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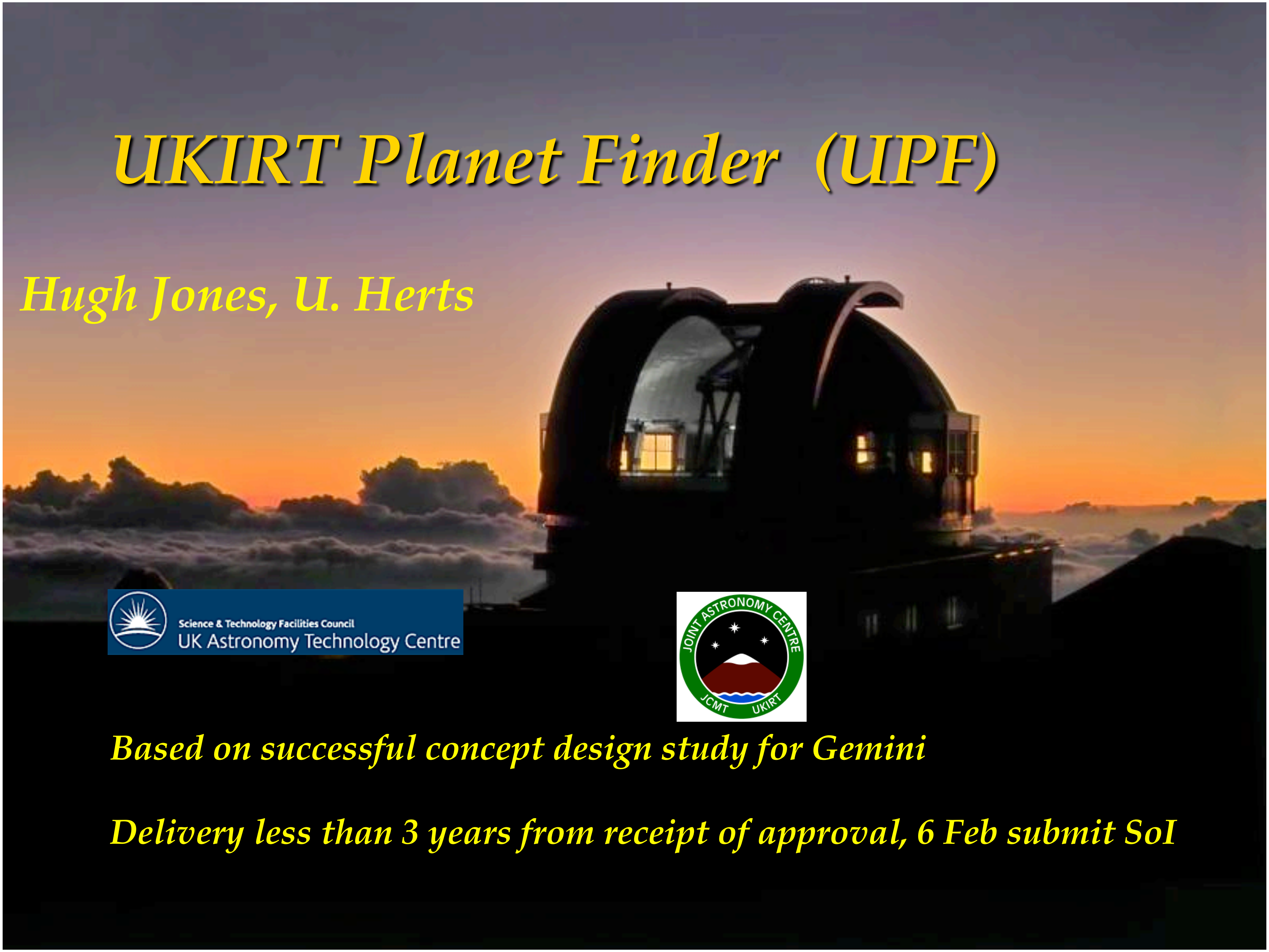
European Week of Astronomy and Space Science

Registration now open

University *of* Hertfordshire

UKIRT Planet Finder (UPF)

Hugh Jones, U. Herts



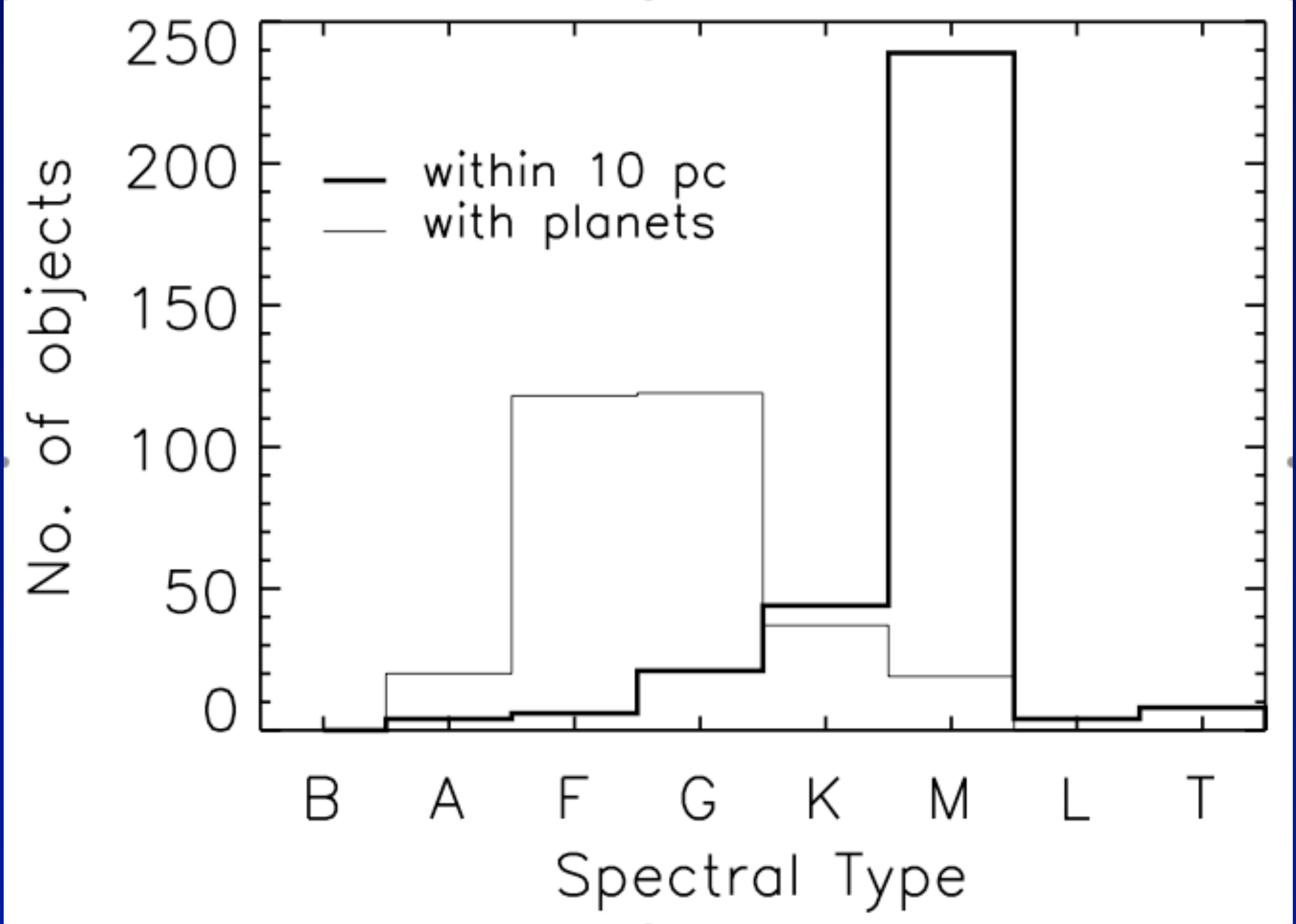
Science & Technology Facilities Council
UK Astronomy Technology Centre

JOINT ASTRONOMY CENTRE
JCMT UKIRT

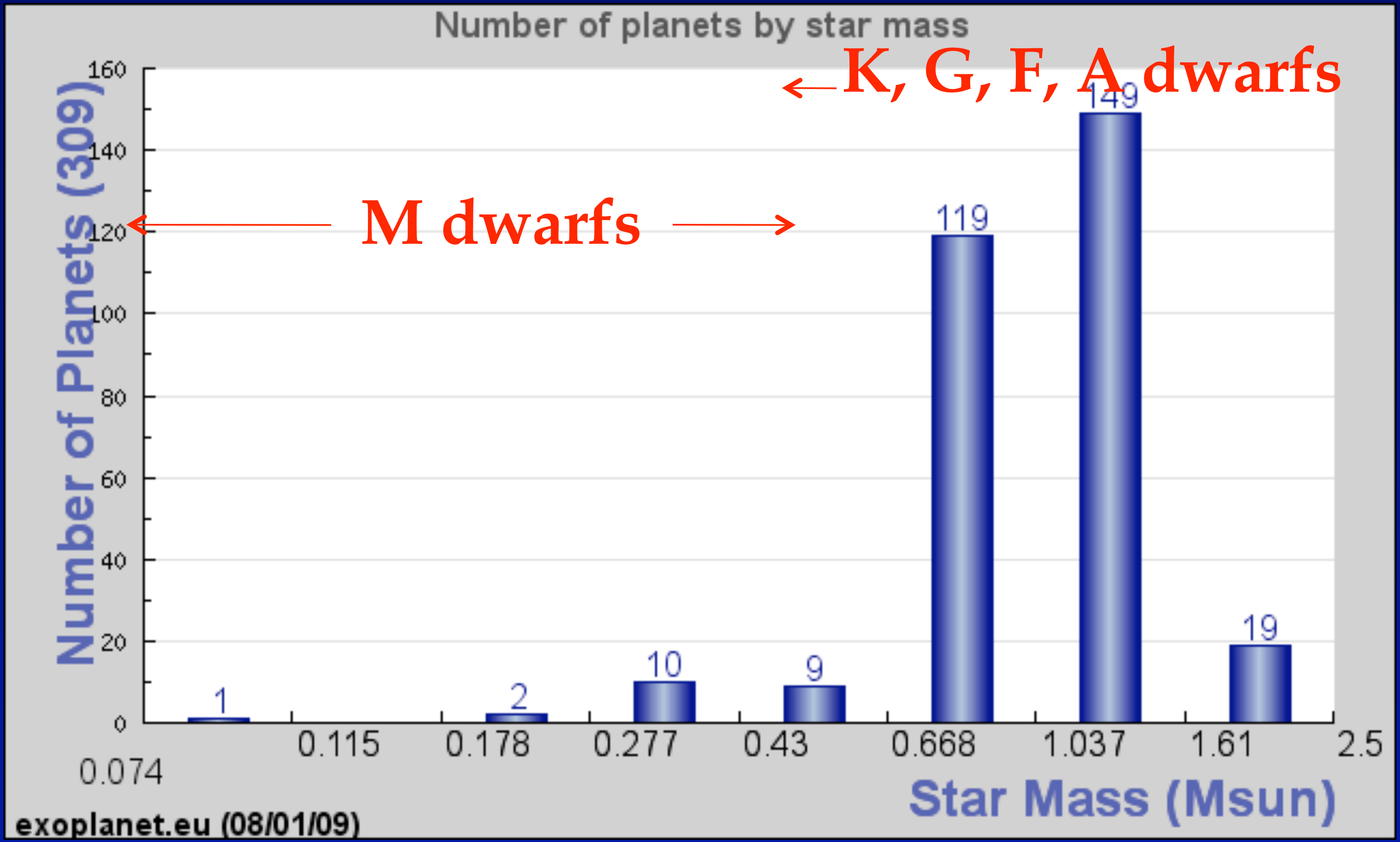
Based on successful concept design study for Gemini

Delivery less than 3 years from receipt of approval, 6 Feb submit SoI

Exoplanets around the majority of stars (M dwarfs)?

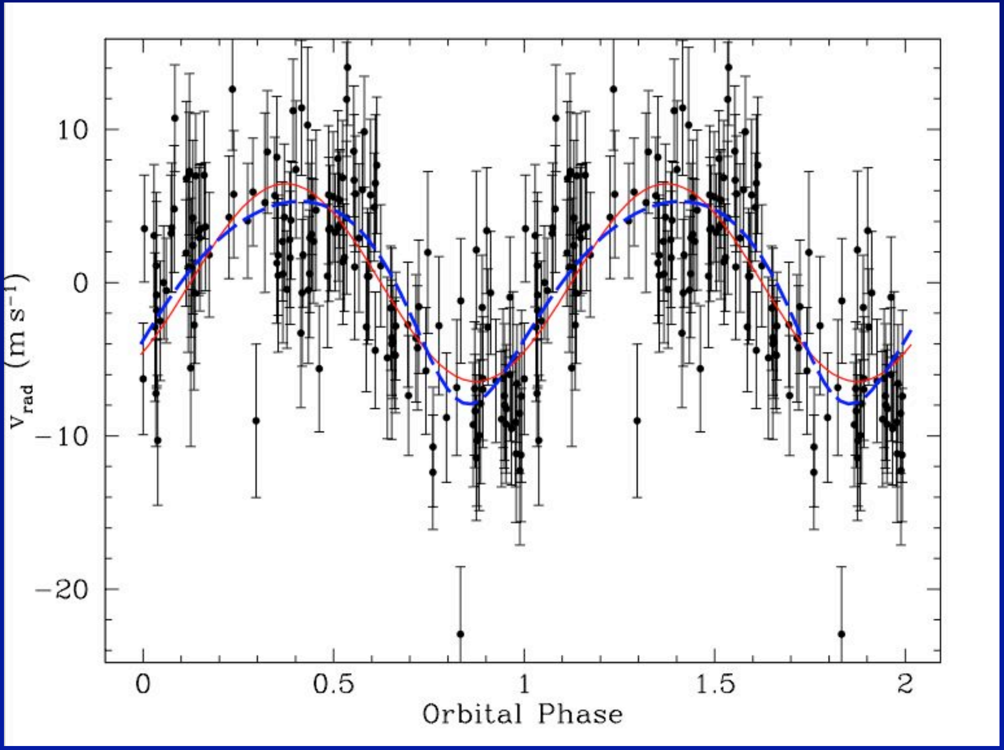


Astrophysically … a void



Optical RVs are hardwork for M dwarfs

Low mass planets are being discovered around M dwarfs but tough even with Keck



Gl876 (M4V), 4.7pc

1.9 day period

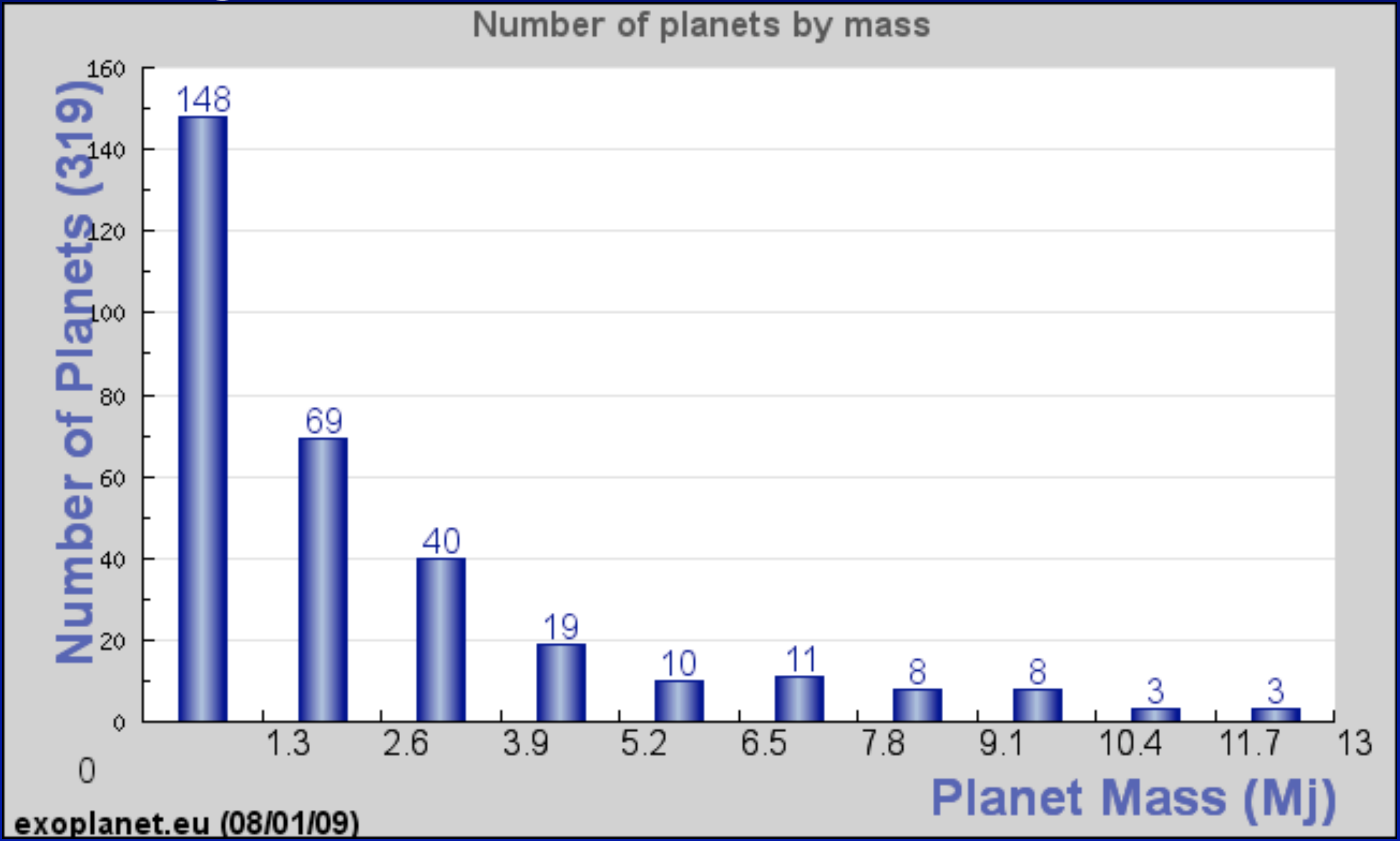
Msini=7.5M_{Earth}

1997-2005 Keck monitoring including data on 6 consecutive nights

Rivera et al. 2005

Plenty of low-mass planets though at 5 Earth masses we are close to detection threshold

Low-mass planets dominate despite strong bias against detection

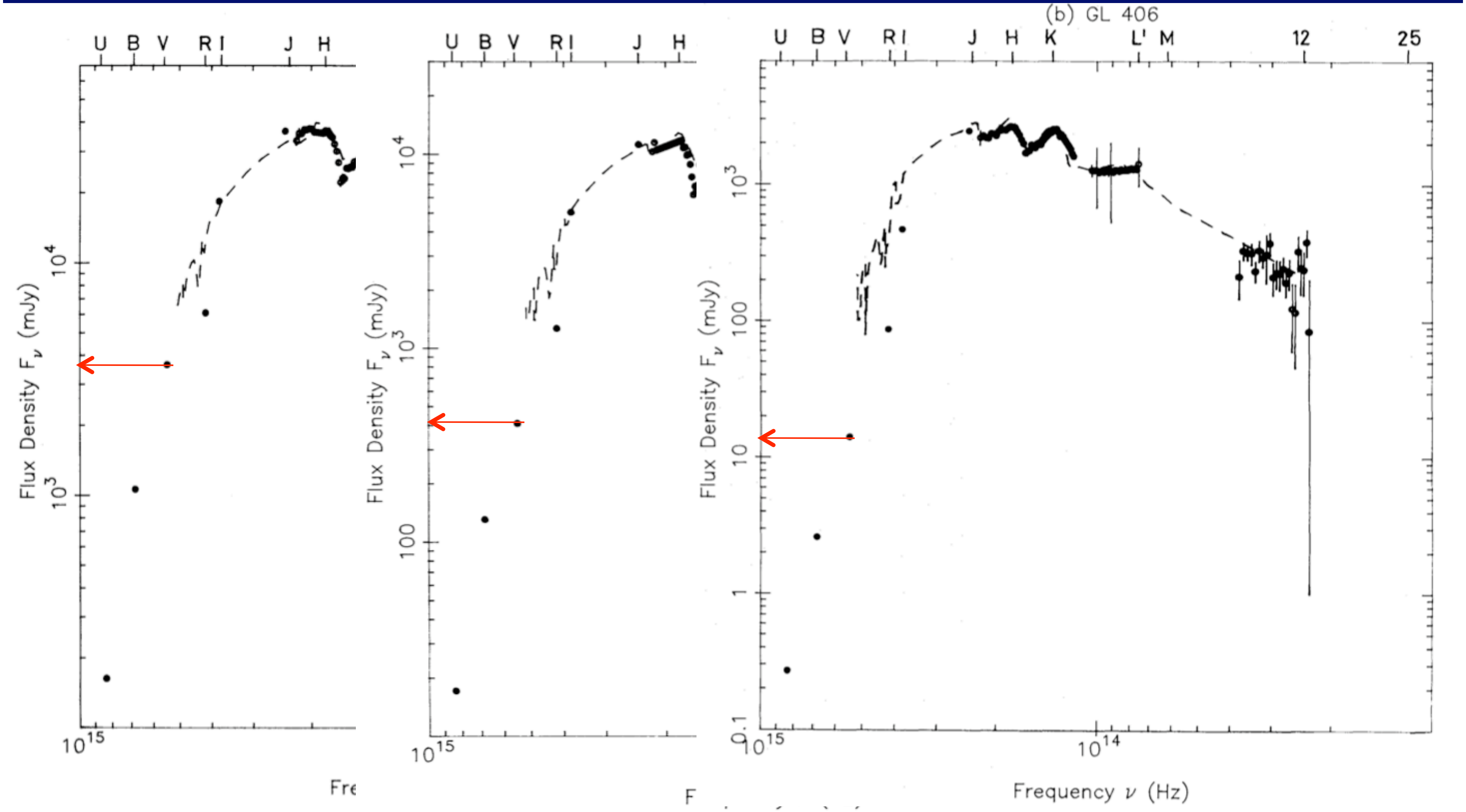


exoplanet.eu (08/01/09)

Why the infrared?

Berriman & Reid 1987

M2 **M4** **M6**

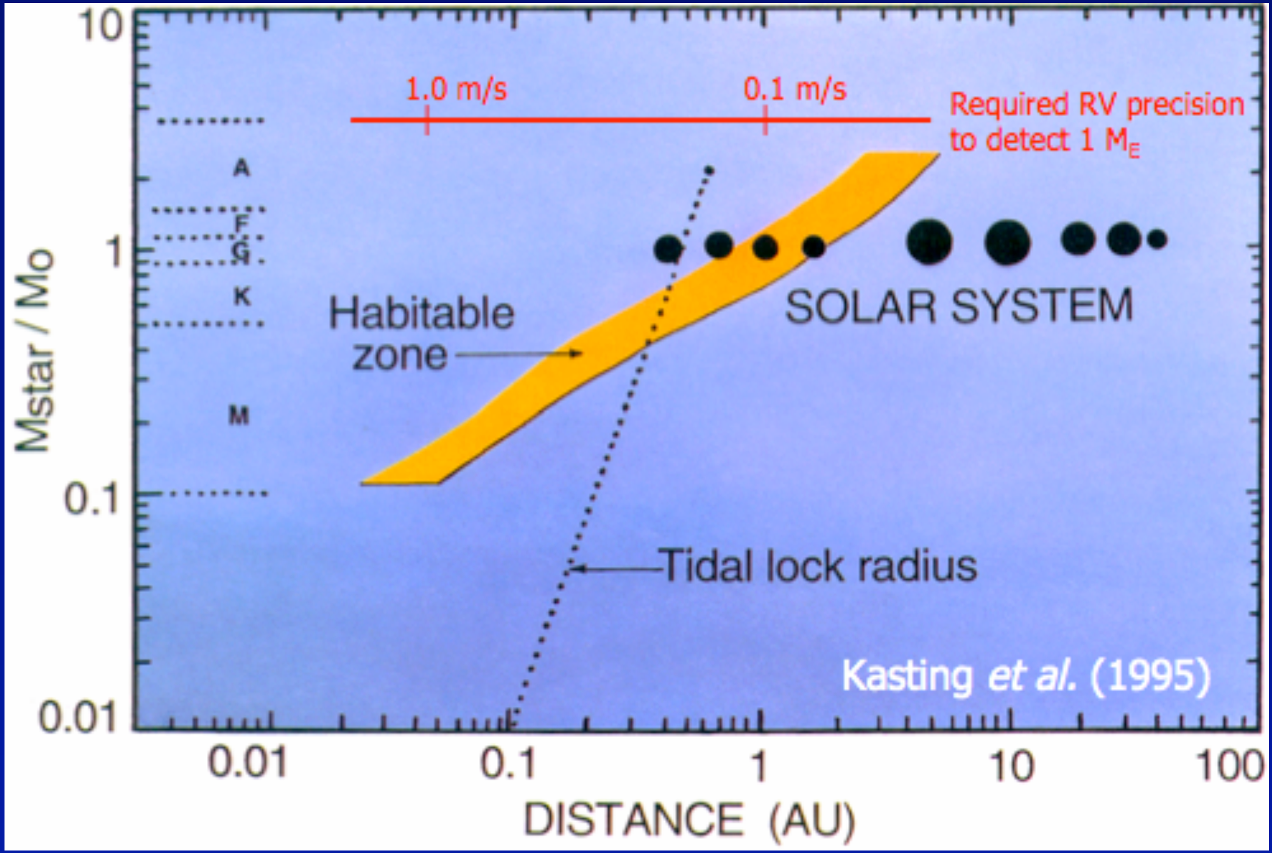


Habitable zones more accessible

- The habitable zones of low-mass stars have shorter orbital periods

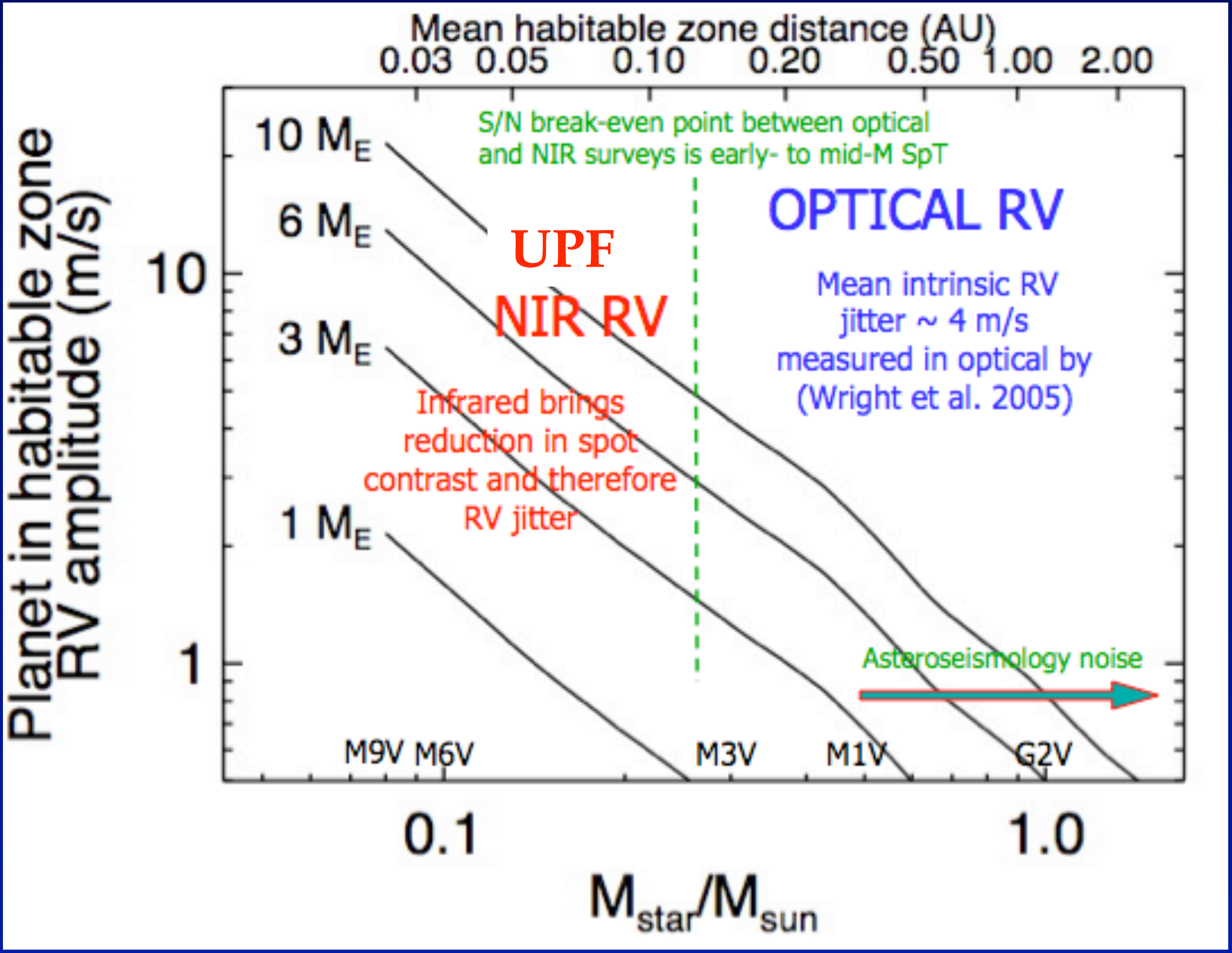
Habitable zone inside 0.3 AU for M dwarfs

Tidally locked planets may or may not be good places to look for life

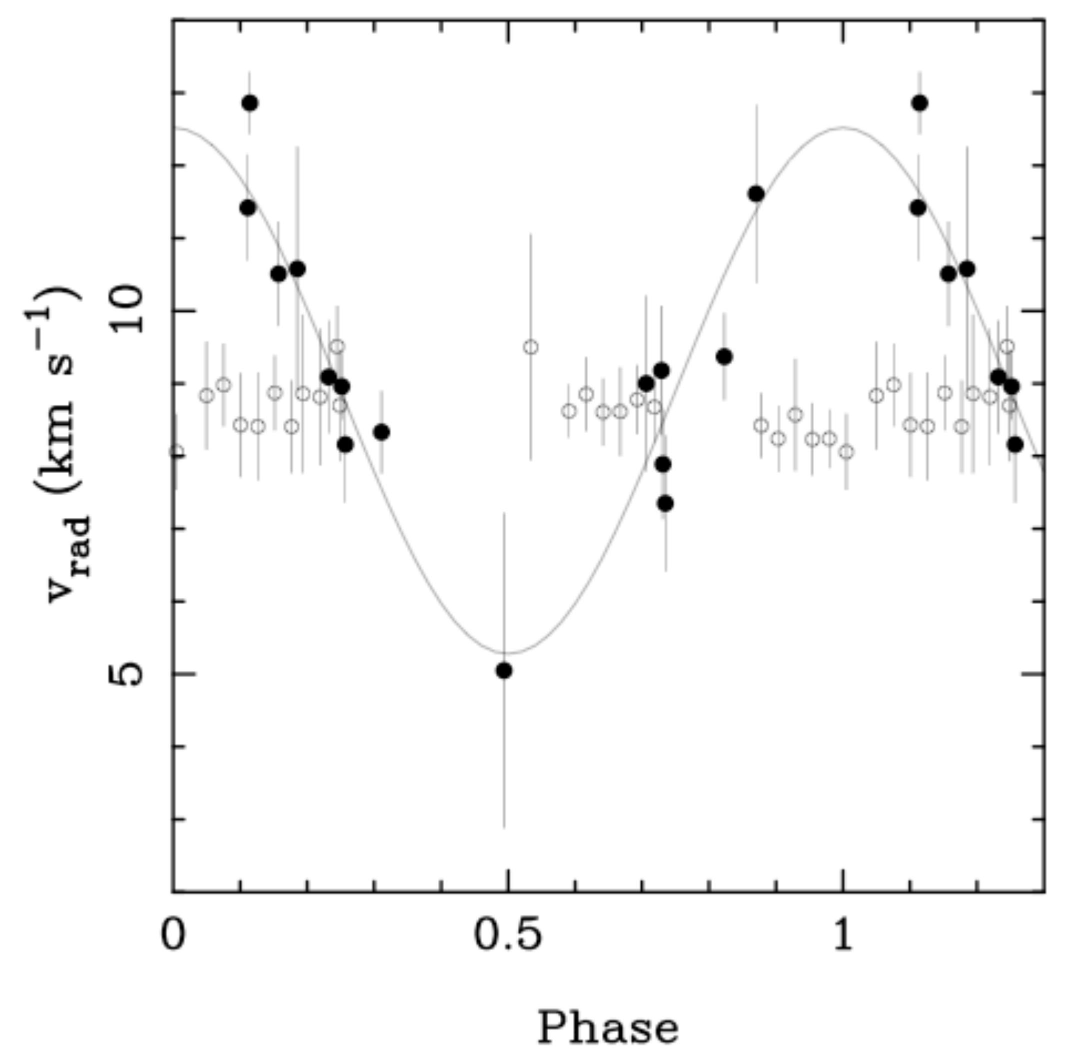


Kasting *et al.* (1995)

The potential in the infrared



RVs in IR and visible for LP944-20 (nearby late-type M dwarf)



Solid circles – HIRES (optical)

Open circles – NIRSPEC (infrared)

Martin et al. 2007

Technical challenges of RV in the NIR

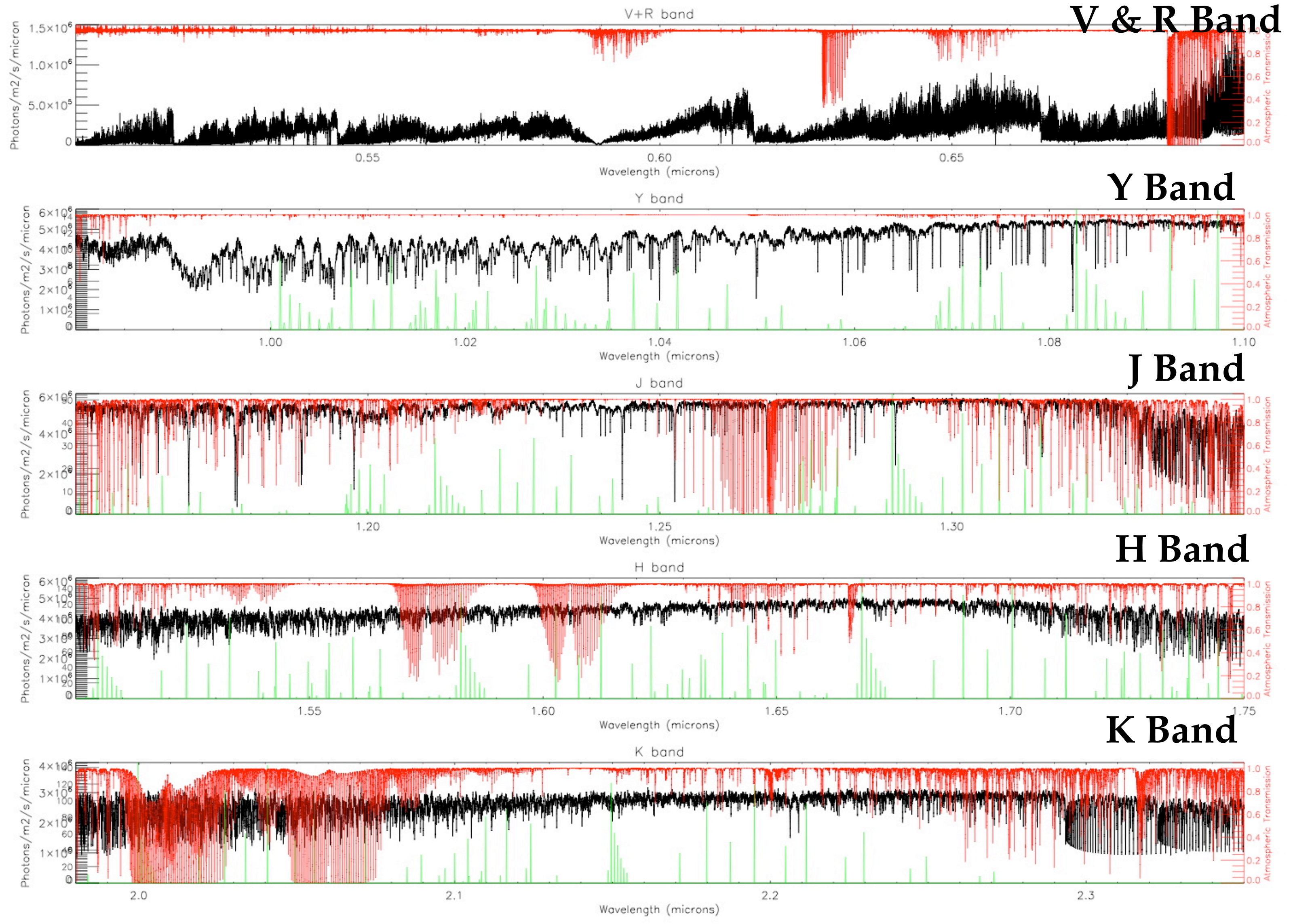
- Simultaneous wavelength fiducial covering NIR is required for high precision RV spectroscopy
  - Suitable gas/gases for a NIR absorption cell
  - Use simultaneously exposed arcs (Th-Ar, Kr, Ne, Xe) and ultra-stable spectrograph
    - ~ 300 bright lines to monitor drift during observing (using super exposure and sub-array reads of arc lines)
    - ~ 1000 lines for PSF and wavelength calibration (daytime)
  - Use of a laser comb possible following R&D
- Significant telluric contamination in the NIR
  - Mask out ~ 30 km/s around telluric features deeper than 2%
  - At R=70,000 (14,000 ft, 2 mm PWV, 1.2 air-mass) this leaves 87% of Y, 34% of J, and 58% of H
  - Simulations indicate resulting ‘telluric jitter’ ~ 0.5 m/s

Atmospheric limits?

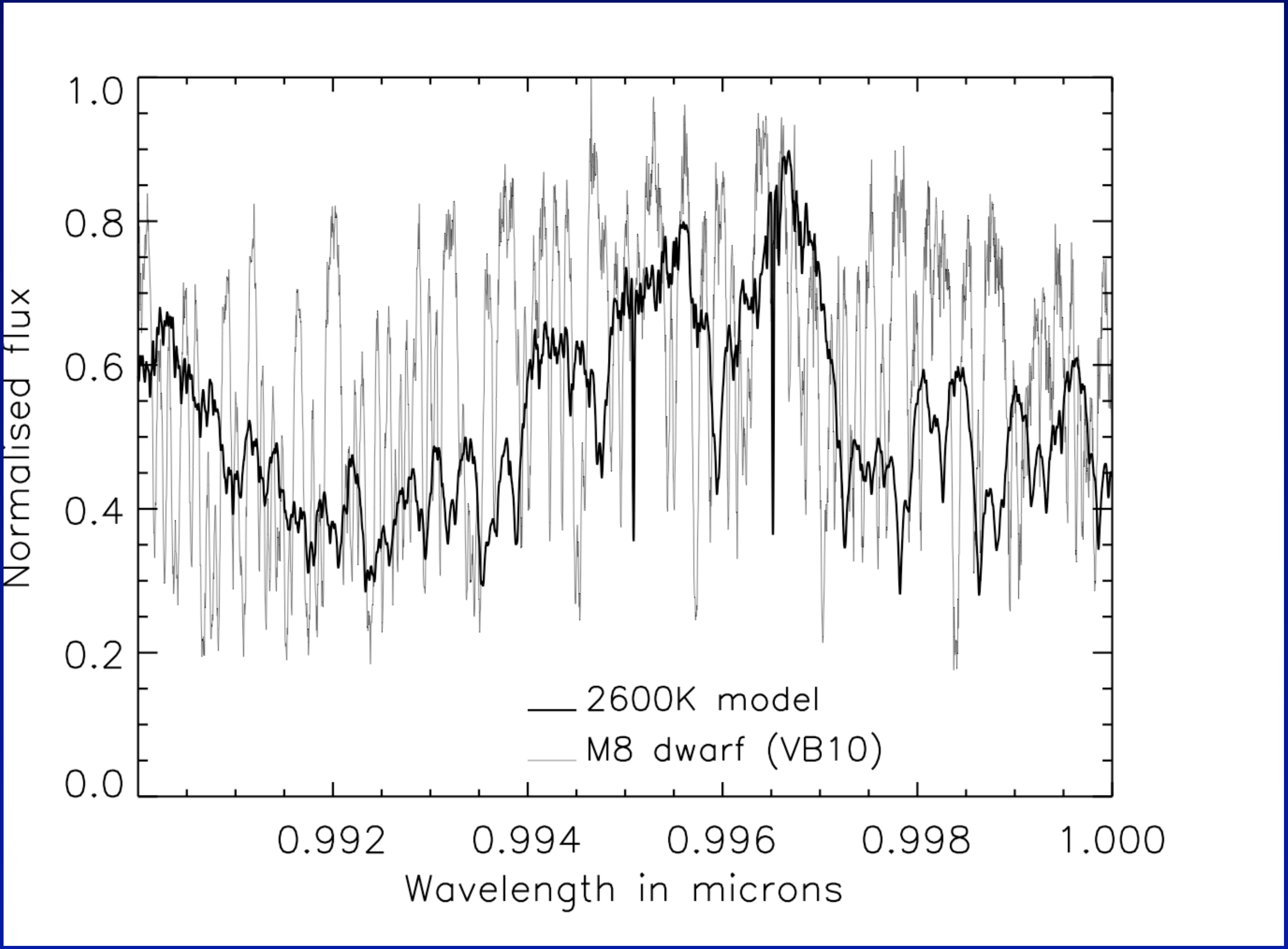
Mauna Kea is best site to avoid tellurics

M6V
T_{eff} = 2800 K
Log g = 5
v sin *i* = 0 km/s

Model
Telluric
OH



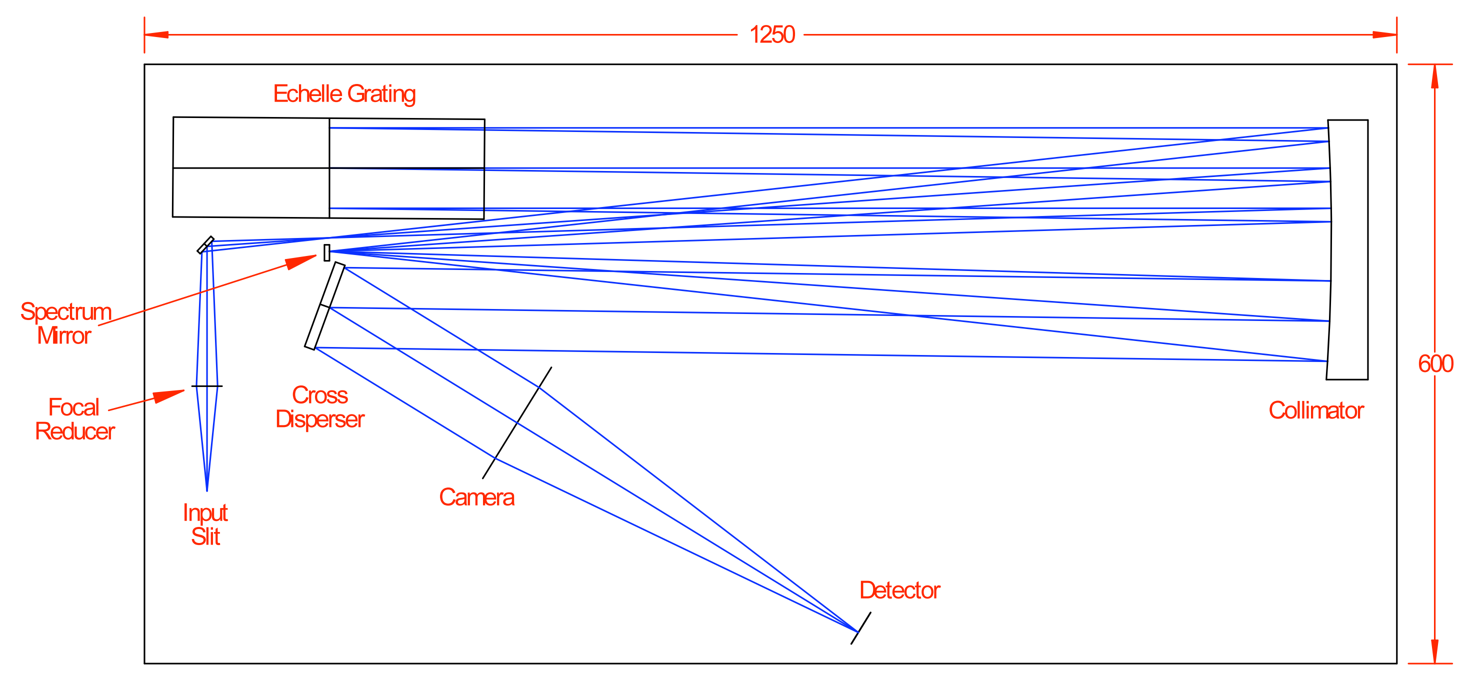
Radial velocity information



UPF Design Baseline Concept

- Cross dispersed echelle spectrograph
- White pupil collimator design
- Refractive camera
- Optical design similar to HARPS, UVES, MRS spectrographs
- Fixed echelle, cross disperser, camera
  - No mechanisms (in main optical path)
- Floor mounted, fibre fed

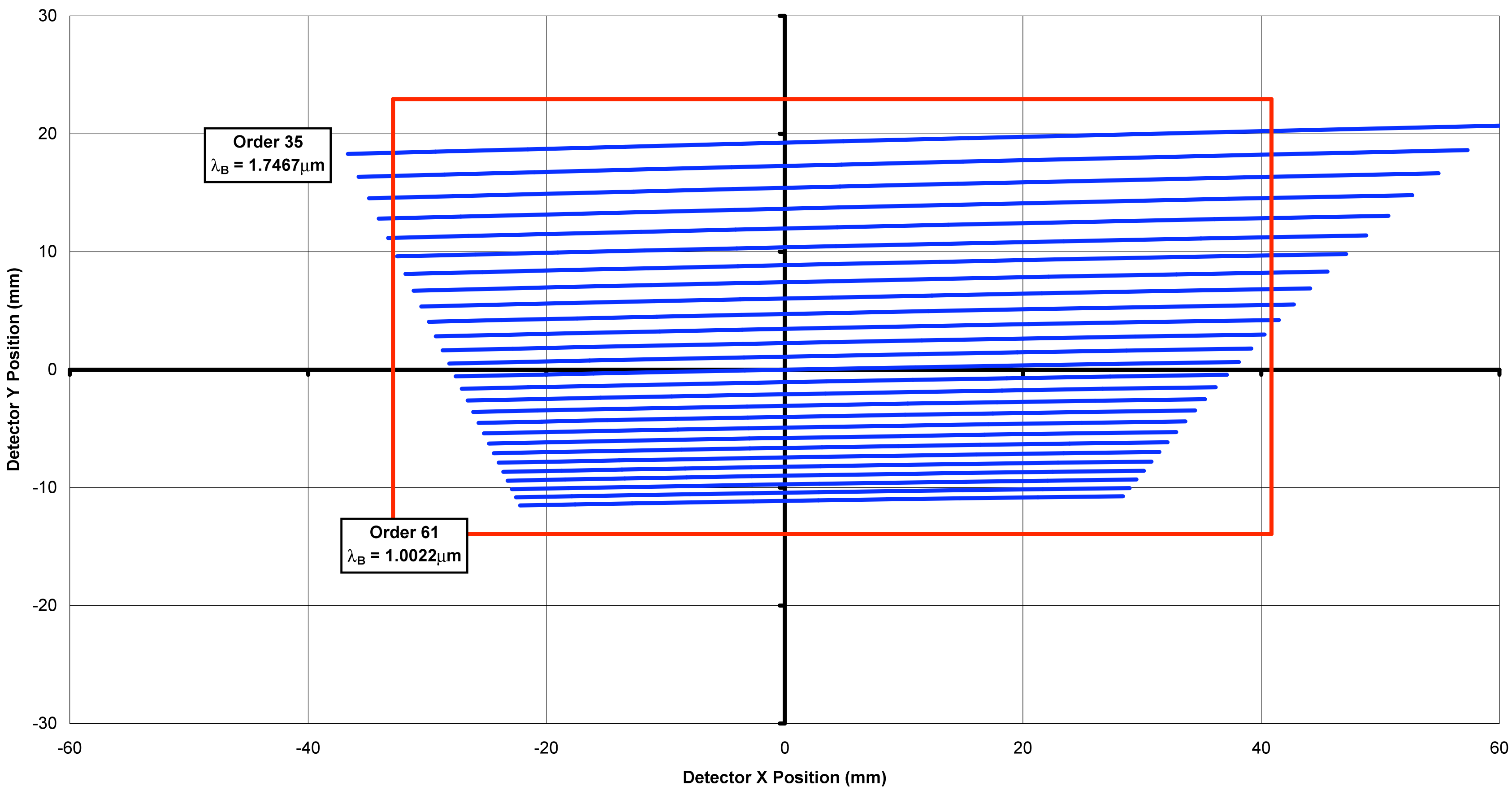
UPF Optical Layout



- Input slit
  - 0.46 arcsec wide
  - 0.36 x 0.047mm effective size, f/5
- Focal reducer
  - Convert from f/5 to f/12.5
- Single collimator
  - Off axis parabola, f=1000mm, 340 x 260 mm
  - 80mm collimated beam diameter
- Spectrum mirror
  - Flat, 250 x 6 mm

- Echelle
  - 31.6 lines/mm, R4 (75° blaze angle)
  - 320 x 100mm
- Cross disperser
  - Reflective grating, 100 lines/mm, m=1
  - 110 x 90mm
- Camera
  - f=400mm, f/5
- Detector
  - 2 x $2K^2$ HAWAII-2RG arrays

UPF Spectral Format

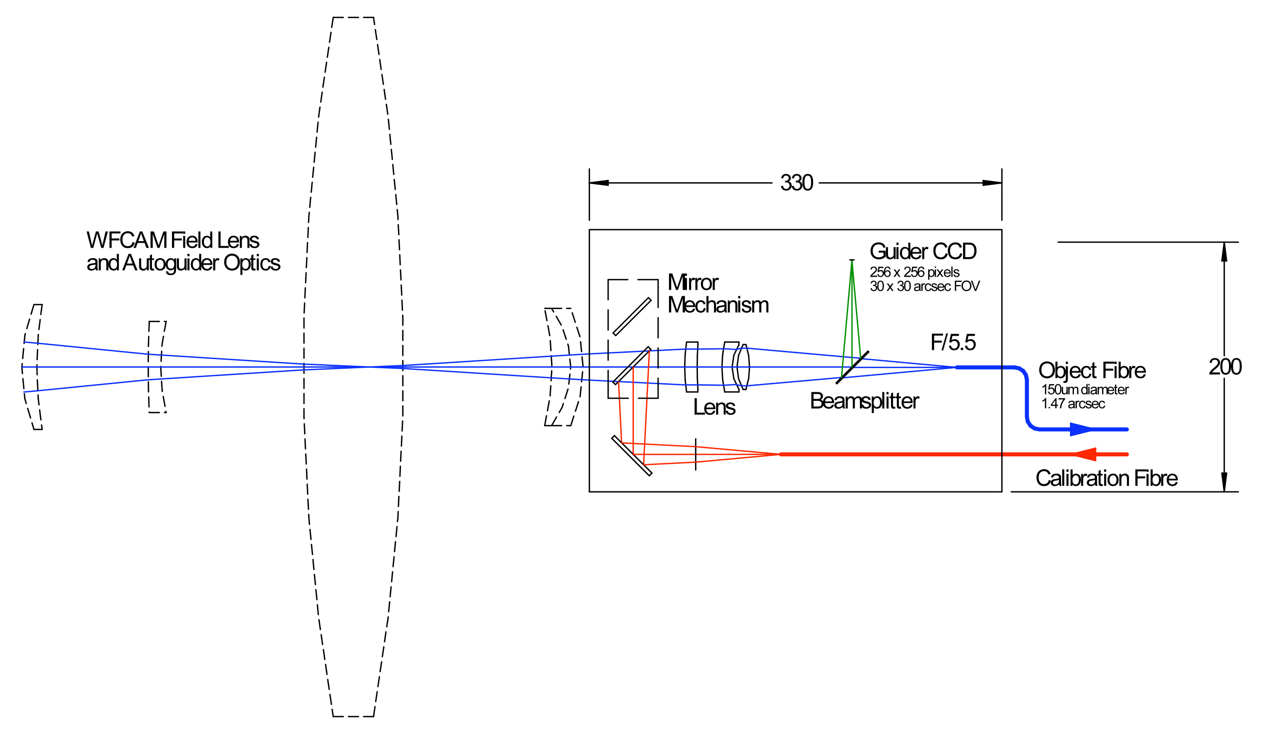


□ Detector array footprint

2 x 2K^2 HAWAII-2RG arrays

73.728 x 36.864mm

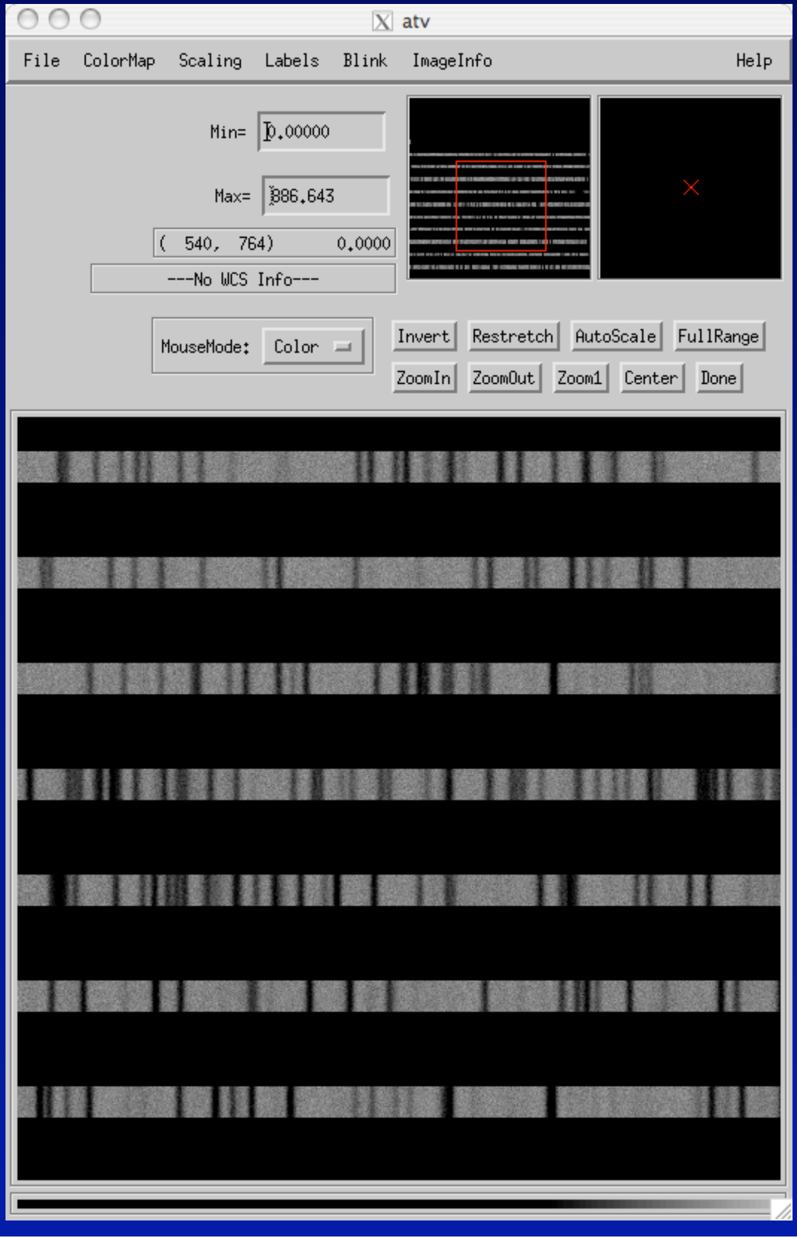
WFCAM Mounted Fibre Pickoff



- **Fibre pickoff and acquisition system mounted behind WFCAM field lens and guider optics**
- **Guide camera rigidly mounted to fibre pickoff to minimise guider error**
- **Second fibre from calibration source, coupled into object fibre via mirror mechanism, for daytime calibration**

Simulations

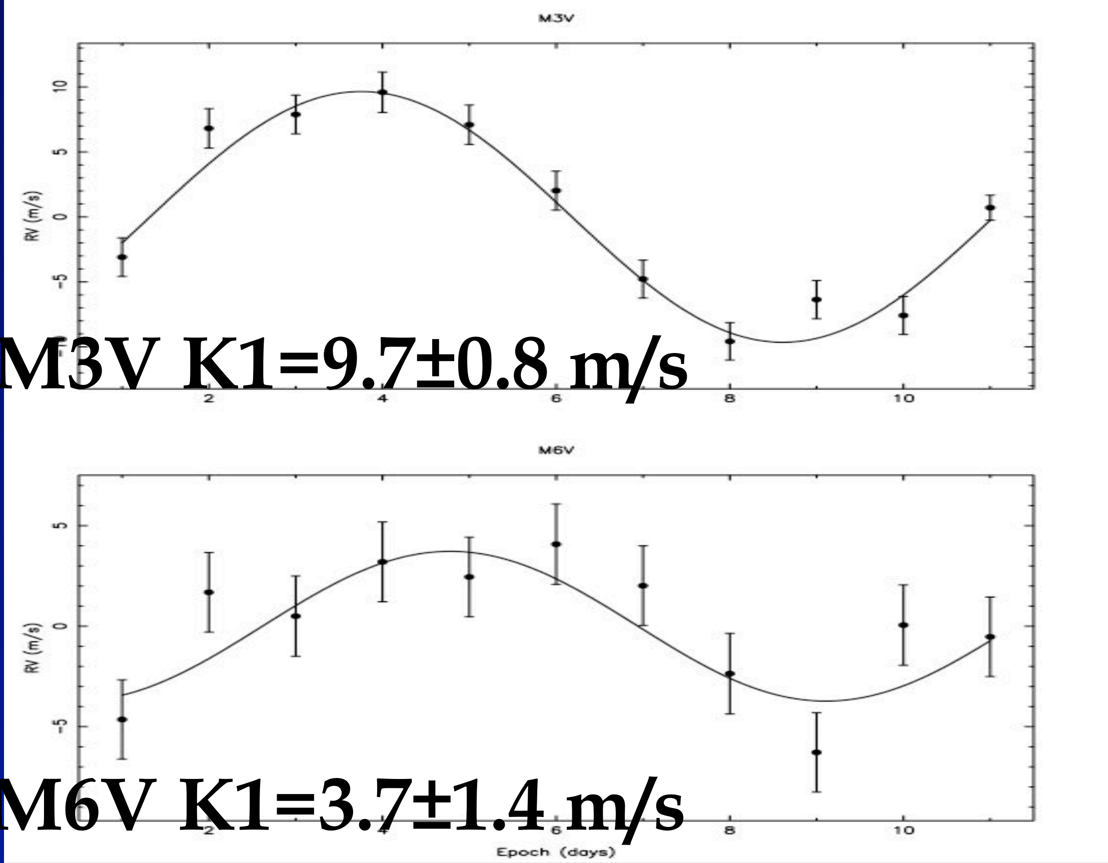
- **Outputs:**
  - 2-D image
  - 1-D photon, error, S/N spectra



Analysis of simulated M dwarfs

- **Analysis of simulated spectra**
- **11 simulated spectra uniformly sampled in period (10 days)**
- **M3V K1=10.0 m/s**
- **M6V K1=5.0 m/s**
- **Each spectrum:**
- **0.98-1.10 um (Y band)**
- **v sin *i = 5 km/s***
- **Scaled to J=9.0, Int. time=900 s**
- **S/N~150, R=70,000**
- **Telluric absorption, 0-100 m/s**
- **'Telluric clean' regions of Y selected but no telluric mask**

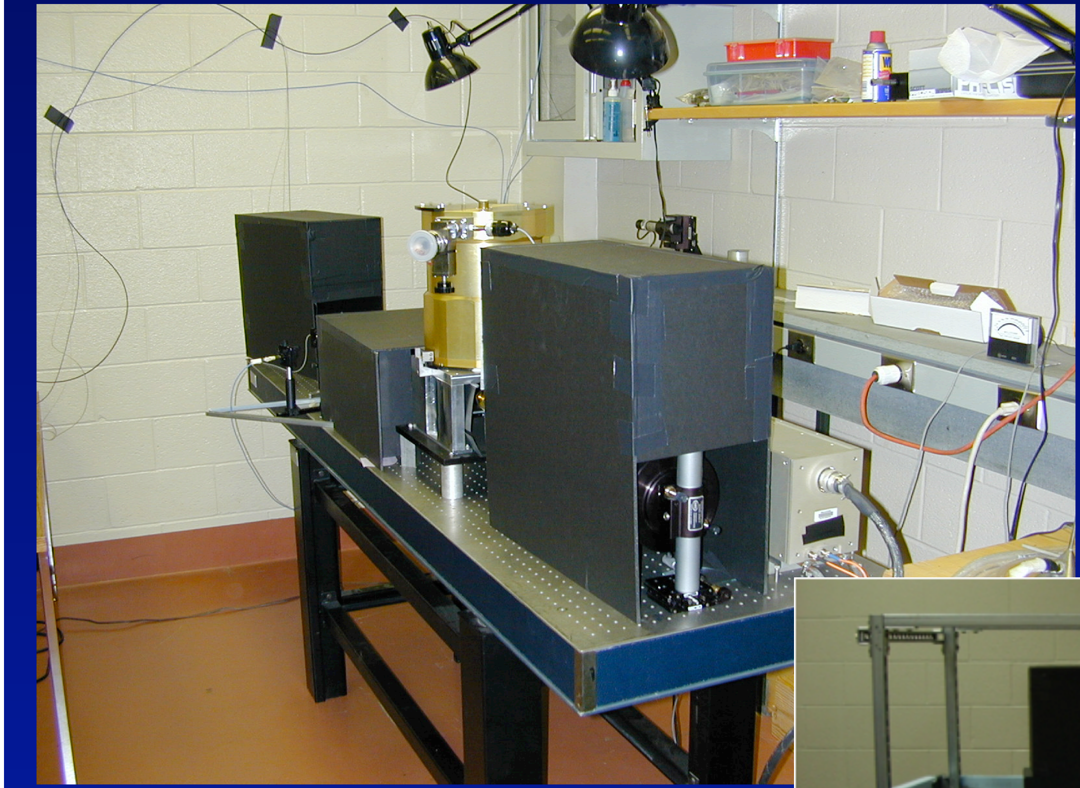
- **RESULTS (Y band only):**
- **M3V - K1=9.7±0.8 m/s**
- **M6V - K1=3.7±1.4 m/s**
- **RV code agrees with independent Bouchy analysis**
- **Effect of telluric jitter, ~0.5 m/s**



M3V K1=9.7±0.8 m/s

M6V K1=3.7±1.4 m/s

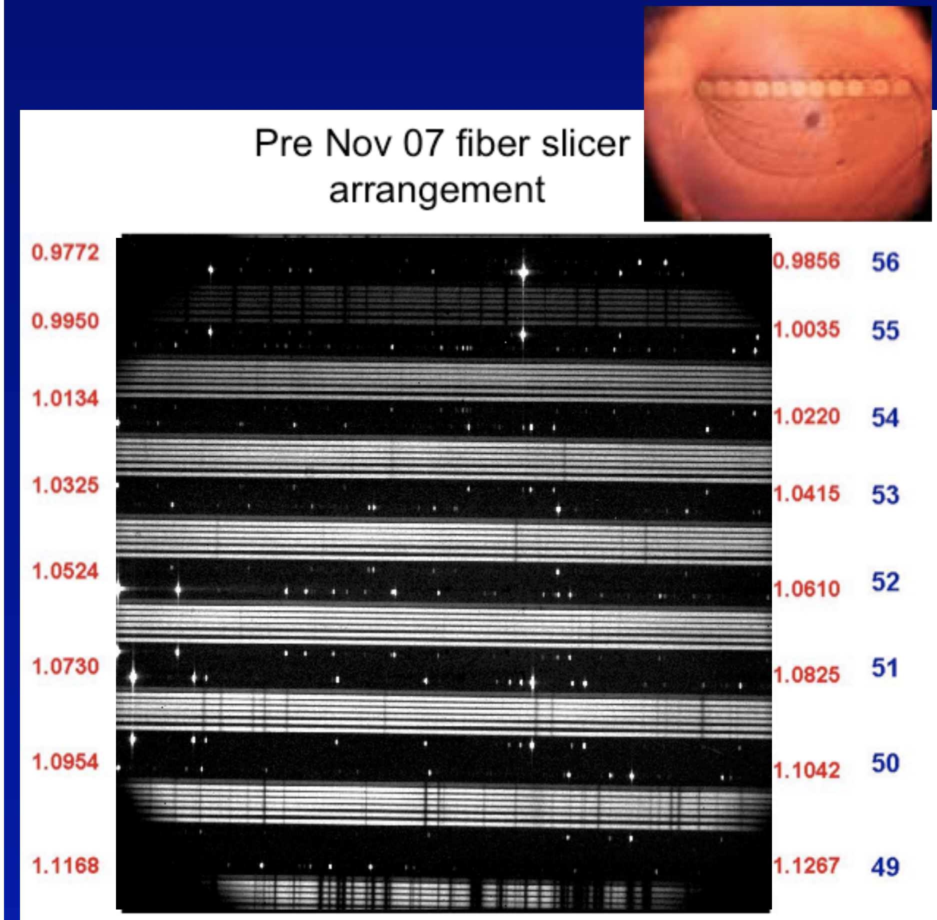
Pathfinder - test bed for IR stability measurements on Sun

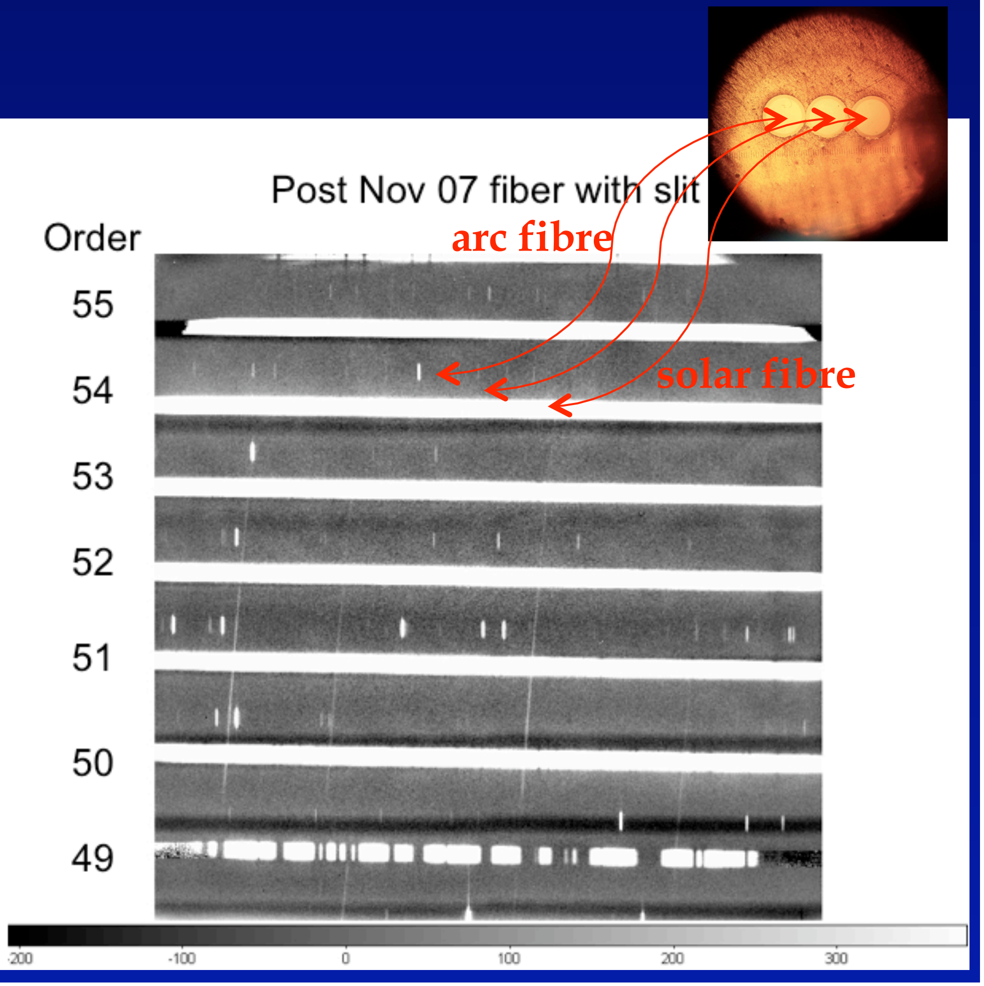


With insulation jacket

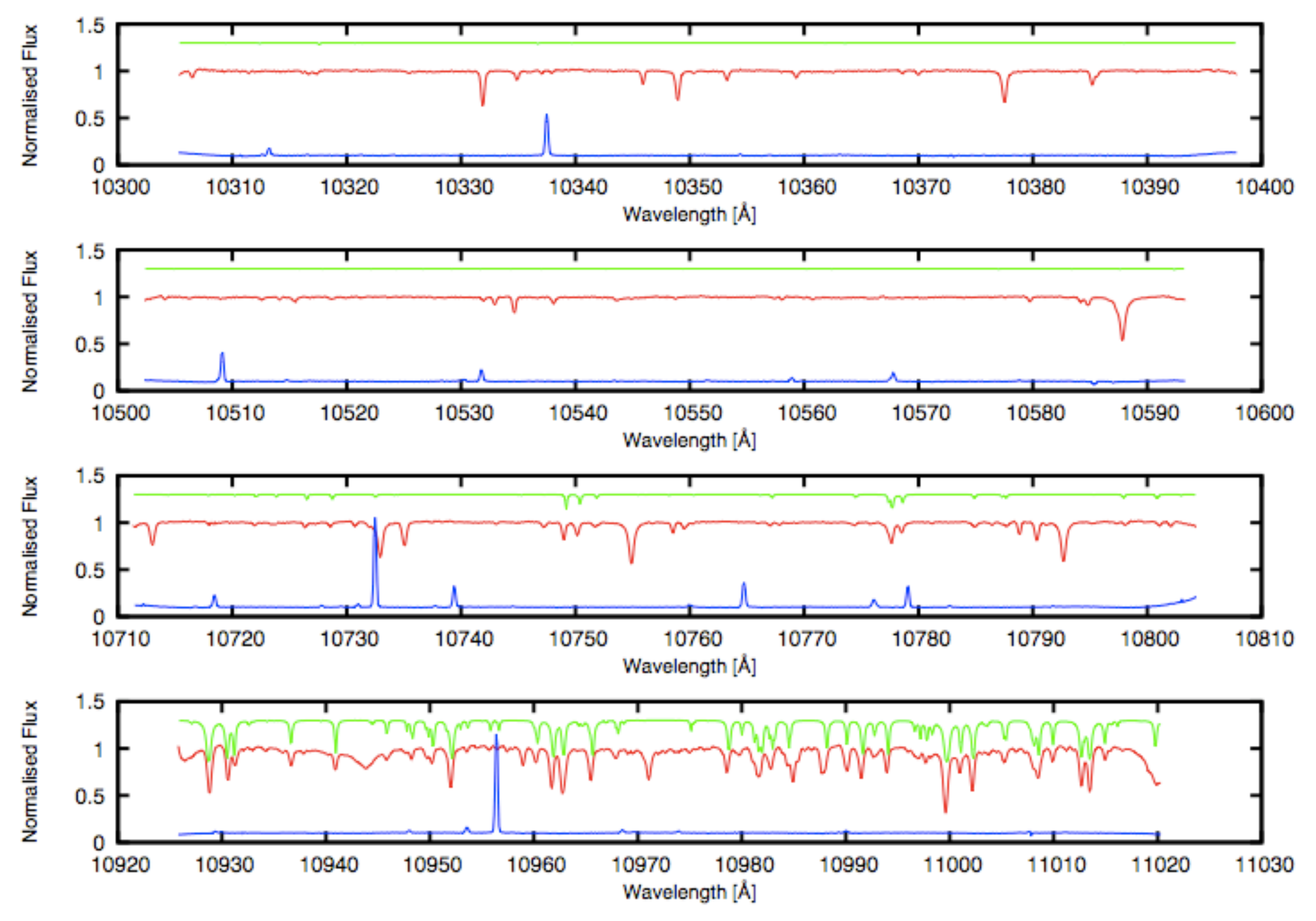
Pathfinder - test bed for IR stability measurements

Solar spectrum plus ThAr in Y band (1.05um) at 50k resolution


Pre Nov 07 fiber slicer arrangement

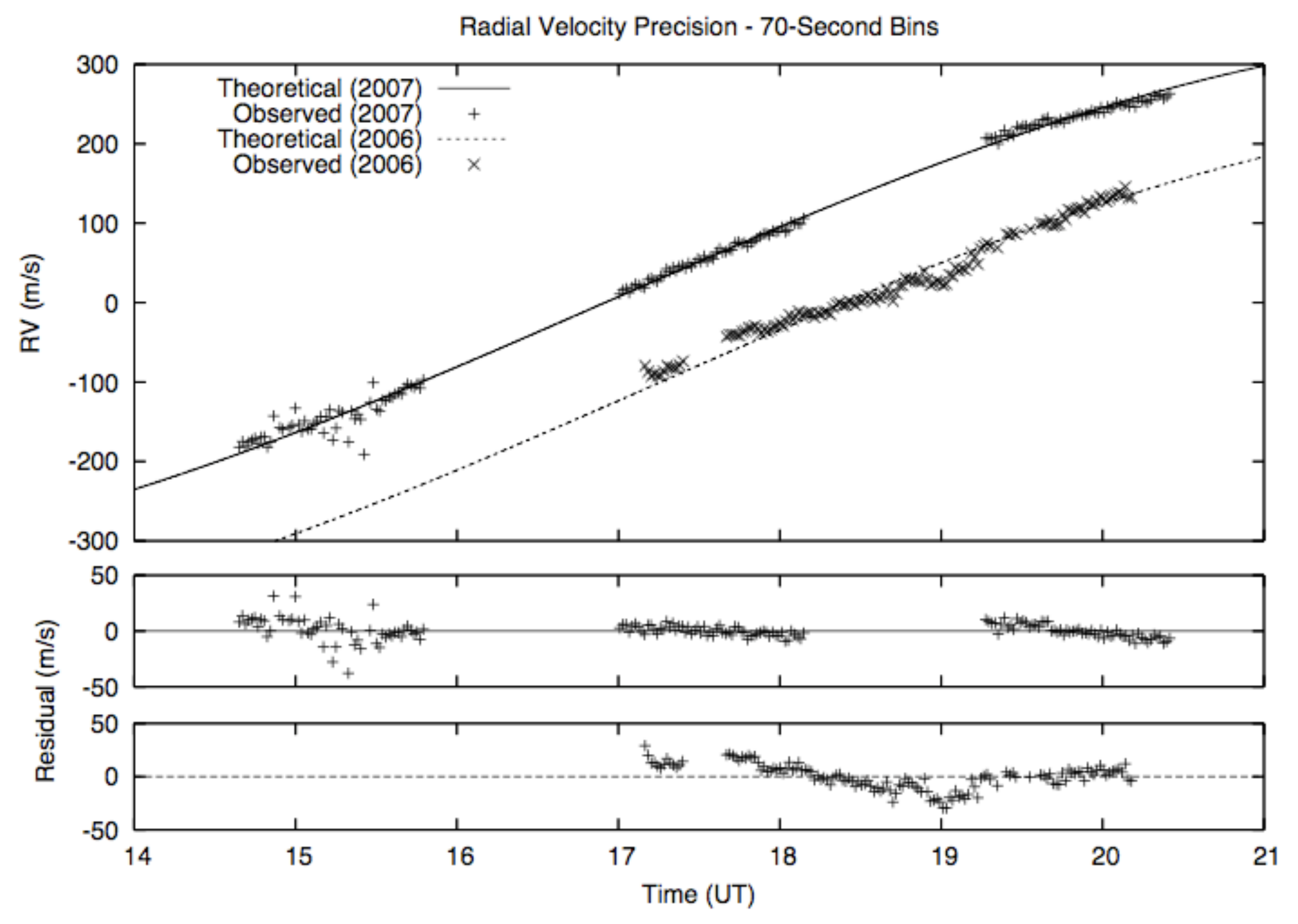

Post Nov 07 fiber with slit

Y- Band Spectra with ThAr lamp

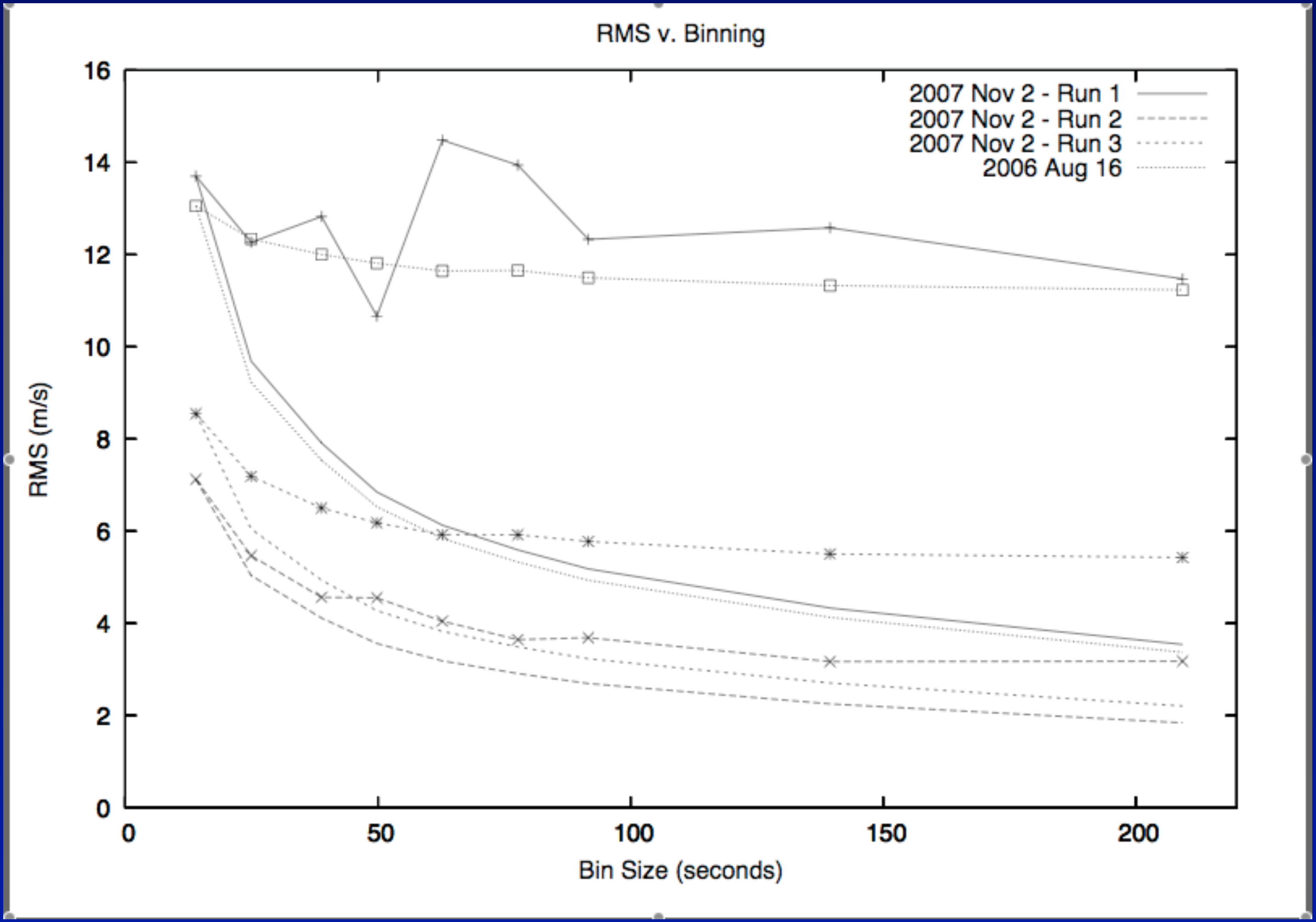


Red – observed, Green – telluric model, Blue – ThAr/10

Ongoing programme - different optical configurations

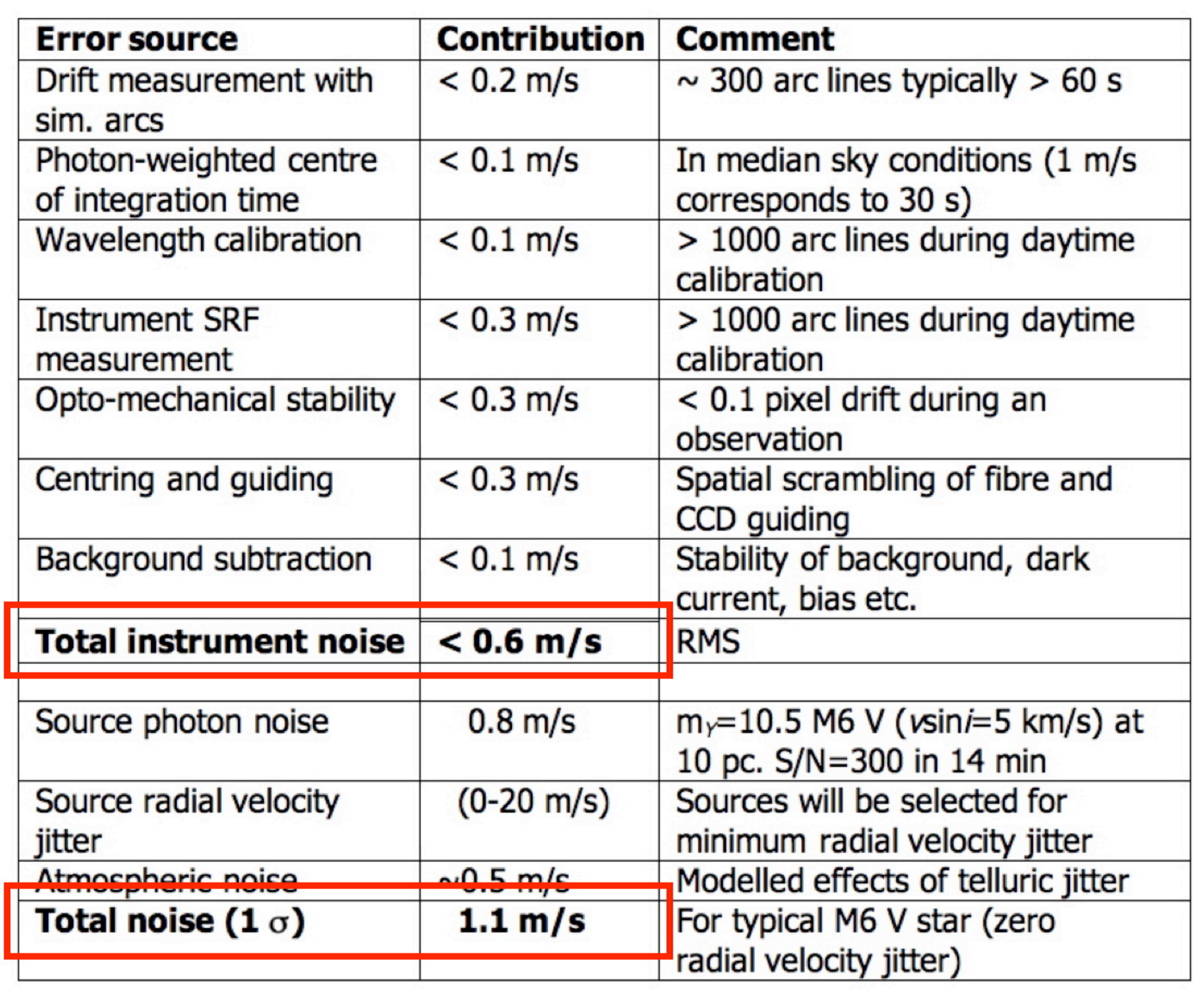


Pathfinder RMS on Sun for different configurations



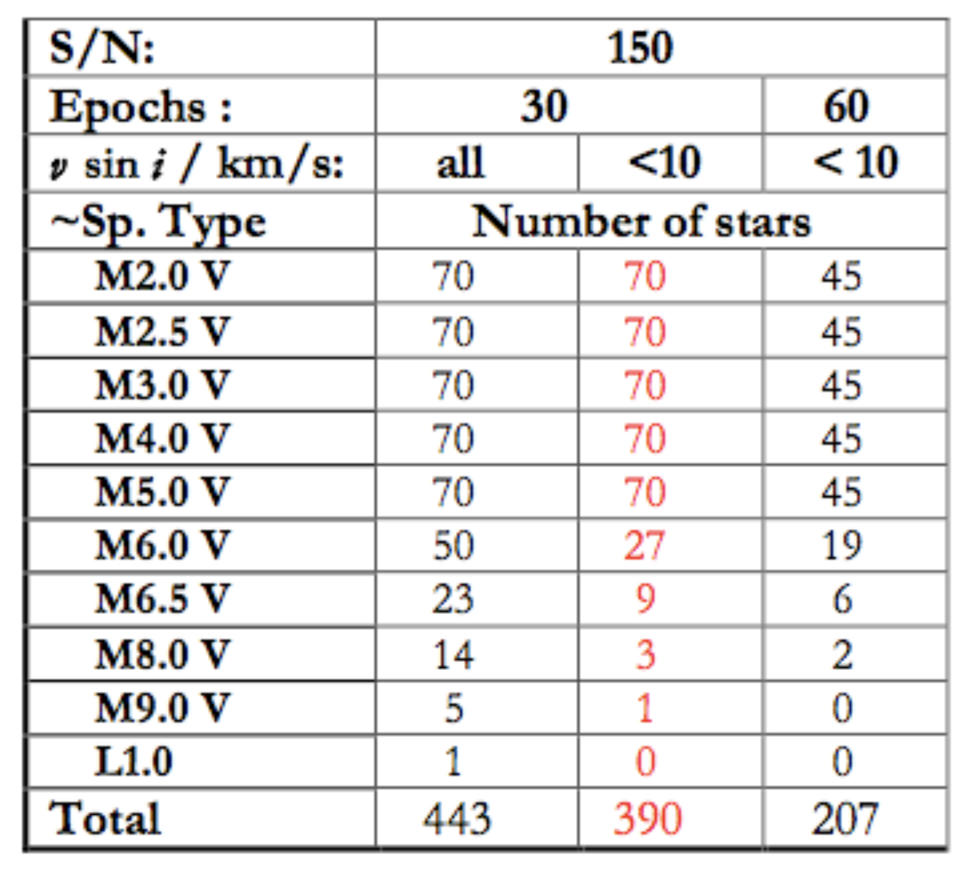
Ramsey et al. 2008, PASP, 120, 887

Instrument expectations



Error source	Contribution	Comment
Drift measurement with sim. arcs	< 0.2 m/s	~ 300 arc lines typically > 60 s
Photon-weighted centre of integration time	< 0.1 m/s	In median sky conditions (1 m/s corresponds to 30 s)
Wavelength calibration	< 0.1 m/s	> 1000 arc lines during daytime calibration
Instrument SRF measurement	< 0.3 m/s	> 1000 arc lines during daytime calibration
Opto-mechanical stability	< 0.3 m/s	< 0.1 pixel drift during an observation
Centring and guiding	< 0.3 m/s	Spatial scrambling of fibre and CCD guiding
Background subtraction	< 0.1 m/s	Stability of background, dark current, bias etc.
Total instrument noise	**< 0.6 m/s**	RMS
Source photon noise	0.8 m/s	m_Y=10.5 M6 V (*v*sin*i*=5 km/s) at 10 pc. S/N=300 in 14 min
Source radial velocity jitter	(0-20 m/s)	Sources will be selected for minimum radial velocity jitter
Atmospheric noise	~0.5 m/s	Modelled effects of telluric jitter
Total noise (1 σ)	**1.1 m/s**	For typical M6 V star (zero radial velocity jitter)

Mock UKIRT survey – 100 night/yr for 5 years assuming std overheads



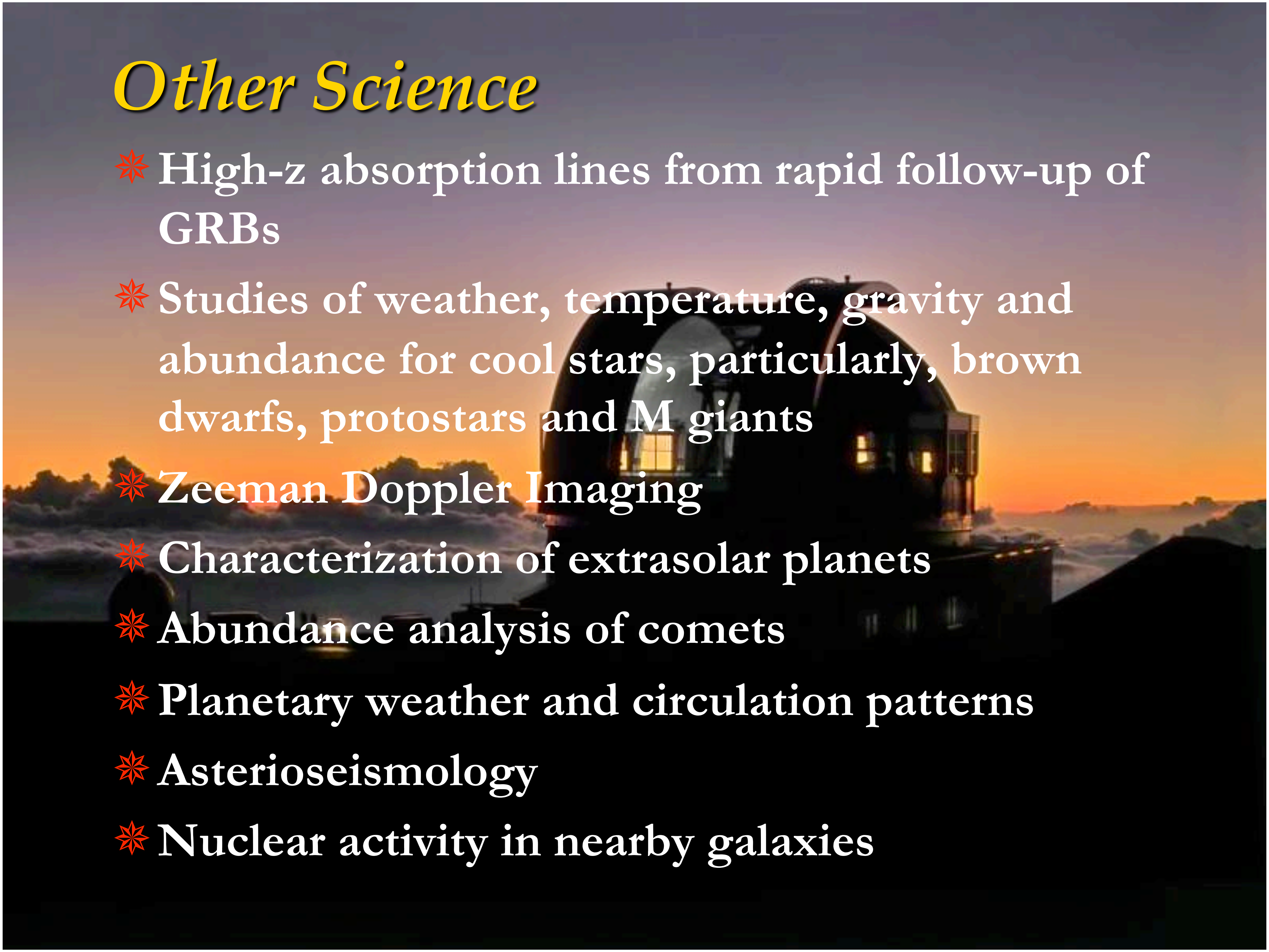
S/N:	150		
Epochs :	30		60
$v \sin i$ / km/s:	all	<10	< 10
~Sp. Type	Number of stars		
M2.0 V	70	70	45
M2.5 V	70	70	45
M3.0 V	70	70	45
M4.0 V	70	70	45
M5.0 V	70	70	45
M6.0 V	50	27	19
M6.5 V	23	9	6
M8.0 V	14	3	2
M9.0 V	5	1	0
L1.0	1	0	0
Total	443	390	207

Y=11.3 J=10.7 H=10.2, S/N=150 in 1hr

Conclusion

- <5 m/s reached on Sun in 1 minute
- Modelling indicates 1 m/s is achievable
- Limits probably driven by stability of stars
- Method to detect Earth-mass planet in a habitable zone
- Conservative design can achieve science goals

http://www.roe.ac.uk/ukatc/projects/upf/



Other Science

- High-z absorption lines from rapid follow-up of GRBs
- Studies of weather, temperature, gravity and abundance for cool stars, particularly, brown dwarfs, protostars and M giants
- Zeeman Doppler Imaging
- Characterization of extrasolar planets
- Abundance analysis of comets
- Planetary weather and circulation patterns
- Asterioseismology
- Nuclear activity in nearby galaxies

Fourier Analysis

- Doppler info of spectrum
- F(l) related to df/dl.

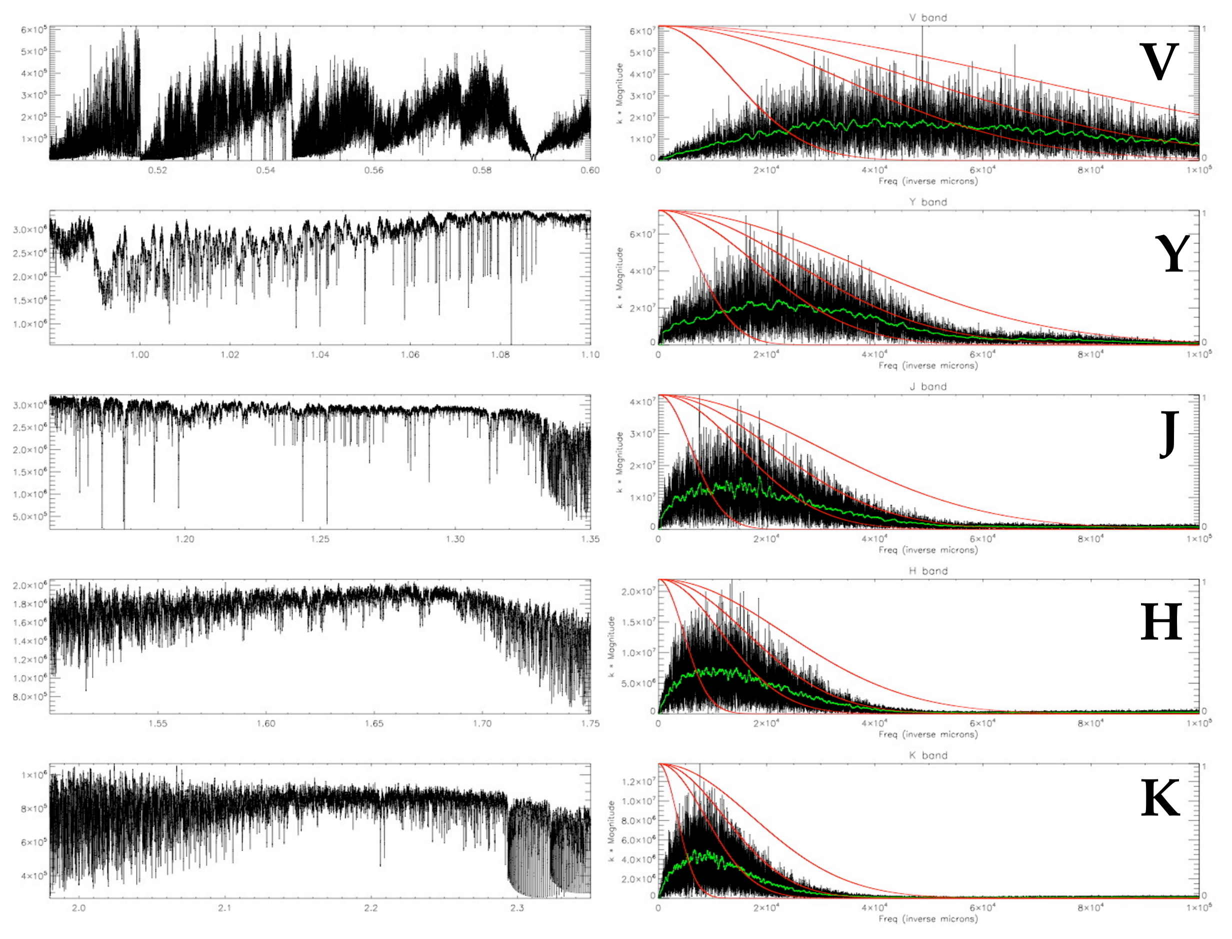
- FT (df/dl) = k f(k) where
- spatial freq k = 2p/l

- Plot k f(k) vs k for M6V
- and v sin i = 0 km/s

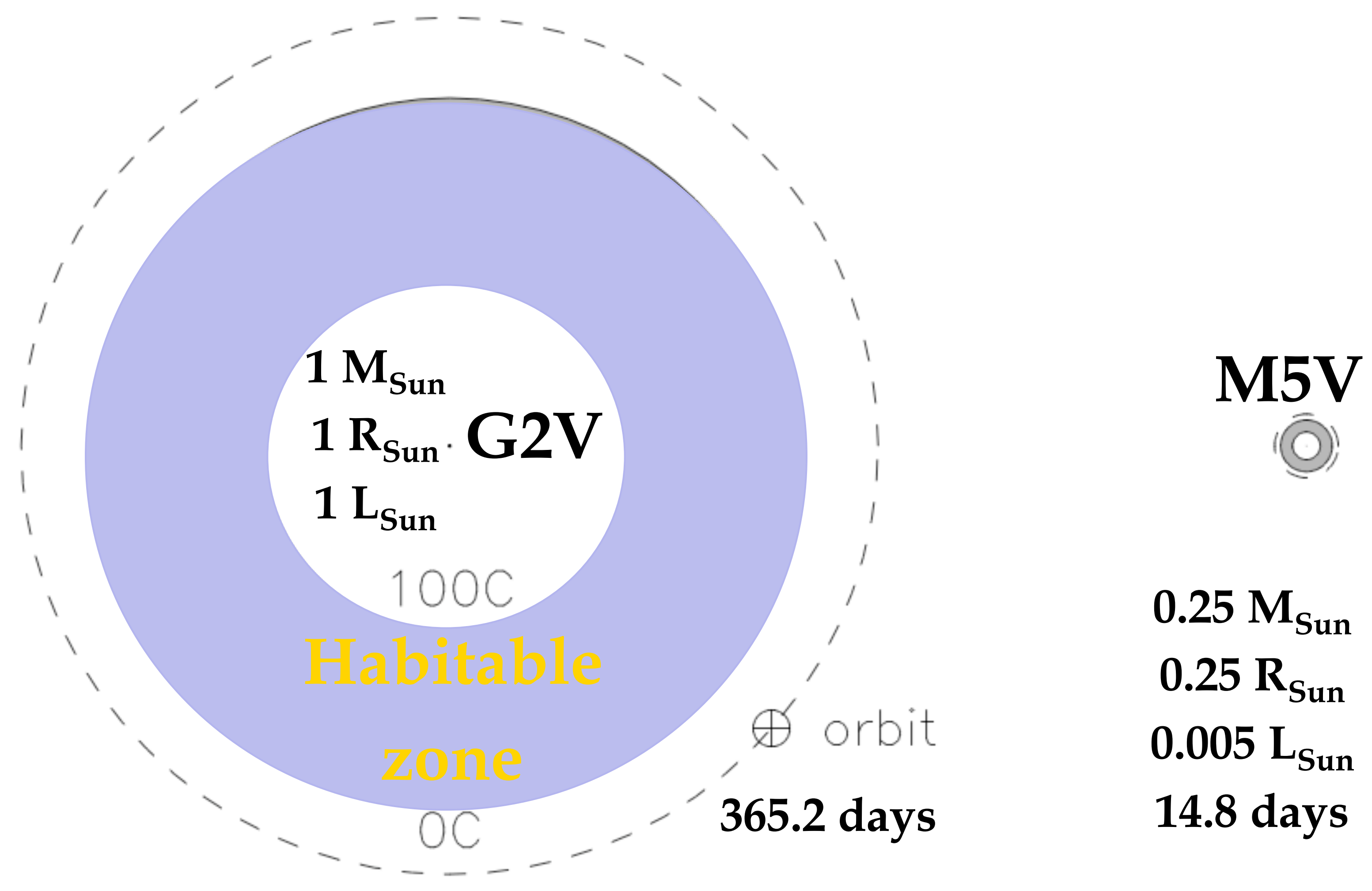
- Over-plot FT (Gaussian PSF)
- for R=20k, 50k, 70k, 100k

- RESULT:
- optimum R ~ 70,000

F(l) FT (df/dl)



Habitable zones



1 M_{Sun}
1 R_{Sun}
1 L_{Sun}

G2V

Habitable zone

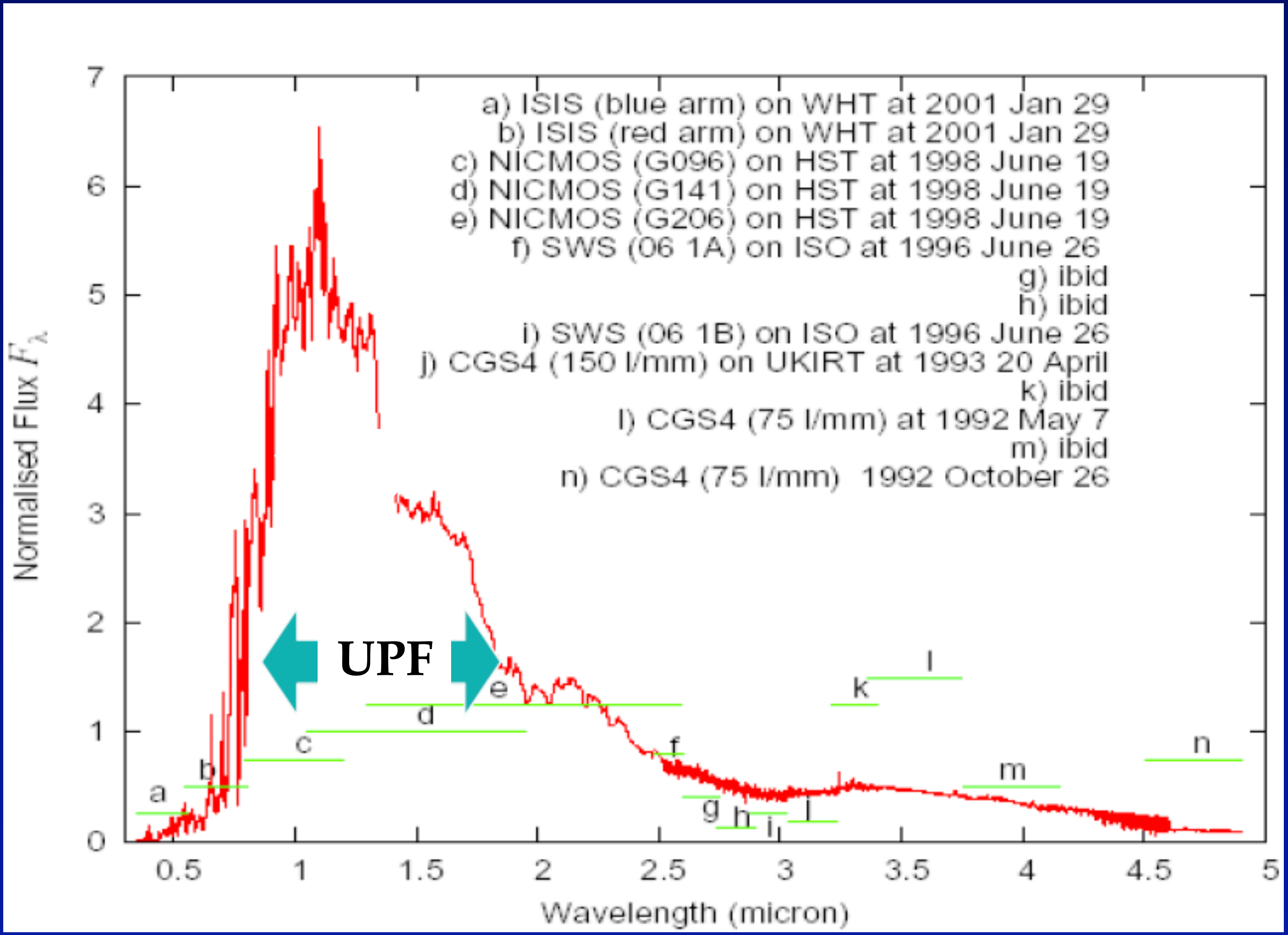
365.2 days

M5V

0.25 M_{Sun}
0.25 R_{Sun}
0.005 L_{Sun}
14.8 days

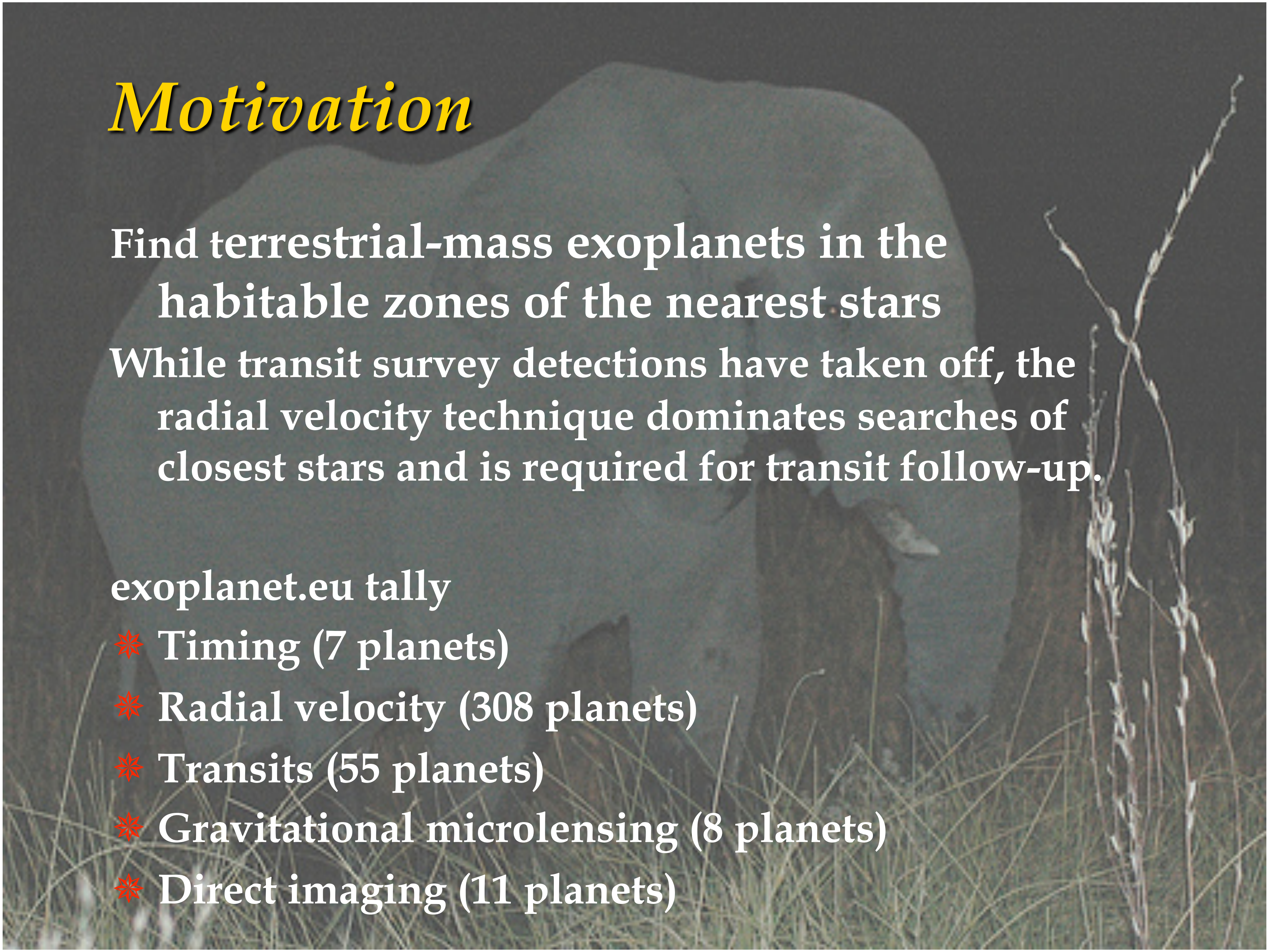
RV amplitude (m/s) 0.06 1.0

Why the infrared?



@M6 – flux x50

Pavlenko et al. 2006



Motivation

Find terrestrial-mass exoplanets in the habitable zones of the nearest stars

While transit survey detections have taken off, the radial velocity technique dominates searches of closest stars and is required for transit follow-up.

exoplanet.eu tally

- Timing (7 planets)
- Radial velocity (308 planets)
- Transits (55 planets)
- Gravitational microlensing (8 planets)
- Direct imaging (11 planets)