Binary Black Hole Merger Produces Short GRB in AGN Disk: The Case of S241125n

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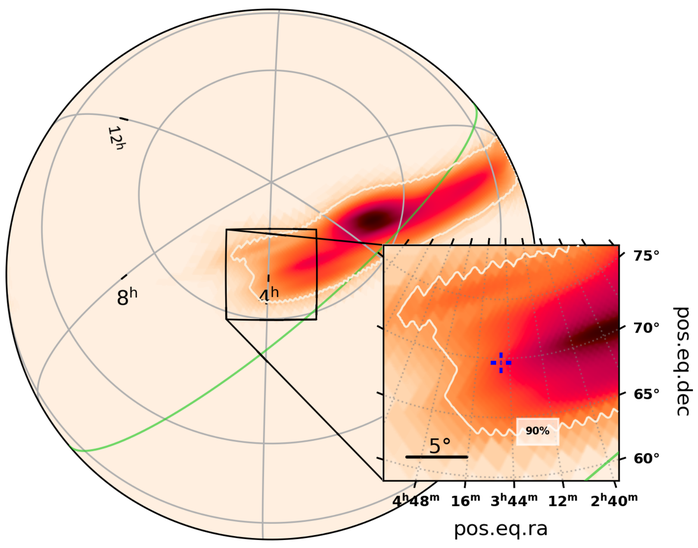
Abstract

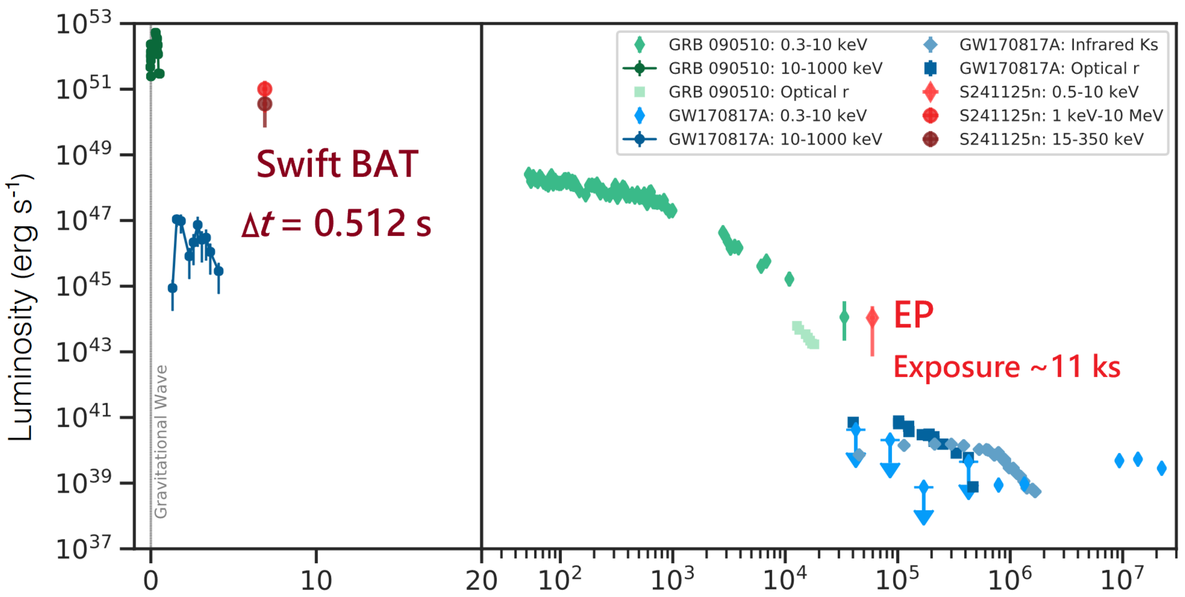
Recently, the gravitational wave (GW) event for black hole (BH)-BH mergers, LIGO/Virgo/KAGRA (LVK) S241125n, has been reported to coincide with a short gamma-ray burst (GRB) and X-ray afterglow emission. If they were actually associated, it could potentially unveil the environments of mergers and provide attractive targets for multi-messenger observations. We summarize these observations and model it as the emission associated with a binary BH merger of total mass $> 100\,M_\odot$ occurring within an active galactic nucleus (AGN), where the merger remnant accretes disk material at hyper-Eddington rates. The resulting jet could lead to the GRB associated with the GW event. The GRB, detected by Swift-BAT, exhibits a Comptonized spectrum with an unusually soft photon index, which is consistent with emission from the jet interacting with the dense AGN disk environment. Its X-ray afterglow shows an unusually hard spectrum, indicating possible strong absorption by a high column density typical of AGN disks. Furthermore, the time delay between the GW and GRB signals, the duration of the GRB, as well as their luminosities, can be fitted within reasonable disk parameter ranges and with a BBH merger of total mass $> 100\,M_\odot$. We highlight the importance of identifying the host galaxy and constraining the orbital eccentricity of the merger to test the model.

The GW–GRB Association



- **GW**: $d_L = 4173 \pm 1590$ Mpc ($z = 0.73$) and with probabilities as BBH of $> 99\%$ (LIGO Scientific Collaboration et al. 2024).
- The 90% credible region covers an area of 2196 deg^2, which occupies 5.32% of the whole sky.
- The candidate **EM** counterparts (both the prompt and afterglow of the GRB) lie within the 90% credible region.

The Prompt and Afterglow of the GRB



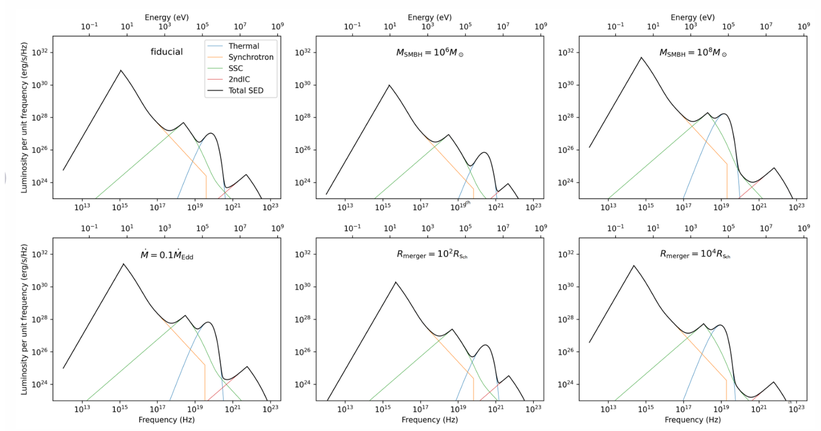
- The energy and luminosity of S241125n are similar to those of short GRBs, but the observed **spectral** characteristics differ.
- The **prompt's** ($15 - 350$ keV) photon index is $-2.2^{+0.6}_{-0.8}$, likely **softer** than the typical prompt value of ≈ -1.5; the **afterglow** ($0.5 - 10$ keV) shows an absorbed power-law with index $-0.43^{+0.76}_{-0.74}$, significantly **harder** than the usual value of -2.
- This GRB is located at a Galactic latitude of approximately 12 degrees, near the **Galactic** plane (< 10 degrees); no definitive optical counterpart has been identified.

Theoretic Explanation

- We interpret it as the emission associated with a **binary BH merger** occurring with in an **AGN**, where the **massive** merger remnant ($150 M_\odot$ is assumed) **accretes** disk material at hyper-Eddington rates. The resulting **jet** could lead to the GRB associated with the GW event.

Prompt Emission Mechanism

The expected SED of a GRB originating from a BBH merger in AGN disks



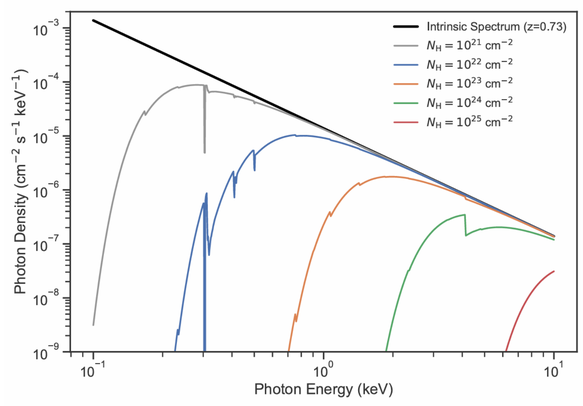
t_{delay}=11.264s
$L_{breakout}$=1.01×10^{51}erg s^{-1}
fix $\gamma_{sf,f} = 15$ and $\theta_j = 0.1$

$\tilde{H} \approx 5.69 \times 10^{12}$ cm
$\tilde{\rho} \approx 4.20 \times 10^{-9}$ g cm^{-3}

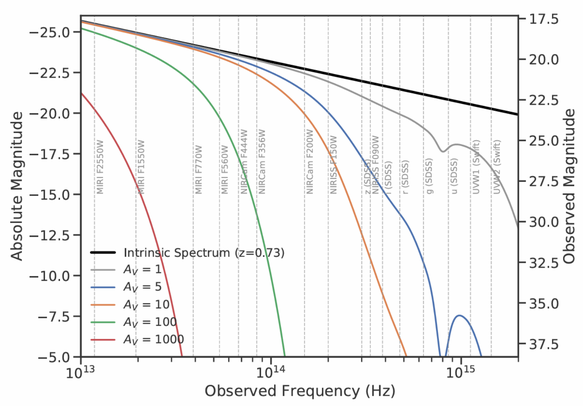
Standard disk with:
$M_{SMBH} = 10^7 M_\odot$
$\dot{M} = 0.01 \dot{M}_{Edd}$
$\tilde{\alpha} = 0.05$
$R_{merger} \approx 800 R_S$
$\Delta t \cdot (1+z) = 0.729$s

Afterglow

X-ray absorption effects on a power-law spectrum of initial photon index = 2 emitted from redshift z = 0.73 and observed at z = 0.



Extinction effects of **infrared**, **optical** and **UV** bands from a synchrotron spectrum emitted at z = 0.73 and observed at z=0.



Discussion and Outlook

- The lack of a detected host galaxy favors the scenario of BHs captured by AGN disks around lower-mass SMBHs.
- Further conducting deep-field observations of the host galaxy
- Further fitting analysis of multi-messenger signals (e.g., eccentricity estimate from GW).

Reference

S.-R. Zhang, et al., "S241125n: Binary Black Hole Merger Produces Short GRB in AGN Disk," ArXiv e-prints, May 2025 (Submitted). arXiv:2505.10395 [astro-ph].

SCAN ME for more information about my research on compact objects in AGN disks

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