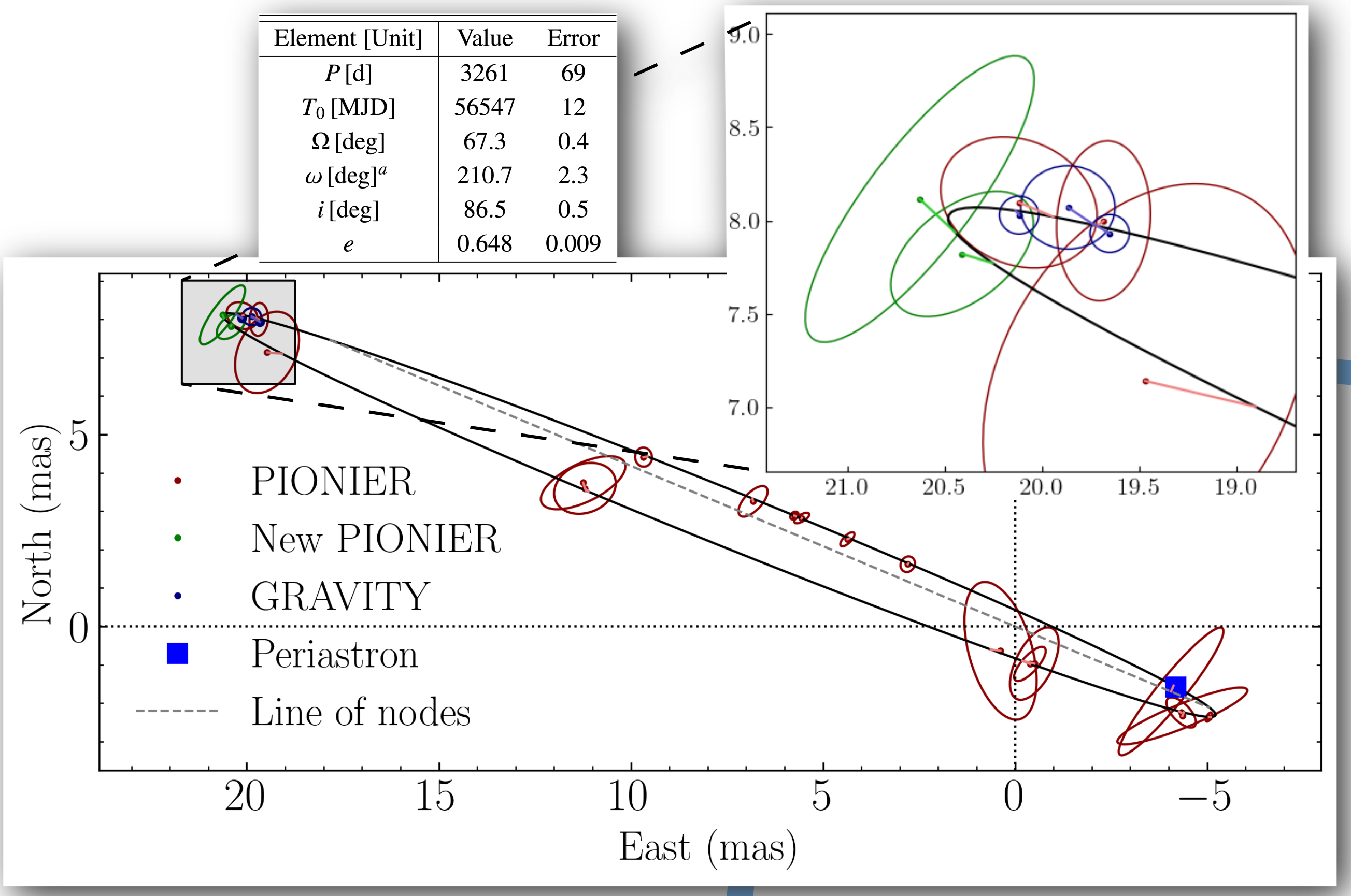
Constraining the dynamical mass of the massive binary 9 Sagittarii

M. Fabry[1], C. Hawcroft[1], A.J. Frost[1], L. Mahy[2,1], P. Marchant[1], J-B. Le Bouquin[3], and H. Sana[1]

[1] Institute of astronomy, KU Leuven, Belgium
[2] Royal Observatory of Belgium
[3] Institute of Planetology and Astrophysics, Grenoble University, France

Introduction

Massive binaries are **scarce yet instrumental** in the calibration of stellar evolution models. Long-period double lined spectroscopic binaries (SB2s) that are also resolved offer an excellent alternative to eclipsing SB2s to derive dynamical masses. 9 Sgr has a period of 9 years and has been monitored spectroscopically and interferometrically since 2009. However, **tension exists in the literature** between the spectroscopically and interferometrically inferred inclinations, **casting doubt** on the current spectroscopic analysis.



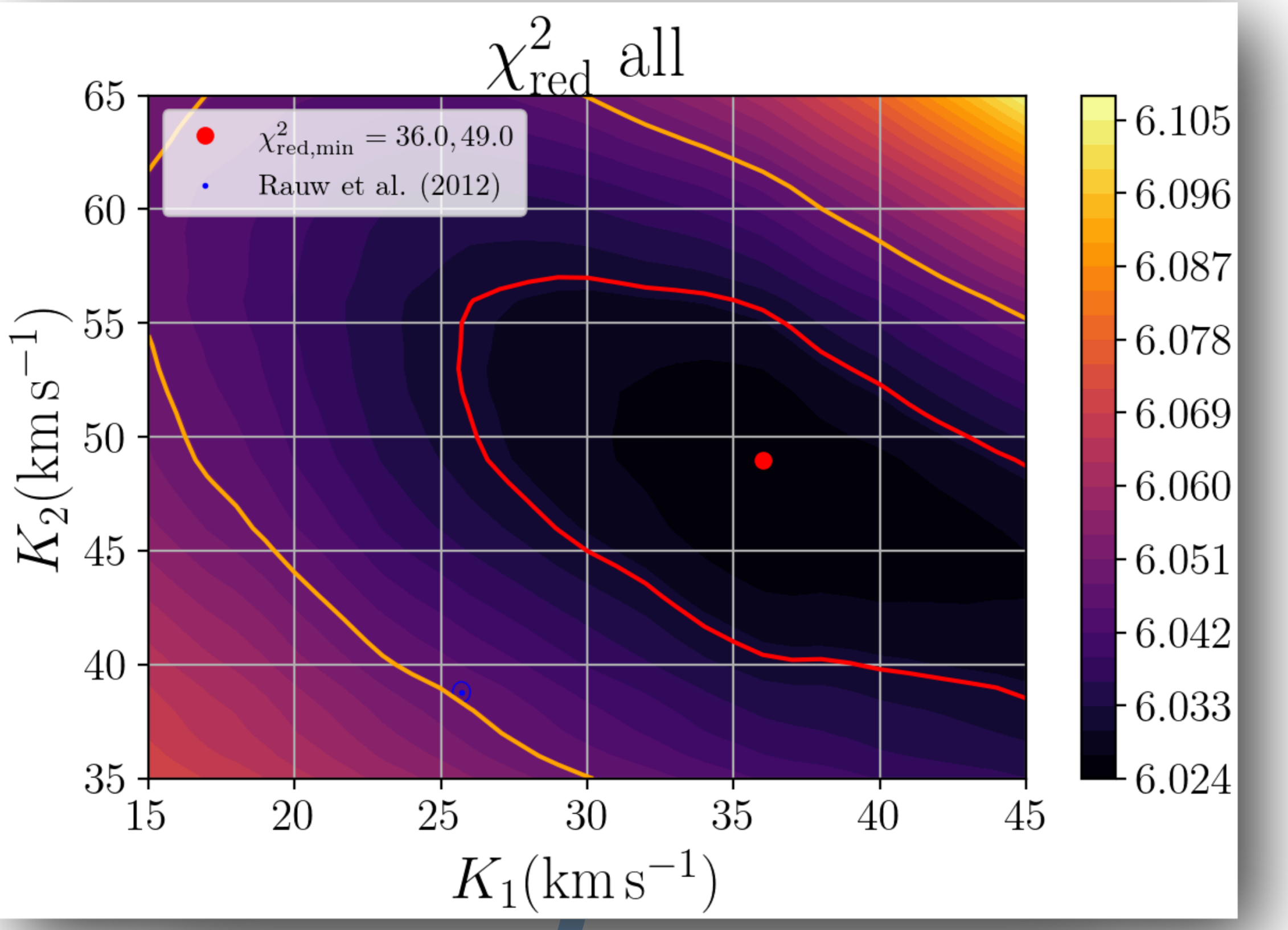
Element [Unit]	Value	Error
P [d]	3261	69
T_0 [MJD]	56547	12
Ω [deg]	67.3	0.4
ω [deg][a]	210.7	2.3
i [deg]	86.5	0.5
e	0.648	0.009

Geometric orbit

We use relative astrometry from VLTI/PIONIER and VLTI/GRAVITY and the orbital fitting tool `spinOS` to determine the period P, the eccentricity e, the time of periastron passage T_0 and the Euler angles i, Ω and ω defining the orientation of the orbit on the sky.

We corroborate the results from Le Bouquin et al. (2017) that the **orbit is very eccentric**, and has a period of 9 years.

The interferometry puts a **strict constraint on the inclination** of $i > 85^\circ$, while the spectroscopic solution from Rauw et al. (2012) required $i \approx 45^\circ$.



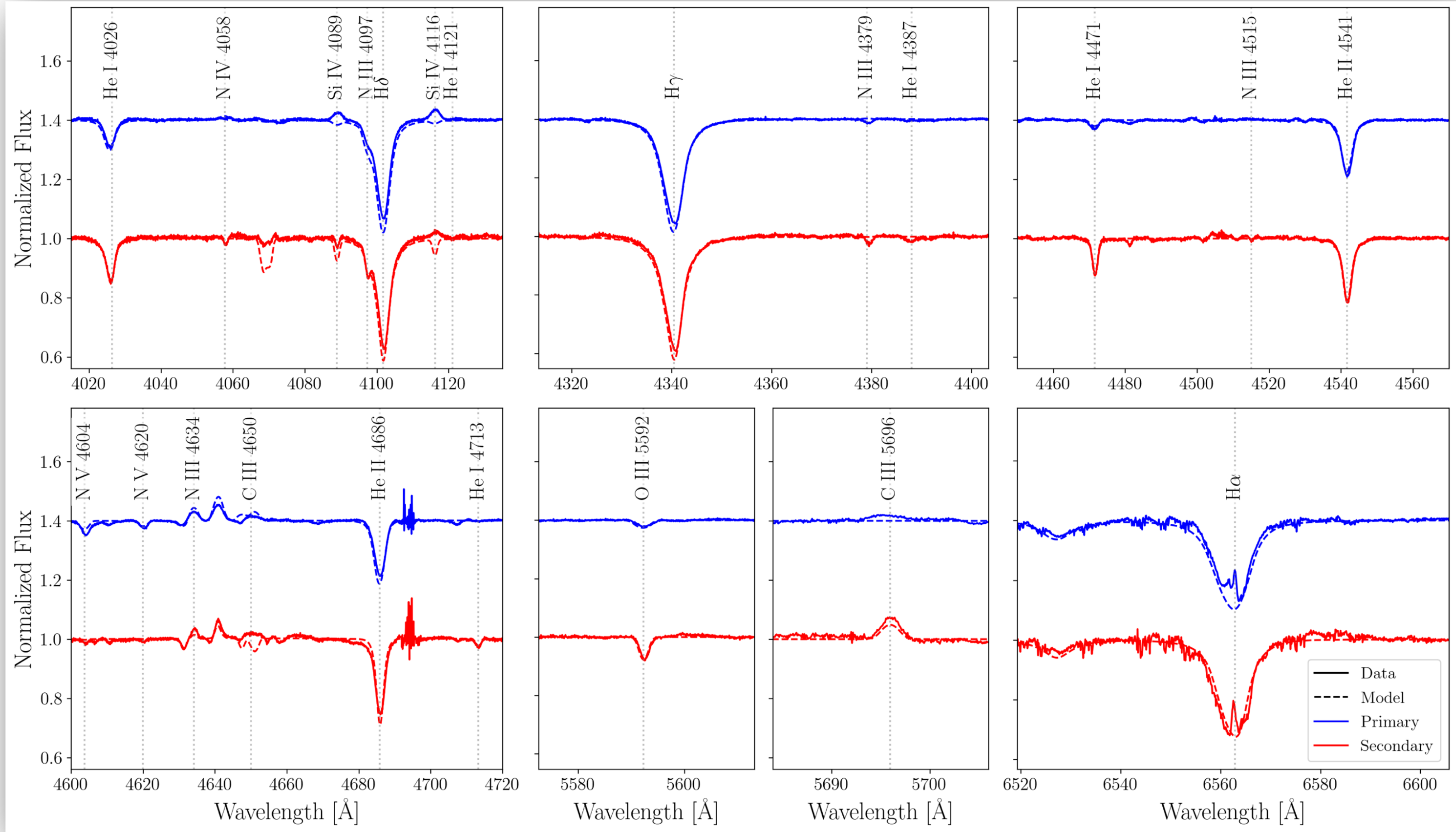
Semi-amplitudes	Data	MC median	σ_-	σ_+
$K_1 ({\rm km\,s^{-1}})$	36	36	35	40
$K_2 ({\rm km\,s^{-1}})$	49	50	47	53

Spectral disentangling

Instead of relying on fitted spectral lines to determine the radial velocity (RV) semi-amplitudes, as done in the studies of Rauw et at. (2012, 2016), we employ **grid-based Fourier spectral disentangling** based on `fd3` (Hadrava, 1995, Ilijic et al. 2004, Ilijic, 2017).

While fixing the other orbital elements to those found from the geometrical orbit, we sample the (K_1, K_2) space and determine the RV semi-amplitudes that minimize the chi-squared statistic between the recombined disentangled spectra and the observed spectra.

We find a minimum at $(K_1, K_2) = (36, 49)$ km s^{-1}, and a Monte Carlo sampling (MC) around this minimum shows **our results are distict** from $(K_1, K_2) = (26, 39)$ of Rauw et al. (2012). The combined geometrical orbit and RV semi-amplitudes result in **dynamical masses of 53 and 39 $M_\odot$**.



Atmospheric modeling

We adjust `FASTWIND` models to obtain estimates for atmospheric parameters of effective temperature $T_{\rm eff}$, surface gravity $\log g$ and elemental abundances of both components.

We find very **low $\log g$ for dwarf O stars**, most likely due to repeated normalization in the disentangling methodology.

Furthermore, making **quantitative abundance determinations are challenging**, although we detect hints of **enchanced N in the primary** and **enhanced C in the secondary**.

Evolutionary modeling

We use the Bayesian analysis tool BONNSAI (Schneider et al. to compare our inferred stellar parameters to the evolutionary models from Brott et al. (2011).

In the primary, we find a hint of nitrogen enrichment in the best fit atmosphere model. This **suggests enchanced internal mixing processes** in very massive stars compared to the implementation of Brott et al. (2011). To match the enhanced N in the atmosphere model of the primary, **fast rotation is required** in the evolutionary model, which in turn requires a **misaligned rotation axis** to the orbital axis.

The secondary star has most likely not evolved from baseline CNO values, and we find the components are **coeval at about 1 Myr**.

	FASTWIND		BONNSAI	
Parameter(Unit)	Primary	Secondary	Primary	Secondary
$T_{\rm eff}$ [kK]	46.0 ± 1.0	42.0 ± 1.0	$46.0^{+0.6}_{-1.0}$	41.9 ± 0.9
$\log(g/[{\rm cgs}])$	3.87 ± 0.20	3.87 ± 0.20	$4.10^{+0.02}_{-0.06}$	$4.12^{+0.06}_{-0.07}$
$\log \frac{\dot M}{M_\odot/{\rm yr}}$	-6.6 ± 0.2	-6.6 ± 0.2	…	…
$f_{\rm cl}$	29 ± 5	22 ± 3	…	…
$v \sin i$ [km s^{-1}][a]	102^{+8}_{-12}	67^{+6}_{-13}	…	…
$v_{\rm rot}$ [km s^{-1}]	…	…	330^{+26}_{-30}	70^{+8}_{-15}
$Y_{\rm He}$	0.25 ± 0.04	0.24 ± 0.03	$0.28^{+0.08}_{-0.02}$	0.26^{b}
[C/H] + 12	$8.17^{+0.60}_{-0.55}$	$9.12 \pm 0.10^{*}$	$7.12^{+0.55}_{-0.05}$	8.13^{b}
[N/H] + 12	$8.45^{+0.10}_{-0.29}$	7.42 ± 0.10	$8.72^{+0.10}_{-0.27}$	7.64^{b}
[O/H] + 12	$8.63^{+0.10}_{-0.70}$	$8.64^{+0.10}_{-0.13}$	$8.55^{+0.01}_{-0.61}$	8.55^{b}
$\log(L/L_\odot)$	5.68 ± 0.08	5.35 ± 0.08	$5.67^{+0.06}_{-0.07}$	$5.33^{+0.08}_{-0.06}$
R [$R_\odot$]	10.8 ± 1.0	8.9 ± 1.2	$10.73^{+0.79}_{-0.61}$	$8.73^{+0.75}_{-0.67}$
$M_{\rm spec}$ [$M_\odot$]	32.1 ± 16.0	18.9 ± 10.1	…	…
$M_{\rm evol}$ [$M_\odot$]	…	…	53.8 ± 4.7	$37.0^{+2.0}_{-2.3}$
Age [Myr]	…	…	$1.00^{+0.80}_{-0.41}$	$1.00^{+0.48}_{-0.58}$

Read the full paper from A&A:

Conclusion

9 Sgr is a very massive O+O binary of 53 and 39 $M_\odot$, and is one of the most massive galactic binaries ever resolved. It serves as a valuable anchor point in the upper left HRD to gauge stellar evolution models.

Get spinOS at GitHub!