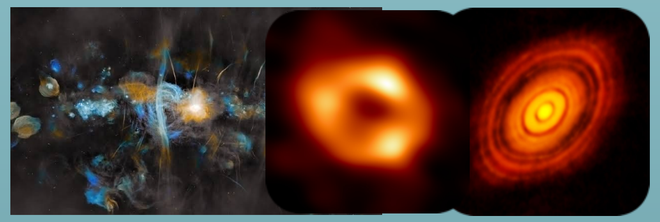
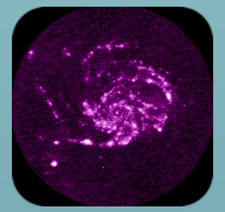
Multi-messenger science with ET

S.D. Vergani

LUX
Observatoire de Paris
UNIVERSITÉ PARIS SCIENCES & LETTRES
cnrs

Multi-wavelength Astrophysics





INFRARED OPTICAL UV X-rays GAMMA




SKAO

ALMA

ROMAN SPACE TELESCOPE

NASA | ESA | CSA jwst

VERA C. RUBIN OBSERVATORY

ULTRASAT Ultraviolet Transient Astronomy Satellite

UVEX

einstein probe 爱因斯坦探针 exploring the dynamic x-ray universe

SVOM

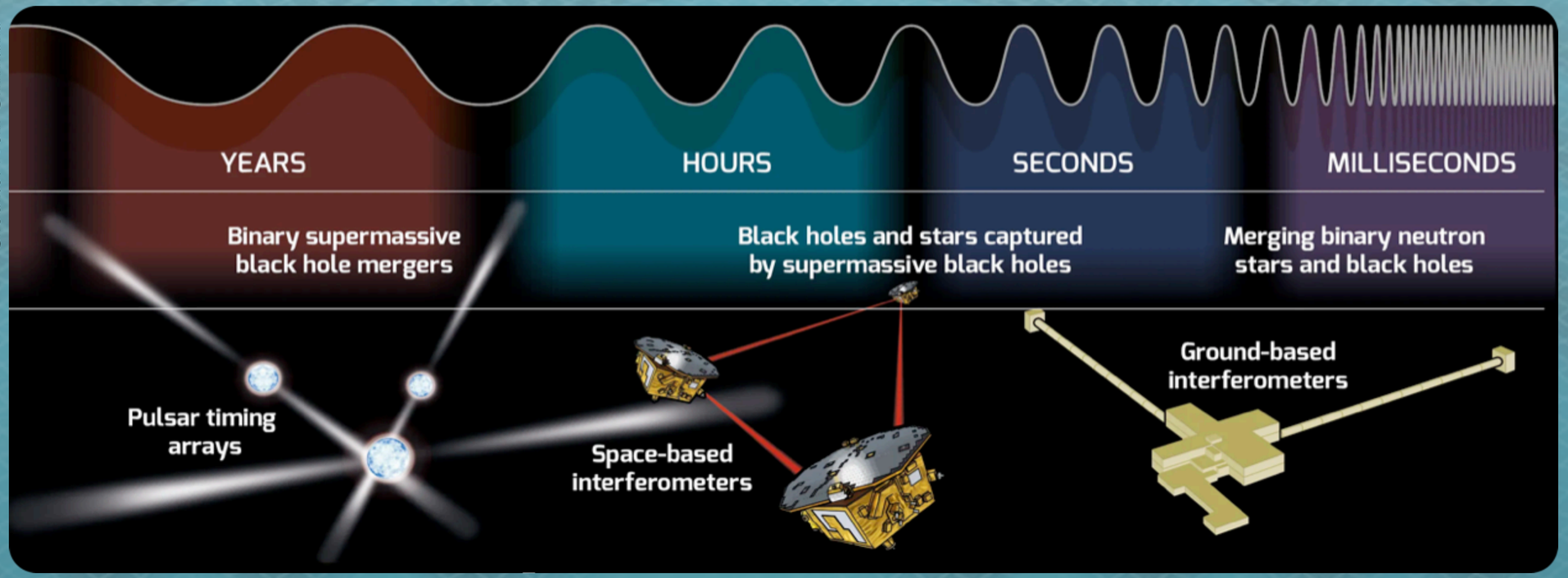
Fermi Gamma-ray Space Telescope

CTAO

ESO

esa newathena

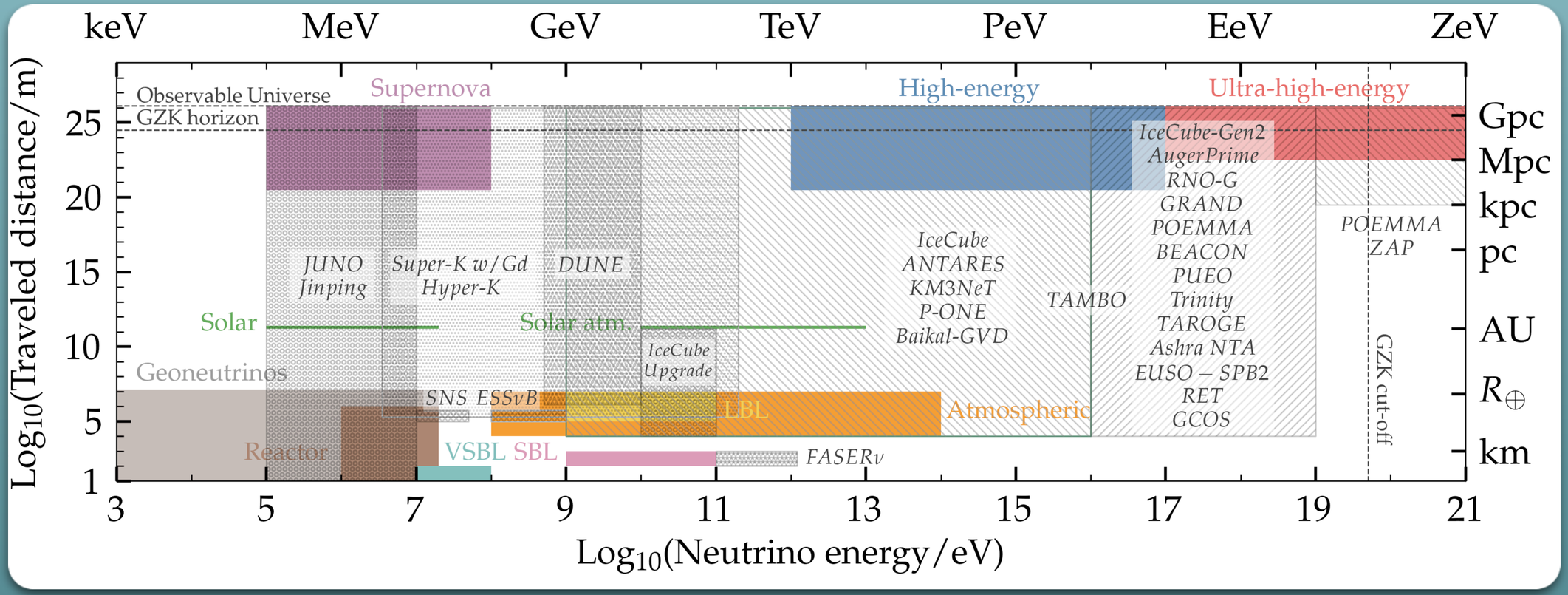
Multi-messenger Astrophysics: GW



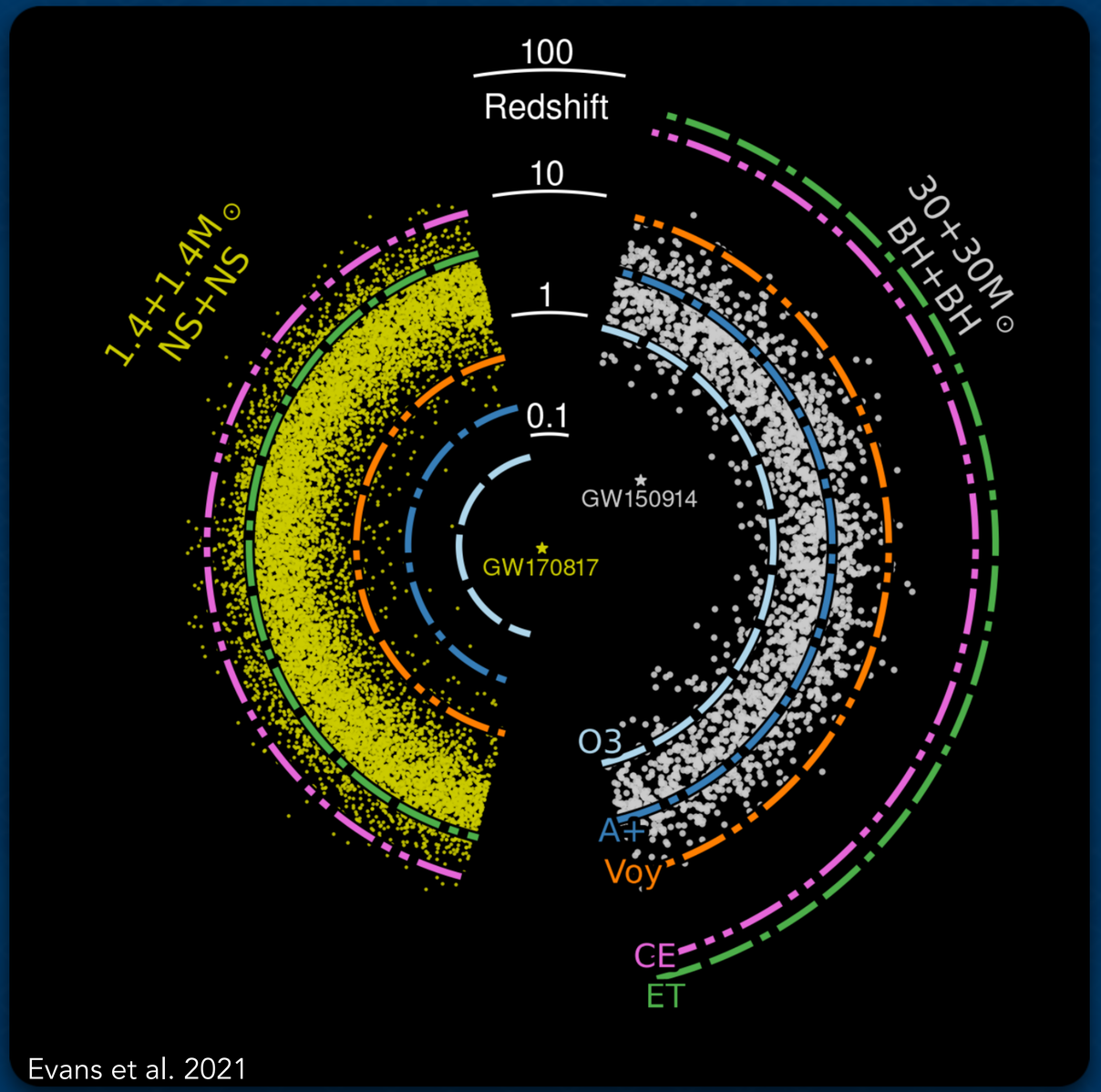
Credits: Ben Gilliland

Multi-messenger Astrophysics: ν

Ackermann et al. 2022



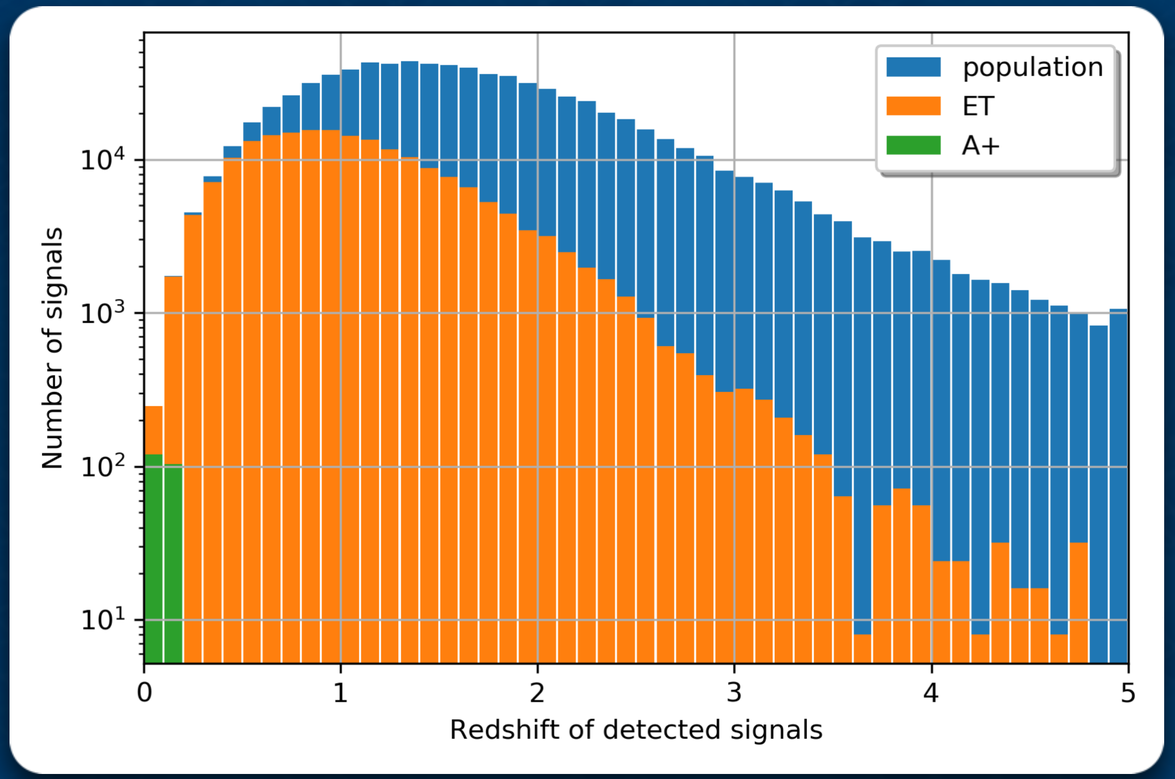
Gravitational Wave Astrophysics



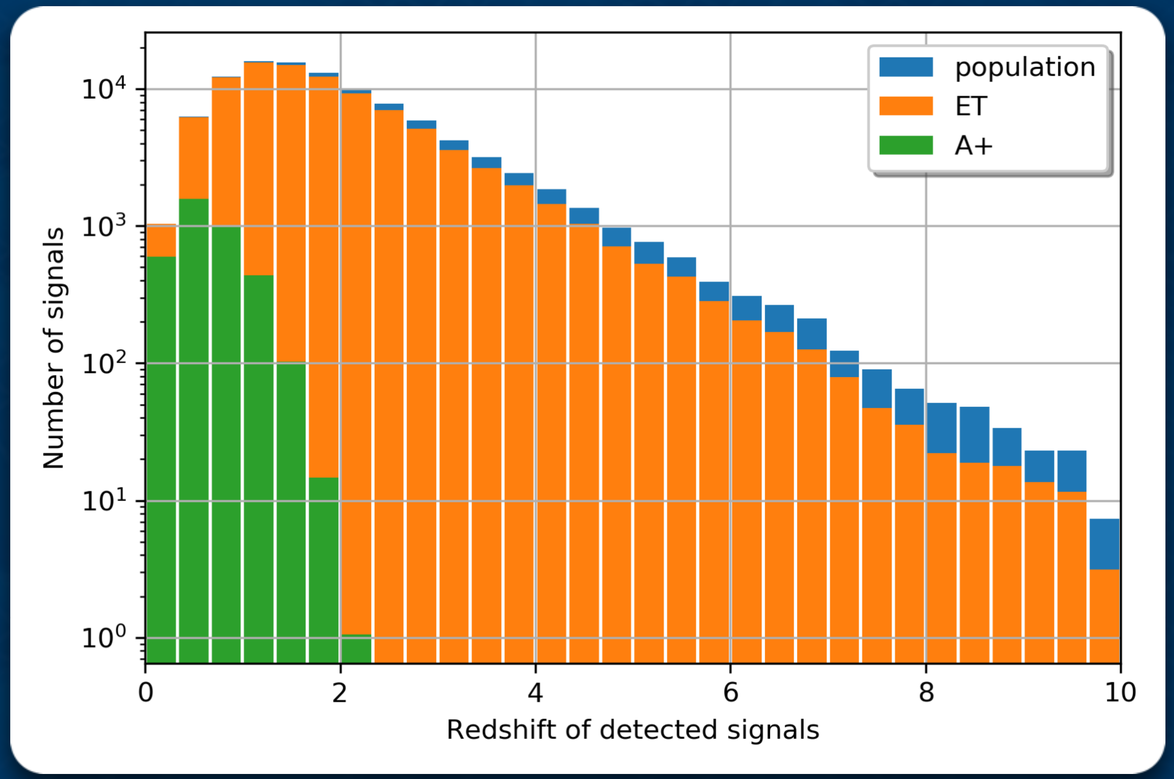
Evans et al. 2021

Gravitational Wave Astrophysics: ET

BINARY NEUTRON-STAR MERGERS (BNS)



BINARY BLACK-HOLE MERGERS (BBH)



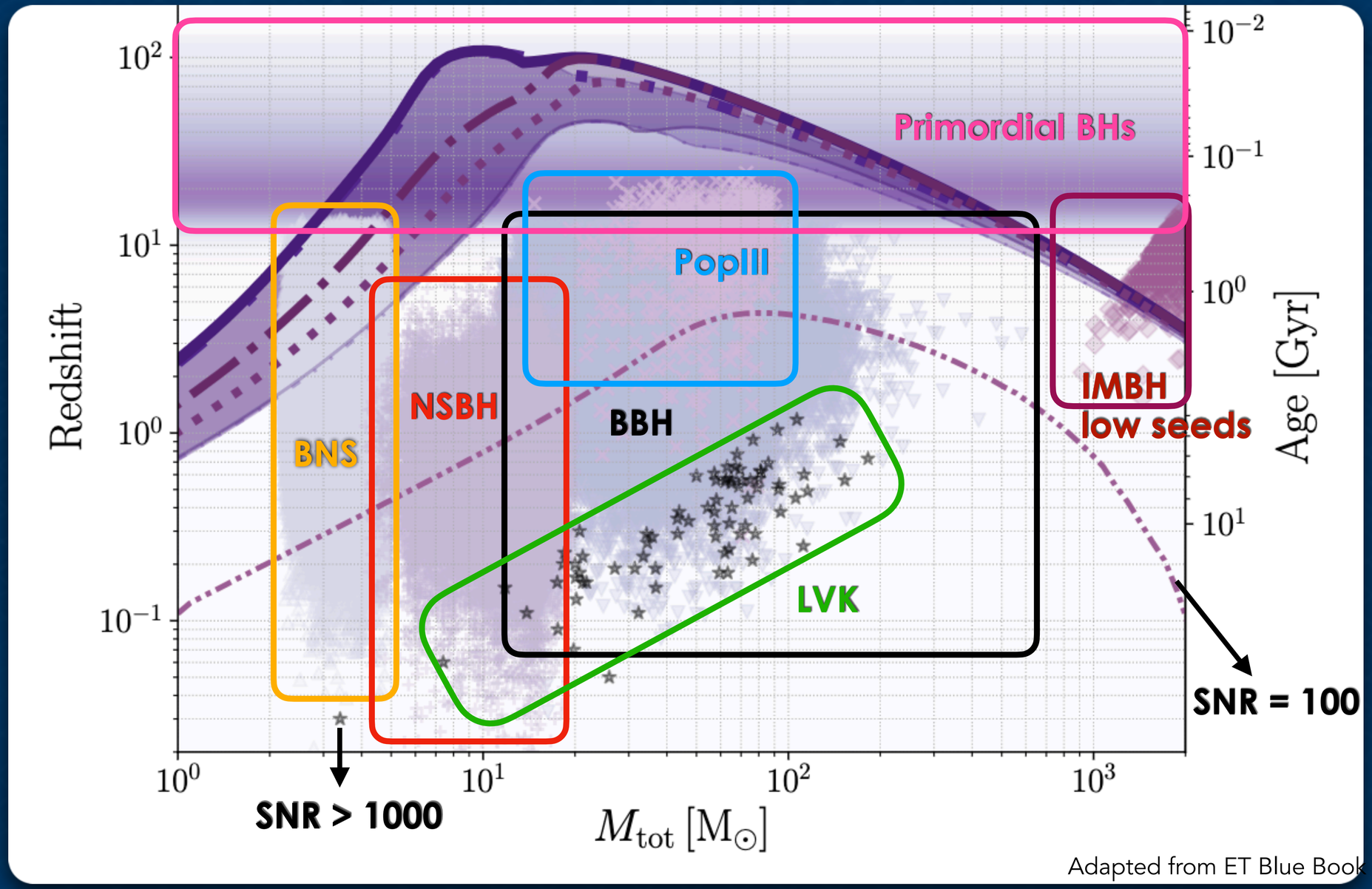
Credits: M. Branchesi

Sampling astrophysical populations of binary system of compact objects along the cosmic history of the Universe

10^4 BNS detections per year

10^5 BBH detections per year

Gravitational Wave Astrophysics: ET



Adapted from ET Blue Book

ET Blue book arXiv:2503.12263

Multi-messenger astrophysics

Not only

EM and GW detection of the same “event”

but more globally

Exploring & Understanding the Universe
with the help of both messengers

Stellar evolution & formation of compact binaries

- How do massive stars evolve?
- What are the channels bringing to compact binary mergers?
- What are the factors that impact the formation of compact binary mergers?

Rates

Masses

Spins

Environment

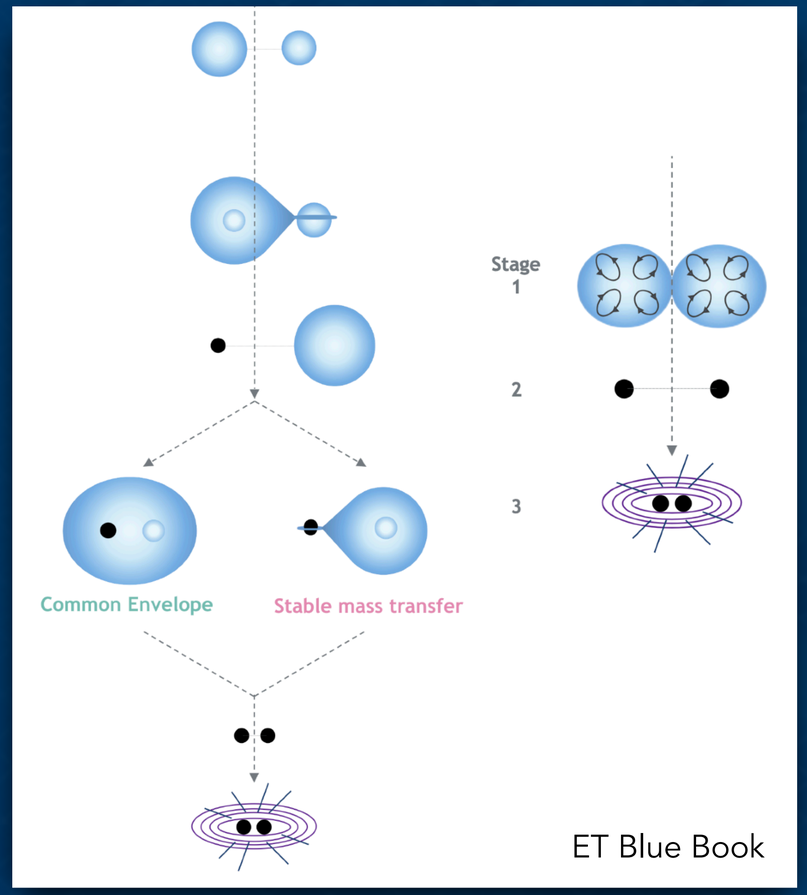
Delay times

Host galaxies

Eccentricity

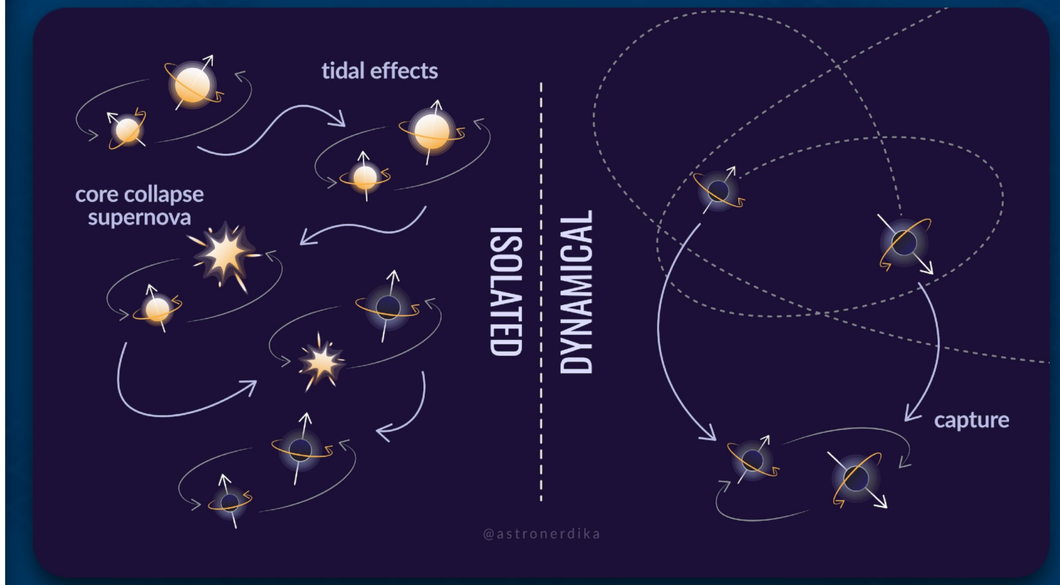
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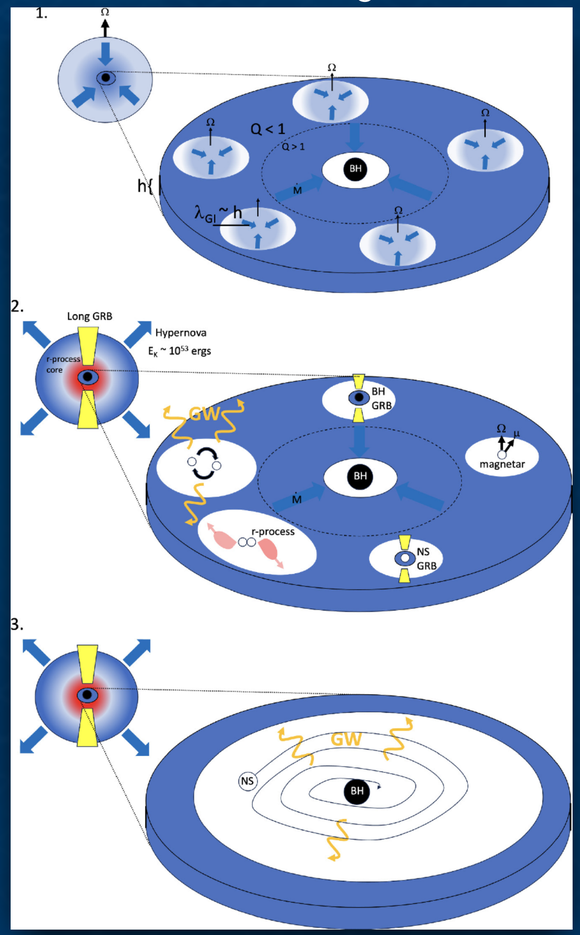
Common envelope vs
Chemical Homogeneous Evolution

Credits: Shanika Galaudage



Isolated vs Dynamical channels

Metzger et al. 2024



Fragmentation

Multi-messenger astrophysics

- What are the properties of primordial BH (mass, spin, evolution,…)?
- What are the properties of PopIII stars?
- How was the Universe enriched of heavy elements?
- How do galaxies evolves?
- Cosmological constants
- …?

Multi-messenger astrophysics

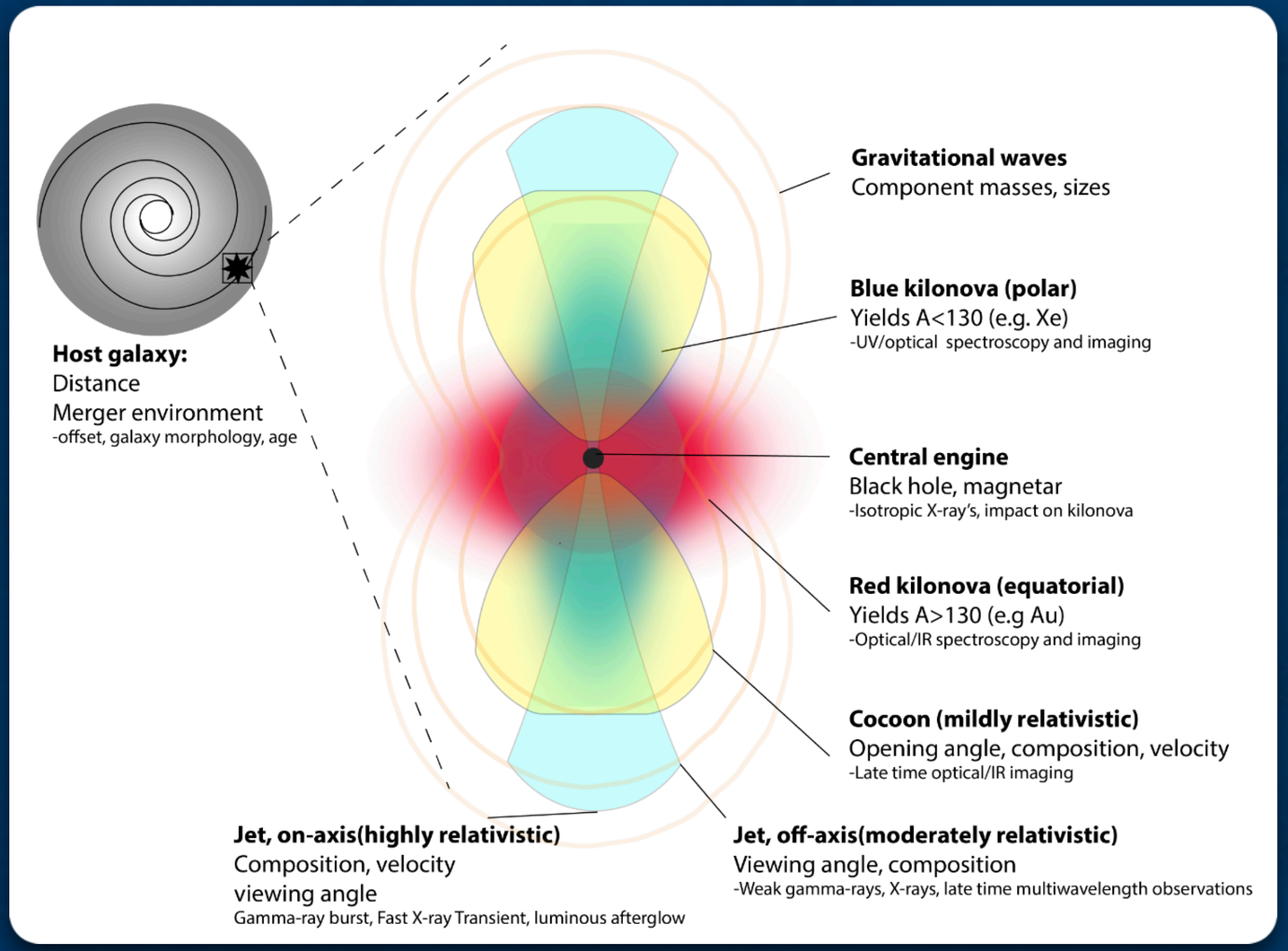
Not only

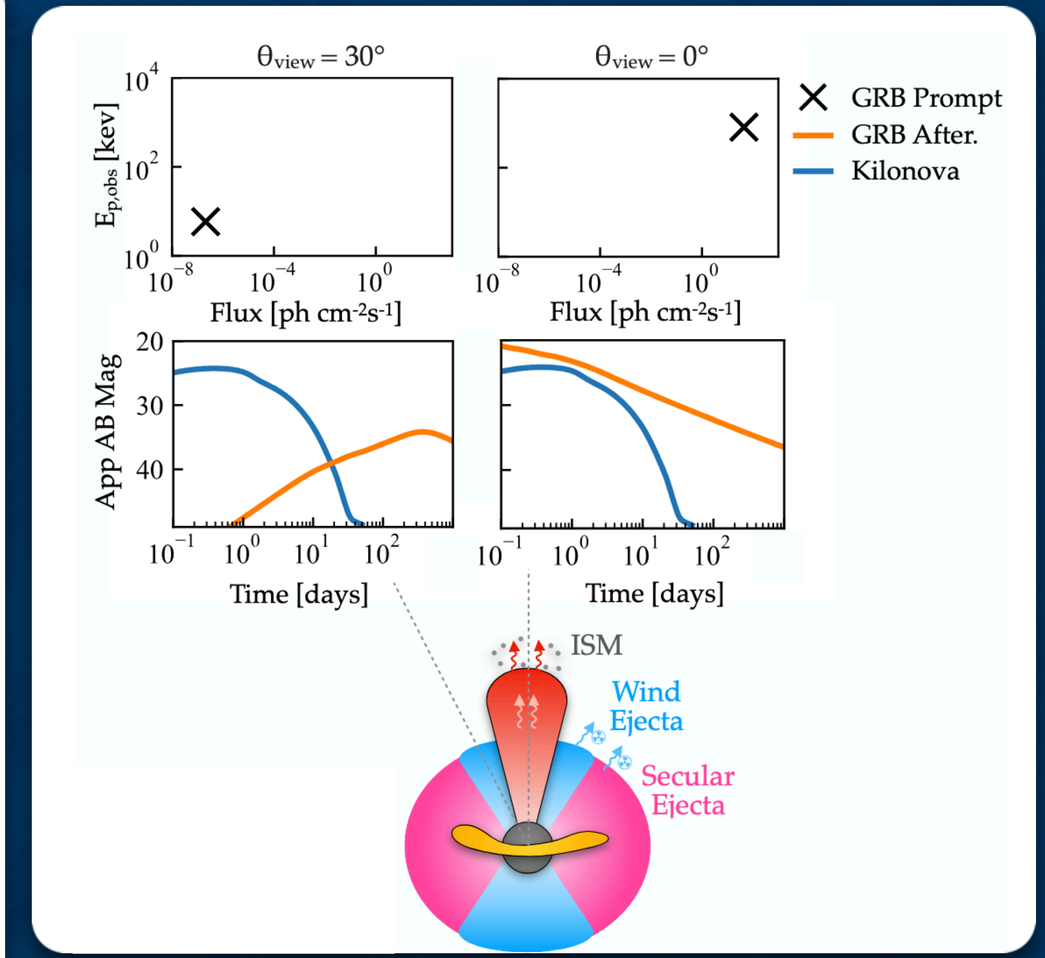
EM and GW detection of the same “event”

but more globally

Exploring & Understanding the Universe
with the help of both messengers

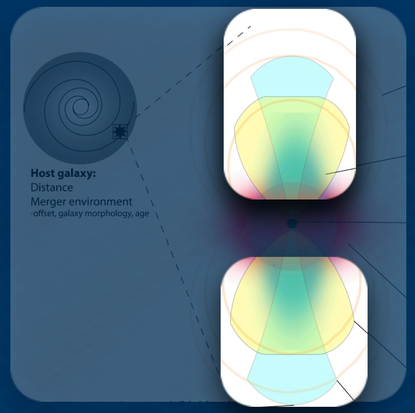
GW & EM BNS (and NSBH) mergers





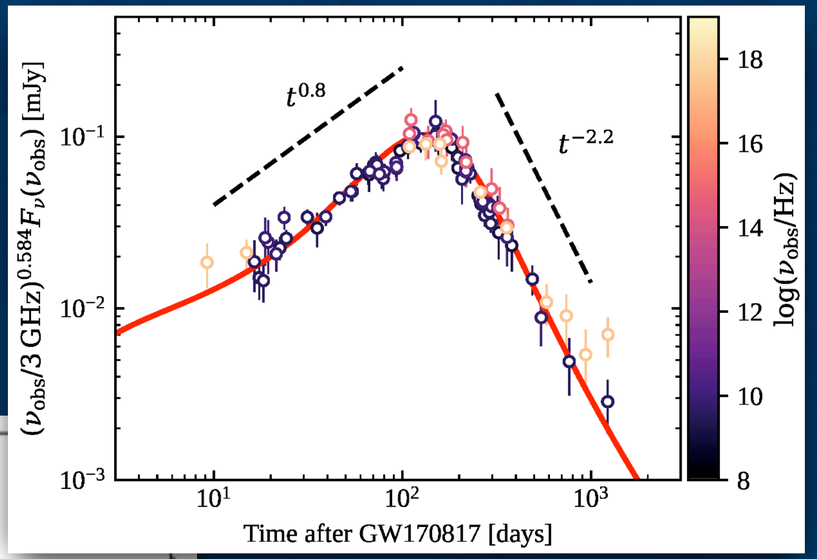
ET Blue book arXiv:2503.12263

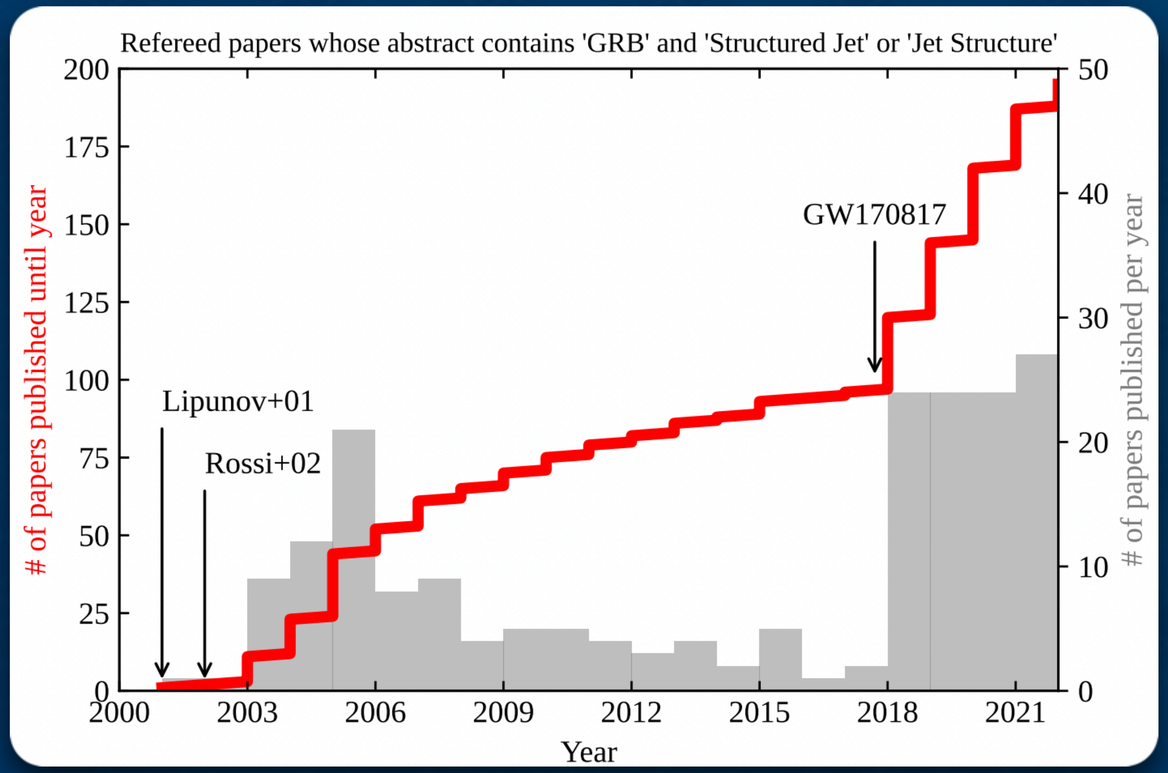
Jets



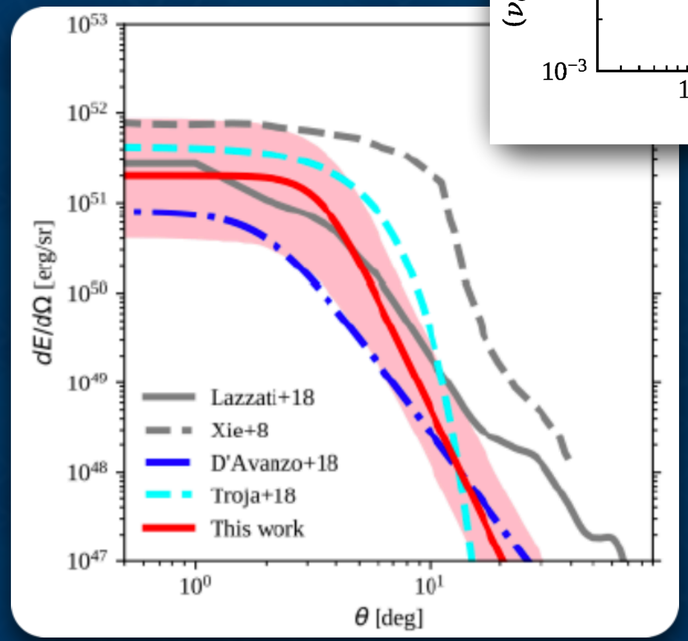
- What is the structure of BNS merger jets?
- How do jets expand in the BNS environments?
- How are afterglows produced?

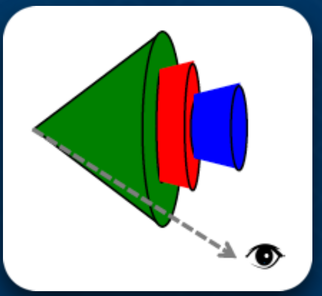
Off-axis GRB afterglow





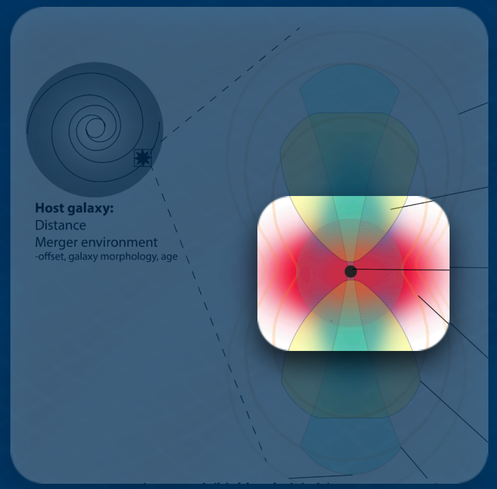
Salafia+22



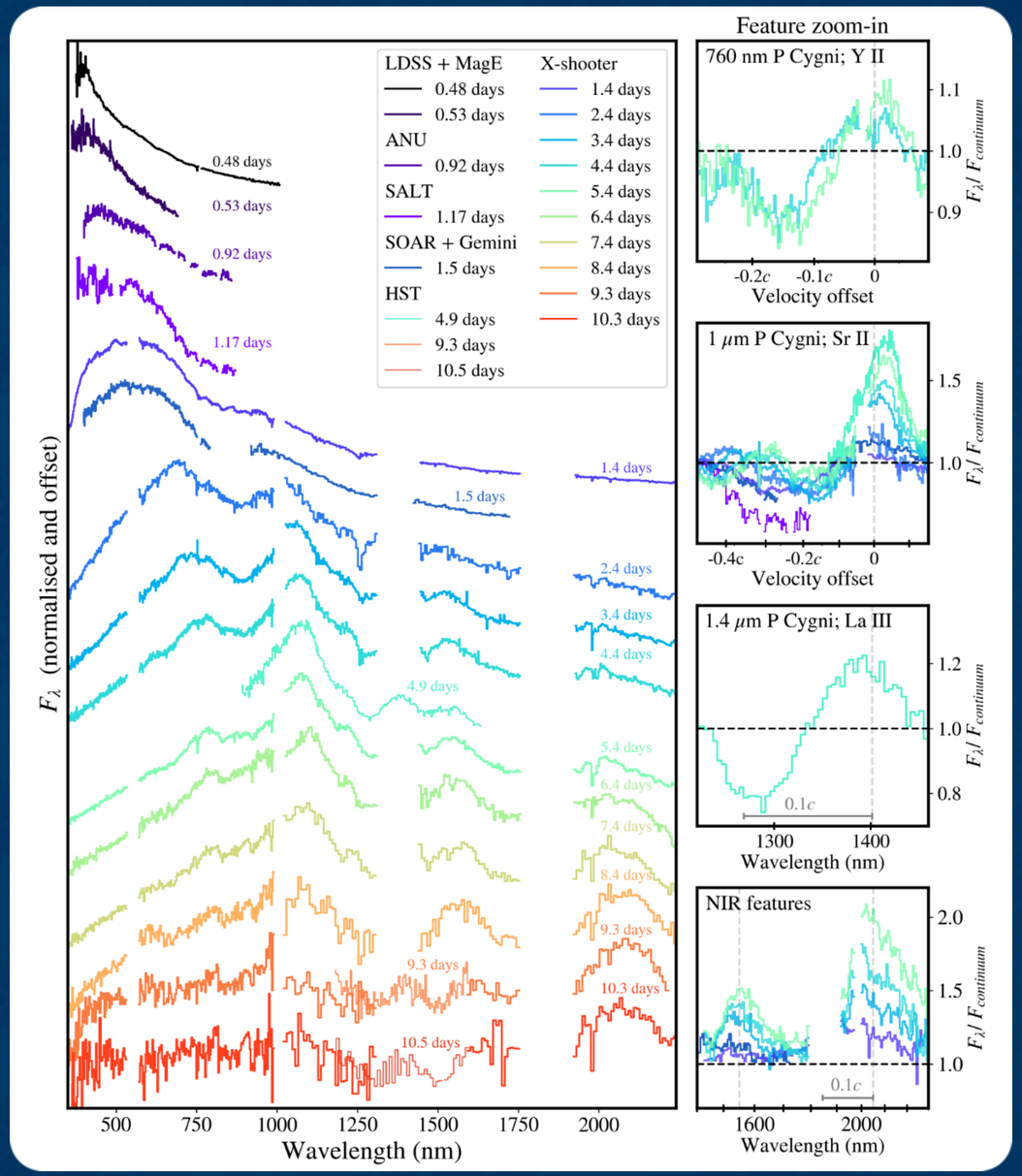


Ghirlanda et al. 2019

Kilonova

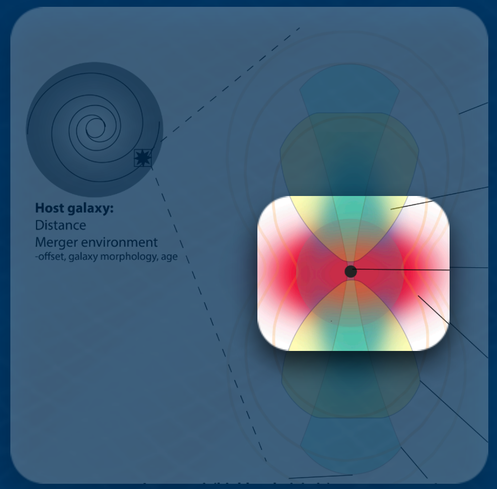


- What are the characteristics of the ejecta (neutron fraction, velocity,…)?
- What are the elements produced by kilonovae?

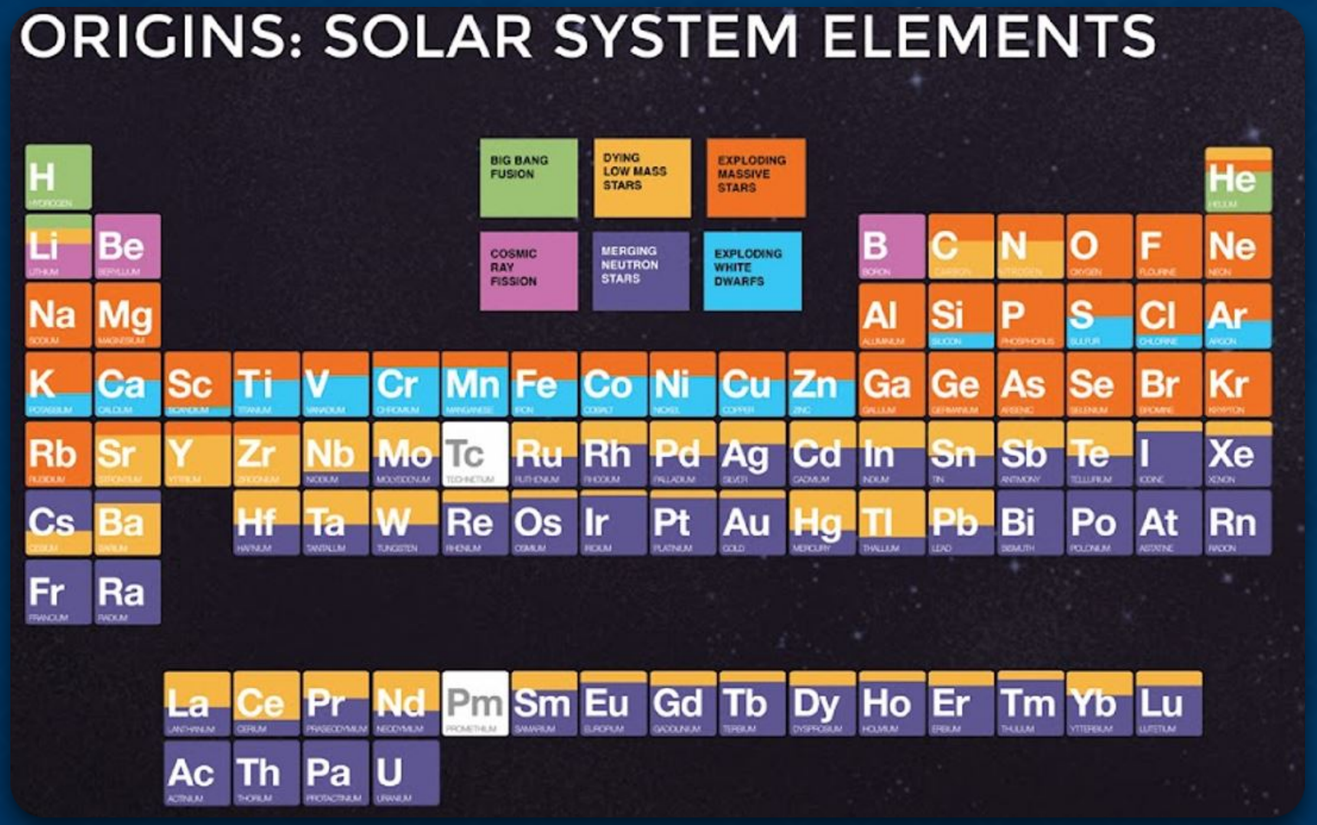


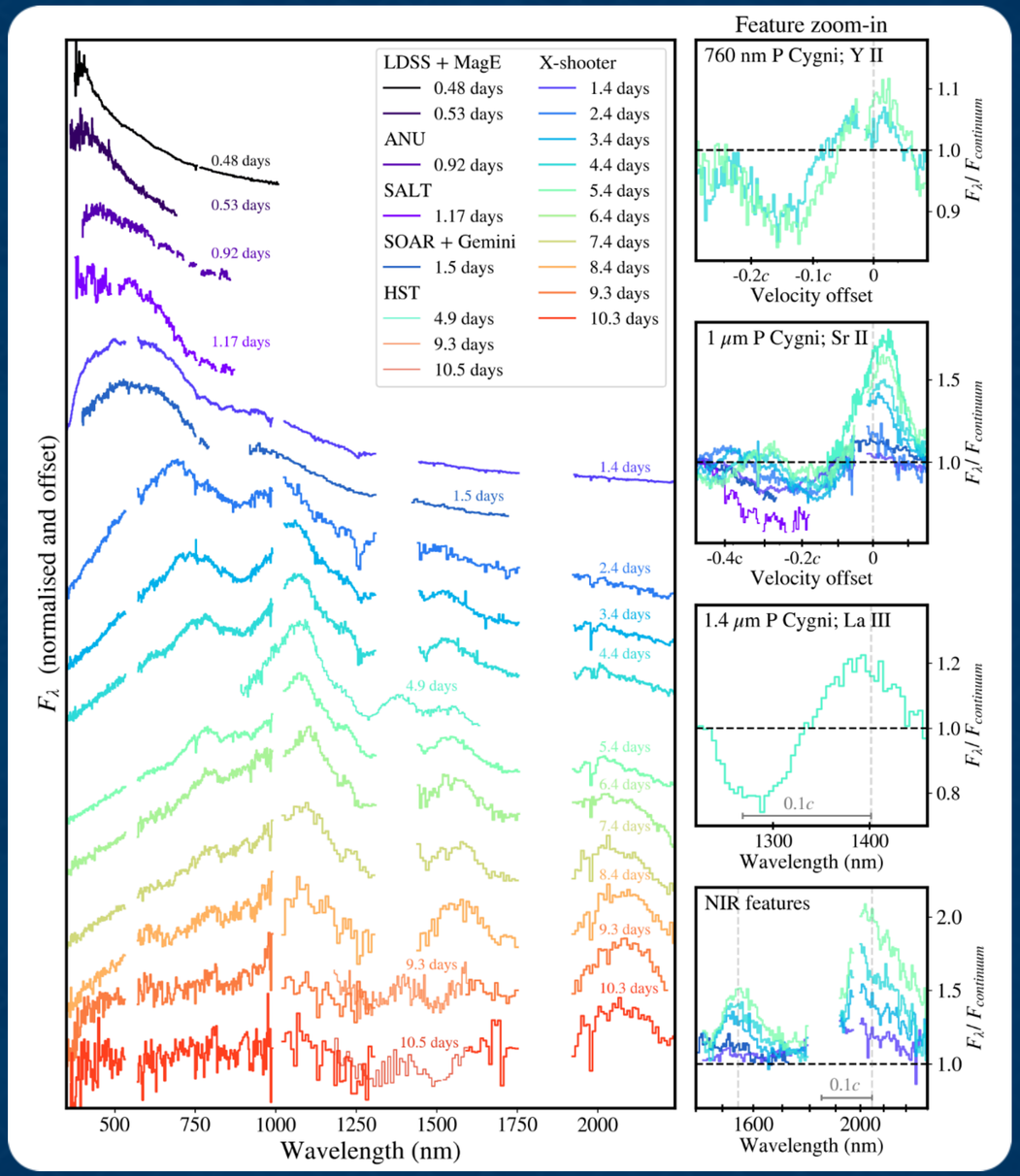
Snepen et al., see also Pian et al. Gillanders et al. Hotokezaka et al,…

Kilonova



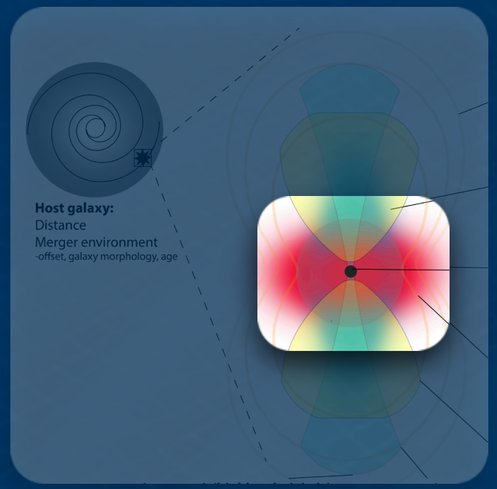
Credits: NASA



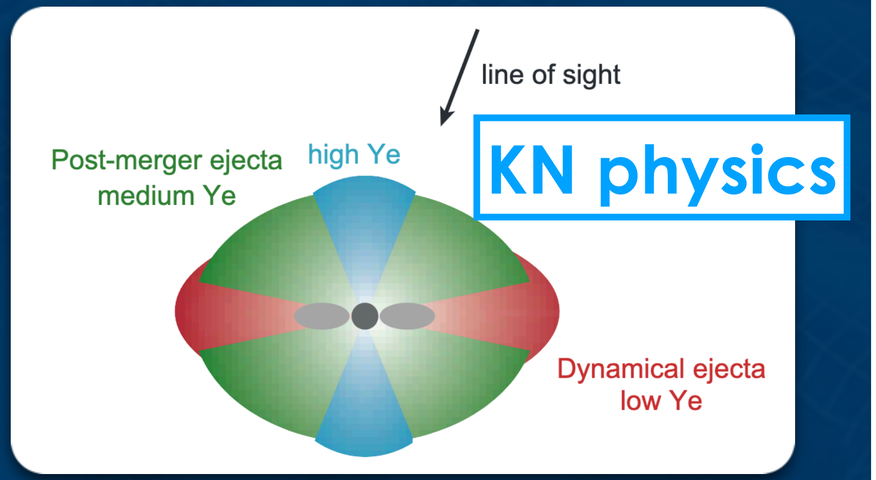


Sneppen et al., see also Pian et al. Gillanders et al. Hotokezaka et al,...

Kilonova



Lots of unknown !



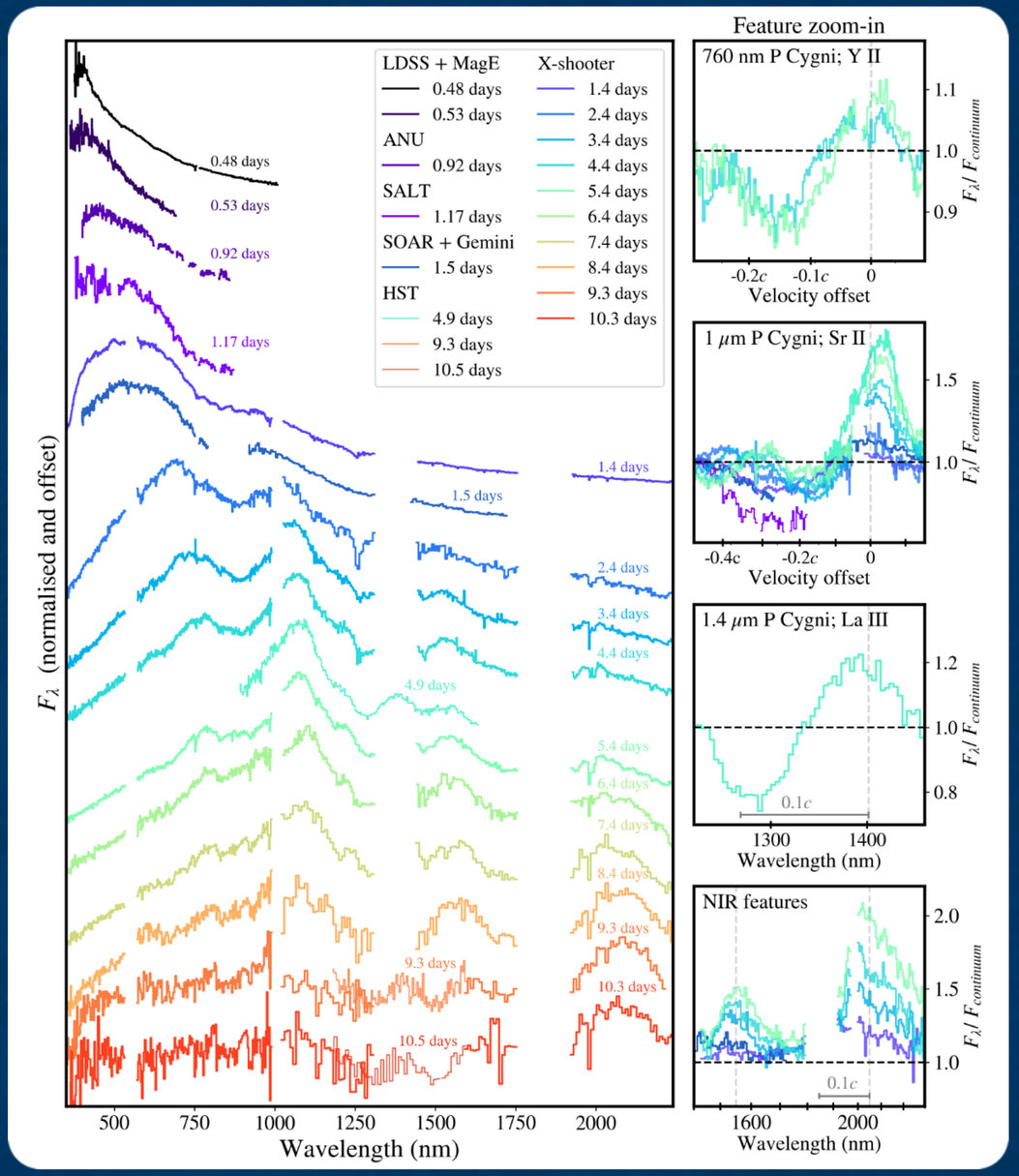
KN physics

Atomic physics

Atomic transitions

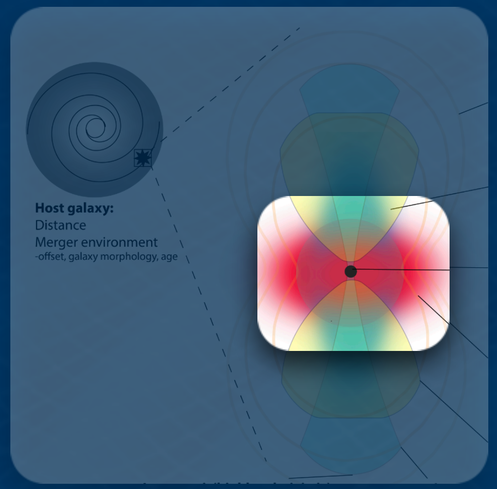
Oscillator strengths

LTE vs Non-LTE models

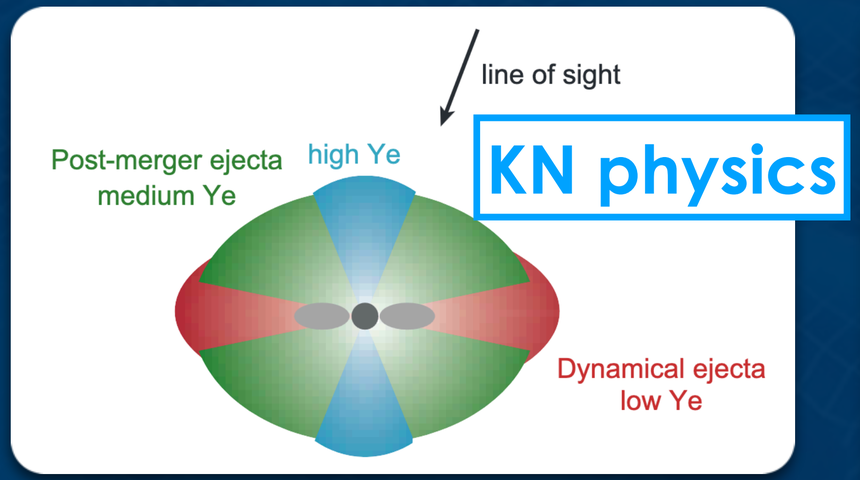


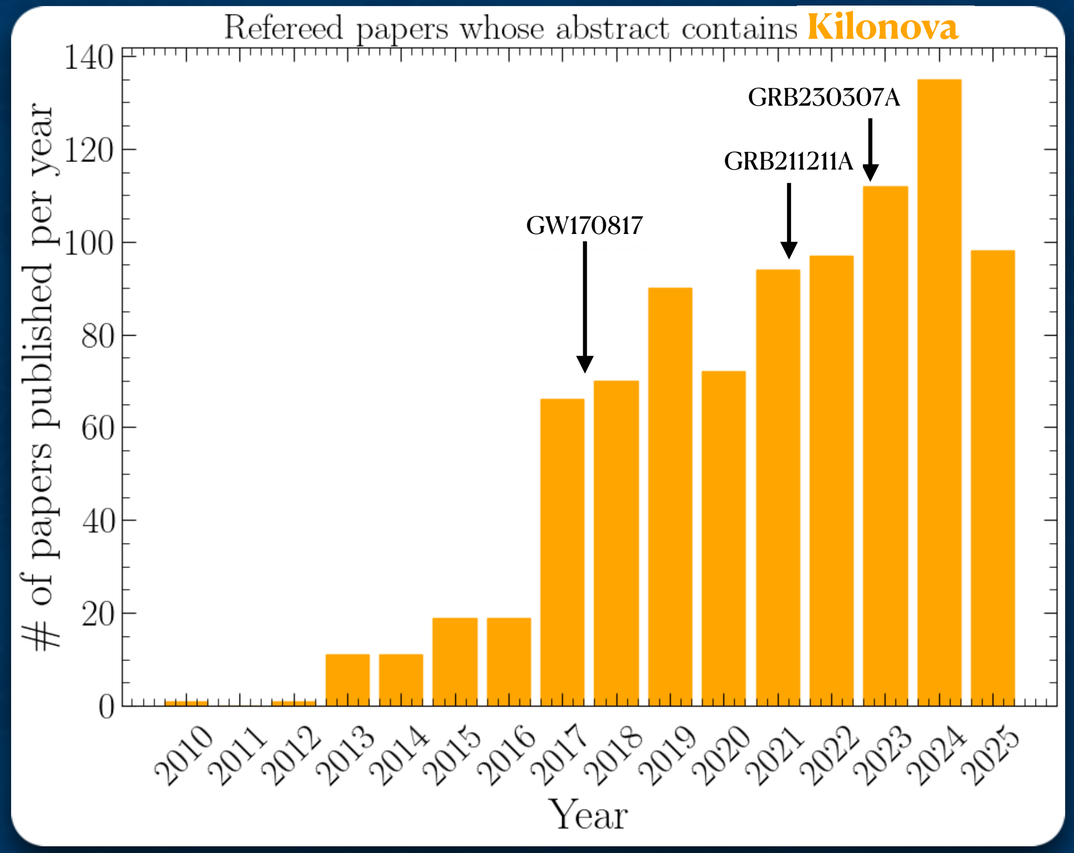
Sneppen et al., see also Pian et al. Gillanders et al. Hotokezaka et al,...

Kilonova



Lots of unknown !





Atomic physics

Atomic transitions

Oscillator strengths

LTE vs Non-LTE models

Host galaxy (or globular cluster)



Redshift

Environment properties

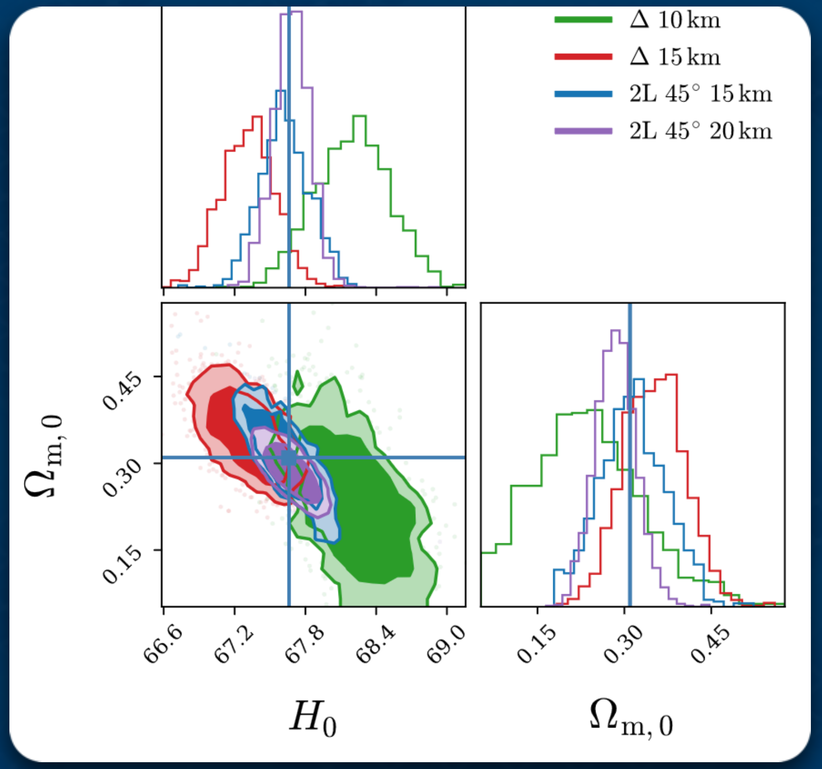
- hosting system
- BNS region (SF region? Offset?)

- How do massive stars evolve?
- What are the channels bringing to compact binary mergers?
- What are the factors that impact the formation of compact binary mergers?



Cosmology : H_0

< 2% precision with ~50 events in total



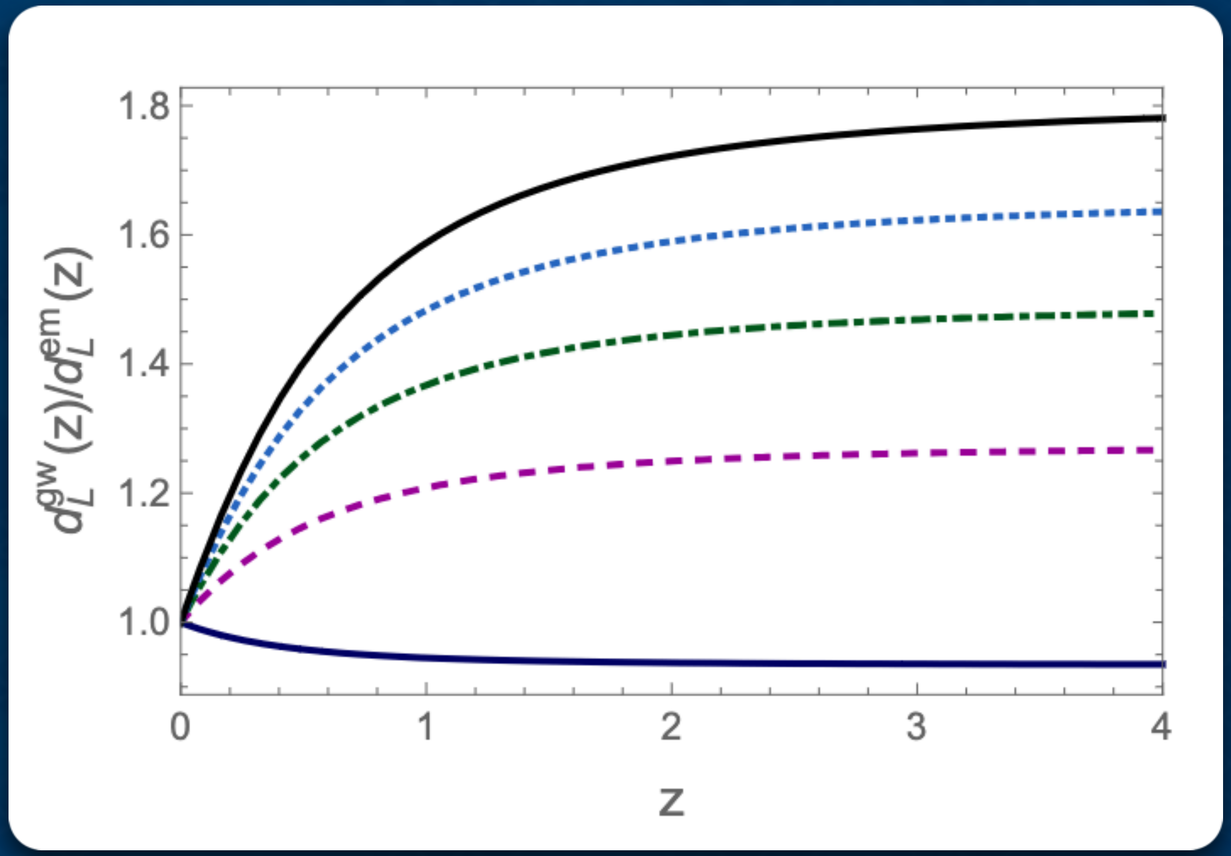
~40 events per year with redshift

Configuration	$\Delta H_0/H_0$
Δ-10km	0.009
Δ-15km	0.007
2L-15km-45°	0.006

Branchesi et al. 2023

Cosmology : modified gravity





ET Blue book arXiv:2503.12263

Even 1 event at high-z can discriminate!

Multi-messenger astrophysics

EM will be the bottleneck!

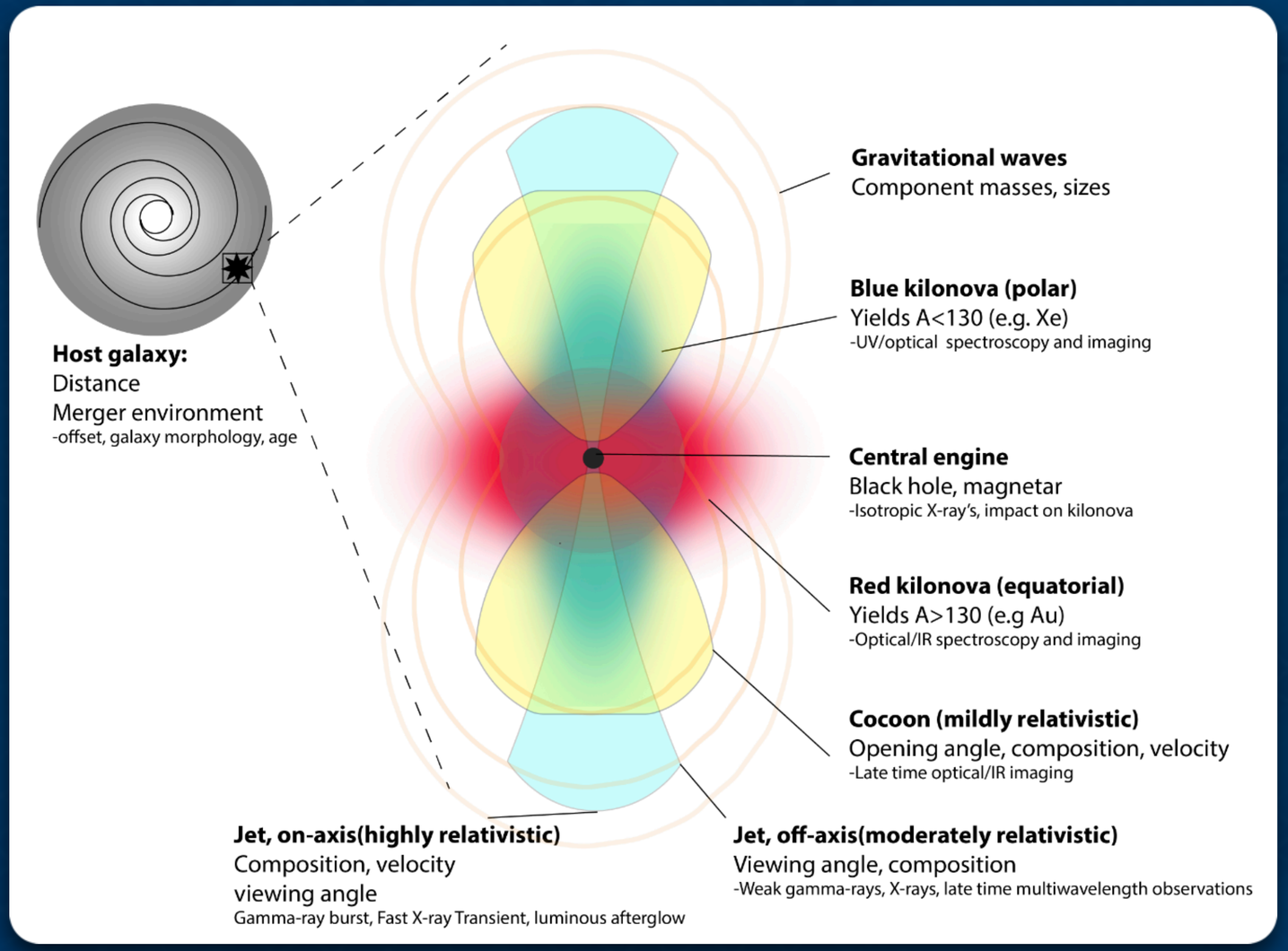
Not only

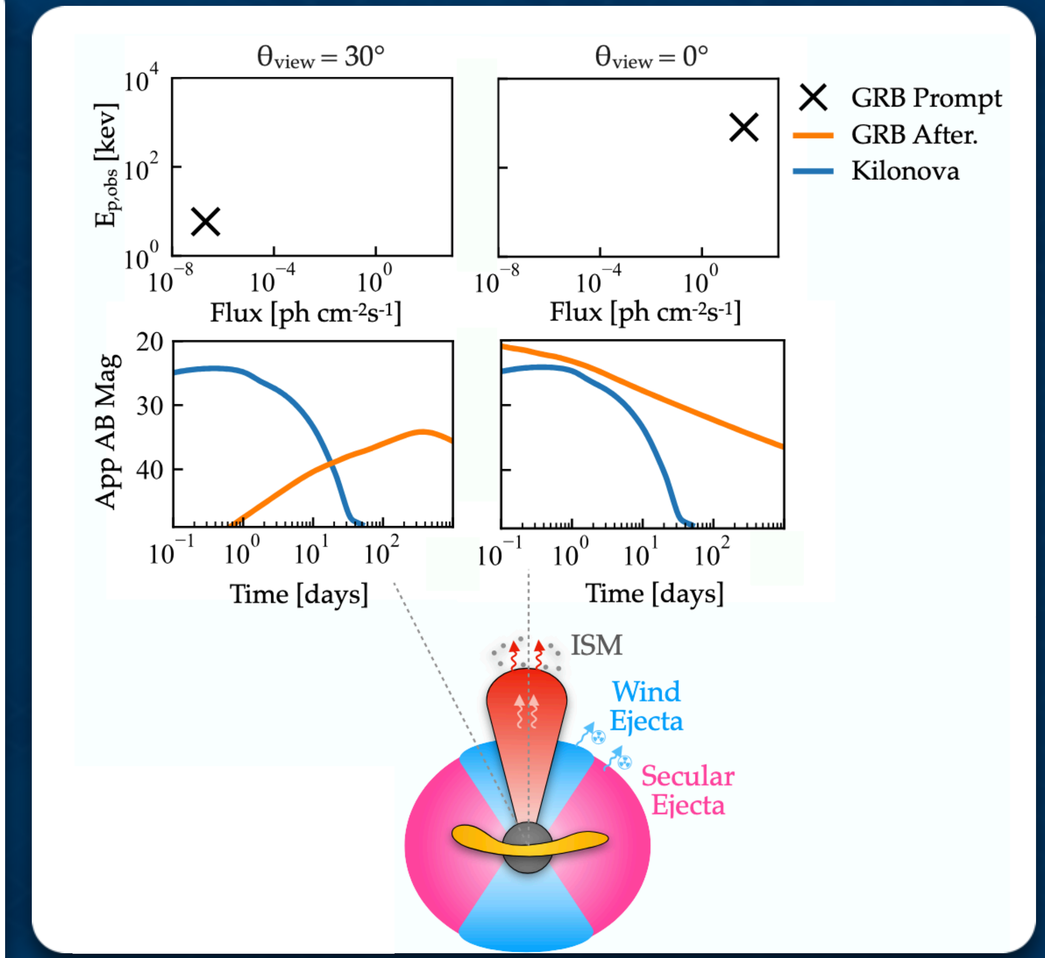
EM and GW detection of the same “event”

but more globally

Exploring & Understanding the Universe
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GW & EM BNS (and NSBH) mergers





ET Blue book arXiv:2503.12263

GW & EM BNS (and NSBH) mergers

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 deg²	>22 mag	1000-1800	~1000 / ~ 1"	1 day	~arcsec²	>24 mag	1000-1800	>1000	1 day	Ideally nightly monitoring of the evolution for ~1week. However at such late time most counterparts will reach exteremely faint magnitudes (m~30 AB)
Optical	>1 deg²	>22 mag	500-900	~1000 / ~ 1"	12 hr	~arcsec²	>24 mag	500-900	>1000	12 hr	Ideally nightly monitoring of the evolution for ~1week. However at such late time most counterparts will reach exteremely faint magnitudes (m~30 AB)
UV	>1 deg²	>22 mag	300-500	~1000 / ~ 1"	< 1 hr	~arcsec²	>24 mag	300-500	>1000	< 1 hr	Ideally nightly monitoring of the evolution for ~2-3 days.

ET Blue book arXiv:2503.12263

GW & EM BNS (and NSBH) mergers

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

ET Blue book arXiv:2503.12263

GW & EM BNS (and NSBH) mergers

OFF-AXIS AFTERGLOW

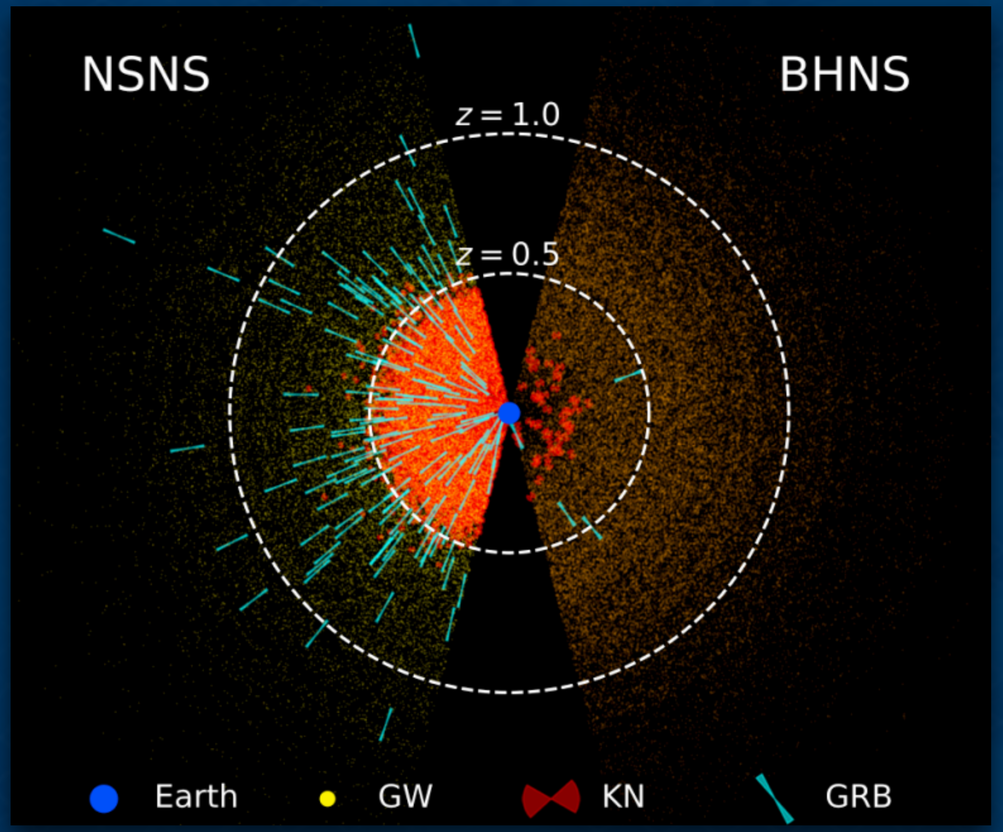
SEARCH

CHARACTERIZATION

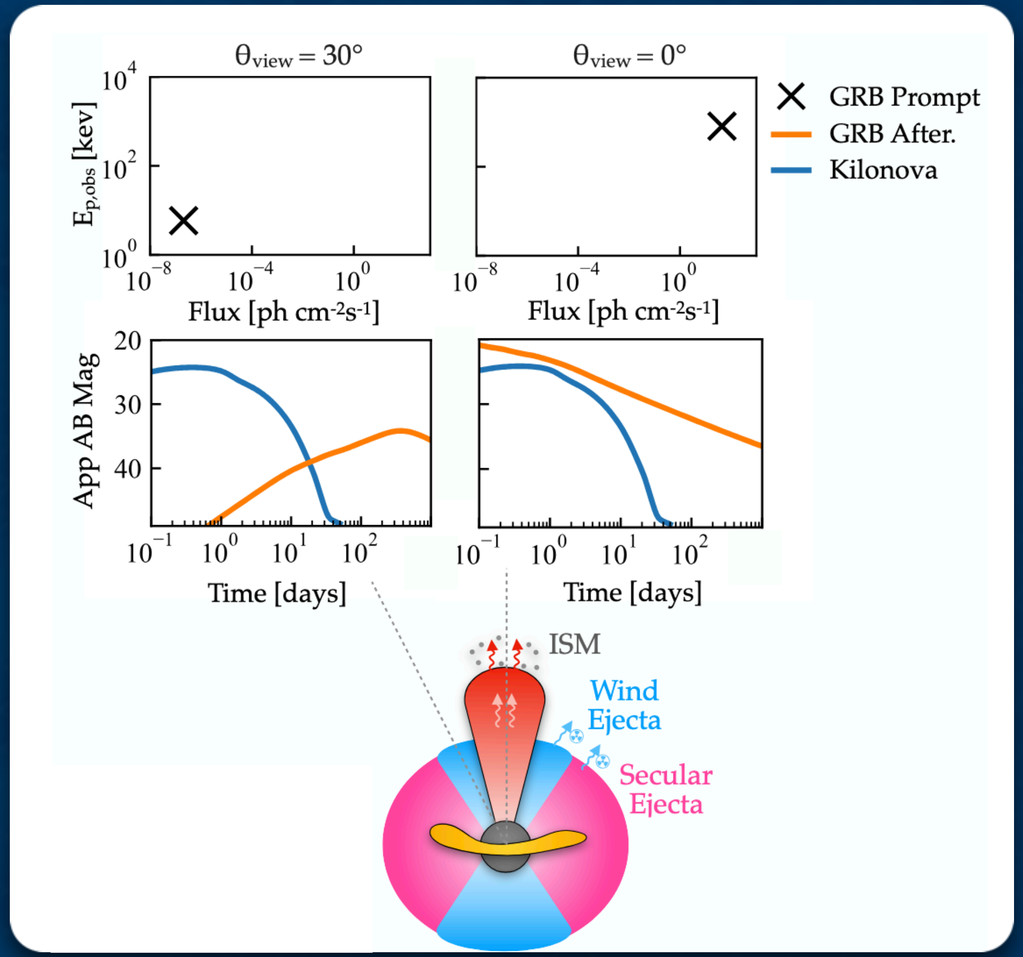
	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay	FoV	Sensitivity	Spectral range (nm)	Spectral / Spatial Resolution	ToO delay
Radio	≥ 1 deg^2	< 10^{-2} mJy	> 1 GHz	--/~arcsec	Few days to years!	Some arcsec^2	< 10^{-3} mJy	> 1 GHz	--/~arcsec	logarithmic monitoring for days, months,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

ET Blue book arXiv:2503.12263

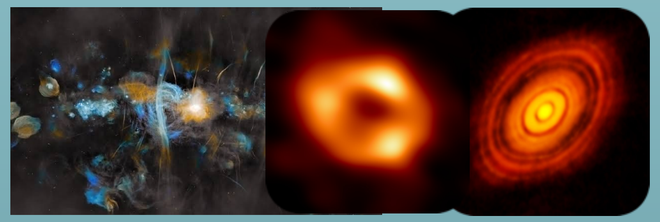
GW & EM BNS (and NSBH) mergers

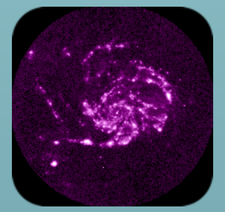


ET Blue book arXiv:2503.12263



Electromagnetic Astrophysics





INFRARED OPTICAL UV X-rays GAMMA



SKAO

ALMA

NASA | ESA | CSA

jwst

ROMAN SPACE TELESCOPE

VERA C. RUBIN OBSERVATORY



ULTRASAT
Ultraviolet Transient Astronomy Satellite

UVEX

einstein probe

exploring the dynamic X-ray universe

SVOM

Fermi Gamma-ray Space Telescope

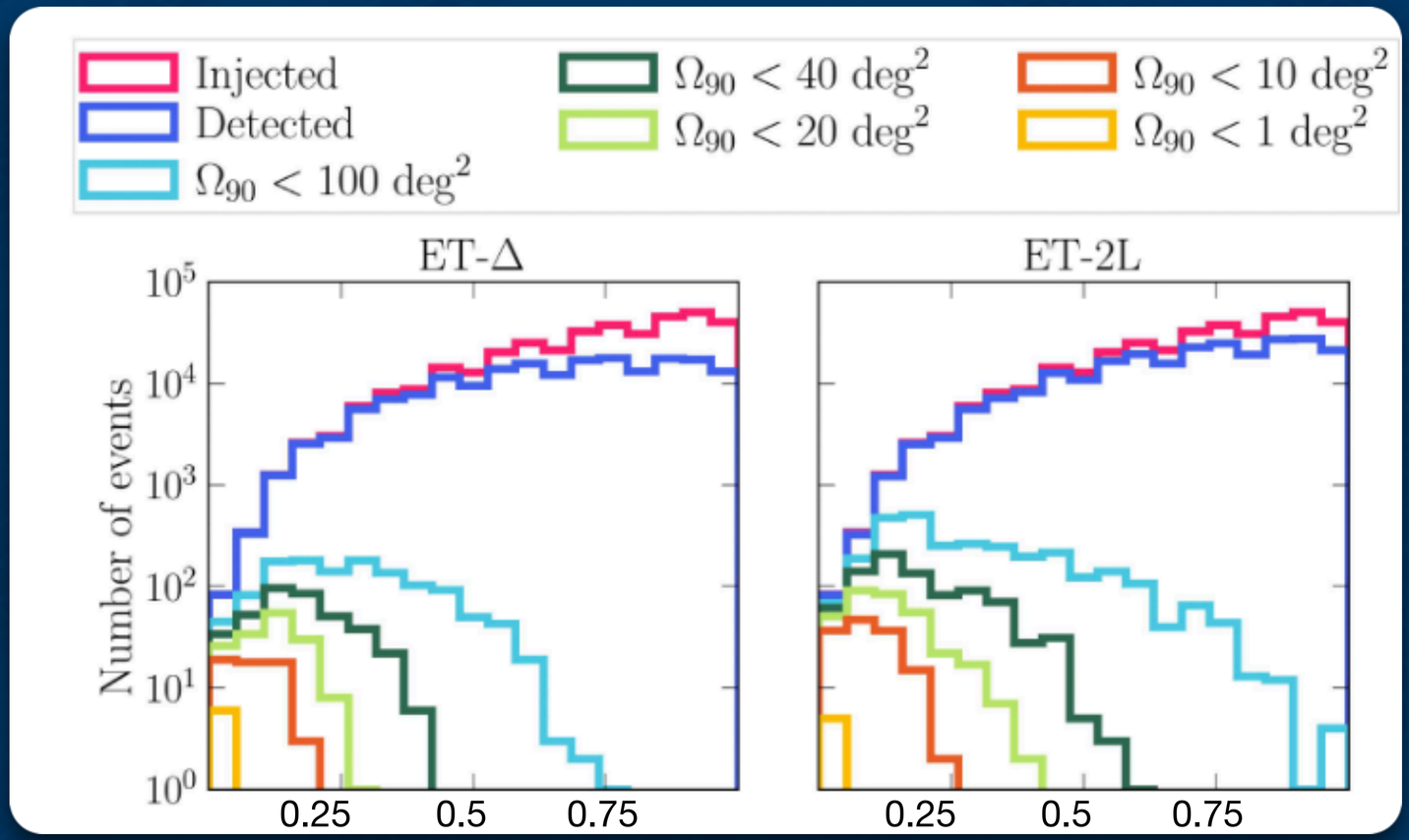
CTAO

ESO

esa newathena

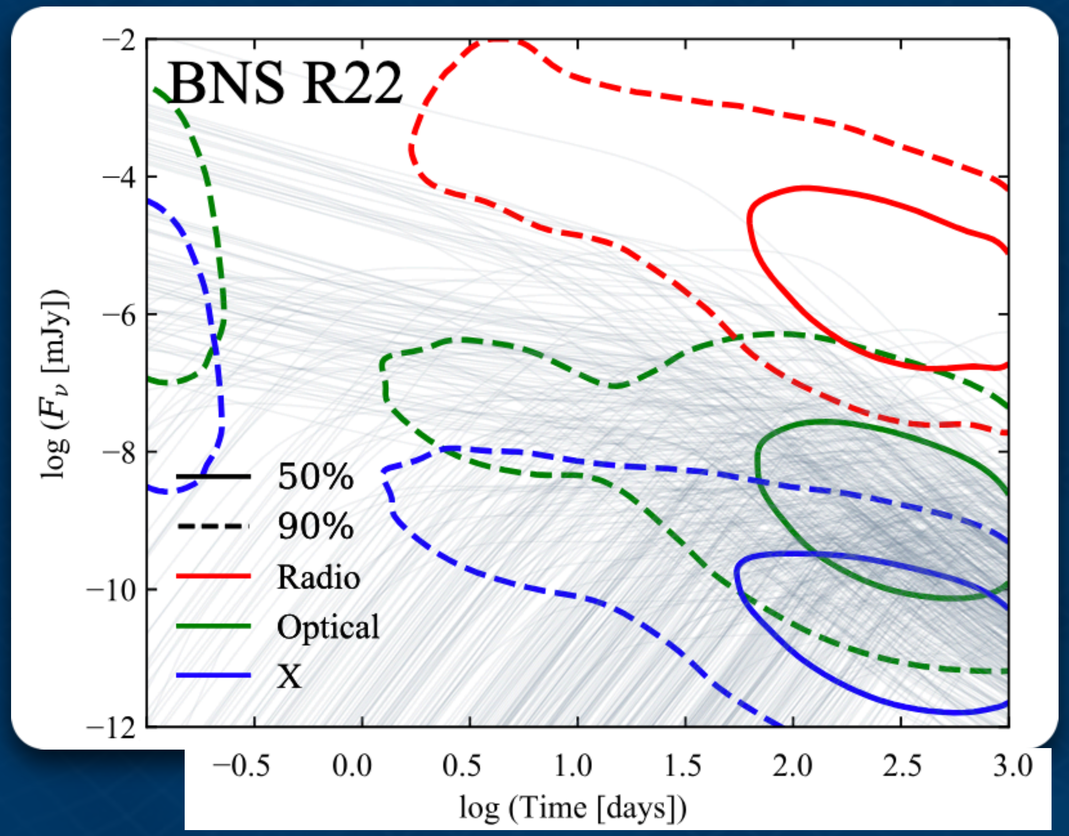
GW & EM BNS (and NSBH) mergers

Loffredo et. al. 2025



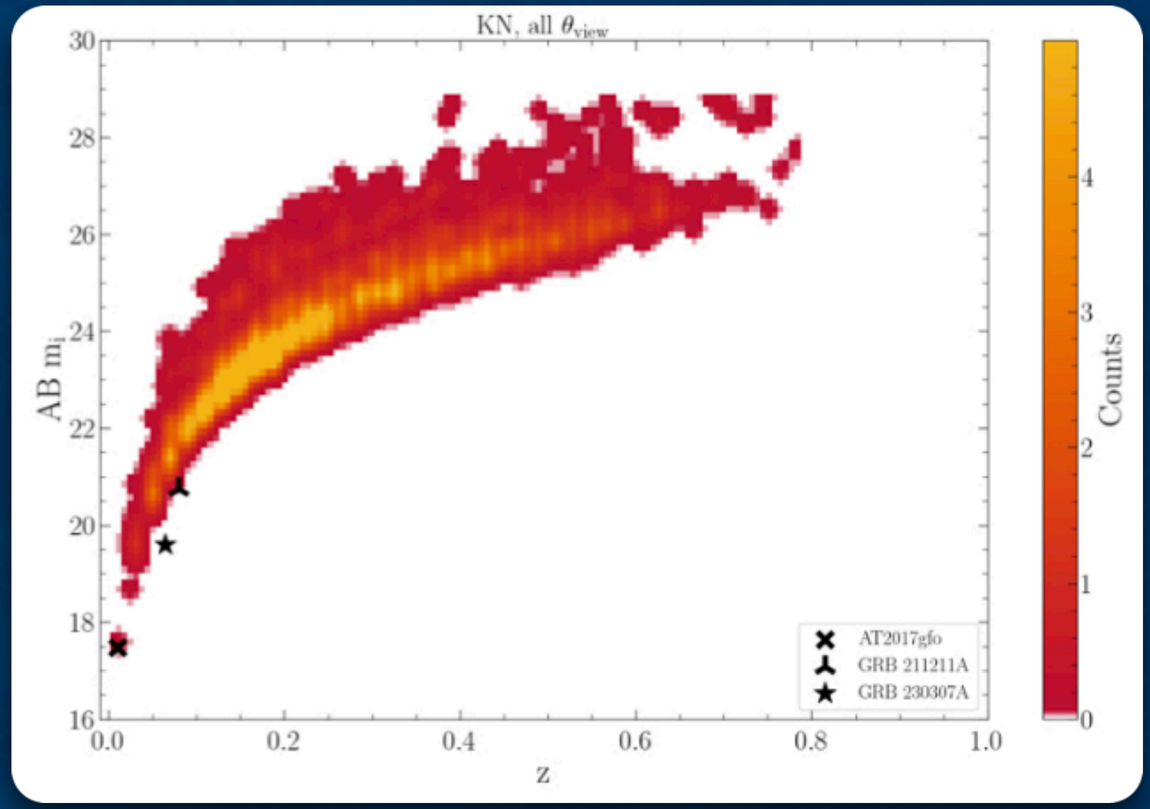
GW & EM BNS (and NSBH) mergers

Afterglows



ET Blue book arXiv:2503.12263

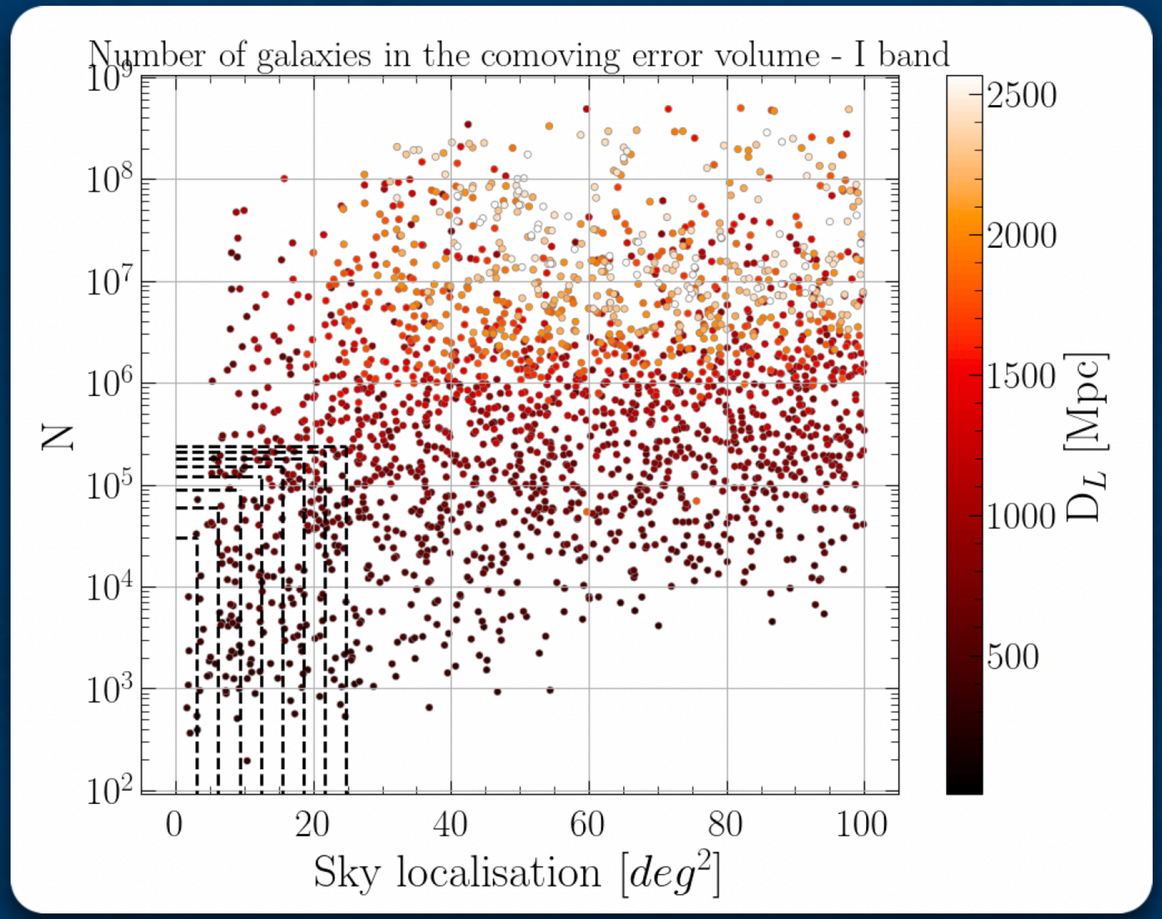
Kilonovae



Bisero et al. 2026

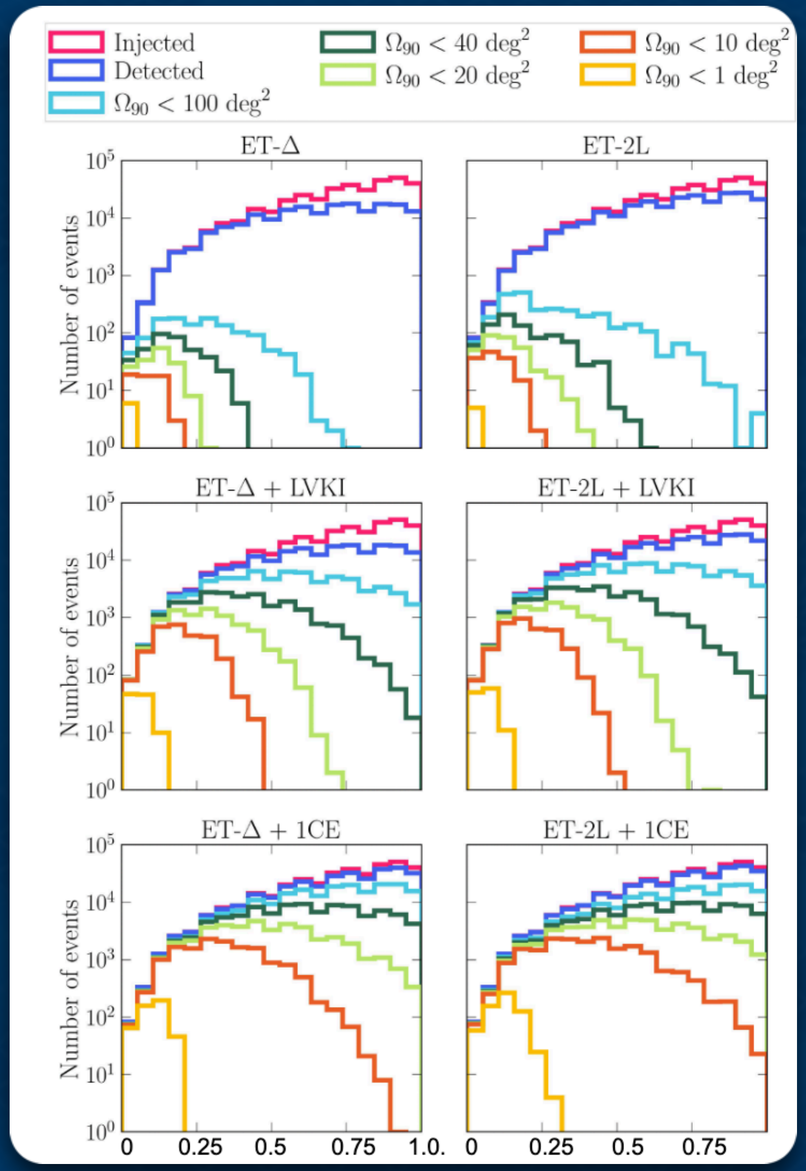
GW & EM BNS (and NSBH) mergers

Galaxy targeted searches



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GW & EM BNS (and NSBH) mergers



Loffredo et. al. 2025

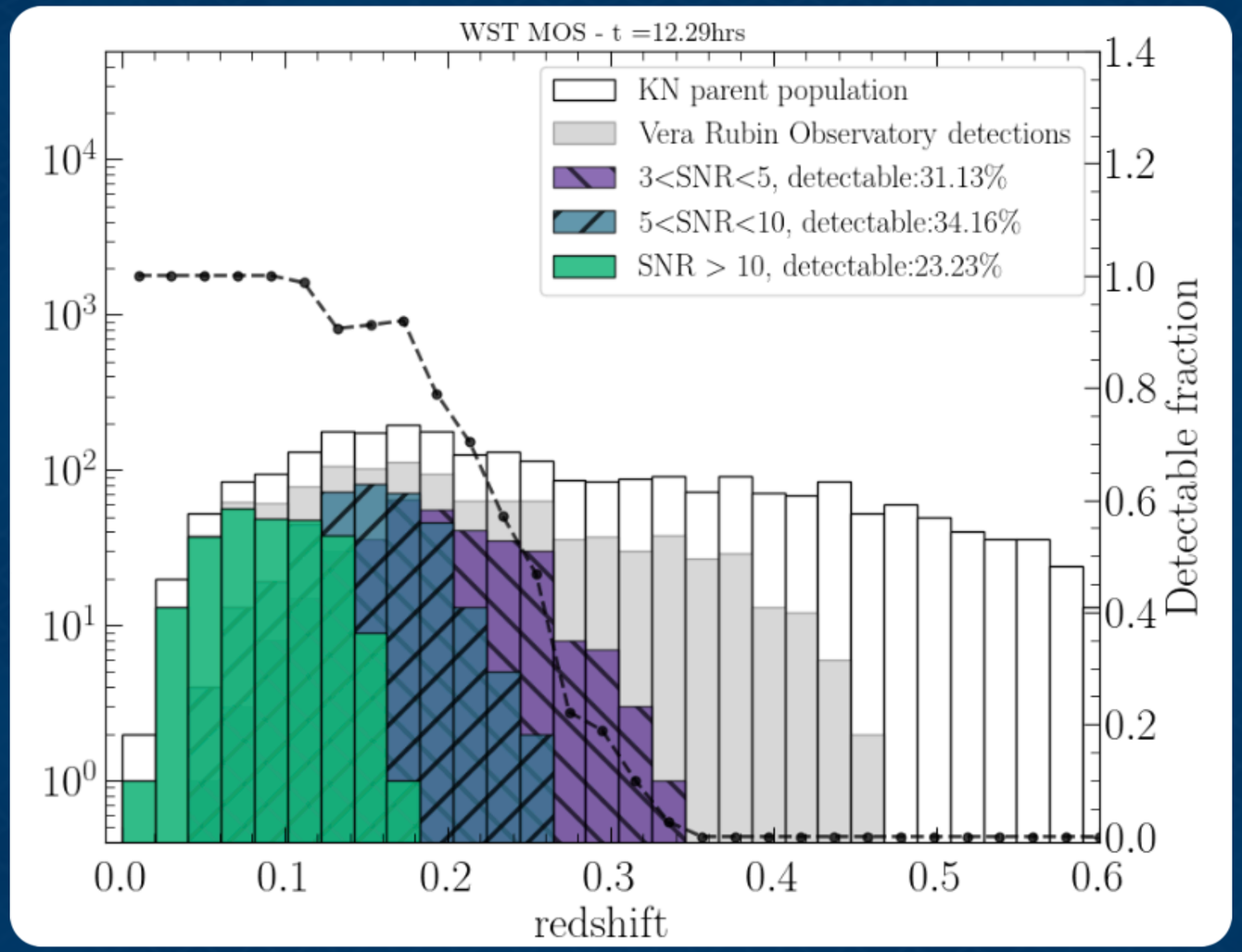
ET+VRO 8 – 50 KNe per year

x 10 for ET-LVKI+VRO

x 3 ET-CE+VRO

Kilonova: Vera Rubin Observatory

Spectroscopy is needed to identify and study!



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Thank you!