

Observatoire
de Paris

PSL



S.D. VERGANI

MULTI-MESSENGER ASTROPHYSICS IN THE ET ERA



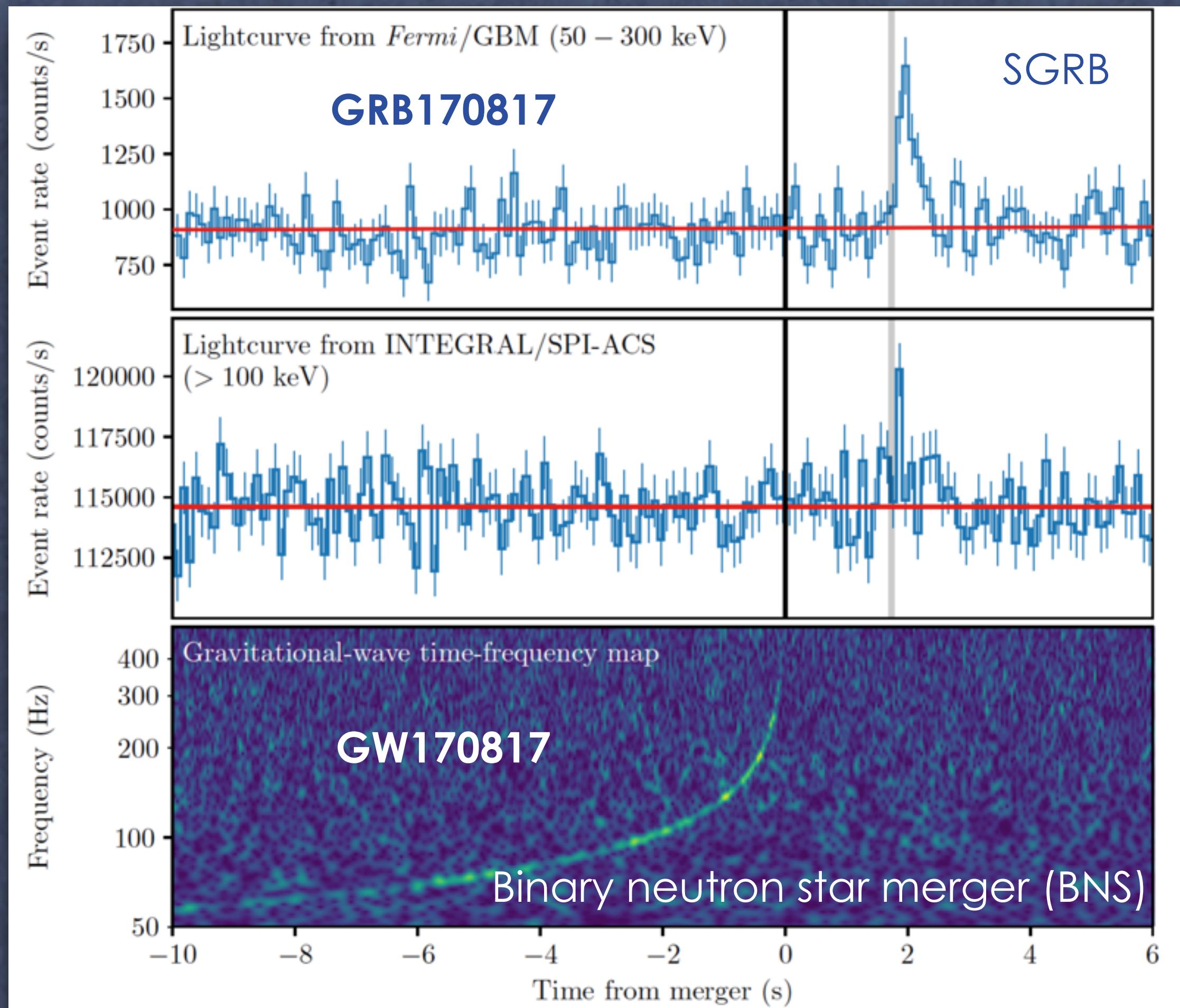
Colombo et al. 2025

Loffredo et al. 2025

ET Blue Book arXiv:2503.12263

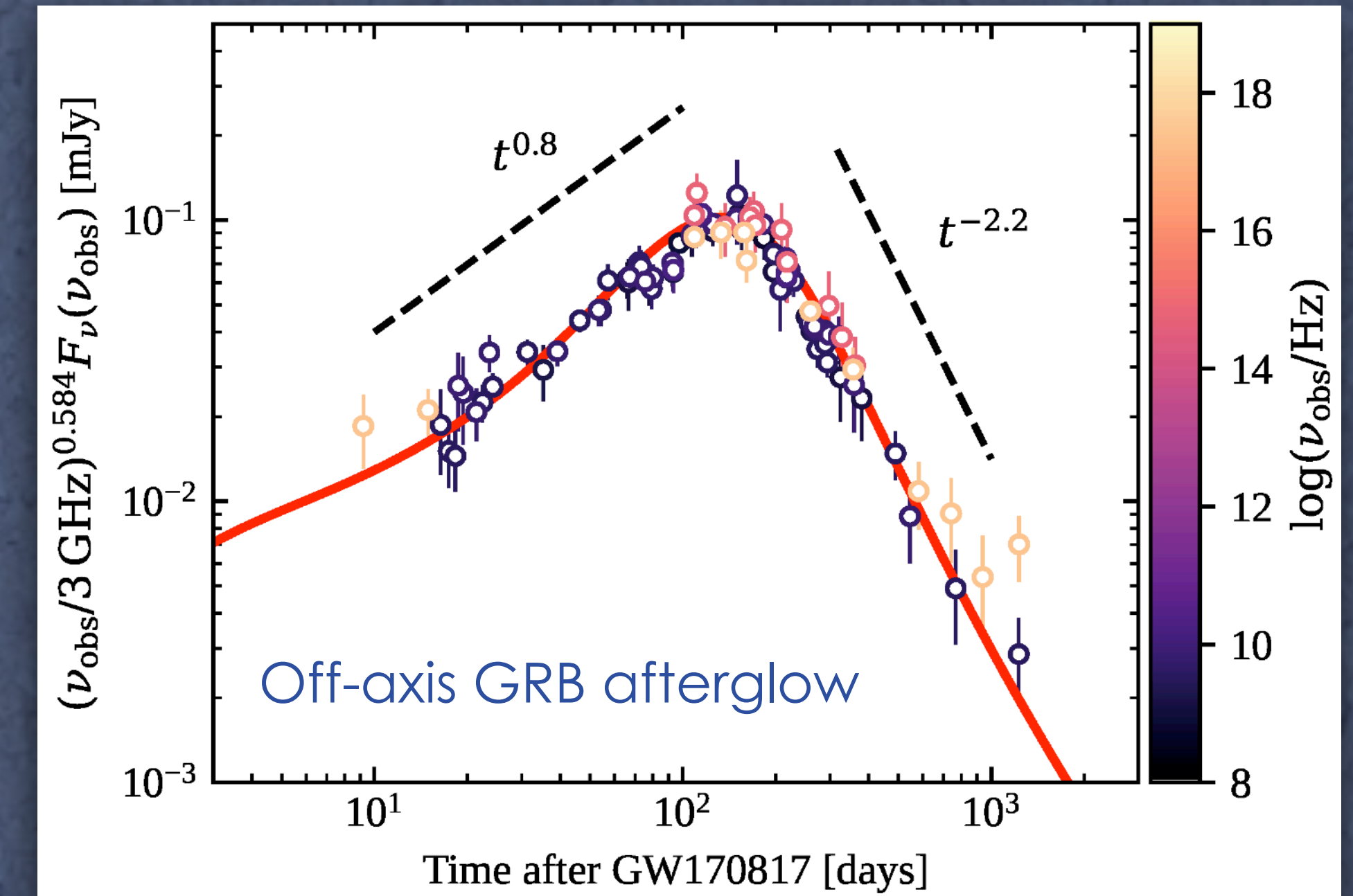
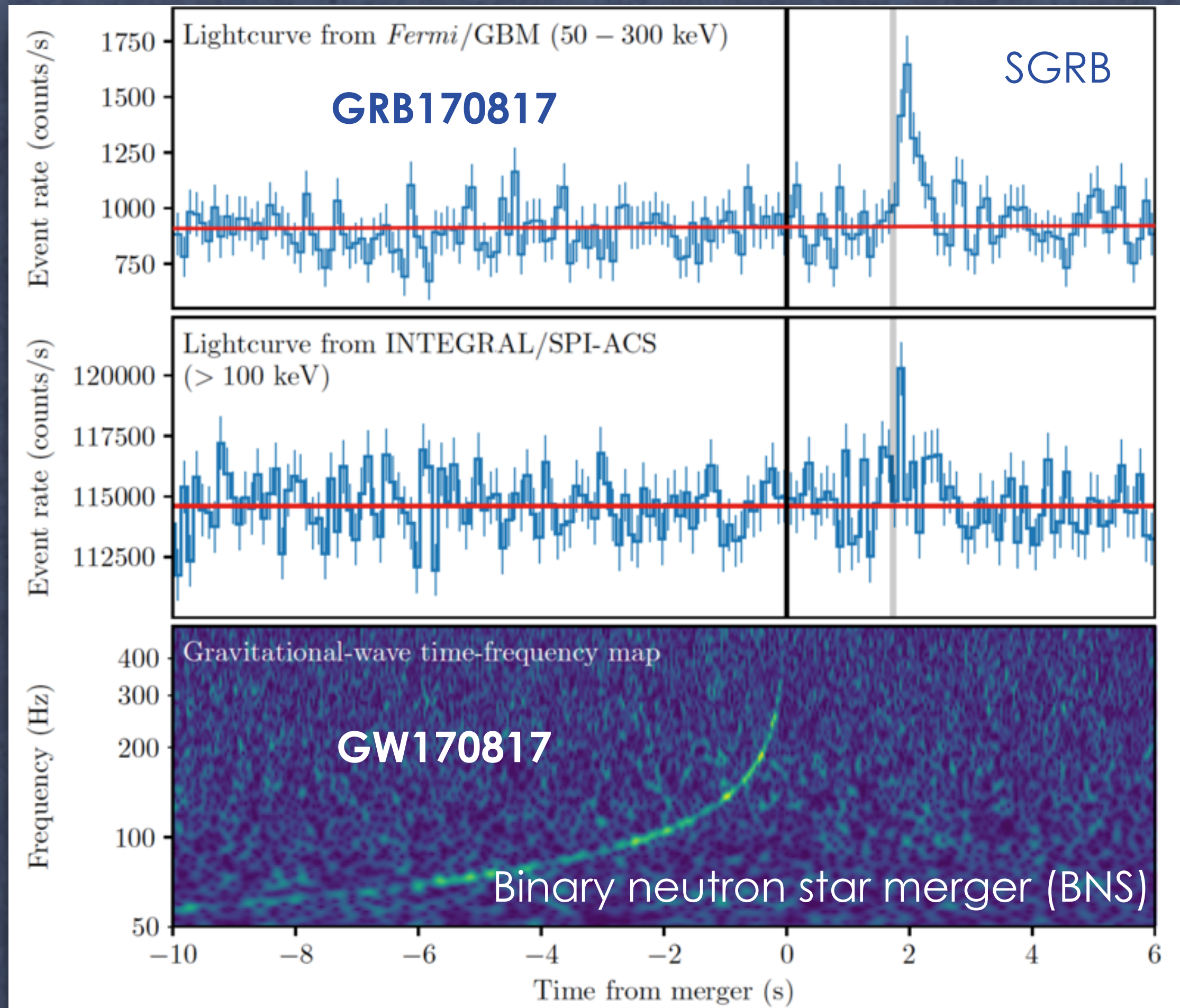
Bisero et al. 2025

BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?



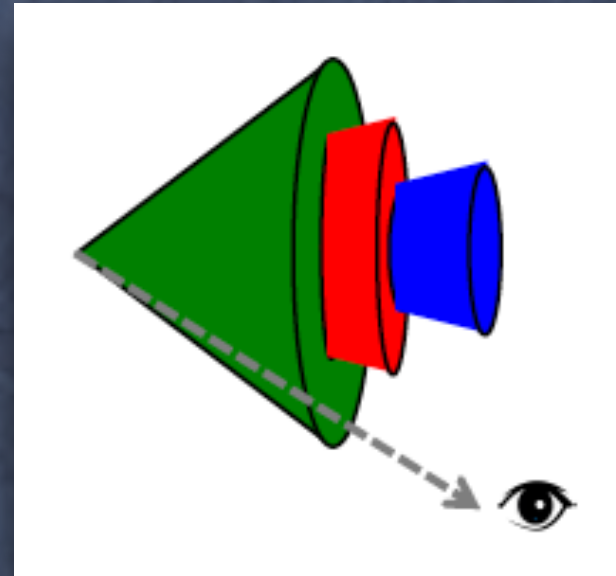
Off-axis GRB afterglow

BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?

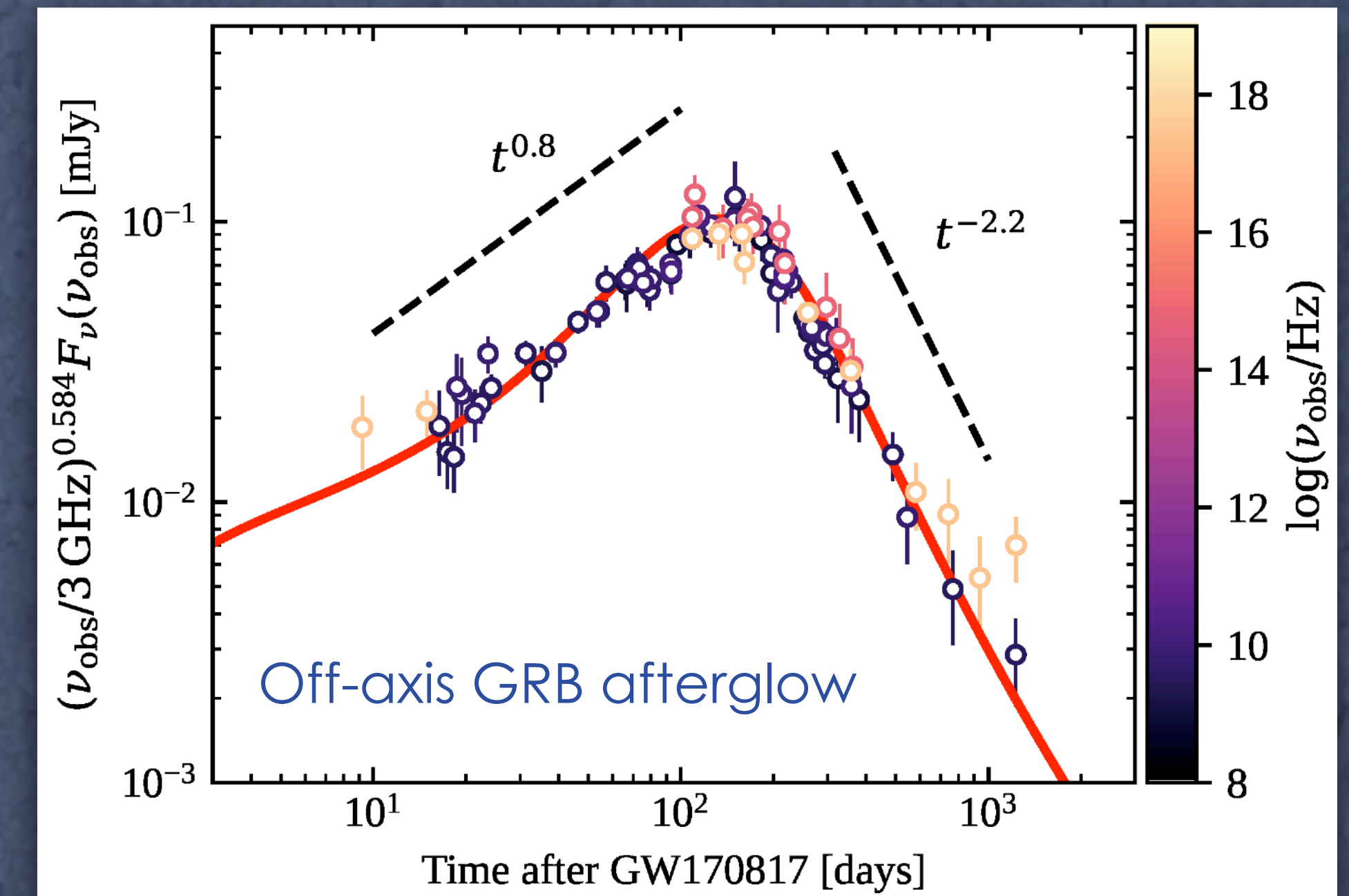
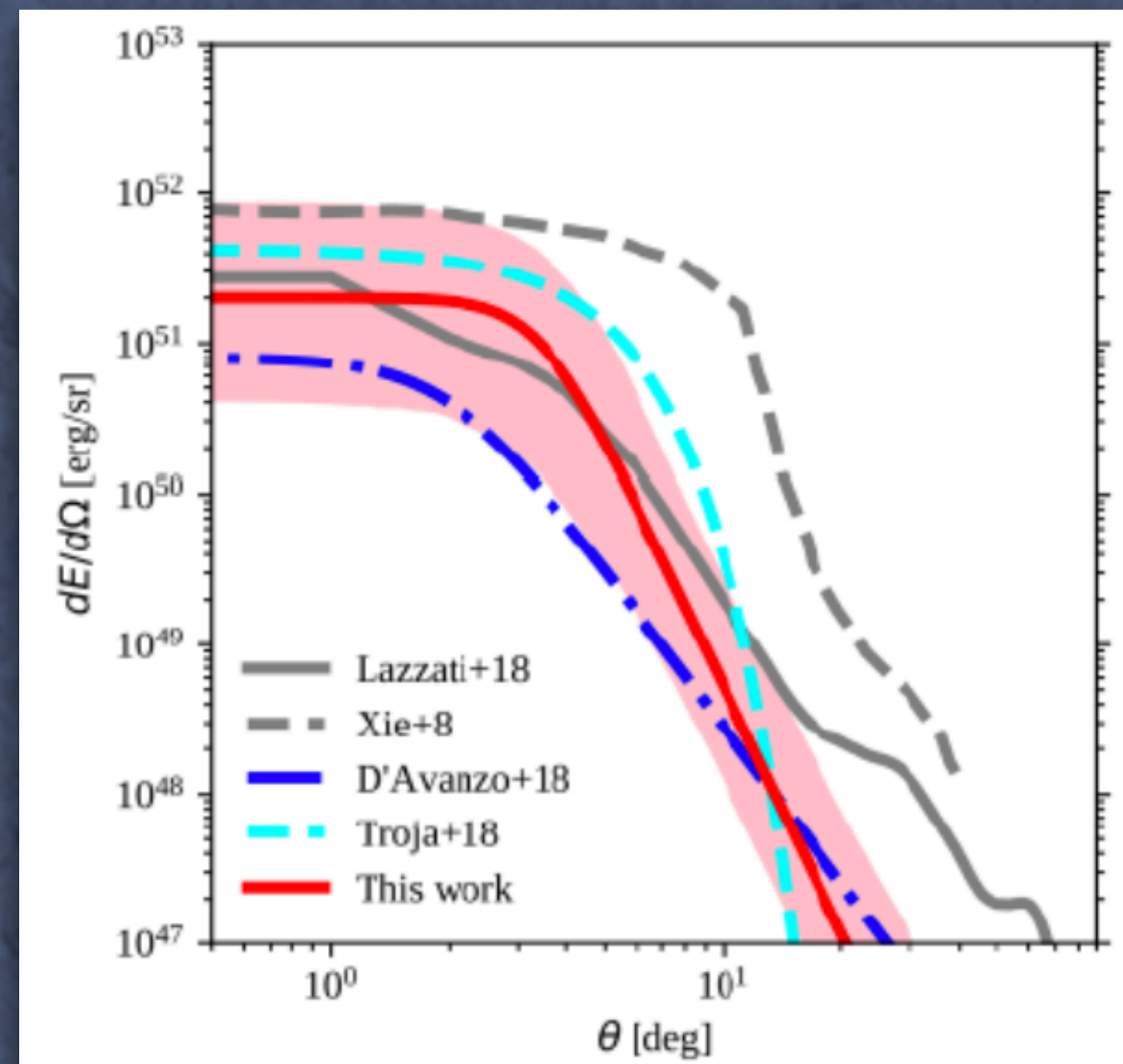


Salafia & Ghirlanda 2022

BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?



Ghirlanda et al. 2019

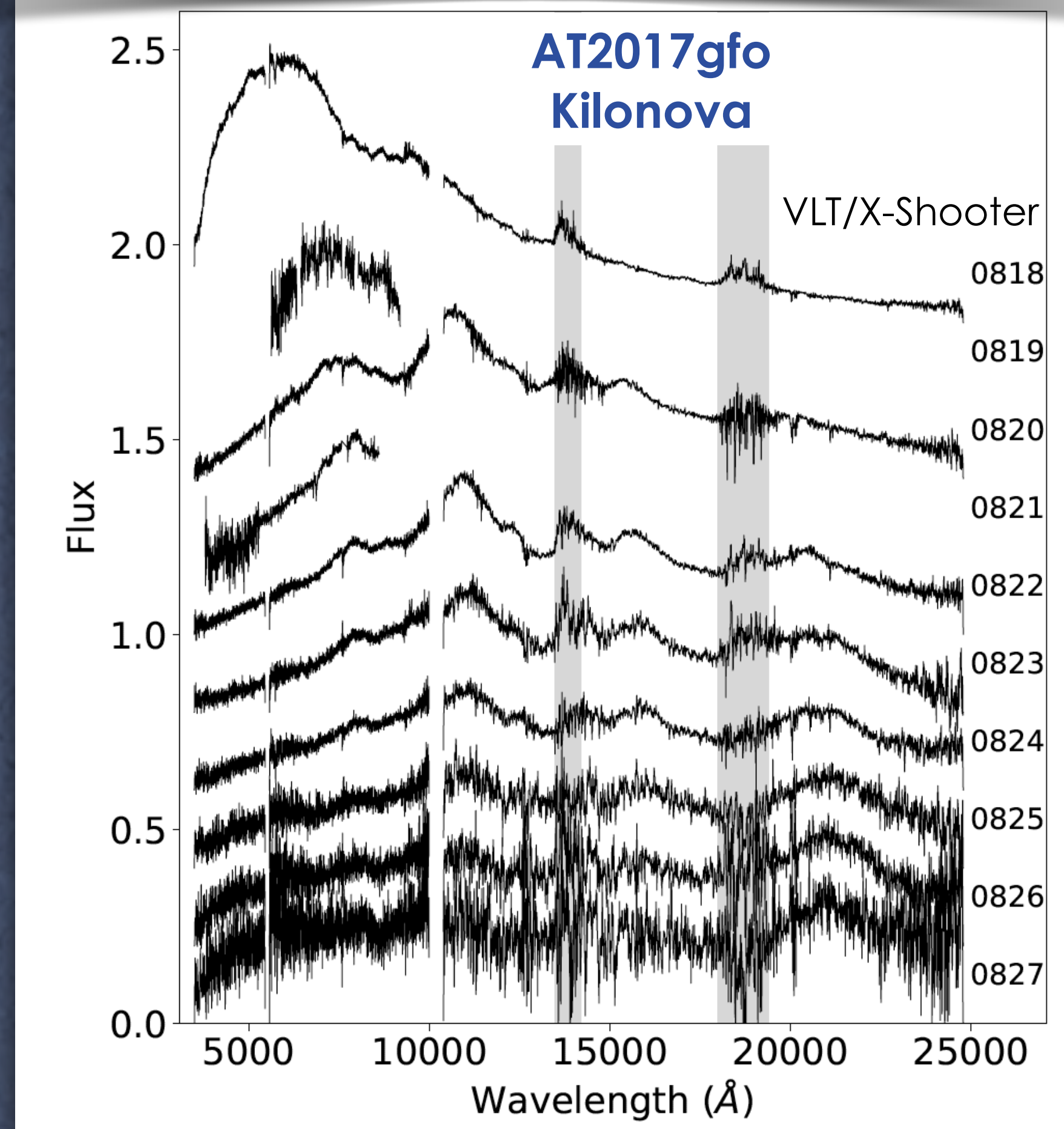
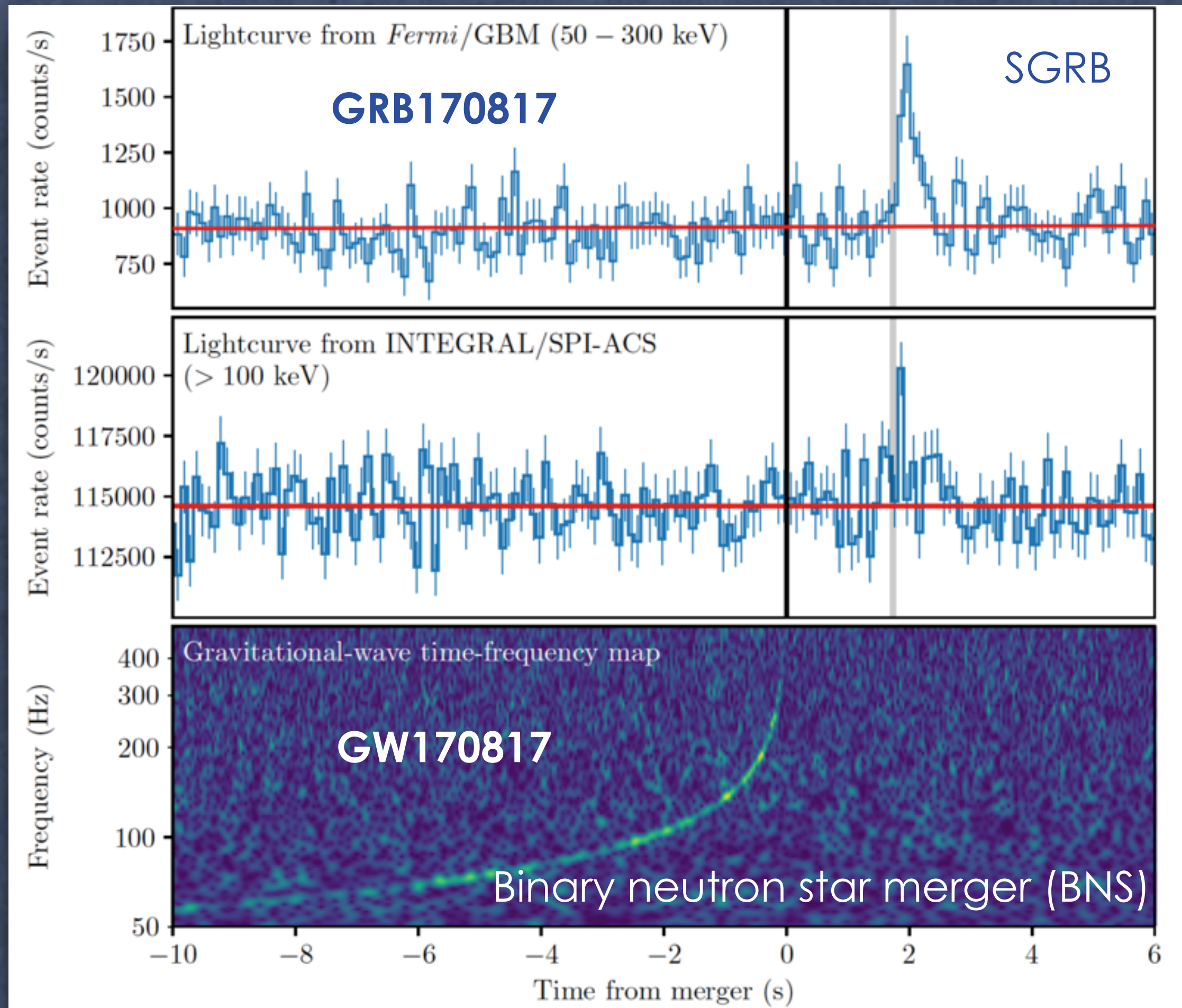


Salafia & Ghirlanda 2022

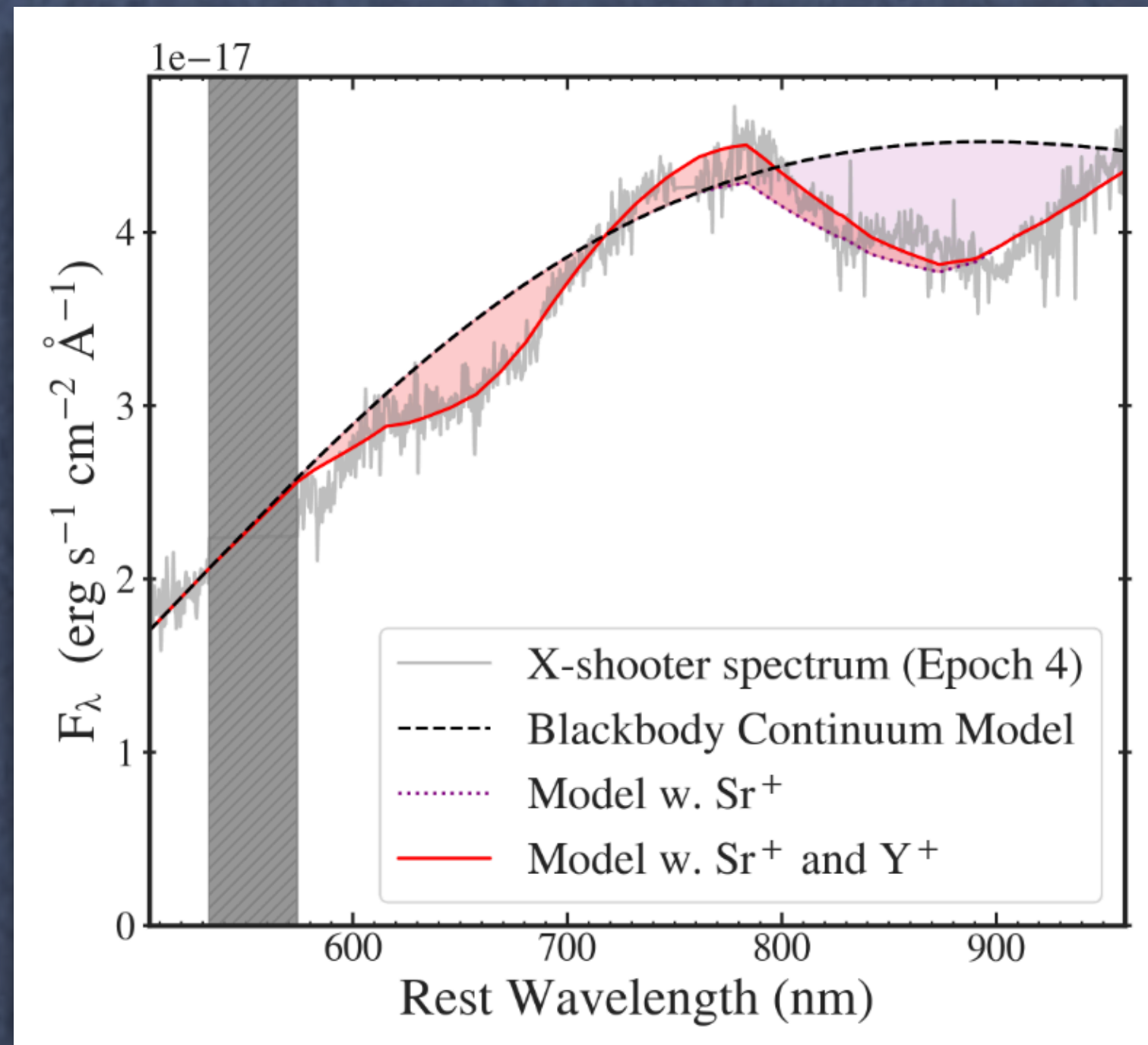
1st observations of off-axis GRB afterglow
Jet structure!

BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?

1st extensive study of kilonova!



BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?



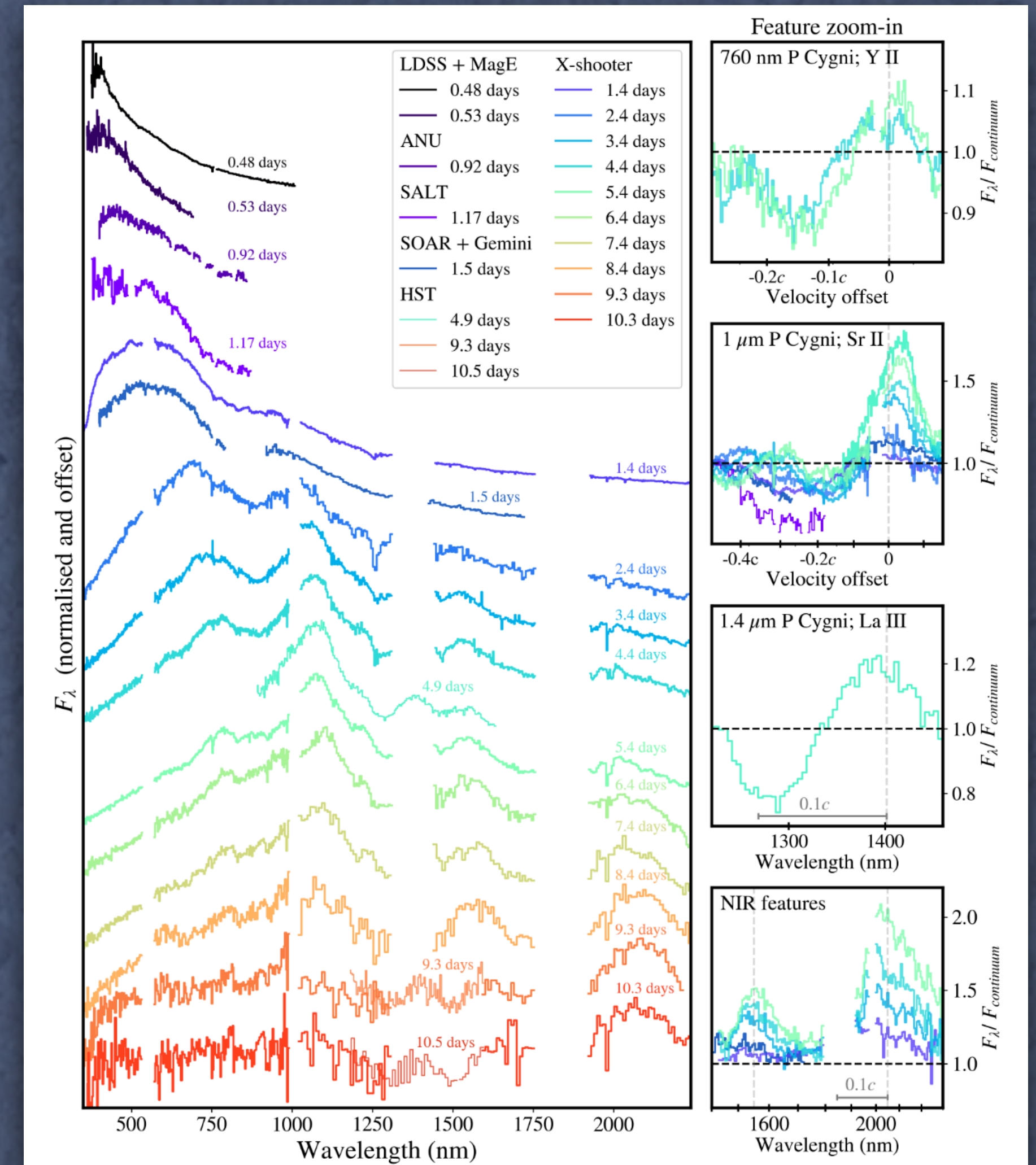
Sneppen+ series of papers

See also (among others)

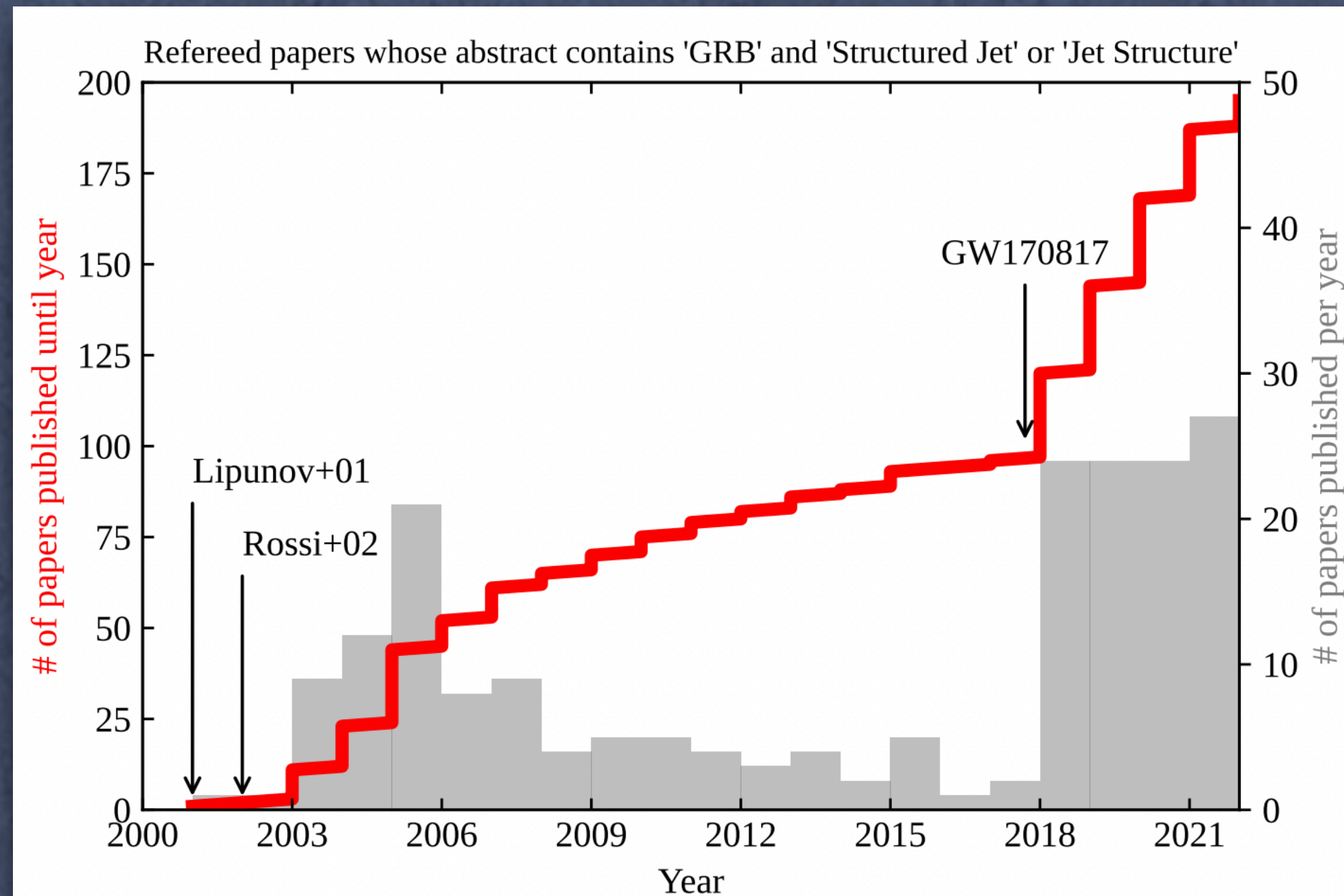
Hotokezaka+ 2023

Gillanders+ 2024

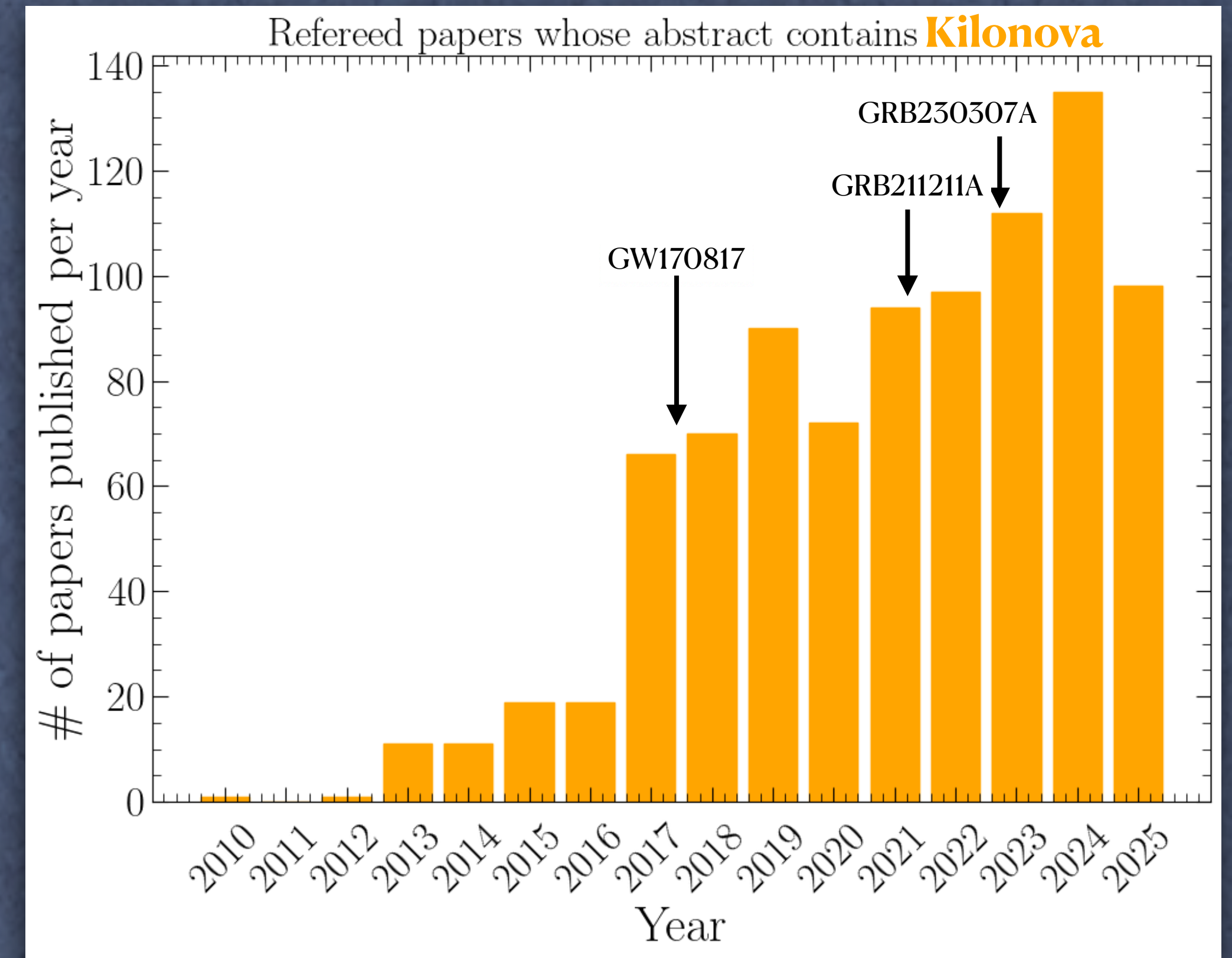
Heavy element nucleosynthesis



BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?

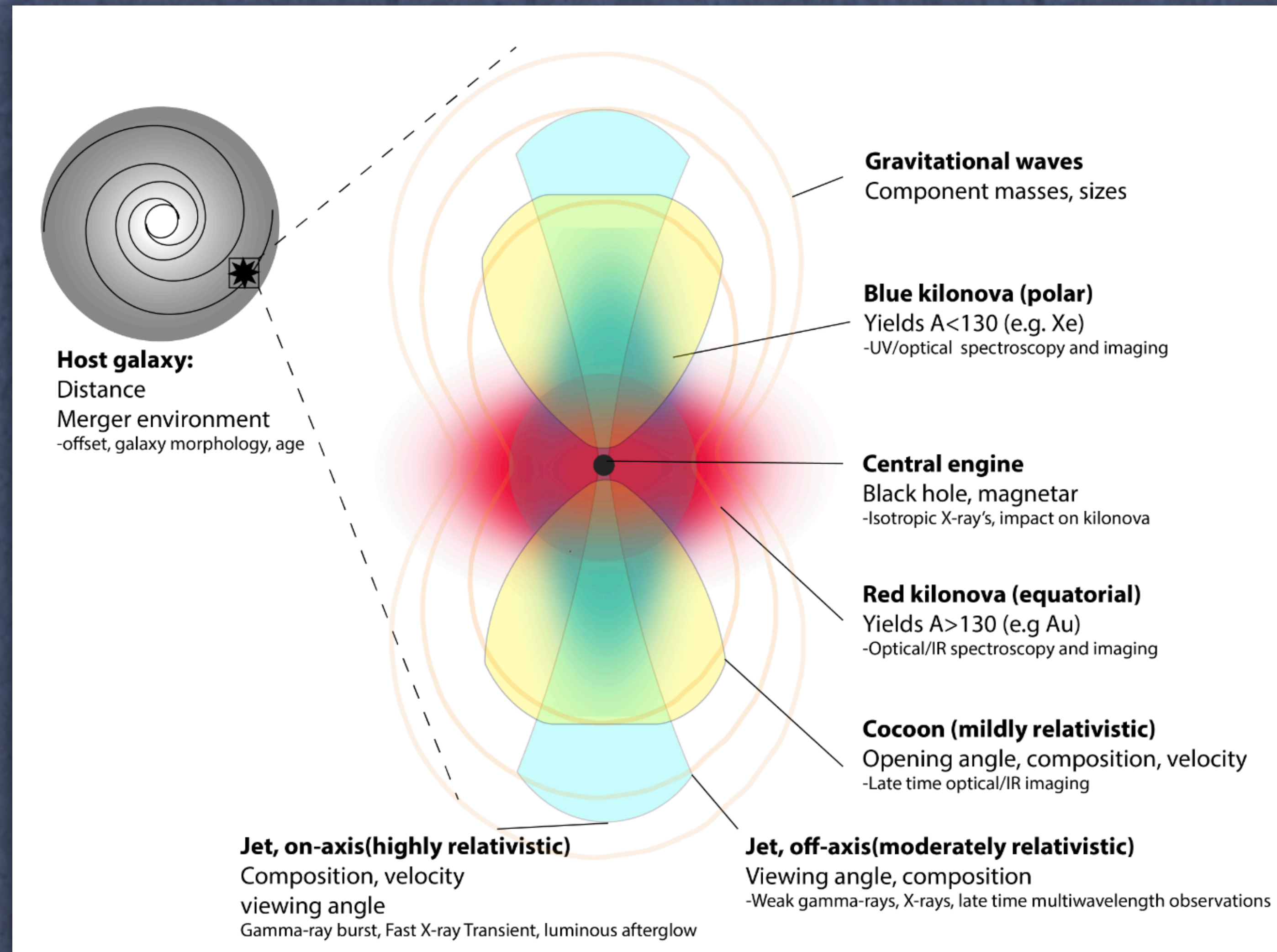


Salafia+22

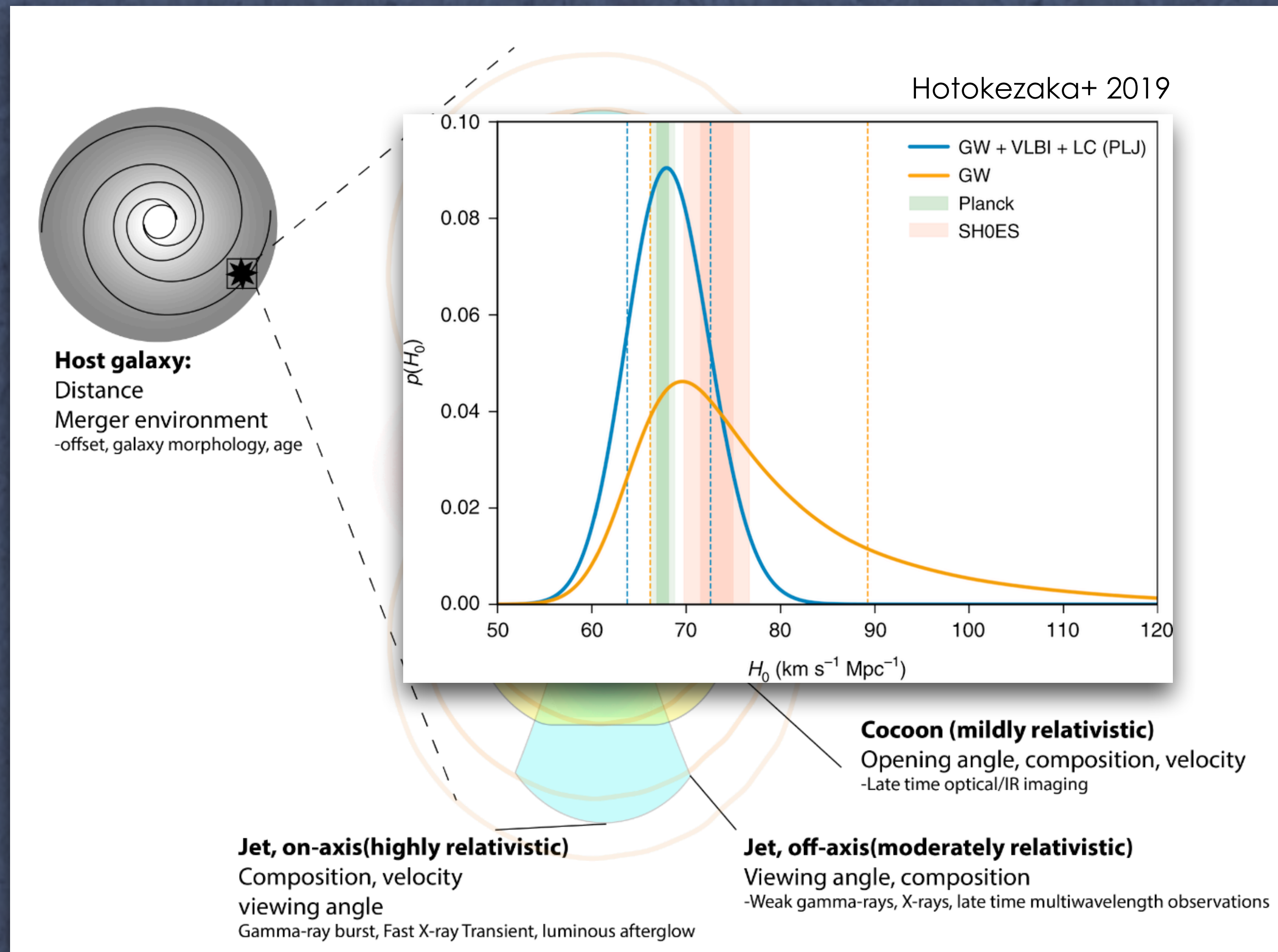


~100 papers on atomic data for KN interpretation
>200 papers on AT2017gfo

BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?



BNS MULTI-MESSENGER ASTROPHYSICS: WHERE DO WE STAND?

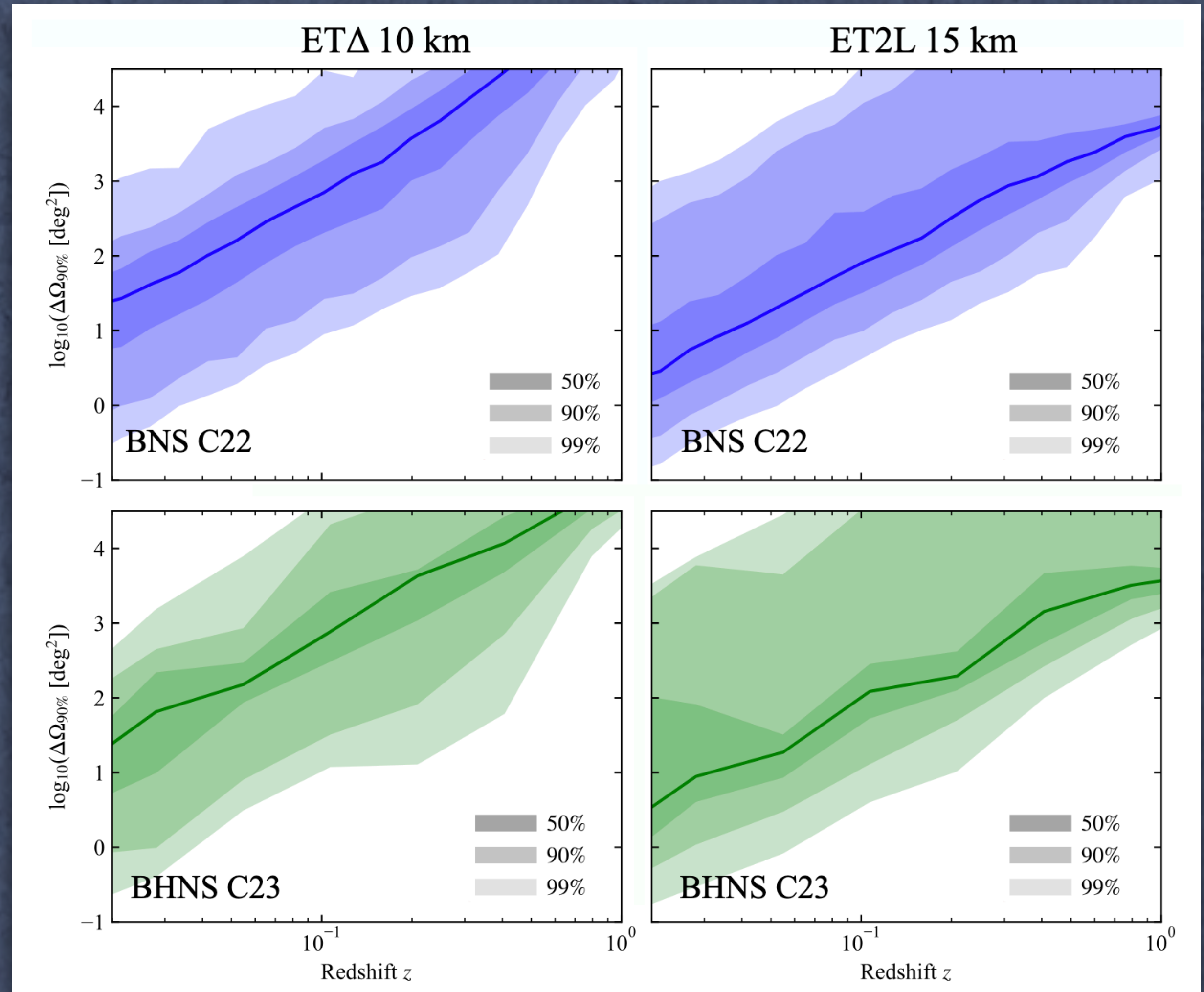
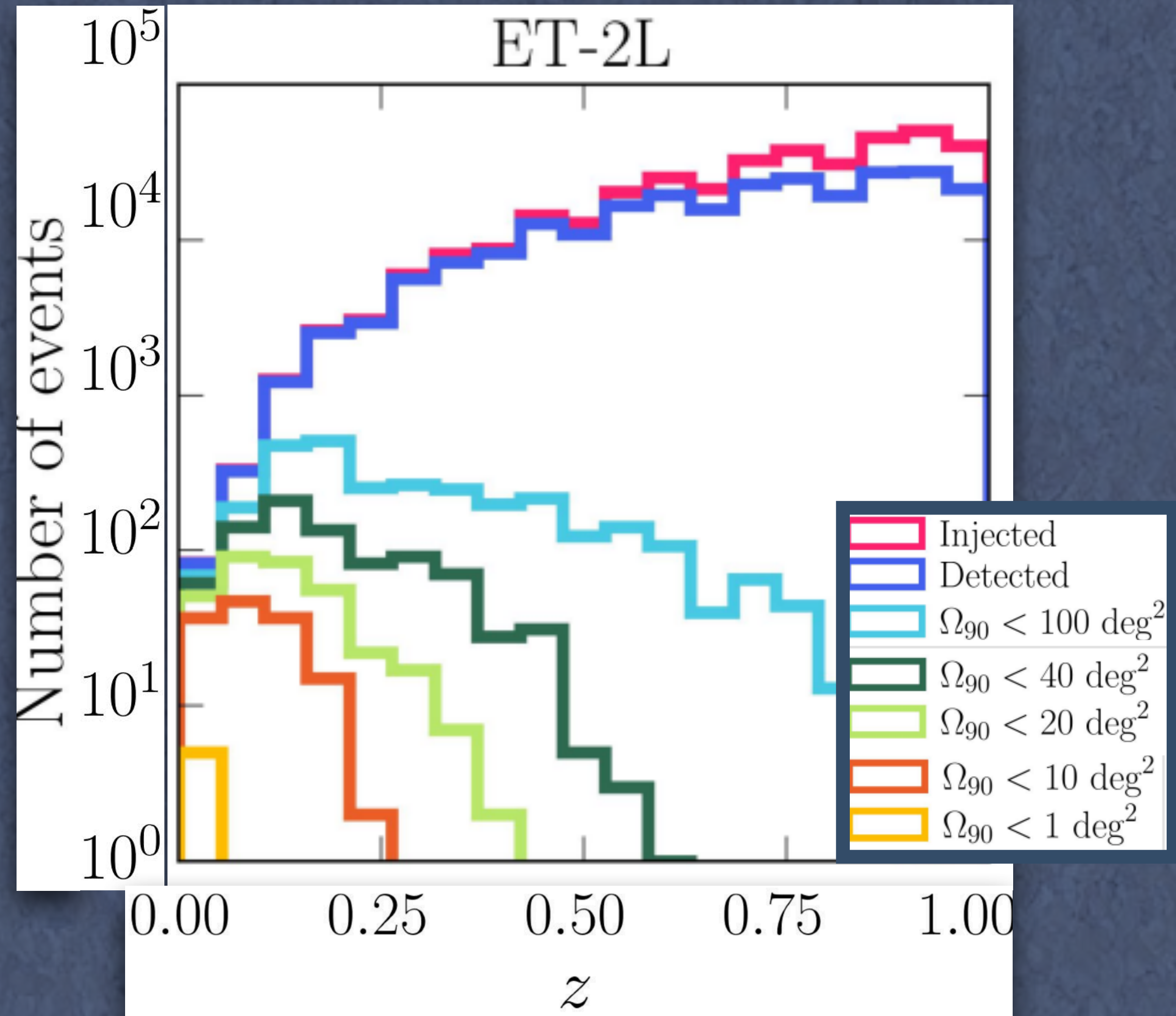


BNS MULTI-MESSENGER ASTROPHYSICS: SOME OPEN QUESTIONS

- What is/are the path/s of stellar evolution towards BNS?
- Are jets always associated with BNS?
- Is the jet structure universal?
- What are the elements produced by BNS?
What is their contribution to r-process nucleosynthesis enrichment?
- Is the global picture correct?
- What is the remnant?
- ...and BHNS !

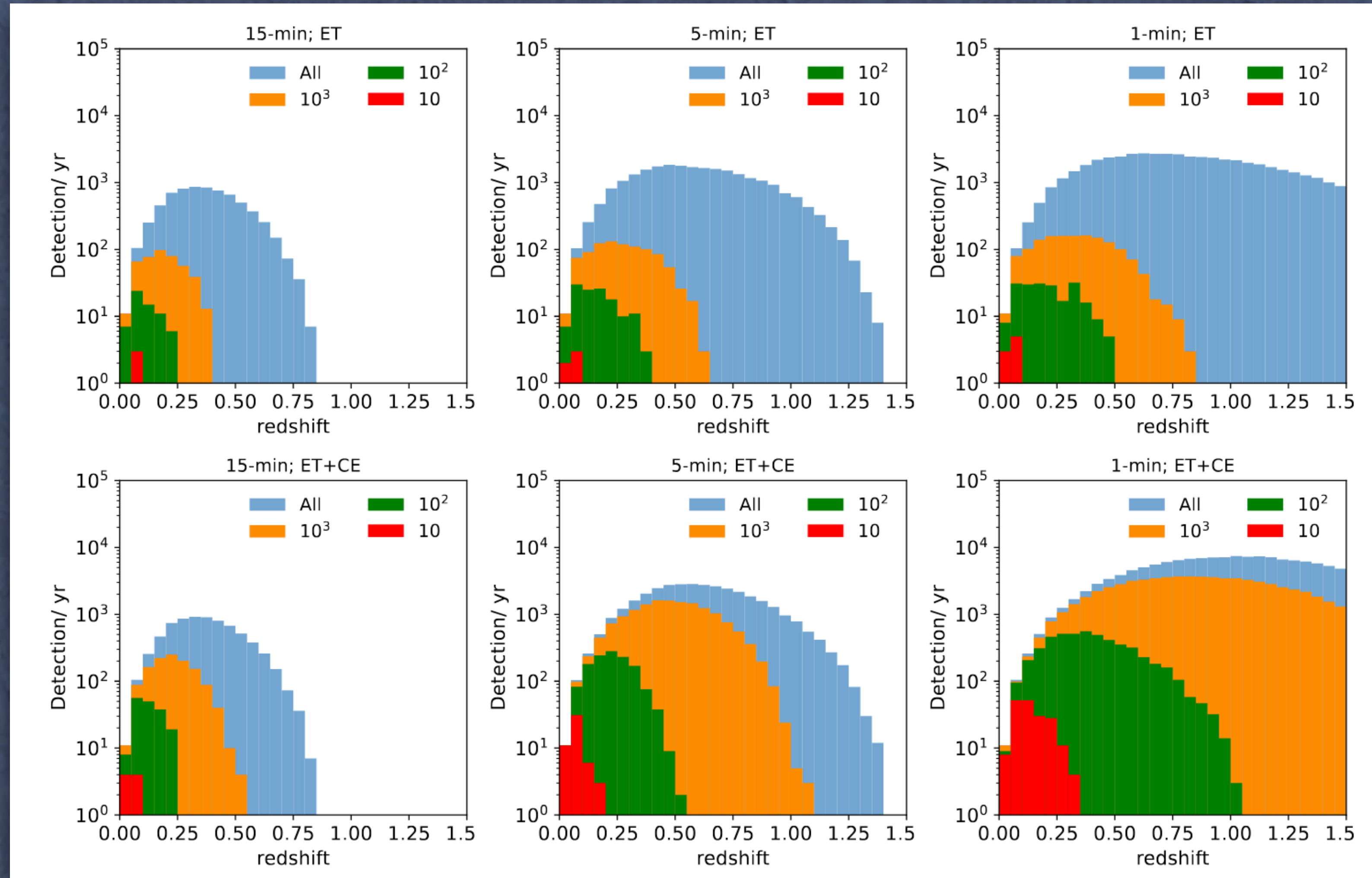
BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Loffredo et al. 2025



ET Blue book arXiv:2503.12263

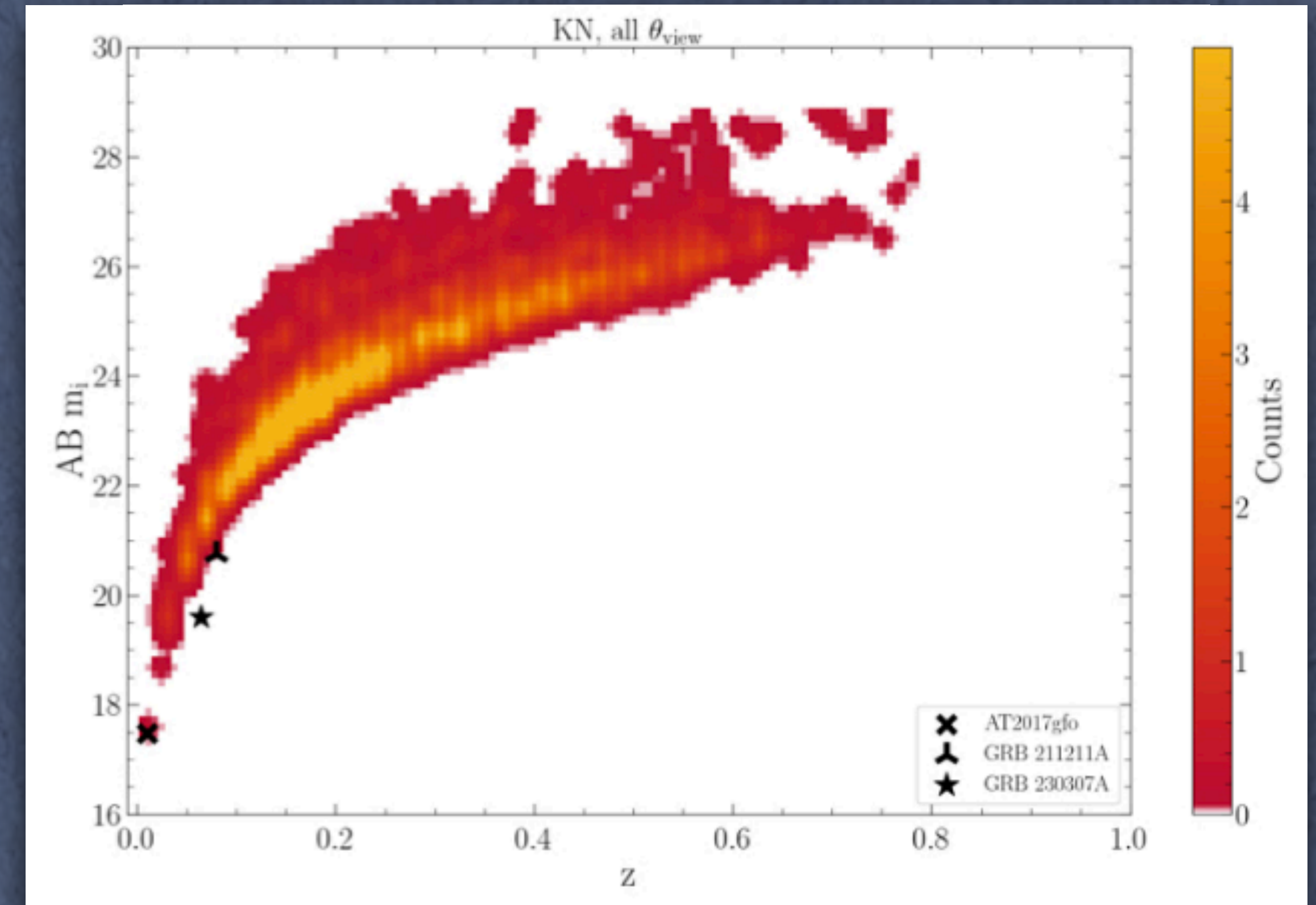
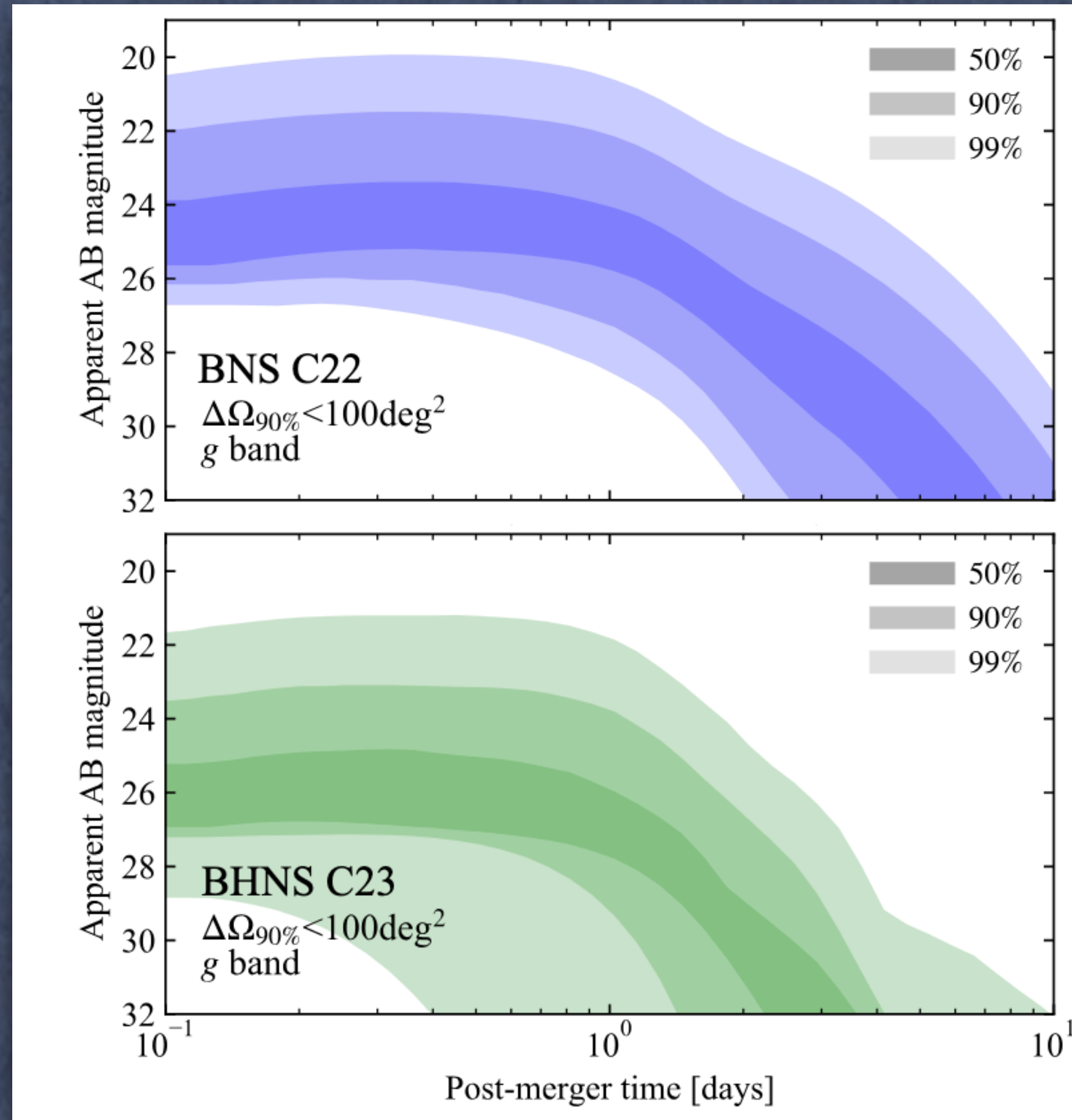
BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:



BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Kilonovae

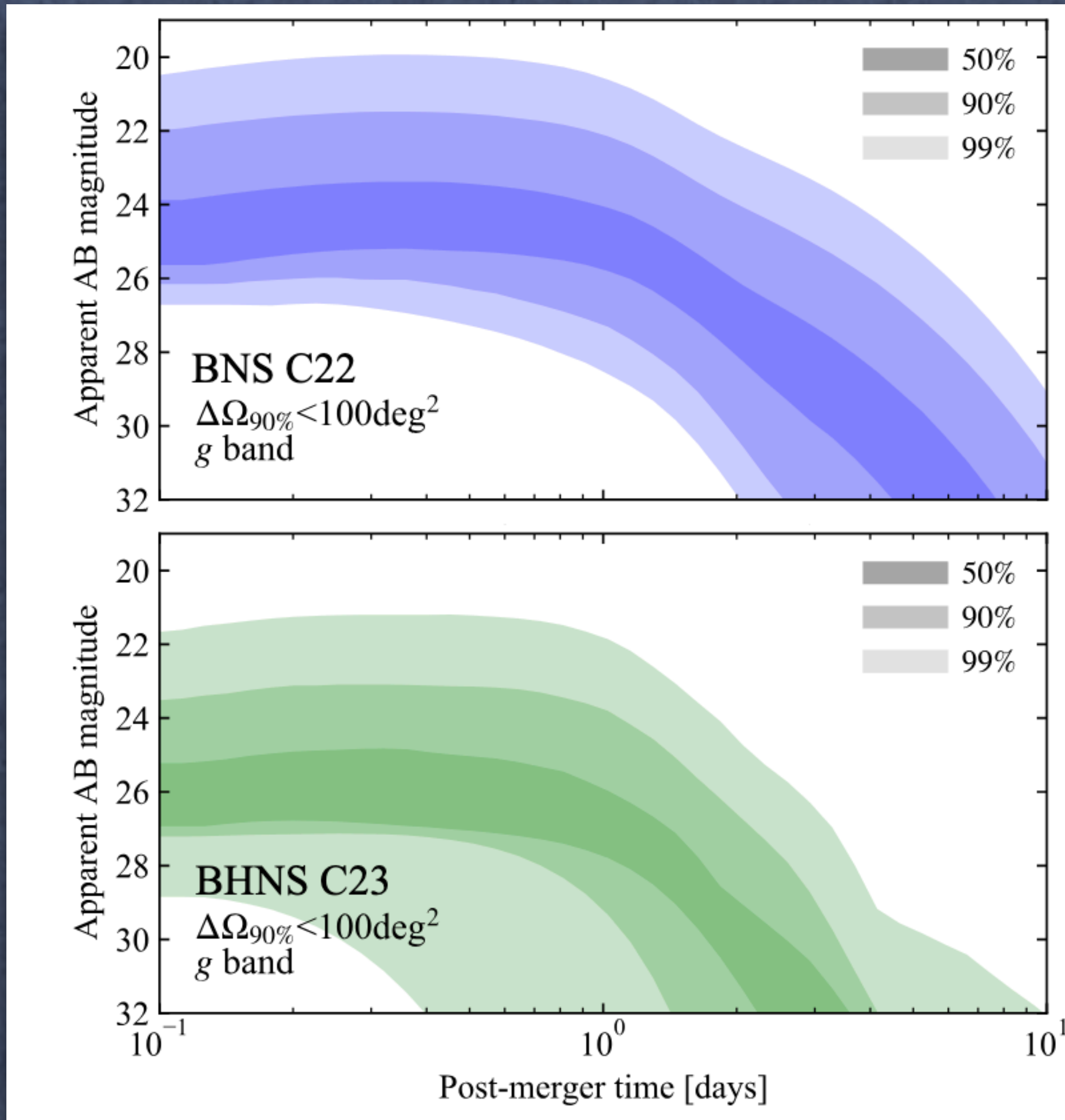
Bisero et al. 2025



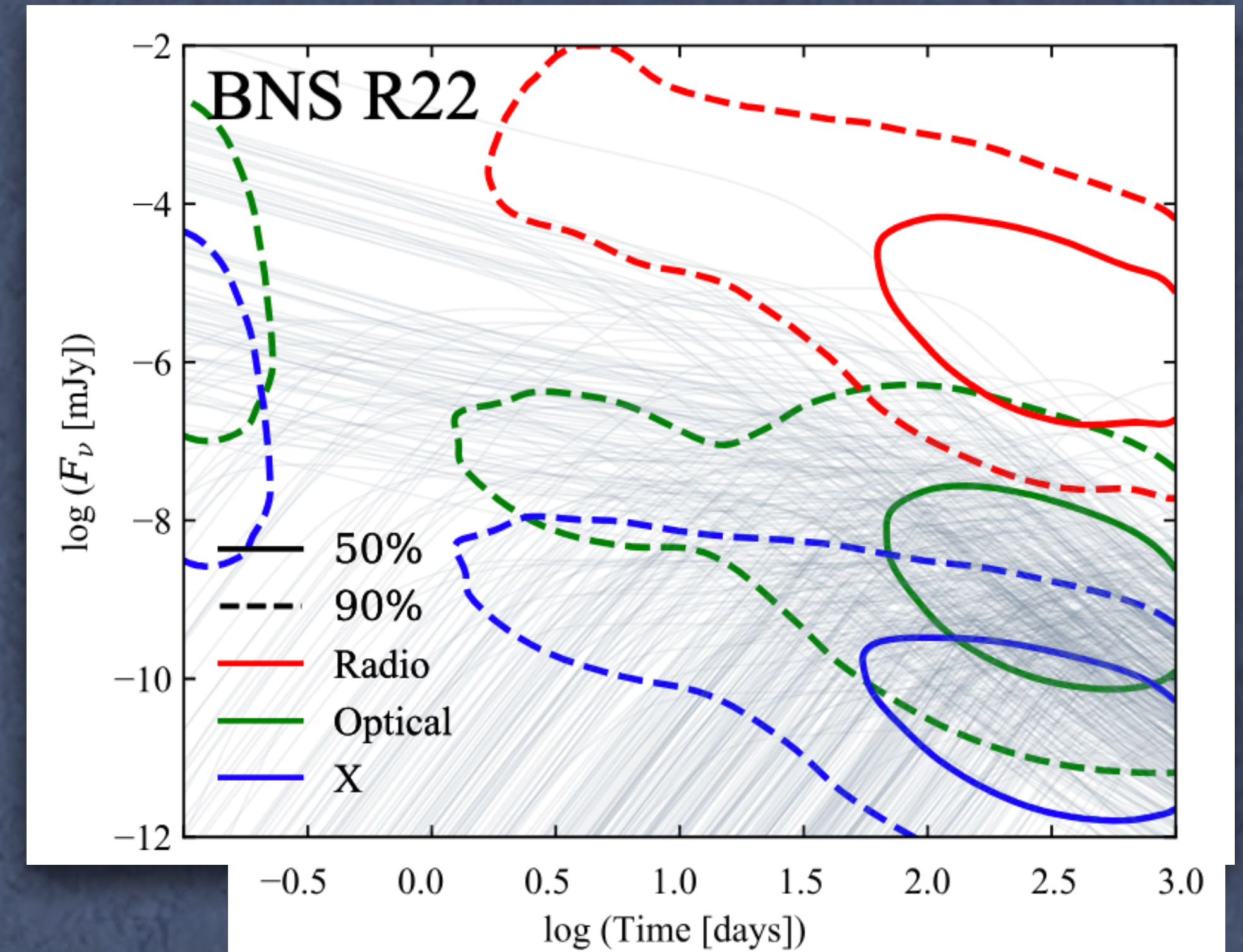
ET Blue book arXiv:2503.12263

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

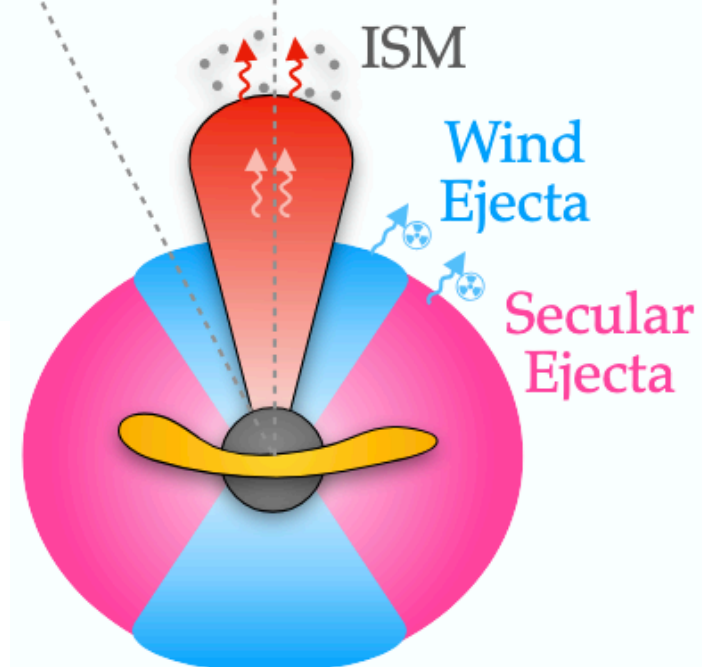
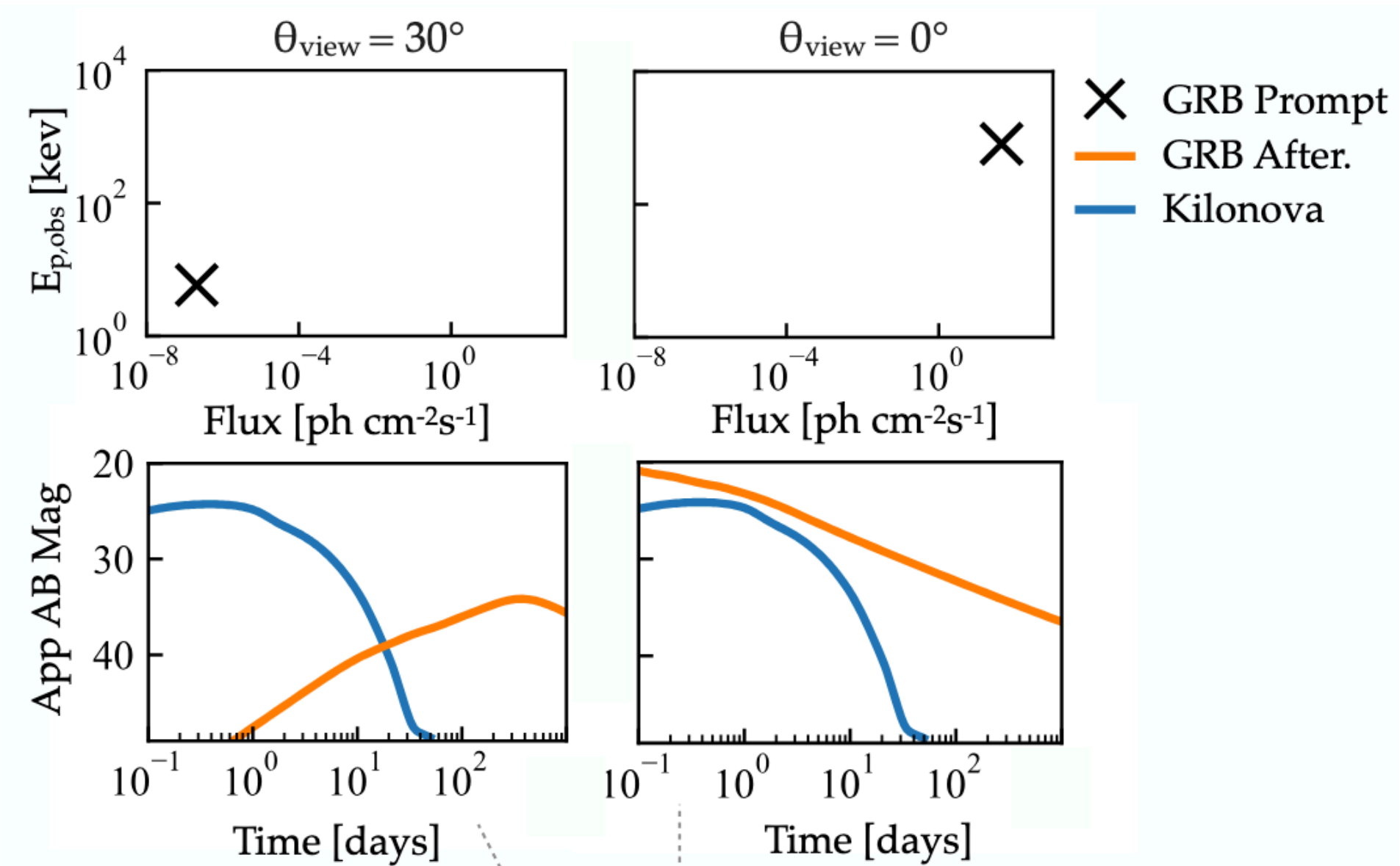
Kilonovae



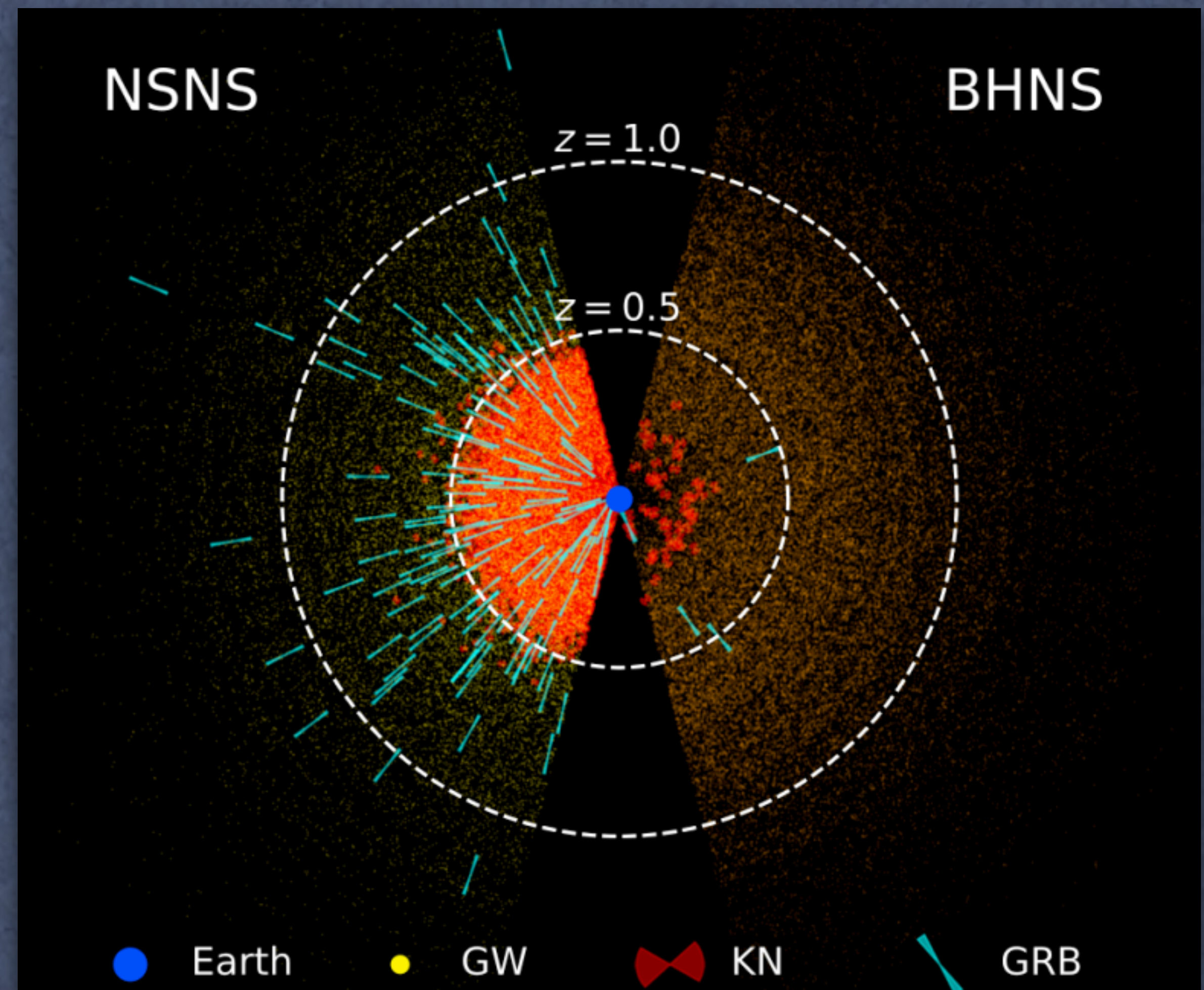
Afterglows



BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:



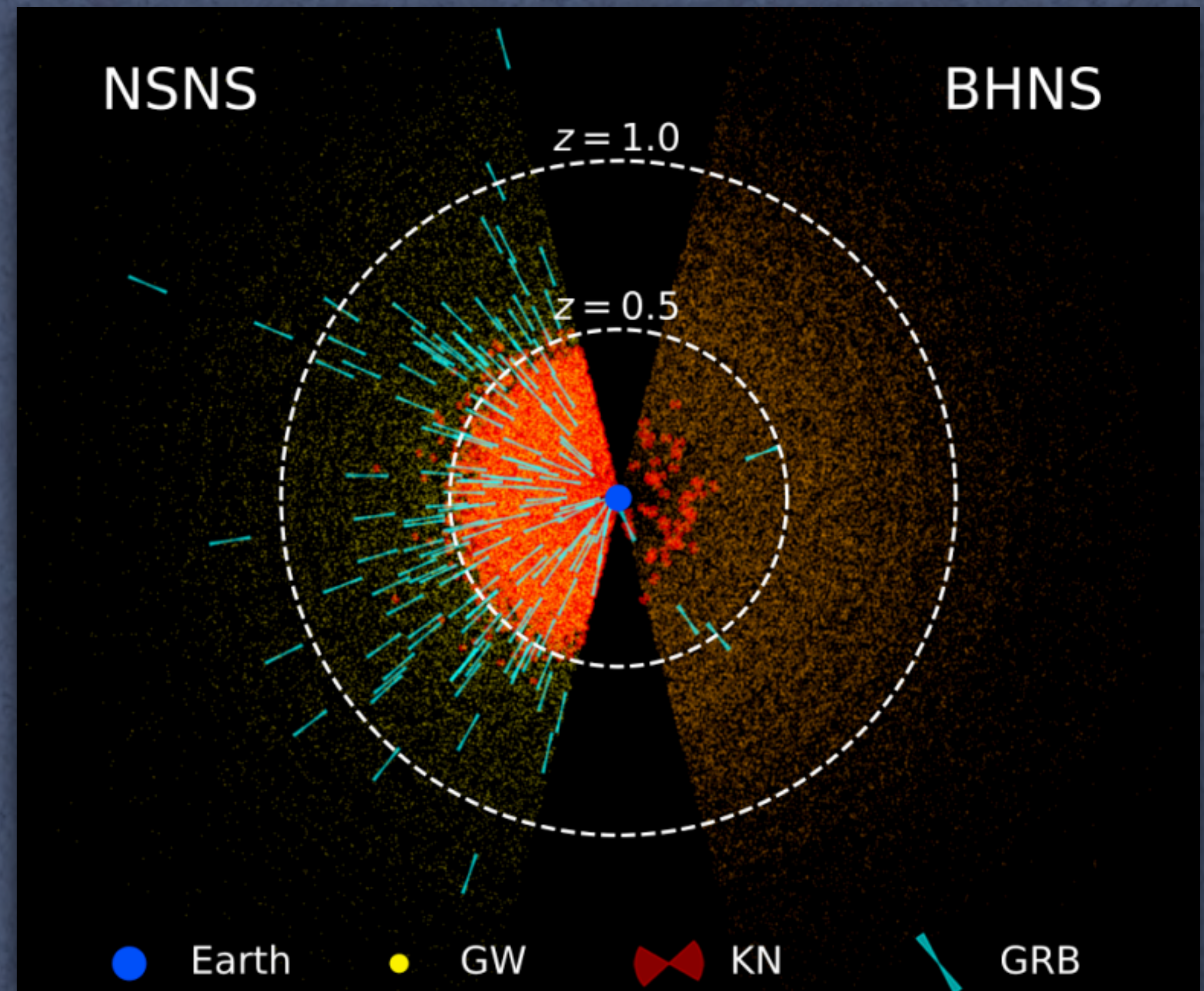
5



BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Not only *we can detect*
We want to *identify* and *study*

We need instruments
to search
to identify
AND to characterise
(lightcurves & spectra)

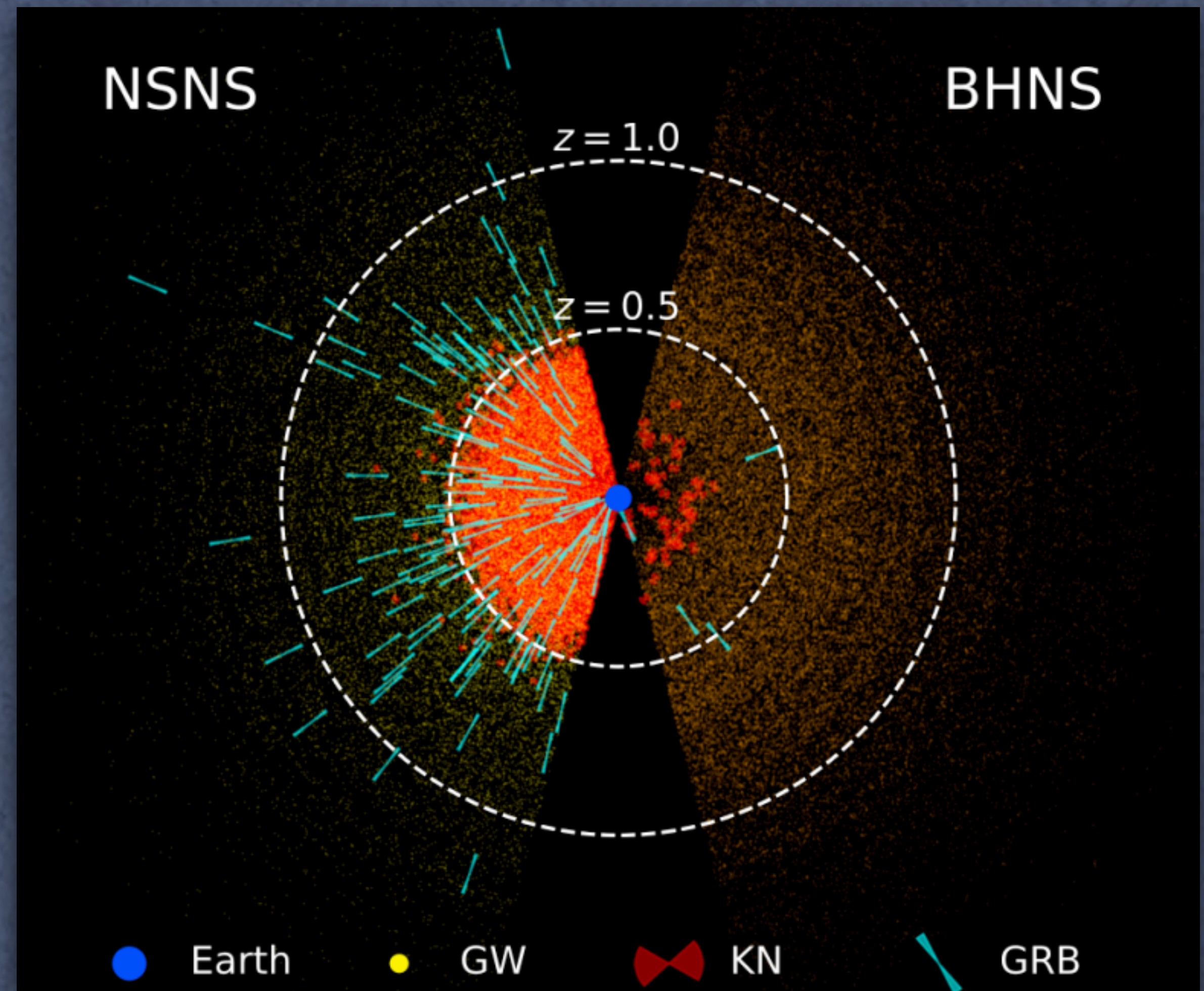


BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Not only *we can detect*
We want to *identify* and *study*

On-axis case:

We need GRB satellites
providing good localization!



BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

ON-AXIS GRB and AFTERGLOW

SEARCH

CHARACTERIZATION

	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay
Radio		0.1 mJy	> 1 GHz	-- / ~ 1"	hours	arcsec ²	0.01 mJy	> 1 GHz	--/~arcsec	monitoring Log scale
NIR	~ few arcmin ²	21 mag	1000 - 1800 nm	-- / ~ 1"	minutes	arcsec ²	24 mag (phot.) 22 mag (spectr.)	1000-1800 nm	low-mid / 1"	< 12 hr
Optical	~ few arcmin ²	22 mag	500 - 900 nm	-- / ~ 1"	minutes	arcsec ²	26 mag (phot.) 22 mag (spectr.)	300-900 nm		
X-ray	~ tens of arcmin ²	10 ⁻¹³ erg cm ⁻² s ⁻¹	0.2-10 keV	a few arcsec	< hours	~ tens of arcmin ²	10 ⁻¹⁶ erg cm ⁻² s ⁻¹	0.2-10 keV	a few arcsec	< hours
γ-ray	~10 sr	~1 ph cm ⁻² s ⁻¹	10 keV - 10 MeV	arcmin						
VHE	>1 deg ²	< 10 ⁻¹⁰ erg cm ⁻² s ⁻¹	10 GeV - 30 TeV	DE/E ~20% 0.1-1 deg	< hours	1 deg ²	< 10 ⁻¹¹ erg cm ⁻² s ⁻¹ @100 GeV	10 GeV - 30 TeV	DE/E ~20% 0.1 deg	< hours

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

OFF-AXIS AFTERGLOW

SEARCH

CHARACTERIZATION

	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay
Radio	$\approx 1 \text{ deg}^2$	$< 10^{-2} \text{ mJy}$	$> 1 \text{ GHz}$	--/~arcsec	Few days to years!	Some arcsec ²	$< 10^{-3} \text{ mJy}$	$> 1 \text{ GHz}$	--/~arcsec	logarithmic monitoring for days, months, years
NIR	$\approx 1 \text{ deg}^2$	$> 24 \text{ mag (AB)}$ $< 10^{-3} \text{ mJy}$	$> 1000 \text{ nm}$	--/~arcsec	Few days to years!	$\sim \text{arcsec}^2$	$> 24 \text{ mag (AB)}$ $< 3 \times 10^{-4} \text{ mJy}$	1000-1800 nm	low-mid / ~1"	ToO at first then logarithmic monitoring
Optical	$\approx 1 \text{ deg}^2$	$> 26 \text{ mag (AB)}$ $< 10^{-4} \text{ mJy}$	500 - 900 nm	--/~arcsec	Few days to years!	$\sim \text{arcsec}^2$	$> 27 \text{ mag (AB)}$ $< 5 \times 10^{-5} \text{ mJy}$	500 - 900 nm	low-mid / ~1"	ToO at first then logarithmic monitoring
X-ray	$\approx 1 \text{ deg}^2$	$< 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ $< 10^{-7} \text{ mJy}$	0.2-10 keV	--/few arcsec	Few days to years!	$\sim \text{arcsec}^2$	$< 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1}$ $< 10^{-8} \text{ mJy}$	0.2-10 keV	--/few arcsec	logarithmic monitoring for days, months, years
γ-ray	$\sim 10 \text{ sr}$	0.01-0.1 $\text{ph cm}^{-2} \text{ s}^{-1}$	3 keV - 10 MeV	--/arcmin						

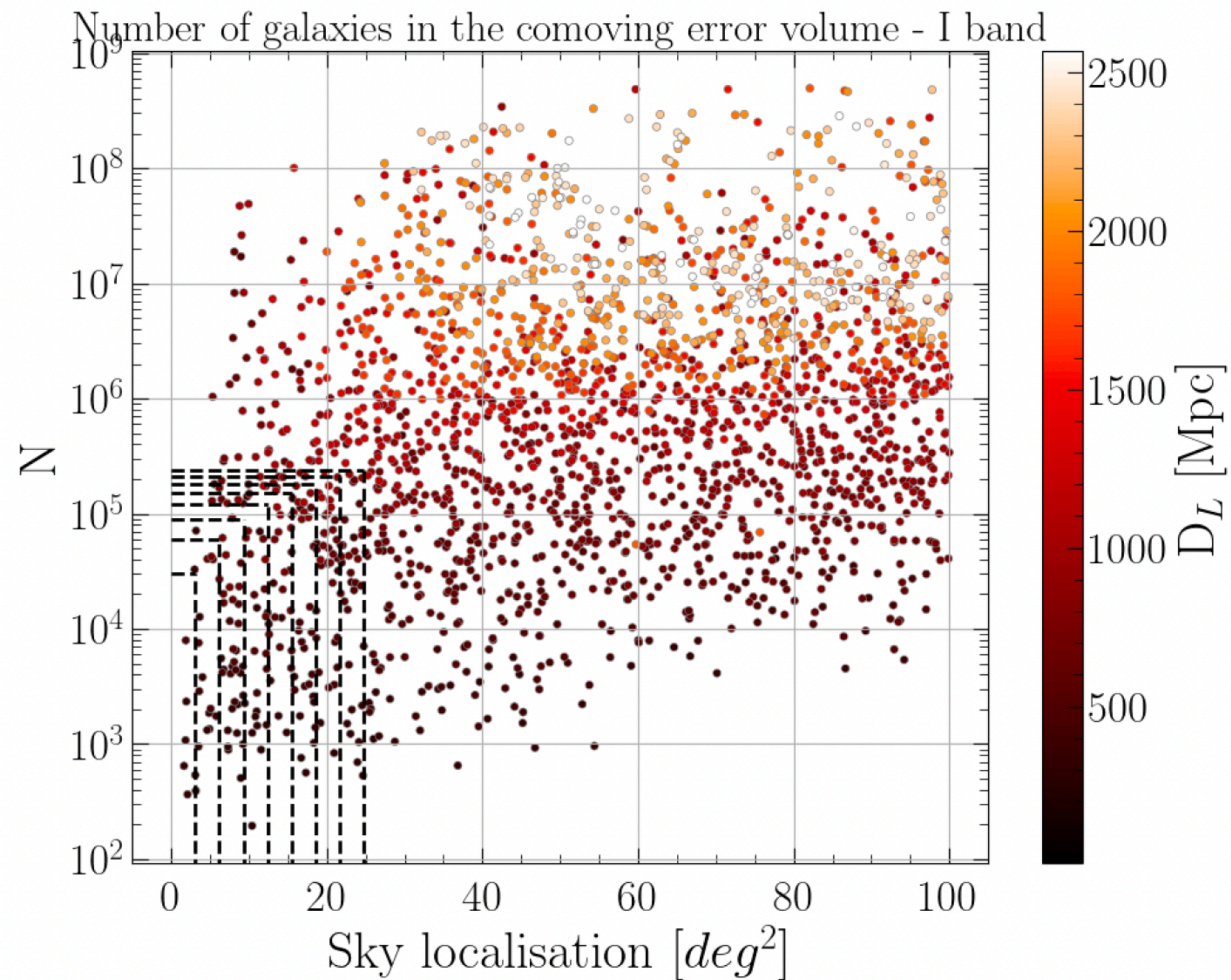
BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

KILONOVA											
SEARCH						CHARACTERIZATION					
	FoV	Sensitivity (AB)	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay	FoV	Sensitivity (AB)	Spectral range (nm)	Spectral Res.	ToO delay	
NIR	>1 deg ²	>22 mag	1000-1800	~1000 / ~ 1"	1 day	~arcsec ²	>24 mag	1000-1800	>1000	1 day	Ideally nightly monitoring of the evolution for ~1week. However at such late time most counterparts will reach extremely faint magnitudes (m~30 AB)
Optical	>1 deg ²	>22 mag	500-900	~1000 / ~ 1"	12 hr	~arcsec ²	>24 mag	500-900	>1000	12 hr	Ideally nightly monitoring of the evolution for ~1week. However at such late time most counterparts will reach extremely faint magnitudes (m~30 AB)
UV	>1 deg ²	>22 mag	300-500	~1000 / ~ 1"	< 1 hr	~arcsec ²	>24 mag	300-500	>1000	< 1 hr	Ideally nightly monitoring of the evolution for ~2-3 days.

Live table on current and future EM facilities: <https://apps.et-gw.eu/tds/ql/?c=17760>

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Bisero et al. 2025

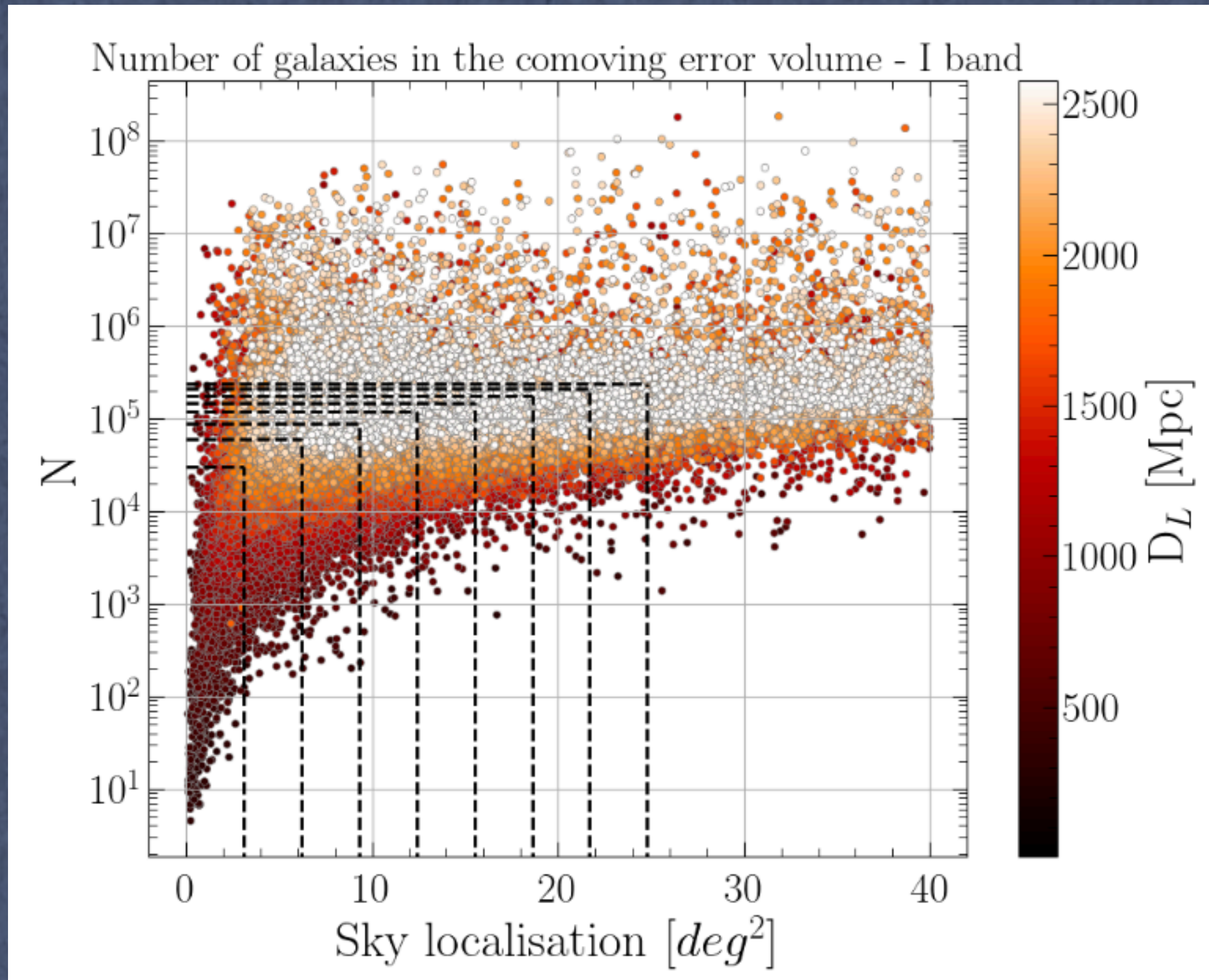


Faintness
Comoving error volume

Huge number of galaxies
Hundreds of transients per deg^2

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Bisero et al. 2025



Faintness
Comoving error volume
Large number of events!

Huge number of galaxies
Hundreds of transients per deg^2

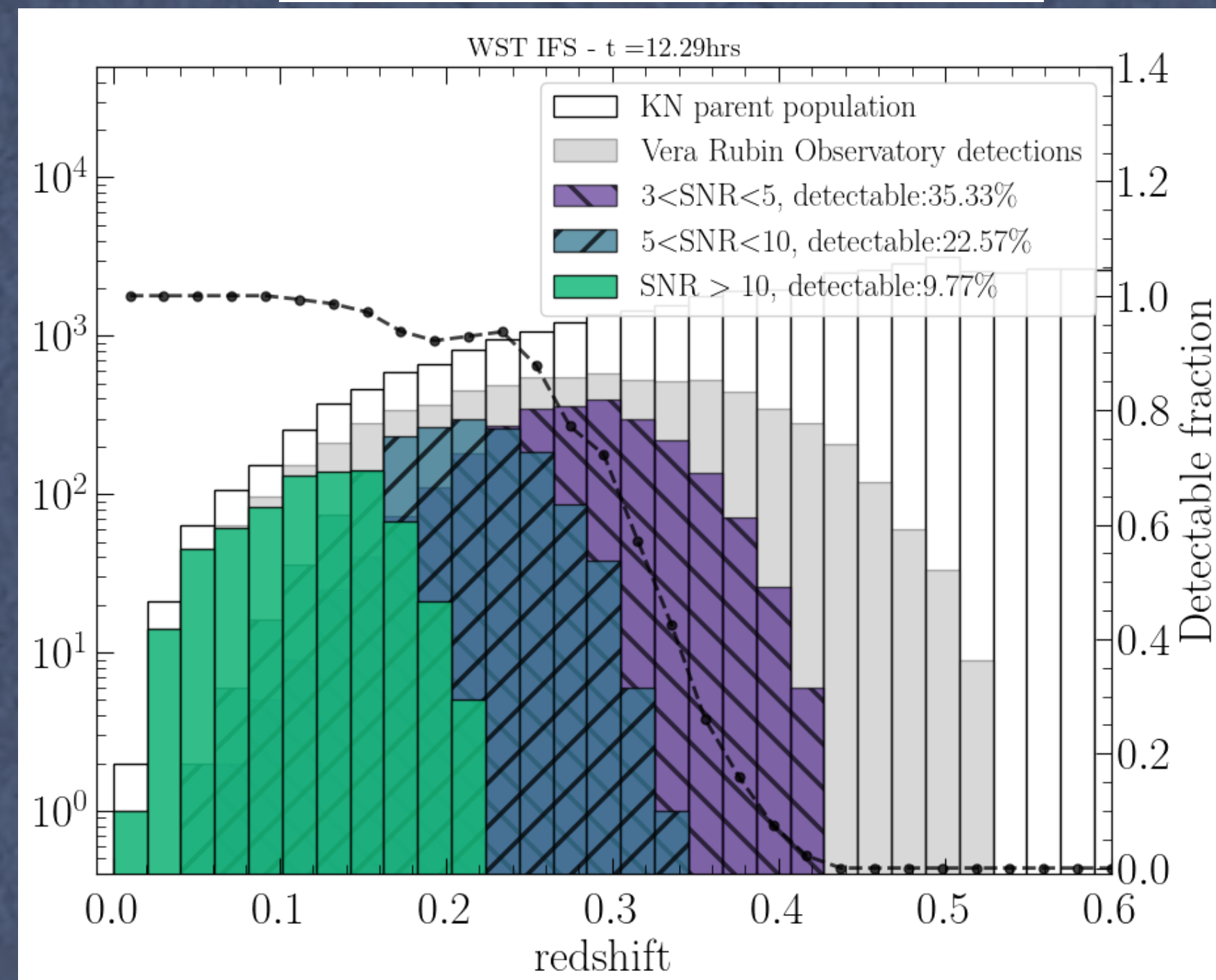
Selection Criteria!

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

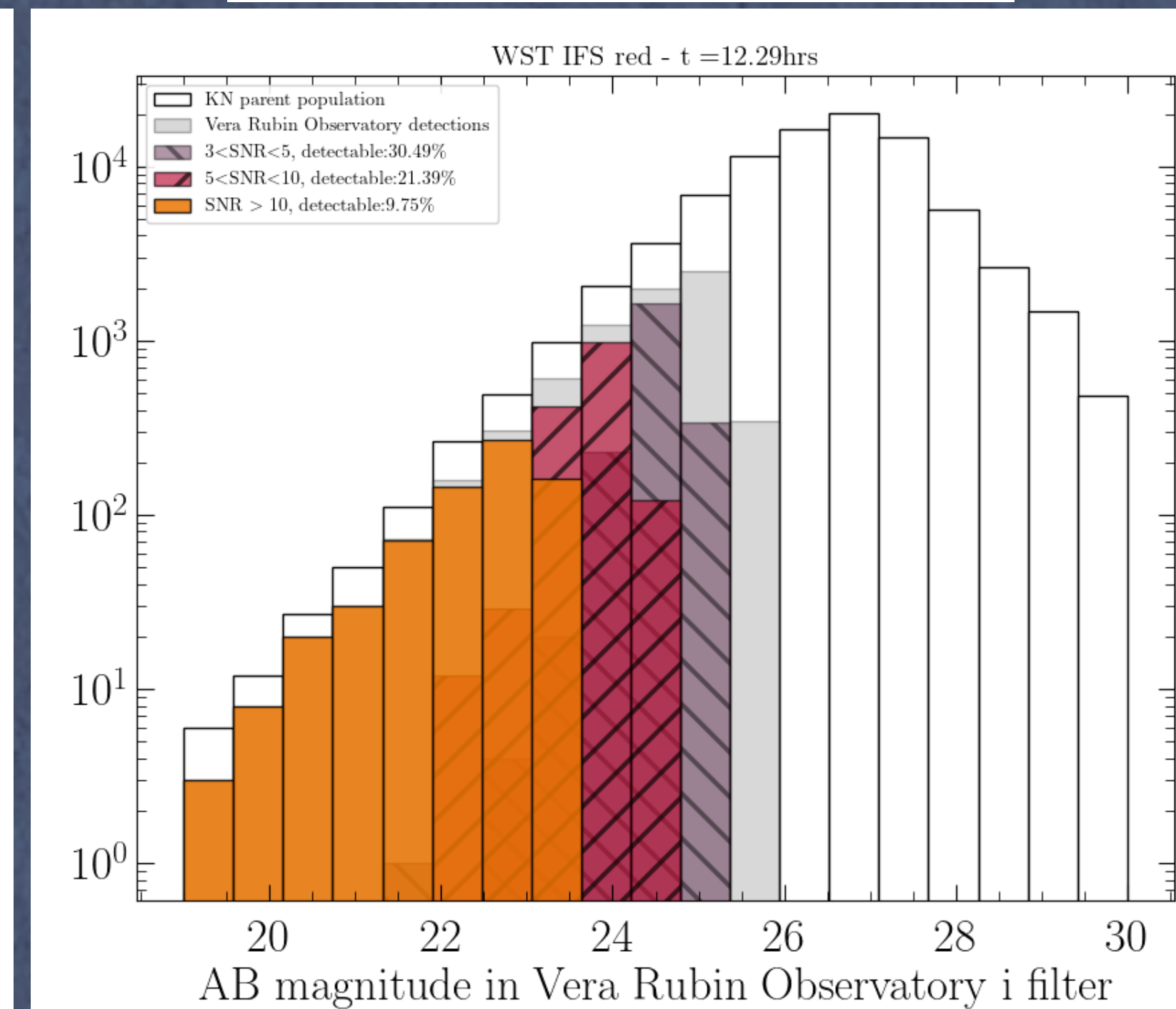
- A new way to explore the universe: GW will detect large numbers of events over a large volume
- BNS multi-messenger astrophysics will have a unique impact on different fields
- Faint EM counterparts, large error regions and comoving volumes
- Red flag warning: High-energy facilities! **THESEUS** Yellow Book in prep.
- Optical-NIR: sensitivity + spectroscopy + large FoV
ideally a dedicated large telescope with deg^2 FoV and IFU **WST** Bisero+2015
(+ Loffredo et al. 2025 on VRO)
- EM fundamental to have a complete GW parameter estimation

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

Redshift horizon



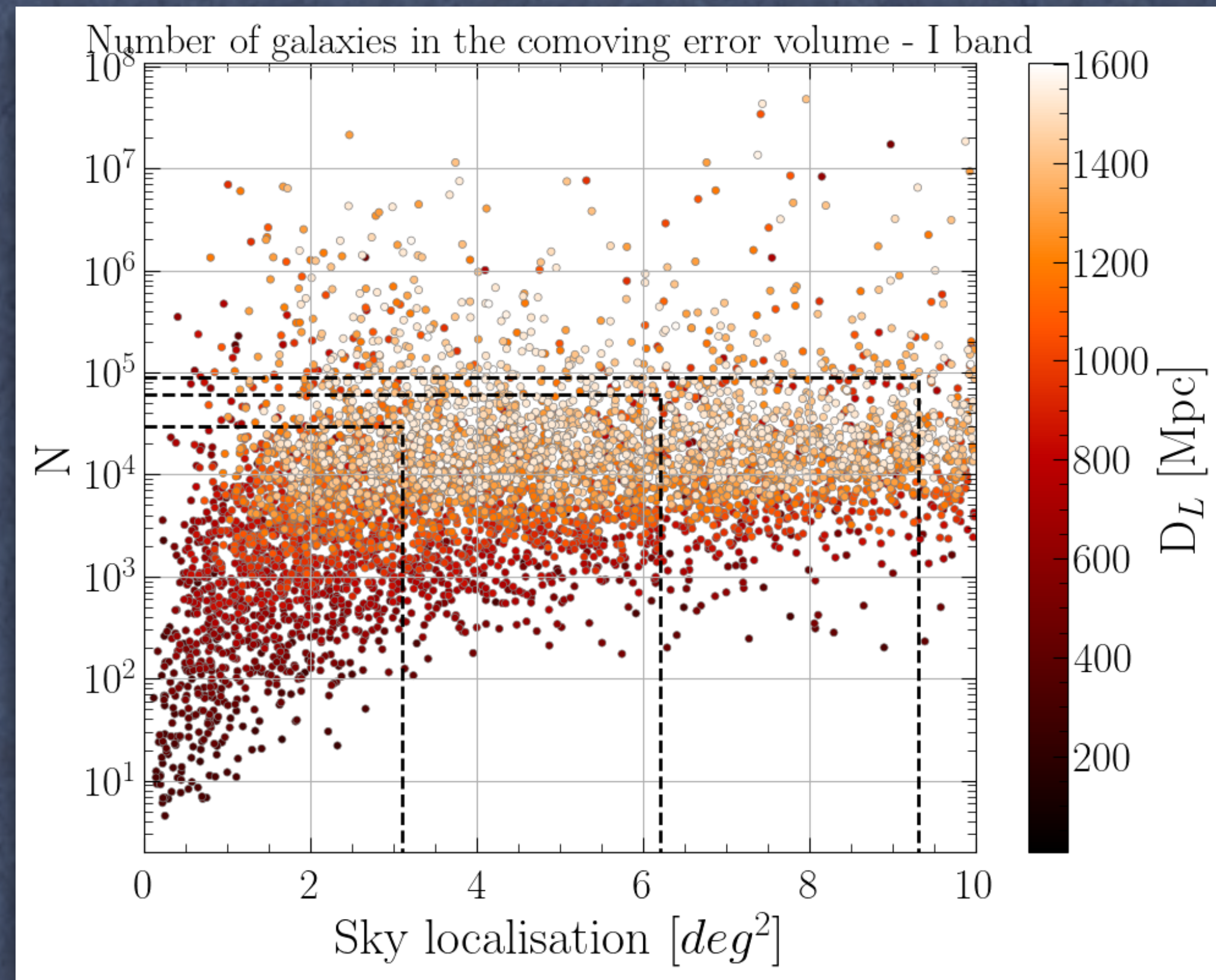
Magnitude limits



BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:

~ 500 events yr^{-1}
over the whole sky

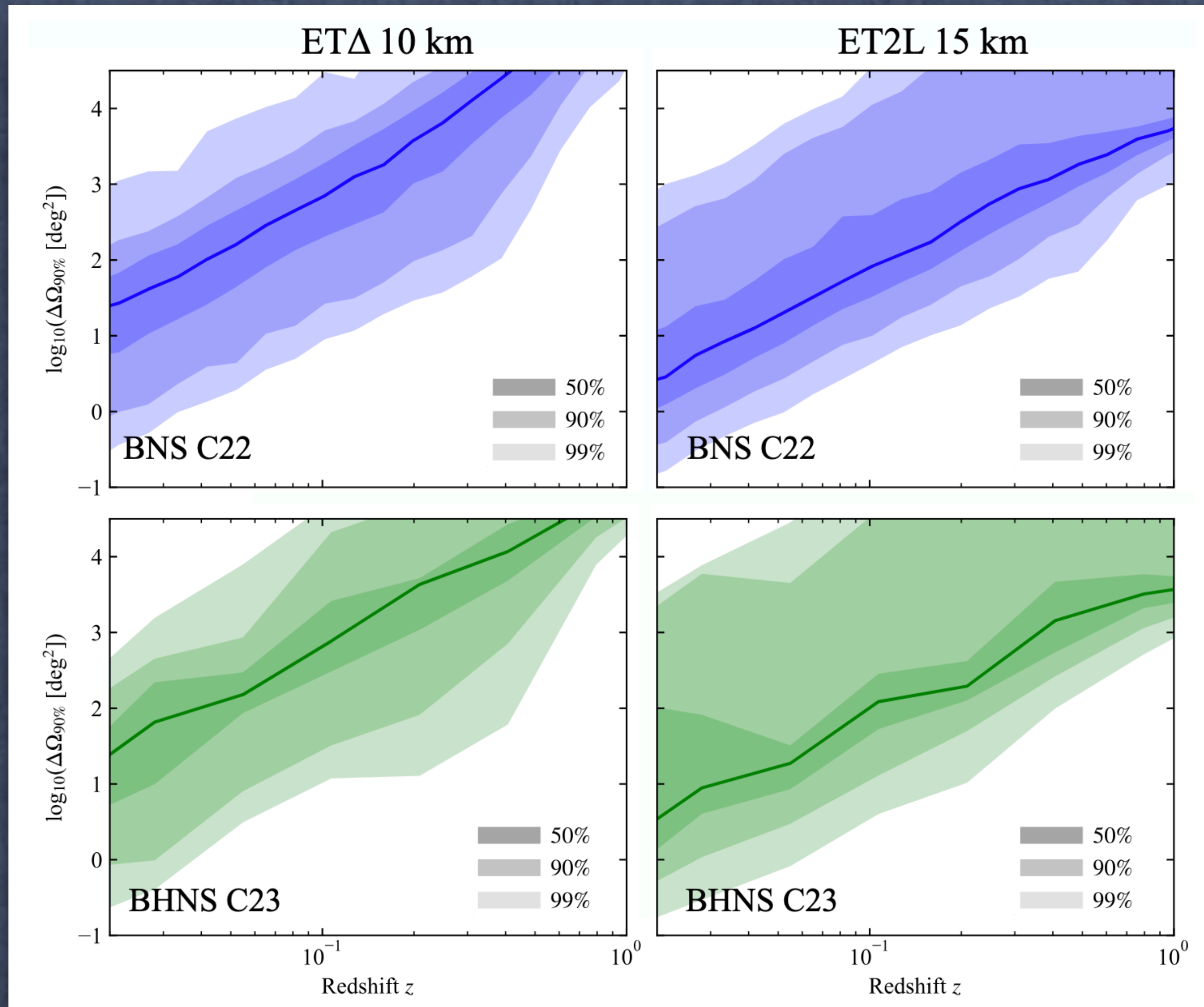
$$z < 0.3$$



Bisero +25

THANK YOU!

BNS MULTI-MESSENGER ASTROPHYSICS WITH ET:



Kilonova detection rate

