# Wind from black hole accretion disks

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# Contents

- 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?

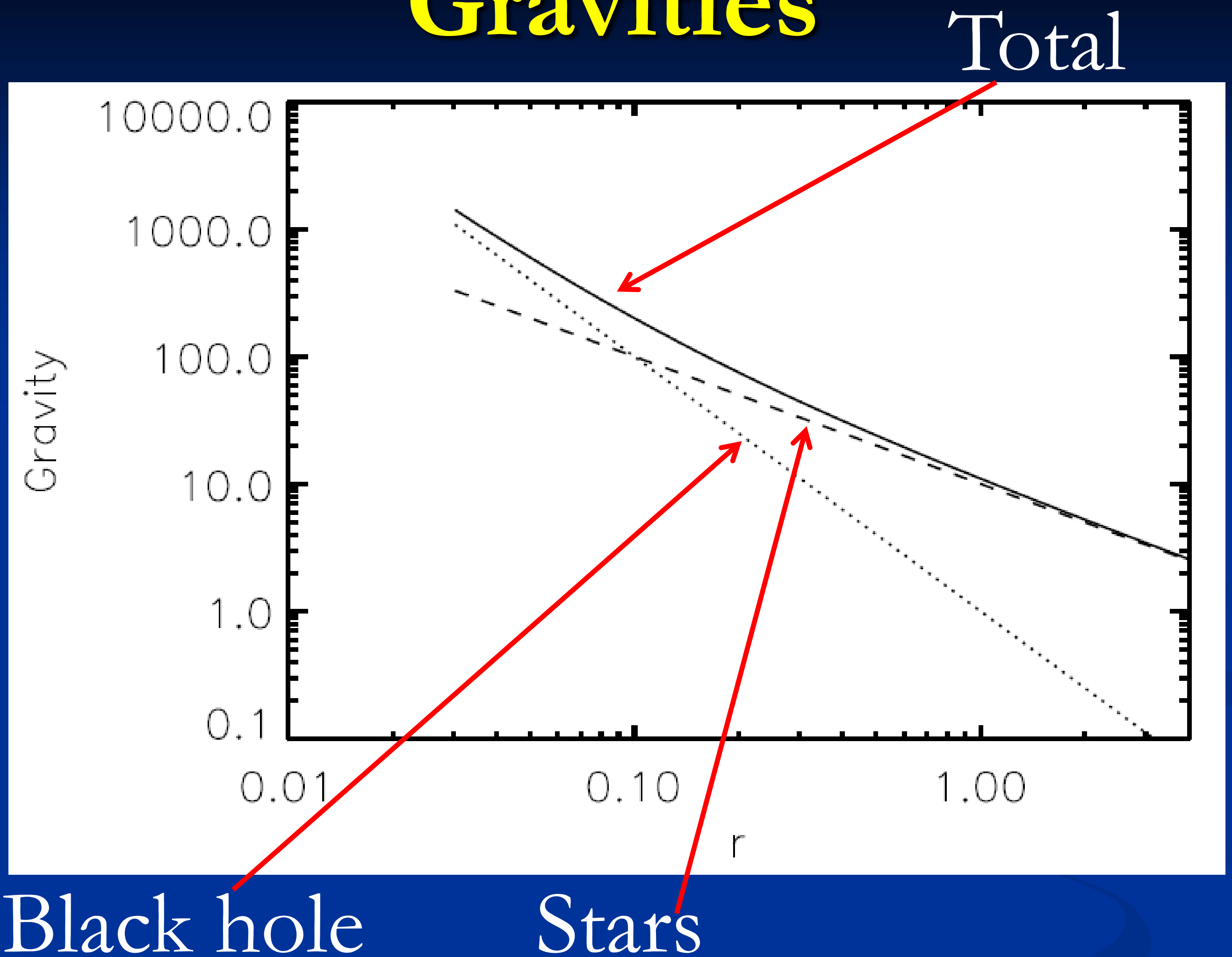
Bu et al. 2016a, 2016b

- $\dot{M}_{\rm wind}(r) = \dot{M}_{\rm BH}\left(\frac{r}{20r_s}\right)$ (Yuan et al. 2015)
- Question: how large r can be?
  - Perform simulations around the Bondi radius.
  - Gravity of nuclei star cluster are included:

$$\psi = \psi_{BH} + \psi_{star}$$

$$\psi_{star} = \sigma^2 \ln(r) + C$$

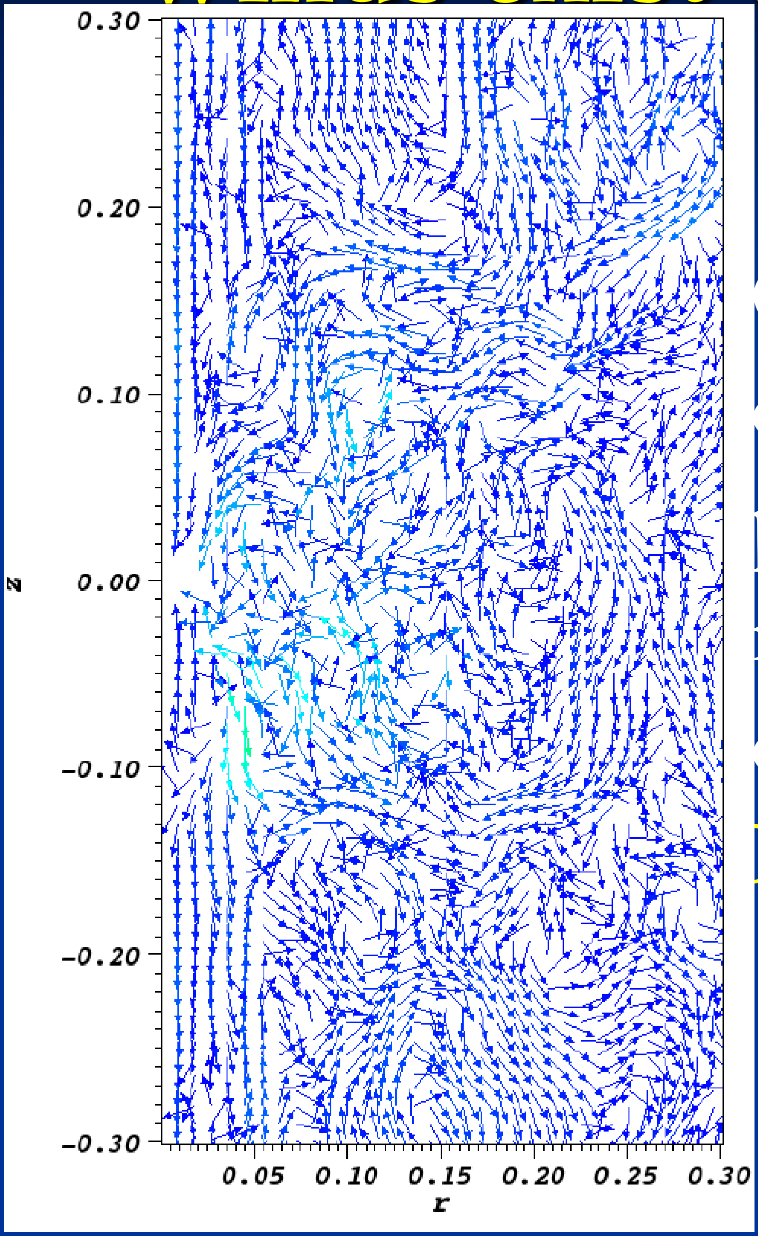
# Gravities




r>0.1 star gravity dominates

r<0.1 black hole gravity dominates

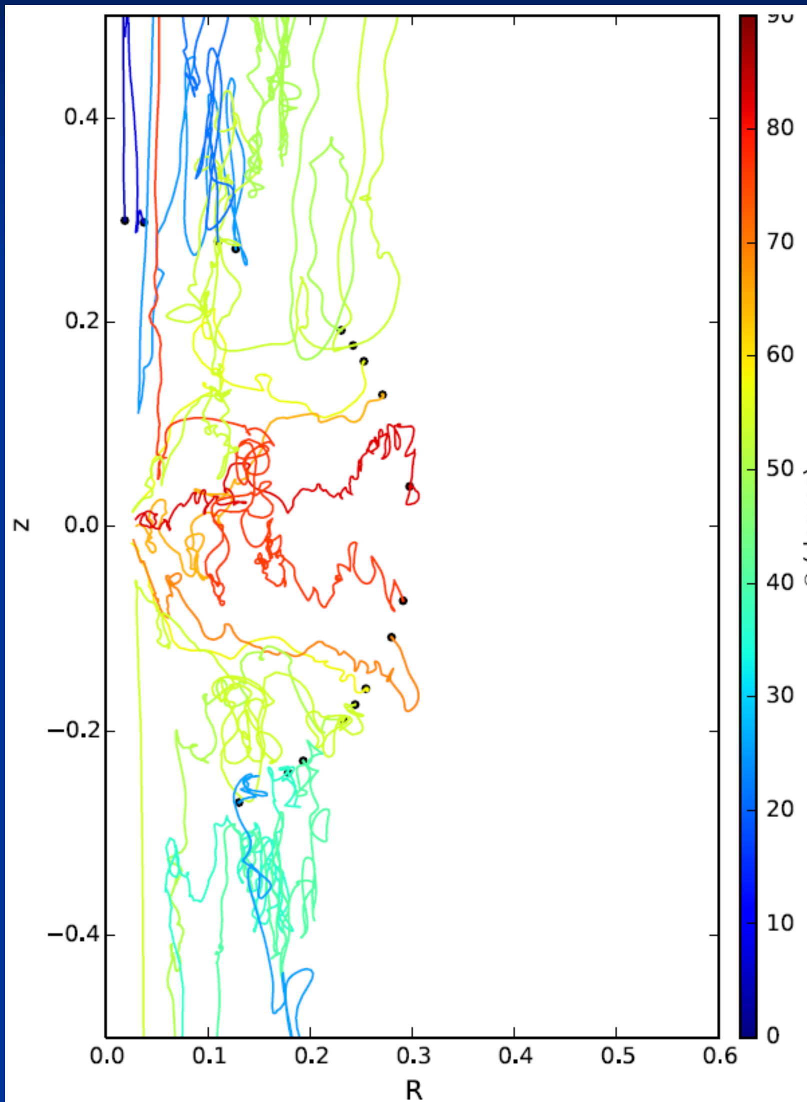
# Winds exist or not? (streamline)




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**

$$R_A \equiv GM_{\rm BH}/\sigma^2.$$

R_A is similar to Bondi radius, if velocity dispersion σ 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

$$\frac{D\rho}{Dt} = -\rho\nabla\cdot\mathbf{v},$$

$$\rho\frac{D\mathbf{v}}{Dt} = -\nabla P + \frac{1}{4\pi}(\nabla\times\mathbf{B})\times\mathbf{B} - \rho\nabla\Phi,$$

$$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla\cdot\mathbf{v} - \Lambda,$$

$$\frac{\partial\mathbf{B}}{\partial t} = \nabla\times(\mathbf{v}\times\mathbf{B}),$$

- 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

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

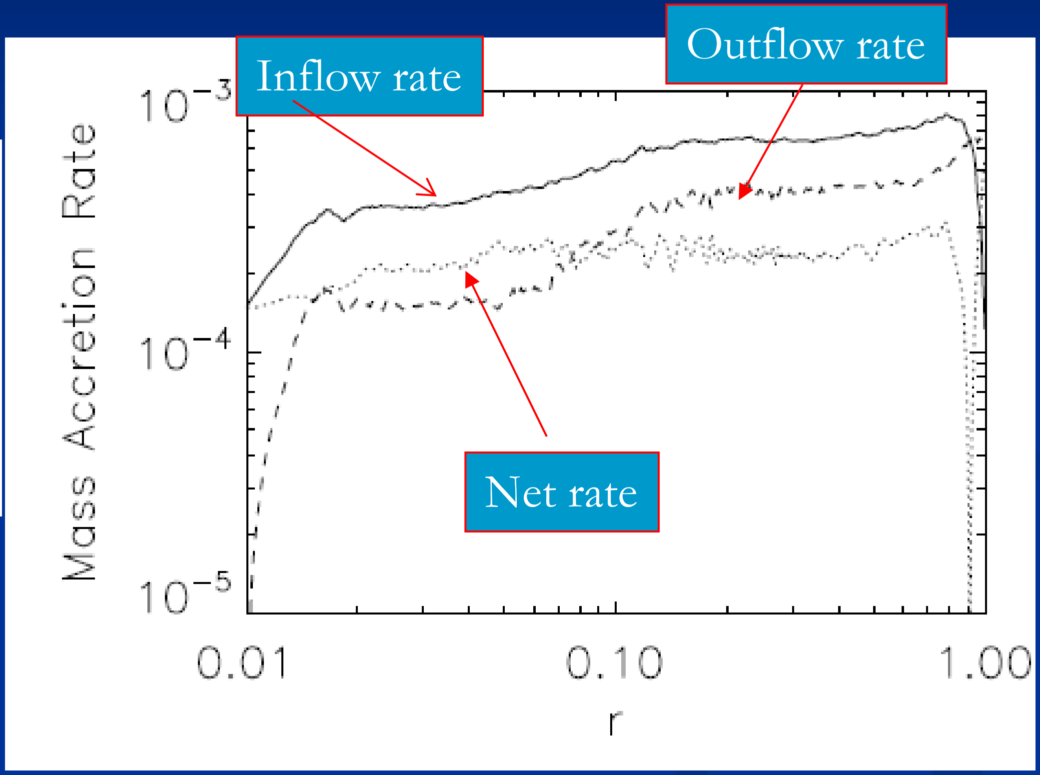
- Model parameters:
  - $H/r=0.1$
  - Magnetic field with only radial component is put inside 3 scale height around equatorial plane.

# Mass fluxes

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

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

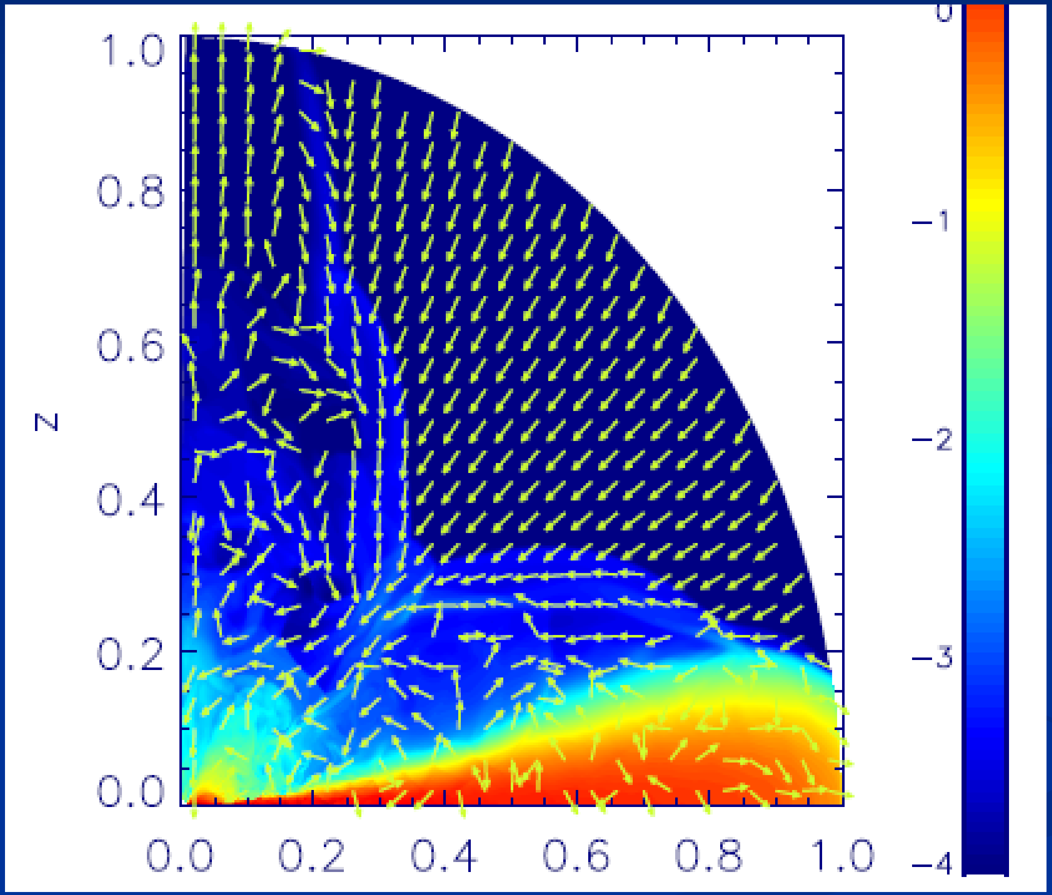
$$\dot{M}_{\rm net}(r) = \dot{M}_{\rm in}(r) - \dot{M}_{\rm out}(r).$$




Mass outflow rate is not zero. Are they real?

# Winds exist or not?

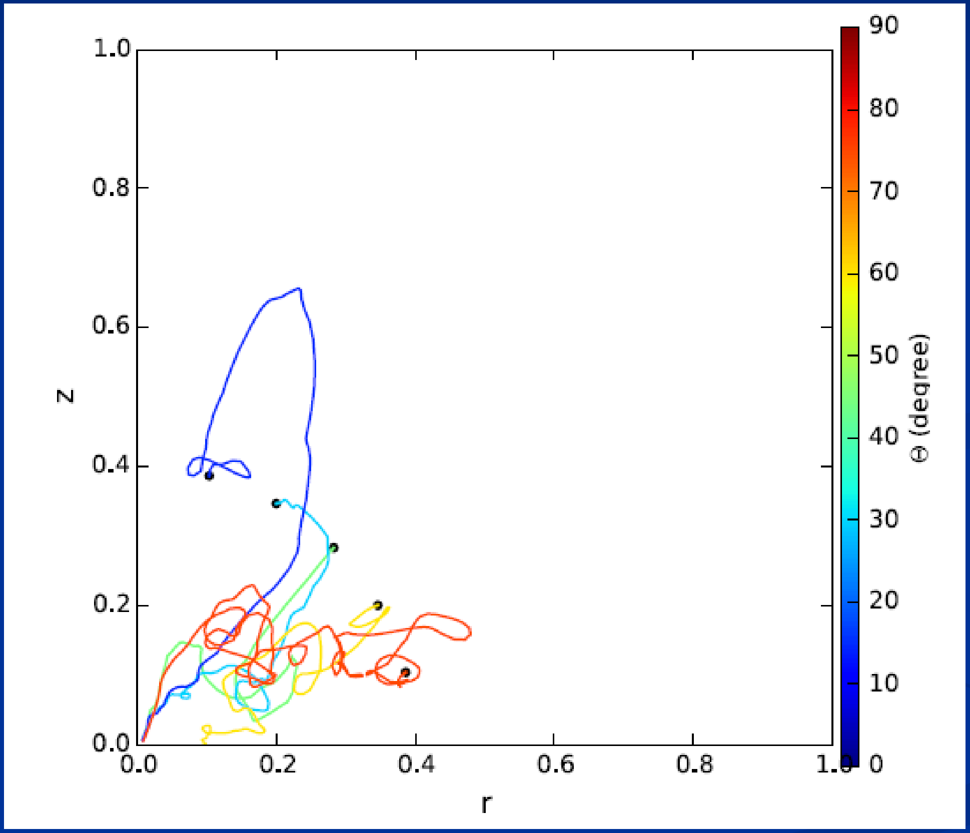
Velocity vector




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.)?

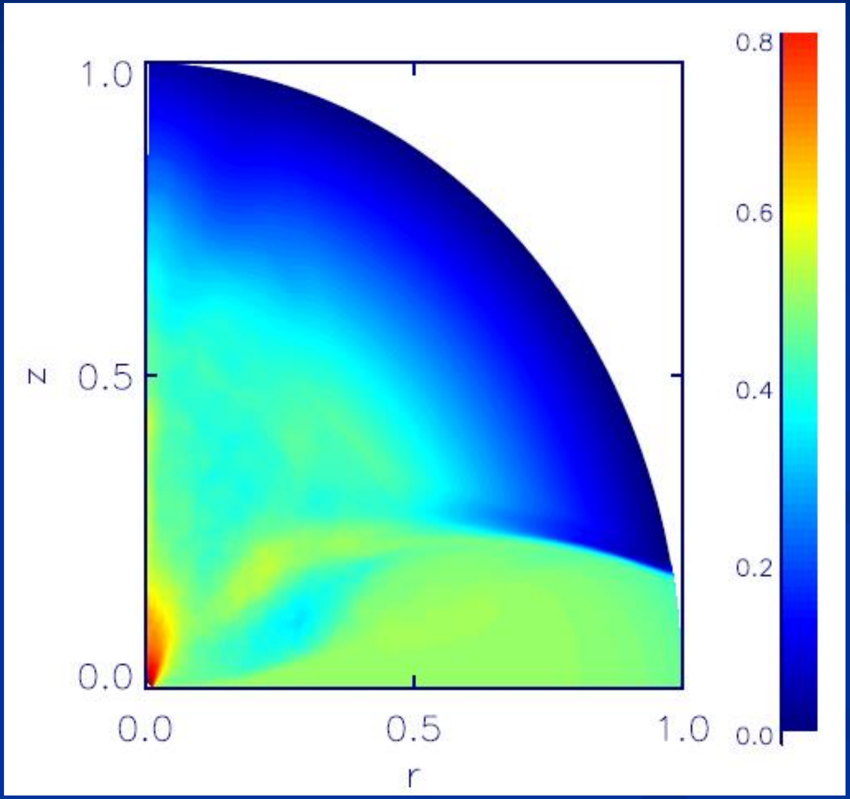
Trajectories of virtual particles:




In the region r<0.5, there is no real outflow/wind.

# Why no winds ?

Energy of the disk:
$(E_k+E_t+E_B)/E_G < 1$




**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!!!