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

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LUX, Observatoire de Paris

Image: Yuri Beletsky, LIGO/T. Pyle

Challenges in the research of the EM counterpart of ET detections

Larger volume
of the Universe explored

↓

Huge number of **BNS**
detections

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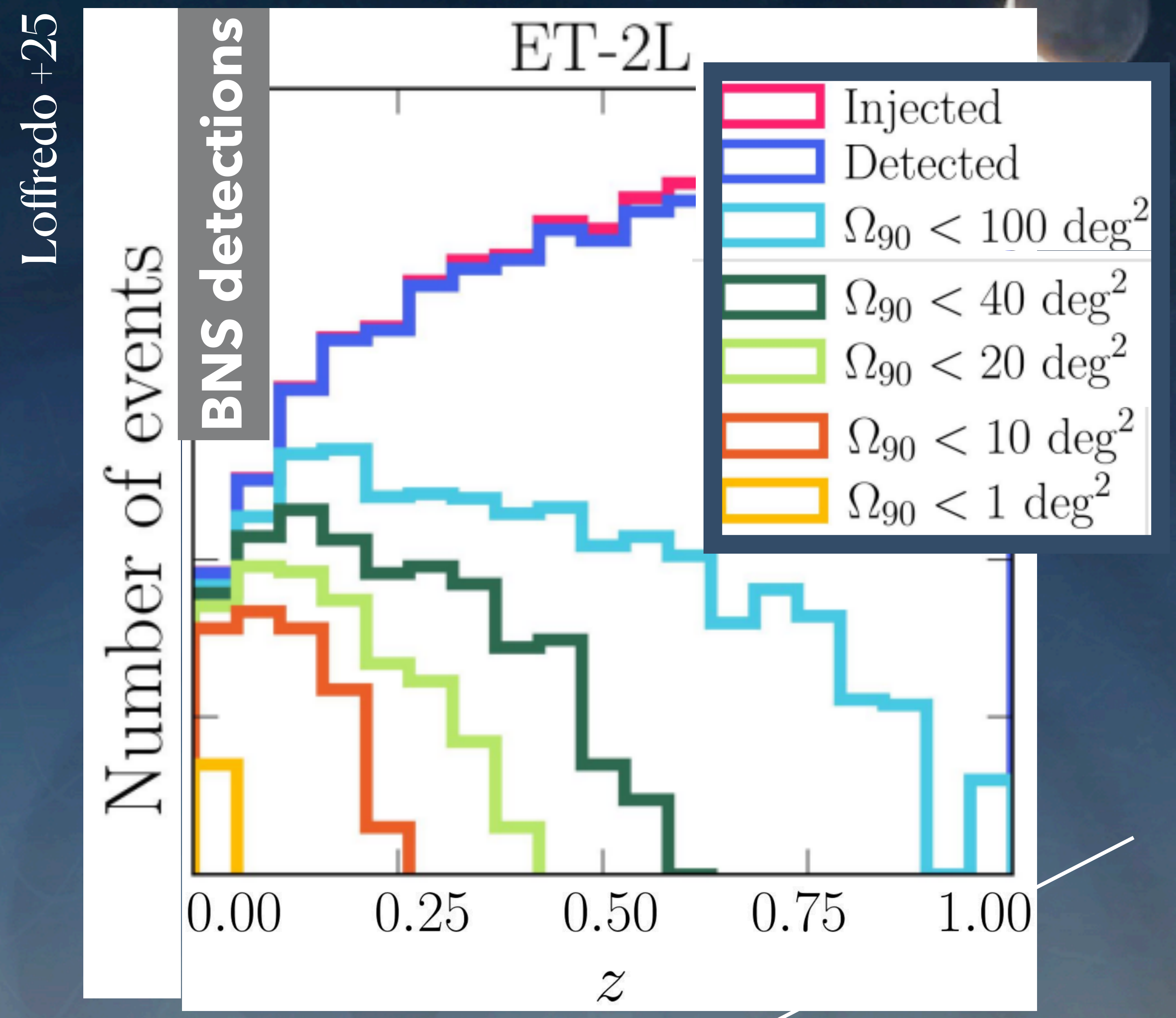
How to detect, identify and characterise their EM counterparts?

Challenges in the research of the EM counterpart of ET detections



Larger volume
of the Universe explored

Huge number of **BNS** detections

Large **errors** on **sky localisation**

How to detect, identify and characterise their EM counterparts?

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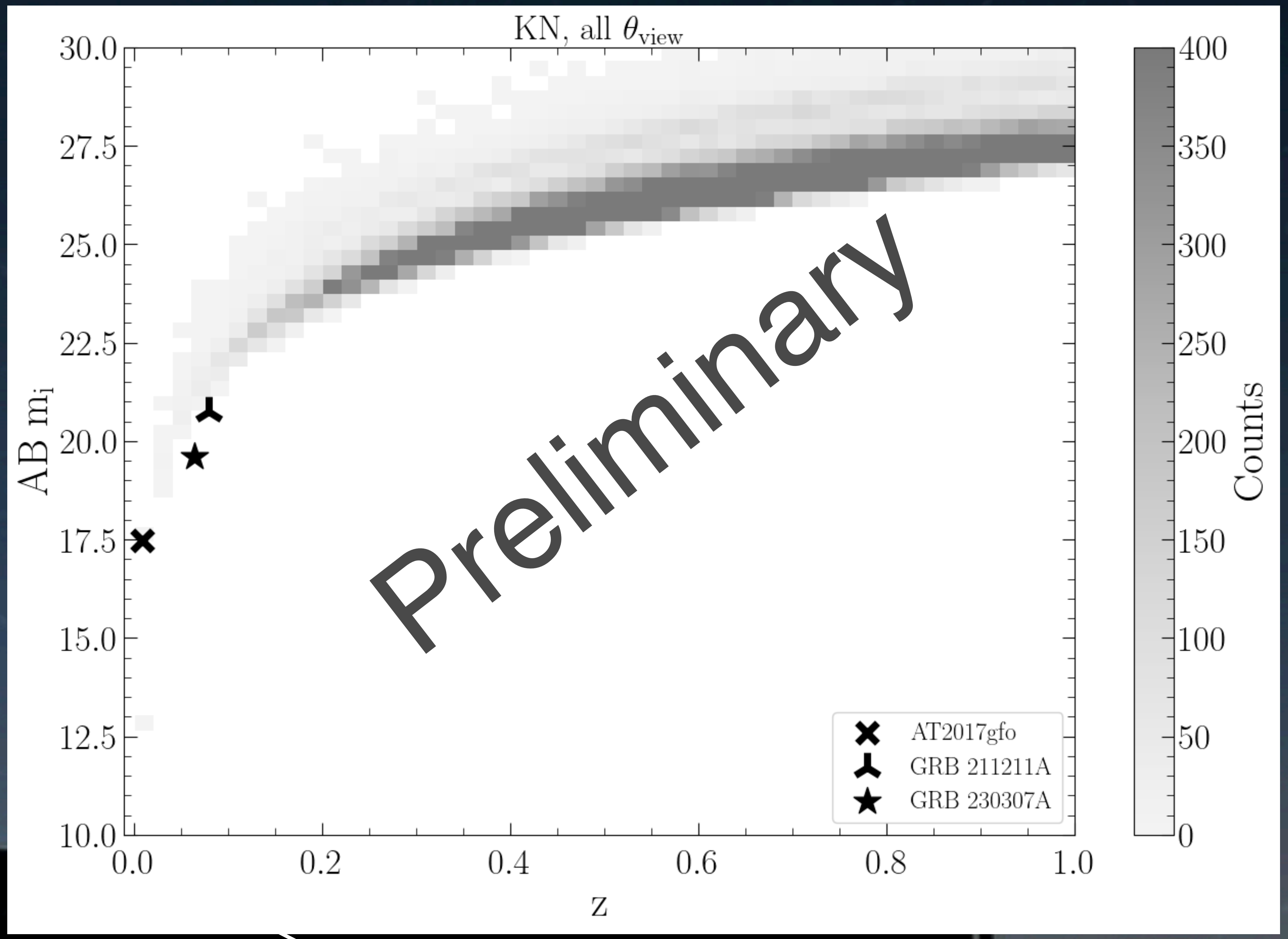


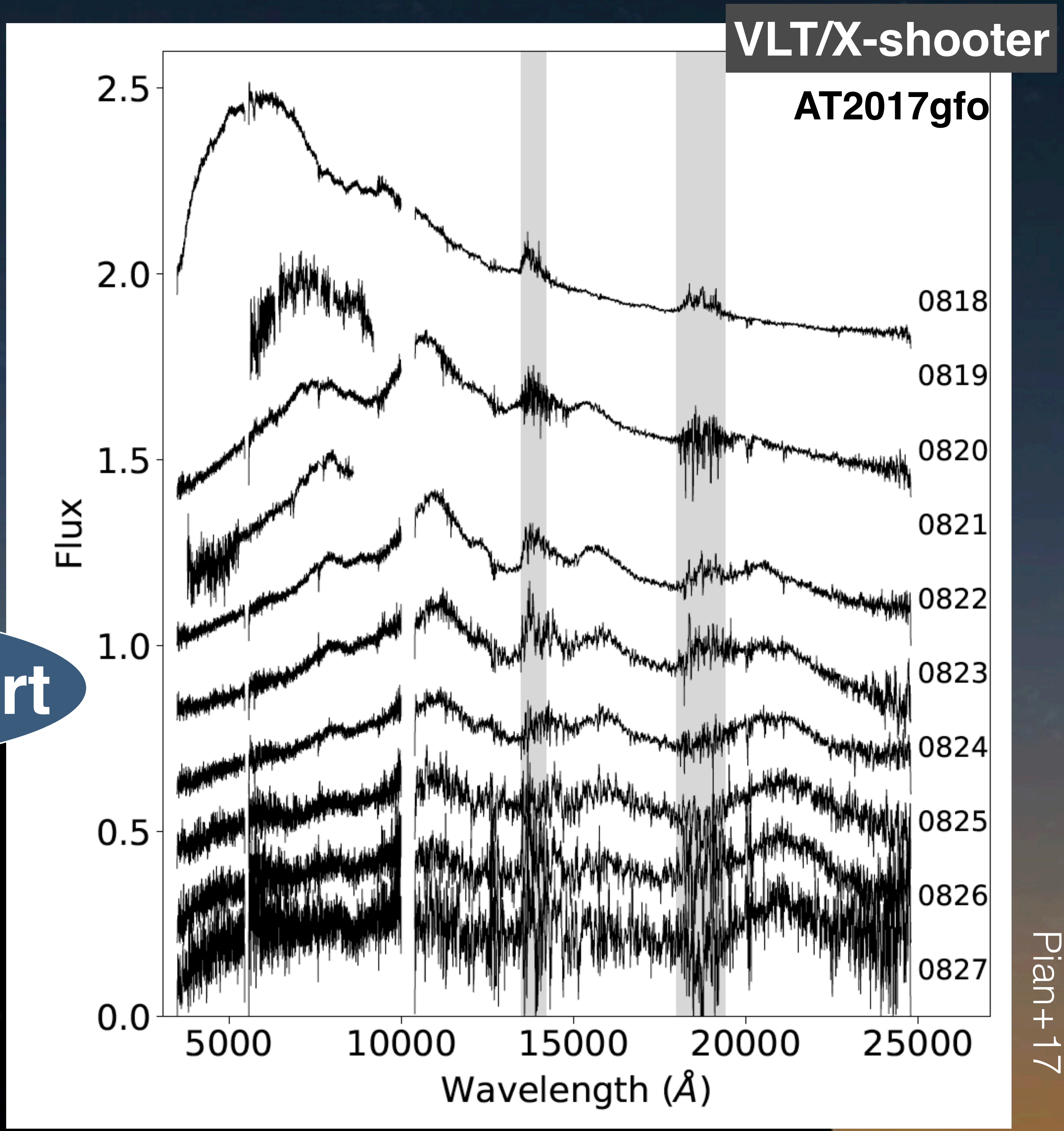
How to detect, identify and characterise their EM counterparts?

Large **errors** on **sky localisation**

Faint optical-NIR counterparts for increasing redshift

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

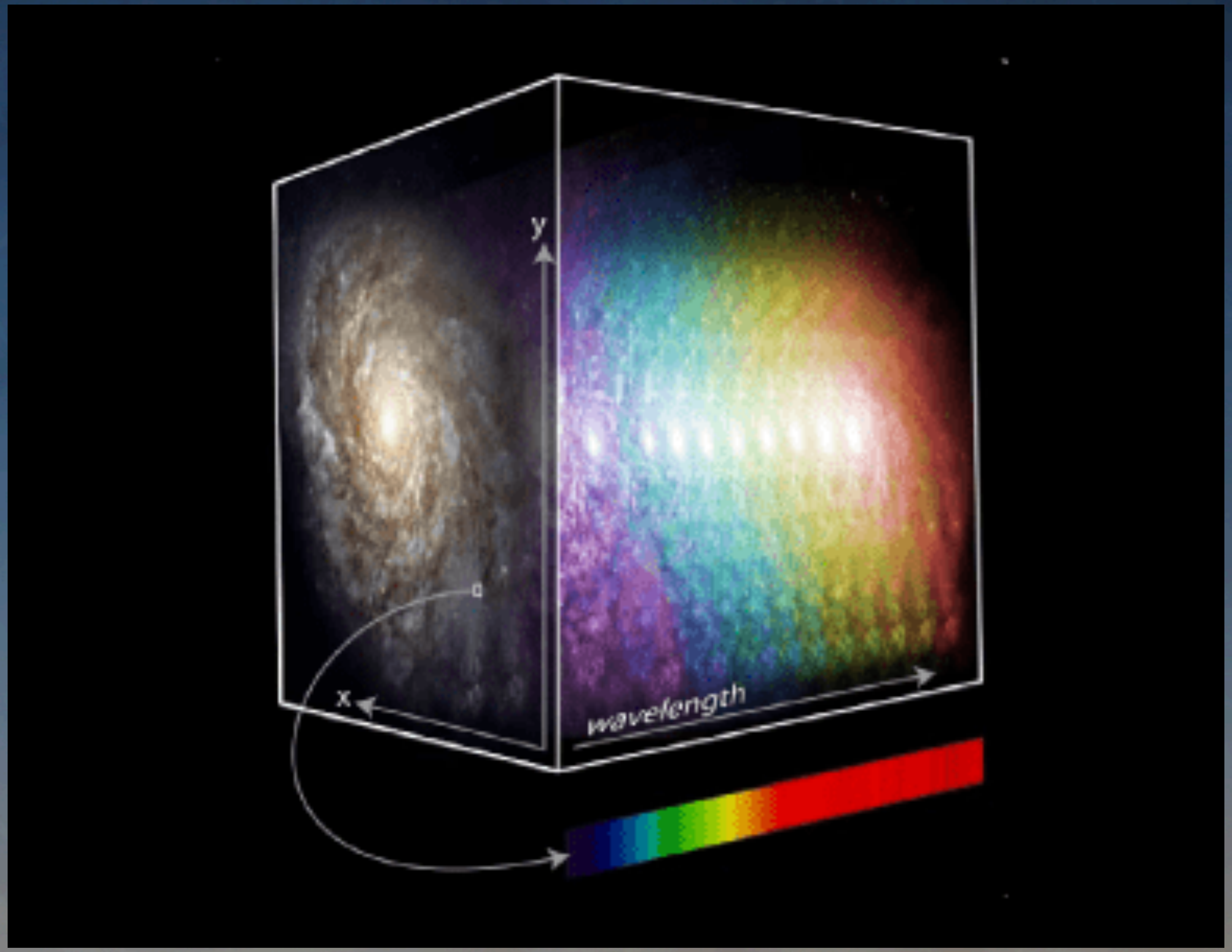
Huge amount of transients in the GW error region → **EM counterpart**

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

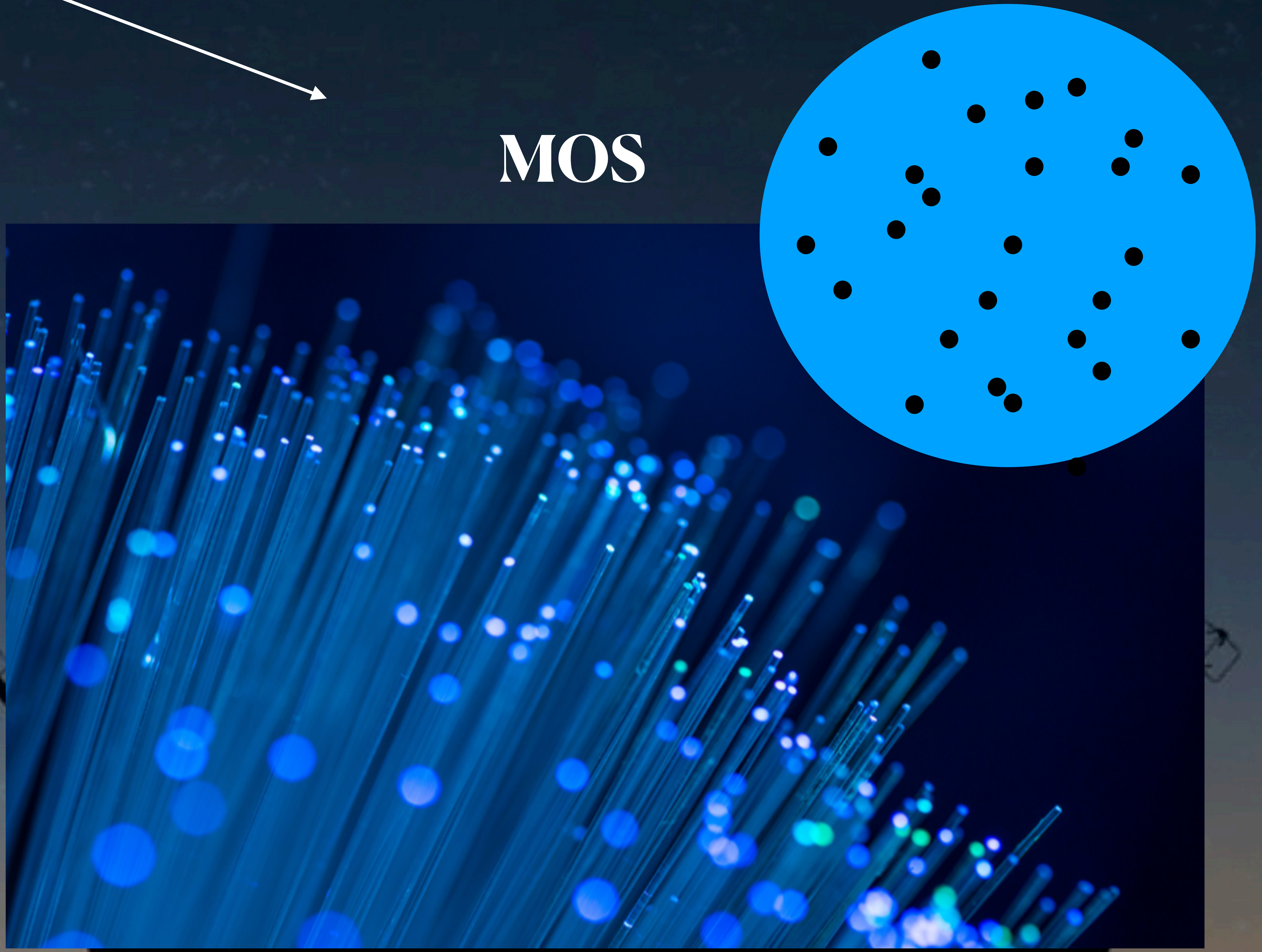
Integral Field and Multi-Object Spectroscopy

IFS



A spectrum for each pixel
of the 2D field image

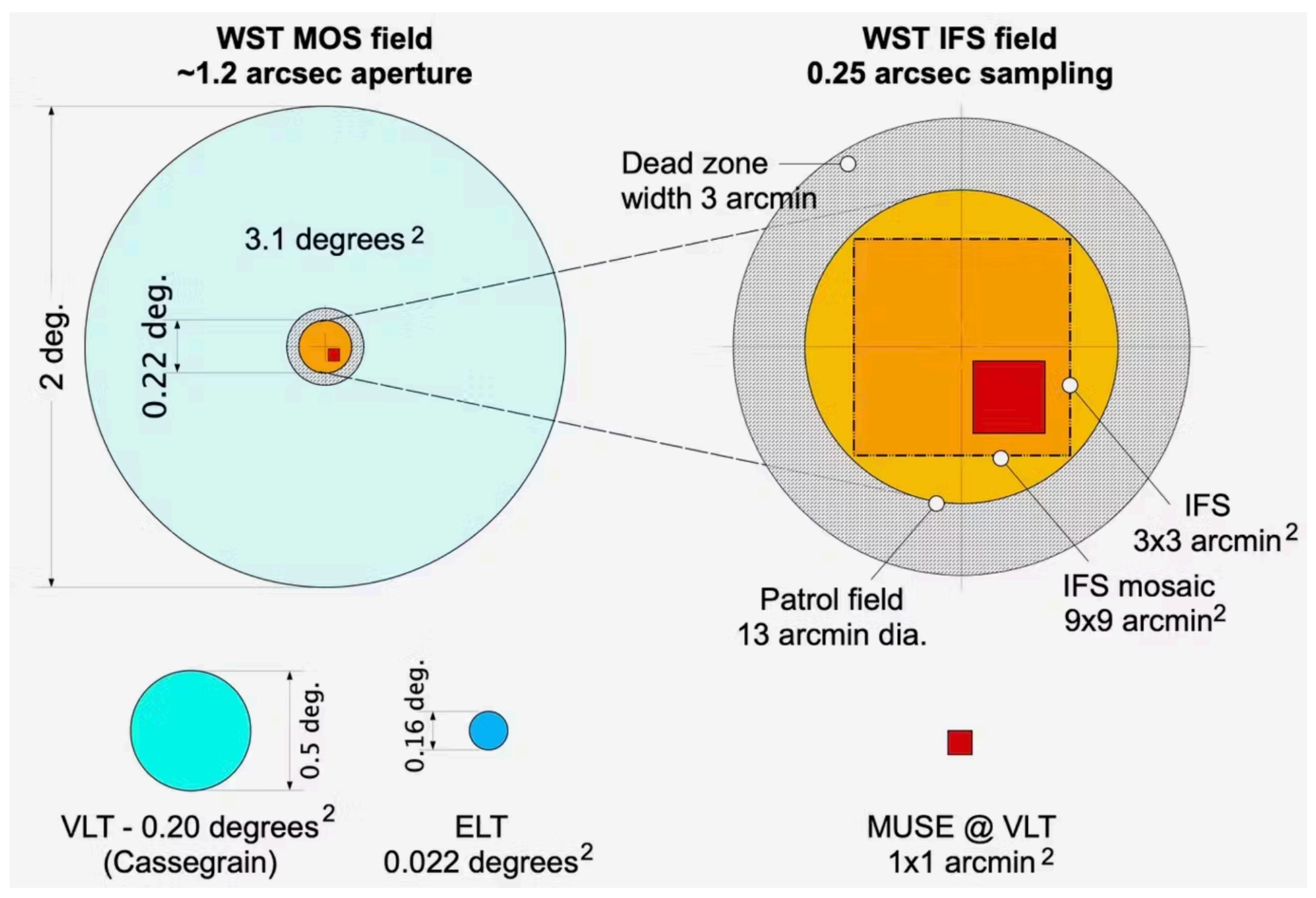
MOS

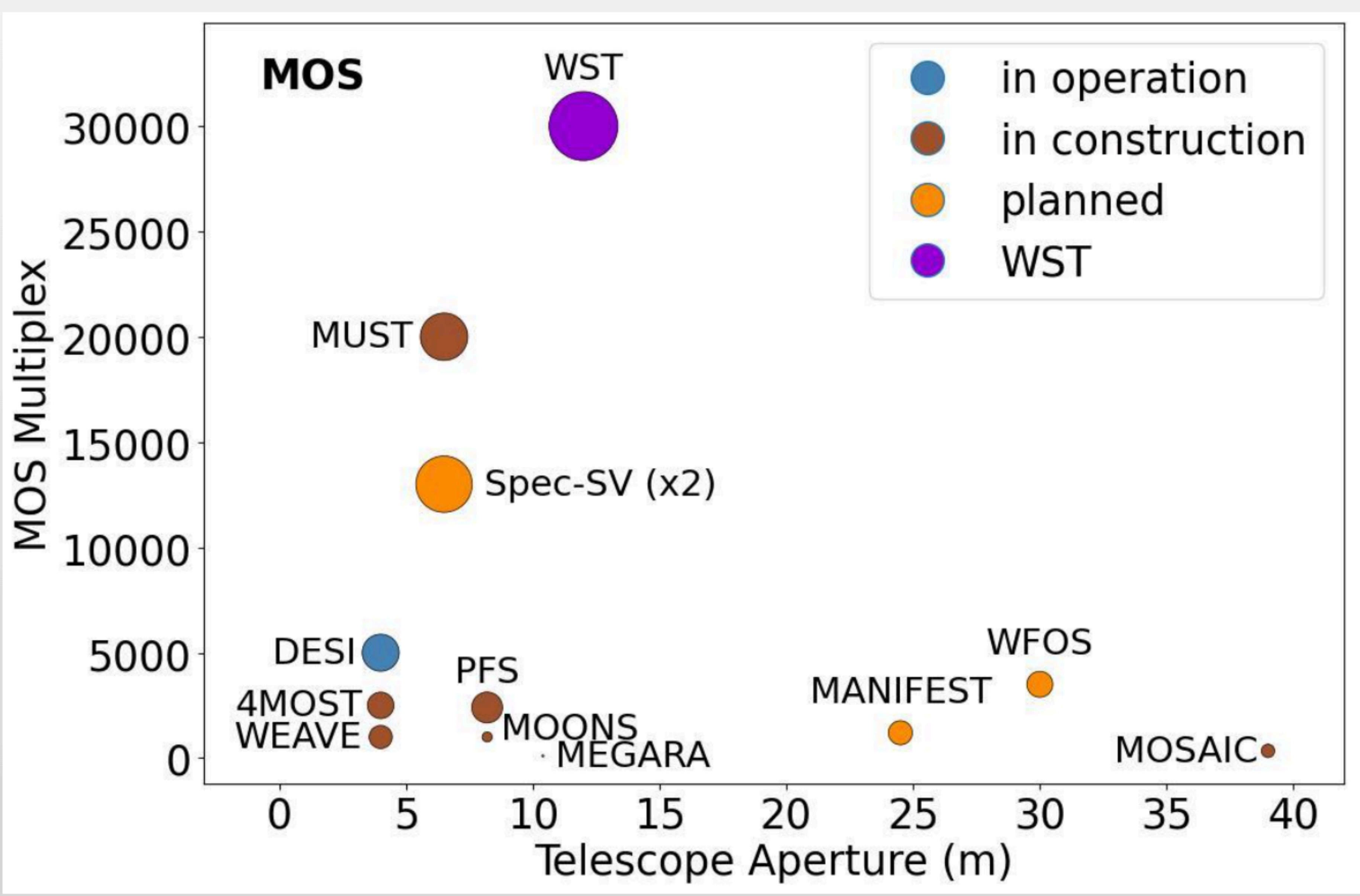


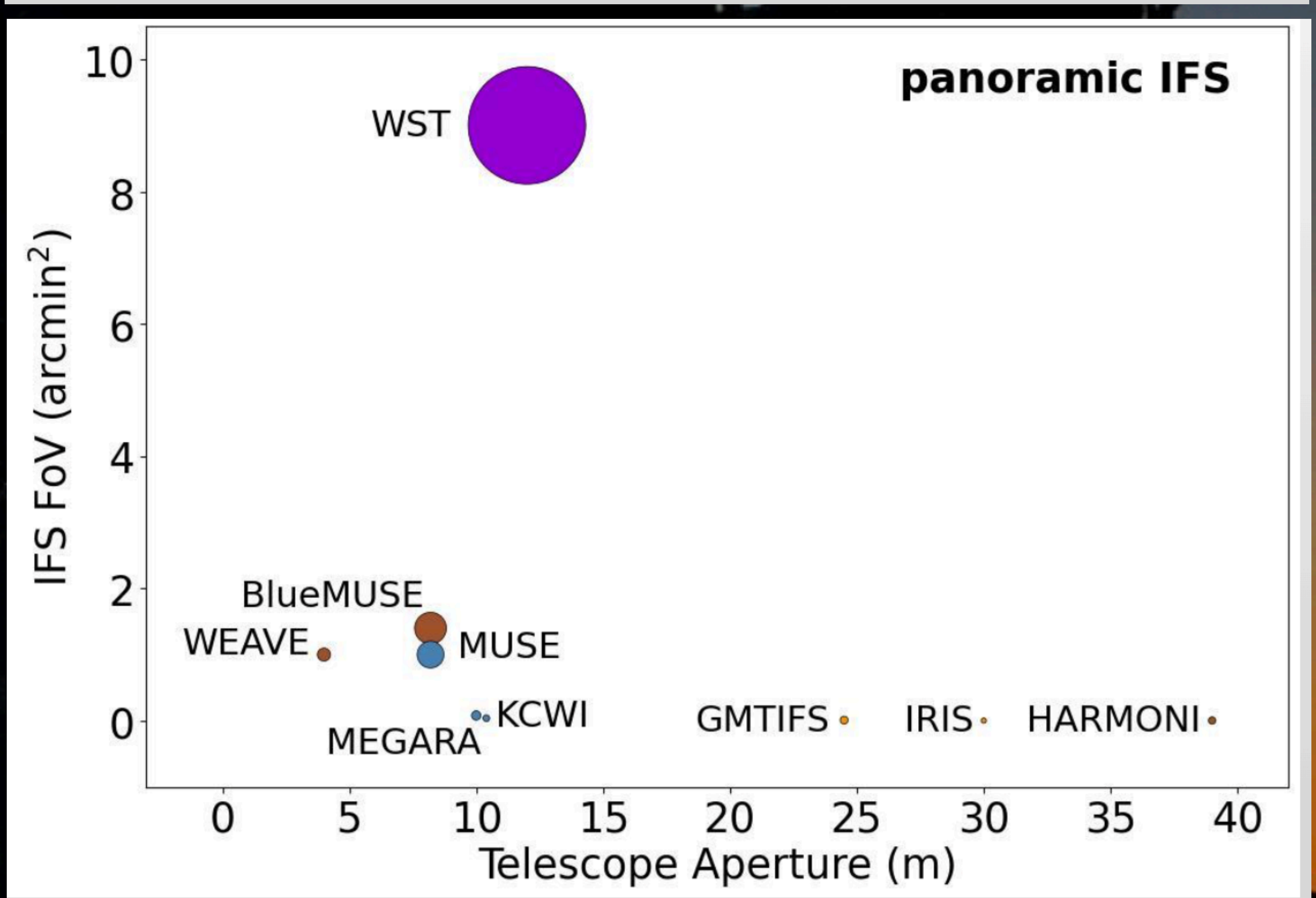
Fibres positioned on the localisation of
the sources of interest

IFS and MOS with the Wide-field Spectroscopic Telescope

WST







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

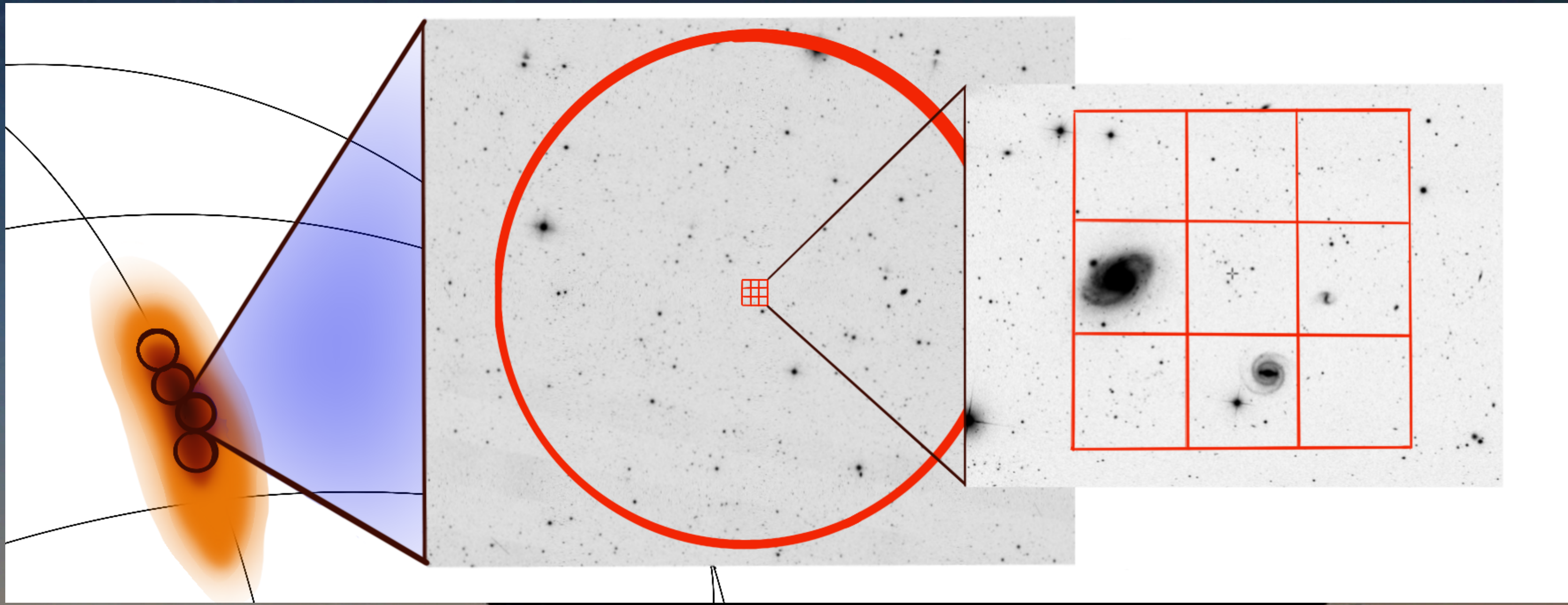
Development of the observing strategy

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

ET BNS populations

KN + GRB emission

WST

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

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

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

ET-WST synergy

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GSSI

GSSI

WST

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

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

- **redshift**
- **sky localisation**
- **viewing angle**
- **magnitude**

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

- **NSs equation of state: APR4 and BLh**
- **NSs mass distribution: gaussian and uniform**

ET-WST synergy

Simulations

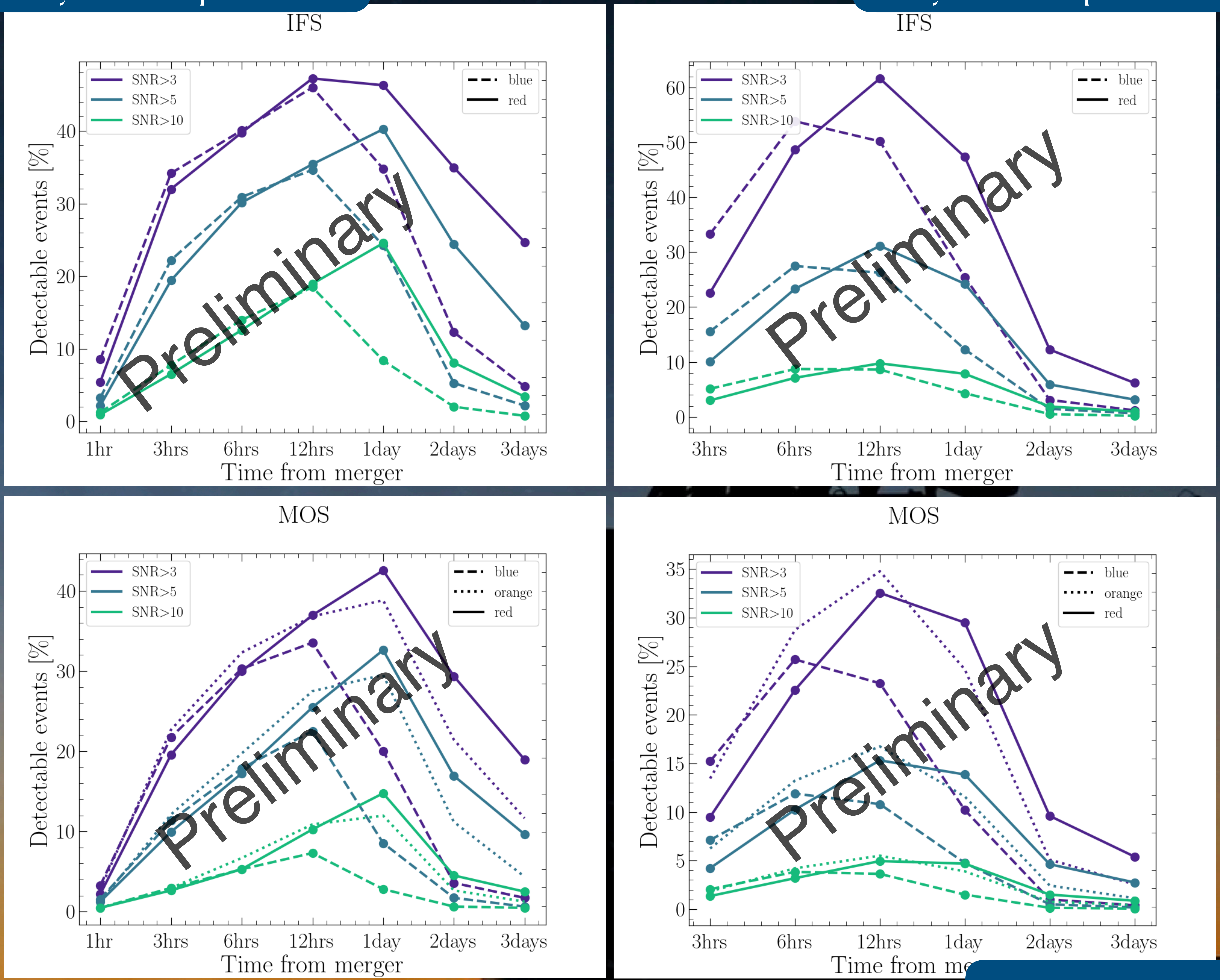
Percentage of detectable KN at different times post-merger

1 year of ET operations

10 years of ET operations

AT2017gfo KN model

KN theoretical models



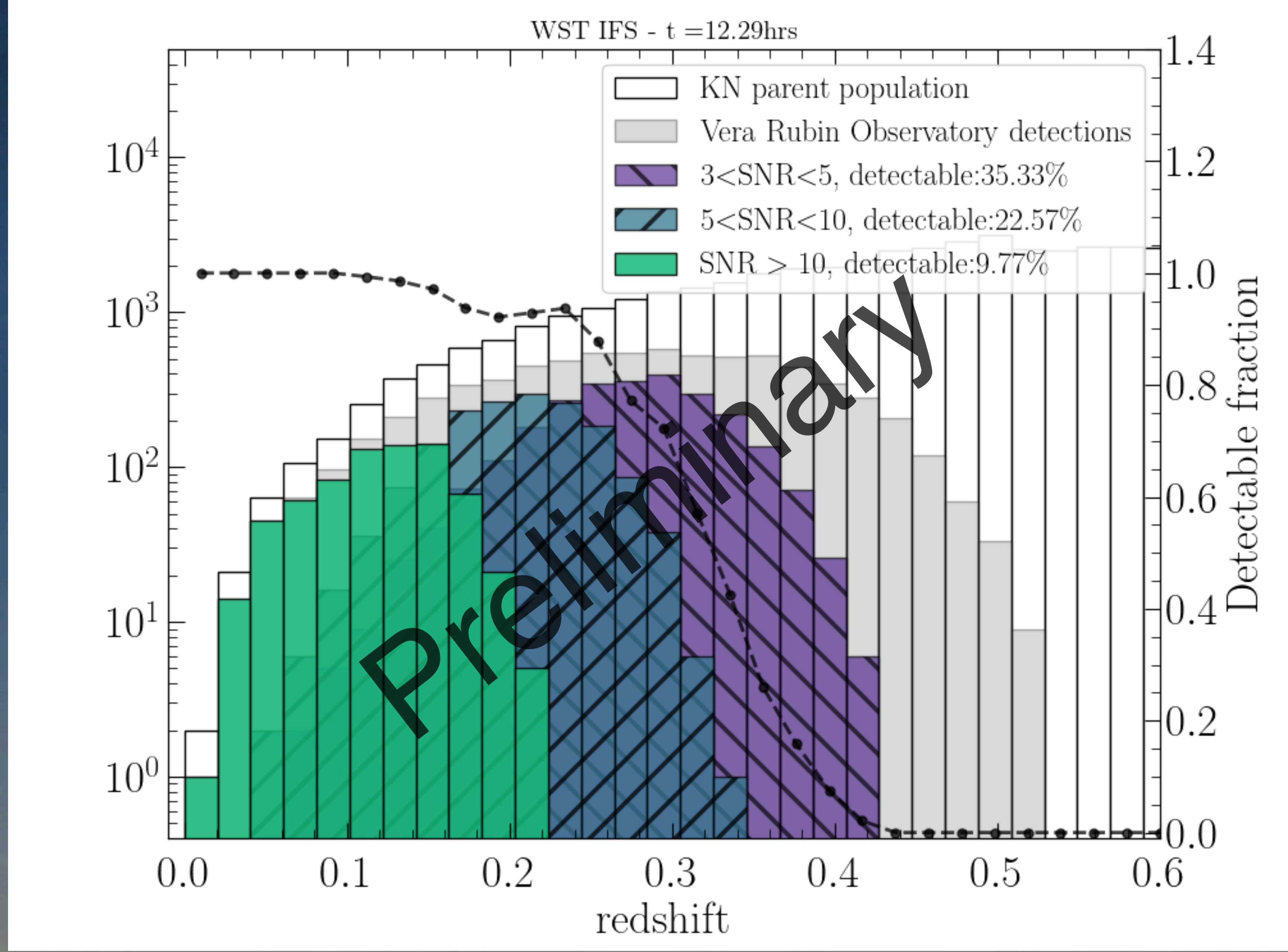
BLh gaussian

Bisero et al. 2025 in prep

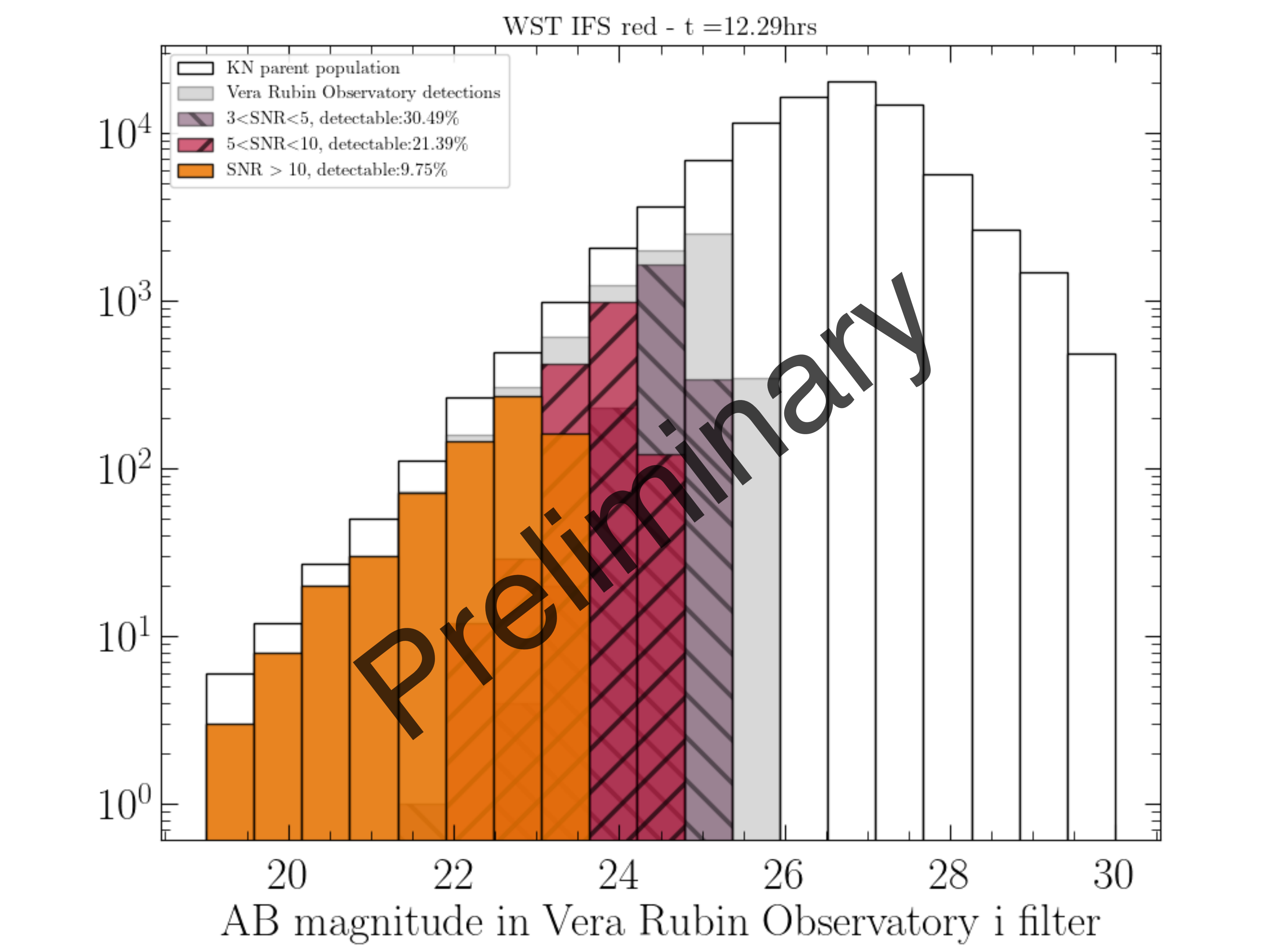
ET-WST synergy

Simulations

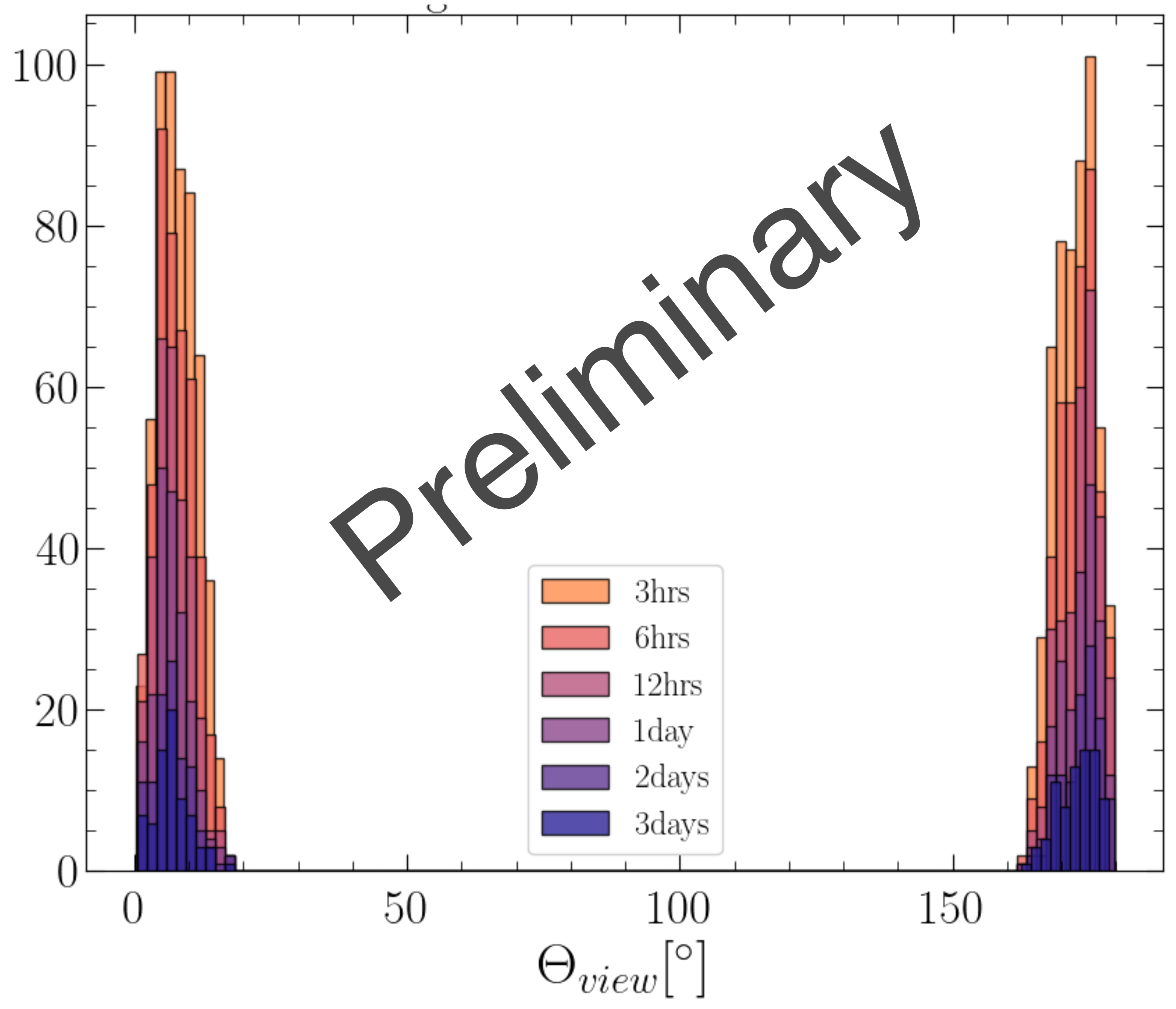
Detections horizon



Magnitude limits



Afterglow contribution



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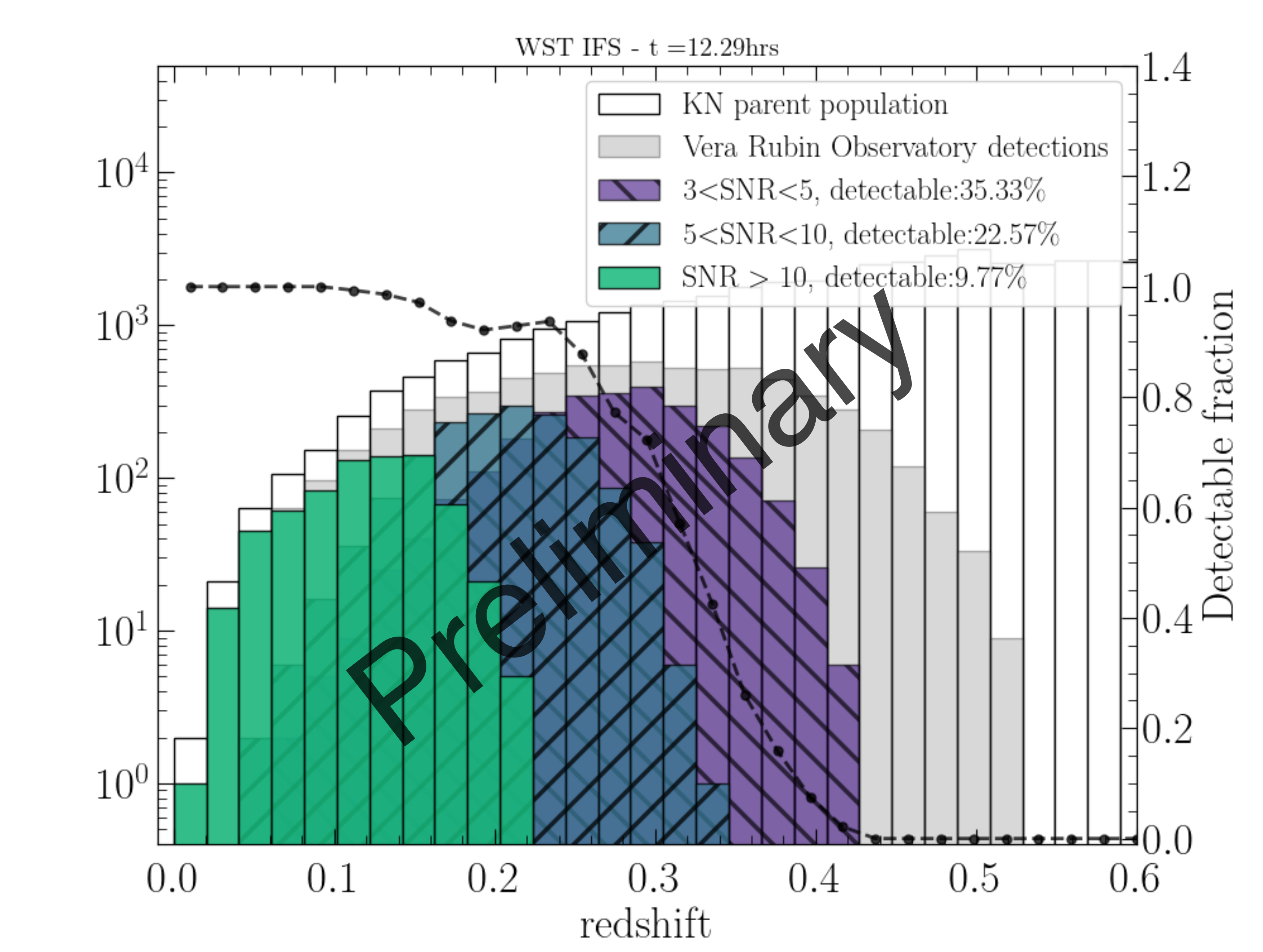
White: ET+CE **BNS** detections in **10 years** of operations
Grey: Vera Rubin Observatory **KN** detections
Colored: WST **KN** detections

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

ET-WST synergy

Simulations

Detections horizon



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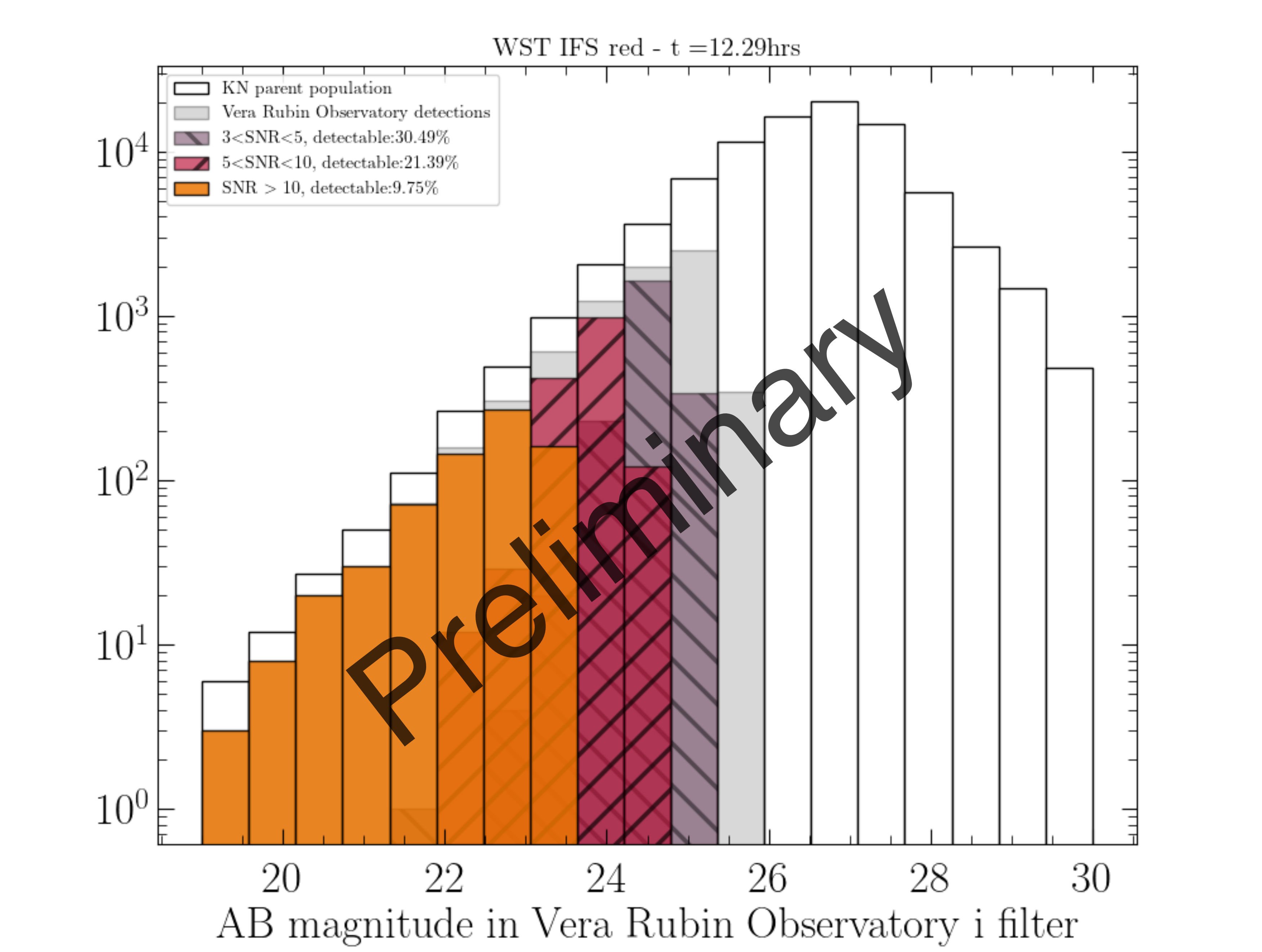

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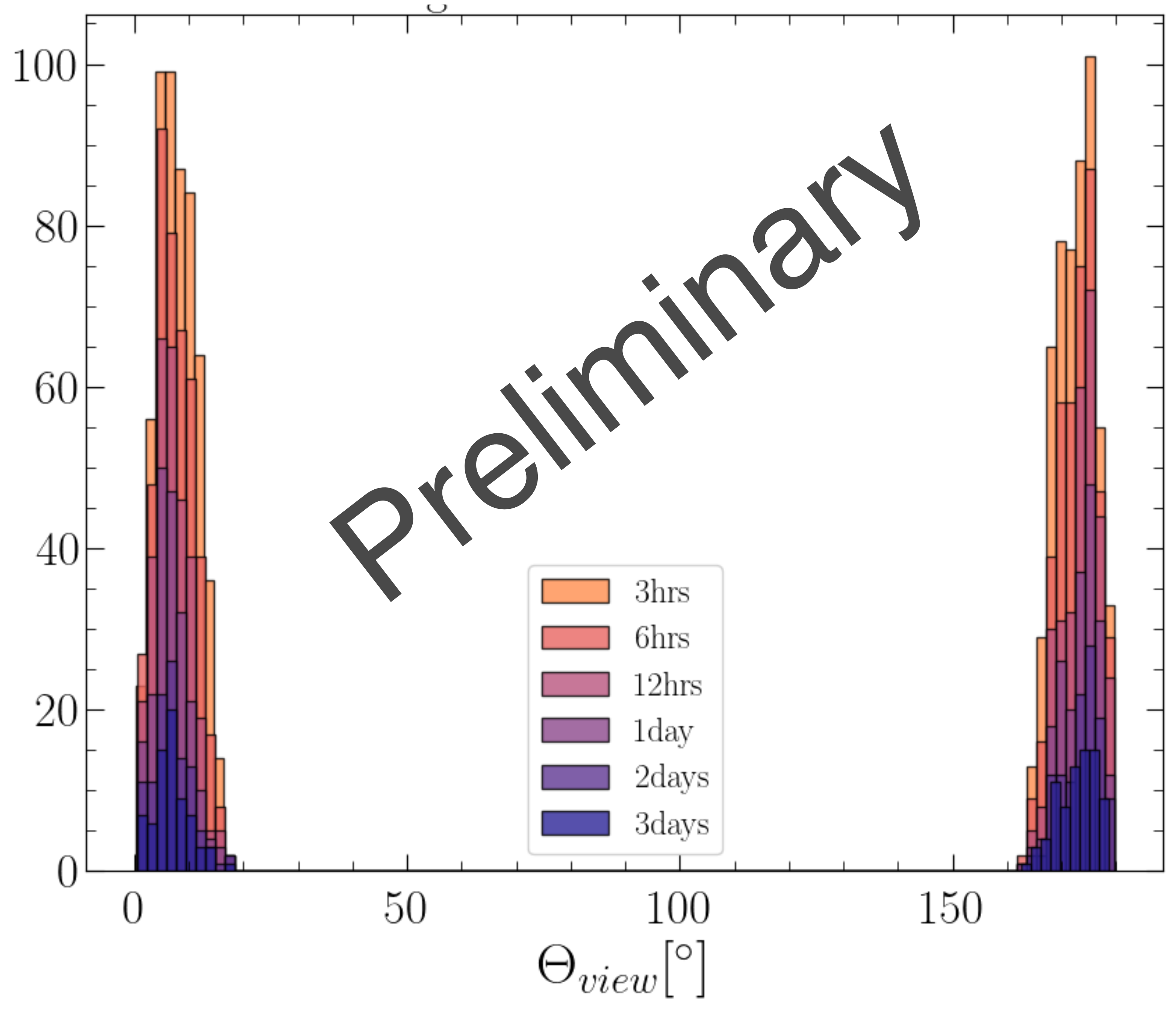

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See Hazra's Talk!

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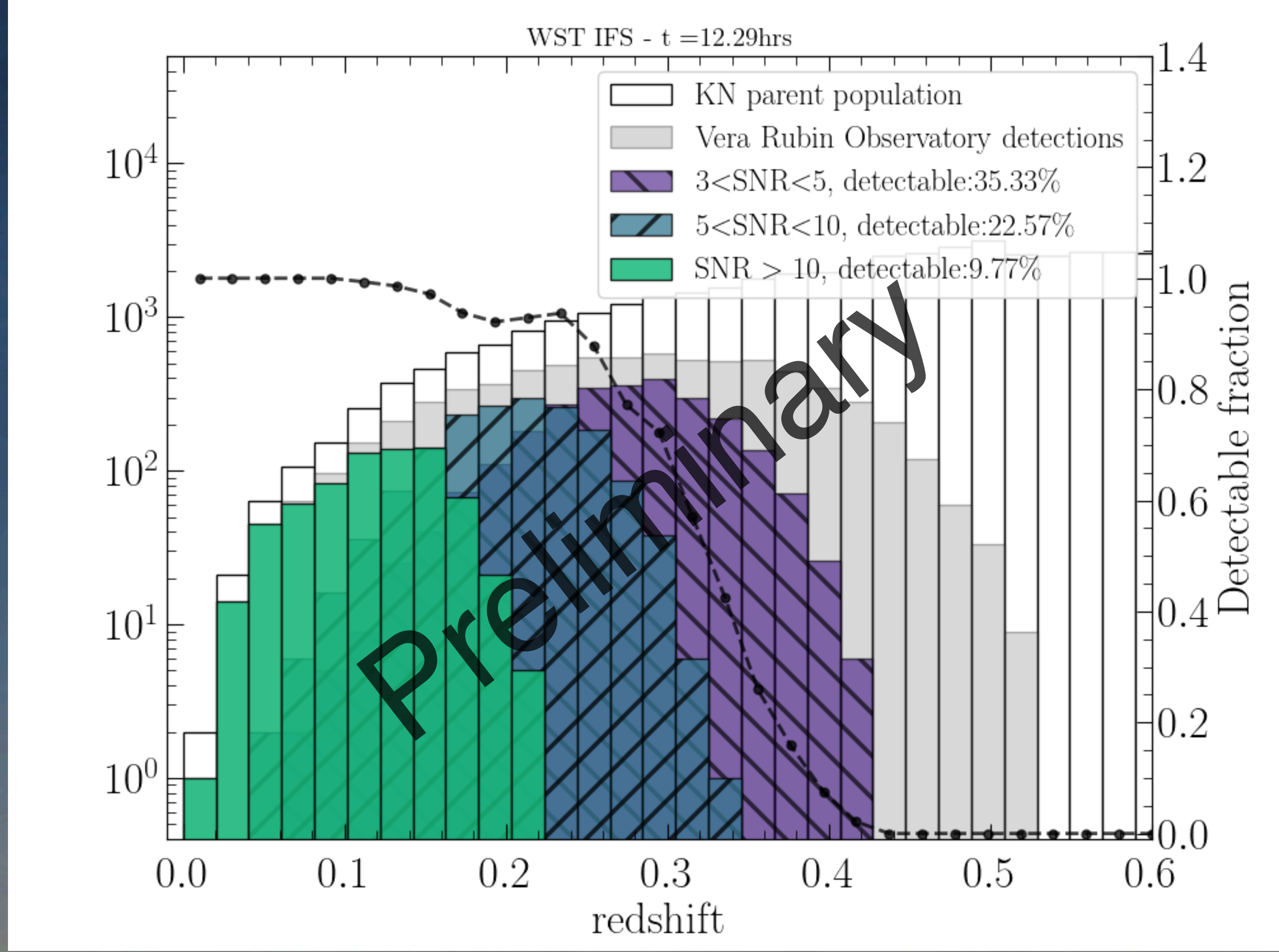

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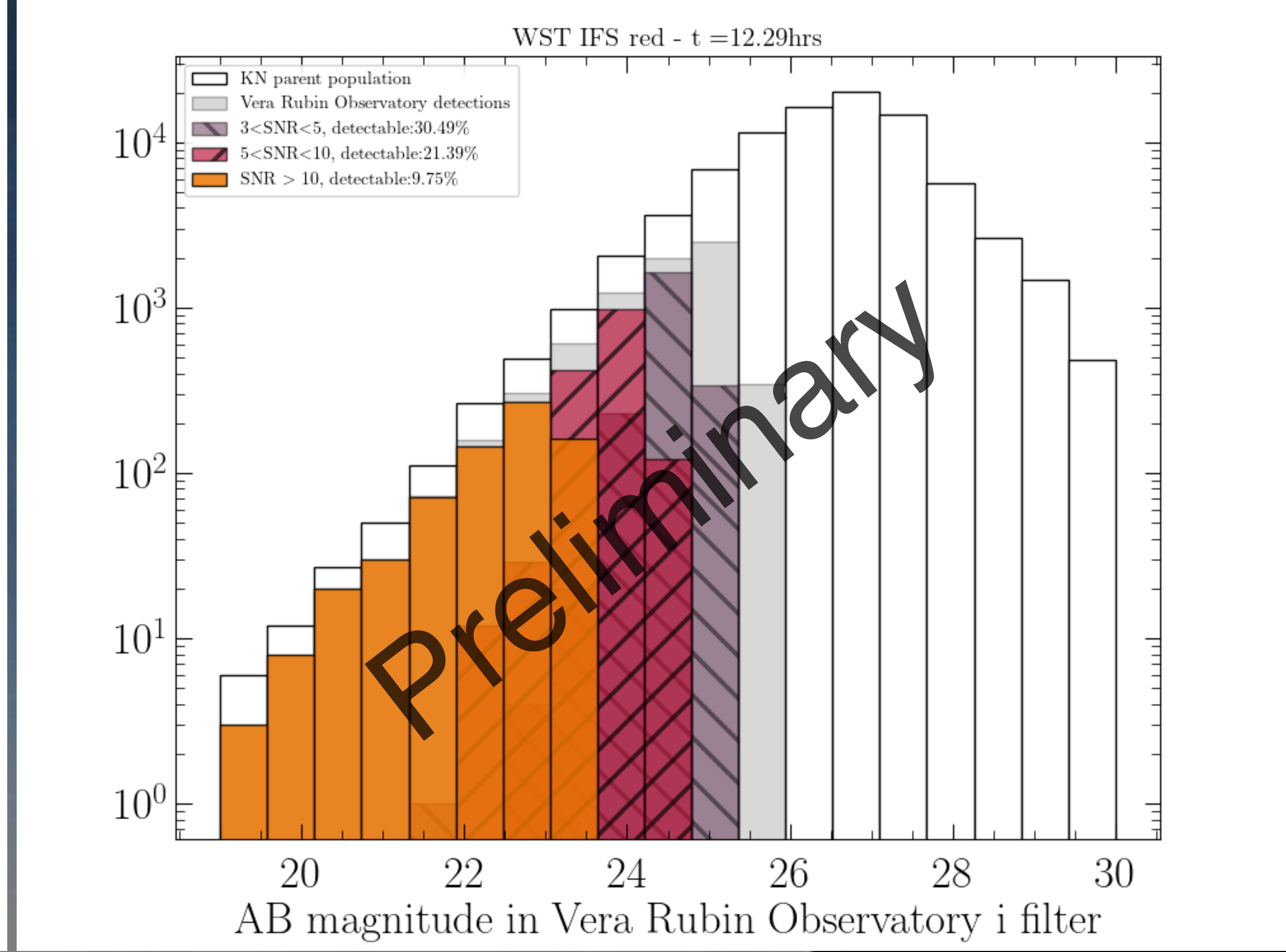

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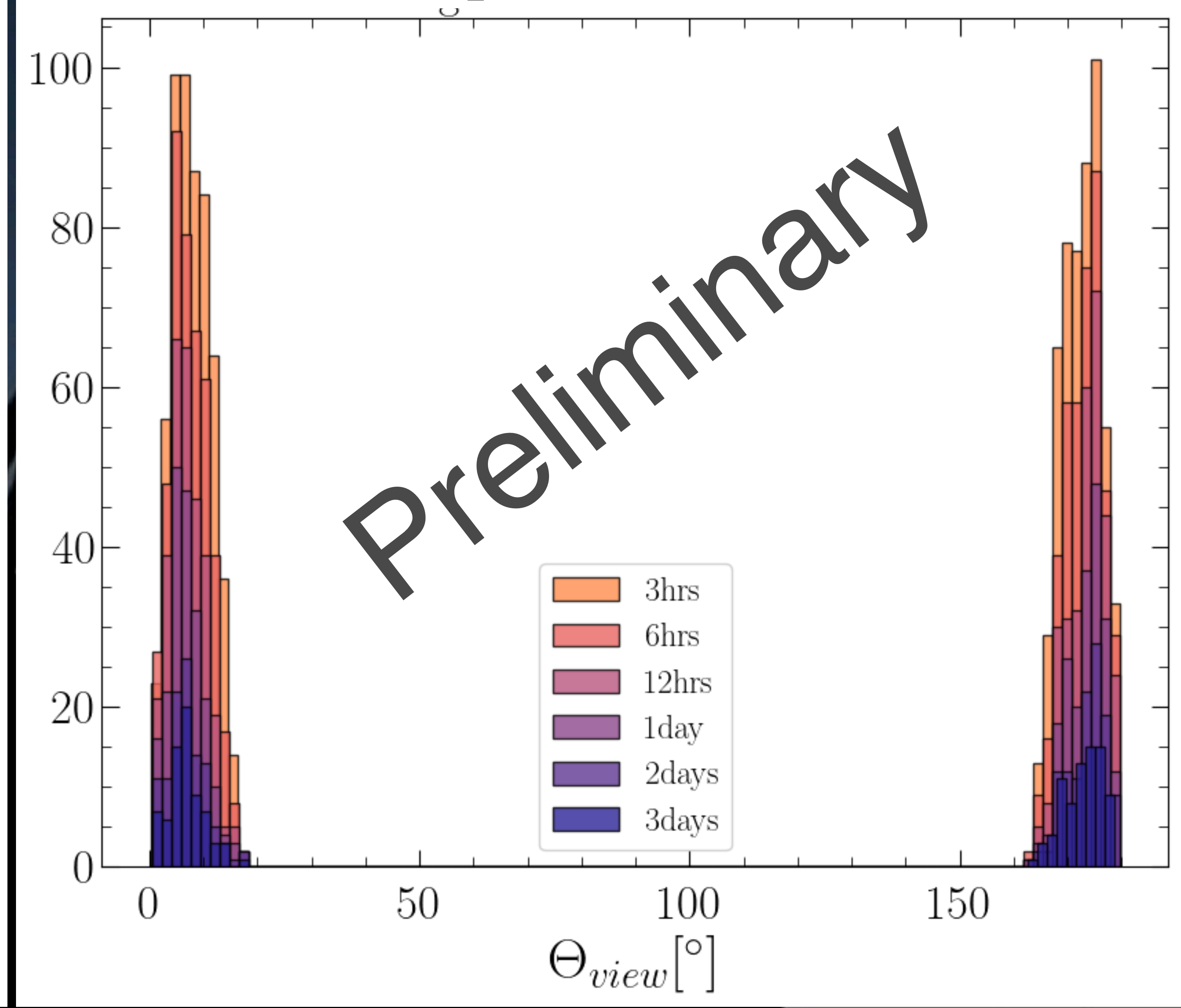

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Colored: Sources where the afterglow outshines the KN among WST detections with the IFS red arm

How can we detect, identify and characterise these counterparts with WST?

ET-WST synergy

Observing strategy

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

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

$$n_{\rm gal} \sim V_C \cdot n_{m_1<m<m2}$$

Number of galaxies whose distance is consistent with the 3D GW localisation

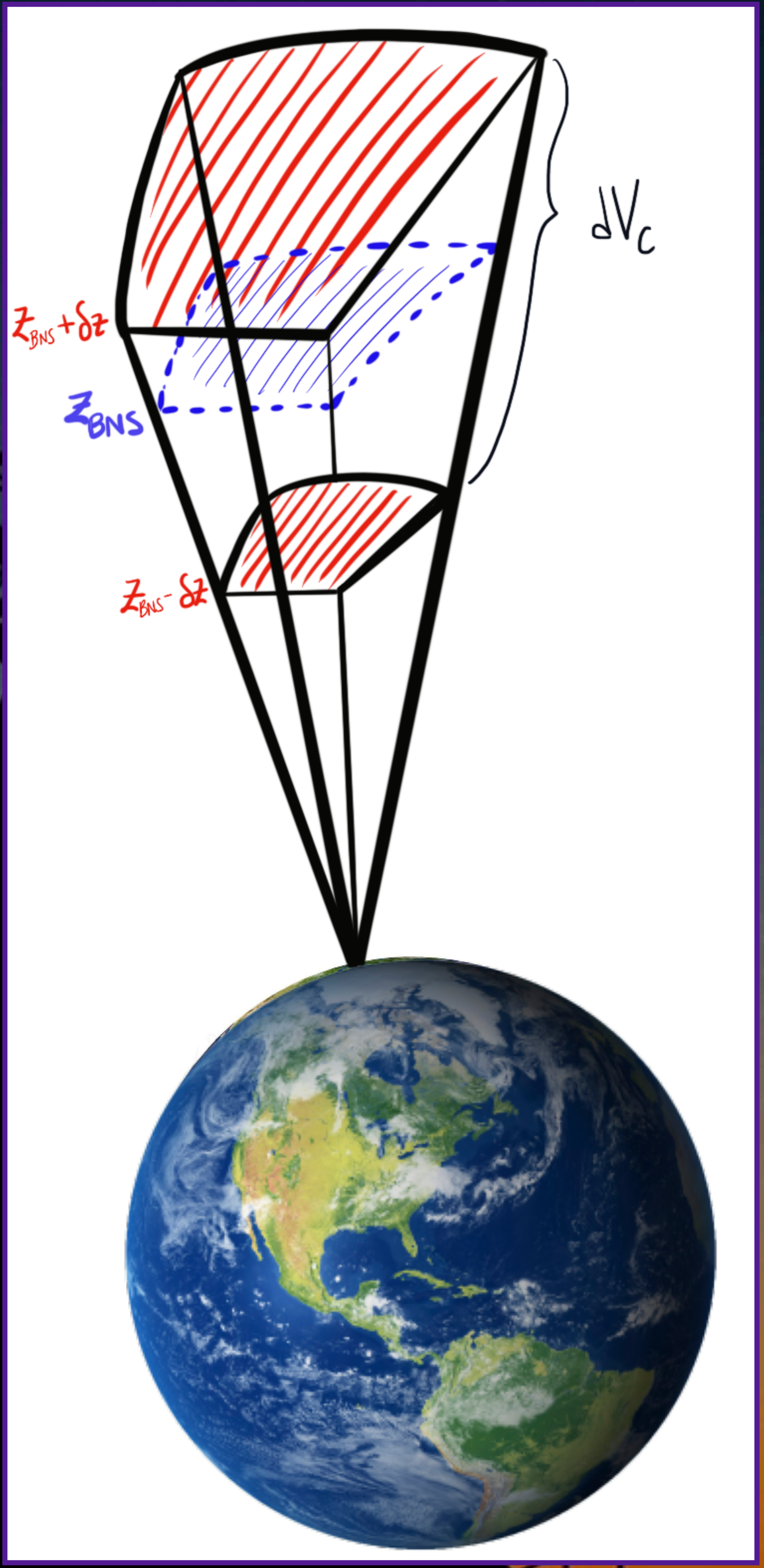
$$D_L - \Delta D_L \to z - \delta z$$

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

Schechter function parameters from Ilbert et al. 2005

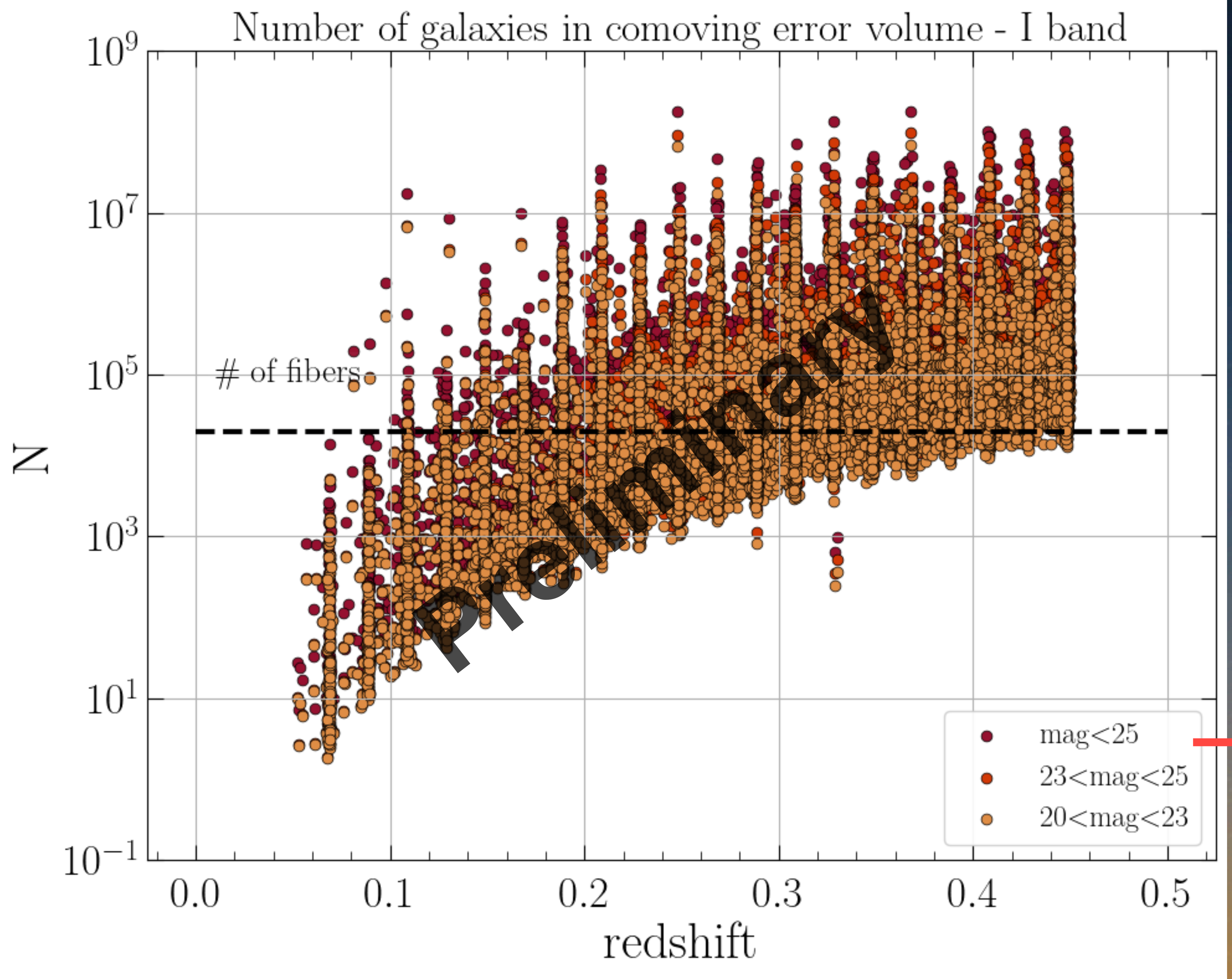
$$n_{m_1<m<m2} = \int_{m_1}^{m_2} \Phi(m)\, dm$$

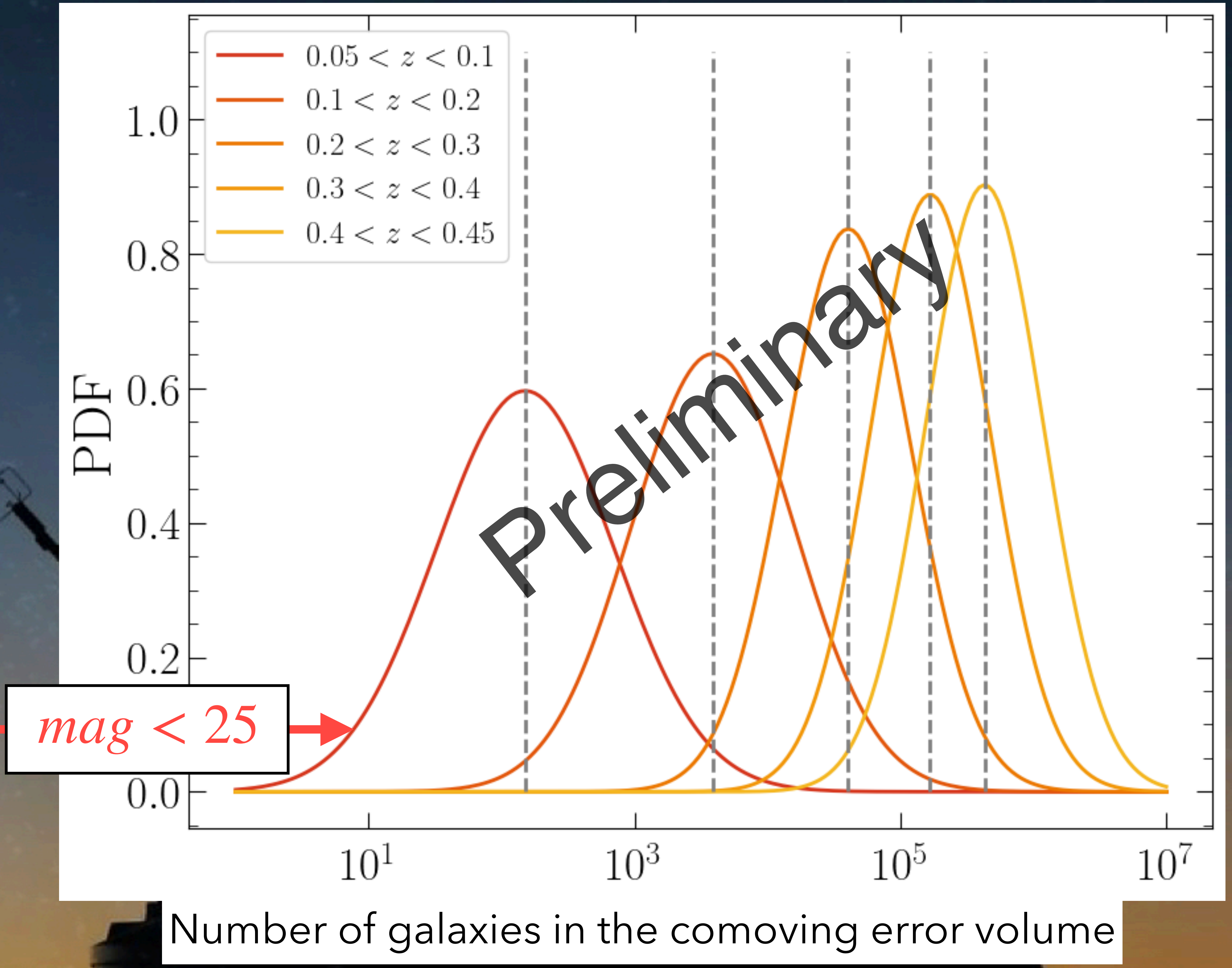
$[Mpc^{-3}]$ $[mag^{-1}Mpc^{-3}]$



ET-WST synergy

Observing strategy





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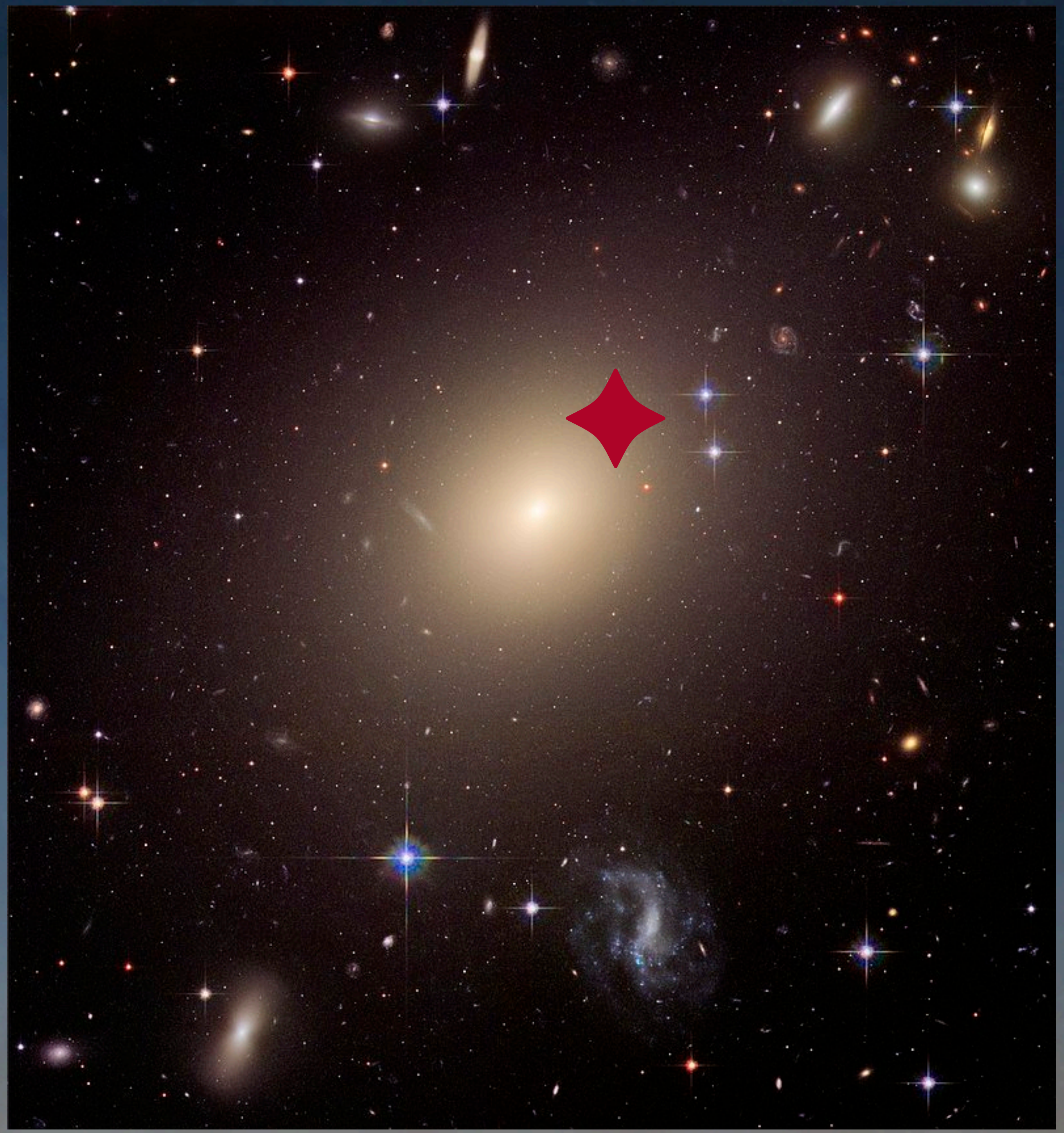
ET-WST synergy

Observing strategy

Possible issues with a galaxy-targeted strategy:



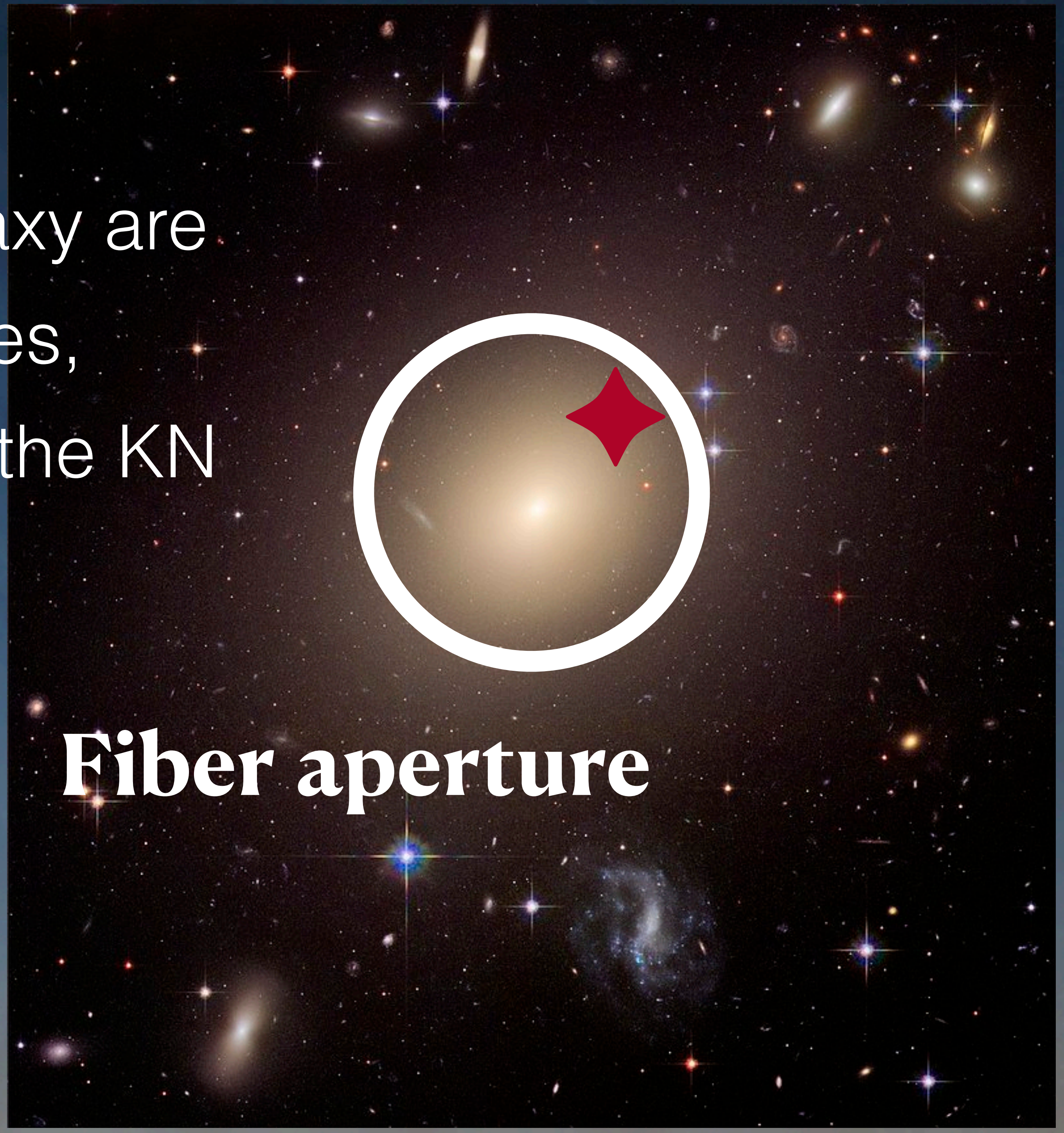
Credits: HST

ET-WST synergy

Observing strategy

Possible issues with a galaxy-targeted strategy:

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



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ET-WST synergy

Observing strategy

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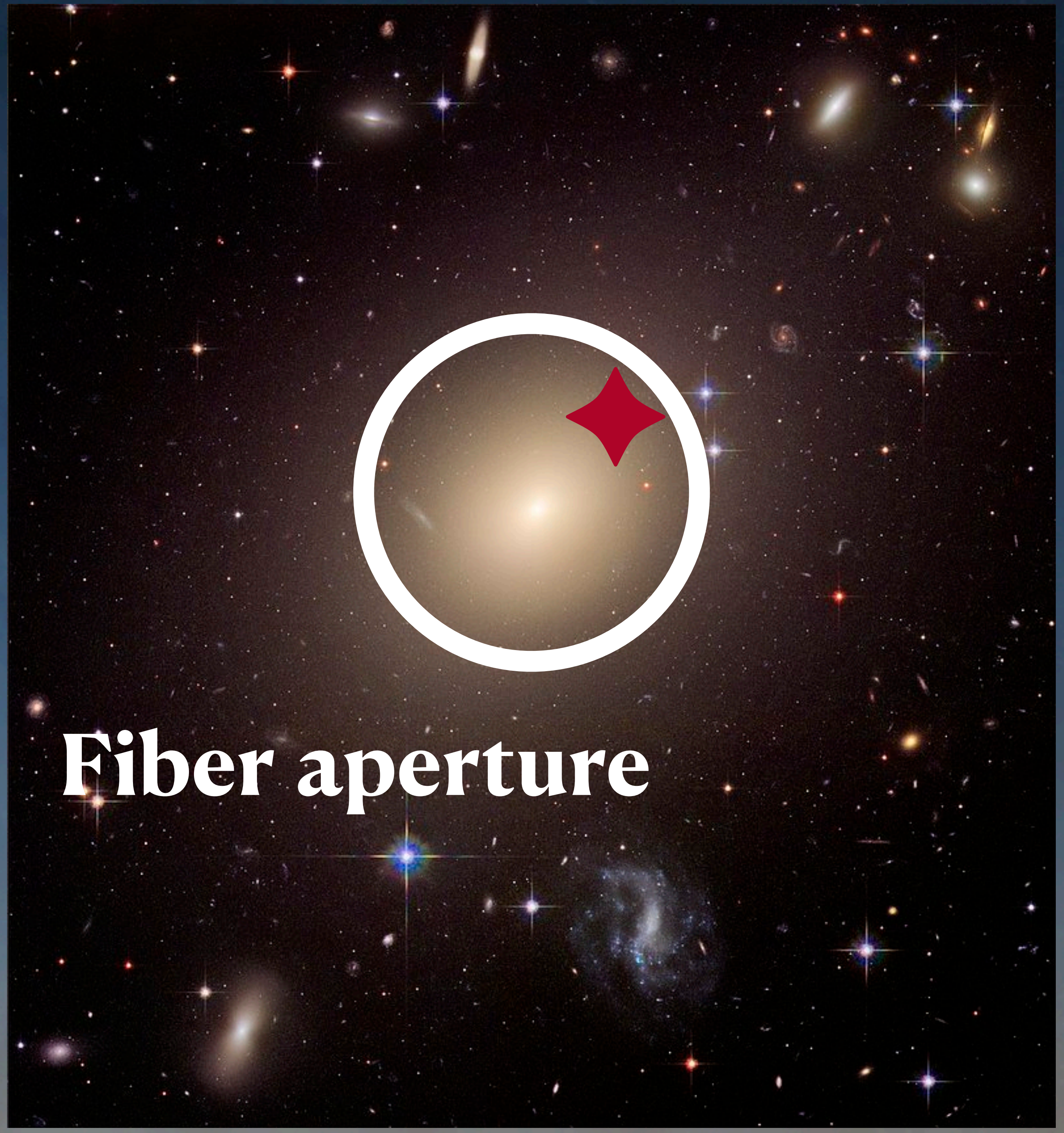

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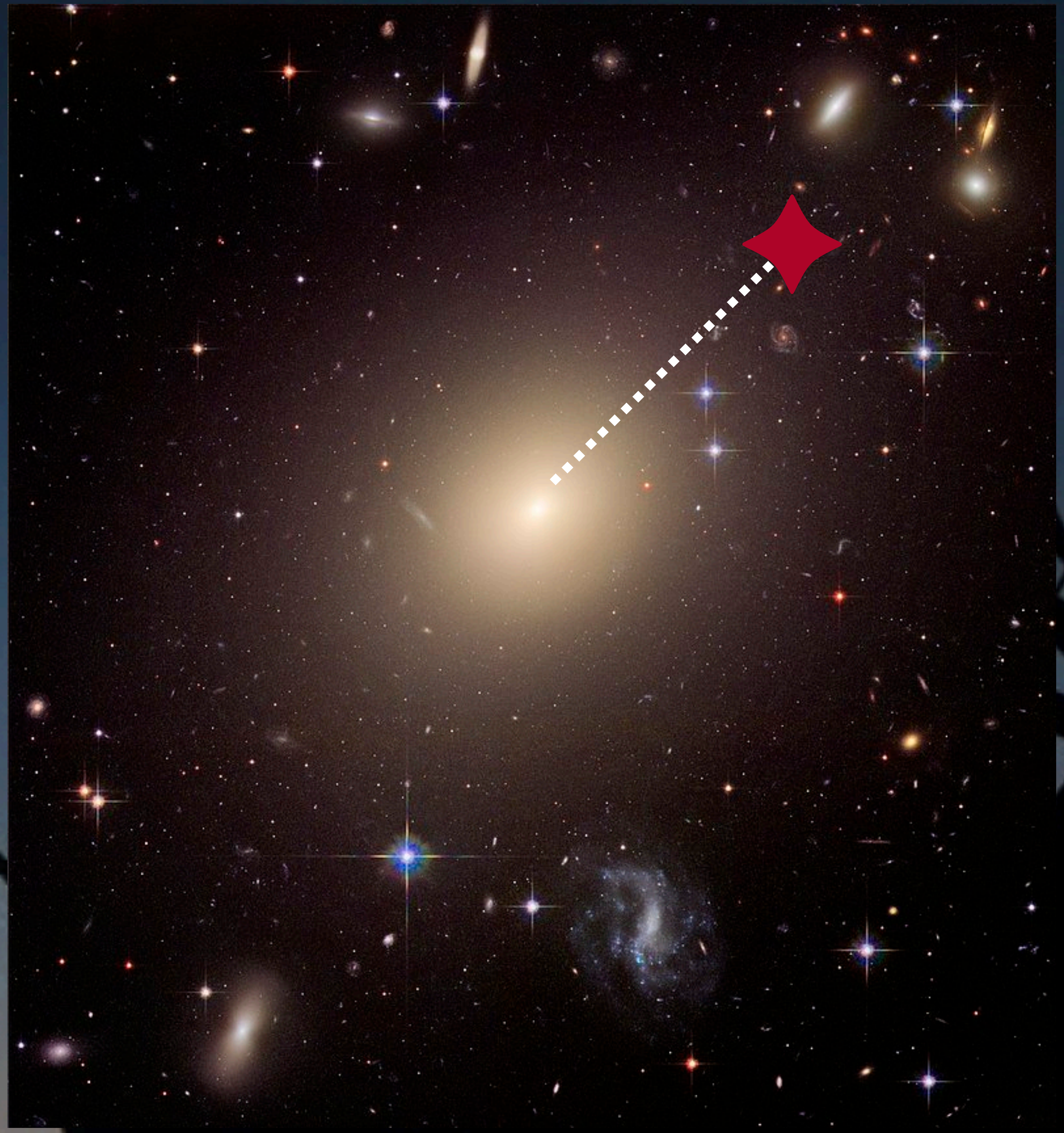

ET-WST synergy

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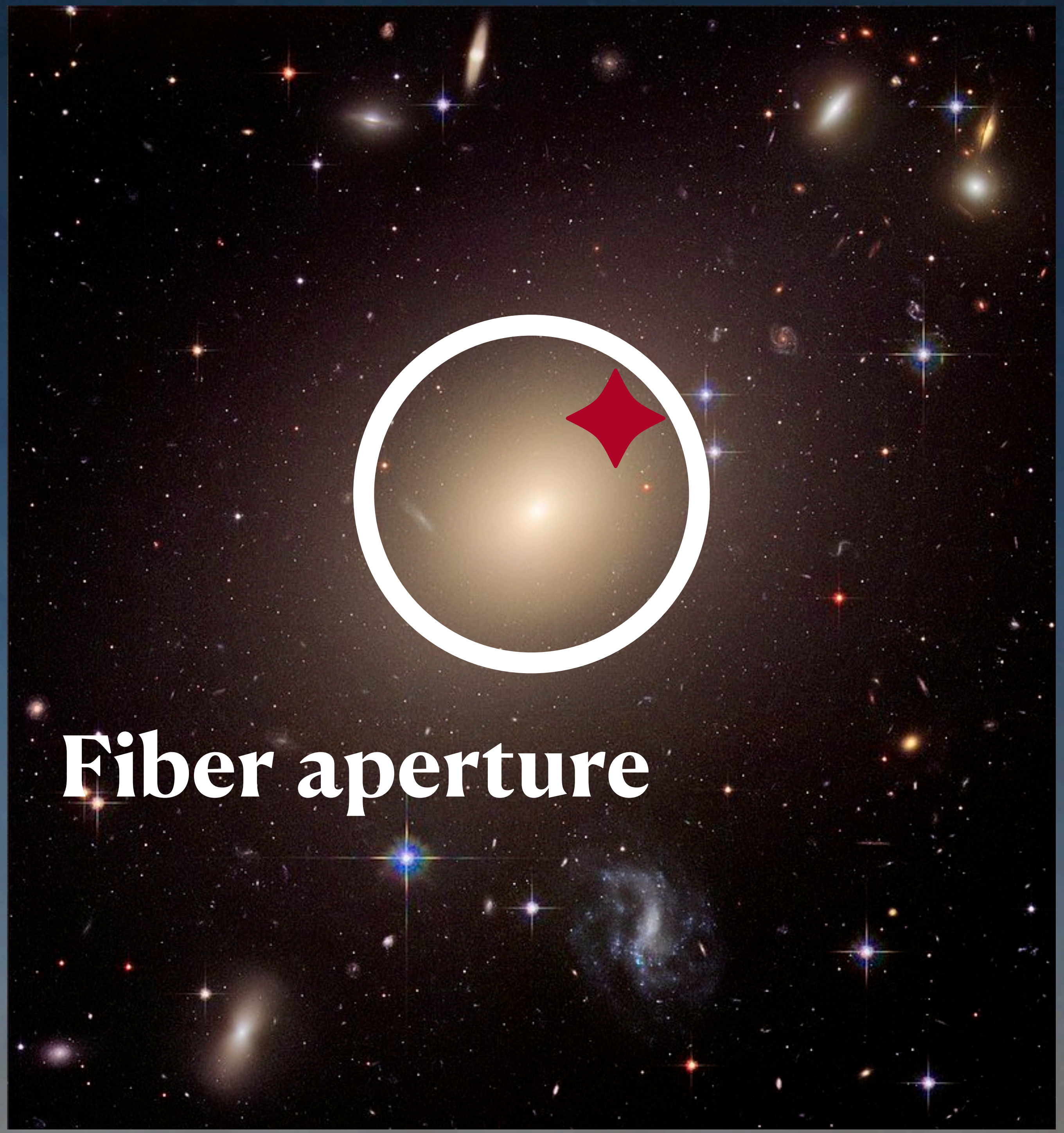

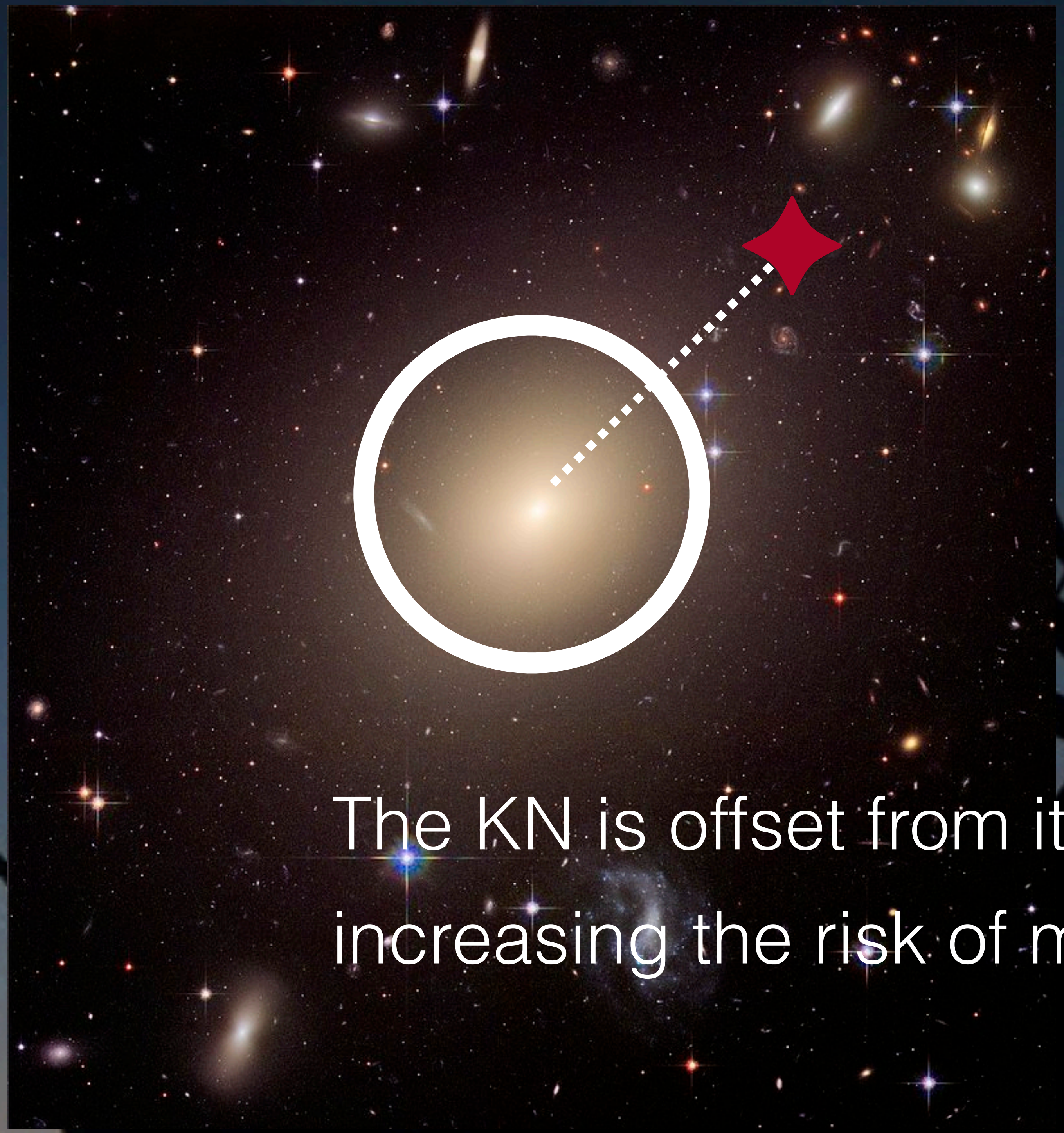

The KN is offset from its host galaxy, increasing the risk of missing the detection

ET-WST synergy

Observing strategy

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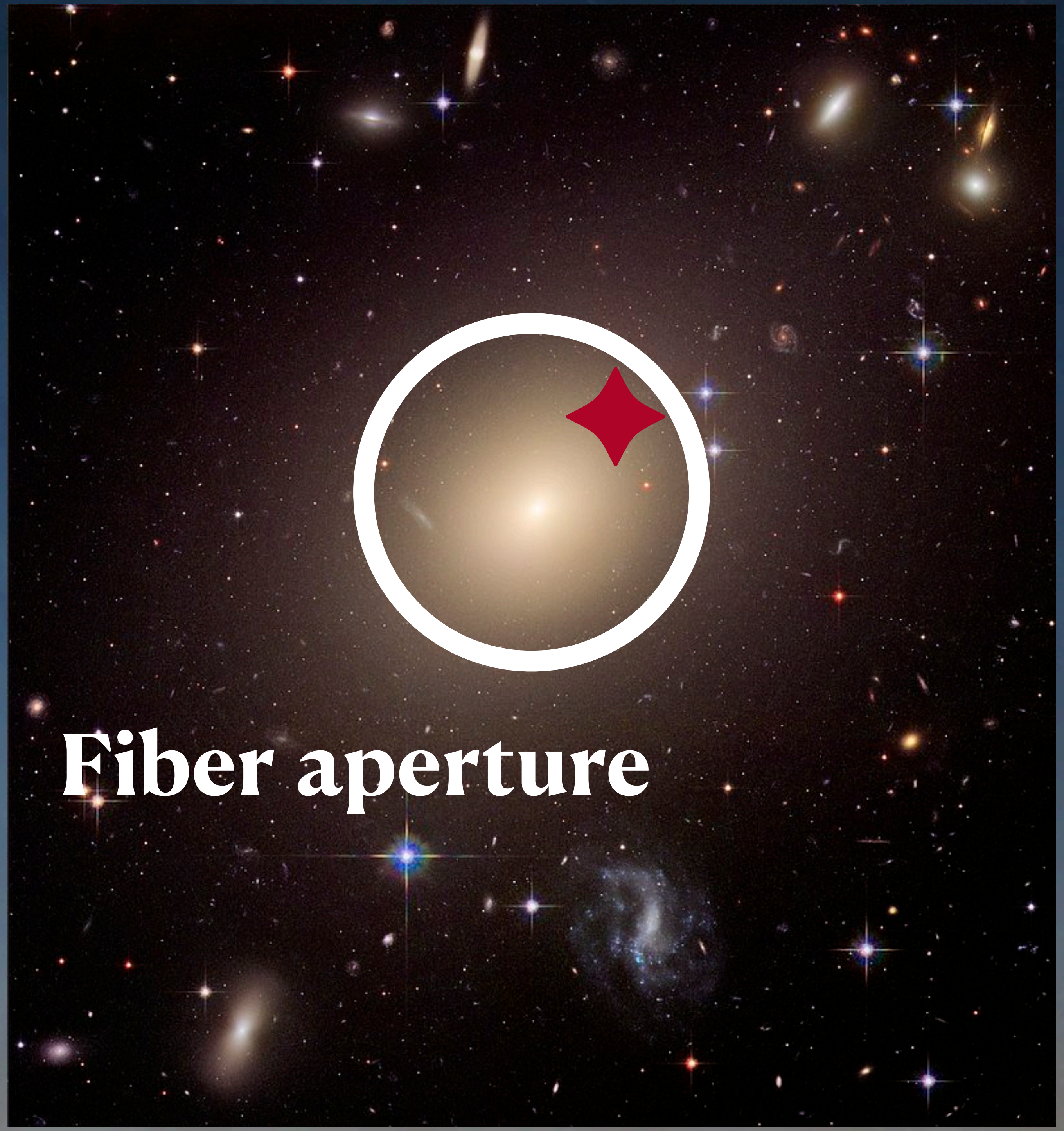

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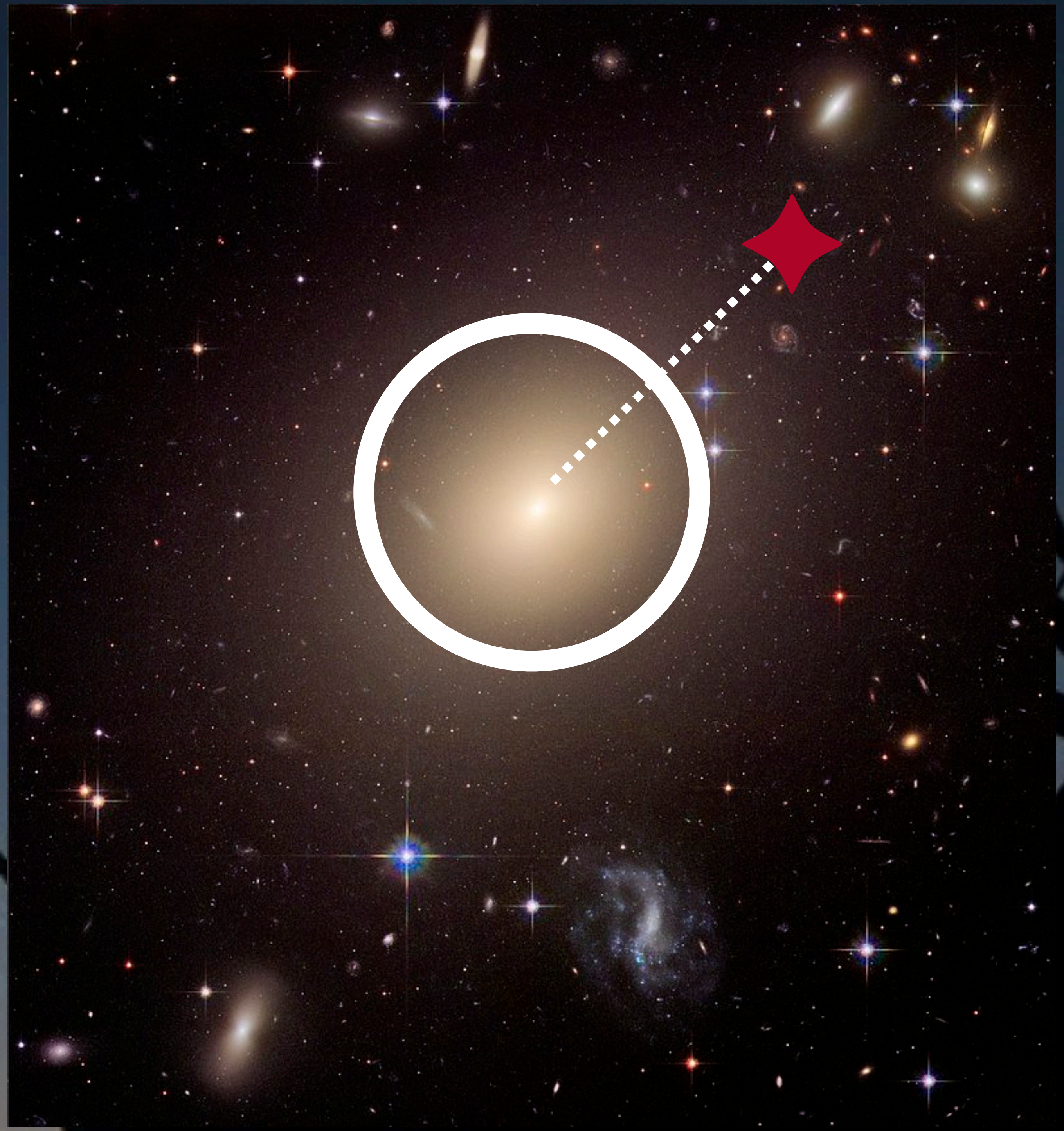
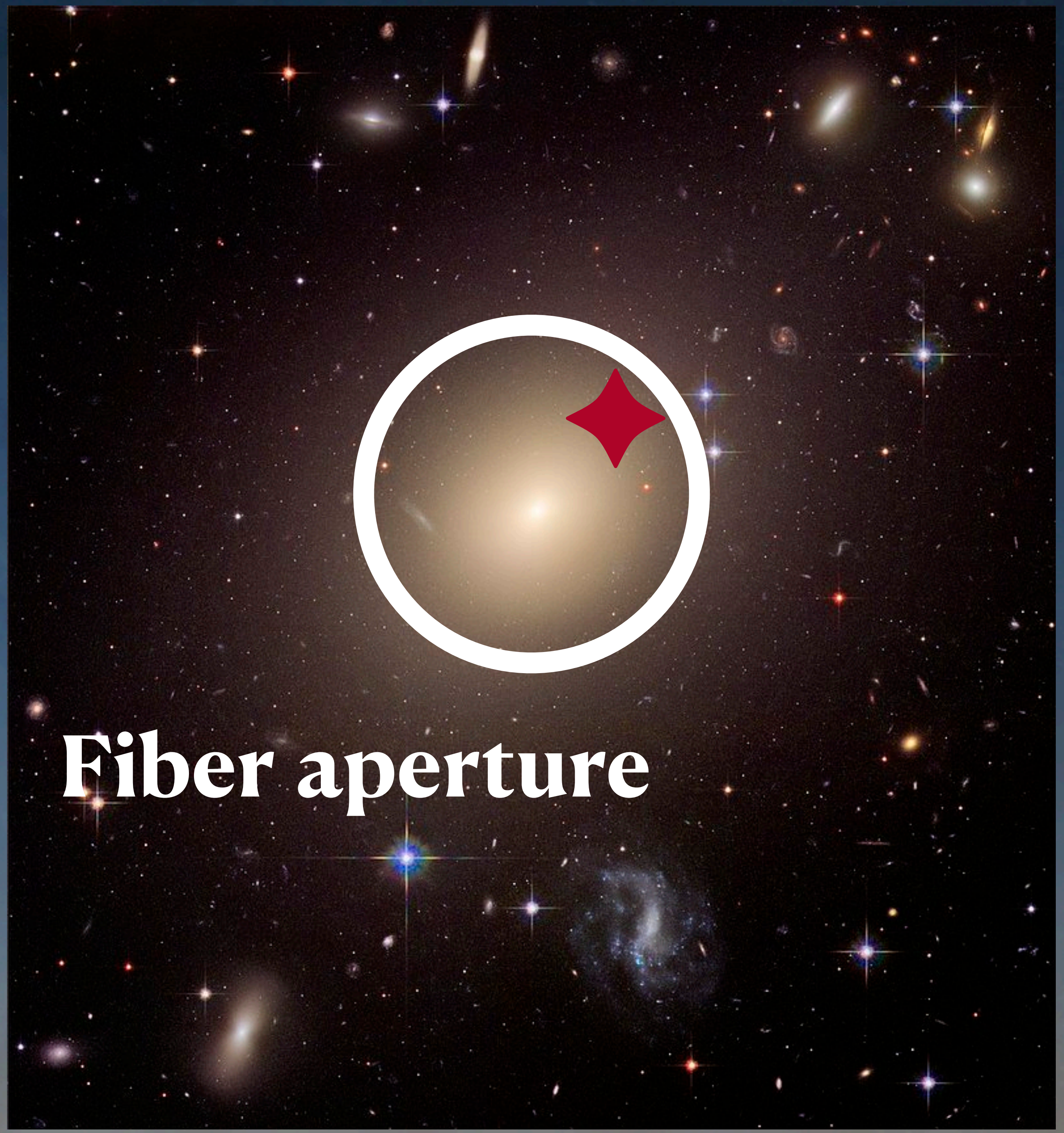


Galaxies typically brighter than KN

ET-WST synergy

Observing strategy

Possible issues with a galaxy-targeted strategy:



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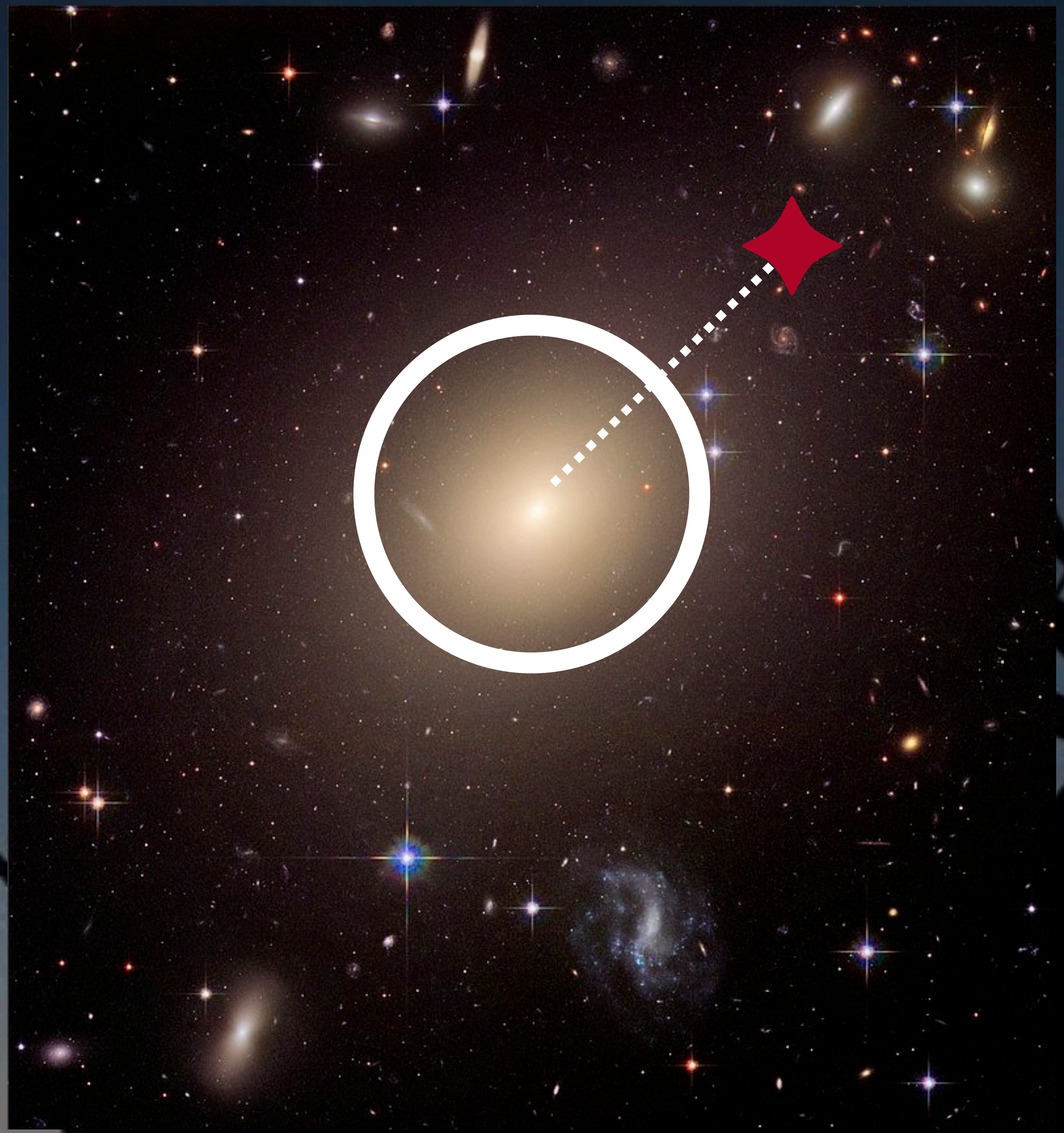


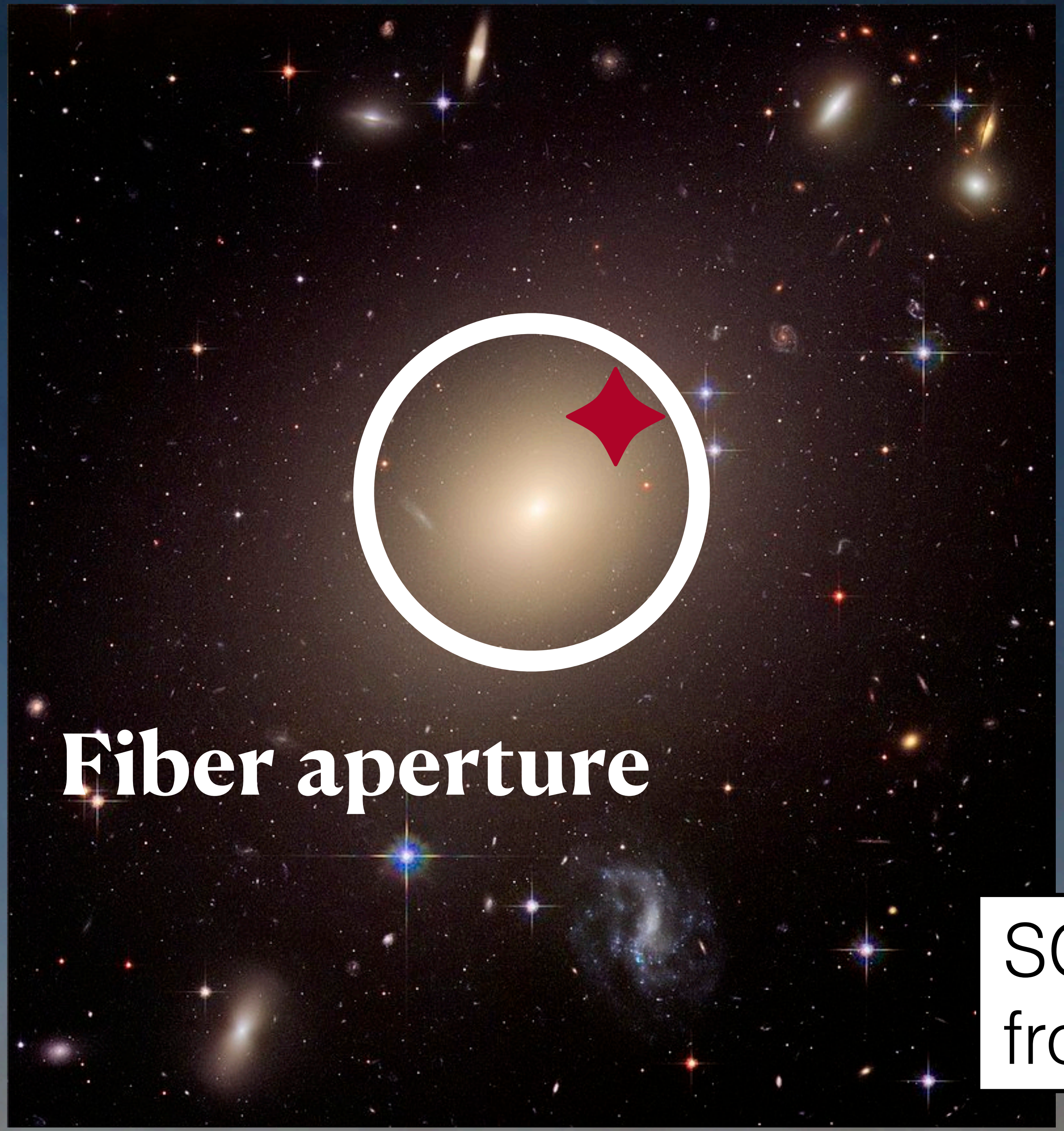
Galaxies typically brighter than KN

Spectral subtraction needed in these cases

ET-WST synergy

Observing strategy

Possible issues with a galaxy-targeted strategy:



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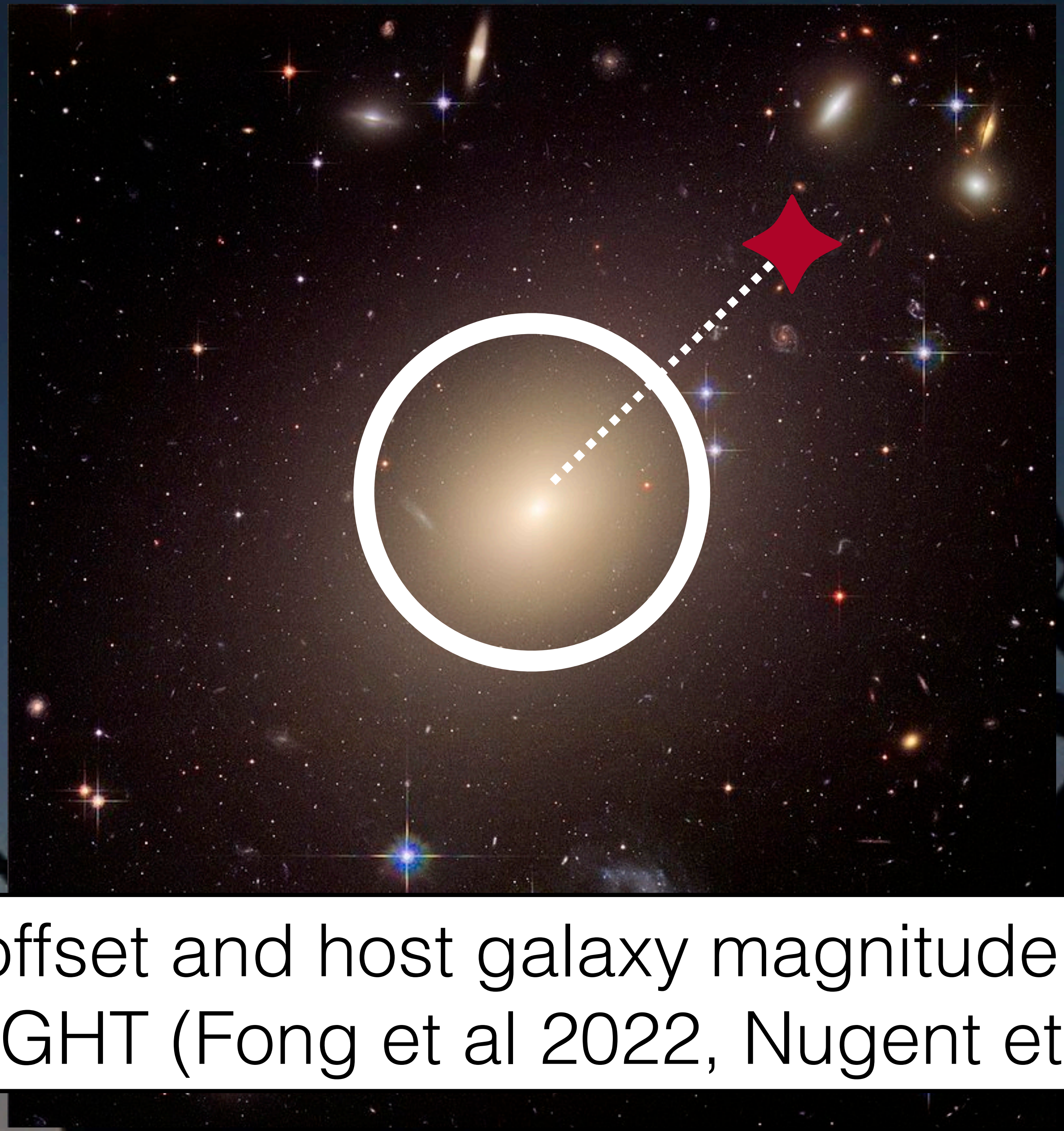


SGRBs offset and host galaxy magnitude at z<0.5 from BRIGHT (Fong et al 2022, Nugent et al 2022)

Galaxies typically brighter than KN

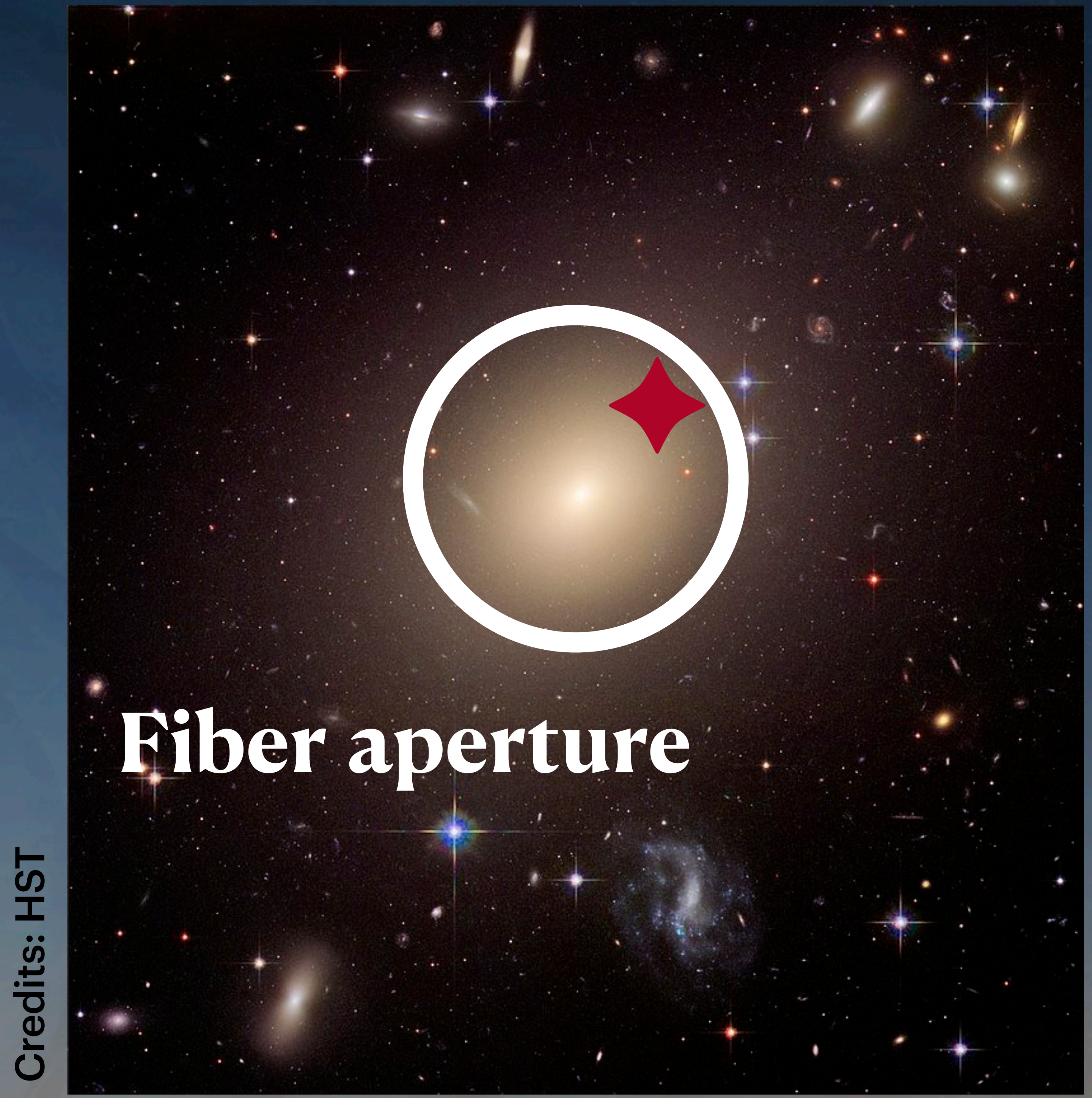
Spectral subtraction needed in these cases

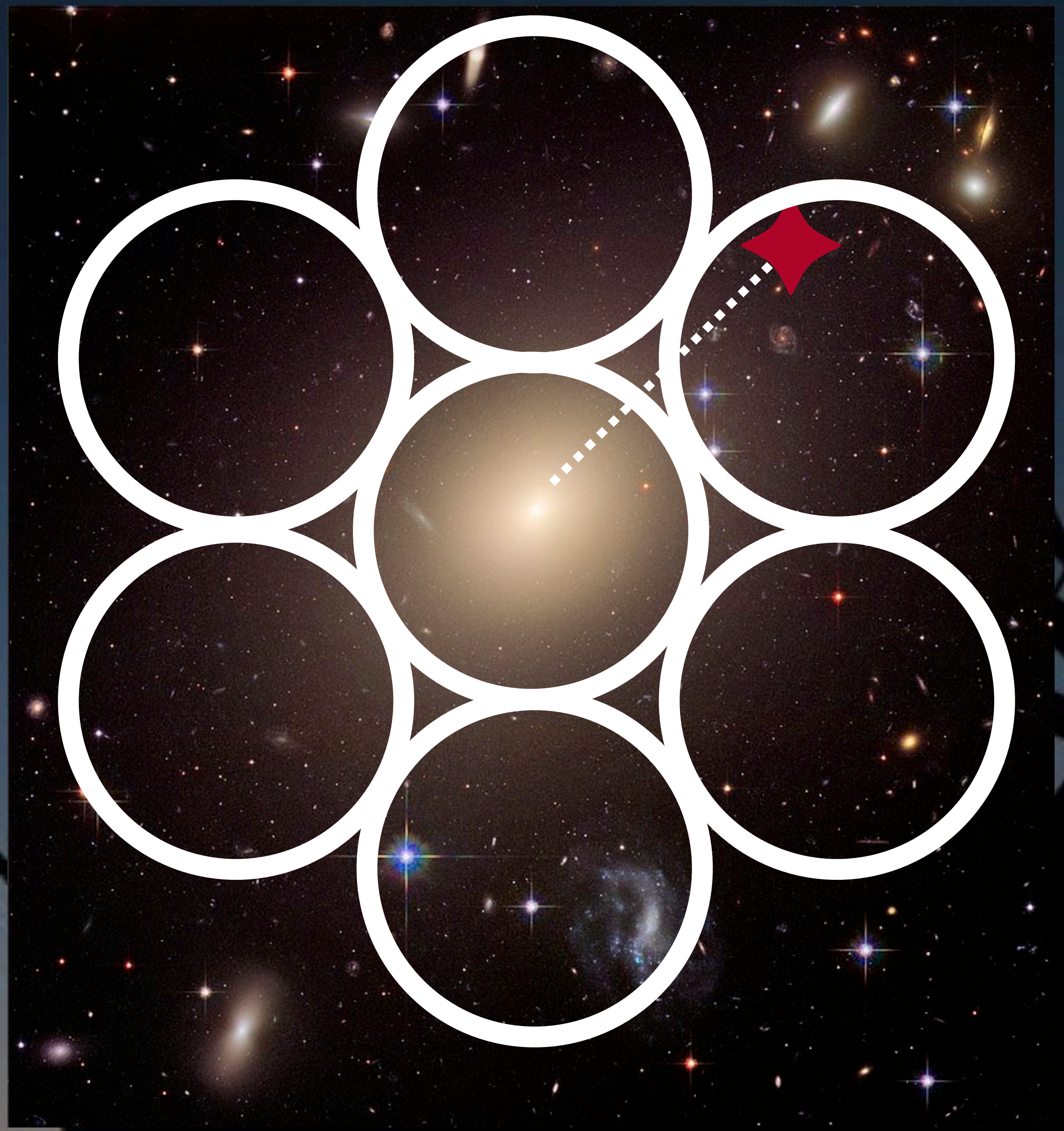
- SGRB offset is **larger than fibres aperture** and **larger than the host r_e** in most cases
- **Surface brightness** at the SGRB location is **comparable or fainter** than KN magnitude

ET-WST synergy

Observing strategy

Possible issues with a galaxy-targeted strategy:





Galaxies typically brighter than KN

Spectral subtraction needed in these cases

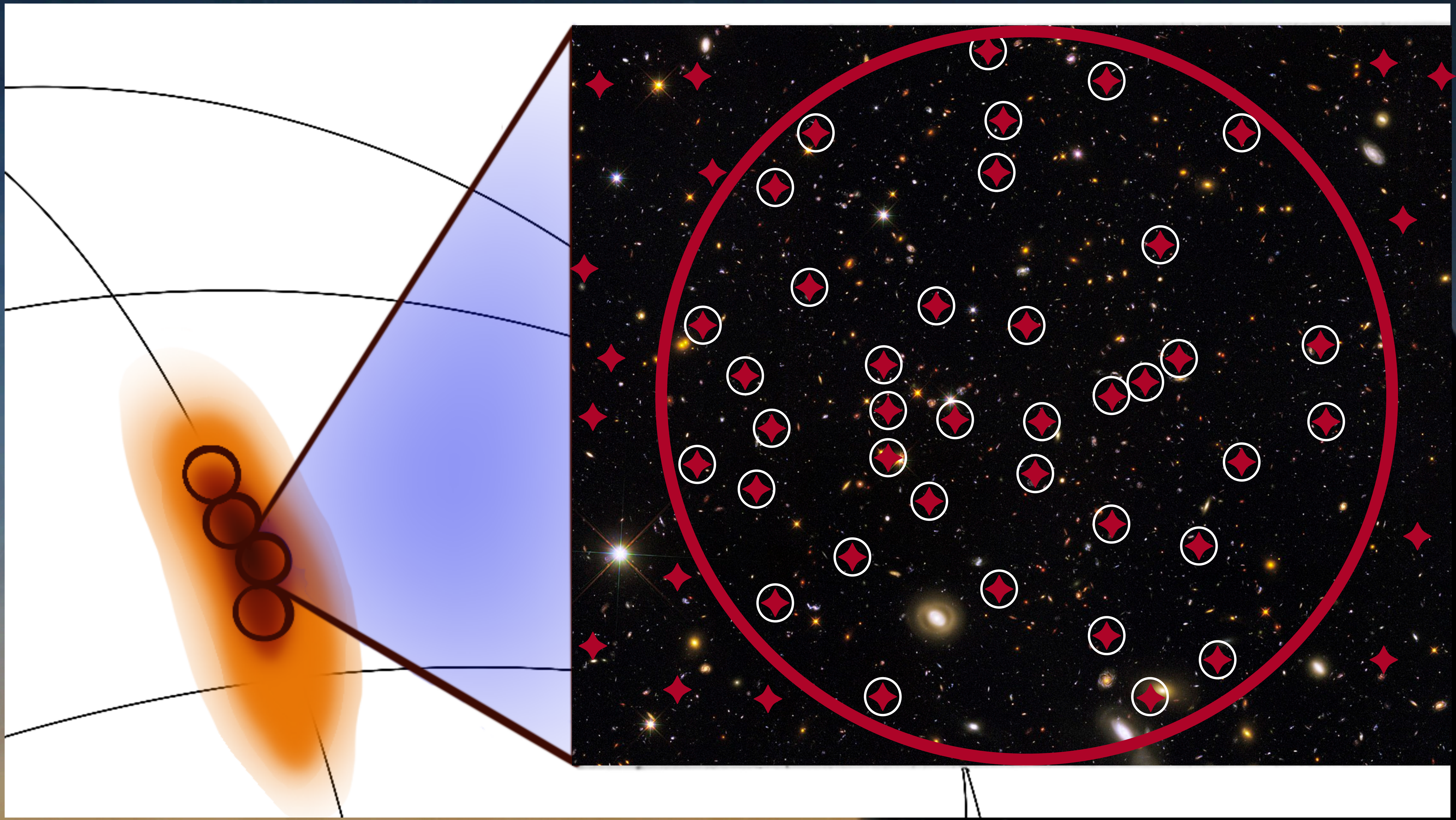
Mini-IFUs with fibres bundles would be great for handling these cases

+ IFS for the closest events

ET-WST synergy

Observing strategy

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!

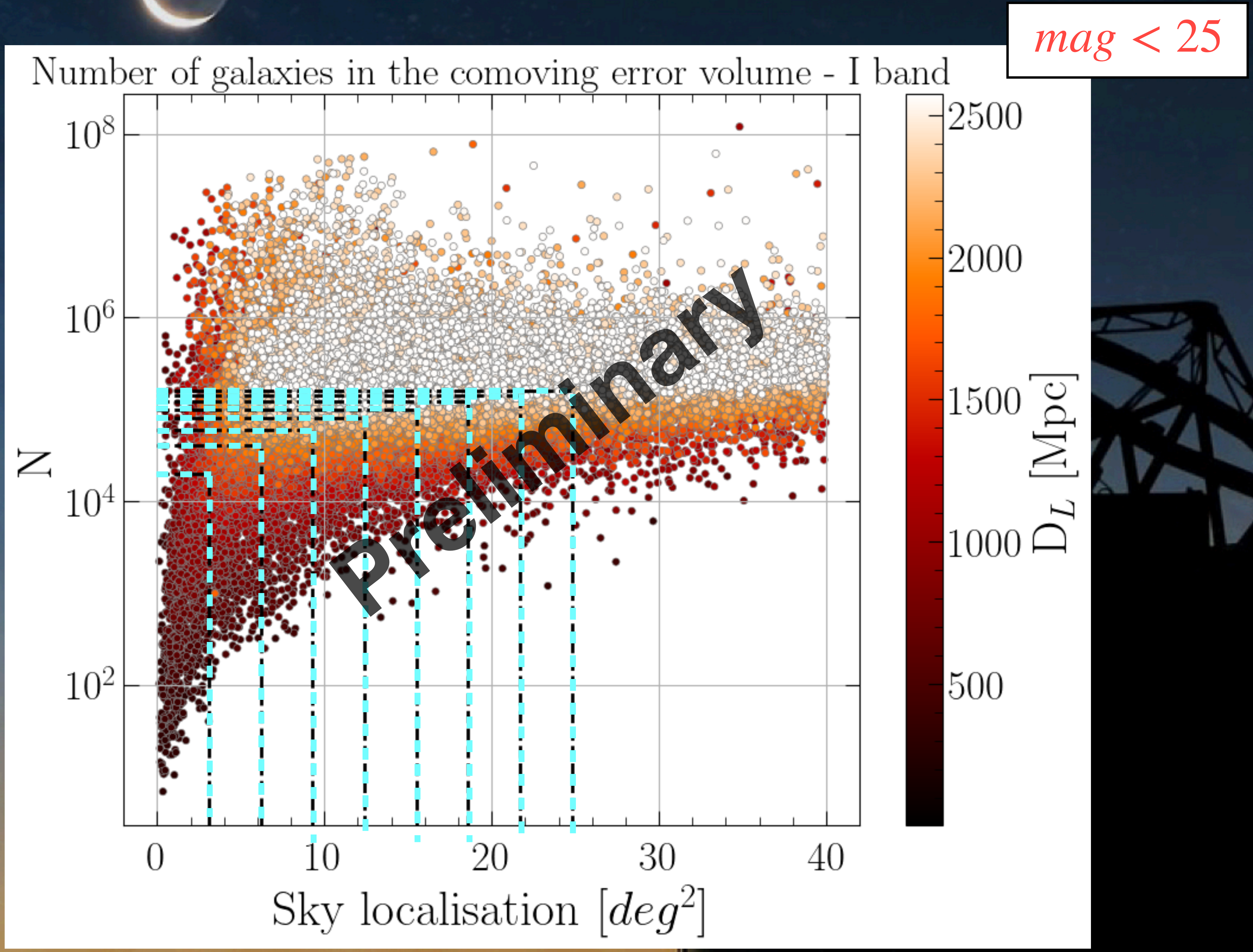
- This work can be adapted to make predictions for **LVK O5**, with IFS and MOS facilities available at the time of O5 operations

Backup

ET-WST synergy

Galaxies in the BNS comoving volume

8h



Bisero et al. 2025 in prep


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