Blue Planets Orbiting Red Dwarfs

Andreas Quirrenbach and the CARMENES Consortium
CARMENES – the Acronym

- Calar Alto
- High-Resolution Search for
- M Dwarfs with
- Exo-Earths
- With Near-Infrared and Optical
- Echelle Spectrographs
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

- \( P_{\text{HZ}} (0.4 \, M_\odot) = 25 \, \text{d} \)
- \( P_{\text{HZ}} (0.3 \, M_\odot) = 18 \, \text{d} \)
- \( P_{\text{HZ}} (0.2 \, M_\odot) = 12 \, \text{d} \)
A New Niche
The SED of M-Type Stars

If possible, you want to observe here!

“classical” visible light RV instruments
PHOENIX models
Rotation of M Stars and Brown Dwarfs

Reiners & Basri, 2008
Precision Achievable for Different Rotational Velocities

accuracy [m/s]

vsini [km/s]

R = 20000
R = 60000
R = 80000
R = 100000
Relative Precision Achievable for M4 Star in Visible and Near-IR

![Graph showing relative precision for M4 Star in Visible and Near-IR](image)
Let’s Talk About \( j \)itter

RV curve of the active M9 dwarf LP-944 20

Martin et al. 2006

UVES (visual)

NIRSPEC (nIR)
Observing Strategy

- Start with a larger sample of ~600 stars
- Pre-cleaning (echelle spectra, active stars, fast rotators, binaries) \(\Rightarrow\) 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)
  \(\Rightarrow\) 22500 measurements
- Time: 15 min + overhead \(\Rightarrow\) 3.5 measurements/hour
  \(\Rightarrow\) 30 measurements/night \(\Rightarrow\) 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)

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

$\langle d_{S1+S2+S3} \rangle = 13 \, \text{pc}$
Scientific Preparation: Input
Catalog and pre-Observations
Detectability Simulations

![Graph showing detectable planet mass in HZ vs. stellar mass for different spectral types. The graph includes data points for various spectral types (M0-M7), with each point color-coded by $v_{\text{sin}i}$ (km/s). The graph also shows trends for different velocity offsets (1 m/s and 10 m/s).]
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

CalUnit

NIR Spectrograph

VIS Spectrograph

XPM
Instrument Location

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

• Optical spectrograph
  – 0.53 … 1.05 $\mu$m, $R = 82,000$
  – Precision $\sim 1$ m/s
  – Vacuum tank, temperature stabilized
  – 4k x 4k deep depletion CCD detector

• Near-Infrared spectrograph
  – 0.95 … 1.7 $\mu$m, $R = 82,000$
  – Vacuum tank, cooled to 140K, stabilized
  – Precision goal 1 m/s
  – Two 2k x 2k Hawaii 2.5 $\mu$m detectors
The NIR Requirements Dilemma

• We want:
  – High resolution
  – Good sampling (Nyquist)
  – Large wavelength coverage (0.95…1.7 μm)
  – 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)

- N2 gas out
- LN2 in
- Vacuum Vessel
- Evacuation Port
- Sorption Pump
- Final Heat Exchanger
- Intermediate Exchanger
- Evaporator Unit
Front End Layout

VIS fiber head

NIR fiber head

Double ADC
Calibration: Wavelength Reference

- Hollow cathode lamps for daily and master calibrations

(Kerber et al. 2008)

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 0\textsuperscript{th} order from \textit{échelle}

Fiber link to Hamamatsu PMTs located outside the instrument vessel
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