An Examination of Black Hole Spin

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273H Project

Project Overview

- Modeling the spin of black holes
- Find how the spin of a black hole is related to its other physical properties
- Research the current models used to determine spin
- Focus on the emission spectrum of the BH and the iron Kα line
- Model the effects of doppler shift and gravitational redshift on the emission spectrum

Project Plan

Discussion

Discuss my questions with someone more knowledgeable

Modeling

Using my understanding of the math to make models of BH data

01

02

03

04

05

Research

Reading articles on black hole models for spin

Mathematical understanding

Understand the equations used in most models of spin

Written Analysis

Analyze my conclusions from this project

Expected Outcomes

With this project I hope to:

- Understand black hole properties
- Become more informed on the current state of black hole research
- Understand the math and physics that govern black holes
- Gain experience plotting astrophysical data and improve my computational skills, specifically in python
- Make connections between the content from PHYS273 and the physics of spinning black holes

Black holes is the topic in astrophysics that interests me the most so I am very excited to learn more about them in a more rigorous setting. I want to get a better conceptual understanding of the physics of black holes but I am especially excited to get exposed to some of the math and more complex concepts.

Articles I have read

How to Measure the Spin of a Black Hole (NASA)

- How spin rates affect the radius of the accretion disk
- How this then relates to the X-ray spectrum
- Gravitational effects on the emission spectrum
- How this can be used to determine the spin

https://www.nasa.gov/image-article/how-measure-spin-of-black-hole/

Articles I have read

Measuring the spin of rotating Black Holes (UC Berkeley)

This article provided a brief description of the processes that contribute to the change the profile of the Fe – Kα line

- Doppler effect: change of frequency of EM waves due to relative motion
- Gravitational redshift: wavelength increase of EM waves as they pass through gravitational wells.
- Relativistic Beaming: x-rays emitted from the ISCO of the accretion disk become blue shifted due to relativistic effects

https://ulab.berkeley.edu/static/doc/posters/s182.pdf

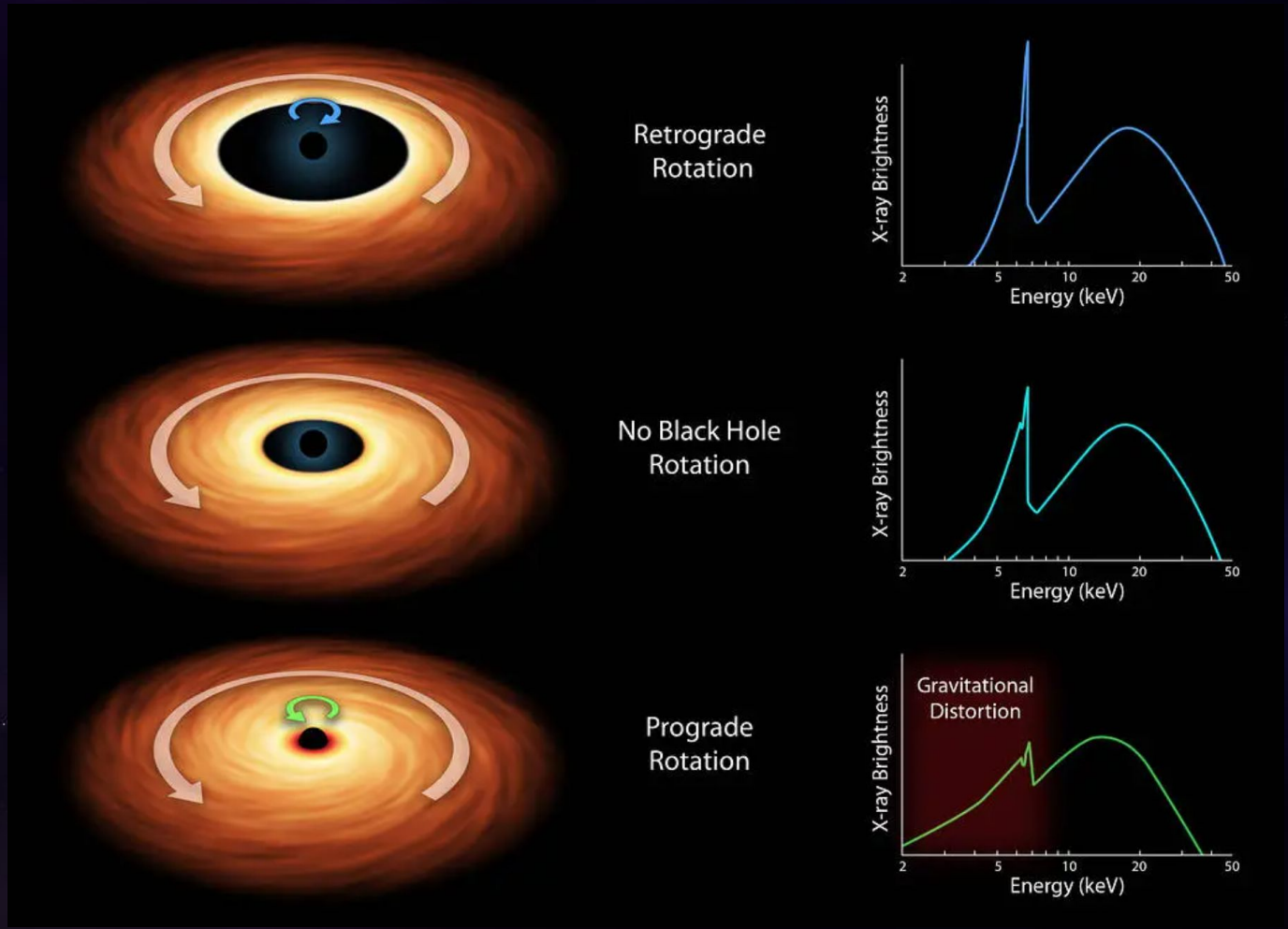

Image source: https://www.nasa.gov/image-article/how-measure-spin-of-black-hole/

Articles I have read

Observational Constraints on Black Hole Spin (Chris Reynolds)

This article provided a great introduction to black hole physics that will be very useful in continuing my research for this project:

- Physics of a spinning black hole
- Concept of a dimensionless spin parameter *a* (between -1 and 1)
- Equations that are dependent on the spin parameter
- Innermost stable circular orbit (ISCO)

https://www.annualreviews.org/content/journals/10.1146/annurev-astro-112420-035022

Articles I have read

Observational Constraints on Black Hole Spin (Chris Reynolds)

This article also outlines several different methods for determining the spin of black holes:

- X-Ray Reflection method
- Thermal Continuum fitting: based on the fact that spin effects temperature of the disk
- Black Hole Spin from Gravitational Waves
  - The GW waveform that we can detect is affected by the magnitude and directions of BH spins

https://www.annualreviews.org/content/journals/10.1146/annurev-astro-112420-035022

Equations Used

Spin Parameter

$$a \equiv \frac{J_c}{GM^2}$$

$$-1 \leq a \leq 1$$

ISCO

$$r_{ISCO} = \left\{3 + Z_2 \mp [(3 - Z_1)(3 + Z_1 + 2Z_2)]^{1/2}\right\} r_g$$

$$Z_1 = 1 + 1(1 - a^2)^{1/3}[(1 + a)^{1/3} + (1 - a)^{1/3}]$$

$$Z_2 = (3a^2 + Z_1^2)^{1/2}$$

Extractable Energy from Rotation

$$E_{spin} = \{1 - \tfrac{1}{2}[1 + \sqrt{1 - a^2})^2 + a^2]^{1/2}\}Mc^2$$

Lense-Thirring precession

$$\Omega_{LT} = \frac{2a(GM)^2}{c^5 r^3}$$

Effective Spin (merging BHs)

$$X_{eff} = \frac{M_1 a_1 + M_2 a_2}{M_1 + M_2} L$$

Other Sources

I read a few other sources for some additional background information. None of them related to the project as much as the ones previously discussed but provided some interesting background information.

- A new Method to Measure Black Hole Spin (video)
- Black Hole Spin Energy Contribution to Black Hole Mass and the Spin Energy Reservoir article
- Probing the origin of the iron Kα line article
- Measuring the Spin of a Black Hole article
- Active Galactic Nuclei article from GSFC

What I Have Learned

- Why black holes produce iron Kα lines in the X-ray emission spectrum
- How this line profile is affected by the gravitational effects of the black hole
- What is the ISCO and how it is related to the spin of the black hole
- How iron Kα lines can be used to determine spin (X-Ray Reflection method)
- That gravitational waves can also be a method for determining spin

Interesting finding: if a BH spins with $a > 1$ then the event horizon goes away and the singularity would be visible! But this is impossible. (Reynolds)

Next Steps

- Have a meeting with Chris Reynolds
- Try to understand the equations or models used in the X-ray reflection method
- Further research into how the blueshift from rotation can also be used to find spin
- Plot these equations/relationships for different BH parameters

Challenges

- Narrowing the scope of my project into a more focused topic
    - Focus on the iron Kα X-ray line and how the effects of doppler shift and gravitational redshift relate to the spin
- Relating my project to the topics discussed in class
    – Focusing on the X-ray emission and changes in wavelength should help with this
- Using Python to simulate these properties

Questions?