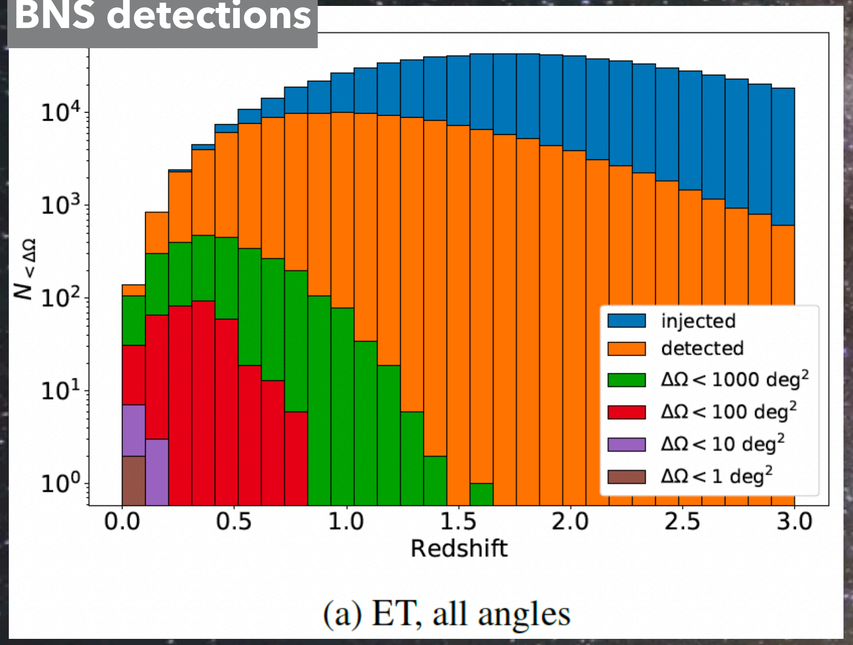
ET-WST synergy for next generation gravitational wave multi-messenger observations

Sofia Bisero
Supervisor: Susanna Vergani
GEPI, Observatoire de Paris

Credit: Anton Petrus

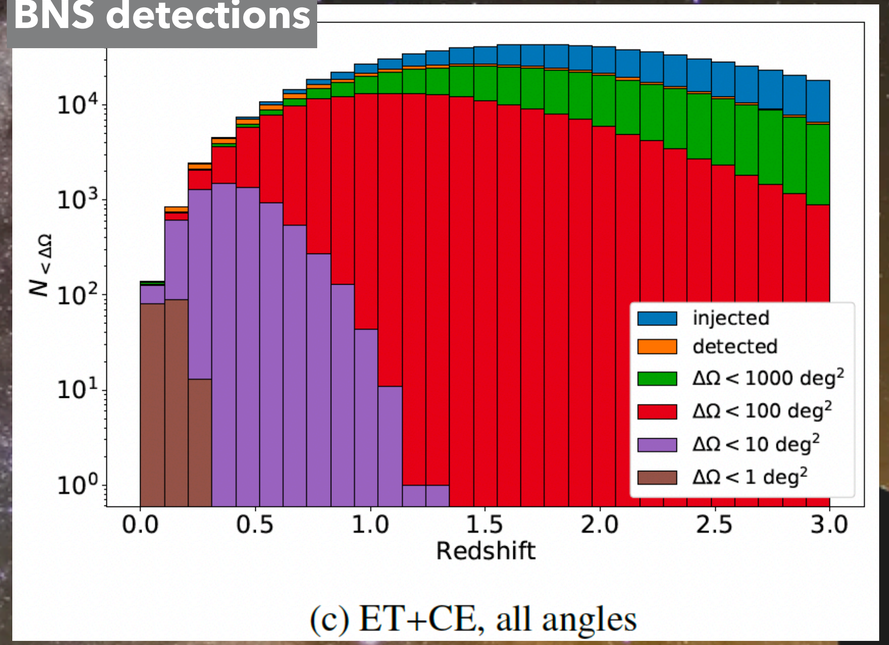
Challenges in the research of the EM counterpart of next generation GW detections

BNS detections



(a) ET, all angles

BNS detections



(c) ET+CE, all angles

Ronchini +22

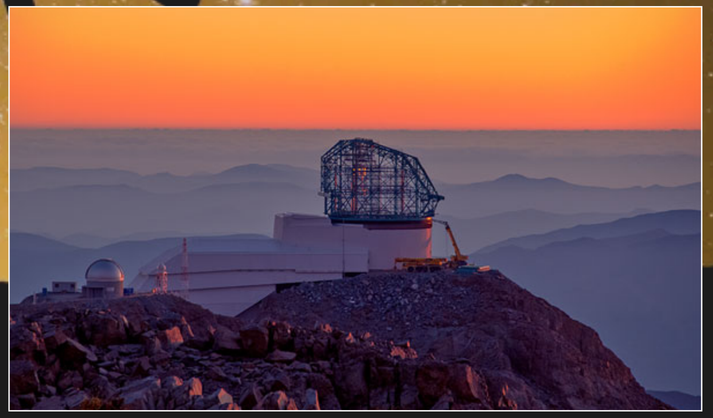
Larger volume
of the Universe explored

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**



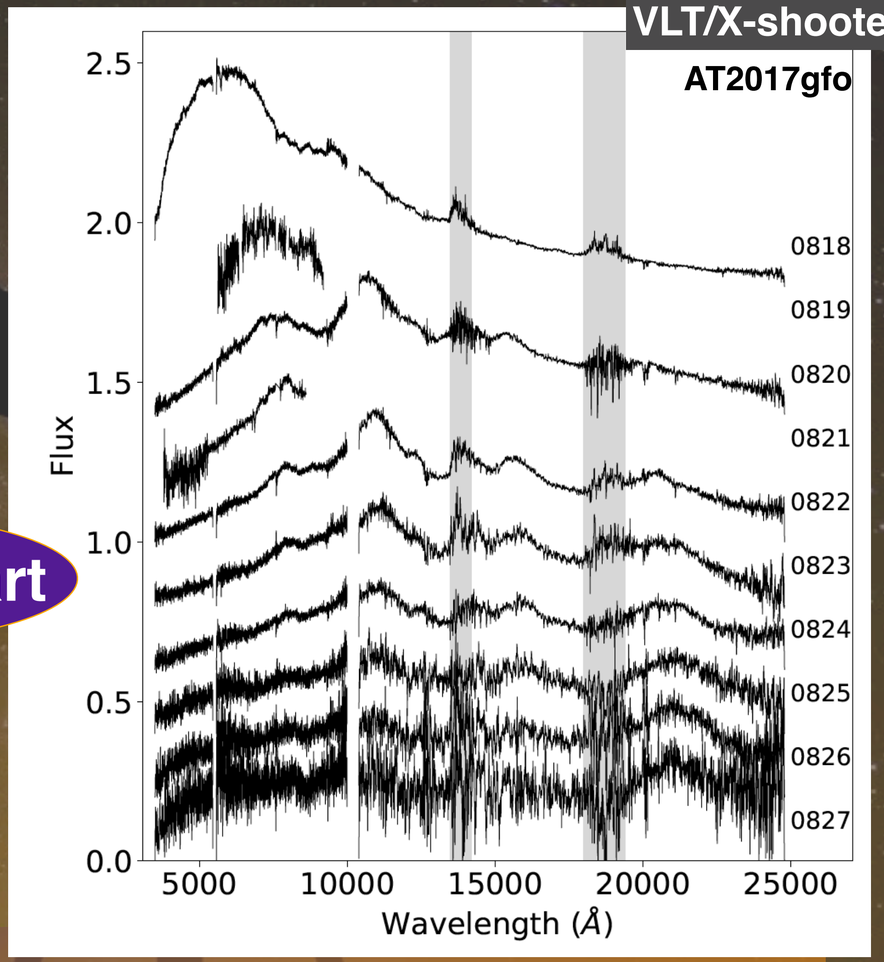
Spectroscopy: the bottleneck of gravitational wave multi-messenger science

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

Huge amount of transients in the GW error region

→ **EM counterpart**

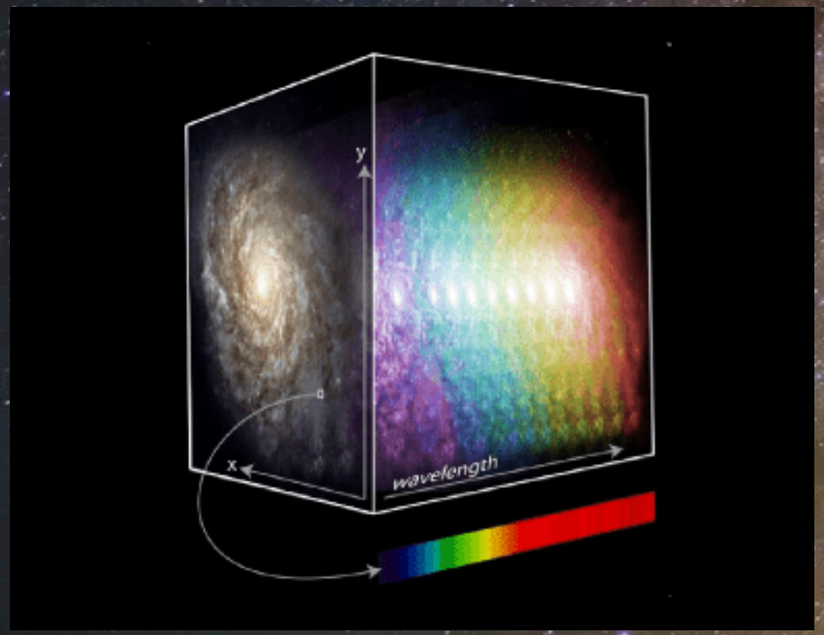
gather the **spectroscopic data** required for their **identification**



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

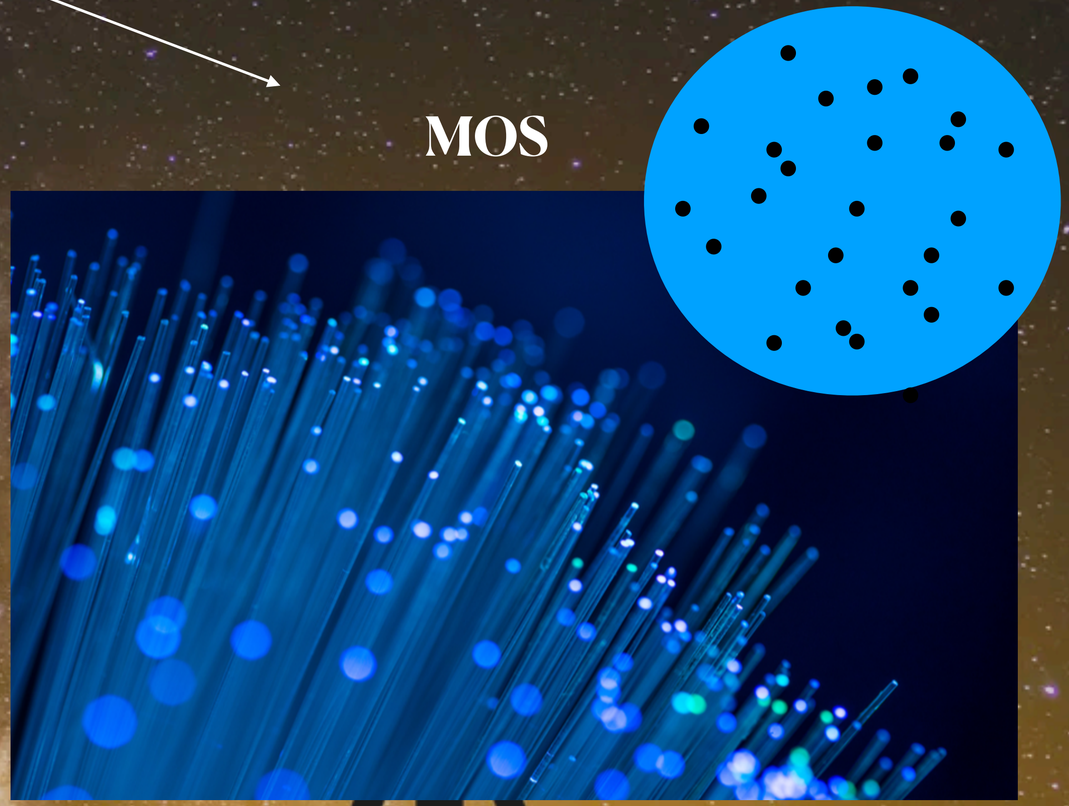
Integral Field and Multi-Object Spectroscopy

IFS



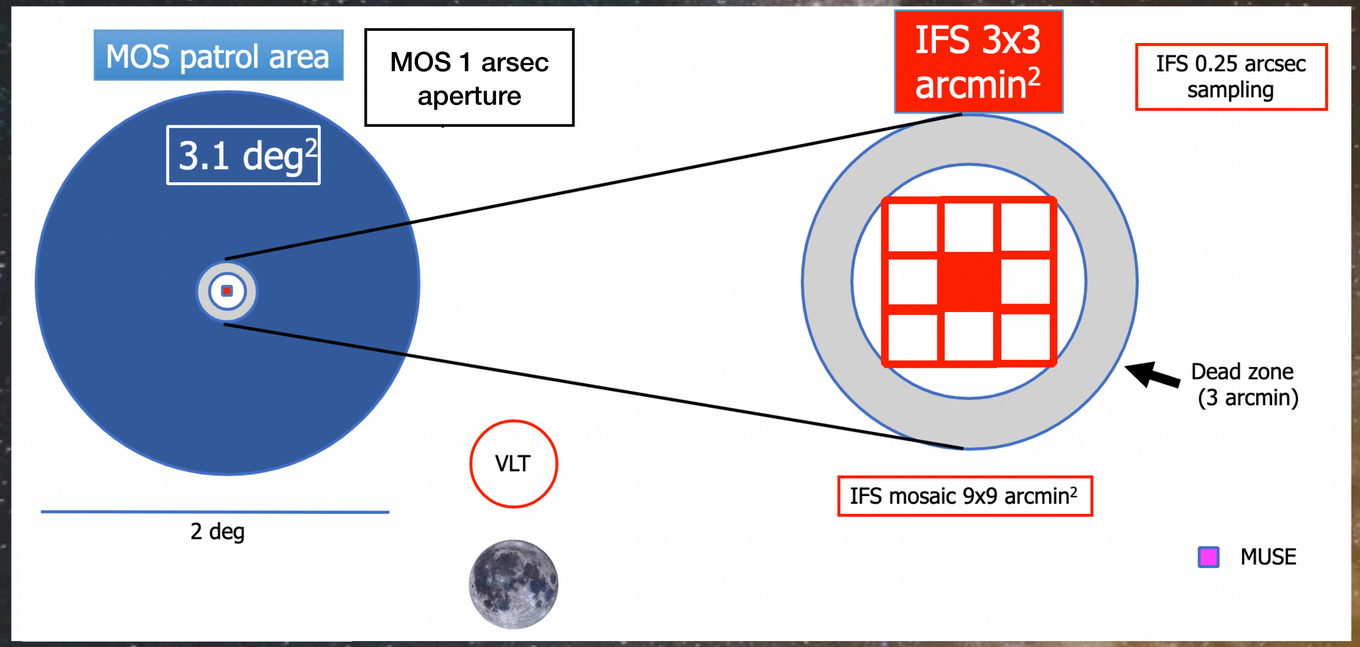
A spectrum for each pixel
of the 2D field image

MOS



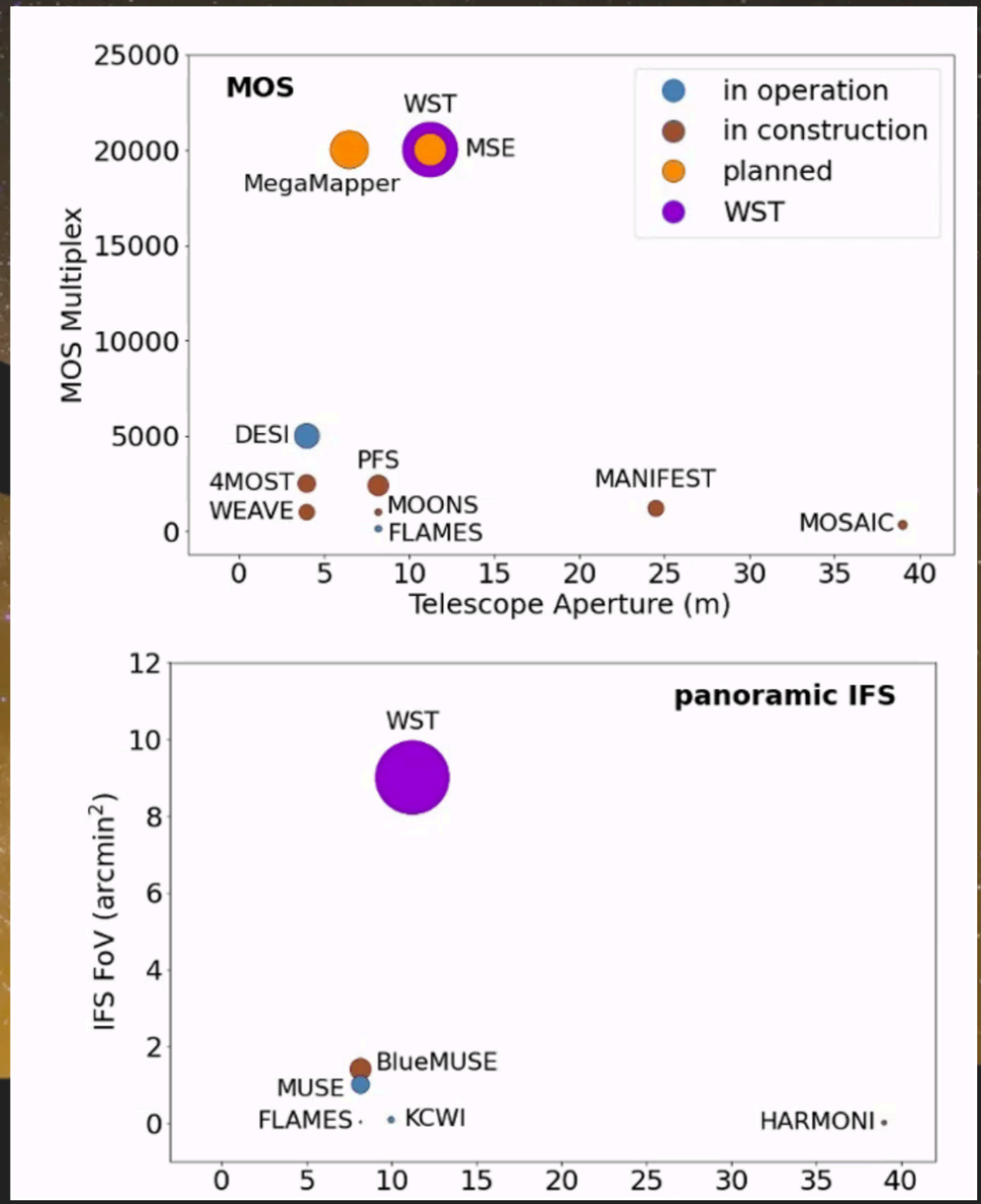
Fibres positioned on the localisation
of the sources of interest

IFU and MOS with the Wide-field Spectroscopic Telescope

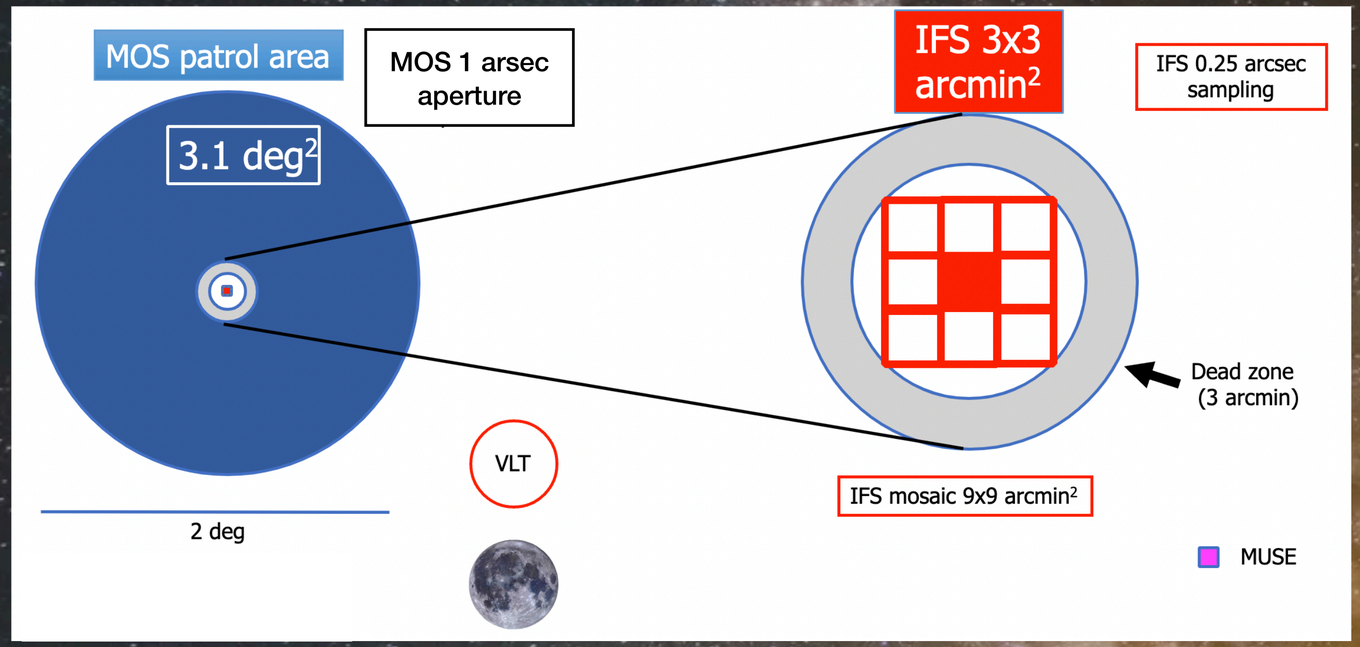


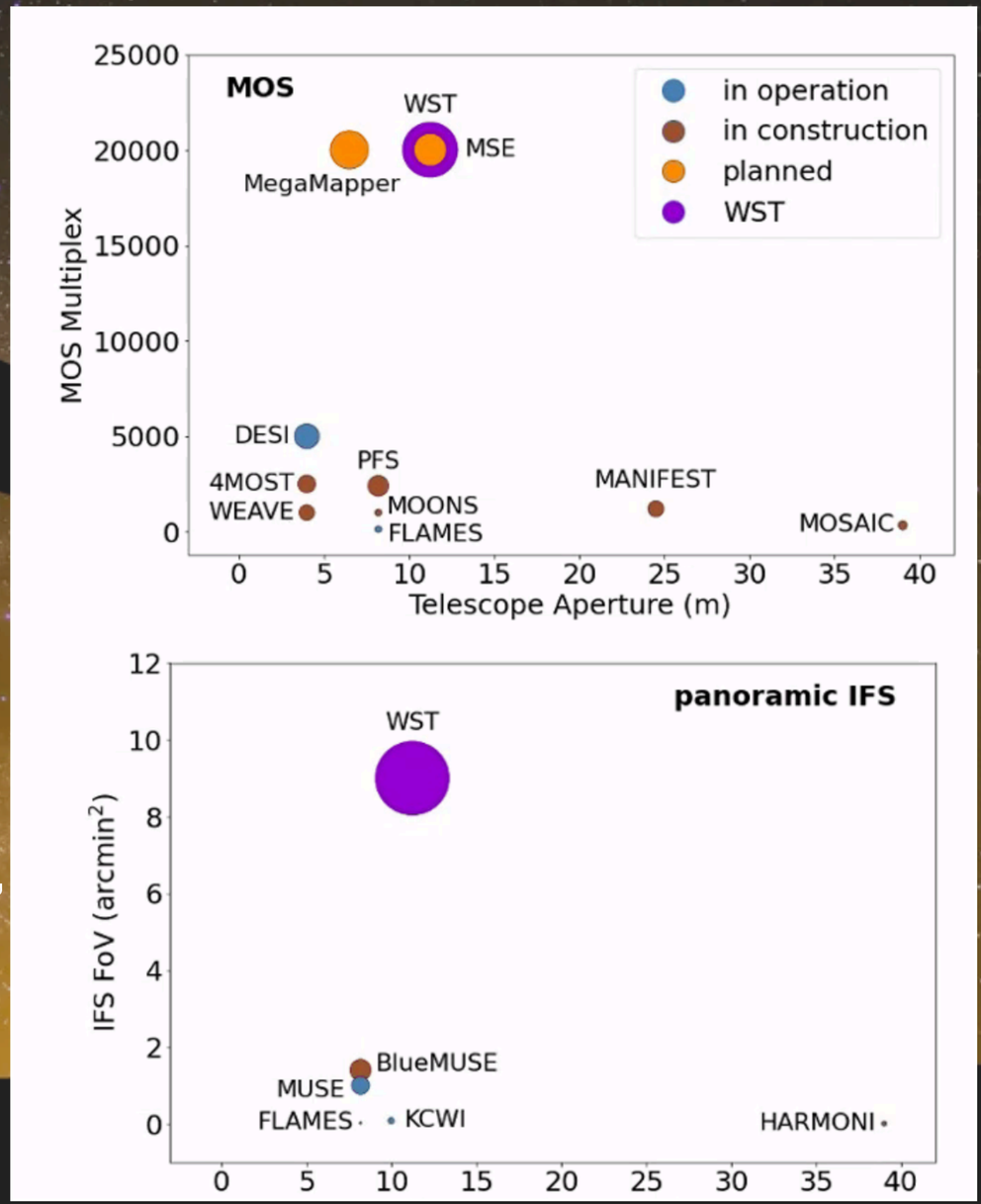
PI: Roland Bacon **(CRAL)**

- **10m** primary mirror
- **Large field of view** and high **multiplexing**
- Simultaneous **IFU** and **MOS**



IFU and MOS with the Wide-field Spectroscopic Telescope





Preparing an observing strategy

Science case within the WST Time Domain Working Group
"**WST - ET synergies for BNS multi-messenger observations**"

Division 4 of the **ET OSB:**
Multimessenger Observations

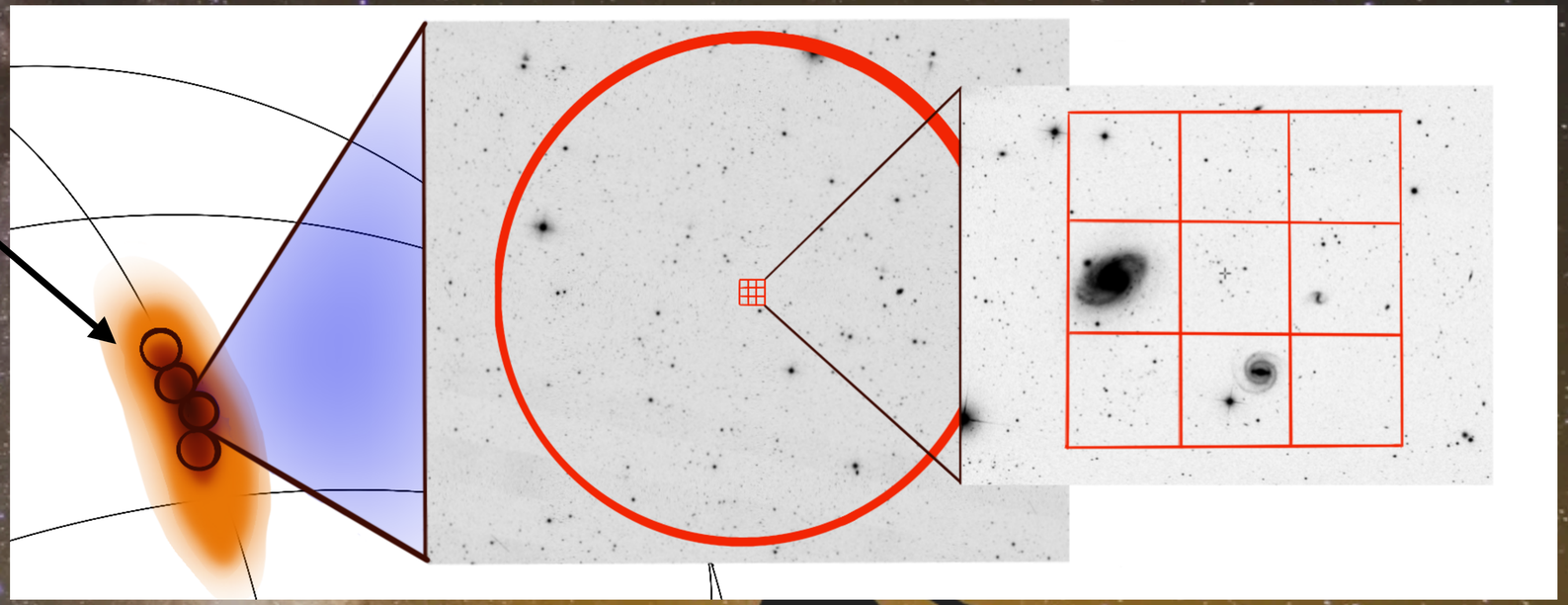
IFU and MOS with the Wide-field Spectroscopic Telescope

Preparing the observing strategy

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

Credits: WST White Paper



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?

IFU and MOS with WST: simulations

GSSI group

G S
S I

ET BNS populations

G S
S I

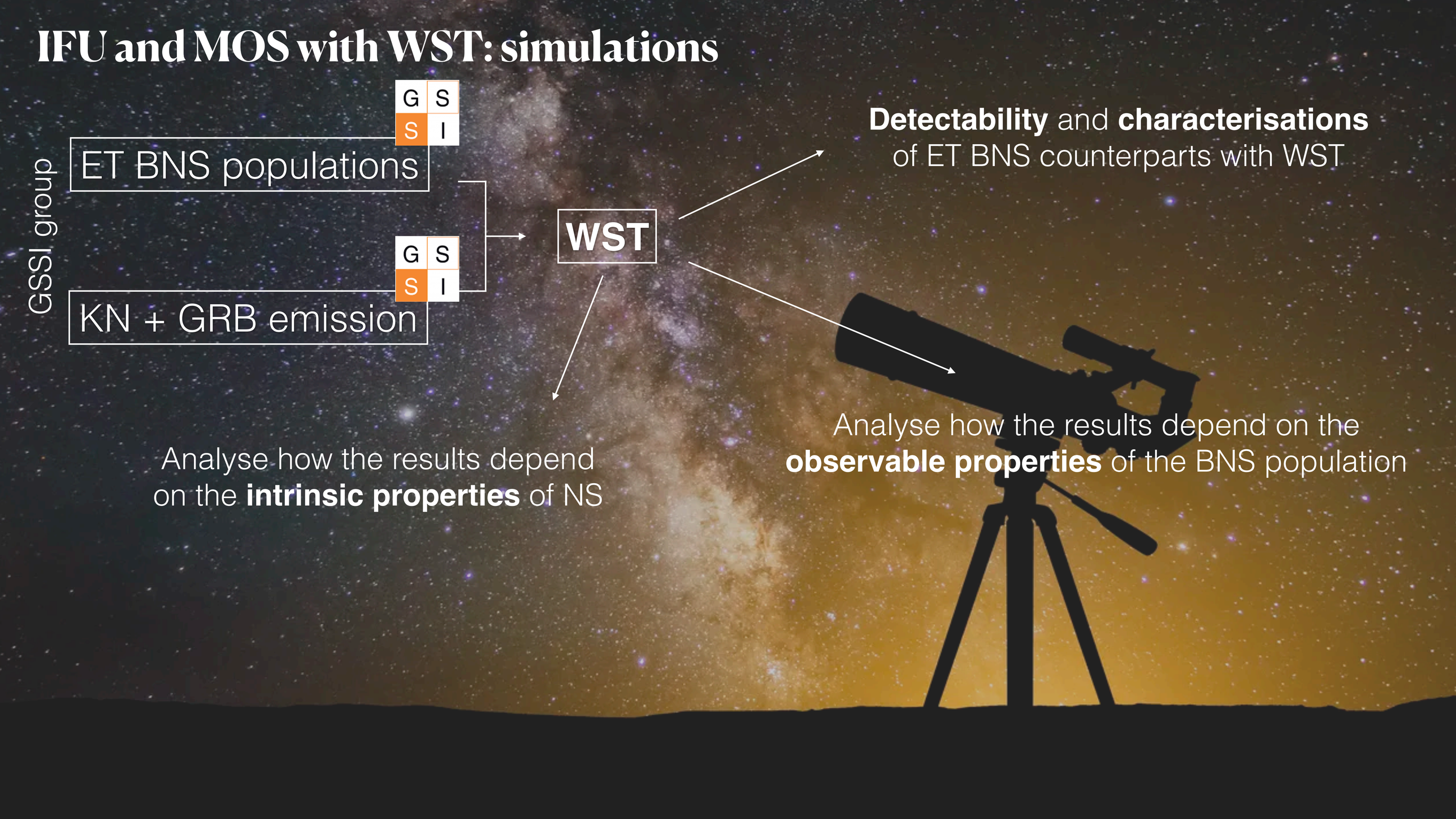
KN + GRB emission

WST

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

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

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



IFU and MOS with WST: simulations

GSSI group

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ET BNS populations

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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

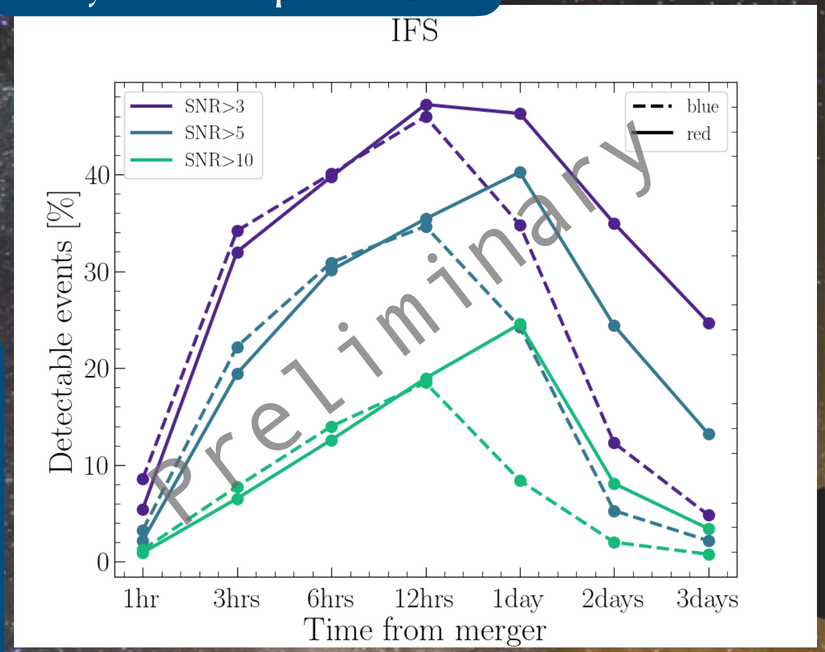
1 year of ET operations

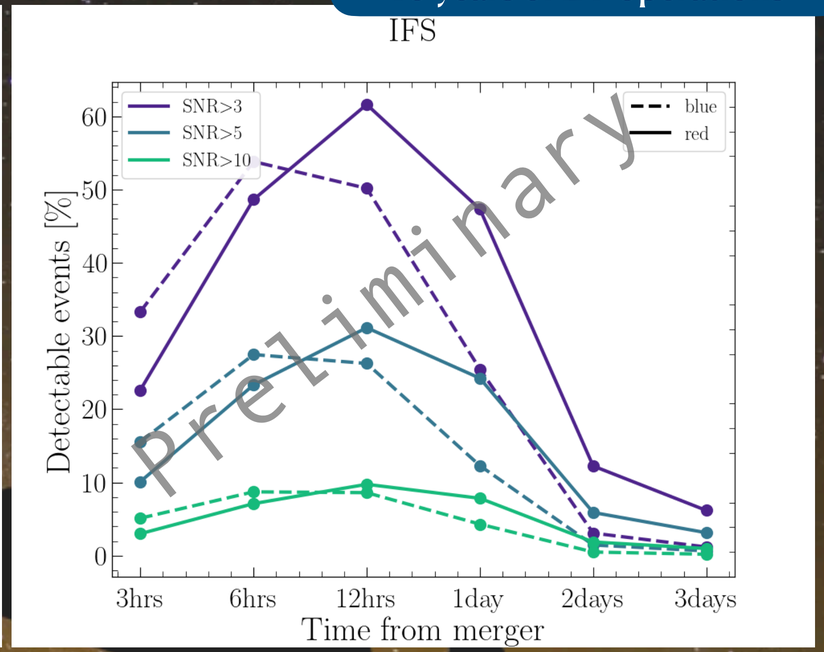
10 years of ET operations

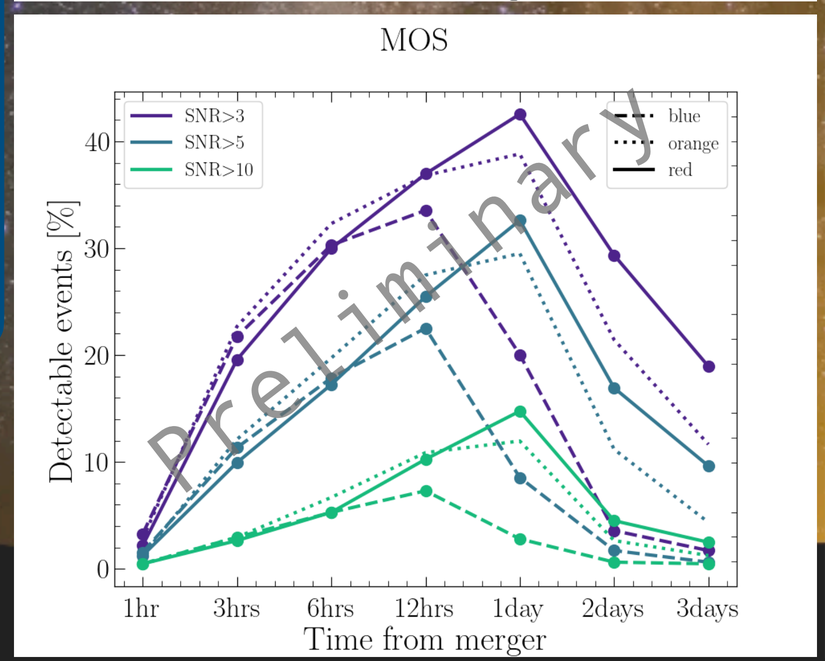
AT2017gfo KN model

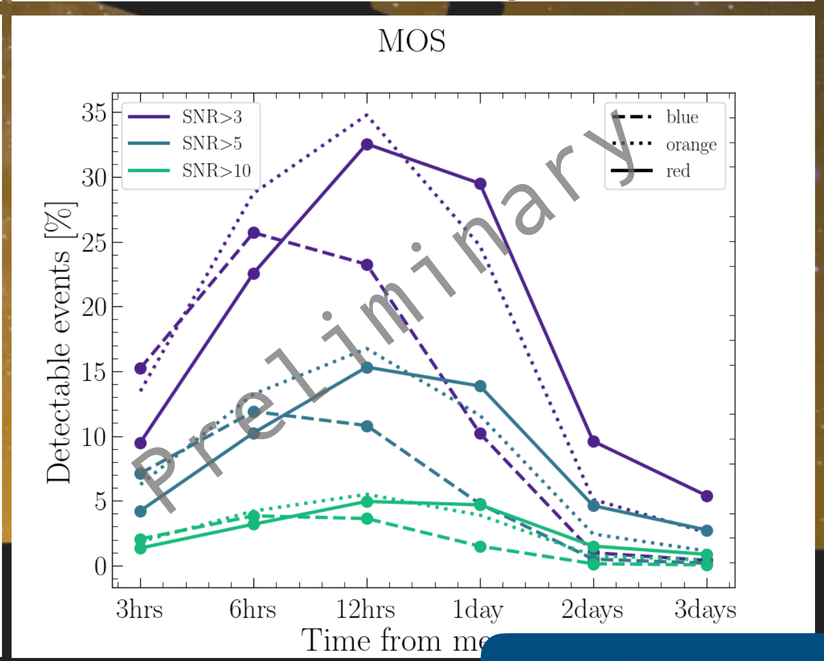
KN theoretical models

BLh gaussian



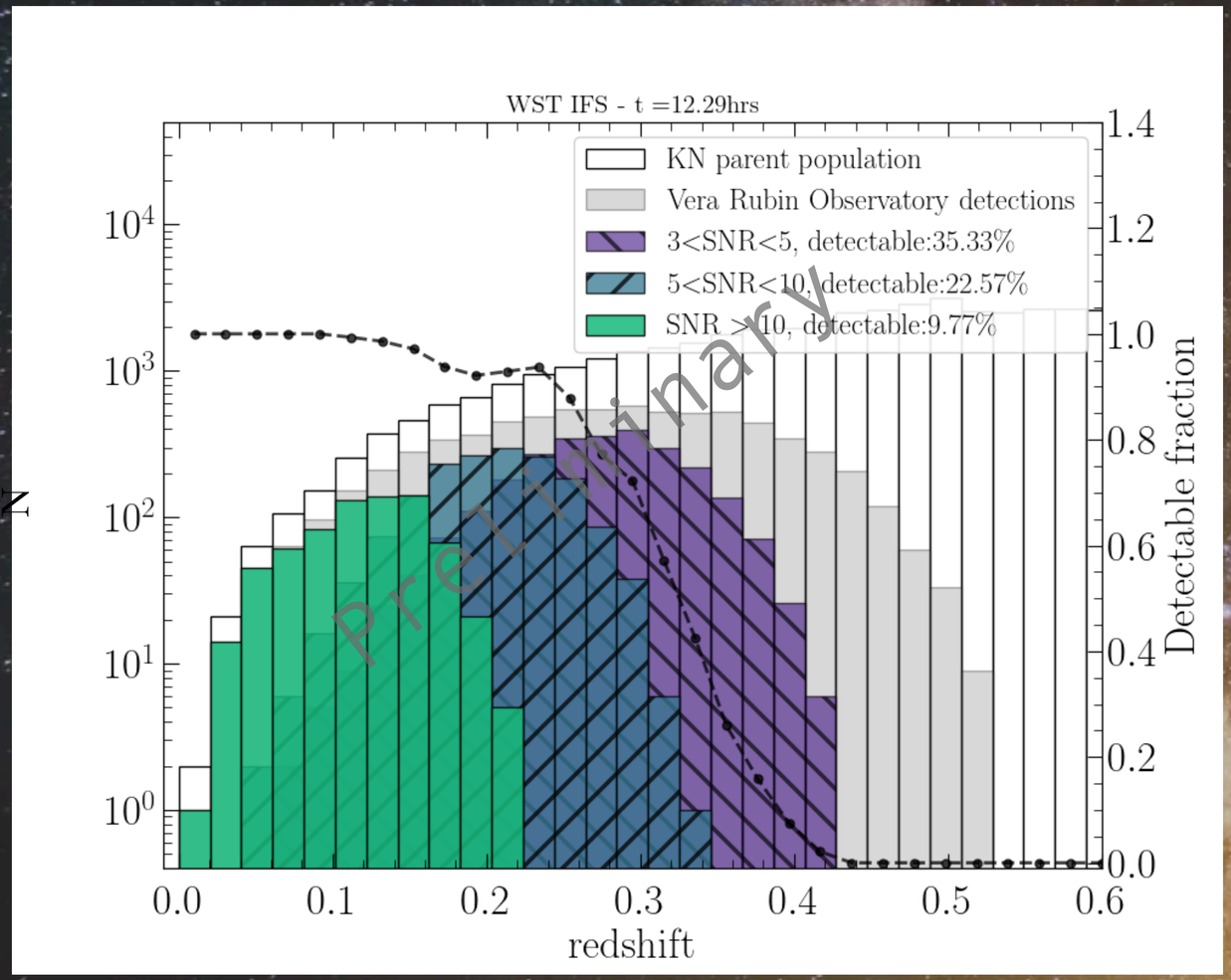


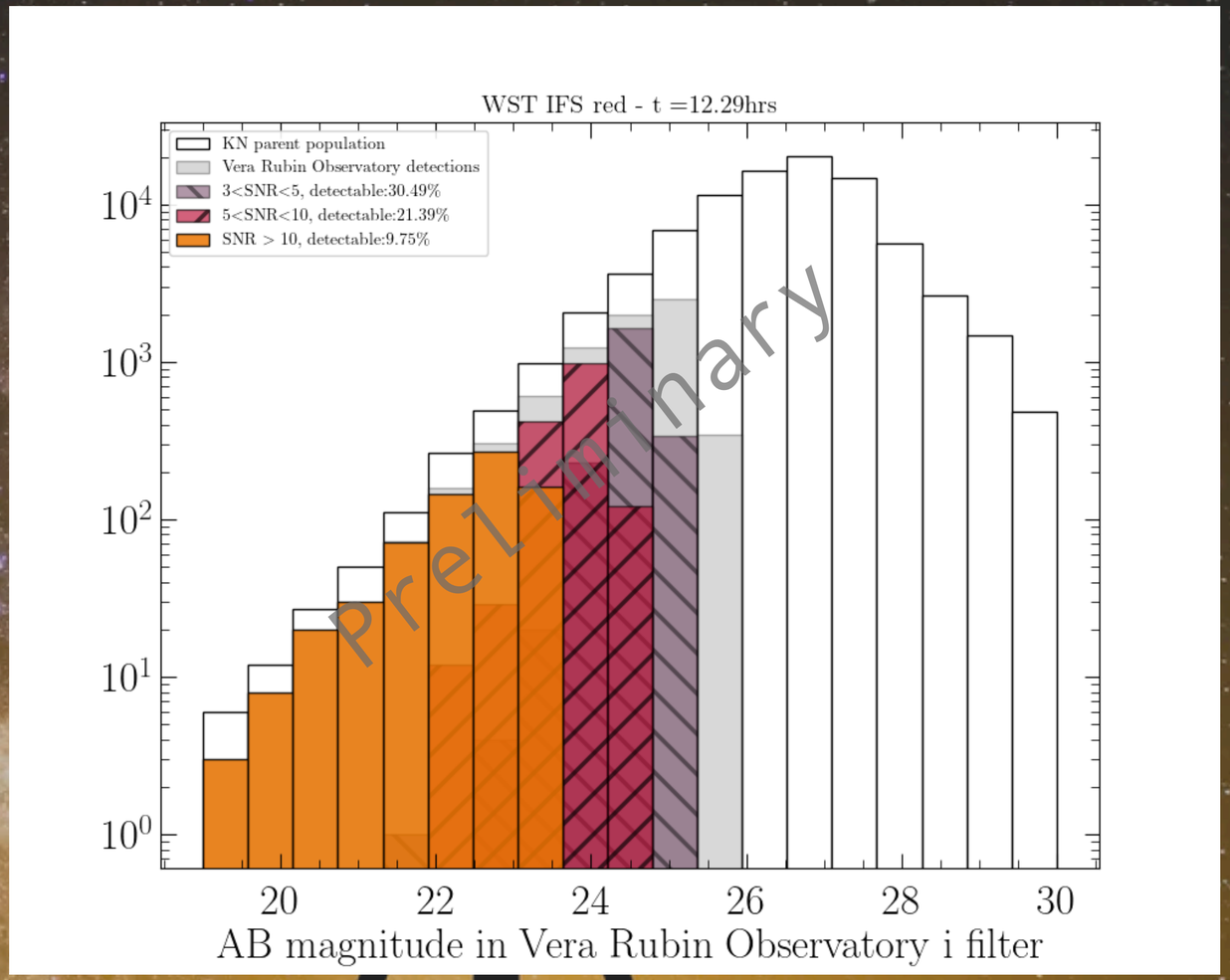




ET-WST synergy

Simulations



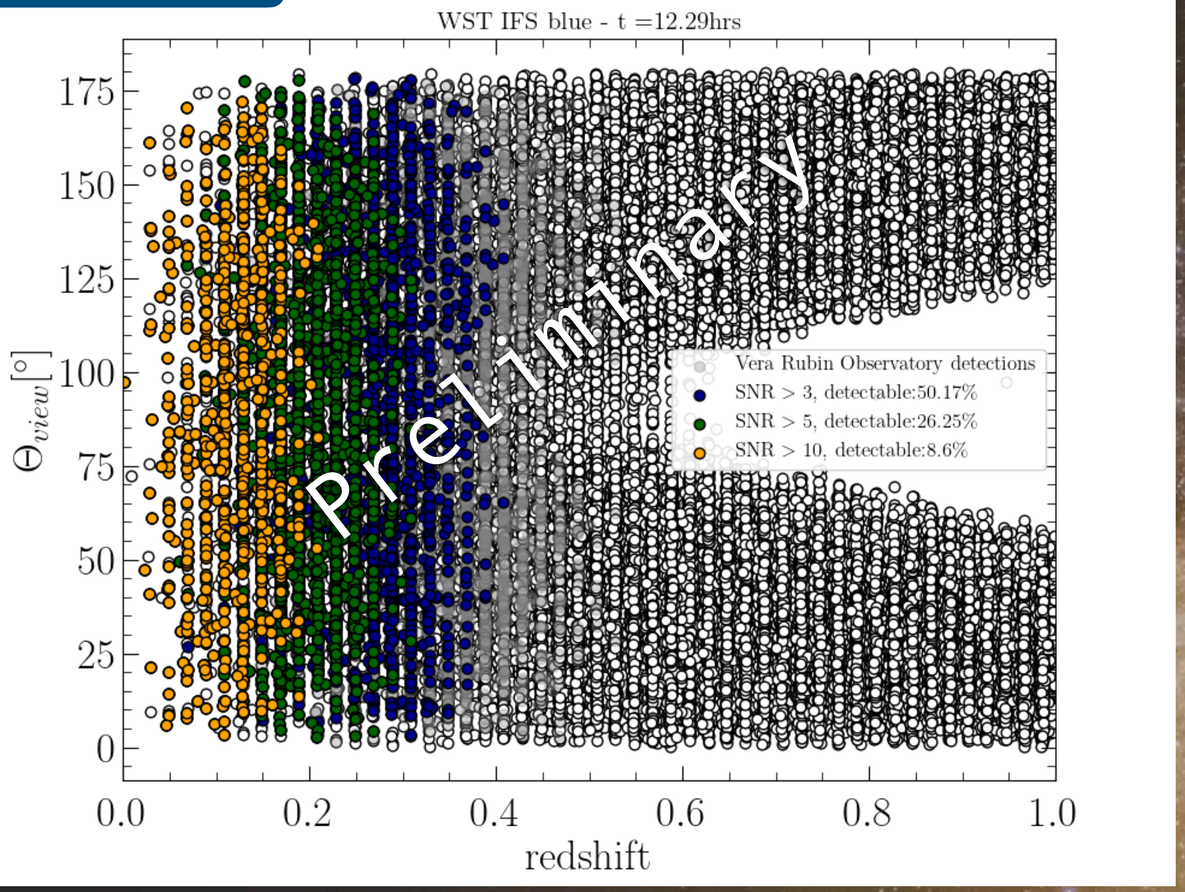


White: ET+CE **BNS** detections in **10 years** of operations
Grey: Vera Rubin Observatory **KN** detections
Colored: WST **KN** detections

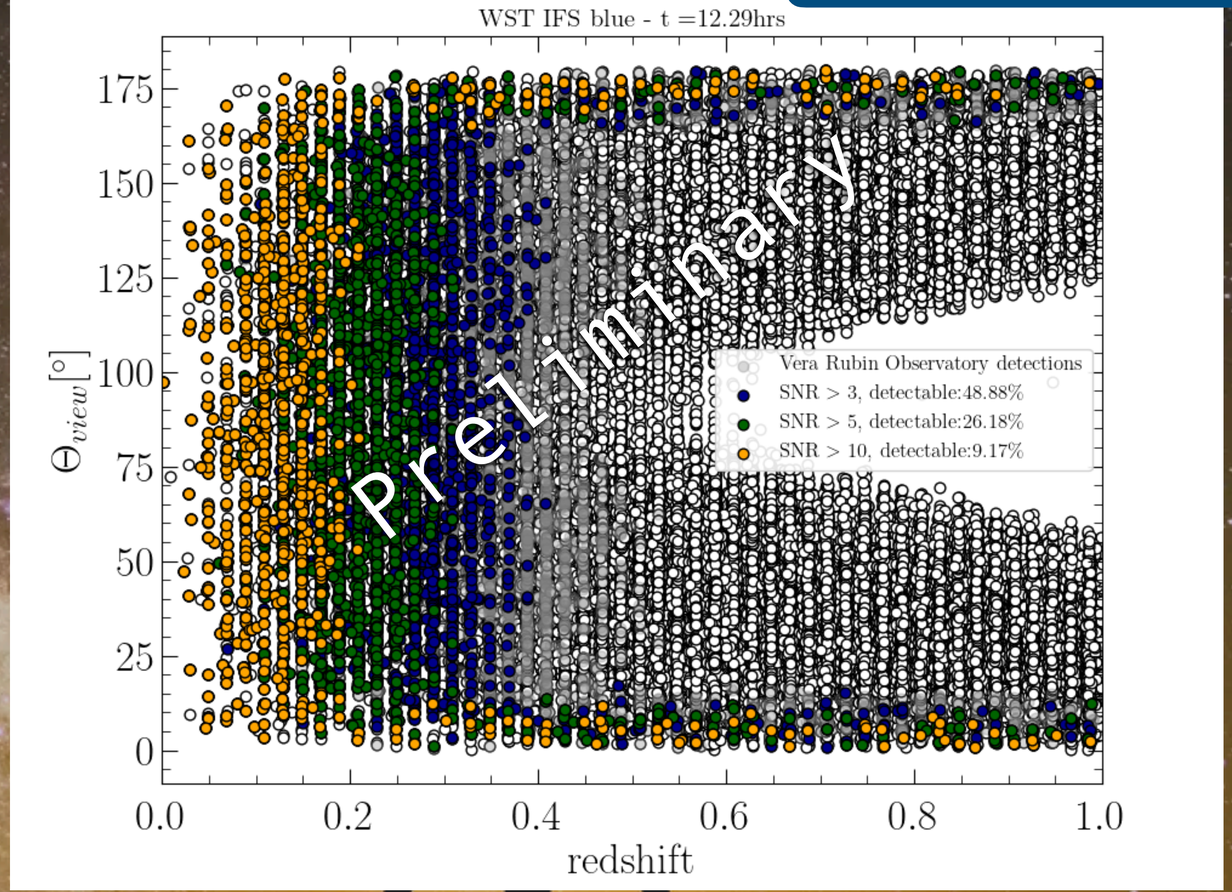
ET-WST synergy

Simulations

KN only



KN+GRB afterglow

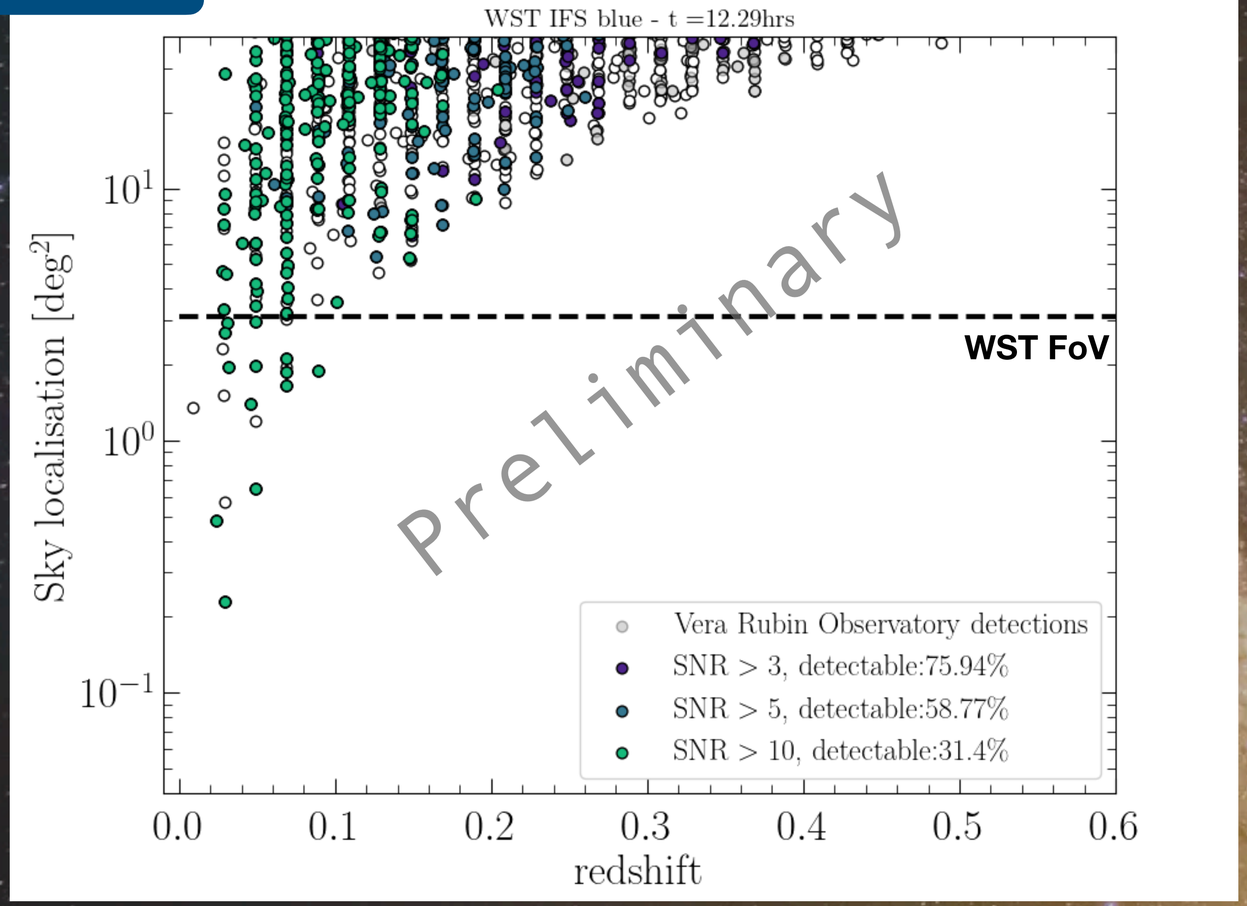


White: ET + CE **BNS** detections in **10 years** of operations
Grey: Vera Rubin Observatory **KN (+ GRB)** detections
Colored: WST **KN (+ GRB)** detections

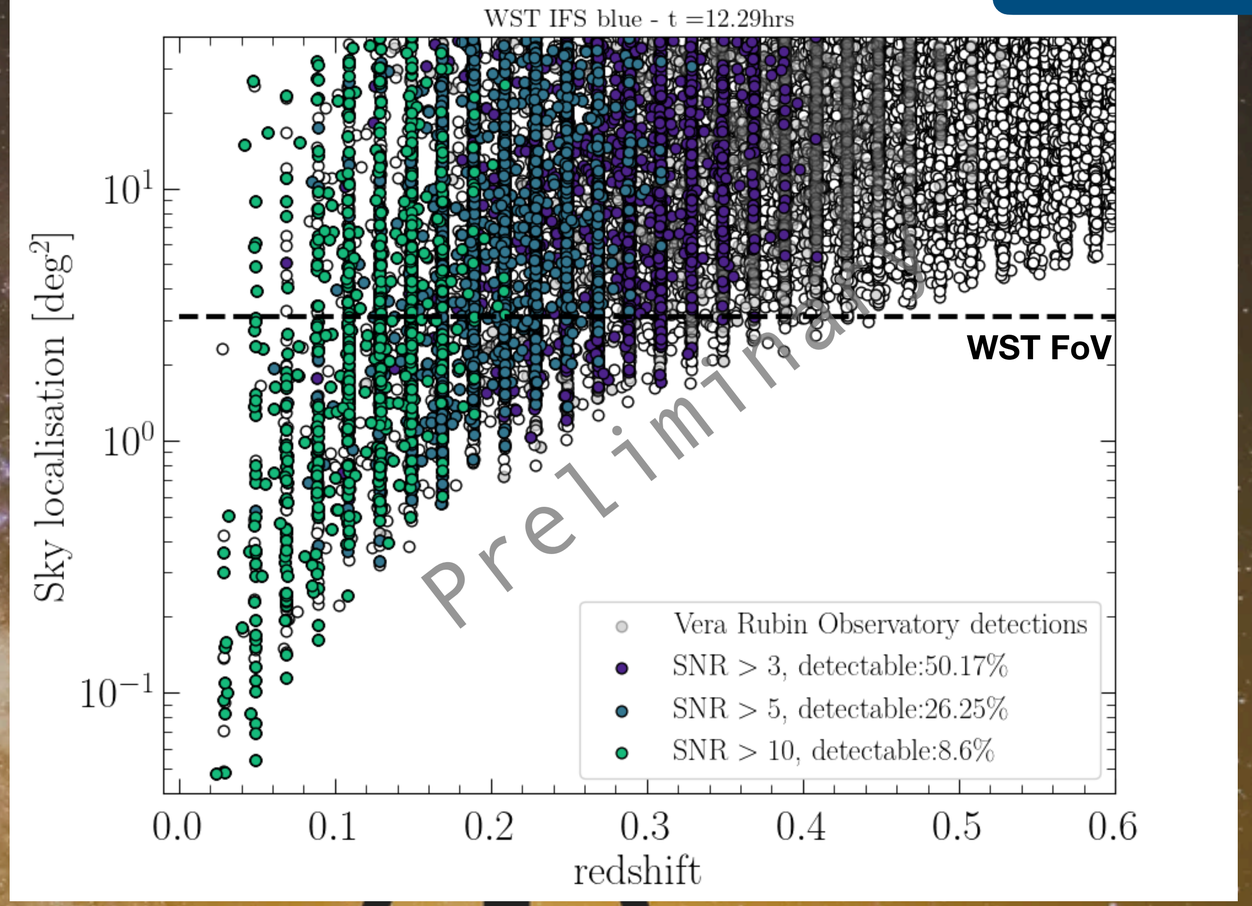
ET-WST synergy

Simulations

ET



ET+CE

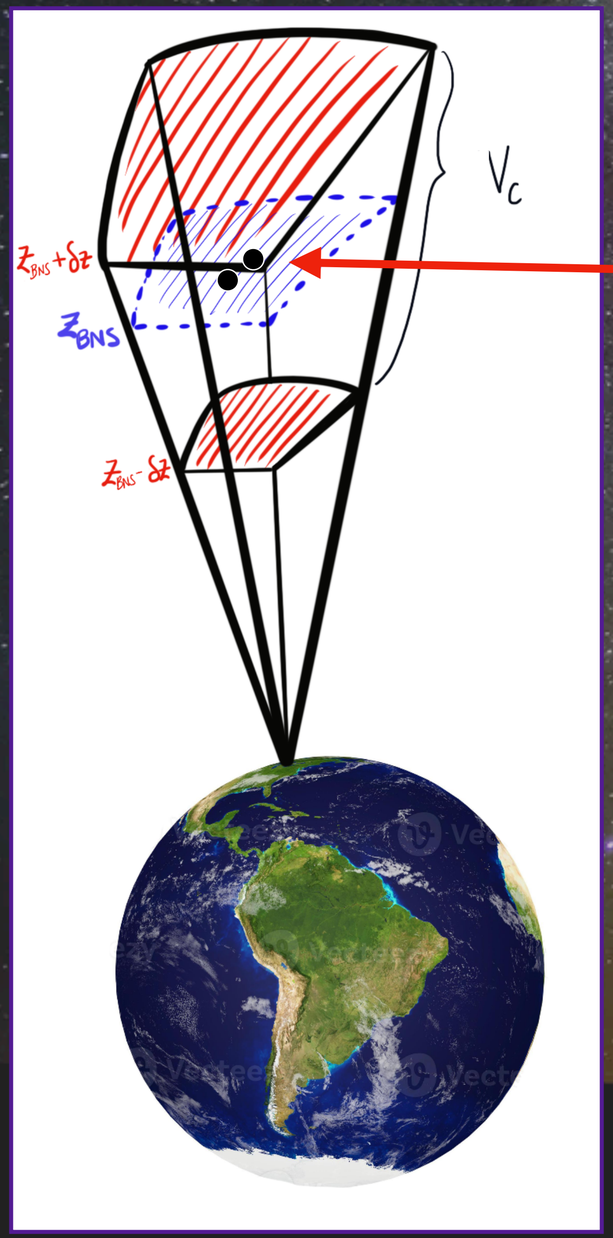


White: ET (+ CE) **BNS** detections in **10 years** of operations
Grey: Vera Rubin Observatory **KN** detections
Colored: WST **KN** detections

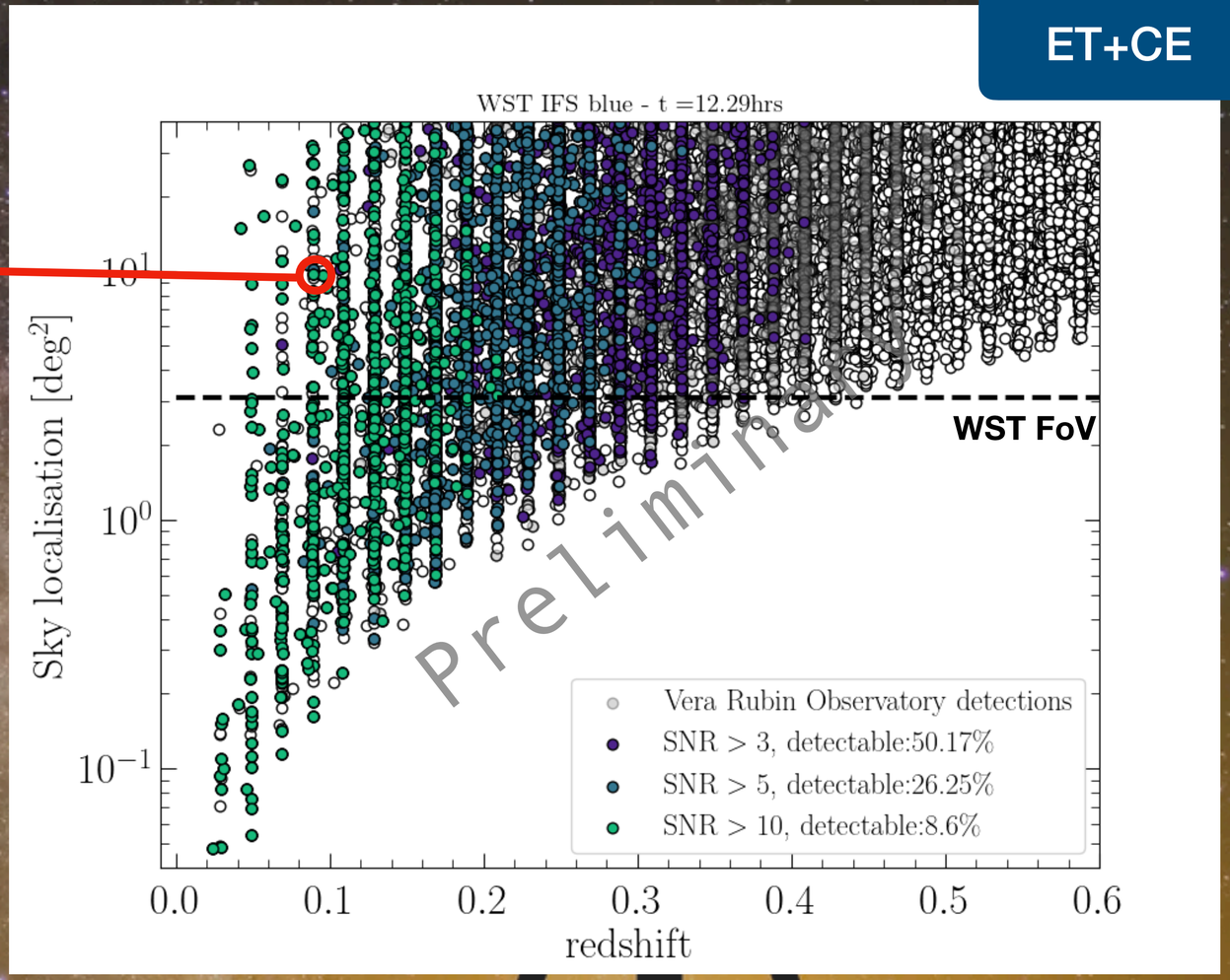
ET-WST synergy

Simulations

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



ET+CE

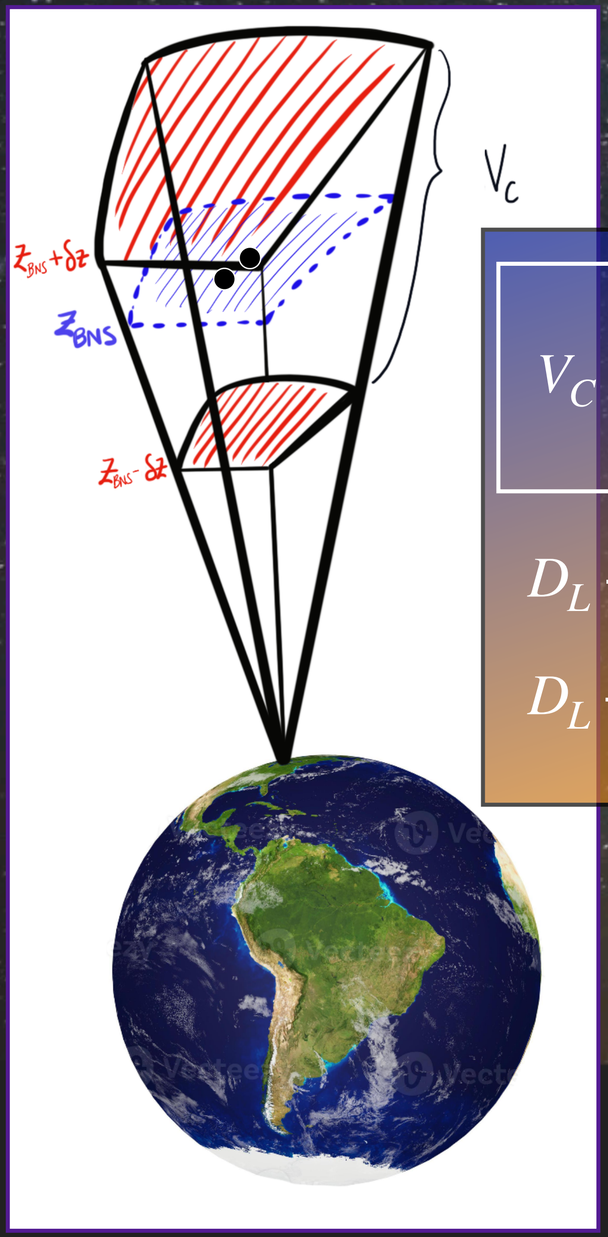


How many **galaxies** can be found
in the **comoving error volume** of each BNS?

ET-WST synergy

Galaxies in the BNS comoving volume

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

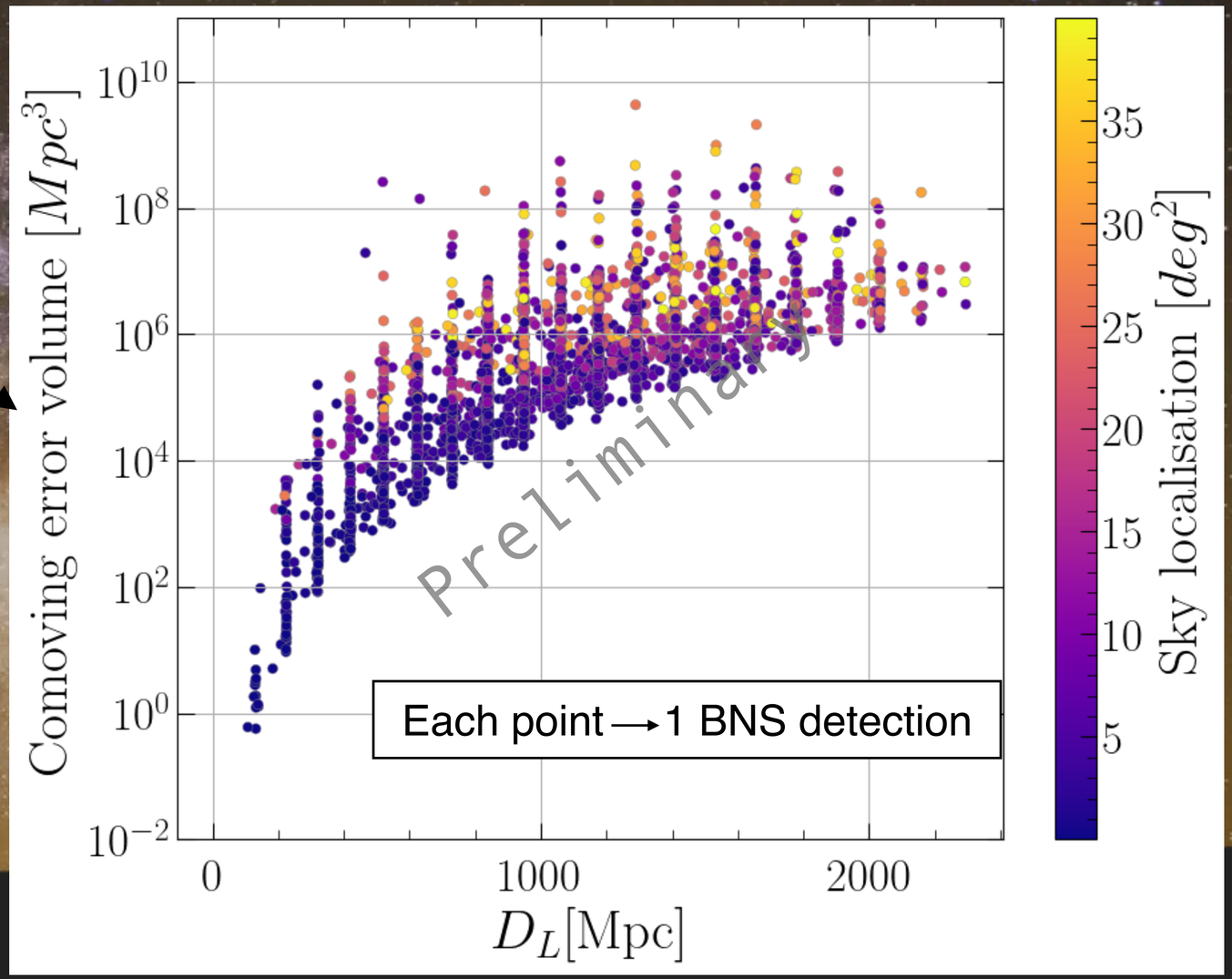


$$V_C \sim \Omega \int_{z-\delta z}^{z+\delta z} \frac{d^2 V_C}{d\Omega dz} dz$$

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

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

Comoving Error Volume



ET-WST synergy

Galaxies in the BNS comoving volume

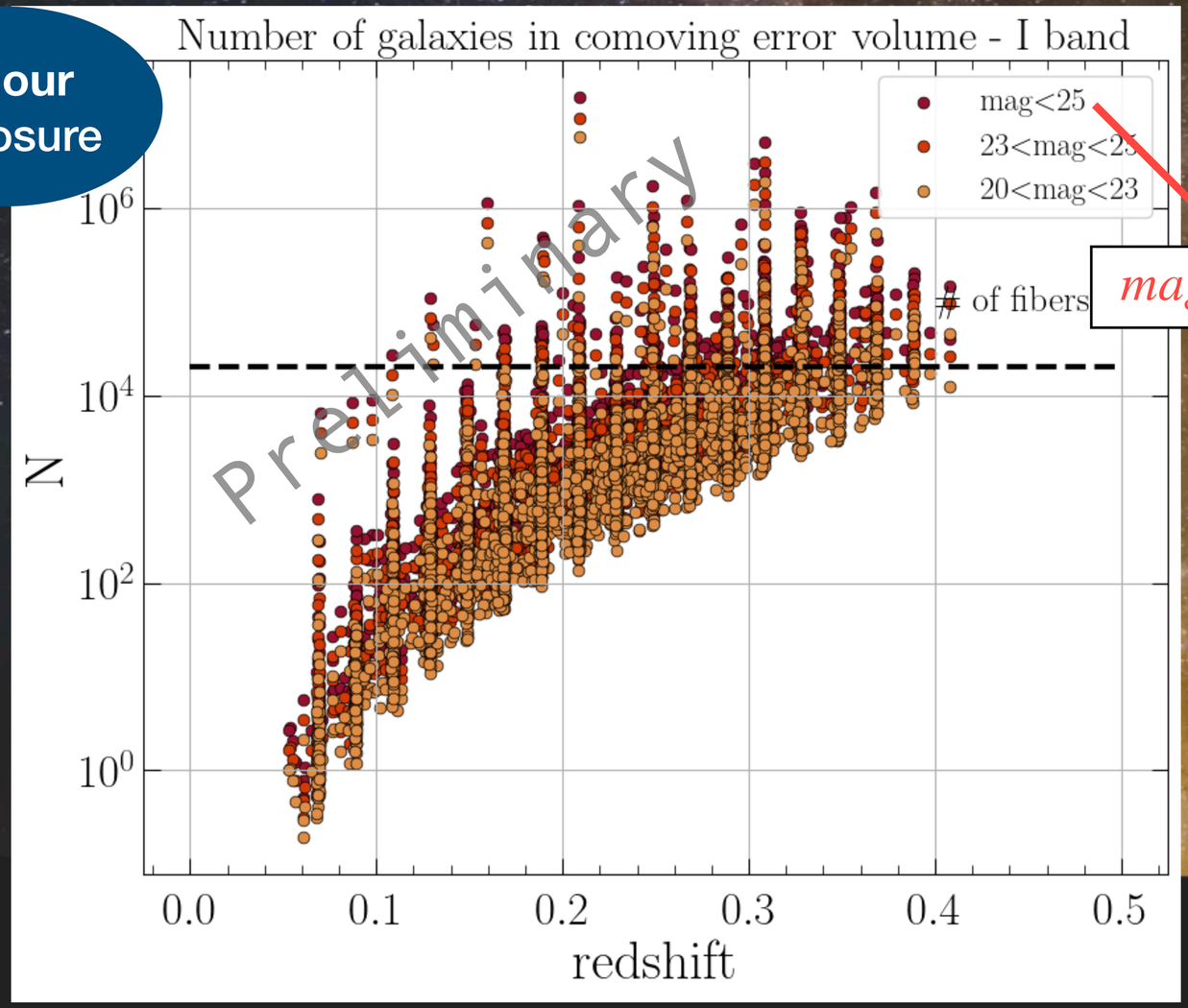
Schechter function parameters from Ilbert et al. 2005

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

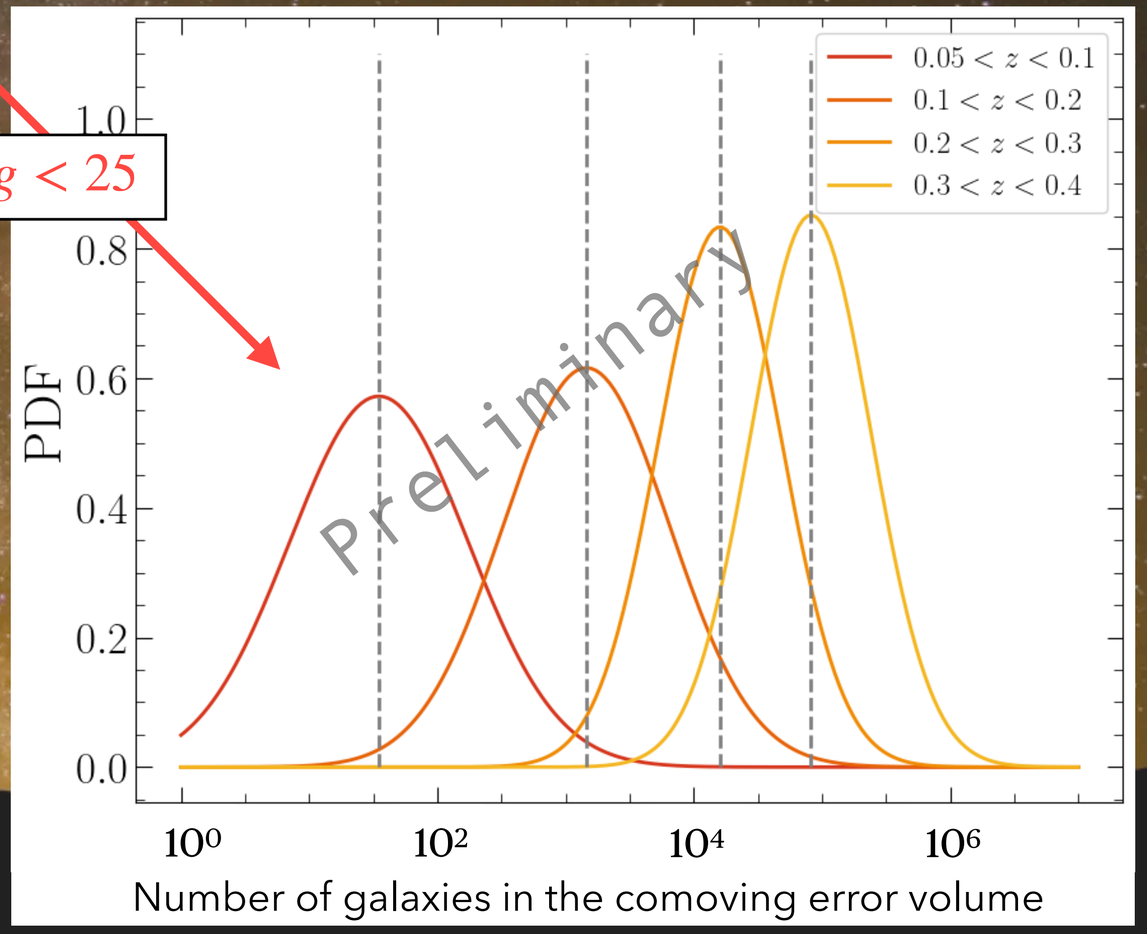
$$n_{m_1<m<m2} = \int_{m_1}^{m_2} \Phi(m)\, dm$$

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

1 hour exposure

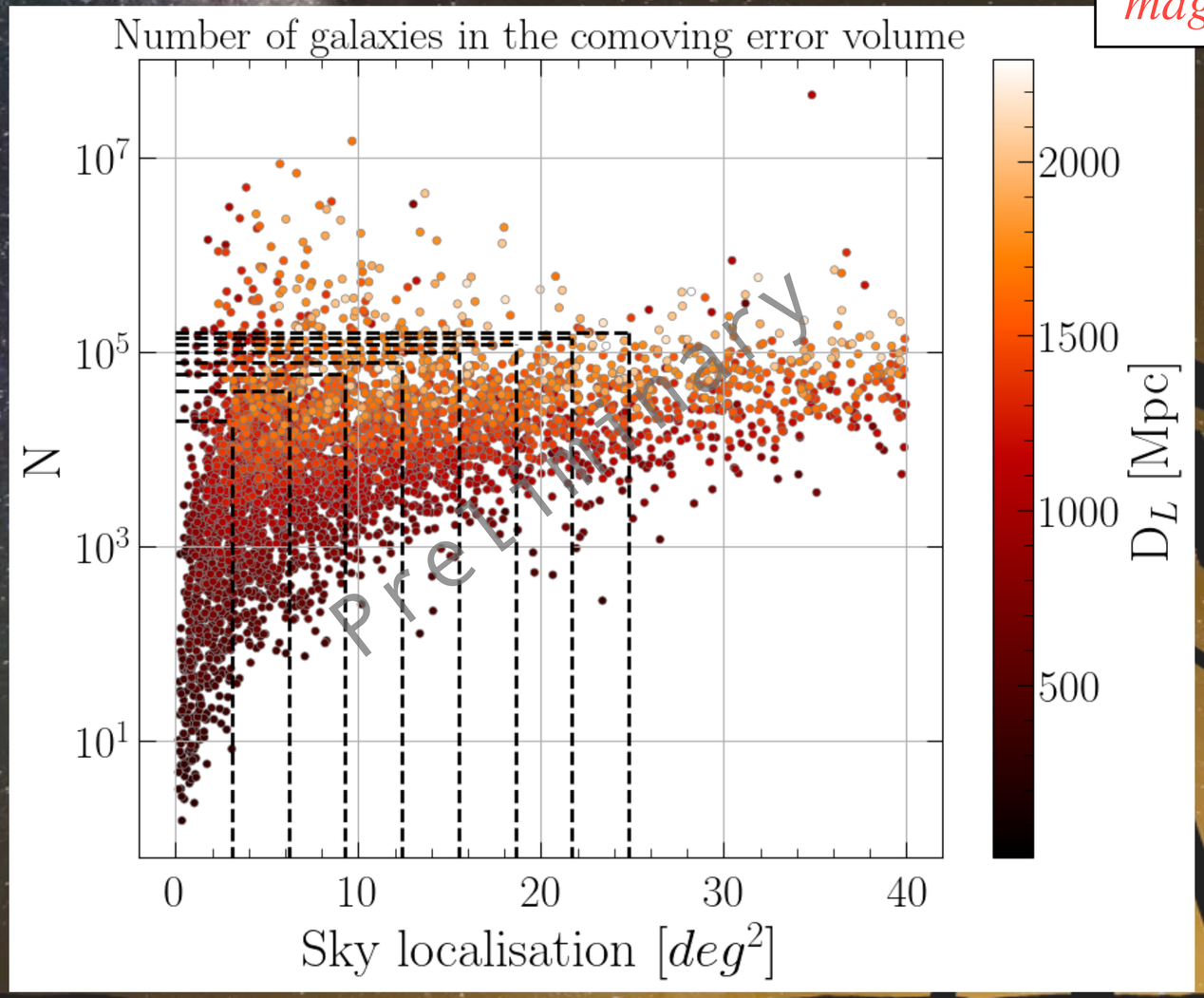


mag < 25



ET-WST synergy

Galaxies in the BNS comoving volume



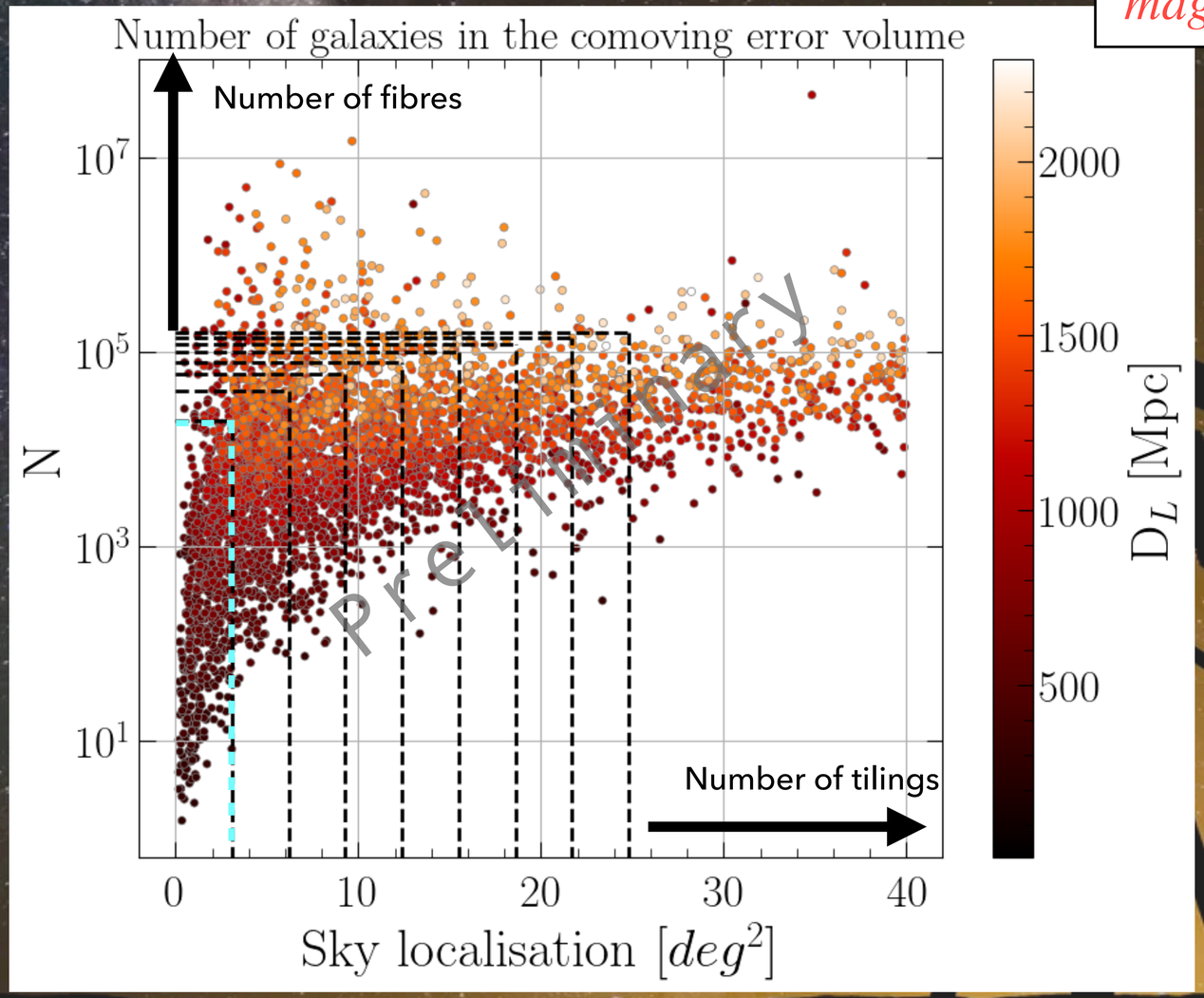
mag < 25

1 hour exposure

ET-WST synergy

Galaxies in the BNS comoving volume

1h



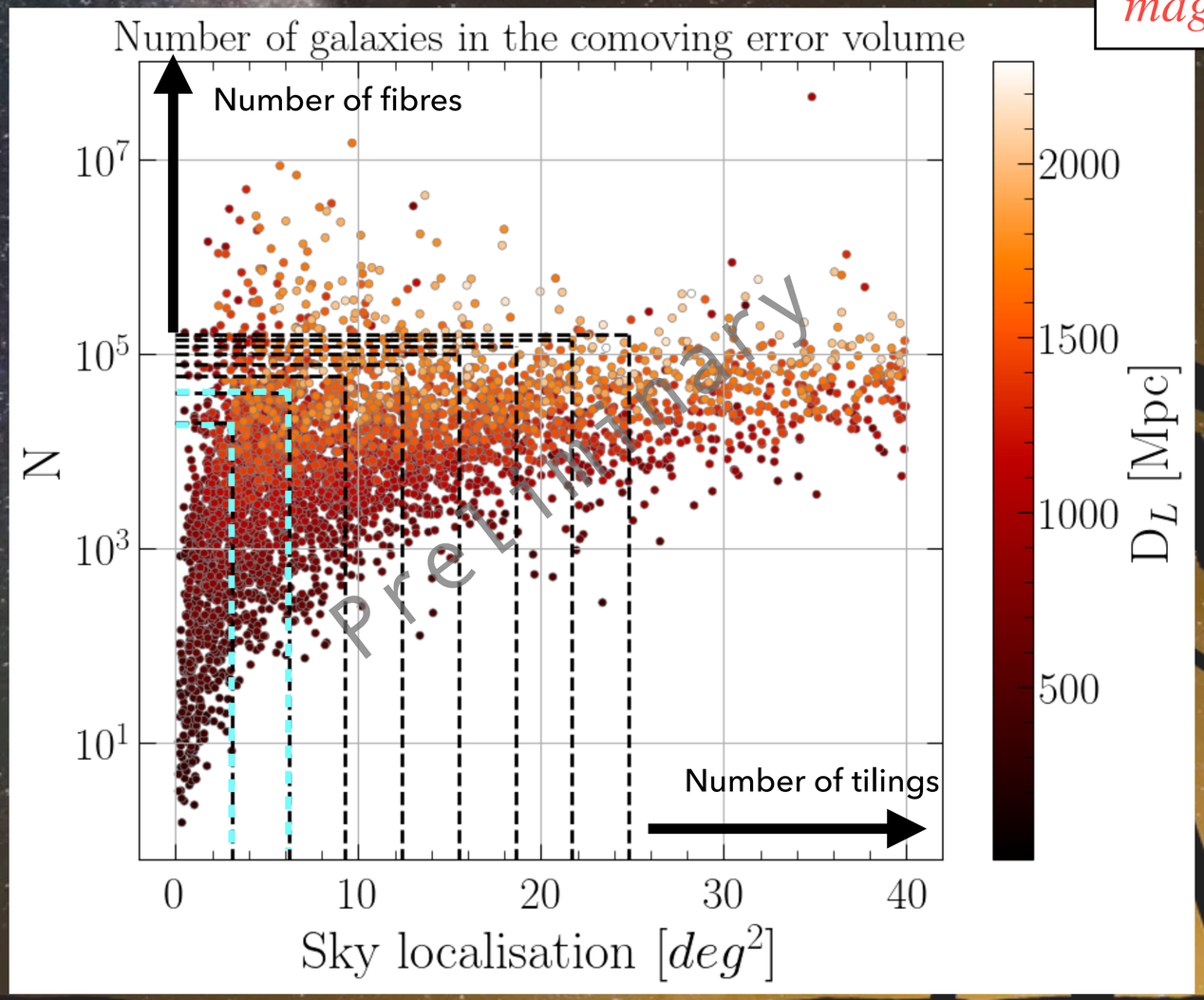
mag < 25

1 hour exposure

ET-WST synergy

Galaxies in the BNS comoving volume

2h



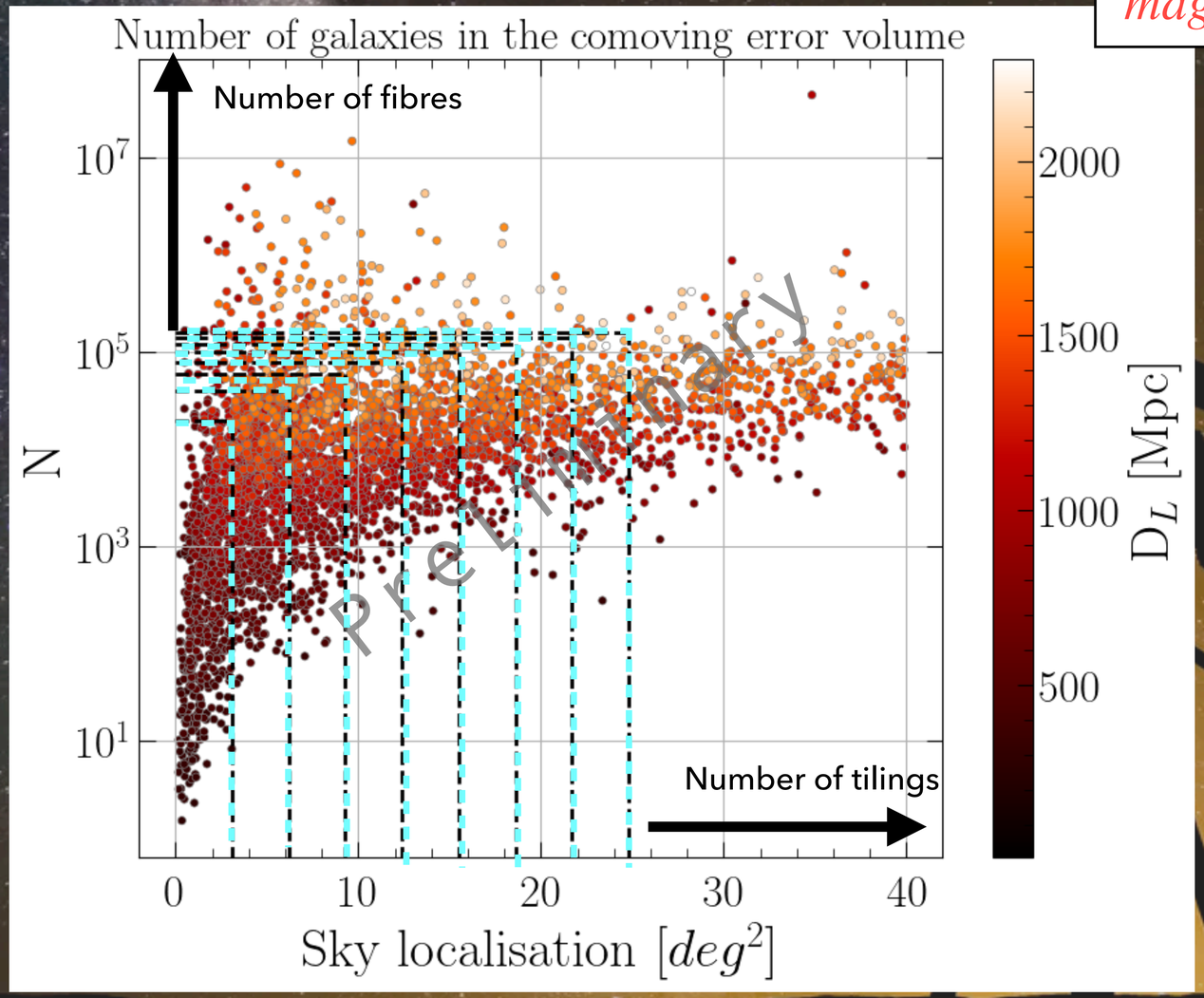
mag < 25

1 hour exposure

ET-WST synergy

Galaxies in the BNS comoving volume

8h



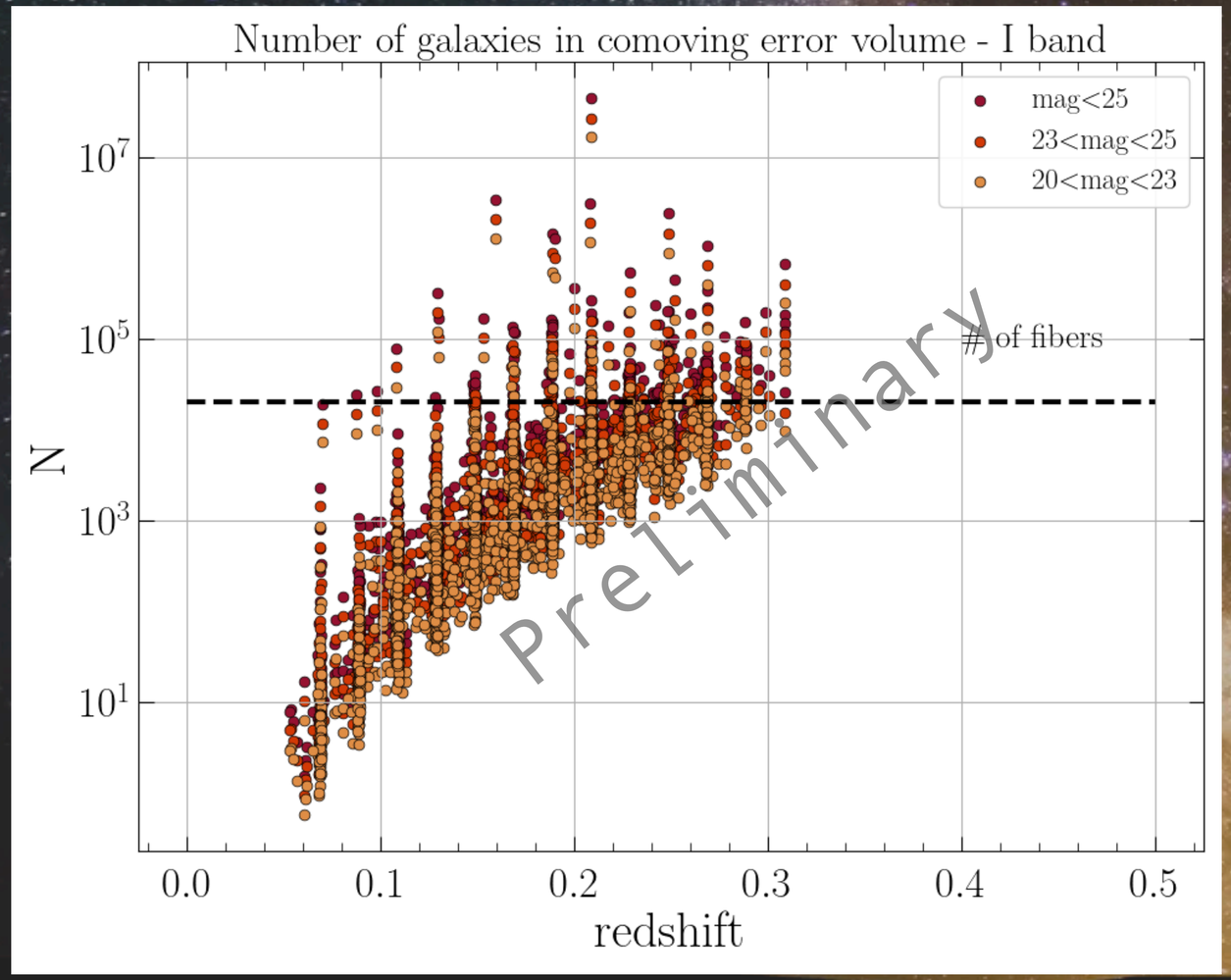
mag < 25

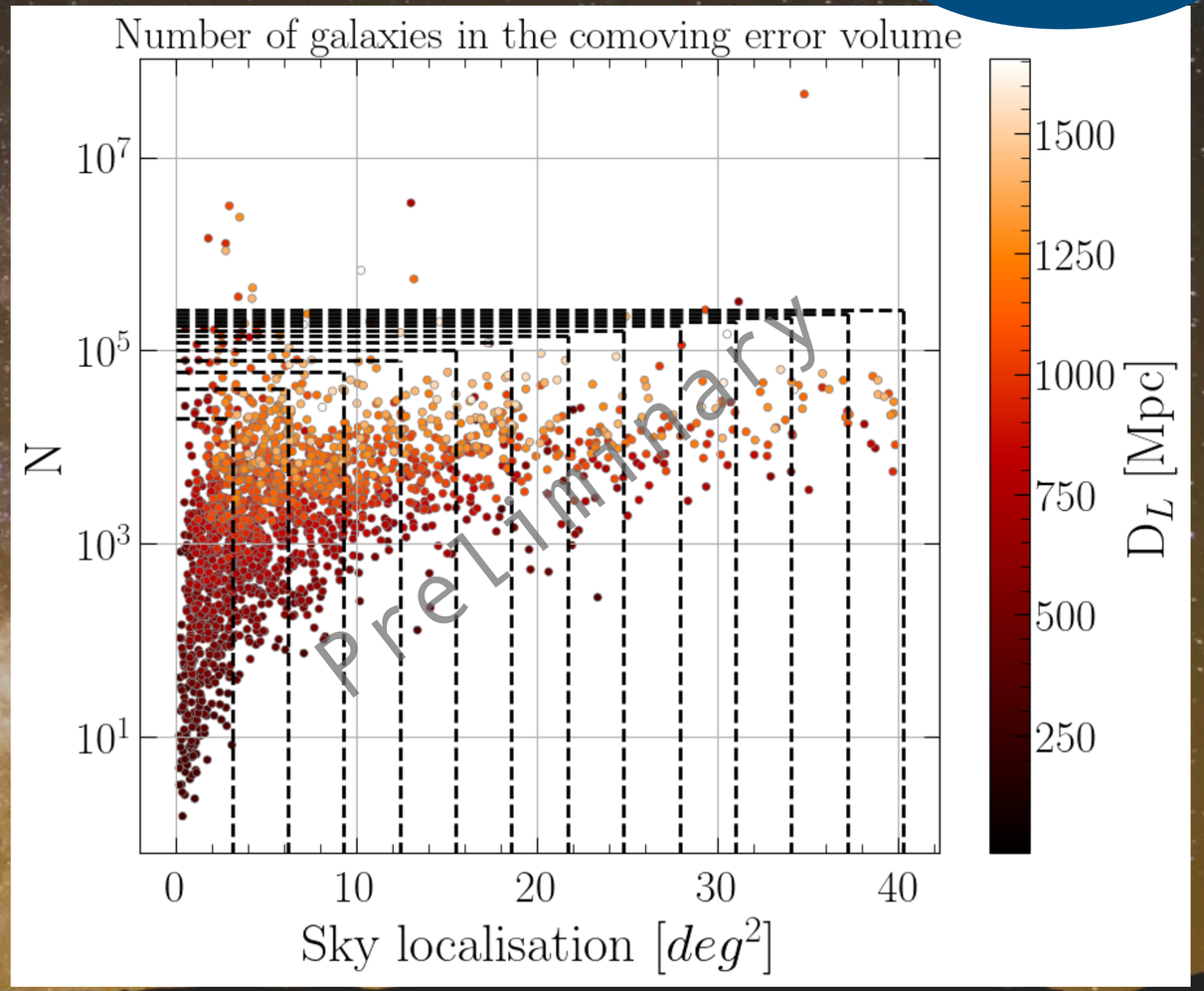
1 hour exposure

ET-WST synergy

Galaxies in the BNS comoving volume

30 minutes exposure



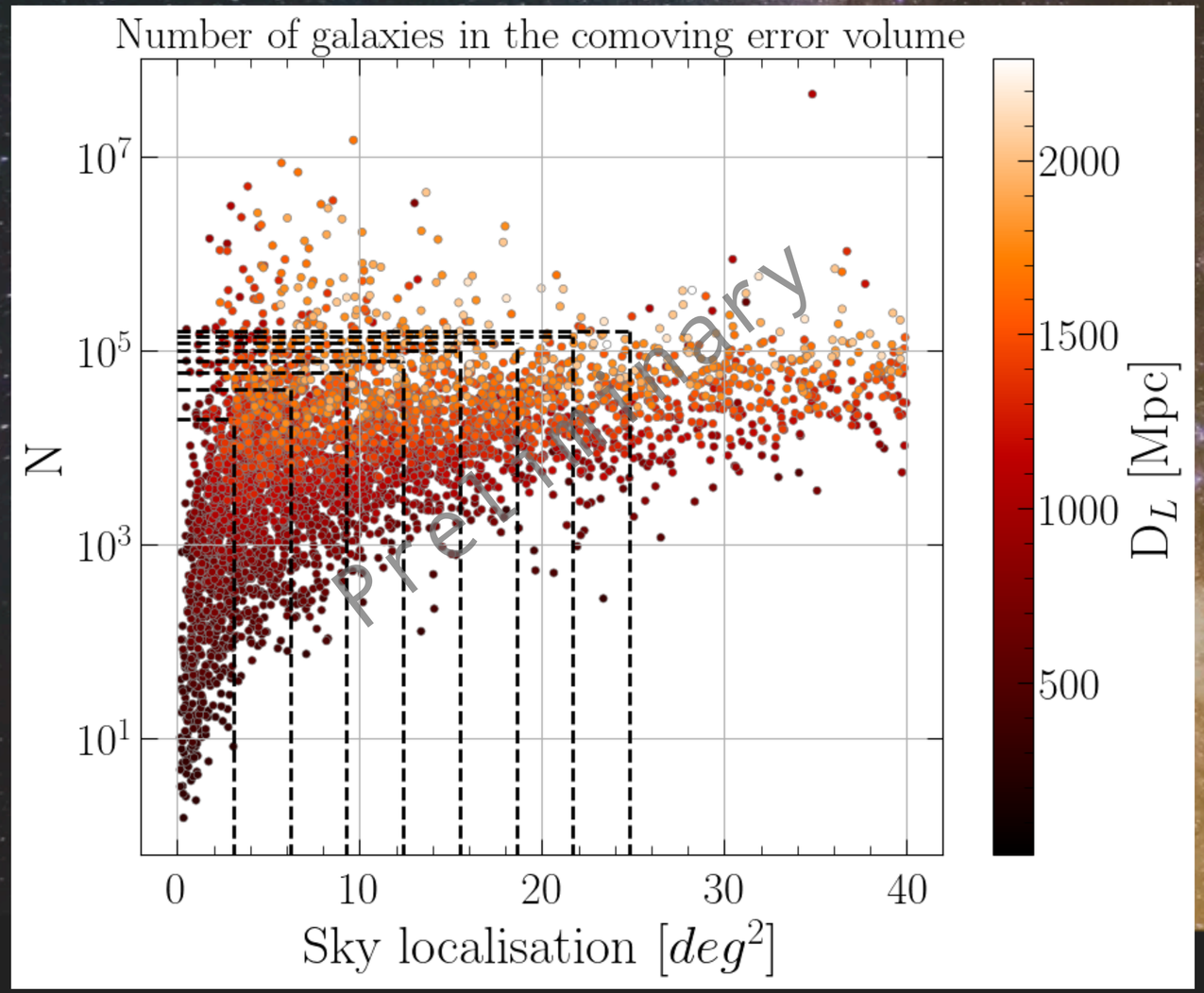


ET-WST synergy

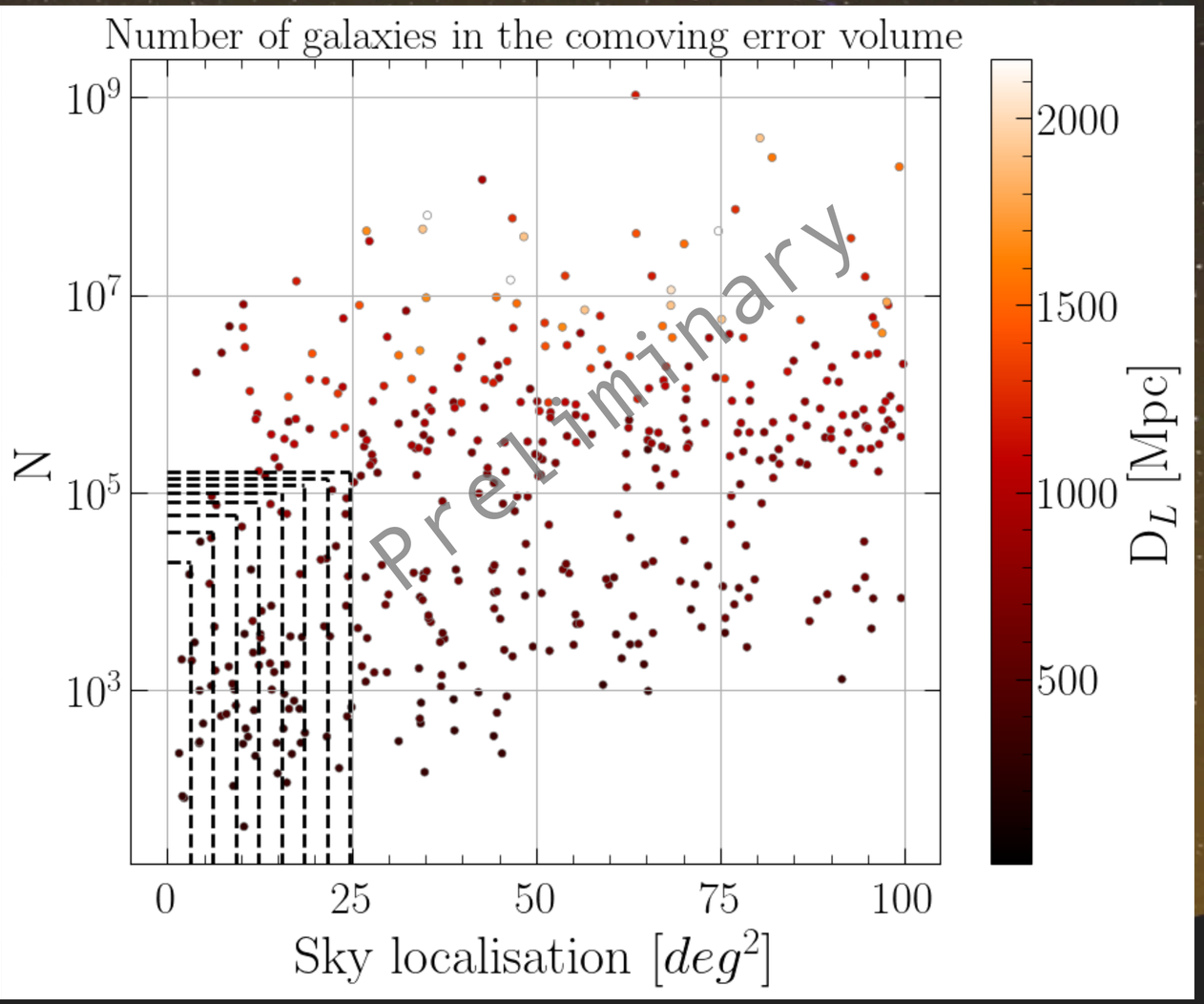
Galaxies in the BNS comoving volume

1 hour exposure

ET + CE



ET



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**

- In a stand alone scenario a galaxy targeted research can be performed, using WST **~20000 fibres** to cover the huge amount of galaxies expected to be found in the large error regions of GW signals

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

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

- 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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