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
Gamma-ray binaries

Dubus 2013
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 of 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.
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.
The binary orientation of the LMC P3. This is calculated assuming a $M_{\text{star}} = 33.5 \, M_{\odot}$ and radius of $R_{\text{star}} = 14.5 \, R_{\odot}$ and $M_{p} = 1.4 \, M_{\odot}$.
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 light curves folded on 16.58 d (Abramowski et al. 2015)
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 \((e=0.31 \pm 0.16)\) 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.

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

An et al. 2017
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 gives a different binary orientation and gives an eccentricity of closer to $e \sim 0.5$ and a higher mass function $f \sim 0.004$
- 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 $36351 \pm 53$ 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 opens up interesting questions about interpreting the multi-wavelength behaviour.
Thank you