The SpeX Prism Library Analysis Toolkit (SPLAT)

Tools for Characterizing Exoplanet Spectra

Adam J. Burgasser (UC San Diego)

Spectroscopy of Exoplanets 9 July 2018

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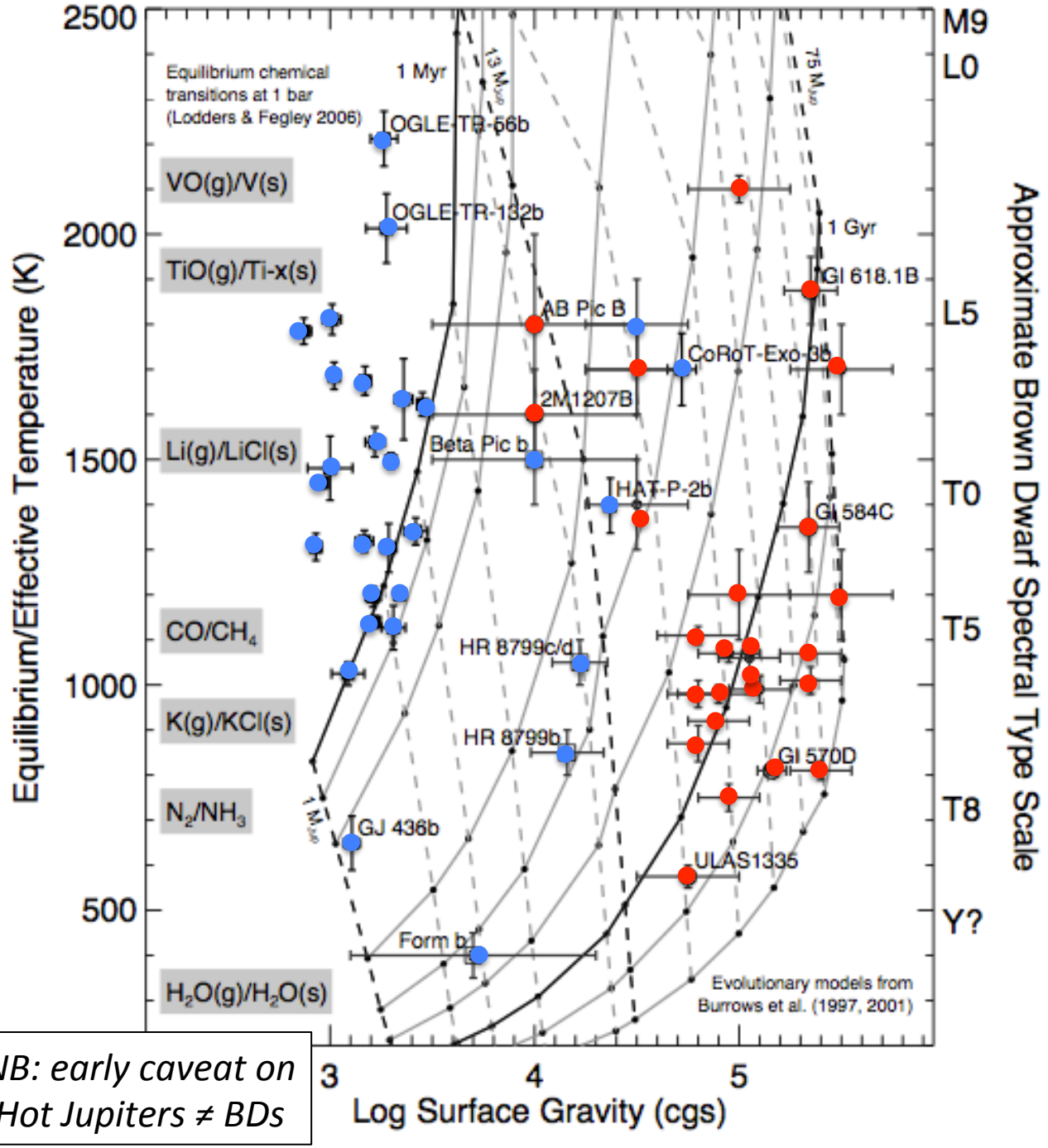


NB: early caveat on Hot Jupiters ≠ BDs

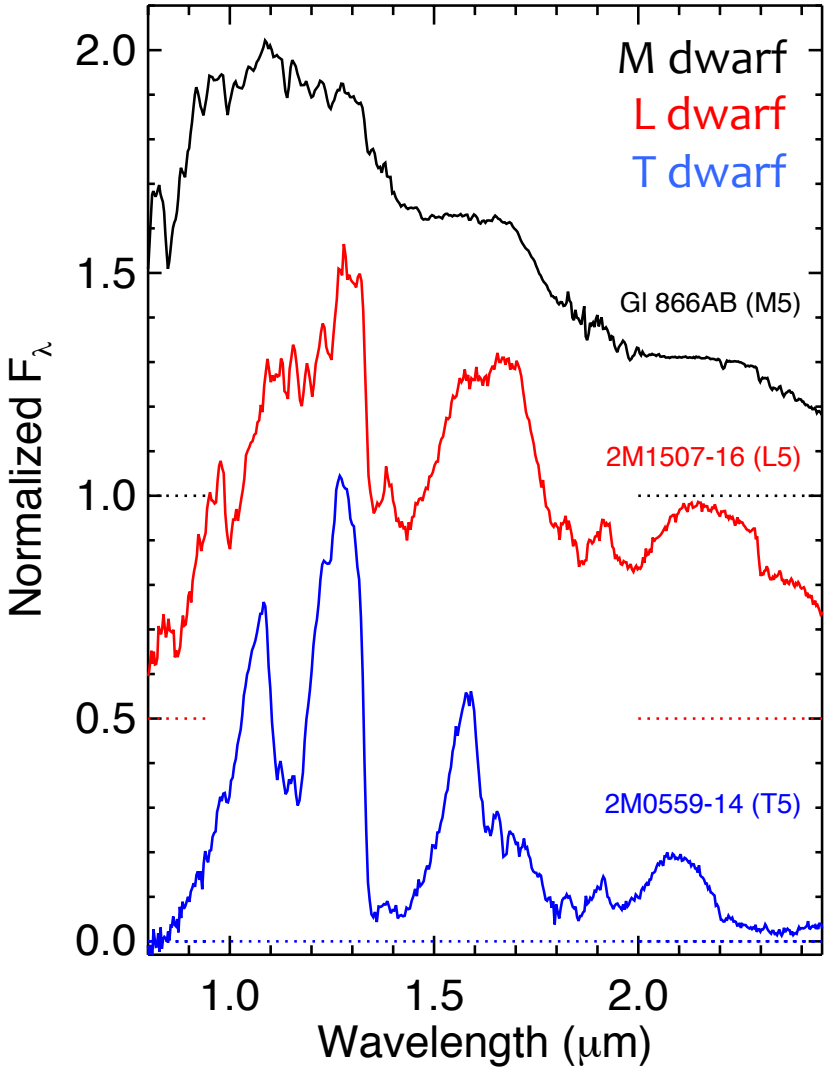
There is significant overlap in the physical properties of young brown dwarfs and massive exoplanets.

Burgasser (2009)

EGPs: Torres et al. (2008); Marois et al. (2008); Kalas et al. (2008); Lagrange et al. (2008)

BDs: Kirkpatrick et al. (2001); Wilson et al. (2001); Chauvin et al. (2005); Burgasser et al. (2006); Saumon et al. (2006); Mohanty et al. (2007); Burningham et al. (2008); Cushing et al. (2008)

The near-Infrared is an essential spectral window for studying brown dwarf & exoplanet spectra



Strong, distinct and broad molecular features & atomic lines => well-suited for low- (and high-) resolution spectroscopy

Key diagnostics of temperature, surface gravity, metallicity, cloud behaviors, multiplicity, etc. are apparent in NIR spectra

Both current (Keck/OSIRIS, HST/WFC3, GPI, SPHERE, P1640) and future (JWST, FINESSE, Ariel, Twinkle) spectroscopic capabilities focus on NIR region

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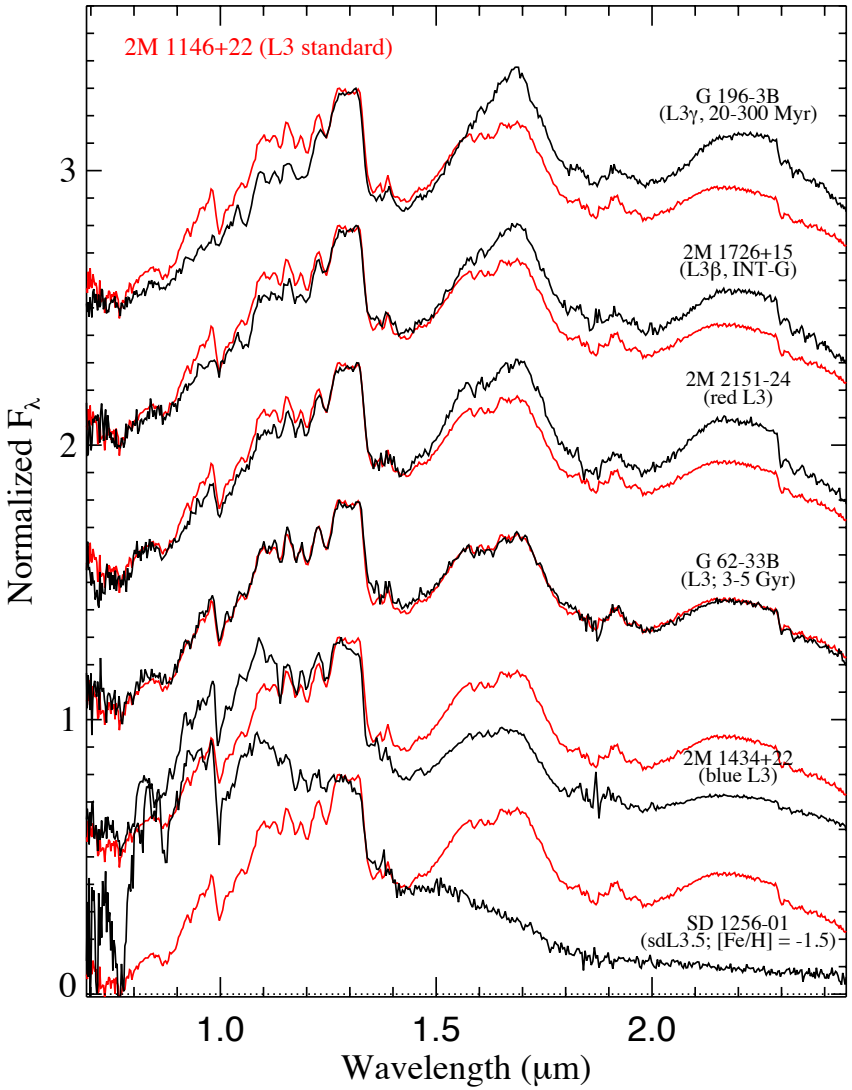

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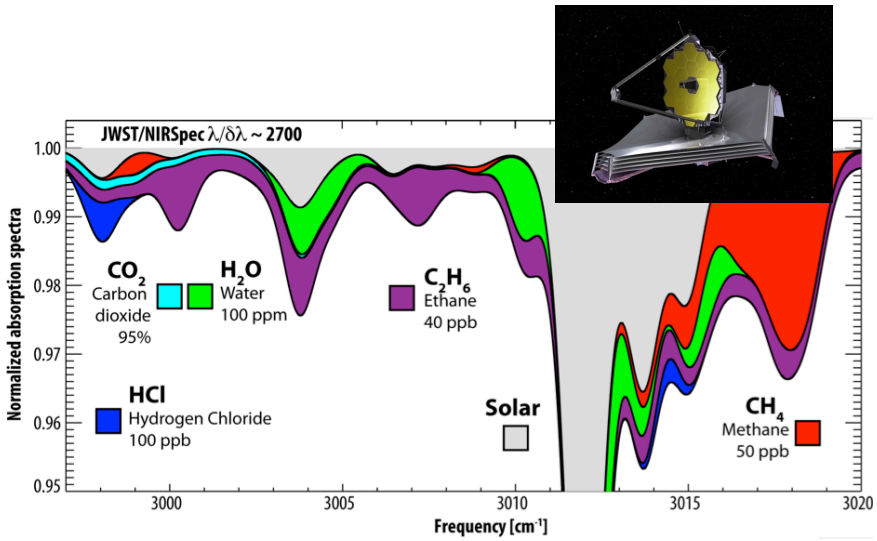

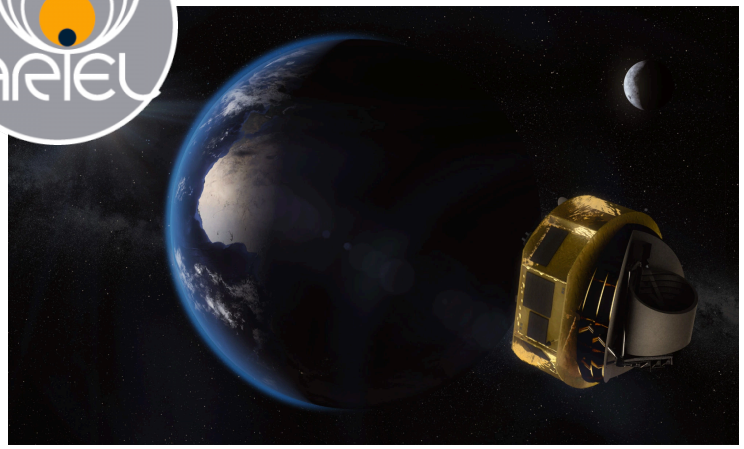

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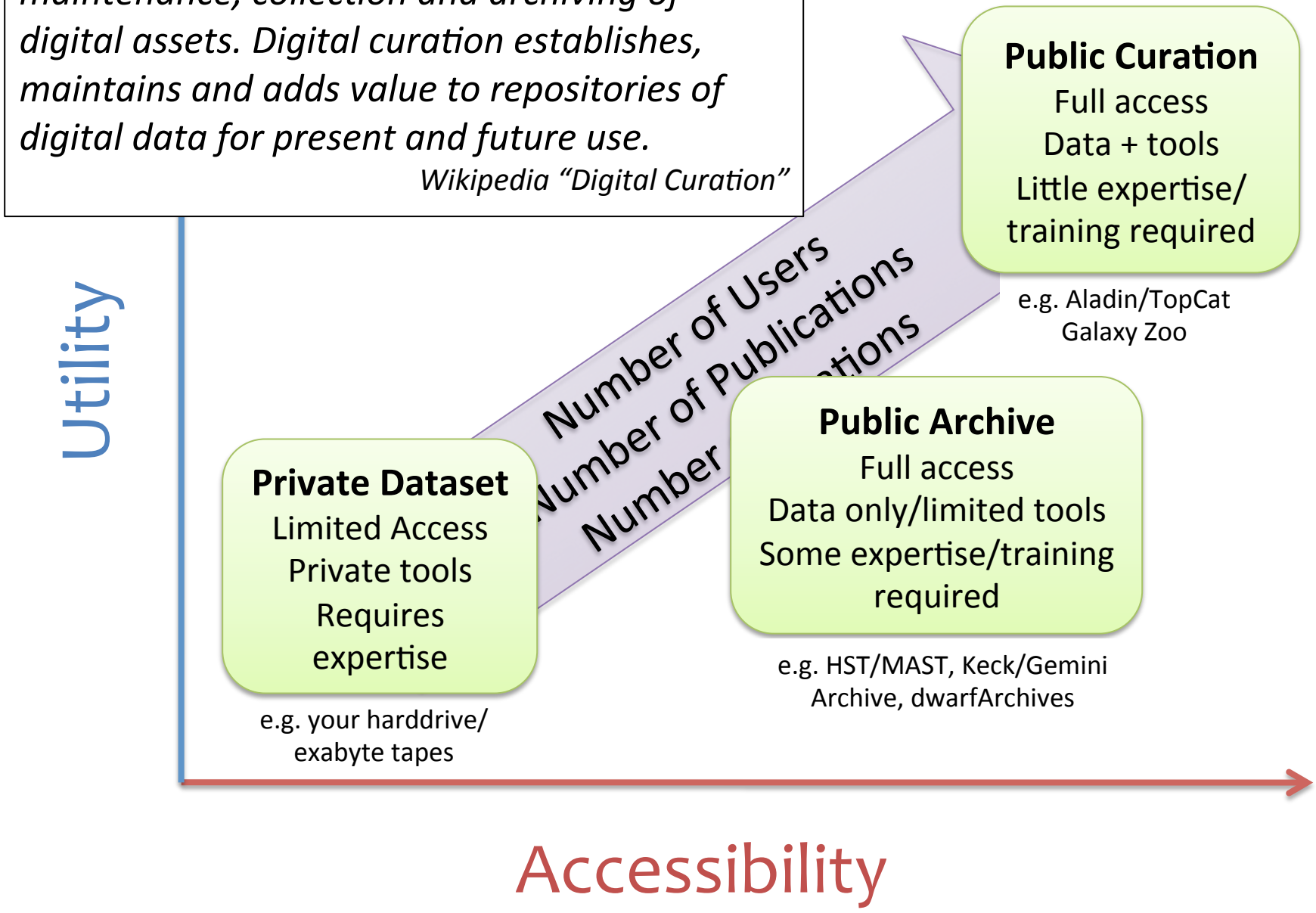
"Digital curation is the selection, preservation, maintenance, collection and archiving of digital assets. Digital curation establishes, maintains and adds value to repositories of digital data for present and future use.

Wikipedia "Digital Curation"



SPLAT is a **Digital Data Curation**

- **Spectral Data Archive**: >2000 publically-available low-resolution ($\lambda/\Delta\lambda \approx 100$) NIR (0.8-2.5 μm) spectra of low-temperature stars & brown dwarfs collected with the IRTF SpeX spectrograph
- **Spectral Analysis Tools**: >100 functions allowing spectral measurement & manipulation, visualization, comparison to models, contextual analysis, etc.
- **Additional Digital Assets**: 15 sets of spectral models; >100 filter profiles for spectrophotometry; photometric & astrometric database; tools for accessing Vizier, SIMBAD, NASA ADS; etc.

Download at https://github.com/aburgasser/splat/
Documentation at http://splat.physics.ucsd.edu

Innovations in open code development

astropy
A Community Python Library for Astronomy

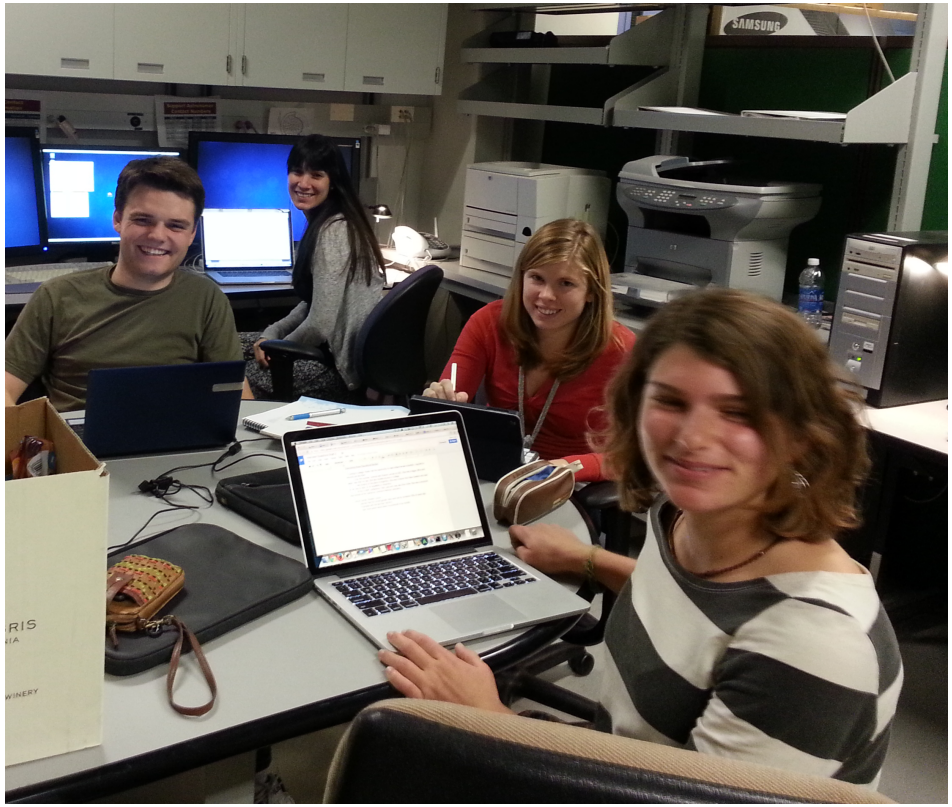
.astronomy

.dotastronomy hack session

AAS Hack Day

astropy/LSST coordination meeting

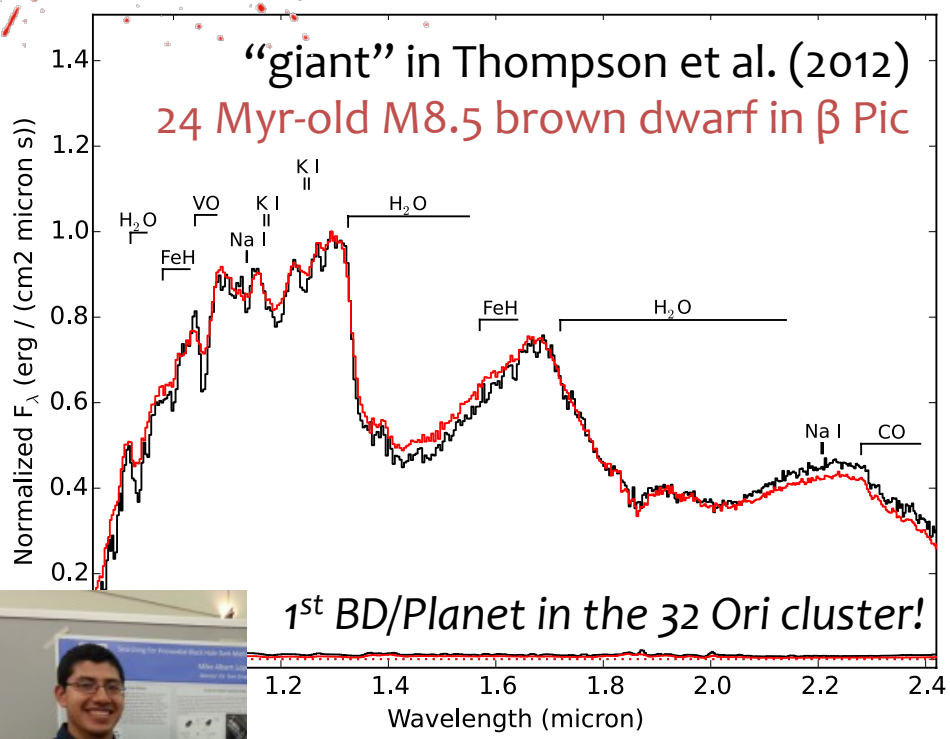
Student-centered design for student-led research

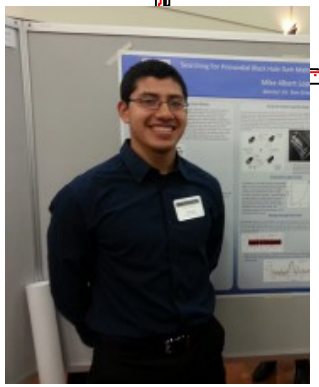


SPLAT-hack group in Feb 2014

The SPLAT code was developed in Python collaboratively by UCSD undergraduates in Physics, Engineering, Computer Science, Biological Science, & Arts/ Humanities through a series of 10-week challenge projects

SPLAT Science: Young Free-floating Planets



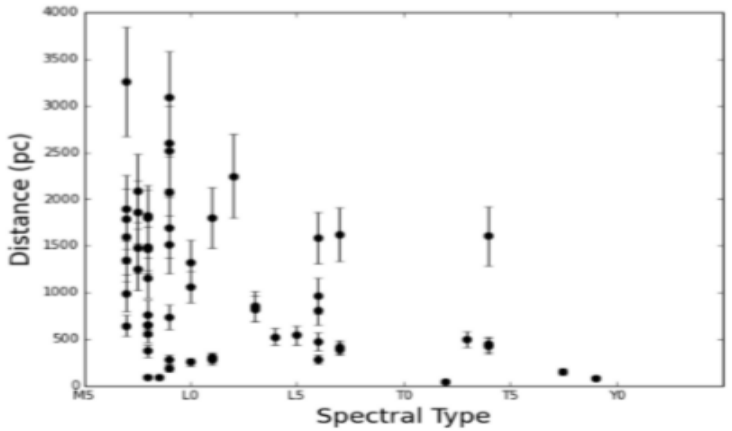


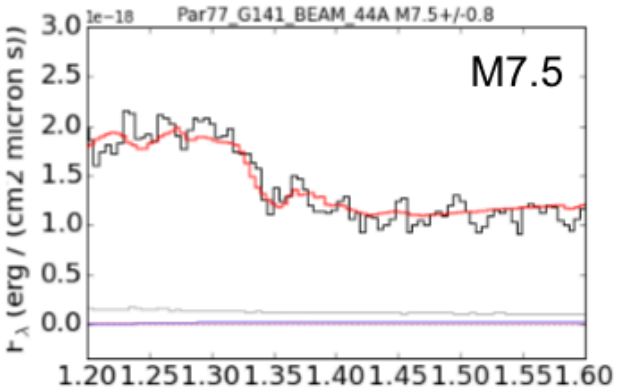
WISE 0528 was originally mis-classified as a giant star, but **Mike Lopez** determined that it is a young (24 Myr), **planetary-mass** (12 M_{Jup}) brown dwarf in the 32 Orionis cluster (~100 pc)

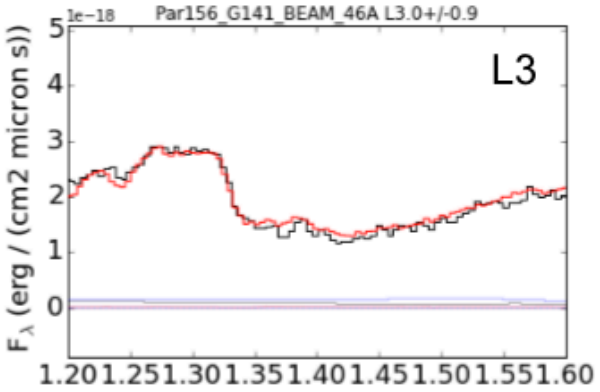
Burgasser, Lopez et al. (2016, ApJ, 820, 32)
Now graduate student at Ohio State University

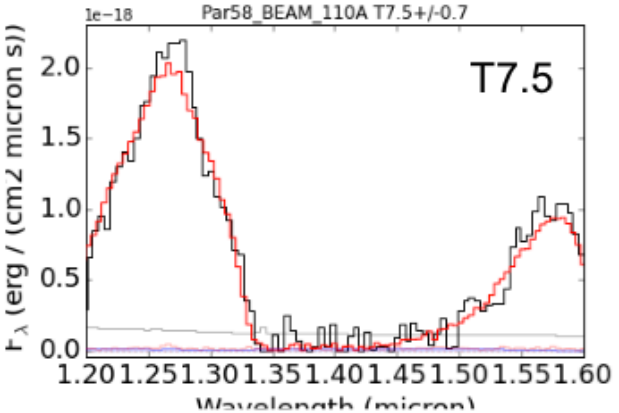
SPLAT Science: BD Probes of the Galaxy

Using deep WFC3 spectroscopy from the WISP & HST-3D Surveys, **Christian Aganze** is identifying and classifying MLT dwarfs on kiloparsec scales



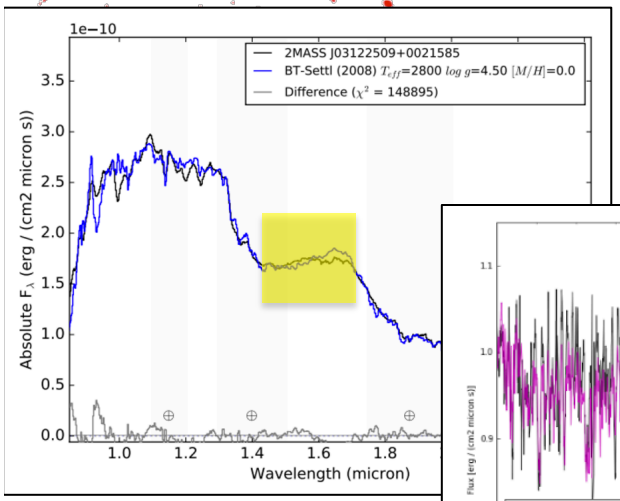


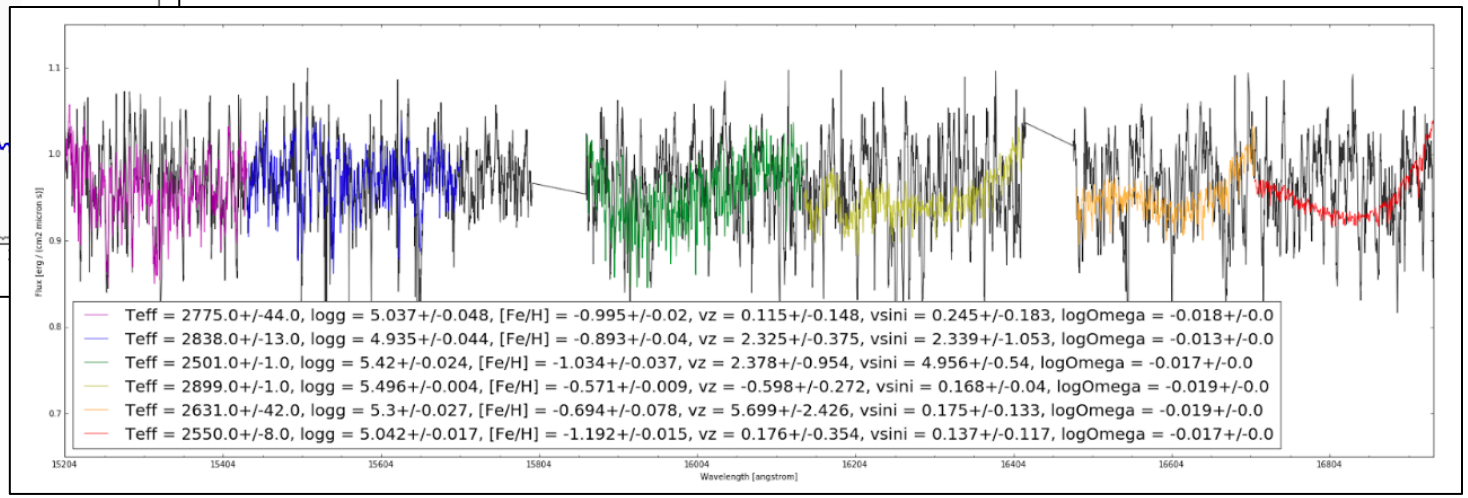




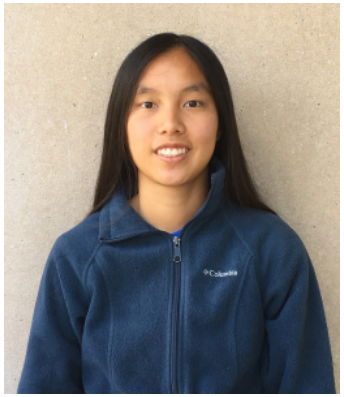
Aganze, Burgasser, et al. (2018, in prep)

SPLAT Science: RV and Abundance Analysis of High Resolution APOGEE data



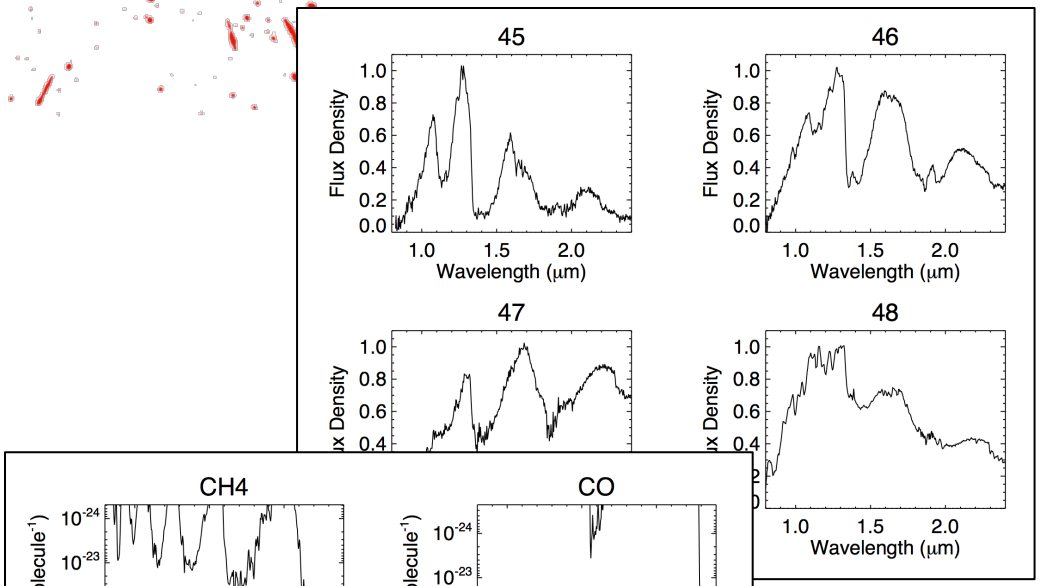


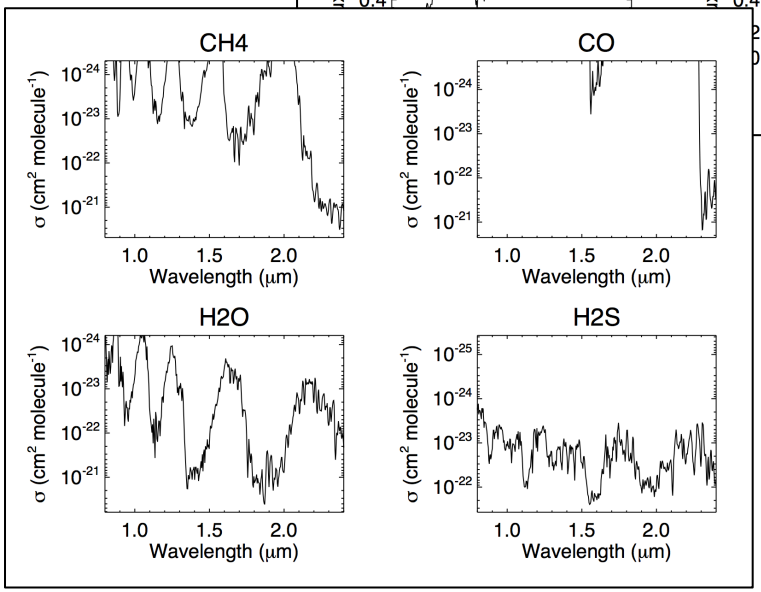
SPLAT tools can characterize both low and high-resolution spectra



Birky, Burgasser et al. (2018 in prep)

SPLAT Education: Spectral classification & opacity cards





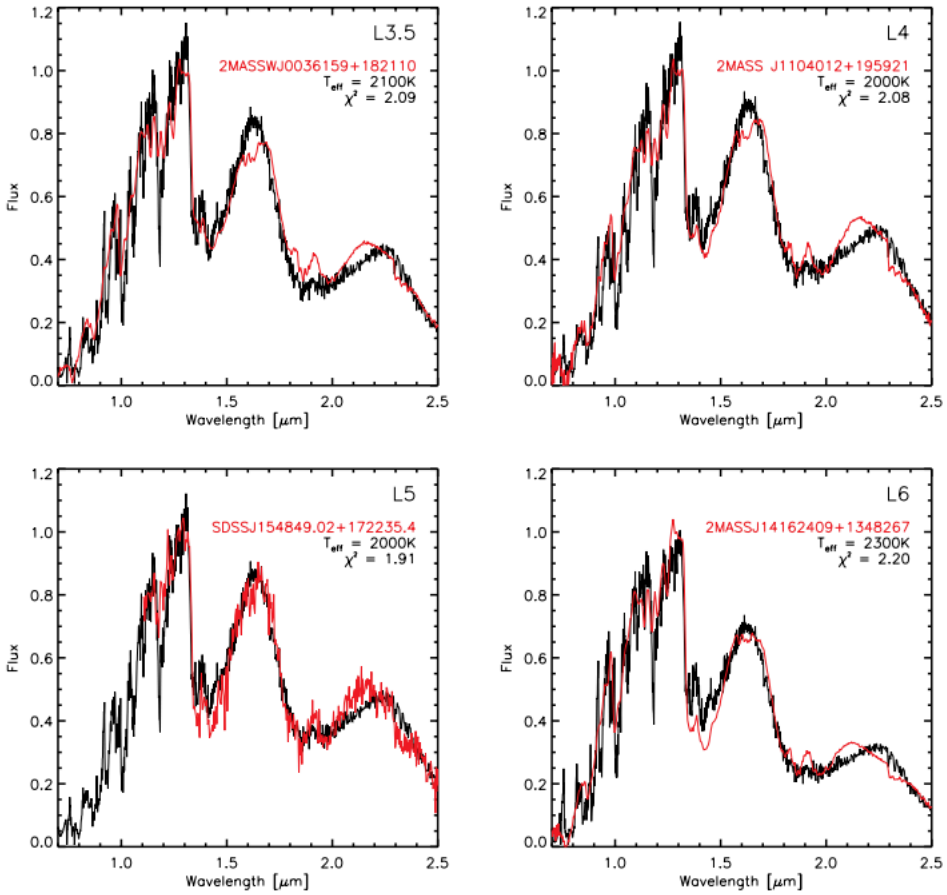
Spectra and opacity cards have been used to introduce students and the public to the process of stellar spectral classification and how we use spectra to infer composition and chemistry

SPLAT Art

Effervescent by Adrian Phillips and Natasha Banchik

more at http://www.projectplanetaria.org

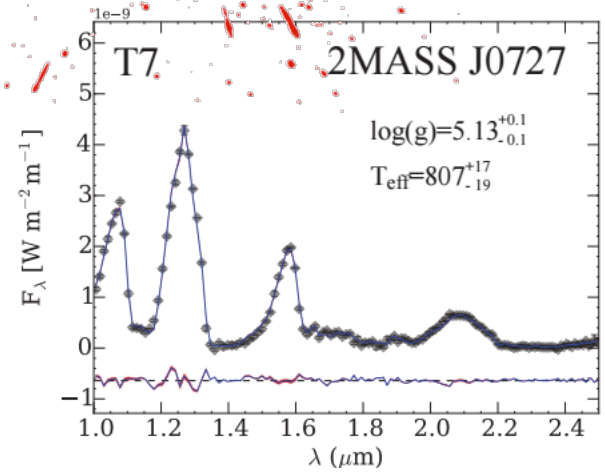
SPLAT ***Exoplanet*** Science: Atmosphere Model Development

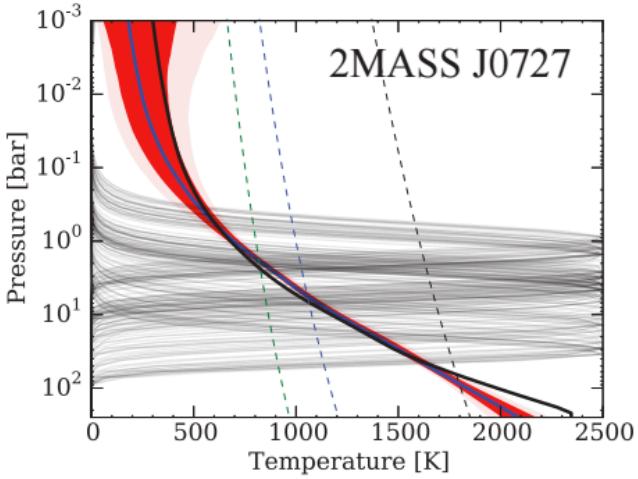


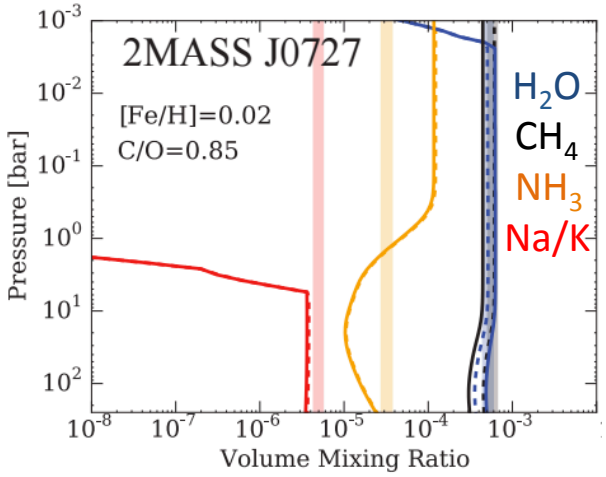
Juncher et al. (2017)

At the current state of the art for atmospheric modeling, low-resolution, well-calibrated spectra are ideal for examining **new opacity calculations, prescriptions for cloud opacity and retrieval methods**

SPLAT ***Exoplanet*** Science: Atmosphere Model Development



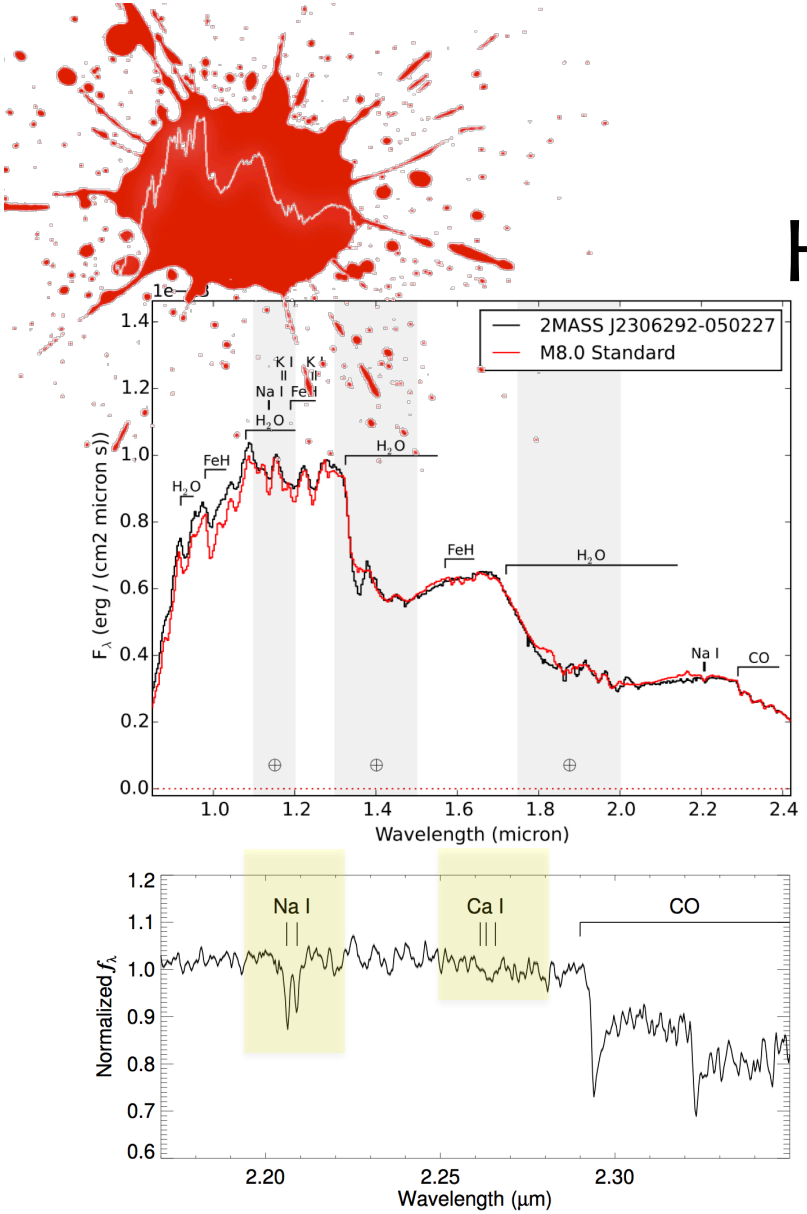




Line et al. (2017)

At the current state of the art for atmospheric modeling, low-resolution, well-calibrated spectra are ideal for examining **new opacity calculations, prescriptions for cloud opacity and retrieval methods**

SPLAT ***Exoplanet*** Science: Host Star Characterization

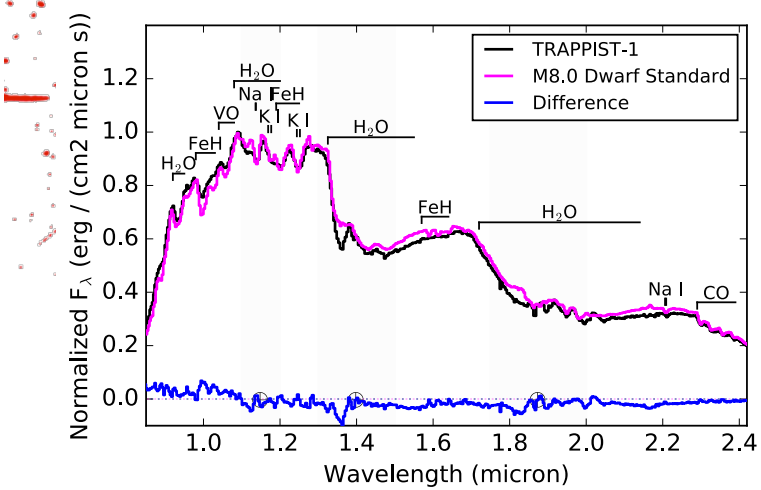


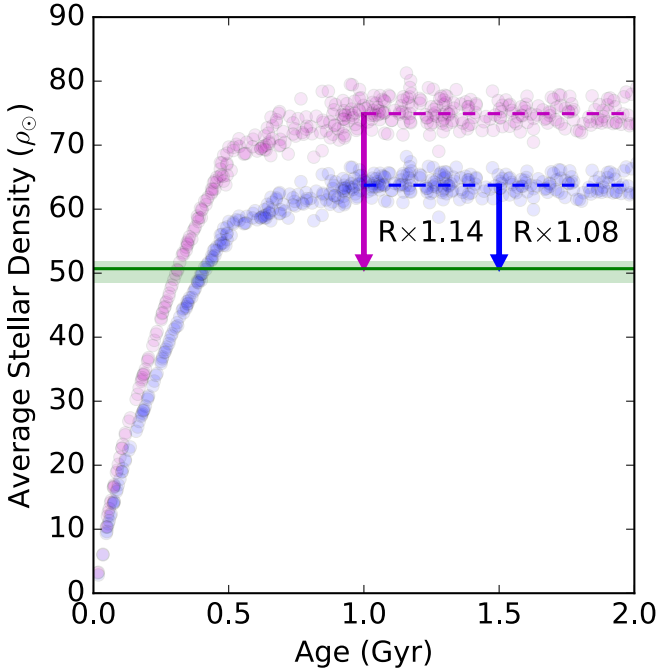
Gillion et al. (2016)

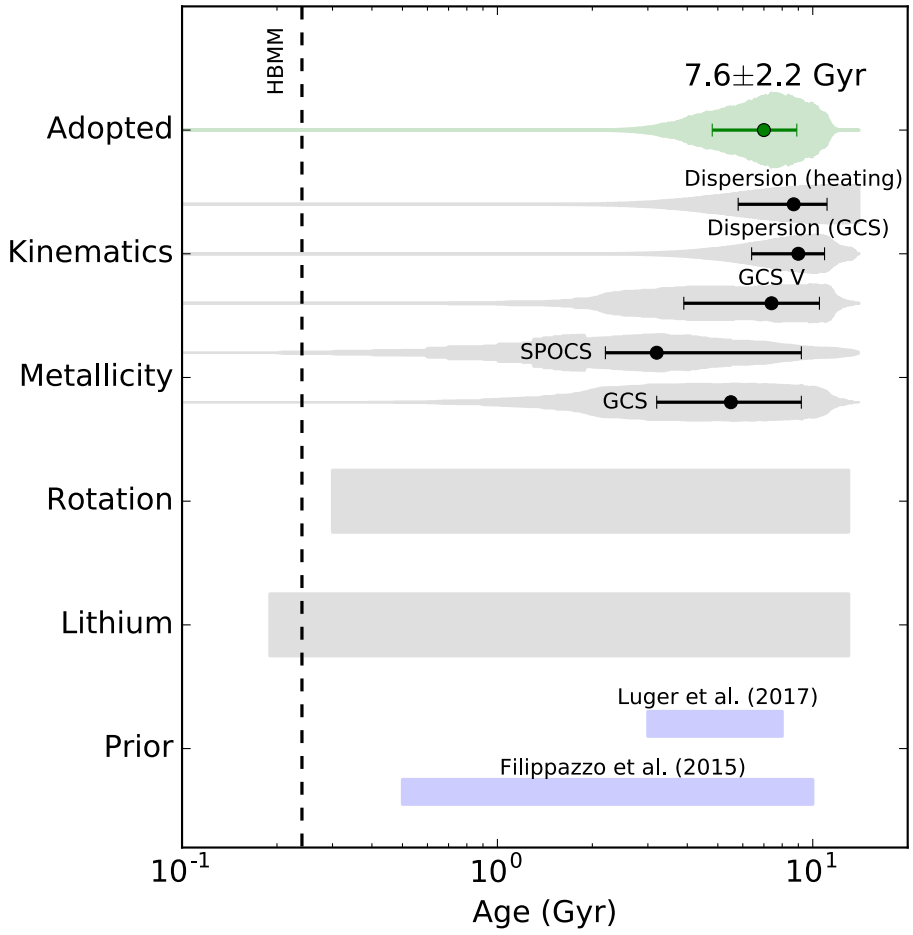
also Terrien et al. (2012, 2015), Newton et al. (2014)

SPLAT tools & empirical relations allow for the characterization of ultracool host stars to **terrestrial planets like TRAPPIST-1**

SPLAT ***Exoplanet*** Science: Host Star Characterization





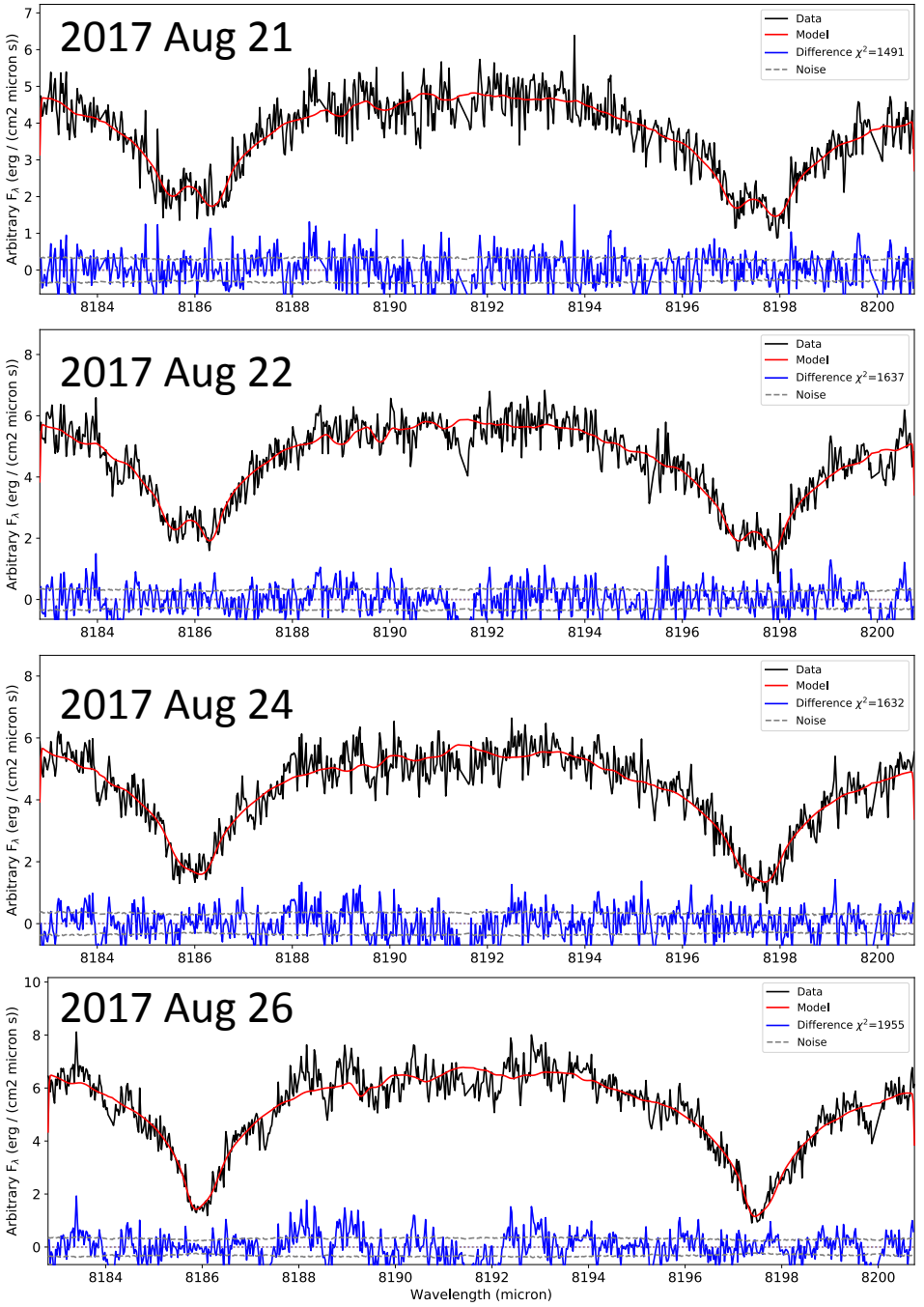


Burgasser & Mamajek (2017)

SPLAT *Exoplanet* Science: Host Star RVs

Forward-modeling tools have now been developed to model low-temperature, single- and double-lined RV variables, useful for binaries and (potentially) exoplanet companions to ultracool dwarfs

Triaud, Burgasser et al. (2018, in prep)

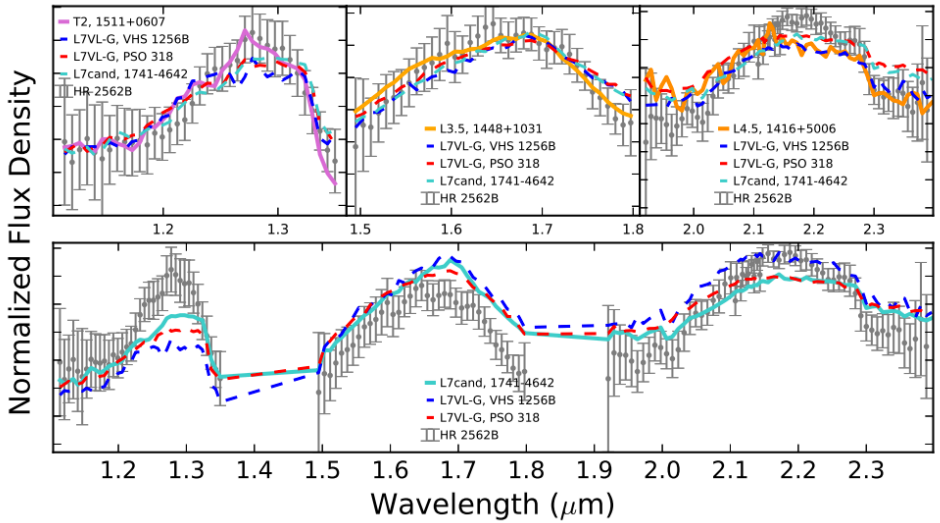


SPLAT ***Exoplanet*** Science: Directly Detected Atmospheres

Low-resolution BD spectra are ideal templates for **characterizing exoplanet photometry and spectrophotometry**

SpeX resolution well-matched to

- HST/WFC3 ($\lambda/\Delta\lambda \approx 130$-$210$)
- Project 1640 ($\lambda/\Delta\lambda \approx 50$)
- **GPI ($\lambda/\Delta\lambda \approx 30$-$80$)**
- VLT/SPHERE ($\lambda/\Delta\lambda \approx 30$-$50$)
- JWST/NIRSPEC ($\lambda/\Delta\lambda \approx 100$)
- Ariel ($\lambda/\Delta\lambda \approx 100$)
- Twinkle ($\lambda/\Delta\lambda \approx 300$)



Konopacky et al. (2016, ApJ, 829, L4)

Requests to the community

Observers: please make your published spectral data publically available (cf. Exeter HST: https://bd-server.astro.ex.ac.uk/exoplanets)

Theorists: please make your published spectral models and pressure-temperature profiles publically available (cf. France Allard's page at http://perso.ens-lyon.fr/france.allard)

Opacitists: please make cross-section *spectra* publically available in forms observers can easily use (happy about HAPI!)

Instrumentalists: please make your filter profiles publically available (cf. Spanish Virtual Observatory), and observers use with care!

Let's have proper community tests of spectral models vs. spectral data (cf. Helling et al. 2008; but only compares models to models)

Exoplanet transmission spectra data

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55_Cnc_e
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GJ_3470
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Atmospheric Library of Far Away Worlds

Transmission Spectra and Chemistry Data

Please see the paper below and Readme file for more details.

Reference

A library of ATMO forward model transmission spectra for hot Jupiter exoplanets
Jayesh M. Goyal, Nathan Mayne, David K. Sing, Benjamin Drummond, Pascal Tremblin, David S. Amundsen, Thomas Evans, Aarynn L. Carter, Jessica Spake, Isabelle Baraffe, Nikolay Nikolov, James Manners, Gilles Chabrier and Eric Hebrard

Click on the header of any numeric column to sort by that column value or

Enable filtering and sorting

System	Tstar (K)	[Fe/H]star	Mstar (Msun)	Rstar (Rsun)	loggstar (m/s2)	a (AU)	Mp (Mjup)	Rp (Rjup)	gp (m/s2)	Teqp (K)	Vmag	Discovery Paper	Updated Reference
55-Cnc-e	5196	0.31	0.91	0.94	4.43	0.02	0.03	0.17	21.4	2349	5.95	Winn et al. 2011aa	Demory et al. 2016aa
GJ-0436	3416	-0.03	0.51	0.46	4.83	0.03	0.08	0.37	13	669	10.68	Gillon et al. 2007aa	Lanotte et al. 2014aa
GJ-1214	3026	0.39	0.15	0.22	4.94	0.01	0.02	0.25	7.6	547	14.67	Charbonneau et al. 2009aa	Harpse et al. 2013aa
GJ-3470	3652	0.17	0.51	0.48	4.78	0.04	0.04	0.35	6.8	604	12.27	Bonfils et al. 2012aa	Biddle et al. 2014aa
HAT-P-01	5975	0.13	1.15	1.17	4.36	0.06	0.53	1.32	7.46	1322	10.4	Bakos et al. 2007aa	Nikolov et al. 2014aa

Cross section data for $^{52}Cr^{1}H$

Reminder: the cross sections provided by this page are calculated at **zero-pressure** (*i.e.* Doppler-broadened lines only). If you enter your email address below it will only be used to inform you of fixes to the service in case it fails. Alternatively, please email christian.hill@ucl.ac.uk.

The default format of the .sigma data file is a single column of cross section points (in cm^2/molec), one for each wavenumber bin selected, starting at ν_{min} and spaced by $\Delta\nu$. Select two-column output below if you want each cross section point preceded explicitly by the wavenumber at the centre of the bin it applies to.

$\Delta\nu$:

ν_{min} (0 - 15000 cm^{-1}):

ν_{max} (0 - 15000 cm^{-1}):

T (100 - 3000 K):

Two-column output: ν and σ:

Submit

Thank you EXOMOL!

Online absorption cross section service: this cross section has been generated from data in the University of Waterloo Diatomic Database of P. F. Bernath [Burrows *et al.* (2005)] for the ExoMol project [Tennyson and

What do you want SPLAT to do for you?

What data would benefit your work?

What analysis tools do you need?

What ancillary data do you need?

How can we improve SPLAT's functionality to make it highly user-friendly (esp. for students)?

Download at https://github.com/aburgasser/splat/
Documentation at http://splat.physics.ucsd.edu