Wind from black hole accretion disks

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Where or whether does wind production stop at larger radii of a *hot accretion flow*?

Can wind be produced by MHD mechanism in a *thin disk*?
Topic 1:

Where or whether does wind production stop at large radii in hot accretion flow?
Whether or where does the wind stop to be produced?

Bu et al. 2016a, 2016b

\[ \dot{M}_{\text{wind}}(r) = \dot{M}_{\text{BH}} \left( \frac{r}{20 r_s} \right) \] (Yuan et al. 2015)

**Question:** how large \( r \) can be?

- Perform simulations around the Bondi radius.
- Gravity of nuclei star cluster are included:
  \[ \psi = \psi_{BH} + \psi_{\text{star}} \]
  \[ \psi_{\text{star}} = \sigma^2 \ln(r) + C \]
Gravities

Black hole
Stars

$ r > 0.1 \text{ star gravity dominates}$

$ r < 0.1 \text{ black hole gravity dominates}$
Winds exist or not? (streamline)

Close to the pole, there are one or two streaming lines pointing from small to larger radii. Other regions are full of turbulent motions. It is hard to find winds!
Winds exist? (trajectories)

It is hard to find trajectories which extended from the starting point to large radii and never cross the starting radius again.

Winds are very few!
Winds production stops at

\[ R_A \equiv \frac{G M_{\text{BH}}}{\sigma^2} \]

\( R_A \) is similar to Bondi radius, if velocity dispersion \( \sigma \) is similar to the gas sound speed at the Bondi radius.
Topic 2:

Can the same mechanism produce wind in a thin disk?
Motivations

- **Observations:**
  - Winds are common in luminous AGNs (e.g., BAL quasars) and the soft state of black hole X-ray binaries.

- **Theory:**
  - Strong wind can be produced naturally in hot accretion flows (Prof. Yuan’s talk)
  - In many cases, radiation mechanism is not enough since too low L & too strong ionization (e.g., Miller et al. 2006; Tombesi et al. 2011, 2013)
  - Does the same mechanism (as in hot accretion flow) work for thin disks?
Equations of simulations

Assumptions:

- Neglecting radiative transfer, because radiative force is much smaller than gravitational force.
- Including a cooling term to keep the disk thin.
Initial conditions

- A rotationally supported thin disk embedded in a low density non-rotate medium.

\[
\rho(R, \theta) = \rho_0 \exp \left( -\frac{\cos^2 \theta}{2(h/r)^2 \sin^2 \theta} \right),
\]

and

\[
p(R, \theta) = \frac{GMR(h/r)^2 \sin^2 \theta}{(R - 2r_g)^2} \rho(R, \theta),
\]

- Model parameters:
  - H/r=0.1
  - Magnetic field with only radial component is put inside 3 scale height around equatorial plane.
Mass fluxes

\[ \dot{M}_{\text{in}}(r) = 2\pi r^2 \int_0^\pi \rho \min(v_r, 0) \sin \theta d\theta, \]

\[ \dot{M}_{\text{out}}(r) = 2\pi r^2 \int_0^\pi \rho \max(v_r, 0) \sin \theta d\theta, \]

\[ \dot{M}_{\text{net}}(r) = \dot{M}_{\text{in}}(r) - \dot{M}_{\text{out}}(r). \]

Mass outflow rate is not zero. Are they real?
Winds exist or not?

Outflow is only in the high latitude region close to the rotational axis. Corona and disk main body region is turbulence dominated.
Wind exist or not (cont.)?

In the region $r<0.5$, there is no real outflow/wind.
Why no winds?

Energy of the disk:
\[
\frac{(E_k + E_t + E_B)}{E_G} < 1
\]

The gas is bound!
Summary

- In a hot accretion flow, wind production stops at the Bondi radius.
- MHD mechanism alone can not produce wind from a thin disk.
- Additional forces required; but MHD must at least be helpful, even necessary

THANKS!!!