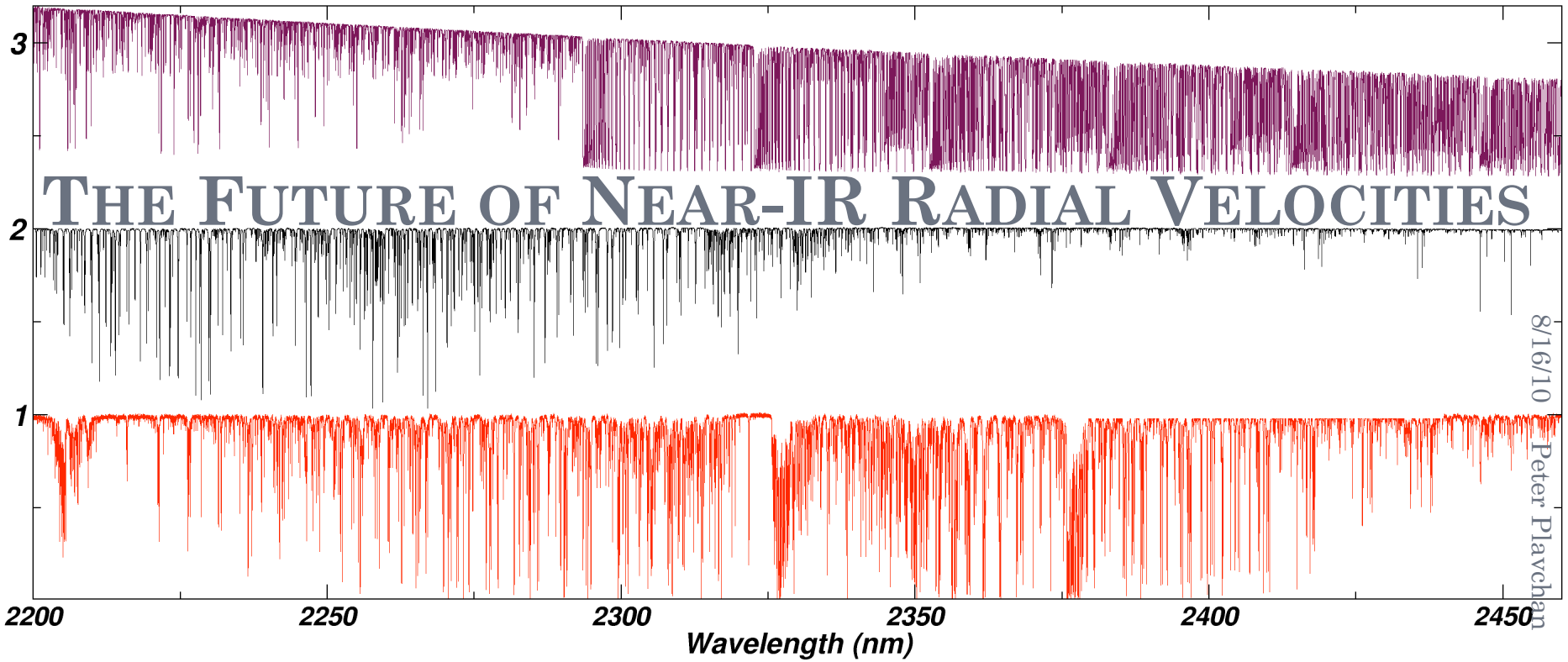


The Future of Near-IR Radial Velocities

Peter Plavchan

NASA Exoplanet Science Institute, Caltech

Guillem Anglada, Chas Beichman, David Ciardi, Scott Diddams, John Johnson, Sean Mills, Steve Osterman*, Lisa Prato, Russel White

8/16/2010 Penn State RV Workshop

* Steve Osterman kindly let me plagiarize/adapt the first half of my talk from his material.

Many interesting talks and posters about Near-IR RVs:

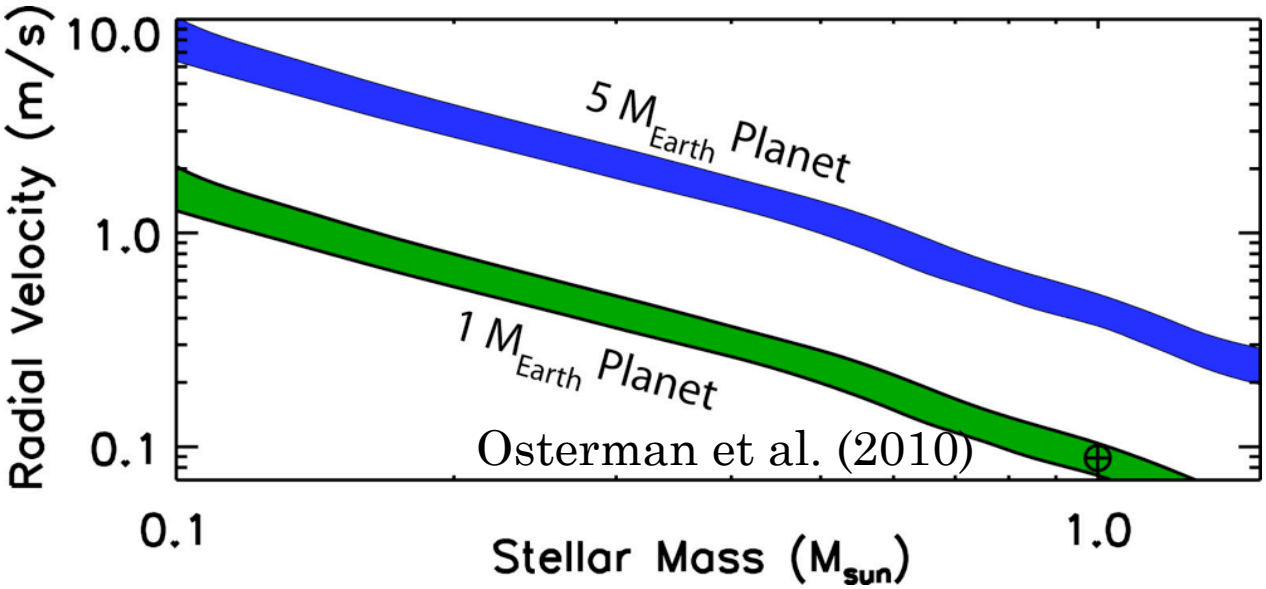
Guillem Anglada	Gas Cells poster
Angelle Tanner	Telluric RVs with NIRSPEC + Russel White poster
Pedro Figueira	RVs with CRIRES
Suvrath Mahadevan	Pathfinder NIR HET Spectrograph
John Barnes	UKIRT Planet Finger design
Eduardo Martin	NAHUAL-NIRINTS
Andreas Quirrenbach	CARMENES + Caballero poster
Franklyn Quinlan	NIST NIR laser frequency comb
Jamie Lloyd	TEDI
Cullen Blake	Telluric RVs
James Beletic	NIR Detectors
Stephen Redman	Uranium-Neon Lamps poster

LOOK FOR PLANETS AROUND RED, LOW MASS STARS IN THE NIR:

- Larger RV signature for a given planet mass in the habitable zone

LOOK FOR PLANETS AROUND RED, LOW MASS STARS IN THE NIR:

- Larger RV signature for a given planet mass in the habitable zone
  - Lower stellar temp → H.Z. is closer to the host
  - Lower stellar host mass
  - Tighter orbit leads to shorter period (weeks)



Stellar RV for planet in the habitable zone. Osterman et al. (2010), derived from Kasting (1993, fig. 15).

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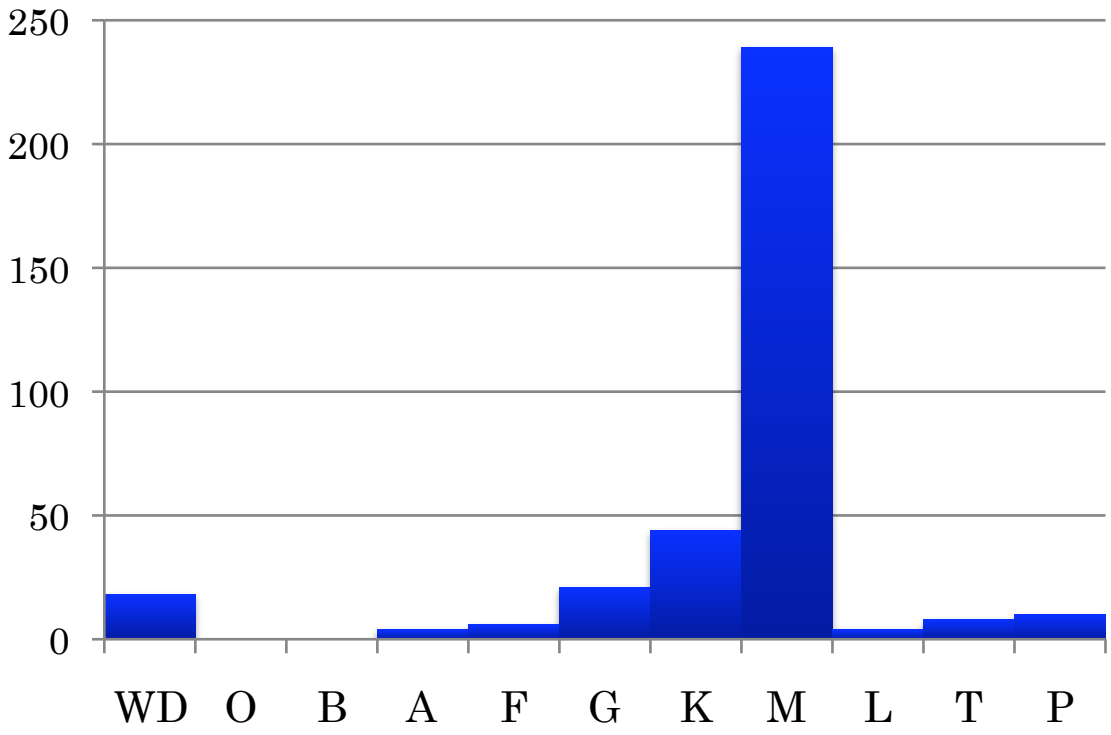

Data from *RECONS* survey values (Jan 2009) showing predominance of class M stars within 10 pc. (Osterman et al. 2010)

LOOK FOR PLANETS AROUND RED, LOW MASS STARS IN THE NIR:

- Larger RV signature for a given planet mass in the habitable zone
- Large number of host stars within 10pc
- Cool stars brightest in the Near-IR
  - Only 4 >M4 dwarfs with V<12
- No shortage of narrow spectral features

Precision Near-IR Radial Velocities would allow us to address:

- How common are planets around K/M stars?
- What are the planet masses and orbits?
- How do the parameters depend on stellar mass?
- Many ancillary science topics:
  - stellar rotation, binaries, variability of fine structure constant, Galactic Center dynamics, etc.

- What is the youngest star orbited by a "hot Jupiter"?

Testing Planet Formation & Migration Theories

- Gas Giants form beyond the snow line at $r > 2 - 4$ AU

  Must happen <u>before</u> H_2 is lost to UV evaporation

- Migration follows formation

  Must also happen <u>before</u> primordial gas disk dissipates

By peering through the dust obscuring young stars, we could constrain time-scale & mechanism of migration

The only real issue here is using the word precision when discussing NIR spectroscopy…

Near-IR RV Precision Techniques

Historically, 'precision' spectroscopy in the NIR has been anything but precise, lagging behind optical efforts

Current and future efforts span ~4 orders of magnitude in precision:

- Telluric lines: ~20 – 50 m/s
  - See Angelle's talk
- Gas absorption cells: ~1 – 5 m/s
- Laser combs: potential for ~1 cm/s

IDEAL WAVELENGTH STANDARD

- Dense array of uniformly spaced, uniformly bright lines
- Frequencies traceable to a fundamental standard
- Precision and long term stability should exceed the ultimate precision of the spectrograph

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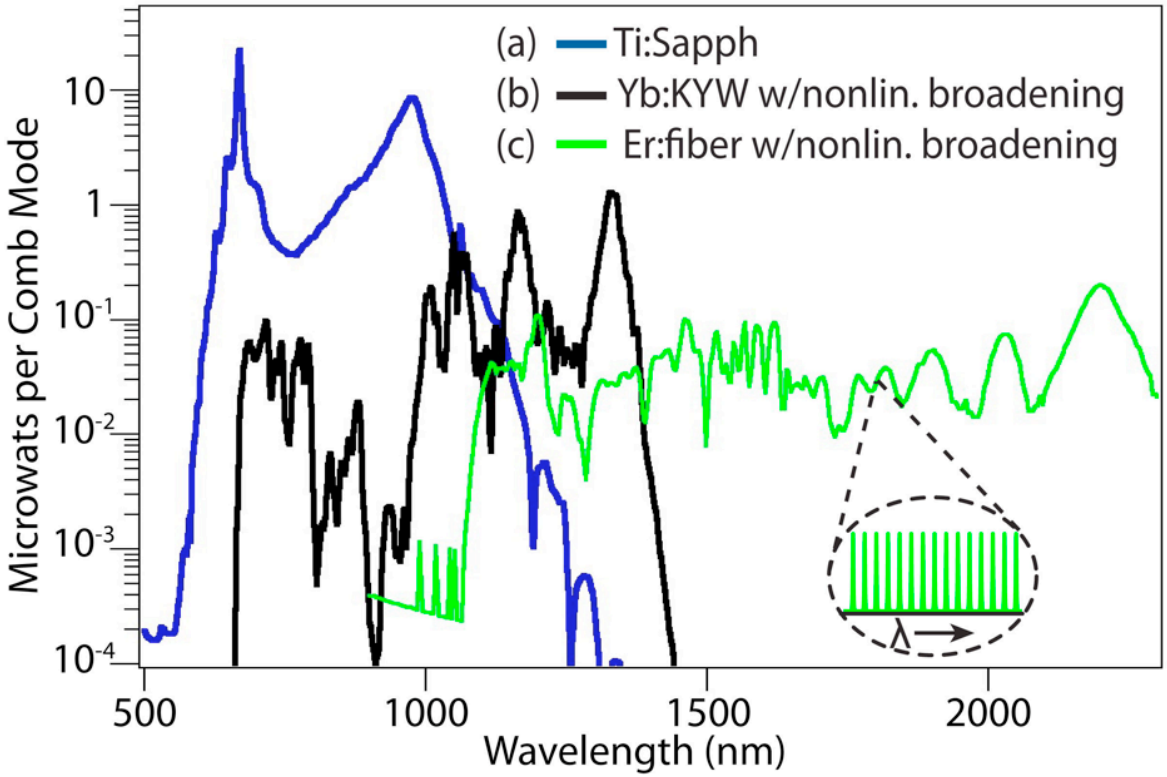
→A laser Frequency Comb meets these requirements:

- The LFC creates a high precision "optical frequency ruler."

$$f_n = nf_r + f_0$$

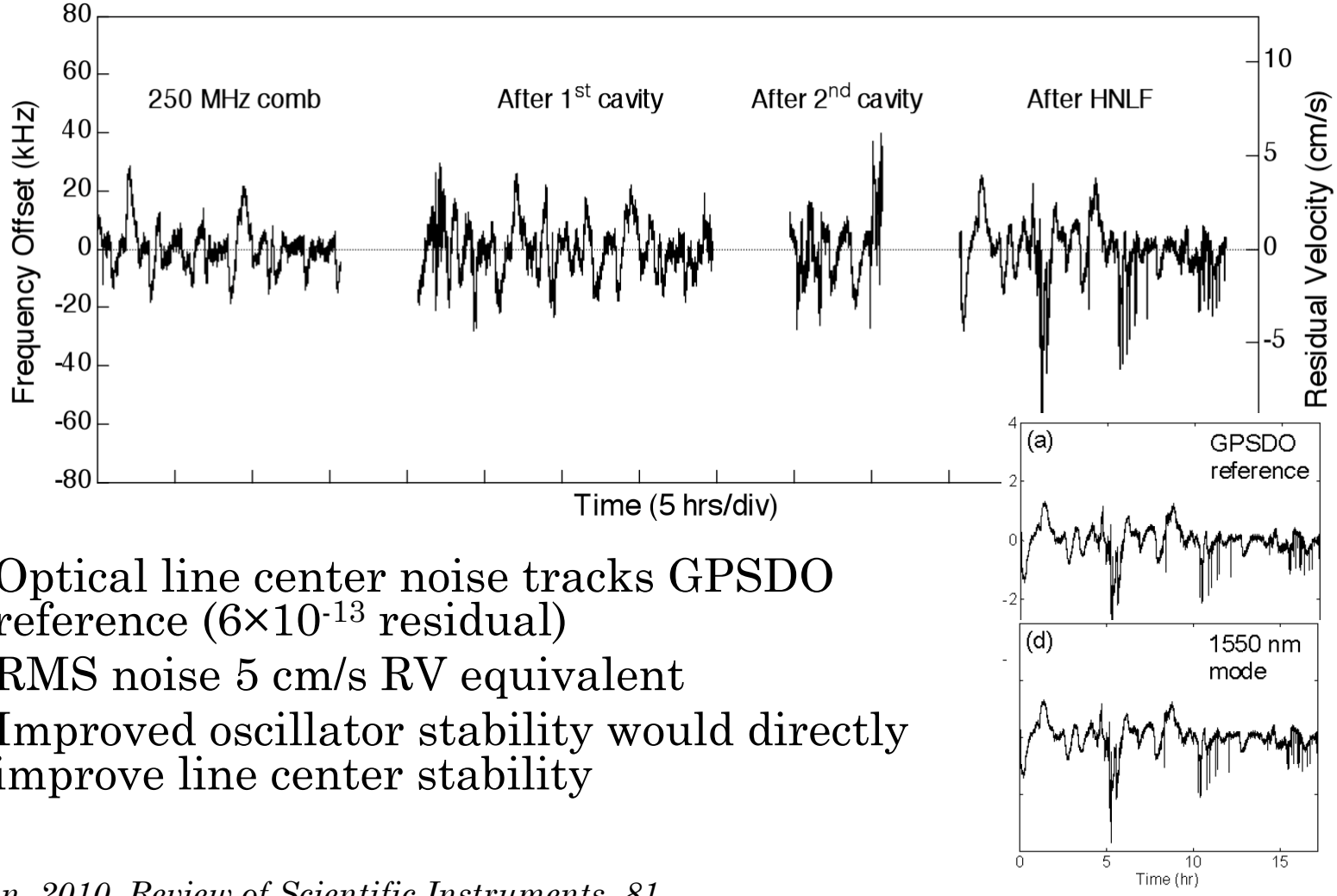
- This relation is <u>exact</u> (measured to 10^{-19}).

Frequency combs span the visible and Near-IR



Osterman et al. (2010)

Comb Stability



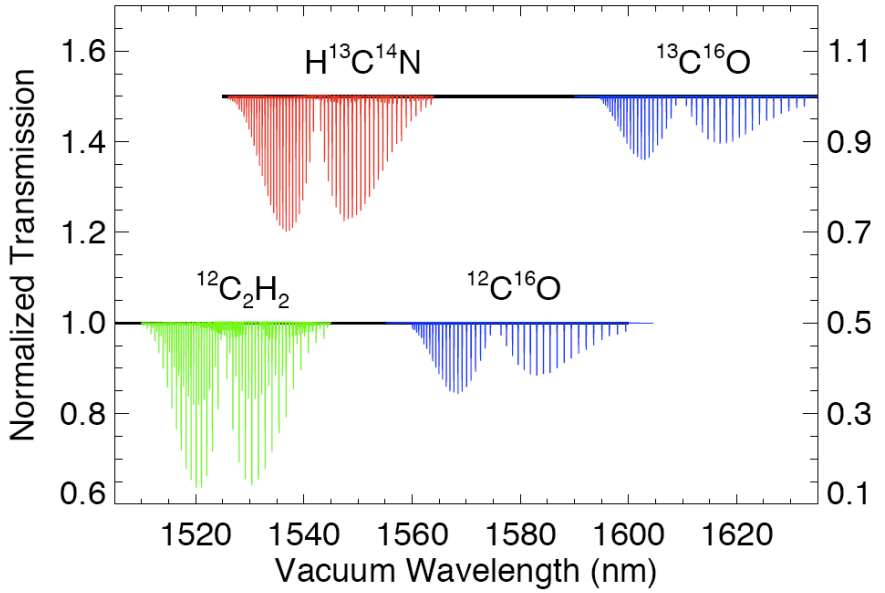
- Optical line center noise tracks GPSDO reference (6×10^{-13} residual)
- RMS noise 5 cm/s RV equivalent
- Improved oscillator stability would directly improve line center stability

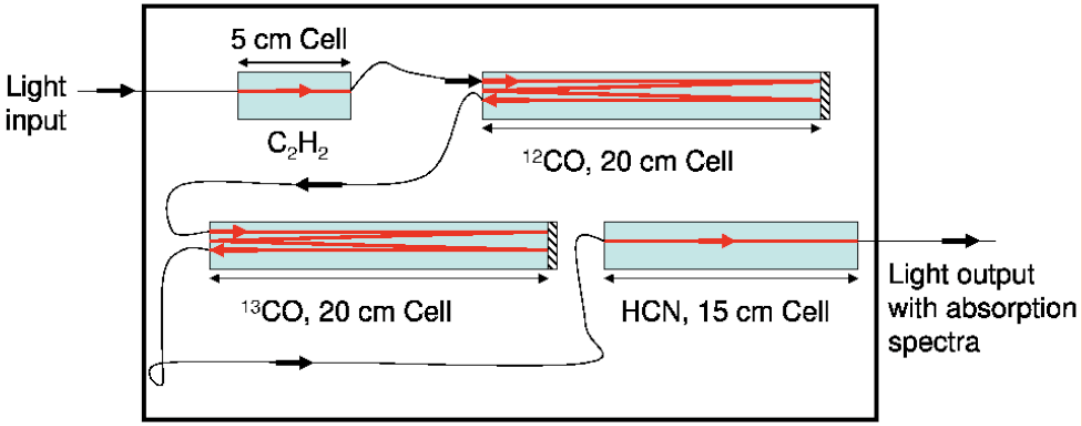
Quinlan, 2010, Review of Scientific Instruments, 81

Stay tuned for Quinlan's talk on Wednesday!

Absorption Cells – H band

- *M*olecular sources (C_2H_2, ^{12}CO, ^{13}CO and HCN) provide limited coverage at H-band. Cascaded cells possible but…
  - Limited coverage (1.51-1.63 μ m requires 4 species)
  - Complicate the spectra
  - Attenuate science signal





Mahadevan and Ge, ApJ 692:1590–1596, 2009

Absorption Cells – K band
Bean et al (2010)

- At AAS meeting, announced a new gas absorption cell for near-IR radial velocities that achieved ~5 m/s precision with CRIRES.

→ Ammonia gas

How I got sucked into this

I was interested in:

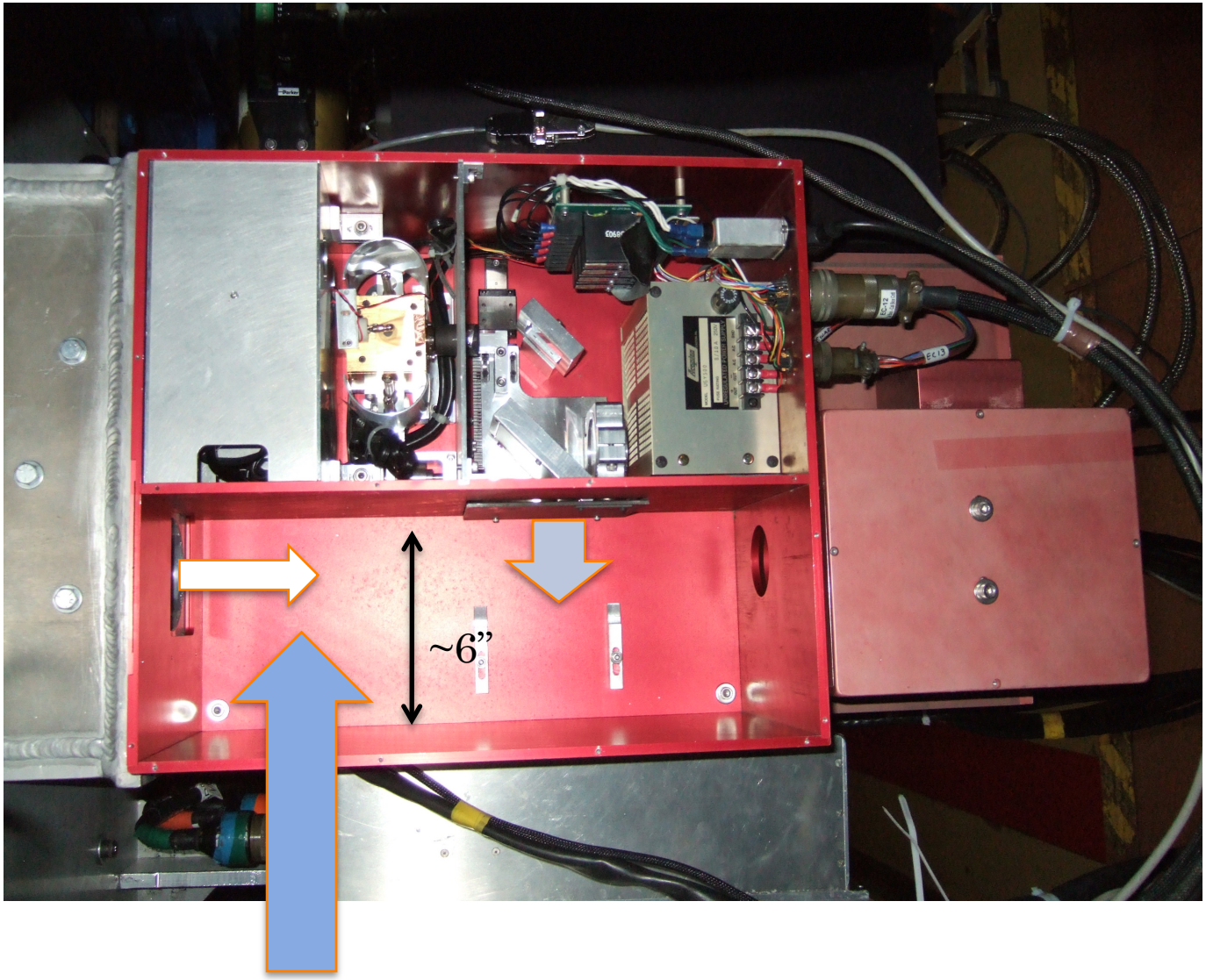
- Follow-up of M dwarf transit candidates
- Follow-up of disk eclipsing embedded YSOs

At September 2009 Keck Science Meeting:

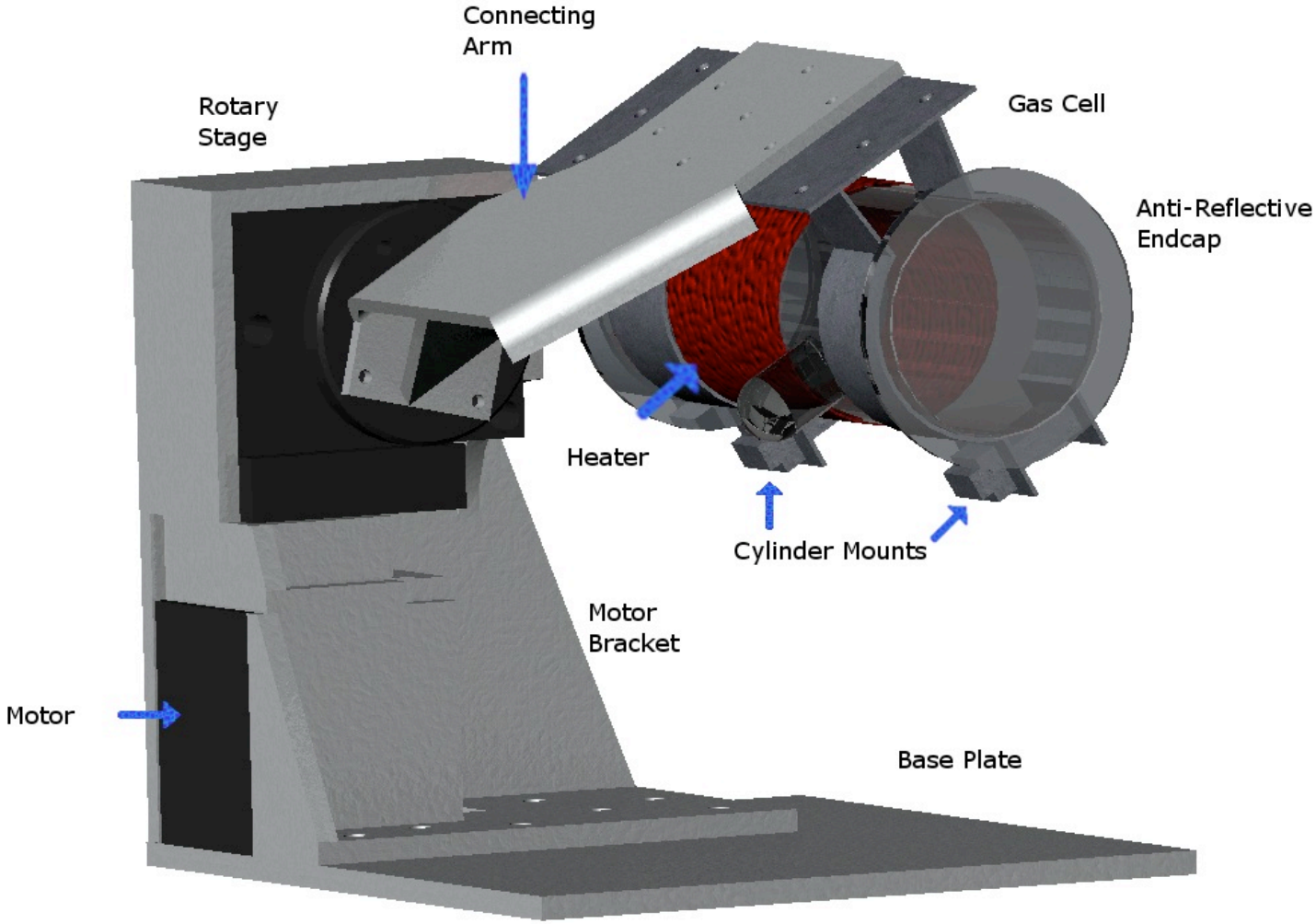
- In open session, I put forward a straw-man proposal to add a laser comb to an upgraded NIRSPEC

Fast forward to January 2010, I reached agreement with IRTF to build and bring a gas cell & NIST's laser comb to test on CSHELL in fall 2010.

CSHELL: 17 YRS OLD,R~45K,5NM ORDER

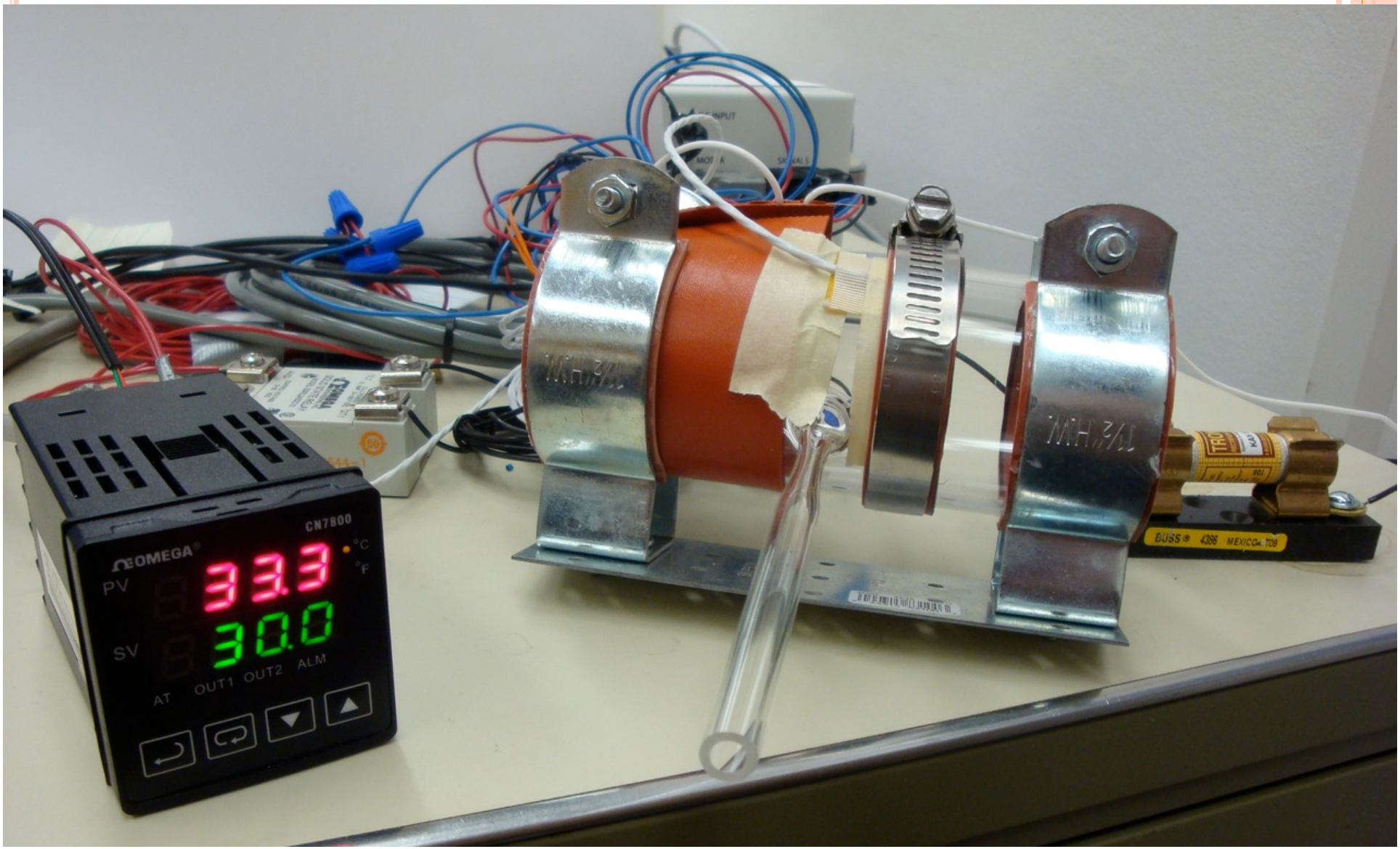


Absorption Gas Cell

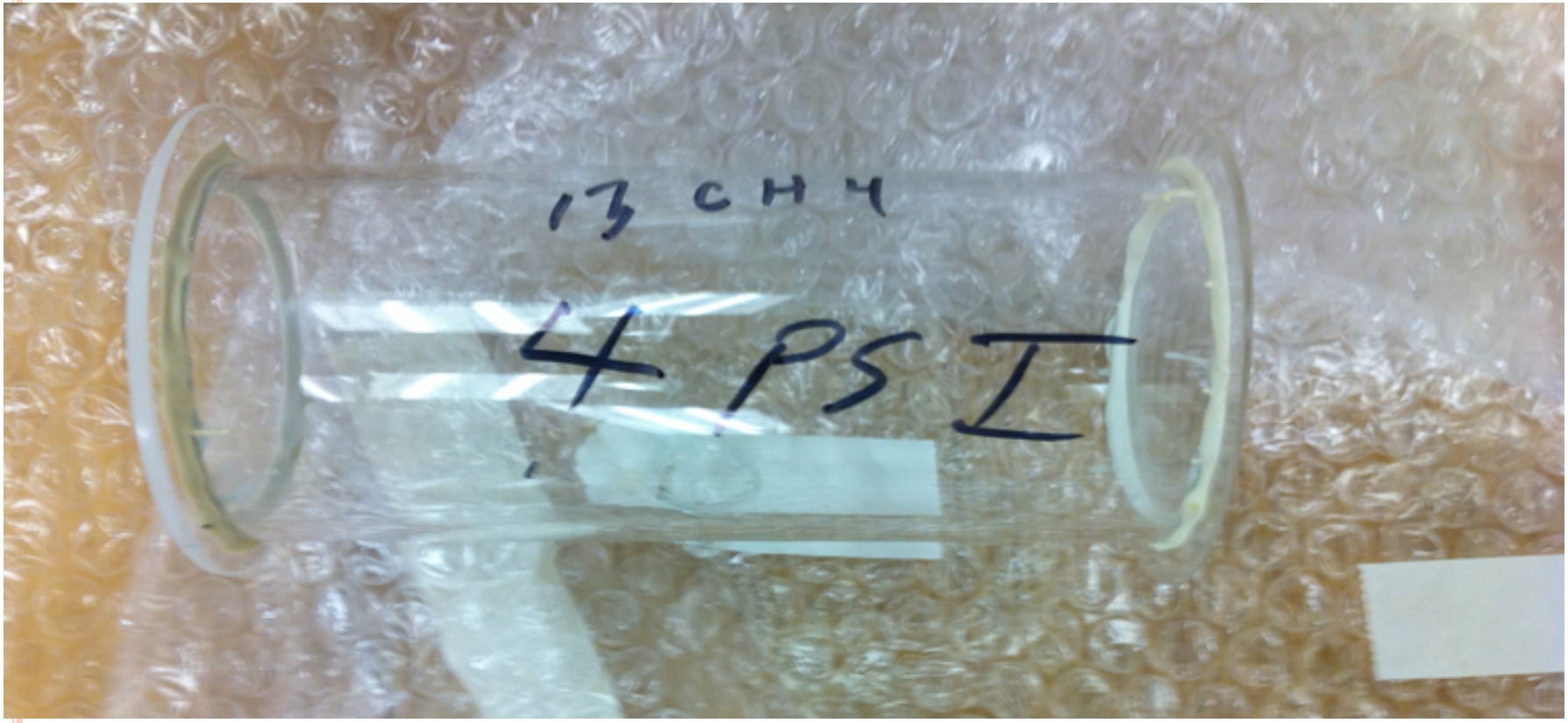


Anglada, Plavchan et al., in prep.

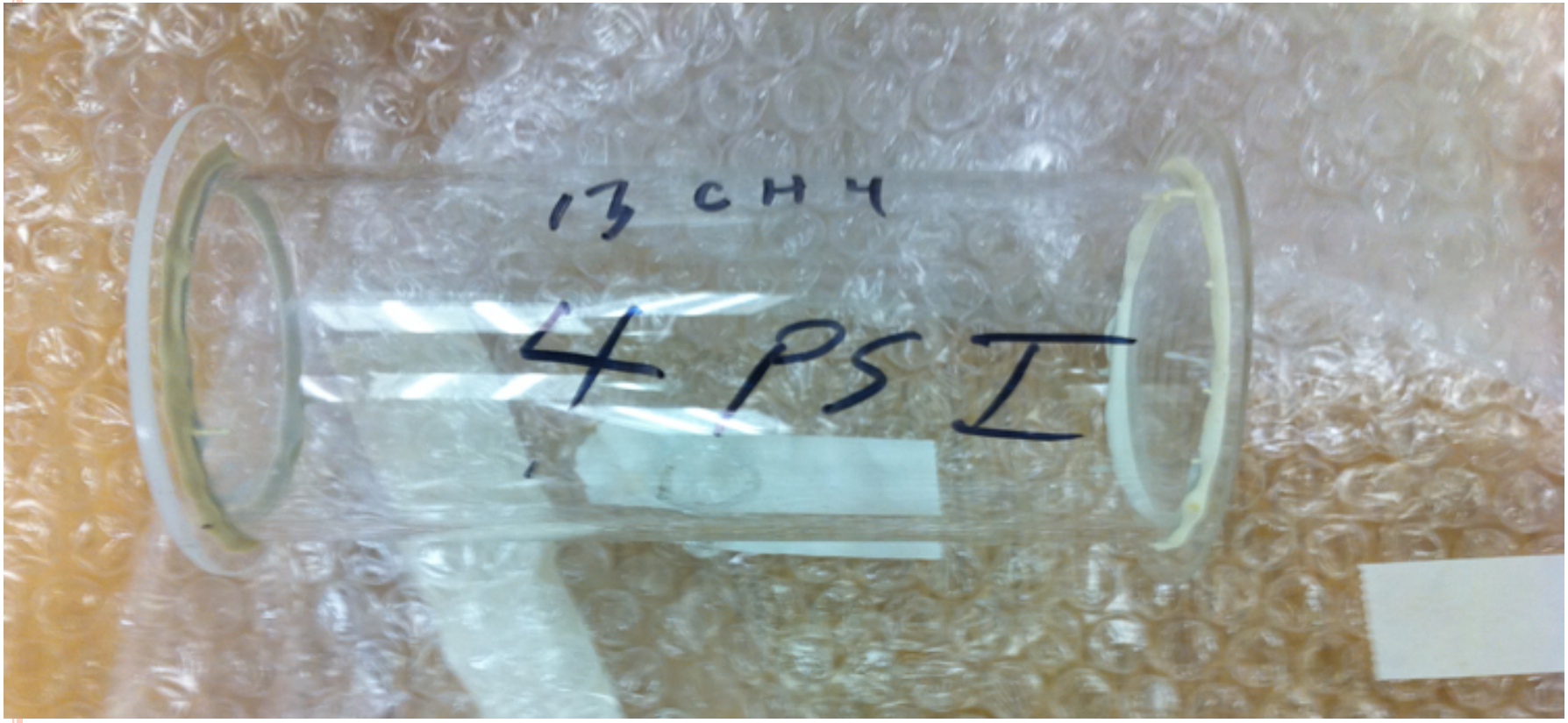
Thermally Controlled
→ ~1 m/s per 10K noise removed



Completed Cell



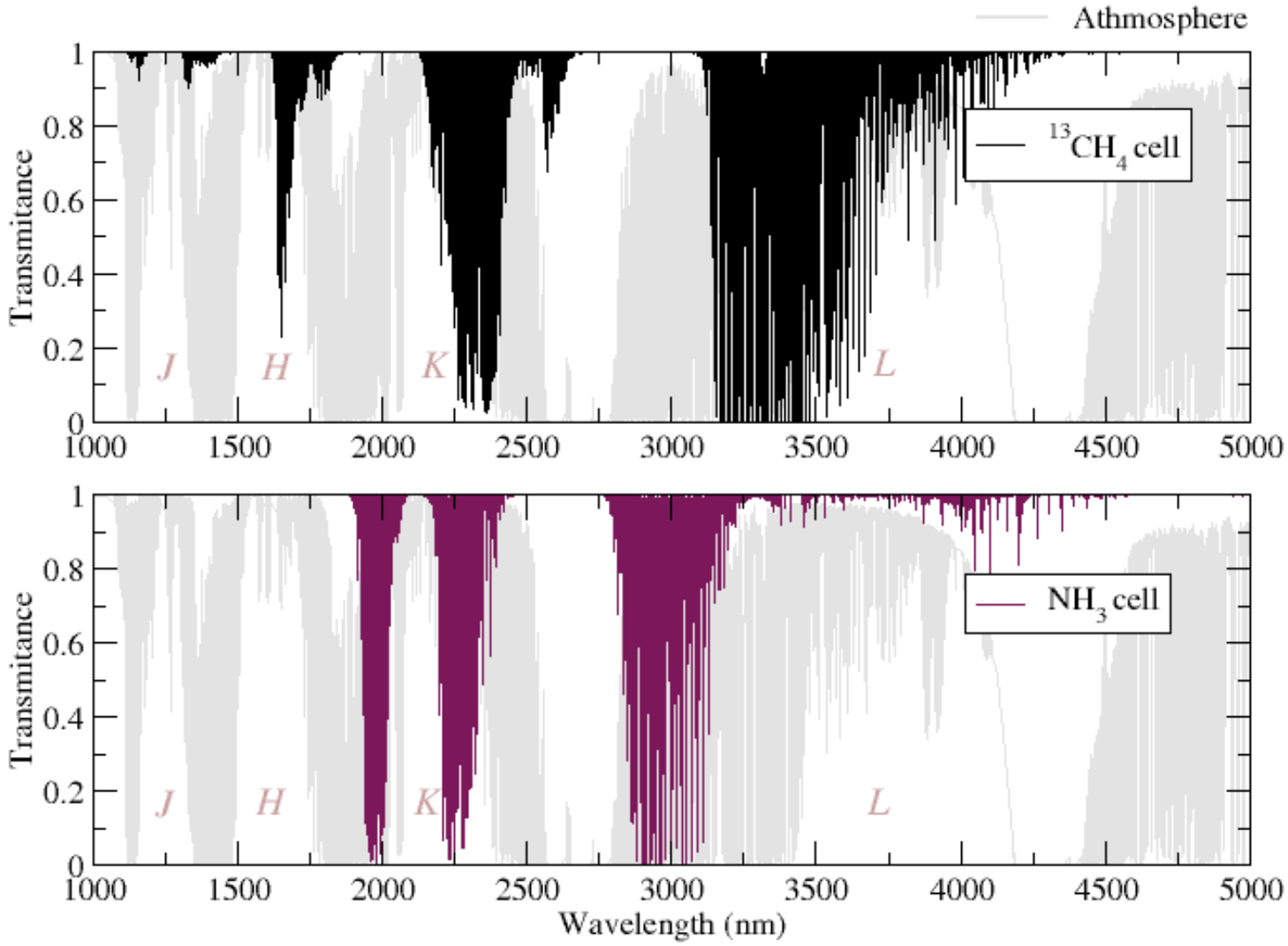
Choice of gas: METHANE, aka: MAGS: Methane Absorption Gas cellS



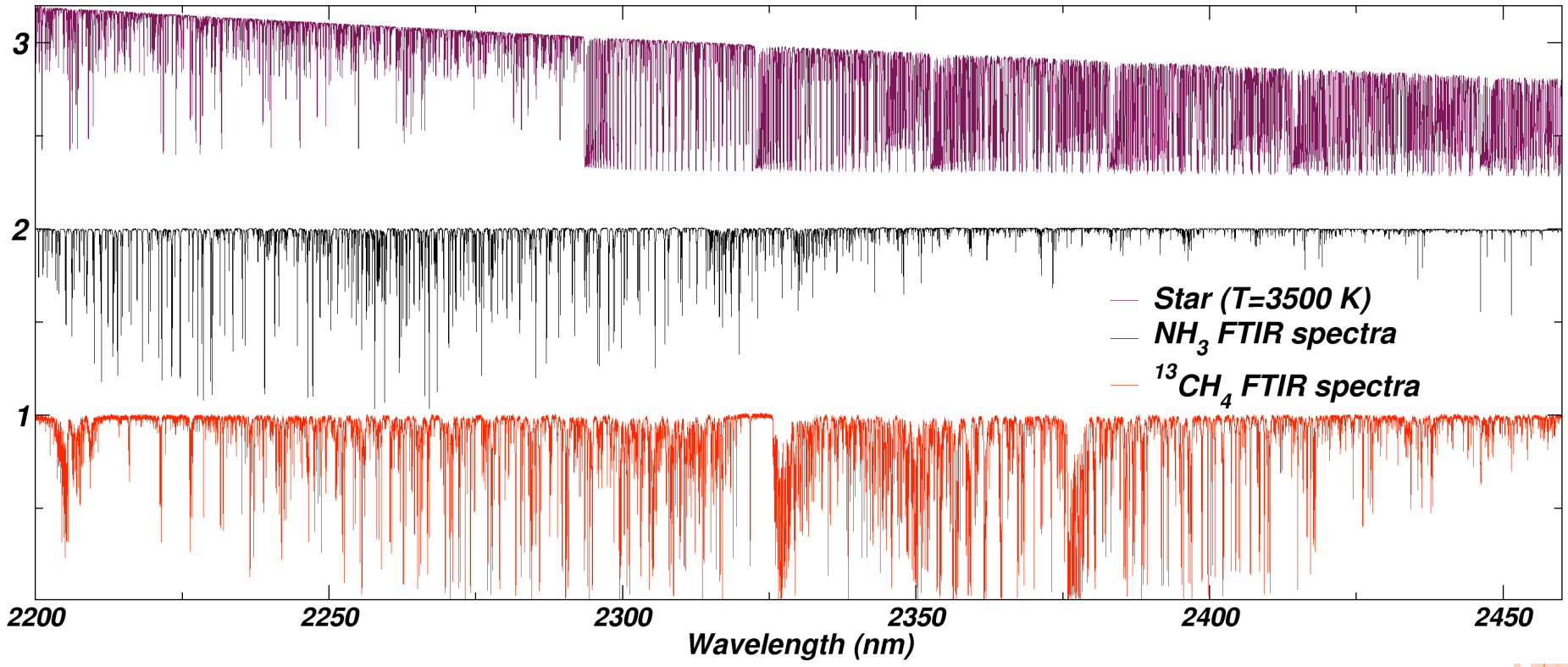
Why has methane been missed?

- Telluric methane!
- By using an isotopologue or deuterated methane, the reduced mass changes.
  - The ro-vibrational lines shift by ~5-10 nm!
  - Credit: Guillem Anglada

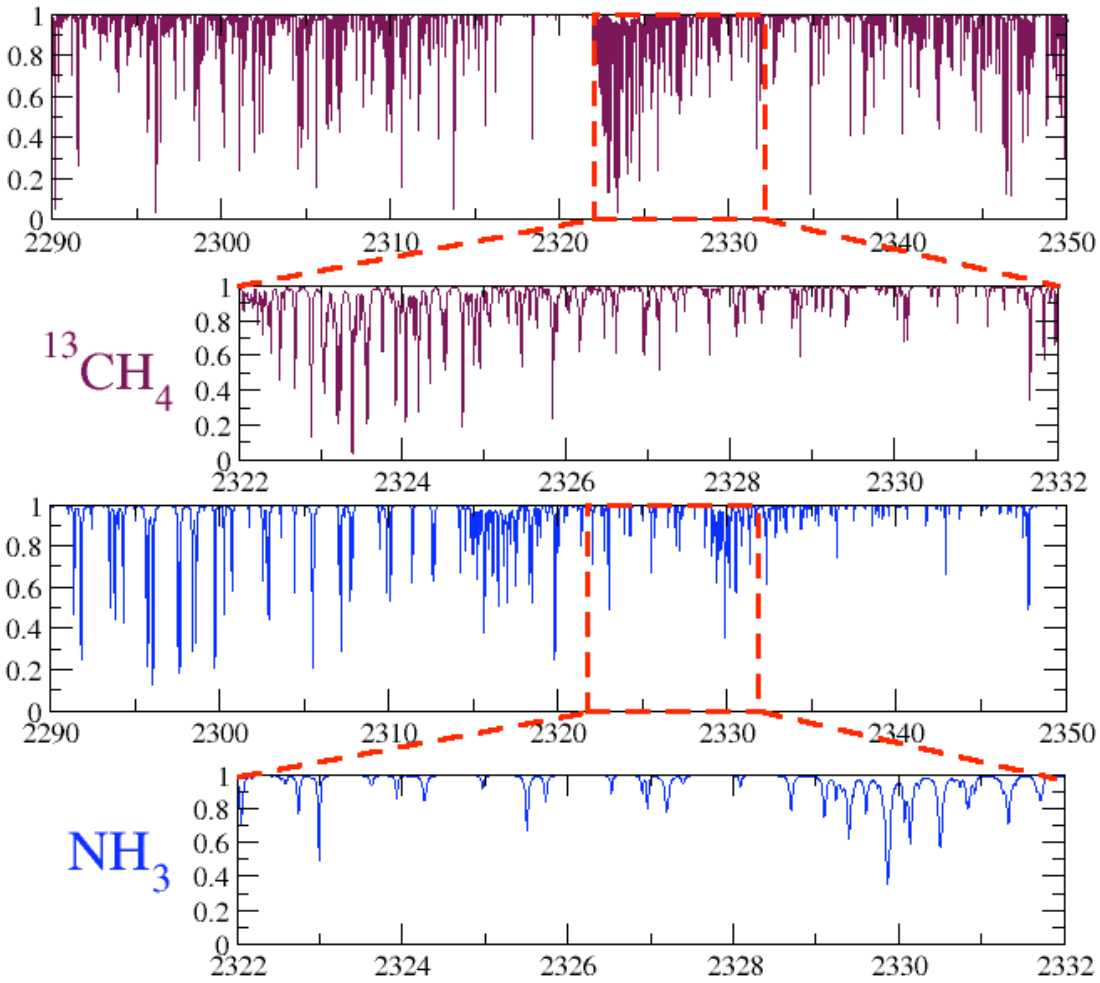
Choice of Gas



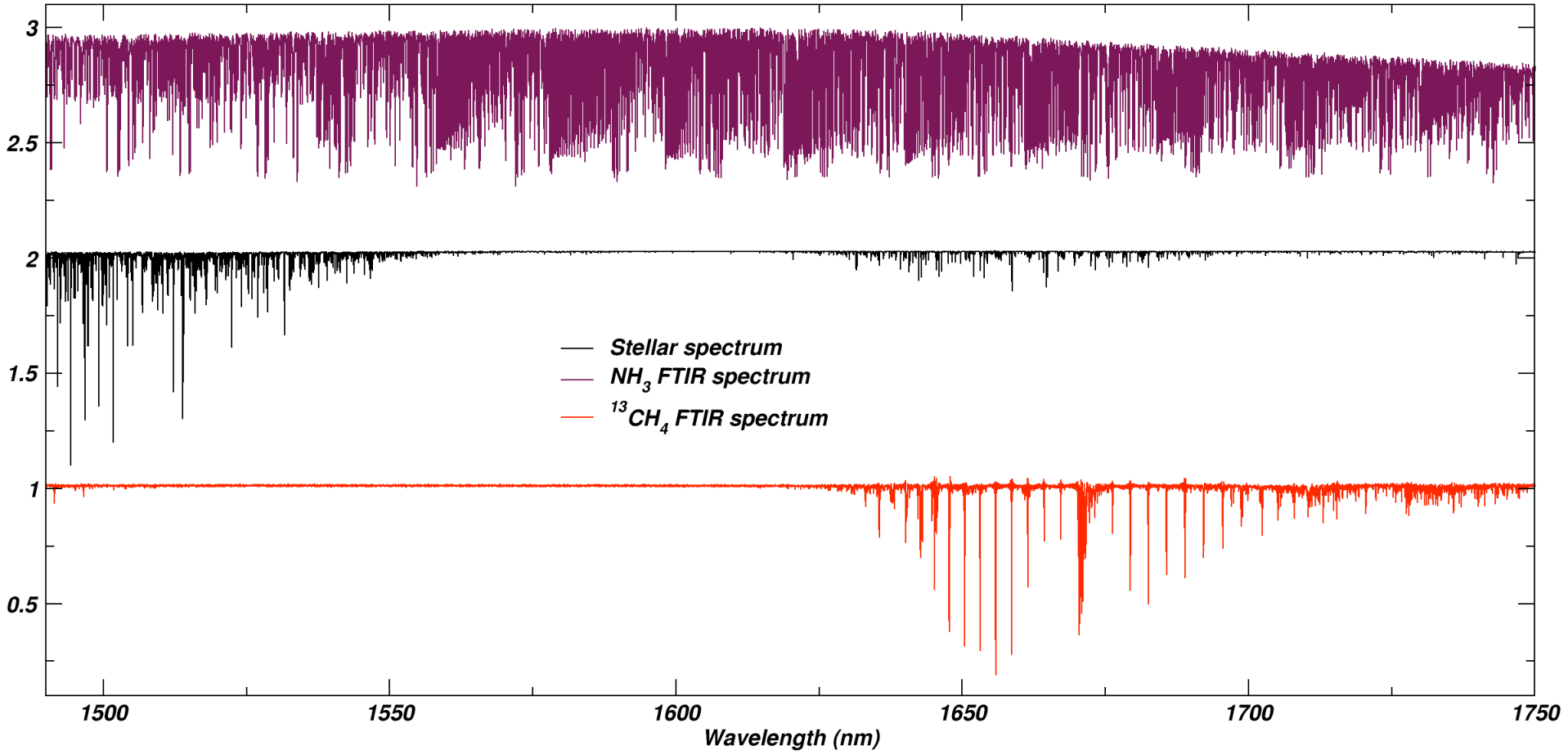
K-BAND


3
2
1
Star (T=3500 K)
NH3 FTIR spectra
13CH4 FTIR spectra
2200
2250
2300
2350
2400
2450
Wavelength (nm)

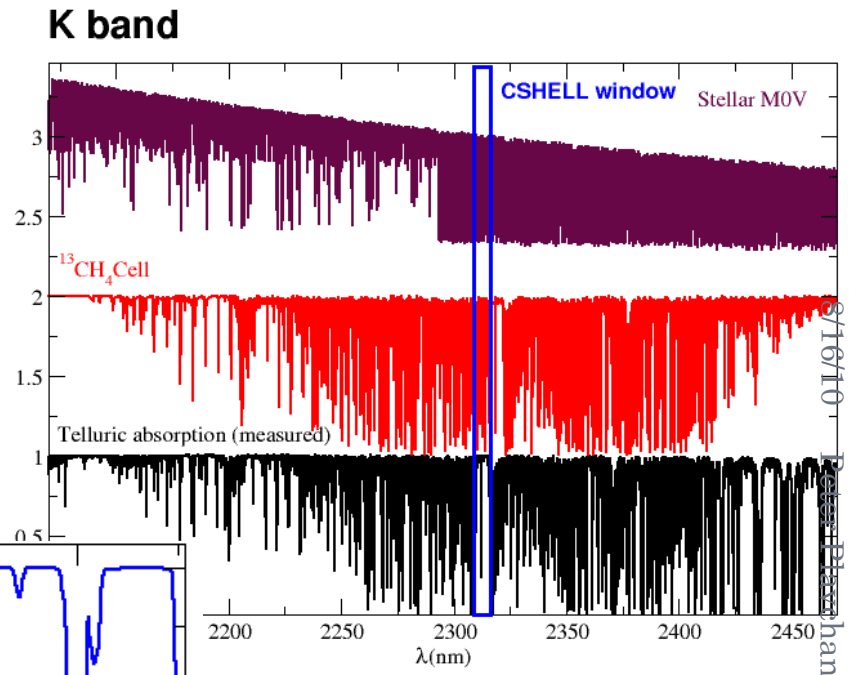
Methane vs. Ammonia: Greater line density

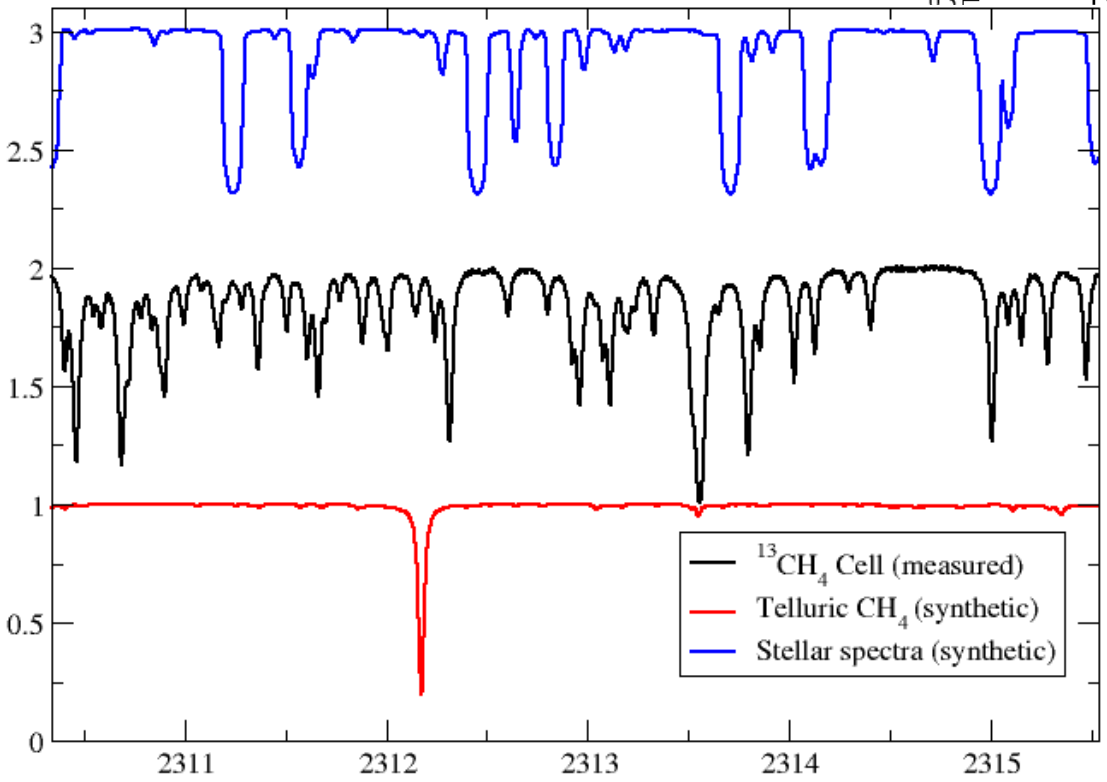


H-BAND


3
2.5
2
1.5
1
0.5
Stellar spectrum
NH3 FTIR spectrum
13CH4 FTIR spectrum
1500
1550
1600
1650
1700
1750
Wavelength (nm)

CSHELL WINDOW



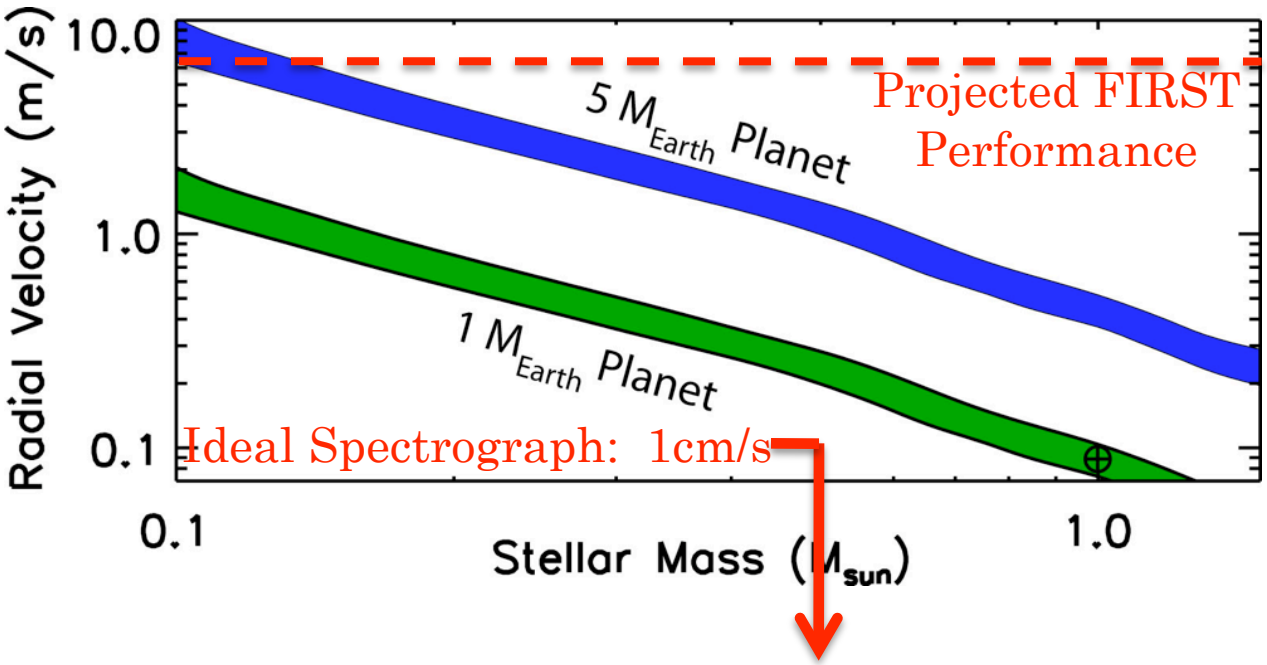


Near Future Plans: IRTF/CSHELL

- September 2010: Assemble and integrate gas cell at IRTF
- November 2010: Transport NIST comb to IRTF for an engineering run with CSHELL instrument
  - Test comb in parallel with absorption cell
  - Characterize CSHELL stability
  - Observation of RV standards
- IRTF Semester 2010B
  - Two science runs with the absorption gas cells
- Gas Cells and FTIR spectra will be available to community to use in 2011A.

Expected RV Sensitivity

- Using an ideal spectrograph, the NIST comb can support a terrestrial planet search out to class G stars
- With CSHELL we could support a terrestrial planet search of ~5M_e planets around M stars – e.g. ~5-10 m/s



Long-Term Future Plans: IRTF

C-SHELL/IRTF RV~30 m/s (@ S/N~150)

R = 46,000
Central Wavelength : 2310 nm (K band)
Number of pixels : 256
Wavelength range : 5 nm

VS.

i-shell/IRTF funded RV~2.5 m/s

R = 70,000
Central Wavelength : 2300 nm (K band)
Number of pixels : 9000
Wavelength range : 250 nm

Long-Term Future Plans: Keck

- NIRSPEC is a R~33k NIR cross-dispersed spectrograph
  - Calibration unit and physical space limitations do not currently permit the addition of an absorption gas cell
- In July 2010, Phase II proposal approved for a design study to:
  - Upgrade NIRSPEC detectors and electronics as a "high priority"
  - PI: Ian McLean & UCLA IRlab

Long-Term Future Plans: Keck

- I put in a Phase I proposal for a design trade study:
  - Upgrade the NIRSPEC detectors and add a laser comb, fiber scrambler + absorption gas cell to the calibration unit
  - Build a new AO-optimized compact R~100k near-IR echelle spectrograph, optimized for near-IR radial velocities
  - Incorporate a near-IR "red arm" into a possible replacement for HIRES.
- Phase II proposal submitted for a design study to replace the NIRSPEC calibration unit to permit the addition of gas cells, fiber scrambler and a laser comb
- Design study is now underway

➔ Simultaneously feed both iSHELL and NIRSPEC with one laser comb

➔ There is potential to utilize and optical + near-IR simultaneous RV monitoring to advance the RV precision done with iodine cells.

The End