

Astronomy of Exoplanets with Precise Radial Velocities

Workshop Summary

Dave Latham

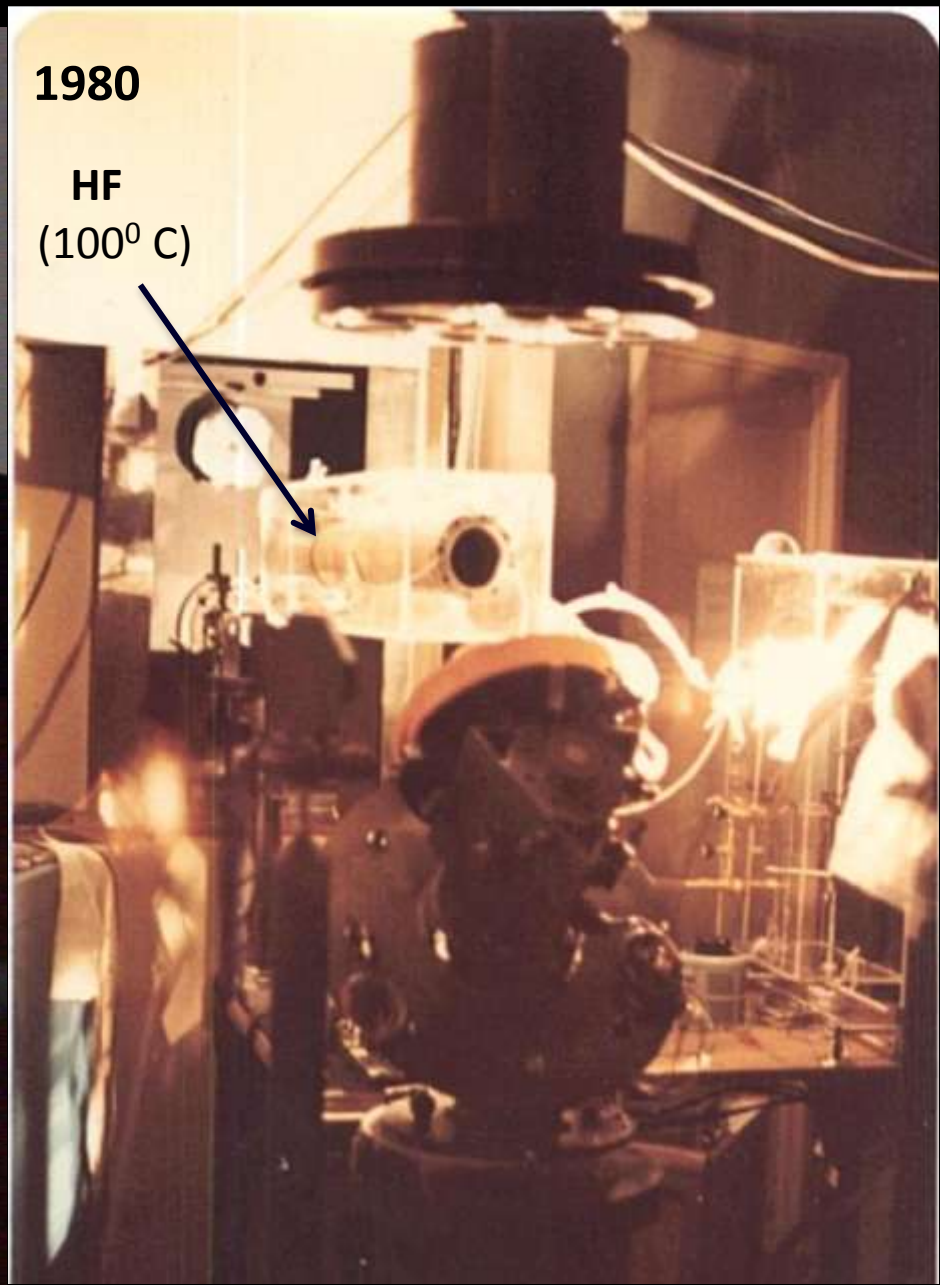
Harvard-Smithsonian Center for Astrophysics

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Goal of the workshop:
Look towards the future.

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Look towards the future.

But first a little historical context



Reticon self-scanned Silicon diode arrays

256

1024

1872 15 x 750 μm



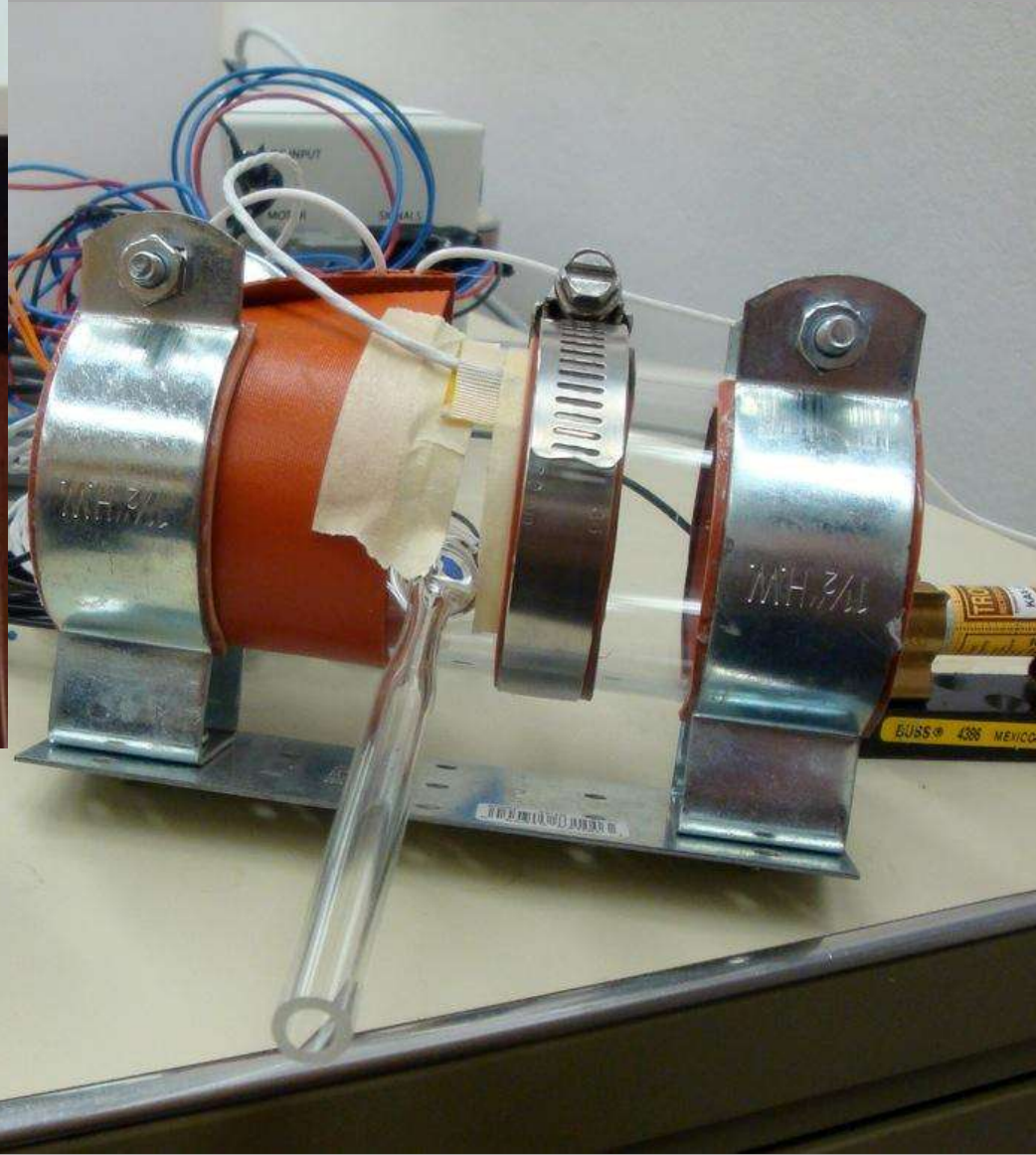
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Look towards the future.

Reality of the workshop:

- Moving into the Infrared
 - 12 oral, 8 poster
- Understanding/improving the visible
 - 14 oral, 9 poster
- General understanding
 - 15 oral, 10 poster

Why so much interest in the IR?

- The pendulum has swung towards M dwarfs
 - Host star is less massive → larger K
 - Habitable Zone closer in → larger K
 - More likely to transit, deeper light curve dip
 - JWST spectroscopy of rocky planet atmosphere ...
- <10 m/s velocity precision now demonstrated
 - CRIRES: vB10 (Bean), TW Hya (Figueira)
 - maybe 1 m/s is possible ...



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Achieving metre per second precision with UKIRT Planet Finder

- Metre per second RV precision is equivalent to <0.001 of a pixel
- Large wavelength coverage in single exposure
 - Hundreds of spectral features
- Highly stable instrument
 - Guiding at fibre input
 - Fibre scrambling
 - Fibre agitator – reduces modal noise
 - No other mechanisms (fixed focus)
 - Floor mounted instrument – ground based
 - Under vacuum – removes effects of air turbulence
 - Located in Coude room or instrument enclosure
 - Less than 2K annual temperature variation
 - Active temperature stabilisation
 - $\pm 0.05\text{K}$ over 24 hours
- Combination of these measures plus long exposure integration



New Instruments ...

- Pathfinder on HET
- UKIRT Planet Finder
- NAHUAL on GranTeCan
- CARMENES at Calar Alto
- FIRST/IRET at APO



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Understanding/improving the visible

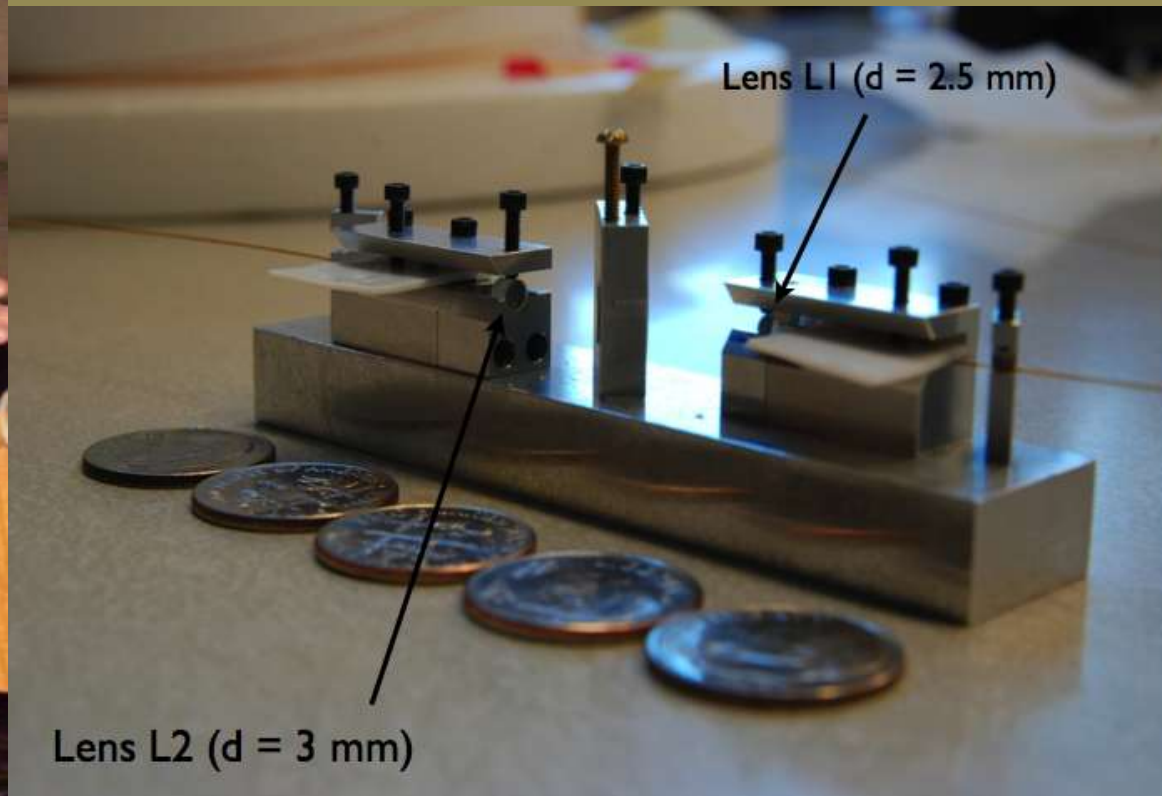
- Error budget – what dominates?
 - HIRES torture tests, fiber scrambler



HIRES RV Errors

- Guiding
- Zonal aberrations / vignetting
- Fibers (The Solution!)
- Scattered light - HIRES
- Sky subtraction for faint targets

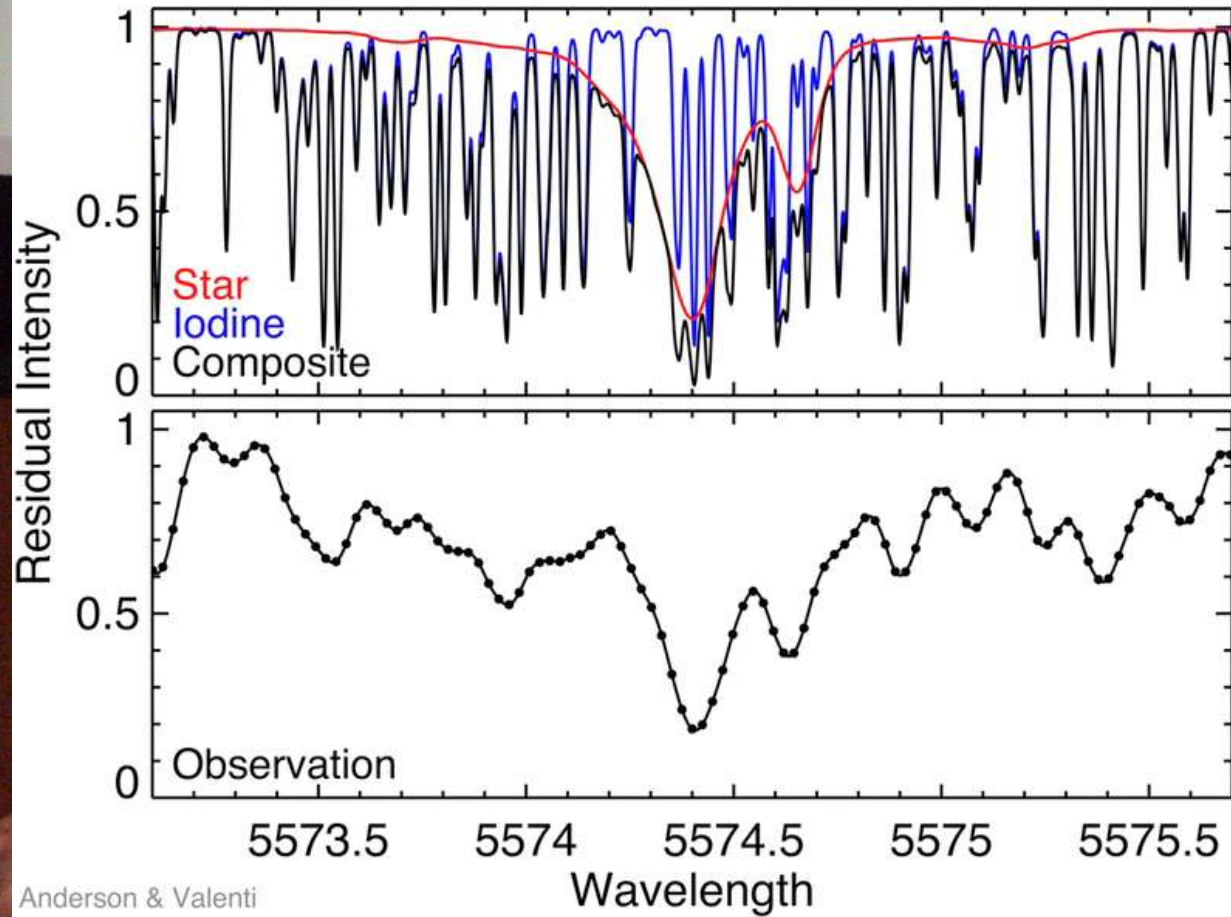
Scrambler for HIRES



Understanding/improving the visible

- Error budget – what dominates?
 - HIRES torture tests, fiber scrambler
 - Data reduction – New ways to reduce HIRES data

Template from iodine exposures



Understanding/improving the visible

- Error budget – what dominates?
 - HIRES torture tests, fiber scrambler
 - Data reduction – New ways to reduce HIRES data
 - Data reduction – ongoing HARPS development

“Keep on moving”

Improvements since 2003:

- Remove atmospheric effects
- Improve barycentric correction
- Correct ThAr lines catalog
- Improve and stabilize wavelength calibration
- Correct for ‘color’ (continuum) variations
- Correct for lamp aging
- Remove background and contamination
- Improve cross-correlation and masks
- Integrate laser frequency combs and Fab
- Blaze function correction

and ... **continuously debug SW!**



Next level of data reduction



Understanding/improving the visible

- Error budget – what dominates?
 - HIRES torture tests, fiber scrambler
 - Data reduction – New ways to reduce HIRES data
 - Data reduction – ongoing HARPS development
 - HARPS hardware projects
 - Better fibers, etalon and laser comb λ calibration

Still Learning How Fibers Work

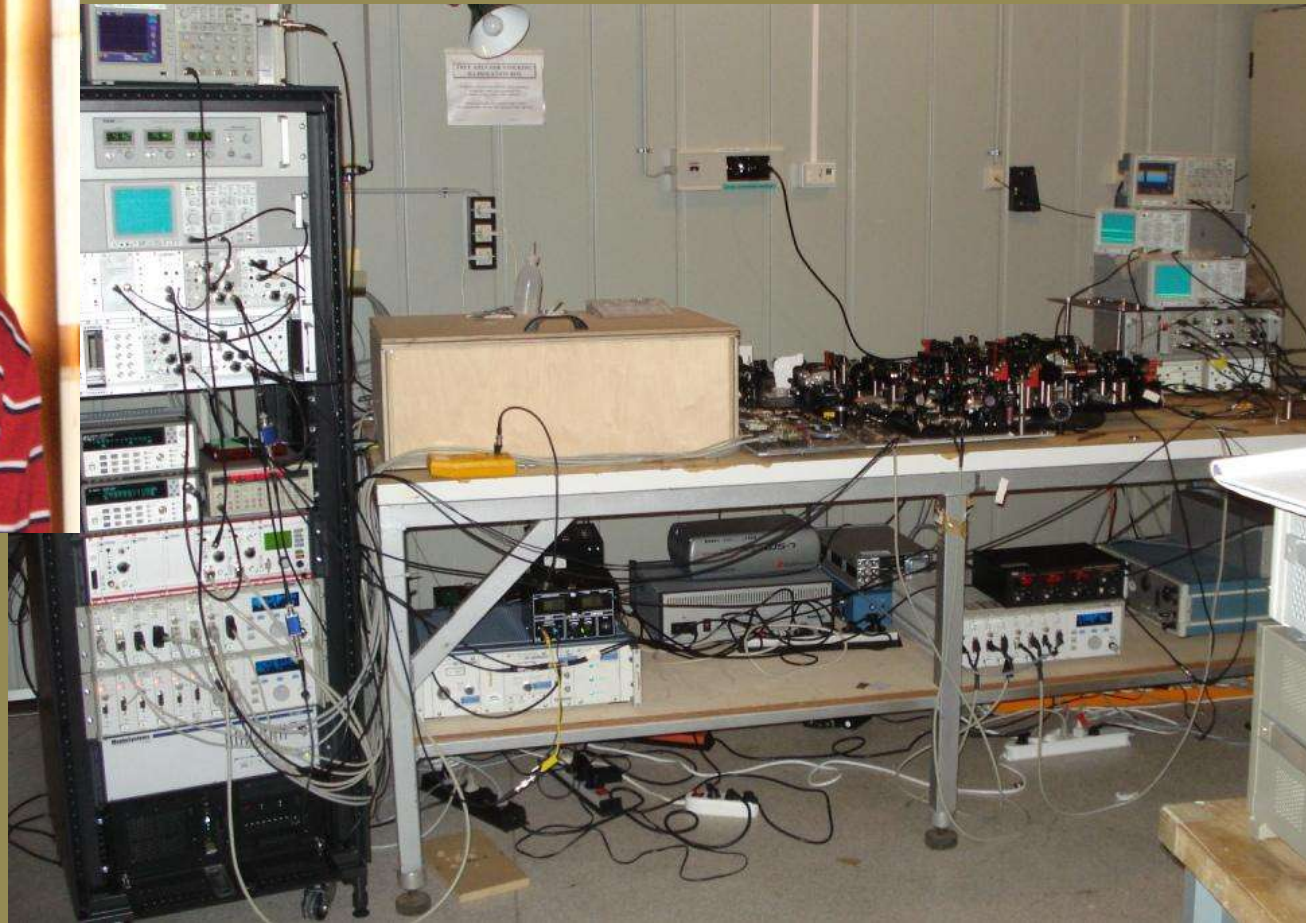
- Tutorial from Larry
- Near field and far field both matter
- Square/hexagonal fibers hold promise
- Avoid pupil illumination

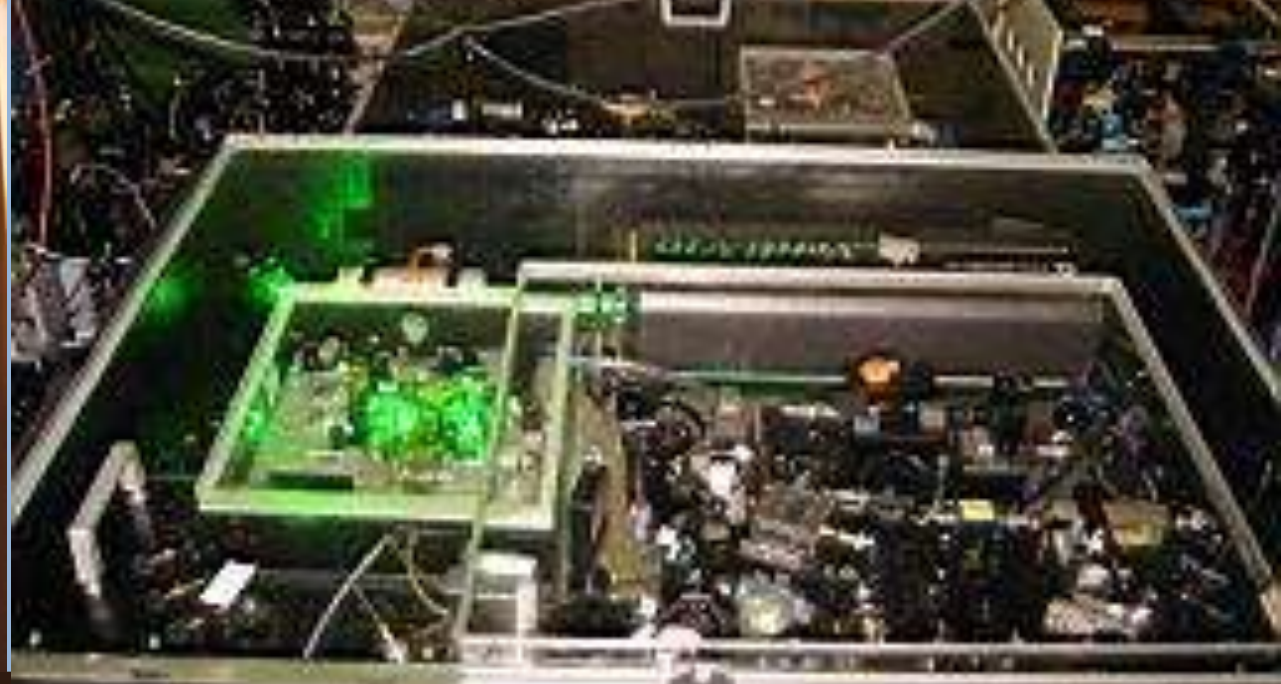


Still learning to improve combs

- How to broaden the spectral range?
- How to get stable suppression of sidelobes?
- Etalon calibrated with comb is appealing

La Silla 2009





What is the future of CMOS for PRV?



Understanding/improving the visible

- Error budget – what dominates?
 - HIRES torture tests, fiber scrambler
 - Data reduction – New ways to reduce HIRES data
 - Data reduction – ongoing HARPS development
 - HARPS hardware projects
 - Better fibers, etalon and laser comb λ calibration
- Stellar contributions – seven presentations
 - Debra, Jason, Isabelle, Lucianne, Valeri, Nuno, Xavier



Telluric Lines – Friend or Foe?

- Progress in using telluric lines
 - O₂ lines corrected for winds → 2 m/s (Pedro)
- Progress in models for telluric lines
 - Use or remove? (Chad, Cullen)

Calculating Telluric Models

Line Parameters



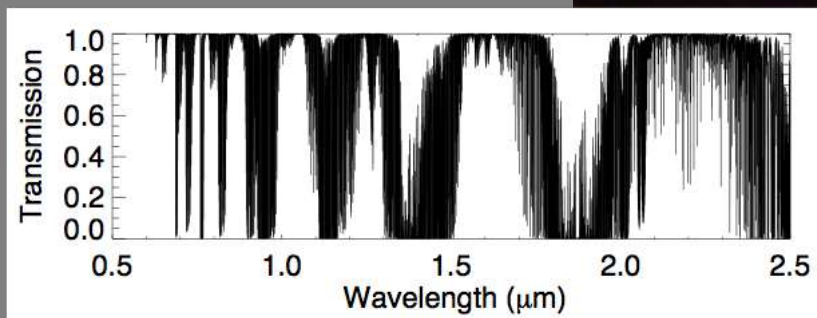
Center, Intensity, Pressure Shift, Temperature Shift, Energy, Width from Theory and Experiment



Climatology



Winds, Temperature, Pressure, Composition



New Visible Instruments ...

- Carnegie Planet Finder at Magellan
- EXPERT at KPNO
- Chiron at CTIO
- PARAS on Mount Abu
- Harvester on Palomar
- ESPRESSO on VLT 10 cm/s
- GCLEF on GMT
- CODEX on ELT 1 cm/s



Characterizing the Host Stars

- Asteroseismology to the rescue
- But don't forget the role binaries play



Thanks to the Panel



Thanks to Our Hosts!

