# Recent results on jets inferred properties

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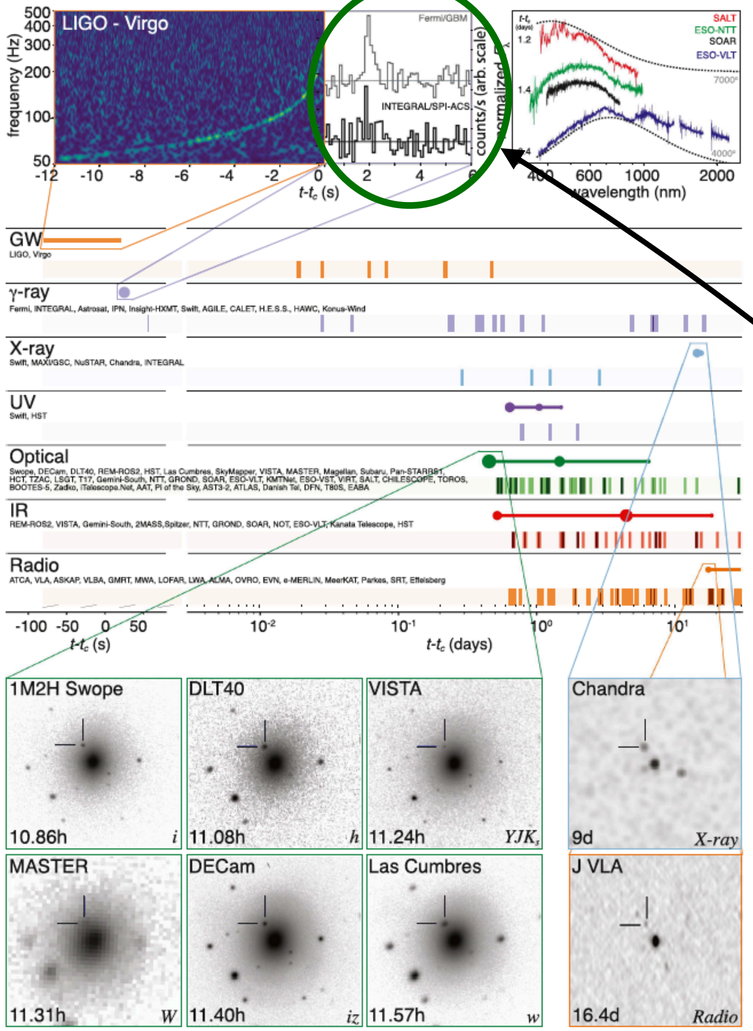
arXiv:2005.01754

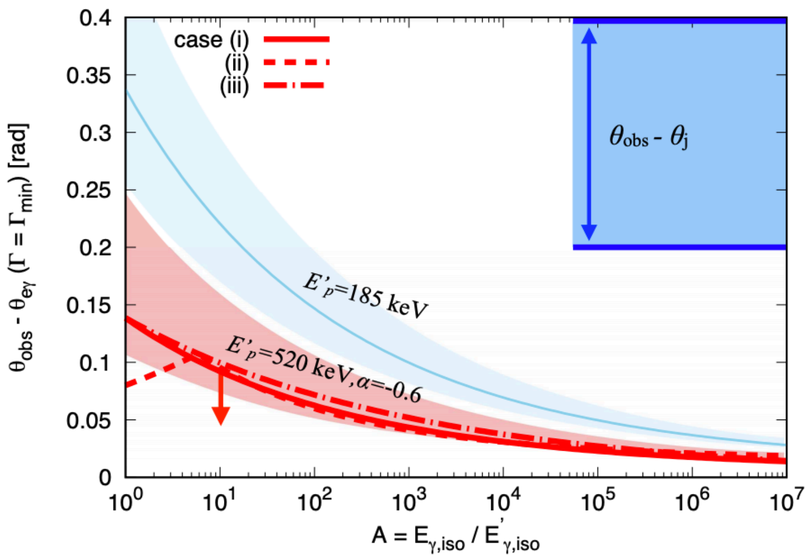
**TCAN workshop (Rochester & worldwide) July 2020**

erc TReX

# GW170817 - the second multimessanger

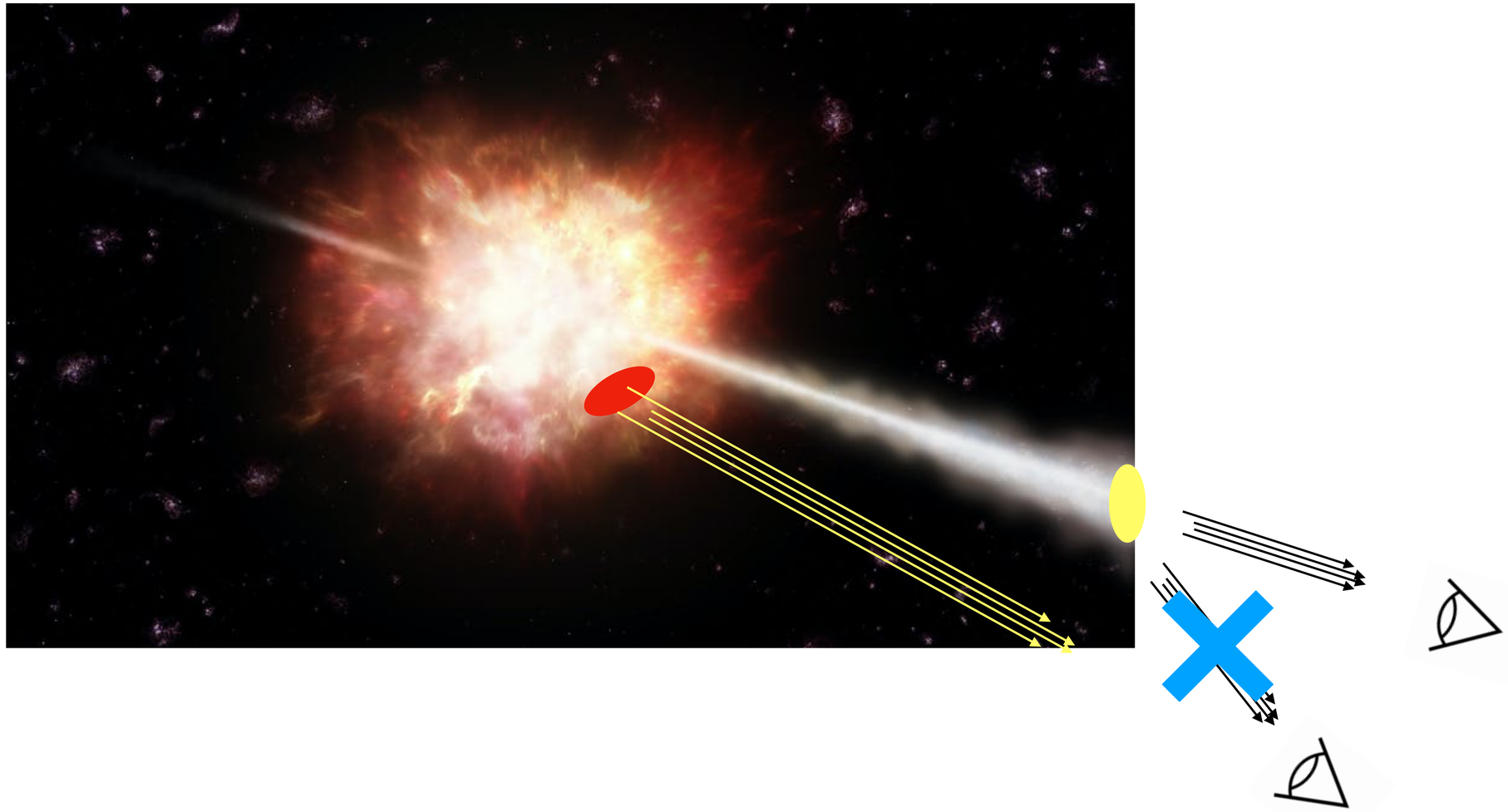
Credit: Abbott et al., 17



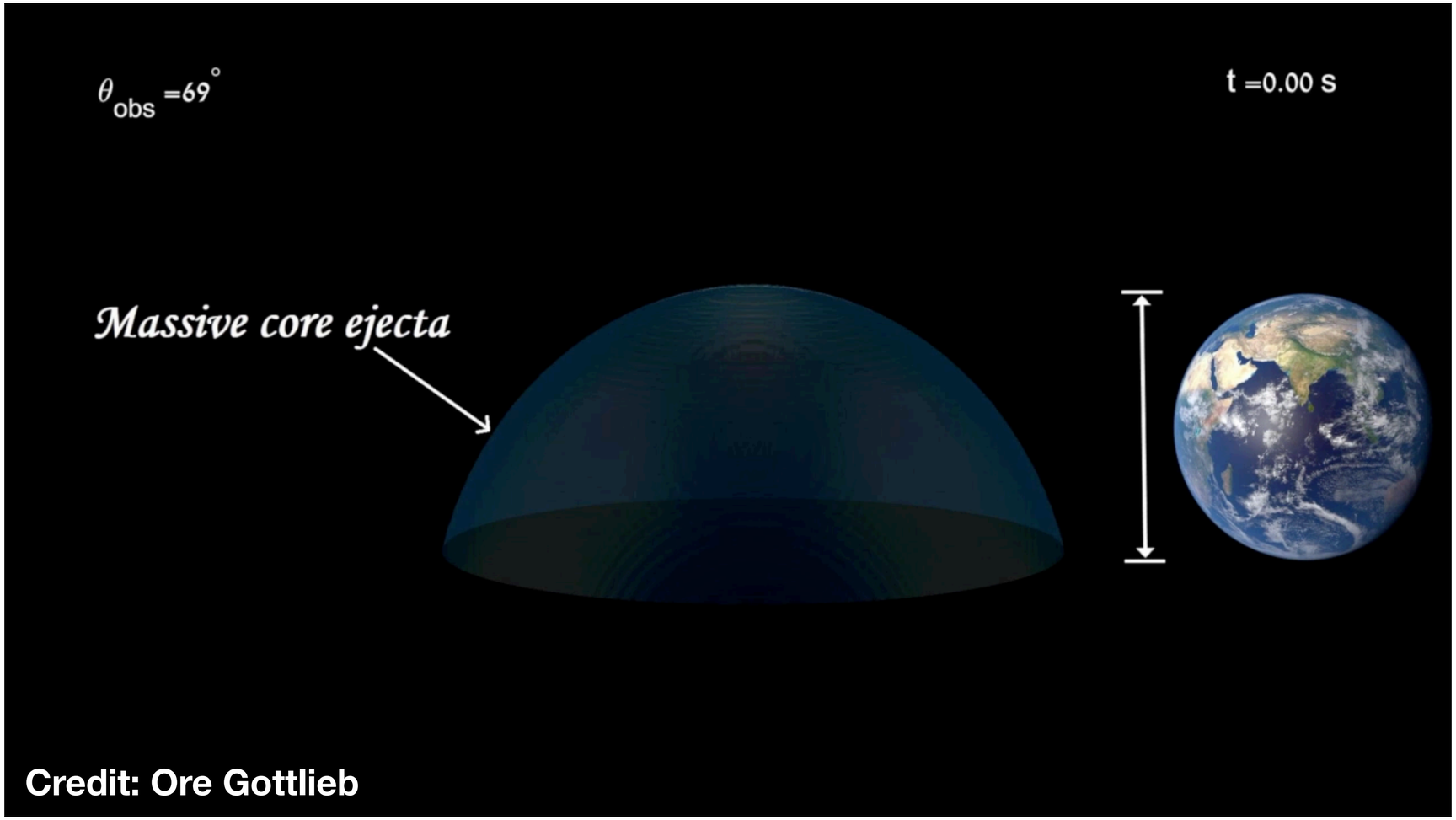




**This was not a regular sGRB viewed off axis (Matsumoto, Nakar, TP, 19a,b)**

**See Nakar 2019 for an excellent review on all aspects of 170817**

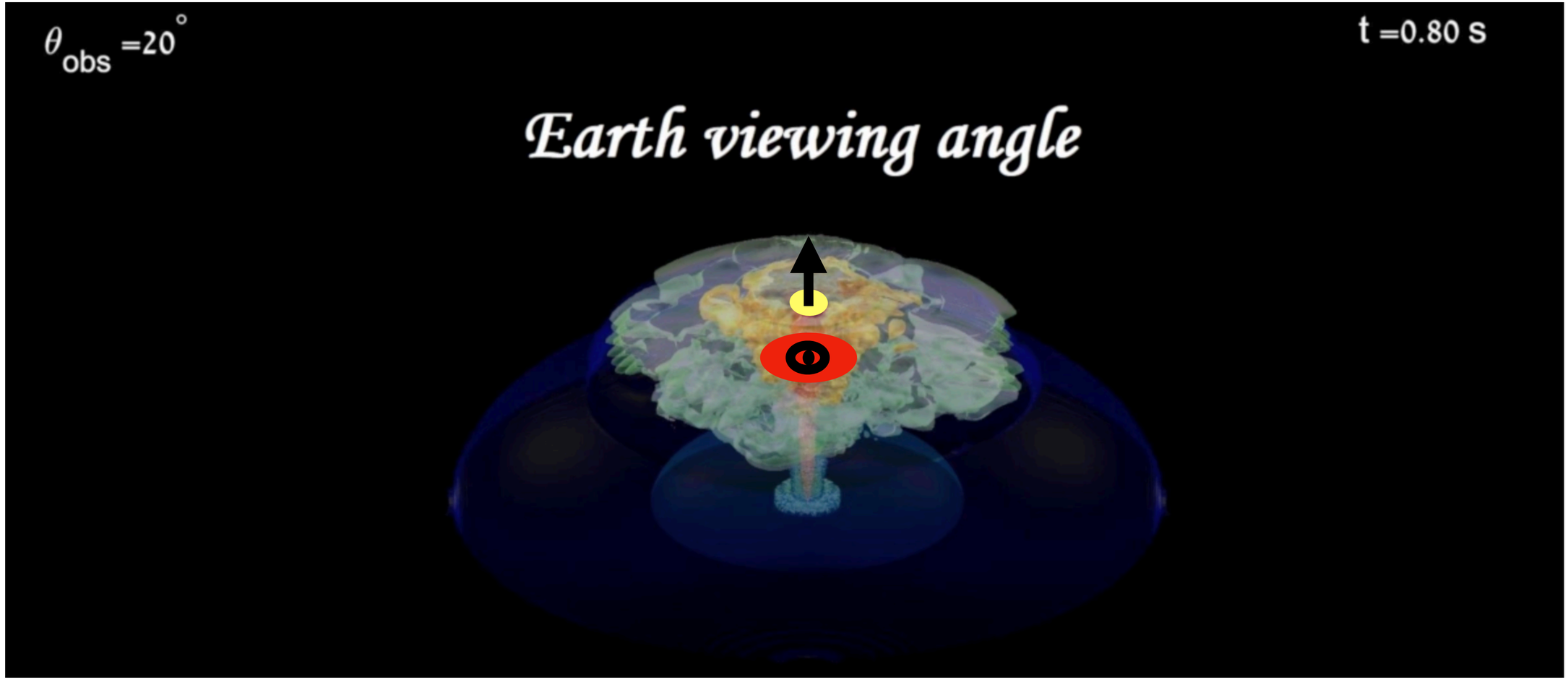


# The Initial Phase

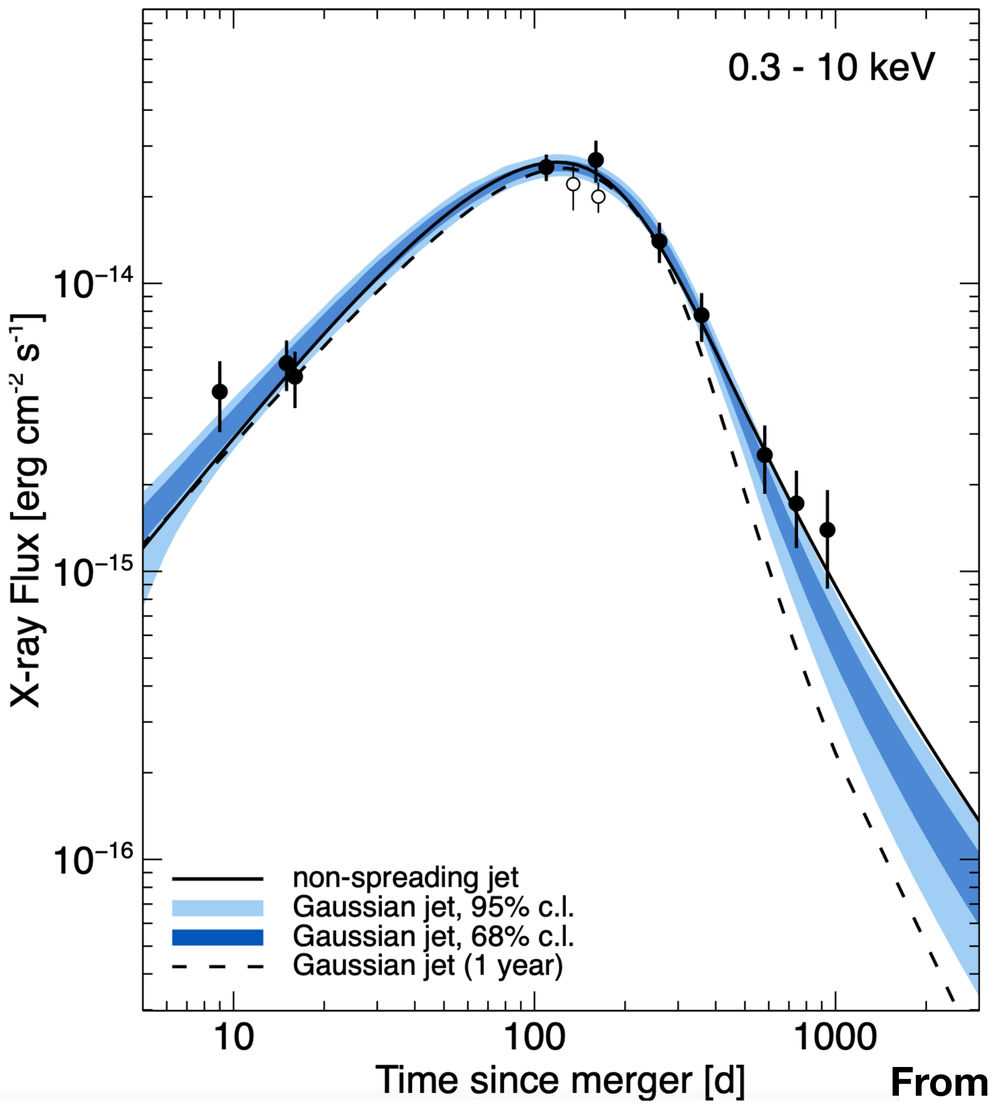


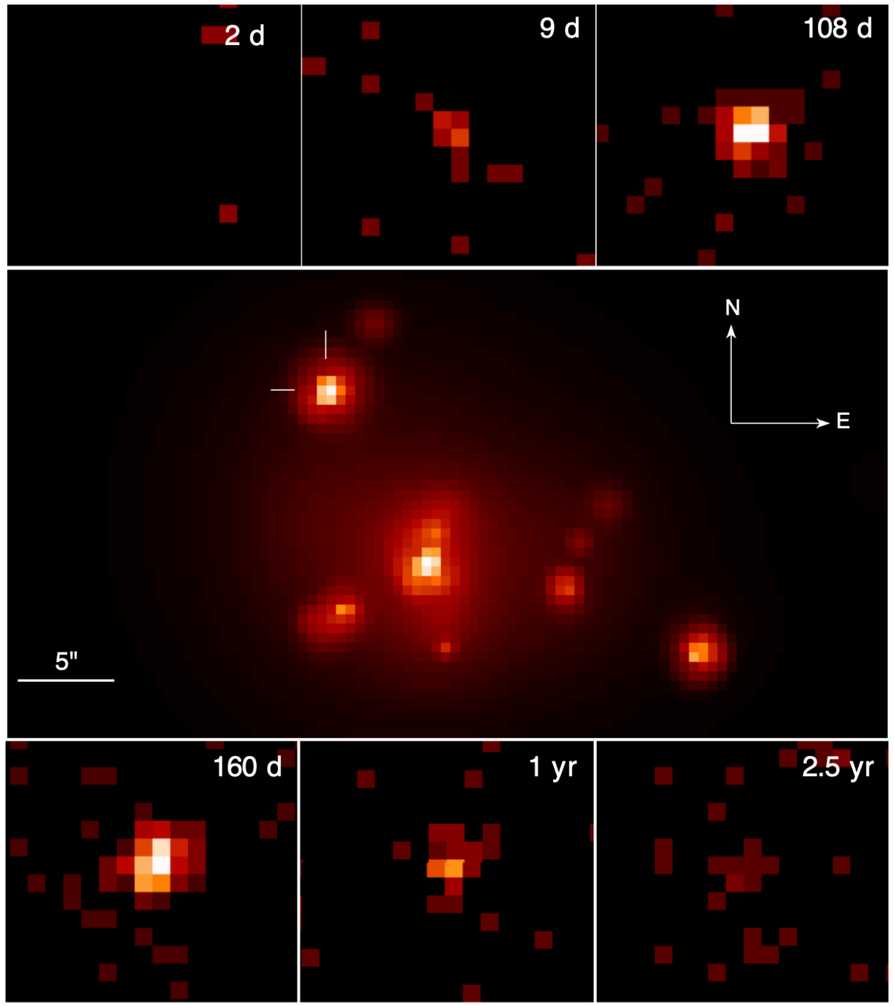

Credit: Ore Gottlieb

# The Initial Phase



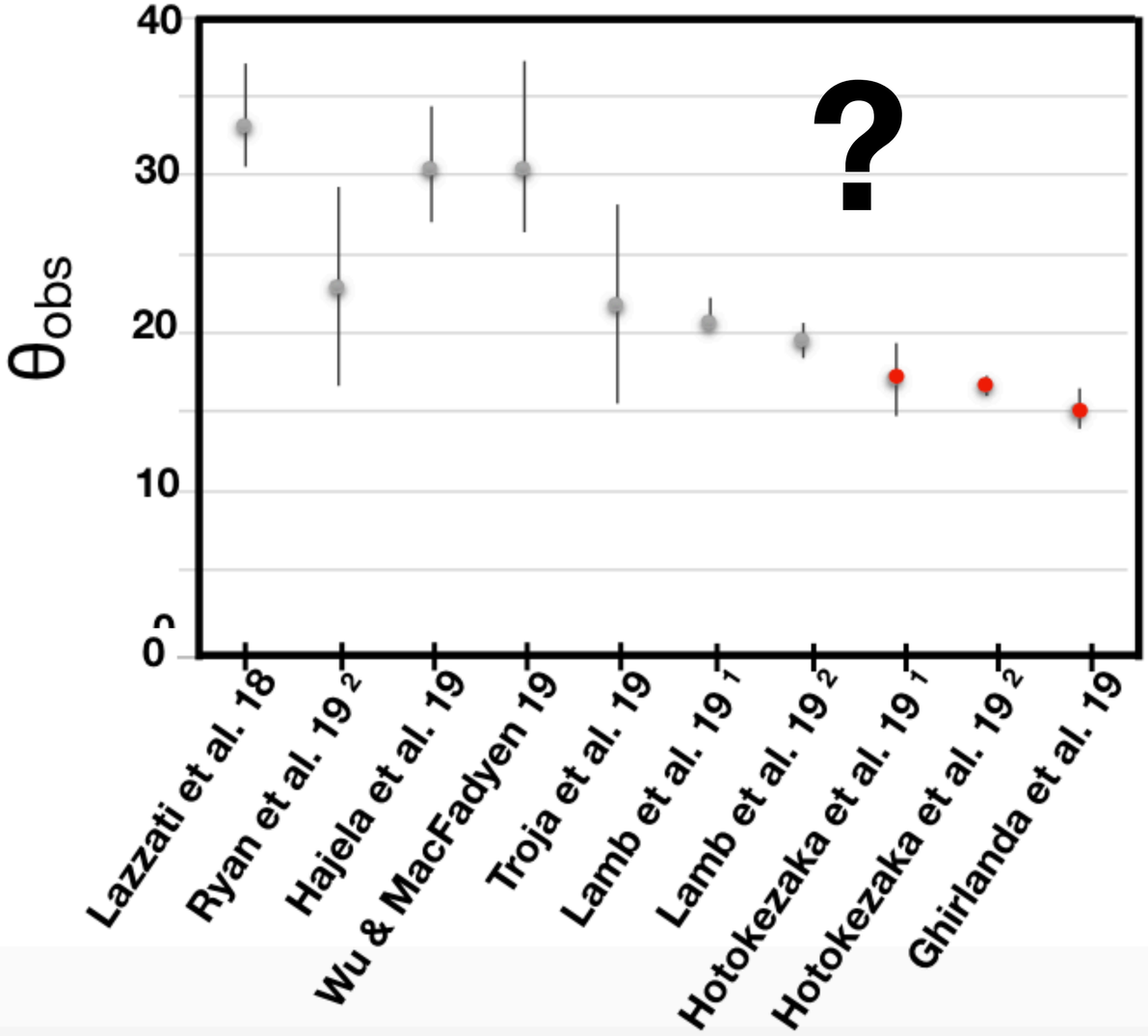
# GW 170817 Afterglow



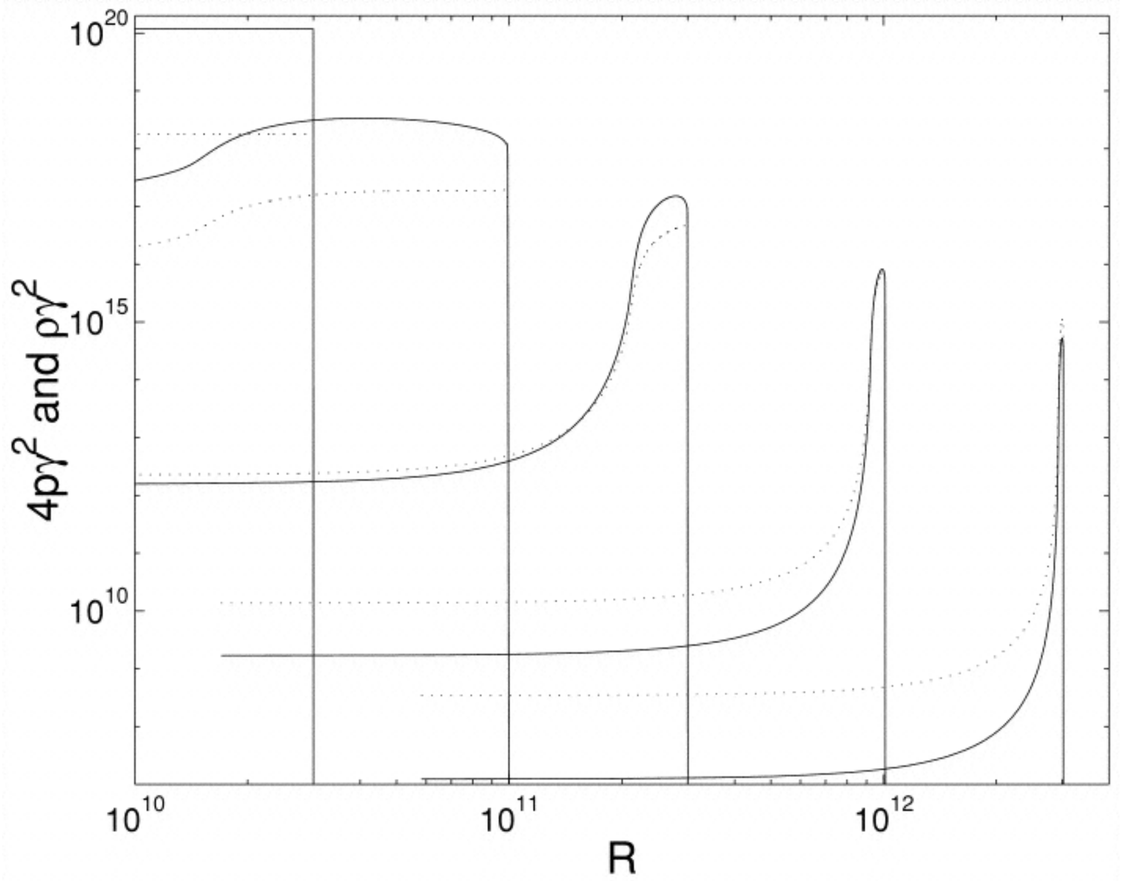




**From Troja + 2020**

# Viewing angle estimates



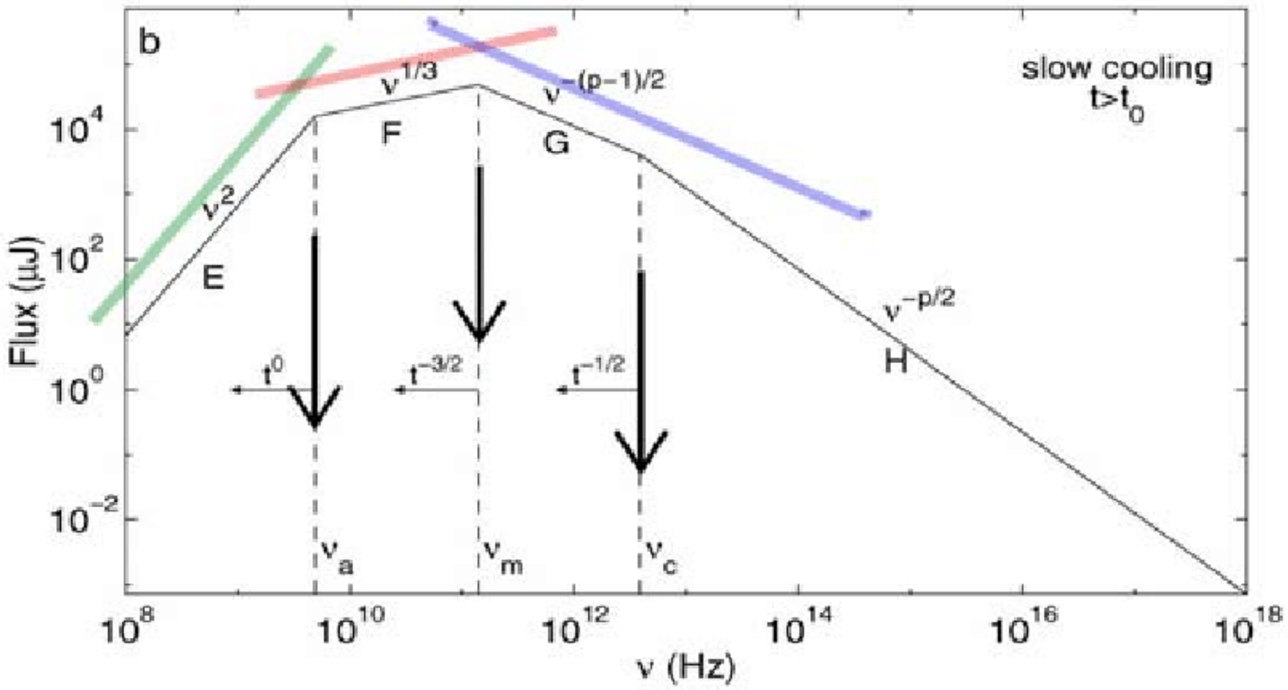

# Afterglow modeling




**E - Energy**
**n - external density**
**$\Gamma$ - the Lorentz factor**

**The Blast wave (Blandford McKee 76)**

# Synchrotron Radiation




Sari, TP, Narayan 98

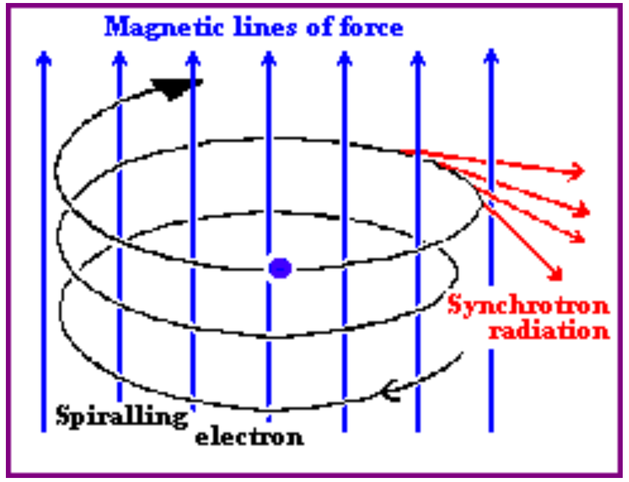
**The shock accelerate electrons and generates magnetic fields**

**$\varepsilon_e$ - electrons' equipartition parameter**

**p - electrons' distribution power law index**

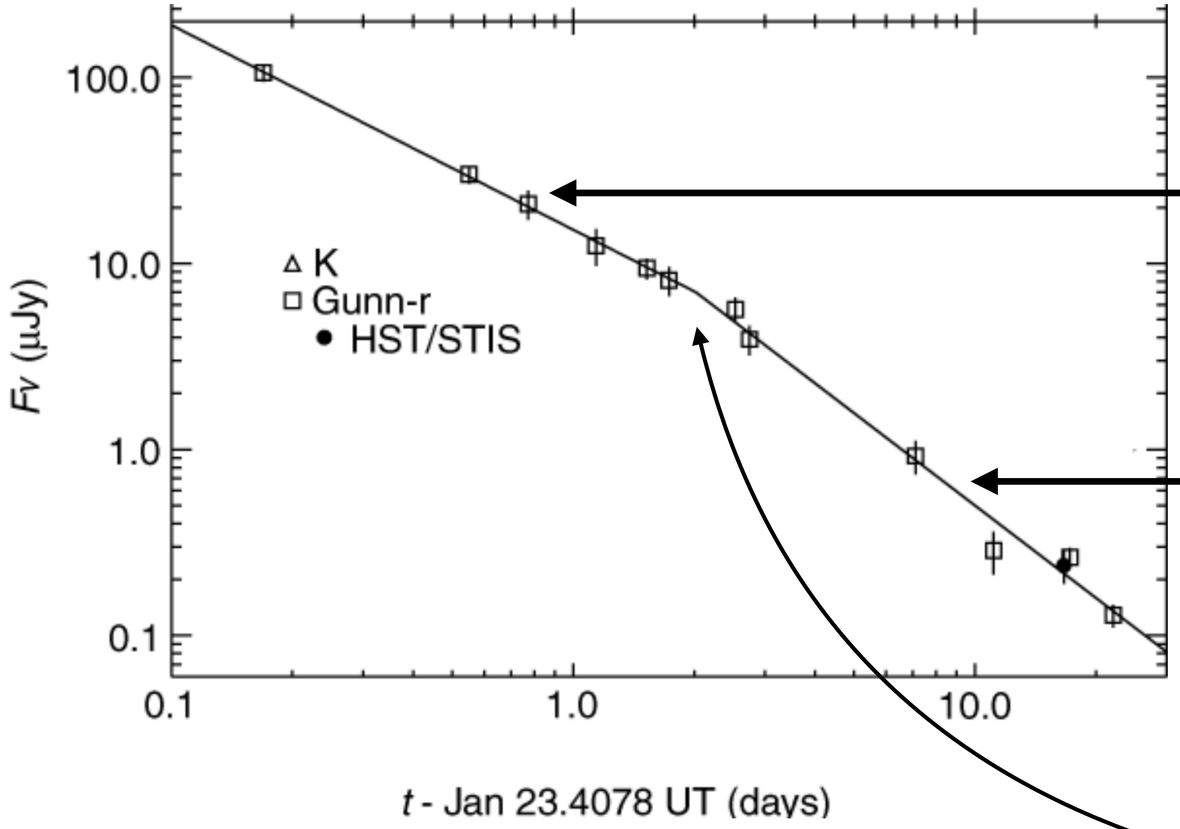
$$n(\gamma) \propto \gamma^{-p}$$

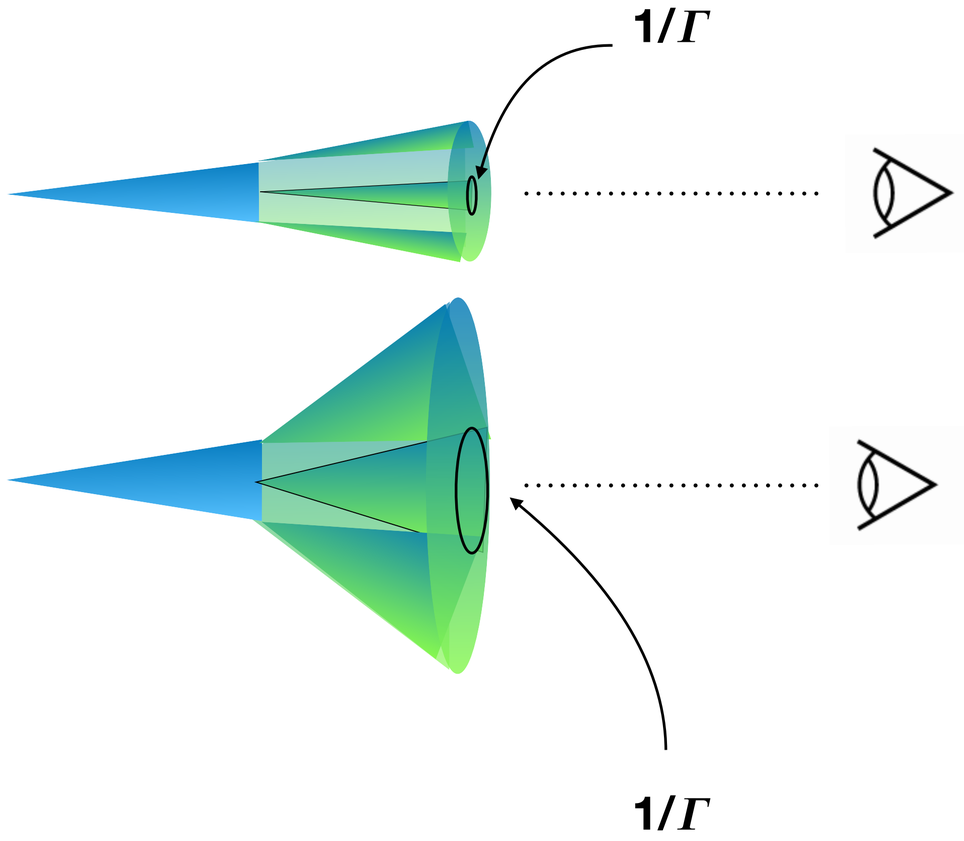
**$\varepsilon_B$ - magnetic equipartition parameter**



# Jet Break (Sari + 99)

**Figure 2: Optical and infrared light curves of the transient afterglow of GRB990123 from 4 hours to 23 days after the burst.**

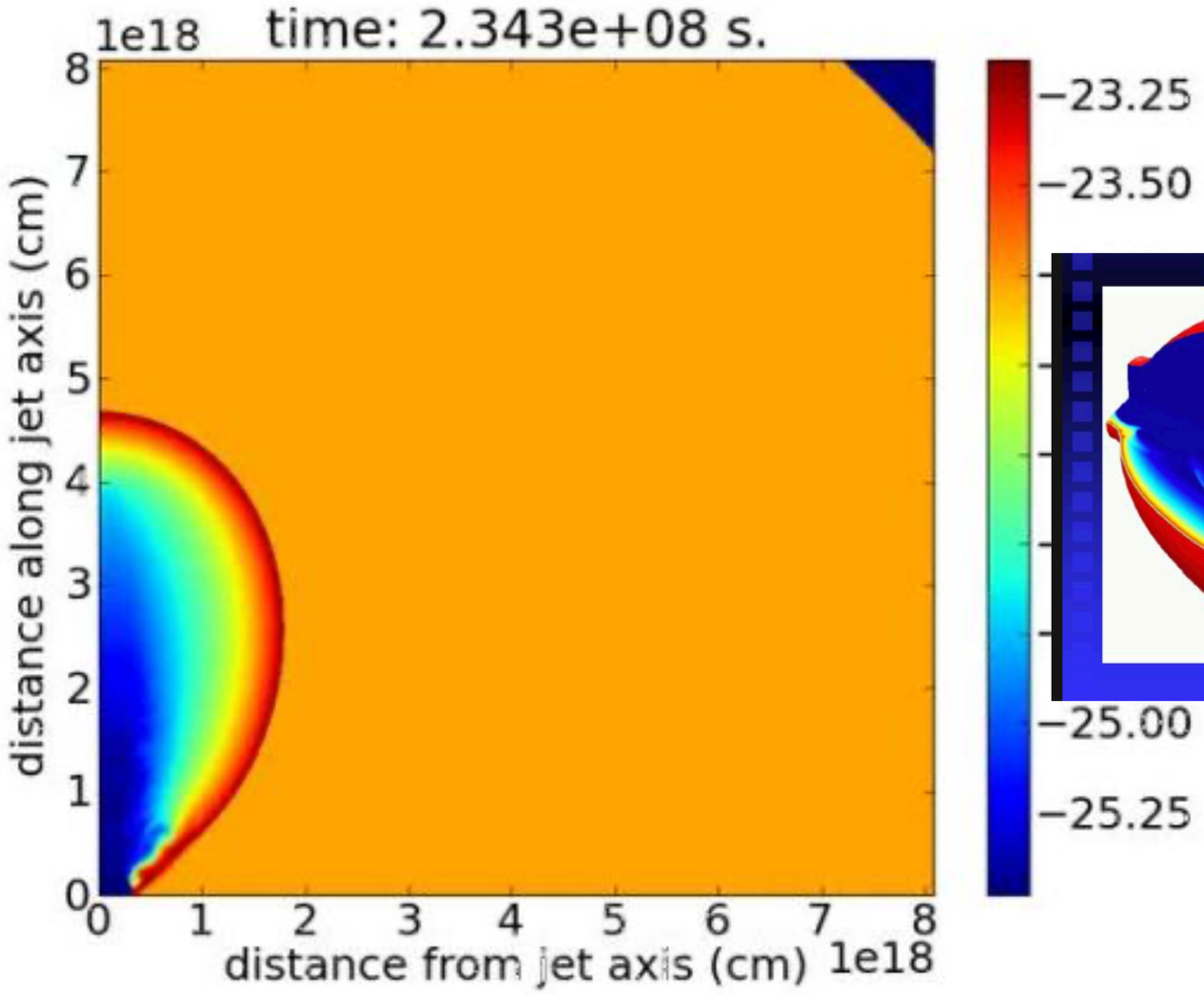


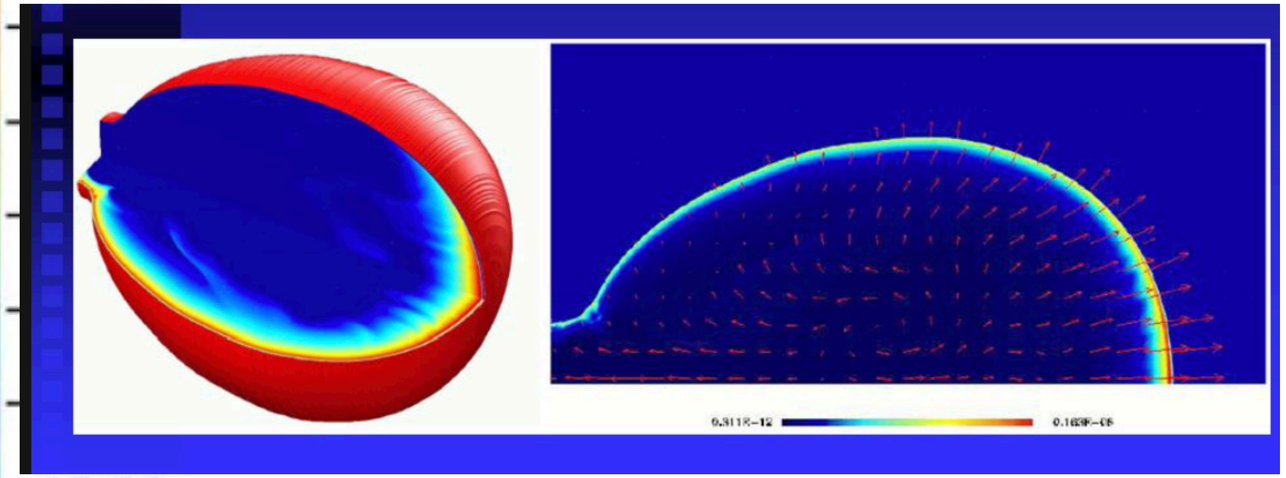

$\Gamma \approx 1/\theta_j$

Kulkarni + 99

# Jets dynamics

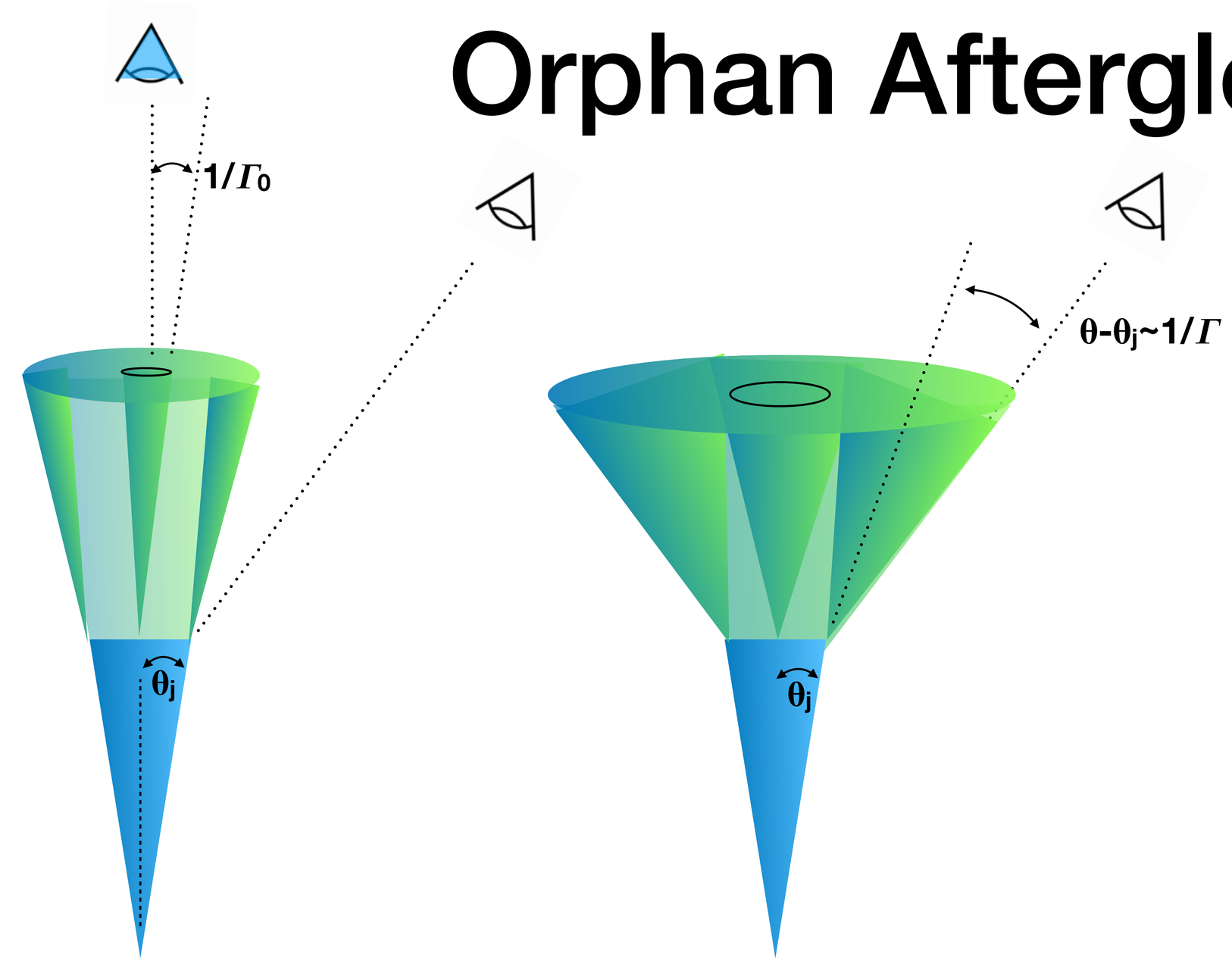



Van Eerten + 2018



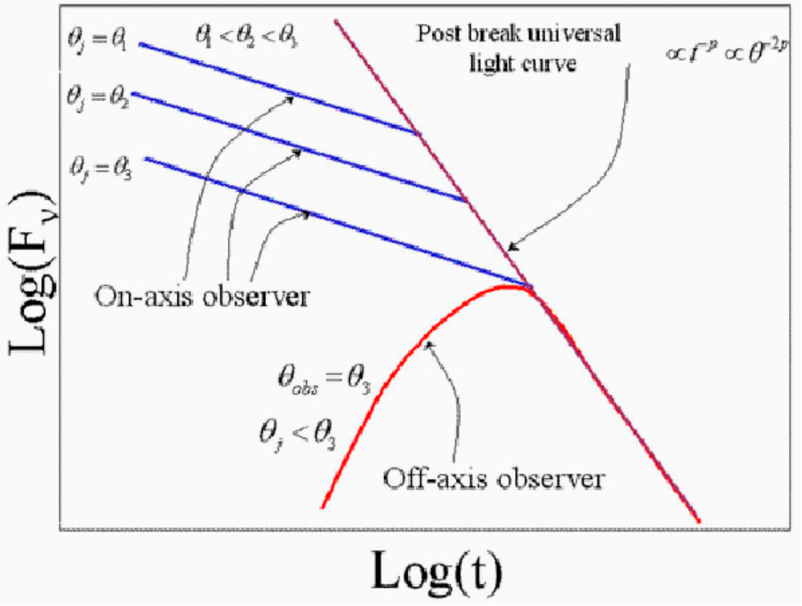
Granot + 2001

# Orphan Afterglow




Early (large $\Gamma > 1/\theta_j$ )

Late (low $\Gamma < 1/\theta_j$ )




**Can we estimate the viewing angle from the afterglow peak?**

# Orphan afterglow light curve

$$t_p \propto \left(\frac{E}{n}\right)^{1/3} \left(\theta_{\rm obs} - \theta_j\right)^2 \propto \frac{l}{\Gamma^2 c}$$

$$\propto \left[\left(\frac{E}{n}\right)^{1/3} \theta_j^2\right] \left(1 - \frac{\theta_{\rm obs}}{\theta_j}\right)^2$$

$$F_{\nu,p} \propto \left[E\, n^{\frac{p+1}{4}} \epsilon_e^{p-1} \epsilon_B^{\frac{p+1}{4}} \theta_j^{-2p}\right] \nu^{-\frac{p-1}{2}} D^{-2} \left(\frac{\theta_{\rm obs}}{\theta_j}\right)^{-2p}$$

Nakar + 2003; Nakar, Tp 2020

$\nu$ - observed frequency

$F_\nu$ - observed flux

$t_p$ - peak time

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E - Energy

N - external density

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$\varepsilon_e$ - electrons' equipartition parameter

p - electrons' distribution power law index

$\varepsilon_B$ - magnetic equipartition parameter

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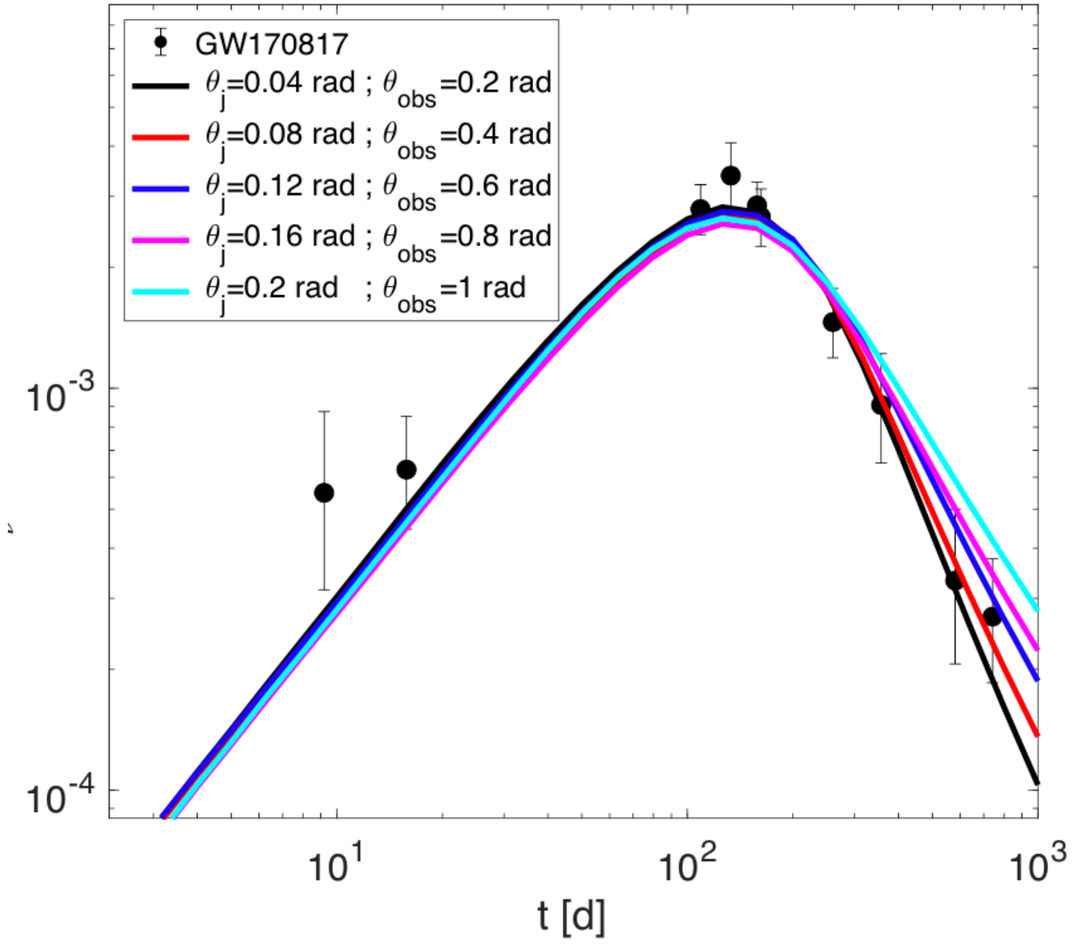
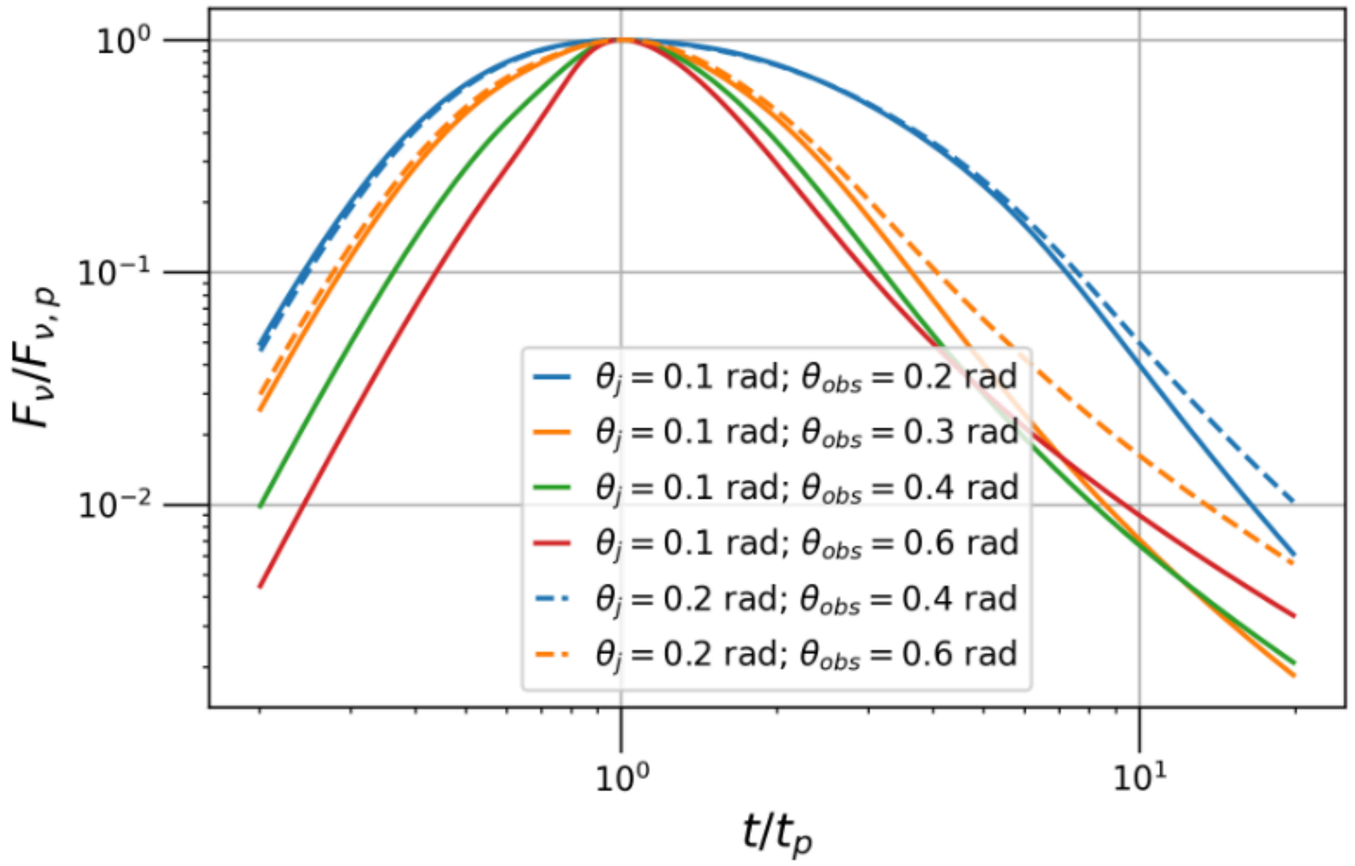
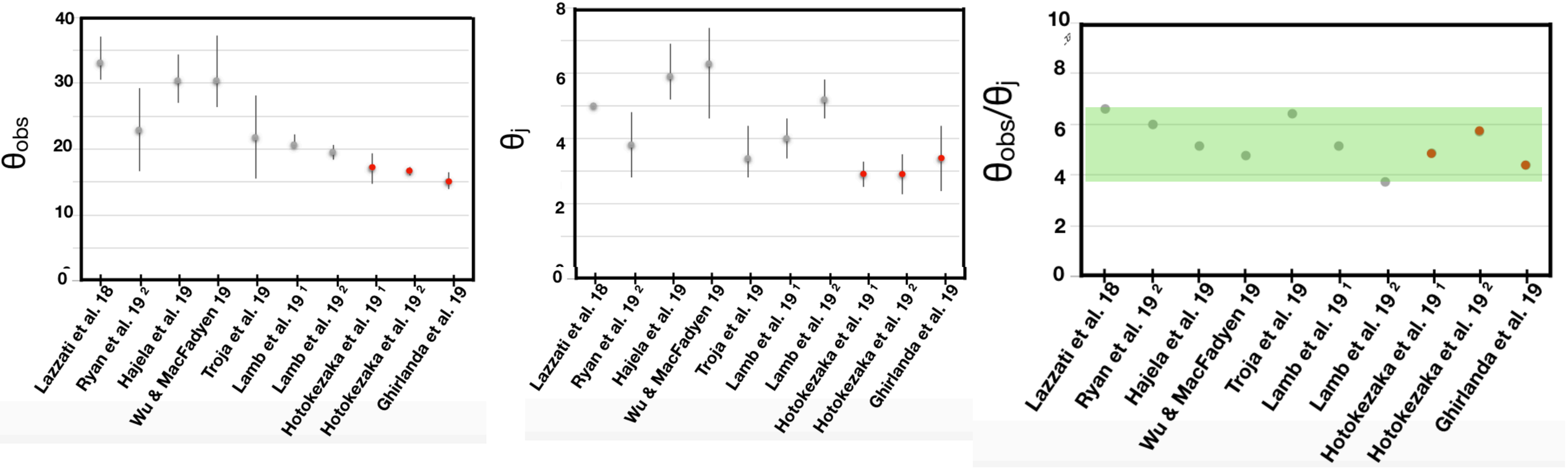
D - distance

# Numerical Examples

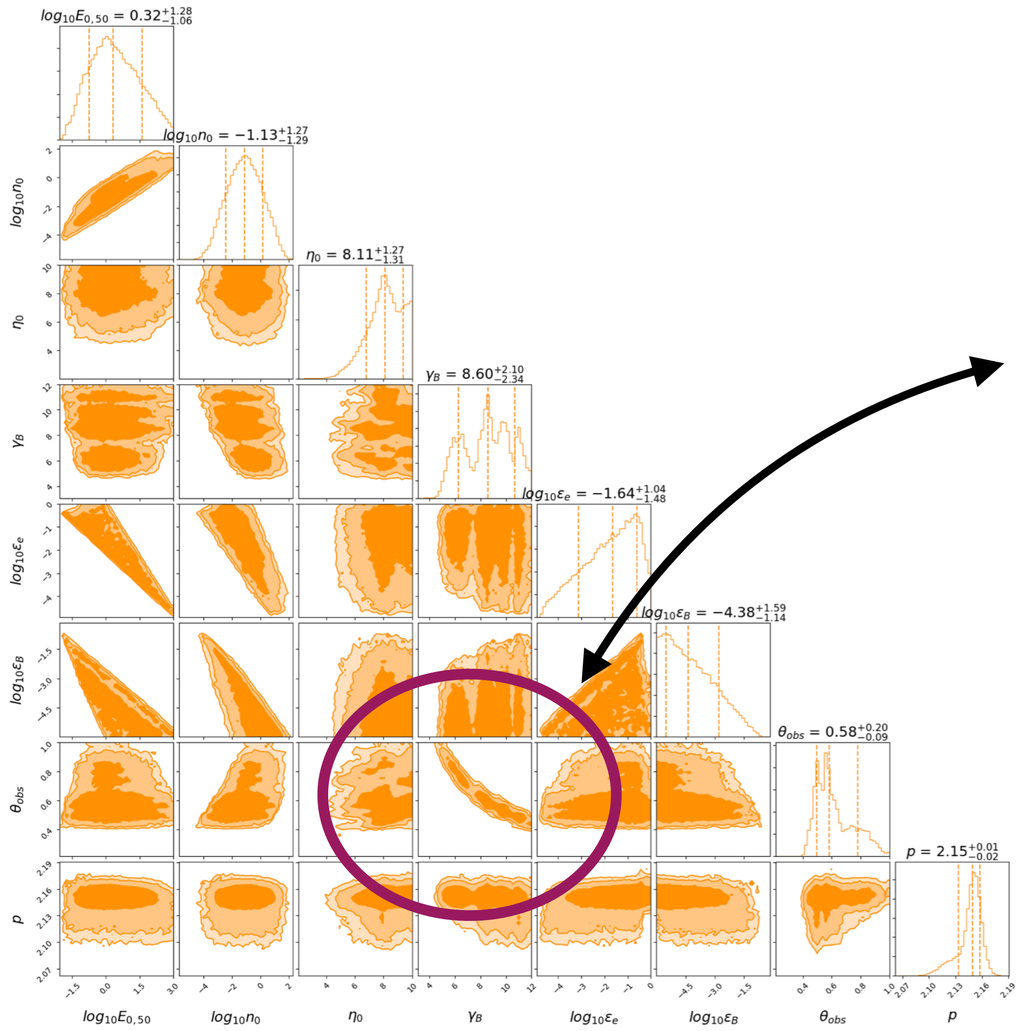


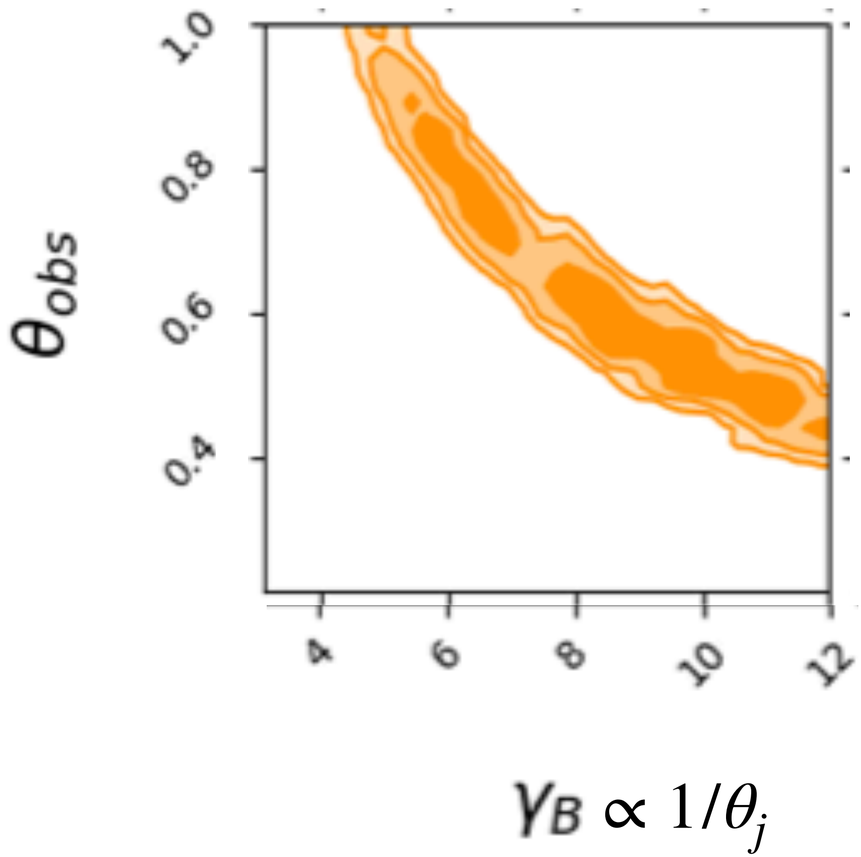



# Viewing angle estimates

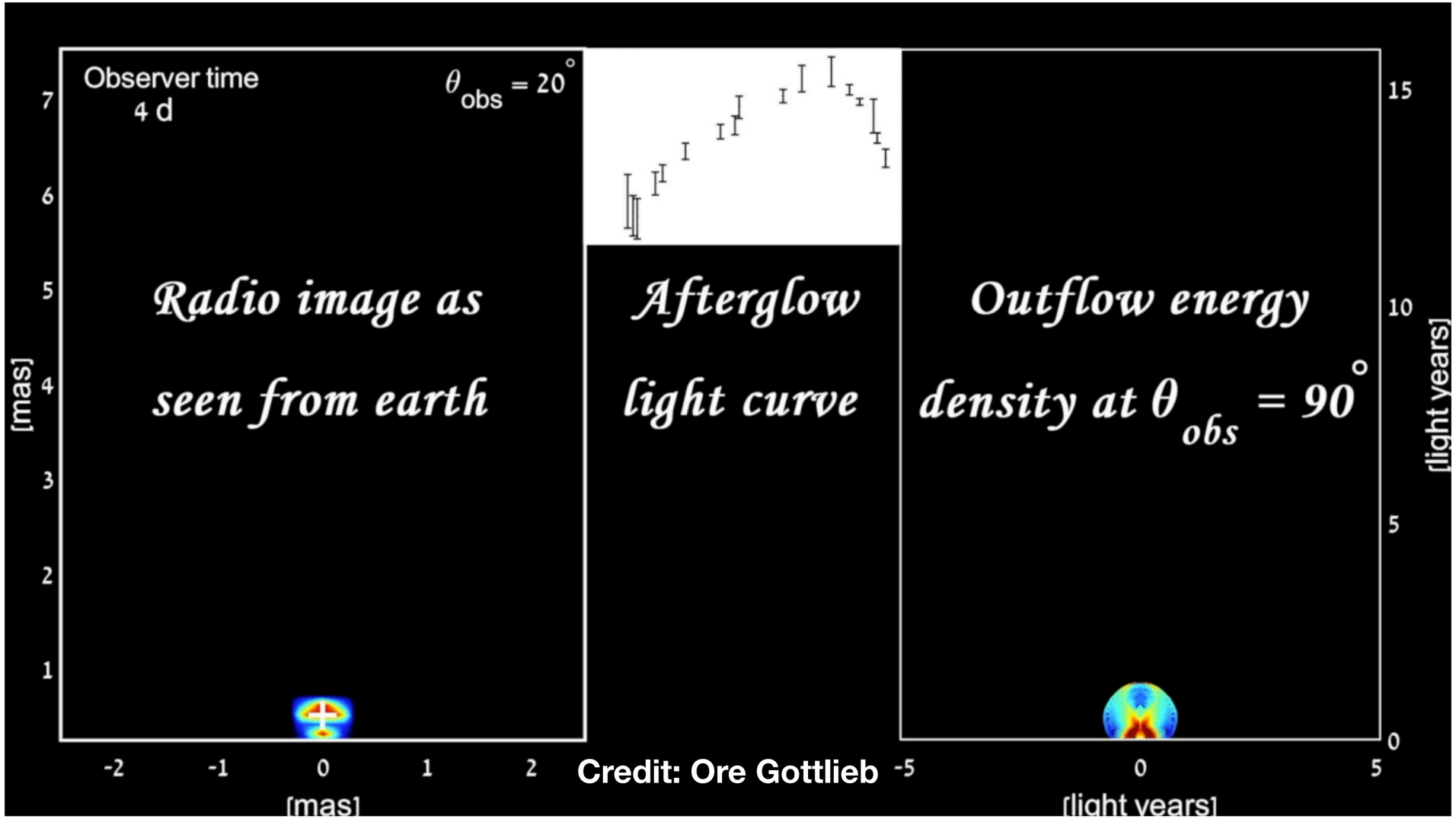


# Unnoticed Degeneracy at work (e.g. Hajela 2019)



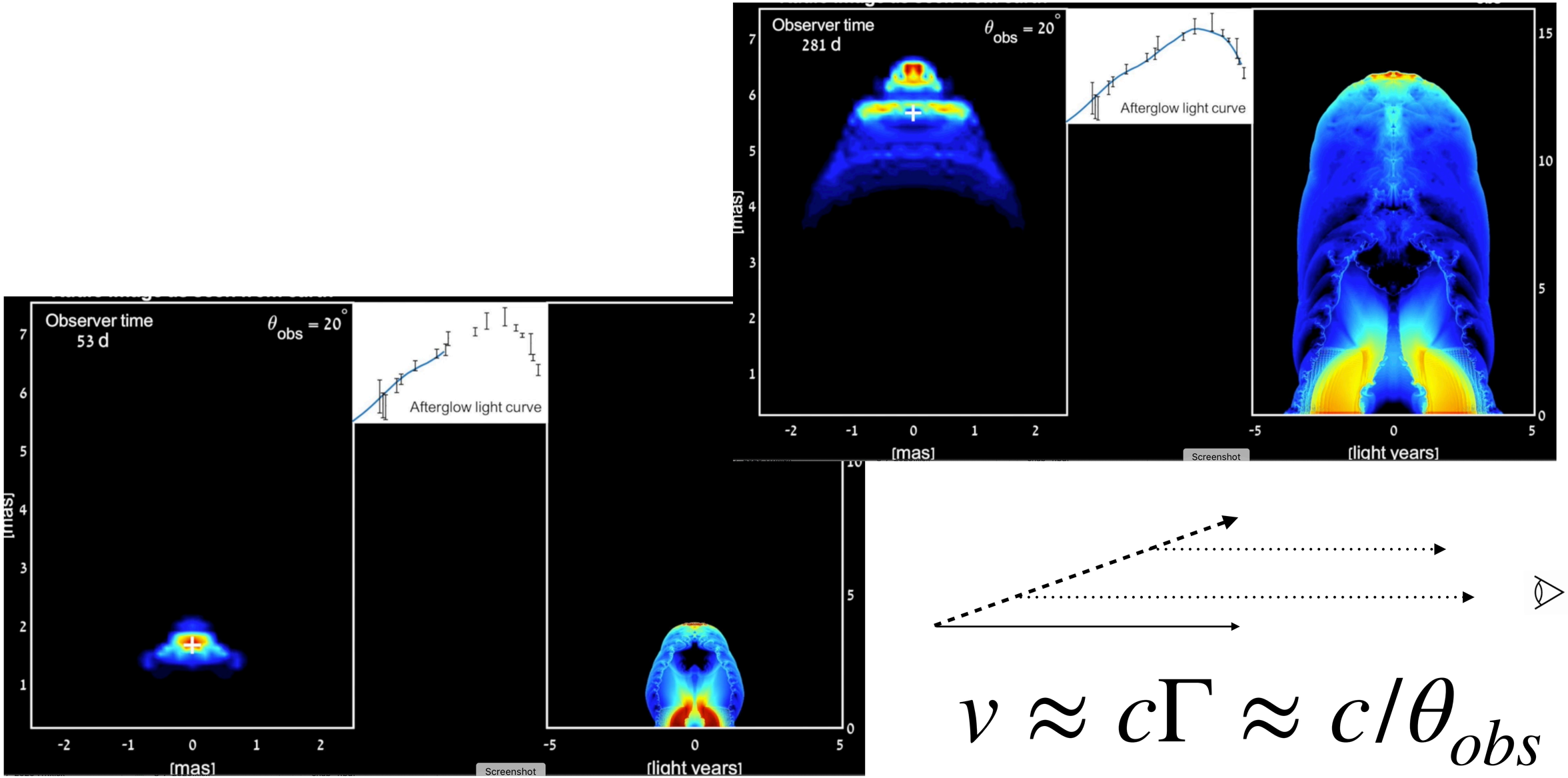



# Breaking the symmetry
# Centroid motion




Credit: Ore Gottlieb

# Superluminal Motion






$$v \approx c\Gamma \approx c/\theta_{obs}$$

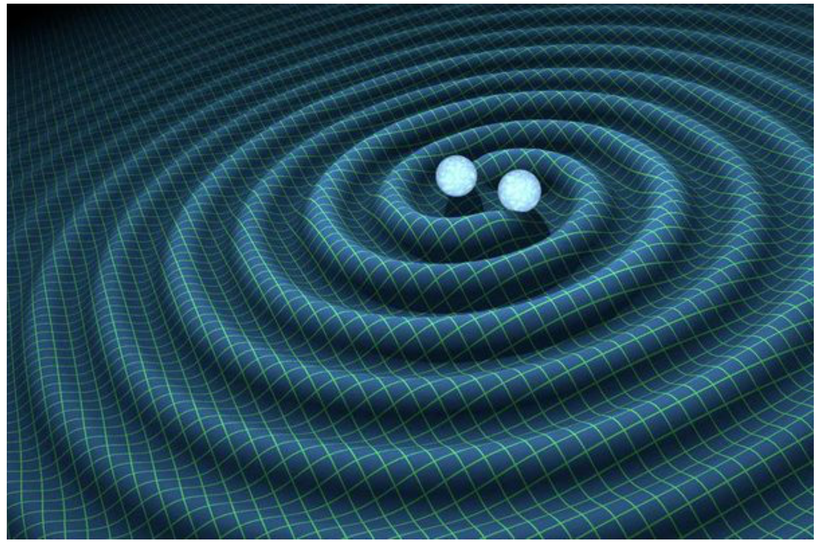
# $H_0$ from GW (Schutz, 1986)

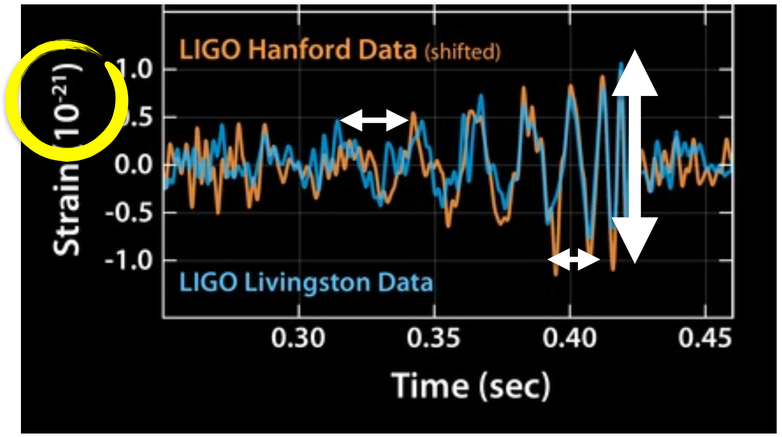
$$\langle h \rangle = 1 \times 10^{-23} m_T^{2/3} \mu f_{100}^{2/3} r_{100}^{-1}$$

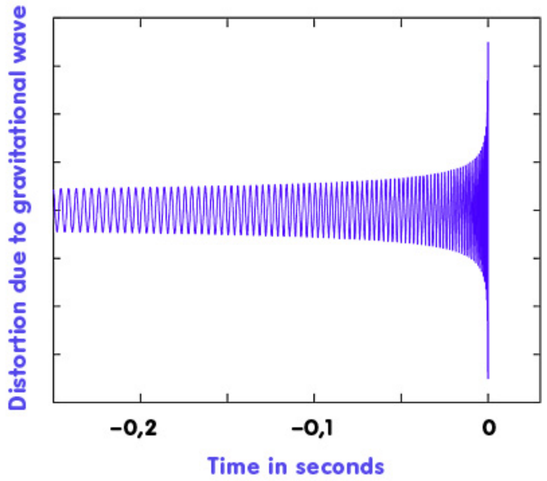
frequency will change on a timescale

$$\tau = f/\dot{f} = 7.8 m_T^{-2/3} \mu^{-1} f_{100}^{-8/3} \text{ s}$$

$$\boxed{r_{100} = 7.8 f_{100}^{-2} (\langle h_{23} \rangle \tau)^{-1}}$$





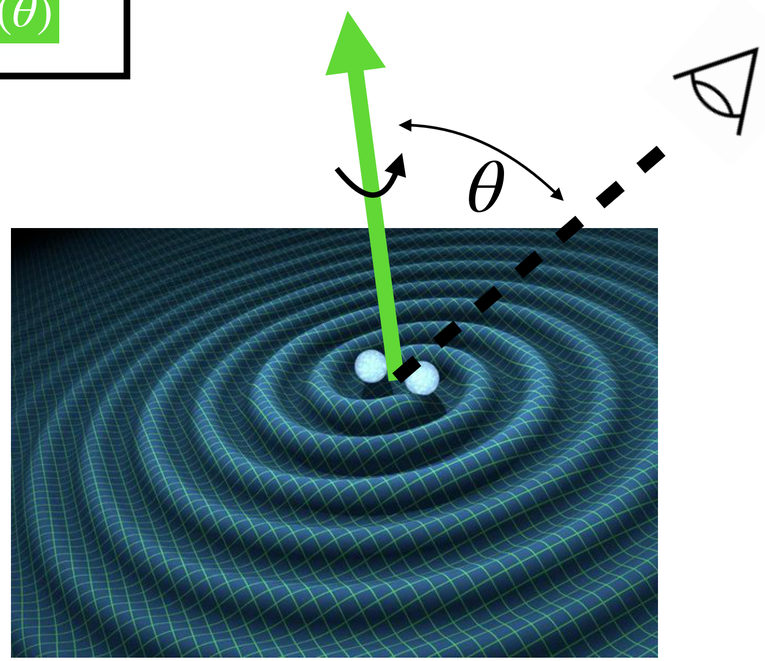



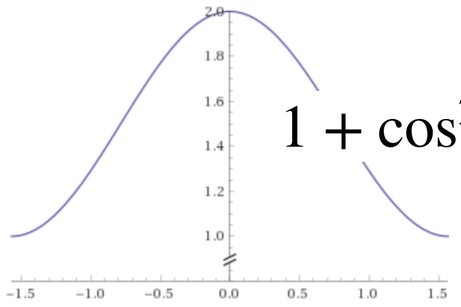
# The viewing angle

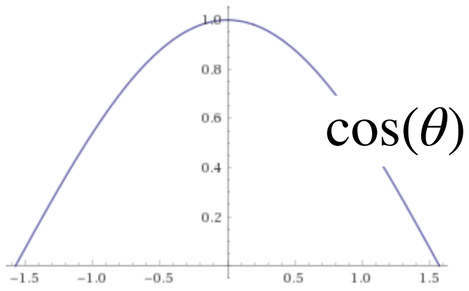
$$h_+ = \frac{2\mathcal{M}_z^{5/3}[\pi f(t)]^{2/3}}{D_L}\left[1+\cos^2(\theta)\right] \quad \propto \cos(\theta)$$

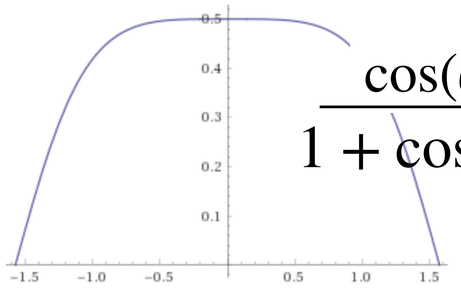
$$h_\times = \frac{4\mathcal{M}_z^{5/3}[\pi f(t)]^{2/3}\cos(\theta)}{D_L} \quad \propto \cos(\theta)$$

$$\boxed{r_{100} = 7.8 f_{100}^{-2}(\langle h_{23}\rangle \tau)^{-1} f(\theta)}$$

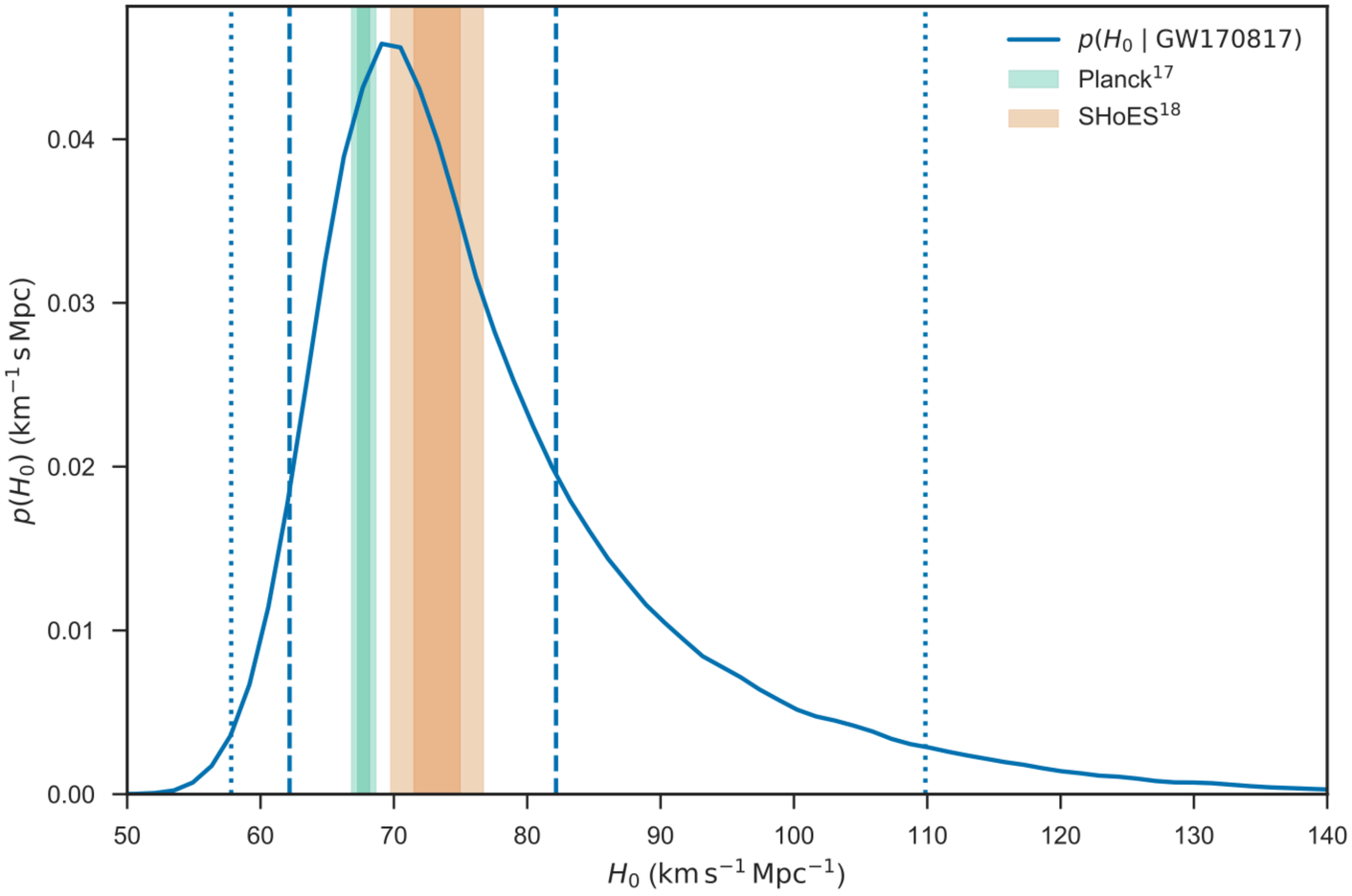


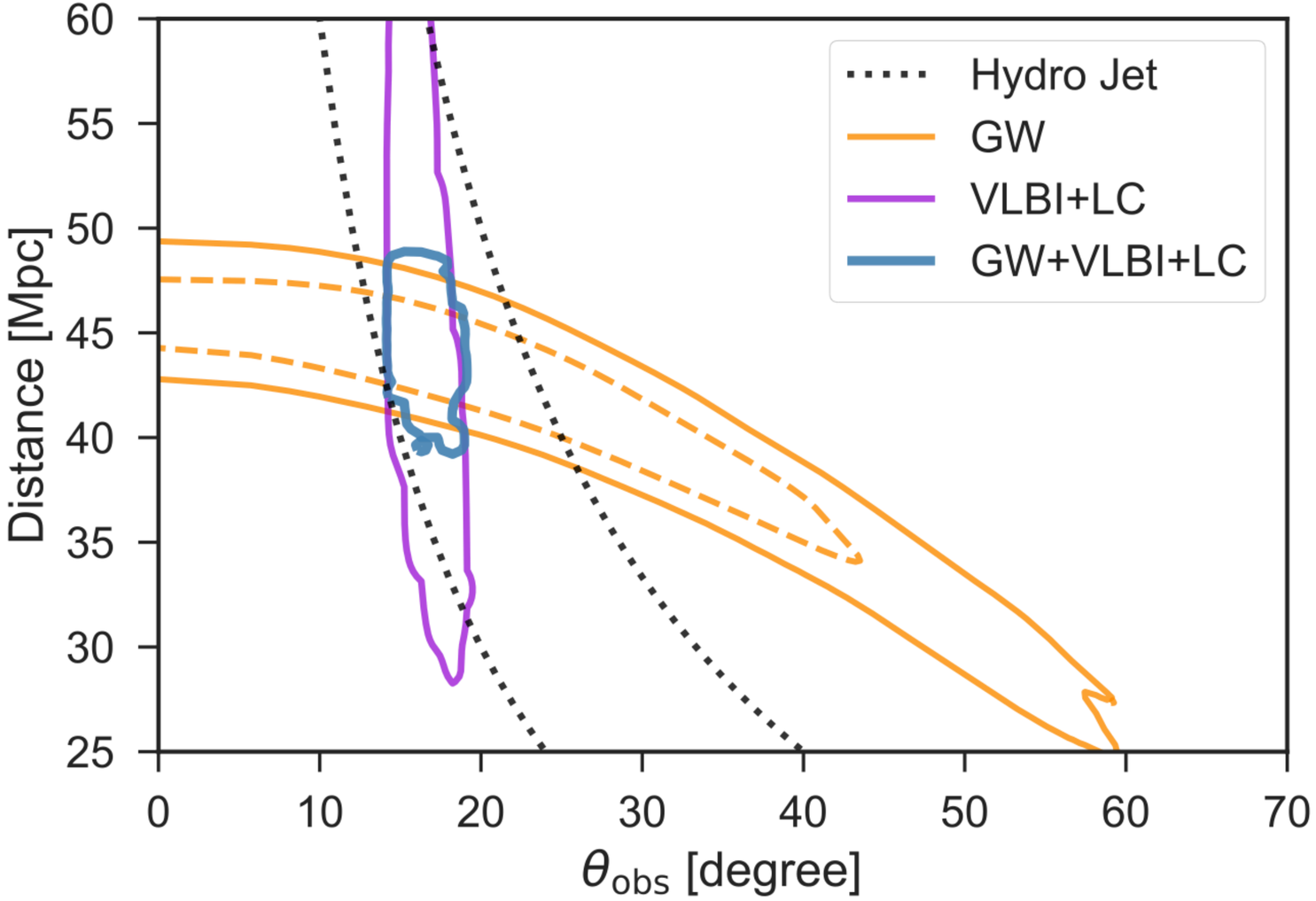
# $H_0$ from GW 170817 (Abbott + 17)




$\theta < 40^o$

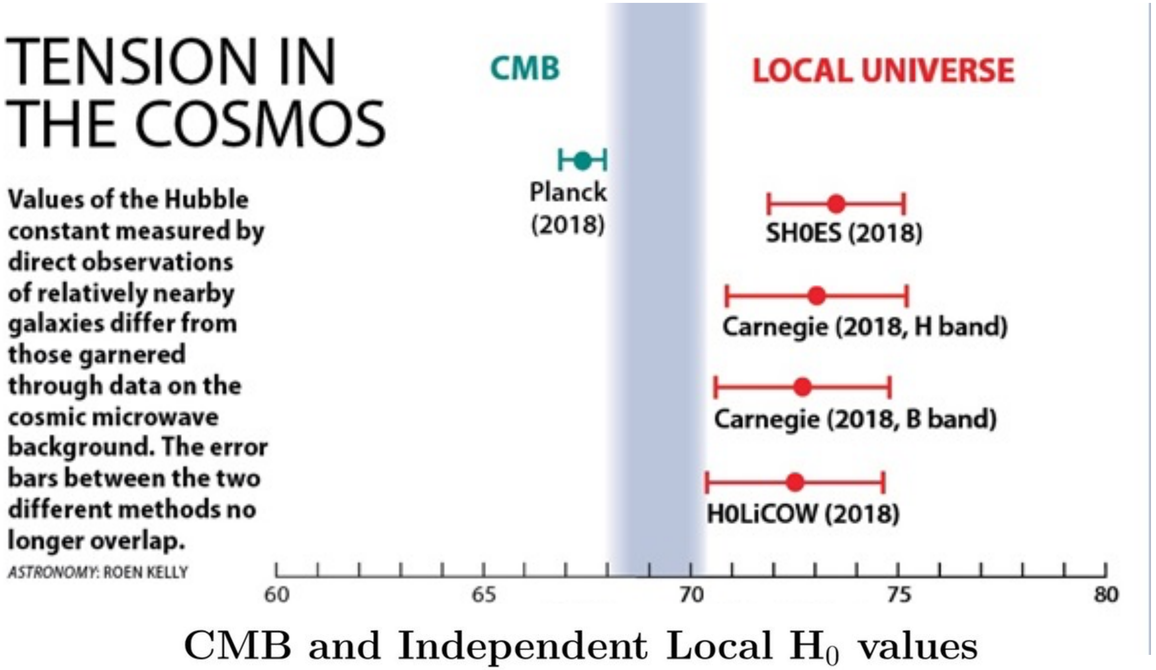
# With centroid motion (Hotokezaka + 18)

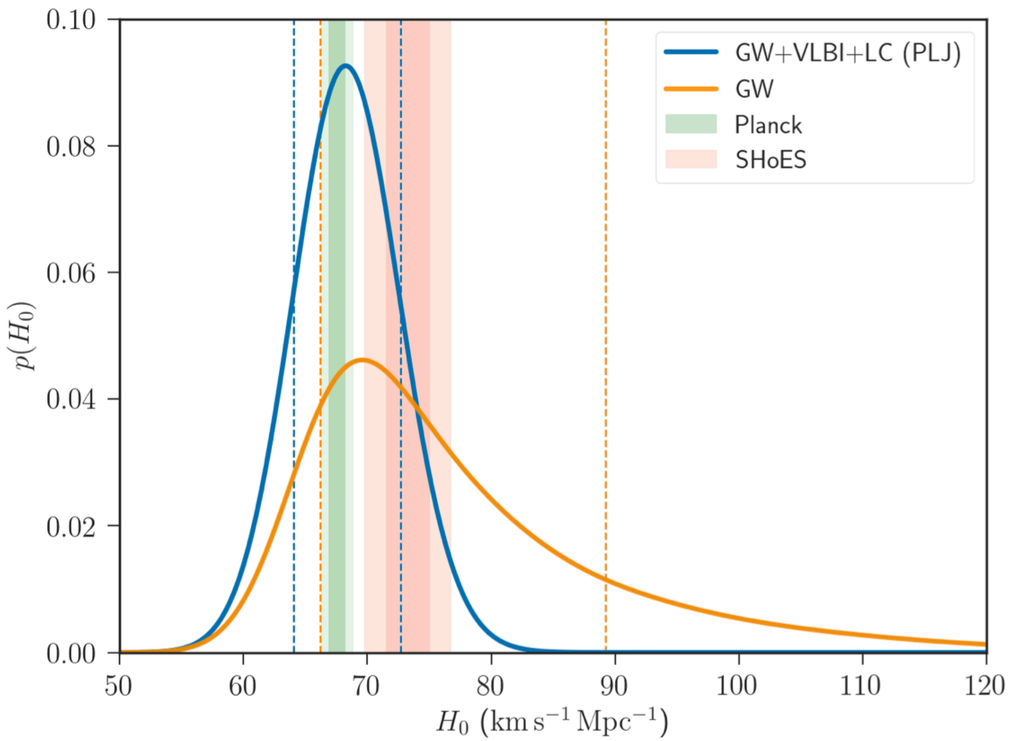
$$v \approx 3 - 4c => \Gamma \approx 3 - 4 => \theta \approx 0.25 - 0.33$$

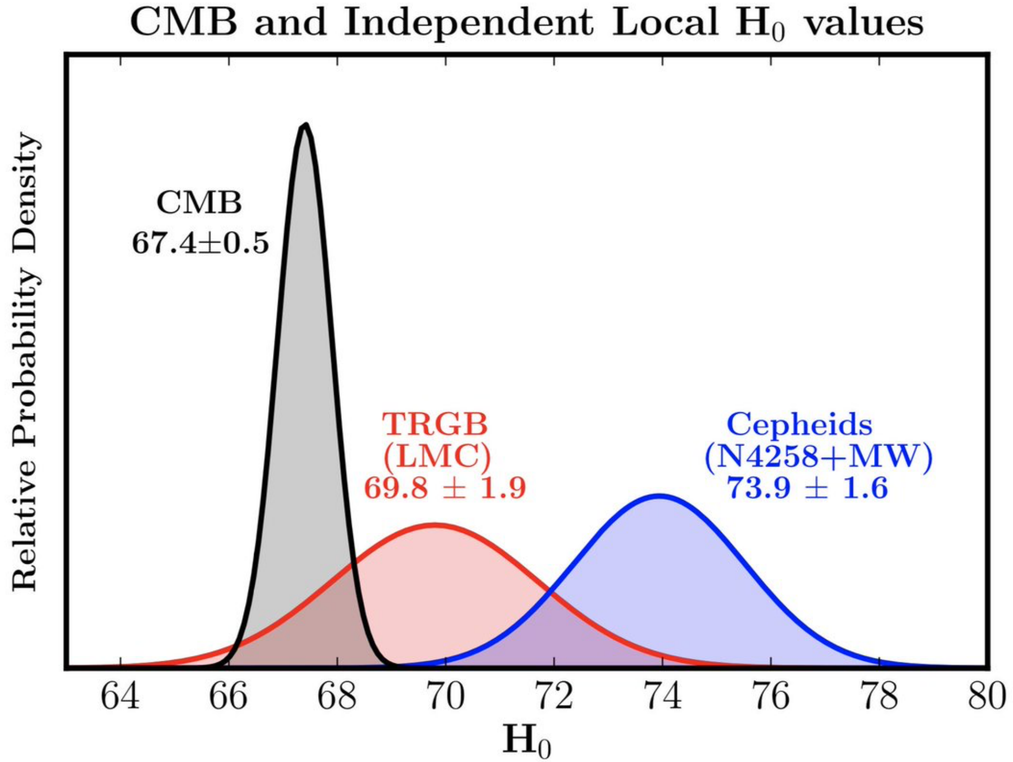


# $H_0$

- Abbott+ 2017 15% error in $H_0$
- Hotokezaka + 2018 7% error in $H_0$



# Errors in $H_0$

- Distance estimate. $D \propto \cos(\theta)/D$
  - The viewing angle $\delta \cos(\theta) \approx \theta \delta\theta$
  - GW amplitude $\delta h/h \approx (S/N)^{-1} \propto D$
- Proper motion (determination of v) $\delta v \propto v_p/v \propto 1/D$

■ => Need intermediate distance merger.

GW 170817 was almost at optimal distance

# Error budget in GW 170817

- Abbott + 15% ($\delta\theta \approx 15\,\%$ - dominated by viewing angle error )
- Hotokezaka + 7% ($\delta\theta \approx 2\,\%$ ; $\delta v_p \approx 6\,\%$ ; $\delta h \approx 5\,\%$)

# Future Samples

- To get to 1% error we need either
  - > 200 low quality events $1\,\% = 15\,\% / \sqrt{N_{low}}$
  - > 16 high quality events $1\,\% = 4\,\% / \sqrt{N_{high}}$
  - Concerns about systematics

**O3 rates => measurements $H_0$ with GW from BNS mergers are unlikely to resolve the $H_0$ tension in the near future.**

# Conclusions

- There is a degeneracy in the afterglow light curve between the observing angle and the width of the jet that produced the emission.
- Light curve along is insufficient to determine the observing angle or any other parameter of the jet
- Observing angle can be determined from higher quality data beyond just the light curve..
- This limits “high quality” mergers to be “local” limiting their rate regardless of the GW detectors sensitivity
- Still a small number of “high” quality events can supersede in the final results the larger  number of “low” quality events.