SONG and HERCULES

Synergies with SONG

Karen Pollard
Director
UC Mt John Observatory
Tekapo
New Zealand

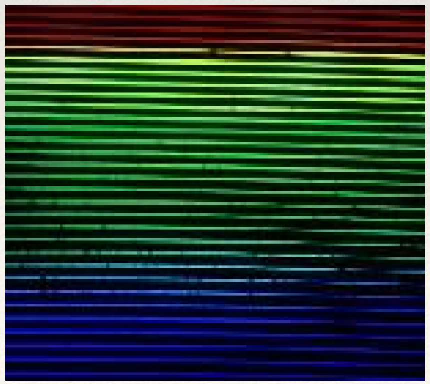
Synergies with SONG

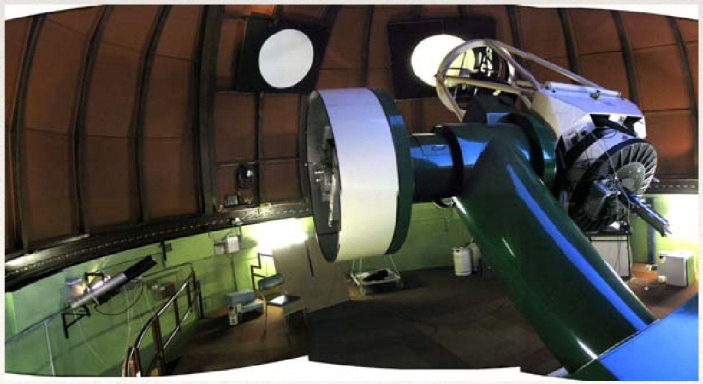
Excellent instruments on small telescopes can do cutting-edge research in "niche areas"

In particular, high-precision, -efficiency, -resolution and -stability spectrographs on small 1-2 class telescopes, by themselves or in a network, are particularly useful for key projects in stellar astrophysics, eg

- Asteroseismology of various types of pulsators
- LPVs and modes of pulsating stars
- Radial velocities of binary star systems, and star-exoplanet systems
- Chemical abundances and fundamental parameters of individual stars

…





Synergies with SONG

Key features of a responsive small telescope/observatory/network (such as Mt John or SONG):

- A unique/useful geographical locations (long & lat)
- Can combine with other observatories (WET, multi-site-campaigns,…)
- Can respond to events quickly (transients/time domain)
- Can obtain data over many years (long-term variability)
- Can support space observatories to obtain complementary and simultaneous data (multi-messenger approach)

- **Design/construction of telescopes/instruments develops local expertise**
- **Provides hands-on training for students**
- **Outreach role of astronomy to interest & educate public about science**

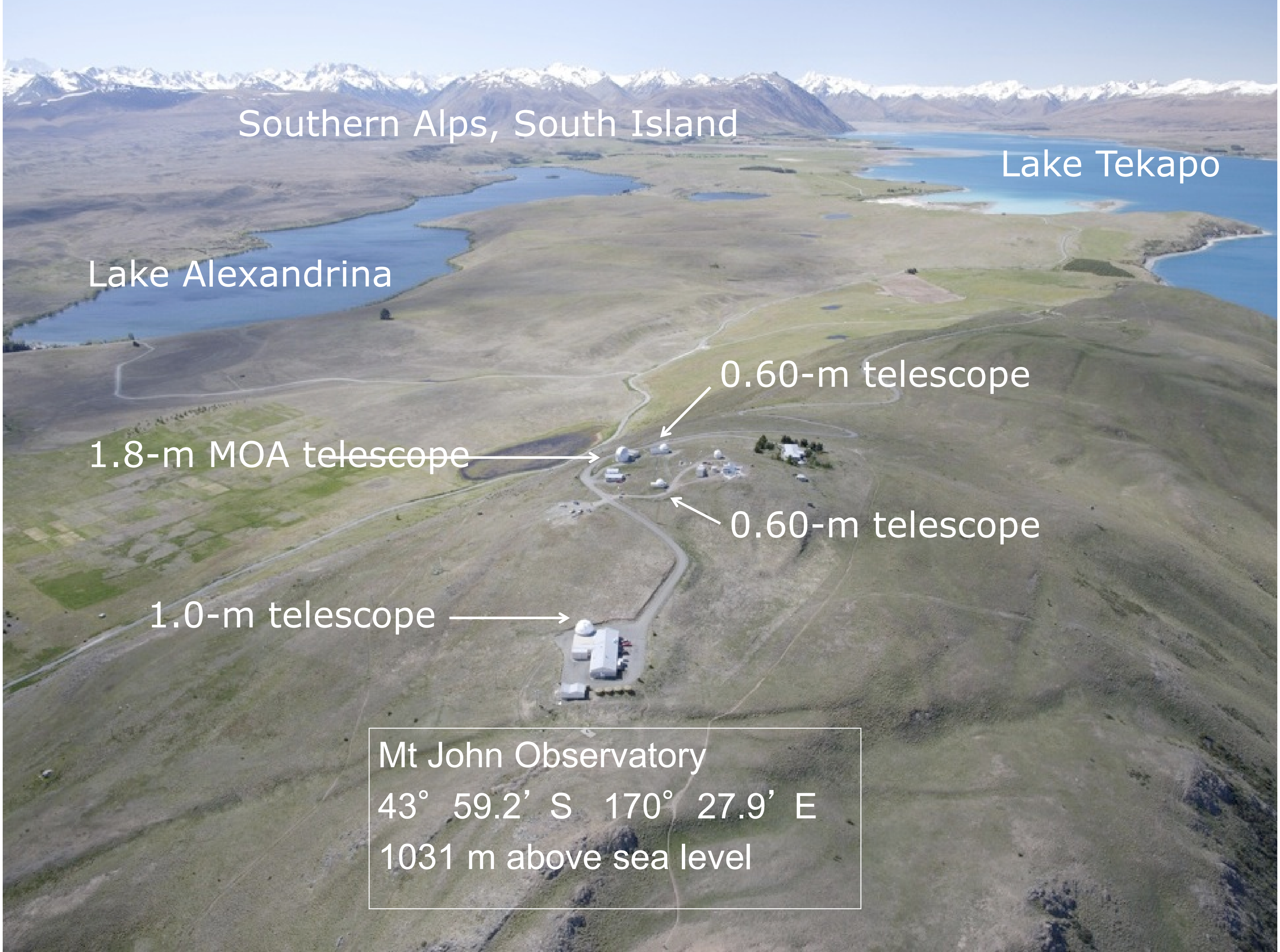
UC Mt John Observatory

At UC we own and operate New Zealand's only professional optical astronomical observatory.

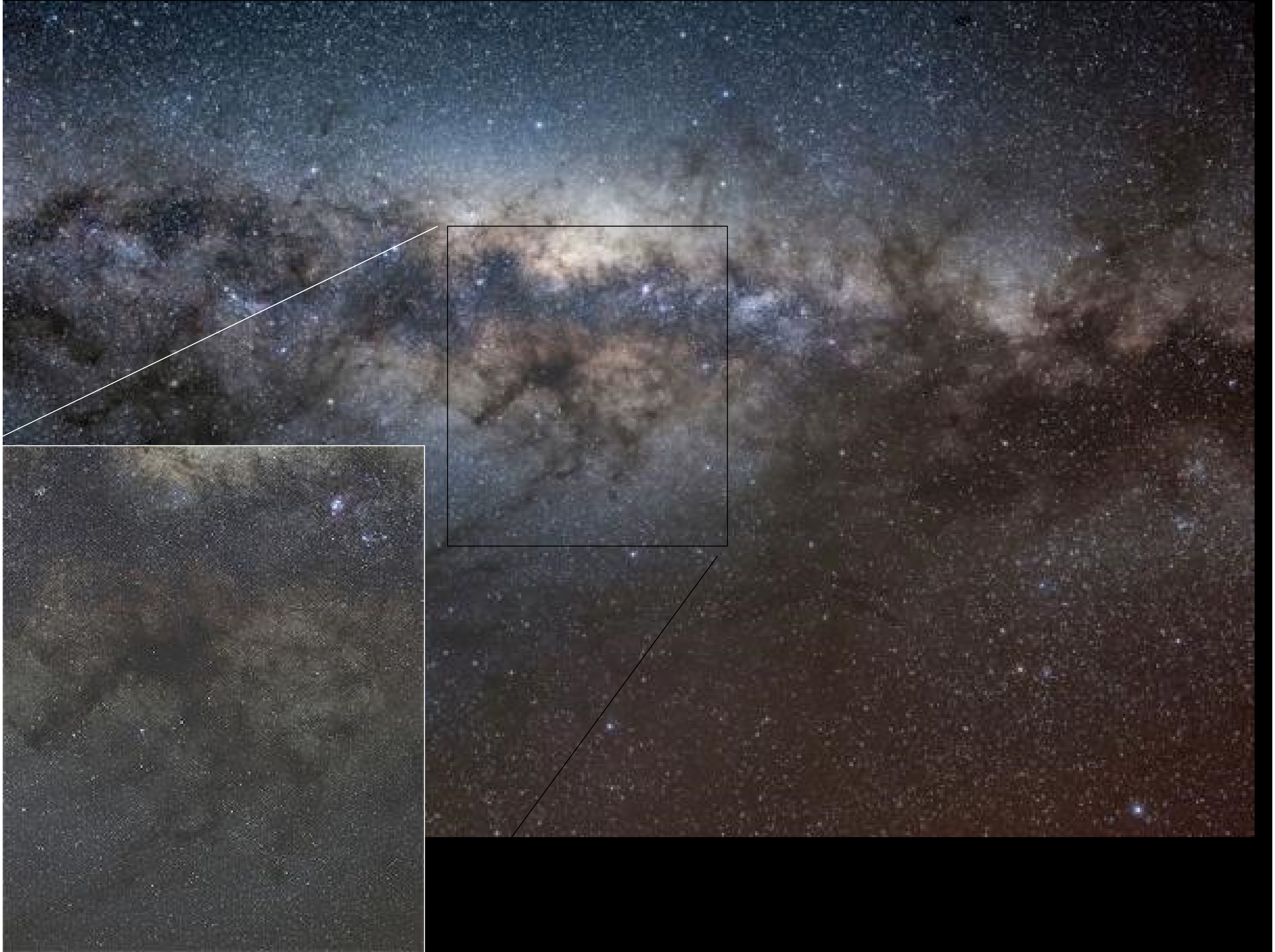
Our students get hands-on experience using the telescopes.

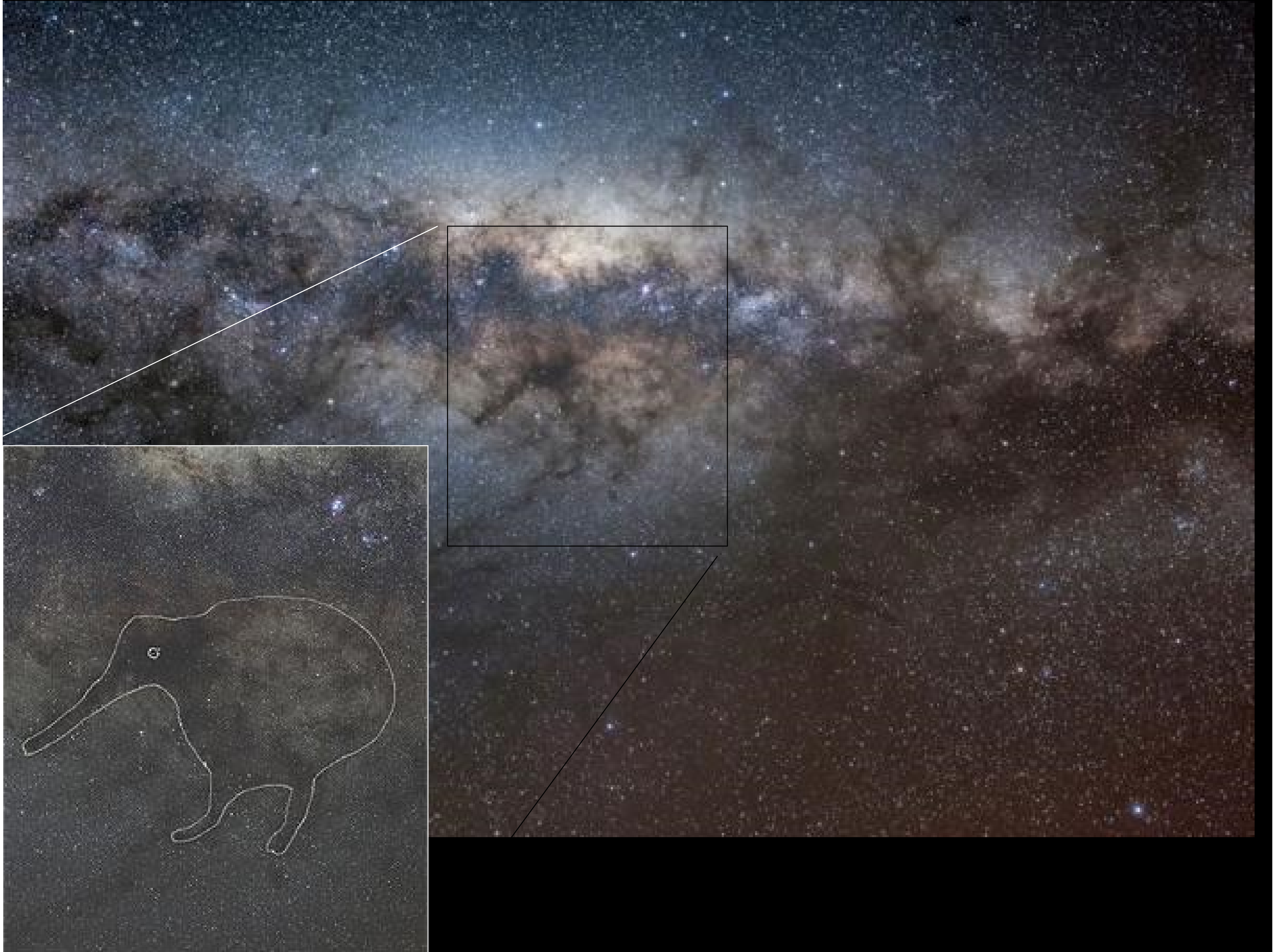
New Zealand


North Island
South Island
Mt John Observatory,
Lake Tekapo
University of
Canterbury,
Christchurch
A 3 hour
drive


Southern Alps, South Island
Lake Tekapo
Lake Alexandrina
0.60-m telescope
1.8-m MOA telescope
0.60-m telescope
1.0-m telescope
Mt John Observatory
43° 59.2' S 170° 27.9' E
1031 m above sea level

Fraser Gunn, Telescope observing technician, astrophotographer





UC Mt John Observatory 0.6m telescopes

Optical Craftsman 0.6m (OC)

Currently a robotic CCD imaging BVgri telescope + spectrograph (UC/AAVSO)

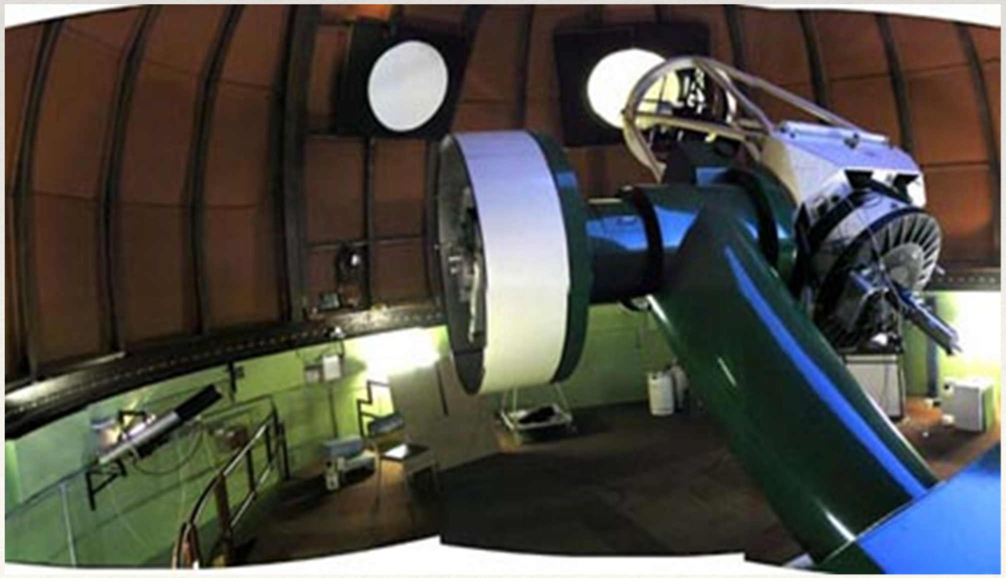
Boller & Chivens 0.6m (B&C)

Currently CCD imaging in simultaneous gri for research and eyepiece for public outreach)

UC Mt John Observatory 1.0m telescope

1.0-m telescope installed in 1987

Designed & built in the Dept of Physics and Astronomy, UC



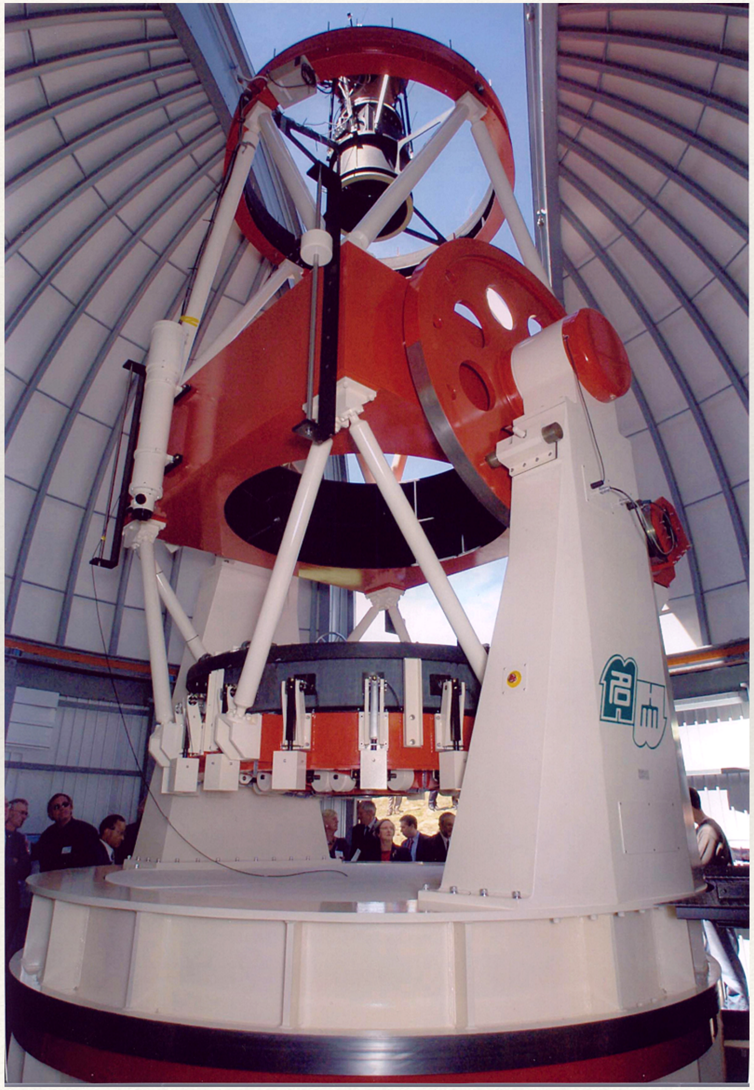
UC Mt John Observatory 1.8m MOA telescope

1.8m MOA telescope; Alt-az;

wide-field (2.5 deg), prime-focus camera with 10 E2V CCDs

MOA: A Japanese-New Zealand collaboration to search for planets using gravitational microlensing

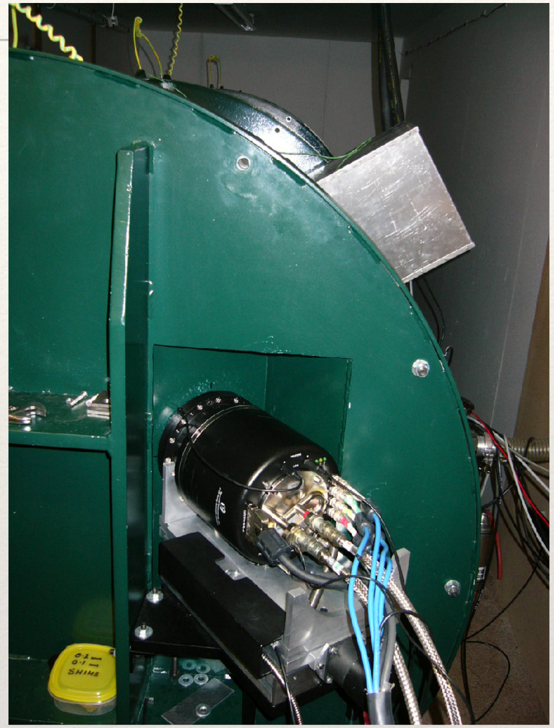
Possible modification to include fibre-fed KiwiSpec spectrograph



HERCULES spectrograph

(High Efficiency and Resolution Canterbury University Large Echelle Spectrograph)

Designed & built in the Dept of Physics and Astronomy, University of Canterbury



- High precision fibre-fed echelle spectrograph with good stability over long periods of time.
- Spectrograph is mounted on a stable optical bench, enclosed within a vacuum vessel in a thermally insulated room. The light is fed to spectrograph along 20 m of optical fibre.
- Continuous wavelength coverage from λ=380–880 nm in 86 orders with a 50mm square 4kx4k CCD.
- Three fibres resolving powers of R~40,000 (100 μm) and R~70,000 (50 μm fibre, or 100 + 50 μm slit).
- Can be used with or without iodine cell
- Develops/uses local expertise

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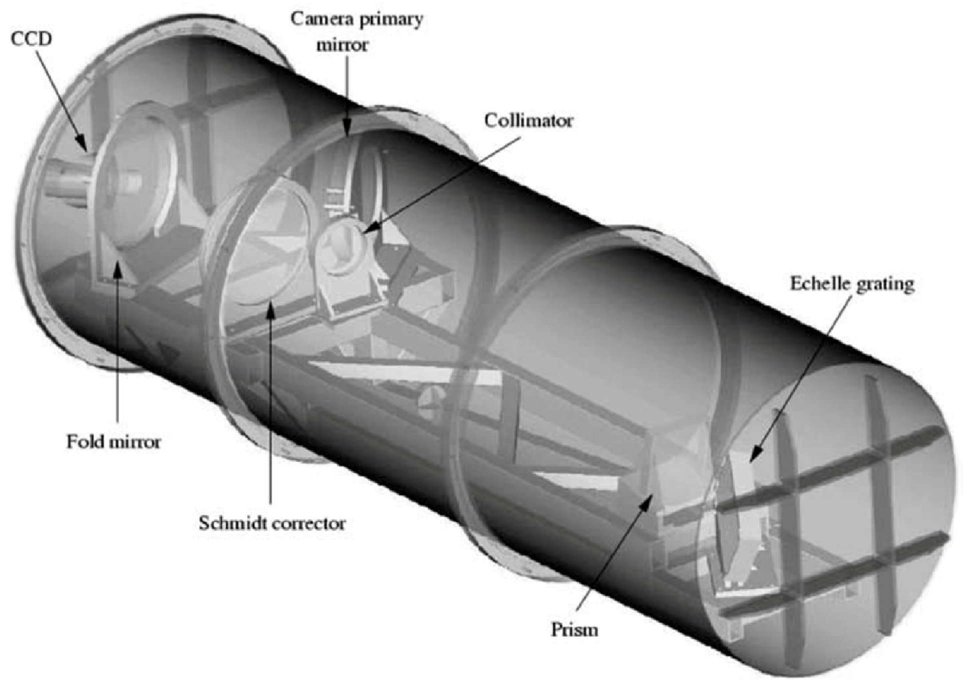

Figure 6. The HERCULES spectrograph inside the vacuum tank. The tank is formed in three sections. The first section, which encompasses the camera optics, is rigidly connected to the spectrograph bench. The lid (on which the camera is mounted) and the other two sections are free to roll away on rails. All optical mounts are fabricated from cast aluminium. The mirrors are all supported by a thin stainless steel band. There is minimal provision for optical alignment as a single alignment is made during final assembly.

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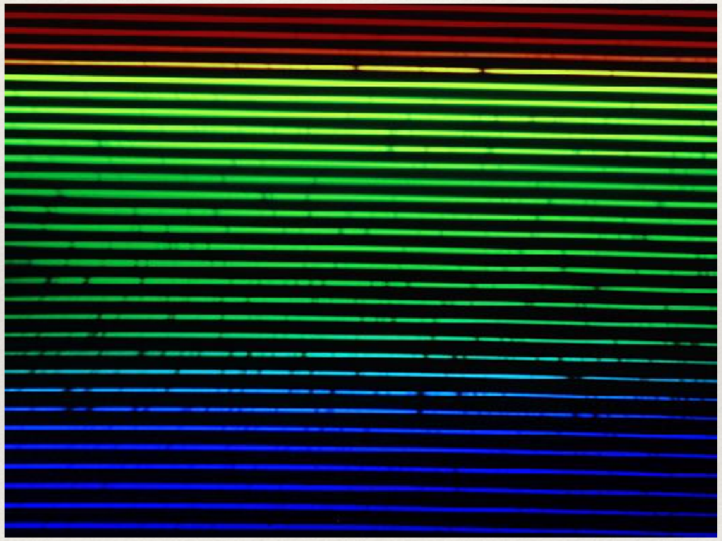


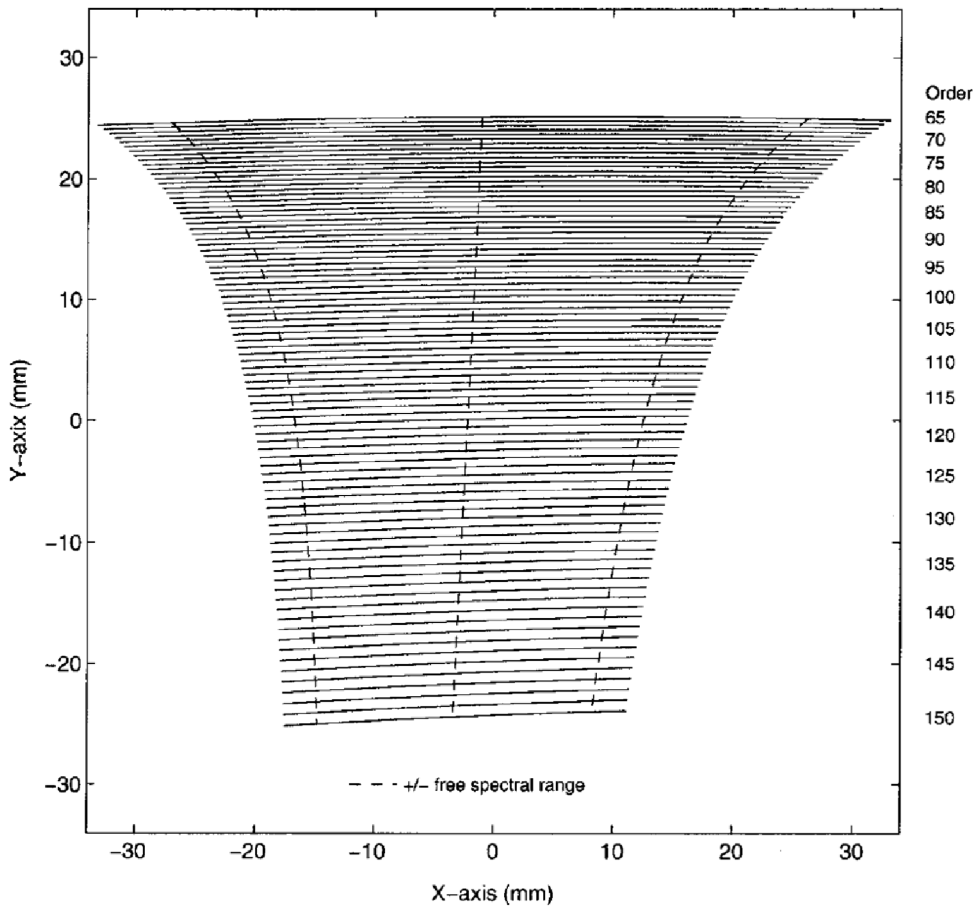
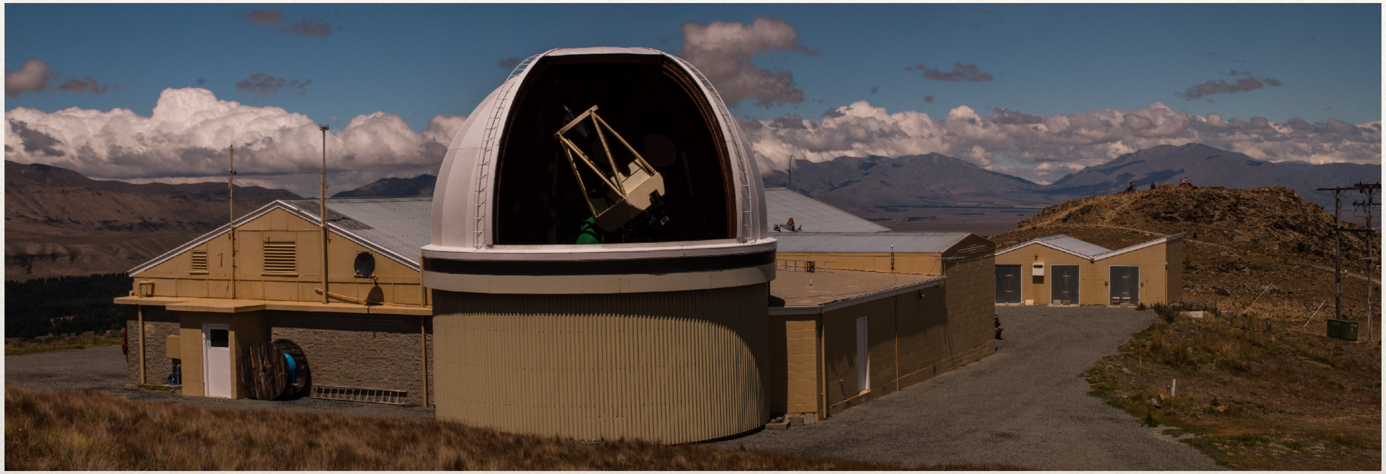
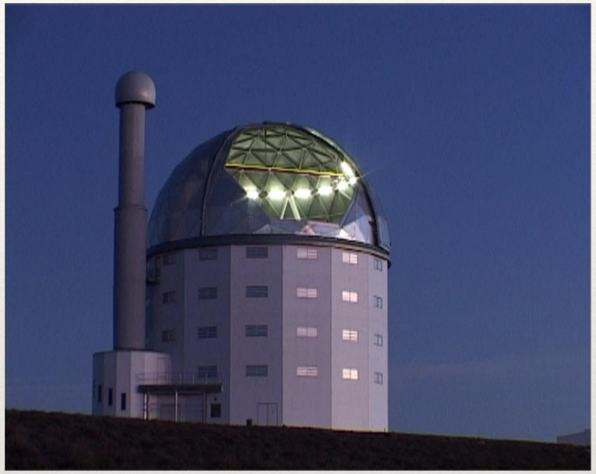


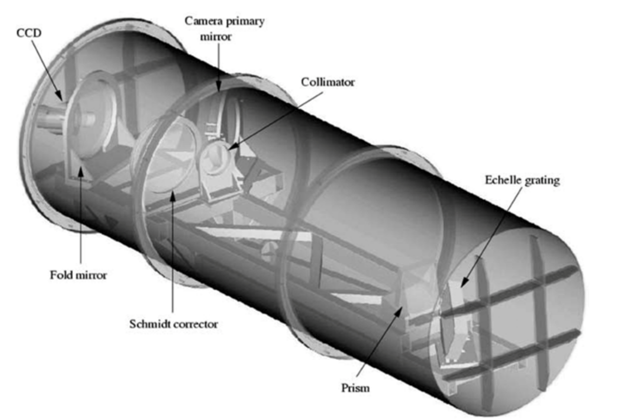
Figure 4. The spectral format of HERCULES. Shown are orders $m = 65$ ($\lambda_B = 875.1$ nm) to $m = 150$ ($\lambda_B = 379.3$ nm). The CCD has been rotated by 3° so that the slope of the orders is minimized. This has the effect of slightly increasing the average line tilt.

HERCULES and HRS/SALT and KIWISPEC

Optical /mechanical design/construction telescopes/instruments has helped develop local expertise







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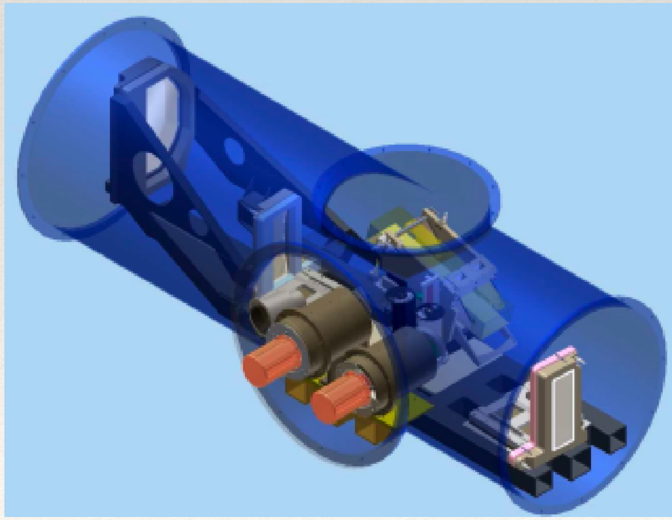
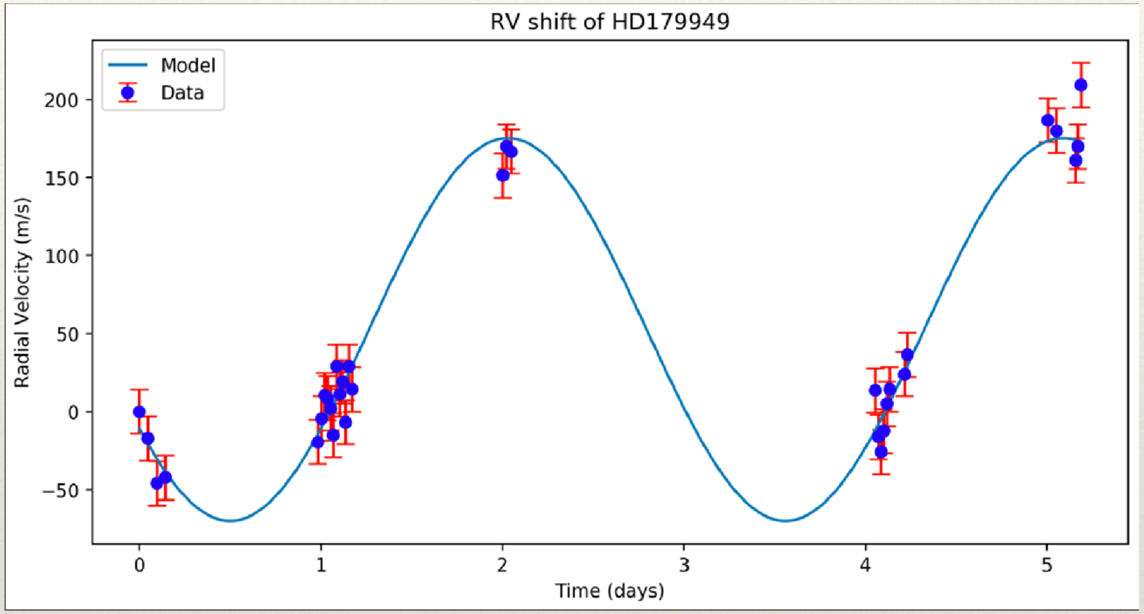
UC PhDs: Stuart Barnes, Andrew Rakich, Steve Gibson



Exo-planets (rv technique)

- 1^{st} year student observing project of exoplanet host star HD179949
- Fibre1, R~41000, 6 nights of observation (snow night3), std reduction + auto-cross-correlation of best orders, rms = 15 m/s
- P=3.0925, msini=0.92, a=0.045



Property	Value	Uncertainty	Units
Orbital Period	3.06	±0.148	days
Semi-Major Axis	0.0442	±0.00249	AU
sin(i) Mass	1.01	±0.173	M_{Jup}

Jesse Satherley ASTR211 project

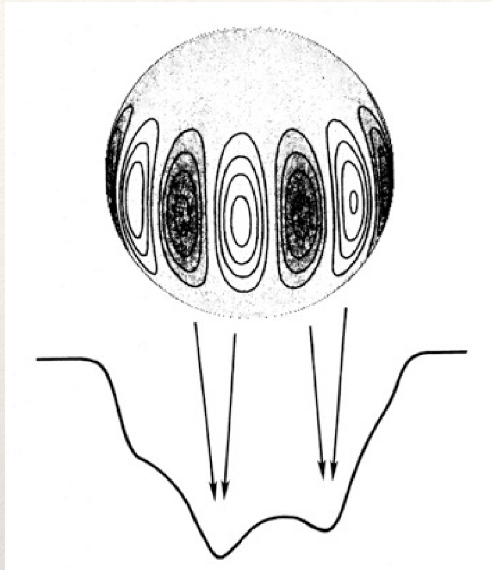
Recent examples of types of collaborative stellar astrophysics research

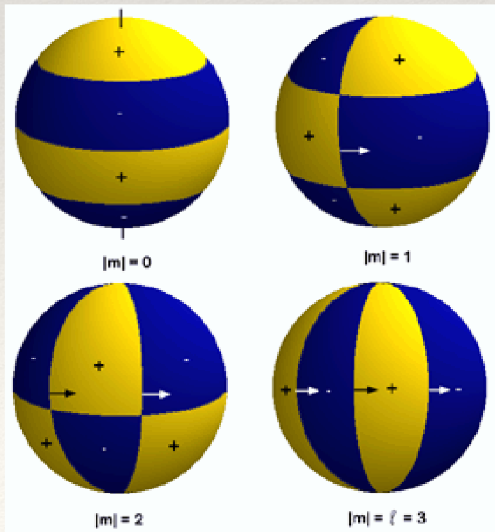
- Long-term studies of **LPVs in non-radially pulsating stars**, MUSICIAN project: **γ Dor stars/δ Scuti, SPB/β Cephei** (CoRoT, TESS,…) [with P. De Cat, D. Wright, E. Brunsden, …]
- Spectroscopic studies of **protoplanetary disks** around young stars, especially **β Pictoris** [with W. Tobin, K. Zwintz, A. Bayo, E. Brunsden.]
- **Spectroscopic Binaries** in the Gaia-ESO Survey, [with T. Merle, M. Van der Swaelmen, S. Van Eck, A. Jorissen]
- Spectroscopic study of **η Car** for study of eccentric binary and wind collision characteristics, [with A. Daminelli]
- VLTI/GRAVITY studies to characterise convection on surface of evolved AGB stars [with Claudia Paladini]
- **Outreach: Lucky Imaging** of planets [with Otago Museum]


29 July 2018
University of Canterbury Mt John Observatory
Boller and Chivens 0.6m Telescope
UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND
OTAGOmuseum

How do non-radial pulsations affect the stellar spectrum?

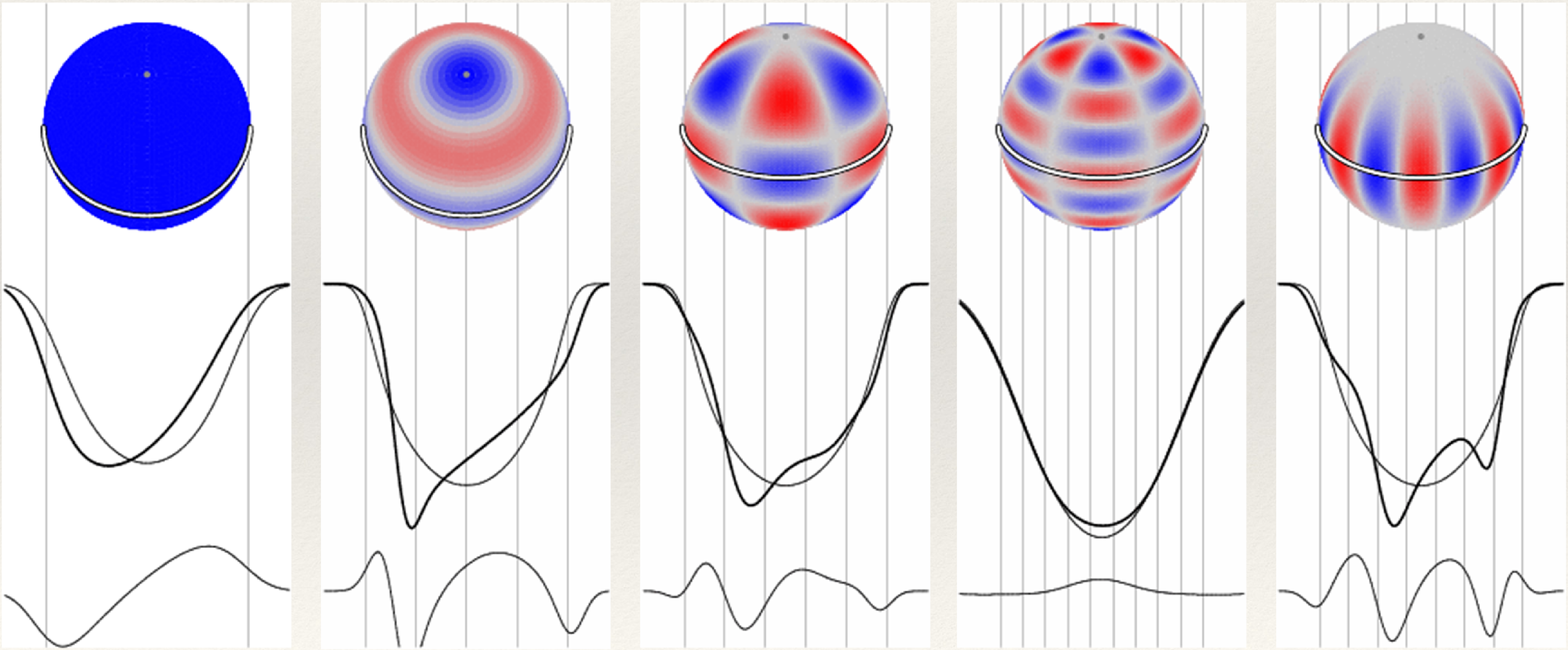
- Surface distortions cause Doppler shifts (and temperature effects) in radiation emitted
- Doppler-shifted elements contribute to different sections of the spectral line causing line profile variations (LPV)
- LPV depends on the exact mode of the non-radial pulsation.
- Spectroscopic analysis provides additional and complementary information to high-precision space-based photometry (such as CoRoT, MOST, Kepler, BRITE…) *eg cancellation effects, high l*





Non-radial pulsations cause distinctive line profile variations

l=0 m=0	*l=4 m=0*	*l=5 m=3*	*l=9 m=-3*	*l=7 m=7*
radial mode	*zonal mode* *axisymmetric mode*	*prograde mode* *tesseral mode*	*retrograde mode* *tesseral mode*	*sectoral mode*



Telting (2008)

γ Doradus and δ Scuti stars

Pulsating radial & non-radial A–F stars

On or near main sequence

γ Dor have high-order non-radial g modes with periods of 0.3–3 days

δ Sct have non-radial p modes with periods of 0.3–6 hours

Similar pair of p/g mode pulsators: β Cephei and SPB stars

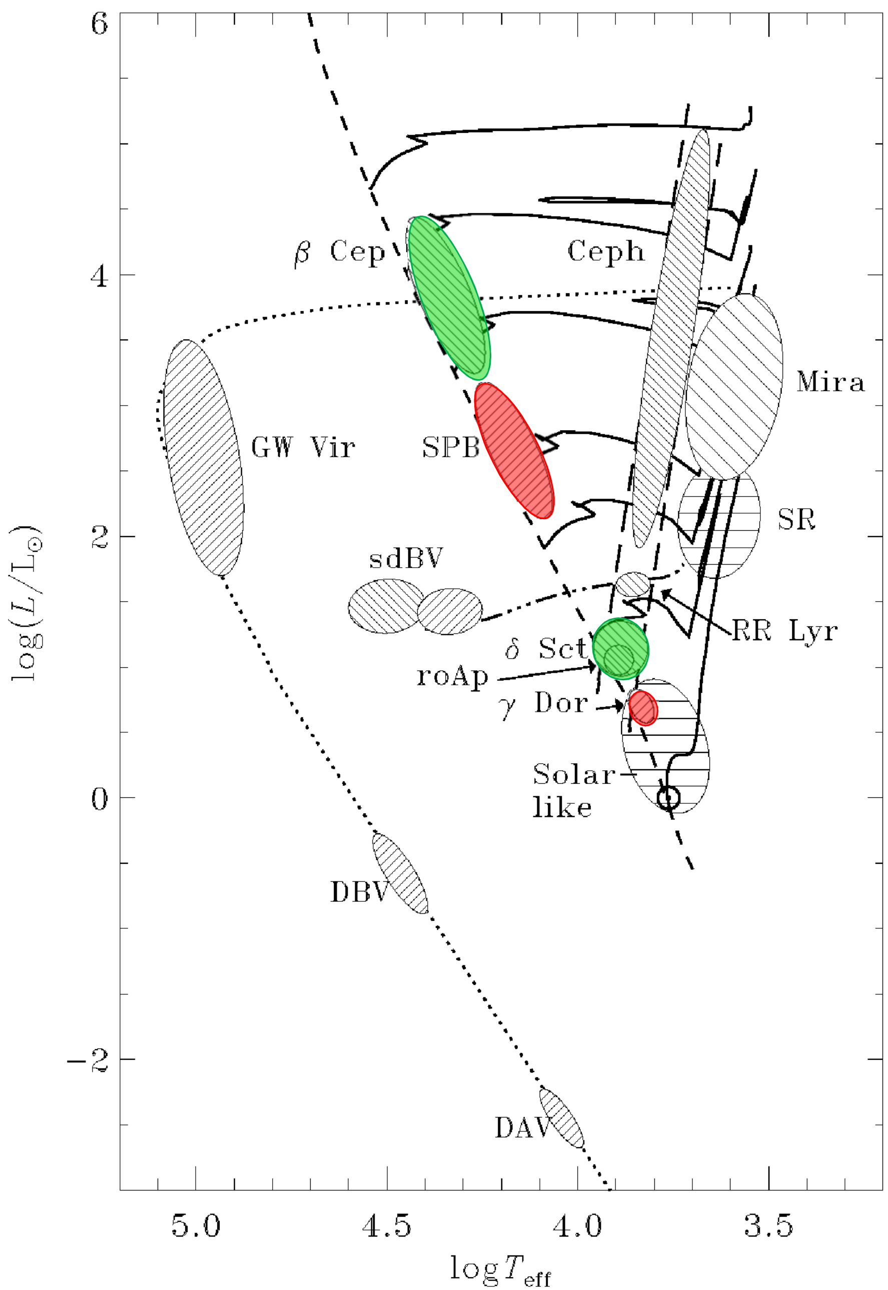


Figure from J. Christensen-Dalsgaard

Long-term studies of non-radially pulsating stars, MUSICIAN project: gamma Dor stars (CoRoT, TESS,…),

collaboration with De Cat, Wright, Brunsden, …

- More than 7800 HERCULES spectra of > 65 southern γ Doradus stars/candidates have been obtained over 11 years. We present a zoo of pulsational behaviour of 58 stars as exhibited in the cross-correlated line profiles.

Line Profiles of Single Stars

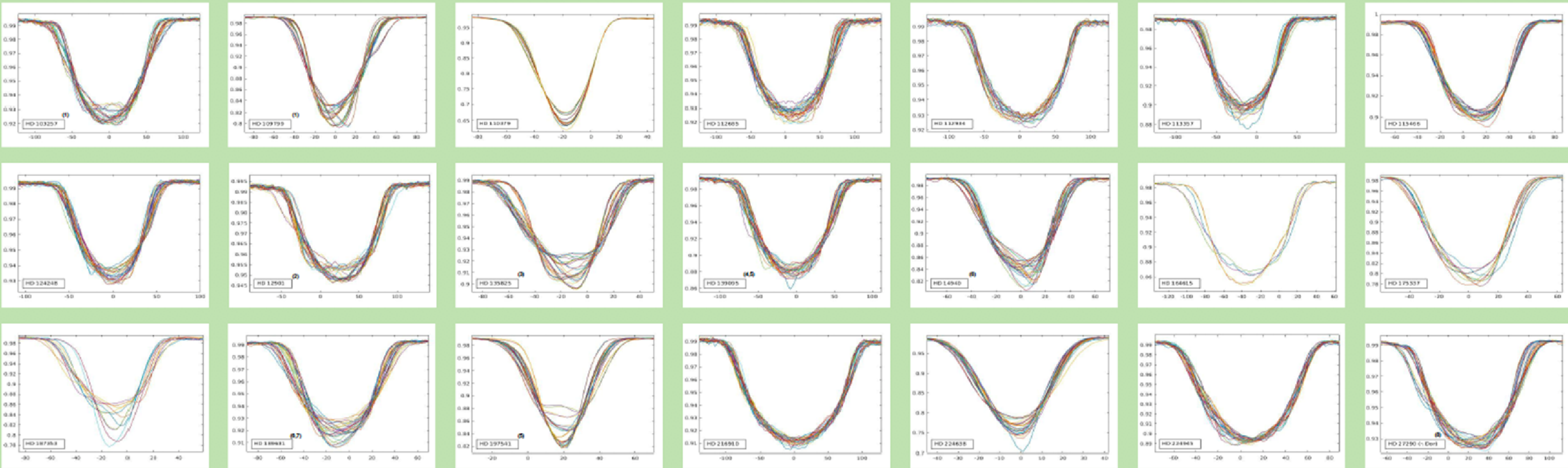
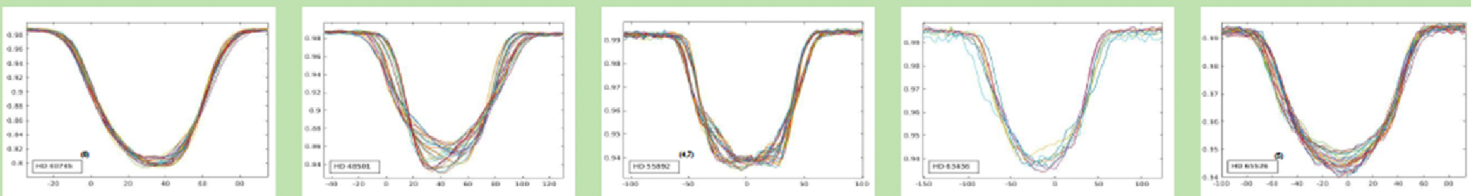


Figure Details

All figures are produced in axes of relative normalised intensity against velocity (kms-1) with the star identified in the insert. Each figure is restricted to 30 cross-correlated observations for clarity. Typically 3000-4000 spectral lines with equivalent width greater than 0.1 nm are masked, avoiding telluric and hydrogen regions.



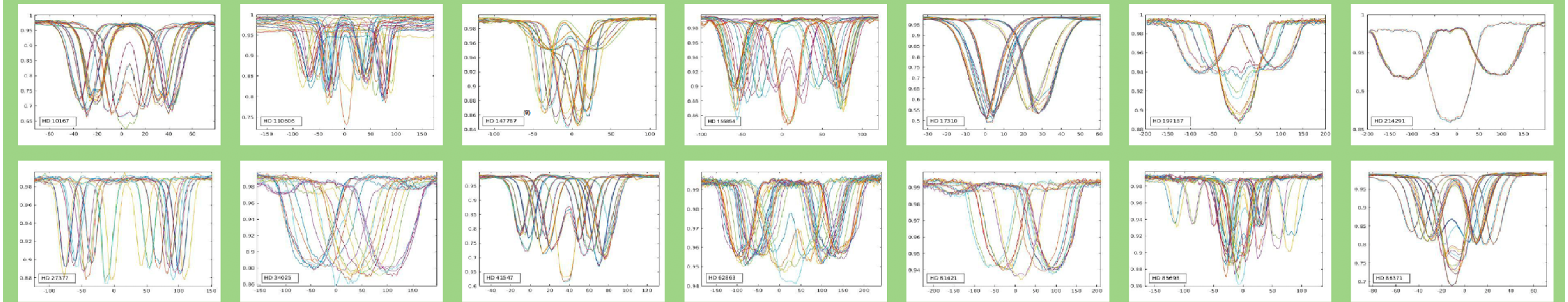
Single Star Analysis

Line profile variations of single stars are analysed using radial velocity variations and with pixel-by-pixel techniques. Most show the three-bump structure of the most common pulsation mode found in these stars, (l,m) = (1,1). This is likely to be identification bias as these modes have high amplitudes.

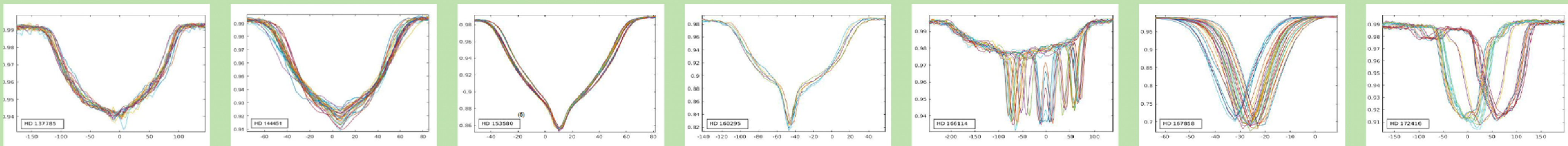
Long-term studies of non-radially pulsating stars, MUSICIAN project: gamma Dor stars (CoRoT, TESS,…),

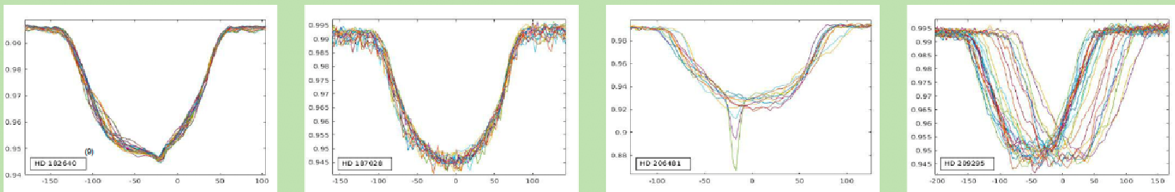
- As the programme progresses we are developing more precise line profile analysis techniques including the resolution of pulsation in binary stars.

Line Profiles of Separated (SBII) Binary Stars



Line Profiles of Blended (SBII) and Single (SBI) Binary Stars





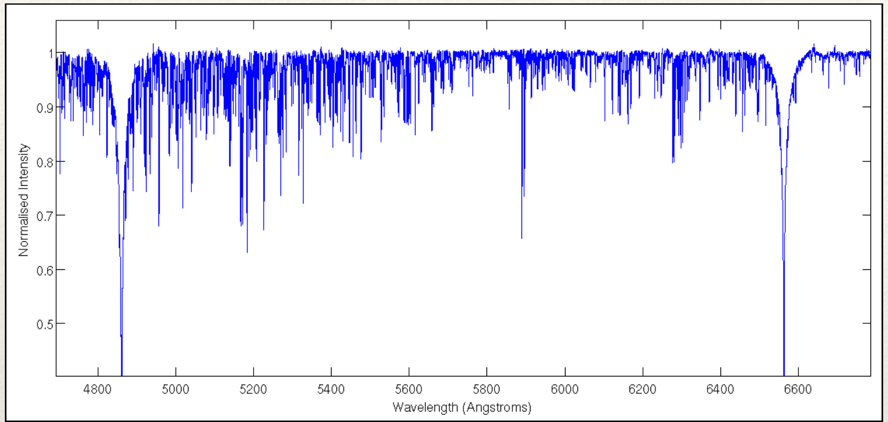
Binary Analysis

The line profiles of binaries require careful treatment to separate pulsation from binary motion. In some cases pixel-by-pixel variations with a mask can be effective (e.g. HD182640) but separated SBII spectra require tracking through the orbital phase. This can distinguish the pulsating component.

References for Analyses

(1) Shutt et al., in preparation
(2) Brunsden et al., 2012b
(3) Brunsden et al., 2012b
(4) Wright, 2008
(5) Sekaran, 2016
(6) Maisonneuve et al., 2011
(7) Greenwood, 2012
(8) Davie, 2013
(9) Brunsden et al., 2018

Long-term studies of non-radially pulsating stars, MUSICIAN project: gamma Dor stars (CoRoT, TESS,…),



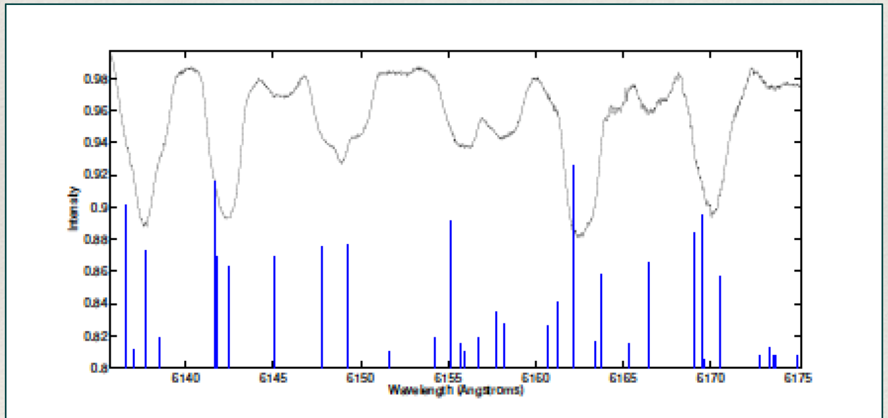
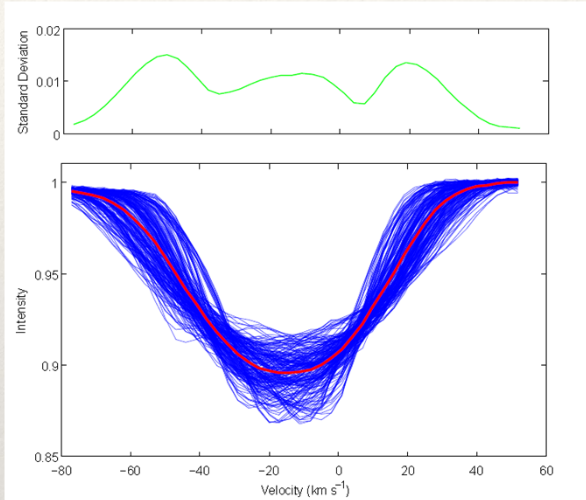


Figure 2.5 — Example of a scaled δ-function template (blue) for cross-correlation with part of the spectrum (black) of γ Doradus.



Example analysis:

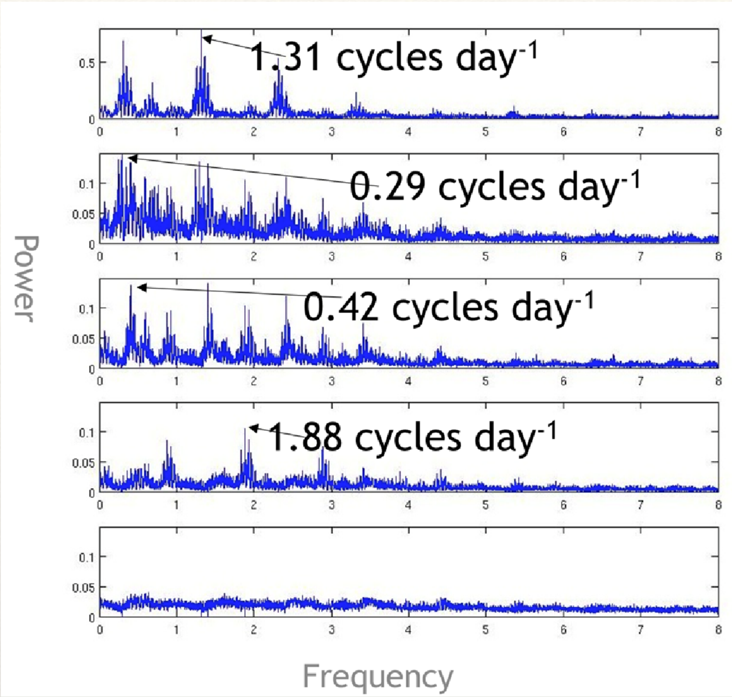
Visually identify line profile variations

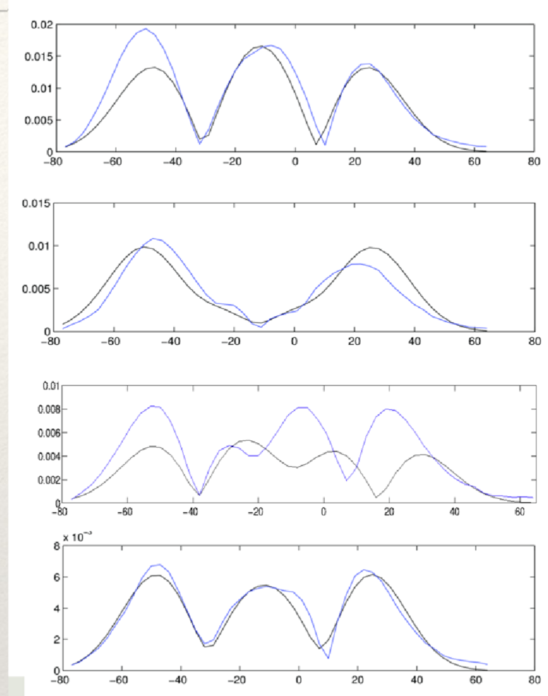
Cross correlation method to enhance S/N

Determine frequencies present in line profile variations

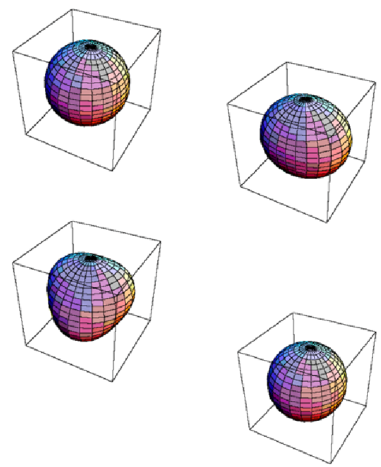
- Fourier analysis of moments
- Fourier analysis pixel-by-pixel across line profile

Long-term studies of non-radially pulsating stars, MUSICIAN project: gamma Dor stars (CoRoT, TESS,…),





Frequency order	Frequency (cycles day^{-1})	Period (hours)	Mode
1	1.315	18	(1,1)
2	0.290	83	(2,-2)
3	1.405	17	(4,0)
4	1.883	13	(1,1)



For each frequency, match observed variations to synthetic line profiles for different pulsation modes

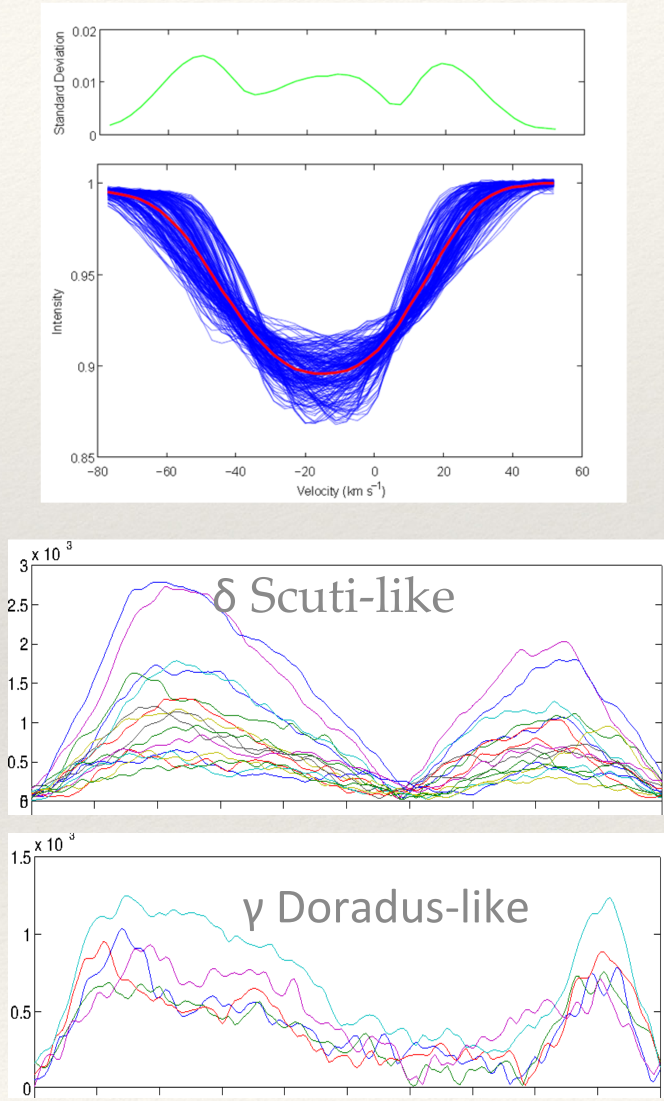
Simultaneous multi-frequency fits

Long-term studies of non-radially pulsating stars, MUSICIAN project: gamma Dor stars (CoRoT, TESS,…),

Detailed analyses (frequencies and modes of dozen or more individual stars, including several binary systems

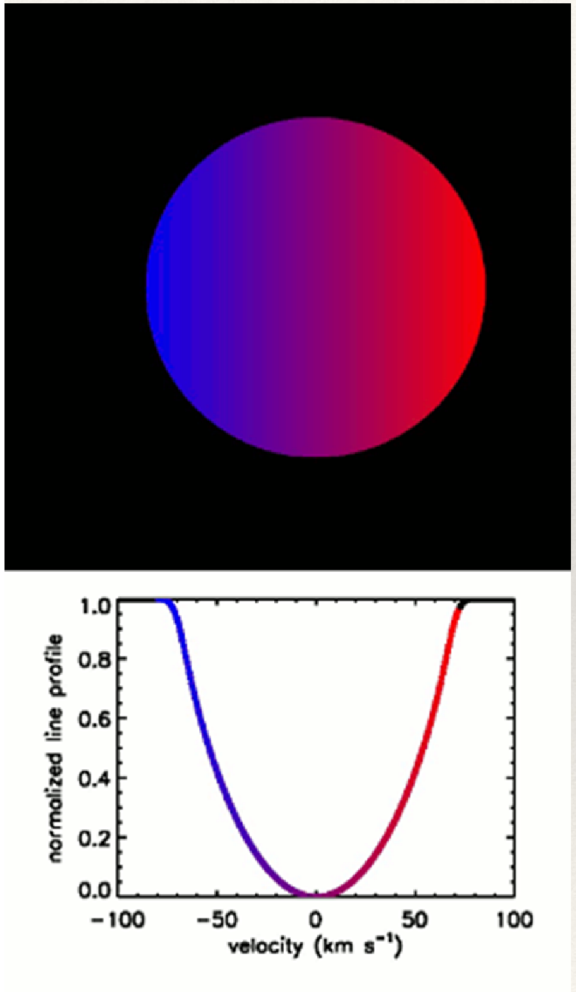
Complications in analyses:

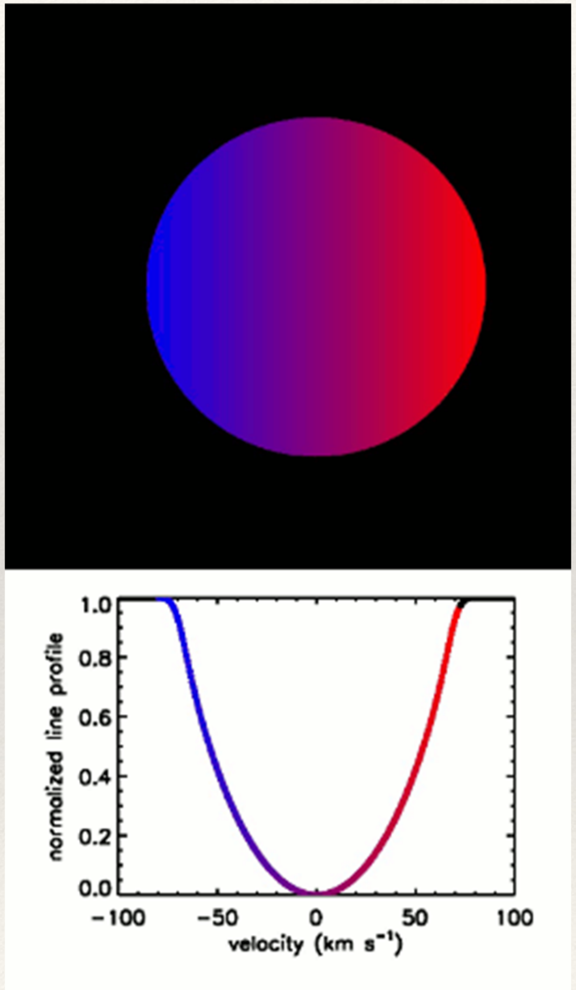
- Get fewer frequencies in spectroscopic analyses – complement with space photometry (TESS, …)
  Some frequencies not in common, *cancellation effects?,*
- Rapid Rotation: affects the asymptotic equal period spacing, spherical harmonic modes deformed, wave guide effect …
- Offset variation with respect to line centre difficult to model. Rotating models (Townsend) suggest maybe due to wave leakage from interior propagation zone



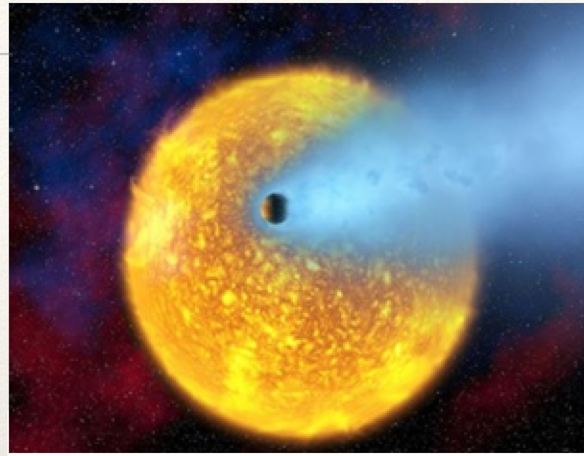
HD49434 CoRoT target

How can transits affect the stellar spectrum?





Doppler tomography (MC Johnson website)



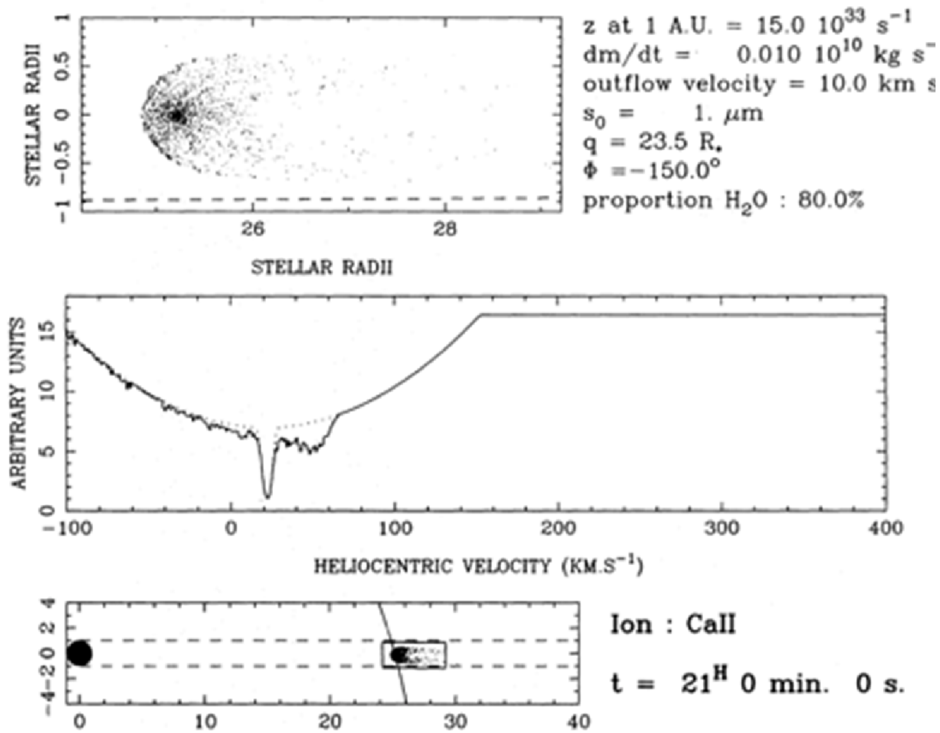
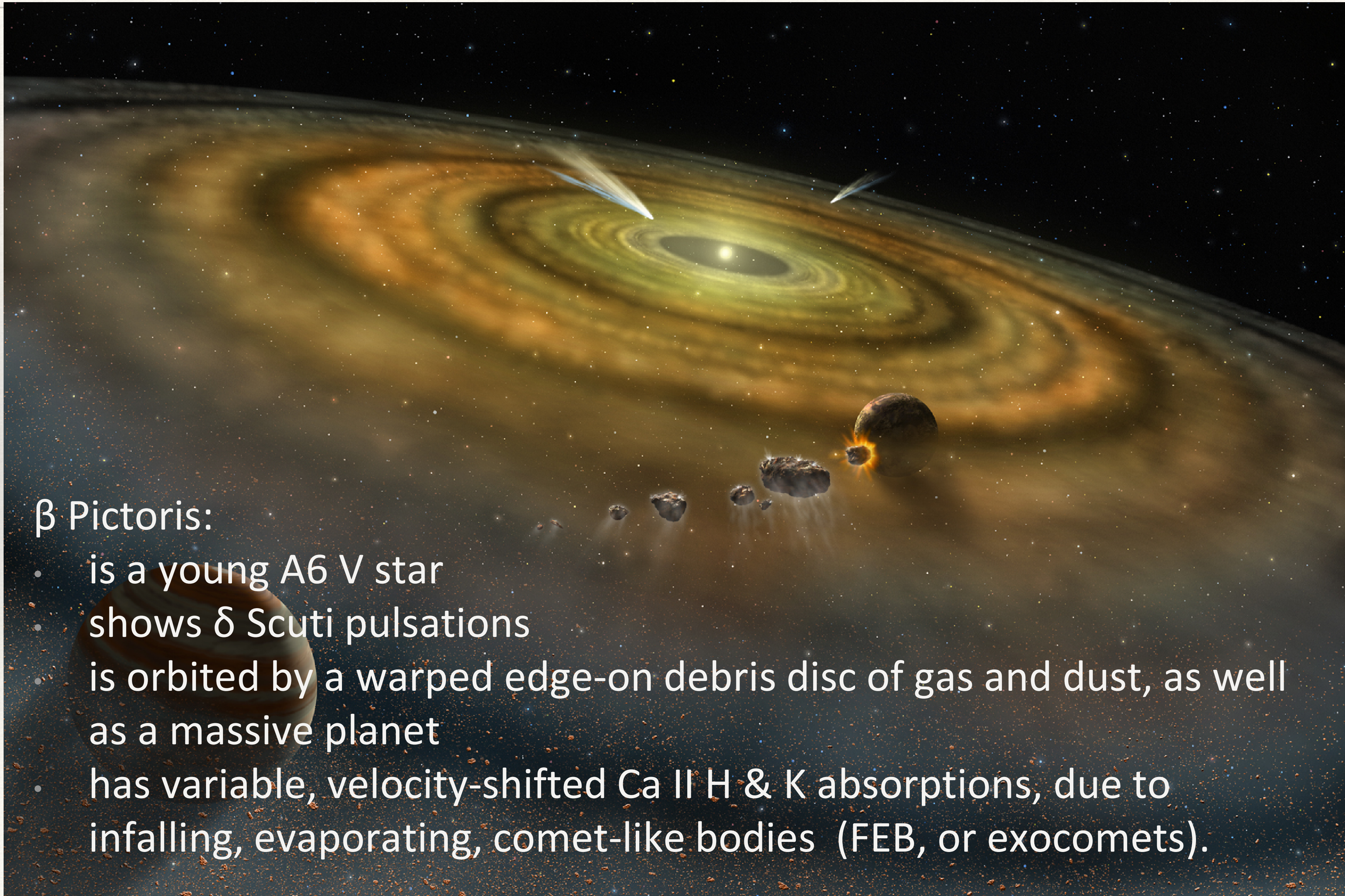


Fig. 7. Same as Fig. 5 but after 21^h. An additional absorption component is clearly present

β Pictoris



β Pictoris:

- is a young A6 V star
- shows δ Scuti pulsations
- is orbited by a warped edge-on debris disc of gas and dust, as well as a massive planet
- has variable, velocity-shifted Ca II H & K absorptions, due to infalling, evaporating, comet-like bodies (FEB, or exocomets).

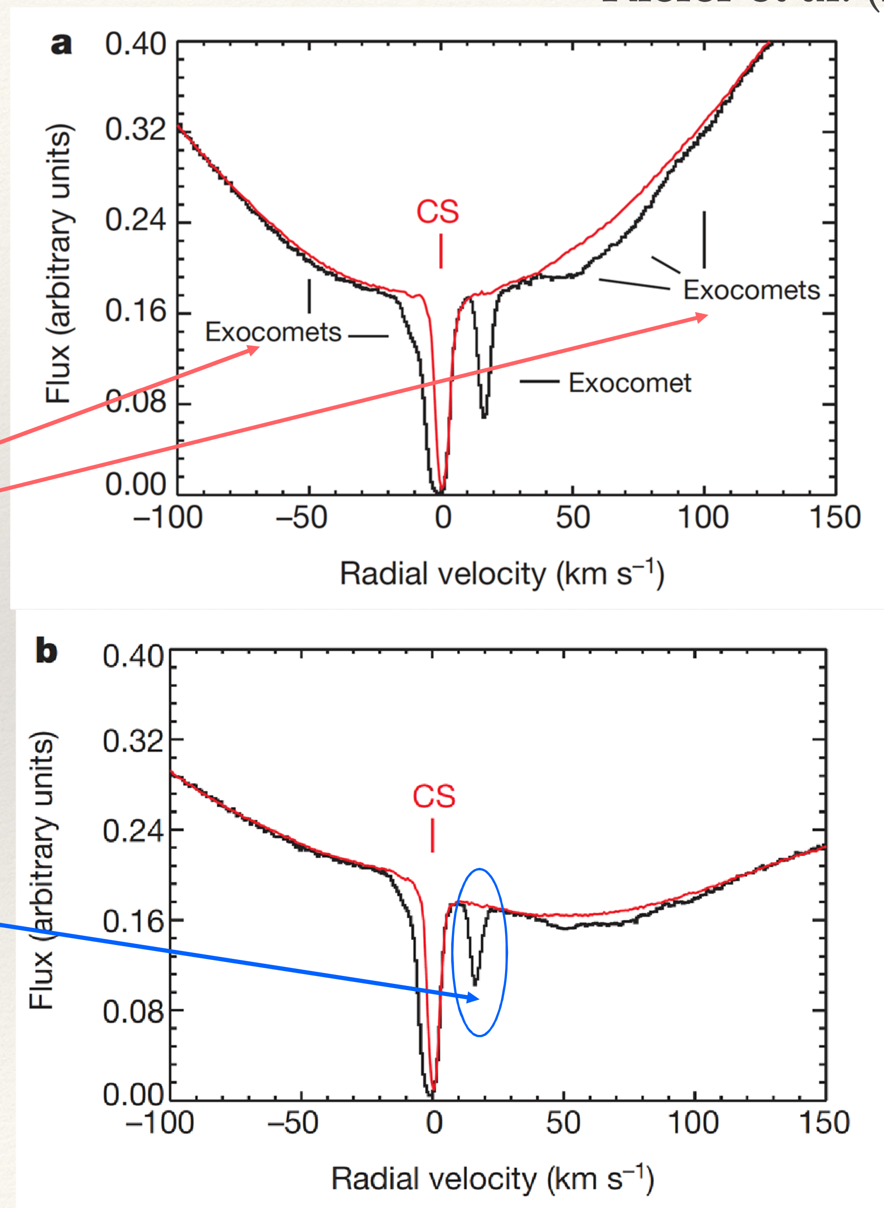
β Pictoris: two families of comets

Kiefer et al. (2014)

Kiefer et al. (2014) analysed HARPS data from 2003-2011 using Ca II H & K lines and found that β Pic's comets divided into two families:

Pop "S": Shallow, broad absorptions larger mean velocity and velocity range

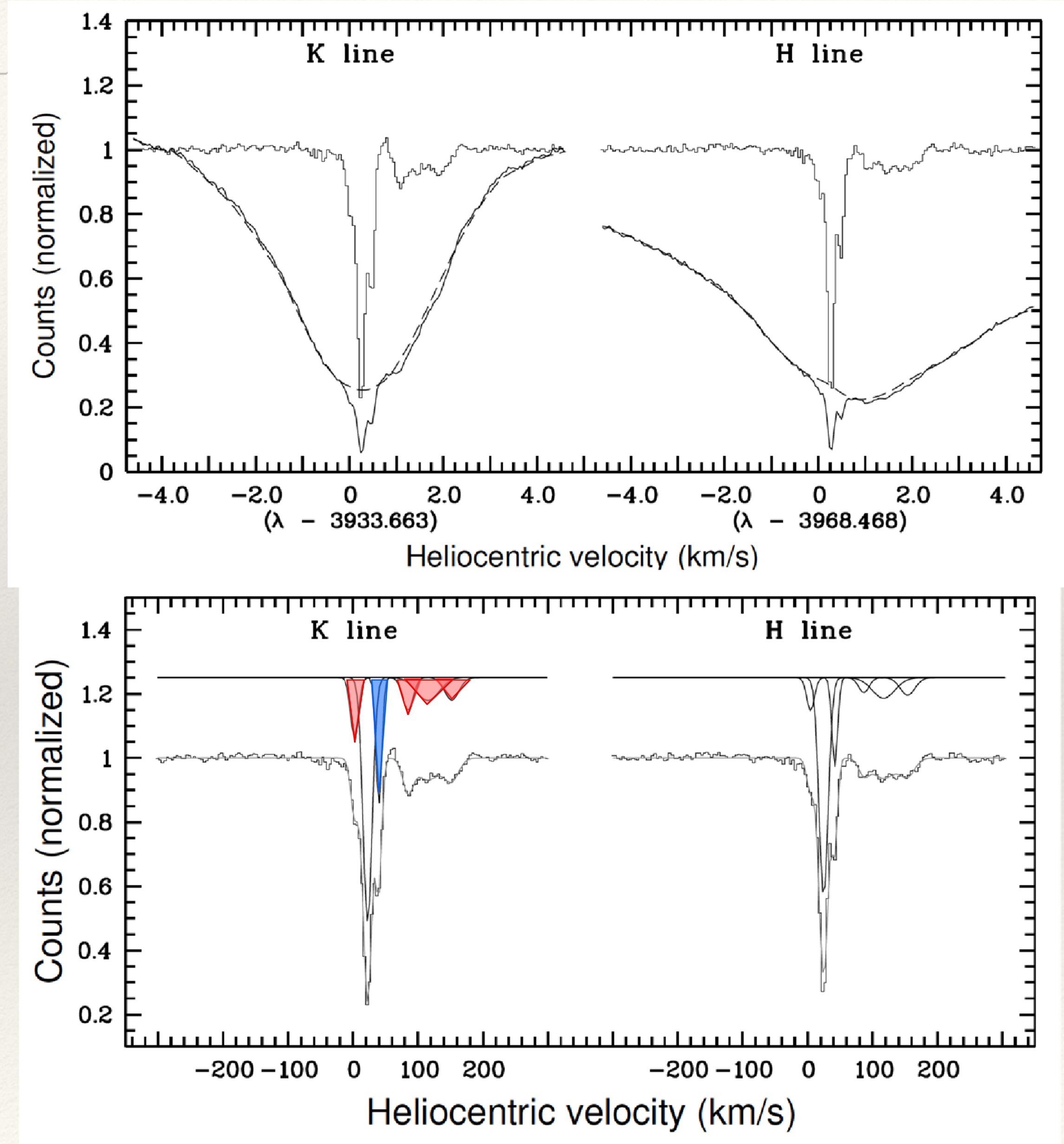
Pop "D" : Deep, narrower absorptions, smaller mean velocity and velocity range



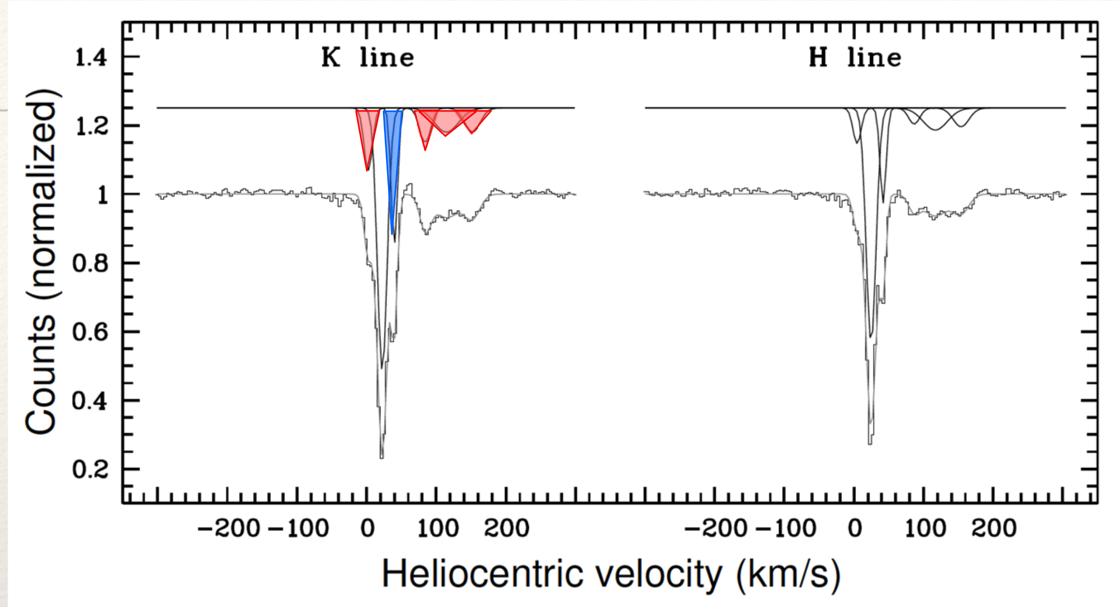
β Pictoris: our spectra and analysis

We have been monitoring β Pictoris at Mt John since 1994.

Fit absorptions: K depth (pK), H depth (pH), radial velocity (RV), and FWHM.

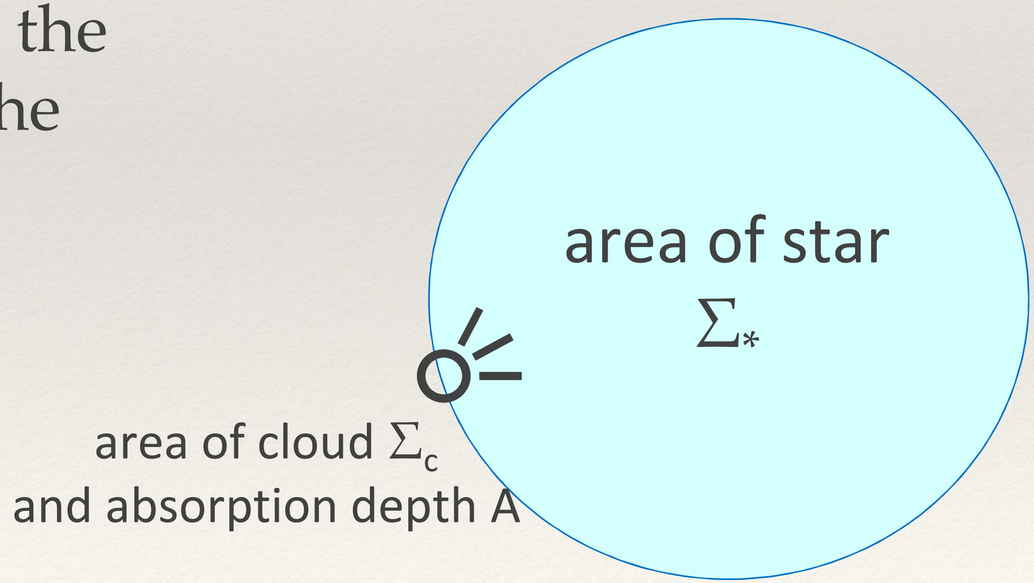


β Pictoris: our spectra and analysis

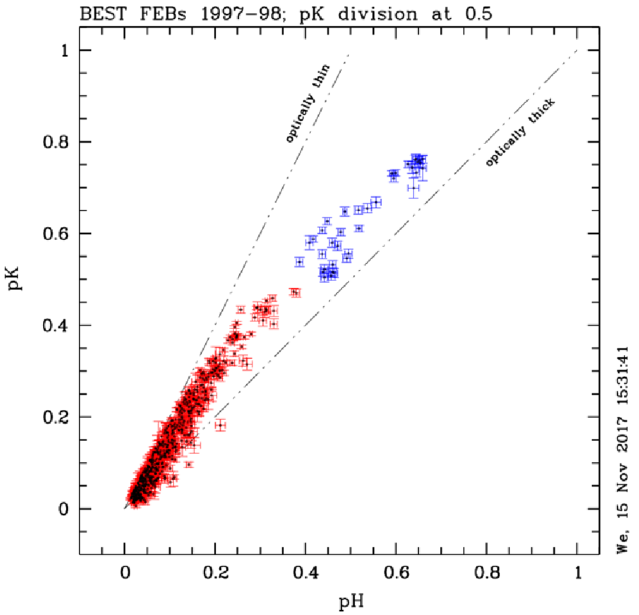


The H and K depths of each depend physically on:

- A, the obscuring Ca^+ cloud's absorption depth;
- ⟨ $= \Sigma_c / \Sigma_*$, the ratio of the area of cloud Σ_c over the area of stellar disc Σ_*



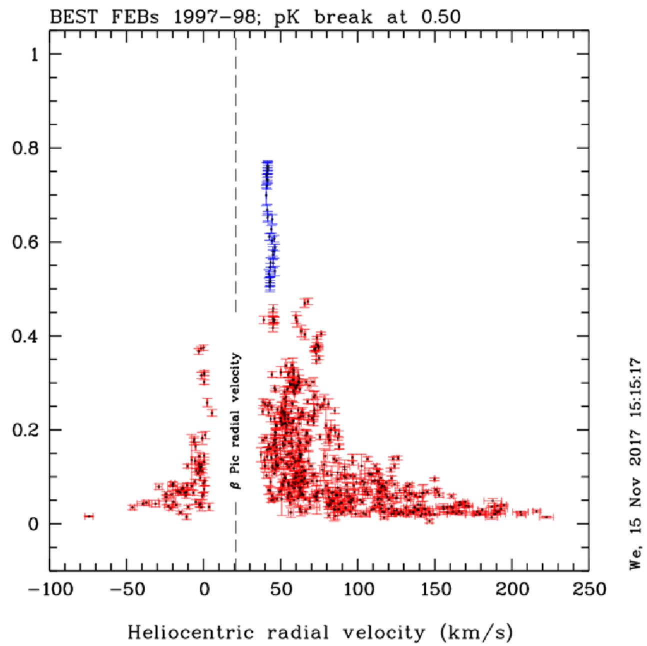
β Pictoris: our spectra and analysis

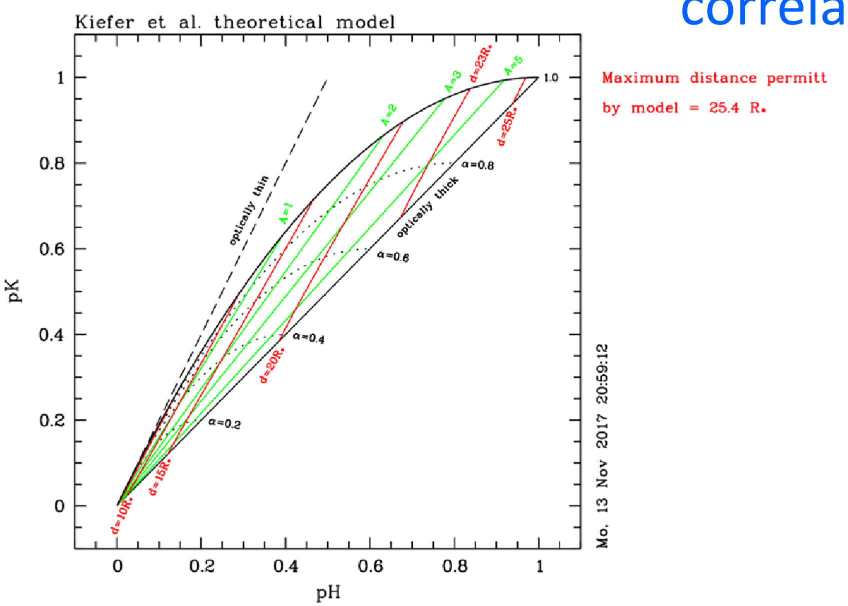


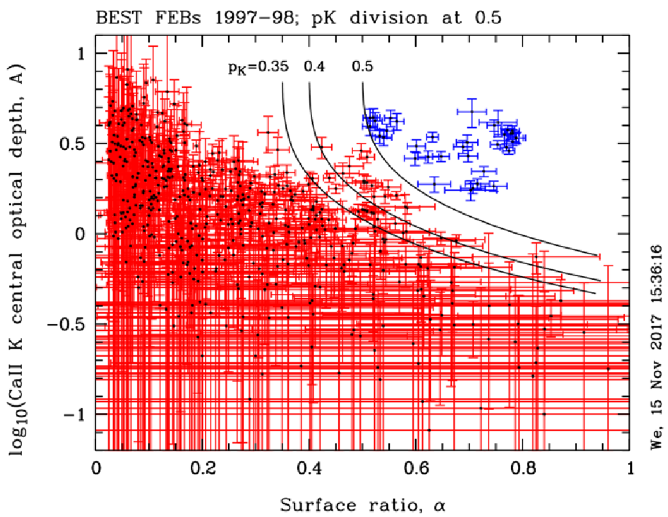
Characteristics of the two families of comets are clearly separated on these plots,

red points = shallower Population S

blue points = more tightly correlated population D.





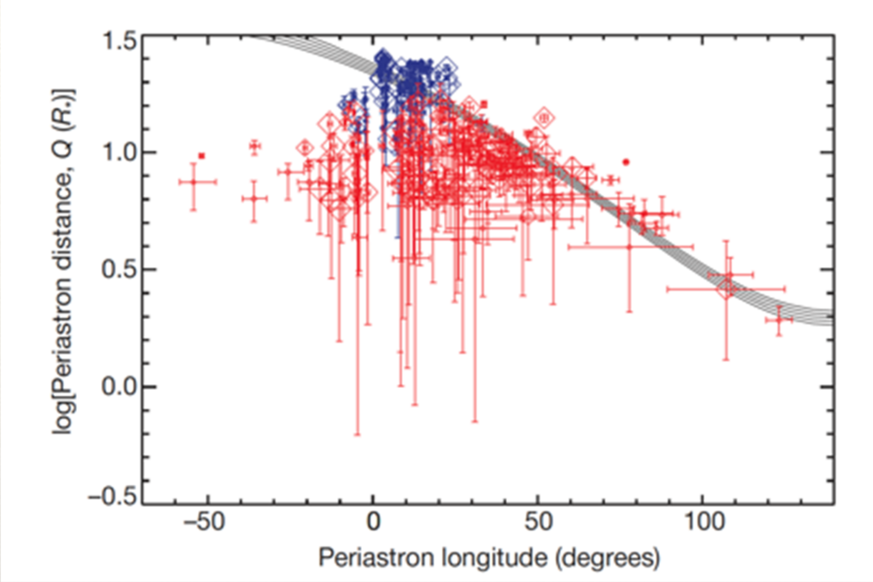


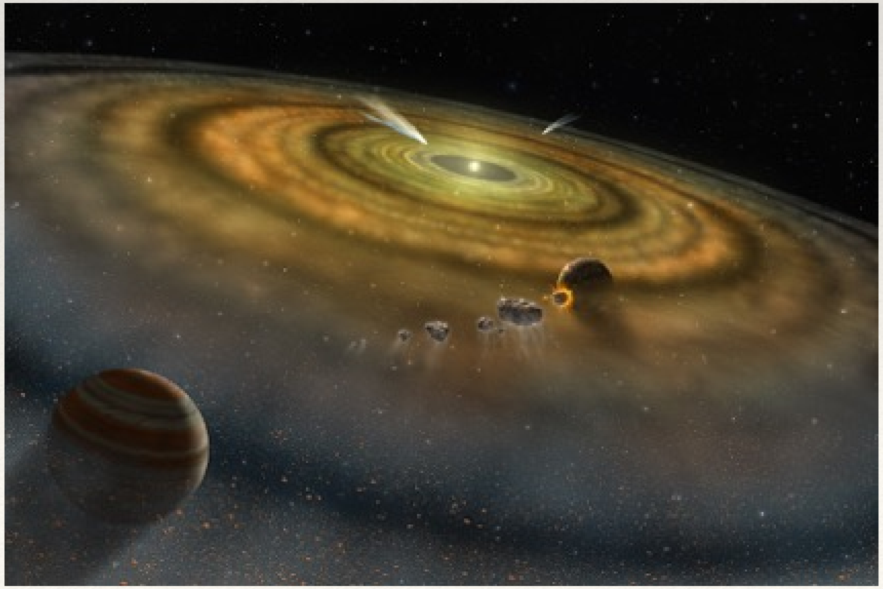
β Pictoris: interpretation

Two families of comets with different physical and dynamical properties:

Pop “S”: old comets, some of which have been perturbed into stargrazing orbits by mean motion resonances with a massive planet.

Pop “D”: perhaps recent fragmentation of one, or a few, parent bodies. The deep absorptions occur in streams that last for weeks, far exceeding the crossing time of individual comets.





Summary: Synergies with SONG

SONG and UC Mt John Observatory

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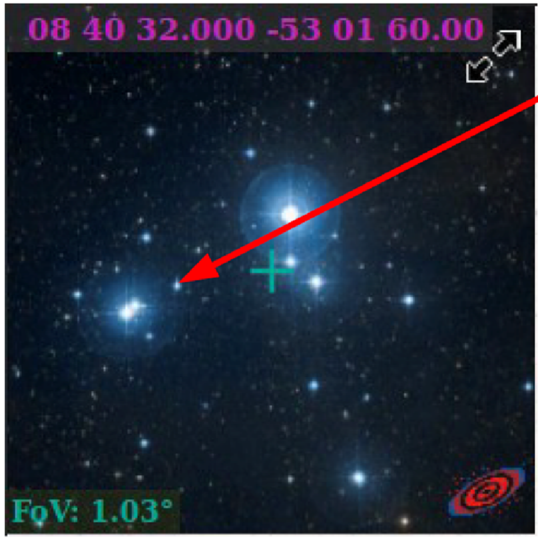
Spectroscopic Binaries in the Gaia-ESO Survey

Spectroscopic Binaries in the Gaia-ESO Survey

collaboration with T. Merle, M. Van der Swaelmen.

The unique SB4 candidate in GES

Open Cluster IC2391



HD 74438
V = 7.6
Spectral type: A2V
M ~ 3 M⊙

In open cluster IC 2391
V_{OC} = 14.8 ± 1.0 km/s

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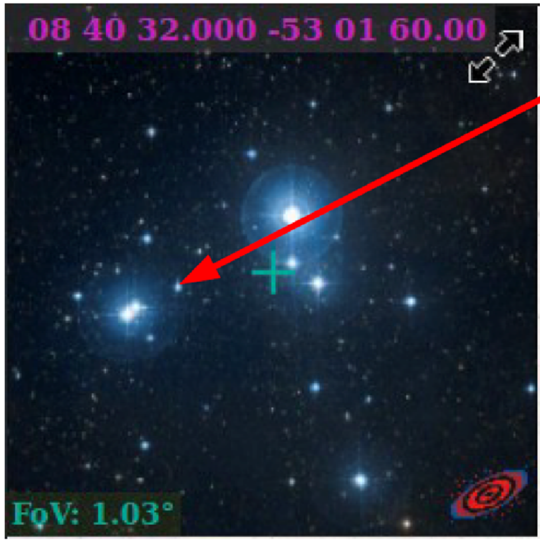
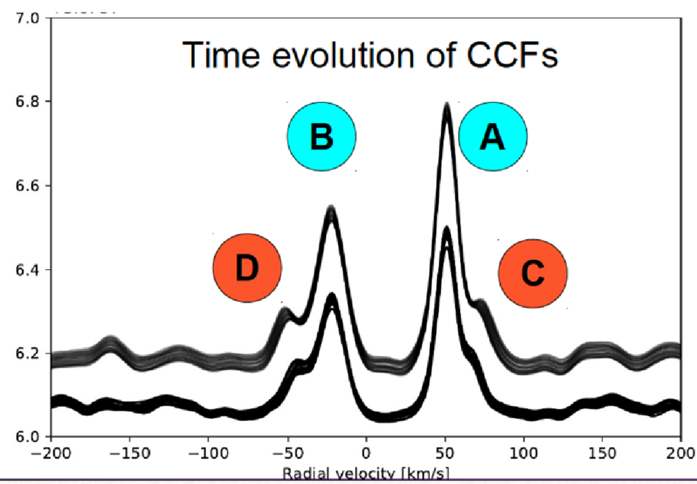


HD 74438
V = 7.6
Spectral type: A2V
M ~ 3 M☉

In open cluster IC 2391
V_{OC} = 14.8 ± 1.0 km/s

UVES
R = 47000
45 exposures in < 2.5 h
Merle+ 2017



Spectroscopic Binaries in the Gaia-ESO Survey

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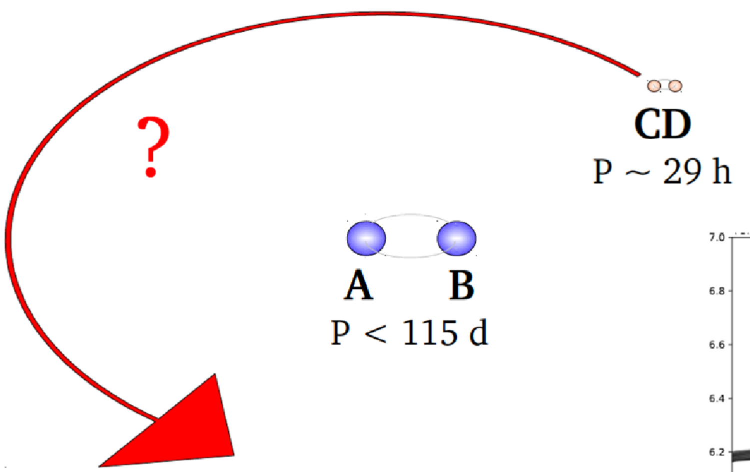
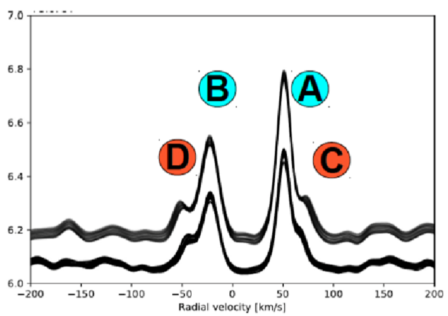
The unique SB4 candidate in GES: what can we say

Système HD 74438



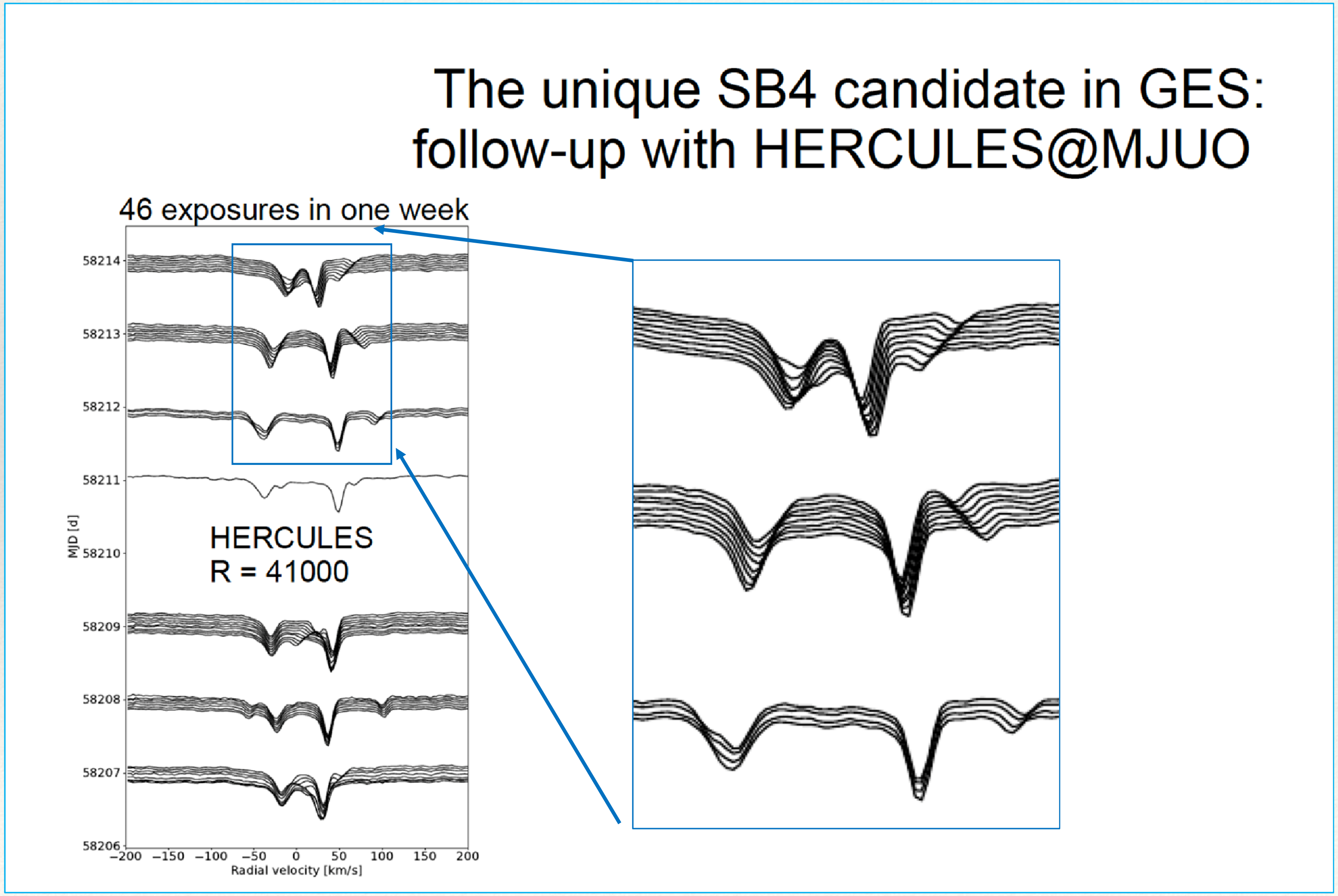


Follow-up

- with HERCULES (R=41000) at Mount John University Observatory in New-Zeland
- With HRS@ SALT (R=40000 & 65000) in South Africa

Spectroscopic Binaries in the Gaia-ESO Survey

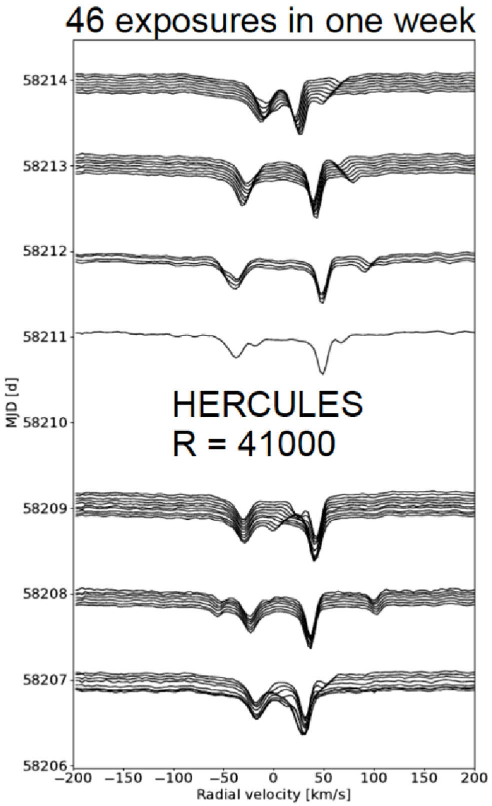
collaboration with T. Merle, M. Van der Swaelmen.

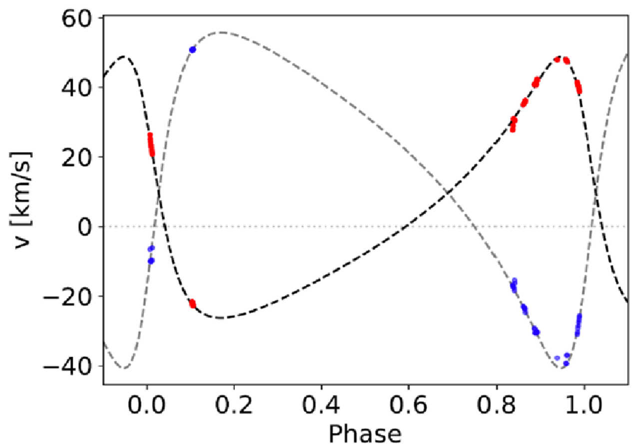


Spectroscopic Binaries in the Gaia-ESO Survey

collaboration with T. Merle, M. Van der Swaelmen.

The unique SB4 candidate in GES: follow-up with HERCULES@MJUO





Orbital element of the AB pair:
period = 40 d, eccentricity = 0.5

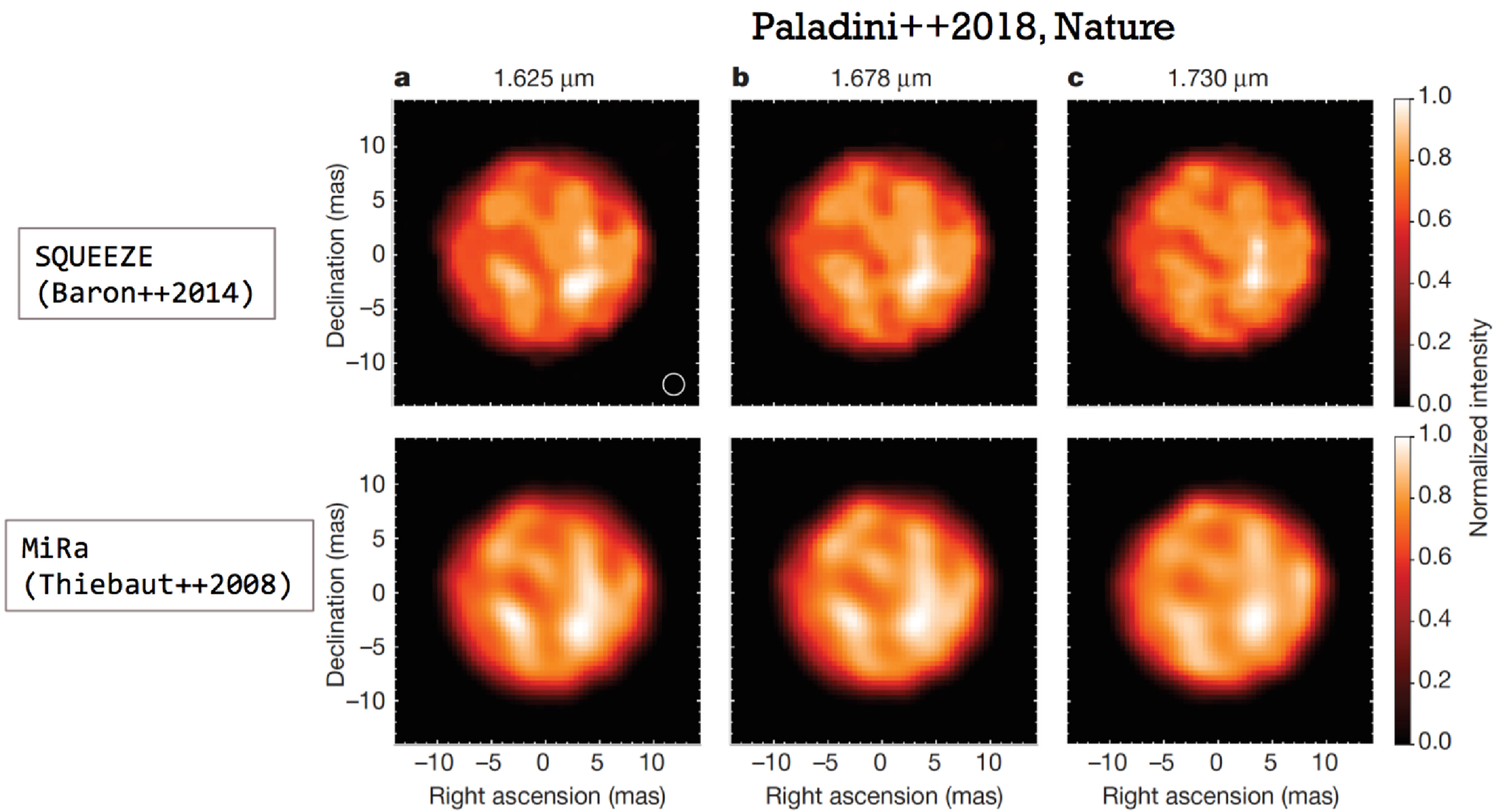
Tricky to fit CD pair (work in progress)

Few SB4 known:

- KIC4247791: 2 EBs (Lehmann+2012)
- EPIC220204960: 2 EBs M stars (Rappaport+ 2016)

VLTI/GRAVITY studies to characterise convection on surface of evolved AGB stars

THE (SUR)FACE OF PI[1] GRU

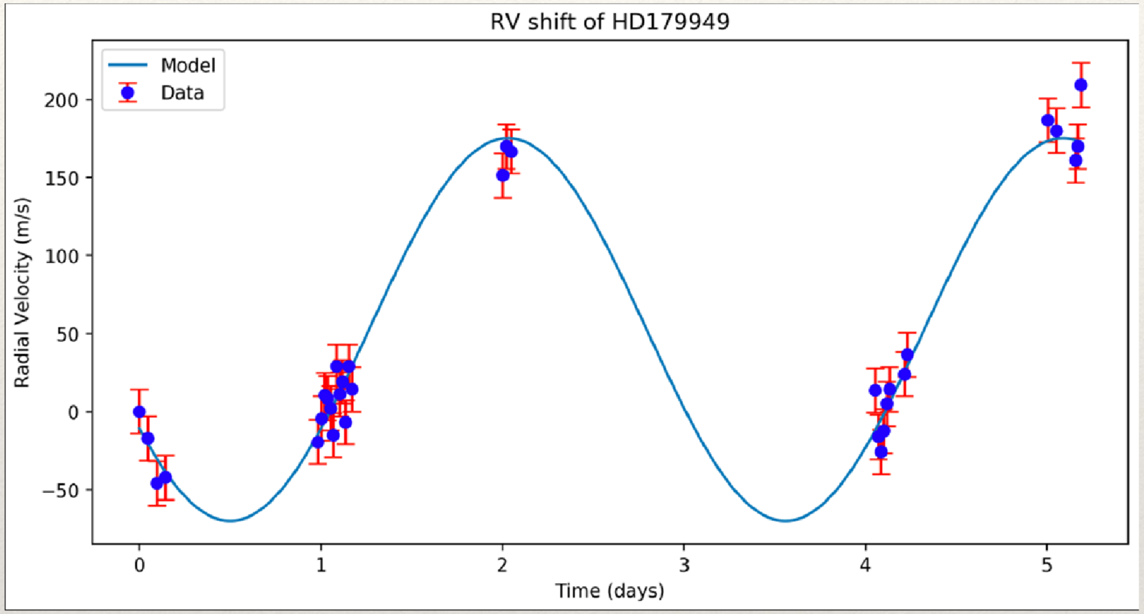


S-type AGB semiregular variable [collaboration with Claudia Paladini]


29 July 2018
University of Canterbury Mt John Observatory
Boller and Chivens 0.6m Telescope
UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND
OTAGOmuseum

Exo-planets (rv technique)

- 1st year student observing project of exoplanet host star HD179949
- Fibre1, R~41000, 6 nights of observation (snow night3), std reduction + auto-cross-correlation of best orders, rms = 15 m/s
- P=3.0925, msini=0.92, a=0.045



Property	Value	Uncertainty	Units
Orbital Period	3.06	±0.148	days
Semi-Major Axis	0.0442	±0.00249	AU
sin(i) Mass	1.01	±0.173	M_{Jup}

Jesse Satherley ASTR211 project

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