A simultaneous model fitting of GW and EM data of mergers: breaking model degeneracies in GW170817

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<u>Outline</u>

1. GW170817
2. GRB 170817A
3. GW170817 afterglow modeling
4. Gravitational Waves modeling
5. Joint fit of gravitational and electromagnetic data
6. Results: GW170817
7. Results: GW170817, but further!
8. Conclusions

Joint fit of gravitational and electromagnetic domains

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Break/ease model degeneracies

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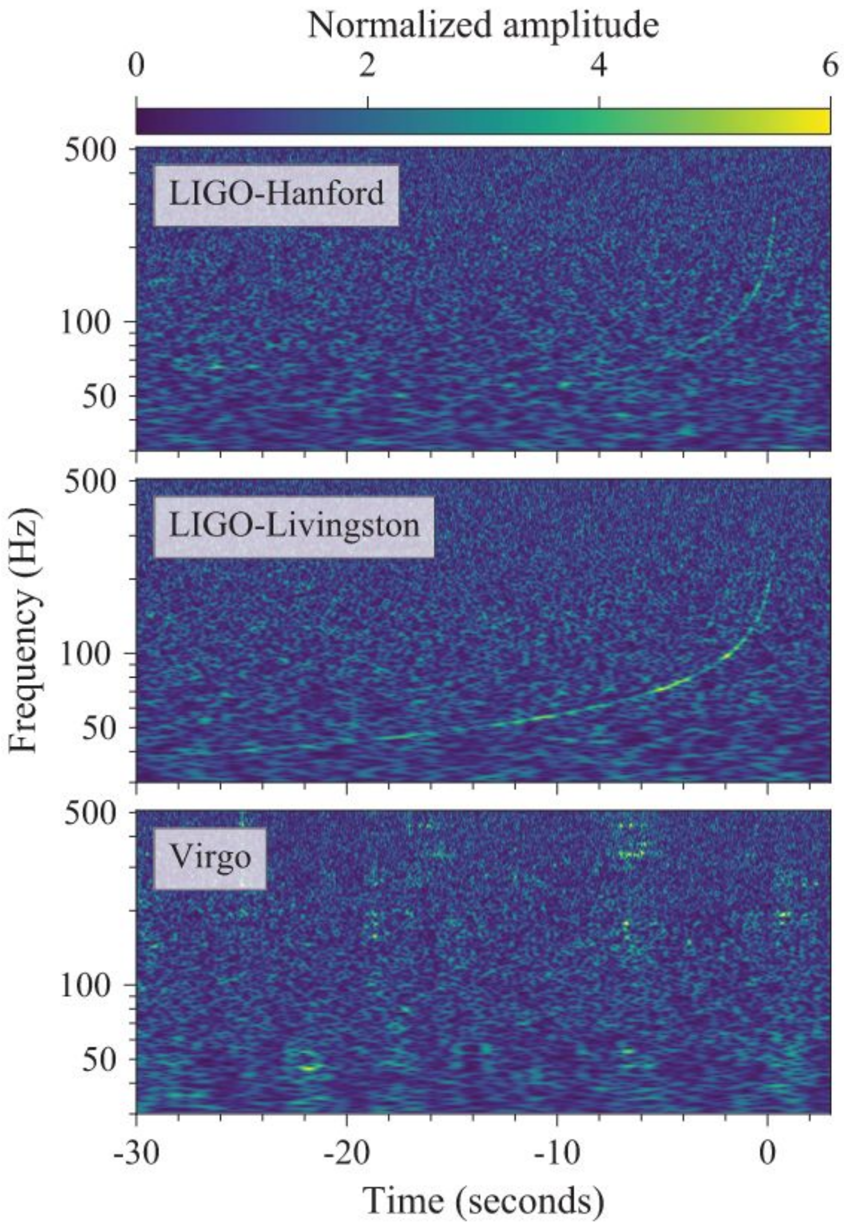
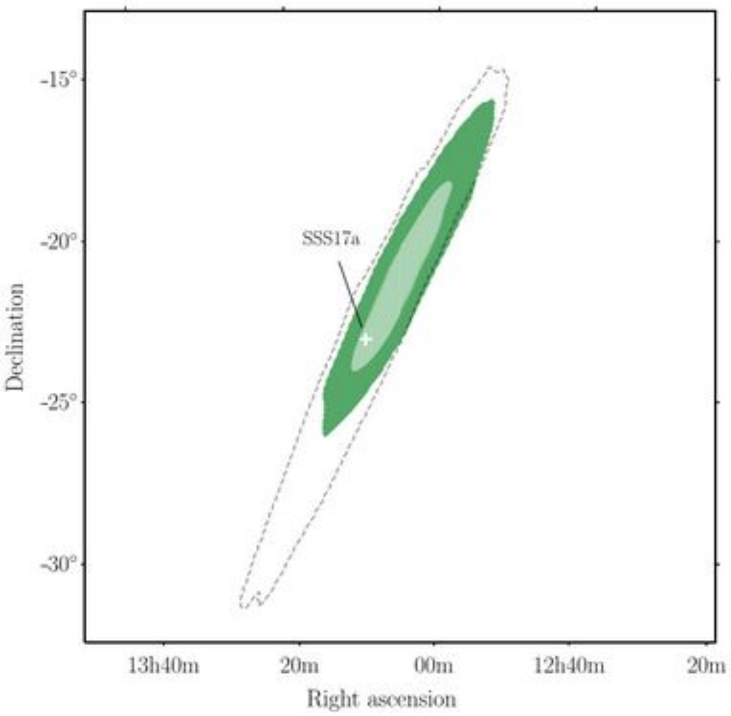
More accurate measurements of the <u>inclination</u> (geometry)



Abbott et al, 2017

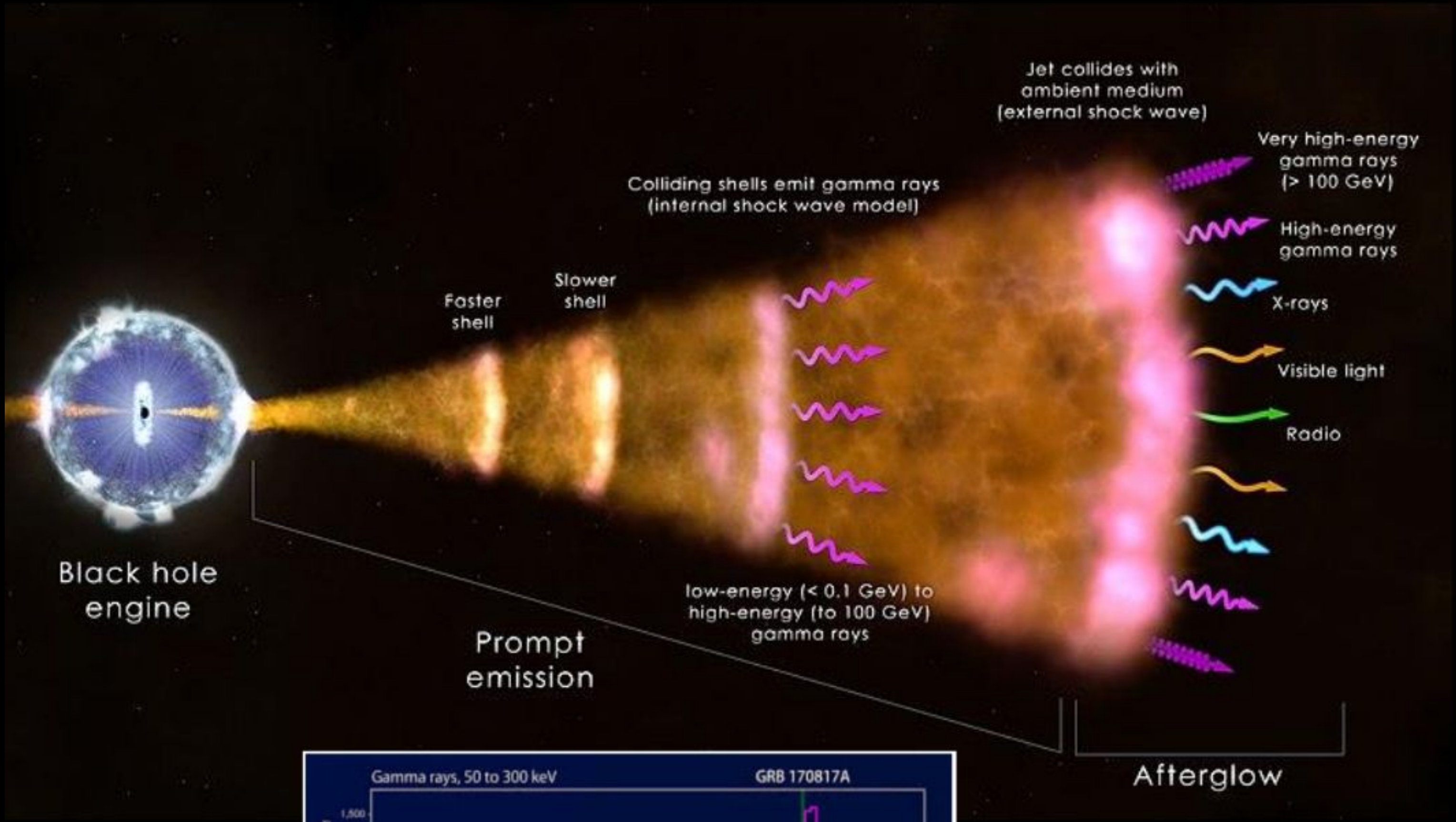
GW170817

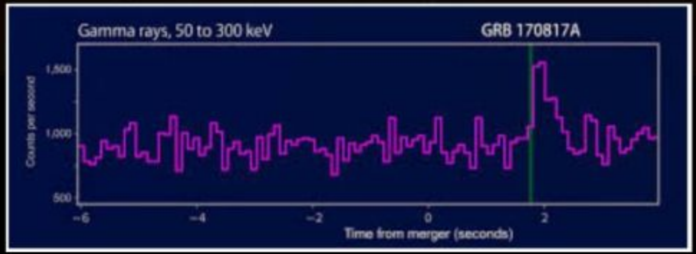
- Detectable for about 100 seconds.
- Relatively close distance: 41 Mpc.
- Binary neutron stars merger.



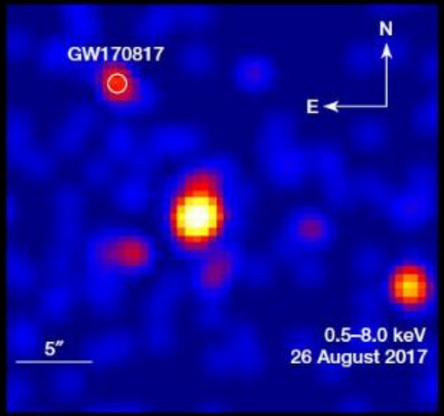
Abbott et al, 2019

GRB 170817A

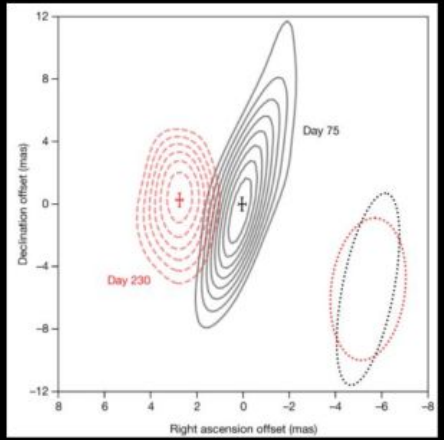




Fermi and INTEGRAL



Chandra observations
Troja et al, 2017



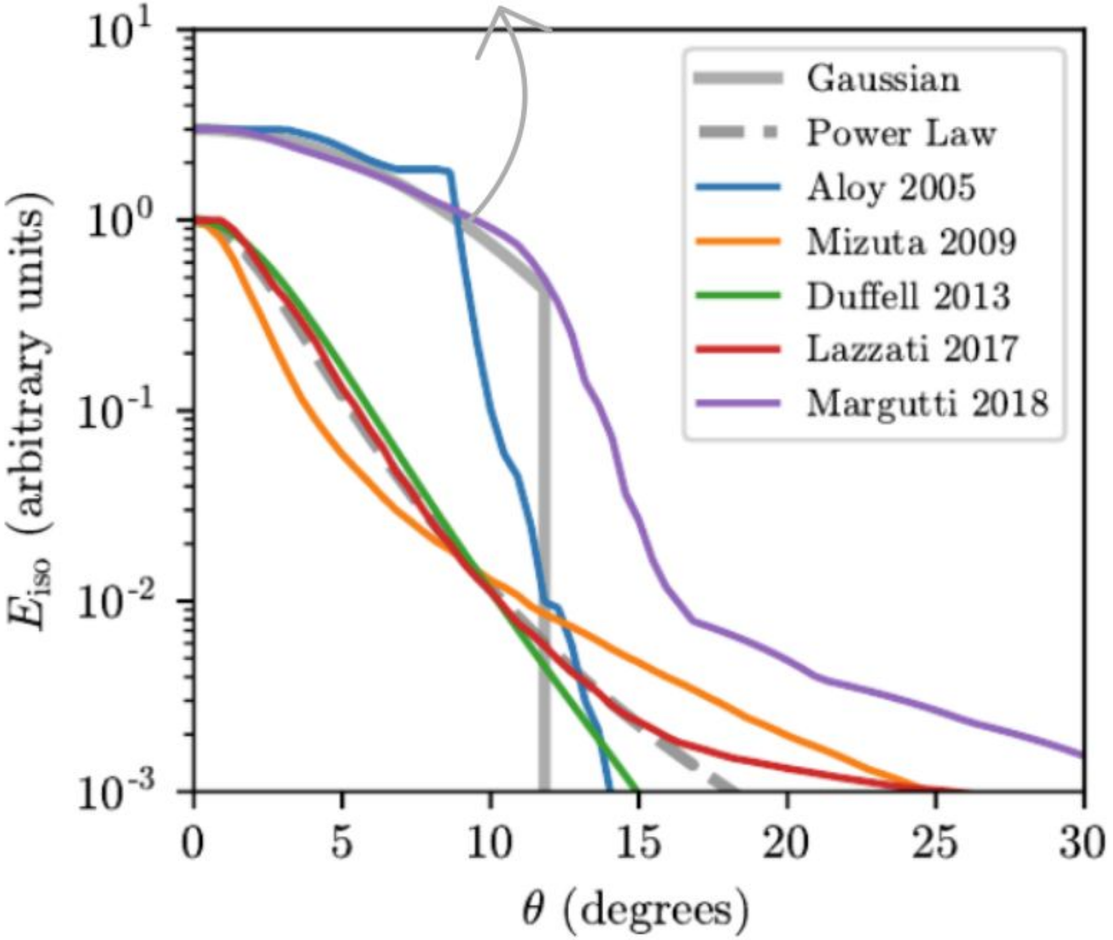
VLBI at 4.5 GHz
Mooley et al, 2017

GW170817 afterglow modeling

Gaussian structured jet

$$E(\theta) = E_0 \, e^{-\theta^2/2\theta_c^2}$$

Ryan et al, 2020



•Model: **`afterglowpy`** (*Ryan et al, 2020*)

θ_V	Jet orientation
θ_c	Opening angle of the jet
E_0	Isotropic equivalent energy
n_0	homogeneous circumburst medium number density
θ_W	Jet total width
p	power-law slope of the electron population
ϵ_e	fraction of post-shock internal energy in the accelerated electron population
ϵ_B	fraction of post-shock internal energy in magnetic field
d_L	luminosity distance - <u>FIXED</u>

GRB 170817A - Afterglow

Low luminosity of the Gamma ray emission

Atypical temporal evolution of the afterglow

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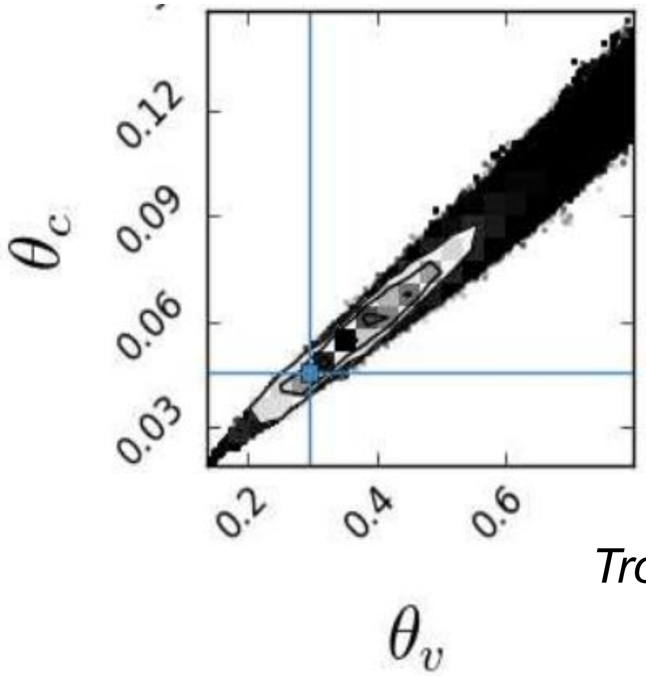
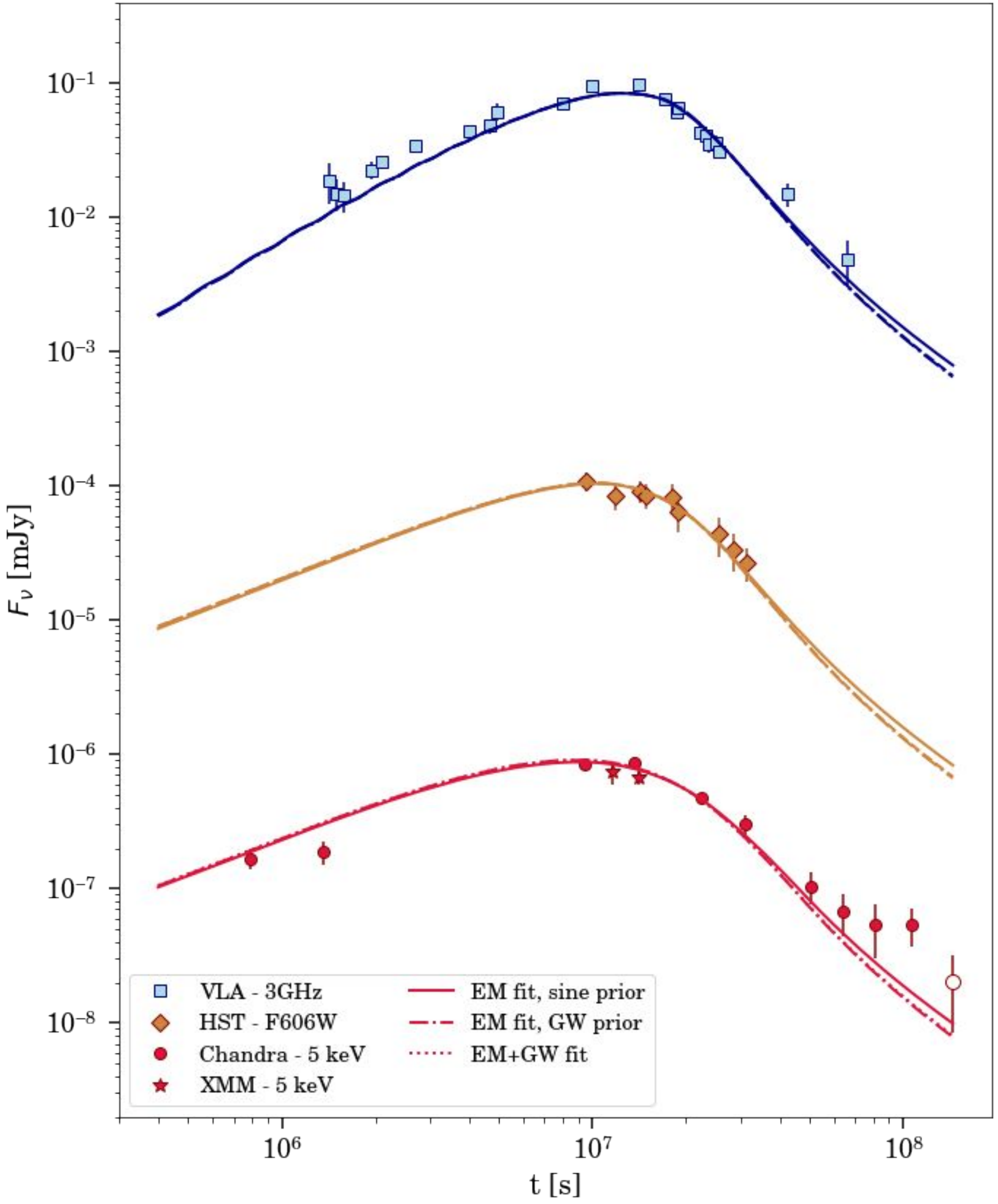
Highly-relativistic structured jet seen at 20-30° from its axis



Degeneracy between the angles

A proper scaling of them leads to similar light curves

Troja et al. 2019

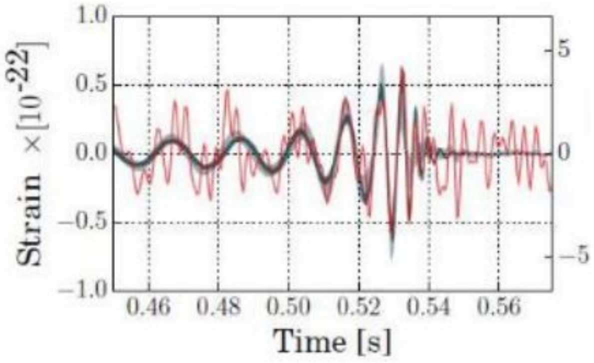


Gravitational waves modeling

1	$\mathcal{M}$	Chirp mass	or	m_1	Mass 1
2	q	Mass ratio		m_2	Mass 2
3	a_1	Spin amplitude 1			
4	a_2	Spin amplitude 2			
5	θ_1	Tilt angle between the spin 1 and the orbital angular momentum			
6	θ_2	Tilt angle between the spin 2 and the orbital angular momentum			
7	$\phi_{1,2}$	Azimuthal angle between the spin vectors			
8	ϕ_{jl}	Azimuthal angle between total angular momentum and orbital angular momentum			
9	d_L	Luminosity distance			
10	DEC	Declination	FIXED to NGC 4993		
11	RA	Right ascension			
12	$\cos(\theta_{JN})$	Cosine of the inclination angle	or	θ_{JN}	Inclination angle
13	ψ	Polarization angle			
14	ϕ	Phase			
15	Λ_1	Tidal deformability parameters of the primary neutron star	or	$\tilde{\Lambda}$	Dimensionless tidal parameters
16	Λ_2	Tidal deformability parameters of the secondary neutron star		$\delta\tilde{\Lambda}$	

$$m_1 \geq m_2$$

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$



+ 10 calibration parameters for each detector

$$\tilde{\Lambda} = \frac{16}{13}\frac{(m_1 + 12m_2)m_1^4\Lambda_1 + (m_2 + 12m_1)m_2^4\Lambda_2}{(m_1 + m_2)^5}$$

Joint fit of gravitational and electromagnetic data

1. Fit of GW data
2. Fit of EM data
3. Fit of EM data with GW-informed prior on the viewing angle
4. Joint fit of EM and GW datasets

$$\text{Posterior} = \frac{\text{Likelihood x Prior}}{\text{Evidence}}$$

Likelihood = EM Likelihood x GW Likelihood

Gaussian distributions

3 relevant **parameter sets:**

Electromagnetic
→ $E_0, \theta_c, \theta_W, n_0, p, \epsilon_e, \epsilon_B$

Electromagnetic and gravitational wave
→ θ_V

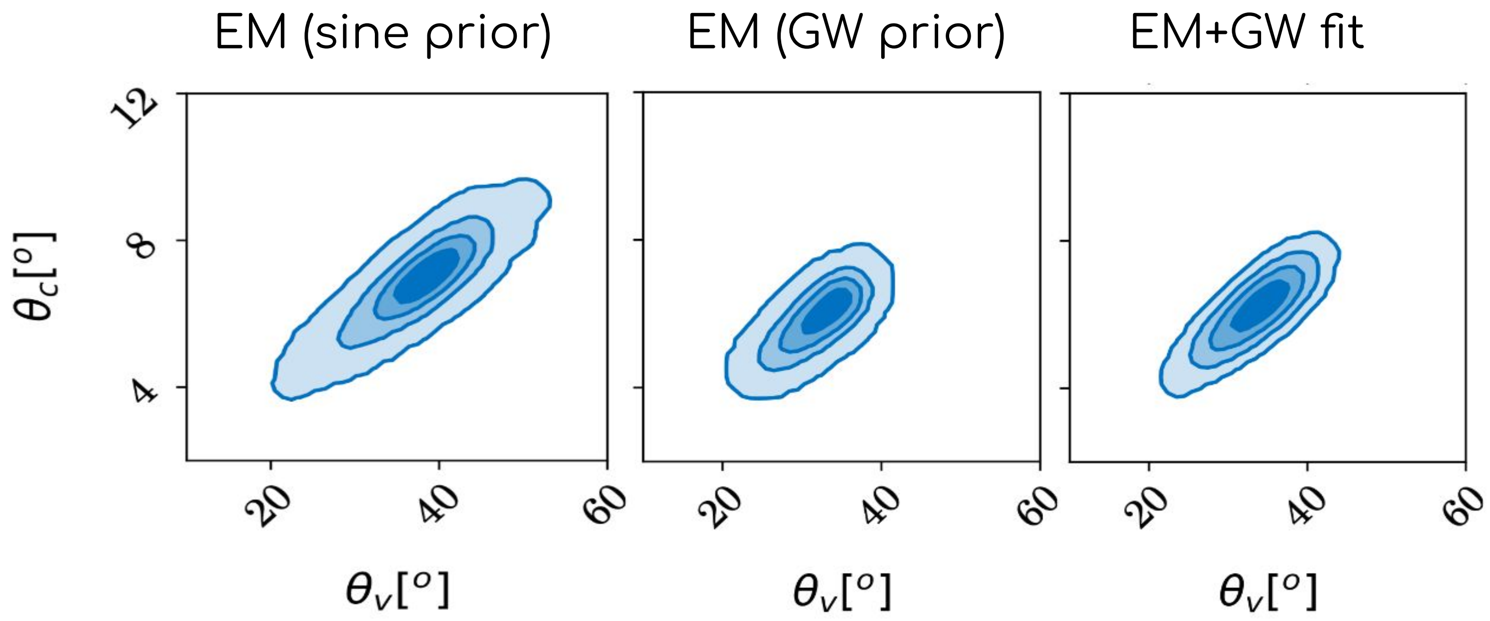
Gravitational wave
-> $mass\ ratio, chirp\ mass, spins$ ...

Joint fit of GW and GRB data

Preliminary

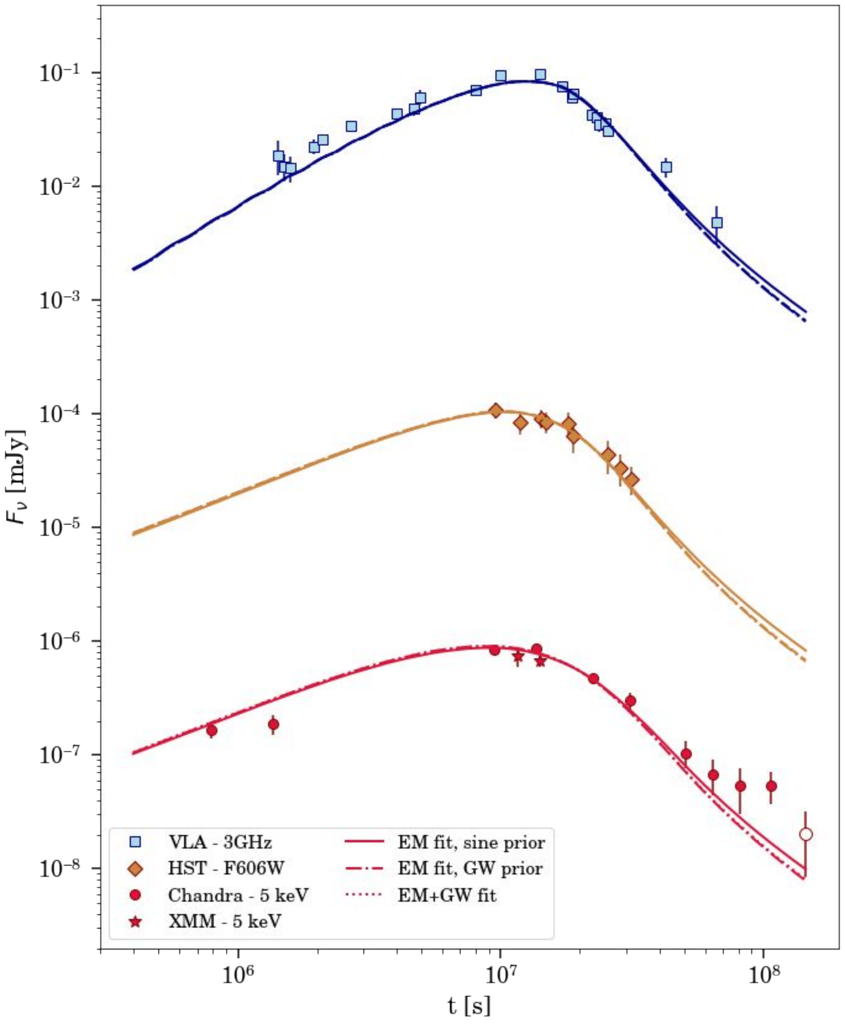
$\theta_v = 90° - |\theta_{JN} - 90°|$

	GW-only	EM-only (sine prior)	EM-only (GW-informed prior)	EM+GW
θ_v [°]		39^{+2}_{-2}	33^{+2}_{-2}	34^{+2}_{-2}
θ_{JN} [°]	151^{+3}_{-3}			146^{+2}_{-2}

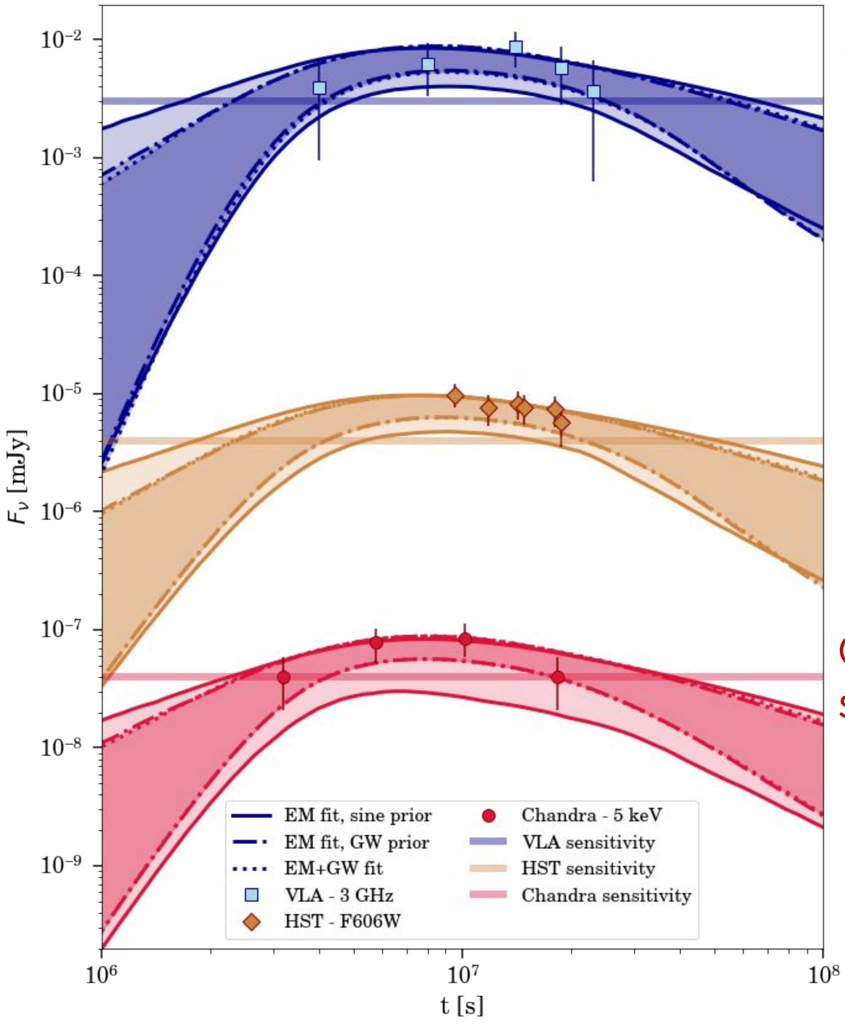


GW170817, but further!

Preliminary



d_L = 136.5 Mpc



VLA sensitivity

HST sensitivity

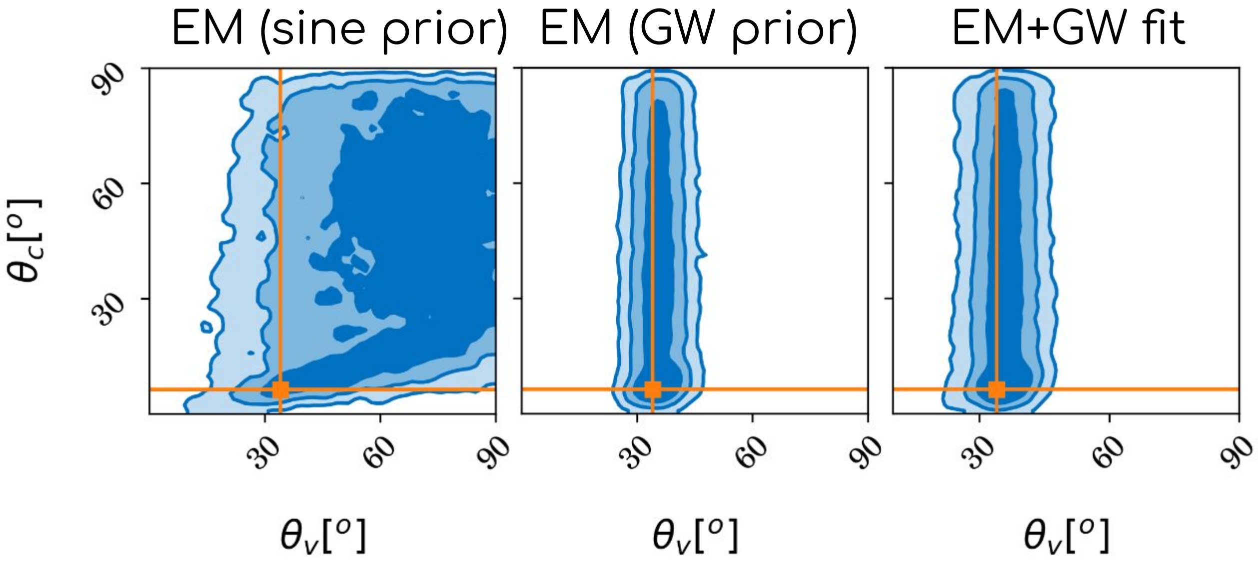
Chandra sensitivity

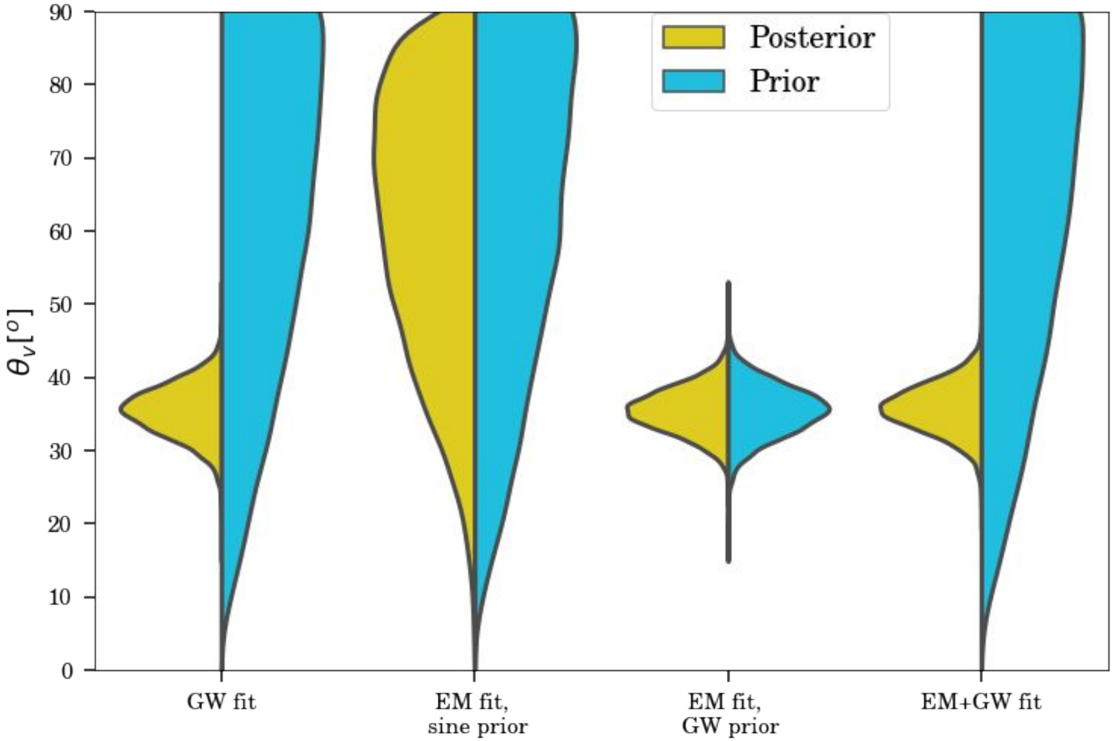
d_L = 136.5 Mpc

GW170817, but further!

Preliminary

	GW-only	EM-only (sine prior)	EM-only (GW-informed prior)	EM+GW
θ_v [°]		64^{+21}_{-17}	36^{+3}_{-3}	36^{+3}_{-3}
θ_{JN} [°]	150^{+6}_{-6}			144^{+3}_{-3}





Conclusions

Multimessenger astrophysics provide untapped, qualitatively different and complementary types of information

- The **geometry** of the system is of fundamental importance, as it can be linked to the r-processes in the kilonova and the relativistic jet theory;
- The GW information is useful to ease the degeneracy between the jet opening angle and the viewing angle.
- Fixing the luminosity distance, for a further event GWs are fundamental to retrieve the viewing angle, but the jet opening angle remains unconstrained.

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THANK YOU
for your attention!

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Degeneracy between distance and inclination