Collisional vs. Collisionless Processes

(an astrophysical perspective)

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collision frequency:

\[
\nu_{ei} = \frac{4\sqrt{\pi}}{3} \frac{e^2 q_i^2 n_e \ln \Lambda}{m_e m_i(v_e^2 + v_i^2)^{3/2}} \simeq 3 \frac{n_e \ln \Lambda}{T_e^{3/2}} \text{ s}
\]

- solar wind
- shocks
- reconnection
- application to astrophysical accretion flows?
The solar wind

- highly collisionless

- $T_e$ in fast solar wind increases outwards, with halo distbn of higher-$E$ electrons
  $\Rightarrow$ heating/acceleration

- ion cyclotron waves? lower hybrid waves?
  $\Rightarrow$ electron-ion coupling via wave-particle energy exchange
Planetary/interplanetary bow shocks

(c.f. Burgess session on Tues)

- also collisionless
- electron heating/acceleration observed
Supernova shocks

- collisionless, high-$M$
- evidence for electron heating and acceleration from X-ray bremsstrahlung and radio synchrotron spectra
Reconnection

(c.f. Owen session on Tues)

In situ evidence of magnetic reconnection in turbulent plasma

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• collisionless
• observed in terrestrial magnetotail, magnetosheath
• heating and acceleration of both ions and electrons detected in turbulent reconnection
Accretion disks

Standard model:

- **constant mass inflow:** \( \dot{M}_a = 2\pi r (-v_r) \int \rho dz \)

- **Keplerian rotation:** \( \Omega = (GM/r^3)^{1/2} \)

- **collisional, but viscosity inefficient at angular momentum transport**

- **turbulent MHD stresses generated by magnetorotational instability** –
  \( W_{r\phi} = \langle B_r B_\phi \rangle / 4\pi \) can transport angular momentum:
  \( \dot{M}_a \sim -(2\pi / \Omega) \int W_{r\phi} dz \)

- **radiatively efficient:** gravitational binding energy radiated locally \( \Rightarrow \) geometrically thin \( (h \ll r) \)
- Internal energy conservation: \( F(r) \sim 3GM \frac{\dot{M}_a}{8\pi r^3} \)
- X-rays generated in a diffuse, magnetized corona \( \Leftrightarrow \) solar corona
- Relativistic jets probably accretion powered, Poynting-flux dominated

![Diagram: 3C273 spectrum with thermal and inverse Compton components.](image)
Low-$M_a$ systems:

- collisionless ($t_{ei} > t_{inflow} = r/v_r$)
- turbulent
- geometrically thick, 2-temperature plasma: $T_i \approx 10^{12}$ K, $T_e \approx 10^{10}$ K

Critical assumption: electron-ion thermal coupling via wave-particle processes negligible $\Rightarrow$ ion pressure supports a “fat torus” geometry and internal energy is advected into the black hole rather than radiated away by electrons

Unresolved issue: to what extent can wave-particle processes couple the electrons and ions and which are the most relevant microprocesses?