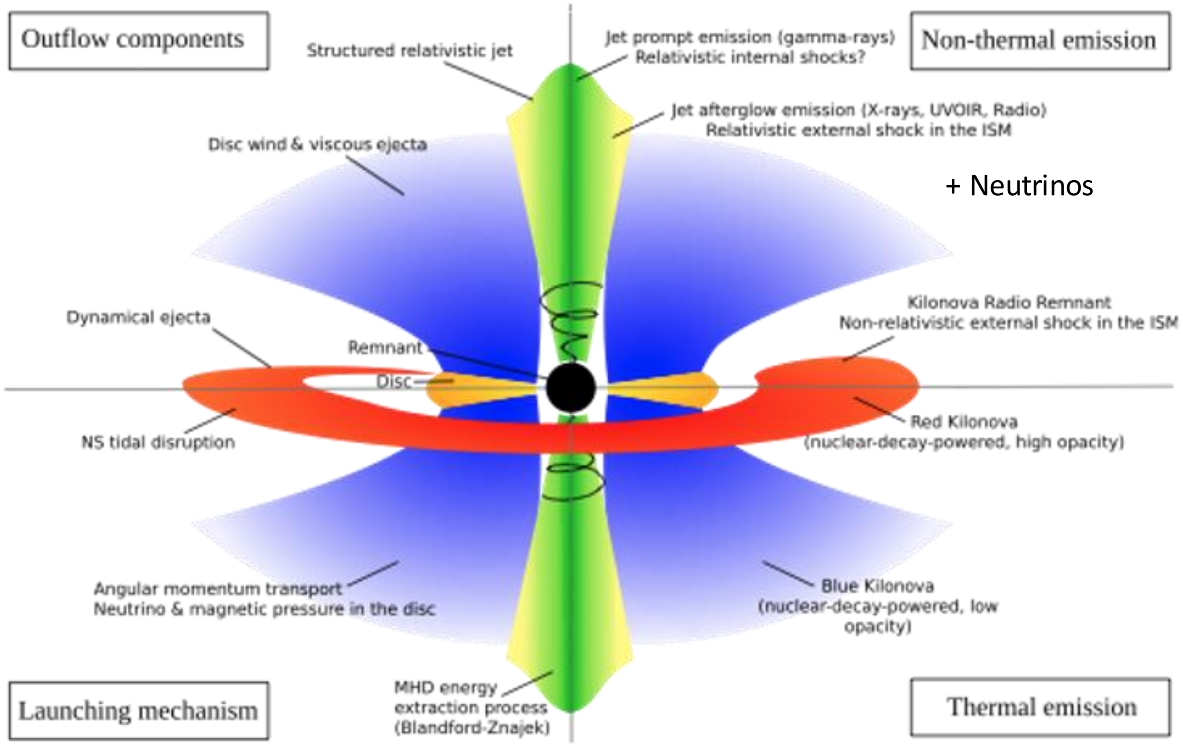
Einstein Telescope
Observational Science Board
(OSB)
Division 4 : Multi-messenger Observations

Giancarlo Ghirlanda, Susanna Vergani, Stephen Smartt

Detections

We should consider: GW + any combination of KN, Afterglow, GRB and Neutrini

Best of MM inference from JOINT GW+EM detections. Synergy between source properties and detection ability



Barbieri et al. 2019

INTRINSIC PROPERTIES:
- Source nature
- Masses
- Ejecta
- Remnant and jet power
- Jet energy structure
- ...

INSTRUMENTATION /FACILITIES

OBSERVING STRATEGIES

EXTRINSIC PROPERTIES:
- Ambient (close and galactic scale)
- Orientation
- ...

Science Goals

1.Study and development of models of EM components (thermal and non–thermal) and neutrino emission from CB mergers

2. Study and development of models for EM emission and neutrino emission from (I)MBH mergers.

3. Simulation of lightcurves and SED of EM counterparts at different frequencies and distances

4. Census of EM facilities / surveys / catalogues (present and future) and their relevant properties for EM searches and multi-messenger astrophysics.

5. Study of observational strategies and their prioritization for the different bands & facilities.

6. Definition of physical parameter space (mass, dynamical state, geometric distribution, remnant nature, outflows chemical and physical properties) accessible by joint GW+EM observations and exploitation of the joint data analysis inferences based on either single events and sample studies.

7. Identification of data needed to improve / make possible multi-messenger studies and strategies to obtain them with current / future EM facilities

Work Packages (preliminary)

WP1: EM + ν counterparts CB mergers (model & simulations) <--- Div. 3

WP2: EM+ ν counterparts from MBH mergers <--- Div. 3

WP3: Observational strategies/synergies

WP4: Astrophysical implications of MW–MM studies

WP5: Defining and Preparing EM observations needed in advance to perform MM studies

WP3 & WP5 feed Div-S

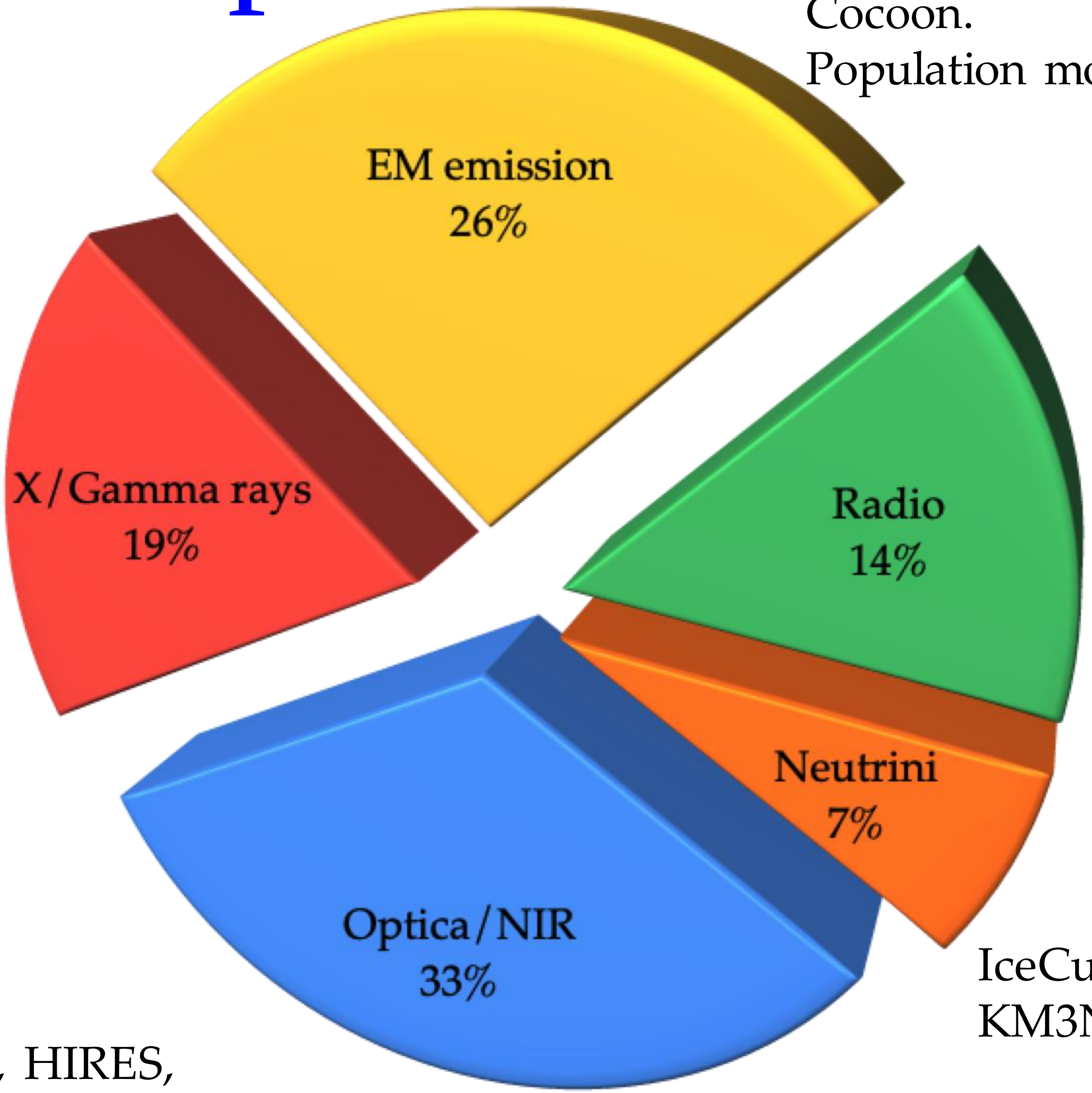
Other synergies: Div. 5-6-7

Div.4 Expertise

Kilonova
Jet
Cocoon.
Population models

Science :
Origin of r-process
Nucleosynthesis
Chemical evolution
NS equation of state
Magnetar formation
BH formation
Hubble constant
Binary star evolution
NS formation channels
BH – NS mass gap
Jet physics
High energy physics
Fundamental physics

Swift, Fermi
ATHENA
SVOM
Hermes
CTA



JVLA, VLBI
MeerKAT
ASKAP
SKA

IceCube
KM3Net

VLT
VRO (LSST)
ELT(Harmoni, HIRES,
Micado, MOSAIC)

ET Detection efficiency for Binary Neutron Star mergers

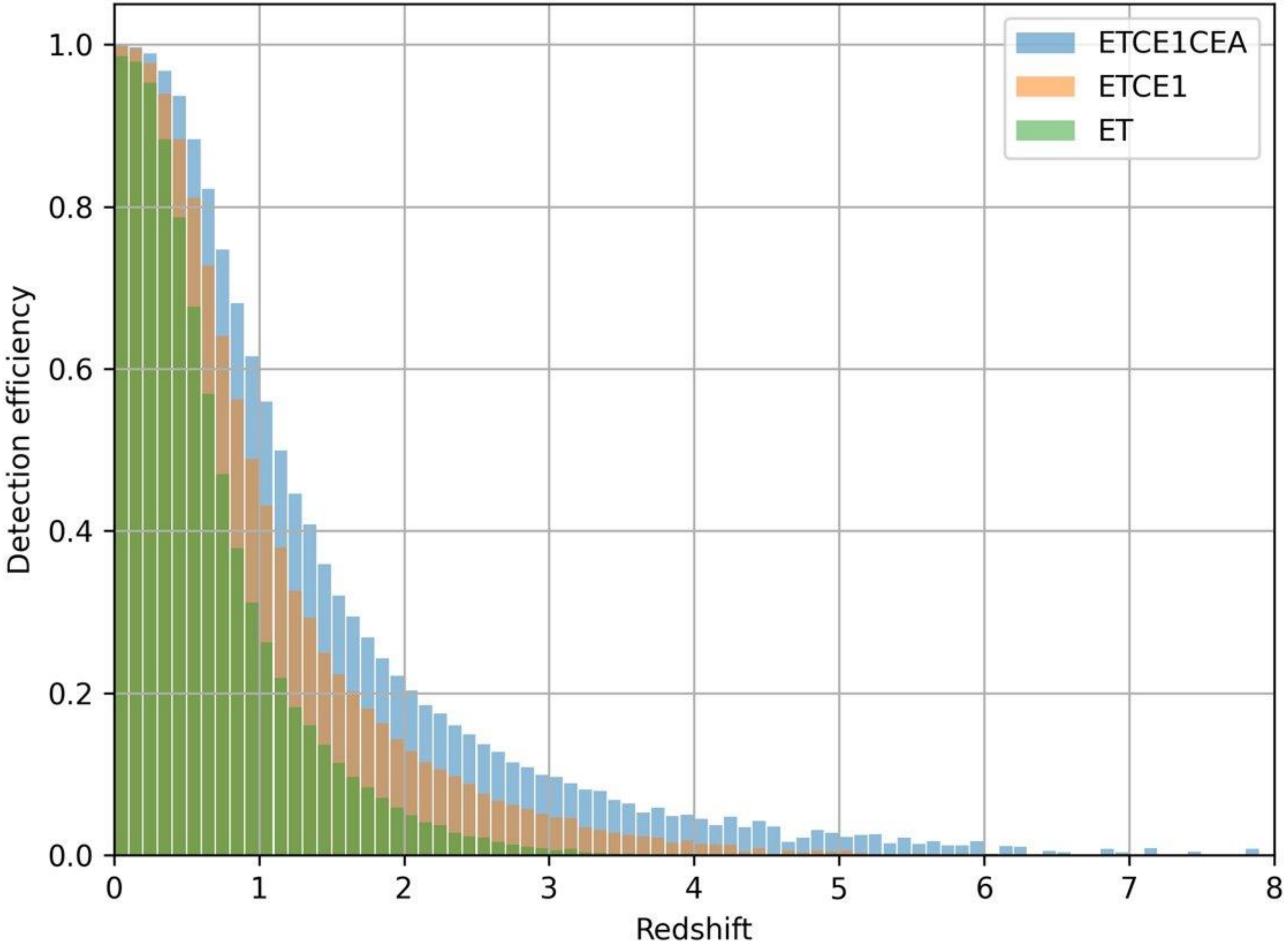


Image Credit :
Marica Branchesi

MMA science : rates
Kilonova counterparts of compact mergers

Local rates from LVC O3a :

$R_{BNS} = 320^{+490}_{-240}$ per Gpc3 per yr

Within a distance of 100Mpc

$R_{BNS} = 1^{+2}_{-1}$ per yr

Difficulty in finding counterpart = EASY!

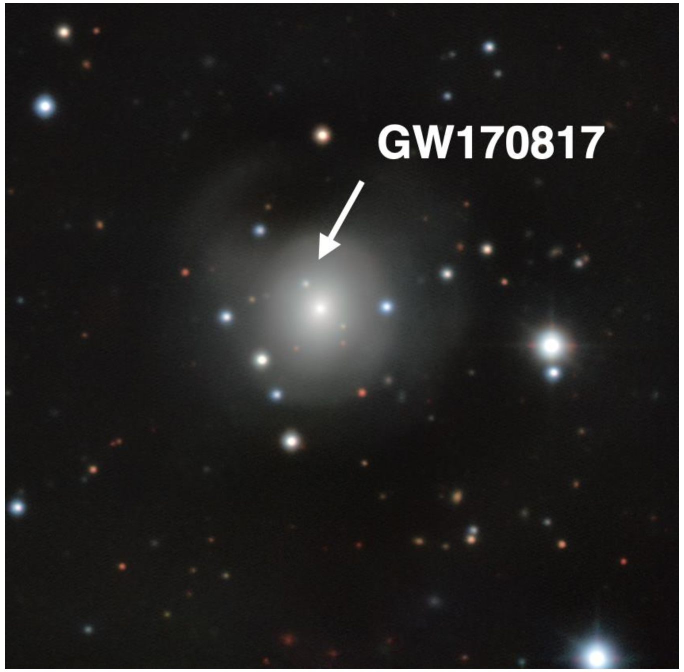
Within D = 200Mpc

$R_{BNS} = 11^{+16}_{-8}$ per yr

Difficulty = Achievable

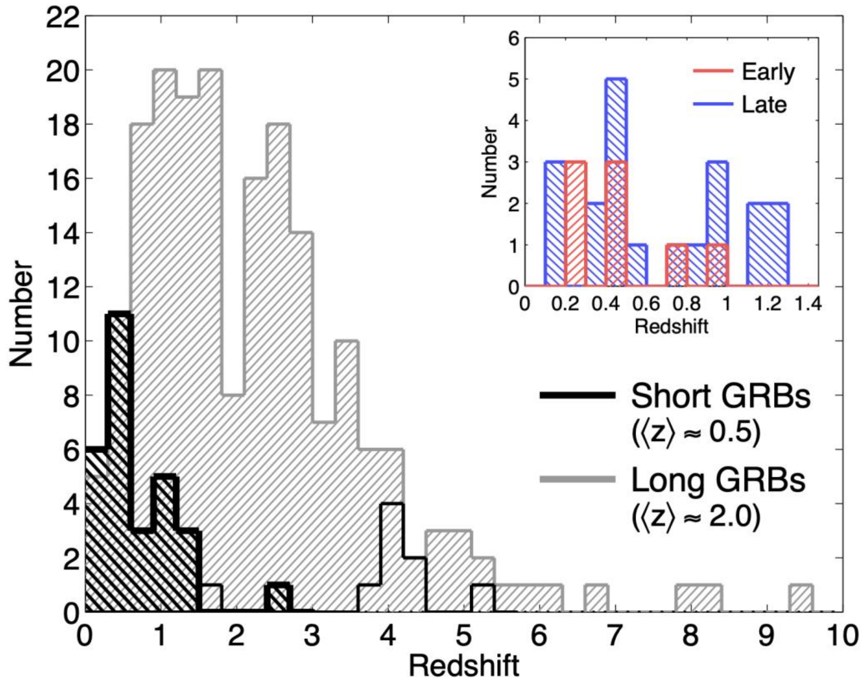
Within D = 400Mpc, $R_{BNS} = 86^{+131}_{-64}$ per yr

Difficulty = HARD



NGC 4993
40Mpc

Short GRBs – observed redshift distribution



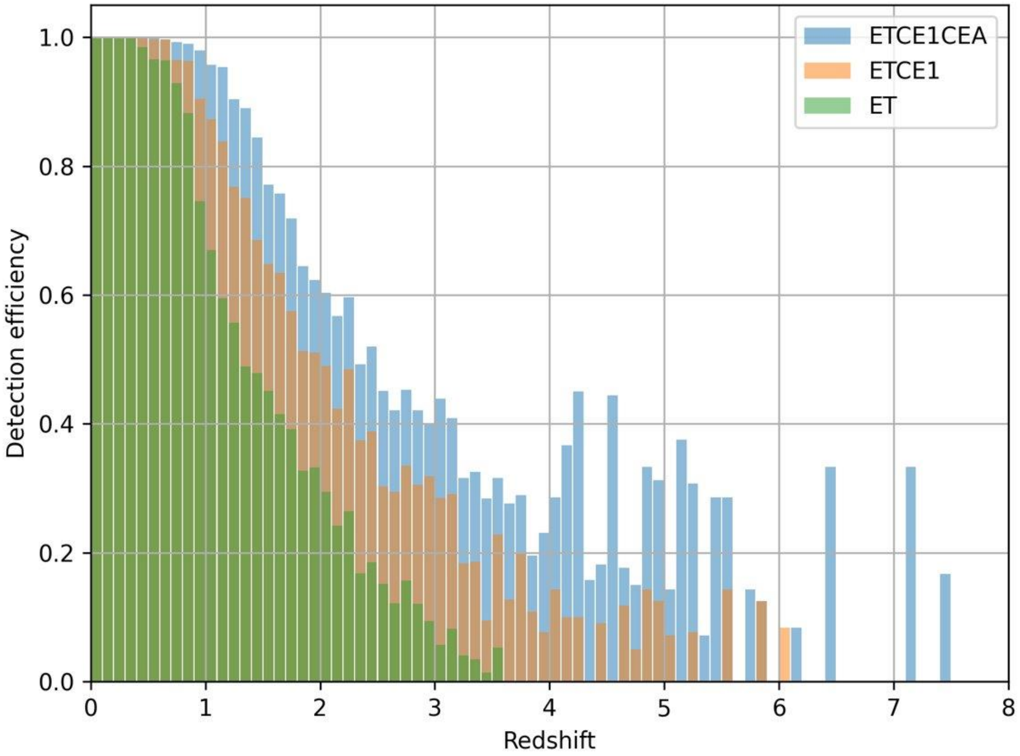
Berger ARAA (2014)

The redshift distributions of detected sGRBs seems to match well the ET z distribution

Viewing angle dependence – GRB implications

Face-on (viewing angle < 10 deg^2)

Potential short GRBs



All orientation

Likely no GRB

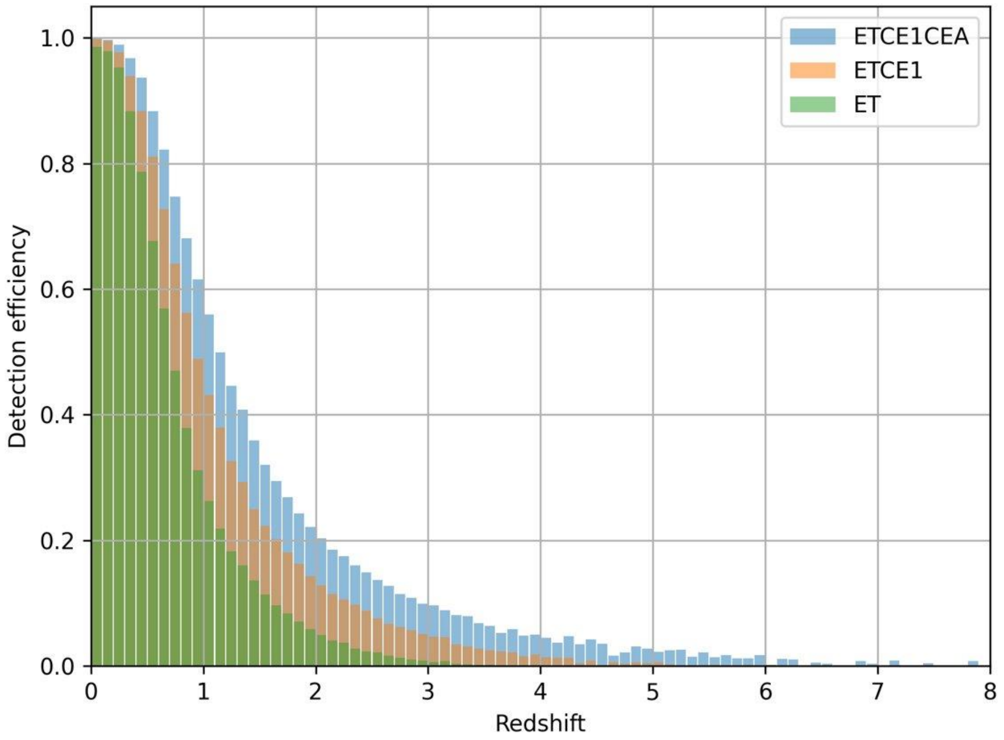
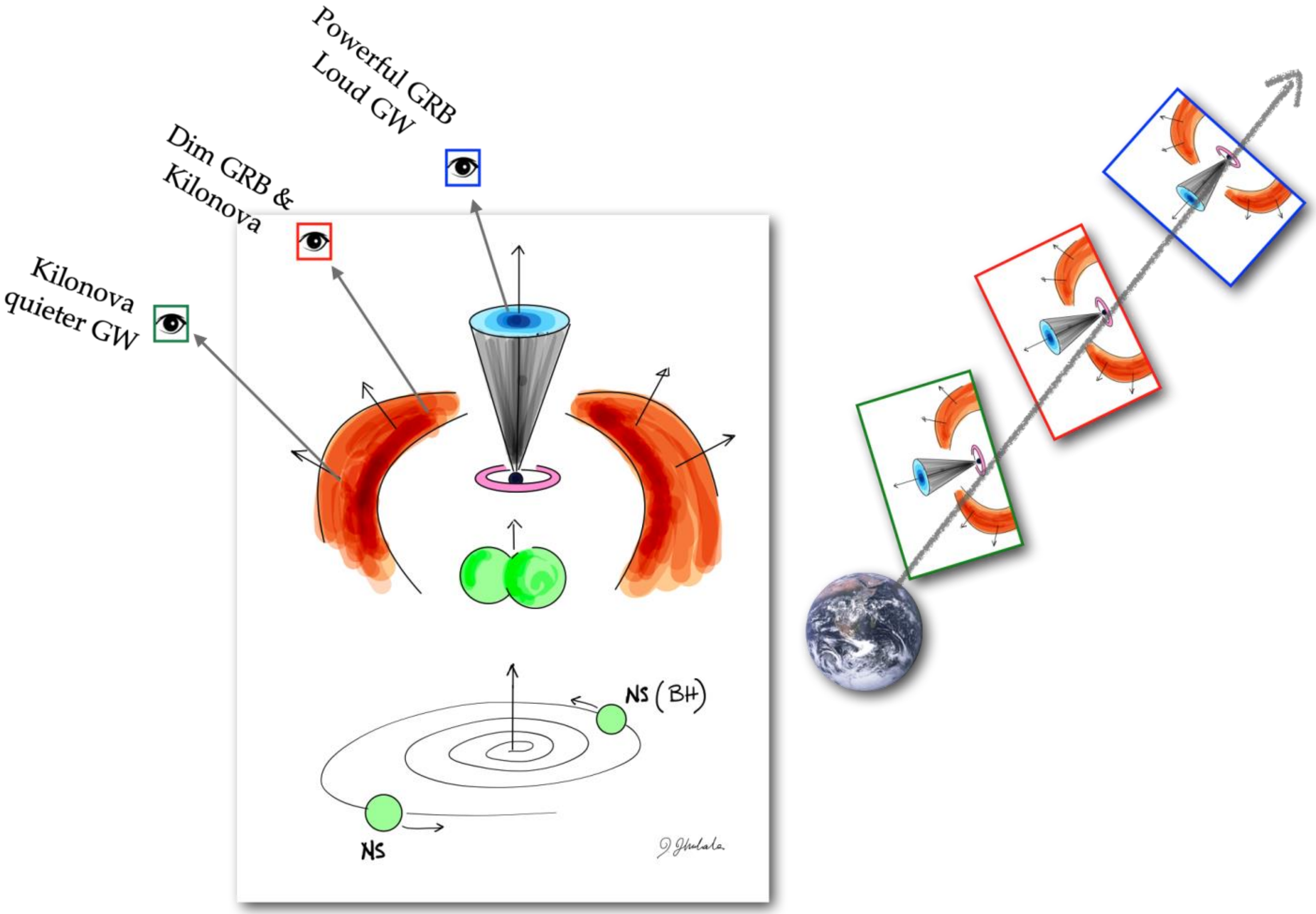
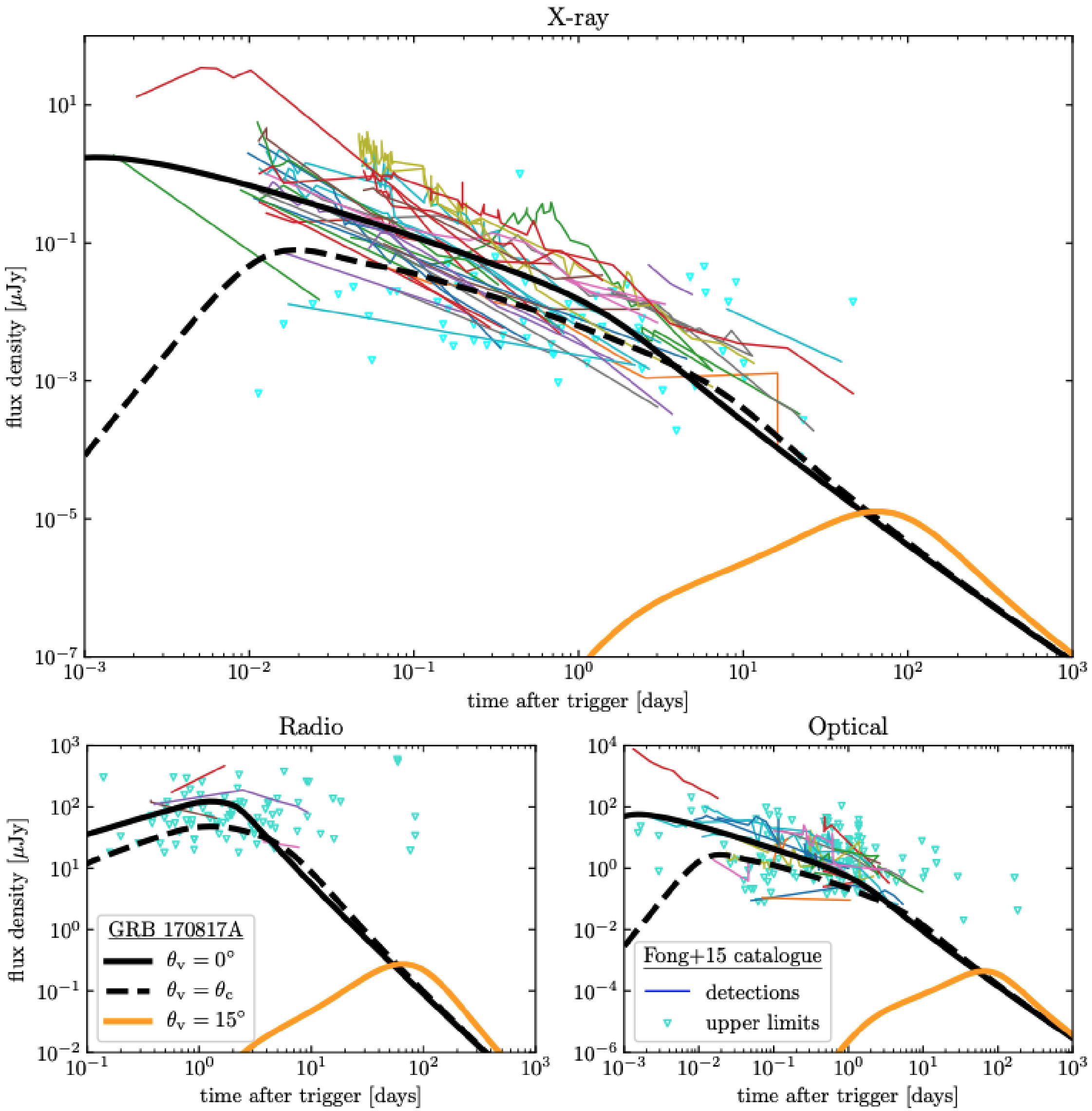


Image Credits:
Marica Branchesi

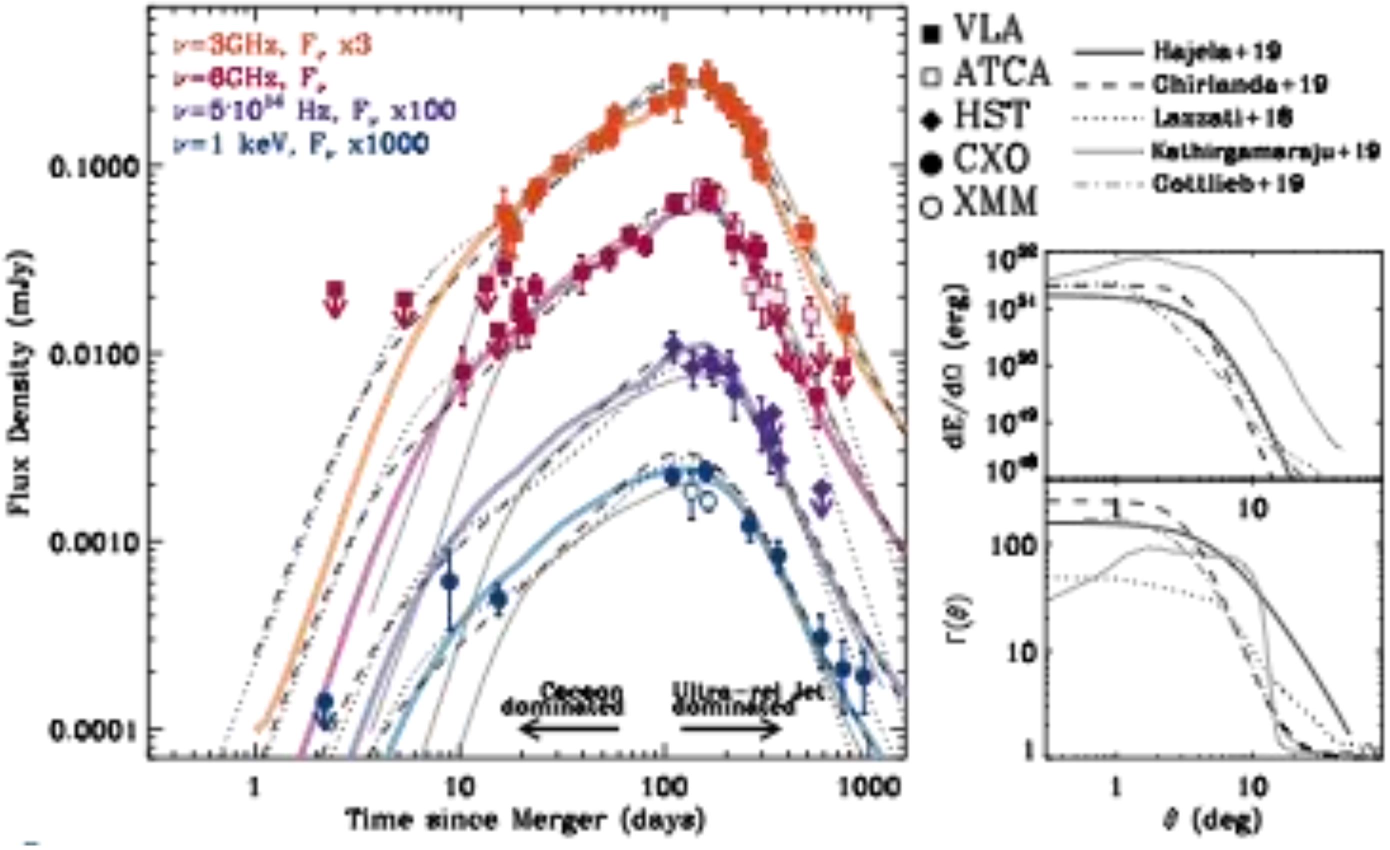
GRB orientation effects





Salafia et al. 2019

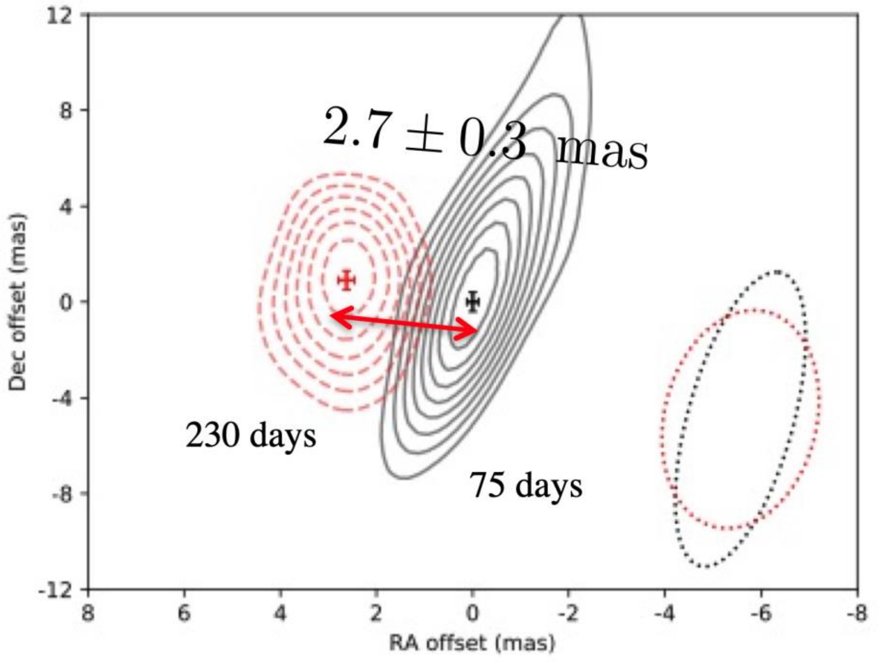
Non-thermal EM emission components



Margutti & Chornock 2020

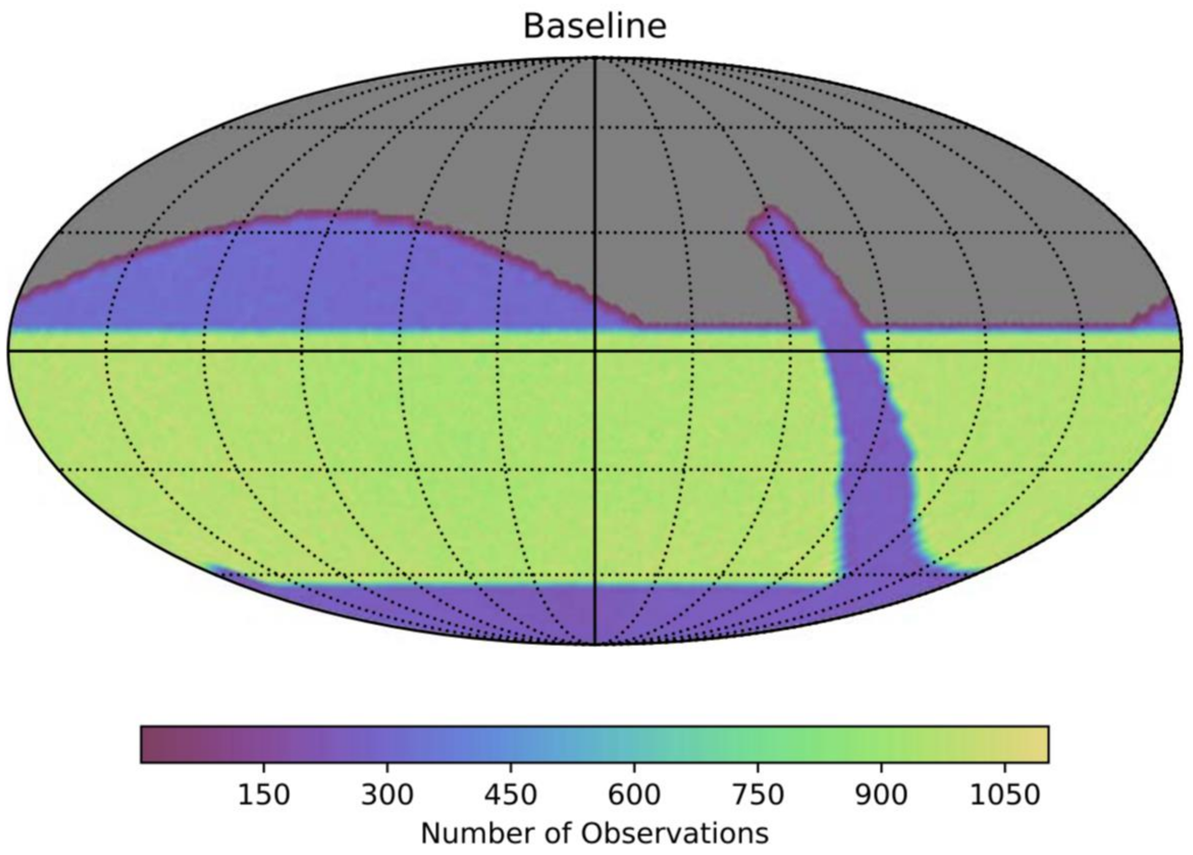
MW follow up of relatively close events unveils the structure of the jet

Radio imaging of very close events provides independent orientation



Mooley+2018

Legacy Survey of Space and time
Deep images of whole of southern sky

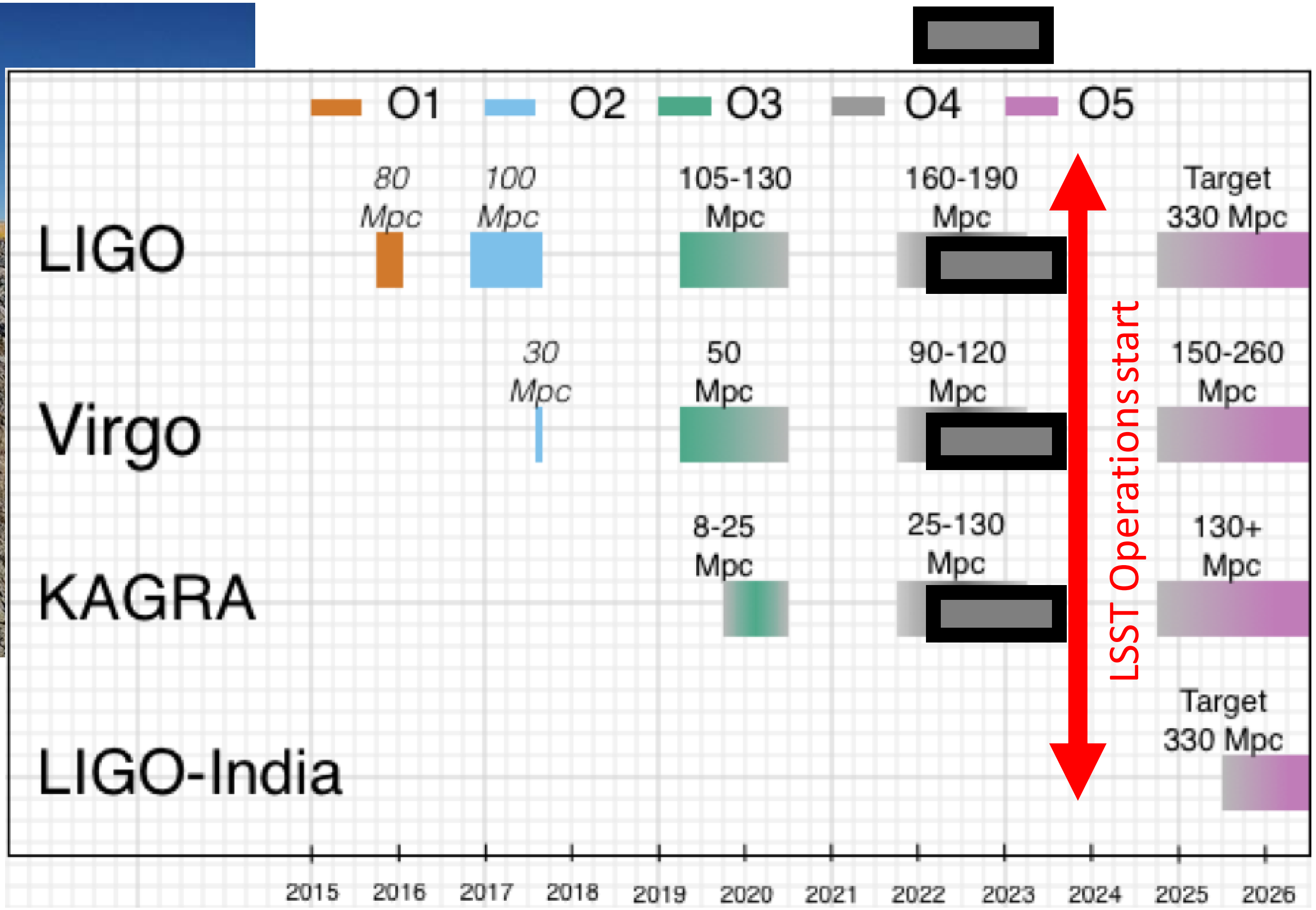


	5σ single visit	10 yr depth
u	23.9	26.1
g	25.0	27.4
r	24.7	27.5
i	24.0	26.8
z	23.3	26.1
y	22.1	24.9

Numbers from LSST Science Requirements
Ivezic et al.

Image credit : Rubin Observaory, L. Jones & P. Joahcim

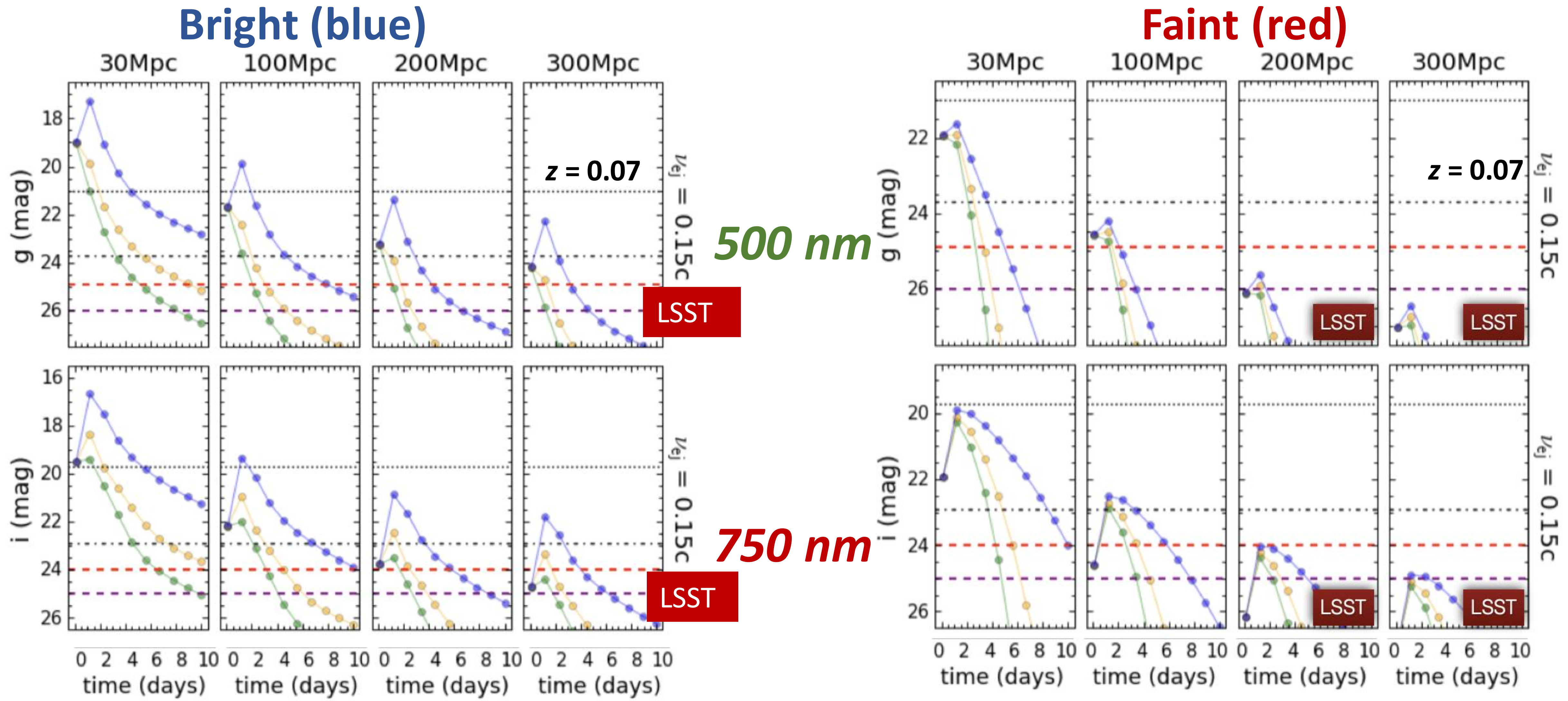
Rubin Observatory : 6m aperture telescope with 10 square degree camera



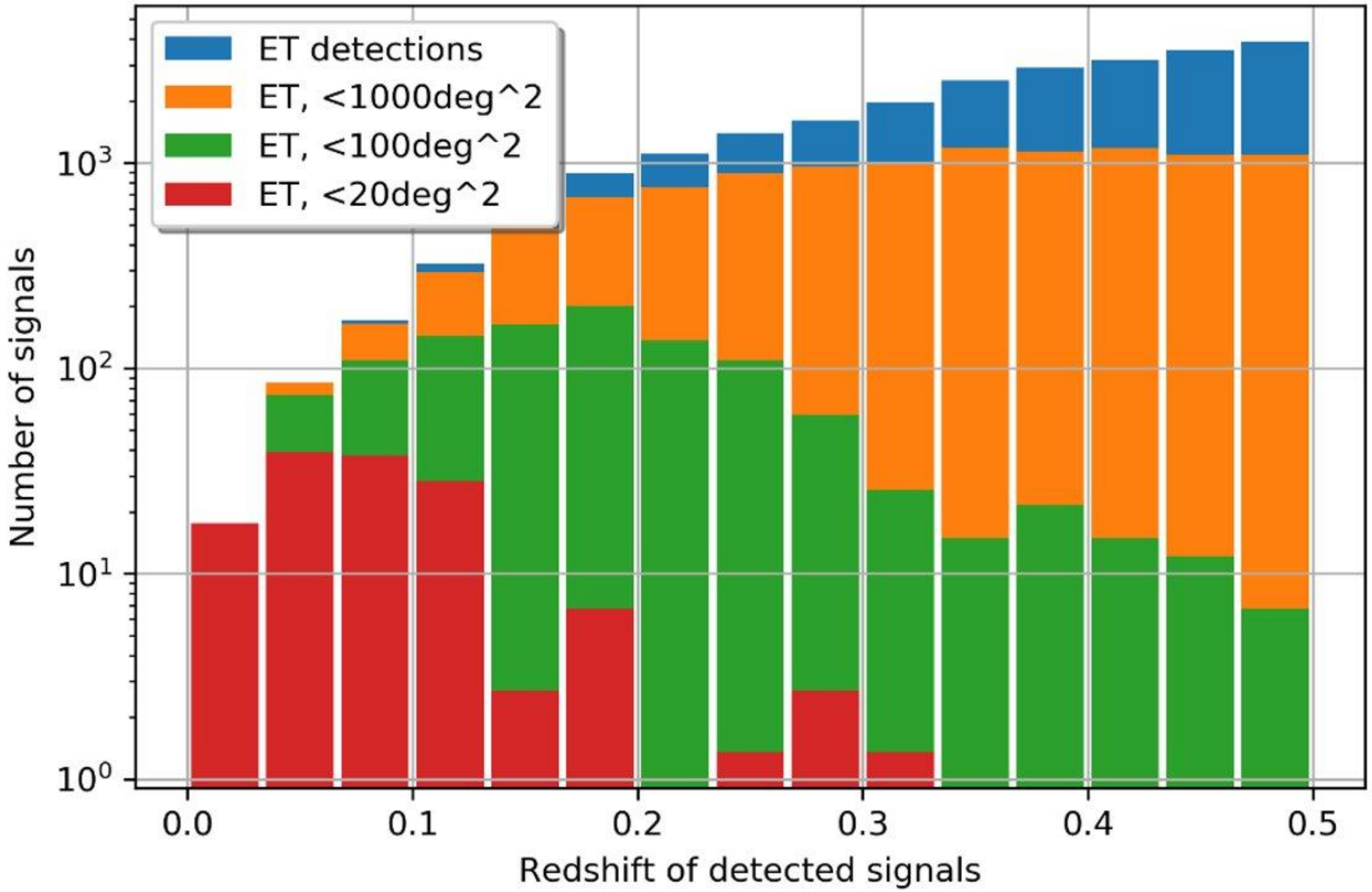
LSST Science operations start : Q4 2023
Survey duration:
2023 to 2033

LSST kilonova sensitivities : Transient and Variable Star Science Collaboration

Margutti et al. – whitepaper on cadence and strategy submitted to the LSST SCOC



Sky localizations – critical for MMA



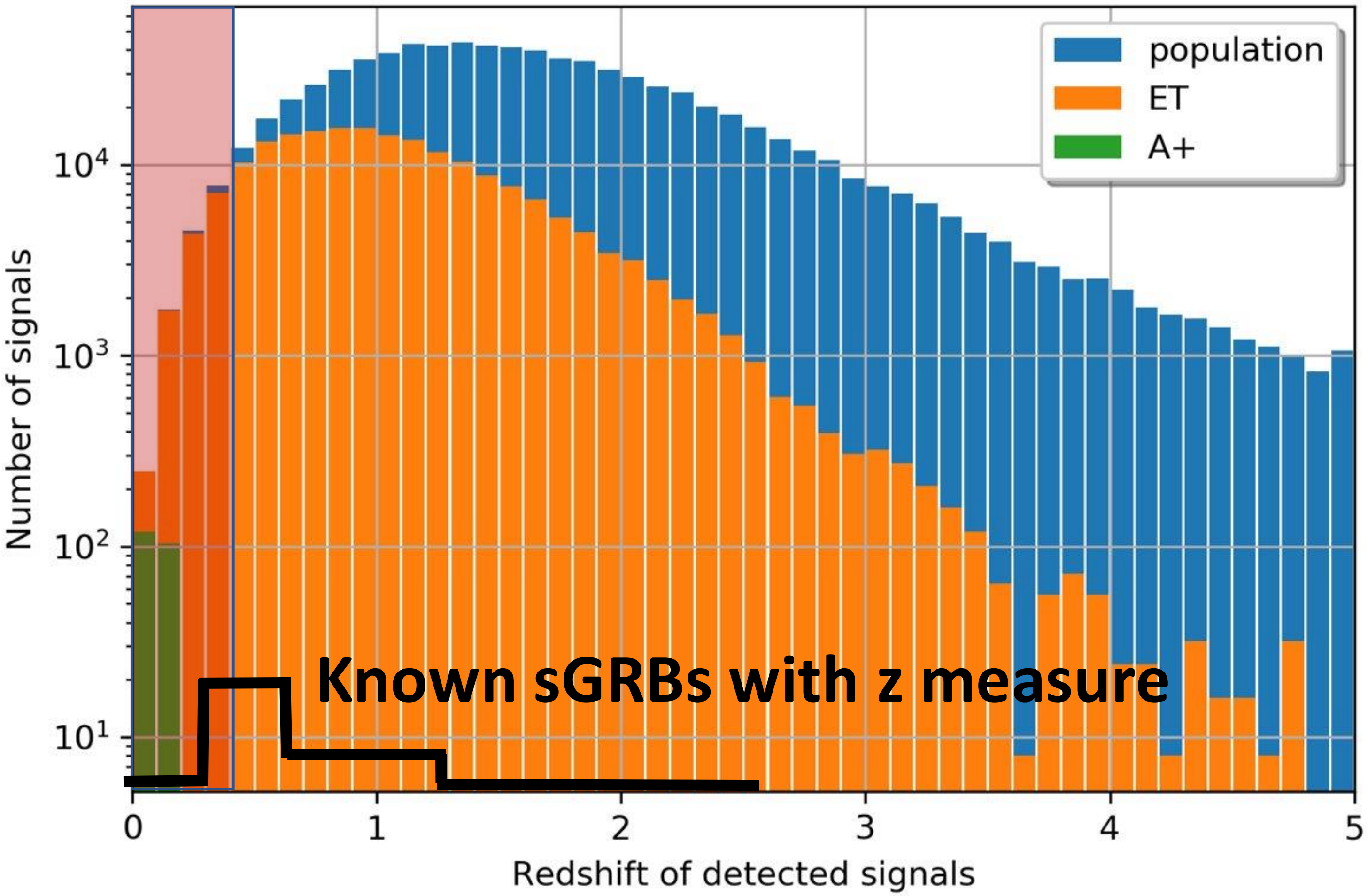
Straightforward science at
A < 20 sq deg
~100 per yr
~50 per yr visible for LSST
Deep LSST reference sky by time of ET

<u>But 6-8m will be needed</u>

A < 1000 sq deg
z < 0.5 difficult
10,000 per year
3 per day – too many for follow-up

Hard redshift limits for 6-8m telescopes for kilonova detection

z < 0.4 is hard limit for kilonova (thermal)



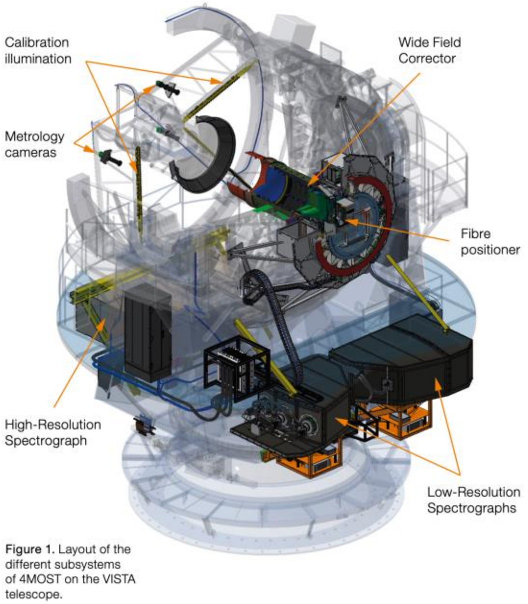
z = 0.4
r (obs frame) ≈ 26 magnitude (AB)
For a KN with
g (rest frame) ≈ -15.6

Total per year = 10^5
Optical/NIR detectable ≈ 10^4

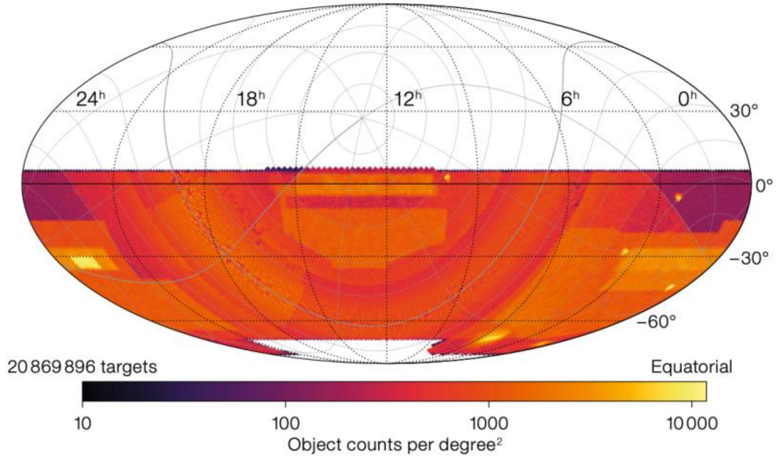
Locating sGRB afterglows (for Redshifts) : difficult beyond z = 0.5 - 1.0

Image Credit :
Marica Branchesi. Numbers for sGRBs from Berger ARA&A

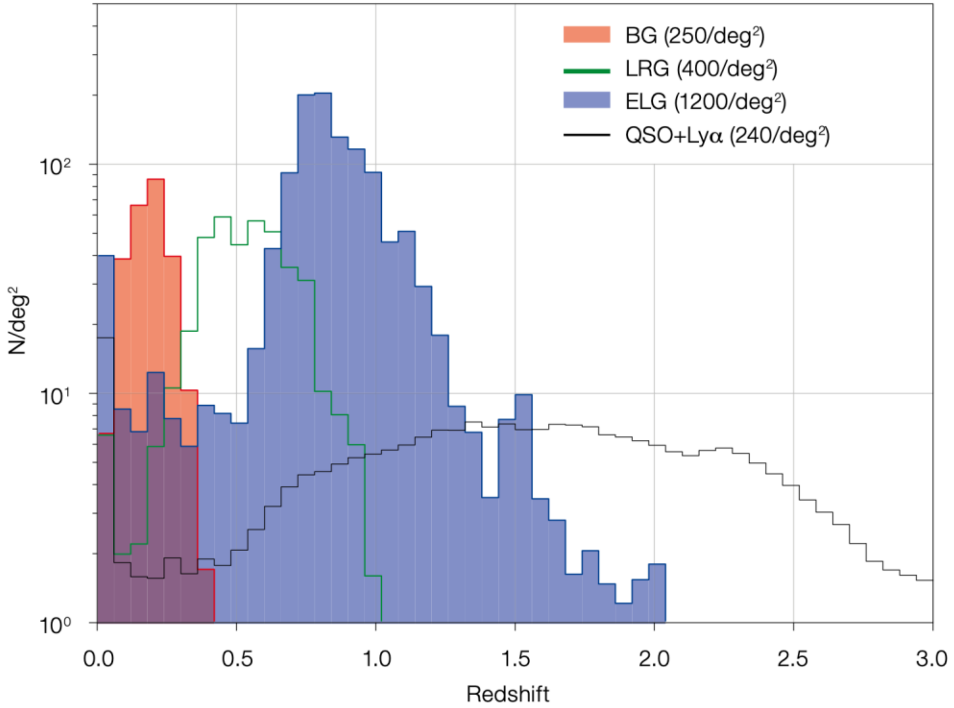
Galaxy redshift surveys: 4MOST



VISTA Telescope +
4MOST instrument with
1624 fibres (low-res)



20 million galaxies



Redshift distribution – public surveys and

4MOST - 4-metre Multi-Object Spectroscopic Telescope

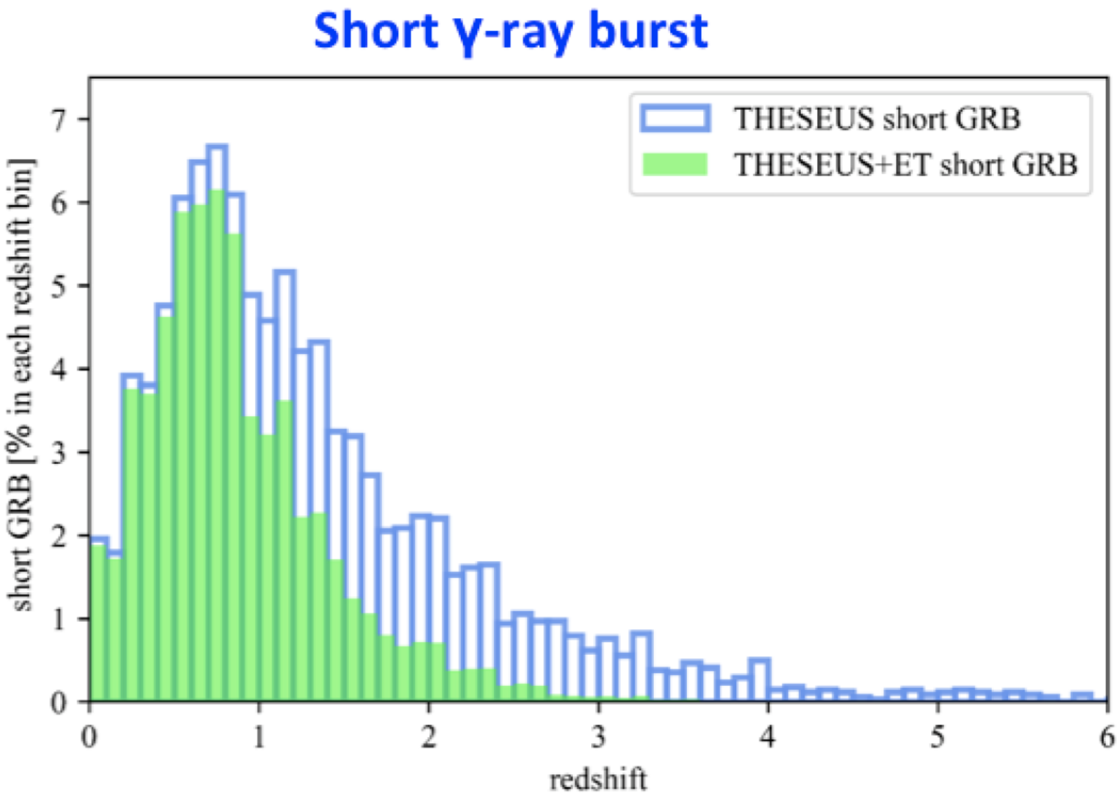
+ WHT and Weave (1000 fibres)
And Mauna Kea Explorer (4000 fibres)

Division 4 : Conclusion 1 (optical-NIR)

- Only the Rubin Observatory (6-8m aperture) is sufficient
- Rubin observatory will have completed deep image of southern sky by 2033
- Excellent quality, deep reference images – critical for difference imaging and finding optical – near IR counterparts
- ET : 100 per year visible and detectable
- ~50 nights per year required or ~20% of telescope
- We require Rubin to still be operational beyond the end of current surveys.

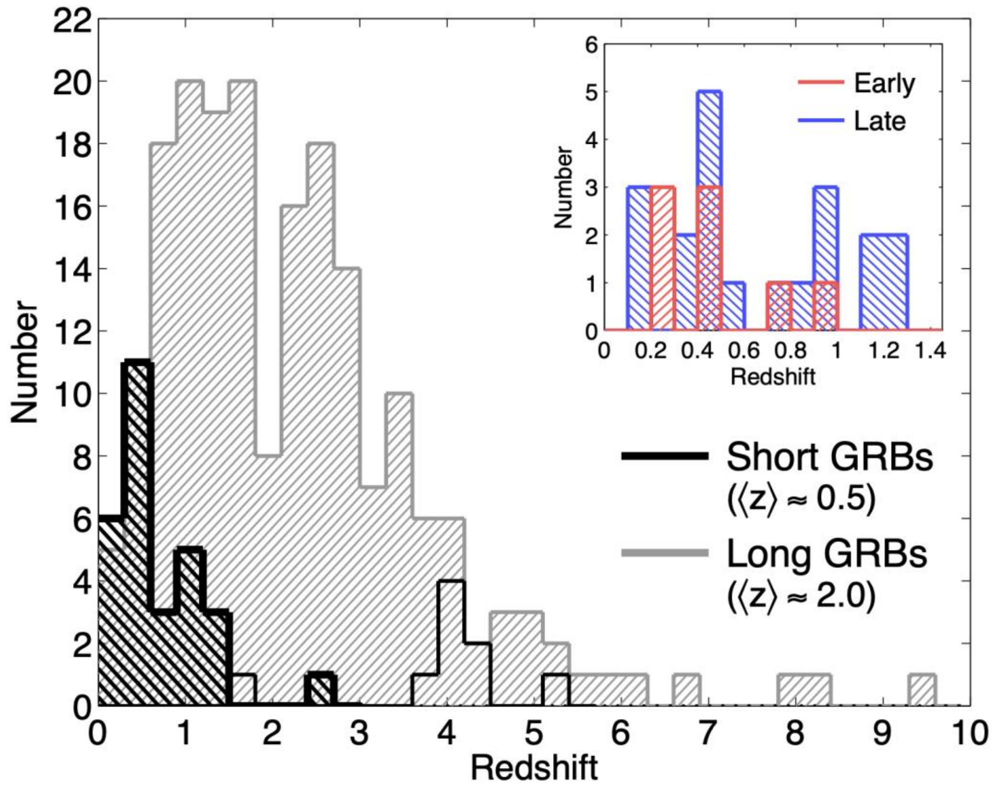
Short GRBs – observed redshift distribution

Projected



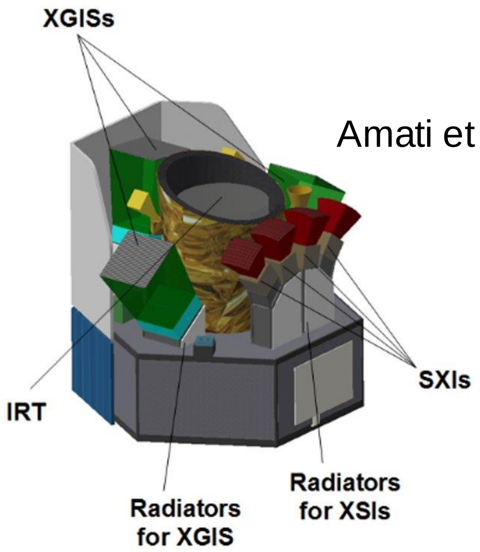
See Ciolfi et al. 2021, arXiv:2104.09534

Observed to date



Division 4 : Conclusion 2 (high energy)

- Number of distant face-on BNS GW sources >> nearby sources
- GRB + x-ray satellite capable of localizations of afterglows is required



Amati et al. 2018

<u>A mission like THESEUS running in the 2030 – 2040 timeframe essential</u>

- **WIDE FIELD OF VIEW (more than 1sr) with ACCURATE LOCALIZATION (down to 0.5’-1’ in the X-rays)**
- **WIDE SPECTRAL COVERAGE from 0.3 keV up to several MeV**
- **an on-board prompt (few minutes) follow-up with a 0.7 m CLASS IR TELESCOPE** with both imaging and spectroscopic capabilities

Division 4 : To do

Work to do :

- Build on the Branchesi et al. Work to date
- Detection efficiencies for a luminosity distribution of optical/NIR kilonovae – which is currently unknown
- Detection efficiencies for non—thermal emission components (GRB prompt and afterglow) based on census of EM facilities and simulated EM emission from population models
- Explore possible particle signal from CB mergers
- Are there galaxy redshift surveys that are required beyond those proposed by 4MOST, WEAVE and the MSE? How to make the best use of them?
- Which kilonovae can be observed by E-ELT : what is response time for a 30m telescope ?
- Lobby for GRB + x-ray missions not yet funded : critical to MMA and all the science tgat follows