Low−Γ Jets from Compact Stellar Mergers: Candidate Electromagnetic Counterparts to Gravitational Wave Sources

Gavin P Lamb[1] and Shiho Kobayashi[1]

@lamb_gl
GRAMPA 2016 - IAP 2/06/2016

Summary

EM counterparts: Radio flares; Kilonova; SGRB; Off/On-axis (orphan) afterglow

GW triggered search can reveal hidden population of low Lorentz factor merger jets

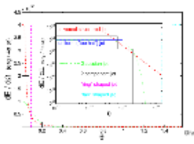
Strong candidate for EM follow-up searches

Determine Lorentz factor distribution of jets

@lamb_gl GAVIN P LAMB - 2/03/2016

Structured Jets

So far, assumed uniform jet Lorentz factor and energy density:



Granot 2006

A jet with intrinsic structure may have low Lorentz factor wings - these will produce similar orphan afterglows

If such structure is present within SGRB jets then the rate of on-axis orphan afterglow will be higher than estimated

Lamb & Kobayashi (in prep)

EM Follow-up Searches

Isotropic emission - kilonova
- *Fainter and longer than thought* (Tanaka 2015)
- *Peak 24-22 magnitude*

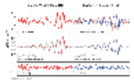
Collimated emission - on-axis orphan afterglow
- *With GW detection on-axis probability higher than the beaming factor*
- *85% of on-axis orphan afterglow brighter than 21 magnitude*

Great follow-up potential for transient search telescopes e.g. BlackGEM, iPTF/ZTF, Pan-STARRS, GOTO, Kiso, SkyMapper, Subaru, HSC, LSST, LT/LT2, PIRATE

Radio follow-up e.g. VLA, SKA, LOFAR, APERTIF, MWA

Compact Stellar Mergers

- Black hole (BH), Neutron star (NS)
- BHBH, GW detected
  - NSBH, NSNS - next breakthrough - expected soon!!!



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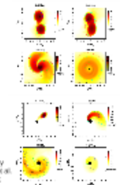
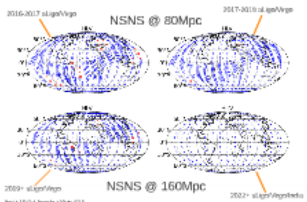


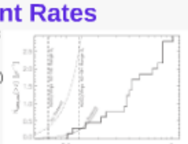
Numerical simulations show that compact binary mergers launch energetic subrelativistic and mildly relativistic outflows (Rosswog et al. 2000; Ruffert et al. 2001; Yamamoto et al. 2006; Rezzolla et al. 2010; Kiuchi et al. 2010)

GW Source Sky Localisation



Event Rates

- Swift detects ~10 SGRB per year
- Redshift for ~1/4
- Metzger & Berger (2012) <0.03 SGRB per year within aLIGO range by Swift
- By considering the all sky rate:

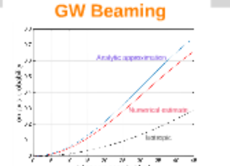


Metzger & Berger 2012

estimate 2.6 on-axis orphan afterglow per year within 300 Mpc (NSNS)

This assumes the jet-opening angle does not depend on the Lorentz factor.
If a relation exists the rates could be higher

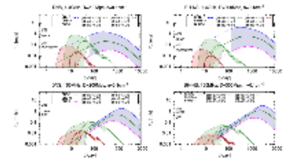
GW Beaming



- GW strongest on-axis (Kochanek & Piran 1993)
- With GW detection, on-axis probability higher than isotropic
- We assumed all jets have opening angle 20 degrees
- Lorentz factor - opening angle relation? Jet could be wider!?

Radio flares

- Interaction of ejecta with surrounding medium
- Peak on month to year timescale (Nakar & Piran 2011)



Hotokezaka et al. 2016 - NSNS(left)/NSBH(right) at aLIGO detection limit

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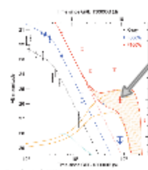

Tanvir et al. 2013

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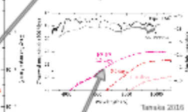


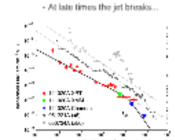
Tanaka 2016

- Peak in *i* ~24 magnitude (Tanaka 2016)

Short Gamma-ray Bursts and Afterglows

- Bright bursts of gamma-rays, duration < 2 s
- X-ray, optical, and radio afterglow on second/day/weeks timescale
- Relativistic jets with opening angle 3-15 degrees

- At late times the jet breaks...



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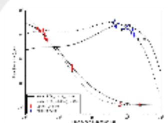
On-axis Orphan Afterglow?

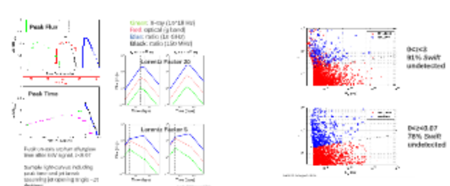


Cenko et al. 2015

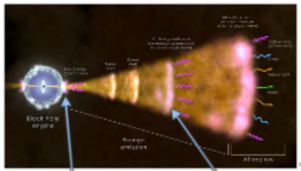
- On-axis afterglow - no high energy trigger
- One known detection; +1 discovered before trigger alert (Cenko et al. 2015)
- Why no gamma-rays? Too faint? Suppressed?

Monte Carlo

Using a=1.75 for Lorentz factor distribution, and Wanderman & Piran (2015) luminosity and redshift distributions:



GRBs: the Fireball Model



NASA

- The photospheric radius

$$R_{*} \propto E^{1/2}\Gamma^{-1/2}$$

- The dissipation radius

$$R_d \propto \Gamma^2$$

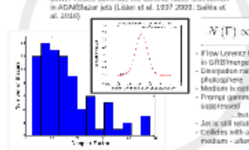
- Ultrarelativistic: Lorentz factor >100

Lorentz Factor Distribution

Difficult to measure accurately in short GRBs

Astrophysical Jets

- Lower values dominate the Lorentz factor distribution in AGN/Blazar jets (Lister et al. 1997 2000; Saikia et al. 2016)



Saikia et al. 2016

$$N(\Gamma) \propto \Gamma^{-a}$$

- If low Lorentz factor (<<100) in GRB/merger jet
- Dissipation radius below photosphere
- Medium is optically thick
- Prompt gamma-rays suppressed

...but...
- Jet is still relativistic
- Collides with ambient medium - afterglow!!!

Jets from NSNS/NSBH Mergers

- If Lorentz factor follows a power-law distribution
- Low values dominate
- Prompt emission is suppressed
- On-axis orphan afterglow

- With a GW trigger, can we detect these afterglows???

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http://adsabs.harvard.edu/abs/2016arXiv160502769L

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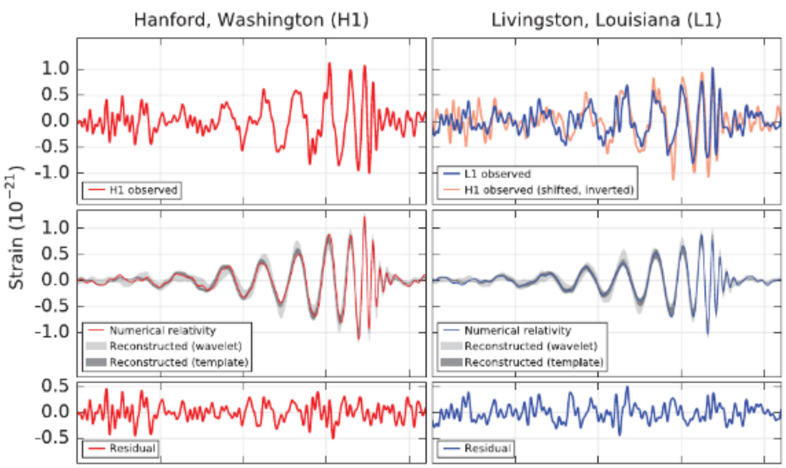
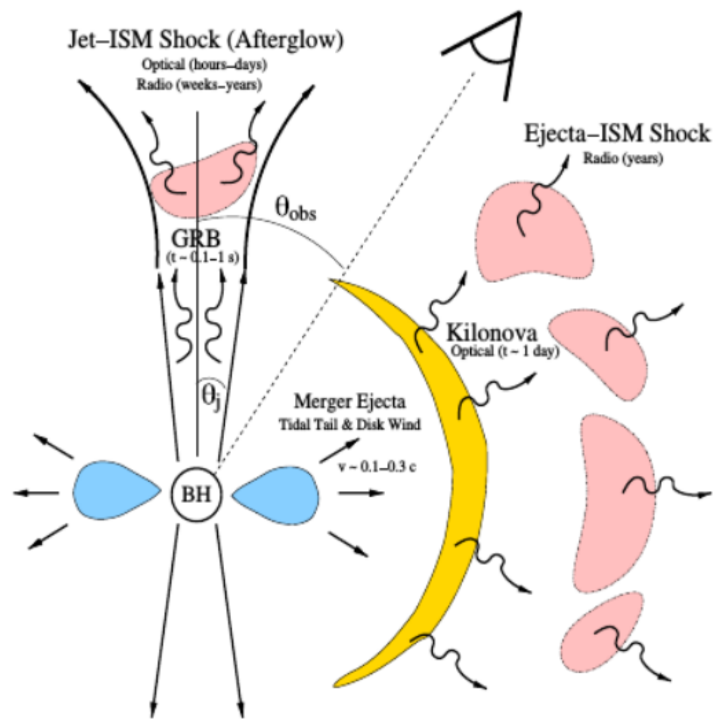


Abbott et al. 2016

No counterpart expected!!!



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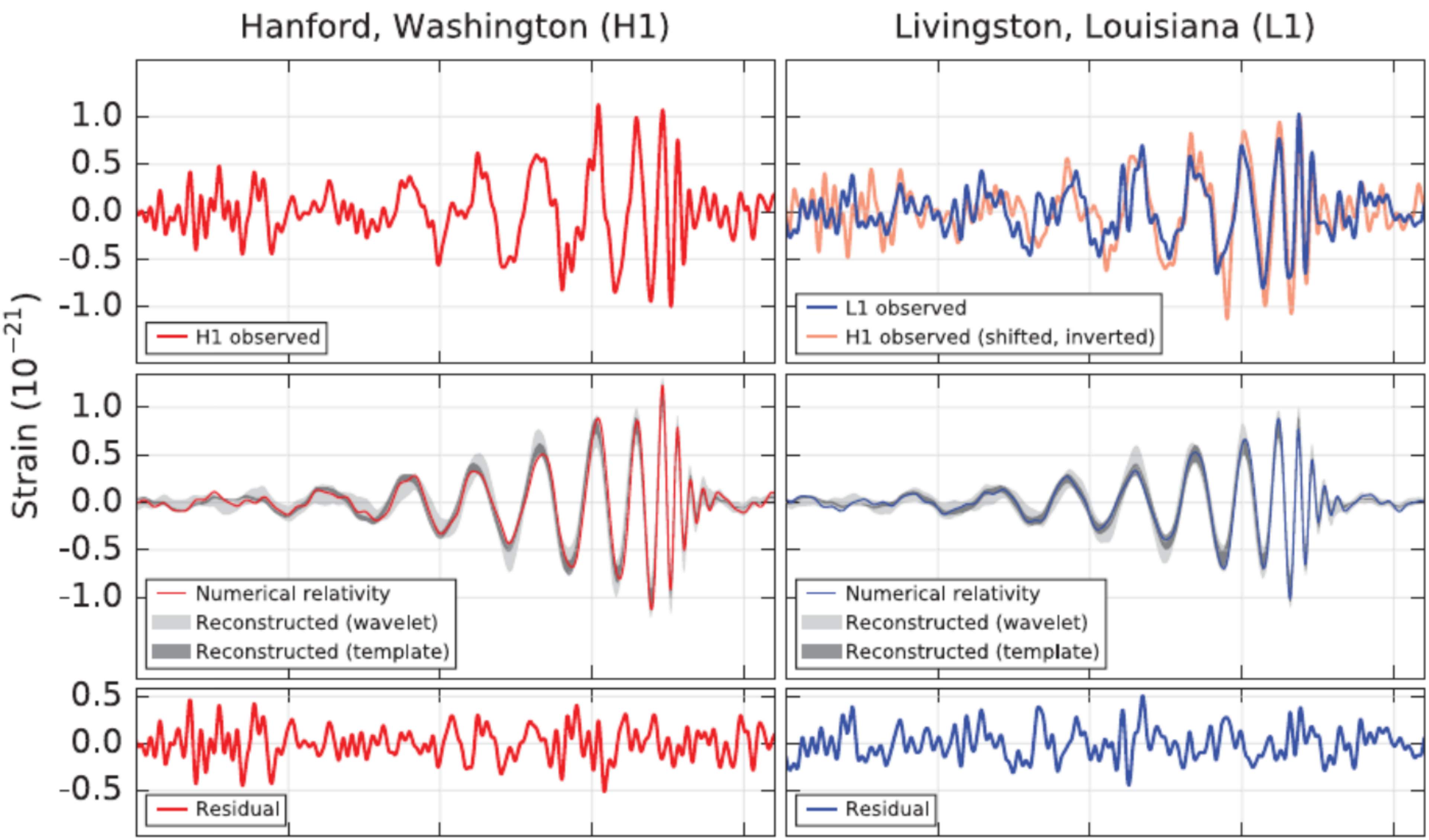

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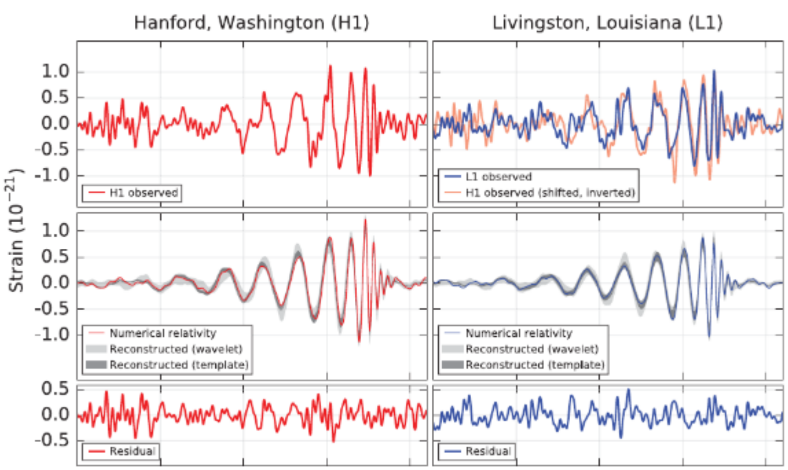

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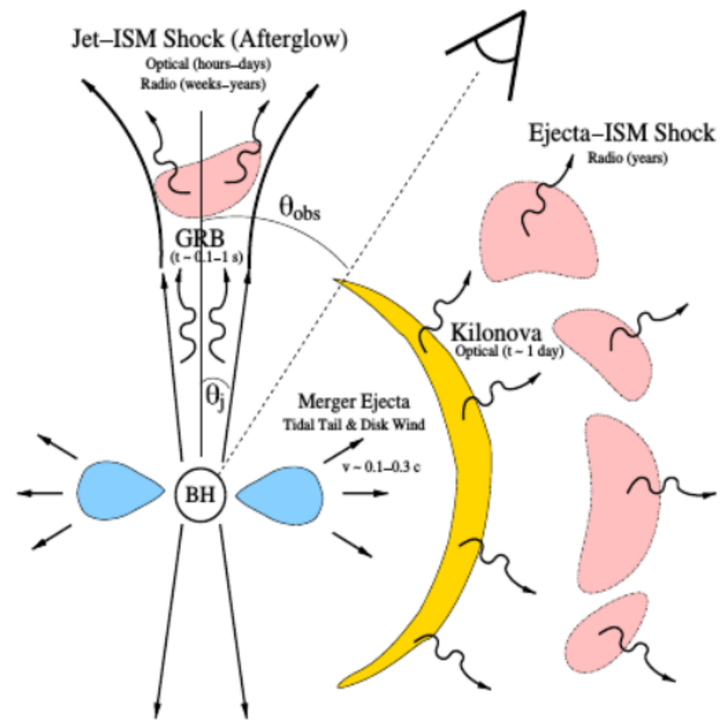

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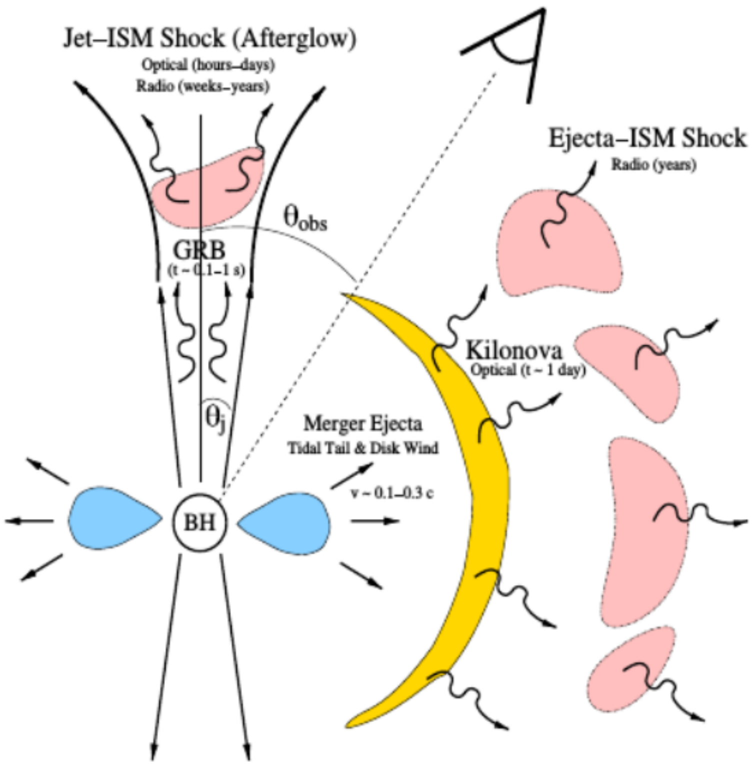

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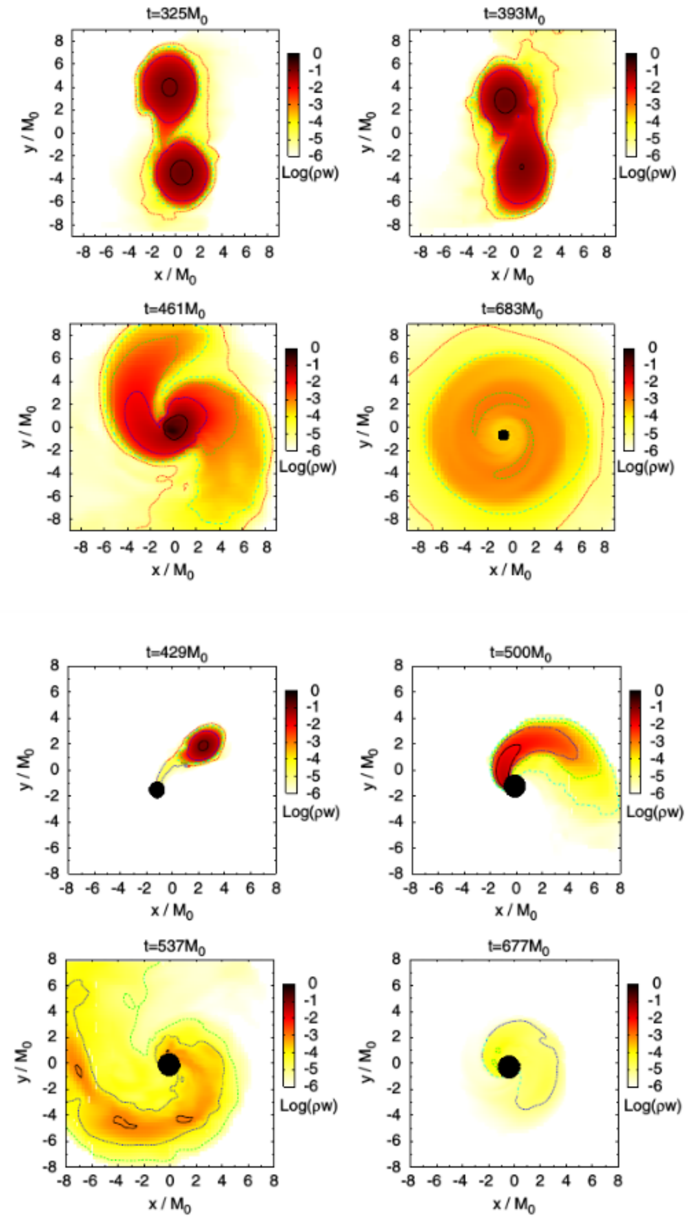

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Yamamoto et al. 2008: top 4 - NSNS density map; bottom 4 - NSBH density map

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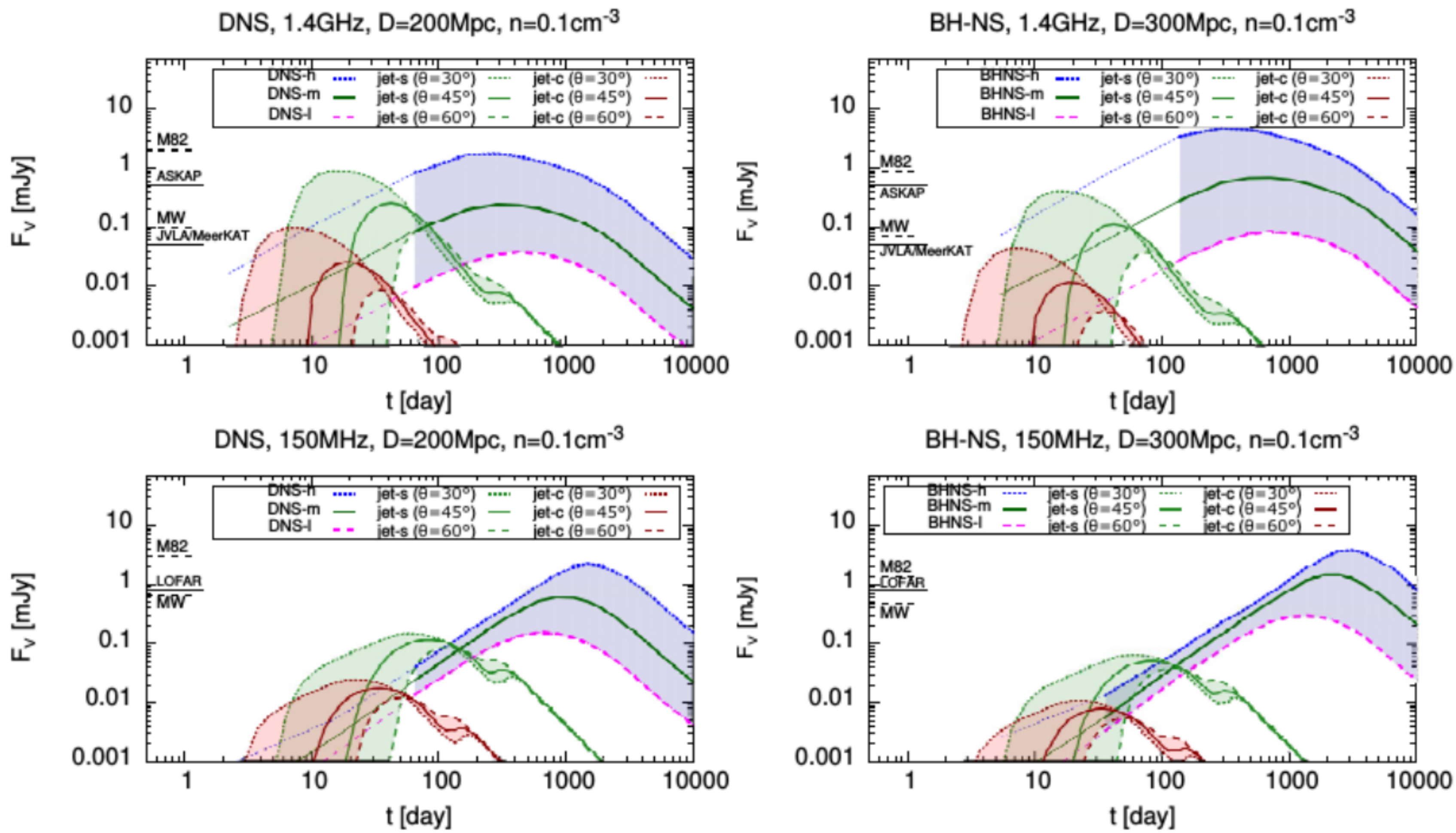

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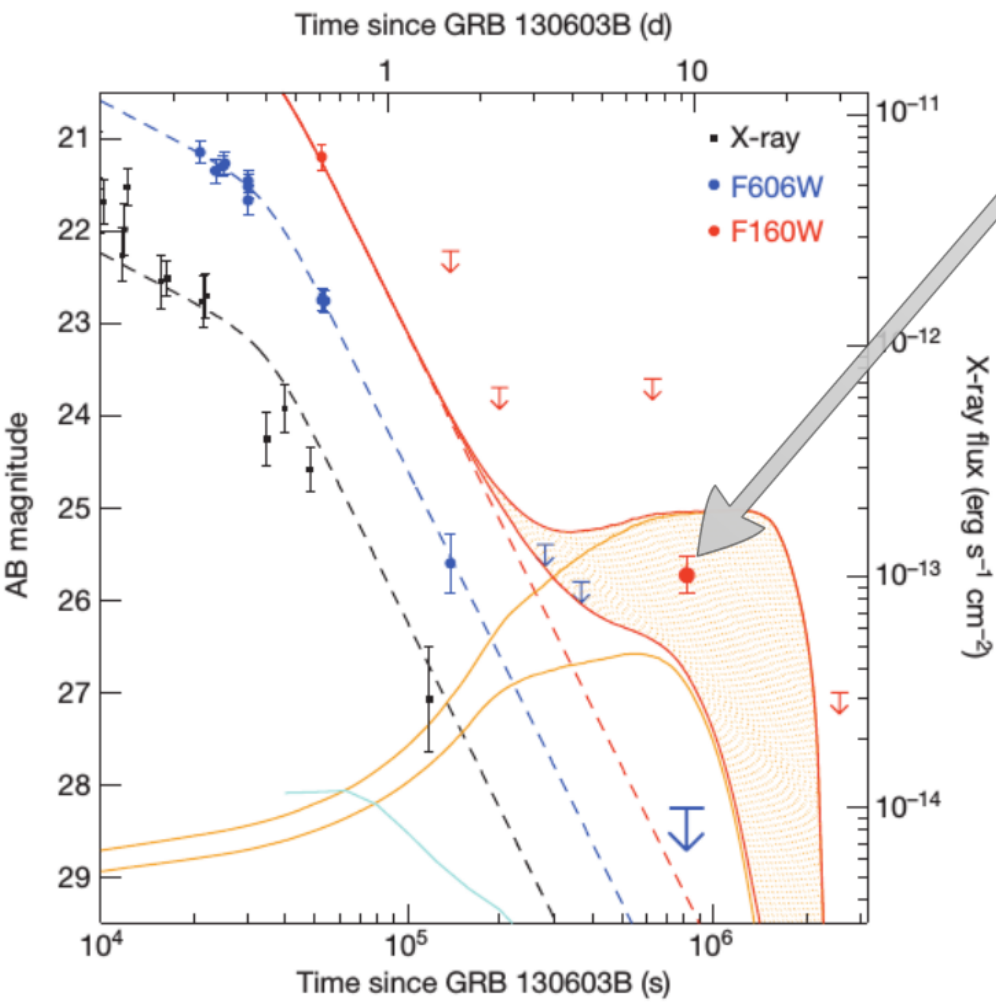

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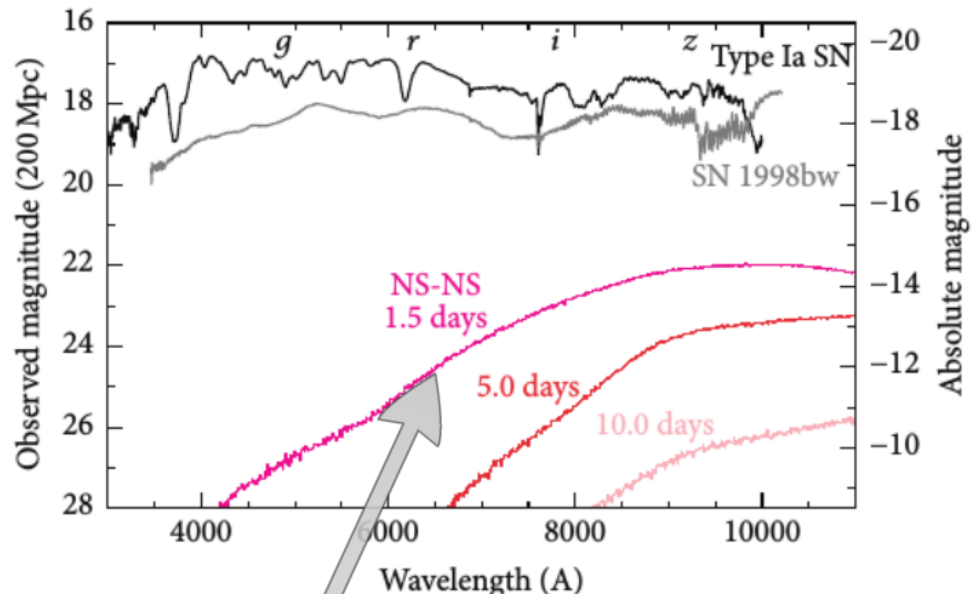

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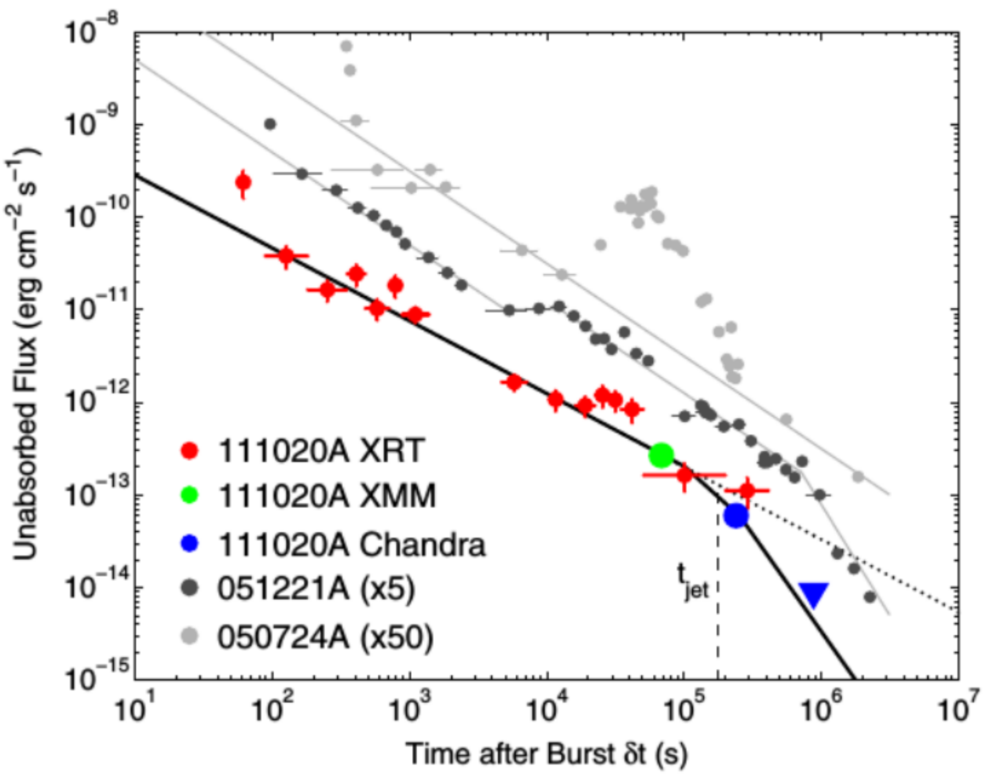

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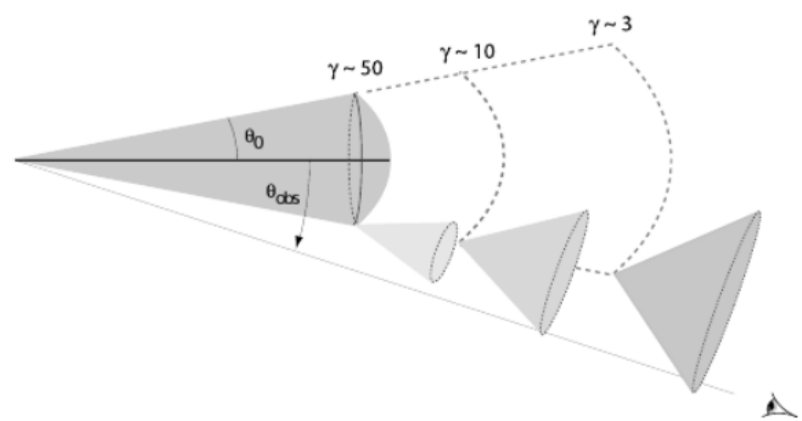

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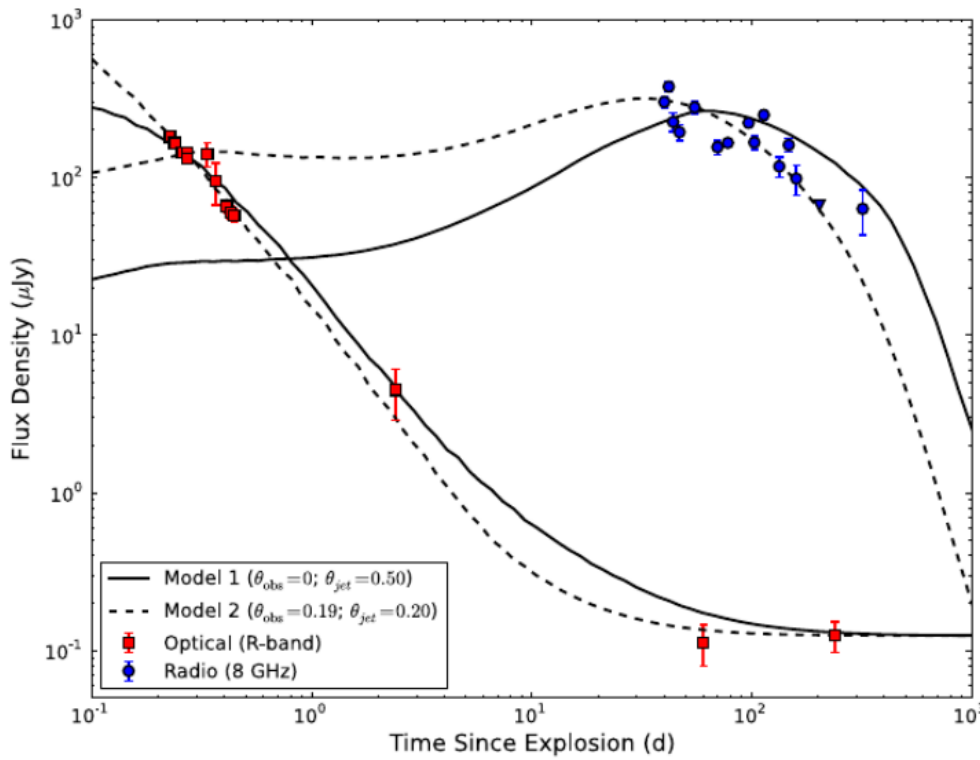

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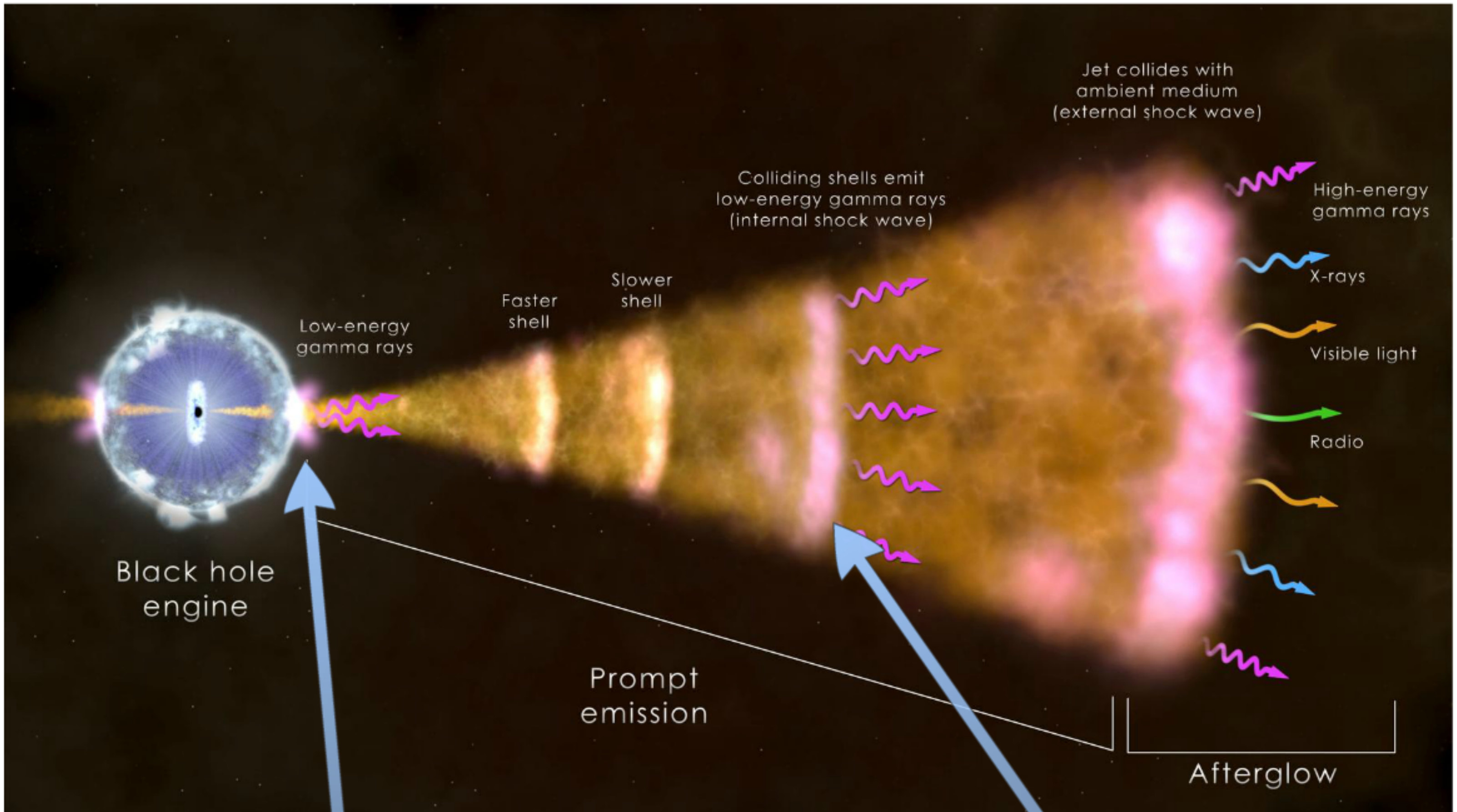

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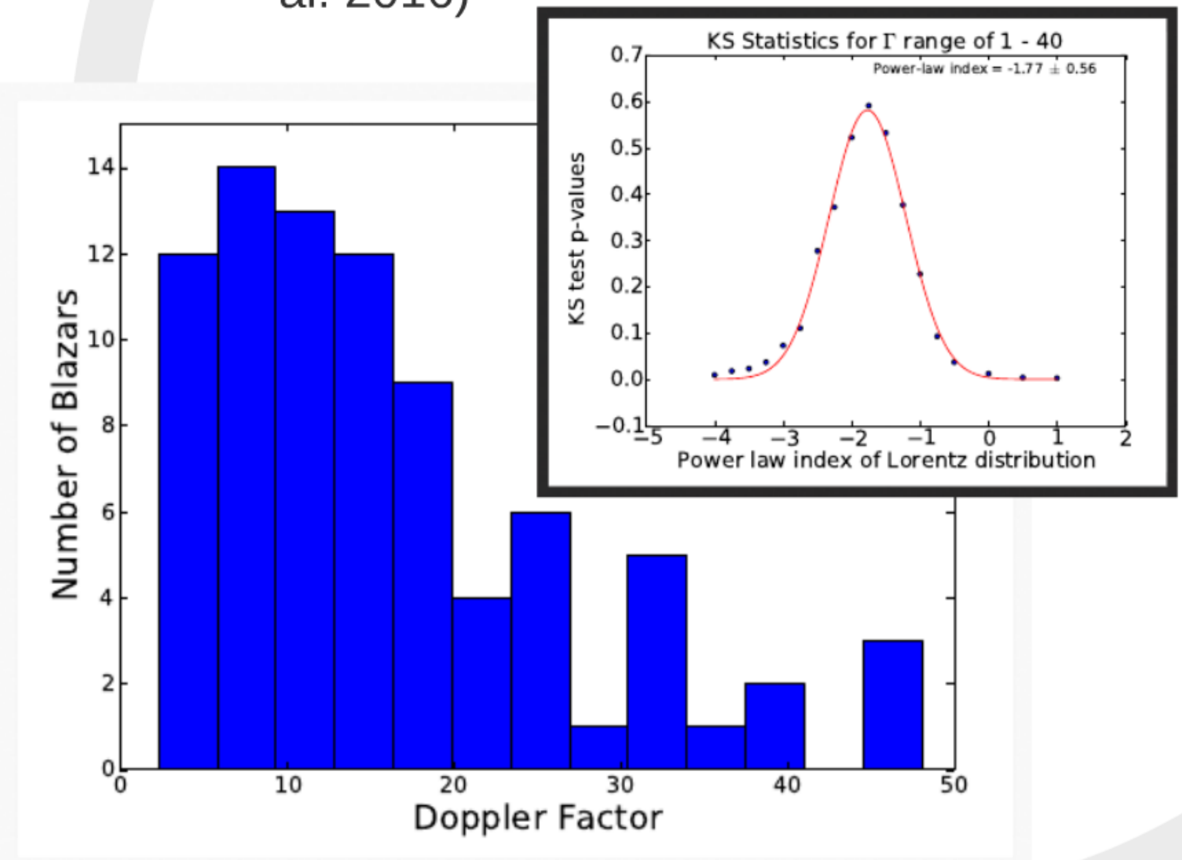

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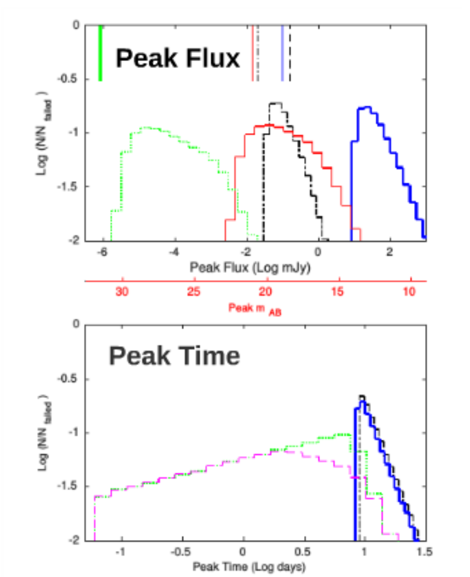

Peak on-axis orphan afterglow time after GW signal, z<0.07

Sample light-curves including peak time and jet break assuming jet opening angle ~20 degrees

Green: X-ray (10^18 Hz)
Red: optical (g band)
Blue: radio (10 GHz)
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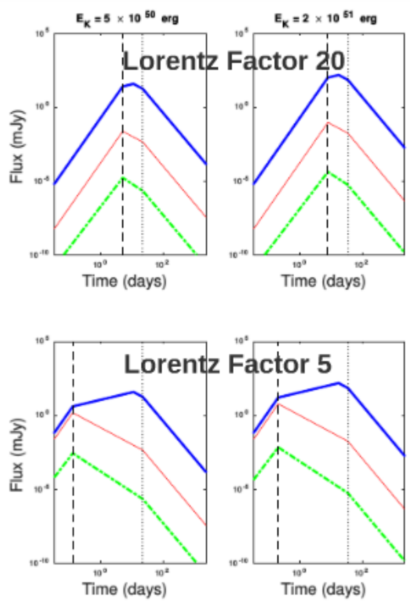
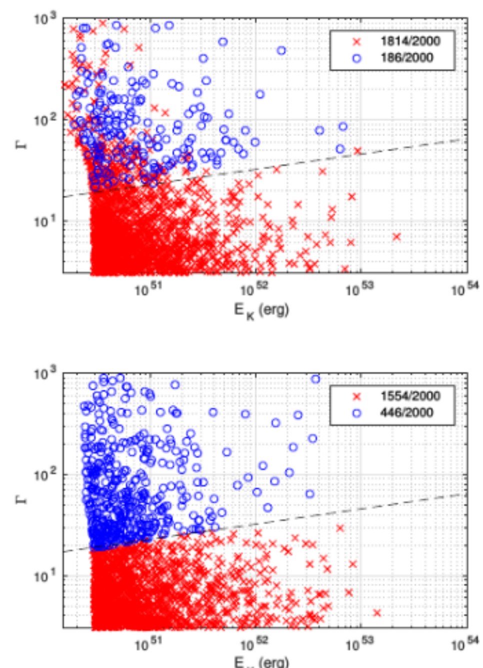


Lamb & Kobayashi 2016



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0<z<3
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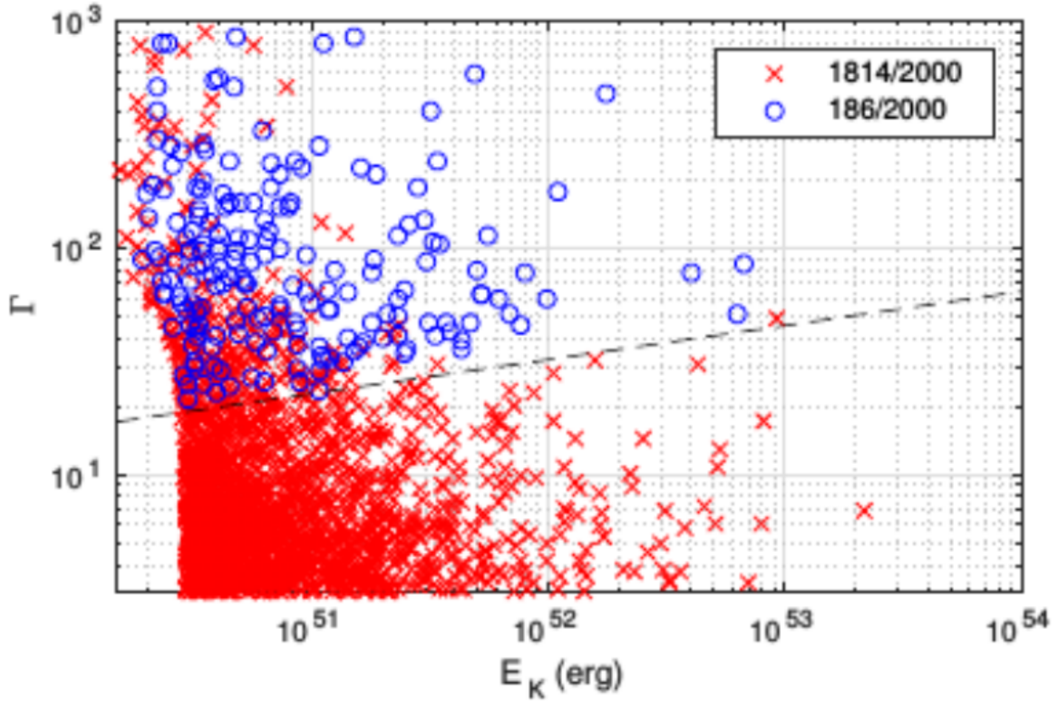

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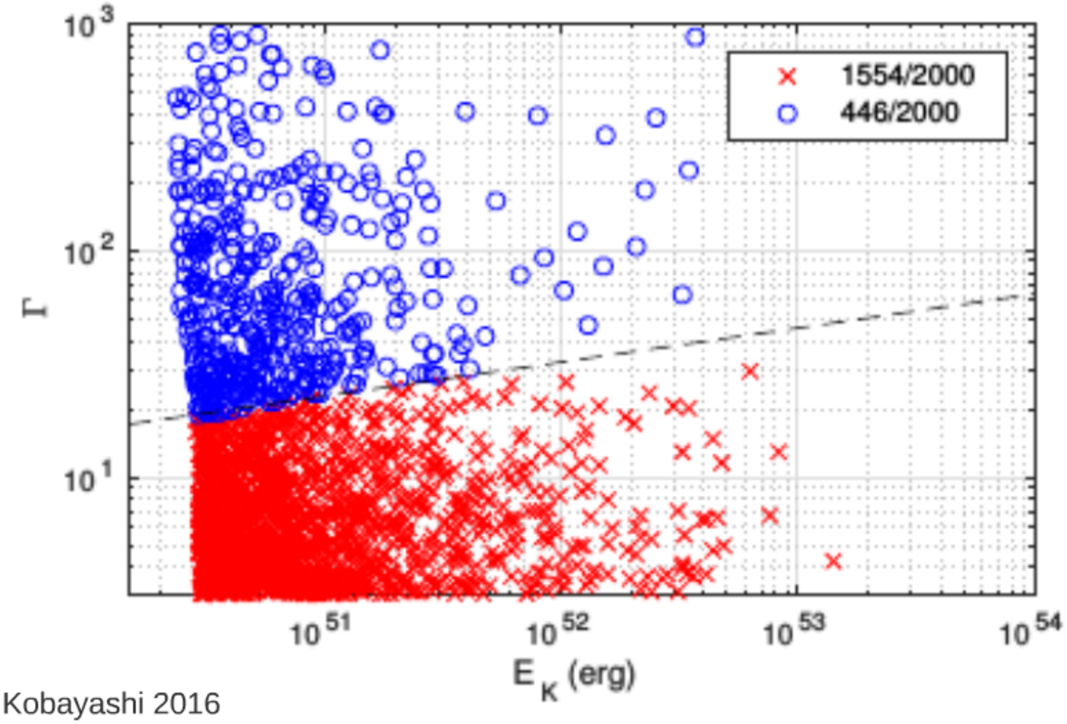

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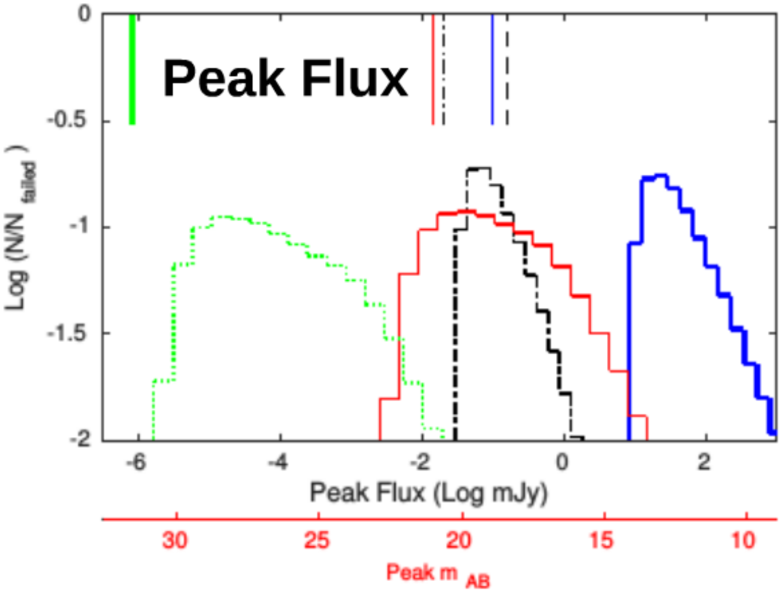

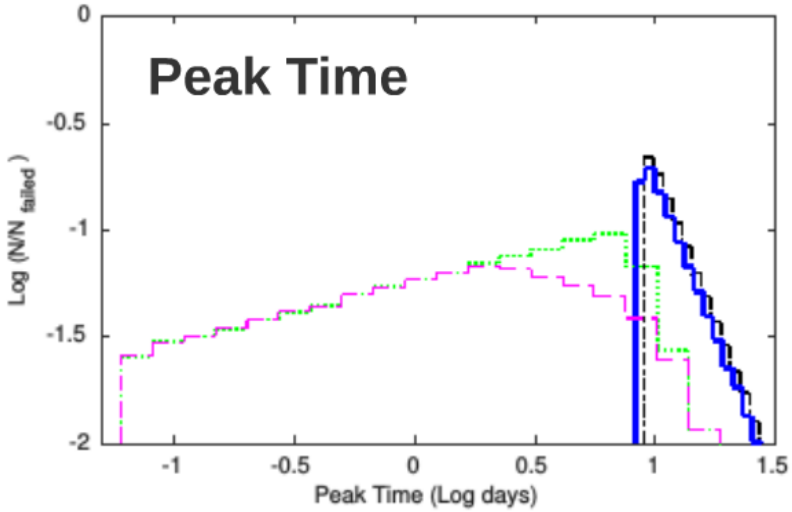

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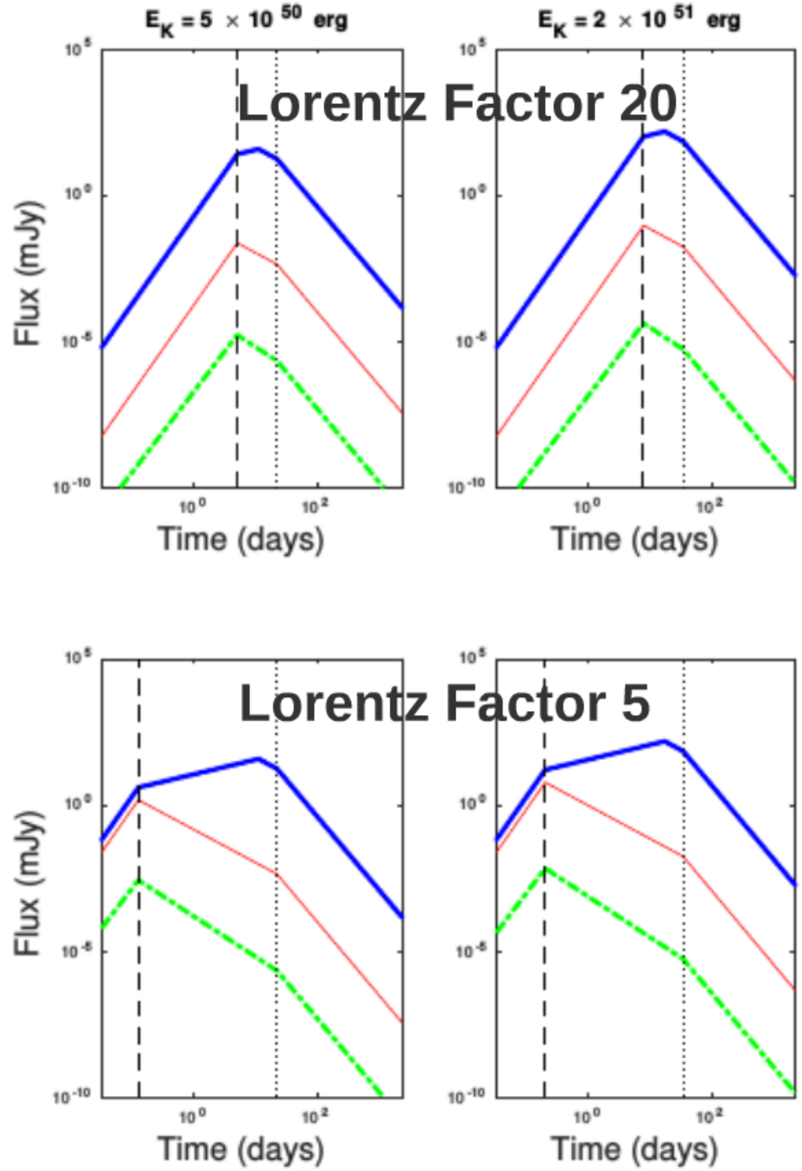

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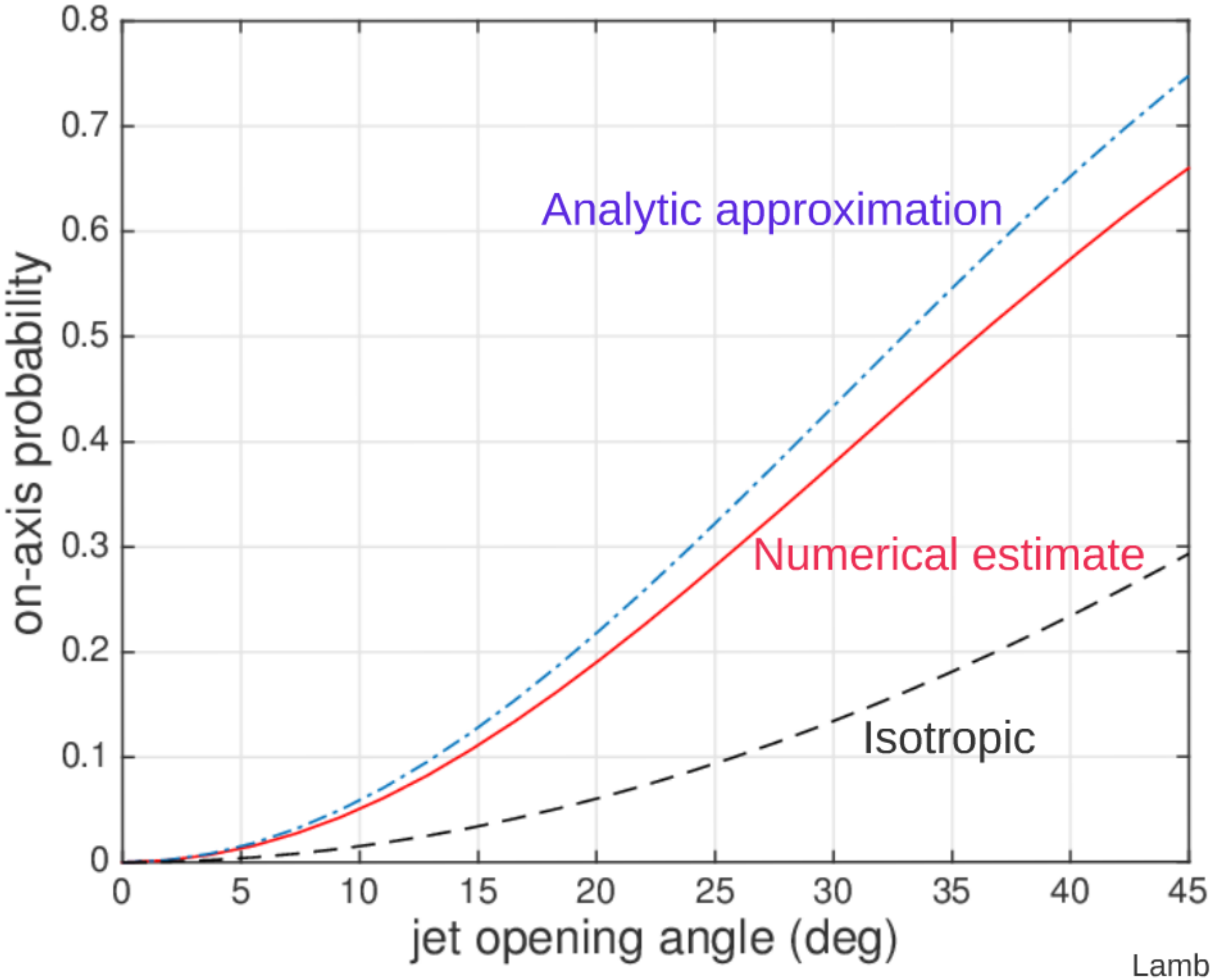

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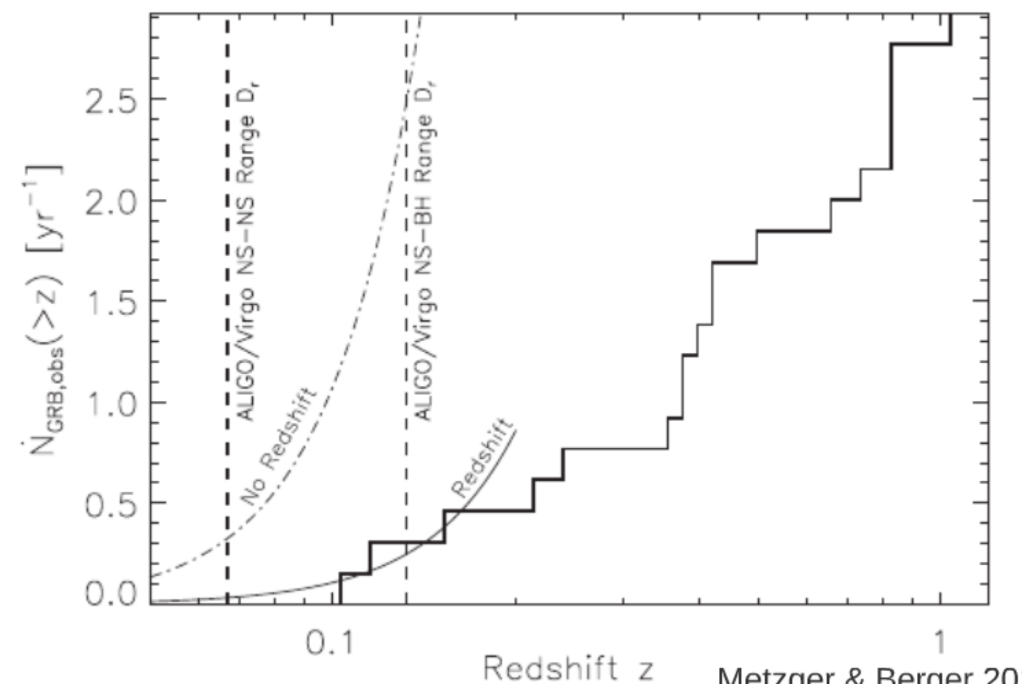

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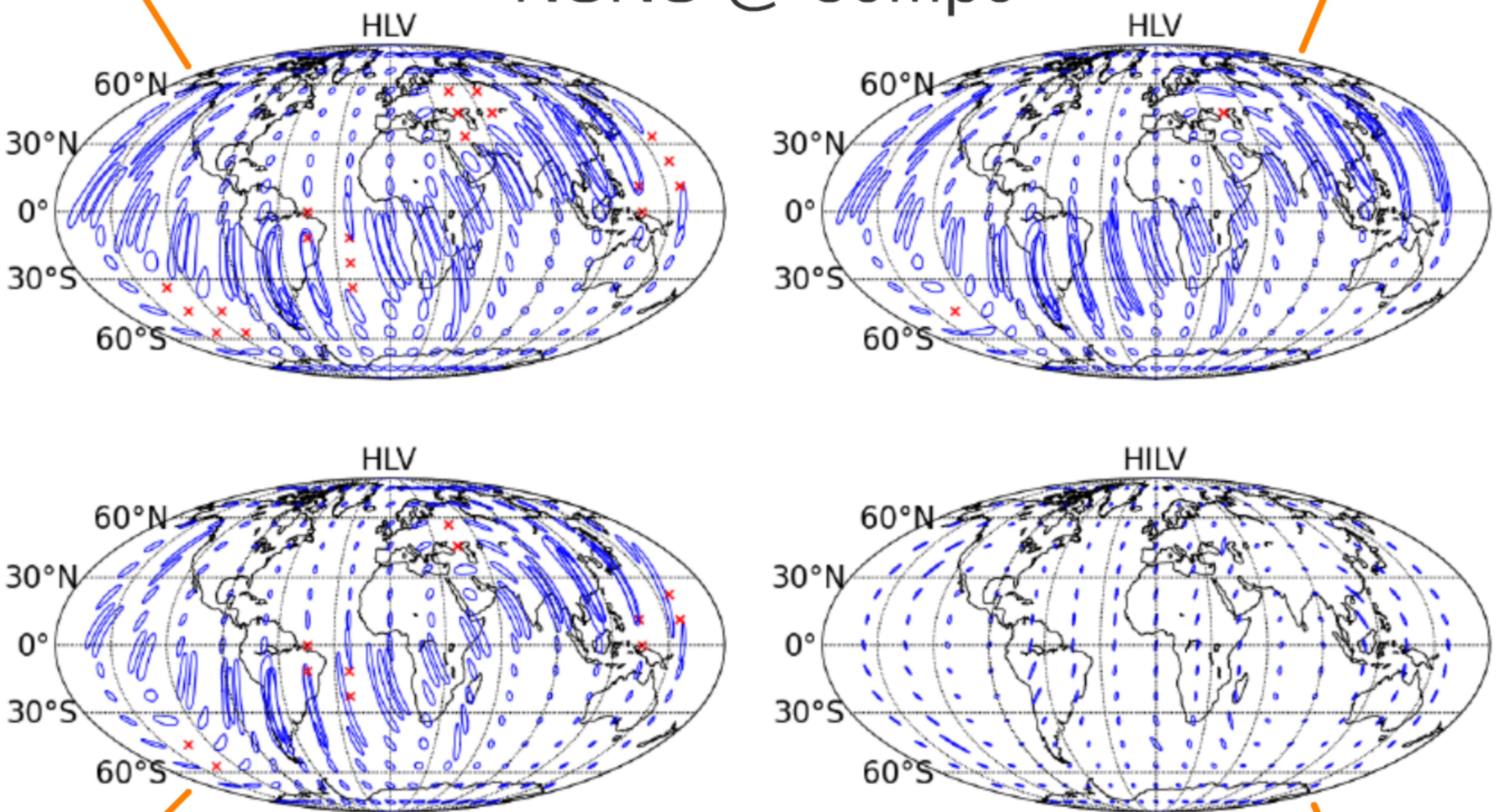
2016-2017 aLigo/Virgo

NSNS @ 80Mpc

2017-2018 aLigo/Virgo



2019+ aLigo/Virgo

NSNS @ 160Mpc

2022+ aLigo/Virgo/India

Aasi + LIGO & Accadia + Virgo 2014

EM Follow-up Searches

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- *Peak 24-22 magnitude*

Collimated emission - on-axis orphan afterglow

- *With GW detection on-axis probability higher than the beaming factor*
- *85% of on-axis orphan afterglow brighter than 21 magnitude*

Great follow-up potential for transient search telescopes e.g. BlackGEM, iPTF/ZTF, Pan-STARRS, GOTO, Kiso, SkyMapper, Subaru, HSC, LSST, LT/LT2, PIRATE

Radio follow-up e.g. VLA, SKA, LOFAR, APERTIF, MWA

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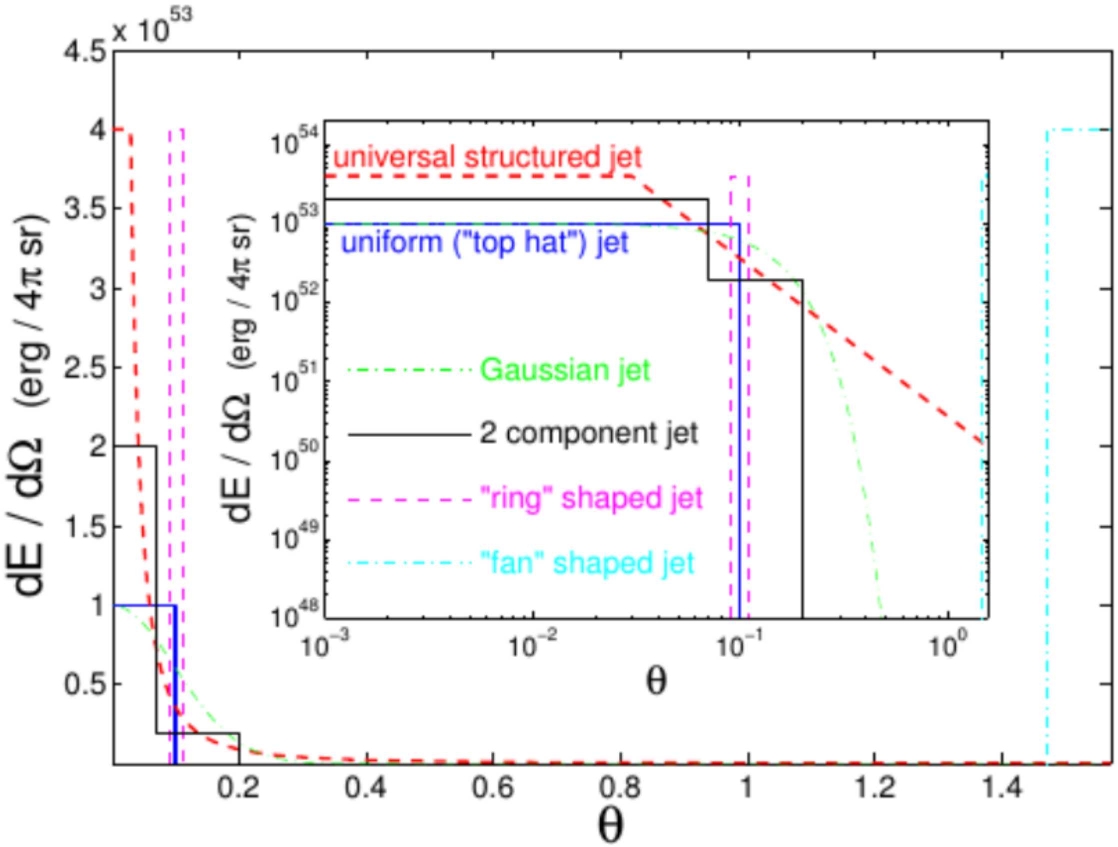

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