The Planet Harvester Spectrometer

PRV Behind a Next-Generation AO System

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Decadal Response

- With the demise of SIM, the task of identifying “habitable” planets is on RV surveys alone

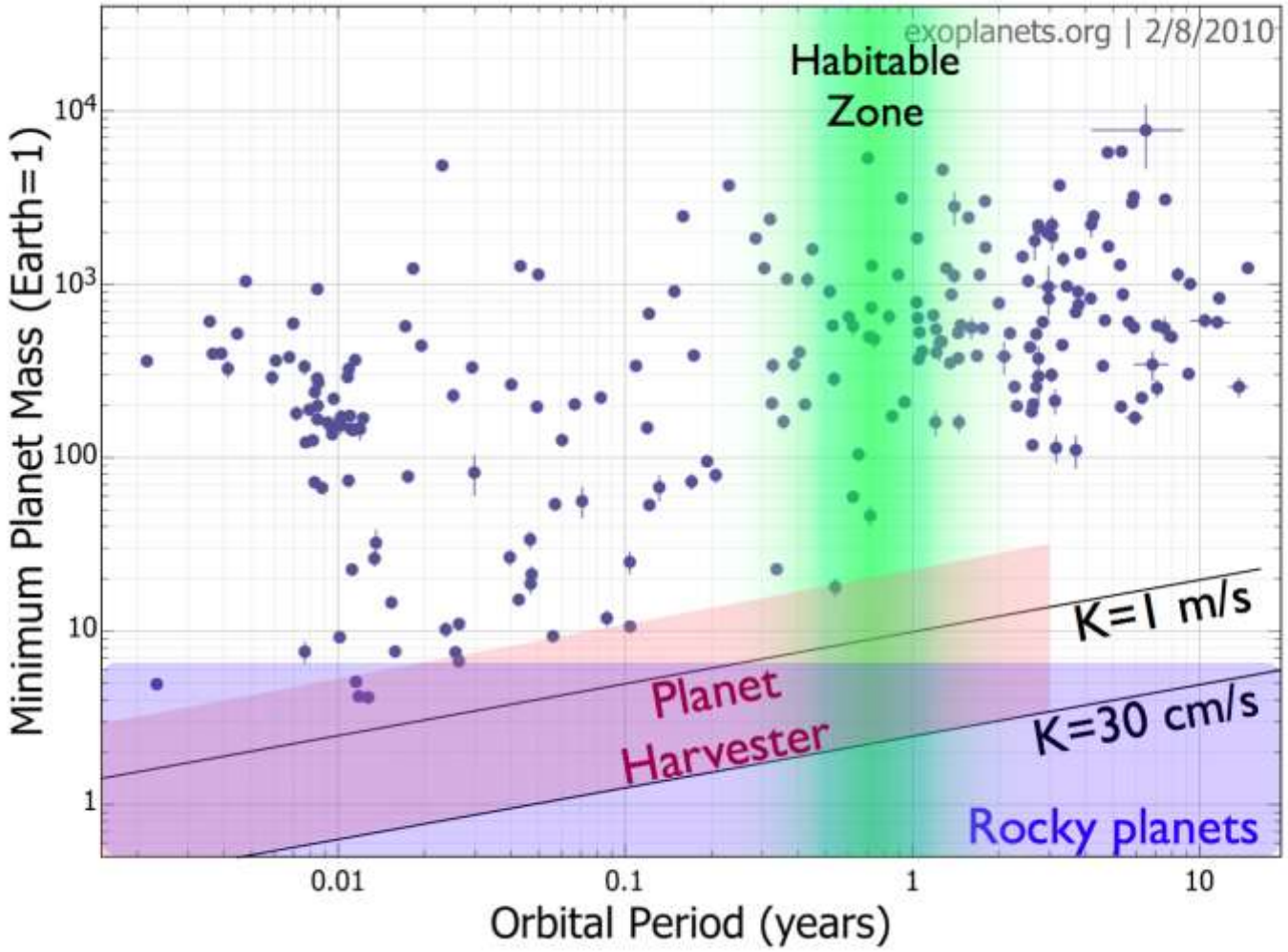
  “It will be important to make strategic investments in new ground-based capabilities during the coming decade. One important component will be the aggressive development of ground-based high precision radial-velocity surveys of nearby stars at optical and near-infrared wavelengths"

- The next generation of exoplanet studies requires the next generation of instrumentation

The Harvester Project: Science Goals

- Greatly expand and refine the estimate of eta_Earth, specifically for P = 100 - 400 days
- Identify nearby census of rocky planets
- Identify promising targets for JWST and other future space missions

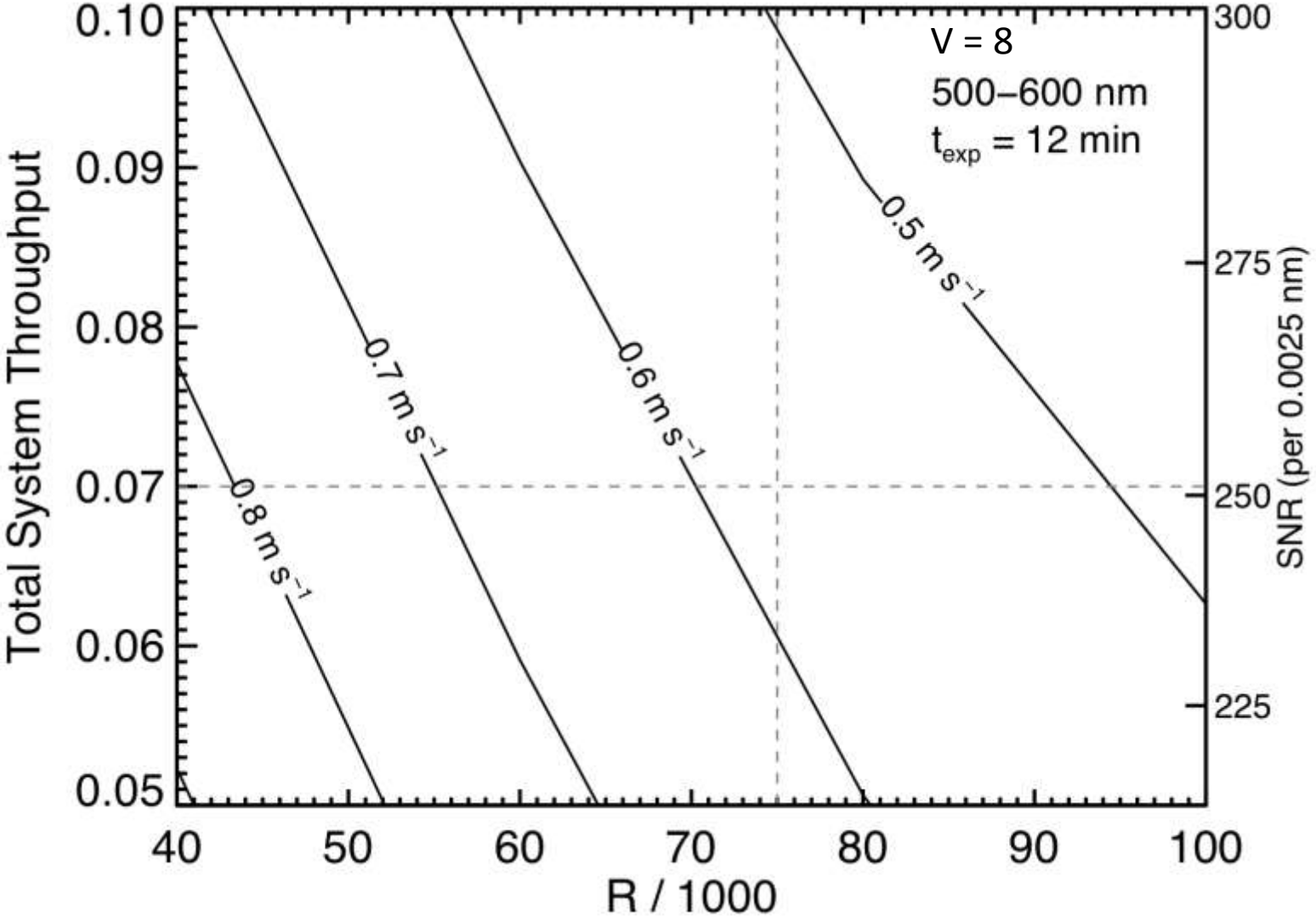
Harvester Discovery Space



Requirements

- A purpose-built, RV spectrometer
  - R > 70,000
  - Stable line-spread function
  - Stabilized Temperature and Pressure
  - Stable mechanical setup
  - Stable guiding
- Many nights (> 50) on a 4m-class telescope (The Palomar 5m will do just fine)
- Treat this scientific endeavor as a "physics experiment" rather than a multi-purpose observing program.
  - Not a mulit-purpose instrument
  - Single-minded approach to identifying nearby, rocky planets in the "habitable zones" of nearby Sun-like stars

RV precision vs. Resolution



The State of the Art

- The vast majority of exoplanet discoveries have come from Doppler methods
- Two techniques used for all planets that have been detected or verified with Doppler methods
  - Iodine Cell
  - Stable-platform (HARPS)

Defining Some Terms

- Line Spread Function (LSF)
- Instrumental Profile
- PSF (my sloppy terminology, please use context)

The Iodine Cell Technique

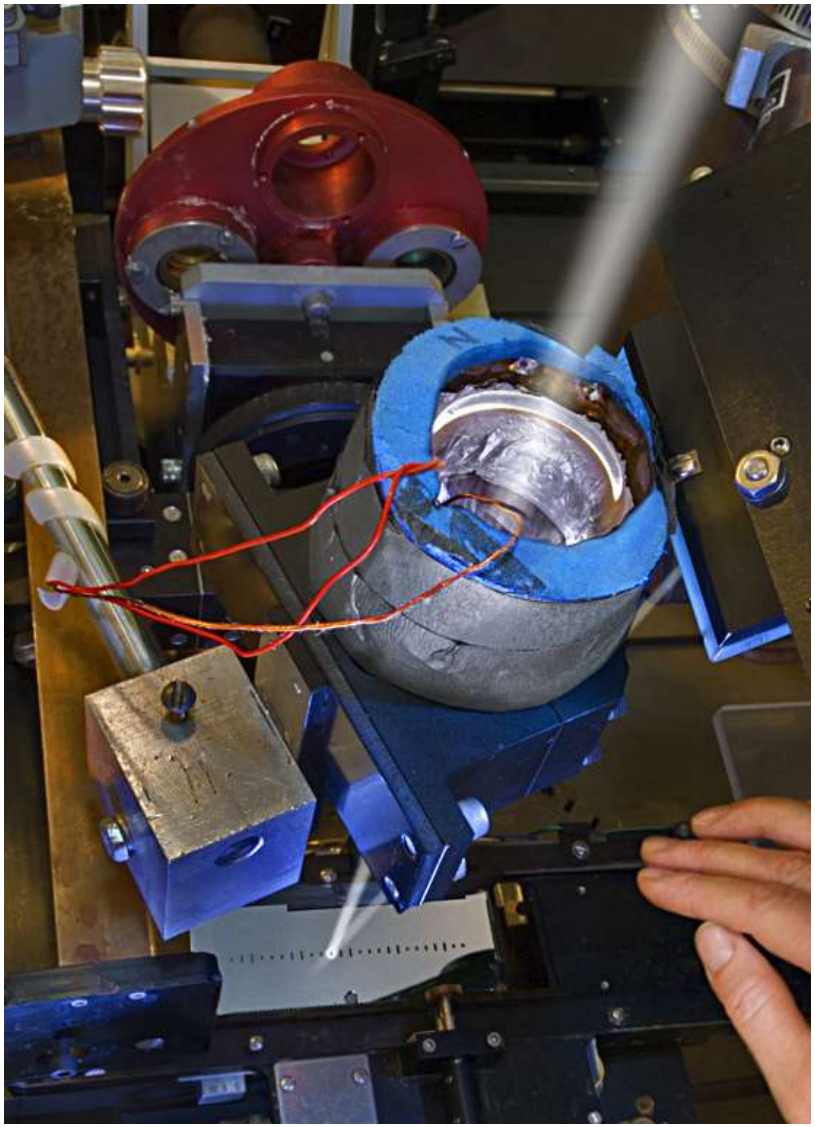
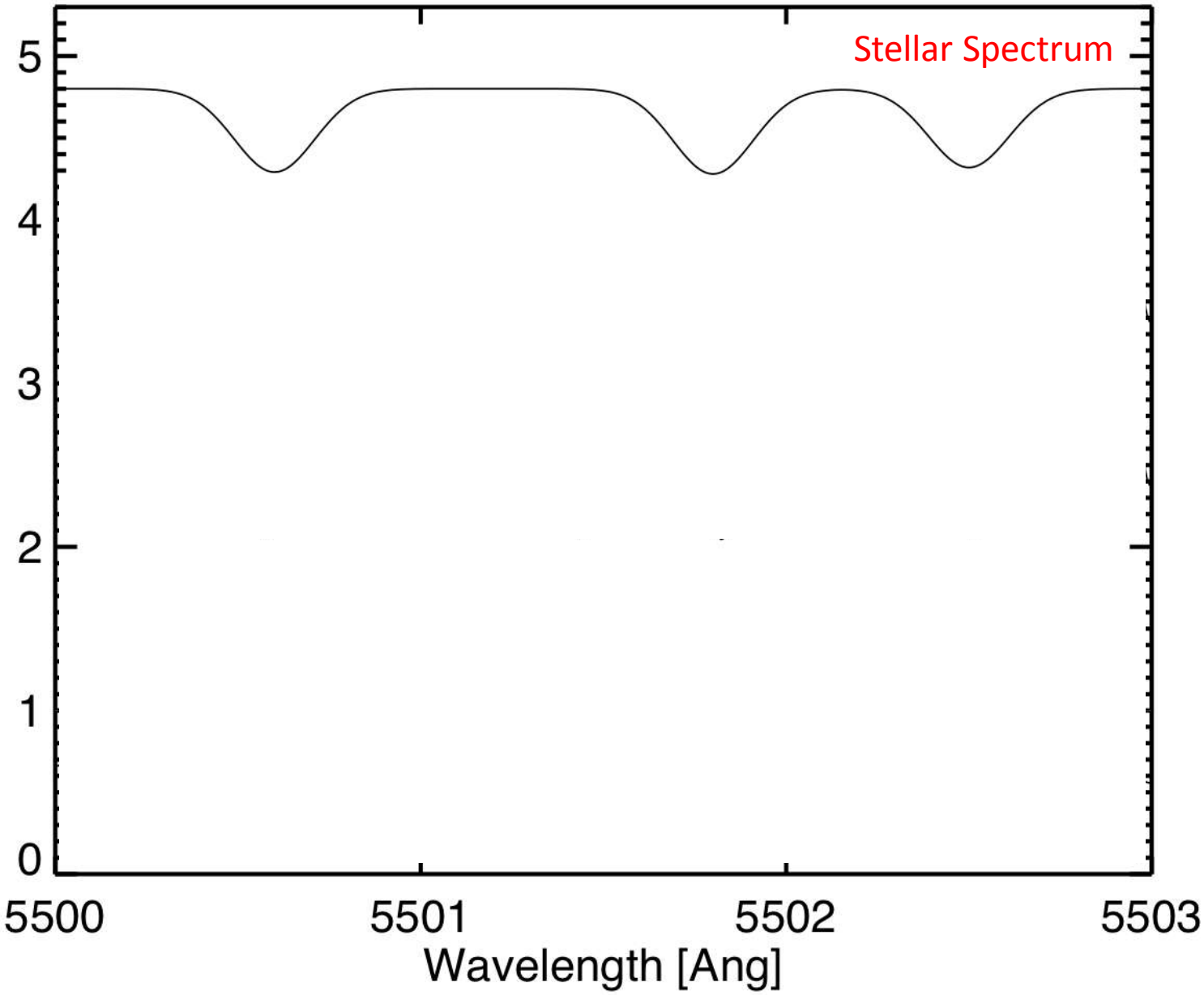
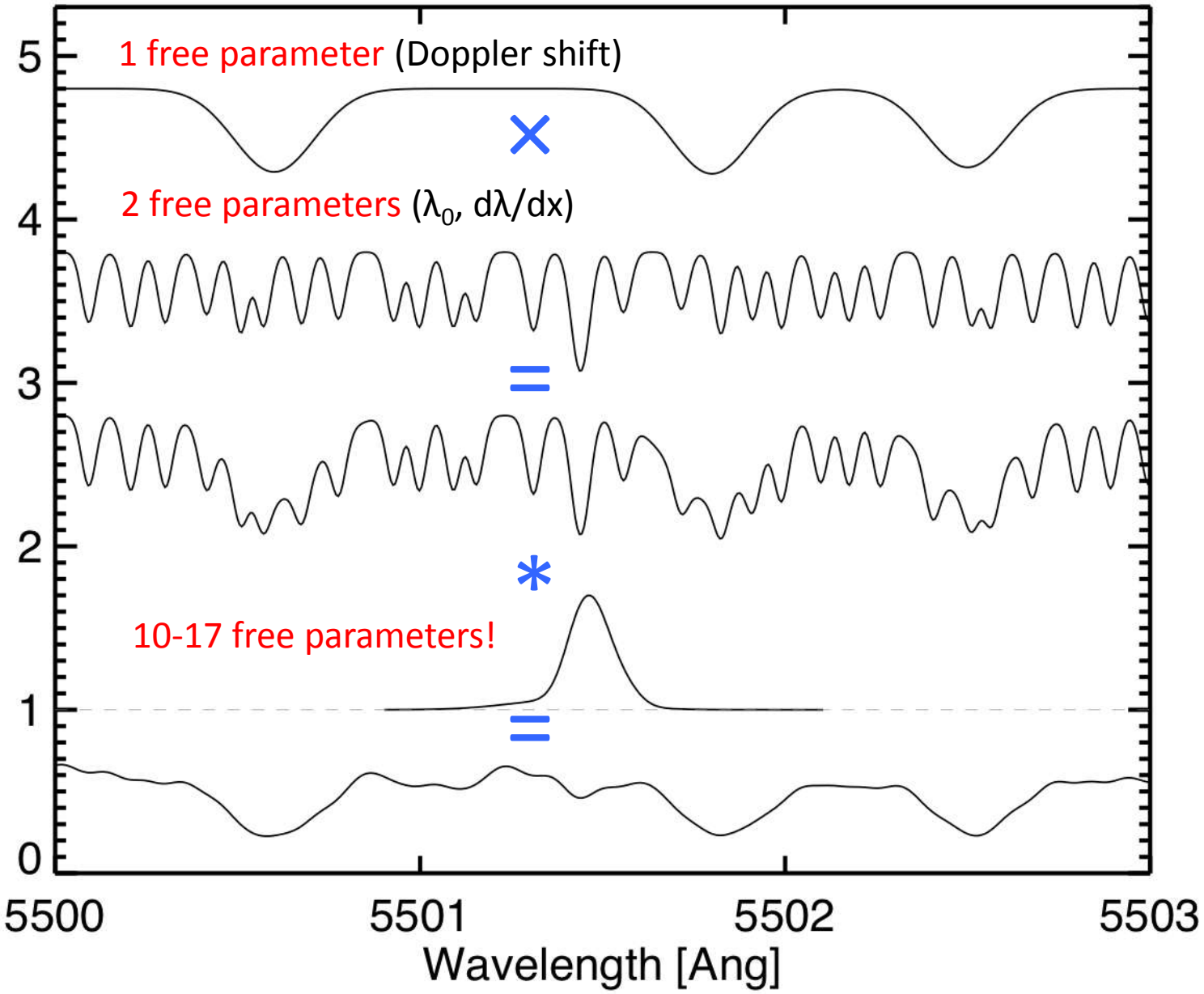


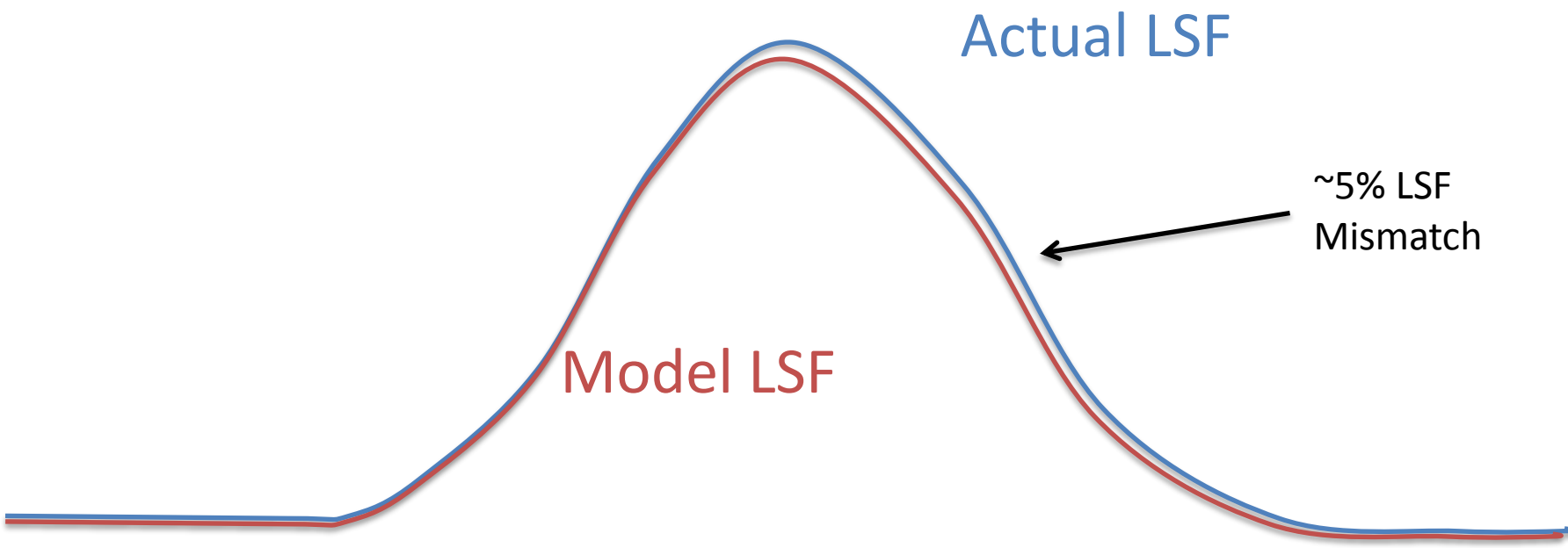
Photo courtesy of
Laurie Hatch

- High-resolution echelle spectrometer
- Pyrex cell containing gaseous iodine
- Temperature controller
- Actuator
- Duct tape


Stellar Spectrum
5
4
3
2
1
0
5500
5501
5502
5503
Wavelength [Ang]


1 free parameter (Doppler shift)
2 free parameters (λ0, dλ/dx)
10-17 free parameters!
5
4
3
2
1
0
5500
5501
5502
5503
Wavelength [Ang]

The Effect of LSF Mismatches



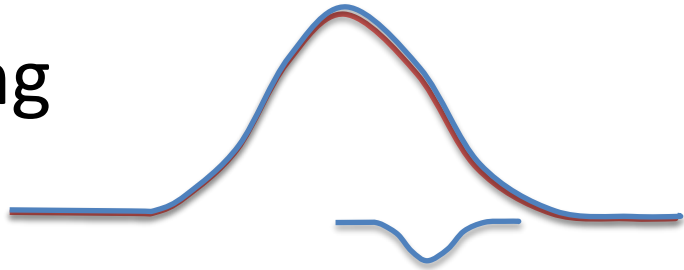
Cartoon Line-Spread Function (LSF)

Hurt twice by the LSF

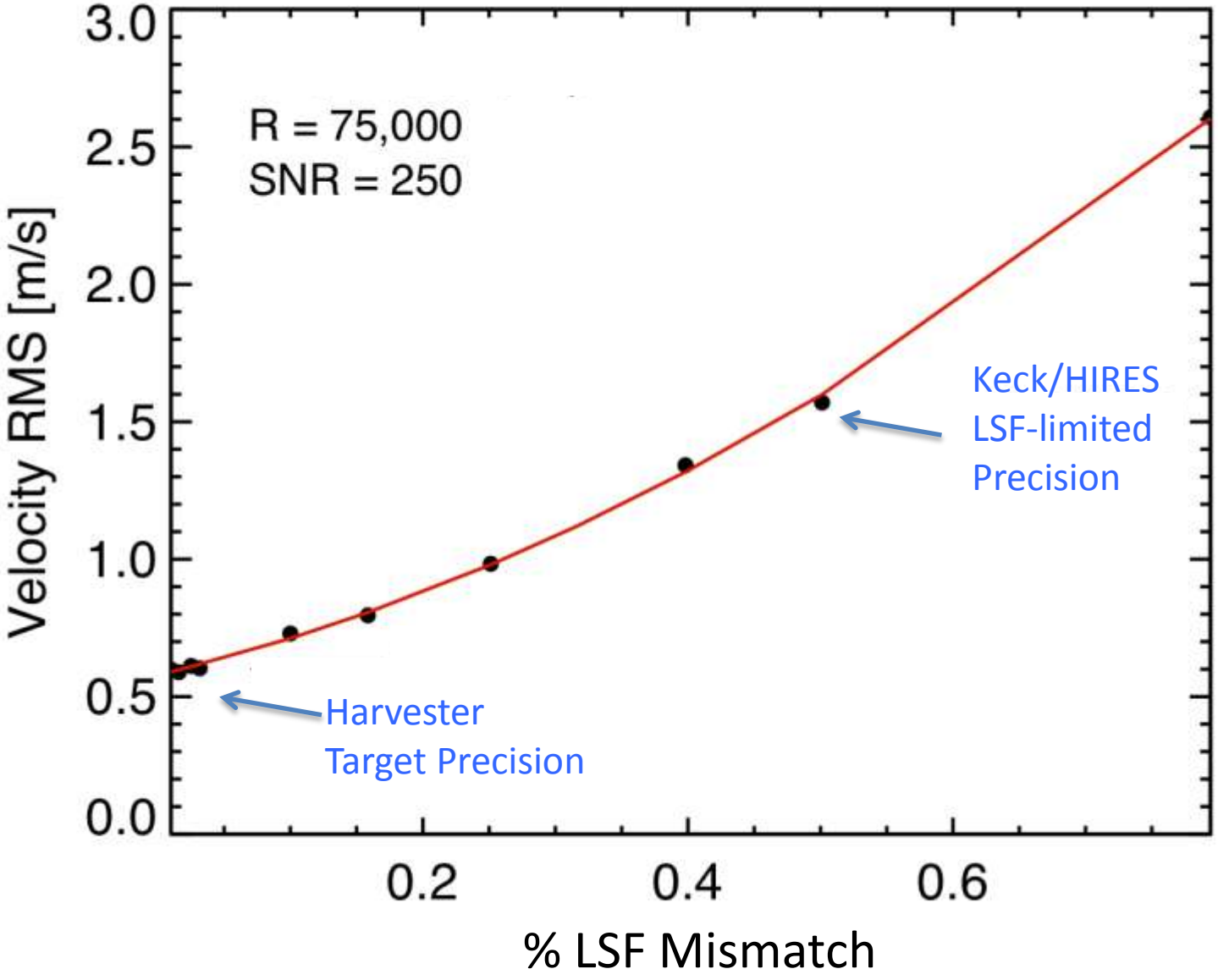
- In the modeling of each observation, LSF asymmetry is degenerate with Doppler shift
- In the deconvolution of the template, the wrong LSF kernel is removed

Simulating LSF Mismatches

- Create mock observations using
  - The NSO Atlas
  - Our FTS Iodine transmission spectrum
  - A perfect Gaussian LSF
- Forward-model using an imperfect LSF
  - Perturb LSF shape by adding/subtracting a smaller Gaussian with a random offset
  - Measure LSF mismatch amount as % w.r.t. peak



Simulated LSF Mismatches

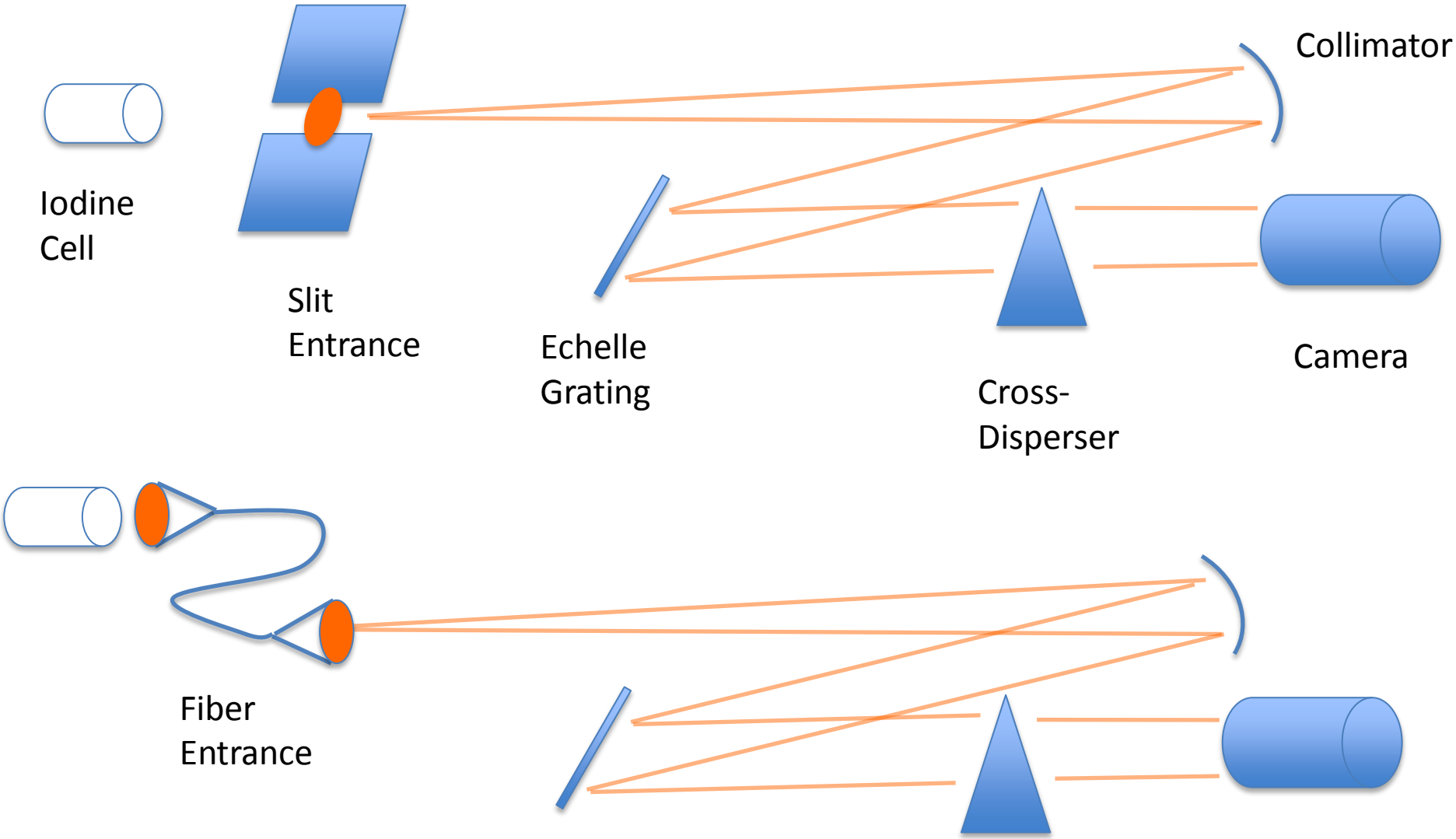


The Harvester Path to Sub-m/s

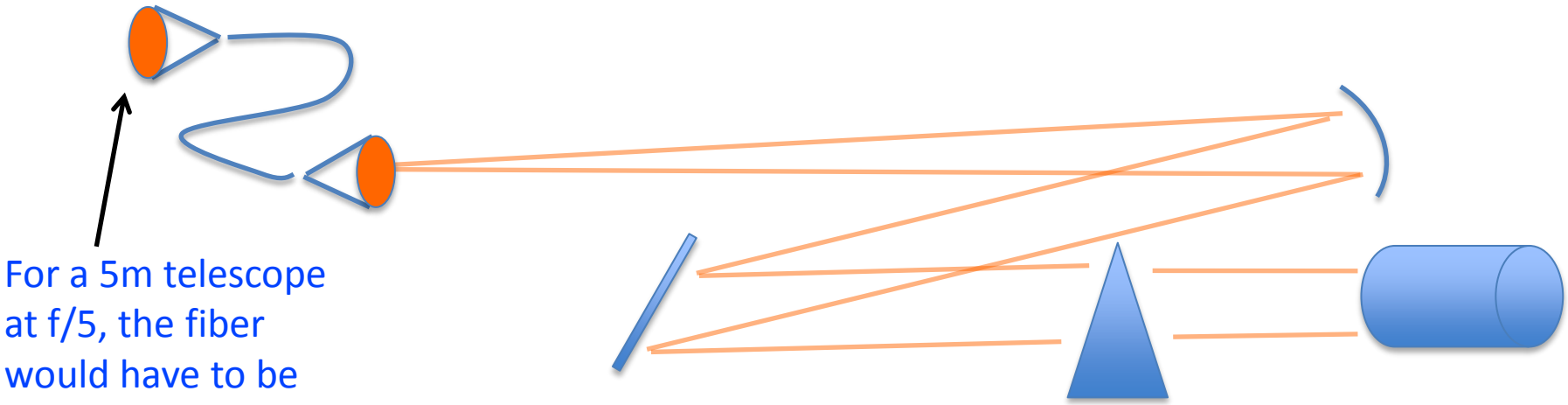
- We want to leverage our legacy of expertise with the iodine cell method
- Keep simultaneous wavelength reference afforded by iodine cell
  - Avoid drifts due to aging in ThAr lamps
  - Also track residual changes to LSF
- Incorporate stable-platform approach
- Build with an MRI-sized budget (< $3M)

The Stable-Platform Approach

- Minimize error sources
- Fiber-feeding stabilizes the LSF through mode-scrambling
  - There's a reason why you never hear "LSF" or "IP" in HARPS talks
- Temperature and Pressure Stabilization of the spectrometer
  - Lock down the wavelength scale


Collimator
Iodine
Cell
Slit
Entrance
Echelle
Grating
Cross-
Disperser
Camera
Fiber
Entrance

Problem: Big Telescope = Big Beam

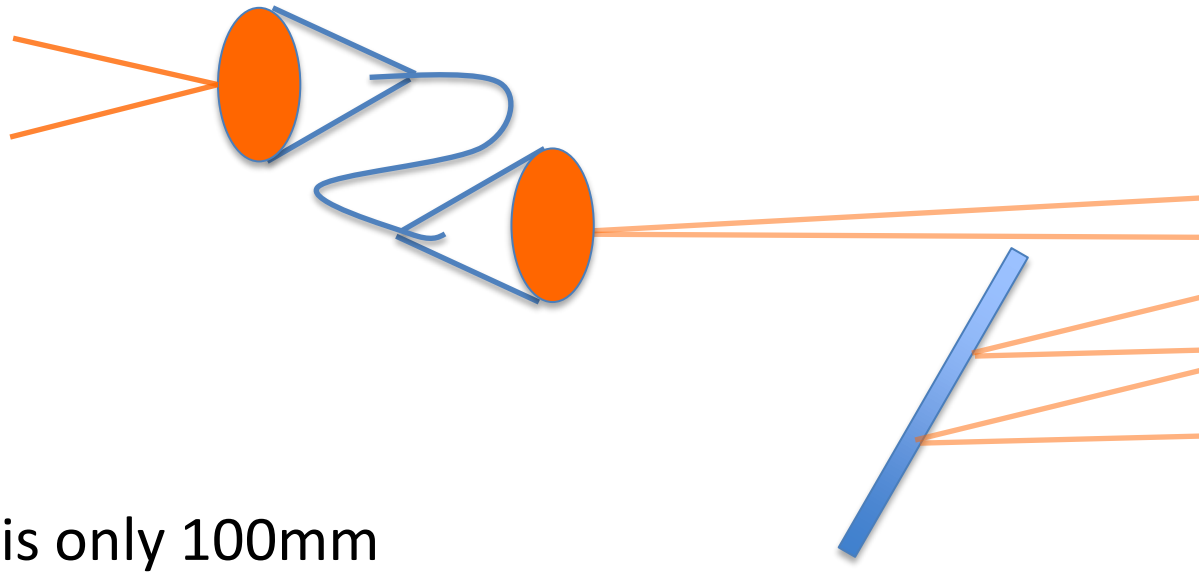


For a 5m telescope at f/5, the fiber would have to be 350 um to match to 1” seeing!

Larger Beam =
Larger Optics =
Tighter tolerances
Less stable spectrograph
More expensive optics

Solution: Improve the Seeing

Palm 3000
Adaptive Optics
System



With AO our beam is only 100mm
on a 5 m telescope

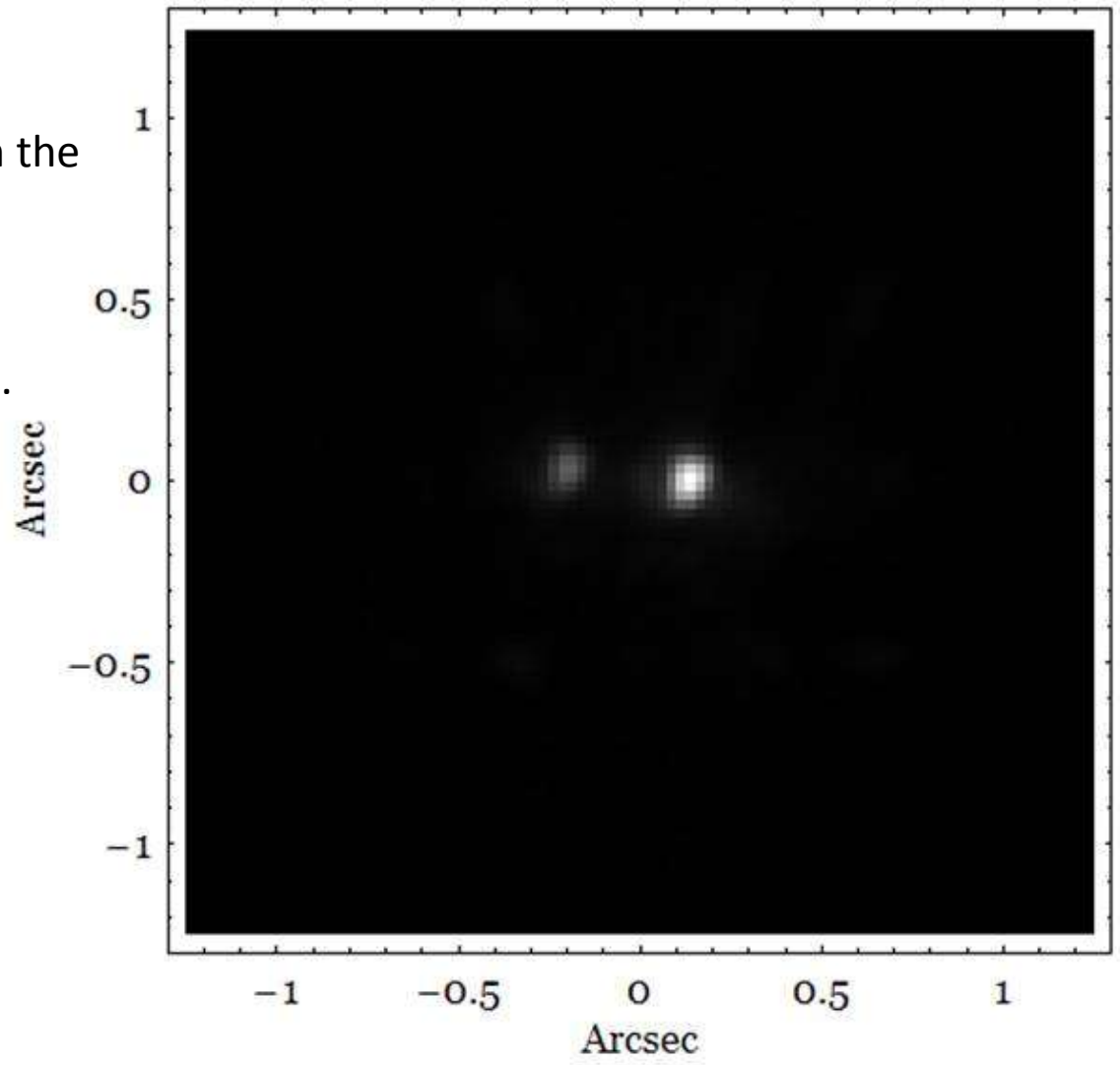
Palm 3000

- 3388 Actuator Next-Generation AO
  - ATI proposal funded
  - commissioning set for Spring 2011
- Visible Light Correction

Palm 3000

V-Band image with the Well-Corrected Sub-aperture

Gene Serabyn et al.



Advantages of AO

- Smaller image PSF = Smaller spectrometer
  - Smaller, inexpensive optics
  - Easier to control Temp and Pressure
- Milliarcsecond guiding, repeatable image placement
  - Reduce the amount of LSF variation we have to model
- We are exploring the best method of mode scrambling and attenuation of modal noise (Yale Doppler Diagnostic Facility)

Temperature and Pressure Stabilization

- Mount in a vacuum chamber in a constant-gravity environment
- Temperature control to < 0.01 K
- Pressure control to < 0.01 mbar

Extending Into the Red

- More lines (although line density lower in red)
- Flux peak of later-type stars
- Lower star-spot contrast for reduced jitter
- Better jitter diagnostics with red vs. “green”

Building in Hooks for a Laser Comb

See A. Szentgyorgyi

- In collaboration with the Harvard/MIT LFC Team
- Use an LFC from ~600nm to ~750nm
- Anchor to Iodine wavelengths
- Trust spectrometer stability such that simultaneous LFC is not needed
  - Fire LFC during slews to bracket observations
- Note that PHS is fully functional without LFC
  - LFC is an add-on for ~50% improvement in precision
  - Redundant set of wavelength calibrators
  - LFC may eventually replace the iodine cell

Harvester: Combining the best from many approaches

- Iodine cell for simultaneous wavelength reference
- AO for a smaller, rock-stable, affordable spectrometer
- Extension into the red with an LFC

Thank you