A Metallicity Classification System for T Subdwarfs

Adam Burgasser (UC San Diego)

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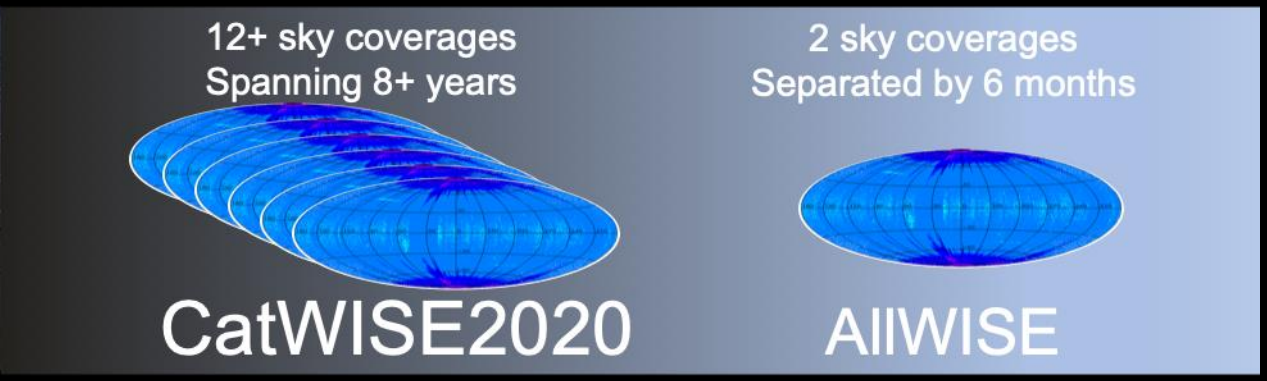
Citizen Scientists: Nikolaj Stevnbak Andersen, Paul Beaulieu, **Thomas P. Bickle**, Guillaume Colin, Jean Marc Gantier, Leopold Gramaize, Les Hamlet, Ken Hinckley, Martin Kabatnik, Frank Kiwy, David W. Martin, Diego H. Massat, William Pendrill, Arttu Sainio, Jörg Schümann, Melina Thévenot, Jim Walla, and Zbigniew Wędracki

and the Backyward Worlds: Planet 9 Collaboration

The Backyard Worlds: Planet 9 Search for Nearby Neighbors

Kuchner et al. 2017; http://backyardworlds.org

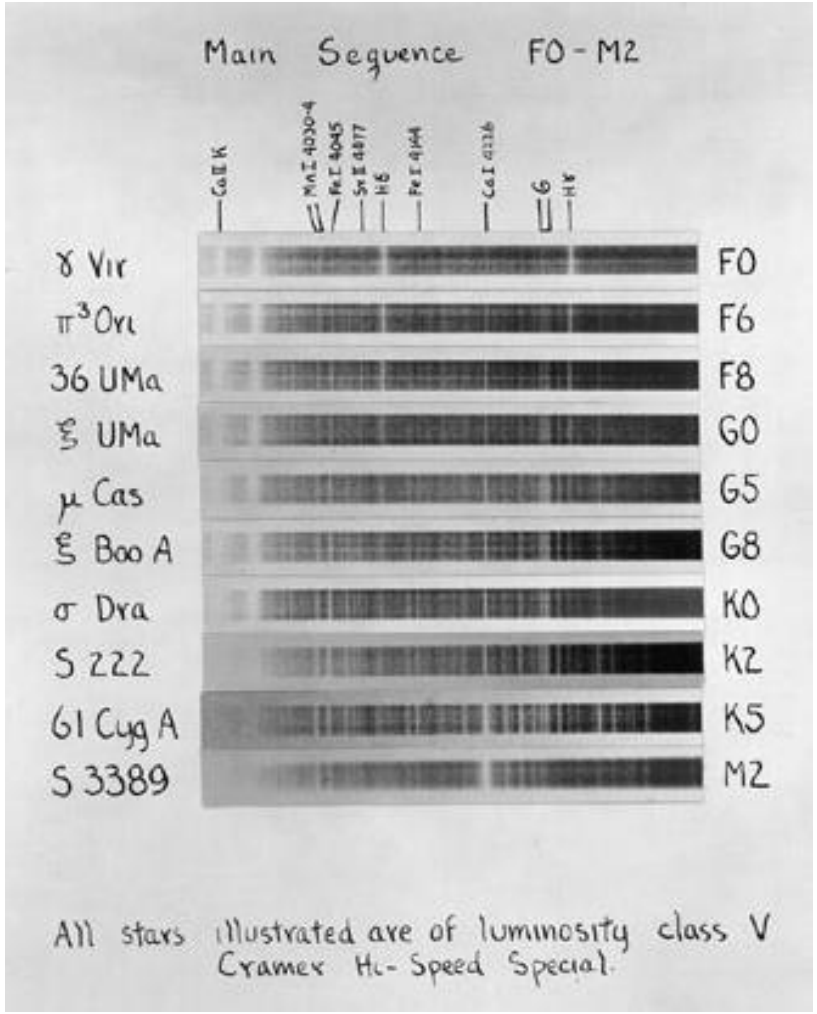
This citizen science program has engaged nearly 100,000 citizen scientists to discover hundreds of faint moving sources in multi-epoch mid-infrared data from WISE/NeoWISE



The MK System for Spectral Classification

Bill Morgan on the MK System (1984):

"…a specific methodology that makes possible the construction and use of systems of classification based on the particular observed characteristics of stellar spectra that have been selected to define the frames of reference. ***These systems must be autonomous****; that is, they are to be defined completely by the appearance of the spectral features in arrays of standard stellar spectra, in a specified interval of wavelength."*

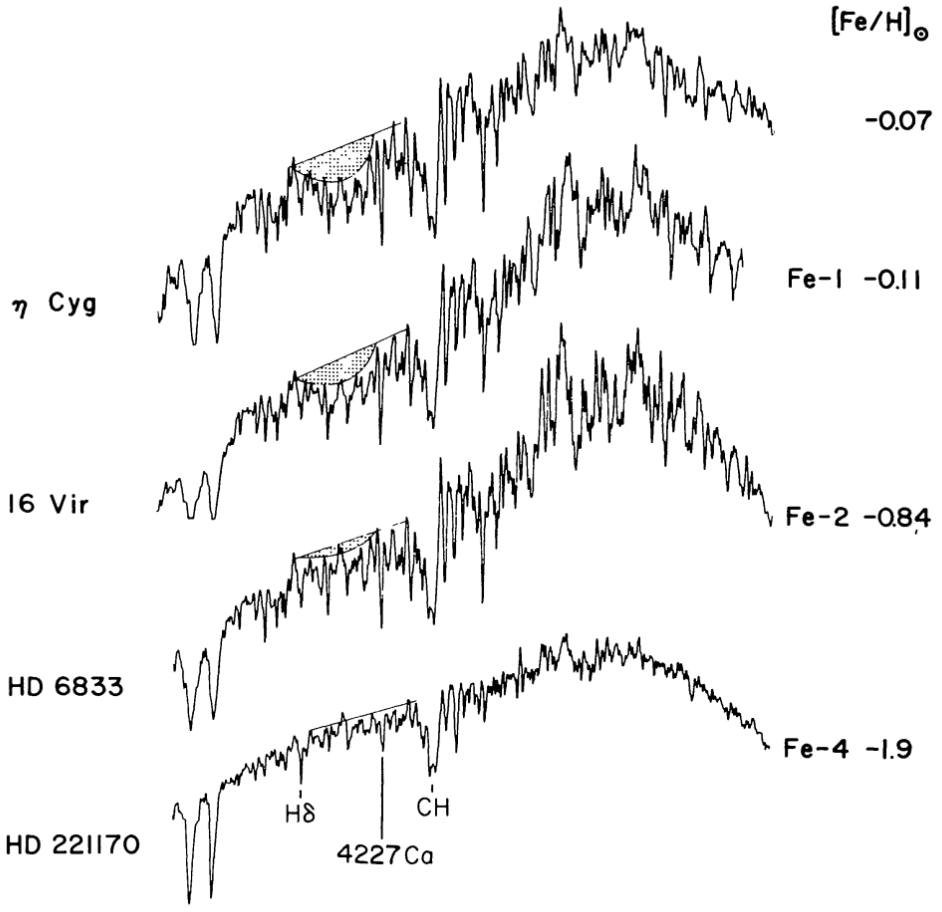


from *An Atlas of Stellar Spectra with an Outline of Spectral Classification* (Morgan, Keenan & Kellman 1943)

The MK System for Spectral Classification

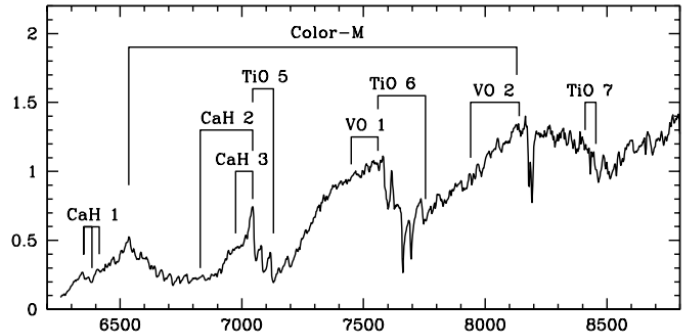
"Any system that is to remain useful must be flexible enough to adapt not only to improved techniques of measurement but also to new theoretical insights into the variables that actually determine the energy spectrum of a star in all of its fascinating but sometimes frustrating detail."

Phil Keenan (1985, IAU Symp 111)

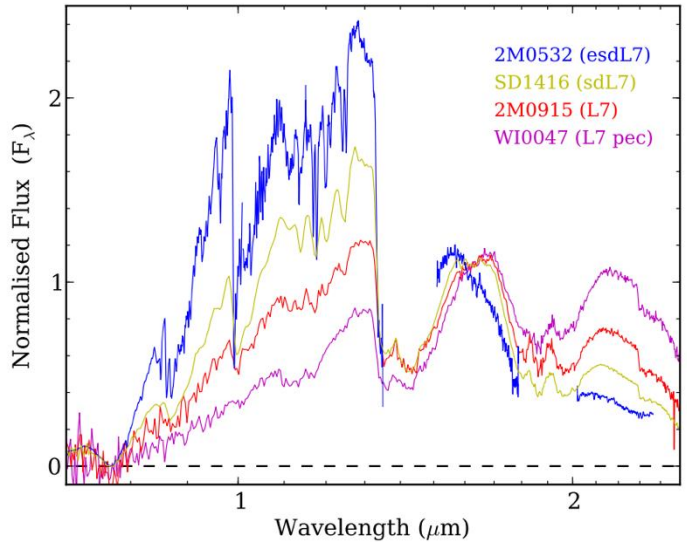


Why do we need a metallicity scheme for T dwarfs?

Existing schemes for M & L dwarfs



Gizis et al. (1997); **Lepine et al (2003,** 2007)



Burgasser et al. (2007); **Zhang et al. (2017**-2019)

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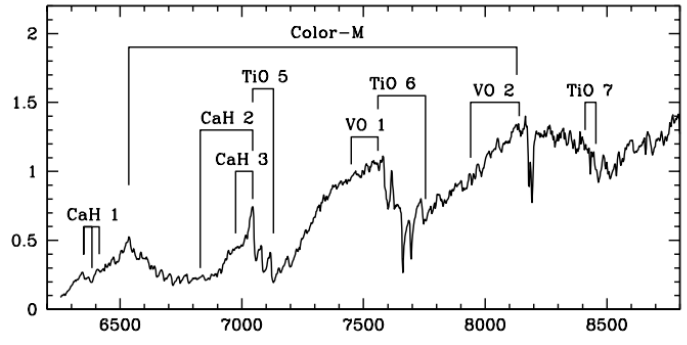

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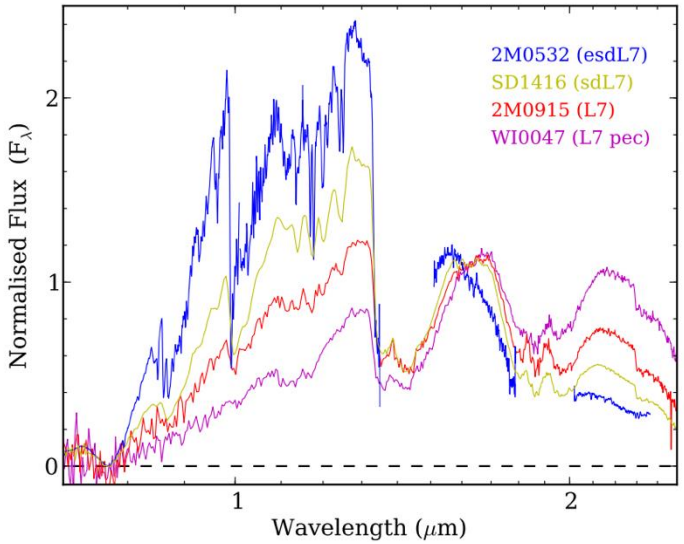

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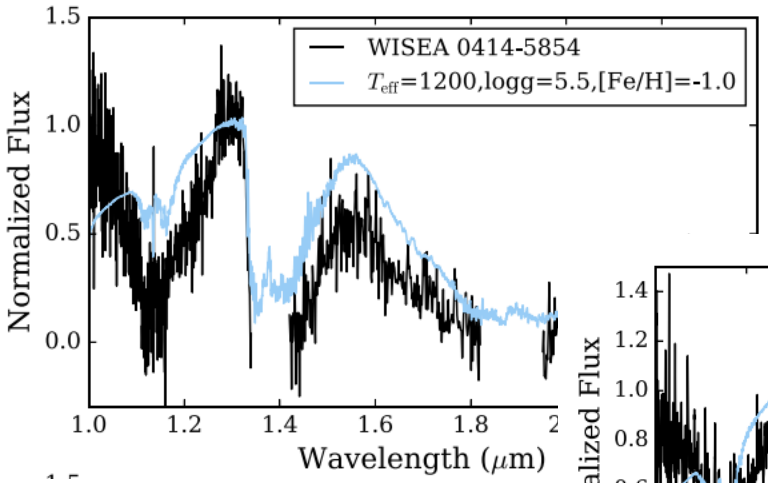
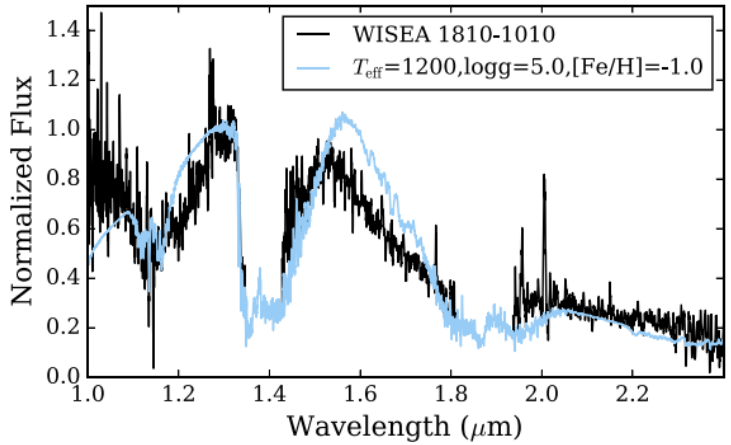
Detection of metal-poor/halo T dwarfs

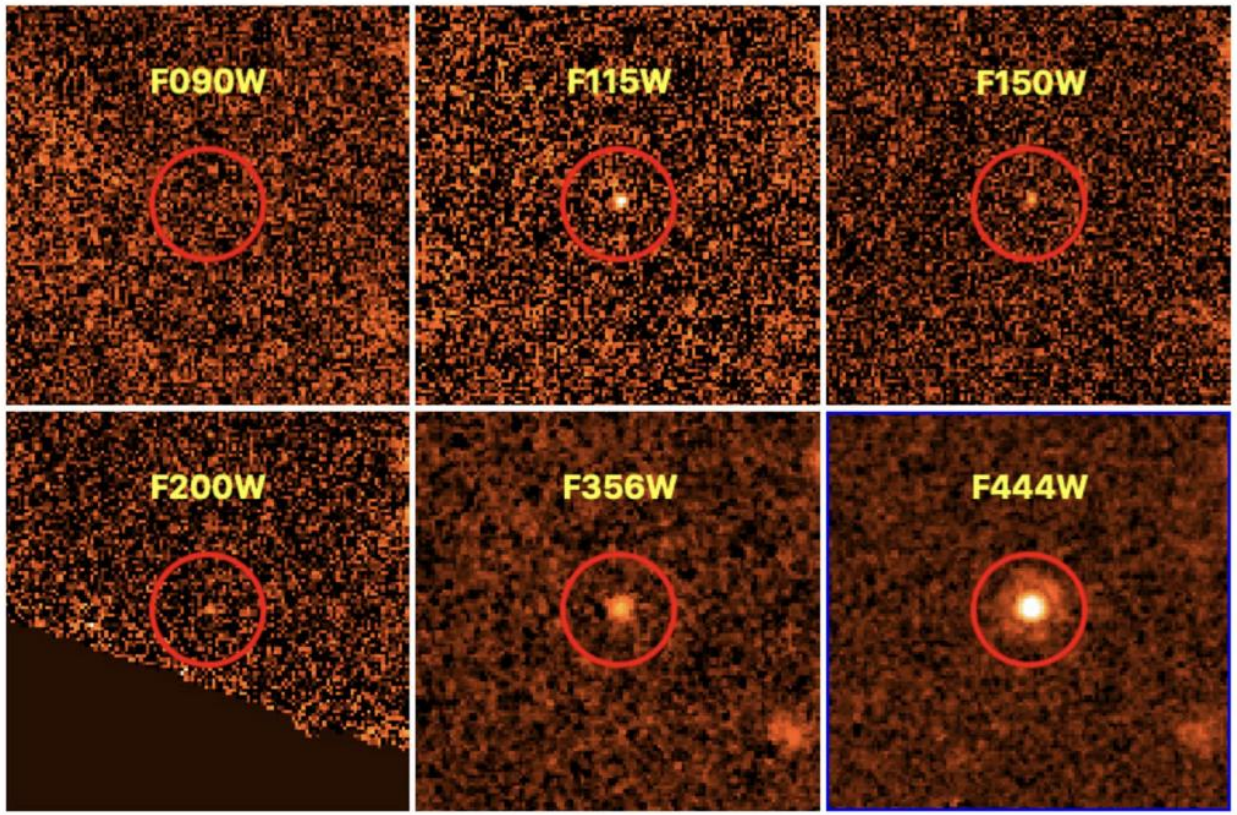


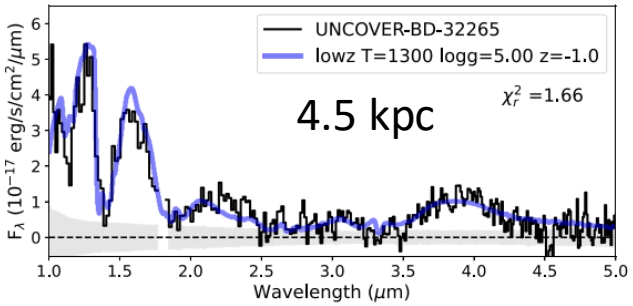


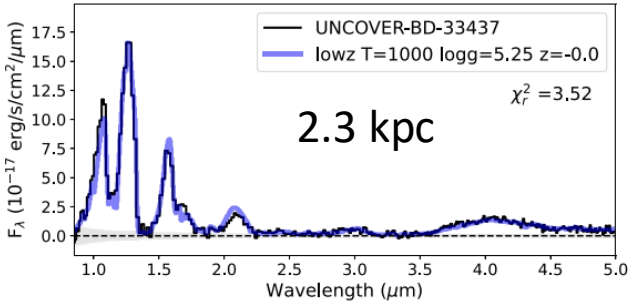
Burningham et al. (2010); Pinfield et al. (2012); Mace et al. (2013); Kellogg et al. (2018); Greco et al. (2019); **Schneider et al. (2020);** Meisner et al. (2021); Kirkpatrick et al. (2021); Brooks et al. (2022); Burgasser et al. (2024)

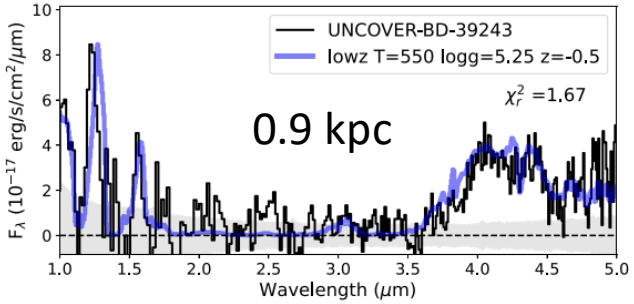
Why do we need a metallicity scheme for T dwarfs?

JWST's "rubies"



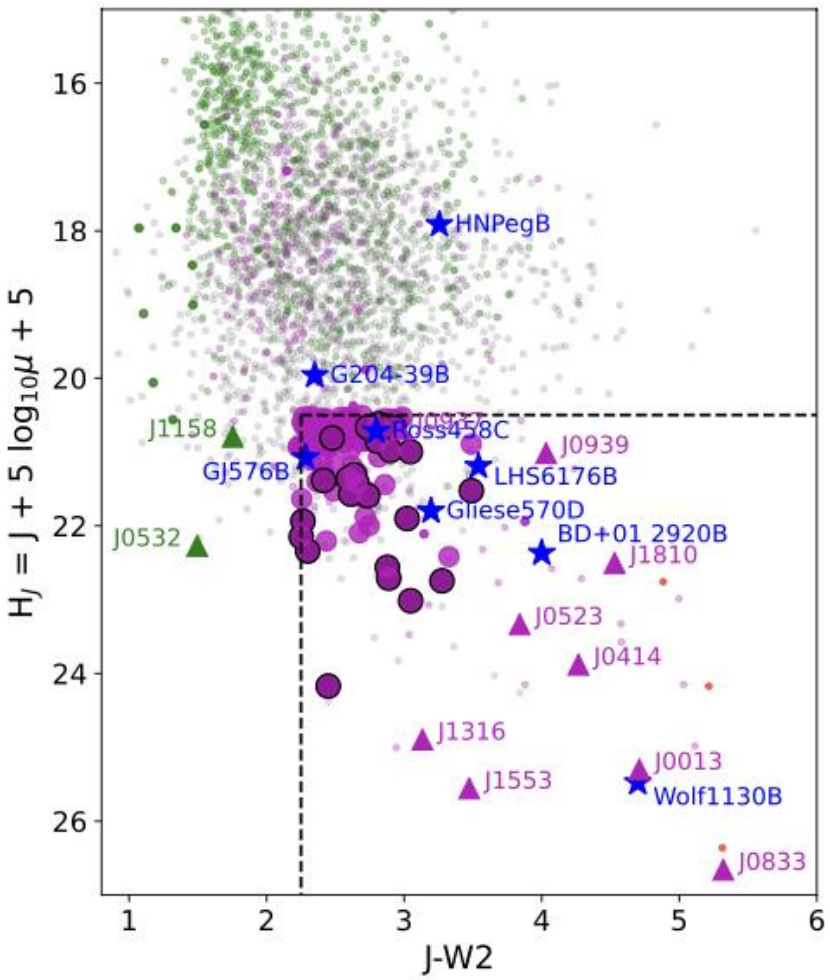






Nonino et al. (2023); Glazebrook et al. (2023); Wang et al. (2023); **Burgasser et al. (2024)**; Hainline et al. (2024); Holwerda et al. (2024)

The Spectral Sample



BYW sample: color & reduced proper motion selection

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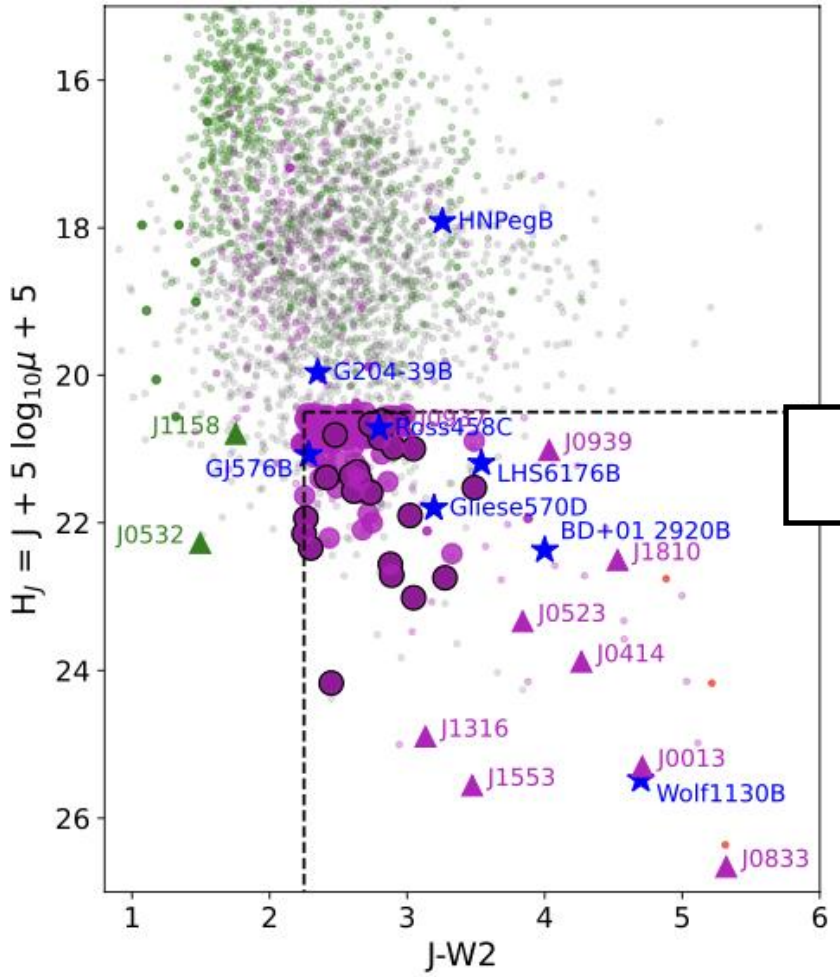

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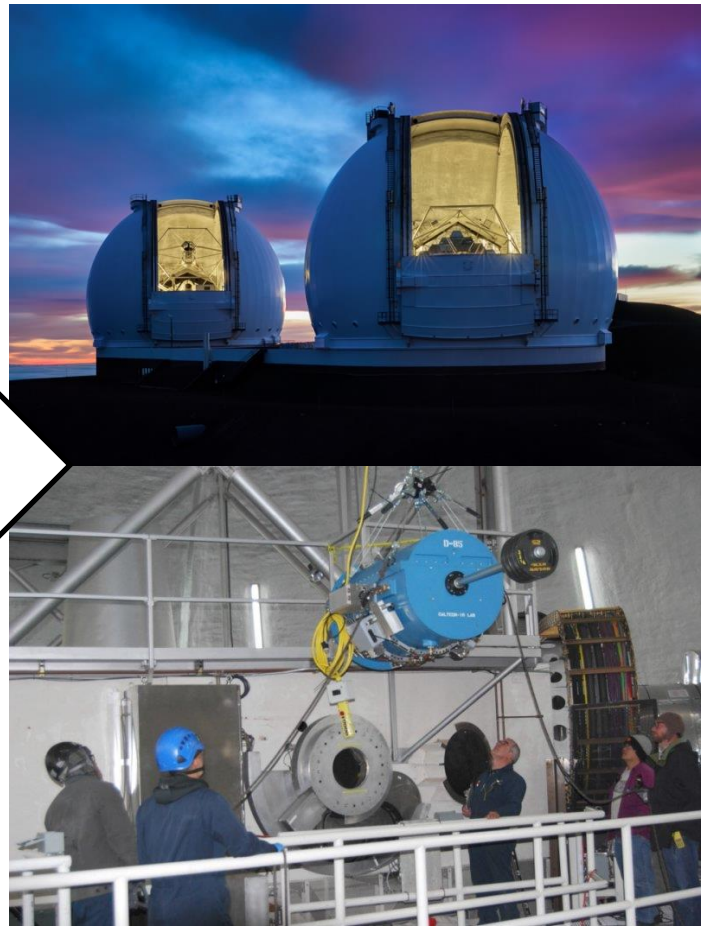

Keck/NIRES spectrograph

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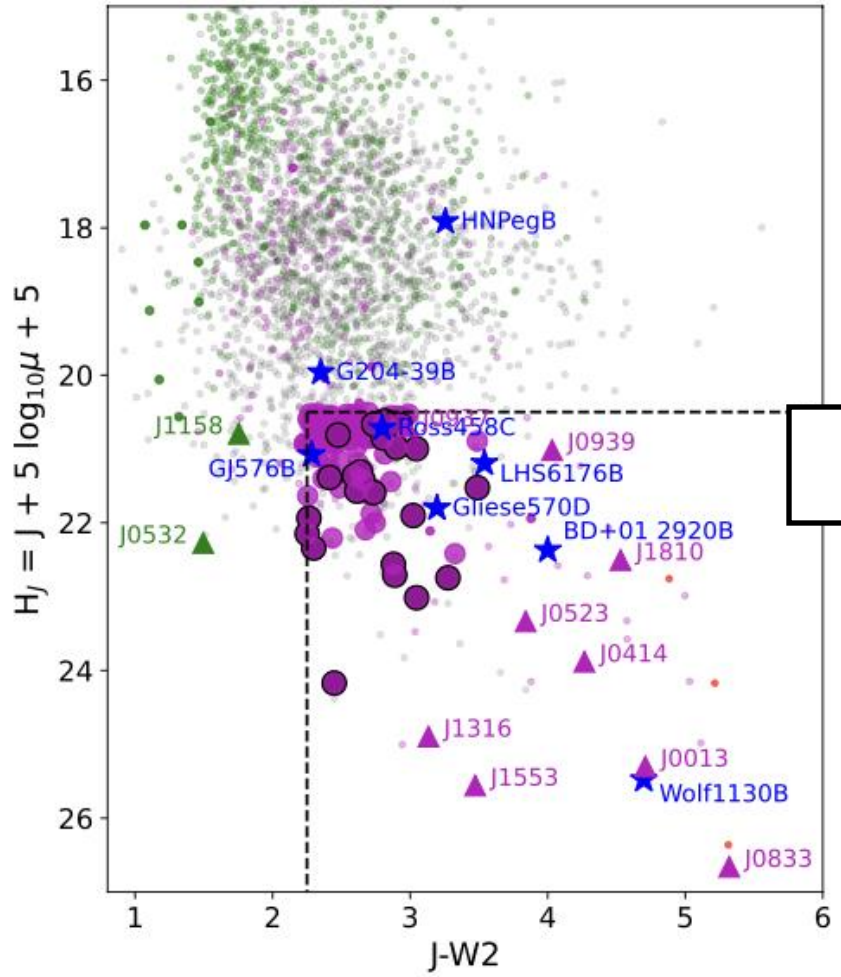

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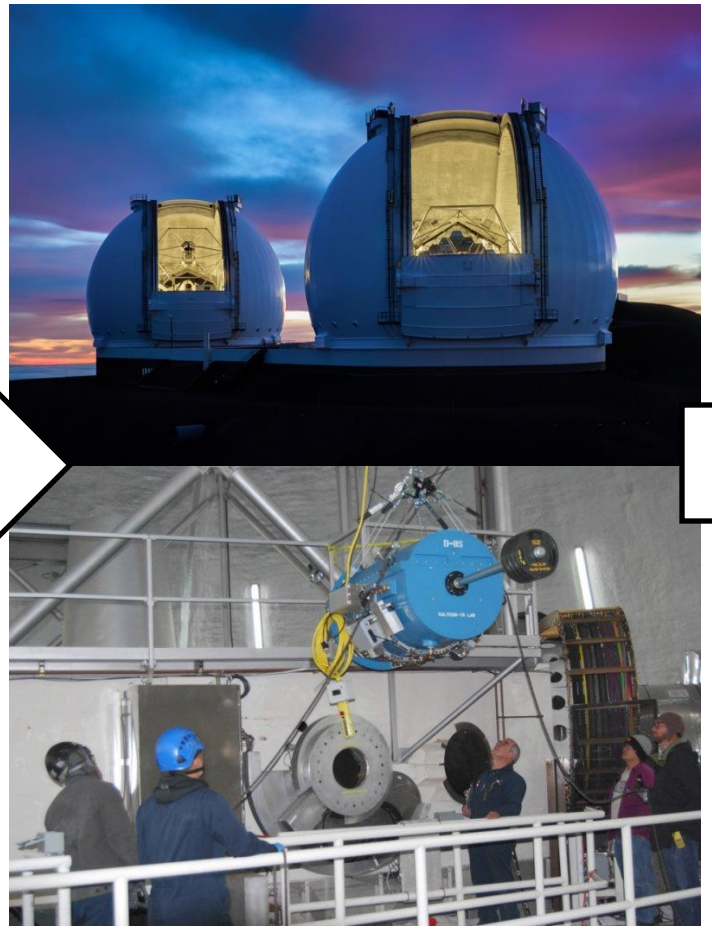

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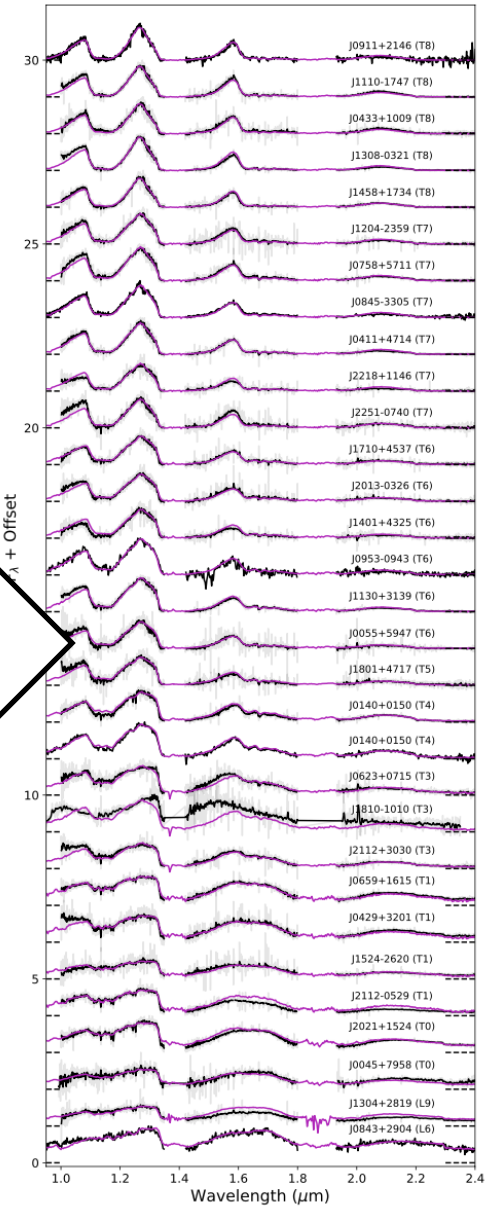
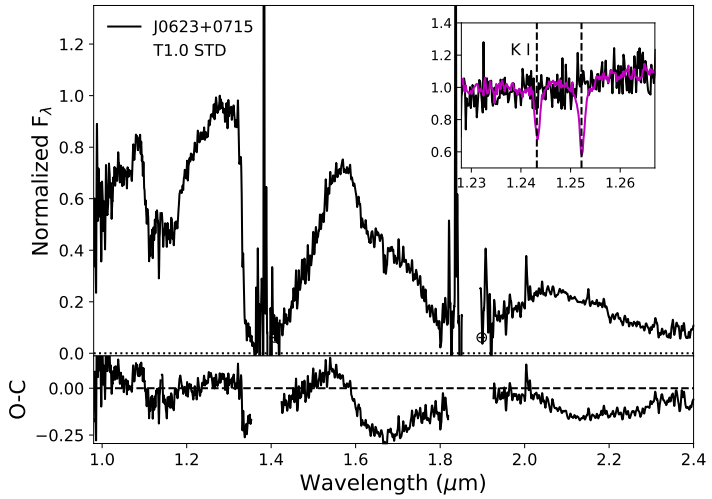


Lots o’ spectra

How do we know which are metal poor?

Criteria for being metal poor:

- Deviant from dwarf standards
- Weak/absent K I lines
- Low metallicity model fit
- Extreme UVW kinematics



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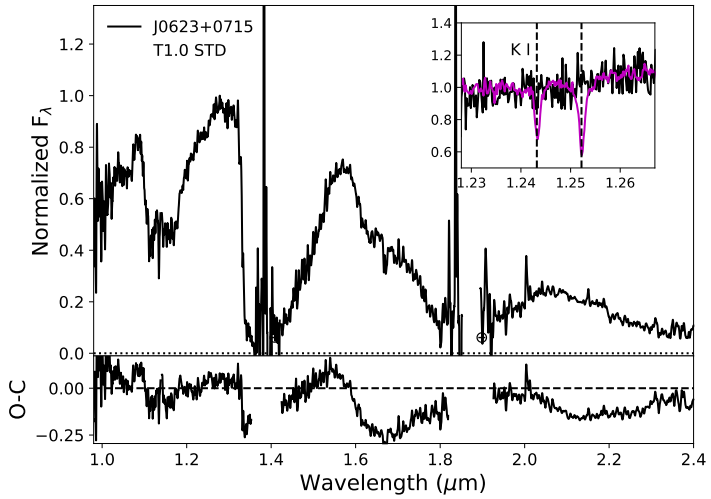

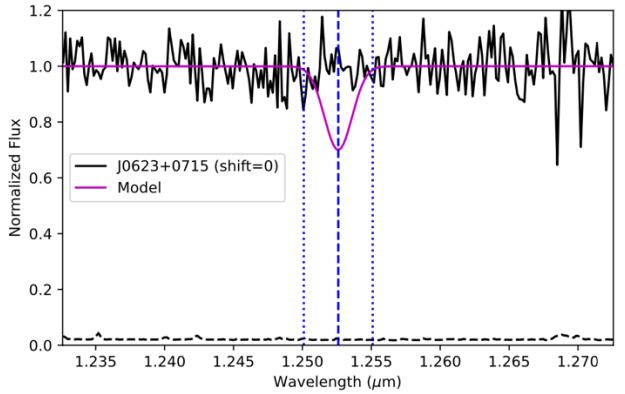

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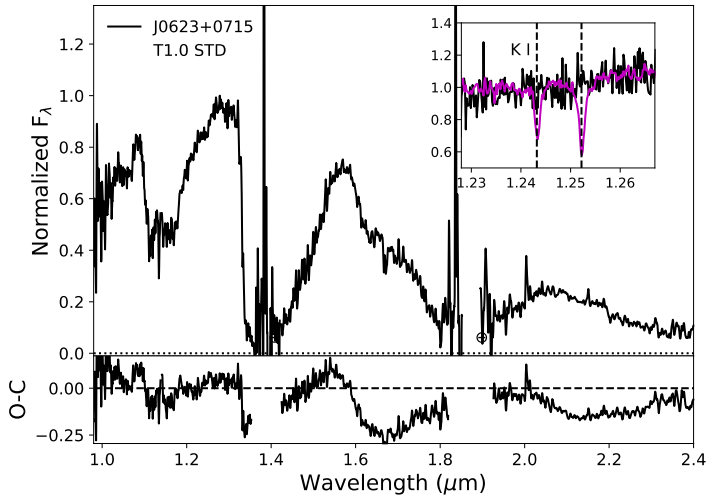

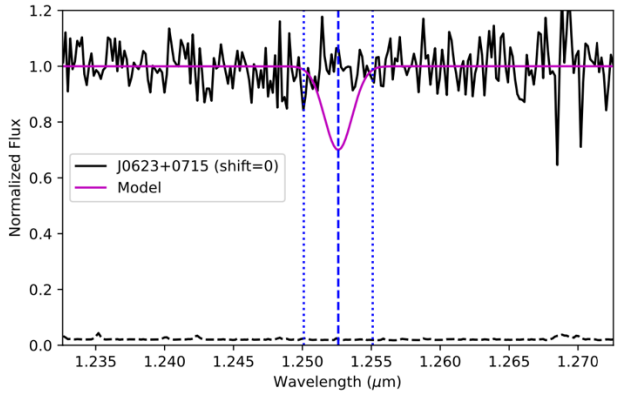

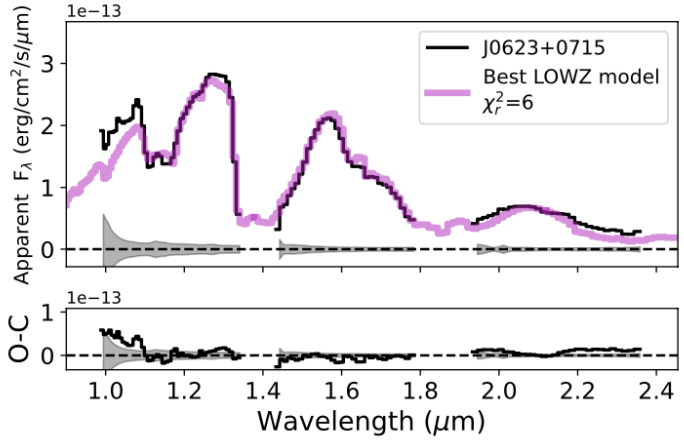

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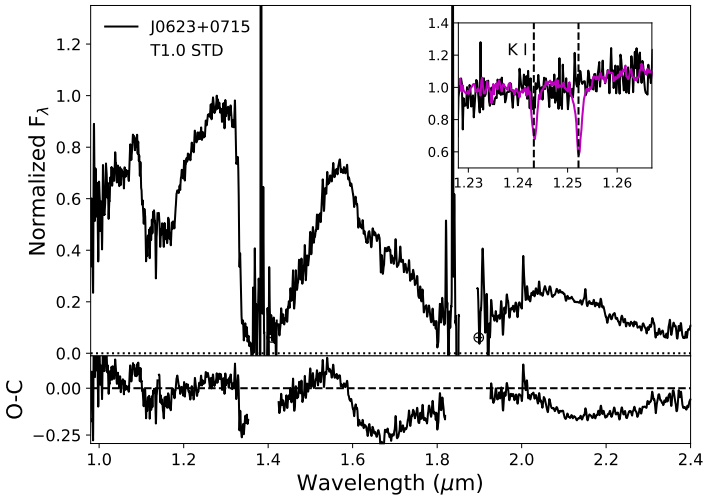
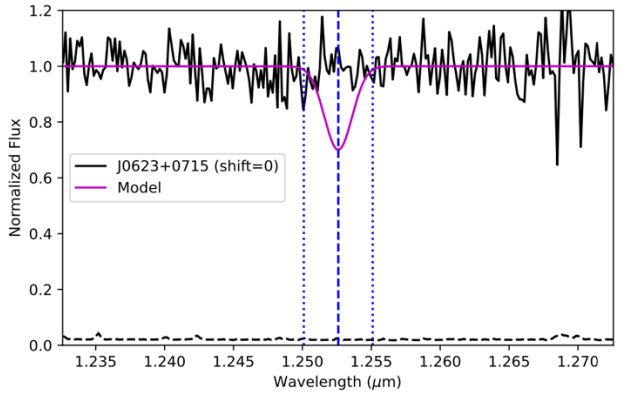
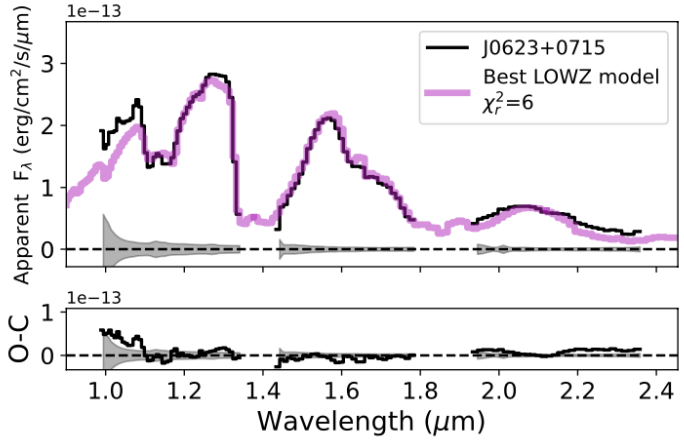
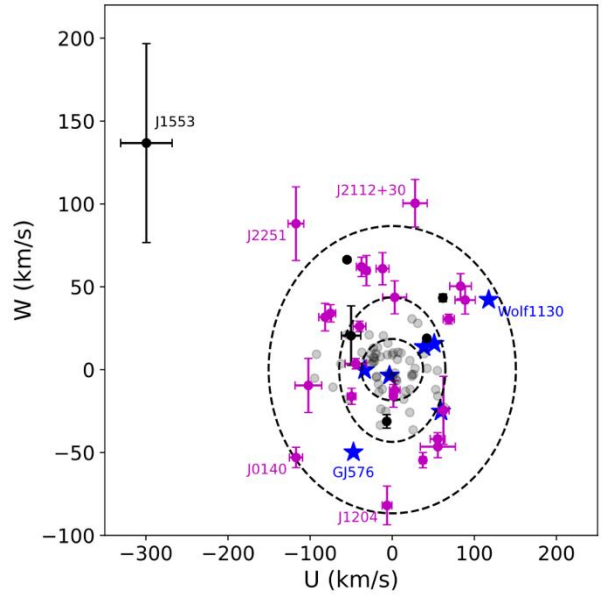
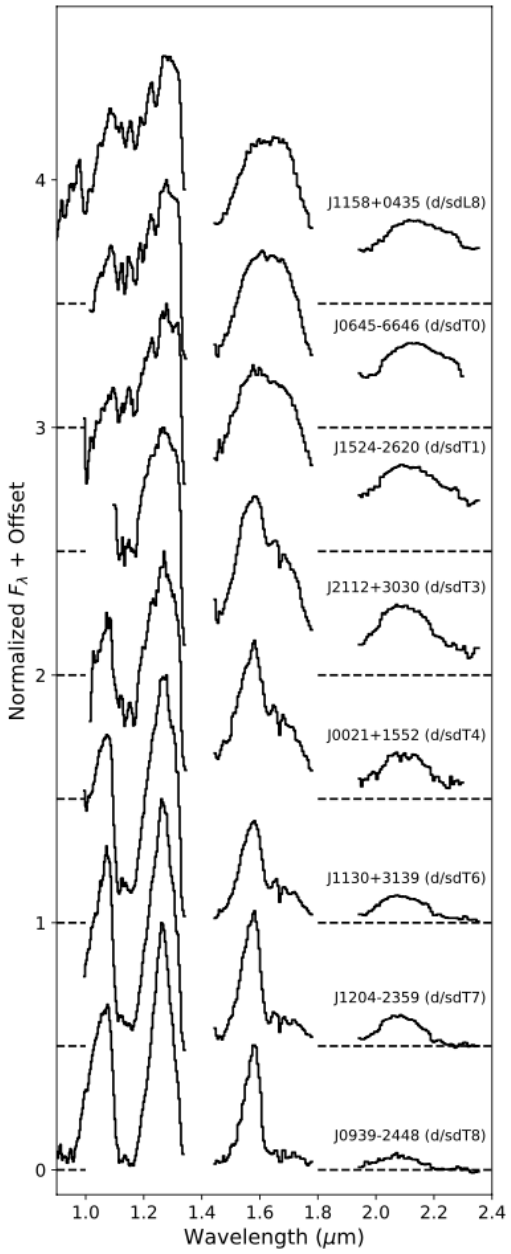


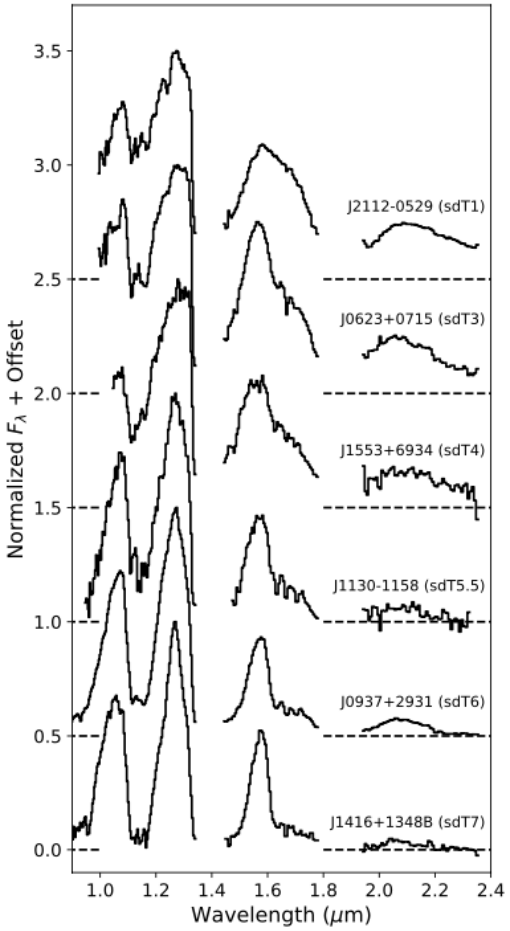


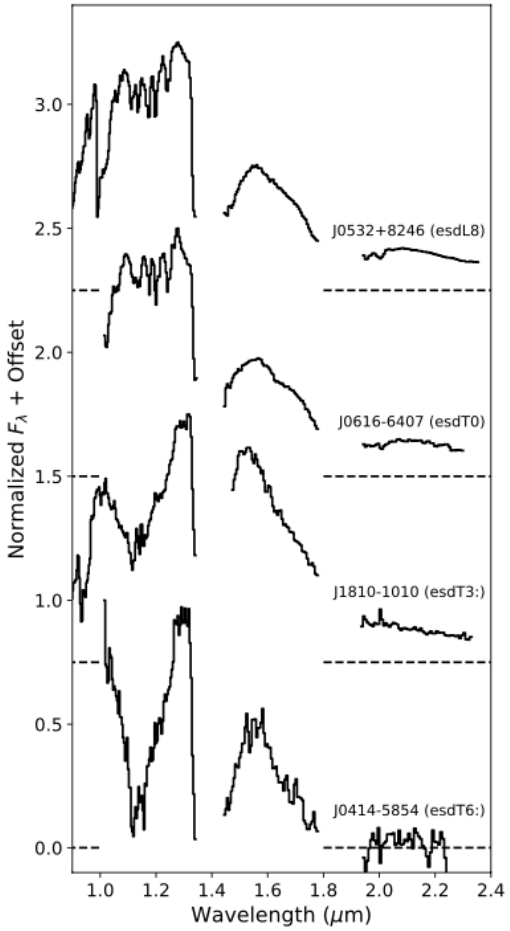




Spectral Standards and Metallicity Classes



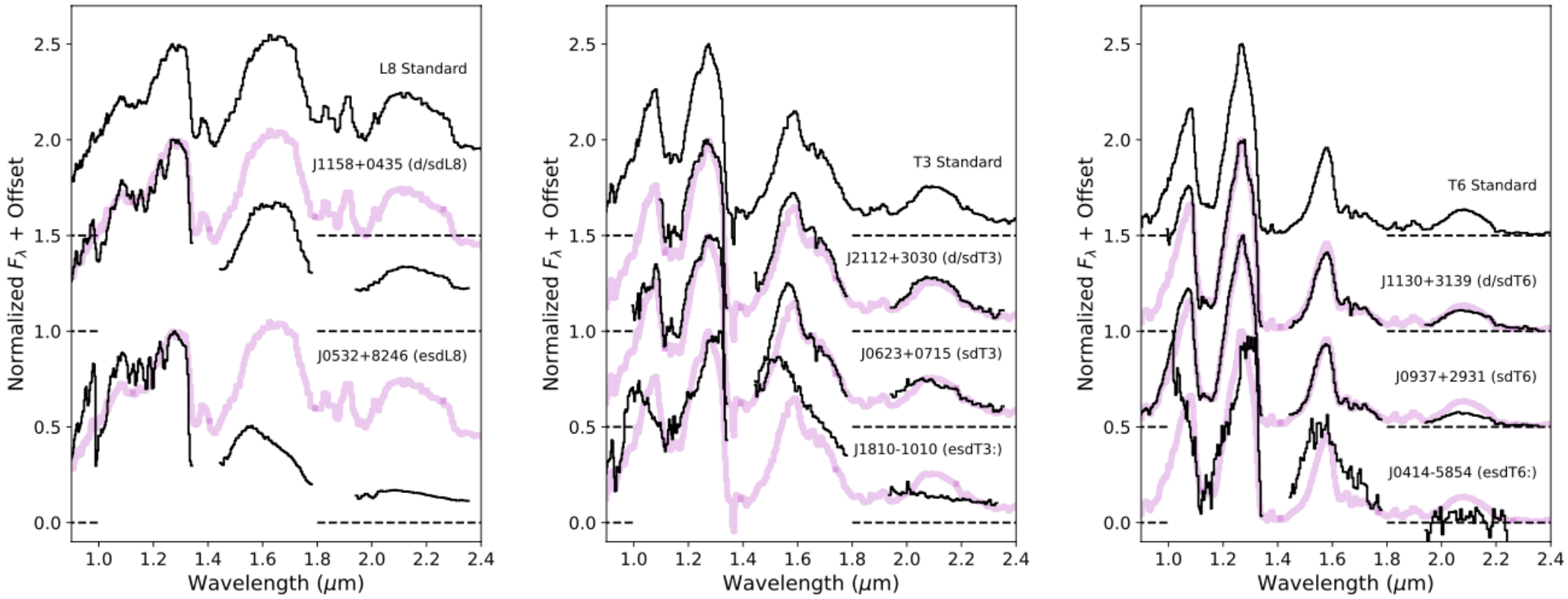




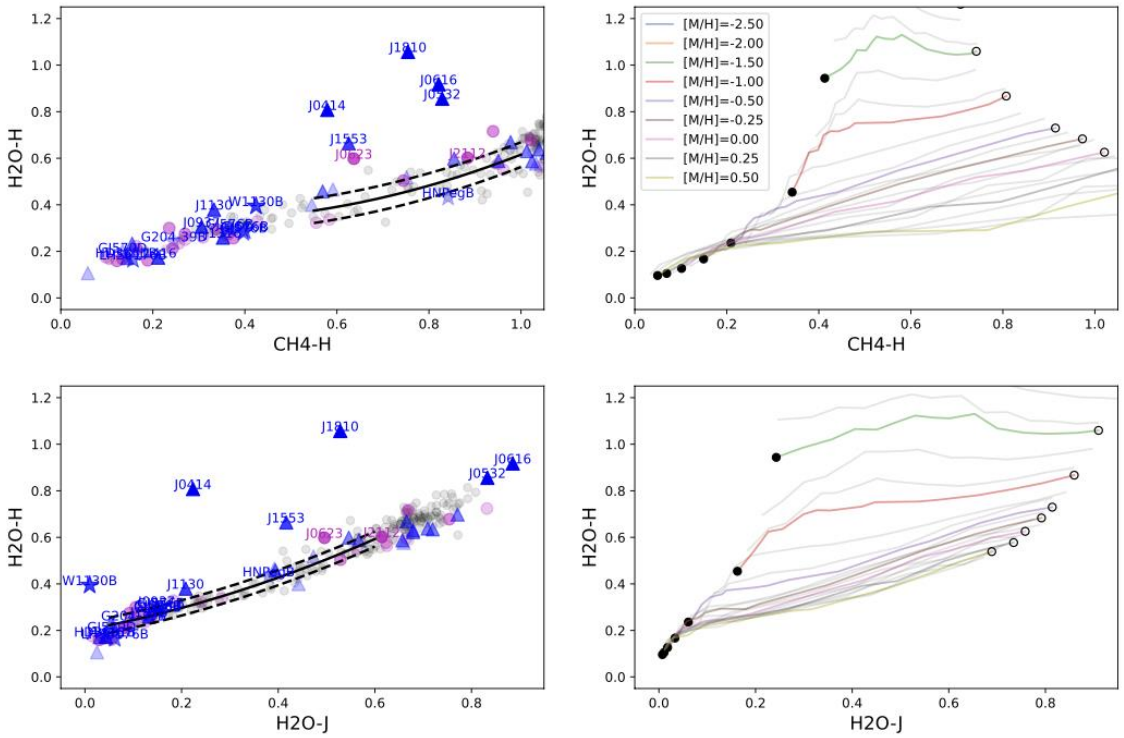
We define three subsolar metallicity classes for T dwarfs with partial spectral type coverage:

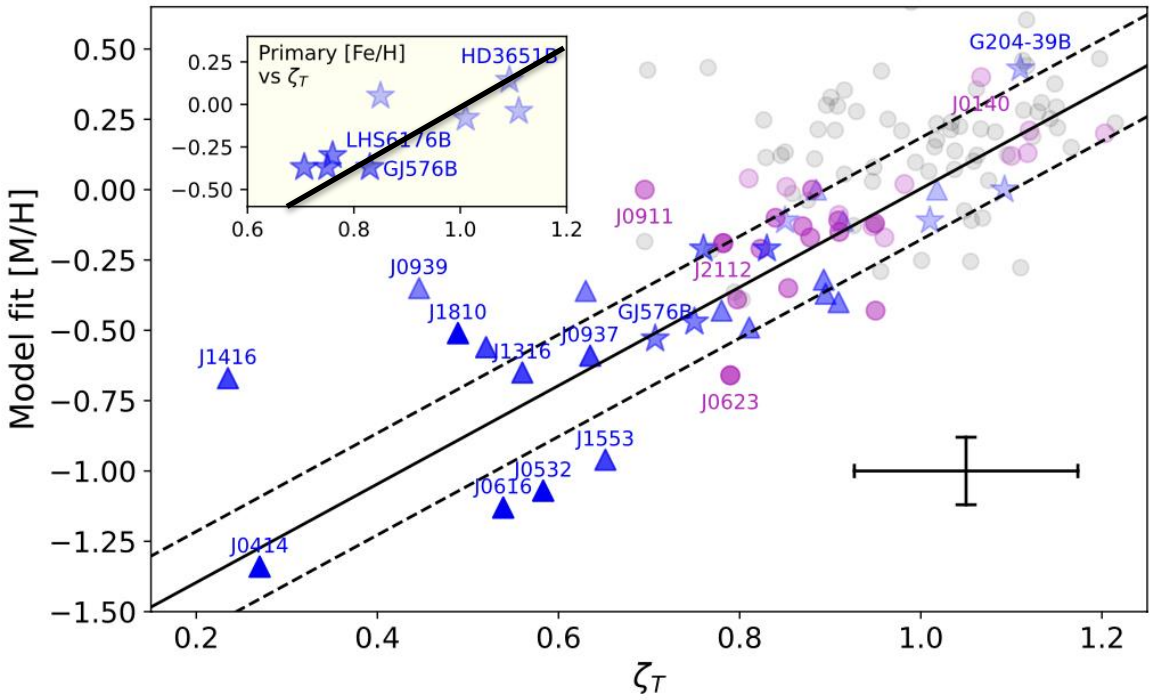
- d/sd: [M/H] = –0.29±0.15
- sd: [M/H] = –0.56±0.17
- esd: [M/H] = –1.12±0.11

Spectral Standards and Metallicity Classes



A Metallicity Index for T dwarfs

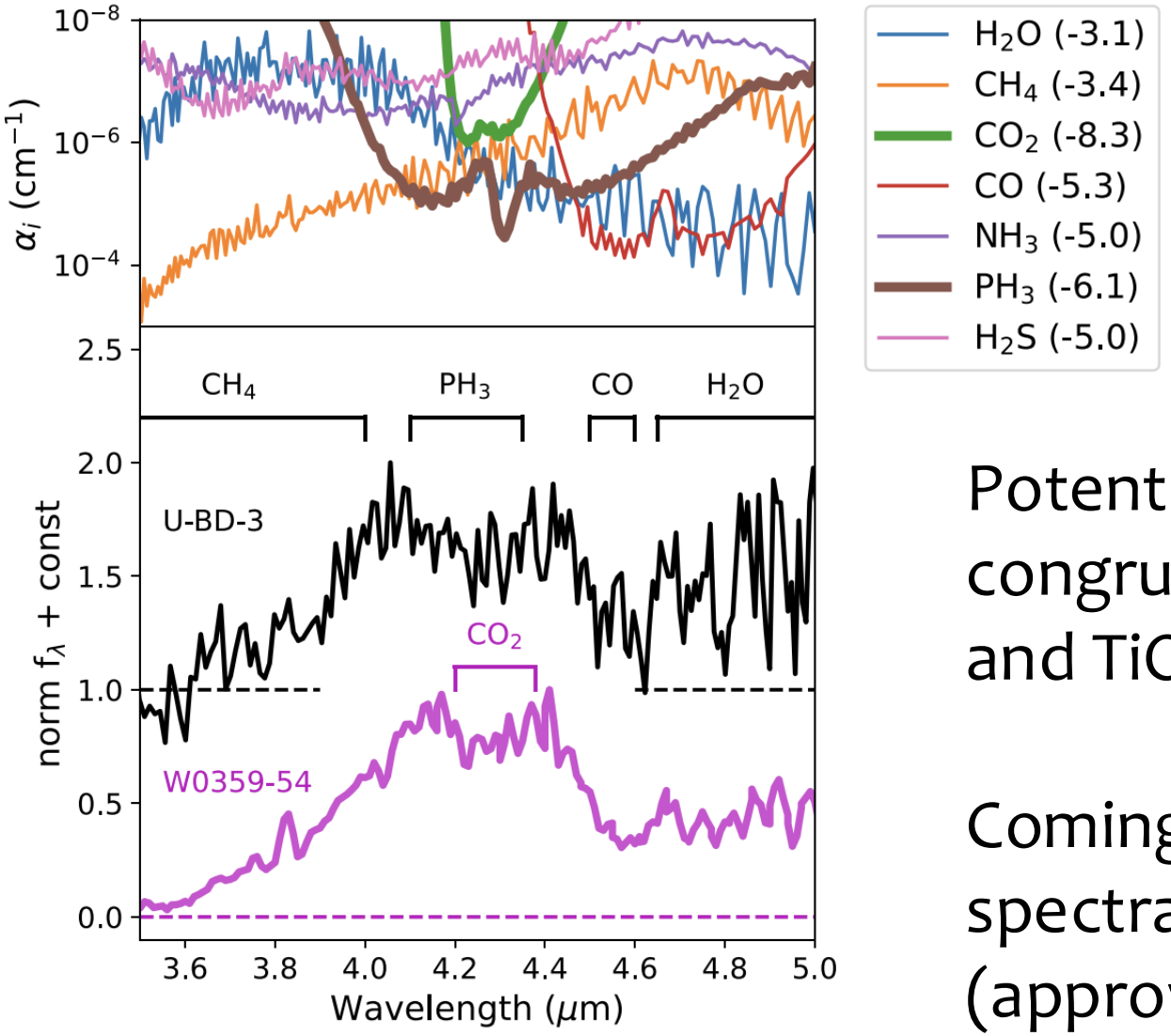




cf. ζ index for M dwarfs (Lepine et al. 2007)

More Work is Needed!

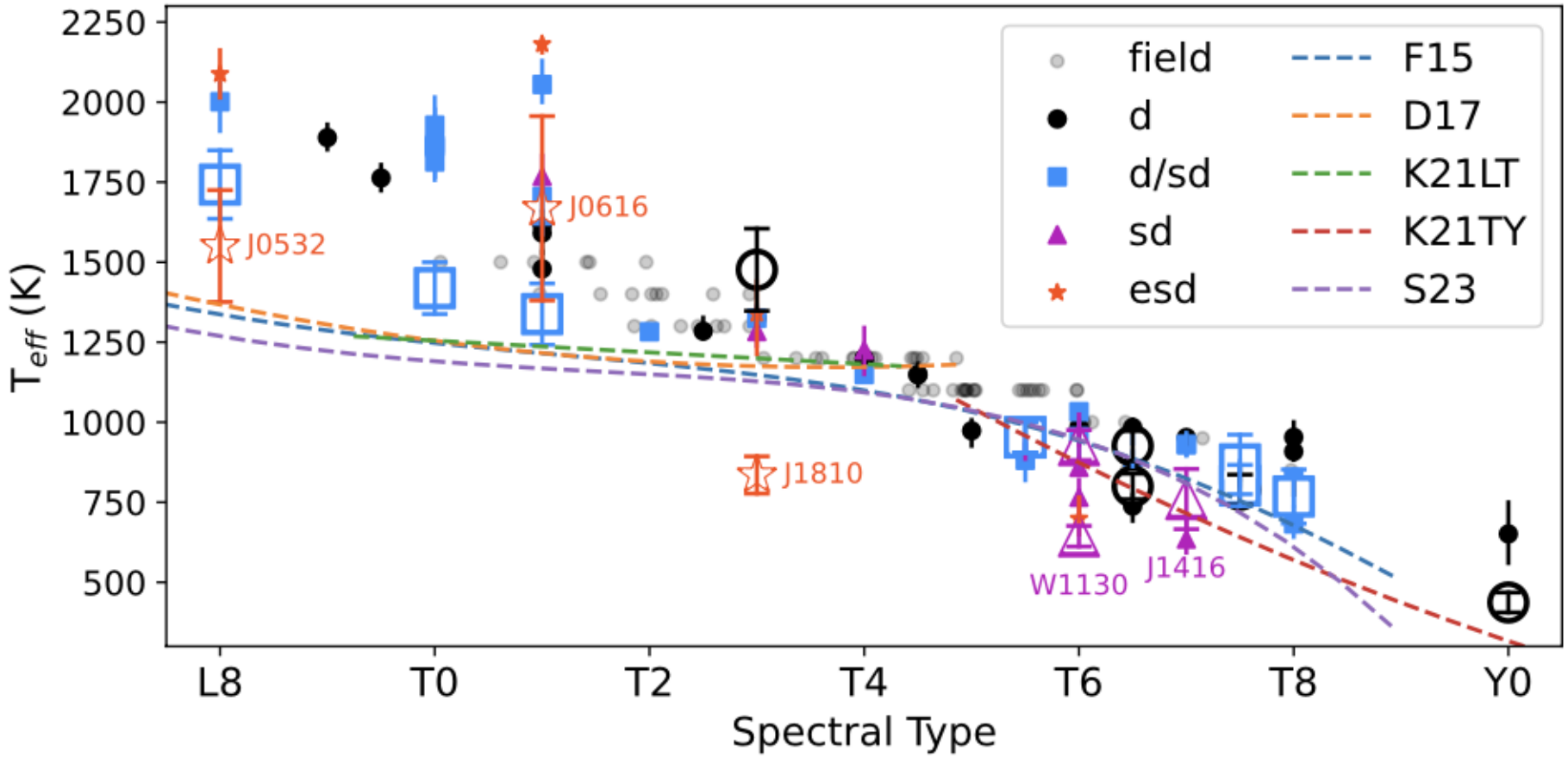
- More discoveries needed to fill in the sd & esd classes, and identify potential usd classes ([M/H] ≤ -2)
- "Standards require high observational characterization" ➔ broader spectral and photometric coverage, parallaxes
- M subdwarfs defined in optical, L subdwarfs defined in near-infrared, T subdwarfs defined in mid-infrared?
- Improve models and some chemical mysteries
- Next up: Y subdwarfs (the Accident; Kirkpatrick et al. 2021)



Why is Adam so obsessed with PH_3?

Potential metallicity signature congruent with TiO/CaH in M dwarfs and TiO/condensates in L dwarfs

Coming soon: JWST NIRSpec & MIRI spectra of local T subdwarfs (approved Cycle 3)


2250
2000
1750
1500
1250
1000
750
500
T_{eff} (K)
L8
T0
T2
T4
T6
T8
Y0
Spectral Type
field
d
d/sd
sd
esd
F15
D17
K21LT
K21TY
S23
J0532
J0616
J1810
W1130
J1416