X-ray Emission Signatures from Stellar Death Leading to Black Hole Formation

Physics of the Cosmos 2nd Early Career NASA Workshop 23-25 Sep 2025

Author : Alaa Salah Afifi

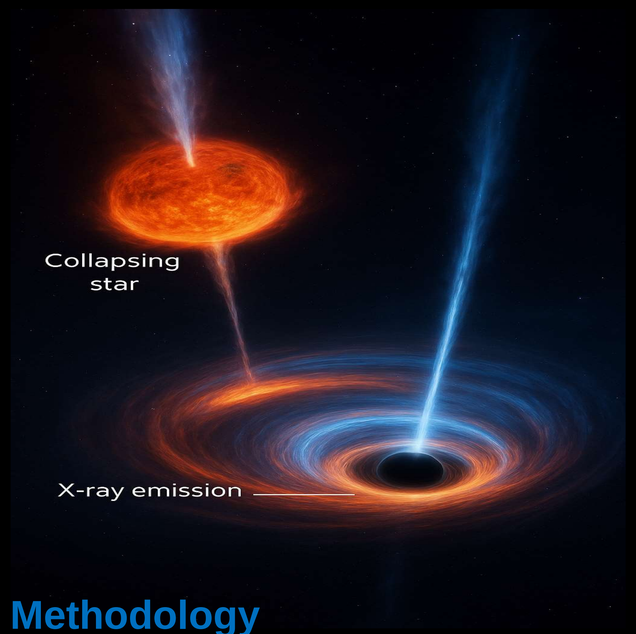
Affilation : Kepler space University

Abstract

Massive star collapse may lead to supernova explosion, direct collapse, or fallback accretion black hole formation. X-ray emission signatures reveal collapse channels, birth spin, and exotic cooling, providing a unique window into black hole formation

Introduction

The fate of giant stars depends on unknown processes, and X-rays can trace these processes. By correlating light curve evolution with spectral diagnostics, X-ray research could uncover how black holes form and challenge physics. supporting NASA's Physics of the Cosmos goals by probing black hole formation pathways.



Methodology

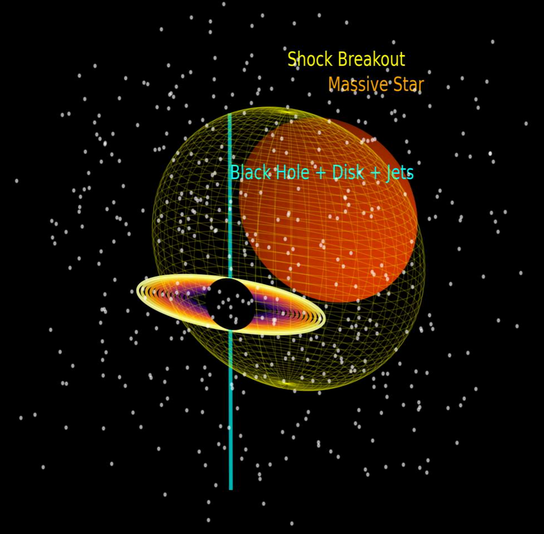
Modeled stellar collapse using fallback accretion, shock breakout, and jet formation, examining progenitor mass, metallicity, and environment. Created synthetic light curves and spectra for X-ray signal diagnostics.

X-ray output scales with fallback accretion

Rate.

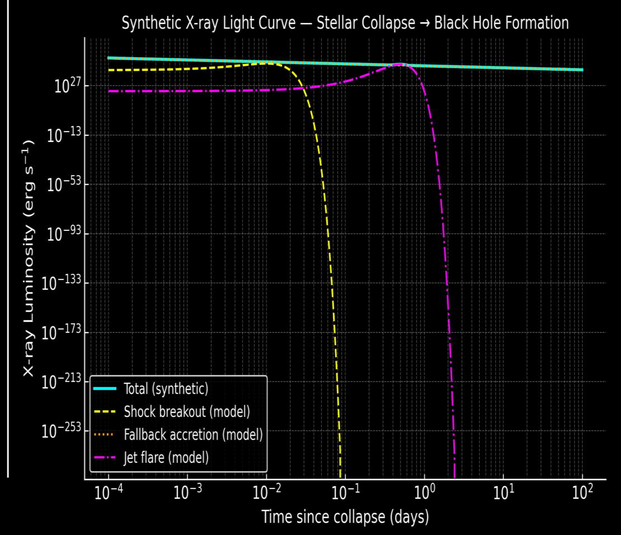
$L_X \propto \dot{M}_{fb} c^2$

X-ray luminosity scales with fallback accretion Rate where $\dot{M}_{fb}$ is the mass inflow rate .



Key Findings:

- **Shock breakout produces short X-ray peaks.**
- **Fallback accretion creates long power-law tails.**
- **Jet activity can cause re-brightening flares.**



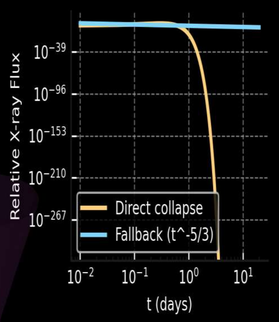
Results/Data Analysis

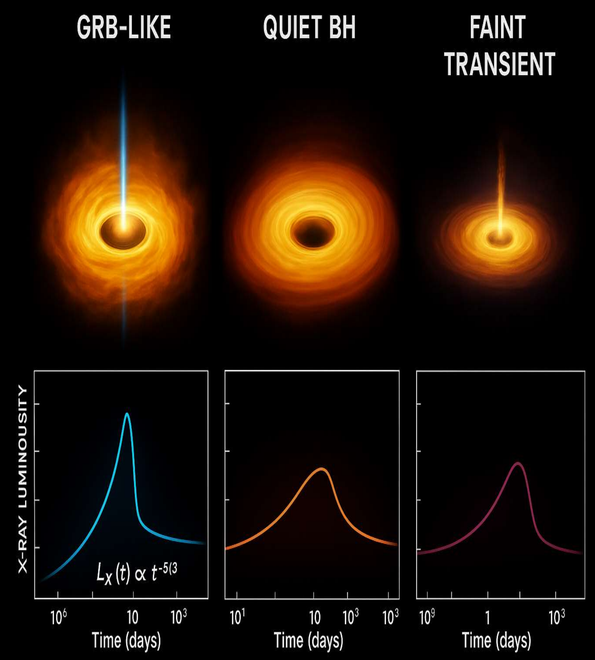
Light Curve Signatures

Synthetic curves show a sharp shock breakout peak followed by a power-law decay.
Breakout duration (t_{sb}) scales with stellar radius
Fallback tail slope depends on progenitor mass and metallicity.

$$L_X(t) \propto t^{-\alpha}, \alpha \approx \frac{5}{3}$$

.





Spectral Diagnostics

Spectral diagnostics differentiate early and late phases of breakout emission, with more massive stars causing brighter and less metal-poor stars causing longer fallback emission.

conclusion

X-ray observations provide a powerful window into the birth of black holes.
By tracing shock breakout peaks and fallback accretion tails, we can distinguish between stellar collapse pathways and constrain the role of progenitor mass, metallicity, and spin. These diagnostics not only reveal how massive stars die but also open opportunities to test extreme physics beyond the Standard Model.

References

•Fryer, C.L., Belczynski, K., Wiktorowicz, G., Dominik, M., Kalogera, V. & Holz, D.E. (2012) *Compact Remnant Mass Function: Dependence on the Explosion Mechanism and Metallicity*. Astrophysical Journal, 749(1), 91.
•O'Connor, E. & Ott, C.D. (2011) *Black Hole Formation in Failing Core-Collapse Supernovae*. Astrophysical Journal, 730(2), 70.
•Sukhbold, T., Ertl, T., Woosley, S.E., Brown, J.M. & Janka, H.T. (2016) *Core-Collapse Supernovae from 9 to 120 Solar Masses Based on Neutrino-Powered Explosions*. Astrophysical Journal, 821(1), 38.
•Woosley, S.E. & Heger, A. (2012) *Long Gamma-Ray Transients from Collapsars*. Astrophysical Journal, 752(1), 32.

Author contact

afifialaa036@gmail.com
LinkedIn: Scan QR below