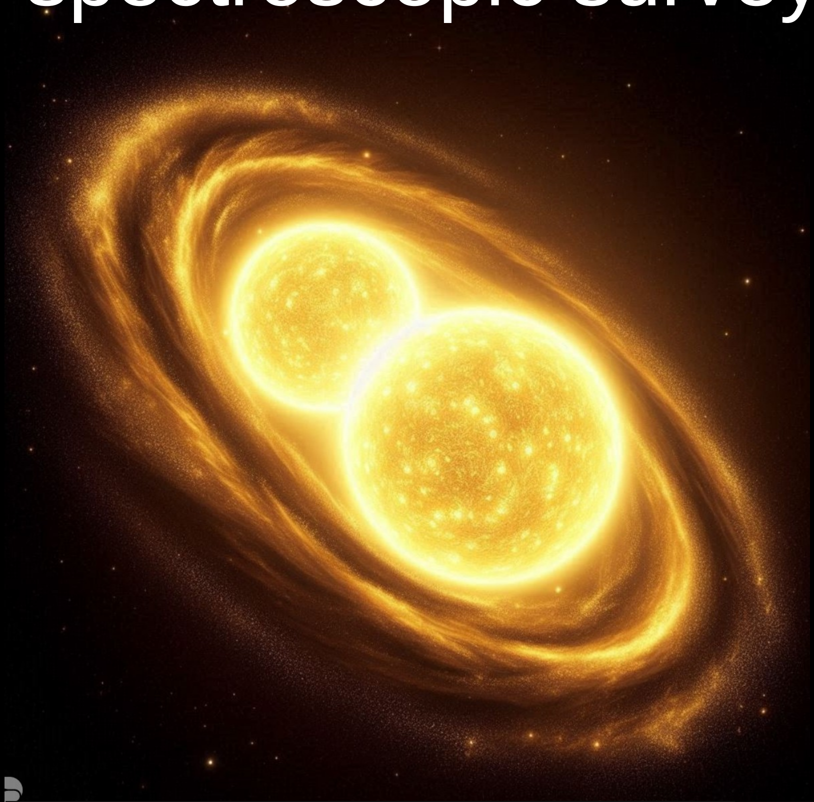
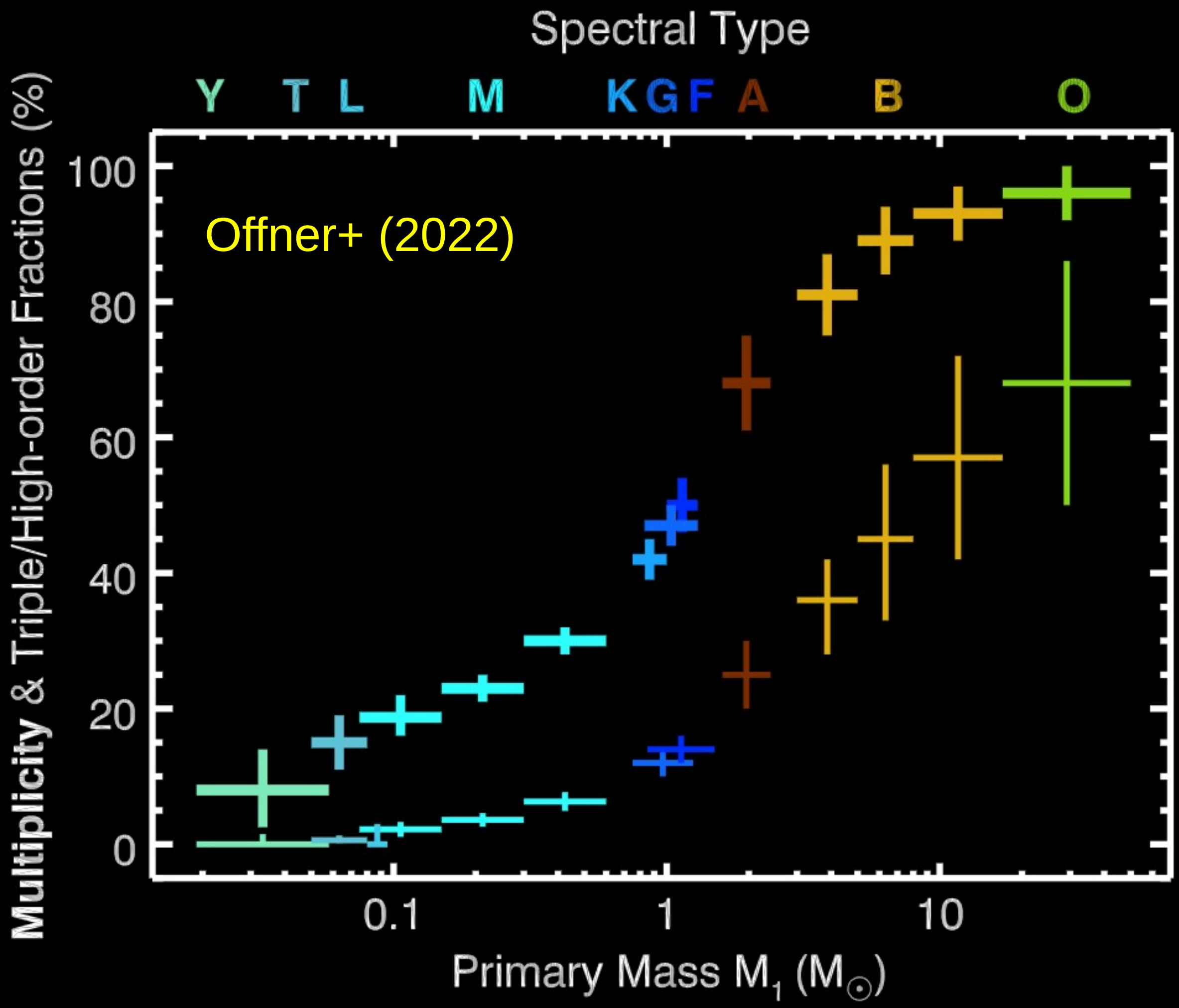
Binaries through cross-calibration of Galactic spectroscopic surveys



Thibault Merle (ROB/ULB)
Gregor Traven (Univ. of Ljubljana)
and 4MOST Multiplicity Working Group

Ubiquitous binaries



In solar-type stars:
Multiplicity fraction: 40±5%
(Moe et Di Stefano 2017)

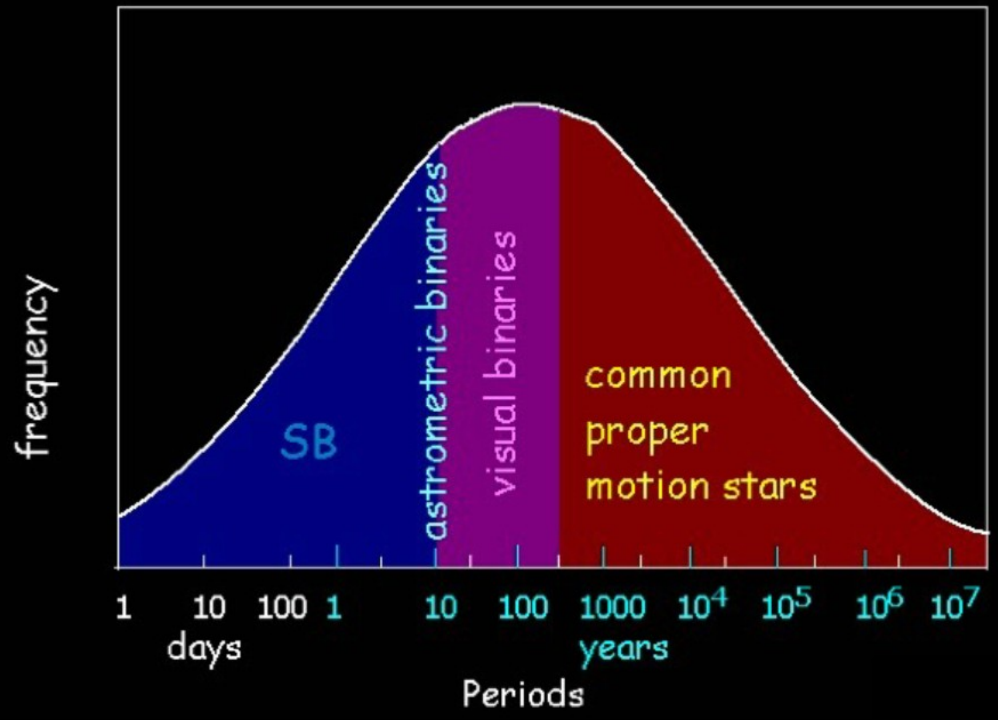
Binary fraction: 30±4%
Higher-order fraction: 10±2%

Spectroscopic binaries = SB
SB = close binaries

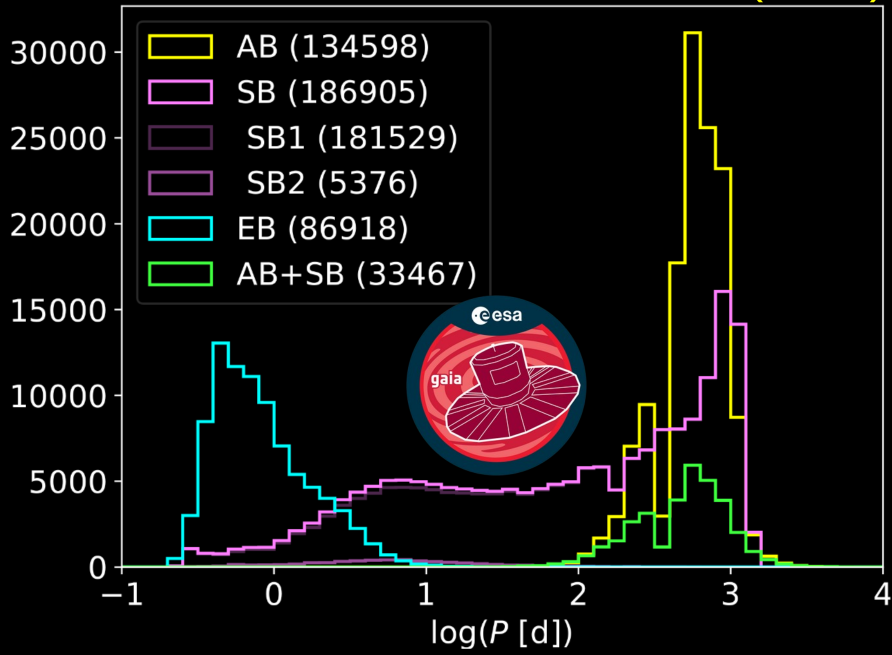
See also: Duquennoy & Mayor (1991), Raghavan+ (2010), Tokovinin (2014), Duchêne & Kraus (2013), Moe & Di Stefano (2017), Furhmann+ (2017), etc.

Ubiquitous binaries

Traven+ (2019)

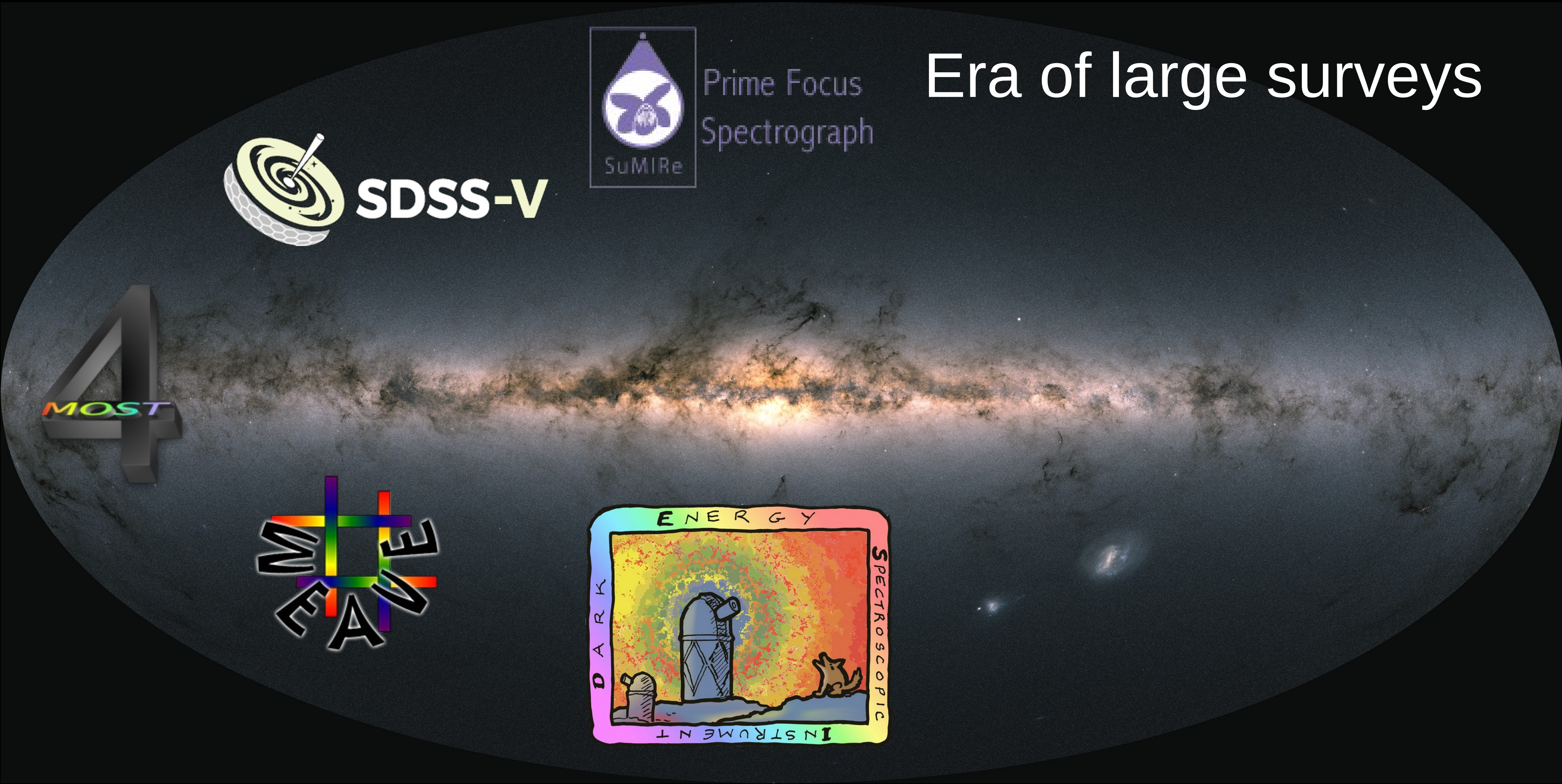


Merle (2023)



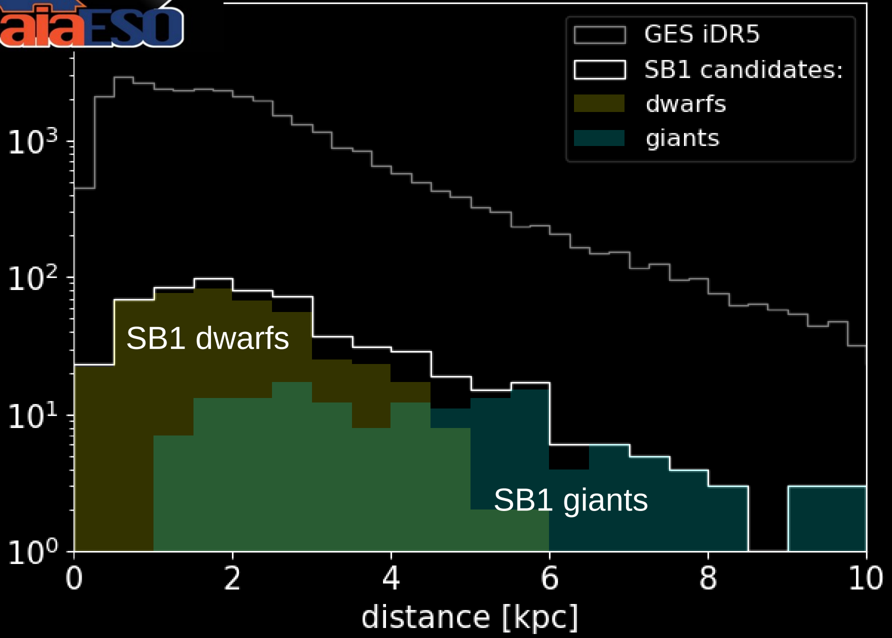
Close binary fraction ~ 15% (similarly found in the Gaia-ESO Survey combining SB1 and SB2)

Era of large surveys

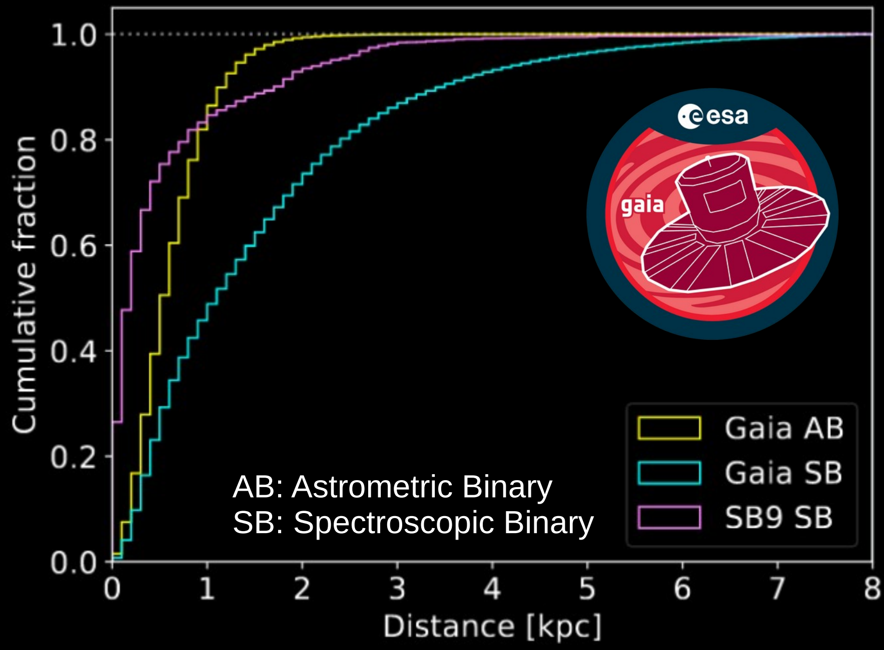


Why spectroscopic binaries (SB)?

Merle+ (2020)

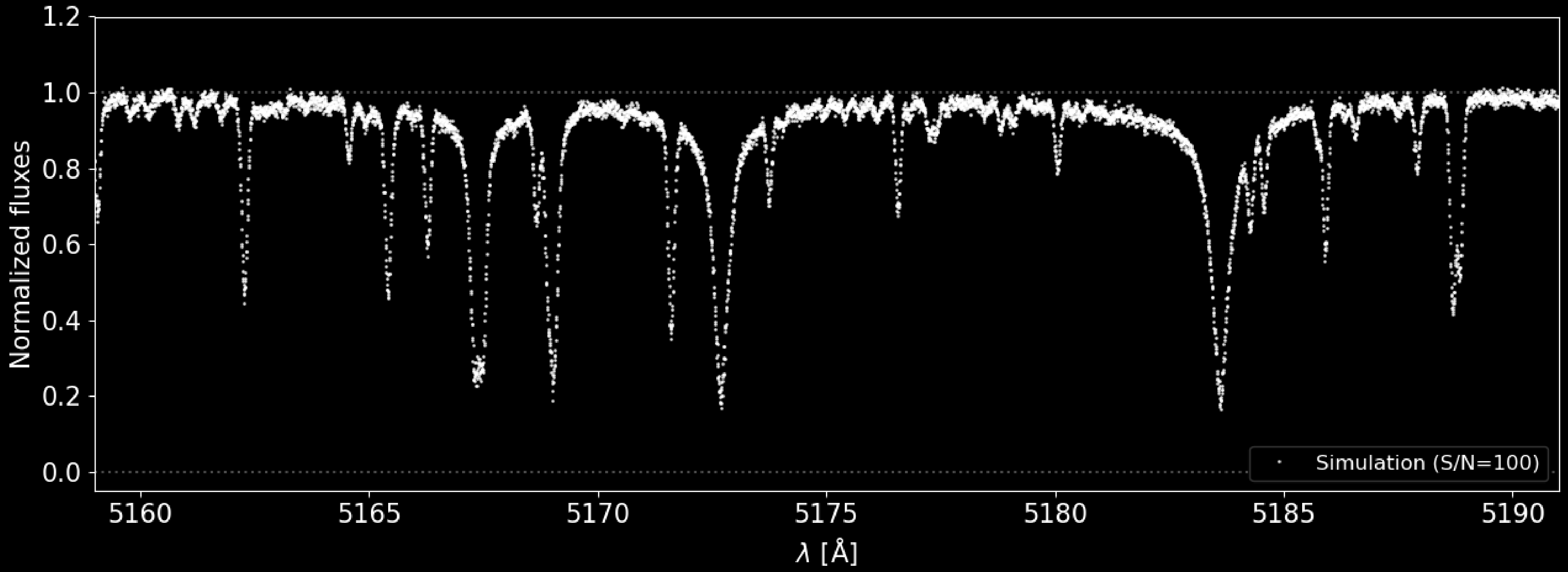


Van der swaelmen+, accepted

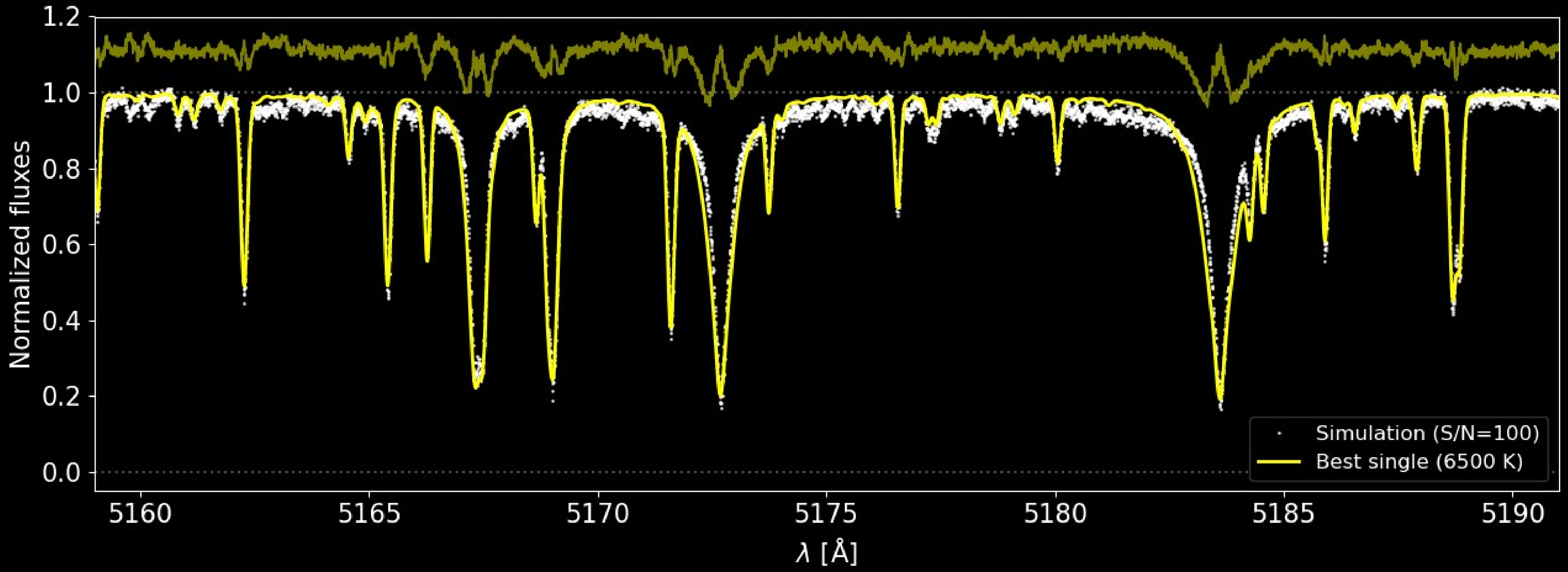


- SB detection is insensitive to the distance
- SB probe the larger range of orbital period, from EB to AB

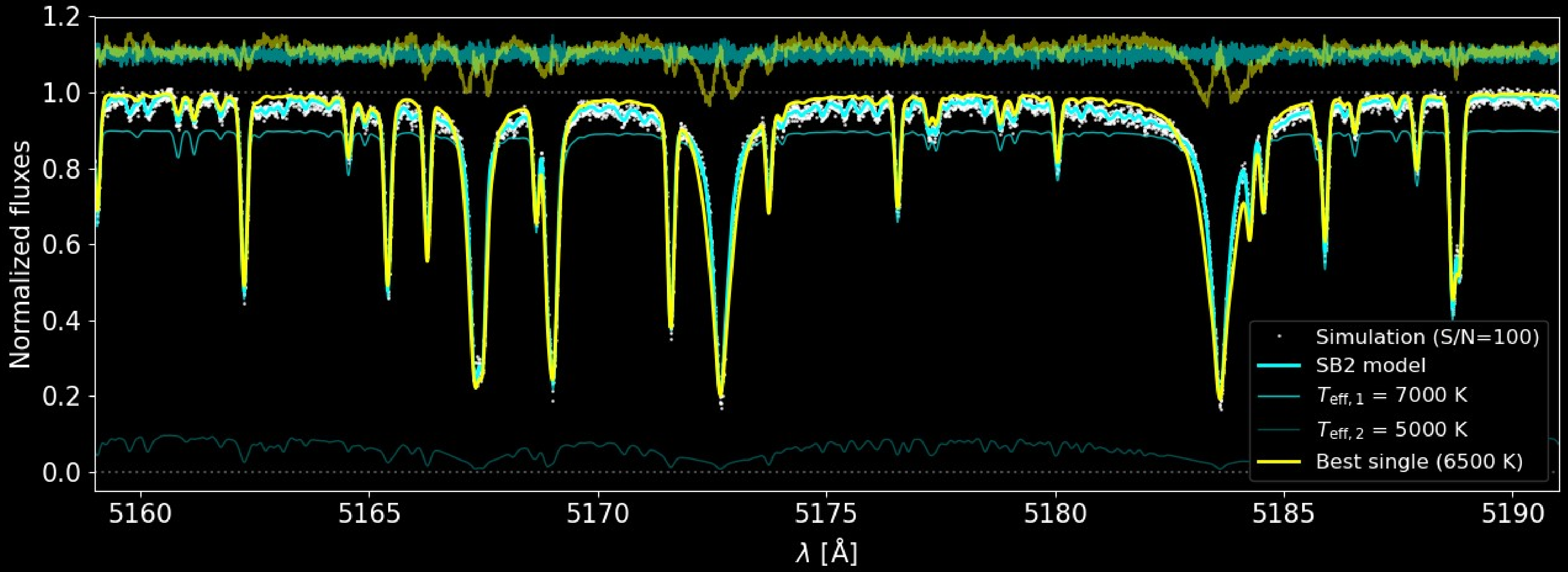
How can SB alter atmospheric parameters?



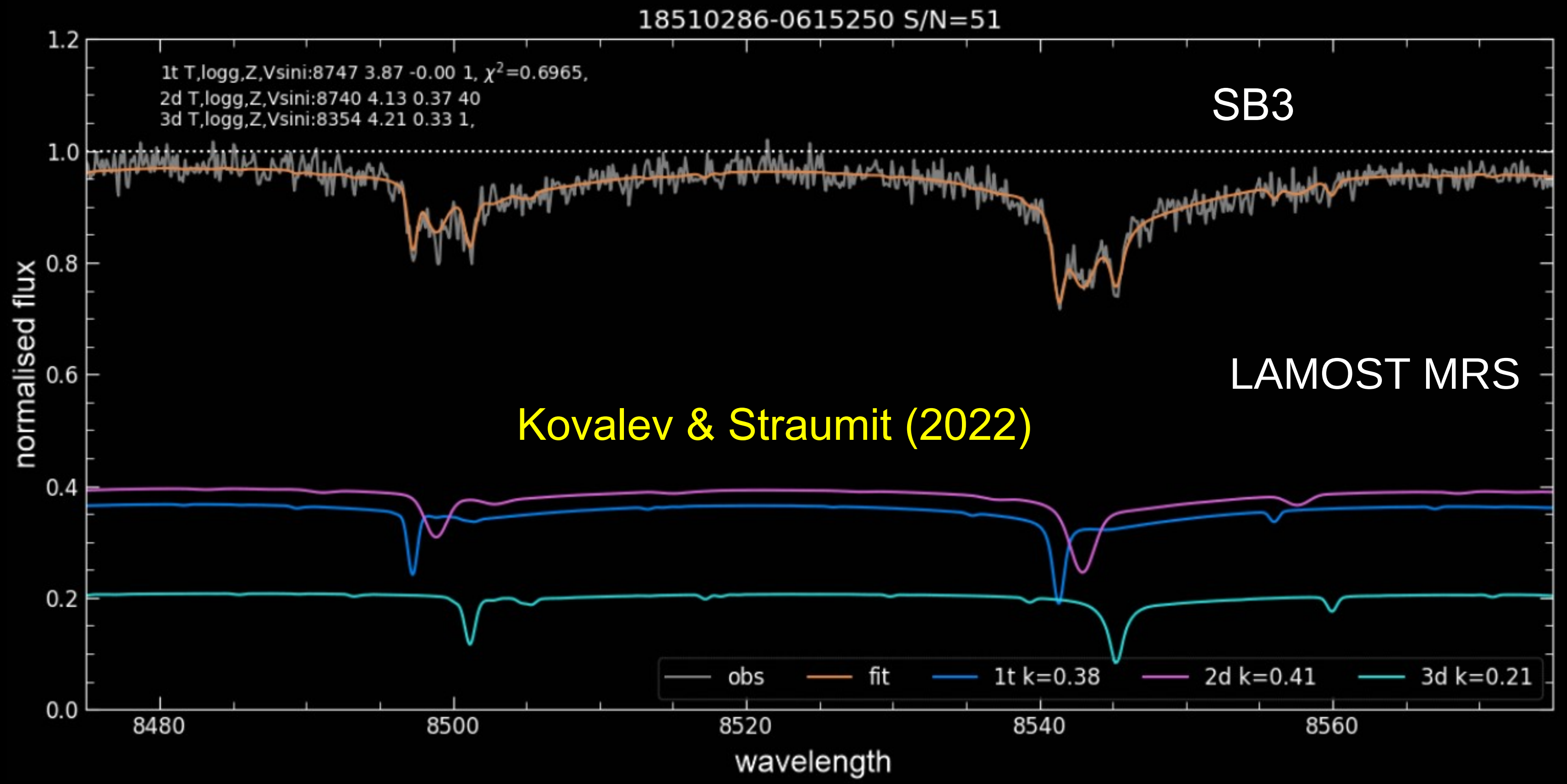
How can SB alter atmospheric parameters?



How can SB alter atmospheric parameters?

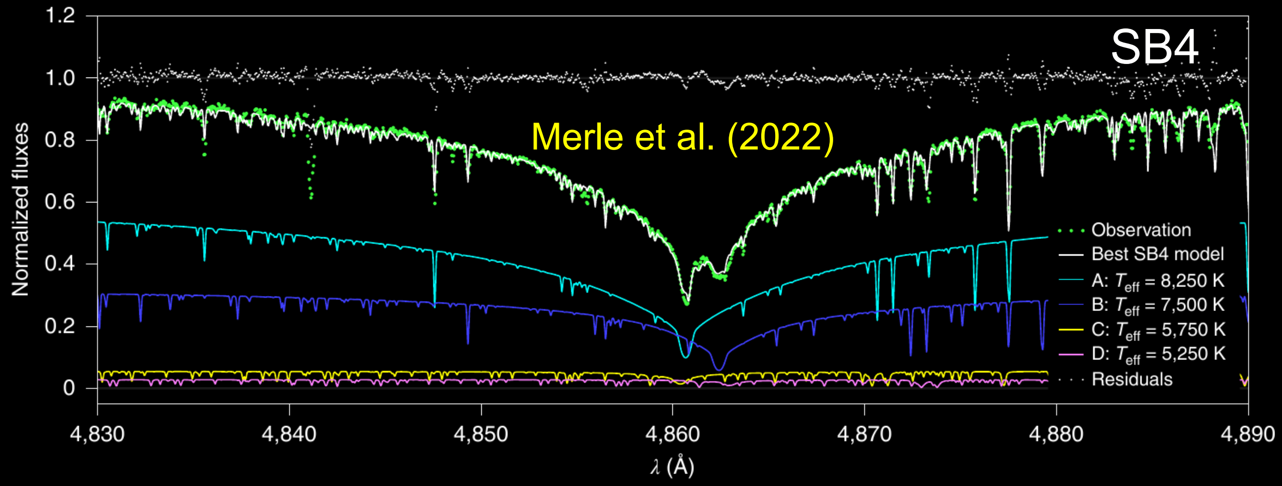


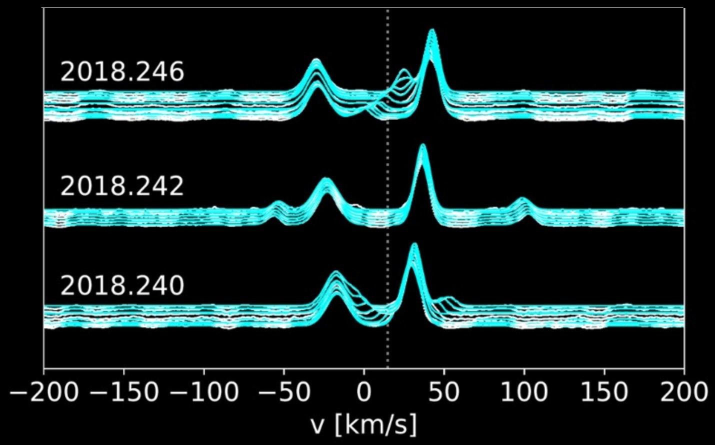
How can SB alter atmospheric parameters?



How can SB alter atmospheric parameters?

Gaia-ESO Survey + HRS/SALT + HERCULES/UCMJO

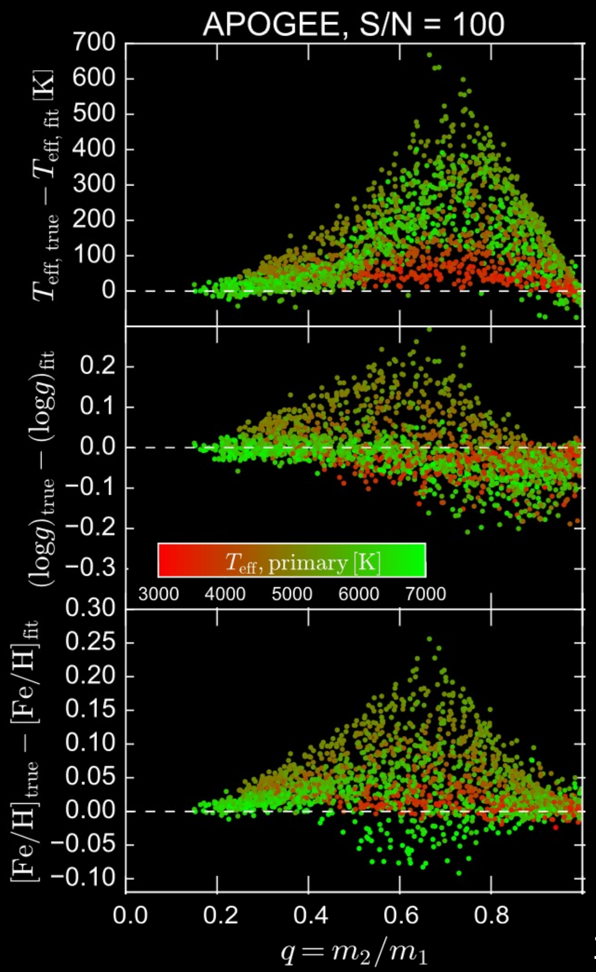




How can SB alter atmospheric parameters?

For unresolved SB2, there are systematic biases in the derived stellar parameters and elemental abundances

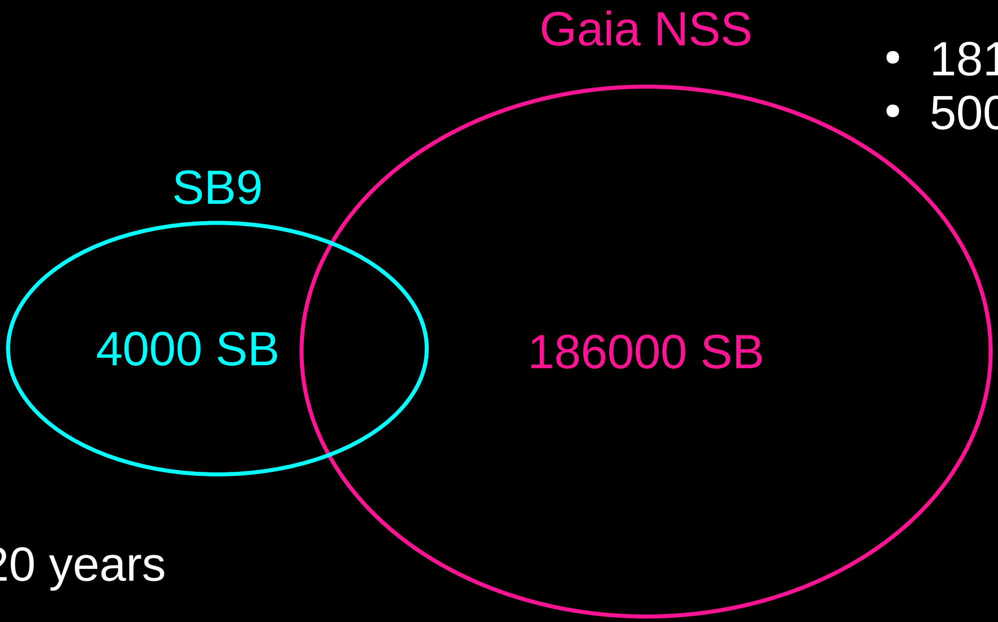
- APOGEE spectra of solar-type stars (El-Badry+ 2017):
  - 300 K in temperature
  - 0.1 dex in [Fe/H]
  - 0.1 dex in log g
- SEGUE spectra of S/N ≥ 25 (Schlesinger+ 2010):
  - 80 K in temperature
  - 0.1 dex in [Fe/H]
  - smaller impact on log g



Why cross-calibrating/validating binaries?

- 181000 SB1
- 5000 SB2

Max period ~1000 d

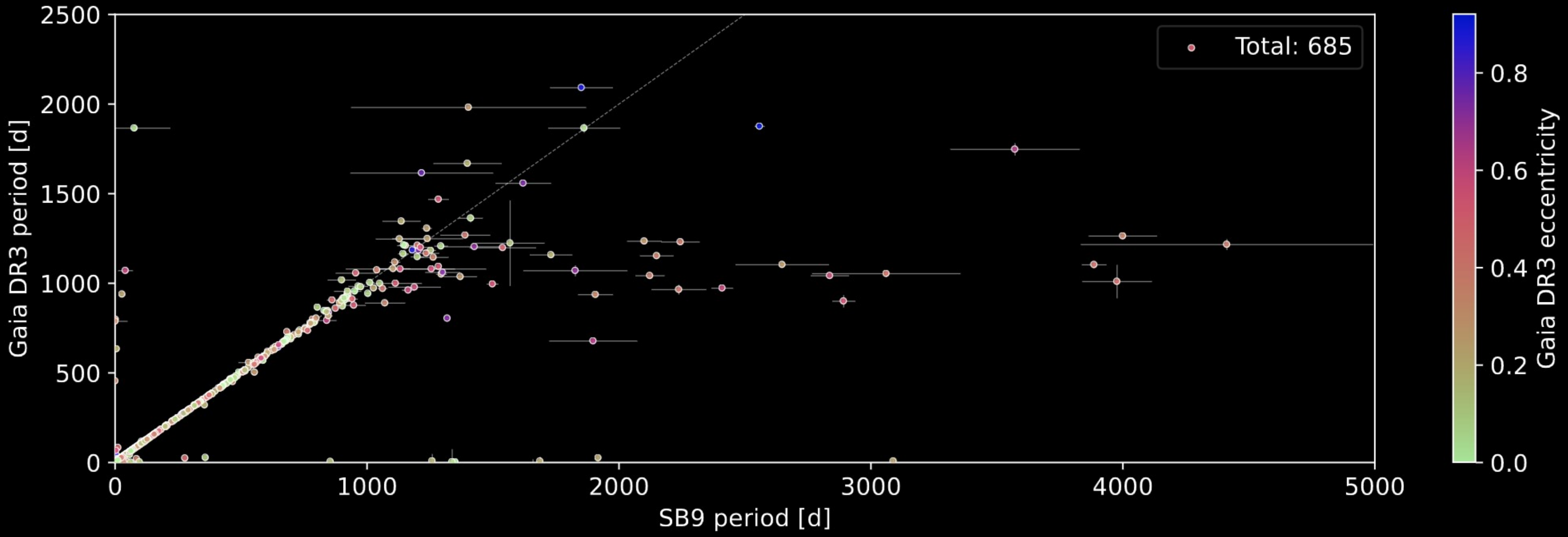


- 2800 SB1
- 1200 SB2

Max period: ~320 years

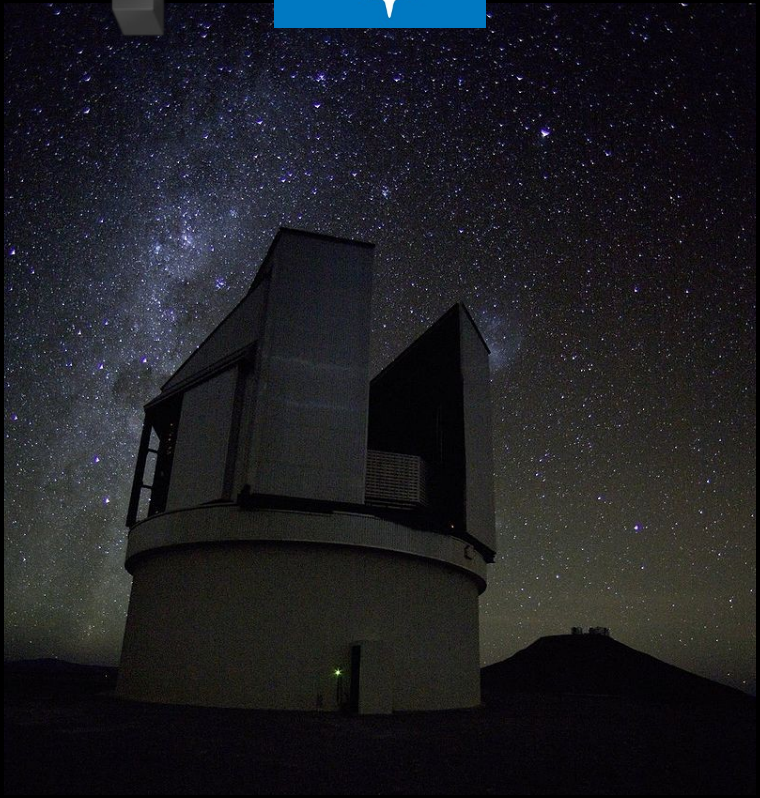
SB9 (Pourbaix+ 2004) x Gaia DR3 Non-Single Stars (Gaia col., Arenou+ 2022)

Why cross-calibrating/validating binaries?



SB9 (Pourbaix+ 2004) x Gaia DR3 Non-Single Stars (Gaia col., Arenou+ 2022)

4MOST Galactic Surveys



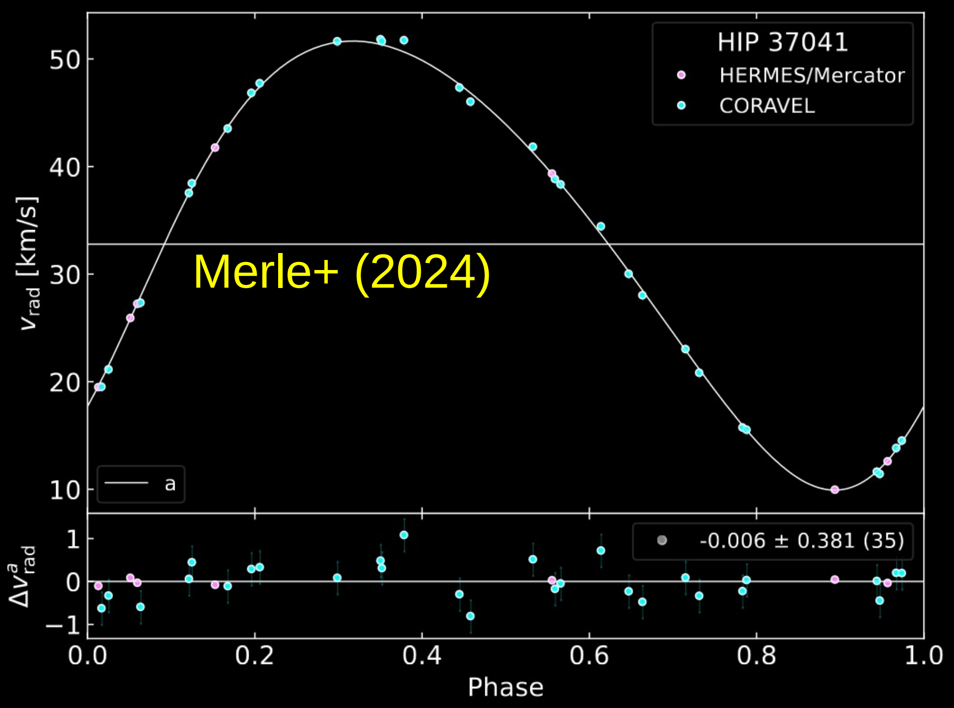
- 4-m Multi-Object Spectroscopic Telescope on VISTA/ESO (de Jong+ 2019)
- 2400 fibres per single exposure
- 4 square degrees field of view
- Optical wavelength coverage
- Low-resolution: 4 000 – 8 000, 1 600 fibres, Vmax ~20
- High resolution: ~20 000, 800 fibres, Vmax ~16
- 5 y survey starting in 2025

SB in 4MOST

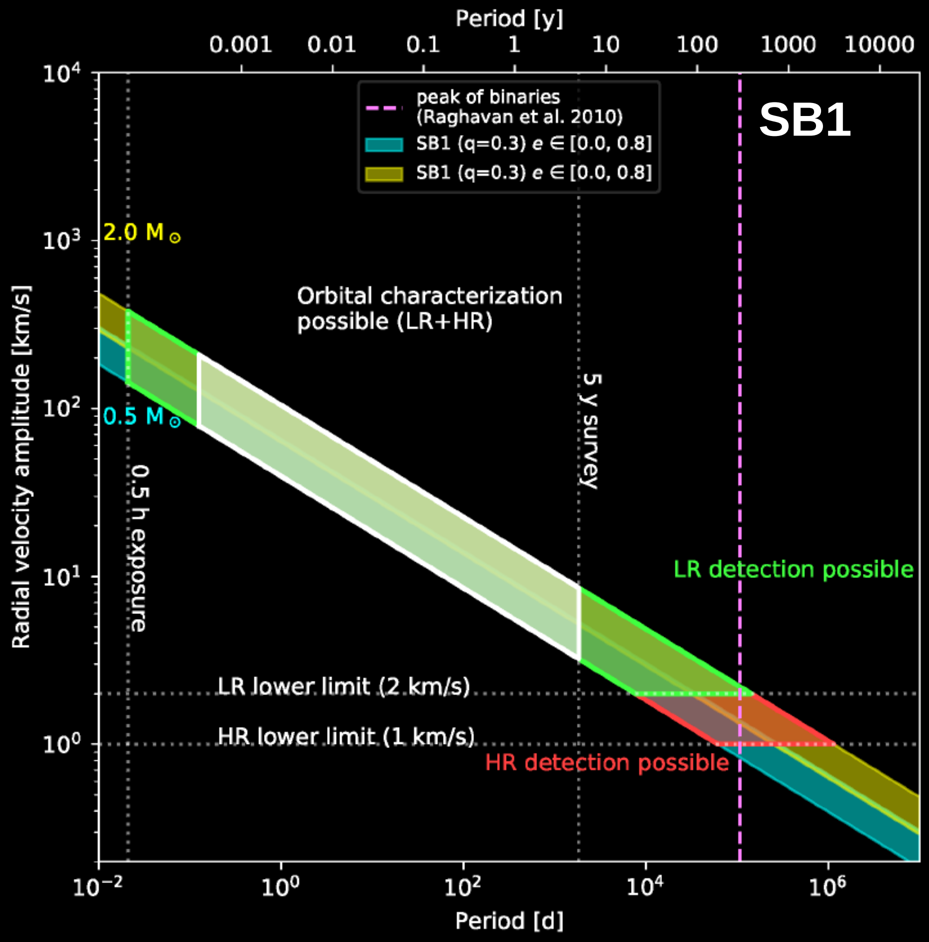
Multiplicity Working Group lead by G. Traven and T. Merle

Infrastructure Working Group 3 lead by M. Valentini
- Pipeline Calibration and Science Verification
- Cross-surveys calibration

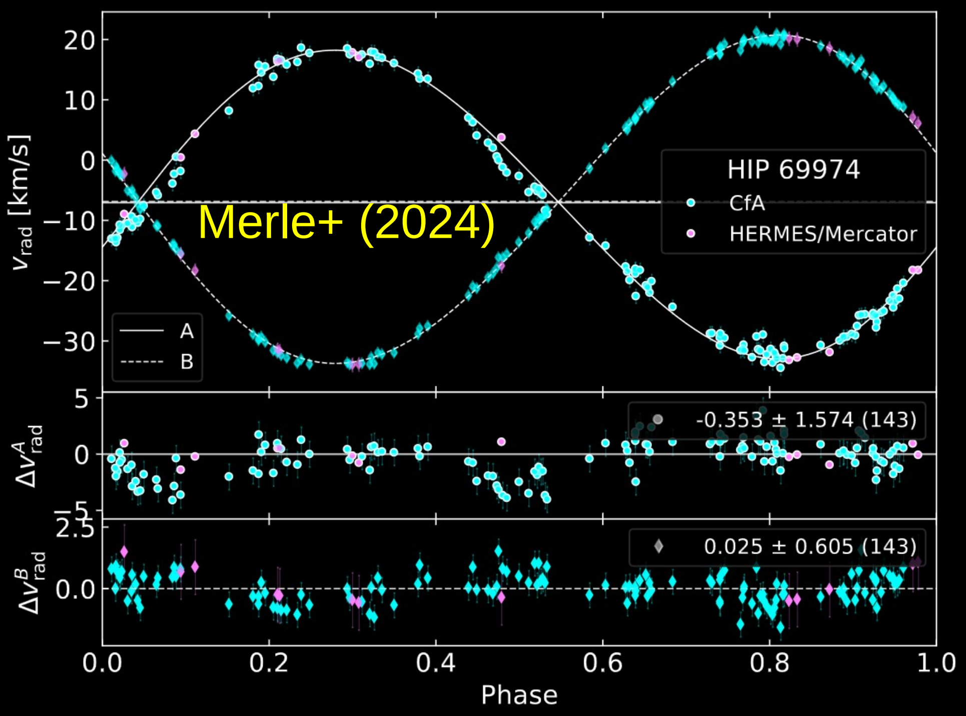
SB1 in 4MOST



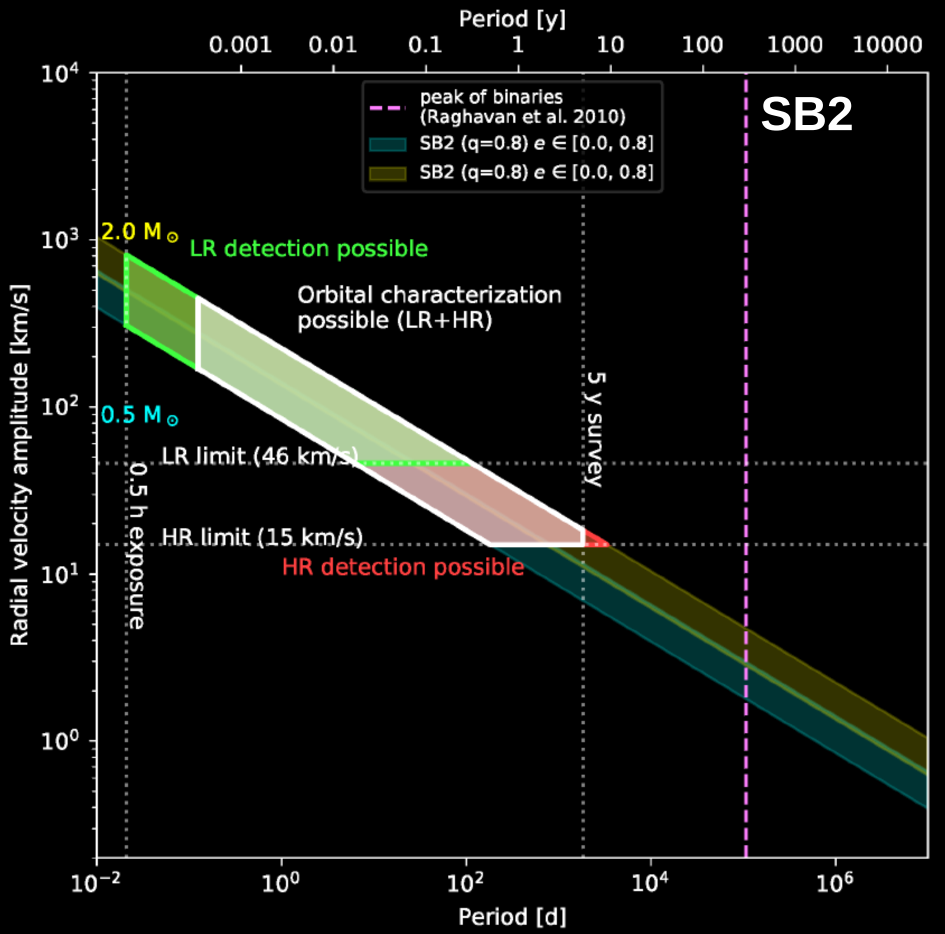
$$K \propto (M_1/P)^{1/3} \quad \sin i / \sqrt{(1-e^2)} \quad q/(1+q)^{2/3}$$

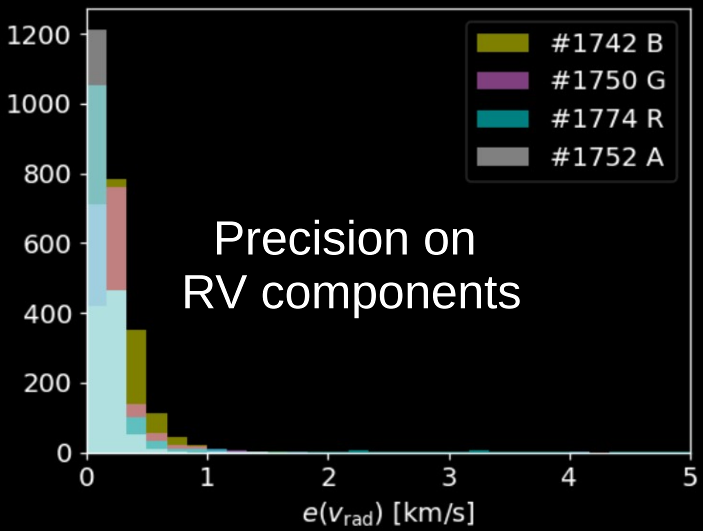


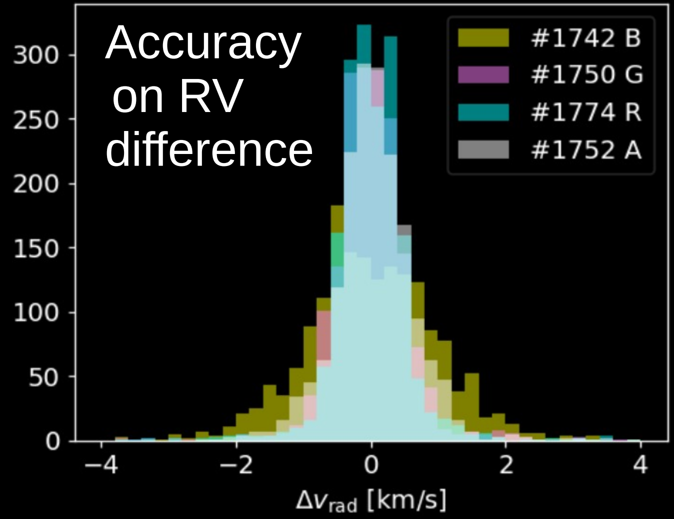
SB2 in 4MOST



$K_1 \propto (M_1/P)^{1/3}$ $\sin i / \sqrt{(1-e^2)}$ $q/(1+q)^{2/3}$
$K_2 \propto (M_2/P)^{1/3}$ $\sin i / \sqrt{(1-e^2)}$ $q/(1+q)^{2/3}$







Detection of 4MOST HR SB2

- DOE (Merle+ 2017) adapted (2.6.1) and implemented in the 4MOST galactic pipeline (4GP)
- Test sample of 1000 twins SB2 composite spectra:
  - Computation at solar metallicity
  - Following random normal *N*(0, 100) radial velocities
  - $v \sin i = 0$ km/s
  - S/N = 100
- Combining the three arms (B, G & R) seems provide the best results
- Performance on SB2 detection for HRS
  - Individual RV components
    - Precision: 0.13 ± 0.04 km/s
    - Accuracy: 0.04 ± 0.41 km/s
  - RV difference between components
    - Detection threshold: 22.5 km/s
    - Precision: 0.20 ± 0.05 km/s
    - Accuracy: 0.5 ± 0.4 km/s

Cross surveys

Sample of ~10^5 common stars among 5 Galactic archaeology surveys with different wavelength coverages, resolutions and epochs:

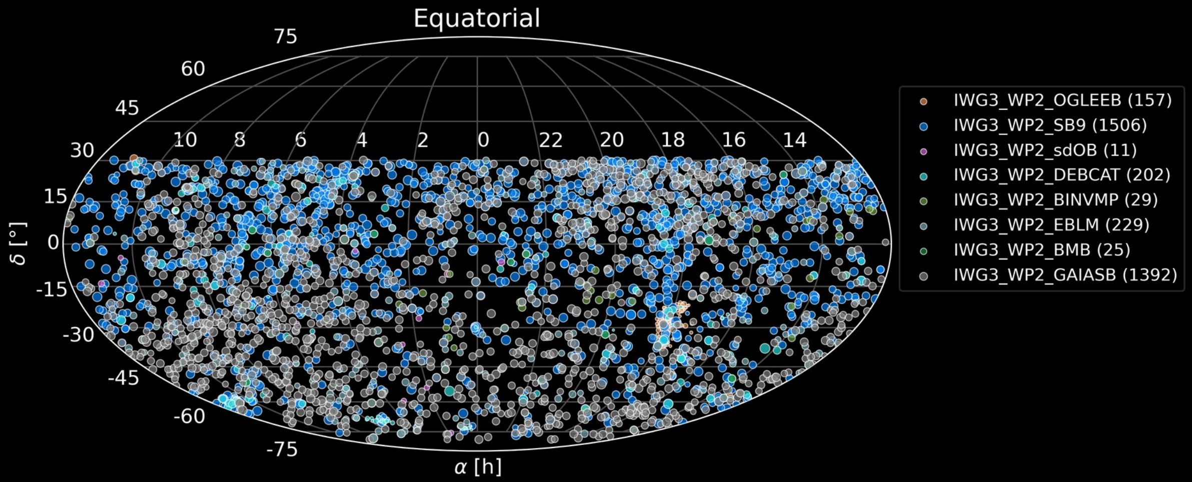
- 4MOST (4 m Multi-Object Spectrograph Telescope)
- WEAVE (WHT Enhanced Area Velocity Explorer)
- SDSS V (Sloan Digital Sky Survey) MWM (Milky Way Mapper) (APOGEE &)
- DESI (Dark Energy Spectroscopic instrument) MWS (Milky Way Survey)
- PFS (Prime Focus Spectrograph)

In the field: $-30° \leq \delta \leq +30°$

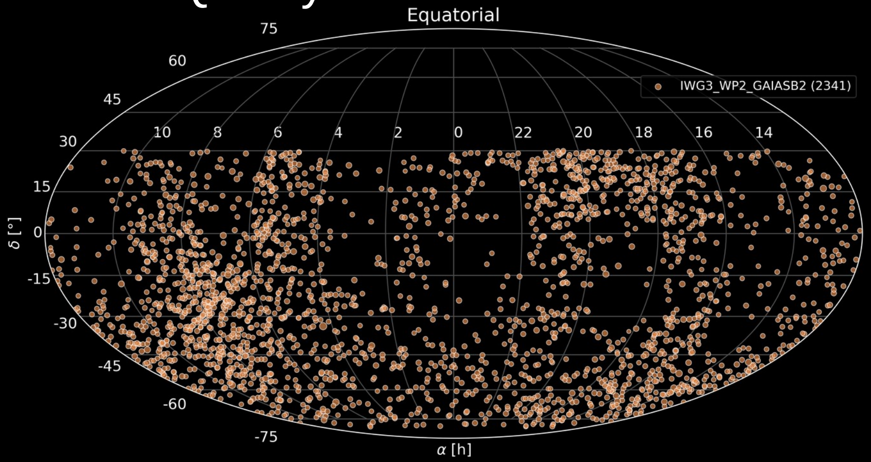
➔ benchmark stars, RV standards, spectroscopic standard fields, etc.

4MOST catalogue of binaries

Quality 1 ~3500



Quality 2 ~2300

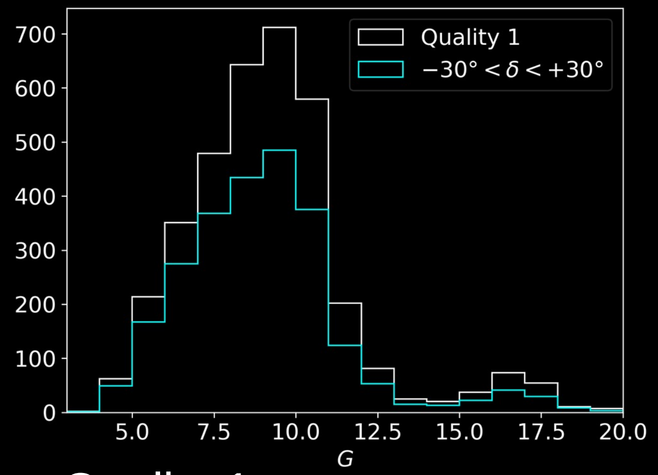


- Quality 1
  - SB9 (Pourbaix+ 2004)
  - Gaia SB2 (Gaia collab., Arenou+ 2022, significance >100, 50, 20 for SB2, SB2C, SB+EB)
  - DEBcat (Southworth 2015), etc.
- ~70% with -30° ≤ δ ≤ +30°

- Quality 2: Gaia SB2
- ~60% with -30° ≤ δ ≤ +30°

4MOST catalogue of binaries

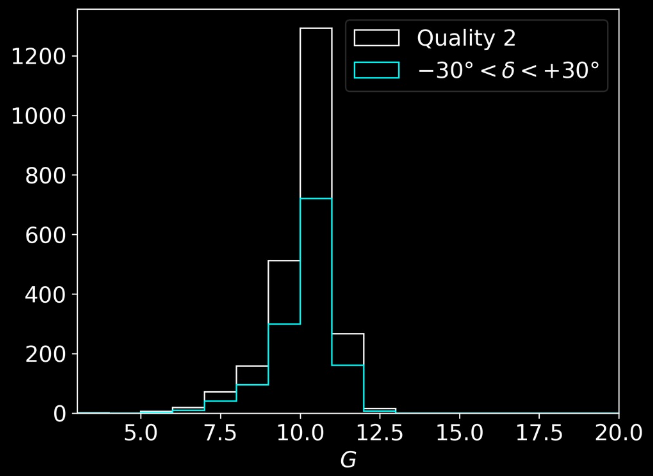
Quality 1 ~3500



- Quality 1
  - SB9 (Pourbaix+ 2004)
  - Gaia SB2 (Gaia collab., Arenou+ 2022, significance >100, 50, 20 for SB2, SB2C, SB+EB)
  - DEBcat (Southworth 2015), etc.

- ~70% with -30° ≤ δ ≤ +30°

Quality 2 ~2300

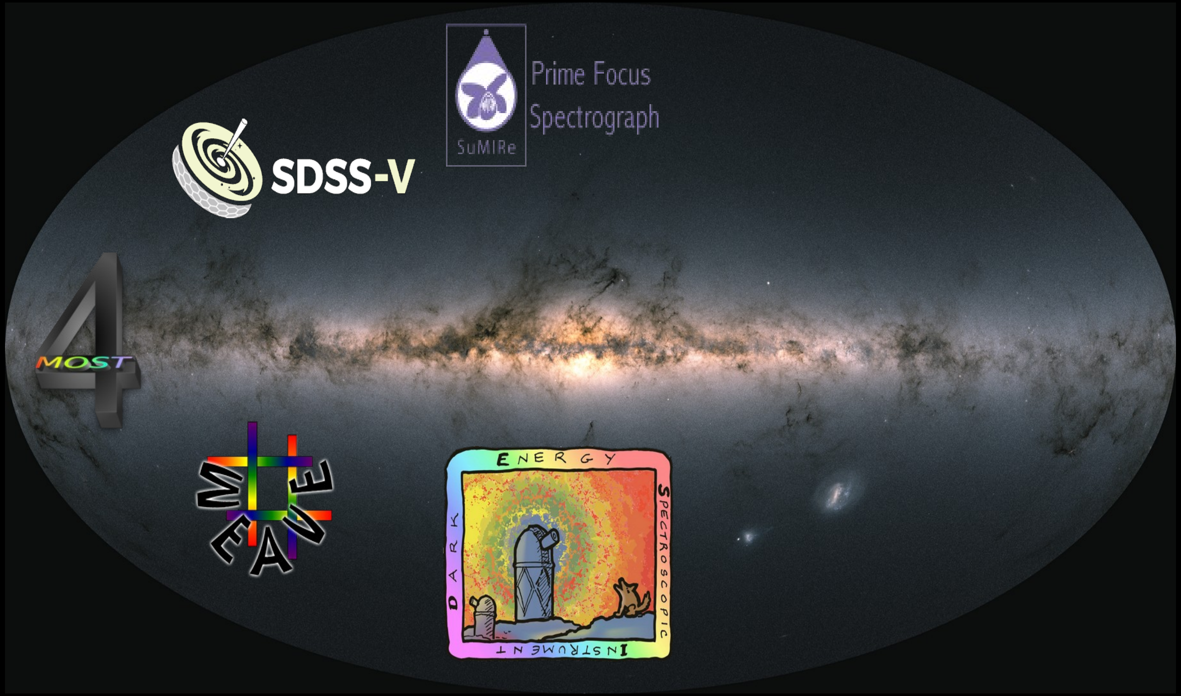


- Quality 2: Gaia SB2

- ~60% with -30° ≤ δ ≤ +30°

Binaries in cross-surveys

- Only 4MOST present a sample of well known spectroscopic binaries
  - RV standards ➔ spectrograph zero points
  - Can we get a better assessment of the zero RV of various spectrographs from SB2 than from single stars?
- Serendipitous discoveries of SB1
  - Increase the number of epochs
  - Detect new SB taking advantage of longer baselines (~10 of years) by combining various surveys.
- Explore detection limits for SB2 in different surveys/spectroscopic regimes



Summary

- Binaries are ubiquitous

  Spectroscopic binaries bridge short periods (~few days) to moderate periods (few 10 years)

- SB can alter the atmospheric parameters derived for single stars

- 4MOST survey has a unique catalogue of binaries of more than 2000 binaries in the cross-surveys declination range $-30° \leq \delta \leq +30°$

- Possible serendipitous discovery of binaries (SB1) in the cross-surveys sample

Backup

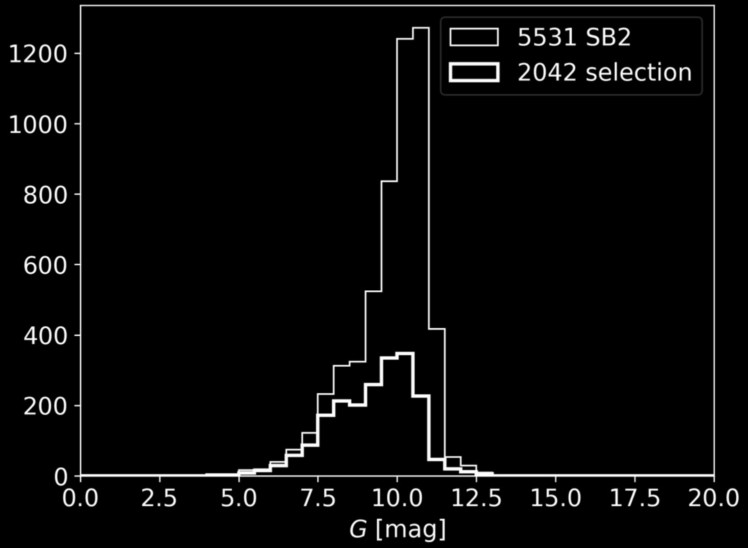
Detection of SB with 2 (or more) visible components

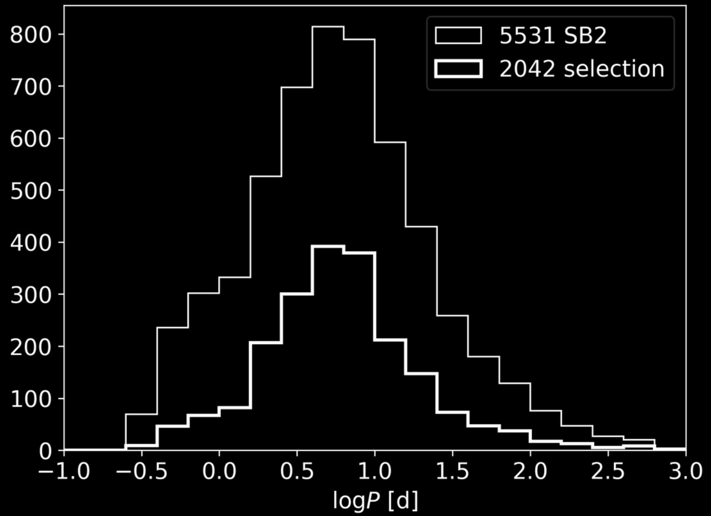
- **Detection Of Extrema (DOE)**
  - Developed and used in Merle et al. (2017)
  - Github: https://github.com/thibaultmerle/doe
  - Version: 2.6.1

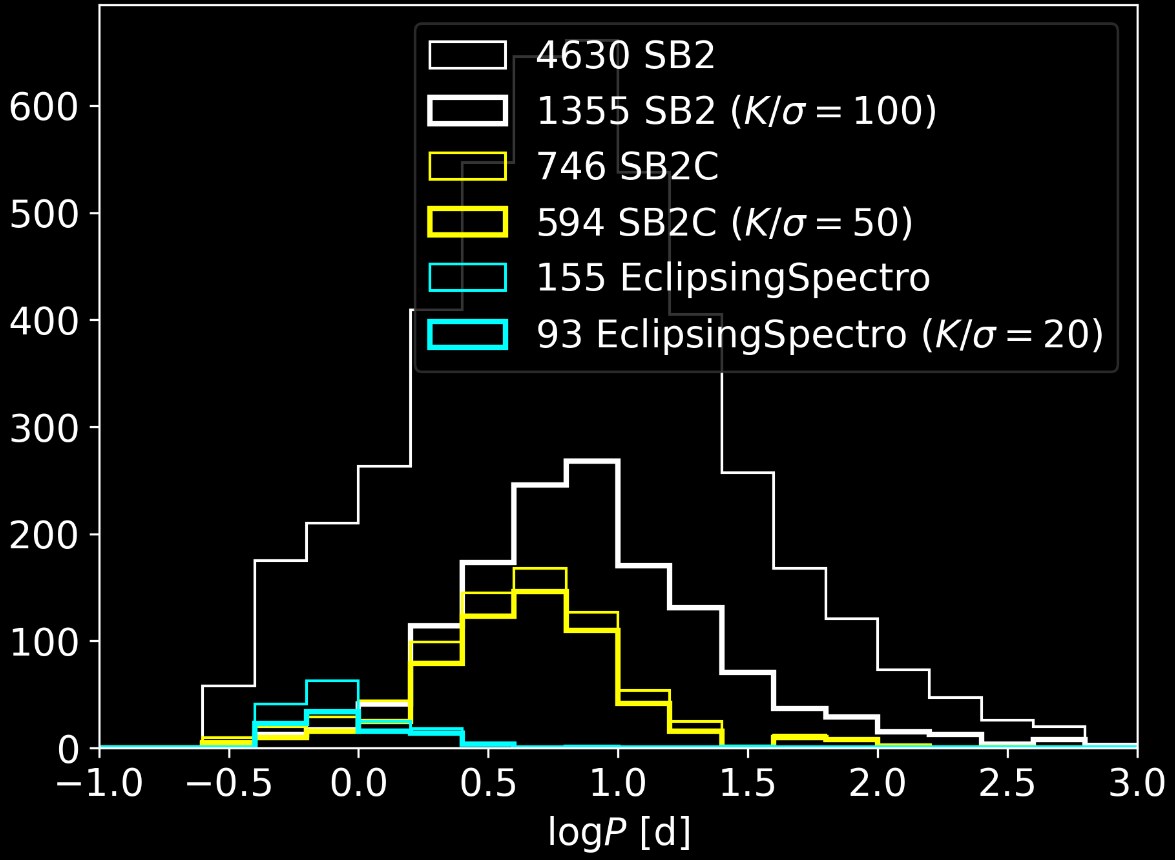
- Also used in:
  - Kravchenko et al. (2019) – Betelgeuse
  - Traven et al. (2020) – GALAH
  - Merle et al. (2022) – spectroscopic quadruple
  - Van der Swaelmen et al., accepted – GES

- Implementation in the 4MOST galactic pipeline:
  - On branch develop_doe_new in fourgp/doe
  - Updated to 2.6.1

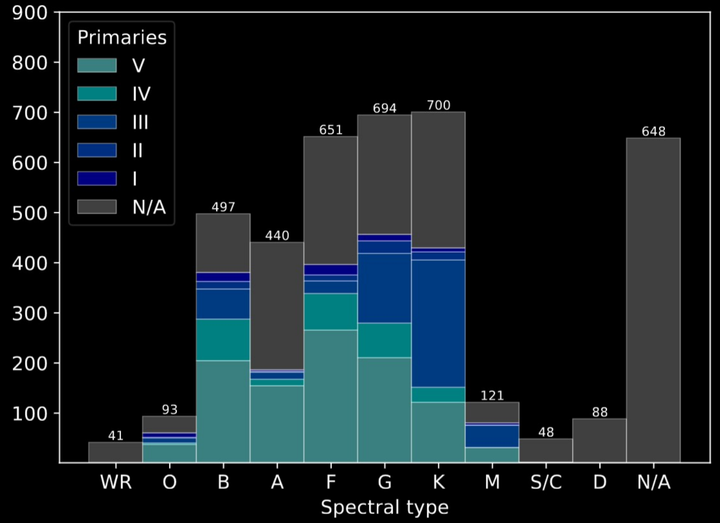
Gaia SB2 selection

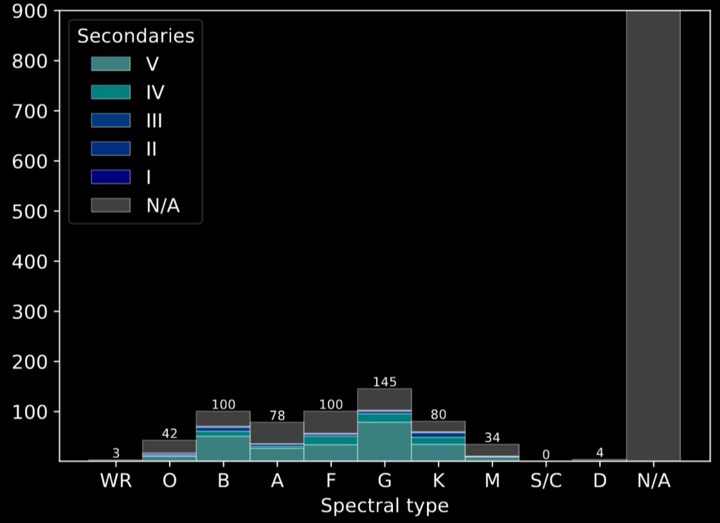


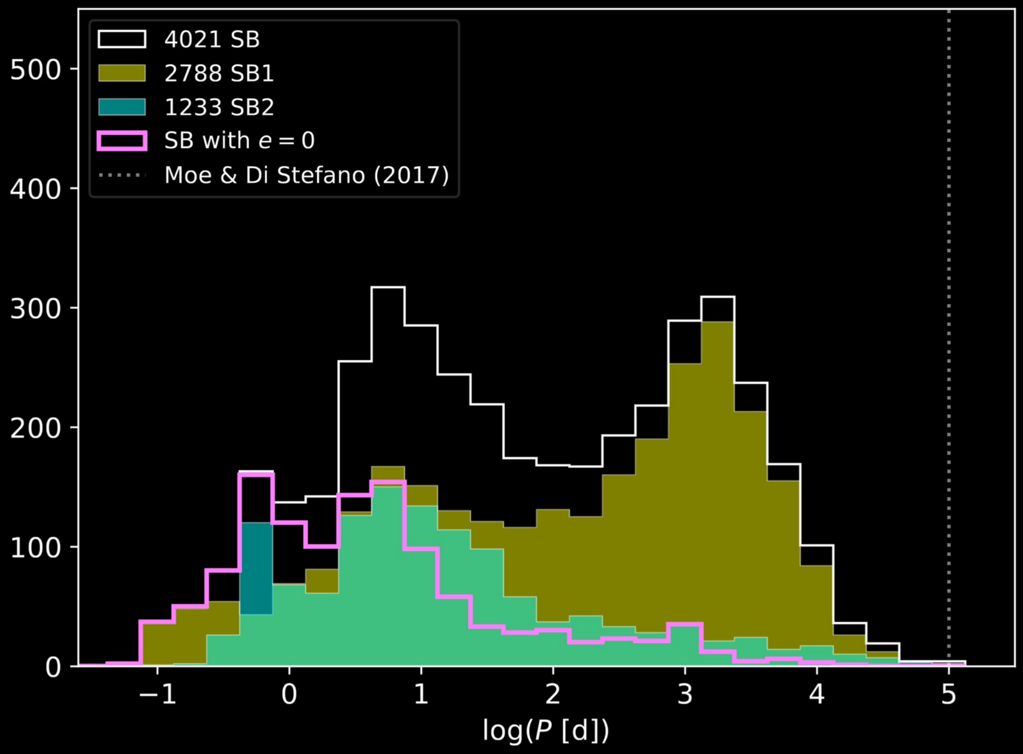




SB9 catalogue







CCF from RV/4GP and templates