Hot Accretion with Saturated Conduction

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Short Story

Hot Accretion -> Weak Collisionality -> Large conduction
(modulo tangled magnetic fields)

New Self-Similar ADAF solution with saturated conduction:

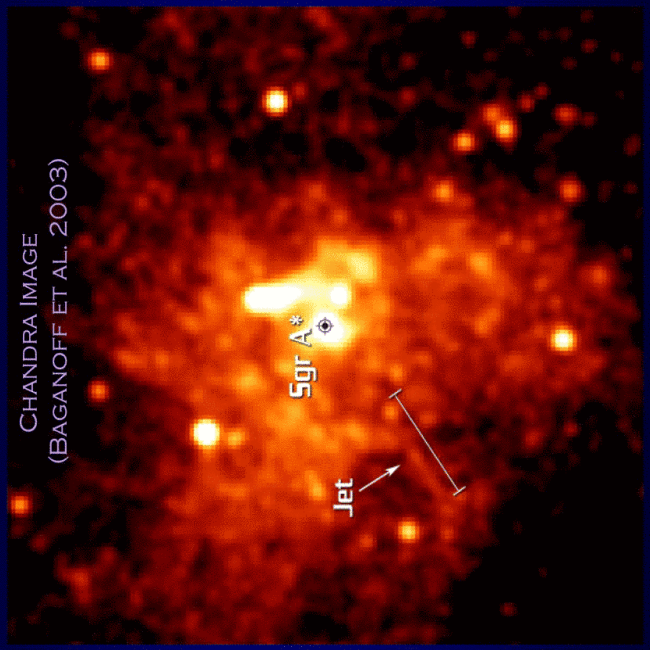
- hotter, reduced free-free radiative efficiency,
- may also reduce cyclo-synchrotron efficiency

Additional consequences:

- Reduced Bondi capture rate?
- "microscopic" viscous stress tensor?
- Disk evaporation?
- ADIOS, CDAFs?

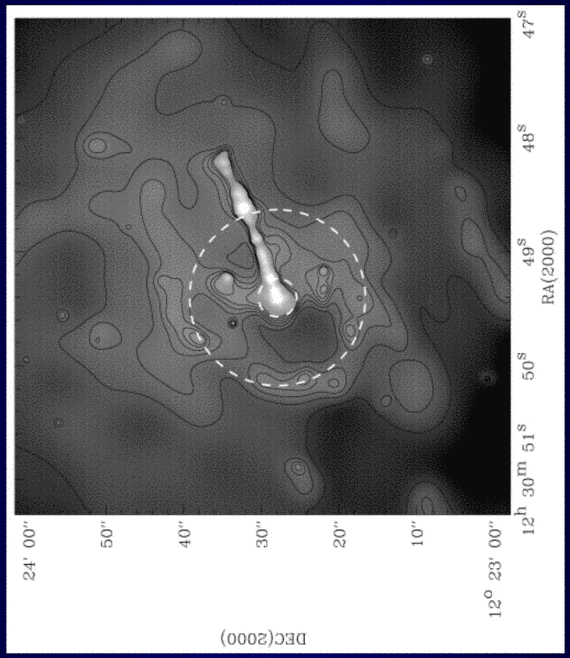
Hot Flows

Chandra Image
(Baganoff et al. 2003)



Hot Flows

M87 (Di Matteo et al. 2003)



- Infer density and temperature from X-ray profile
- Apply standard Bondi theory for gas capture
- Deduce low radiative efficiency

Radiatively Inefficient Accretion Flows

ADAFs: radial advection a key ingredient

Narayan & Yi (1994) + Ichimaru, Rees et al., Abramowicz et al.

ADIOS: positive Bernoulli constant implies powerful outflows

Blandford & Begelman (1999)

CDAFs: unstable entropy gradient implies convection

Narayan et al. (2000), Quataert & Gruzinov (2000)

Numerical simulations: different dynamical structure

Hawley, Balbus & Stone (2001) + others

Constraints on Collisionality

One-Temperature: ion and electron mean free paths are

$L \sim 10^4 (T^2/n)$ cm

Table 1. Observational Constraints on Collisionality

Nucleus	$n_{1''}$ (cm^{-3})	$T_{1''}$ (10^7 K)	R_1 (cm)	l_1/R_1	l_1/R_{cap}
Sgr A*	100	2.3	1.3×10^{17}	0.4	0.4
NGC 1399	0.3	0.9	3.1×10^{20}	0.009	0.02
NGC 4472	0.2	0.9	2.5×10^{20}	0.016	0.07
NGC 4636	0.07	0.7	2.2×10^{20}	0.032	0.6
M87	0.17	0.9	2.7×10^{20}	0.018	0.02
M32	0.07	0.4	1.2×10^{19}	0.2	1.3

$L > 10^{4\text{-}5}$ Schwarzschild radii in all cases

L/R increases as $R^{-3/2-p}$ for density going as $R^{-3/2+p}$

=> Weakly Collisional Regime appears likely

Saturated ("flux-limited") Conduction

Maximal electron conductive flux:

- thermal energy content times characteristic speed ("free-streaming")

- independent of temperature gradient (only direction)

Occurs when mean free path is comparable to temperature "scale-height"

- $l/R \sim 1$ or larger, seems likely for nuclei just discussed

Simple Cowie & McKee (1977) scaling: $F_s = 5\,\Phi_s\,\rho\,c_s^3$ (uncertain)
(for equal ion and electron temperatures)

Independent of temperature gradient: self-similar scaling possible
(would not obtain for standard Spitzer conduction law)

ADAF Solutions with Saturated Conduction

Equations: Mass, momentum, energy conservation (Narayan & Yi 1994)

$$v\frac{dv}{dR} = R(\Omega^2 - \Omega_K^2) - \frac{1}{\rho}\frac{d}{dR}(\rho c_s^2), \qquad (1)$$

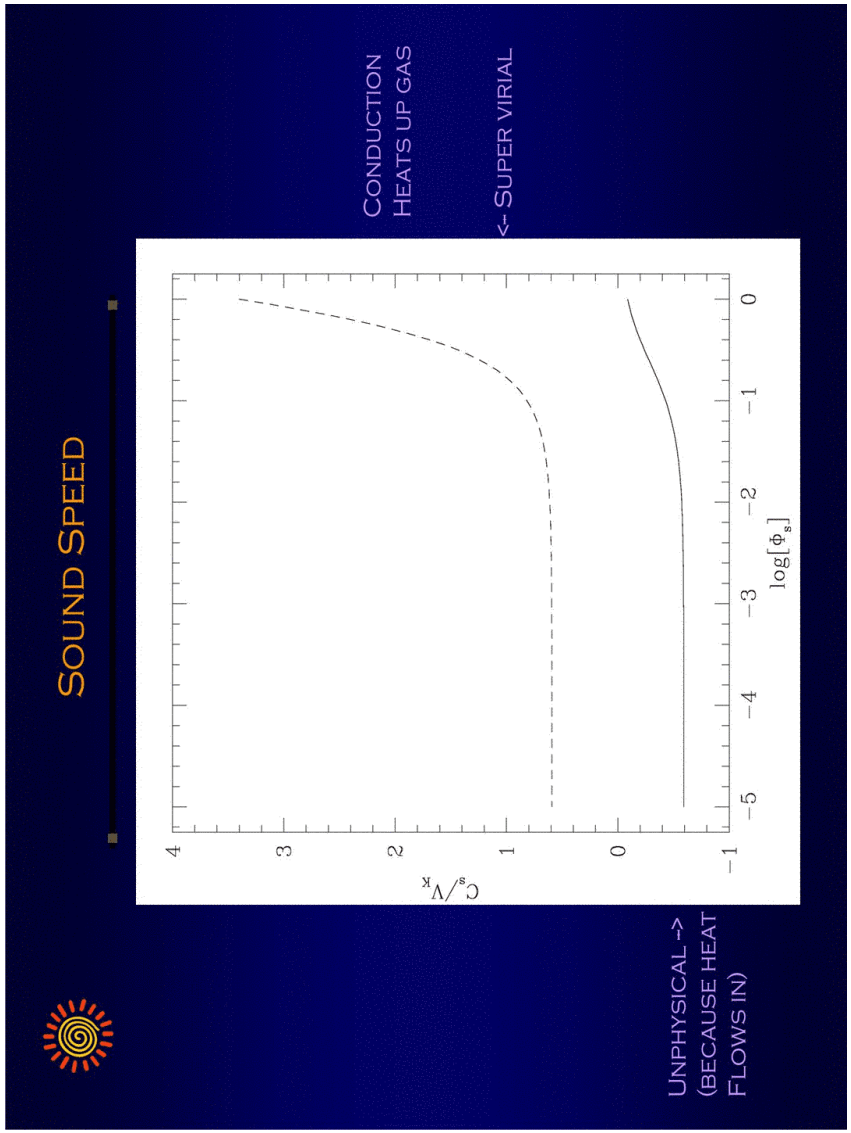
$$v\frac{d(\Omega R^2)}{dR} = \frac{1}{\rho R H}\frac{d}{dR}\left(\frac{\alpha \rho c_s^2 R^3 H}{\Omega_K}\frac{d\Omega}{dR}\right), \qquad (2)$$

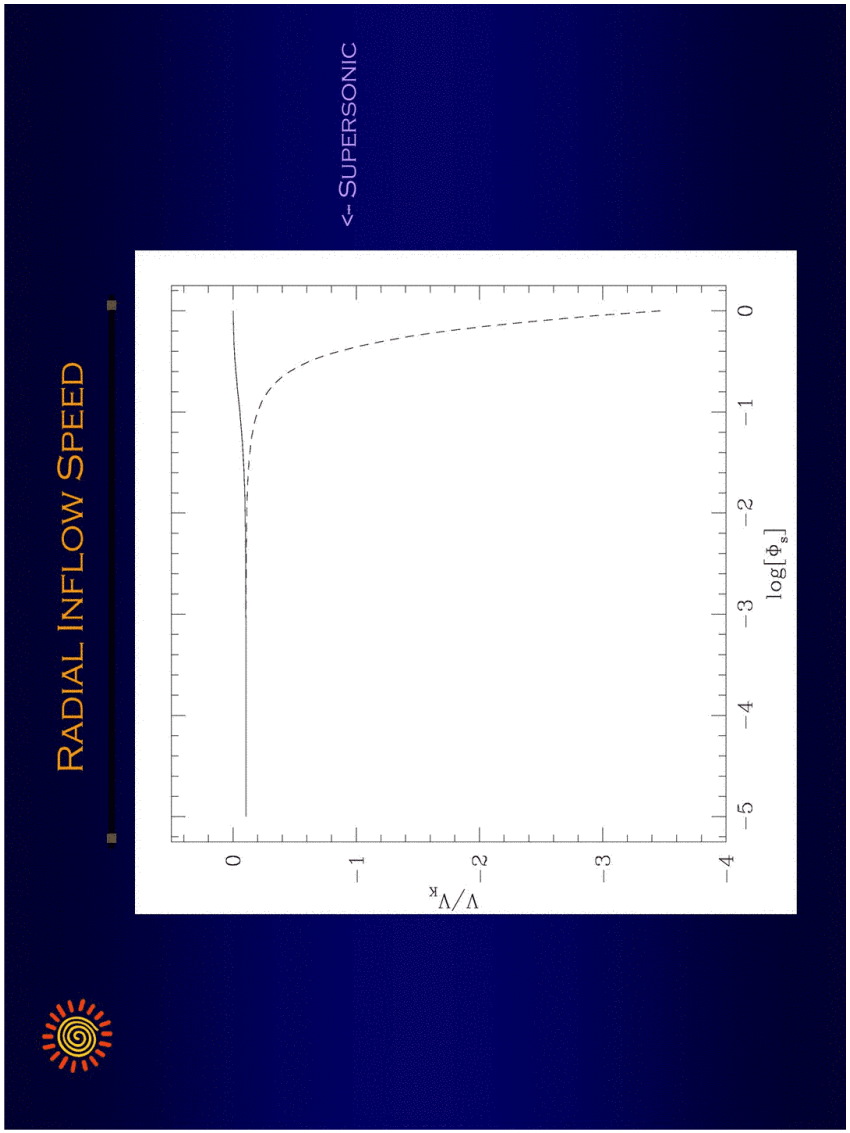
$$2H\rho v T\frac{ds}{dR} = f\frac{2\alpha\rho c_s^2 R^2 H}{\Omega_K}\left(\frac{d\Omega}{dR}\right)^2 - \boxed{\frac{2H}{R^2}\frac{d}{dR}(R^2 F_s)}, \qquad (3)$$

Solutions of the form:

$$\rho = \rho_0 R^{-3/2},\ v = v_0 R^{-1/2},\ \Omega = \Omega_0 R^{-3/2},\ c_s^2 = c_{s0}^2 R^{-1}, \qquad (4)$$

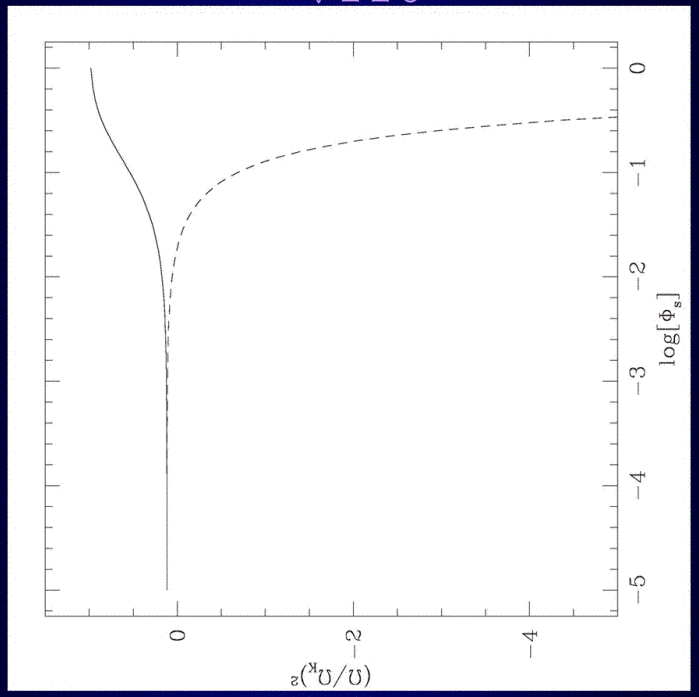
Quartic property lost => numerical solutions to c_s/V_K polynomial


Sound Speed
Conduction
Heats up gas
<- Super virial
Unphysical ->
(because heat
flows in)
c_s/V_k
$\log[\Phi_s]$


Radial Inflow Speed
<- Supersonic
V/V_k
$\log[\Phi_s]$

Squared Angular Velocity

$\Omega^2=0$ are Bondi-like solutions

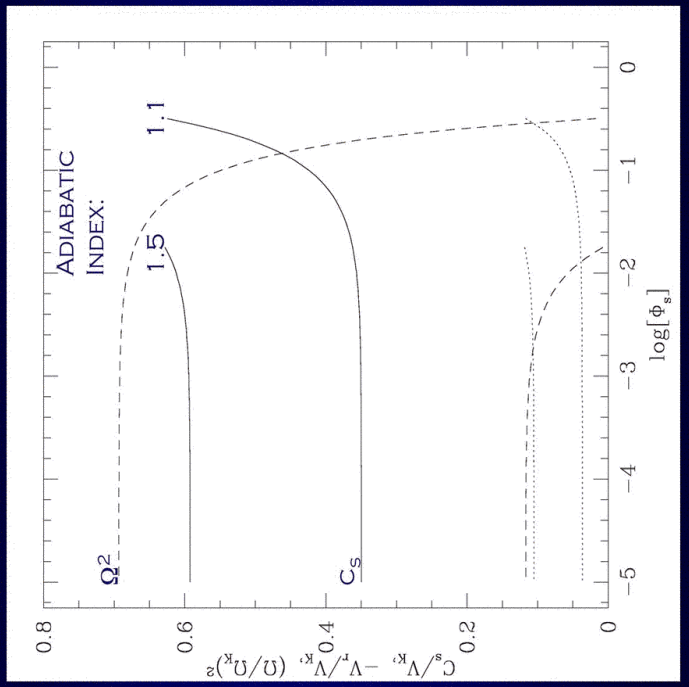


<- negative Ω^2 : Effective Breakdown of solutions

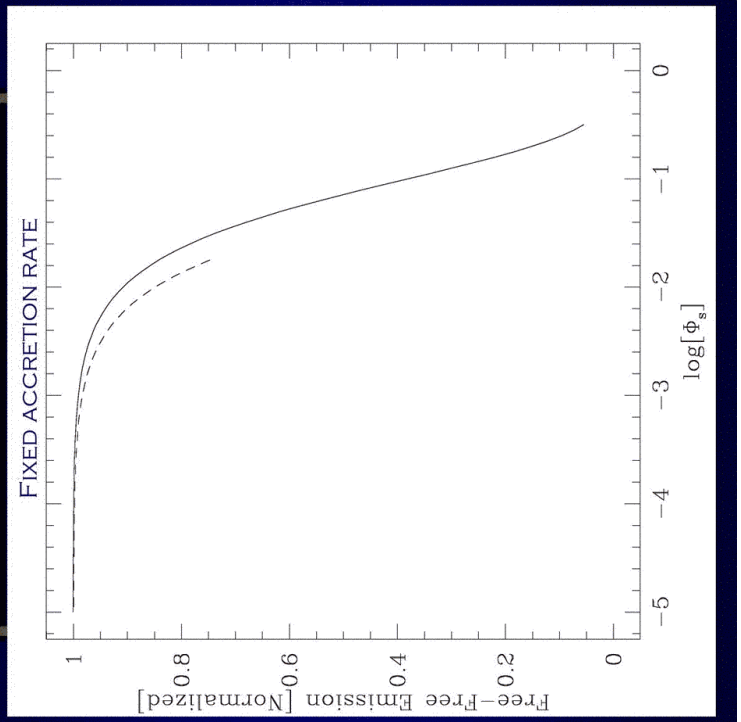
Adiabatic Index Dependence

Advection Parameter: F=1

Viscosity Parameter: α=0.2



Free-Free Emission



Additional Consequences

2-Temperature => Loss of self-similarity

=> energy lost at expense of hottest electrons in inner regions
=> much reduced cyclo-synchrotron emission?

Ability of captured gas to heat up ambient gas:

=> reduced rate of gas capture (Gruzinov 1998)?

Flow dynamics fundamentally modified by weak-collisionality:

- Balbus (2001); Quataert, Dorland, Hammet (2002)
- "microscopic" viscous stress tensor important?

ADIOS/CDAF scenarios:

- Bernoulli constant irrelevant (flow is fundamentally diabatic)
- convective modes neutralized by conduction

Evaporation of an underlying thin disk:

F_s is comparable to surface viscous disspation rate
=> evaporation energetically possible?