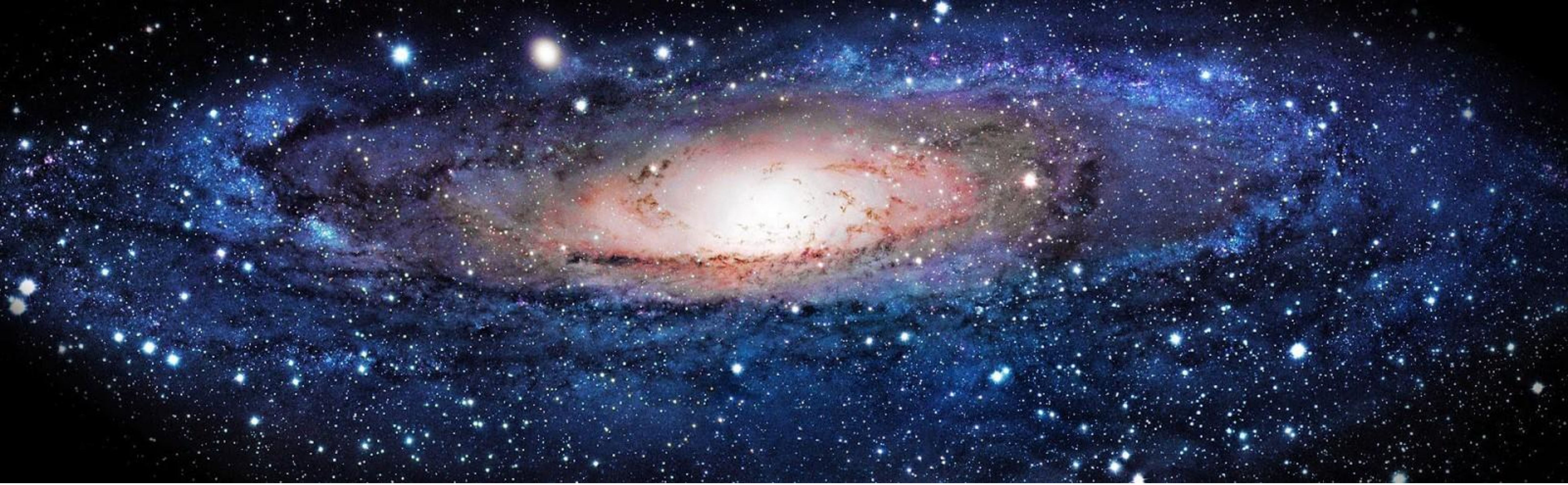
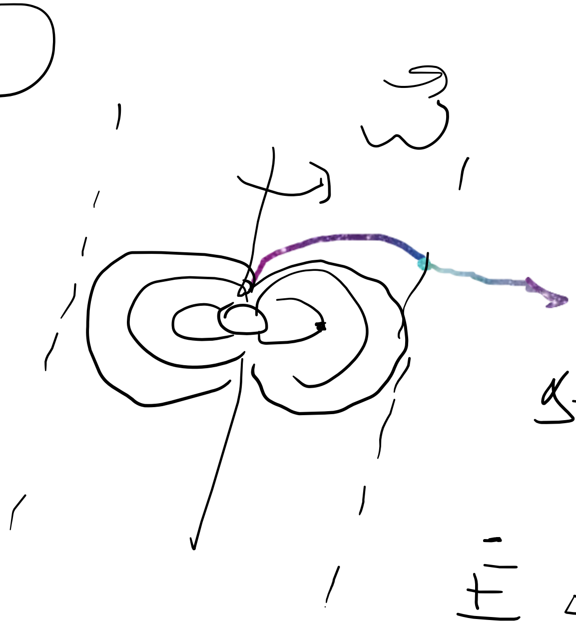


Модуль. Астрофизика.

Семинар 6. (04.11)

(1)



$v = \omega \cdot r$

$c = \omega R_e$

$R_e = \frac{c}{\omega}$

$\Delta t = P \left(\simeq \frac{R_e}{c} \sim \frac{1}{\omega} \right)$

$B(R_e) = B_0 \left(\frac{R_e}{R_0} \right)^{-3}$

$\dot E = \frac{B^2(R_e)}{8\pi} \cdot \frac{4}{3}\pi R_e^3 \frac{1}{\Delta t}$

$\dot E = \frac{B_0^2}{8\pi} \frac{R_0^6}{R_e^6} \frac{4}{3}\pi R_e^3 \left(\frac{P}{2\pi} \right)^{-1} = 2 \frac{B_0^2 R_0^6}{6\pi R_e^3} \frac{1}{P} =$

$= \frac{B_0^2 R_0^6 \omega}{6 R_e^3}$

$B_0 R_0^3 = \mu \qquad R_e = c/\omega$

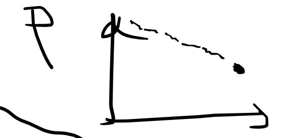
$\dot E = k \cdot \frac{\mu^2 \omega^4}{c^3}$

$\dot E_{rot} = \left(\frac{I\omega^2}{2} \right)' = I \omega \dot\omega$

$I \omega \dot\omega = k \frac{\mu^2 \omega^4}{c^3} \qquad \dot\omega = k \frac{\mu^2 \omega^3}{I c^3}$

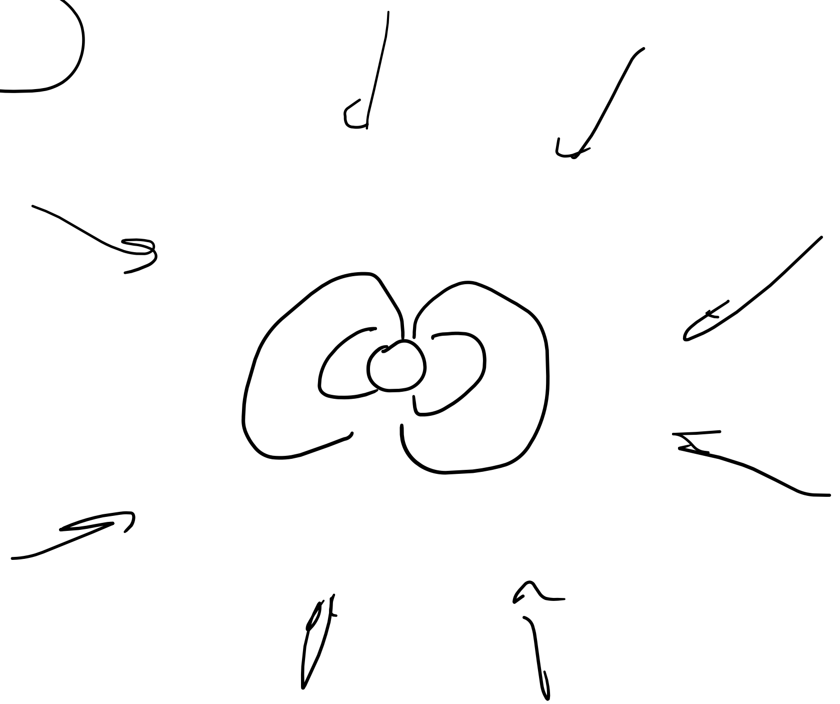
$\omega = \frac{2\pi}{P} \qquad \dot\omega = -\frac{2\pi}{P^2} \dot P$

$P \dot P = \frac{2}{3} \frac{\mu^2}{I c^3} (2\pi)^2 \qquad P^2 - P_0^2 = 2[\ldots] \qquad P \sim \sqrt{t},\ P \gg P_0$



$\tau_{ch} = \frac{P}{2\dot P}$

(2)



$$\frac{B^2(R_A)}{8\pi} = \frac{1}{2}\rho v^2$$

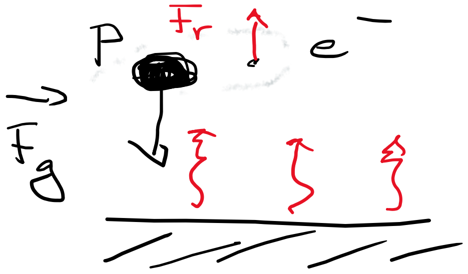
$$v = \sqrt{\frac{2GM}{R_A}}$$

$$\dot{M} = 4\pi R_A^2 \rho v$$

$$R_A \sim \frac{B_0^{4/7}}{\dot{M}^{2/7}}$$

$$R_A = R_0$$

3 L_{Edd}

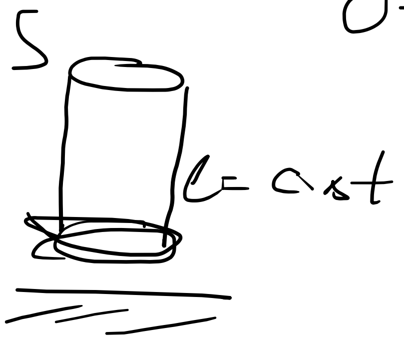


$F_g = F_r$ $\quad F_g = G\frac{M m_p}{r^2}$

I – поток $\quad I = \frac{L}{4\pi r^2}$

$$\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2$$

$$F_r = \left(\frac{I}{c}\right)\cdot \sigma_T$$



$\ominus$ r_e $\quad m_e c^2 = \frac{e^2}{r_e}$

$$r_e = \frac{e^2}{m_e c^2}$$

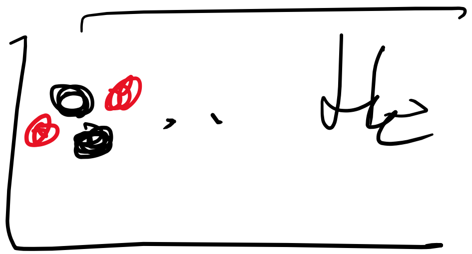
$$\varepsilon = P_r = \frac{I S \Delta t}{c \cdot \Delta t \cdot S} = \frac{I}{c}$$

$V = c\Delta t \cdot S$

$E = I \cdot S \cdot \Delta t$

$\sigma_T \sim \pi \cdot r_e^2$

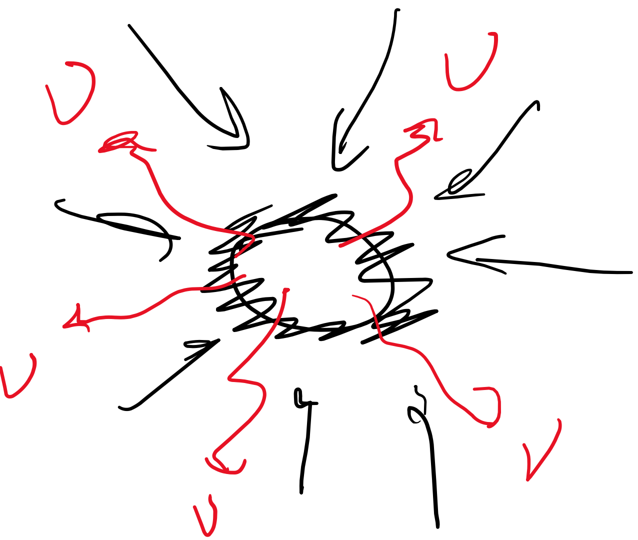
$$G\frac{M m_p}{r^2} = \frac{I}{c}\sigma_T = \frac{L_{Edd}}{4\pi r^2}\frac{\sigma_T}{c}$$

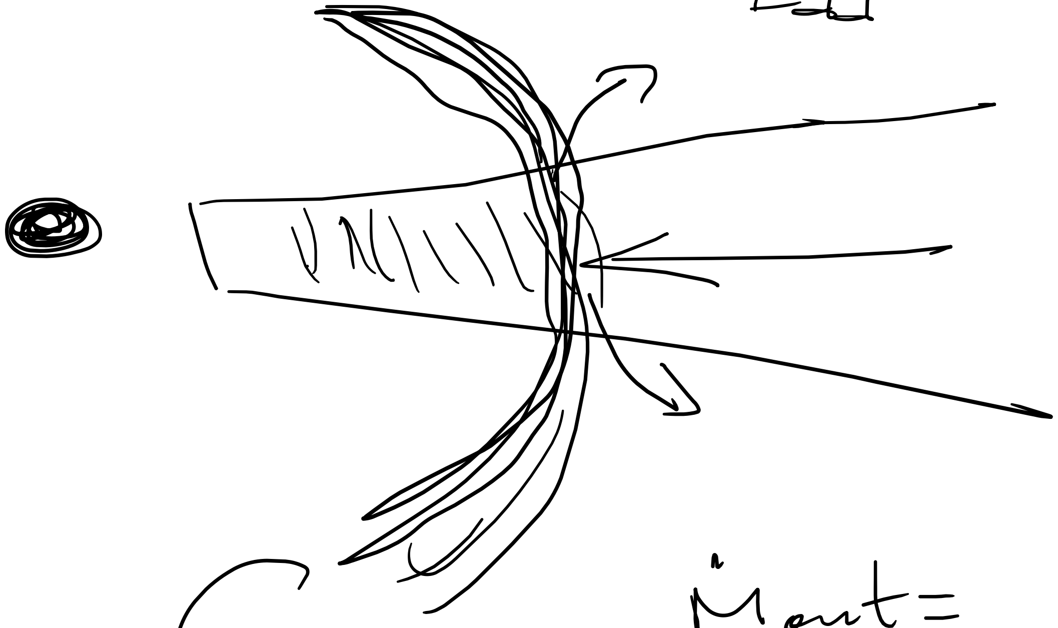


$$L_{Edd} = \frac{4\pi G M m_p}{\sigma_T}\cdot c = 1{,}38\cdot 10^{38}\,\frac{\text{эрг}}{c}\,\frac{M}{M_\odot} \approx 10^5 L_\odot \frac{M}{M_\odot}$$

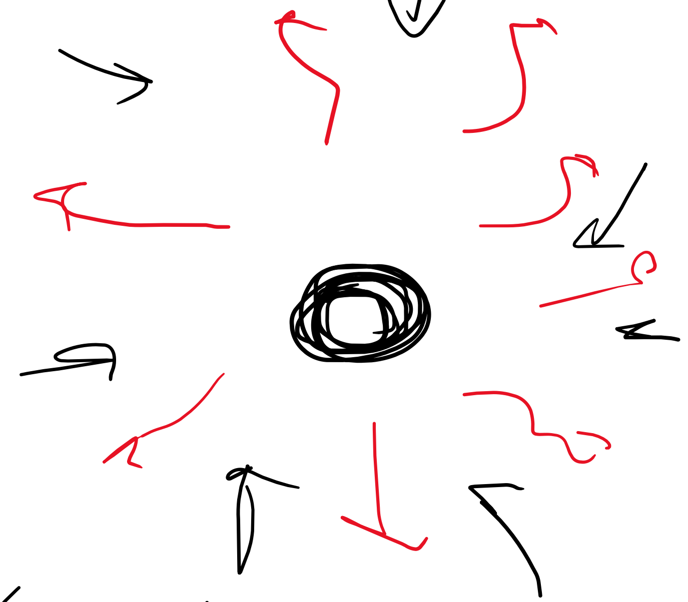
$L_{acc} \sim 10^{20} \cdot \dot{M}$

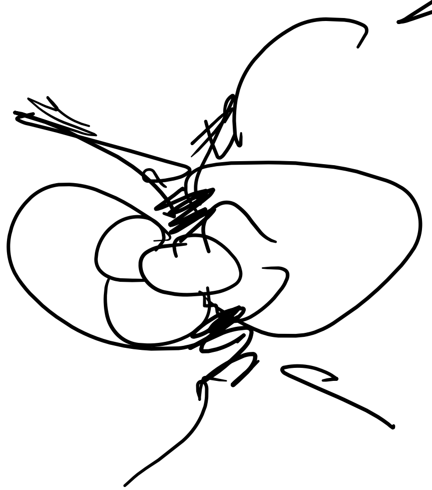
$\dot{M}_{Edd}$ Эддингтон





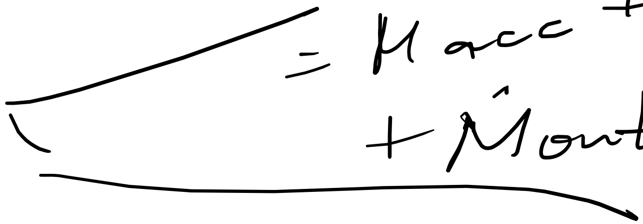
$\dot{M}_{out}$

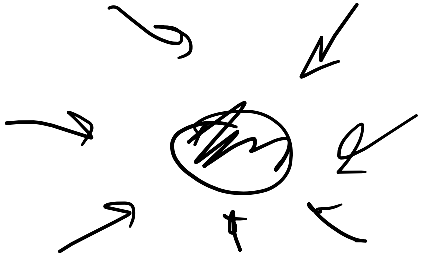




$\dot{M}_{out} =$
$= \dot{M}_{acc} +$
$+ \dot{M}_{outflow}$

$\dot{M}_{acc} < \dot{M}_{Edd}$



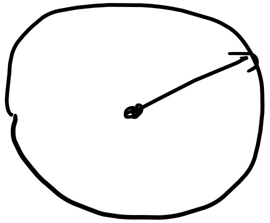


$L_{TOT} \lesssim L_{Edd}$

$L_{QSO} = 10^{45}$ эрг/с

$M_{bh} \gtrsim 10^{7} M_{\odot}$

(3)



R_g: $c = \sqrt{\frac{2GM}{R_g}}$

$$R_g = \frac{2GM}{c^2} = 3\,\text{km}\,\frac{M}{M_\odot}$$

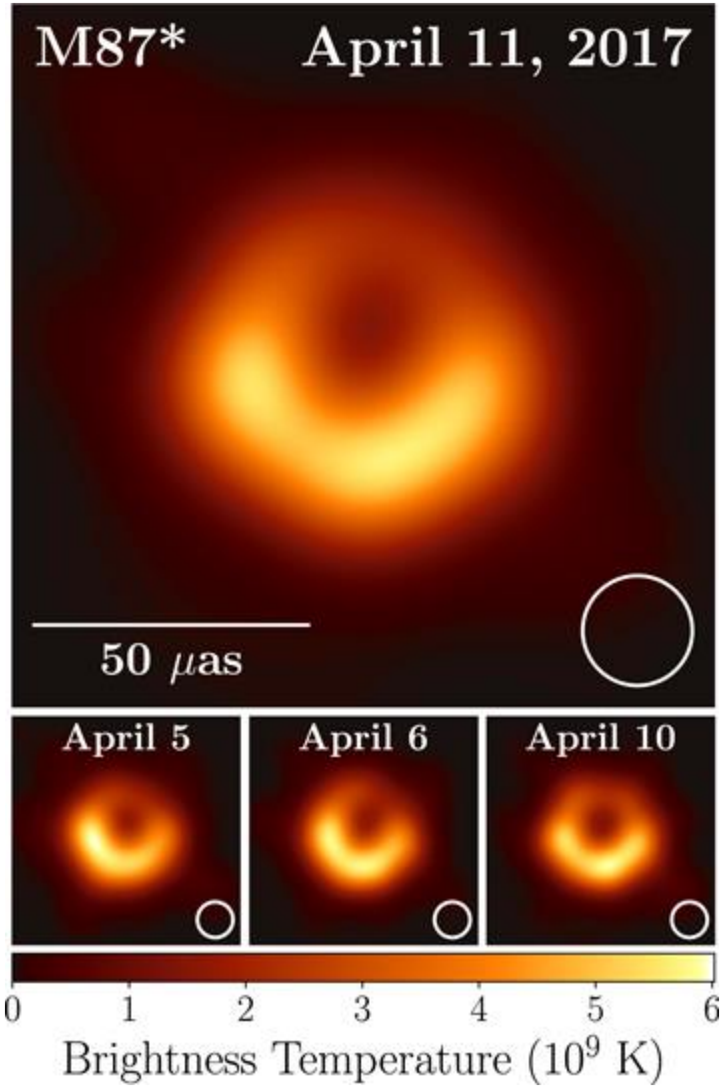
$$v_\varphi \sim \sqrt{\frac{GM}{r}} \qquad v_r \ll v_\varphi$$

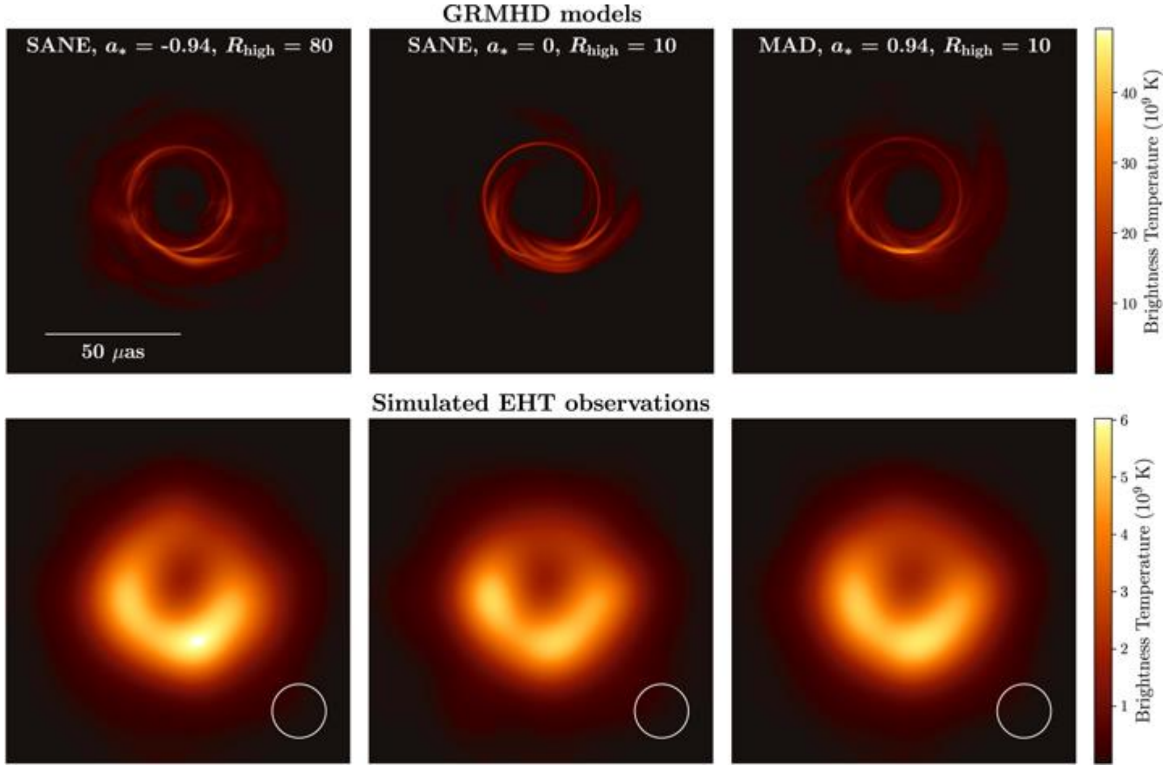
ISCO

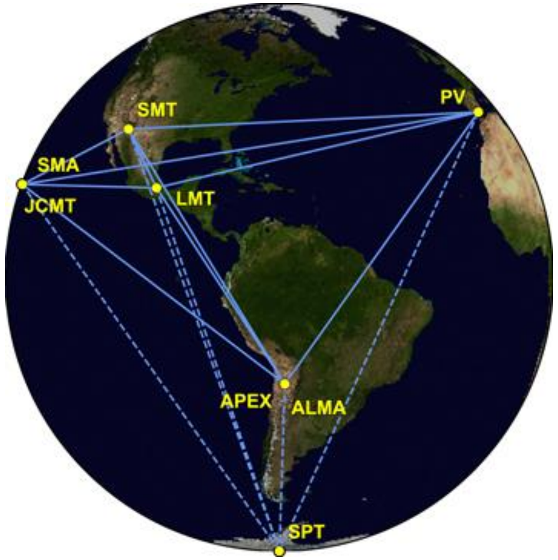
$$R_{ISCO} = 3R_g = \frac{6GM}{c^2}$$

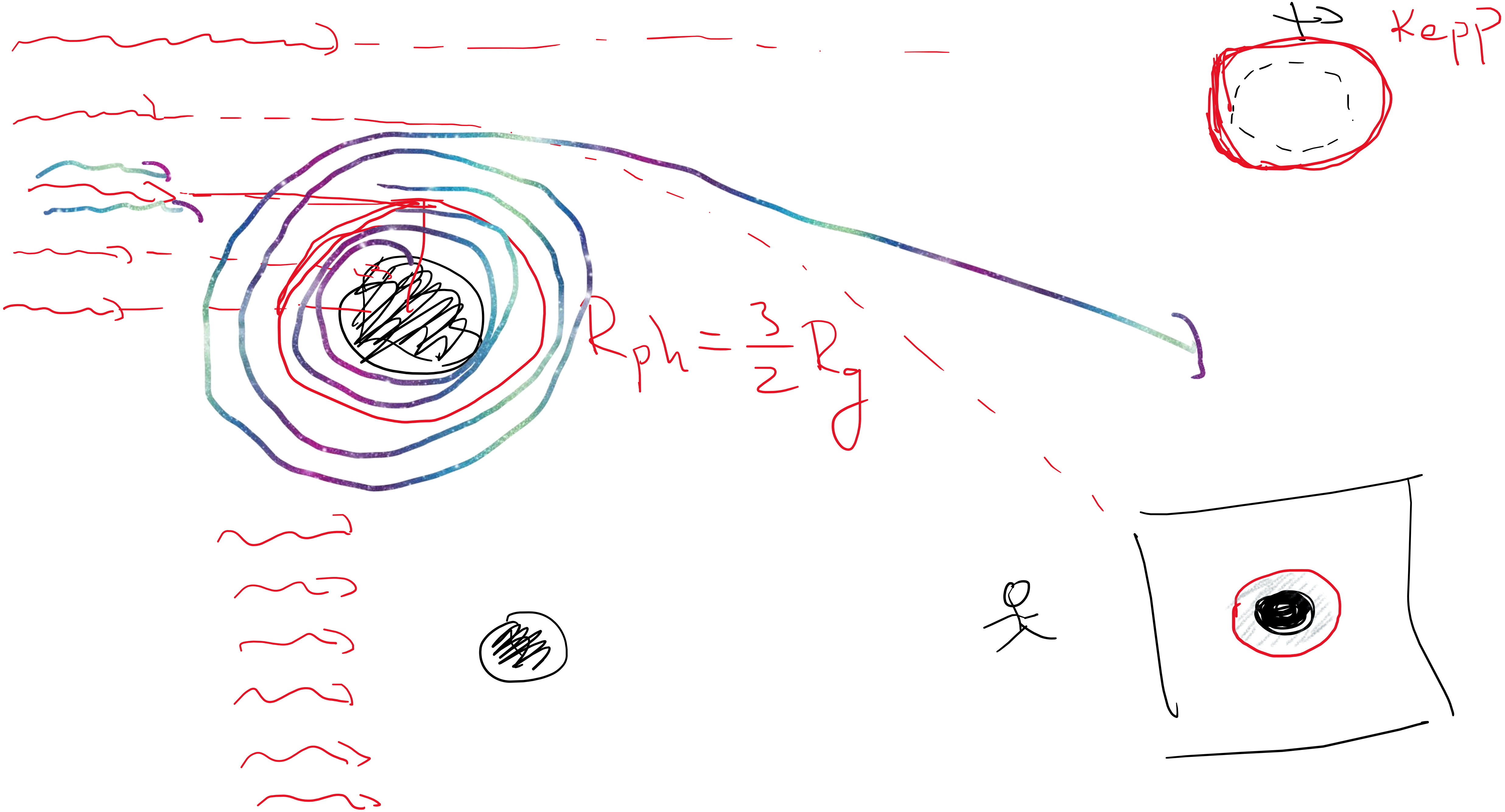
Черная дыра в M87

https://iopscience.iop.org/article/10.3847/2041-8213/ab0ec7



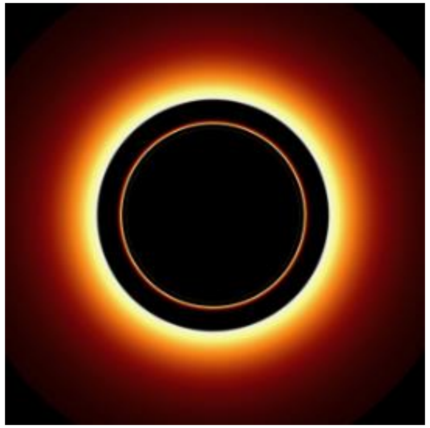





Kepp
$R_{ph} = \frac{3}{2} R_g$

Тень черной дыры, последняя устойчивая орбита и яркое кольцо

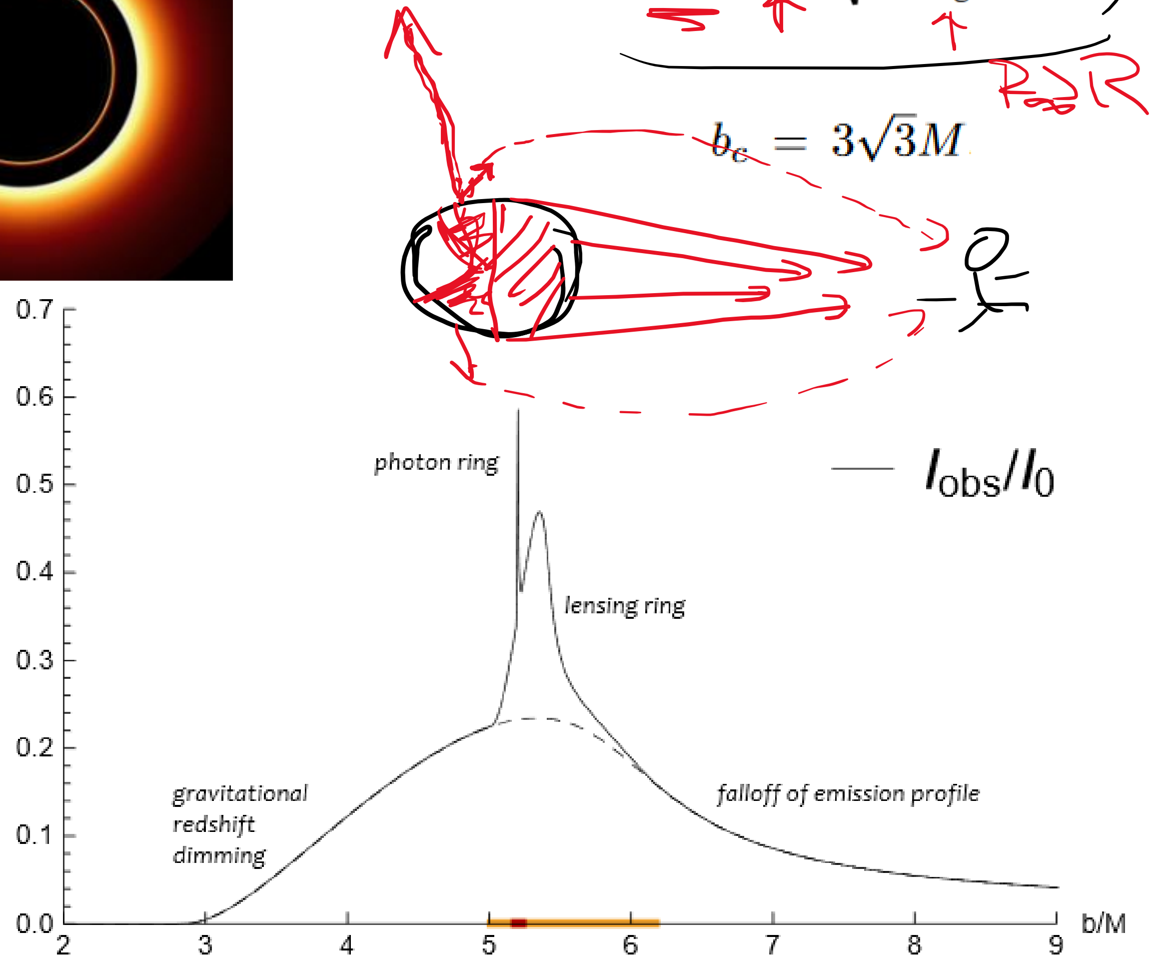
$R_{sl} = \frac{2GM}{c^2}$ $\quad \frac{2 R_{sl}}{d_G}$ $\quad \alpha \sim \frac{2 R_{sl}}{d_G}$ [rad]

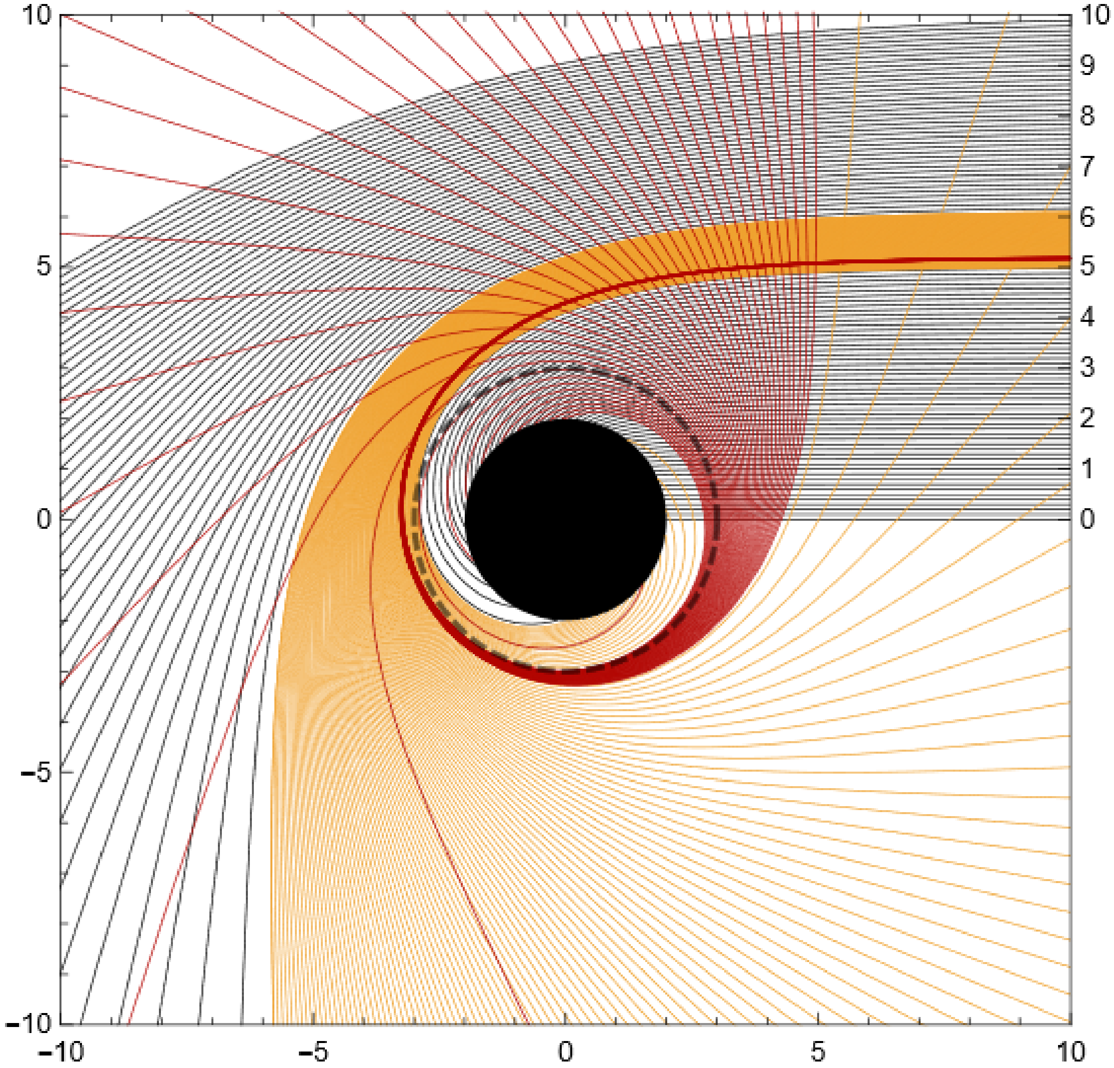


$$R_\infty = R / \sqrt{1 - r_g / R}$$

$R_\infty > R$

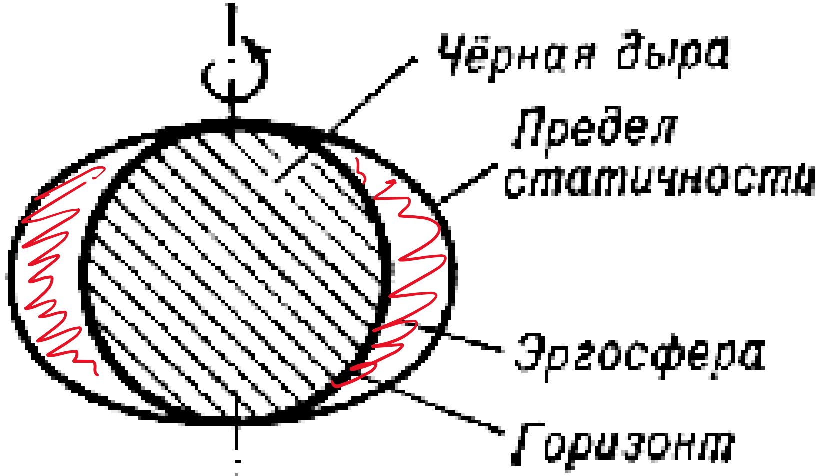
$$b_c = 3\sqrt{3}M$$





1906.00873

Вращающиеся черные дыры



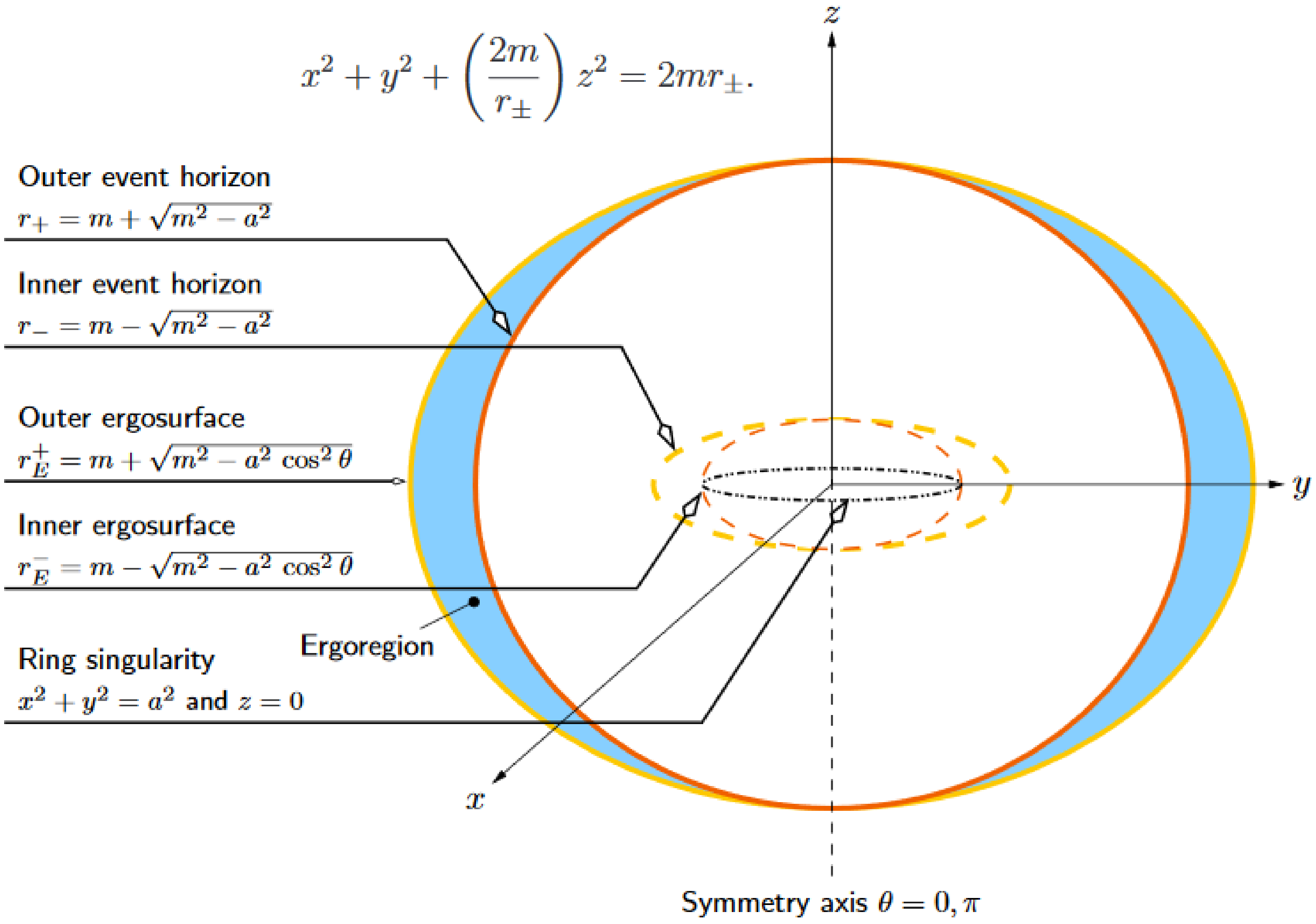
$$r = M + \sqrt{M^2 - a^2 \cos^2\theta}$$

http://www.astronet.ru/db/msg/1188232

$0 \leq a \leq 1$

0,998

42%



0706.0622

4) Планковские единицы

$\hbar, c, G$ $\quad t_{pl} \sim 10^{-43}$ с $\quad l_{pl} = t_{pl} \cdot c \sim 10^{-33}$ см

$$[L_p] = [\hbar]^x [c]^y [G]^z$$

$$г \cdot см^2 \cdot с^{-3} = (г \cdot см^2 \cdot с^{-1})^x (см \cdot с^{-1})^y (см^3 \cdot с^{-2} \cdot г^{-1})^z = г^{x-z} \cdot см^{2x+y+3z} \, с^{-x-y-2z}$$

$$\begin{cases} 1 = x - z \\ 2 = 2x + y + 3z \\ -3 = -x - y - 2z \end{cases}$$

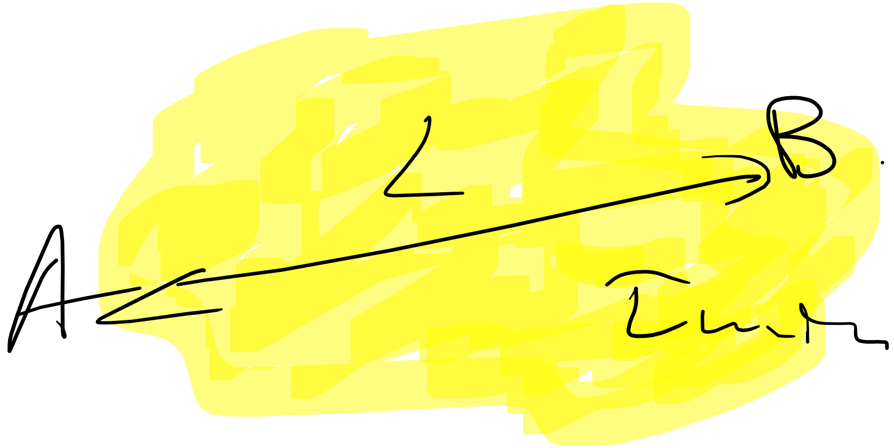
$z = -1$

$x = 0$

$y = 5$

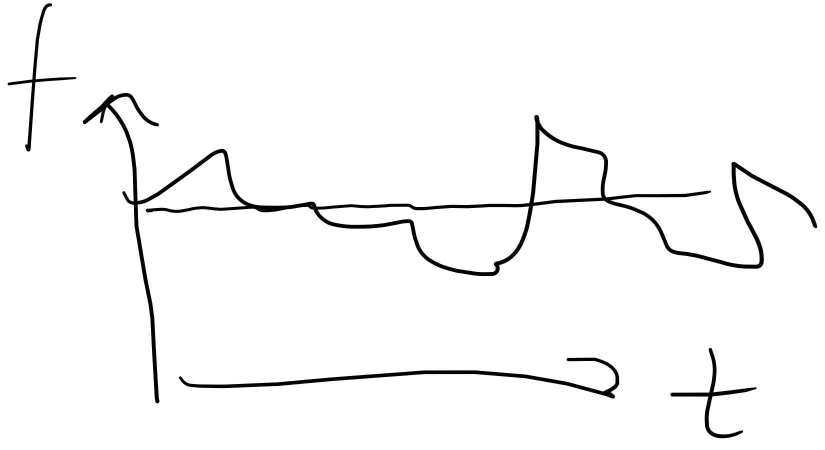
$$L_p = \frac{c^5}{G} = 3 \ldots 10^{59} \frac{эрг}{с} = 10^{26} L_\odot$$

(5) Перем. QSO.



$$\tau_{min} = \frac{L}{v_s}$$

$t_{QSO} \sim$ days



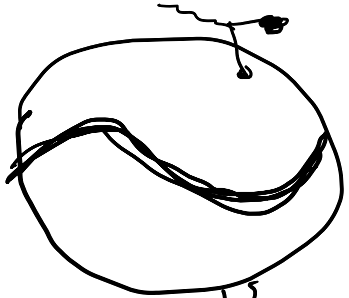
$$L_{max} = \tau_{min} \cdot c$$

$$L \ll 10^5 \cdot 3 \cdot 10^{10} \sim 3 \cdot 10^{15}\ \text{см}$$

$\sim 0{,}001$ пк

~ 200 ае.

(6)



$\Delta p \, \Delta x \sim \hbar$

$D_{BH} = 2R_g = \lambda_c$

$E = h\nu$ $\quad \nu = c/\lambda$

$\lambda_c = \frac{\hbar}{mc}$

$E = h\frac{c}{\lambda} = mc^2$

$\Delta x \Delta p = \hbar = h/2\pi$

$\Delta p = mc \Rightarrow \Delta x = \frac{\hbar}{mc}$

$kT = h\nu = hc/\lambda$

$\lambda = 2R_g$

$\lambda = 2\pi \cdot 2 \frac{2GM}{c^2}$

$L = 4\pi R_g^2 \sigma T^4$

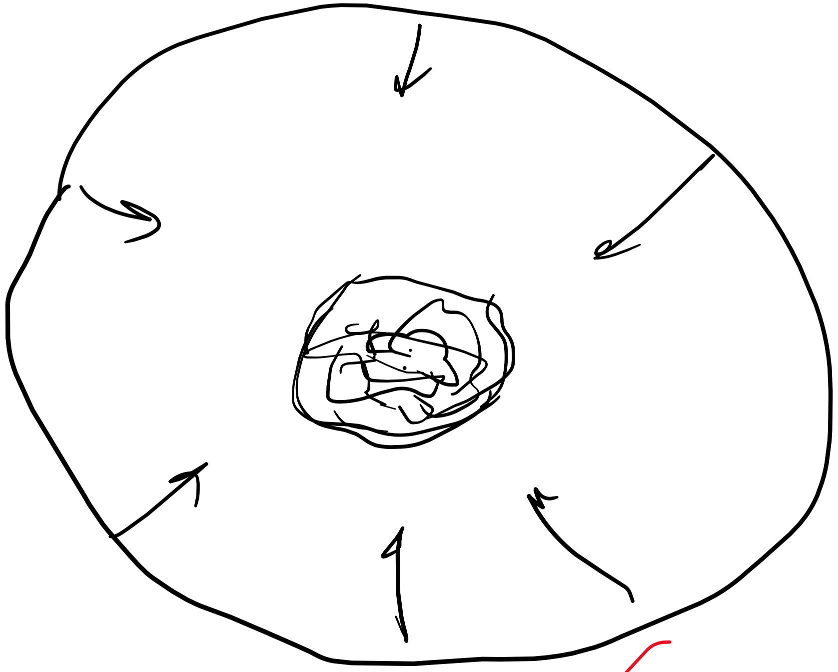
$T = \frac{h\nu}{k} = \frac{hc}{k\lambda} = \frac{hc^3}{k 8\pi G M}$

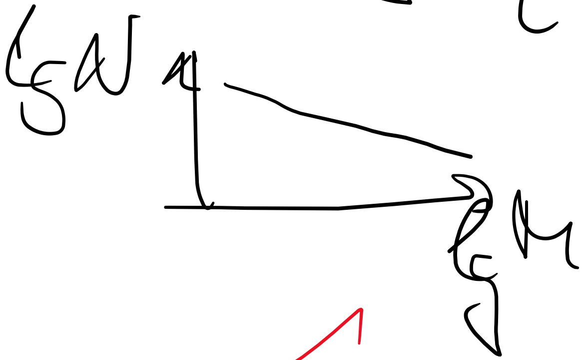
$\sigma = \frac{\pi^2 k^4 (2\pi)^3}{60 h^3 c^2}$

$L = \dot{M} c^2$

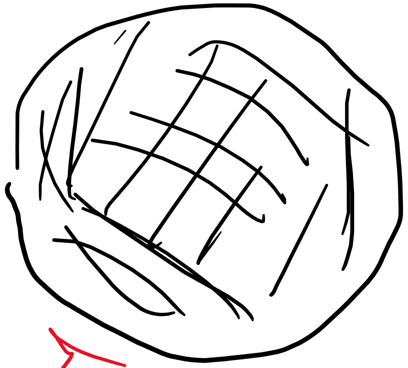
$M^2 \dot{M} \sim \frac{hc^3}{G^2}$

$\tau \sim \frac{G^2 M^3}{hc^4} \sim M^3$





$T \sim \frac{1}{M}$



$T = 2{,}73\,K$

$M(T = 2{,}73\,K) = ?$

$M(\tau \sim 10^{10}\ \text{лет}) \sim 10^{15}\ \text{г}$

$\ell_{AB} > c \cdot \tau_{un}.$

$M \sim R$

$\langle \rho \rangle \sim R^{-2}$