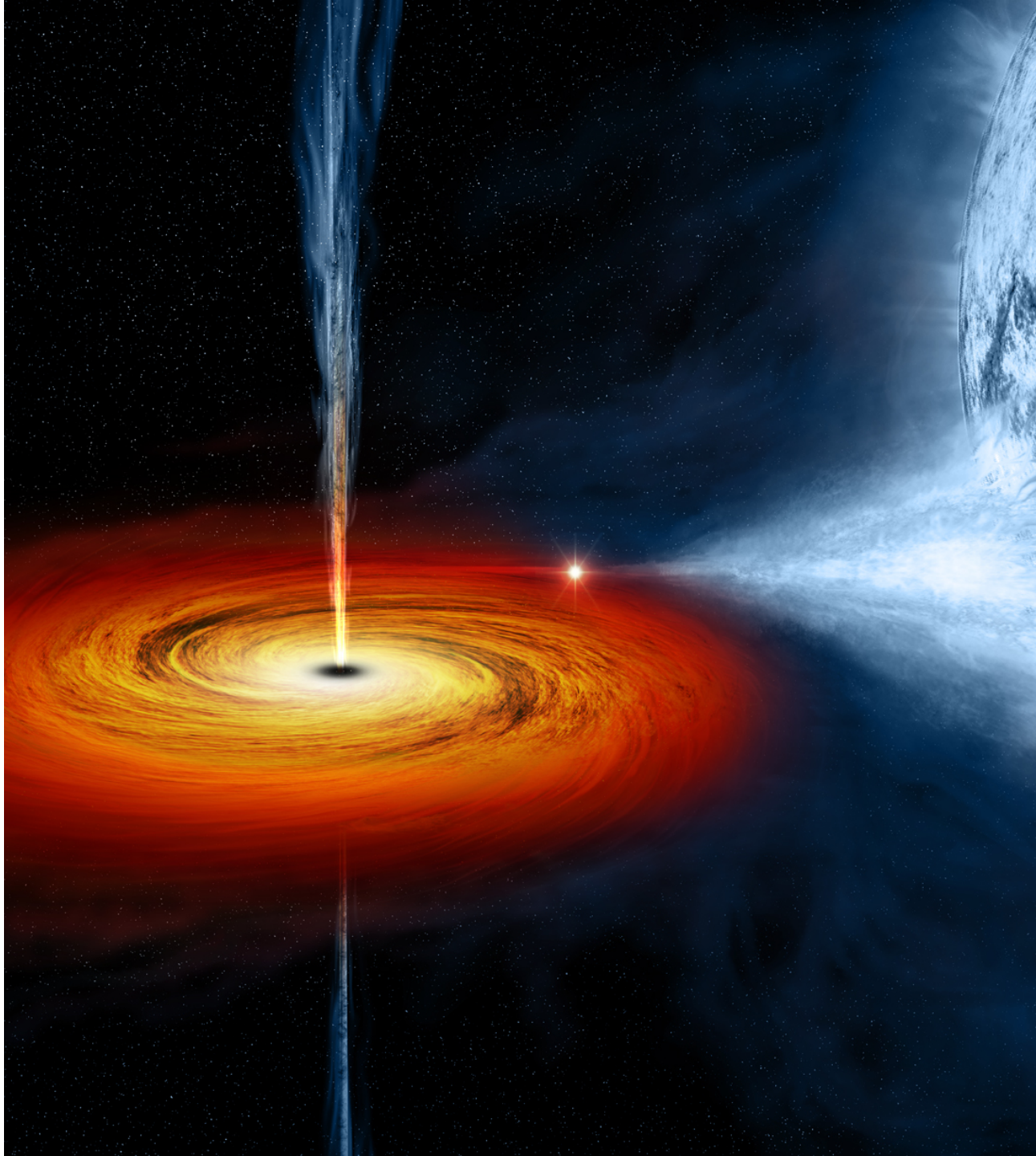
PHY 7097 | Modern Astrophysics

Lecture XIV.

Accretion



UF | UNIVERSITY of FLORIDA

Imre Bartos | Spring 2018

Hydrodynamic spherical accretion onto a black hole

Bondi radius --- defiones **effective area** of accretion, where the black hole's escape velocity is the same as the thermal velocity of the gas.:

$$r_{\rm B} = \frac{2GM}{c_\infty^2}$$

Bondi accretion:

$$\dot{M}_{\rm BH} = \frac{4\pi G^2 M^2 \rho_\infty}{c_\infty^3}$$

Bondi-Hoyle-Lyttleton accretion:

$$\dot{M}_{\rm BH} = \frac{4\pi G^2 M^2 \rho_\infty}{(c_\infty^2 + v_\infty^2)^{3/2}}$$

More details: Edgar 2004 (https://arxiv.org/abs/astro-ph/0406166)

Shapiro & Teukolsky (14.3)

Where does spherical accretion occur?

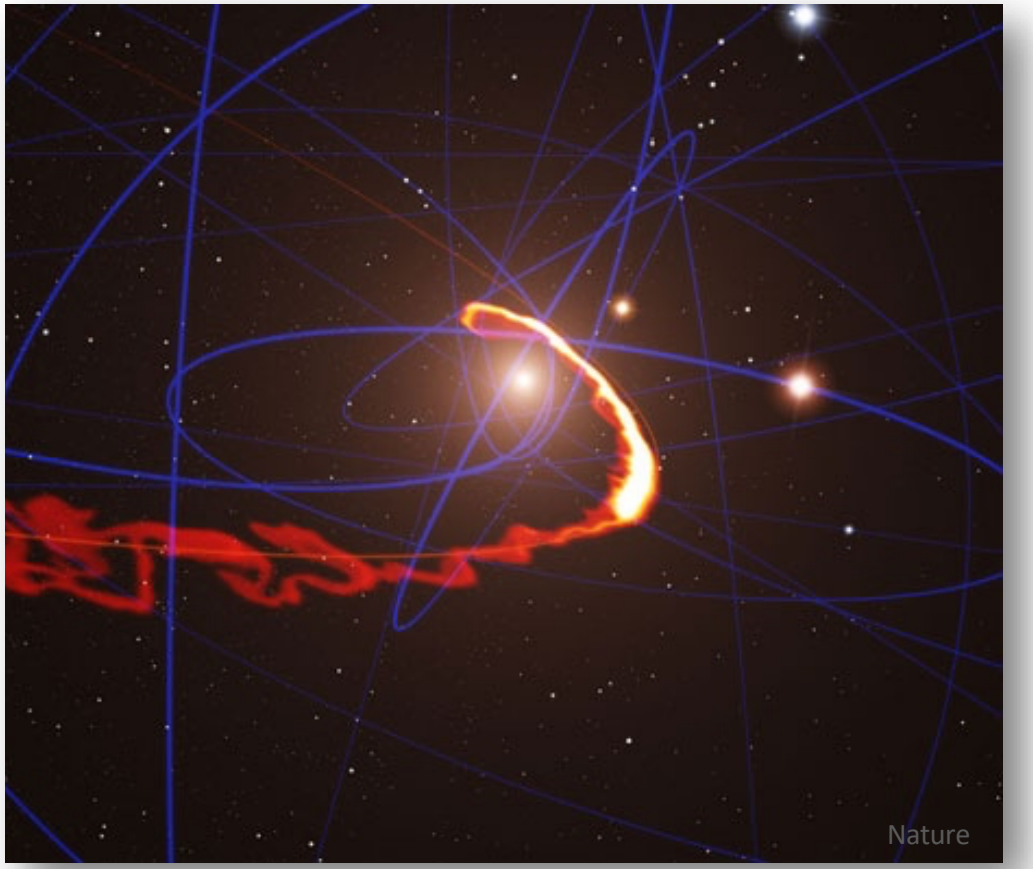
It is rare --- typically there is angular momentum.

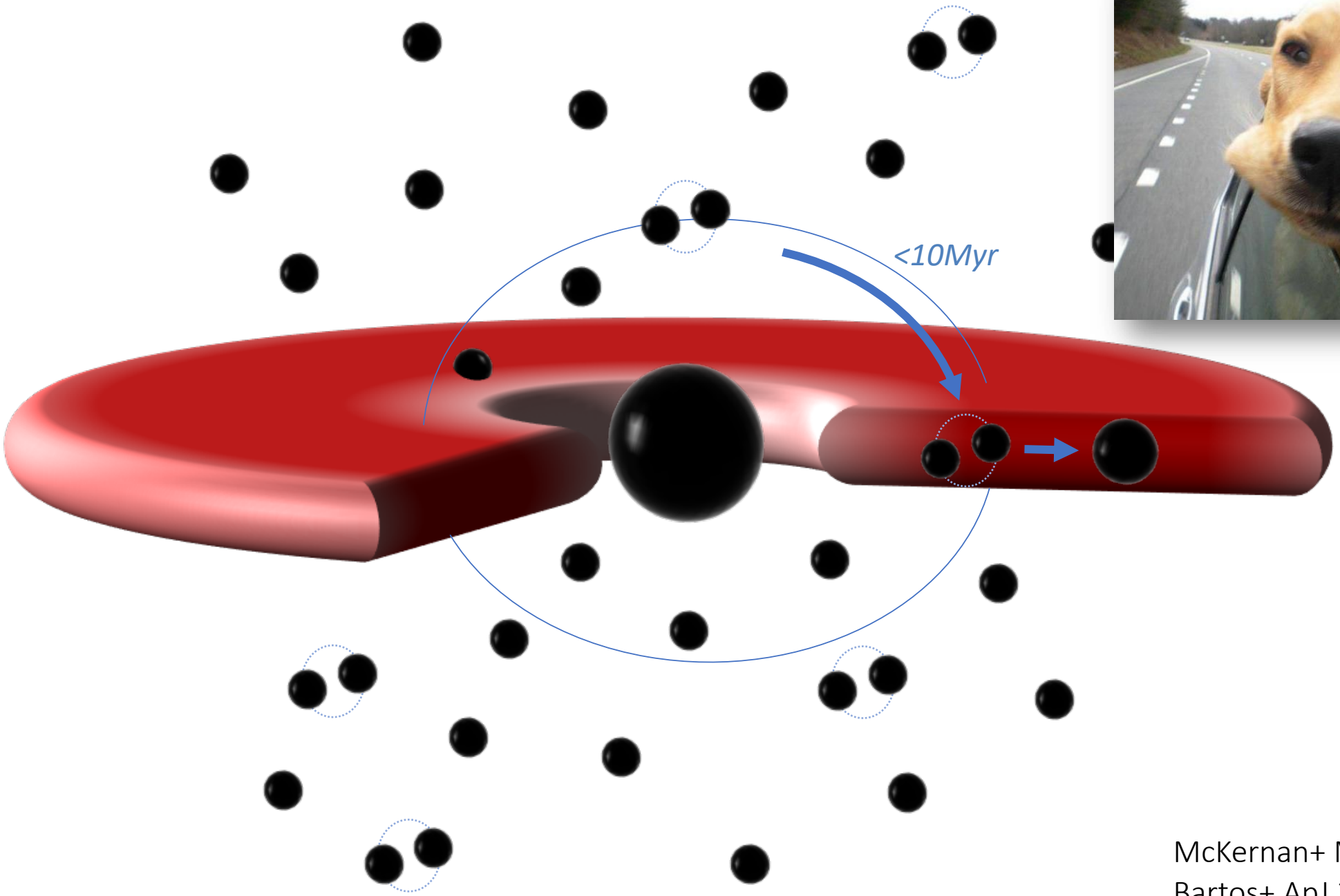
- Planet formation from protoplanetary disk
- Accretion of interstellar gas onto a solar-mass BH

$$\dot{M} = 8.77 \times 10^{-16} \left(\frac{M}{M_\odot} \right)^2 \left(\frac{\rho_\infty}{10^{-24}\ \mathrm{g\ cm^{-3}}} \right) \left(\frac{a_\infty}{10\ \mathrm{km\ s^{-1}}} \right)^{-3} M_\odot\ \mathrm{yr}^{-1}$$

Shapiro & Teukolsky (14.3)

- Black hole + gas cloud encounter





McKernan+ MNRAS 2012
Bartos+ ApJ 2017

Dynamical friction

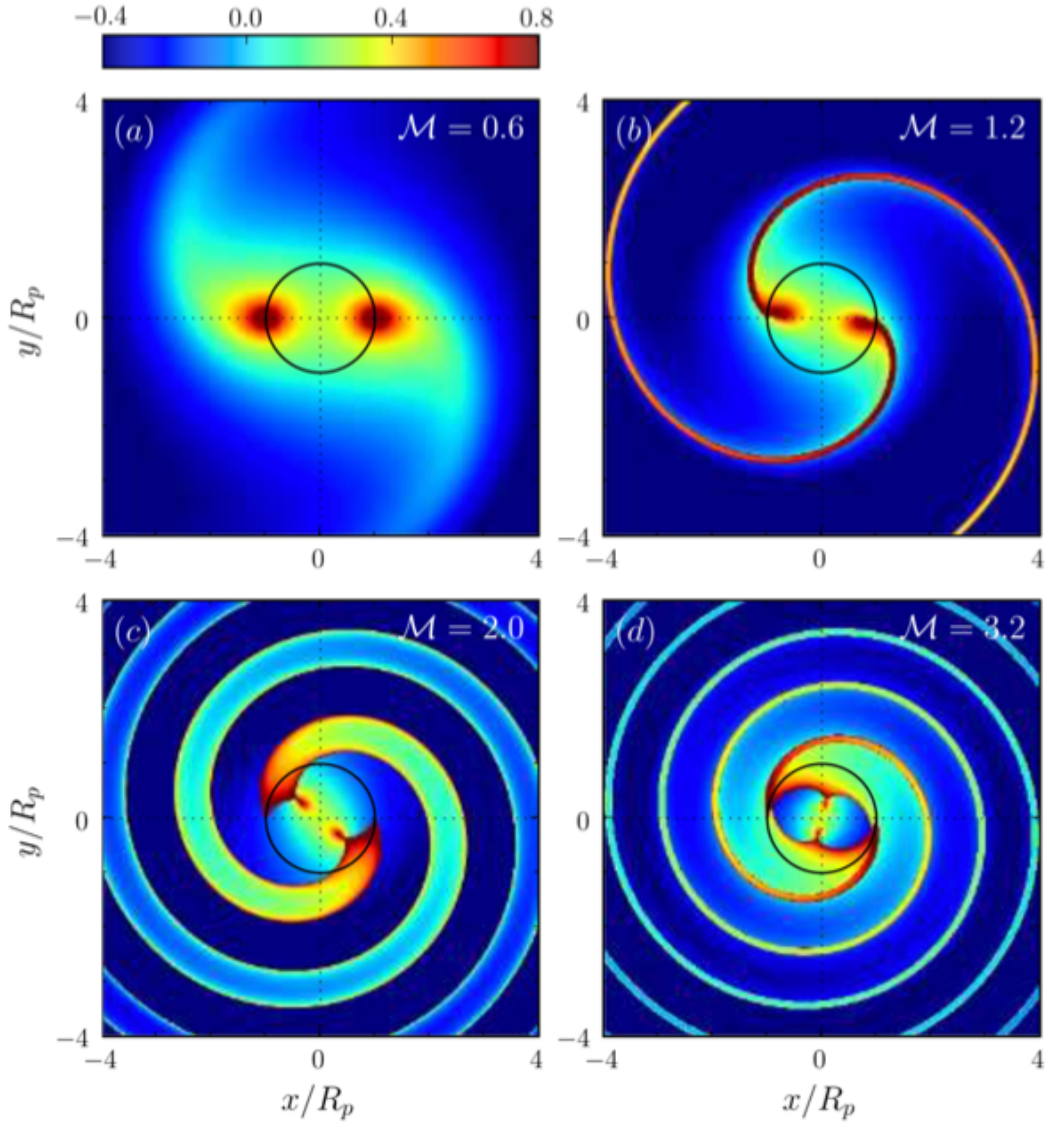


FIG. 1.— Distributions of the dimensionless perturbed density $\mathcal{D}$ in a steady state for (*a*) $\mathcal{M} = 0.6$, (*b*) 1.2, (*c*) 2.0, and (*d*) 3.2 on the orbital plane ($z = 0$). The perturbers of equal mass located at $(x, y) = (\pm R_p, 0)$ are moving in the counterclockwise direction along a circular orbit marked by the black circle in each frame. Colorbar labels $\log \mathcal{D}$.

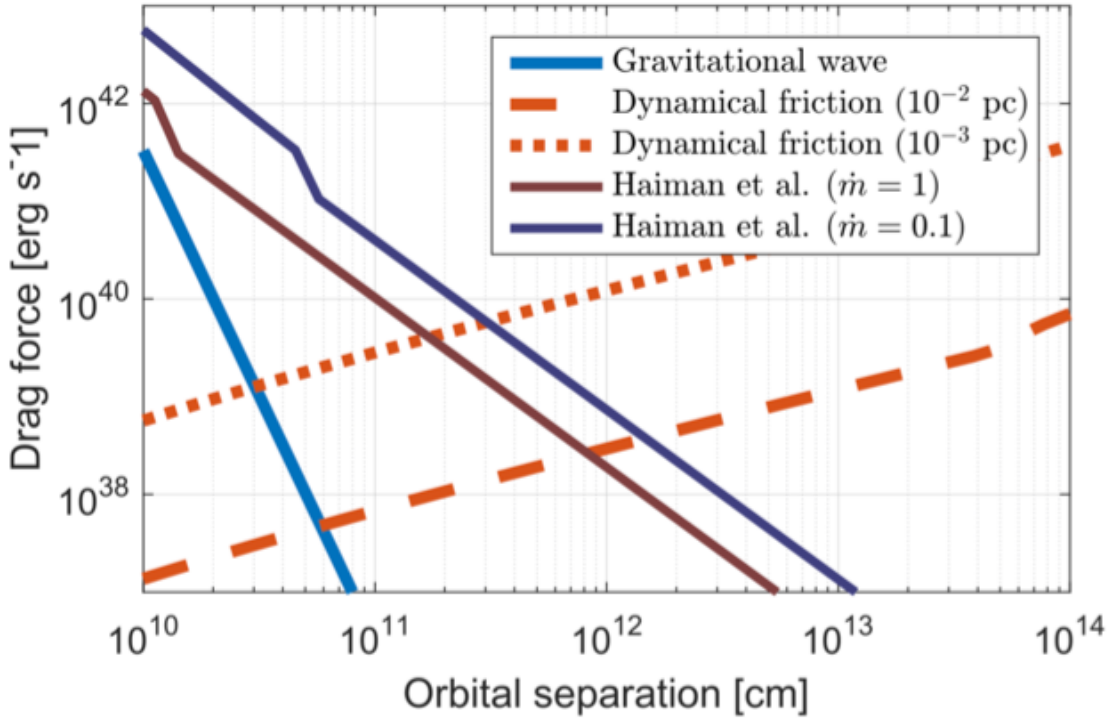


Figure 1. Drag force (energy-loss rate) for binary BHs within a gas disk as a function of orbital separation due to the emission of gravitational waves (solid lines) and dynamical friction at different orbital radii (see legend). The parameters adopted are $M_1 = M_2 = 10\,M_\odot$ and $M_\bullet = 10^6\,M_\odot$.

Kim, Kim & Sanchez-Salcedo 2008

Bartos+ 2017

Radiation from spherical accretion

- Gas heats up as it falls in → radiates (mainly thermal Bremsstrahlung radiation)
- Most emission will come from the innermost part of the accretion where the gas is hottest.

$$L_{\rm ff} = 1.2 \times 10^{21} \left(\frac{n_\infty}{1\ {\rm cm}^{-3}} \right)^2 \left(\frac{T_\infty}{10^4\ {\rm K}} \right)^{-3} \left(\frac{M}{M_\odot} \right)^3 {\rm erg\ s}^{-1}$$

- Mostly hard X-rays and gamma rays (up to ~10 MeV) for 1 solar mass BHs.
- Bigger BH → **softer** spectrum
- Very low efficiency for BHs! (Spherical accretion on to NSs can have 10% efficiency!)

$$\varepsilon = \frac{L_{\rm ff}}{\dot{M}c^2} \sim 6 \times 10^{-11} \left(\frac{n_\infty}{1\ {\rm cm}^{-3}} \right) \left(\frac{T_\infty}{10^4\ {\rm K}} \right)^{-3/2} \left(\frac{M}{M_\odot} \right)$$

Shapiro & Teukolsky (14.4)

Radiation from spherical accretion

$$L_{\rm ff} = 1.2 \times 10^{21} \left(\frac{n_\infty}{1\ {\rm cm}^{-3}} \right)^2 \left(\frac{T_\infty}{10^4\ {\rm K}} \right)^{-3} \left(\frac{M}{M_\odot} \right)^3 {\rm erg\ s}^{-1}$$

<u>Is this detectable?</u>

(at what distance?)

Typical detector sensitivities:

- Fermi-Gamma-ray Burst Monitor: 10^{-7} erg s^{-1} cm^{-2}
- Chandra (X-rays): 4×10^{-15} erg s^{-1} cm^{-2}

Eddington luminosity

For high accretion rates, the outwards radiation pressure can compensate for the inward gravitational pull.

$$L_{\rm Edd} = \frac{4\pi G M m_{\rm p} c}{\sigma_{\rm T}}$$

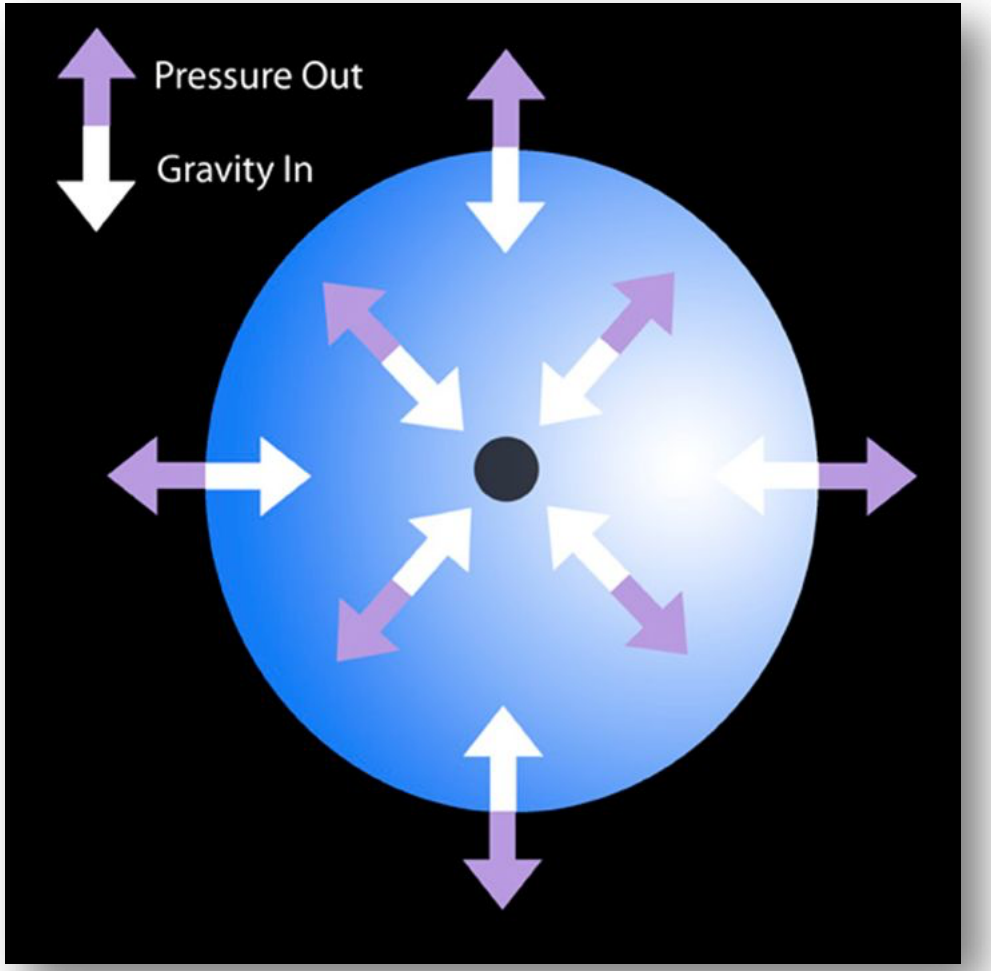
$$= 1.26 \times 10^{38} \left(\frac{M}{M_\odot}\right) {\rm erg/s} = 3.2 \times 10^4 \left(\frac{M}{M_\odot}\right) L_\odot$$

Not exact, depends on many things like chemical composition.

Eddington accretion rate:

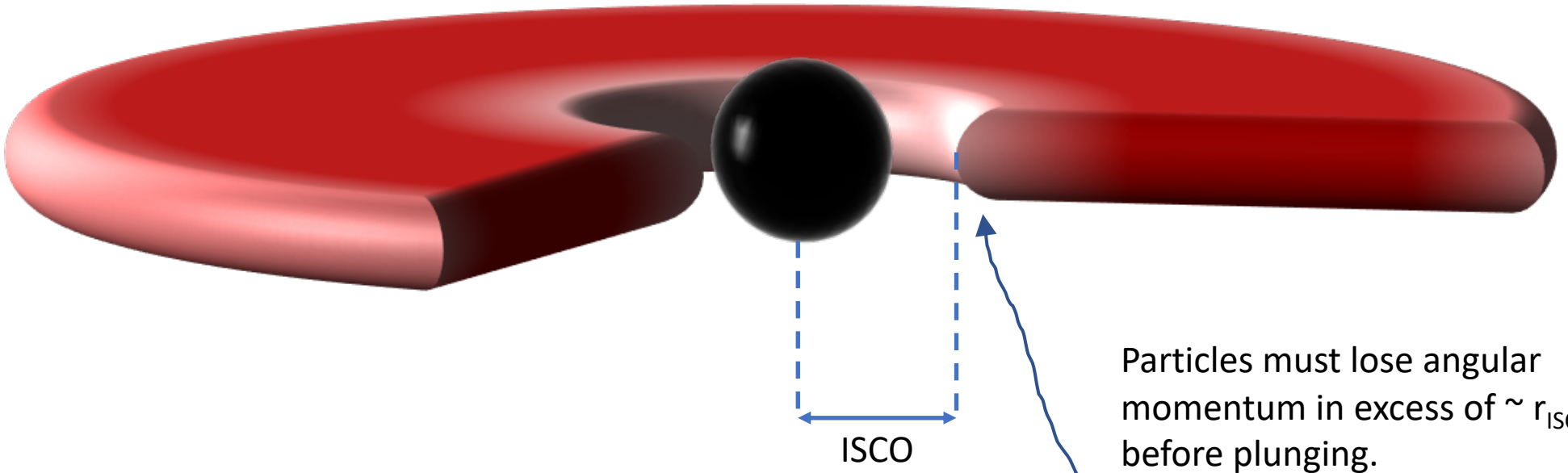
$$L = \epsilon \dot{M} c^2$$

efficiency (e.g., 0.1)



Disk Accretion

BH:



Radiation efficiency: U/m

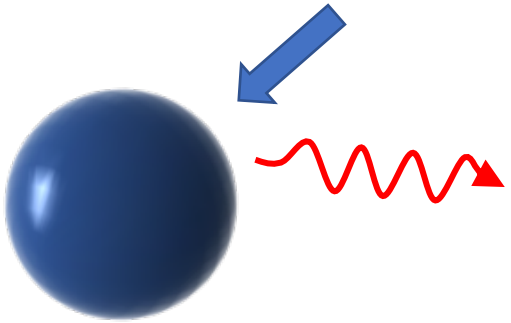
Schwarzschild BH:	5.7%
Kerr BH:	≤ 42%

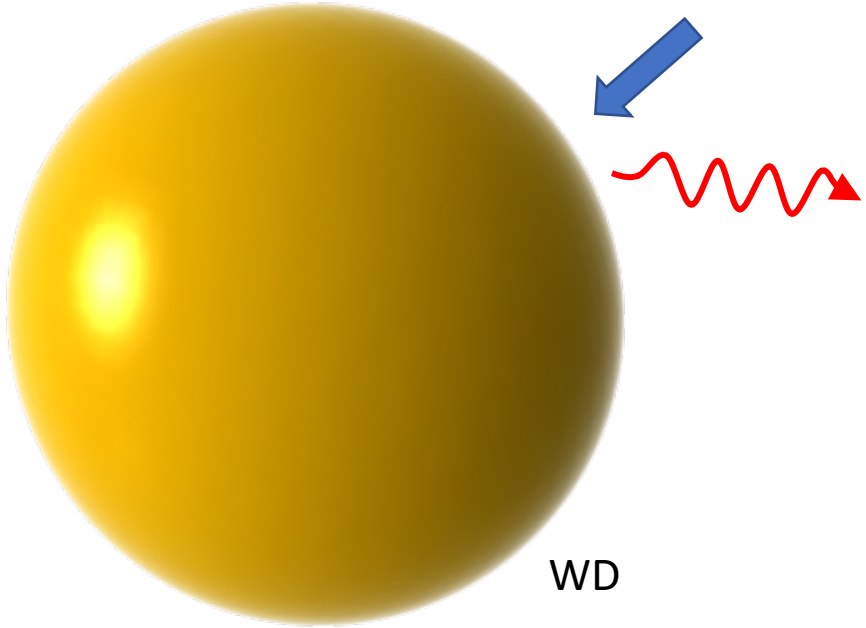
Most radiation will come from the innermost parts of the disk.

(Nuclear fusion: 0.7%)

(Gasoline: 0.00000003%)

Efficiency for WDs and NSs





WD or NS: particle collide with the stellar surface → kinetic energy is radiated away → order of magnitude of total luminosity is independent of the nature of the flow (spherical or disk).

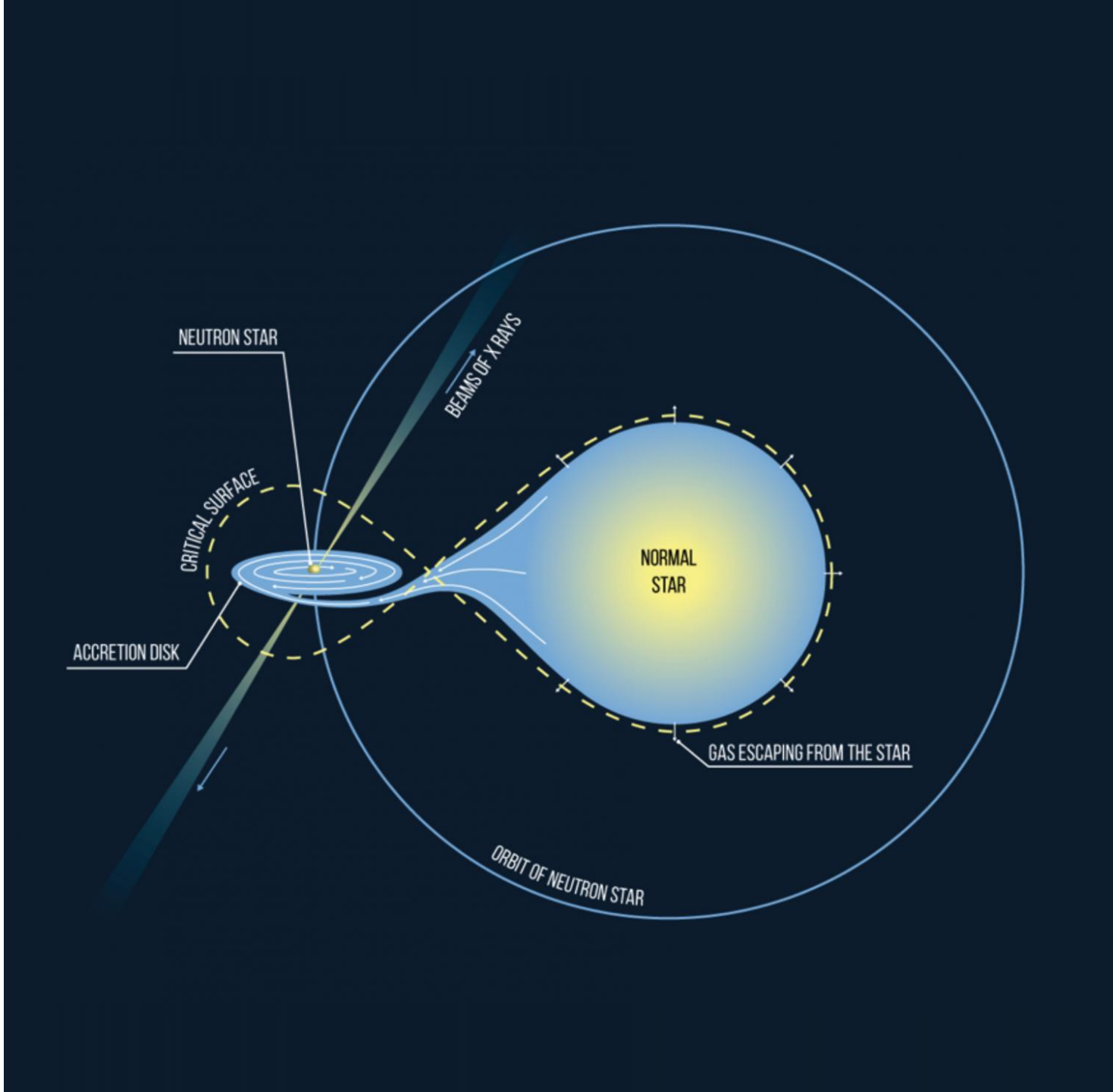
Total luminosity: $L = G\dot{M}M/R$

X-ray binaries

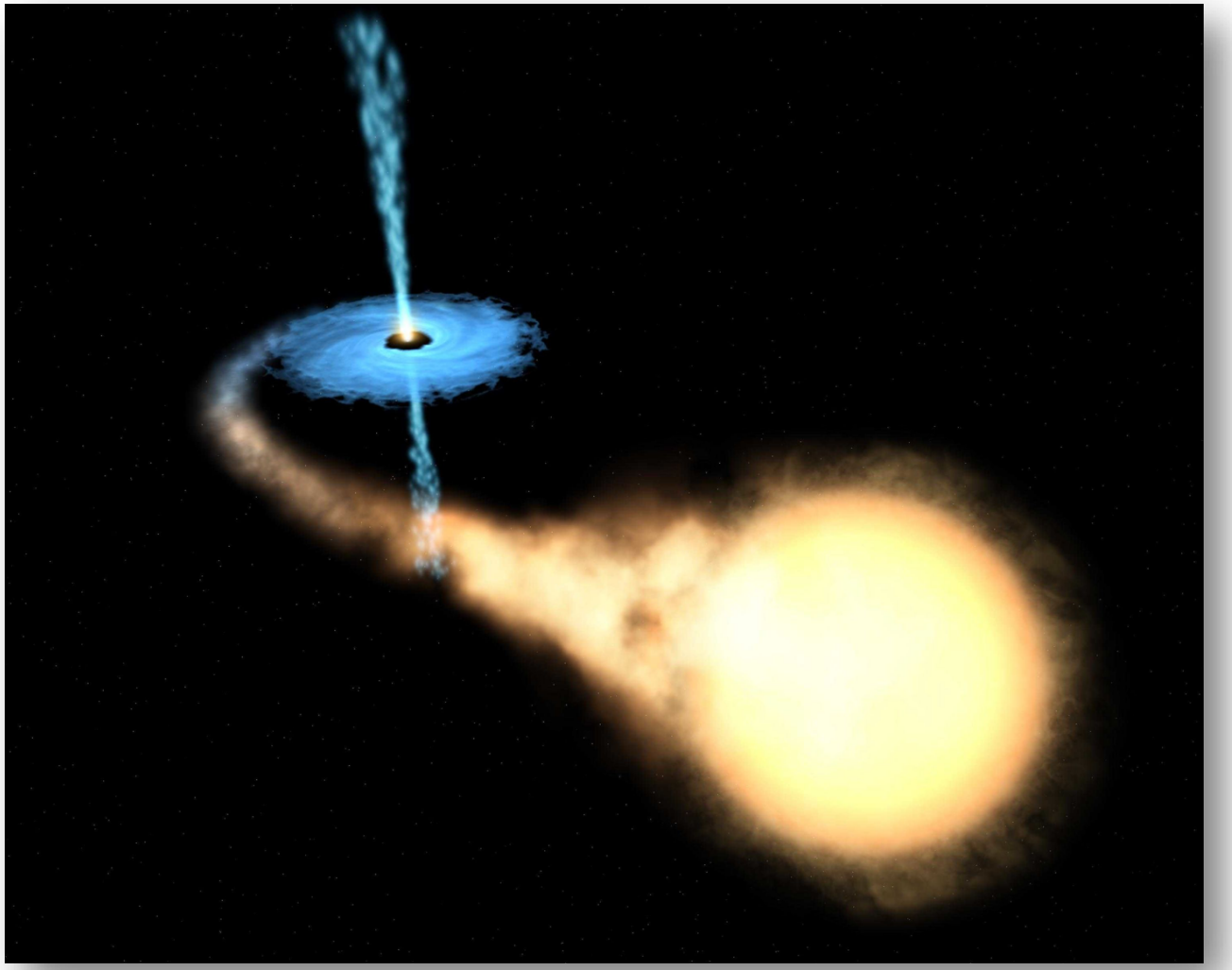
- Roche lobe overflow
- Stellar wind

X-ray radiation is strong and detectable (no background)

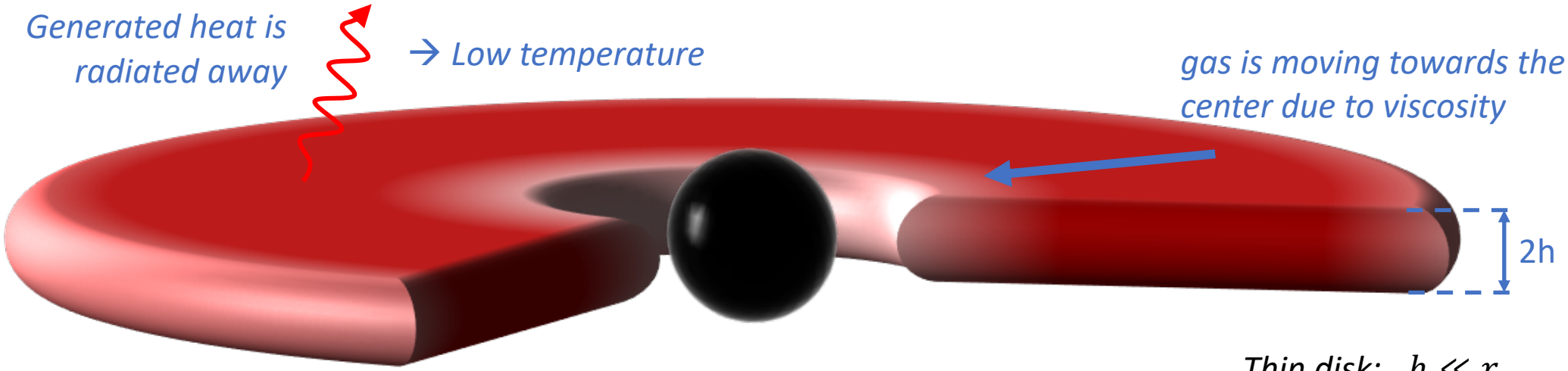
- Low-mass X-ray binary
  - Smaller companion (e.g. main sequence)
  - Roche lobe
  - Faint in optical
- High-mass X-ray binary
  - Massive star companion (e.g. blue supergiant)
  - Massive star bright in optical
- Microquasars
  - Also emits radio – jet is important
  - Small relative of quasars



X-ray binaries



Thin disk accretion



Thin disk: $h \ll r$

- Simplifies calculations
- Allows efficient radiation

Viscosity in disk:

- Poorly understood
- Small-scale turbulence
- Magnetic fields

Shakura & Sunyaev (1973)

Assume viscosity is due to turbulence.
Viscosity coefficient in turbulence:

$$\nu = v_{\text{turb}} l_{\text{turb}}$$

$$v_{\text{turb}} \leq c_s \qquad l_{\text{turb}} \leq h$$

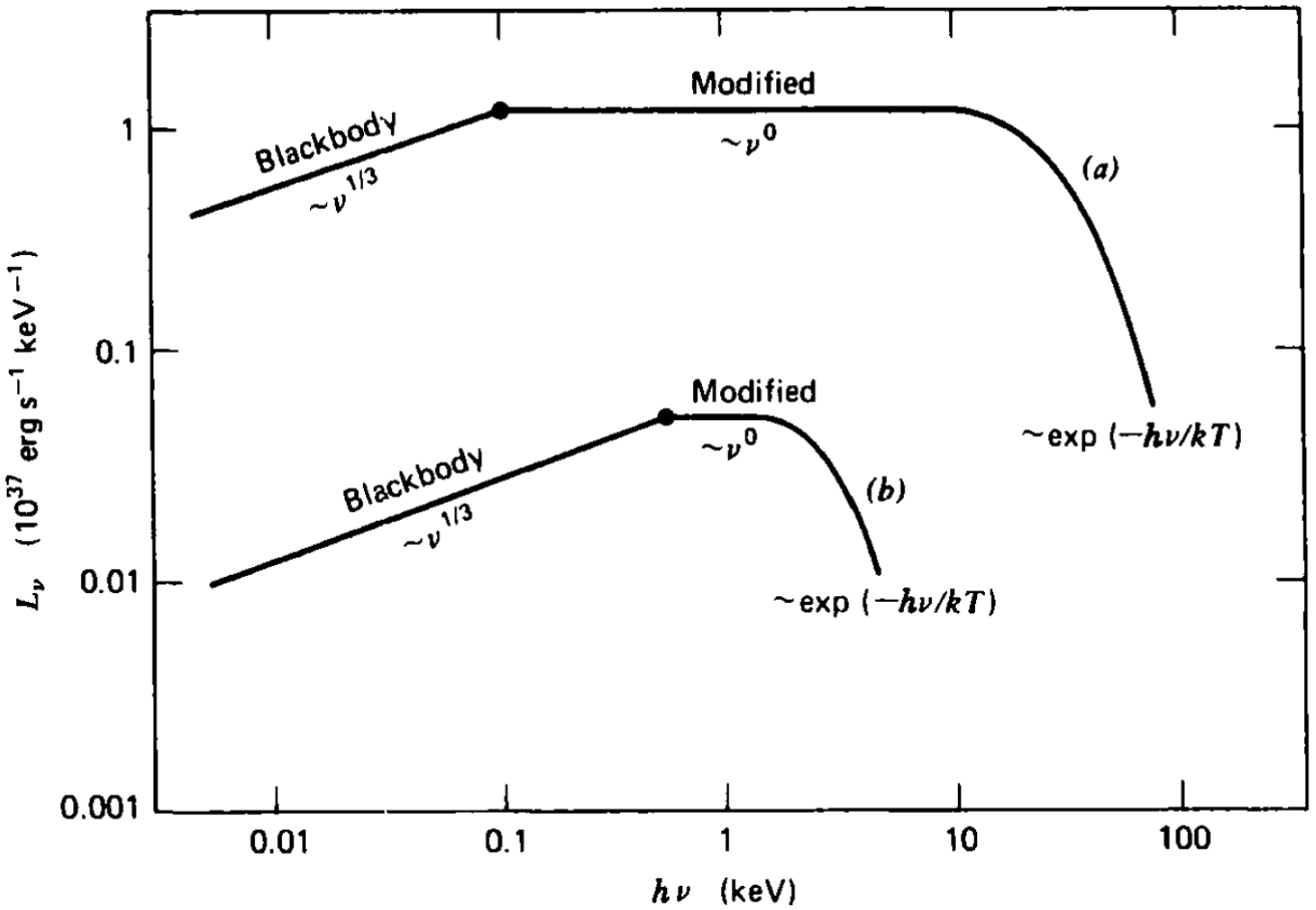
$$\nu = \alpha c_s h$$

$$0 \leq \alpha \leq 1 \quad \alpha\text{-disks}$$

α is a free parameter that is measured empirically. It falls within 0.1 – 1.

Thin disk accretion

$$T_s = (2 \times 10^9\ \mathrm{K})\alpha^{2/9}\left(\frac{M}{M_\odot}\right)^{-10/9} \dot{M}_{17}^{8/9}\left(\frac{r}{r_s}\right)^{-17/9} \mathcal{G}^{8/9}$$



Different regions with different emission mechanisms.

Heavier BH → softer spectrum.

Active galactic nuclei

Bright galactic center, due to an accreting supermassive BH.

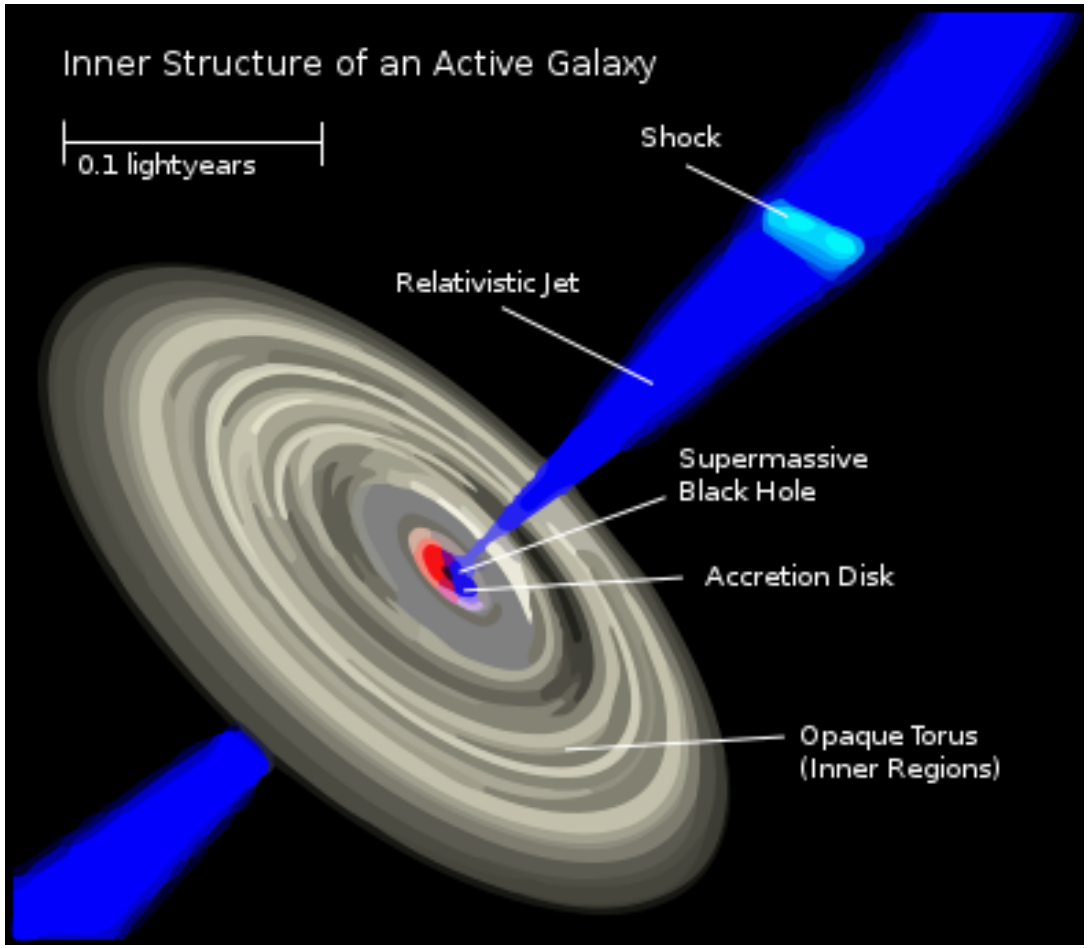
Galaxy hosting an AGN is called an active galaxy.

Properties depend on:

- Mass of BH
- Accretion rate
- Orientation of disk
- Obscuration (e.g. dust)
- Presence or absence of jet.

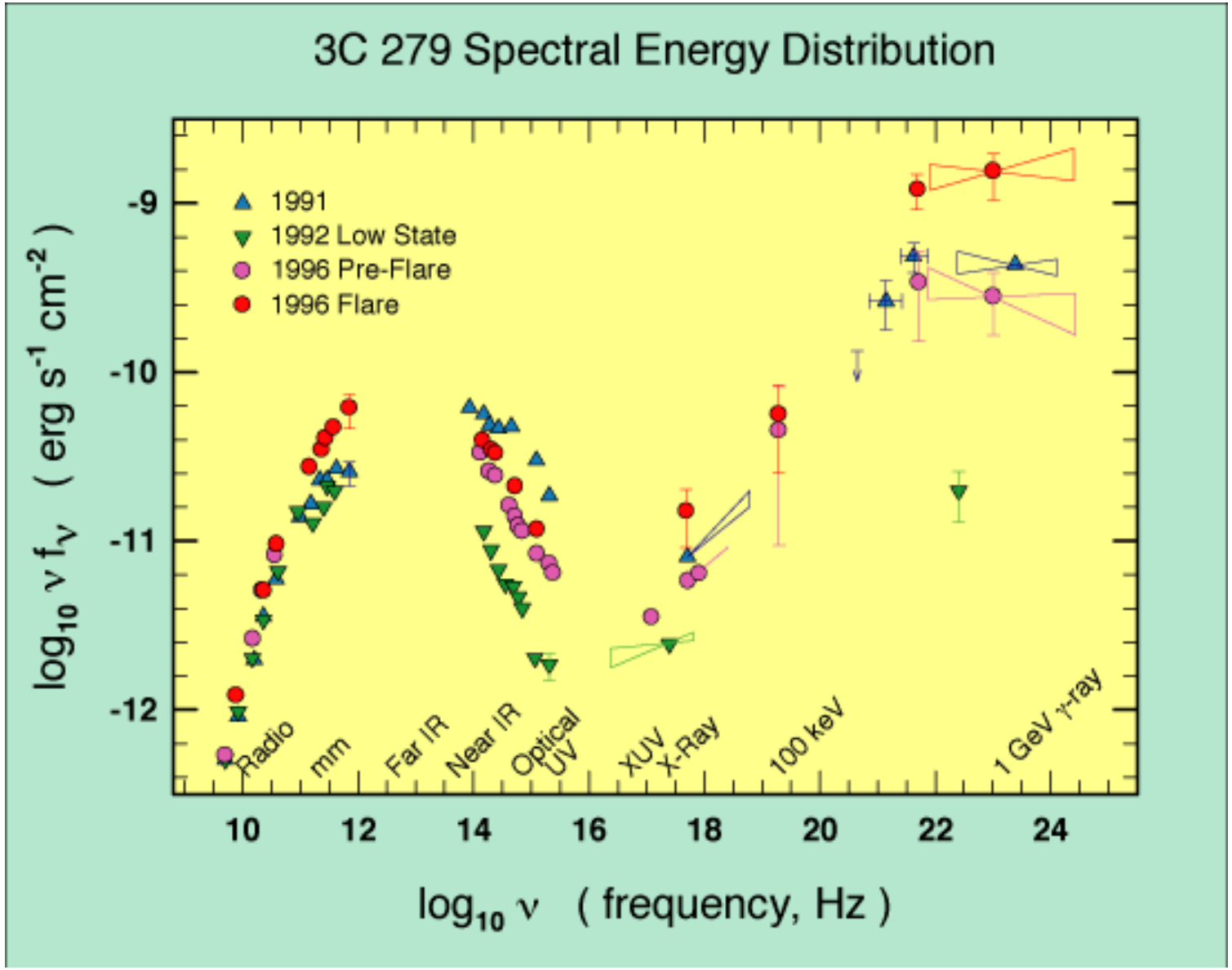
Subcategories:

- Quasars
- Blazars



(Wikipedia)

Active galactic nuclei



Active galactic nuclei

A variety of classifications exist.

Radio-loud AGN --- the jet dominates the radio and possibly all other emission.

Radio-quiet AGN --- no jet or not relevant (e.g. pointing in some other direction).

Features of different types of galaxies

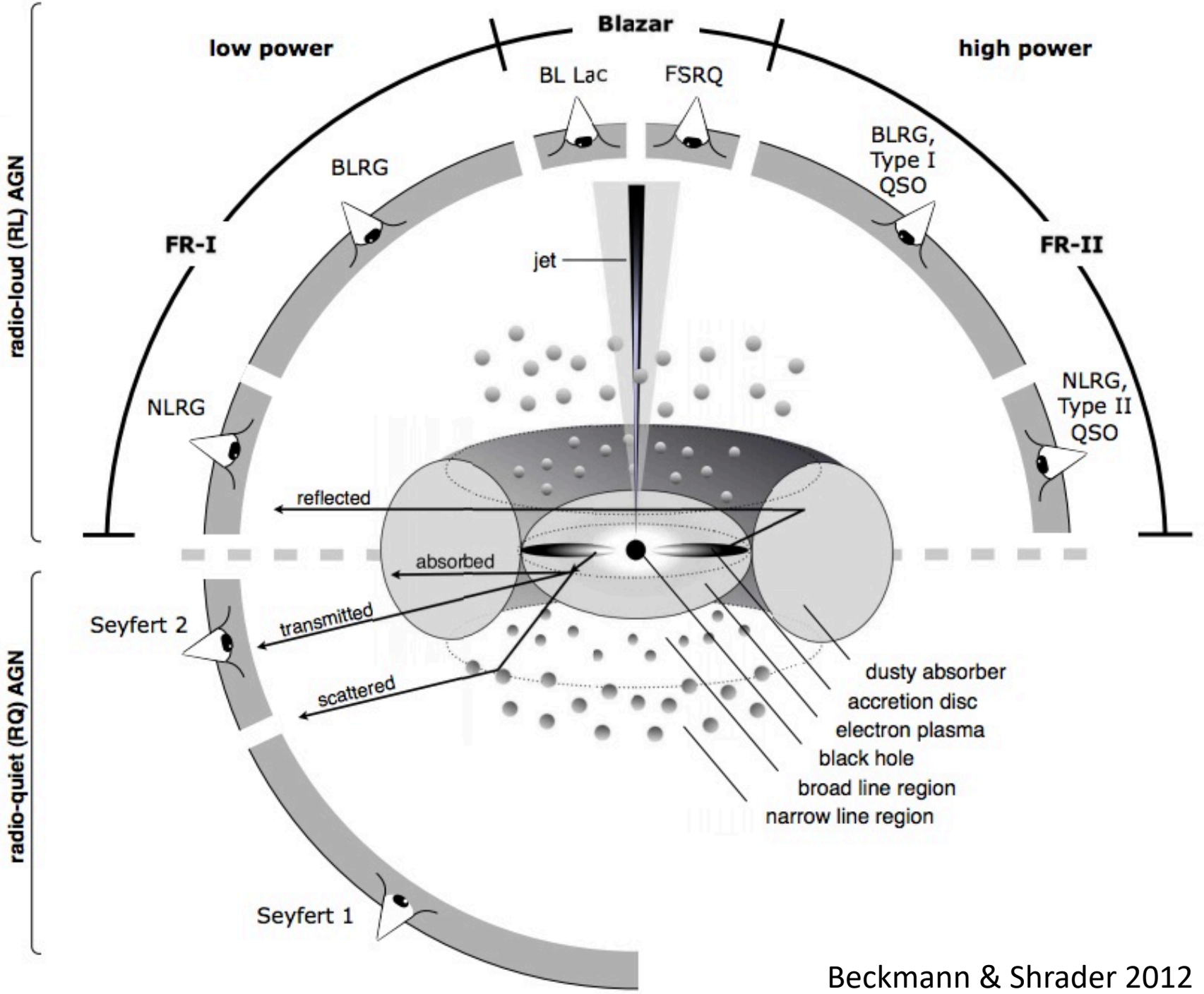
Galaxy type	Active nuclei	Emission lines		X-rays	Excess of		Strong radio	Jets	Variable	Radio loud
		Narrow	Broad		UV	Far-IR				
Normal	no	weak	no	weak	no	no	no	no	no	no
LINER	unknown	weak	weak	weak	no	no	no	no	no	no
Seyfert I	yes	yes	yes	some	some	yes	few	no	yes	no
Seyfert II	yes	yes	no	some	some	yes	few	no	yes	no
Quasar	yes	yes	yes	some	yes	yes	some	some	yes	some
Blazar	yes	no	some	yes	yes	no	yes	yes	yes	yes
BL Lac	yes	no	no/faint	yes	yes	no	yes	yes	yes	yes
OVV	yes	no	stronger than BL Lac	yes	yes	no	yes	yes	yes	yes
Radio galaxy	yes	some	some	some	some	yes	yes	yes	yes	yes

Classification

This is not certain.

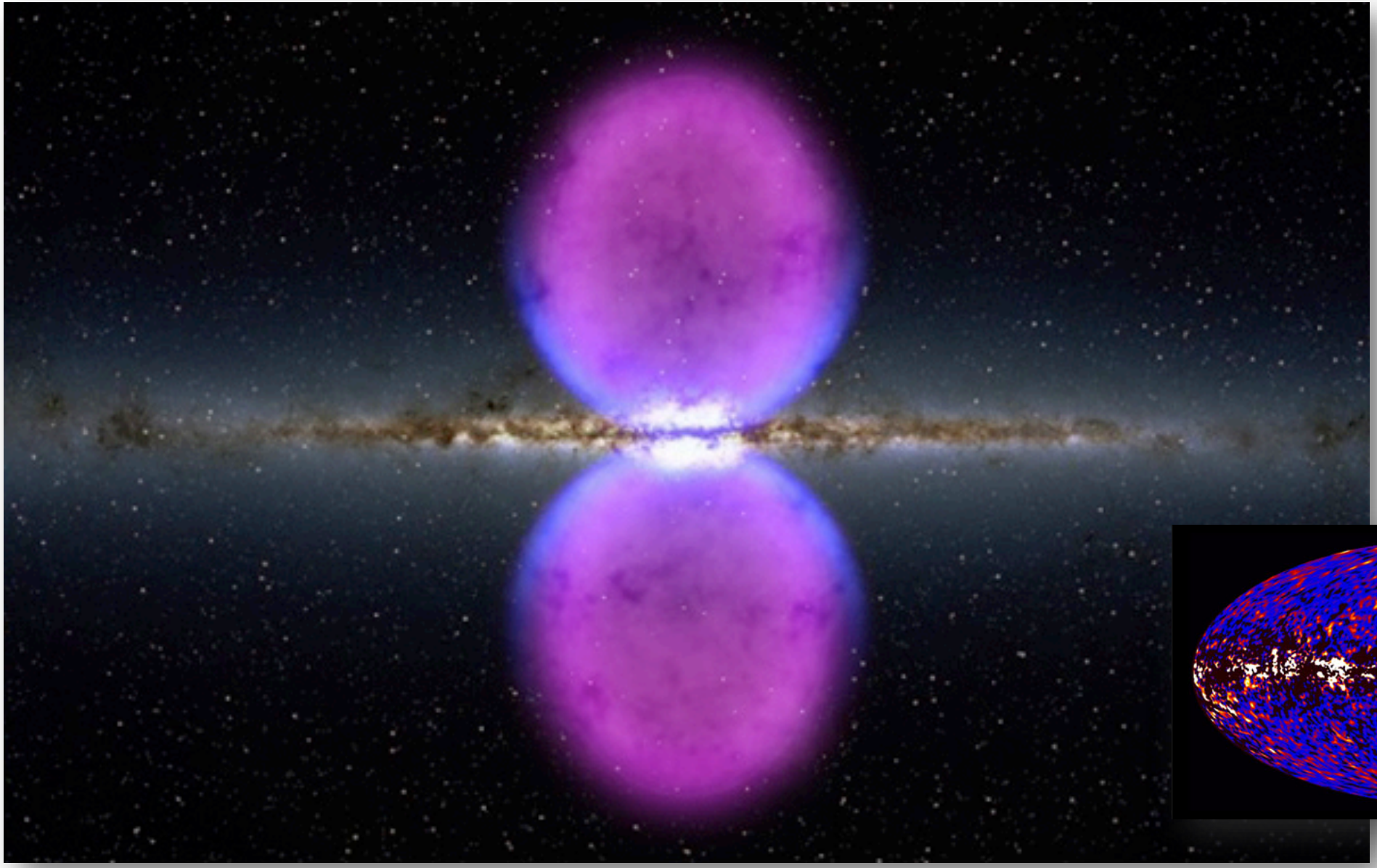
Quasar (quasi stellar object) – high-power AGN.

Blazar (BL Lac object + quasar) – jetted AGN where we look down the jet.

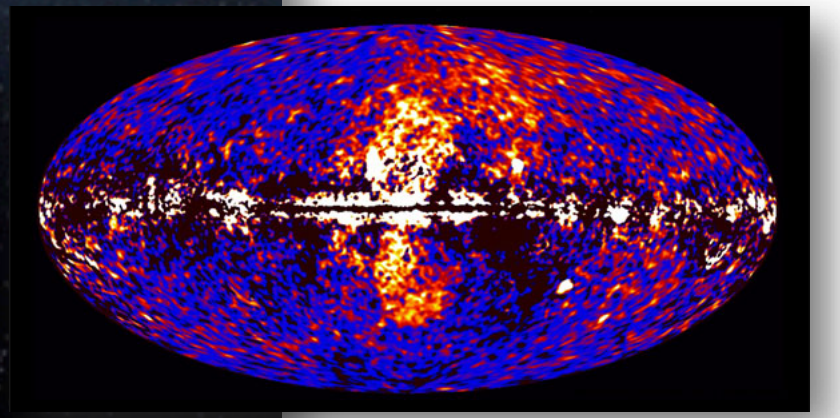


Beckmann & Shrader 2012

Fermi bubbles



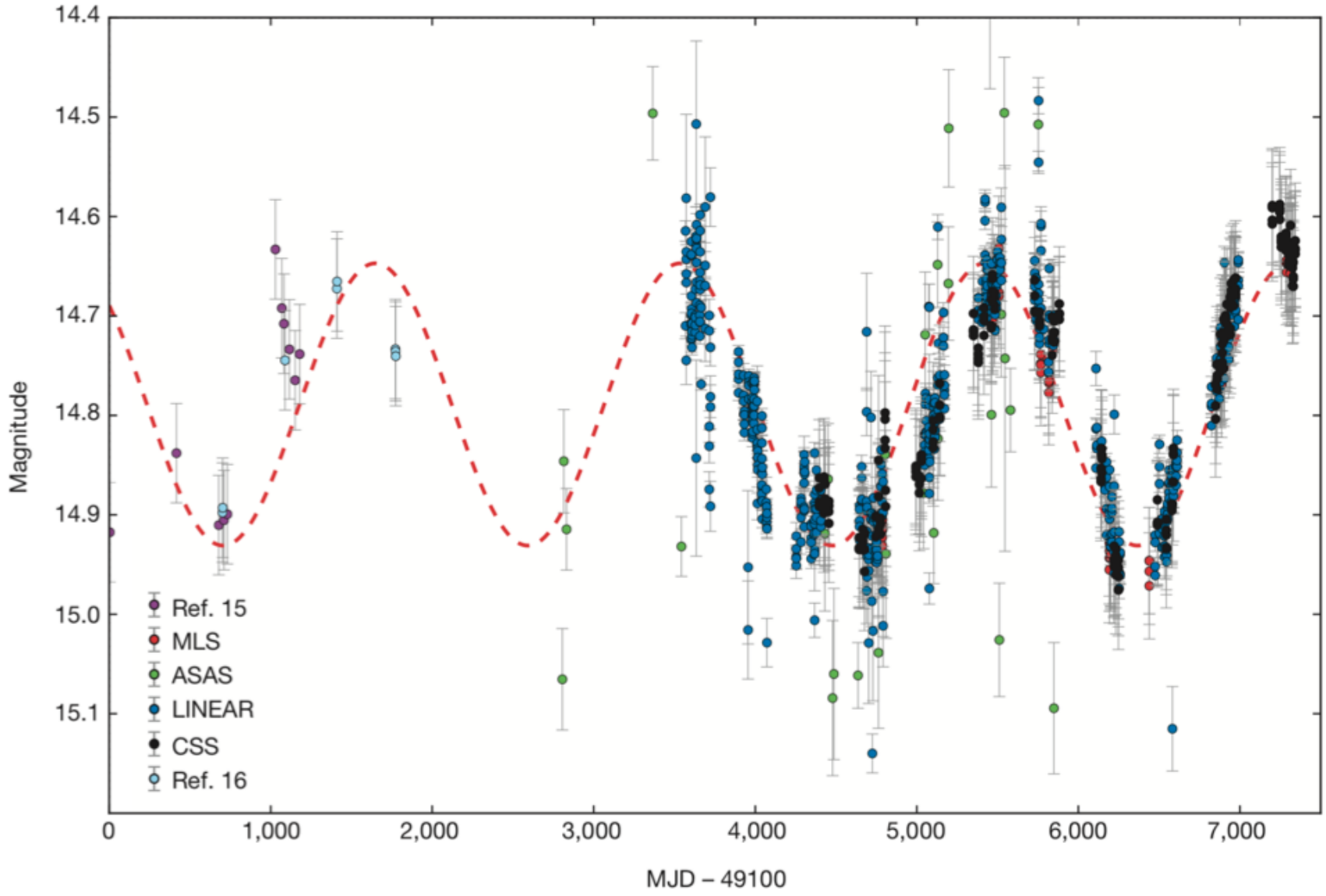
Right now the Milky Way is not an active galaxy.



Quasar variability

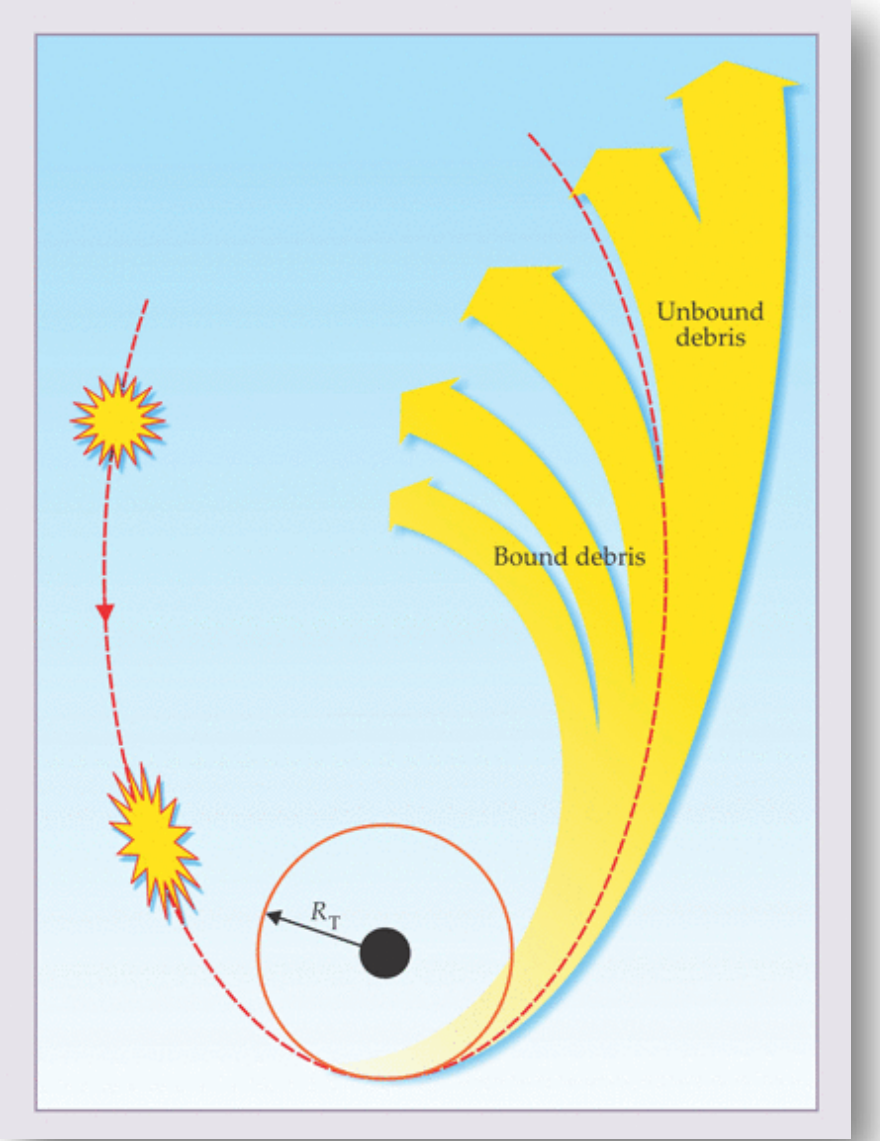
- Red noise

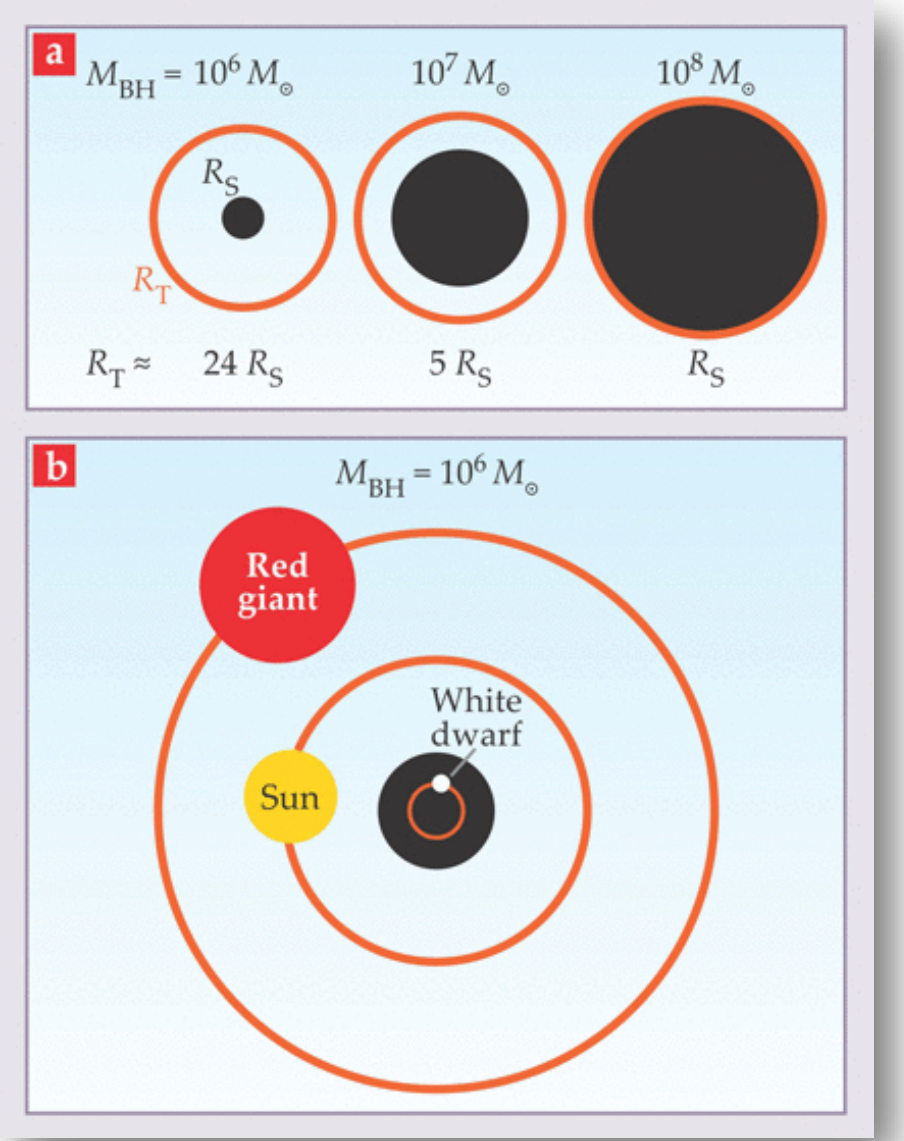
  (damped random walk)
- SMBH binary?



Graham+ Nature 2015

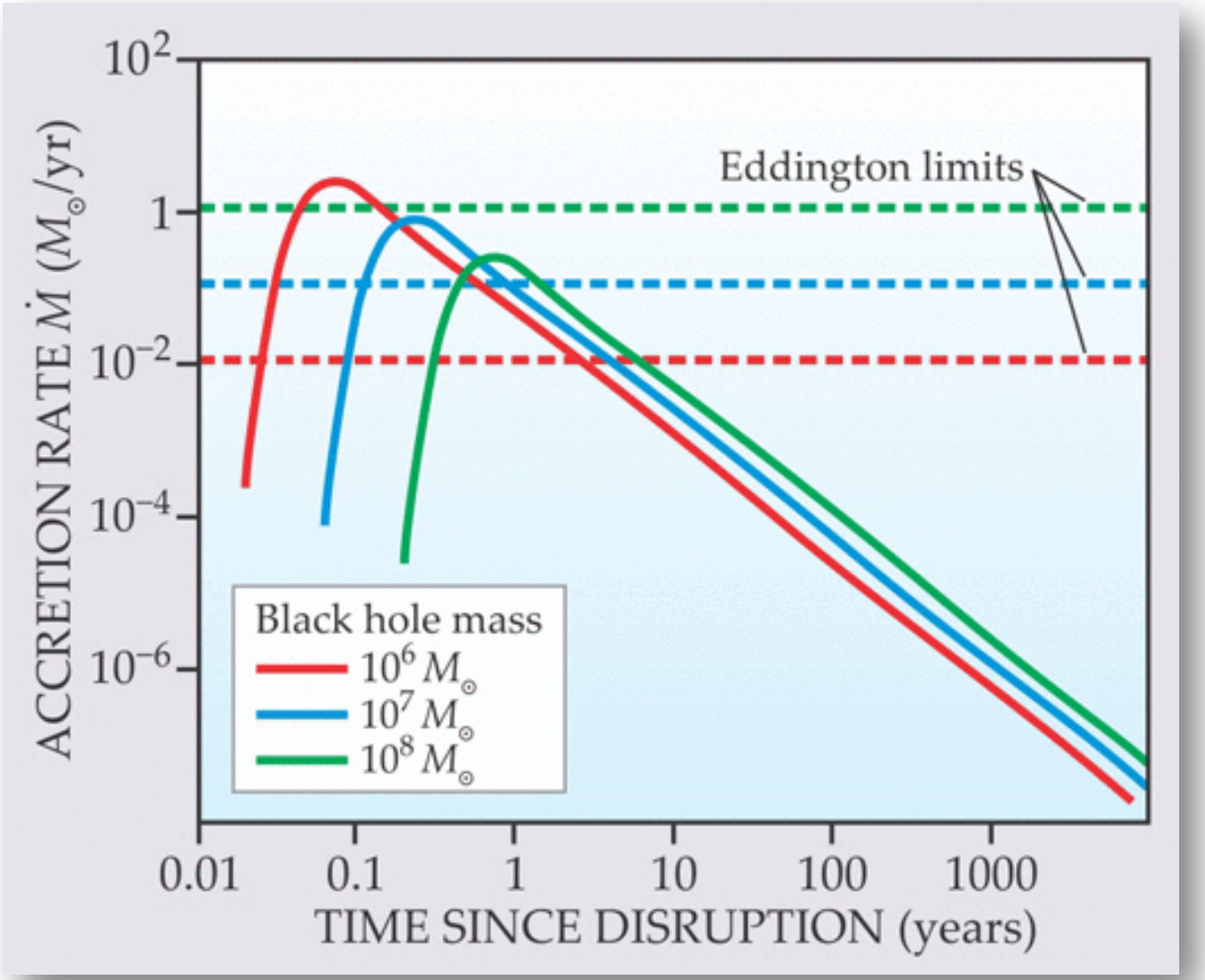
Tidal disruption events





http://physicstoday.scitation.org/doi/10.1063/PT.3.2382

Tidal disruption events



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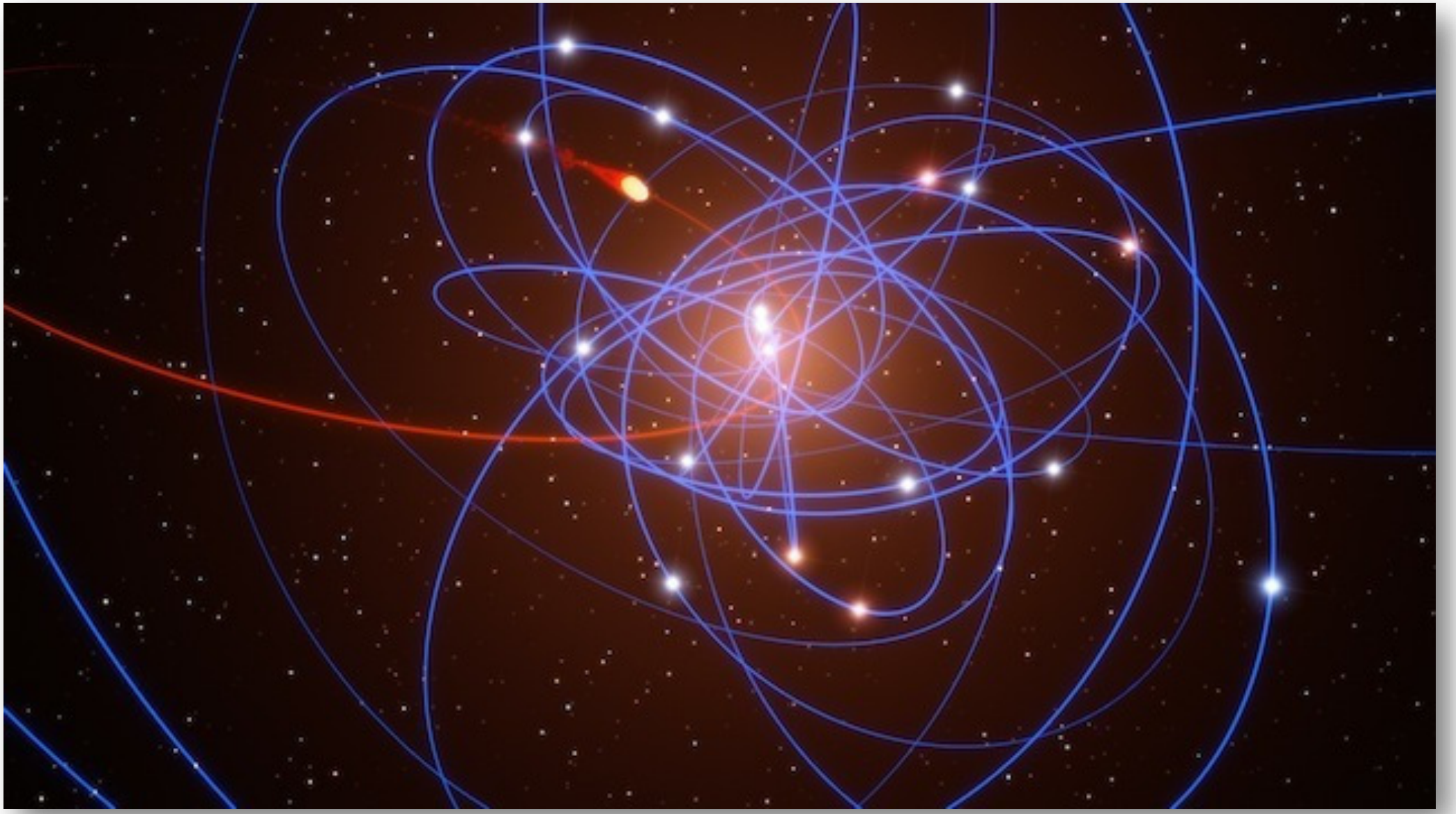
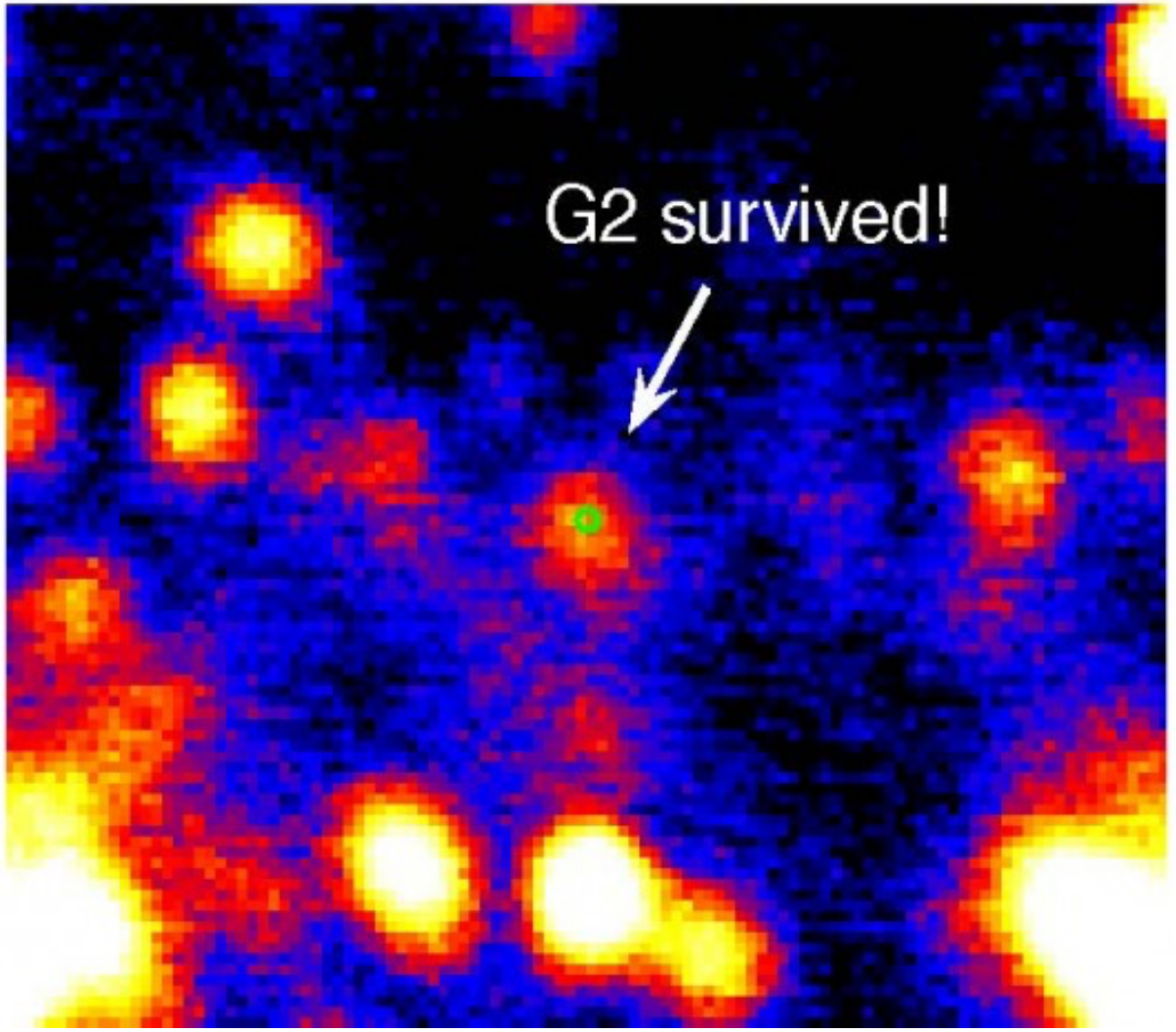
G2 gas cloud



G2 gas cloud