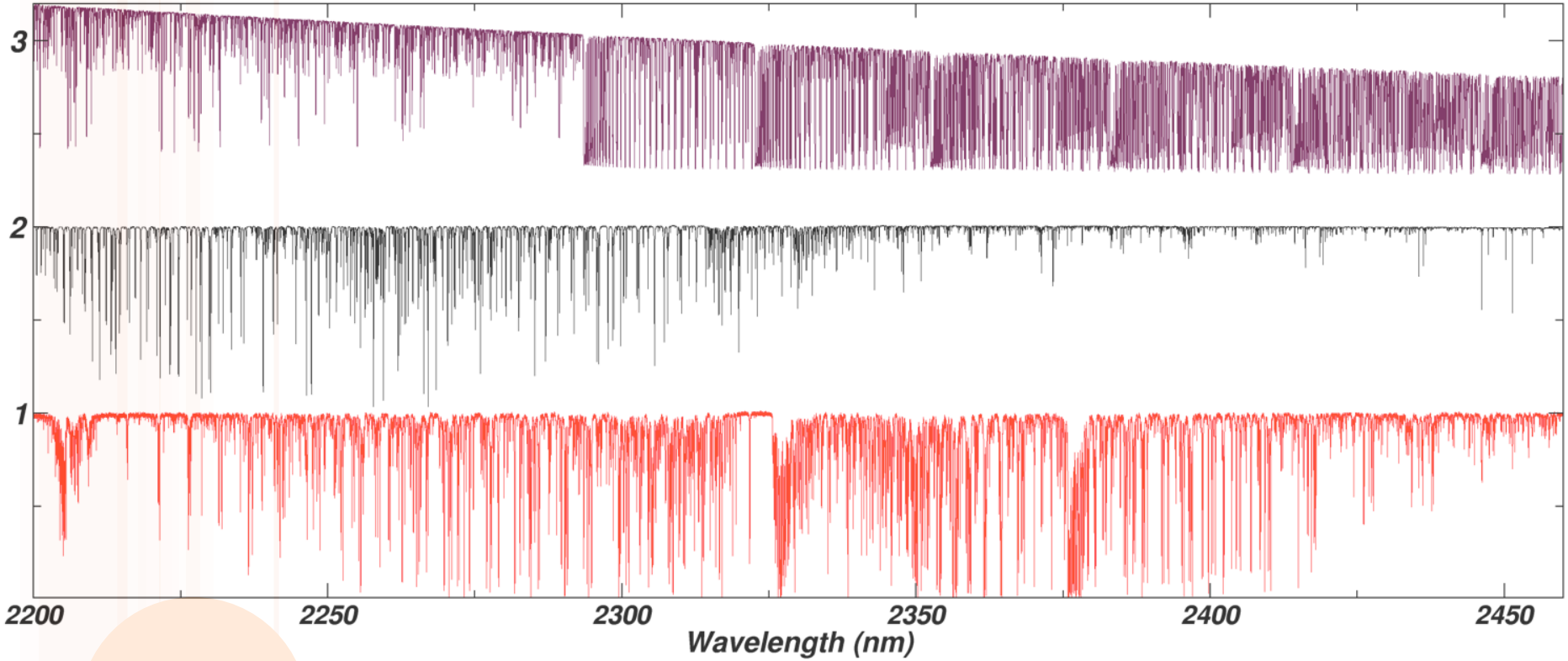


New Near-IR Techniques for Precision Radial Velocities

Peter Plavchan, NASA Exoplanet Science Institute

Funding provided by: NExScI, JPL Center for Exoplanet Science

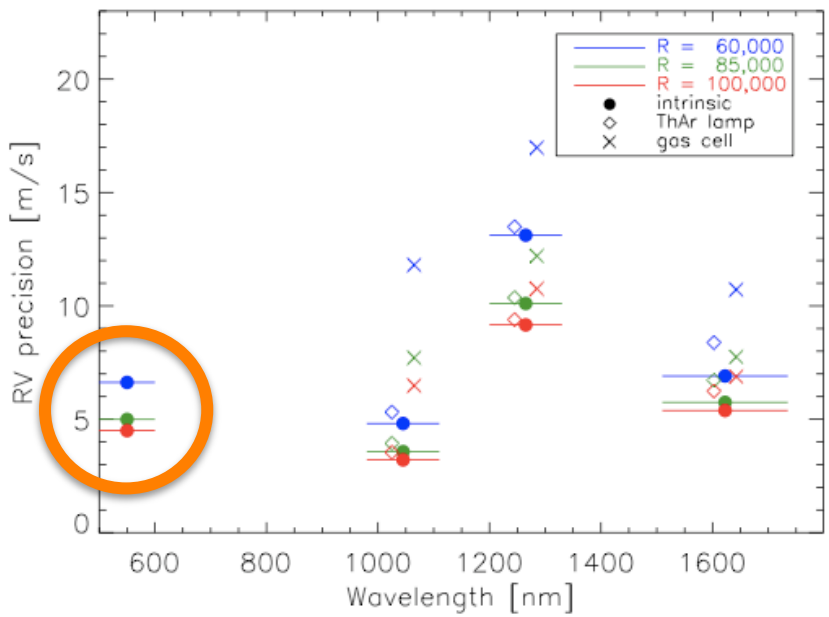
Near-IR Collaboration & Friends	
NExScI/JPL/ Caltech	**Sean Mills,** Peter Gao, Chas Beichman, John Johnson, Bertrand Mennesson, Kent Wallace, Gautam Vasisht, Pin Chen, David Ciardi, Stephen Kane, Kaspar von Braun, Keeyoon Sung, Geoff Bryden, Karl Stapelfeldt Chemists: Edgardo Garcia & Nate Lewis (Caltech) FTIR: Keeyoon Sung, Linda Brown and Tim Crawford (JPL)
Carnegie DTM	**Guillem Anglada**
Georgia State	Russel White, Cassy Davison, Angelle Tanner
UCLA	Mike Fitzgerald, James Larkin, Ian McLean
Lowell	Lisa Prato, Christopher Crockett
IRTF	John Rayner, Morgan Bonnet, George Koenig, Alan Tokunaga
U Colorado / NIST	Steve Osterman / Scott Diddams
Glasswork	Rick Gerhart and Caltech glass shop, Thurston Levy and Glass Instruments Inc, Scot Howell and Mindrum Precision

The M Dwarf Opportunity

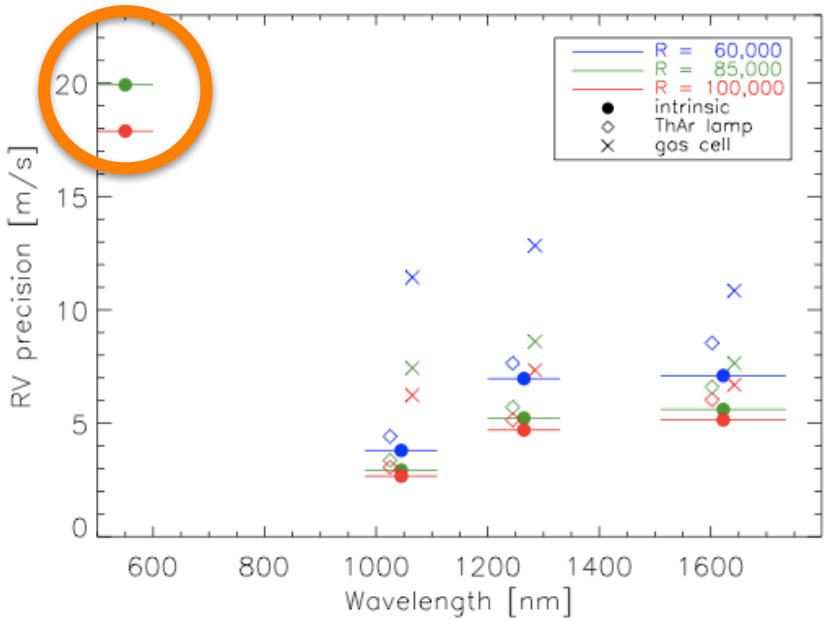
- 70% of main sequence stars are M dwarfs
  - Abundant within 10 pc
  - Habitable zones are closer in with shorter periods, but tidal locking an issue
  - Transits are deeper ~$(R_p/R_*)^2$
  - Radial velocity amplitudes are larger
- Span a factor of ~5 in Mass/Radius, ~10^3 in Luminosity
  - For comparison, all of AFGK stars span a factor of ~2.5 in Radius, ~5 in mass, ~300 in Luminosity
- M dwarfs are red, V-K > ~3.5
  - Only 4 >M4 with V<12

RV content of M dwarfs as a function of wavelength

3500 K ~ M3



2800 K ~ M6

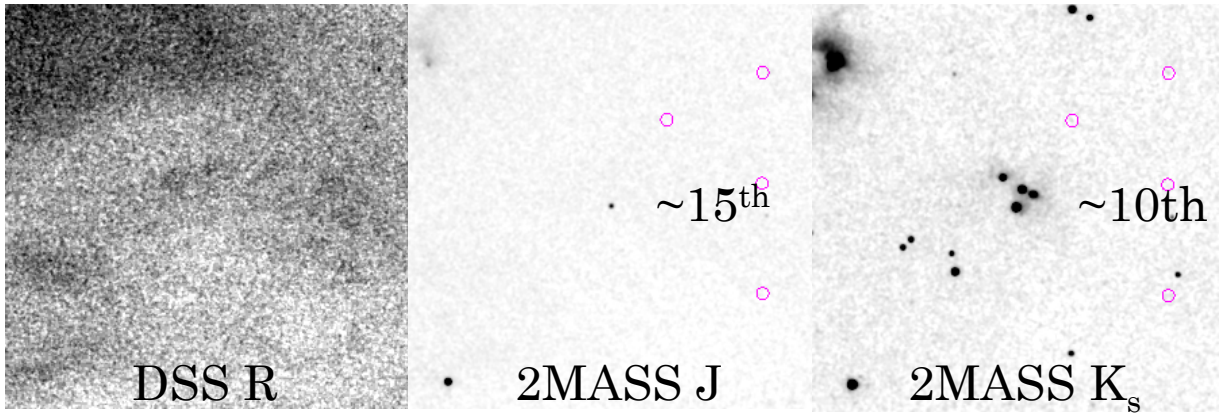


Reiners et al. 2009

Why go to the Near-Infrared for RVs?

- Some non-exoplanet science:
  - With 10 cm/s long-term precision, can initiate a ~10 year survey to directly measure the expansion of the Universe with high-z galaxies
  - With a 30m telescope, can characterize non-Newtonian orbits at the Galactic Center
- "Unconventional" exoplanet science:
  - Embedded YSOs with high extinction → too red for the visible

Rho Oph
~ 2 Myr
A_J=5



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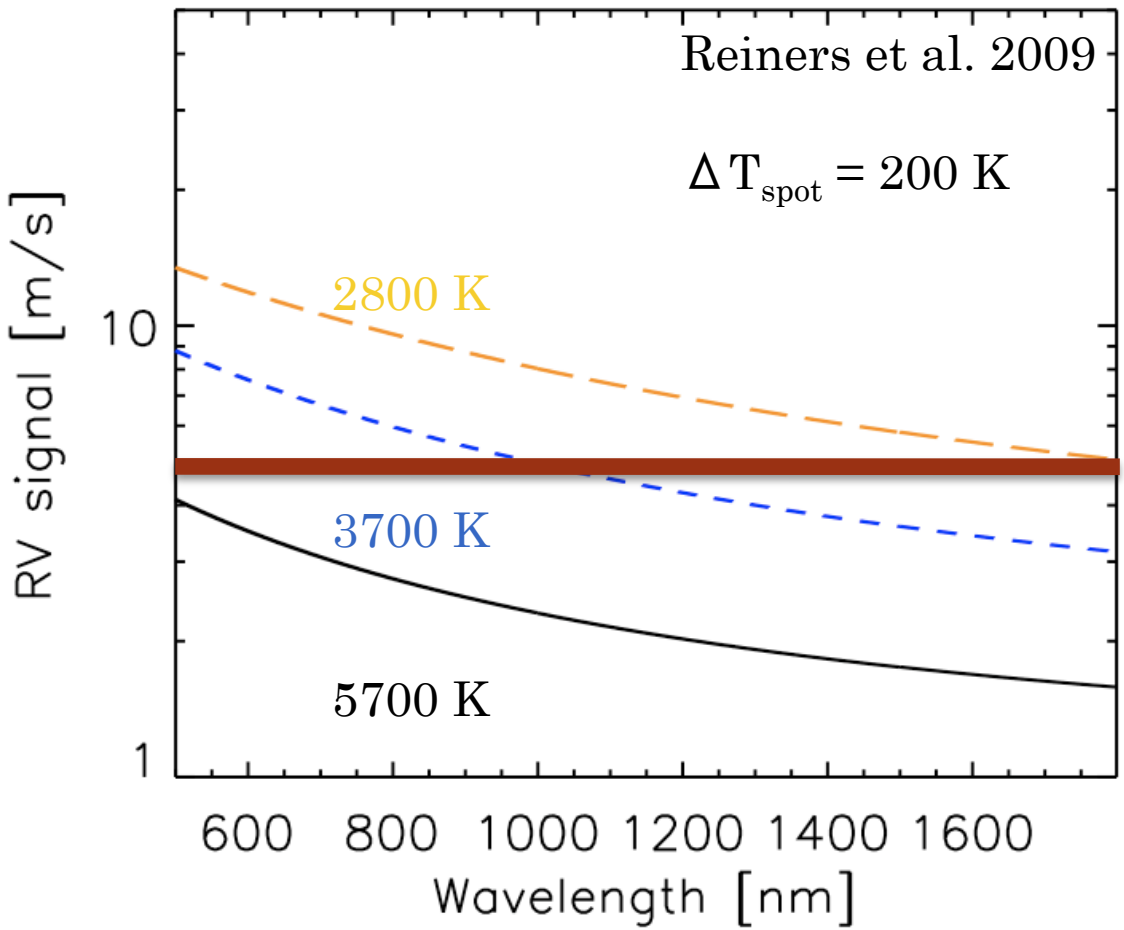
- "Unconventional" exoplanet science:
  - Embedded YSOs with high extinction → too red for the visible
    - Constrain the formation epoch, dynamics, and migration of planets, which must take place before the primordial gas disk dissipates at ~5 Myr, ie:

What is the youngest star with a hot Jupiter?

Why go to the Near-Infrared for RVs?

- Some non-exoplanet science:
  - With 10 cm/s long-term precision, can initiate a ~10 year survey to directly measure the expansion of the Universe with high-z galaxies
  - With a 30m telescope, can characterize non-Newtonian orbits at the Galactic Center
- "Unconventional" exoplanet science:
  - Embedded YSOs with high extinction → too red for the visible
  - Young and/or active stars → Less stellar RV noise in the NIR
  - Combine optical + NIR RVs → Characterize, identify, and perhaps remove sources of stellar RV noise for solar-type main-sequence stars

Single Star Spot RV Noise Toy Model



Posters by Isabelle Boisse, Andreas Quirrenbach

NRC 2010 Decadal Survey

"The first task on the ground is to improve the precision radial velocity method …. With a new generation of high-resolution spectrometers in the optical and near-infrared, a velocity goal of 10 to 20 centimeters per second is realistic."

The US RV community response*: Yes, we can do that.

Signed by over 50 of the US attendees at Penn State RV Workshop, August 2010, representing a significant fraction of the US RV community

Our Road-Map to Addressing the Decadal Survey Challenge

- We are using CSHELL on IRTF as a testbed for several NIR RV techniques, adapted from the visible
  - 17 years old
  - 256x256 detector
  - R ~ 45k
  - single order spanning 5 nm @ 2.3 μm (≈ 13 Å @ 600 nm)

→ Really not what we want to be using long term, but CSHELL an excellent instrument to try new things.

Our Road-Map to Addressing the Decadal Survey Challenge

- We are using CSHELL on IRTF as a testbed for several NIR RV techniques, adapted from the visible
- We plan to apply these techniques to CSHELL's successor, iSHELL (~2014)
  - R~70k
  - cross-dispersed immersion grating
  - ~250 nm spectral grasp

Our Road-Map to Addressing the Decadal Survey Challenge

- We are using CSHELL on IRTF as a testbed for several NIR RV techniques, adapted from the visible
- We plan to apply these techniques to CSHELL's successor, iSHELL (~2014)
- We are conducting a design study to upgrade NIRSPEC on Keck II
  - Leverage NIRSPEC's existing hardware investment (~$8M in 1998)
  - Cross-dispersed, Quasi-Littrow Echelle, R~33K
  - Cryogenic, temperature, pressure, gravity stabilized
  - Can use a couple of tricks to get to R~47K and then R~95K
  - Replace the detectors with H2RG's
    - RV precision currently limited by mid-90s detectors
  - Replace the calibration unit

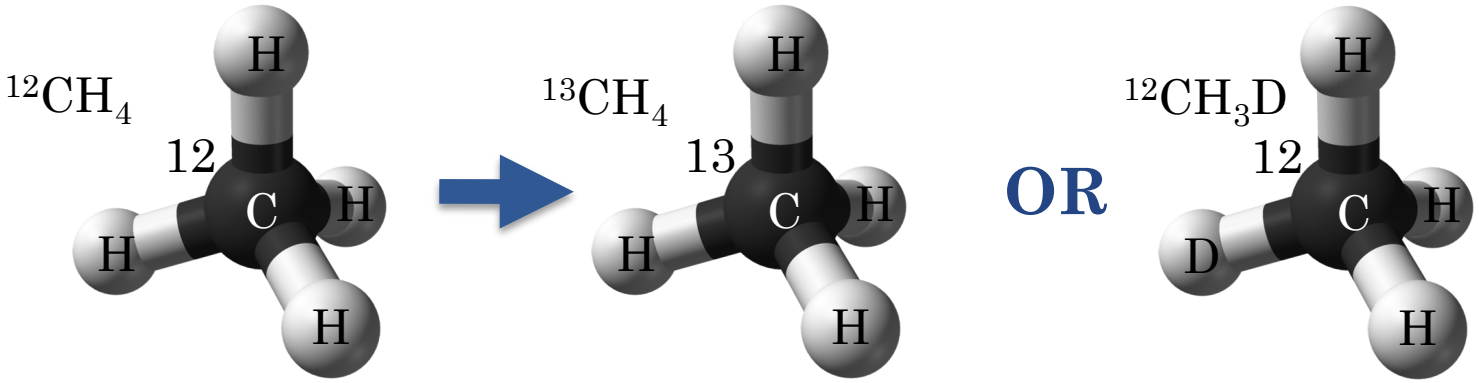
Techniques for Precision RVs

- Historically, 'precision' spectroscopy in the NIR has been anything but precise, lagging behind visible work
- Current and future efforts span ~4 orders of magnitude in precision:
  - Telluric lines: ~25 – 100 m/s (Chris Crockett's talk)
  - Gas absorption cells: ~5 m/s (Bean et al. 2010, this work)
  - Fiber scramblers: non-circular fiber cores (visible to date, this work)
  - Stabilized Fabry Perot etalons:potential for ~10 cm/s (visible to date)
  - Laser combs: potential for ~1 cm/s (visible + H-band: Osterman et al. 2010)
  - Uranium-Neon emission lamps (PATHFINDER + Mahadevan et al.)
  - Adaptive Optics

Choice of gas: METHANE

Why has methane been missed?

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



Choice of gas: METHANE

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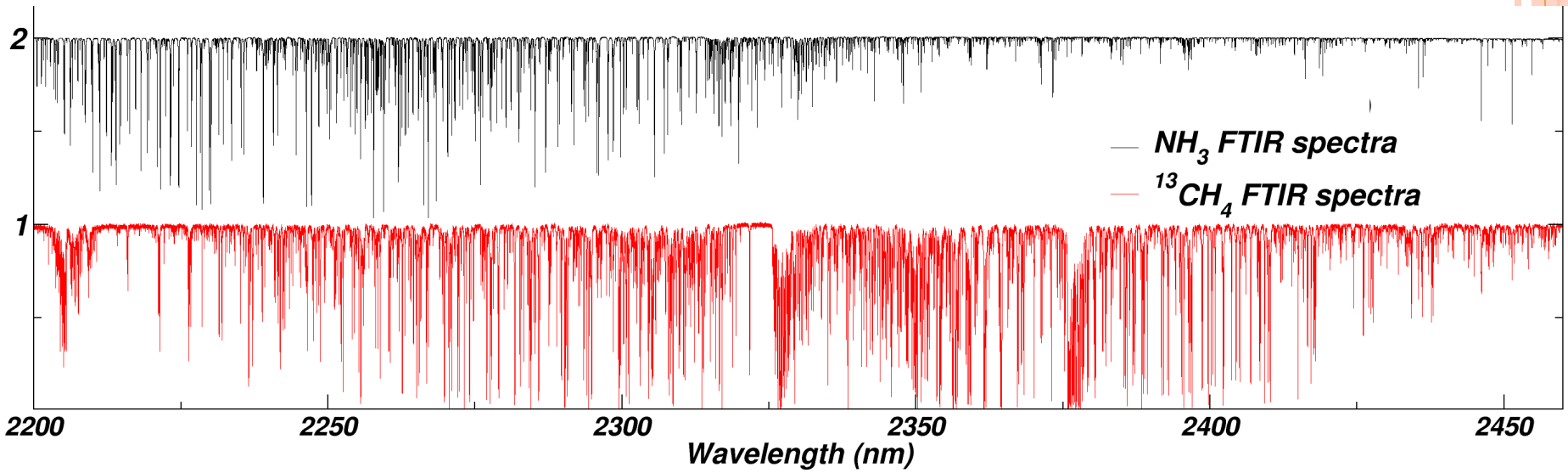
- Telluric methane!
- By using an isotopologue or deuterated methane, the reduced mass changes.
  - The ro-vibrational lines shift by ~10 nm!

→Effectively, a whole new gas.

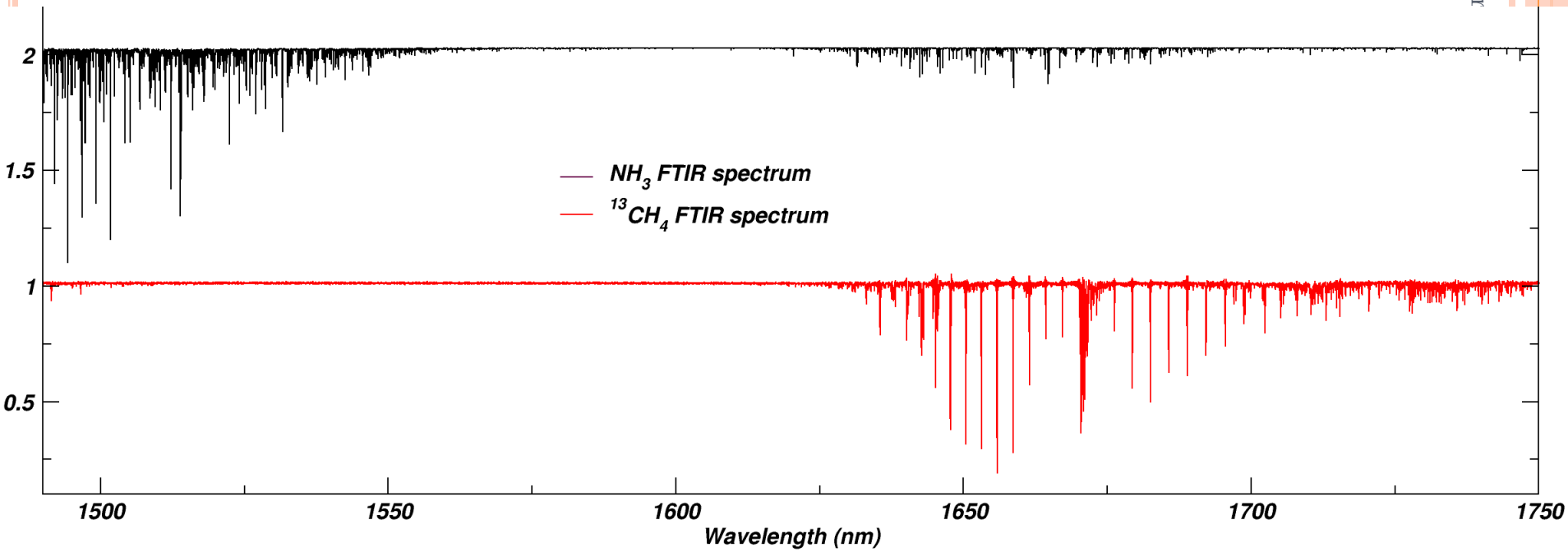
→Can operate at room temperature!

→Greater line density than Ammonia

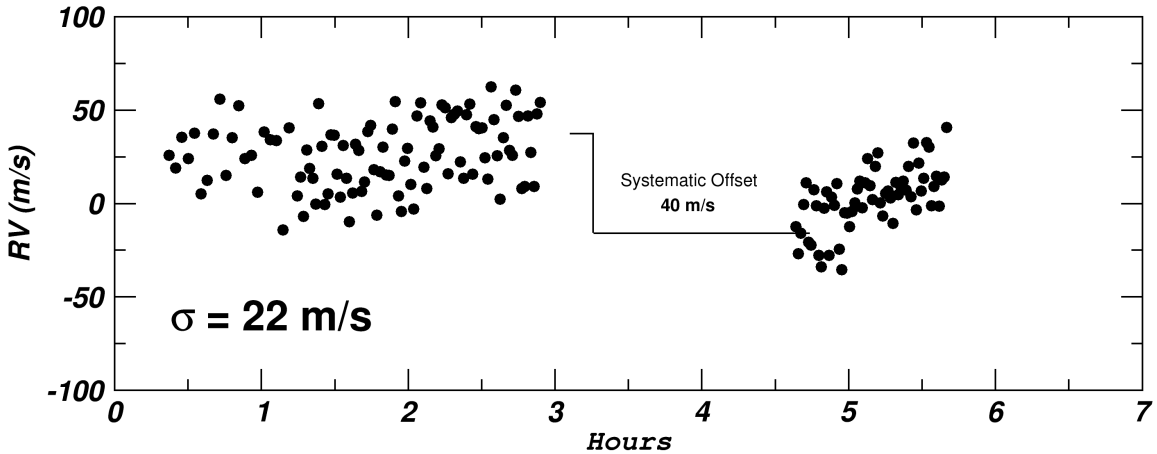
Gas Cell Spectra: K-band



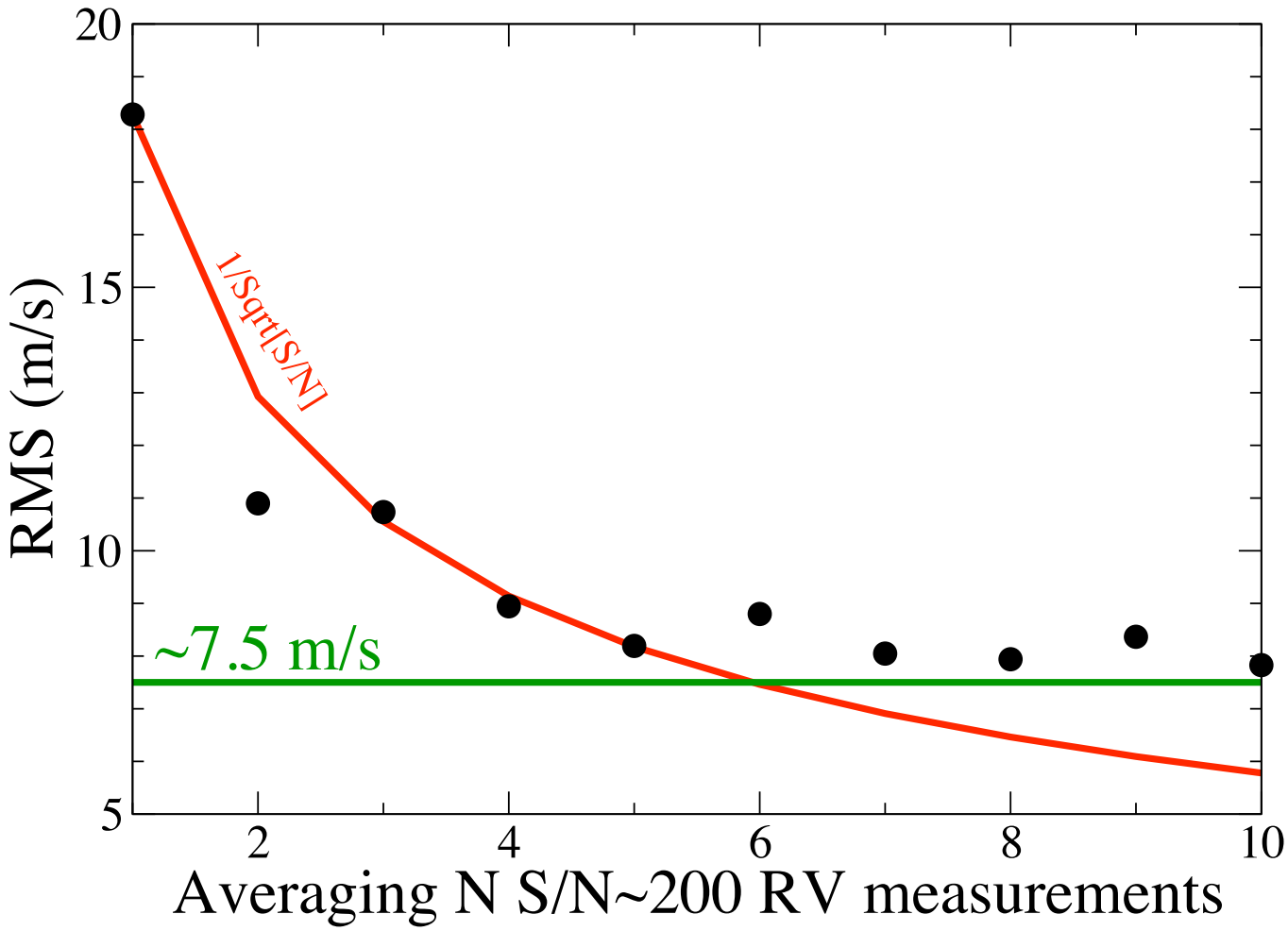
Gas Cell Spectra: H-band



Preliminary Data Analysis



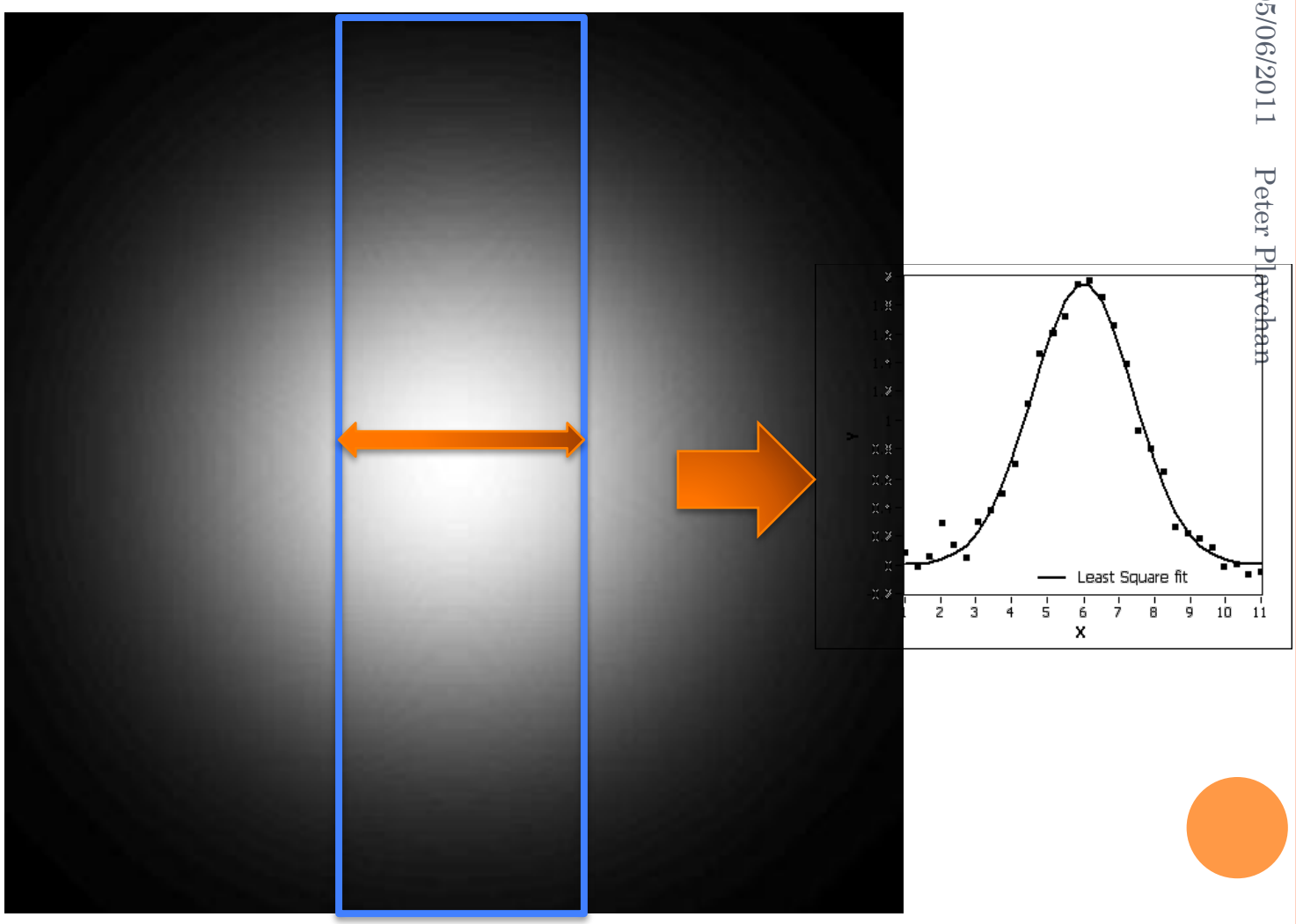
Noise Floor?


20
15
10
5
RMS (m/s)
1/Sqrt[S/N]
~7.5 m/s
2
4
6
8
10
Averaging N S/N~200 RV measurements

Current Status

- Ongoing survey of young, low mass stars in nearby moving groups, previously neglected by visible RV surveys
- Technique & first light paper in prep.
- Data pipeline refinement ongoing
- Systematic RV jumps indicate we need to obtain better empirical stellar templates
  - 3 hr CRIRES proposal submitted
  - This is a solvable problem
- Once resolved, intra-night measurements point to long-term precision of ~20-40 m/s, given sufficient S/N, corresponding to sensitivity to sub-Jovian mass planets
- With ~250nm spectral grasp, iSHELL will improve the RV precision obtainable with our gas cell by a factor of ~7, to ~3-5 m/s
- Gas Cells and FTIR spectra available to the community to use!

Limiting RV Noise Source: PSF stability



Non-Circular Core Fibers

Efficient Modal Scrambling
Low Focal Ratio Degradation
Visible → NIR

Fiber Scrambler

- Negligible throughput loss with our scrambling technique
- Improves PSF centroid and FWHM stability by factors of >10
- Improves corresponding LSF stability without stabilizing the spectrograph
- Easier to model LSF and improves resulting RV precision
- Take to IRTF in ~fall 2011.

Summary

- There are a lot of interesting science cases enabled by a precision RV NIR spectrograph beyond looking for planets around M dwarfs
- We can borrow a lot of the precision RV techniques developed in the visible, and adapt them to the NIR
  - Gas cells, spectrograph stabilization, fiber scramblers, laser combs, etc.
- We are actively testing several of these techniques now
- We have laid out an instrumentation roadmap for CSHELL→iSHELL→upgraded NIRSPEC that leverages existing hardware investments.