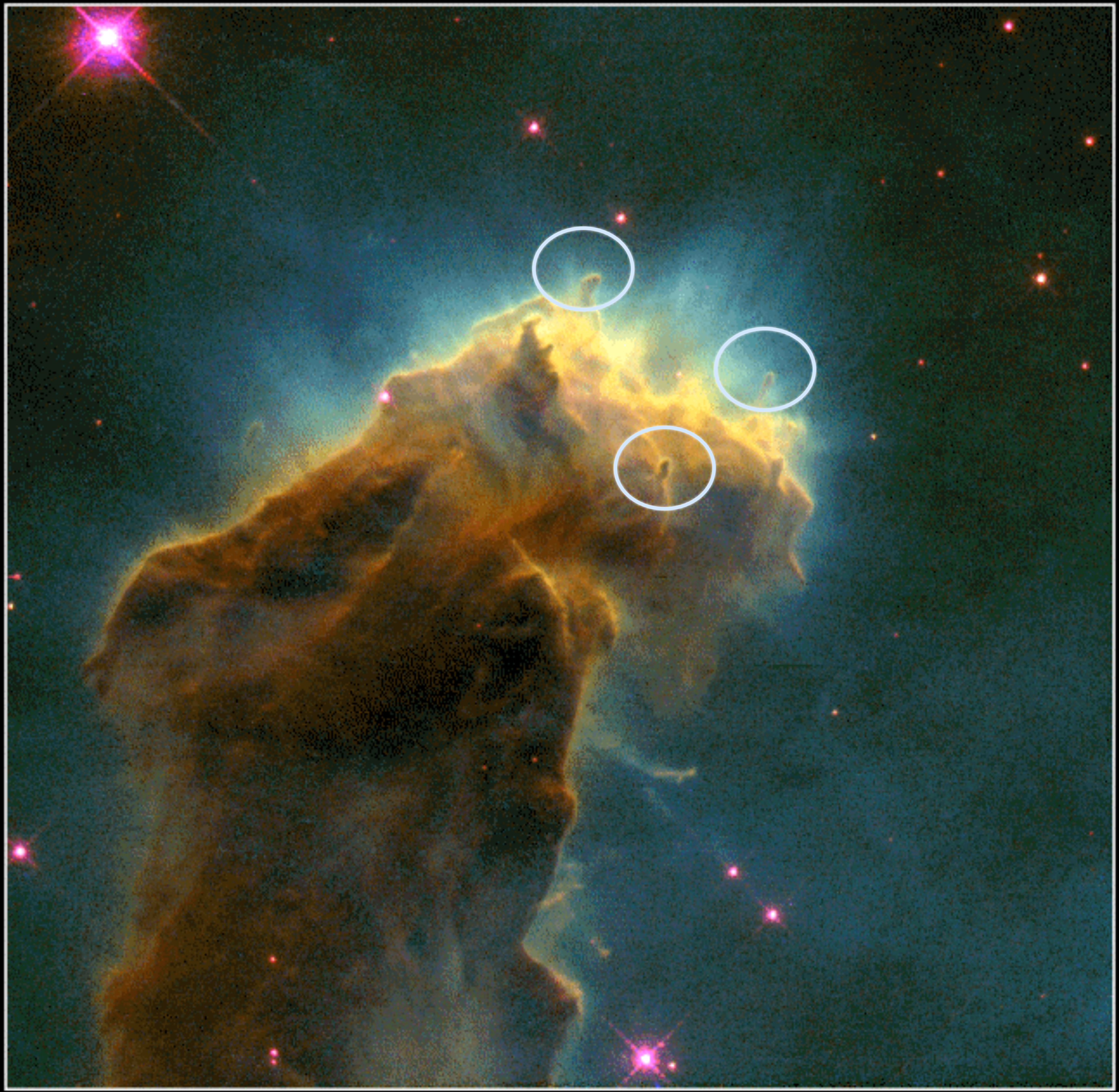
Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA



Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Eagle Nebula
M16

Hubble Heritage

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

- Gravity and energy are the keys to understanding star formation & evolution.

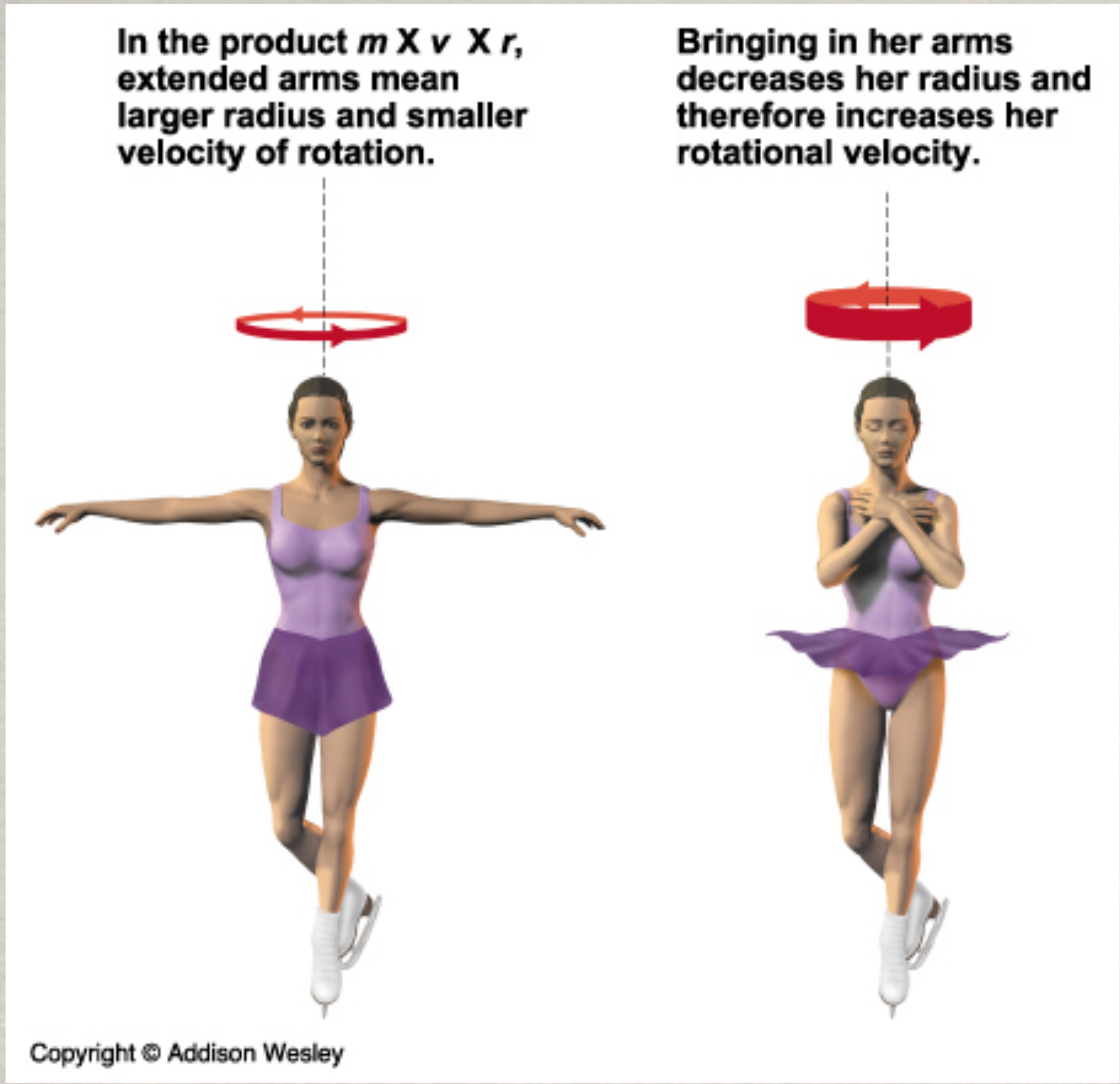
    - **Gravity** is constantly trying to **pull matter toward the center** of mass of a gas cloud or a star.
    - Since stars do not have an infinite supply of energy, they must readjust their structure in response to the energy supply. **Initially, gravitational collapse is the only source of heat.** Later, nuclear reactions power a star; the thermal pressure from the heat at the core balances gravity. When the nuclear energy is exhausted, the star's structure must again change in response to the changing energy balance.

- **Stars begin as roughly spherical, cold (10 K) molecular clouds.** They rotate very slowly. Then, the self-gravity of the cloud causes the gas to contract toward the center, further increasing the density.

Conservation of Angular Momentum plays an important role in the evolution of a star-forming nebula. Angular Momentum (L) is defined as:

$$L = M V R$$

where M = mass of the cloud, V = rotational velocity of the cloud, and R = cloud radius. For an isolated cloud, **angular momentum must be conserved** (that is, remain constant) as the cloud gravitationally collapses. But, for to be constant while is decreasing (and does not change), must increase; thus, **the star must rotate faster as it collapses**.


In the product m X v X r, extended arms mean larger radius and smaller velocity of rotation.
Bringing in her arms decreases her radius and therefore increases her rotational velocity.
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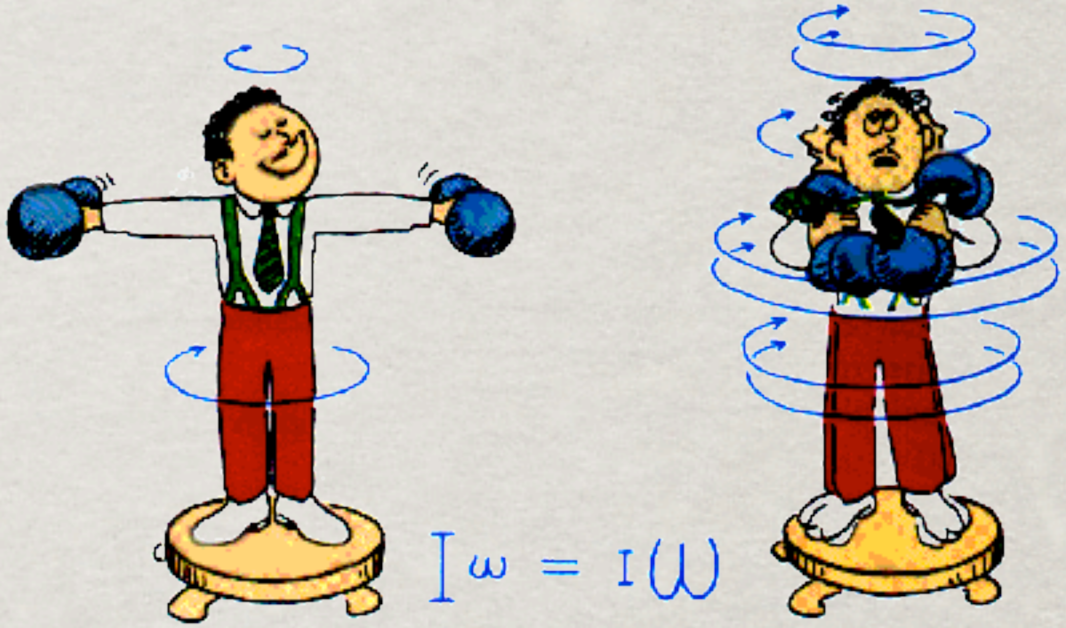

Iω = IΩ

$$L = M V R$$

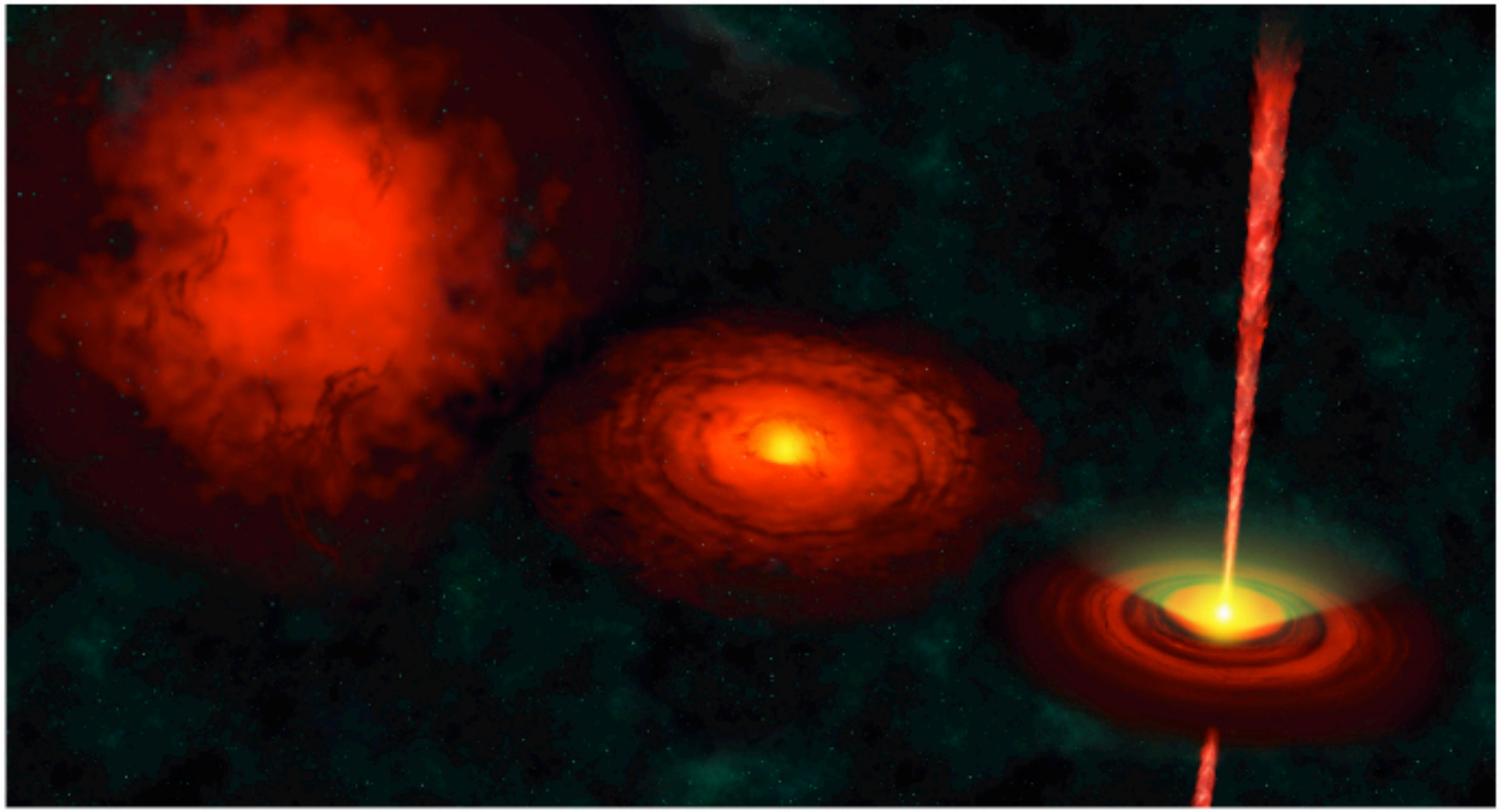
Stages of star formation

(1) Large amounts of gas assemble and form a Giant Molecular Cloud (GMC)

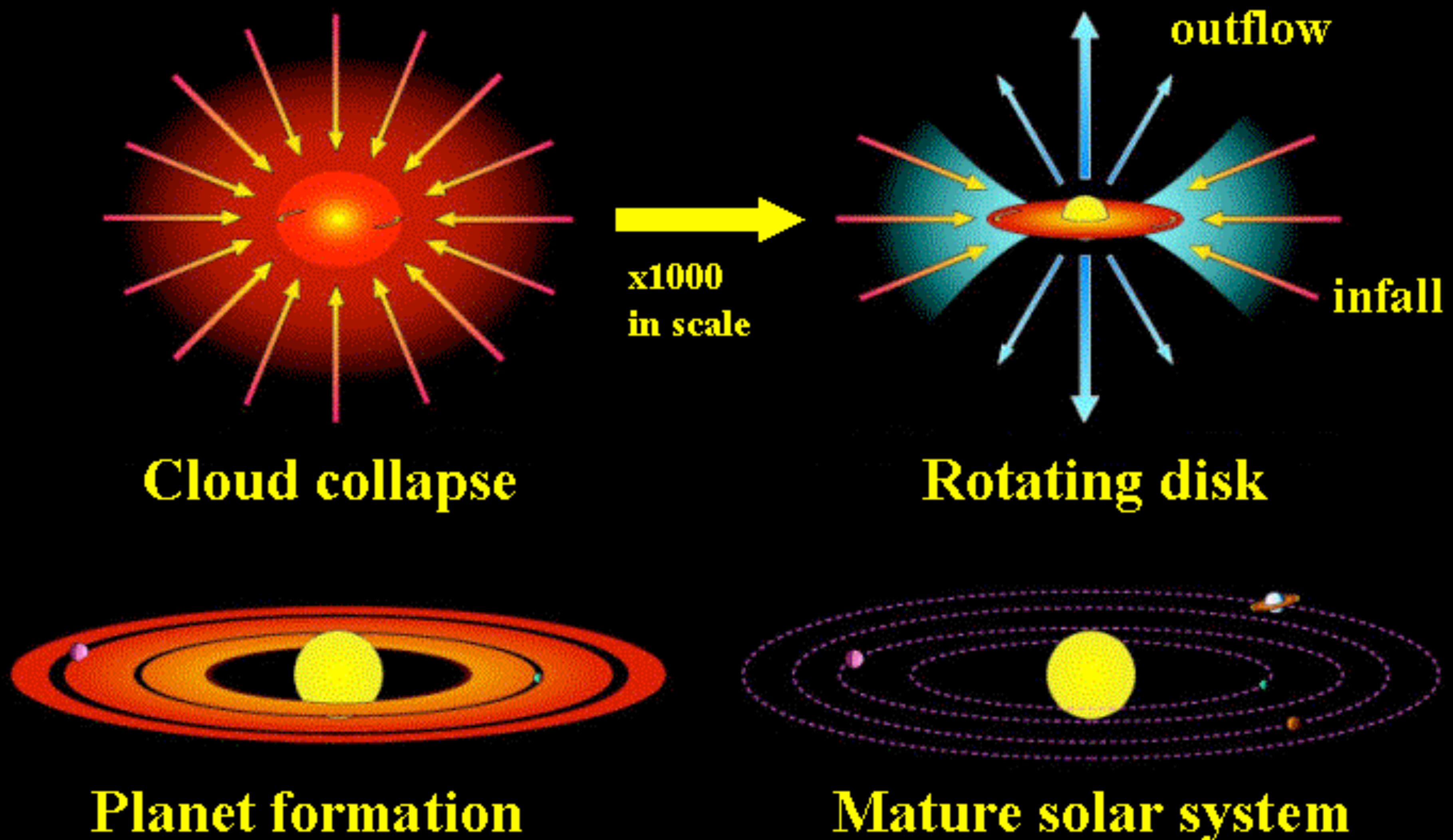
(2) Free-fall collapse of a gas clump inside GMC

(3) Slow collapse Formation of disk

(4) Star forms at the center Jet and bipolar out flow



How are single stars born?

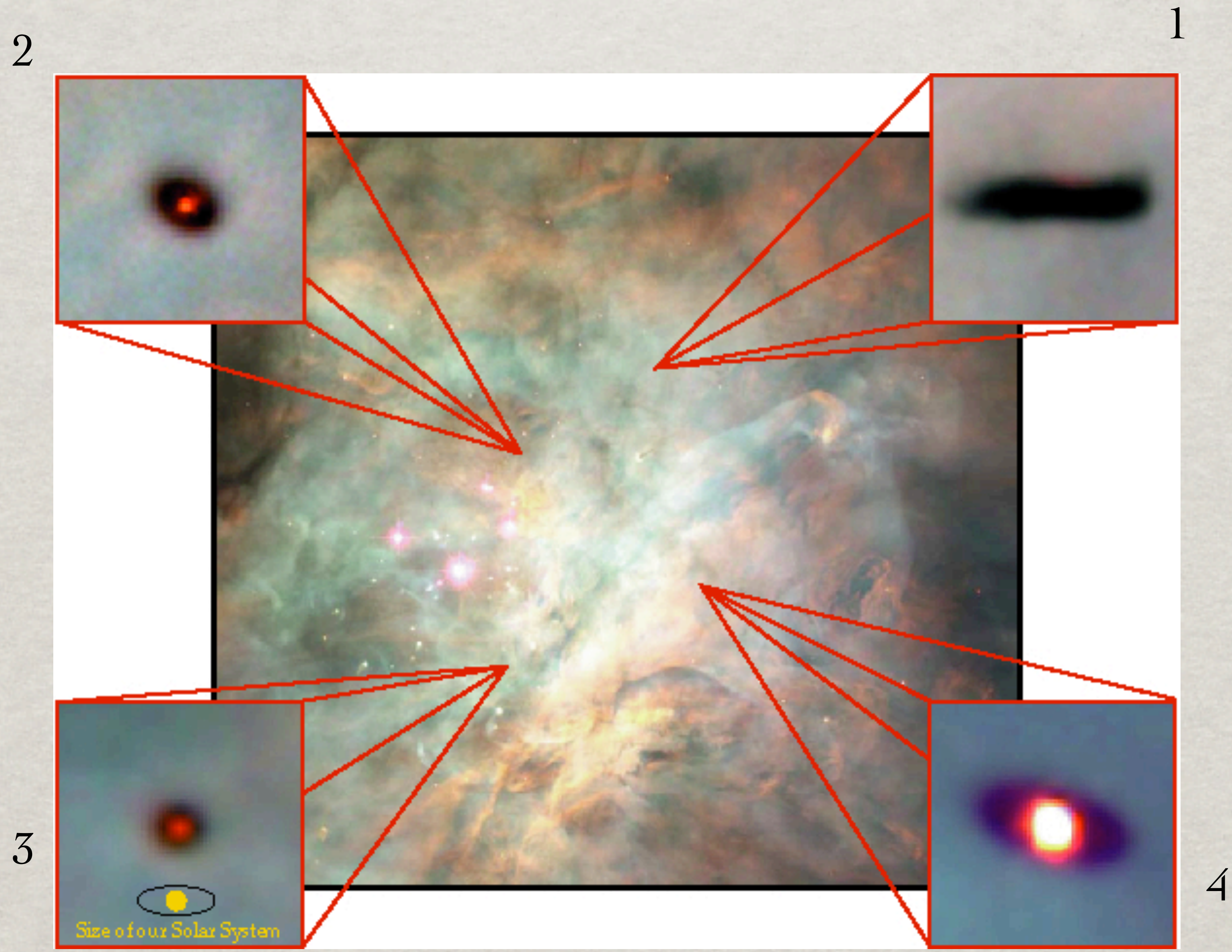


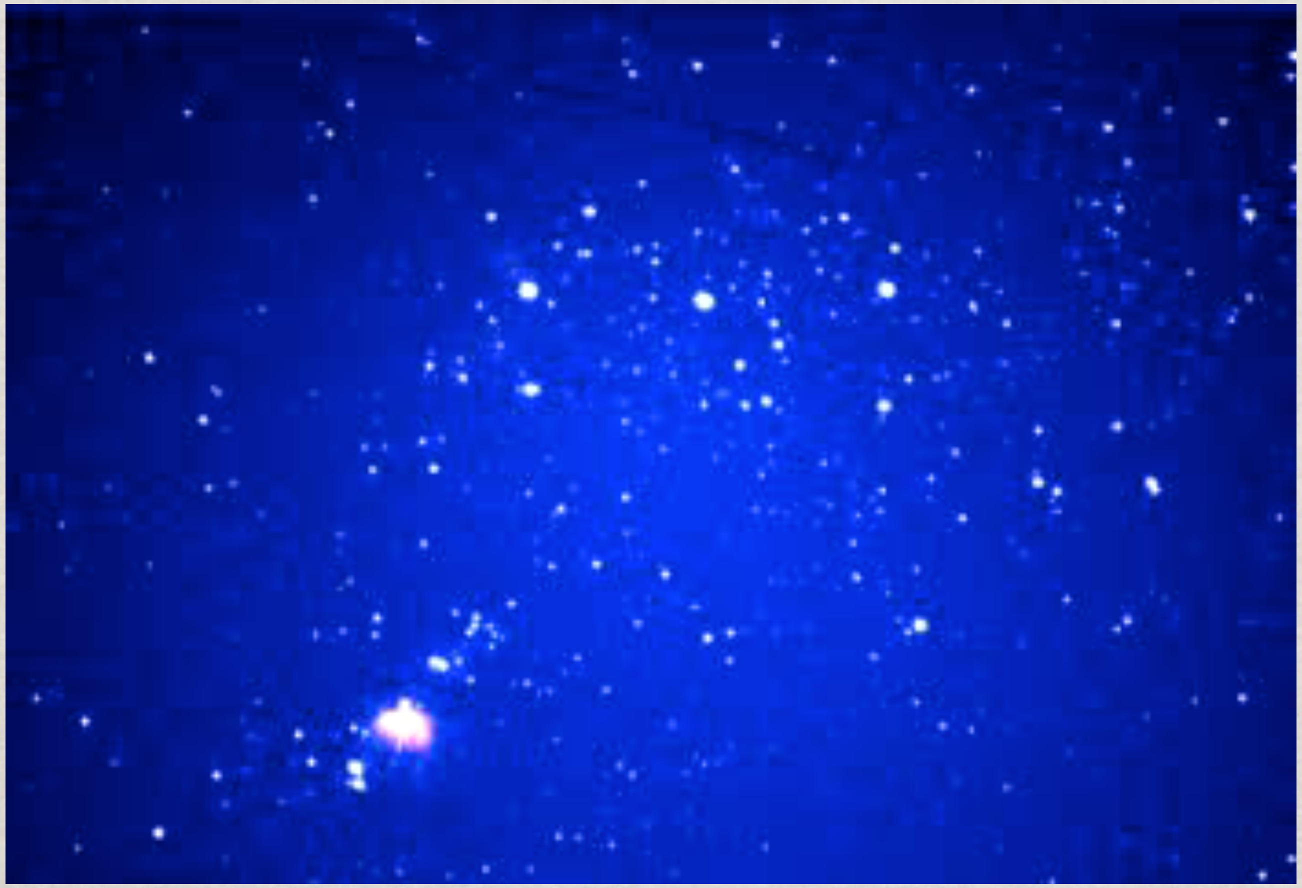
Scenario largely from indirect tracers.

Fig. by McCaughrean

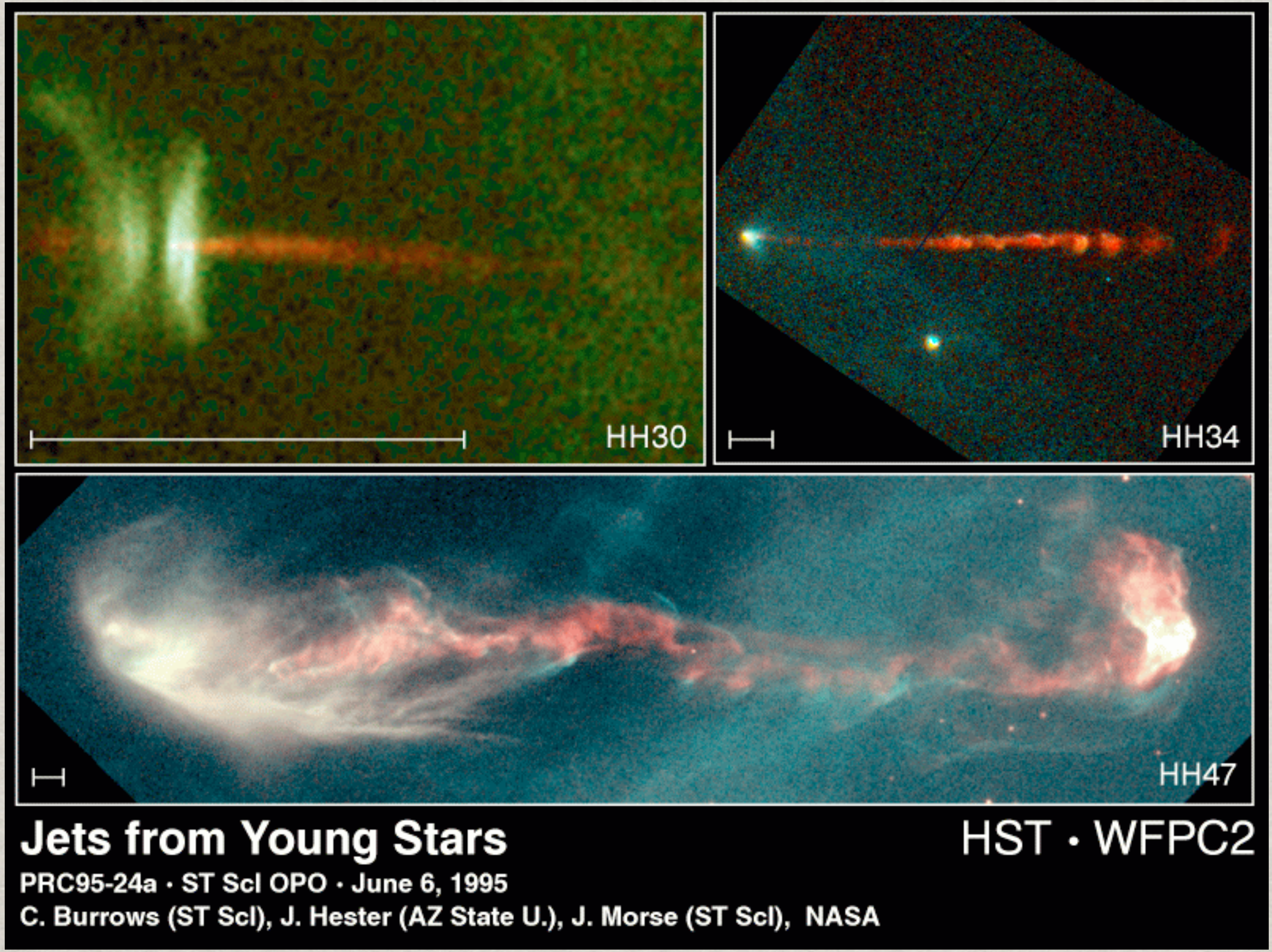

Orion Nebula

Orion Nebula: examples of regions of forming stars and disks





Jets and outflows: signatures of forming stars



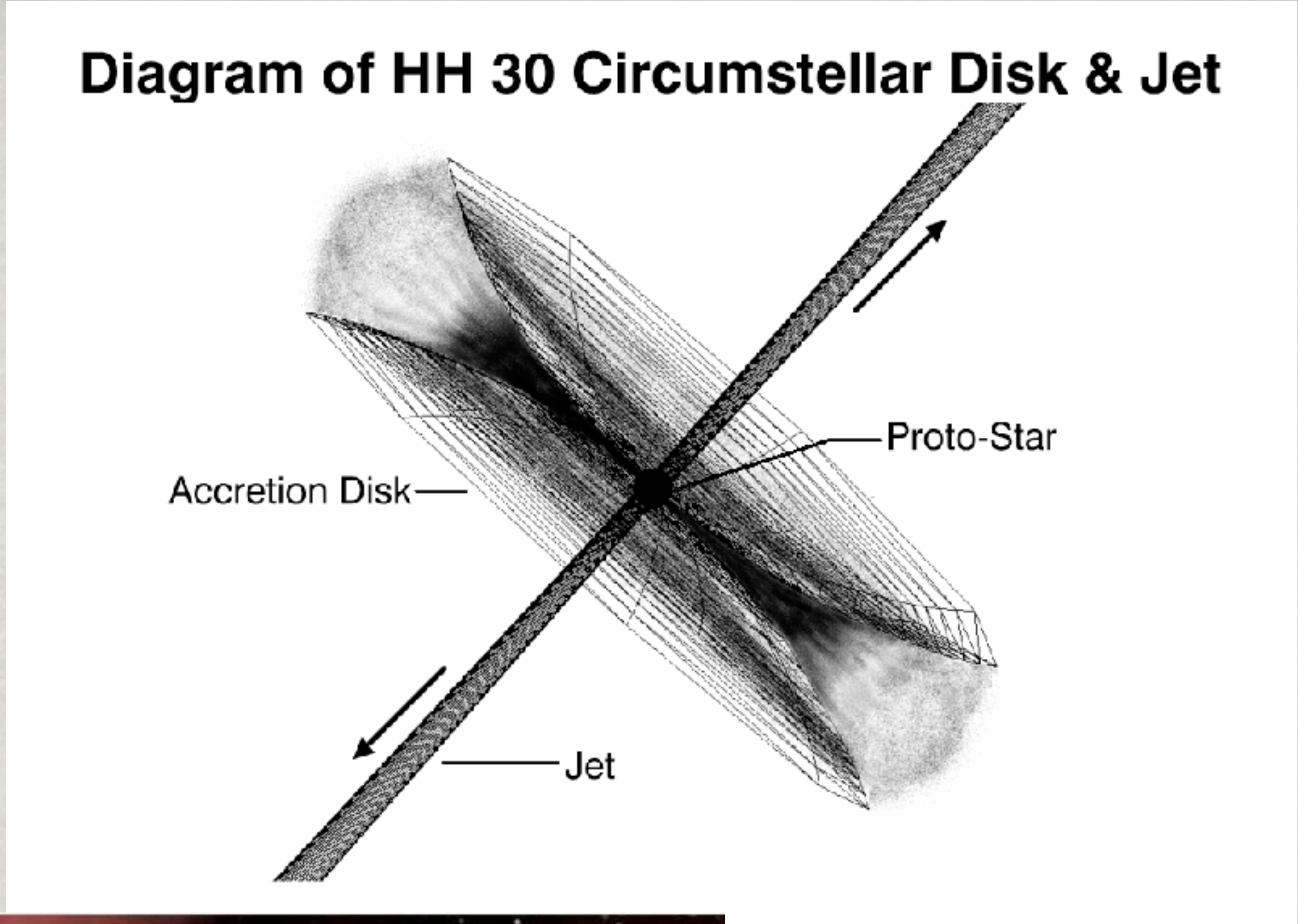
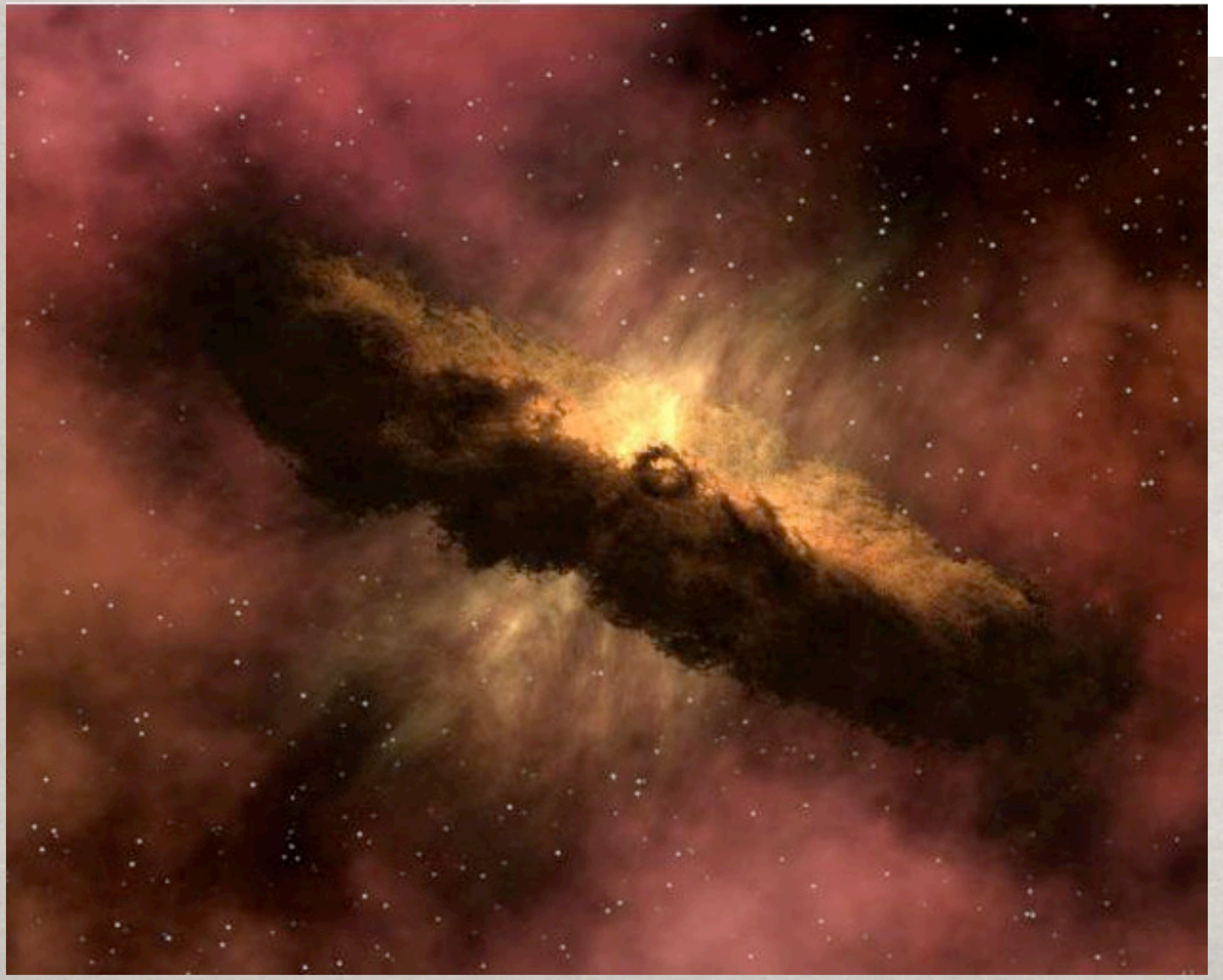


Diagram of HH 30 Circumstellar Disk & Jet
Proto-Star
Accretion Disk
Jet



Pillar and Jets HH 901/902

Hubble Space Telescope • WFC3/UVIS

NASA, ESA, and M. Livio and the Hubble 20th Anniversary Team (STScI)

STScI-PRC10-13a

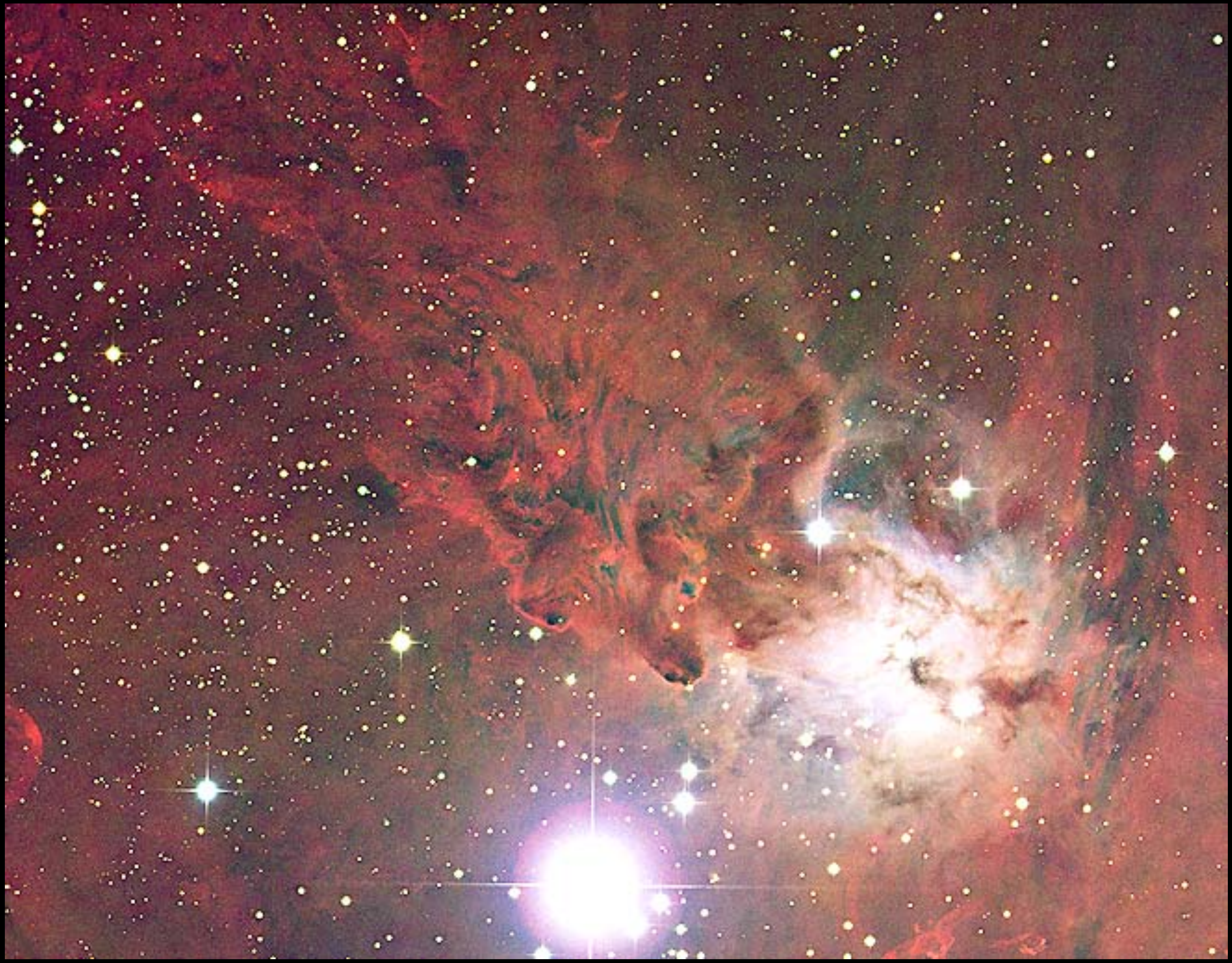
HH 901/902 Details

Hubble Space Telescope • WFC3/UVIS

NASA, ESA, and M. Livio and the Hubble 20th Anniversary Team (STScI)

STScI-PRC10-13d

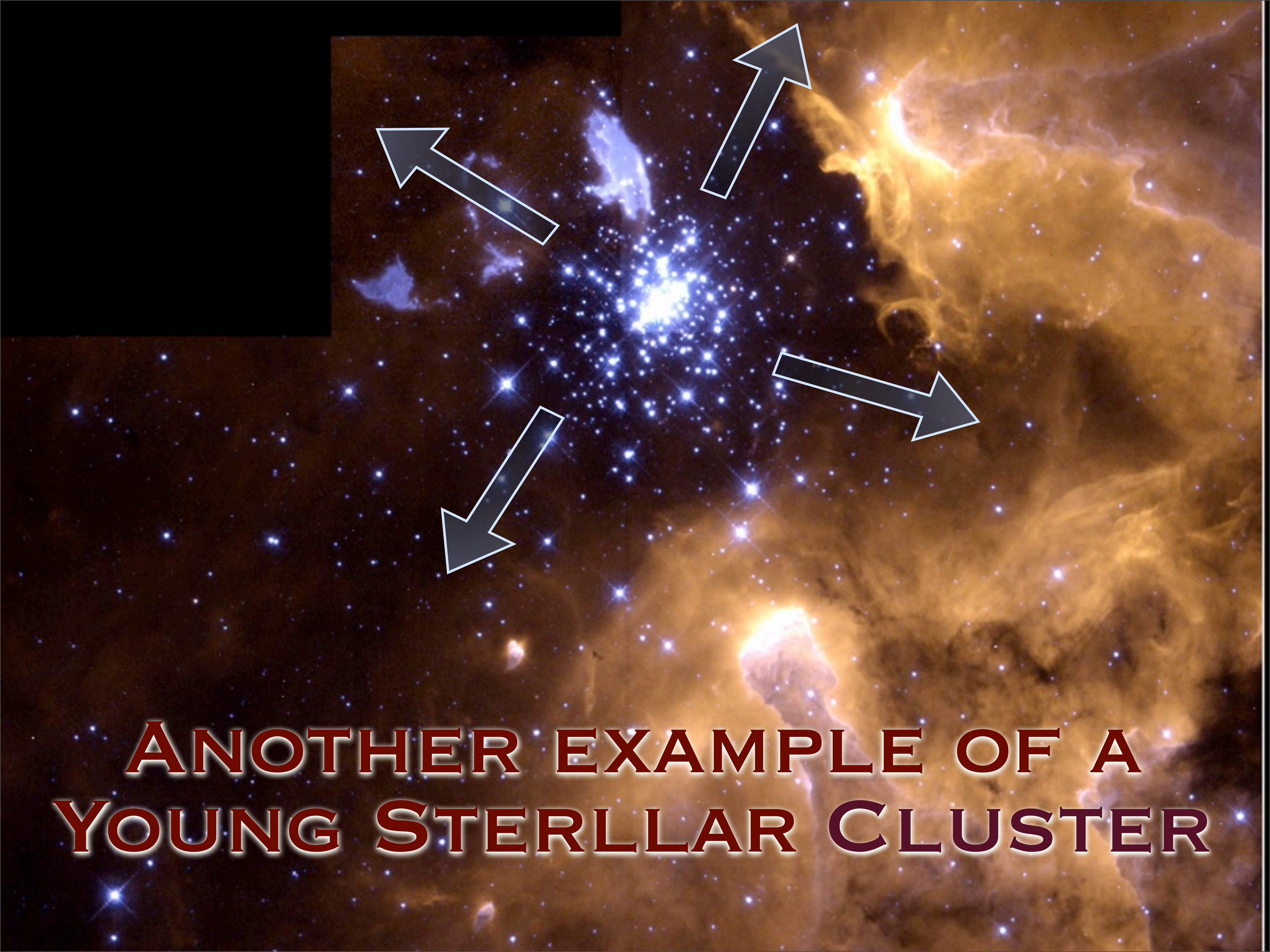
Fox Fur Nebula: young stellar cluster pushes the gas out gradually dispersing the giant molecular cluster, which gave birth to the cluster



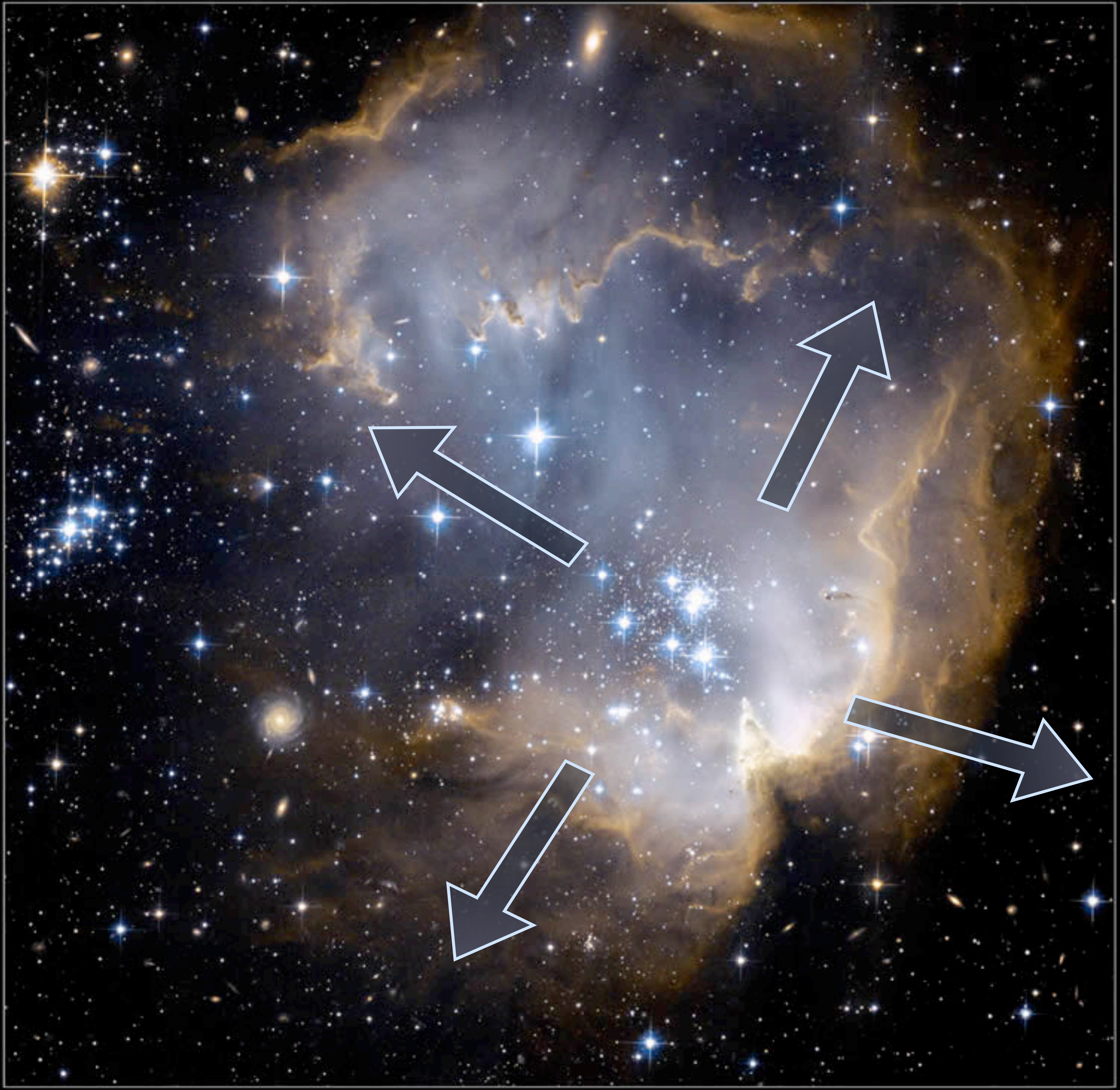
Fox Fur Nebula: young stellar cluster pushes the gas out gradually dispersing the giant molecular cluster, which gave birth to the cluster


Another example of a
Young Sterllar Cluster

Another example of a Young Sterllar Cluster



Hubble



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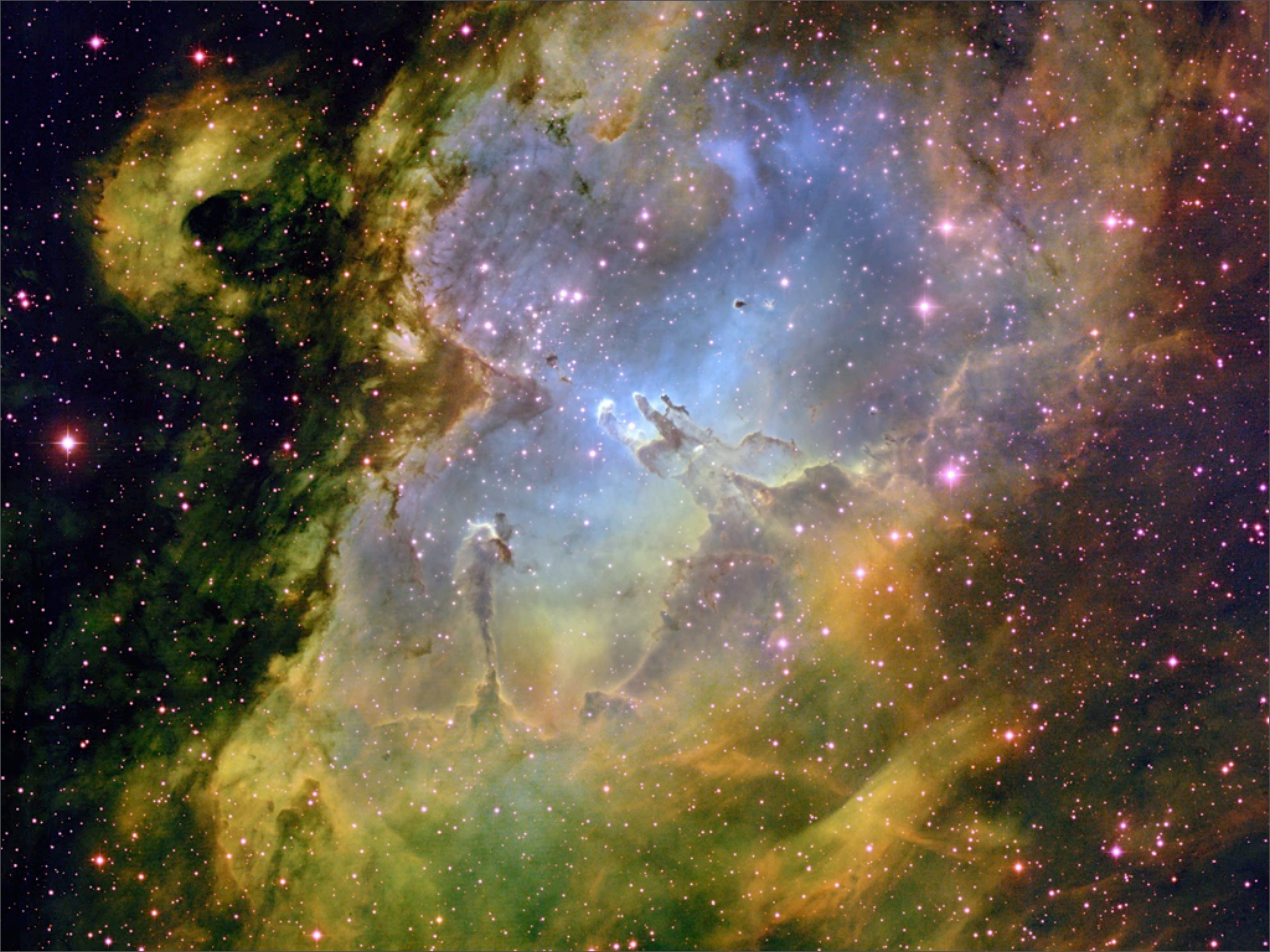
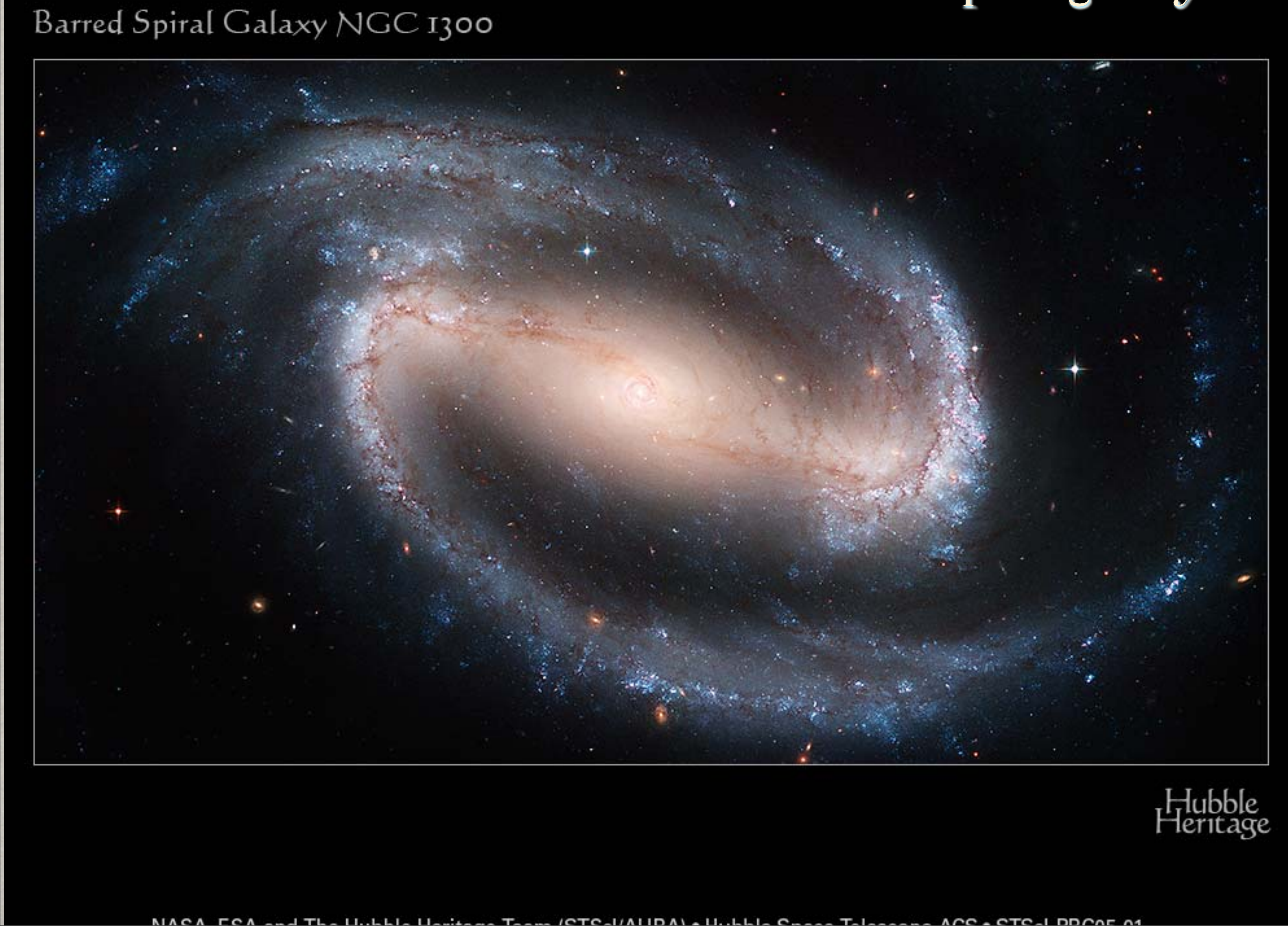


Star formation in a spiral galaxy



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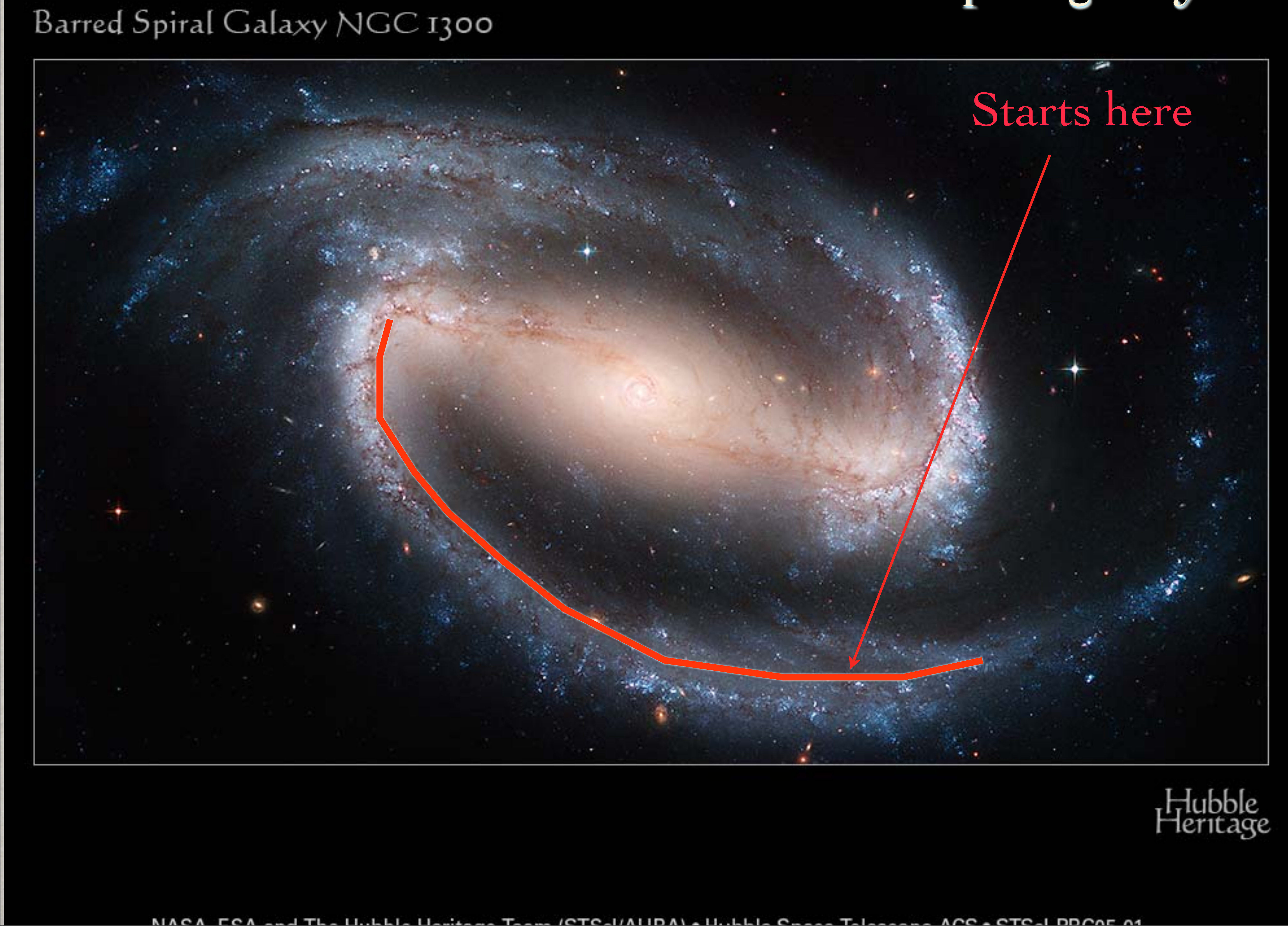
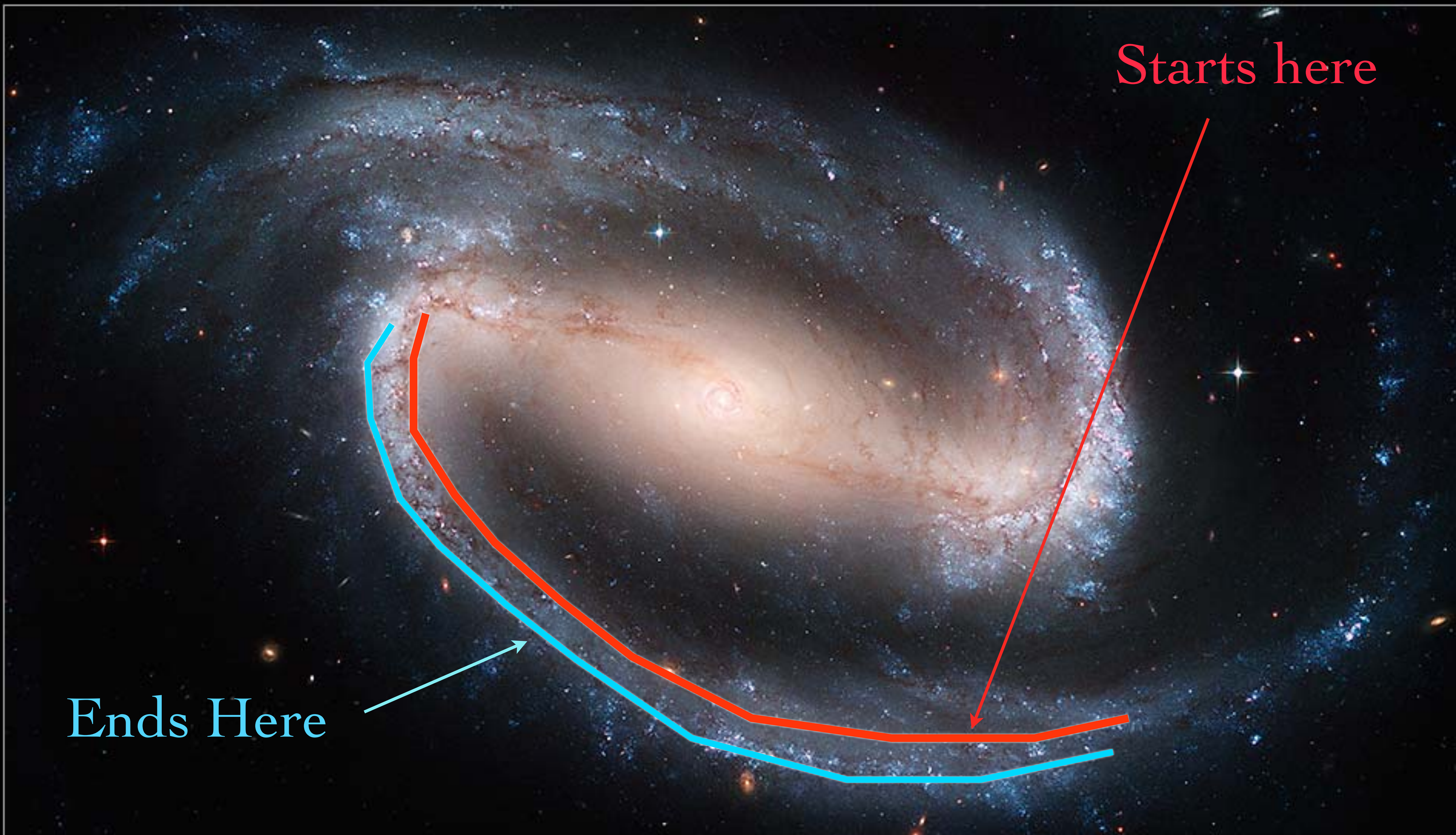


Star formation in a spiral galaxy

Barred Spiral Galaxy NGC 1300



Hubble Heritage

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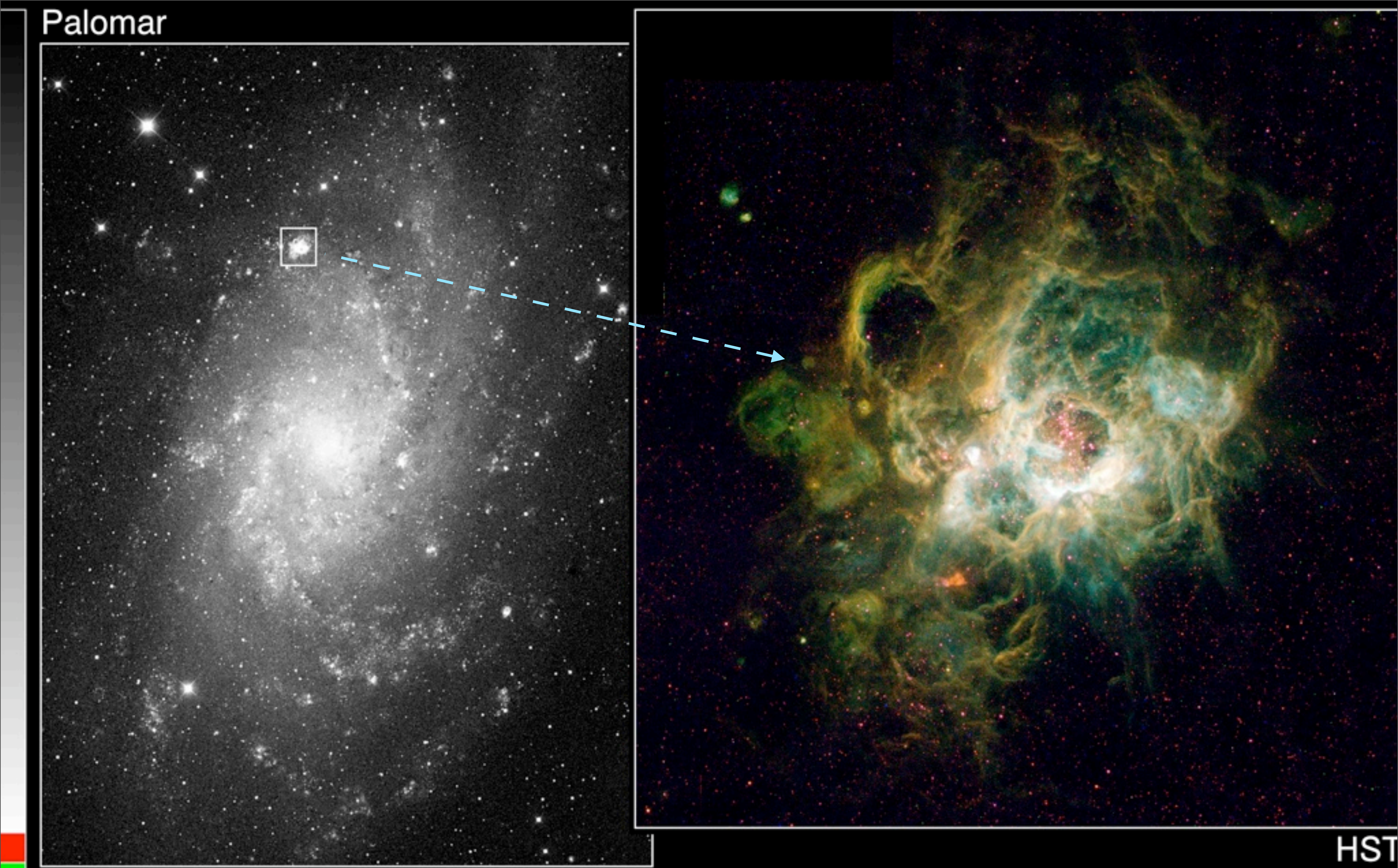


NGC 604 in Galaxy M33

Hubble Space Telescope • Wide Field Planetary Camera 2

PRC96-27 • ST ScI OPO • August 7, 1996 • Hui Yang (U.IL) and NASA

Appearance

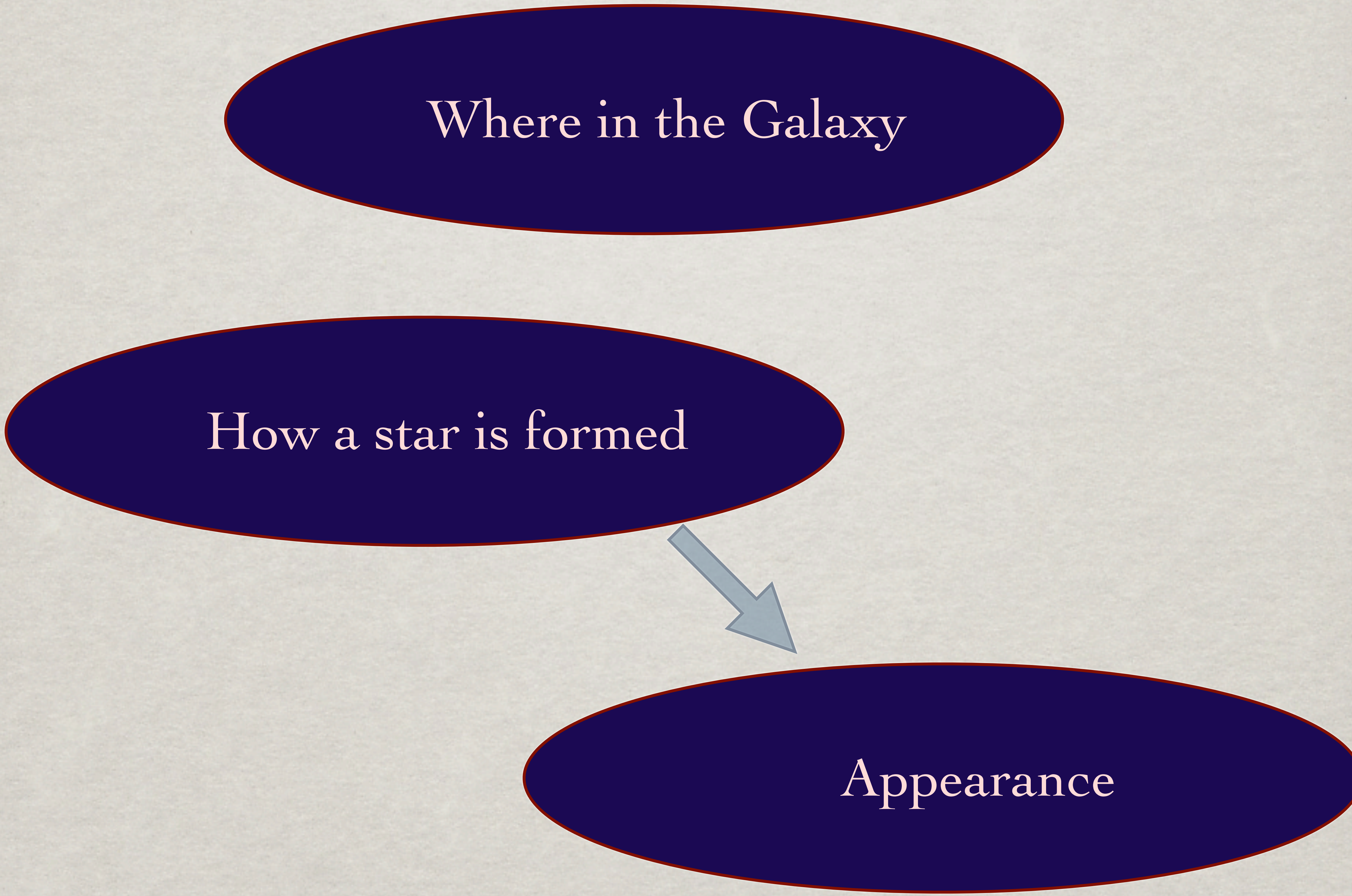
Where in the Galaxy

Appearance

Where in the Galaxy

How a star is formed

Appearance


Where in the Galaxy
How a star is formed
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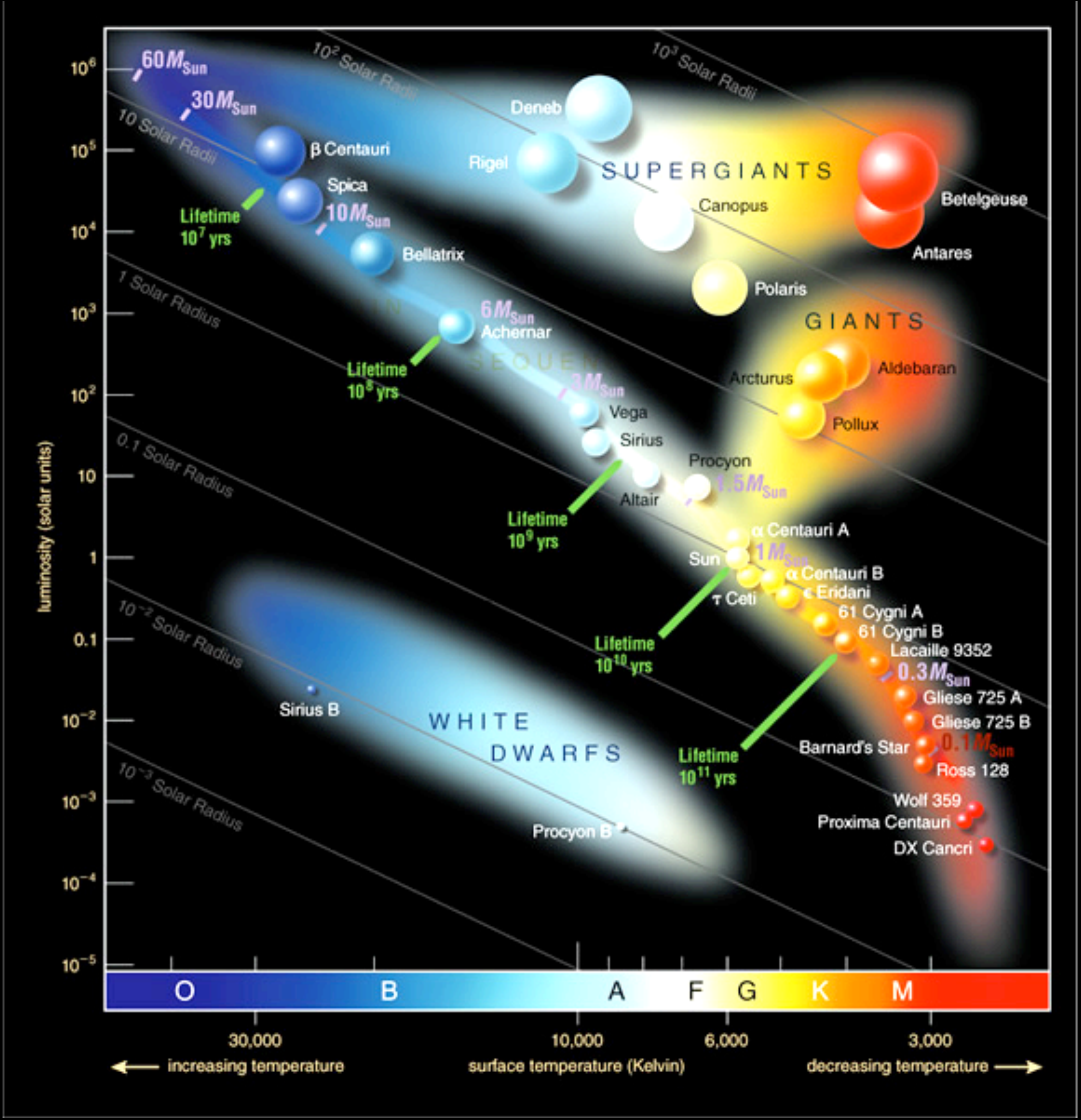
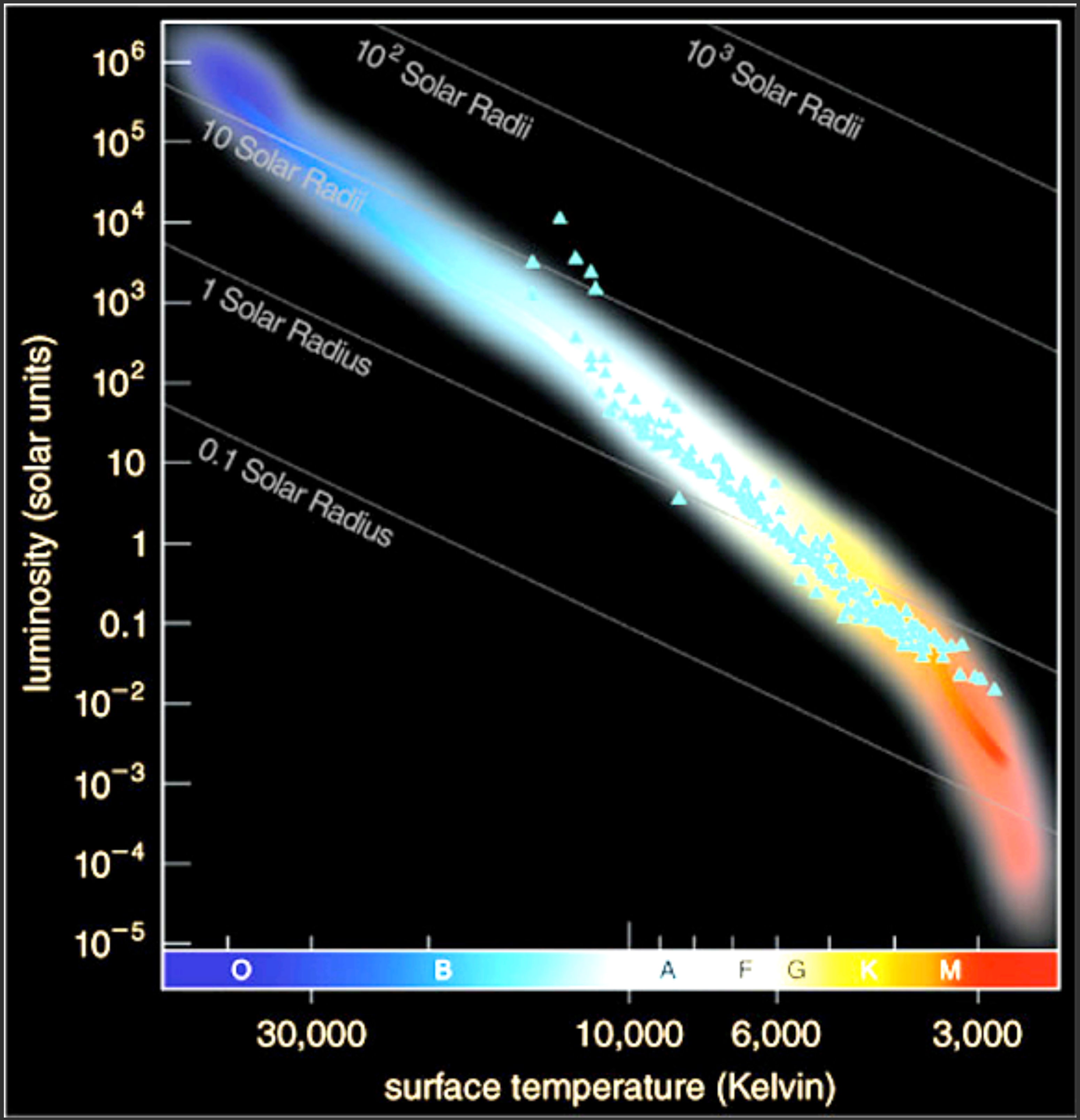
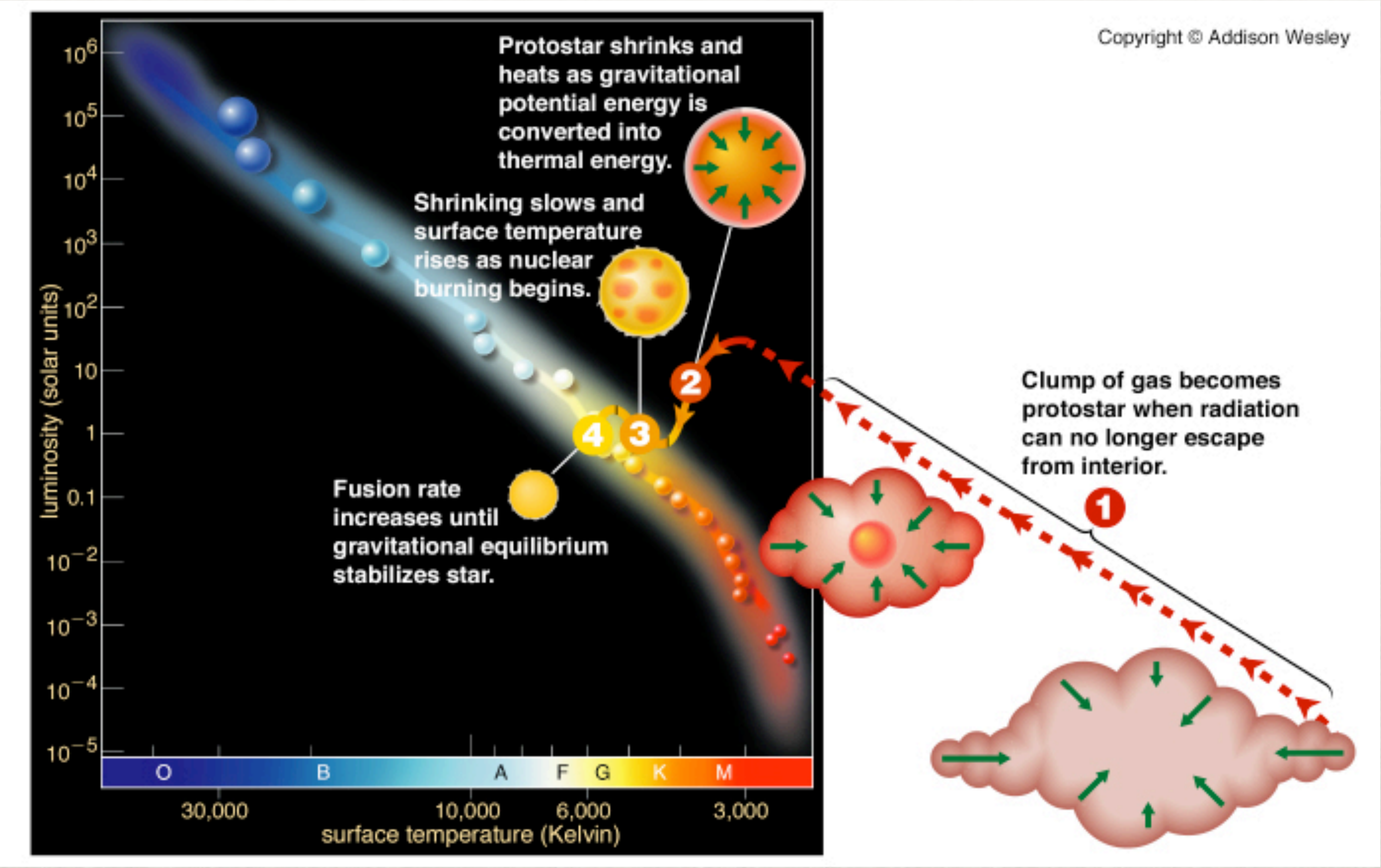
Explaining the HR diagram



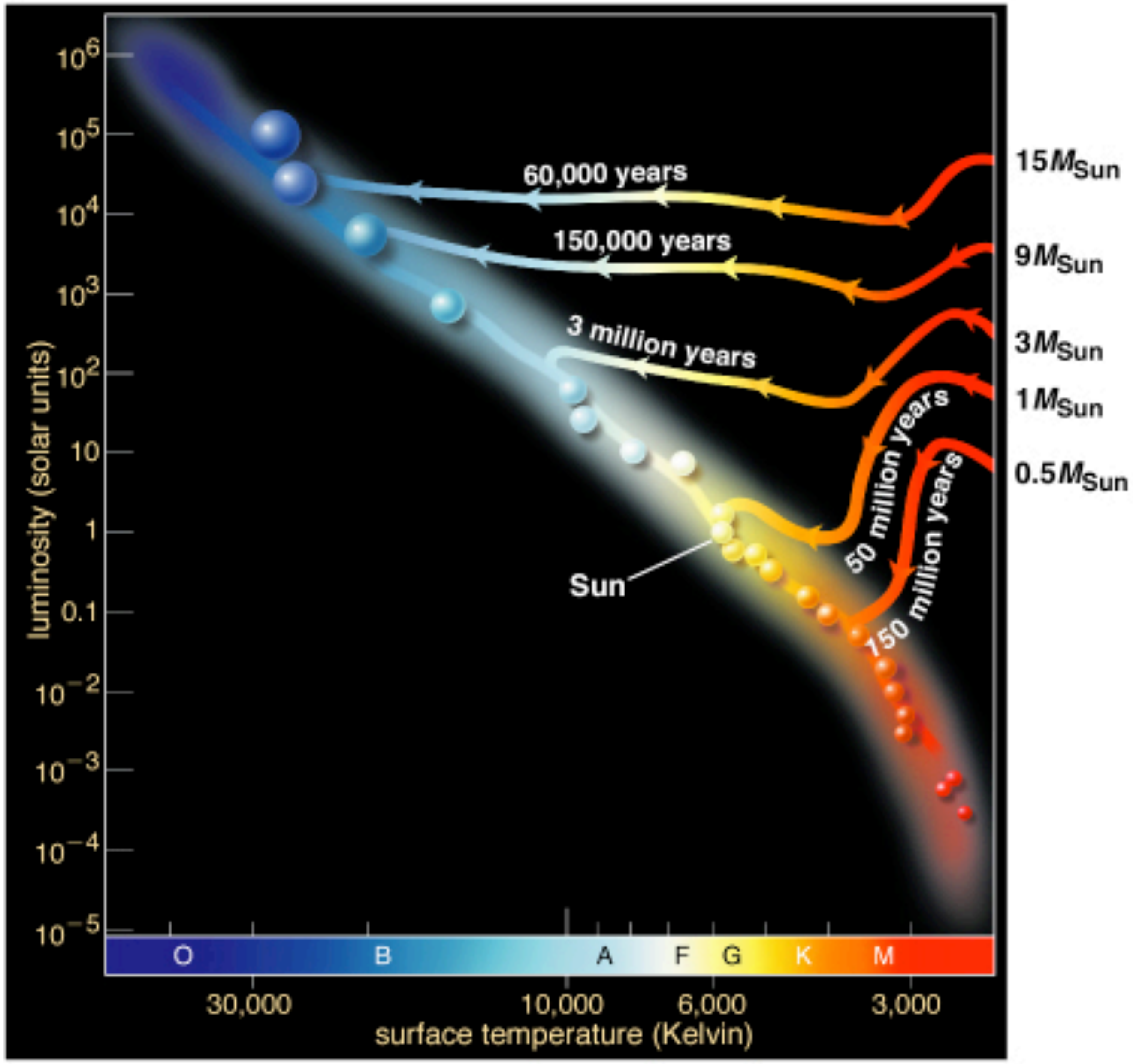
Properties of stars on the main sequence



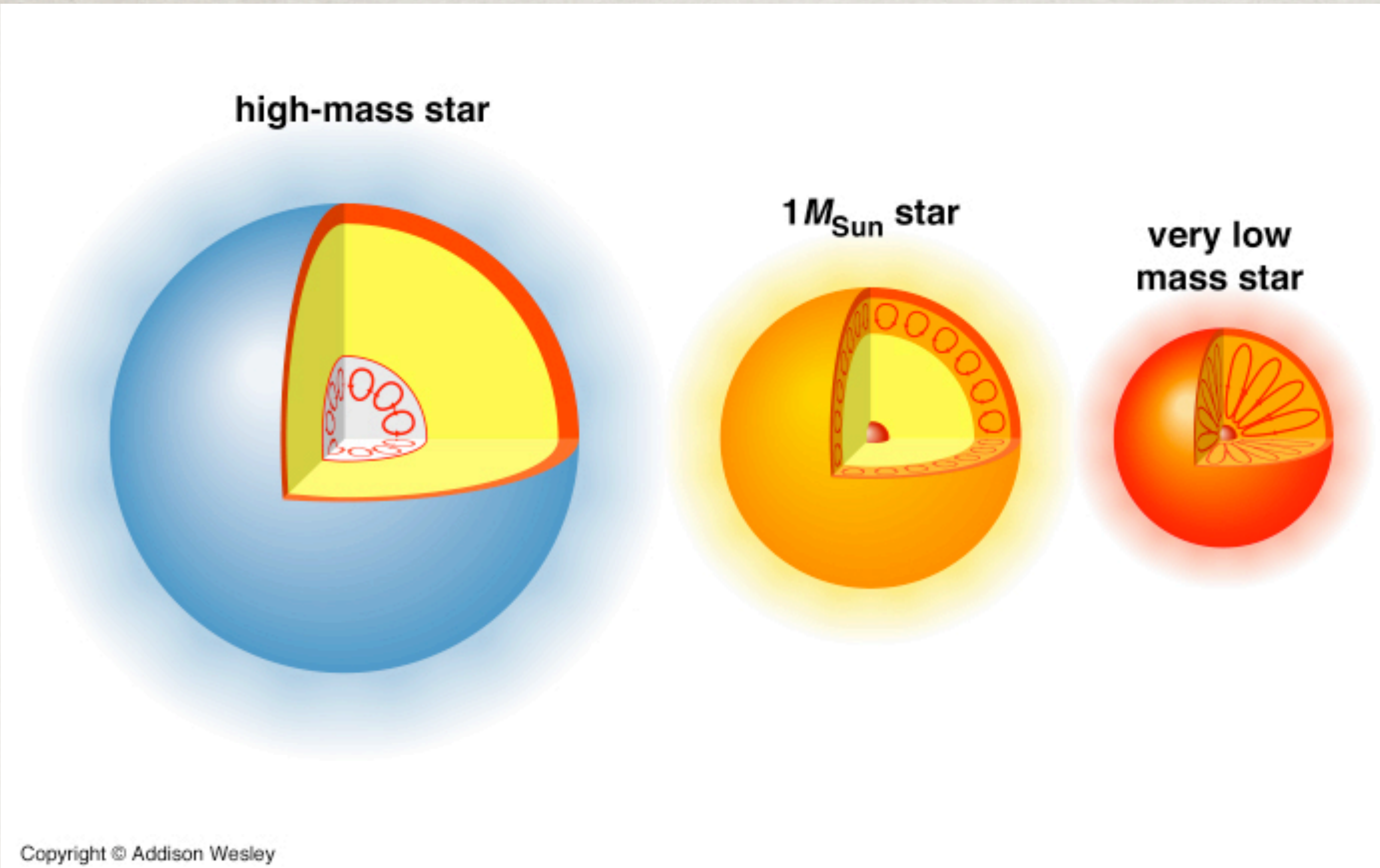
Explaining the HR diagram: how a proto-star 'moves' on the HR diagram



It takes different time for stars to settle on the main sequence



More massive stars form much faster than small stars


high-mass star
1 M_{Sun} star
very low
mass star
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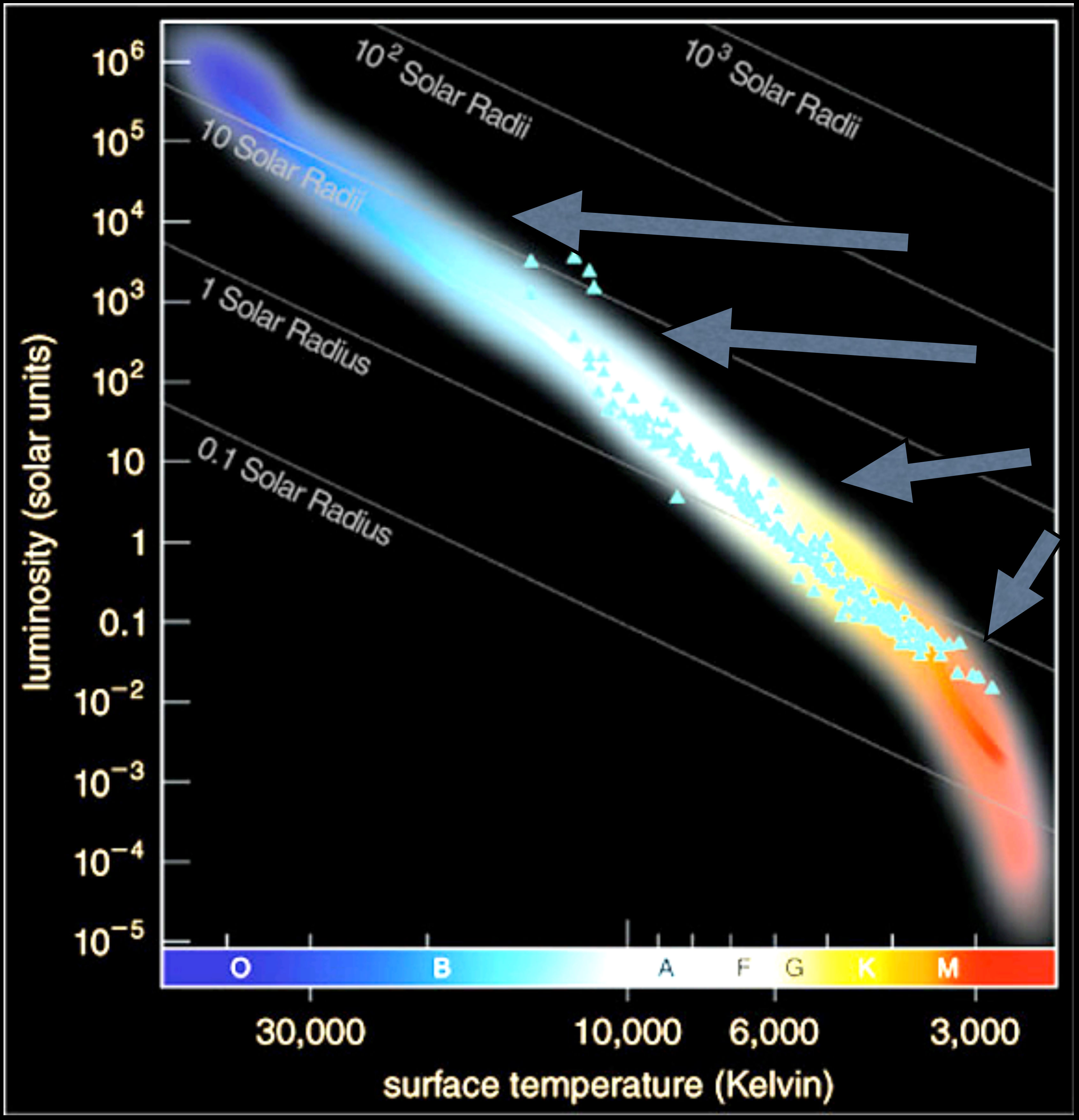
Explaining the HR diagram



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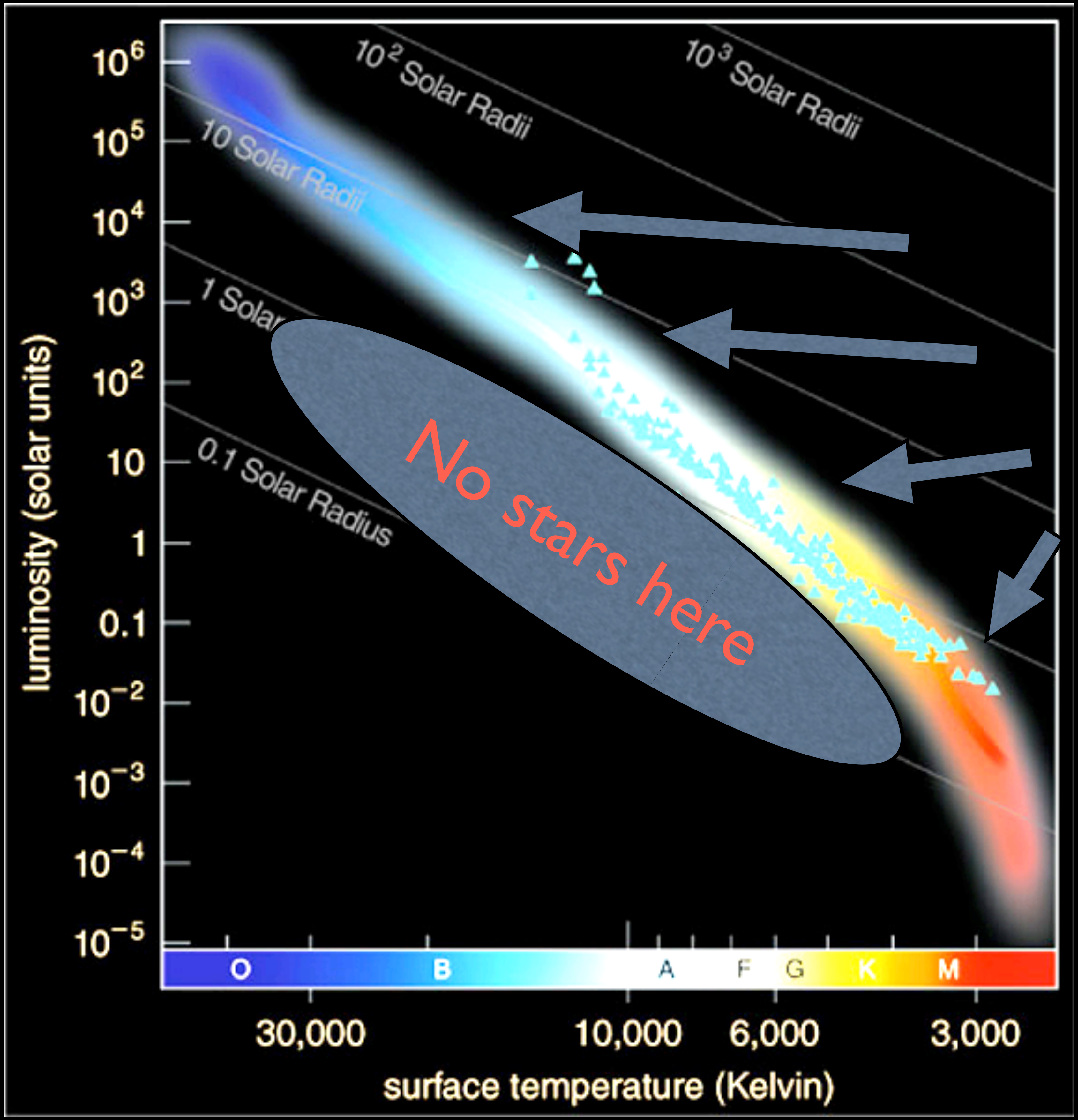

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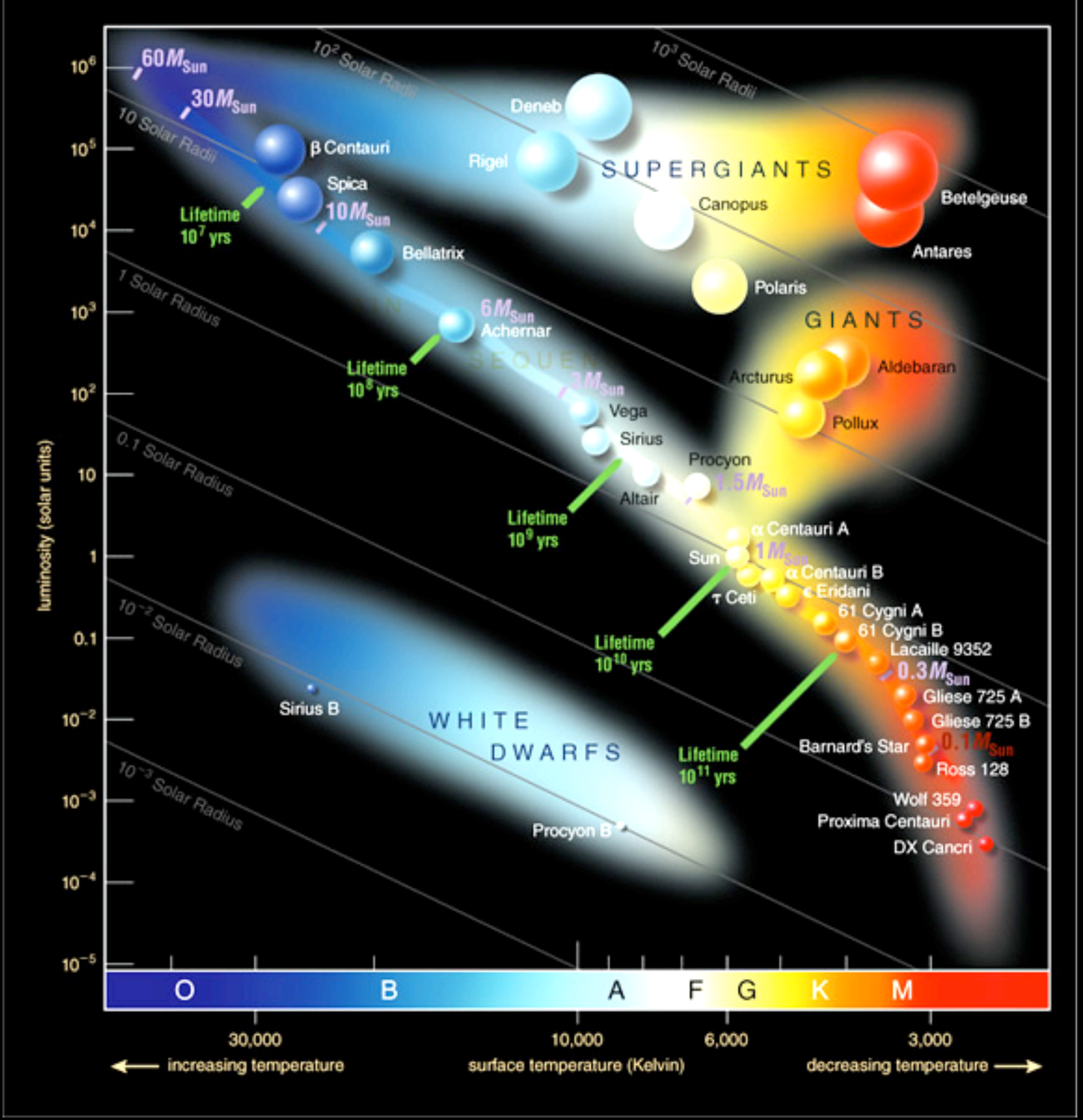

- The evolution of a protostar can be followed on the H-R diagram. The early protostar is relatively cool and low luminosity. So, the star first appears on the extreme lower right portion of the H-R diagram.

- The protostar's **initial free-fall contraction** is slowed by the increasing density and internal pressure at its center. The star still is not hot enough to begin nuclear reactions so it must contract further as it radiates energy from its surface.

- During its **slow contraction phase**, the protostar converts gravitational energy into heat energy. Half the energy is radiated into space and the other half goes to further raise the temperature of the protostar's core.

- Finally, when the core is hot enough (about 15,000,000 K for a 1Msun star), **thermonuclear reactions** begin. At this point, the star enters onto the Main Sequence of the H-R diagram for the first time. For a star like the Sun, it will remain on the Main Sequence for about 10 billion yrs.

- While **on the Main Sequence, stars are in pressure equilibrium**. That is, there is a balance between the force of gravity (directed toward the star's center) and thermal (or heat) pressure caused by energy released from the nuclear reactions in the core (directed outward). During its life on the Main Sequence, the star neither expands nor contracts.

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