UPF

UKIRT PLANET FINDER

University of Hertfordshire

Joint Astronomy Centre — JCMT UKIRT

Science & Technology Facilities Council
UK Astronomy Technology Centre

13 October 2009

Reasons to build

- Community says it cares (letters of support from 26 UK astrophysics groups)
- Community writes applications (e.g. ESO C TAC 'problem')
- Community writes papers (last year 655 refereed)
- Media (public) cares (exoplanets dominate press)
- Governments care, eg. Clinton televised announcement of ALH84001
- Long colourful history, e.g. warning to anyone who finds themselves transported back to the 17th century

Giordano Bruno

- Italian philosopher
- Advocate of heliocentrism and the infinit universe

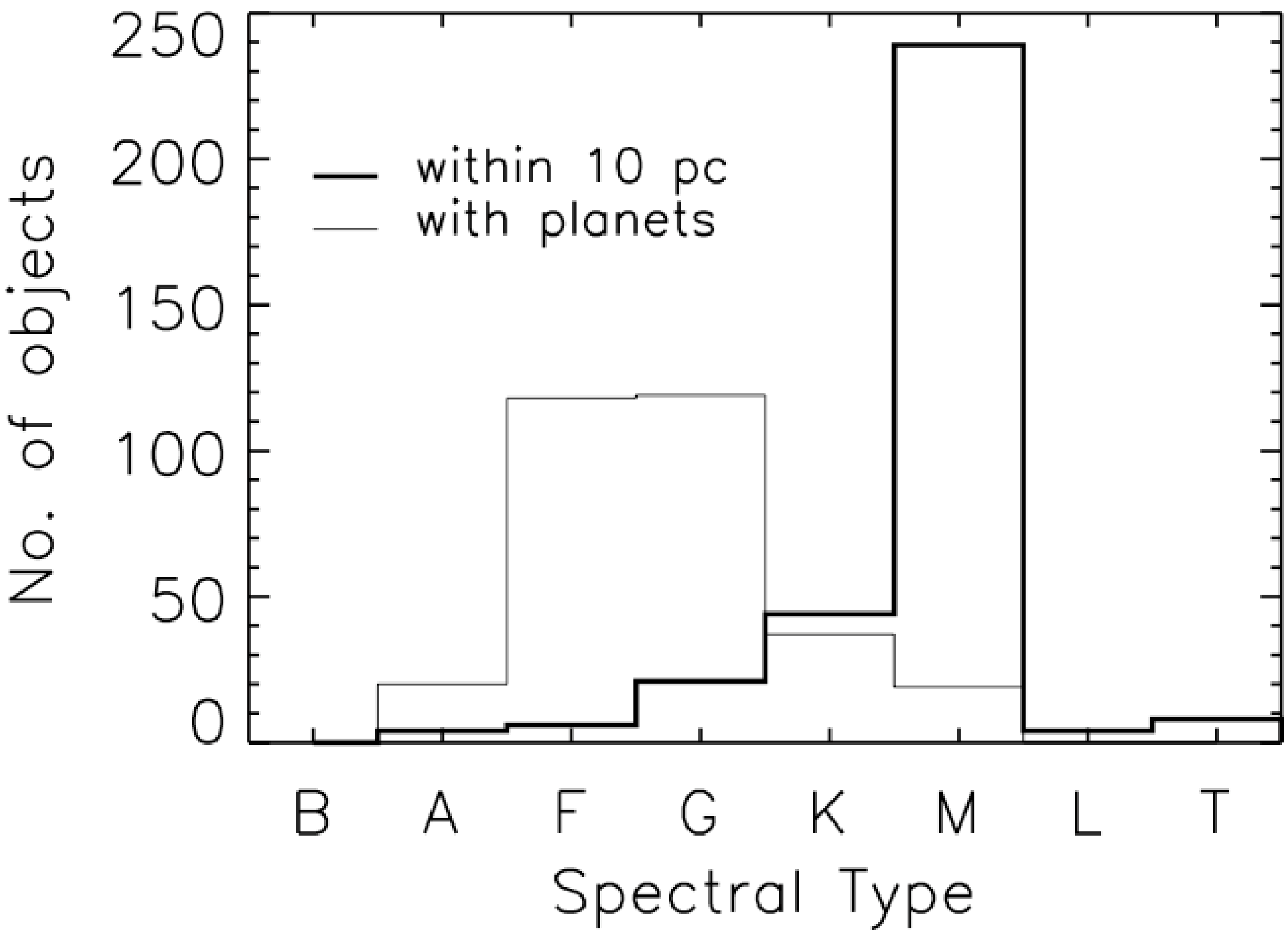
“In space there are countless constellations, suns and p because they give light; the planets remain invisible, t There are also numberless earths circling around their than this globe of ours. For no reasonable mind can a that may be far more magnificent than ours would no similar or even superior to those upon our human earth.’

- In 1600 AD Bruno was burned at the stake in Rome as a heretic by the Roman Inquisition!
- In 1962 Giordano Bruno pardoned by catholic church

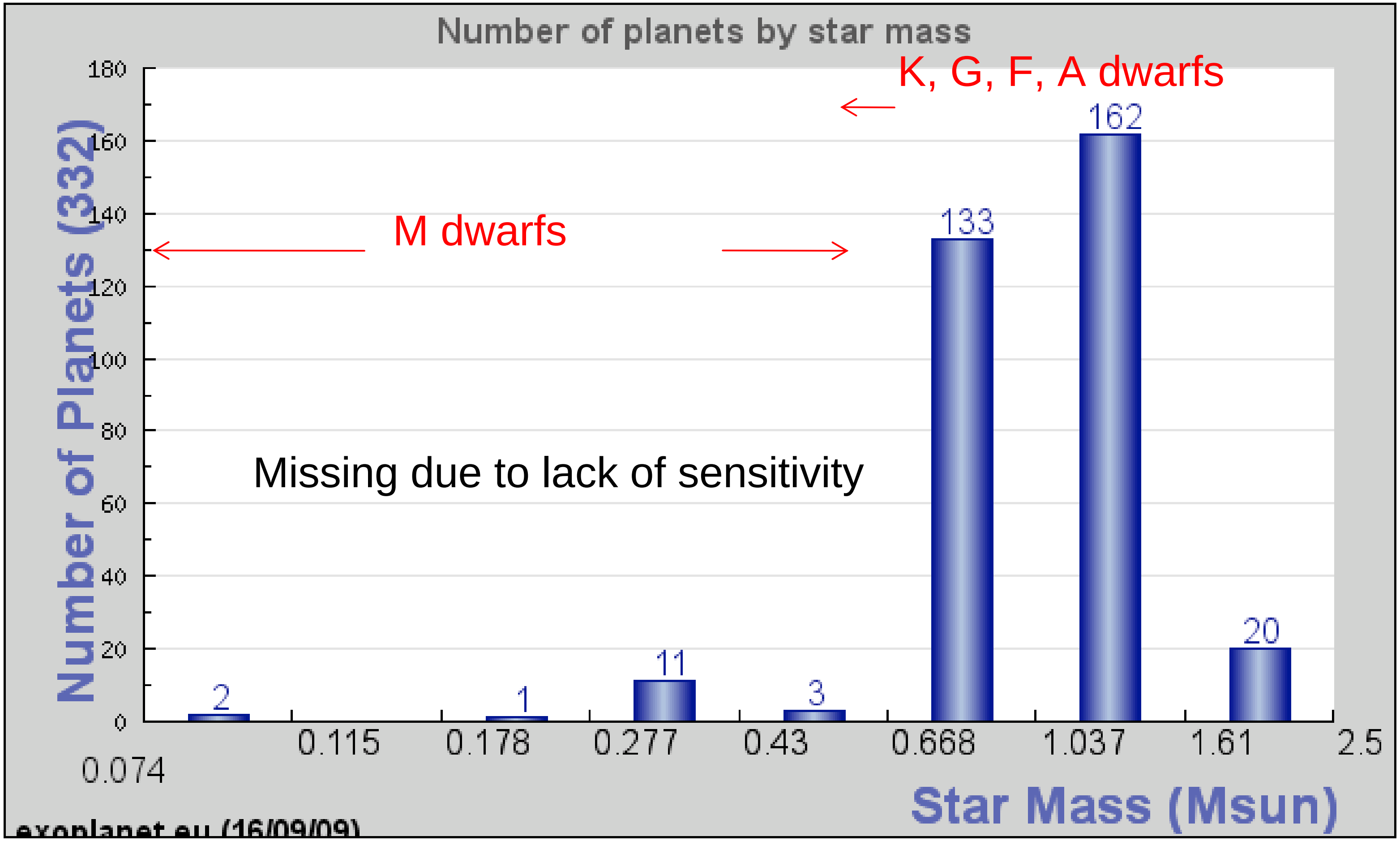
The holy grail of exoplanet hunting – Earth-mass planets

- Earth-mass planets in the habitable zones of the nearest stars
- Majority of planets found to date are giants
- Smaller planets can be found around smaller stars

Are there planets around the majority of stars (M dwarfs)?

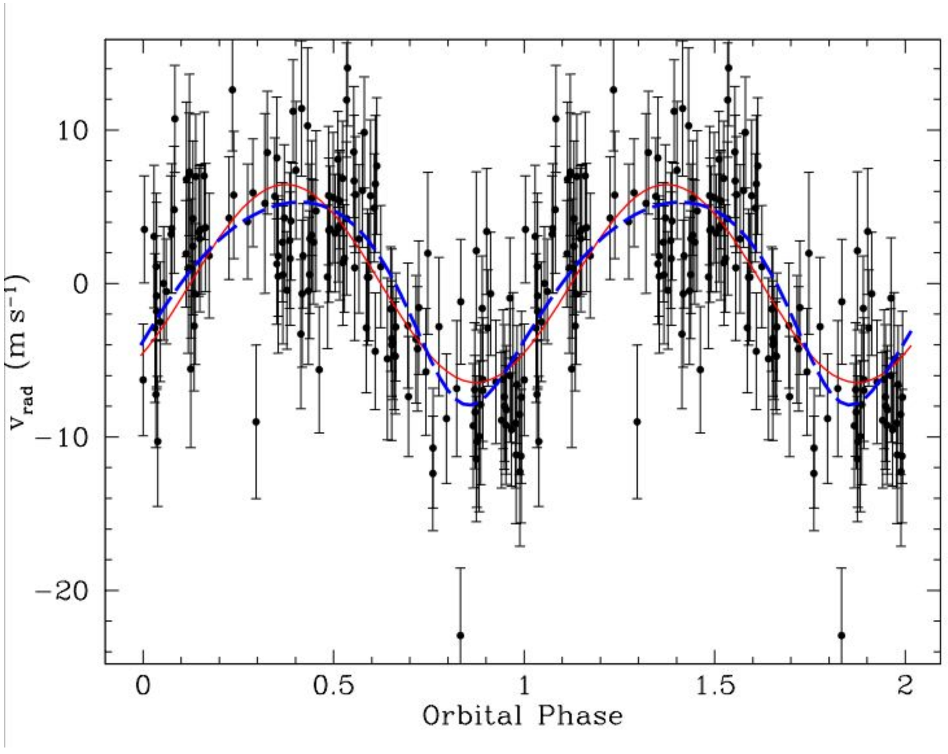


Astrophysically …unexplored



Optical RVs is hard work for M dwarfs

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



Gl876 (M4V), 4.7pc

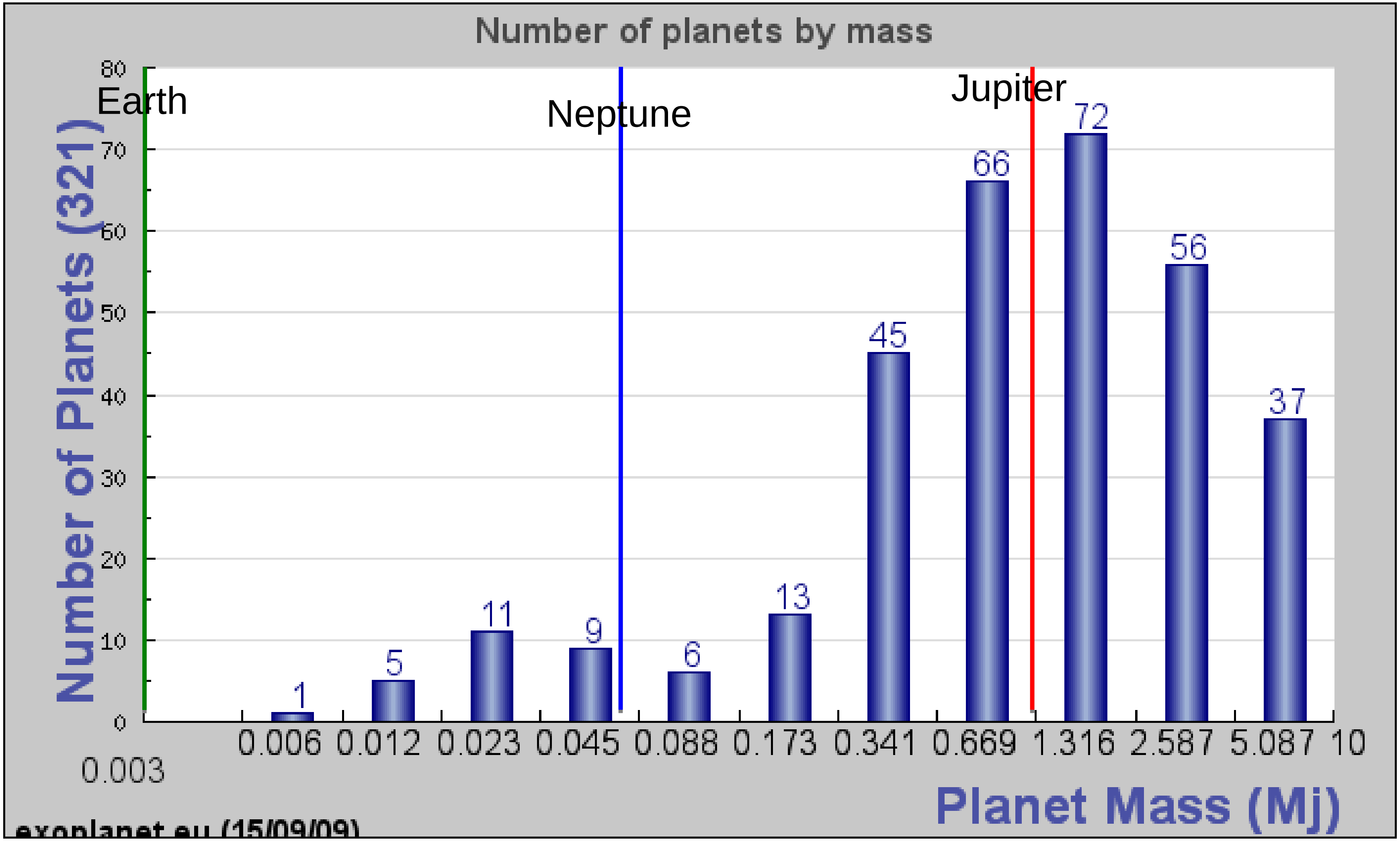
1.9 day period

Msini=7.5M_{Earth}

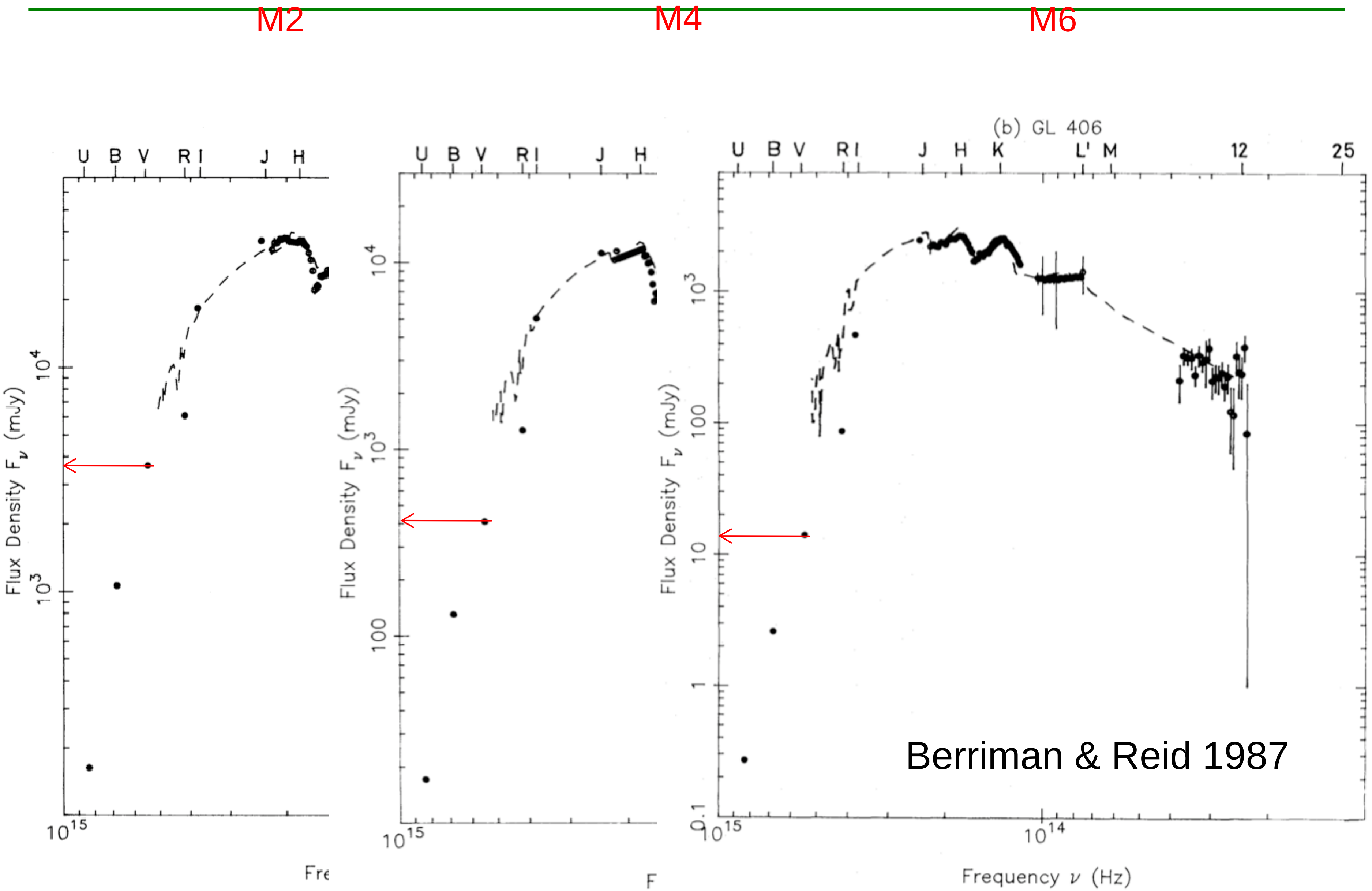
1997-2005 Keck monitoring including data on 6 consecutive nights

Rivera et al. 2005

Planet mass function



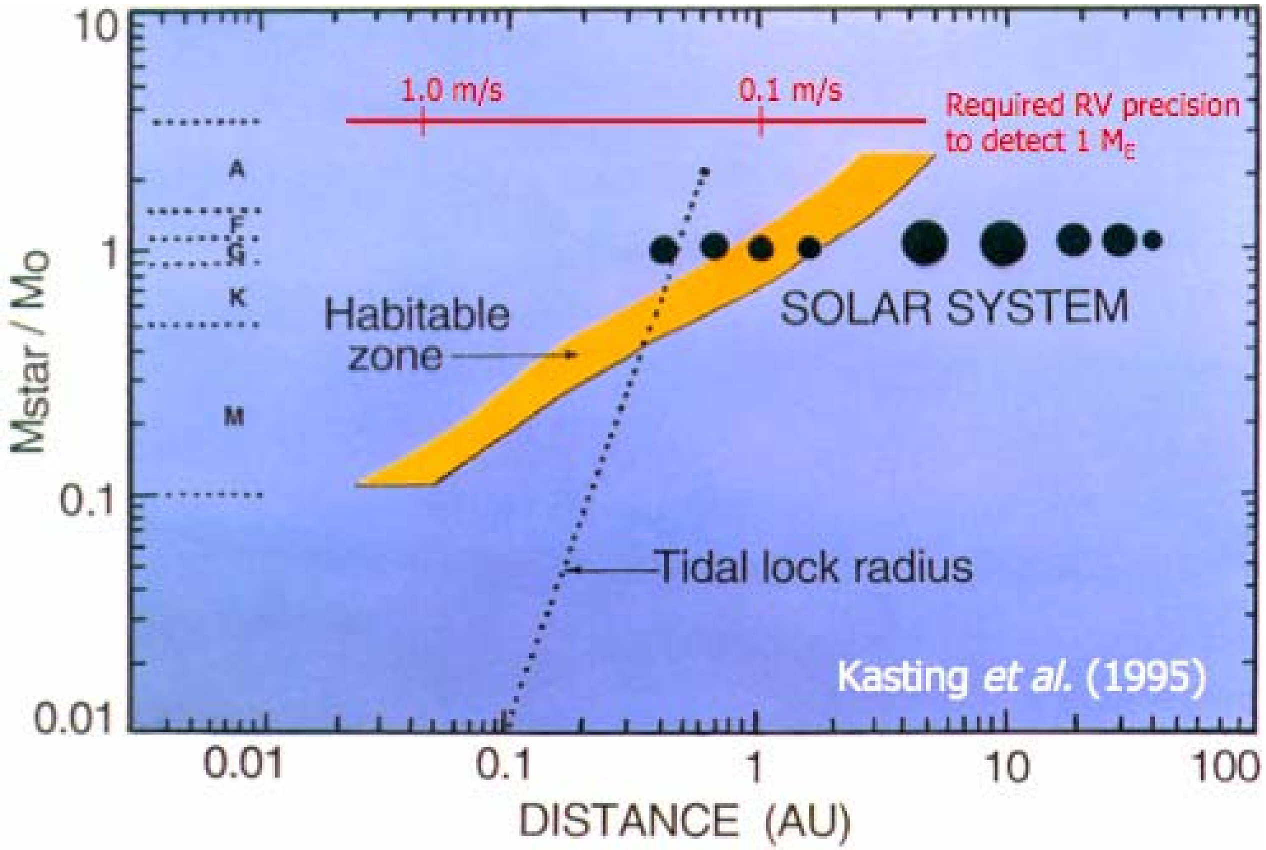
Why the infrared?



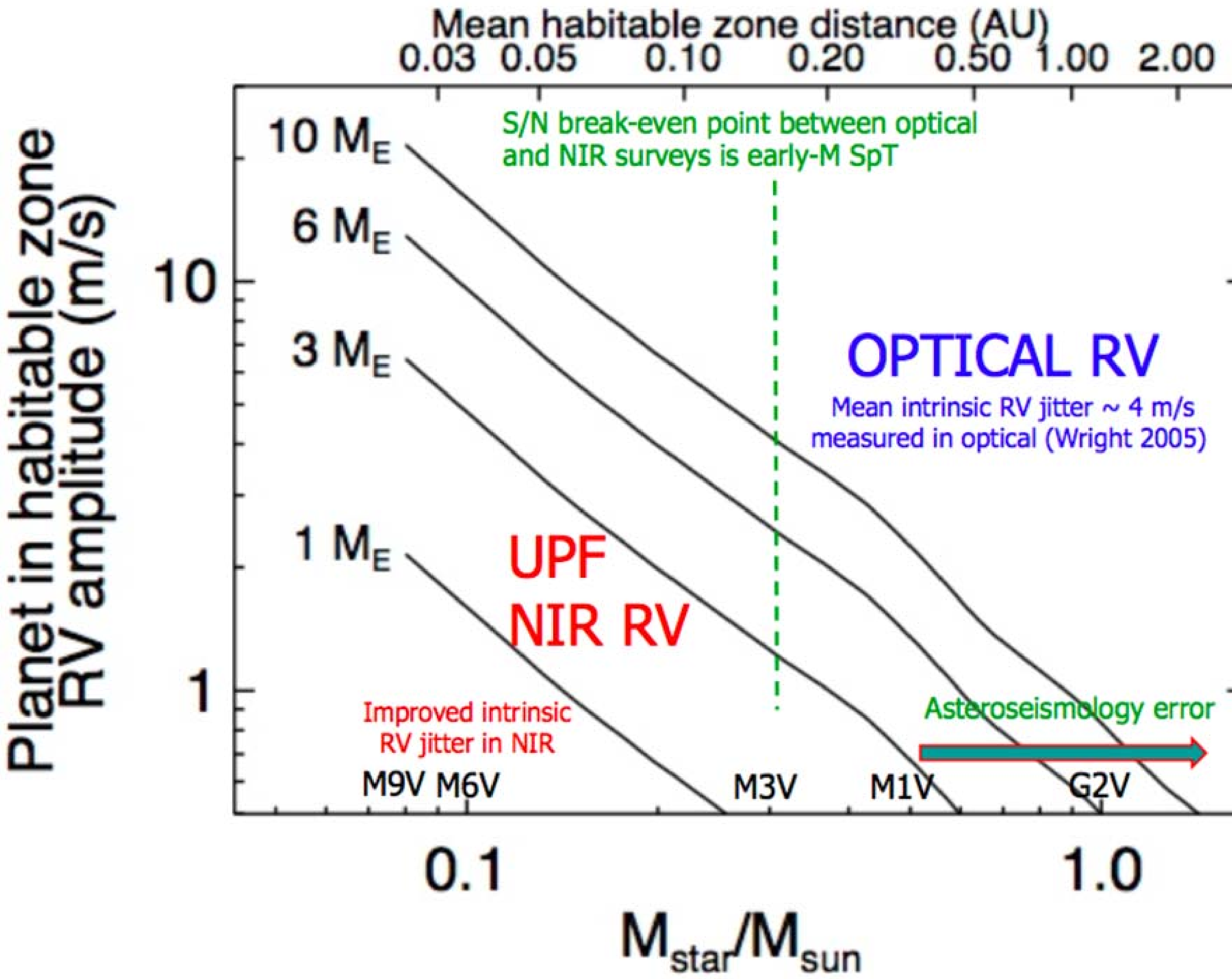
Accessible habitable zones

Habitable zone inside 0.3 AU for M dwarfs

Impact of tidal locking unclear



The potential in the infrared



Mock UKIRT survey

194night/yr for 5yrs @ Y=11.75 J=11.25 H=10.75, S/N=150 in 1hr, 30 epochs

~Sp Type:	Mass	No. of stars
M2.5 V	0.3	200
M3.0 V	0.24	200
M4.0 V	0.19	200
M5.0 V	0.15	200
M6.0 V	0.12	114
M6.5 V	0.1	37
M8.0 V	0.09	14
M9.0 V	0.08	5
Total		970

Survey size of 1000 recommended by NASA exoplanet community report

Surveys

- Closest 1000 M dwarfs → Closest exoplanets to below 1 M_{Earth}
- 10000 M dwarfs for transitting exoplanets within 50pc → 100 transitting exoplanets
- 200 brown dwarfs → Reconaissance of low-mass planet formation

Other Science

- Ionisation history of the Universe from rapid follow-up of z>7 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
- Asteroseismology
- Nuclear activity in nearby galaxies

Exoplanet competition

- Super high precision optical surveys

Keck, HARPS, AAT

- Other IR-stabilised spectrographs – none fully funded

(also plans Discovery Channel, Subaru, Okayama .. and for E-ELT, TMT)

Instrument/ Telescope	λ - λ/Δλ	First Light	Comment PRV ✓✖
CARMENES /Calar Alto	0.5-1.8/80k	2014	PRVS design ✓
SPIROU/CFHT	0.9-2.5/50k	2014	Polarimeter ✓
Nauhal/GTC	1-?/70k	2014	PRVS design ✓
GIANO/TNG	1-2.5/50k	2011	MultipleModes ?
HET	1-1.8/74k	2015	PRVS Design ✓

- Space/IR transit missions

COROT, Kepler, Mearth, WTS

Challenges of RV in the NIR

- Significant telluric contamination in the NIR
  - Mask out ~ 30 km/s around telluric features deeper than 2%
  - At R=70,000 (14,000 ft, 2.5 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

➡ Simulation – significant benefit to Mauna Kea

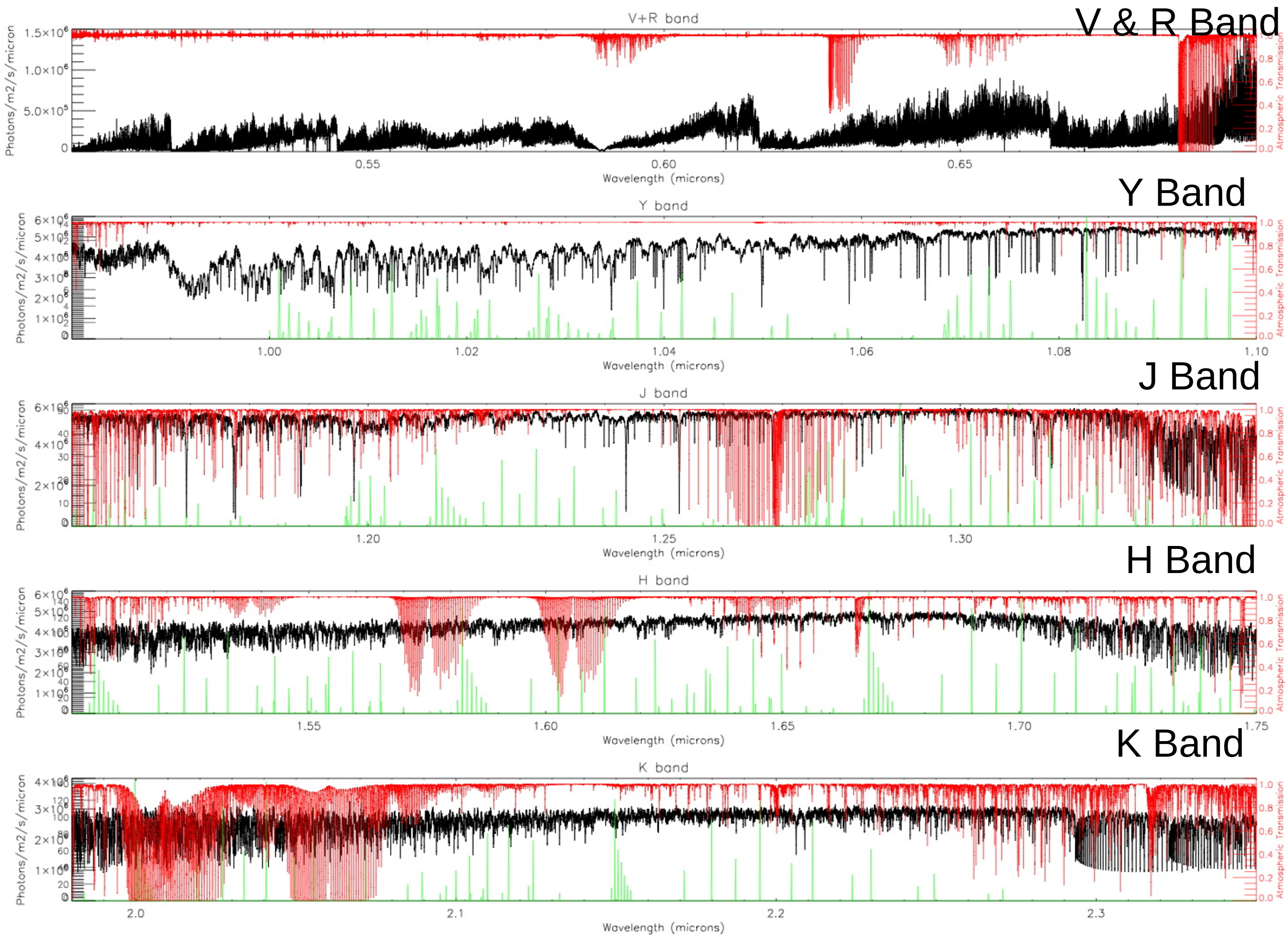
- Simultaneous wavelength fiducial covering NIR is required for high precision RV spectroscopy
  - Suitable gas/gases for a NIR absorption cell
  - Use simultaneously exposed arcs (Th-Ar, Kr, Ne, Xe) and ultra-stable spectrograph
  - Use of a laser comb possible following R&D

➡ Simulation / Prototype

Atmospheric limits?
Mauna Kea is best site to avoid tellurics

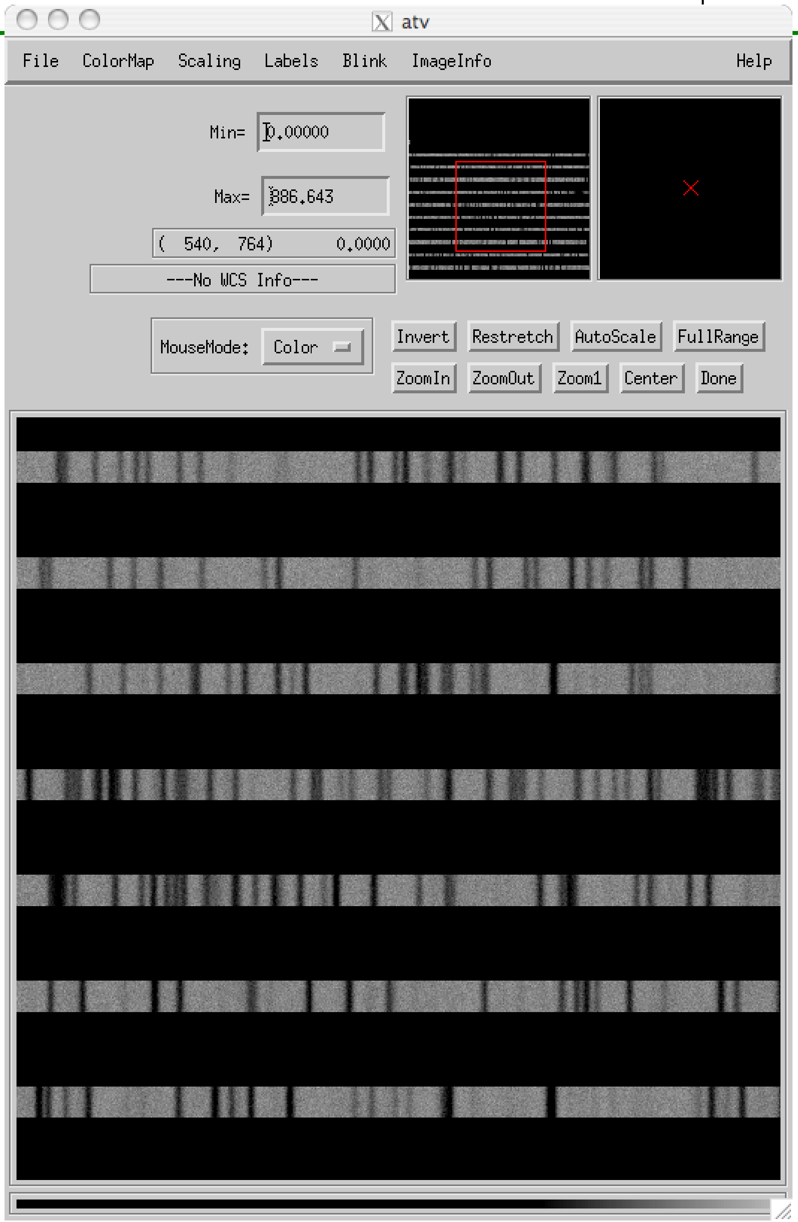
M6V
T_{eff} = 2800 K
Log g = 5
v sin i = 0 km/s

Model
Telluric
OH



Simulations

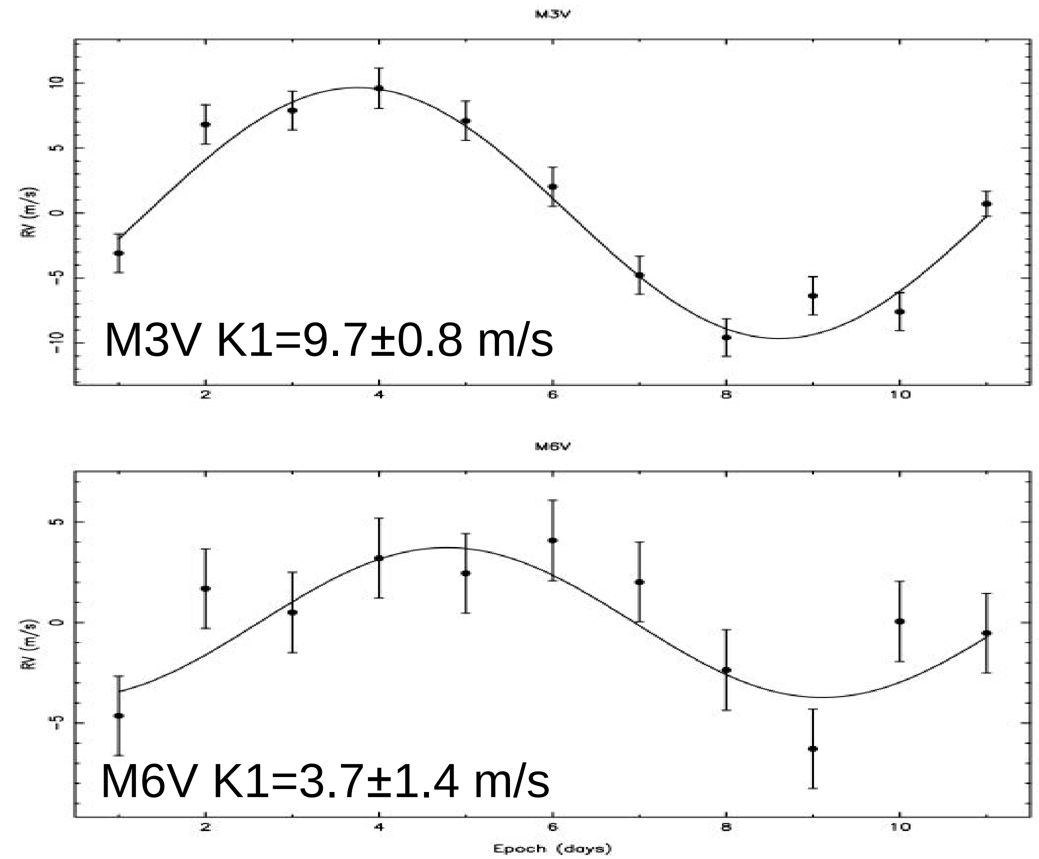
- Outputs:
  - 2-D image
  - 1-D photon, error, S/N spectra



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

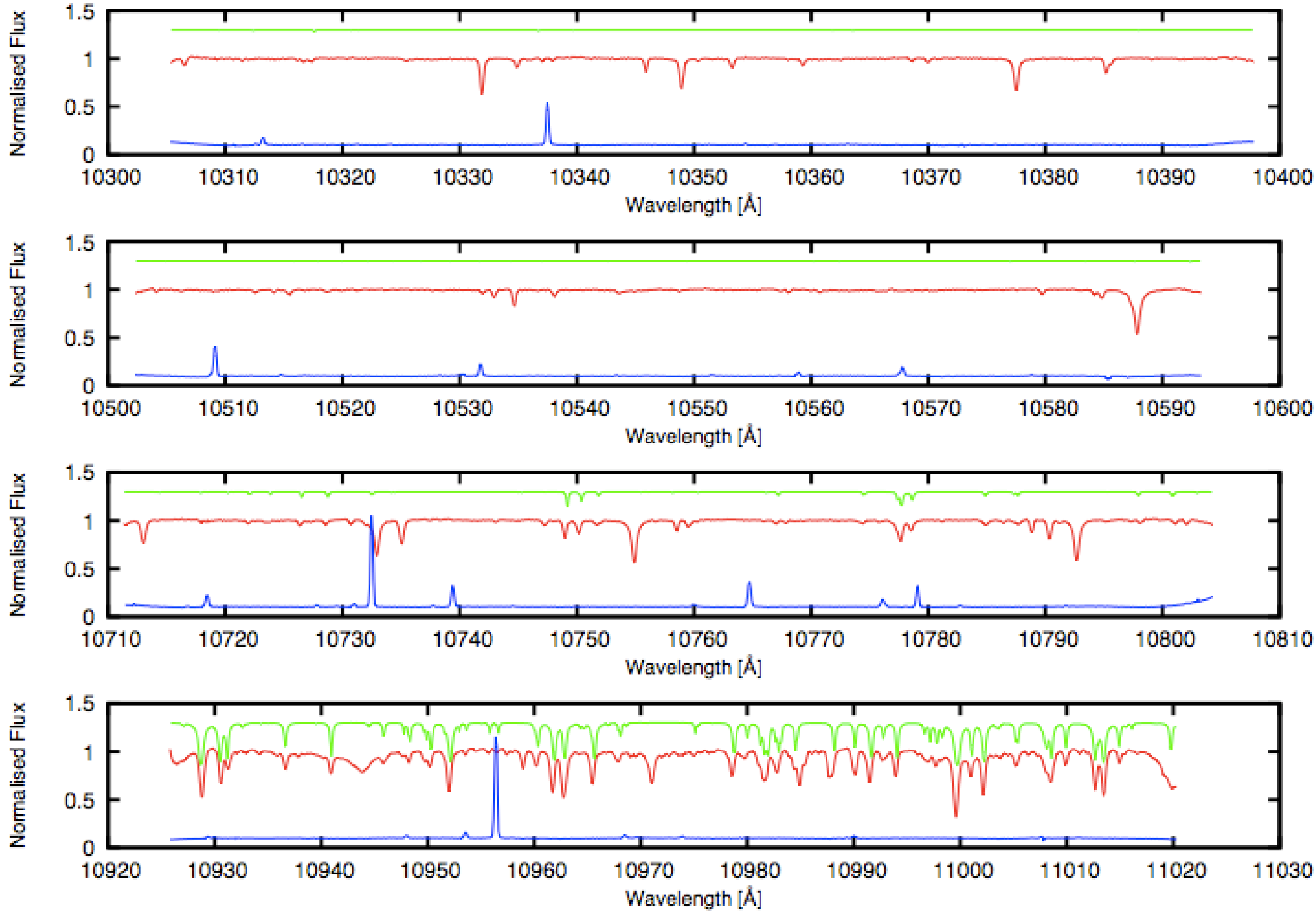
- RESULTS (Y band only):
- M3V - K1=9.7±0.8 m/s
- M6V - K1=3.7±1.4 m/s
- RV code agrees with independent Bouchy analysis
- Effect of telluric jitter, ~0.5 m/s



PRVS Pathfinder - test bed for IR stability measurements on Sun

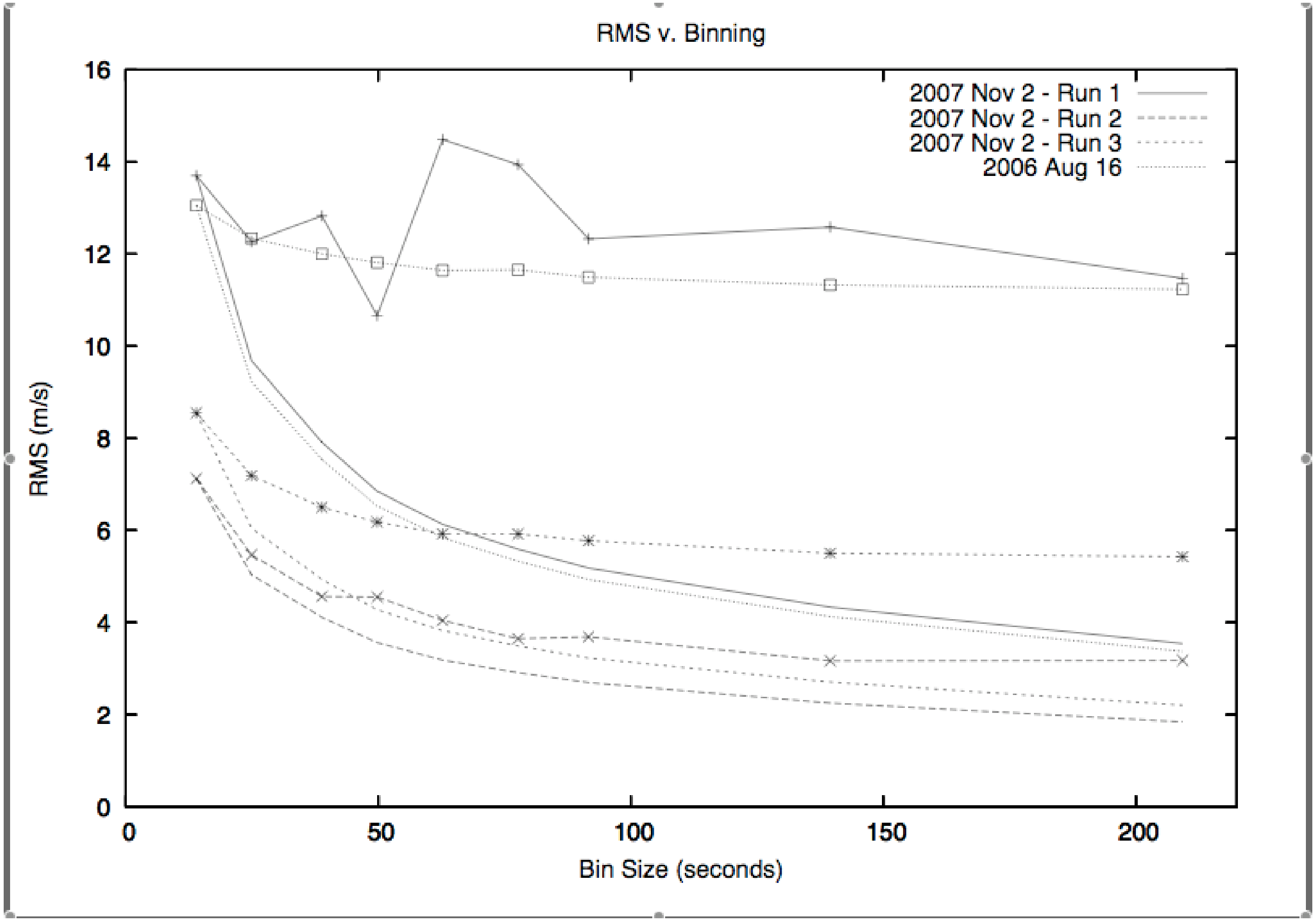
With insulation jacket

Y- Band Spectra with ThAr lamp – change background



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

Pathfinder RMS on Sun for different configurations



Precision improvement of 2 orders of magnitude - Ramsey et al. 2008, PASP, 120, 887

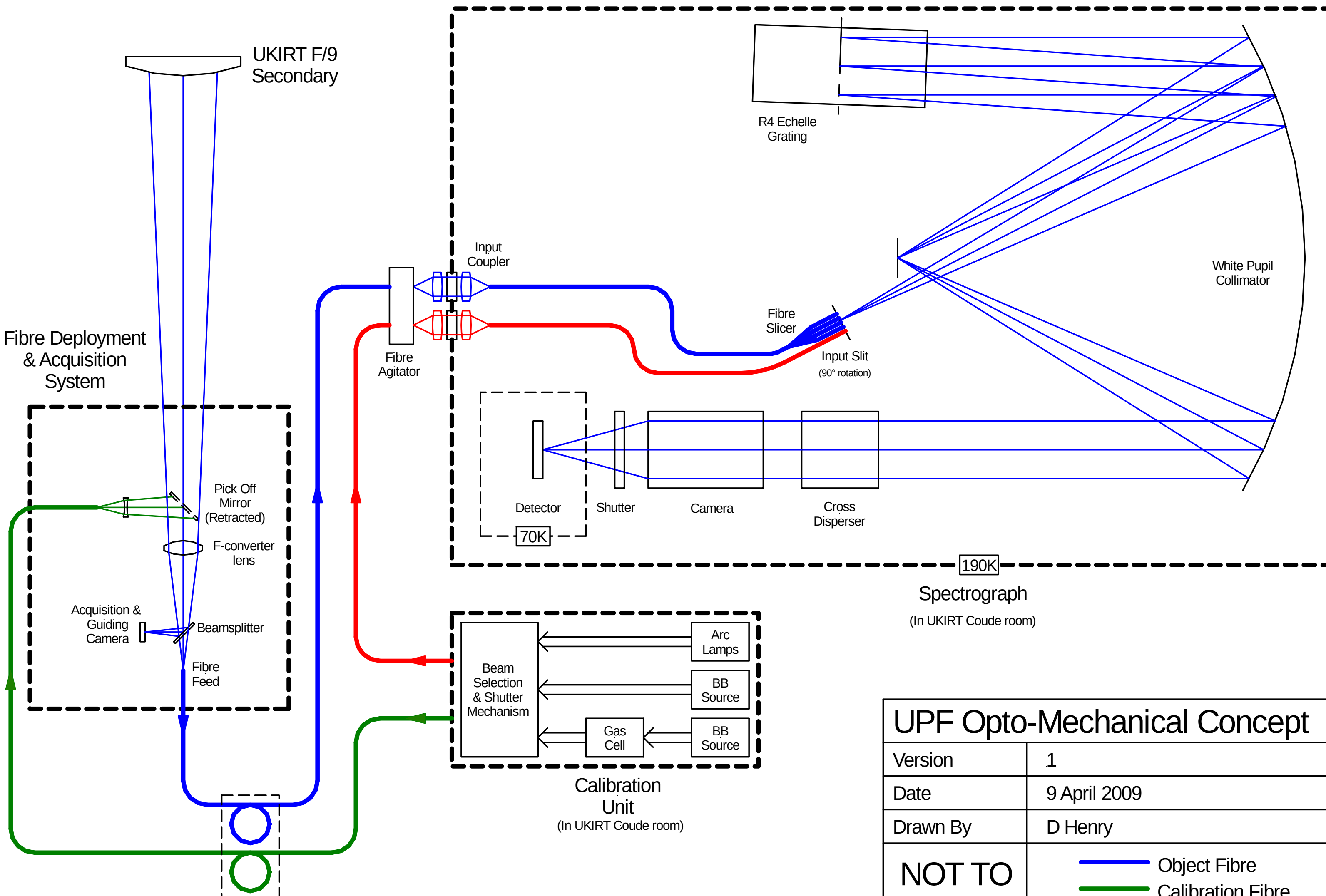
UPF Design Baseline Concept

- Design inherited from Gemini PRVS
- Optical design similar to HARPS, UVES, MRS spectrographs
- Cross dispersed echelle spectrograph
  - White pupil collimator design
  - Refractive camera
  - No mechanisms (in main optical path)

- Fibre fed
  - Fibre deployment system located on WFCAM cryostat

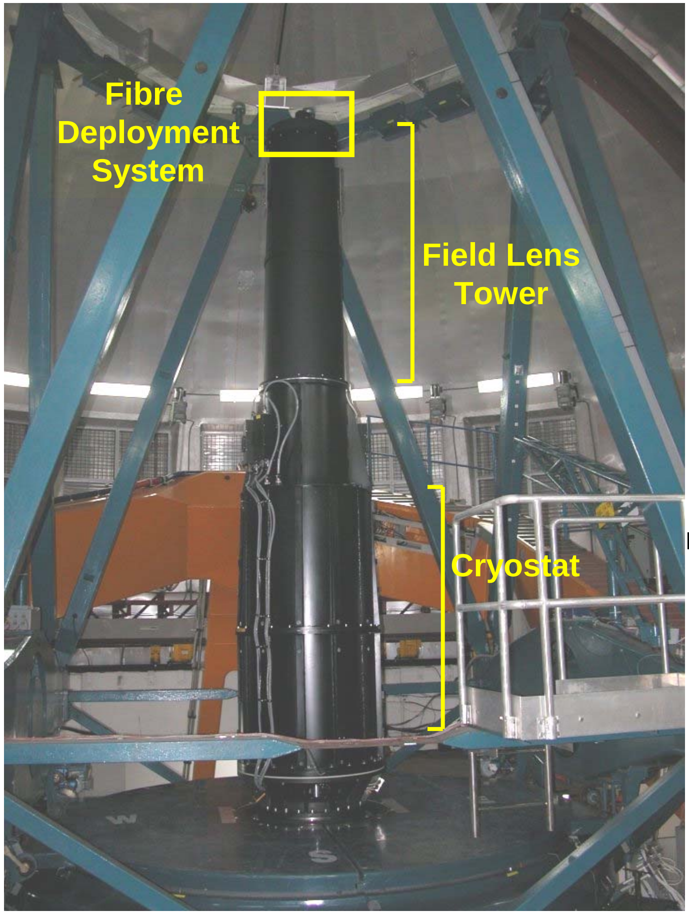
- Spectrograph and calibration unit located in Coude room

Instrument Concept

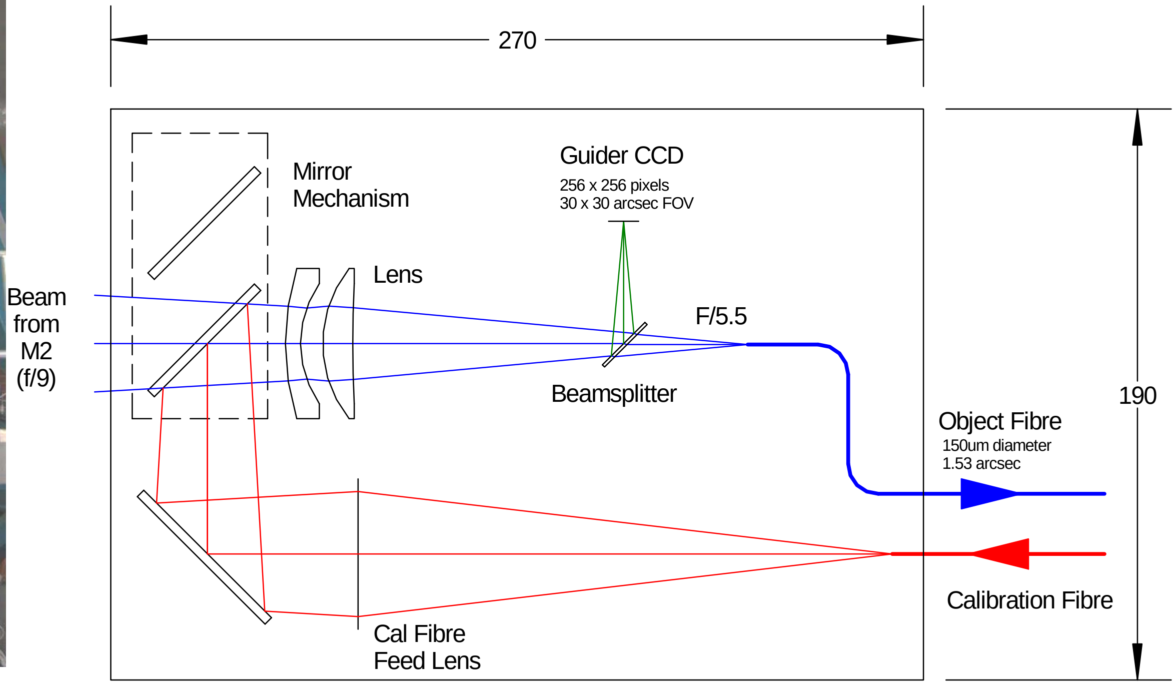


UPF Opto-Mechanical Concept	
Version	1
Date	9 April 2009
Drawn By	D Henry
NOT TO SCALE	Object Fibre Calibration Fibre Reference Fibre

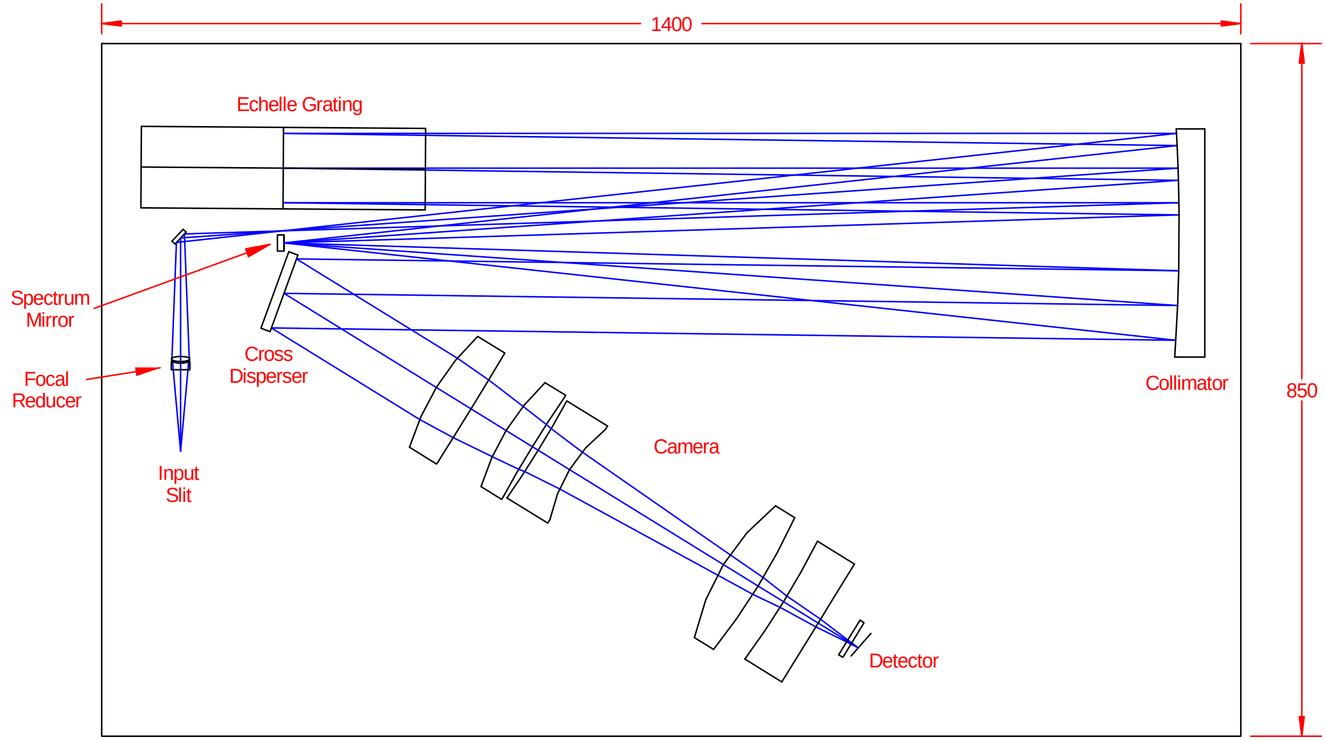
Fibre deployment and acquisition



- Remove field lens tower (normal operation for WFCAM installation/removal)
- Cryostat remains in place
- Fit second tower containing fibre pickoff & guiding assembly at f/9 focus

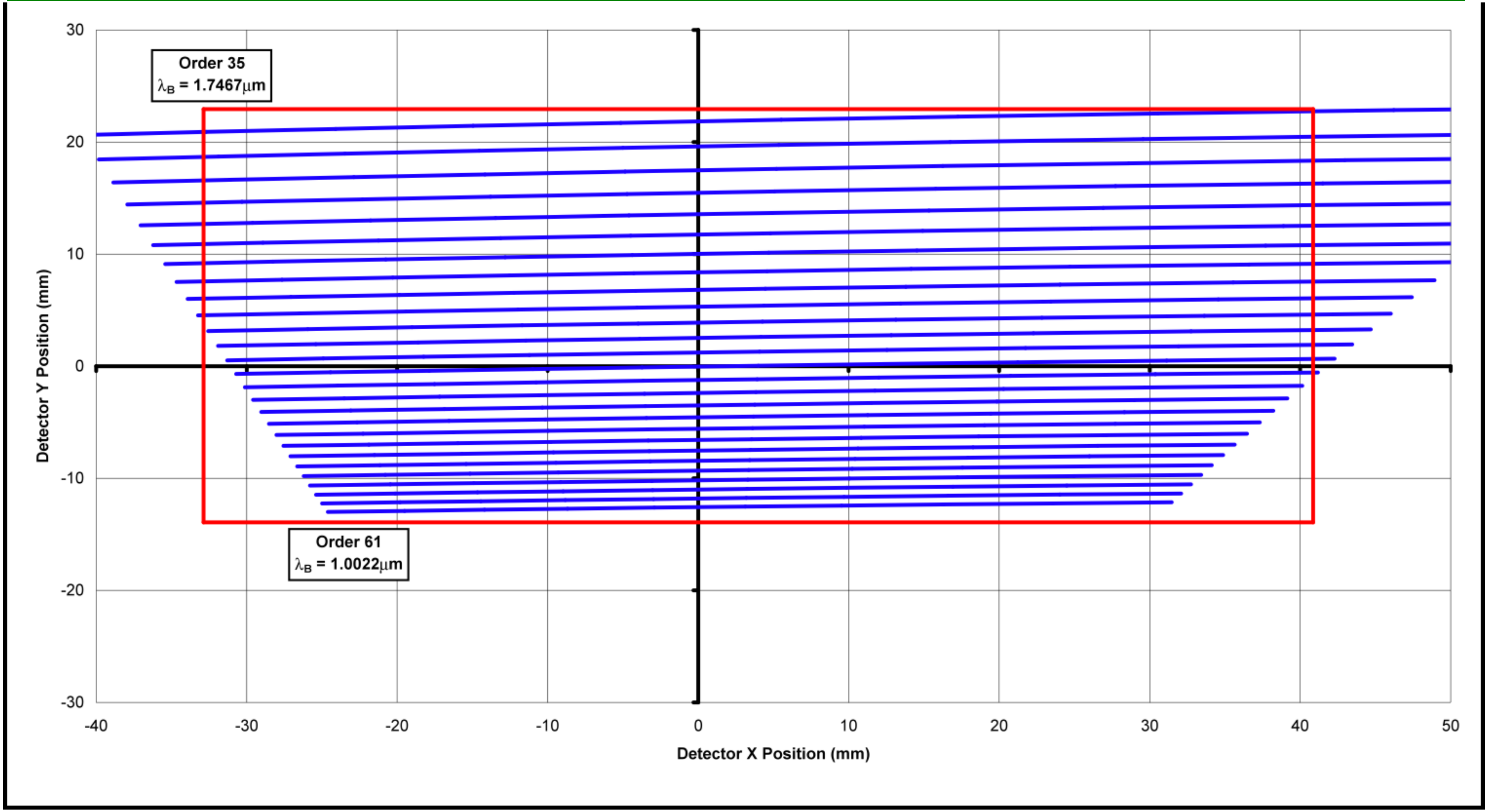


Spectrograph Optical Layout



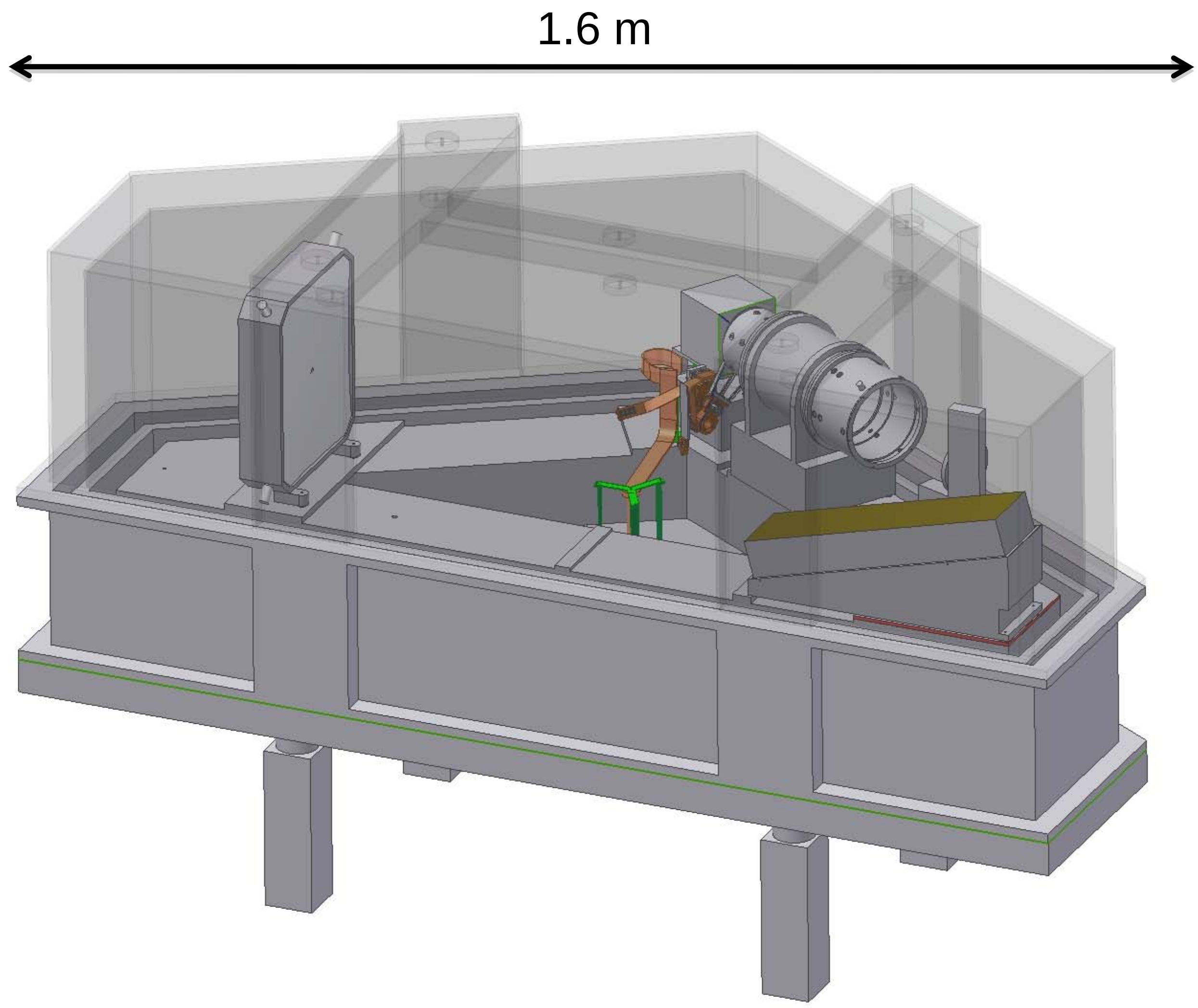
- Input slit
  - 0.46 arcsec wide, 0.36 x 0.047mm effective size, f/5
- Focal reducer
  - Convert from f/5 to f/13
- Single collimator
  - Parabolic mirror, f=1100mm, 85mm collimated beam diameter
- Spectrum mirror
  - Spectrally dispersed image at intermediate focal plane
- Echelle
  - 31.6 lines/mm, R4 (75° blaze angle)
- Cross disperser
  - Reflective grating
- Camera
  - f=450mm, f/5.3
- Detector
  - 2 x 2K^2 HAWAII-2RG arrays

UPF Spectral Format



Detector array footprint
2 x 2K² HAWAII-2RG arrays
73.728 x 36.864mm

Cryostat 3D view



Achieving metre per second precision

- 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 in fibres
  - No other mechanisms (fixed focus, single grating, single filter)
  - Floor mounted instrument – gravitationally stable, so no flexure
  - Under vacuum – removes effects of pressure and humidity variation
  - Located in Coude room or instrument lab
    - Less than 2K annual temperature variation
  - Active temperature stabilisation of spectrograph optical bench
    - ±0.05K over 24 hours
- Simultaneous calibration via reference fibre – tracks drift in wavelength scale over an integration

Instrument expectations

Error source	Contribution	Comment
Drift measurement with sim. arcs	< 0.2 m/s	~ 300 arc lines typically > 60 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
Photon-weighted centre of integration time	< 0.1 m/s	Median sky conditions (1m/s corresponds to 30s)
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 non-source noise	**< 0.6 m/s**	RMS
Source photon noise	0.8 m/s	m_V=10.5 M6 V (*v*sin*i*=5 km/s) at 10 pc S/N=150 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	
Total noise (1 σ)	**1.1 m/s**	For typical M6 V star at 10 pc (no radial velocity jitter)

Schedule

UPF

- Goal is to maximise science impact by earliest on-sky availability.
- 34 months is driven by long-lead items

• Science Detectors	12 months
• Cross Disperser	12 – 15 months
• Echelle	4 – 6 months
• Main Optics	5 – 7 months
• Cryostat	4 months

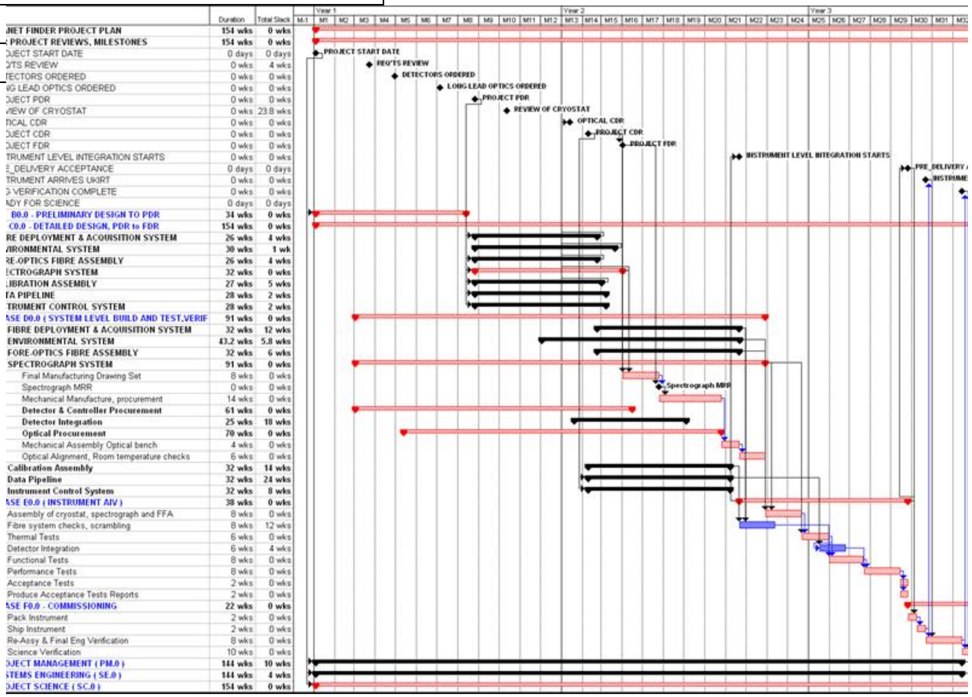
- Hence early emphasis on optics specification and detector selection
- Critical Paths are Spectrograph Optics and Design/Build
  - Followed closely by Environmental System (Cryostat)
- Risk analysis indicates a contingency of 4 months is required

Schedule - Milestones

Milestone	Month	Comment
Requirements review	3	Update of OCDD and FPRD to reflect UKIRT
Detector selection and ordering	4	Detectors are long lead & prone to delay
Order long lead optical components	7	
PDR	8	
CDR	14	Full Review with Customer attendance
FDR	15	Close-out of actions from CDR
Phase D – System Level AIV starts	19	
Phase E - Instrument AIV starts	21	
Instrument delivered to UKIRT	30	
Ready for Science	34	End of Project

Start in Jan 2010

Delivery late 2012



Summary

- Low-risk – Existing design achieves science goals
- Low-cost detection of Earth-mass planets in habitable zones of *closest* stars
- Inspirational new field re-connecting astrophysics to the rest of science
- Immense media (public) and community interest