Probing the structure of ultrafast disk winds in AGN with Monte Carlo simulations

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Hagino et al. (2015)
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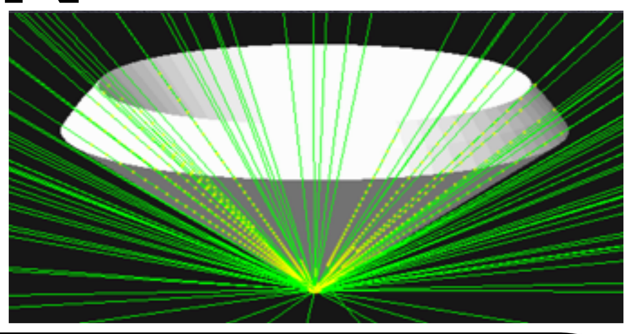


1. Introduction

Highly ionized absorption lines with extremely high velocity seen in many AGN indicate the existence of **ultra-fast outflows (UFOs)**. The velocity of these outflows often reaches **~30% of the speed of light** so that they are thought to make a significant contribution to **the feedback process on to their host galaxies**. However, launching mechanisms and energetics of UFOs are still uncertain due to the lack of knowledge of their physical properties such as the geometry and velocity and density structures.

We have developed a new Monte Carlo simulation code, which can self-consistently calculates the X-ray radiation reprocessed in AGN outflow. By utilizing our Monte Carlo simulation code, we analyzed the X-ray data of UFOs.

2. Monte Carlo simulations of the wind

The spectral model of the disk wind is constructed in the following steps:

1. Determine the ionization structure of the wind by calculating the ionization state along the stream line.
2. Calculate the radiation transfer in the wind with the Monte Carlo method.

Radiation transfer calculation

We use our Monte Carlo simulation code called **MONACO** (Odaka+2011), which can calculate radiative transfer in complicated geometries.

Implemented physical processes for the wind simulation

- Photoionization
- Compton scattering
- Photoexcitation
- Doppler effect

Density and velocity structure

Radial velocity : CAK velocity law (often used for O-star winds)

$$v_r(l) = v_0 + (v_\infty - v_0)\left(1 - \frac{R_{min}}{R_{min}+l}\right)^\beta$$

Turbulent velocity : Constant intrinsic turbulence + velocity shear

$$v_{turb}(i) = v_t + \frac{v_r(i) - v_r(i-1)}{\sqrt{12}}$$

Azimuthal velocity : Conservation of angular momentum

$$v_\phi(R) = v_{\phi 0}\frac{R_0}{R}$$

Density : Conservation of mass

$$\dot{M}_{wind} = 1.23 m_p n v_r 4\pi D^2 \frac{\Omega}{4\pi}$$

Disk wind geometry

We adopted a biconical wind geometry (Knigge+1995)

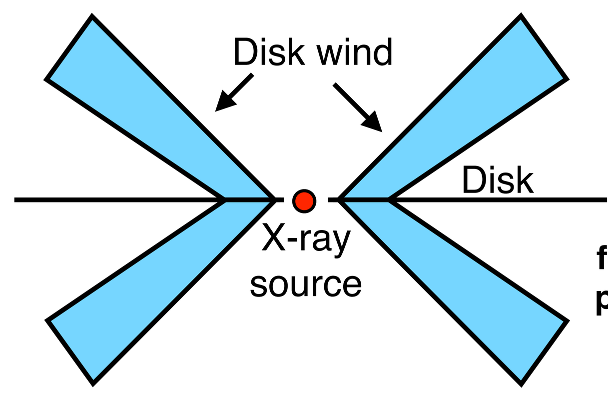


Fig.1 Schematic view of the wind geometry

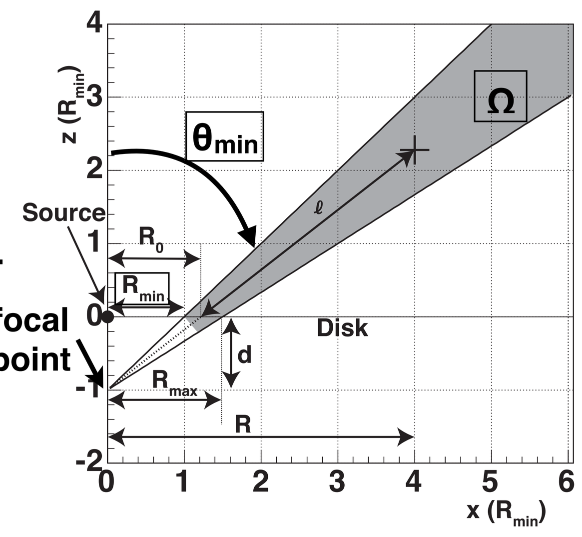


Fig.2 Adopted geometry and geometric variables

Geometry is determined by 3 parameters **(R_{min}, θ_{min}, Ω)**

Ionization calculation

The ionization structure of the wind is sequentially calculated from the inner shell to the outer shell.

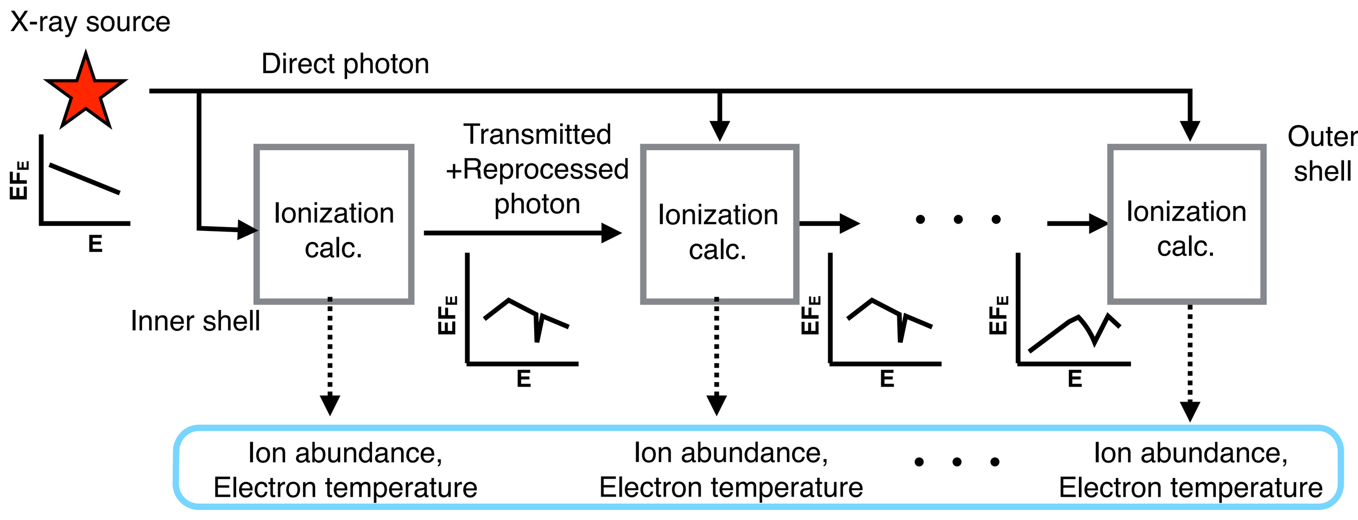
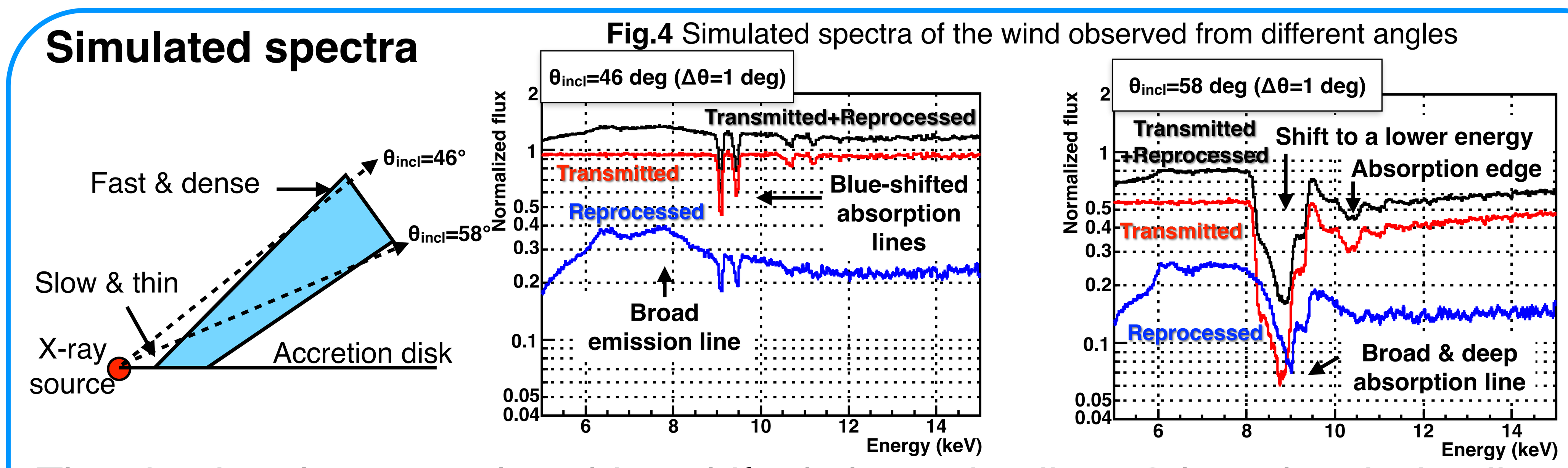


Fig.3 Schematic view of the ionization calculation

Simulated spectra

Fig.4 Simulated spectra of the wind observed from different angles

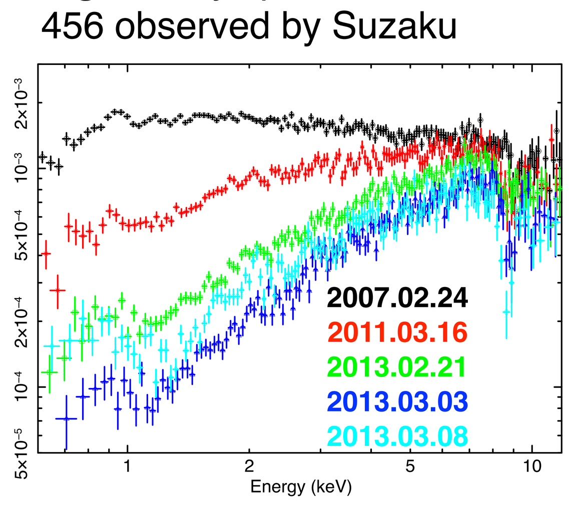


The simulated spectra show blue-shifted absorption lines & broad emission lines like the observational spectra. Also, we found that **the absorption line structure heavily depends on the viewing angle of the wind.**

3.Application to the observational data: PDS 456

We applied our spectral model to the observed spectra of the UFOs. Here, we used Suzaku data of PDS 456 (M_{BH}~2×10⁹M⊙).

Fig.5 X-ray spectra of PDS 456 observed by Suzaku



Tab.1 Fixed simulation parameters

L	4×10
Γ	2.5
v	v
v	1000 km/s
β	1

Ṁ	8M
R	20R
Ω	0.15
θ	48°

Fig.7 Contour plots of the outflowing angle and the terminal velocity for all the observations.

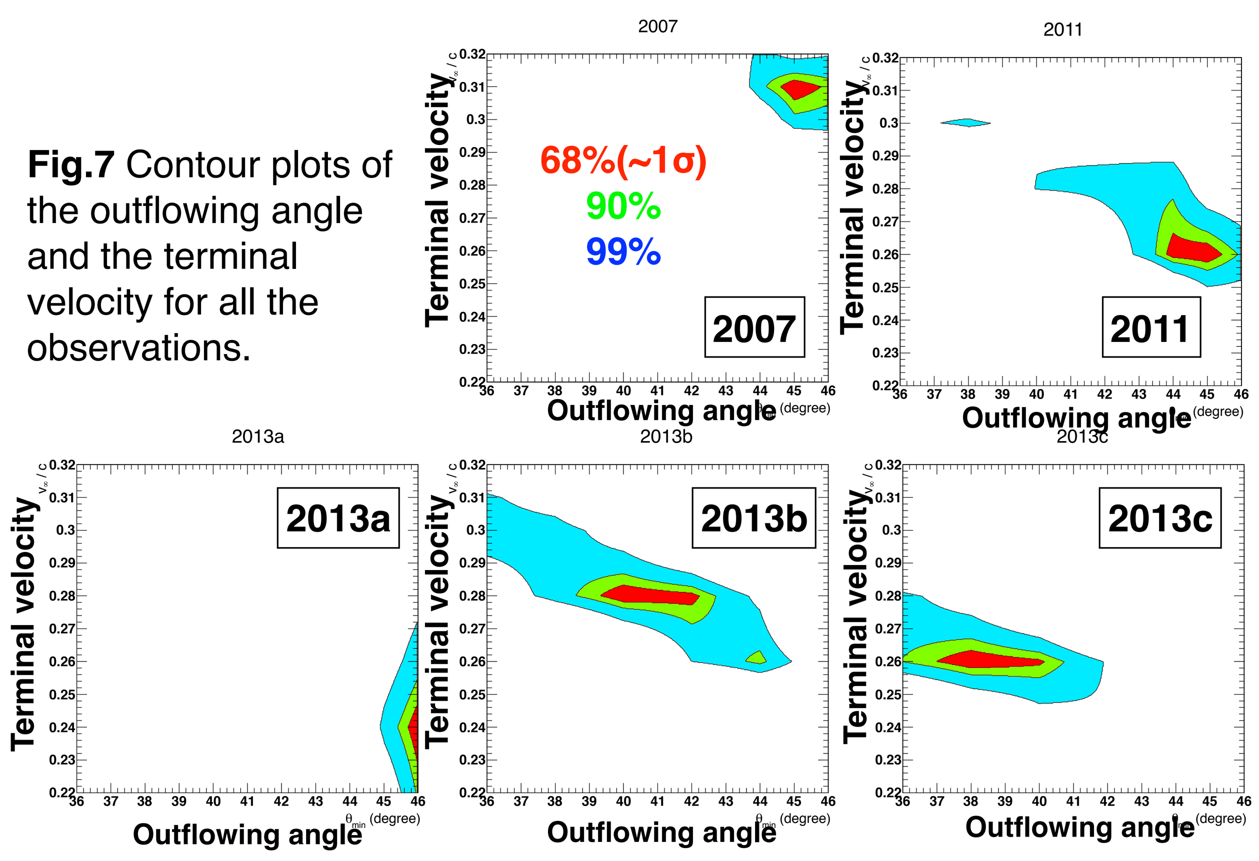
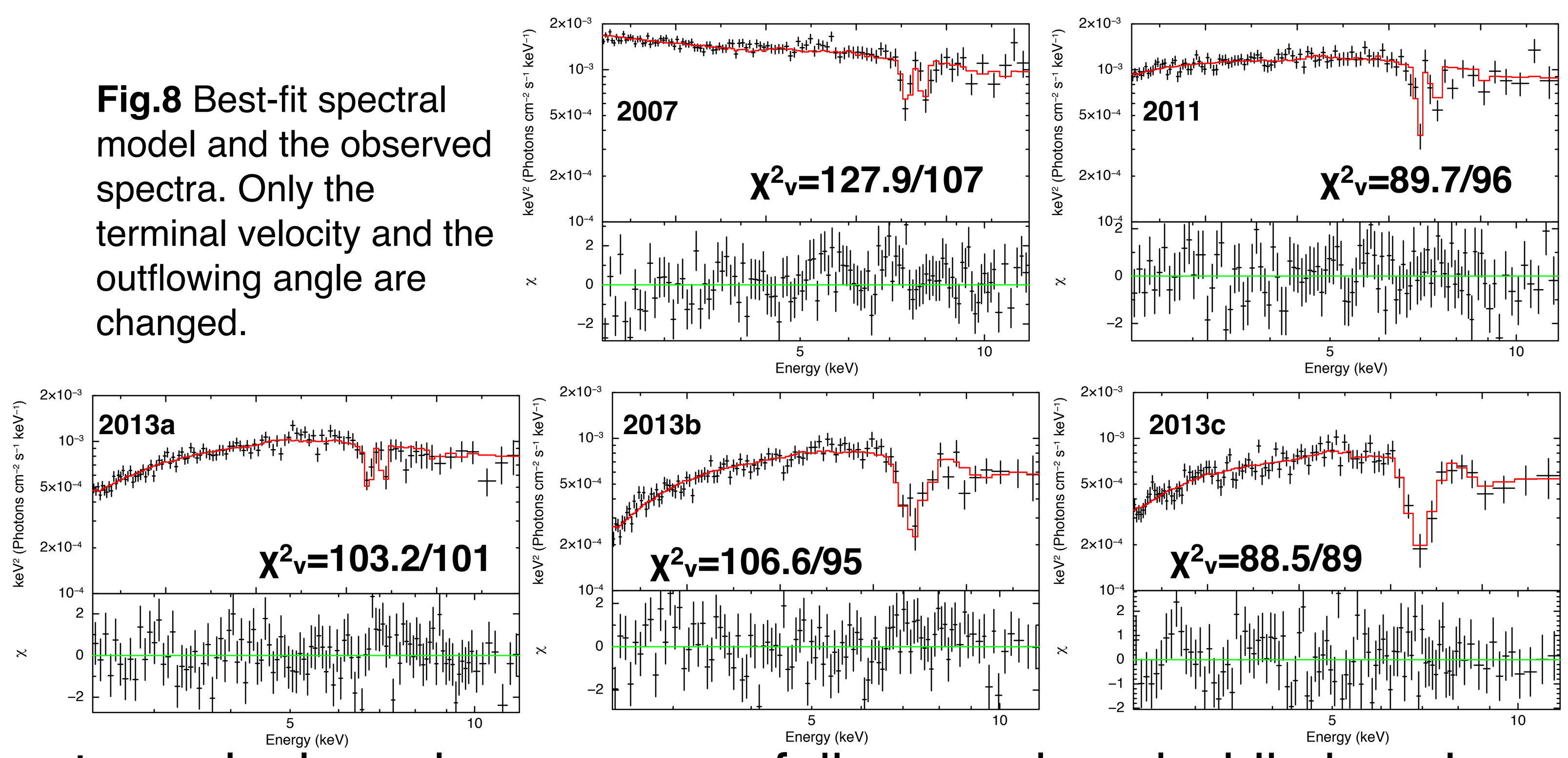


Fig.8 Best-fit spectral model and the observed spectra. Only the terminal velocity and the outflowing angle are changed.



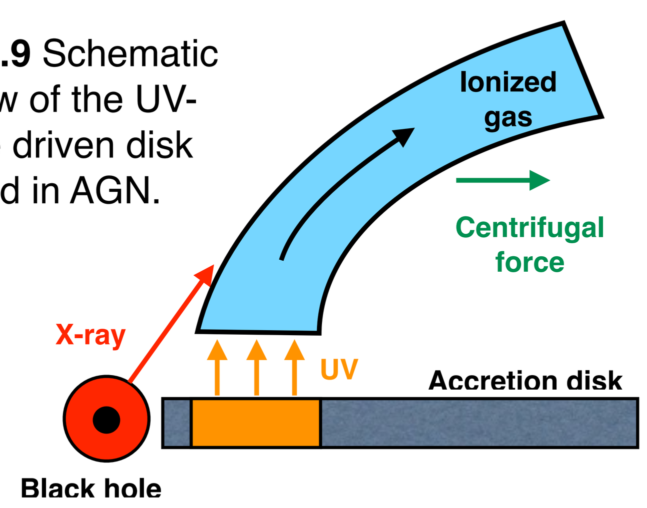
All the spectra of PDS 456 in different epochs have been successfully reproduced while keeping all the fundamental parameters constant except for the terminal velocity and the outflowing angle.

4. Launching mechanism of the wind

Here, we discuss whether the wind simulated above can be launched by the UV-line driving mechanism.

In the UV-line driving mechanism, the wind is launched by the radiation pressure via bound-bound transitions in the UV-band.

Fig.9 Schematic view of the UV-line driven disk wind in AGN.



According to the full numerical calculation of UV-line driven winds for 10⁹M⊙ black hole performed by Shane Davis, the mass loss rates of 30–50% of the mass inflow rate are expected. Therefore, the UFOs with $\dot{M}_{wind}/\dot{M}_{in}$≃0.3 observed in PDS 456 can be launched by UV line driving.

5. Conclusions

We constructed a new X-ray spectral model of the UFOs.

- ✓ The spectral variability of the absorption line feature can be explained by the change of the velocity and the outflowing angle of the wind. This result implies the instability of the wind from the observational aspect.
- ✓ The mass outflow rate are consistent with the values expected by the theoretical calculation of the UV-line driven disk wind.