Spectroscopic binary stars with TIGRE

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Outline

1. Spectroscopic binary stars
2. TIGRE observations of random stars
3. A well-aimed search using Gaia DR2 data
4. Interesting star
5. Conclusions & Outlook

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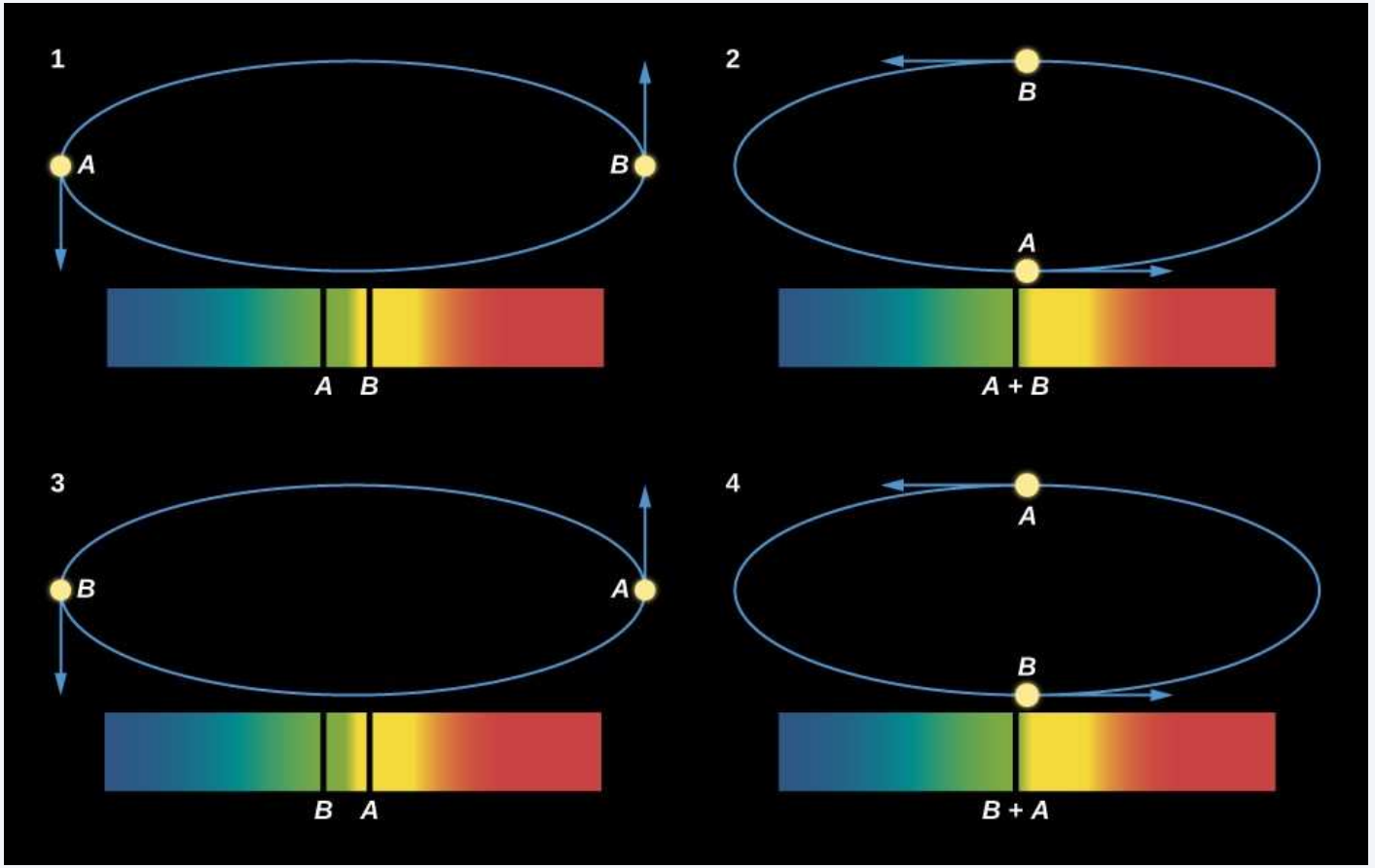
Binary Stars

Detecting binary stars

- About half of the stars in the Universe can be found in binary or multiple stellar systems
- Important for the determination of stellar parameters (mass!)
- There exist several methods to detect binary stars

Spectroscopic binary



Spectroscopic binary stars

Spectroscopic binary stars

- Doppler effect in spectral lines
- SB1: single-lined spectroscopic binary
- SB2: double-lined spectroscopic binary
- Measurement of the radial velocity
- Good spectral resolution, many spectral lines
- We only need a moderate signal to noise
- Monitoring
- $\rightarrow$ **TIGRE!**
- The automatic reduction pipeline of TIGRE contains a routine to measure the radial velocity of a star
- Precision ≈ 0.11 km/s

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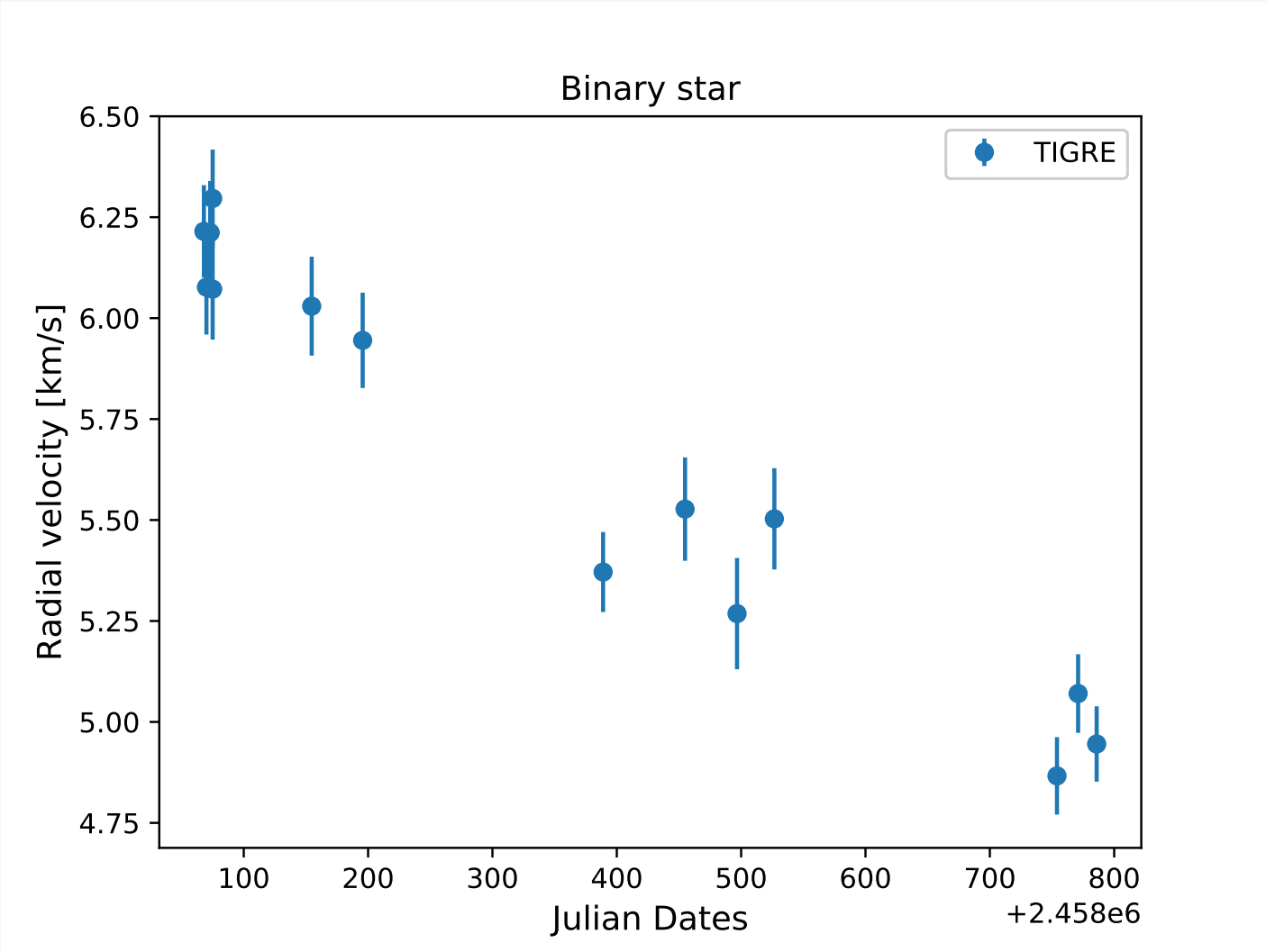
TIGRE observations of Stars

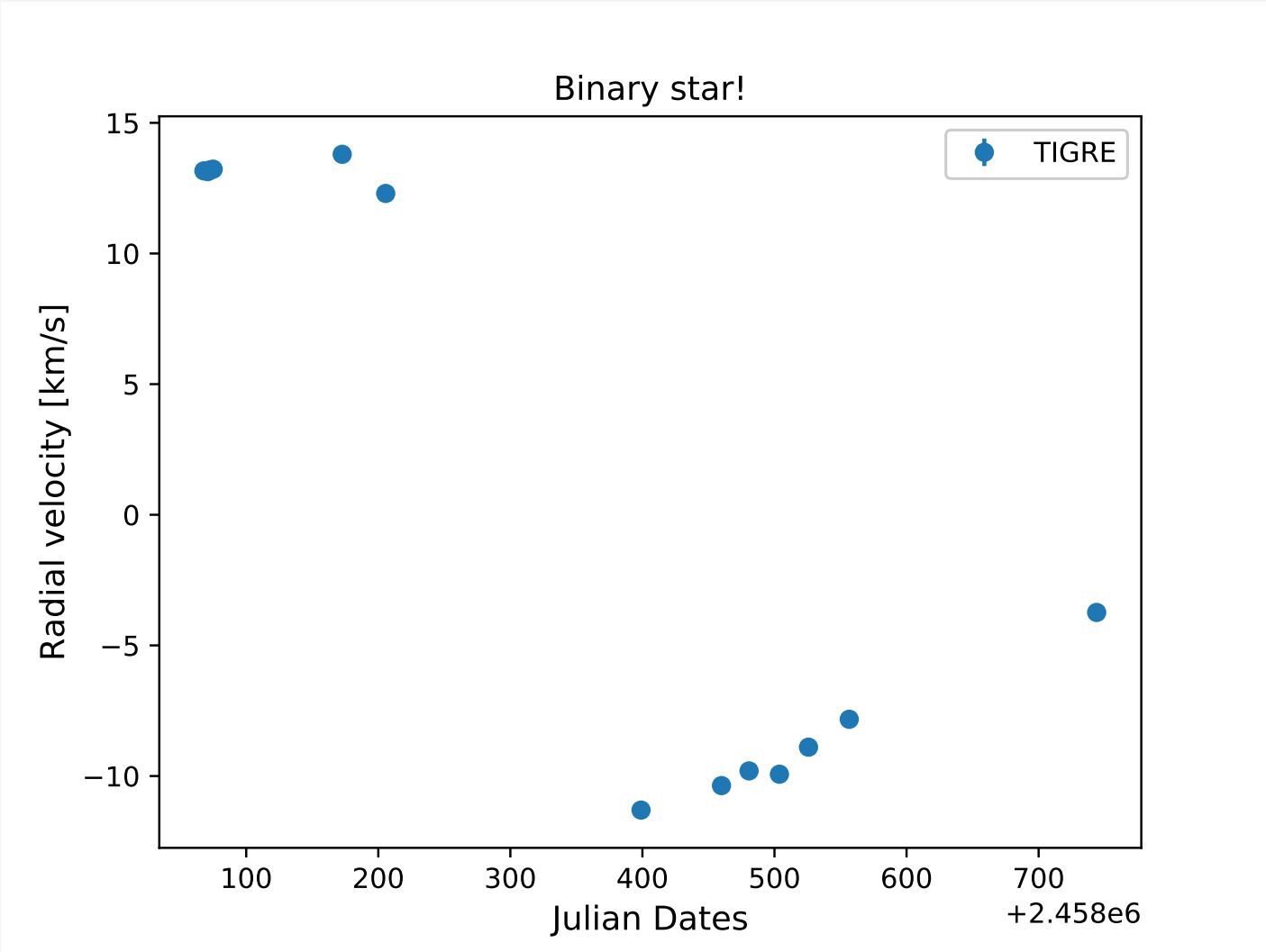
TIGRE Sample

- A sample of 30 Stars
- Easy to observe by the TIGRE telescope
- Relatively bright stars ($m_V < 8.5$), with no spectra observed so far
- Measured Gaia parallax
- The idea was to classify the stars
- Instead of taking one spectrum, take a few spectra over a longer period to check for variations in the RV
- Detection of 3 stars with RV variations!

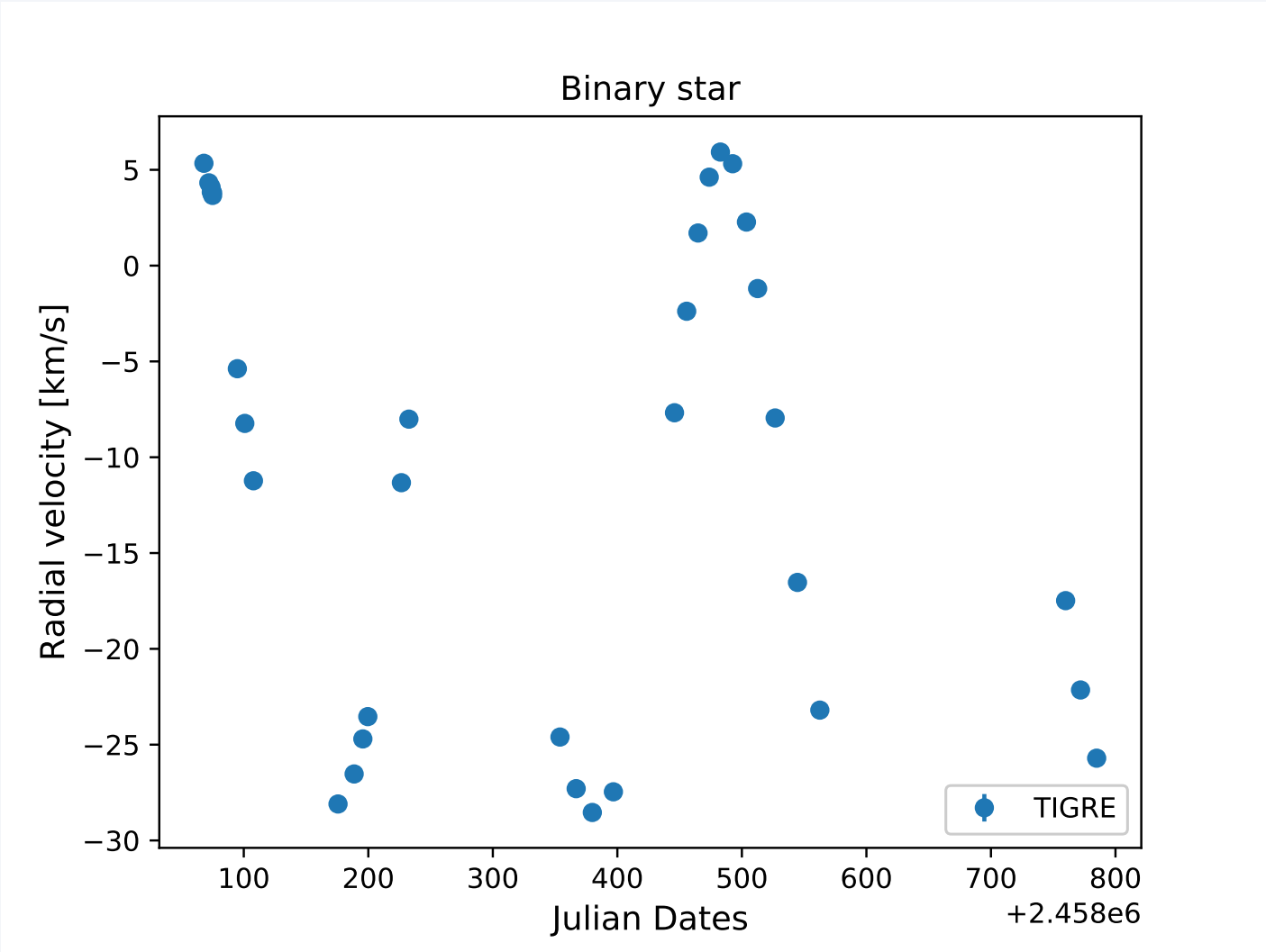
A (long period) binary star



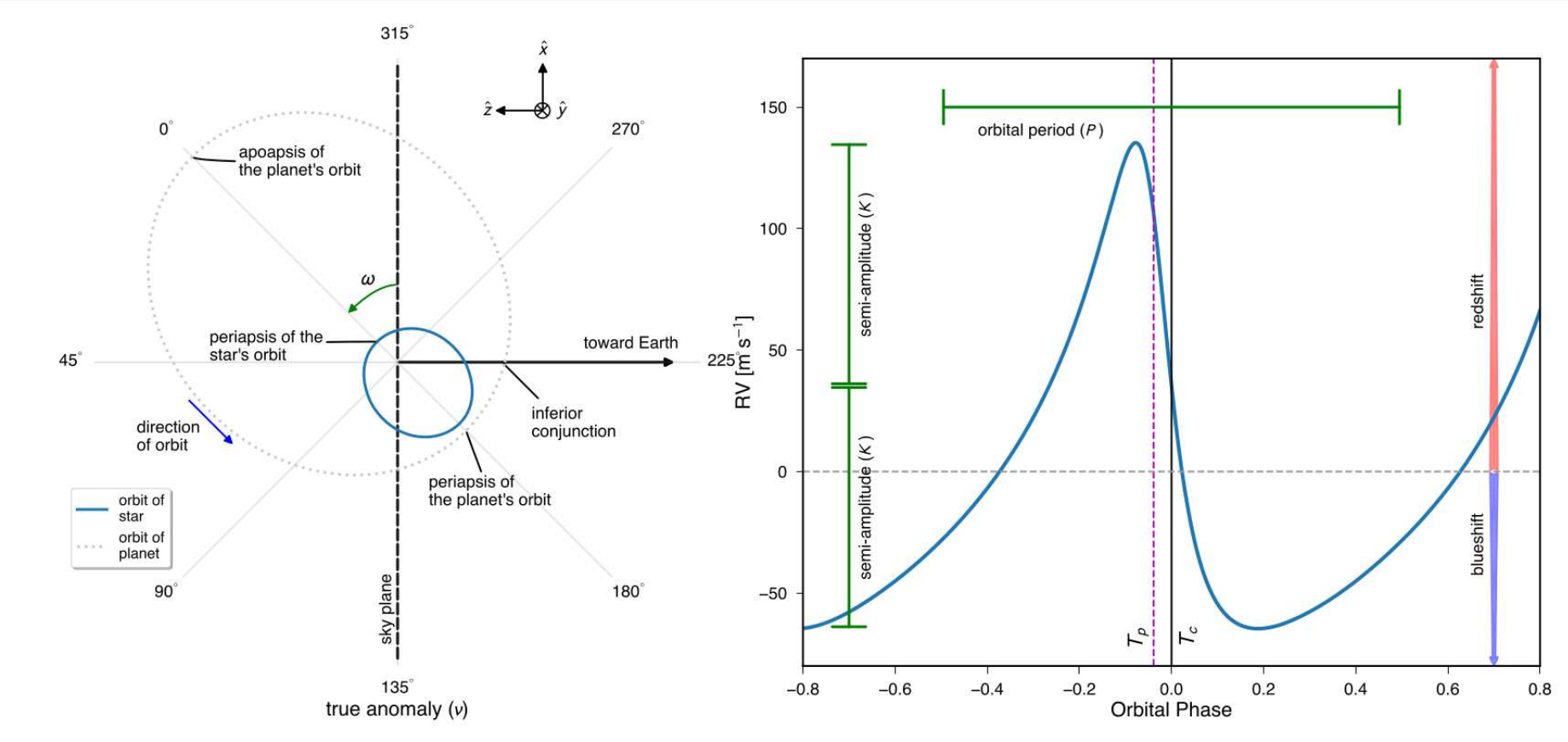
Another binary star!



A third binary star



Binary Orbits



Binary Orbits

Parameters of binary orbits

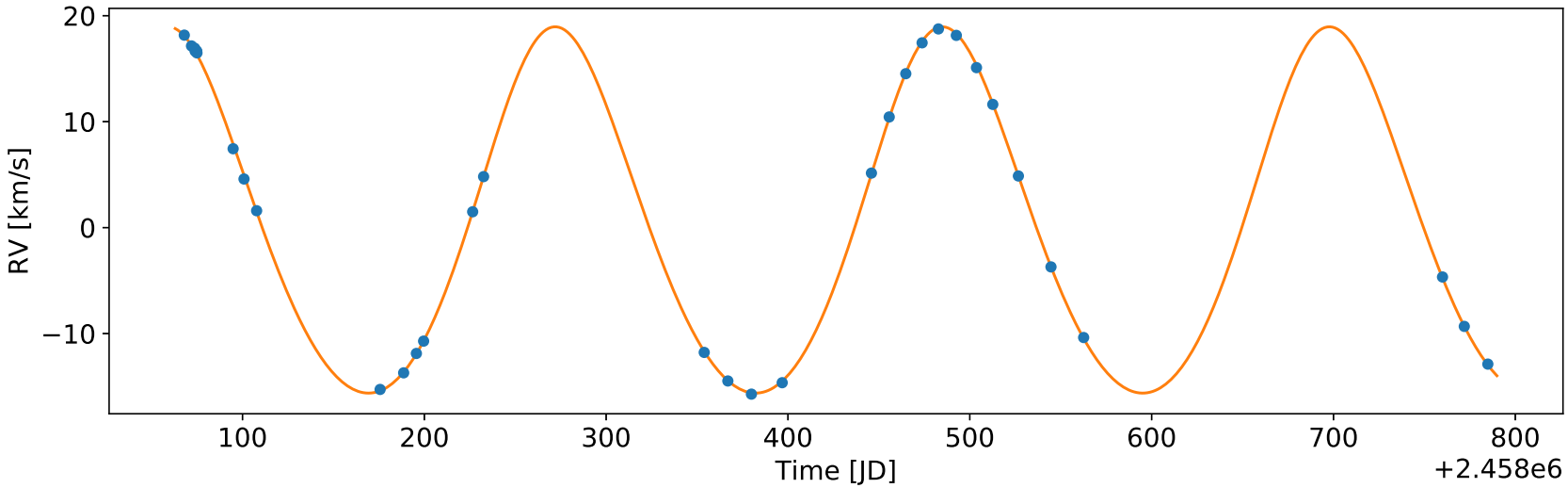
- P: Orbital period
- T_c: Time of inferior conjunction
- K: Velocity semi-amplitude
- e: Eccentricity
- ω: Argument of periapsis of the star's orbit
- i: Orbital inclination (unknown)
- v_{rad}: Radial velocity of the system

Binary Orbits

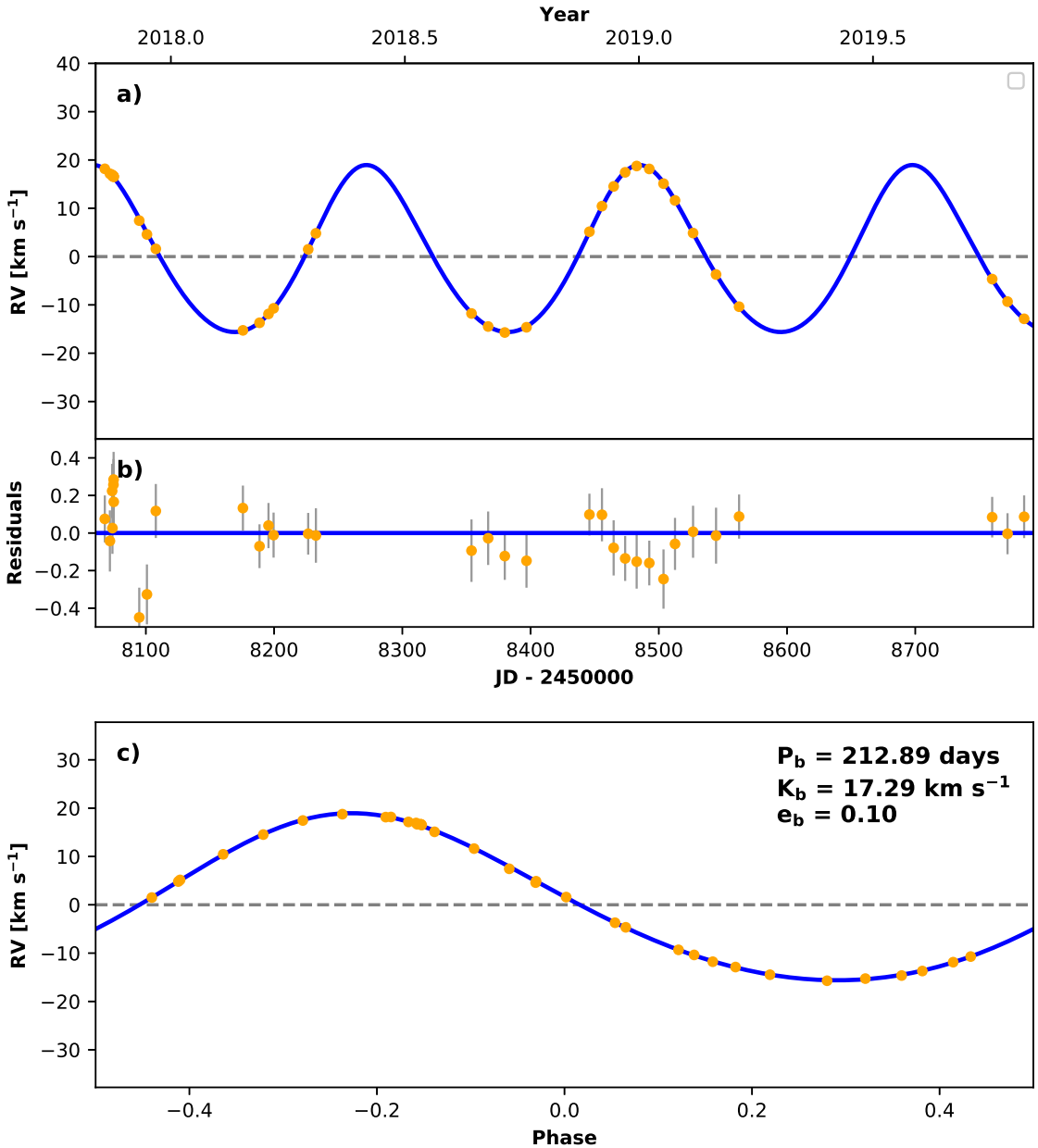
RadVel: The Radial Velocity Fitting Toolkit

- Fulton, Petigura, Blunt & Sinukoff (2018)
- Python package for fitting radial velocity curves
- Developed for exoplanets
- Can fit a given number of planets to the observed RV curve
- Works also with binary stars!

A third binary star



A third binary star



A third binary star

Orbital parameters

- $P = 212.83$ days
- $K = 17.29$ km/s
- $e = 0.10$
- $T_c = 2458107.4$ JD
- $\omega \approx 345°$
- Mean RV is $v_{\mathrm{rad}} = -12.84$ km/s

A third binary star

Determining the mass

- Using Kepler's third law
- Mass function: $f = \frac{M_2^3 \sin^3 i}{(M_1+M_2)^2} = \frac{P_{\rm orb} K^3}{2\pi G}(1-e^2)^{3/2}$
- Mass function $f = 0.11227 M_\odot$
- From stellar evolution tracks we can determine the mass of star 1
- Assuming $M_1 = 2.5 M_\odot$, we obtain $M_2 \geq 0.93 M_\odot$
- This is a minimum mass, because of unknown $\sin i$

TIGRE observations of Stars

extended TIGRE Sample

- Detection of 3 stars with RV variations!
- Continue observations to obtain RV curves
- Observe the other stars again later to check for long period binaries
- We extended the sample to a total of 133 stars
- We have found already more spectroscopic binary stars
- Determine their orbital parameters

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Gaia DR2

A well-aimed search using Gaia DR2 data

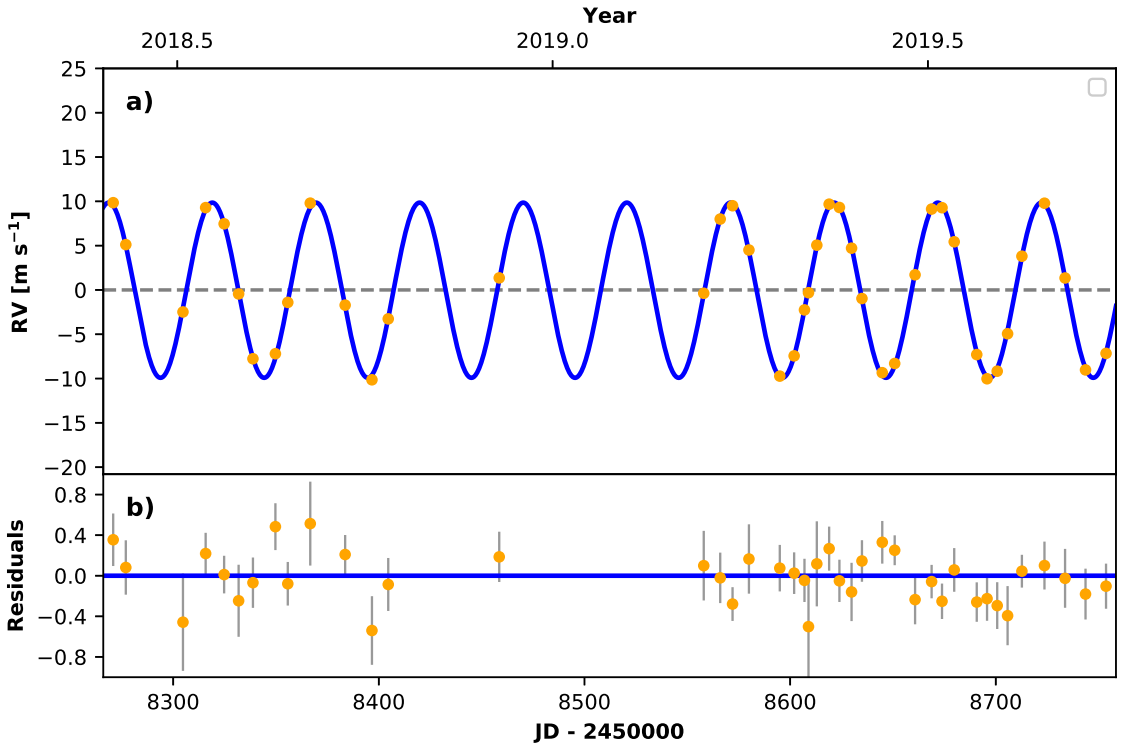
- Gaia DR2 has now RV measurements!
- Some of them have large errors.
- Due to RV variations? Binaries?
- Selected 19 bright stars ($m_G < 7.0$ mag)
- With large errors > 2 km/s
- Observable by TIGRE, no RV report in SIMBAD
- Exposure time for one spectrum is just 60 seconds
- Check for RV variations

Gaia DR2

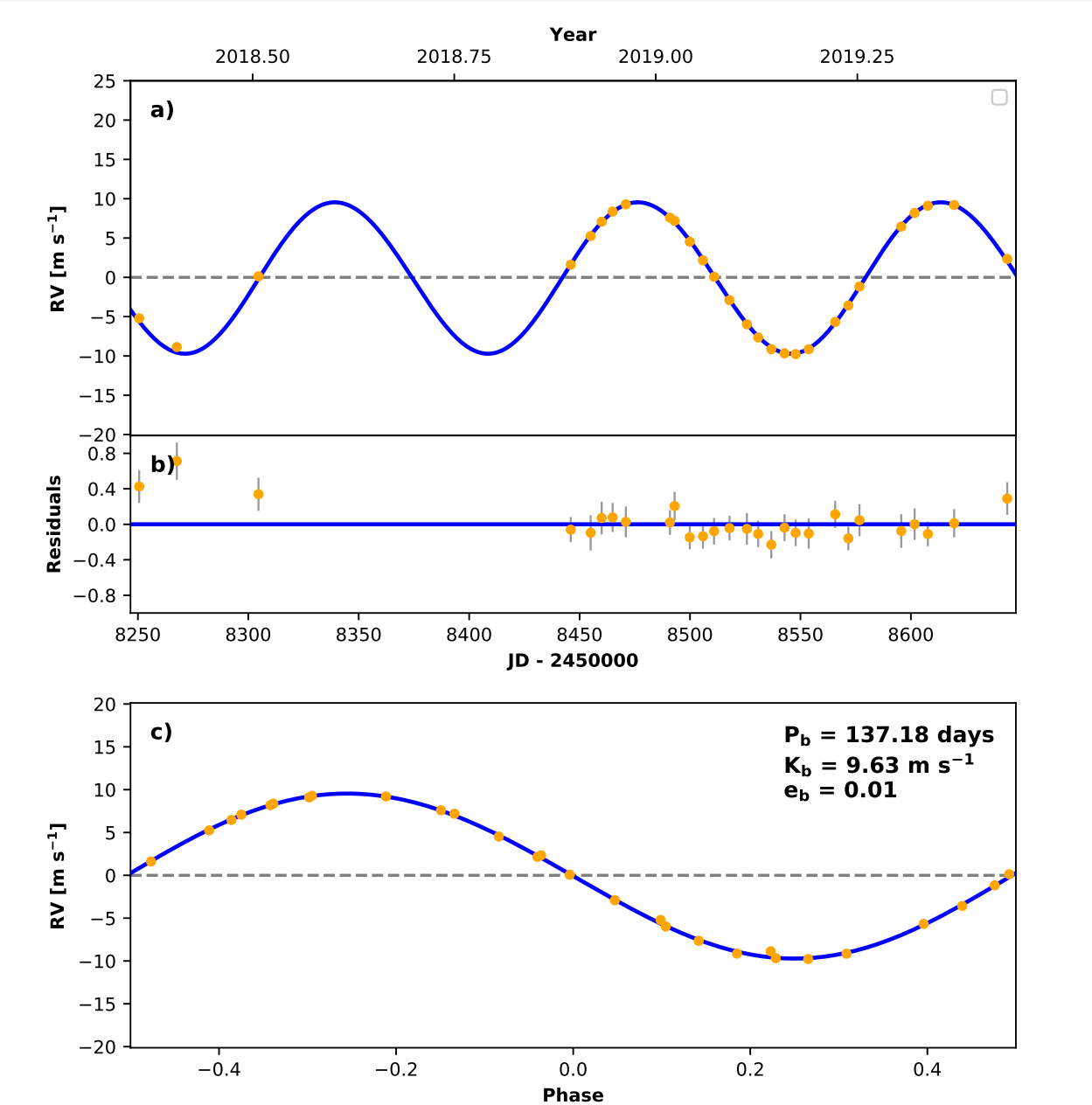
A ~~well~~ perfectly-aimed search with Gaia DR2

- Result: All 19 stars are spectroscopic binaries!
- Different periods
- Five stars with $P < 365$ days
- Some long period (still to be determined)
- Still observing to take RV curves
- Determination of orbital parameters
- Extended the sample to an error > 1 km/s now having a total of 42 stars

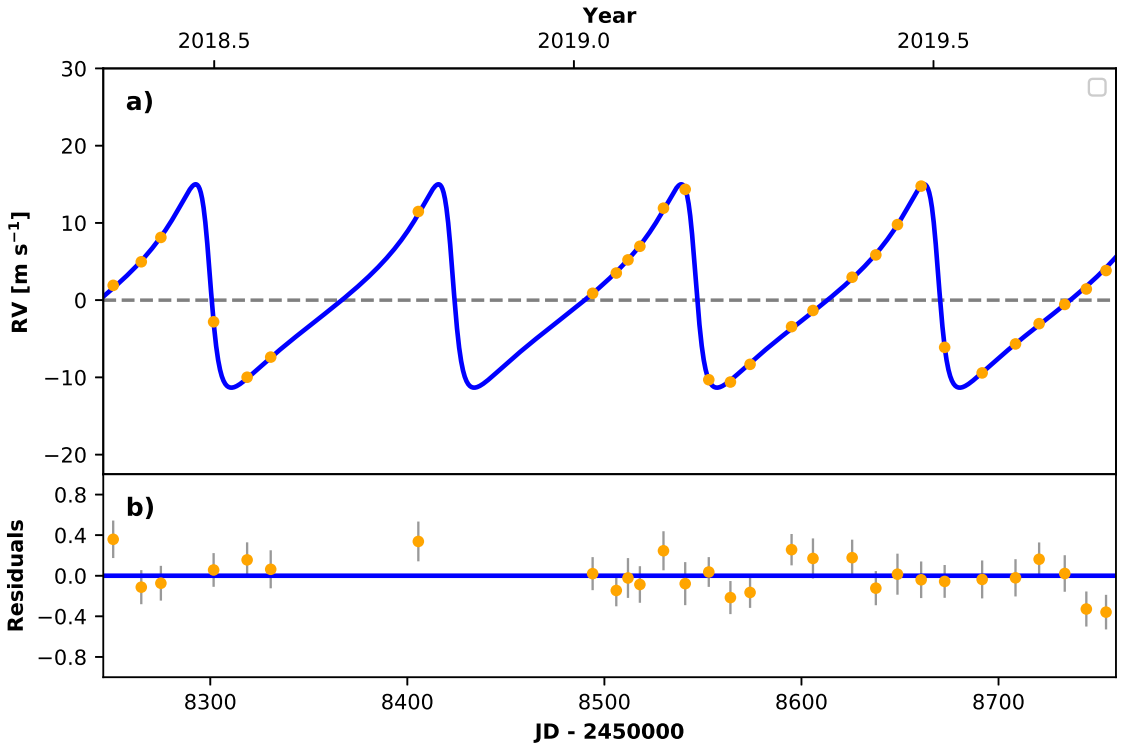
Star 1


Year
2018.5
2019.0
2019.5
a)
RV [m s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 50.39 days
K_b = 9.89 m s^{-1}
e_b = 0.00
RV [m s^{-1}]
Phase

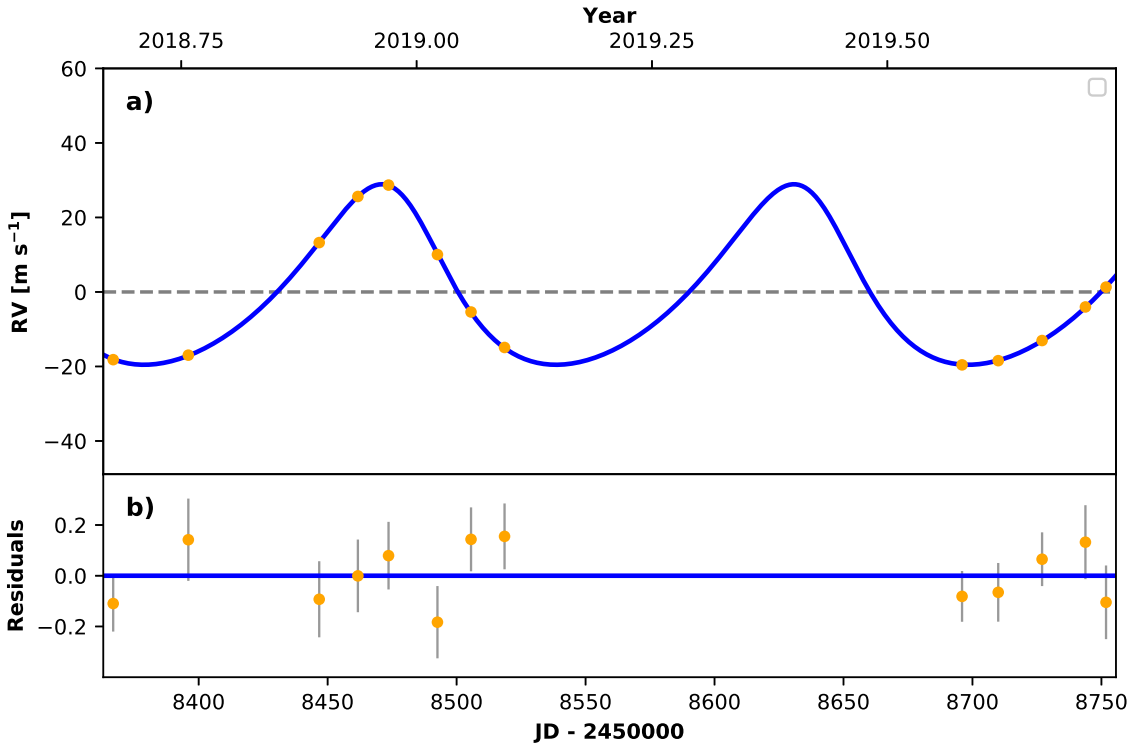
Star 2


Year
2018.50
2018.75
2019.00
2019.25
a)
RV [m s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 137.18 days
K_b = 9.63 m s^{-1}
e_b = 0.01
RV [m s^{-1}]
Phase

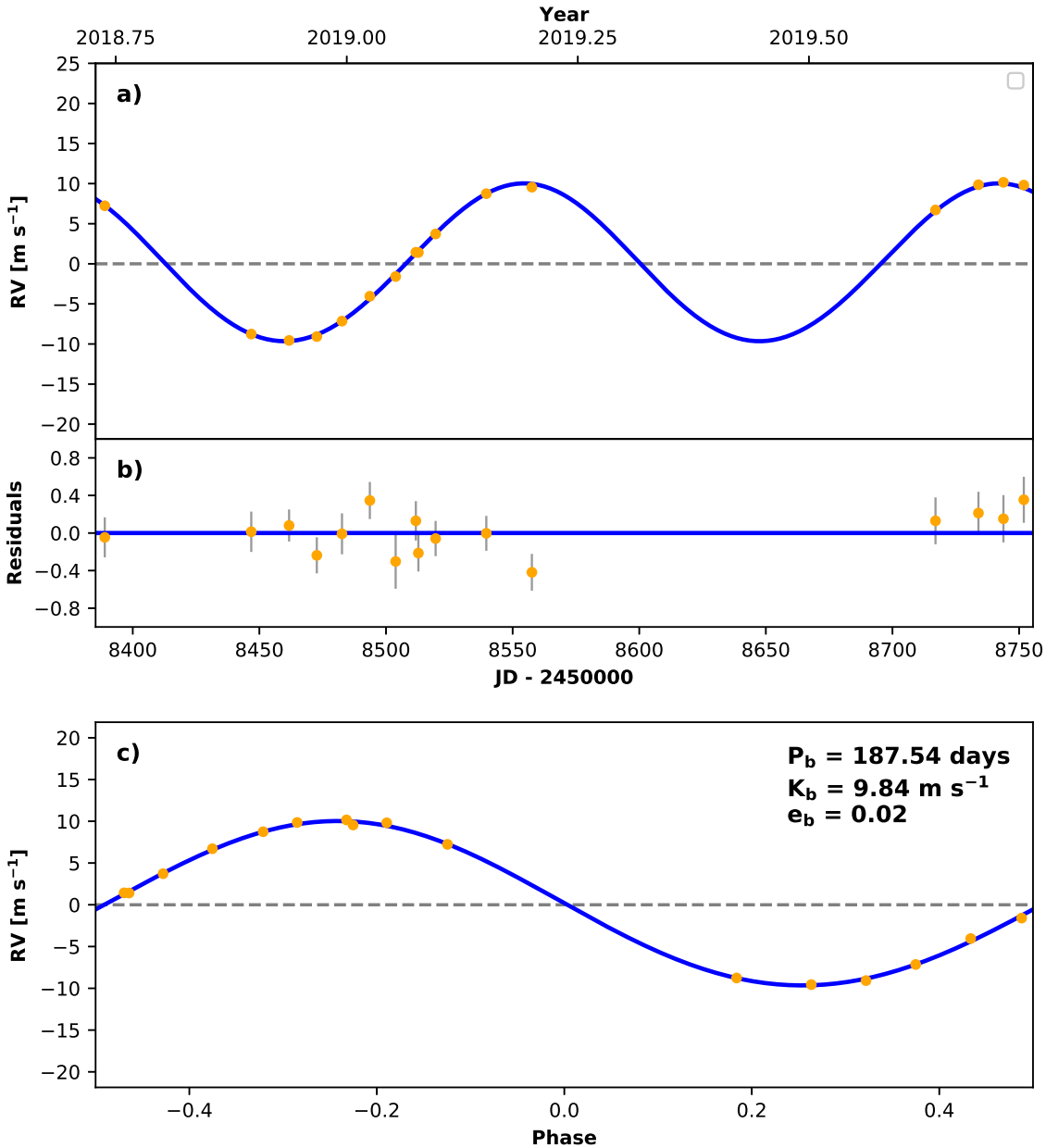
Star 3


Year
2018.5
2019.0
2019.5
a)
RV [m s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 123.22 days
K_b = 13.17 m s^{-1}
e_b = 0.60
RV [m s^{-1}]
Phase

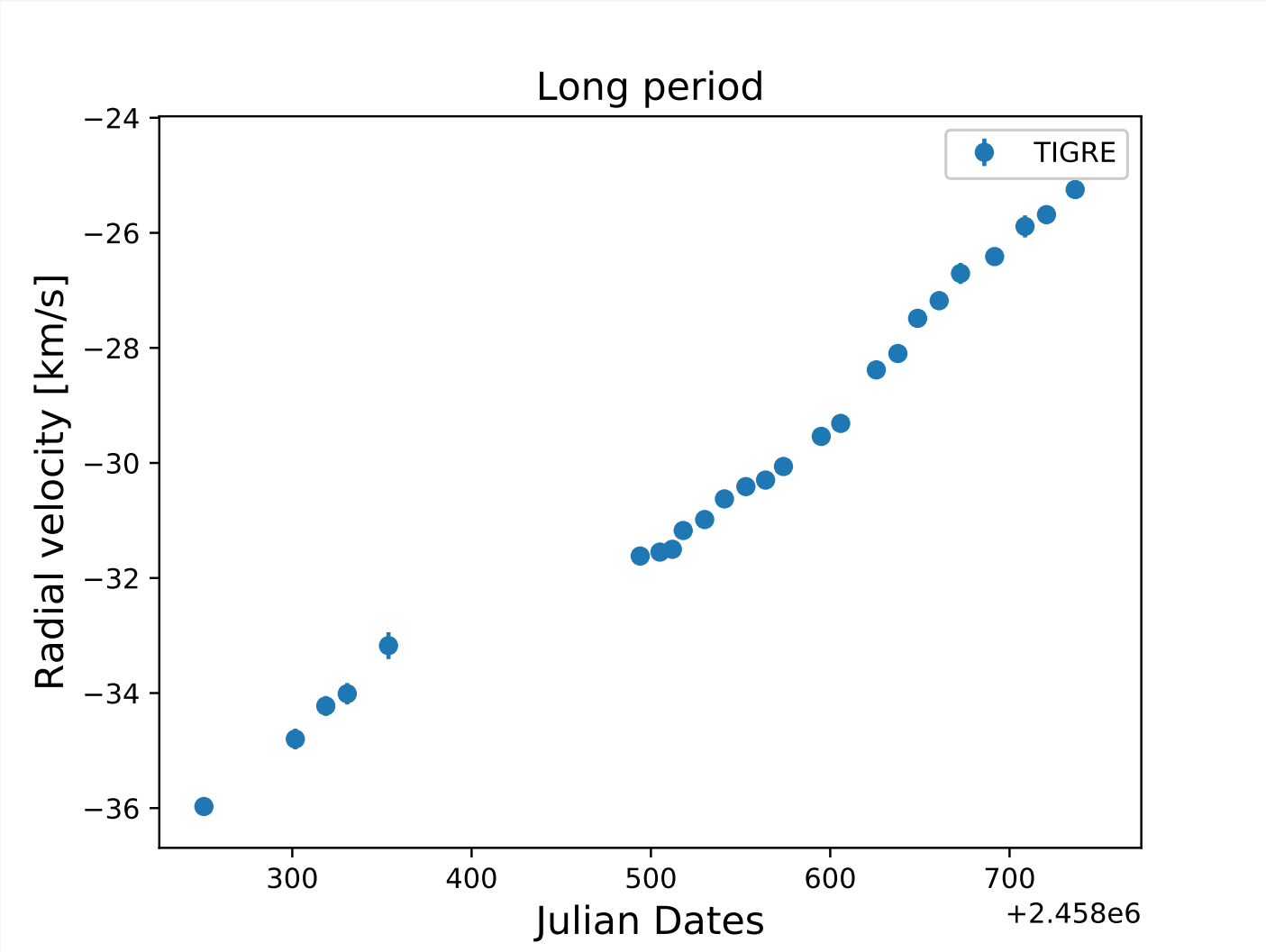
Star 4


Year
2018.75
2019.00
2019.25
2019.50
a)
RV [m s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 159.73 days
K_b = 24.23 m s^{-1}
e_b = 0.23
Phase

Star 5


Year
2018.75
2019.00
2019.25
2019.50
a)
RV [m s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 187.54 days
K_b = 9.84 m s^{-1}
e_b = 0.02
RV [m s^{-1}]
Phase

Long period binary



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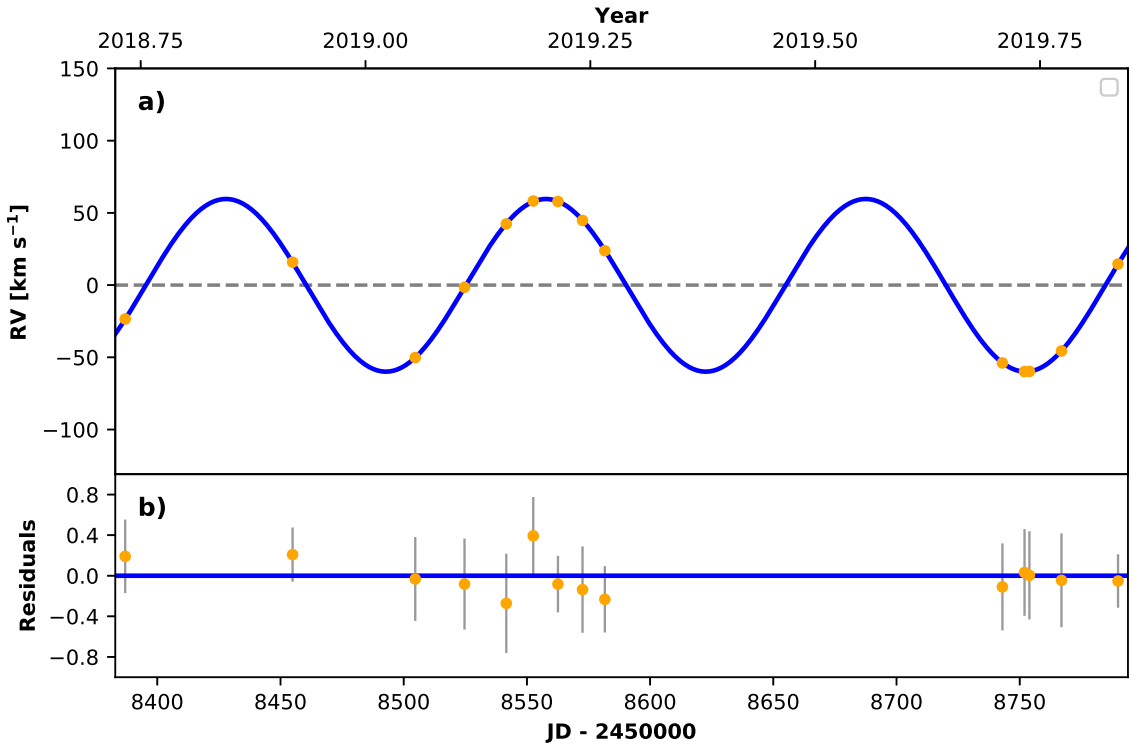
Binary Star

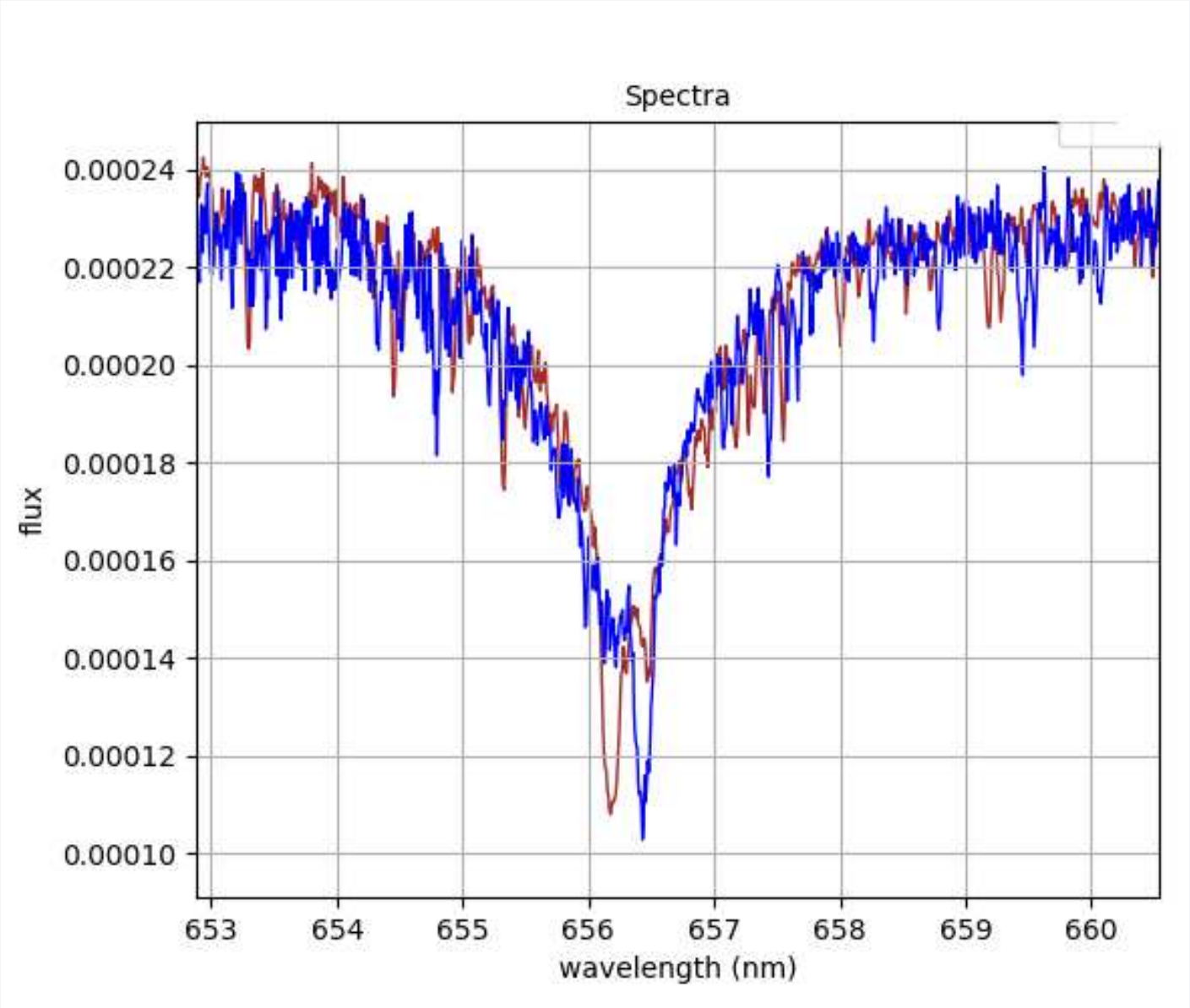

Year
2018.75
2019.00
2019.25
2019.50
2019.75
a)
RV [km s^{-1}]
b)
Residuals
JD - 2450000
c)
P_b = 129.81 days
K_b = 59.78 km s^{-1}
e_b = 0.00
RV [km s^{-1}]
Phase

Binary Star

Weird Binary Star

- Period $P = 129.75$ days
- Amplitude $K = 59.77$ km/s
- Circular orbit
- SIMBAD: A0 star
- Mass function $f = 2.86807 M_\odot$
- Assuming $M_1 = 2.3 M_\odot$, we obtain $M_2 \geq 3.88 M_\odot$
- What?

Binary Star


Spectra
flux
0.00024
0.00022
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
653
654
655
656
657
658
659
660
wavelength (nm)

Binary Star

Double-lined spectroscopic binary (SB2)

- It is an SB2 binary star!
- TIGRE measures the velocity of the secondary star!
- Probably a giant star with a massive MS star
- (Don't trust SIMBAD)
- Still need to take high S/N spectra
- We can analyze both stars and determine the parameters of the system, including the masses

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Spectroscopic binary stars

Conclusions & Outlook

- We discovered new spectroscopic binaries
- Some are bright!
- We have determined the orbital parameters of a few
- We found an SB2 star!
- Observations with TIGRE will continue
- We will discover new binary stars
- Determine the orbital parameters
- Determine the stellar parameters of the visible star
- Determine masses of the system etc.