Accretion Disc Around Black Hole

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PandA @ UNM

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Outline

Gargantua

Black Holes

Snack on Stars

Disc Dynamics
- Transportation of Angular Momentum
- Accretion and Instability

Temperature

Summary

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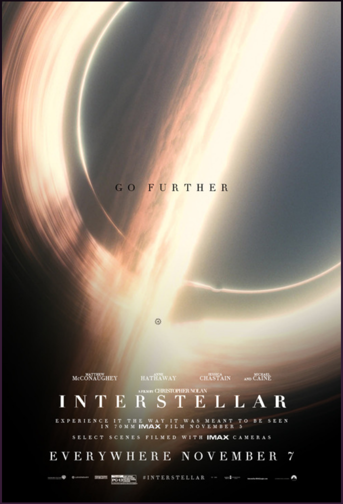
Gargantua

A SMBH in the movie *Interstellar*



Gargantua

Questions

- Where is the disc from?
- Why is this a round disc?
- Where does the jets go?
- Why is the temperature so low?

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Black Holes

Facts

- Most black holes generate very strong gravitational fields near its surface.
- General relativity is used instead of Newtonian gravity.
- Schwarzschild radius is $R_S = 2r_g = \frac{2GM_{BH}}{c^2}$.
- Ergosphere is a special region of a rotating black hole (Kerr black hole). Nothing can stay put inside ergosphere relative to distant stars.

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Snack on Stars

Where is the disc from?

The disc comes from a red giant. Tidal force tears the star apart.

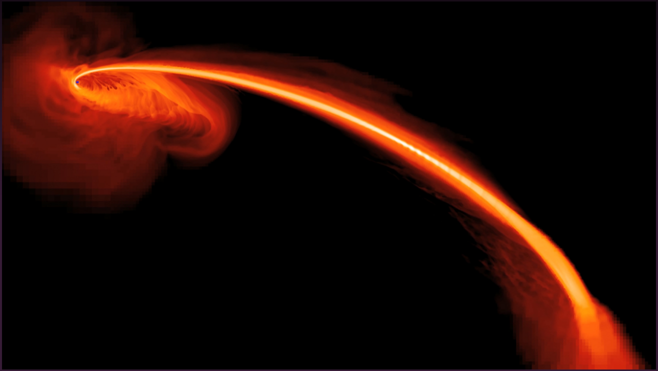
Tidal Force

The difference between the two parts of an object because of the size effect.

Tidal Disruption Radius

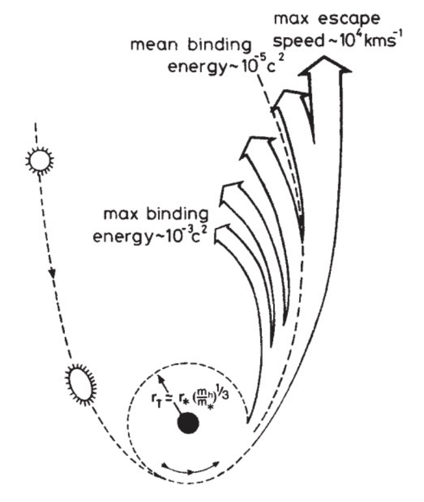
$$R_T \propto R_\star \left(\frac{M_{BH}}{M_\star} \right)^{1/3} \tag{1}$$

Snack on Stars



http://hubblesite.org/newscenter/archive/releases/2012/18/image/a/

Snack on Stars



M. REES, 1988. BH Mass: 10^6–10^8 solar masses.

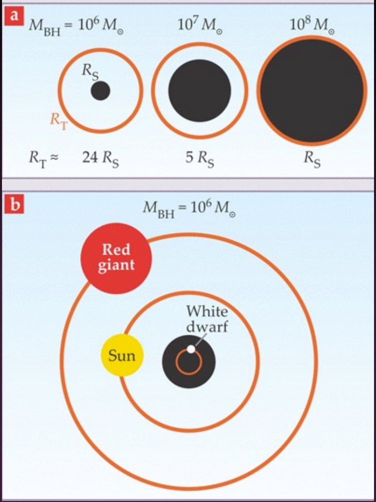
Snack on Stars

Schwarzschild radius VS Tidal Disruption Radius

$$R_S = 2r_g = \frac{2GM_{BH}}{c^2} \propto M_{BH} \tag{2}$$

$$R_T \propto M_{BH}^{1/3} \tag{3}$$

Snack on Stars



http://scitation.aip.org/content/aip/magazine/physicstoday/article/67/5/10.1063/PT.3.2382 For our sunlike star, $R_S \to R_T$ at about $M_{BH} \to 10^8 M_\odot$.

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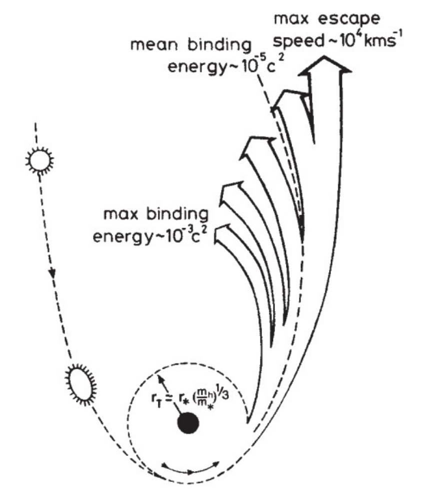
Snack on Stars



M. REES, 1988. BH Mass: 10^6–10^8 solar masses.

Transportation of Angular Momentum

Turbulent Viscosity

Conservation of momentum

$$\frac{\partial \rho \vec{v}}{\partial t} + \nabla \cdot (\rho \vec{v}\vec{v} + P) = 0. \tag{4}$$

Perturbation

$$\vec{v} = \vec{w} + \vec{u}. \tag{5}$$

Final equation

$$\frac{\partial w_i}{\partial t} + w_j \frac{\partial w_i}{\partial x_j} = \frac{1}{\rho} \frac{\partial}{\partial x_j} (\bar{\tau}_{ij} - \rho \bar{v_i v_j}), \tag{6}$$

where

$$\frac{1}{\rho} \frac{\partial}{\partial x_j} \bar{\tau}_{ij} \equiv -\frac{1}{\rho} \frac{\partial P}{\partial x_i} + \nu \nabla^2 w_i \tag{7}$$

$$\tau_{R,ij} \equiv -\rho \bar{v_i v_j} \qquad \text{Reynolds stress.} \tag{8}$$

Transportation of Angular Momentum

Viscosity Coefficient

Viscosity coefficient connects the radial structure and vertical structure of the disc.
But the viscosity coefficient usually has a lot of assumptions.
Alpha viscosity is

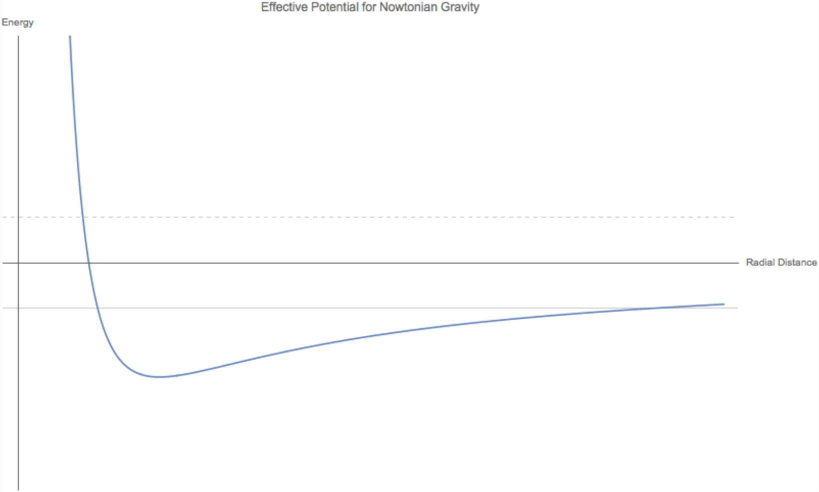
$$\nu = \alpha c_s h, \tag{9}$$

which will be used to calculate the effective temperature of the disc in the following slides.

Accretion & Instability

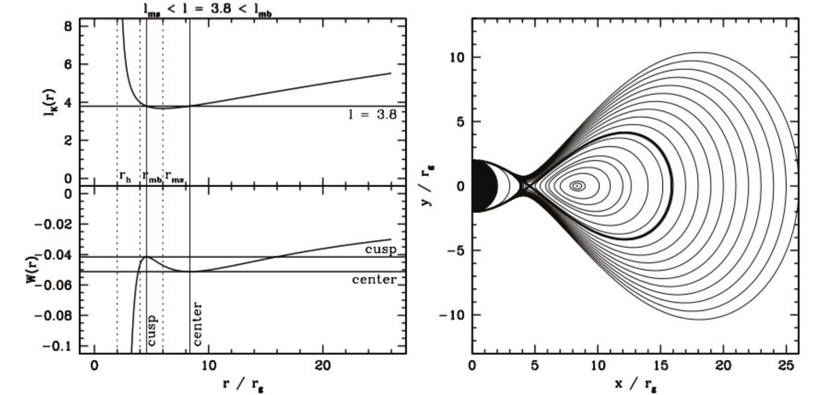
ISCO

Innermost stable circular orbit is a orbit inside which no stable Keplerian orbit is possible. It is about radial and zenith stability.
To find it we can check the second order derivatives of effective potential.



Accretion & Instability

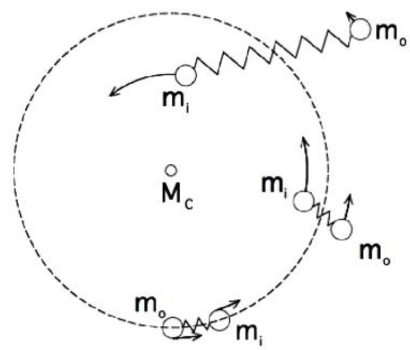
Gravitational Runaway Instability



Equipressure lines of accretion the disk. $W(r)$ is the effective potential. The interesting part is that Keplerian circular orbit can only stay at a distance r_{center}, which is very different from Newtonian gravity. $r_g = \frac{GM_{BH}}{c^2}$. B. Paczynsky, P. J. Wiita, 1980.

Accretion & Instability

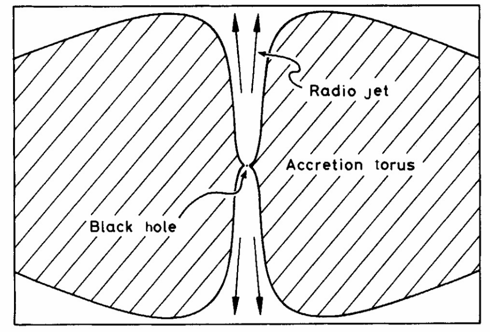
MRI



http://www.scholarpedia.org/article/Magnetorotational_instability. The spring is responsible for the transfer of momentum. If the inner mass loses momentum, it will drop rapidly inward, the outer one gains momentum thus moving outward. The spring will be stretched and exerts more force. The momentum transfer becomes more efficient.

Jets

BlandfordZnajek Process



A torus. M. J. Rees et al, 1982.

The Poynting flux is

$$L_{EM} \leq B_{pH}^2 r_g^2 (J/J_{max})^2 c, \tag{10}$$

B_{pH} drops then the jets eventually disappear.

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Temperature

Effective Temperature of A Disc

Heat production is

$$Q_+ = \Sigma\nu \left(r\frac{\partial \Omega_K}{\partial r} \right)^2 = \frac{9}{4}\Sigma\nu \frac{GM_\star}{r^3}. \tag{11}$$

Assuming a powerlaw surface density $\Sigma \propto r^{-\eta}$, and plug in accretion rate $\dot{M} = -2\pi\Sigma r v_r$

$$Q_+ \propto \dot{M}\Omega_K^2. \tag{12}$$

Effective Temperature

Effective temperature is defined as the temperature in an assumed black body,

$$2\sigma T_{eff}^4 = Q_+ \propto \dot{M}\Omega_K^2, \tag{13}$$

Surface density $\downarrow \rightarrow \dot{M} \downarrow \rightarrow$ effective temperature $\downarrow$.

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Summary

Summary

- Source of the disc: a destroyed star
- Round disc: angular momentum transport
- Jets: $L_{EM} \propto B_{pH}^2$, density $\downarrow \rightarrow$ jets $\downarrow$
- Temperature: $T_{eff}^4 \propto \dot{M}\Omega_K^2$, surface density $\downarrow \rightarrow \dot{M} \downarrow \rightarrow$ effective temperature $\downarrow$.