Accurate dynamical masses from binaries with extreme brightness ratios

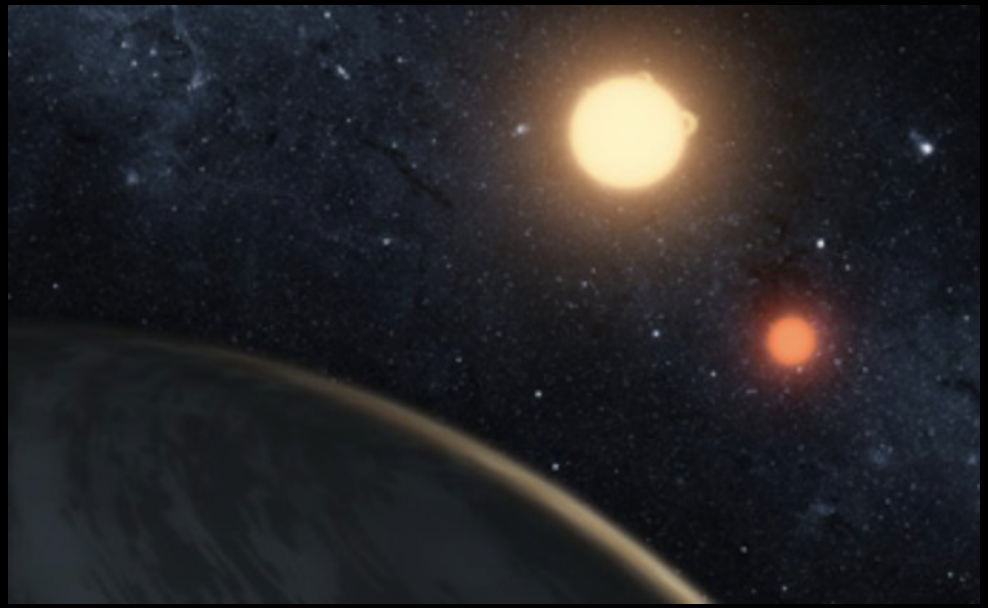


Image credits: NASA

European Research Council
Established by the European Commission

UNIVERSITY OF BIRMINGHAM

Daniel Sebastian, University of Birmingham

The EBLM project

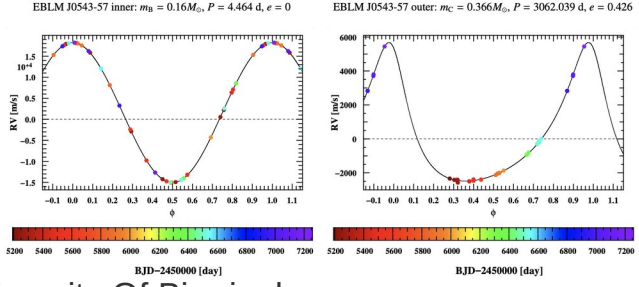
Eclipsing Binary - Low Mass

- Eclipsing FGK-M binaries EBLM I - Triaud et al. 2013
- Jupiter-like transit light curves
  - WASP
  - TESS
  - CHEOPS ...

WASP , Pollacco et al. 2006

- High contrast binaries (**ΔF ~1e-4 (SB1)**)
- Radial velocity survey ~ 200 EBLM

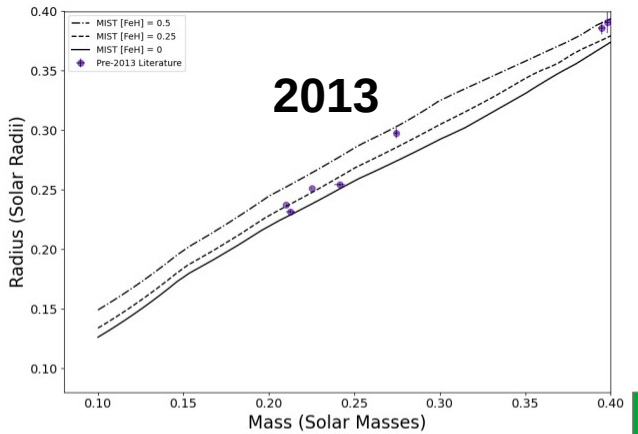
  Optical spectra (CORALIE, HARPS, ESPRESSO, SOPHIE)

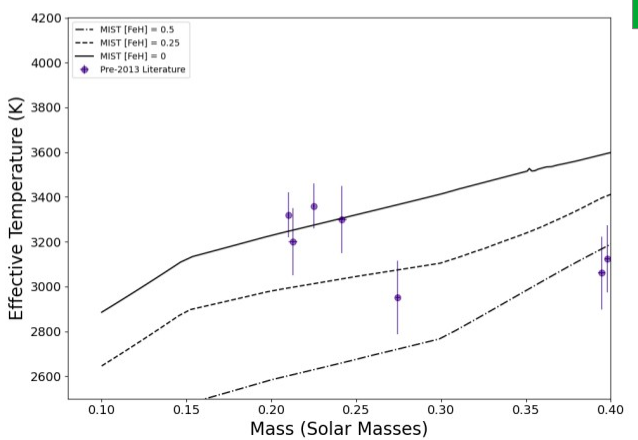


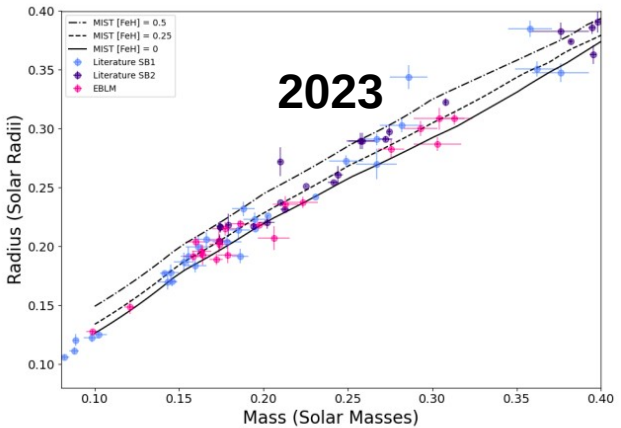
EBLM IV - Triaud et al. 2017

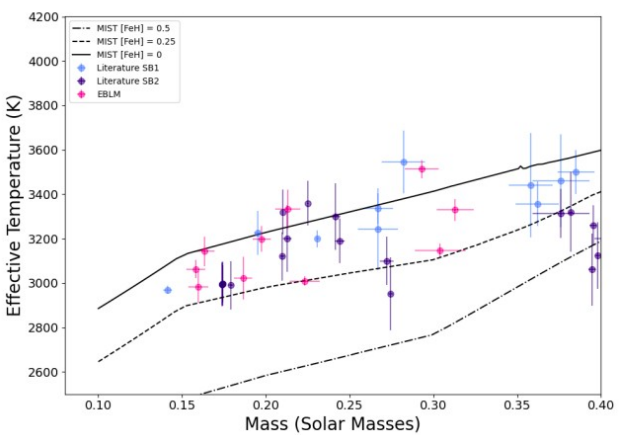
Main Goal of the EBLM project

- Empirical mass-radius relationship





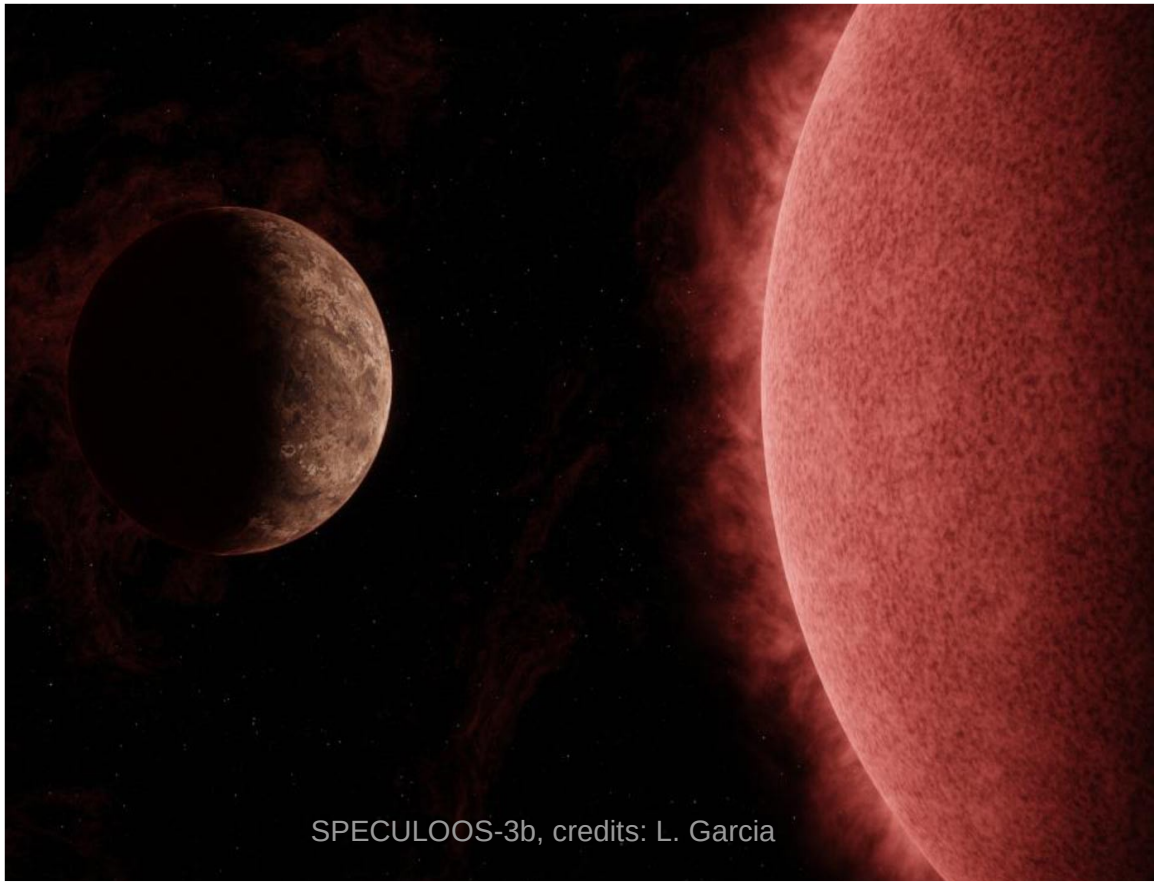




Maxted et al. 2023

Why low-mass stars?

- **< 0.35$M_\odot$** - low-mass Main-sequence
- Fully convective cores
  - improve models for stellar masses and radii
    - Radius inflation? e.g. Spada et al. 2013
  - Characterisation of terrestrial planets
  - Trappist-1, LP 890-9c, SPECULOOS-3b, …
    - Planet masses, radii & atmospheres

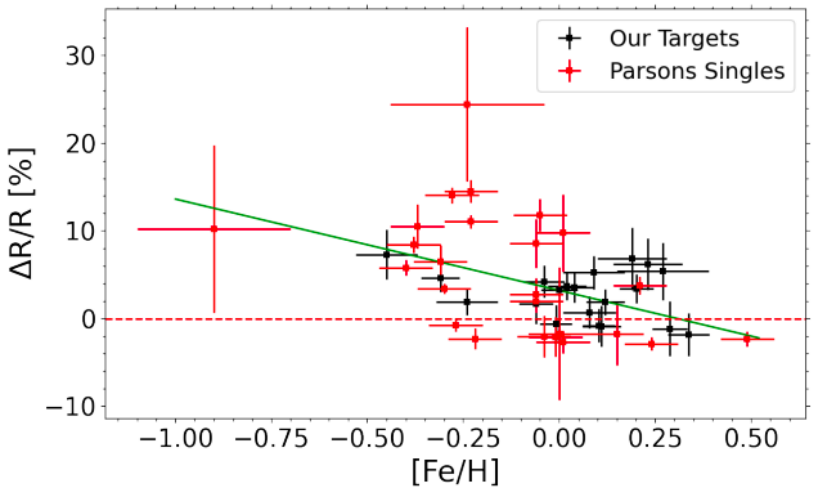


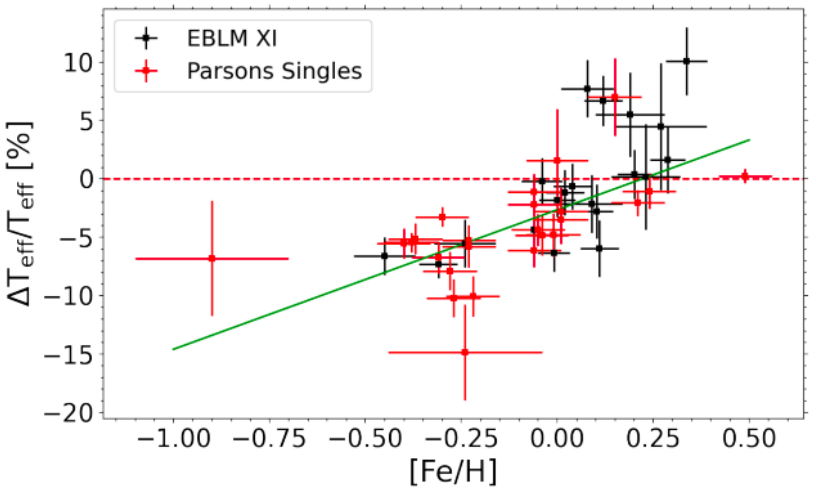
SPECULOOS-3b, credits: L. Garcia

Impact of the EBLM project

- Good agreement to stellar evolutionary models
  - Radii – few percent
  - Effective Temperatures ~100K

EBLM XI - Swayne et al. 2024

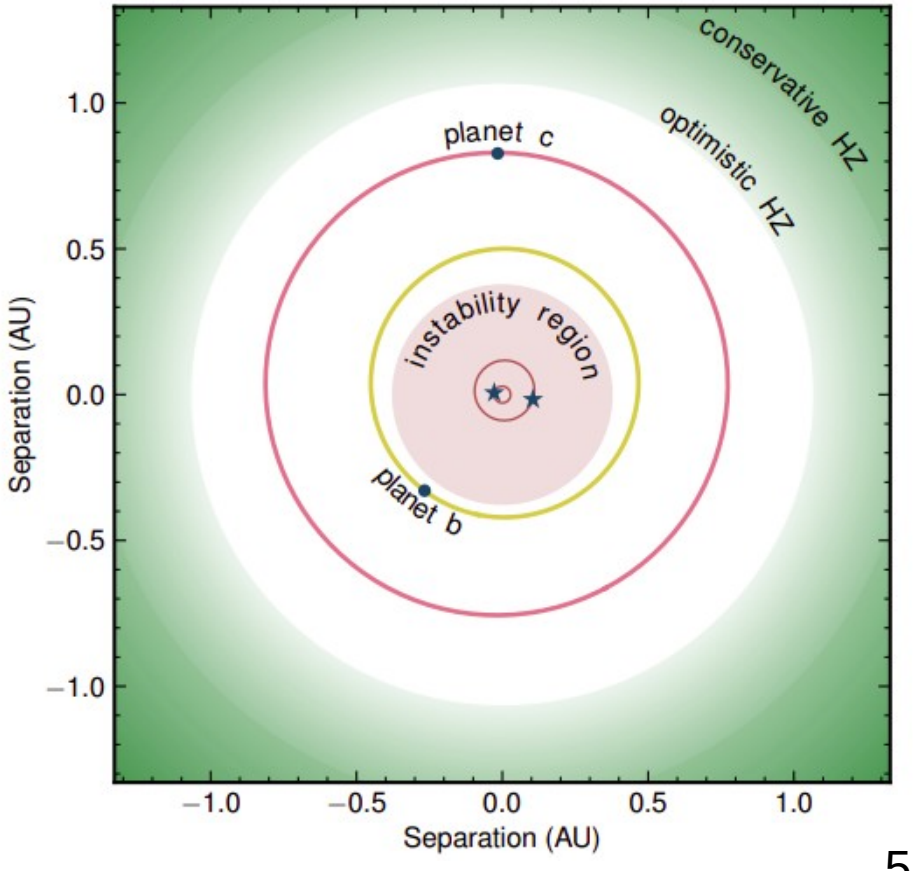




Impact of the EBLM project

- Detection of circumbinary planets
- **e.g. TOI-1338 / BEBOP-1 / EBLM J0608-59**

  (Talk by Lalitha Sairam)

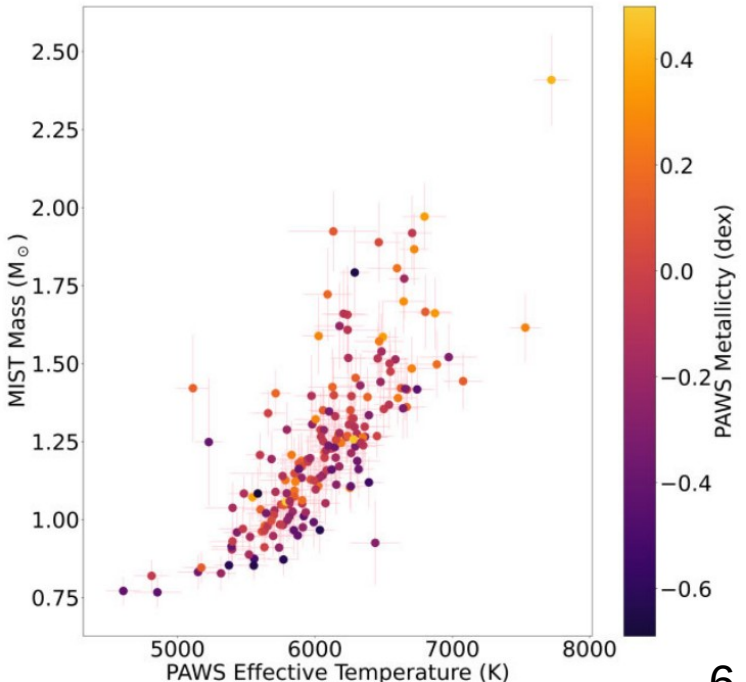


Standing et al. 2023

Impact of the EBLM project

Primary parameters are essential

- Homogenous characterisation of 179 FGK-M primaries BEBOP V - Freckelton et al. 2024
  - Using >4500 high-resolution spectra
    - Primary metallicities, T_{eff}
    - Primary masses and radii (MIST)



Impact of the EBLM project

Primary parameters are essential

- Homogenous characterisation of 179 FGK-M primaries BEBOP V - Freckelton et al. 2024
  - Using >4500 high-resolution spectra
    - Primary metallicities, T_{eff}
    - Primary masses and radii (MIST) - model dependent

EBLM often not on binary catalogues such as DEBcat Southworth 2015

- Stellar density from eclipse light curves EBLM XII - Davis et al. 2024
  - **Accurate M_1** using R_1 (Gaia)
    - relies on R_1

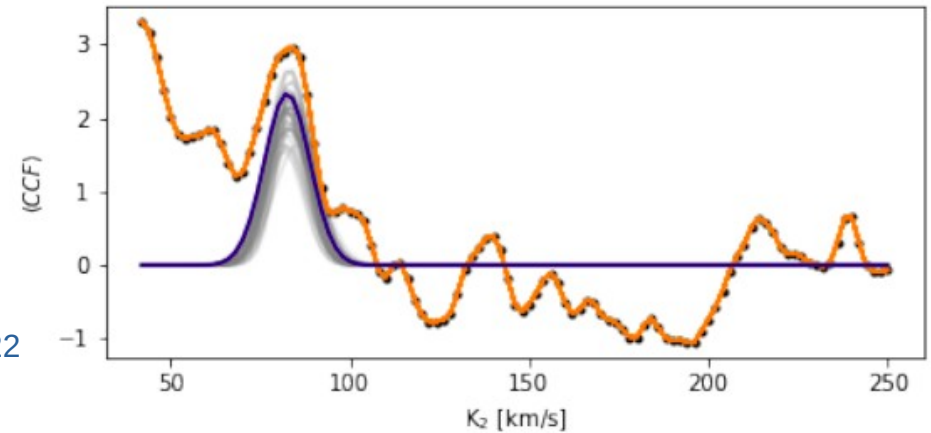
Dynamical masses

Turning the SB1 into SB2
- Model independent masses!

Lower contrast in NIR (SPIRou)

e.g. **EBLM J0113+31**

Maxted et al. 2022



Combined Cross-correlation
- in secondary rest-frame (vary semi-amplitude)

- Primary signal main source of noise
- Not detectable in optical spectra (?)

Dynamical masses from HRCCS

Planet atmospheres contrast (1e-5) detected!

nature

Explore content · About the journal · Publish with us · Subscribe

nature › letters › article

Published: 27 June 2012

The signature of orbital motion from the dayside of the planet τ Boötis b

Matteo Brogi, Ignas A. G. Snellen, Remco J. de Kok, Simon Albrecht, Jayne Birkby & Ernst J. W. de

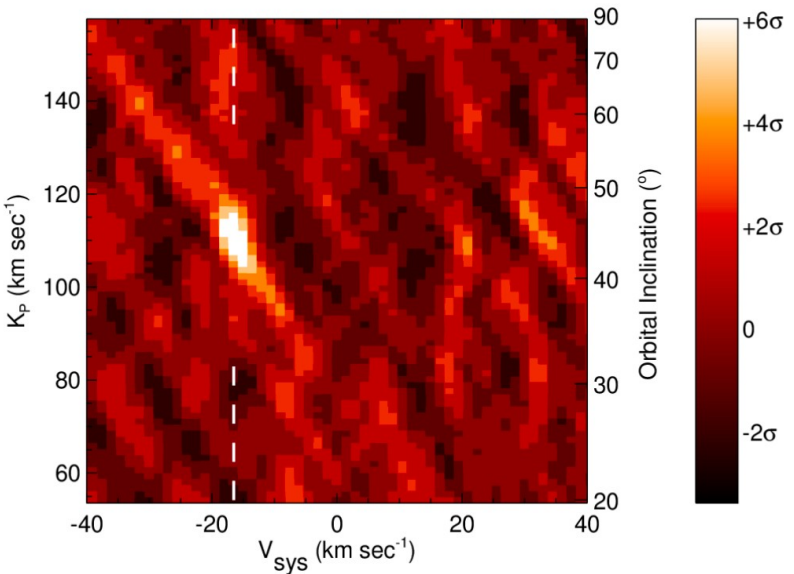
The Astronomical Journal, 161:209 (27pp), 2021 May https://doi.org/10.3847/1538-3881/abe768

A Near-infrared Chemical Inventory of the Atmosphere of 55 Cancri e

Emily K. Deibert[1,2], Ernst J. W. de Mooij[3], Ray Jayawardhana[4], Andrew Ridden-Harper[4], Suresh Sivanandam[1,2], Raine Karjalainen[5,6,7], and Marie Karjalainen[5]

[1] David A. Dunlap Department of Astronomy & Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada; deibert@astro.utoronto.ca
[2] Dunlap Institute for Astronomy & Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada
[3] Astrophysics Research Centre, Queen's University Belfast, Belfast BT7 1NN, UK
[4] Department of Astronomy, Cornell University, Ithaca, New York 14853, USA
[5] Astronomical Institute, Czech Academy of Sciences, Fričova 298, 25165, Ondřejov, Czech Republic
[6] Instituto de Astrofísica de Canarias, c/ Vía Láctea s/n E-38205 La Laguna, Tenerife, Spain
[7] Isaac Newton Group of Telescopes, Apartado de Correos 321, Santa Cruz de La Palma, E-38700, Spain

Received 2020 November 2; revised 2021 February 1; accepted 2021 February 16; published 2021 April 7



Brogi et al. 2012

EBLM = Eclipsing Binary – Low Mass

Detrending in HRCCS

In IR:

Fitting & filtering

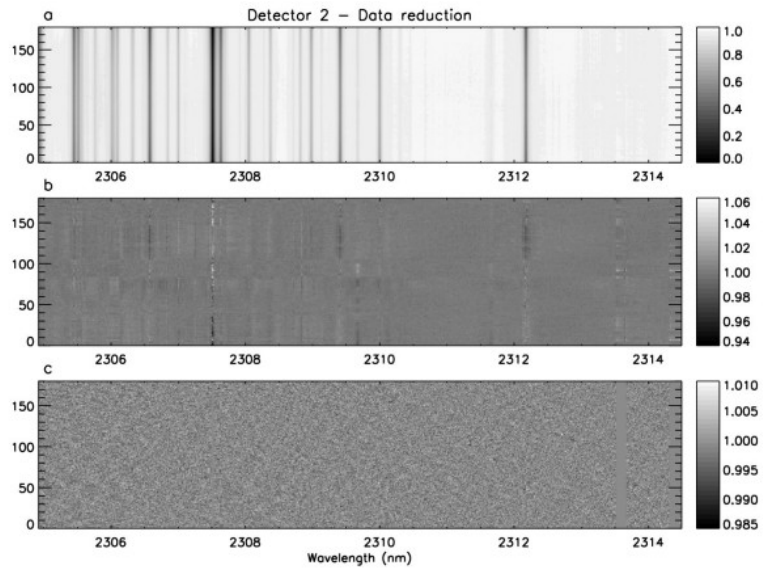
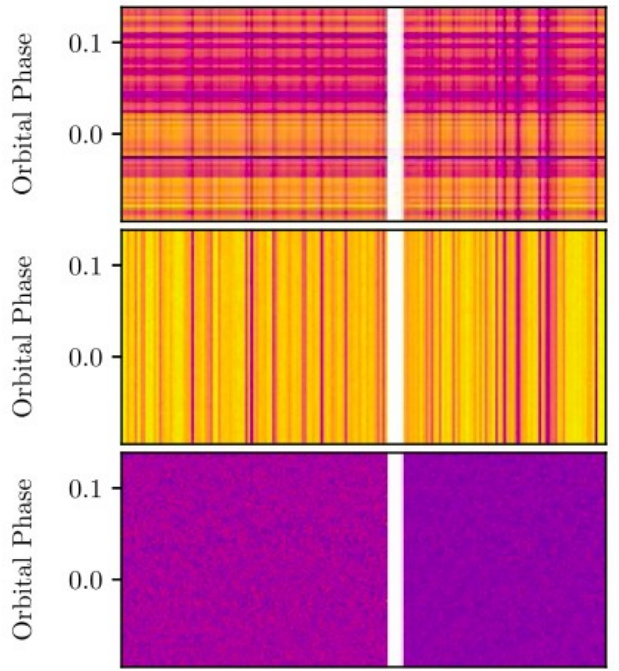


Fig. S2: An example of our data reduction chain, showing the spectral series from CRIRES detector

Brogi et al. 2012

Singular value decomposition (SVD)

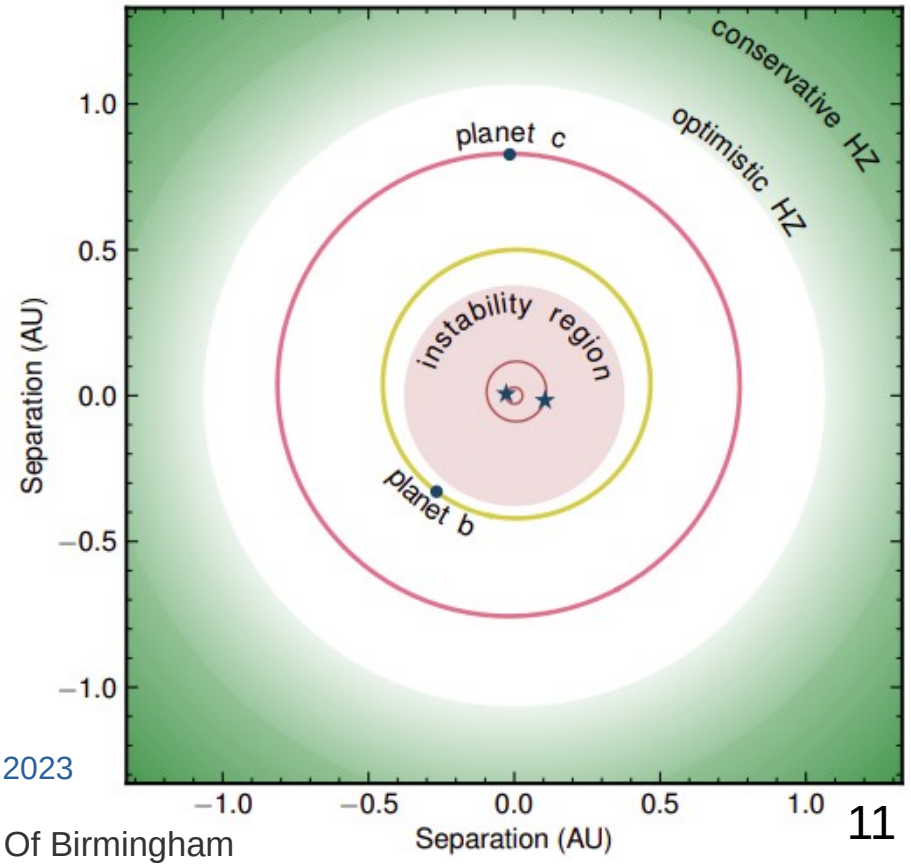


Deibert et al. 2021

High contrast binaries

TOI-1338 / BEBOP-1 / EBLM J0608-59

- **1.1 + 0.3 M_{sun} eclipsing binary**
- **contrast ratio 0.2% (SB1)**
- **103 ESPRESSO@VLT spectra**

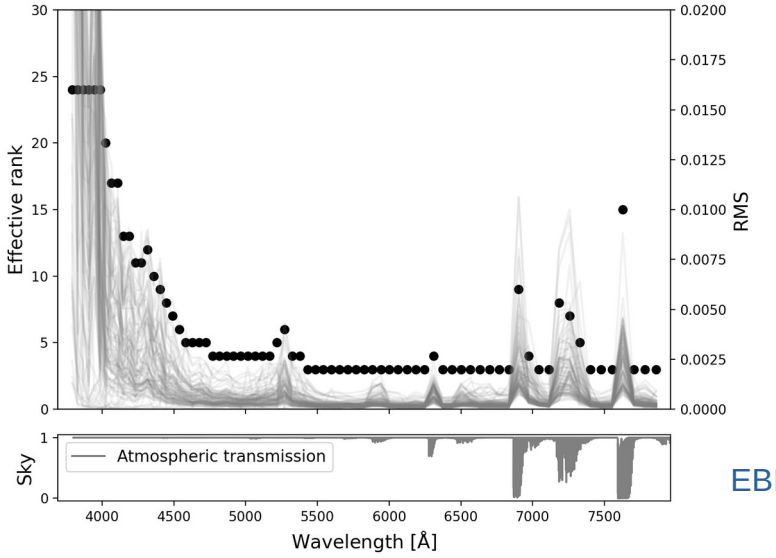


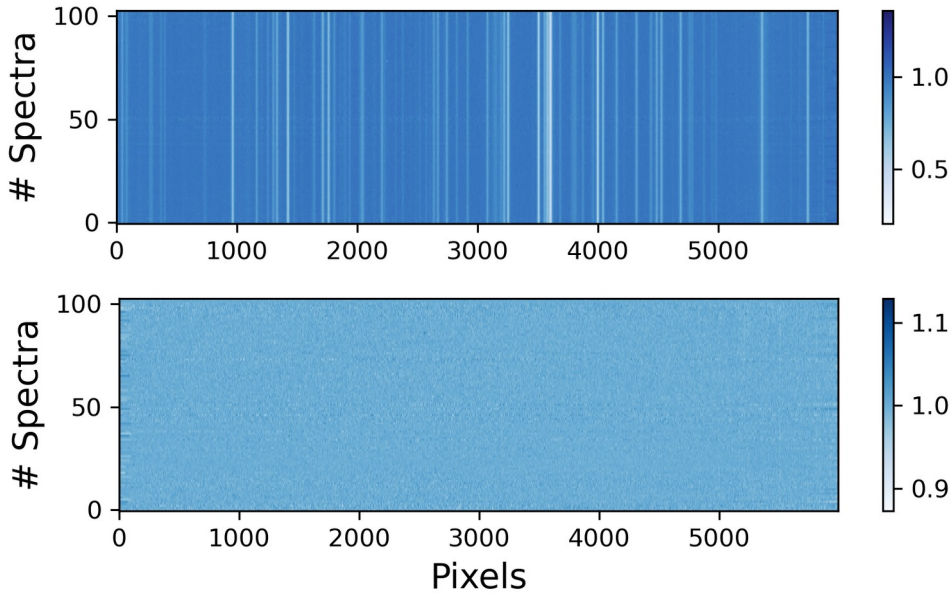
Standing et al. 2023

High contrast binaries

TOI-1338 / BEBOP-1 / EBLM J0608-59

- **removal of primary lines via SVD**
- **Use ‘effective SVD rank’** Roy and Vetterli 2007



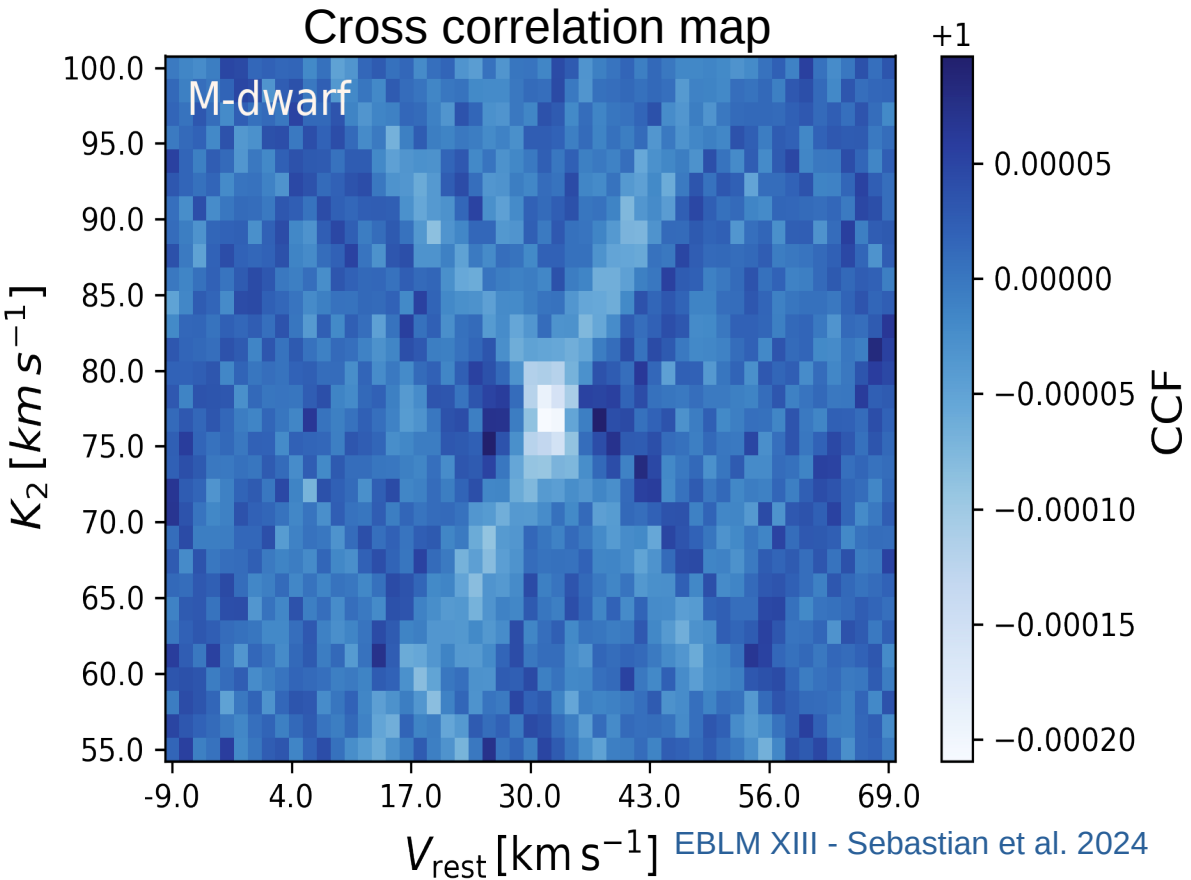


EBLM XIII - Sebastian et al. 2024

High contrast binaries

TOI-1338 / BEBOP-1 AB / EBLM J0608-59

- **CCF with line mask**
- **11 σ detection of the M-dwarf!** (Secondary SNR < 0.1!)
- **Signal is still intact after SVD!**



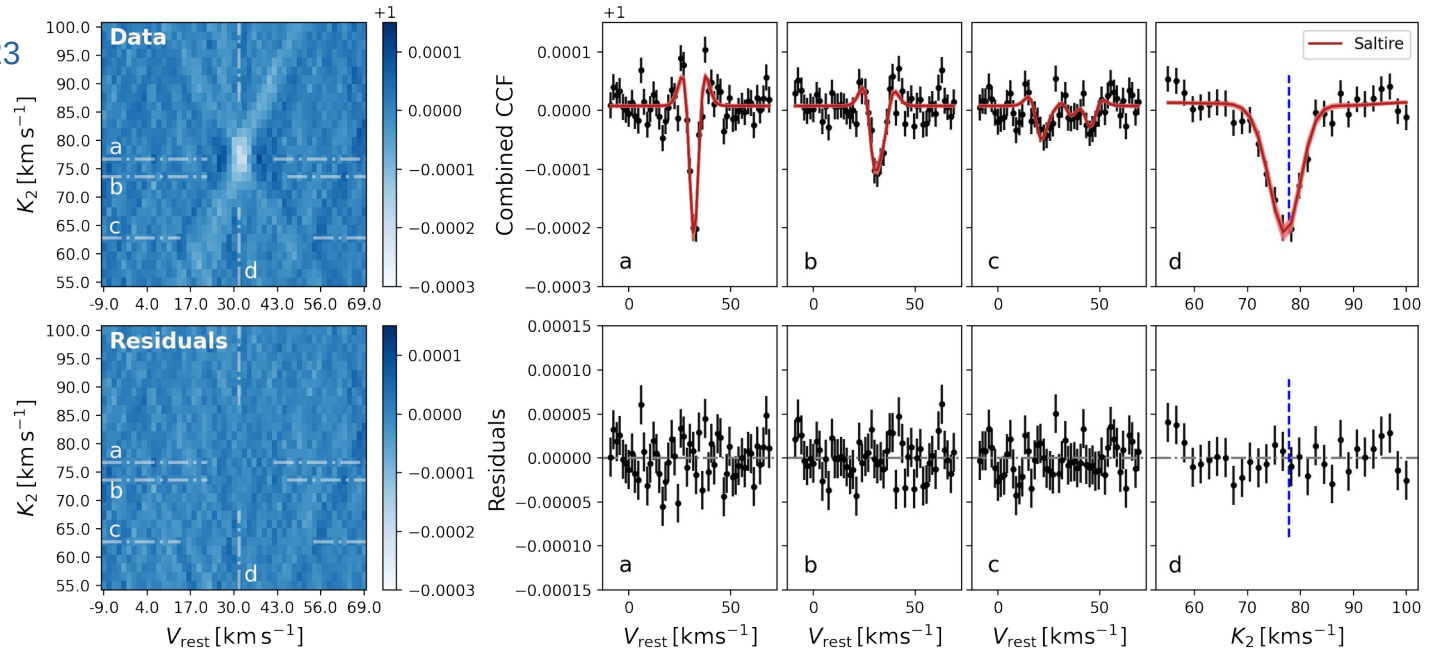
EBLM XIII - Sebastian et al. 2024

Measuring accurate masses

Saltire model Sebastian et al. 2023

- Available on Github

- Full noise analysis



TOI-1338 / BEBOP-1 AB / EBLM J0608-59

EBLM = Eclipsing Binary – Low Mass

Measuring accurate masses

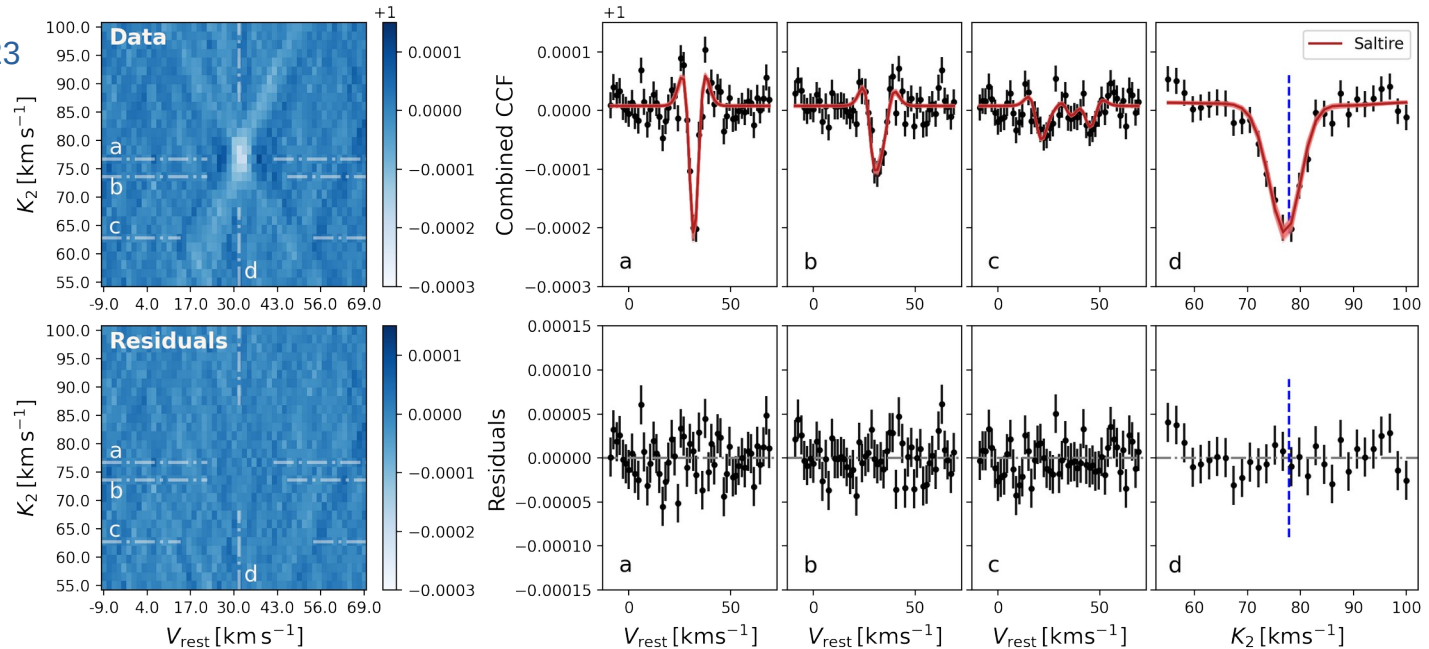
Saltire model Sebastian et al. 2023

- Available on Github

- Full noise analysis

- 0.307 ± 0.003 $M_\odot$ **(1%)**
- 1.098 ± 0.017 $M_\odot$ **(1.6%)**

EBLM XIII - Sebastian et al. 2024



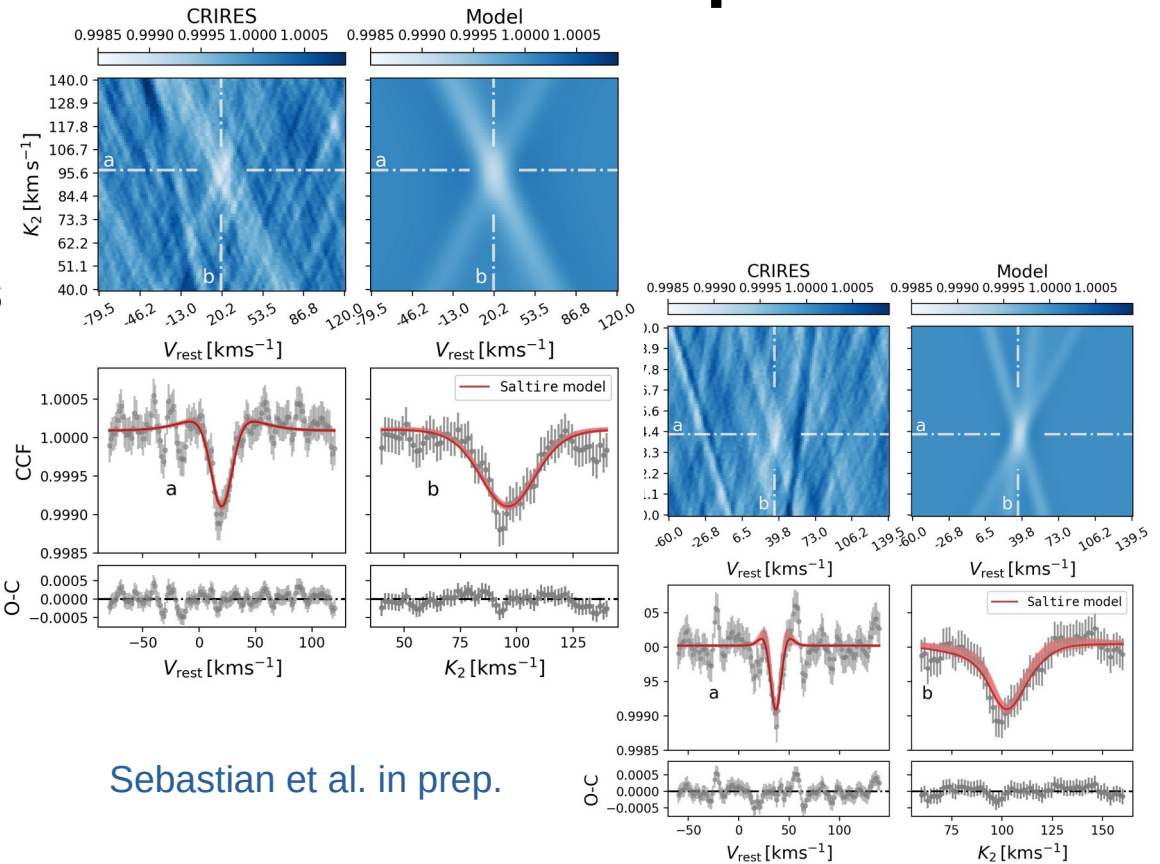
TOI-1338 / BEBOP-1 AB / EBLM J0608-59

- **Fully consistent (1 σ) with standard SB1 measurements** Kostov et al. 2020

To the bottom of the main-sequence

CRIRES$^+$ observations, K-band

- Strong telluric + primary contributions
- 3 EBLM with M_2 ~ 0.1 $M_\odot$!
- metallicities, masses and radii!



Sebastian et al. in prep.

EBLM = Eclipsing Binary – Low Mass

Summary

- EBLM project - Primary characterisation is important
  - Model dependency questioned
- Entering a new phase
  - Turning SB1 to SB2 – dynamical masses
    - Saltire model for accurate mass estimation
    - Validate previous results
- Pushing towards lowest mass stars using IR observations
- Applicable to other high-contrast binaries -> red giants

https://github.com/dsagred/saltire

Papers:

Saltire: a model to measure dynamical masses for high-contrast binaries and exoplanets, 2024MNRAS.52710921S

The EBLM project - XIII. The absolute dynamical masses of the circumbinary planet host TOI-1338/BEBOP-1, 2024MNRAS.530.2572S

Outline

- Introduction EBLM project
- Dynamical masses in the optical
- Expanding into to bottom of the main-sequence