The era of Multi-Messenger astrophysics

GW State of the Art

GWs and photons provide complementary information about the physics of the transient

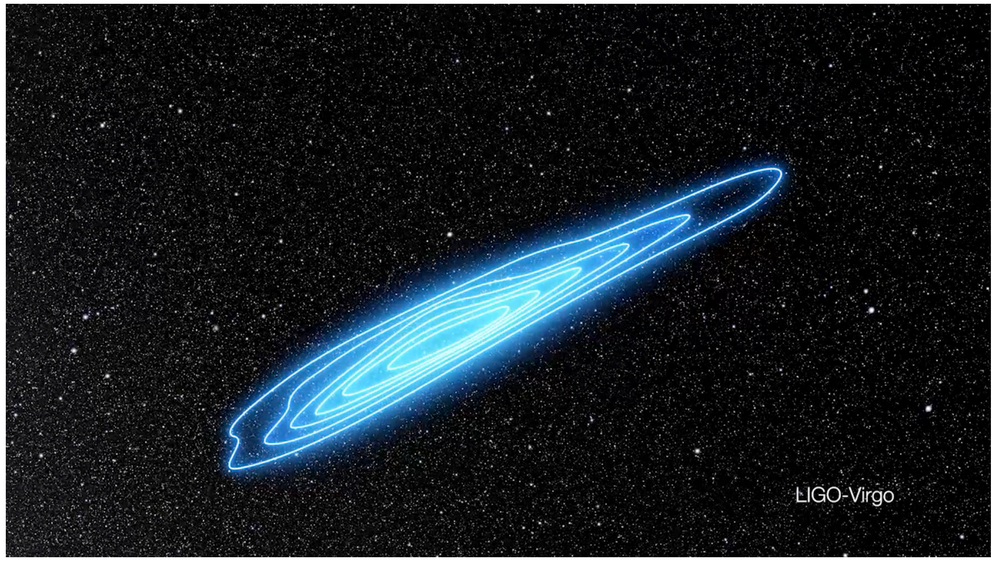
GW	EM
• Mass	• Arcsec sky localization
• Spin	• Host galaxy
• System orientation	• z
• $d_L(z)$	• Emission process
• $\mathscr{R}(z)$	• Acceleration mechanism

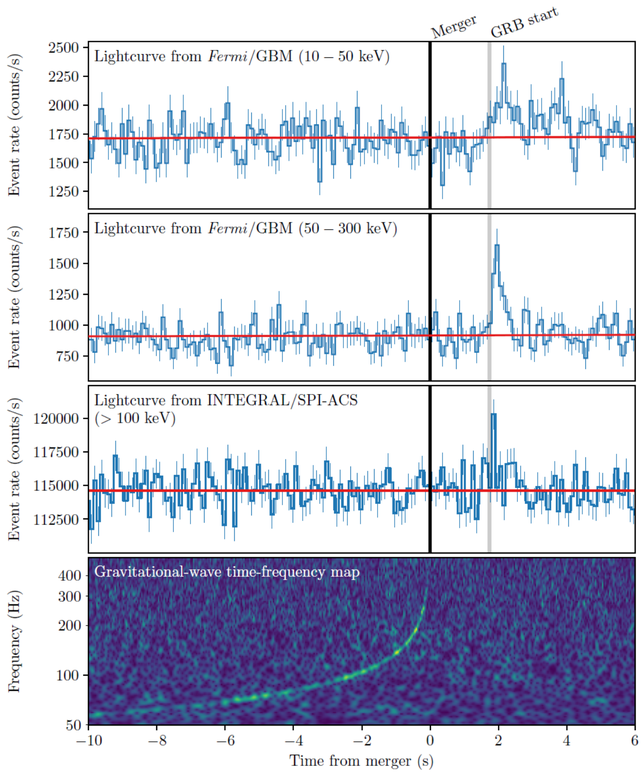
How?

CBCs CCSNe Isolated NS

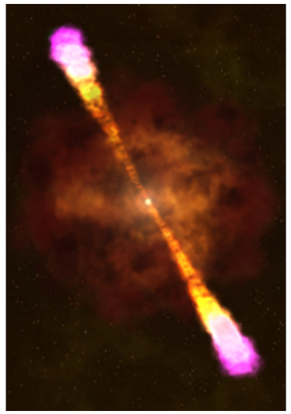
Why is this so important?

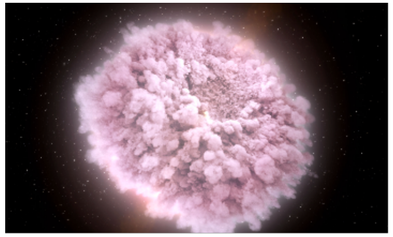
GW170817: one event to rule them all

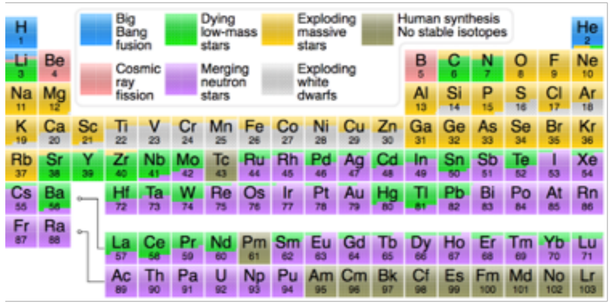


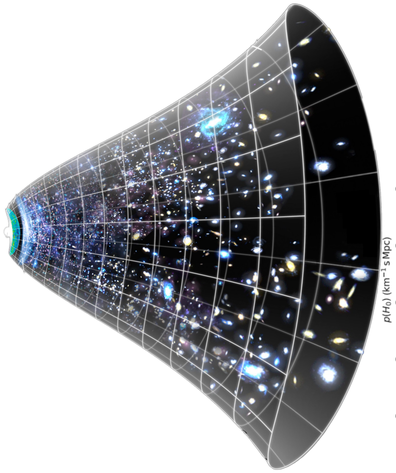


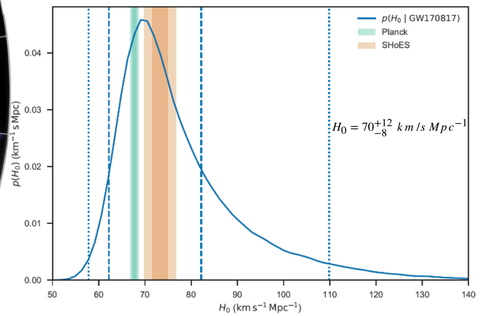
GW170817: one event to rule them all

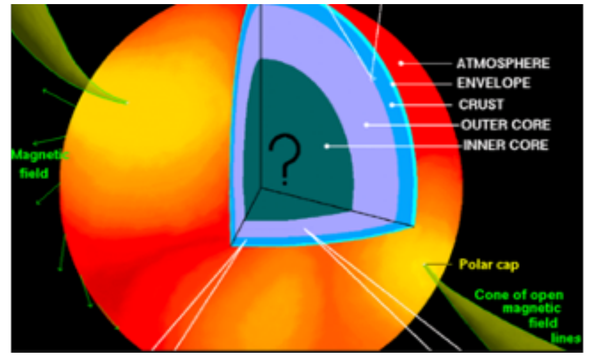












But what about other CBCs?

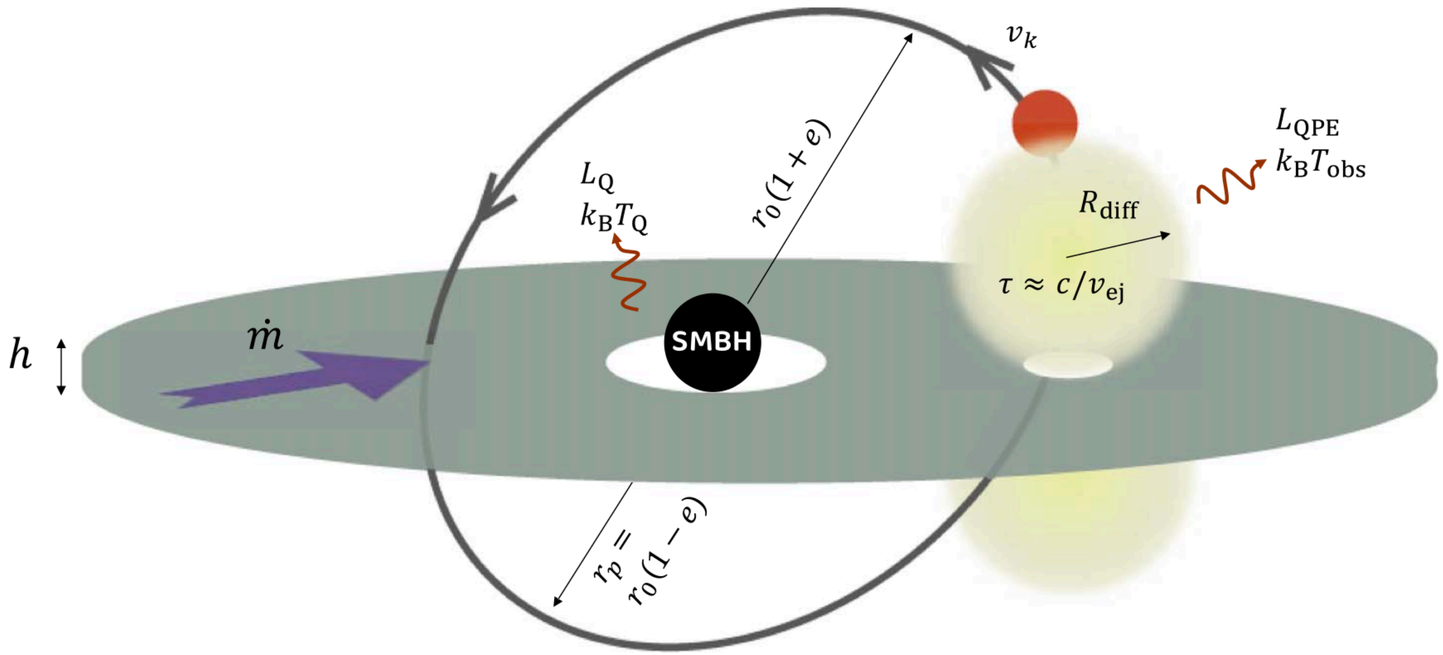
BBH

GW190521

The primary falls in the mass gap by (pulsational) pair-instability SN

m1: 85^{+21}_{-14} M⊙,

m2: 66^{+17}_{-18} M⊙



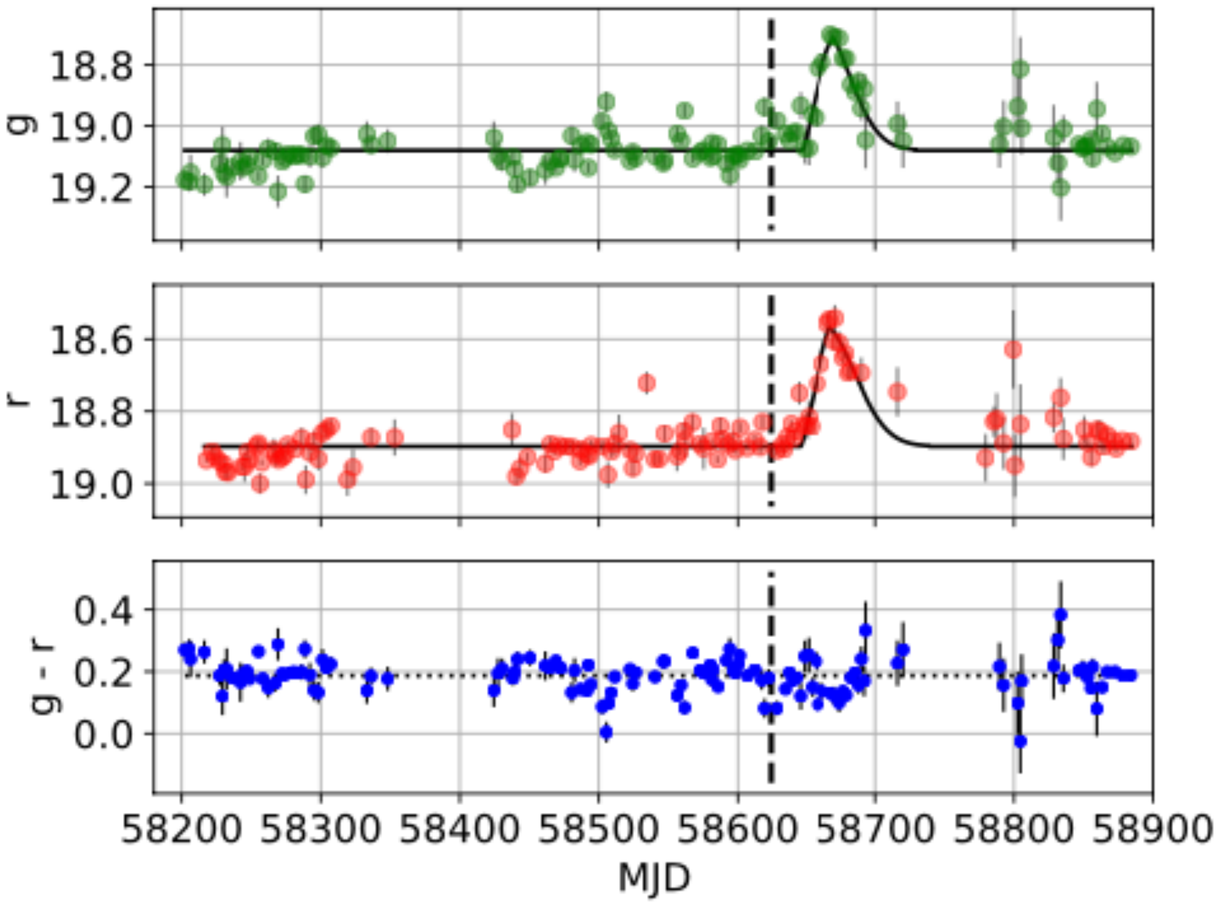
BBH

GW190521

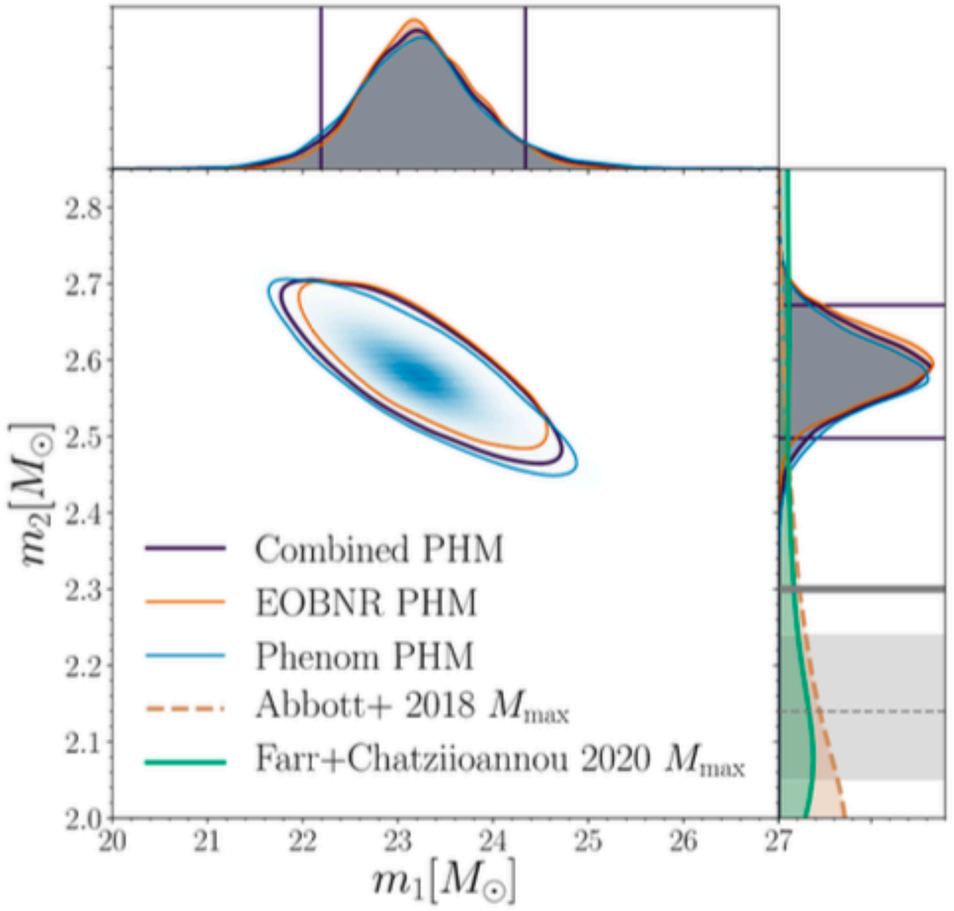
The Zwicky Transient Facility (ZTF) detected a candidate optical counterpart in AGN J124942.3+344929

Dynamical channel?

Preferred common origin of the two transients



NSBH



- GW event observed by the two LIGO detectors and Virgo
- m1: $23.2^{+1.1}_{-1.0}$ M⊙; m2: $2.59^{+0.08}_{-0.09}$ M⊙

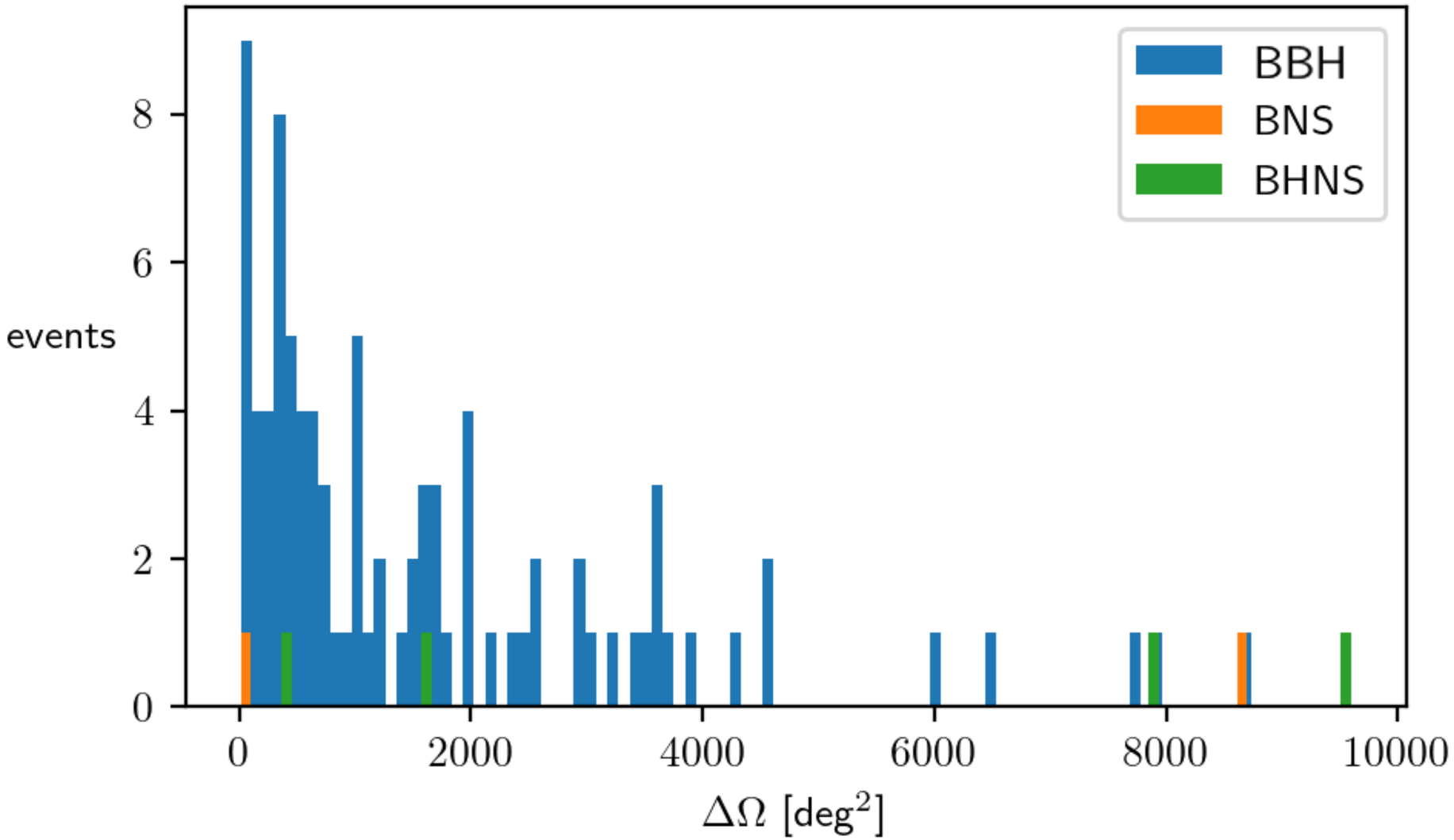
BBH or NS-BH merger?

- 90 % C.R.: 18.5 deg2; DL=241^{+41}_{-45} Mpc
- No EM counterpart

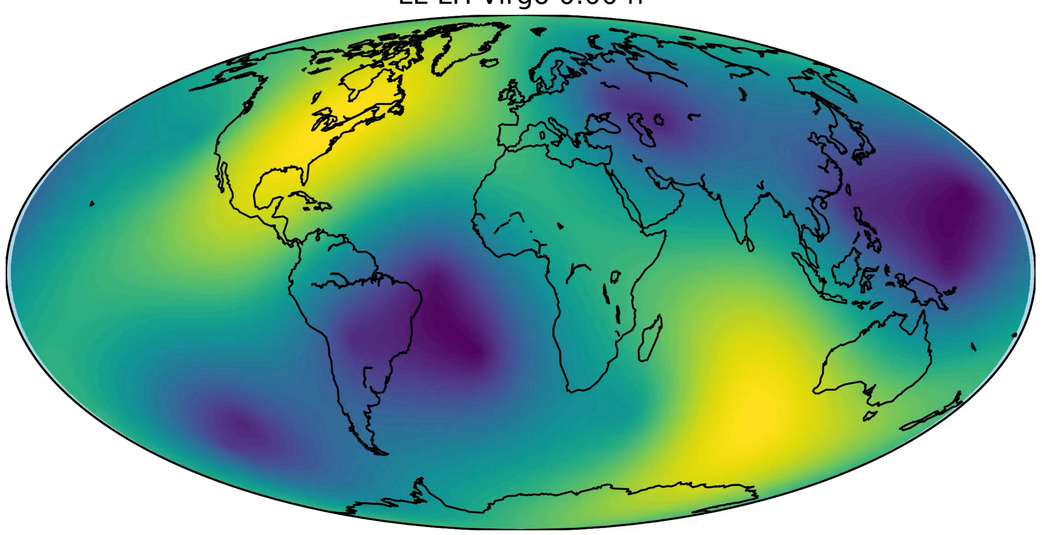
- First direct evidence that NS-NS mergers are progenitors of at least a fraction of short GRBs
- First evidence for a structured jet for GRBs
- First unambiguous observational evidence for a kilonova
- First observation of a kilonova in association with both a short GRB and a GW event
- Evidence for NS-NS mergers as heavy element factories

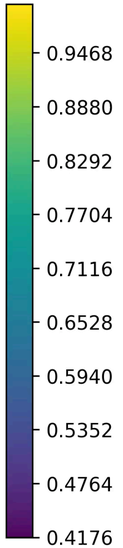
- Do all NS-NS mergers produce short GRBs?
- Are KNe associated to every short GRB?
- What is the GRB central engine/NS-NS merger outcome?
- Do NS-BH and BBH mergers have EM counterparts?
- ...and much more!

On the sky localization

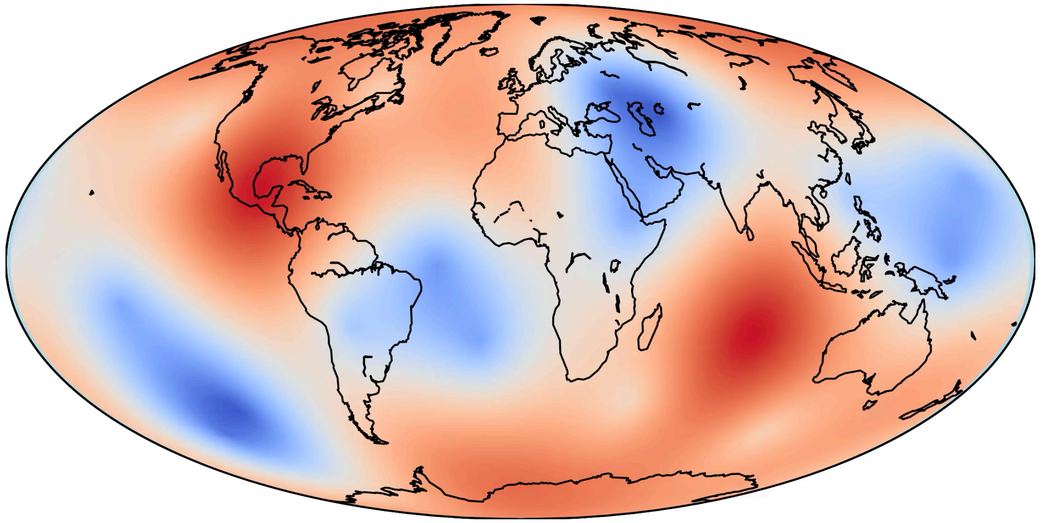


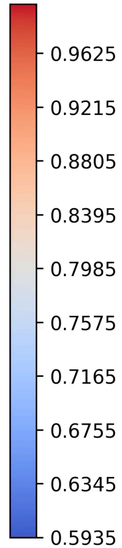
LL-LH-Virgo 0.00 h



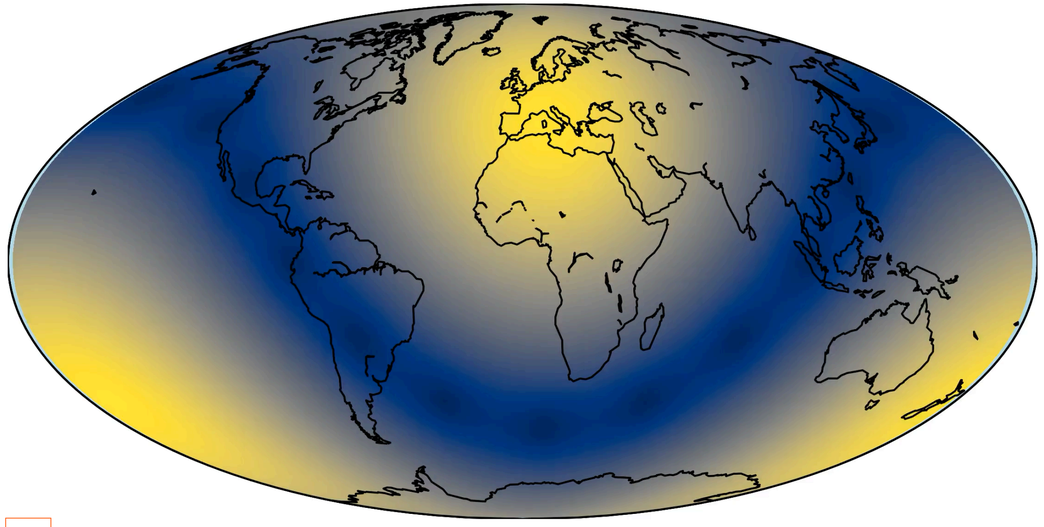


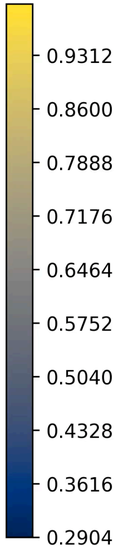
LH-LL-Virgo-KAGRA 0.00 h



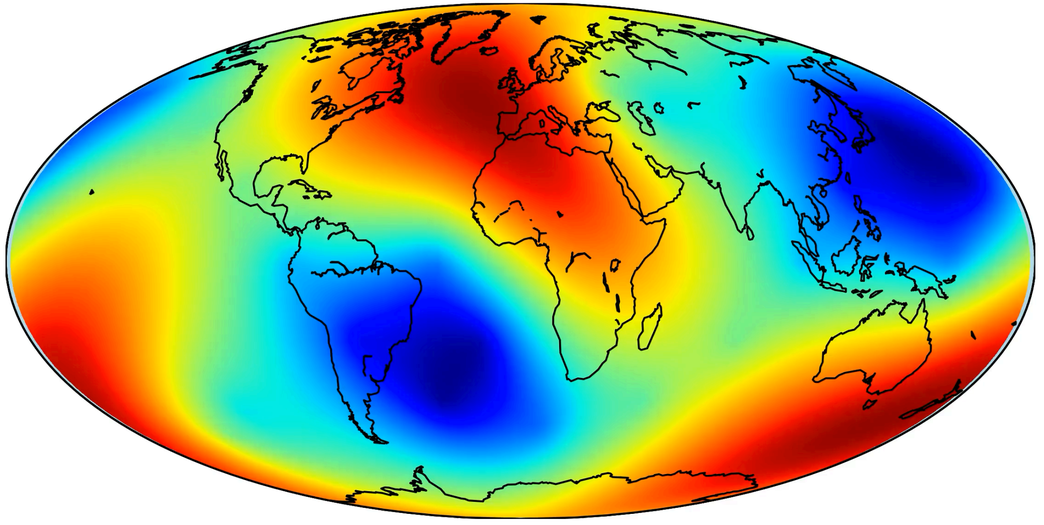


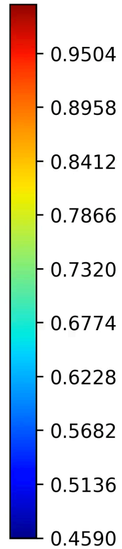
ETA-ETB-ETC 0.00 h



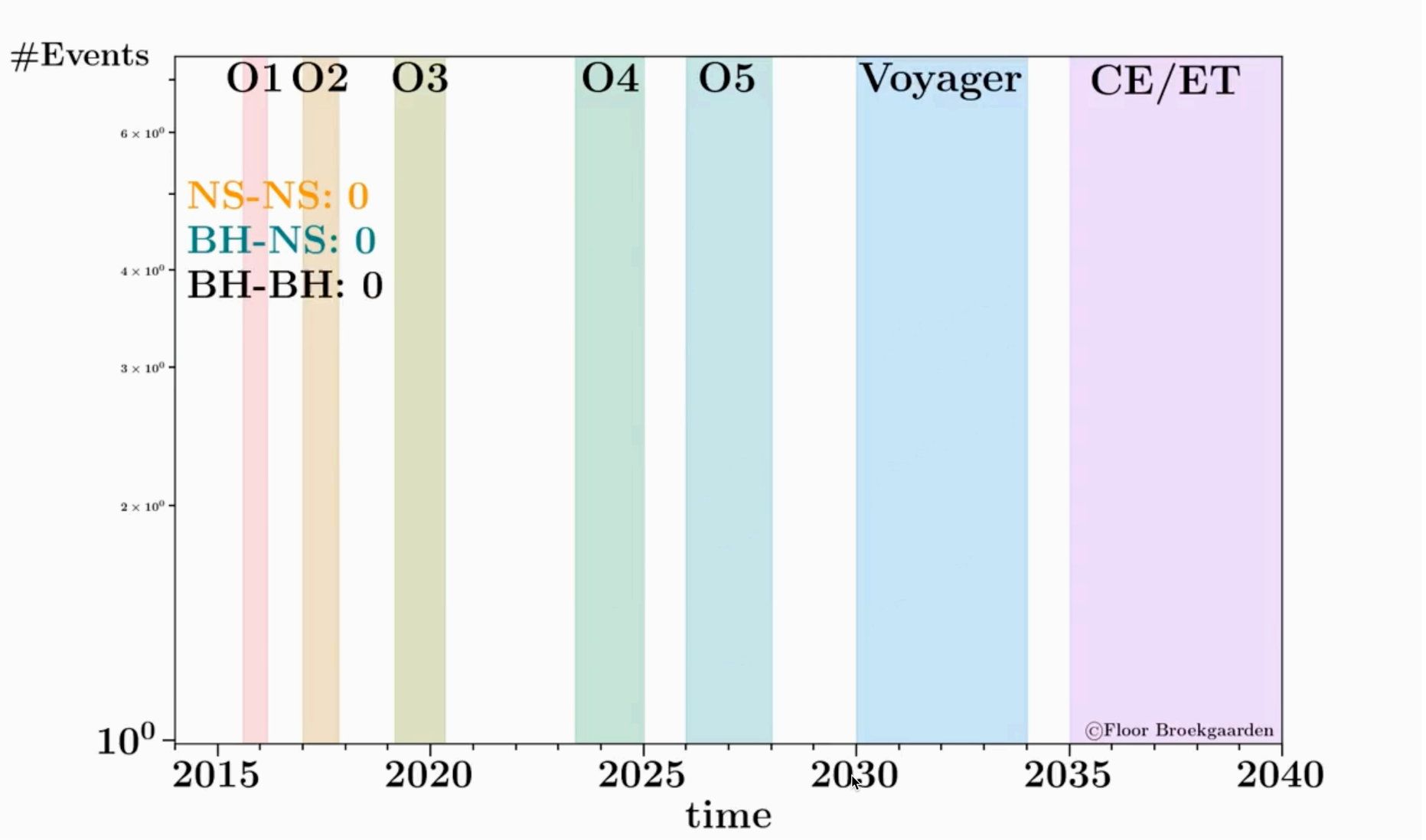


ETA-ETB-ETC-CEL-CEH 0.00 h



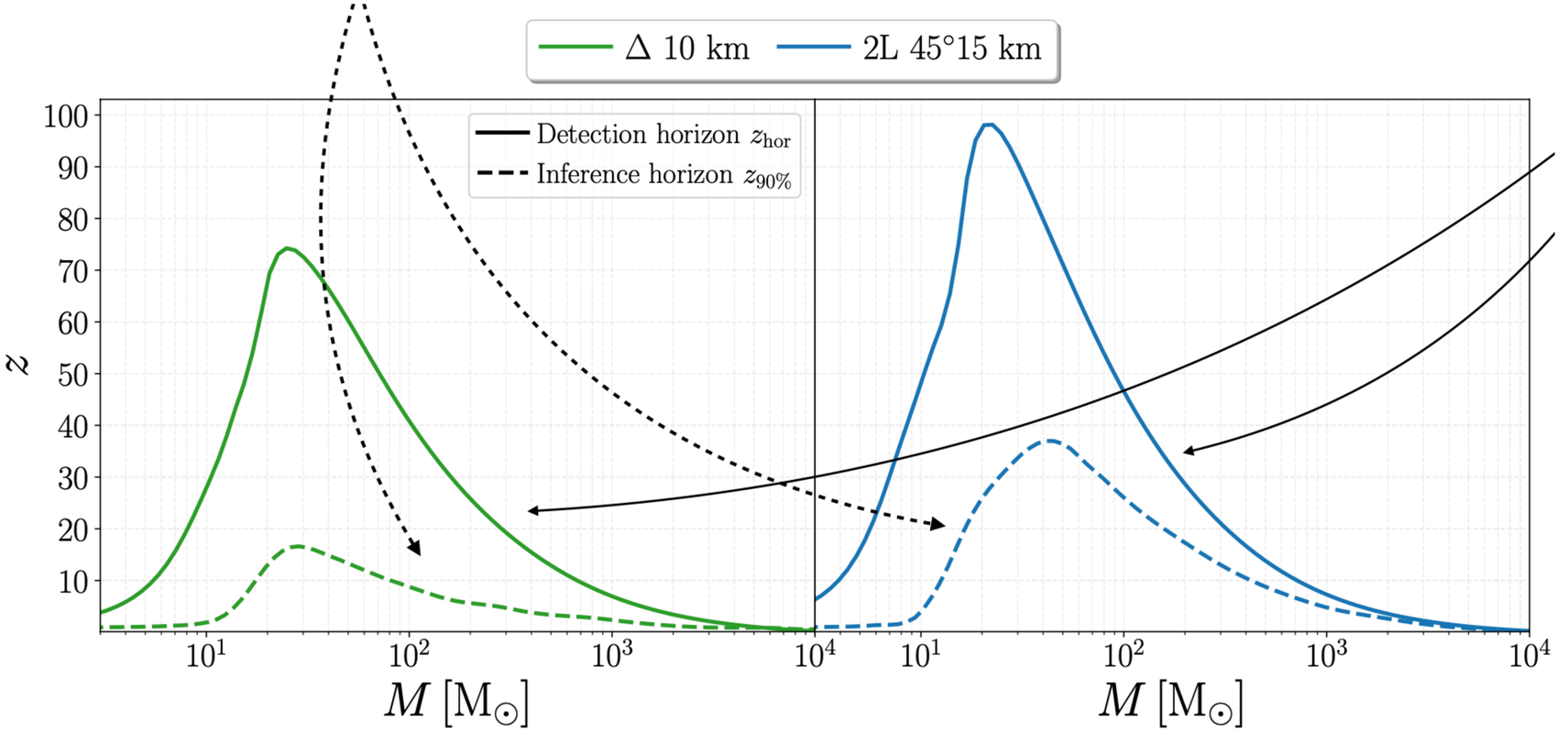


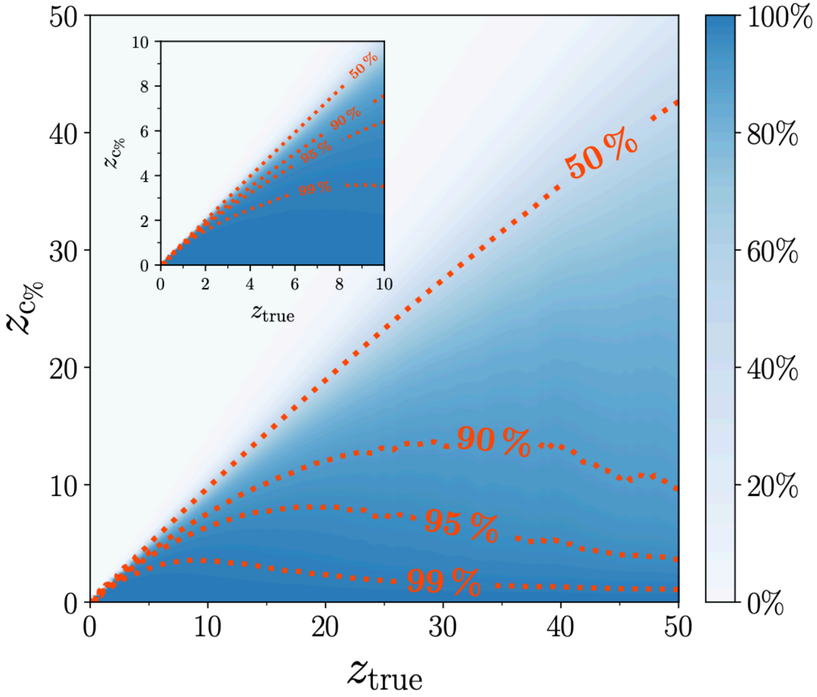
Snap into the present / near future



3G detectors and Observational strategies

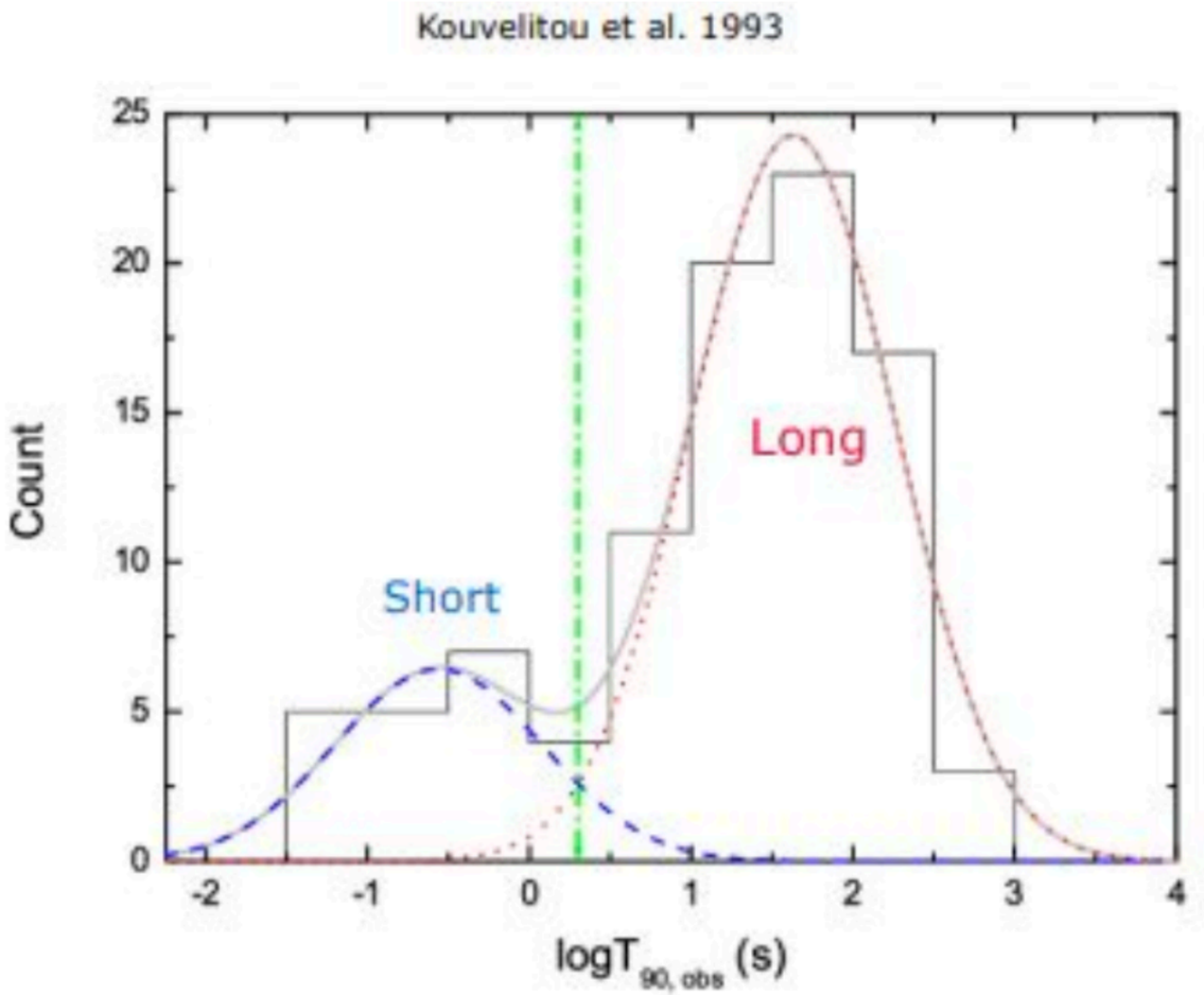
M. Mancarella, F. Iacovelli, D. Gerosa
2303.16323





Searching where nobody searches

GRB weirdness

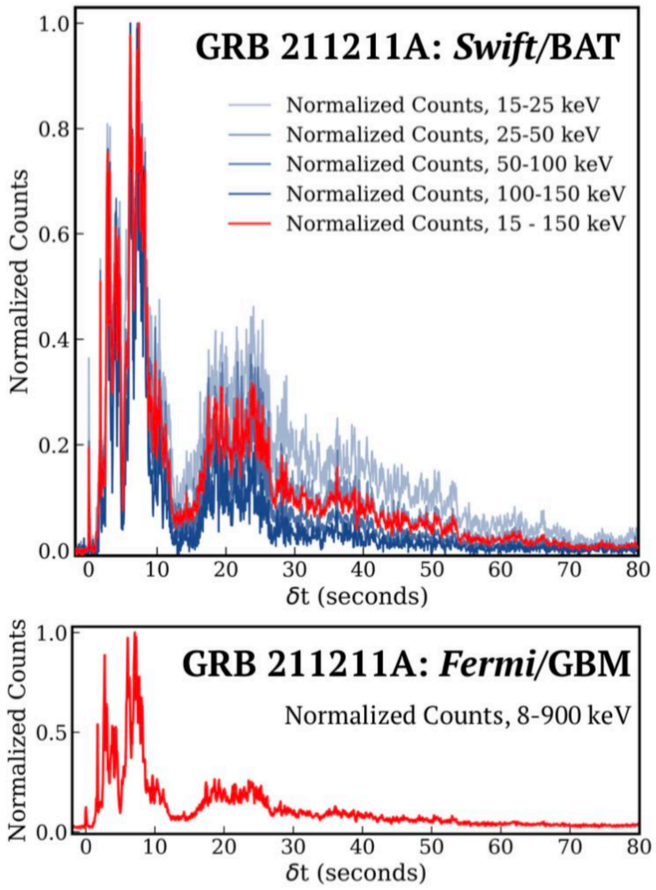


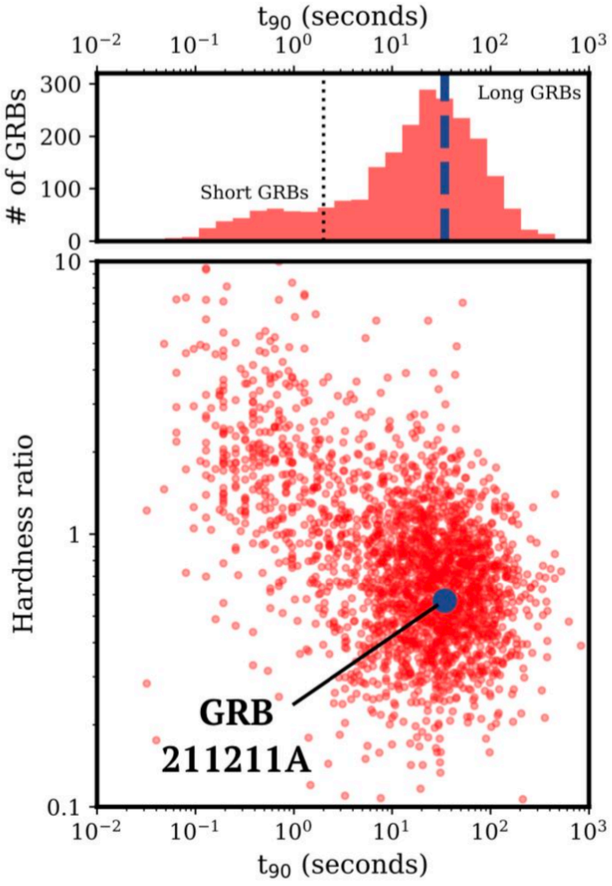
Missing pieces in the GRB physics

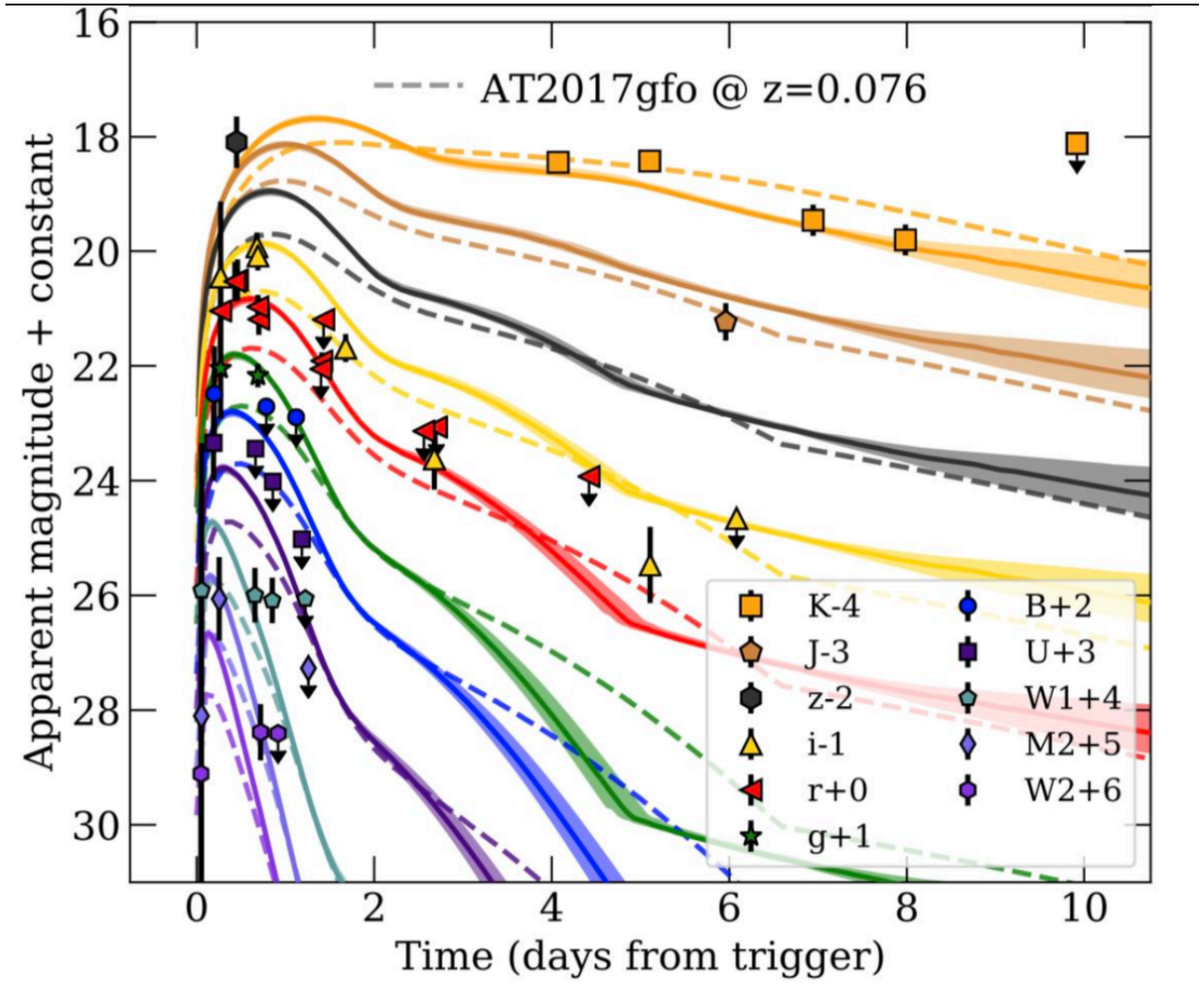
Misclassification

GRB weirdness… can be useful

GRB211211A and GRB230307A: long GRBs from CBC?

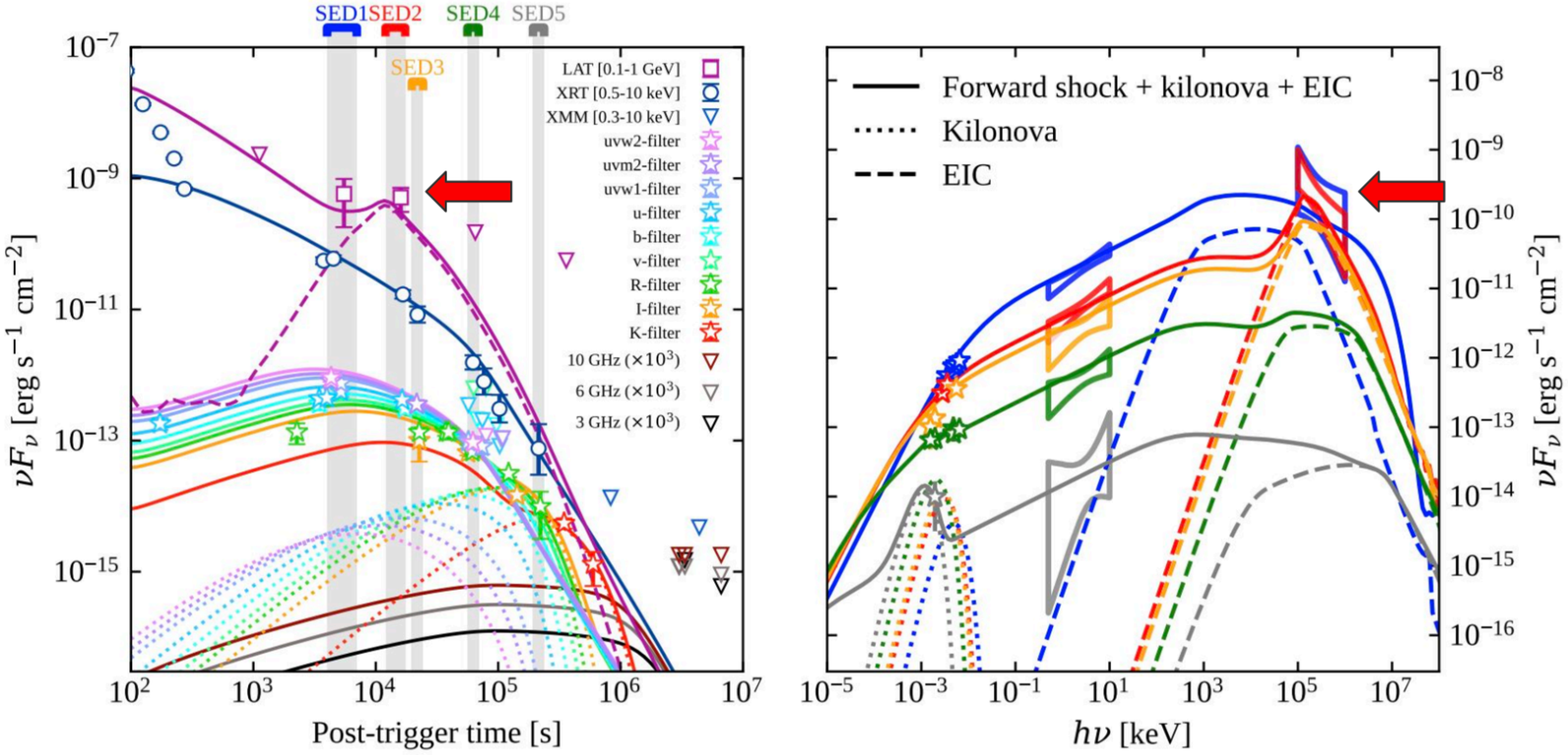






GRB weirdness… can be useful

The GeV emission is in EXCESS with respect to synchrotron emission



External Inverse Compton

GeV and (possibly) sub-TeV emission can be expected from CBC at even later times!

- Detection of counterparts are dependent on MeV detectors but Mev detectors (Fermi/GBM) have larger localization area

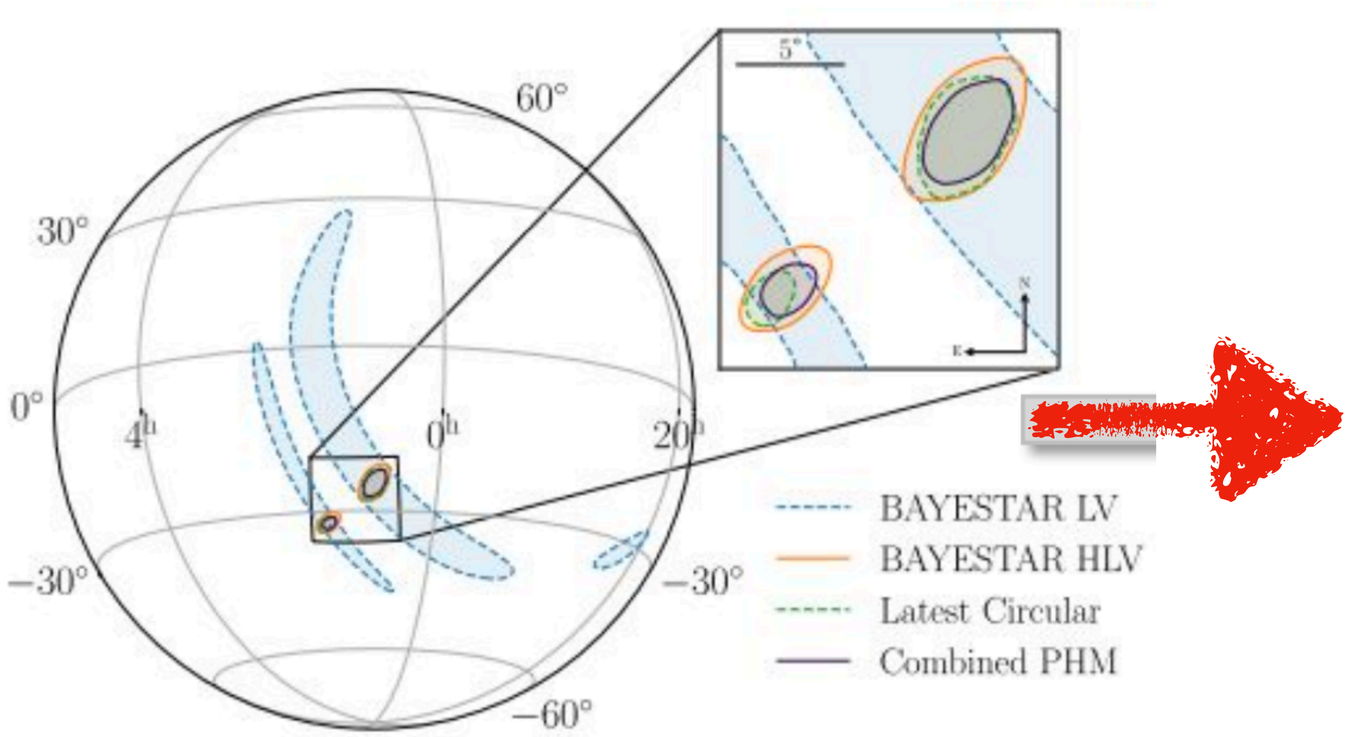
- Swift/BAT ~100 keV can localize better but has 30% less detection than GBM

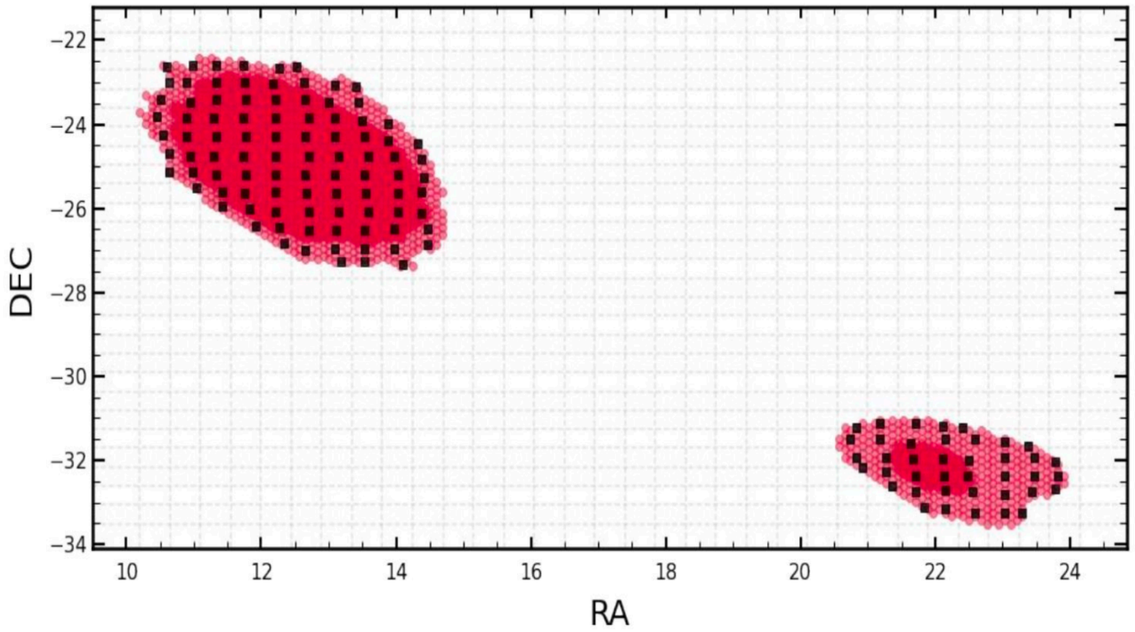
- Requirement: detectors with large FoV (>10 sq. deg.) and better localization (~1-deg)

- ***GeV/ TeV facilities can help in this regard!***

NEW OBSERVATIONAL STRATEGY

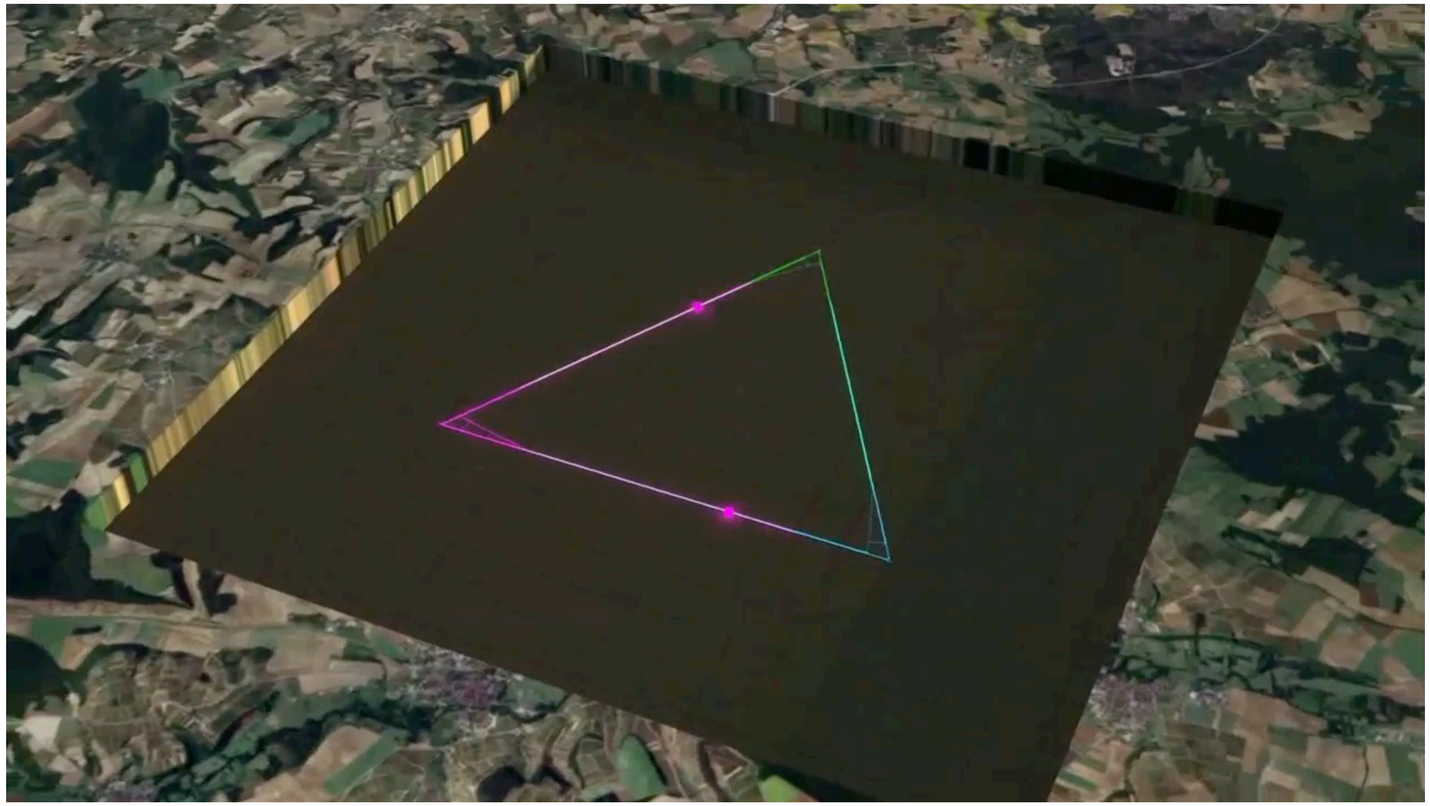
GeV

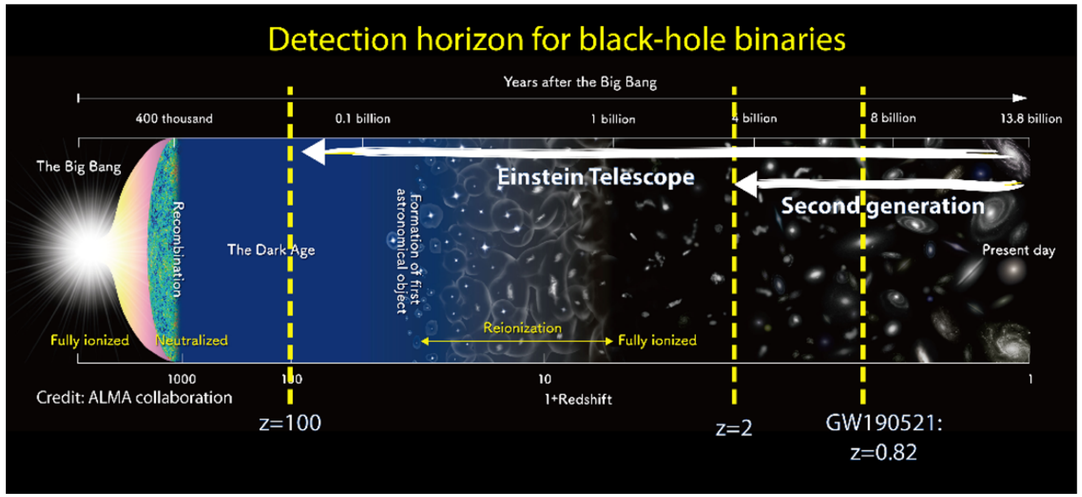




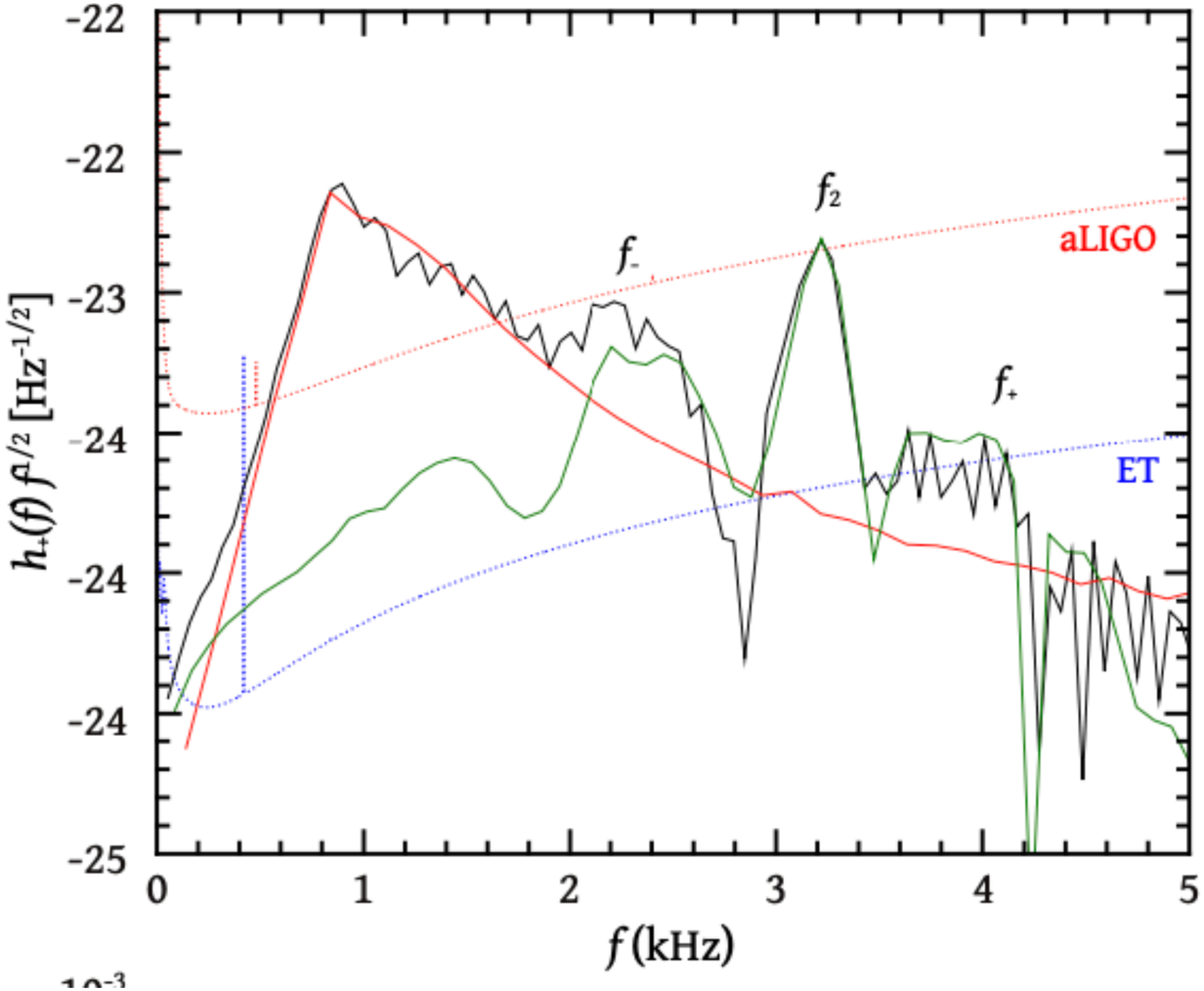
- Making grids of ~0.5 deg: psf of Fermi/LAT @ 1 GeV
- Search for GeV excess over the GW patch

3G detectors and Observational strategies



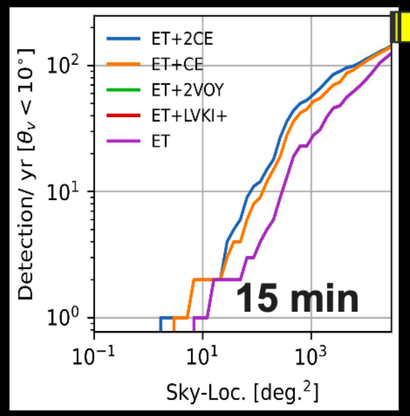


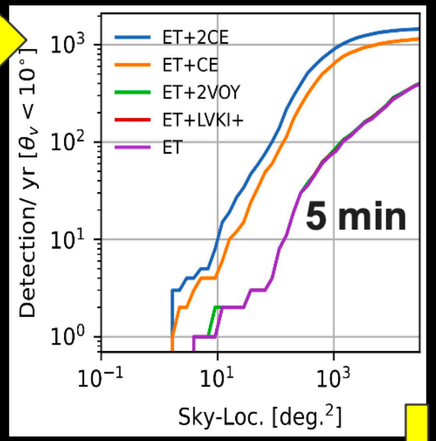
GW pre-alert strategy



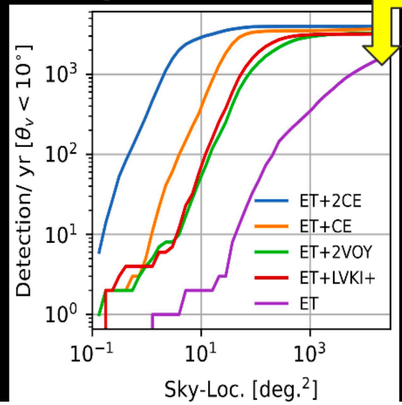
TeV

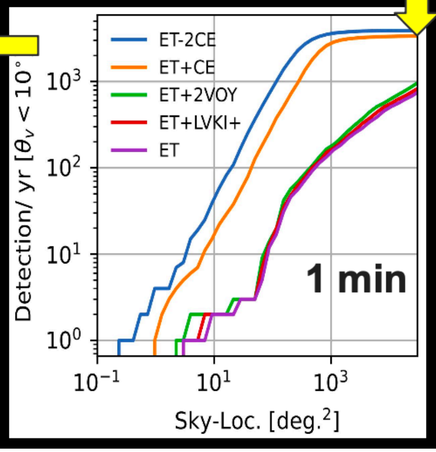
Sky-localization capability:





Merger



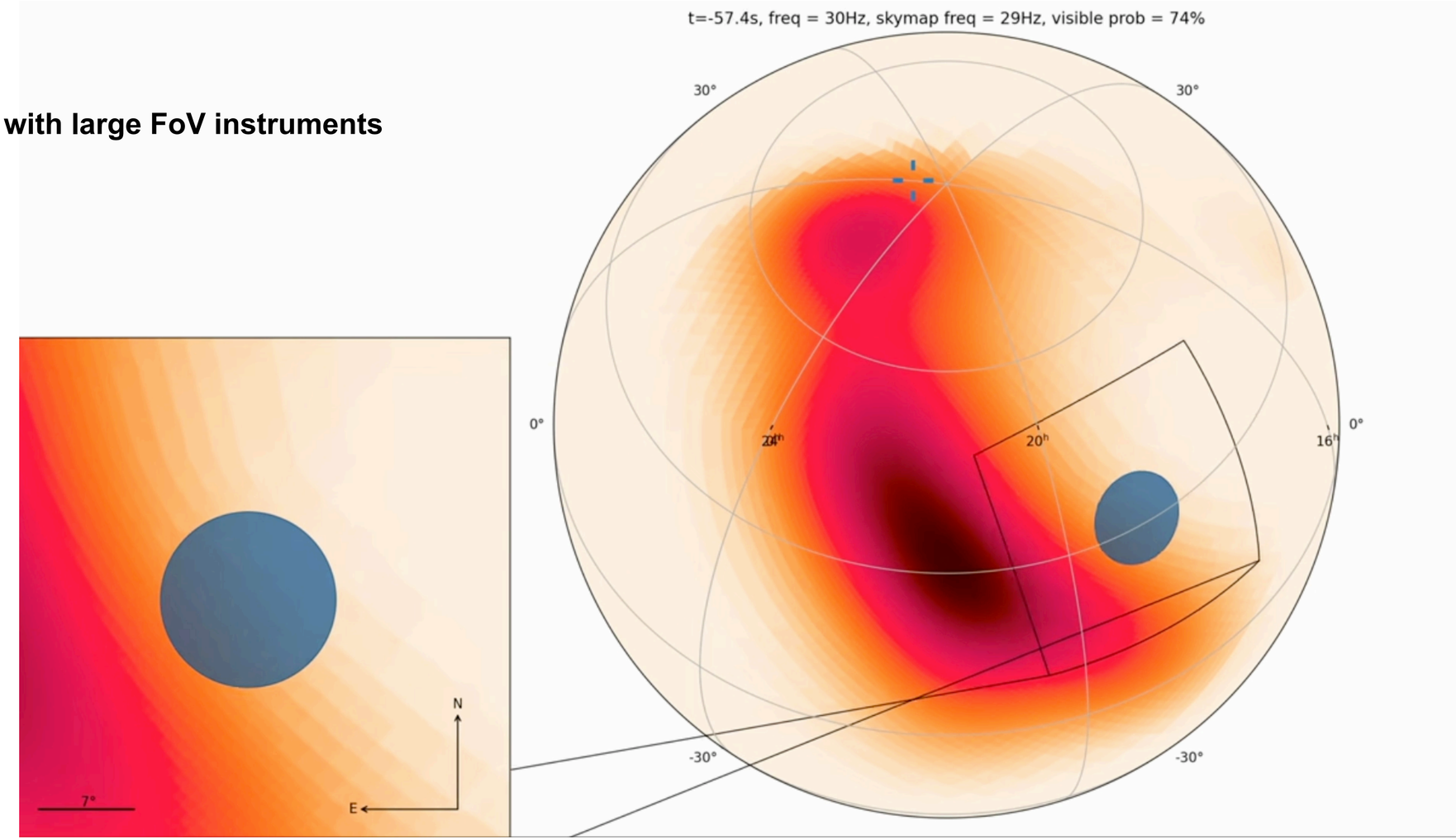


Detector	Ω [deg^2]	All orientations			
		15 min	5 min	1 min	0 min
ET + CE	100	442	1325	5075	123303
ET	100	90	130	208	436

Detector	Ω [deg^2]	Viewing angle (<10^0)			
		15 min	5 min	1 min	0 min
ET + CE	100	21	71	314	3376
ET	100	3	6	13	40

- ET, CE, CTA synergy to help discovering prompt emission of GRBs in VHE gamma-rays: about 20 VHE counterparts to be detected using ~5% of the CTA time.

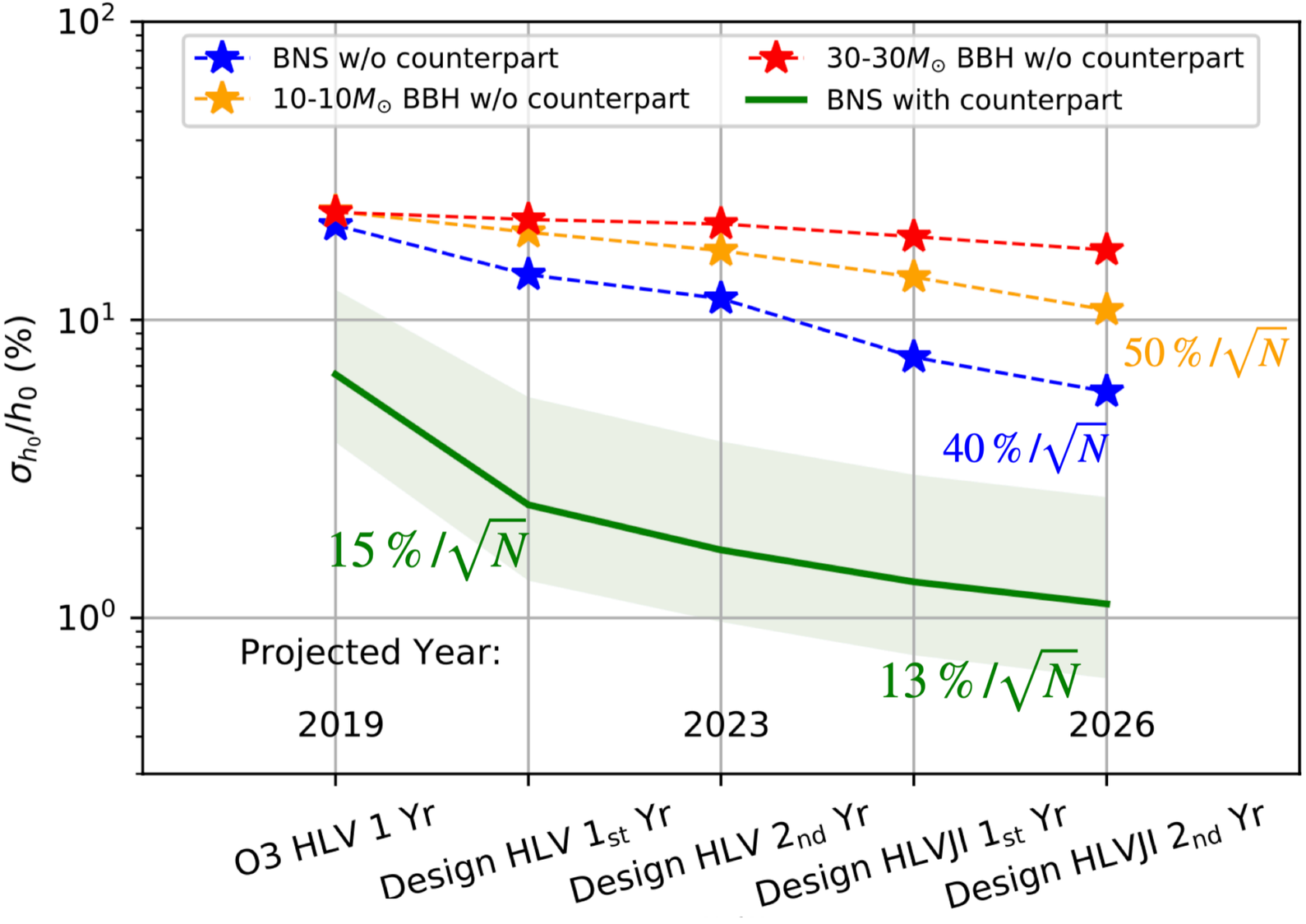
- Pre-alert scheme can be applied during O5 with large FoV instruments



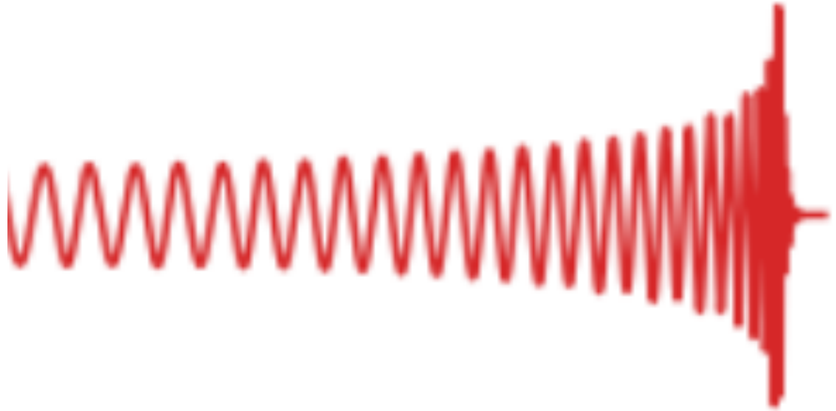
Cosmology with standard sirens

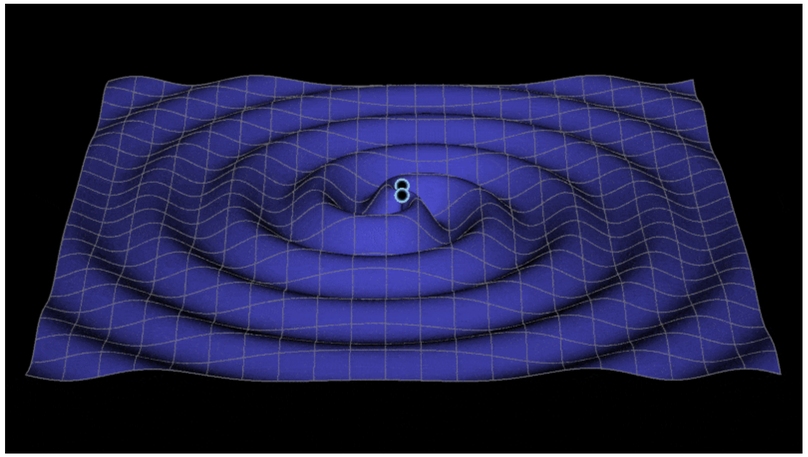
Is that really worth it?

(Spoiler: yes!)

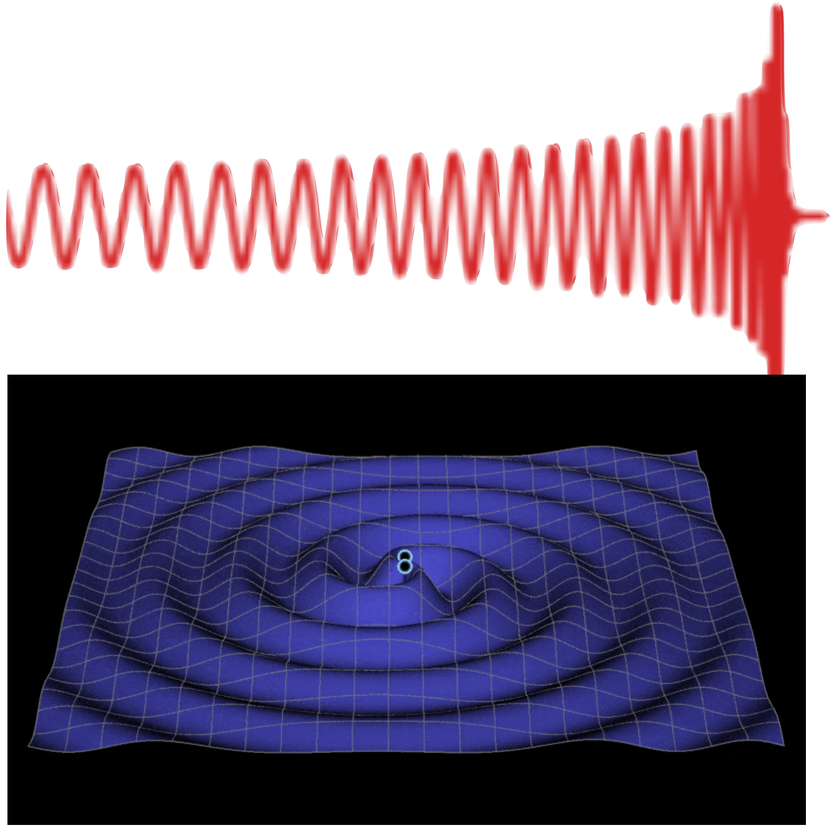

BNS w/o counterpart
10-10$M_\odot$ BBH w/o counterpart
30-30$M_\odot$ BBH w/o counterpart
BNS with counterpart
10^2
10^1
10^0
σ_{h_0}/h_0 (%)
$50\,\%/\sqrt{N}$
$40\,\%/\sqrt{N}$
$15\,\%/\sqrt{N}$
$13\,\%/\sqrt{N}$
Projected Year:
2019
2023
2026
O3 HLV 1 Yr
Design HLV 1st Yr
Design HLV 2nd Yr
Design HLVJI 1st Yr
Design HLVJI 2nd Yr

The big skeleton in the closet: $\iota - d_L$ degeneracy





The big skeleton in the closet: $\iota - d_L$ degeneracy

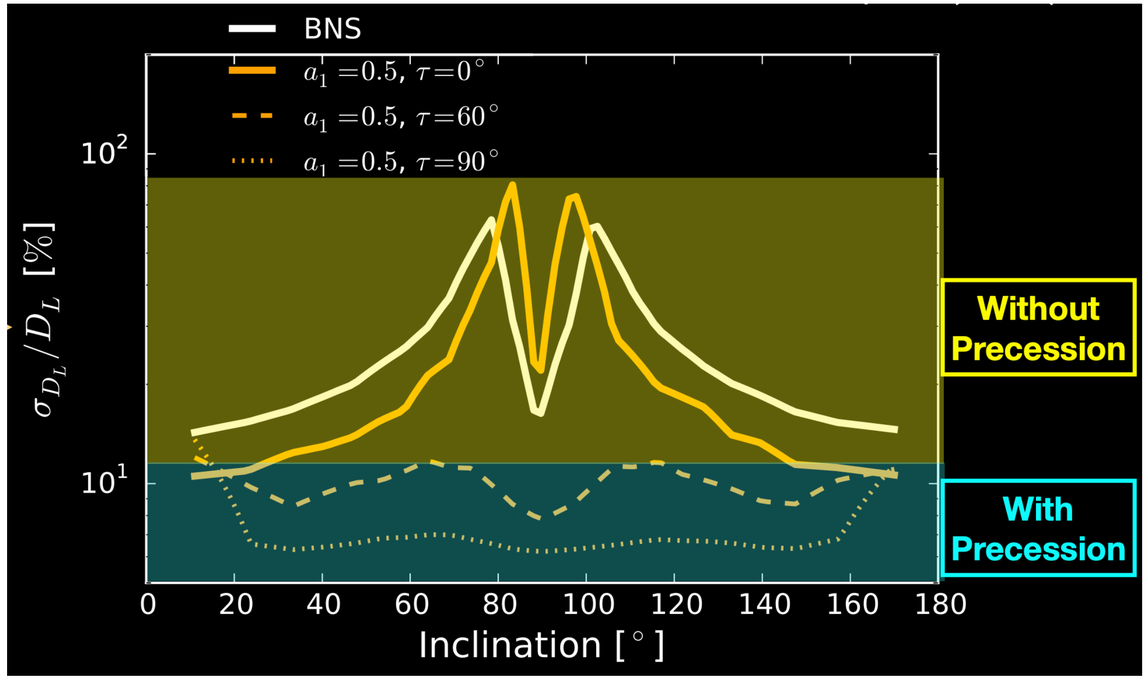


Break $\iota - d_L$ degeneracy

- Polarization ⟶ Network of detectors

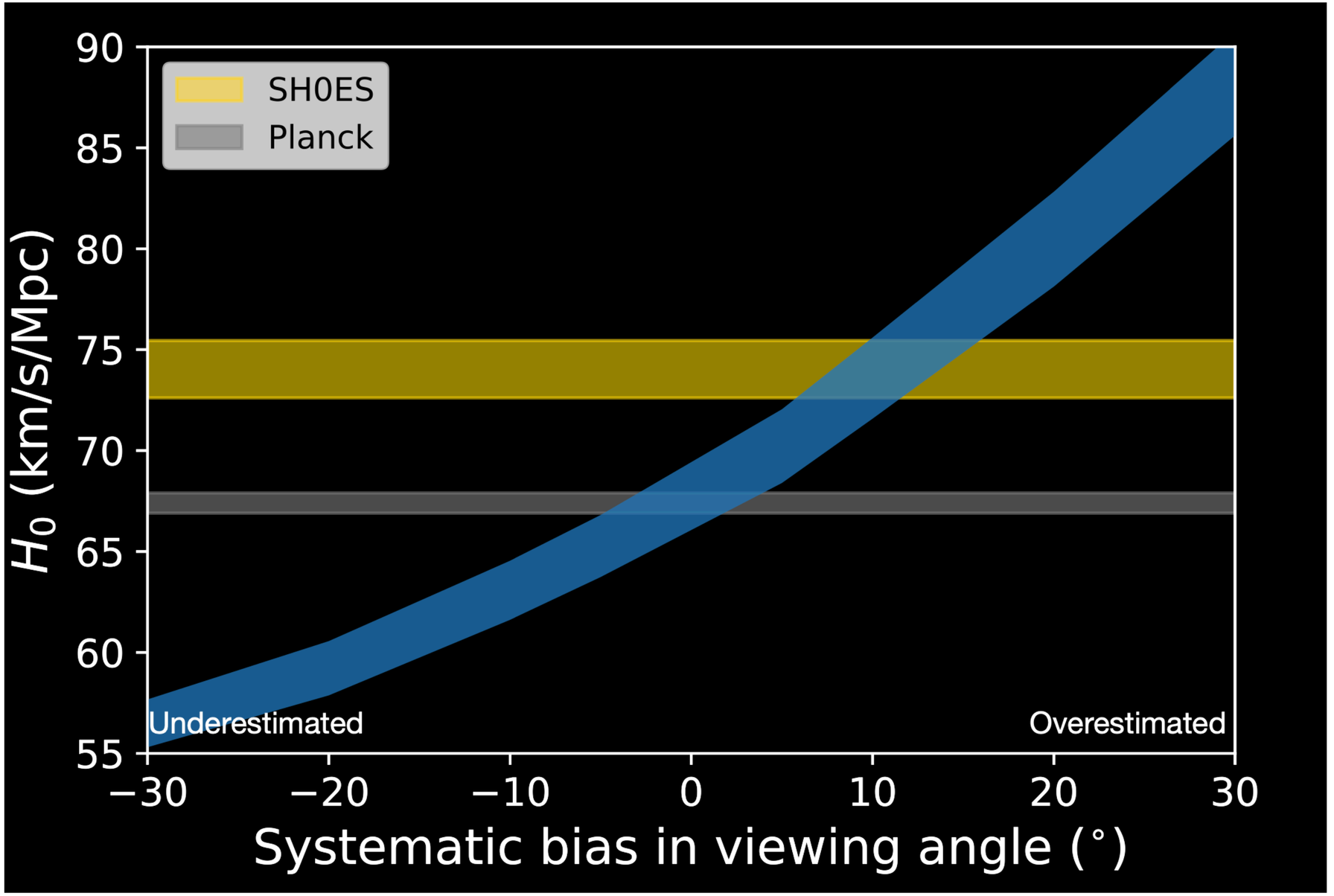
- Precession

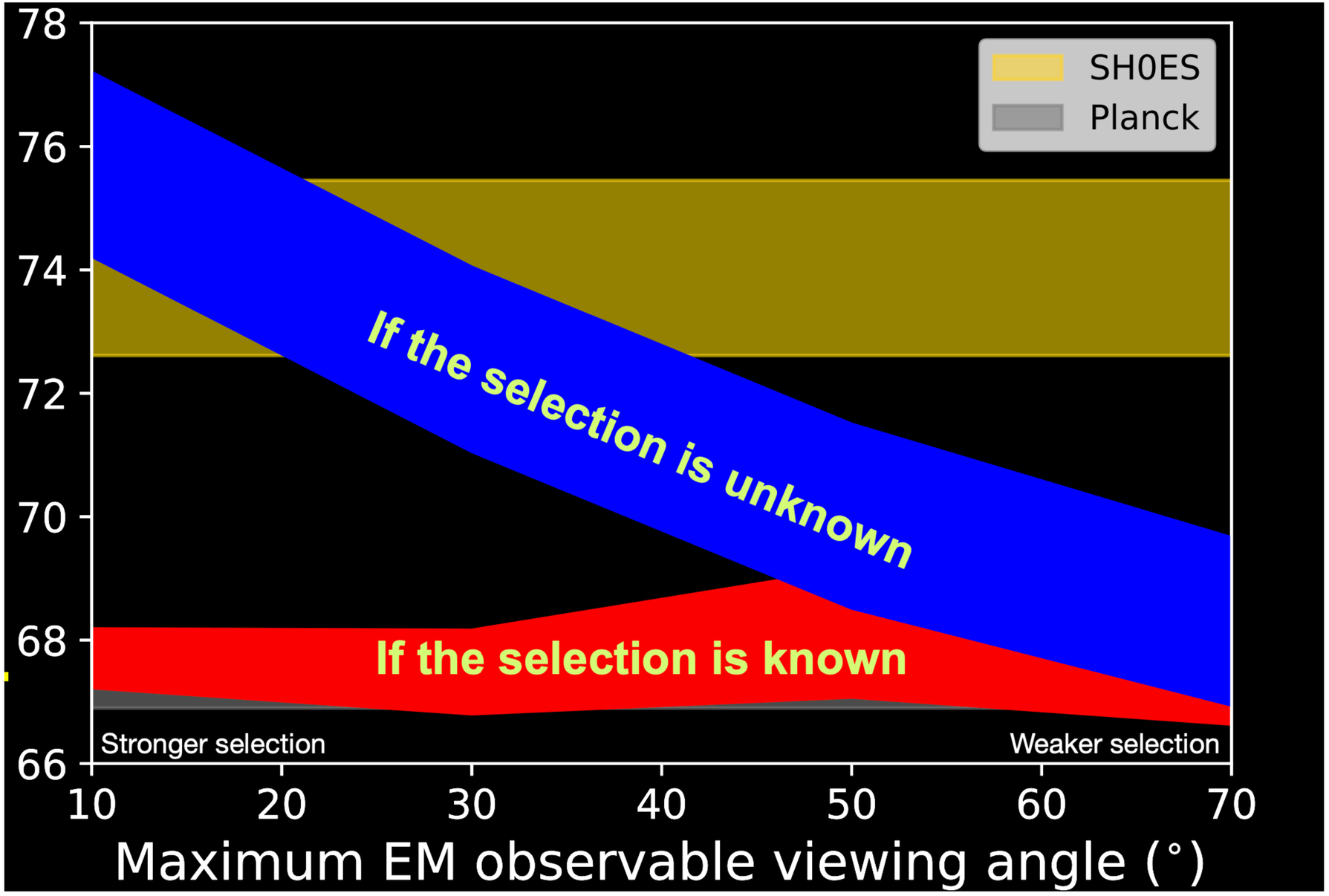
NSBH mergers can provide more precise Hubble constant measurement if their astrophysical rate is constrained.



- EM counterpart ⟶ EM selection bias!

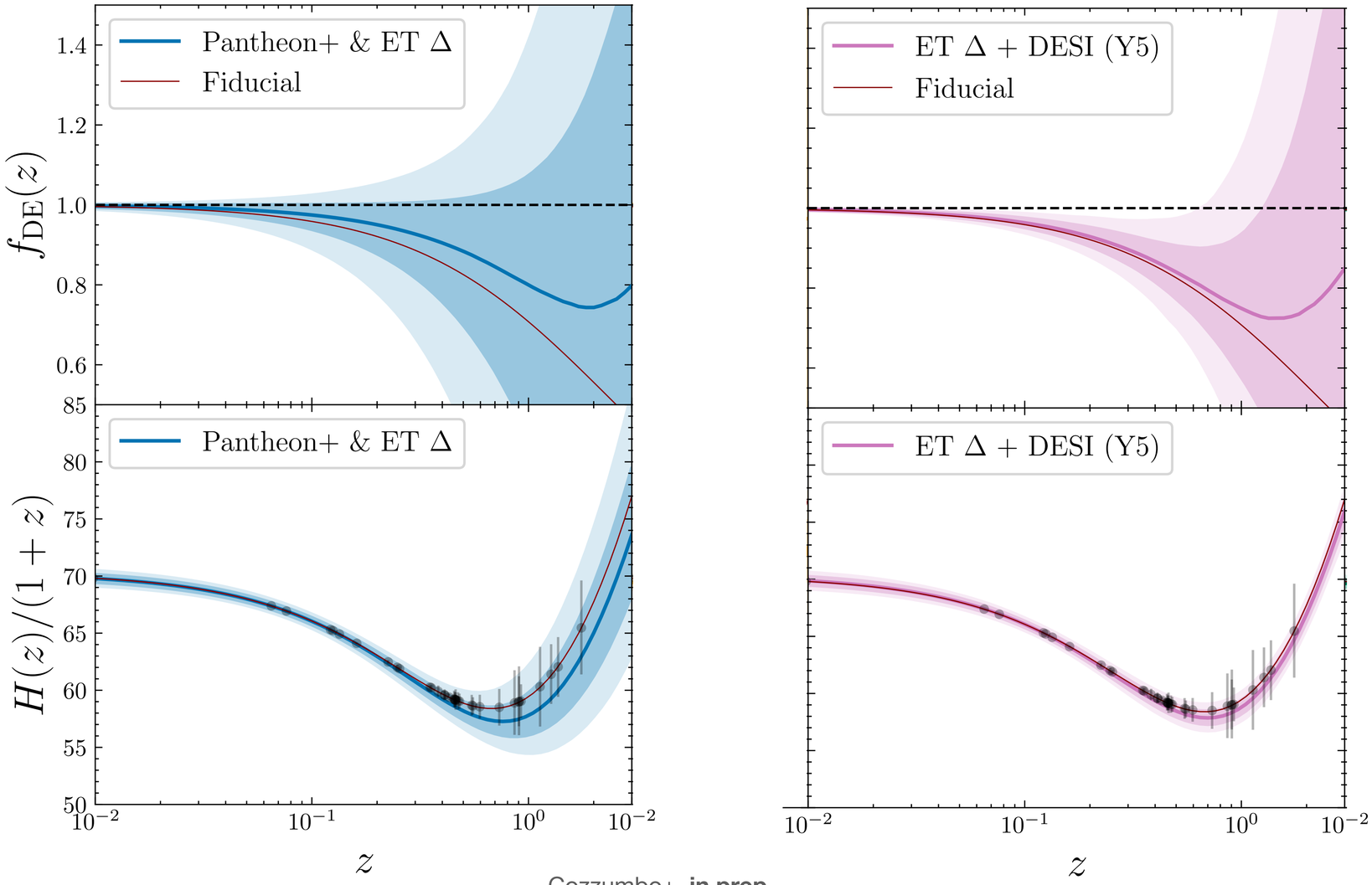
A factor of 5 to10 fewer events are required to reach the same Hubble constant precision if the viewing angle is constrained.


SH0ES
Planck
90
85
80
75
70
65
60
55
H_0 (km/s/Mpc)
Underestimated
Overestimated
−30
−20
−10
0
10
20
30
Systematic bias in viewing angle (°)


78
76
74
72
70
68
66
SH0ES
Planck
If the selection is unknown
If the selection is known
Stronger selection
Weaker selection
10
20
30
40
50
60
70
Maximum EM observable viewing angle (°)

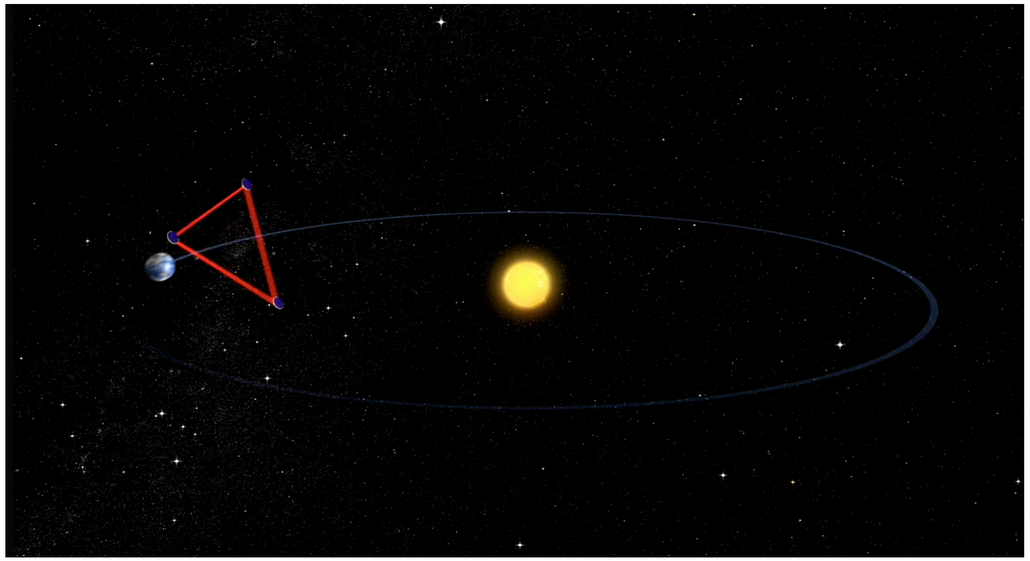
Multi-probe cosmology is the key!

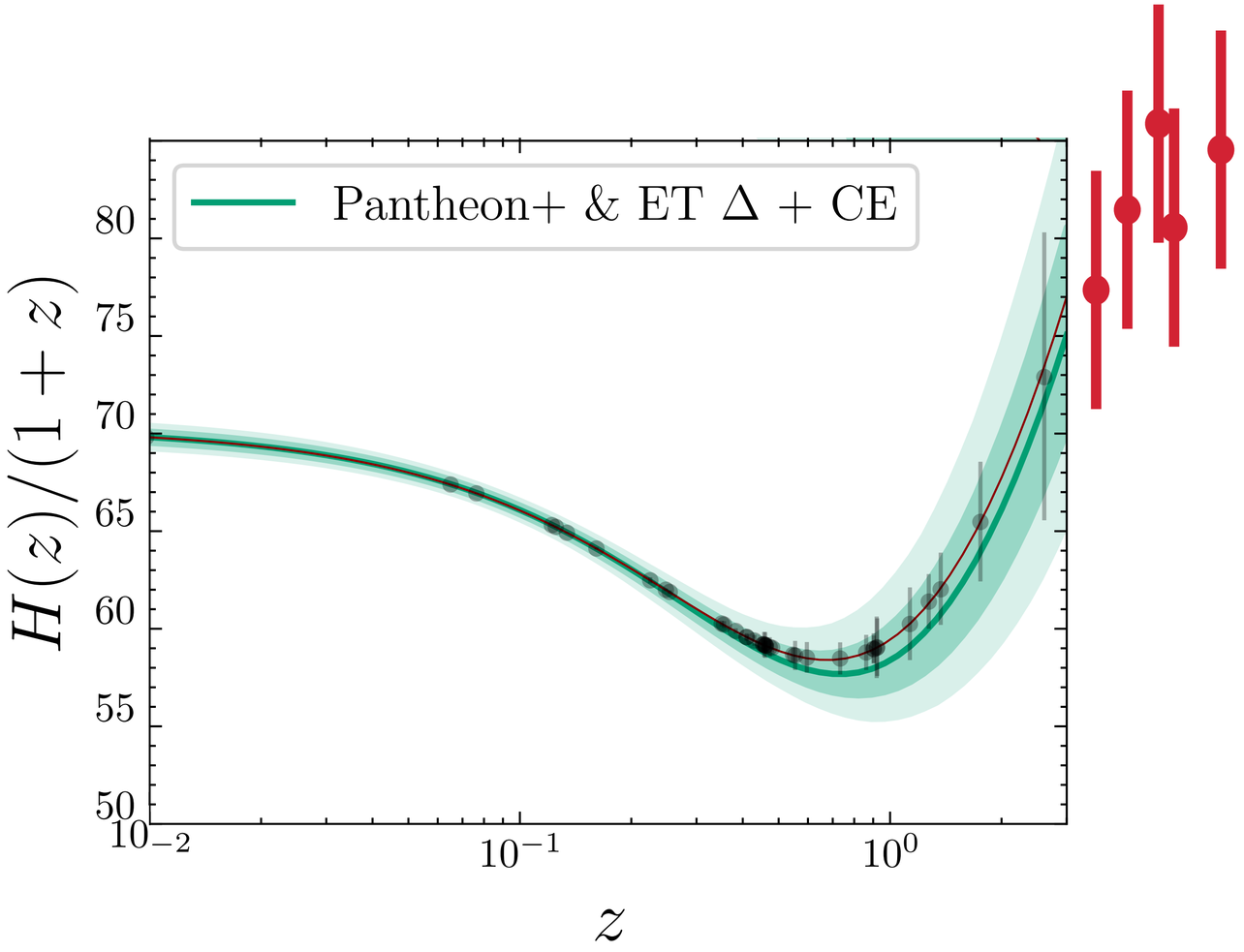
ModIC with Bright Sirens for 3G detectors



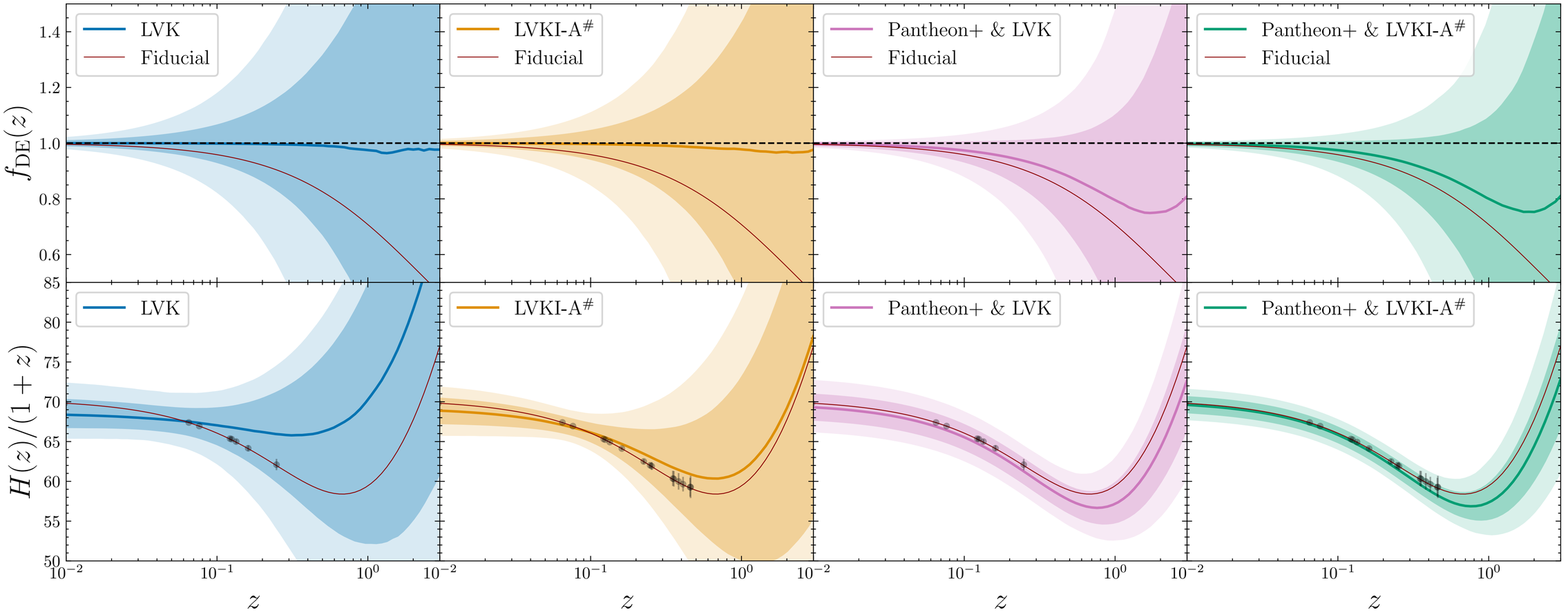
Cozzumbo+, **in prep.**

New sources @ higher z






Thank you for the
attention!


LVK
Fiducial
LVKI-A#
Fiducial
Pantheon+ & LVK
Fiducial
Pantheon+ & LVKI-A#
Fiducial
$f_{\rm DE}(z)$
1.4
1.2
1.0
0.8
0.6
LVK
LVKI-A#
Pantheon+ & LVK
Pantheon+ & LVKI-A#
$H(z)/(1+z)$
85
80
75
70
65
60
55
50
10^{-2}
10^{-1}
10^{0}
z