The Origins of Hot Subdwarf Stars as Illuminated by Composite-Spectrum Binaries

Michele A. Stark
(Penn State University)
Advisor: Richard A. Wade

Plan of Attack

I. What a hot subdwarf is

II. Why hot subdwarfs are cool

III. How hot subdwarfs gets hot

IV. How we are cool:

   a. 2MASS
   b. Spectroscopy
   c. Nature of the companions

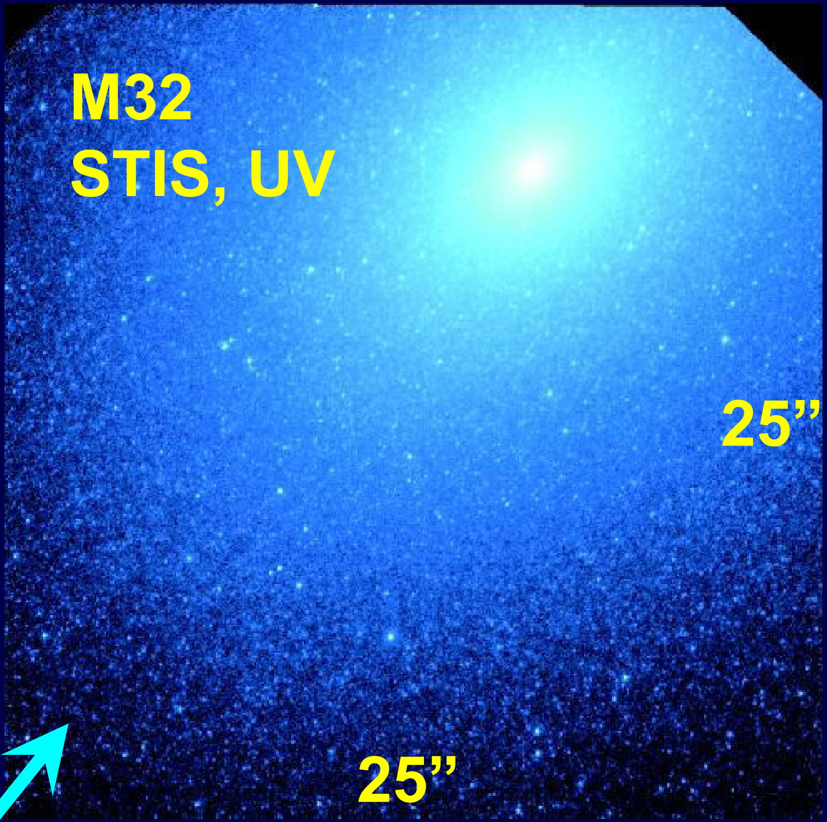
V. What does it all mean?

I. Hot Subdwarf Classification

	Subdwarf B (sdB)	Subdwarf O (sdO)
T_{eff} (K)	~20,000–30,000	> 30,000
Main Spectral Feature	Hydrogen	Helium
L & log g Dispersion	Small	Large
Evolutionary Paths to T, L, log g	Single	Multiple

II. Why hot subdwarfs are cool…

- Galactic field *Extended Horizontal Branch* (EHB) stars
  - $M_{tot} = \sim 0.5\ M_{\odot}$
  - $M_{env} < \sim 0.01\ M_{\odot}$
- Source of "UV-upturn" (or "UVX") seen in old stellar populations
- EHB stars have been imaged in UVX galaxies



Brown et al. 2000, ApJ, 532, 308

III. How a hot subdwarf gets hot: Binary Formation Scenario

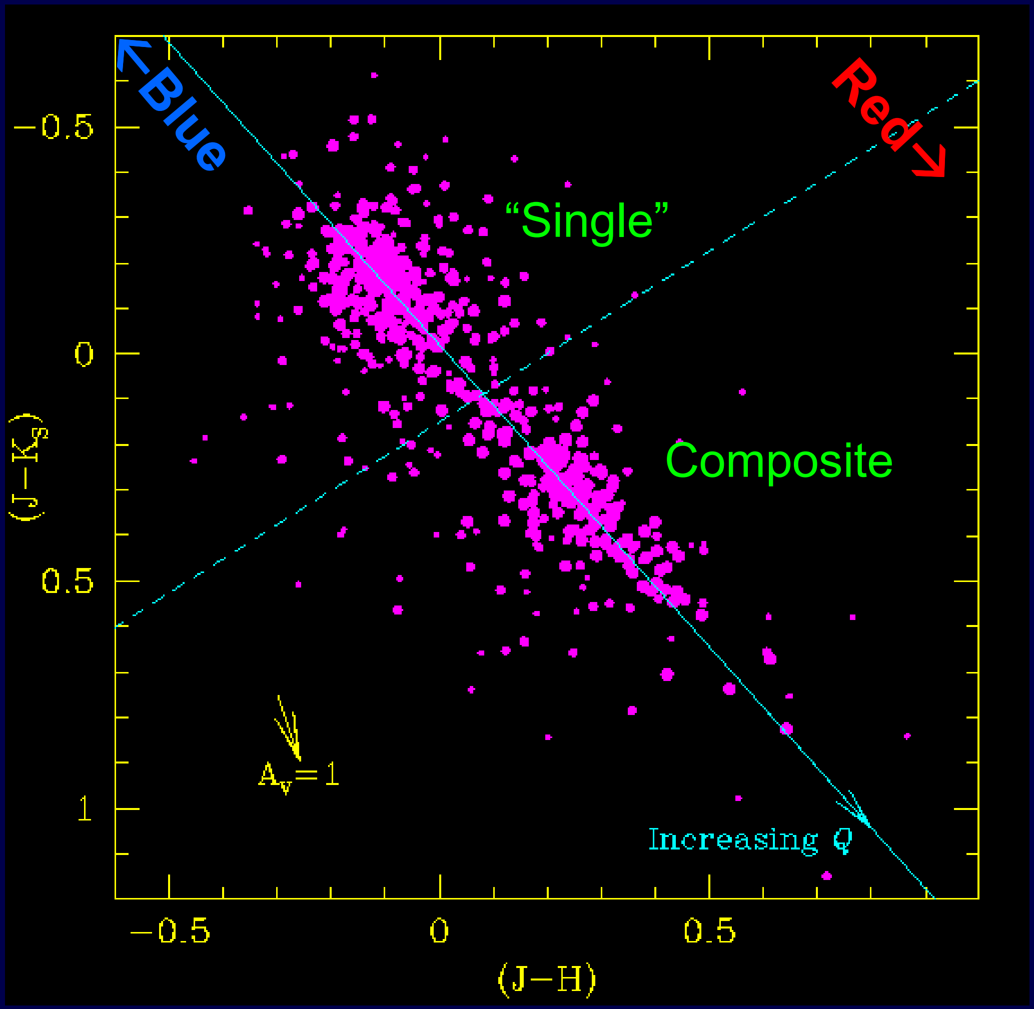
- Current scenario for Galactic field sdB formation
- **<u>Idea:</u>** Binary interactions → significant mass loss
  (i.e., Mengel et al. 1976; Han et al. 2002, 2003)
- **<u>Consequence:</u>** nearly all sdB should be found in "*close*" binary systems
- **<u>Known Binary Companions:</u>**
  - white dwarfs (P ~ hours → 30 days)
  - handful of *very* low mass dM (M ~ 0.08 $M_{\odot}$)
  - GK-type stars ("long period," >years = unknown)

IV. How we are cool

- **Idea:**
  - Use late-type companions to better understand sdBs (*L*, d, population, etc.)
- **How?:**
  - 2MASS → sdBs w/ unresolved late-type companions (*J* [1.2 μm], *H* [1.65 μm], and K_s [2.2 μm])
  - Spectroscopically study the companions
- **Goals & Future Significance:**
  - Identify nature & physical parameters of the companions
  - Determine physical parameters of sdBs in composites
  - Provide limits for binary formation channels

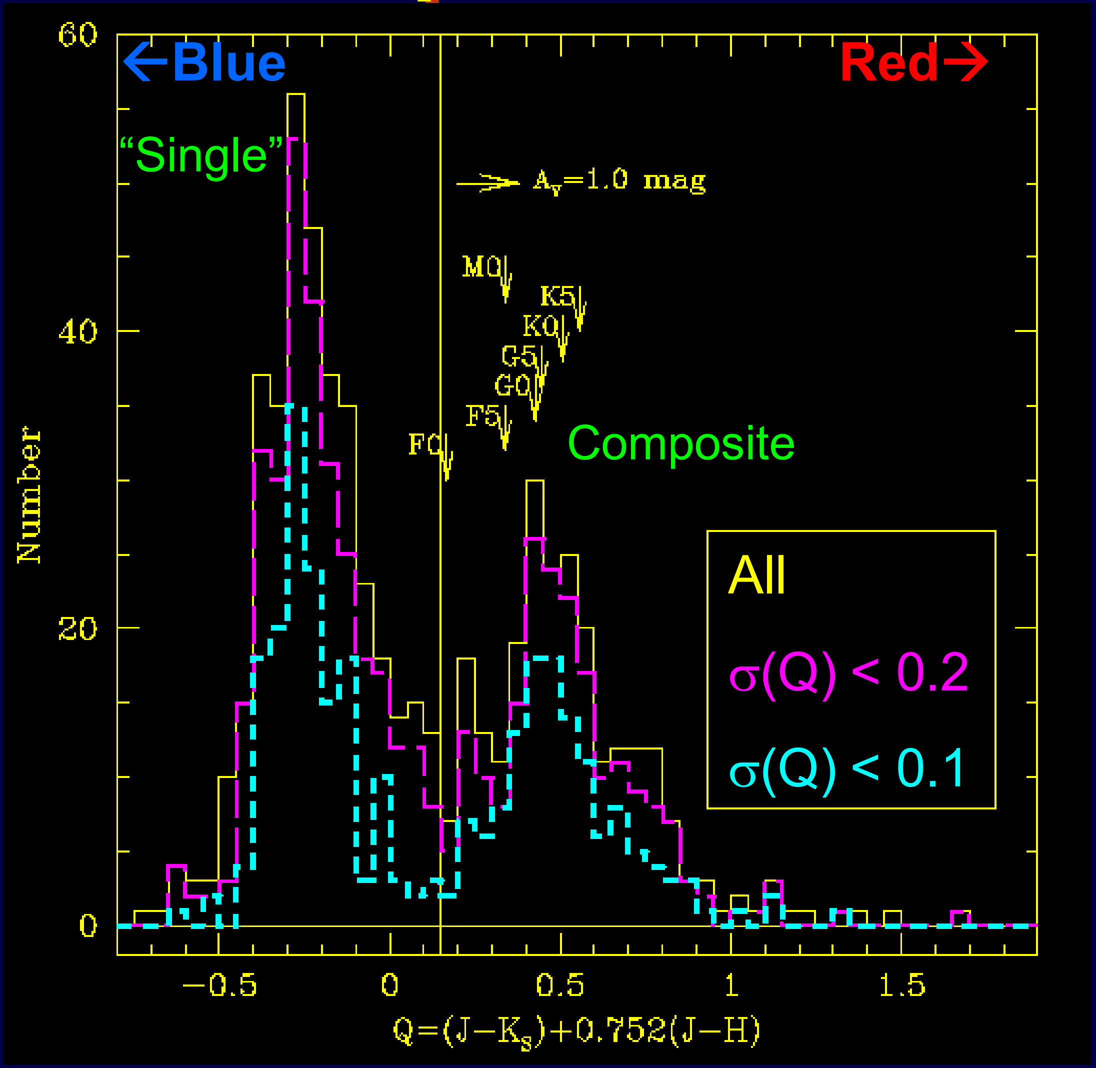
IVa. 2MASS Composites

- Two distinct "clumps" in 2MASS ($J-K_S$) vs. ($J-H$) color-color space:
  - "Single" colored
  - Composite colored



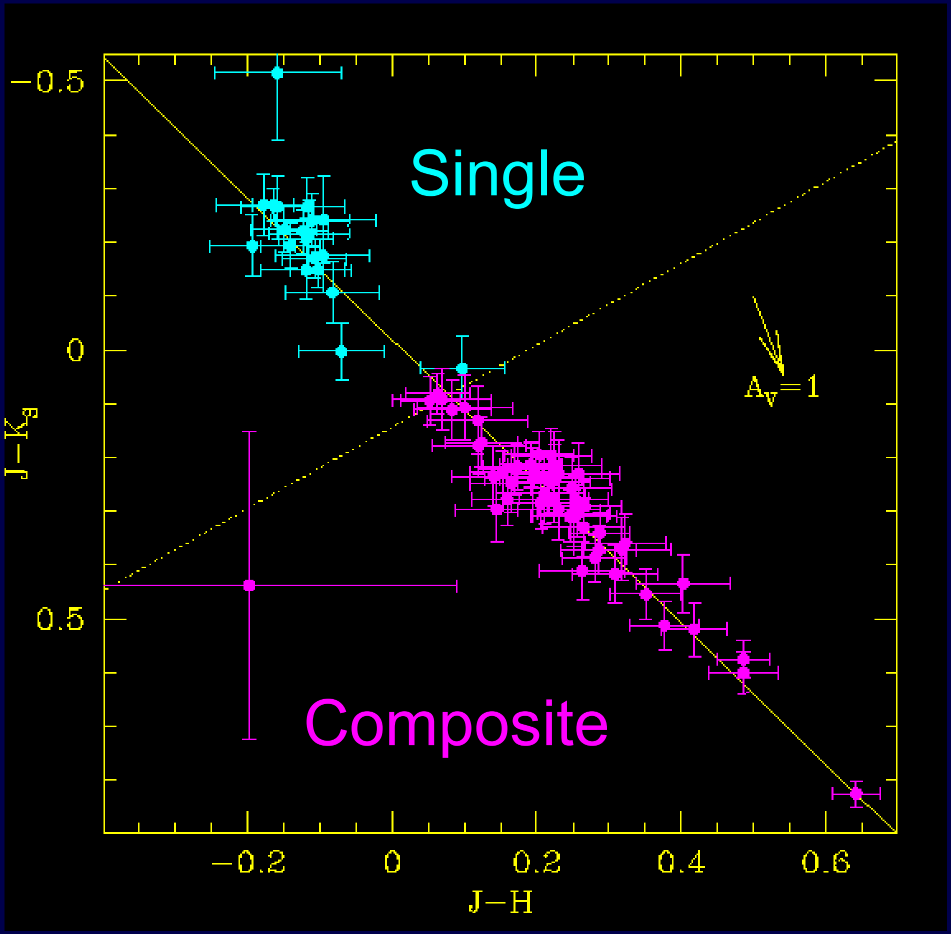
IVa. 2MASS Composites

- **Companions:**
  - Late F, G, K only
  - No dM or early F (most pronounced in the best photometry sample, $\sigma(Q) < 0.1$)
- **Magnitude Limited:**
  - 60±4% "single" (357)
  - 40±4% composite (237)
- **"Volume" Limited:**
  - 75±4% "single" (309)
  - 25±4% composite (104)



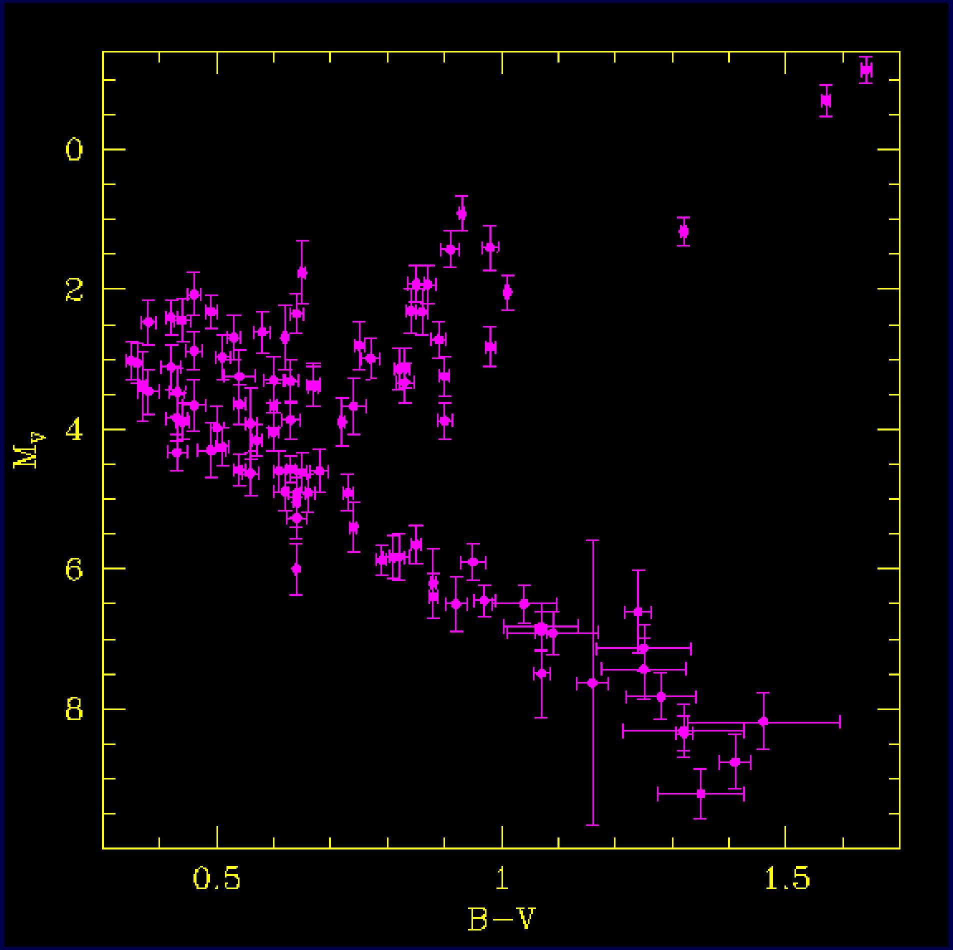
IVb. Spectroscopic Sub-Samples

- Hot Subdwarfs
  - 21 single
  - 53 composite
    - V< 13.5
    - $J-K_S$ > +0.5



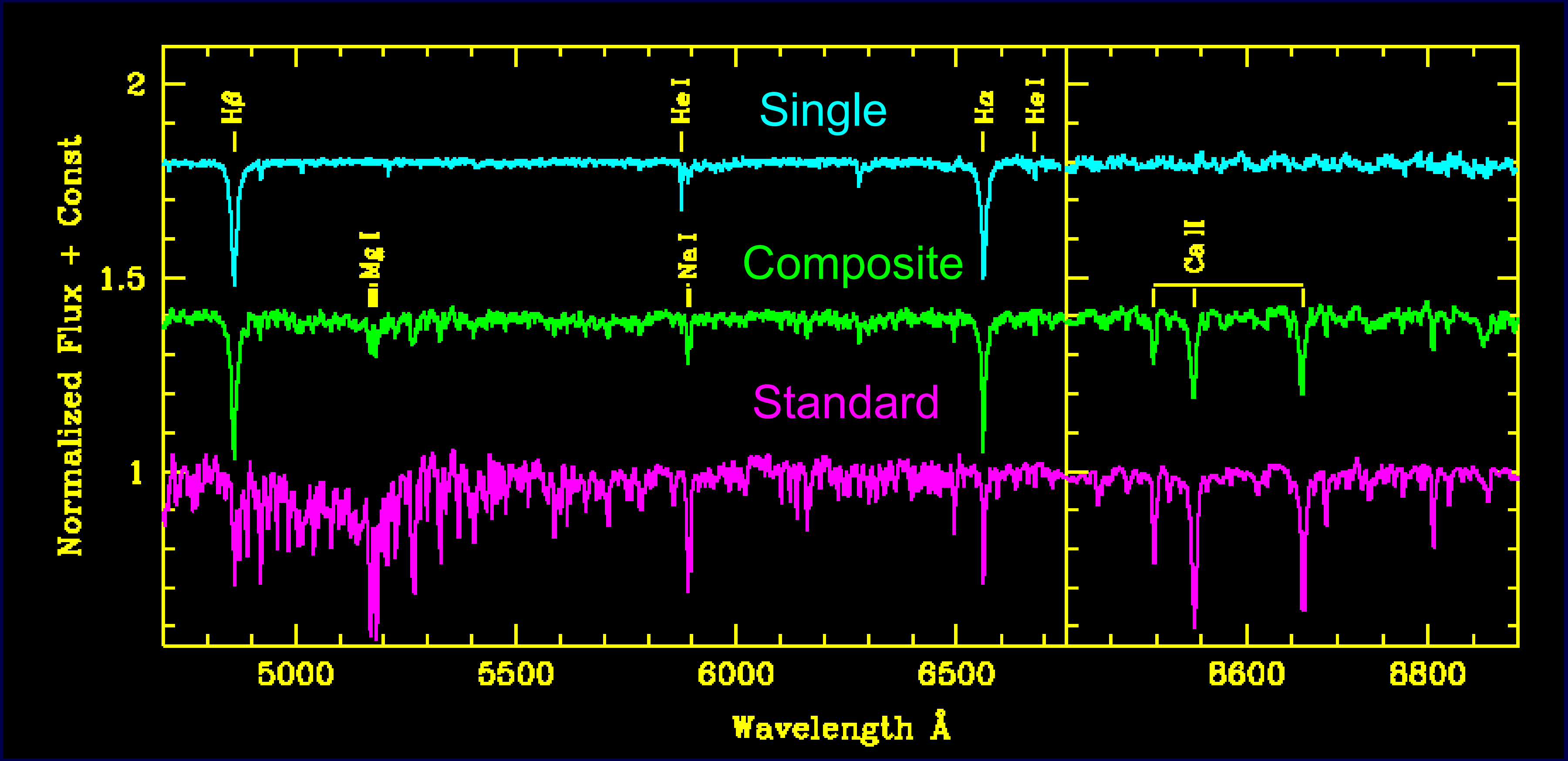
IVb. Spectroscopic Sub-Samples

- “Standards”
  - 84 stars
  - Pop I, MS and SG
  - M_V from HIP π



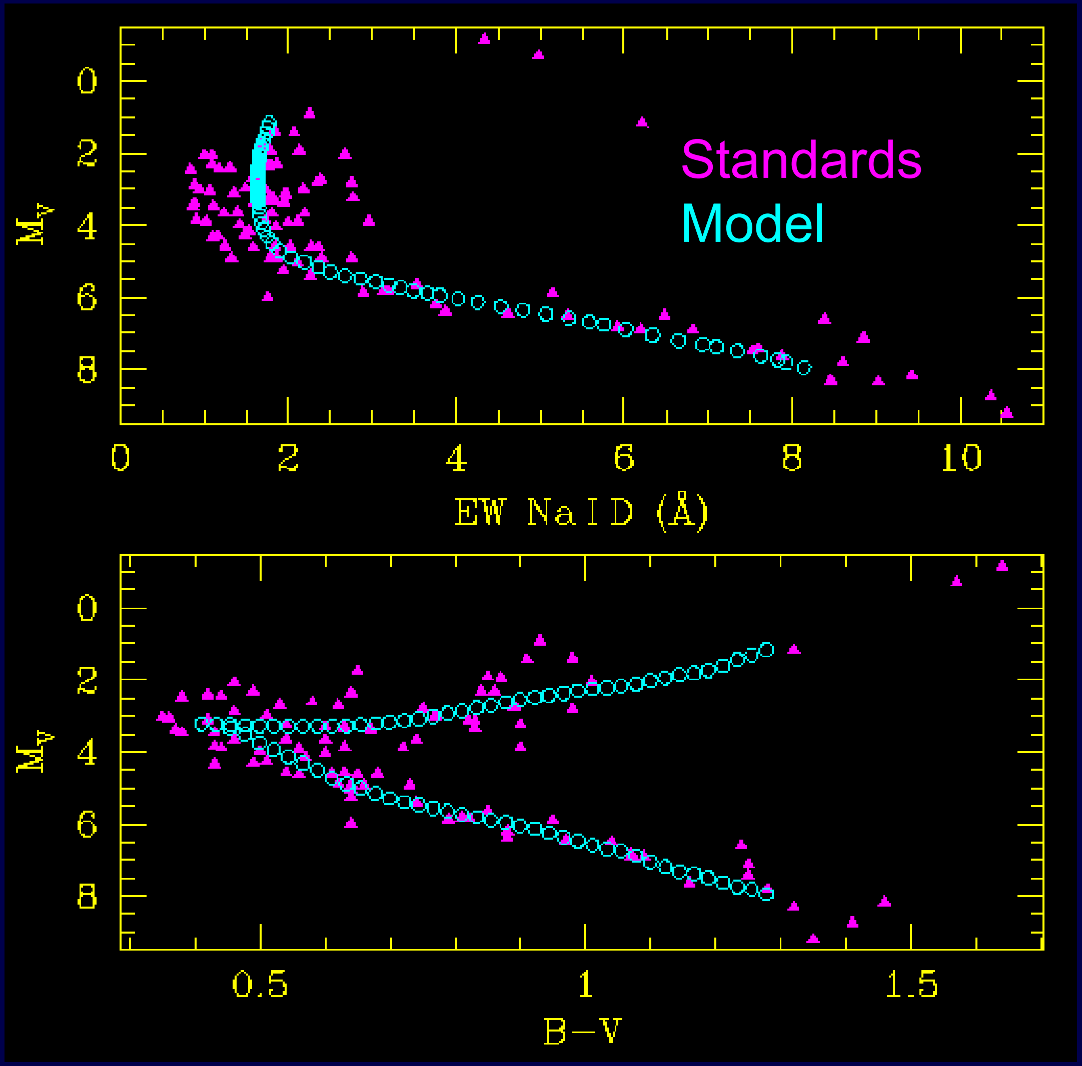
IVb. Spectra Obtained

- KPNO 2.1m GoldCam, McDonald 2.7m LCS
- ~4600–8900 Å, ~1.3 Å/pix



IVc. Refining Model Grid

- Fit standard star parameters
- Use fits to interpolate grid
- Compare grid to observed hot subdwarf composites

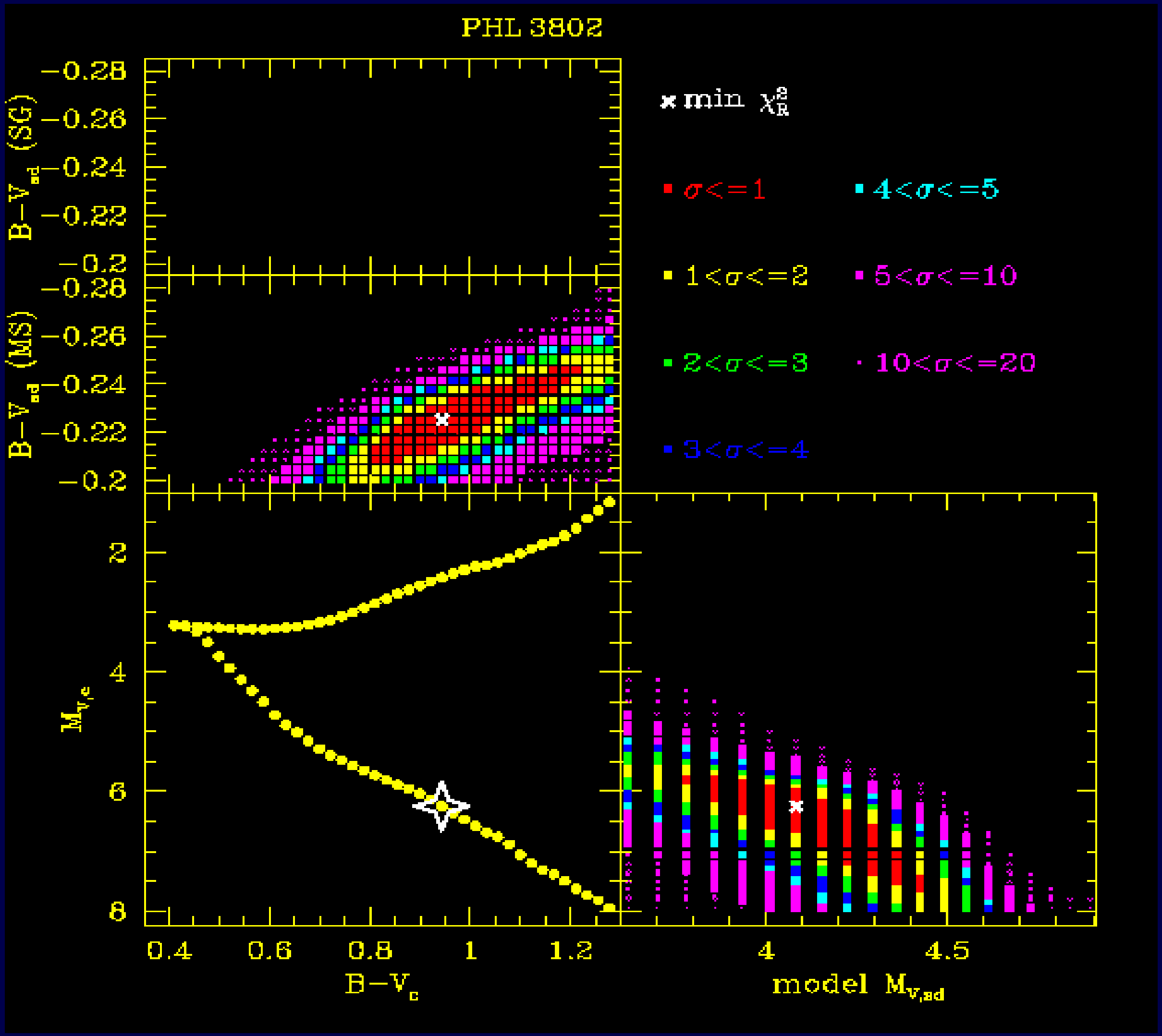


IVc. Refining Model Grid

- Take interpolated EWs/colors and predict the EWs/colors if diluted by a sdB
- Unable to flux calibrate → used Kurucz flux distributions to compute dilutions at different wavelengths
- Compare predicted diluted EWs/colors to observed composites…

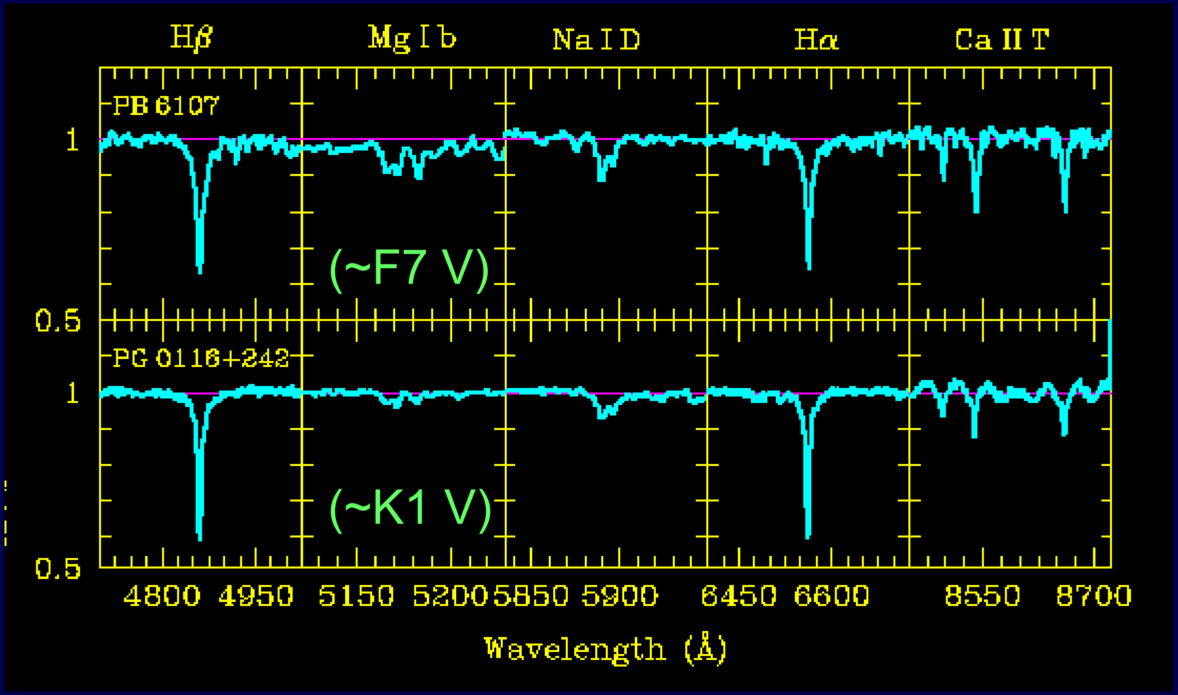
IVc. Individual Fits

- Best fit comp:
  - $(B\text{-}V)_c \approx +0.95$
  - $M_{V,c} \approx 6.25$
  - ~K2
- Best fit sdB:
  - $(B\text{-}V)_{sdB} \approx -0.22$
  - $M_{V,sdB} \approx 4.10$



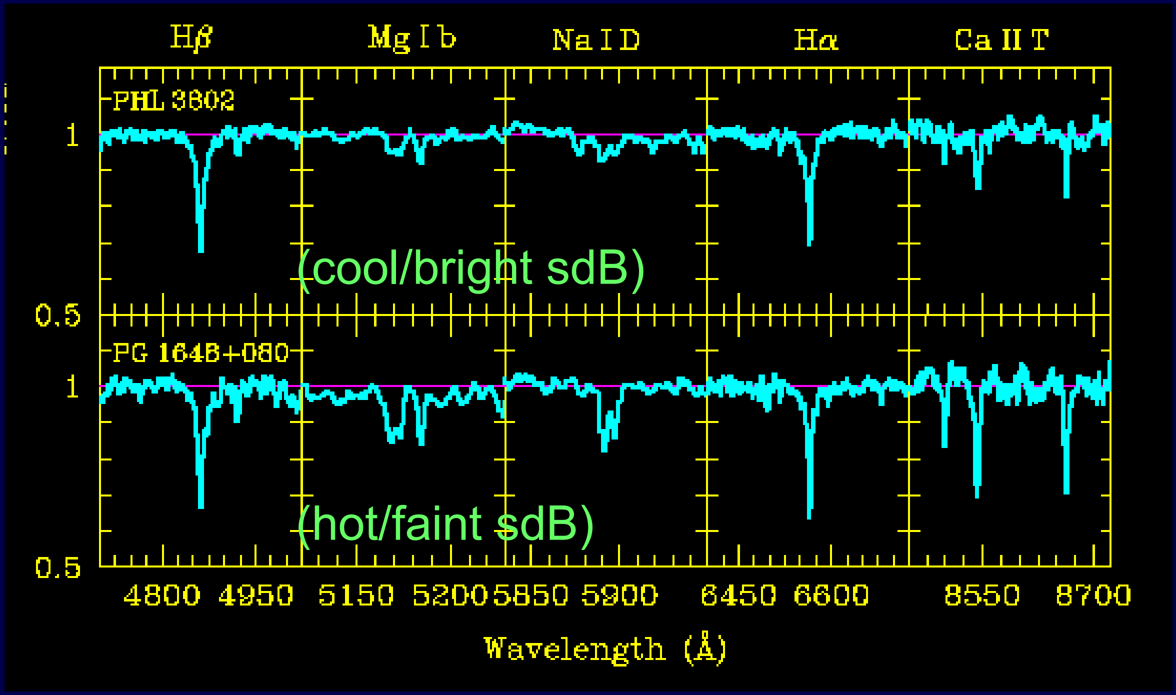
IVc. Individual Fits

- Same sdB, different comp.
  - $(B\text{-}V)_{sdB} \sim -0.24$
  - $M_{V,sdB} \sim 4.3$
  - $(B\text{-}V)_c \sim +0.7, +0.9$
  - $M_{V,C} \sim 5.3, 6.0$



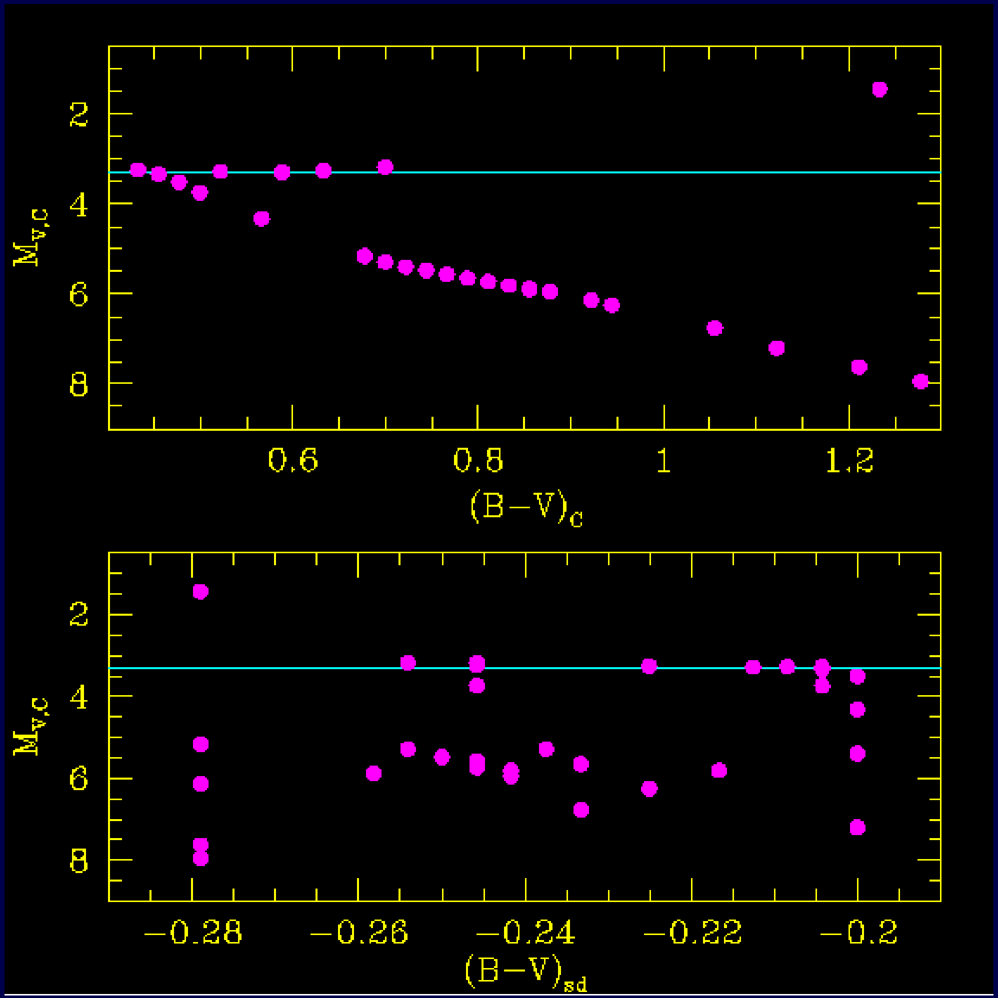
IVc. Individual Fits

- Same companion, different sdB
  - $(B-V)_c \sim +0.9$
  - $M_{V,C} \sim 6.0$
  - $(B-V)_{sdB} \sim -0.22, -0.26$
  - $M_{V,sdB} \sim 4.1, 4.7$



IV. Preliminary Fit Summary

- Majority of companions are best fit with main sequence
- A few appear to be subgiants
- Cover the range of subdwarf temperatures (no temperature bias or trends evident)



IV. Preliminary Fit Summary

- Work remains to be done over next ~6 months:
  - Refine model grids and model-matching technique
  - Investigate possible reddening effects
  - Verify results do not change for terminal-age EHB

V. What does it all mean?

- Goals & Future Importance:
  - Identify nature & physical parameters of the companions
  - Determine physical parameters of sdBs in composites
  - Provide limits for binary formation processes
    - Refine binary formation rates for Algols, SN Ia, CV, etc.
    - Refine population synthesis models for UV-upturn

V. What does it all mean?

- 2MASS Results:
  - Fraction of composite sdB in current samples:
    - 40% (magnitude limited)
    - 25% (volume limited)
  - There are no companions of dM type or earlier than ~mid-F type in current sdB samples
- (Preliminary) Spectroscopy Results:
  - Most late-type companions are fit by main sequence stars
  - There are a handful of subgiants

Special Thanks to:

G. B. Berriman

T. Bogdanovic

J. Ding

R. Ganguly

K. A. Herrmann

K. T. Lewis

A. Narayanan

NASA-GSRP

NOAO Graduate Travel Support

Pennsylvania Space Grant Consortium

Sigma Xi Grants-in-Aid of Research

Zaccheus Daniel Foundation for Astronomical Science