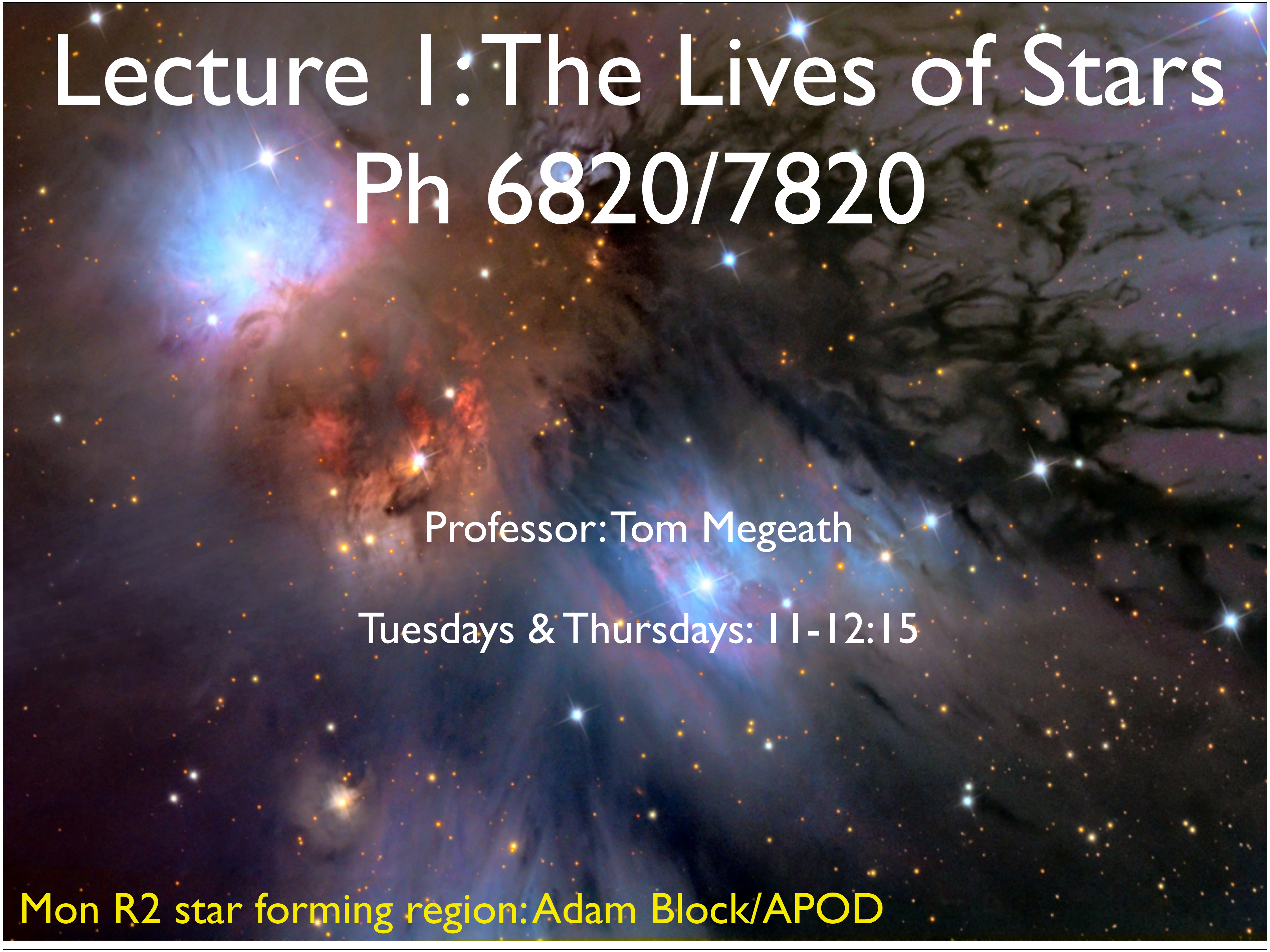
Lecture 1: The Lives of Stars
Ph 6820/7820

Professor: Tom Megeath

Tuesdays & Thursdays: 11-12:15



Mon R2 star forming region: Adam Block/APOD

Syllabus – PHYS6820/7820

Version 1/8/2011: Subject to change

Prof. Tom Megeath **MH 4012** **Spring 2010**

Date	Chapter	Topic (schedule approximate; subject to change)
11 Jan 2011	Hartmann 1	1. Class syllabus, introduction to star formation
13 Jan 2011	Hartmann 2	2. Molecular Clouds: Observed Properties
18 Jan 2011	Hartmann 2	3. Stability and Lifetimes of Clouds, **HW 1 released**
20 Jan.2011	Hartmann 3	4. Molecular Cores: Observed Properties,
25 Jan 2011	Hartmann 4	5. Stability and Collapse of Cores
27 Jan 2011	Hartmann 3	6. Magnetic fields, **HW 1 due, HW 2 released**
01 Feb 2011	Hartmann 5	7. Protostars: basic properties
03 Feb 2011	Hartmann 5	8. Protostellar evolution
08 Feb 2011	Hartmann 7	9. Disk Accretion, **HW 2 due, HW 3 released**
10 Feb 2011	Hartmann 8	10. Disk Structure
15 Feb 2011	Hartmann 10	11. FU Ori, and Magnetospheric accretion
17 Feb 2011	Hartmann 10	10. Outflows **HW 3 due, HW 4 released**
22 Feb 2011	Hartmann 11	11. Pre-main sequence
24 Feb 2011	Hartmann 12	12. Disk evolution
01 Mar 2011	Hartmann 6	13.The IMF: **HW 4 due, Midterm handed out**
03 Mar 2011	Hartmann 6	14. Clusters and Associations
08 Mar 2011		Spring Break
10 Mar 2011		Spring Break
15 Mar 2011	Hartmann 4, notes	15. Massive star formation: **Midterm Due, HW 5 released**
17 Mar 2011	notes	16. Massive star formation
22 Mar 2011		17. Overview of post-main sequence evolution
24 Mar 2011		18. Low mass star evolution: **HW 5 due, HW 6 released**
29 Mar 2011		19. Low star evolution
31 Mar 2011		20. Low star evolution
05 Apr 2011		21. Massive star evolution: **HW 6 due, HW 7 released**
07 Apr 2011		22. Massive star evolution
12 Apr 2011		23. Massive star evolution:
14 Apr 2011		24. Nucleosynthesis: **HW 7 due, HW 8 released**
19 Apr 2011		25. Nucleosynthesis
21 Apr 2011		26. White dwarfs
26 Apr 2011		27. White dwarf supernovae: **HW 8 due**
28 Apr 2011		28. Neturon stars
5 May 2011	**All**	**FINAL EXAM due: TAC Meeting**

Books:

The main books are:

Accretion Processes in Star Formation 2nd edition by Hartmann

Stellar Interiors by Hansen & Kawaler (& Trimble)

Other books that are useful (but not necessary):

Clayton: Principles of Stellar Evolution and Nucleosynthesis

Lectures:

PDF files of the lecture slides will be available on the class website: http://astro1.physics.utoledo.edu/~megeath/A6820/A6820.html

These will become available after class.

Office hours:

Please set up an appointment. I will try to be in at

Monday 12:30-2 PM, Wednesday 12:30-2 PM

Grading:

60% 8 homeworks

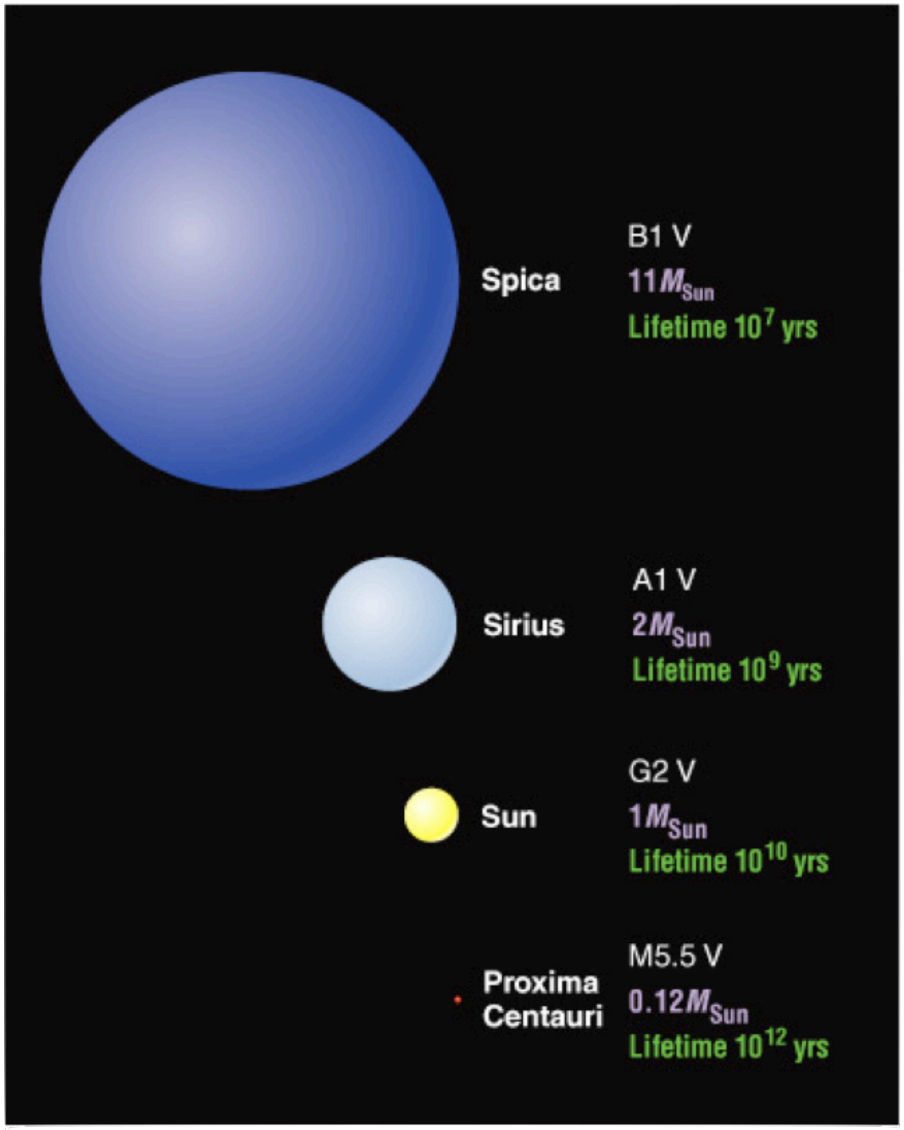
30% 2 exams

10% Proposal and TAC participation

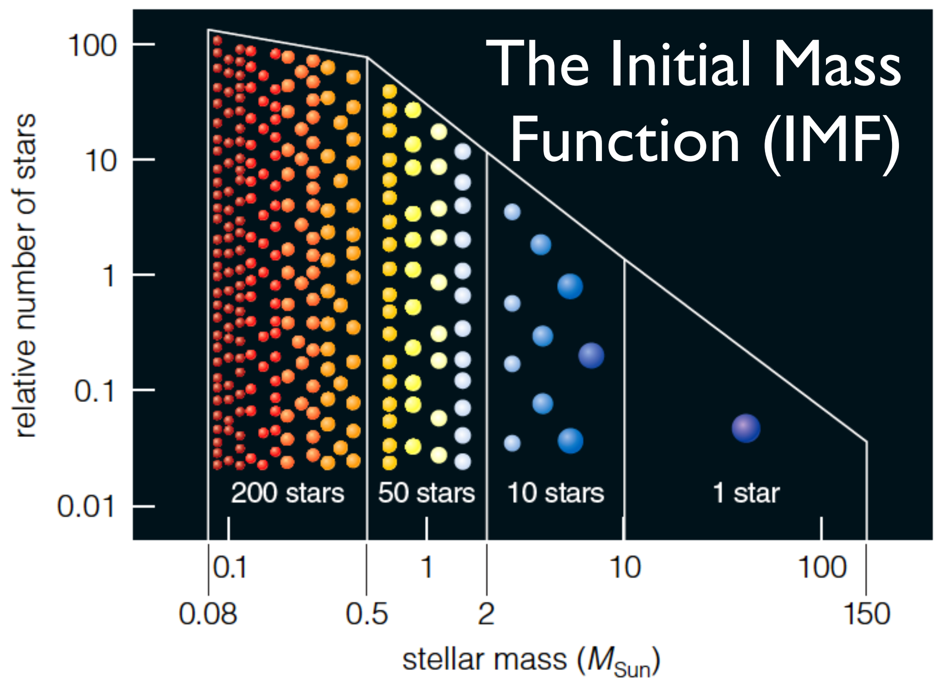
Today

- Motivation
- Brief review of pre-main sequence stars from last semester
- An introduction to YSOs and molecular clouds
- A brief digression on SEDs on classification
- Important problems in star formation

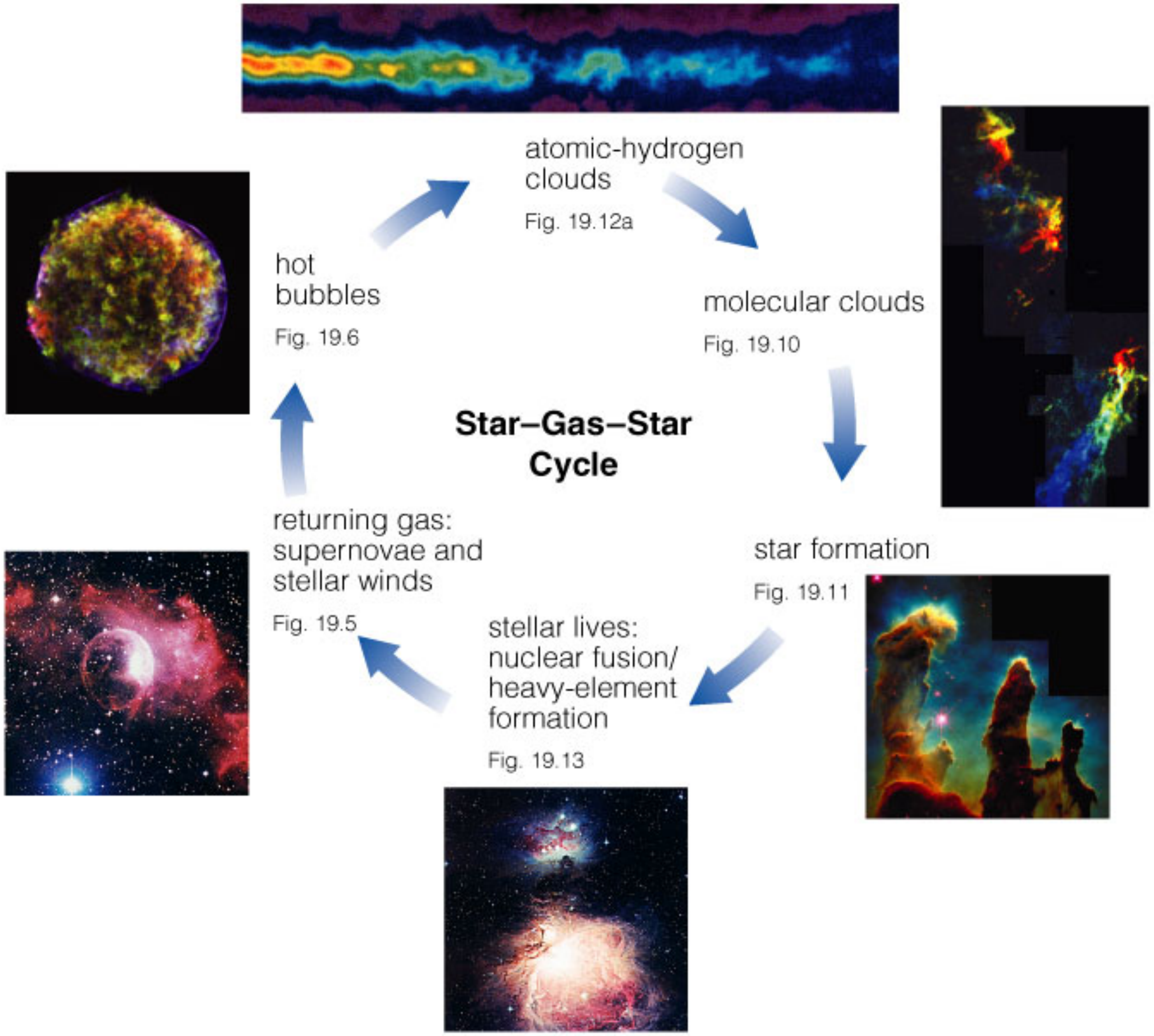
Why study the lives of stars?



Motivation: Mass Dependent Stellar Evolution



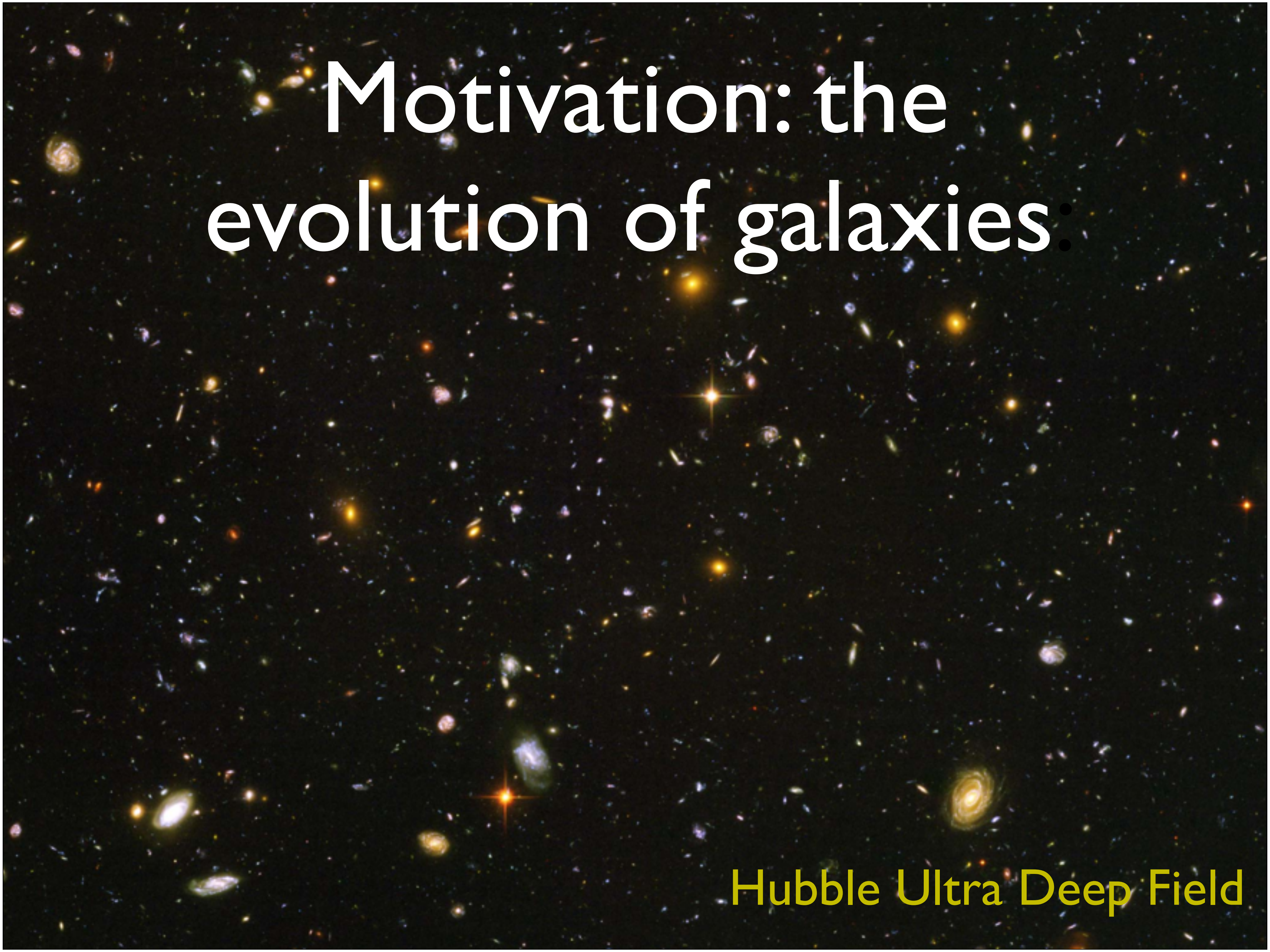
Motivation: Cosmic Recyling



Stars are responsible for:

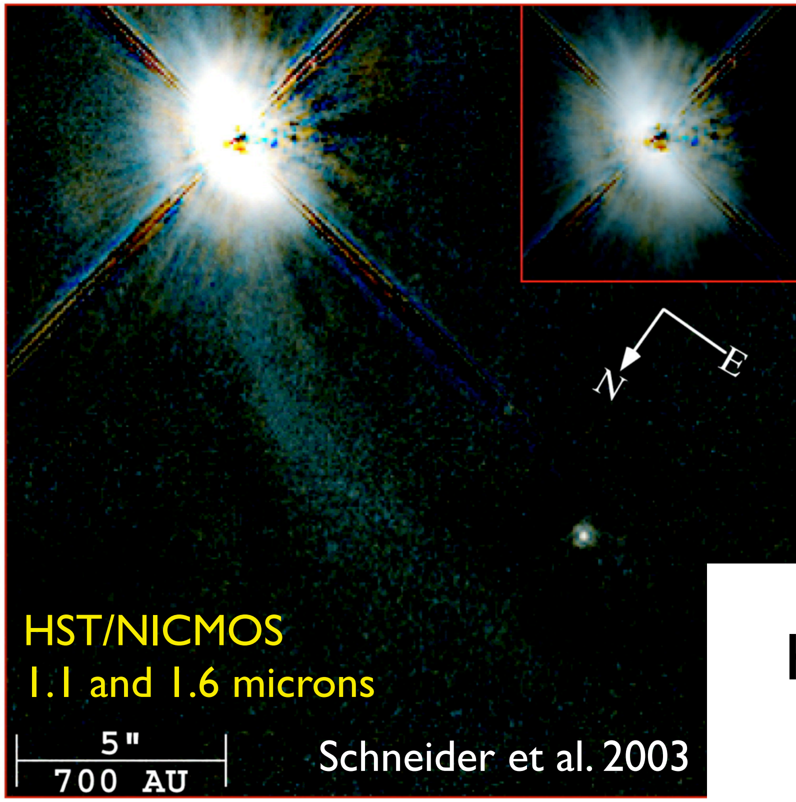
- Production of elements heavier than Helium
- Most of the kinetic energy in the ISM
- Production of dust grains

Motivation: the evolution of galaxies:



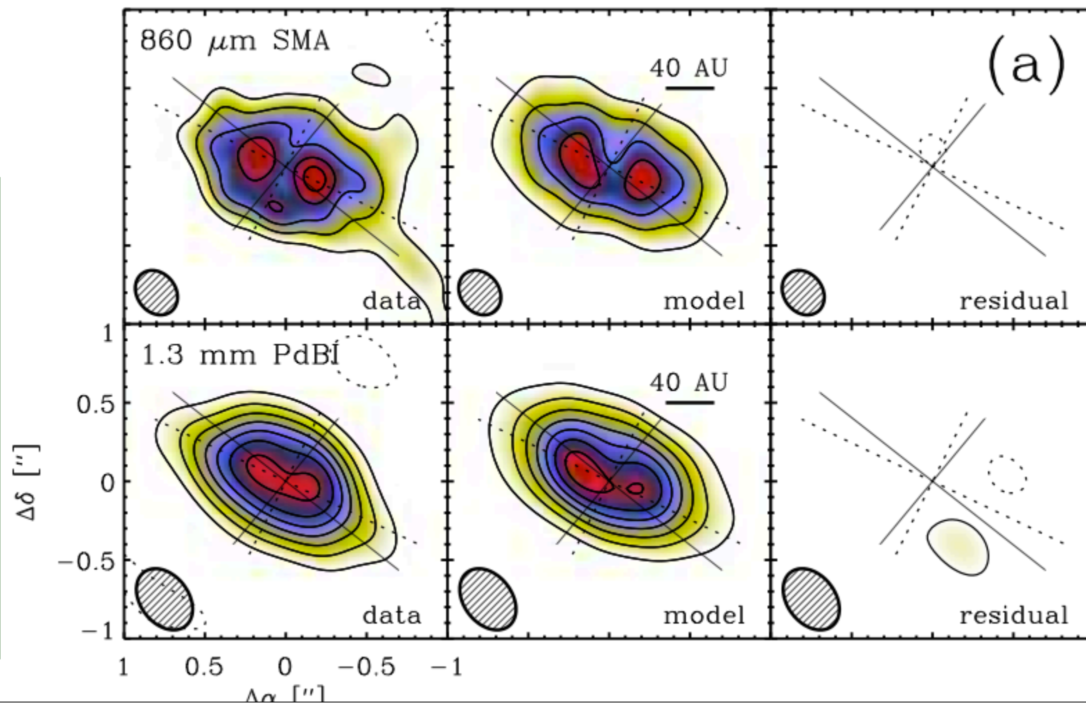
Hubble Ultra Deep Field

Motivation: Planet Formation



Hughes et al. 2009

GM Aur Protoplanetary Disk



Example: a disk around GM Aurigae, a pre-main sequence star in the Taurus Molecular Cloud. A gap in the disk may be generated by a planet.

Review:

Properties of a constant density star

In the fall semester, we made use of the fact that "stars do not twinkle", i.e. stars are self gravitating, thermally supported, massive spheres of gas which are in hydrostatic equilibrium. We further, for the sake of developing intuition, determined the properties of a star with the assumption of constant density. The resulting **approximate** equations are the following:

Constant volume density:

$$\rho = \frac{3M}{4\pi R^3} \tag{1}$$

Central pressure

$$P_c = \frac{3}{8\pi} G \frac{M^2}{R^4} \tag{2}$$

Central temperature

$$T_c = \frac{\mu m_H}{2K} G \frac{M}{R} \tag{3}$$

Pre-Main Sequence Evolution

In the pre-main sequence phase, the star is powered by the liberation of gravitational potential energy through the slow, quasistatic contraction of the star. This can be seen by using the constant density approximation.

The gravitational potential energy for a constant density star is:

$$U = -\frac{3}{5}\frac{GM^2}{R} \tag{5}$$

Then assuming virial equilibrium and assuming thermal gas pressure:

$$W = \frac{1}{2}U \tag{6}$$

The luminosity can be then be related to the change in radius:

$$L = \frac{dW}{dt} = -\frac{3}{10}\frac{GM^2}{R^2}\frac{dR}{dt} \tag{7}$$

We can also plot pre-main sequence evolution in terms of T_c vs P_c

$$T = 4.1 \times 10^6 \mu \left(\frac{M}{M_\odot}\right)^{\frac{2}{3}} \rho^{-\frac{1}{3}}$$

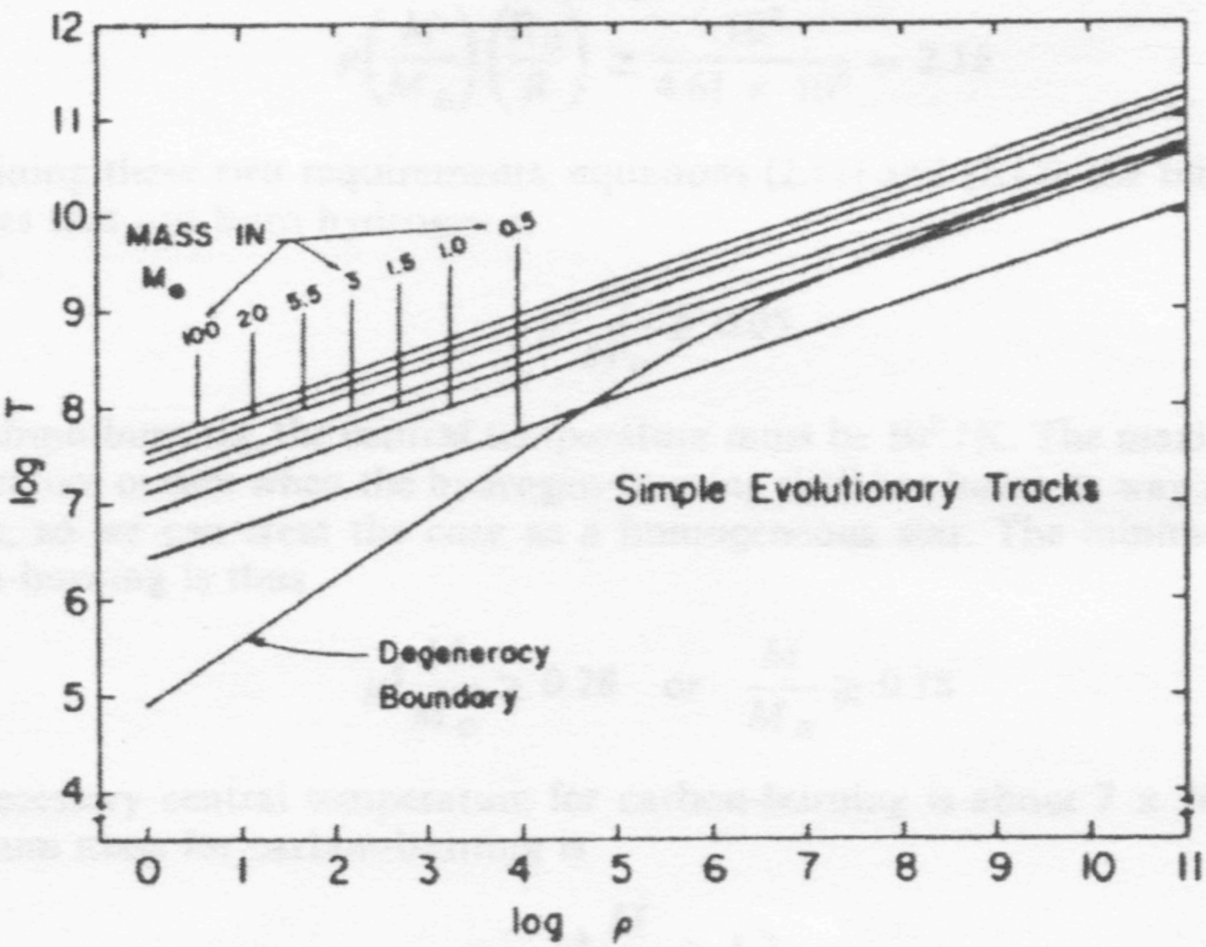
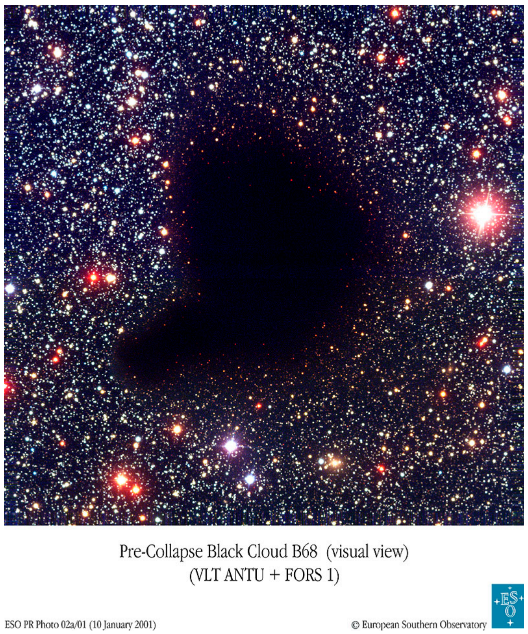


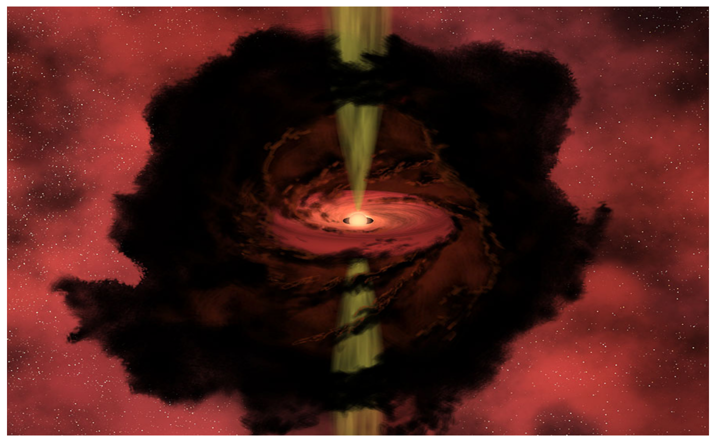
Figure 1. Simple evolutionary tracks for the internal conditions of stars of various masses.

From:
Stellar Evolution:
Stein & Cameron

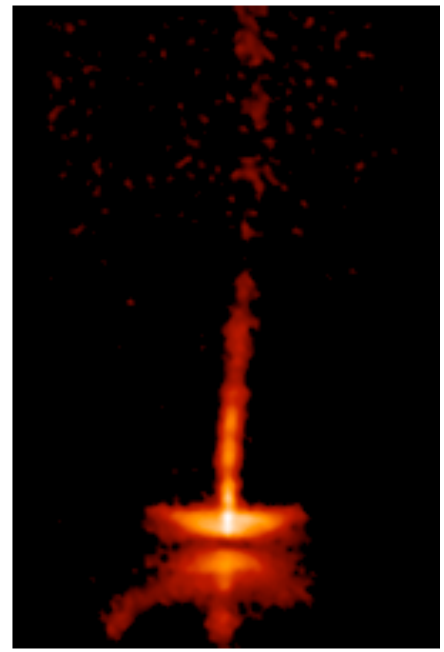
Molecular Clouds and Young Stellar Objects



Starless Molecular cloud core



Protostar in collapsing cloud core



Pre-main sequence object with disk

T Tauri stars: the stars of (Alfred) Joy

In 1945, Alfred Joy identified the class of variable stars known as T Tauri stars.

T-Tauri stars are variable, low mass stars found toward complexes of dark clouds and reflection nebula.

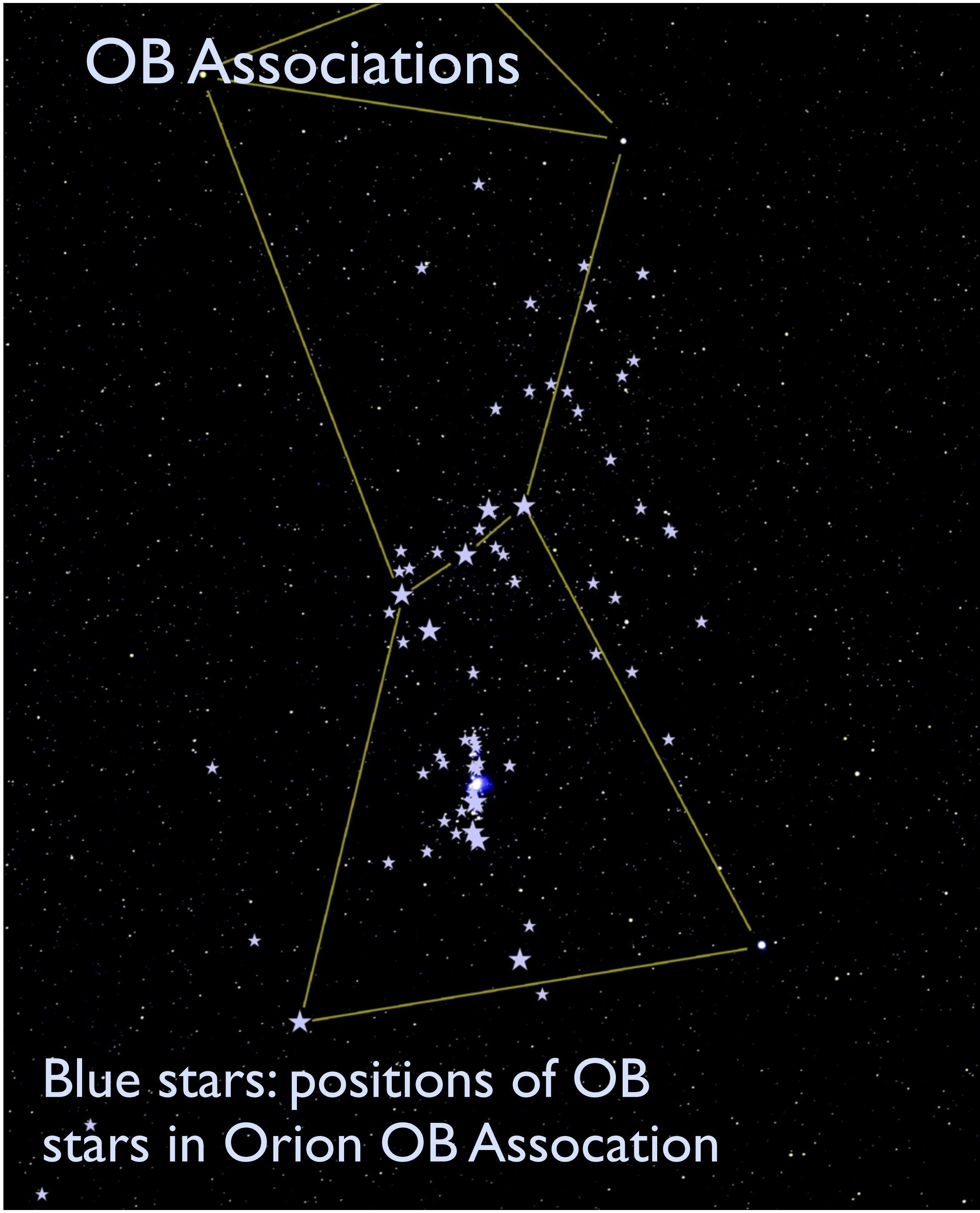
They are named after the prototype object in the Taurus molecular cloud: T Tauri.

They have been shown to be low mass stars in a pre-main sequence phase.

In 1960, George Herbig noted a class of intermediate mass stars, Herbig Ae/Be stars, that are more massive stars analogs to T-Tauri stars

Current estimates is that our galaxy is forming a few stars per year.

Perseus Molecular Cloud: APOD



OB Associations & T Associations

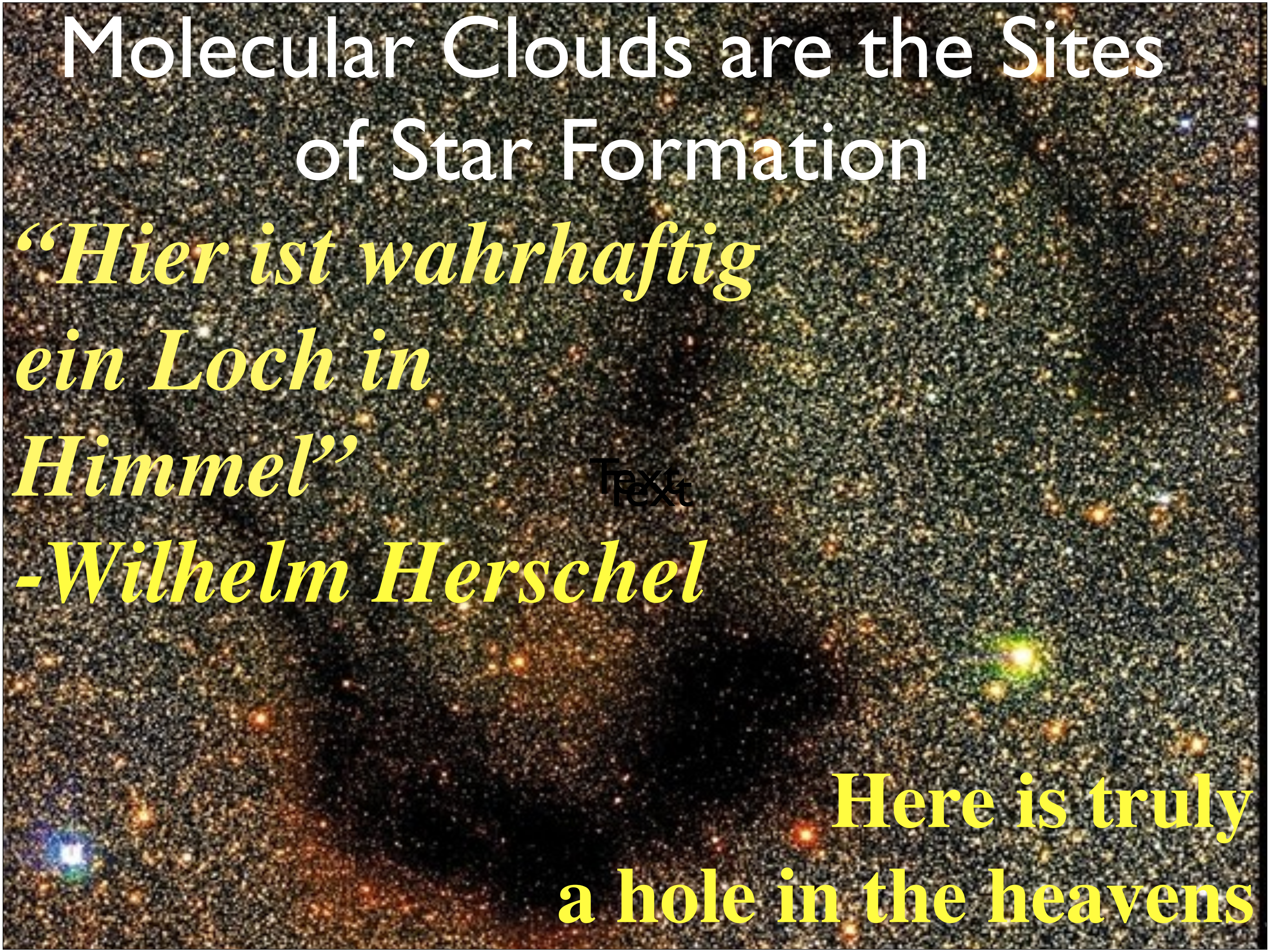
In the 1950s, Armenian Astronomer Victor Ambartsunian reasoned that observed unbound associations with 10-100 OB stars must be expanding from sites of recent star formation.

He also reasoned that unbound associations of T-Tauri stars, or T-associations, had similar implications.

He also noted that OB assocations have many T-Tauri type stars.

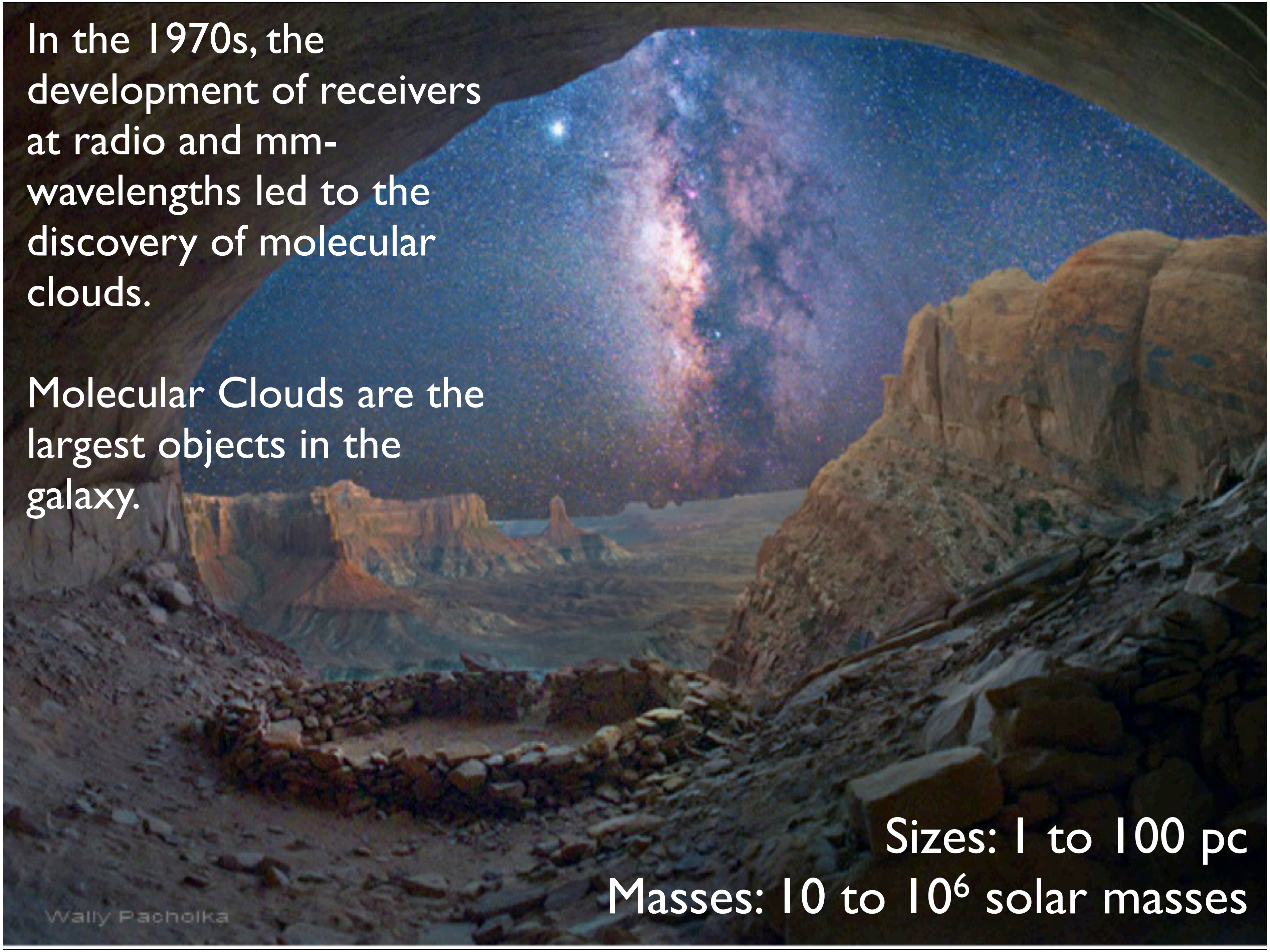
Victor Ambartsumian

Molecular Clouds are the Sites of Star Formation



In the 1970s, the development of receivers at radio and mm-wavelengths led to the discovery of molecular clouds.

Molecular Clouds are the largest objects in the galaxy.

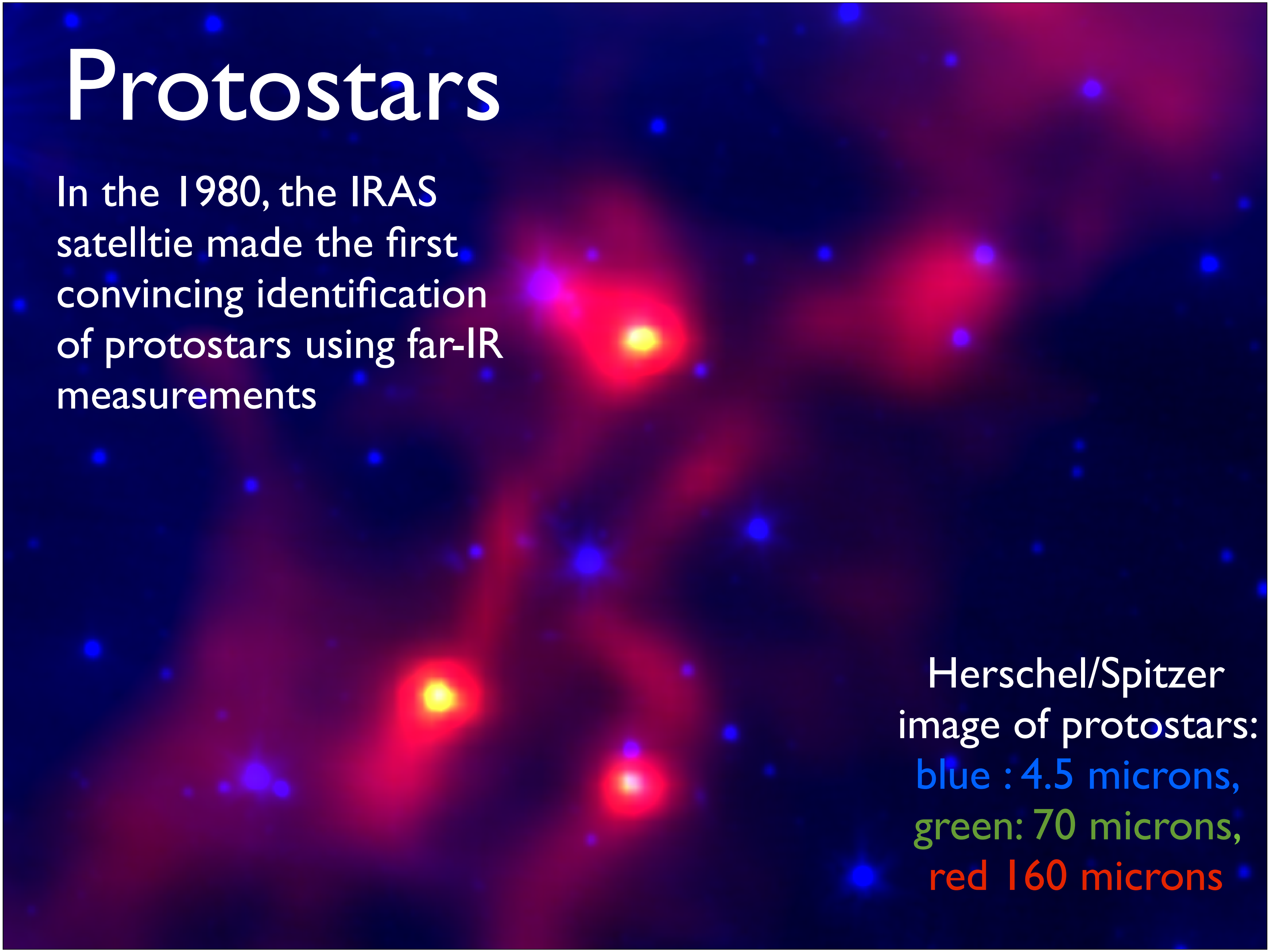


Sizes: 1 to 100 pc

Masses: 10 to 10^6 solar masses

Protostars

In the 1980, the IRAS satelltie made the first convincing identification of protostars using far-IR measurements

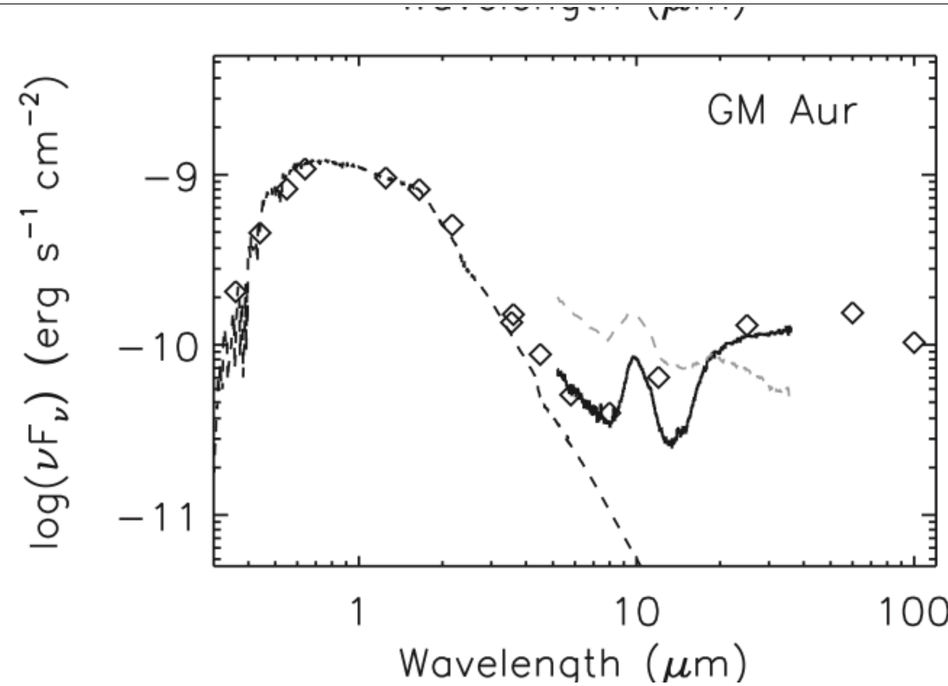


Herschel/Spitzer image of protostars:
blue : 4.5 microns,
green: 70 microns,
red 160 microns

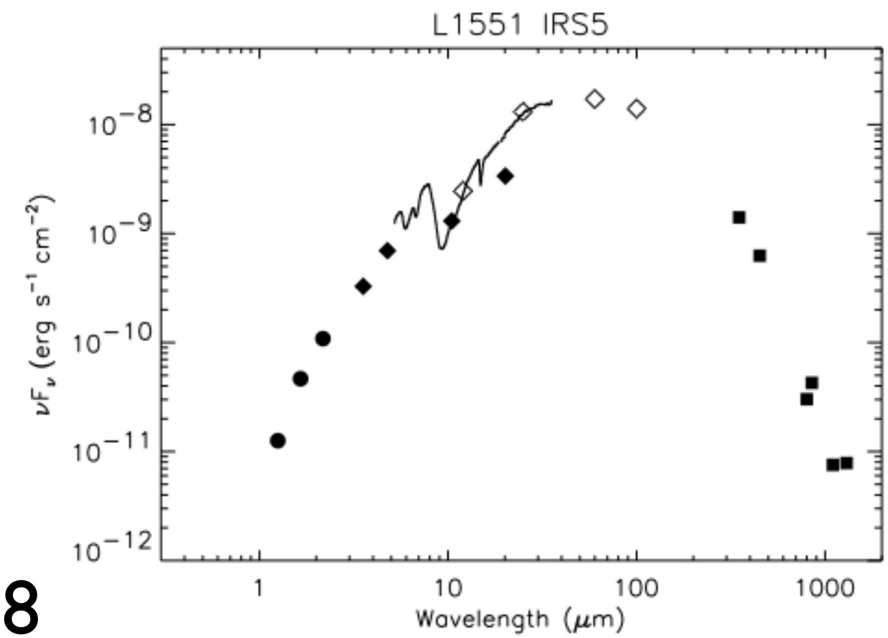
Young Stellar Object

- Expansive definition: a young pre-main sequence star or protostar.
- Restricted defintion: a young pre-main sequence star or protostar surrounded by a dusty disk or envelope.

Spectral Energy Distribution



Pre-main sequence star
Furlan et al. 2009



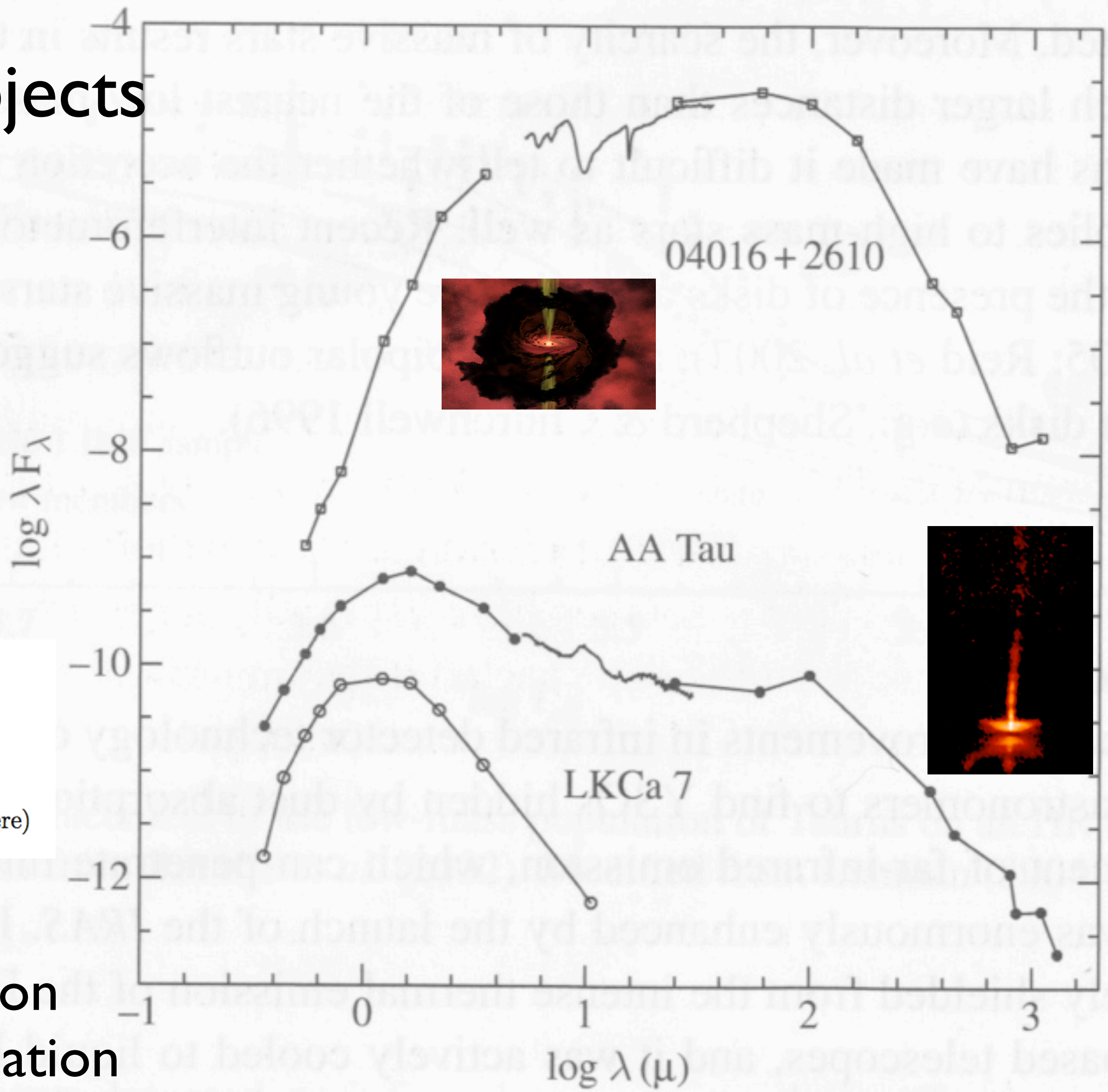
Protostar
Furlan et al. 2008

Classification of Young Stellar Objects (YSOs)

Spectral Index

$$\alpha = \frac{dlog(\lambda F_\lambda)}{dlog(\lambda)}$$

- $\alpha > 0.3$ is a Class I source
- $-0.3 < \alpha < 0.3$ is a flat spectrum source
- $-3 < \alpha < -0.3$ is a Class II
- $\alpha = -3$ is a Class III object (pure photosphere)



Hartmann: Accretion Process in Star Formation

The SEDs of Young Stellar Objects: Comparison to Theory

ADAMS, LADA, AND SHU

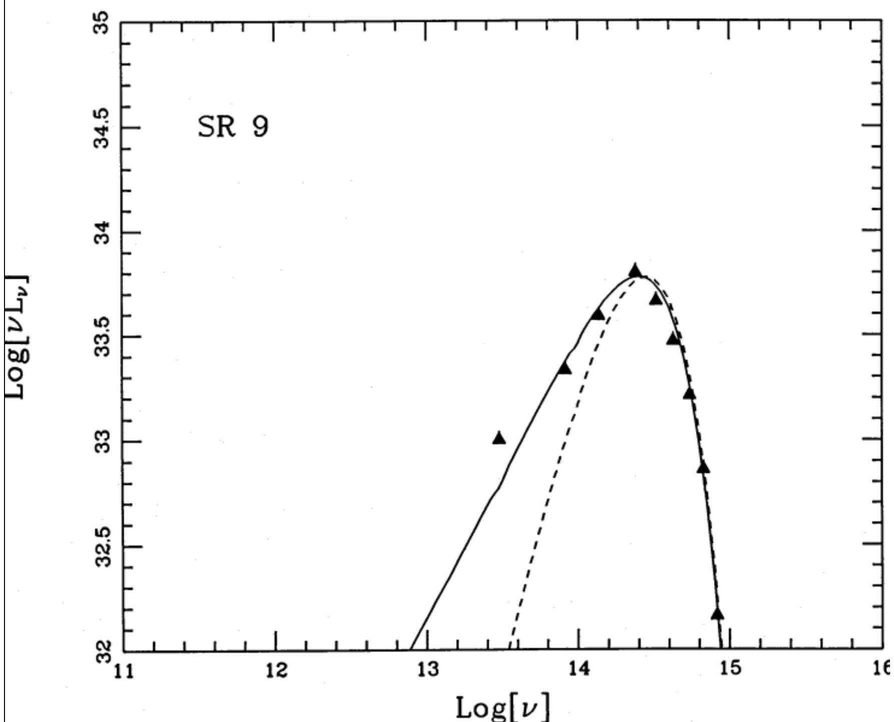
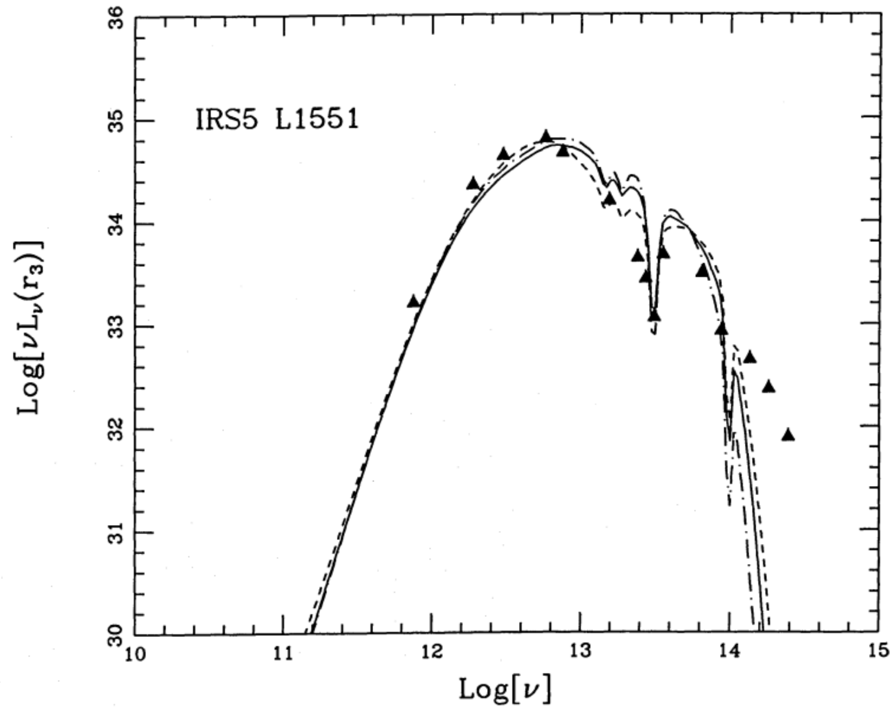


FIG. 2a

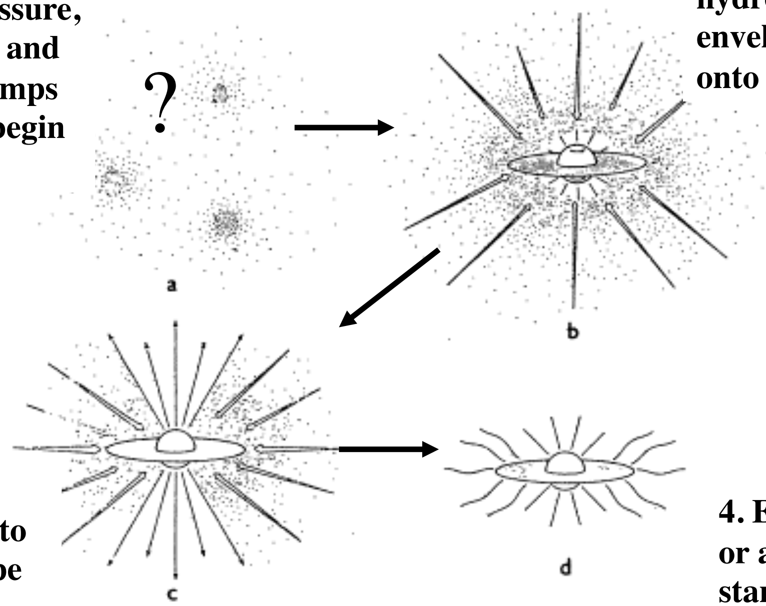


Adams, Lada & Shu 1987 312, 788
(841 citation to date)

Standard Model of Low Mass Star Formation

1. Cloud supported by thermal pressure, magnetic fields and turbulence, clumps fragment and begin collapse

2. Formation of hydrostatic core with envelope of gas accreting onto core (Class 0)



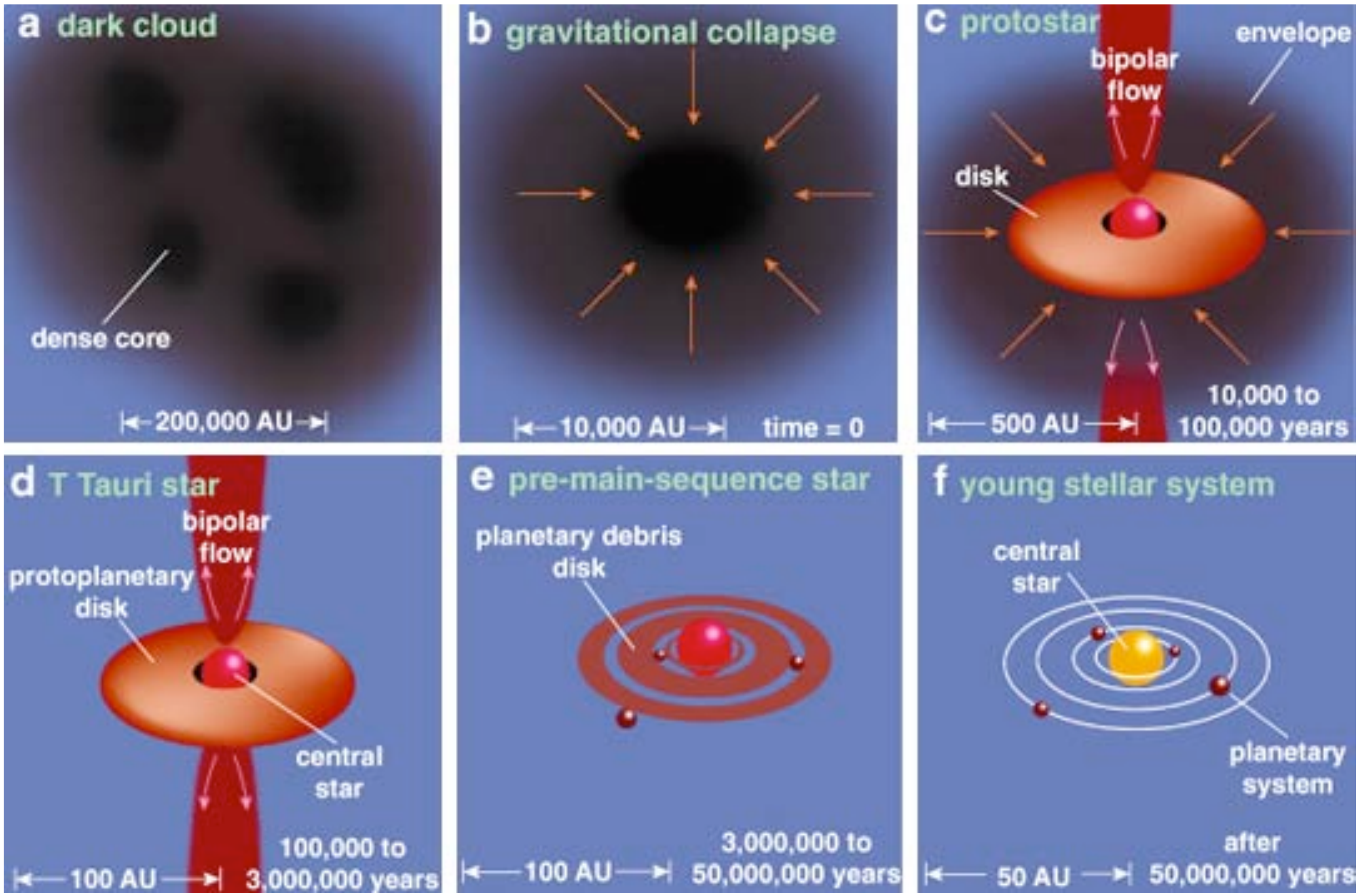
3. Disk forms, outflow begins to disrupt envelope (Class 1)

4. Envelopes dissipated or accreted, disk and star remains (Class 2)

Figure 7 The four stages of star formation. (*a*) Cores form within molecular clouds as magnetic and turbulent support is lost through ambipolar diffusion. (*b*) A protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (*c*) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (*d*) The infall terminates, revealing a newly formed star with a circumstellar disk.

Shu, Adams & Lizano (1987)

Stages of Star Formation



There are three major timescales in stellar evolution:

The **free fall time** is the time for which a gas cloud collapse onto a protostars (this is really the lower limit, since it assumes no pressure, just gravity):

$$t_{ff} = \left(\frac{3\pi}{32G\rho} \right)^{\frac{1}{2}} \tag{10}$$

For a density of 10^4 H_2 molecules cm^{-3} and assuming a 9% He/H ratio by number, we get a volume density of $4.5x10^{-20}$ cm^{-3} and a free fall time of 300,000 years.

The **Kelvin-Helmholtz** time is the duration over which a star can produce luminosity through quasistatic contraction (i.e. the pre-main sequence phase).

$$t_{KH} = \frac{GM^2}{RL} \tag{11}$$

For a M = 1 $M_\odot$, R=2 $R_\odot$ and, L = 5 $L_\odot$, $t_{KH} = 30 \times 10^6$ years.

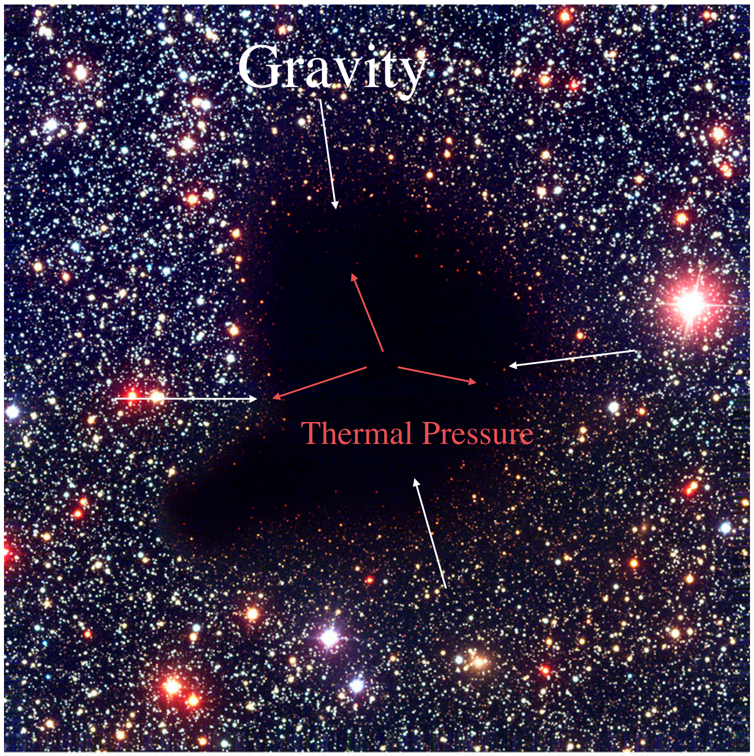
The **nuclear time** is the duration over which a star contain sustain itself by fusion of Hydrogen atoms. This is given by:

$$t_{nuc} = 10^{-3} \frac{Mc^2}{L} \tag{12}$$

For a star with M = 1 $M_\odot$ and L = 1 $L_\odot$, then $t_{nuc} = 10^7$ years.

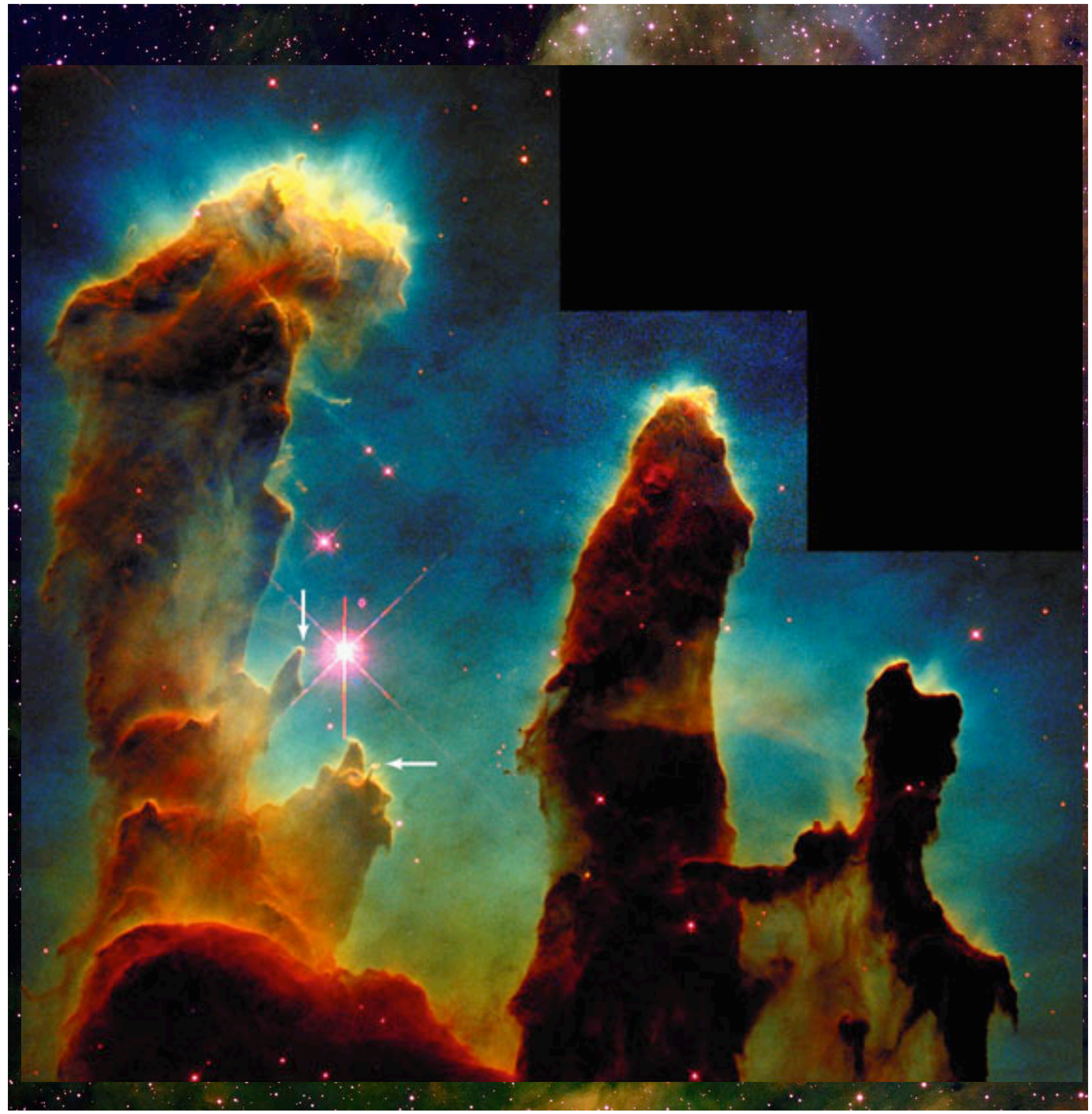
Major Problems in Star Formation

1. What Initiates Star Formation?

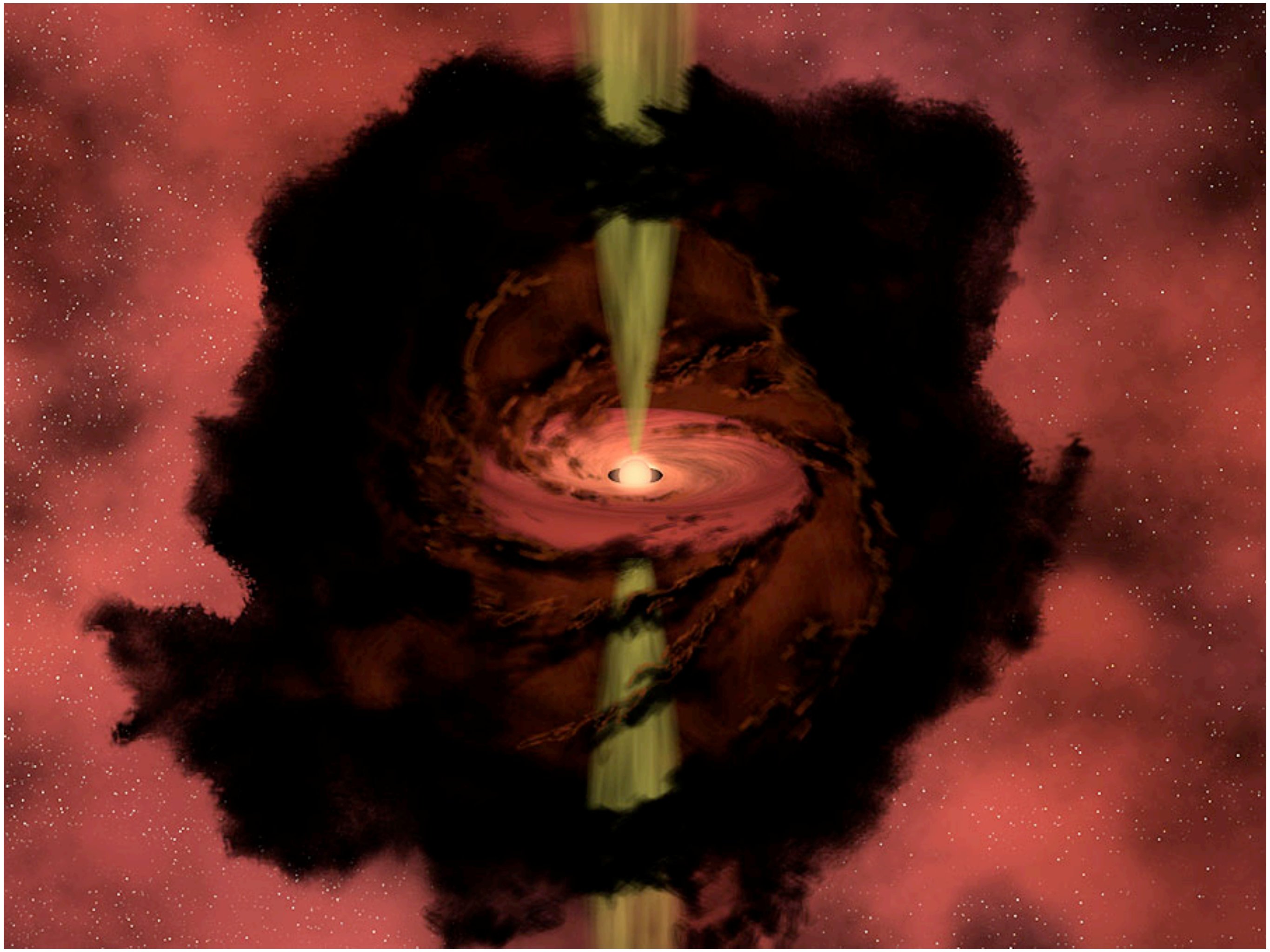


Pre-Collapse Black Cloud B68 (visual view)
(VLT ANTU + FORS 1)

ESO PR Photo 02a/01 (10 January 2001)



2. What Processes Govern Protostellar Evolution and Determine the Stellar Mass and Rotation Rate?



3. How do Massive Stars Form?

The Eddington Limit: where does radiation pressure balance gravity.

$GM\rho/R^2 = L\rho\kappa/c4\pi R^2$

Accretion is fueled by gravity:

$L/M = 4\pi cG/\kappa$

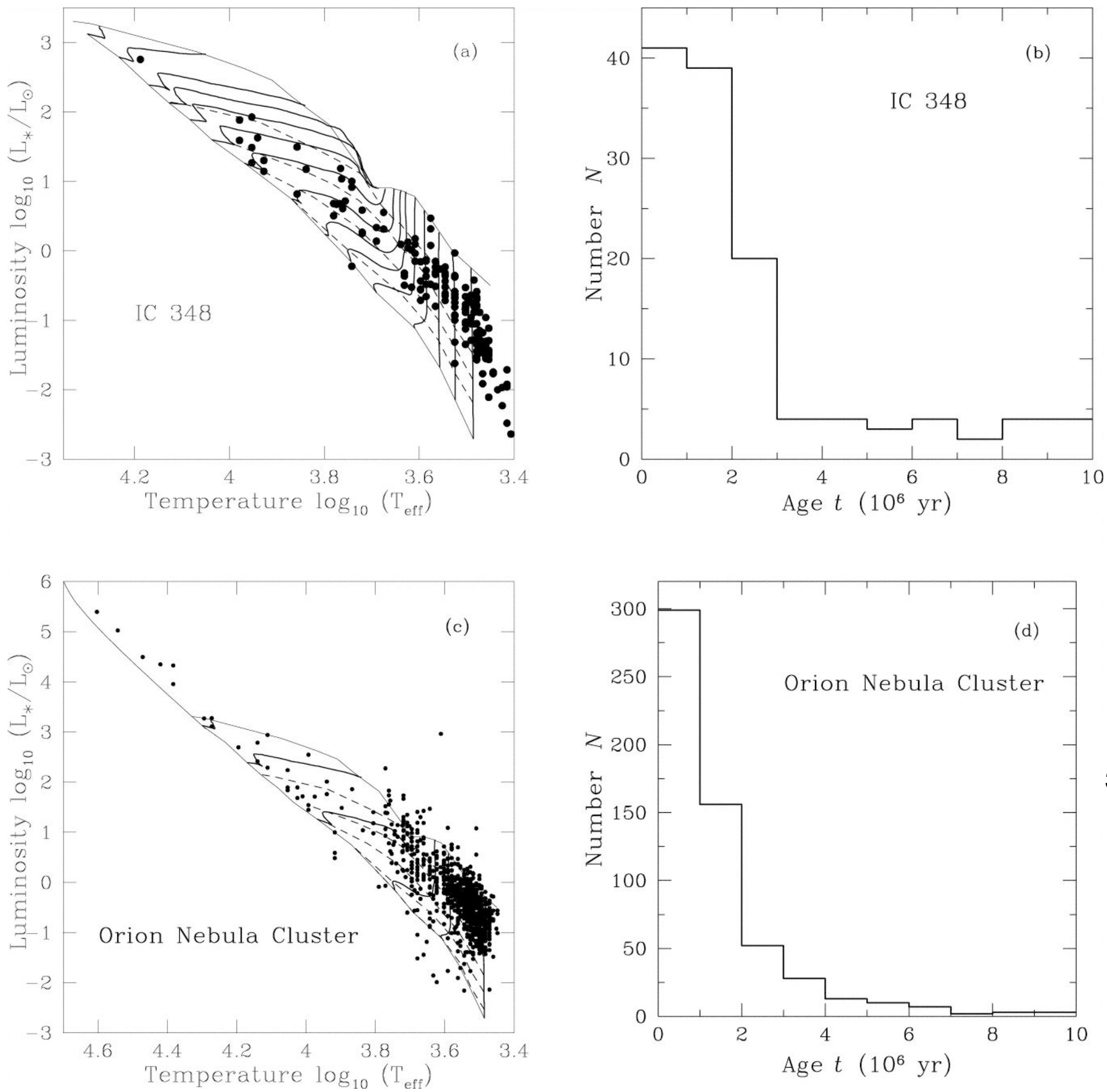
$\kappa = 100\ cm^2/g$ (for interstellar dust)

L/M = 128 Lsun/Msun

Approximately $L = M^3$

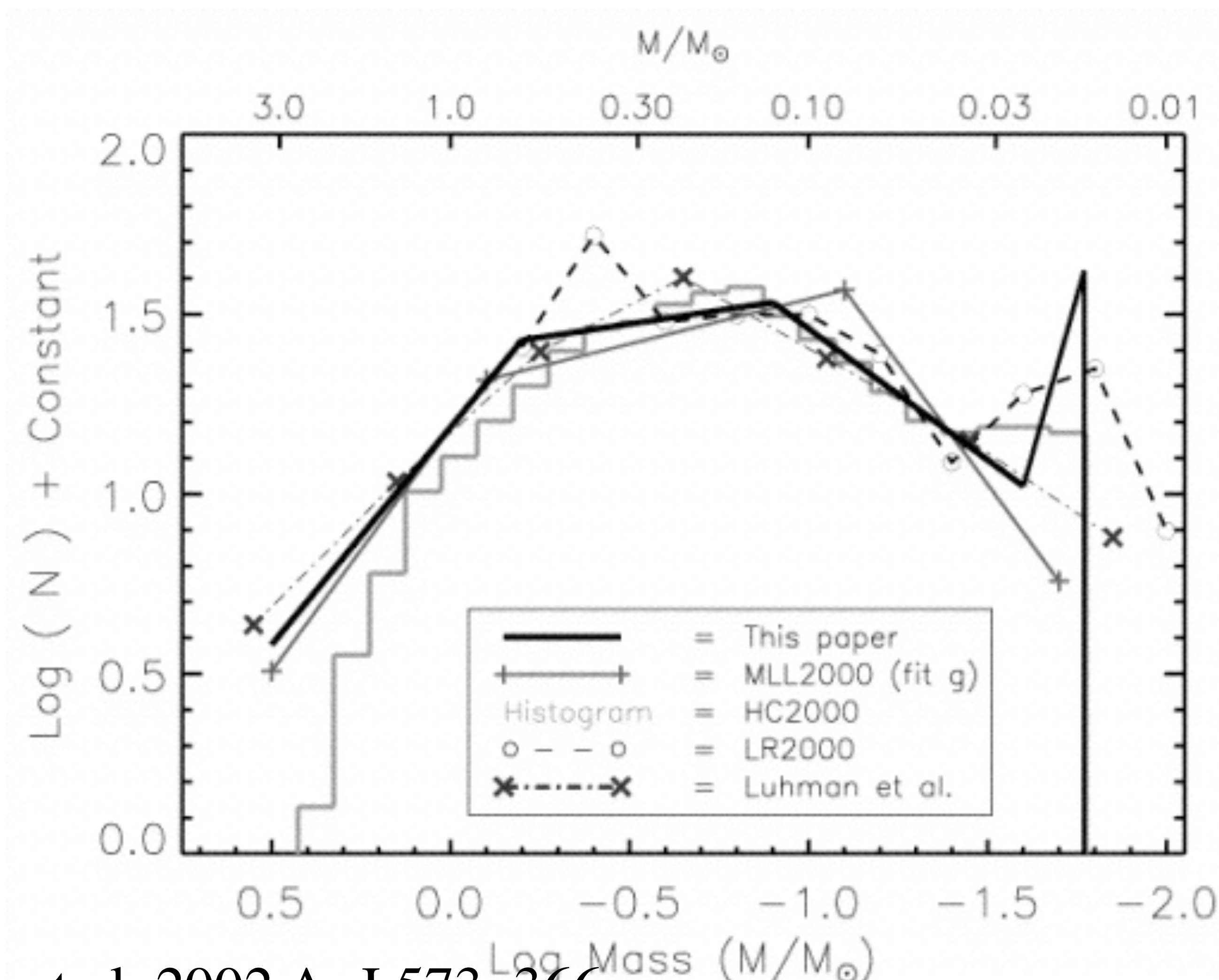
Thus around 10 Msun, L/M exceeds Eddington Limit.

4. What is Lifetime of Molecular Clouds (and the Duration of Star Formation)?



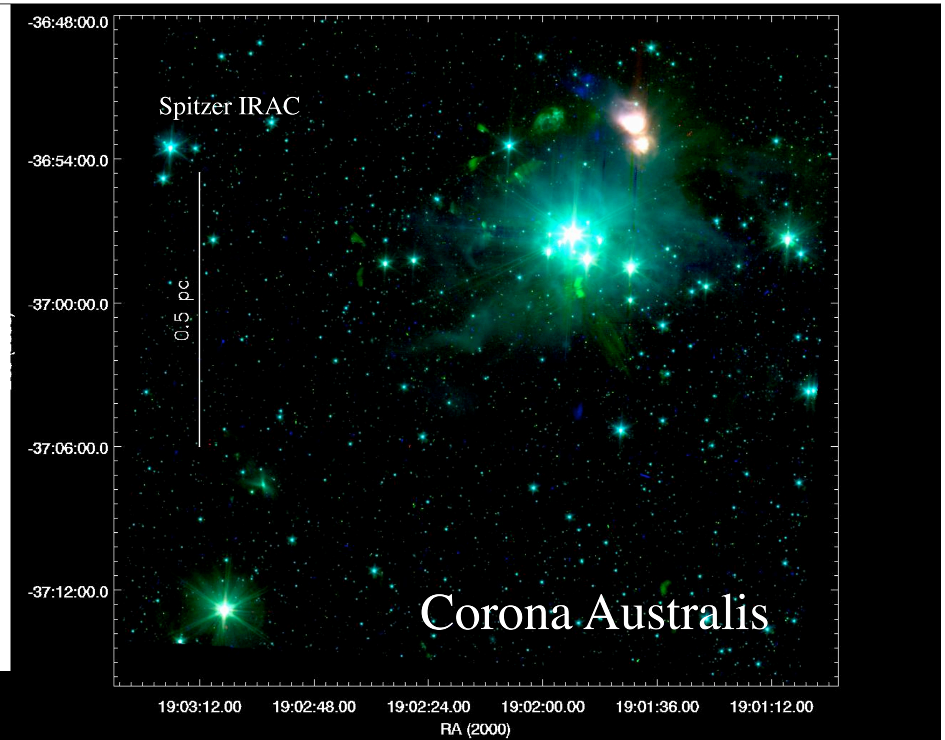
Palla & Stahler
540:255–270, 2000

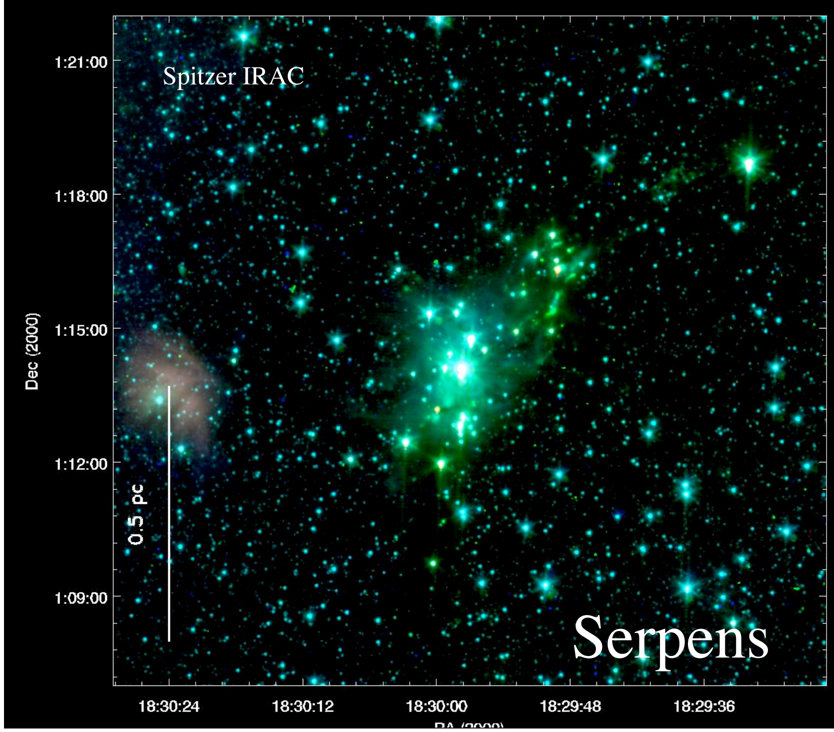
5. What Physics Determines the Initial Mass Function?

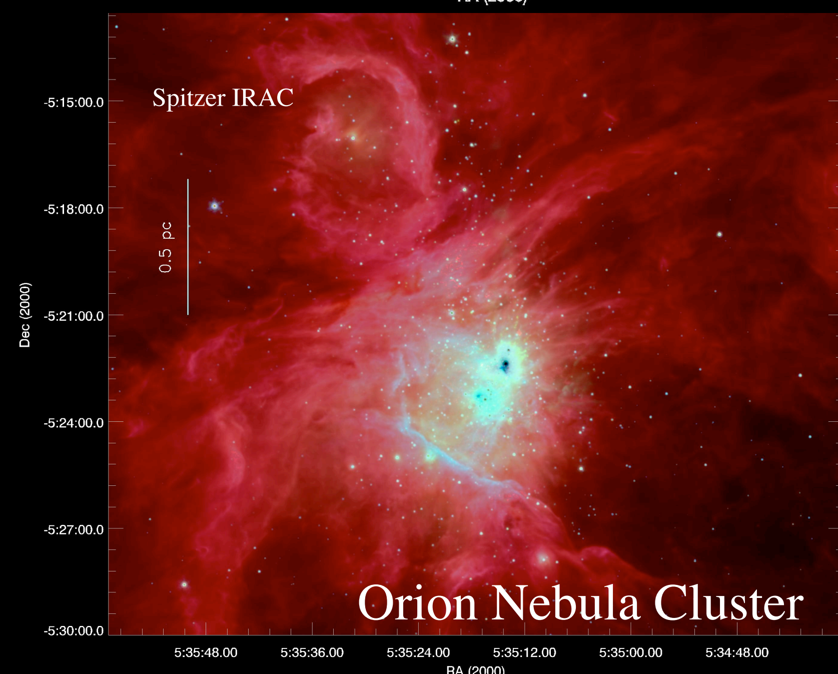


Muench et al. 2002 ApJ 573, 366.

6. What Physics Regulates the Rate & Efficiency?

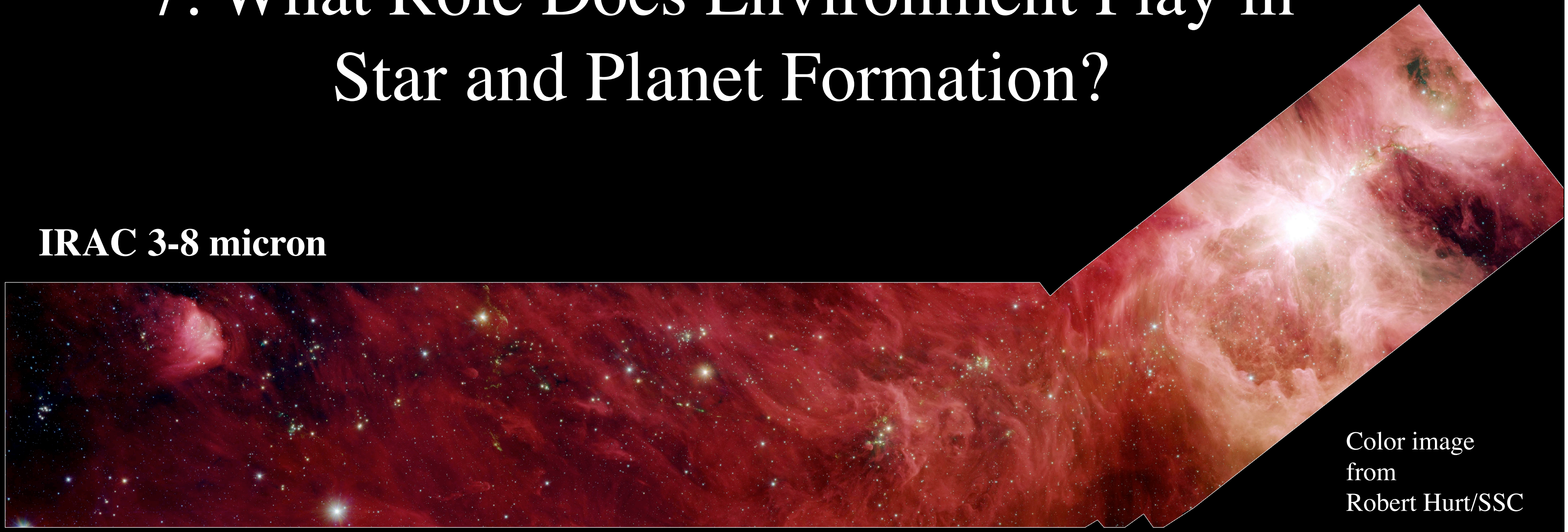






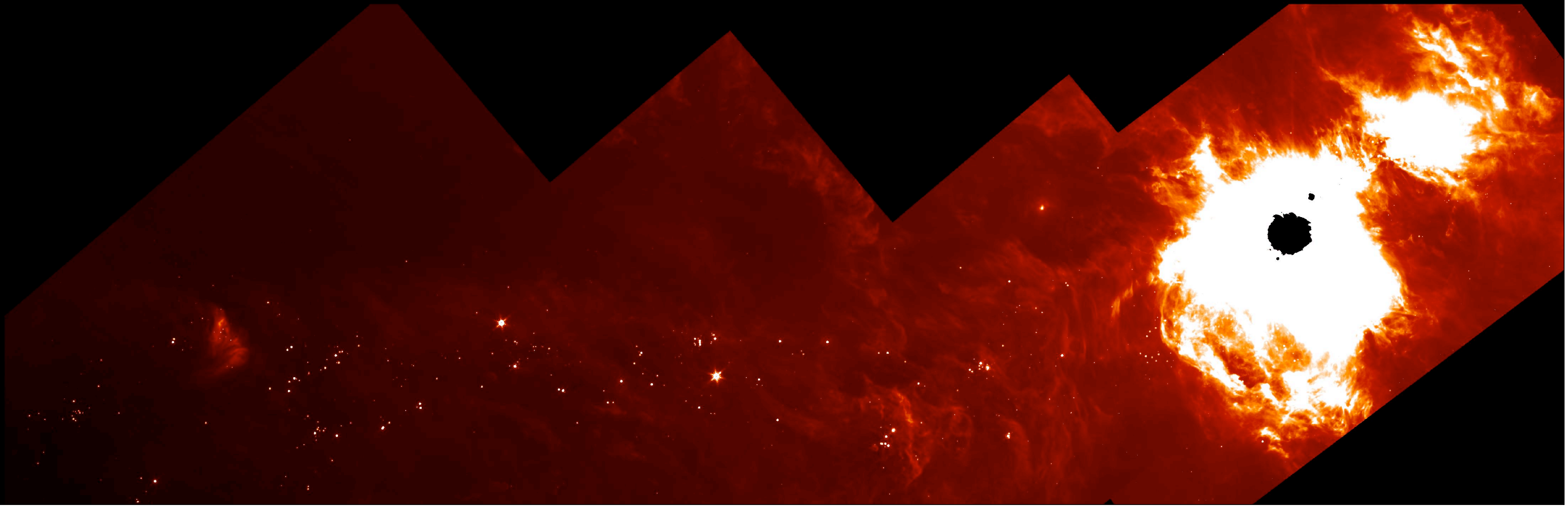
7. What Role Does Environment Play in Star and Planet Formation?

IRAC 3-8 micron



Color image from Robert Hurt/SSC

MIPS 24 micron



8. What Physics Regulates Star Formation in Clusters?