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Searching for Habitable Planets around M Dwarfs

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and the CARMENES Consortium

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The 3.5m Telescope on Calar Alto (Southern Spain)

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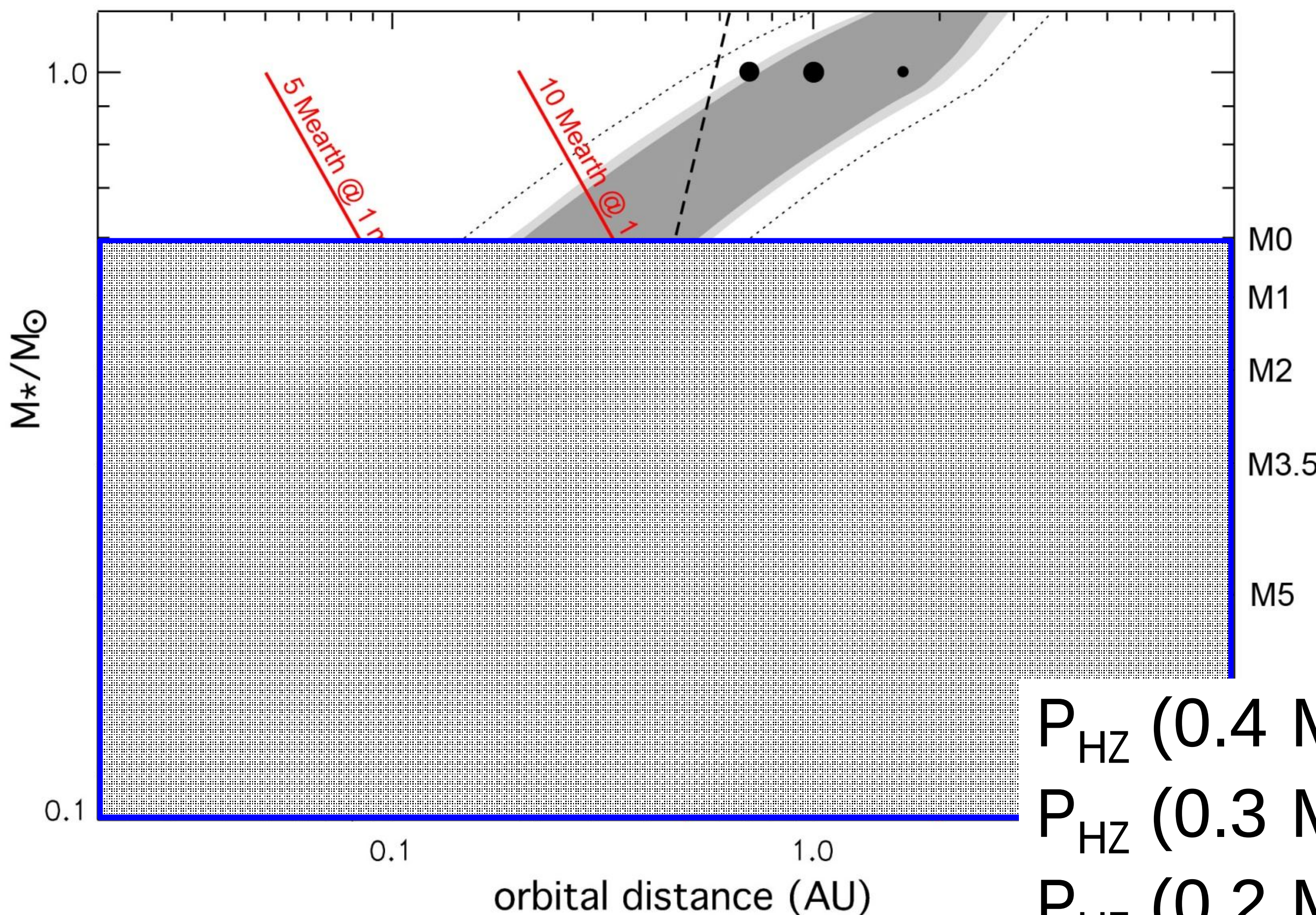
Goals and Plan for CARMENES

- Search for Earth-like “habitable” planets around low-mass stars (M-stars)
  - Number and formation mechanisms
  - Properties and “habitability”
- Survey of 300 M stars
  - Simultaneously in visible light and near-infrared
- 10 data points per star and year
  - 600 to 750 nights needed
  - Guaranteed in contract with CSIC and MPG

Why M Dwarfs?

- M dwarfs are very abundant (almost 2/3 of all stars) and thus nearby
  - Excellent targets for follow up
- M dwarfs are small (**<** 0.5 $M_{\odot}$) and faint $\Rightarrow$ "habitable zone" is close to star $\Rightarrow$ relatively large signal $\Rightarrow$ good chance to find Earth-like planets
- Currently no instrument optimized for M stars exists

A “shortcut”: M-type dwarfs

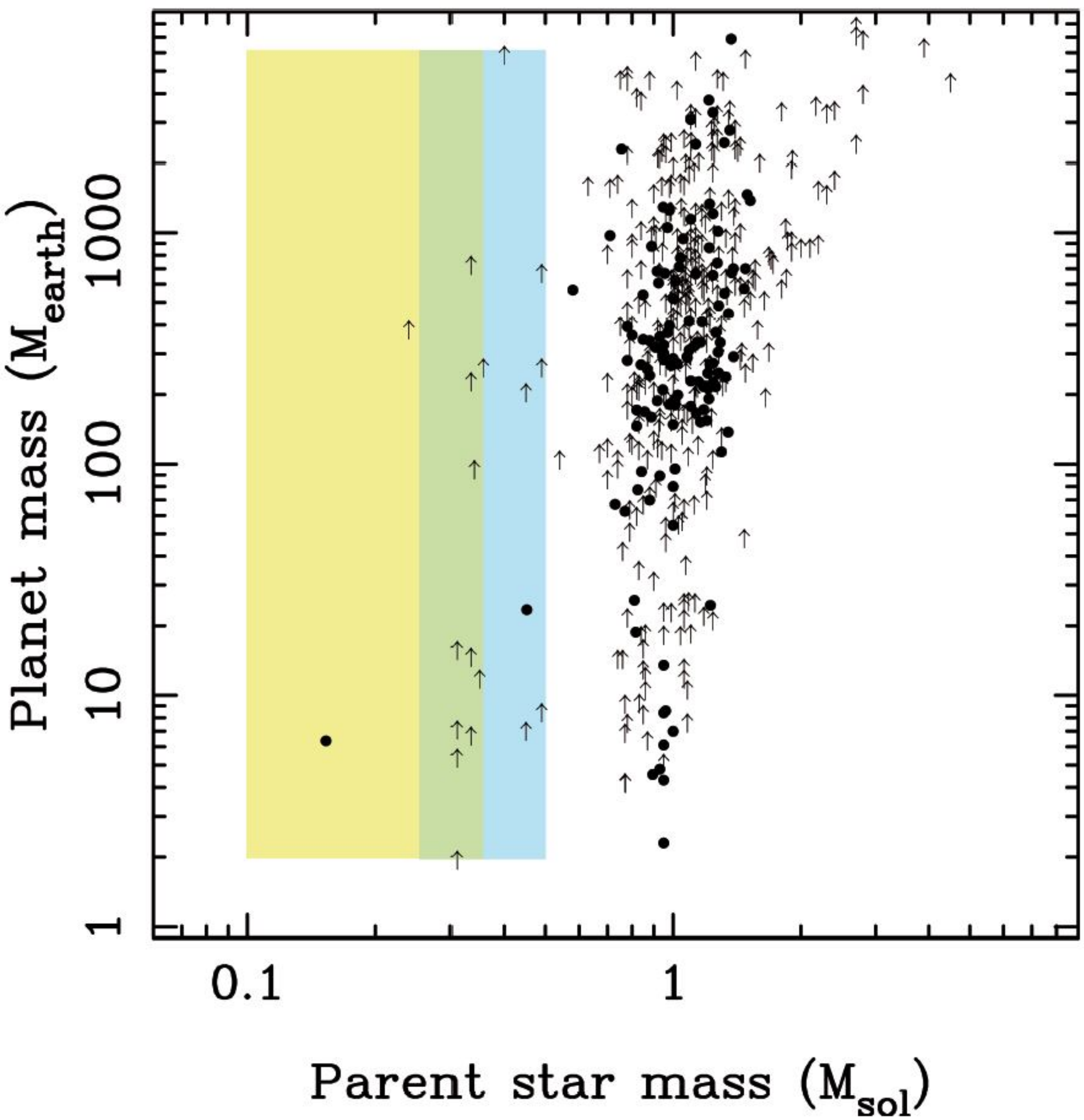


P_{HZ} (0.4 $M_\odot$) = 25 d

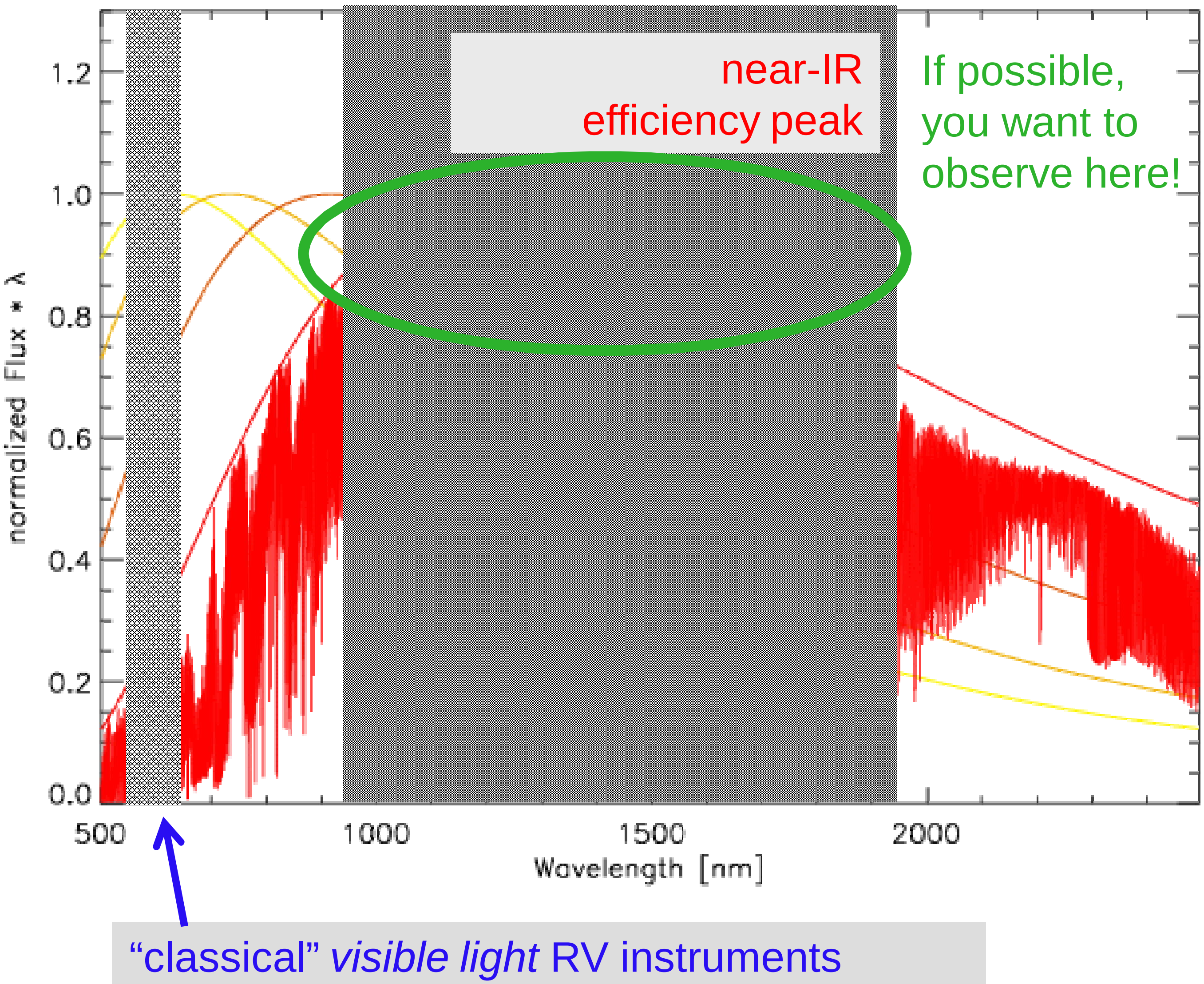
P_{HZ} (0.3 $M_\odot$) = 18 d

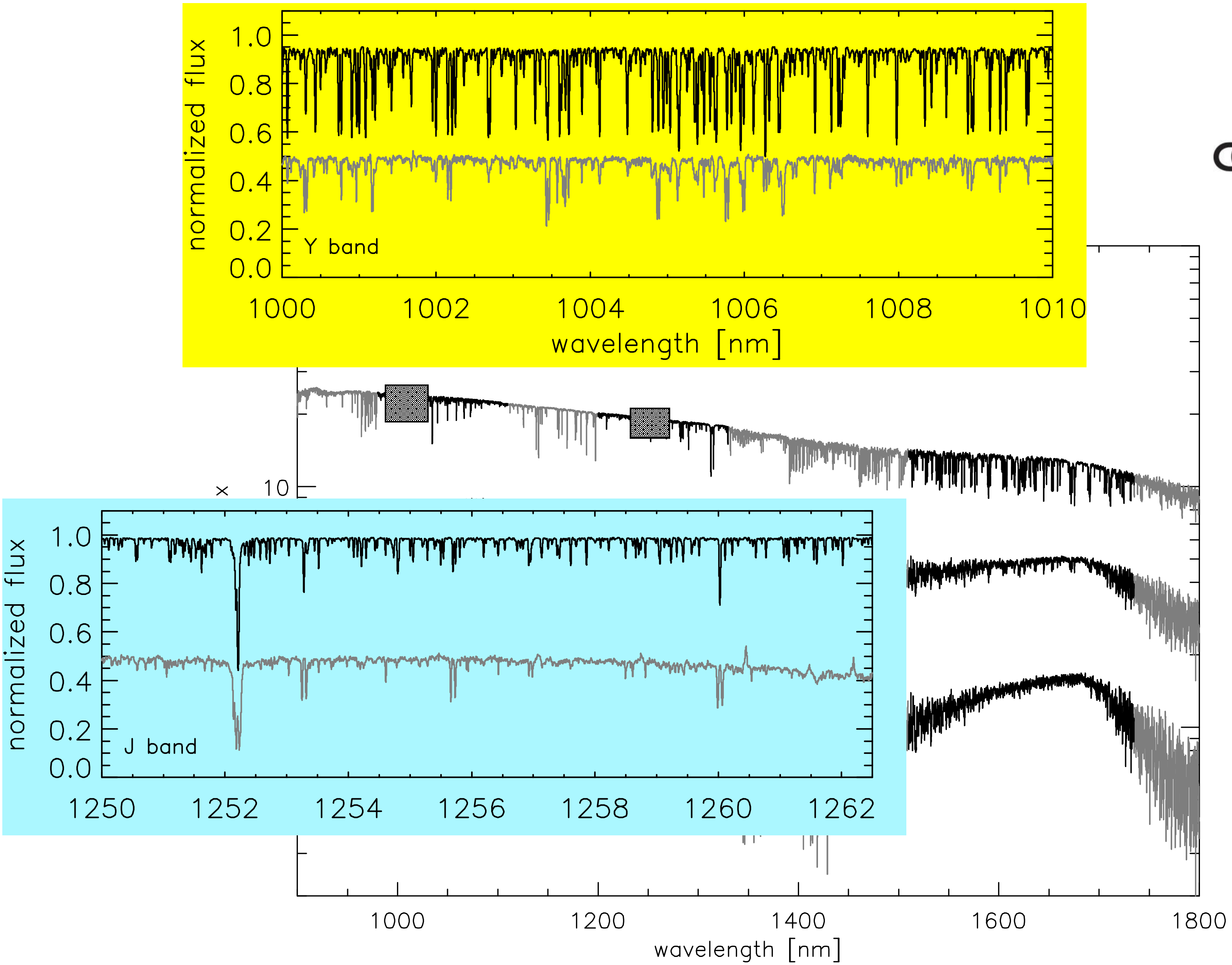
P_{HZ} (0.2 $M_\odot$) = 12 d

A new niche



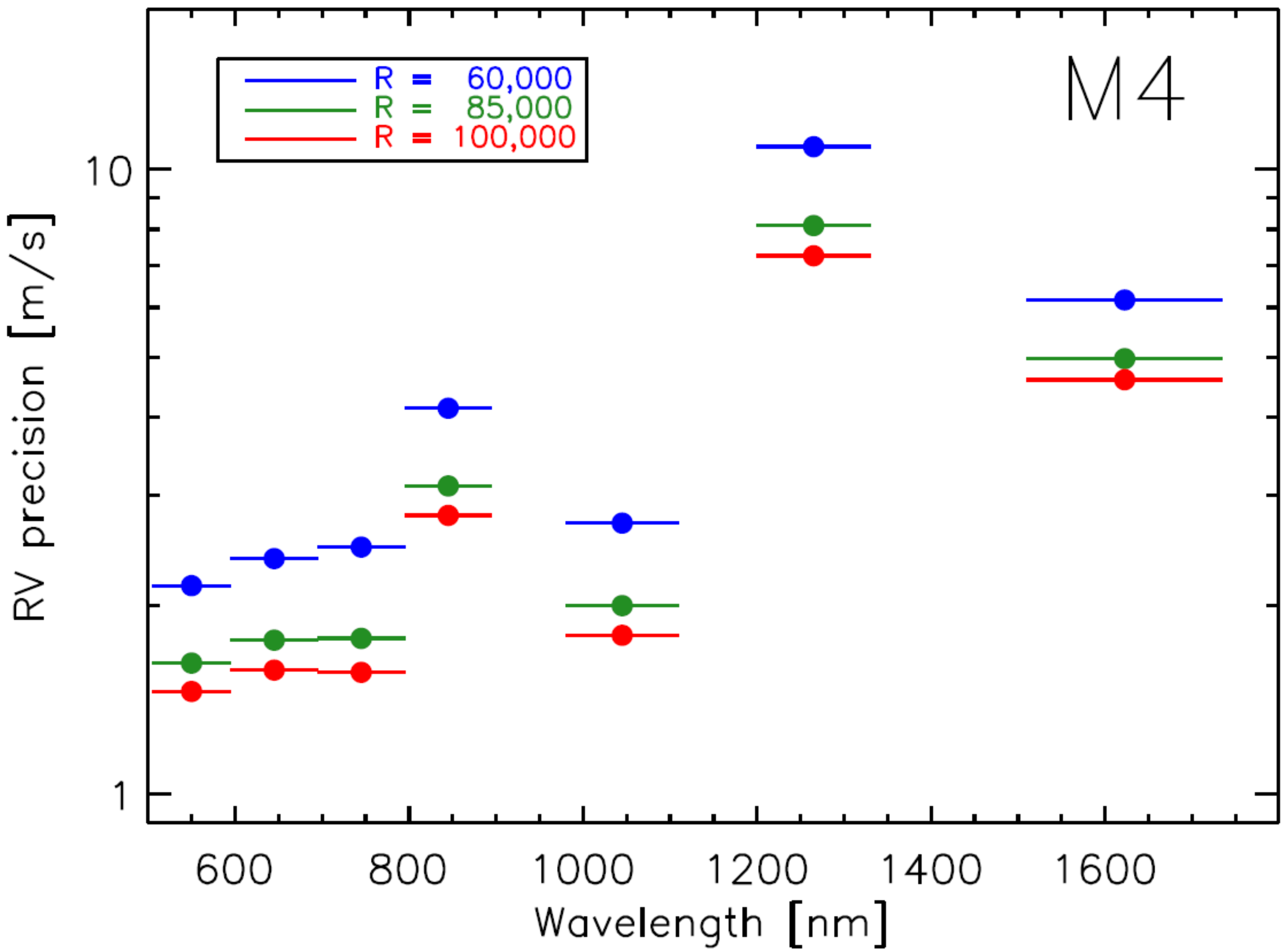
The SED of M-type stars



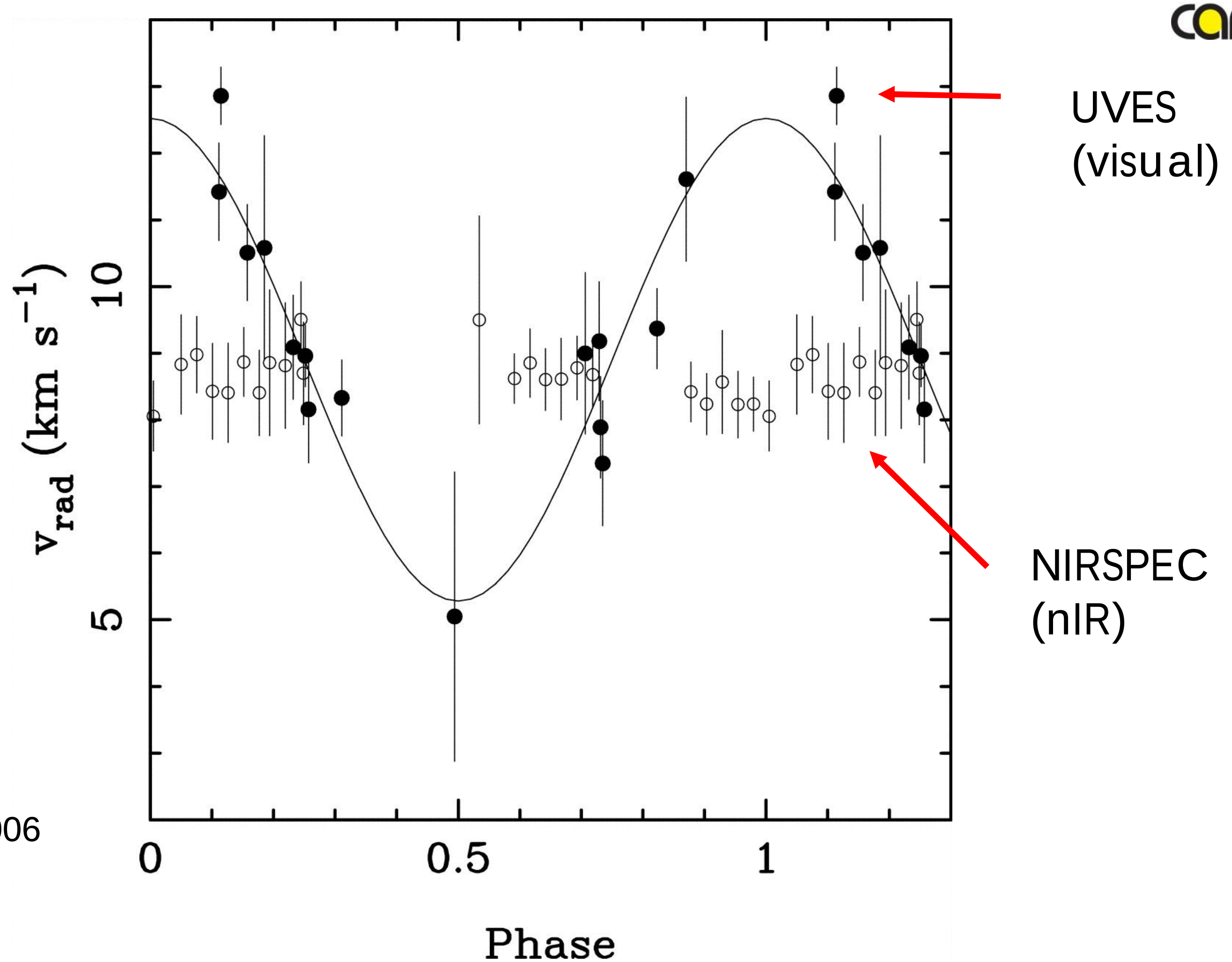


PHOENIX models

Relative Precision Achievable for M4 Star in Visible and near-IR



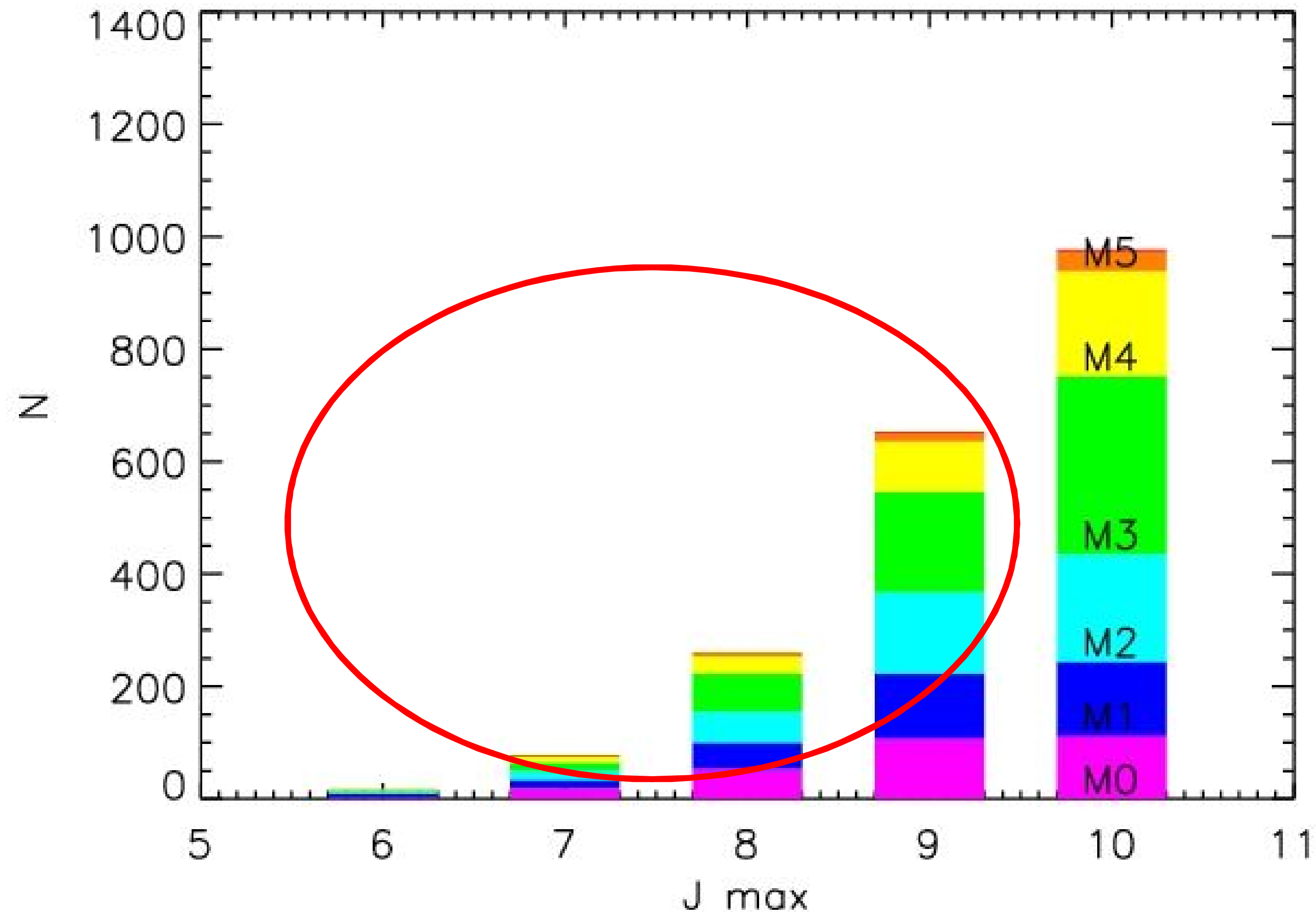
Let's talk about jitter



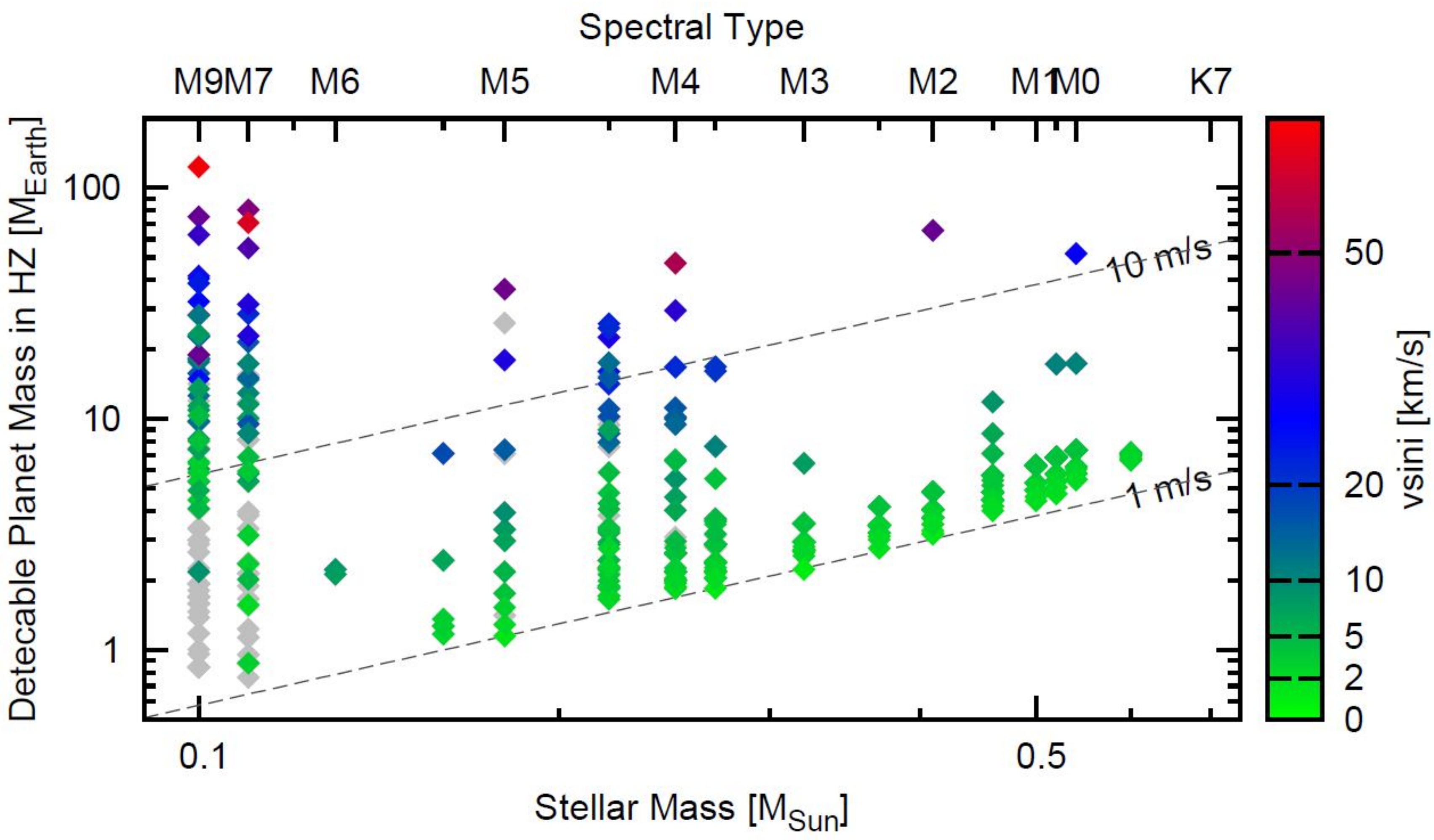
Martin et al. 2006

RV curve of the active M9 dwarf LP-944 20

Stellar sample



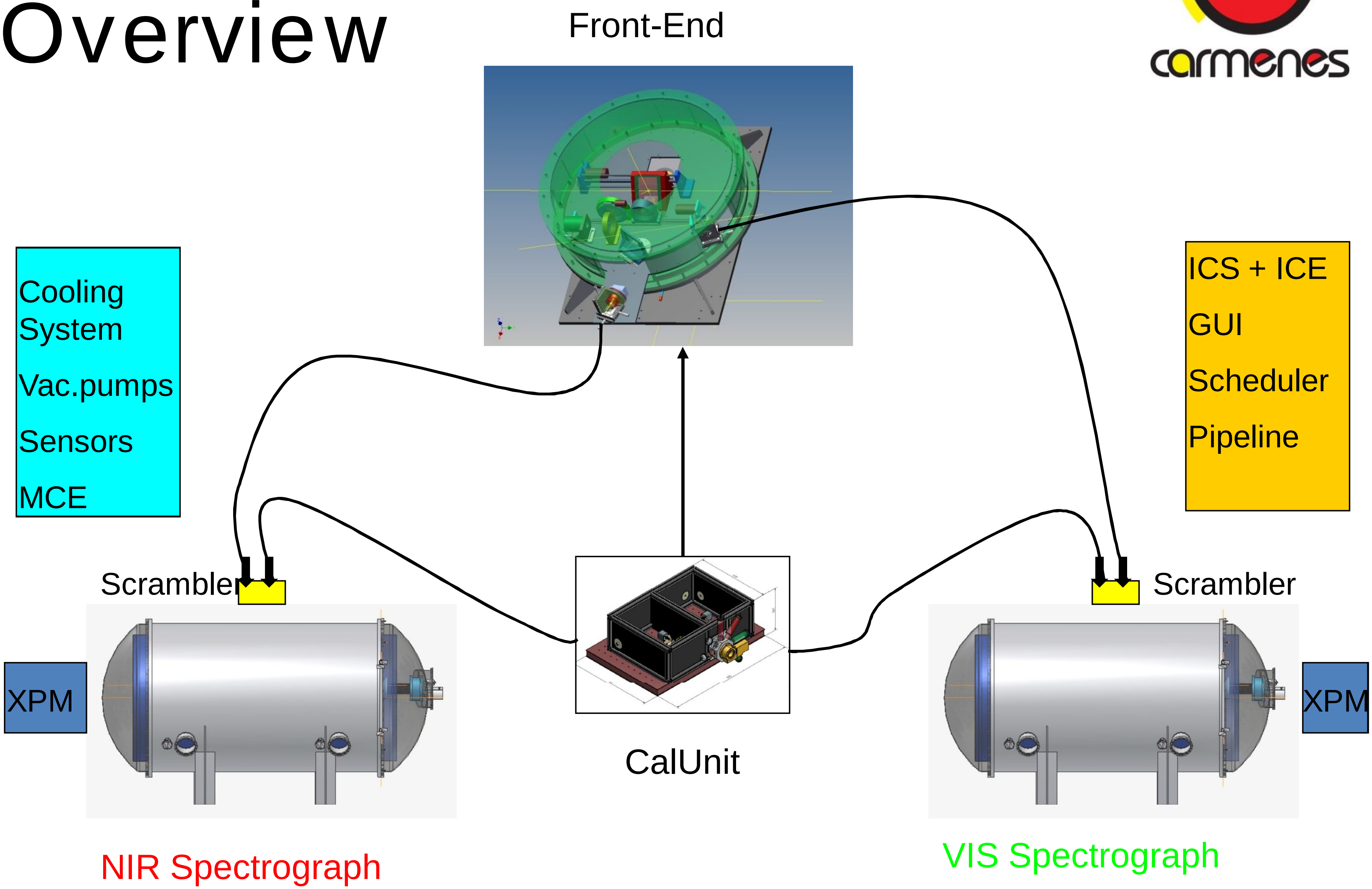
Detectability simulations



Guiding Principles for Instrument

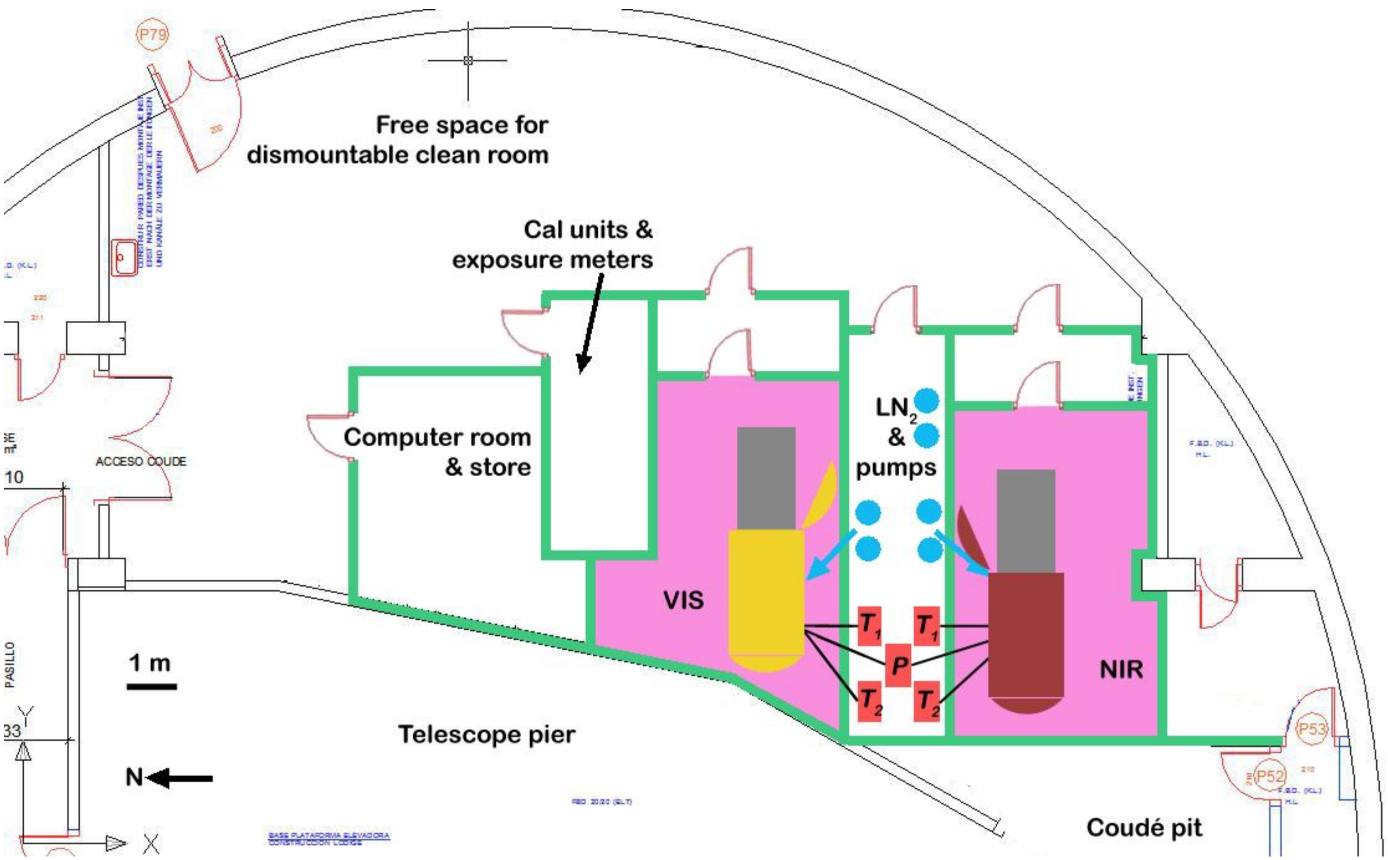
- Single-purpose instrument
  - Design driven by survey requirements
- High stability for terrestrial planet detection
  - Thermal and mechanical stability
  - Stable input
  - No moving parts in spectrographs
- High resolution for slow rotators
- Large wavelength coverage for discrimination against intrinsic variability
- High efficiency for faint stars

Instrument Overview



Instrument Location

- 1 Climatic room for each channel.
- Environmental conditions: 285-288 ±1 K.



Properties of Spectrographs

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- Optical spectrograph
  - 0.53 … 1.05 µm, R = 82,000
  - Precision ~1 m/s
  - Vacuum tank, temperature stabilized
  - 4k x 4k deep depletion CCD detector
- Near-Infrared spectrograph
  - 0.95 … 1.7 µm, R = 82,000
  - Vacuum tank, cooled to 140K, stabilized
  - Precision goal 1 m/s
  - Two 2k x 2k Hawaii 2.5 µm detectors

Spectrograph Layout

White pupil fiber-fed echelle spectrograph

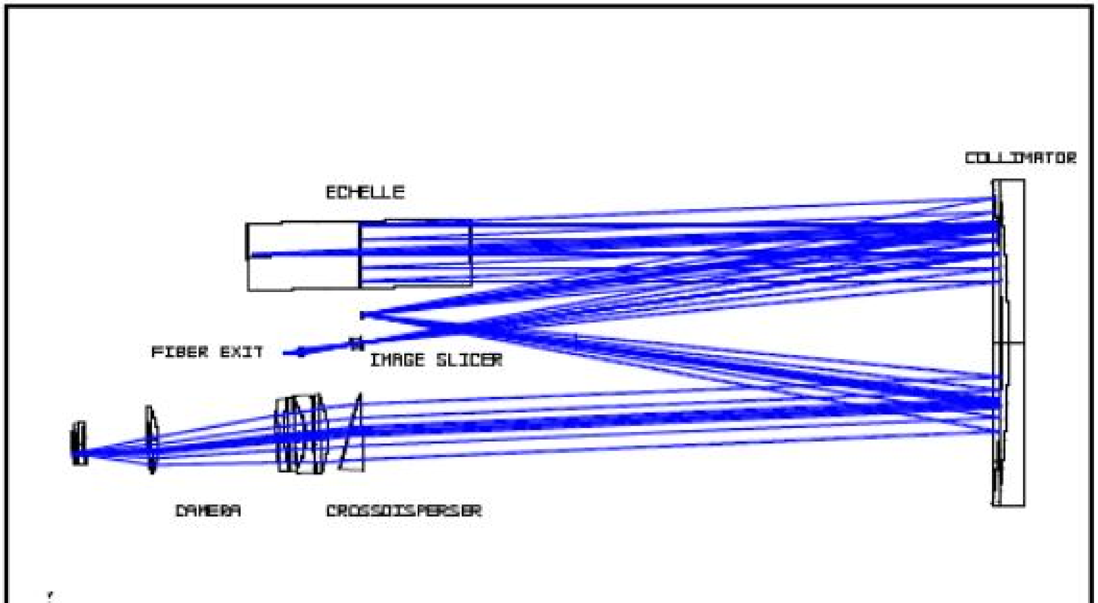
FiberExit-FNoptics-Slicer

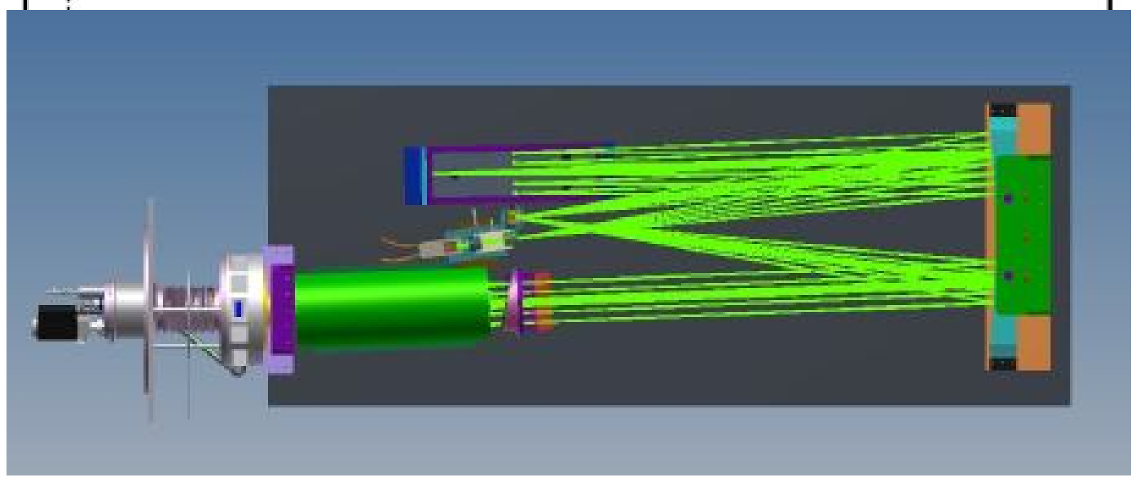
Single-piece Collimator (3passes)

R4 Echelle grating

Grism cross-disperser

Dioptric camera





Spectrograph and Vacuum Tank Layout

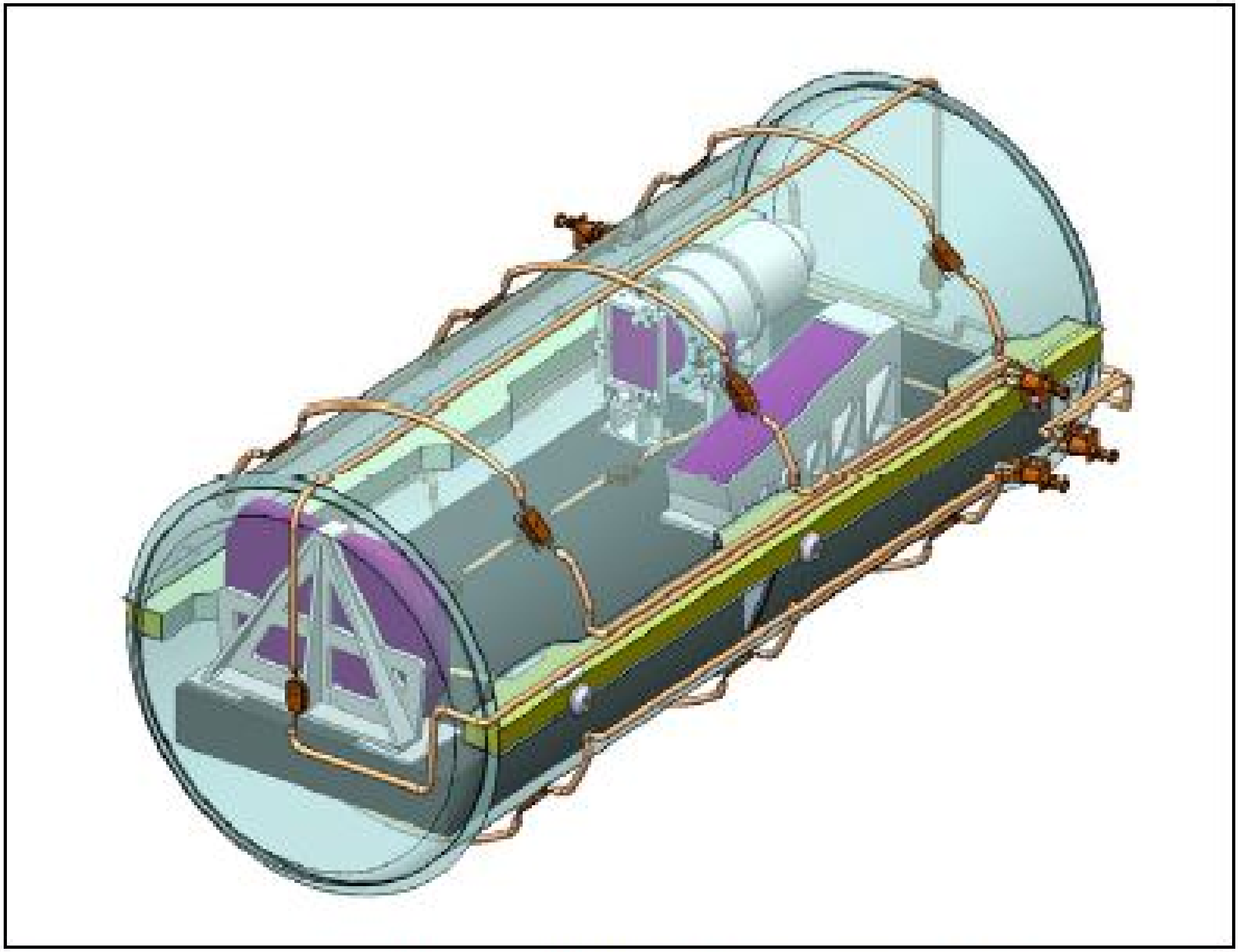
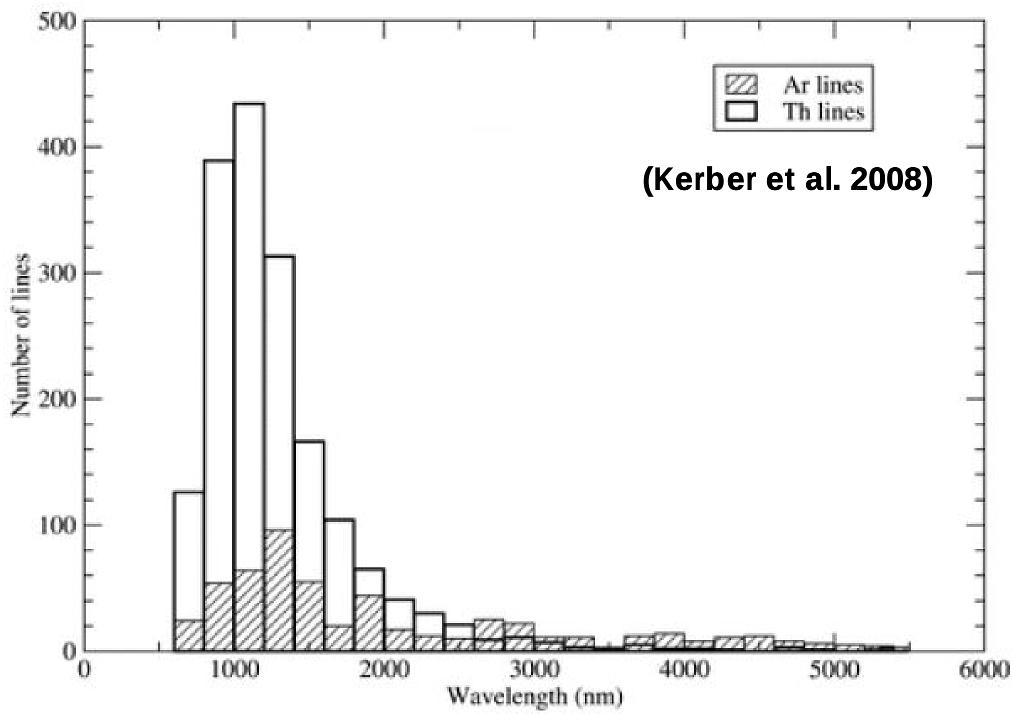
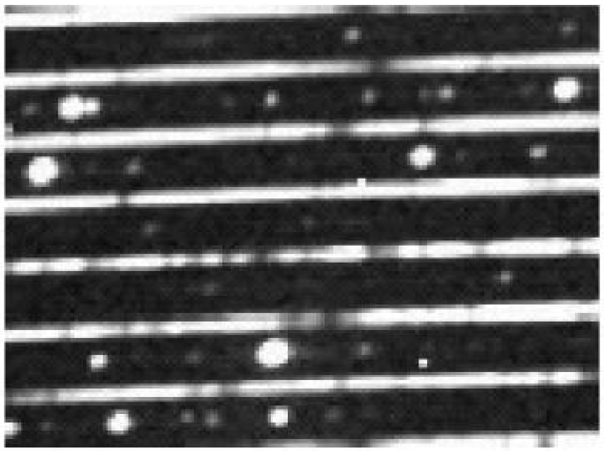


Figure 2. General view of the CARMENES NIR Optical Bench fully assembled.

Calibration: Wavelength reference

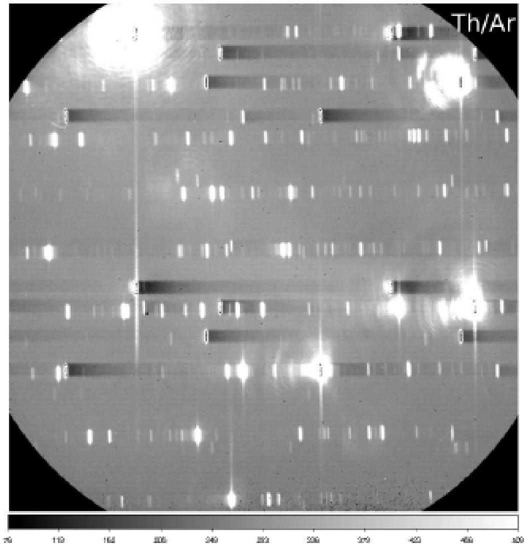
- Hollow cathode lamps: Thorium-Argon-Neon for daily and master calibrations.

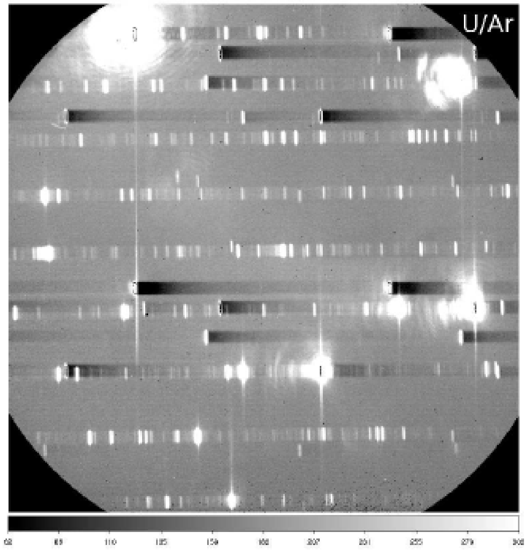


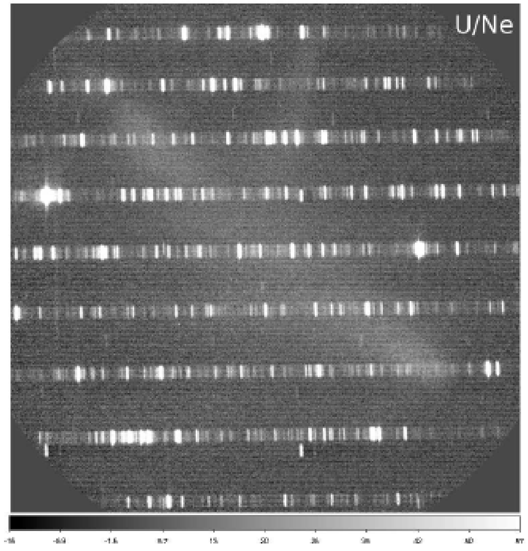


Enough suitable Th-Ar lines in the NIR range

Comparison of Th/Ar, U/Ar and U/Ne Lamps



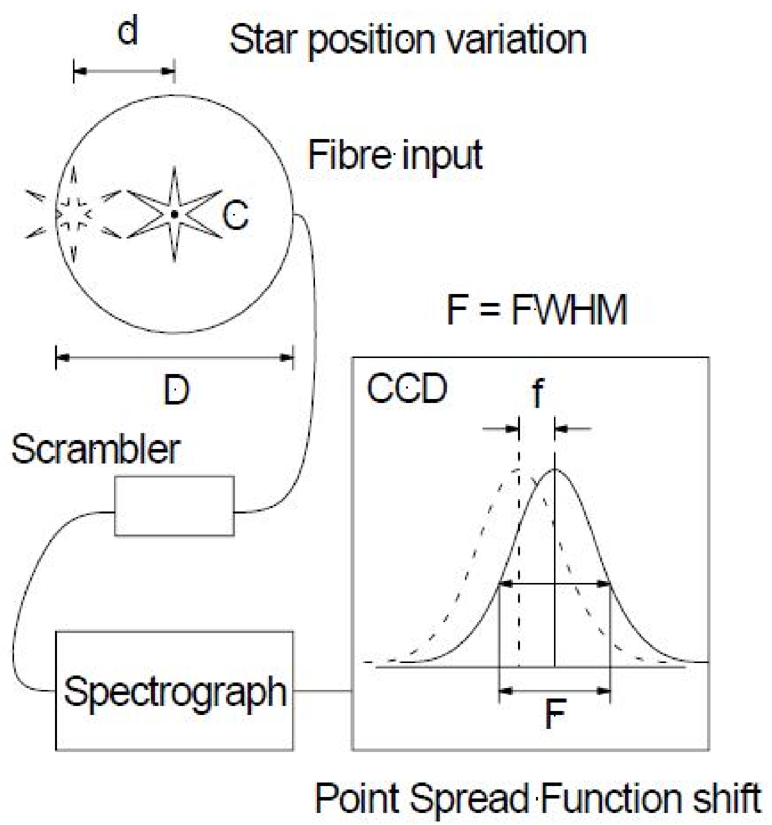




Redman et al. 2011

Requirements for RV precision

- Stability of slit illumination and instrument are requirements for high RV precision.
- Current solutions for this unavoidable problem are:
  - Highly stable injection of light in the fibre (only possible with precise guiding ~0.1")
  - Image scrambler



Avila & Singh (2008)

Near field and far field scrambling

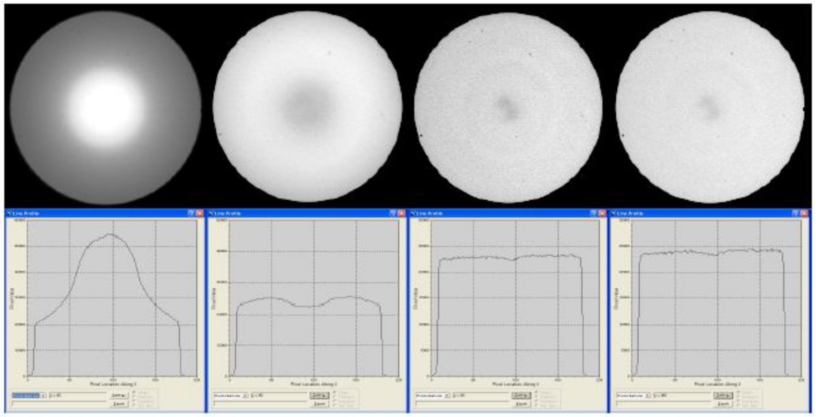


Figure 3. Near field scrambling patterns in a 600 µm, 3 m FVP fibre. From left: a 250 µm spot is centred on the fibre. The spot is shifted by 175 µm. The spot is in the centre but the fibre is squeezed with ΔFRD = 20%. The spot is shifted by 175 µm and fibre squeezed.

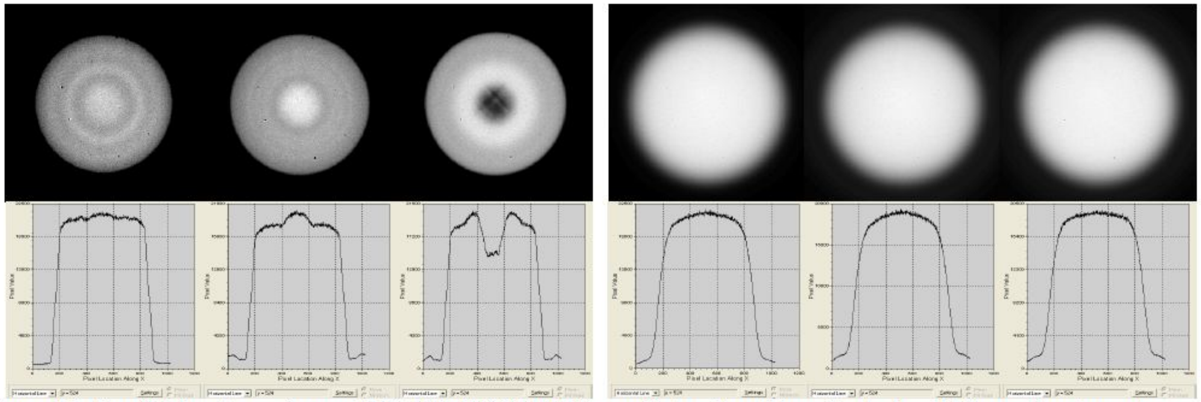


Figure 13. Far field patterns from a WF 200x200/420 N CeramOptec 3 m fibre. Spot size: 150 µm, input aperture beam: F/2.3. Three pictures left: the fibre is free and the spot is at the centre, +50µm and -50µm. The three on the right, the fibre is squeezed (ΔFRD=5%) and the spot is at the centre, +50µm and -50µm

RV error sources

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_Y=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)

Wavelength calibration

Exposure meter

Current approach: do the best

Scrambling

Reduction strategy

Scrambling

RV error sources from Barnes & Jones, UKIRT planet finder.

The CARMENES Consortium

- Landessternwarte Königstuhl, U Heidelberg, Germany
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- Hamburger Sternwarte, U Hamburg, Germany

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- Universidad Complutense de Madrid, Madrid, Spain
- Institut de Ciències de l'Espai, Barcelona, Spain
- Instituto de Astrofísica de Canarias, Tenerife, Spain
- Centro de Astrobiología, Madrid, Spain

- Centro Astronómico Hispano-Alemán

Time Line

Official Start	11/2010
Preliminary Design	to 07/2011
Final Design	07/2011 – 07/2012
Construction	07/2012 – 10/2013
Commissioning	11/2013 – 02/2014
Data Taking	03/2014 – 12/2018