

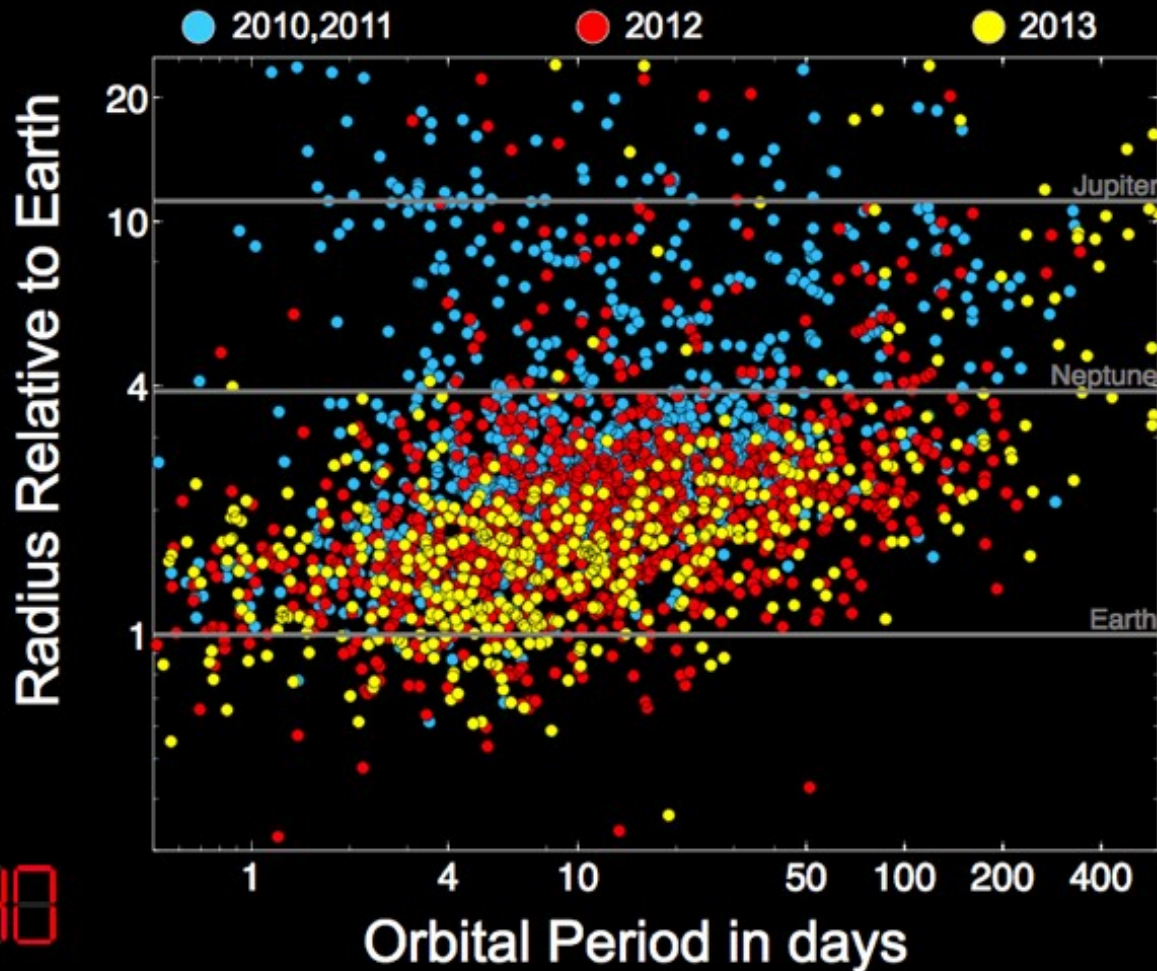


# Searching for exoplanets and understanding their stars with CARMENES

Pedro J. Amado  
and the CARMENES consortium

# “The Exoplanet Revolution”

8 to 1000 in 18 years!



2040



# From hot Jupiters to temperate super-Earths

- M stars offer a shortcut
  - M stars less luminous  $\Rightarrow$  Temperate planets are closer in (HZ at 10s of days)
  - Are easier to find for dynamical methods  $\Rightarrow$ 
    - RV signal  $\propto M^*-2/3$ ;
    - transit depth  $\propto R^*-2$
    - RV signal  $\propto a^{-1/2}$ ;
    - transit probability  $\propto a^{-1}$ ;
    - transit depth  $\propto a^{-2/3}$
  - Very numerous and nearby (75% of stars; 50% of Ms are  $< 0.2 M_{\odot}$ )

# M Dwarf Properties



$$0.07 < \text{mass} < 0.6 M_{\text{sun}}$$

G2

$$M = 1 M_{\text{sun}}$$

$$R = 1 R_{\text{sun}}$$

$$T = 5800 \text{ K}$$

M3

$$M = 0.45 M_{\text{sun}}$$

$$R = 0.45 R_{\text{sun}}$$

$$T = 3500 \text{ K}$$

M6

$$M = 0.12 M_{\text{sun}}$$

$$R = 0.18 R_{\text{sun}}$$

$$T = 2900 \text{ K}$$

Earth

--sizes to scale--

Figure credit: J. Bean

# HZ planet properties

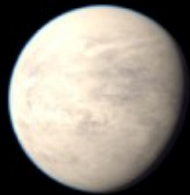


## Conservative Selection of Potentially Habitable Exoplanets

0.1 to 10 Earth Masses or 0.5 to 2.0 Earth Radii, Conservative Habitable Zone

Confirmed

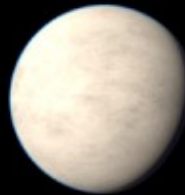
Unconfirmed



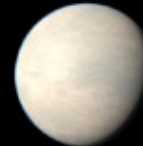
Kepler-283 c



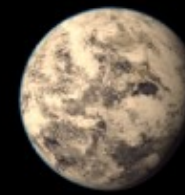
Gliese 667C f



HD 40307 g



Kepler-62 f



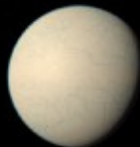
Gliese 180 c



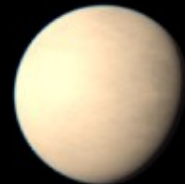
Gliese 581 g



Kepler-186 f



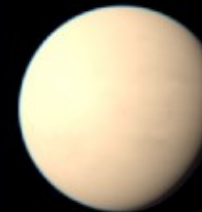
Gliese 667C e



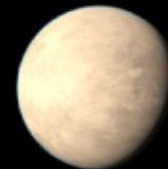
Gliese 581 d



Earth



Gliese 422 b



Gliese 682 b

# CARMENES





## Calar Alto Instrumentation Workshop

IAA-Granada, June 11-13, 2008

- Home
- Program
- Registration
- Deadlines
- Participants
- Accommodation
- Social Events
- Travel info
- Granada info

### The next generation instrument for calar Alto's 3.5m telescope

[!!NEW!! for Conference Dinner pictures click here](#)

**SOC:** J. Alves, M. Casali, M. Colless, R. García-López, T. Henning, J. Masegosa, S. Pedraz, F. Prada, D. Reimers, H.W. Rix, M. Roth, S. Sánchez, U. Thiele, S. Warren

**LOC:** J. Alves, J. Masegosa, S. Pedraz, S. Sánchez, U. Thiele

**Rationale:**

There is a growing realization that 4m class telescopes have an important role to play in frontline Astrophysical research in the beginning of the 21st century. And as always, outstanding scientific breakthroughs are associated with outstanding instrumentation. To attack the pressing scientific challenges of the day, from Extra-Solar Planets to Cosmology, Calar Alto Observatory is now searching for outstanding ideas for the next generation instrument for its flagship telescope, the 3.5m.

The presentation and discussion of ideas on the next generation instrument will take place in a workshop in Granada, 11-13 June 2008, at the Instituto de Astrofísica de Andalucía (IAA-CSIC). Following the workshop, there will be a Call for Proposals for Instruments open to the entire community. The selection of the best proposals will be done shortly after involving the Calar Alto Scientific Advisory Committee, and up to two design studies will be funded by Calar Alto.

## A high resolution multi-object spectrograph for Calar Alto

Eike Guenther, Thuringer Landessternwarte

Up to now, most infrared high resolution spectrographs have only limited spectral ranges. However, the large detector arrays that are now available allows us to built cross-

## A high-resolution near-infrared spectrograph for the CAHA 3.5-m telescope

Pedro J. Amado González, IAA

In this talk, we present a proposal for a new instrument for the 3.5m telescope at Calar Alto, Almería, Spain. This instrument will be a high-resolution near-infrared spectrograph

## Multi-Object High-Resolution Spectrograph

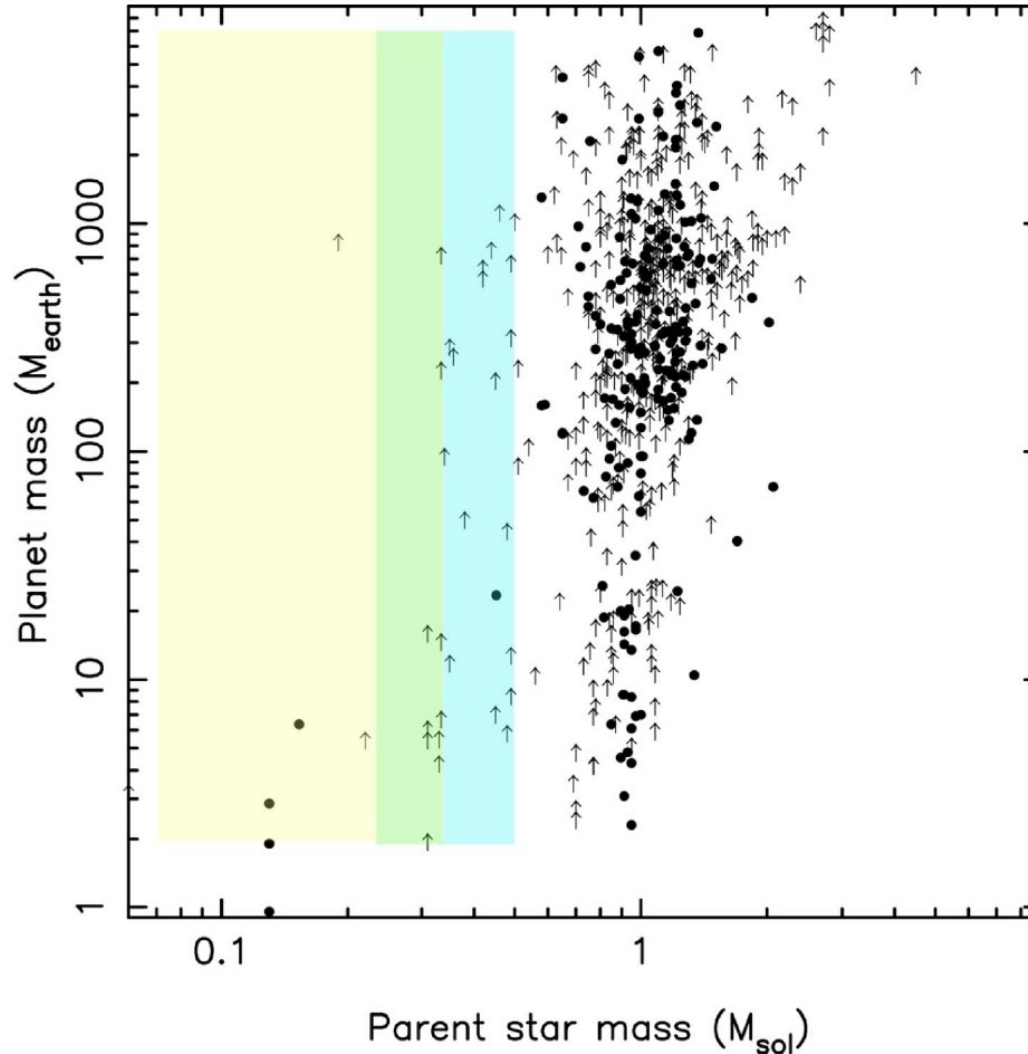
Andreas Quirrenbach, Landessternwarte Heidelberg

Scientific drivers, technical approaches, and potential consortium arrangements for the construction of a (massively?) multiplexed high-resolution spectrograph will be discussed.

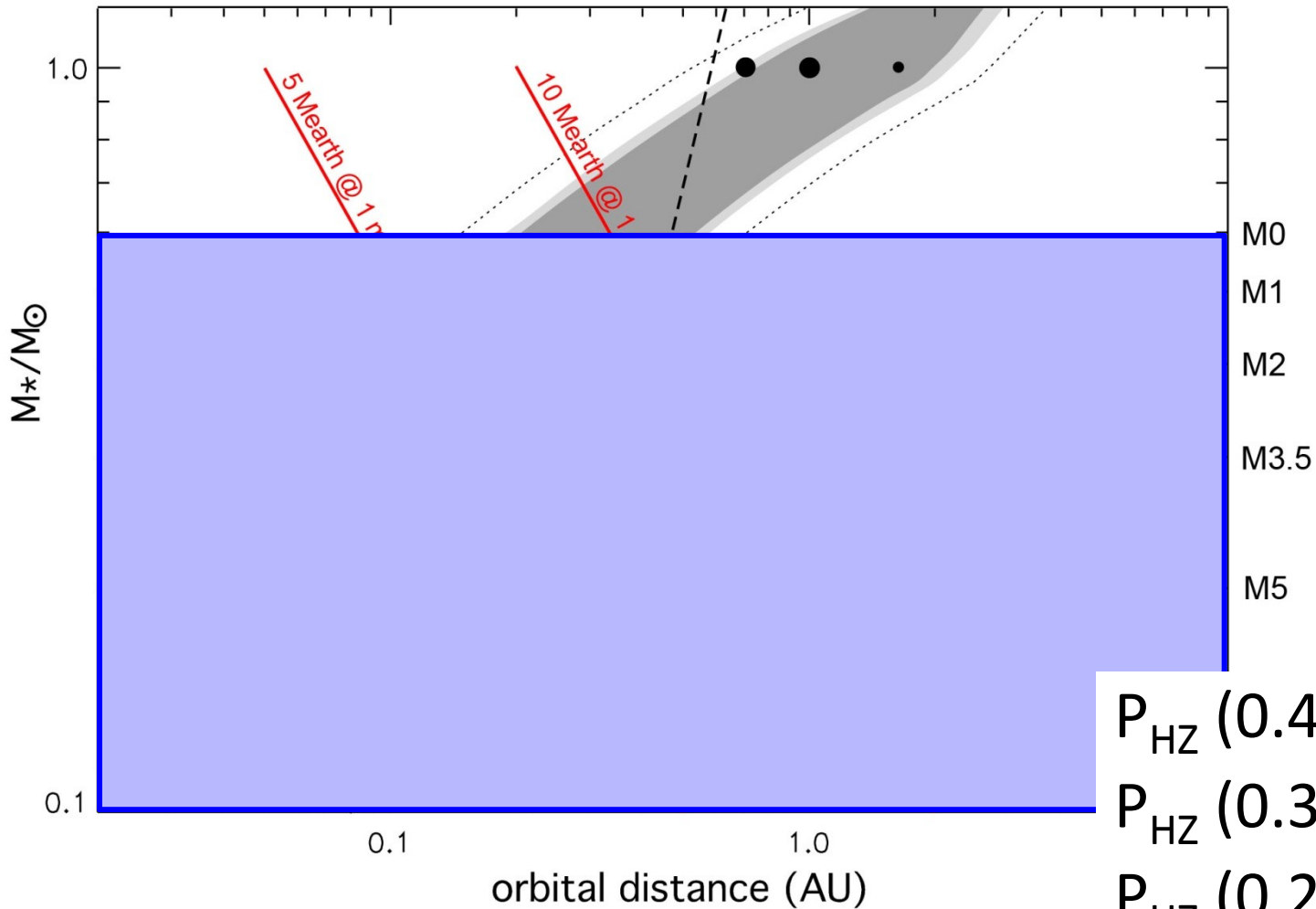


<b>Pre-selection</b>	January 2009
<b>CDR</b>	October 2009
<b>pCDR</b>	July 2010
<b>Green light</b>	November 2010
<b>PDR</b>	July 2011
<b>optics-FDR</b>	April 2012
<b>FDR</b>	February 2013
<b>MAIV</b>	2014-fall 2015
<b>First light, commissioning</b>	Spring 2015 (VIS) Fall 2015 (NIR)
<b>Start of survey</b>	End 2015
<b>End of survey</b>	End 2018

# An unexplored niche

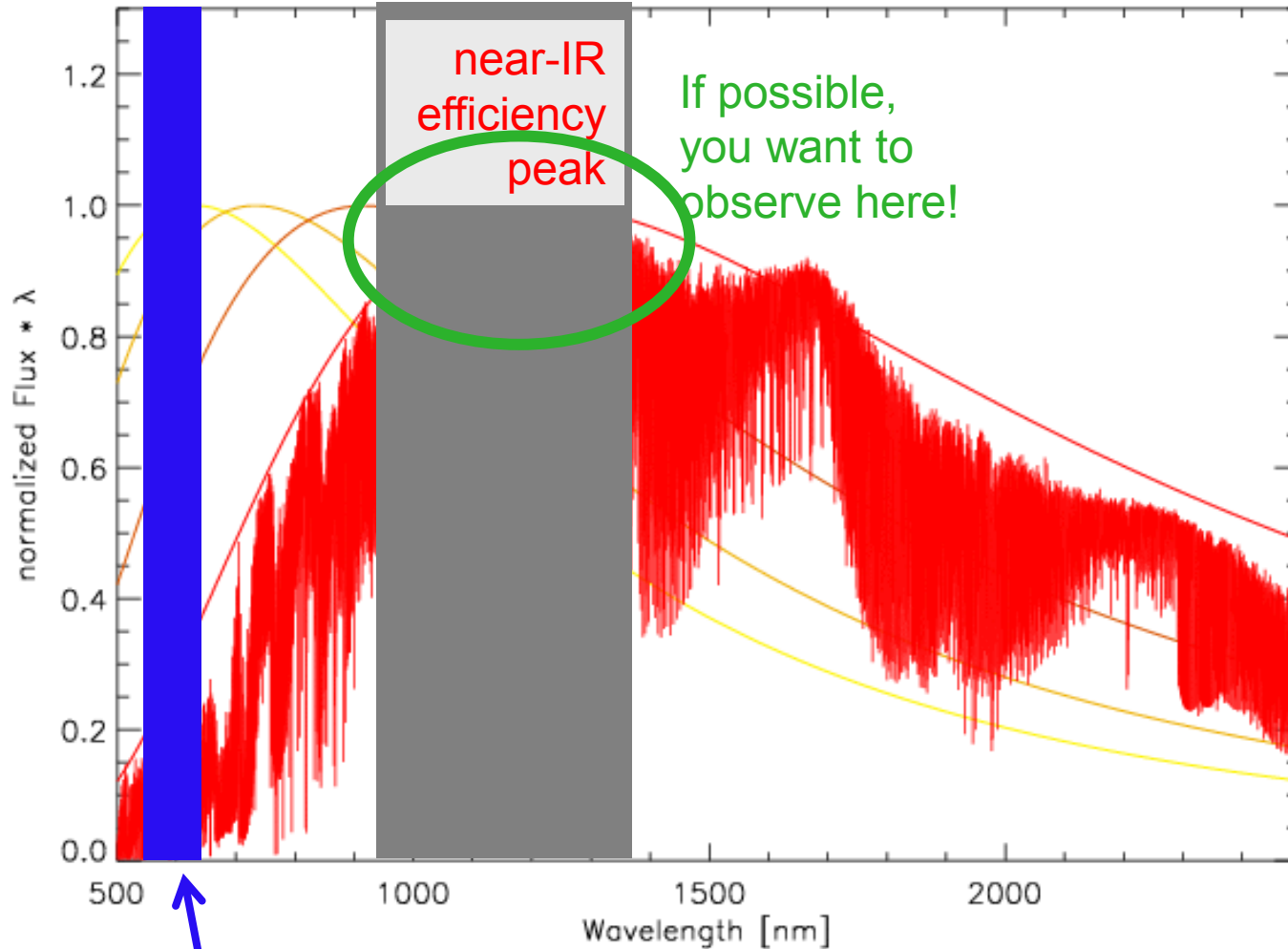


# Goal: Detecting Earth-like planets



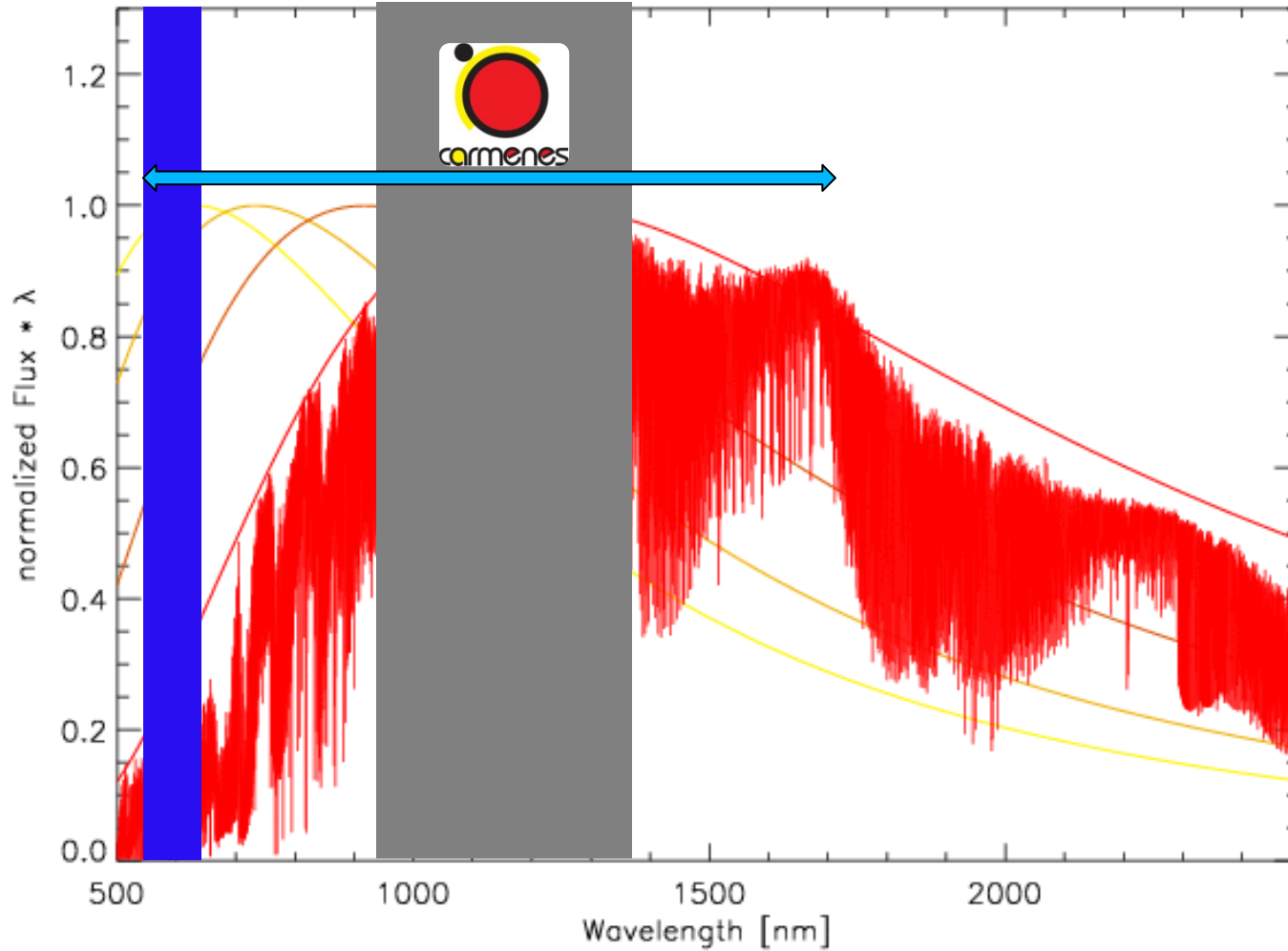
$P_{\text{HZ}} (0.4 M_\odot) \sim 25 \text{ d}$   
 $P_{\text{HZ}} (0.3 M_\odot) \sim 18 \text{ d}$   
 $P_{\text{HZ}} (0.2 M_\odot) \sim 12 \text{ d}$

# The SED of M-type stars



"classical" *visible light* RV instruments

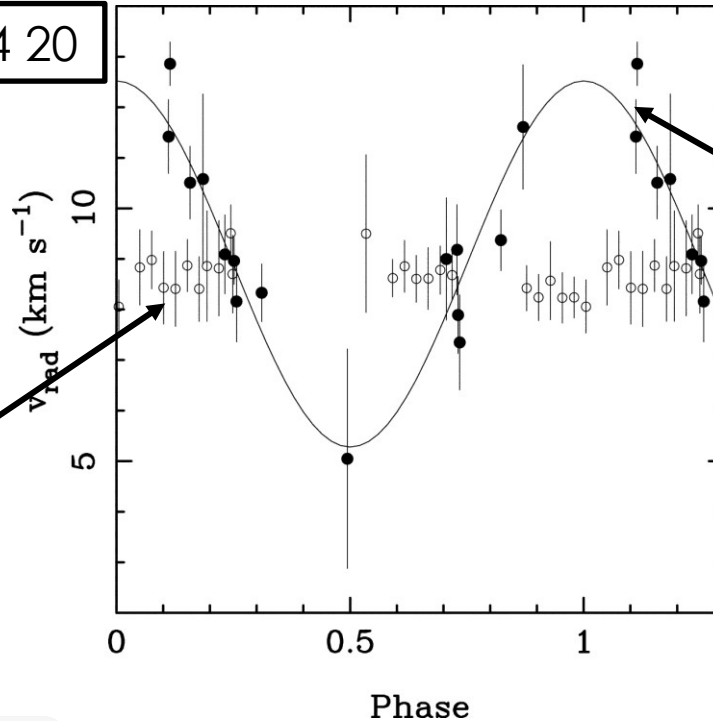
# Instrument capability: Large wavelength coverage



# Instrument capability: VIS+NIR



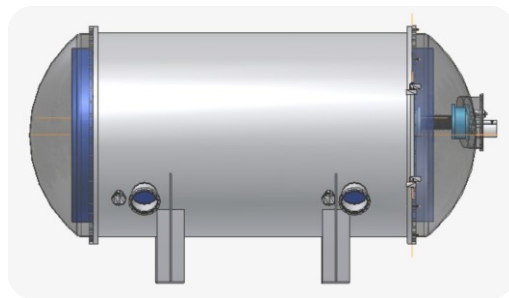
Active M9 Dwarf LP-944 20



UVES (visual)

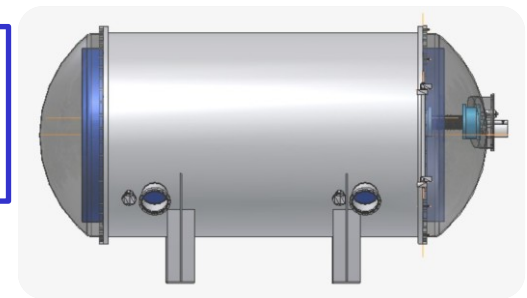
NIRSPEC (NIR)

(Martin et al. 2006)



NIR Channel

To characterize  
type of variability



VIS Channel



# The CARMENES instrument

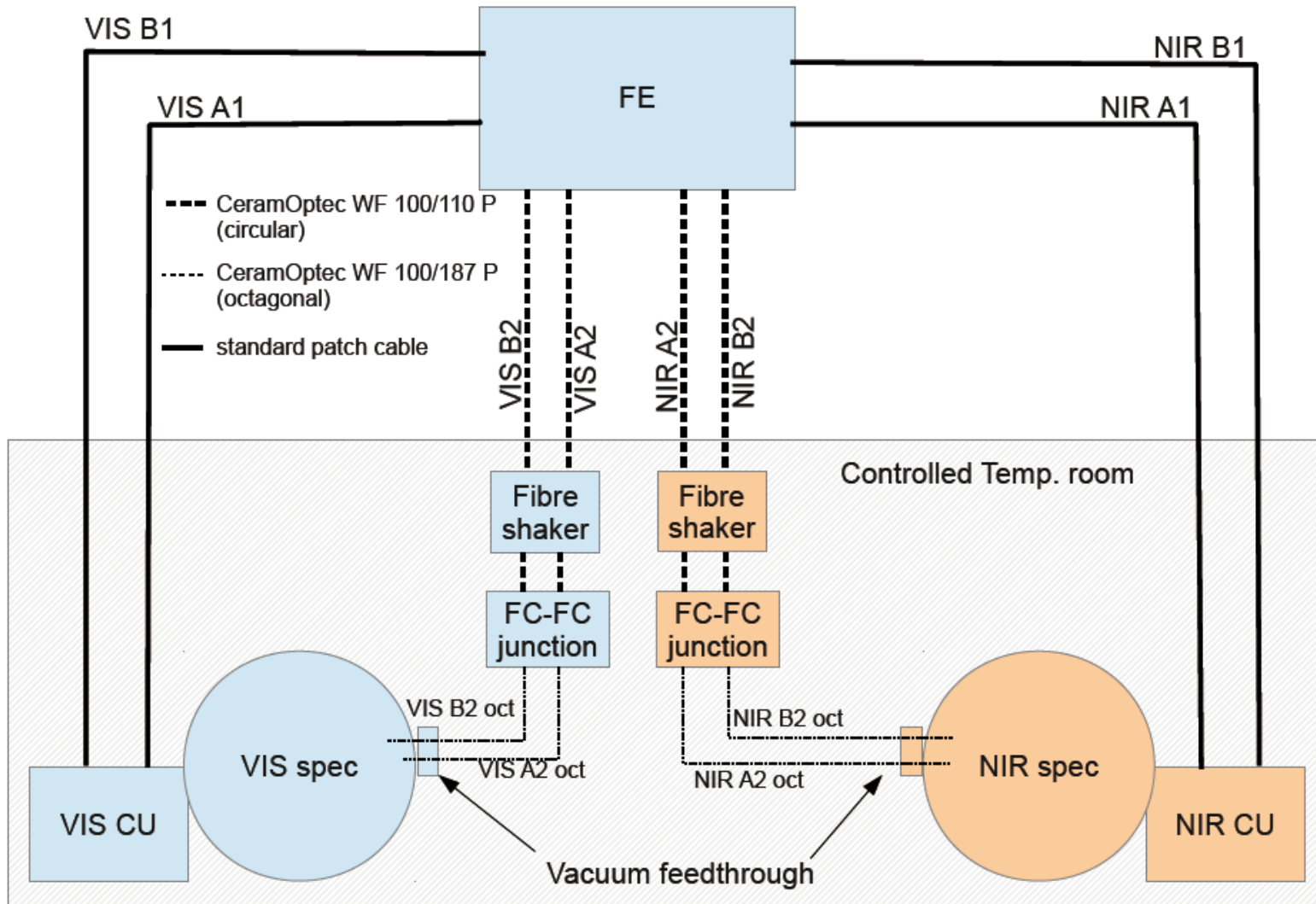


Single-purpose, high-stability instrument

- Precision requirement  $\sim 1$  m/s (goal for NIR)

<b>Basic engineering parameters</b>	<b>NIR channel</b>	<b>VIS channel</b>
<b><math>\Delta\lambda</math> [nm]</b>	950-1700 (29 orders)	550-950 (53 orders)
<b>Cross disperser</b>	Grism, infrasil	Grism, LF5 glass
<b>Working T [K]</b>	$\sim 140$	$\sim 295$
<b>Detector(s)</b>	2 x 2kx2k Hawaii 2-RG (2.5 $\mu\text{m}$ )	1 x 4kx4k e2v CCD231-84
<b>Calibration <math>\lambda</math></b>	U-Ne [F-P etalon]	Th-Ar-Ne [F-P etalon]
<b>Optical parameters</b>	Fixed $R=82,000$ , 2.8-pix sampling ( $>2.3$ pix), 7-pix inter-fibre spacing	

# The CARMENES instrument



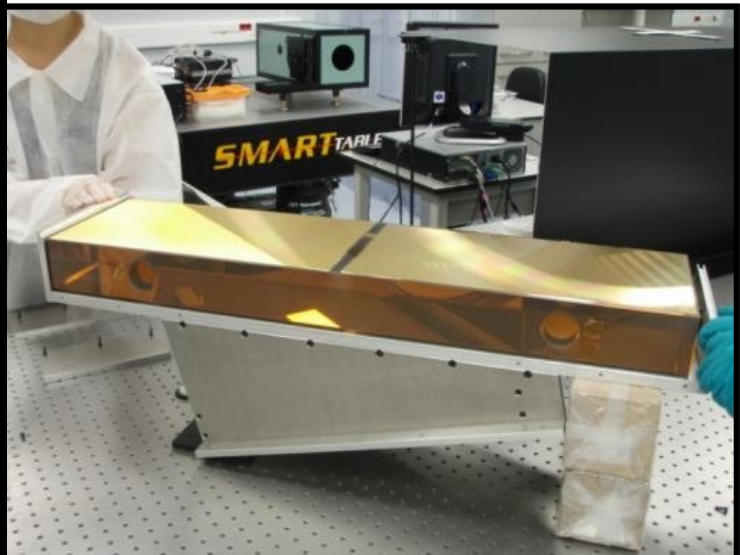
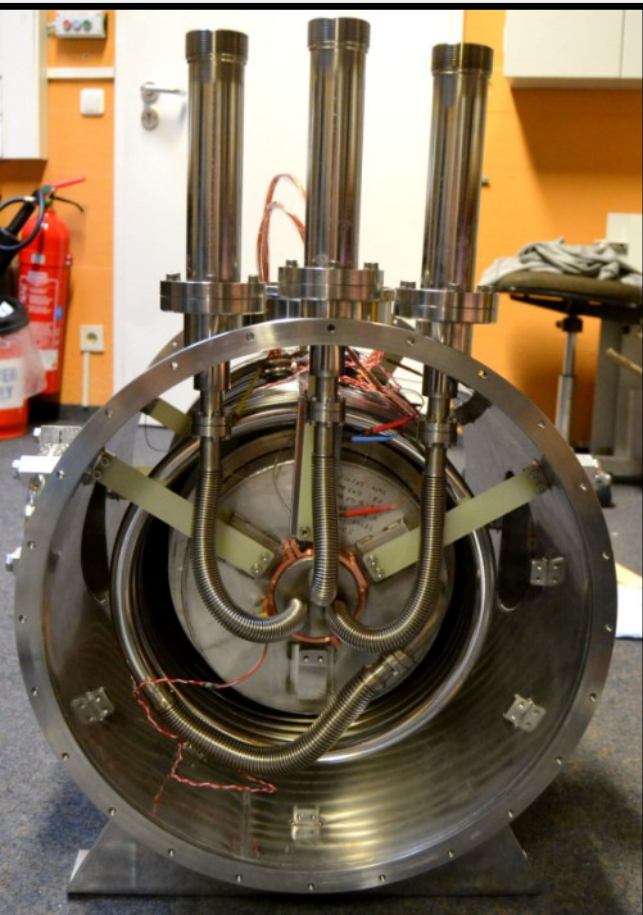
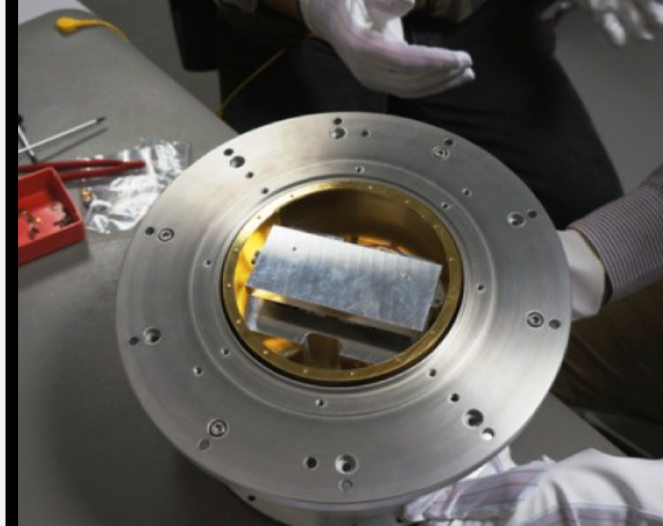
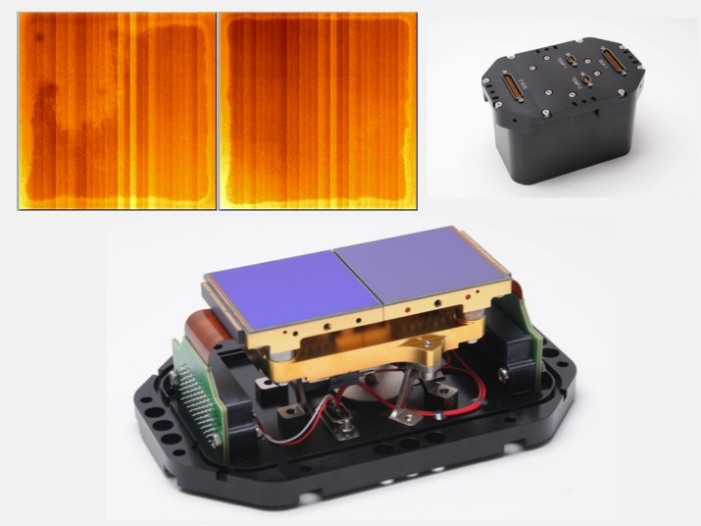
# CARMENES at CAHA



CCD (DLR)



Calar Alto



# Project schedule



- **Pre-selection:** *Jan 2009*
- **CDR** (Conceptual Design Review): *Oct 2009*
- **pCDR** (post-CDR): *July 2010*
- **Green light:** *Nov 2010*
- **PDR** (Preliminary Design Review): *July 2011*
- **oFDR** (optics Final Design Review): *Apr 2012*
- **FDR** (Final Design Review): *Feb 2013*
- **MAIV:** *now...*
- **First light, commissioning:** Spring 2015 (VIS), Fall 2015 (NIR)
- **Start survey:** End 2015

# Primary science objective



Carry out a survey of 300 late-type main sequence stars with the goal of detecting low-mass planets (50-100) in their habitable zones (a few transiting!)



Focus on very cool stars with spectral types later than M4V and moderately active stars (VIS+NIR spectrographs)  $\Rightarrow$  Milestone:  $2 M_{\oplus}$  planet in the habitable zone of an M5V star



*Bonus:* Very nearby stars  $\Rightarrow$  Further characterization of planets

# CARMENES survey: target selection



- Our fiducial value is  $SNR=150$  at  $J=9$
- We define slightly *different magnitude cuts* at different spectral types
- Given the expected signals, *SNR requirements can be relaxed for later spectral types*

- This is reflected in the CARMENCITA database, where all the information is centralized
- Collected catalog data from a variety of sources: PMSU, RECONS, literature, ...

Spectral type	J
M0	<7.0
M1	<7.5
M2	<8.0
M3	<8.5
M4	<9.0
M5	<9.5
$\geq M6$	<10.0

# Science preparation



- Need to determine stellar properties a priori to optimize survey ↔ CARMENCITA database
- Critical information:
  - Teff & SpTyp
  - NIR & VIS photometry
  - Distance
  - Multiplicity
  - $v \sin i$
  - Activity
- Non-critical info: kinematics, abundances, age, variability, and additional activity indicators

# Asteroseismology of M dwarfs



Exciting mechanisms: Epsilon mechanism, Flux blocking by convection, Stochastic (?)

# Asteroseismology of M dwarfs



Exciting mechanisms: Epsilon mechanism, Flux blocking by convection, Stochastic (?)

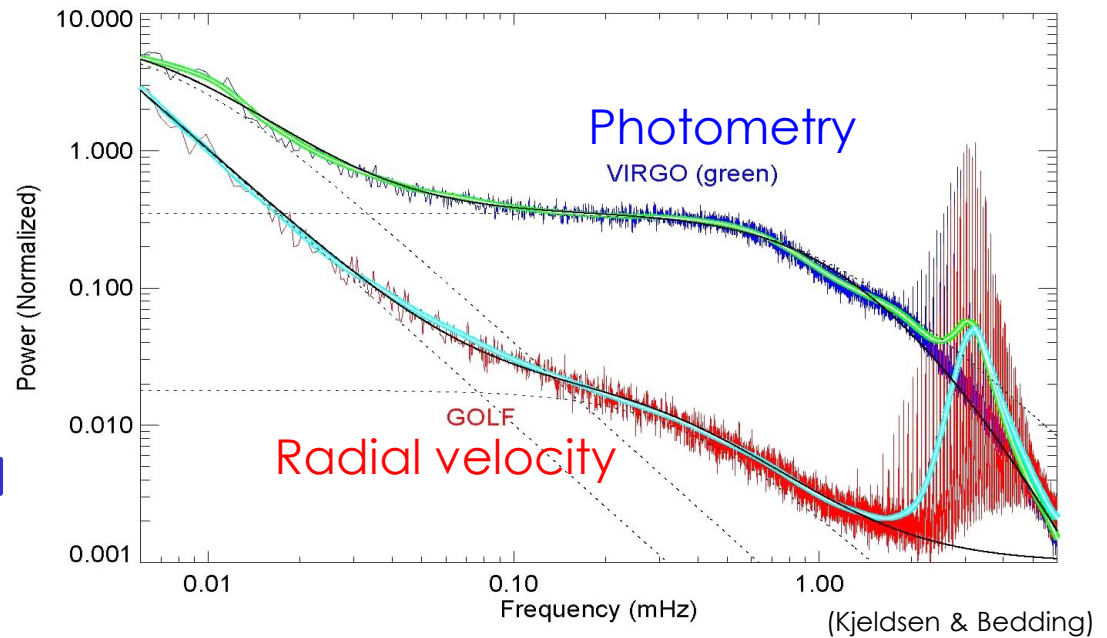
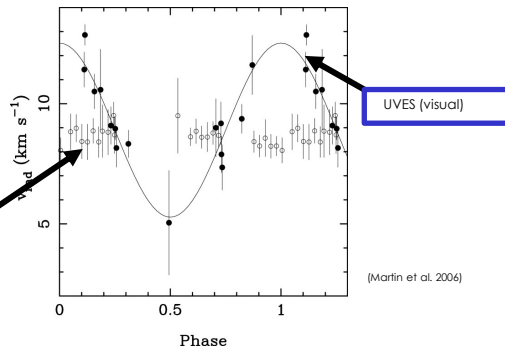
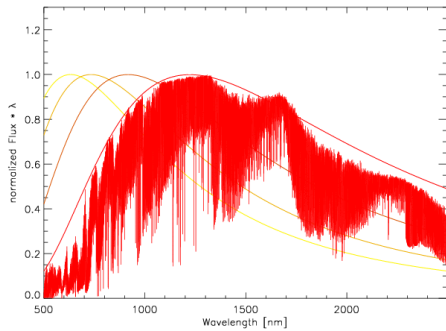
$\epsilon$  mechanism & Flux blocking by convection  
Rodríguez-López et al. (2012, 2014)

Mass ( $M_{\odot}$ )	$P$	Excit. mechan.	Comments	e-fold < age
0.10–0.40	4–11 h	$\epsilon$ (D)	Age $\lesssim$ 2 Myr	$\times$
0.40–0.60	1–2 h	F-b	Age $\leq$ 50 Myr	$\times$
	1–3 h	F-b, $\epsilon$ ( $\text{He}^3$ )	g-modes	$\checkmark$
0.20–0.30	20–30 min	$\epsilon$ ( $\text{He}^3$ )		$\checkmark$
0.35–0.60	20–60 min	F-b		$\checkmark$

# Observations of oscillations in M dwarfs



## Velocity vs. Intensity observations

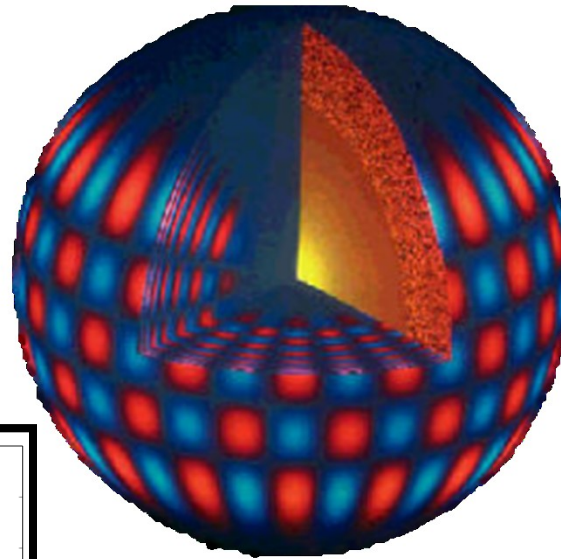


Stellar granulation noise larger in intensity than in velocity -> RVs more efficient than photometry for detection.

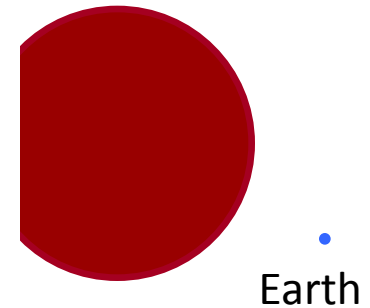
# Oscillations in M dwarfs: First results?



$0.07 < \text{mass} < 0.6 M_{\text{sun}}$

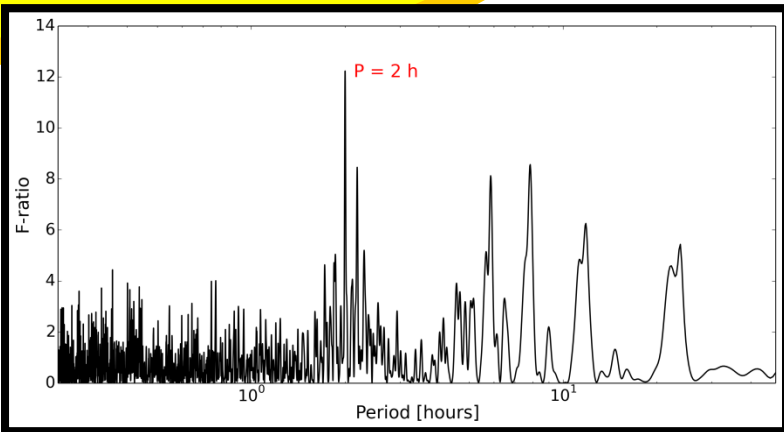


M6  
 $M = 0.12 M_{\text{sun}}$   
 $R = 0.18 R_{\text{sun}}$   
 $T = 2900 \text{ K}$



--sizes to scale--

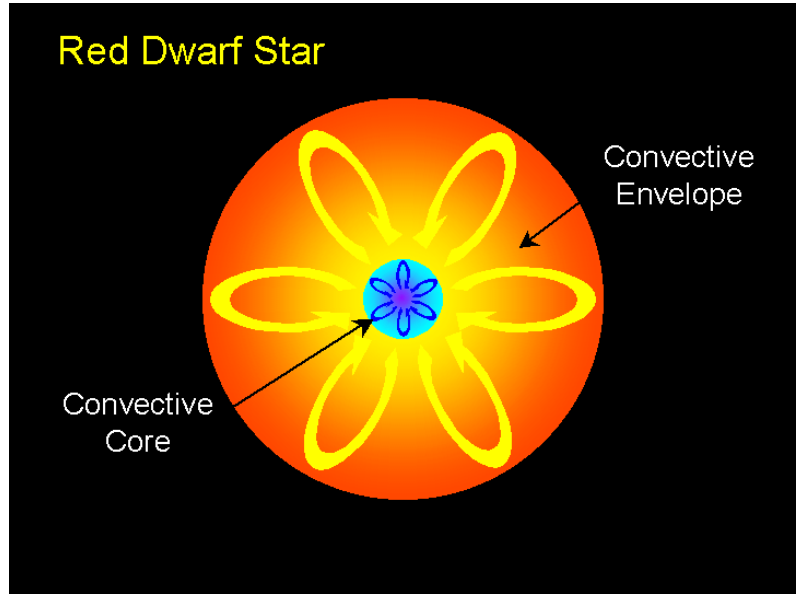
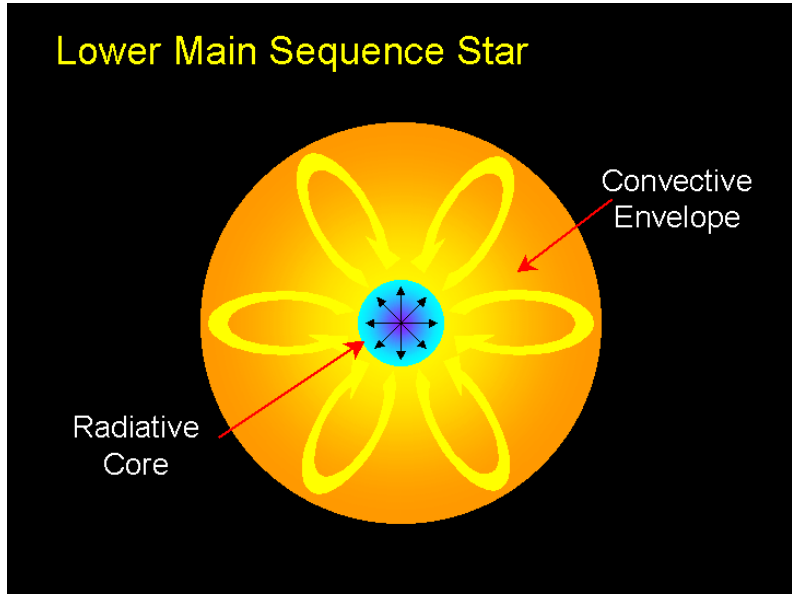
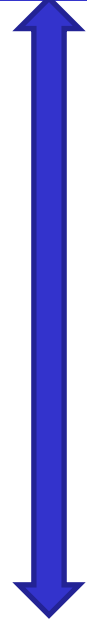
$M = 0.45 M_{\text{sun}}$   
 $R = 0.45 R_{\text{sun}}$   
 $T = 3500 \text{ K}$   
 $P \sim 2 \text{ h}$



# Implications: Internal structure

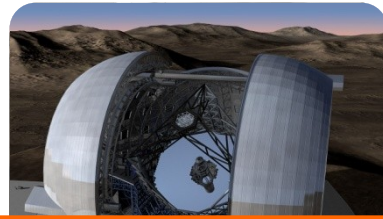


Spectral type  
M3.5?

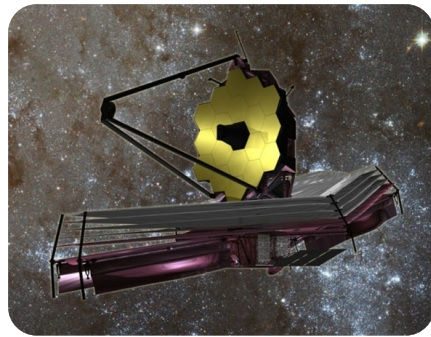


**Pulsations will help determining the frontier between partially- and fully-convective structure in M dwarfs**

# Conclusions



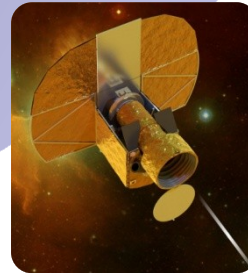
**But the future is even more exciting!**



**2018**



**2016**



**2014**



**2012**



**We have come a long way in a short time...**