THESEUS role in Multi-Messenger Astrophysics

WG2 coordinators: G. Stratta (INAF-OAS), R. Ciolfi (INAF-OAP), S. Paltani (University of Geneva), L. Rezzolla (ITP Frankfurt)

Main contribution from (so far):

S. Ascenzi, A. Capone, S. Celli, I. Di Palma, M. Fasano, P. Fermani, B. Gendre, L. Hanlon, G. Lamb, A. Martin-Carrillo, A. McCann, G. Oganesyan, E. Palazzi, S. Ronchini, A. Rossi, O. Salafia, L. Salmon, S. Vinciguerra, A. Zegarelli

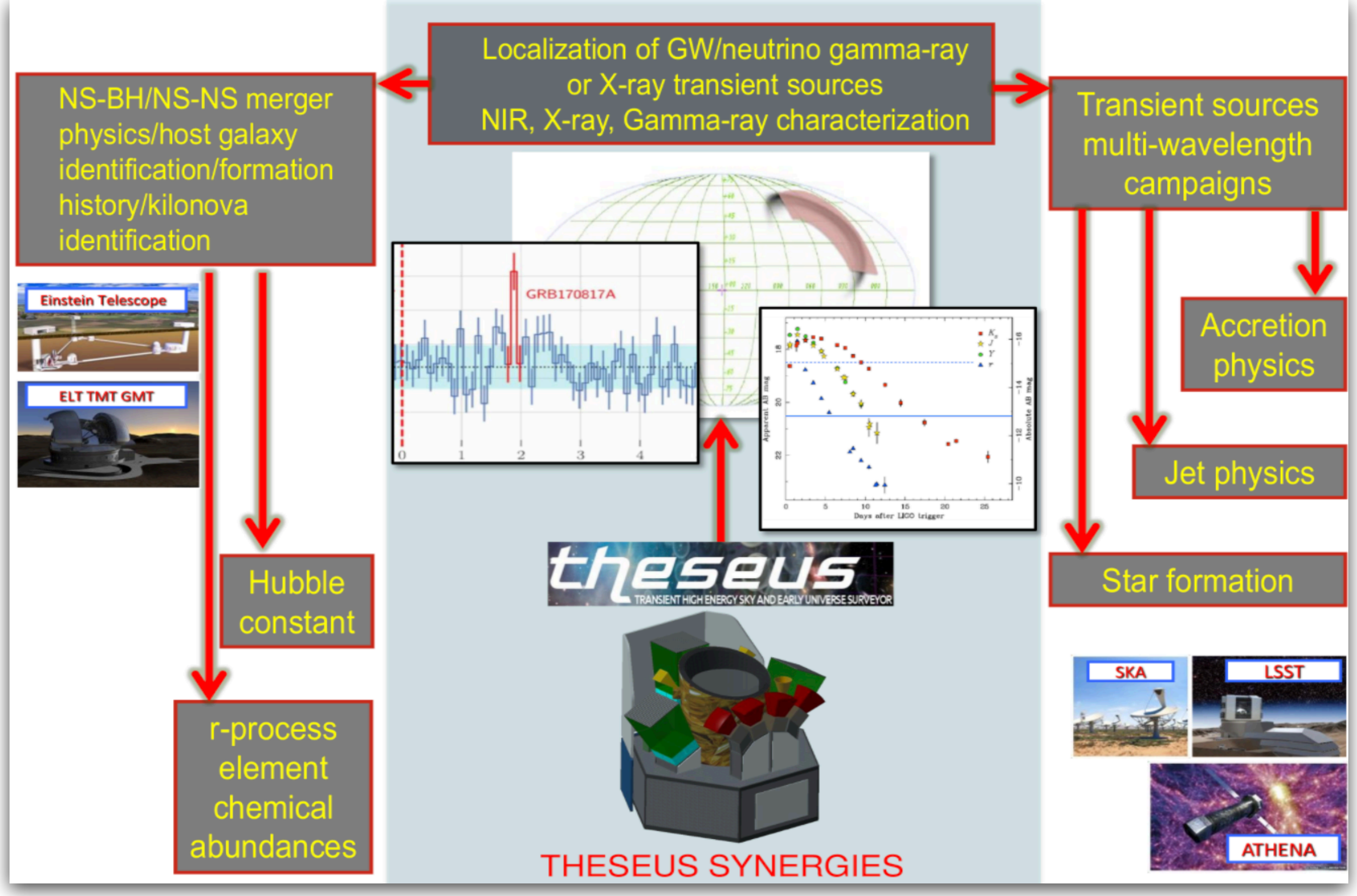
THESEUS role in MM astrophysics

- Detect and localize the e.m. counterpart of GW and neutrino sources during 2030s

- The huge gamma- and X-ray FoV will enable to find the counterpart for very poorly localized sources

- Sky coordinates will be fast communicated to activate MW campaigns in synergyes with excellent facilities as SKA LSST E-ELT and Athena

Stratta et al. 2018, Adv. Sp. R., 62, 662, 2018
arxiv: 1712:08153v3



https://www.isdc.unige.ch/theseus/

WG2 list of priorities

- By the end of 2019 a list of main scientific issues to be assessed by WG2 was defined

please, have a look at it !

From THS-INAF-SCI-TN-0001_SWGs_priorities.pdf
(see https://www.isdc.unige.ch/theseus/swg2-repository.html)

3 WG2 – Multi-messenger astrophysics (Stratta, Ciolfi, Paltani, Rezzolla)

p2.1 Define as best as possible the expected advances in multi-messenger astrophysics in the next decade, the most reliable and the possible scenarios for GW and neutrino detectors at beginning of the '30s;

p2.2 Quantify as best as possible the impact of Theseus on the understanding of the nature and physics of merger-type GW sources (mostly NS-NS and possibly NS-BH or even BH-BH), as well as on their use for cosmology, as a function of the total number of short GRBs detected and localized within 10 arcmin (current requirement is 40, which needs to be better justified). Also, assess the further impact of having a fraction of these (1/3, 1/2, 2/3) localized on board within a few arcsec and with an on-board redshift estimate.

p2.3 Assess the Theseus capability of detecting and localizing short GRBs with SXI and XGIS through their soft extended emission and/or X-ray afterglow emission (conversion to the actual expected rate will then be done by combining results of this study with normalized short GRB population synthesis model and MOS results).

p2.4 Assess the capabilities of Theseus to detect, localize and possibly characterize, most "nearby" short GRBs with associated GW signal, by assuming GRB170817A/GW170817 as a template (prompt emission with soft component, early X-ray emission, Kilonova emission in the NIR), including expected horizon and limiting off-axis angle for such events. (note: because of the much softer energy band and better sensitivity of SXI+XGIS w/r to current GRB detectors, Theseus should be capable of detecting event with a larger off-axis w/r to GW179817) .

p2.5 Further assess the possibility of detecting with SXI the post-merger soft X-ray emission predicted if the remnant is a highly magnetized fastly spinning NS instead of a BH (including comparison of the expectations by this model with limits from current observations).

p2.6 Further assess the capabilities of Theseus of detecting, localizing and characterizing e.m. counterparts of other classes of GW sources, mostly asymmetric core-collapse SNe (e.g., through detection of associated soft / under-luminous GRB-like or shock break-out emission) but also e.g., magnetars.

p2.7 A significant amount of work is needed to quantify, or at least describe in more detail, the impact of Theseus on neutrino astronomy.

p2.8 For both GW and neutrino sources, assess the scientific return expected from Theseus target of opportunity (formally called "external trigger") capabilities, for Phase A baseline (despite spacecraft agility and autonomy, and because of mission operation control issues) limited to 12 hr within working days with a goal of 4 hours (similarly to Athena).

Proposed list of urgent issues

1. SGRB prompt emission and EE: detection with THESEUS
2. SGRB soft X-ray plateau emission: detection with THESEUS/SXI
3. SGRB jet afterglows in THESEUS
4. short GRB detections with redshift and H_0
5. Kilonovae: detection with THESEUS/IRT

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Almost completed

Other important issues

1. Quantify impact of THESEUS in NS-NS/NS-BH(BH-BH) nature as a function of total number of short GRBs and their localization accuracy (p2.2)
2. Detection, localization and characterization with THESEUS of short GRBs like GRB 170817 (p2.4)
3. Bursting GW sources: detection of nearby low-luminosity GRBs, ULGRBs, SBOs, SGRs with THESEUS (p2.6)
4. Quantify THESEUS impact in Neutrino Astronomy (p2.7)
5. THESEUS follow-up (3/months) of neutrino and GW external triggers (baseline reaction time: 12hr (goal: 4hr)): assess scientific return (p2.8)

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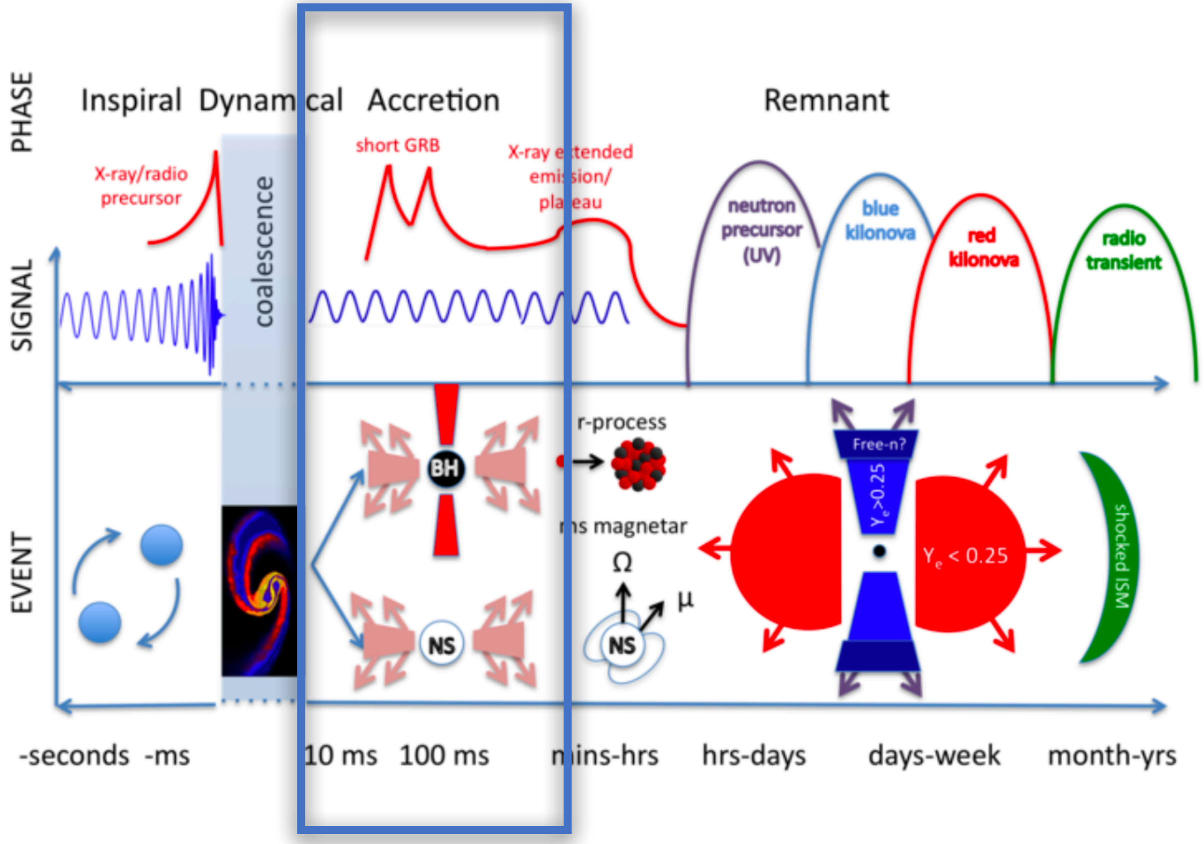
Work in progress...

1. SGRB prompt emission and "Extended Emission": detection with THESEUS

Main contribution from (so far):

G. Stratta (INAF-OAS), R. Ciolfi (INAF-OAP), A. Martin-Carrillo (Dublin Univ. College)

Short GRB on-axis prompt emission



Predicted THESEUS detection rate of "standard" on-axis short GRB (Jan2020)

MOS results (credit: A. Rocchi)	Detection rate (yr^{-1})
Detected (by XGIS or SXI) short GRBs	10.5 +/- 1.9
Detected (by XGIS) short GRBs	10.5 +/- 1.9
Detected (by SXI) short GRBs	0.3 +/- 0.3
Fully characterized short GRBs	3.8 +/- 1.0

- THESEUS will detect **few tens of on-axis "standard" short GRBs** in 3 yrs, ~40% of which will be detected with the IRT

Off-axis prompt emission: the case of GW/GRB170817

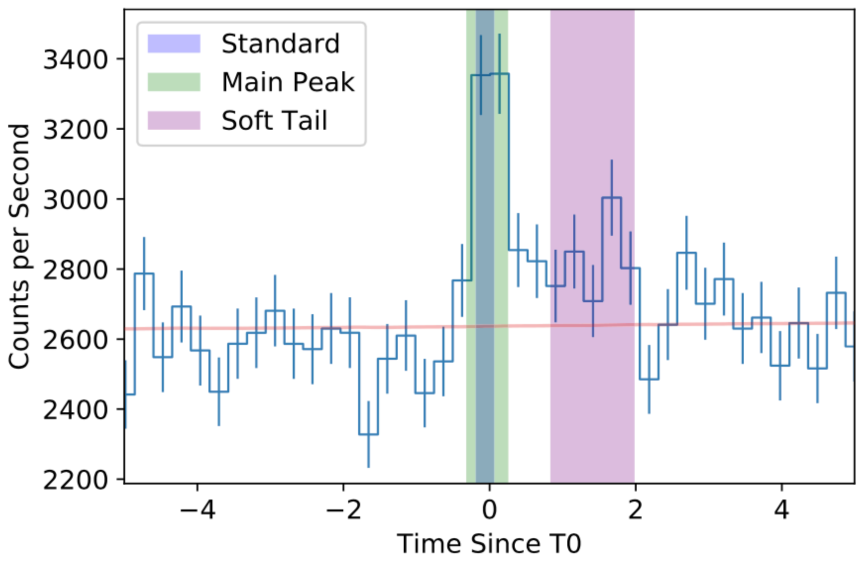
- Main Peak

Model: Componized spectrum (exponential cutoff)
PL index alpha=-0.62+/-0.40
Epeak=185+/-62 keV (nuFnu) (Ecut=Epeak/(2+alpha))
Flux=(3.1 +/- 0.7)x10-7 erg s-1 cm-2, 10-1000 keV
Fluence=(1.8+/-0.4)x10-7 erg cm-2
NH=7.5x10^20 cm^-2 (based on NGC 4993's Av=0.338)
T=0.6s

- Soft Tail

Model: BB
KT=(10.3+/-1.5)keV
Flux=(0.53 +/- 0.1)x10-7 erg s-1 cm-2, 10-1000 keV
Fluence=(0.61+/-0.12)x10-7 erg cm-2
NH=7.5x10^20 cm^-2 (based on NGC 4993's Av=0.338)
T=1s

Goldstein et al. 2017



Simulations with XSPEC v12

XGIS-X (2-30 keV) V7	MP σ	ST σ
0 deg	6.4	3.6
15 deg	4.5	2.8
30 deg	1.5	1.0
XGIS-S (20 keV-2MeV) V7		
0 deg	13	-
15 deg	11	-
30 deg	5	-
SXI (0.3-5 keV)	-	-

- THESEUS/XGIS could had detected both the Main Peak and Soft Tail of GRB 170817 @ 40 Mpc
- THESEUS/XGIS can detect a GRB 170817-like burst up to 70 Mpc at ~3 (4) σ level in the 2-30 keV (20 keV - 2 MeV) band

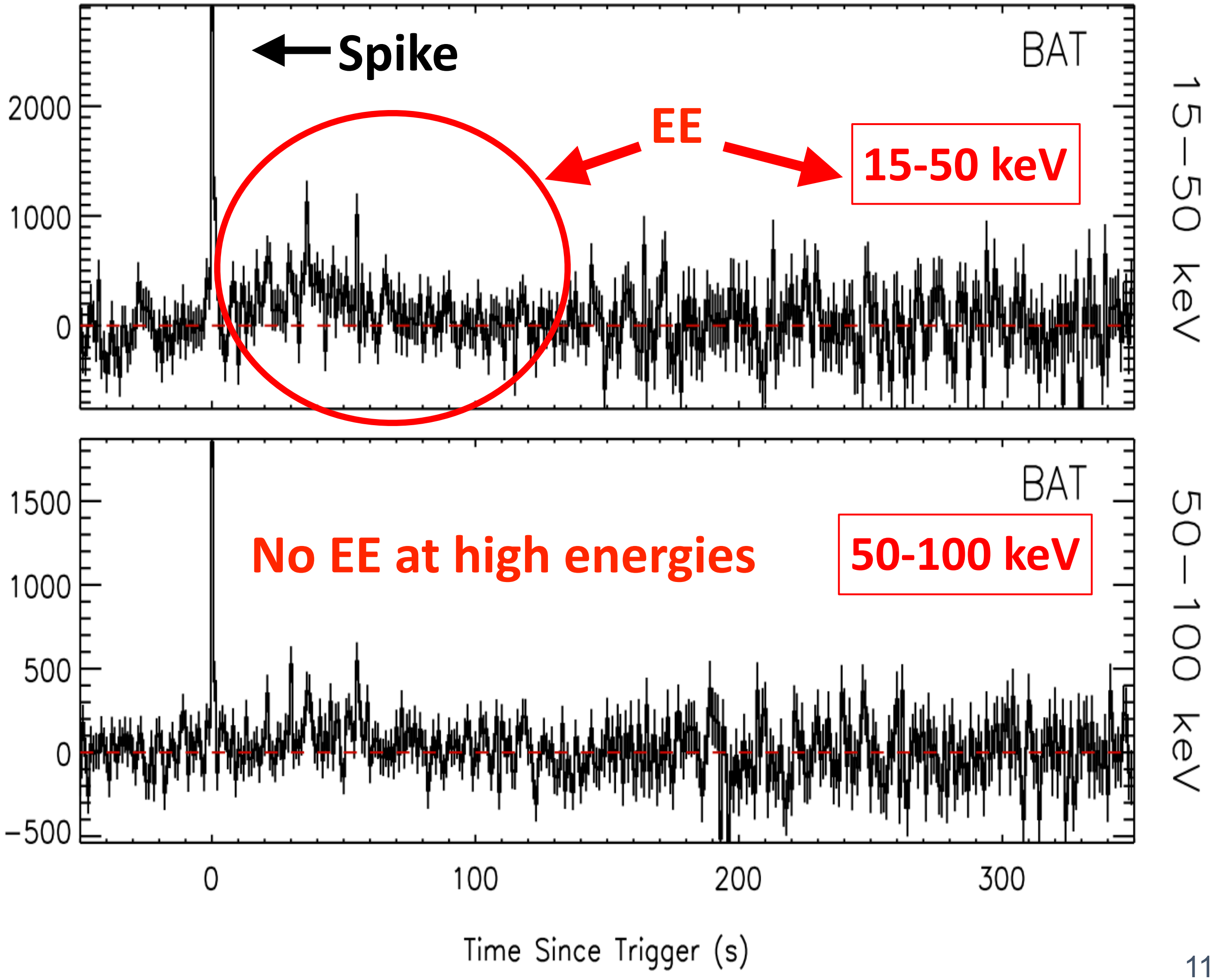
On-axis Short GRB with Extended Emission

- GRBs of mixed type: hard spike of short duration (<1-2s) + Extended (10-100s) X-ray emission

- Why EE is interesting?

1. due to its softness, it can play a crucial role in detecting GW e.m. counterpart detections with X-ray surveyors as THESEUS
2. Despite its still unknown origin, several scenarios predict larger collimation angle w/r to main spike
3. It adds information on the physics of NS-NS/NS-BH mergers (possibly produced by magnetar spin-down radiation, e.g. Bucciantini+2011, Metzger+2012, but see also Lyutikov 2013)

Short GRB 090531B Kaneko et al. 2015



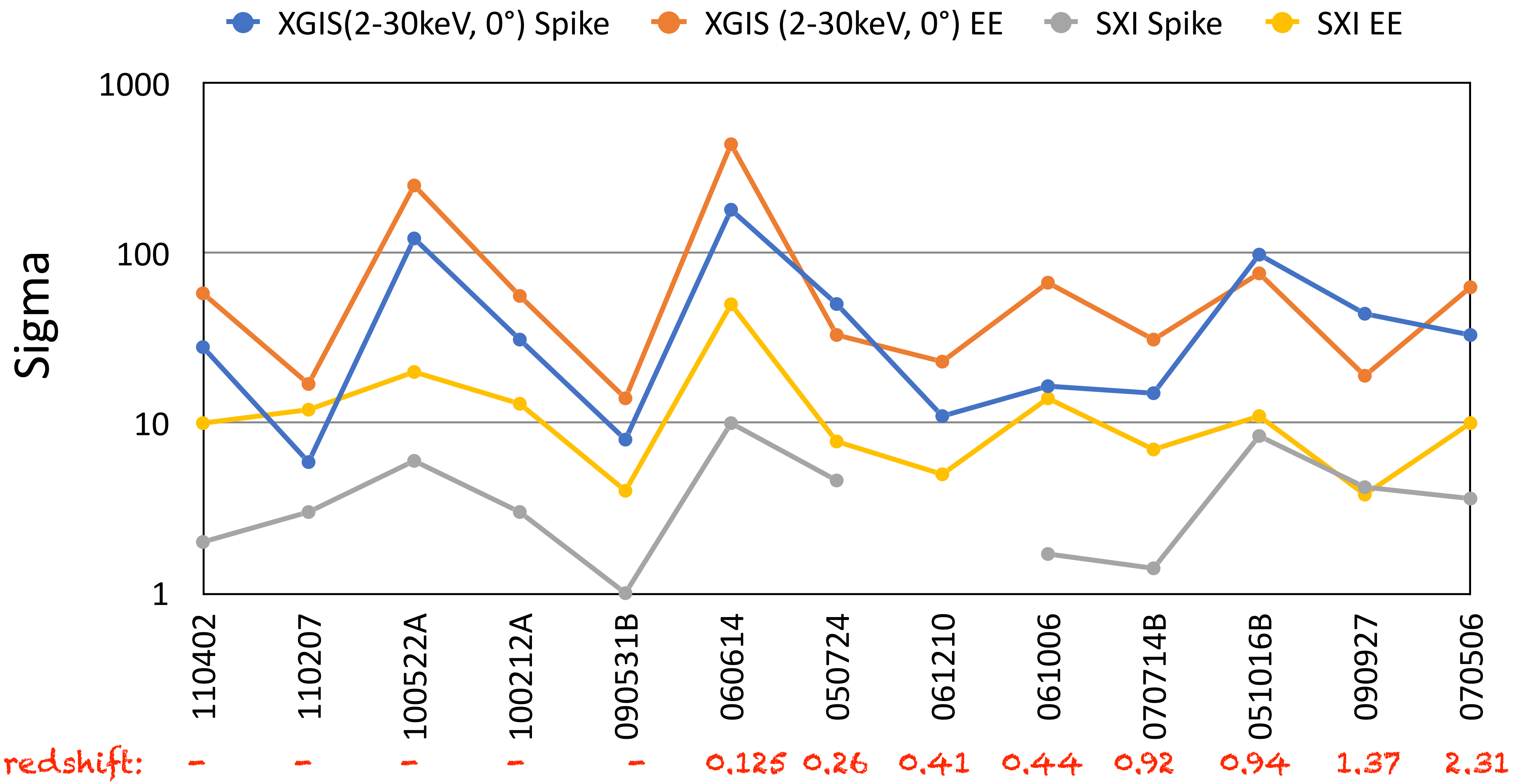
Spike and EE simulations with THESEUS

- Kaneko+2015 provide spectral parameters for a sample of short GRB + EE observed with Fermi/GBM and Swift/BAT
- We simulate 5 short GRB+EE with spectral parameters from Fermi/GBM+Swift/BAT joint analysis + 8 short GRB+EE observed with Swift/BAT with known redshift

GRB name	T_0 time UT	T_{90}[a] (s)	T_{spike} (s)	T_{EE} (s)	B_{spike}[b] (s)	B_{EE}[b] (s)	Afterglow[c]	z
BAT								
050724[d]	12:34:09	96	2.76	107	−0.02	3.04	XOR	0.258
051016B	18:28:09	4	4.03	33	0.07	4.23	XO	0.9364
060614[d]	12:43:49	108.7	5.89	169	−1.55	7.24	XO	0.125
061006[d]	16:45:51	129.9	2.05	113	−23.2	2	XO	0.4377
061210[d]	12:20:39	85.3	0.13	77	0.21	1.04	X	0.4095
070506	5:35:58	4.3	5.25	15	3.75	38	XO	2.31
070714B[d]	4:59:29	64	2.88	39	−0.8	32.29	XO	0.92
080503[d]	12:26:13	170	0.38	147	0.11	6	XO	–
090531B[d]	18:35:56	80	1.02	54	0.29	2.04	X?	[illegible]
090927	10:07:16	2.2	2.18	28	0.06	2.95	XO	1.37

Swift/BAT Short GRB+EE at known redshift from Kaneko+15

Short GRB: spike vs EE detection significance



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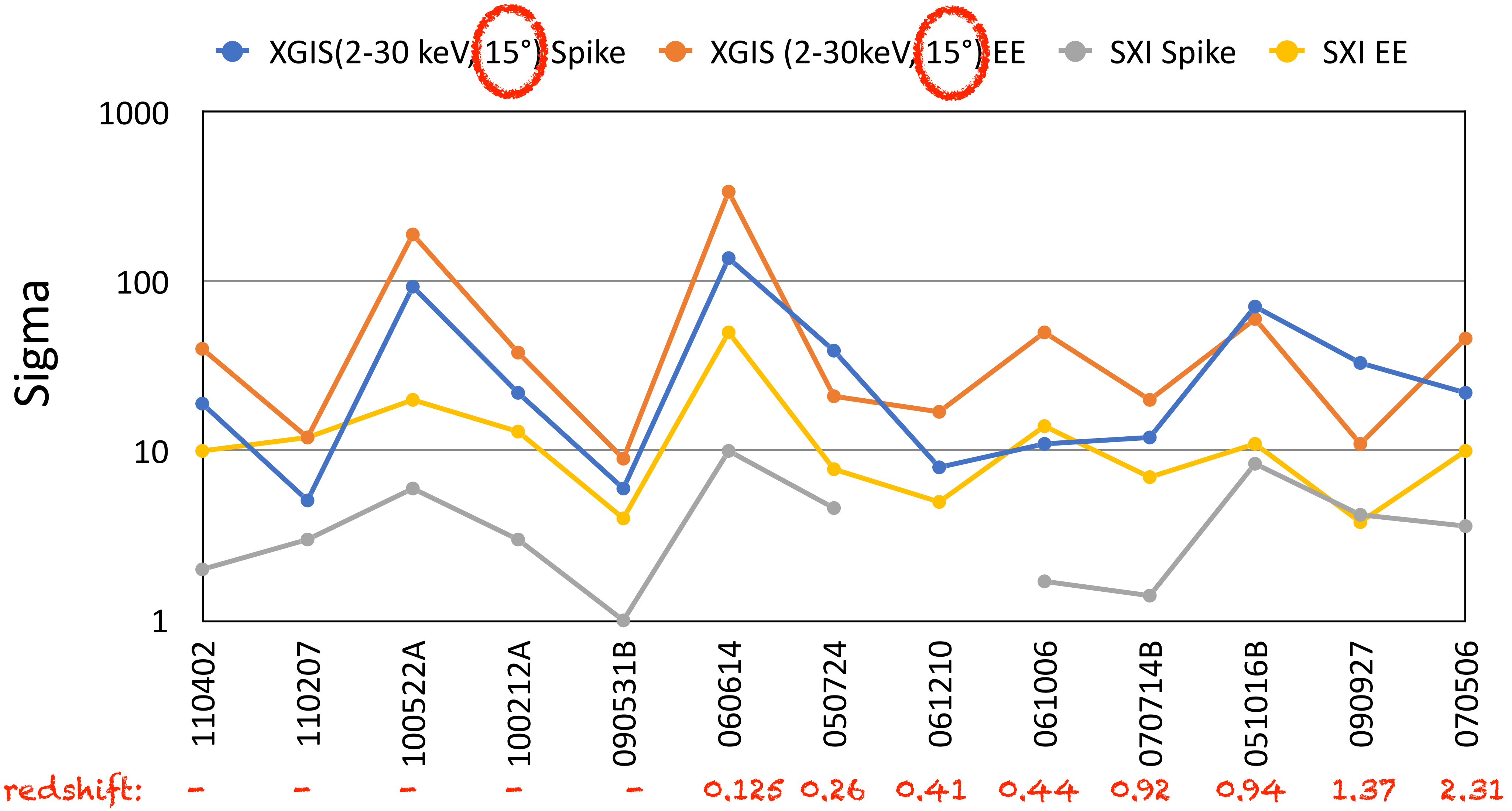

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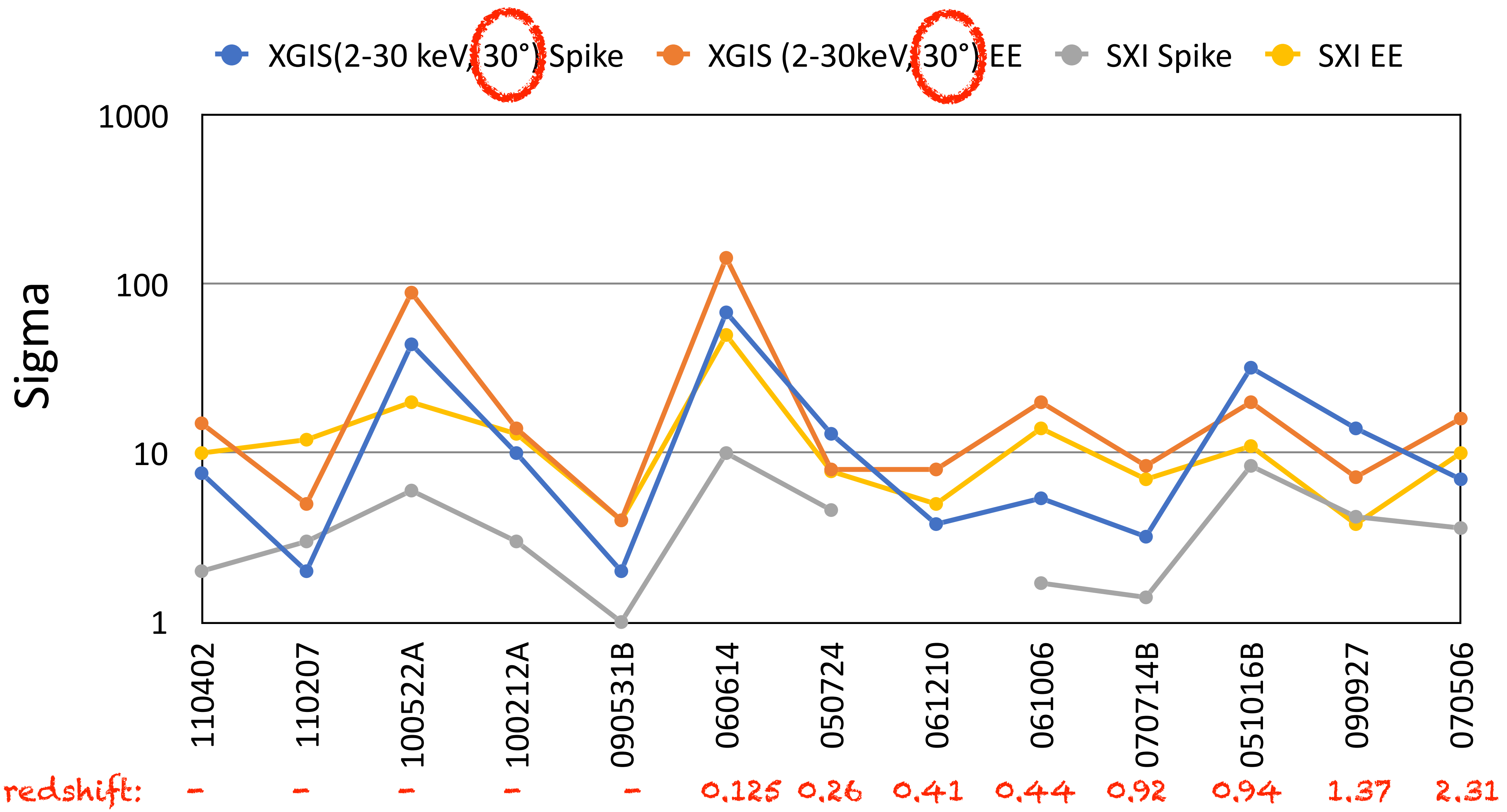
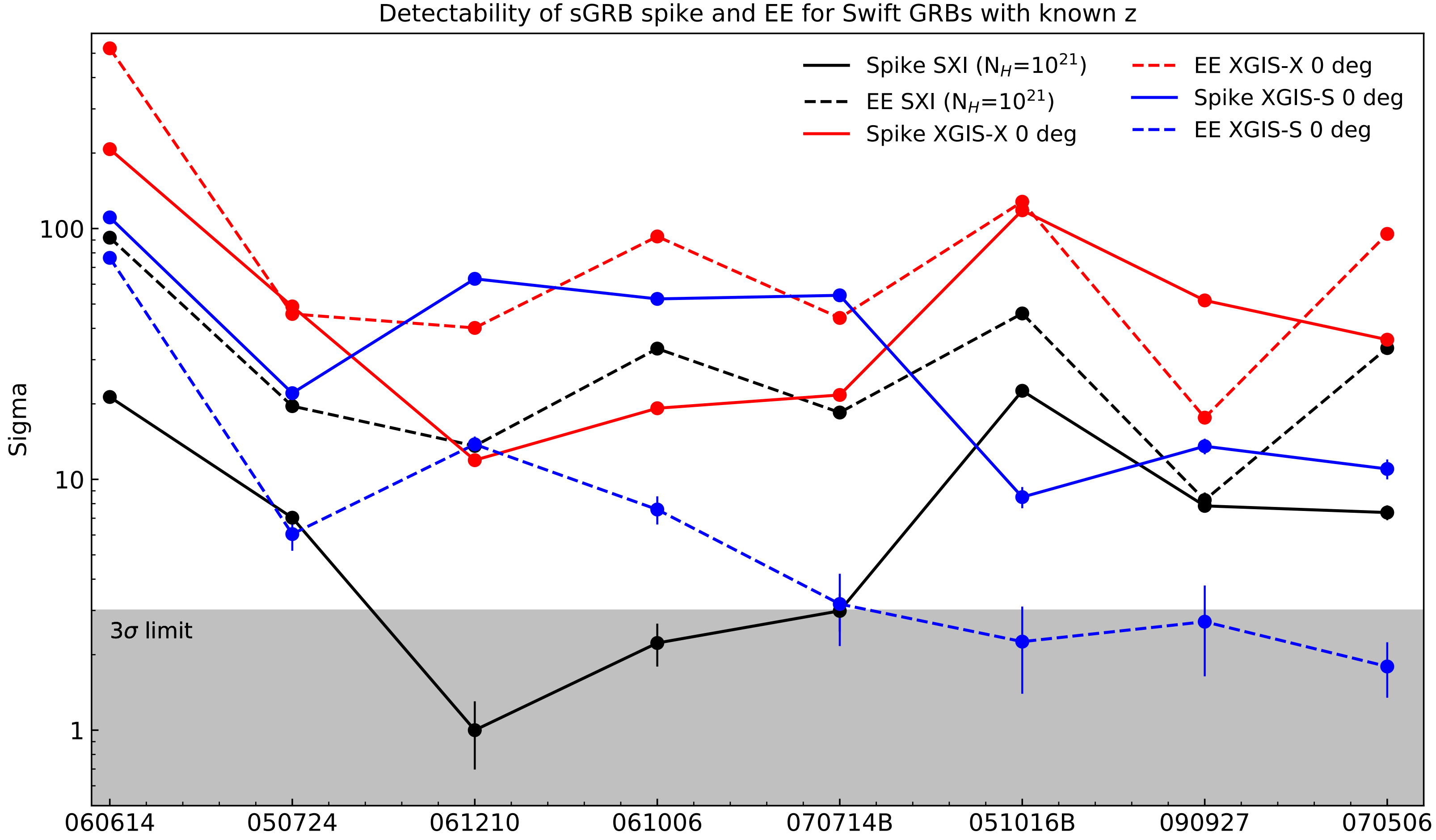


Short GRB: spike vs EE detection significance

Figure by A.Martin-Carrillo



redshift: 0.125 0.26 0.41 0.44 0.92 0.94 1.37 2.31

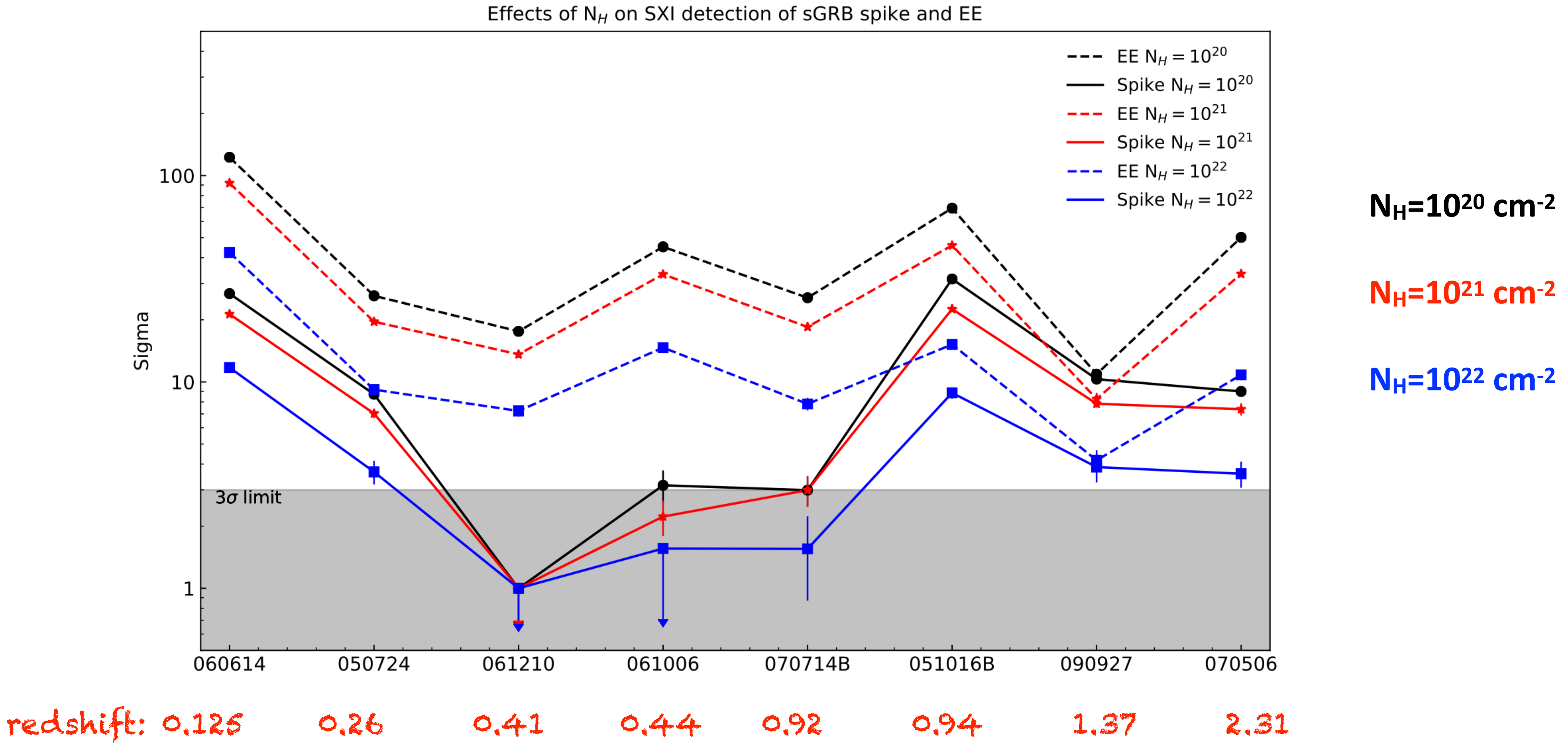
XGIS-X (2-30 keV)

XGIS-S (20 keV-2MeV)

SXI (0.3-5 keV)

Spike and EE detection with SXI: N_H effects

Figure by A.Martin-Carrillo

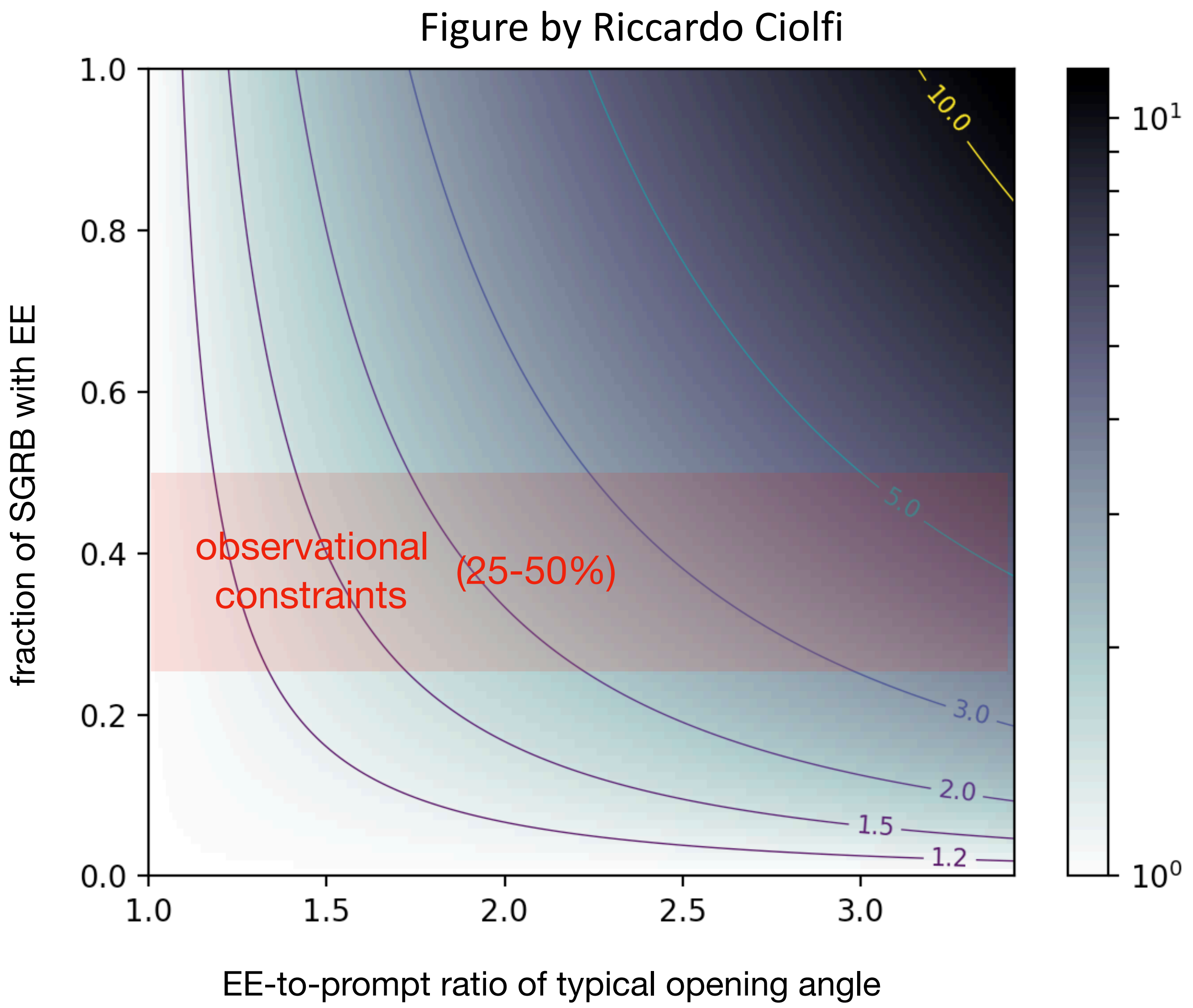


Preliminary conclusions

- The Extended Emission can be detected in all short GRBs analyzed so far (13), 8 of which span $0.1<z<2$
- EE is detected with higher significance w/r to the initial hard spike in:
  - XGIS: 10/13 (~80%) using on-axis and off-axis calibration files
  - SXI: 13/13 (independently on assumed NH)

—> encouraging results on the possible role of the EE in the true detection rate of GW-BNS/short GRBs and their localization

SGRB detections with XGIS in 3 yrs: including the EE



- EE may have larger opening angle α w/r to the main prompt spike (e.g. Bucciantini+2011, Lyutikov 2013)

- Fractions ***f*** of short GRBs+EE
  - 7% from BATSE data (Bostanci+13)
  - 5% Fermi/GBM data (Kaneko+15)
  - 2-25% from Swift/BAT (15-350 keV) data (Norris+10, Lien+16)
  - **75% from Swift/BAT+XRT data (Kisaka+17) —> ~50% of short GRB have an EE**

- The plot shows the increase factor of GW e.m. counterpart detections considering the EE in addition to on-axis short GRBs, as a function of ***f*** and α

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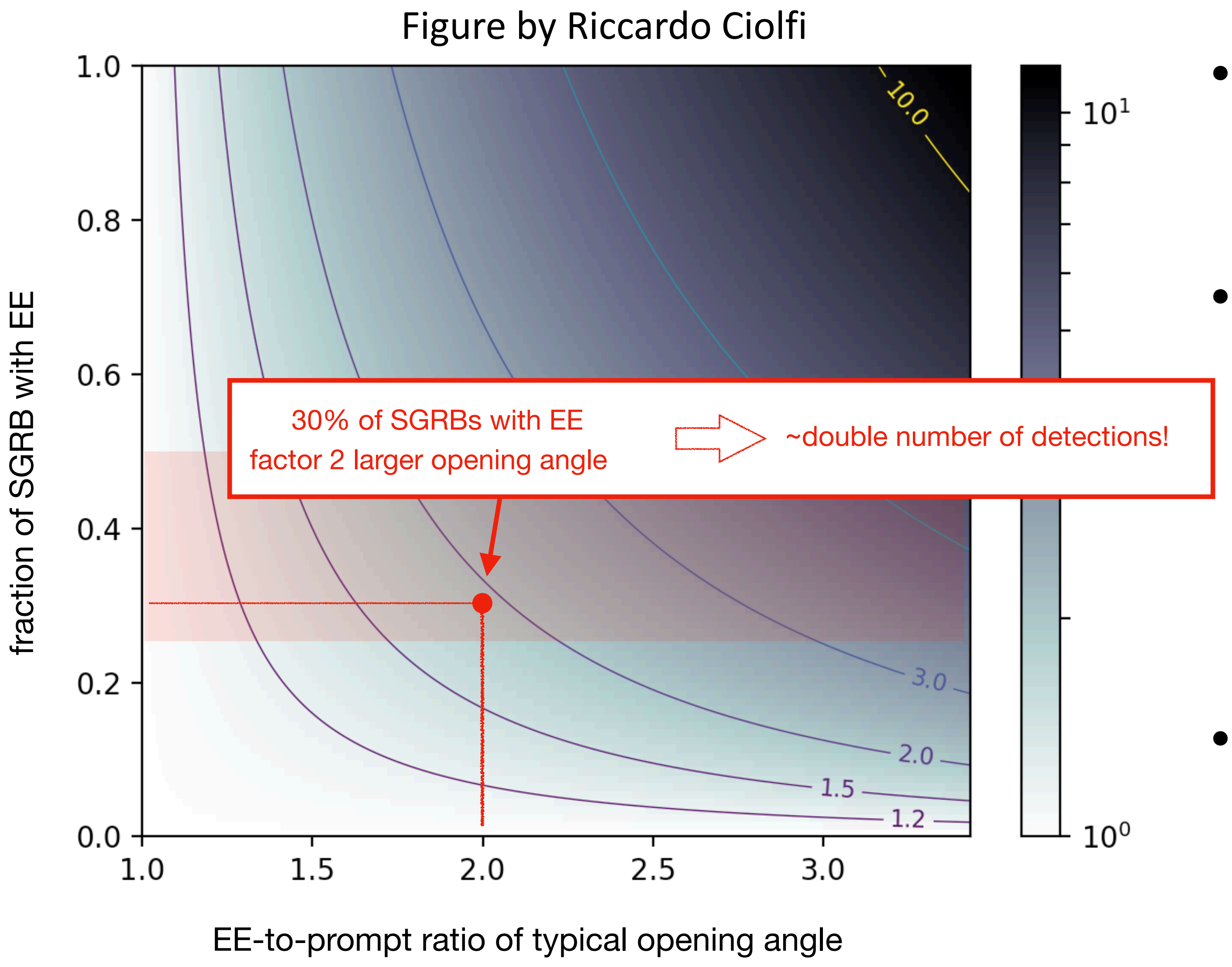

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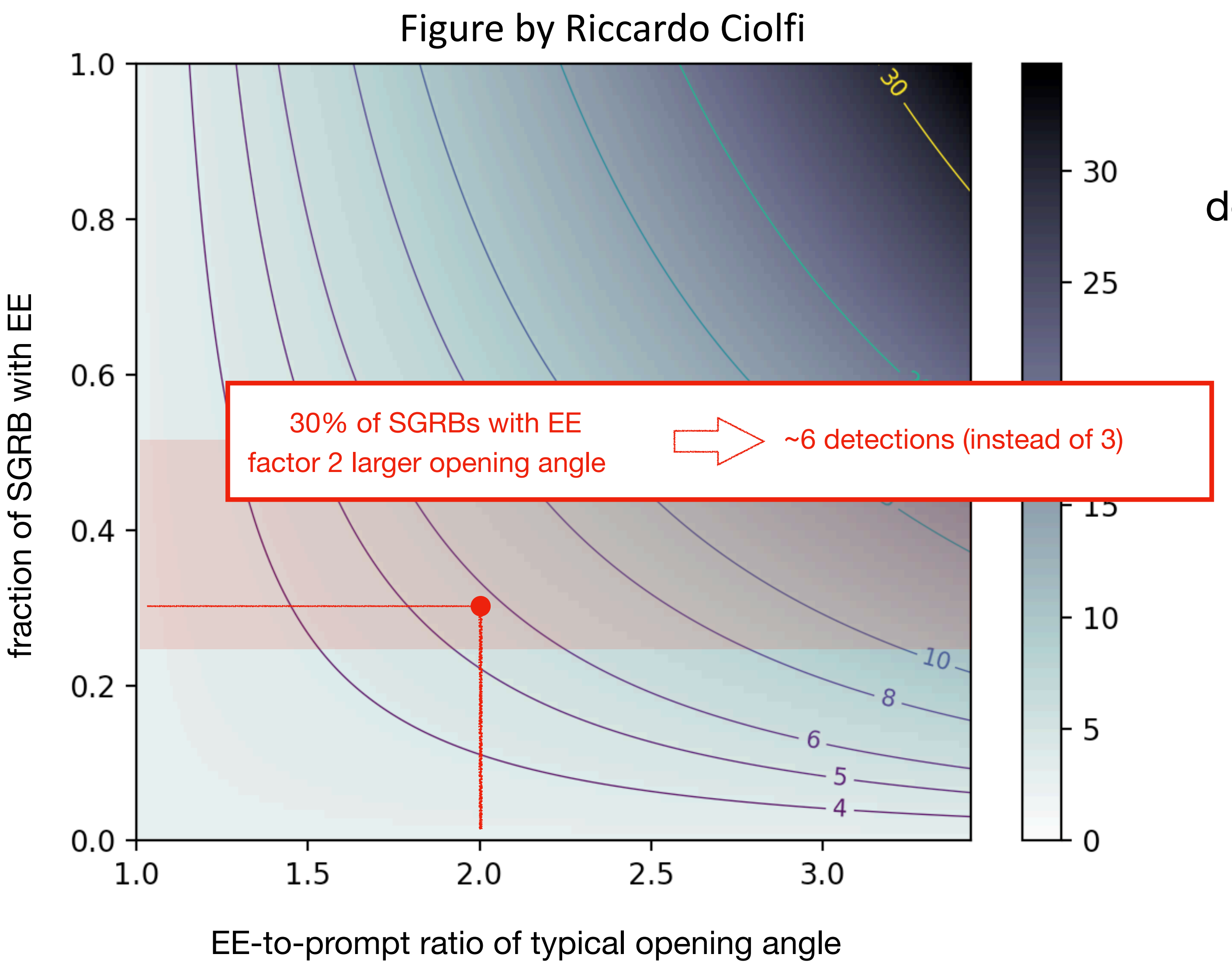


detections with GW counterpart (2G only)
when including the EE
as a function of ***f*** and α

(assuming N=3 without EE)

- THESEUS can shed light on the origin and properties of EE
- EE could really make the difference in terms of number of detections in multimessenger context

2. SGRB soft X-ray plateau emission: detection with THESEUS/SXI

Main contribution from (so far):

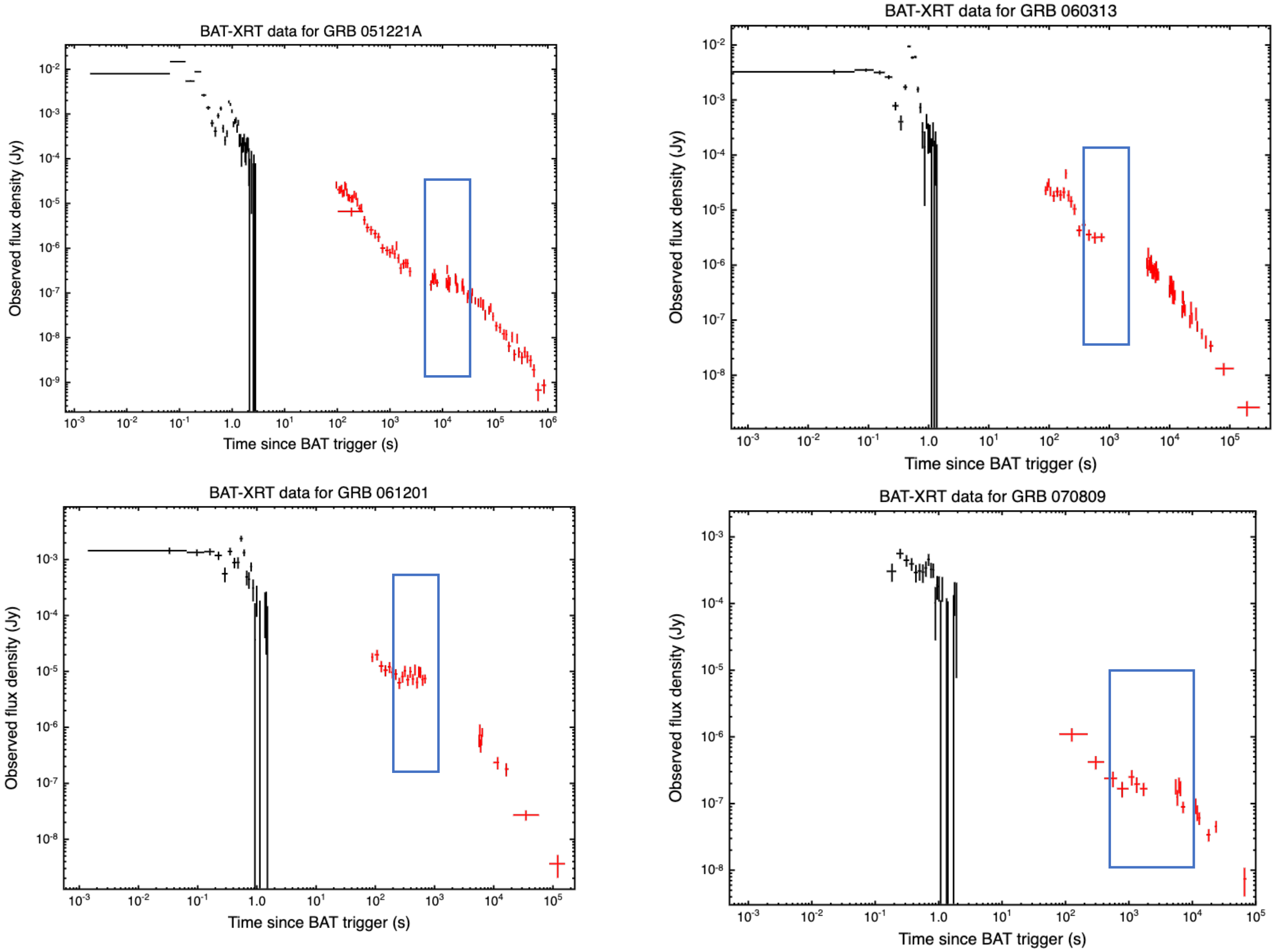
G. Oganesyan (GSSI), S. Ronchini (GSSI), R. Ciolfi (INAF-OAP),

A. Martin-Carrillo (Dublin Univ. College)

Short GRB X-ray afterglow plateaus

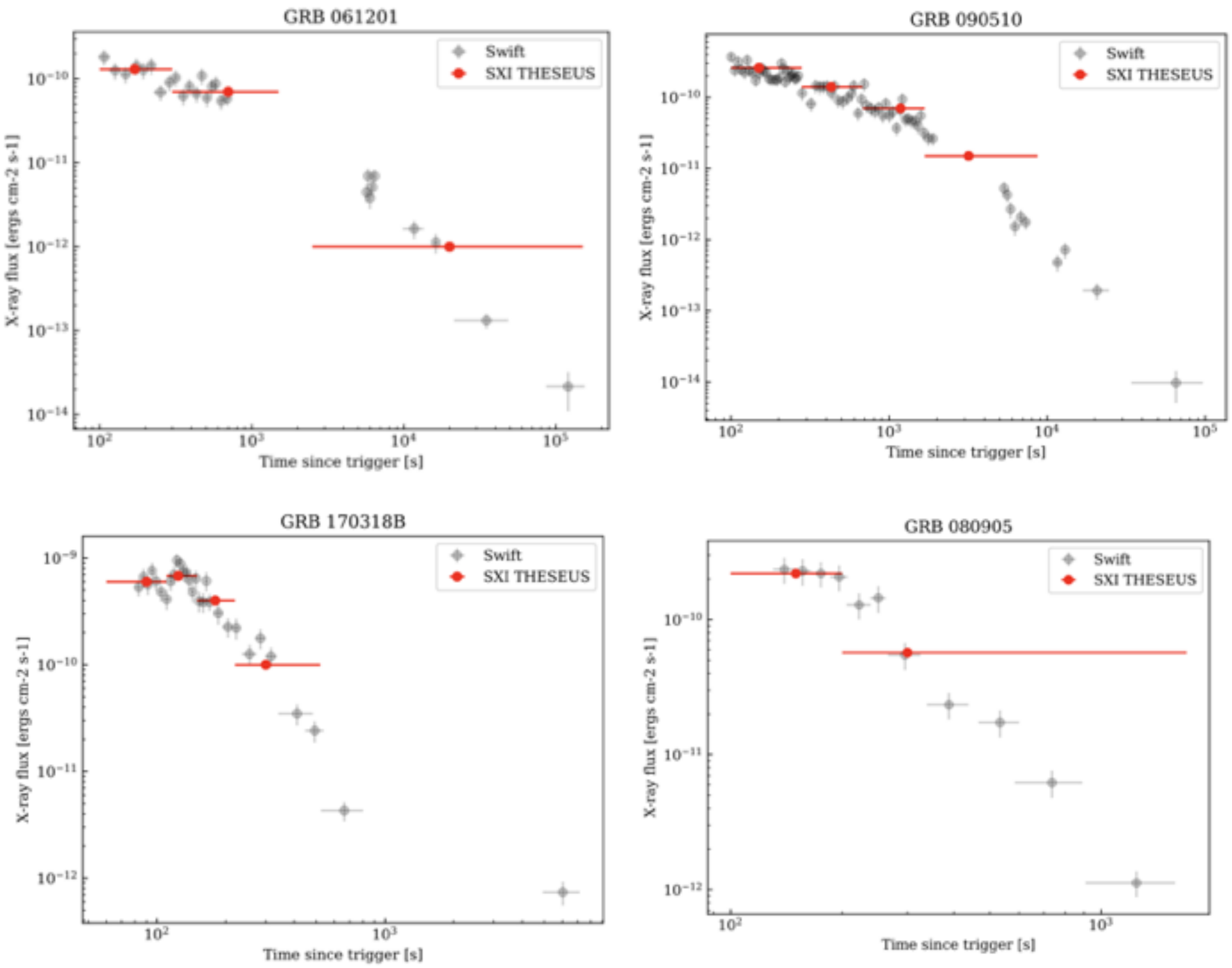
- Detected in 70% long and >30% short GRB X-ray afterglows (0.3-10 keV)
- Duration: varies between few 100s-1day
- Origin: continuous energy injection onto forward shock from magnetar (e.g. Metzger+2010), or stratified jet (e.g. Oganesyan+2020,HLE), accreting BH(e.g. Lei+2017)
- Potentially less collimated than short GRB prompt emission (e.g. >30°-40°, B. Zhang+2013)

Example of short GRB with X-ray plateau (from Swift XRT Repository)



X-ray plateaus with SXI

- THESEUS/SXI can detect a fraction of short GRB X-ray plateaus
- Synergies with GW detectors will enable to unveil its origin
- Post-plateau phases too faint for THESUS —> synergies with Athena crucial for plateau characterizations



Figures by A. Martin-Carrillo

SGRB with X-ray plateau in Swift data (https://www.swift.ac.uk/xrt_live_cat/)

criterion: at least a lightcurve segment with temporal slope in the range [-0.8,0.8]

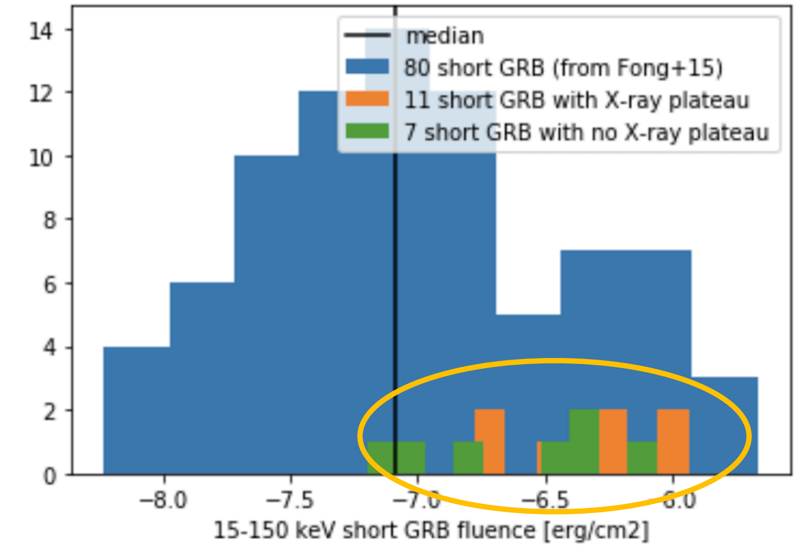
⟶ then, human check and comparison with literature (e.g. Tang+2019, Sarin+2020)

Result: ~15 years: 115 Swift BAT SGRBs ⟶ 18 have XRT data between 100s and 100ks ⟶ 11 with plateau (7 with z), 7 without plateau

⟶ 11/18 ~ 60% SGRBs with plateau

but **we take 30%** to be conservative towards observational bias

the 18 reference events all belong to the brightest half



from Swift SGRBs with plateau and known z we get a range of fluxes for each given distance (blue stripe)

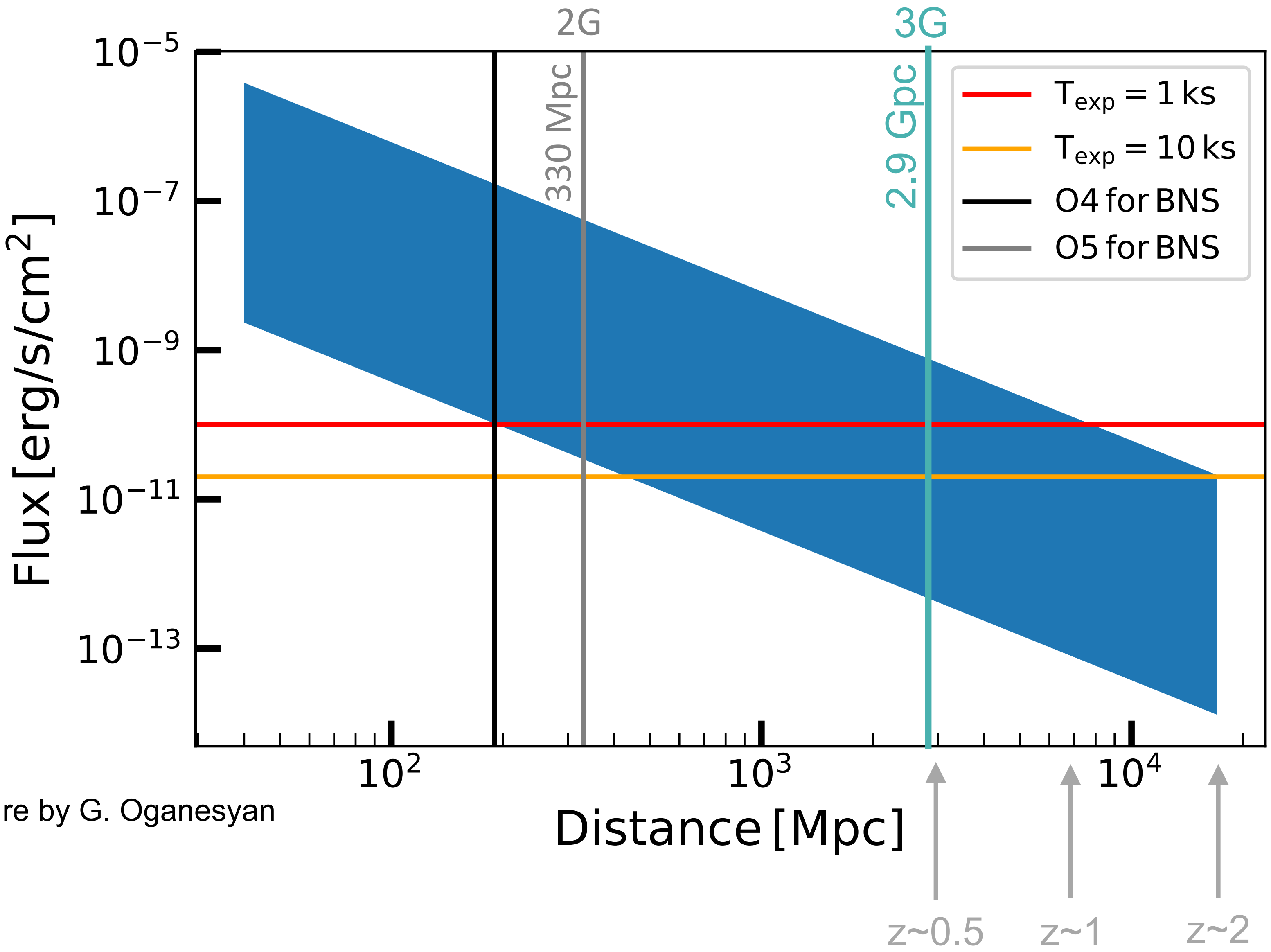
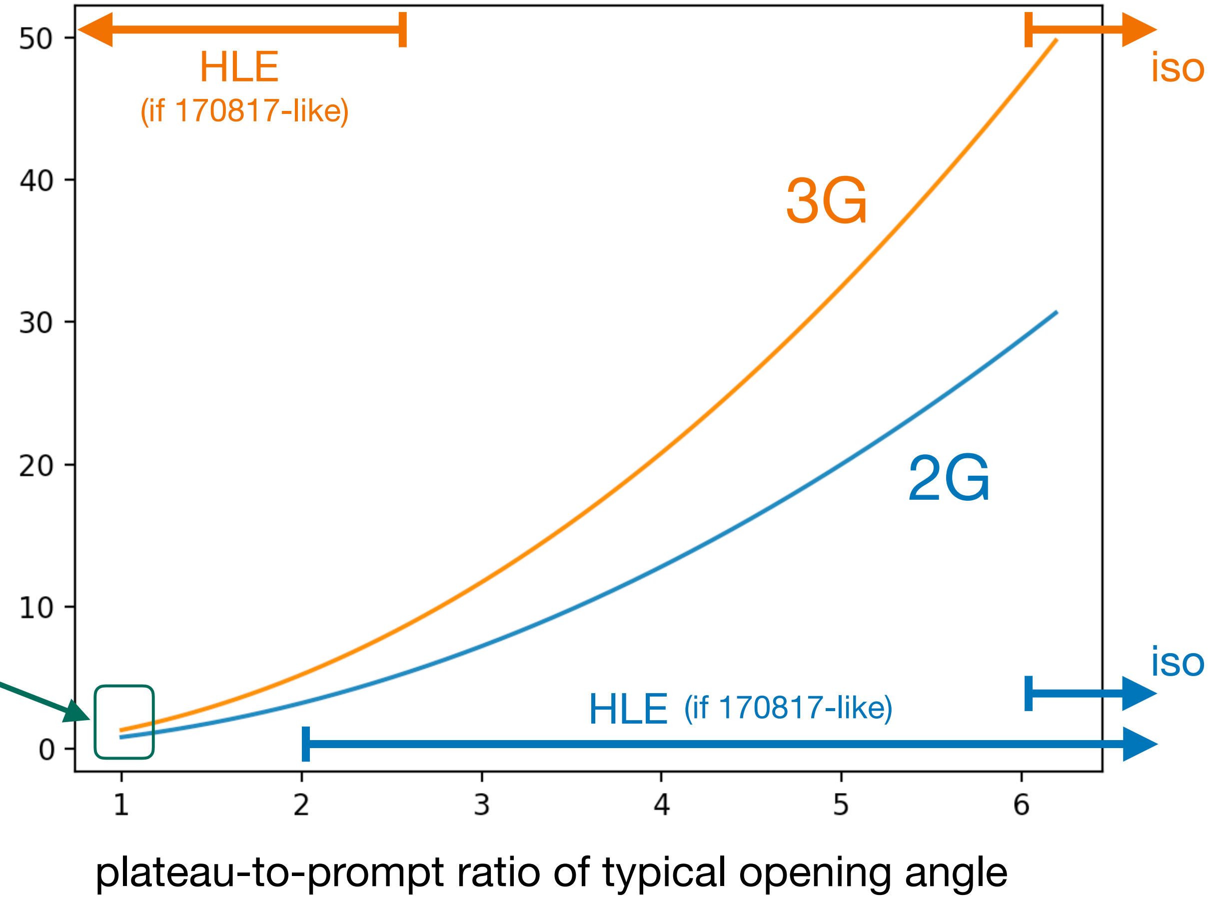


figure by G. Oganesyan

~2.9 Gpc reference distance for ET only

X-ray plateau detections with SXI in 3 yrs vs. half-opening angle

on-axis XGIS detections of SGRBs in 3yr
x
fraction with X-ray plateau (~30%)
x
fraction of detectable X-ray plateaus (with 1ks exposure)



(assuming here prompt opening angle 3-15 deg)

model examples:

- X-ray plateaus from high latitude emission
  Ascenzi+2020
- X-ray plateaus isotropic and spindown-powered
  Siege & Ciolfi 2016

Preliminary conclusions

- SXI can detect a good fraction of (on-axis) X-ray plateaus within 2G and 3G distance
  Typical X-ray plateau luminosities correspond to fluxes above SXI threshold up to 200 Mpc (~all of them) with 1ks exposure, and the brightest ones up to several Gpc

- If plateaus have emission solid angle larger than prompt emission —> SXI alone can detect an interesting number of orphan plateaus (i.e. without prompt SGRB) as X-ray transients associated with a GW event
  - current models suggest tens of events in 3yrs is possible

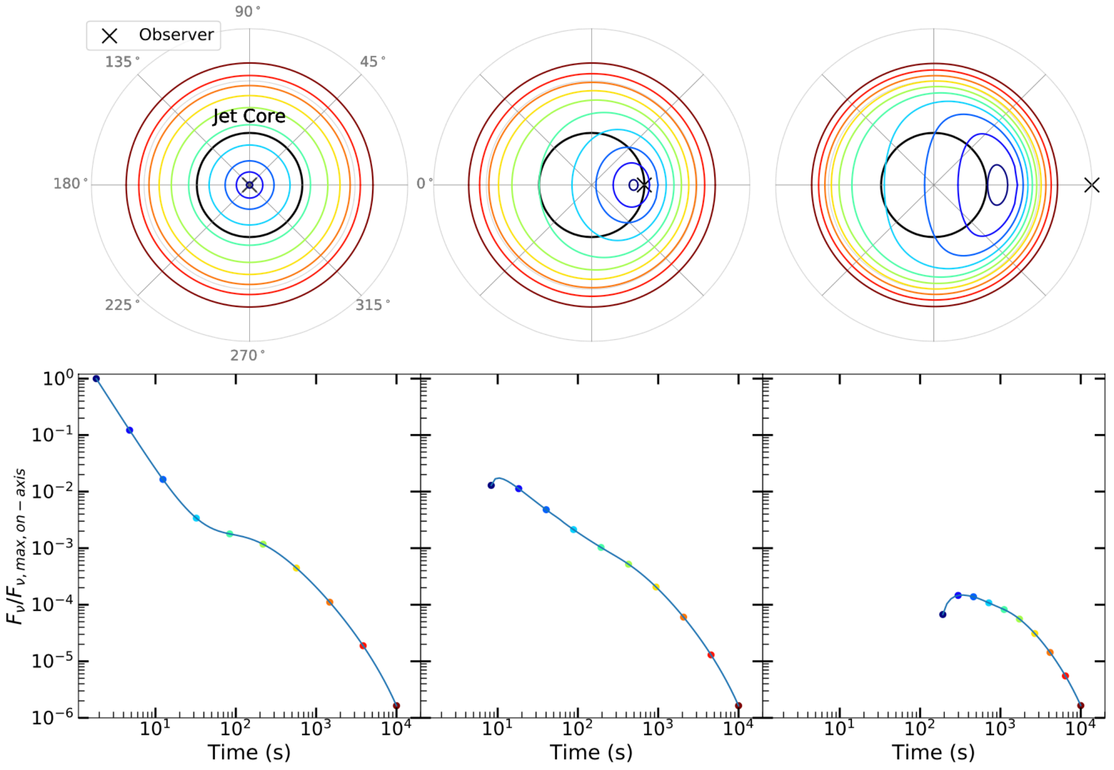
2.1 Theoretical predictions from High Latitude Emission model

Main contribution from (so far):

S. Ascenzi (INAF-OAB), S. Vinciguerra (MPI)

High Latitude Emission

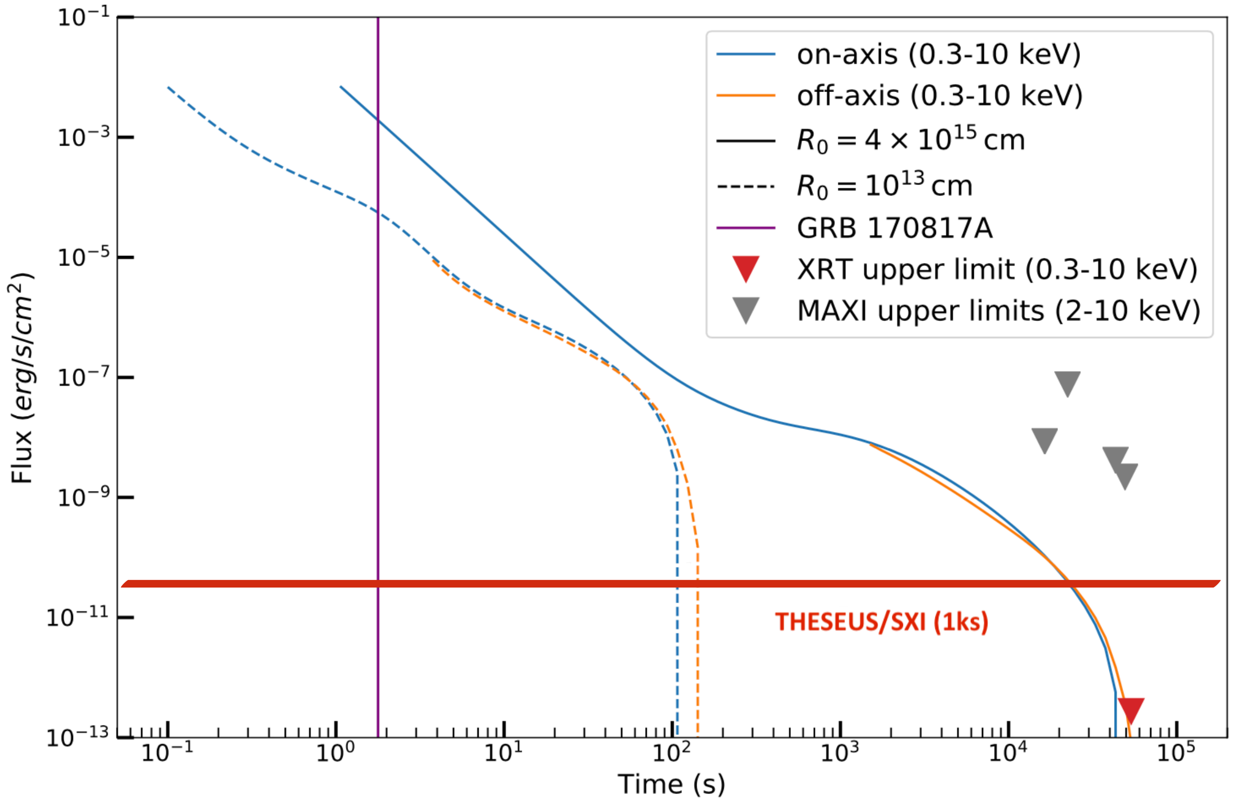
- High latitude emission (HLE): delayed emission from relativistic jet edges —> originally proposed to explain the ending phase of prompt emission ("steep decay", e.g. Liang+2006)
- Assuming a structured jet, HLE from internal shock can explain both the steep decay and the plateau phase of X-ray afterglows (Oganesyan+2020)
- HLE can be detected from an observer on- and off-axis (Ascenzi+2020, Beniamini+2020)

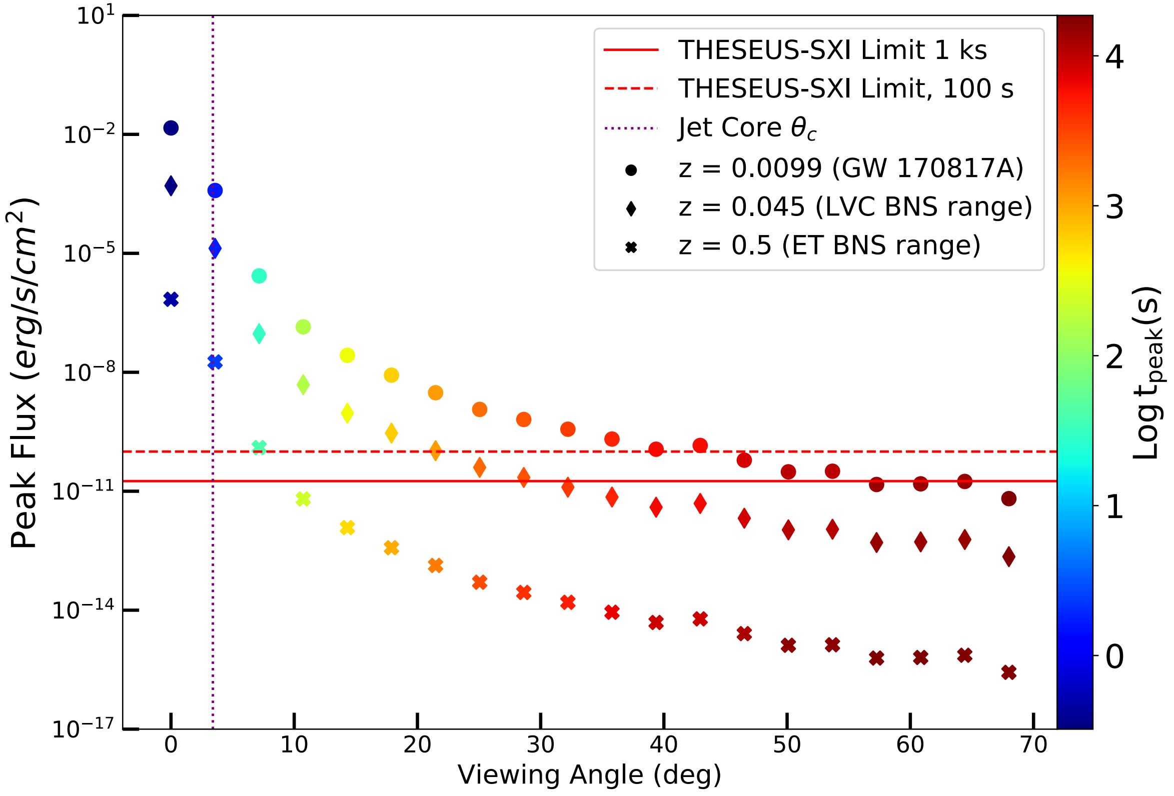


Ascenzi et al. 2020

GRB 170817A - predicted HLE

Figures by Stefano Ascenzi

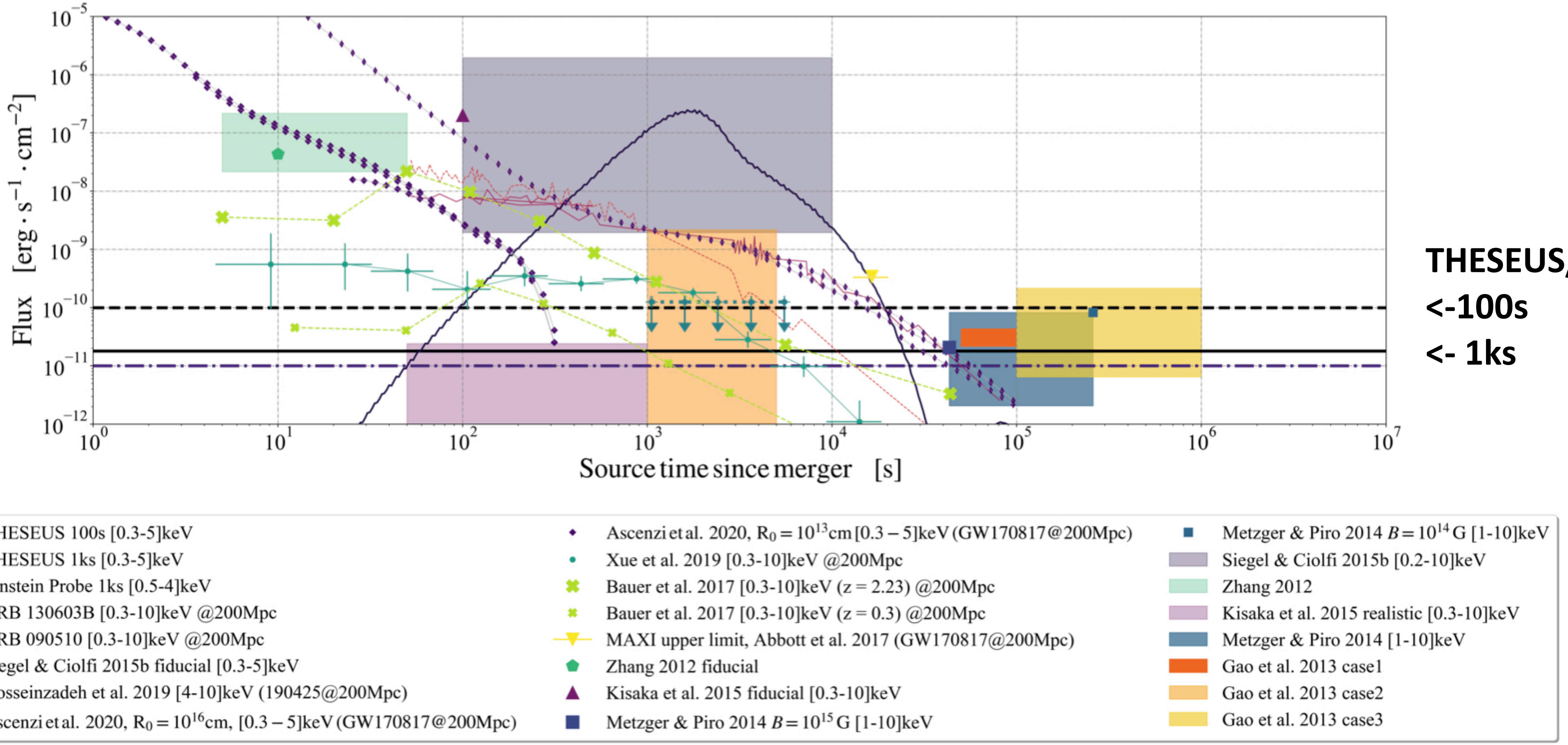




THESEUS/SXI could have detected the HLE from GRB 170817 relativistic jet up to ~30 deg off-axis with 1ks exposure (~8 deg off-axis if it were at z=0.5)

Expected X-ray emission @ 200 Mpc

Figure by S. Vinciguerra

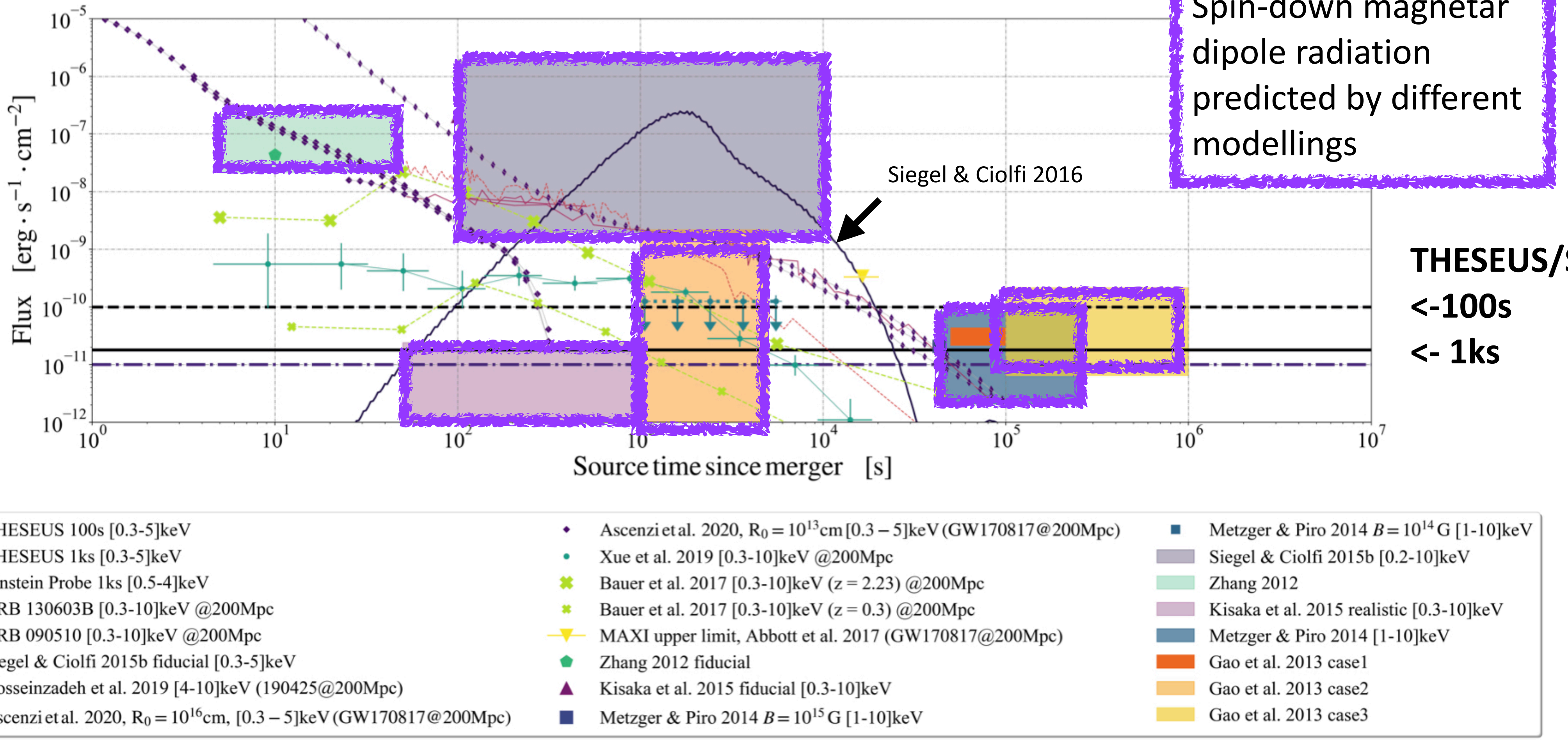


THESEUS/SXI
<-100s
<- 1ks

Expected X-ray emission @ 200 Mpc

Figure by S. Vinciguerra

Spin-down magnetar dipole radiation predicted by different modellings



THESEUS/SXI
<-100s
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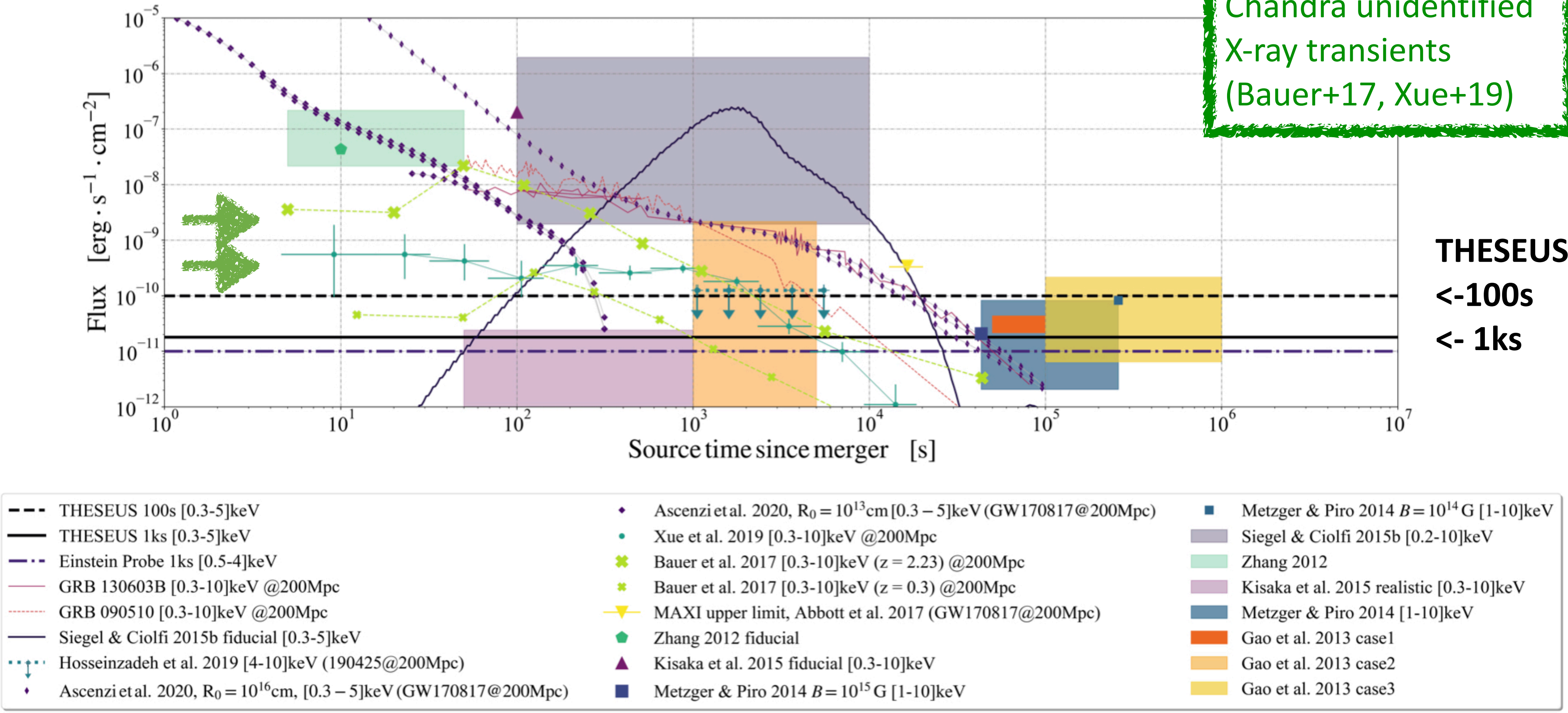
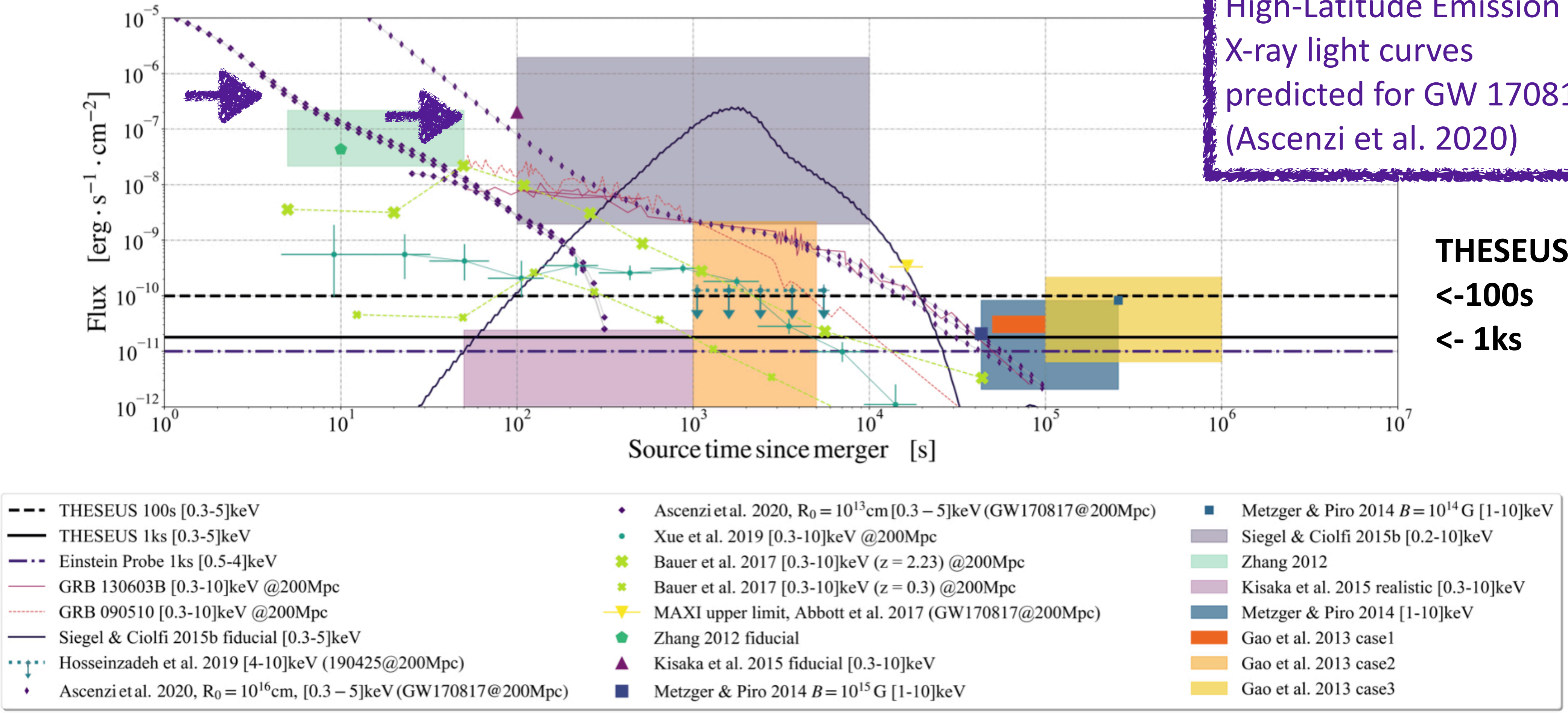


Chandra unidentified X-ray transients (Bauer+17, Xue+19)

THESEUS/SXI
<-100s
<- 1ks

Expected X-ray emission @ 200 Mpc

Figure by S. Vinciguerra



High-Latitude Emission X-ray light curves predicted for GW 170817 (Ascenzi et al. 2020)

THESEUS/SXI

<-100s

<- 1ks

3. SGRB jet afterglows in THESEUS

Main contribution from (so far):

G. Lamb (University of Leicester), O. Salafia (INAF-OAB), R. Ciolfi (INAF-OAP)

GRB 170817A-like jet afterglows

assuming Ghirlanda+2019 jet structure

(model Salafia+2019)

$$E(\theta) = \frac{E_c}{1+(\theta/\theta_c)^{5.5}}$$

$$\Gamma(\theta) = 1 + \frac{\Gamma_c - 1}{1+(\theta/\theta_c)^{3.5}}$$

$E_c = 2.51^{+7.49}_{-2.01} \times 10^{52}\,\mathrm{erg}$

$\Gamma_c = 251$

$\theta_c = 3.^\circ 4$

$n = 5 \times 10^{-3}\,\mathrm{cm}^{-3}$

$p = 2.15$

$\sqrt{\varepsilon_B} = 0.1$

Predicted X-ray max flux as a function of the source distance and inclination angle

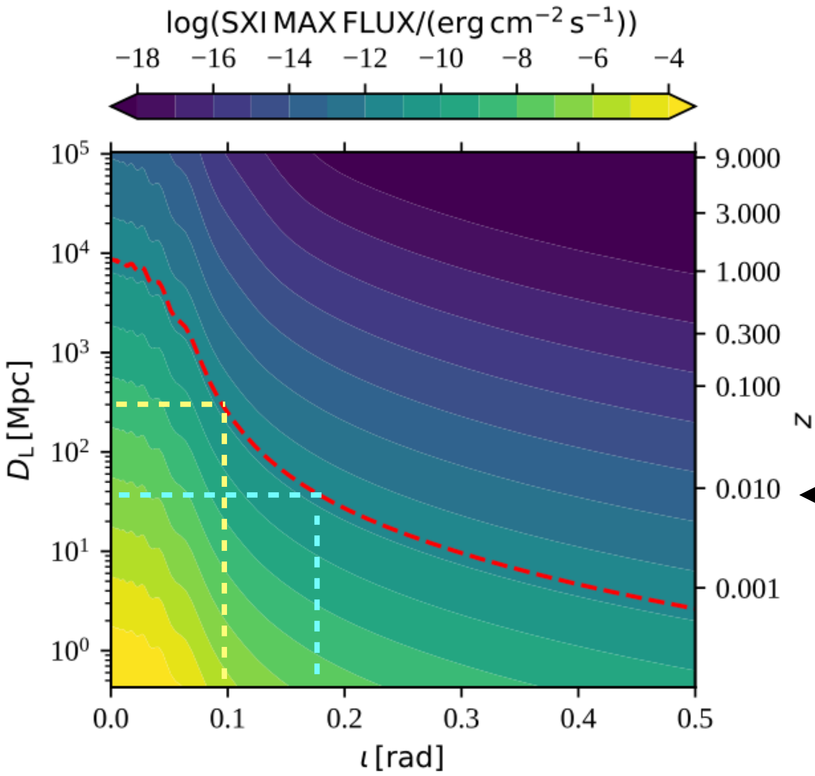


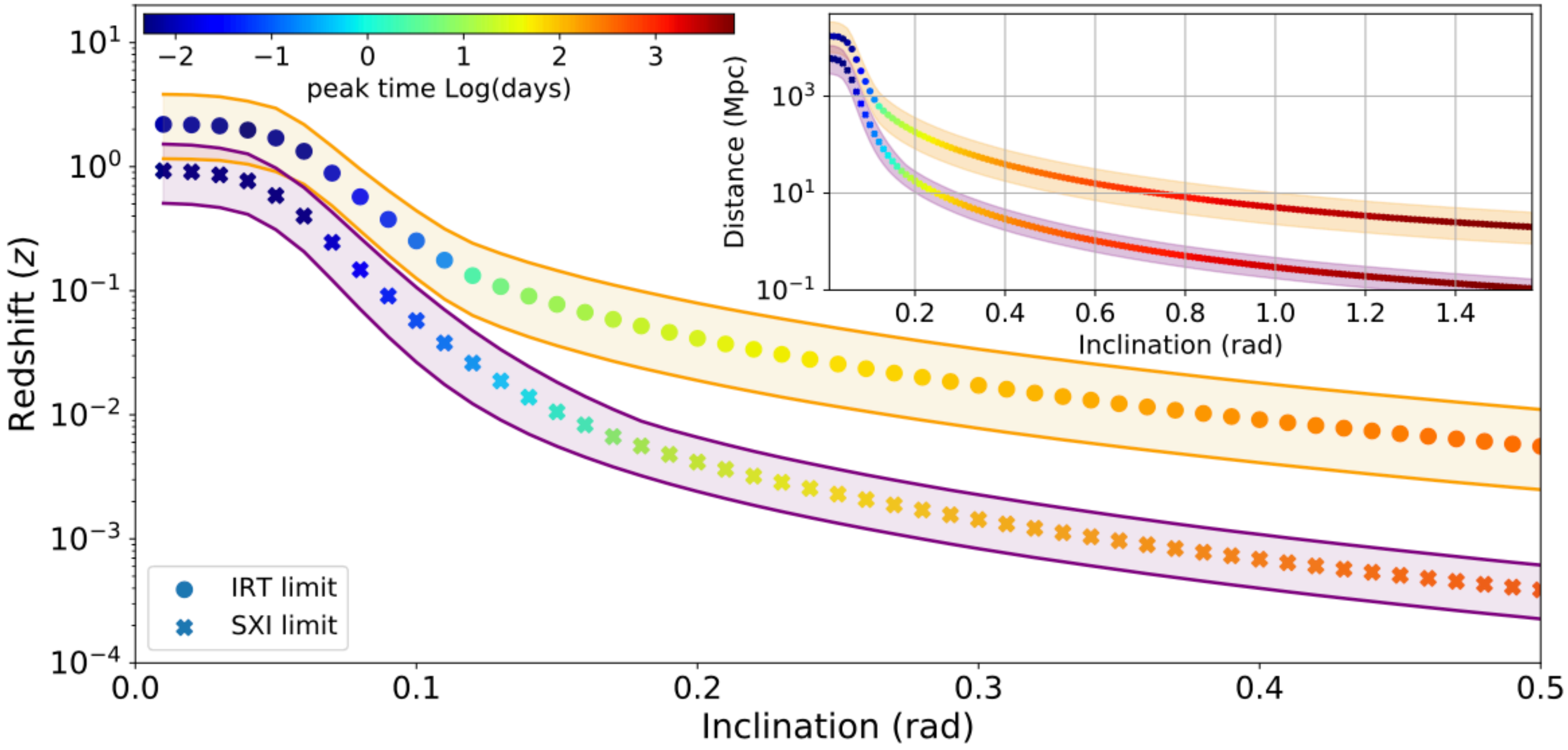
Figure by Om Sharan Salafia

2G distance reach ~<5°

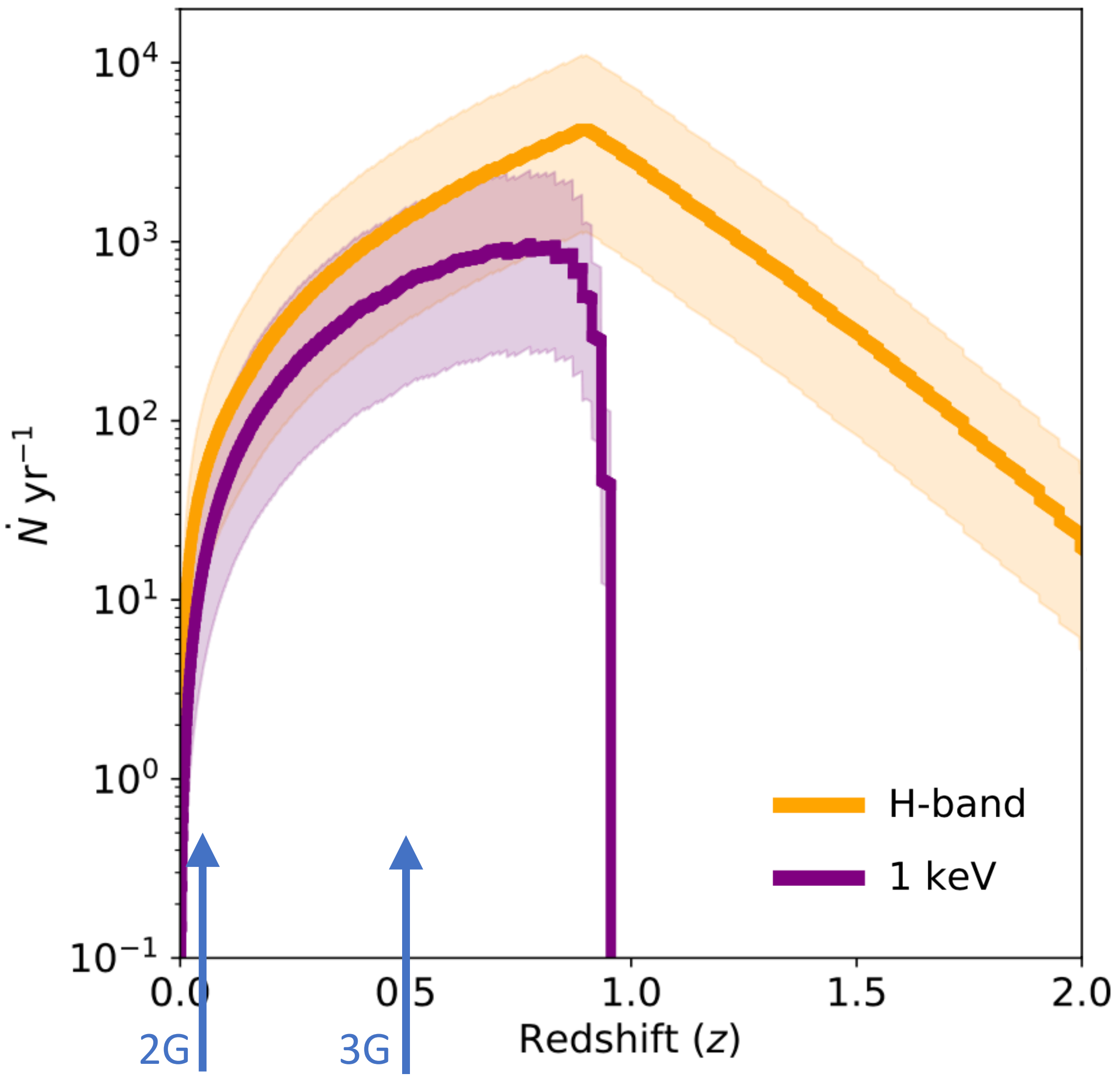
GRB 170817A distance ~< 10°

GRB 170817A-like jet afterglows

Figure by Gavin Lamb



GRB 170817A-like jet afterglows: rate of detectable events



- within GW distance for 2G

  SXI: few per yr

  IRT: ~10 per yr

- within GW distance for 3G

  SXI: few hundreds per yr

  IRT: ~1000 per yr

assuming SGRB population
by Wanderman & Piran 2015
(normalized to LVC BNS merger rate)

Preliminary conclusions

- IRT can detect 170817-like SGRB jet afterglows up to ~10 Gpc (best case on-axis)
- SXI limited to closer distances by factor ~2 (on-axis) or worse
- ready to make similar estimates for any jet properties
- rate of detectable events for a given SGRB population (WP15) seems promising → need to establish the actual fraction of THESEUS SGRB detections (within 2G or 3G) for which an afterglow detection will be made with SXI and/or IRT

4. short GRB detections with redshift and H_0

Main contribution from (so far):

A. Rossi, G. Stratta

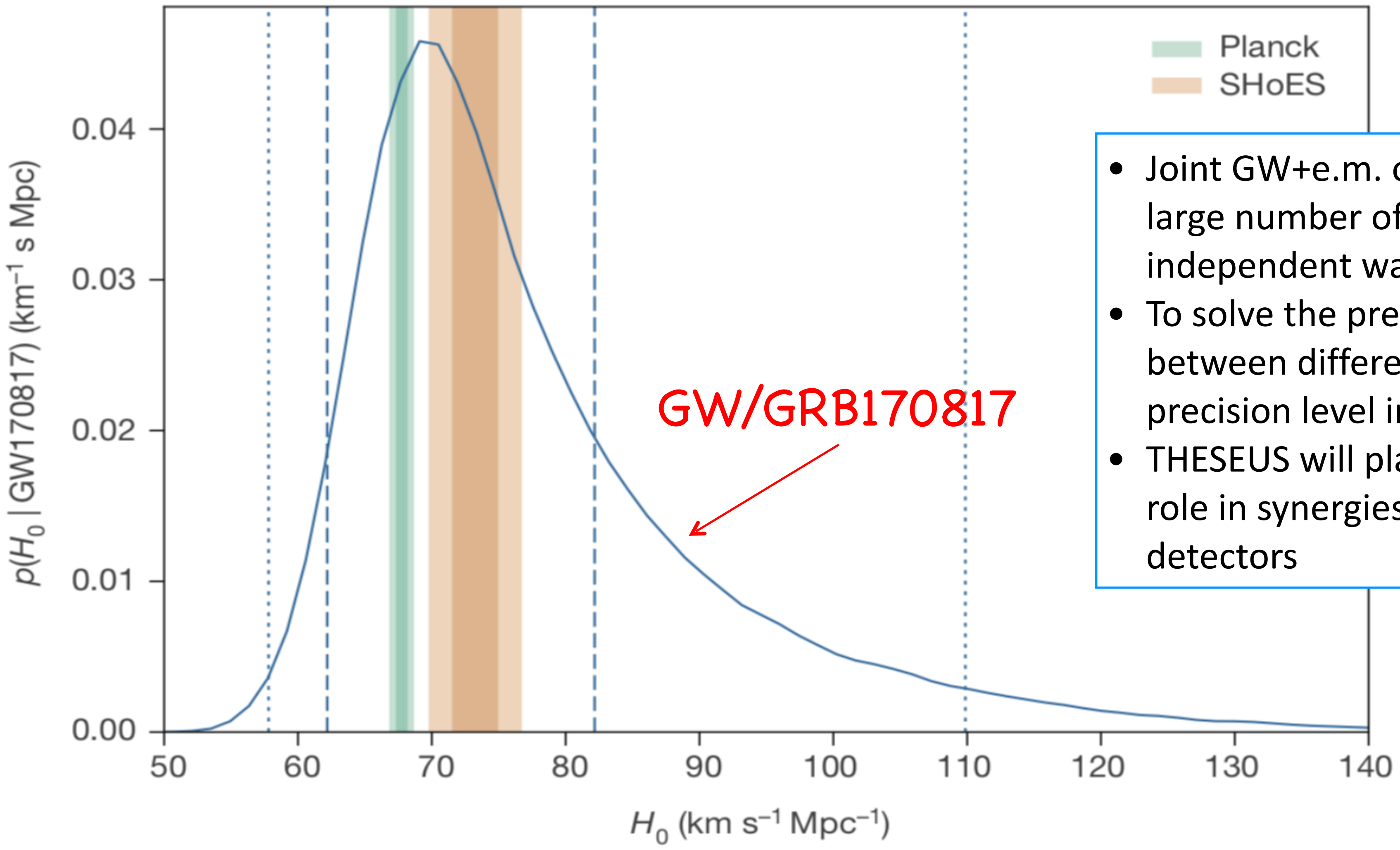
(INAF-OAS)

L. Salmon, L. Hanlon, A. Martin-Carrillo

(Dublin Univ. College)

A new independent measure of H0

LVC, Nature 2017, 551, 85

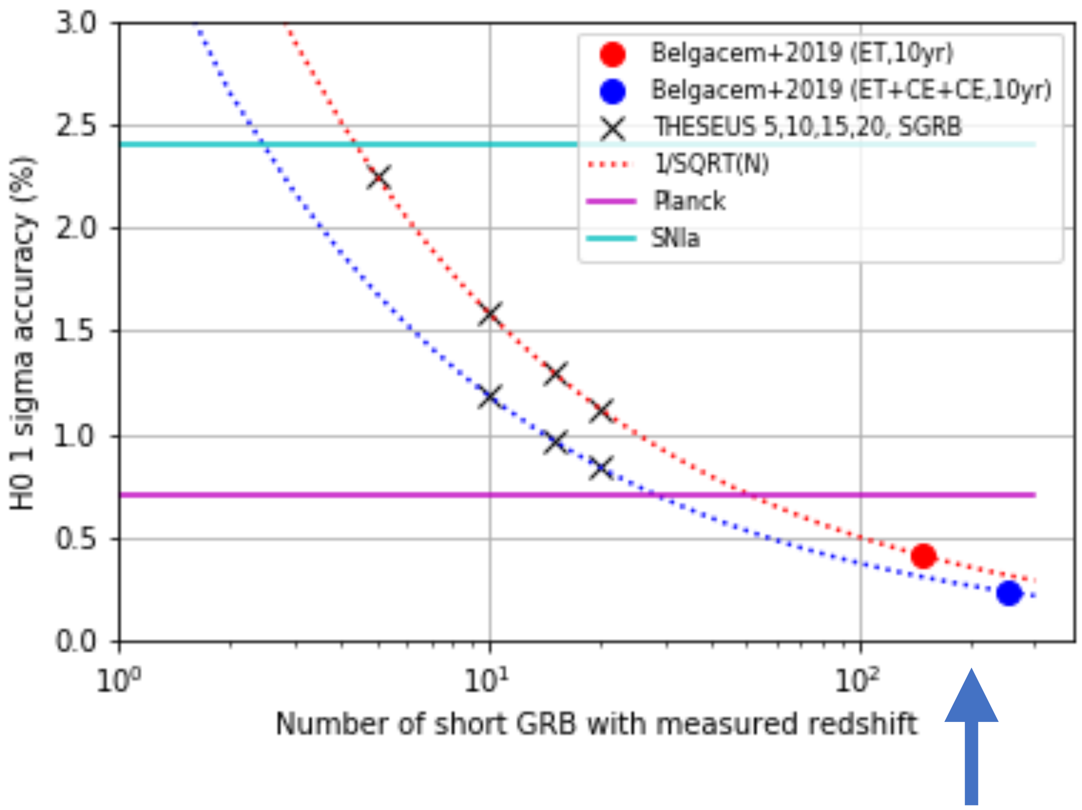


- Joint GW+e.m. observations of a large number of CBCs —> new independent way to measure H0
- To solve the present tension between different measures ~1% precision level in required
- THESEUS will play a significant role in synergies with 3G GW detectors

Measuring H0 with THESEUS + 3G GW interferometers

- **THESEUS+ET (z<0.5):**
  - THESEUS/XGIS on-axis short GRBs @ z<0.5 **~10-15**
  - **~5 with localization accuracy 1''**
  - **~5-10 with localization accuracy <15'-7' :** by activating quick follow-up with other facilities to measure z **—> ~<1.5%**
  - if additional 10-15 X-ray transients will be detected (i.e. off-axis short GRBs)**—> ~1%**

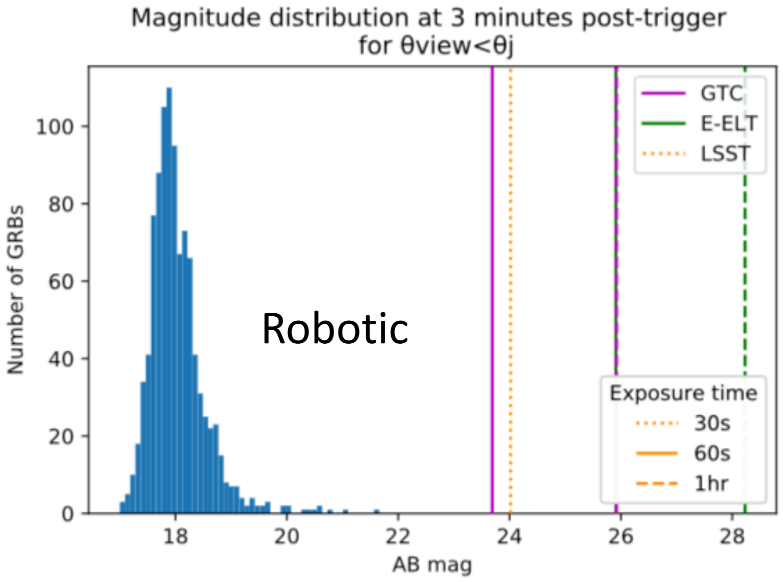
- **THESEUS+ET+CE+CE:**
  - THESEUS/XGIS short GRBs ~ 30
  - **~ 10-15 with IRT**
  - **—> ~1.2-1%**



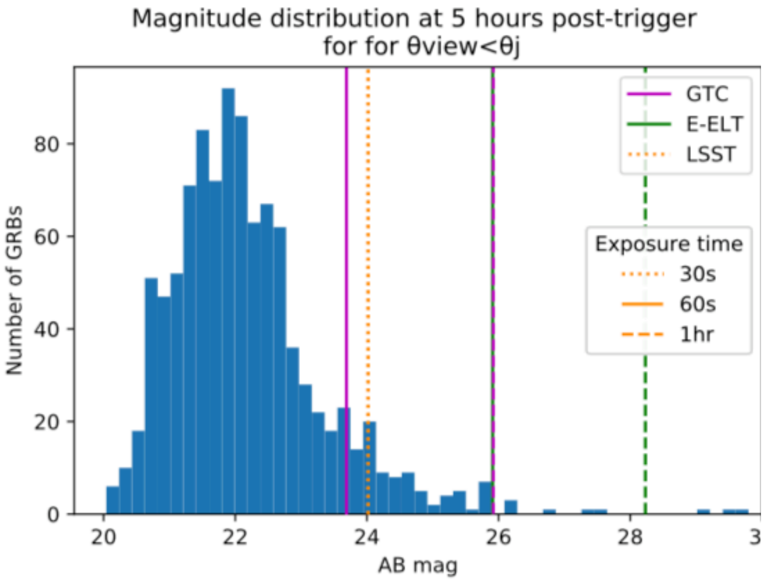
results obtained by Belgacem+2019 Assuming 10 yrs of short GRBs observations with THESEUS/XGIS-like detector in synergy with 3G interferometers

Measuring z for on-axis short GRBs with localization accuracy of several arcmin

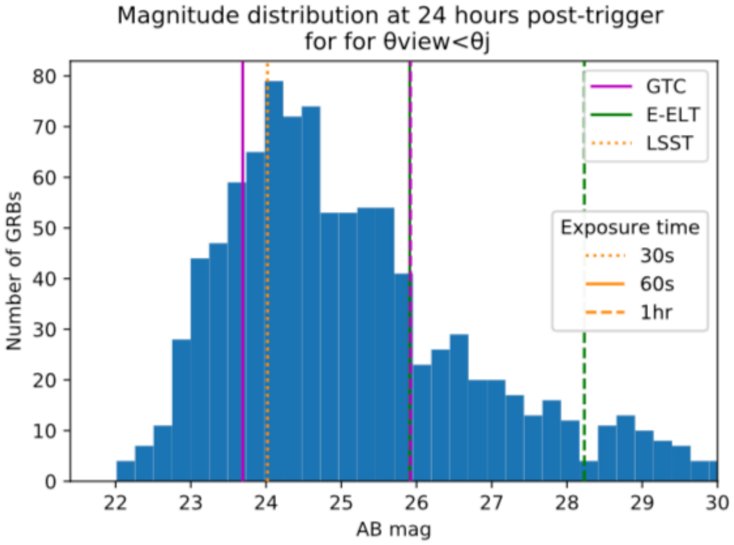
Figures by L. Salmon



(a) Number of GRBs per magnitude at 3 minutes post-trigger



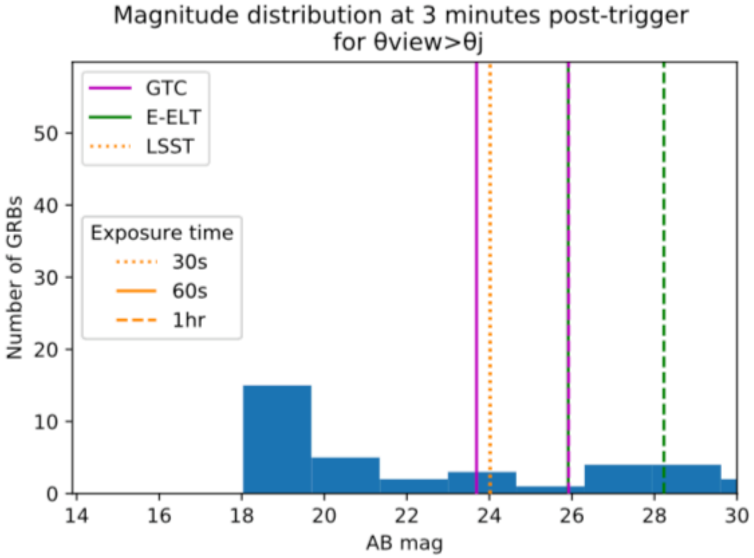
(b) Number of GRBs per magnitude at 5 hours post-t



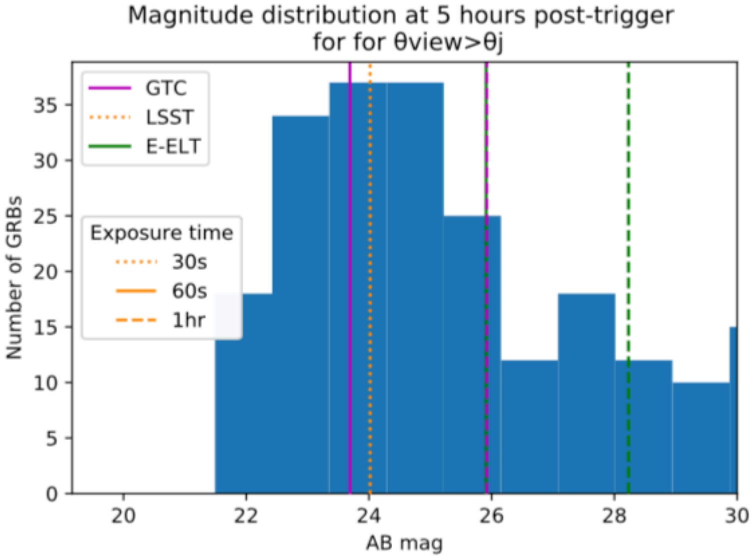
(c) Number of GRBs per magnitude at 24 hours pos trigger

1000 synthetic optical afterglow light curves build with python module “afterglowpy” (Ryan et al. 2019) assuming typical short GRB intrinsic parameters + top-hat jet model

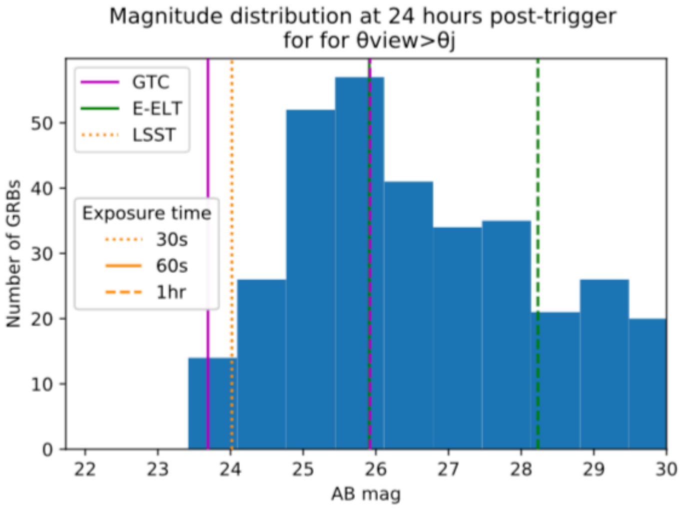
Measuring z for off-axis short GRBs with localization accuracy of several arcmin



(a) Number of GRBs per magnitude at 3 minutes post-trigger



(b) Number of GRBs per magnitude at 5 hours post-trigger



(c) Number of GRBs per magnitude at 24 hours post-trigger

- Off-axis viewing angle (5°<θ<30°)—> early afterglow flux rises with time
  - advantages: relaxed time constraints to follow-up
  - disadvantages: faint transients

Preliminary conclusions

- THESEUS+ET: ~1.5 % precision level in the H0 measure can be reached by providing quick follow-up observations
    - ~1% can be reached if ~10-15 GW sources will be detected as X-ray transients (i.e. off-axis GRB) with SXI

- THESEUS+ET+CE+CE: ~1.0 % with possibility to measure z onboard with IRT

5. Kilonovae: detection with THESEUS/IRT

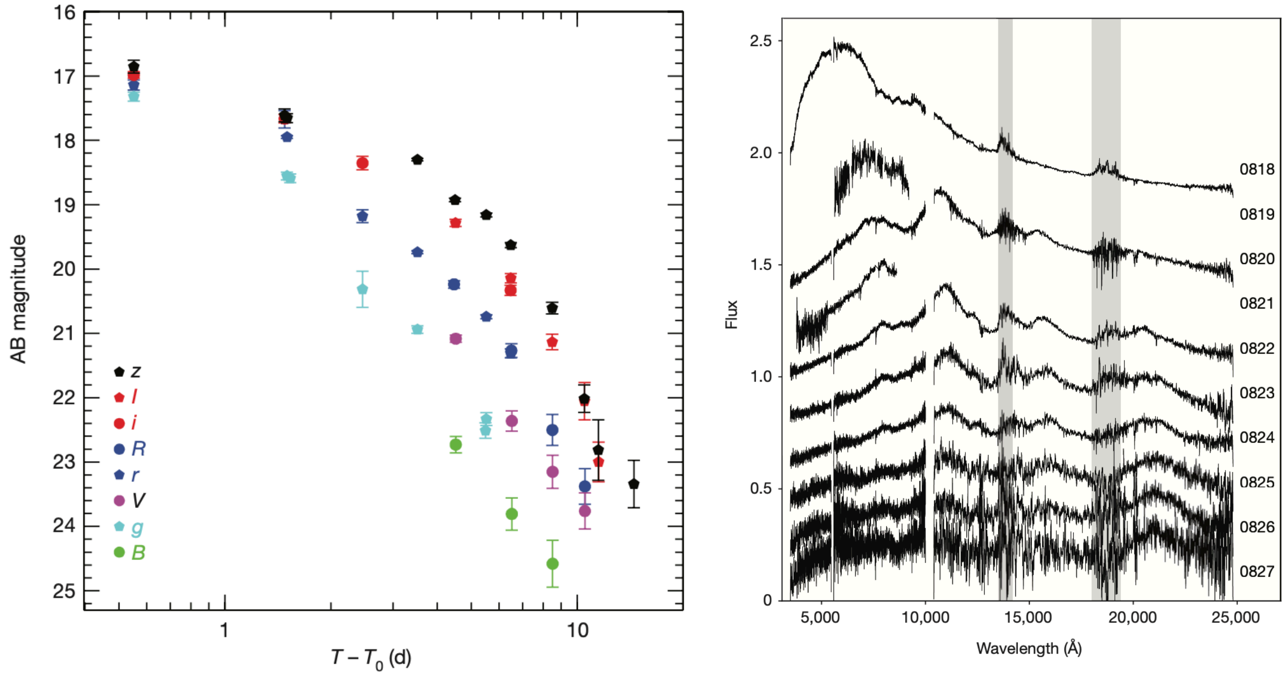
Main contribution from (so far):

E. Palazzi, A. Rossi (INAF-OAS)

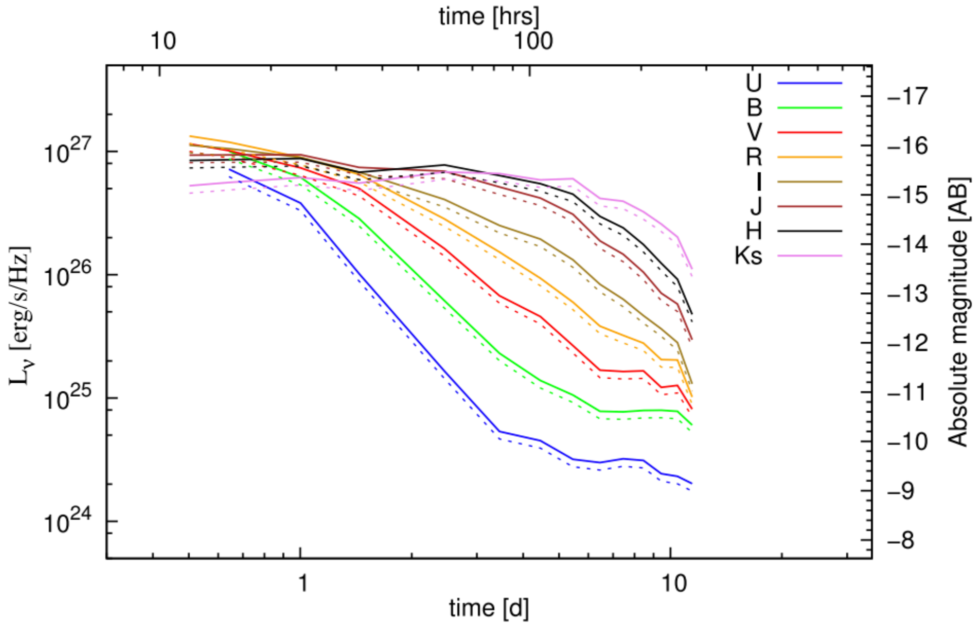
AT2017gfo

- AT2017gfo is the best monitored kilonova so far associated with NS-NS merger sources GW 170817

- AT2017gfo light curve in different bands were obtained from Rossi et al. 2020 that used early photometric data + X-shooter spectra taken between 1 and 10 days convolved with optical filters



Pian et al. 2017

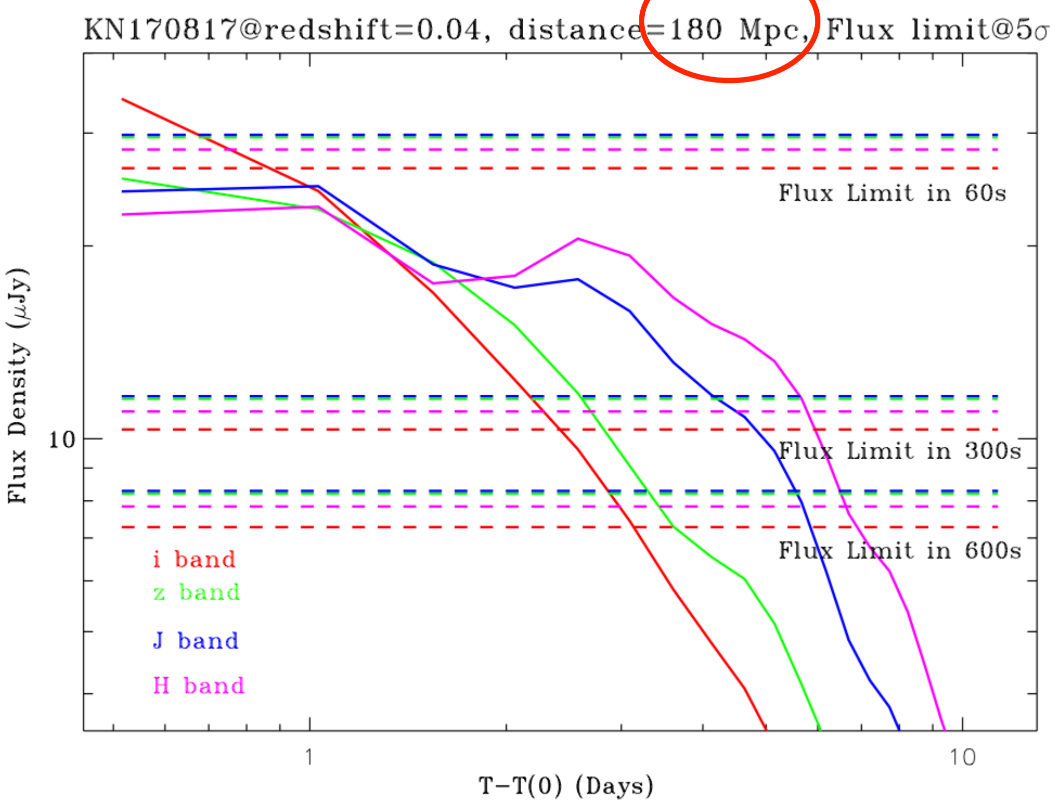


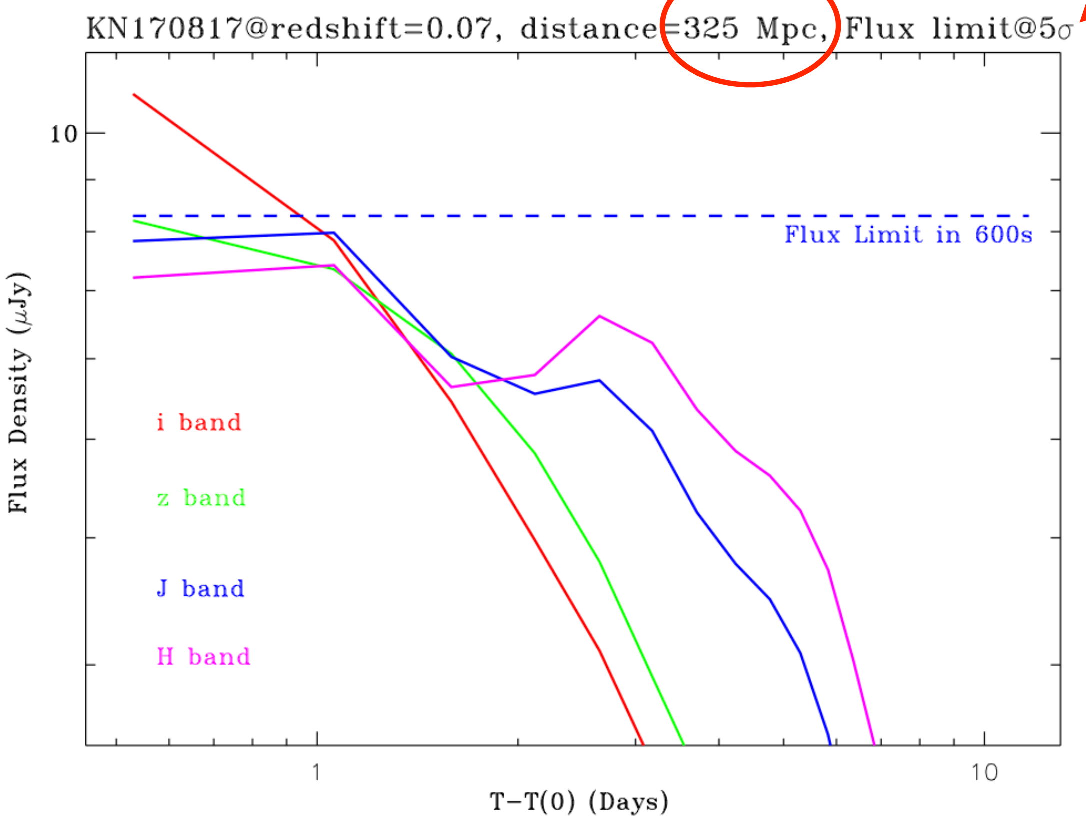
Rossi et al. 2020

AT2017gfo-like kilonova with IRT

AT2017gfo curves from Rossi et al. 2020

Simulations performed with ETC: THESEUS_IRT_Sensitivity_SWG_HT_V6.1.3 + Teledyne,





At 5σ IRT can detect KN peak (<few hrs) in 1 filter (i-band): 180 Mpc with 60s and ~325 Mpc with 600s (z=0.07)

Full SED can be build at 180 Mpc up to ~2.5(3) days with 300s (600s)

Preliminary conclusions

- If all BNS were associated to AT2017gfo-like kilonova, then by assuming a BNS density rate of 1090 [2810 - 110] Gpc^{-3} yr^{-1} (Abbott+2020), we expect:
  - ~25 [6-60] BNS+KN/yr within 180 Mpc that can be detected with IRT with 60s
  - ~all BNS detected with 2G can potentially be detected with IRT with 600s

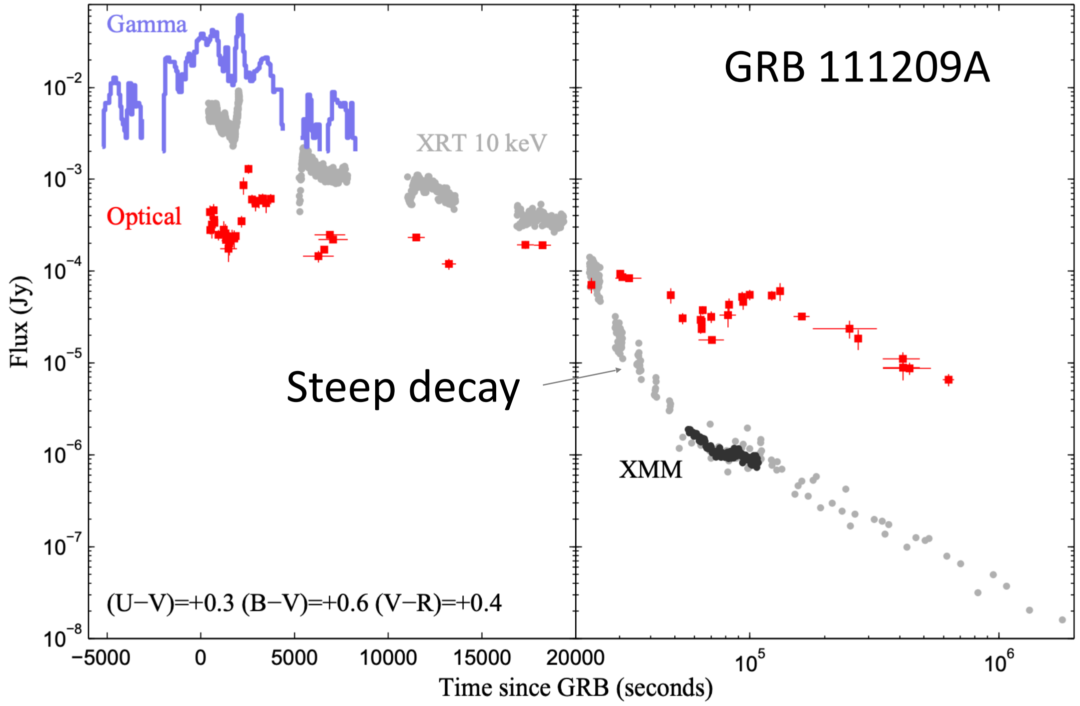
Ultra-long GRBs with THESEUS

Main contribution from (so far):
B. Gendre, A. McCann
University of Western Australia

Gendre+2013

Ultra-long GRBs

- Class of rare class of long GRBs with prompt emission of exceptional duration
- still unknown progenitors
    - Blue giant stars
    - LGRB+magnetar remnant
    - ..?
- So far, only 5 cases with known redshift and <z>~0.9 (e.g. Gendre+13,+19)

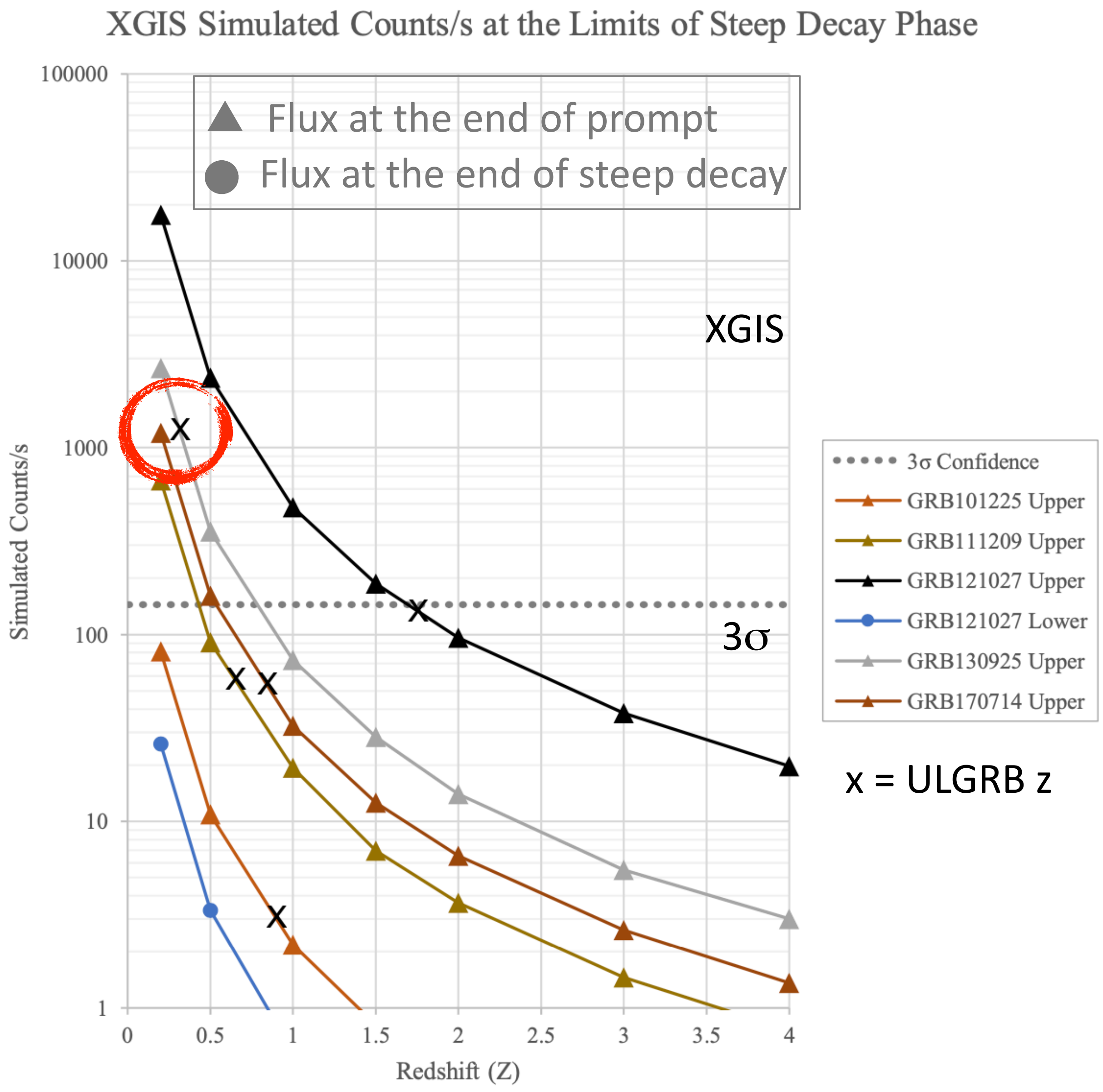


Name	Duration (T_{90},s)	Duration (T_X,s)	Redshift
GRB 101225A	$> 7,000$	5296	0.847
GRB 111209A	25,000	25,400	0.677
GRB 121027A	$> 6,000$	8000	1.77
GRB 130925A	4,500	10000	0.35
GRB 170714A	420	16,600	0.793

Gendre+2019

Ultra-long GRB (XGIS-X)

- Only 1 ULGRB (130925A at z=0.35) above threshold up to the end of the ultra-long prompt emission (triangles)
  - Still above threshold if 2 times farther
- +3 ULGRB above threshold if they were more nearby by a factor of ~1.2-2

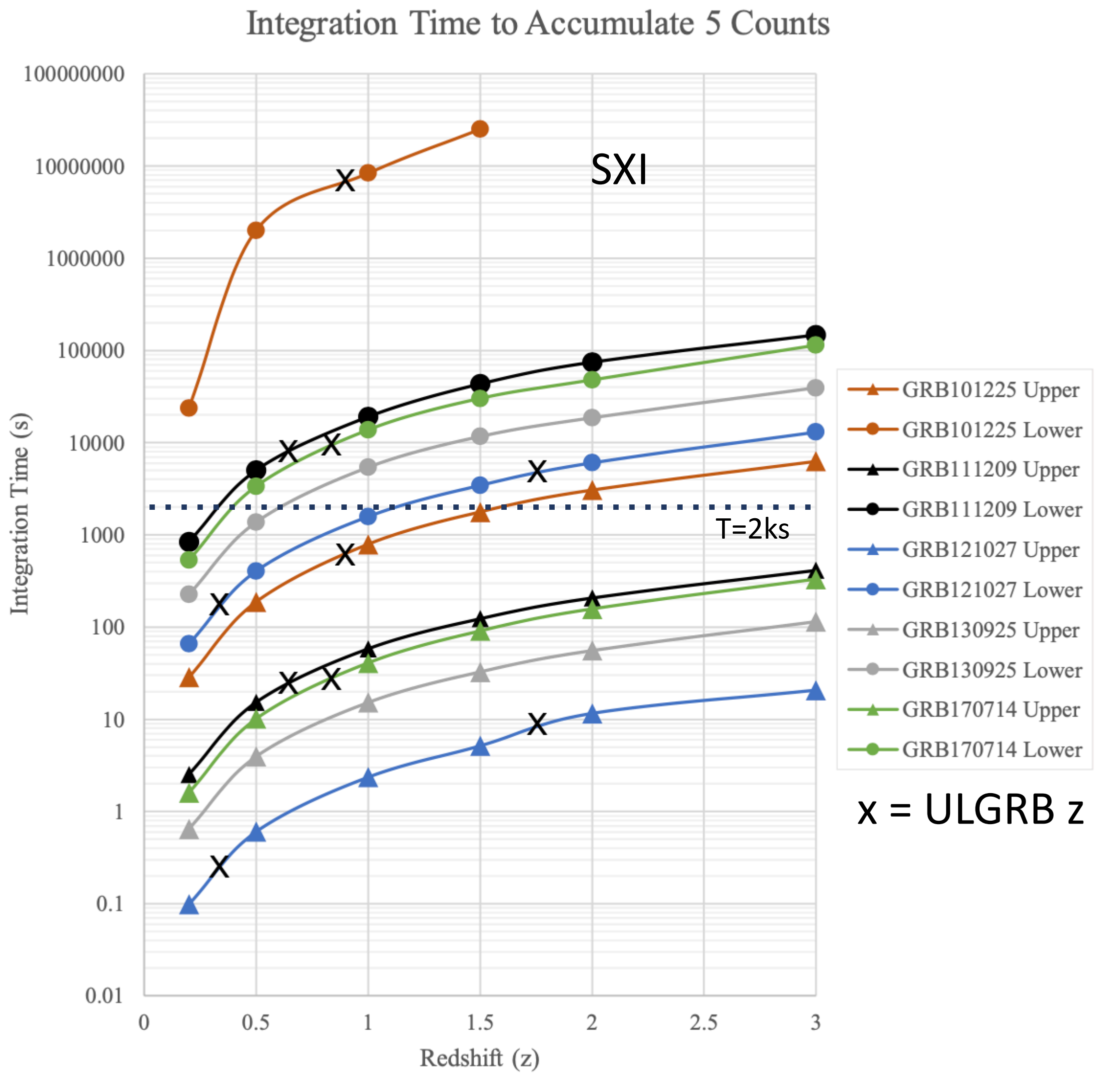


Ultra-long GRB (SXI)

Flux at the end of prompt (triangles)
Flux at the end of steep decay (circles)

- All 5 ULGRBs could had detected with SXI up to the end of prompt phase (triangles), with T_{int}=[0.5-700]s

- 4 over 5 (80%) ULGRB down to the end of the steep decay (circles), with T_{int} =[500 s - 10 ks] (1 case with T_{int} of <2 ks)



Preliminary conclusions

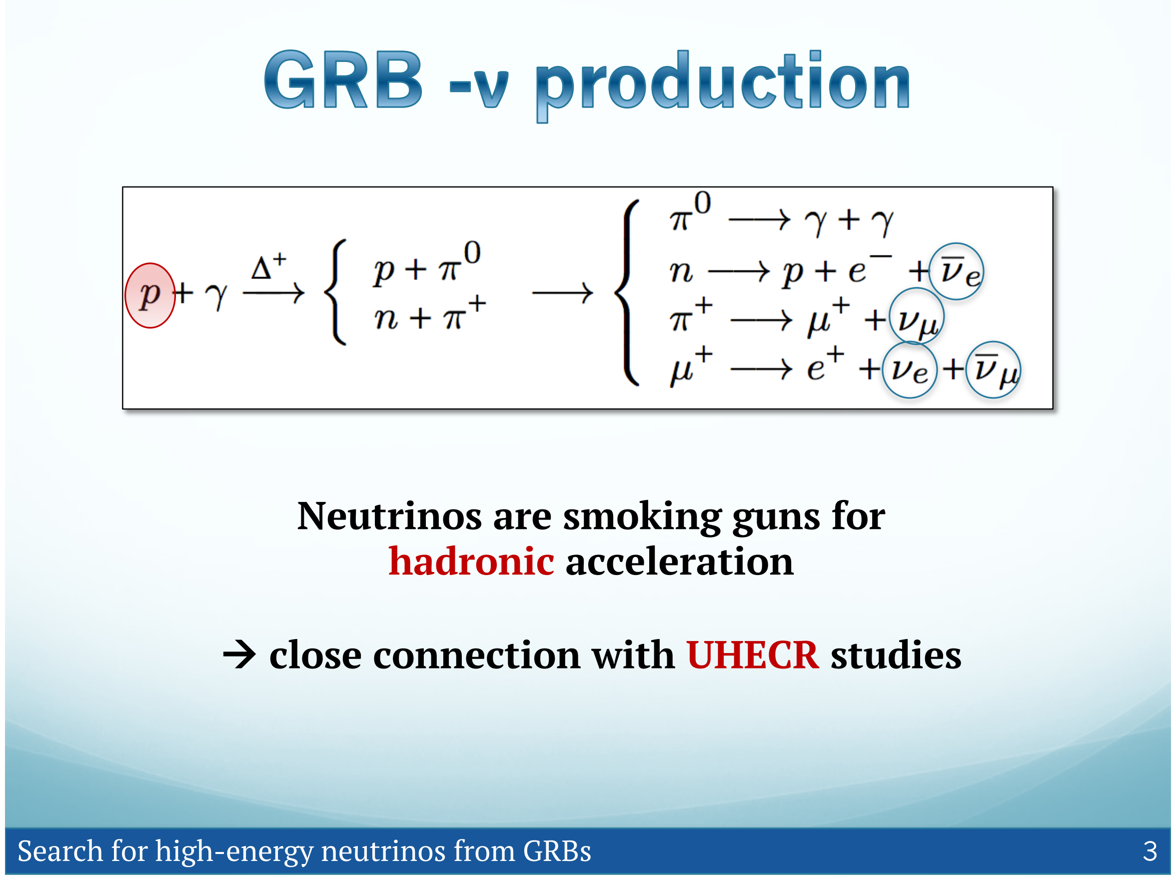
- THESEUS/SXI is best suited to detect ULGRBs w/r to XGIS
- MM data will likely be available only for the most nearby sources —> both XGIS and SXI can detect ULGRBs

The role of THESEUS in Neutrino Astronomy

Main contribution from (so far):
A. Capone, S. Celli, I. Di Palma, M. Fasano, P. Fermani, A. Zegarelli
(Università di Roma)

The role of THESEUS in Neutrino Astronomy

- Recent discoveries with IceCube:
  - Diffuse flux of VHE ν (10TeV-10PeV) (Aartsen+2013)
  - First extra-galactic neutrino sources: blazar TXS0506+056 (Aartsen+2018)
- HE ν are unique signature of accelerated hadrons at the source —> connection with UHCRs & most extreme accelerators in the Universe
  - GRBs
  - AGN
  - star-forming galaxies
- So far, no ν detections from GRBs —> constraints on energy transferred to baryons in the acceleration process and on the bulk jet Lorentz factor

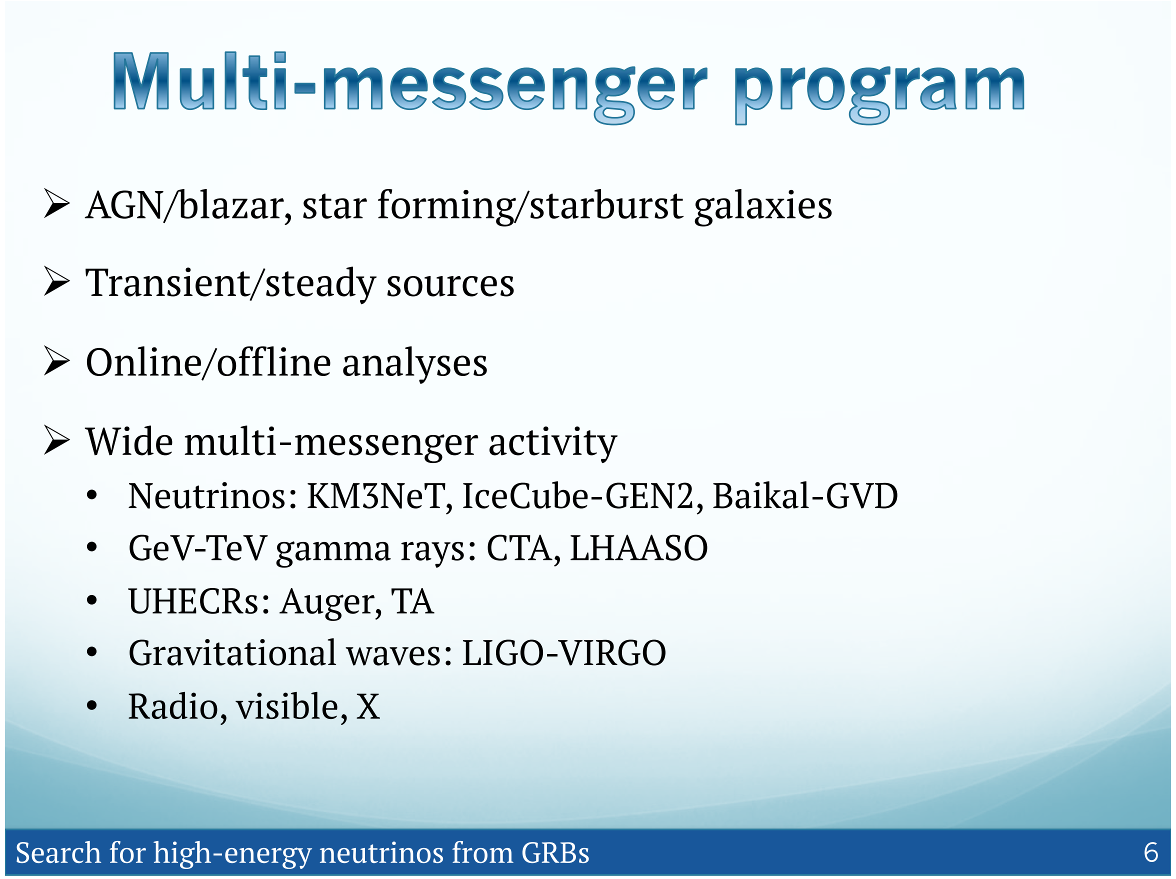


The role of THESEUS in Neutrino Astronomy

- THESEUS will ensure GRB observations in the golden era of neutrino Multi-km3 detectors

- THESEUS will detect also soft / faint long GRBs that have been suggested as better target for ν detection

- Short GRBs are also expected to be ν sources and GW sources



THESEUS and large volume neutrino telescopes

A. Capone, S. Celli, I. Di Palma, M. Fasano, P. Fermani, A. Zegarelli

Recently, a diffuse flux of astrophysical very-high-energy neutrinos (10 TeV-10 PeV) was discovered by IceCube [1], though the origin of such events is still to date unknown. In addition, the first extra-galactic neutrino source was identified in the blazar TXS0506+056 [2], which adds up to the only two known sources of neutrinos, both belonging to the local Galactic environment, i.e. the Sun and the supernova SN1987A. High-energy neutrinos provide unique signatures of the presence of accelerated hadrons at the source. Emerging from hadronic collisions with characteristic energies 20 times smaller than the energy of the accelerated protons, the properties of the neutrino events detected so far points towards cosmic objects capable of producing energies as high as the EeV. These sources are possibly responsible for the flux of Ultra High Energy Cosmic Rays (UHECRs) as well. Hence it of paramount importance to address the question on the origin of the neutrinos, as th

the Universe.

Within our Galaxy, no sources ar

except for the cosmic rays possil

Galactic disk. However, these are

References:

[1] M. G. Aartsen et al. Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector. Science, 342:1242856, 2013a. doi: 10.1126/science.1242856.

[2] M. G. Aartsen et al. Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A. Science, 361:eaat1378, July 2018. doi: 10.1126/science.aat1378.

[3] G. Pagliaroli, C. Evoli, and F. L. Villante. Expectations for high energy di use galactic neutrinos for different cosmic ray distributions. Journal of Cosmology and Astroparticle Physics, 11:004, November 2016. doi: 10.1088/1475-7516/2016/11/004.

[4] M. Ahlers and F. Halzen. Opening a New Window onto the Universe with IceCube. Progress in Particle and Nuclear Physics, Volume 102, p. 73-88, 2018.

[5] E. Waxman and J. Bahcall. High Energy Neutrinos from Astrophysical Sources: An Upper Bound. Phys. Rev. D59, 023002, 1999.

[6] M. G. Aartesen et al. Search for steady point-like sources in the astrophysical muon neutrino

....

Contribution for the "Yellow Book" section on MM astrophysics

- Status of the art on recent neutrino discoveries and main extra-galactic sources
- Lesson learned from GW/ GRB 170817
- General role of THESEUS

Next steps:
Further quantifications of scientific achievements in neutrino astronomy with THESEUS

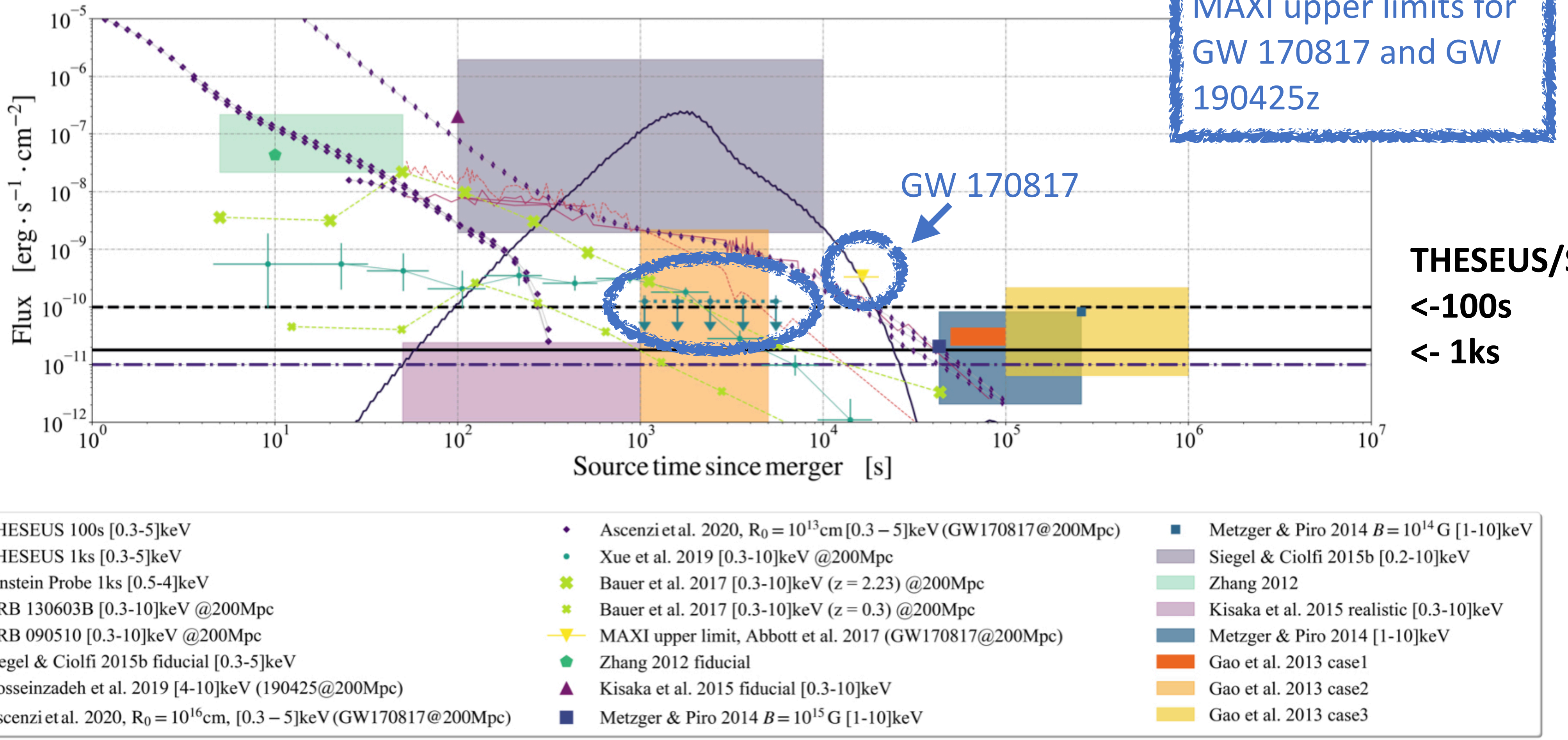
Summary and conclusions

- **The study of the role of THESEUS in MM astrophysics during 2030s is in good shape and several issues have been deeply investigated**
  - “non-standard” Short GRB prompt emission: off-axis (the case of GRB170817), short GRB+EE
  - Expected detection rate increase from less collimated components: EE, plateaus
  - Optical and X-ray afterglow detectability according to most recent jet models
  - Role of THESEUS in measuring H0
  - Core collapsing stars: the case of ULGRBs
- **Next steps:**
  - Further quantification of the role of THESEUS in Neutrino Astronomy during 2030s
  - Quantification of the impact of THESEUS in NS-NS/NS-BH(BH-BH) nature as a function of total number of short GRBs and their localization accuracy (p2.2)
  - Bursting GW sources: detection of nearby low-luminosity GRB, SBO, SGRs with THESEUS (p2.6)
  - THESEUS follow-up (3/months) of neutrino and GW external triggers (baseline reaction time: 12hr (goal: 4hr)): assess scientific return (p2.8)

Backup SLIDES

Expected X-ray emission @ 200 Mpc

Figure by S. Vinciguerra



MAXI upper limits for GW 170817 and GW 190425z

THESEUS/SXI
<-100s
<- 1ks