# Feedback Dominated Accretion Flows(FDAF)


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Astrophysical Black Holes: A Rapidly Moving Field

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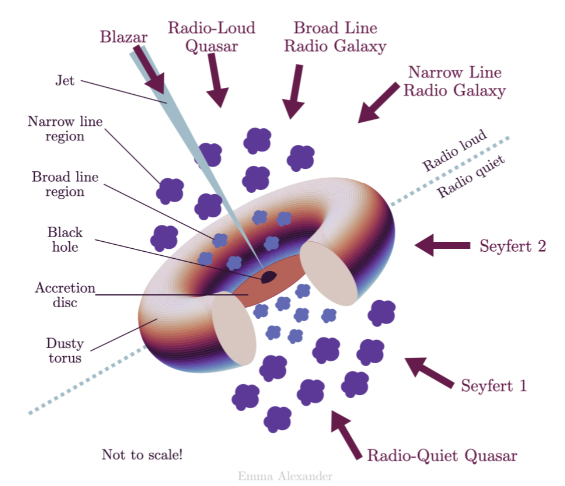
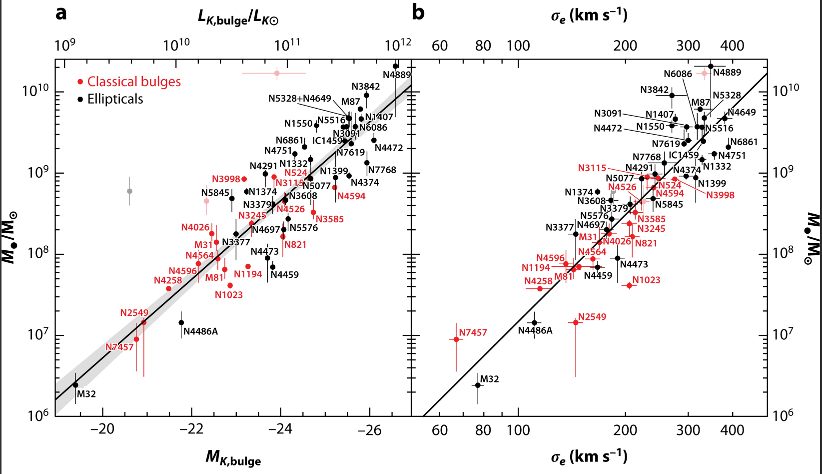
# AGN

## Unified Model




Emma Alexander

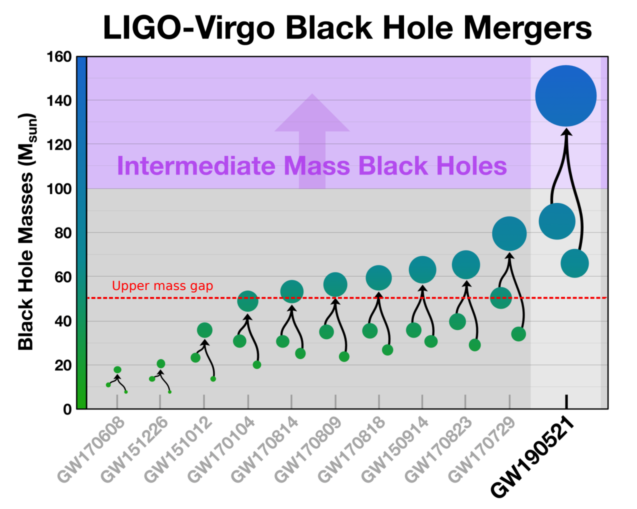
# AGN - Galactic properties & SMBH mass correlation




Kormendy J, Ho LC. 2013.
Annu. Rev. Astron. Astrophys. 51:511–653

Kormendy & Ho (2013)

# Black holes - First IMBH and mass gap SBHs




LIGO/Caltech/MIT/R. Hurt (IPAC)

# AGN - Importance

By studying and understanding AGNs we can learn about:

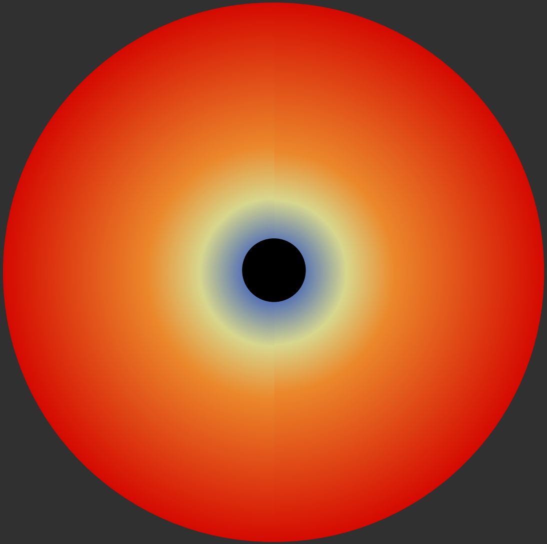
- Galaxy evolution
- SMBH formation/evolution
- Gravitational waves sources

# Accretion Disk - Shakura Sunyaev Model

Shakura & Sunyaev (1973) first suggested a simplified model for accretion disks that assumes :

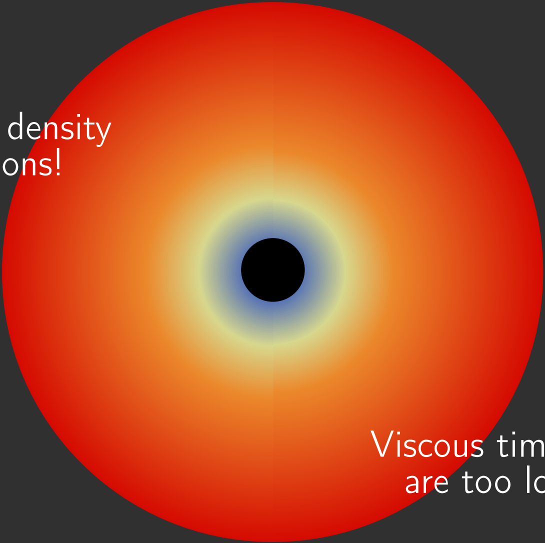
- Axisymmetry
- Local thermal equilibrium
- Averaged vertical structure
- Thin disk - $\frac{H}{R} \ll 1$
- Optically thick - $\tau > 1$
- diffusive evolution of gas surface density - $\Sigma$.
- Effective viscous angular momentum transport - $\nu = \alpha c_s H$ , $\alpha \leq 1$ , with timescales - $t_{\text{visc}} \sim \frac{1}{\alpha \Omega_k} \left(\frac{H}{R}\right)^{-2}$
- Keplerian gas rotation

# Shakura-Sunyaev



Shakura & Sunyaev (1973)

# Shakura-Sunyaev - Issues

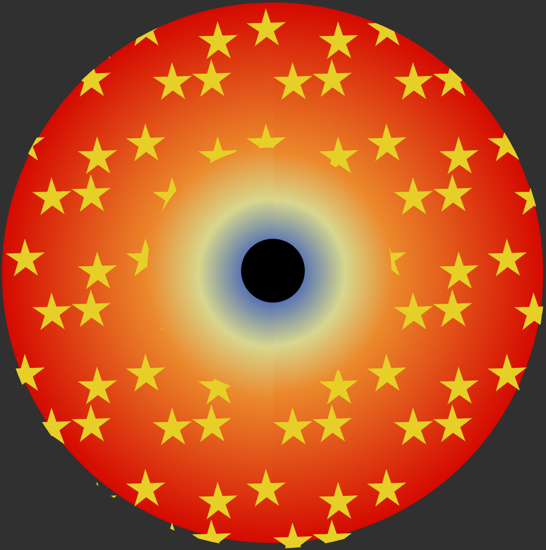


Unstable to density perturbations!

Viscous timescales are too long!

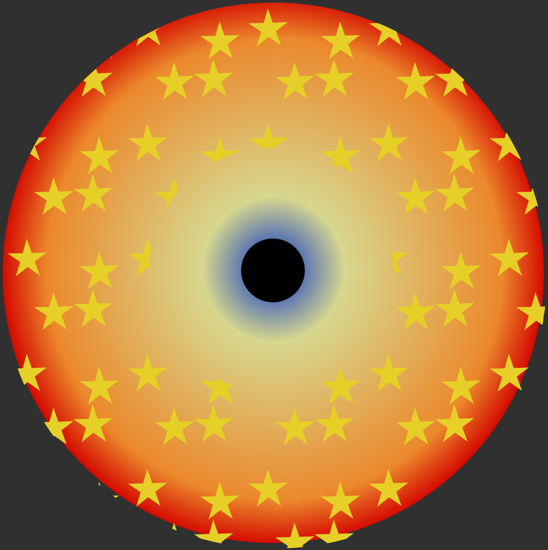
Shakura & Sunyaev (1973)

# Self stabilizing disk



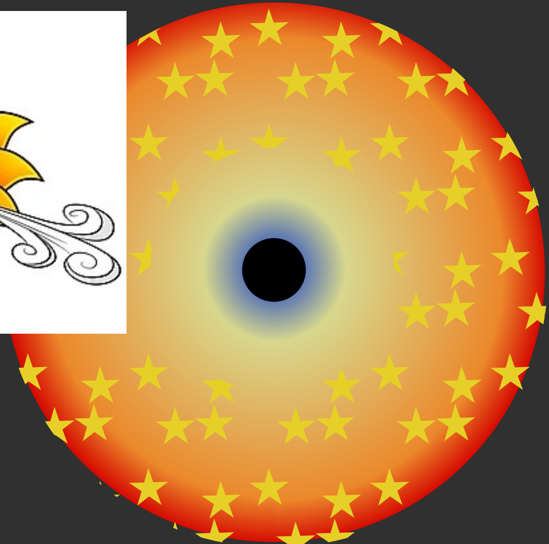
Thompson et al. (2005); Sirko & Goodman (2003)

# Self stabilizing disk



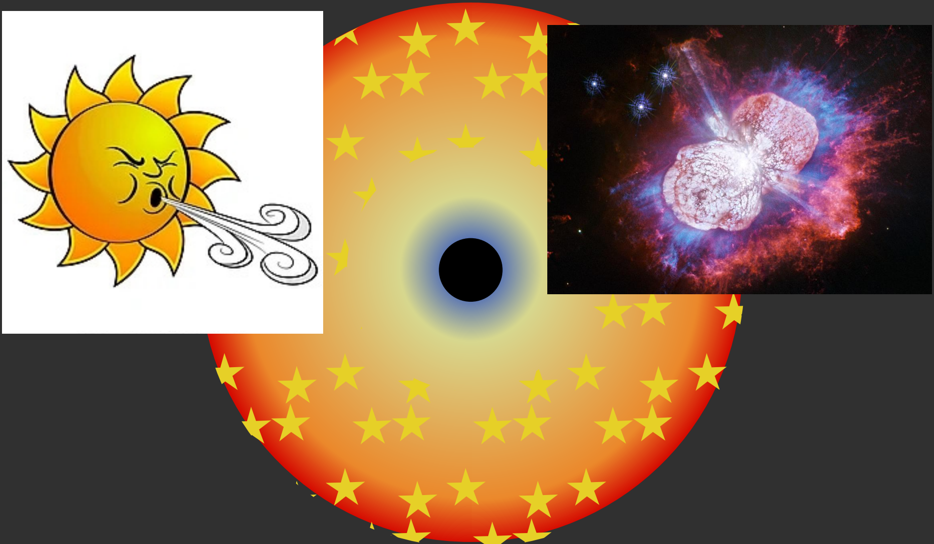
Thompson et al. (2005); Sirko & Goodman (2003)

# Self stabilizing disk



Thompson et al. (2005); Sirko & Goodman (2003)

# Self stabilizing disk



Thompson et al. (2005); Sirko & Goodman (2003)

# FDAF - Feedback Dominated Accretion Flow

- If stars are formed in the disk $\Rightarrow$ stellar mass black holes and neutron stars (NS) are formed.
- Black holes embedded in gas will accrete onto themselves. We correct Bondi-Hoyle (Hoyle & Lyttleton, 1939; Bondi, 1952) for finite scale height of disk + velocity shear within disk rate - $\dot{m}_{\mathrm{RBH}}$.

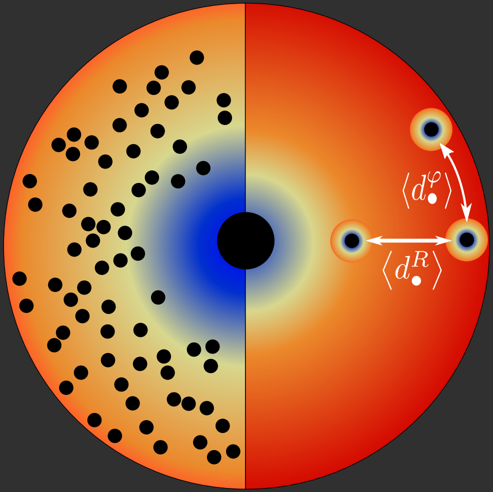
Black holes form small accretion disks that radiate heat.

$$L_\bullet = \eta c^2 \times \min\left(\dot{m}_{\mathrm{RBH}}, \dot{m}_{\mathrm{Edd}}\right)$$

In the continuum approximation with black hole number surface density $S_\bullet$ the total accretion feedback heating surface density is

$$Q_\bullet^+ = S_\bullet L_\bullet$$

# FDAF - Effective Heat mixing




Gilbaum & Stone (2022)

$$\mathfrak{M}_R \equiv 2\pi R H S_\bullet \geq 1$$
$$\langle d_\bullet^R \rangle = \frac{1}{2\pi R S_\bullet} \Rightarrow$$

$$\langle d_\bullet^\varphi \rangle = \frac{2\pi R}{2\pi R \Delta R S_\bullet} \approx \frac{1}{H S_\bullet} \Rightarrow$$
$$\mathfrak{M}_\varphi = H^2 S_\bullet \geq 1$$

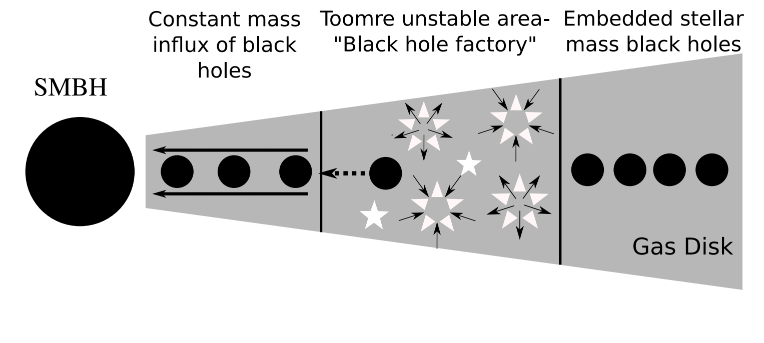
$$\frac{\mathfrak{M}_\varphi}{\mathfrak{M}_R} = \frac{H}{2\pi R} \leq 1$$

# FDAF

$$\sigma T_{\rm c}^4 \left(\frac{3}{8}\tau + \frac{1}{2} + \frac{1}{4\tau}\right)^{-1} = \frac{9GM}{8R^3}\nu\Sigma + S_\bullet L_\bullet$$ - Thermal stability

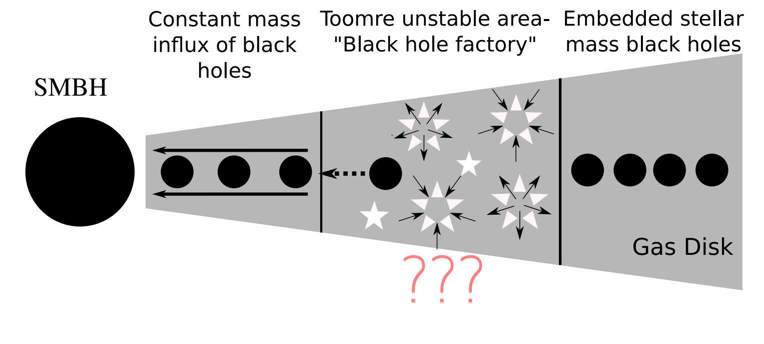
Pileup regime: $\begin{cases} Q_T = 1 & \text{if } \mathfrak{M}_\varphi \geq 1 \\ \mathfrak{M}_\varphi = S_\bullet H^2 = 1 & \text{otherwise} \end{cases}$

# FDAF




Gilbaum & Stone (2022)

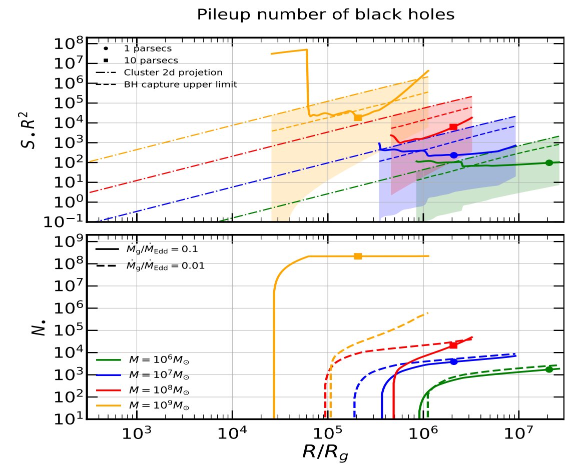
# FDAF




Gilbaum & Stone (2022)

# FDAF

## "Pile up" solution results - Number of black holes




Gilbaum & Stone (2022)

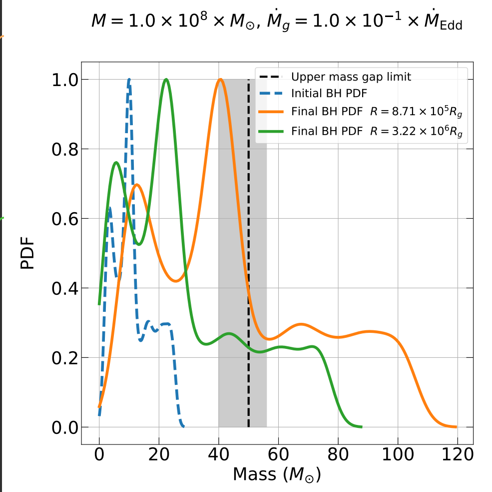
# FDAF

## “Pile up“ solution results - Mass growth of embedded objects

Mass function after growth at $R/R_g = 3.2 \times 10^6$

Mass function after growth at $R/R_g = 8.7 \times 10^5$

Initial mass function



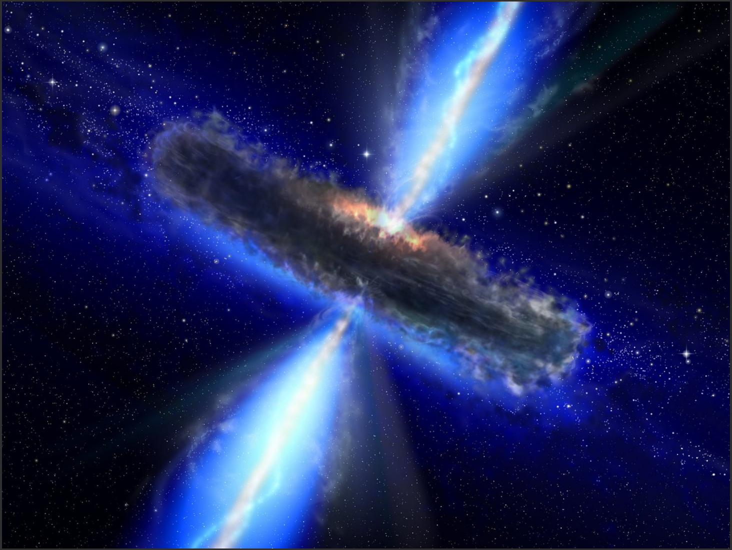

Gilbaum & Stone (2022)

# Results - Main attributes

- A combined regime, BH mass influx at small radii and pileup at large radii.
- A large number of embedded compact objects in the disk.
- Thicker disk - large scale height of the disk .
- Shorter viscous timescales.
- Mass growth of black holes beyond the mass gap
- Mass growth of neutron stars which might collapse into black holes.

# Discussion - Applications

- We will apply our better AGN model to make better predictions for the AGN channel of producing GW sources:
  1. Event rates
  2. BH mass function
- Our model can provide initial conditions for vacuum galactic nuclei after the AGN ends, useful for dynamics:
  1. TDE rates
  2. Long-term evolution of galactic nuclei



# Thank You For Listening!