The Bluest, the Fastest and the X-ray Bright:

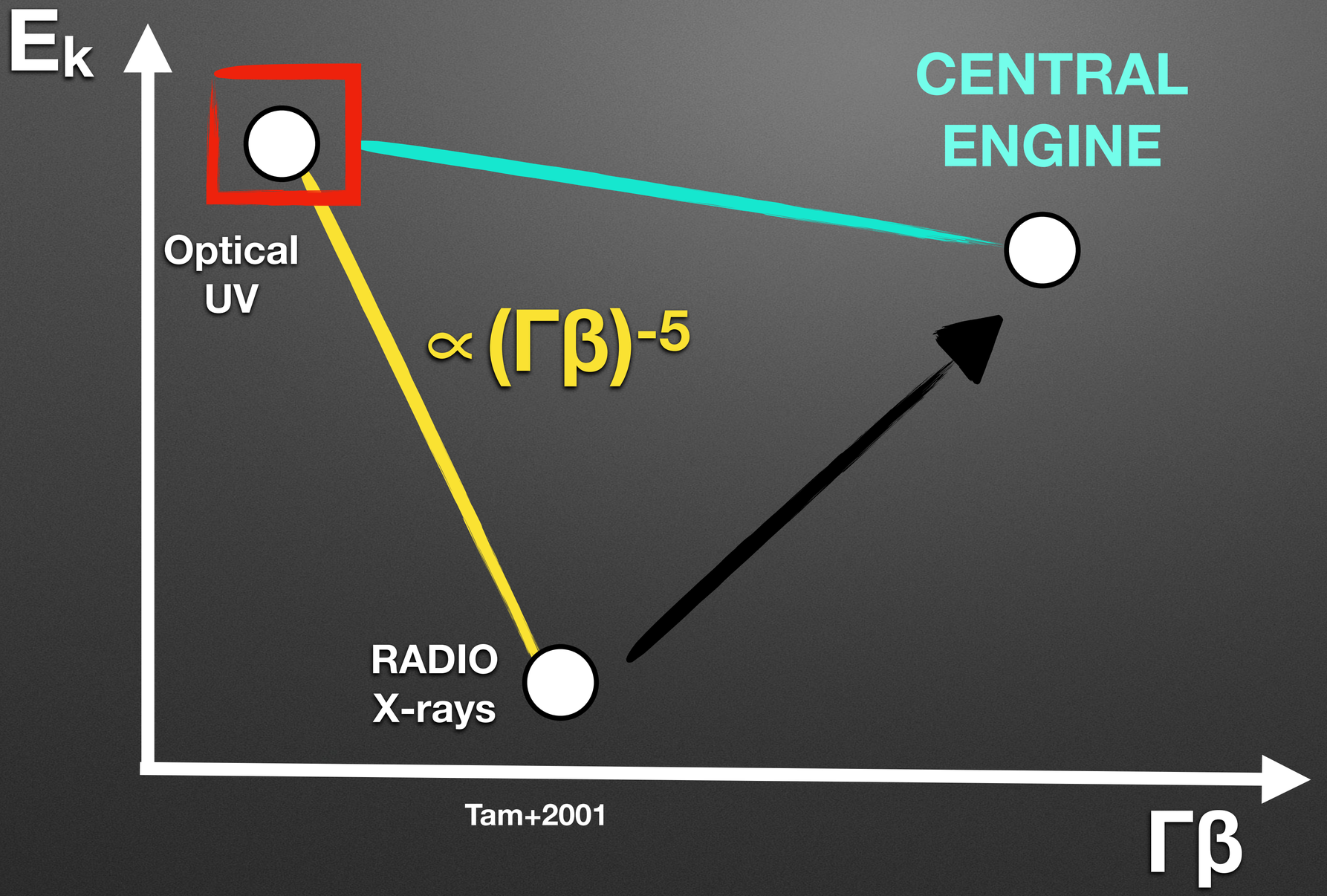
CCSNe and FBOTs

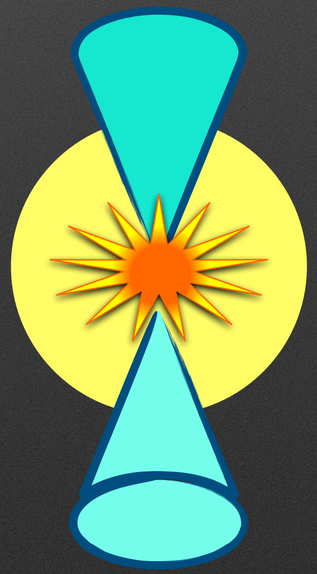
Raffaella Margutti (UC Berkeley)

"We always find something, eh Didi, to give us the impression we exist?"

To Guido, Alicia and Neil

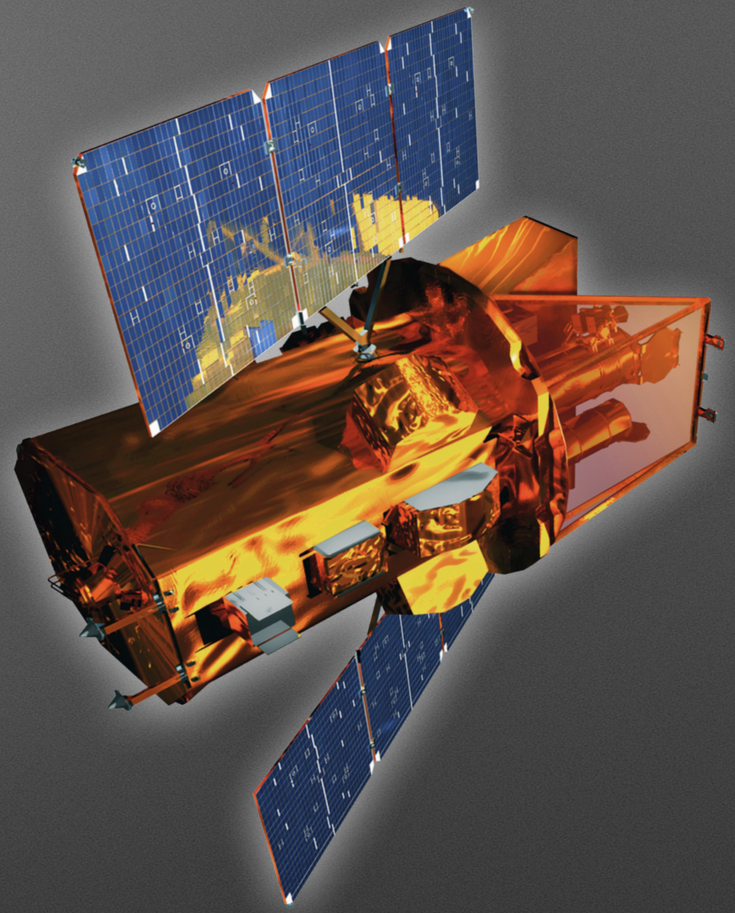
Energy Partitioning





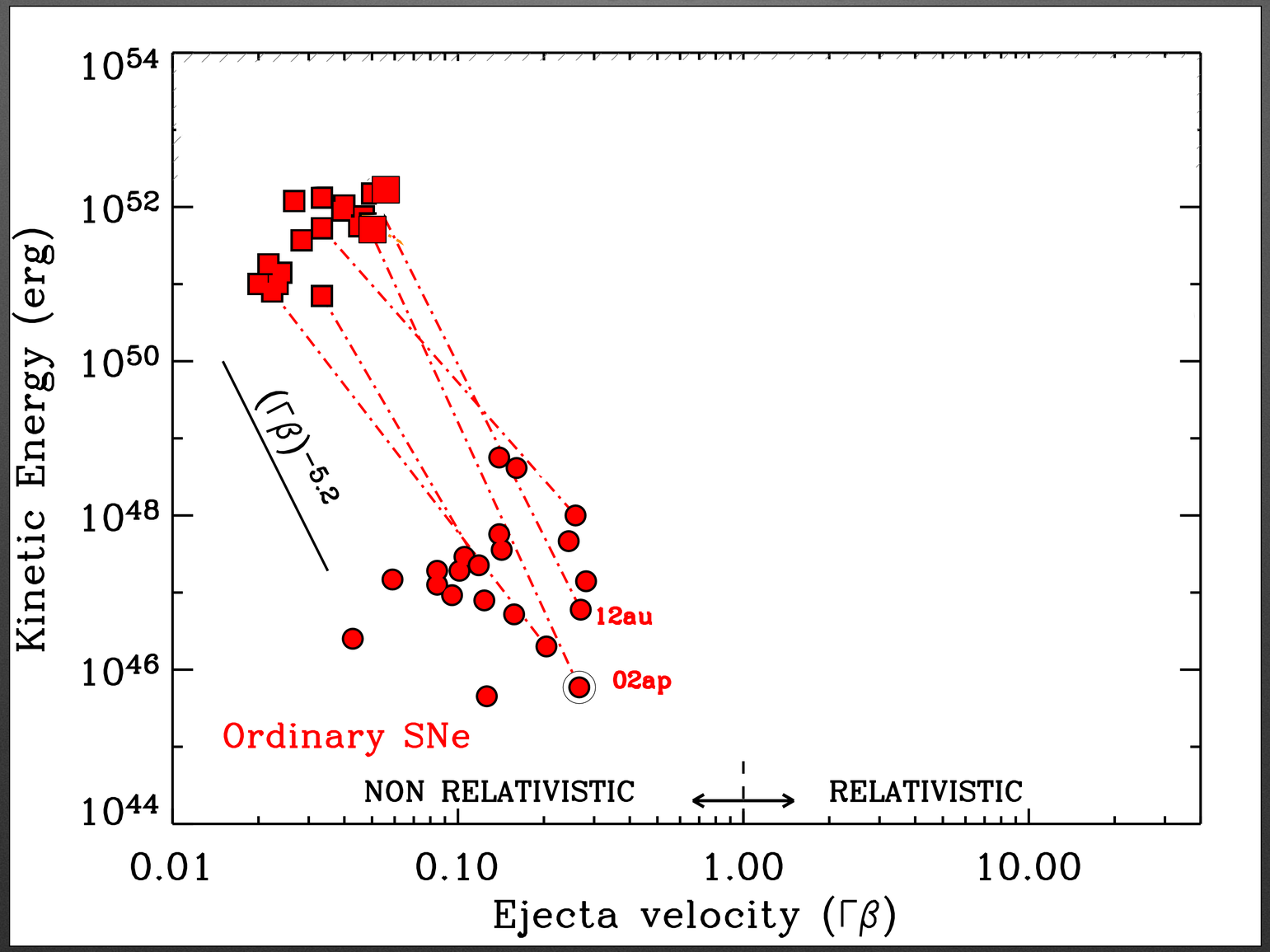
Key Strengths:

- Extremely **fast** re-pointing capabilities
- **Multi-wave** coverage at the *same* time
- **Public** data, immediately



Unique X-ray and UV time-domain machine

“Ordinary” CCSNe



Margutti +13, +14; Kamble +13; Soderberg +06, +10

Two ways to be UV/X-ray Bright:

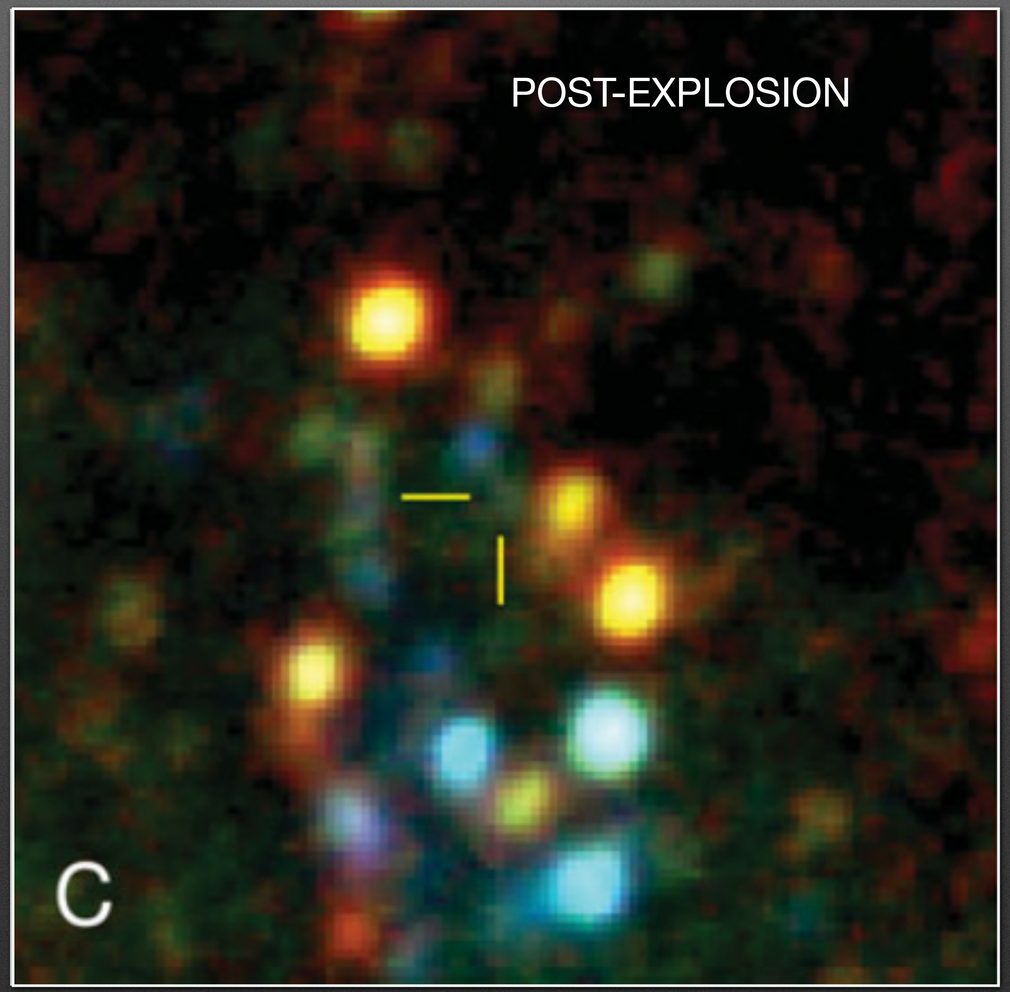
“FUTURE”

- Central Source of Energy (BH, magnetar spin down)

“PAST & PRESENT”

- Shock Break Out emission (From progenitor or innermost medium)
- Shock interaction w. extended medium

Why?

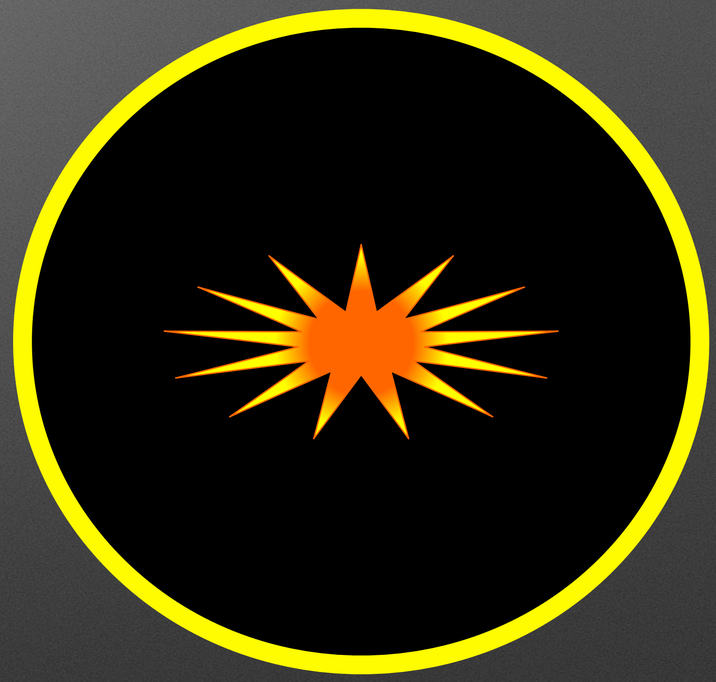


Mattila+2010

Why?

The last thousand years

?



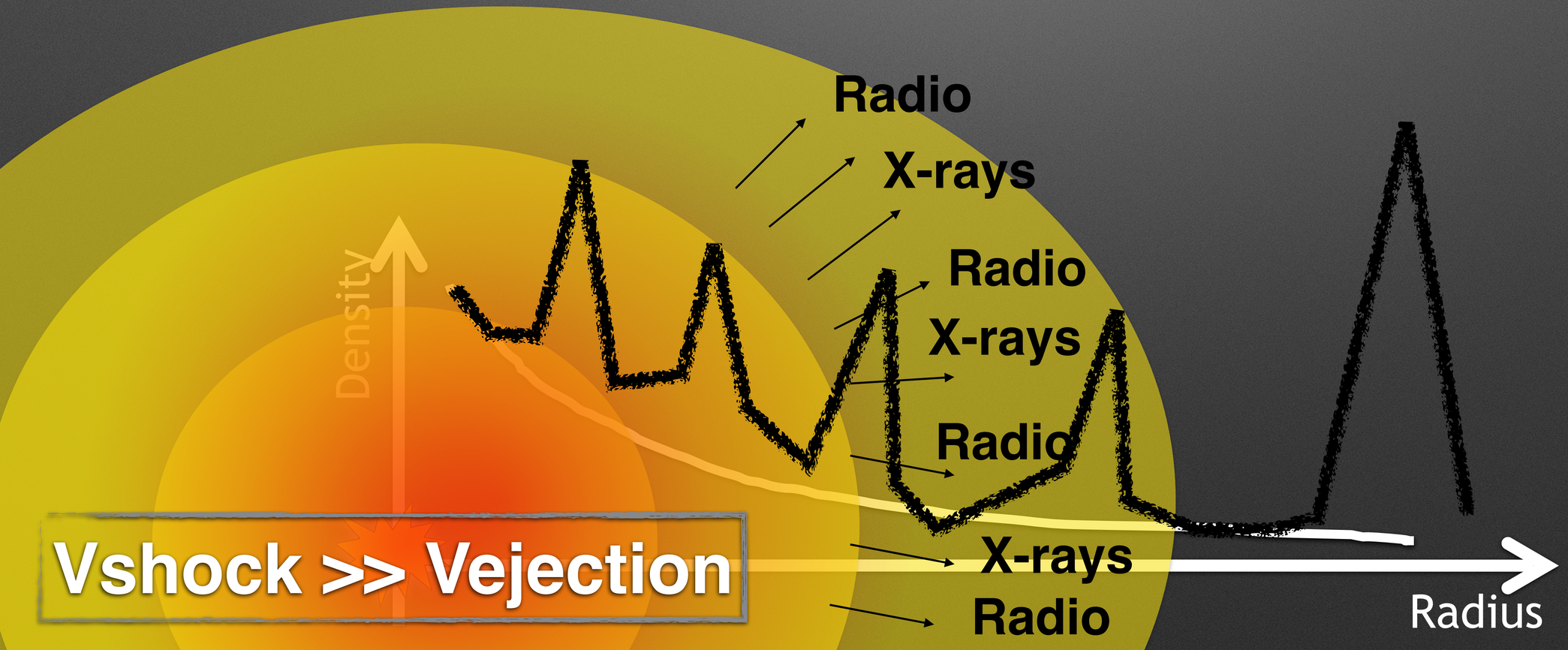
- Chemical enrichment of the CSM
- Structure of the star at the time of explosion
- Physics of mass loss in evolved massive stars

Smith ARA&A 2014
Brethauer+ 2022

Phase of stellar evolution that cannot be probed otherwise

How?

The last thousand years

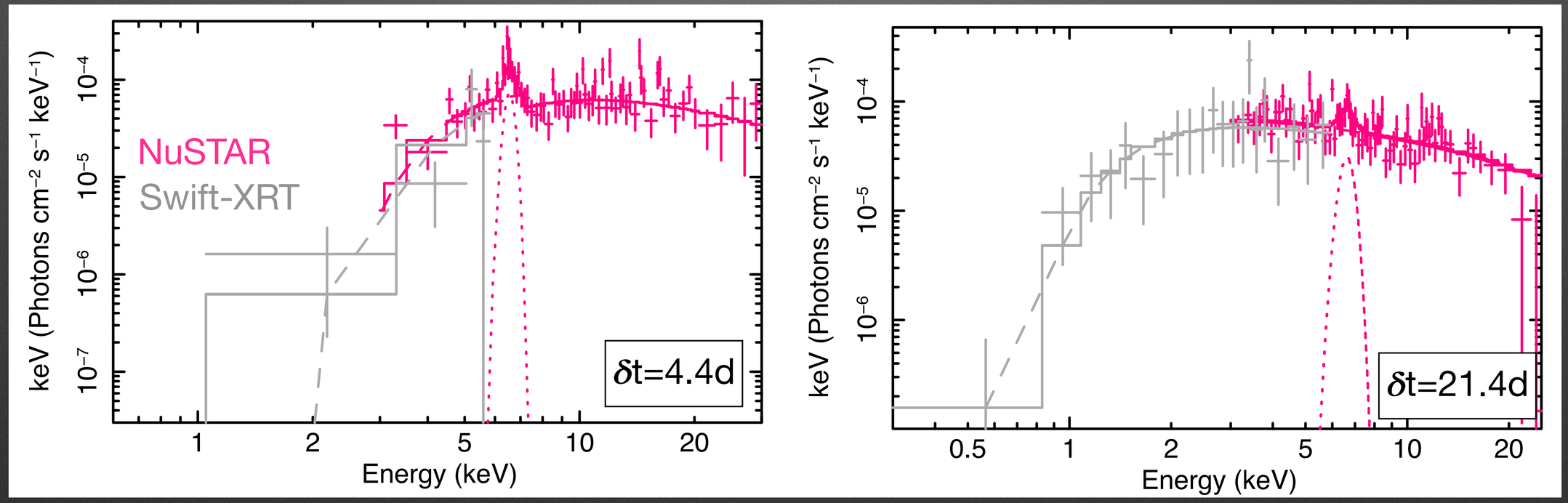


Vshock >> Vejection

Shock interaction with extended CSM

SN2023ixf (Type II, d~ 7Mpc) → **i.e. VERY nearby!!!!**

Jacobson-Galan+23; Hiramatsu+23; Zimmerman+24; Bostroem+24 ; Soraisam+23; Jencson+23; Chandra+24

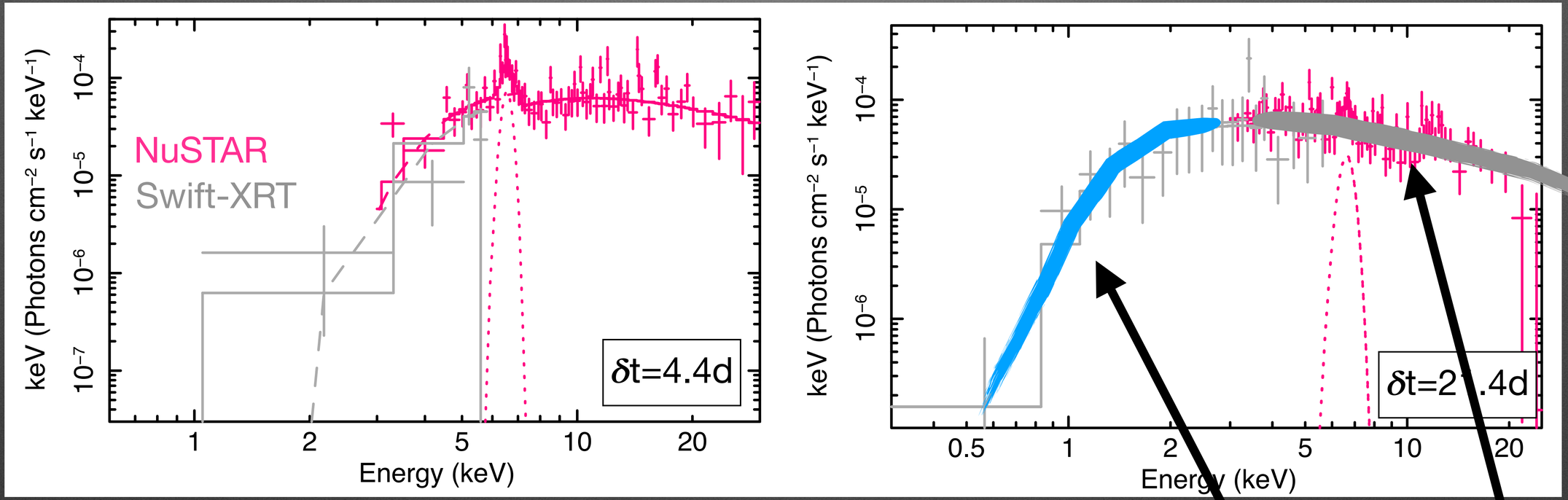


Nayana+ 2025

Fast re-pointing
Coordination with other observatories

SN2023ixf (Type II, d~ 7Mpc)

Absorbed Bremsstrahlung Spectrum



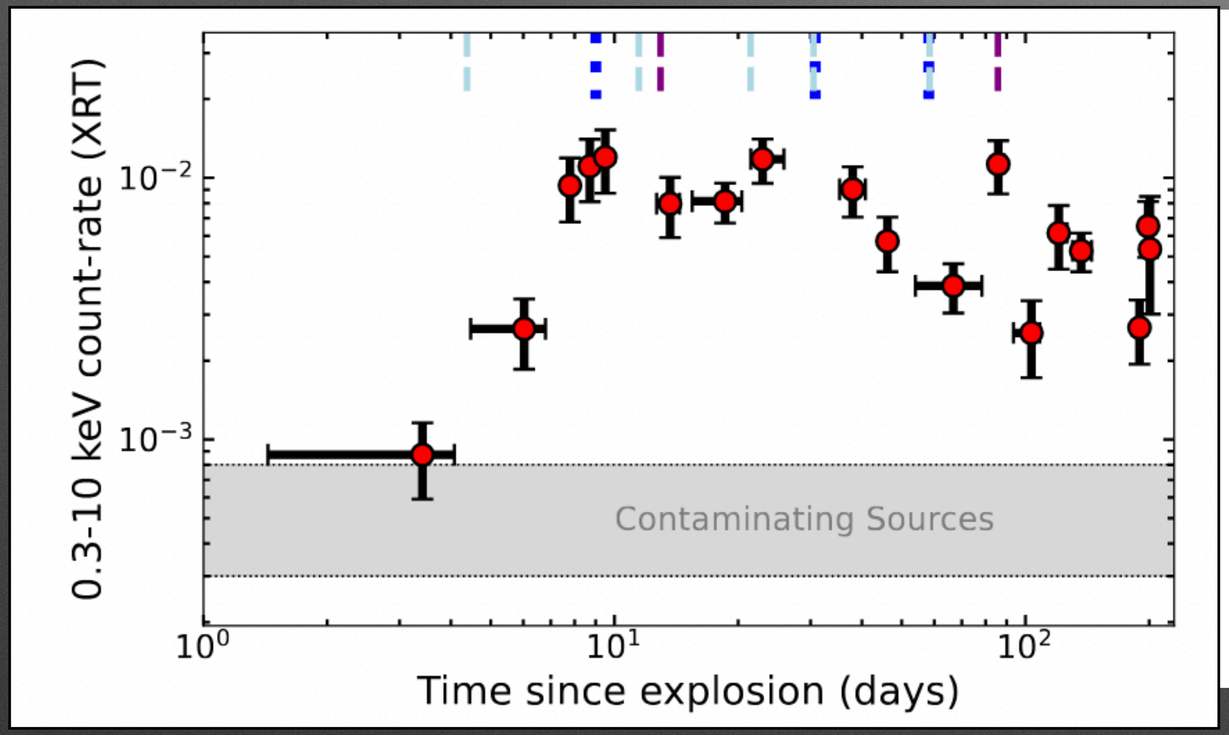
NH

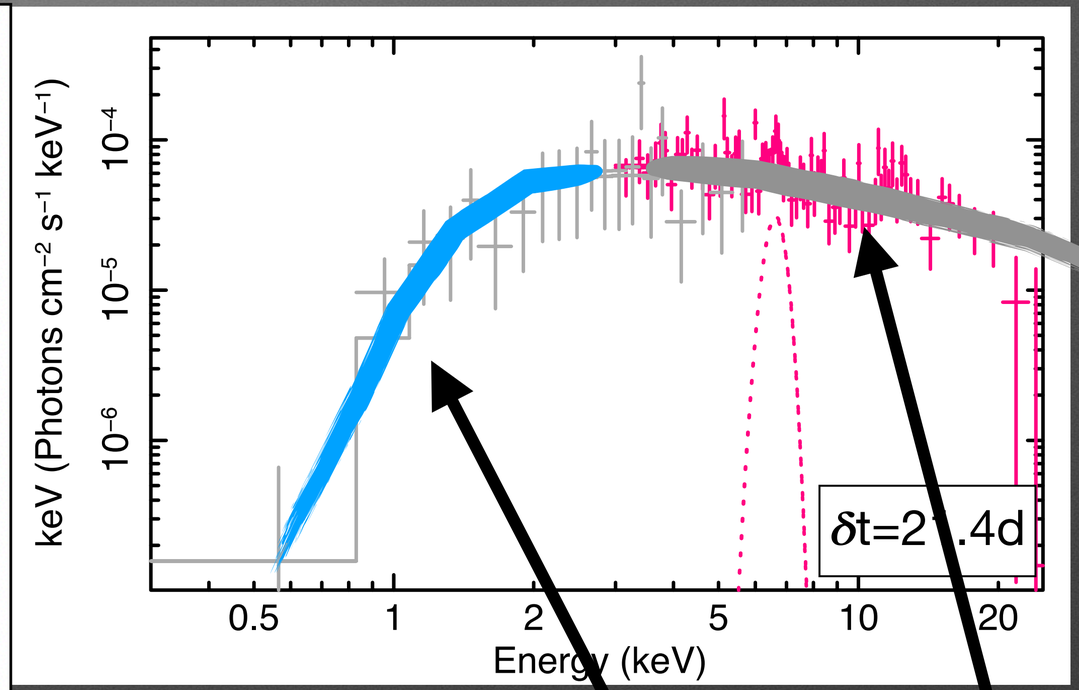
T

Fast re-pointing
Coordination with other observatories ⟶ **Broad-band** X-ray spectrum

SN2023ixf (Type II, d~ 7Mpc)

Swift-XRT light-curve:

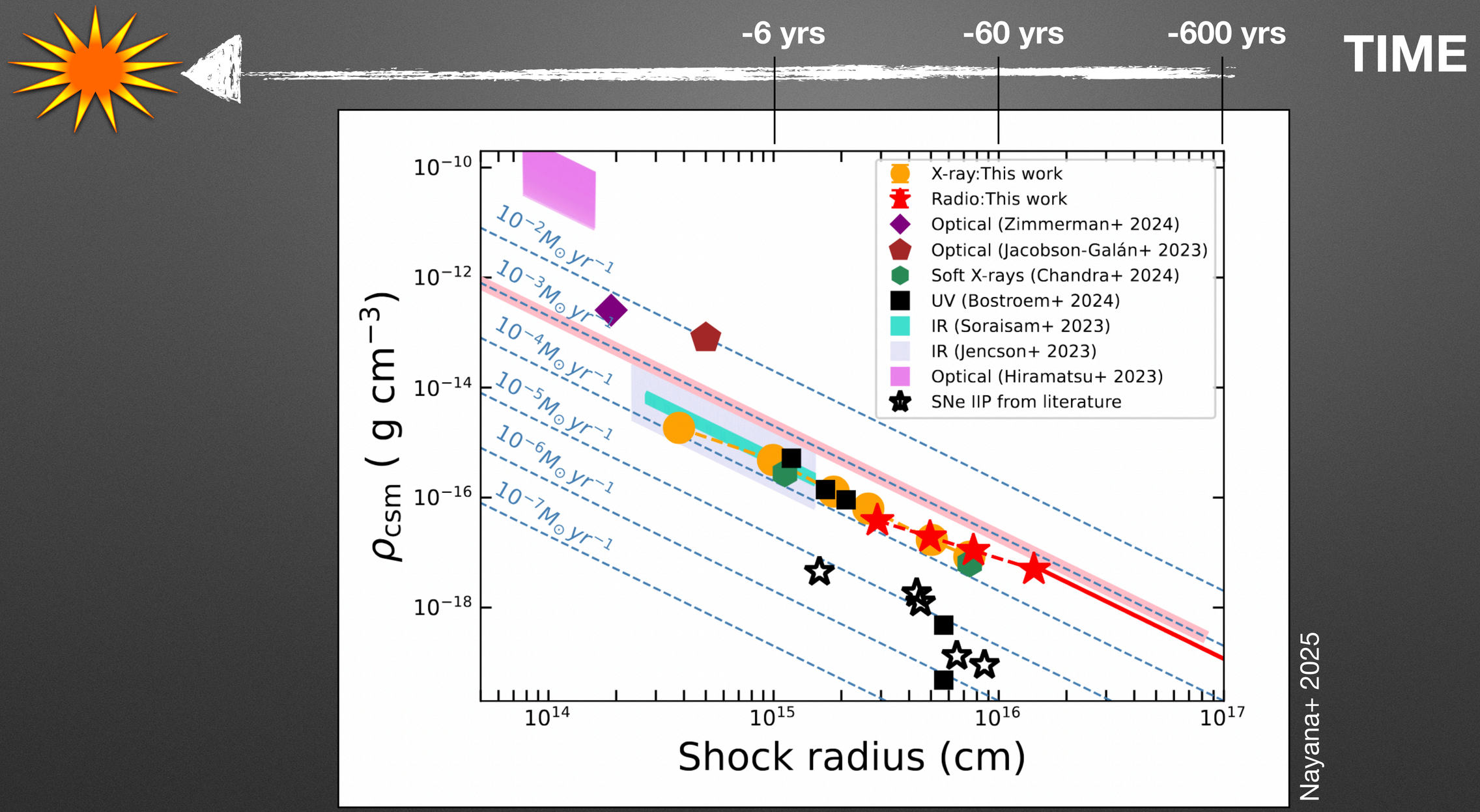




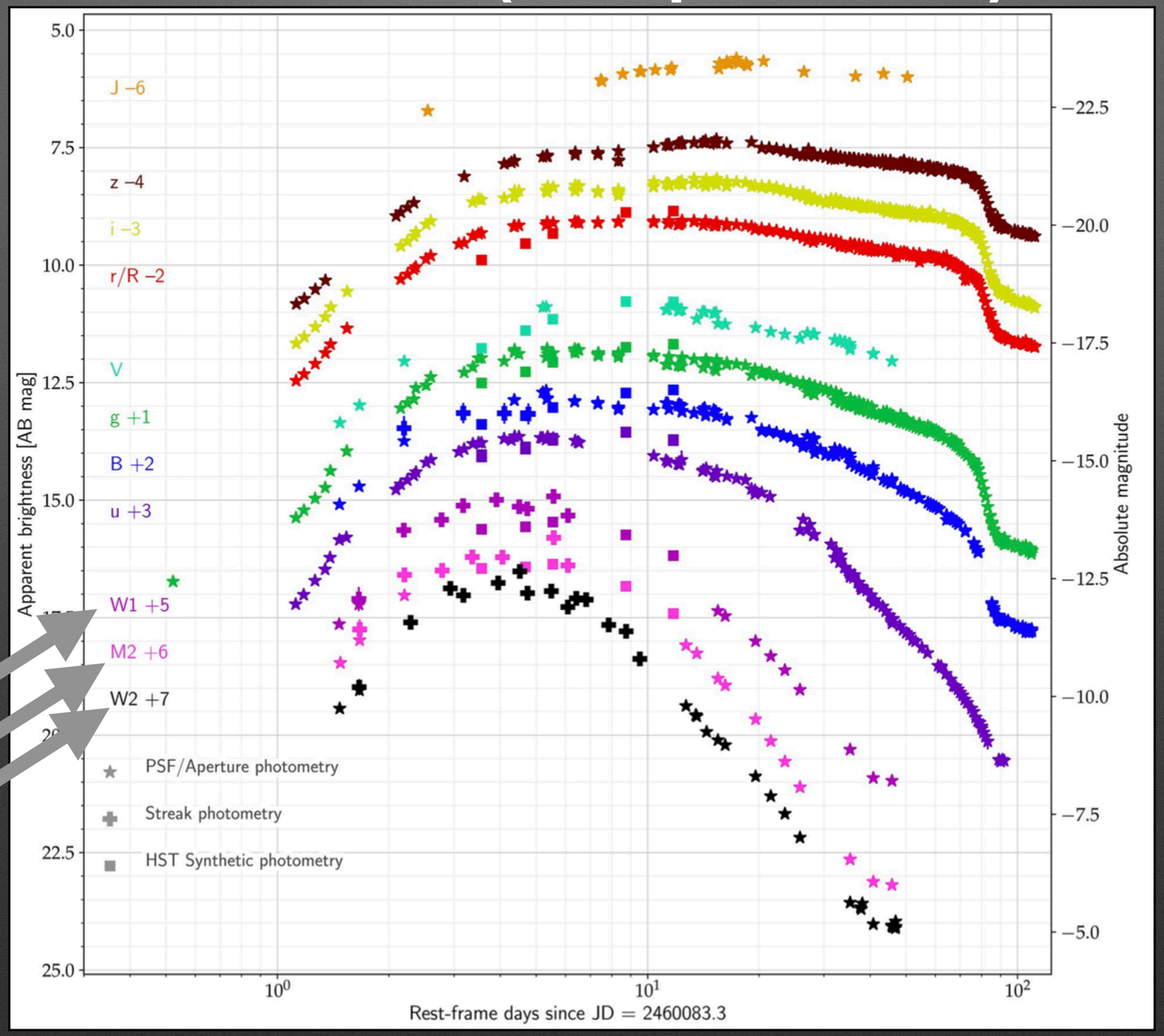
NH(t)

T(t)

Fast re-pointing
Coordination with other observatories ⟶ **Broad-band** X-ray spectrum


-6 yrs
-60 yrs
-600 yrs
TIME
X-ray:This work
Radio:This work
Optical (Zimmerman+ 2024)
Optical (Jacobson-Galán+ 2023)
Soft X-rays (Chandra+ 2024)
UV (Bostroem+ 2024)
IR (Soraisam+ 2023)
IR (Jencson+ 2023)
Optical (Hiramatsu+ 2023)
SNe IIP from literature
$10^{-2} M_\odot yr^{-1}$
$10^{-3} M_\odot yr^{-1}$
$10^{-4} M_\odot yr^{-1}$
$10^{-5} M_\odot yr^{-1}$
$10^{-6} M_\odot yr^{-1}$
$10^{-7} M_\odot yr^{-1}$
ρ_{csm} (g cm^{-3})
Shock radius (cm)
Nayana+ 2025

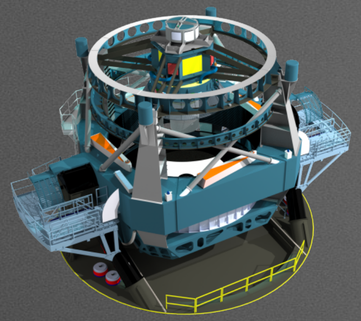
SN2023ixf (UV-optical-NIR)



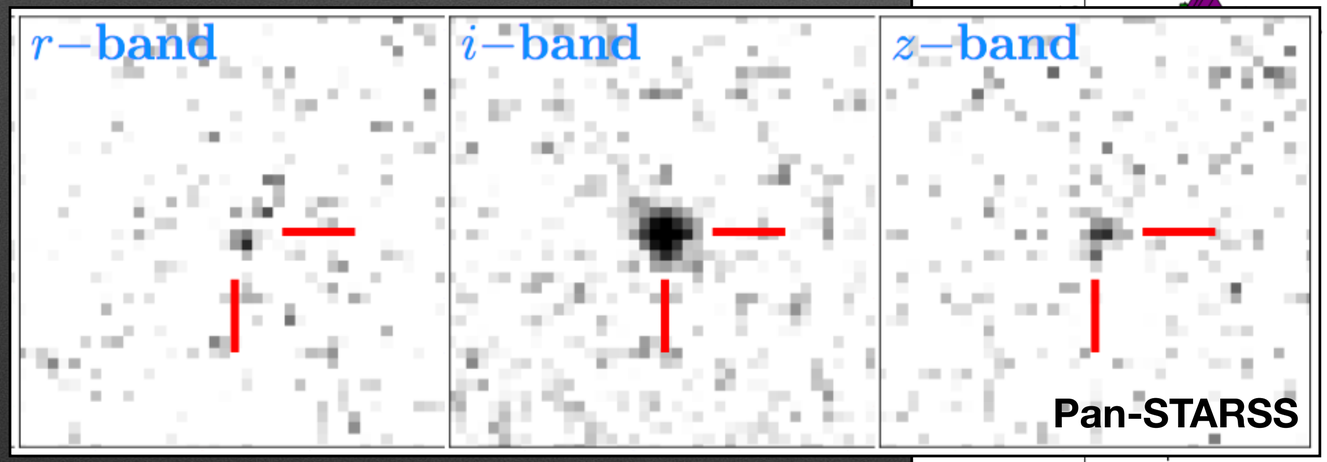
Extremely UV bright!

Zimmerman+24

LSST on Vera C. Rubin

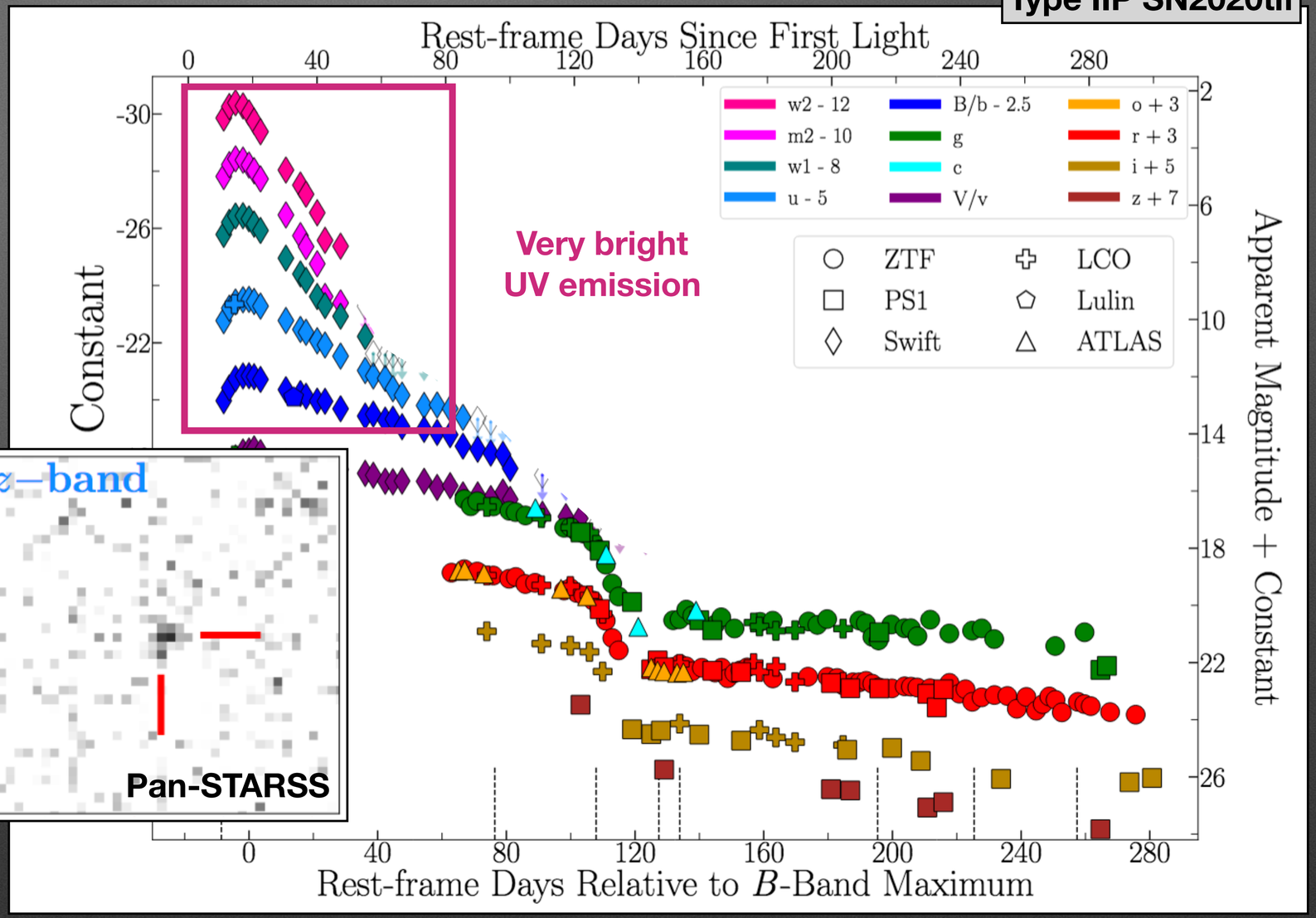


Pre-explosion detection of outbursts!



Jacobson-Galan+2022

Type IIP SN2020tlf

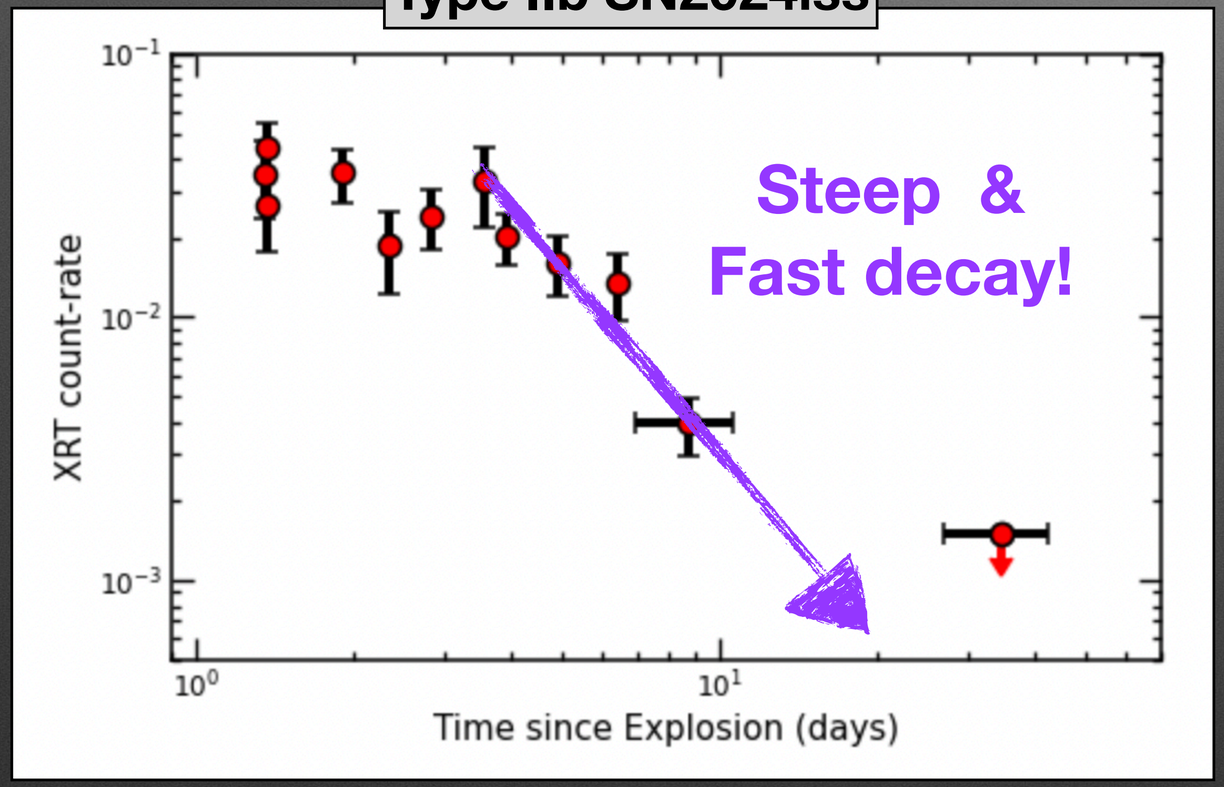


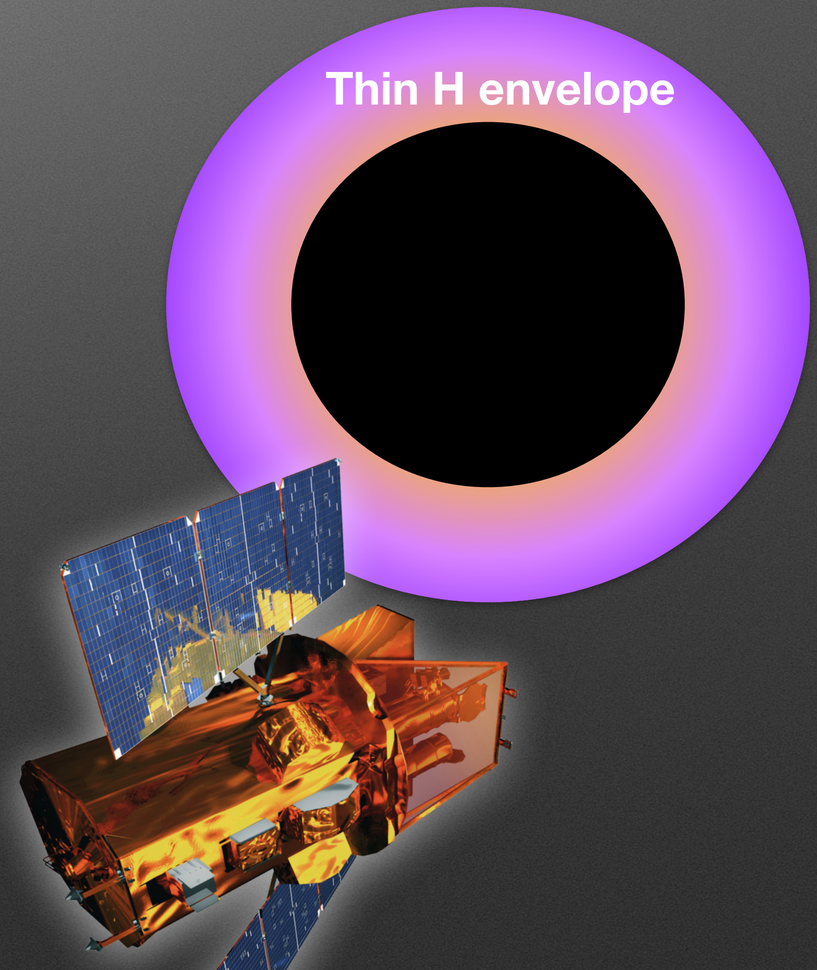
Jacobson-Galan+2022

See also Bruch+2021, +2023; Morozonova+2017, +2018, +2020

Shock interaction with innermost CSM

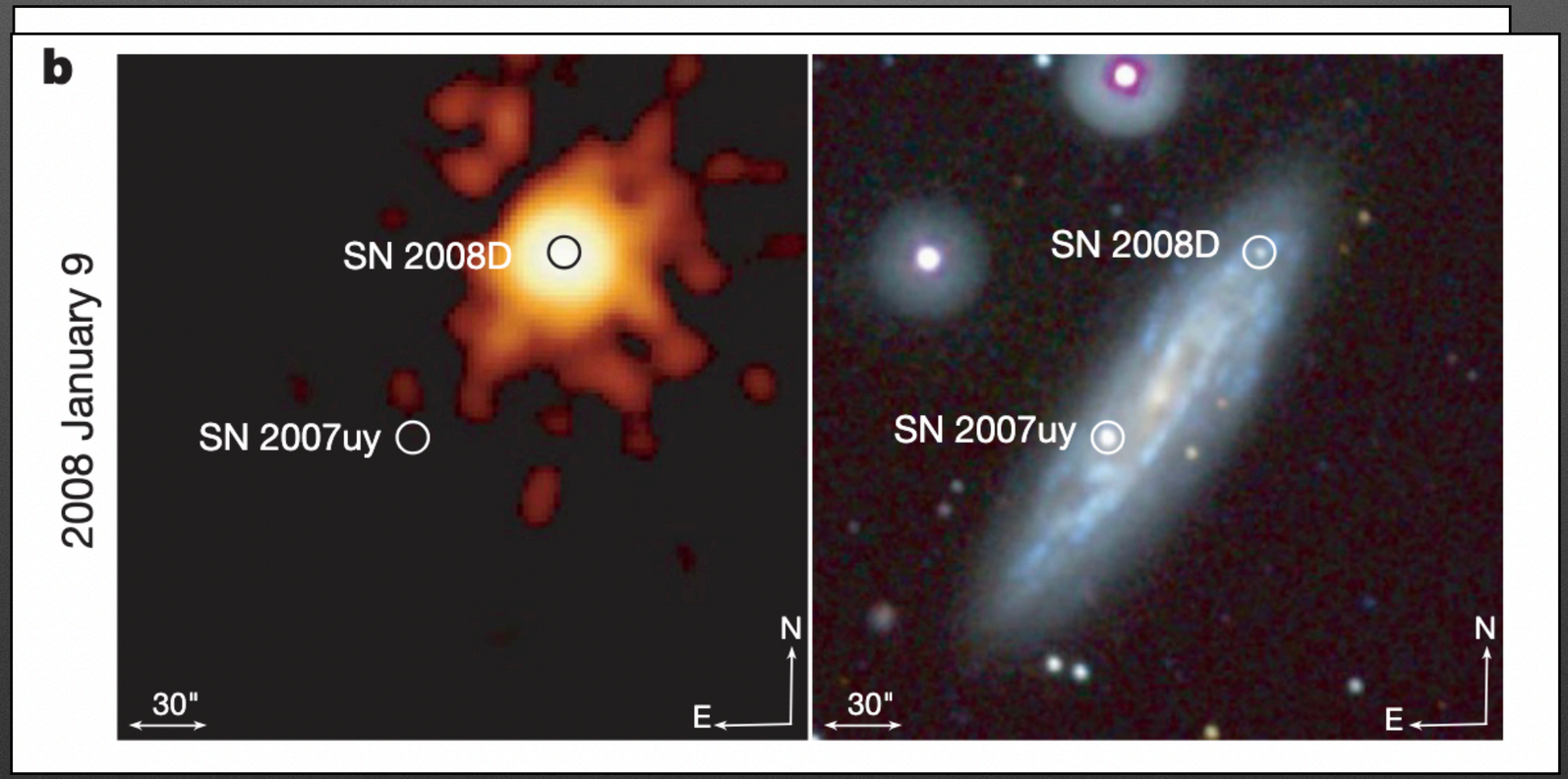
Type IIb SN2024iss





Shock Break Out (SBO)

e.g., Waxman 2017 for recent review



Soderberg+2008

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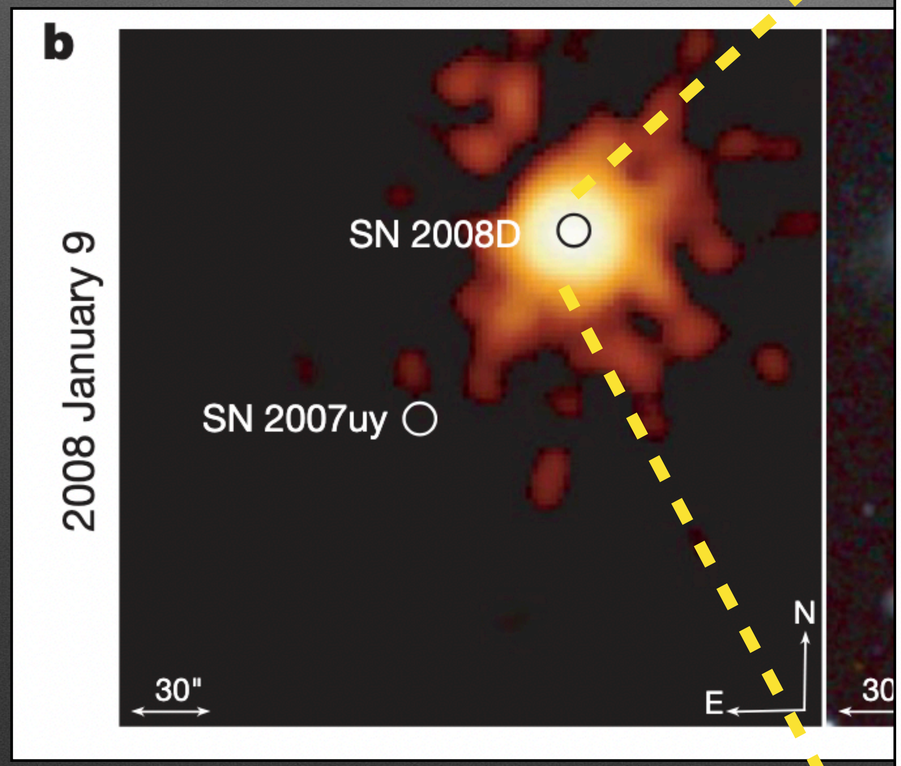
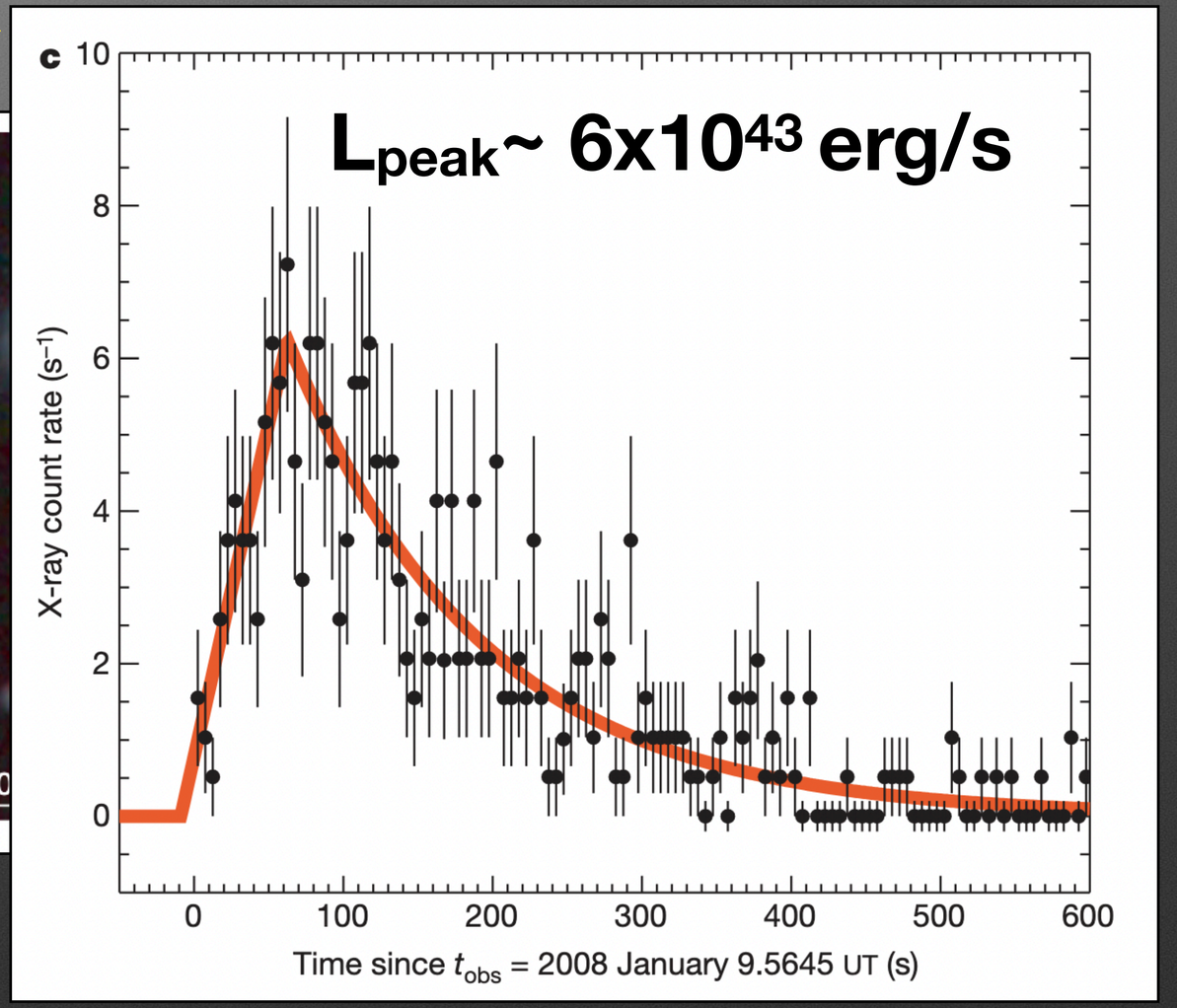
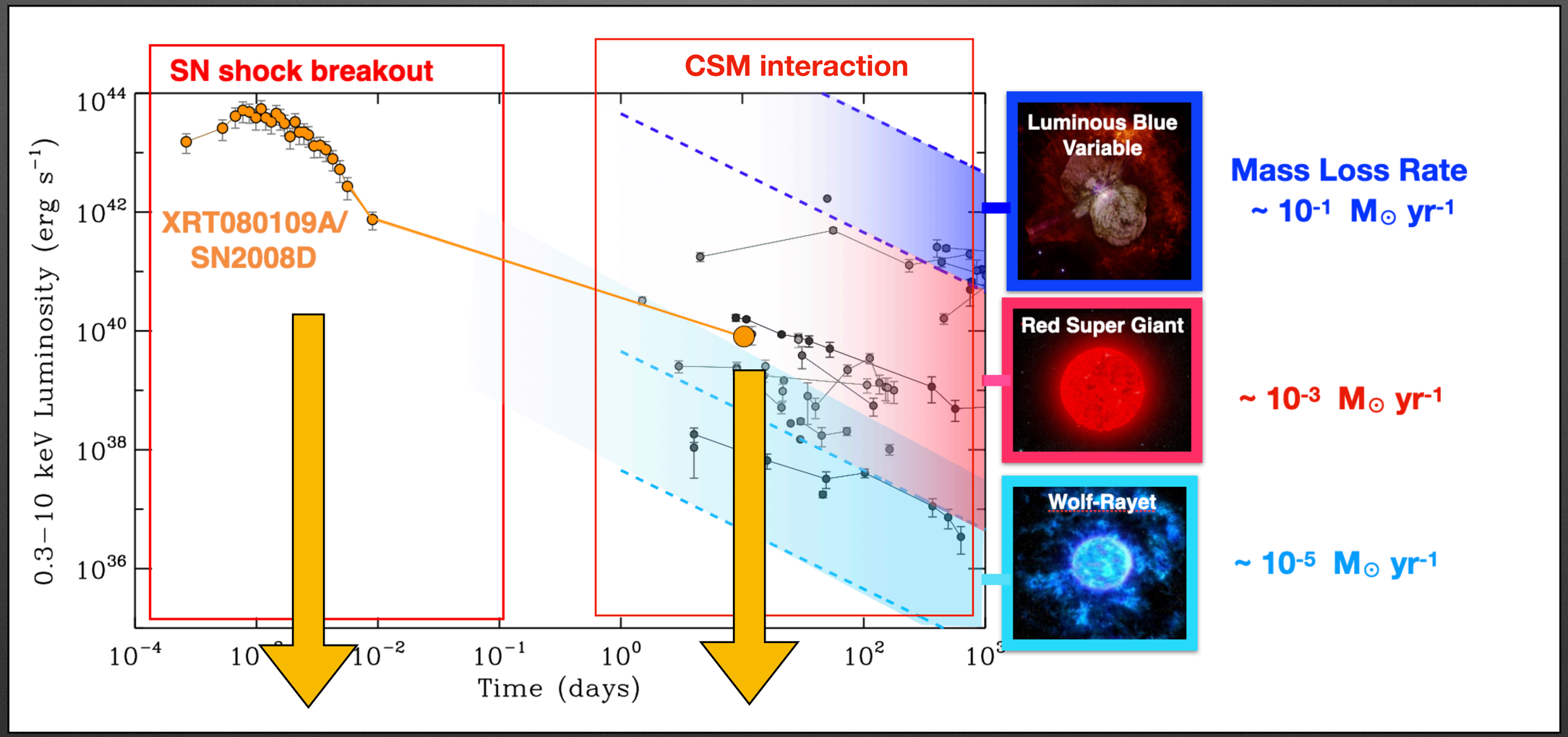




⇨ Constraints on the progenitor structure

Soderberg+2008

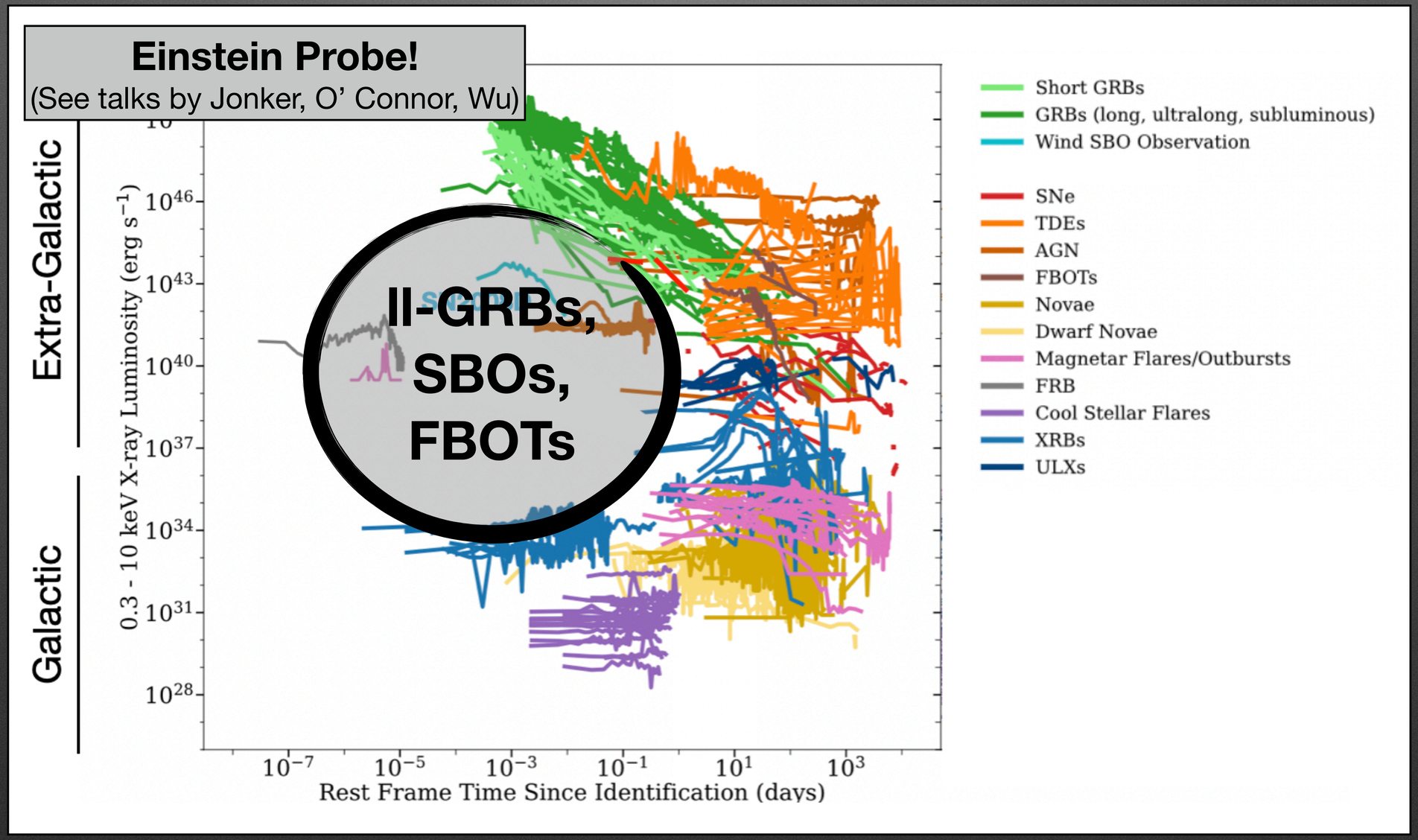
An End-to-End experiment



Progenitor Structure

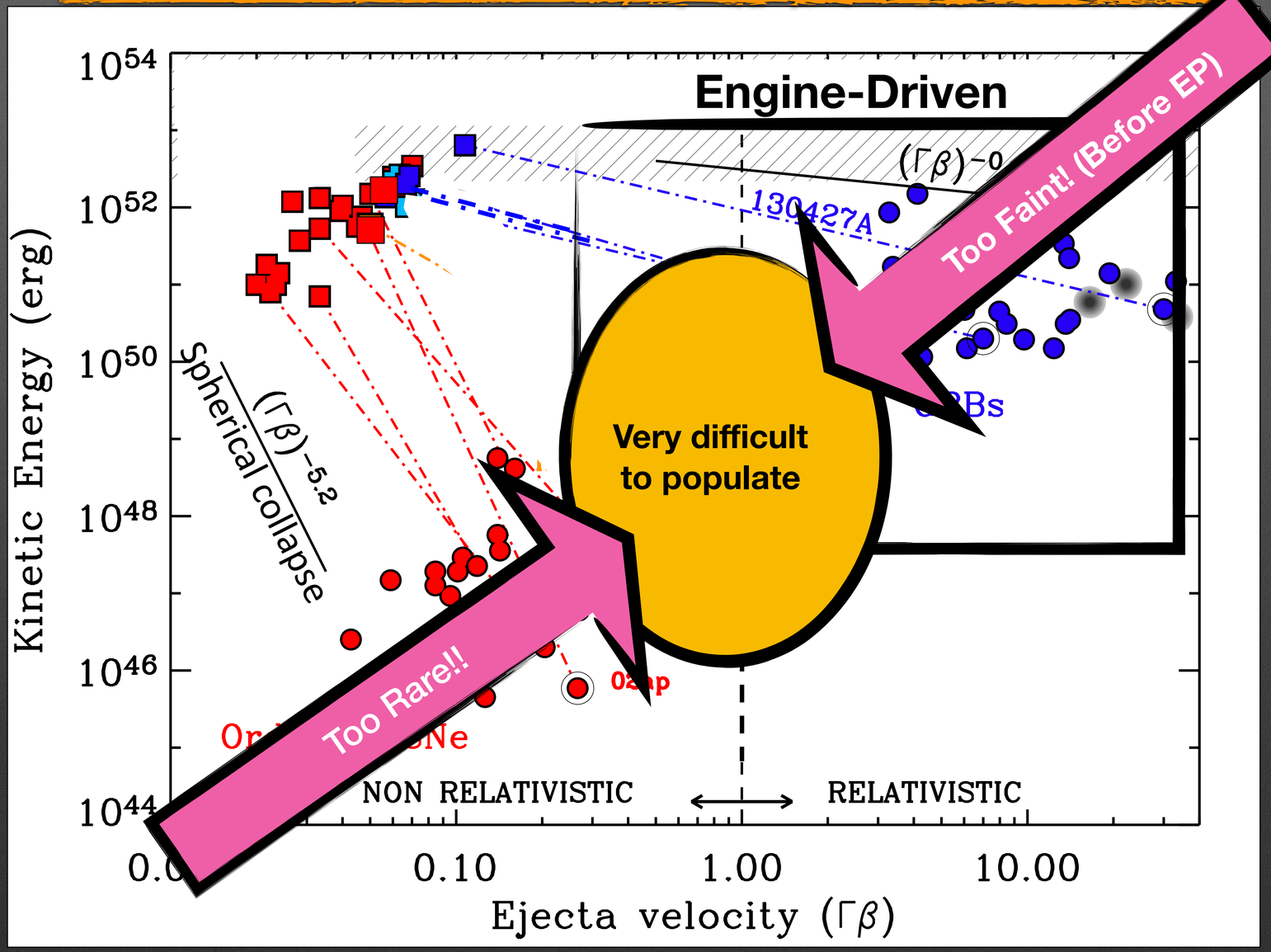
CSM

X-ray Phase Space of Transients



Polzin+24

Engine-Driven Explosions



Margutti +13, +14; Kamble +13; Soderberg +06, +10

Two ways to be UV/X-ray Bright:

“FUTURE”

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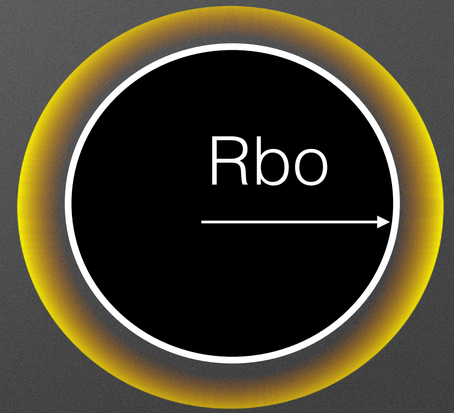
“PAST & PRESENT”



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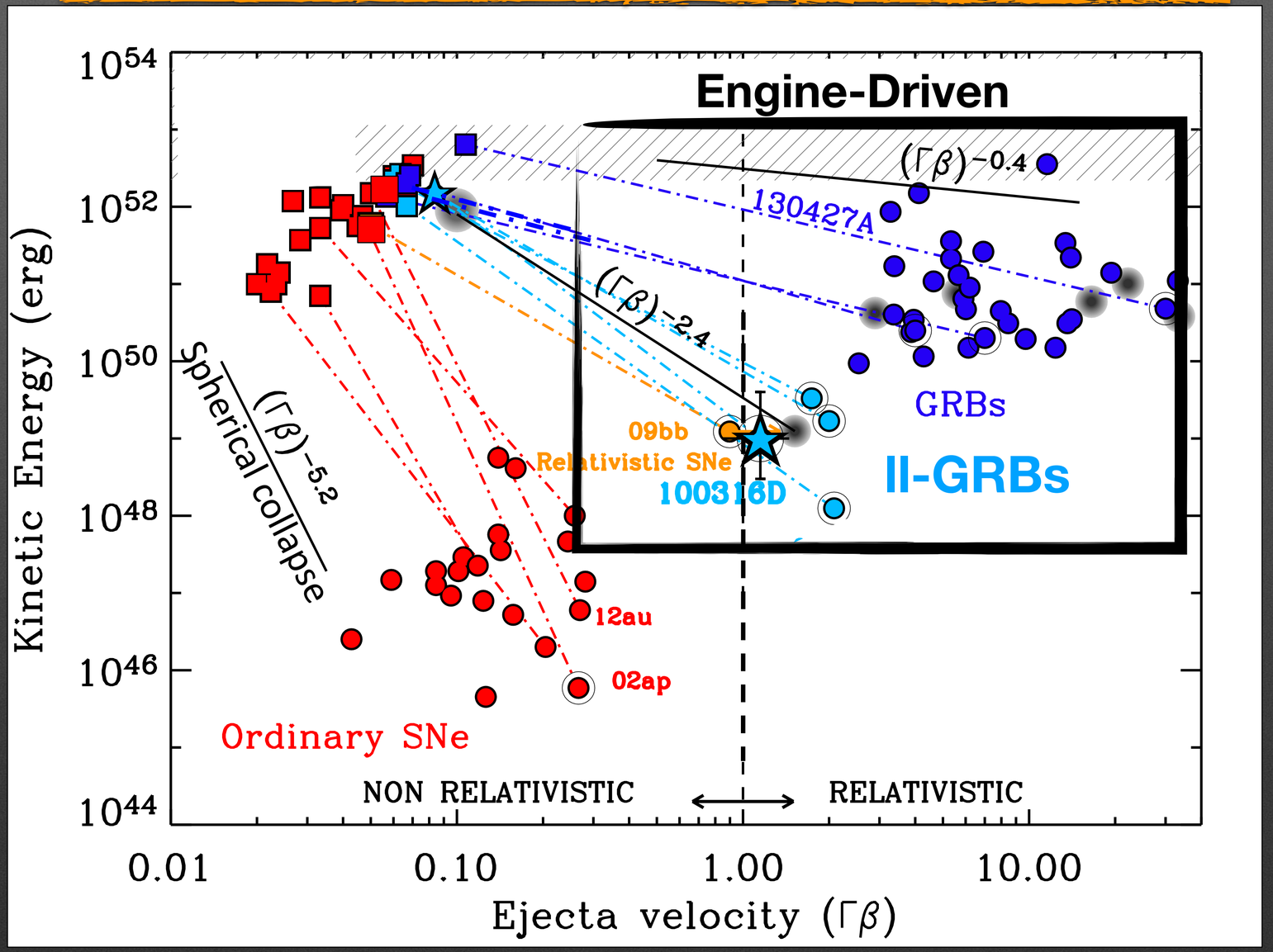
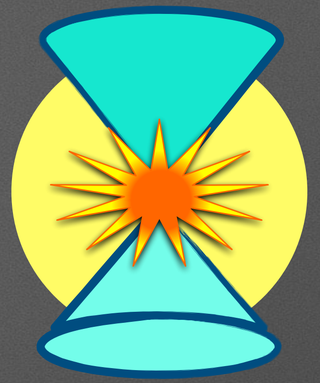
Engine-Driven Explosions

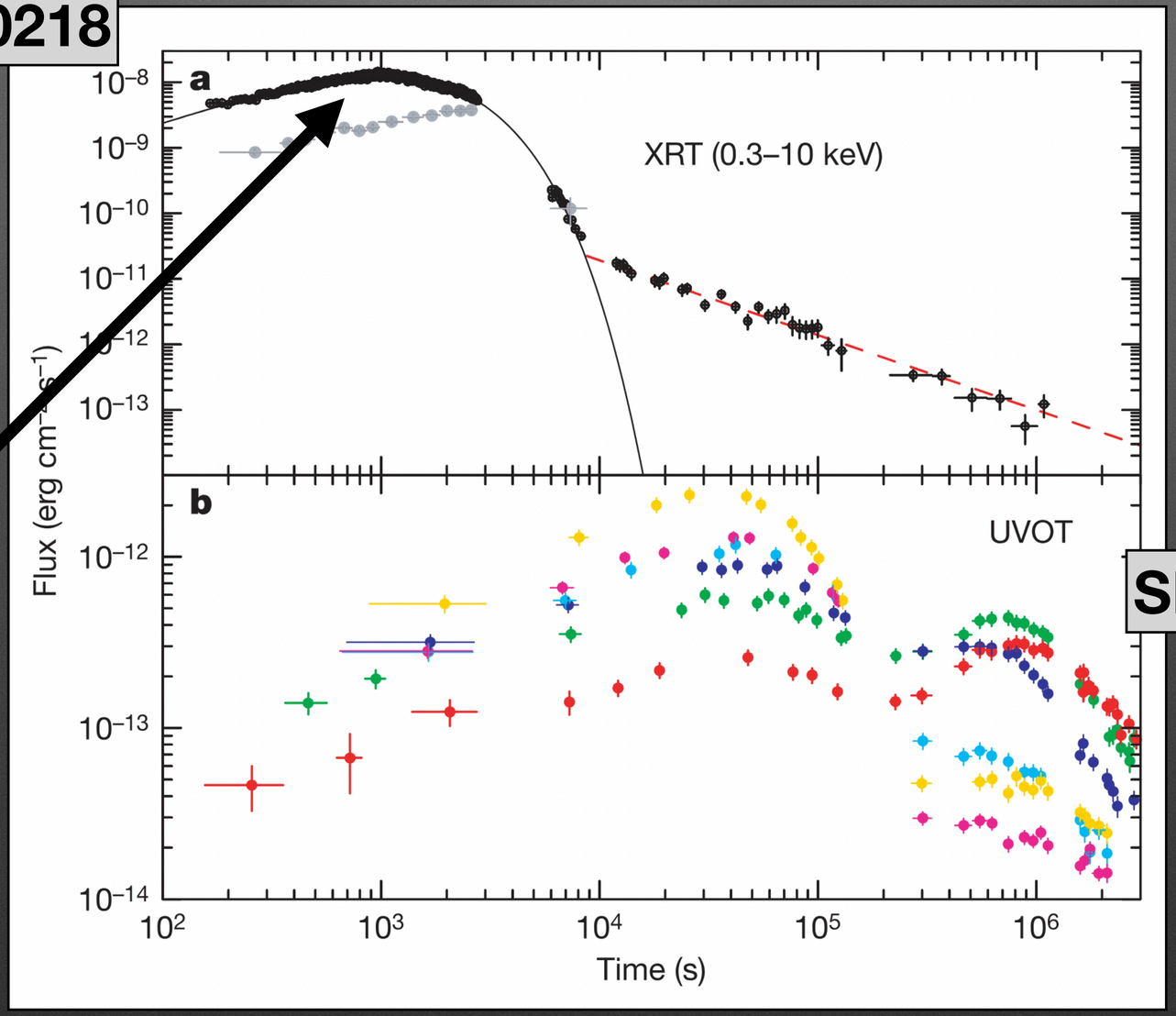


Margutti +13, +14; Kamble +13; Soderberg +06, +10

ll-GRBs



GRB060218



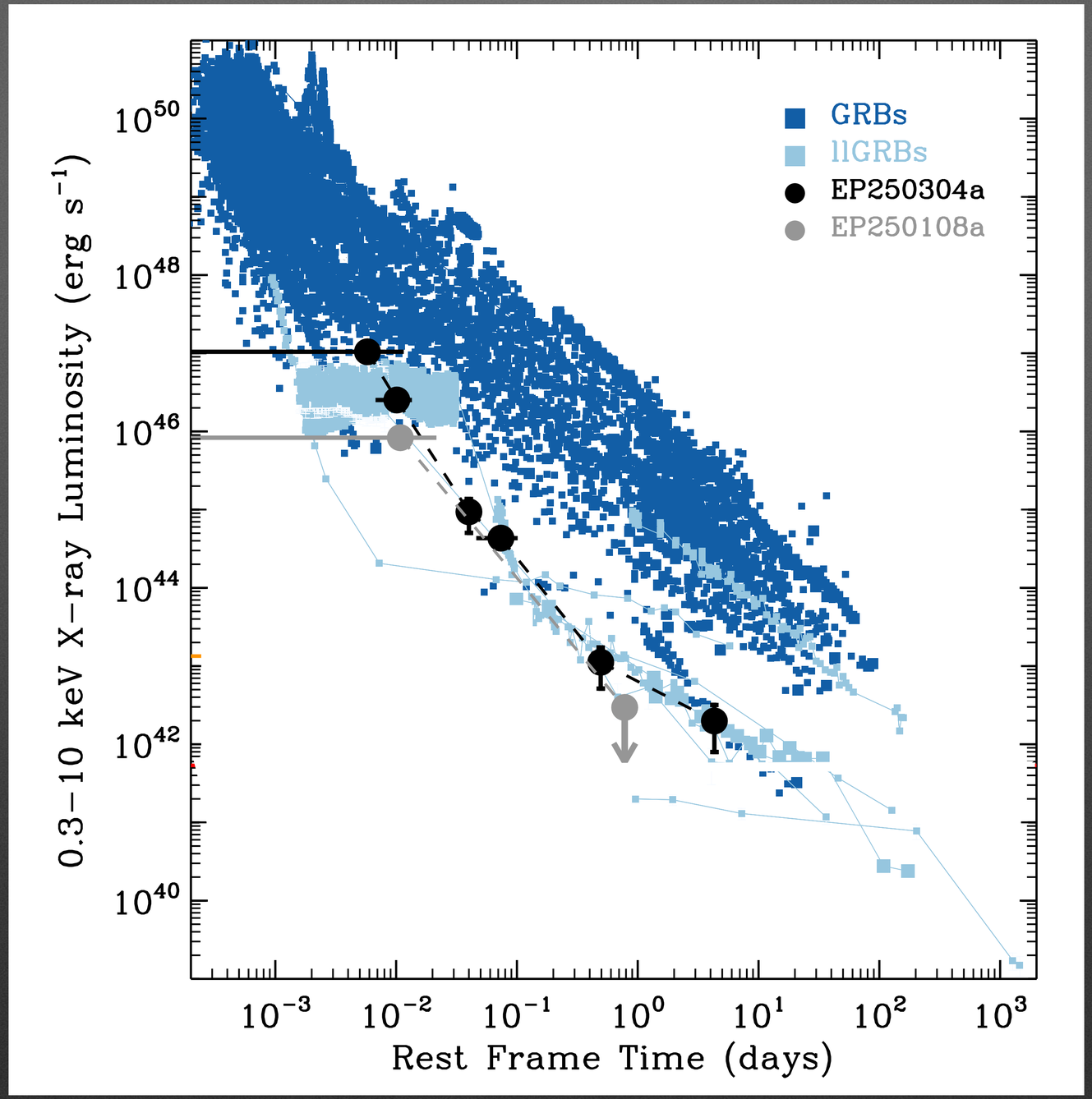
e.g.,
Nakar &
Sari 2010

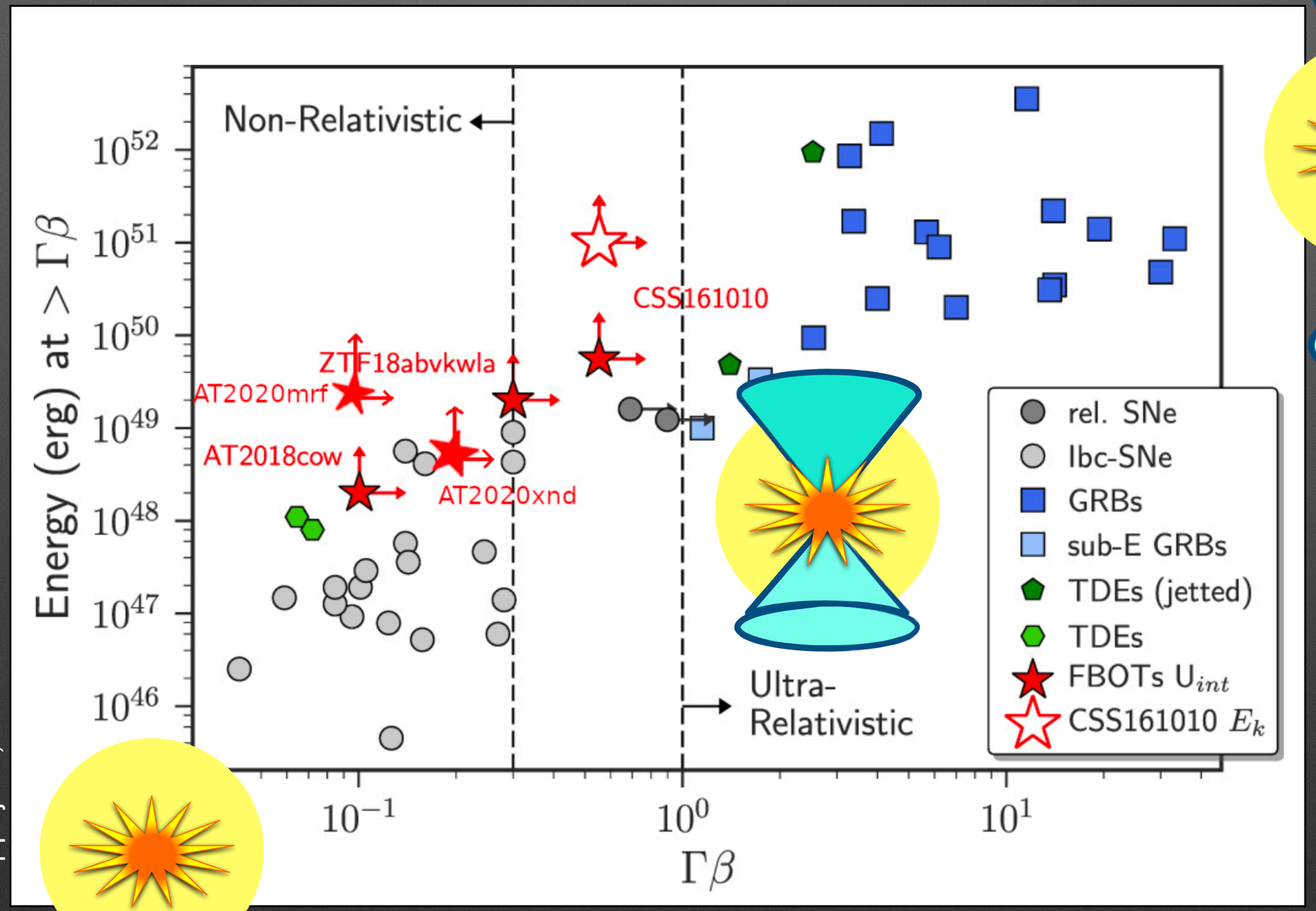
(rel) SBO signature

SN2006aj

UV & X-ray luminous!

Campana+2006 (+ many others!!)


GRBs
llGRBs
EP250304a
EP250108a
0.3−10 keV X−ray Luminosity (erg s^{-1})
10^{50}
10^{48}
10^{46}
10^{44}
10^{42}
10^{40}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Rest Frame Time (days)

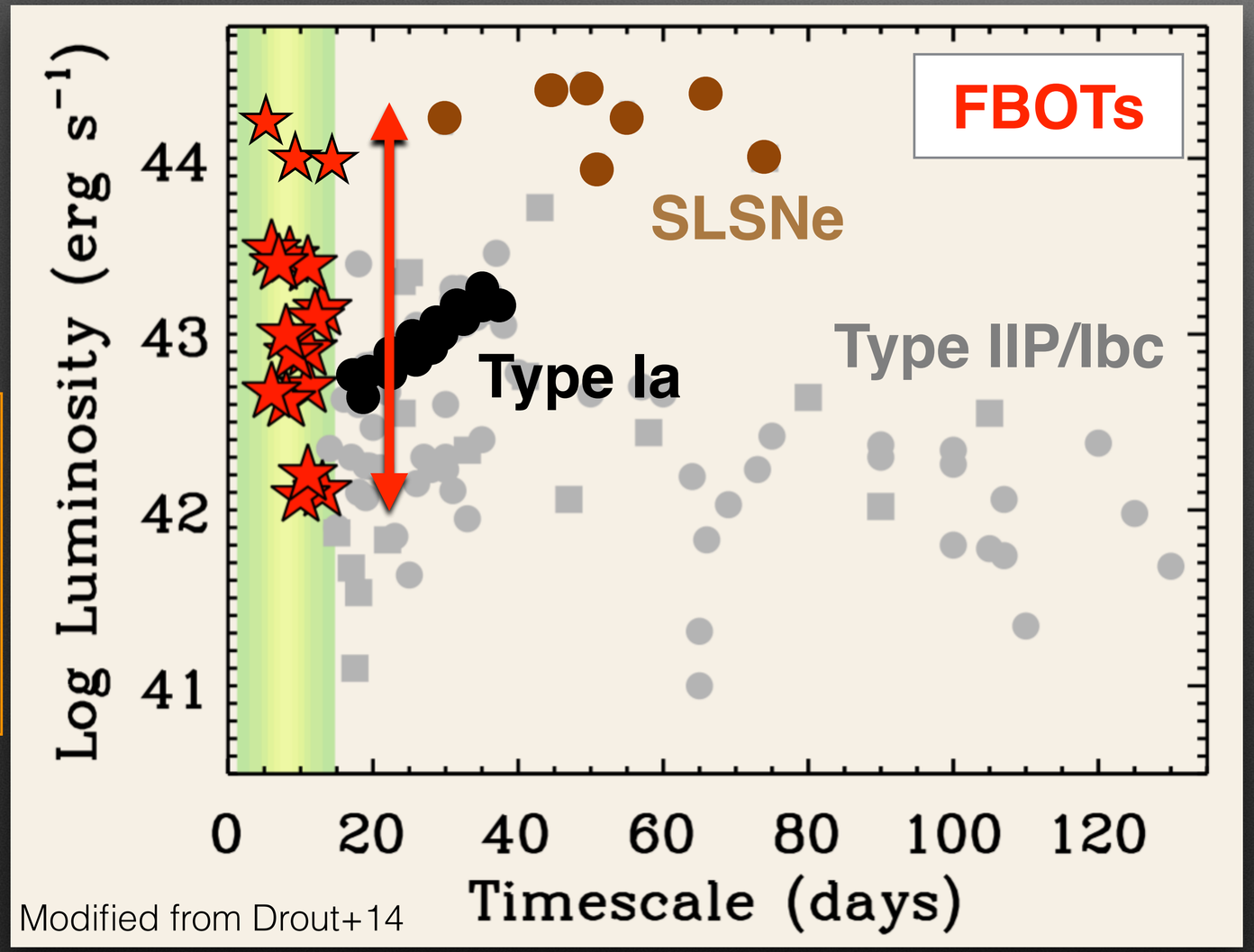


Coppejans, RM+20

Fast Blue Optical Transients

See Perley talk!

Sample studies: Drout+14 (PanSTARSS), Tanaka+16 (Subaru), Arcavi+16 (SNLS+PTF), Pursiainen+18 (DECam), Ho+2023 (ZTF)



Modified from Drout+14

UV/Optical bolometric luminosity

Fast Blue Optical Transients

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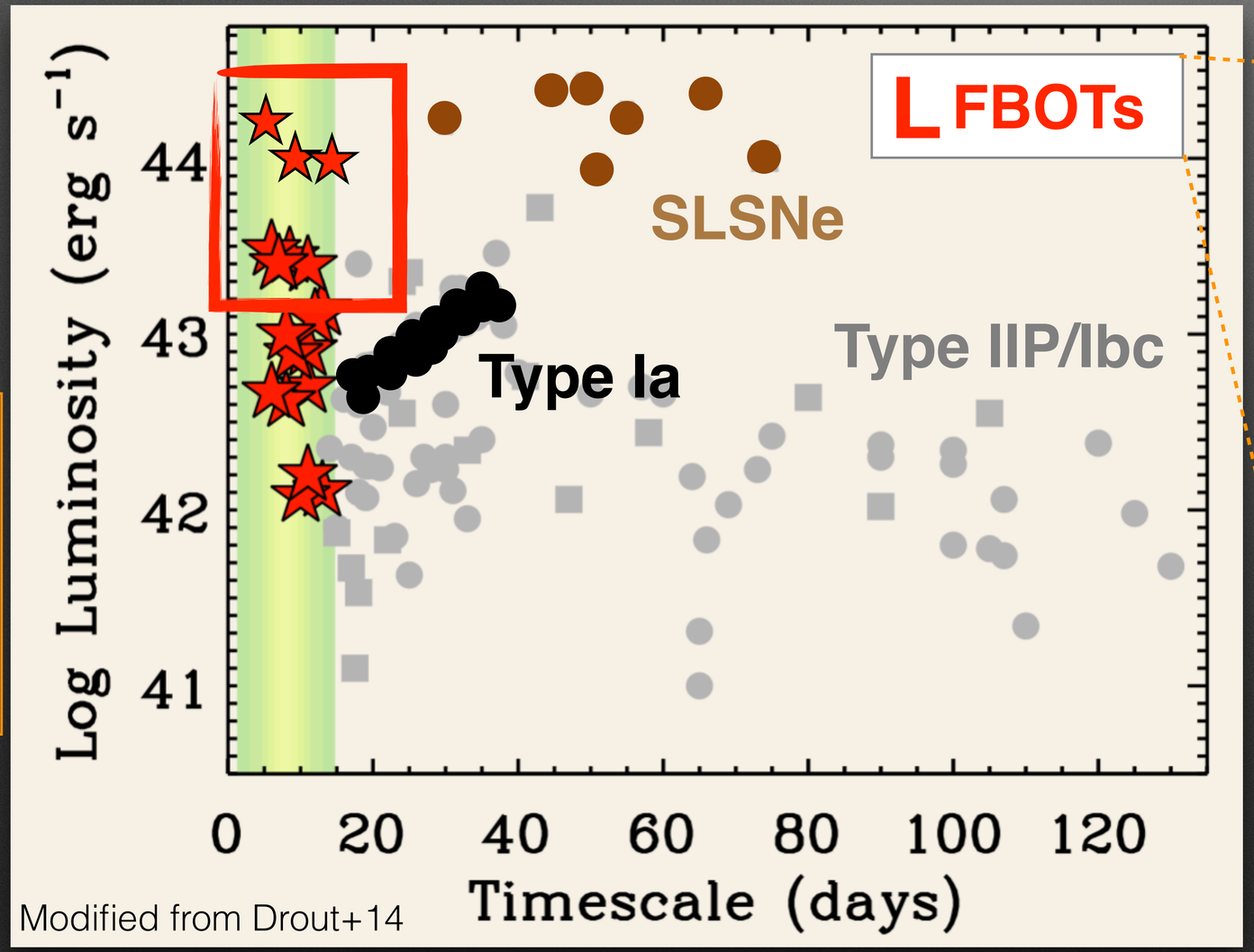
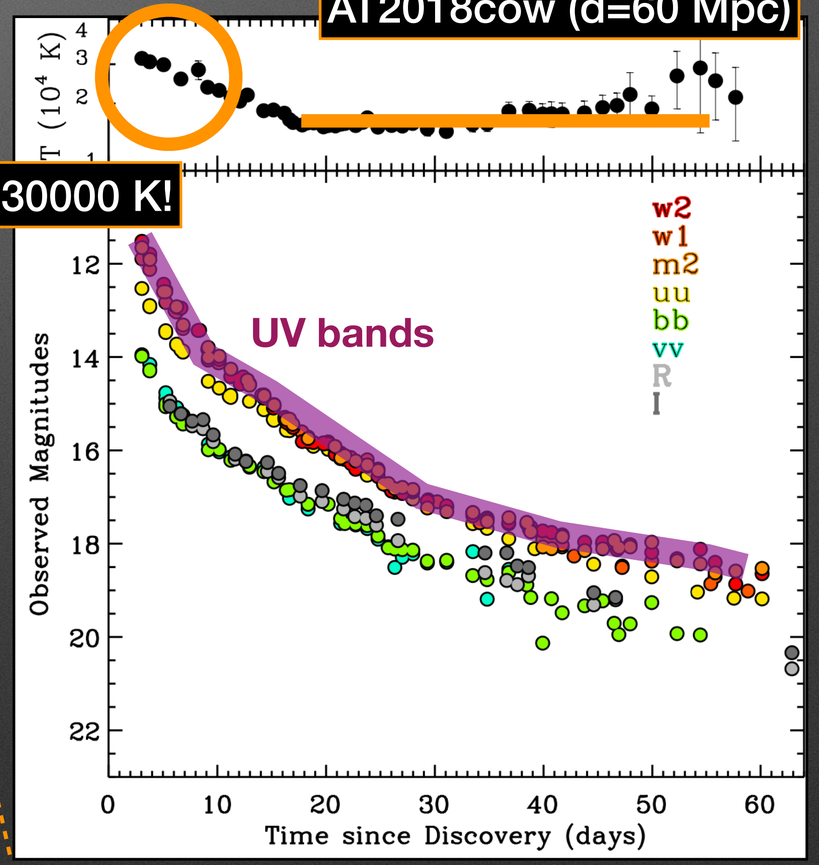


Modified from Drout+14

AT2018cow (d=60 Mpc)

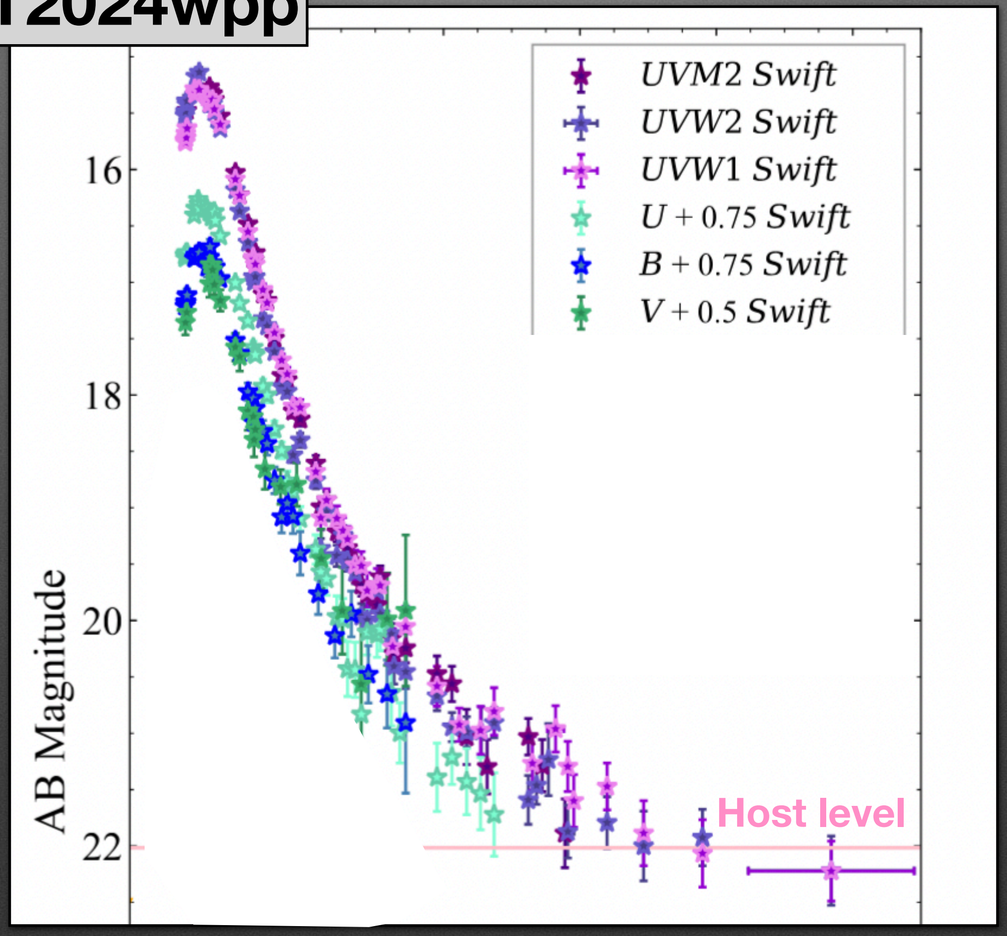
T>30000 K!



Luminous UV emission!

AT2024wpp

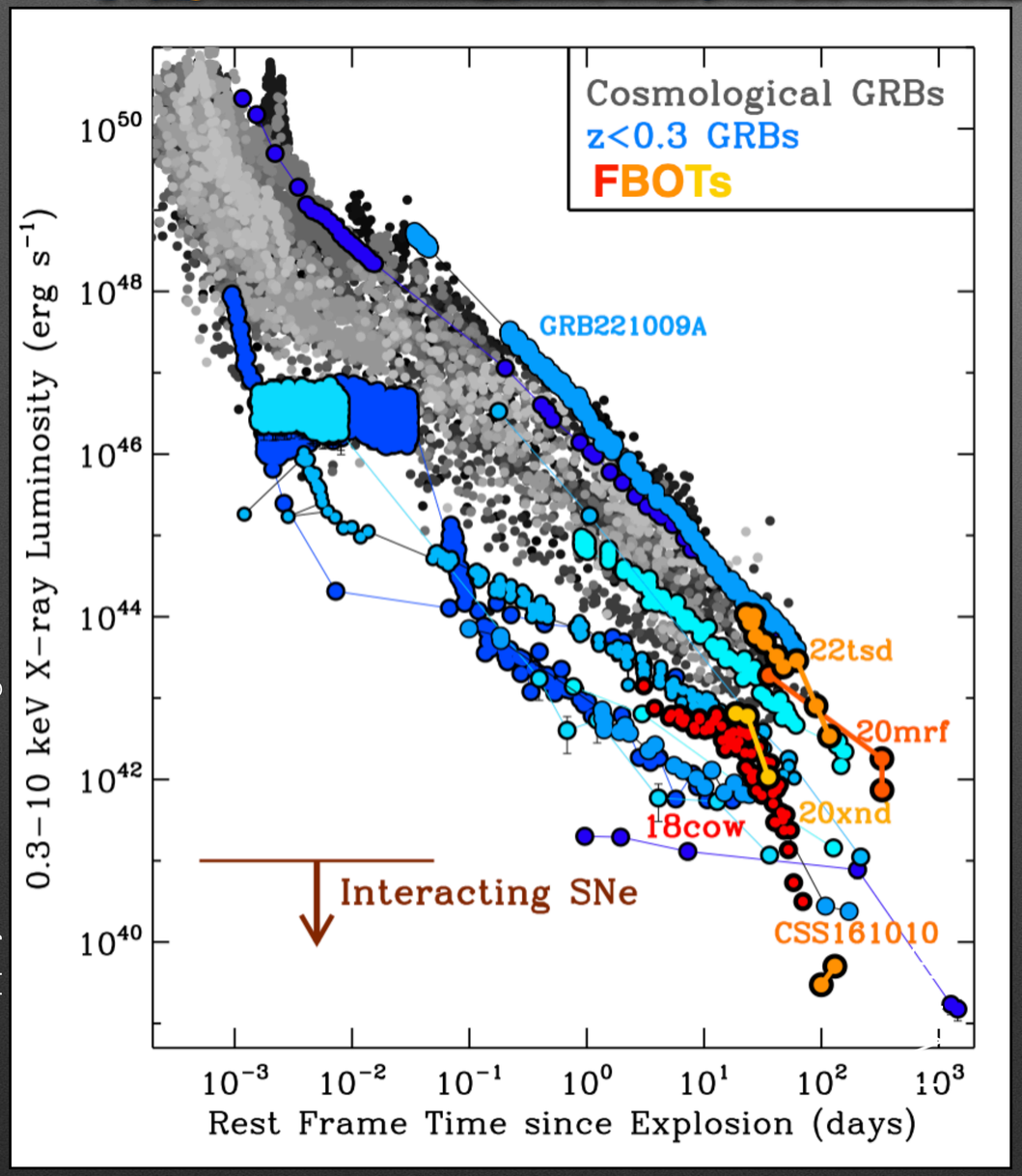
LeBaron+



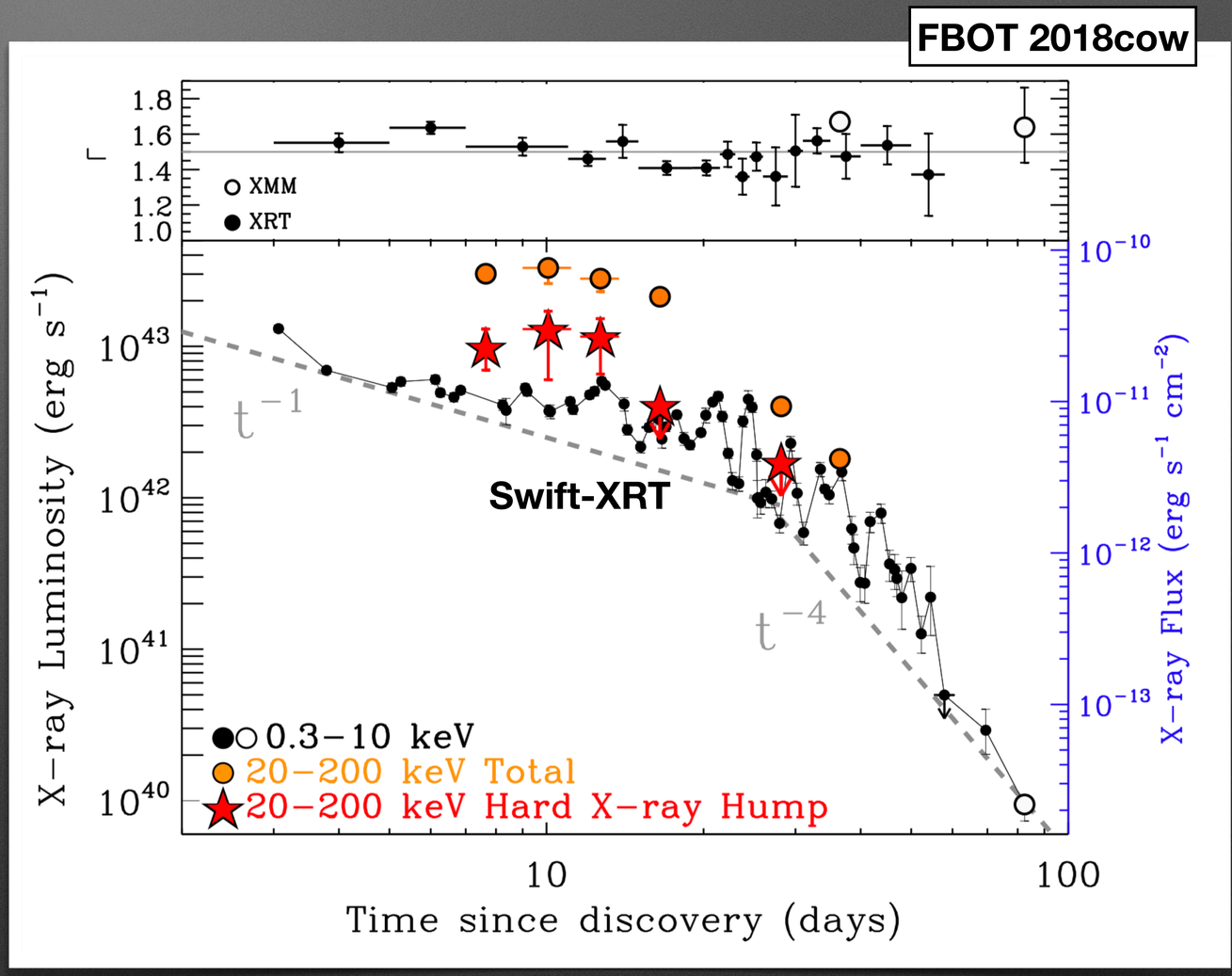
Amazing Swift-UVOT data set
[from GO program, PI Margutti]

See Perley talk!

Luminous, Variable, non-thermal X-rays



RM+19, Coppejans, RM+20, Bright, RM+22, Ho+19, Ho+20, Ho+21; Yao+2022

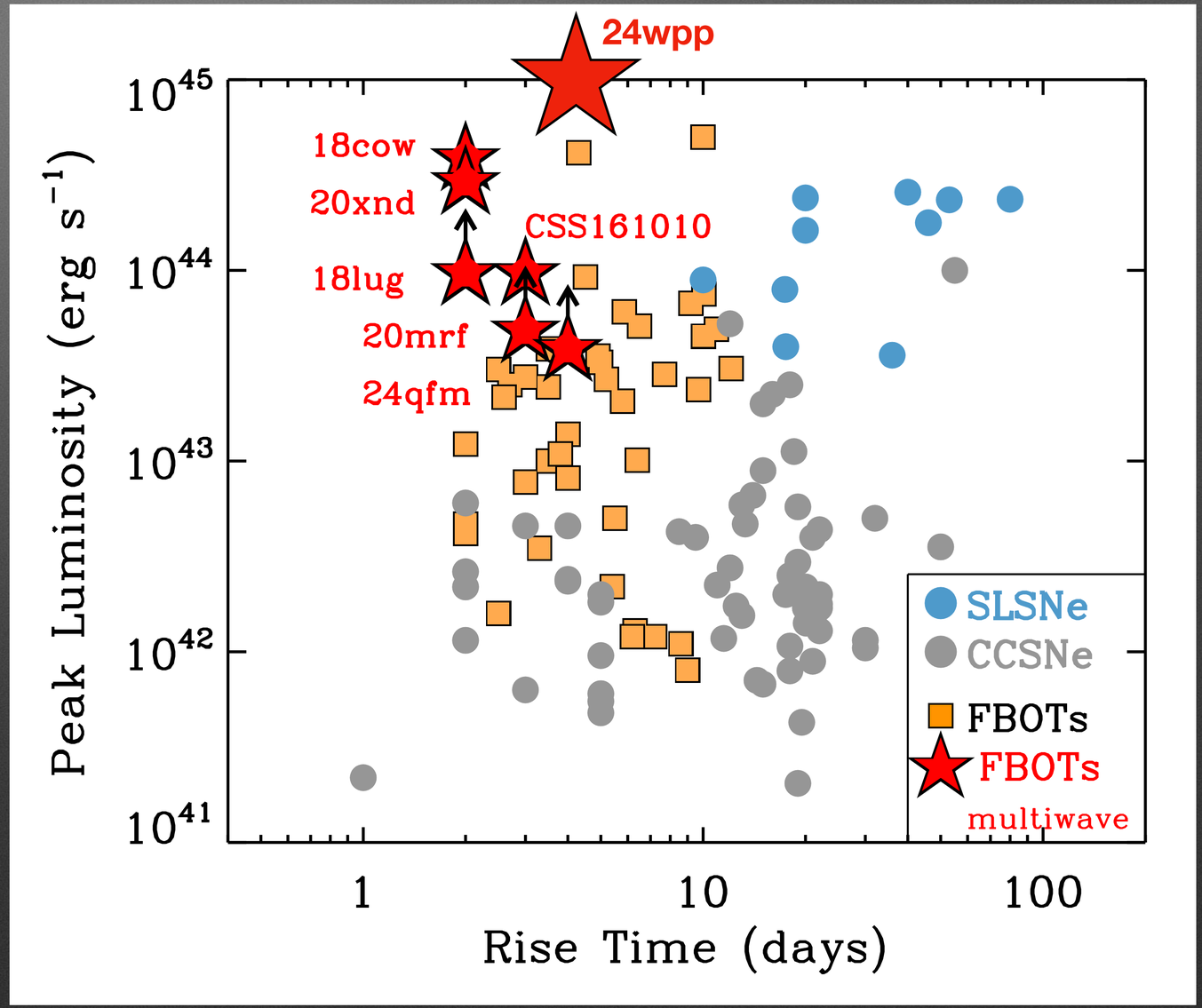


RM+19, see also Kuin+18, Rivera Sandoval+18

Not consistent with shock interaction

Take home message

- The most optically luminous FBOTs are multi-wave sources
- FBOTs can launch relativistic outflows (GRB-like or TDE like!)

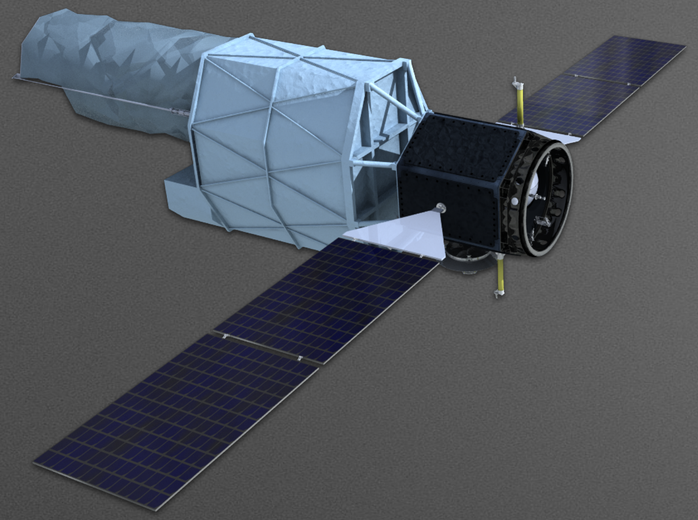


"It sort of makes you stop and think, doesn't it."

UVEX

PI: Fiona Harrison

See Kasliwal talk!



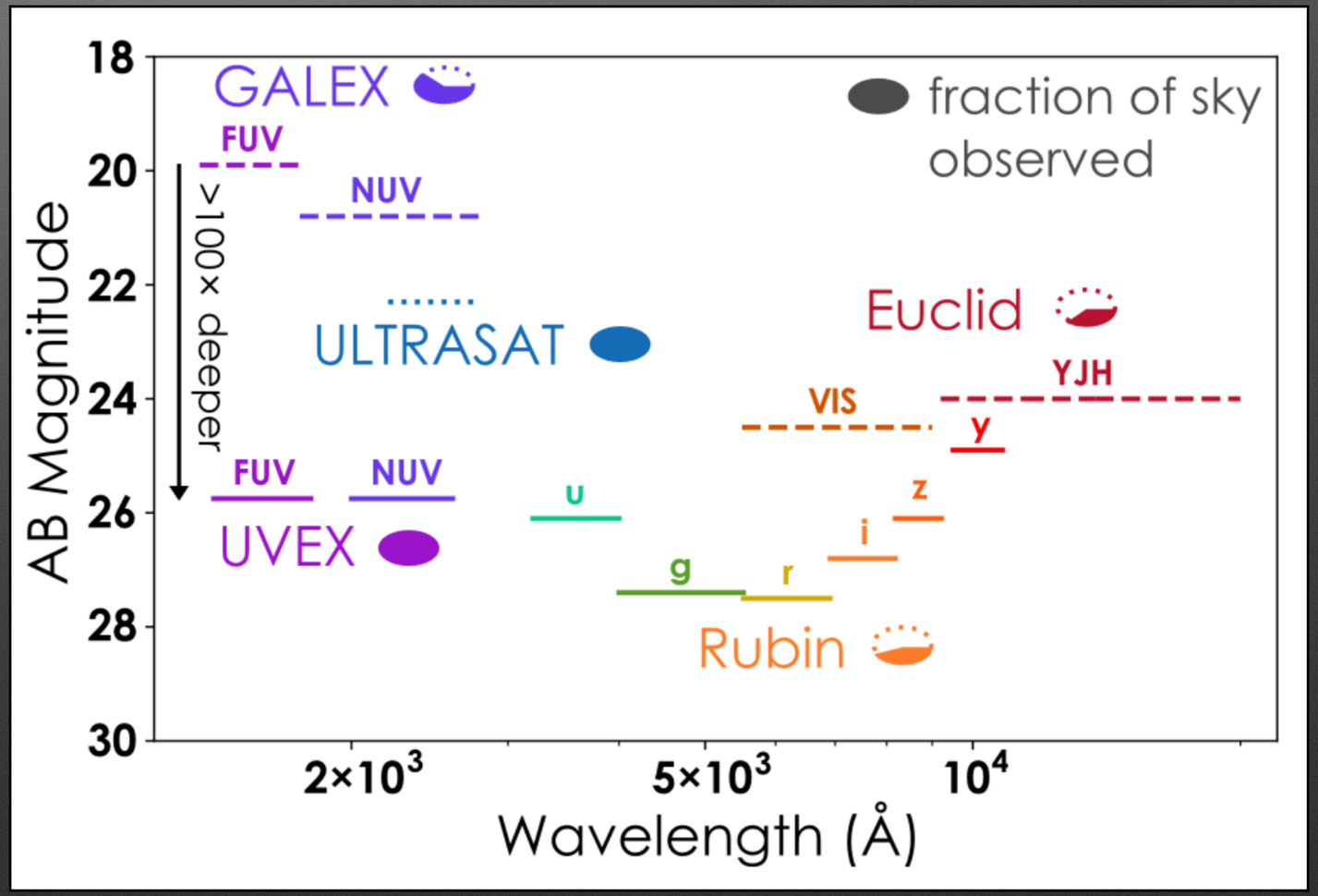
(MIDEX, selected for launch)

UVEX Mission Parameters

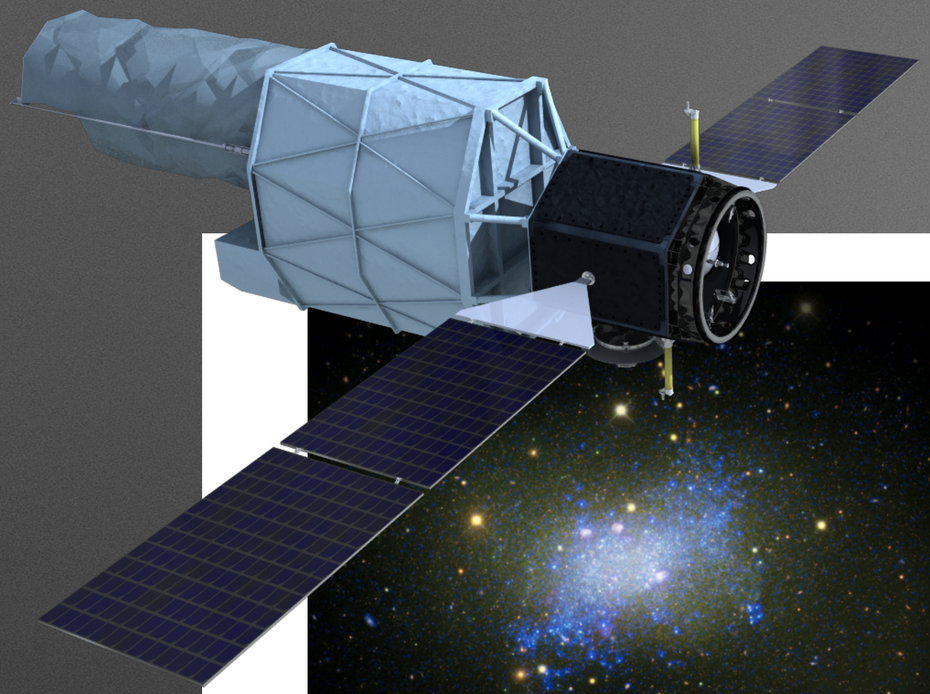
2030

Science Mission	Launch: ~~2028~~, duration 2 years
Imaging FOV	3.5° x 3.5°
Image Quality (HPD)	< 2.25″
Imaging Bandpass	FUV: 1390–1900 Å NUV: 2030–2700 Å
Sky Survey Depth	> 25.8 mag (FUV and NUV)
Spectrograph	2°-long slit, multiple widths
Spectrograph Bandpass	1150–2650 Å
Spectrograph Resolution	R > 1000
Orbit	Elliptical 17 R_e x 15 R_e, 13.7 days
Instantaneous Sky Accessibility	> 70%
Average ToO Response	< 3 hours

https://www.uvex.caltech.edu/



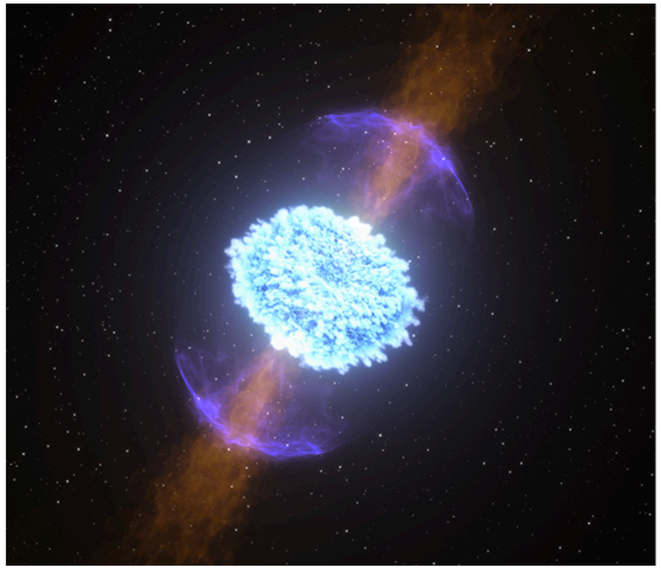
Kulkarni+21



UVEX science pillars

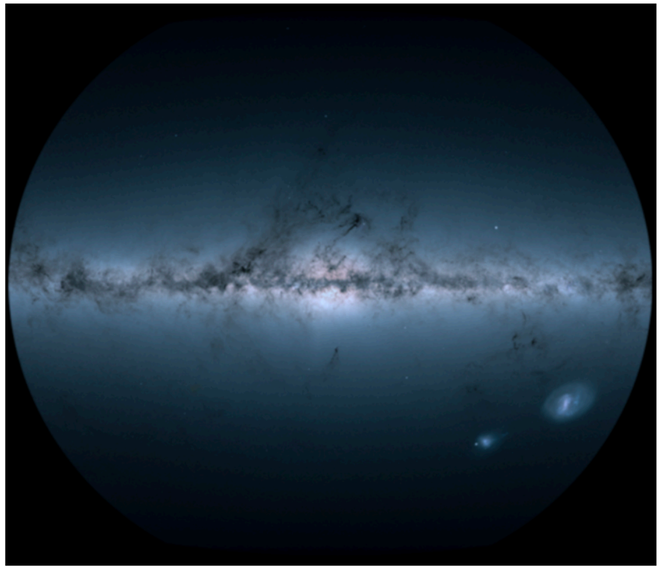
The Low-Mass, Low-Metallicity Galaxy Frontier

UVEX will identify low-mass, low-metallicity galaxies in the nearby Universe, diagnose the nebular emission of analogs to high-redshift galaxies, and study hot stars in the Large and Small Magellanic Clouds, our neighboring low-metallicity laboratories.



New Views of the Dynamic Universe

UVEX will probe the short-lived UV emission from merging neutron stars, perform spectral follow-up of the first hours of core collapse supernovae, and provide a community resource for target-of-opportunity observations.



A Legacy of Deep, Synoptic All-Sky Data

By performing a cadenced all-sky survey 50–100x more sensitive than GALEX, UVEX will generate a wealth of photometric and spectroscopic data, opening vast discovery space for the future, with depth and resolution matching modern optical and infrared surveys.

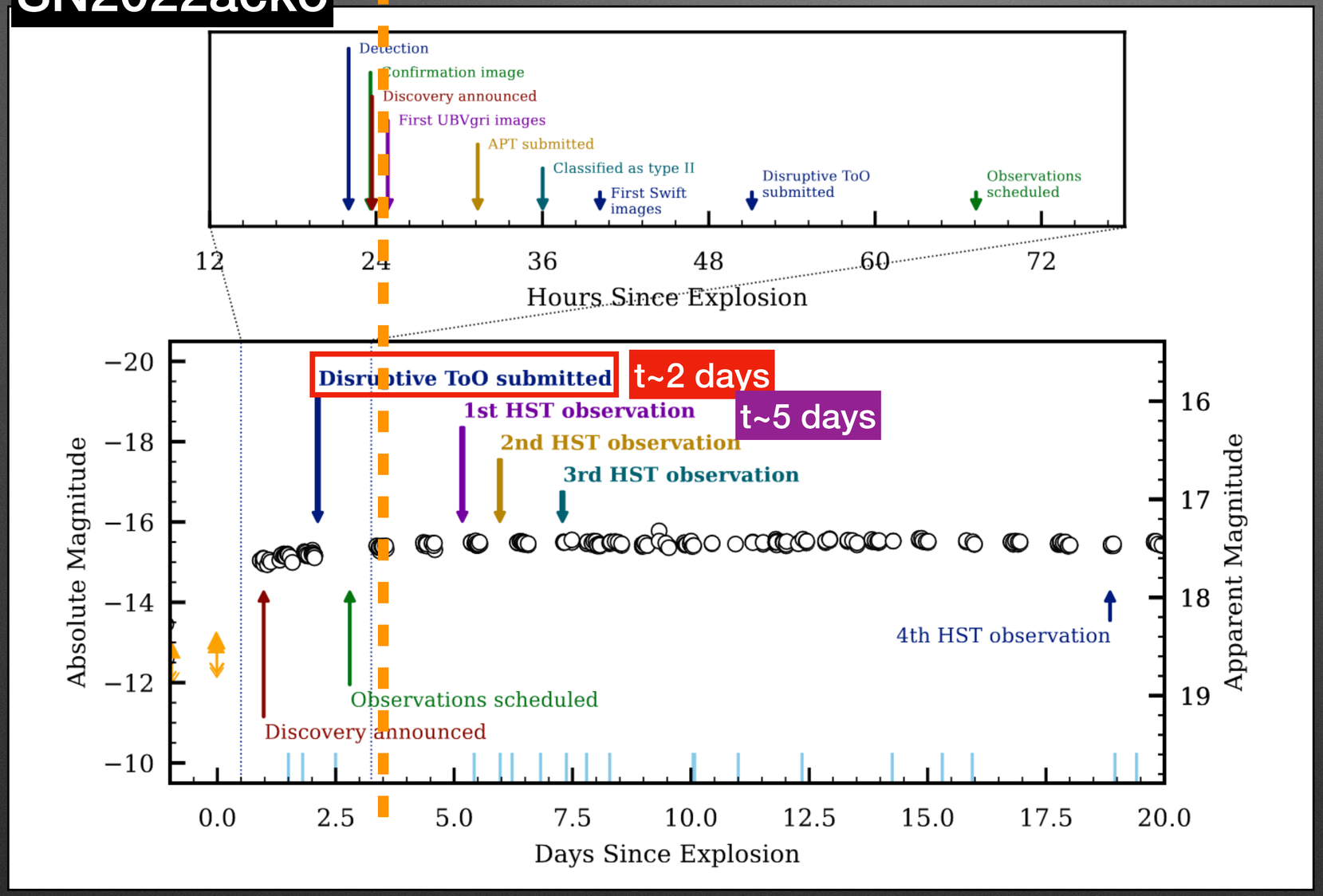
https://www.uvex.caltech.edu/

What is really new?

i.e. transformative vs. incremental capabilities

SN2023ixf @3.6 d

SN2022acko

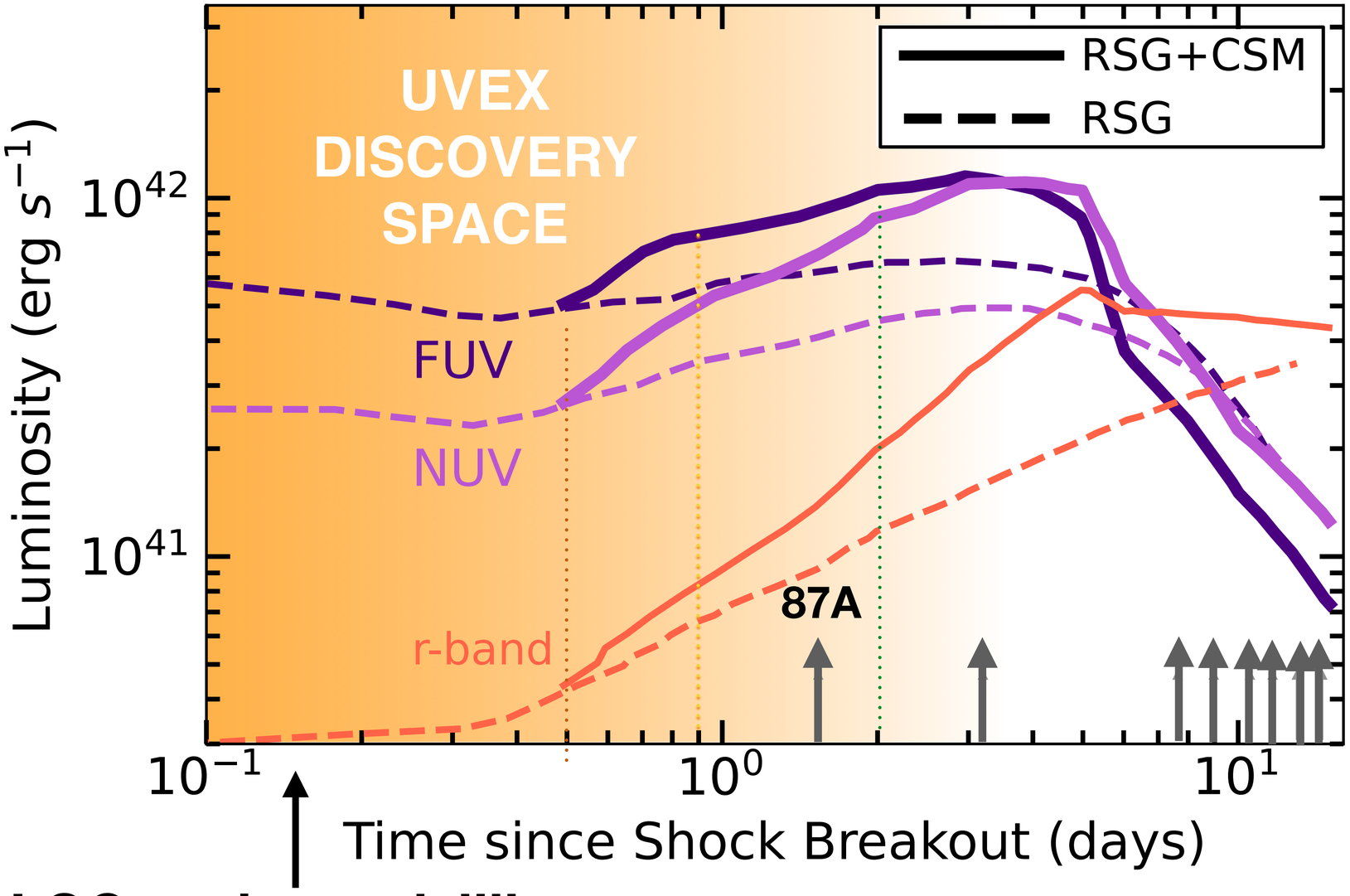


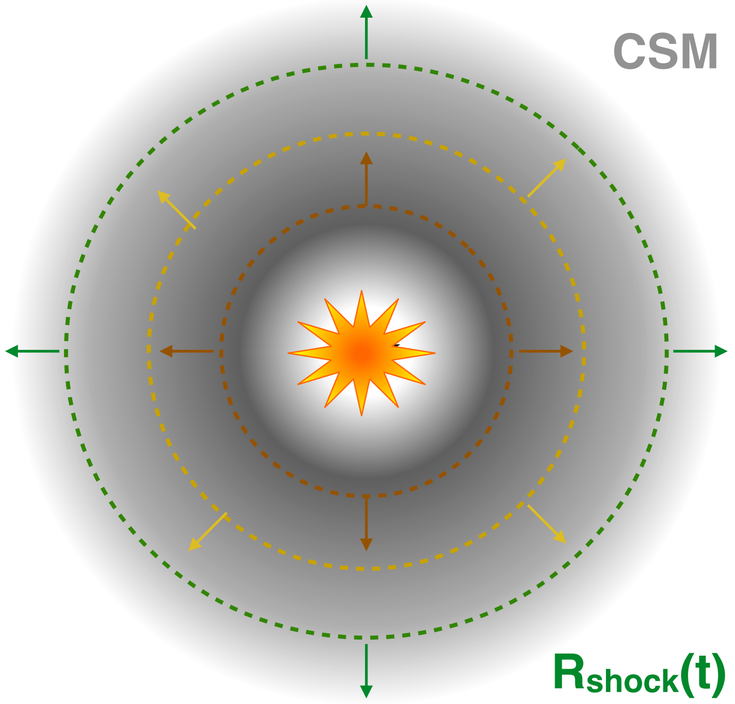
Prompt UV spectroscopy (~ 3 hrs)

The first early far UV spectra of a IIP SN

Bostroem+23

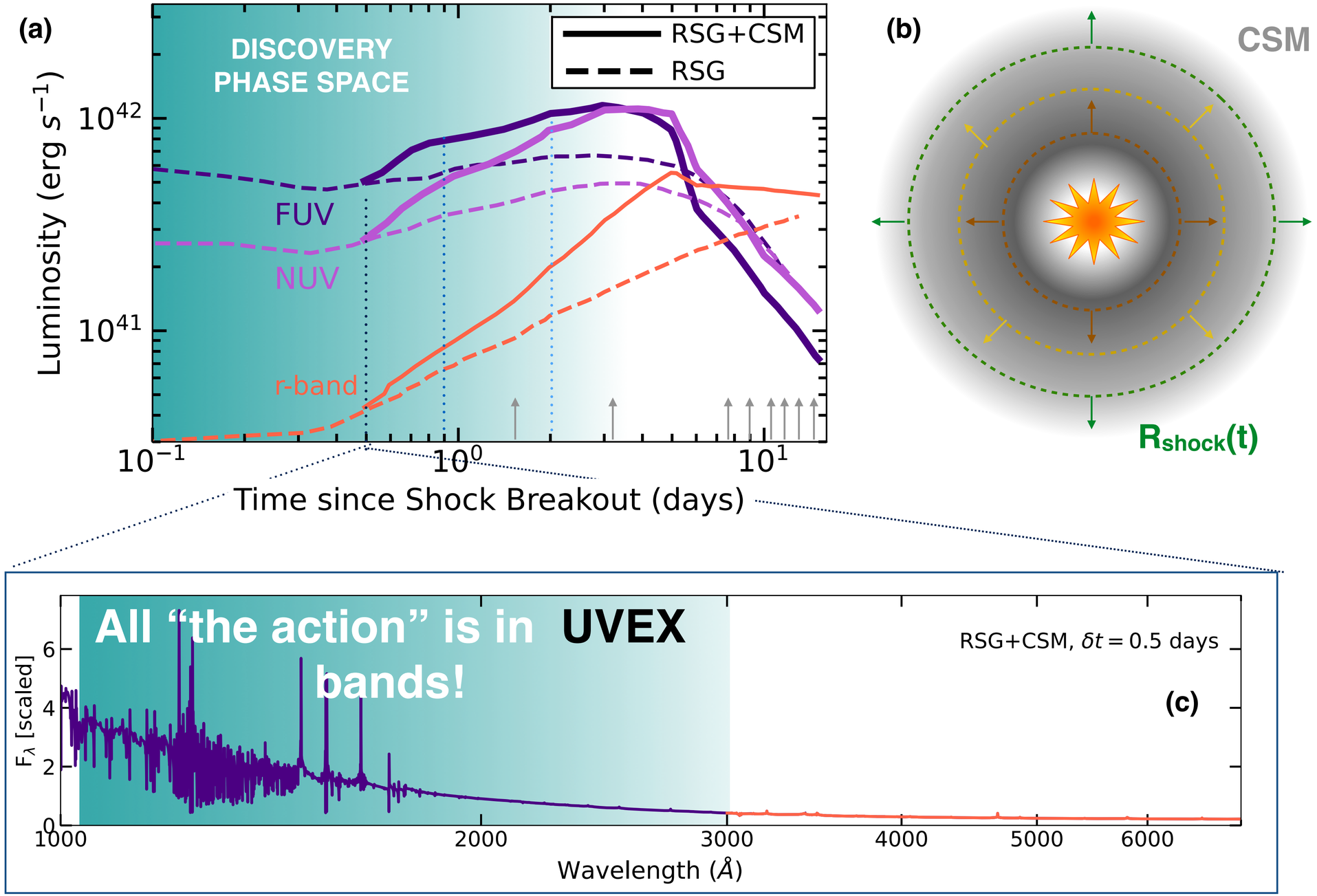
Explosion of a Red Super Giant with and without dense circumstellar medium (CSM)





LOG scale x-axis!!!!

Models by Luc Dessart

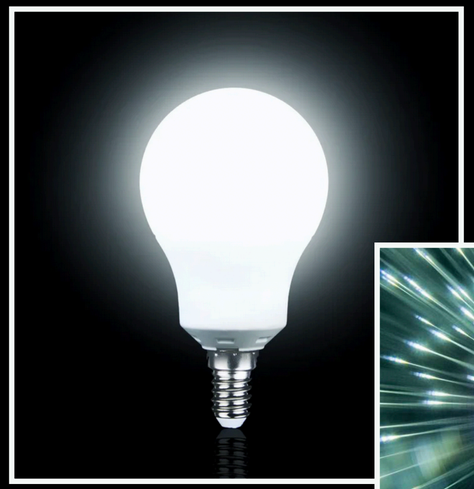

(a)
DISCOVERY
PHASE SPACE
RSG+CSM
RSG
FUV
NUV
r-band
Luminosity (erg s^{-1})
10^{42}
10^{41}
10^{-1}
10^{0}
10^{1}
Time since Shock Breakout (days)
(b)
CSM
$R_{shock}(t)$
All "the action" is in UVEX bands!
RSG+CSM, $\delta t = 0.5$ days
(c)
F_λ [scaled]
0
2
4
6
1000
2000
3000
4000
5000
6000
Wavelength (Å)

(UC Berkeley center for)
Multi-messenger Research on AstroPhysical Transients and OutReach

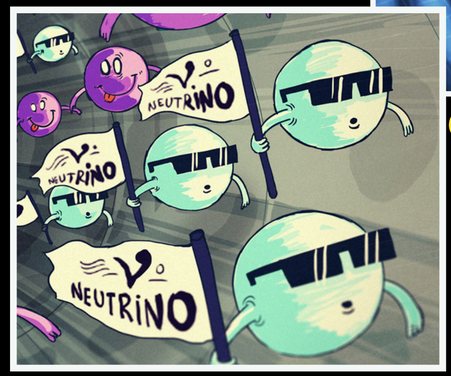
Multi-RAPTOR

Director: Prof Raffaella Margutti

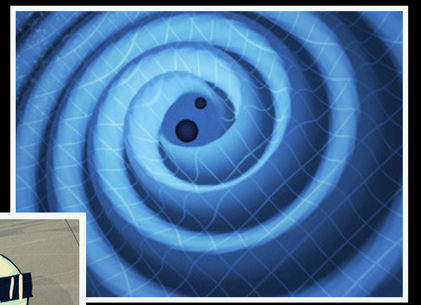
Four messengers of information to study the fourth dimension: TIME

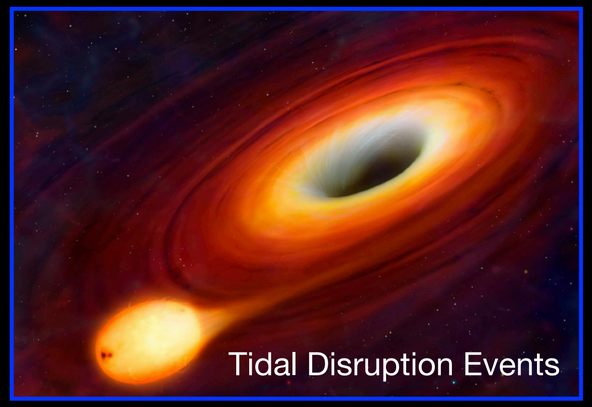

Light


Cosmic rays

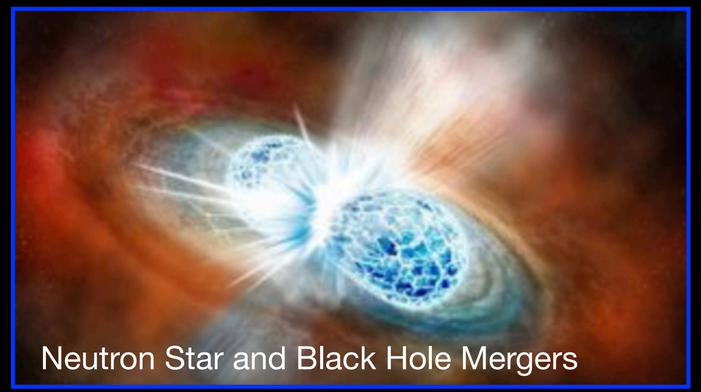


Neutrinos


Gravitational Waves


Tidal Disruption Events


Stellar Explosions


Neutron Star and Black Hole Mergers

(This is not)

…..The End…

"What we call the beginning is often the end. And to make an end is to make a beginning.
The end is where we start from."

T. S. Eliot