O and B Subdwarfs

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O/B Subdwarfs

• Similar to O stars
O/B Subdwarfs

- Similar to O stars ✗
- Similar to B stars
O/B Subdwarfs

- Similar to O-stars: ✗
- Similar to B-stars: ✗
- Similar to cool subdwarfs
O/B Subdwarfs

- Similar to O stars ✗
- Similar to B stars ✗
- Similar to cool subdwarfs ✗
- Stars 🌟
O/B Subdwarfs

- Similar to O stars ✗
- Similar to B stars ✗
- Similar to cool subdwarfs ✗
- Stars ✓
The Game Plan

- Pathways to Formation
- Spectral Classification
- Selected Case Studies
Recipe for O/B Subdwarfs

• Ingredients: Unknown
  • Try: one low-mass red giant
  • Substitute: two low-mass white dwarfs
• Preparation time: Varies
• Other requirements: A really big kitchen
Recipe for O/B Subdwarfs

1. Ascend the Red Giant Branch
   - Decreasing temperature
   - Increasing luminosity
   - Inert helium core
   - Hydrogen-burning shell
Recipe for O/B Subdwarfs

1. Ascend the Red Giant Branch
   - Decreasing temperature
   - Increasing luminosity
   - Inert helium core
   - Hydrogen-burning shell
   - Core becomes degenerate

Heber (2009) pg. 212
Recipe for O/B Subdwarfs

- Degeneracy from Pauli Exclusion Principle
  - One fermion per quantum state in given system
  - “Degenerate” when all lower states filled
- Also leads to Chandrasekhar limit for white dwarfs
- Higher pressure (from higher minimum momentum) when electrons crammed into smaller space
  - From Heisenberg Uncertainty Principle: \( \Delta x \Delta p_x \approx \hbar \)
- Pressure mostly dependent on density: \( P \sim \rho^{5/3} \)
Recipe for O/B Subdwarfs

2. Undergo the Helium Flash
   - Threshold: $10^8$ K, 0.5 M☉
   - Helium ignites near center
   - Reversion to $PV = nkT$
   - Explosive expansion
   - Thermalization spreads
   - 5% of Helium burned

Heber (2009) pg. 212
Recipe for O/B Subdwarfs

2. Undergo the Helium Flash
   - Reaches $10^{11}$ L⊙
   - Timescale: 10 seconds
   - Not observed
     - Core expansion
     - Envelope contraction
     - Opposite Red Giant

Heber (2009) pg. 212
Recipe for O/B Subdwarfs

3. Fall down to the Horizontal Branch
   - Timescale: radiation emergence after helium flash
   - Position depends on hydrogen remaining
   - Normally: ascend Asymptotic Giant Branch
     - Envelope expands

Recipe for O/B Subdwarfs

3. Fall down to the Horizontal Branch

- Subdwarf O scenario #1: post-Red Giant Branch mass loss
- Do not pass Asymptotic Giant Branch
- Go directly to white dwarf cooling sequence
- "Extreme" Horizontal Branch
- $0.5 \, M_\odot$ fixed at helium flash

Recipe for O/B Subdwarfs

4. Partially ascend the Asymptotic Giant Branch

- Subdwarf O scenario #2: post-Horizontal Branch mass loss
- Turbulent rotational mixing?

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Recipe for O/B Subdwarfs

5. Complete Asymptotic Giant Branch evolution
   • Move towards white dwarf cooling sequence
   • Subdwarf O scenario #3: post-Asymptotic Giant Branch, pre-white dwarf
   • Surrounded by planetary nebula?

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Recipe for O/B Subdwarfs

6. Become a white dwarf
7. Find another white dwarf

• Subdwarf O scenario #4: white dwarf merger

• Product below Chandrasekhar limit

• Type Ia supernovae?

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Recipe for O/B Subdwarfs

8. Alternative: overflow your Roche lobe as Red Giant

- Due to three-body problem
- Mass transfer from “donor” to “gainer”
  - Donor expanding
- Decreases separation

Recipe for O/B Subdwarfs

8. Alternative: overflow your Roche lobe as Red Giant
   • Continues even after gainer more massive
     - Gainer not expanding
   • Increases separation
   • Ends when donor envelope exhausted

Recipe for O/B Subdwarfs

8. Alternative: overflow your Roche lobe as Red Giant
   • Can also share envelope
     - Friction leads to ejection
   • Leaves helium core
     - Assuming helium burning
   • Subdwarf B scenario #1: post-Horizontal Branch Roche lobe overflow

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Recipe for O/B Subdwarfs

9. Wait

- Subdwarf O scenario #5: evolved from subdwarf B
- Energy generation in core still possible
- Not hidden in envelope

Recipe for O/B Subdwarfs

- Review of scenarios
  - post-Reg Giant Branch: O
  - post-Horizontal Branch: O
  - pre-white dwarf: O
  - white dwarf merger: O
  - from subdwarf B: O
  - Roche lobe overflow: B

- Why named O/B subdwarfs?
Spectral Classification

- Spectra collected 1986, Palomar-Green survey
- 2300+ identified by 2004
- Naming conventions from Drilling, et. al (2002)
- Only use blue (400 nm - 490 nm) region
- Three parts: temperature, luminosity, helium

sdO8VIII:He7
Spectral Classification

• First part: temperature
• “sd-“ prefix
• “-C” suffix if carbon-rich
• B or O from temperature
  - Also 9 to 0: B1 < B0 < O9
• More precisely: from ionization ratios, à la MK system

Image: Gray and Corbally (2009) pg. 150
Spectral Classification

Image: Gray and Corbally (2009) pg. 150
Spectral Classification

- Second part: luminosity

- From line widths (compared to own sd temperature class)
  - VI narrower
  - VII average
  - VIII broader

- Or, mirror equivalent MK temperature class, ex. sdB5IV for an sdB5 star with lines like MK B5 IV

Image: Gray and Corbally (2009) pg. 153
Spectral Classification

![Spectral Classification Diagram](Image: Gray and Corbally (2009) pg. 153)
Spectral Classification

- Third part: helium
- “:” separator prefix
- From ratios of hydrogen and helium line depths
- From 0 (no helium lines)
- To 40 (no Balmer lines)

Image: Gray and Corbally (2009) pg. 151
Spectral Classification

Image: Gray and Corbally (2009) pg. 151
Case Studies

Asteroseismology

• Some sdB stars pulsate

• About 40 known

• Pressure and gravity modes
  - Similar to earthquakes

• Probe stellar interiors

• Image: EQ Pisces (sdB) observed for K2

Case Studies

UV “Upturn”

• sdB stars also found in globular clusters

• Elliptical galaxies not expected to have hot stars

• Caveat: sdB formation pathways murky

• Image: M32 (elliptical) in near-UV

Case Studies

Exoplanets

• One for V391 Pegasus

• Two for HW Virgo

• Hot Jupiters can survive Red Giant Branch?

• Image: artist rendering of hot Jupiter orbiting hot star


Case Studies

Doug’s Office

- Phi Perseus: sdO / Be binary
- Be gainer close to critical rotation
- Likely began as 5, 6 $M_\odot$ close binary
- Higher-mass star evolved first
- Mass transfer from Roche lobe overflow
  - Also angular momentum?
- Yields 1 $M_\odot$ sdO, 10 $M_\odot$ Be

Image: Bill Pounds (1999)
In Summary

• Formation scenarios murky
  - All involve unexplained mass loss
  - All involve helium flash from degeneracy
• Nomenclature non-standard
• Further study required

• Useful for:
  - Stellar interiors
  - Early-type galaxies
  - Exoplanets
  - Doug’s office
References


• Gies, Doug. Private conversations. 2014.


