



## NAHUAL:

# A MID & HIGH RESOLUTION IR SPECTROGRAPH FOR A 10-M SEGMENTED TELESCOPE (GTC)

### Motivations:

To extend the parameter space of planet searches  
(ages, masses, rotation).

Follow-up of NIR transit searches.

Very low-mass primaries (Martin et al. 2006, Blake et al. 2007,  
T Tauri stars (Huélamo et al. 2008), Young MS stars, Red giants

Zapatero Osorio et al. 2007, 2009)



# Community interest

- 7 workshops held so far (La Gomera, Segovia, Jena, Cádiz, Miami, Fuerteventura, Sintra).
- Next workshop in Fuerteventura, 16-18 Dec 2009, <http://www.reun-prep-cons11-fuerteventura.com/>
- About 100 different participants in those workshops
- Seed for instrument proposed for Calar Alto 3.5-m (CARMENES)
- Other similar projects in other observatories (PRVS)
- Need for high-precision RV capabilities mentioned in Exoplanet Task Force and Blue Dots reports.
- **Funding collected since 2005:**
- 600 Keuros from MEC
- 200 Keuros from Tautenburg
- 100 Keuros from IAC
- 40 Keuros in Ireland
- 40 Keuros from Lisbon



# Observing modes

NAHUAL team driven: Single object. High stability (no moving parts).  
R=60,000. Wav. Range=0.9–1.8 microns. FOV=3 arcsec.  
CD completed.

GTC driven: Multi-object capability.  
R=20,000. Range=0.95–2.45 microns. FOV $\approx$ 10 arcmin.  
CD study funded.

Long-term NIRSPEC RV data (2001-2008) of VB10 has rms of 300 m/s  
Zapatero Osorio, Martin, et al. 2009, A&A

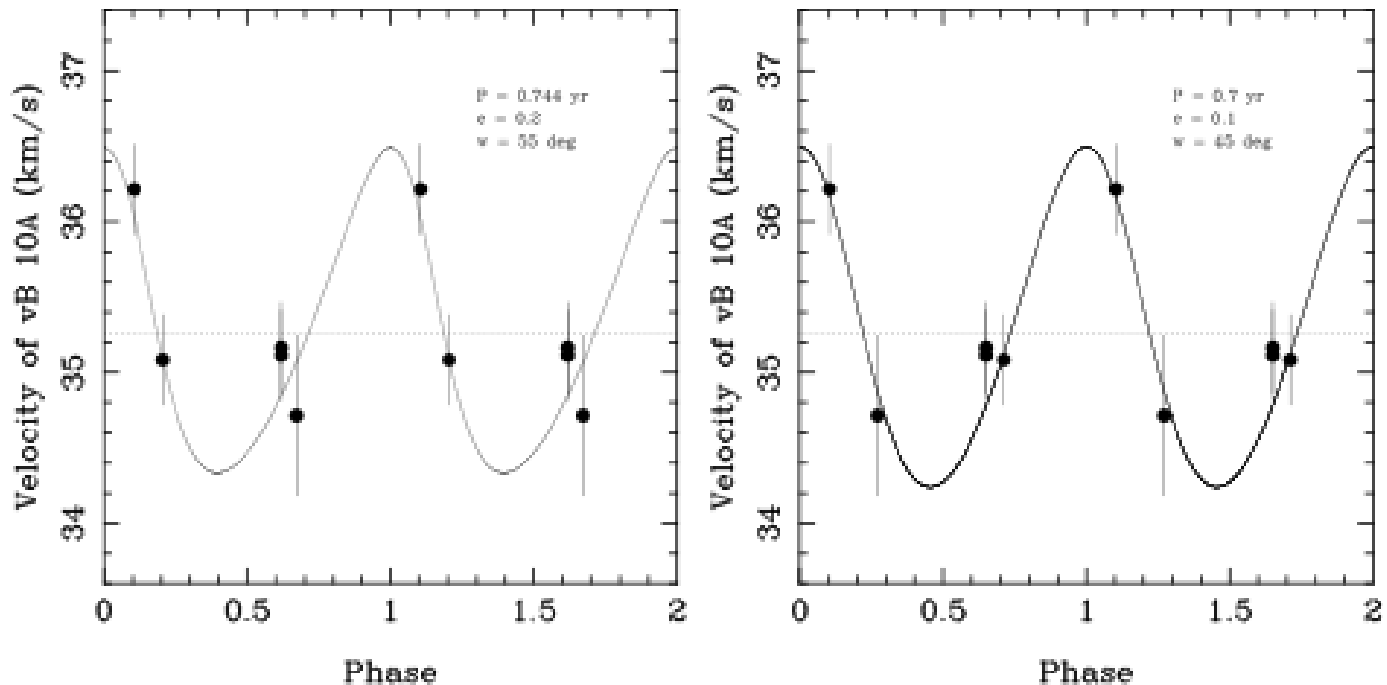
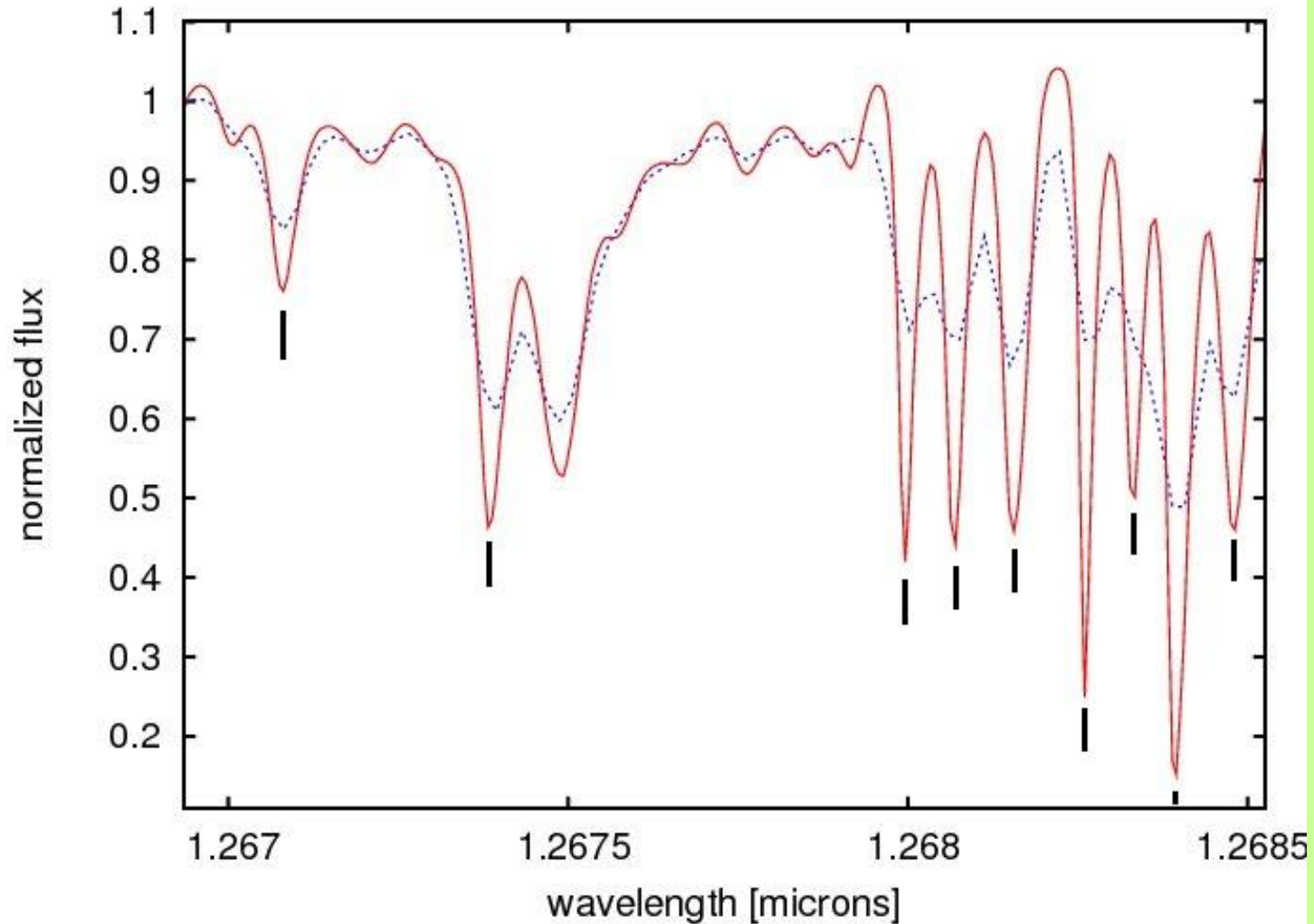


Fig. 3.— NIRSPEC radial velocities of vB 10 (filled circles) folded in phase using the same orbital parameters than in Fig. 2 (left panel), and using slightly different orbital period, eccentricity, and argument of periapsis (right panel). These spectroscopic observations cannot constrain the orbital solution precisely, but they are consistent with the presence of a small body around vB 10. The horizontal dotted line denotes the “systemic” velocity of the pair. Note that two periods are depicted in the diagrams.

Mass of companion  $\approx 6.4$  Jupiters; Pravdo & Shaklan 2009

What can we do to improve the precision?



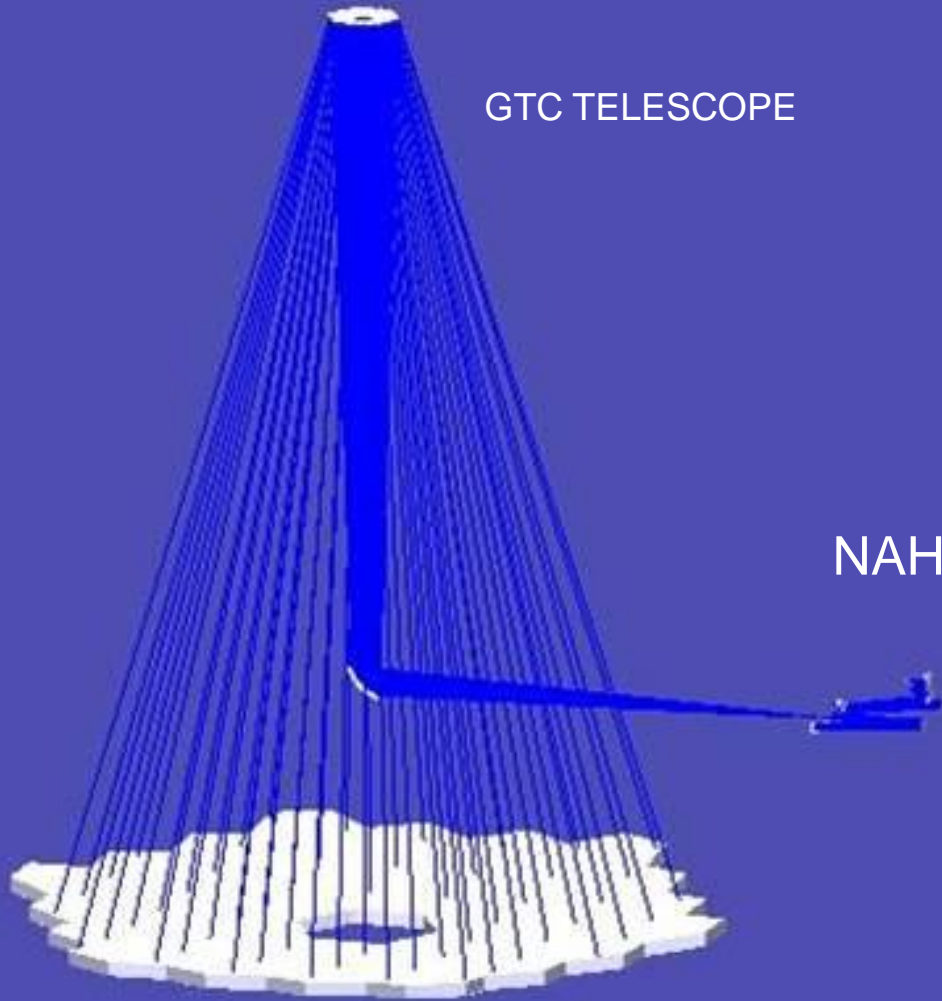
Deconvolution by F. Rodler, precision 120 m/s



# Nahual project web page

<http://www.ucm.es/info/Astrof/nahual/>

GTC TELESCOPE



NAHUAL

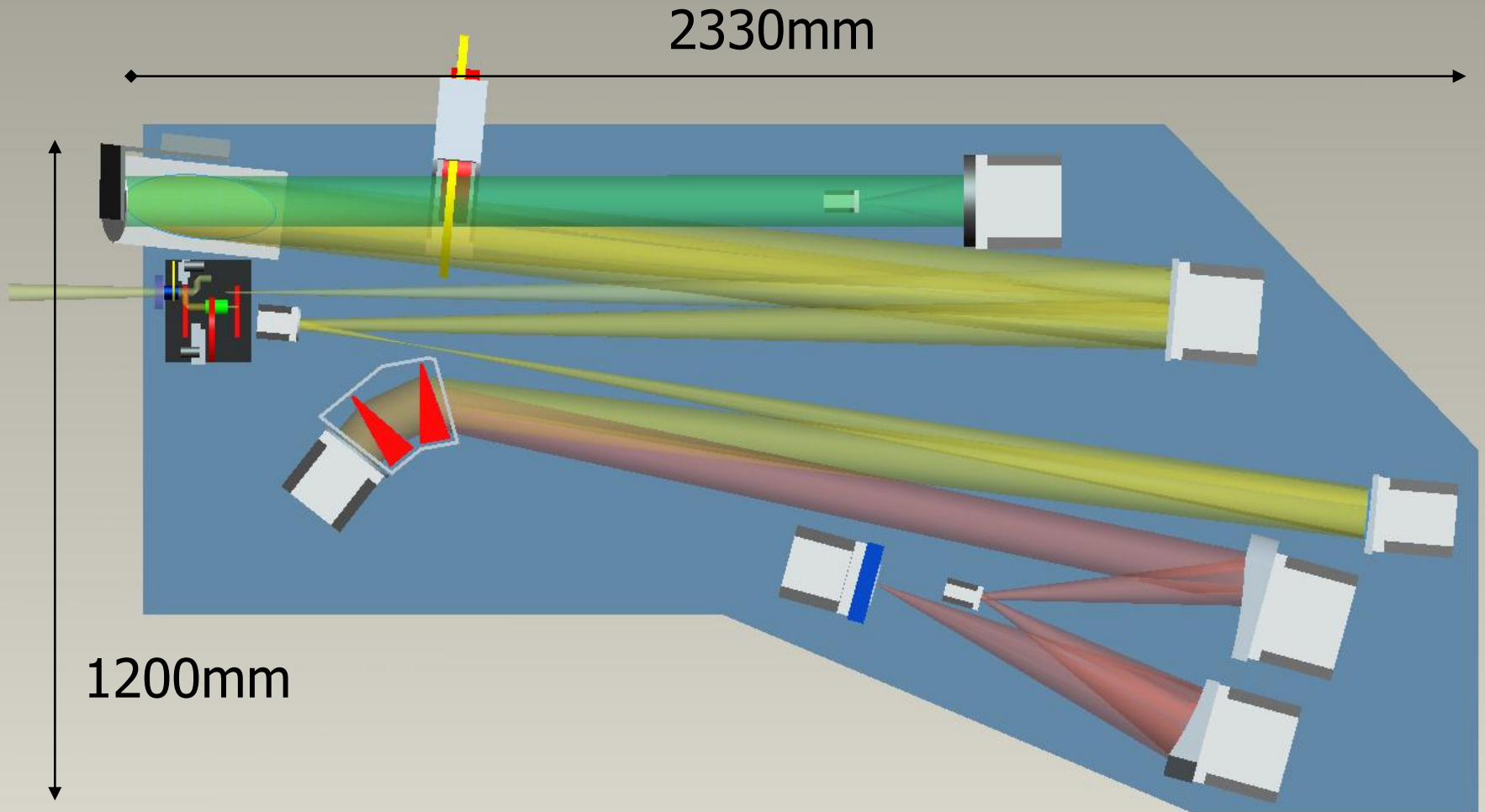


Martín et al. 2005, AN

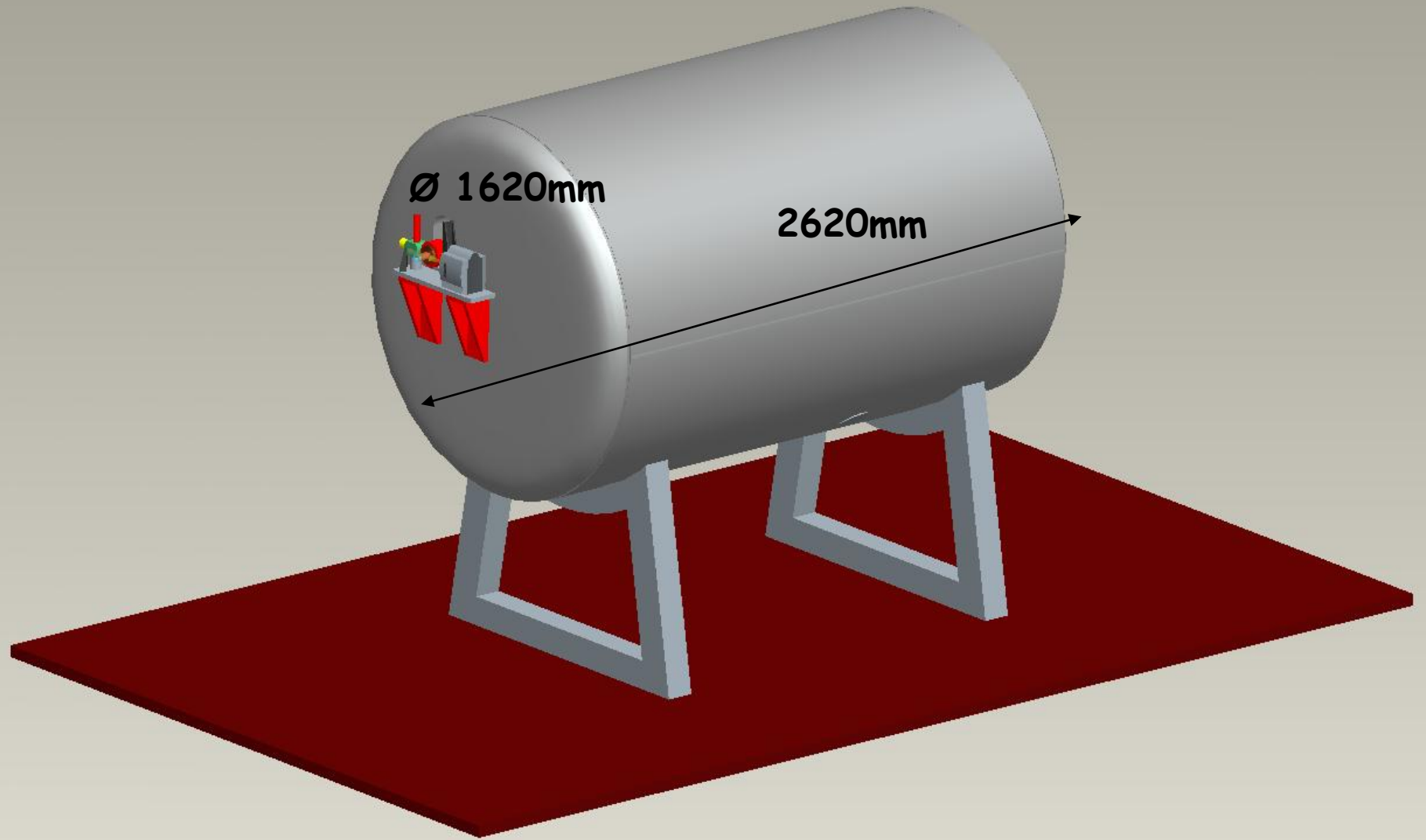




# Conceptual mechanical design

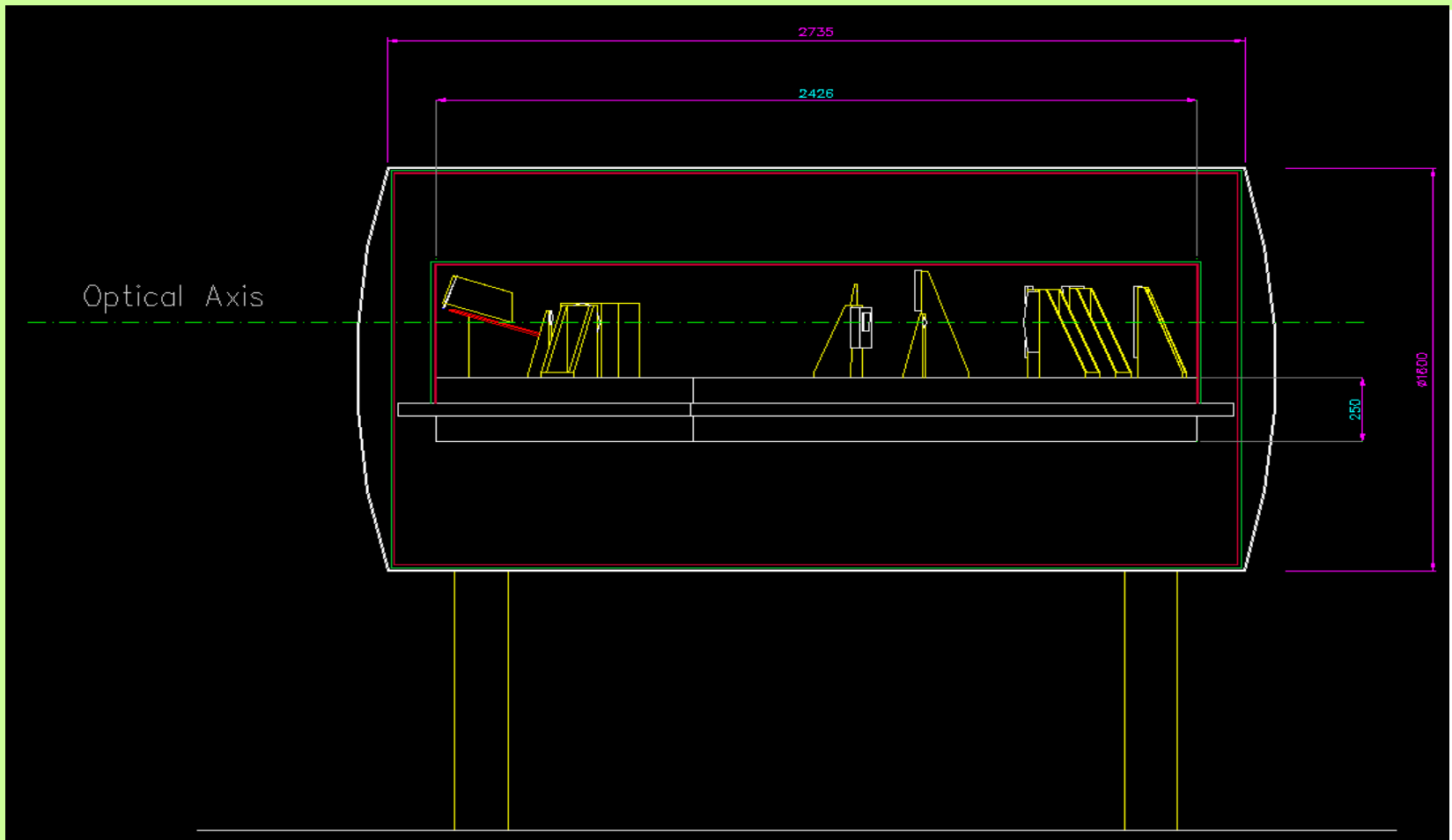








# High stability cryostat

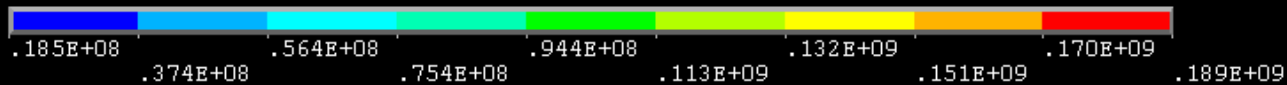
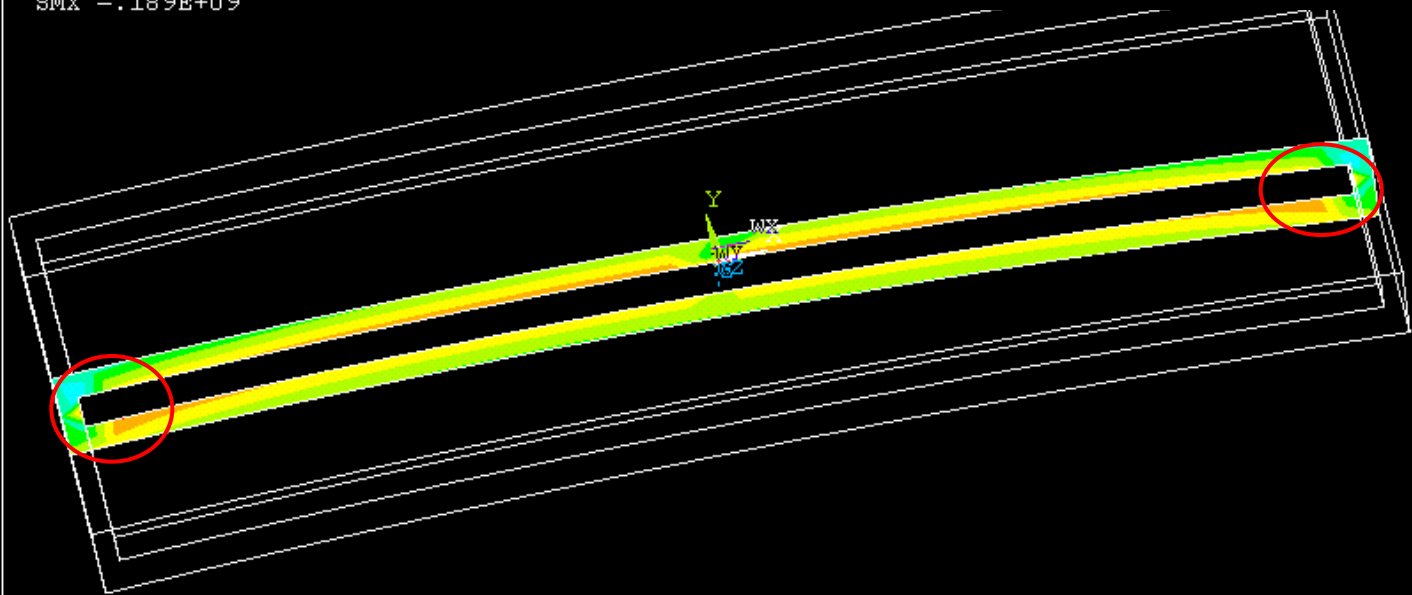
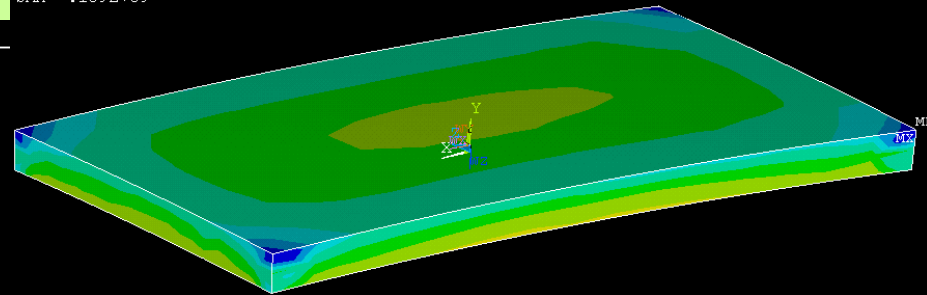


Collaboration between Arcetri, IAC and Lisbon

# Single vessel e=40 mm (wall thickness)

DMX = .186543  
SMN = .185E+08  
SMX = .189E+09

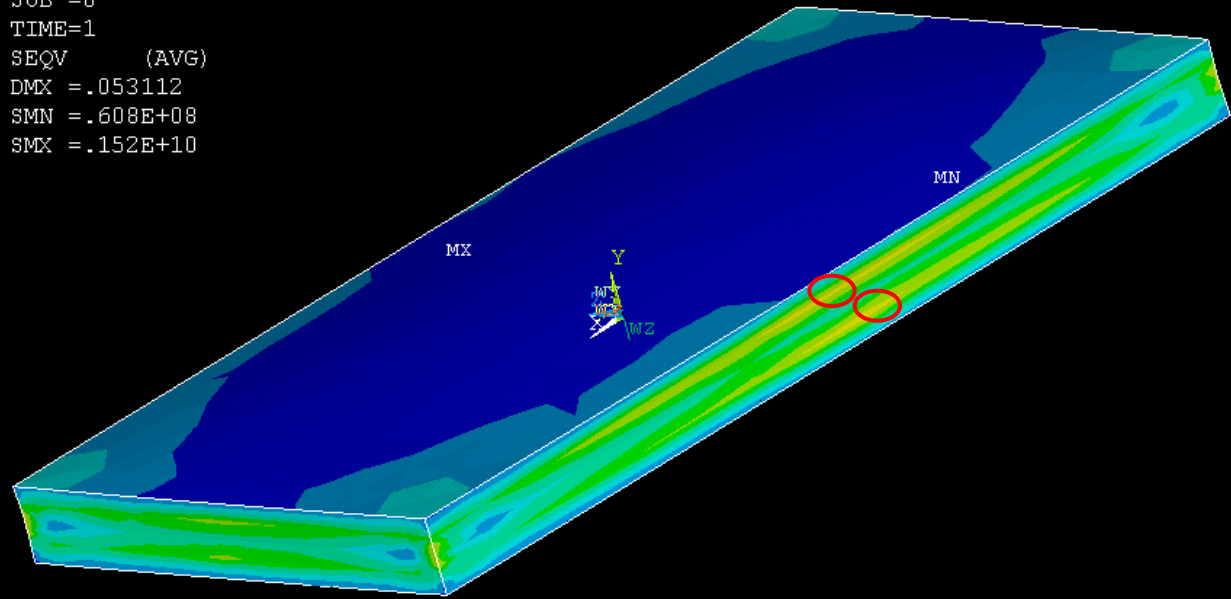
1  
NODAL SOLUTION  
STEP=1  
SUB =9  
TIME=1  
SEQV (AVG)  
DMX = .186543  
SMN = .185E+08  
SMX = .189E+09



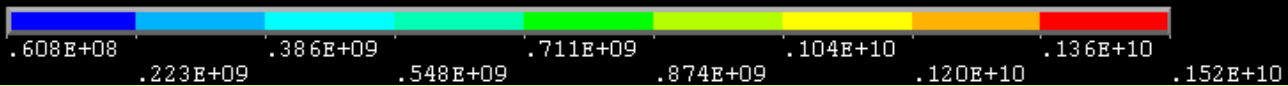
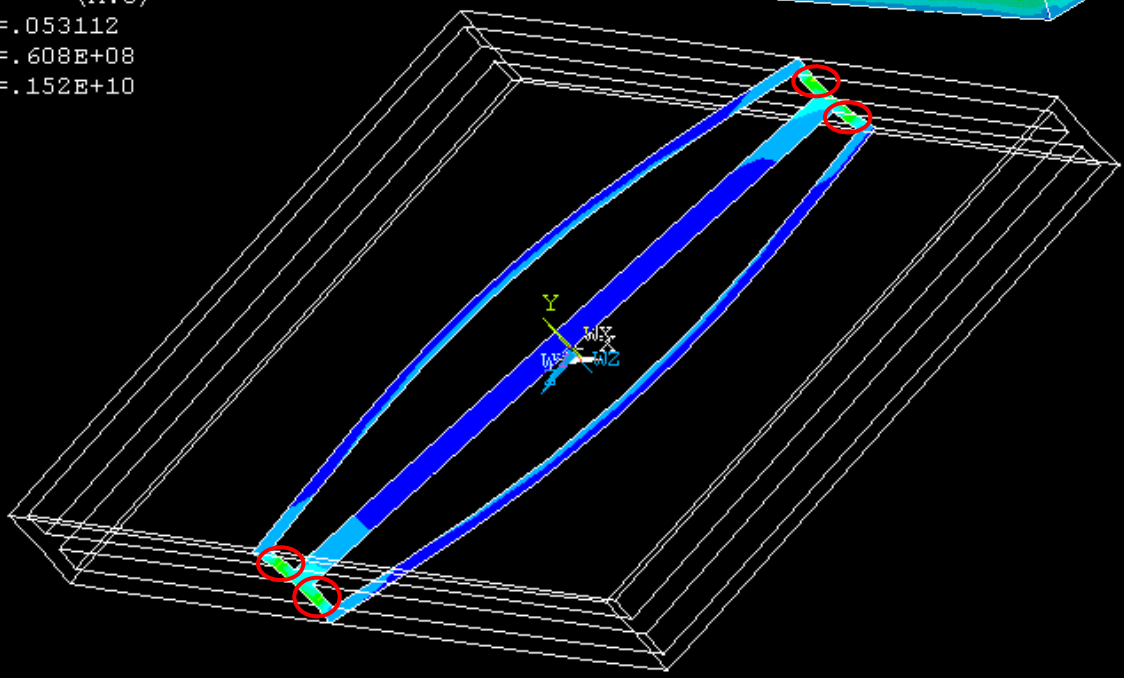
Thermal Budget

Double vessel  
 $e=20$  mm (wall thickness)

SUB =8  
TIME=1  
SEQV (AVG)  
DMX =.053112  
SMN =.608E+08  
SMX =.152E+10



TIME=1  
SEQV (AVG)  
DMX =.053112  
SMN =.608E+08  
SMX =.152E+10





# Prisms of ZnSe

Ohara GmbH  
150.00  $\pm$ 1.0 mm  
50.00  $\pm$ 1.0 mm  
40.000 euros

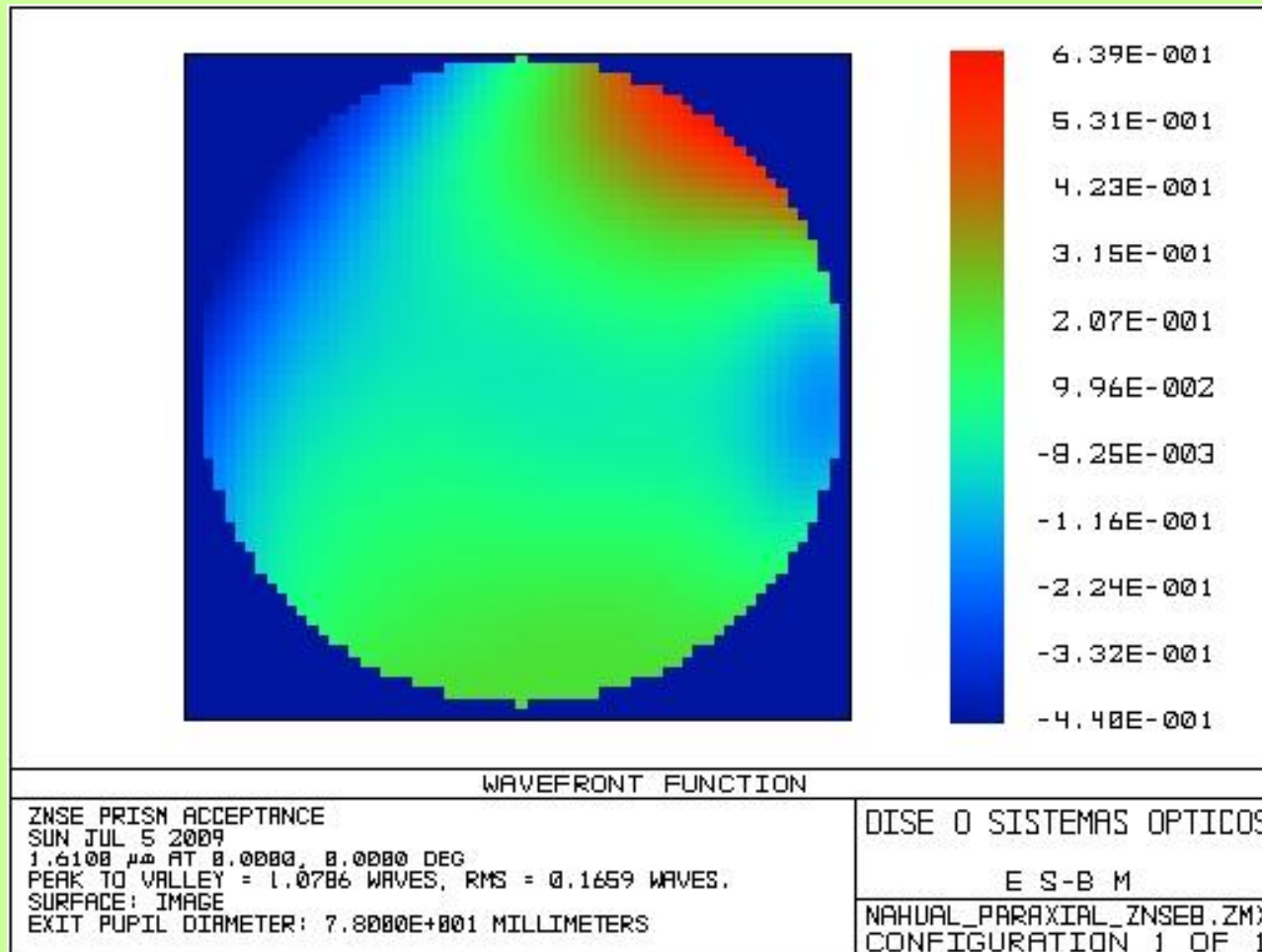


# Satisfactory delivery to TLS



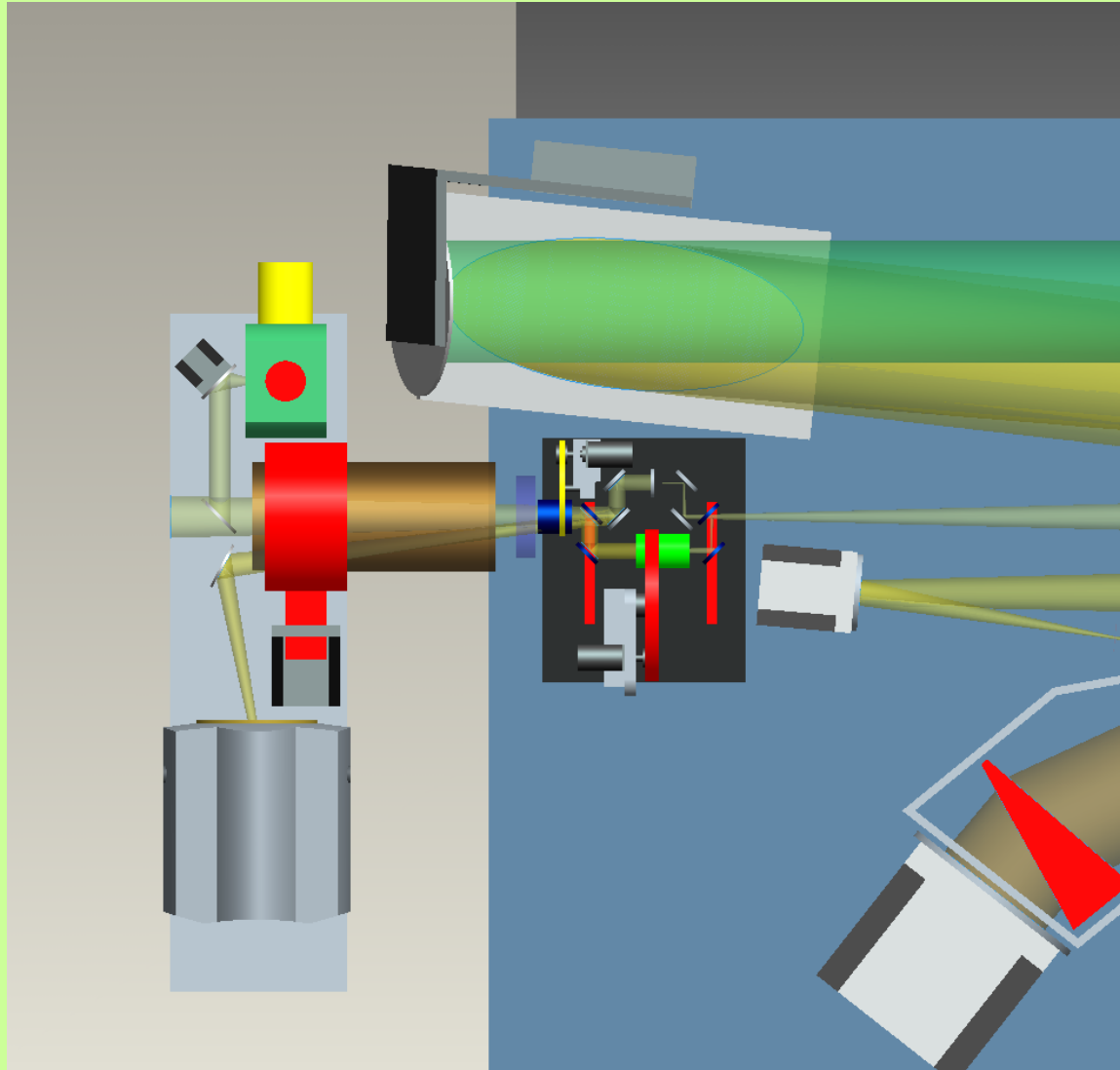


Zemax model to place in pupil (returning mirror) to consider the effects of The prisms WFE. It contains 37 zerniques (with tilt and focus removed).  
- There are two passes and is scaled from 0.632 to the working wavelength.





# Gas cells

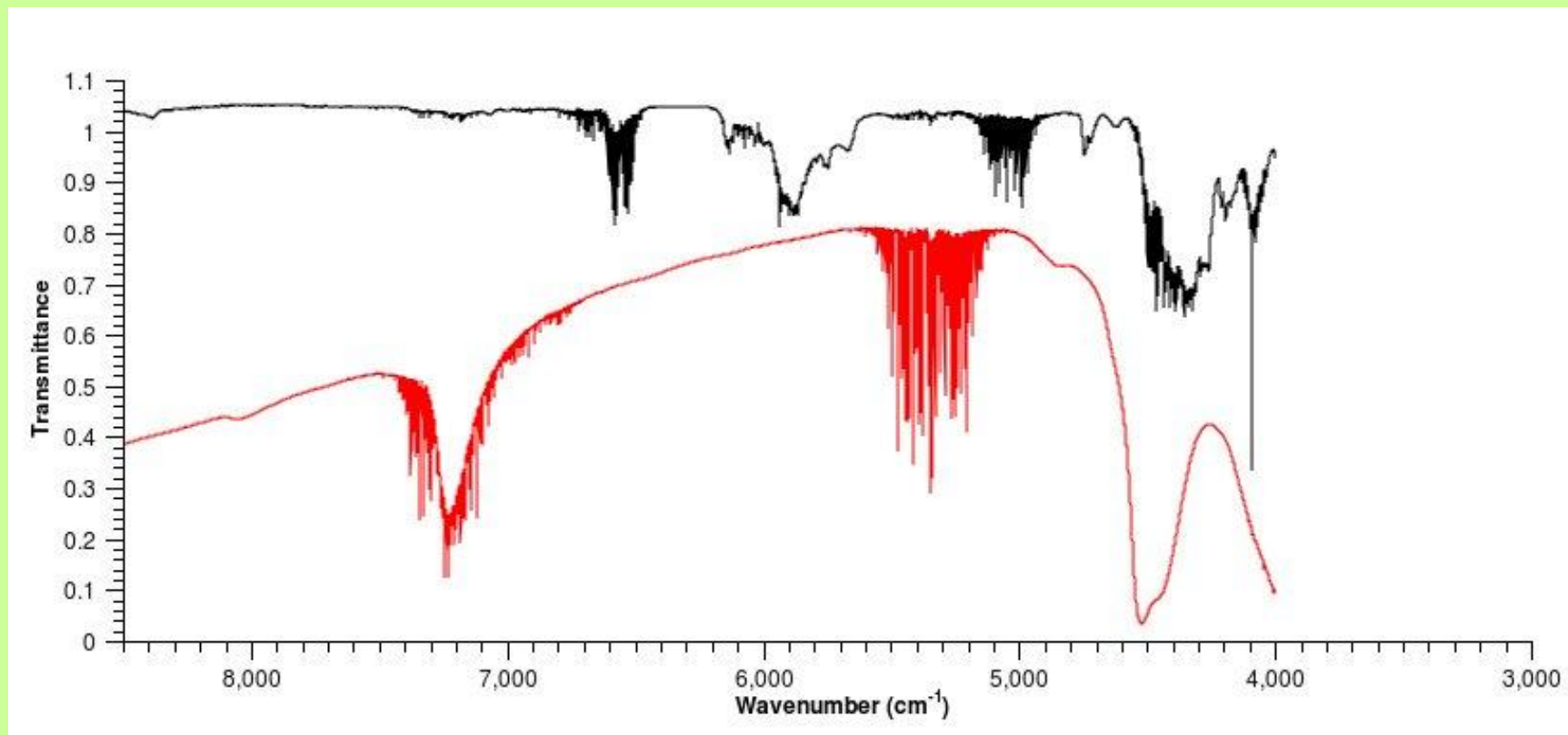


# Gas cell development

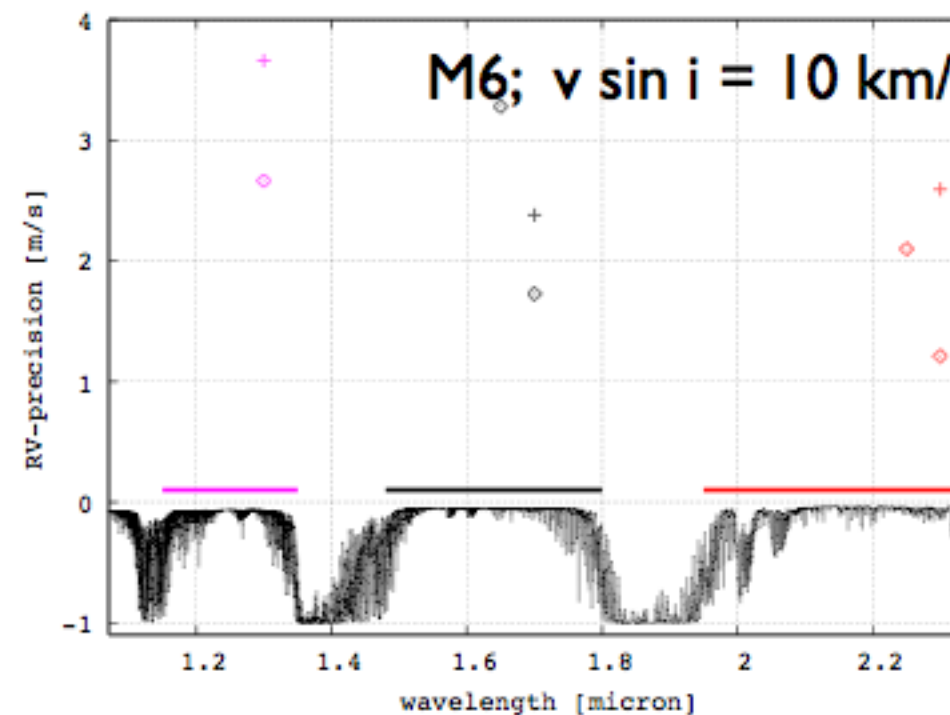
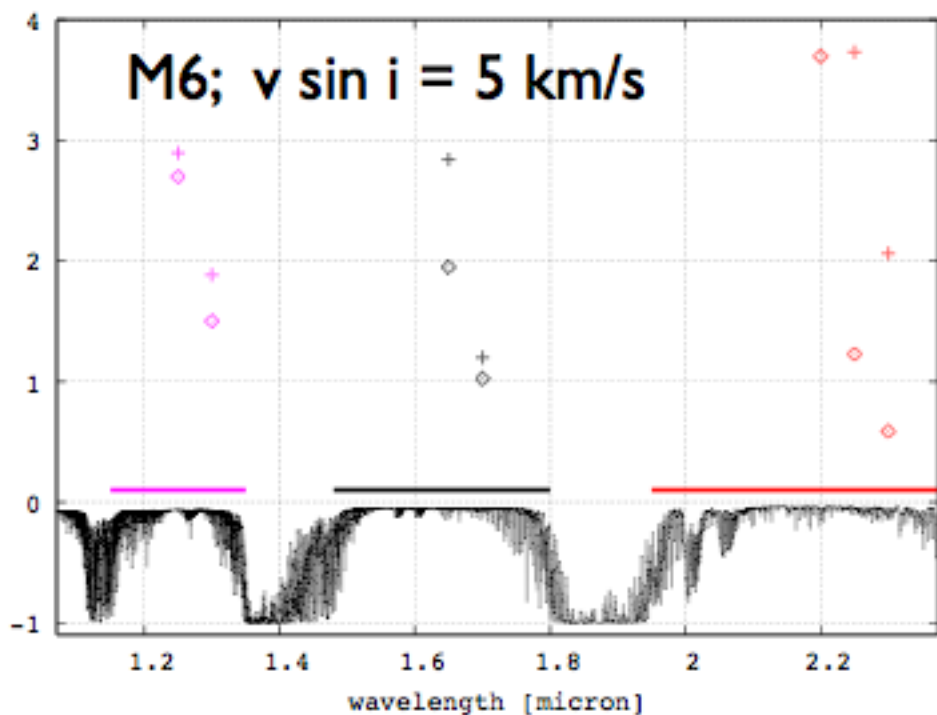
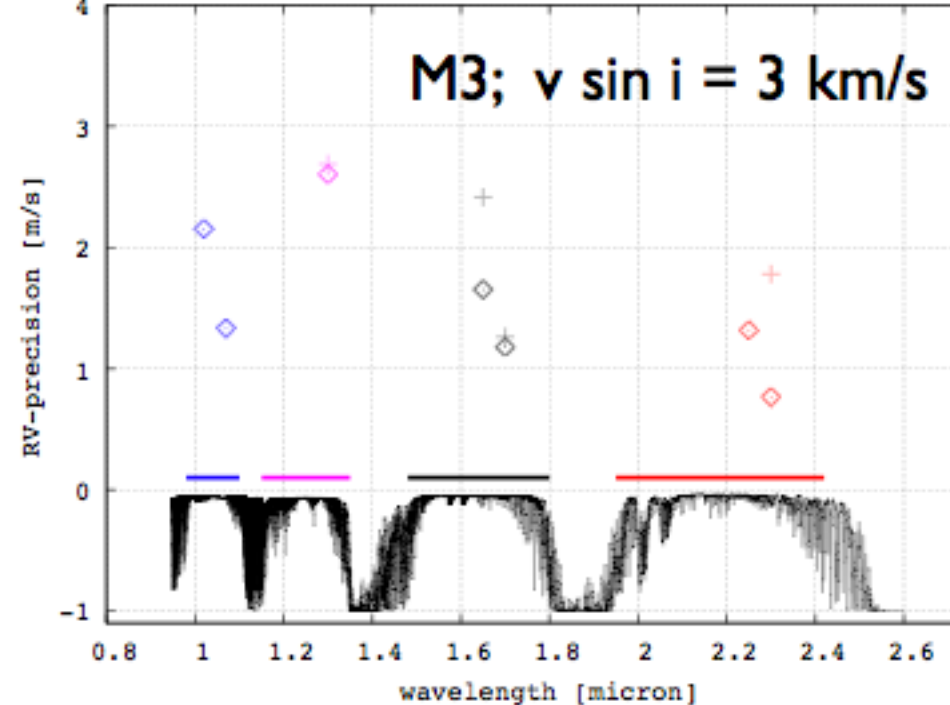
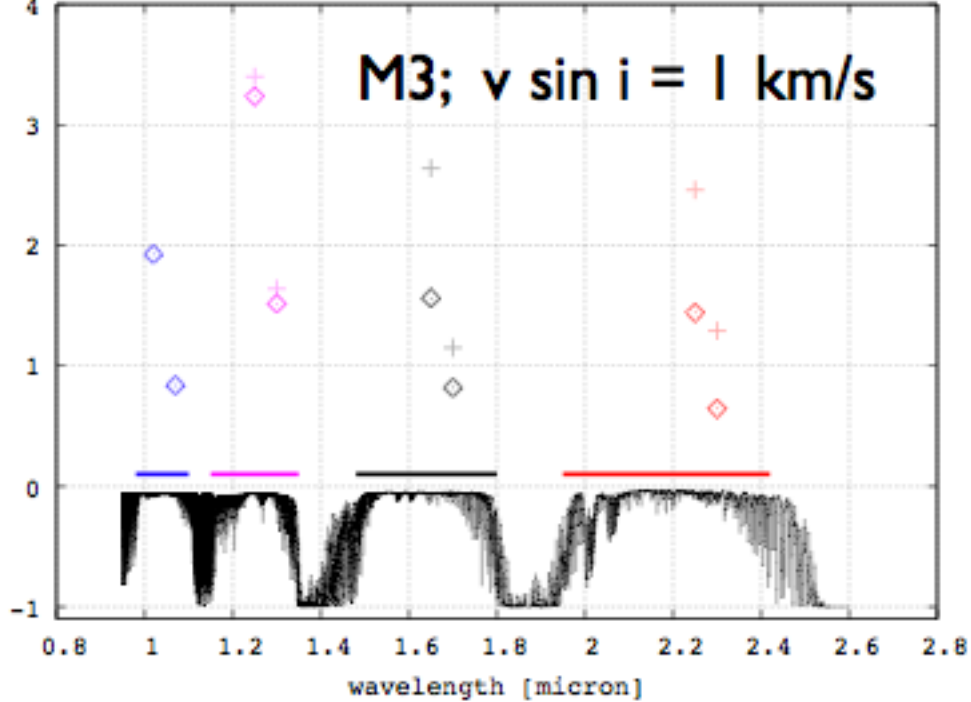




# Mid-resolution gas cell spectra



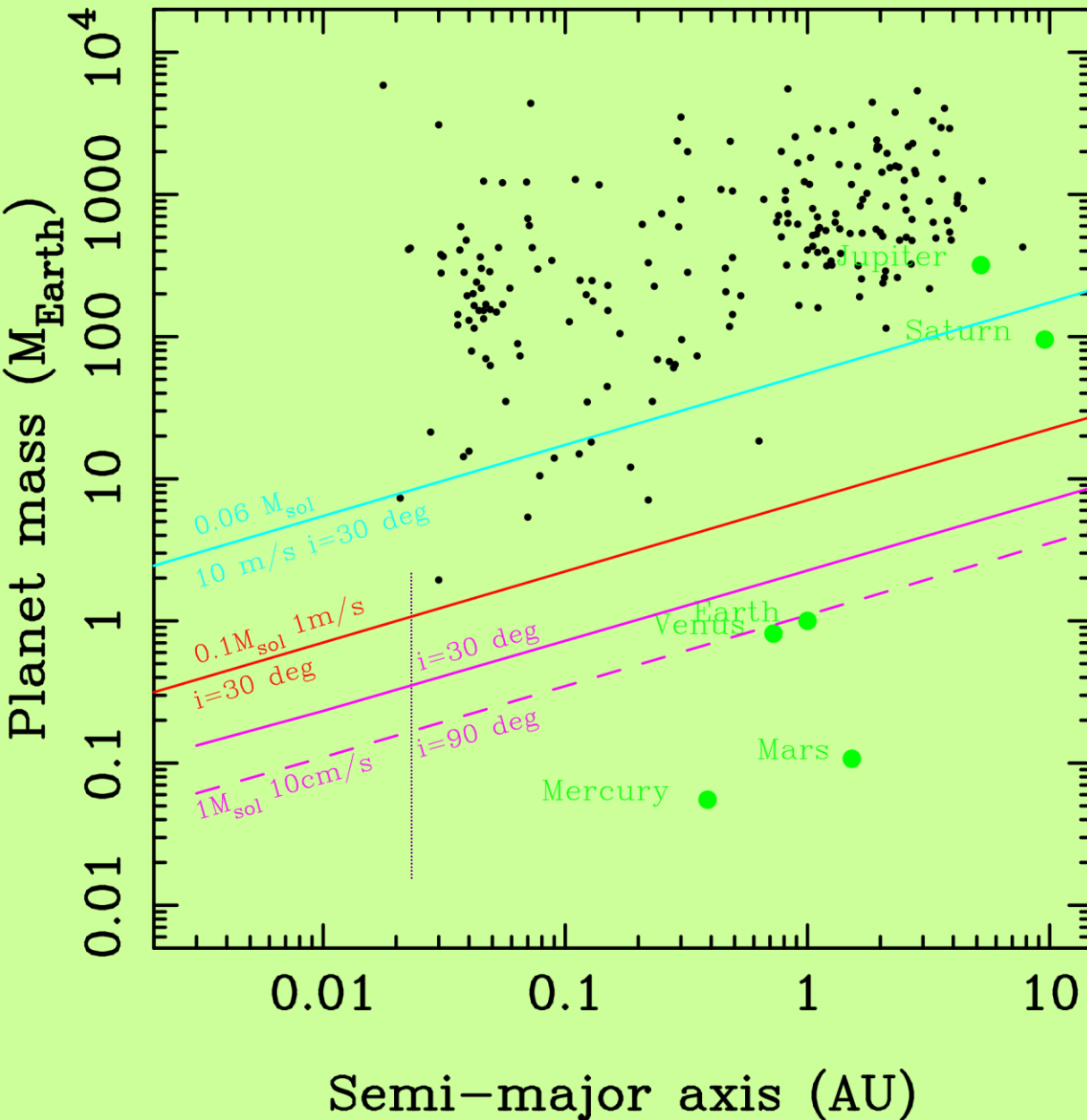
Collaboration with R. Peale group (UCF)





# NAHUAL SENSITIVITY

Figure by M.R. Zapatero Osorio



$e = 0.3$   
 $i = 30^\circ$   
Primary dM5  
Mass  $0.2 M_{\text{sol}}$

3 m/s ((3 sigma) in 300 s  
for  $K=9$  and  $D = 10$  m.

$D=40\text{m} \Rightarrow K=12-14 \Rightarrow L$  and  $T$   
dwarfs  $\Rightarrow$  **lowest mass planets**  
around the **lowest mass**  
primaries?





# Summary

- Study to consider NAHUAL as mid and high-resolution near-infrared spectrograph common-user @ GTC in 2016 approved.
- 5 years of experience and about 1 million euros of development investment as of 2009.
- NAHUAL experience is applicable to other (bigger or smaller) telescopes, such as CARMENES @ Calar Alto and the ELTs.
- Calar Alto status uncertain ...



# Crazy things happen

