Fermi and gravitational waves

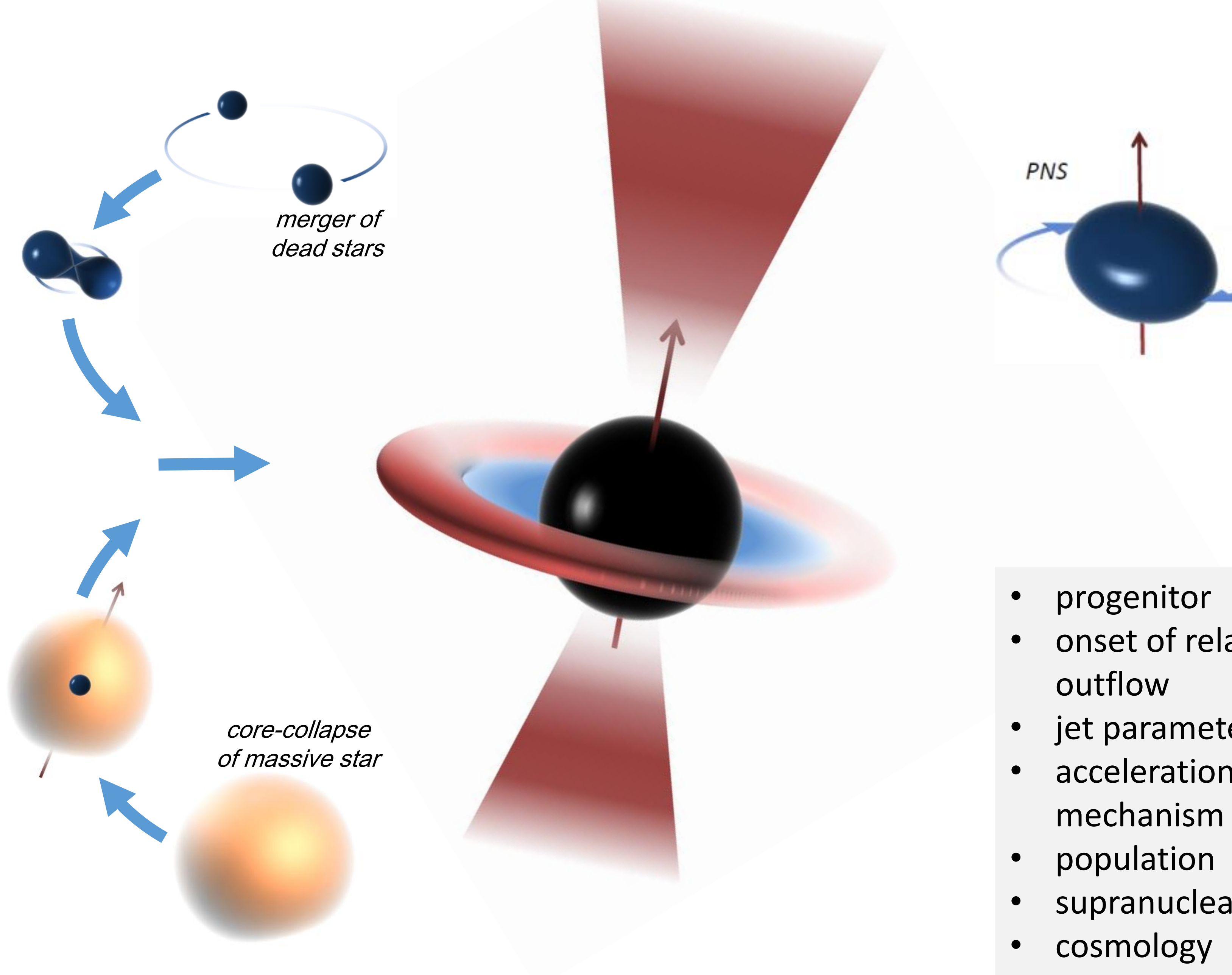
What can be done with
0, 1, 10, 100 joint GW-Fermi
detections?

1. open questions
2. progenitors
3. progenitor ←→ outflow
4. multimessenger prospects

Imre Bartos
Columbia University

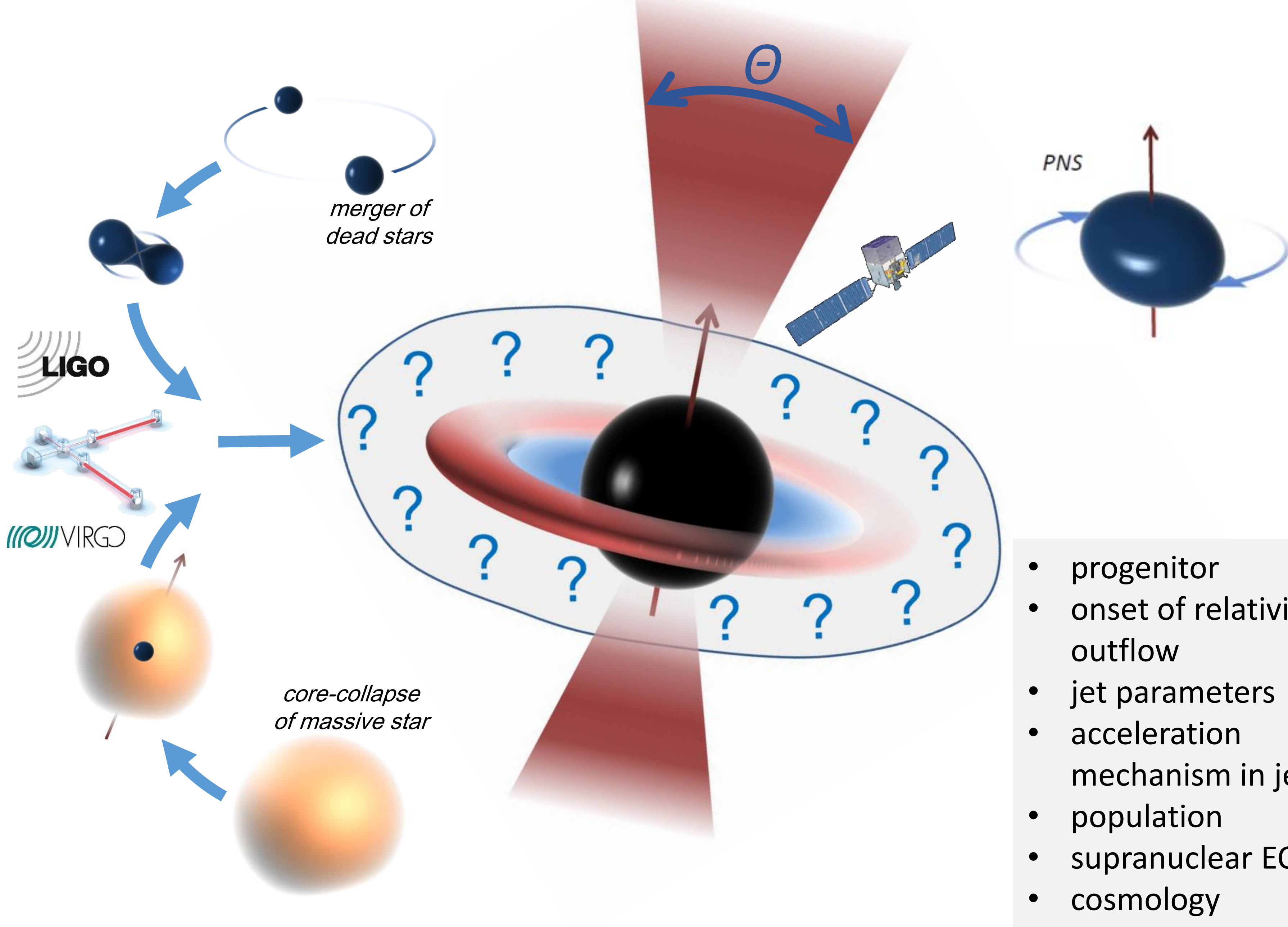
Fermi-LIGO workshop Caltech, Mar. 14, 2015

Open questions



- progenitor
- onset of relativistic outflow
- jet parameters
- acceleration mechanism in jet
- population
- supranuclear EOS
- cosmology

Open questions



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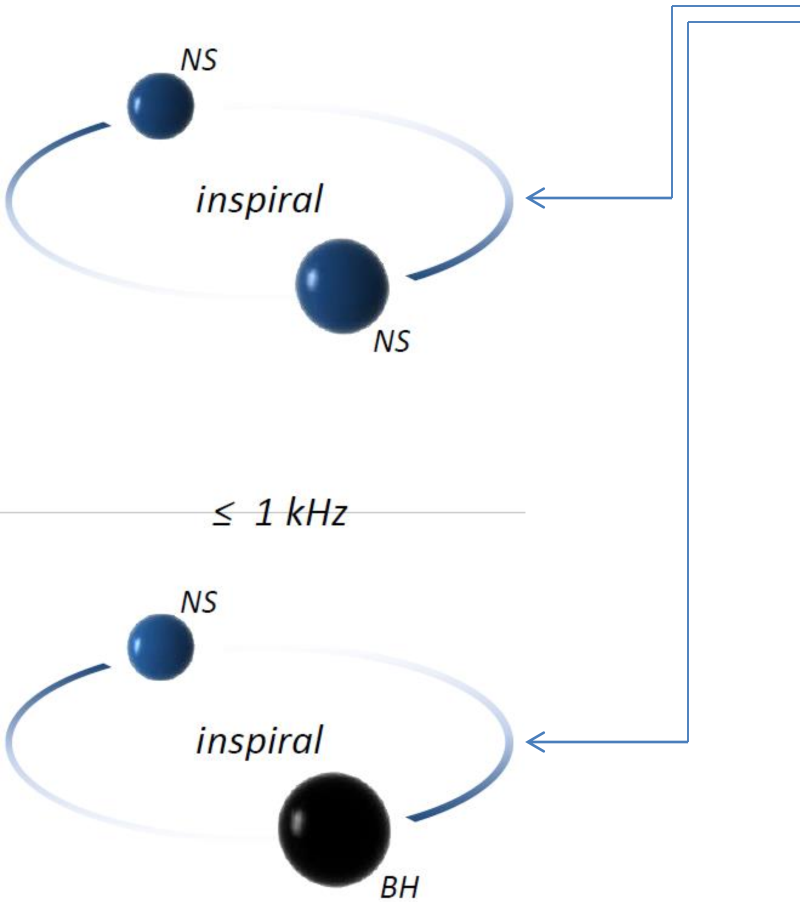
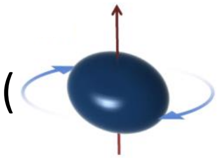
PROGENITORS: GWS FROM COMPACT BINARY MERGERS

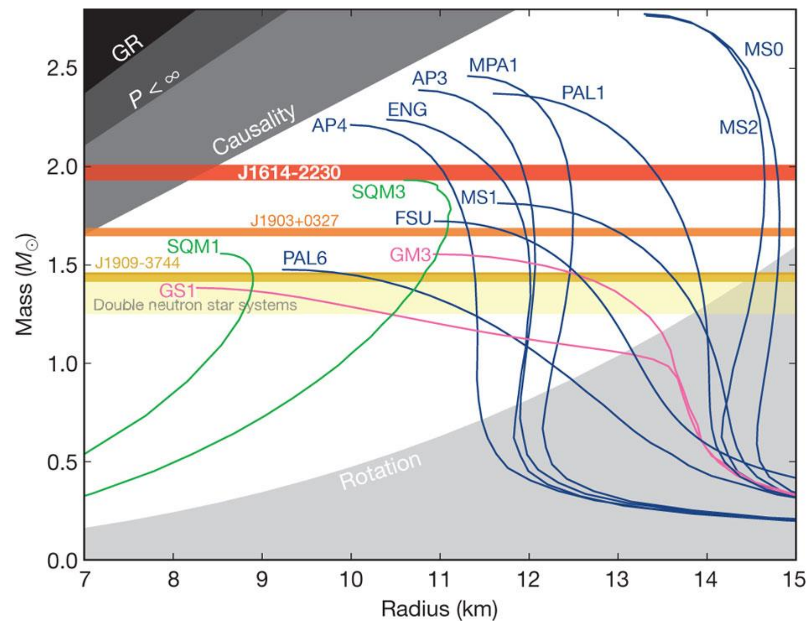


Progenitors of short GRBs ()

Jet beaming angle (structure) ←→ population

NS nuclear equation of state (mass + radius)

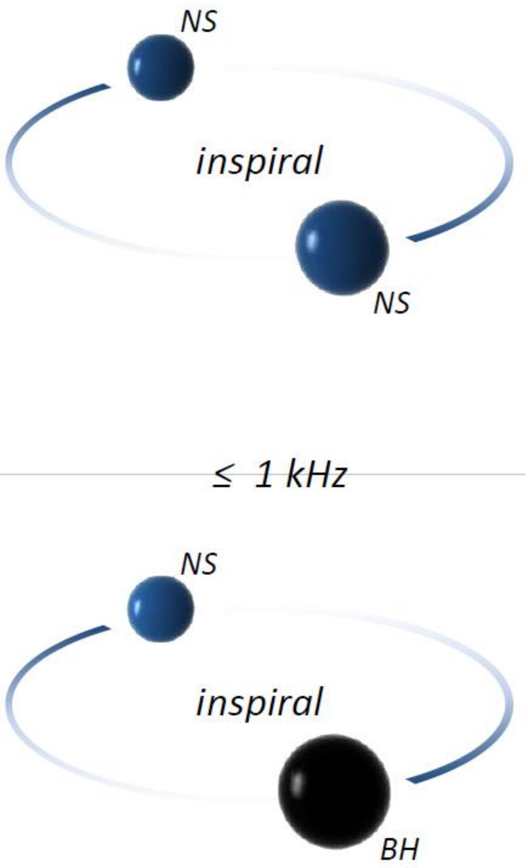
ΔR ~ 1km at 100 Mpc *(Read et al. 2009)*



Alternative cosmological distance ladder
(Schutz 1986)

Bartos et al CQG 2013

PROGENITORS: GWS FROM COMPACT BINARY MERGERS



Bartos et al CQG 2013

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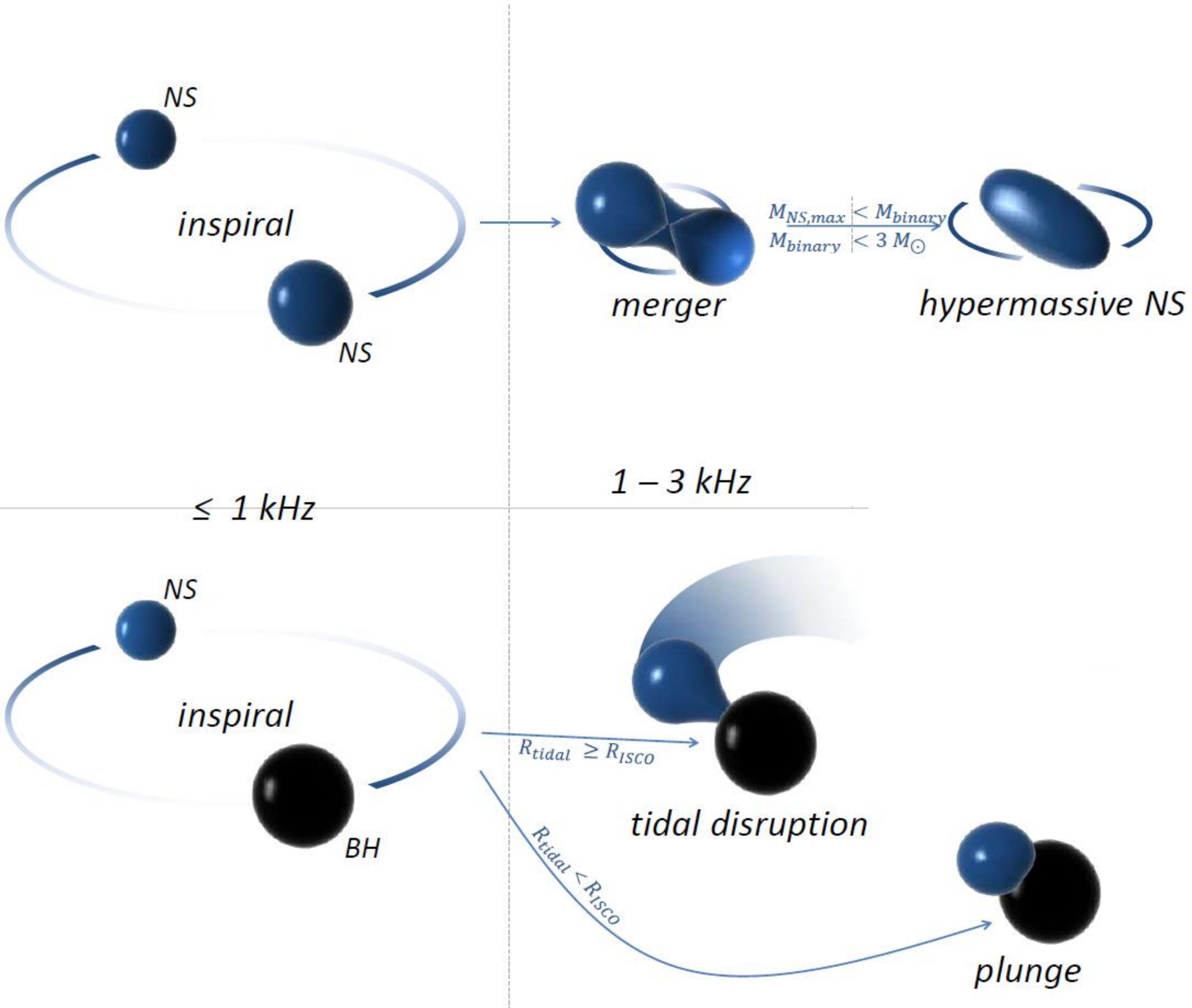
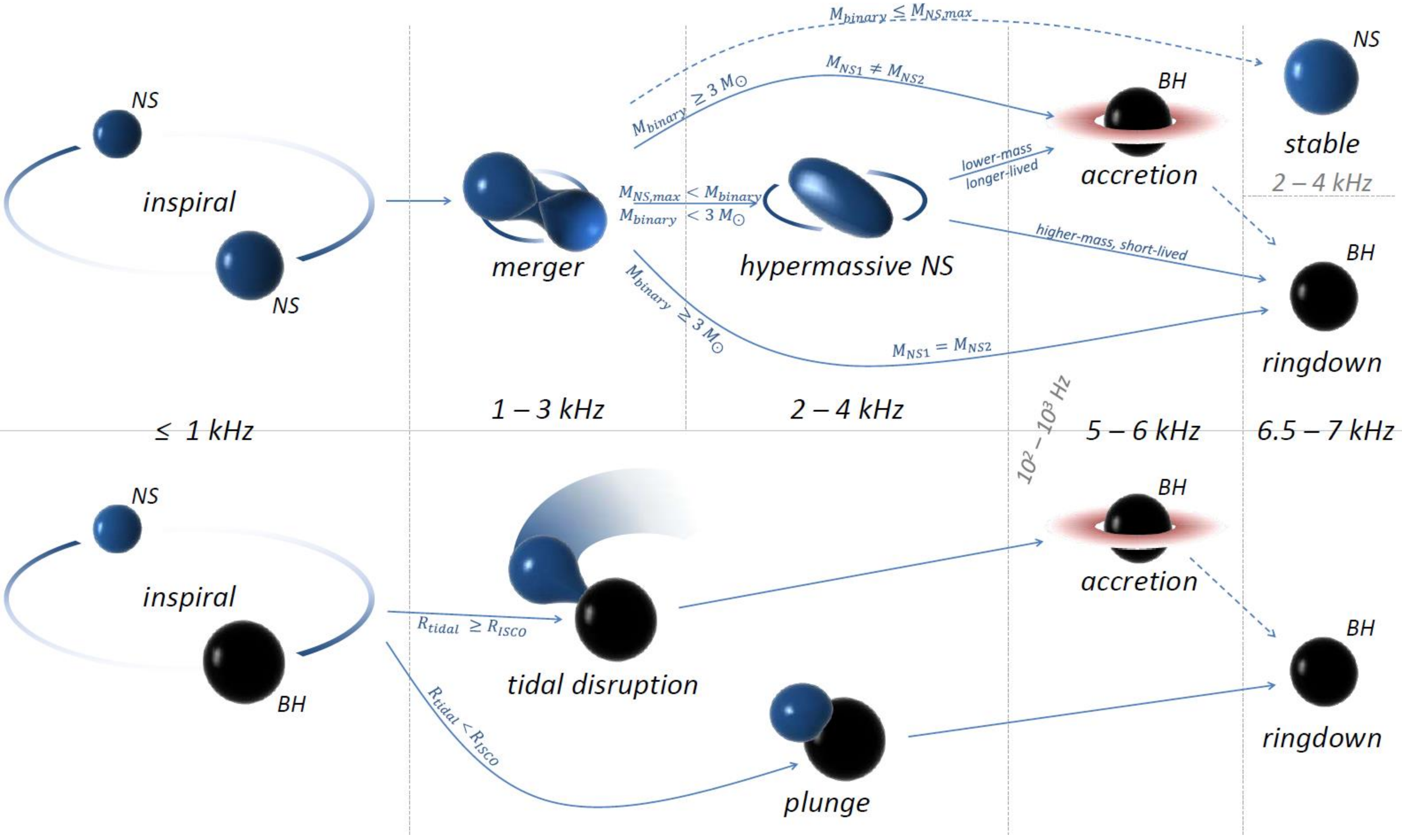


Bartos et al CQG 2013

PROGENITORS: GWs FROM COMPACT BINARY MERGERS



Bartos et al CQG 2013

GWs from rapidly rotating cores?

Relevant distance scale:

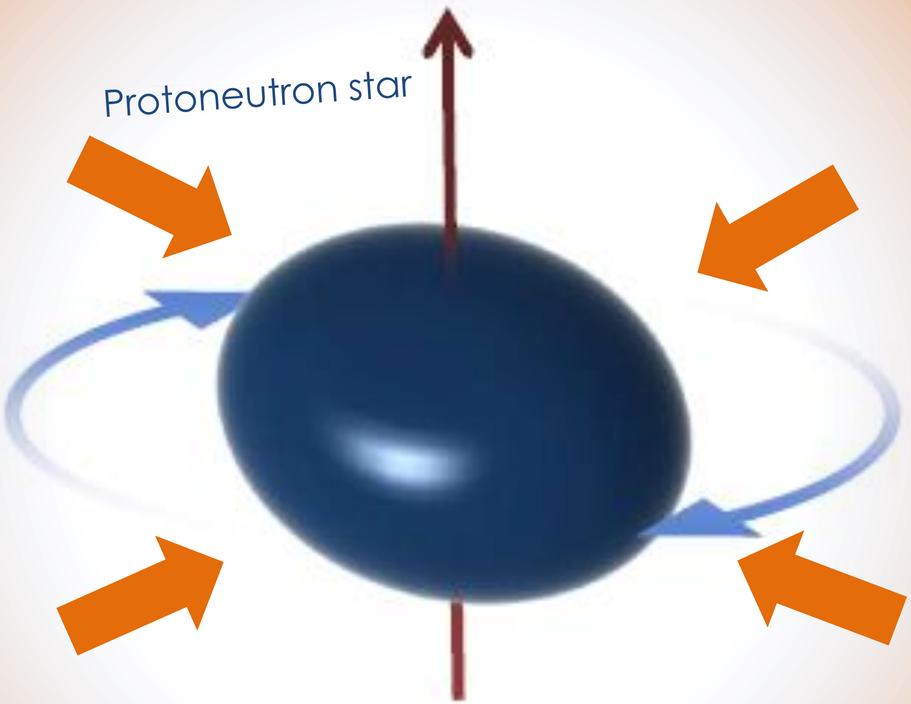
Low-luminosity GRB / CCSN with jets: 10^2-10^3 Gpc^{-3} yr^{-1}

(Guetta & della Valle 2006; Soderberg+ Nature 2010)

(Beaming factor ~ 10)

→ **50-100 Mpc!**

PROGENITORS: GWs FROM STELLAR CORE COLLAPSE



Differential rotation (e.g. Corvino et al. 2010)

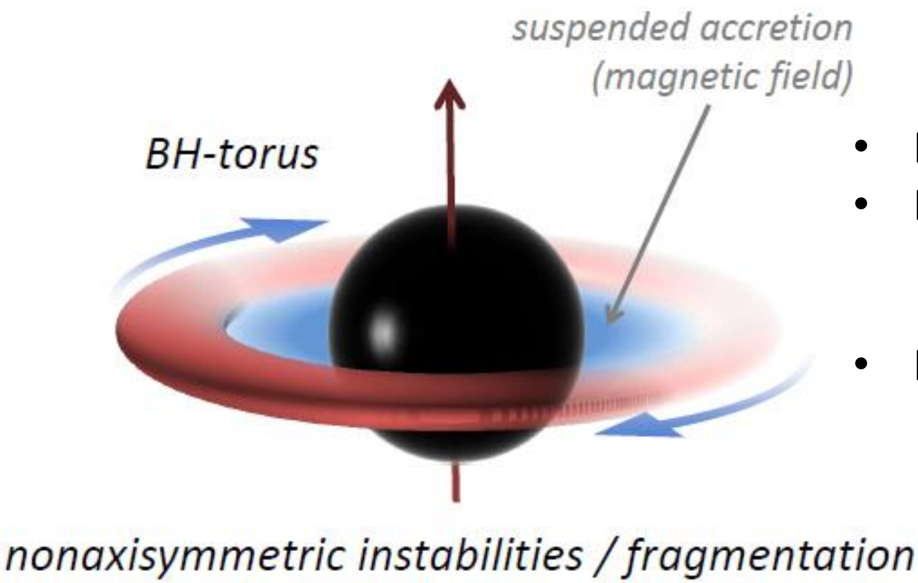
- **Dynamical instabilities** *(shorter time scale)*
- **Secular instabilities** *(longer time scale)*
- **Magnetic distortion**

Fallback accretion? *(Piro and Thrane, 2012)*

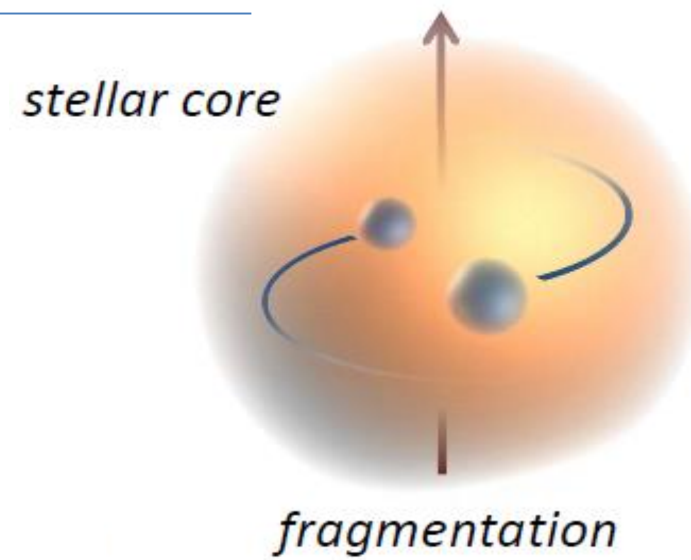
Accretion from binary companion

$$E_{\rm GW} \approx 10^{-2} M_\odot c^2 \left(\frac{\epsilon}{0.2}\right)^2 \left(\frac{f}{2\,\rm kHz}\right)^6 \left(\frac{M}{1.4\,M_\odot}\right) \left(\frac{R}{12\,\rm km}\right)^2 \left(\frac{\tau}{0.1\,\rm s}\right)$$

Bartos *et al* CQG 2013

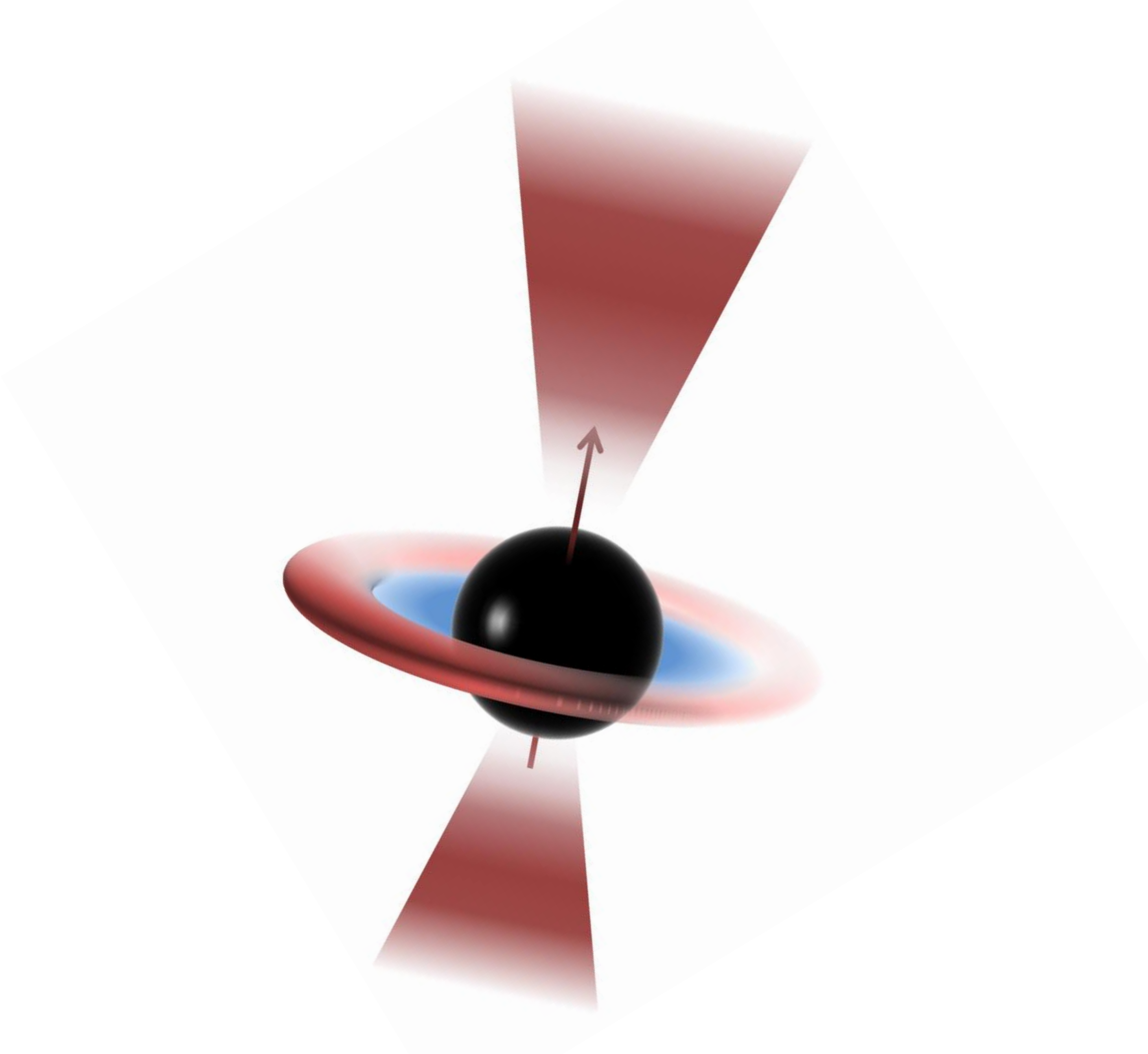


- Magnetically arrested disk
- Disk fragmentation *(Nakamura & Fukugita 1989)*
  Observed in simulations *(Duez et al. 2004, Giacomazzo et al. 2011)*
- Papaloizou-Pringle instability
  Simulations of initially axisymmetric disks
  (Kiuchi et al. 2011)

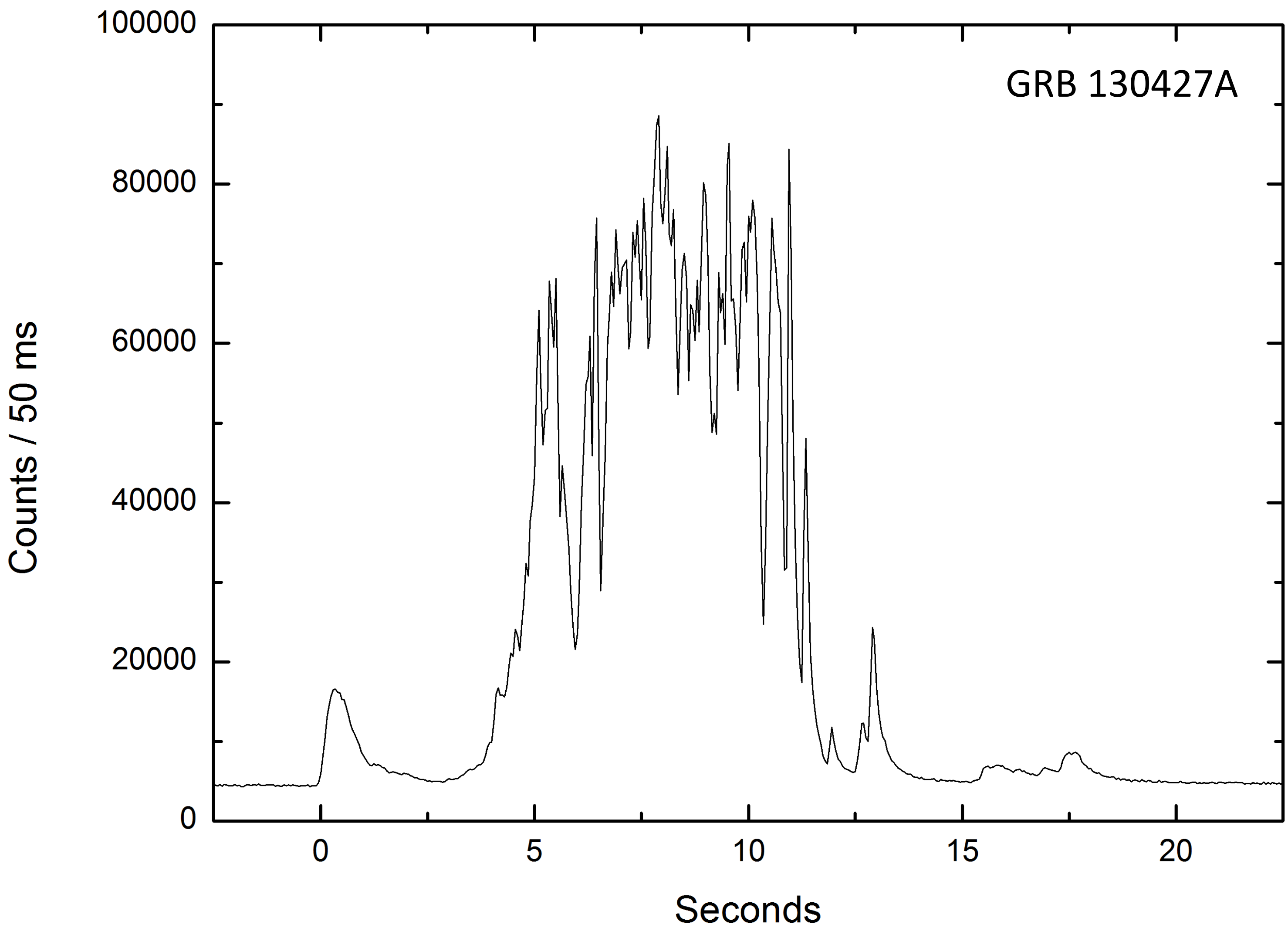


(Bonnell and Pringle, 1995)
Observed in simulations *(Zink et al. 2006)*
Not clear with current stellar models

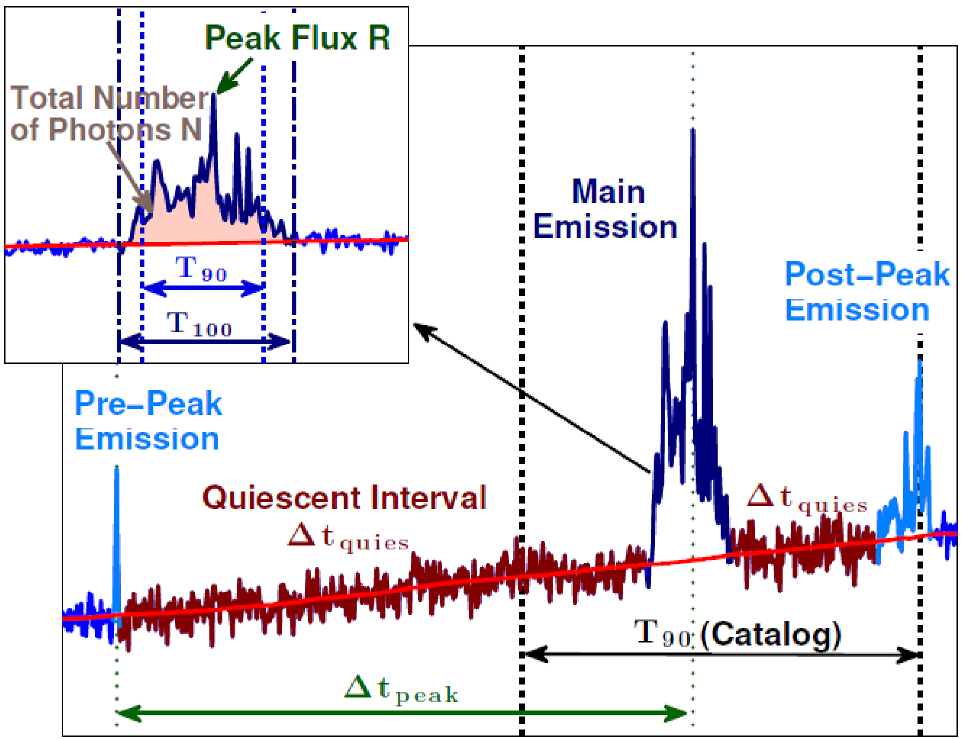
Bartos *et al* CQG 2013

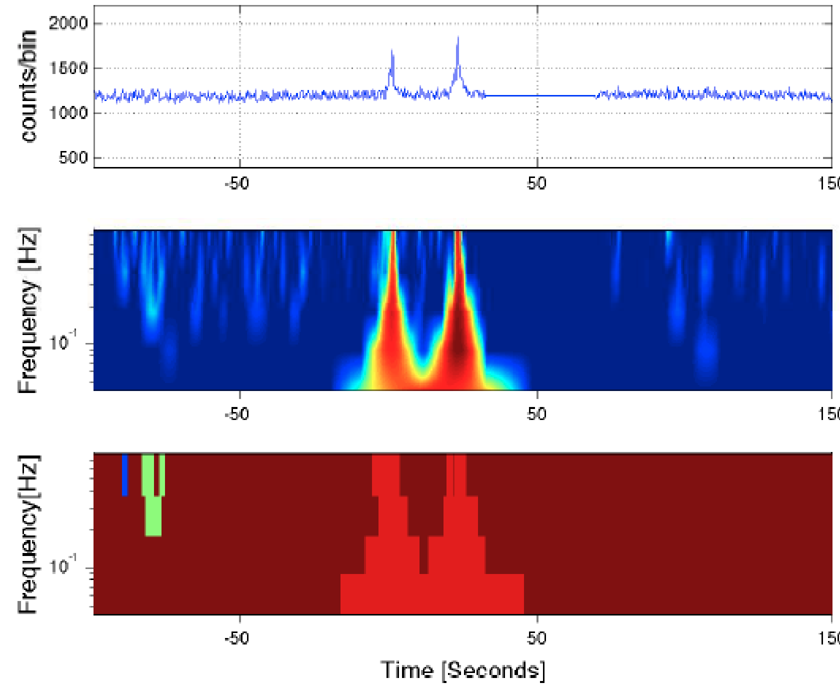


GRB emission episodes (precursors)

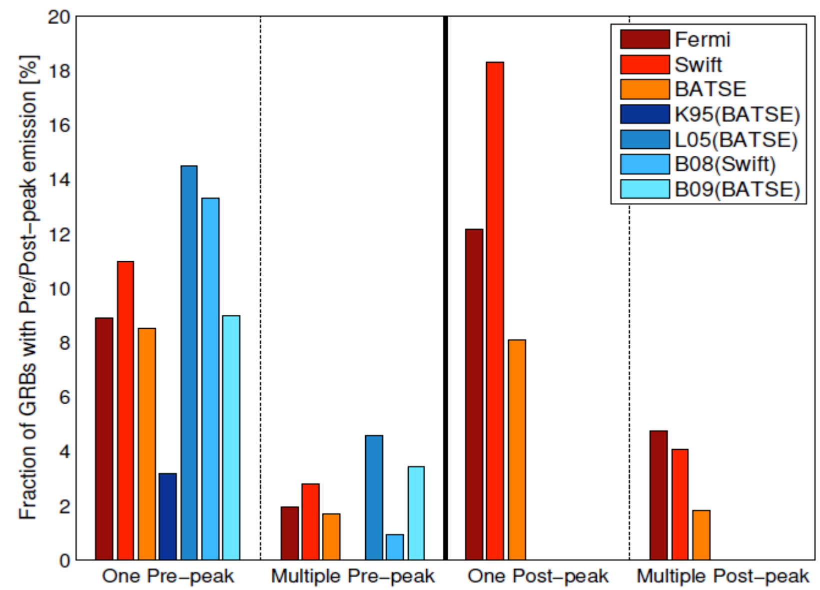


GRB EMISSION EPISODES (PRECURSORS)

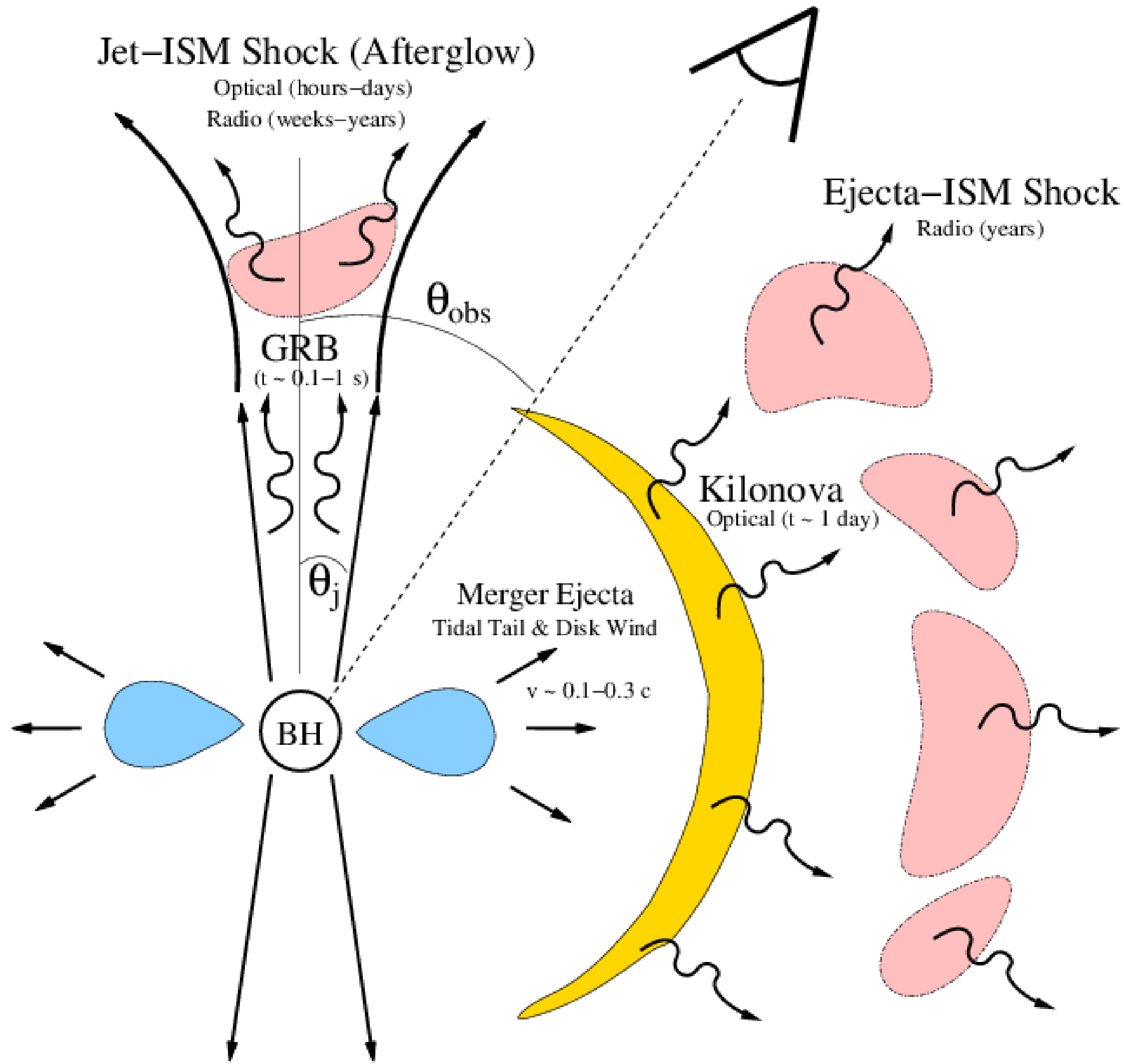




Automated survey of BATSE, Fermi and Swift GRBs (2710)
Conclusion --- precursors likely from same central engine activity

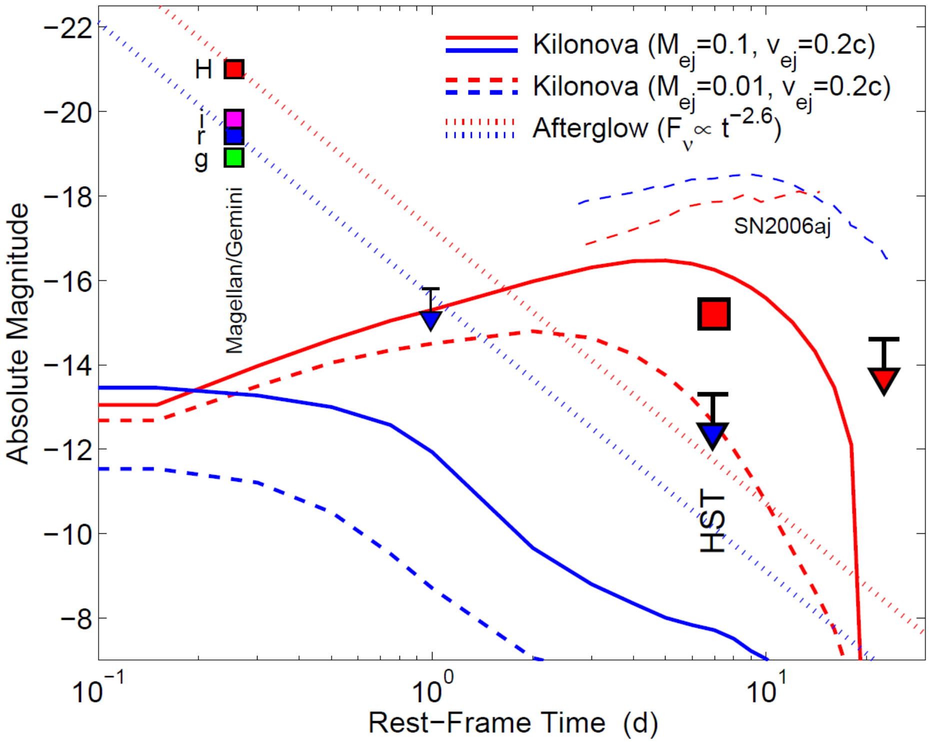


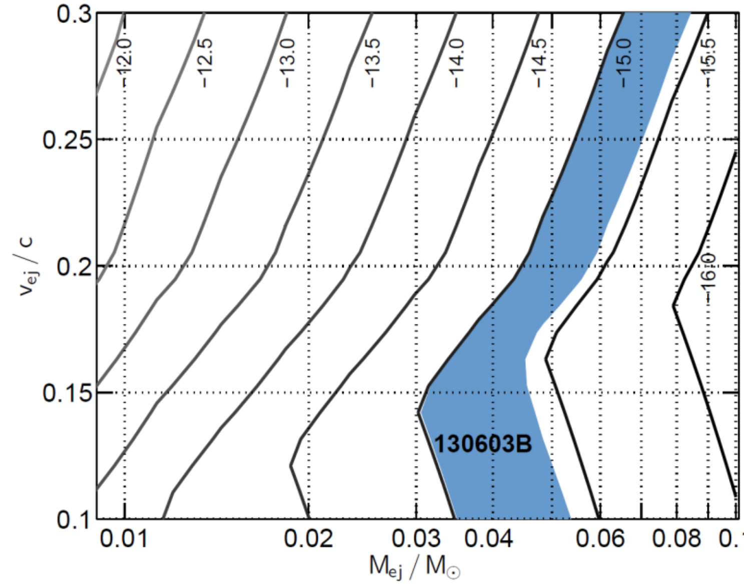
Charisi, Marka, Bartos MNRAS 2014



Metzger & Berger 2012

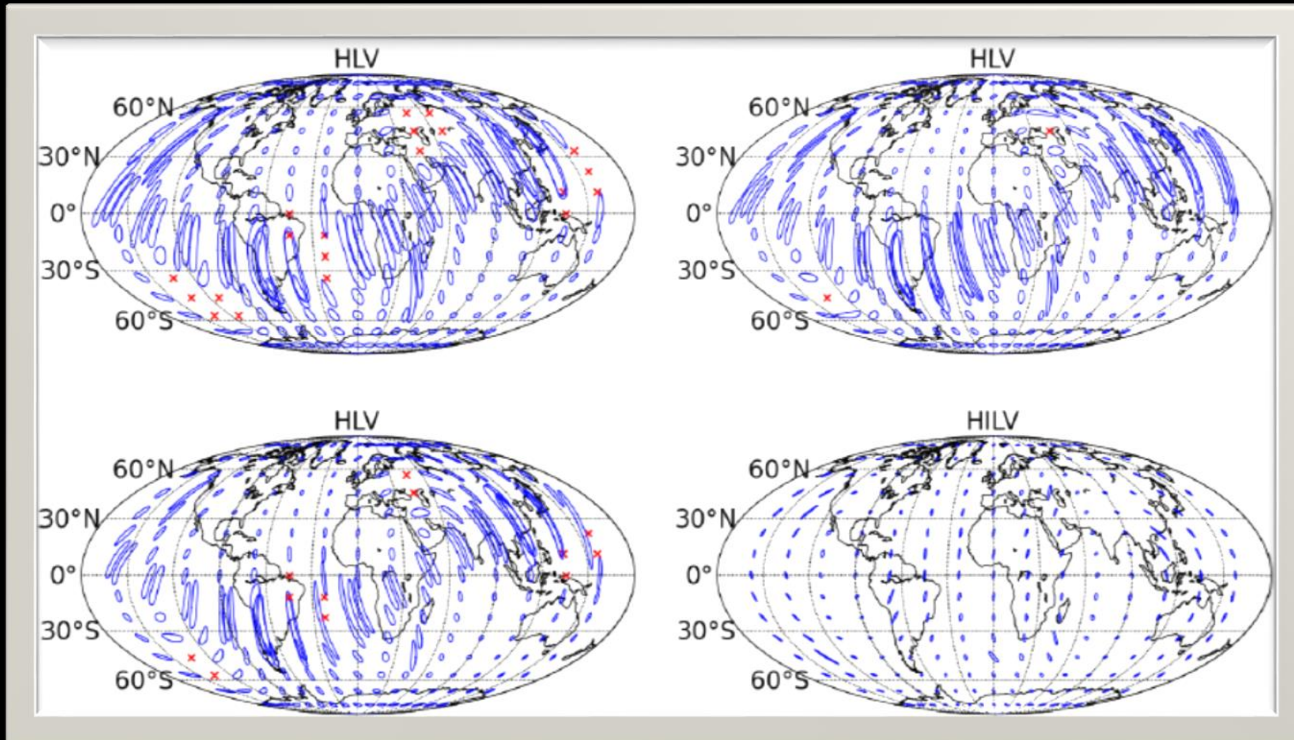
KILONOVAE





Berger et al 2013

- ✓ Kilonova found coincident with GRB 130603B (Tanvir et al Nature 2013)
- ✓ Estimates on ejected mass/velicty from compact binary merger
- ✓ Consistent with expected emission properties



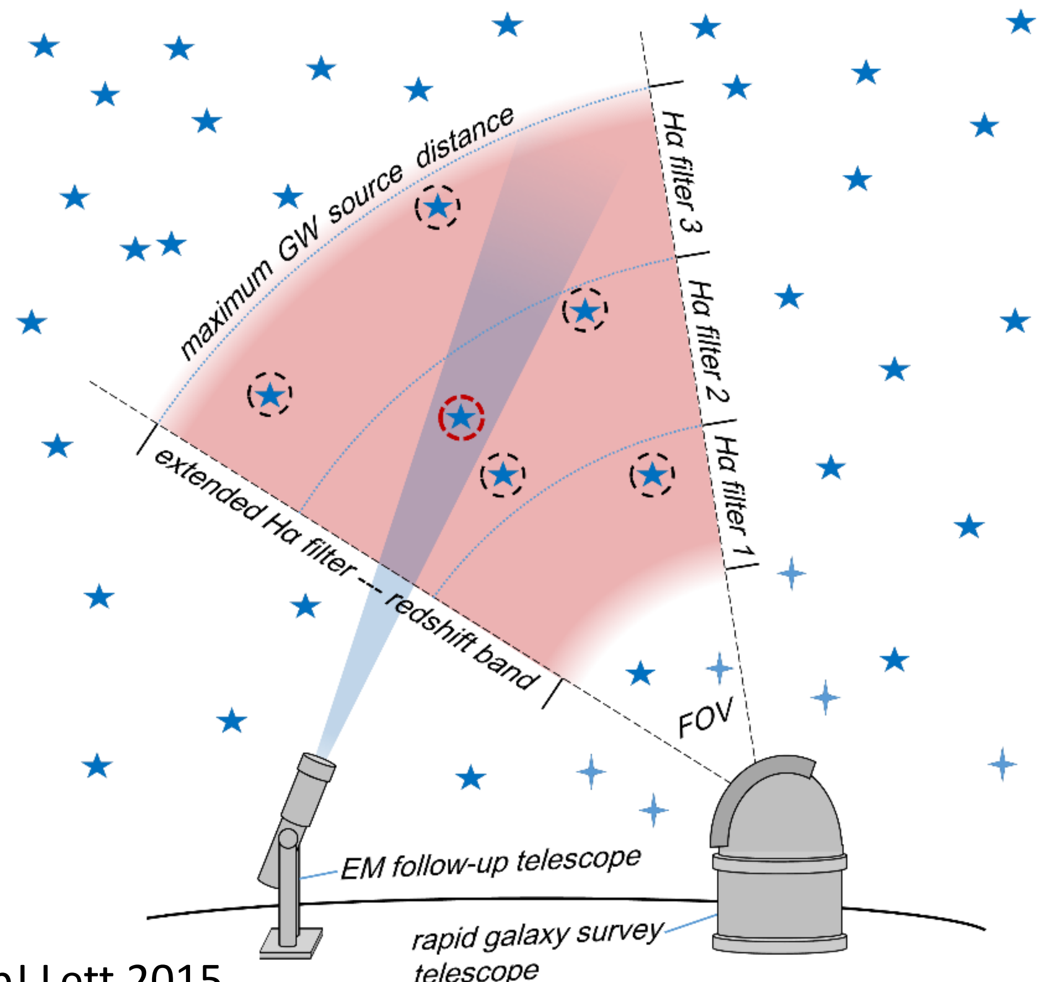
Sensitivity Timeline

Aasi et al. 2013

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 $5\,\mathrm{deg}^2$	$20\,\mathrm{deg}^2$
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

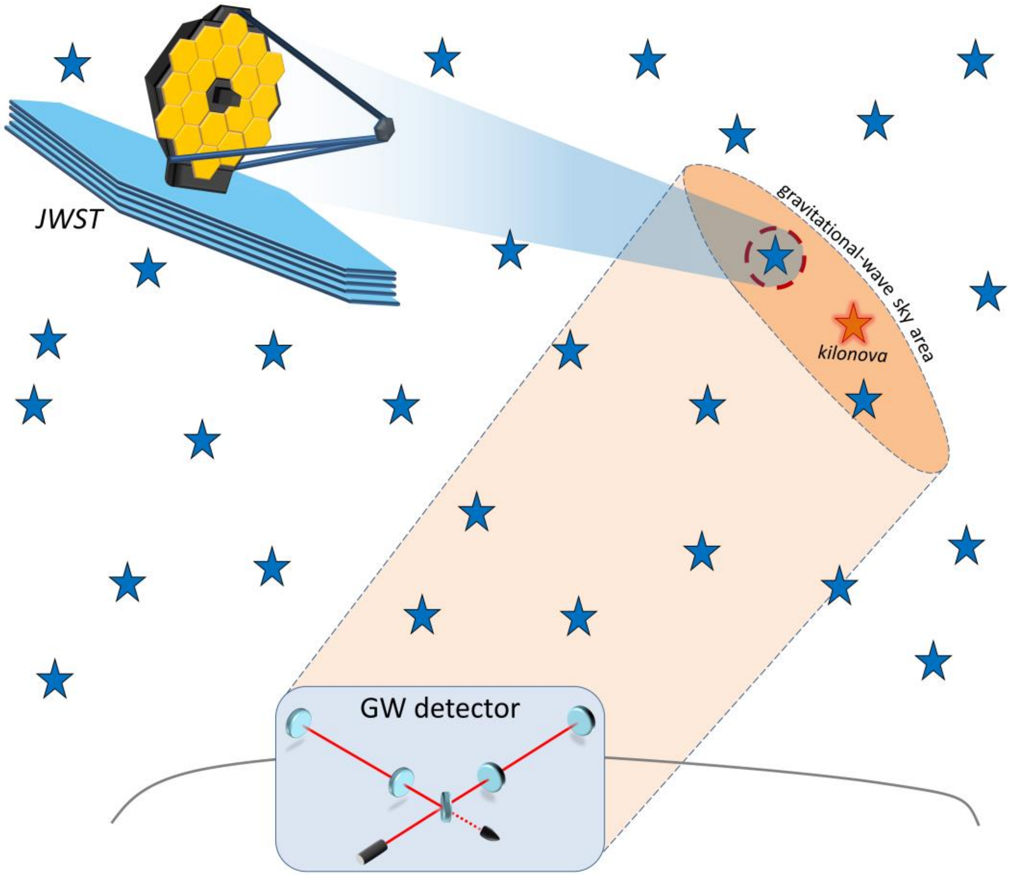
Catalog on the fly

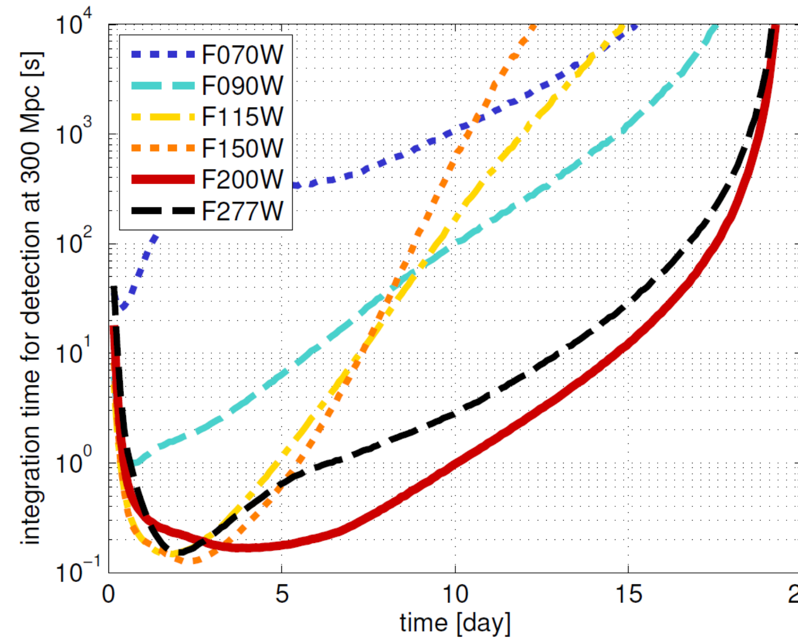
- Can we make a catalog in the right time frame, distance range and sky area?
  - ✓ 1 week
  - ✓ 200-500 Mpc
  - ✓ 100 deg^2
- Extended H-alpha survey (R-band comparison)
  - We only want to find galaxies within horizon distance
  - We don’t necessarily need more info than this as long as catalog is complete
- Meter class telescopes work.
- Don’t need very high completeness (Hanna et al 2014)



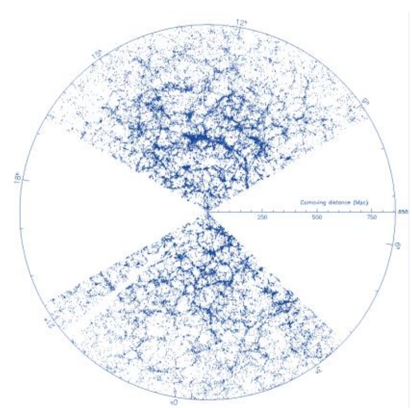
Bartos et al ApJ Lett 2015

JWST IN DETECTING KILONOVAE





JWST can detect kilonovae from far beyond the GW horizon distance for accurate pointing.



Main limitations:

- small FOV
- slow slewing

- *Galaxy catalog --- scan 10 deg^2 in < 3 h*
- *Other messengers (e.g. γ) can significantly reduce this time.*

Summary

Fermi+GW detections:

- 0 a. unexpected progenitor
  b. unexpected beaming angle
- 1 a. specify progenitor
  b. relative timing
  c. we may already know quite a bit from GW / kilonova / etc.
  d. 1st non-binary merger – protoneutron star / other instabilities
- 10+ a. progenitor-accretion-outflow properties
  b. beaming
  c. population
  d. nuclear EOS
  e. cosmology