（別紙様式２）

フォトンサイエンス国際卓越大学院プログラム（XPS）

光科学特別実習　報告書

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Research title

X-ray spectral analysis of the AGN using the Monte Carlo simulation code MONACO

Background of my research topic

Almost all the large galaxies have Super Massive Black Holes (SMBHs) with a mass - times the solar mass at the galactic centers. Bright ones of those are called Active Galactic Nuclei (AGN). X-rays can be used to observe the high-energy regions in the AGN center. The X-ray spectra of some AGNs show blue-shifted absorption lines. These are probably due to absorptions by the outflow from the accretion disk, which reaches at 0.1-0.3 times the speed of light and is called Ultra Fast Outflow (UFO). Note that UFO does not mean "Unidentified Flying Object". In addition, X-ray observations suggest the existence of clumpy absorbers that partially absorb X-rays in some AGN central regions. With Radiation-Magneto Hydro Dynamic (R-MHD) simulations, Takeuchi+13 and Kobayashi+18 reported that the disk wind is driven by radiation pressure and becomes clumpy due to Rayleigh-Taylor Instability in the region away from the center (Figure 1).

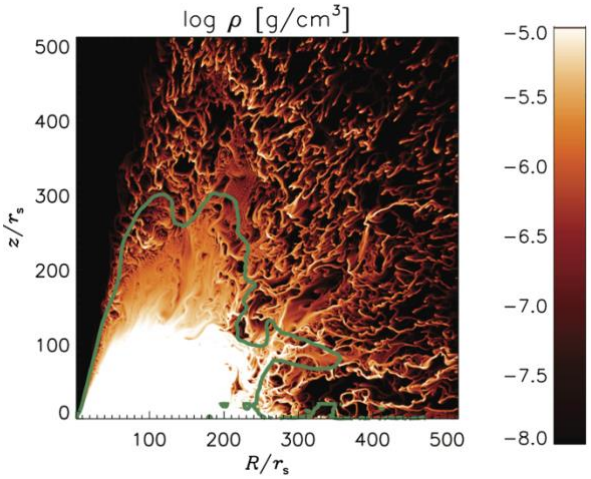

Figure 1: 2D structure of the outflow around a BH with 10^6 solar mass simulated by a R-MHD code. A clumpy structure is shown in the distant region (Takeuchi+13).

My ongoing research

We are working on an observational verification of the theoretical picture that disk wind (UFO) collapses into a clumpy absorber due to Rayleigh-Taylor Instability.

The AGN named IRAS 13224-3809 (hereafter IRAS 13224) was observed by the XMM-Newton X-ray satellite in 2016 for a long period of about two weeks. The observations showed that the X-ray luminosity varied between an order of magnitude. The UFO absorption lines were shallower, and the outflow velocity was faster when the AGN was brighter in X-rays (Parker+17, Pinto+18). We believe that there is a partial absorber in the vicinity of this object based on the analysis of spectral variability. Thus, this source is ideal for studying the relationship between UFOs and partial covering absorbers.

Previous X-ray spectral analysis has not been able to solve the parameter degeneracy of partial absorbers and other components due to the complex entanglement of spectral components. However, using a new method called spectral-ratio fitting, we found that the outflow velocity of the partial absorber is comparable to that of a UFO and is even faster at brighter times. That's why we could cancel out the time-invariant parameters and concentrate on restricting the partial absorber parameters by taking the ratio of intensity-sliced spectra.

Purpose for visiting

The UFO component of the current analysis uses a phenomenological model. Monte-Carlo simulation is the best way to consider the complex geometry of our physical picture. Therefore, we incorporated the disk-like geometry into the Monte Carlo simulation code MONACO (MONte Carlo simulation for Astrophysics and COsmology; Watanabe et al. 2006; Odaka et al. 2011) to see if the X-ray spectrum can be explained and to verify the validity of

our model. In IRAS 13224, the shape of the UFO absorption lines varies with luminosity. In other words, the geometric structure of the disk wind changes with luminosity variation. We will use MONACO to reproduce the variation of UFO spectra depending on luminosity change and constrain the actual physical picture from the assumed variation of the geometric structure.
In this program, I visited Dr. Misaki Mizumoto, Assistant Professor (The Hakubi Project) at the Graduate School of Science, Kyoto University. He has been my collaborative researcher since I was a master's student, and he has published several papers using the results of MONACO simulation.
There are two primary purposes of my visit to him; (1) to have a face-to-face discussion with him, while we have discussed regularly online for the past few years, and (2) to learn how to use MONACO in detail.

A valuable week at Kyoto University

The week I spent in Kyoto turned out to be meaningful.
First of all, I achieved objective (1) more than I expected: I was given a desk in the same room with him for four days, and we started discussing it as soon as we came up with a question. The results we achieved in such a short period were much more significant than my usual progress, and I was reminded of the importance of face-to-face discussions. I gave an oral presentation on the research results obtained through the discussions at the "Black Hole Jet, Accretion Disk, and Disk Wind Research Meeting" on January 25. I also realized after I came back that once we had a close discussion, I was able to ask questions to him actively and discuss even online.
As for the second objective (2), I was also satisfied with the results: although it was the first time I used MONACO, I had already installed and tested MONACO before the visit to start the exercise smoothly. By arranging the gas around the SMBH along with the geometric structure of the disk wind and emitting X-rays isotropically from the center, we calculated the interaction of photons and simulated the X-ray spectrum that we can observe. Unfortunately, I could not reproduce the entire observed spectrum during my visit, but now that I understand the details of the setup, I plan to do fine-tuning by myself.
Lastly, I was feeling very nostalgic because I studied at Kyoto University when I was an undergraduate student. As a result, I spent a meaningful week outside of my research, going out for drinks with my Kyoto University friends and visiting familiar restaurants.

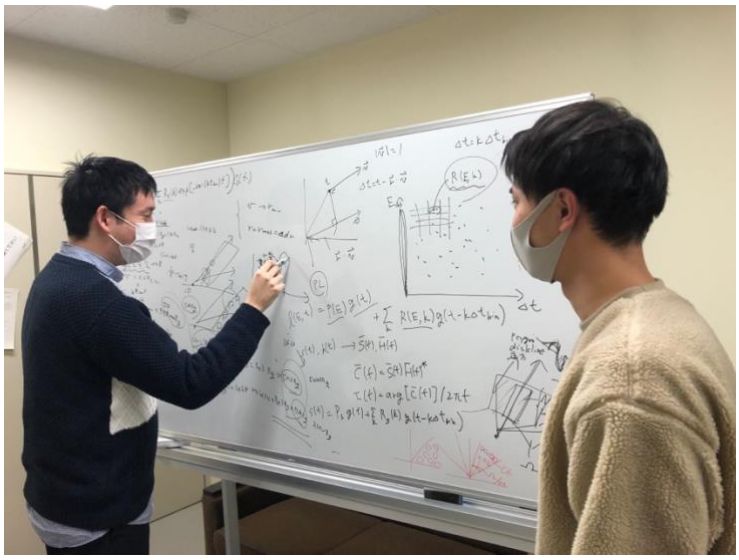

Figure 2: Discussion with Mizumoto-san

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