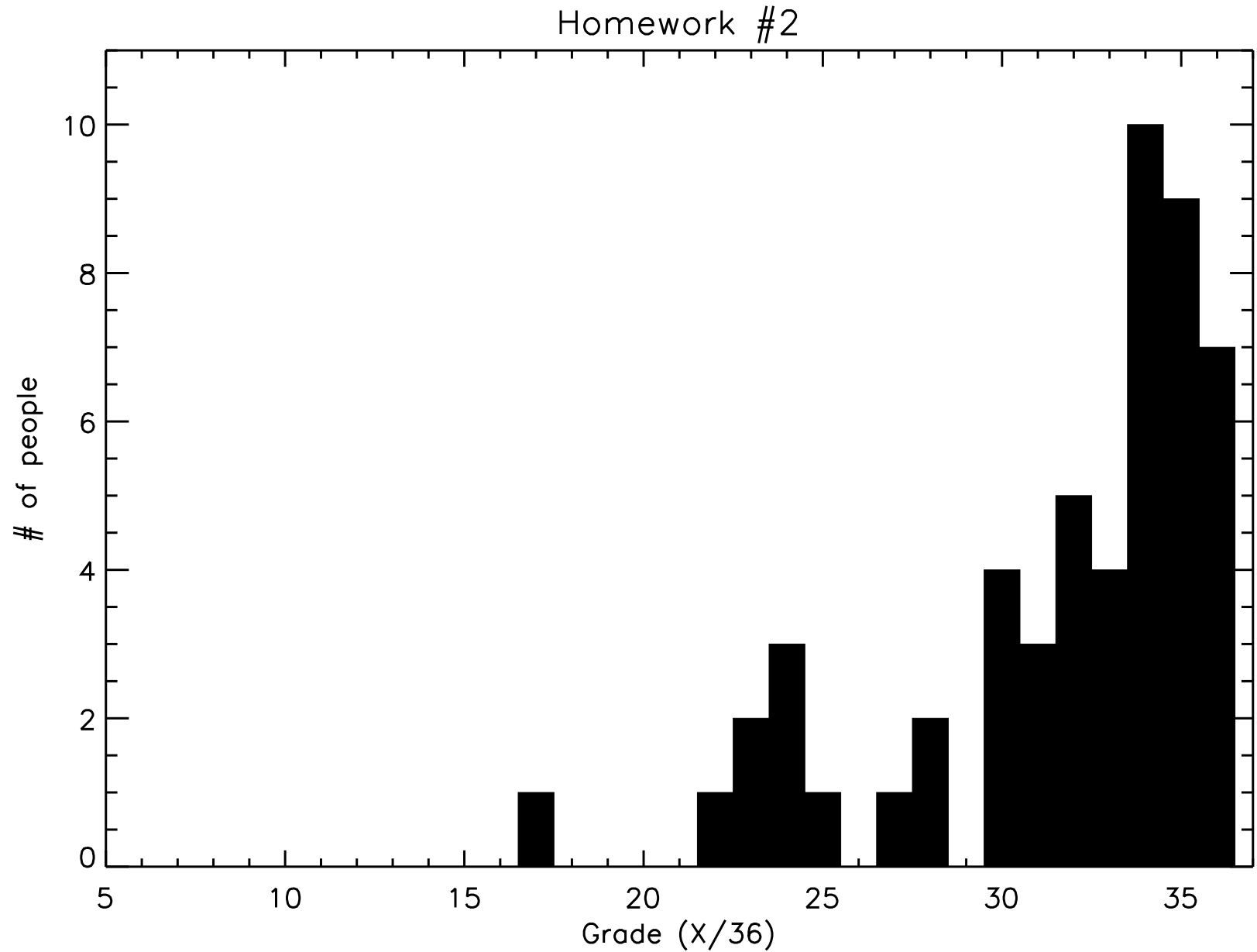


# Homework #2



# Exam #1

---

will be returned on Tuesday

# Exam #1

---

## Combined Apparent Magnitude

$$m_1 = 4, m_2 = 3 \qquad m_2 - m_1 = -2.5 \log(f_2/f_1)$$

$$-1 = -2.5 \log(f_2/f_1)$$

$$0.4 = \log(f_2/f_1)$$

$$2.5 = f_2/f_1$$

$$\text{so } f_2 = 2.5f_1, f_1 + f_2 = 3.5f_1$$

$$m_2 - m_{1+2} = -2.5 \log(2.5f_1 / 3.5f_1)$$

$$3 - m_{1+2} = 0.37$$

$$m_{1+2} = 2.63$$

# Exam #1

---



scientific  
calculator



graphing  
calculator

# Short Project

---

due November 21 **by 11:00AM**

Project: select a topic from the website list and...

- 1) Write a two-page summary of the topic and its importance to astronomy
- 2) Complete a “cover sheet” page including a short abstract and technical description of an observation that you would want to carry out related to this topic.
- 3) Prepare a short (4-minute) clear presentation explaining the topic and proposed observations
- 4) Summarize the topic and proposed observations as a conference-quality research poster

**Projects will be done in groups of 4; each group member picks ONE of these four things to do.**

# Short Project

---

due November 21 **by 11:00AM**

Two-page summary:

- explains your topic (audience: peers)
- clarifies its importance to astronomy
- discusses outstanding questions or next steps
- cites *at least* two papers from literature

Graded on: quality of writing, organization, clarity, demonstration of understanding underlying concepts

# Short Project

due November 21 **by 11:00AM**

Cover sheet:

**Name:** \_\_\_\_\_

**DUE:** Nov 21, 2017  
(by 11:00AM)

**Topic:** \_\_\_\_\_

**Abstract** (in 3-5 sentences explain your topic and your proposed observations):

**Telescope?**

**Image or spectrum?**

**When will you take these observations?**

**How much time do you estimate needing?**

**Technical Justification** (1/2 page justifying your choice of telescope, observation type, time estimate, and what your proposed observations would contribute to the astronomy community's understanding of your topic):

Graded on: quality of writing, clarity, choice of proposed observations, demonstration of understanding underlying concepts

# Short Project

---

due November 21 **by 11:00AM**

## Presentation:

- Keynote, Powerpoint, PDF, online (Prezi, etc.)
- gives *succinct* summary of topic, its importance, and proposed future work
- should include at least one visual (figure from paper or similar)
- should *not* be read from a script or notes
- four minutes takes *a lot* of planning!

Graded on: organization, timeliness, quality of presentation skills, demonstration of understanding underlying concepts



# Short Project

---

due November 21 **by 11:00AM**

## Poster:

- Keynote, Powerpoint, PDF; printable as a 36"x44" poster

*(but submit electronically! no need to print!)*

- gives summary of topic, its importance, and proposed future work (including text summary and representative figures)

- includes reference list and figure captions; should serve as a stand-alone summary

Graded on: organization, clarity, visual presentation, demonstration of understanding underlying concepts

# Short

Poster:

—Keynote

36"x44"

(but submit by 11:00AM)

—gives you 15 minutes

proposes your research

represents your research

—includes a Q&A session

serve as a poster

Graded components

demonstrate your

## A Spatially - Resolved Study of the GRB 020903 Host Complex Mallory Thorp, Emily M. Levesque (University of Washington)

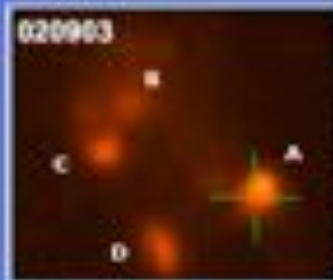


Fig. 2 GRB 020903 host galaxy complex. A marks the GRB location, B, C, and D mark distinct host regions. See Levesque et al. (2015) for details.

Long duration gamma-ray bursts (LGRBs) are excellent tools for studying star formation in distant galaxies. High-redshift galaxies often have significant star formation relative to their luminosity and similar morphologies to LGRB host galaxies (Fynbo et al. 2007). However, more recent studies suggest LGRBs are preferentially located in uniquely low-metallicity environments (Fruchter et al. 2006, Wierwright et al. 2007), and fall below the mass-metallicity and luminosity-metallicity relations for star-forming galaxies out to  $z=1$  (Modjaz et al. 2008, Kocevski et al. 2009, Levesque et al. 2010a,b). Determining the characteristics of LGRB hosts allows us to evaluate their effectiveness as probes for regular star-forming galaxies.

The host galaxy for GRB 020903 is one of only a few hosts where spatially-resolved observations are possible, and images suggest that it is the best example of a host consisting of multiple interacting components. This galaxy offers the unique opportunity to compare the GRB region of the galaxy (A) to the other host regions (B,C,D).

We were allocated 4.5 hours of observing time through the Gemini Fast Turnaround program on the Gemini Multi-Object Spectrograph (GMOS) at Gemini-S. Between 2016 Nov 5 and 2016 Dec 2, longslit observations were acquired at two specific position angles:  $PA_1$  (35.06°) to capture host regions A (the explosion site) and B, and  $PA_2$  (28.34°) to capture regions C and D, both using the 0.3" slit. The full set of observations span an observer-frame spectral range of ~3700-9400Å for  $PA_1$ , and ~5000-9400Å for  $PA_2$ . The data were reduced using the *gmoss* IRAF package, and the spectra were extracted using *apAll* in the *noao* IRAF package.



Fig. 3 The GMOS slit position used to observe the host regions of the GRB complex.



We extracted a composite spectrum of regions A&B, a portion of which is shown in figure 3 (top). The position of the H $\beta$ , [OIII] 4959, and [OIII] 5007 emission lines confirm that the redshift of regions A&B match the GRB redshift of  $z=0.251$ .

The composite spectrum for C&D is far dimmer than that of A&B. Surprisingly, H $\beta$ , [OIII] 4959, and [OIII] 5007 are detected at different wavelengths (fig. 3, bottom) than the A&B spectrum, indicating that C&D are at  $z=0.662$  rather than  $z=0.251$ . Until now it was assumed that all four regions were members of the host complex.



Fig. 3 Spectra of the A&B (top) and C&D (bottom) host regions.

By extracting the H $\beta$  line profiles of the A&B spectrum, we can discern separate peaks for the two regions. This indicates that A&B are both star-forming regions at  $z=0.251$ . The C&D regions cannot be distinguished in our data; it is unclear whether one or both are dominating the spectrum and not physically associated with A&B.

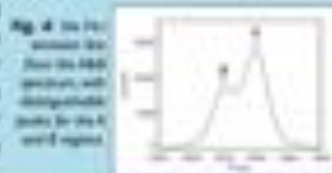


Fig. 4 The H $\beta$  line profile extracted from the A&B spectrum, with separate peaks for the A and B regions.

### What's next?

Our future work will focus primarily on the A&B spectrum. We will separate the spectra for the two regions to compare their metallicities and star formation rates. From these we will determine how the environment of the GRB explosion site compares to the rest of the host complex. We will also pursue new observations to determine whether C and D are indeed both at  $z=0.662$  (or if one is a weakly star-forming/non-star-forming member of the GRB host complex) and to analyze how the proximity of C affects observations of the B spectrum.

### References

- Fruchter A.S. et al. 2006, *Nature*, 441, 463
- Fynbo J. P. U., Hjorth J., Møller S. L., Sørensen J., Wierwright J., Jørgensen F., Gammie J., & Jørgensen A. O. 2007, *arXiv:astro-ph/0704022*
- Kocevski D., Modjaz A.A., & Modjaz M. 2009, *ApJ*, 700, 157
- Modjaz M. et al. 2008, *ApJ*, 671, 1136
- Levesque E. M., Berger E., Rowley L. J., & Berger M. H. 2010a, *ApJ*, 718, 698
- Levesque E. M., Rowley L. J., Berger E., & Berger M. H. 2010b, *ApJ*, 718, 1157
- Wierwright, C., Berger E., *Papadopoulos* S.E. 2007, *ApJ*, 657, 307

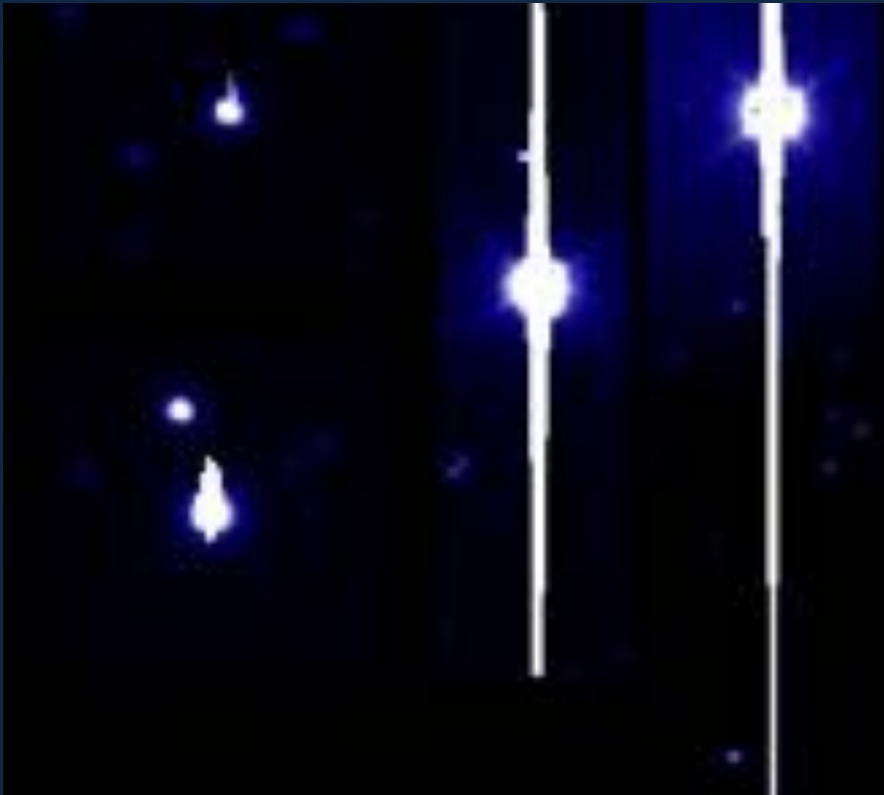
# Short Project

due November 21 **by 11:00AM**

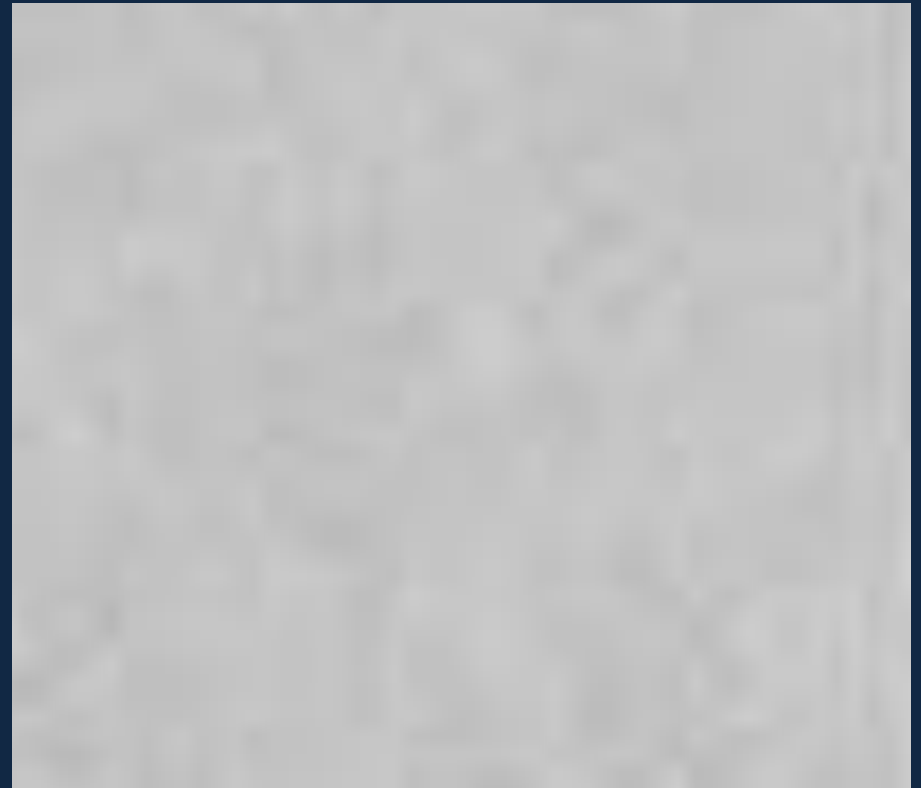
## Exposure times

We can use an object's brightness to estimate the exposure time that we need...

**Too long:**



**Too short:**



# Short Project

due November 21 **by 11:00AM**

## Exposure times

We can use an object's brightness to estimate the exposure time that we need...

**Too long:**



~~Too short!~~ enough!



# Short Project

due November 21 **by 11:00AM**

---

## Exposure times

To determine how long we expose on something we start with the signal-to-noise ratio:

$$\frac{S}{N} = \frac{F}{\sqrt{F + n_s(B + \sigma_{\text{read}}^2)}}$$

$F$  = flux from source,  $B$  = flux from background,  
 $n_s$  = number density of source counts,  $\sigma_{\text{read}}^2$  = readout noise

# Short Project

due November 21 **by 11:00AM**

## Exposure times

To determine how long we expose on something we start with the signal-to-noise ratio:

$$\frac{S}{N} = \frac{F}{\sqrt{F + n_s(B + \sigma_{\text{read}}^2)}}$$

If the source flux dominates:

$$\frac{S}{N} = \sqrt{F}$$

$F$  = flux from source,  $B$  = flux from background,  
 $n_s$  = number density of source counts,  $\sigma_{\text{read}}^2$  = readout noise



# Short Project

due November 21 **by 11:00AM**

## Exposure times

To determine how long we expose on something we start with the signal-to-noise ratio:

$$\frac{S}{N} = \frac{F}{\sqrt{F + n_s(B + \sigma_{\text{read}}^2)}}$$

If background flux dominates:

$$\frac{S}{N} = \frac{F}{\sqrt{n_s B}}$$

$F$  = flux from source,  $B$  = flux from background,  
 $n_s$  = number density of source counts,  $\sigma_{\text{read}}^2$  = readout noise

# Short Project

due November 21 **by 11:00AM**

Exposure times

**In reality...**

Embedded LCOGT Exposure Time Calculator

Provide values for two of these, then click Calculate

S/N:	20	Magnitude:	18	ExpTime (sec):	
------	----	------------	----	----------------	--

Telescope/  
Instrument:

Moon phase:

Calculate

Calculated Values

S/N:	20	Magnitude:	18	ExpTime(sec):	87	P&DN:	15.5
------	----	------------	----	---------------	----	-------	------

[\(Additional values +\)](#)

UBVRI in Vega magnitudes; ugriz in AB magnitudes

**...or find successful  
previous examples of  
similar observations!**

$F$  = flux from source,  $B$  = flux from background,  
 $n_s$  = number density of source counts,  $\sigma_{\text{read}}^2$  = readout noise

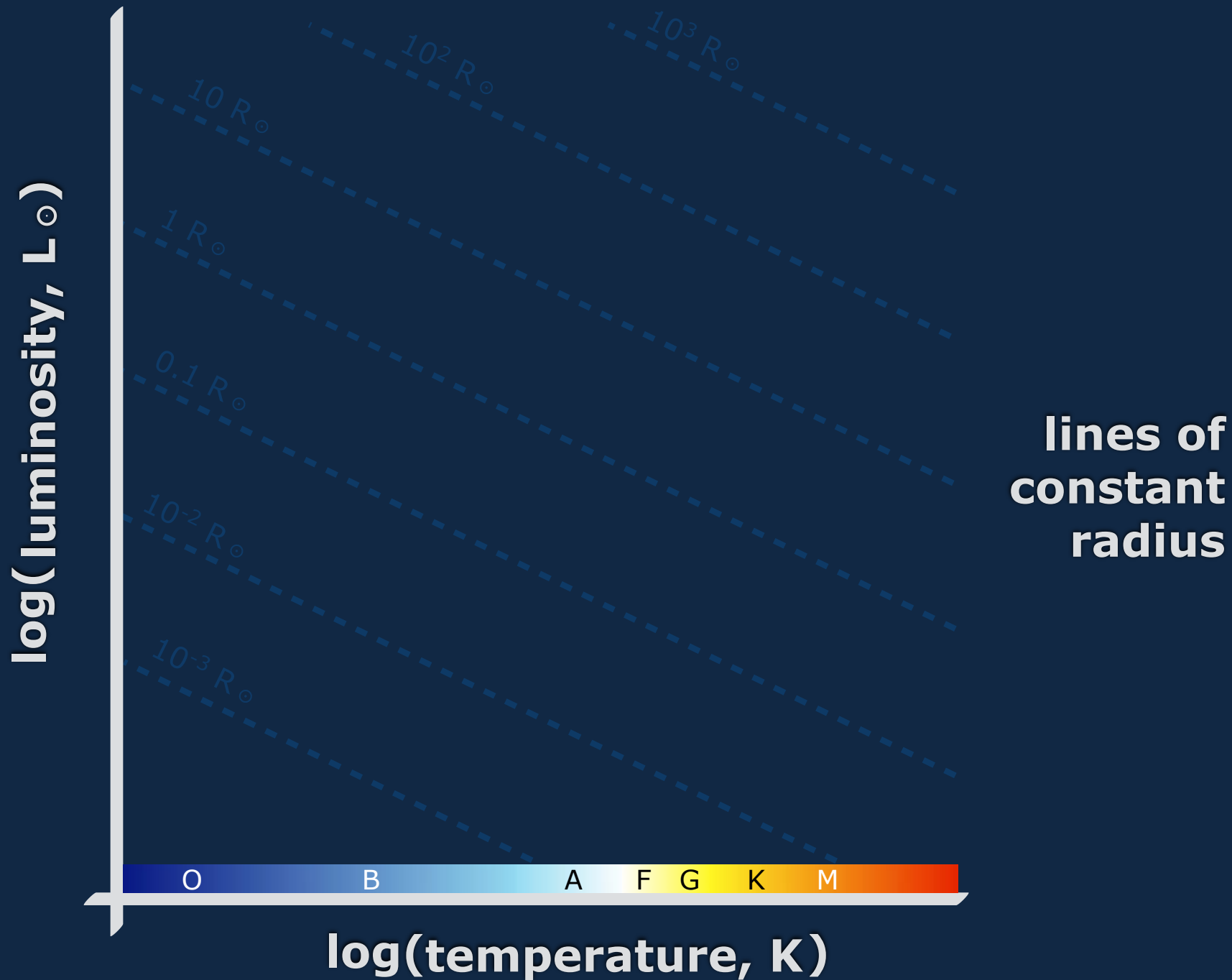


# Properties of Stars

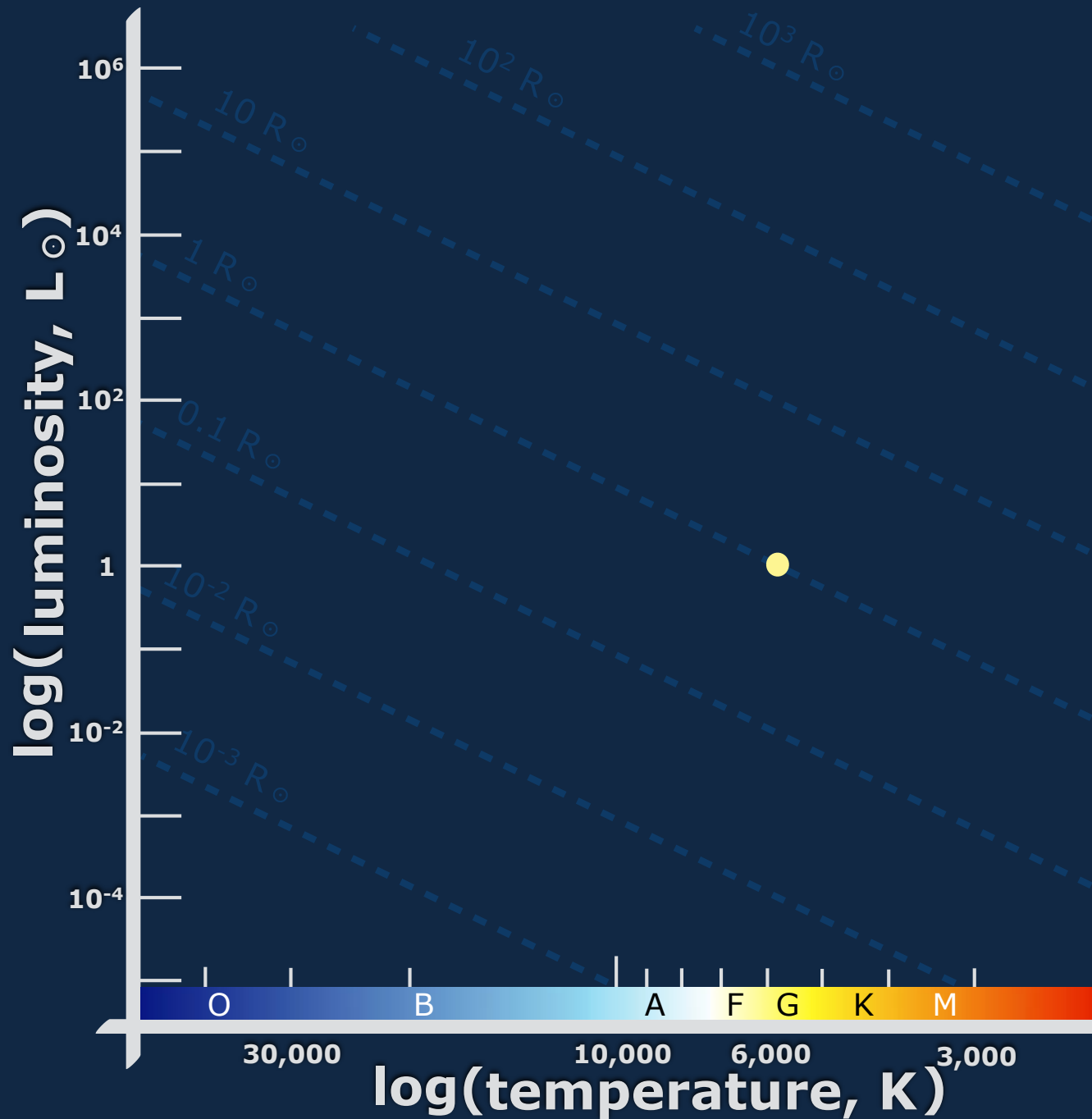
---

- ~~1) Distance — parallax, Cepheids~~
- ~~2) Velocity — proper motion, radial velocity~~
- 3) **Brightness** - magnitudes, luminosity
- 4) **Temperature** - effective temp (usually)
- 5) **Mass** - luminosity, binaries
- 6) **Radius** - lunar, interferometry,  
binaries, L & T

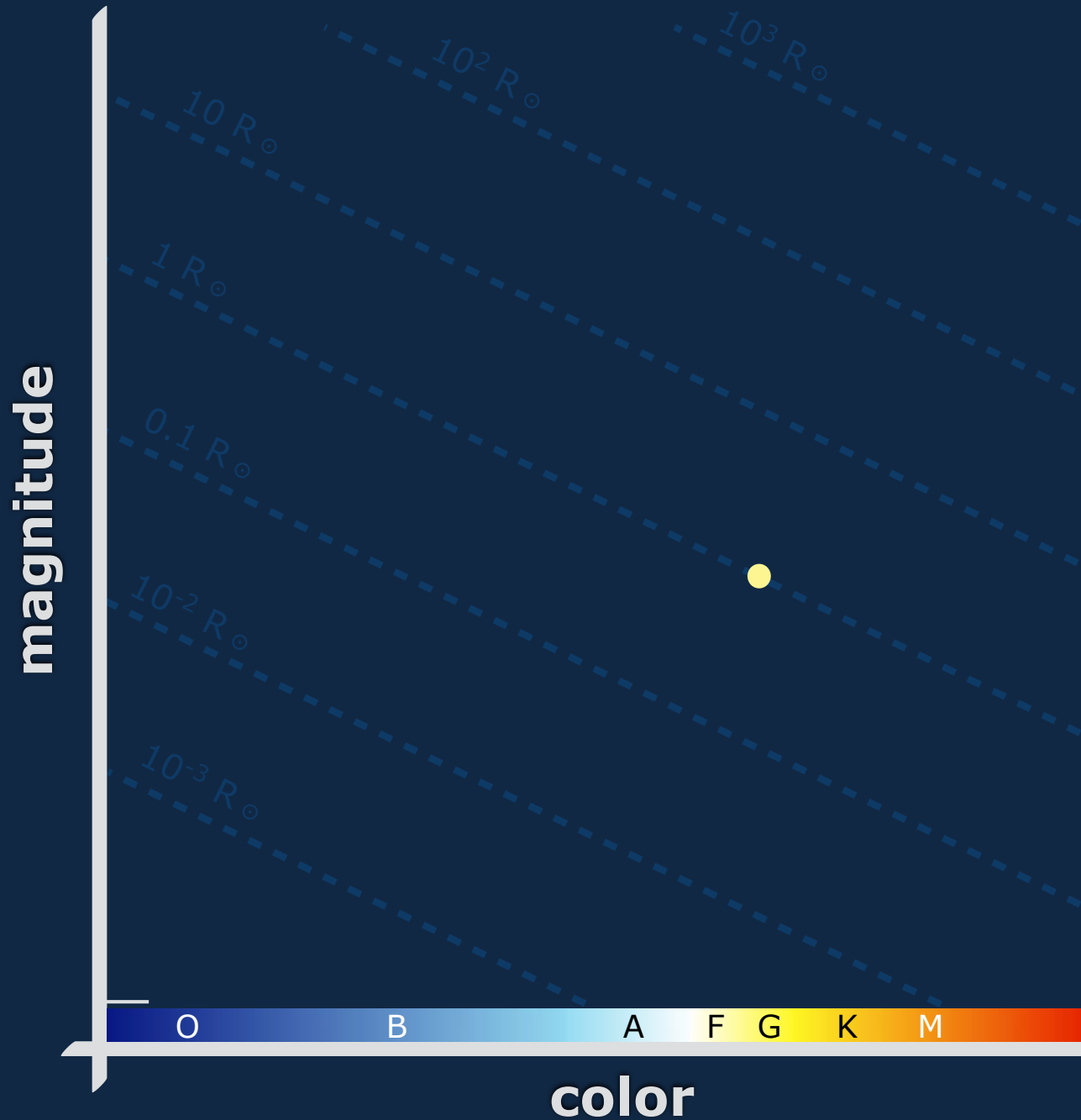
# The Hertzsprung-Russell Diagram



# The Hertzsprung-Russell Diagram



# The Color-Magnitude Diagram



# Stellar Structure

---

## Basic Stellar Structure Equations

1) Equation of State:

$$PV = nRT$$

$$P \propto T, P \propto 1/V \sim \rho, P \propto \rho T \text{ so}$$

$$P = (k/\mu m_H) \rho T$$

$$\text{where } 1/\mu = 2X + (3/4)Y + (1/2)Z$$

$$\text{with radiative } P: P = (k/\mu m_H) \rho T + (a/3)T^4$$

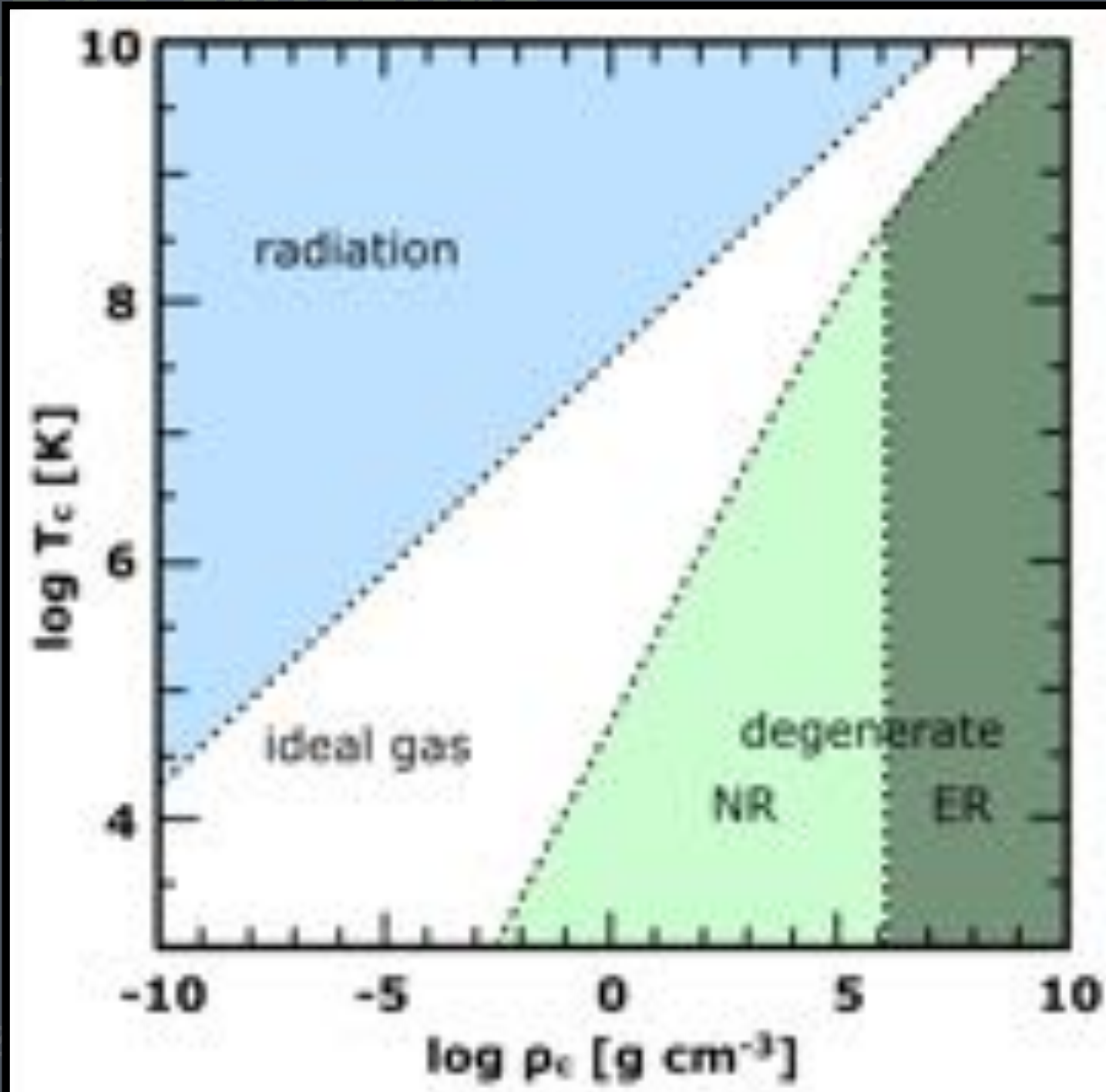
$k$ =Boltzmann constant,  $a = (8\pi^5 k^4)/(15h^3 c^3)$

$X$ =H mass fraction,  $Y$ =He mass fraction,  $Z$ =metals

# Stellar Structure

## Basic

### 1) Equa



$k$ =Boltz

$X$ =H mass fraction,  $Y$ =He mass fraction,  $Z$ =metals

# Stellar Structure

---

## Basic Stellar Structure Equations

1) Equation of State:  $P = (k/\mu m_H)\rho T + (a/3)T^4$

2) Hydrostatic Equilibrium:

$$\frac{\Delta P(r)}{\Delta r} = \frac{-GM(r)\rho(r)}{r^2}$$

Center of star:  $r=0$ ; surface of star:  $r=R$  (stellar radius)

# Stellar Structure

---

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---

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4) Luminosity gradient (in TE):

$$\frac{\Delta L(r)}{\Delta r} = 4\pi r^2 \rho(r)(\epsilon - \epsilon_\nu)$$

$\epsilon(\rho, T, \text{comp})$ ,  $\epsilon_\nu$  = neutrino energy

Center of star:  $r=0$ ; surface of star:  $r=R$  (stellar radius)

# Stellar Structure

---

## Basic Stellar Structure Equations

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4) Luminosity gradient (in TE):  $\frac{\Delta L(r)}{\Delta r} = 4\pi r^2 \rho(r)(\epsilon - \epsilon_v)$

5) Temperature gradient:

$$\kappa \propto \rho T^{-3.5} = \text{"opacity"}$$

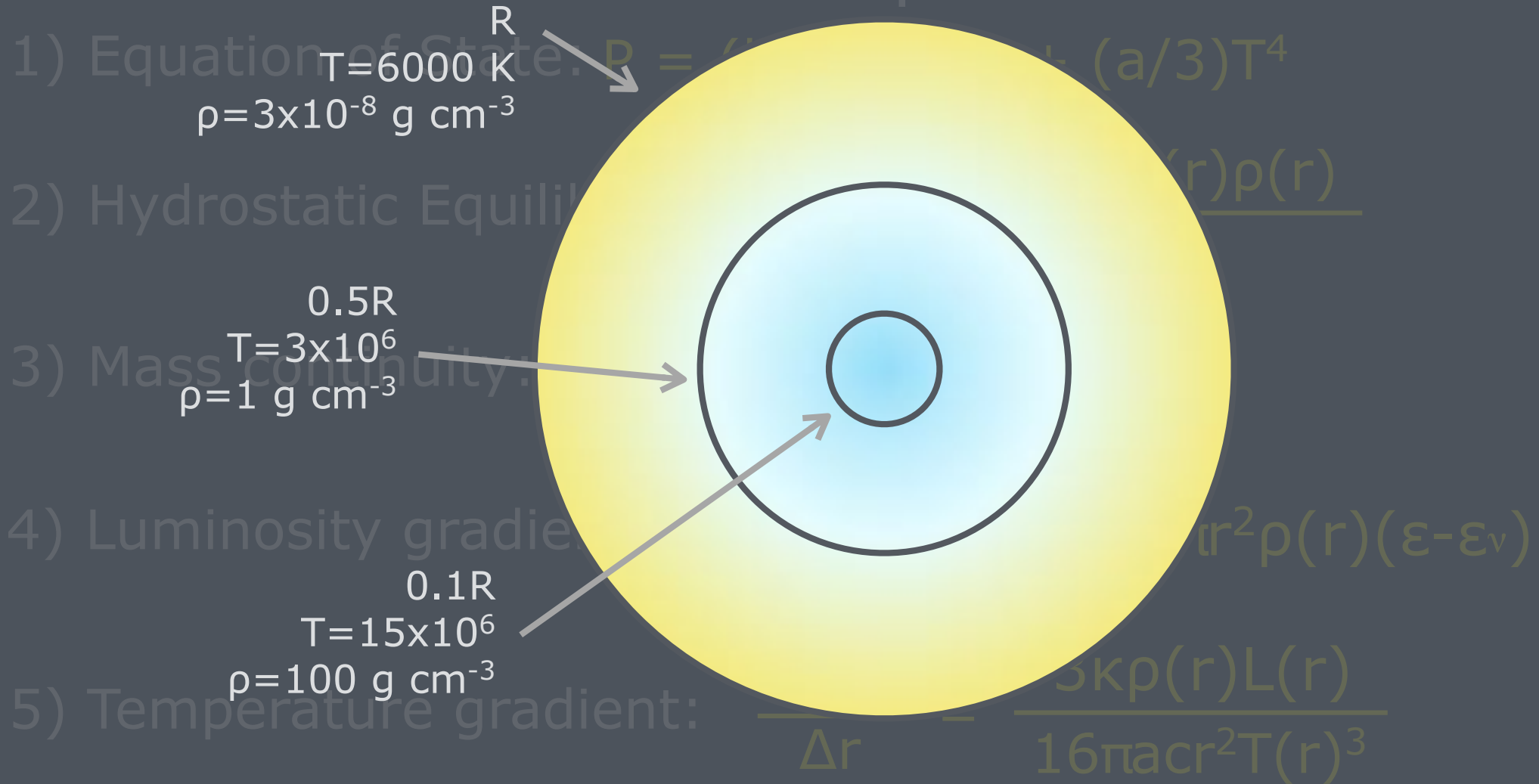
$$a = (8\pi^5 k^4)/(15h^3 c^3)$$

$$\frac{\Delta T(r)}{\Delta r} = \frac{-3\kappa \rho(r)L(r)}{16\pi a c r^2 T(r)^3}$$

Center of star:  $r=0$ ; surface of star:  $r=R$  (stellar radius)

# Stellar Structure

## Basic Stellar Structure Equations



# Star Formation

---


Orion constellation

**M42 - Orion Nebula**



# Star Formation

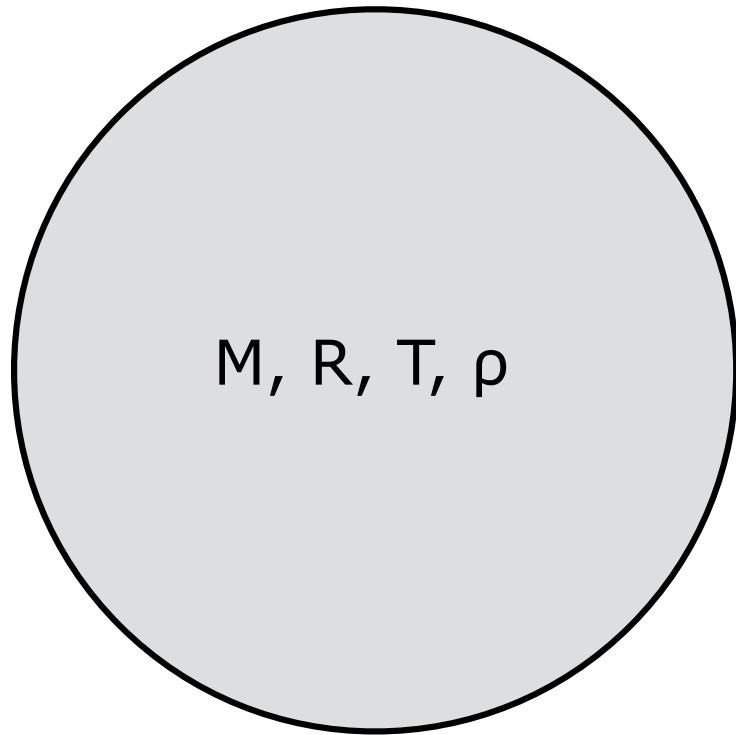
Consider a spherical homogenous cloud:


$$E_{\text{kin}} = -\frac{1}{2}E_{\text{pot}}$$

← **virial theorem**

# Star Formation

Consider a spherical homogenous cloud:



$$E_{\text{kin}} = -\frac{1}{2}E_{\text{pot}} \quad \leftarrow \text{virial theorem}$$

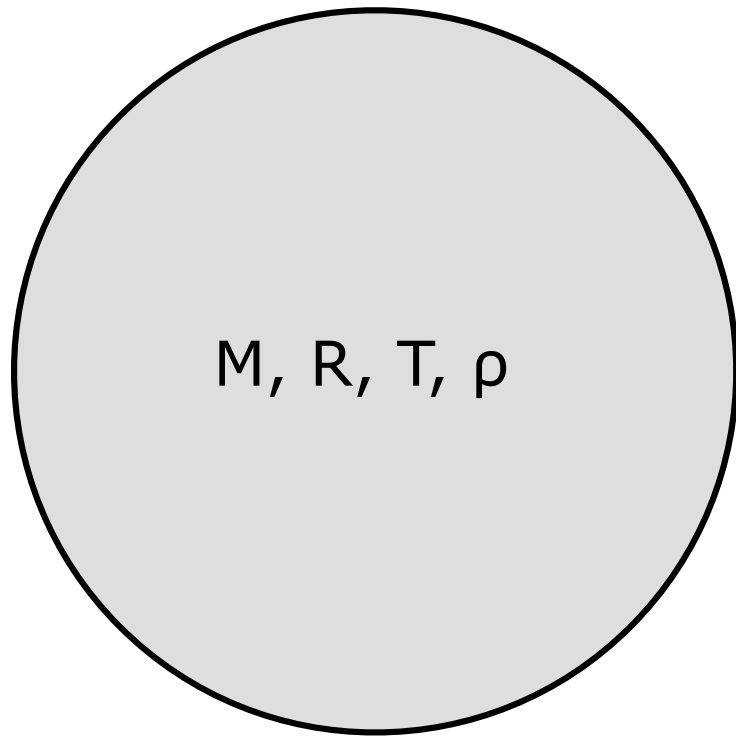
$$E_{\text{kin}} = (3/2)NkT, \quad N = M/\mu m_{\text{H}}$$

$$E_{\text{pot}} = (3/5)(GM^2/R), \quad R = (3M/4\pi\rho)^{1/3}$$

**What condition do we need to meet for collapse?**

# Star Formation

Consider a spherical homogenous cloud:



$$E_{\text{kin}} = -\frac{1}{2}E_{\text{pot}} \quad \leftarrow \text{virial theorem}$$

$$E_{\text{kin}} = (3/2)NkT, \quad N = M/\mu m_H$$

$$E_{\text{pot}} = (3/5)(GM^2/R), \quad R = (3M/4\pi\rho)^{1/3}$$

**What condition do we need to meet for collapse?**

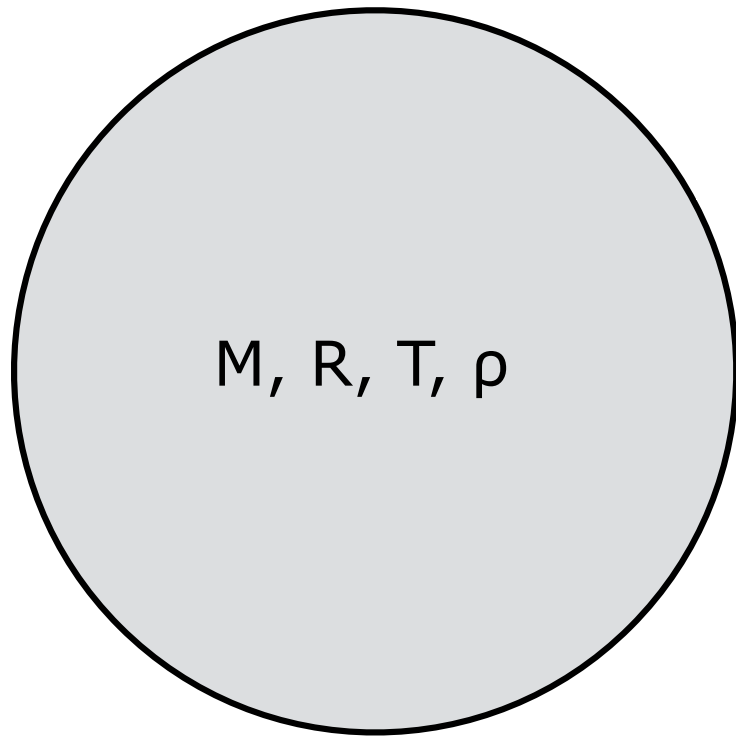
$$E_{\text{kin}} < -\frac{1}{2}E_{\text{pot}}$$

$$M > M_J \equiv \frac{5kTR}{G\mu m_H}$$

**Jeans mass**

# Star Formation

Consider a spherical homogenous cloud:



$$E_{\text{kin}} = -\frac{1}{2}E_{\text{pot}} \quad \leftarrow \text{virial theorem}$$

$$E_{\text{kin}} = (3/2)NkT, \quad N = M/\mu m_H$$

$$E_{\text{pot}} = (3/5)(GM^2/R), \quad R = (3M/4\pi\rho)^{1/3}$$

**What condition do we need to meet for collapse?**

$$M > M_J \equiv \frac{5kTR}{G\mu m_H}$$

**Jeans  
mass**

$$\left( R < R_J \equiv \frac{G\mu m_H M}{5kT} \right)$$



# Star Formation


Consider a spherical homogenous cloud:


$$E_{\text{kin}} = -\frac{1}{2}E_{\text{pot}} \quad \leftarrow \text{virial theorem}$$

## DISCUSSION QUESTION

What processes might cause our cloud to exceed the Jeans criteria?

(think, discuss, then answer)


$$M > M_J \equiv \frac{5kTR}{G\mu m_H}$$

**Jeans  
mass**

$$\left( R < R_J \equiv \frac{G\mu m_H M}{5kT} \right)$$

# Star Formation

---

Galaxy mergers



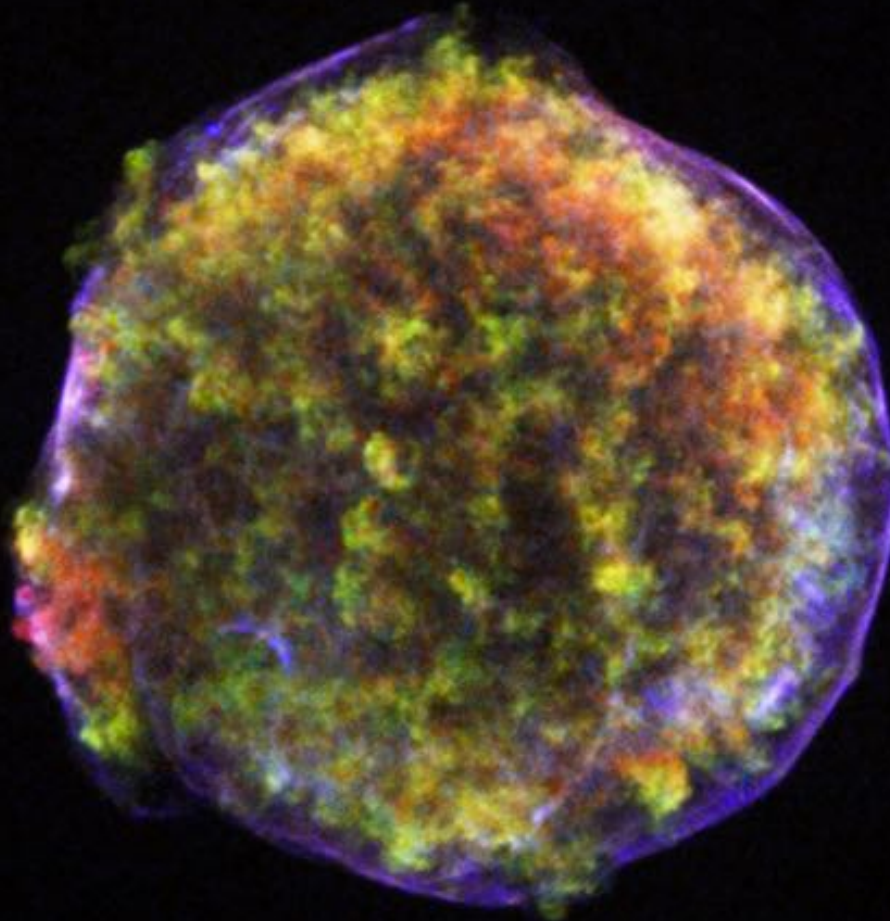
**The “mice” galaxies**

# Star Formation

---

Galaxy mergers

Supernovae



**SN 1572 remnant**

# Star Formation

---

Galaxy mergers

Supernovae

Density Waves

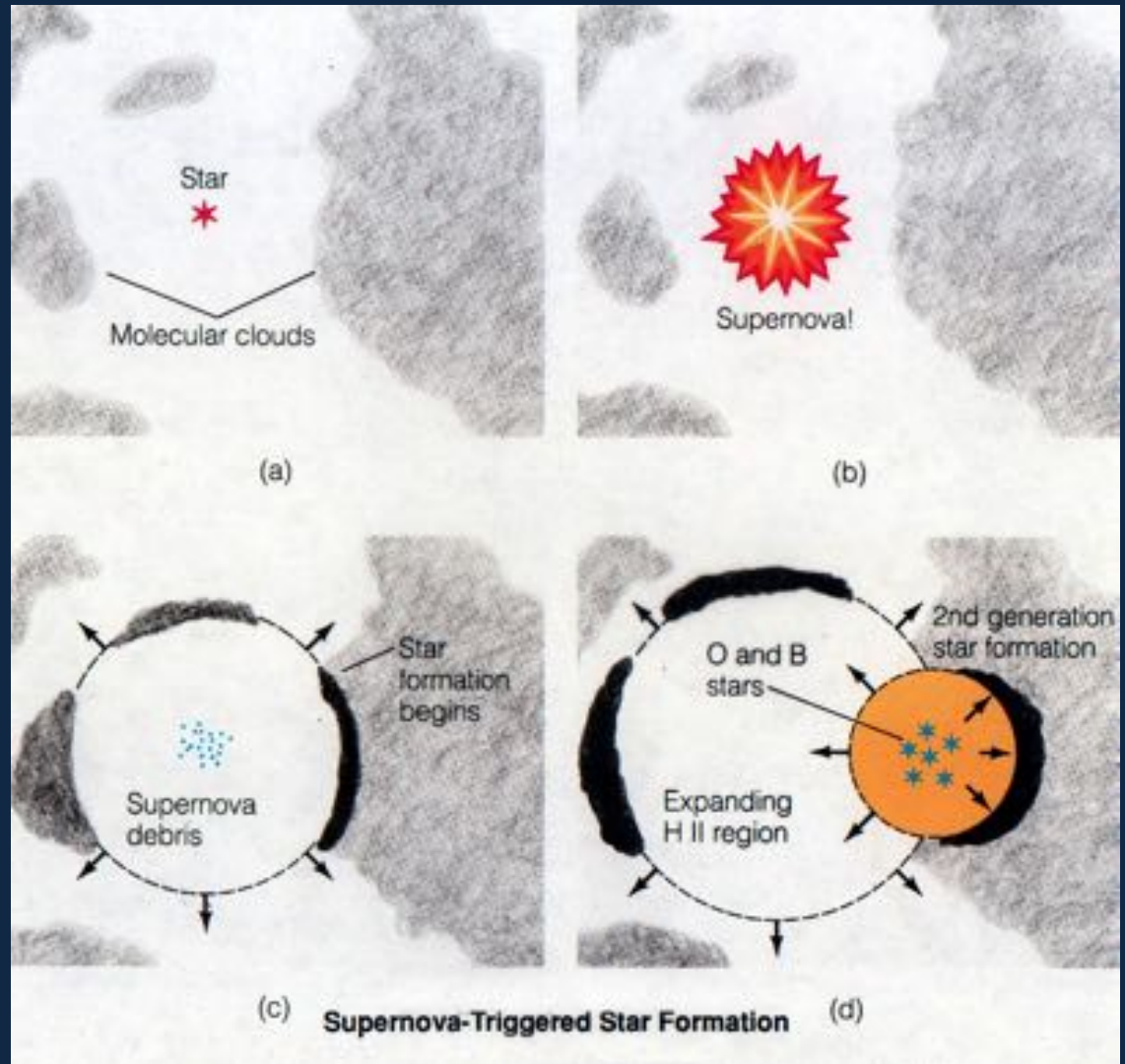
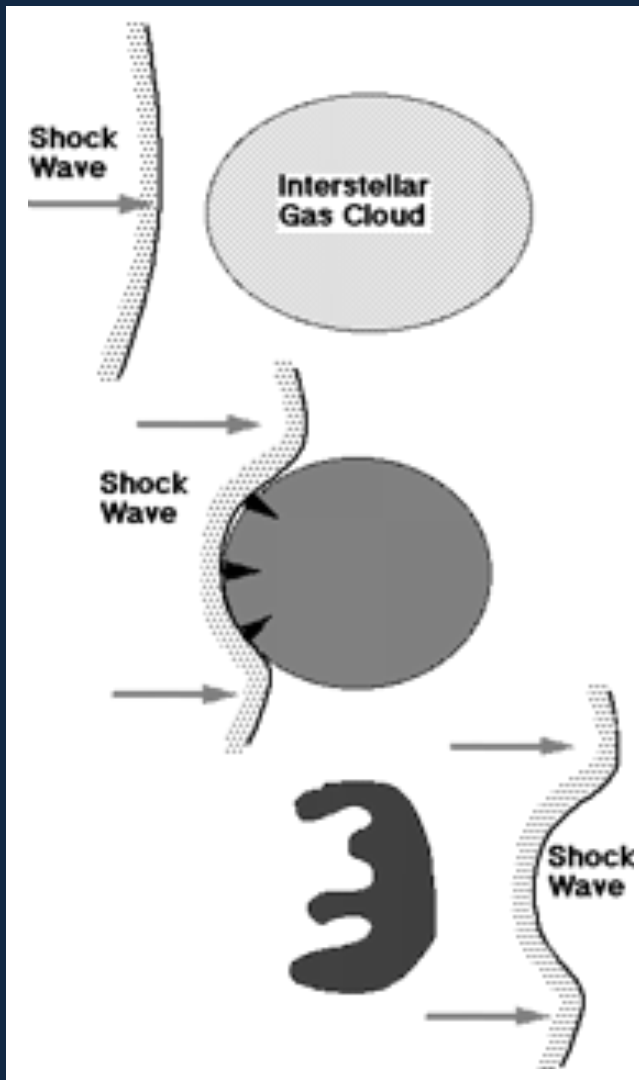
**SN**

**simulation**

# Star Formation

## Birth Sequence

- trigger kicks off process in an interstellar gas cloud





# Star Formation

---

## Birth Sequence

- trigger kicks off process in an interstellar gas cloud
- cloud fragments and collapses [ $M_J$  and  $R_J$ ...]
- early collapse is isothermal; E radiated away
- interior becomes adiabatic; E trapped so T rises
- protostellar core forms ( $\sim 5\text{AU}$ ) w/ free-falling gas above
- dust vaporizes as T increases

# Star Formation

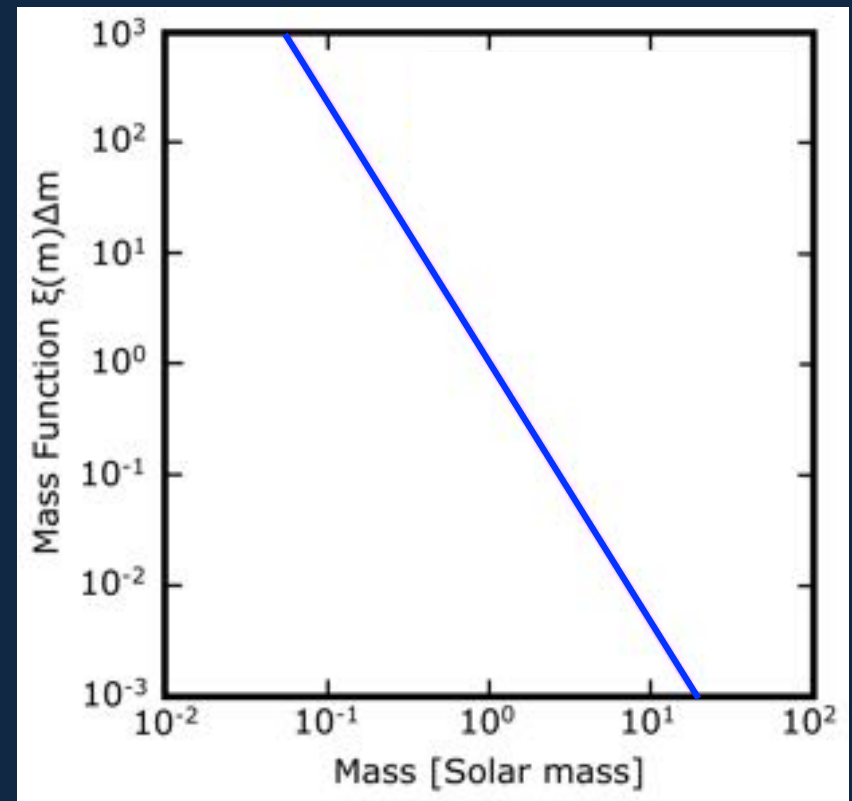
Unfortunately, no good quantitative theory to predict star formation rate or stellar mass distribution!

## IMF = Initial Mass Function

$N(m)dm$  = # stars in mass range  $m$  to  $m+dm$

$$N(m)dm \propto (m/M_{\text{sun}})^{-\alpha}$$

$\alpha = 2.35$  (Salpeter IMF)



# Star Formation

Unfortunately, no good quantitative theory to predict star formation rate or stellar mass distribution!

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$$N(m)dm \propto (m/M_{\text{sun}})^{-\alpha}$$

$\alpha = 2.35$  (Salpeter IMF)

Is it universal?

