Spherical Accretion and AGN Feedback

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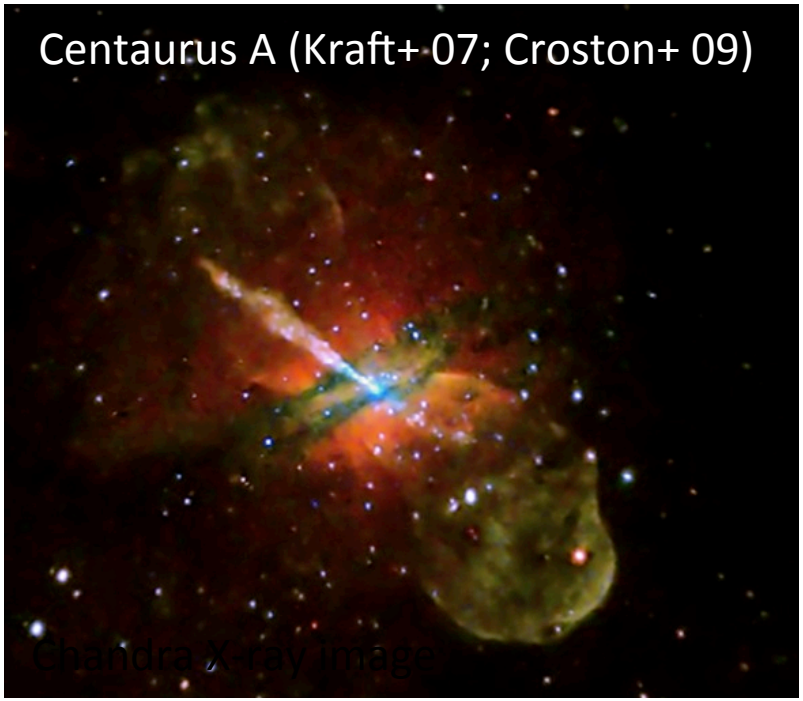
Issues for Bondi Accretion



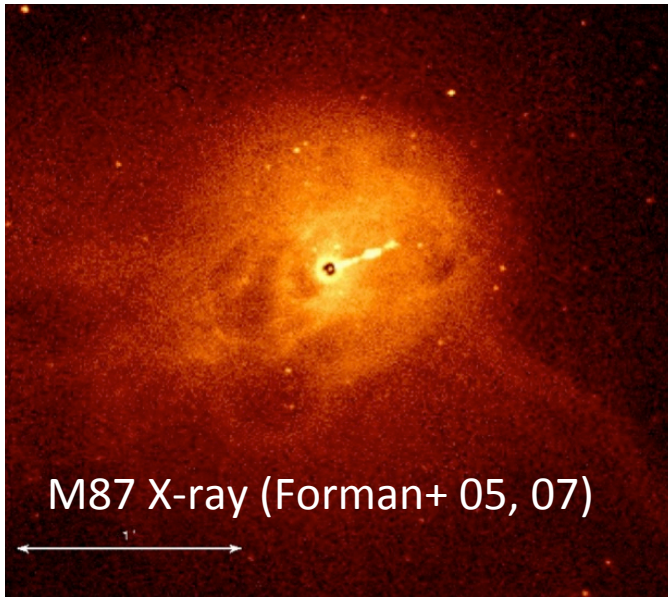
What is the role of spherical accretion in the radio mode AGN feedback cycle?
Allen+ 06; Rafferty+ 06; Russell+ 13

If accreting at the Bondi rate, the radiative efficiency of M87 is ~10^{-5} (Di Matteo+ 03)

A 1.7×10^{10} $M_\odot$ SMBH in NGC 1277 (van den Bosch+ 12) would requires ~10^{-7} (Fabian+ 13)

Why does spherical accretion produce so little radiation?
radiative inefficiency – Narayan & Yi 94
outflow – Blandford & Begelman 99

How is the flow affected by angular momentum?
Inogamov & Sunyaev 10; Narayan & Fabian 11



Viscosity Can Remove Small Angular Momentum

Flux freezing means fluid motion change B and particle magnetic moments, $\frac{mv_\perp^2}{2B}$, are conserved between collisions

⇒ fluid motion drives anisotropy in particle velocity distribution, countered by collisions, $\tau_{pp} \approx 700\ (kT)^{3/2}\ n_e^{-1}$ yr

Gives a small net pressure anisotropy, $\Delta = p_\perp - p$, where $p_\perp$ is the pressure perpendicular to the field

Braginskii (1965; eg, Kunz+ 2012): $\Delta = \tau_{ii} p_i (\mathbf{bb} : \nabla \mathbf{v} - \frac{1}{3} \nabla \bullet \mathbf{v})$

The viscous stress tensor is the *anisotropic part of the total stress,* $\mathbf{T} = \Delta(3\mathbf{bb} - \mathbf{1})$

The Braginskii viscosity is $\mu = \tau_{ii}\, p_i$ and equals the Spitzer (field free) viscosity

It is effective at dissipating angular momentum, especially inside the Bondi radius, where the gas temperature rises, since $\mu \propto T^{5/2}$

Angular momentum is not the main issue for Bondi accretion

Particle Mean Free Paths are Macroscopic

Particle mean free paths scale as $\lambda \propto \frac{T^2}{n_e} \propto T^{1/2}\Sigma^{3/2}$, where $\Sigma = \frac{kT}{n_e^{2/3}}$ is the entropy index.

For the central entropies of galaxy groups and clusters, the proton mean free path will always exceed the radius not far inside the Bondi radius

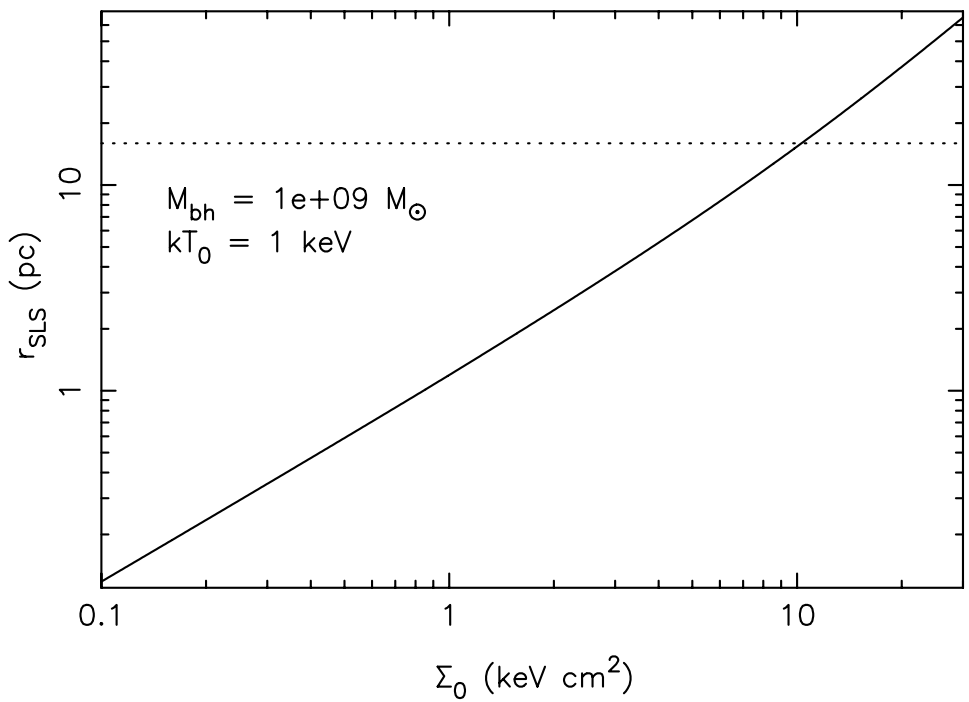
Radius of the *surface of last scattering:*

(for isentropc, hydrostatic gas)

Within the Bondi radius,

$$r_{\rm SLS} = \left(\tfrac{2}{3} r_{\rm Bondi} \lambda_0^2\right)^{1/3} \propto \Sigma M_{\rm bh}^{1/3}$$

Inside $r_{\rm SLS}$, *fluid approximation fails*



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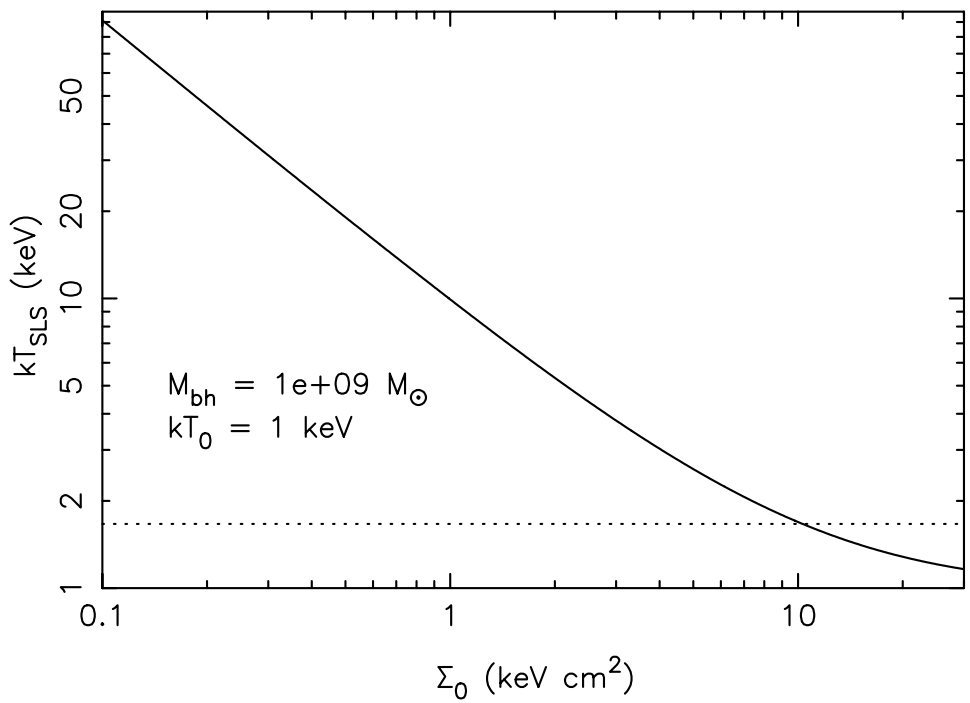
Temperature at the surface of last scattering:

(for isentropic, hydrostatic gas)

Within the Bondi radius,

$$T_{\rm SLS} \propto \frac{M_{\rm bh}^{2/3}}{\Sigma}$$

Fluid approximation fails for $T > T_{\rm SLS}$



Inside the Surface of Last Scattering

WITH NO MAGNETIC FIELD: Only particles with low angular momentum (< J_{min}) are swallowed in a single orbit – for weakly bound orbits around a non-rotating black hole,

$$J_{\min} = \frac{4GM_{\rm bh}}{c}$$

Most particles orbit many times before being swallowed
=> accretion rate well below the Bondi accretion rate

Particle distribution found by solving the Boltzmann equation with Coulomb scattering – ie, the Fokker-Planck equation

Analogous to the "loss-cone" problem for stars orbiting a massive black hole (Bahcall & Wolf 1977; Lightman & Shapiro 1977; Shapiro & Marchant 1978)

Particles are lost mainly from near r_{crit}, where the change in angular momentum during a single orbit is ~J_{min}

Scaling: For $r_{crit} < r < r_{SLS}$, $f(\mathbf{r},\mathbf{v}) = K|E|^{1/4}$, where $E = \frac{1}{2}v^2 - \frac{GM_{\rm bh}}{r}$

$$\frac{r_{\rm crit}}{r_{\rm SLS}} \approx \left[\frac{16GM_{\rm bh}}{c^2 r_{\rm SLS}}\right]^{4/9} \quad \text{and} \quad \frac{\dot{M}}{\dot{M}_{\rm Bondi}} \approx 0.25\left(\frac{r_{\rm crit}}{r_{\rm SLS}}\right) \approx 0.0095 M_{\rm bh,\,9}^{8/27}\Sigma^{-4/9}$$

Heat Must Flow Outward

Typical energy per particle of few times the binding energy at r_{crit} flows outward, yielding heating power

$$\dot{M}_{\rm Bondi}\frac{5kT_0}{2\mu m_{\rm H}}\frac{r_{\rm Bondi}}{4r_{\rm SLS}}$$

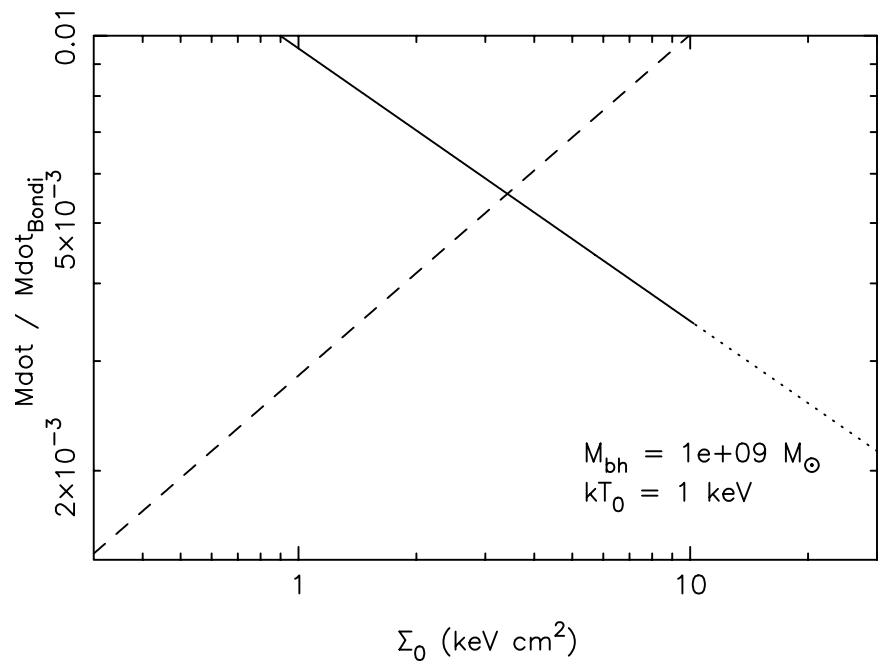
Well short of the heat required to prevent cool cores from cooling, but can prevent gas cooling on scales comparable to the Bondi radius

Heat flow requires supersonic convection to exceed

$$\frac{5kT_0}{2\mu m_{\rm H}}\dot{M}_{\rm Bondi}$$

Heat flux will generally drive convection in $r_{SLS} < r < r_{Bondi}$, raising the entropy of gas arriving at r_{SLS} and further suppressing accretion and making $r_{SLS} \geq 0.25\ r_{Bondi}$ or

$$\Sigma > 3\frac{M_9^{2/3}}{kT}\ \text{keV cm}^2$$



Spherical accretion rate << Bondi rate

Effect of Magnetic Field

In steady spherical flow, transverse separation of fluid elements ~ r and radial ~ v_r

⇒ frozen in field is stretched radially, tending towards monopolar, unless v_r / r declines inward

Conservation of magnetic moment in a monopolar field has the same effect on v_r and v_t as conservation of angular momentum with no field – field free solution holds

Realistic flow solutions will be more complicated: magnetic pressure ~ $1/r^4$ for monopolar field, so p_B grows faster than $p_{\rm gas}$ (~ $1/r^{2.5}$); stellar mass loss may matter

BUT, if there is significant thermal conduction from within the Bondi radius (cf. Shcherbakov & Baganoff 2010), long particle mean free paths break the fluid approximation

⇒ *flow must be treated as a nearly collisionless plasma*

Summary

- Hot gas accreting onto the central supermassive black hole in groups and clusters generally becomes collisionless not far inside the r_{Bondi}
- As a result, the accretion rate is reduced by orders of magnitude below the Bondi accretion rate
- Heat must flow outward for the "collisionless" flow to proceed, further suppressing accretion and helping to prevent gas near the Bondi radius from cooling
- Heat outflow sets an entropy floor near the Bondi radius
- Magnetic field complicates matters, but the flow must be treated as a nearly collisionless plasma