Final Paper Detection of hot spot near the orbit of the massive black hole SgrA* (accretion disk)

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1 Description

Testing general relativity and the massive black hole paradigm in the closest massive black hole candidate: "Detection of orbital motions near the last stable circular orbit of the massive black hole SgrA? " Astronomy Astrophysics, 618, L10 (2018) GRAVITY Collaboration , Abuter, R. et..al

2 Introduction

This paper is about a group of scientists. They observe a black hole located at the center of Milky Way (SergA). In their report they conclude that continuous positional and polarization changes of the compact source SgrA* in high states (flares") of its variable near-infrared emission with the near-infrared GRAVITY-Very Large Telescope. In this essay I show what they found. My thoughts about it and some extra information. I will try/attempt to use only what we have learned(I do understand) in High Energy Astrophysics course

3 Observations

In three prominent bright flares, the position centroids exhibit clockwise looped motion on the sky, on scales of typically amplitude of 150 [μas] as over a few tens of minutes, corresponding to about 30 percent the speed of light (0.3*c) .Modelling with relativistic ray tracing shows that these findings are all consistent with a near face-on, circular orbit of a compact polarized "hot spotöf infrared synchrotron emission at approximately six to ten times the gravitational radius of a black hole of 4 million solar masses.

3.1 Tools and General Data

They used the GRAVITY instrument combines the four 8 m telescopes of the European Southern Observatory.GRAVITY provides high precision narrowangle astrometry and phase-referenced interferometric imaging in the astronomical K-band (2.2[μm]). It combines the light from four Unit Telescopes (UTs) or Auxiliary Telescopes (ATs), measuring the interferograms from six baselines simultaneously. The instrument has three main components: the IR wavefront sensors; the beam-combiner instrument; and the laser metrology system (eso.org). GRAVITY instrument sound like improved calorimeter They observed two bright flares with a peak approaching the flux of S2 on July 22 and July 28, 2018, as well as a fainter flare ($0.3 - 0.5 \times S(S2)$) on May 27, 2018. These flares lasted for 30–90 min.

3.2 Predictions

Let's talk about what we may expect/want to see. It is a black hole. So we expect it to have even horizon, and highlly energetic accretion disc. We can predict even horizon and define very precise. We can do it by using Schwarzschild radius $r_s = \dfrac{2GM}{c^2}$. It gives us $1.18 * 10^(10)[m] = 0.0789[au]$. It can be called as r_{cutoff}

(a distance at which we will not be able to see any light being emitted). Note, it does not apply Hawking radiation because it is a different beast. If it was not for him, I would never argue with my high school teach that black hole can loss"its mass through emitting Hawking's radiation. I got an F for arguing, but it was worth it.

4 Methods, Techniques, Observations, Theories

4.1 Thoughts and Predictions

Their model shows that we should deal with highlly relativistic model. According to Detection of orbital motions near the last stable circular orbit of the massive black hole SgrA, "including light bending, lensing, time dilation, etc.) yield $R{\approx}7{\pm}0.5$ R$_g$, a line of nodes at $\Omega\approx$ 115^o-160^o and an inclination i $\approx$160$^o\pm$10^o , with an orbital period of P $=$ 40$\pm$8 min, for orbits in an angular momentum parameter a $=$ 0 (Schwarzschild) space time"(p. 3). This closed to what we may expect. What's interesting is that P_{model} and $P_{observed}$ are highlly different. It is due to over simplification in ore model. They had a direct access to the data and were able to apply that data to avoid multiple important assumptions. Such as, weigh, luminosity, speed and shape. Important to note that they had 4 groups working on 4 models. That move by itself increase accuracy dramatically. Second, astrometric modelling of orbits, shows models of hot spots on circular orbits in the Schwarzschild metric (angular momentum parameter a $=$ 0) obtained with ray tracing methods of the geodesics, including secondary, tertiary, and quaternary images"(p. 11). As we already noted in our model we did use $P = \sqrt{\frac{4\pi^2 2a^3}{GM}}$ where G is gravitational constant, M object/star mass, a is radius. Meanwhile, in their model they used $P = 2.137(min)\frac{M_{dot}}{4.14*10^6 M_{sun}}(a+(\frac{R}{R_g})^{\frac{3}{2}}$ where a is the spin parameter

$\in [-1, 1]$, and R_g=6.11×1011 [$\frac{M_{sun}}{4.14}$×106M][cm] = 5[μa] and R stays untouched. After ploting a graph we define R=1.17±0.25M_{RISCO}(a = 0) since only partial data was used this result cannot be taken. After some analysis they choose to use same code with angular frequency$\frac{d\phi}{dt}$=Ω=(r$^{3/2}$+a)$^{-1}$. They obtained the following result, The distance of the GC and mass of the central object are fixed atM_{BH}=4.14×106M_{Sun} andR_0=8.127 [kpc]"(Gravity Collaboration et al. 2018).

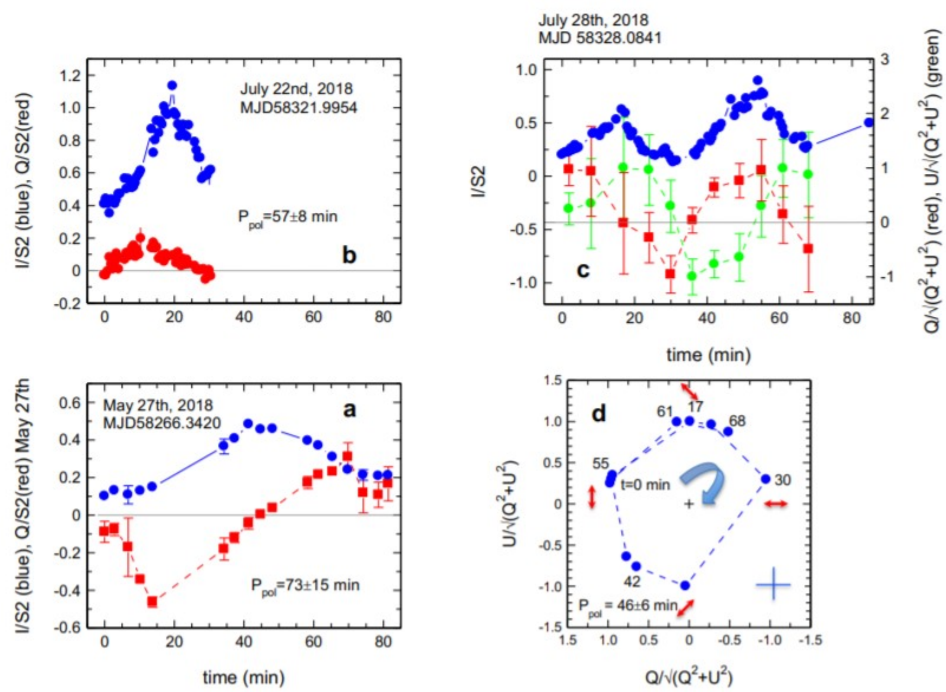
5 Techniques

One of main important techniques they used is, well, observation. All jokes a side, same as we predicted, They used Schwarzschild equation. On top of that they did use the idea of relativistic beaming (same as we did in Lecture 2 slide 10). Detection of orbital motions near the last stable circular orbit of the massive black hole SgrA Figures 1 and B.4 show that flux distribution in all three flares is not strongly peaked, as we would expected to see from relativistic beaming for an inclined orbit. They concluded that the observed flux variations do not reflect variations in beaming and lensing during an orbit but are more determined by the balance of local heating and cooling of the relativistic electrons. In order to show that inclinations of >155 degree (or equivalently <25 degree) would reduce the expected impact of relativistic beaming of radiation to below a factor of 1.5. They used the following assumption: If a relativistic hot spot is moving with

$$\beta = \frac{v}{c}$$

and

$$\Gamma = (1 - \beta 2) - \frac{1}{2}$$



Figur 1: Bottom left (panel a): total flux I/S2 (blue, relative to S2) and Q/I flux ratio as a function of time for the May 27 flare. Top left (panel b): as in (a) but for the July 22 flare. Top right (panel c): I/S2 (blue), $Q/(Q^2+U^2)^{1/2}$ (red) and $U/(Q^2+U^2)^{1/2}$ (green) evolution during the July 28 flare. Bottom right (panel d): evolution of the July 28 flare in the plane of normalized Stokes parameters $Q/(Q^2+U^2)^{1/2}$ (horizontal) and $U/(Q^2+U^2)^{1/2}$ (vertical). The red arrows denote the polarization directions on sky. The blue cross in the lower right denotes a typical error bar

at an angle 90-i relative to the line of sight, emitting a spectrum with spectral index α, S proportional to $v-\alpha$, then the combination of relativistic aberration, time dilation, and Doppler frequency shifting boosts or de-boosts the observed flux density in the stationary observer's frame by a factor (McCrea 1972): $S_{,obs} = v^{-\alpha} \times [\Gamma \times (1 - \beta cos(90^o - i))]^{-(3+\alpha)}$. The synchrotron cooling time

$$\tau = 15 \times \frac{B}{20G}^{-1.5} \frac{\lambda}{2.2\mu m}^{0.5} [min]$$

was used in their analysis because it was not clear if flare durations were defined by cooling time or friction between particles that moves in different directions (differential rotation). On top of that they did observe rotations of polarization angles of the IR synchrotron emission. They were able to improve results from previous reserch NACO polarimetry of a few SgrA* flares (Trippe et al. 2007; Zamaninasab et al.2010; Shahzamanian Eckart 2015) (p. 4). They showed that with P_{pol} proportional $Porbit$ can be taken carry for if B field axis are orthogonal to the orbital axis. They conclude, position of the hot spot could be affected by the propagation angel, and it is possible that location of the hot spot could be affected by rotation in a disk and disk-jet geometry

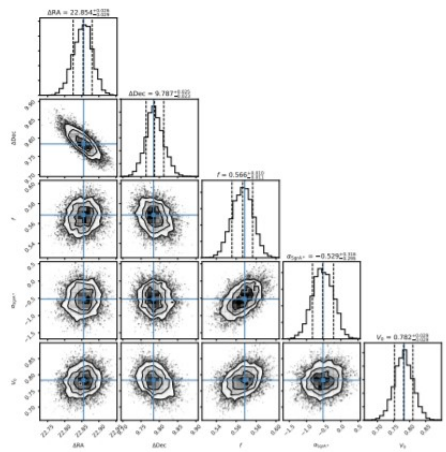
6 Person Opinion

As we learned, learned in class gravitational force F_G proportional to $\frac{1}{r^2}$. This become an extreme closer we to event horizon. At one point this difference force particles closer to even horizon move faster than further one which increase friction between particles and Luminosity as a result. Even if a black hole significantly more massive than than accretion disk. It will cause some wobbling with Period = 349.70164767974404 [s] and v_{me} = 106036310.79233645 [m/s] around black hole where black hole rotating from the center of mas

$r_{fromcenterofmass} = 4.246932729209215e - 57$ [m]. As we increase mass, this will change wobbling radius. It is very likely that some side of accretion disc has greater mass than other due to more densest region of stars. It was very smart to set $B = \frac{2\mu_0 R\sigma}{3}\Omega$ where Ω is spin vector. Setting B field axis orthogonal to the orbital axis will aid us when we will work with Ω . What I still do not understand is why they did not use Chandra or Suzaki telescops. I do realize that it is cheaper to use telescopes build on earth and take optical depth into consideration when you collect your data. Still, in my opinion, it is more convenient to use space telescopes in a long run. You do not need to worry or wonder if your data was affected by Earth atmosphere or it was not. Moreover, we are dealing with relatively complicated data.

7 Data modelling

".We developed four independent codes to fit the coherent signal of SgrA* and S2 and at the same time account for instrumental properties. The codes differ in the fitting approach (MCMC, least-square with parameter grids, etc.), the number of free parameters (e.g. intrinsic source spectral slope is fixed or fitted), and the weighting of closure phase to visibility data. The different choices in the codes are all well motivated and can thus be considered as an exploration of the parameter space."(p 11). As I mentioned before, optical depth could be an issue. They did use MCMC modeling which entirely based on statistics. On the graph $(\alpha SgrA*, t)$ we can see an error $+$-0.3 relative to 0.5 this error looks unreasonably high. Moreover, depend on which graph we use we may get uncertainty all the way up to 80 percent. While I agree that their result look legitimate. Still, absolute error for α SgrA* is unreasonably high. This is reason why in previous section I wrote that it is more convenient to collect data from space and avoid uncertainties related to atmosphere in any shape of form.



Figur 2: a nice plot

They also did not mention number of steps in their code. I know from my own experience of debugging MCMC that number of steps can decrease or increase δ error. On top of that we may get slightly different results in such way that it will change shape of the graph between 10-50 percent depend on quality of our data. While we may conclude that these result are very valid. We cannot ignore that in their model they have one big source of error called atmosphere.

Work Cited

GRAVITY Collaboration , Abuter, R. et..al, October 31^{st} 2018

link: FULL TEXT SOURCES->open:arXiv

$Magneticfieldstrengthofaneutron-star-poweredultraluminousX-raysource$,

M. Brightman et..al, April 2018 link