HOT ACCRETION WITH SATURATED CONDUCTION

COLUMBIA UNIVERSITY

KRYSTEN MENOU

SHORT STORY

# HOT ACCRETION → WEAK COLLISIONALITY → LATE CONDUCTION

(MODULATED MAGNETIC FIELDS)

- HOTTER, REDUCED FREE-FREE RADIATIVE EFFICIENCY,
- MAY ALSO REDUCE CYCLO-SYNCHROTRON EFFICIENCY

# NEW SELF-SIMILAR ADAF SOLUTION WITH SATURATED CONDUCTION:

- REDUCED BONDI CAPTURE RATE?
- "MICROSCOPIC" VISCUOUS STRESS TENSOR?
- ADIOS, CDAFs?
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

$L \sim 10^4 \left( T^2 / n \right) \text{ cm}$

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>$n_{1''}$ (cm$^{-3}$)</th>
<th>$T_{1''}$ (10$^3$ K)</th>
<th>$R_1$ (cm)</th>
<th>$l_i / R_1$</th>
<th>$l_i / R_{\text{cap}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sgr A*</td>
<td>100</td>
<td>2.3</td>
<td>$1.3 \times 10^{17}$</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>NGC 1399</td>
<td>0.3</td>
<td>0.9</td>
<td>$3.1 \times 10^{39}$</td>
<td>0.009</td>
<td>0.02</td>
</tr>
<tr>
<td>NGC 4472</td>
<td>0.2</td>
<td>0.9</td>
<td>$2.5 \times 10^{30}$</td>
<td>0.016</td>
<td>0.07</td>
</tr>
<tr>
<td>NGC 4636</td>
<td>0.07</td>
<td>0.7</td>
<td>$2.2 \times 10^{39}$</td>
<td>0.032</td>
<td>0.6</td>
</tr>
<tr>
<td>M87</td>
<td>0.17</td>
<td>0.9</td>
<td>$2.7 \times 10^{30}$</td>
<td>0.018</td>
<td>0.02</td>
</tr>
<tr>
<td>M32</td>
<td>0.07</td>
<td>0.4</td>
<td>$1.2 \times 10^{19}$</td>
<td>0.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

# $L > 10^{46}$ 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"
- \( L/R \approx 1 \) 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)

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**ADAF Solutions with Saturated Conduction**

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

\[
\begin{align*}
\frac{dv}{dR} &= R(\Omega^2 - \Omega_K^2) - \frac{1}{\rho} \frac{d}{dR}(\rho c_s^2), \\
\frac{d(\Omega R^3)}{dR} &= \frac{1}{\rho R H} \frac{d}{dR} \left( \frac{\alpha \rho c_s^2 R^3 H}{\Omega_K} \frac{d\Omega}{dR} \right), \\
2H \rho v T \frac{d s}{dR} &= f \frac{2 \alpha \rho c_s^2 R^2 H}{\Omega_K} \left( \frac{d\Omega}{dR} \right)^2. 
\end{align*}
\]

# Solutions of the form:

\[
\rho = \rho_0 R^{-3/2}, \quad v = v_0 R^{-1/2}, \quad \Omega = \Omega_0 R^{-3/2}, \quad c_s^2 = c_{s0} R^{-1},
\]

# Quartic property lost \(\Rightarrow\) numerical solutions to \(c_s^2/V_K\) polynomial
**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/GDAF scenarios:

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

# Evaporation of an underlying thin disk:

F_5 is comparable to surface viscous dissipation rate
=> Evaporation energetically possible?