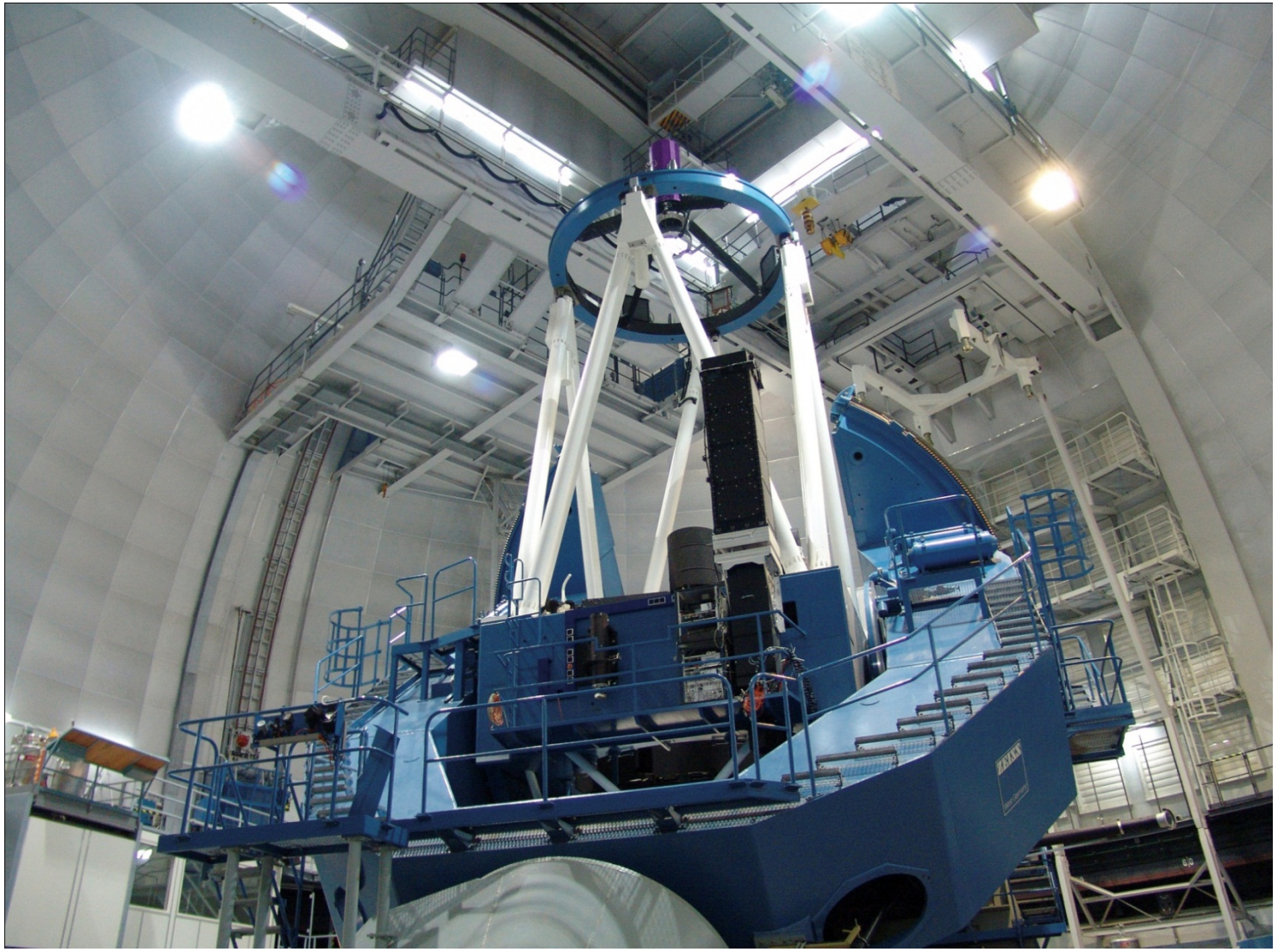
Blue Planets Orbiting Red Dwarfs

Andreas Quirrenbach
and the CARMENES Consortium

CARMENES – the Acronym

- **C**alar **A**lto
- High-**R**esolution Search for
- **M** Dwarfs with
- **E**xo-Earths
- With **N**ear-Infrared and Optical
- **E**chelle **S**pectrographs

The 3.5m Telescope on Calar Alto (Southern Spain)



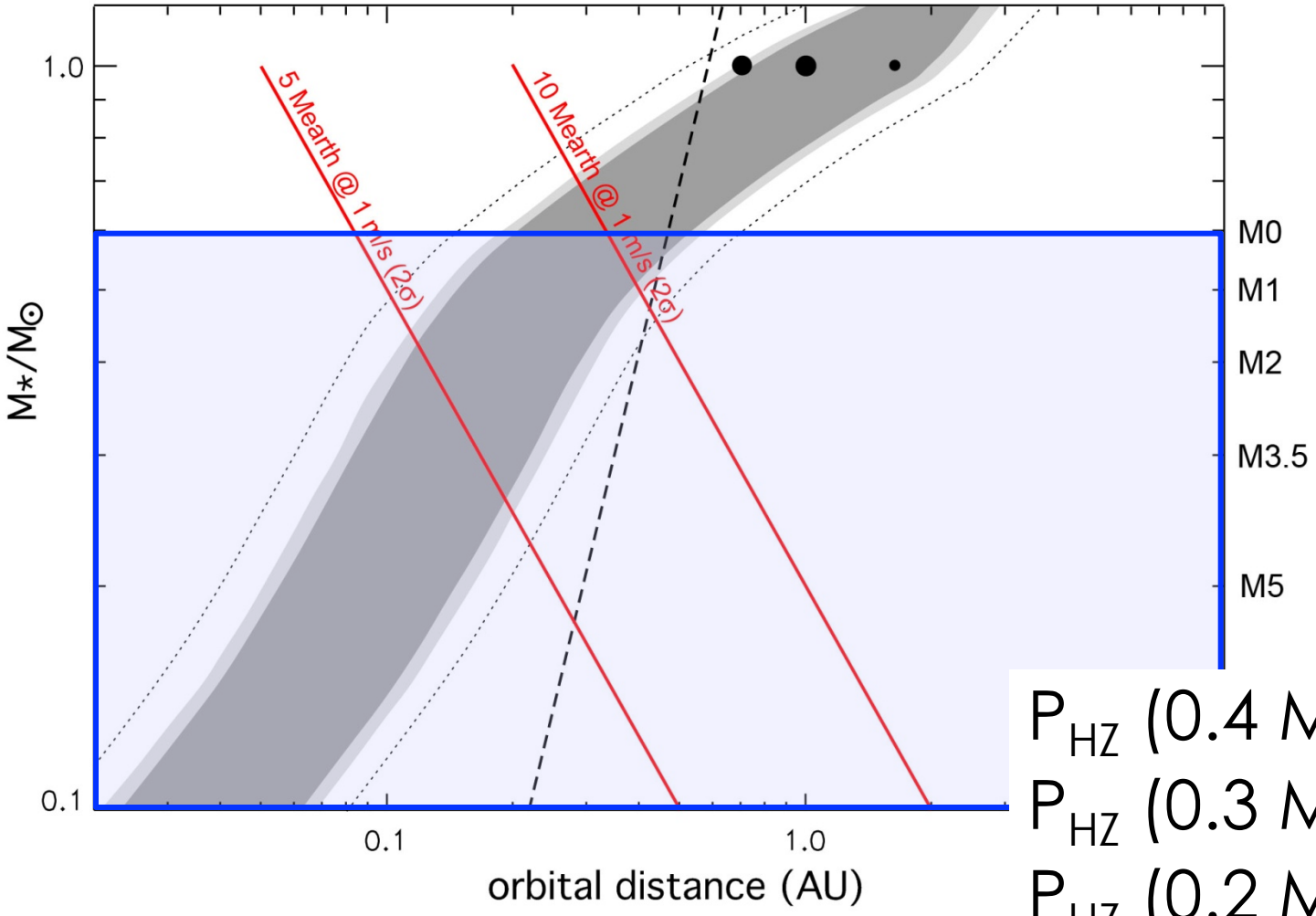
Why M Dwarfs?

- 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 ⇒ "habitable zone" is close to star ⇒ relatively large signal ⇒ good chance to find Earth-like planets
- Currently no instrument optimized for M stars exists

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

A "Shortcut": M-Type Dwarfs

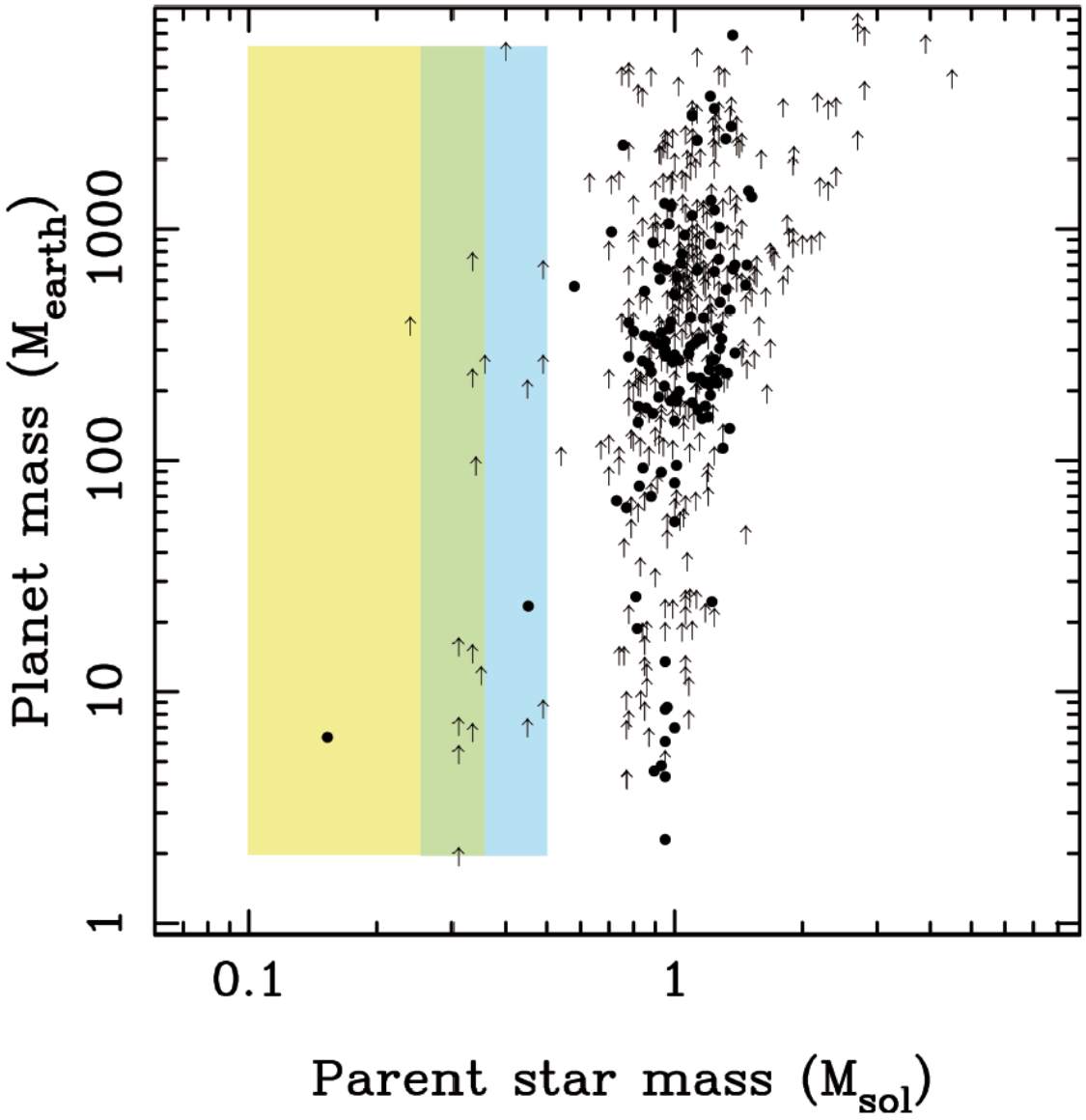


P_{HZ} (0.4 $M_\odot$) = 25 d

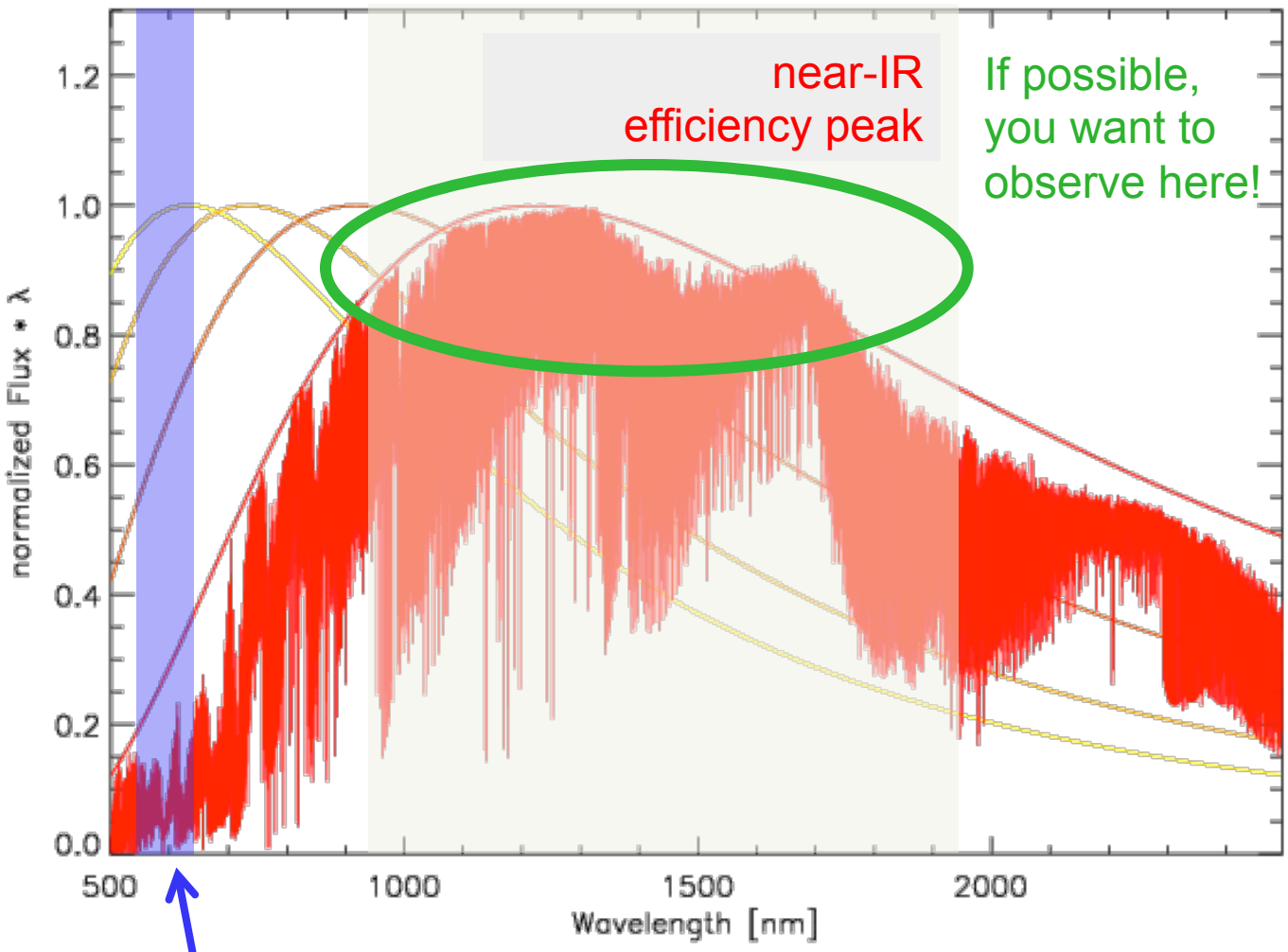
P_{HZ} (0.3 $M_\odot$) = 18 d

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

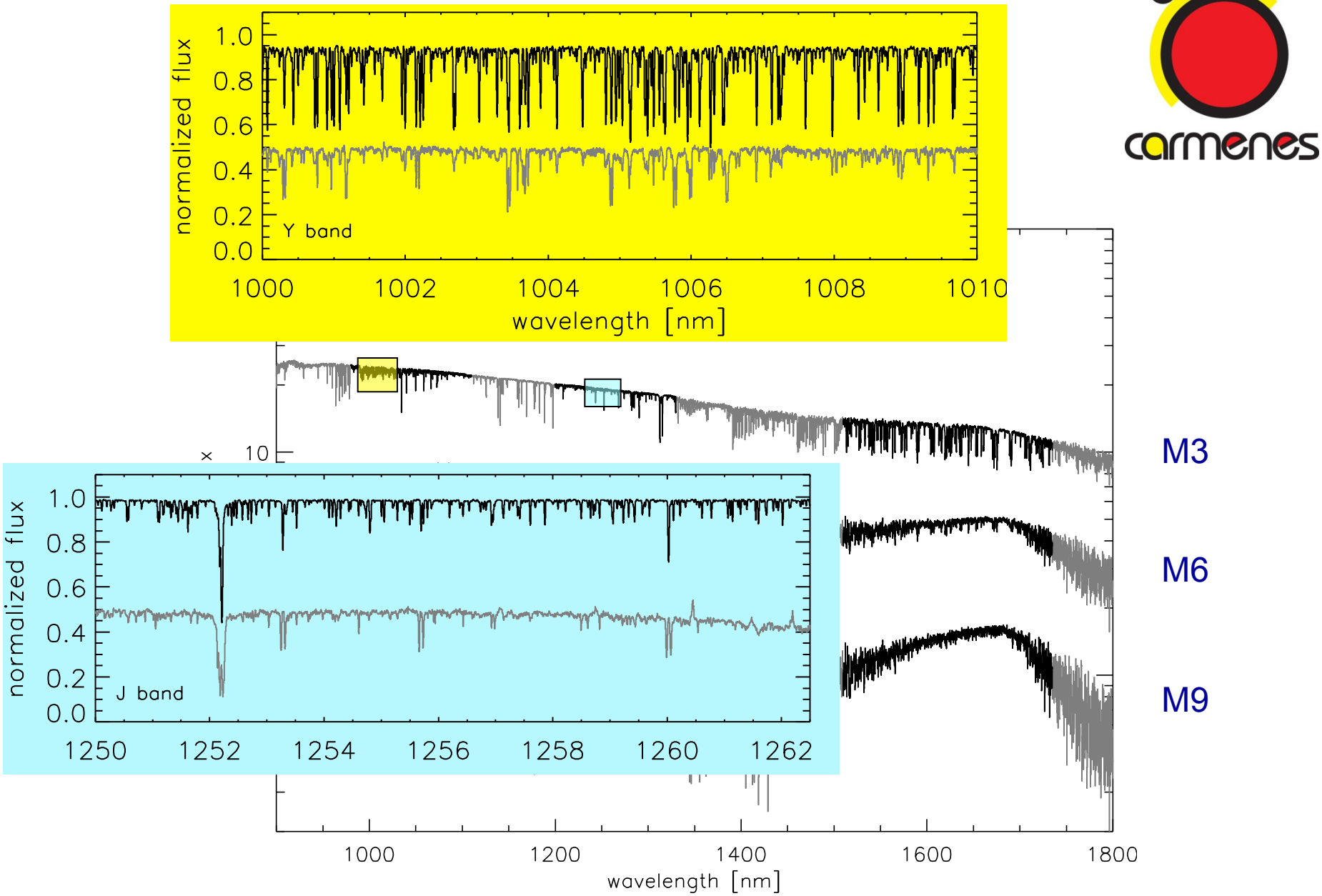
A New Niche



The SED of M-Type Stars

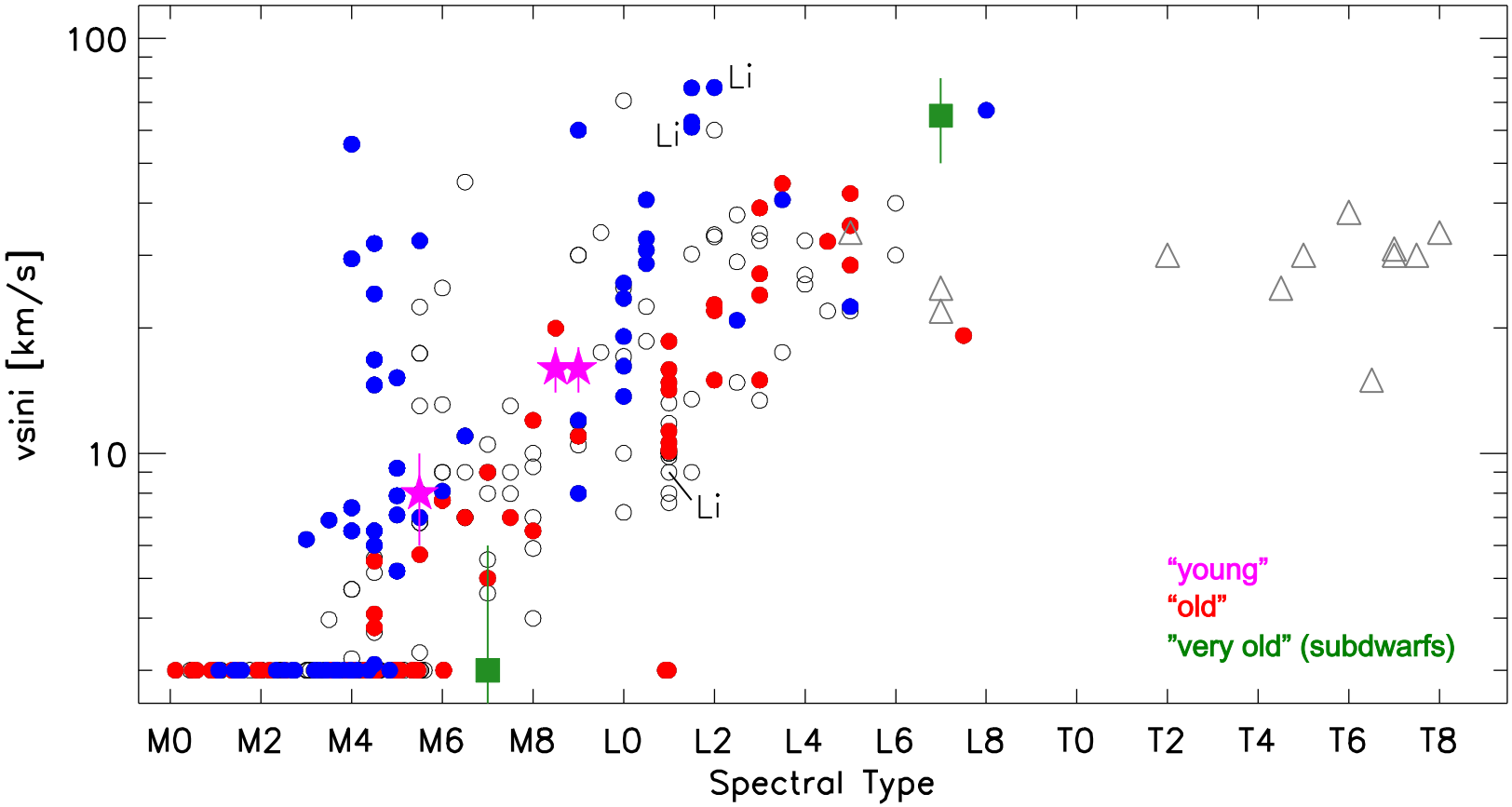


"classical" *visible light* RV instruments



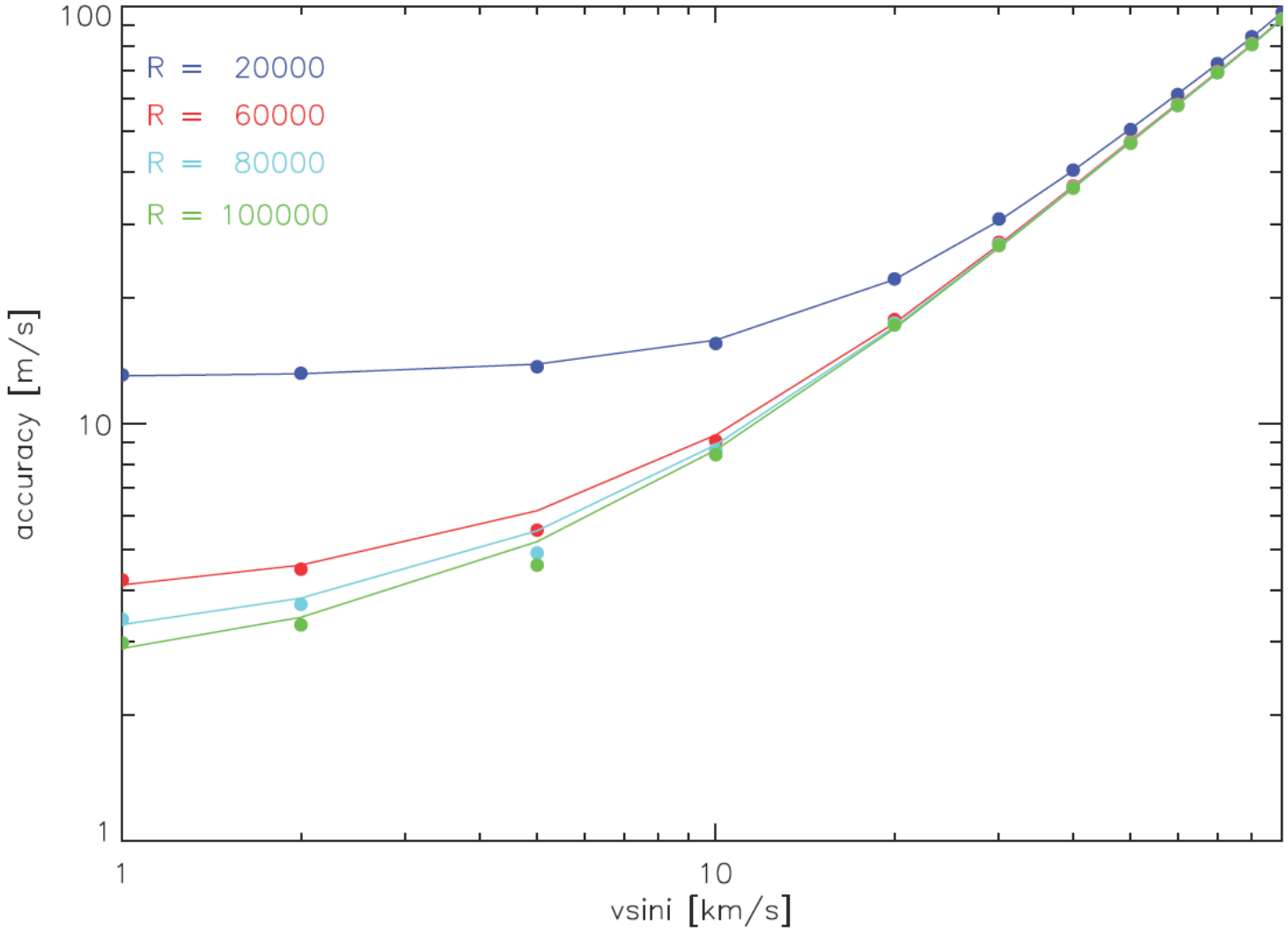
PHOENIX models

Rotation of M Stars and Brown Dwarfs

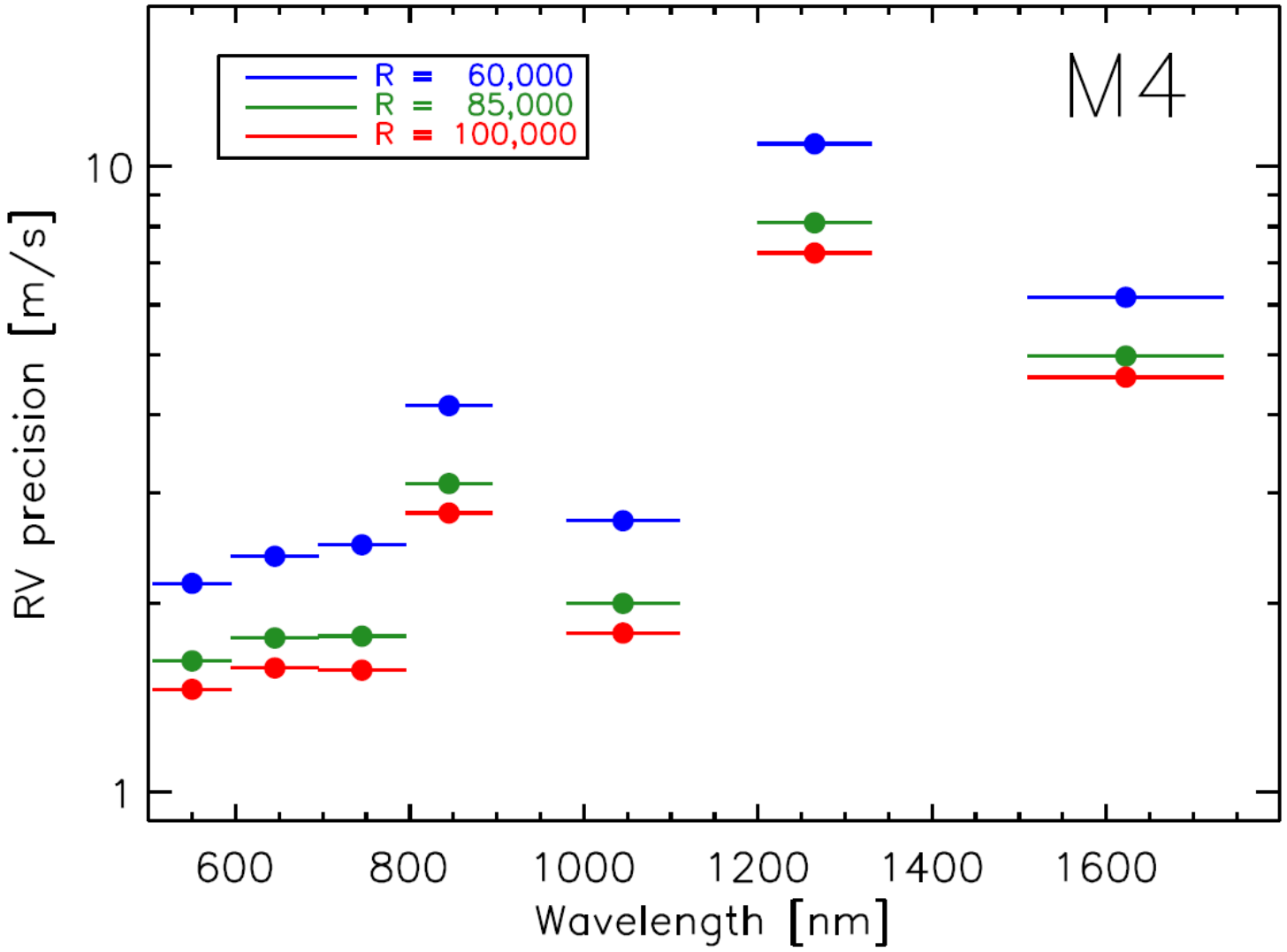


Reiners & Basri, 2008

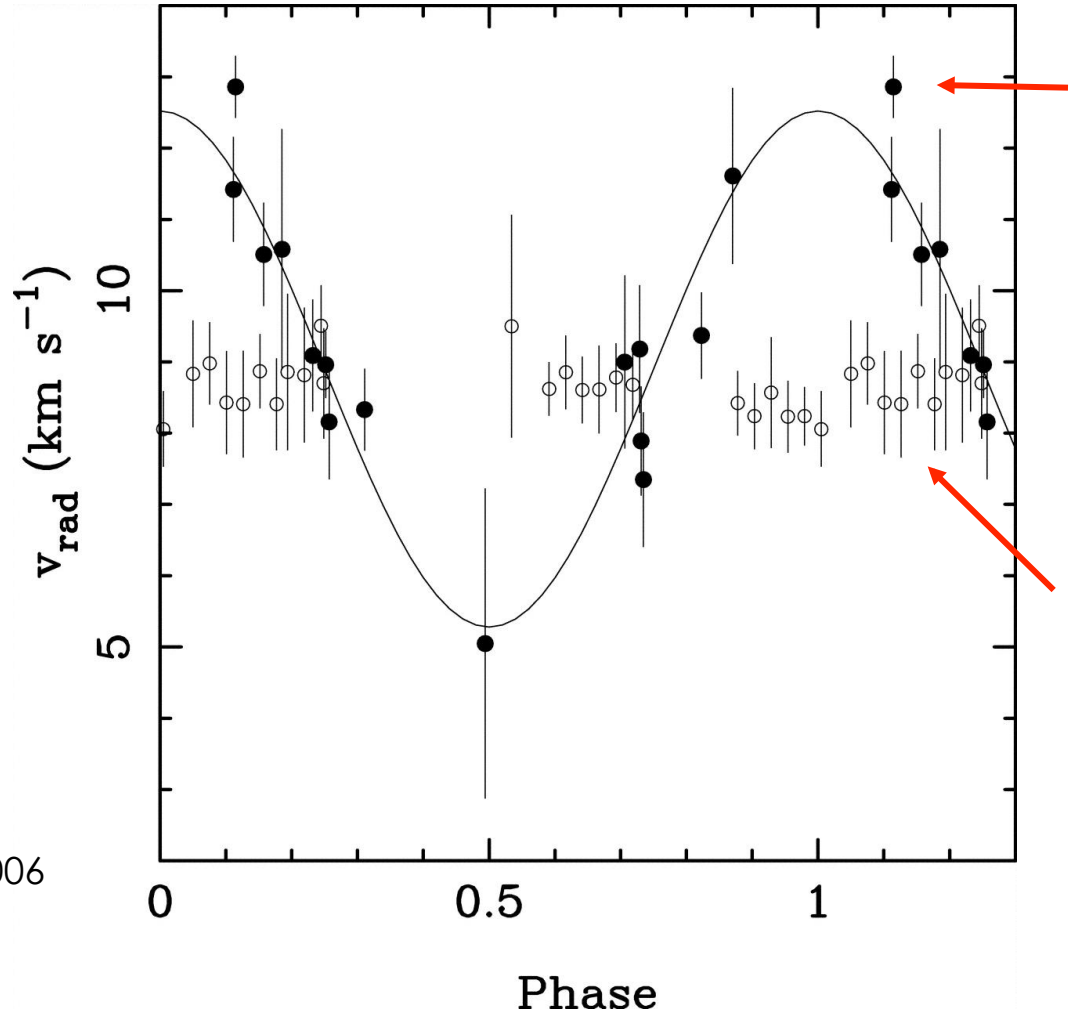
Precision Achievable for Different Rotational Velocities



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



Let's Talk About ji#ter



Martin et al. 2006

RV curve of the active M9 dwarf LP-944 20

Observing Strategy

- Start with a larger sample of ~600 stars
- Pre-cleaning (echelle spectra, active stars, fast rotators, binaries) ⇨ 400-450 stars
- Measurements:
  - 3500 for sample clean-up (5-10 per star)
  - 15000 additional for 300 stars (60 each)
  - 4000 additional for 100 stars (100 each)

  ⇨ 22500 measurements
- Time: 15 min + overhead ⇨ 3.5 measurements/hour ⇨ 30 measurements/night ⇨ 750 nights

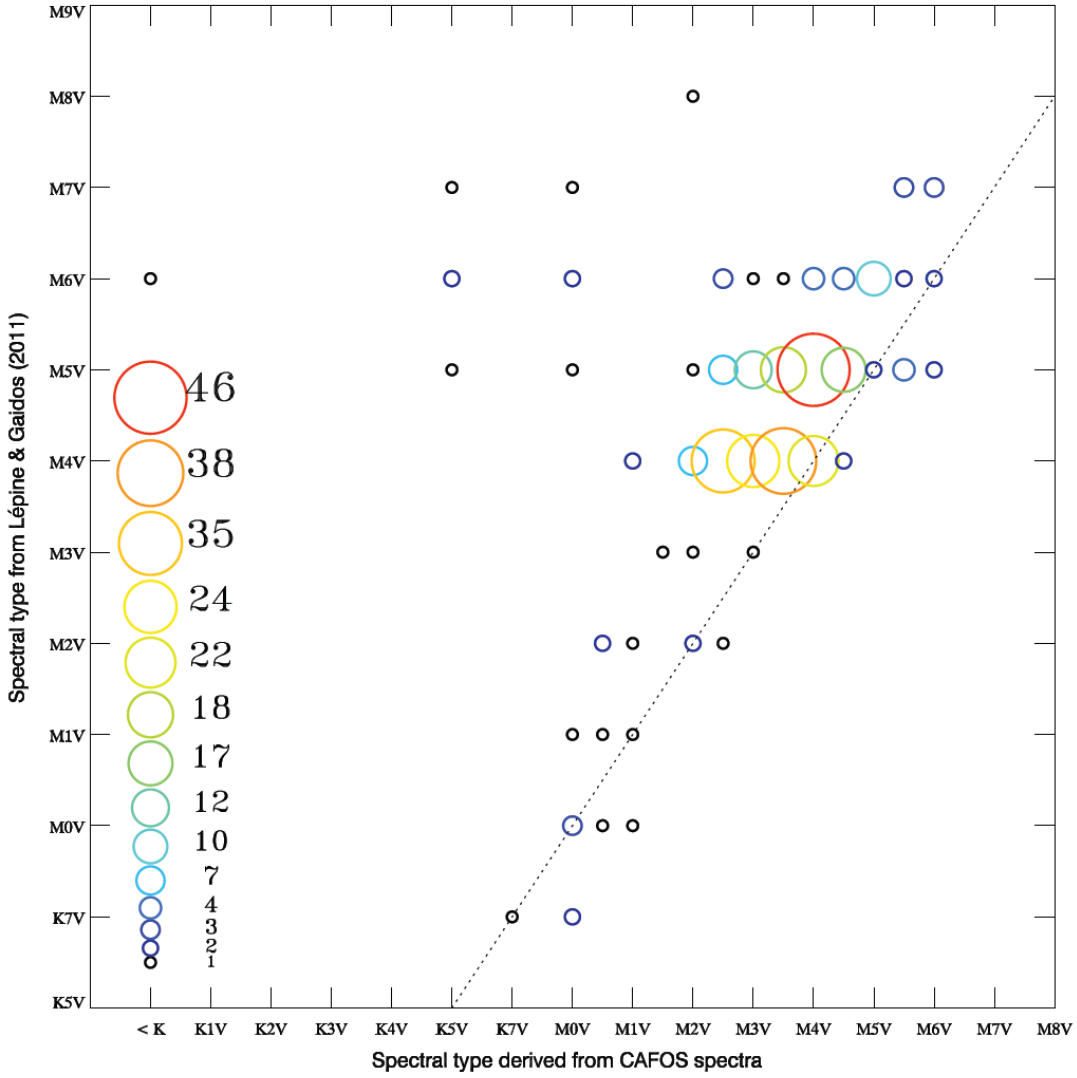
Stellar sample

- **S1: 100 stars with M < 0.25 $M_\odot$ (SpType M4 and later)**
- **S2: 100 stars with 0.30 > M > 0.25 $M_\odot$ (SpType M3-M4)**
- **S3: 100 stars with 0.60 > M > 0.30 $M_\odot$ (SpType M0-M2; bright)**

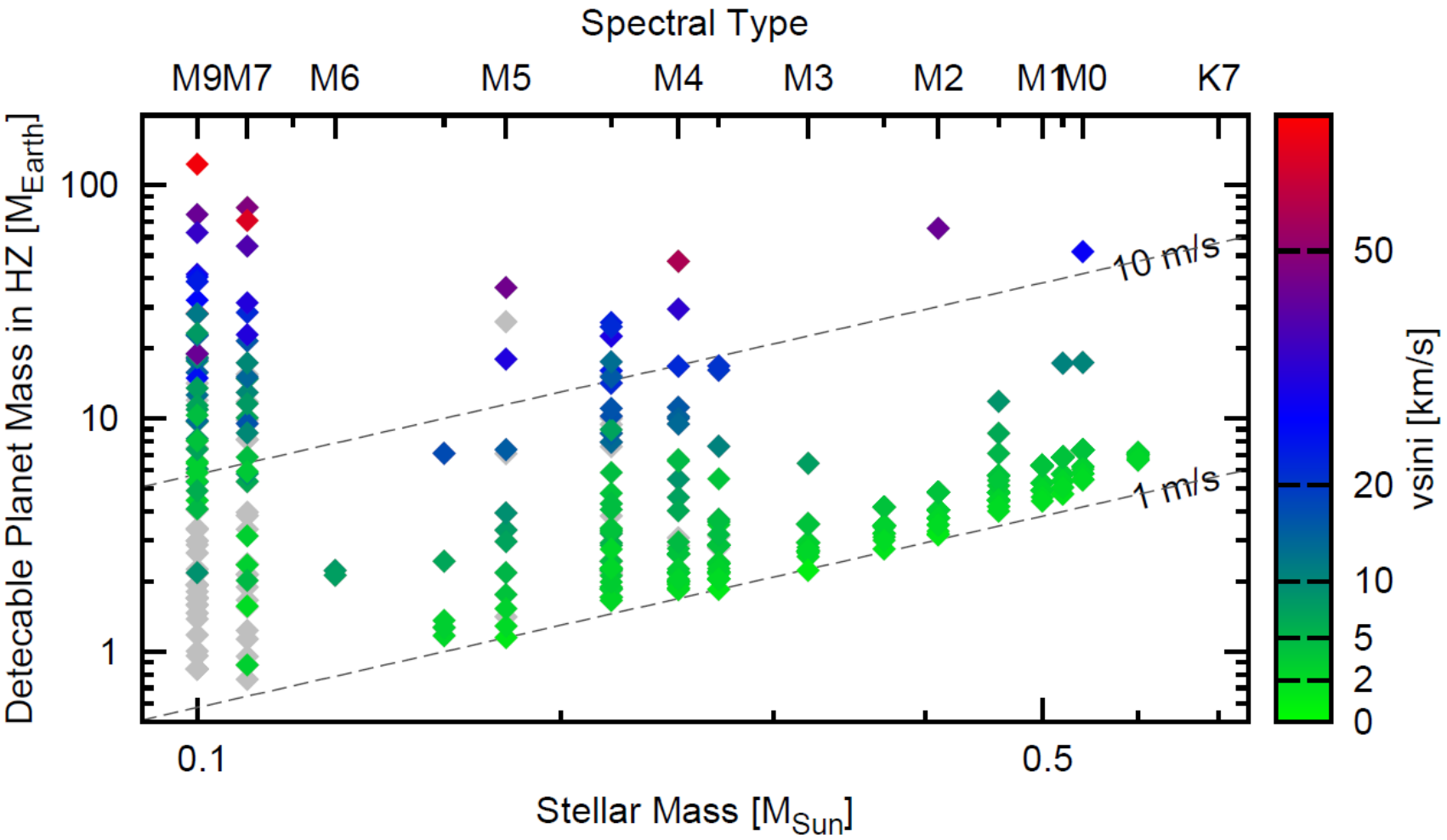
Sample	Spectral type	Mass ($M_\odot$)	J	#
S1	$\geq$M6	$\leq$0.15	$\leq$10.5	12
S1	M5 & M5.5	0.15–0.20	$\leq$10	35
S1	M4 & M4.5	0.20–0.25	$\leq$9.5	143
S2	M3 & M3.5	0.25–0.30	$\leq$9	198
S3	M2 & M2.5	0.30–0.40	$\leq$8.5	121
S3	M1 & M1.5	0.40–0.50	$\leq$8	78
S3	M0 & M0.5	0.50–0.60	$\leq$7.5	55

$\langle d_{S1+S2+S3} \rangle$ = 13 pc

Scientific Preparation: Input Catalog and pre-Observations



Detectability Simulations

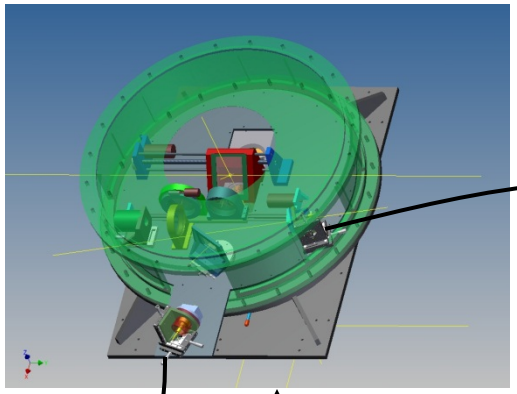


Guiding Principles for Instrument

- 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

Front-End



Cooling System

Vac.pumps

Sensors

MCE

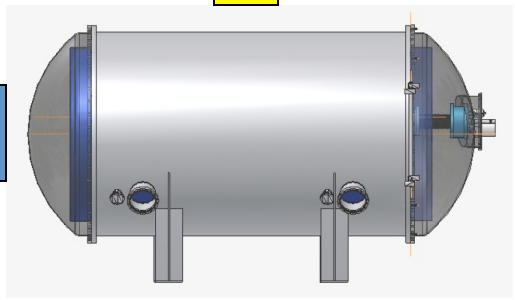
ICS + ICE

GUI

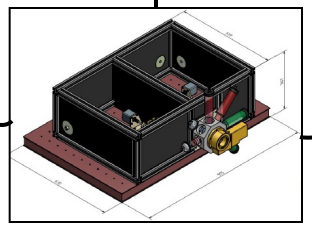
Scheduler

Pipeline

Scrambler

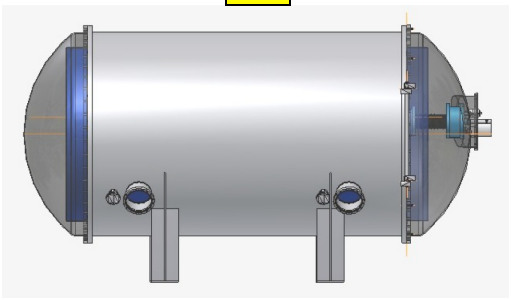


XPM



CalUnit

Scrambler



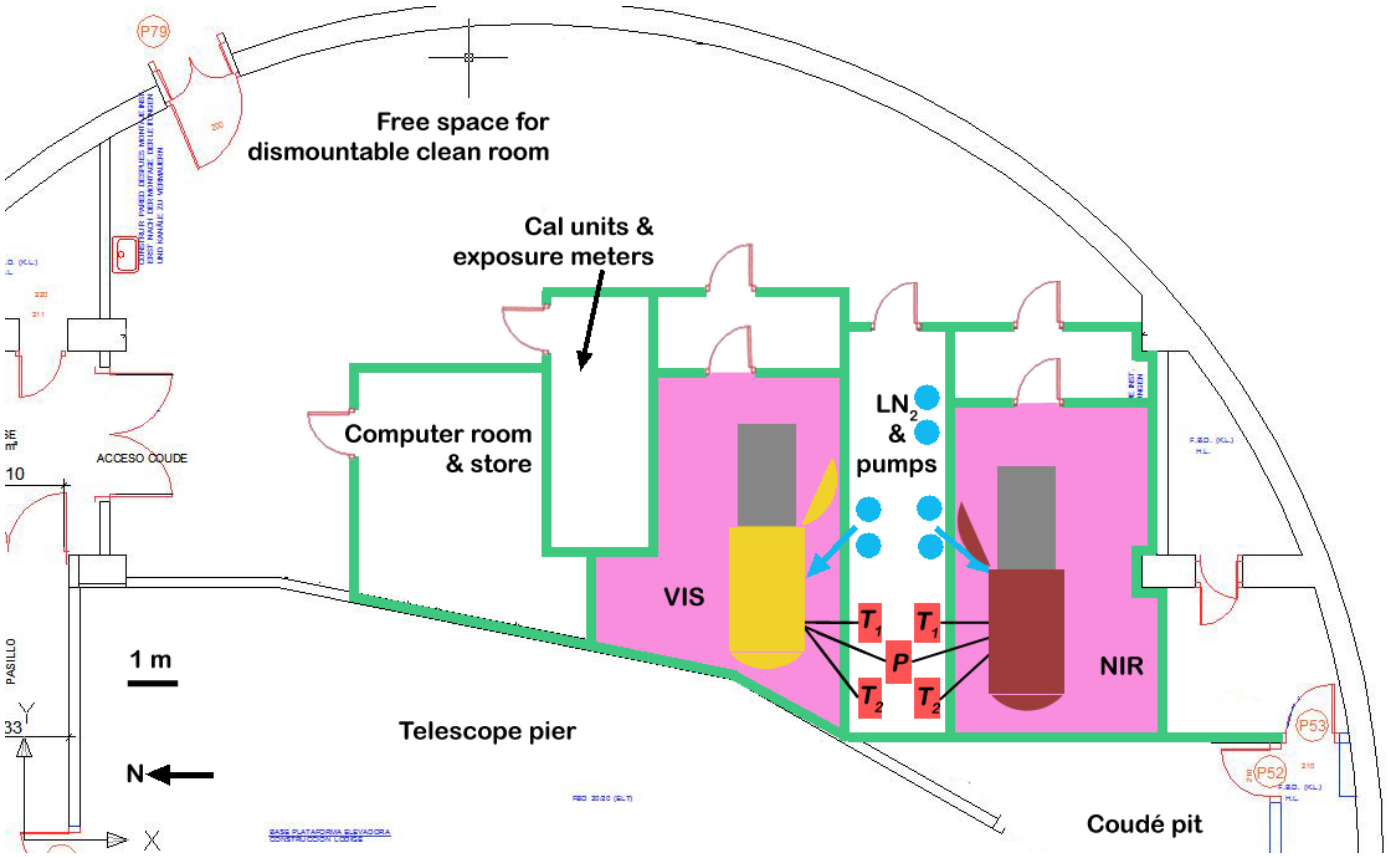
XPM

NIR Spectrograph

VIS Spectrograph

Instrument Location

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



Properties of Spectrographs

- 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

The NIR Requirements Dilemma

- We want:
  - High resolution
  - Good sampling (Nyquist)
  - Large wavelength coverage (0.95…1.7 μ m)
  - No gaps between orders
  - Large inter-order spacing (cross-talk!)
  - High SNR
- We have:
  - 2 x 2048 x 2048 pixels
  - Non-uniform sampling
  - Non-uniform order spacing
  - Non-uniform efficiency (blaze function!)
- We need to compromise!

Spectrograph Layout

White pupil fiber-fed echelle spectrograph

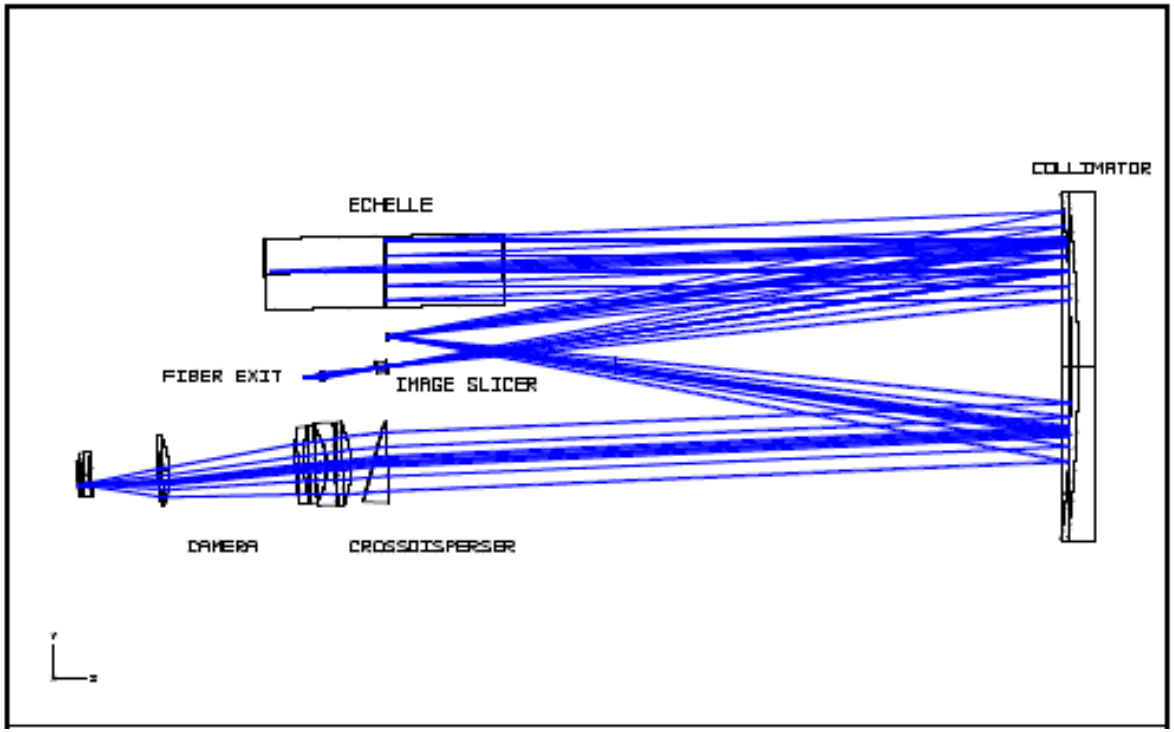
FiberExit-FNoptics-Slicer

Single-piece Collimator (3passes)

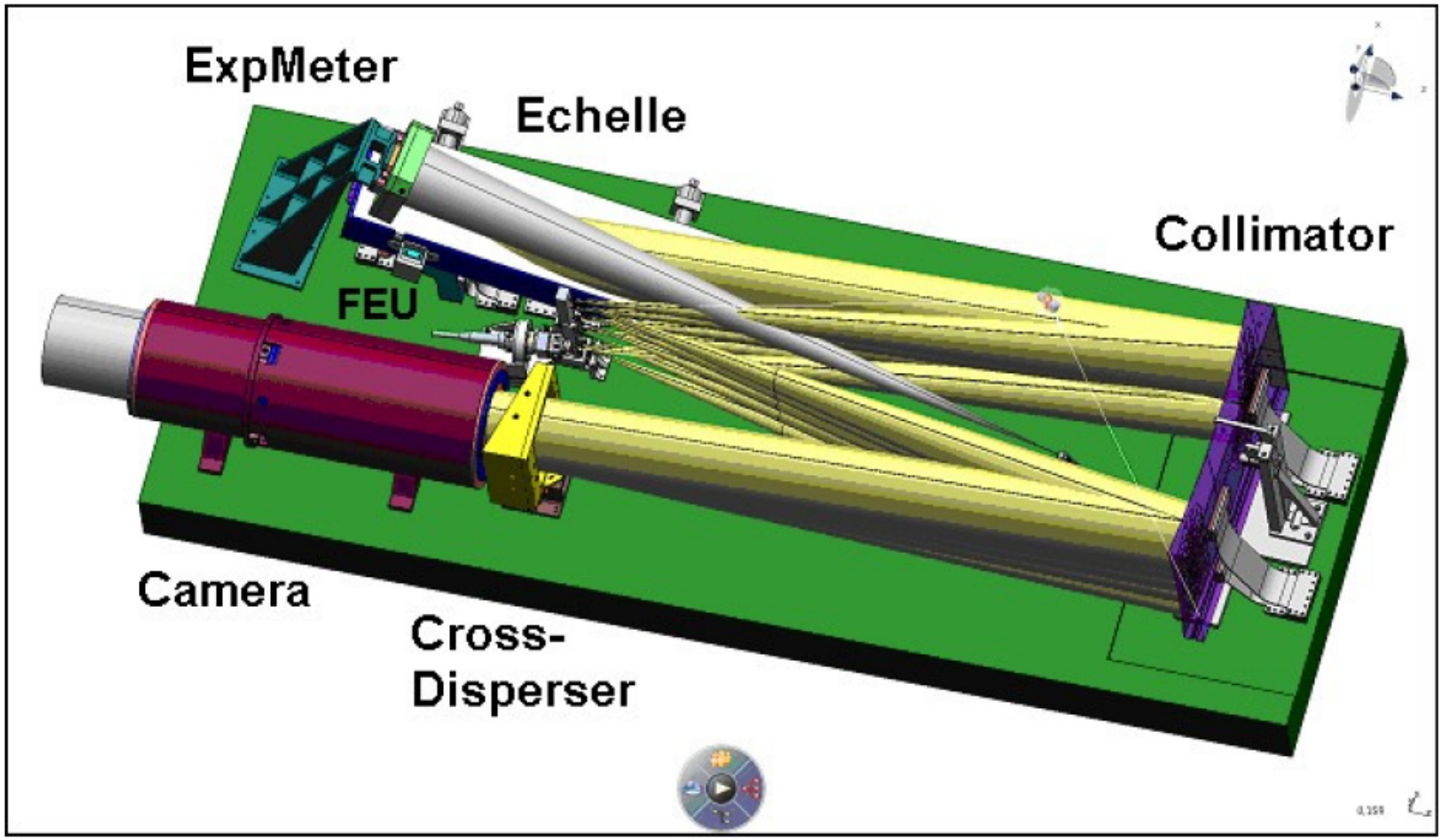
R4 Echelle grating

Grism cross-disperser

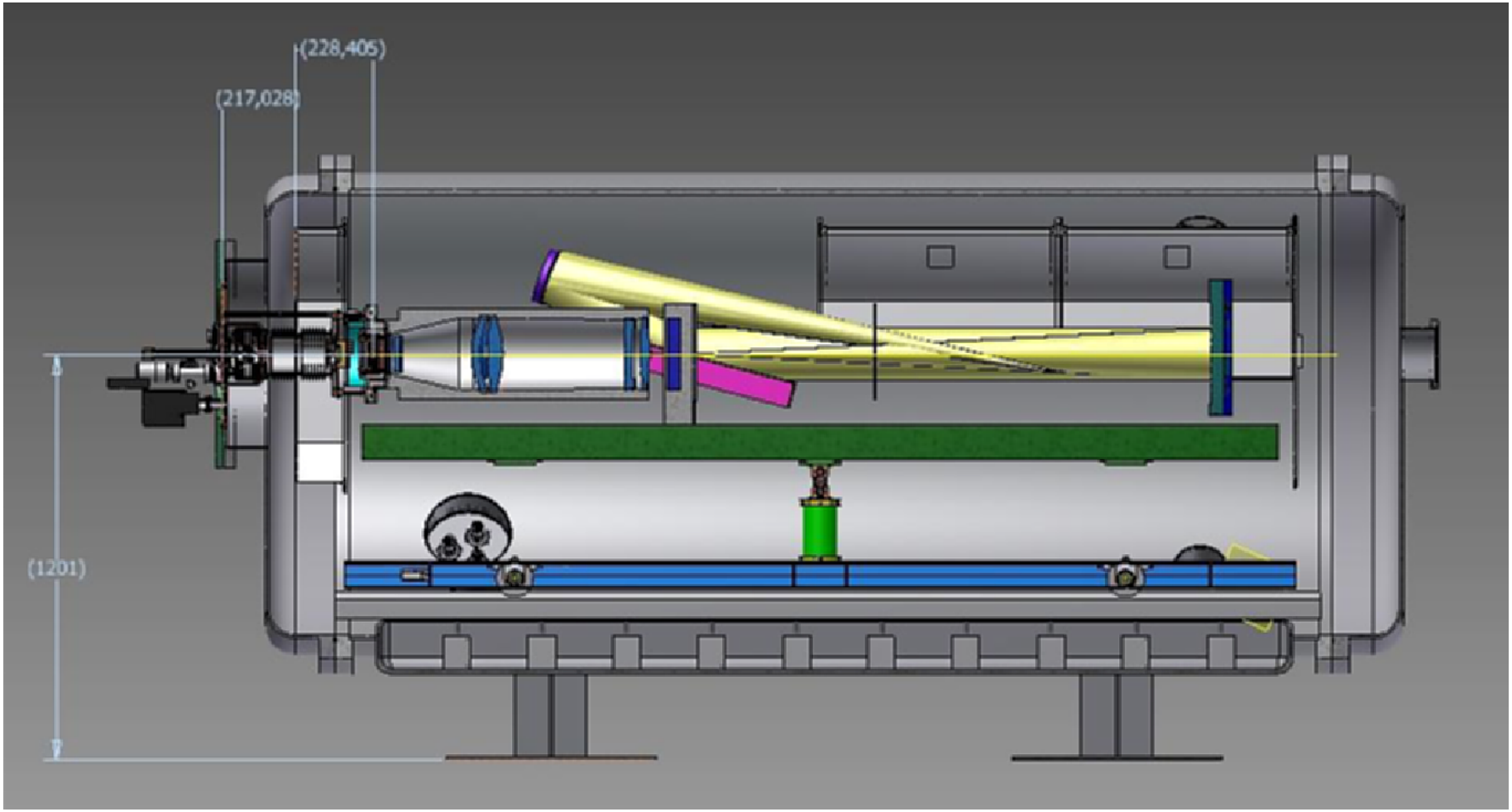
Dioptric camera



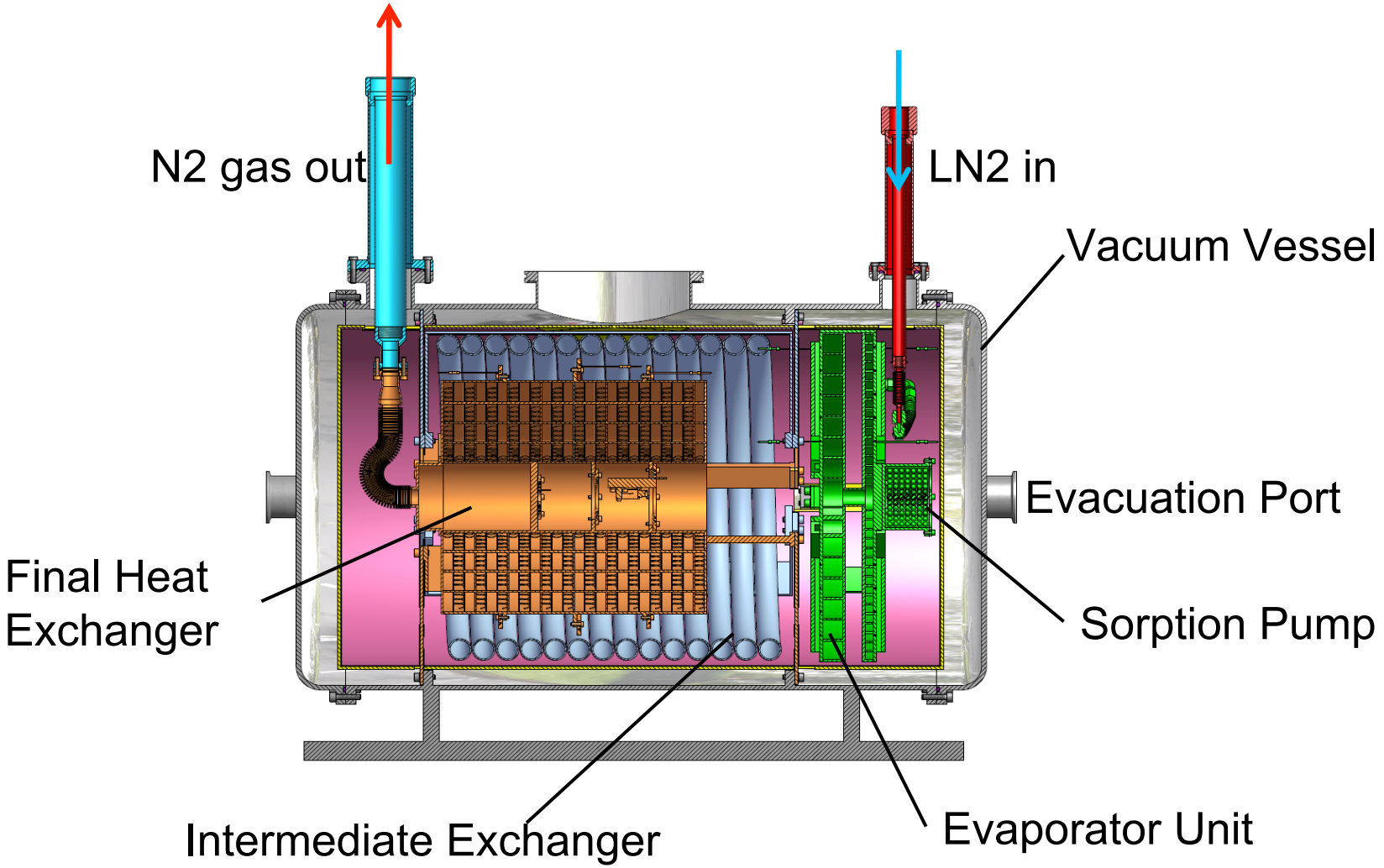
NIR Spectrograph Mechanical Layout



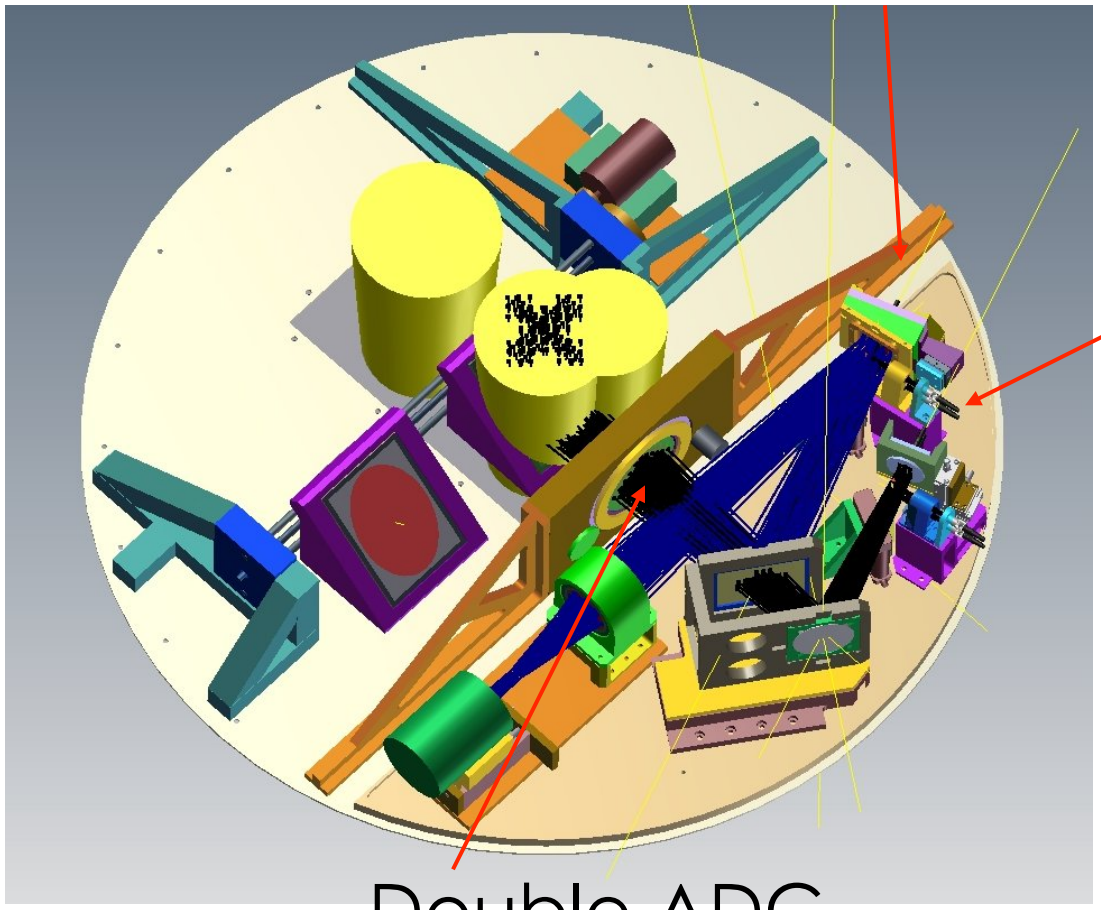
Spectrograph and Vacuum Tank Layout



Cooling Gas Preparation Unit (Collaboration with ESO)

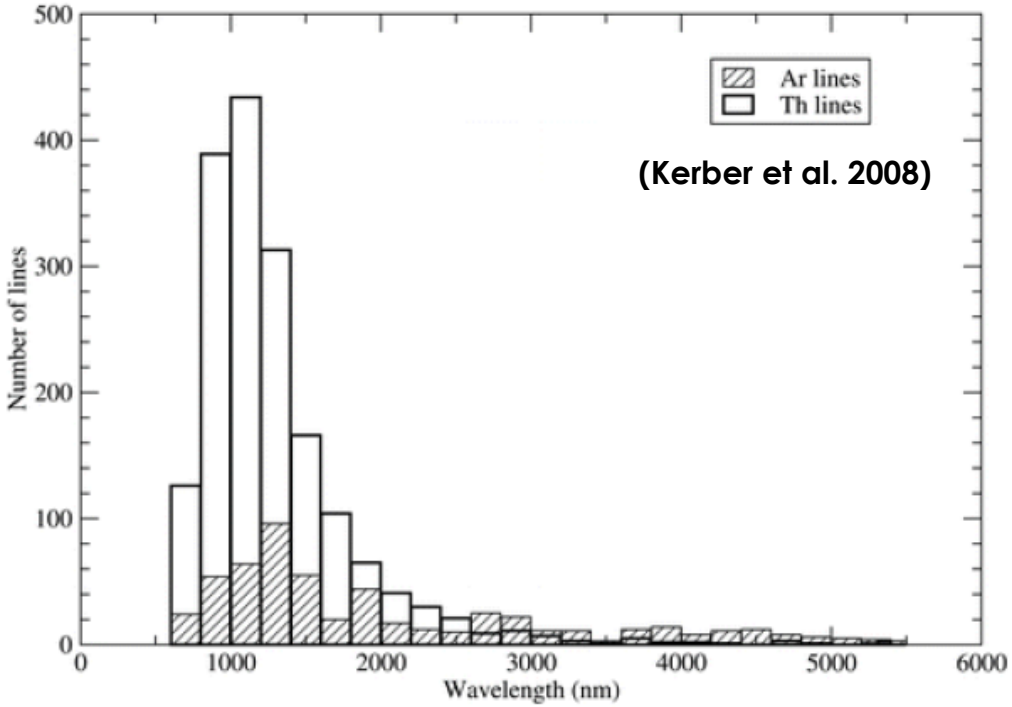


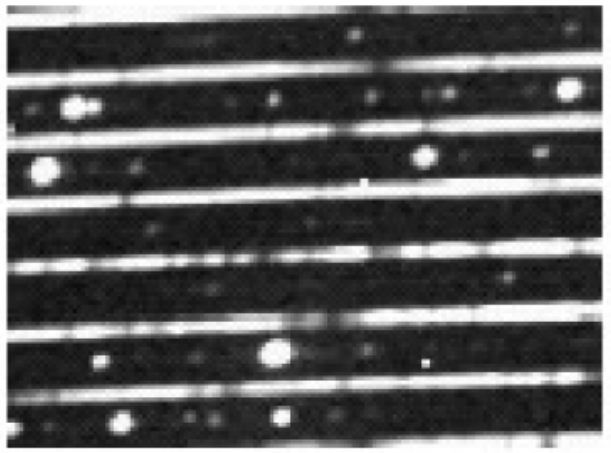
Front End Layout



Calibration: Wavelength Reference

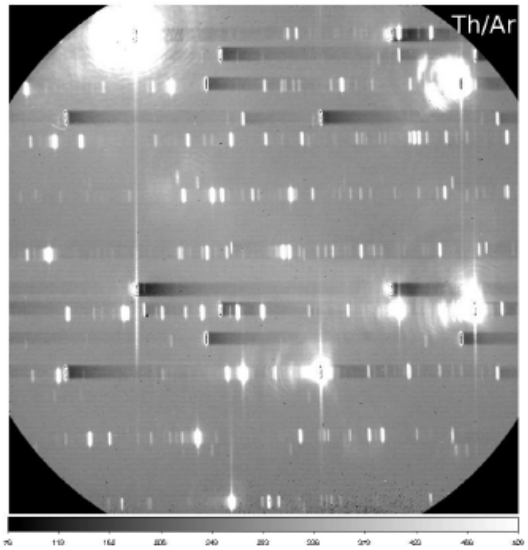
- Hollow cathode lamps for daily and master calibrations

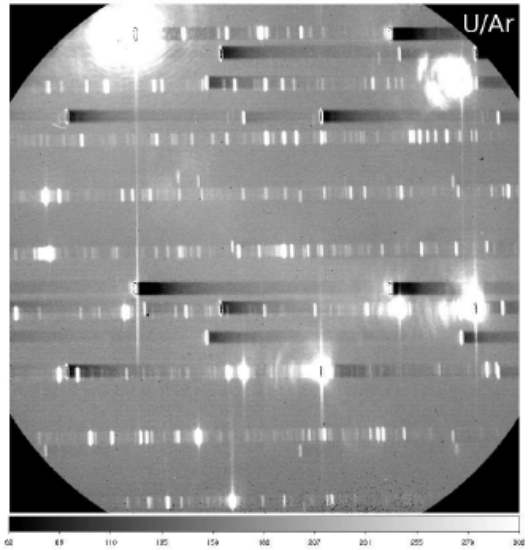


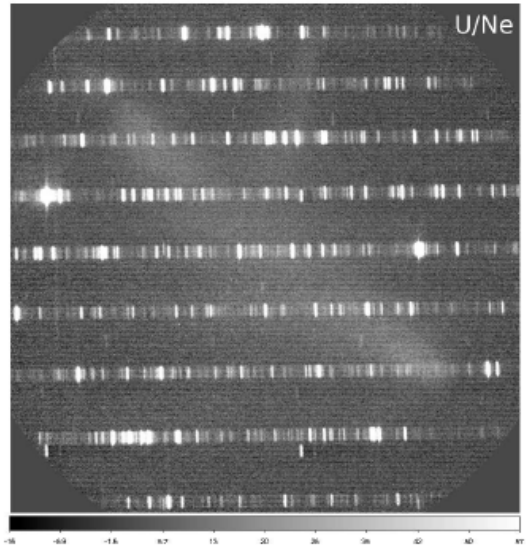


Enough suitable Th-Ar lines in the NIR range (Kerber et al. 2008)

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

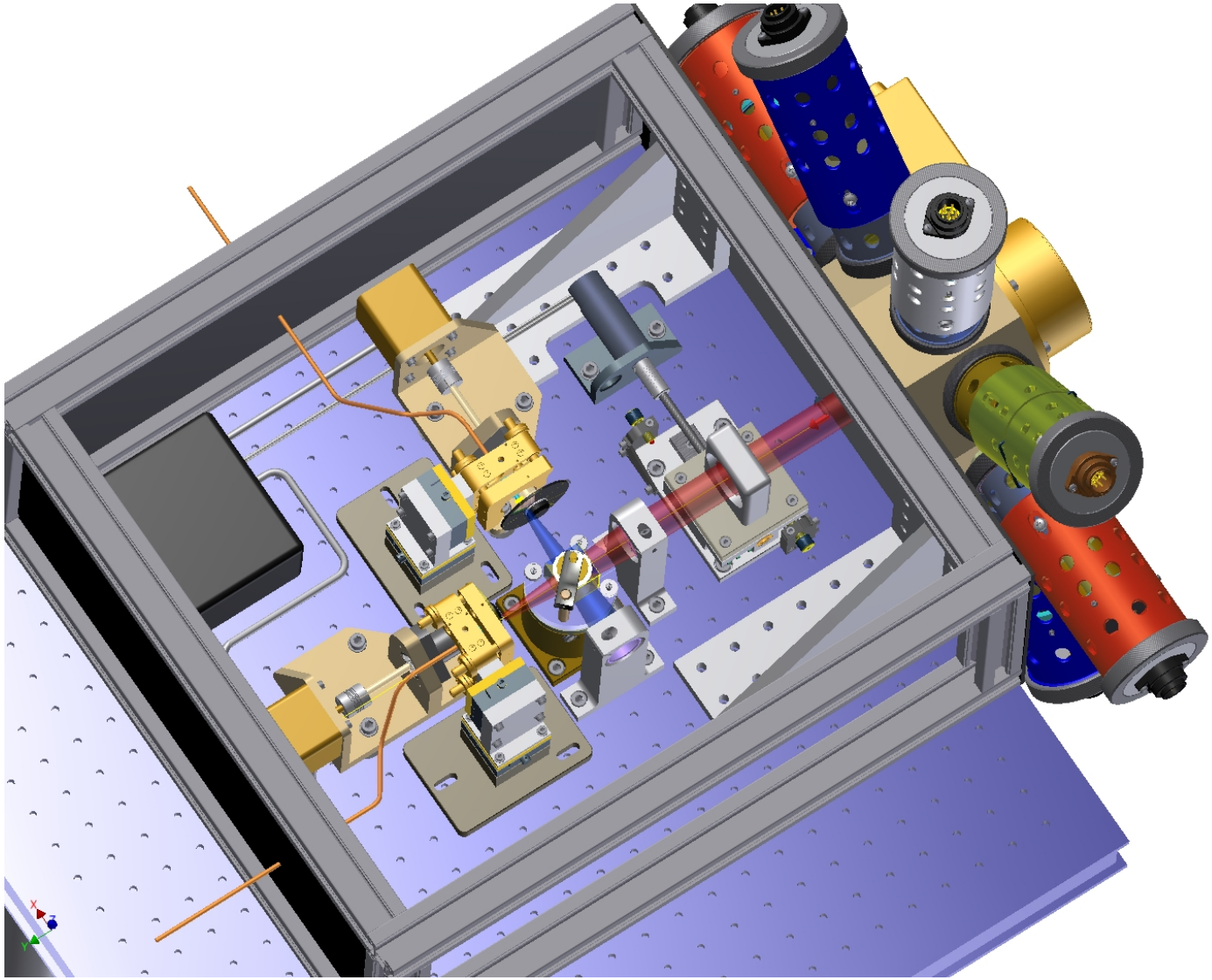






Redman et al. 2011

Calibration Unit

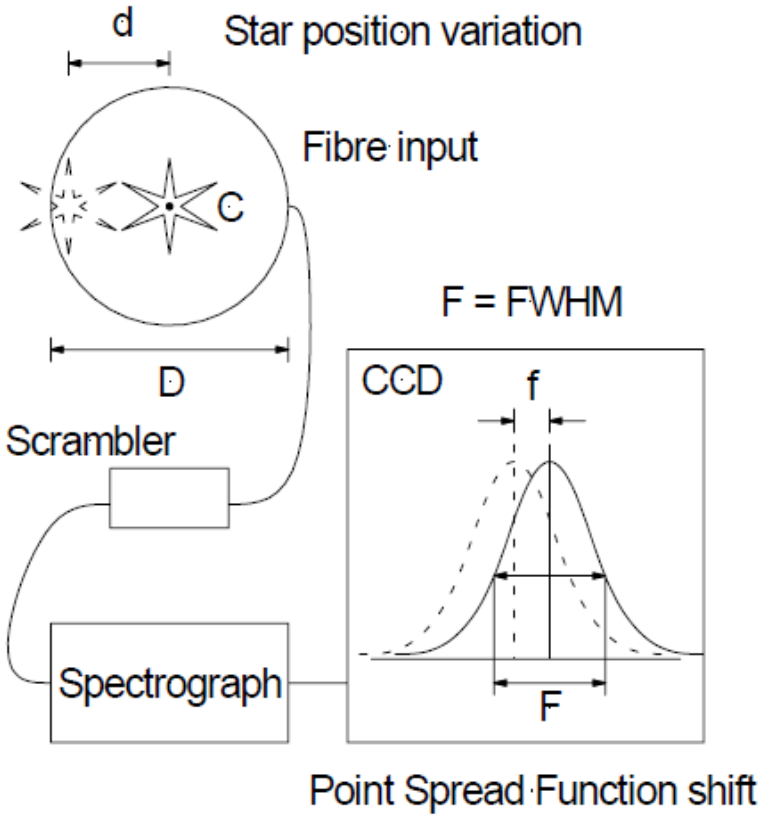


Requirements for RV Precision

Stable slit illumination and instrument are required for high RV precision.

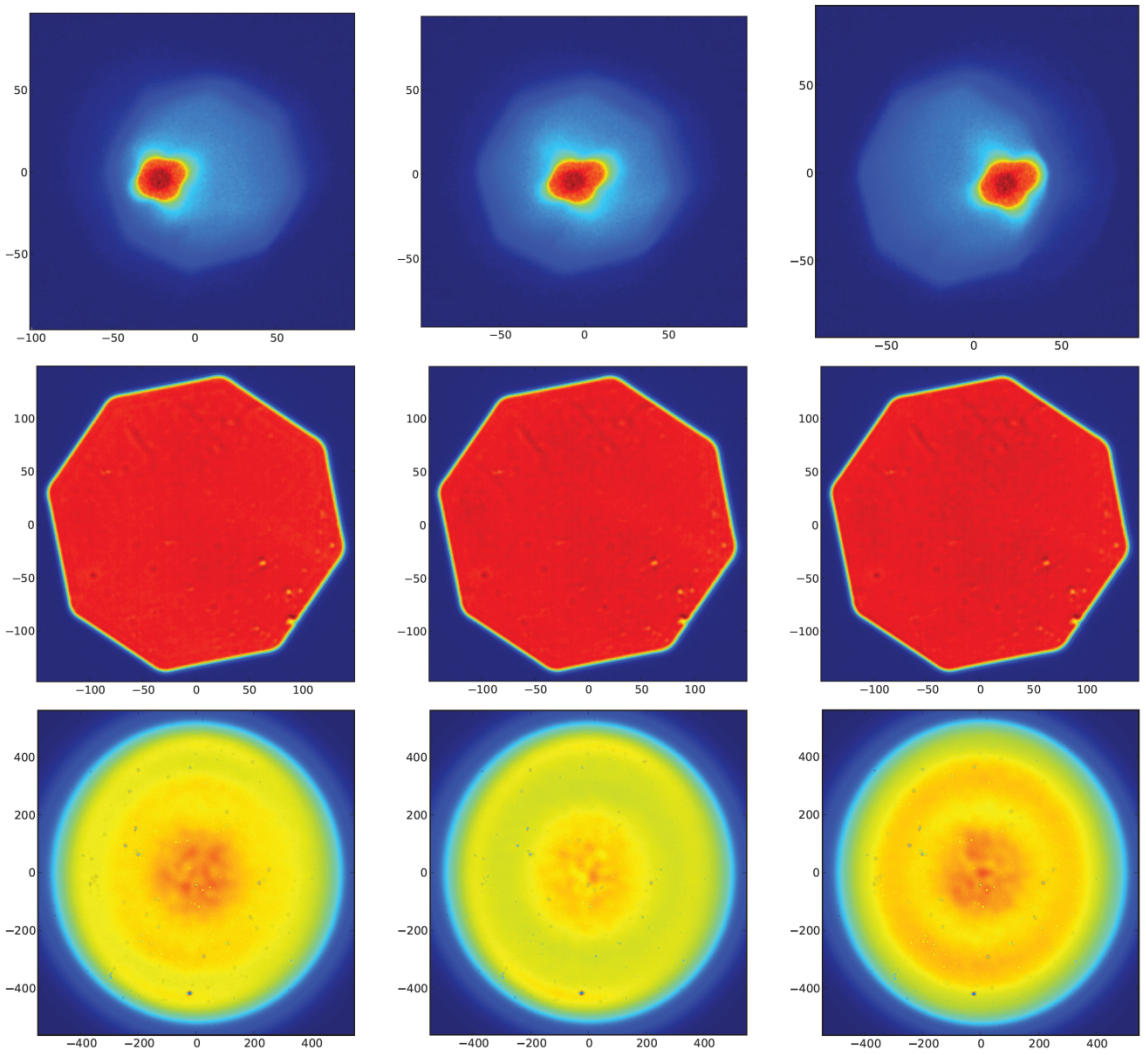
–Highly stable injection of light in the fibre (guiding ~0.1")

–Image scrambler or octagonal fiber



Avila & Singh (2008)

Tests of Octagonal Fibers

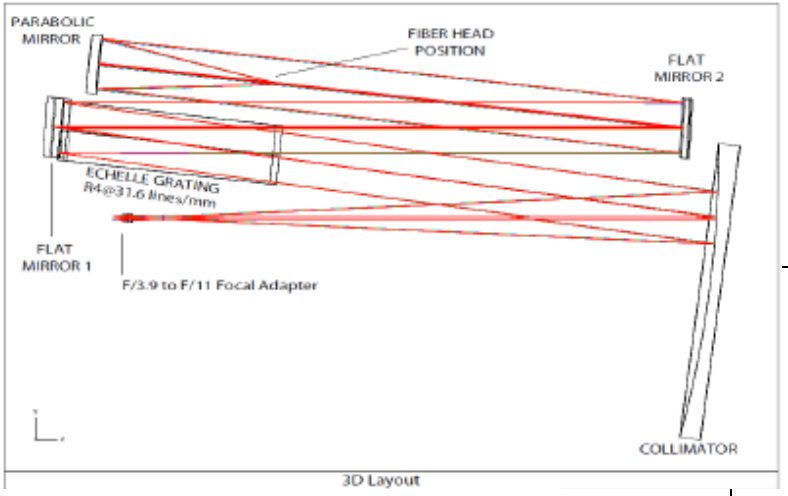


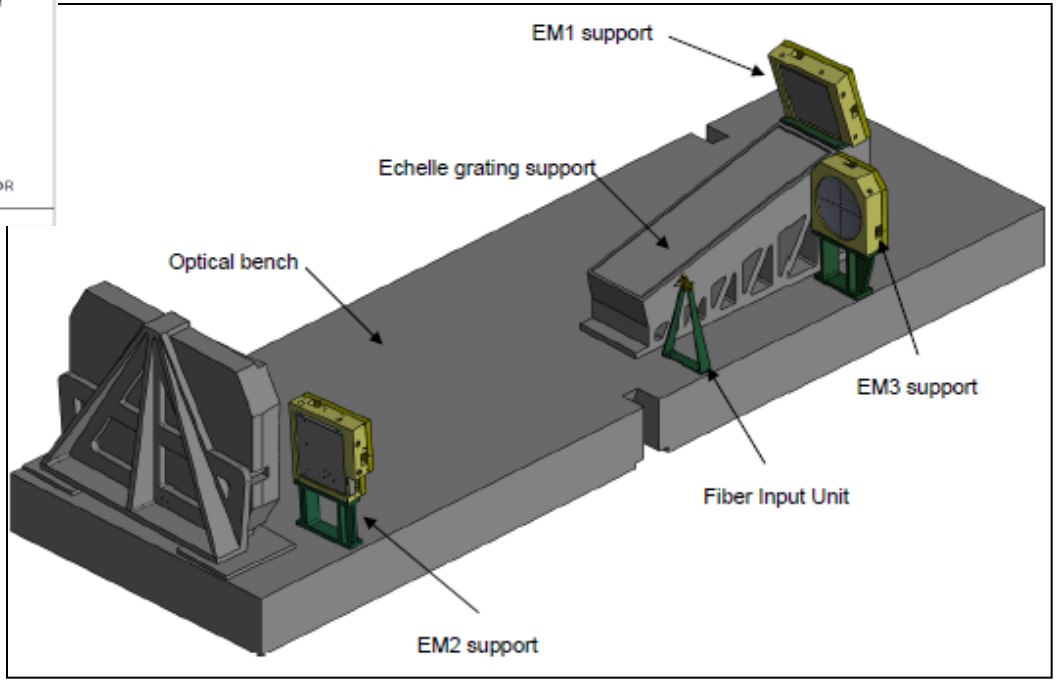
Input

Near Field

Far Field

Exposure Meters

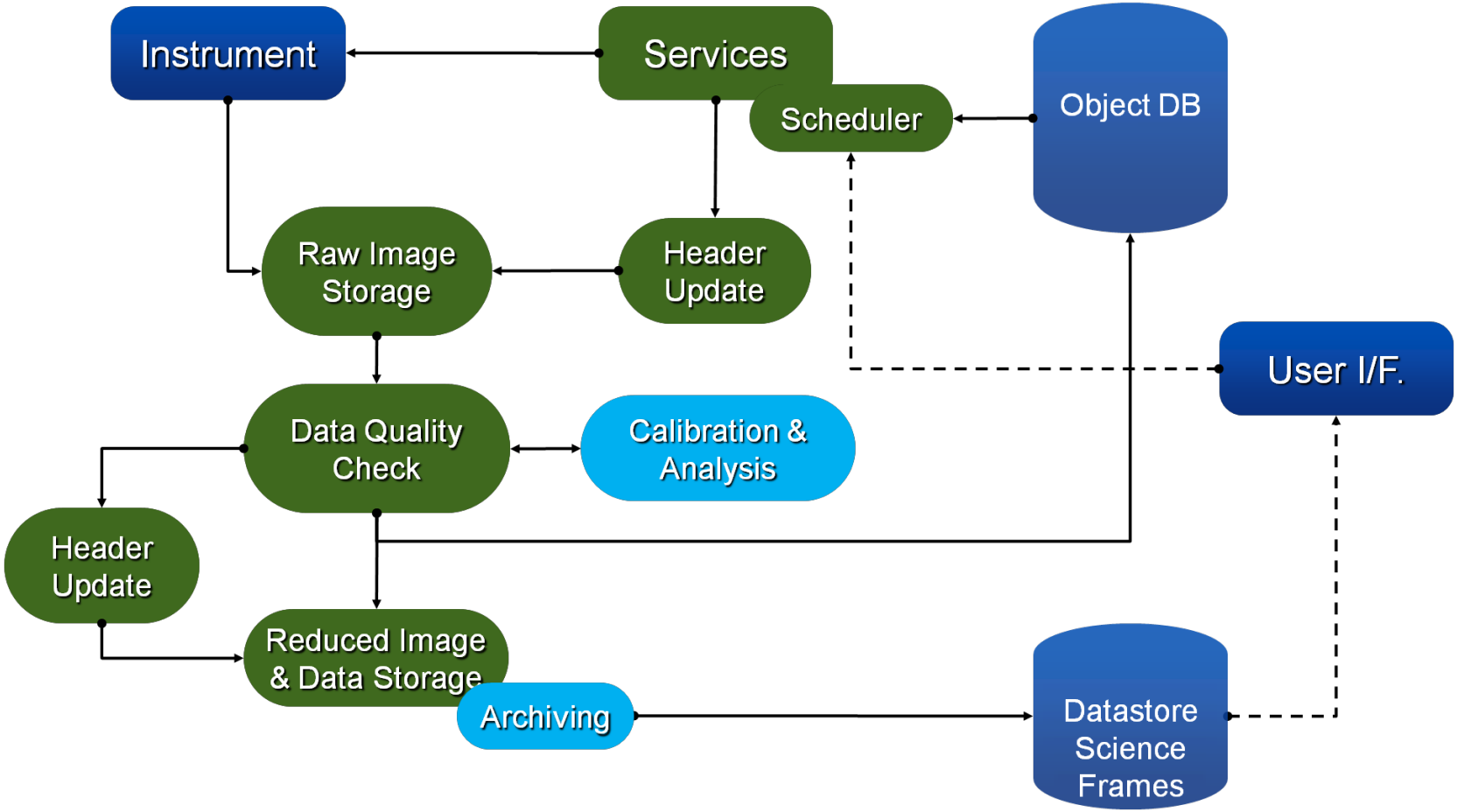




Off-axis system to pick-up 0th order from échelle

Fiber link to Hamamatsu PMTs located outside the instrument vessel

Data Processing



Agreement with MPG and CSIC

- MPG and CSIC will operate the 3.5m telescope from 2014 through 2018
- CARMENES will receive at least 600 useable nights
- An additional 150 nights will be allocated if all goes well

The CARMENES Consortium

- Landessternwarte Königstuhl, U Heidelberg, Germany
- Insitut für Astrophysik, U Göttingen, Germany
- MPI für Astronomie, Heidelberg, Germany
- Thüringer Landessternwarte, Tautenburg, Germany
- Hamburger Sternwarte, U Hamburg, Germany

- Instituto de Astrofísica de Andalucía, Granada, Spain
- 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 – 12/2012
Construction	01/2013 – 06/2014
Commissioning	07/2014 – 12/2014
Data Taking	01/2015 – 12/2018