Determining the orbital parameters for the gamma-ray binaries LMC P3 and 1FGL J1018.6-5856 using SALT/HRS

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Image credit: H. Szegedi

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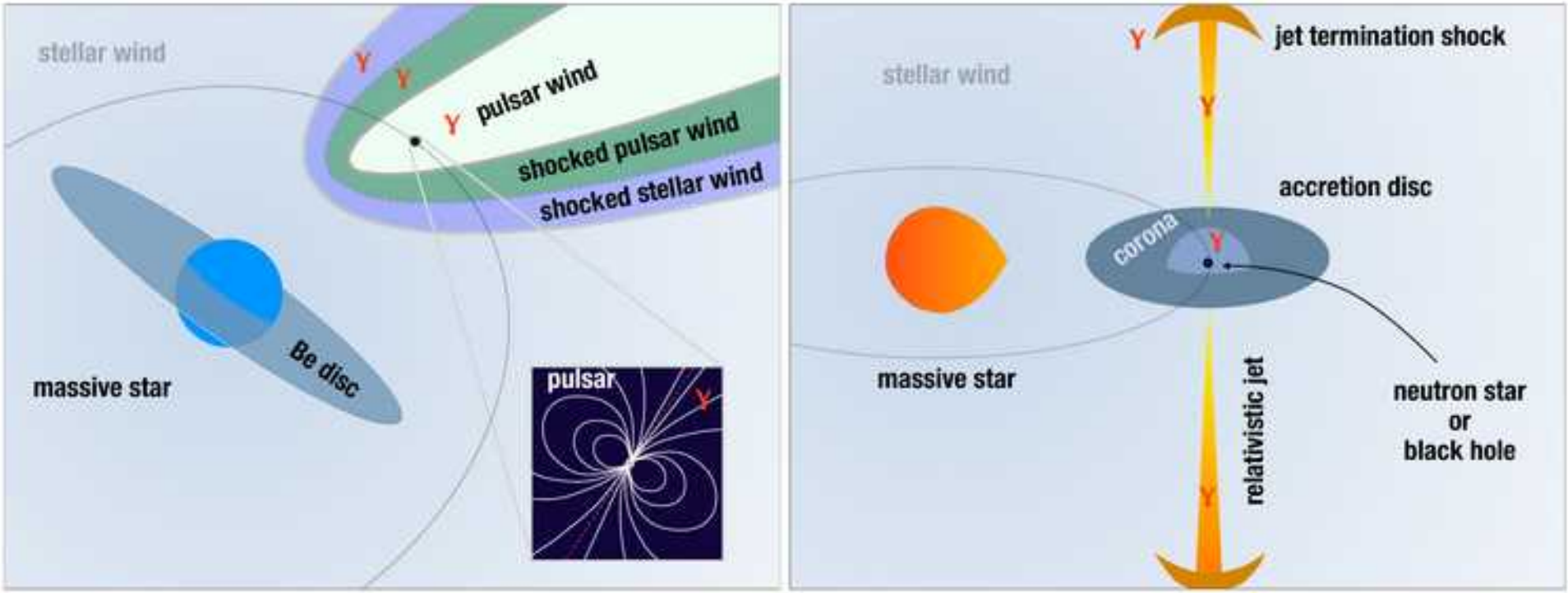
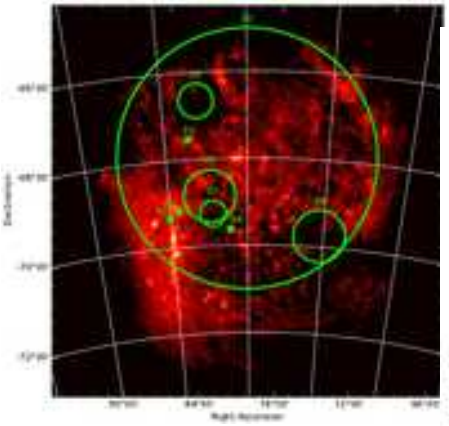
Gamma-ray binaries



Dubus 2013

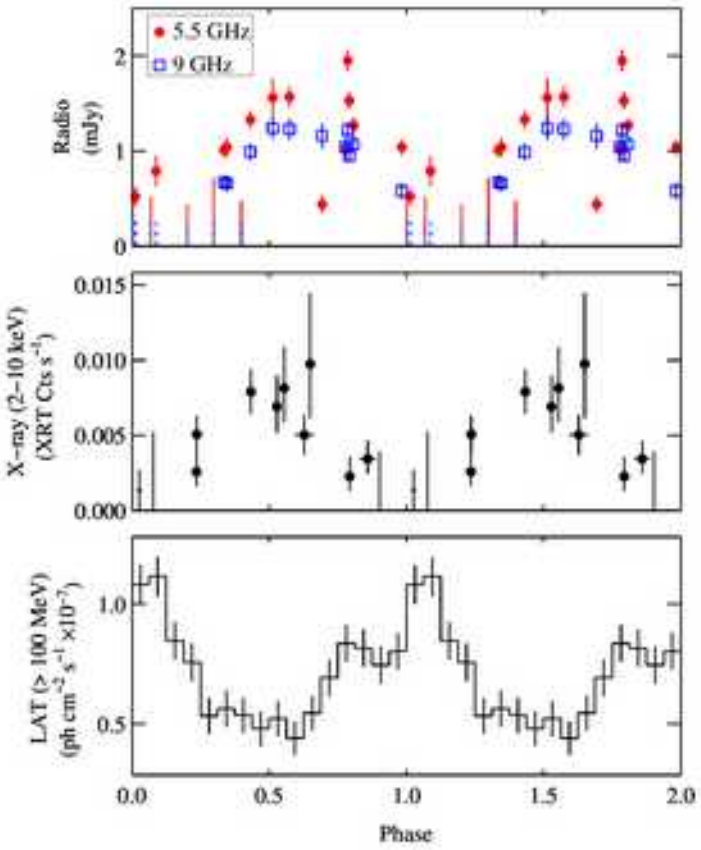
LMC P3

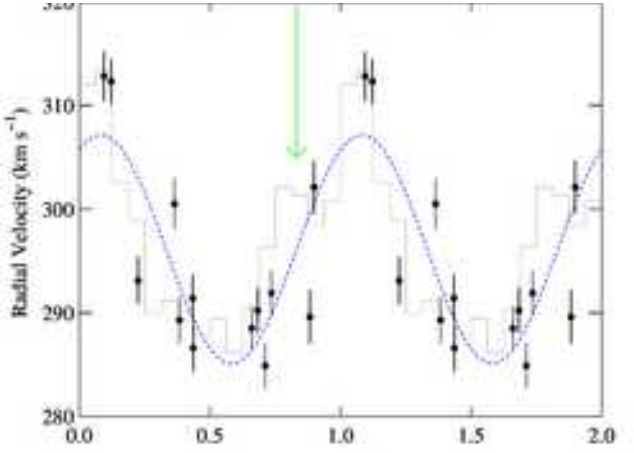


- Gamma-ray emission was first identified, part of the Fermi-LAT deep observations of the LMC, as a point-like source with no known counterpart (Fermi-LAT Collaboration 2016)

- Binary nature was identified through a search for periodic emission in the Fermi-LAT data which subsequently found a 10.301 ± 0.002 days period (Corbet et al. 2016)
  - Radio observations were undertaken with ATCA, X-ray observations with Swift, Gamma-ray observations with Fermi-LAT
  - Folded on the 10.301 period the radio and X-ray observations show a periodicity.
  - However, the X-ray and Radio are out of phase with the gamma-ray observations.
  - This out off phase is seen for other gamma-ray binaries, e.g. LS 5039
- The source was co-incident with the X-ray source CAL 60/ CXOU J053600.0-673507 which has previously been identified as a potential binary system (Crampton et al., 1985; Seward et al., 2012)

- The optical star is identified as a 05 III(f) type star, the earliest of all the gamma-ray binaries.
  - SOAR and SAAO observations folded on 10.301 days.

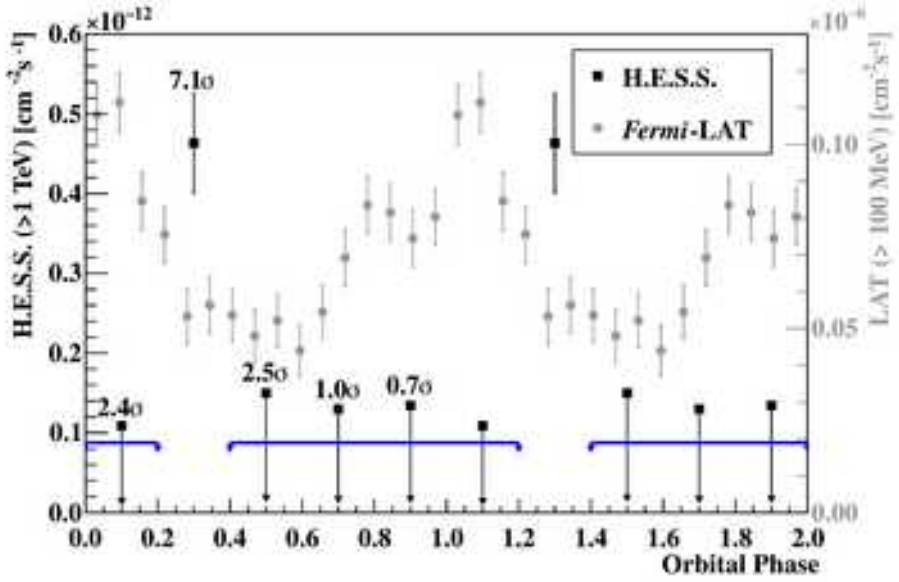


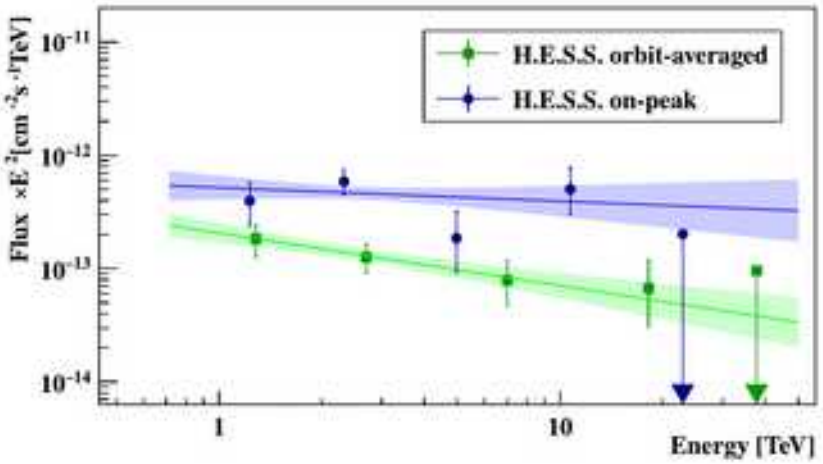


Corbet et al. 2016

H.E.S.S. Observations

- H.E.S.S. observations of the LMC included an effective 100 h observation of LMC P3.
- LMC P3 was detected the source with a 6.4σ significance.
- No significant periodicity could be detected directly with the H.E.S.S. data.
- Folded on 10.301 days the VHE light curve shows a significant detection in only one phase bin.
  - This is off phase with the Fermi-LAT results.

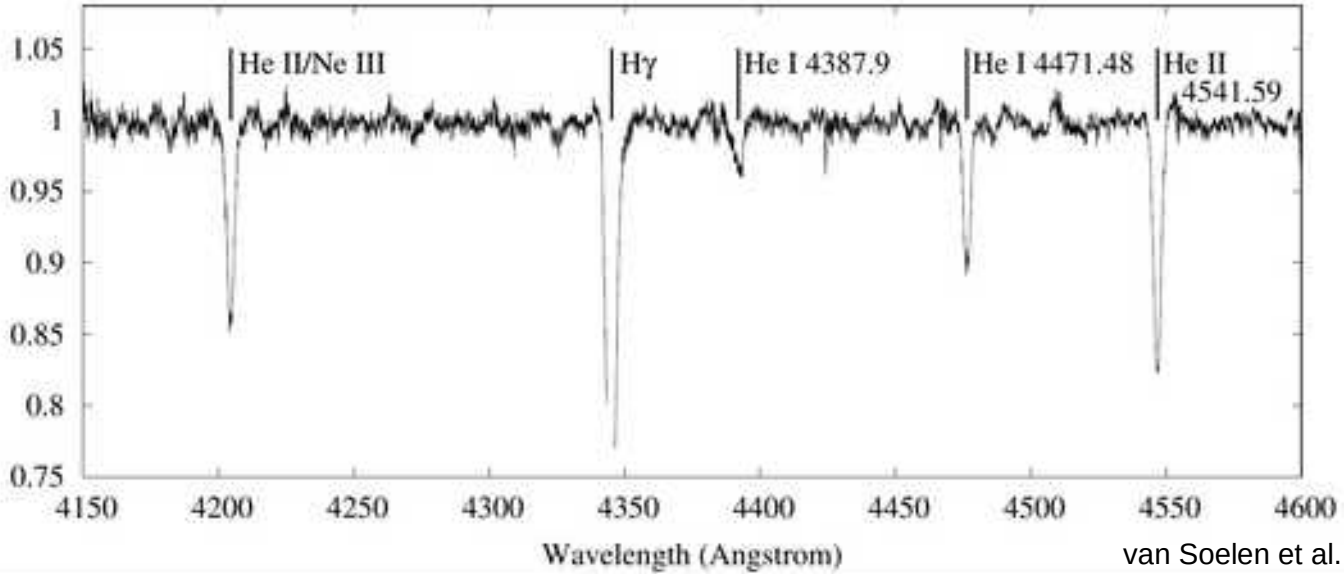




H.E.S.S. Collaboration et al. 2018.

SALT HRS observations

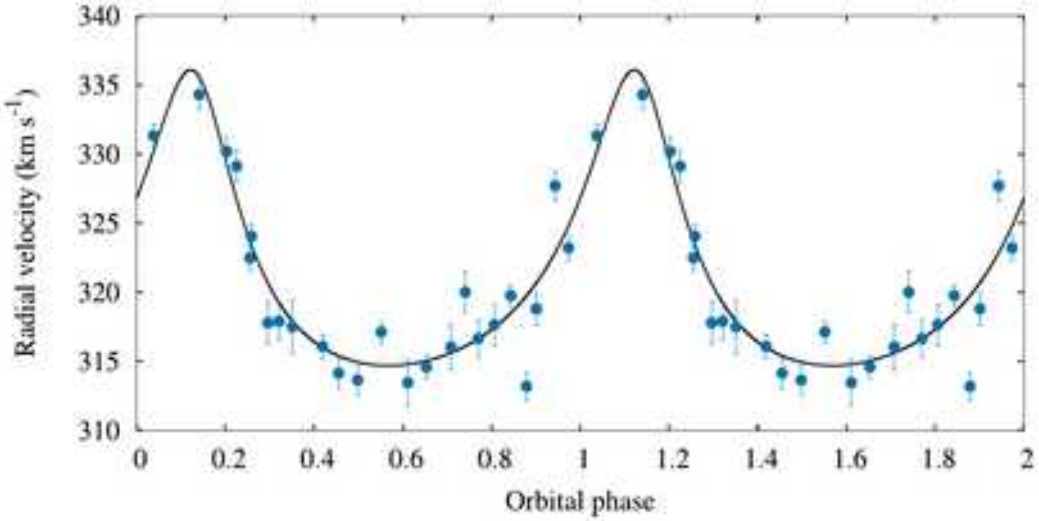
- The system was observed 24 times with the HRS/SALT between 2016 September 14 and 2017 February 06
- Because the target lies within a nebula, and in the LMC, the background in the sky fibre was significantly different from the sky in the target fibre (16’’ separation).
- Restricted performing cross-correlation (rvsao) using the blue part of the spectrum where the sky line contamination was not significant.



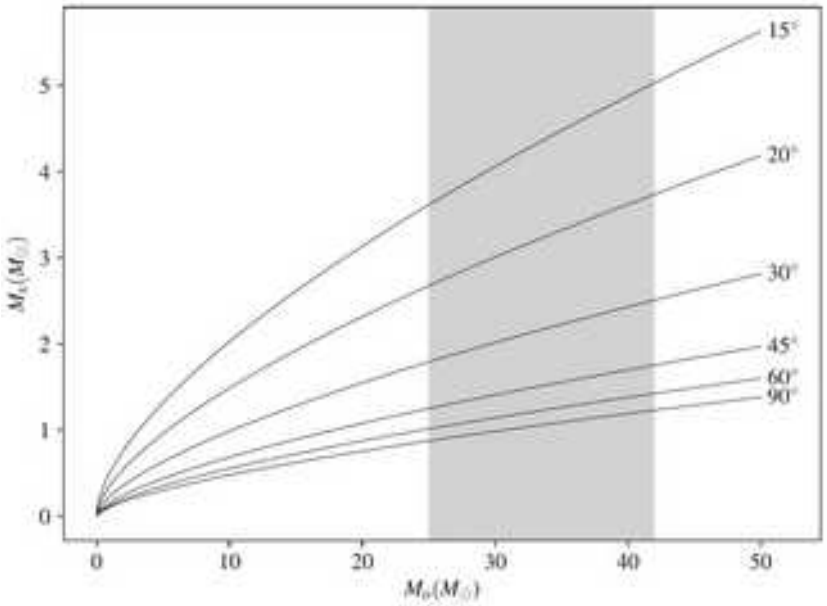
van Soelen et al. 2019

Results

- A free fit to the binary gives a period of 10.314±0.044 days
- But a Lomb-Scargle search for periodicity does not find any significant period
- Adopted a 10.301 day period
- Except for low inclinations, the mass function favours a neutron star companion.



Parameters	Fixed (adopted)
Time of periastron (HJD)	2457412.13 ± 0.29
Orbital period (d)	10.301 ± 0.000
Systemic velocity relative to template (km s^{-1})	0.68 ± 0.55
Systemic velocity (km s^{-1})	321.18 ± 0.85
K (velocity semi-amplitude)	10.69 ± 1.23
Eccentricity	0.40 ± 0.07
Longitude of periastron (deg)	11.3 ± 12.0
Mass function ($M_\odot$)	0.0010 ± 0.0004



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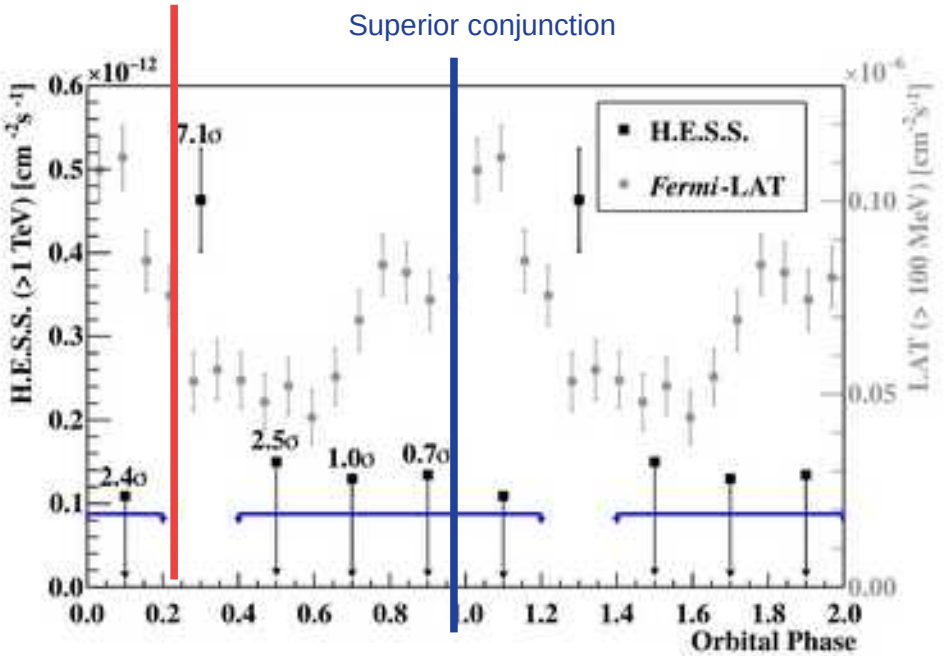
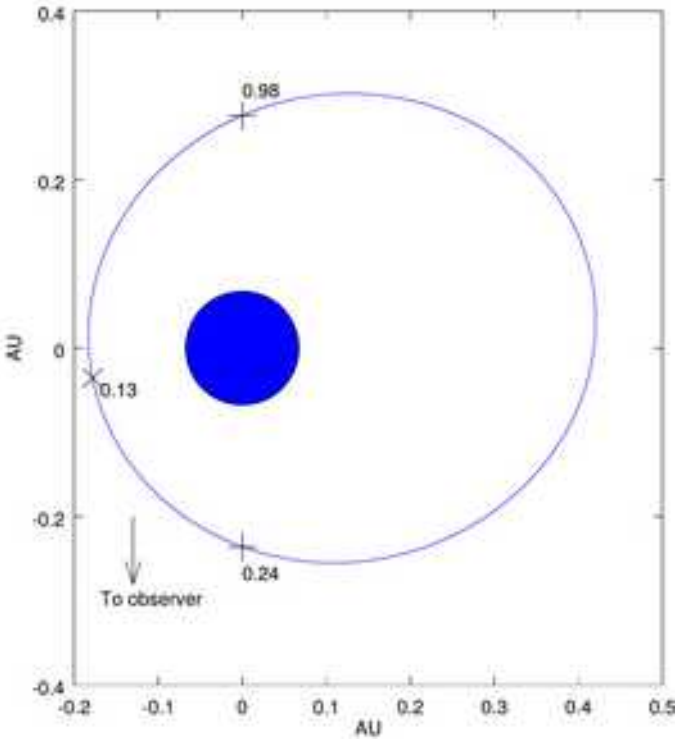
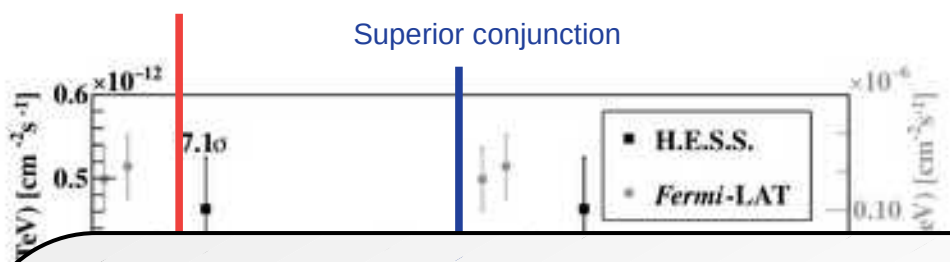
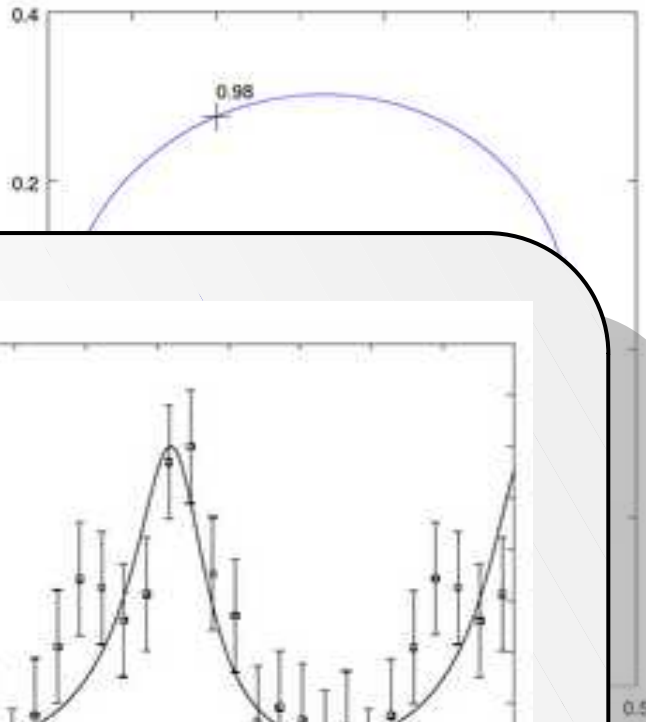


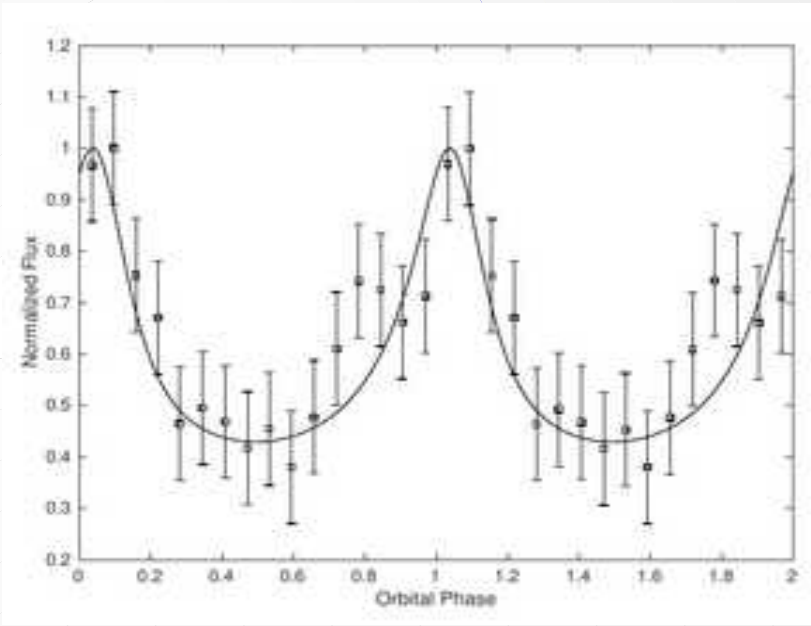


The binary orientation of the LMC P3. This is calculated assuming a M_{star}= 33.5 M_{sun} and radius of R_{star} = 14.5 R_{sun} and M_p = 1.4 M_{sun}.



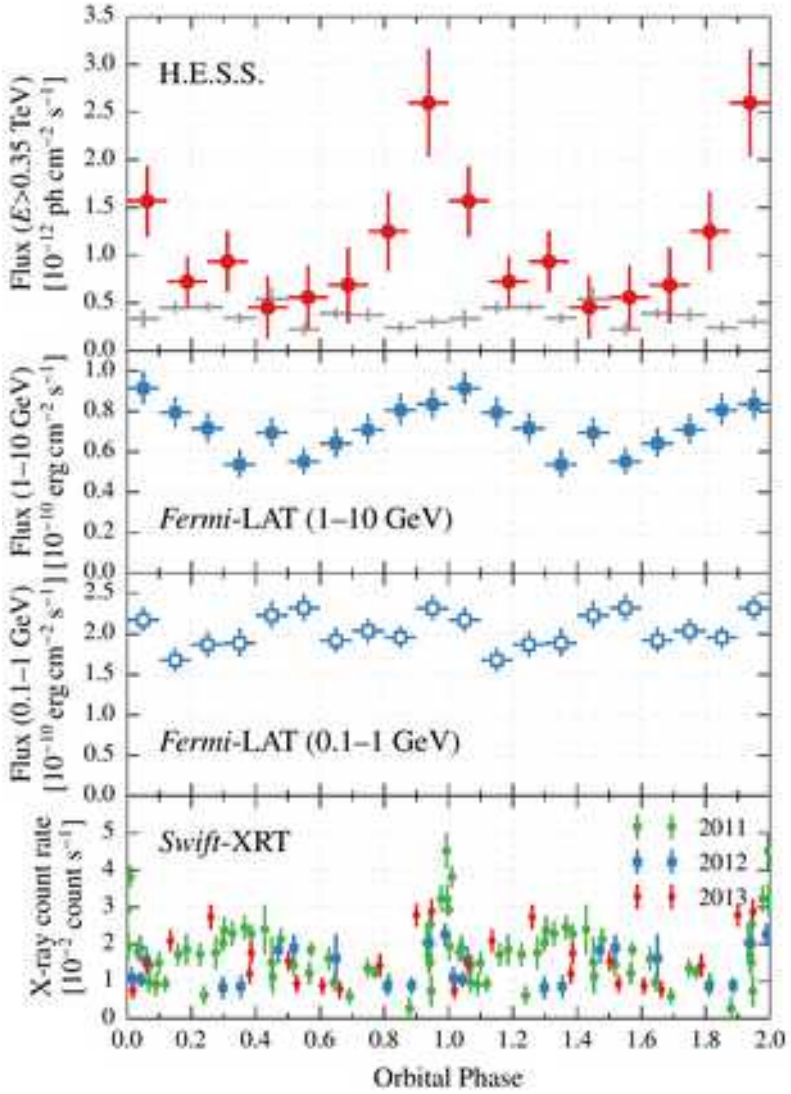


- Xingxing et al. 2020 have suggested a model to explain the GeV emission based on these parameters (within error)
- Emission explained by the IC scattering by the unshocked pulsar wind, taking into account the travel distance.



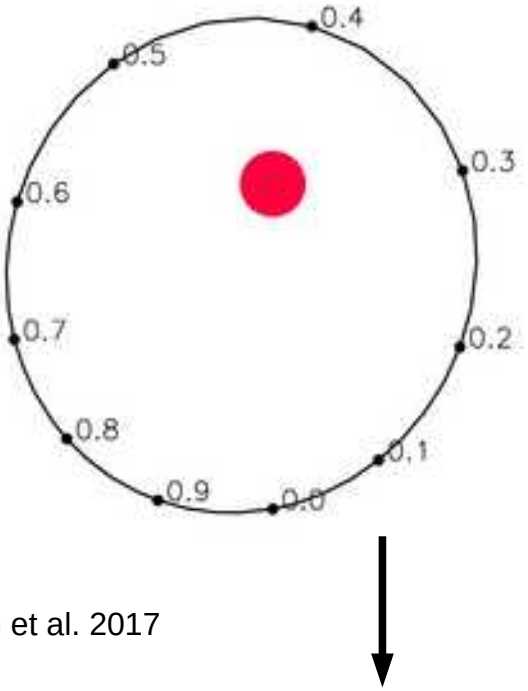
1FGL J1018.6-5856

- Discovered by Fermi-LAT Collaboration (2012) as a variable gamma-ray sources with a period of 16.58 ± 0.04 days co-incident with a O6V((f)) type companion.
- The GeV and TeV emission shows a similar peak
- There is a peak in the X-ray light curve at a similar phase, though a maximum around phase 0.3 as well.
- An et al. 2015 found a 16.544± 0.008 day orbital period from Swift observations

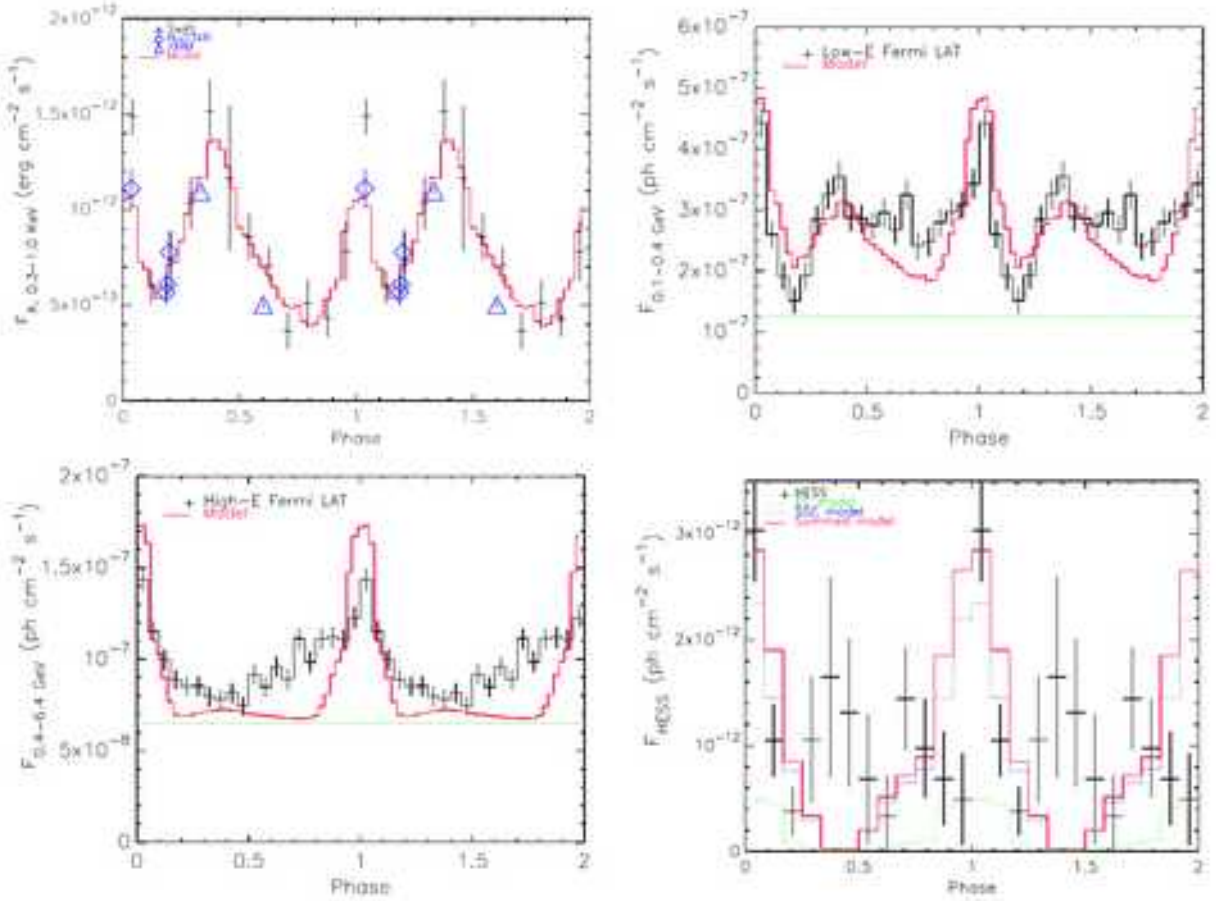


Multi-wavelength liight curves folded on 16.58 d (Abramowski et al. 2015)

1FGL J1018.6-5856



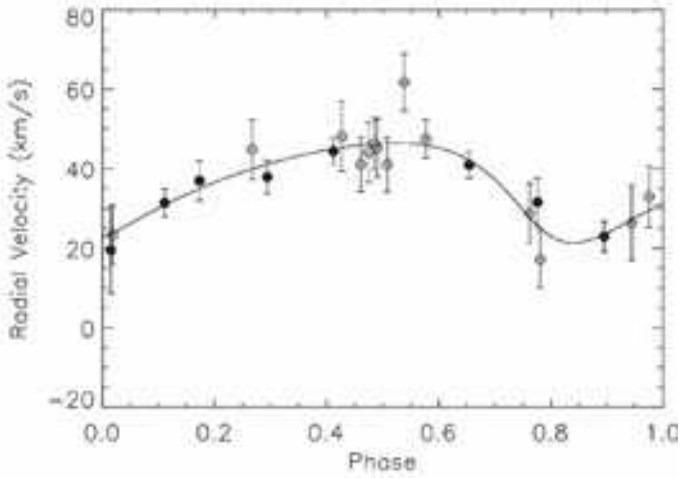
An et al. 2017



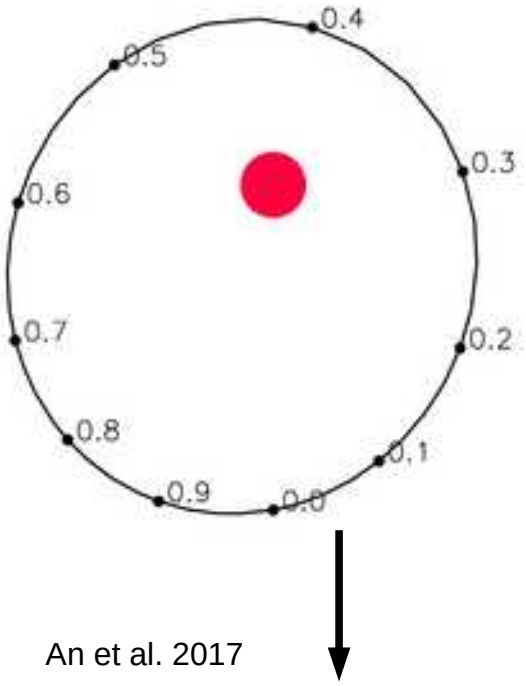
- In An et al. 2017, through modelling the source, it was proposed that the source was eccentric with periastron at phase 0.39 and inferior conjunction at phase 0

1FGL J1018.6-5856

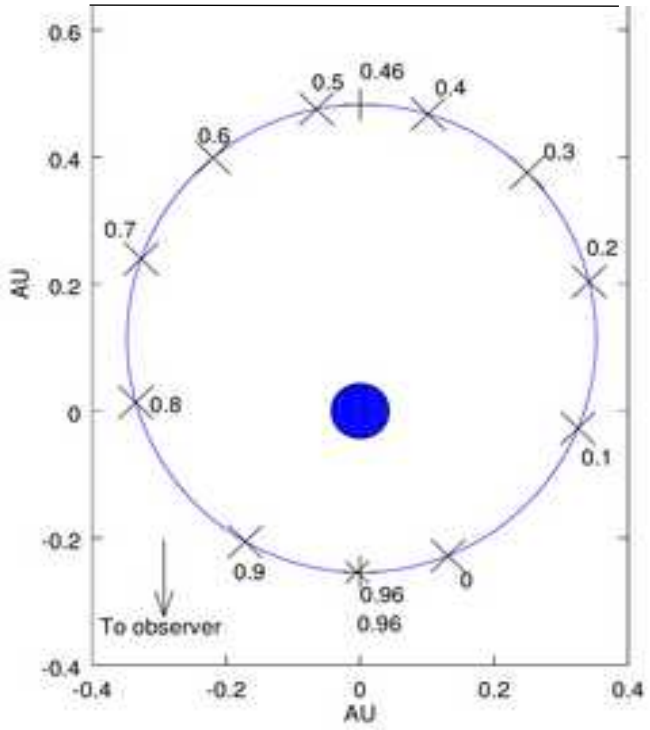
- However Monageng et al 2017 combined new SALT/HRS data with Goodman High-Throughput Spectrograph onboard the SOAR from Strader et al. (2015) and found a very different orbital solution to what was proposed by the modelling
- The eccentricity found (e=0.31 ± 0.16) was similar to the model (e=0.35) but the orientation was different.



Combined radial velocities (Monageng et al. 2017). NB: the choice of phase 0 is different to the gamma-ray observations/modelling



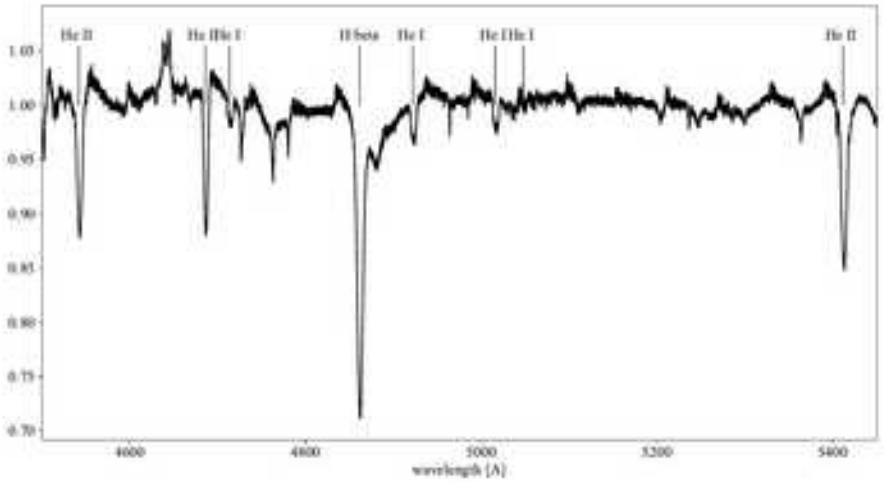
An et al. 2017

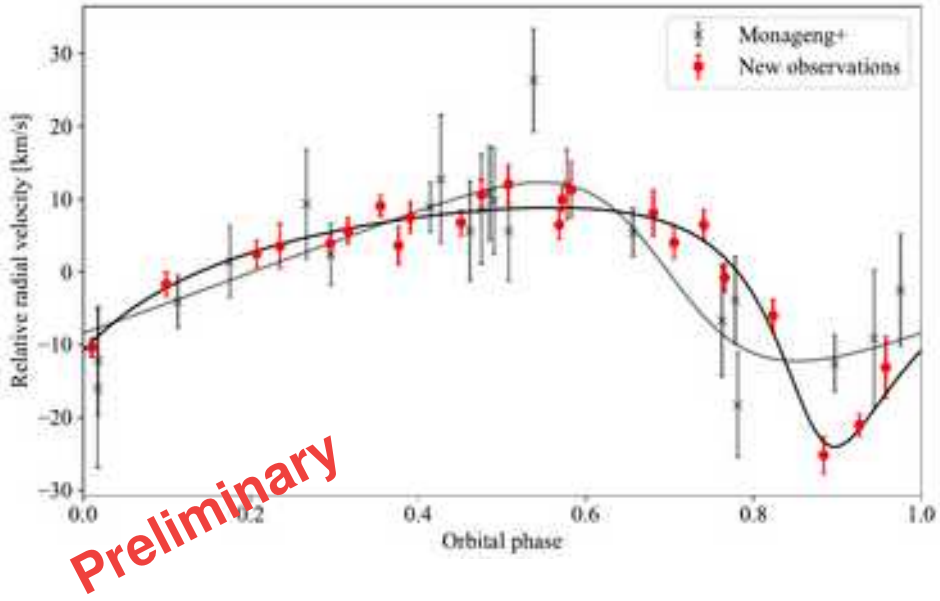


Binary orientation using Monageng+ parameters but the same T_0 time as Fermi-LAT observations

SALT HRS observations

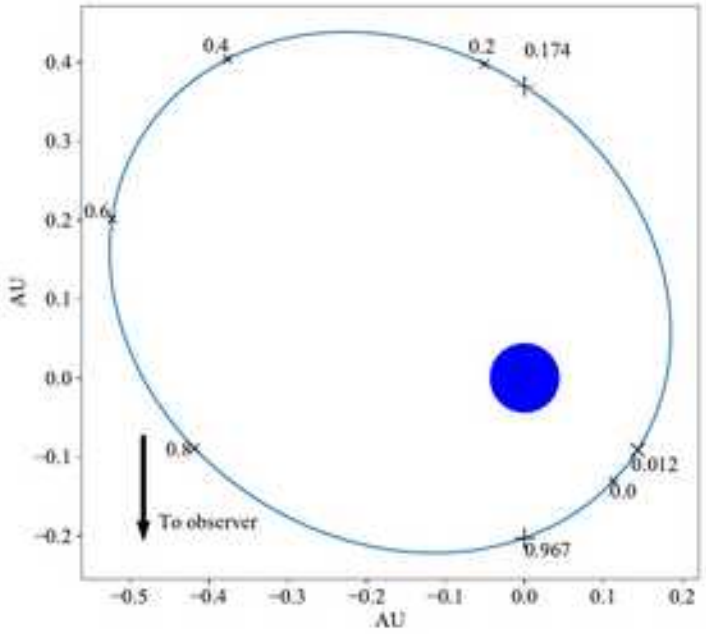
- Source observed 24 times between 2018-05-02 and 2020-06-14 with SALT HRS in LR mode.
- Data reduced with the Kniazev+2016 pipeline. Some artifacts remain from the order merging, but weaker than absorption lines.
- Performed cross-correlations in the region 4500 – 5450 Å using rvsao, using a template created from the observations.
- The preliminary result from the cross-correlation shows a larger amplitude and shifts the position of periastron.
- The errors are only the statistical error based on the line fit.

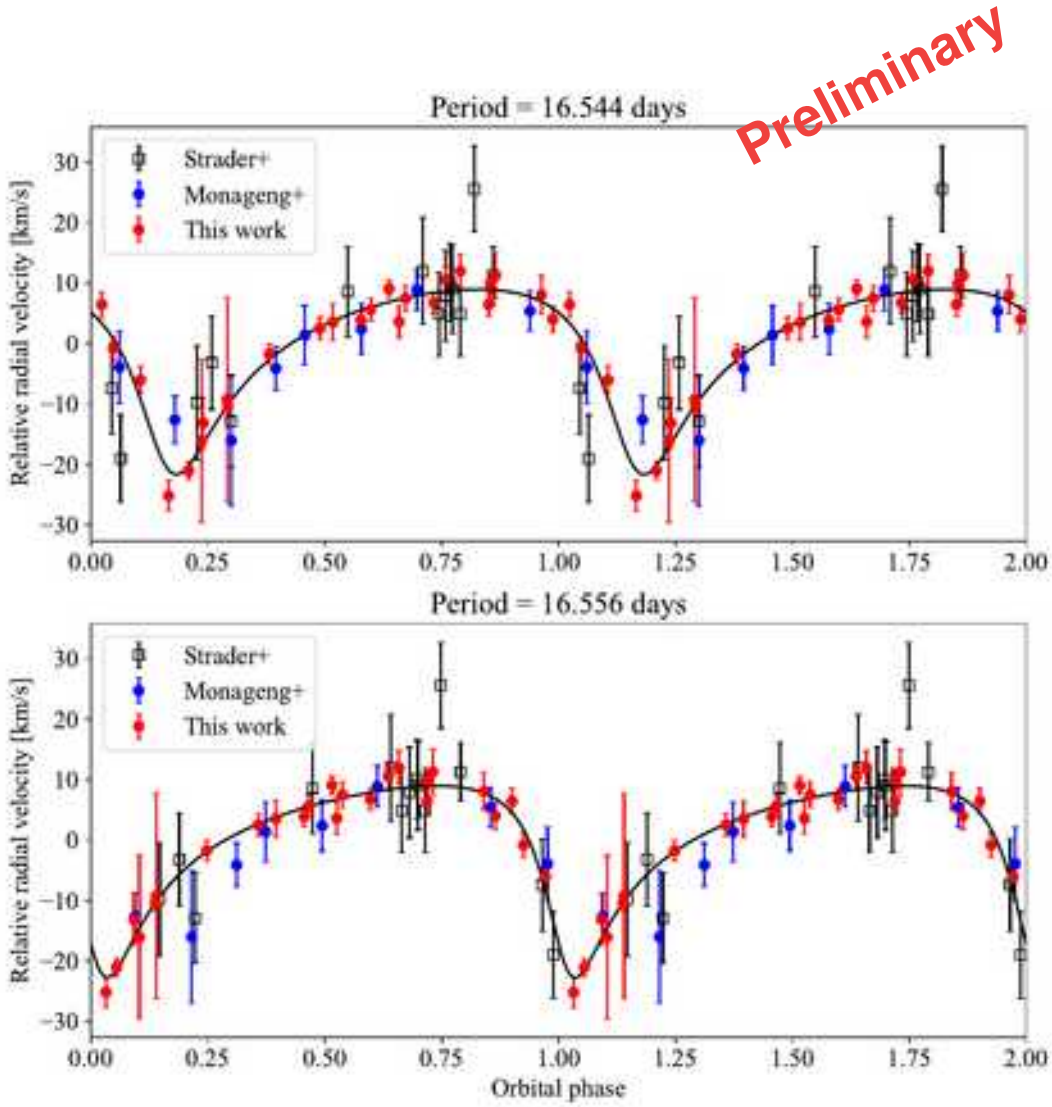




Preliminary new radial velocity results

- The combined fit give a different binary orientation and give an eccentricity of closer to e~0.5 and a higher mass function f ~0.004
- The radial velocity curve is also slightly better fit by a different orbital period.
- However, this is **very preliminary** and need to investigate possible systematic offset between the different data sets.





Conclusions

- LMC P3
  - Using SALT/HRS observations we have the best orbital solution for LMC P3, the first gamma-ray binary detected outside of the Galaxy.
  - A neutron star mass is favored for most inclinations (>30 deg).
  - The spectral model fitting gives a temperature of 36351 ± 53 K
  - The orientation places inferior conjunction at 0.24 and superior conjunction at 0.98
  - A simple toy model shows that this orientation can explain the H.E.S.S. observations either via a gamma-gamma absorption or possibly through additional Doppler boosting.

- 1FGL J1018.6-5856
  - Preliminary results from new observations hinting towards a different orientation
    - Higher eccentricity and mass function
    - Shifted viewing angle
    - Slight difference in best fit period.
  - This this opens up interesting questions about interpreting the multi-wavelength behaviour.

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