Polarimetry simulations of GRS 1915+105 in thermal state with the future IXPE mission

Romana Mikušincová[1,2], Michal Dovčiak[1], Jiří Svoboda[1], Niccolò Di Lalla[3], Giorgio Matt[4], Roberto Taverna[4]

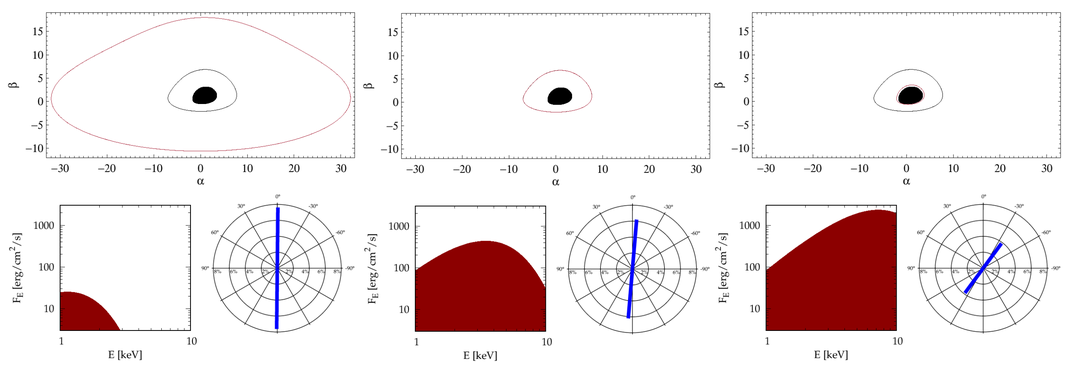
[1]Astronomical Institute of the Czech Academy of Sciences
[2]Institute of Theoretical Physics, Charles University in Prague
[3]Università di Pisa & INFN
[4]Università degli Studi Roma Tre

Introduction

- Imaging X-ray Polarimetry Explorer (IXPE): future space observatory using three identical detectors in order to monitor the polarization in the X-ray waveband
  - launch: April 2021
  - operated by: NASA / Italian Space Agency
  - will observe X-ray Binary sources and help in putting independent constraints on black hole spin and orientation of the system
- GRS 1915+105
  - persistent X-ray Black Hole (BH) binary system with high brightness in the X-rays up till 2018 ($\mathrm{flux}_{2-8keV} = 10^{-8}$ erg/cm^2/s) (Martocchia et al., 2006)
  - BH $M_{BH} = 14 \pm 4 M_\odot$, donor star $M_{donor} = 1.2 \pm 0.2 M_\odot$ (Greiner et al., 2001)

Modeling GRS 1915+105

- Polarimetric characteristics in thermal state emitted by the studied X-ray Binary were modeled using a multicolor blackbody code KYNBB (Dovčiak et al., 2004, 2008)
  - Relativistic thermal radiation from a BH accretion disk with a Novikov-Thorne temperature profile
  - Accounting for polarization properties
  - All relativistic effects taken into account (e.g. rotation of polarization angle)

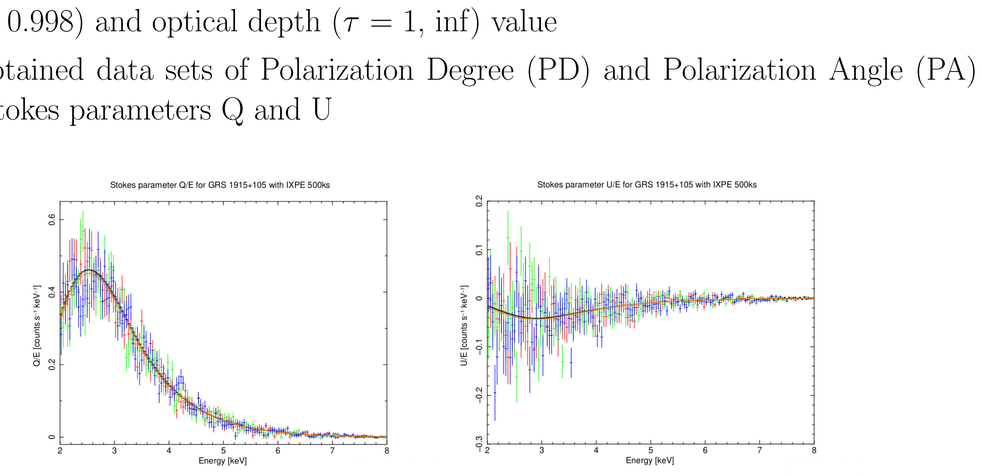


Rotation of PA and increase in observed flux: figure shows a Kerr black hole (BH) with flux and PA and PD for three rings (red) to show different contributions from different radii of the accretion disk. 6 R_g region is depicted by black solid line. The closer to the BH the area of a photon emission is, the higher and more energetic emission due to higher temperature flux (bottom left part of each subfigure) and more prevalent effect of PA rotation (bottom right part of each subfigure) is observed. The most prominent PA rotation is observed from the innermost regions of the accretion disk.

- We model GRS 1915+105 for spin values: a = 0, 0.7, 0.9, 0.998 with inclination of the system i = 70 deg and for accretion disk optical depth values $\tau = 1$, inf

Simulating observations

- We used an X-ray polarimetry simulation framework IXPEOBSSIM
- We performed simulated observations for the studied source in the energy band 2 - 8 keV with the exposure time 500 ks, 250 ks and 125 ks for each modeled spin (a = 0, 0.7, 0.9, 0.998) and optical depth ($\tau = 1$, inf) value
  - We obtained data sets of Polarization Degree (PD) and Polarization Angle (PA) and Stokes parameters Q and U



Simulated Stokes parameters Q/E (left) and U/E (right) for exposure time 500 ks, spin a = 0.7 and optical depth $\tau = 1$. We simulated each of the 3 detector units separately (denoted in the figure as red, green and blue points). The data were fit using absorbed KYNBB (model in black, fit in orange)).

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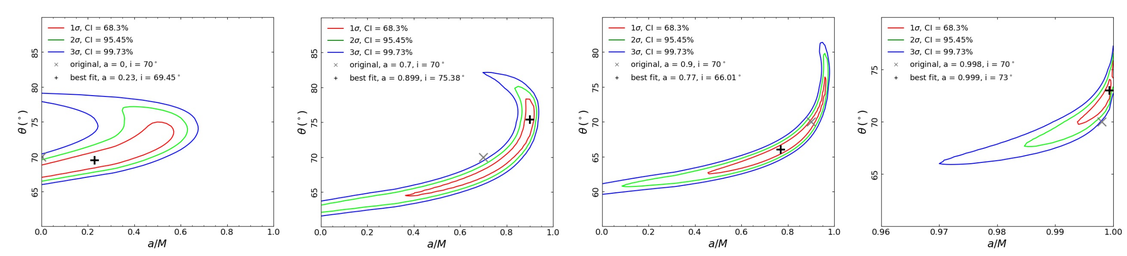
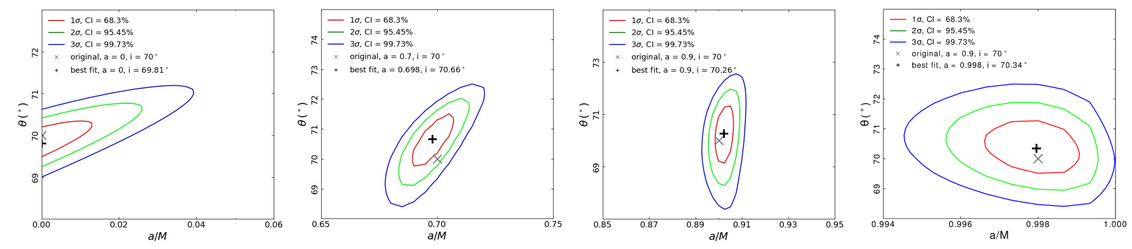
@romy_aat

Results

- We study the robustness of BH spin constraints and resolving geometry of the studied system from polarimetric observations
- We use TBABS+KYNBB to fit simulated data of PD + PA and Stokes Q + U
- We use initial fit value a = 1 for the case of spin a = 0 and a = 0 as an initial value for the cases a = 0.7, 0.9, 0.998 and i = 30 deg for all studied cases
- We performed contour plots of spin versus inclination with spin, inclination and orientation of the system on the sky of the observer as unknown parameters

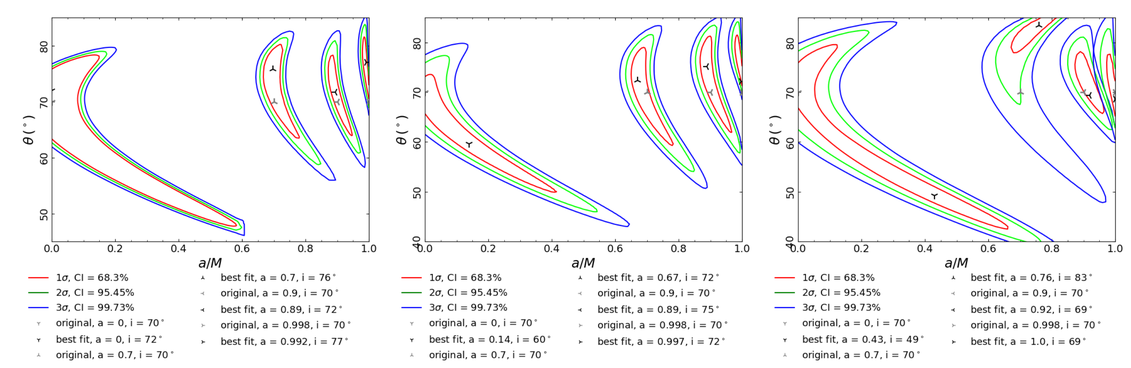


Spin vs. inclination contour plots using PD and PA for the cases of spin (left to right) a = 0, 0.7, 0.9 and 0.998 and optical depth $\tau = 1$. For all of the spin cases the inclination is well constrained, within an interval Δ i $\sim$ 25 deg a = 0, 0.7 and 0.9, while spin is not constrained (for 3 σ the possible spin values are from the entire 0 - 1 interval. The spin case a = 0.998 seems more promising with Δ a $\sim$ 0.03 and Δ i $\sim$ 15 deg. The simulated exposure time was 500 ks.



Contour plot of spin vs. inclination as a result of Stokes Q and U fitting procedure for the values of spin (left to right) a = 0, 0.7, 0.9 and 0.998 and optical depth $\tau = 1$. In this case, both spin and inclination are well constrained for all the performed simulations. Considering 3 σ Confidence level, the successfully fitting spin and inclination values lie in the intervals of Δ a $\sim$ 0.05 and Δ i $\sim$ 5 deg. Performed for a simulation of a 500 ks observation.

- Several issues arise when using PD and PA
  - They are obtained from Stokes Q and U via a non linear transformation resulting in non-gaussian errors
  - The software used for fitting (XSPEC) does not account for PA being a cyclic variable and, therefore, does not calculate the error values properly
  - Due to the form of transformation, PD and PA are insensitive to change of some parameters (e.g. distance)
    $\Rightarrow$ further analysis will only be performed using Stokes Q and U



Comparison of spin vs. inclination constraints for different exposure times: 500 ks (left), 250 ks (middle) and 125 ks (right) for spin values a = 0, 0.7, 0.9, 0.998 and optical depth τ = inf. The higher the exposure, the lower the uncertainty of spin and inclination constraints will be. For this optical depth value, we obtain satisfactory spin constraints for spin a > 0 (Δ a $\sim$ 0.2 for 500 ks exposure to Δ a $\sim$ 0.4 for 125 ks), while we obtain Δ i $\geq$ 25 deg for inclination constraints.

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