ET-WST synergy for next generation gravitational wave multi-messenger observations

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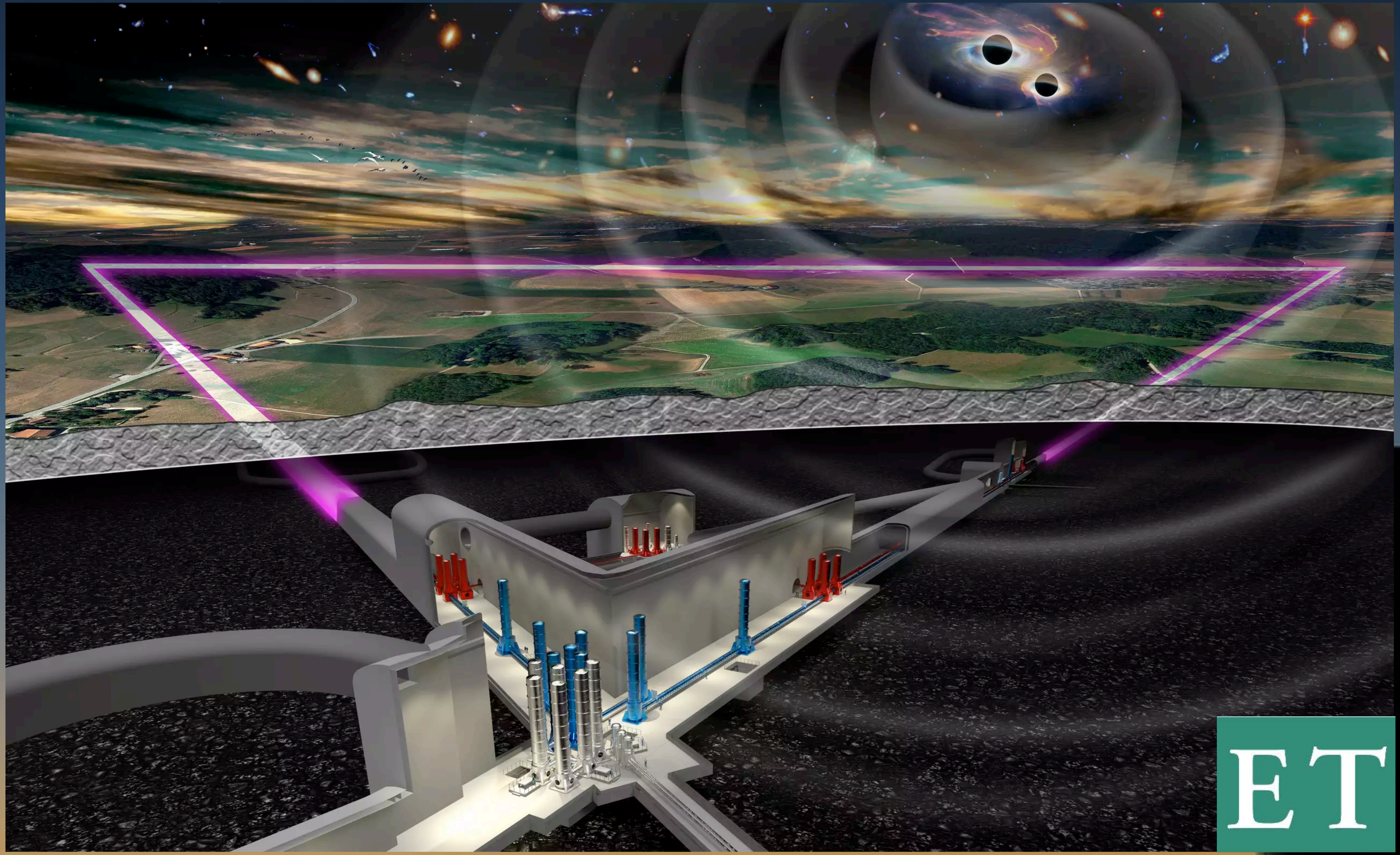
Image: Yuri Beletsky

Next generation gravitational wave interferometers: the Einstein Telescope



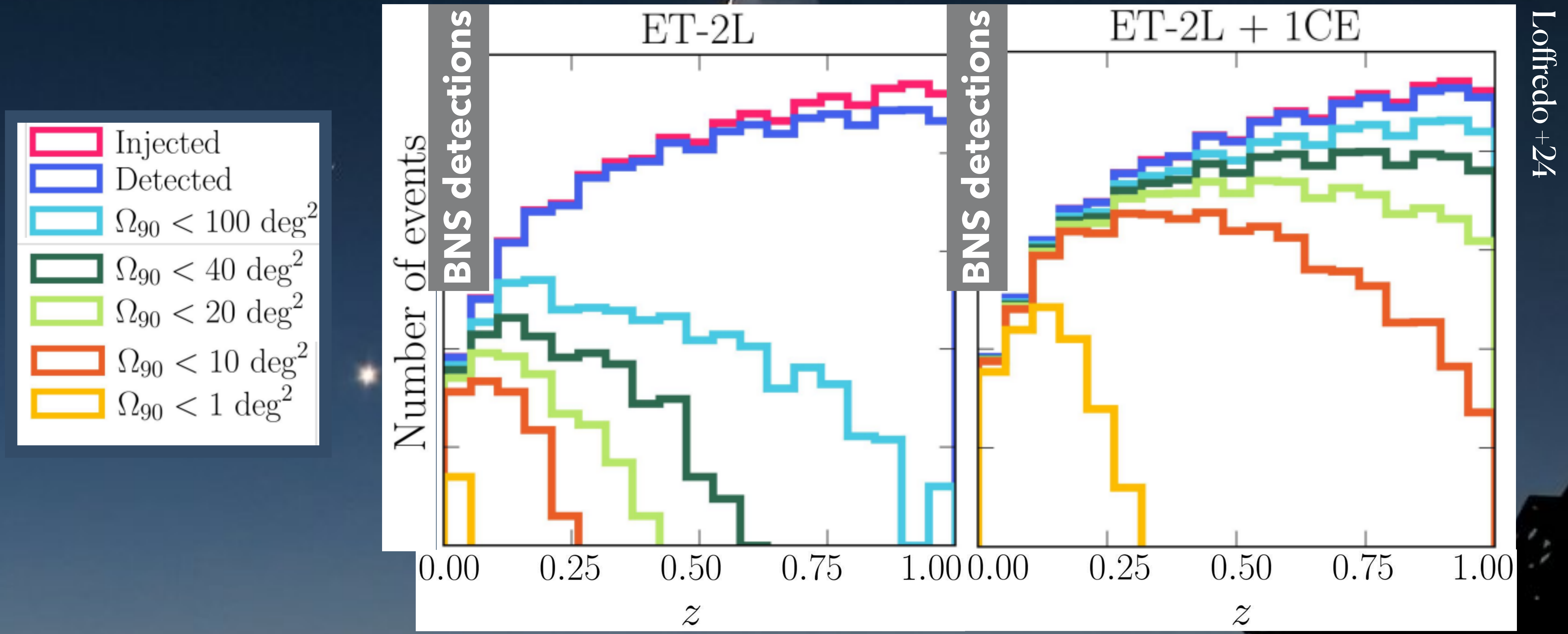
In the **ESFRI** RoadMap

Late 2030s

Possibility of monitoring BNS **before merger**

Sensitivity reaching kHz frequencies: the **post-merger** signal will be accessible

Challenges in the research of the EM counterpart of next generation GW detections



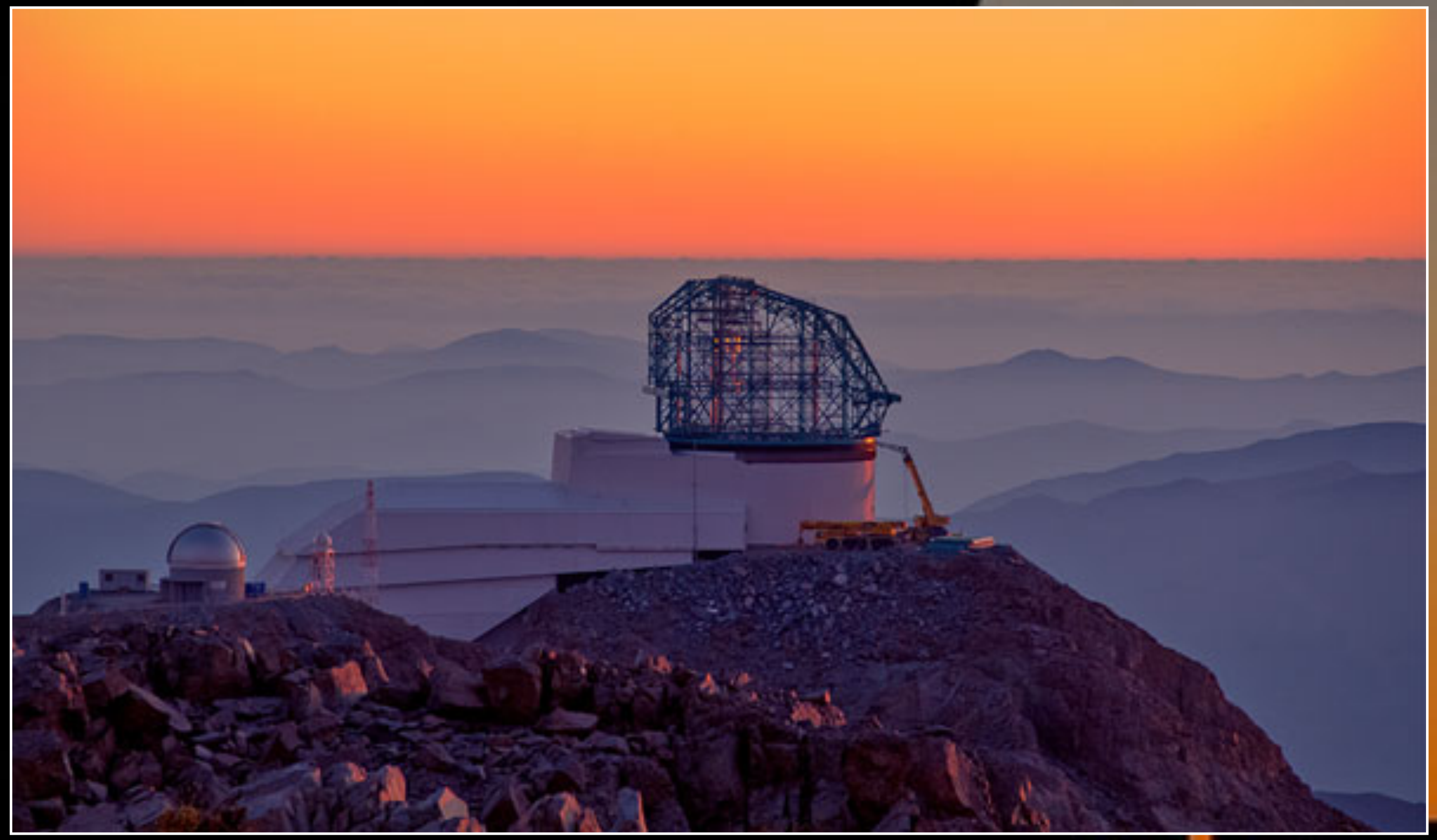
Larger volume
of the Universe explored

Higher number
of BNS detections

Faint optical-NIR EM counterparts to be found within large error regions among a huge number of contaminants

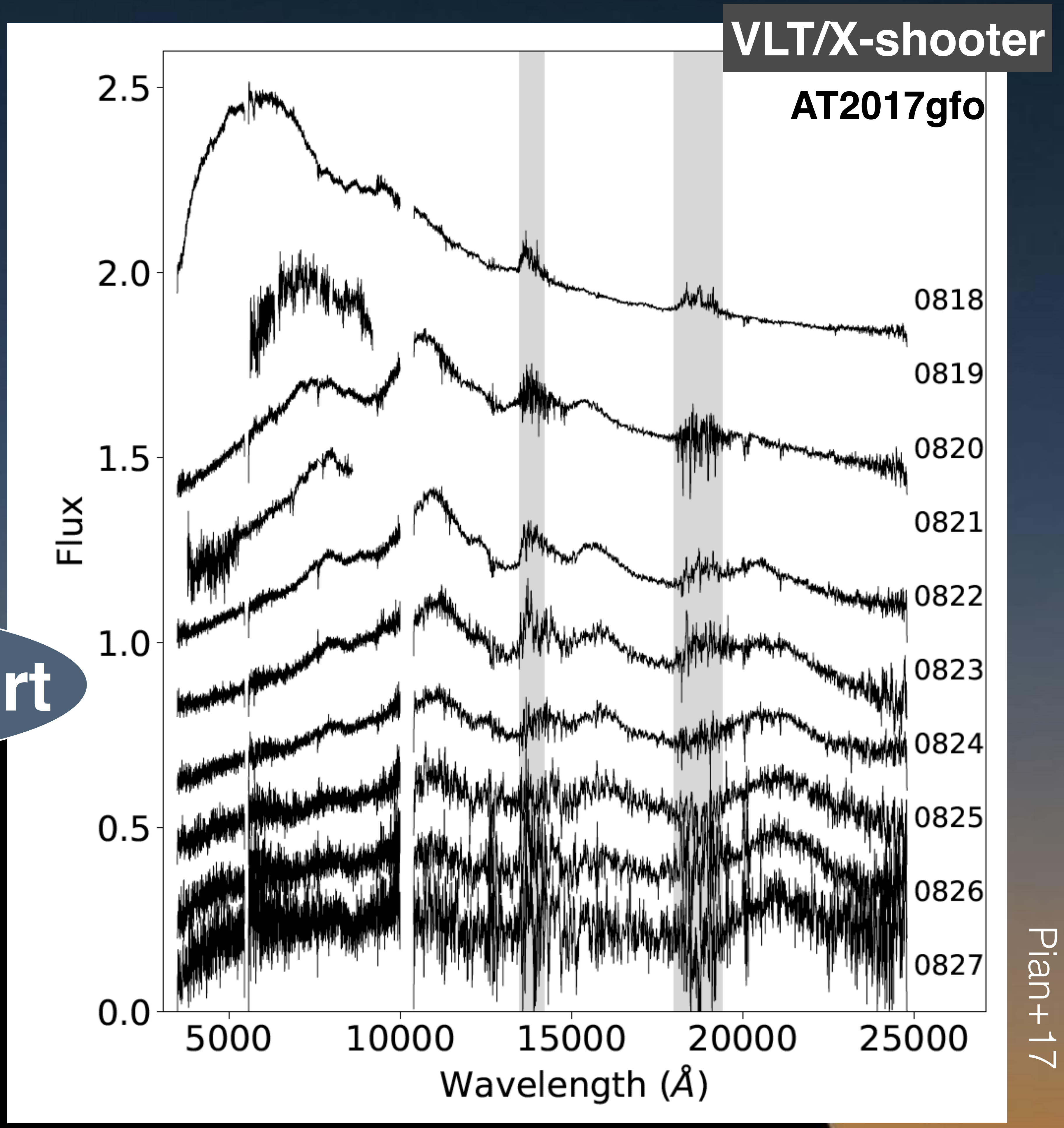
Large field of views and **high sensitivities** will be necessary for the EM follow-up

Photometric observations with facilities like the Vera C. Rubin Observatory, that will scan the sky with high cadence and unprecedented sensitivities, will provide a lot of **counterpart candidates**



Spectroscopy: the bottleneck of next generation GW-MM science

The spectrum of **AT2017gfo**:
important for the study of the physics of the phenomenon,
the environment, heavy elements nucleosynthesis
and for the **KN identification**



Pian+17

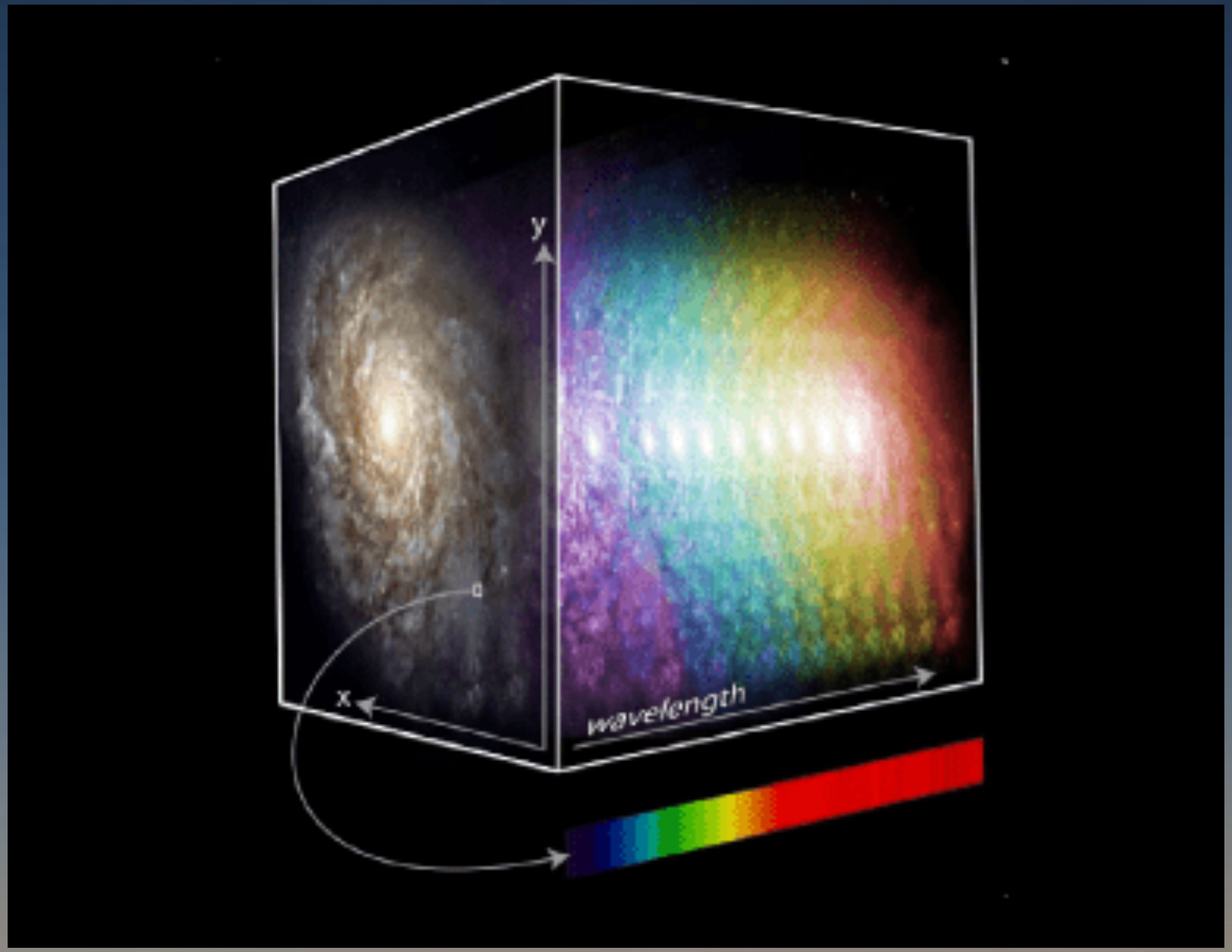
Huge amount of transients in the GW error region → **EM counterpart**

gather the **spectroscopic data** required for their **identification**

The acquisition of **multiple spectra at the same time** can play a key role in identifying and characterising EM counterparts

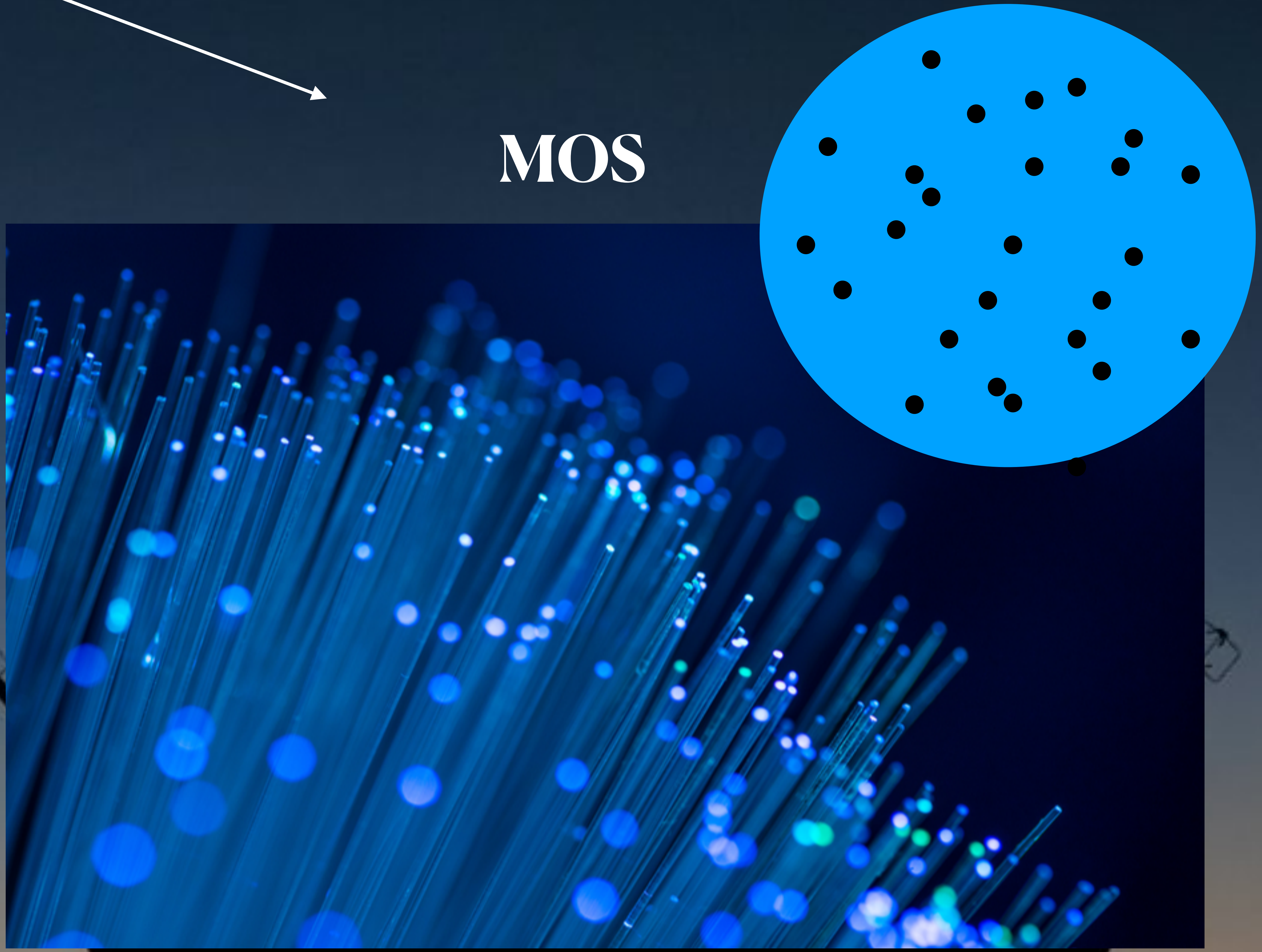
Integral Field and Multi-Object Spectroscopy

IFS



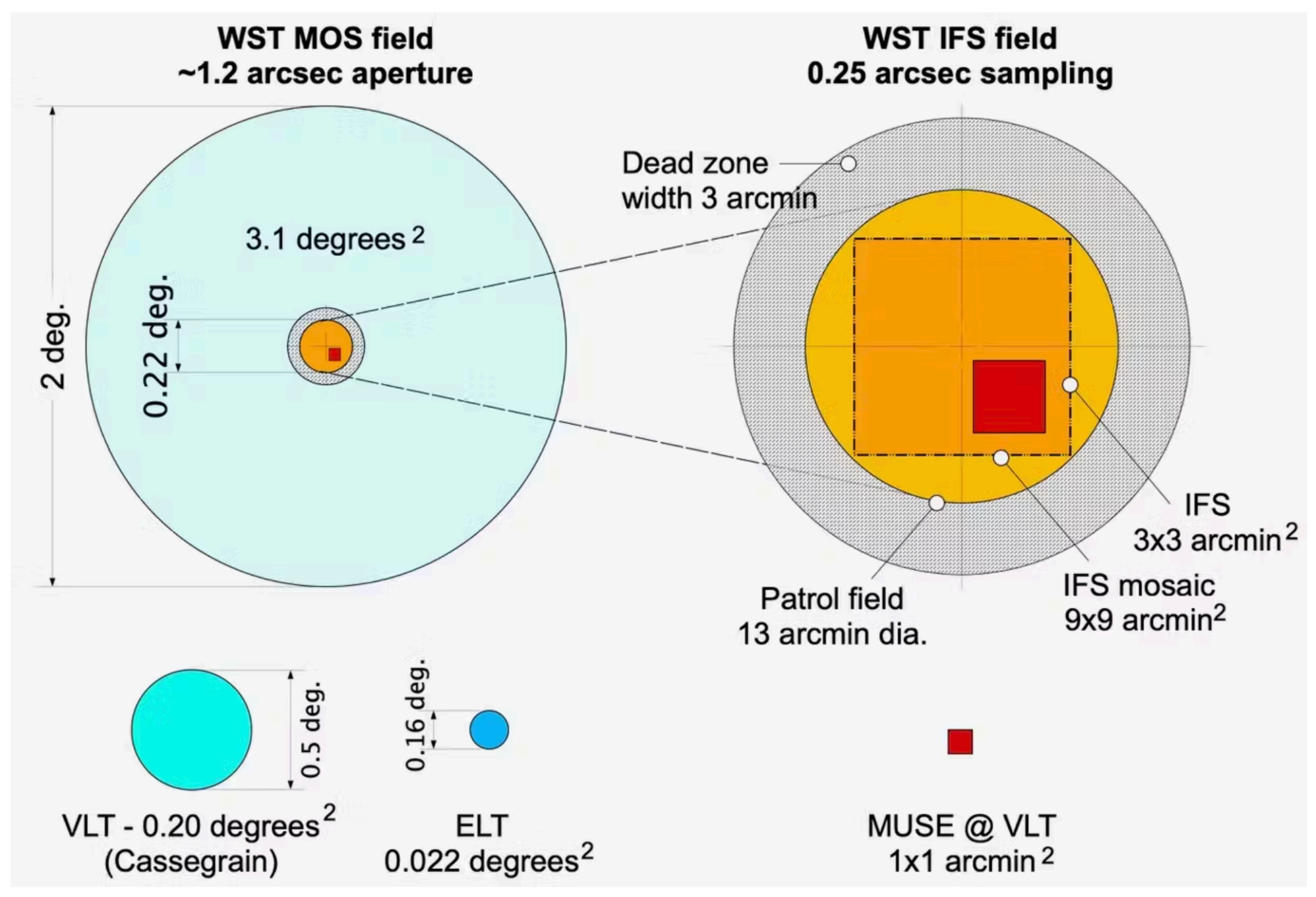
A spectrum for each pixel
of the 2D field image

MOS

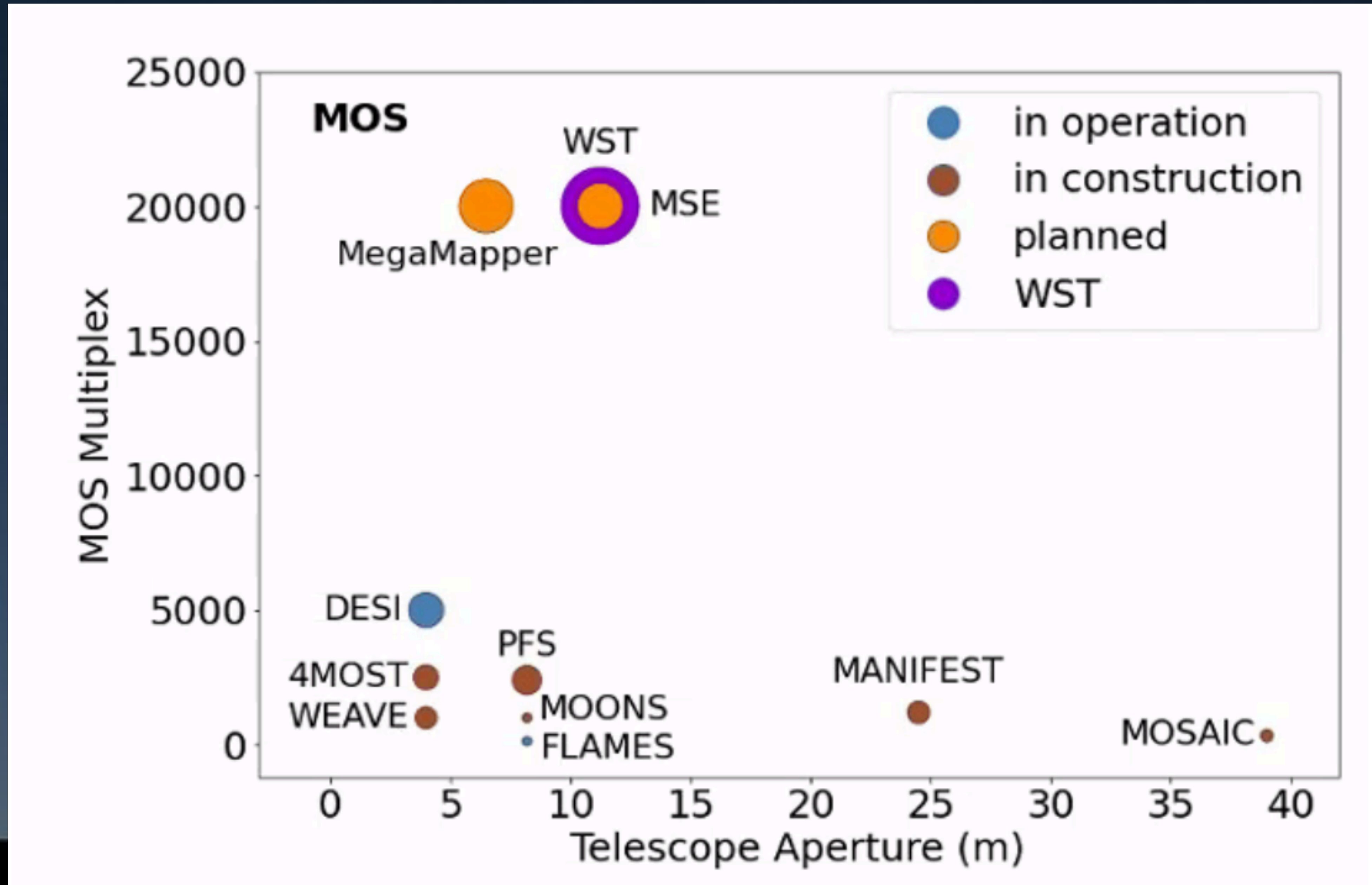


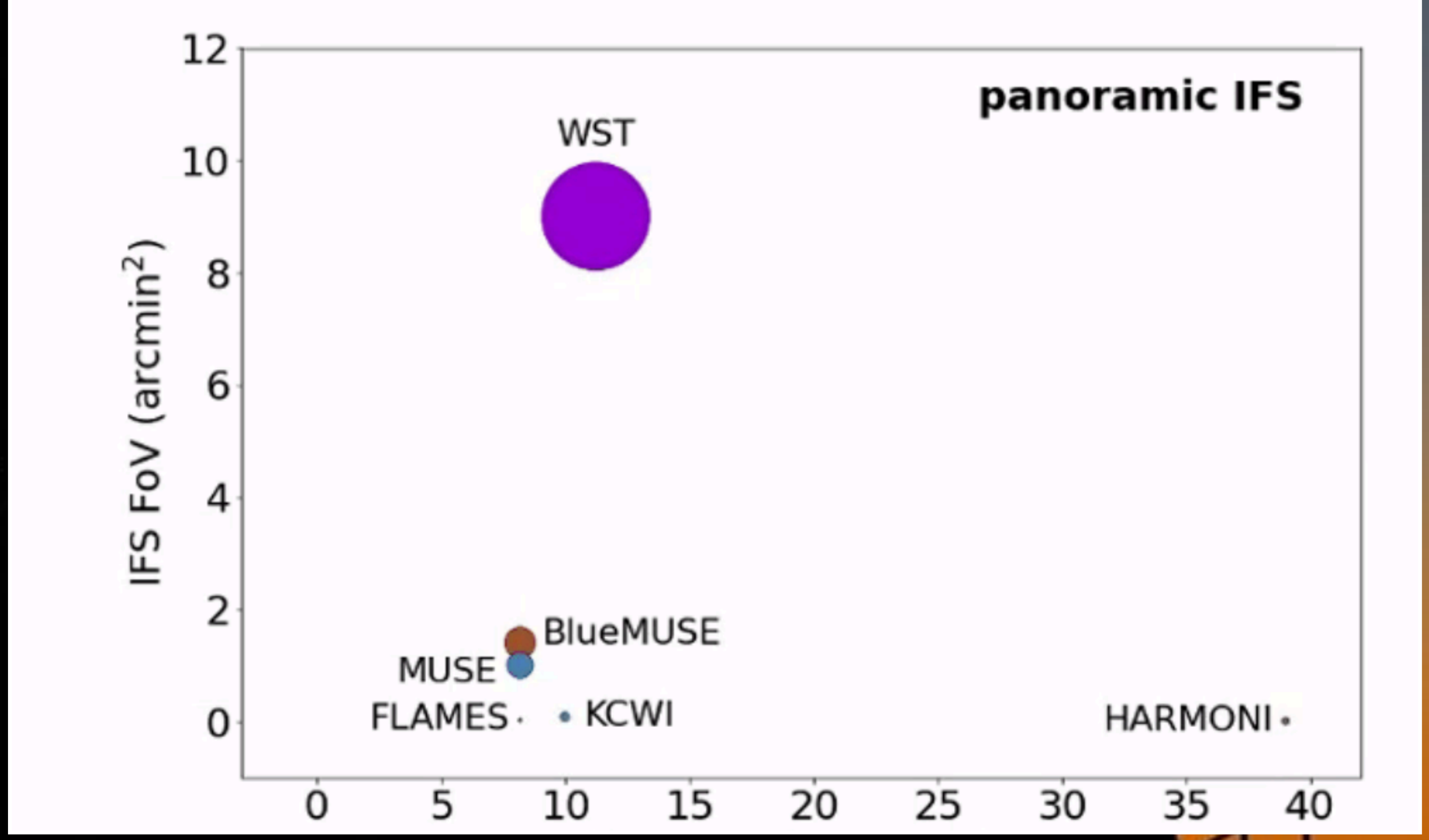
Fibres positioned on the localisation of
the sources of interest

IFS and MOS with the Wide-field Spectroscopic Telescope



PI: Roland Bacon **(CRAL)**





- To be realised in the 2030/40s
- **10m** primary mirror
- **Large field of view** and high **multiplexing**
- Simultaneous **IFU** and **MOS**

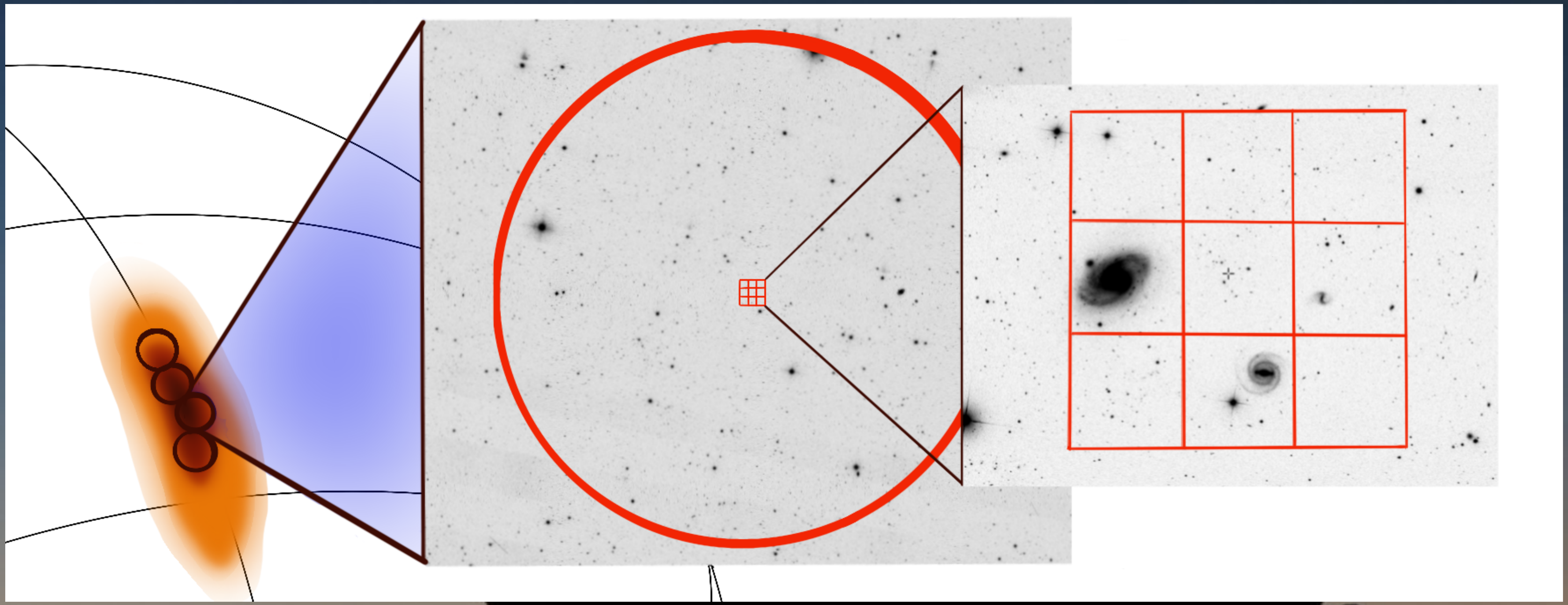
ET-WST synergy

Development of the observing strategy

within the WST Time Domain Working Group and the Division 4 (Multimessenger Observations) of the ET OSB

Credits: WST White Paper

Stand-alone scenario
Galaxy targeted search with IFS and MOS within the GW signal error region



Synergy with optical-NIR photometric observations
IFS and MOS used to target the counterpart candidates found by optical-NIR surveys (Vera Rubin)

How many galaxies will be found in the "comoving error volume" of ET BNS?

What are the properties of ET BNS EM counterparts that are detectable with WST?

ET-WST synergy

GSSI group

GS
SI

ET BNS populations

GS
SI

KN + GRB emission

WST

Detectability and **characterisations** of ET BNS counterparts with WST

Analyse how the results depend on the **intrinsic properties** of NS

Analyse how the results depend on the **observable properties** of the BNS population

ET-WST synergy

GSSI group

G	S
S	I

ET BNS populations

G	S
S	I

KN + GRB emission

WST

Detectability and **characterisations** of ET BNS counterparts with WST

Analyse how the results depend on the **intrinsic properties** of NS

NSs equation of state: APR4 and BLh

NSs mass distribution: gaussian and uniform

Analyse how the results depend on the **observable properties** of the BNS population

redshift

sky localisation

viewing angle

magnitude

ET-WST synergy

Simulations

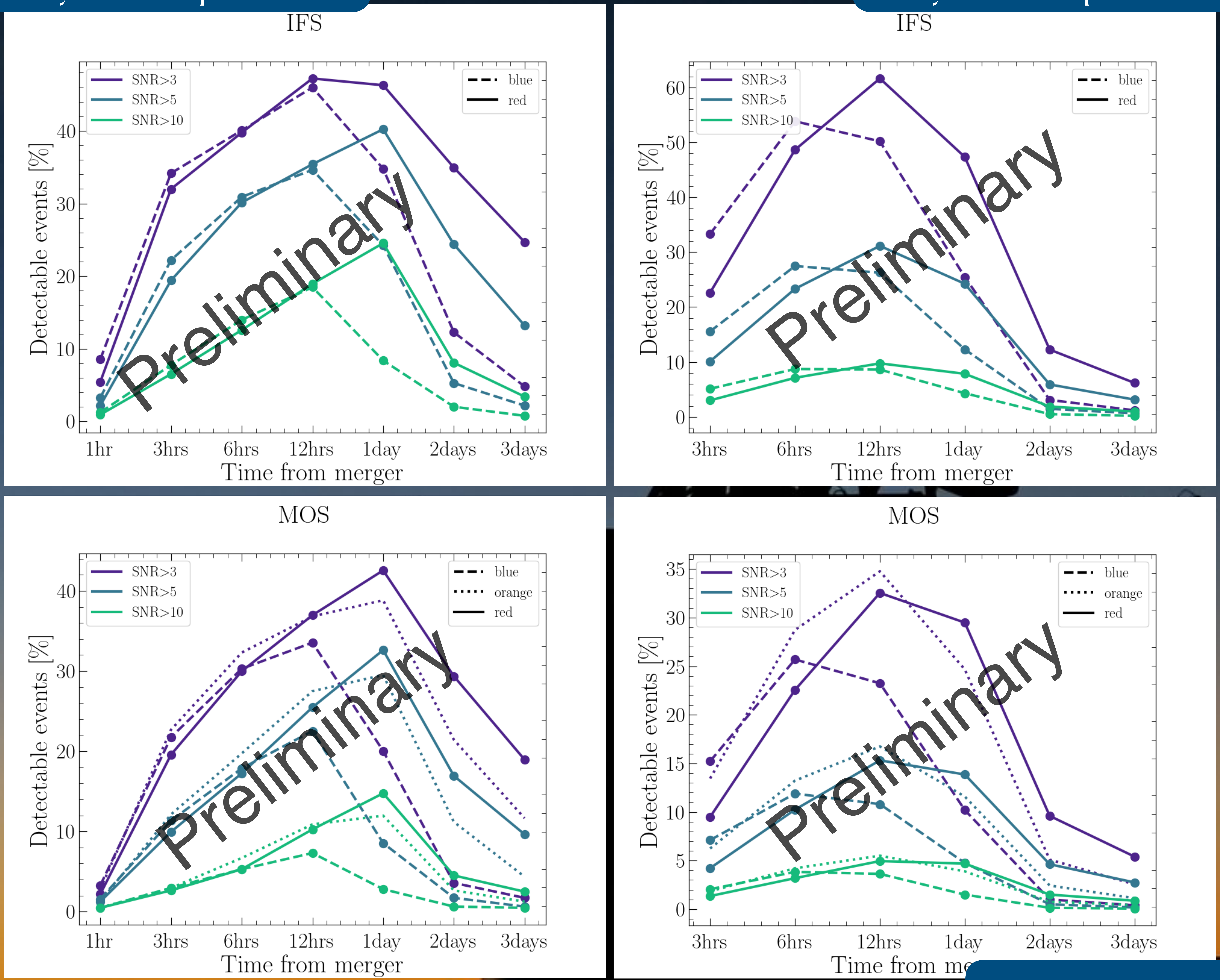
Percentage of detectable KN at different times post-merger

1 year of ET operations

10 years of ET operations

AT2017gfo KN model

KN theoretical models



BLh gaussian

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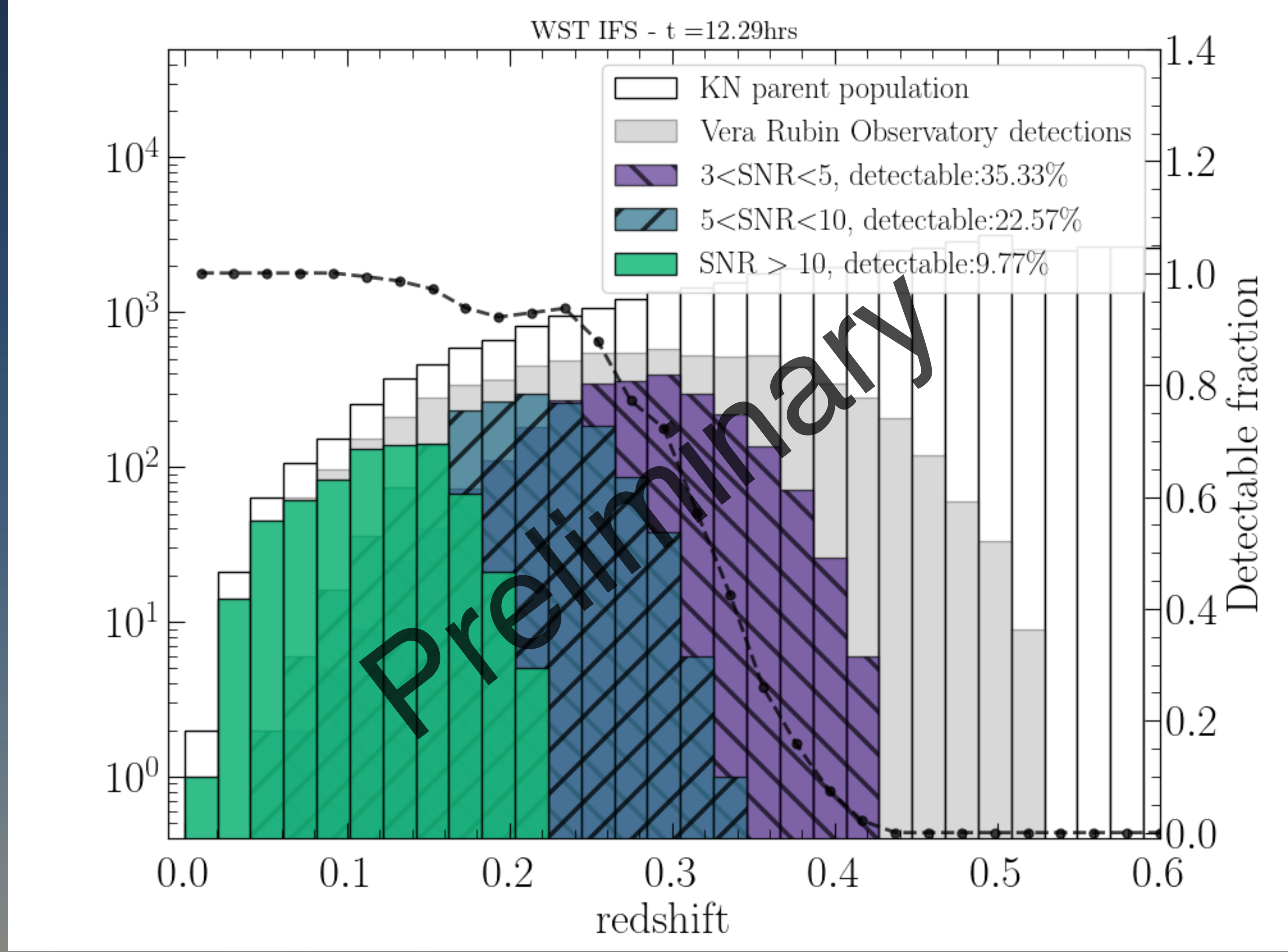
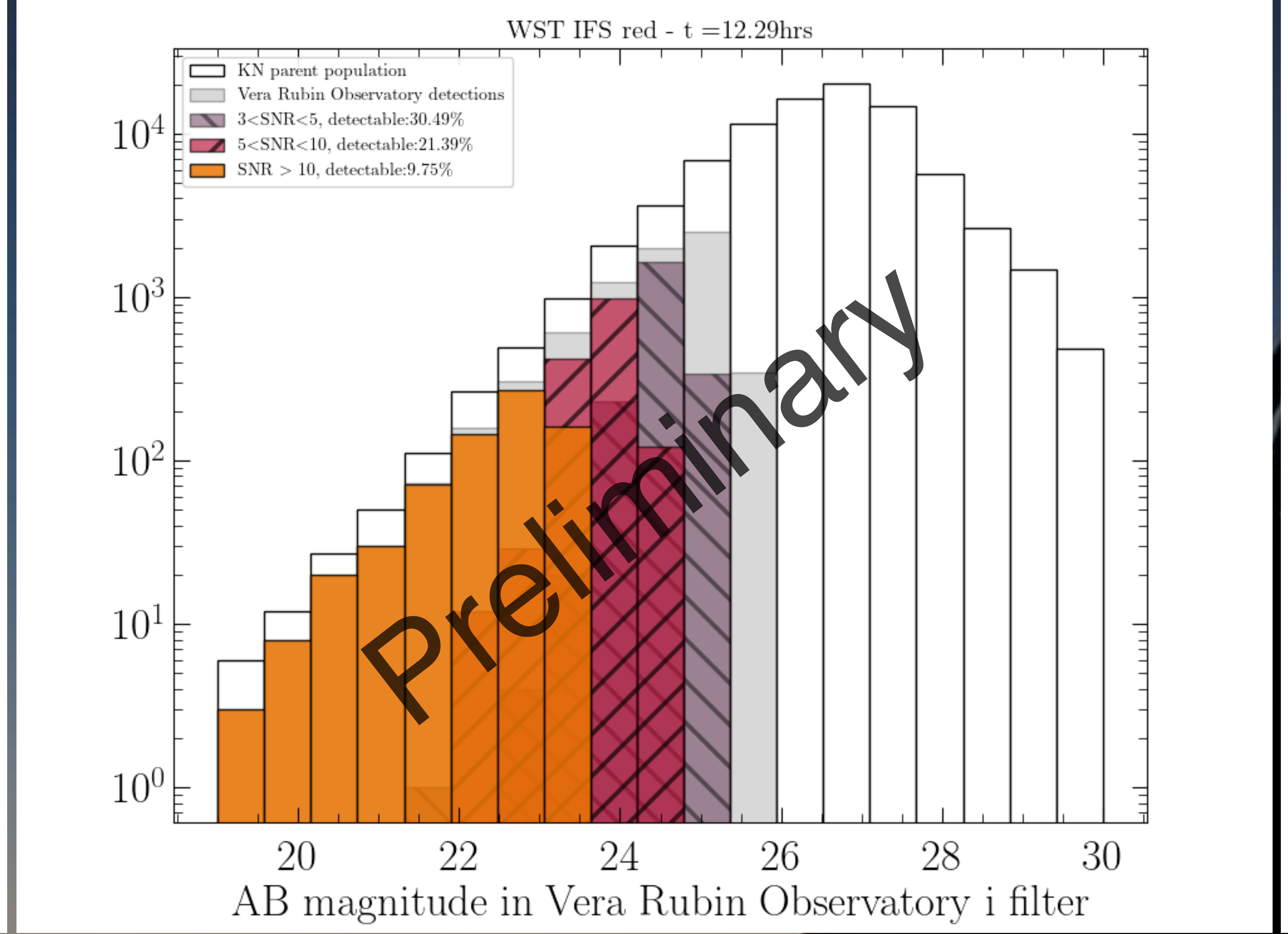
ET-WST synergy

Simulations

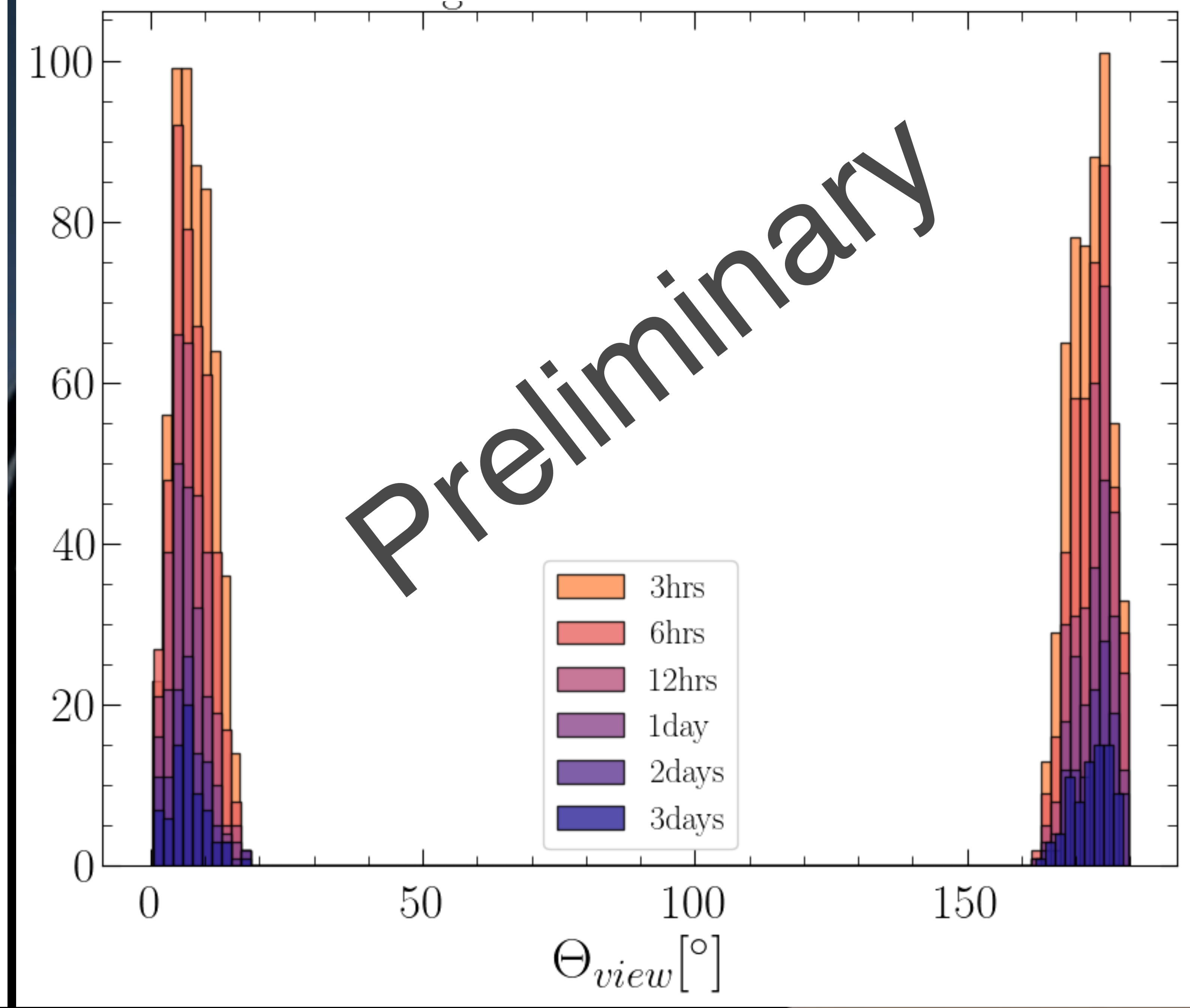
Detections horizon



Magnitude limits



Afterglow contribution



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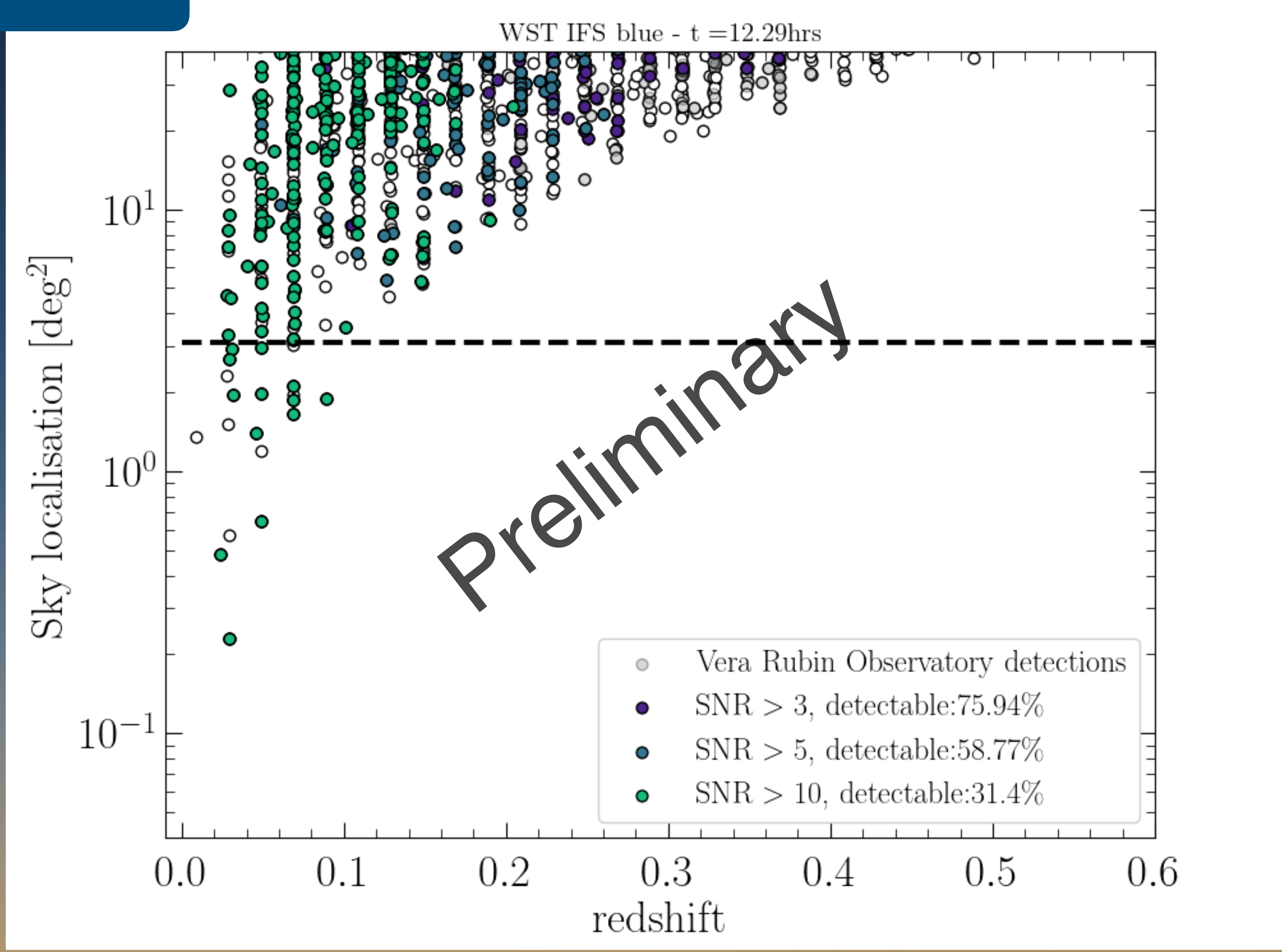
White: ET+CE **BNS** detections in **10 years** of operations
Grey: Vera Rubin Observatory **KN** detections
Colored: WST **KN** detections

Colored: Sources where the afterglow outshines the KN among WST detections with the IFS red arm

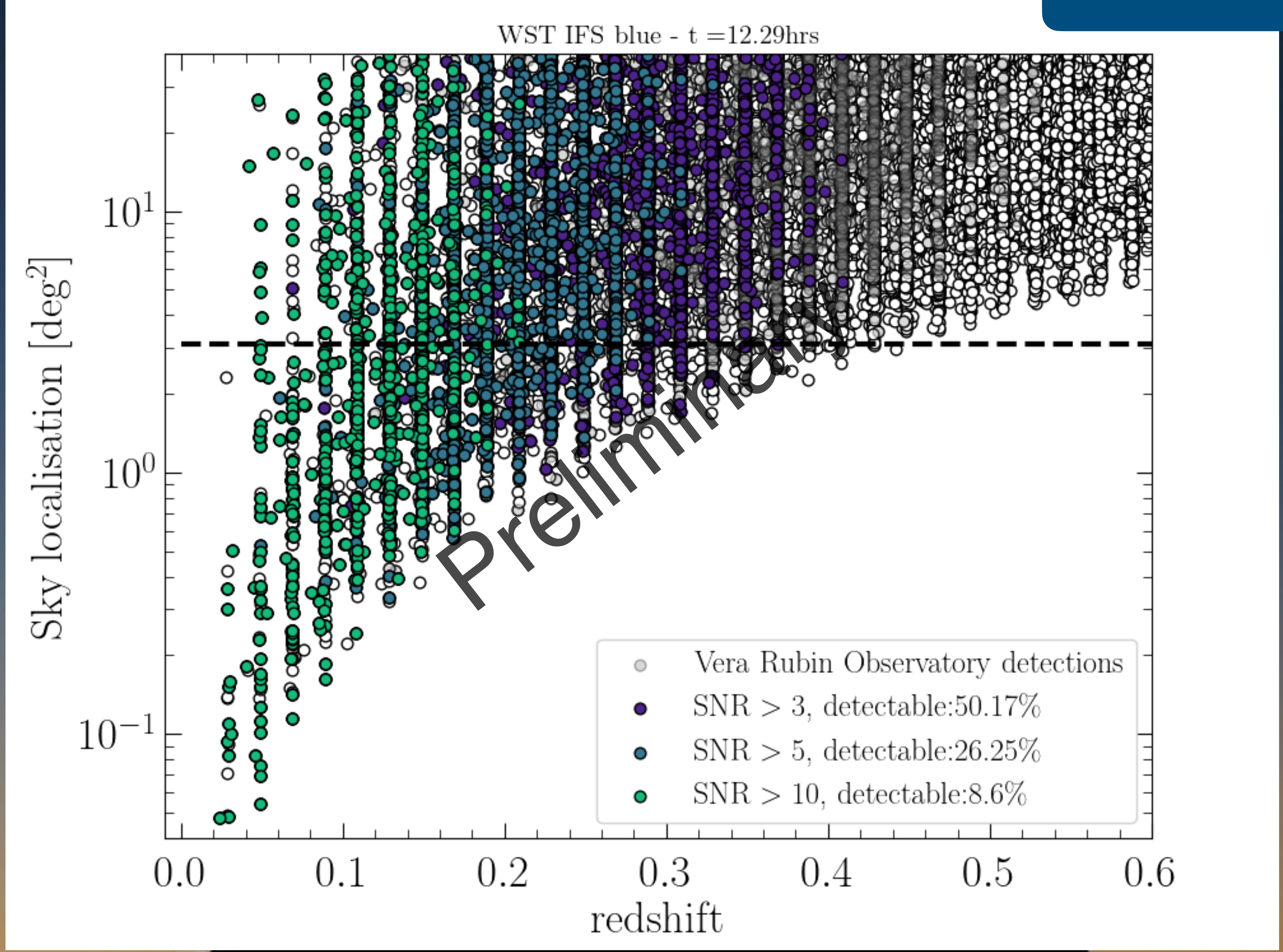
ET-WST synergy

Simulations

ET



ET+CE



Bisero et al. 2025 in prep

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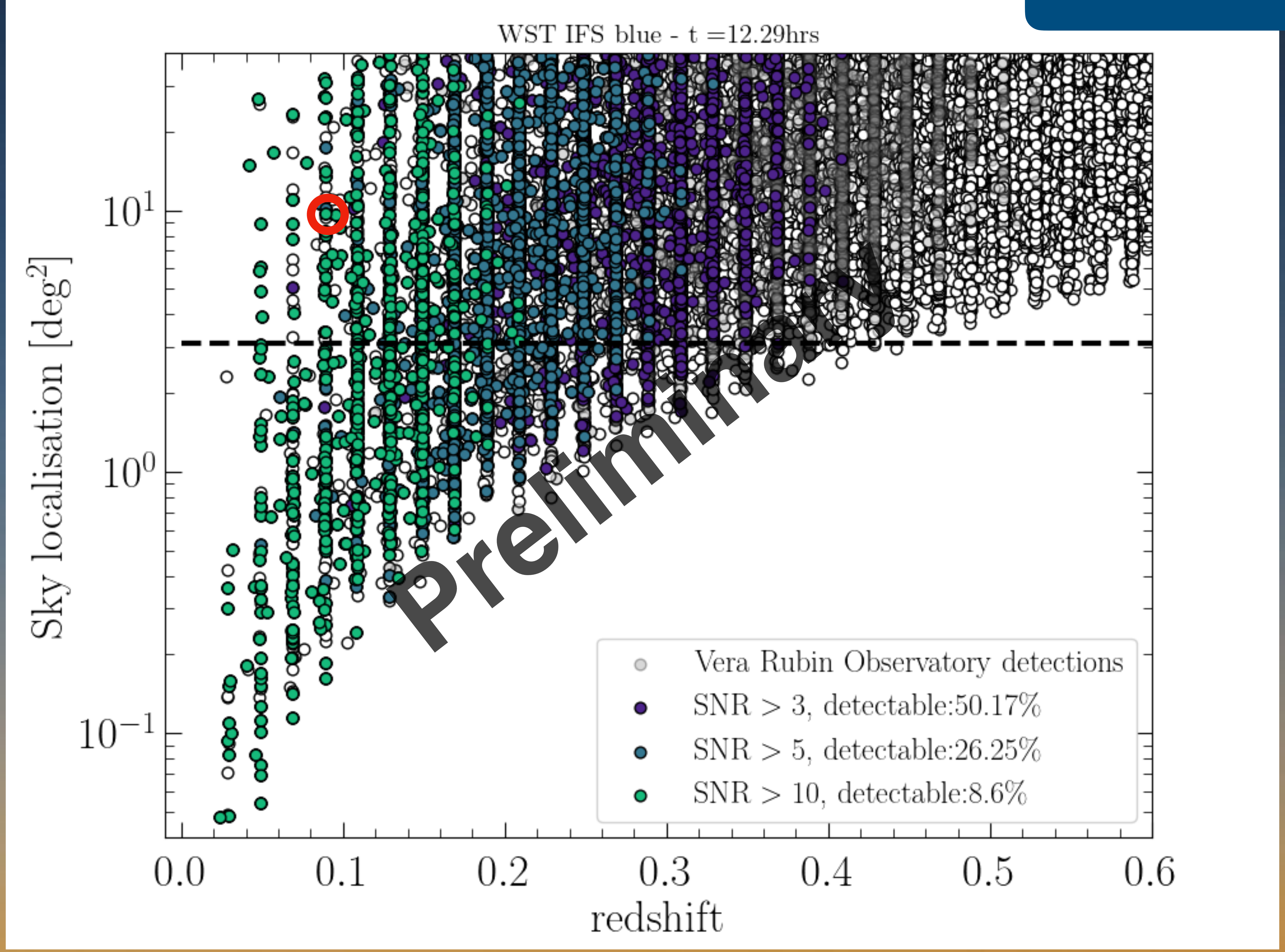
ET-WST synergy

Simulations

ET+CE



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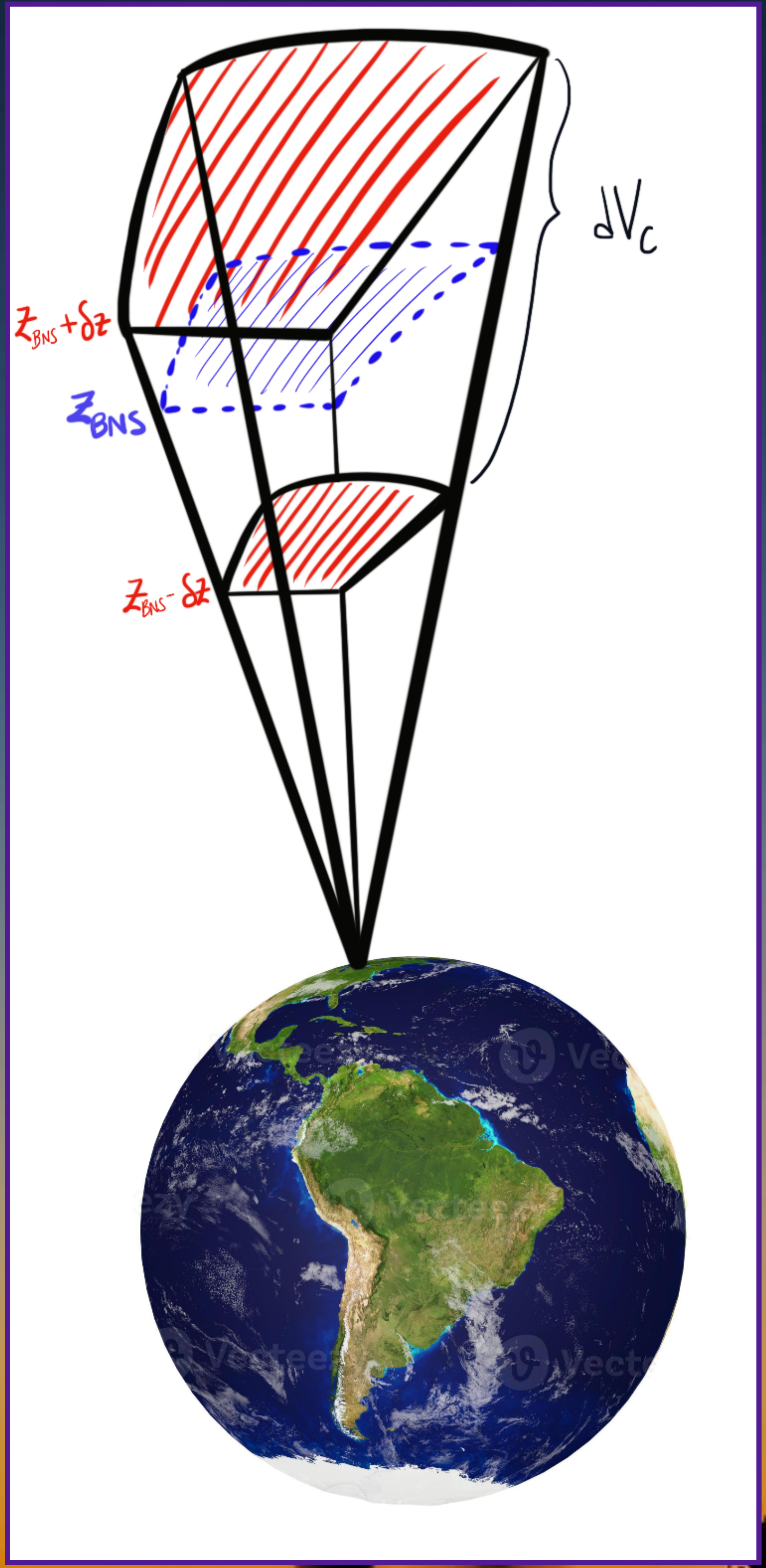
GW alert :
estimate of **luminosity distance** and **sky localisation**

How many **galaxies** can be found in the **comoving error volume** of each BNS?

ET-WST synergy

Simulations

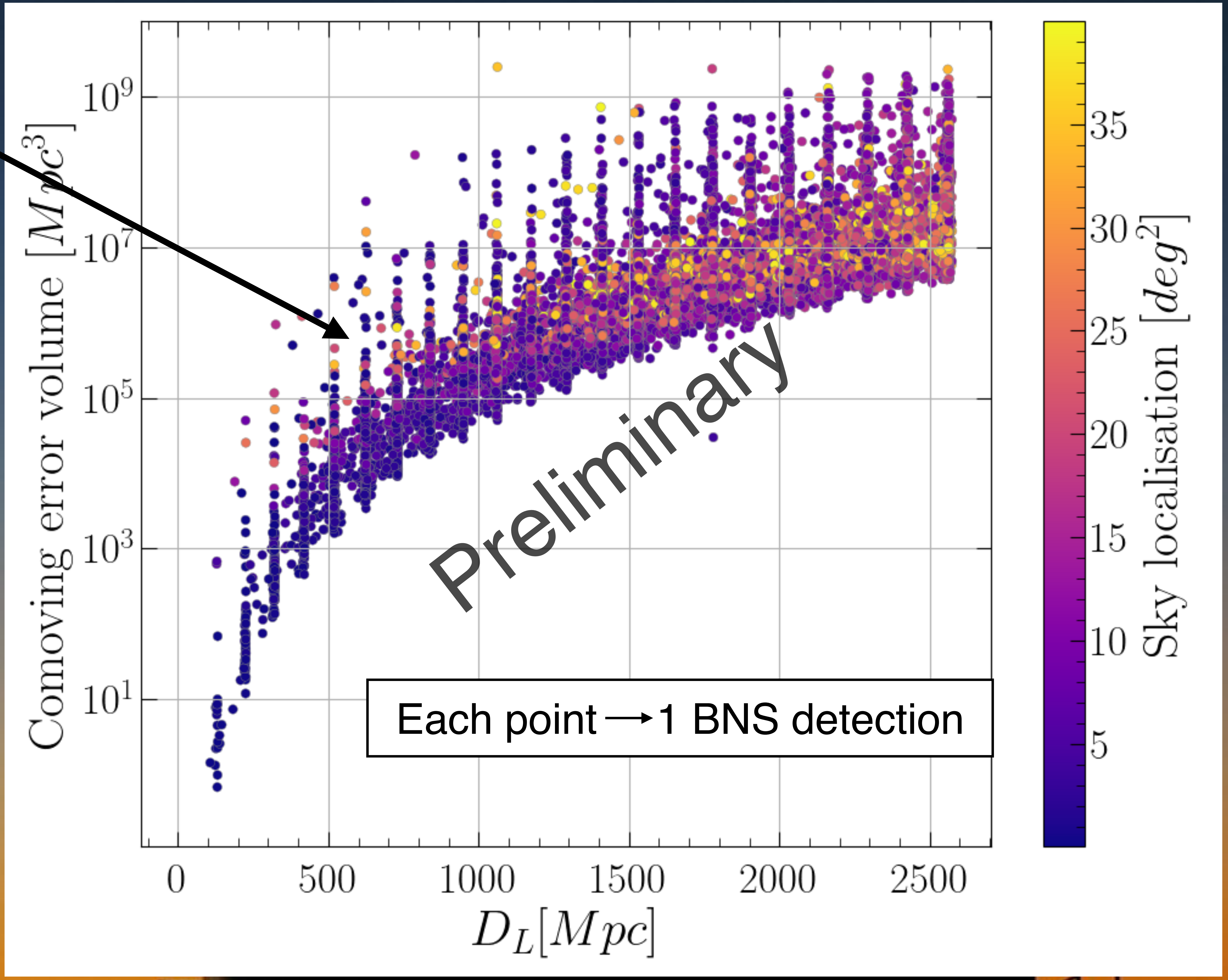


$$V_C \sim \Omega \int_{z-\delta z}^{z+\delta z} \frac{d^2 V_C}{d\Omega dz} dz$$

$$D_L - \Delta D_L \rightarrow z - \delta z$$

$$D_L + \Delta D_L \rightarrow z + \delta z$$

Comoving Error Volume



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ET-WST synergy

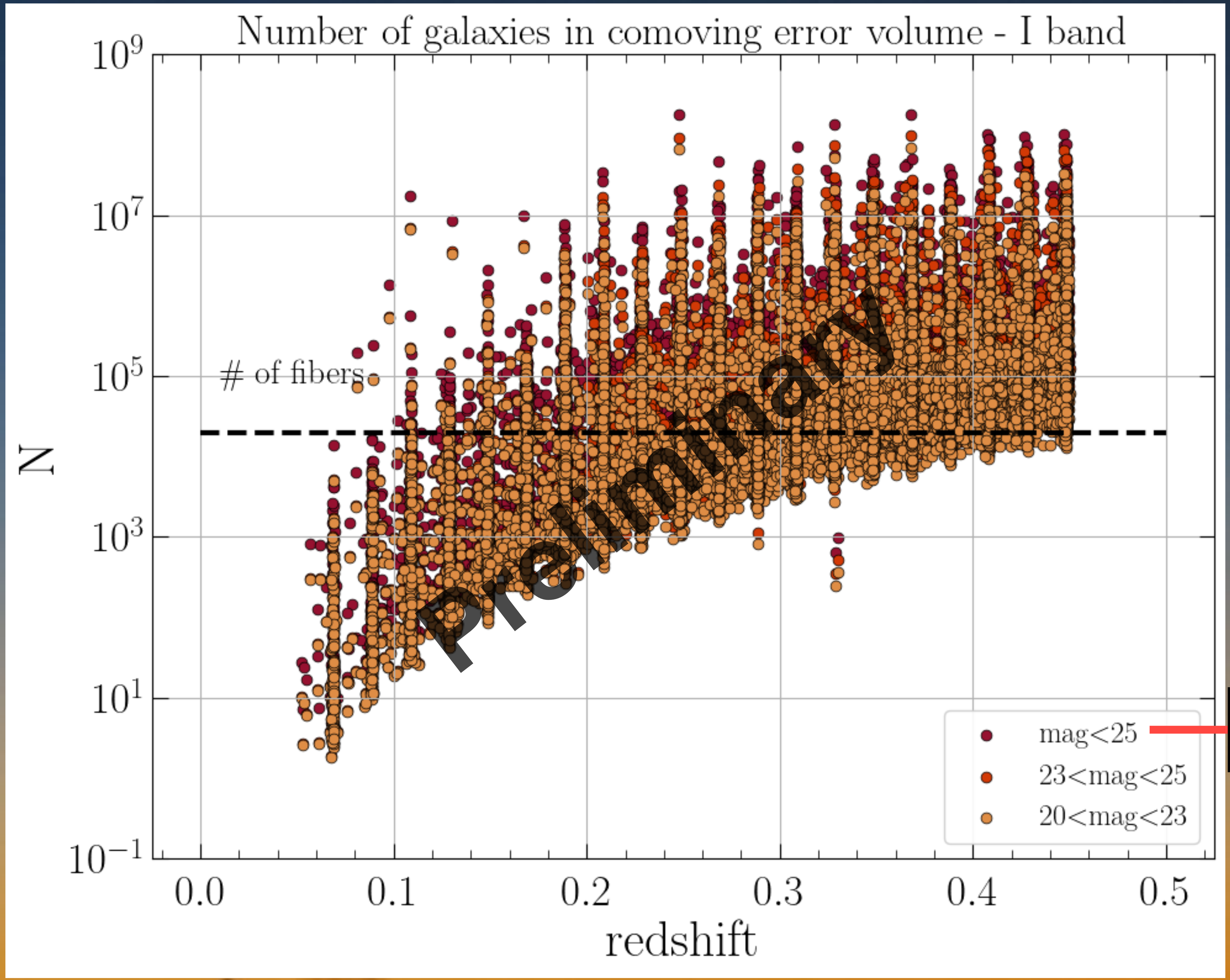
Simulations

Schechter function parameters from Ilbert et al. 2005

Galaxy luminosity function integrated over different magnitude intervals, then multiplied by the comoving error volume

$$n_{m_1<m<m2} = \int_{m_1}^{m_2} \Phi(m)\, dm$$

$[Mpc^{-3}]$ $[mag^{-1}Mpc^{-3}]$



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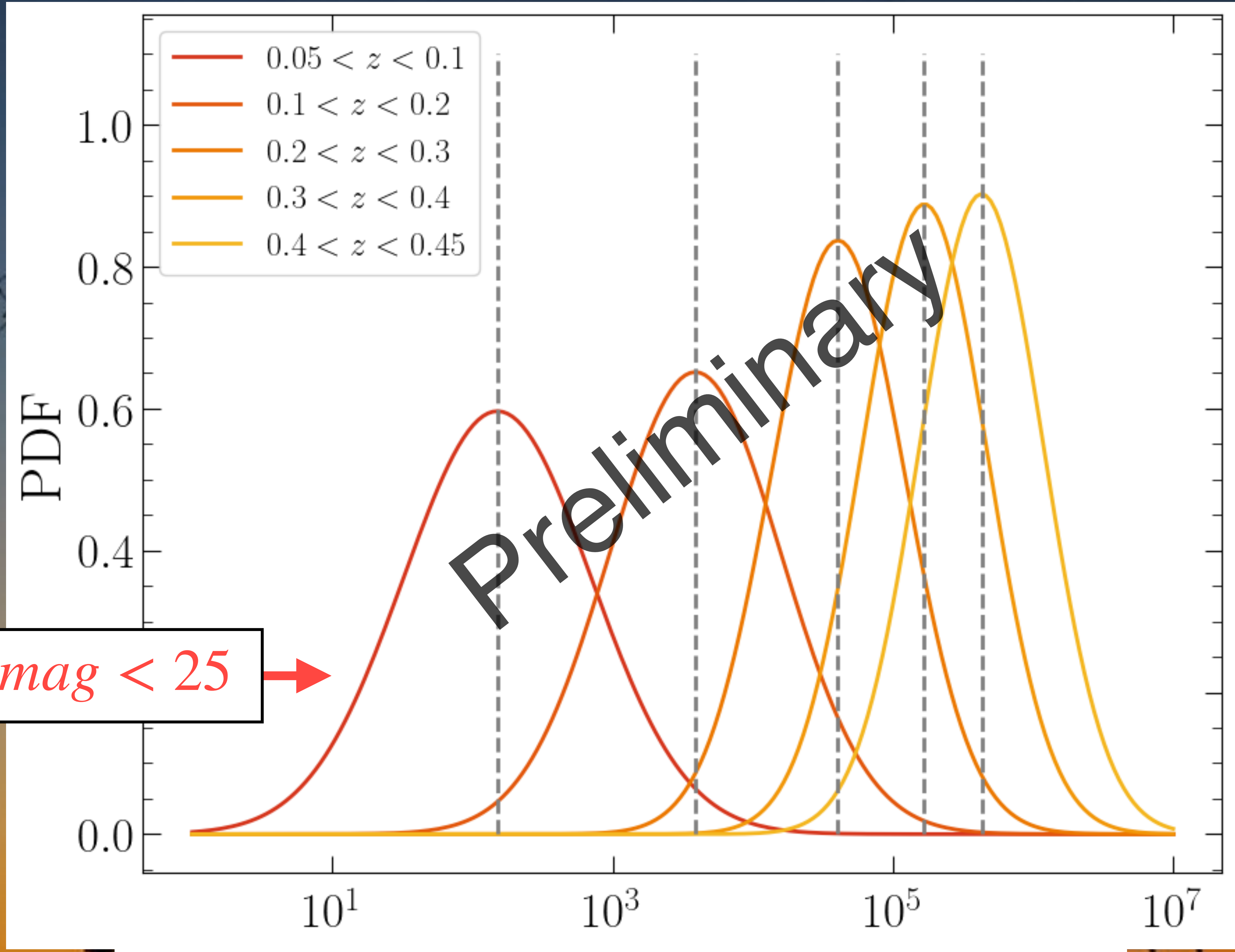
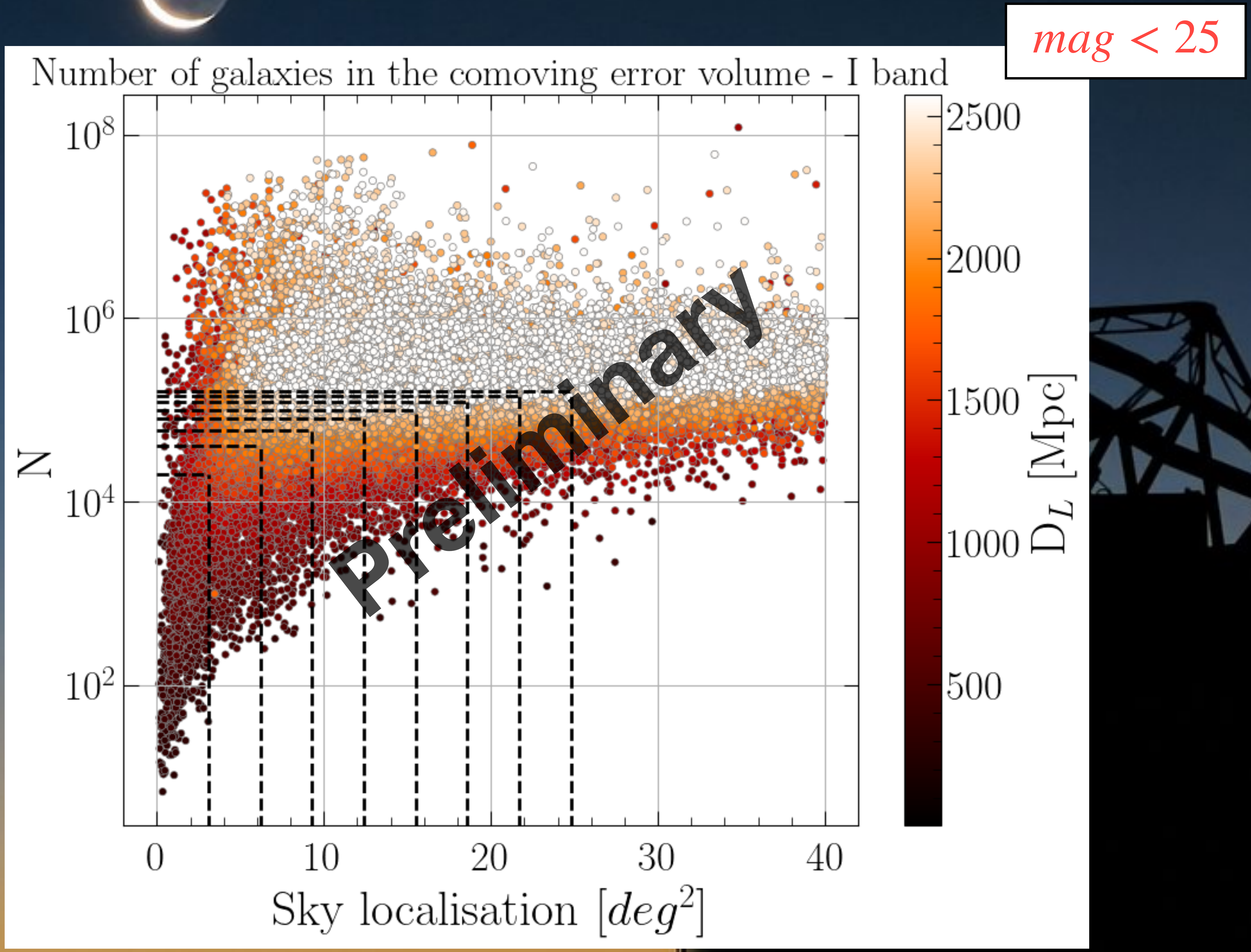
mag < 25



Number of galaxies in the comoving error volume

ET-WST synergy

Galaxies in the BNS comoving volume



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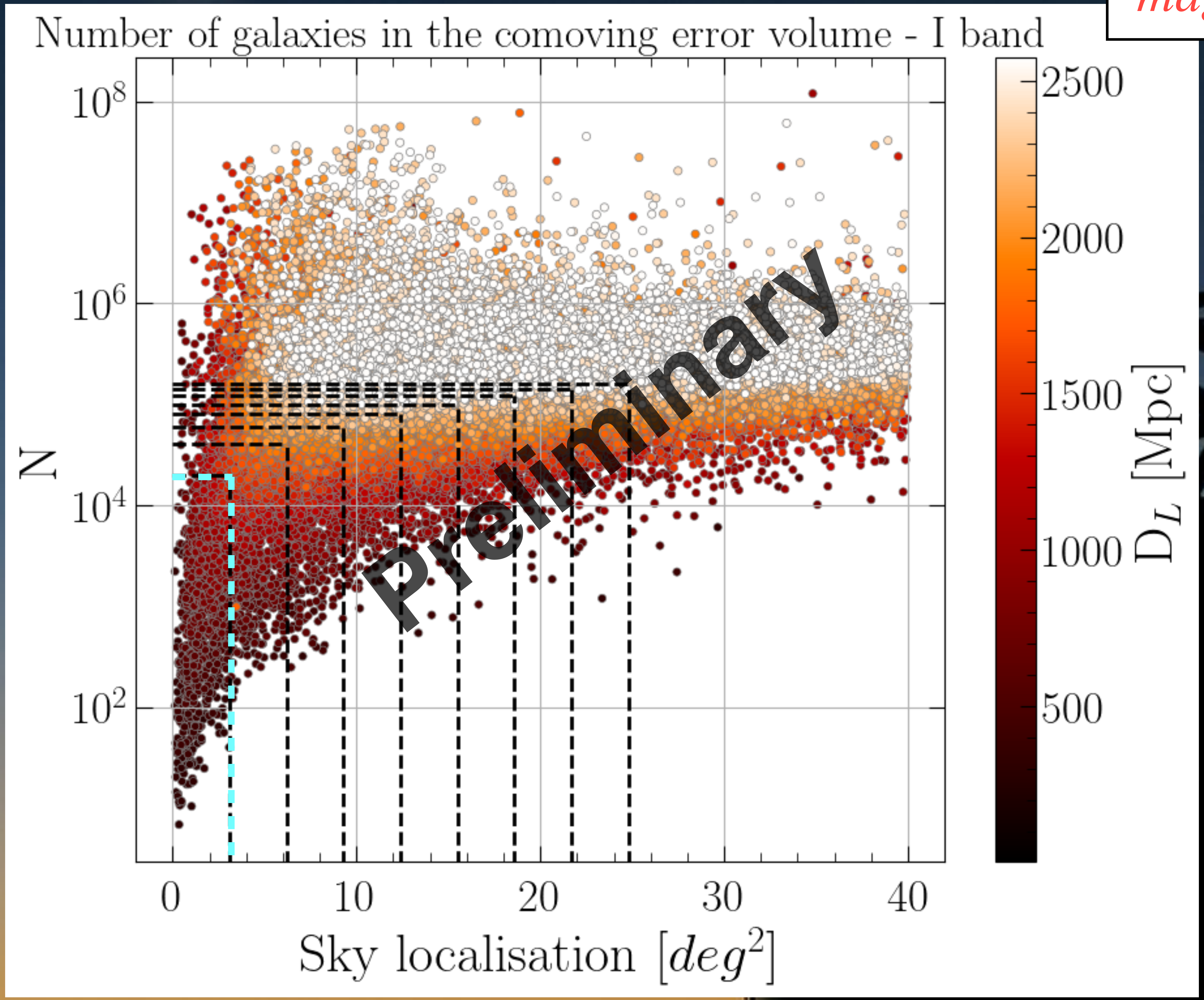
ET-WST synergy

Galaxies in the BNS comoving volume

1h

$mag < 25$



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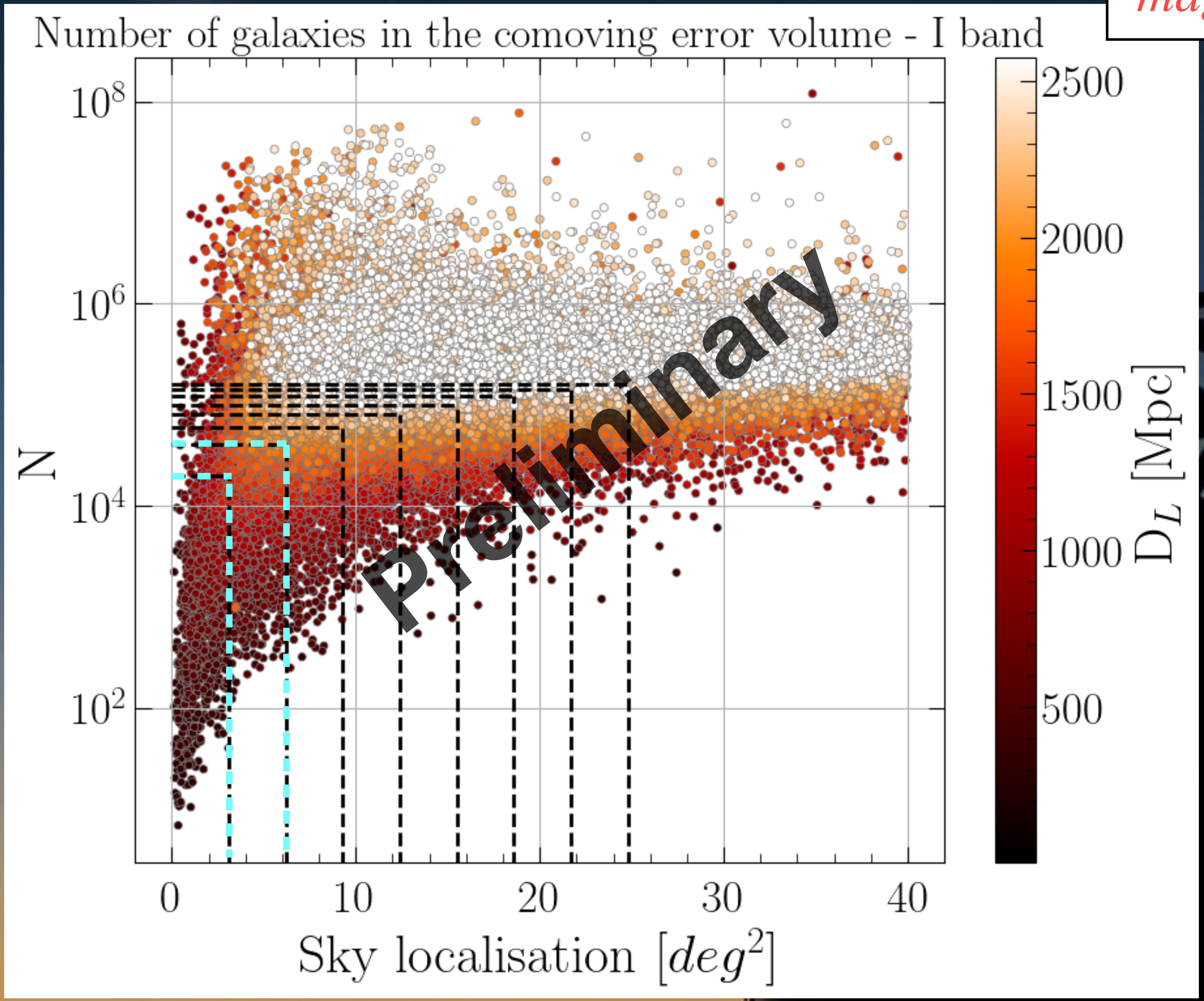
ET-WST synergy

Galaxies in the BNS comoving volume

2h

mag < 25



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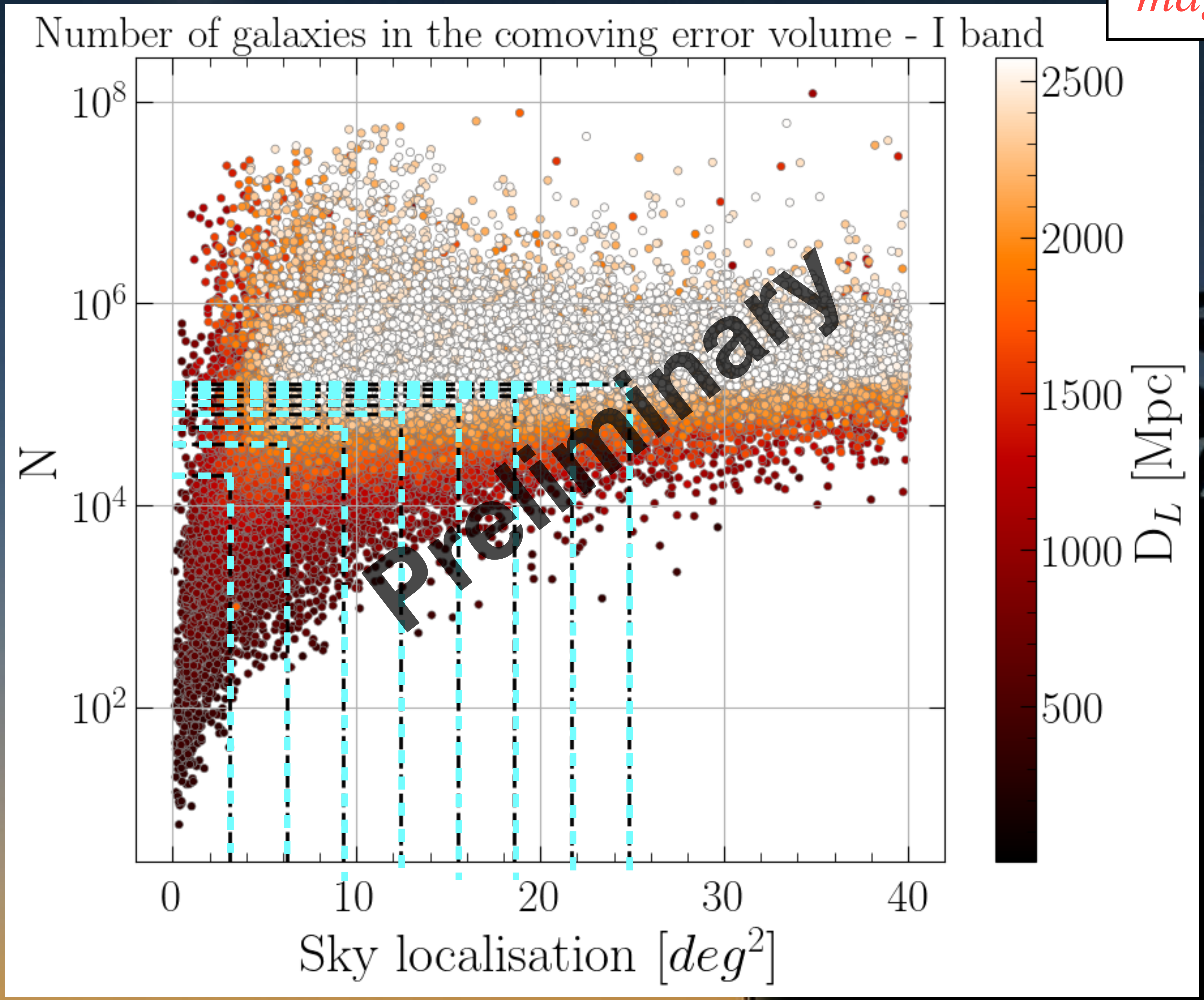
ET-WST synergy

Galaxies in the BNS comoving volume

8h

mag < 25

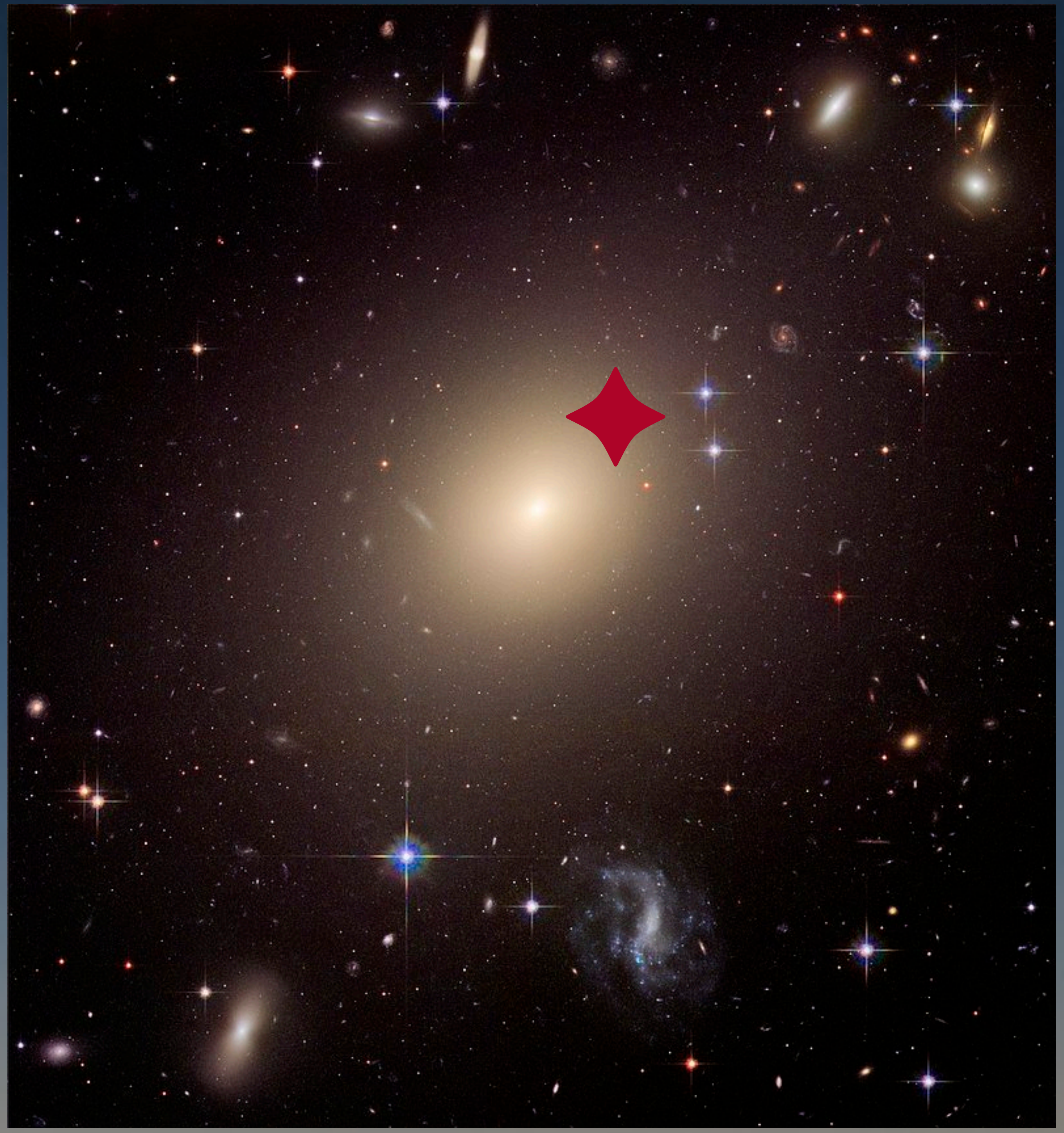


Bisero et al. 2025 in prep

ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:



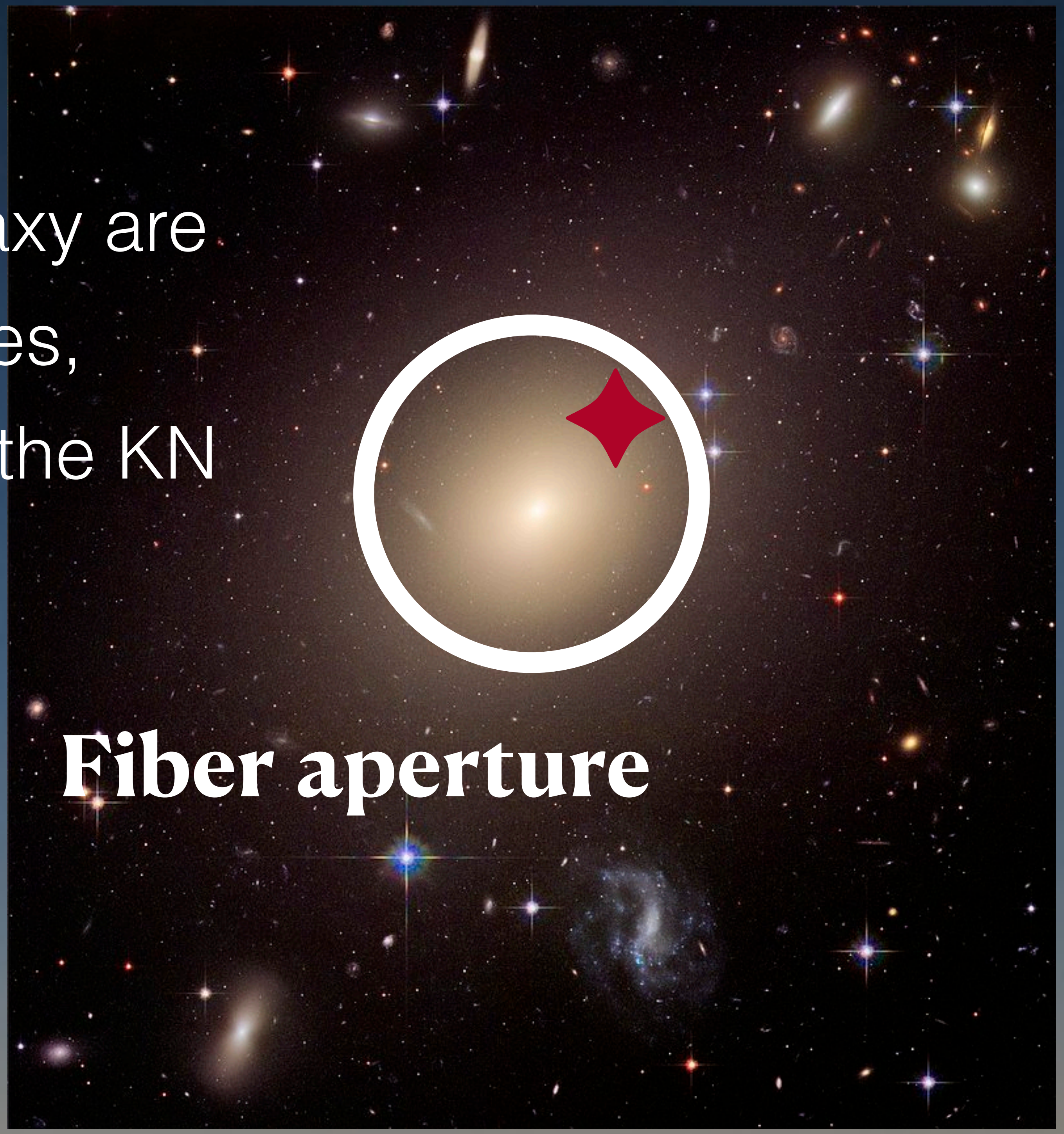
Credits: HST

ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:

The KN and its host galaxy are superposed point sources, with the host outshining the KN



Credits: HST

ET-WST synergy

Galaxies in the BNS comoving volume

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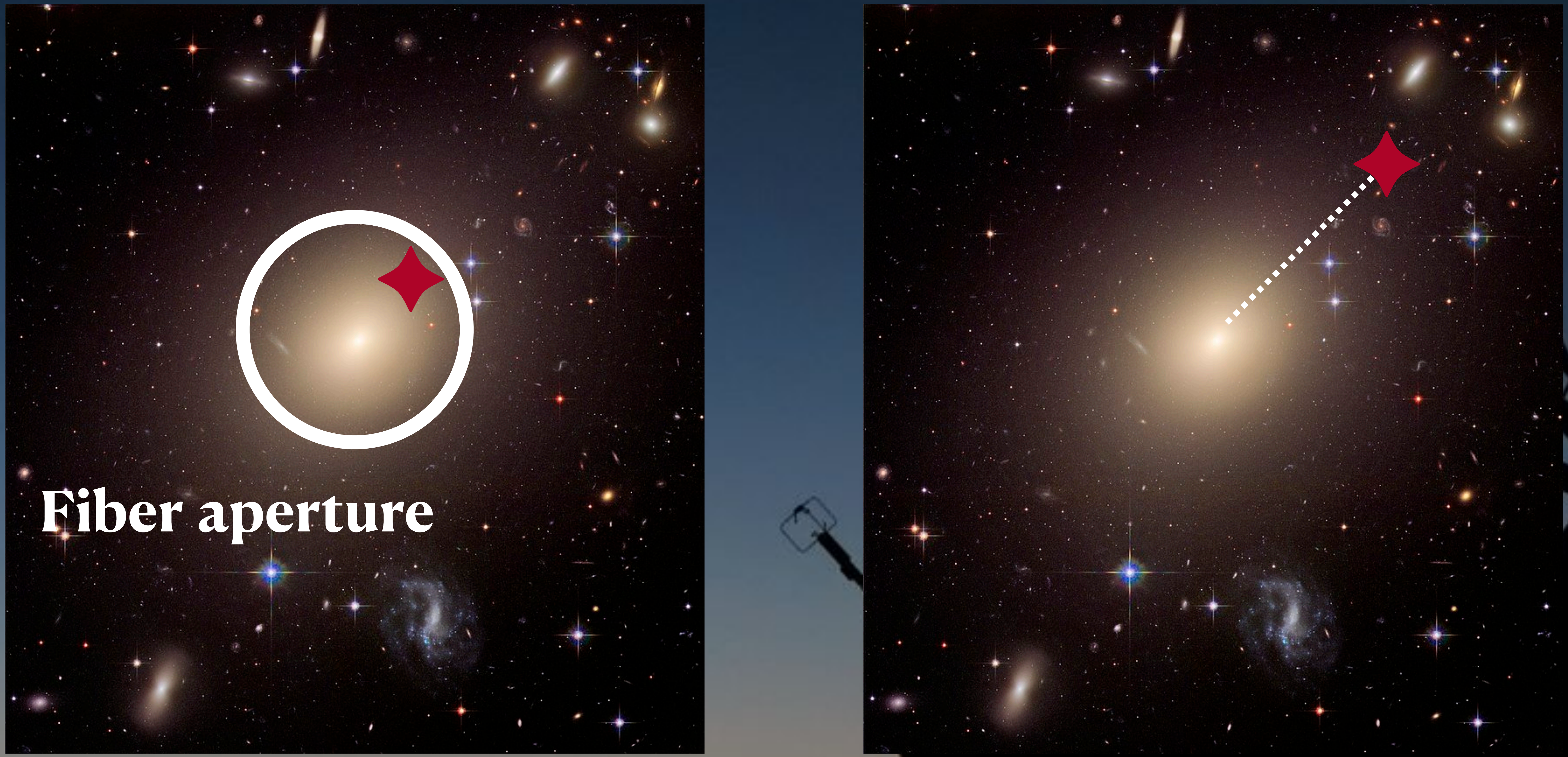
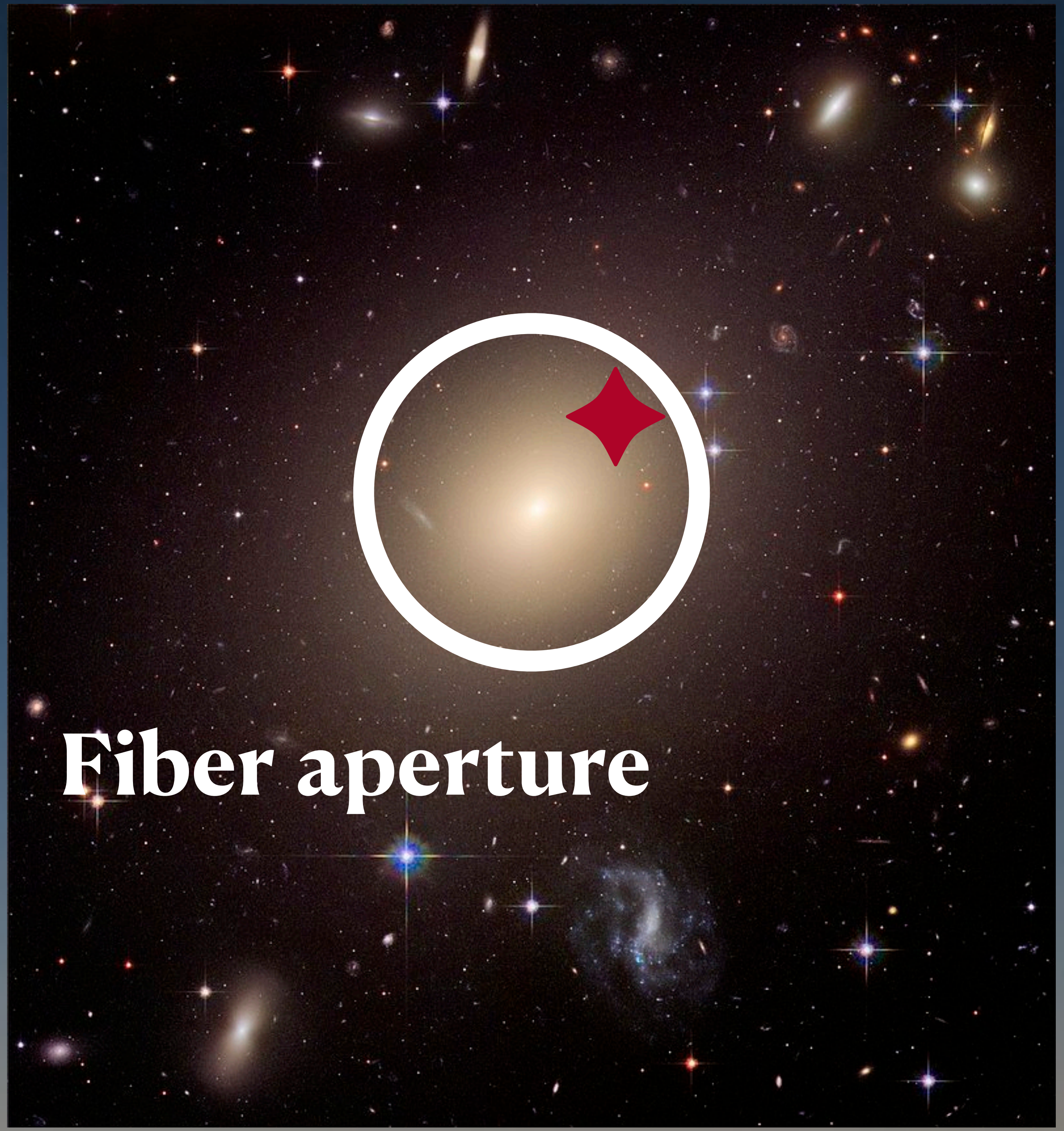


Credits: HST

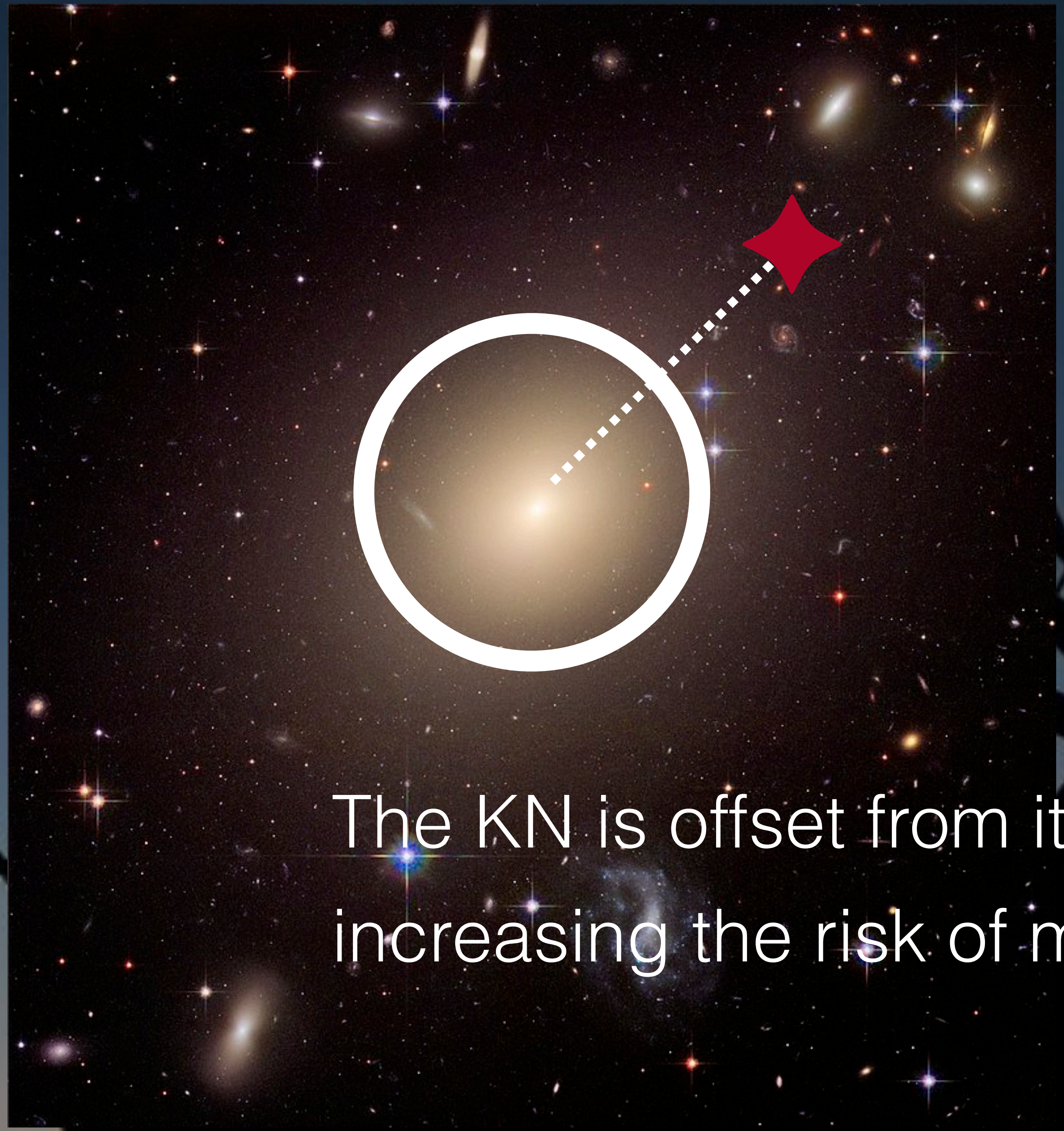
ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:



Credits: HST

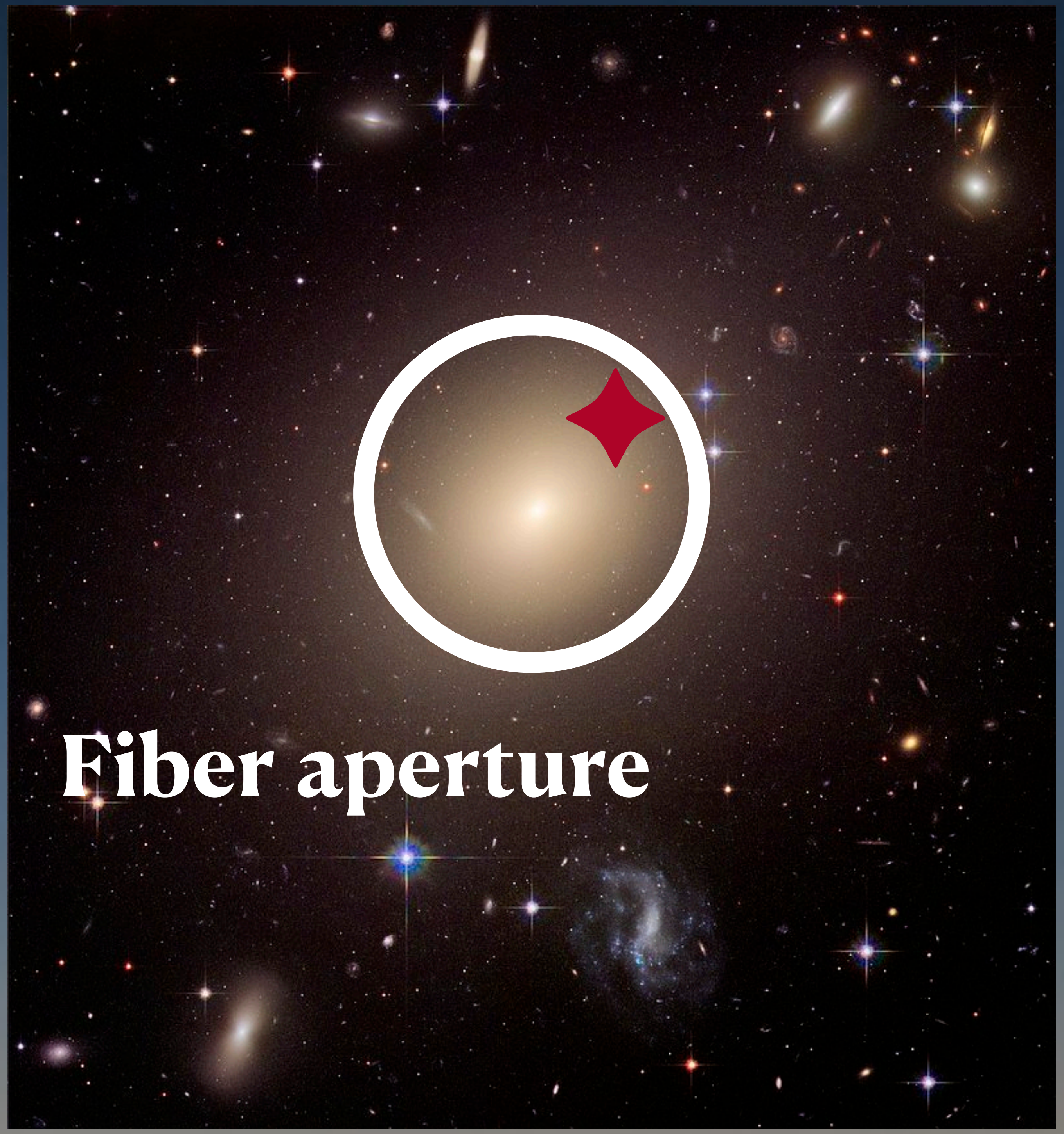


The KN is offset from its host galaxy, increasing the risk of missing the detection

ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:



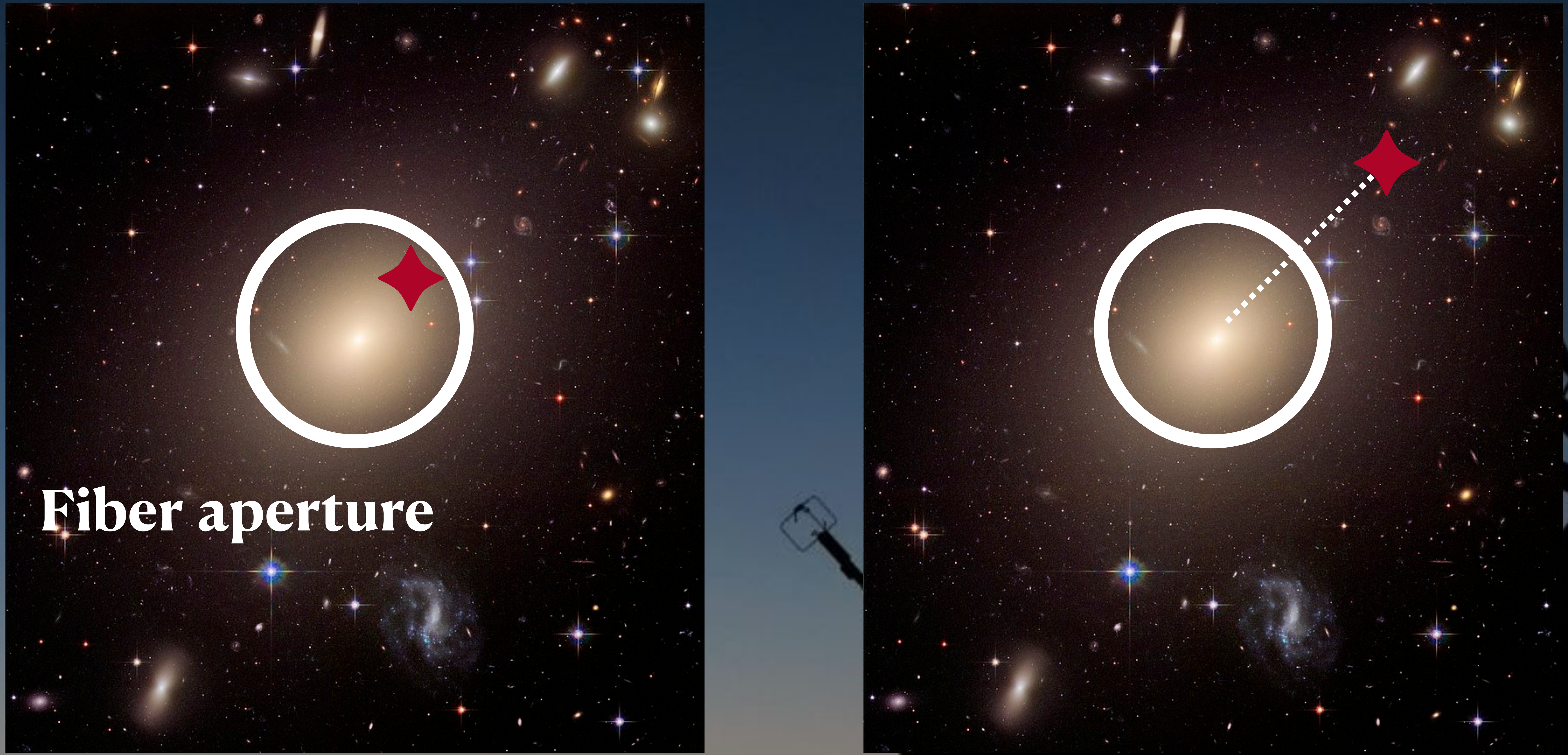
Credits: HST

Mini-IFUs with fibres bundles would be great for handling these cases

ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:



Credits: HST

Possible solutions:

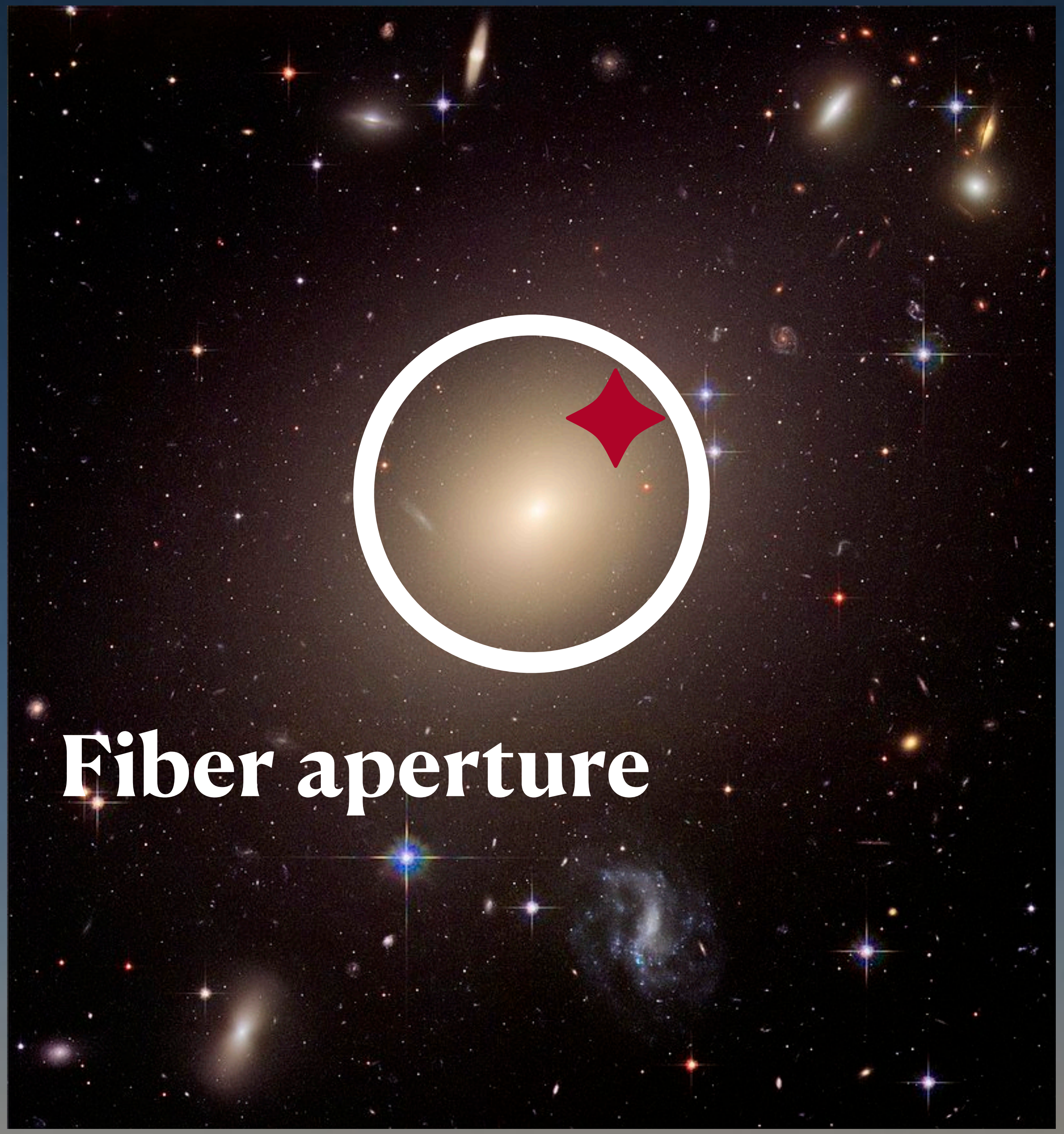
- Limit the stand alone scenario to “golden cases”
- Perform spectral subtraction using previous observations of the host

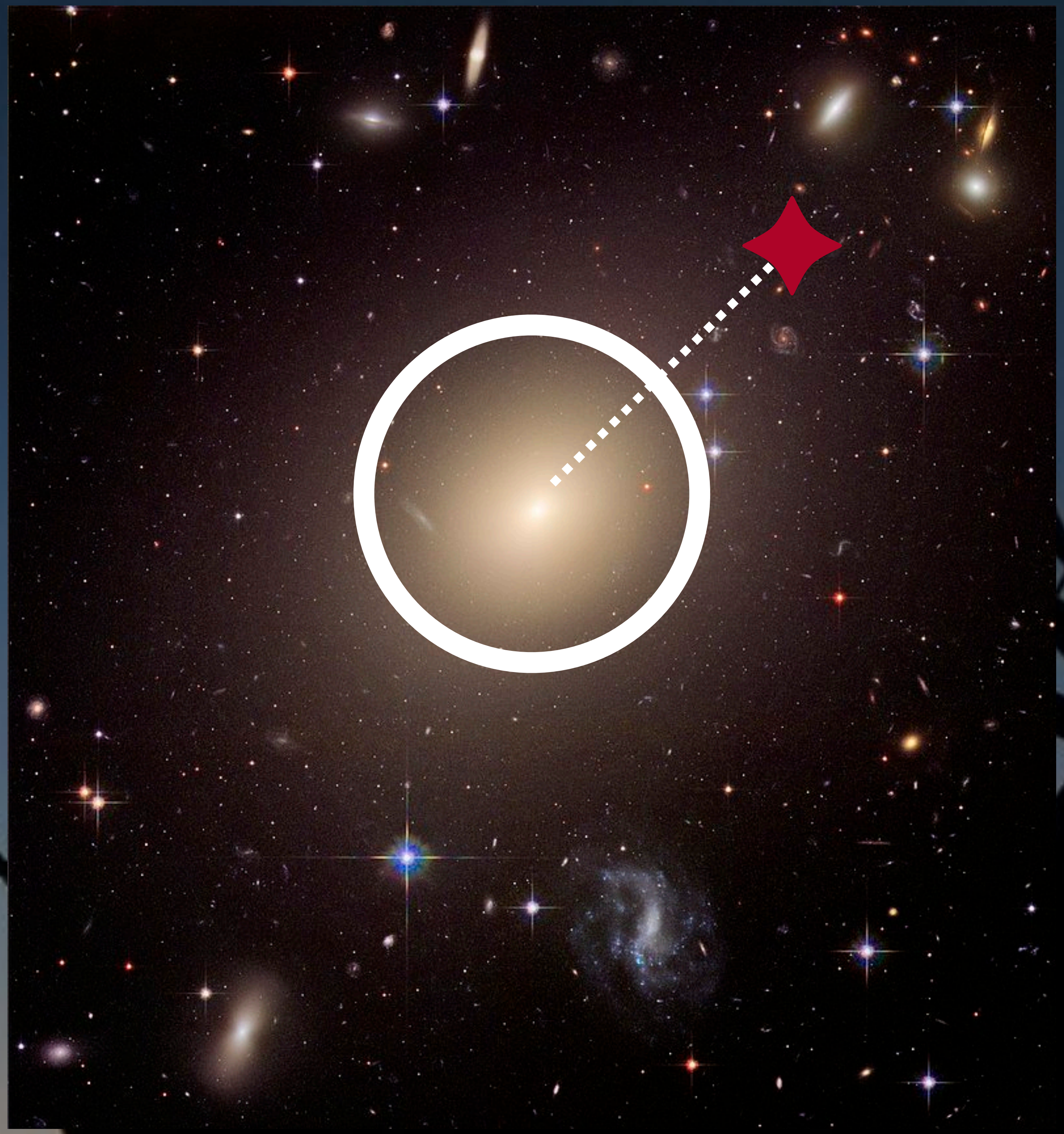
ET-WST synergy

Galaxies in the BNS comoving volume

Possible issues with a galaxy-targeted strategy:

Credits: HST





Possible solutions:

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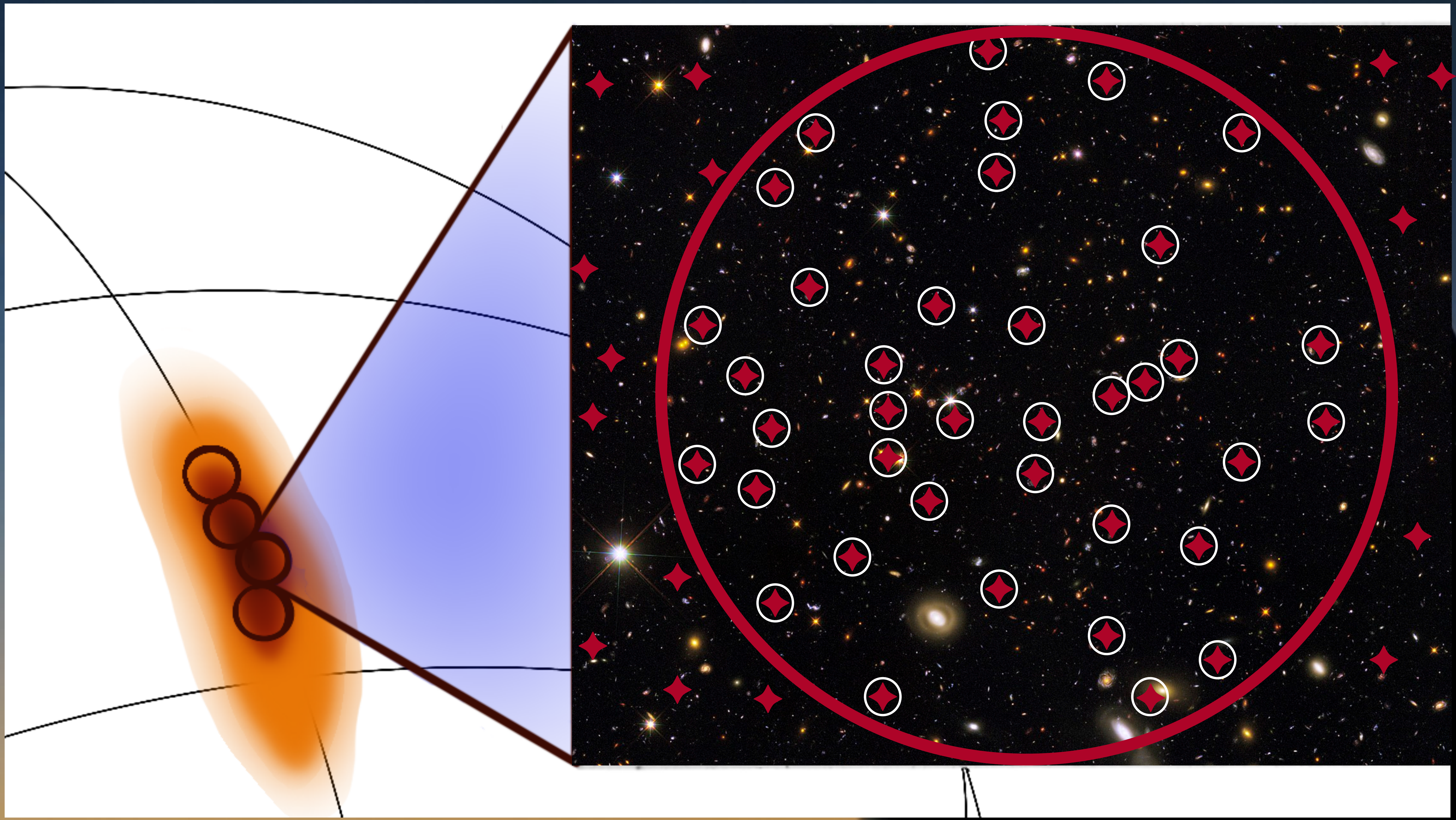
Further investigation of the **angular size** and **magnitudes** of the galaxies in the comoving error volume is ongoing, using the results from current galaxy catalogues

ET-WST synergy

Galaxies in the BNS comoving volume

Alternative strategy:



Target counterpart candidates from wide-field photometric telescopes observations (**Vera Rubin Observatory**) with WST fibres

Conclusions and future prospects

- **IFS** and **MOS** with **WST** are well suited for the **identification** and **characterisation** of **EM counterparts of next generation GW detections**

- WST can be used both **alone** and in **synergy** with **optical-NIR photometric observations**

- With WST, **KN** can be unveiled up to **z~0.4** and **AB magnitude ~25**

- **GRB afterglows** contribution is observable for systems with small viewing angle, up to **~15°,** also at **high redshift**

- This work can be adapted to make predictions for **LVK O5**, with IFS and MOS facilities available at the time of O5 operations

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Thank you!

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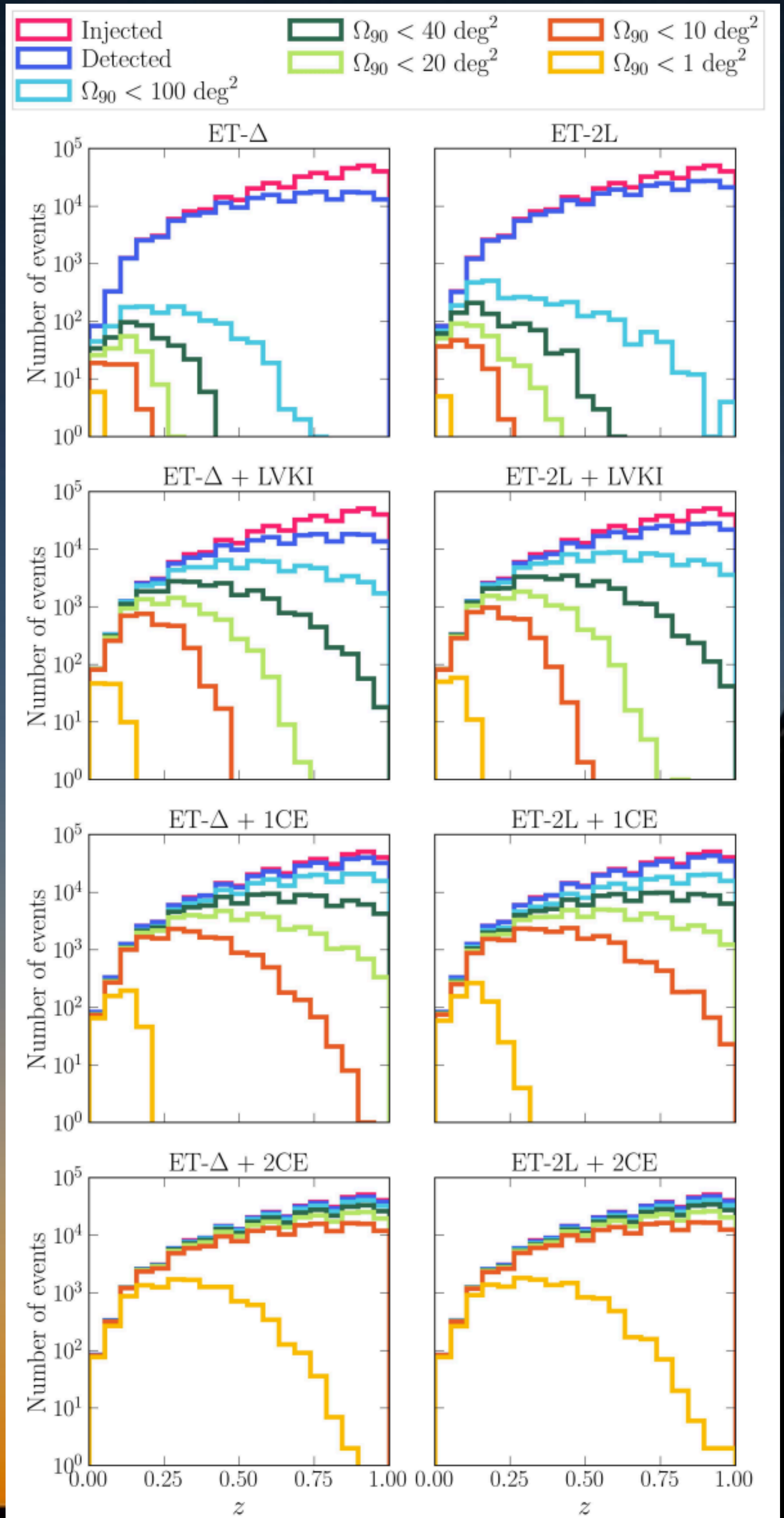
Backup



Injected
Detected
$\Omega_{90} < 100$ deg^2
$\Omega_{90} < 40$ deg^2
$\Omega_{90} < 20$ deg^2
$\Omega_{90} < 10$ deg^2
$\Omega_{90} < 1$ deg^2
ET-Δ
ET-2L
ET-Δ + LVKI
ET-2L + LVKI
ET-Δ + 1CE
ET-2L + 1CE
ET-Δ + 2CE
ET-2L + 2CE
Number of events
10^0
10^1
10^2
10^3
10^4
10^5
0.00
0.25
0.50
0.75
1.00
z

Loffredo+24

Telescope aperture (M1)	12 m seeing limited		
Telescope FoV	3.1 deg^2		
Telescope Spec. range	0.35-1.6 µm		
Operations	MOS and IFS simultaneous operations ToO implemented at telescope and fibre level		
Modes	MOS-LR	MOS-HR	IFS
FoV	3.1 deg^2	3.1 deg^2	3x3 arcmin^2 (mosaic on 9x9 arcmin^2)
Spectral range (simultaneous)	0.37-0.97 µm	0.37-0.97 µm 3-4 windows	0.37-0.97 µm
Spectral resolution	4000	40000	3500
Multiplexing	20000	2000	

WST			
channel	spectral range [Å]	best throughput range [Å]	specte size [Å]
	IFS		
blue	3700-6100	4800-5800	0.64
red	6000-9600	6500-7500	0.97
	MOS		
blue	3700-5350	4800-5300	0.41
orange	5150 - 7400	6000-7000	0.55
red	7200-9700	7300-8300	0.61