Lecture 14 ASTB23

- Stellar Formation
- Stellar Evolution

Jeans instability & the collapse of molecular clouds

James Hopwood Jeans (1877-1946) studied the
stability of molecular clouds
thermal vs. gravitational energy

different forms:
mass criterion
temperature criterion,
radius criterion

Jeans instability & the collapse of molecular clouds

$$t_{ff}^2 \sim \frac{R^2}{v^2} \sim \frac{R^3}{GM} \quad and \quad t^2{}_{sound} \sim \frac{R^2}{v^2{}_s} \sim R^2 \frac{\mu m_H}{kT}$$

$$t_{ff}^2 < t^2{}_{sound}$$

$$kT < \frac{GM\mu m_H}{R}$$

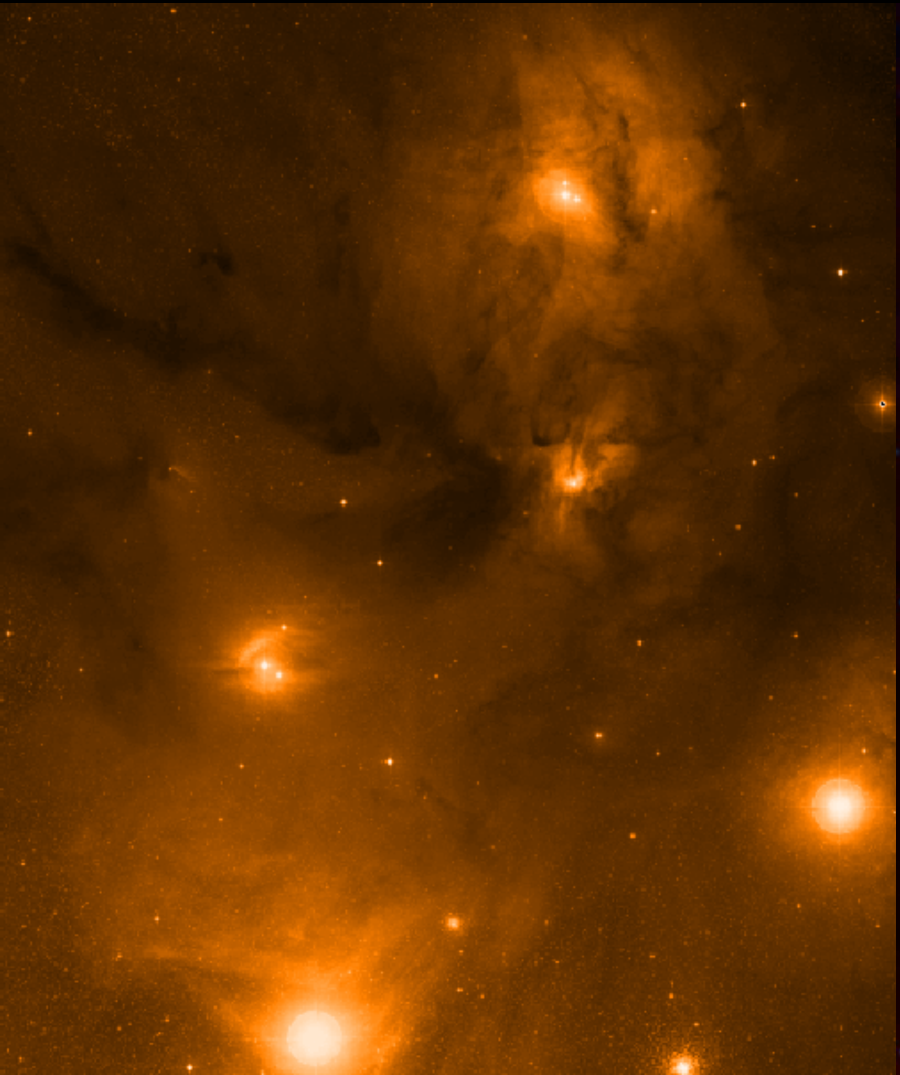
gravity wins the competition with thermal pressure

Jeans instability criterion is essentially energy inequality that can be cast as criterion for R, M, or T

for more info, derivation, cf. ASTC25

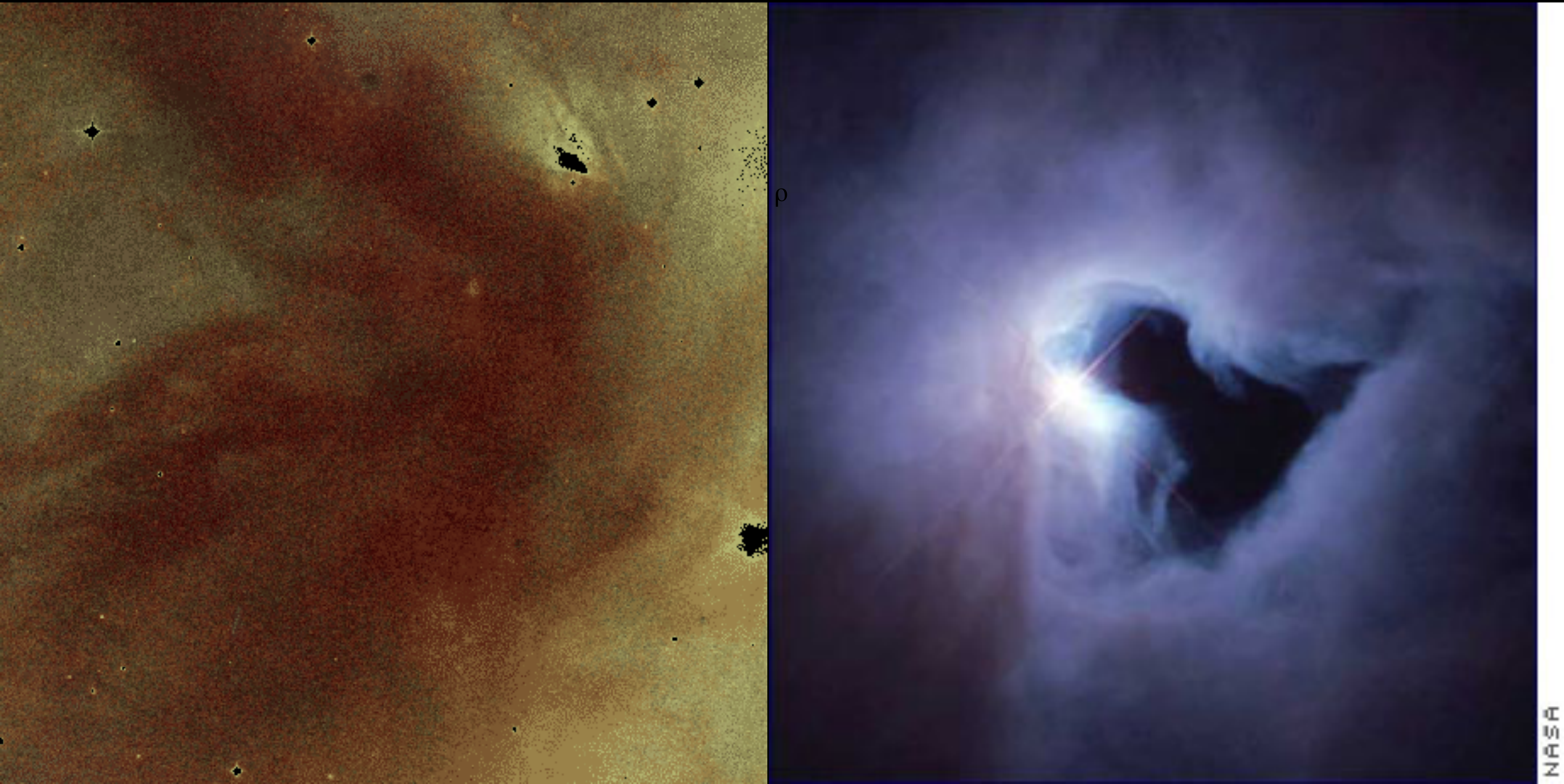
ρ Oph

Giant Molecular Cloud, 160 pc away, contains numerous dark clouds



GMCs contain: dark clouds, cores, Bok globules
GMC mass / solar mass ~ 10^5

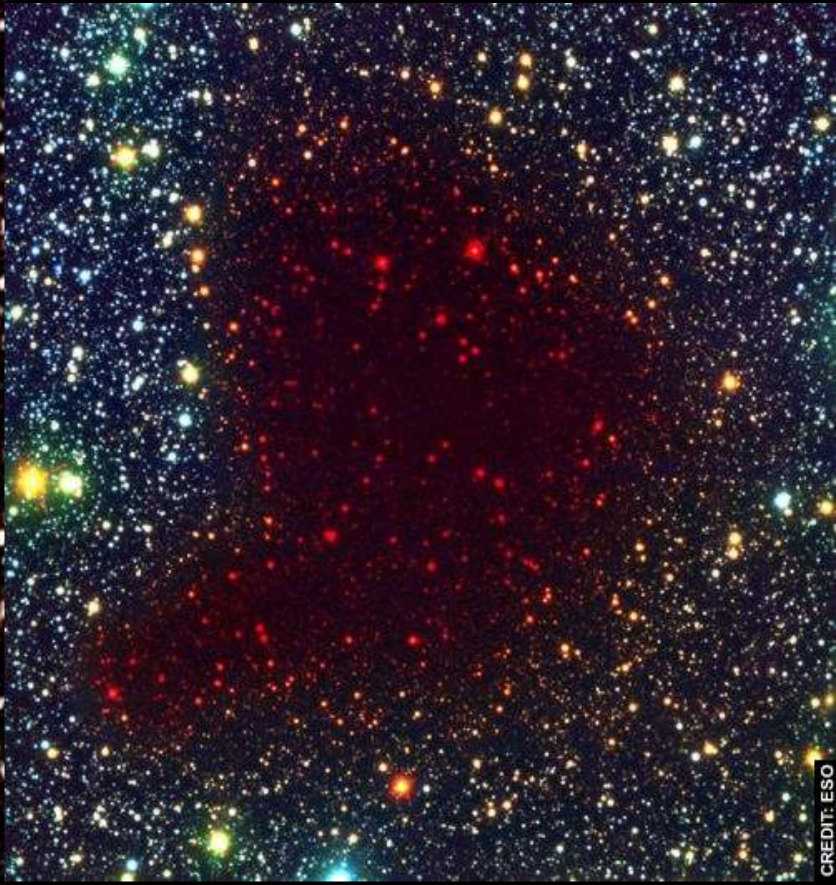
so-called Bok globules (dark, dense cores of GMC)

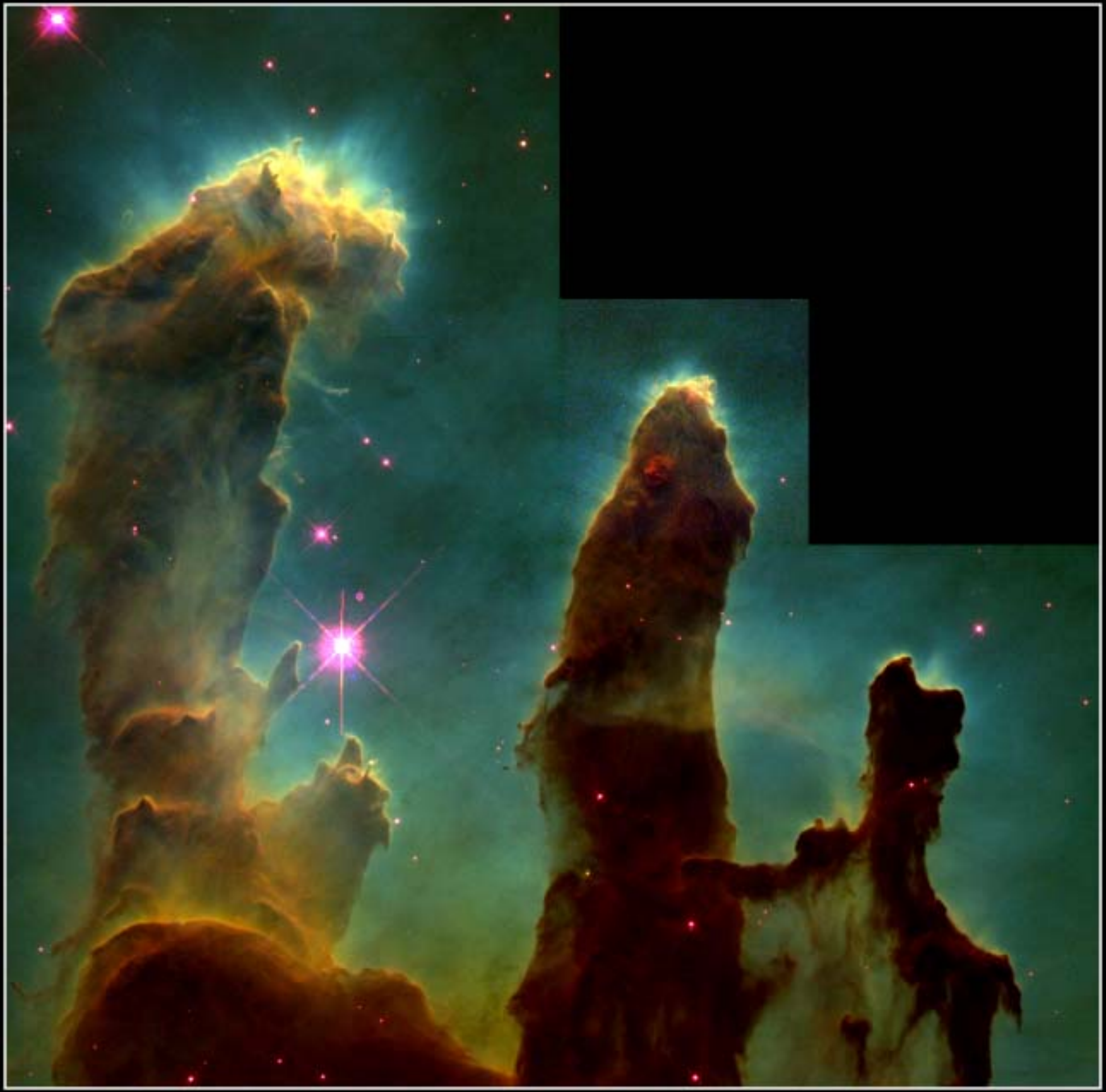


Dark clouds
Radio intensity overlayed on optical and IR images

L57

Barnard 68





Gaseous Pillars · M16 HST · WFPC2

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

UKAFF (UK Astroph. Fluids Facility) supercomputer

Stars are forming in…
these boxes.

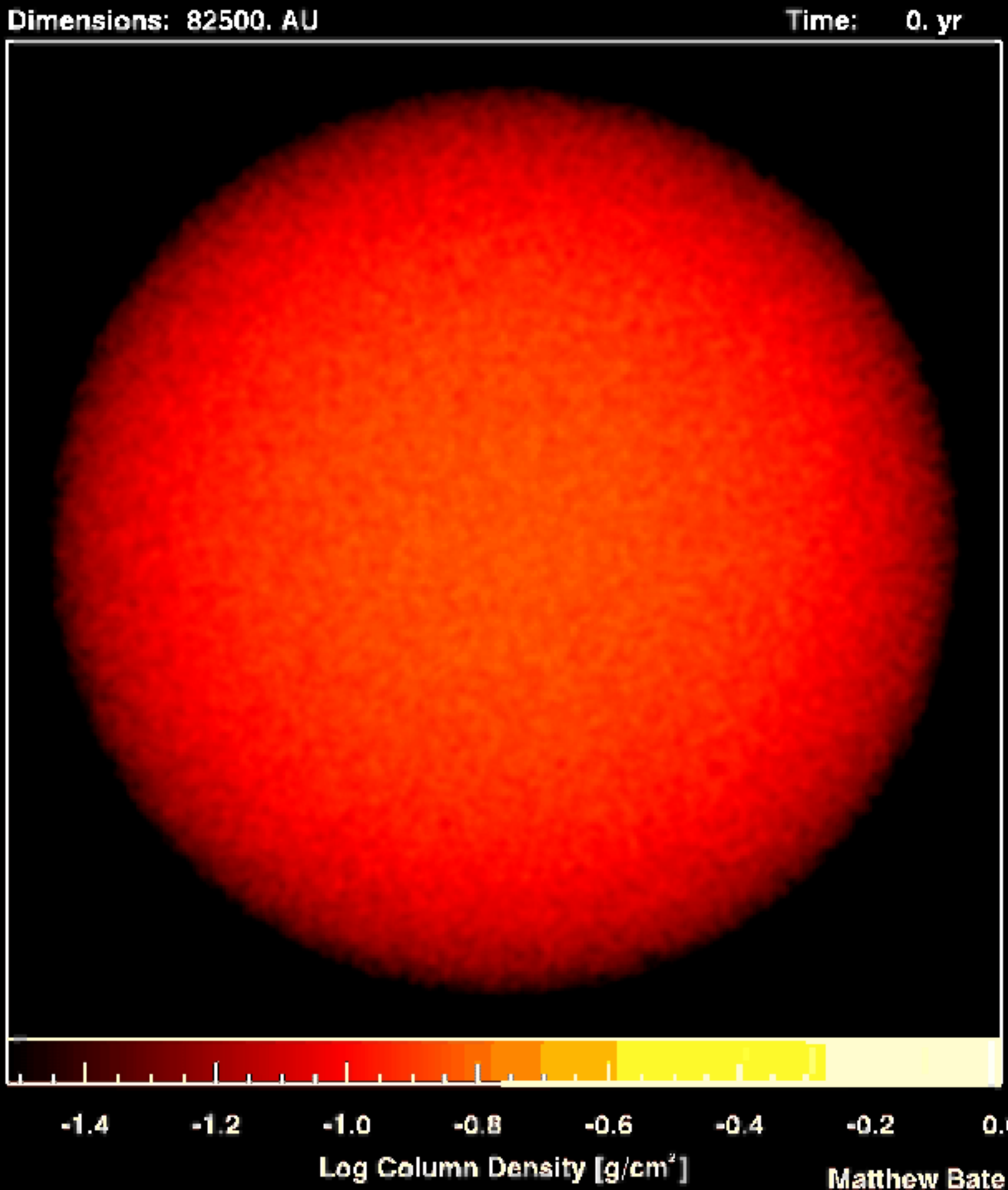
Matthew Bate(2003), Bate and Benz (2003)

SPH, 1.5M particles

starting from
turbulent gas cloud

collapse starts after
turbulence dies down
and Jeans mass
drops below the
cloud mass.

Jeans mass defines
stability against collapse



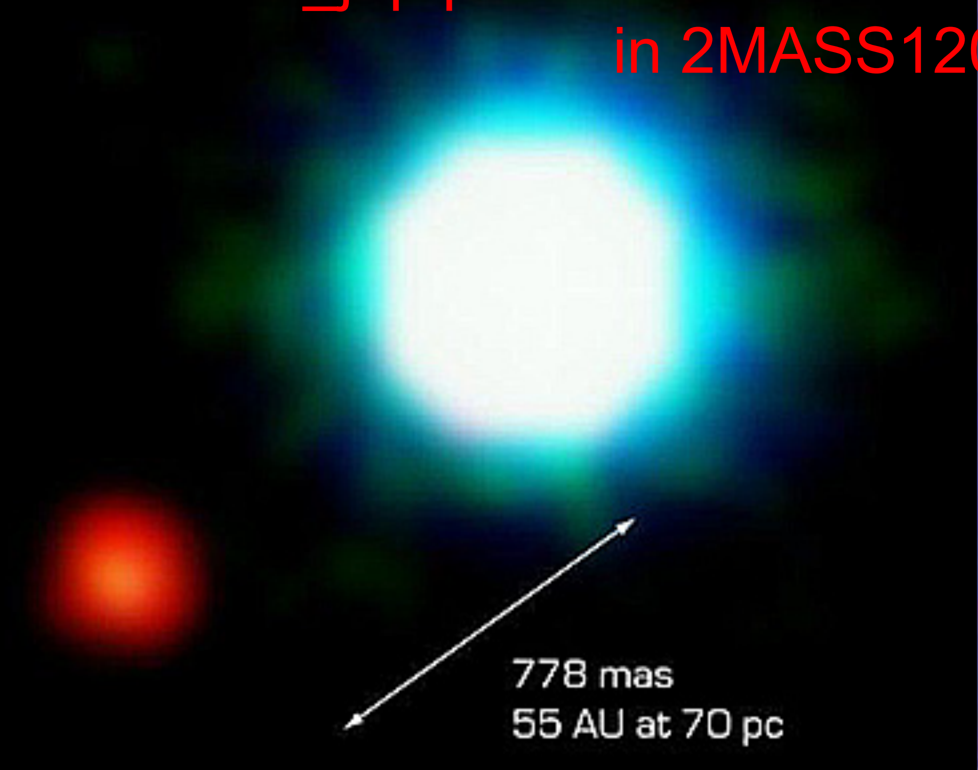
Brown dwarfs - a failed attempt at stardom

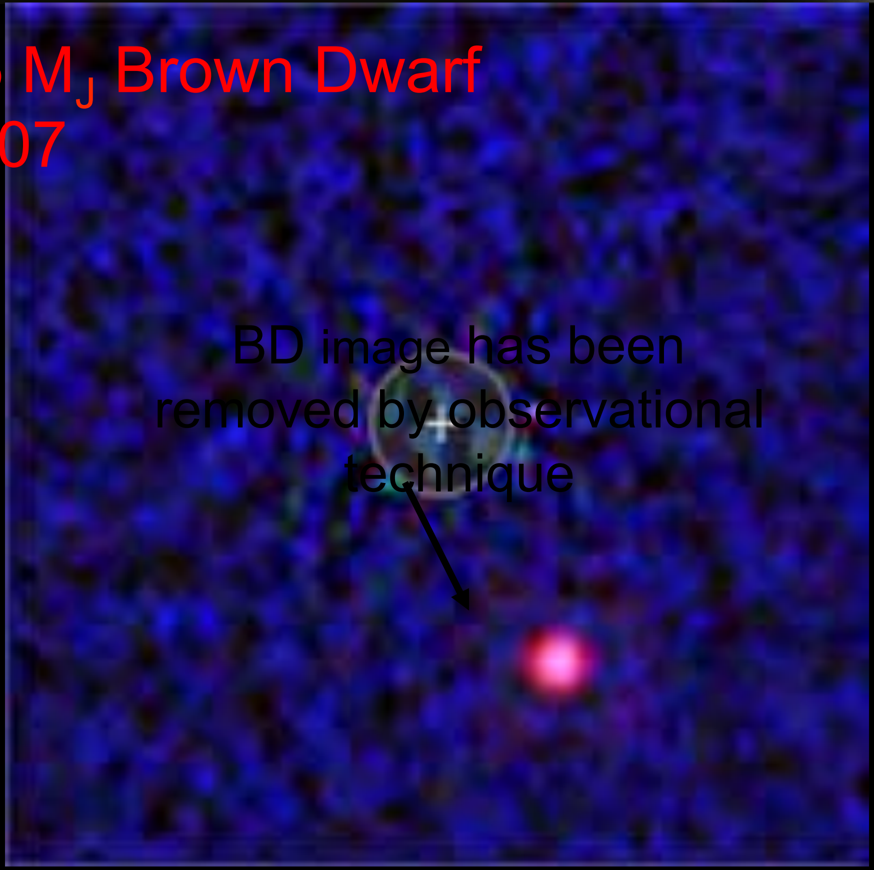
As seen in the simulation of molecular cloud fragmentation, brown dwarfs (smallest objects simulated as white points) form in large numbers, and are mostly dispersed throughout the Galaxy afterwards. Sometimes, they are found as orbital companions to stars (not very frequently, hence the term "brown dwarf desert" by comparison with a larger number of planetary companions to stars.)

And there is even one BD with its own companion of only 5 Jupiter masses!

A strange system discovered in 2003:

5 M_jup planet around a 25 M_J Brown Dwarf
in 2MASS1207





BD image has been removed by observational technique

ESO/VLT AO

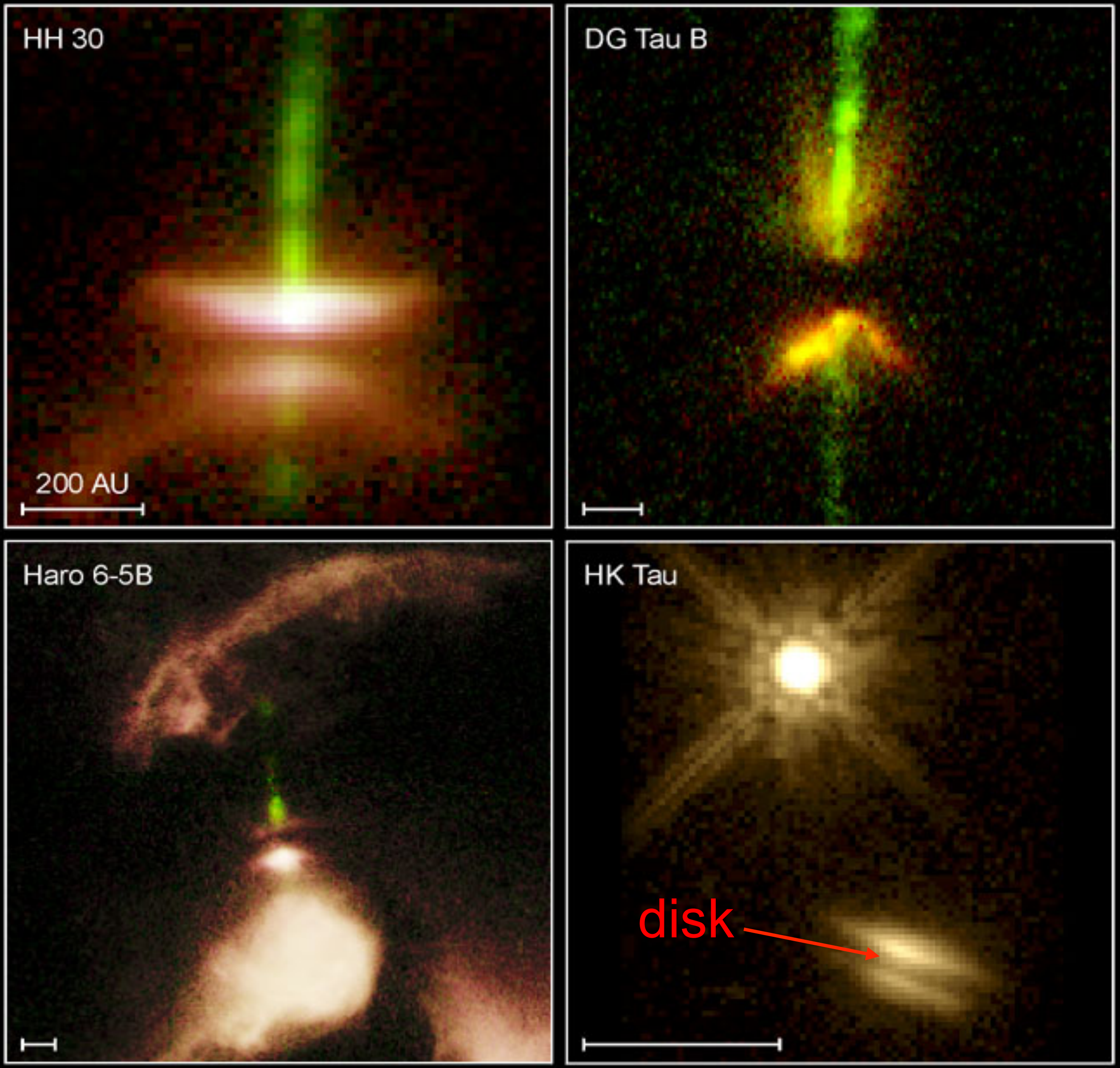
HST/NICMOS,

1.6 µm

Disks - a natural way to stardom

As seen in the simulation of molecular cloud fragmentation, star formation is very non-spherical and not even very axisymmetric: it is 3-D and leads to protostars surrounded by accretion disks.

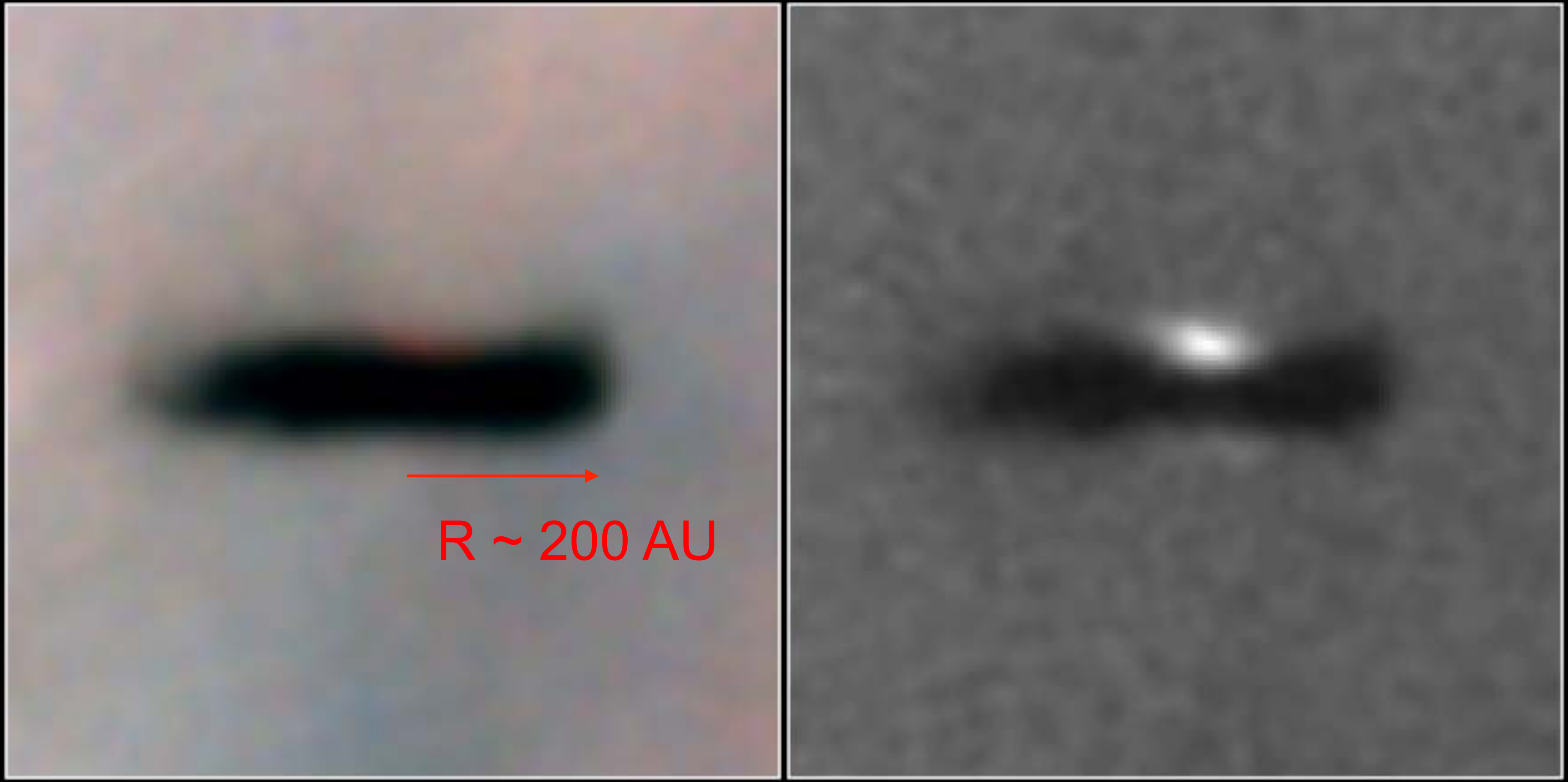
The main physical reason is the angular momentum (L) conservation: before L is transferred outward (e.g. by viscosity), the gas cannot approach the rotation axis; but it has no such restriction on approaching the equatorial plane (or midplane), where it gathers in the form of a rotationally-supported thin disk.



Disks around Young Stars **HST • WFPC2**

PRC99-05b • STScI OPO

C. Burrows and J. Krist (STScI), K. Stapelfeldt (JPL) and NASA



Edge-On Protoplanetary Disk
Orion Nebula

HST • WFPC2

PRC95-45c • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

EVOLUTION OF DISK ACCRETION 395

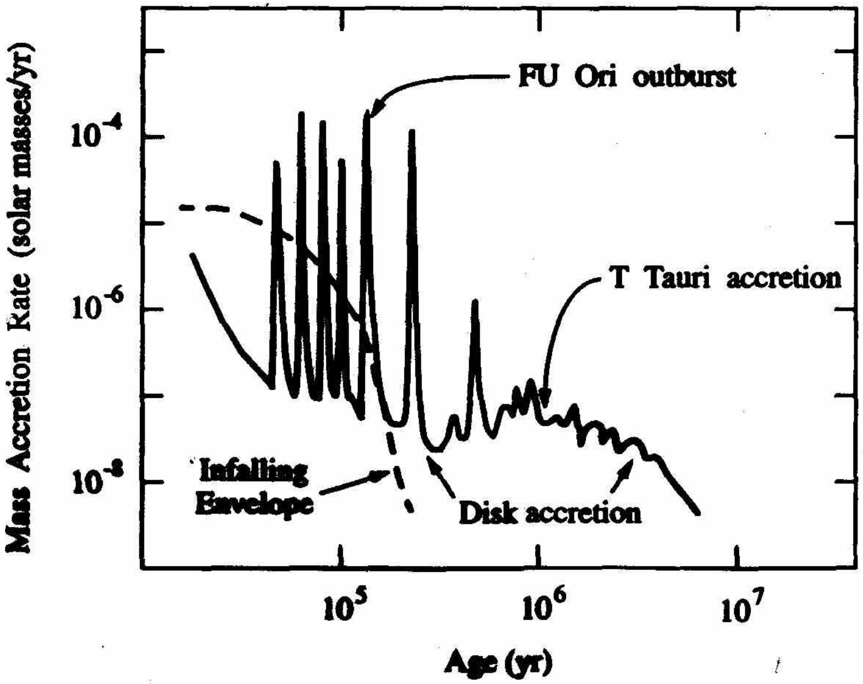


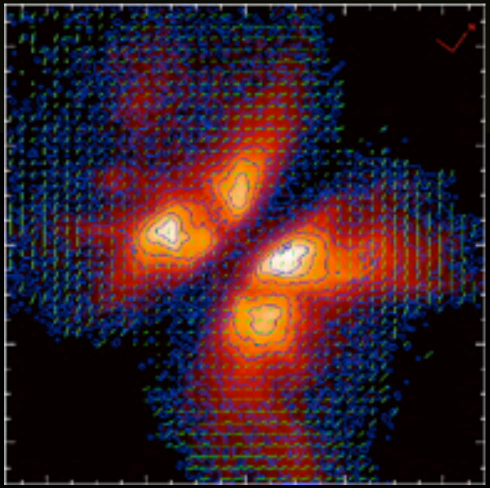
Figure 7. Sketch of disk evolution with time, summarizing the ideas presented in this chapter. The disk remains most of the time in a quiescent state, punctuated by episodes of high $\dot{M}$ as long as the envelope feeds mass to the disk. When infall ceases, the disk evolves viscously, and $\dot{M}$ slowly decreases with time.

Observed dM/dt ~ 10^{-6} M_{sun}/yr for ~0.1 Myr time

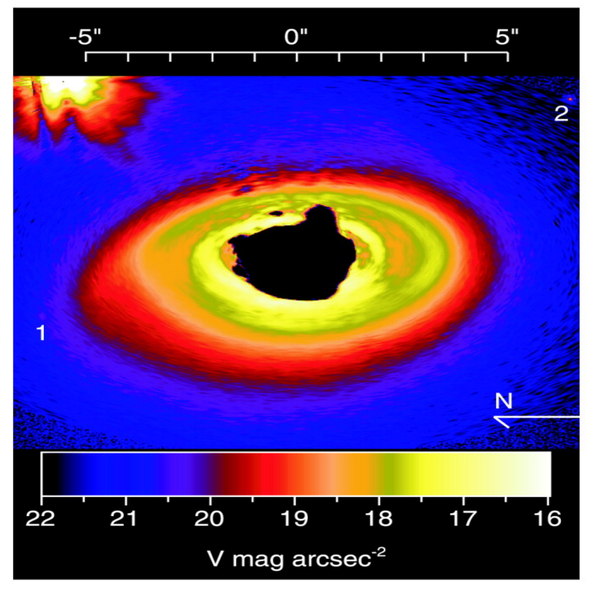
==> total amount accreted ~0.1 M_{sun}

Observed dM/dt ~ 10^{-7} M_{sun}/yr for ~Myr time

==> total amount accreted ~0.1 M_{sun}

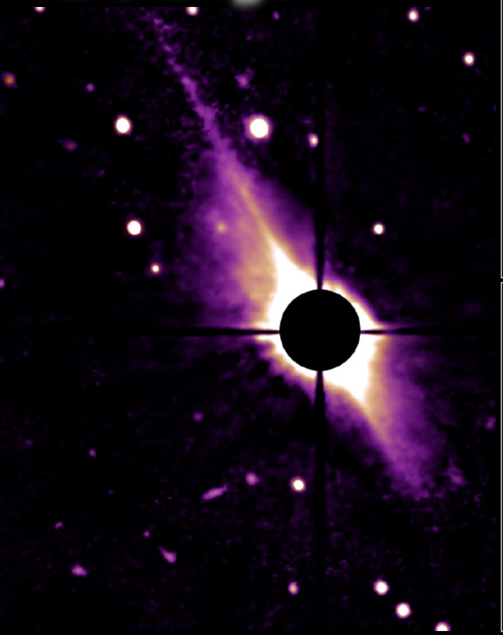


<1 Myr



5 Myr

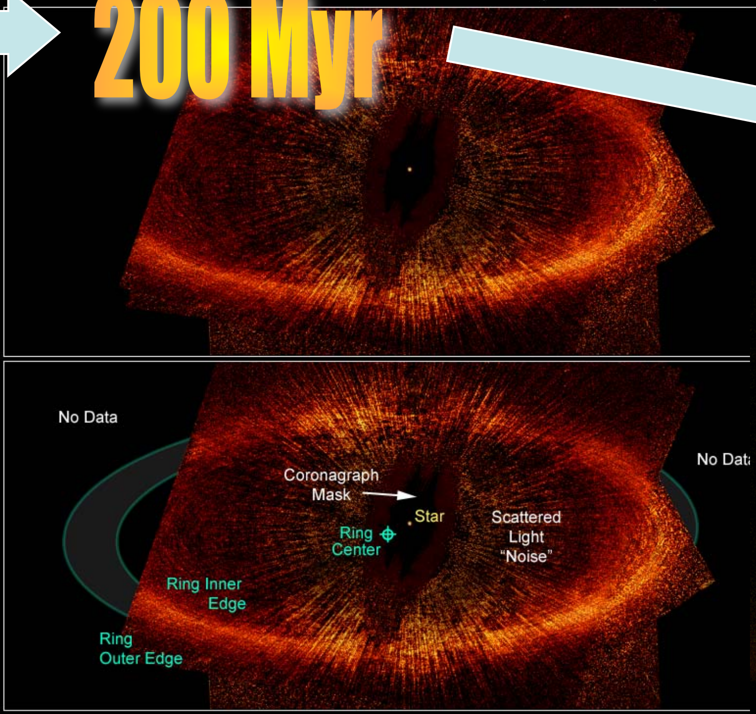
20 Myr



200 Myr

Fomalhaut Debris Ring

Hubble Space Telescope • ACS HRC

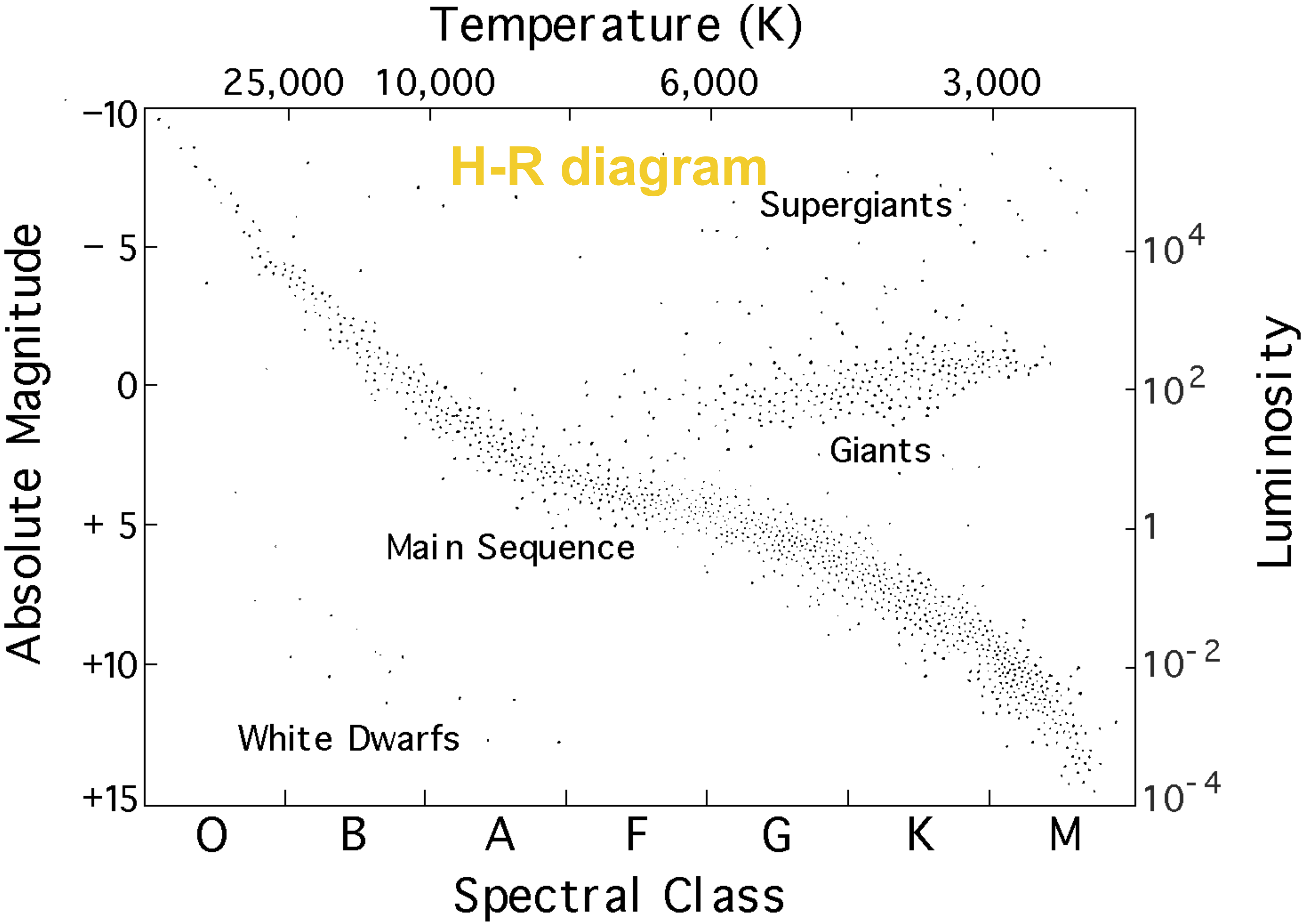


NASA, ESA, P. Kalas and J. Graham (University of California, Berkeley)
and M. Clampin (NASA/GSFC)

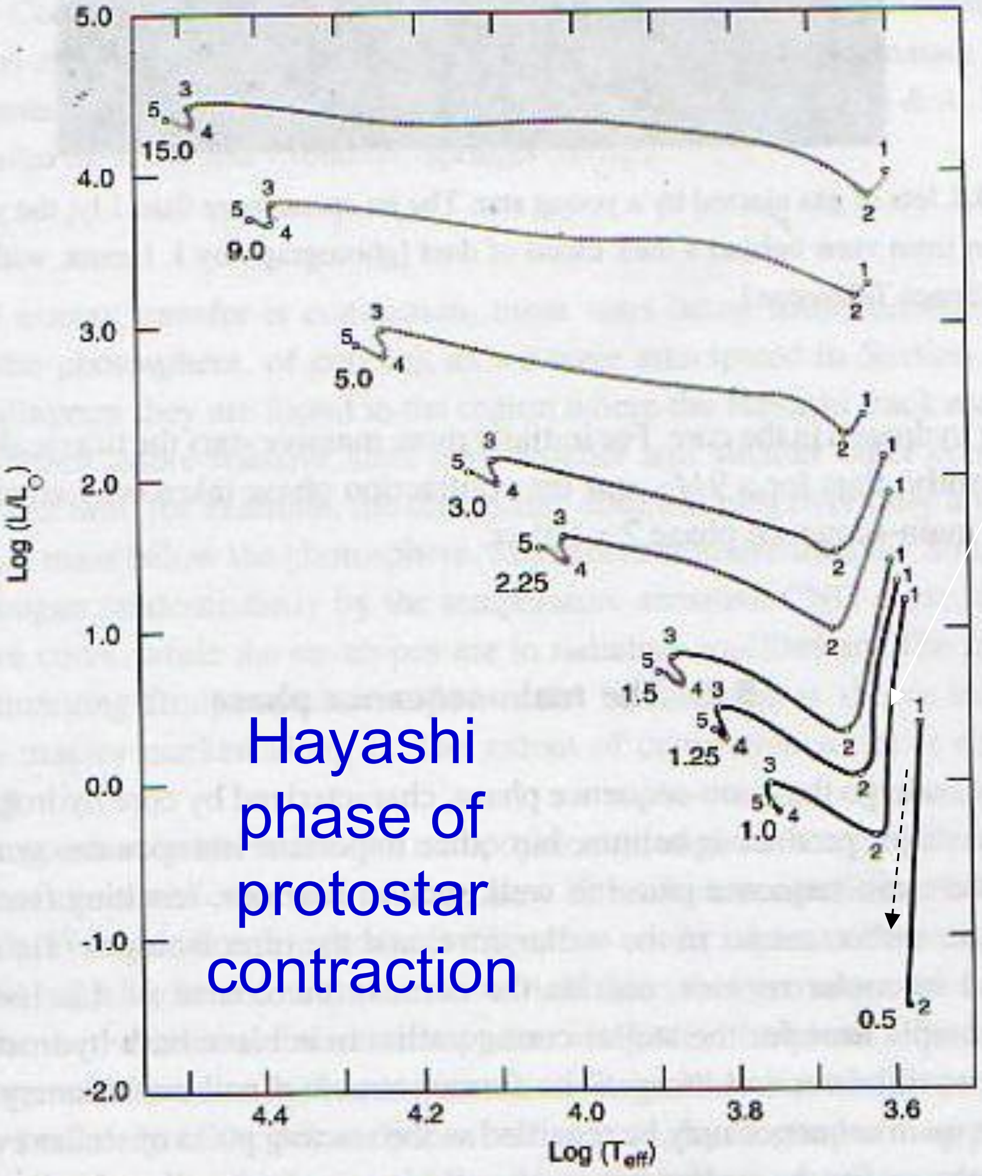
STScI-PRC0

4567 Myr

H-R diagram


Temperature (K)
25,000
10,000
6,000
3,000
−10
− 5
0
+ 5
+10
+15
Absolute Magnitude
10^4
10^2
1
10^{-2}
10^{-4}
Luminosity
Supergiants
Giants
Main Sequence
White Dwarfs
O
B
A
F
G
K
M
Spectral Class

Hertzsprung-Russell diagram



Hayashi phase of protostar contraction

Figure 8.1 Evolutionary paths in the H–R diagram for stars of different initial mass (as marked) during the pre-main-sequence phase. The shade of segments is indicative of the time spent in each phase, ranging from less than 10^3 yr (light) to more than 10^7 yr (dark), as given in Table 8.1 [adapted from I. Iben Jr. (1965), *Astrophys. J.*, 141].

S

Hayashi tracks are ~vertical pieces of evolutionary tracks during the PMS (pre-MS) phase

Evolution of M Dwarf Stars, Brown Dwarfs and Giant Planets
(from Adam Burrows)

Glenn Schneider

NICMOS Project
Steward Observatory