Mass and orbit constraints of the gamma-ray binary LS 5039

Tamás Szalai¹, Gordon E. Sarty^{2,3}, László L. Kiss⁴, József Vinkó¹, and Csaba Kiss⁴

¹Department of Optics and Quantum Electronics, University of Szeged ²Royal Astronomical Society of Canada ³Department of Physics and Engineering Physics, University of Saskatchewan ⁴Konkoly Observatory of the Hungarian Academy of Sciences

IAU Symposium 282 From Interacting Binaries to Exoplanets: Essential Modeling Tools

> Tatranská Lomnica, Slovakia July 18 — 22, 2011



LS 5039: an enigmatic binary

- A high-mass X-ray binary with radio lobes and a very-high energy (VHE) gamma-ray production → it is one of the peculiar gamma-ray binaries
- No signs of an accretion disk
- Source of VHE radiation: inside or outside the binary orbit?
- Primary component: O6.5V((f)) star Secondary component:
 - Black hole (?)
 - Non-accreting young pulsar (?)





Radial velocities and parameters

- The highest resolution, homogeneous spectral dataset for LS 5039 obtained with ANU 2.3m telescope and MPG/ESO-2.2m telescope (FEROS) (~40 hours; 3800-6750 Å; R=23,000)
- A systematic blueshift of H I and He I lines with respect to He II lines (contamination from the stellar wind)
- Orbital parameters from modeling with WD 2003 code
 - → similar results to previous ones, but definitely lower value of eccentricity (~0.25)
- No signs of the pulsation of the O star assumed by Casares et al. (2010)





Mass constraints from MOST-photometry

- Ultraprecise photometry with MOST satellite; possible variability at the level of 2 mmag
- LC simulations with WD-code (with the mass function fixed):
 - Decreasing inclination → no decreasing amplitude (Casares et al. 2005)
 - Amplitude decreases with increasing total mass or decreasing eccentricity

Conclusion:

Photometric analysis support the lower eccentricity and strengthens black hole scenario ($M_x > 1.8 M_{Sun}$), but does not fully exlude the neutron star scenario.





Stellar wind from the O component

- Changes of equivalent widths (EW) of H-alpha between 2.50 and 2.85 Å \rightarrow mass loss rate of the O star: 3.7 – 4.8 x 10⁻⁷ M_{Sun} yr⁻¹
- Significant changes of EWs of two other lines (H-beta, He I λ 5875) during the orbit
- The weakest absorption: $\varphi \sim 0.65-0.75$ (inferior conjuction) \rightarrow focusing of the stellar wind toward the compact object (?)



H-alpha



H-beta



He I λ5875

Mass and orbit constraints of the gamma-ray binary LS 5039

Tamás Szalai¹, Gordon E. Sarty^{2,3}, László L. Kiss⁴, József Vinkó¹, Csaba Kiss⁴

¹Department of Optics and Quantum Electronics, University of Szeged, Dom titr 9., Szeged H-6720, Hungary ²Royal Astronomical Society of Canada, Saskatoon Centre, P.O. Box 317, RPO University, Saskatoon, SK S7N 438, Canada ³Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, SK S7N 5E2, Canada Konkoly Observatory of the Hungarian Academy of Sciences, H-1525 Budapest, P.O. Box 67, Hungary

I. LS 5039: an enigmatic binary

1.5 5039 was originally classified as a high-mass X-ray binary (FMOR, Moth or al. 1997) which has been intensively observed in the natio, spinat/IR, UV and gamma-ray recontingeds in the part years. Parelas at al. (2008) identified established jus in VLNs theoretical. They also found a very high newspy (VHN) gamma-ray source at the conditions of the system pointerfield by Adamaias at al. 2005 in a HTMS survey); theoretical LS 2009 because one of the annual knows gamma-ray

McTwain et al. (2004) showed that the primary is a O6.5(57) star, while of-ital and system parameters were published in different papers (Canara et al. 2005 - CDS) Anapora et al. 2009 - A09, and in our paper, Sarty et al 2011 - 511). One of the major quarkon about 1.5 5039 in the nature of the compact object: while analysis of CDS suggests that the compact object is a black hole, some other authors have argued for a matters-star scenario involving a new-accreding young palsar (see S11 for a service). The situation is further complicated by some results indicating that the high energy reduction might originate from regime for coupled the orbit of the binary (see enforcement in S11), and more reasonly Daract et al. 2011. Harrisofter we show the results (published most of there is detail in S11) of our spectroscopic and photometric analysis concerning mass and obly component.



Fig.1. And Readow of LS 1000 as new to 10000 among our interaction (Also vision of al. 2007). The group astronic and for small white objectives for make sometimates of 1.3 3257 and the position of the VVS parameters and a superior of parameters and a solution of a local solution of an X-ray binary consisting a but size and a black (MARA STOTIAL Write)

XXX

Sarty et al. 2011, MNRAS, 411, 1293

II. Radial velocity analysis

Spectroscopic shortwarkes were carried out on seven nights in 2009 with the schelle spectrograph montated at ANU 2.5m Tolancopa (SEO, Anstralia), and on first nights in 2011 anisy FERIO (André et al. 1999) at WIGESD 2.2 an indexays at L 2528, Chilo. Covering -40 hours with marking uniform sampling of the whole orbit between 3900-6750 Å with a reaching power LAX#23,000 at He, it is the highest resolution, homogeneous spectral dataset over obtained for 1.5 5079.



Acres Hack

in the second

-221 -5 (B) U

Radial velocities (RV) of H I, He I and He II lines were datamained from the shifts of line campuids with respect to the laboratory wavelengths. We detected a -15-20 km s² blasshift between the average RVs of the He II and the Balmar lines, while the RVs of the He I lines are between them. We assume that the shift of the H I and He I lines in due to contamination from stellar wind (san Puls et al 1996). Therefore we used only the RVs of He II liens to fit aclipping binary models using the 2000 version of Wilson-Devineey (WD) code (Wilson & yas Ramme 2003).

Orbital and system managements are presented in Section 3. Our analysis do not expect the results of Canava et al. (2010) denoting the signs of non-radial pailations of the O star in their RV data.

Fig.2. The Arrange mild relation of H 1.0%s, NJ, No. Mi, 1.0023 – the factor increases and only by 3000 spatial) and No. T 5.0200, 1.0000, 2010, 1.0000, 2010, 1.0000, 2010, 1.0000, 2010, 1.0000, 2010, 1.0000, 2.00000, 2.0000, 2.0000, 2.0

IV. Main constraints from MOST-photometry

Personil the amothogonoic dataset we also studied the obstreamly data from the MOST astallity obtained through 15 days in July, 2009. Read on light curve elemitations CBS found that if photometric variability is less than 0.01 mag then the inclination is 30° or less which implies than the mass of the compact object is too high to be a neutron star (not Fig. 3.).

> The MOIT light curve indicates only a possible variability at the level of 2 mmag, with an apparent level minimum at phase $\phi=0.7-0.8$

We did our own light curve simulations with the WD as a check. Our conclusions differ from the ones of CBS. With the mass function flued, the amplitude of the light curve do not decrease with decreasing inclination. Instant, the amplitude decreases with increasing total mass or decreasing eccentricity. A formal fit gave the best result as 34(-26 Mar. e=0.24 and /-50* (44(-1.84 Mar.).

Our results strengthen the black hole scenario, but do not fully exclude that the sumpact object may be a neutron star.

Fig.4. The Planet and Mercel light source from the AUTT development for computed difference from the neuronal relations. Noticel light source advantated with $f(a_1)^{-1}$ (2010) M_{a_1} . M_1 and M_1 are its means of the pinney well for sample of lengt, expenditely, expectively, it is to includent to figure .

ACKNOWLEDGEMENTS. Opportune? Comments'



188.81

This work has been supported by the Australian Restarts Council, the University of Sydney, the Hungarian OTKA Genet 876816 and the "Londtlint" Young Researchers' Program of the Rangarian Academy of Sciences.

compact object (see SIII for the details). Because 1.5 5839 is a single-limit Fig.). Man of the accepted object on a Fig.5. Must of the second dyna at a basiles of mass of the primary he different industries. Writesi have show the basile of the same of the O sing gray regime represents the parallele values of the scooped object in the same of $1 < 30^\circ$ preducing CO (see 30.0). spatroscopic binary, we ware able to determine only the mass function, first natural of the stact value of the mass ratio (g) and the inclination (/). Test (K) 20080 ± 1800 0.24 ± 0.08 207.3 ± 21.6 1.9 ± 1.3 F. then or 7 M. OL. 1 225-24 Ky Harry 77 23.8 + 2.8 177 ± 0.35 ROBES ± ROBES or six 1.68-3 d Opel 2.5 ± 0.1 rheat (Mile) While of the line of the

III. Orbital and system parameters

Based on equivalent width measurements of several interstellar lines we found $B(D-V) = 1.2 \pm 0.1$ mag, which agrees well with pervises results (S11). Therefore we adopt the distance of LS 5009 as well as the orbital period and the parameters of

being

the O common ent altained by COS. The value of T. = HID 24950(T.0) was used

Table 1. Adopted parameters from CDI.

Fig.5. Variability

as the epoch of pariaston. Our ments are

close to certificite additions (COS, AOS), but we found the orbital eccentricity

definitely lower than determined comismaly

This smaller value is more consistent with

the lack of an accretion disk around the

V. Scellar wind from the O component

Changes in the equivalent widths (EW) of H and He lines could be good indicators of physical processes taking place in the stallar wind.

We found that the FW of He is changing from 2.90 to 2.85 Å over the orbital cycle. The average value of 2.70 Å agrees well with provides results (CDS, Fouch-Ramon et al. 2007). Using the method of Puls et al. (1996) we get $3.7 - 4.8 \cdot 10^{7} M_{\odot}$ yr¹ for the mass loss rate of the O star.

We found two other lines, HB and He I 15975, showing significant EW changes during the orbit. 12. The walkast absorption (lowest SW) occurs around $\frac{1}{2} = 0.65 - 0.75$ (at inferior conjunction). A possible explanation may be the focusing of the stellar wind toward the compact object (S11).

Table 1. Orbital parameters of L8 2020.

of the equivalent whiles of He Continue today 100 (top equiv) and He 1 MIRTS (builders ·]·*·· . · ·*·· 29*#H, +*#H, . right) lines during the orbital style

REFERENCES.

Caulie A. et al. 1999; The Meaninger, 95, 8

Midwin M.V. et al. 2004, ApJ, 600, 927 Mash C., et al. 1997, A&A, 323, 805 conian F.A., et al. 2005 thisman, 809, 766 Parales I.M. et al. 2000 theirage 208, 20regions C., et al. 2009, ApJ, 698, 514 (A29) milli Ramon V., et al. 2007, A&A, 473, 545 Puls J. et al. 1998, A&A, 305, 171 larty (3.8., et al. 2011, MD/RAS, 411, 1299 Casses I., et al. 2005, MNRAS, 364, 599 (025) Casses I., et al. 2010, arXiv:1012.4551 Daniel M., et al. 2011, ApJ, 735, 58 COLL

Van R.R. & van Hanne W 2008 **Computing Rinery Star Chemvelon** ver. 4. (Dainewille Univ. of Florida)