Measuring the spin of rotating Black Holes

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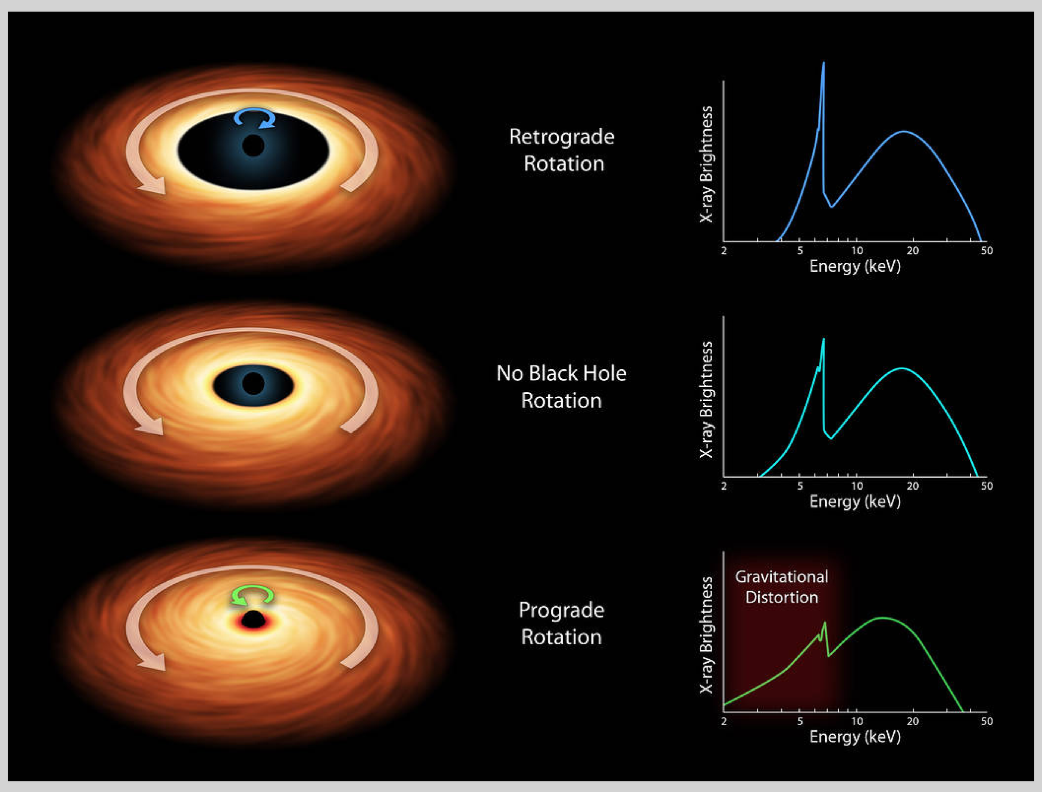
Background and Importance of the Spin Estimate

Origin, Evolution and Destiny of the Universe: The big bang sent matter spinning rapidly into the universe, including black holes. Through careful examination of black holes' spin parameters, we can investigate universal evolution due to black holes' presence during the origin of the universe, as well as their active presence in most galaxies today. Observing the relationship between the stars and black holes of a galaxy is essential to understanding how galaxies formed throughout the cosmos over time as well as their continual evolution. Every object in the universe - from a black hole to a star - spins, and the origin of that spin can be traced back to the beginning of time. The faster a black hole spins, the closer its accretion disk can lie to it - a phenomenon that supports Einstein's theory of relativity. Close examination of spin parameters reflect not only the spin on the universe from the beginning, but also provides evidence for current theories today. Additionally, studying the collapse of a black hole can assist in predicting the destiny of galaxies in the future. Had matter not been spinning after the big bang, we would observe an even distribution of all chemical elements and radiation. However, today we see that there are denser regions in the universe today, observed through current x-ray emission off accretion disks.

The $Fe - K\alpha$ Line Method

- Doppler effect: the change of frequency of electromagnetic waves due to relative motion of the source and observer. Essentially frequency decreases as the observer moves in the opposite direction to the source.
- Gravitational redshift: is that electromagnetic waves passing through a gravitational well experiences increase in wavelength. The way this can be understood is that gravity warps space-time, and photons must expend energy to escape these gravitational wells but must also always travel at the speed of light. By the equation $E = \frac{hc}{\lambda}$ the wavelength of an electromagnetic wave is inversely proportional to its energy, so a photon loses energy to the gravitational well via an increase in its wavelength.
- Relativistic beaming: as the annuli get closer to the ISCO, the gas reaches relativistic speeds, so the x-rays they emit becomes blue-shifted and concentrated in the forward direction towards us, the observers.

These effects combine to create the profile of the $Fe - K\alpha$ line. As annuli become closer to the ISCO, the blue-shift spikes the right-side "horn" and the red-shift lowers the energy contribution from each annuli.



For accreting black holes, ISCO to the event horizon, the more pronounced the relativistic broadening of the $Fe - K\alpha$ line. Using these result, it is possible to calculate the value of ISCO (innermost stable circular orbit - which is the smallest circular orbit for which test particle can stably move around massive object). Following, the derivation of Bardeen, Press, and Teukolsky 1972 for a rotating black hole (Kerr metric solution) spin determines on the value of ISCO, hence using emission lines it is possible to deduce the black hole's spin.

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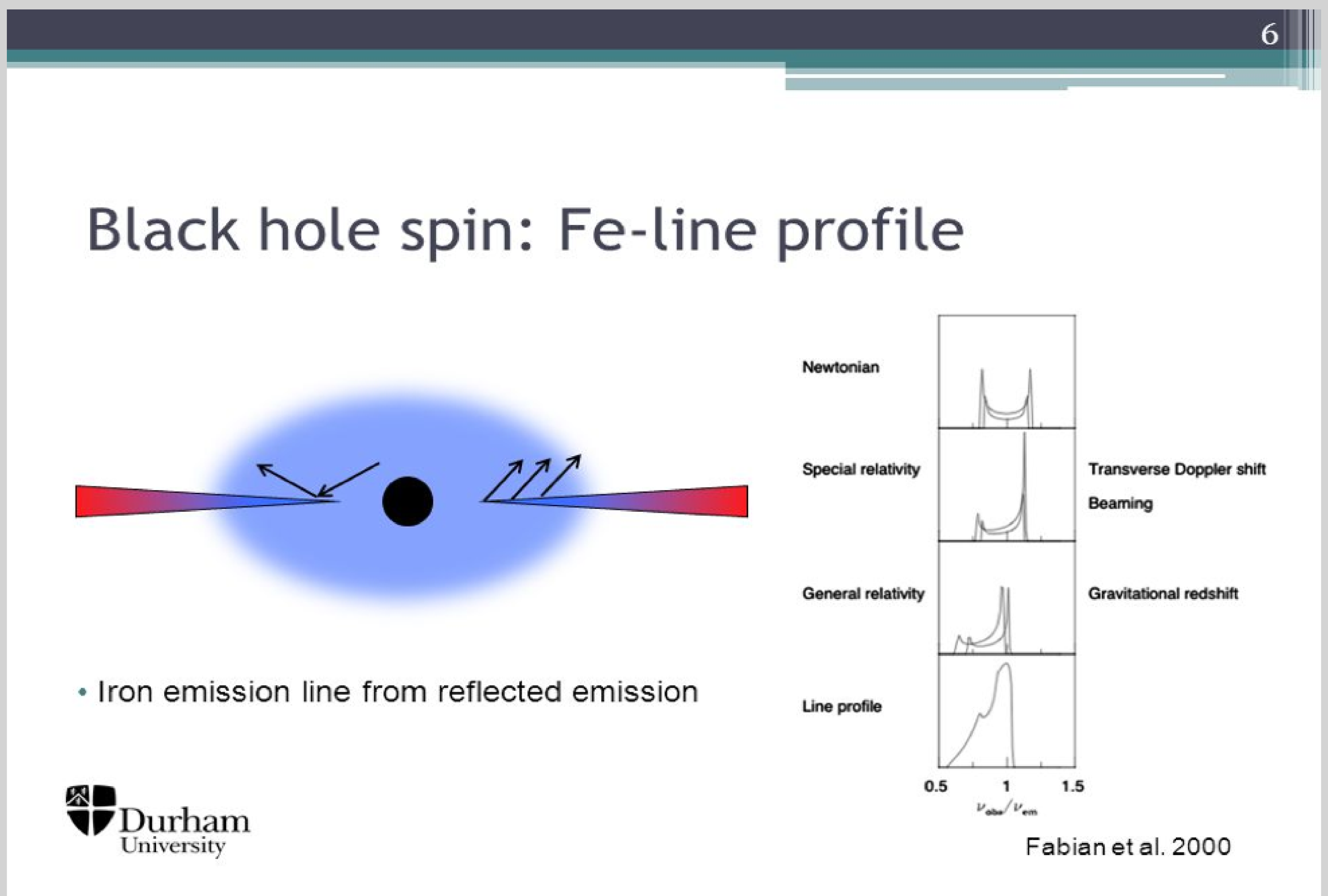
Comptonization and the Reflection Spectrum

The self-irradiation of the accretion disk is not sufficient to remove the K-shell electrons from Fe atoms. The X-rays needed to produce the observed Fe emission spectrum is provided by a Compton upscattering of photons that reflect back onto the accretion disk.

- Essentially the conversion of gravitational potential energy by falling matter into kinetic and thermal energy creates a corona of hot ionized electron gas around the black hole.
- These electrons Compton upscatter photons from the accretion disk, creating an X-ray continuum spectrum.
- Some of the photons from this continuum reflect back onto the accretion disk with enough energy to excite the Fe atoms, generating the $Fe - K\alpha$ line.



Methods

Our project focused on replicating the results of Miller, J. M., et al. (2008) in estimating the spin of GX 339-4, a low mass X-ray binary, using XSPEC X-ray analysis software. Miller et al took spectra from the XIS and HXD instruments aboard Suzaku and fit it using the diskbb model developed by Mitsuda et al. 1984 to examine the $Fe - K\alpha$ "spike" and Comptonization "hump" that is characteristic of disk reflection of the relativistically broadened iron line [Figure]. To measure the spin computationally, the team fit the spectra to a simple disk model and a constant-density ionized disk model convolved with the kerrdisk line function, which has the black hole's spin as free parameter, via XSPEC's kerrconv .

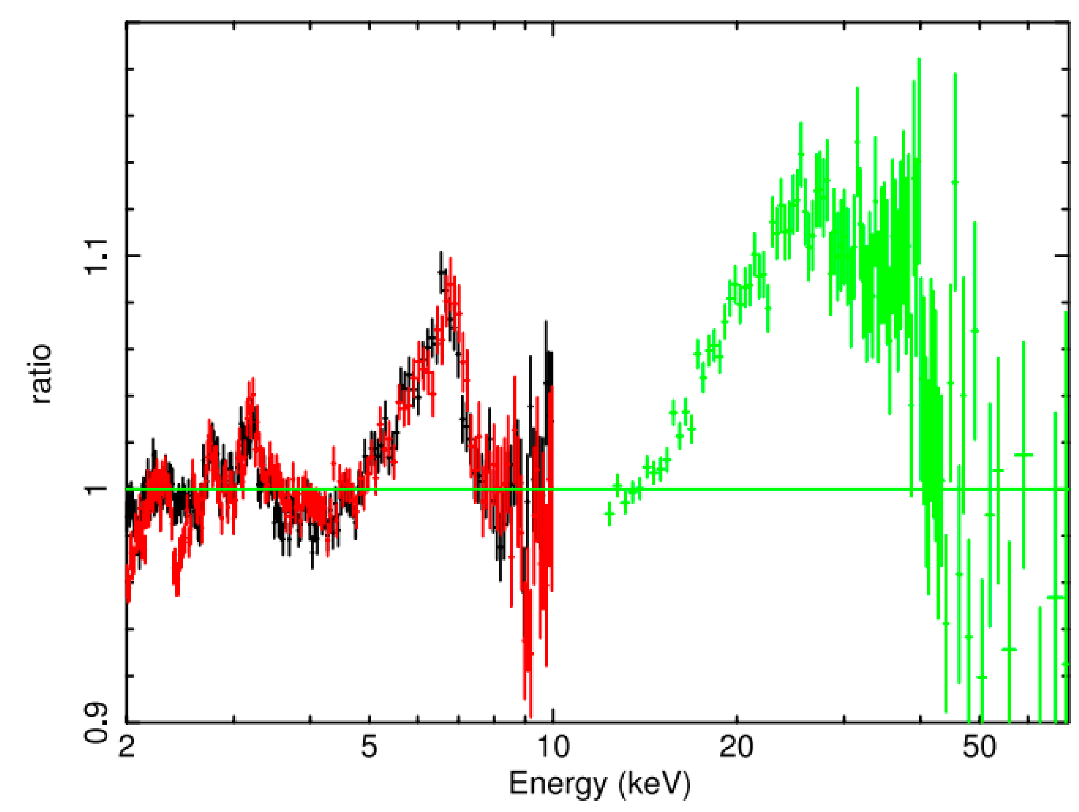


FIG. 1.—Data/model ratio obtained when the *Suzaku* spectra of GX 339−4 are fitted with a phenomenological disk plus power law model. The 4.0–7.0 keV and 15.0–40.0 keV regions were ignored when fitting the model. The curvature at high energy is a clear signature of disk reflection.

Figure: Miller, J.M. et al (2008)

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