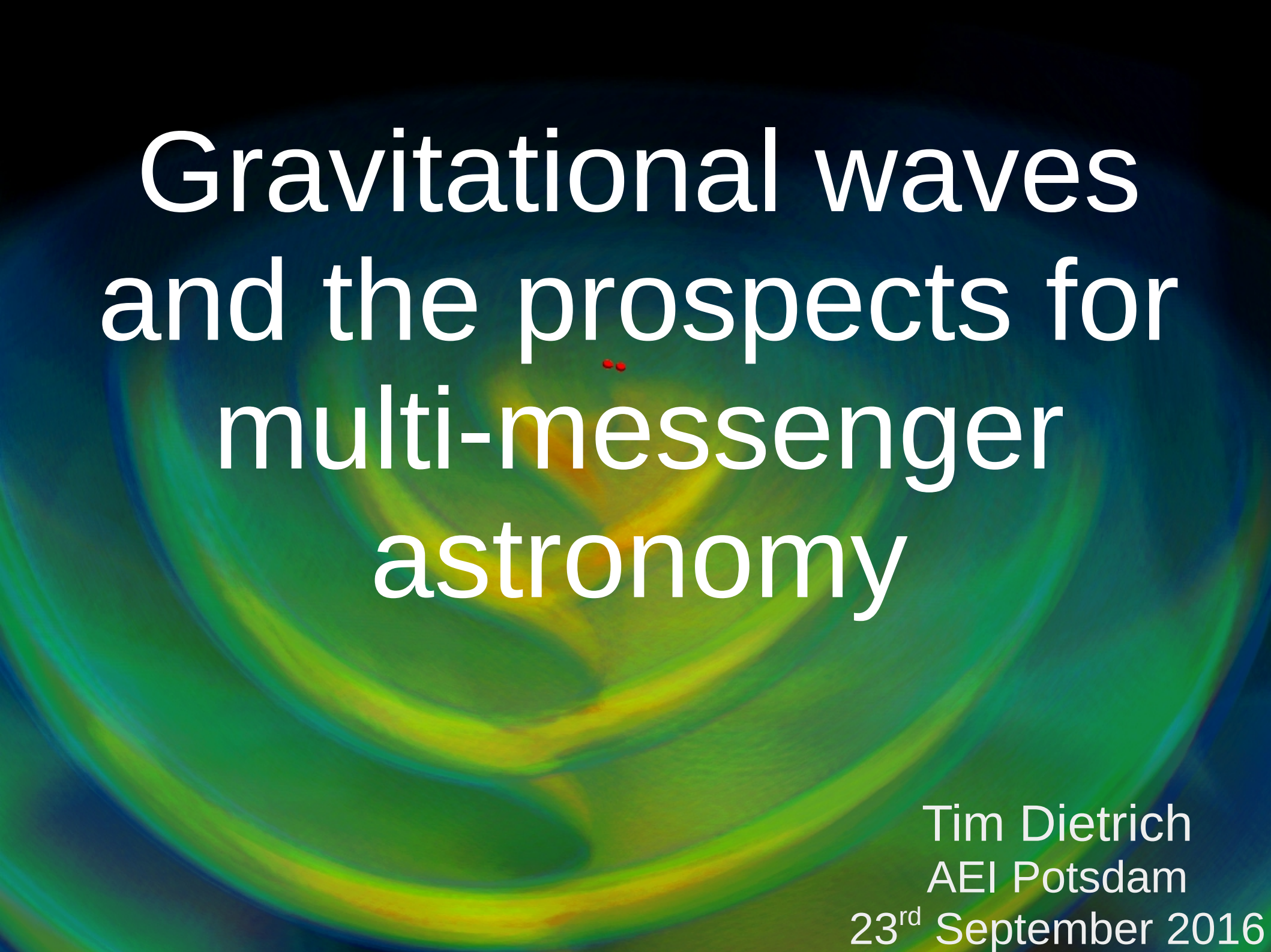


Gravitational waves and the prospects for multi-messenger astronomy

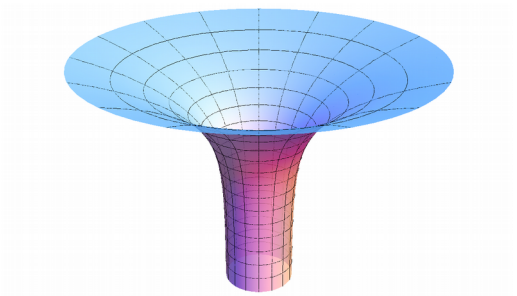
Tim Dietrich
AEI Potsdam
23rd September 2016

What are Gravitational Waves?

“Gravitational waves are 'ripples' in the fabric of spacetime caused by some of the most violent and energetic processes in the Universe.”

LIGO-webpage

Geometry ⟷ **Matter**



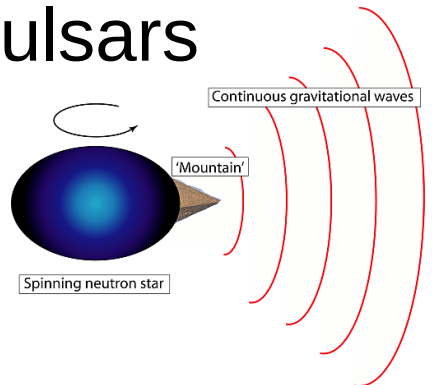
What are Gravitational Waves?

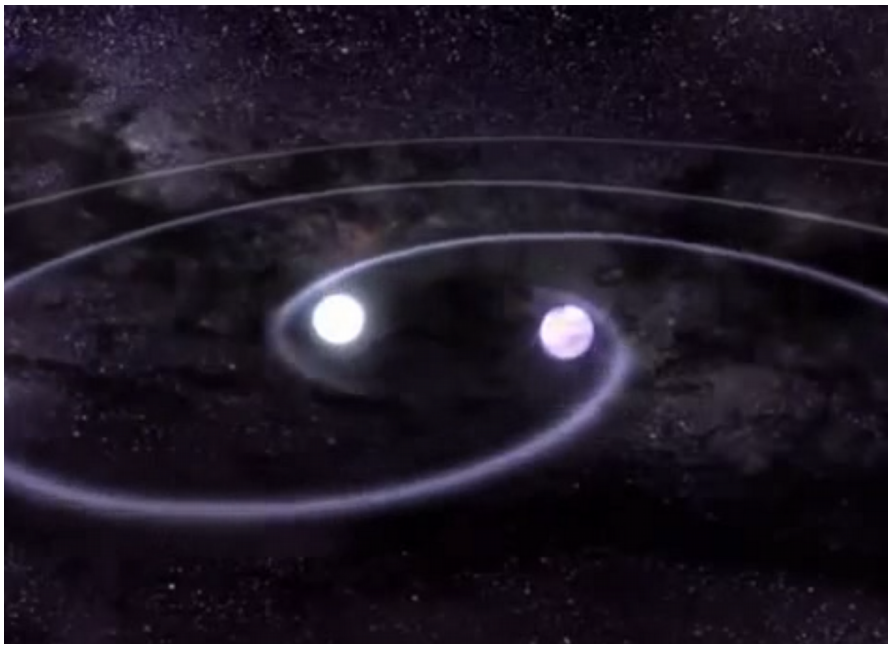
“Gravitational waves are 'ripples' in the fabric of spacetime caused by some of the most violent and energetic processes in the Universe.”

LIGO-webpage

possible sources:

- Compact Binaries Mergers
- Supernovae
- Big bang
- “deformed” Pulsars





https://www.youtube.com/watch?v=2LYZL6EI0xY

Differences EM waves and GWs

- similarities
  - propagation with c
  - amplitude with 1/r
- differences
  - little interaction with matter
  - GWs generated by bulk motion on large scale
  - no monopol and dipole radiation; lowest order radiation is quadrupole

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Quadrupole

strength → $h^{\mu\nu} = \frac{2G}{rc^4}\ddot{Q}^{\mu\nu}_{TT}$

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Quadrupole

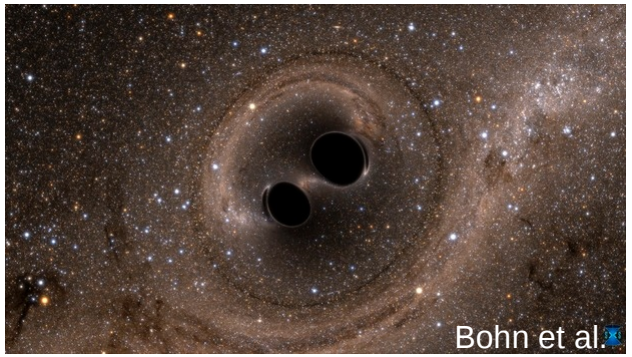
strength

$$h^{\mu\nu} = \frac{2G}{rc^4}\ddot{Q}^{\mu\nu}_{TT}$$

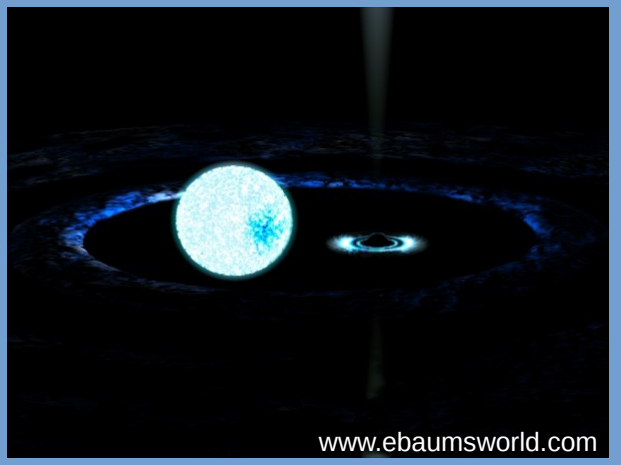
$$h_{\mu\nu} = 4 \times 10^{-22} \left(\frac{r}{100Mpc}\right)^{-1} \left(\frac{v}{0.3c}\right)^{2} \left(\frac{M}{10M_{\odot}}\right)$$

Compact binary merger

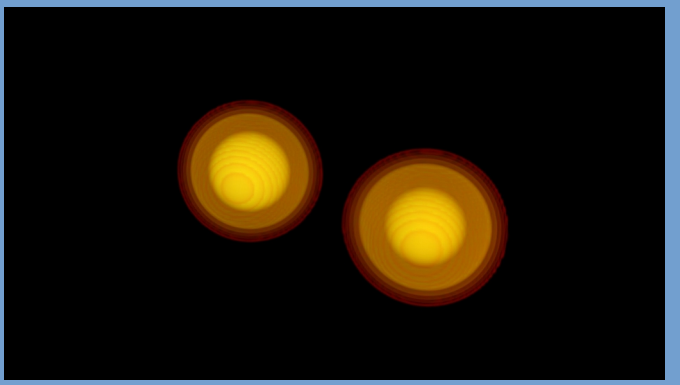
Black hole – Black hole



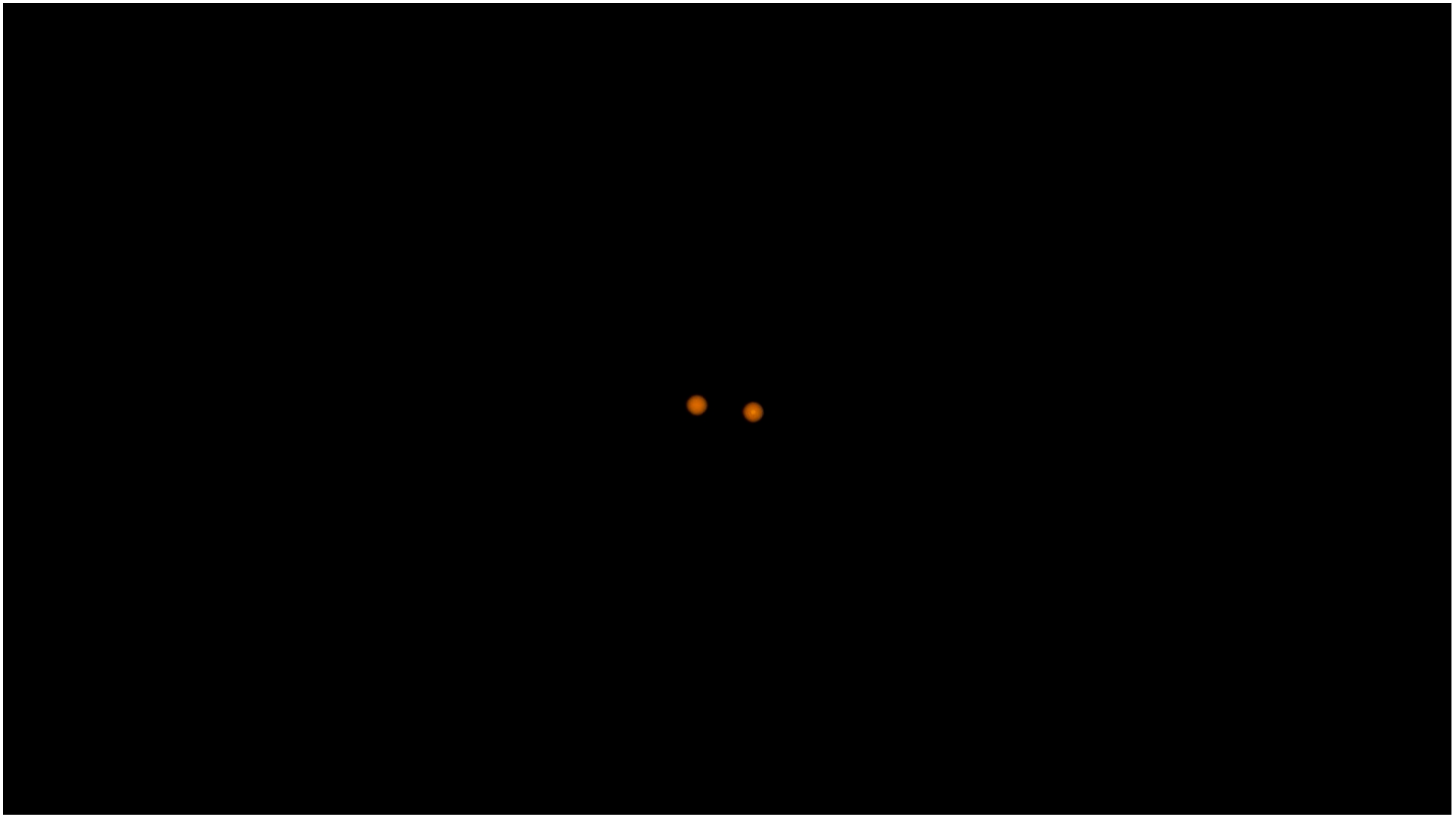
Black hole - Neutron star



Neutron star – Neutron star



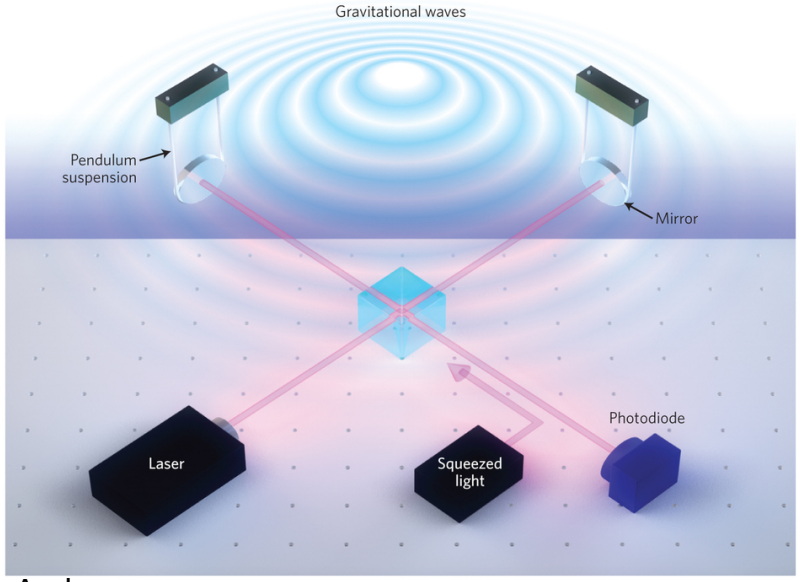
Binary Neutron Star Mergers



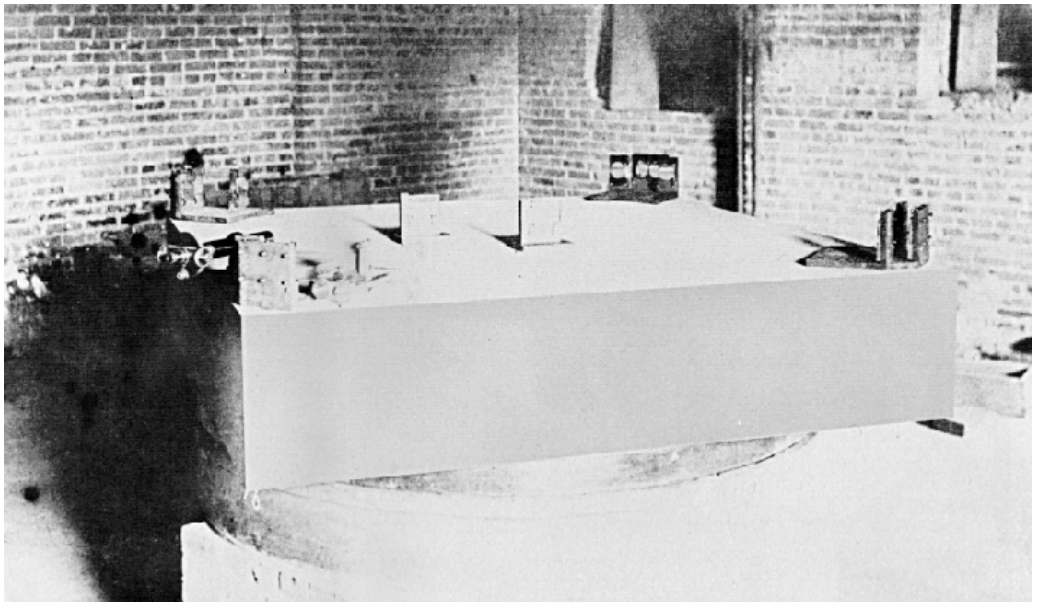
Video-1

The detectors

- Complicated version of Michelson-Morley Experiment

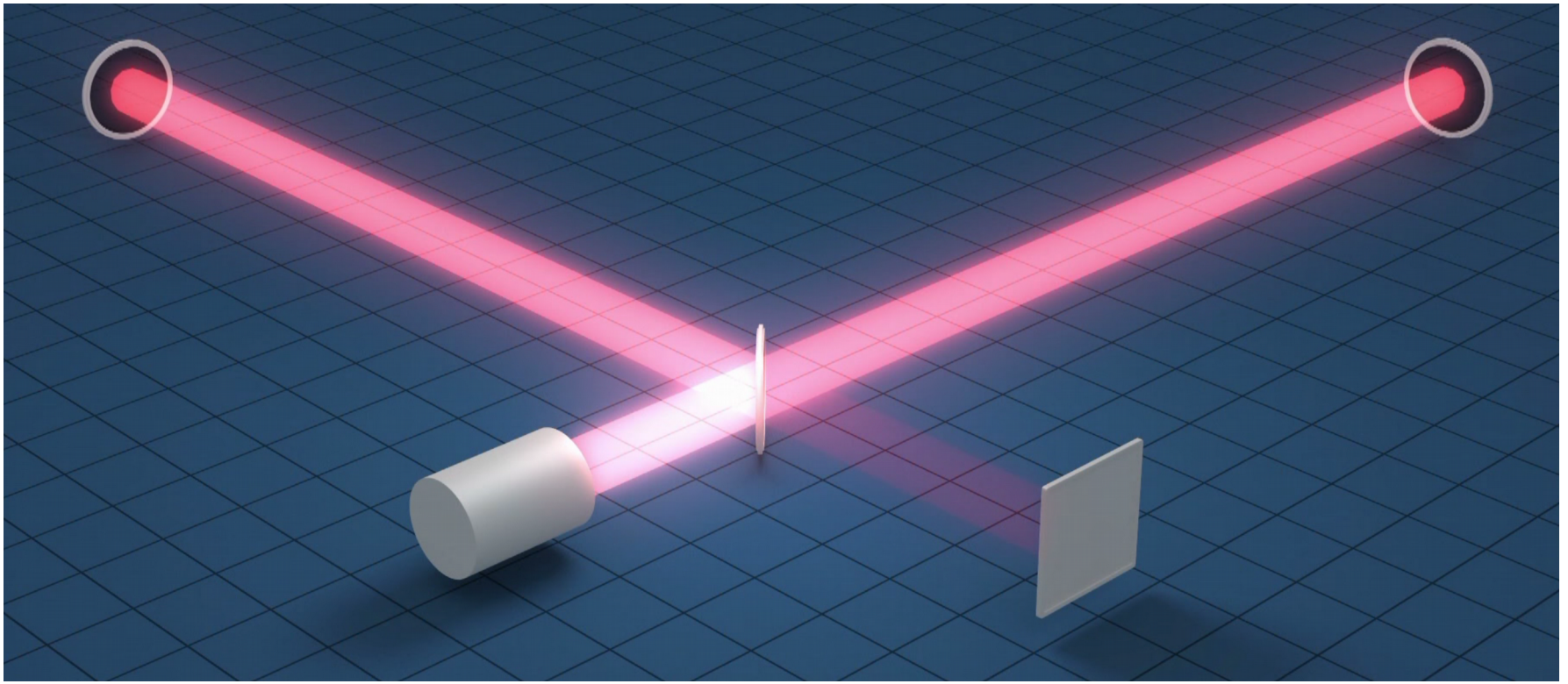


Anderson



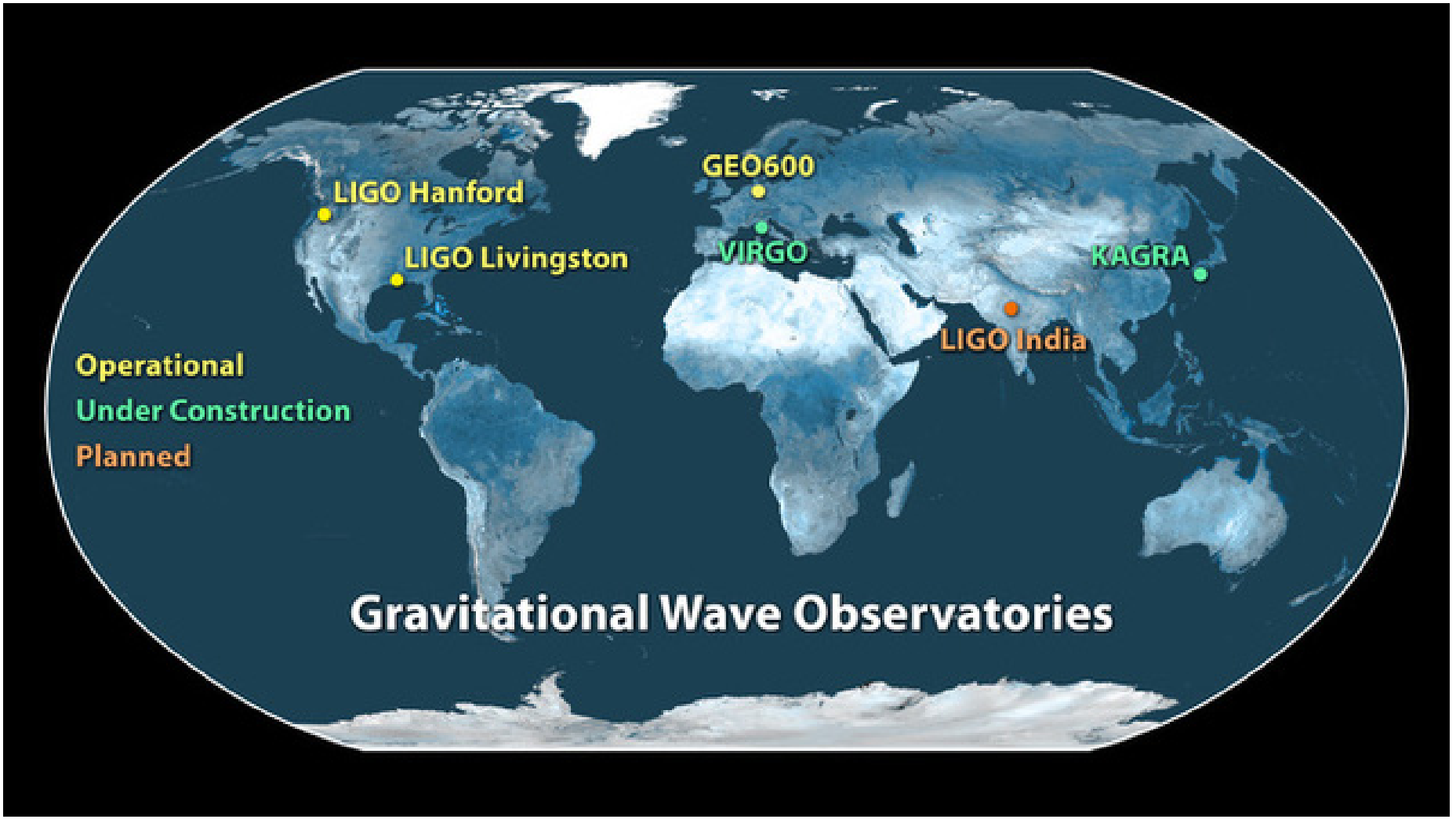
Case Western Research Archive

The detectors



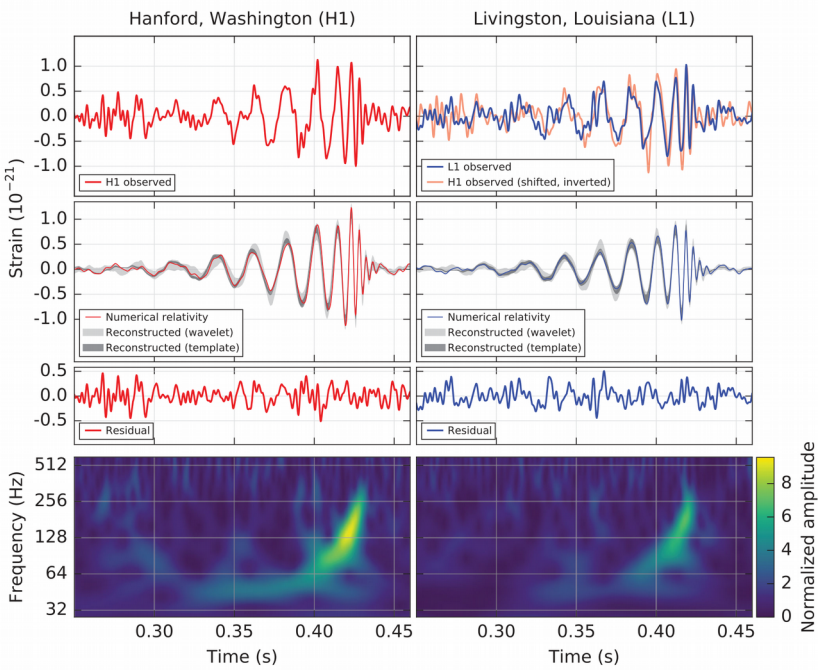
https://www.youtube.com/watch?v=BWJJeJAUdfM

An entire network



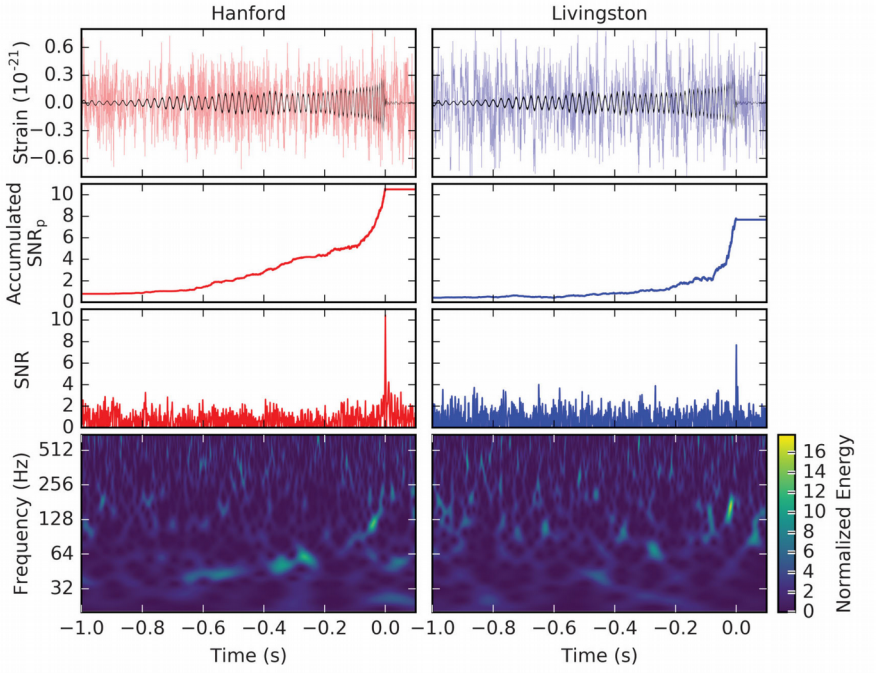
GW detections of BBHs

First direct detection on 14th of September 2015



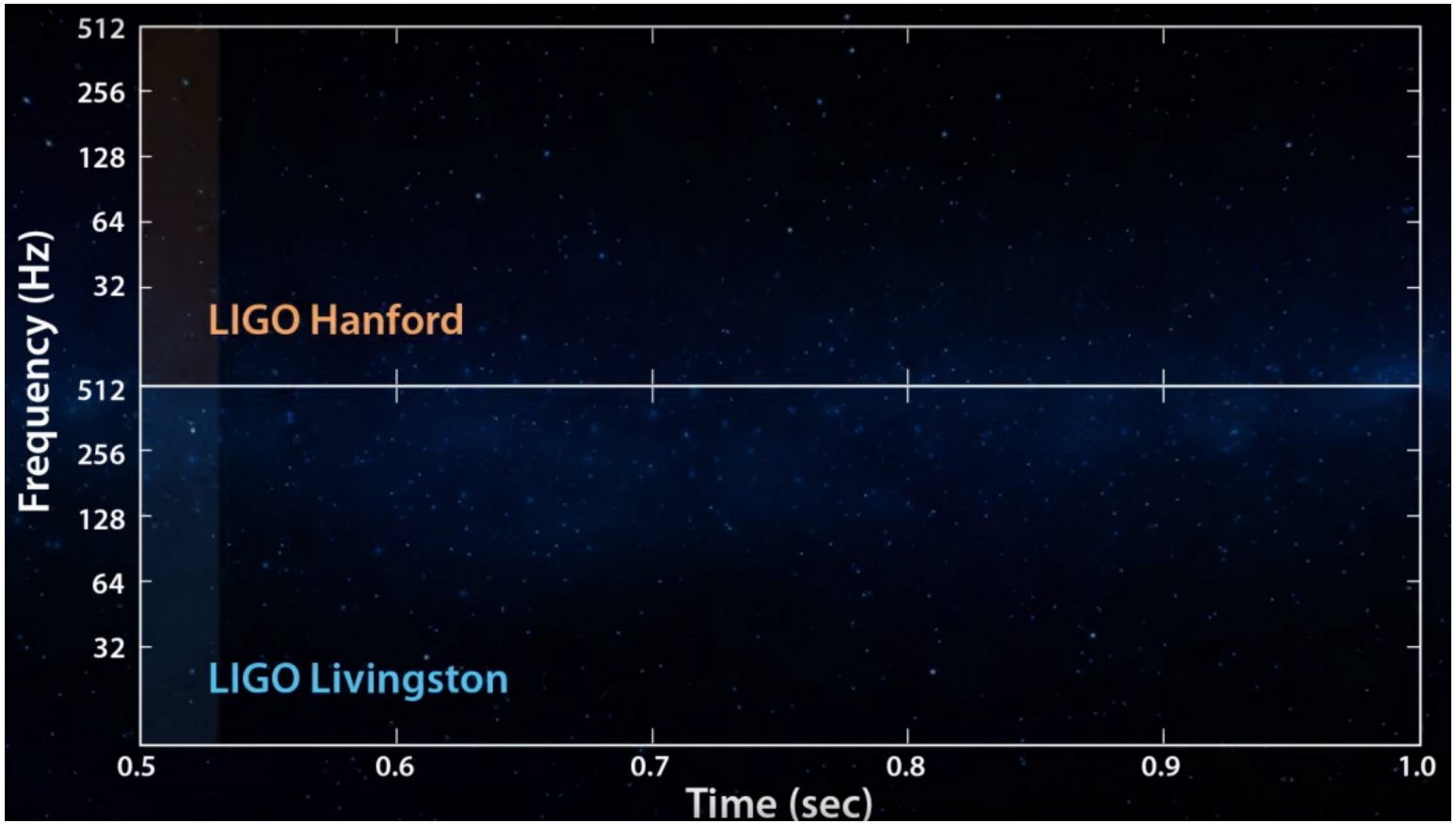
LIGO,Abbott et al. 2016

Second detection on 26th of December 2015



LIGO,Abbott et al. 2016

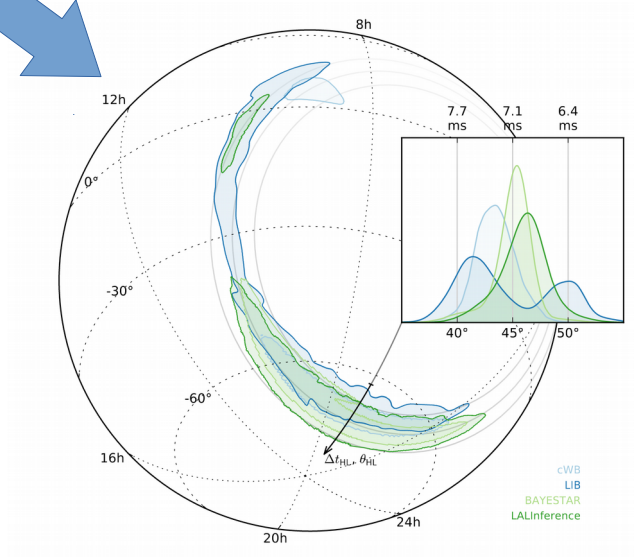
GW detections of BBHs



https://www.youtube.com/watch?v=TWqhUANNFXw

Follow up- searches

- Online interpreation of data with different pipelines



skymap

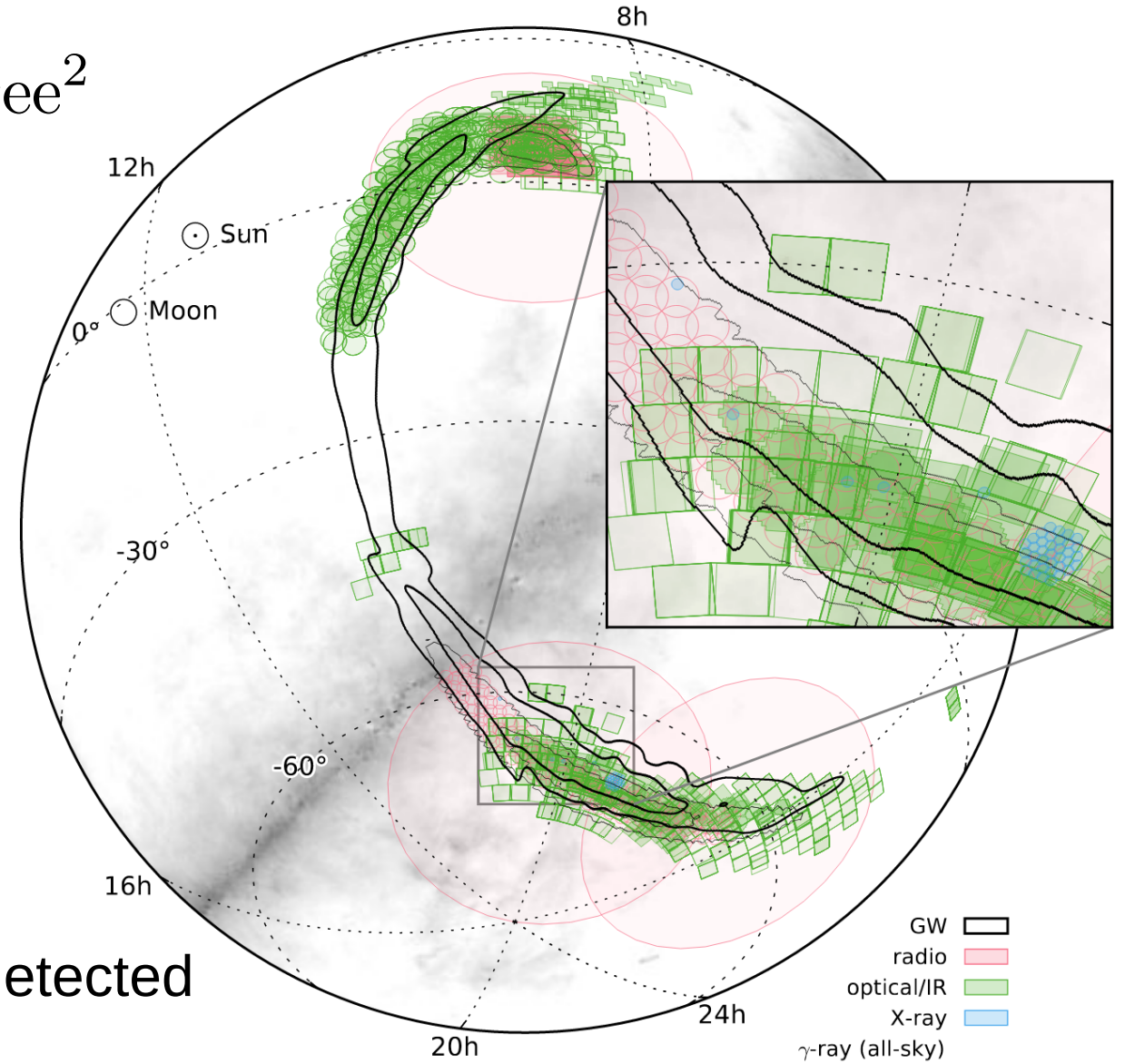
Trigger send

25 participating teams
19 orders of magnitude in wavelength

Abbot et al.

Follow up- searches

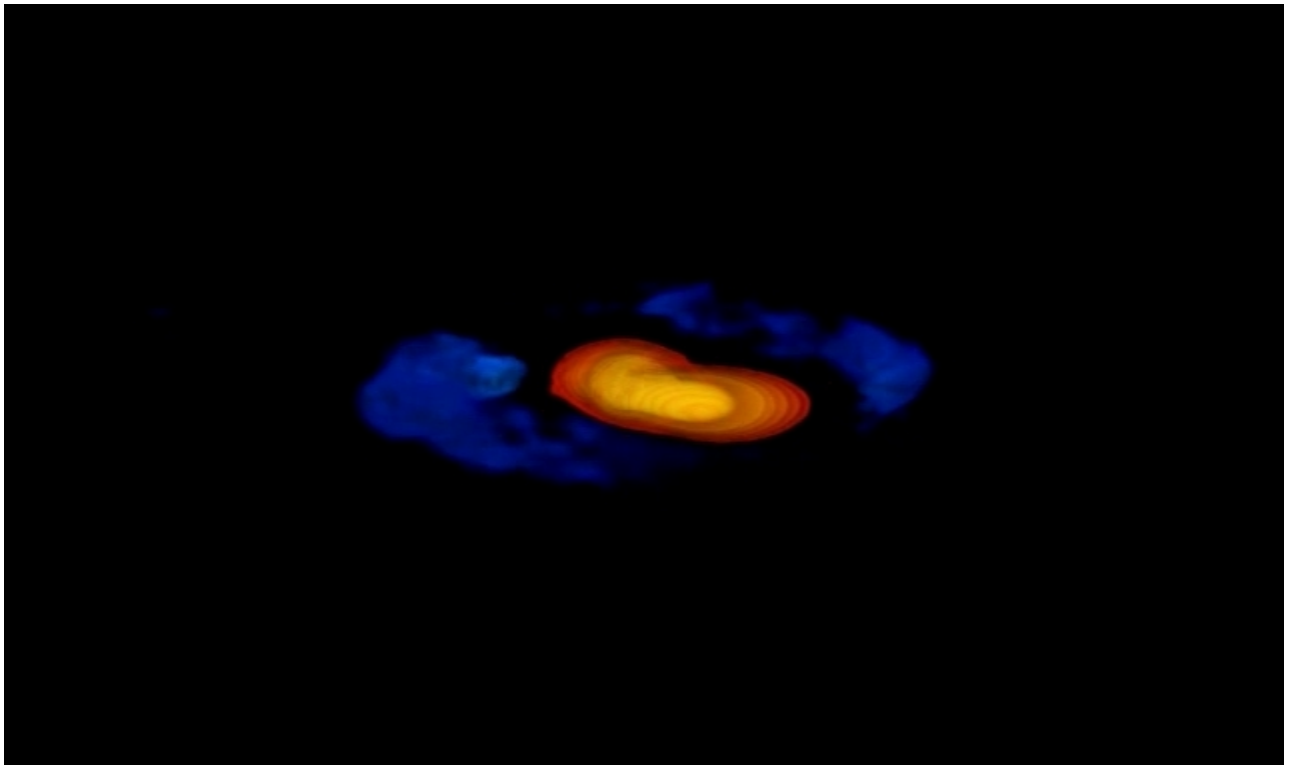
- GW gives $600\ \mathrm{degree}^2$



probably EM counterpart detected

Abbot et al.

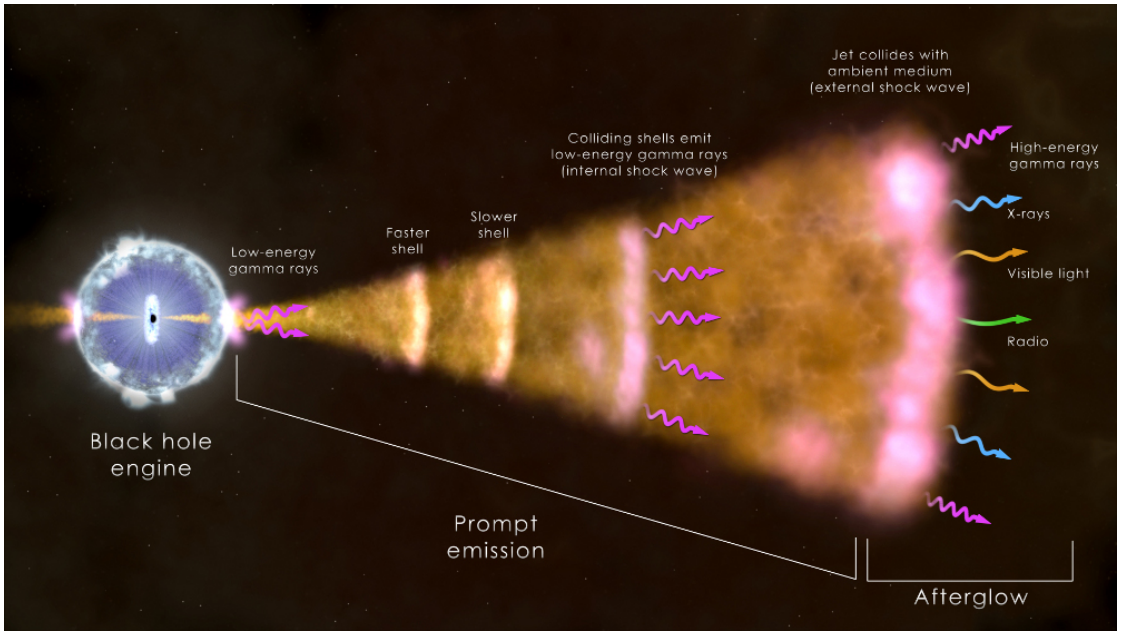
Binary Neutron Star Merger



Video-2

Short Gamma Ray bursts

- ultra-relativistic outflow, or ‘jet’
- GRB with duration < 2s (30%)
- Regions of little or no star formation
  - Rules out massive stars (origin of long GRBs)

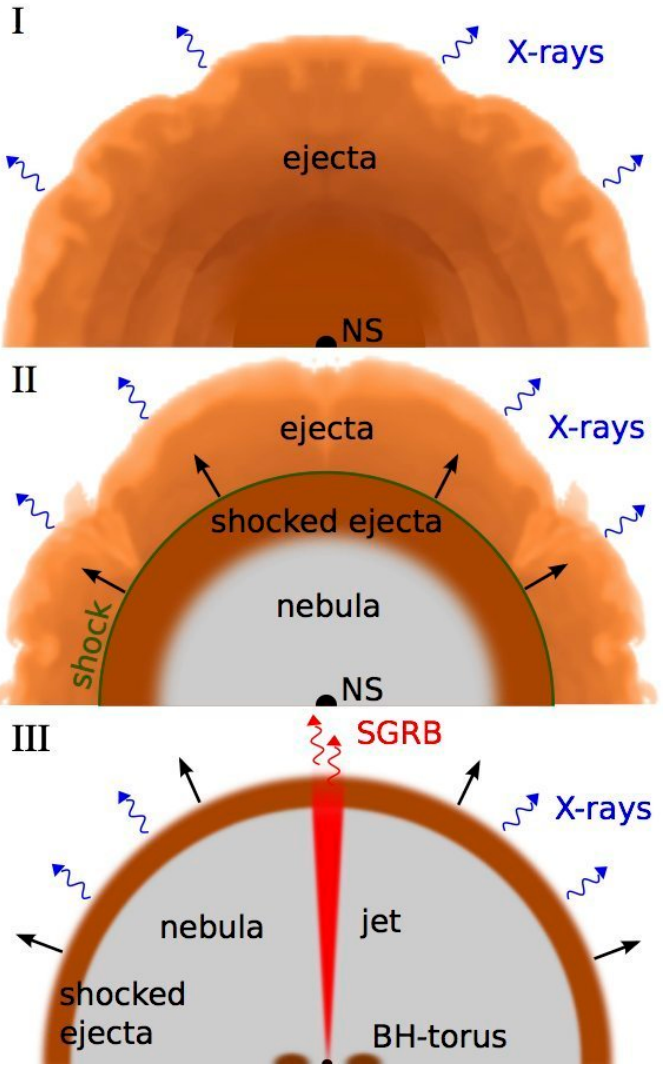


NASA

Short Gamma Ray bursts

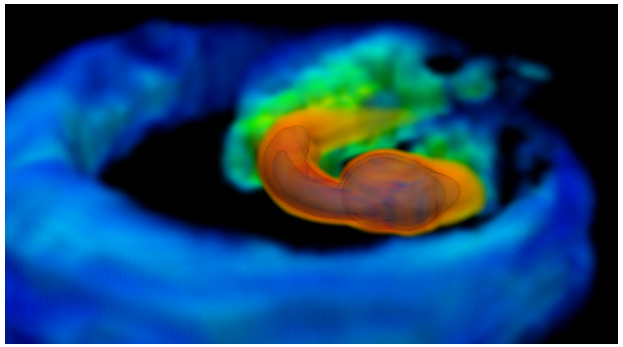
- culminated ultra-relativistic outflows
- with $\sim 10^{48}\mathrm{erg}$
- possible mechanisms:
  - Black hole formation with accretion disk
    - annihilation of neutrino and anti-neutrinos
    - strong magnetic fields

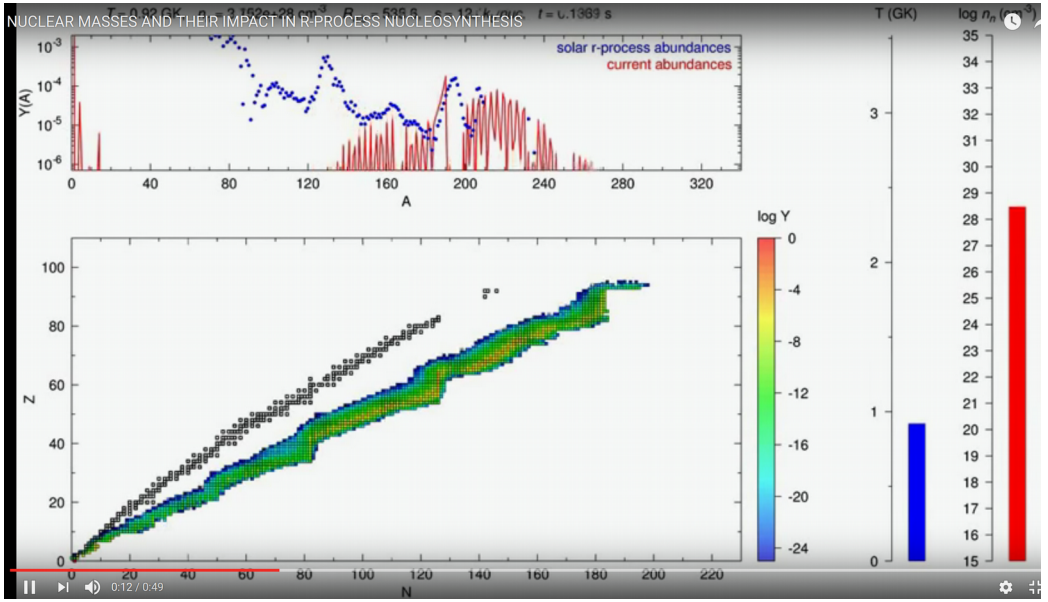
      (Blanford-Znajek process)



Ciolfi, Siegel

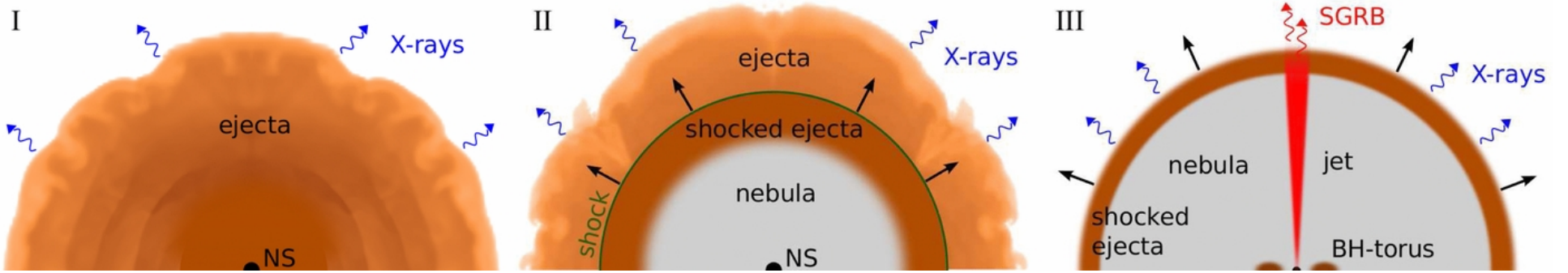
Released Material: Macronovae





https://www.youtube.com/watch?v=T44B9j3Vzxw

- Released material is neutron rich: possibility of r-processes
- EM counterpart in the near infrared hours/days after merger



Ciolfi et al.

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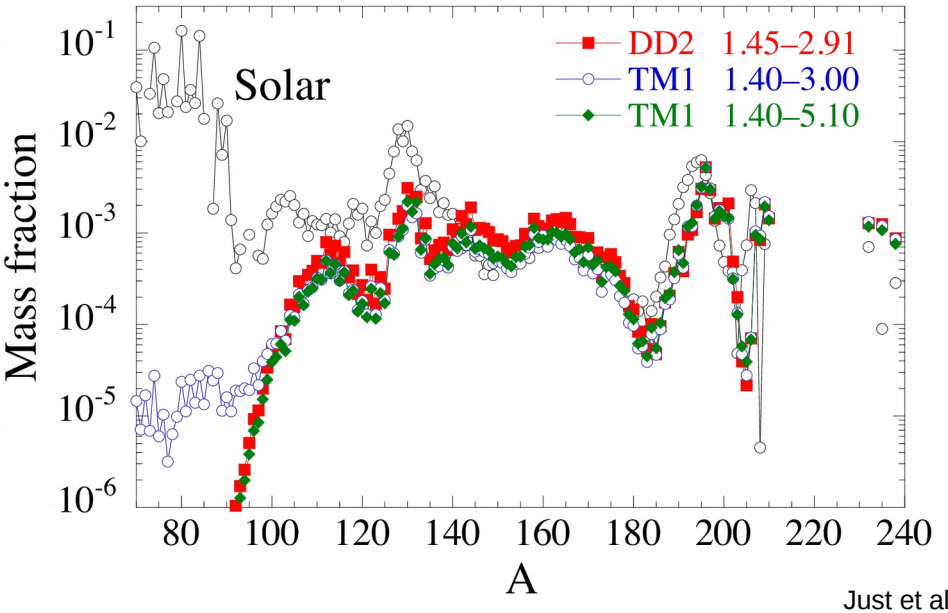


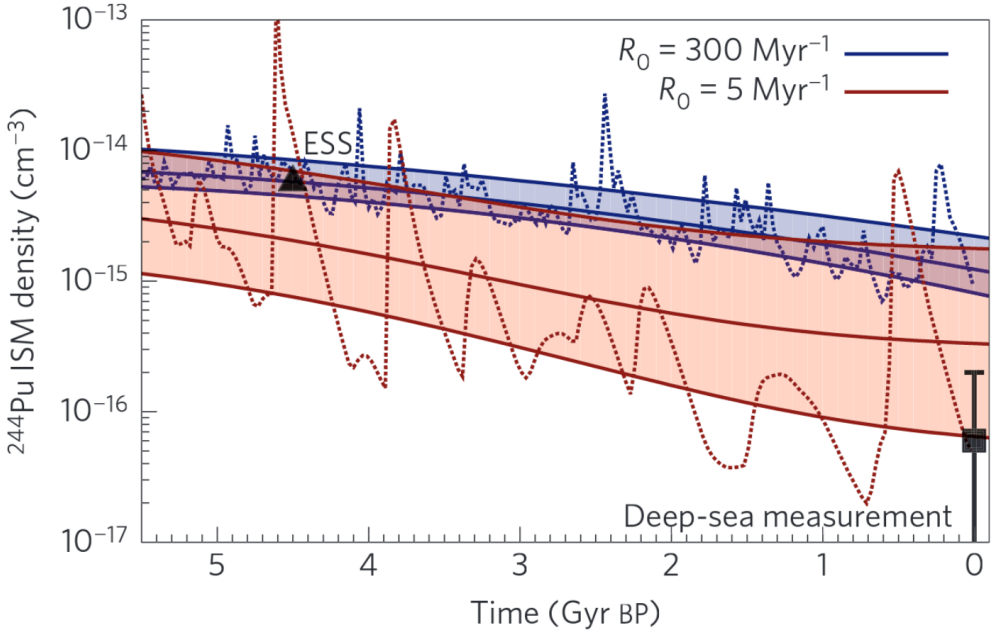
Just et al.

$$t_{\rm peak} = 4.9\ {\rm d} \times \left(\frac{M_{ej}}{10^{-2} M_\odot}\right)^{\frac{1}{2}} \left(\frac{\kappa}{10 {\rm cm}^2 {\rm g}^{-1}}\right)^{\frac{1}{2}} \left(\frac{v_{\rm ej}}{0.1}\right)^{-\frac{1}{2}}$$

Grossman et al.

Released Material: Macronovae

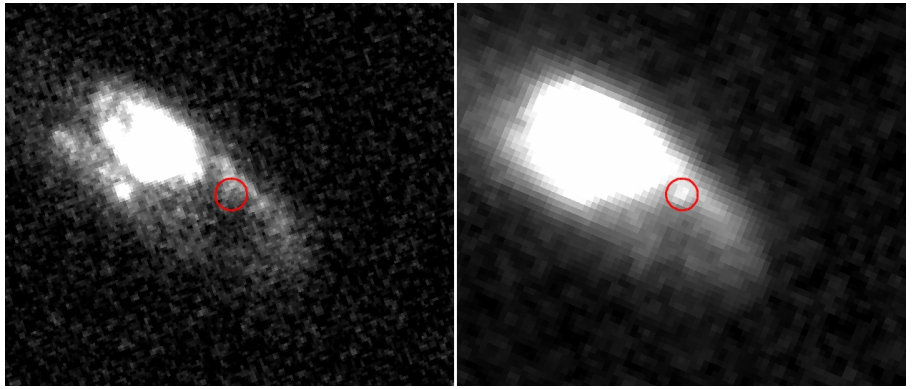
- Released material is neutron rich: possibility of r-processes
- Deep-sea measurements support this observation



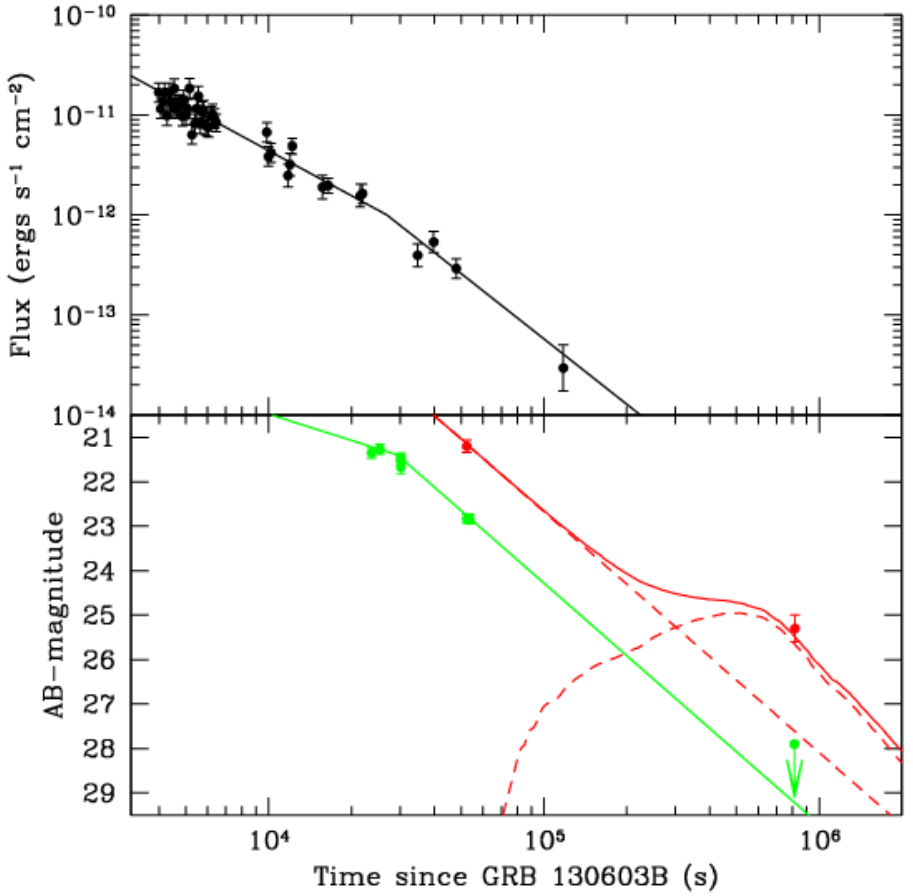
Hotokezaka et al.

Released Material: Macronovae

- sGRB 130603B



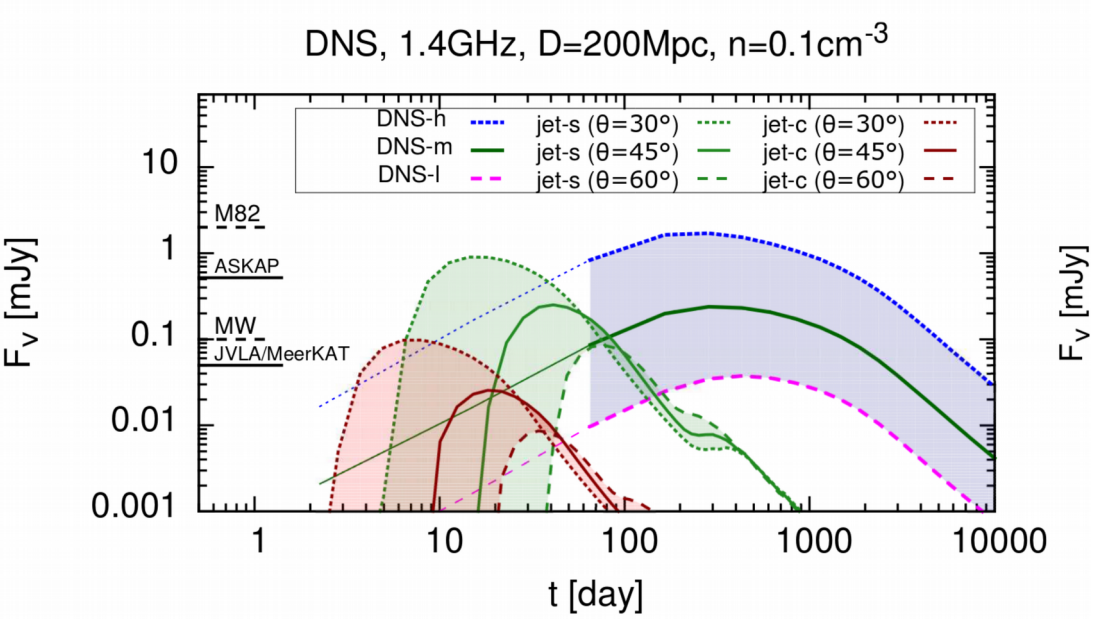
- Also: sGRB050709 and sGRB 060614



Tanvir et al., 2013

Released Material: Radio-Flares

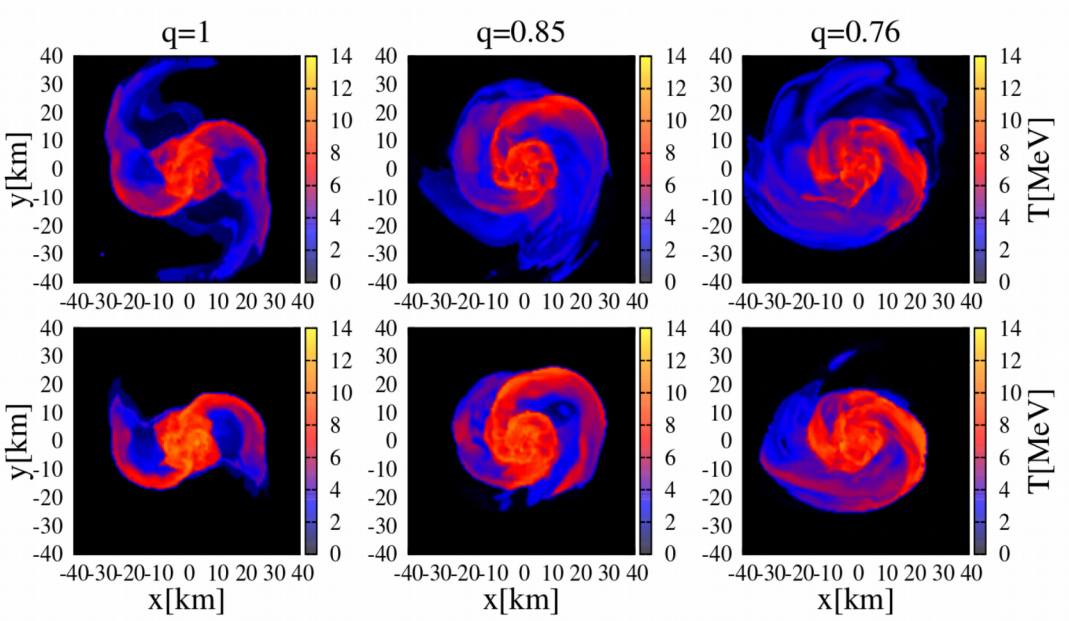
- Mildly and subrelativstic material
- Internal energy converted to accelerate electrons and amplify magnetic field
- synchrotron emission of shock accelerated electrons in an amplified magnetic field



Hotokezaka et al.

Neutrino Emission

- Shock creation leads to temperatures increase
- 10^{53} erg released in form of neutrinos
- Most neutrinos energies of around 20MeV



Lehner et al.

Neutrino Emission

- 10^{53} erg released in form of neutrinos

We will be happy if we see one neutrino

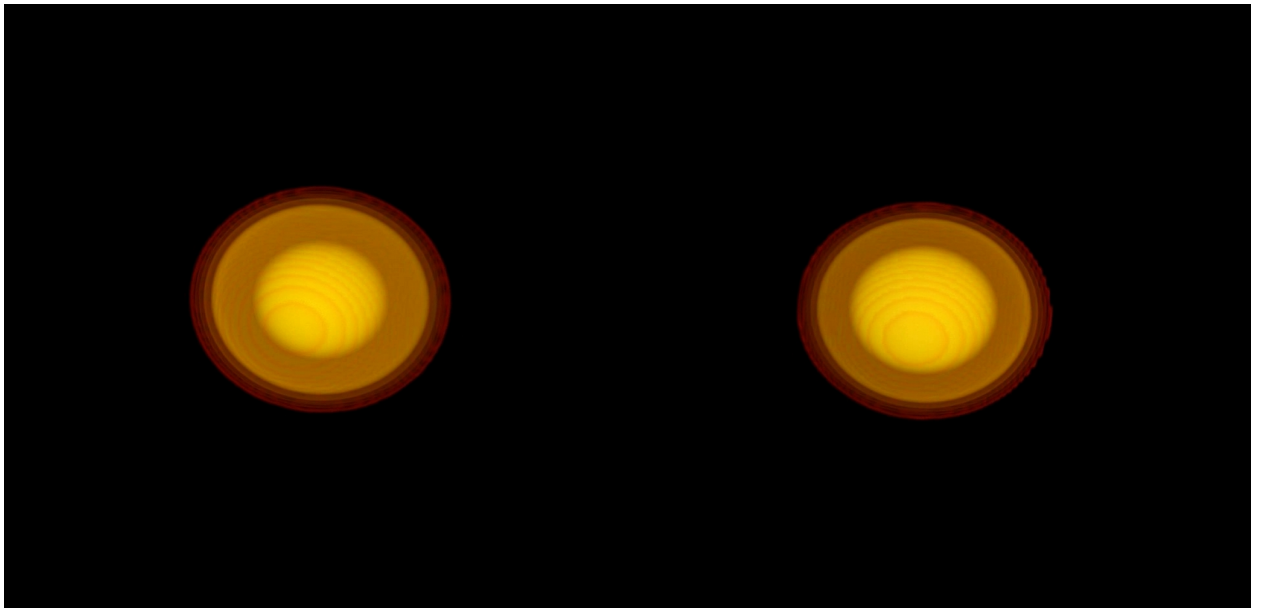
BNS at 10kpc

EoS	q	t [ms]	$\langle E_{\bar{\nu}_e} \rangle$ [MeV]	$\langle E_{\nu_e} \rangle$ [MeV]	$L_{\bar{\nu}_e}$ [10^{53} erg/s]	R_ν [#/ms]
NL3	1.0	3.4	18.5 (22.4)	15.2 (18.3)	0.7	18
NL3	0.85	3.0	15.6 (18.7)	12.6 (15.1)	0.8	18
DD2	1.0	3.3	18.3 (22.1)	14.6 (17.4)	1.1	28
DD2	0.85	2.8	18.1 (21.7)	15.1 (18.0)	1.0	25
DD2	0.76	2.4	19.7 (23.9)	14.8 (17.9)	1.3	36
SFHo	1.0	3.5	24.6 (29.7)	23.5 (28.3)	3.5	121
SFHo	0.85	3.9	17.8 (21.3)	15.3 (17.9)	2.0	50

Lehner et al.

Summary

- First detection of GWs inaugurated the field of gravitational wave astronomy
- Waiting for interesting BHNS or NSNS detection
  - GWs
  - Neutrinos
  - SGRBs
  - Macronovae
  - Radio Flares



Video-3