General Qualifying Exam Solutions: Stellar Astrophysics

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Contents

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 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 Suns 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 λF_λ (or νF_ν) 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)