The Milky Way Big Black Hole (KK 6 Feb 09)

Where in the sky

In Sagittarius (Jousimies) $\alpha = 17h\,49'$ (right ascension) $\delta = -29^\circ$ (declination)

SgrA* — radio source in 1974

in the south in the evening in the summer when you anyway see only ~20 stars

can barely be seen above horizon in Helsinki, 60° but

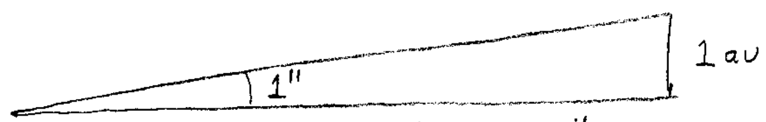
Sirius $\alpha = 6h\,45'$ $\delta = -17^\circ$

seen very well just now (Jan–March) in the evening, Sag is ≈ opposite!

Angles, distances:

$$1'' = \frac{\pi/2}{90\cdot 60\cdot 60} = 4.85\cdot 10^{-6} = \frac{1}{206264.8} \equiv 1\ as$$

$$1\ au = 150\ Mkm = 1.50\cdot 10^{11}\ m = 8'13'' \approx 10^{-5}\ ly$$



$$1\ pc = 2.06\cdot 10^5\ 1.50\cdot 11^{11} = 3.09\cdot 10^{16}\ m = 3.26\ ly$$

$$1\ ly \sim 10^{16}\ m$$

Diffraction limits

$$\frac{\lambda_{yellow}}{D} \approx \frac{500\ nm}{1m} \cong 5\cdot 10^{-7} \sim 0.1''$$

"infrared" NIR

$$\frac{\lambda_{K\ band}}{D} \approx \frac{2000\ nm}{10\ m} \approx 2\cdot 10^{-7} \approx 0.04''$$

adaptive optics!

claim (0810.4947): with interferometry can go to $\approx 0.00001'' = 10\ \mu as$

Extinction (by submicronic dust) towards Sgr:

$$\begin{cases} 10^{-9} \text{ transmitted at } 500\ nm \\ 10^{-1} \quad " \quad " \ 2200\ nm \end{cases}$$

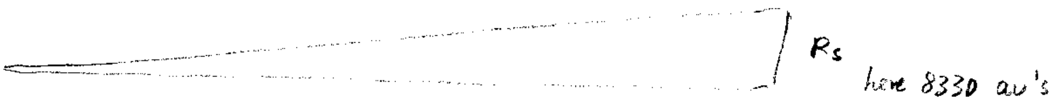
Man on moon: $\theta = \frac{2m}{400\,000\ km} \cong 1''\cdot\frac{1}{k} = mas$

BBH

$$\boxed{\begin{array}{l} M = 4.3 \pm 0.4 \cdot 10^6 M_\odot \\ \text{at } R_0 = 8.33\,\underbrace{\text{kpc}}_{3.09\cdot 10^{19}\,m} = 27000\,ly = 2.57\cdot 10^{20}\,m \end{array}}$$

$$R_s = \frac{M}{M_\odot}\,2.95\,km = 12.7\cdot 10^6\,km \simeq 1.27\cdot 10^{10}\,m \approx 0.08\,au \approx 20 R_\odot$$

$R_\odot = 7\cdot 10^5\,km$



$$\frac{R_s}{R_0} \approx \frac{1.27\cdot 10^{10}}{2.57\cdot 10^{20}} \approx 5\cdot 10^{-11} \approx 10^{-5}\,as \cong 10\,\mu as$$

claim: this ang. res. sh. be attainable "soon" with interferometry

≈ seeing 2 cm on Moon

compare usual BH at $10^3\,ly$

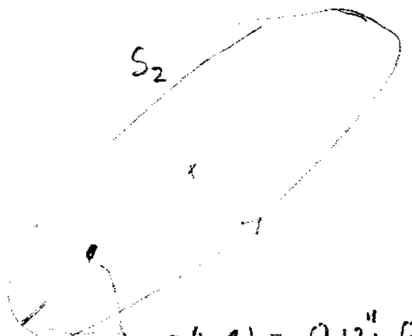
huge difference!

$$\frac{R_s}{R} \approx \frac{10\,km}{10^{3+16}\,m} \approx 10^{-15}$$

"Seeing" BH: Follow 28 stars during 16 a;

Groundbased! fit orbits with single pt mass potential!

$a = 0.12''$
$e = 0.88$
$P = 15.8\,a$
$i = 135°$ clockwise



purely Newtonian! so far

$a(1-e) = 0.12'' \cdot 0.12 = 0.014''$

$= 2.6\cdot 10^{20}\cdot 0.014\cdot 4.8\cdot 10^{-6} = 1.7\cdot 10^{13}\,m \cong 16$ light hours

$$r = \frac{(1-e^2)\,a}{1+e\cos\theta}$$

$\approx 1500\cdot R_s$

Far from BH still!

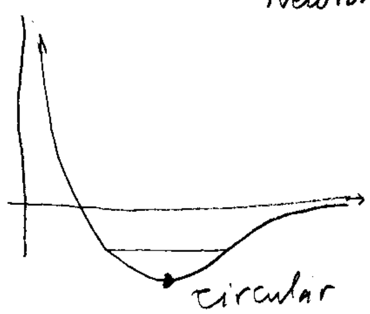
$$\frac{v^2_{orbit}}{c^2} \overset{e<1}{=} \frac{R_{s1}+R_{s2}}{2a}\,\frac{1+e^2+2e\cos\theta}{1-e^2} \le \underbrace{\frac{R_{s1}+R_{s2}}{2a}\,\frac{1+e}{1-e}}_{\text{perihelion velocity}}$$

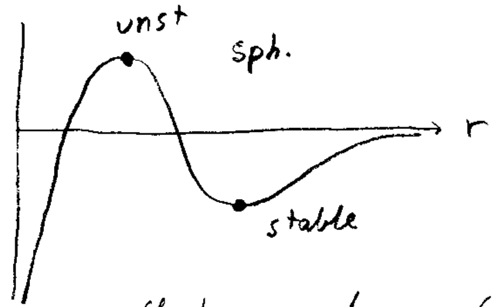
Relativity effects $\sim 1 - \frac{r_s}{r}$ Need $r \gtrsim r_s$

Keplerian orbits

constancy of E & L:

$$\frac{1}{2} m \left(\frac{dr}{d\tau}\right)^2 \underbrace{- \frac{GmM}{r} + \frac{L^2}{2mr^2}}_{\text{Newtonian } V(r)} - \frac{r_s}{r} \cdot \frac{L^2}{2mr^2} = \frac{E^2}{2m}$$





smallest circular $r = 6r_s$

perihelion advance per orbit $\Delta\varphi = \frac{3\pi}{1-e^2} \frac{r_s}{a} = \frac{3\pi}{1+e} \frac{r_s}{a(1-e)}$ ← perihelion distance

Entropy $S = \frac{A}{4G} = 4\pi \frac{M^2}{M_{Pl}^2} \approx 16\pi\, 10^{88} \approx S^{\gamma,\nu}_{\text{universe}}$!!

$$M = 4 \cdot 10^6 \cdot 10^{57} \underbrace{m_p}_{10^{-19} M_{Pl}}$$

NOTE BH does not have baryon number !!

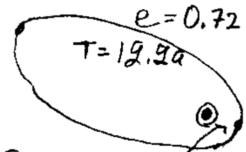
Throw there antimatter : m grows !

Valtonen: Binary BH

OJ 287

at z = large $\frac{v^2}{c^2} = \frac{1-e}{2} \frac{R_s}{a(1+e)}$

$\Rightarrow v = 0.053c$



$M = 1.8 \cdot 10^{10} M_\odot$ $R_s = 360\,\text{au}$

$m = 1.3 \cdot 10^8 M_\odot$ $R_s = 2.6\,\text{au}$

perihel $= a(1-e) = 2980\,\text{au} = 8.3 R_s$

aphel $= a(1+e) = 18140\,\text{au} = 504 R_s$

$$\frac{v^2}{c^2} = \frac{1+e}{2} \cdot \frac{R_s}{a(1-e)} = \frac{1.72}{2} \cdot 8.3 \Rightarrow v = 0.32c$$

Perihel. advance

$$\Delta\theta = \frac{3\pi}{1+e} \frac{R_s}{a(1-e)} = 0.66 = 37.8°/\text{orbit}$$

2nd order GR corr with $J = 0.46 J_{max}$

$$= \frac{10\,d}{12.2\,a} = 0.0022$$