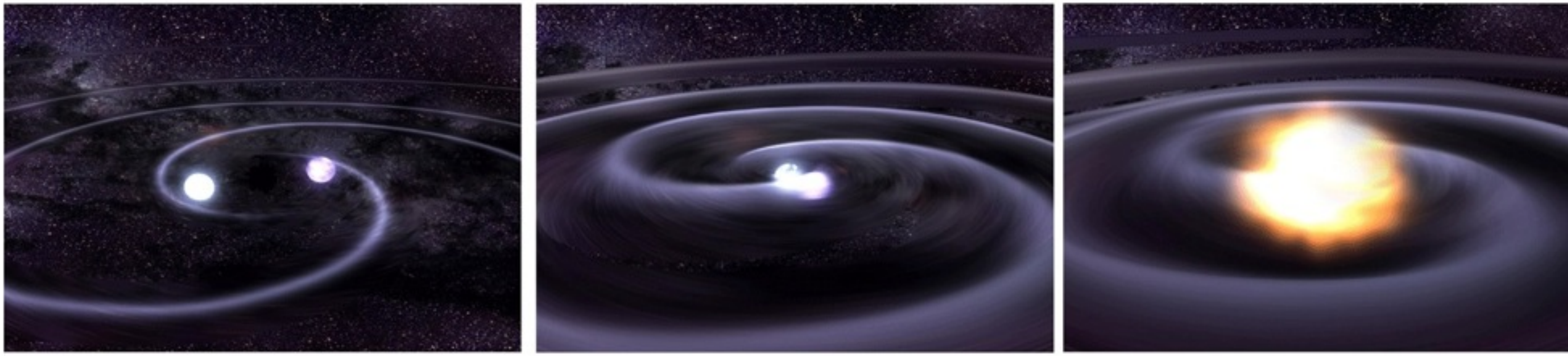


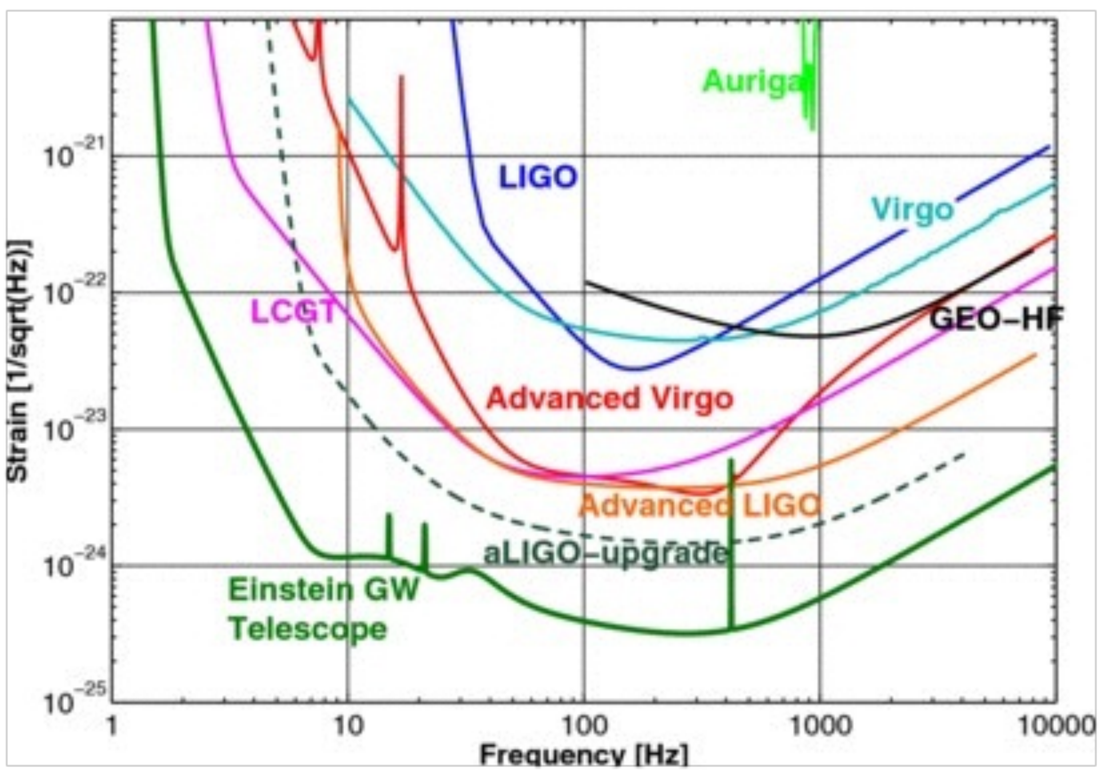
Characterizing the EM Counterparts of Advanced LIGO sources

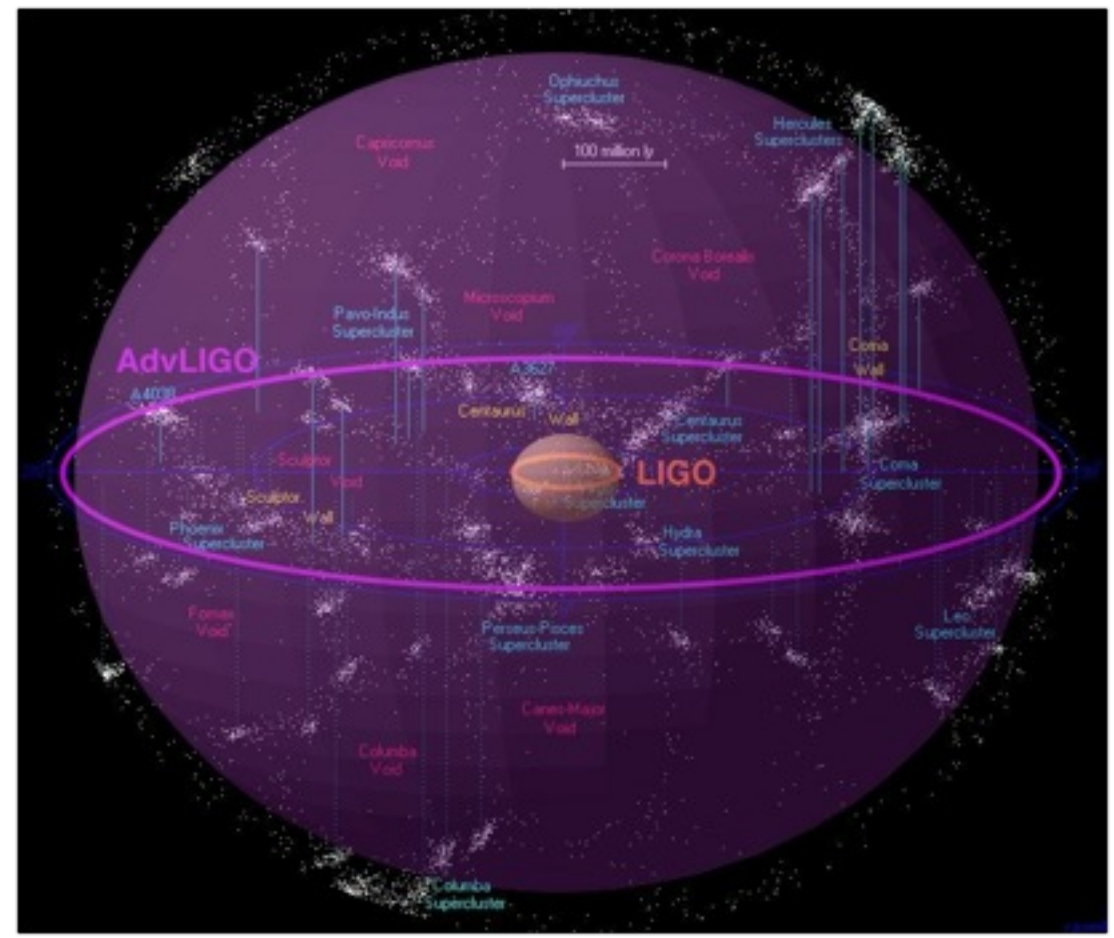
S. Bradley Cenko
TMT Science Forum
24 June 2015

Advanced LIGO/Virgo Network

Hanford + Livingston (aLIGO), Cascina (Virgo), KAGRA (Japan), IndIGO (India?)

aLIGO Sensitivity





By TMT era, binary neutron star mergers out to ~ 200 Mpc

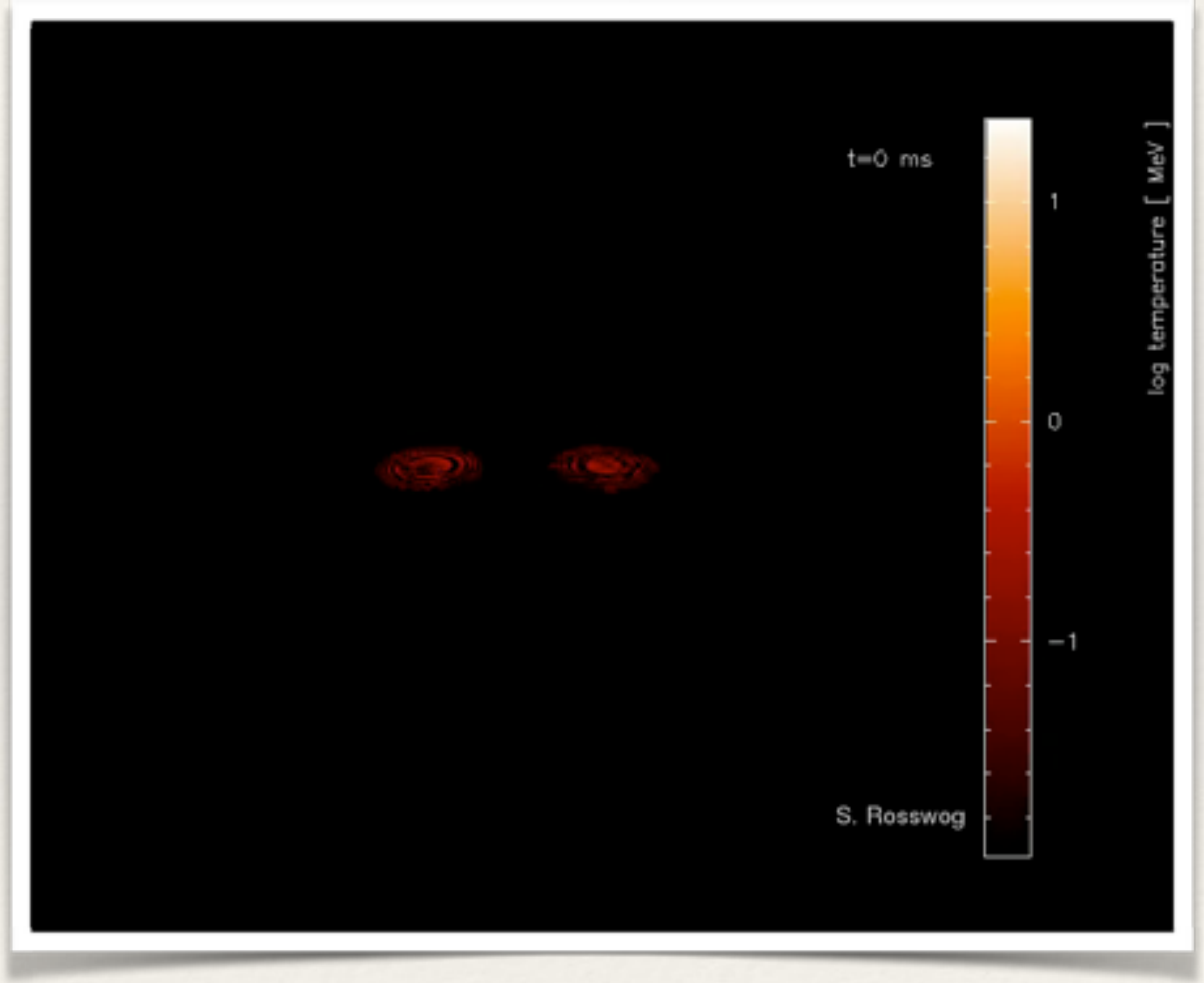
aLIGO Schedule

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

Expect tens of binary neutron star (BNS) detections per year in TMT era (but large uncertainties)!

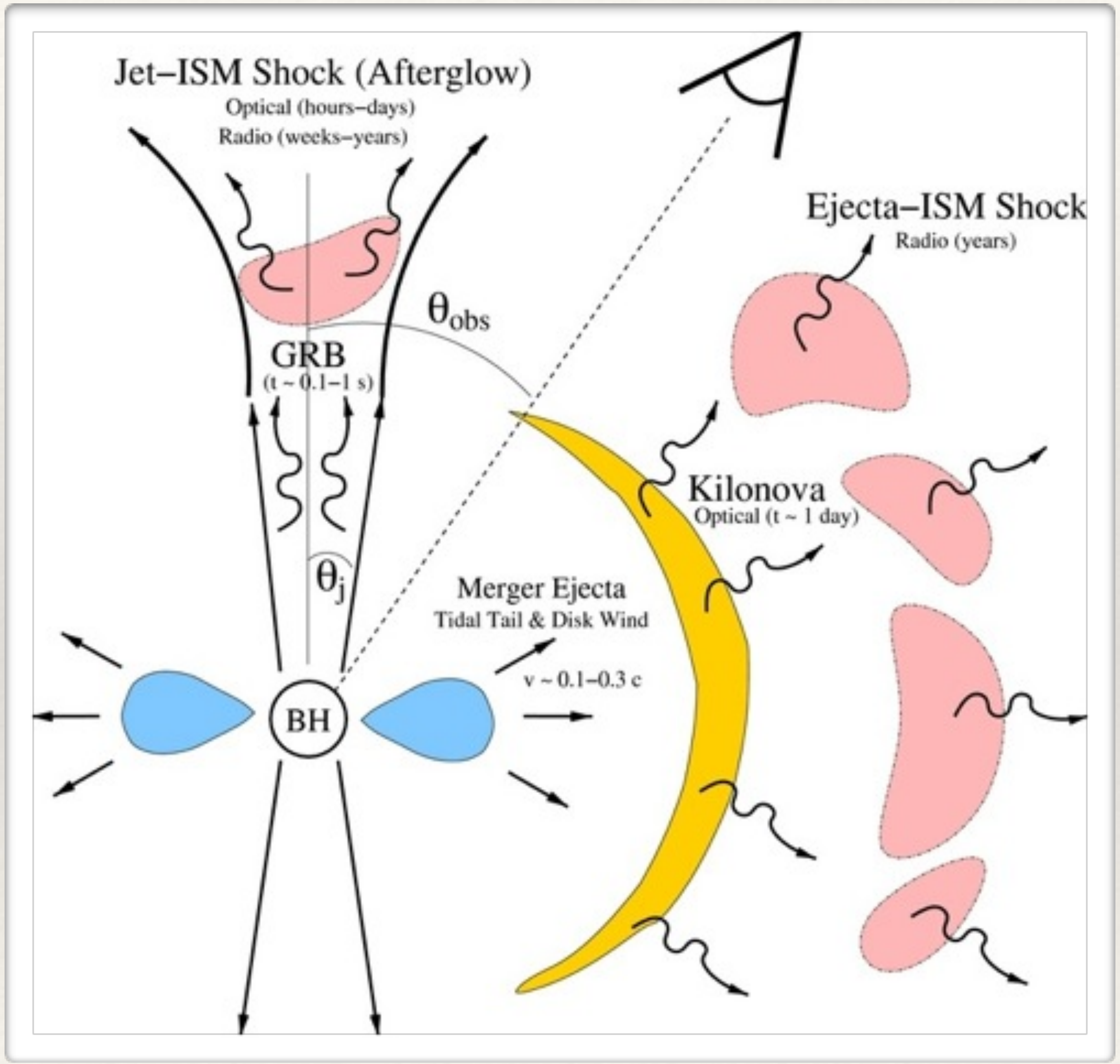
Why Electromagnetic Counterparts?

- GW detectors provide chirp mass, luminosity distance, (crude) inclination angle
- EM counterpart provides:
    - redshift (H_0?)
    - Astrophysical context (host, offset)
    - Composition (r-process nucleosynthesis)
    - Inclination



Rosswog *et al.*, 2012

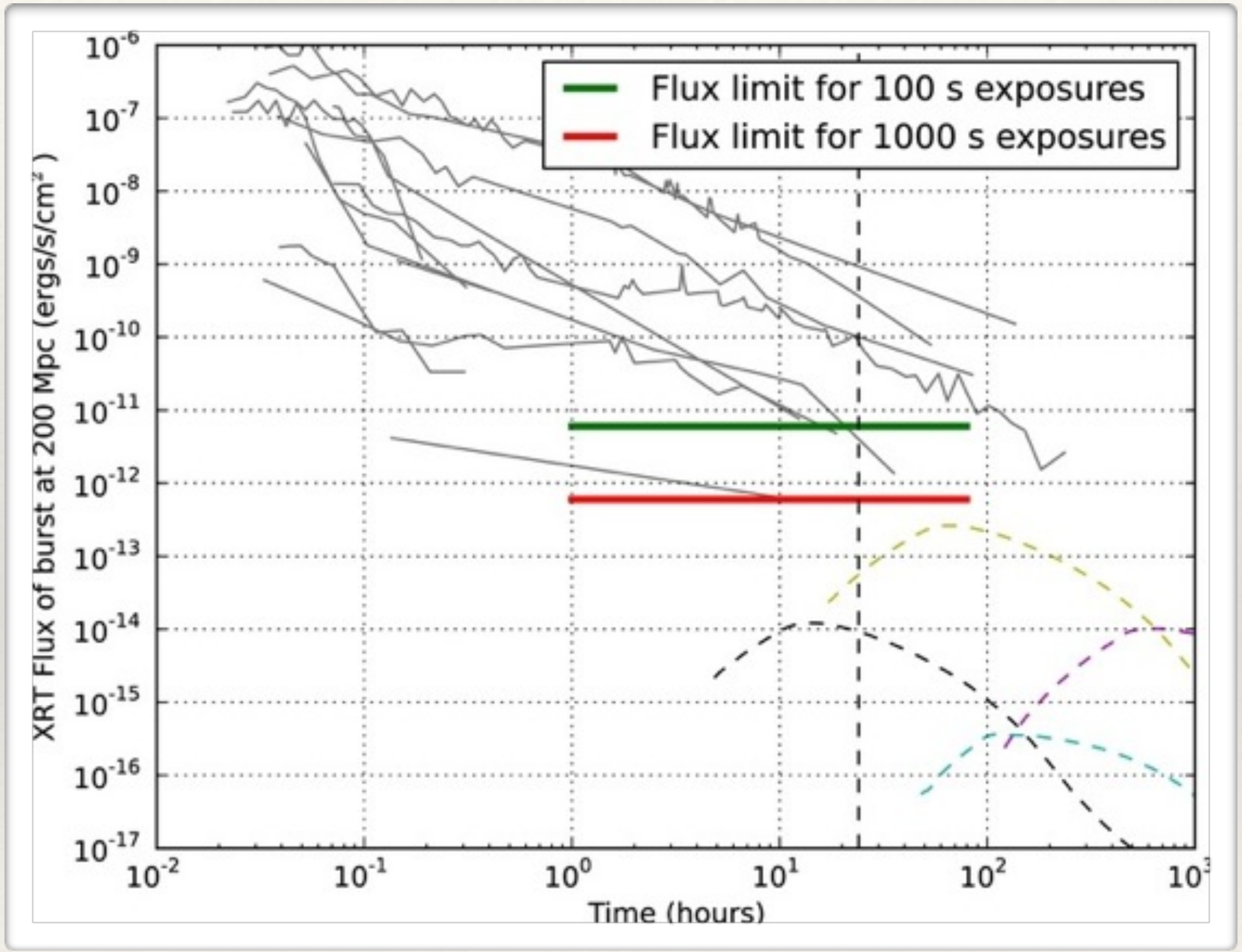
What will an EM counterpart look like?



Metzger & Berger, 2012

On-axis: Short Gamma-ray Burst; Off-axis: Kilonova

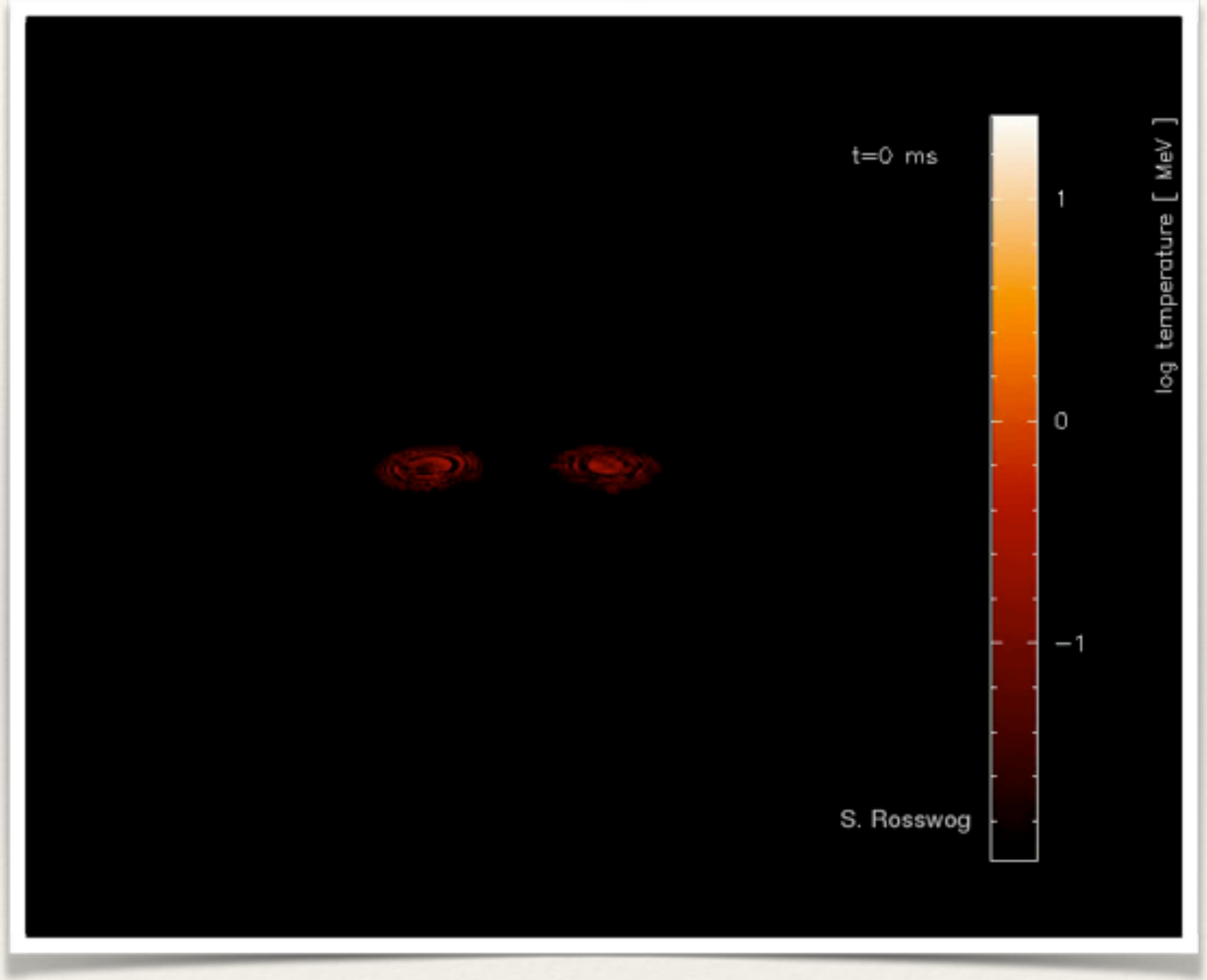
On-Axis Events: Bright but Rare



Kanner *et al.*, 2012

Bright high-energy emission, but only ~ 1/50 events within ultra-relativistic jet opening angle

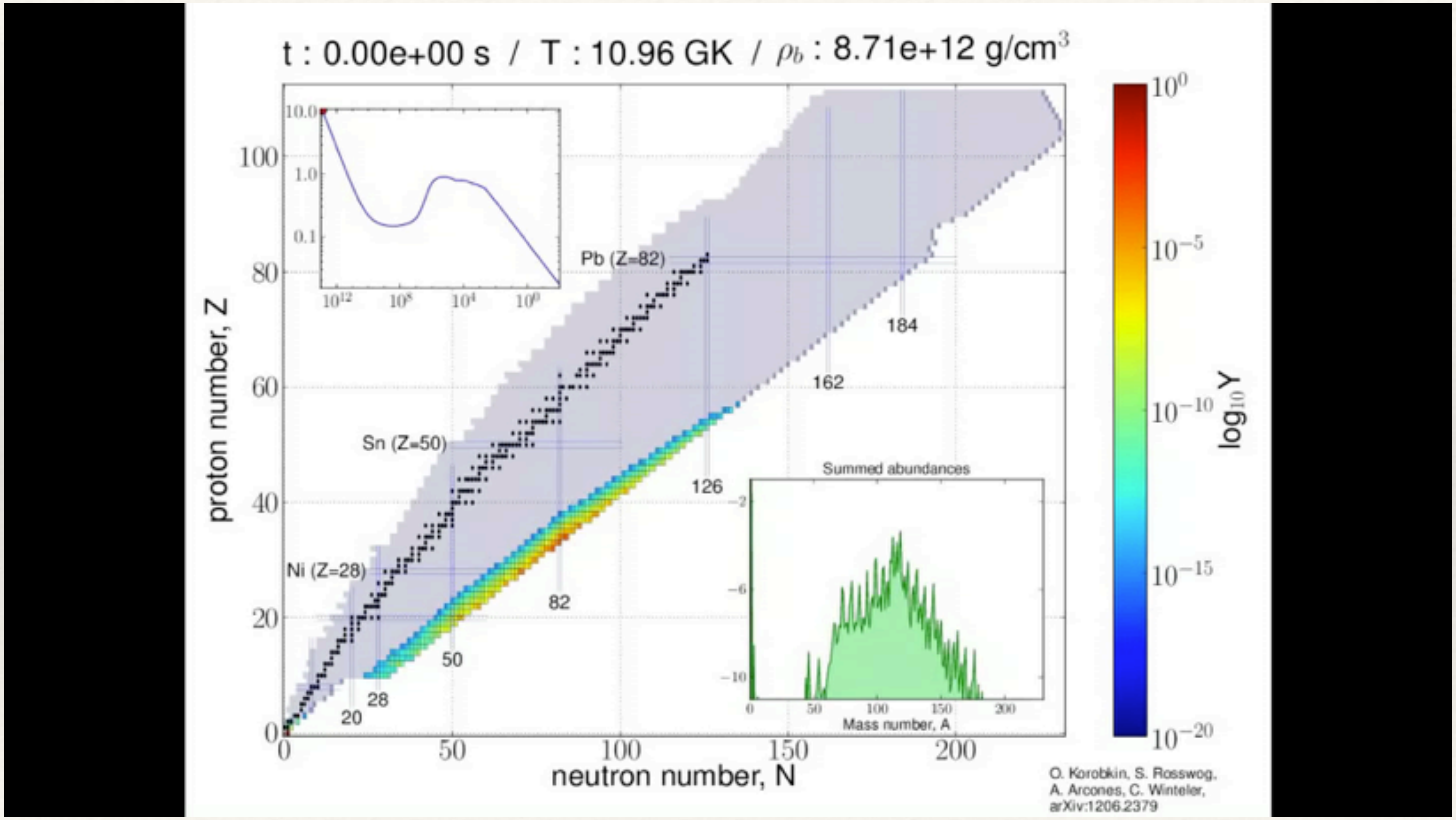
Kilonovae: r-process sites



Rosswog *et al.*, 2012

~ 0.01 M_{sun} ejecta of neutron-rich material with v ~ 0.2c

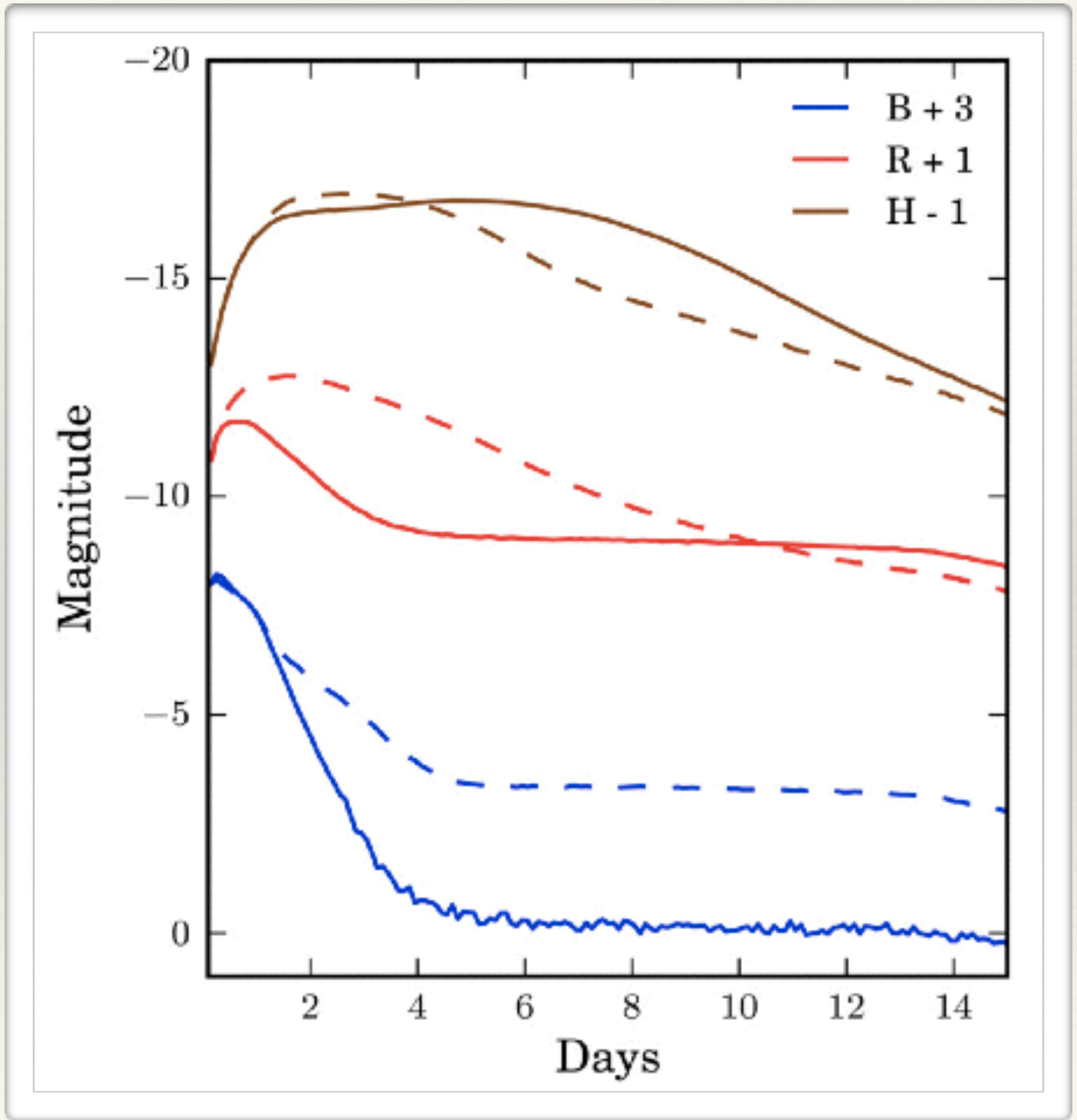
Kilonovae: r-process sites



Possibly dominant site of r-process material in Universe!

Kilonovae: Predicted Light Curves

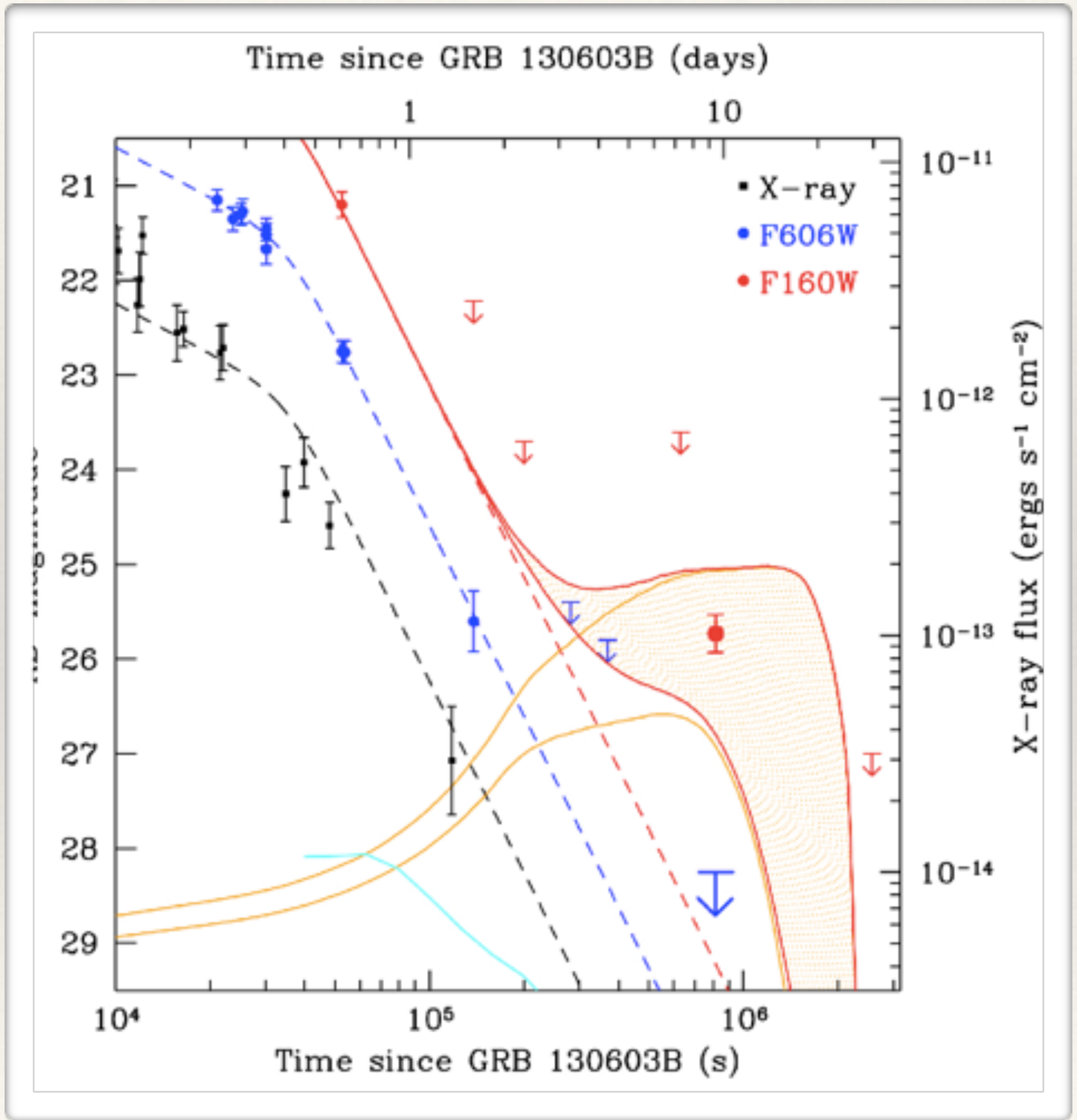
- Time scale:
  - 2 days in B-band
  - 2 weeks in NIR
- Peak magnitude (@ 200 Mpc):
  - B ~ 25 mag
  - R ~ 24 mag
  - H ~ 21 mag



Kasen & Barnes, 2013

Do Kilonovae Exist?

- GRB130603B: Short-hard GRB at $z = 0.36$.
- Late-time (~ 1 week) “bump” in NIR light curve, with no corresponding optical signal
- Still waiting for confirmation from additional nearby short-hard GRBs

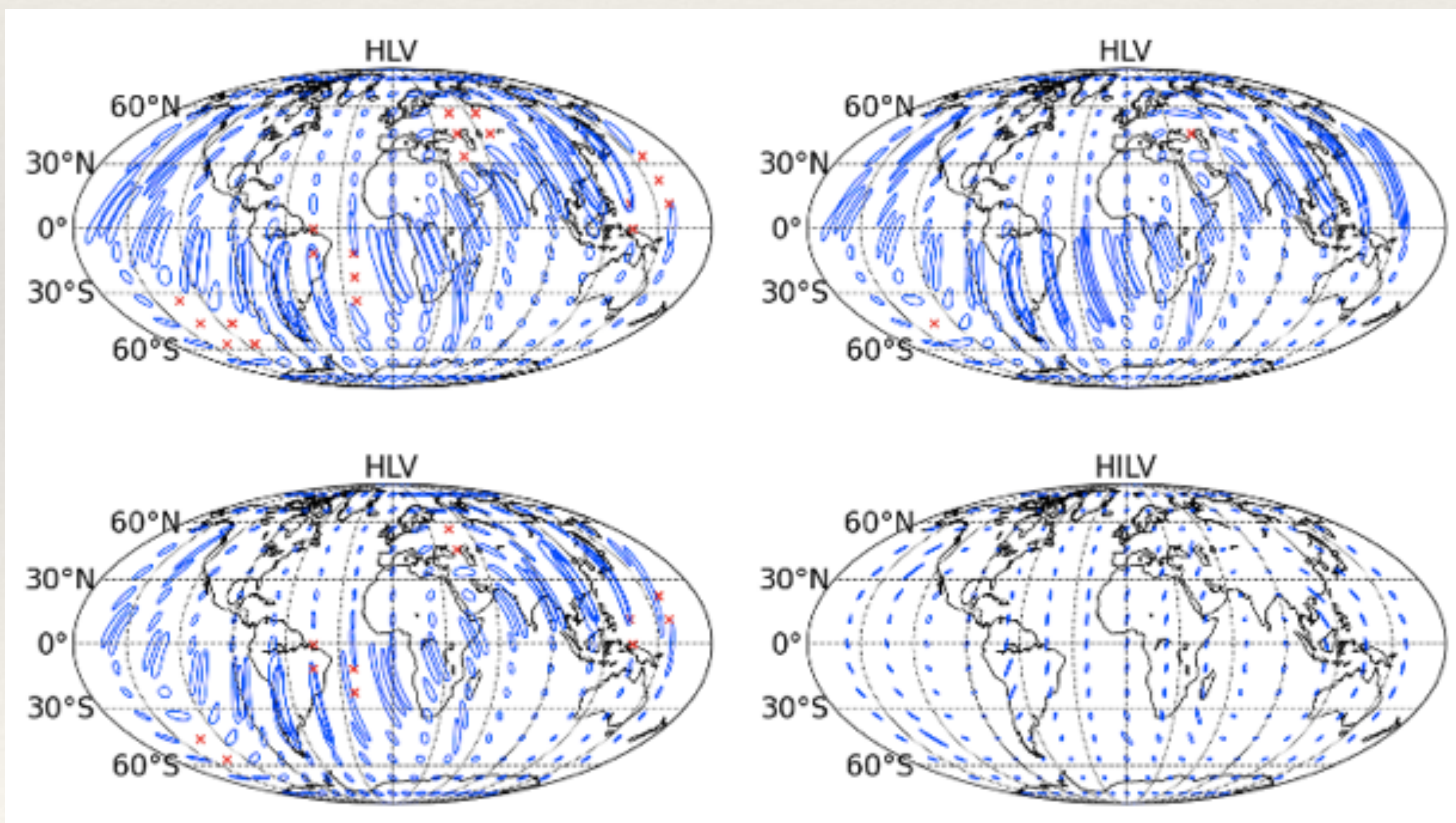


Tanvir *et al.*, 2013

TMT GW Follow-up: Timeline

t_0: GW trigger

t_0 + 2 min: Localization and parameter estimation



Aasi *et al.*, 2013

Localizations (~ 10 deg^2) much too crude for TMT observations

TMT GW Follow-up: Timeline

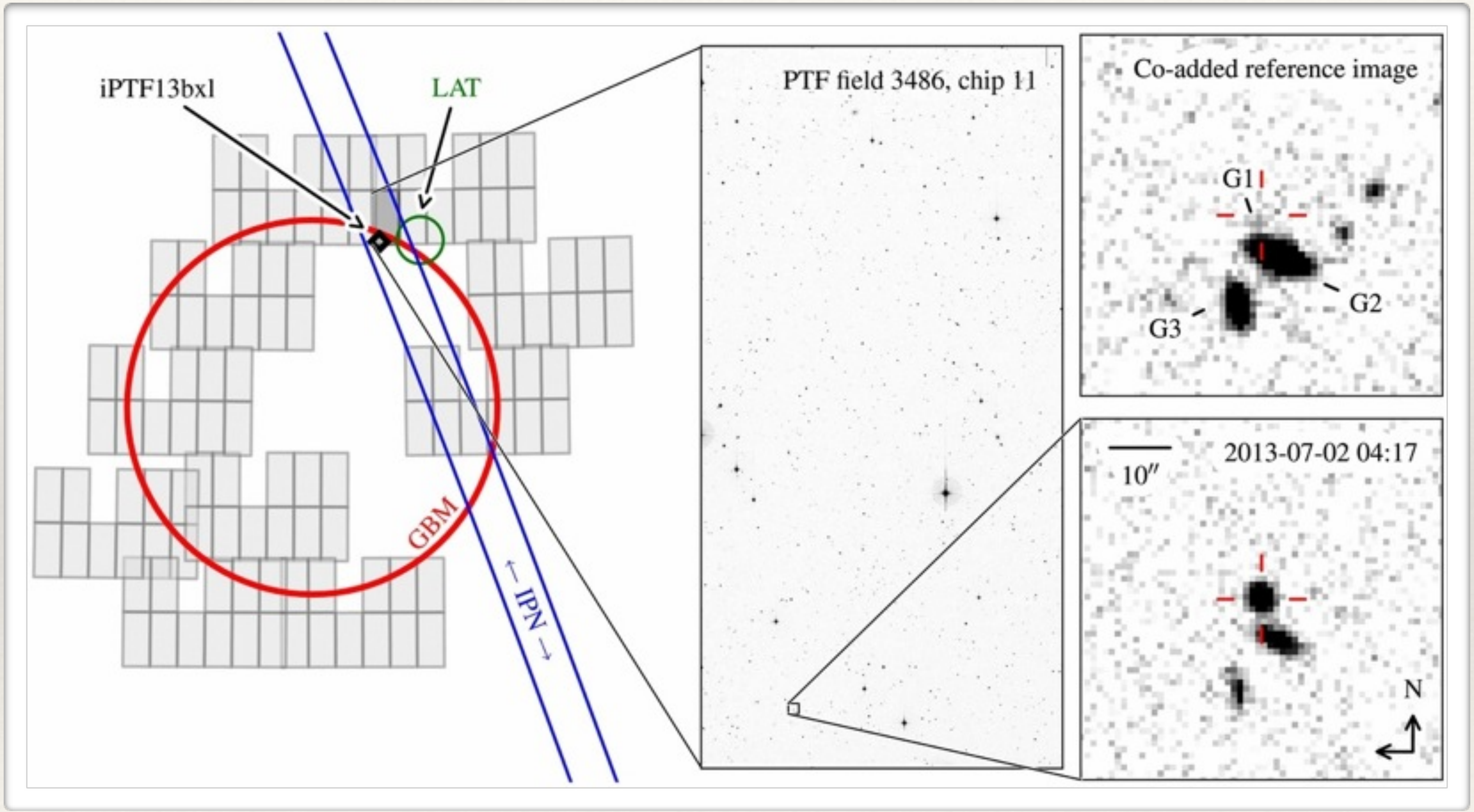
t_0: GW trigger

$t_0 + 2$ min: Localization and parameter estimation

$t_0 + 5$ min: Wide-field counterpart searches

Wide-field surveys (ZTF, HSC, LSST) will tile error regions to search for candidate counterparts

Fermi GRBs: A Trial Run with PTF



Singer *et al.*, 2012

Routinely identify optical afterglows in ~ 100 deg^2 *Fermi*-GBM localizations

Distinguishing Kilonovae

TABLE 1
EXPECTED RATES FOR FAST TRANSIENTS

Object	$\mathcal{R}_{vol}$ ($Mpc^{-3}\ yr^{-1}$)	z_{max}	$\mathcal{R}_{area}$ ($deg^{-2}\ yr^{-1}$)	N	Reference
Type .Ia	10^{-6}	0.5	0.7	1.4	Bildsten et al. 2007
WD-NS mergers	10^{-5}	0.06	2×10^{-2}	3×10^{-2}	Thompson 2009
WD-BH mergers	10^{-5}	0.06	2×10^{-2}	3×10^{-2}	Fryer et al.1999
AIC	10^{-6}	0.06	2×10^{-3}	3×10^{-3}	Darbha et al. 2010
ELDD	3×10^{-7}	0.14	6×10^{-3}	1×10^{-2}	...
Pan-STARRS fast	5×10^{-6}	0.5	3.5	7	Drout et al. 2014

NOTE. — Expected rates for the various contaminants considered in Section 2. $\mathcal{R}_{area}$ is computed assuming an isotropic distribution of sources in a volume defined by the comoving volume at z_{max}. The column N refers to the number of events expected during a search covering 100 deg^2 for 7 days. See § 2.10 or details.

Cowperthwaite & Berger, 2015

Modest number of "fast" contaminants. More "slow" transients (supernovae, AGN), but could be distinguished by light curve, color, *etc.*

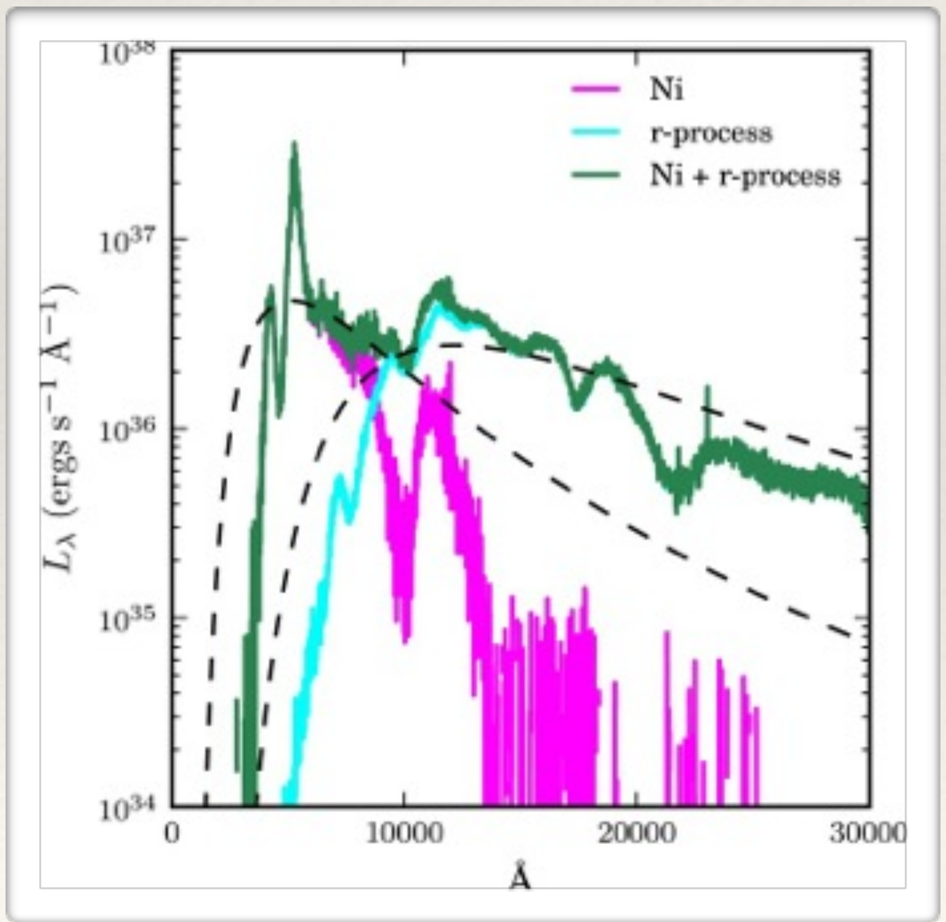
TMT GW Follow-up: Timeline

t_0: GW trigger

t_0 + 2 min: Localization and parameter estimation

t_0 + 5 min: Wide-field counterpart searches

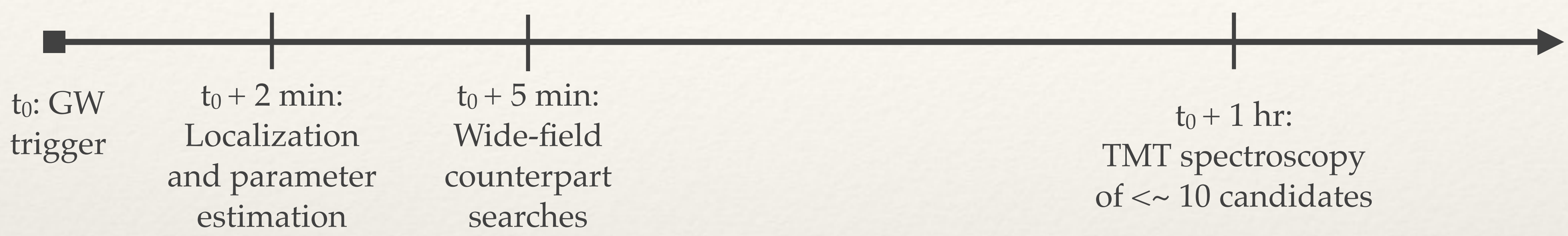
t_0 + 1 hr: TMT spectroscopy of <~ 10 candidates

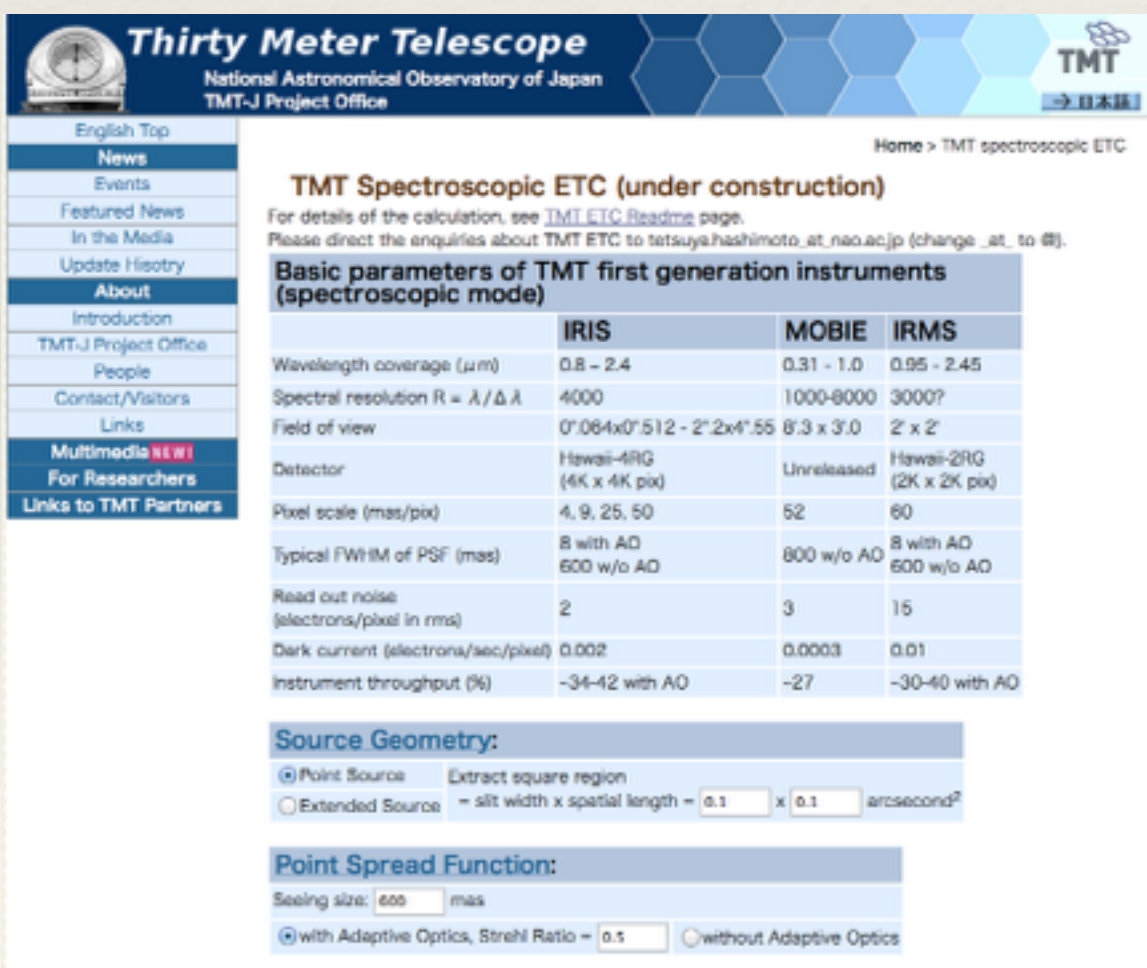


Kasen & Barnes, 2013

Synthetic spectra show contributions from both Ni and r-process nucleosynthesis. As a result, they are clearly distinguishable from other (known) transients.

TMT SNR Estimates





Thirty Meter Telescope
National Astronomical Observatory of Japan
TMT-J Project Office

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Home > TMT spectroscopic ETC

TMT Spectroscopic ETC (under construction)

For details of the calculation, see TMT ETC Readme page.
Please direct the enquiries about TMT ETC to tetsuya.hashimoto_at_nao.ac.jp (change _at_ to @).

Basic parameters of TMT first generation instruments (spectroscopic mode)

	IRIS	MOBIE	IRMS
Wavelength coverage (μm)	0.8 – 2.4	0.31 - 1.0	0.95 - 2.45
Spectral resolution R = λ/Δλ	4000	1000-8000	3000?
Field of view	0".064x0".512 - 2".2x4".55	8'.3 x 3'.0	2' x 2'
Detector	Hawaii-4RG (4K x 4K pix)	Unreleased	Hawaii-2RG (2K x 2K pix)
Pixel scale (mas/pix)	4, 9, 25, 50	52	60
Typical FWHM of PSF (mas)	8 with AO 600 w/o AO	800 w/o AO	8 with AO 600 w/o AO
Read out noise (electrons/pixel in rms)	2	3	15
Dark current (electrons/sec/pixel)	0.002	0.0003	0.01
Instrument throughput (%)	~34-42 with AO	~27	~30-40 with AO

Source Geometry:

Point Source | Extract square region
Extended Source | = slit width x spatial length = 0.1 x 0.1 arcsecond²

Point Spread Function:

Seeing size: 600 mas
with Adaptive Optics, Strehl Ratio = 0.5 | without Adaptive Optics

- Time to reach SNR ~ 10 per resolution element:
  - MOBIE: 10 min
  - IRMS/IRIS: 5 min

TMT Requirements for GW Follow-Up

- Response Time: 1 hr to days (standard queue mode)
- Instrument availability: Continuous
- Bandpass: Optical + NIR
- Resolution: Low to moderate ($v \sim 0.3c$)