Stellar population spectral models from first principles

Ruth C. Peterson

UCO/Lick and
Astrophysical Advances
Topics discussed

• Building and using theoretical spectra
• Advantages for population modeling
• Generating valid stellar spectra; surprises
• Coadding them to get SSP composite spectra
• Limitations and caveats
• Matching optical M31 globular spectra
• Future work
Thanks to …

- J. Strader and SAGES, and R. Schiavon and the Treasury team, my co-conspirators in this
- S. Vogt, M. Bolte, J. Fulbright, and D. Fischer for spectral calibration observations
- NASA LTSA (NAS5-02052) and Hubble Treasury (GO-9455) programs for support
- Many more who have contributed critical input at important times
Generating theoretical spectral templates

• Calculate stellar spectra using Kurucz codes, Castelli models and Kurucz laboratory lines+
• Coadd spectra for stars across the CMD to form composite SSP spectra
• Begun for the mid-UV as a Hubble Treasury program and NASA LTSA
• Extended to the near-UV and optical
  – with J. Strader, J. Brodie, & SAGES
The Advantages for Modeling of a Theoretical Spectral Library

- Complete coverage of parameter space
  - $[\text{Fe/H}] > 0$; $\alpha$-enhanced and scaled solar mixes
  - Stars for all types, even rare and remote ones
- $S/N = \infty$; stellar parameter uncertainty = 0
  - Errors are systematic rather than random
- Consistent metallicity scale for stars, globular clusters, and galaxies
- Spectra are flux-calibrated
  - Coaddition is equally valid at all wavelengths
  - Fractional stellar contributions versus wavelength
- Spectra are very high resolution; degrade to match instrument, velocity dispersion, index
Calculating stellar spectra

• Use Kurucz SYNTHE codes, Castelli models
• Modify Kurucz line lists to match several weak-lined stellar spectra simultaneously
• Add ID’s (Fe I or Ti I) for lines not in the list
• Repeat until all weak-lined stars match
• Repeat all above for stronger-lined stars
• Must match a wide a range of stellar types
• Fits: OK in optical, so-so in mid-UV for Sun
Comparing theoretical to observed spectra

- Plots show the observed spectrum of a star or globular as a heavy line, a normalized relevant theoretical spectrum as a light line, and its atmospheric model parameters.
- Wavelength in Ångstroms is given along the bottom. Ticks on the left represent 10% of the full normalized flux. Zero flux is at the bottom, except the bottom is 50% for 5970Å.
- Some plots have line identifications on top.
- The SiH plot also shows calculations for the same stellar models as the usual spectra, but in which only SiH lines are included.
Near-UV fits (3035-3041Å) after line list fix
SiH identified along the way

- Arcturus is a nearby K giant with an excellent high-resolution, high S/N atlas (Hinkle et al.)
- While fitting its blue spectrum, ≥ 4100Å suddenly many unidentified lines appeared
- Kurucz line lists searched for molecules
- SiH 0-0 bandhead found at 4096Å
- Wavelengths were wrong because energy levels were poorly/sparsely measured
- Kurucz recalculated SiH with modern levels
- Still poorly fit: unidentified lines, 3 isotopes
- SiH extends redward; affects H\(\delta\), CN, CH, Eu II
SiH at 4096Å in a cool dwarf at [Fe/H]=-1.5 and the K giant Arcturus at [Fe/H]=-0.6
Present limitations of these theoretical templates

- Limited to old systems, $\geq 1\text{Gyr}$, by the range of stellar standards for calibration
- Restricted to 2200Å - 9000Å
  - Castelli models stop at 3500K
  - Line-list improvements stop at 9000Å
- Unique? No goodness-of-fit metrics
- Uncertainty in choices of T and weights
Onward to match M31 globulars

• Observations of M31 034-096
  – Keck HIRES 3900-6000Å to set metallicity
  – Keck LRIS 3350-6000Å for age and NH,CH,MgH
  – Star counts from 47 Tuc to infer weights
• Spectral calculations tuned to match
  – [Fe/H] = -0.5 to -1.0; models interpolated
  – [\(\alpha\)/Fe] = 0.0 (solar) to 0.4; models interpolated
  – Individual variations for C,N,Na, …, as needed
• Weighted coaddition of 10-15 stellar spectra of the same [Fe/H], [\(\alpha\)/Fe] => SSP template
How weights are constructed

• Weights for flux-calibrated stellar spectra
  \[ \text{# stars (in CMD region)} \times \text{Radius}^2 \]

• Weights from tracks will also be attempted

• Weights altered when spectra contradict!
  – Mass segregation
  – Unpredictable types such as BHB, blue stragglers

• No colors are used as constraints yet, but they will be
  – Calculate the population’s colors by convolving the composite spectrum with the appropriate filters
Caution required when adopting CMD weights

A Deep, High Resolution Study of the Core of 47 Tucanae

Raja Guhathakurta
Herzberg Inst of Astrophysics
UCO/Lick Obs, UC Santa Cruz

- Extreme mass segregation
- Binary main sequence
- Blue stragglers

Collaborators:
James Clem (University of Victoria), Justin Howell (UCSC),
Peter Stetson (HIA/DAO), & Ron Gilliland (STScI)

KITP Globular Cluster Conference
January 28, 2003
47 Tuc
(Schiavon+)

Triangles show positions of stars included in the composite spectrum
FRACTIONAL CONTRIBUTIONS FOR THE COMPOSITE SPECTRUM \([\text{Fe/H}]= -0.9\)  
\([\text{O,Mg, Si, Ca, Ti/Fe}]= 0.2\)  
\([\text{C/Fe}]= -0.2\)  
\([\text{N/Fe}]= 0.7\)  
\([\text{Na/Fe}]= 0.4\)

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M31 GC 096 Hβ, 5970 Å: ten stars

[Fe/H] = -0.9, [α/Fe] = +0.2
M31 GC 096 4640 - 4720Å: ten stars

[Fe/H] = -0.9, [α/Fe] = +0.2
M31 GC 096 SiH 4110Å, Mgb: ten stars

[Fe/H] = -0.9, [α/Fe] = +0.2
M31 GC 096 LRIS 3200 - 4000Å: ten stars
[Fe/H] = -0.9, [α/Fe] = +0.2
M31 GC 096 LRIS 3900 - 4700Å: ten stars
[Fe/H] = -0.9, [α/Fe] = +0.2
M31 GC 096 LIRS 4600 - 5400Å: ten stars

$[\text{Fe/H}] = -0.9$, $[\alpha/\text{Fe}] = +0.2$
Future work on fundamentals

• Produce grids of stellar spectra, and the composite spectra derived from them for SSP
  – Spanning $-2.3 \leq [\text{Fe/H}] \leq +0.4$, $[\alpha/\text{Fe}] = 0, +0.4$
  – To be archived at Space Telescope MAST
  – Will include atlases of standards (e.g. Sun, Arcturus, Procyon) with fits and line identifications

• Calculate colors and indices from composite spectra

• Calibrate the cluster analysis process by analyzing 47 Tuc spectra of its integrated light and also of its individual red HB stars
Future work on M31 globulars

- Analyze new HIRES spectra of M31 globulars
  - To be observed this year: one typical metal-poor and metal-rich cluster with HST CMD’s to the HB
  - S/N x2 higher to get additional elements, e.g. Ba & Y (s-process), Eu (r-process)
  - Plus one very metal-rich cluster, to derive the high end of the [Fe/H] scale (nearer that of galaxies)
- Analyze existing LRIS spectra for NH in M31
- Derive figure-of-merit metrics from comparisons over a region of parameter space in the grid
- Investigate how colors help constrain fits