

# GENERAL QUALIFYING EXAM SOLUTIONS: STELLAR ASTROPHYSICS

---

Jessica Campbell, Dunlap Institute for Astronomy & Astrophysics (UofT)

## Contents

<b>1</b>	<b>Stellar Astrophysics</b>	<b>2</b>
1.1	Question 1 . . . . .	2
1.2	Question 2 . . . . .	3
1.3	Question 3 . . . . .	4
1.4	Question 4 . . . . .	5
1.5	Question 5 . . . . .	6
1.6	Question 6 . . . . .	7
1.7	Question 7 . . . . .	8
1.8	Question 8 . . . . .	9
1.9	Question 9 . . . . .	10
1.10	Question 10 . . . . .	11
1.11	Question 11 . . . . .	12
1.12	Question 12 . . . . .	13
1.13	Question 13 . . . . .	14
1.14	Question 14 . . . . .	15
1.15	Question 15 . . . . .	16
1.16	Question 16 . . . . .	17
1.17	Question 17 . . . . .	18
1.18	Question 18 . . . . .	19
1.19	Question 19 . . . . .	20
1.20	Question 20 . . . . .	21
1.21	Resources . . . . .	22

# 1 Stellar Astrophysics

## 1.1 Question 1

Sketch out a Hertsprung-Russell diagram. Indicate where on the main sequence different spectral classes lie. Draw and describe the post main-sequence tracks of both low- and high-mass stars.

### 1.1.1 Short answer

Answer.

### 1.1.2 Additional context

Additional context.

- How does metallicity affect this diagram?
- Elaborate on the life sequence of low-mass stars.
- Elaborate on the life sequence of high-mass stars.
- Which direction does radius increase?
- What's the functional form for how radius increases as a function of temperature and luminosity?
- Why can you use the tip of the red giant branch for distance determination?
- How can you use the H-R diagram to determine ages? Which of the two techniques is more accurate?

## 1.2 Question 2

Sketch a plot of radius versus mass for various “cold” objects made of normal matter, including planets, brown dwarfs and white dwarfs. Explain the mass-size relationship for rocky and gaseous objects. Why is there an upper mass limit?

### 1.2.1 Short answer

Answer.

### 1.2.2 Additional context

Additional context.

### 1.2.3 Follow-up Questions

- How do you calculate the Chandrasekhar mass limit?
- Why is Saturn smaller than Jupiter? Or, why do we see a range of radii in extrasolar planets (e.g., hot Jupiters)?

### 1.3 Question 3

Describe the physical conditions that lead to the formation of absorption lines in stars' spectra. What leads to emission lines?

#### 1.3.1 Short answer

Answer.

#### 1.3.2 Additional context

Additional context.

#### 1.3.3 Follow-up Questions

- Why aren't emission and absorption lines delta functions?
- How does this relate to population levels and excitation temperatures?
- Are there emission lines in the Sun? Why is there emission from the Calcium doublet?
- Write down the heat transfer equation. What do solutions look like?

## 1.4 Question 4

Describe these important sources of stellar opacity: electron scattering, free-free, bound-free, and the  $\text{H}^-$  ion.

### 1.4.1 Short answer

Answer.

### 1.4.2 Additional context

Additional context.

## 1.5 Question 5

Describe the processes that can cause pulsations in a stars luminosity, and provide at least one example of a class of stellar pulsation.

### 1.5.1 Short answer

Answer.

### 1.5.2 Additional context

Additional context.

### 1.5.3 Follow-up Questions

- What about the instability strip? RR Lyrae?
- What is the period-luminosity relation?
- What is the form of the period-luminosity relation?
- How would you derive the time scale of pressure waves in a star?
- How would you order-of-magnitude estimate the period for a pulsation?

## 1.6 Question 6

Briefly describe the sources of thermal energy for stars and planets.

### 1.6.1 Short answer

Answer.

### 1.6.2 Additional context

Additional context.

### 1.6.3 Follow-up Questions

- Why do different nuclear reaction pathways have different temperature sensitivities?
- If I assume a constant core temperature on the main sequence, how does stellar radius depend on mass?
- What are some other thermal sources, like say for neutron stars?

## 1.7 Question 7

Describe the process by which supernovae produce light. Why are Type Ia supernovae generally brighter than Type II events?

### 1.7.1 Short answer

Answer.

### 1.7.2 Additional context

Additional context.

### 1.7.3 Follow-up Questions

- When a star goes supernova, how much of the luminous energy generated at the rebound is available for heating the gas? As in, where does the heat come from?
- Are there cases where the rebound shock wave can't blow up the star? Why, and what happens then?



## 1.8 Question 8

Describe the condition for a stars envelope to become convective. Why are low mass stars convective in their outer envelopes while high mass stars are convective in their inner cores?

### 1.8.1 Short answer

Answer.

### 1.8.2 Additional context

Additional context.

### 1.8.3 Follow-up Questions

- How do we know that the Sun's outer envelope is convective?
- How far into the surface of the Sun does the convective zone permeate? How can we measure this?

## 1.9 Question 9

What is Eddingtons luminosity limit? Explain why this limit is important for the properties and lifetimes of massive stars.

### 1.9.1 Short answer

Answer.

### 1.9.2 Additional context

Additional context.

### 1.9.3 Follow-up Questions

- Draw a force diagram of whats happening.
- What particles experience gravity the most?
- What particles experience photon pressure the most?

## **1.10 Question 10**

Explain why we know what the Sun's central temperature ought to be, and how we know what it actually is.

### **1.10.1 Short answer**

Answer.

### **1.10.2 Additional context**

Additional context.

## 1.11 Question 11

Which have higher central pressure, high-mass or low-mass main-sequence stars? Roughly, what is their mass-radius relation? Derive this.

### 1.11.1 Short answer

Answer.

### 1.11.2 Additional context

Additional context.

### 1.11.3 Follow-up Questions

- How would we actually know the central pressure?
- What properties can we measure to test models of stellar structure?

## 1.12 Question 12

Sketch the SED of an O, A, G, M, and T star. Give defining spectral characteristics, such as the Balmer lines and Balmer jump and Calcium doublets, and describe physically.

### 1.12.1 Short answer

Answer.

### 1.12.2 Additional context

Additional context.

### 1.12.3 Follow-up Questions

- Are there emission lines?
- What molecular lines are in the Sun?
- What important lines are there are much longer wavelengths than those in the optical?
- What if the A star had a protoplanetary disk?
- What is the significance of a  $\lambda F_\lambda$  (or  $\nu F_\nu$ ) spectrum?
- How can the relative height of the stellar vs disk bumps change? (i.e., total energy of the system cannot change; dust bump can't be higher than star bump without extinction.)

### **1.13 Question 13**

What can be learned about young stars (T Tauri and pre-main-sequence stars) from an analysis of their spectral features?

#### **1.13.1 Short answer**

Answer.

#### **1.13.2 Additional context**

Additional context.

#### **1.13.3 Follow-up Questions**

- How does the spectrum change as planets start to form?

## 1.14 Question 14

Sketch the spectral energy distribution (SED) of a T Tauri star surrounded by a protoplanetary disk. How would the SED change: (a) if the disk develops a large inner hole, (b) if the dust grains in the disk grow in size by agglomeration (with the same total mass)?

### 1.14.1 Short answer

Answer.

### 1.14.2 Additional context

Additional context.

## **1.15 Question 15**

What are the primary origins of the heat lost to space by infrared luminosity of Jupiter, Earth, and Io?

### **1.15.1 Short answer**

Answer.

### **1.15.2 Additional context**

Additional context.



## **1.16 Question 16**

Explain the observational problem of radius inflation for hot Jupiters and describe two possible solutions.

### **1.16.1 Short answer**

Answer.

### **1.16.2 Additional context**

Additional context.

### **1.17 Question 17**

Explain the effects of an atmosphere on a planets surface temperature and the position of the habitable zone. What special considerations must one make for habitability around M-type stars?

#### **1.17.1 Short answer**

Answer.

#### **1.17.2 Additional context**

Additional context.

### **1.18 Question 18**

Explain the process of nuclear fusion and give two examples of important fusion processes that affect the lives of stars.

#### **1.18.1 Short answer**

Answer.

#### **1.18.2 Additional context**

Additional context.

### **1.19 Question 19**

What is Fermis Paradox? Explain its logic and assess the current state of the Paradox in light of modern knowledge.

#### **1.19.1 Short answer**

Answer.

#### **1.19.2 Additional context**

Additional context.

#### **1.19.3 Follow-up Questions**

- What percentage of stars have planets?

### **1.20 Question 20**

The so-called r- and s- processes are mechanisms that produce elements heavier than iron. Describe these mechanisms and evidence for them from abundance patterns. Where is the r-process thought to act?

#### **1.20.1 Short answer**

Answer.

#### **1.20.2 Additional context**

Additional context.

### 1.21 Resources

- The Fundamentals of Stellar Astrophysics, Collins (2003)
- Stellar Structure and Evolution, Kippenhahn, Weigert & Weiss (2012)
- Evolution of Stars and Stellar Populations, Salaris & Cassisi (2005)
- The Astronomical Reach of Fundamental Physics, Burrows & Ostriker (2014)
- Opacity, Huebner & Barfield (2014)
- Radiative Processes in Astrophysics, Rybicky & Lightman (1979)
- Understanding Variable Stars, Percy (2007)