Observing short-period binaries with FORS

possibilities and challenges

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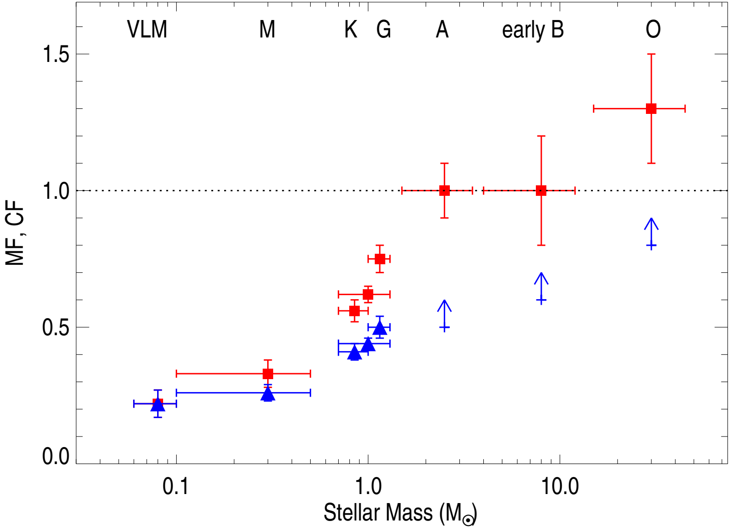
20 years FORS

12.03.19

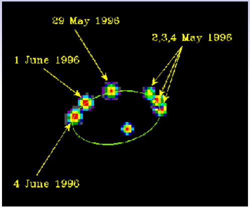
Many stars have companions

Duchene & Kraus 2013



→ stellar evolution cannot be understood without understanding binary evolution

Types of binaries



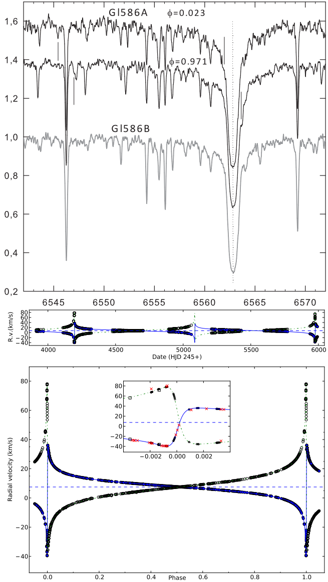
J. Benson et al.

- visual binaries: bound system that can be resolved into multiple stars (e.g., Mizar); can image orbital motion (astrometric binary), periods typically 1 year to several 1000 years.
- spectroscopic binaries: bound systems, cannot resolve image into multiple stars; often short periods (hours. . . months).
- eclipsing binaries: two stars regularly pass in front of one another causing them to dim in brightness as one star blocks the light of its companion. Often in spectroscopic binaries.

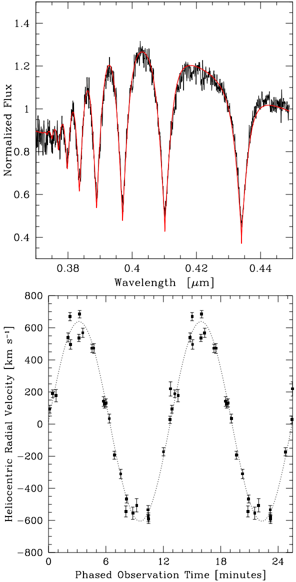
Observing spectroscopic binaries

Period and mass ratio or mass function from the RV curve

Strassmeier et al. 2013



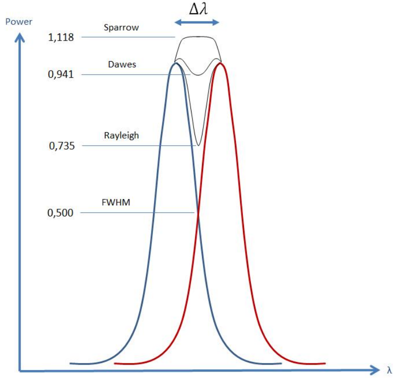
Brown et al. 2011



Requirements for observing radial velocity curves

Spectrograph with

- high resolution
  → ideally $R \gtrsim 100\,000$

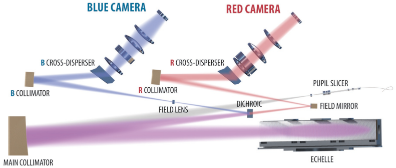


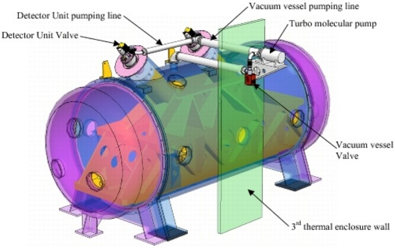
$$R = \frac{\lambda}{\Delta\lambda}$$

Requirements for observing radial velocity curves

Spectrograph with

- high resolution
- high wavelength stability



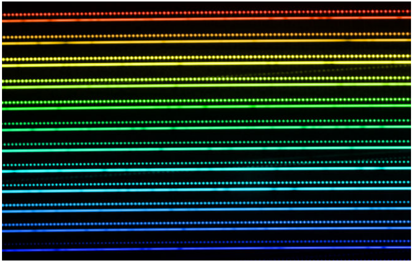


ESPRESSO

Requirements for observing radial velocity curves

Spectrograph with

- high resolution
- high wavelength stability
- excellent wavelength calibration

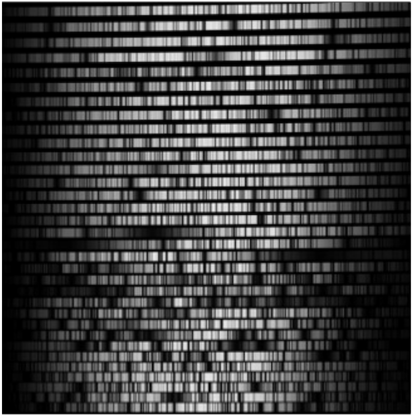


Laser frequency comb

Requirements for observing radial velocity curves

Spectrograph with

- high resolution
- high wavelength stability
- excellent wavelength calibration
- large wavelength coverage
  → ideally 3500-8000 Å

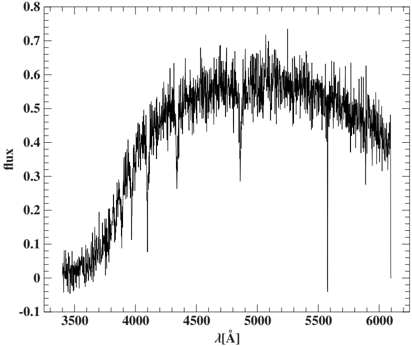


$$\sigma_{\mathrm{N\,lines}} = \frac{\sigma_{\mathrm{1\,line}}}{\sqrt{N_{\mathrm{lines}}}}$$

Requirements for observing radial velocity curves

Spectrograph with

- high resolution
- high wavelength stability
- excellent wavelength calibration
- large wavelength coverage
- high S/N



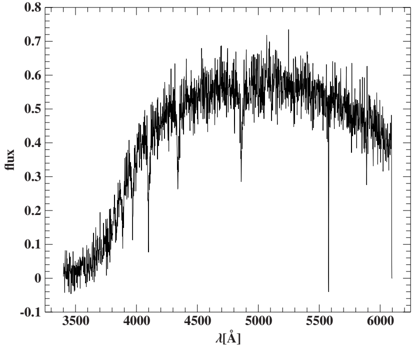
FORS spectrum of OGLE-GD-ECL-10384

$$S/N \sim t_{\mathrm{exp}}^2$$

Requirements for observing radial velocity curves

FORS with

- high resolution
  $R = 780/1420$ ✗
- high wavelength stability
  flexure,... ✗
- excellent wavelength calibration
  no arcs during the night ✗
- large wavelength coverage
  3500/3750 – 6250/5200 ✗
- high S/N

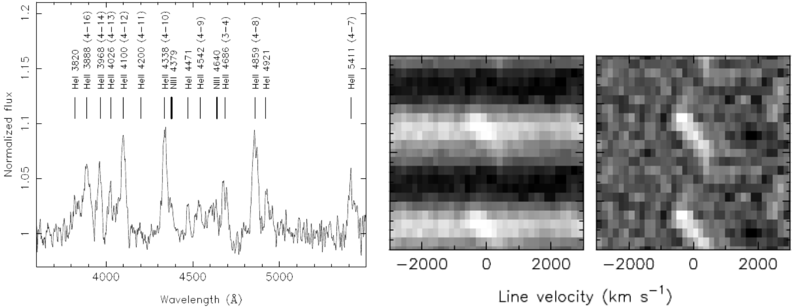


FORS spectrum of OGLE-GD-ECL-10384

$$S/N \sim t_{\rm exp}^2$$

Ultra-compact binaries

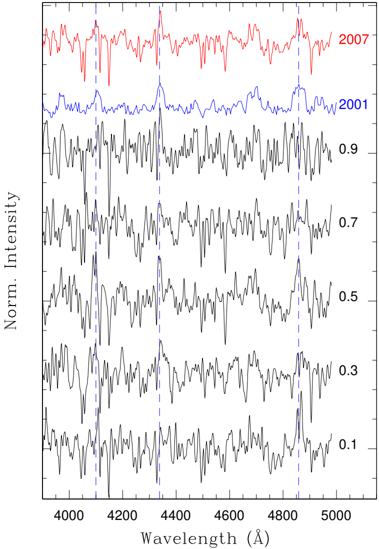
The record holder: **HM Cancri** – A 20 mag 5.4 min interacting binary white dwarf



Roelofs et al. 2010

Ultra-compact binaries

The record holder: **HM Cancri** – A 20 mag 5.4 min interacting binary white dwarf



Mason et al. 2010

However, it has a large RV amplitude!

short period and faint system

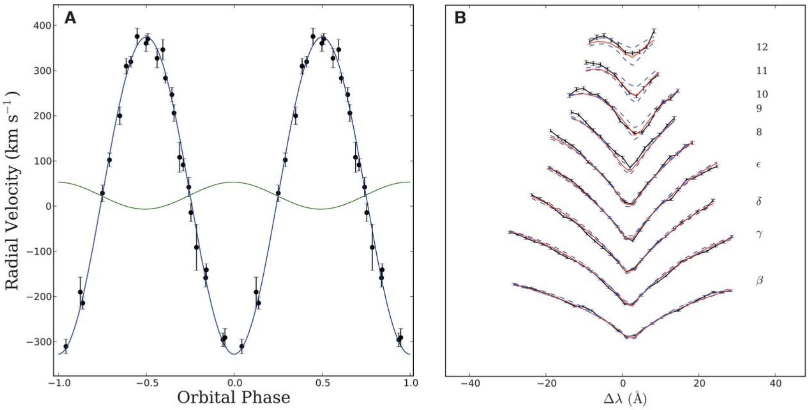
→ exposure time very limited

We need a

- large telescope
- lower resolution
- several orbits

Observed close binaries with FORS

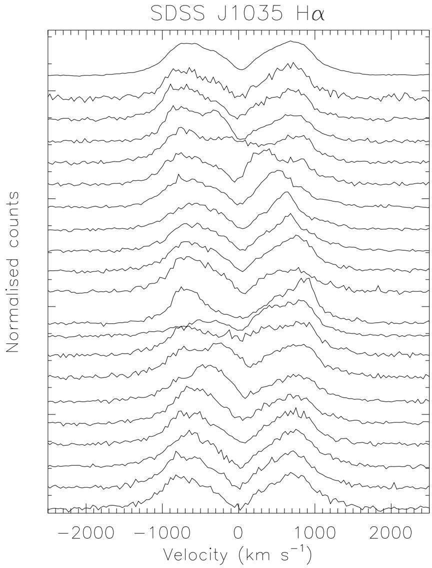
PSR J0348+0432 – A pulsar-white dwarf binary with a 2.46 h orbit

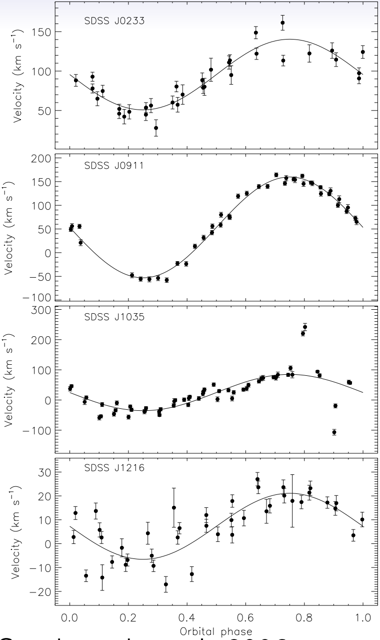


Antoniadis et al. 2013, Science

Observed close binaries with FORS

Cataclysmic variables

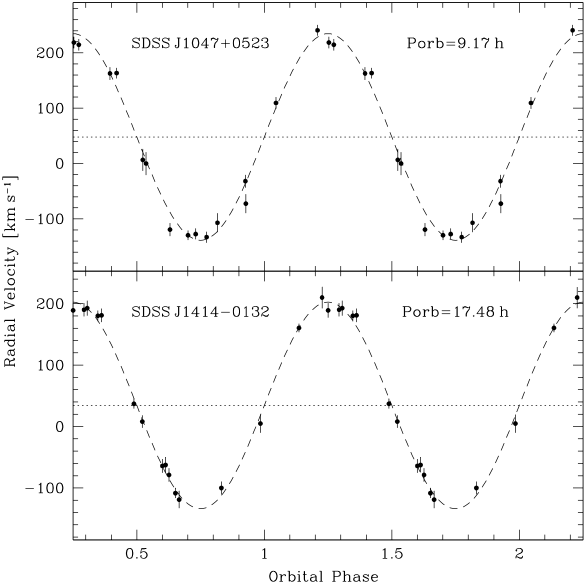




Southworth et al. 2006

Observed close binaries with FORS

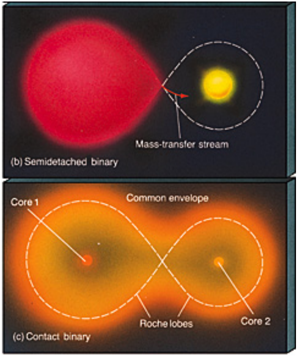
White dwarf + main sequence binaries



Schreiber et al. 2008

Close binaries

→ interaction between components at least once in their lifetime (mostly mass transfer on the red giant branch)



- mass ratio $q = \frac{M_2}{M_1} > 0.67 - 0.83$:
  stable mass transfer
  → Roche lobe overflow

- for $q < 0.67 - 0.83$:
  unstable mass transfer
  → orbit shrinks significantly
  → envelope is ejected by potential energy transfered to envelope

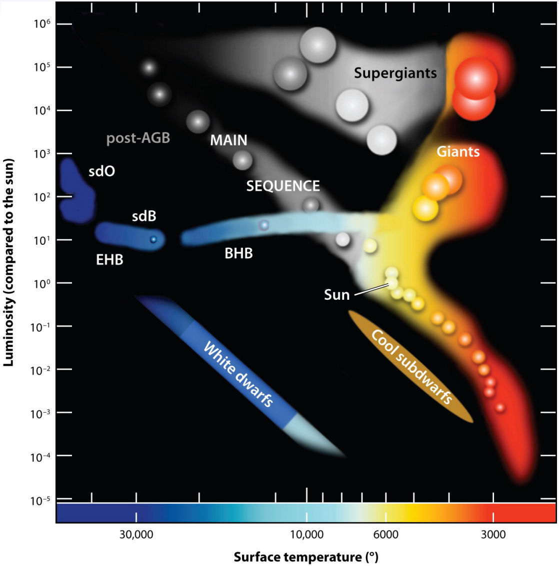
http://lifeng.lamost.org/courses/astrotoday/CHAISSON/AT320/HTML/AT32006.HTM

Common Envelope Evolution

Ohlmann et al. 2016

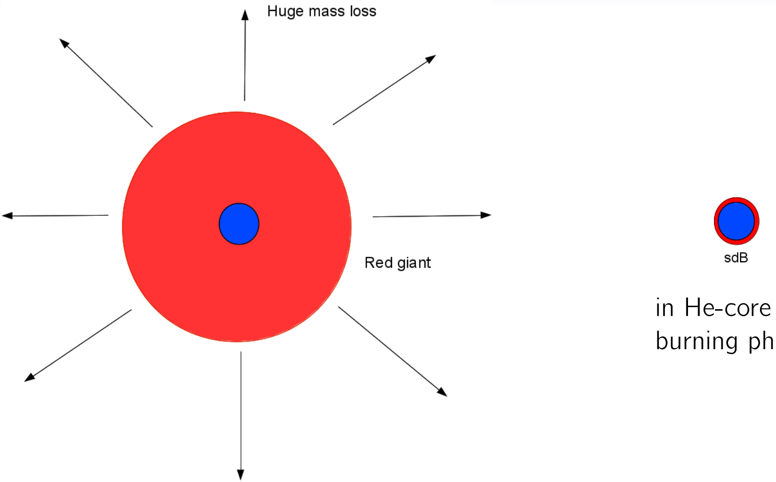
- poorly understood
- very short-lived phase
- observations of post-common envelope systems necessary

Hot subdwarf stars of spectral type B (sdB)



Heber U. 2009.
Annu. Rev. Astron. Astrophys. 47:211–51

Stripped red giant at the tip of the RGB

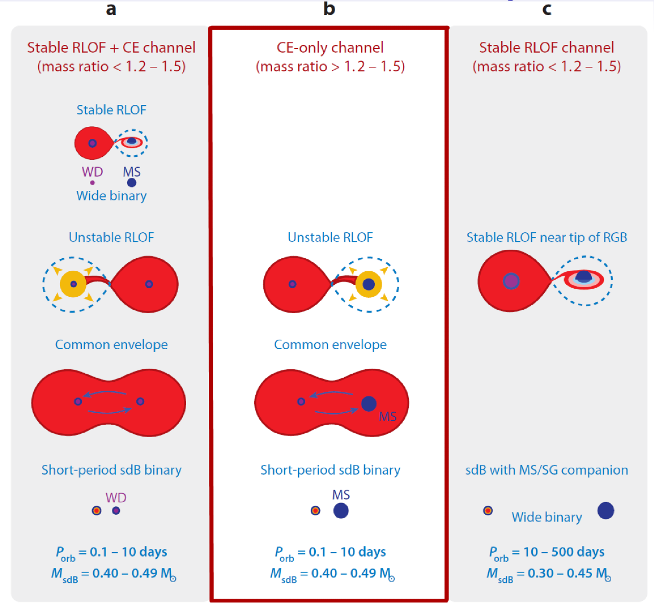


in He-core burning phase

direct observation, e.g., Maxted, .., Schaffenroth 2013, Nature

drawing is not in scale

Formation of sdB binary

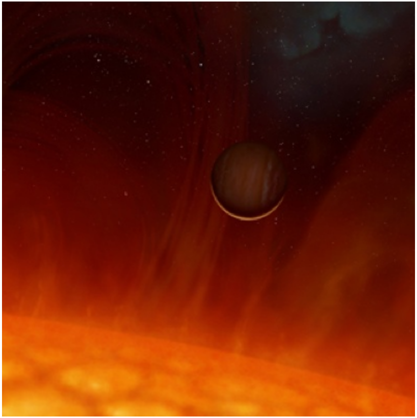


Han et al. (2002,2003)

Formation of sdBs by substellar objects

Soker 1998 AJ

- Orbit of planet in envelope of evolved star
- fate of planet:
  - evaporation
  - merger with the core
  - survival for $\geqslant 10 M_{\mathrm{Jupiter}}$ depending on separation
    $\rightarrow$ ejection of envelope



$\rightarrow$ **studying the influence of planets on stellar evolution**

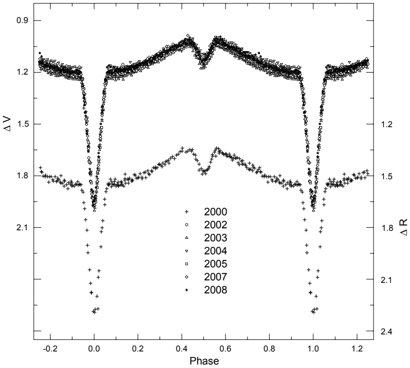
Confirmed substellar objects around sdB stars

- **J082053** (Geier, Schaffenroth et al. 2011):
  K = 47 km/s, P = 0.096 d, $M_2 = 0.045 - 0.068 M_\odot$
- **J162256** (Schaffenroth et al. 2014):
  K = 47.2 km/s, P = 0.070 d, $M_2 = 0.064 M_\odot$
- **V2008**(Schaffenroth et al. 2015):
  K = 54.6 km/s, P = 0.065817 d, $M_2 = 0.069 M_\odot$
- Two reflection effect binaries (Schaffenroth et al. 2014)
  CPD-64 481:
  K = 23.8 km/s P = 0.2772 d, $M_2 > 0.048 M_\odot$
  PHL 457:
  K = 13.0 km/s P = 0.3131 d, $M_2 > 0.027 M_\odot$

HW Virginis systems

eclipsing binaries consisting of **sdB and cool, low mass stellar or substellar companion**

- 20 HW Vir systems published
- very short period $\sim$ 1.5-6 h (separation $\sim 0.5 - 1\, R_{\odot}$)
  - $\Rightarrow$ post common envelope system
- unique lightcurve
  - $\Rightarrow$ huge reflection effect

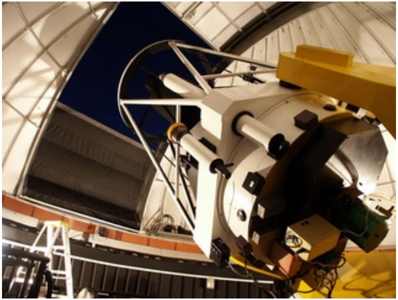


Lightcurve of HW Virginis (Lee et al. 2009)

Ground-based lightcurve surveys

OGLE

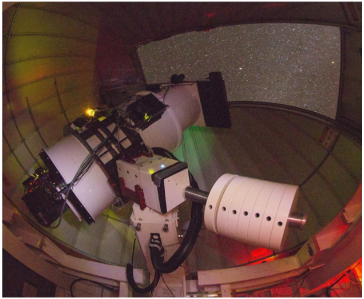
Optical Gravitational Lensing Experiment



→ observation of the lightcurve of many stars in different fields
→ discovery of planetary transits, pulsators, eclipsing binaries

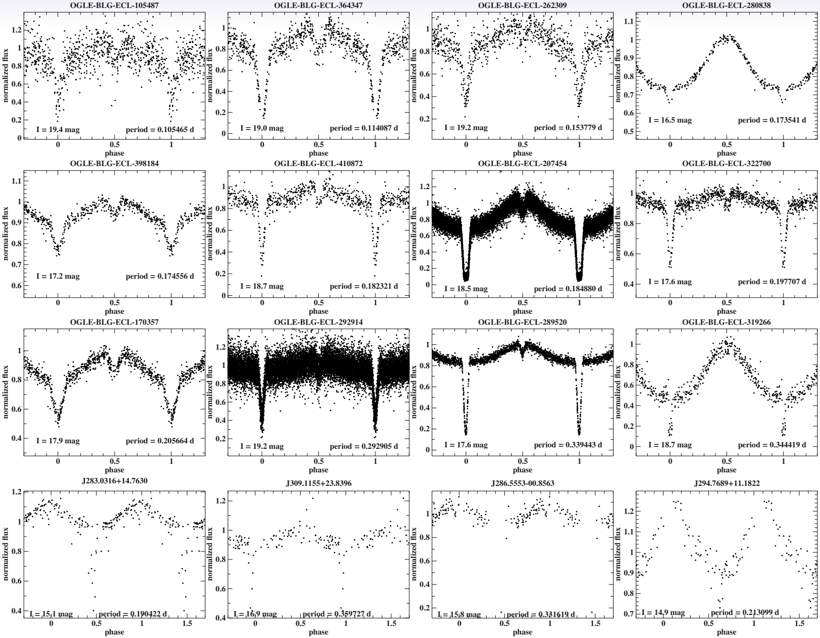
ATLAS

Asteroid Terrestrial-impact Last Alert System

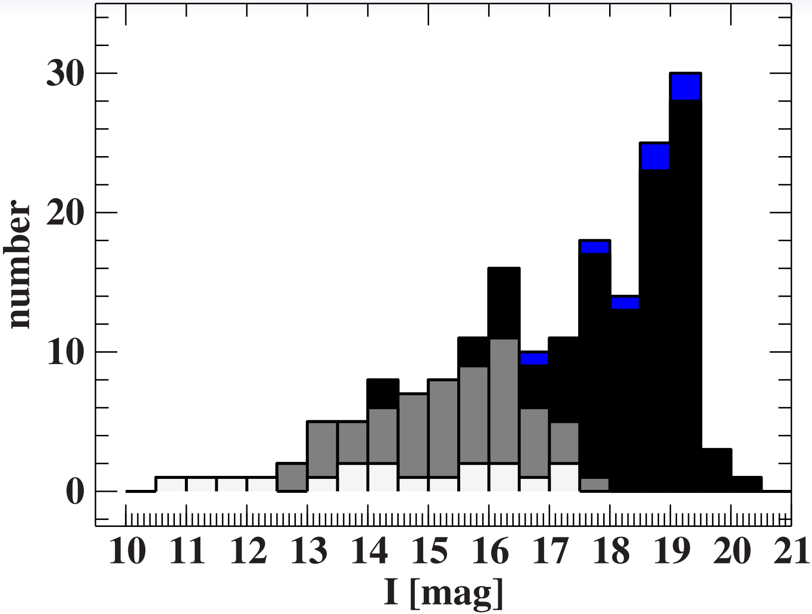


→ a robotic astronomical survey looking for near-earth objects
→ located in Hawaii, planned in the southern hemisphere

150 HW Vir candidate systems: $P = 0.05 - 0.8$ d



Magnitude distribution



The EREBOS project

EREBOS (Eclipsing Reflection Effect Binaries from the OGLE Survey)

- 105 new HW Vir system candidates found in the OGLE and 45 in the ATLAS survey
  $\rightarrow$ homogeneous target selection
- photometric and spectroscopic follow-up of all targets to determine fundamental (M, R), atmospheric (T_{eff}, $\log g$) and system parameters (a, P)
- ESO Large Program (PI: Schaffenroth) for time-resolved spectroscopic follow-up with ESO-VLT/FORS approved for the 23 targets with the shortest periods
- additional spectroscopic and photometric follow-up with all southern telescopes we have access to

EREBOS
God of darkness

Collaboration

Veronika Schaffenroth (PI)

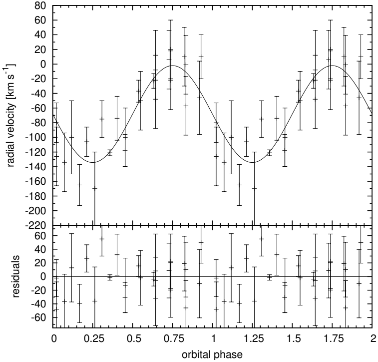
Goals of the EREBOS project

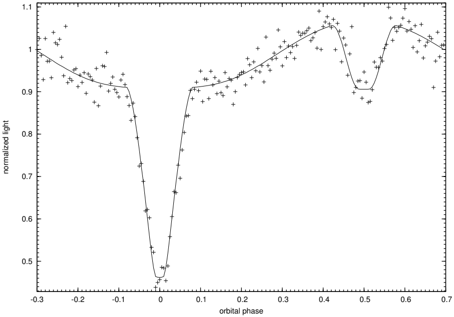
Key questions:

- minimum mass of the companion necessary to eject the common envelope? massive brown dwarfs down to hot Jupiter planets?
- fraction of close substellar companions to sdB stars and comparison with the possible progenitor systems like main sequence stars with brown dwarf or hot Jupiter companions (Gaia)?
- better understanding of the common-envelope phase

Preliminary results of the EREBOS project

OGLE-GD-ECL-10834: an 20th mag HW Vir with a low-mass M dwarf companion





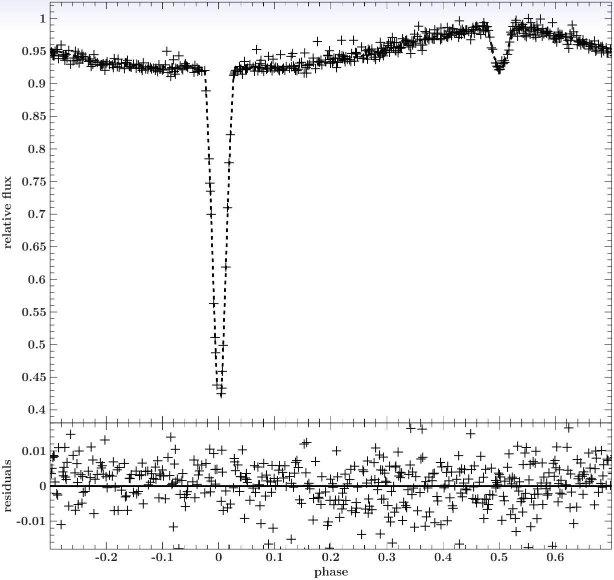
→ spectroscopic follow-up with FORS

K=66 ± 5 km/s, P = 0.07753698 d,

$M_1 = 0.47\,M_\odot$, $M_2 = 0.091 \pm 0.01\,M_\odot$

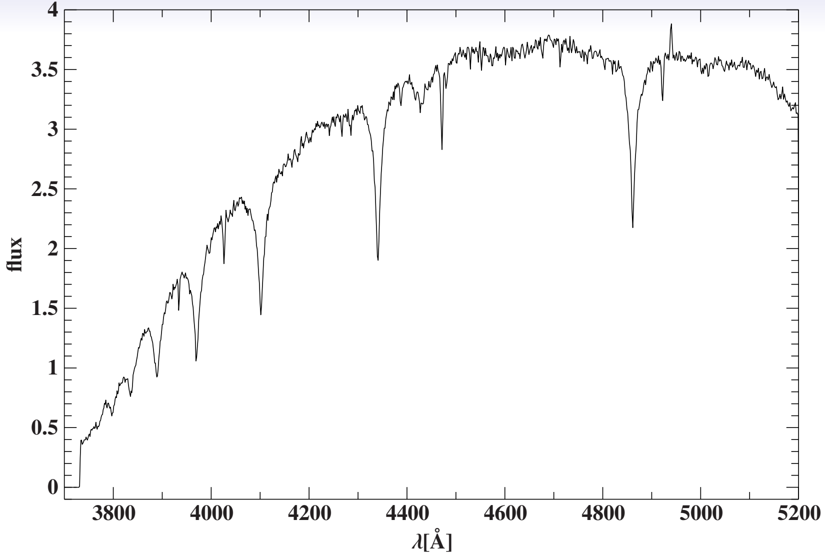
$T_\mathrm{eff} = 27600 \pm 770$ K, $\log g = 5.64 \pm 0.16$, $\log y = -2.54$

OGLE-BLG-ECL-103



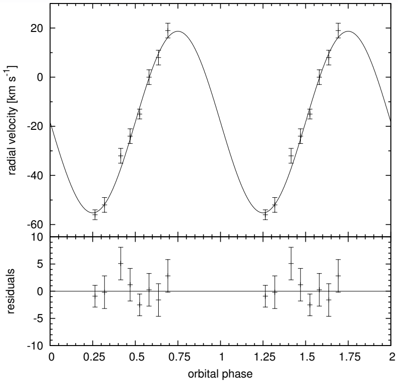
- 18 mag in V
- I band OGLE lightcurve

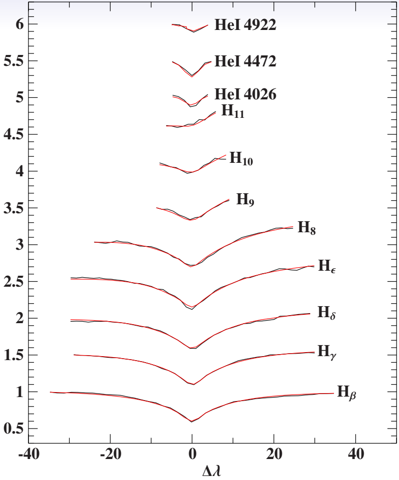
OGLE-BLG-ECL-103



- 18 mag in V
- 43 FORS spectra

Spectral analysis





K	$[\mathrm{km\,s^{-1}}]$	37.0 ± 1.5
P	h	1.867563(42)

Schaffenroth et al. in prep

T_{eff}	[K]	28800 ± 250
$\log g$	[cgs]	5.76 ± 0.05
$\log y$		-2.27 ± 0.13

Results

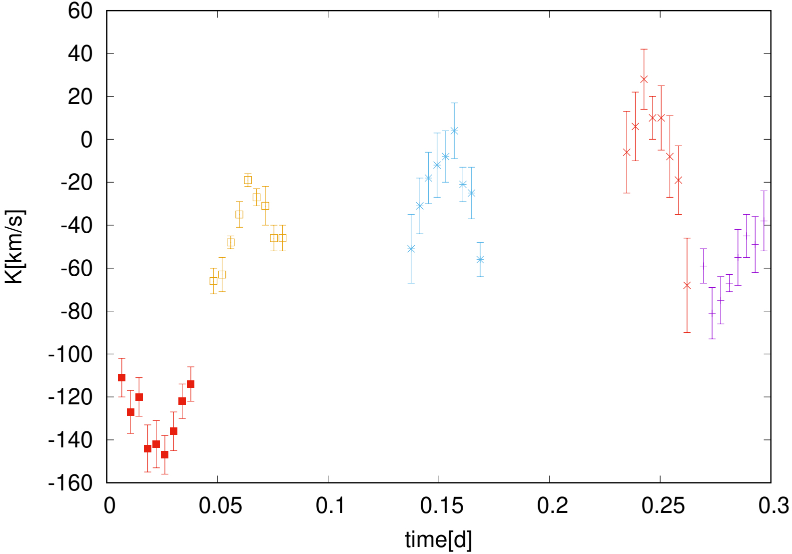
i	$^\circ$	86.55	$\pm$	0.04
M_{sdB}	$M_\odot$	0.47	$\pm$	0.03
M_{comp}	$M_\odot$	0.048	$\pm$	0.003
a	$R_\odot$	0.62	$\pm$	0.02
r_{sdB}	$R_\odot$	0.148	$\pm$	0.0060
r_{comp}	$R_\odot$	0.110	$\pm$	0.0045

Schaffenroth et al. in prep.

$\Rightarrow$ companion is the **lowest** mass **Brown Dwarf** discovered

$\rightarrow$ more FORS data and lightcurves in other bands already observed

Challenges: radial velocity shifts: OGLE114



Flexure

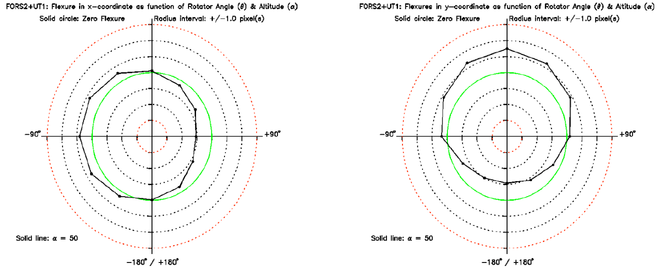


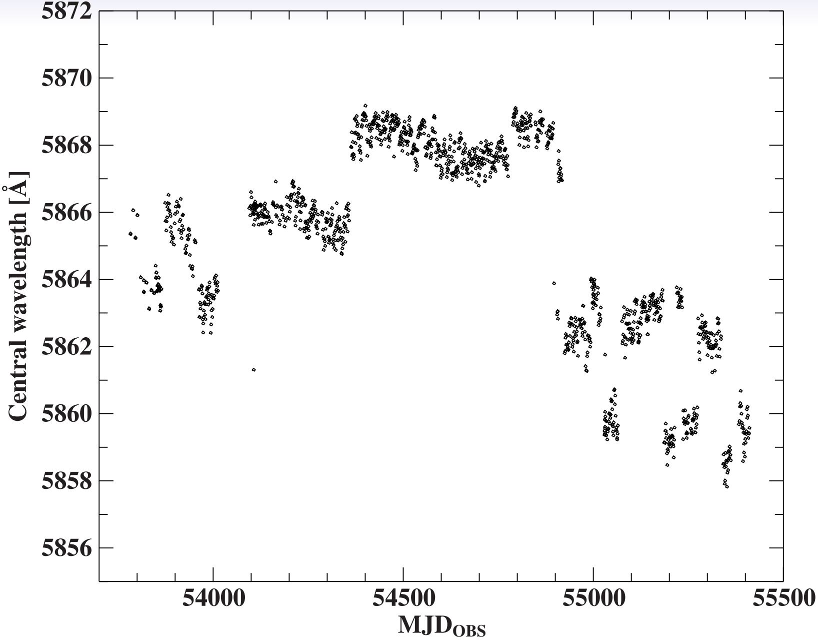
Figure 2.4: Results of flexure measurements as a function of the rotator position for the SR collimator at zenith distance of 40°. The panels show the flexure in *un-binned* pixels across (X) and along (Y) the slit. The solid green circle represents zero-flexure.

zenith distance	COLL_SR	COLL_HR
0°		
15°	<0.″06	<0.″03
30°	<0.″10	<0.″05
45°	<0.″14	<0.″07
60°	<0.″18	<0.″09

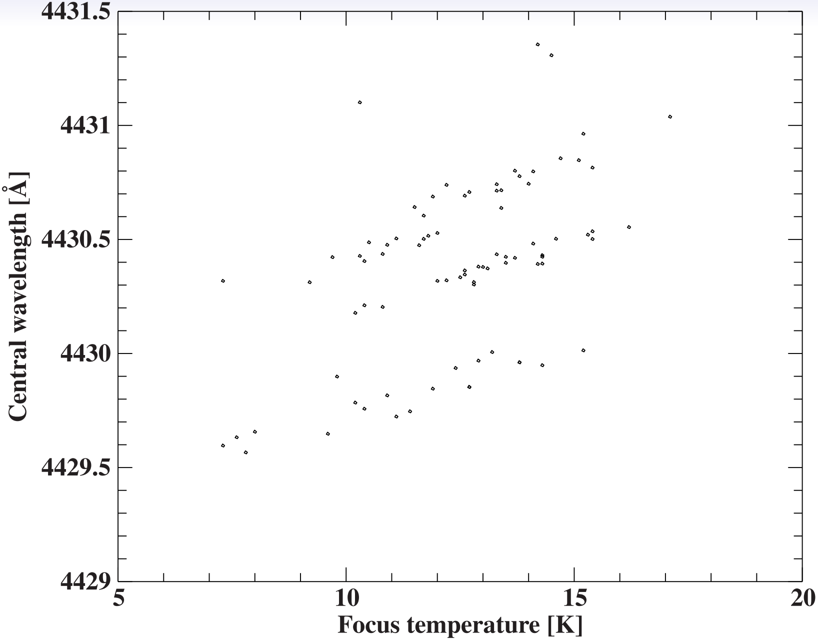
ESO FORS manual → less than 0.2 pixels/hour

no arcs during night possible and only in zenith!

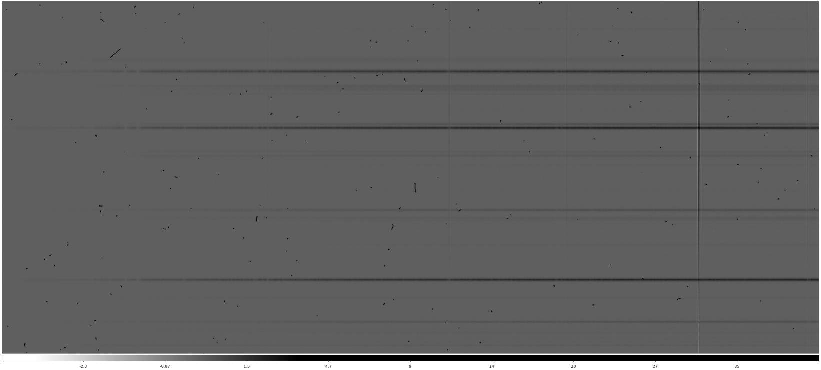
Central wavelength evolution



Trend with temperature

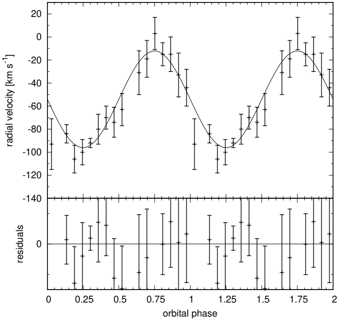


Crowded fields



- many stars on the slit – maybe helpful to calibrate shifts?
- interstellar Ca lines, but only in highest S/N spectra
- period well known, shift velocity manually

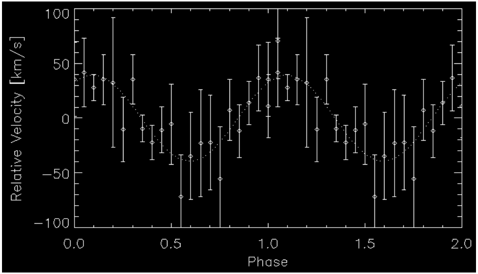
OGLE114 as seen by SOAR/Goodman and FORS



FORS

$K_1 = 41.9 \pm 3.7$ km/s

→ OBs in the same night



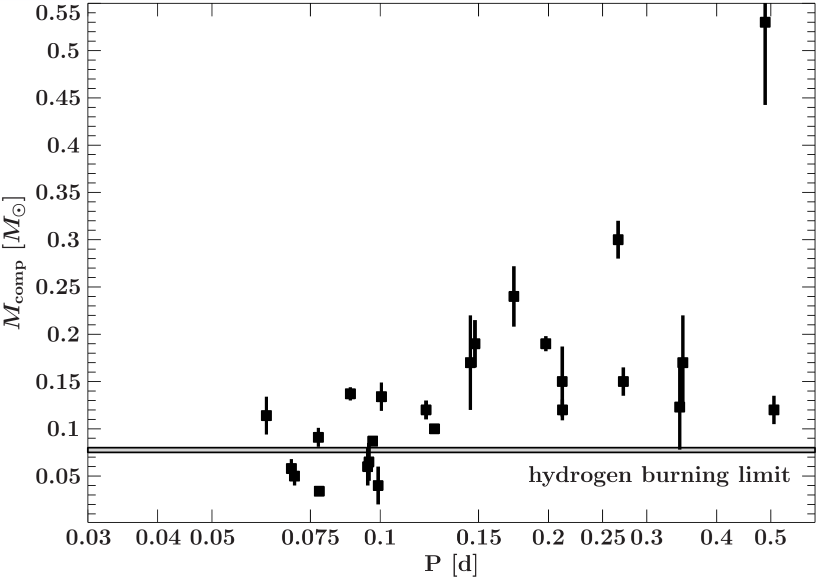
SOAR/Goodman $K_1 = 39 \pm 6$ km/s

Conclusions

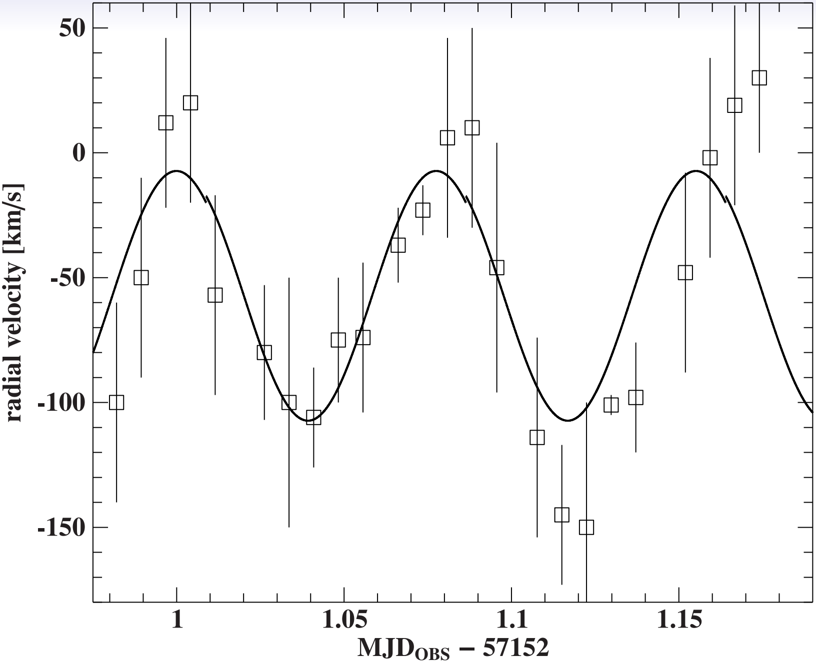
- FORS is **not** the ideal instrument for deriving radial velocity curves
  - → low resolution
  - → small wavelength coverage
  - → arcs only during the day
  - → no skylines in the blue grisms
- However, for faint, short-period binaries with relative large radial velocity shifts FORS is a unique opportunity, as it produces useful spectra with enough S/N for deriving radial velocities
- Combining OBs from different nights is difficult in the blue and has to be taken with caution, consecutive OBs can be combined without problems

Questions?

Preliminary period-companion mass diagram



OGLE10384



Lightcurve analysis