The Nature of Low-Mass Rate Accretion Onto Supermassive Black Holes

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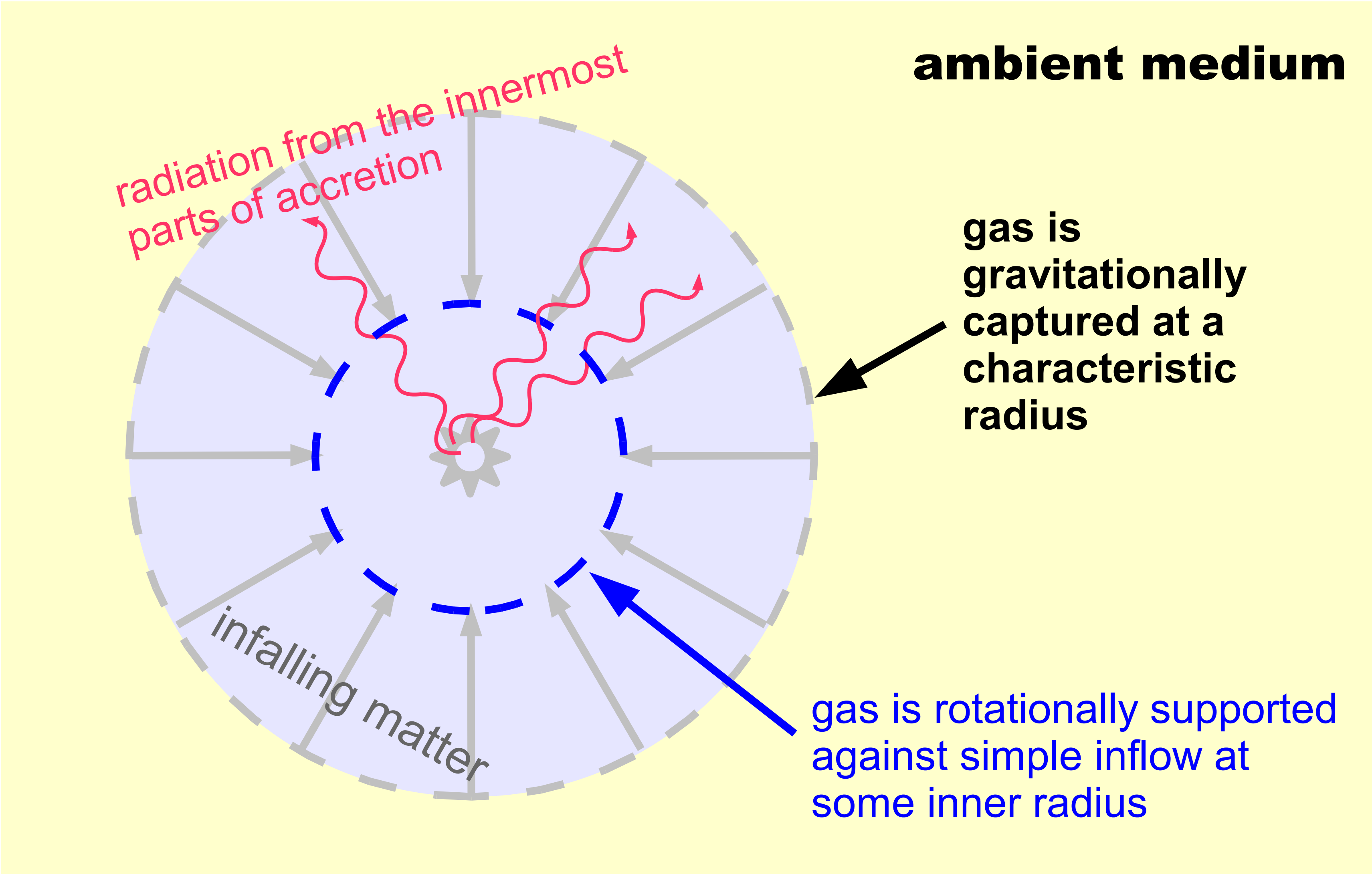
Overview of Talk

- What are supermassive black holes, and how they can be seen?
- What are low luminosity galactic nuclei, and what are their characteristics?
- Strong astrophysical evidence of underluminous black hole accretion: the Sagittarius A black hole and others.
- What are the magnetic field strengths in these objects?
- The relation to my research.

What is a Supermassive Black Hole?

- Primordial black hole formed in galaxies, with masses $M \sim 10^6 - 10^9 M_\odot$.
- Proposed to explain the luminosities of active galactic nuclei and quasars, $L \gtrsim 10^{42}$ erg s^{-1}.
- Evidence for their existence has been confirmed independently by, for example: doppler shifts of gas surrounding black holes, time-resolved orbits stellar orbits.

Gas Captured by a Black Hole Accretes and Radiates



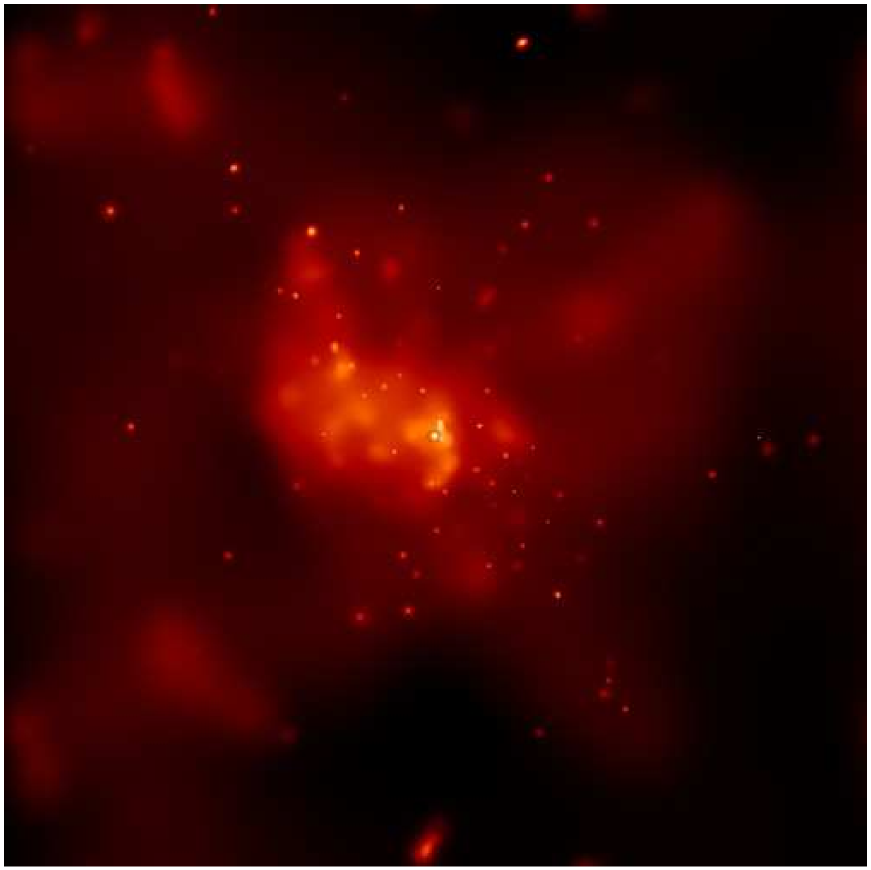
Extreme Luminosity of (Some) Black Holes

- Can be luminous because extremely *efficient* at energy generation, $L \sim 0.1\dot{M}c^2$ as mass falls into black hole.
- A relatively small amount of gravitationally captured matter can produce the enormous energies generated by black hole accretion:
  - $L \sim 10^{42} - 10^{46}$ erg s^{-1} for active galactic nuclei (central black holes $10^6 - 10^8 M_\odot$).
  - $L \gtrsim 10^{46}$ erg s^{-1} for quasars (central black holes $10^8 - 10^{10} M_\odot$.

- However, there is evidence of orders of magnitude more SMBHs than strong emitters (AGNs, quasars, etc.); each galaxy in our local group may have one (Richstone et al., 1998), but none are active.
- AGN's and quasars have luminosities $L \sim L_{\text{Bondi}}$.
- Low luminosity nuclei radiate at $L \ll L_{\text{Bondi}}$.

Evidence for Dim Accretion Nuclei: Sagittarius A

Sagittarius A is the black hole at the center of the galaxy, with calculated mass $M = 2.6 \times 10^6 M_\odot$.



Sagittarius A X-ray image, Chandra X-ray observatory

Other Evidence of Dim Supermassive Black Hole Accretion

Taken from Loewenstein et al. (2001)

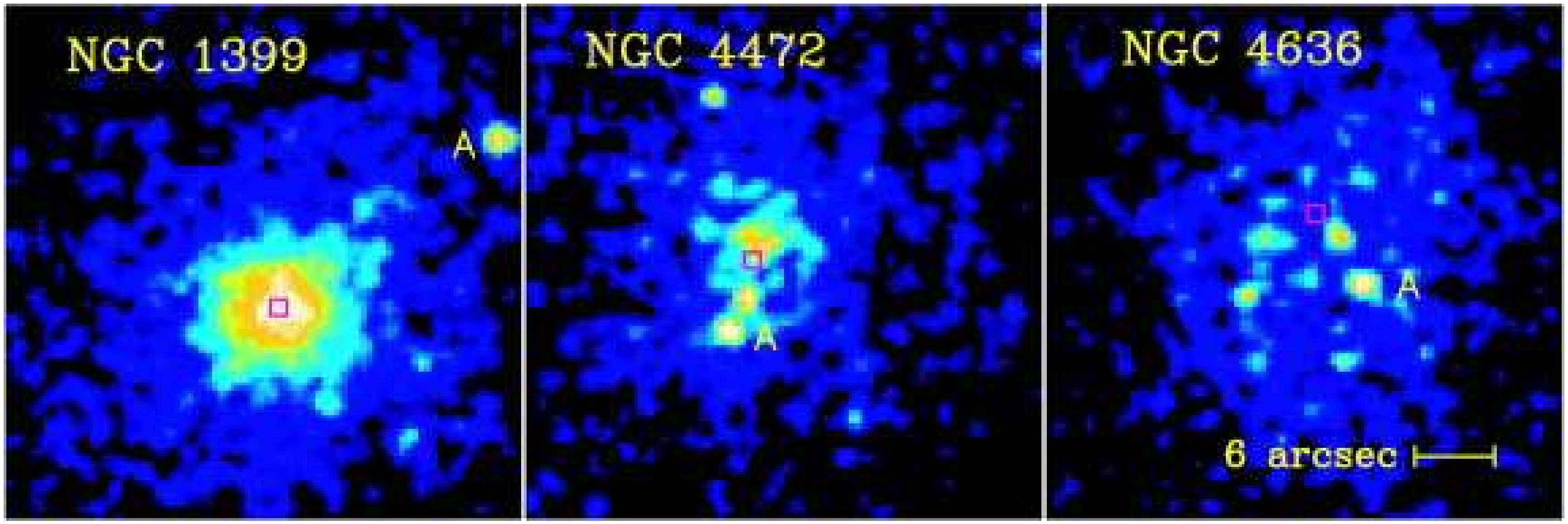


TABLE 1

GALAXY AND ACCRETION FLOW CHARACTERISTICS

Galaxy	d (Mpc)	$M_{\rm SMBH}$ ($\times 10^8\ M_\odot$)	$R_{\rm Bondi}$ (arcsec)	$\dot{M}_{\rm Bondi}$ ($M_\odot$ yr^{-1})	$L_{\rm Edd}$ (ergs s^{-1})	$L_{\rm Bondi}$[a] (ergs s^{-1})	$L_{\rm ADAF}$[b] (ergs s^{-1})	L_X[c] ($\times 10^{38}$ ergs s^{-1})	L_X[d] ($\times 10^{38}$ ergs s^{-1})
NGC 1399	20.5	10.6	0.36	4.0×10^{-2}	1.3×10^{47}	2.3×10^{44}	2×10^{41}	<9.7	<9.7
NGC 4472	16.7	5.65	0.24	7.9×10^{-3}	7.1×10^{46}	4.5×10^{43}	10^{40}	<6.4	<4.9
NGC 4636	15.0	0.791	0.049	8.0×10^{-5}	9.9×10^{45}	4.5×10^{41}	10^{36}	<2.7	<1.8

[a] $0.1\dot{M}_{\rm Bondi}c^2$.
[b] The approximate expectation of the standard ADAF model (see text).
[c] The 2–10 keV upper limit from this Letter for the 3″ box.
[d] The 2–10 keV upper limit at the assumed optical nucleus.

- Baganoff et al. (2003) measures $n_e \sim 10^2$ cm^{-3} and $T_e \sim 2$ keV at $1''$ from Sag. A. Sag. A, located 8.5 kpc away. This implies:
  - $R_{\rm c} \simeq 2.9 \times 10^{17}$ cm $\equiv 2.4''$ from Sag. A.
  - $\dot{M}_B \sim 5.6 \times 10^{-6}\ M_\odot$ yr^{-1}.
  - $L_{\rm Bondi} \sim 3.2 \times 10^{40}$ erg s^{-1}
- However, bolometric luminosity of Sag. A: $L \sim 10^{36}$ erg s^{-1} $\sim 3 \times 10^{-5} L_{\rm Bondi}$!

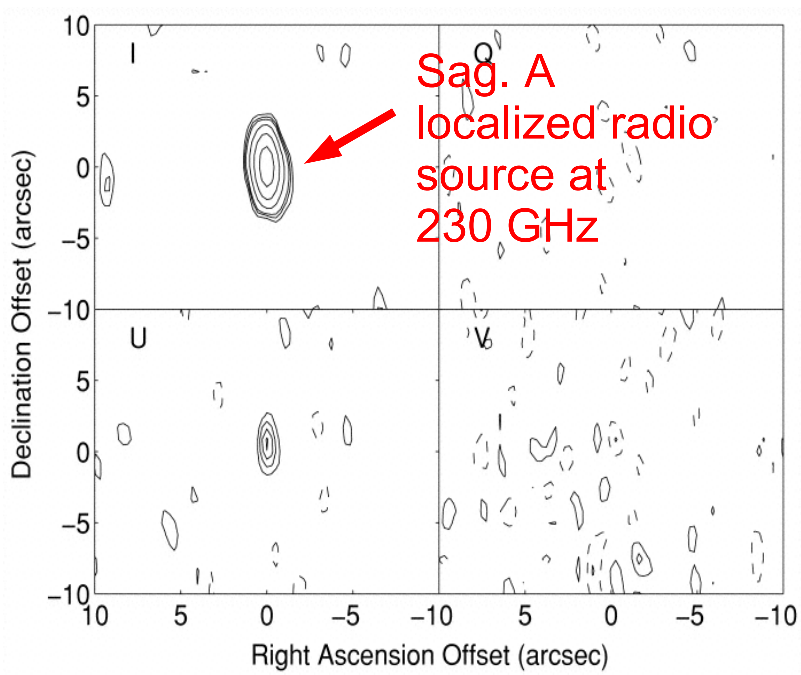
Features of Low Mass Accretion Rate Onto BH's

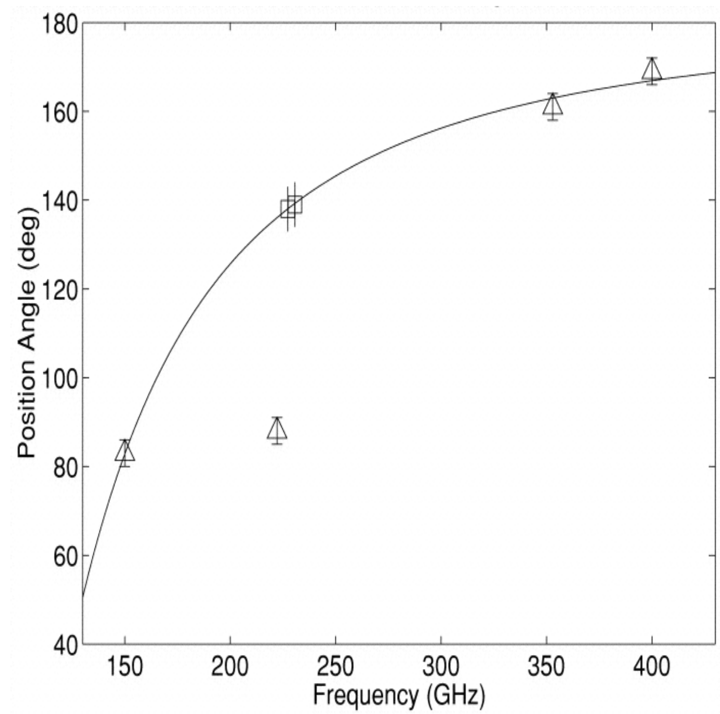
For sufficiently low accretion rates, hot plasma accreting onto black holes becomes radiatively inefficient (Shapiro et al., 1976; Ichimaru, 1977; Rees et al., 1982; Narayan and Yi, 1994)

- **advective**: very little energy is radiated, most of the energy remains in the gas, and $L \ll L_{\text{Bondi}}$
- **cool electrons**: weak ion-electron coupling combined with efficient radiation, $T_e < T_i$.
- **geometrically thick**: ion thermal energy $\sim$ gravitational energy.

Magnetic Fields in Dim Nuclei: Sagittarius A

Taken from Bower et al. (2003)





Faraday rotation measure implies magnetic pressure $\lesssim$ gas pressure (Marrone et al., 2006).

How Does This Fit in My Research?

- These low-accreting plasmas are dilute (mildly collisional to collisionless) $\rightarrow$ dynamically significant viscosities and thermal conductivities.
- Magnetic fields $\rightarrow$ anisotropic viscosities and thermal conductivites can destabilize plasmas (analogous to the MRI).
- Fat disks $\rightarrow$ signficant gradients of temperature and pressure that are unstable to thermal instabilities.

References

D. Richstone, E. A. Ajhar, R. Bender, G. Bower, A. Dressler, S. M. Faber, A. V. Filippenko, K. Gebhardt, R. Green, L. C. Ho, et al., Nature **395**, A14+ (1998), http://www.arxiv.org/astro-ph/9810378.

M. Loewenstein, R. F. Mushotzky, L. Angelini, K. A. Arnaud, and E. Quataert, ApJ **555**, L21 (2001), http://www.arxiv.org/astro-ph/0106326.

F. K. Baganoff, Y. Maeda, M. Morris, M. W. Bautz, W. N. Brandt, W. Cui, J. P. Doty, E. D. Feigelson, G. P. Garmire, S. H. Pravdo, et al., ApJ **591**, 891 (2003), http://www.arxiv.org/astro-ph/0102151.

S. I. Shapiro, A. P. Lightman, and D. M. Eardley, ApJ **204**, 187 (1976).

S. Ichimaru, ApJ **214**, 840 (1977).

M. J. Rees, E. S. Phinney, M. C. Begelman, and R. D. Blandford, Nature **295**, 17 (1982).

R. Narayan and I. Yi, ApJ **428**, 13 (1994).

G. C. Bower, M. C. H. Wright, H. Falcke, and D. C. Backer, ApJ **588**, 331 (2003), http://www.arxiv.org/astro-ph/0302227.

D. P. Marrone, J. M. Moran, J.-H. Zhao, and R. Rao, ApJ **640**, 308 (2006), http://www.arxiv.org/astro-ph/0511653.