STARS
Status, Important Questions, Needed Capabilities

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Status
Example: L and T Dwarfs

- Discovery using SDSS, 2MASS photometry
- Followup Optical and Infrared spectroscopic observations
- Two new spectral classes defined using both optical and IR criteria, opened the way for the active new field of brown dwarf research

IR Spectra of T dwarfs

Keck/NIRC

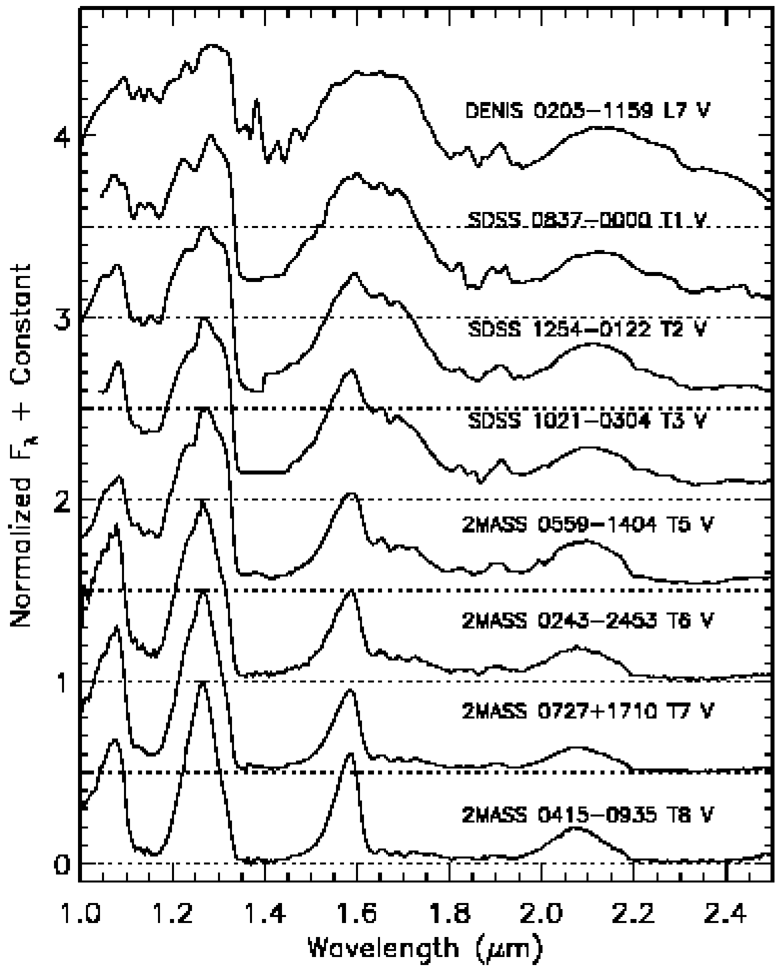


FIG. 11.—Low-resolution spectra of T dwarf standards and the L7 V DENIS 0205−1159AB. Data are normalized at their *J*-band peaks, and zero-point offsets are indicated by dotted lines. Data for DENIS 0205−1159AB (Leggett et al. 2001), SDSS 0837−0000, SDSS 1254−0122, and SDSS 1021−0304 (Leggett et al. 2000) have been degraded to the resolution of the NIRC spectra using a Gaussian filter.

Burgasser et al. 2002

UKIRT/CGS4

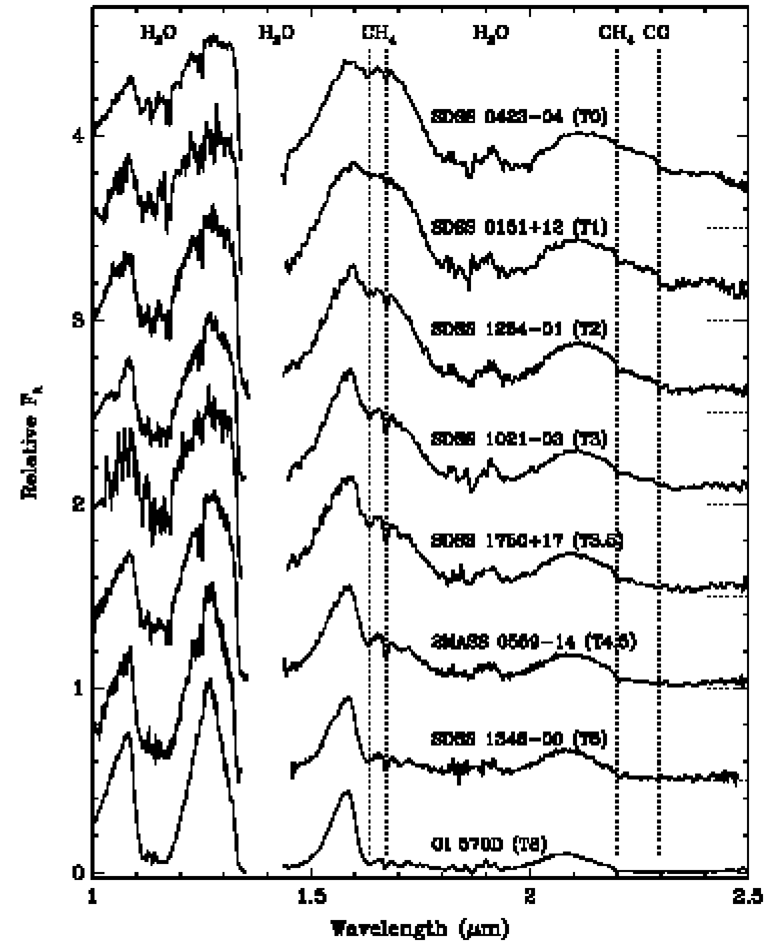
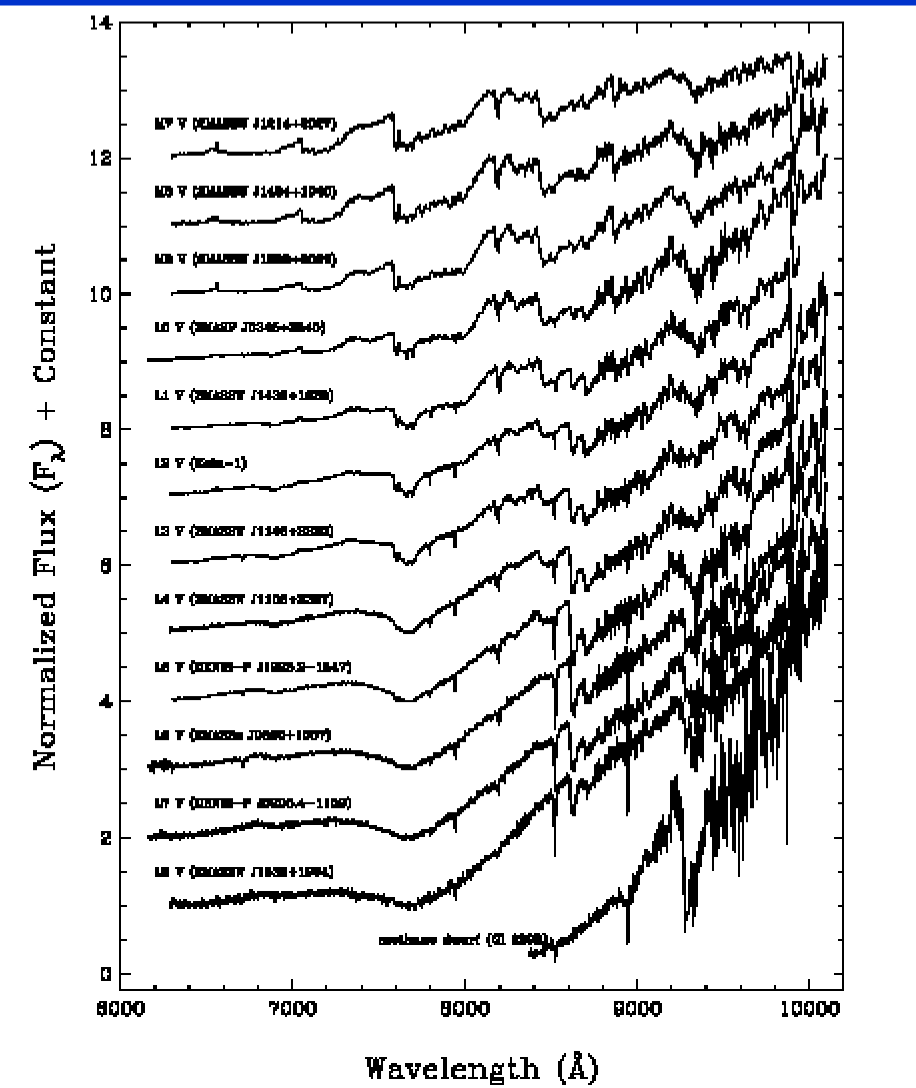


FIG. 8.—T sequence from 1.0 to 2.5 μm. Spectra are normalized at their peaks near 1.3 μm. The wavelengths of broad water absorption bands are indicated. Vertical dashed lines mark the wavelengths of key spectral features due to CH_4 and CO. Classifications are from this paper. Spectra of SDSS 1254−01, SDSS 1346−00, and Gl 570D are from L00b, Tsvetanov et al. (2000), and Geballe et al. (2001b), respectively.

Geballe et al. 2002

Optical spectra of L dwarfs

Keck/LRIS



Kirkpatrick et al 1999

SDSS spectra

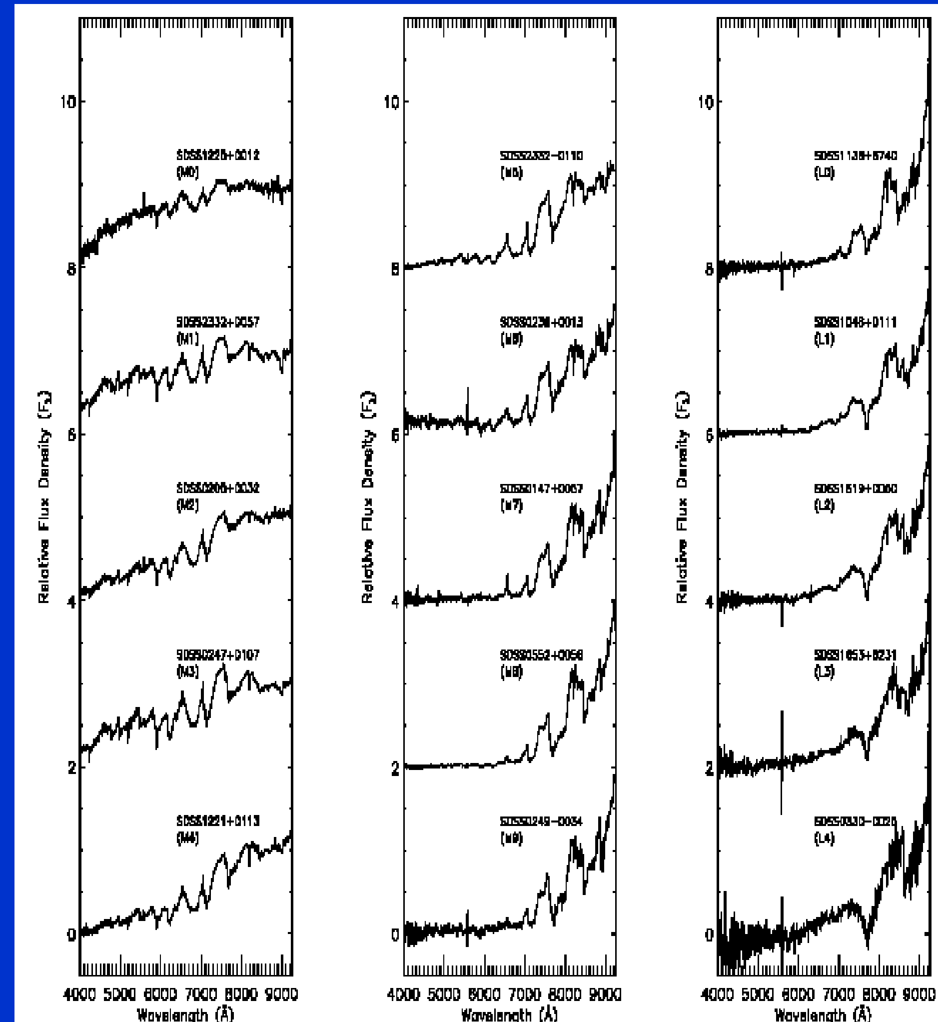


FIG. 5.—SDSS spectrum with highest signal-to-noise ratio at each spectral type. These spectra comprise a set of templates to be used in the SDSS pipeline processing for automatic spectral type identification in the future. Noise spikes near 5600 Å have not been removed.

Hawley et al 2002

Capabilities used:

- 2MASS survey data (IR imaging) – 1.3m
- SDSS survey data (optical imaging) – 2.5m
- Keck/NIRC (low res IR spectra) – 10m
- UKIRT/CGS4 (low res IR spectra) – 3.8m
- Keck/LRIS (low res optical spectra) – 10m
- SDSS survey data (optical spectra) – 2.5m
- Additional – IRTF, ARC, CTIO, KPNO, etc.

Status
Example: L and T Dwarfs

- Success: Several independent groups carried out work, using public and private telescopes, large and small
- Drawback: privileged access to survey (discovery) data, or invitation from group, needed to participate

Important Questions

- ISM and Star Formation
  - What is the 3D distribution of dust in the Galaxy?
  - How do molecular clouds form; role of turbulence and magnetic fields in supporting them?
  - GMC cores generally have $M < M_J$ so how do stars form?
  - Role of rotation, turbulence, magnetic fields during core collapse and accretion?
  - What is the connection between star formation, disks, and planetary system formation?
  - What sets the IMF, can it vary, why and by how much?

Important Questions, cont.

- Stellar Physics and Stellar Evolution
  - Methods for accurate determination of basic stellar parameters – metallicity, mass, age
  - Stellar models don't match the data! (colors, spectra) – need to include magnetic fields, rotation, surface inhomogeneity (3D)
  - What is the real physics controlling convection, magnetic fields and mass loss?
  - What about binary star evolution, leading to CVs and SN Ia?
  - Why are all WD ~ 0.6M_sun and NS ~ 1.3 M_sun?

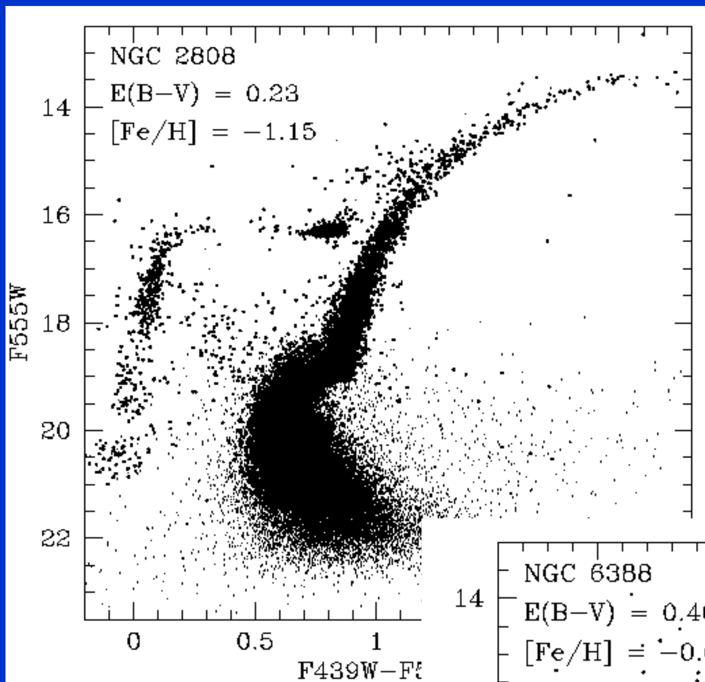
Important Questions, cont.

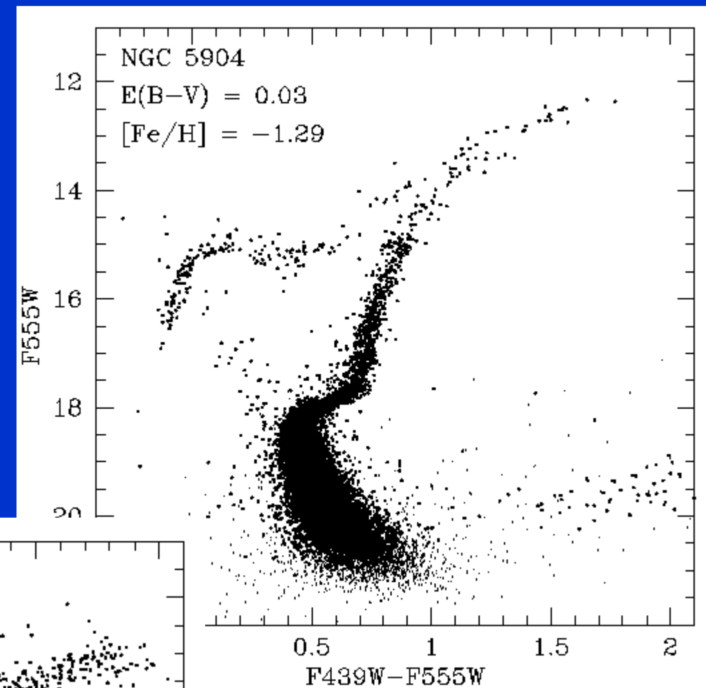
- Origin and evolution of stellar populations in the Galaxy
  - Did the Galaxy form by accretion or collapse? When and how much for each process? NOTE: halo field stars and existing dSph have different abundance patterns → different origin?
  - What controls size and mass scales of "structure formation" – open clusters, globular clusters, dSph? Do all field stars originally form in clusters? Why are there no globular clusters currently forming in the Milky Way?

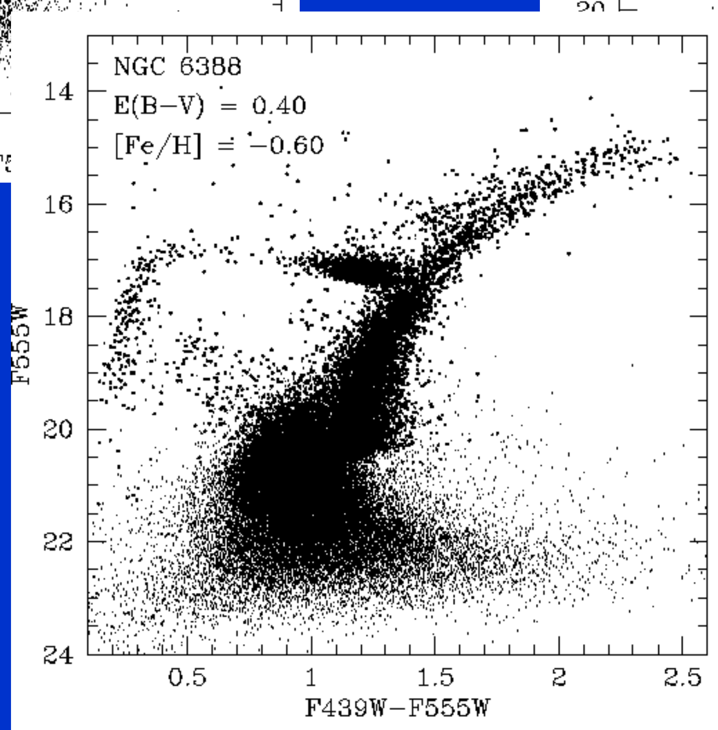
Important Questions, cont.

- Origin and evolution of stellar populations in the Galaxy, continued
  - Galactic chemical evolution – was there a population III? Is the thick disk a separate chemical entity and where did it come from?
  - Is there dark matter in the Galaxy? How much, how is it distributed, is there a stellar component?

Mass Loss on the Red Giant Branch



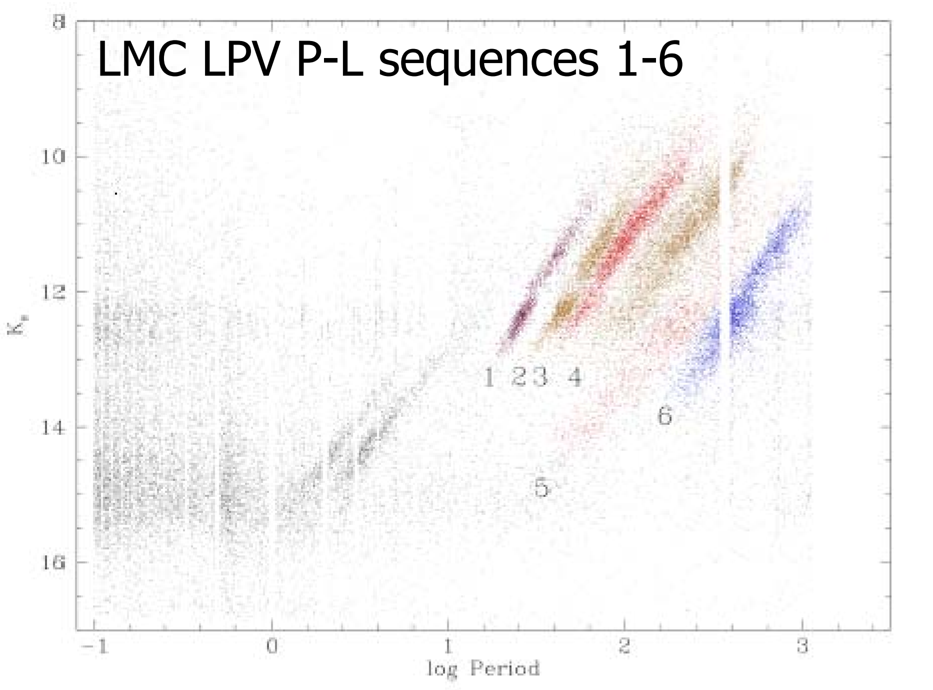


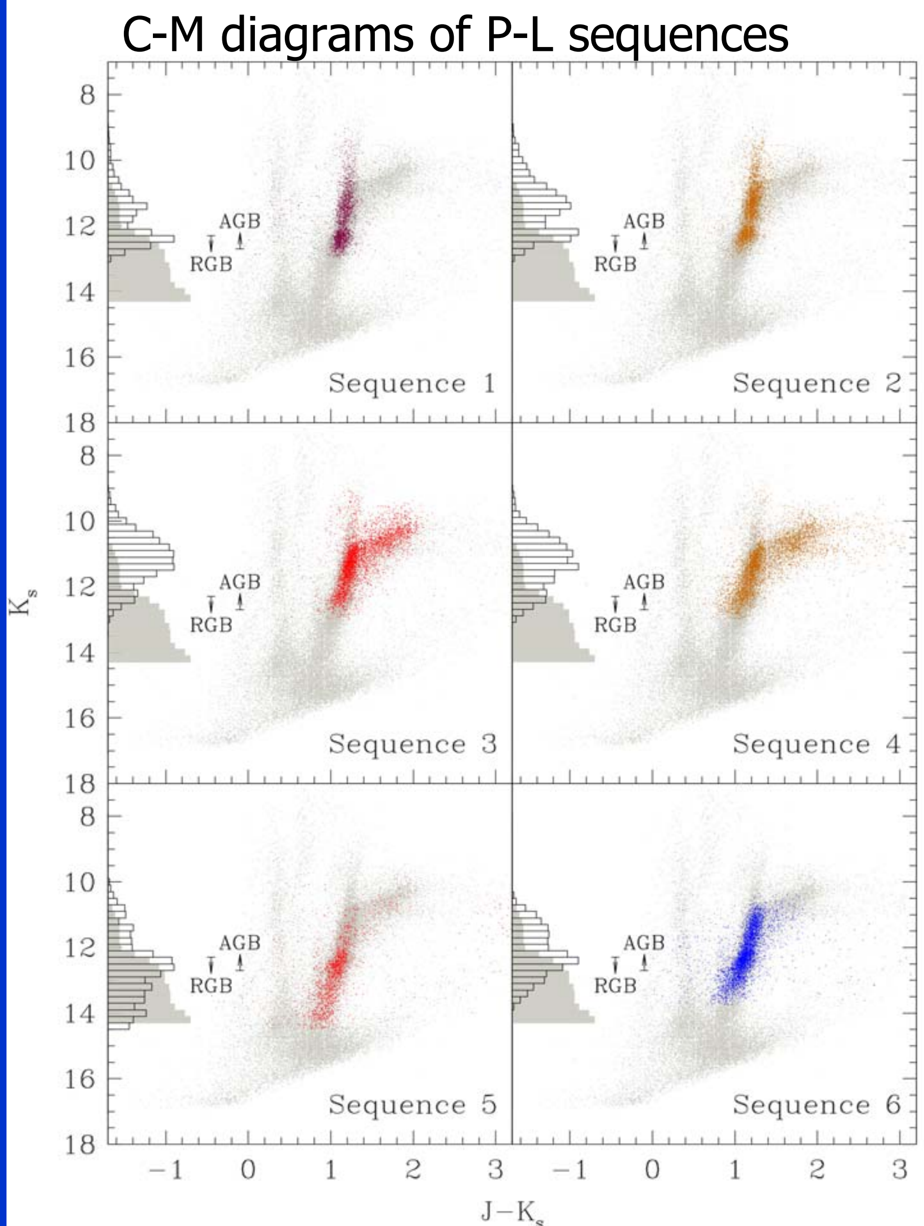


CM diagrams of globular clusters showing effects of mass loss on the RGB by position of HB stars (second parameter effect)

Piotto et al 2002

Red Giant Pulsation → Mass Loss?

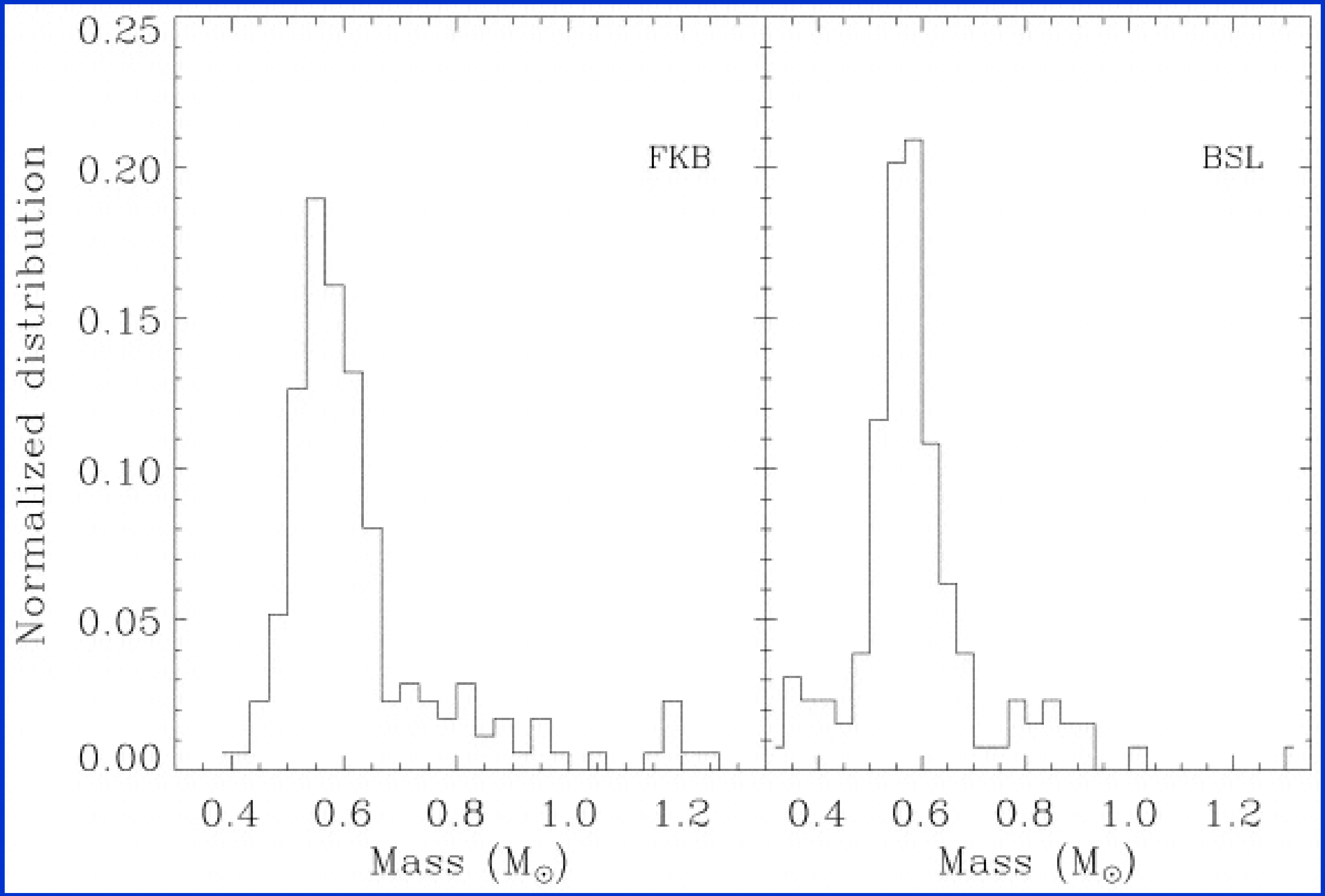




MACHO variable star database – long period pulsation in stars at the tip of the RGB, connection to mass loss?

Fraser et al 2004 (in prep)

Mass Loss Leads to White Dwarf Mass Function



(Finley, Koester & Basri 1997; Bergeron, Saffer & Liebert 1992)

Capabilities used:

- HST WFPC2 – but ground-based CM diagrams required first (2-4m telescopes, optical imaging)
- MACHO survey data – 1.3m telescope, wide-field optical imaging
- Lick 3m, CTIO 1.5m, CTIO 4m optical (blue/UV) spectra, 5A resolution

Galaxy Formation and Chemical Evolution

- Old metal-poor stars in dSph have ~solar alpha-element abundance pattern → unlike halo field and globular cluster stars.
- Enrichment looks like the disk, but at low [Fe/H] → not due to SN Ia Fe-peak enhancement
- Probably means no high mass SN II in dSph → truncated IMF and/or low SFR
- >99% of the Galaxy cannot be result of mergers of current dSph-like objects → implications for accretion scenario of Galaxy formation

Shetrone et al 2003, Tolstoy et al 2003

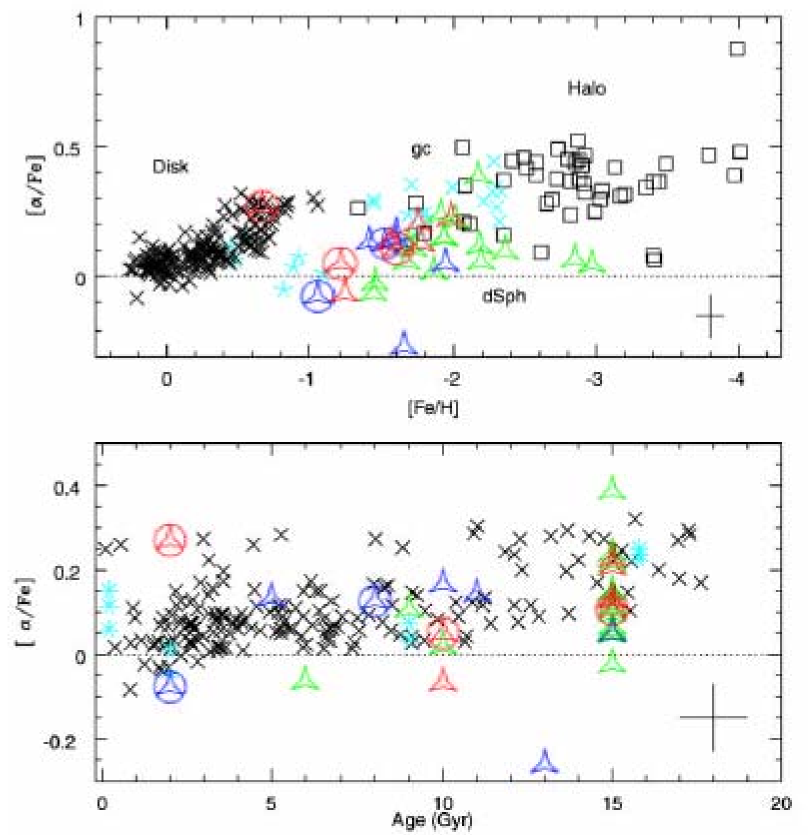


FIG. 15.—The α-element abundances, where [α/Fe] = 1/3 ([Mg/Fe] + [Ca/Fe] + [Ti/Fe]). Our UVES α abundances are plotted vs. [Fe/H] in the top panel and vs. age determined from isochrone analysis in the bottom panel. The symbols are as follows: blue triangles are the Carina data; blue triangle plus circle are Leo I data; red triangles are Sculptor data; and the red triangle plus circle are Fornax data. The green triangles are data on Draco, Ursa Minor, Sextans from SCS01. The black crosses are Galactic disk star measurements from E93; the open squares are halo data from McWilliam et al. 1995 and the light blue stars are UVES data from a study of LMC star clusters of different ages from H00. There are also light blue crosses, which are our Galactic globular cluster measurements combined with those of SCS01. We have plotted an average representative set of error bars in each plot. These plots highlight the differences between the α-element abundances observed in different environments, which are labelled in the upper plot (where " gc " stands for globular clusters).

Capabilities used:

- Keck/HIRES
- VLT/UVES

→ Large telescopes, high resolution optical spectra (R>40,000)

Needed Capabilities

- Large Surveys (multicolor photometry, spectroscopy, time series) – e.g. MACHO, 2MASS, SDSS and extension, WIYN-OCS, MOSAIC, KAOS, Pan-Starrs, LSST
  - Huge samples of stars to obtain statistical picture (e.g. turnoff stars, K giants, M dwarfs, white dwarfs, open clusters, globular clusters)
  - Whole sky coverage for dust maps, stellar pops
  - Astrometry and radial velocities for kinematics
  - Find rare objects (lowest mass brown dwarfs)
  - Transient phenomena – stellar physics (pulsation, mass loss, starspots, binary stars)

Needed Capabilities, cont.

- High resolution (R>40,000) spectra
  - e.g. O/IR echelles on McDonald 2.7m, Lick 3m, 3.5 - 4m's, HET, Gemini, Keck
  - Detailed physics – abundances, convection, mass loss, nucleosynthesis (r,s-processes, isotopes)
  - Velocities – planets, binaries, kinematics in clusters and Local Group galaxies

Needed Capabilities, cont.

- Imaging and spectroscopy of very faint sources (big telescopes)
  - IMF studies in situ
  - Current star and cluster formation in varied environments
  - Results of past star formation – clusters, dSph, field samples
  - High res spectra of faint stars

Needed Capabilities, cont.

- Followup of interesting sources/samples (smaller telescopes)
  - Binary stars – calibrate masses, evolutionary tracks
  - Subdwarfs – early stellar population(s)
  - RGB, HB, AGB stars, PN, white dwarfs – stellar evolution
  - Low mass stars, brown dwarfs – low mass end of the IMF

Needed Capabilities, cont.

- Observing Modes
  - Remote observing
  - Service/queue observing
  - Robotic observing
  - Specialized instrumentation, Cooperative/Shared facilities

Needed Capabilities, cont.

- Access to databases and software tools
  - Large surveys → Large databases
  - Complex data (AO, IFUs, large format CCDs, high resolution and multi-object spectroscopy)
  - Combined projects (data mining + new observations) lead to calibration "challenges"

Needed Capabilities, cont.

- Hands-on graduate student training in Observational Astronomy
  - Even if you get your thesis data from a large survey database, you still need to know acquisition and reduction techniques (i.e. how much to trust the data!)

Thanks to:

- The younger generation (UW graduate students)
- The older generation (UW emeritus professors)