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Brown Dwarfs with Spitzer - an IRS/IRAC Partnership

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Talk Outline

- IRS and IRAC Instrument Synergy
- A recent example
- Pictures!

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IRS Dim Suns Team

- Jim Houck – IRS PI
- Thomas Roellig – Dim Suns Team Lead
- Mike Cushing
- Jeff Van Cleve
- Greg Sloan
- Sandy Leggett
- Amy Mainzer
- Mark Marley
- Didier Saumon
- Davy Kirkpatrick
- John Wilson

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Low-Mass Stellar Objects

- Putting things in perspective
  - *H burning down to 0.08 M_{sun}*
  - *D burning down to 0.013 M_{sun}(13 M_J), takes 1e6 to 1e8 years*
  - *Dust condenses in stellar atmospheres at 1,300 < T < 2,000 K.*
    - Silicate and iron grains.
    - Forms in objects from 0.03 to 0.08 Msun, in 1e8 to 1e9 years
    - Dust clouds fall below photosphere at T < 1,300 K
    - Dust clouds may become disrupted at L-T boundary
  - *Dominant molecules vary with temperature*
    - C in CH_4 for T < 1,300 K, is in CO at higher temperatures
    - N in NH_3 for T < 600 K, N_2 at higher temperatures
  - *Cloud formation*
    - H_20 clouds form in stratosphere at T < 400 K
    - NH_3 clouds form in stratosphere at T < 200 K
  - *Dominant opacity sources H_2, H_2O, CH_4, and NH_3*
- Definitions
  - *M dwarfs for T > 2,400 K*
  - *L dwarfs for 1,300 K > T > 2,400 K*
  - *T dwarfs for 600 K? > T > 1,300 K*
  - *Y dwarfs, planets for T < 600 K?*

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Dim Suns Evolution

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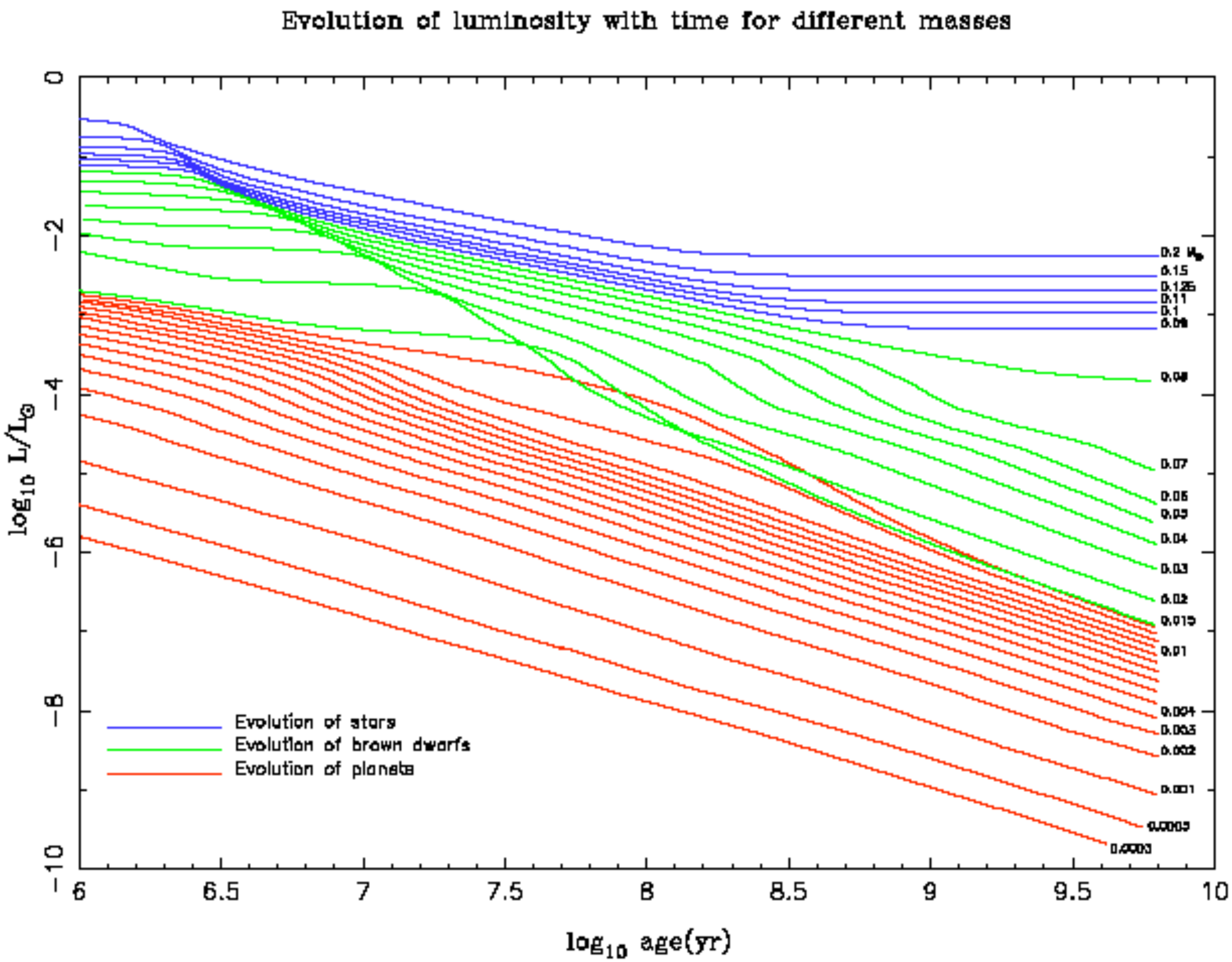

IRS and IRAC

- The IRS and IRAC instruments complement each other for brown dwarf studies
- IRAC
  - *Very high sensitivity*
  - *Short IR wavelengths well-matched to BD T_{eff}s*
  - *Multiple bands allow BD discovery by color*
  - *Can perform area surveys to find targets*
- IRS
  - *High sensitivity, especially in low-res*
  - *Spectral information can give better detailed information about:*
    - chemical composition
    - temperature
    - age
    - atmospheric dynamics
- Both instruments can be used for checking flux calibrations

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IRAC Color Identification

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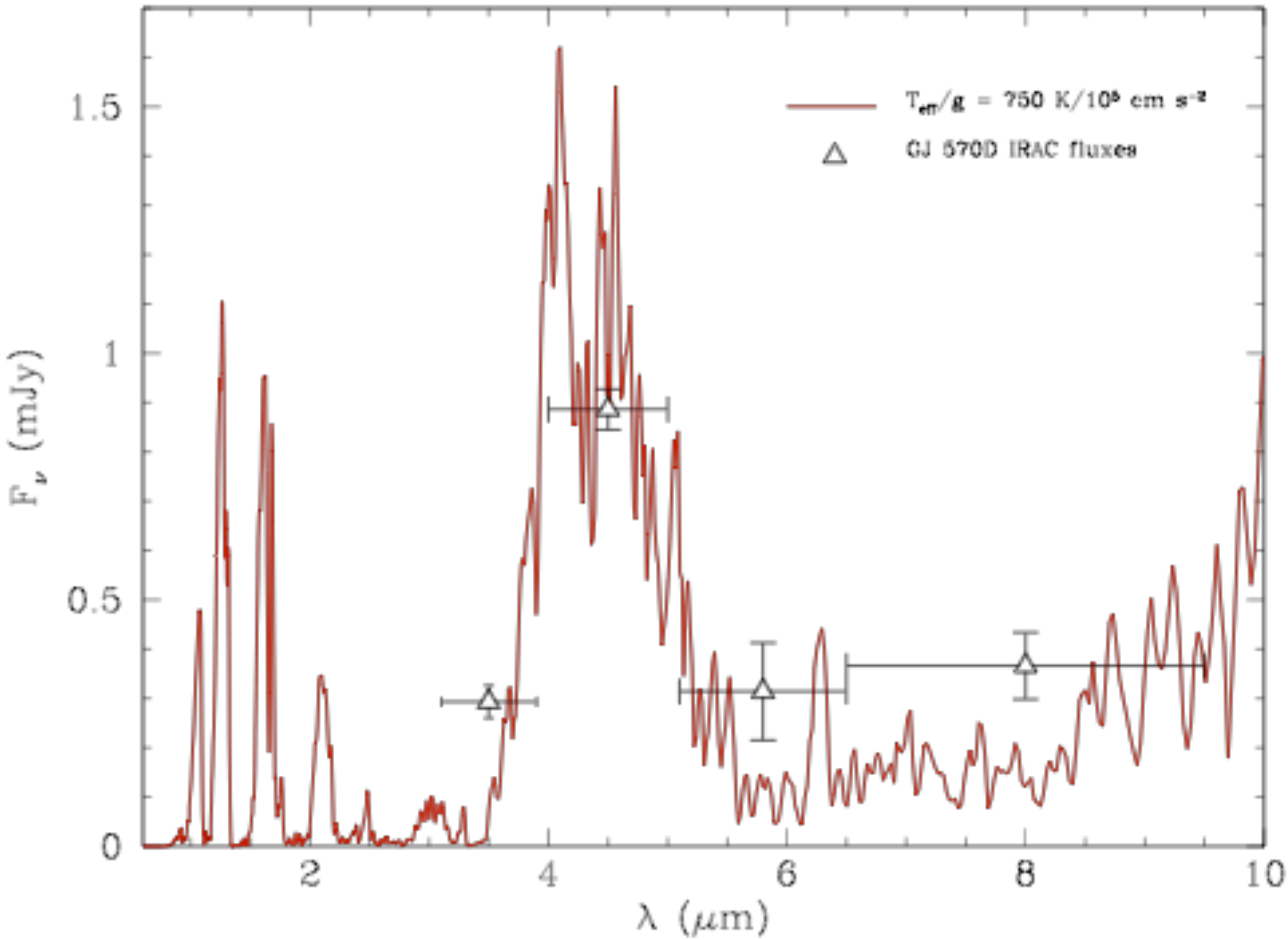
(From Patten et al., 2008)



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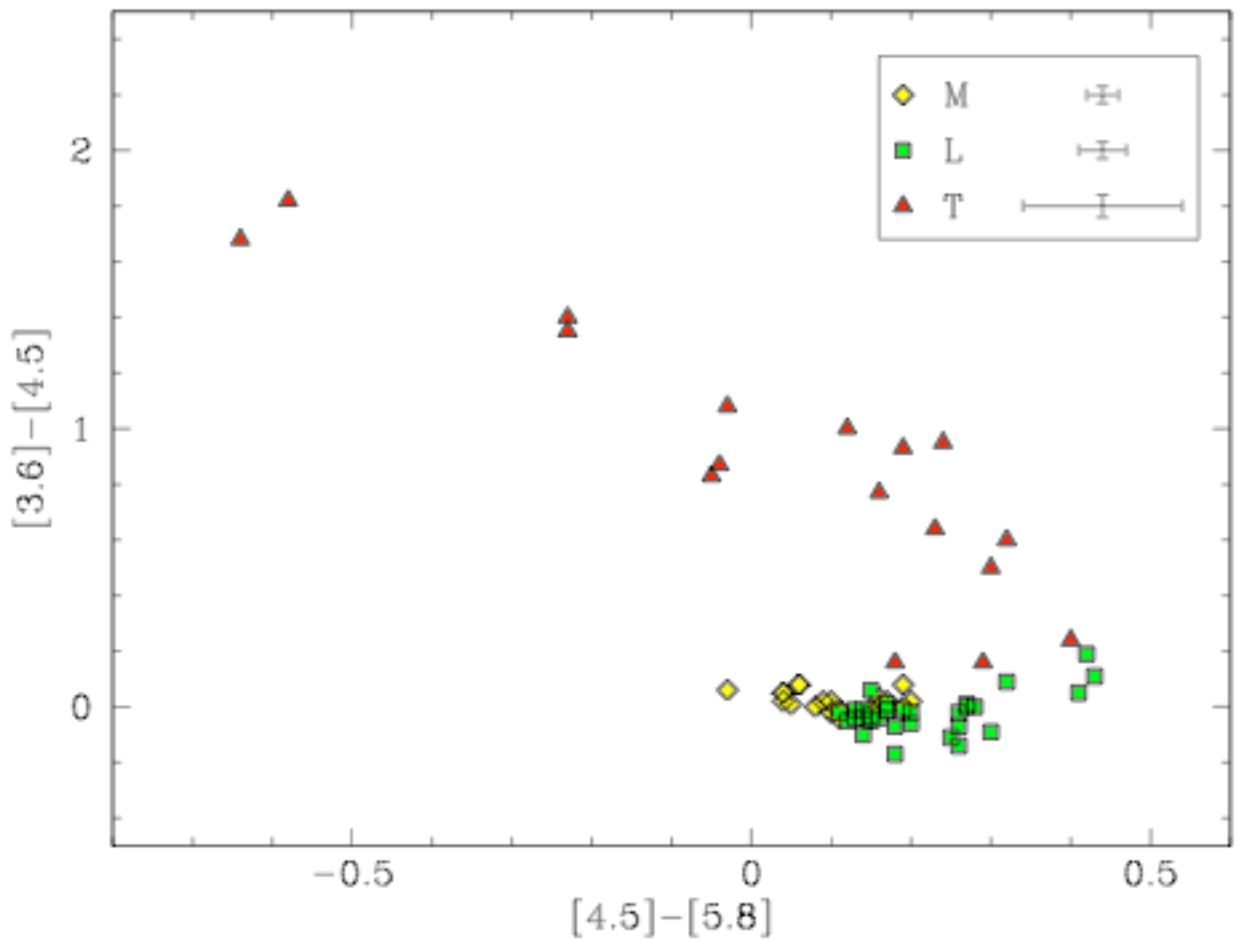
IRAC B-D Color-Color Plot

(From Patten et al., 2008)



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What can the IRS Data Tell Us?

- Unlike the near-IR where the spectrum and opacity sources get very complicated, at wavelengths longer than 15 μm the opacity source is H_2O, which is well-behaved and allows us to determine T_{eff}. This allows the determination of gravity, radius, and mass of the BDs
- Can determine the presence of clouds in the atmosphere much better than in the near-IR.
- Can determine presence of molecular species never seen before, e.g. ammonia
- Can determine whether there is any non-equilibrium chemistry going on.
- May possibly show if there is a stratosphere (temperature inversion) by the enhancement of trace species, such as CO_2, HCN, C_2H_2, C_2H_4, C_2H_6, and CH_2O

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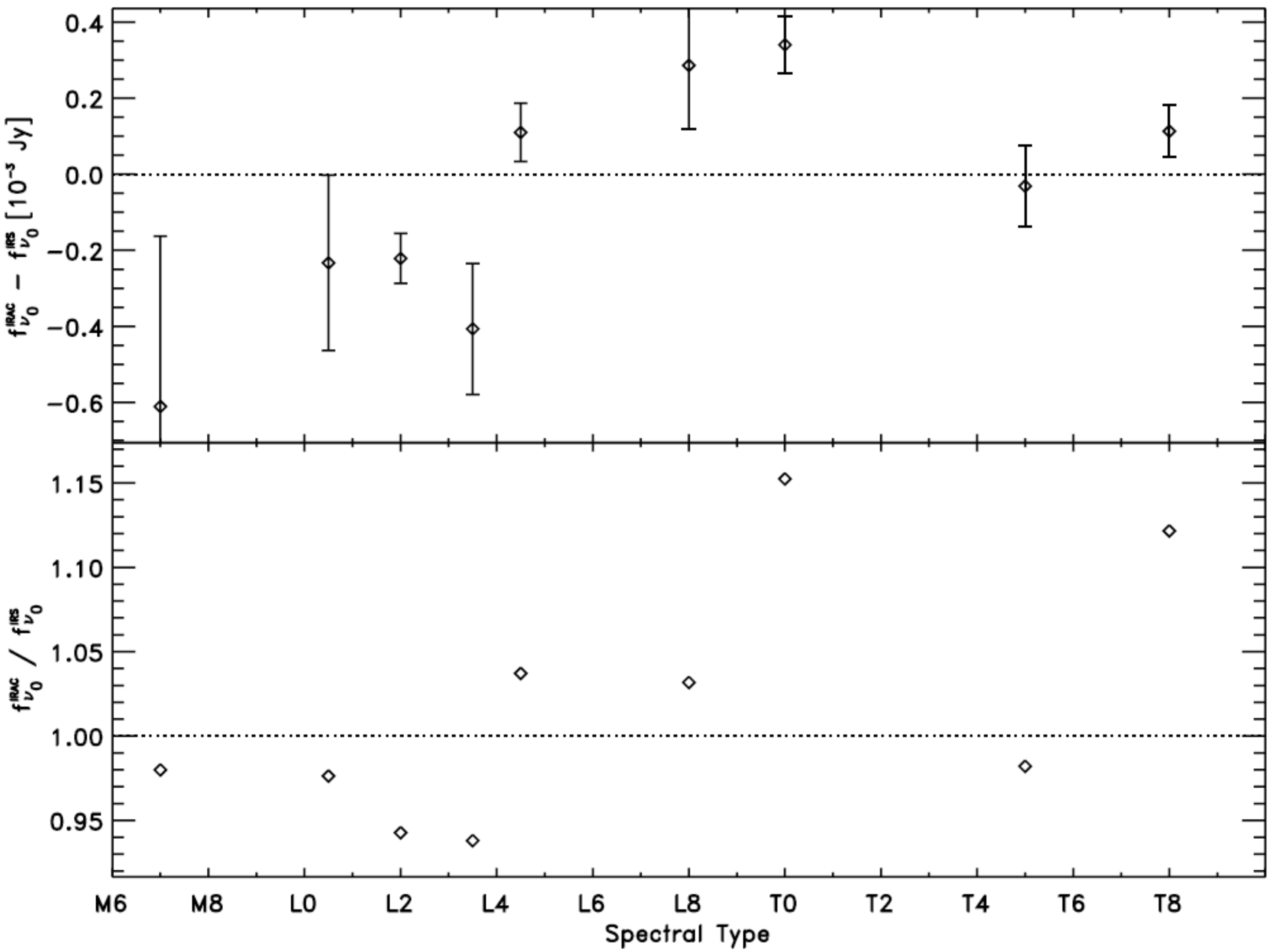
Comparing IRS-IRAC Fluxes

(From Cushing, 2006)



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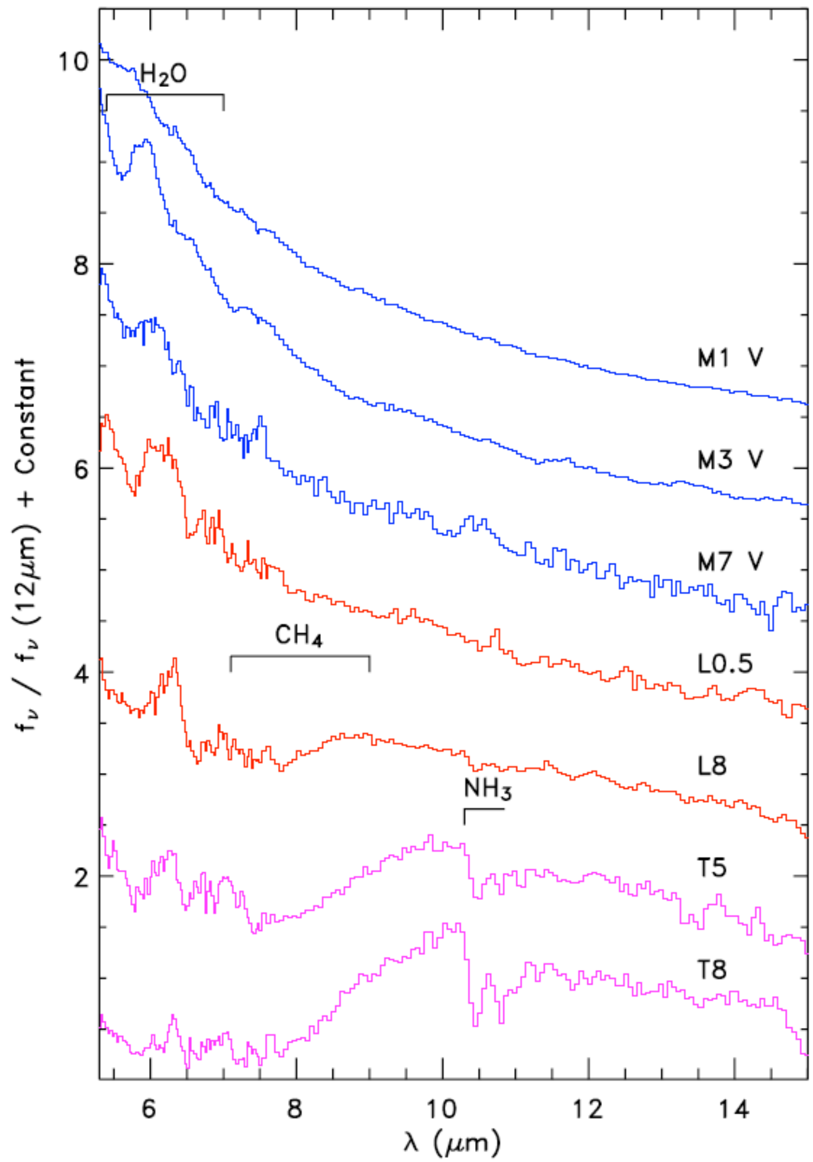
IRS Spectra of BDs



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Chemical Equilibrium

- Where elements reside depends on temperature and pressure. E.g.: $CO + 3H_2 \; <-> \; CH_4 + H_2O$
- If convection carries material to different levels and the reaction rates are not fast, then the chemical balance can get out of equilibrium
- Example: Gl 570D
  - *We find that NH3 is depleted by a factor of 10 at the photosphere*
  - *CO is enhanced by ~ 3 orders of magnitude*
- This is indicative of a dynamic atmosphere, one likely to have bands or other cloud features like Jupiter, instead of a static layered atmosphere
- (For mere details, see Saumon et al., 2006)

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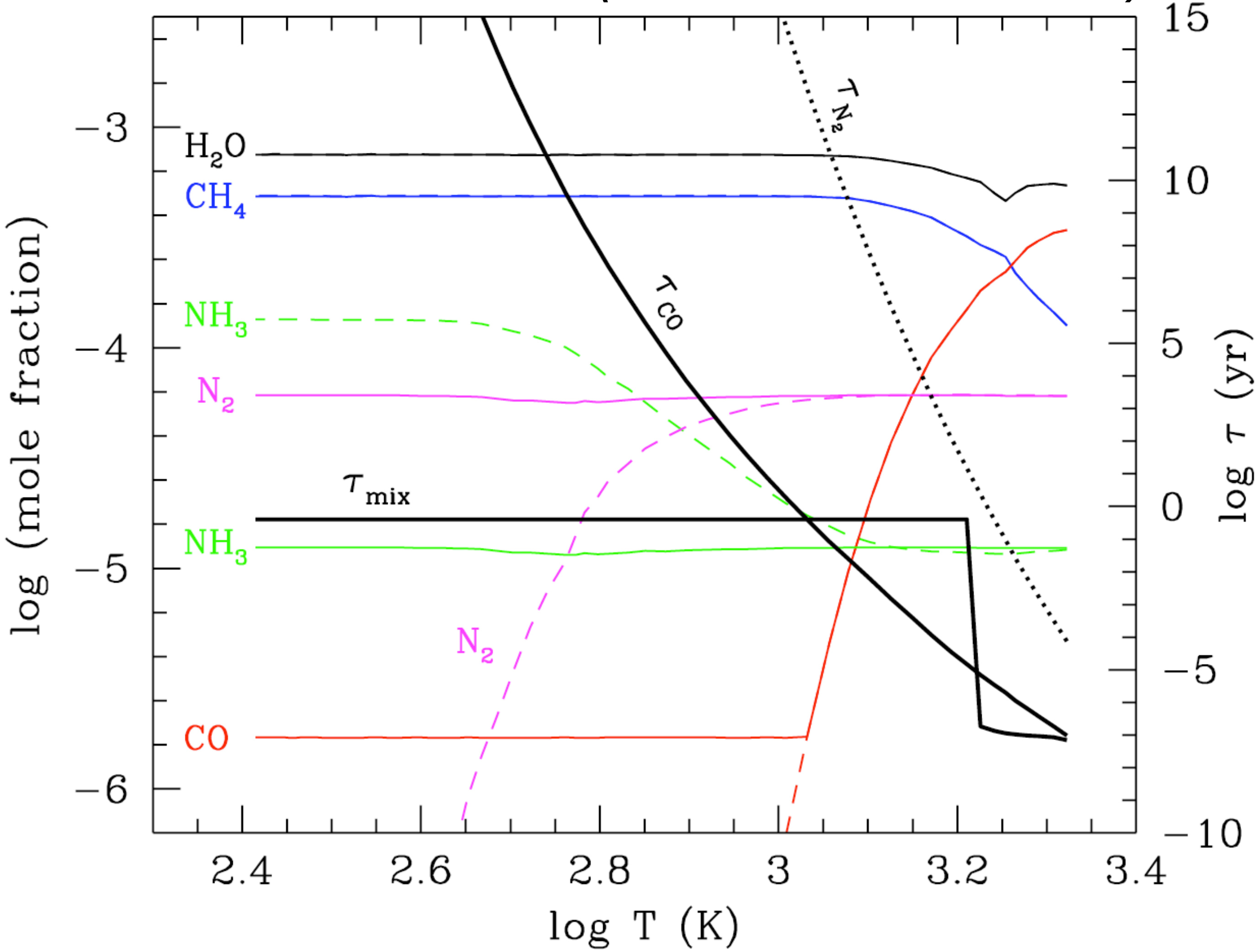
Chem Equil. In Gl570D

(From Saumon et al. 2006)



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Recent Results

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- Spitzer observations for 4 very cool (~600K) dwarfs (Leggett et al., 2009)
- Three are T9 dwarfs (latest currently known), one is T8
- Combined Spitzer IRS, IRAC data with ground-based NIR
- These combinations give:
  - *Ratio of mid to NIR fluxes -> Teff*
  - *The 2.2 and 4.5 μm fluxes -> metallicity, gravity (degenerate however)*
  - *4.5 and 10 μm – vertical atmospherric transport*

Varying the Parameters in the Models

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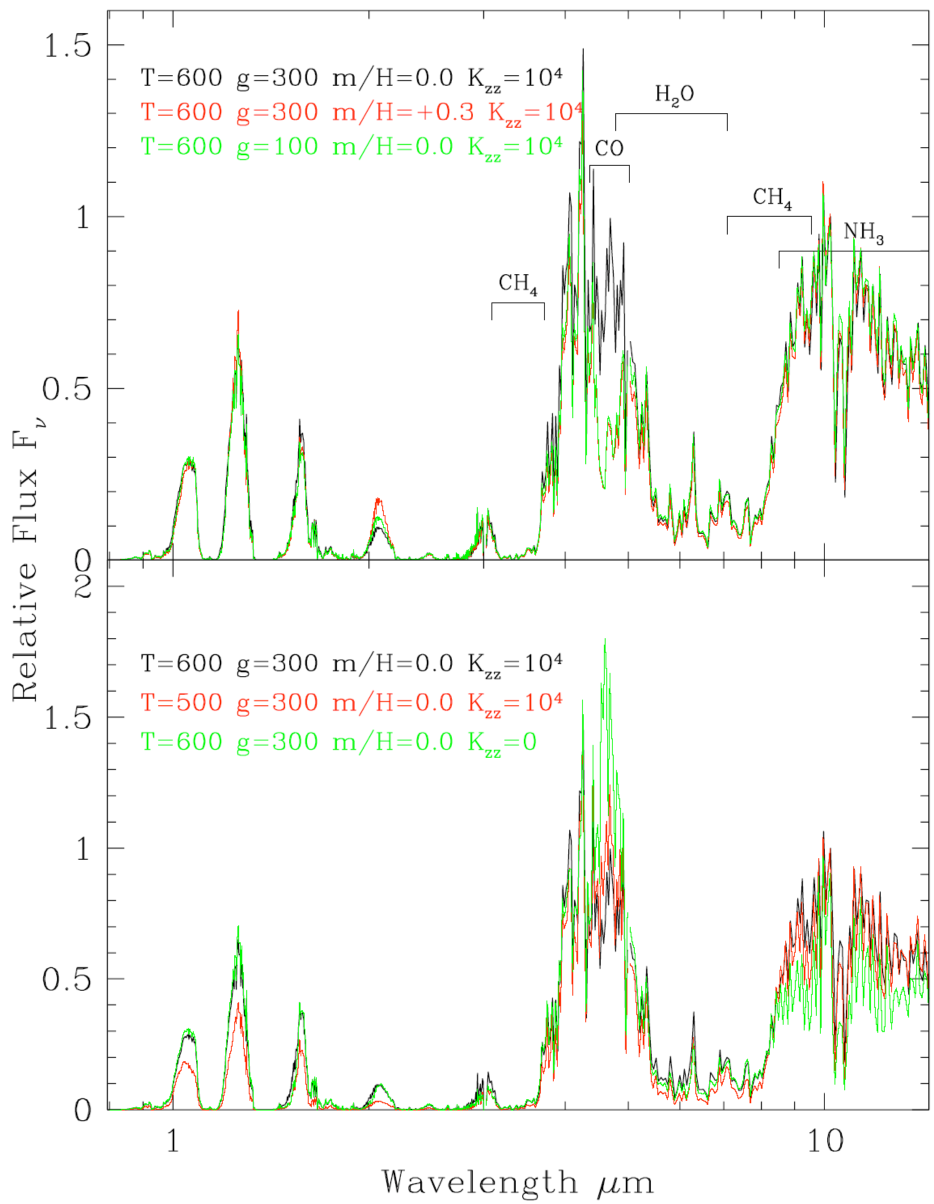

Models are from Marley and Saumon

Top panel: gravity and metallicity are degenerate

Bottom panel: Lower T_{eff} reddens the spectrum, the 4.5 to 10 μm ratio very sensitive to K_{zz}

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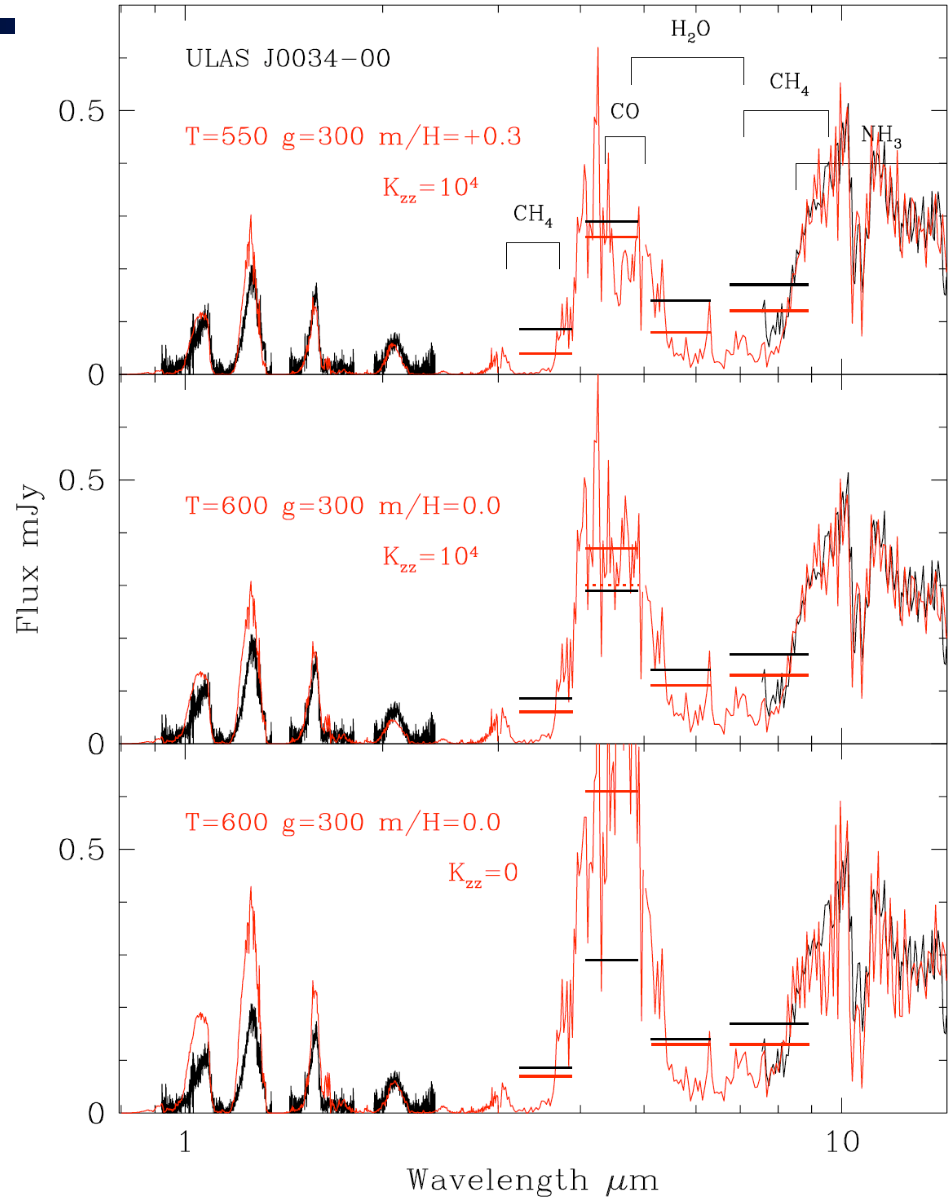
ULAS J0034-00



Red is model, black is measured data. There are known deficiencies in the line lists $0.9 < \lambda_{\mu m} < 1.4$

Note that the IRAC 4.5 band shows that there has to be vertical transport with non-equilibrium chemistry. Need to take this into account when making Y-dwarf search parameter predictions

Perform a least-squares fit to the model parameters

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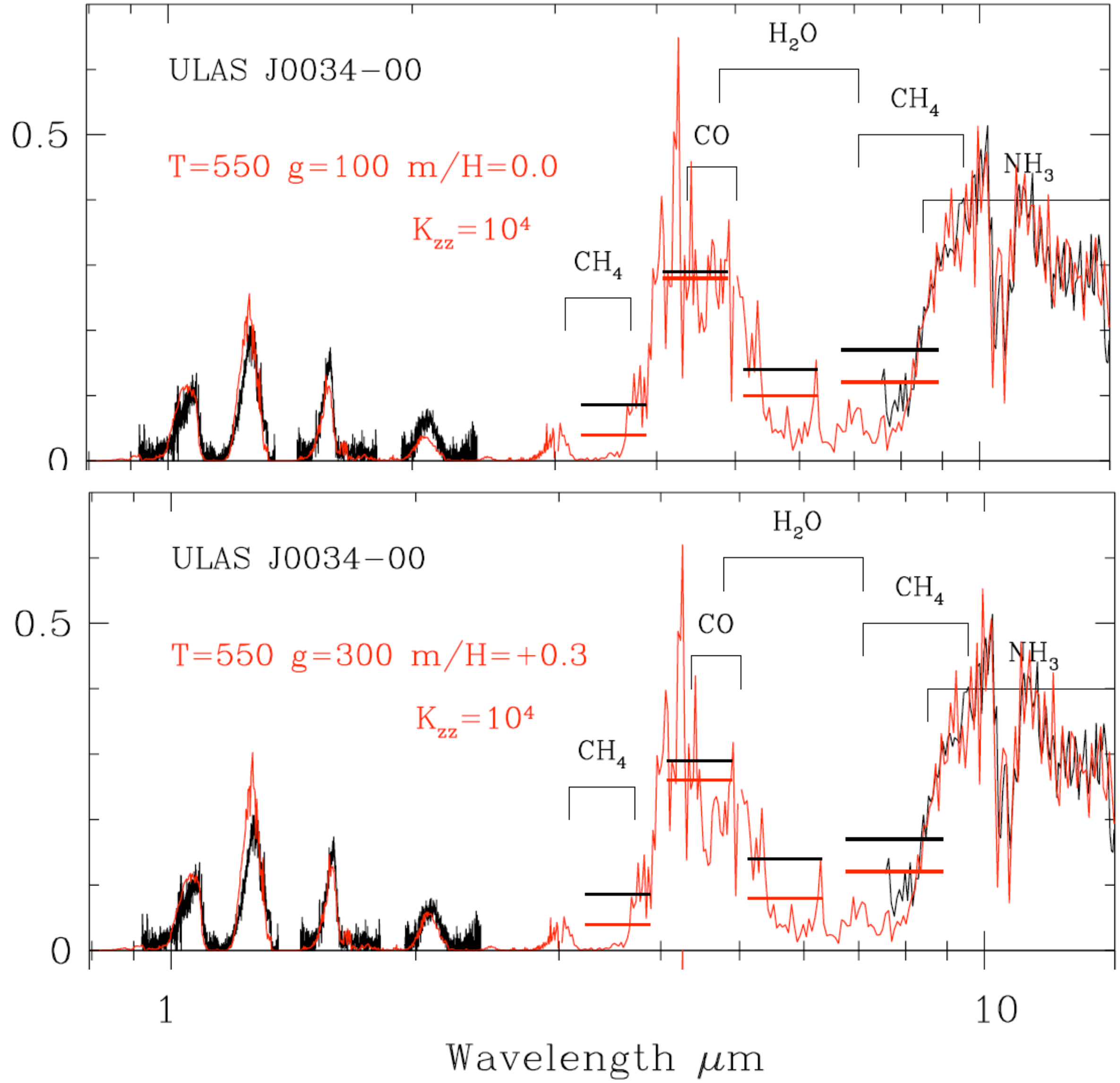
ULAS J0034-00
The Two Best Fits



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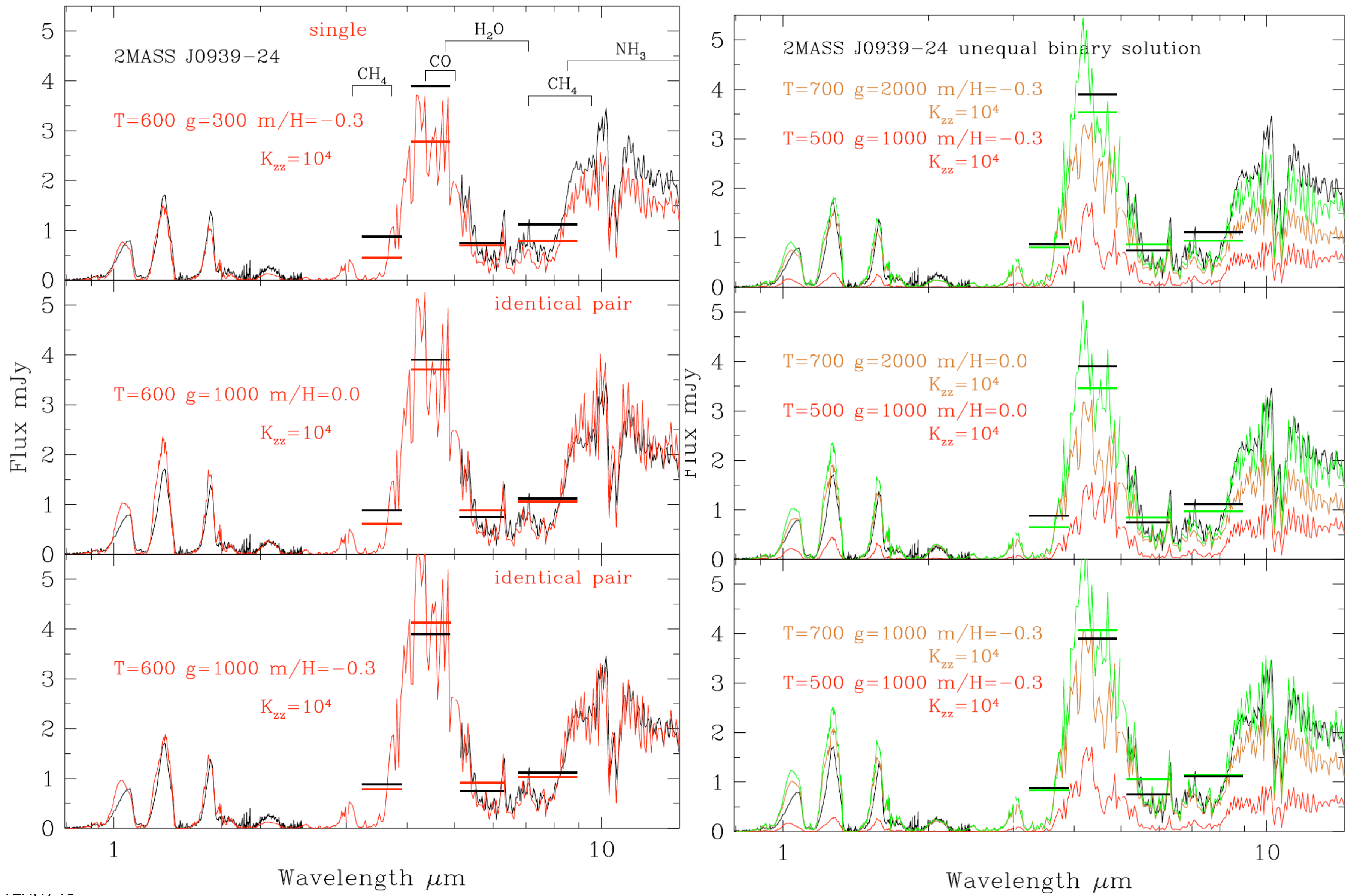
Can Distinguish Unequal Binaries 2MASS J0939-24



IRS Brown Dwarf “Firsts”

- First detection of the 7.8 μm methane band
- First detection of ammonia in a BD atmosphere (at 11.3 μm)
- First detection of non-equilibrium chemistry in a BD atmosphere

And Now What You’ve Really Been Waiting to See

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My Only Photo Of Giovanni!

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Launch + 3 Minutes, Our First Safing

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The First Press Conference

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IOC

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The IRS Ace of Spades

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Pasadena Do-Dah Parade

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Jim Houck

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No Title Needed

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