EFFECTS OF BLACK HOLE SPIN AND MAGNETIC FIELD STRENGTH ON THE WIND

Hai Yang1, Feng Yuan1, Chris White2, and Ye-fei Yuan3

1 Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Nandan Road, Shanghai 200030, China

2 Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

3 Astrophysics Center University of Science and Technology of China Hefei, Anhui, China

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Motivation

- Outflow plays an important role in AGN feedback
- Outflow come from very small scale compare to the major work region of AGN feedback
- So need to have outflow properties at small scale to give larger scale AGN feedback simulation as input setup : mass flux, velocity.

Method

- Code: Athena++(White et al 2016)
  - --Finite volume Godunov schemes
  - --Staggered-mesh constrained transport (CT) method
  - --Static mesh refinement (SMR) grid
- Data process: trajectory method(Yuan et al 2015)
  - -- loyally reflect the motion of fluid element in turbulence accretion flow

Simulation setup

- 3D GRMHD
  - --r: [1.1,1200]r_g , θ:[0,1]π, ϕ:[0,2] π
  - -- N_rX N_θX N_ϕ =352X128X64
- 3 model:
  - --MAD00 (a=0.0, strong magnetic field);
  - --MAD98 (a=0.98, strong magnetic field);
  - --SANE98 (a=0.98, weak magnetic field)

Reference

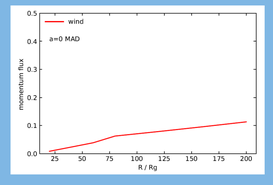
F. Yuan, Z. Gan, R. Narayan, A. Sadowski, D. Bu, and X.-N.Bai, ApJ 804, 101 (2015).

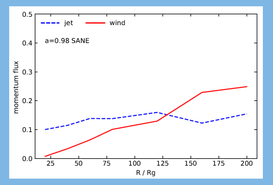
C. J. White, J. M. Stone, and C. F. Gammie, ApJS 225, 22 (2016).

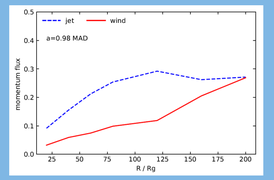
We found that

- **Mass flux of wind**
  - ---small radius: MAD(strong B) > SANE(weak B)
  - ---larger radius: MAD > SANE
  - ---spin BH(a=0.98) > none spin BH
- **Mass flux-weight poloidal speed**
  - ---MAD > SANE (roughly 3 times)
  - ---BH spin has little effect
- **Momentum flux of wind and jet**
  - ---MAD > SANE (Both wind & jet)
  - ---spin BH > none spin BH (Both wind & jet)
  - ---BZ-jet < wind (Both MAD & SANE)
- **Kinetic energy flux of wind and jet**
  - ---MAD > SANE (Both wind & jet)
  - ---spin BH > none spin BH (Both wind & jet)
  - ---BZ-jet > wind (Both MAD & SANE)
- **Total energy flux of wind and jet**
  - --- R=200rg, wind could reach 10-20% of BZ-jet and wind could still locally produce

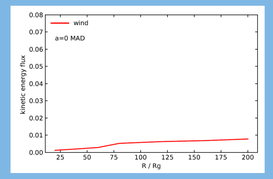
Momentum flux of wind and jet

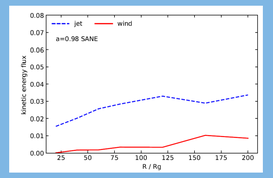


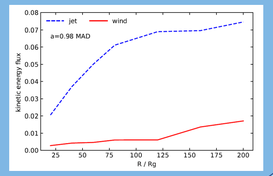




Kinetic energy flux of wind and jet

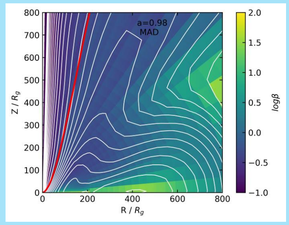




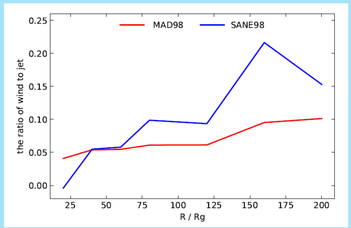


How to define the boundary of BZ-jet and wind?

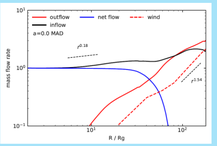
We draw the magnetic field line that connected to the black hole and choose the farthest off axis field line(RED LINE) to be the boundary of the BZ jet

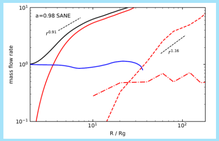


The ratio of total energy flux of wind to jet



Main result



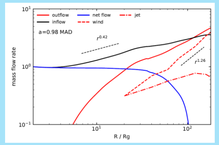


SANE00:

$$\dot{M}(r)_w = \left(\frac{r}{20r_s}\right)^{1.0} \dot{M}_{BH}$$

MAD00:

$$\dot{M}(r)_w = \left(\frac{r}{55r_s}\right)^{1.54} \dot{M}_{BH}$$

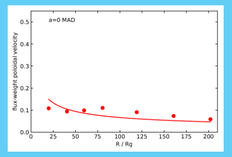


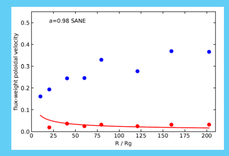
SANE98:

$$\dot{M}(r)_w = \left(\frac{r}{15r_s}\right)^{1.16} \dot{M}_{BH}$$

MAD98:

$$\dot{M}(r)_w = \left(\frac{r}{25r_s}\right)^{1.26} \dot{M}_{BH}$$



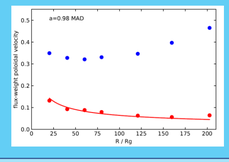


SANE00: $V_p = 0.21V_k$

MAD00: $V_p = 0.66V_k$

SANE98: $V_p = 0.24V_k$

MAD98: $V_p = 0.64V_k$



	SANE00	MAD00	SANE98	MAD98
$\dot{P(r)}_w$	$\approx \frac{4}{100}\dot{M}_{BH}c$	$\approx \frac{10}{100}\dot{M}_{BH}c$	$\approx \frac{25}{100}\dot{M}_{BH}c$	$\approx \frac{27}{100}\dot{M}_{BH}$
$\dot{P(r)}_j$	$\approx \frac{1.0}{100}\dot{M}_{BH}c$	–	$\approx \frac{13}{100}\dot{M}_{BH}c$	$\approx \frac{27}{100}\dot{M}_{BH}$
$\dot{E(r)}_w$	$\approx \frac{0.05}{100}\dot{M}_{BH}c^2$	$\approx \frac{0.8}{100}\dot{M}_{BH}c^2$	$\approx \frac{1.0}{100}\dot{M}_{BH}c^2$	$\approx \frac{1.8}{100}\dot{M}_{BH}c^2$
$\dot{E(r)}_j$	$\approx \frac{0.012}{100}\dot{M}_{BH}c^2$	–	$\approx \frac{3.0}{100}\dot{M}_{BH}c^2$	$\approx \frac{7.0}{100}\dot{M}_{BH}c^2$

$\dot{P(r)}_w$: Wind ; $\dot{P(r)}_j$: BZ-Jet for SANE98&MAD98, Disk-jet for SANE00