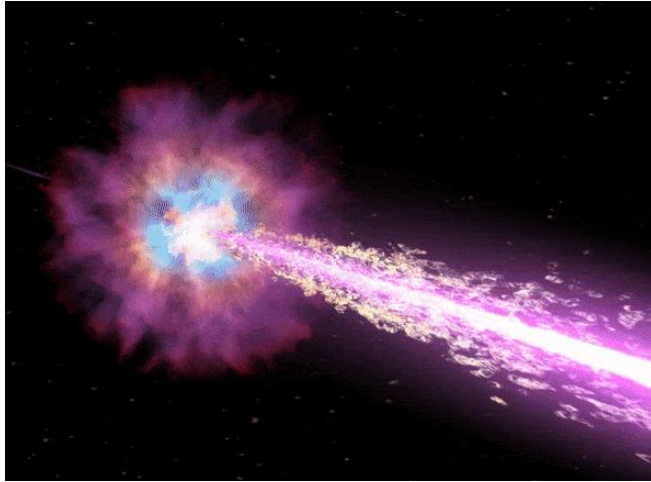


# Extragalactic fast X-ray transient from a weak relativistic jet associated with a Type Ic-BL supernova

Hui Sun

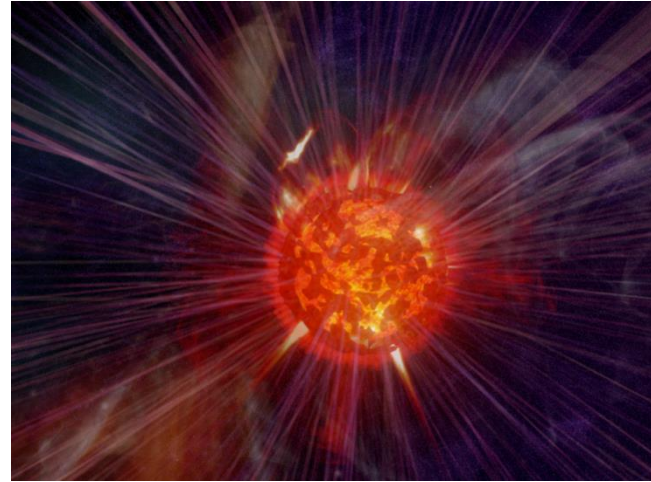
National Astronomical Observatories, CAS  
Einstein Probe Science Center

# Emissions from Massive Star Core Collapse



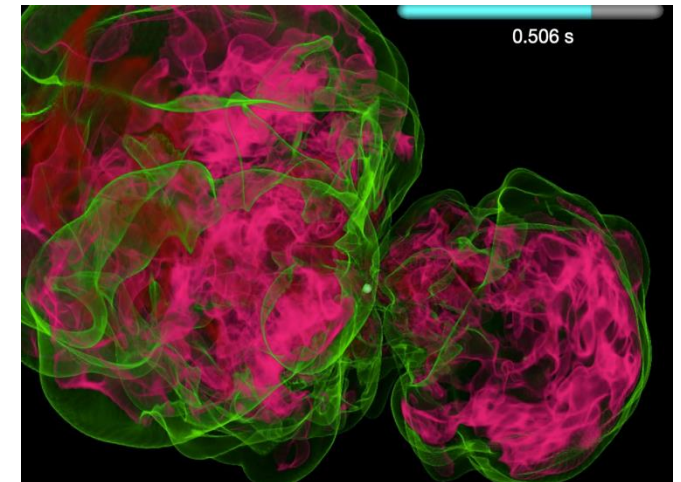
## Gamma-ray burst

- gamma-ray band
- seconds to hours
- thousands detected
- X-ray analogs from the extrapolation



## SN Shock break-out

- soft X-ray band
- hundreds of seconds
- very few X-ray SBOs (XRO 080109, GRB 060218?)



## Supernova

- optical band
- days to weeks
- tens of thousands (nearby)

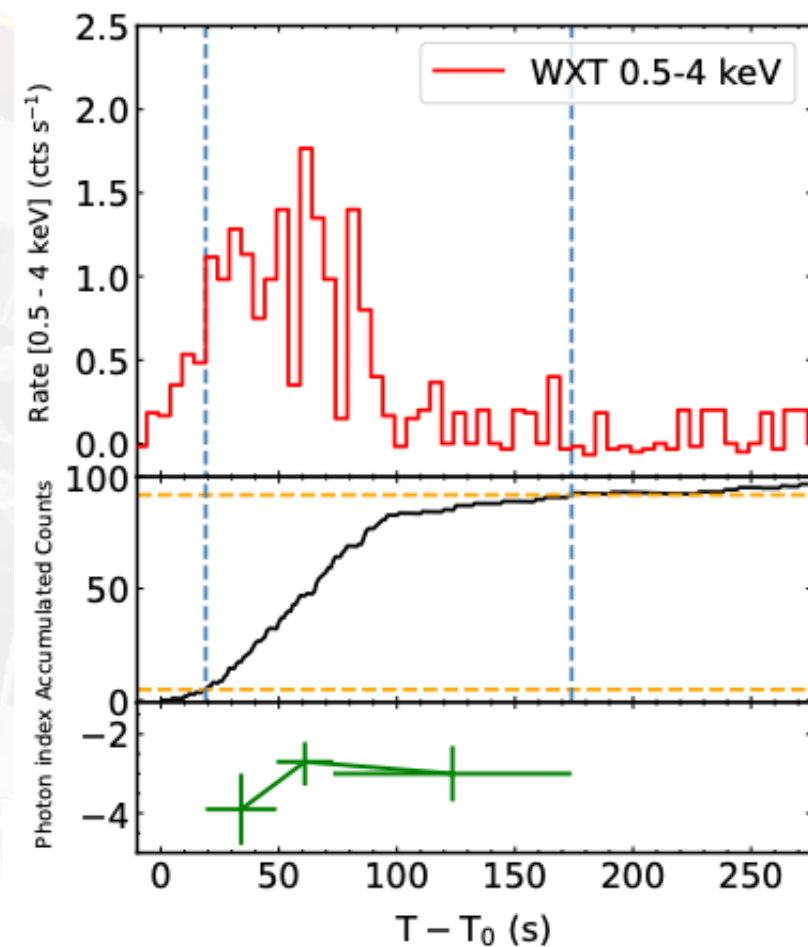
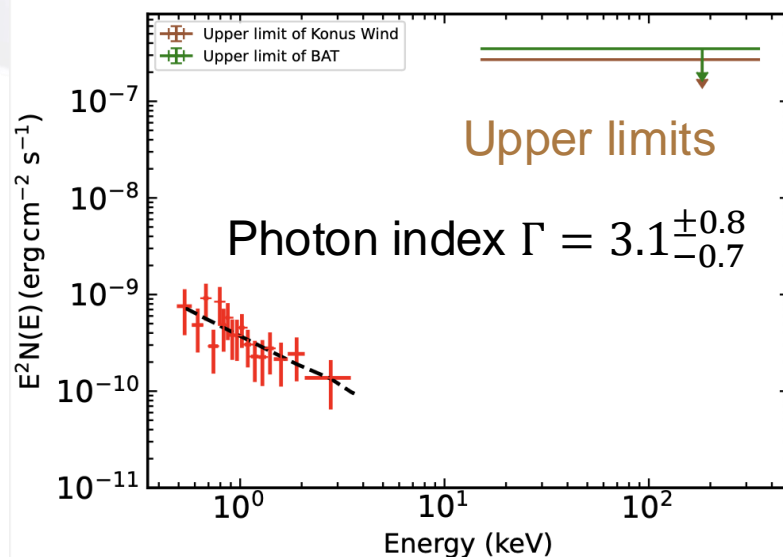
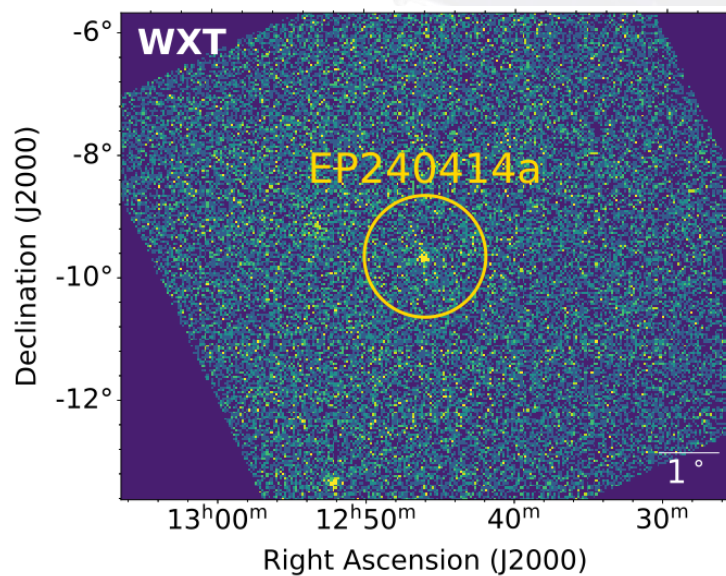
see Yuan Liu's talk on EP240315a

# EP240414a: Detection by the Wide-field X-ray Telescope



$T_0 = 09:49:10$  on 14 April 2024

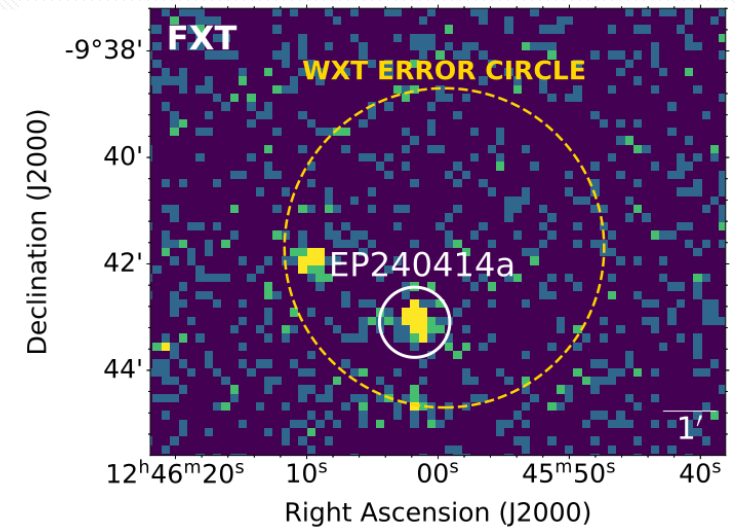
- ✦ Fast X-ray transients ( $T_{90} = 155$  s in 0.5–4 keV)
- ✦ Soft spectrum: photon index 3.1
- ✦ No gamma-ray signals detected: only upper limits given by Konus Wind and Swift/BAT



Sun, Li, Liu et al. accepted for publication in Nature Astronomy arXiv:2410.02315

# Follow-up Reports in GCN Circulars

- 36681. [X-ray transient EP240414a: Chandra late time observation](#)
- 36362. [MeerKAT Discovery of a Probable Radio Counterpart to EP240414a](#)
- 36355. [X-ray transient EP240414a: Detection of associated supernova](#)
- 36189. [EP240414a: Near-IR observations with NIRES and WINTER](#)
- 36187. [EP240414A: Terskol Zeiss-2000 optical upper limit](#)
- 36171. [EP240414a: GMG observation](#)
- 36154. [EP240414a: GSP detects optical candidate counterpart AT2024gsa](#)
- 36150. [EP240414a: Pan-STARRS detects re-brightening of the candidate counterpart AT2024gsa](#)
- 36129. [EP240414a: FP-FXT follow-up observation](#)
- 36094. [EP240414a: Kinder optical counterpart candidate possibly associated with the galaxy SDSS J124601.99-094309.3](#)
- 36091. [EP240414a: EP-WXT detection of a fast X-ray transient](#)



Kinder optical counterpart candidate

FXT observation confirmed the optical detection 2hrs later

TITLE: GCN CIRCULAR  
NUMBER: 36110  
SUBJECT: X-ray transient EP 240414a - GTC spectroscopic observations  
DATE: 24/04/15 09:47:43 GMT  
FROM: Andrew Levan at Radboud University <[a.levan@astro.ru.nl](mailto:a.levan@astro.ru.nl)>

P.G. Jonker (Radboud), A.J. Levan (Radboud), D.B. Malesani (Radboud/DAWN NBI), N.R. Tanvir (Leicester), D. Garcia (IAC), A de Ugarte Postigo (CNRS, OCA, LAM) report for a larger collaboration:

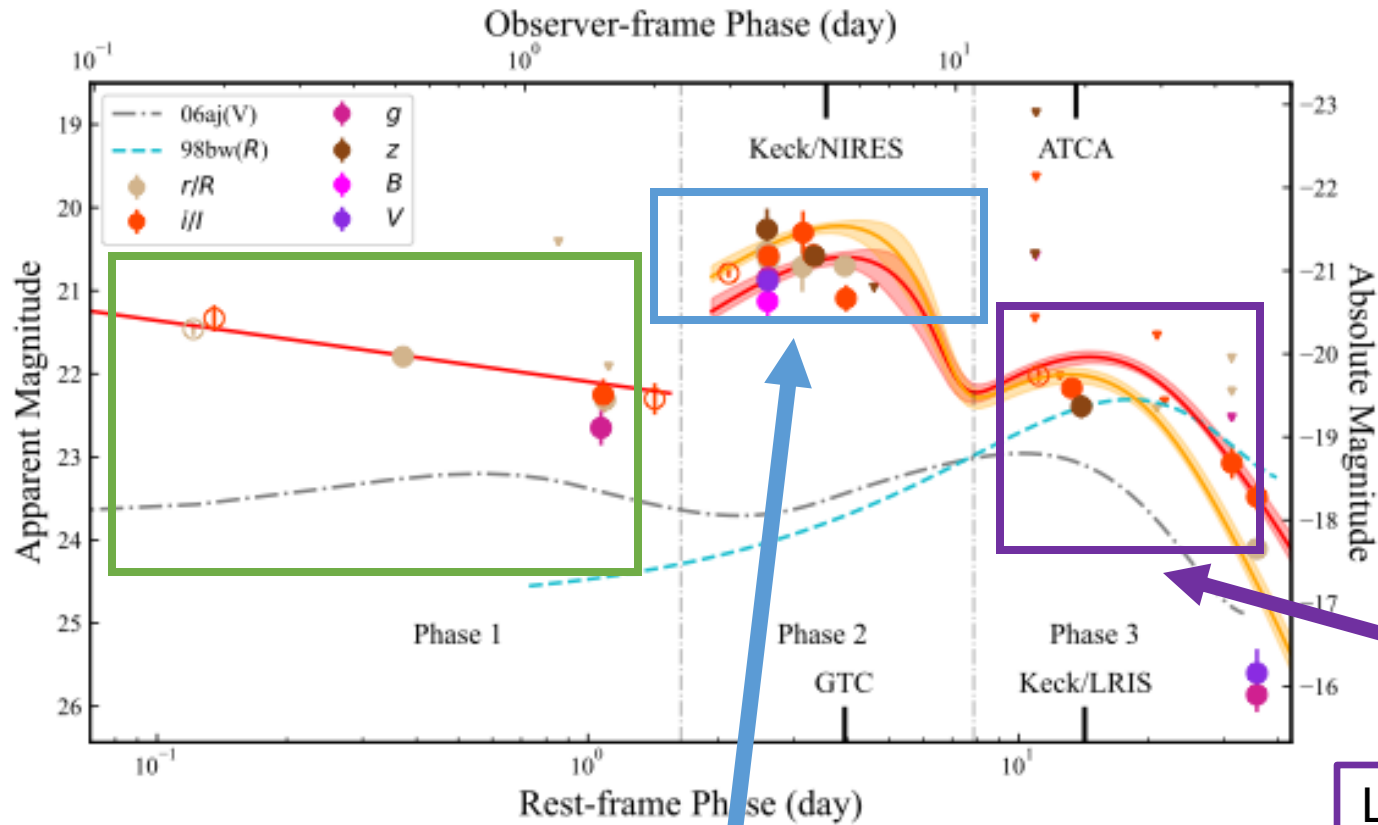
We obtained spectroscopic observations of the counterpart and candidate host galaxy of EP 240414a (Lian et al., GCN 36091; Aryan et al., GCN 36094; Xu et al., GCN 36105) with the GTC telescope equipped with the OSIRIS+ instrument. Observations began at 00:46 UT on April 15, approximately 15 hr after the transient onset. 4x1200 s of exposures were obtained with the slit oriented through both the nucleus of the candidate host galaxy SDSS J124601.99-094309.3 and the counterpart (Aryan et al., GCN 36094).

$z = 0.4$  for the potential host galaxy

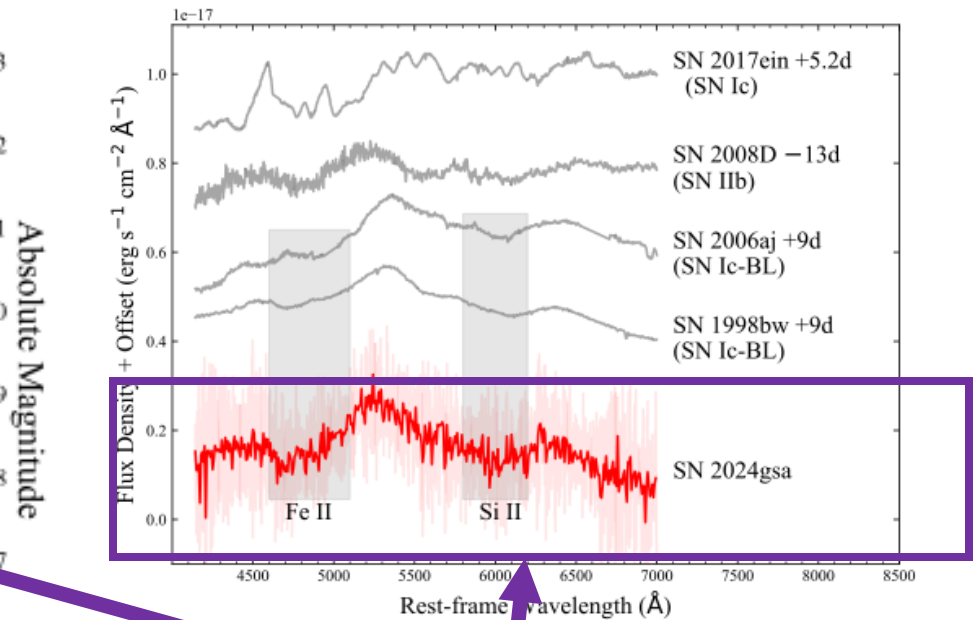
$L_{X,peak} \sim 1.3e48$  erg/s

# Optical: Indication of a Type Ic Broad-lined SN

## Long-term light curve



A bright optical bump at  $T_0+4$  days



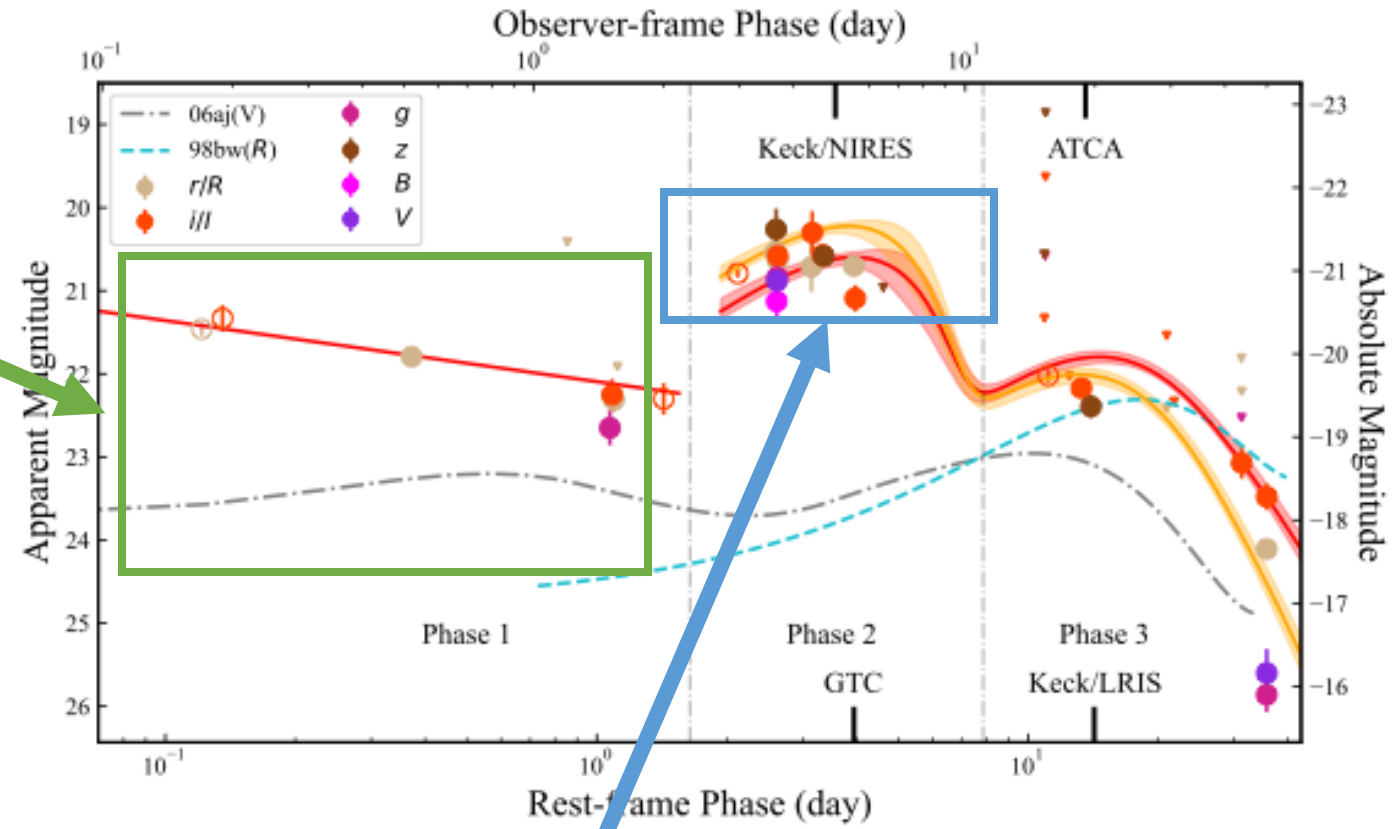
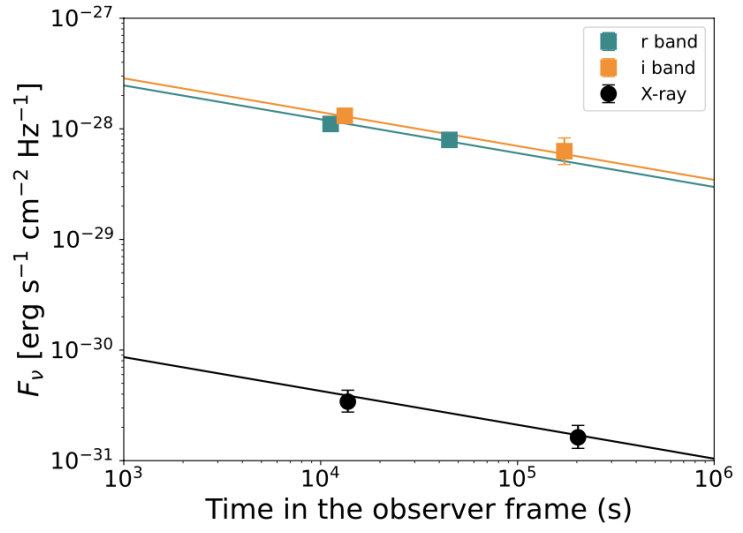
Later rebrightening due to the spectroscopically-confirmed type Ic-BL supernova

**CORE-COLLAPSE OF A WOLF-RAYET STAR**

# Optical: Indication of a Type Ic Broad-lined SN

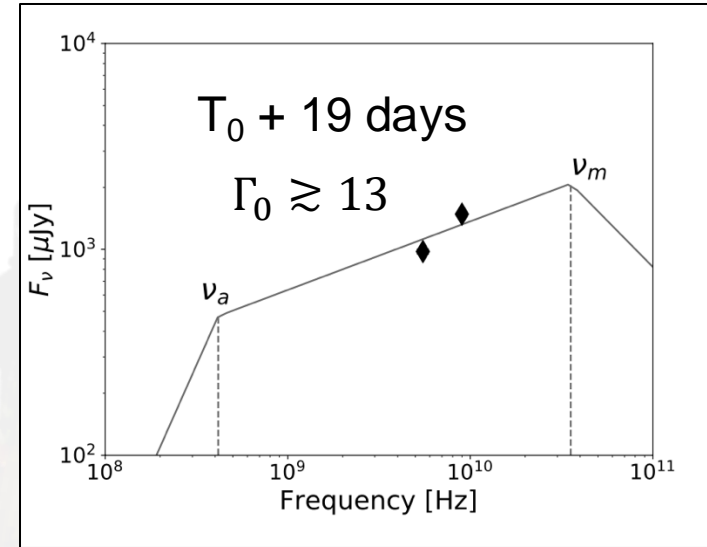
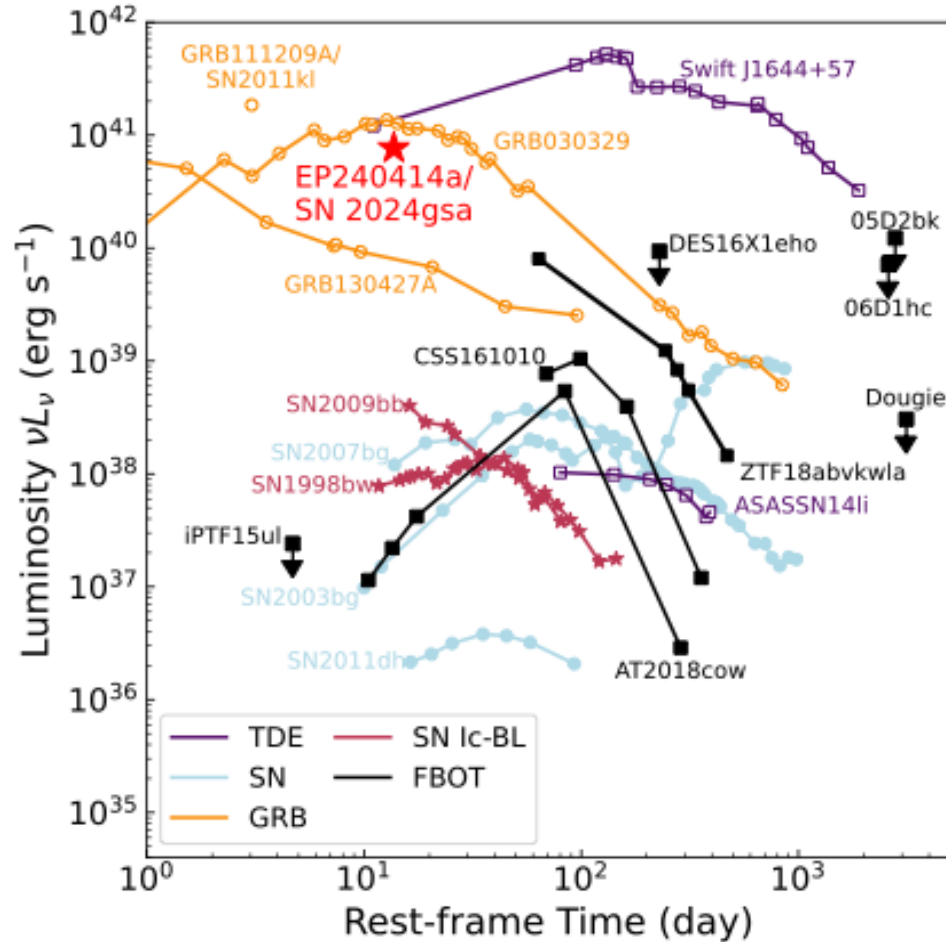
## Long-term light curve

Afterglow from a successful jet



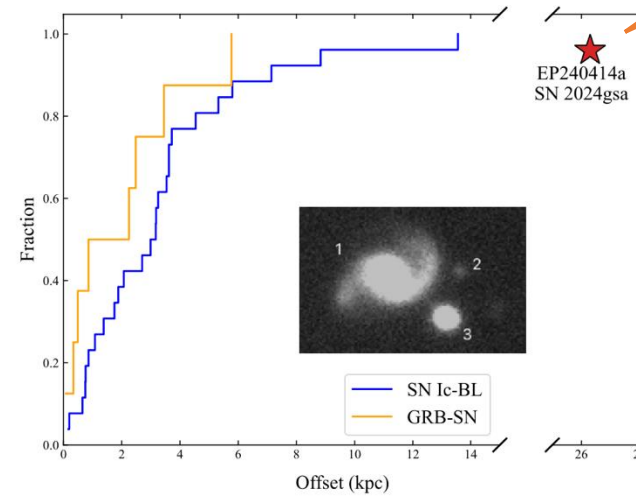
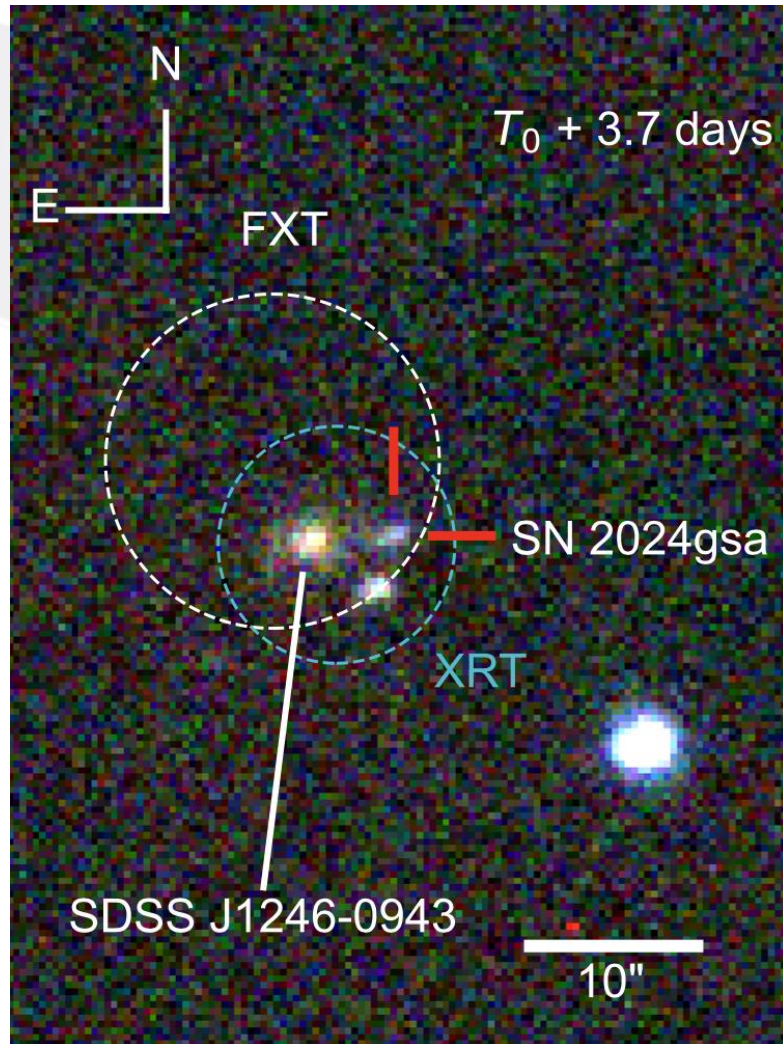
Shock breakout and cooling emission from the expanding hot material at large radii  
**an extended shell**

# Radio: originate from weak-relativistic jet



- ✧ Detected at  $\sim T_0 + 19$  days (ATCA, PI: An Tao)
- ✧ Rising spectrum between 5.5 and 9 GHz
- ✧ Comparable to that of luminous GRBs

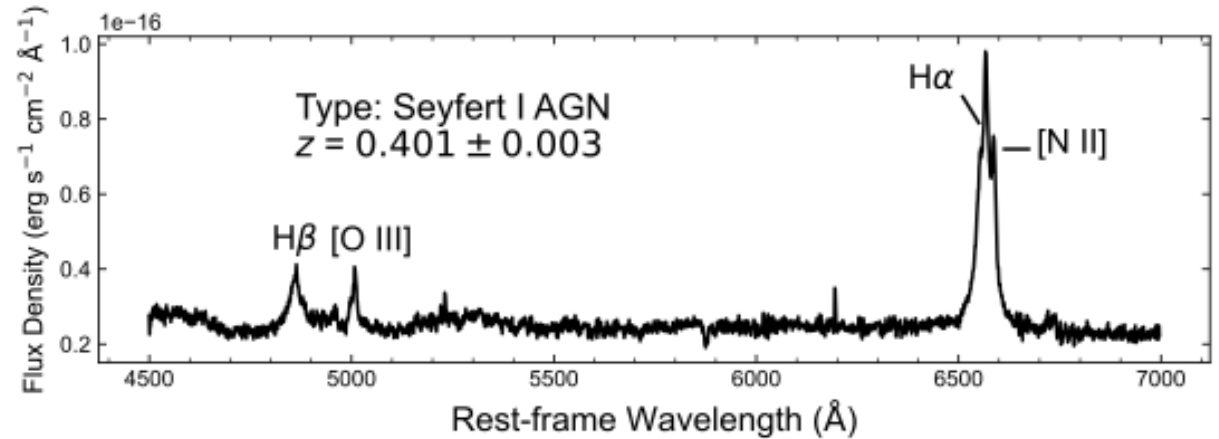
# Host galaxy



SN 2024gsa

Projected offset ~ 26.3 kpc

**Significantly larger than the typical offset for SNe Ic-BL**





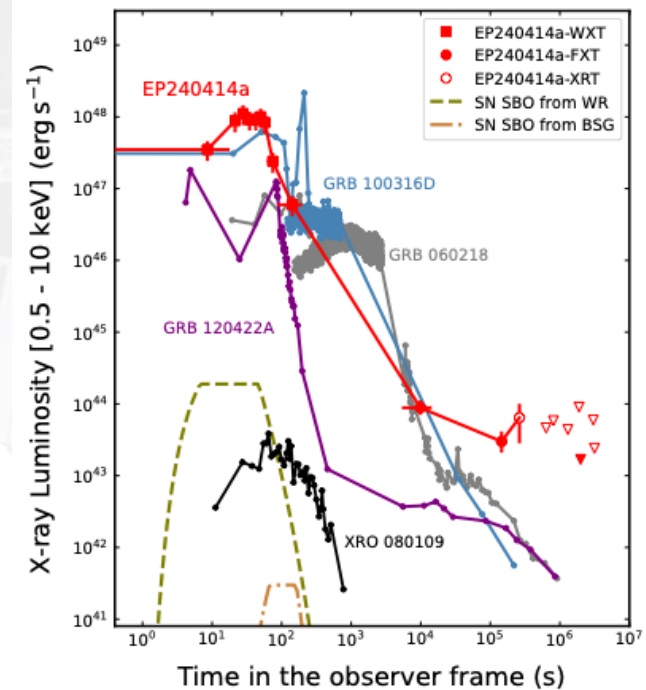
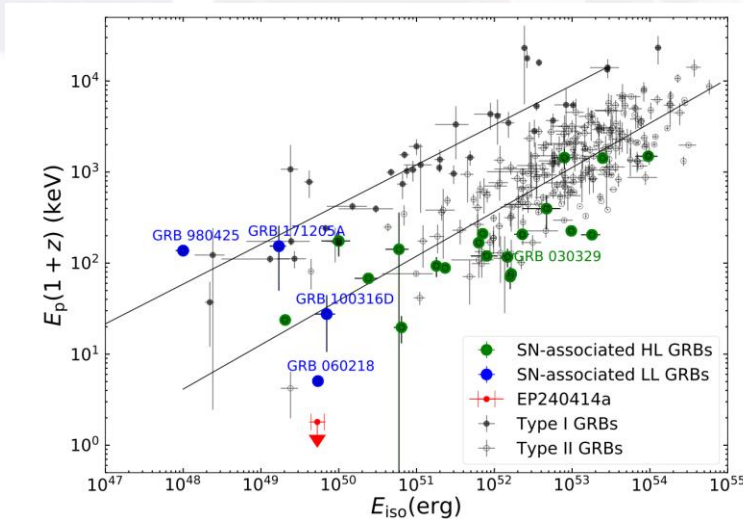
# EP240414a: new type of fast X-ray transient

- ✧ Much **brighter** than theoretical prediction from SN shock breakout
- ✧ Much **softer** spectrum ( $E_{\text{peak}} < 1.3 \text{ keV}$ ), a unique outlier in the “Amati relation”
- ✧ Failed to satisfy the relativistic shock breakout relation
- ✧ Large offset from its host galaxy

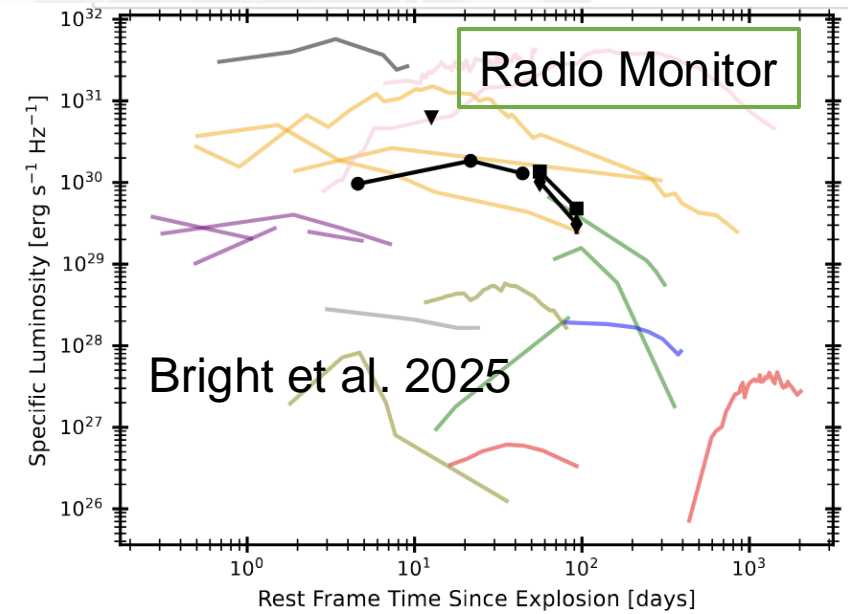
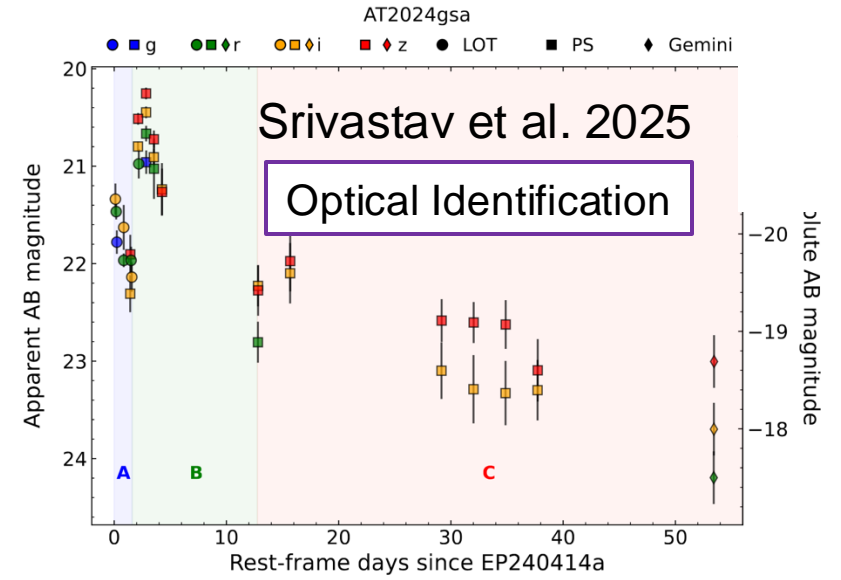
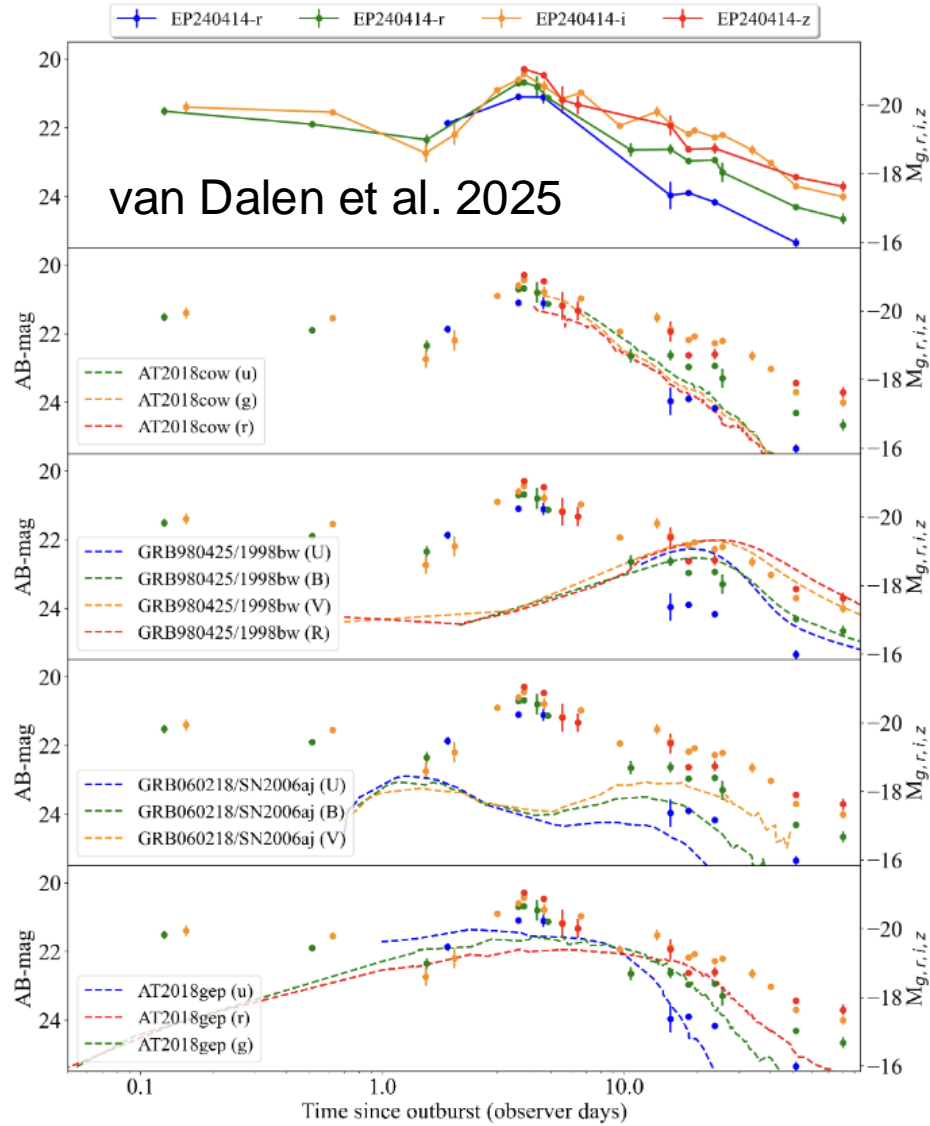
**Soft fast X-ray transient from a weak relativistic jet in an extended shell associated with core-collapse explosion**

$$t_{\text{bo}}^{\text{obs}} \sim 20 \text{ s} \left( \frac{E_{\text{bo}}}{10^{46} \text{ erg}} \right)^{1/2} \left( \frac{T_{\text{bo}}}{50 \text{ keV}} \right)^{-\frac{9+\sqrt{3}}{4}}$$

The relativistic shock breakouts can explain very well the energy, temperature, and timescales of the prompt emission of all observed ll-GRBs (Nakar & Sari 2012)



# Also see ...



# More EP transients have been detected in association with SNe

## GCN Circular 38987

### Subject

EP250108a / SN2025kg: Gemini GMOS-S confirmation of an associated broad-lined SN Ic

### Date

2025-01-19T19:44:15Z (2 months ago)

### From

Andrew Levan at Radboud University <a.levan@astro.ru.nl>

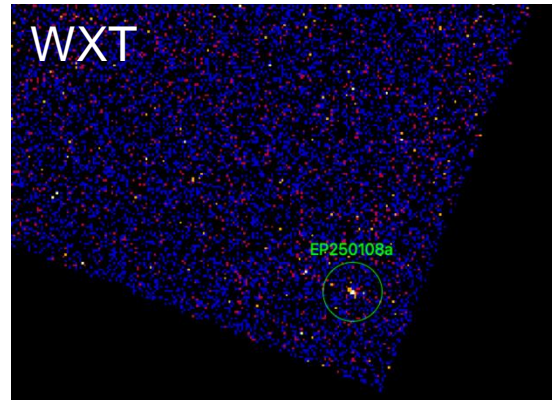
### Via

Web form

Andrew J. Levan (Radboud), Jillian C. Rastinejad (Northwestern), Daniele B. Malesani (DAWN/ NBI and Radboud), Wen-fai Fong (Northwestern), Nial R. Tanvir (Leicester), P.G. Jonker (Radboud), Rob A. J. Eyles-Ferris (Leicester) report on behalf of a larger collaboration:

We obtained spectroscopic observations of the optical counterpart [AT2025kg](#) ("the kangaroo"; Eyles-Ferris, GCN [38878](#); Zhu et al., GCN [38885](#); Malesani et al., GCN [38902](#); Kumar et al., GCN [38907](#); Zhu et al., GCN [38908](#); Levan et al., GCN [38909](#); Izzo, GCN [38912](#); Zou et al., GCN [38914](#); Moskvitin & Spiridonova, GCN [38925](#); Song et al., GCN [38972](#); Eyles-Ferris et al., GCN [38983](#); Xu et al., GCN [38984](#)) to EP250108a (Li et al., GCN [38861](#)) with the GMOS spectrograph mounted on the Gemini-South telescope (PI: Rastinejad; program GS-2024B-Q-105). We obtained 4 x 400 s spectroscopy beginning at 2025-01-19 01:29 UT, approximately 10.5 days after the EP/WXT trigger. Spectroscopy was taken with the B480 grism, covering the spectral range from 4250-8500 AA.

EP250108a/SN 2025kg  
@z=0.176



see Andrew Levan's talk on Tuesday

## GCN Circular 39851

### Subject

EP250304a: VLT/MUSE spectroscopic observation of its associated supernova SN 2025fhm

### Date

2025-03-23T09:41:34Z (3 days ago)

### From

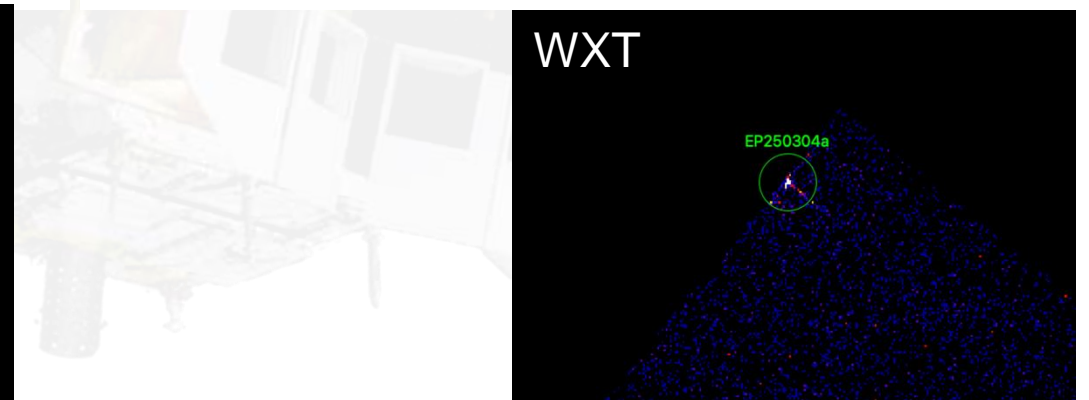
Antonio Martin-Carrillo at UCD,Space Science Group <antonio.martin-carrillo@ucd.ie>

### Via

Web form

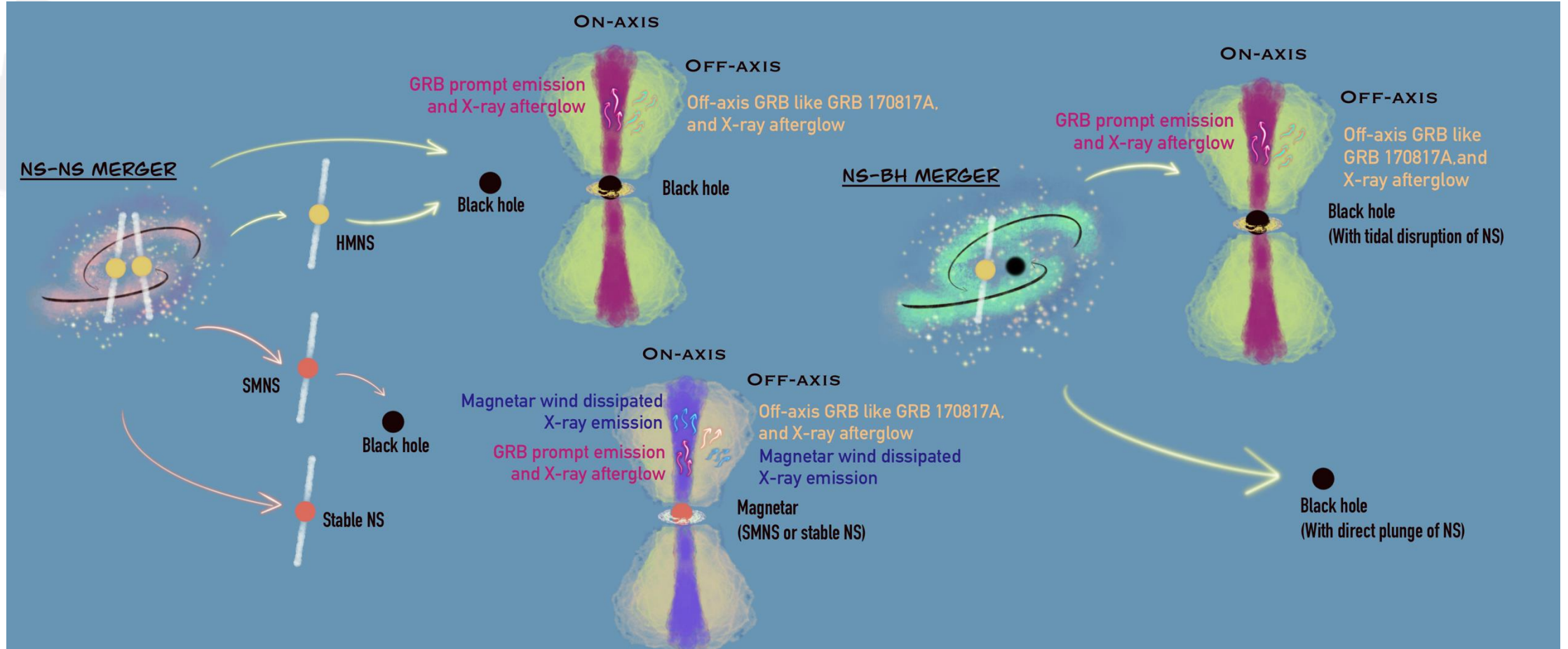
L. Izzo (INAF-OACN and DARK/NBI), A. Martin-Carrillo (UCD), D. B. Malesani (Radboud and DAWN/NBI), A. J. Levan (Radboud and Warwick), P. G. Jonker (Radboud Univ.), L. Cotter (UCD), J. van Dalen (Radboud Univ.), G. Corcoran (UCD), K. Wiersema (Herts), F. E. Bauer (PUC), report on behalf of a larger collaboration:

We observed the optical counterpart (Liu et al., GCN [39583](#); Page et al., GCN [39584](#); Saccardi et al., GCN [39585](#); Shilling et al., GCN [39587](#); Gupta et al., GCN [39593](#); Ghosh et al., GCN [39594](#)) of the fast X-ray transient EP250304a (Chen et al., GCN [39580](#)) using the ESO VLT UT4 (Yepun) equipped with the MUSE spectrograph on 2025-03-22 at 02:45:04 UT (about 18.05 days after trigger, 15 days in the rest frame). A series of 4x470 s exposures were taken for this observation.



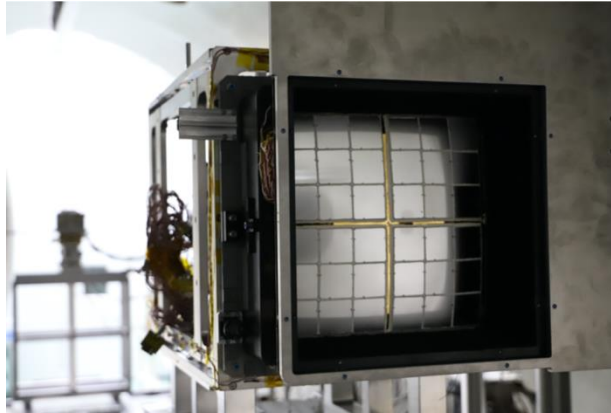
EP250304a/SN 2025fhm @z=0.200

# Coming more new types of fast X-ray transients



Yuan et al. Science objectives of the Einstein Probe mission. Sci. China PMA (2025)

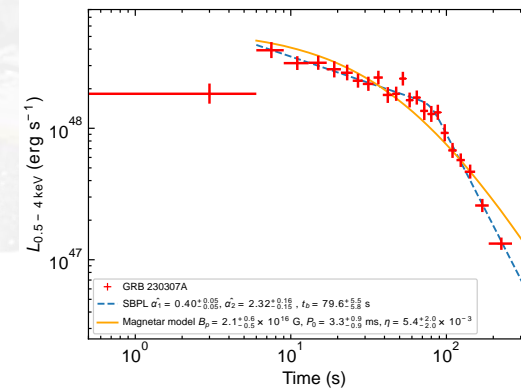
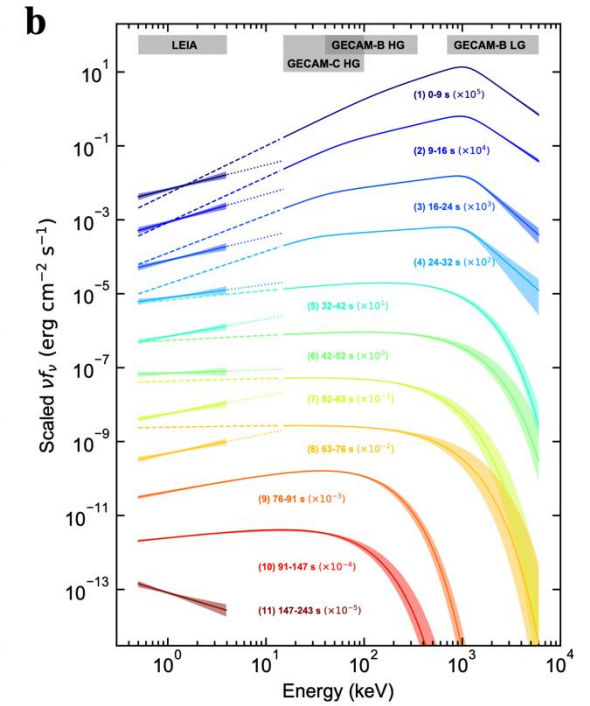
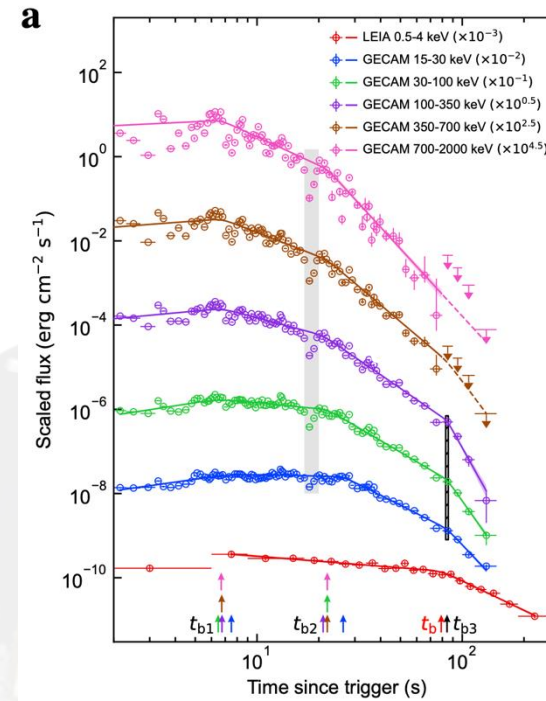
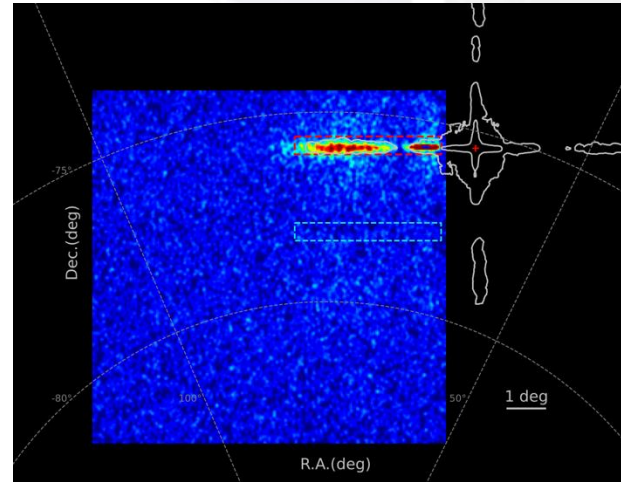
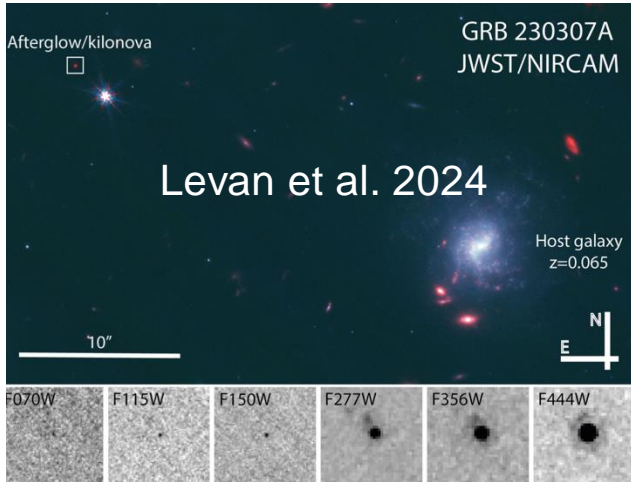
# GRB 230307A: Magnetar Emergence from Compact binary merger



## EP-WXT Pathfinder LEIA

- Launched in July 2022
- 0.5-4 keV
- $18 \times 18 \text{ deg}^2$

## LEIA Image of GRB 230307A



Sun et al. 2025, National Science Review, 12, Issue 3, March 2025,

# Summary



- ✧ EP240414a/SN 2024gsa originated from the core-collapse explosion of an extragalactic massive star with its envelope significantly stripped prior to the explosion.
- ✧ Bridge the gap between traditional GRBs and those broad-lined SNe Ic that do not have any high-energy counterparts, suggesting a diverse zoo of progenitor stars.
- ✧ We are expecting more soft X-ray transients similar to EP240414a or other types in EP data.

**Thank you for your attention!**

[hsun@nao.cas.cn](mailto:hsun@nao.cas.cn)

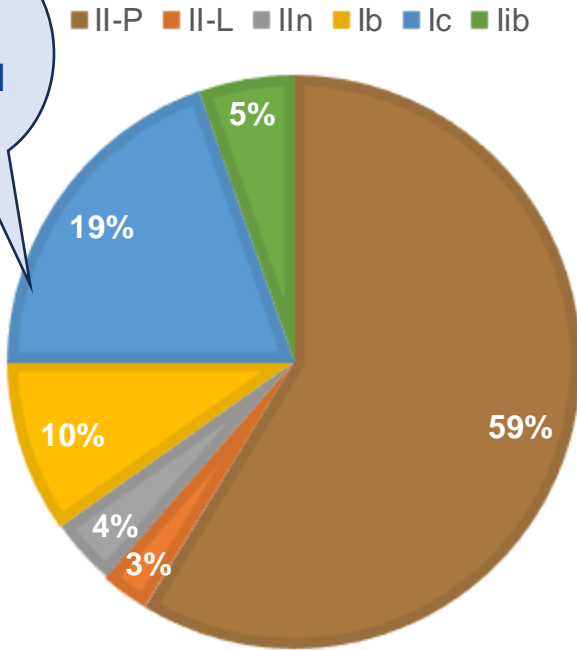


# Event rate density



## CCSN

Type Ic SN

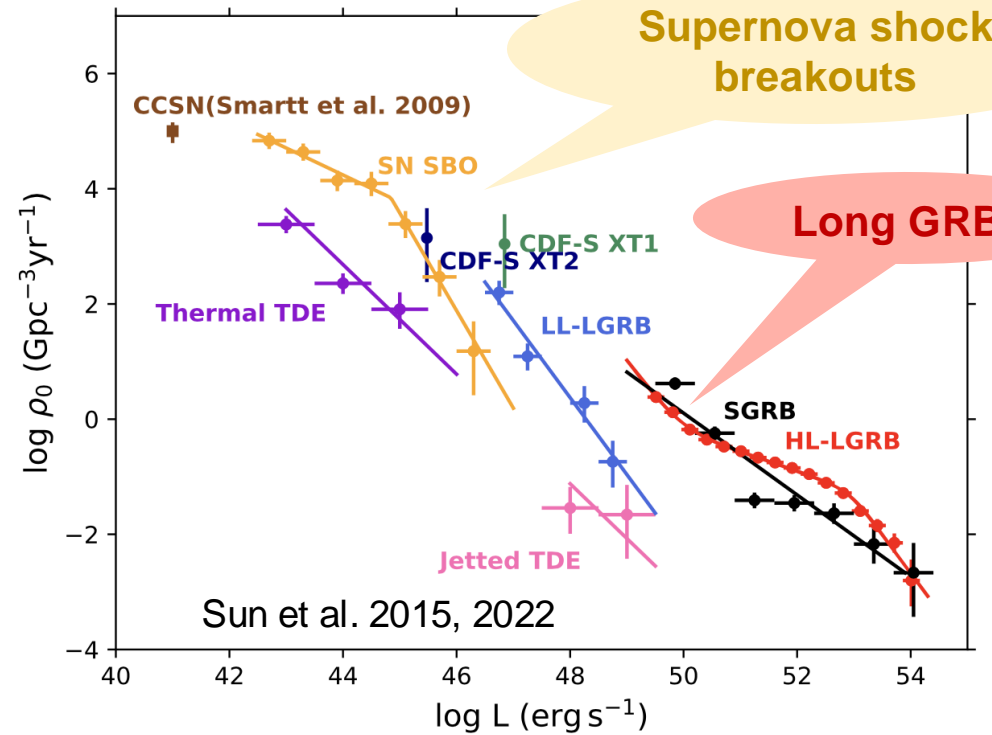


Smartt et al. 2009

### Local event rate densities:

- CCSNe:  $10^5 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- Type Ic SNe:  $2 \times 10^4 \text{ Gpc}^{-3} \text{ yr}^{-1}$   
~20% of CCSN
- LGRBs: ~ a few  $\text{Gpc}^{-3} \text{ yr}^{-1}$   
~  $10^3 \text{ Gpc}^{-3} \text{ yr}^{-1}$   
(Beaming corrected)

## High-energy extragalactic transients



Sun et al. 2015, 2022

### EP240414a-like:

$$\rho_{0, \text{EFXT}}(L_{\text{iso}} > 3.5 \times 10^{47} \text{ erg s}^{-1}) \approx 0.3_{-0.2}^{+0.7} \text{ Gpc}^{-3} \text{ yr}^{-1}$$

EP240414a/SN2024gsa-like events bridge the gap between traditional GRBs and those broad-lined SNe Ic that do not have any high-energy counterparts