# *What did we learn about GRB170817A from its association with GW170817*

**K. G. Arun**

Chennai Mathematical Institute

*Cosmic Fireworks: The Dawn of Multi-messenger Astronomy*

ICTS-TIFR, Bengaluru

19th October 2017

CHENNAI MATHEMATICAL INSTITUTE

indigo



LIGO document G1702069

# Top stories

- Binary neutron stars as progenitors of Short GRBs confirmed.
- Direct evidence for off-axis jet.
- First Confirmed Kilonova. (will not address in this talk.)
- *Physics and astrophysics of off-axis GRBs.*

# Gamma Ray Bursts

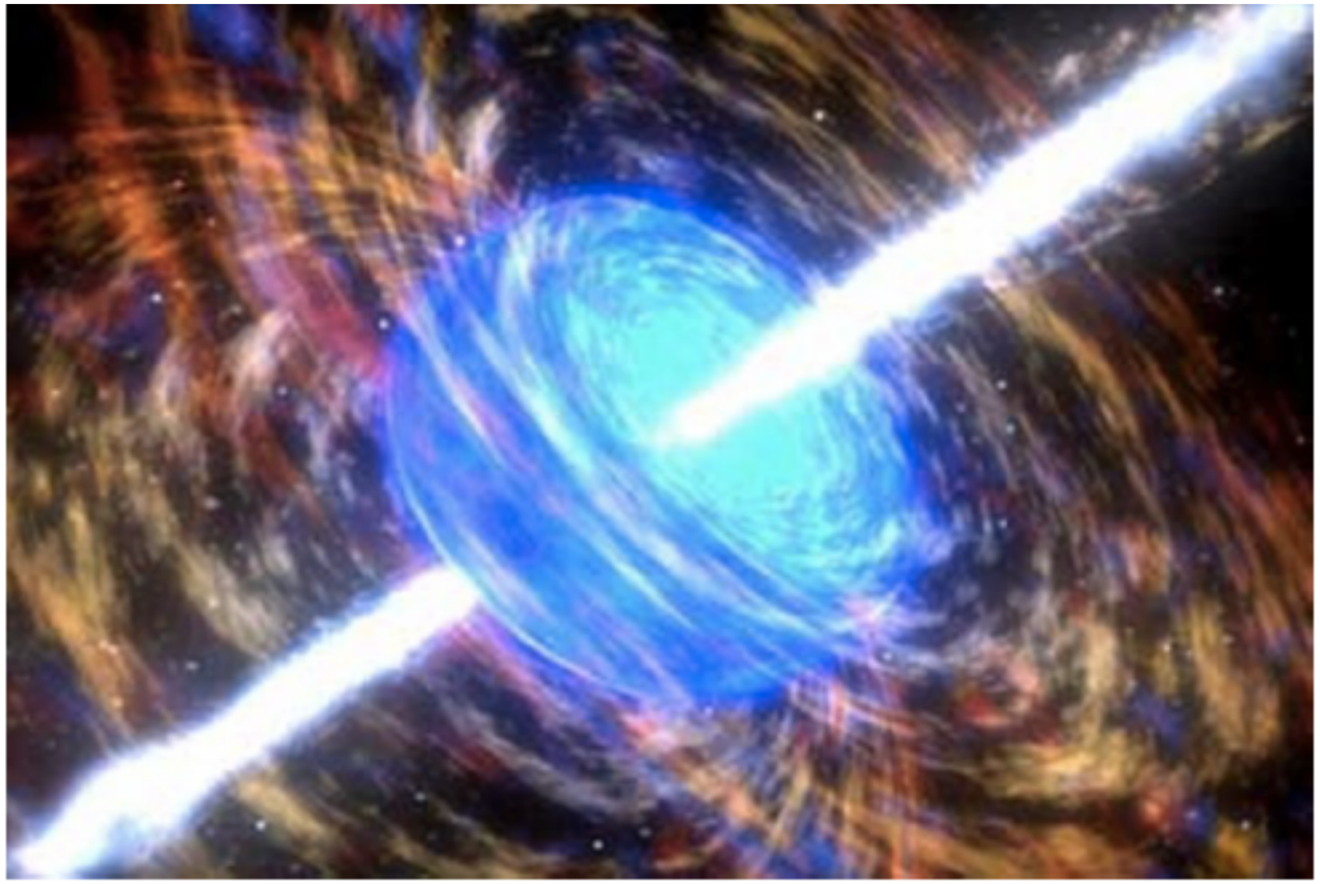
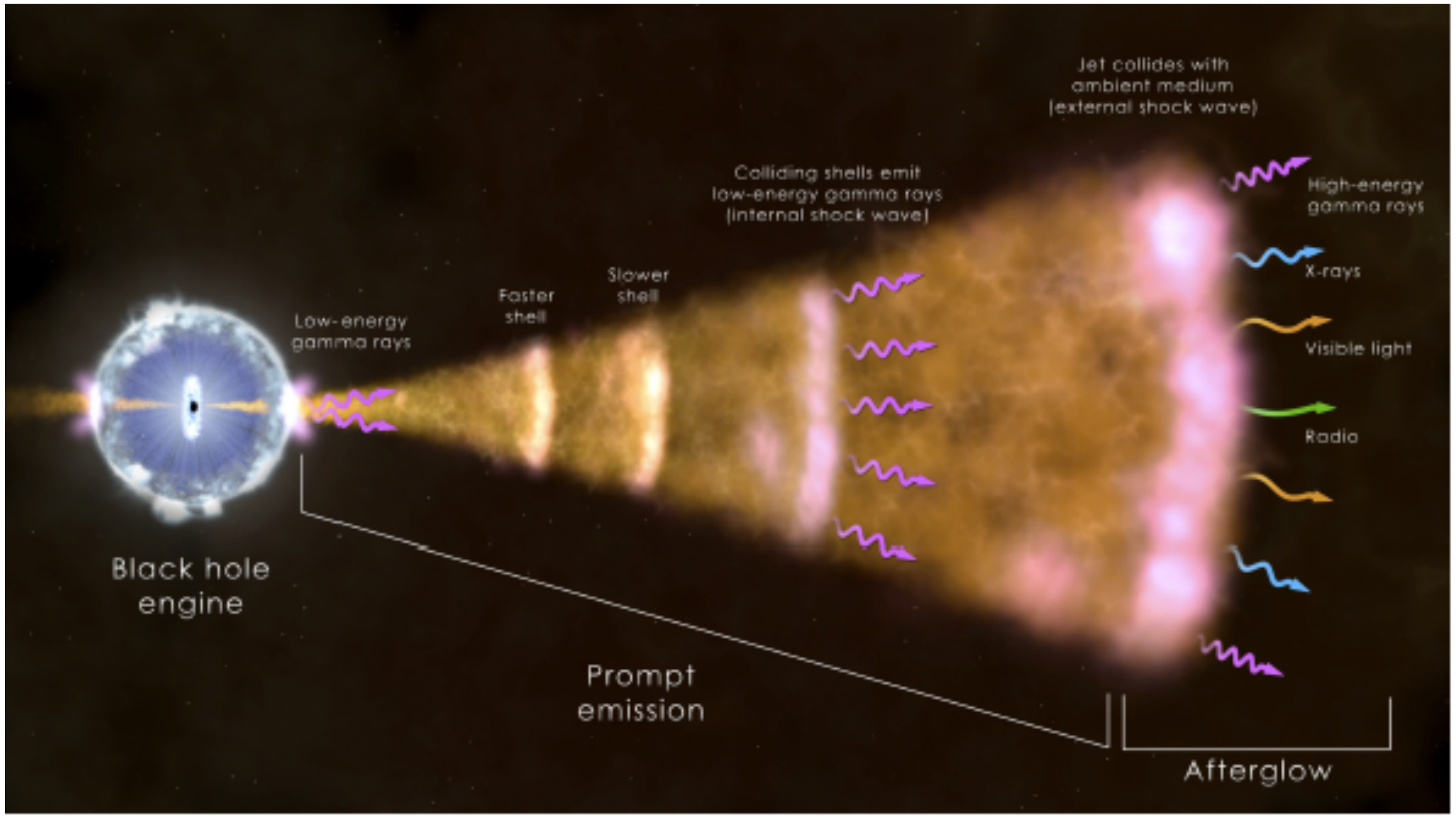


Image: NASA

- Most energetic explosions
- Gamma ray and lower frequencies.
- Collimated, ultra-relativistic jets (Lorentz factor ~100s)
- Model: Black hole powering jet.
- Typical isotropic Energy released: 10^49 - 10^53 ergs.

# Fireball Model

Internal shocks produce gamma rays




External shocks produce Afterglows

Image: NASA

Multi-band afterglows from X rays to Radio

# Gamma Ray Bursts: Long Vs Short

Death of massive stars

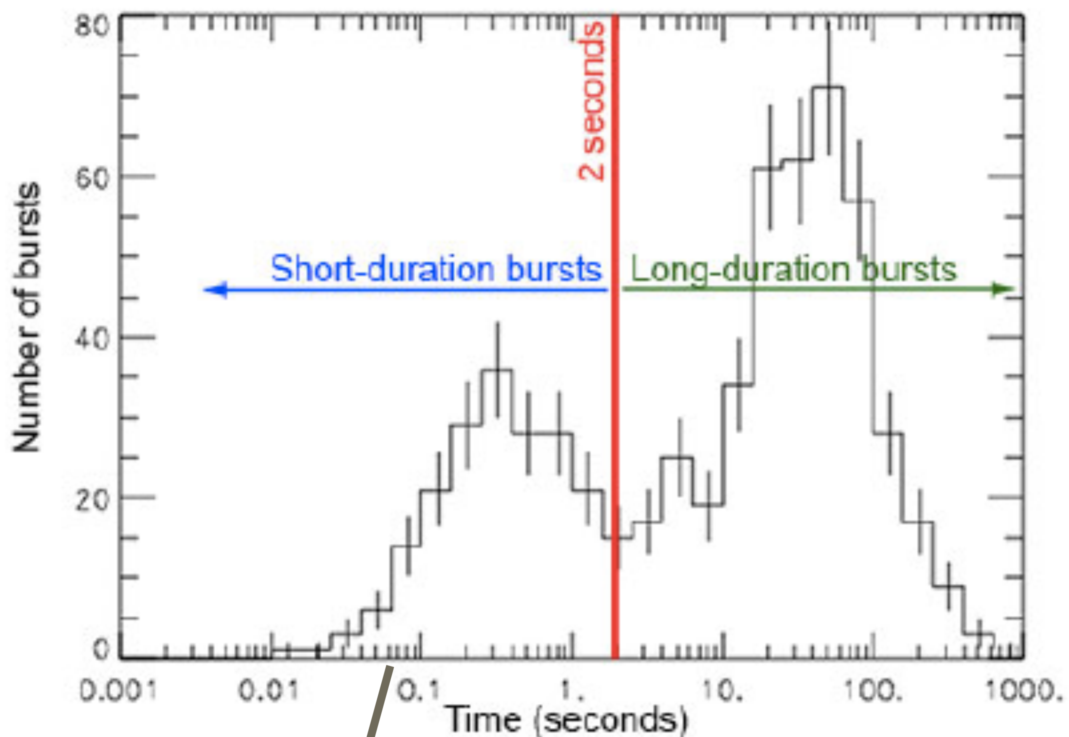



Image: BATSE

NS-NS or NS-BH mergers?

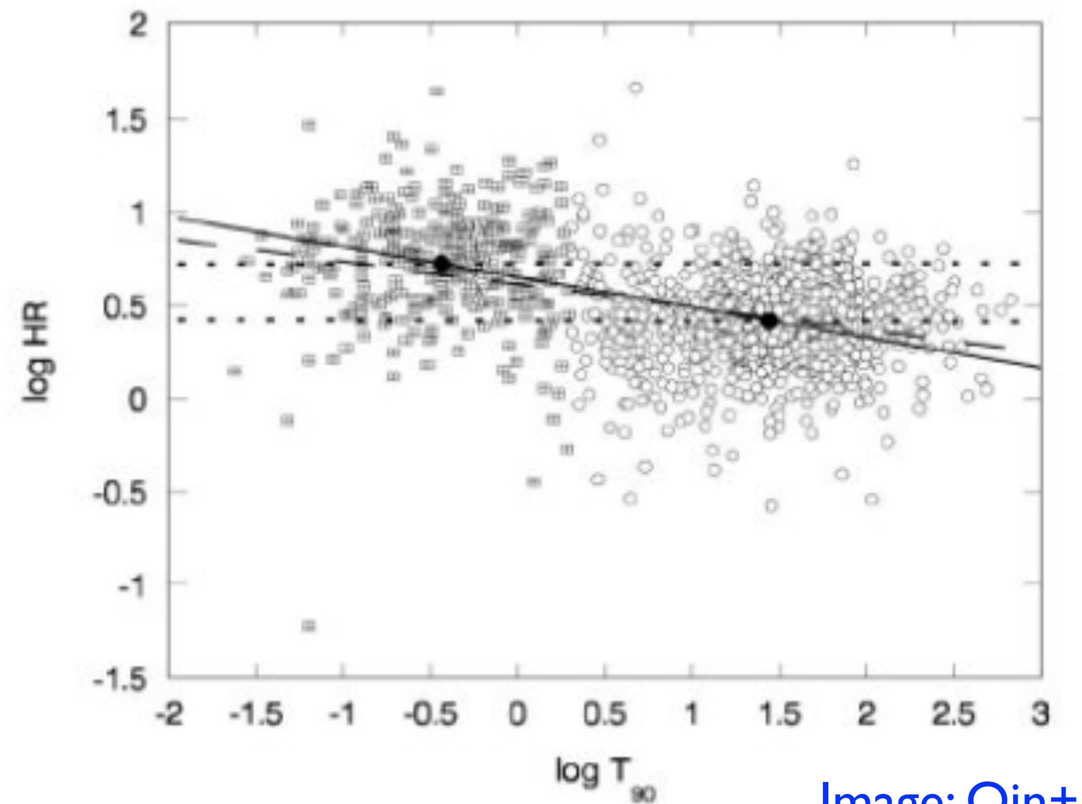



Image: Qin+ 2000

Short hard Vs Long soft

# Origin of Short GRBs

THE ASTROPHYSICAL JOURNAL, 395:L83–L86, 1992 August 20
© 1992. The American Astronomical Society. All rights reserved. Printed in U.S.A.

## GAMMA-RAY BURSTS AS THE DEATH THROES OF MASSIVE BINARY STARS

RAMESH NARAYAN,[1] BOHDAN PACZYŃSKI,[2] AND TSVI PIRAN[3]
*Received 1992 March 24; accepted 1992 June 5*

### ABSTRACT

We propose that gamma-ray bursts are created in the mergers of double neutron star binaries and black hole neutron star binaries at cosmological distances. Two different processes provide the electromagnetic energy for the bursts: neutrino-antineutrino annihilation into electron-positron pairs during the merger, and magnetic flares generated by the Parker instability in a postmerger differentially rotating disk. In both cases, an optically thick fireball of size $\lesssim 100$ km is initially created, which expands ultrarelativistically to large radii before radiating. The scenario is only qualitative at this time, but it eliminates many previous objections to the cosmological merger model. The strongest bursts should be found close to, but not at the centers of, galaxies at redshifts of order 0.1, and should be accompanied by bursts of gravitational radiation from the spiraling-in binary which could be detected by LIGO.

*Subject headings:* accretion, accretion disks — black hole physics — gamma rays: bursts — gravitation — magnetic fields — stars: neutron

# The power of joint detection!

IOP PUBLISHING — CLASSICAL AND QUANTUM GRAVITY
Class. Quantum Grav. **30** (2013) 123001 (38pp) — doi:10.1088/0264-9381/30/12/123001

TOPICAL REVIEW

**How gravitational-wave observations can shape the gamma-ray burst paradigm**

**I Bartos[1,2], P Brady[3] and S Márka[1,2]**

[1] Department of Physics, Columbia University, New York, NY 10027, USA
[2] Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA
[3] Center for Gravitation and Cosmology, University of Wisconsin-Milwaukee, Milwaukee, WI 53211, USA

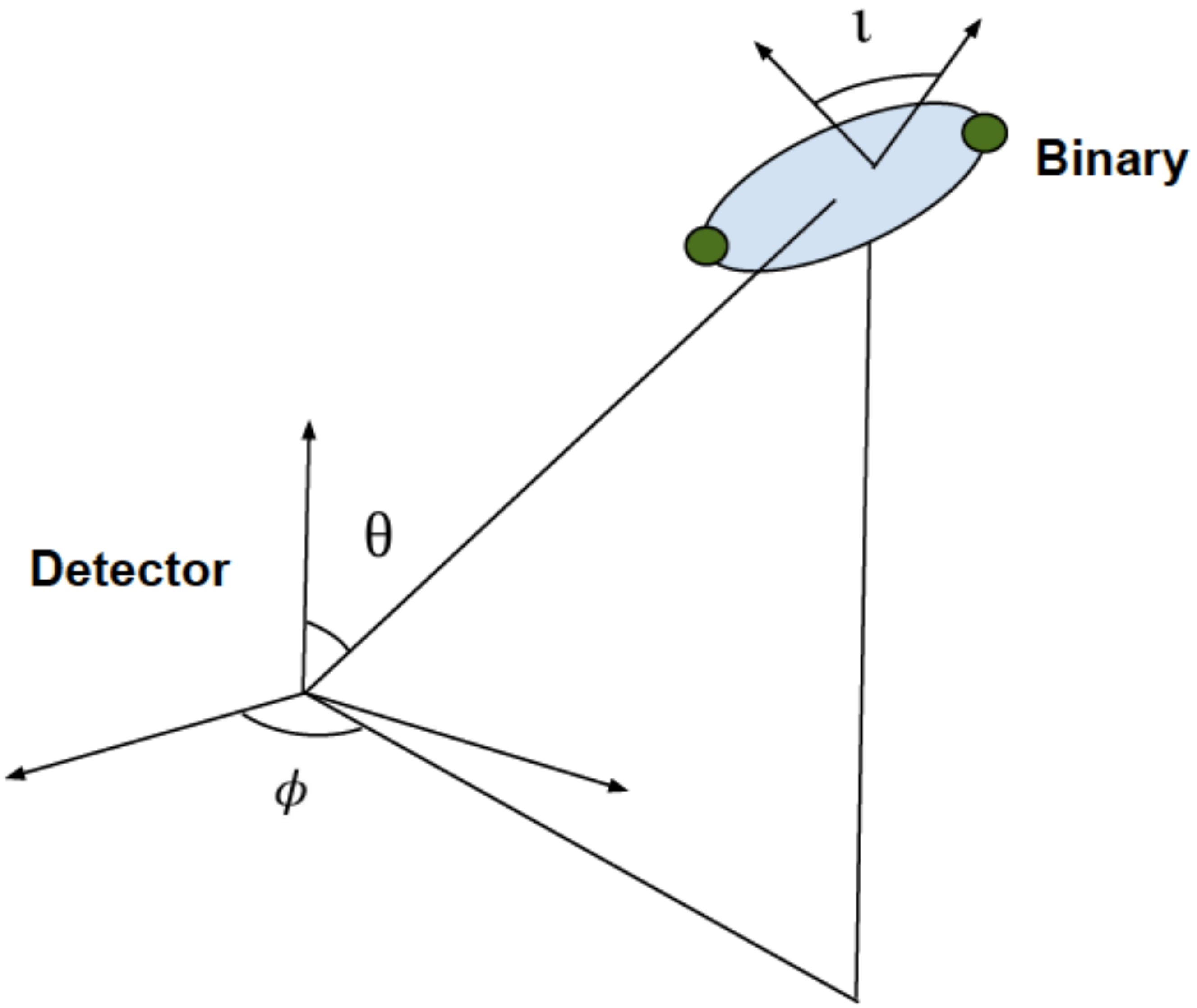
PHYSICAL REVIEW D **90**, 024060 (2014)

**Synergy of short gamma ray burst and gravitational wave observations: Constraining the inclination angle of the binary and possible implications for off-axis gamma ray bursts**

K. G. Arun,[1,*] Hideyuki Tagoshi,[2,†] Archana Pai,[3,‡] and Chandra Kant Mishra[3,§]
[1]*Chennai Mathematical Institute, Siruseri, Tamilnadu 603103, India*
[2]*Department of Earth and Space Science, Graduate School of Science, Osaka University, Osaka 560-0043, Japan*
[3]*Indian Institute of Science Education and Research Thiruvananthapuram, Computer Science Building, College of Engineering Campus, Trivandrum, Kerala 695016, India*
(Received 27 March 2014; published 22 July 2014)

- Nature of the Progenitor.
- Geometry of the jet.
- Structure of the jet.
- Other parameters of the jet and burst.

# Binary Geometry

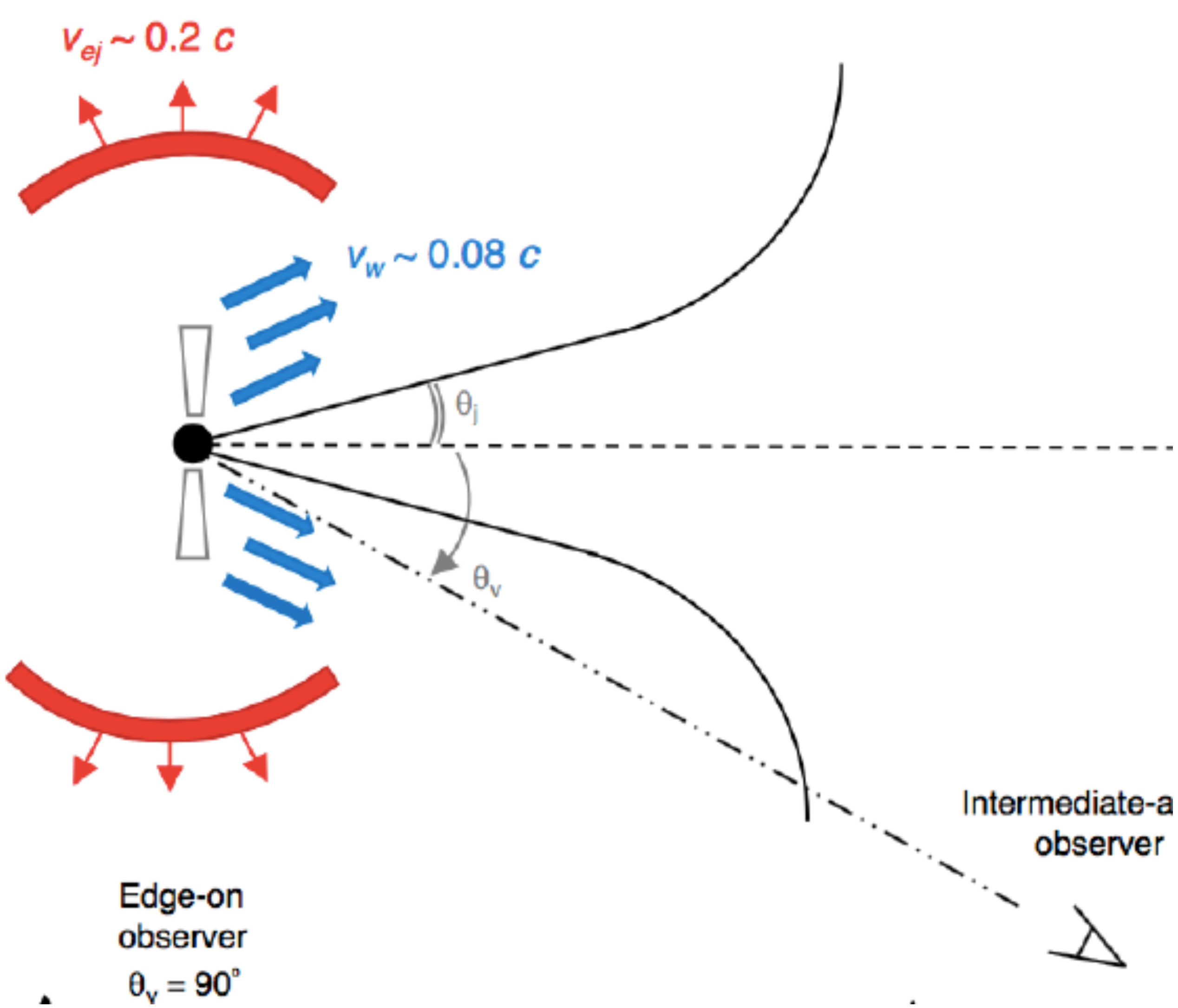



$$h_+ \sim \frac{1+\cos^2\iota}{D_L}$$

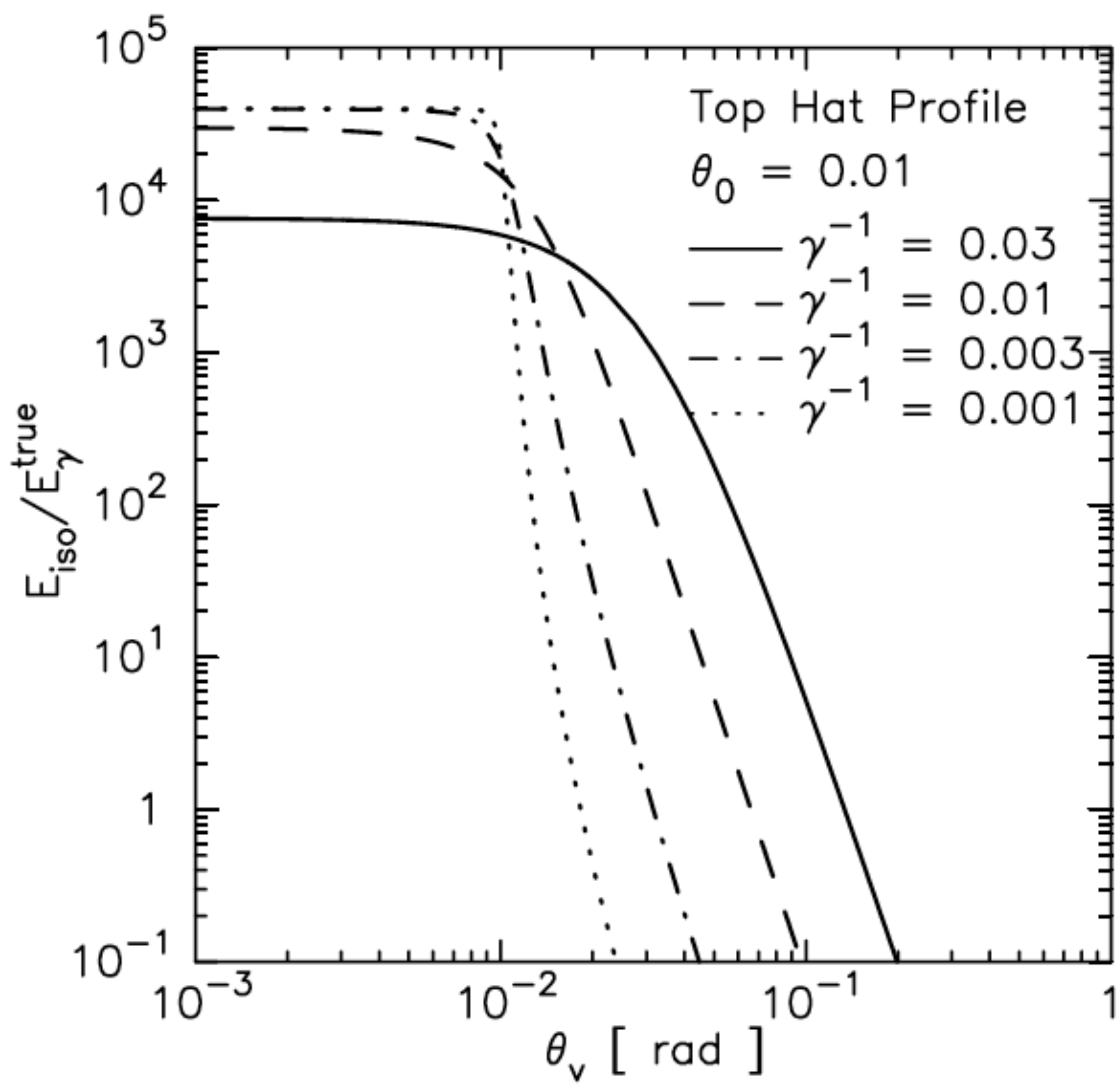
$$h_\times \sim \frac{2\cos\iota}{D_L}$$

Inclination is strongly degenerate with distance

# How Short GRBs are produced..

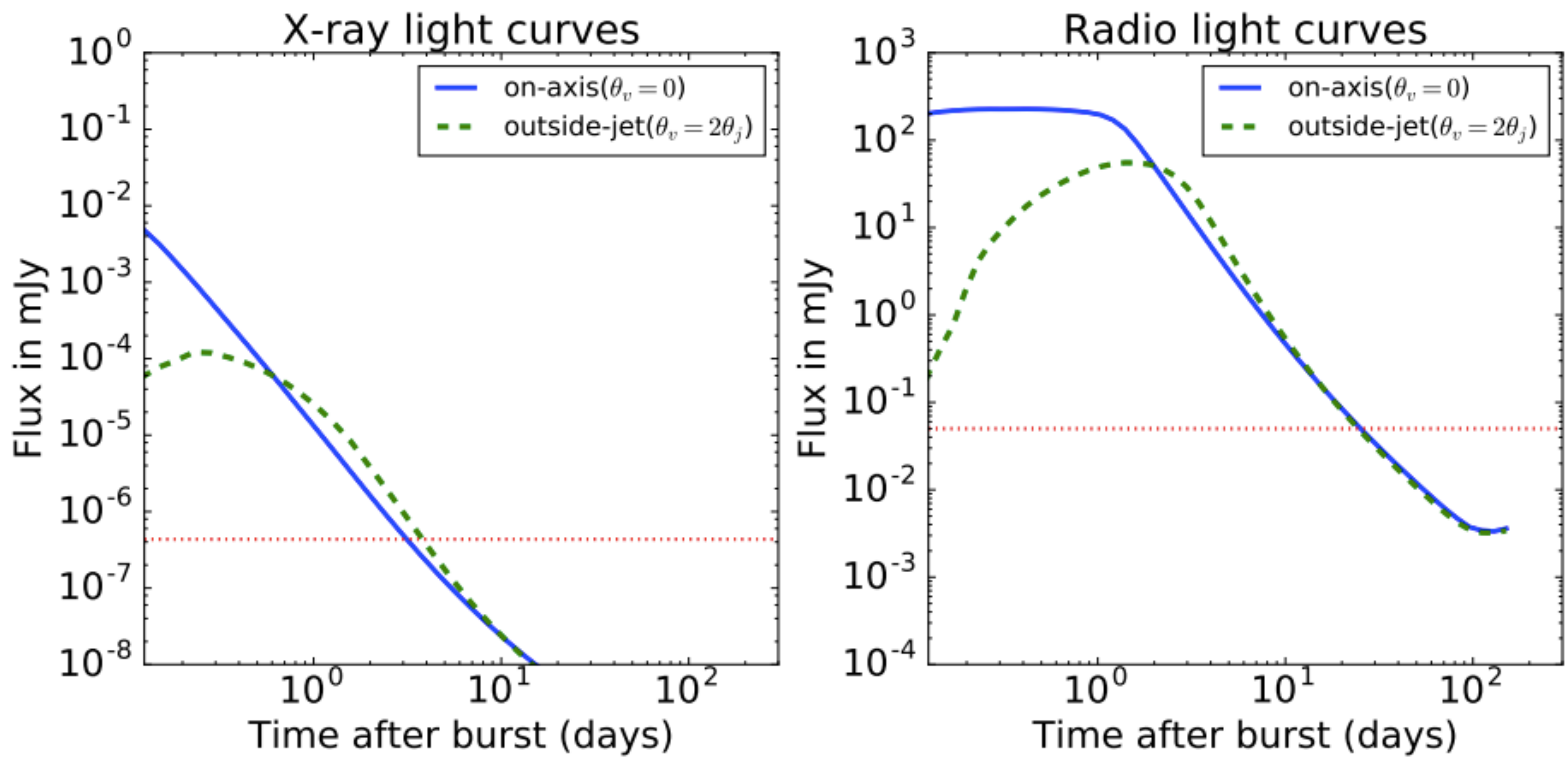



Troja+ 2017




Donaghy+ 2005

# On-axis Vs Off-axis GRBs: Afterglows



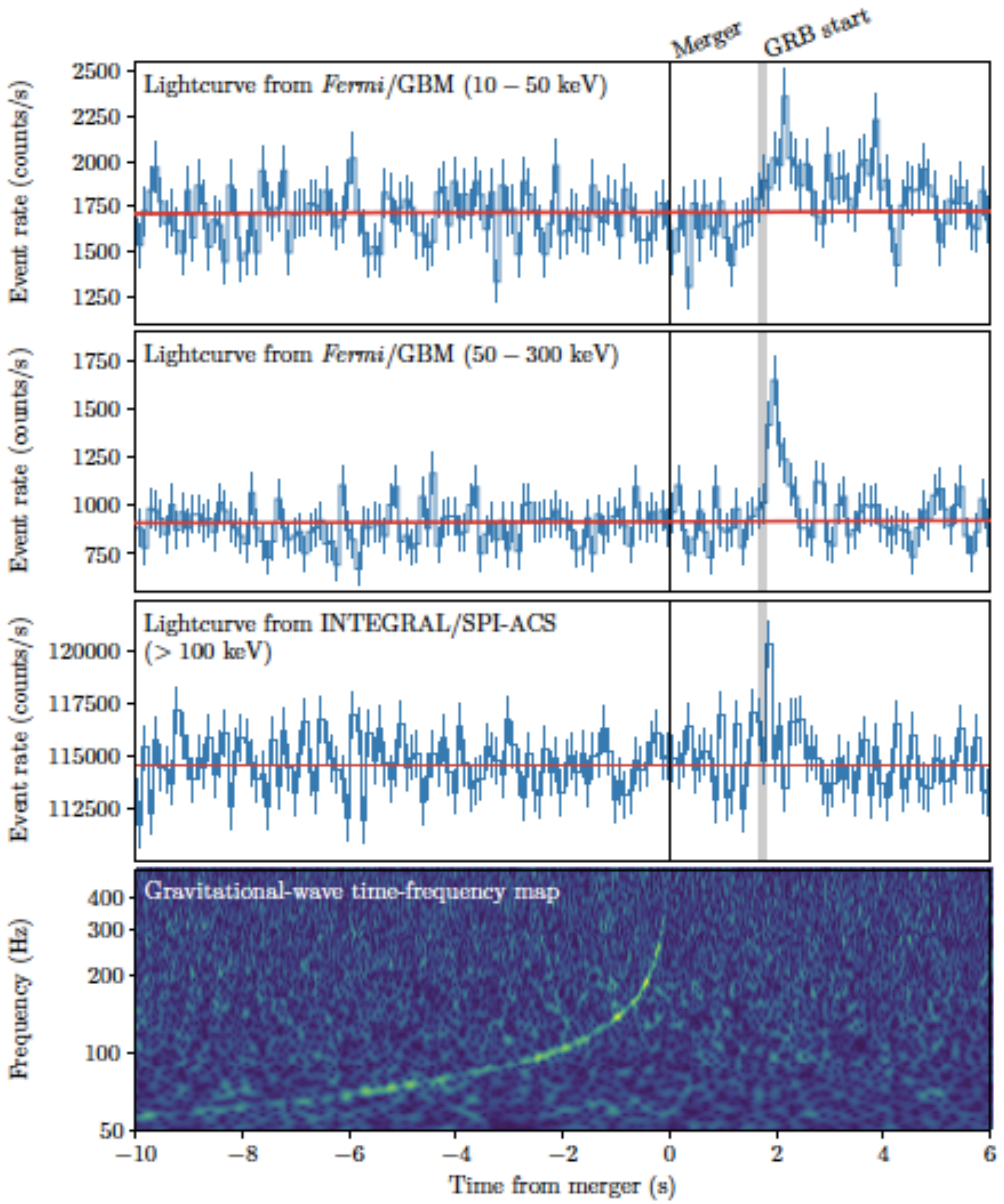

Saleem, Resmi, Pai, Misra, KGA 2017a

# First joint detection

***GW170817 + GRB170817A***

# The Joint detection

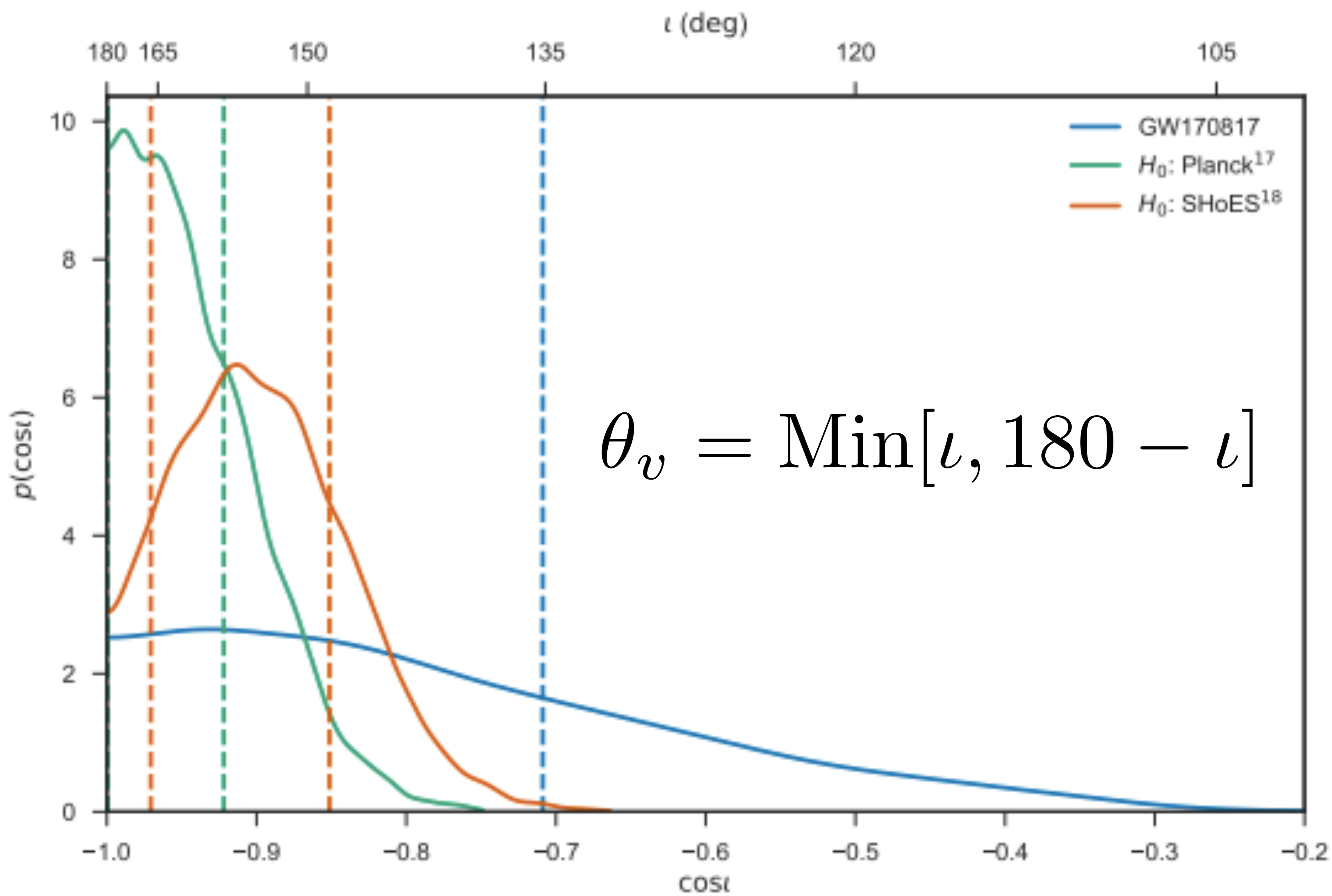
*First ever confirmation that BNS mergers can produce SGRBs*




- Detection of a SGRB by Fermi and INTEGRAL ~2 sec after the LIGO trigger.
- False Alarm Probability ~ 10^-8
- Closest SGRB with known distance.
- *Dimmer by 2-6 orders of magnitude w.r.t "typical" SGRB.*
- Followed up in almost every band of the EM spectrum! (Varun's talk)

# Viewing angle from GWs

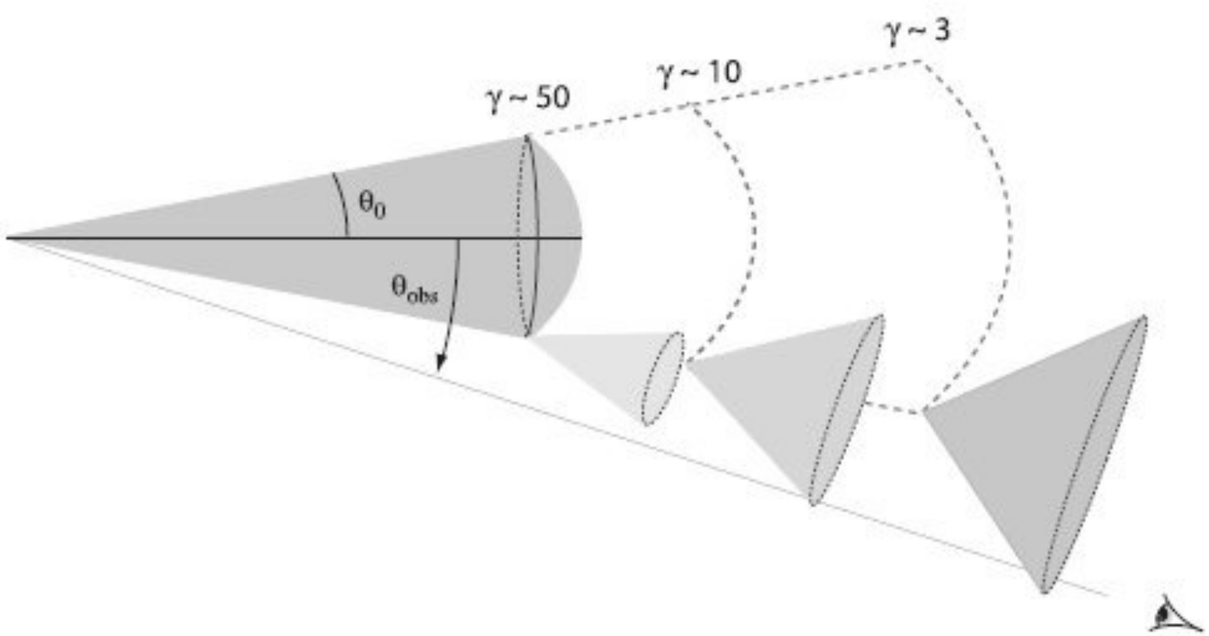
***Direct evidence for off-axisness!***




LVC+6 optical EM groups,Nature (in press) arXiv:1710.05835v1

# Observed features

***Point to off-axisness***




Granot+ 2002

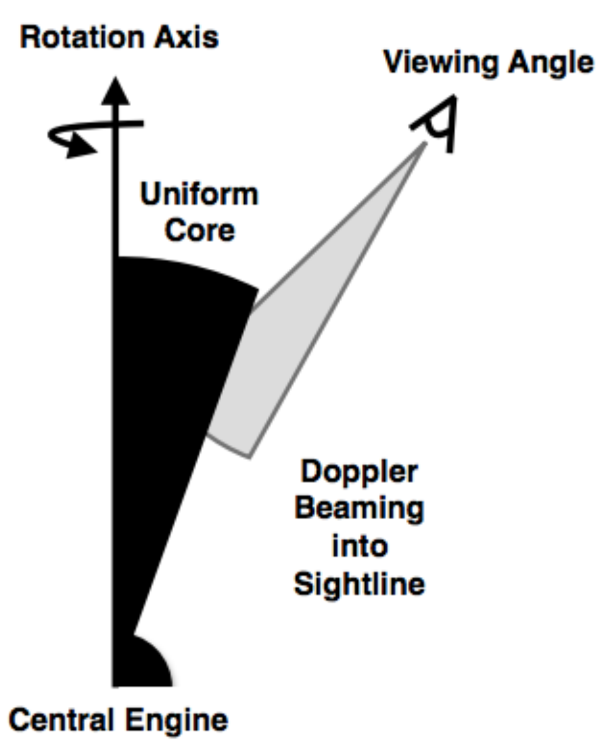
- Weak Prompt emission. *(here 2-6 order of magnitude lower!)*
- Late and weak X ray detection. *(Chandra detected after 9 days!)*
- Radio detection *(JVLA detection)*.

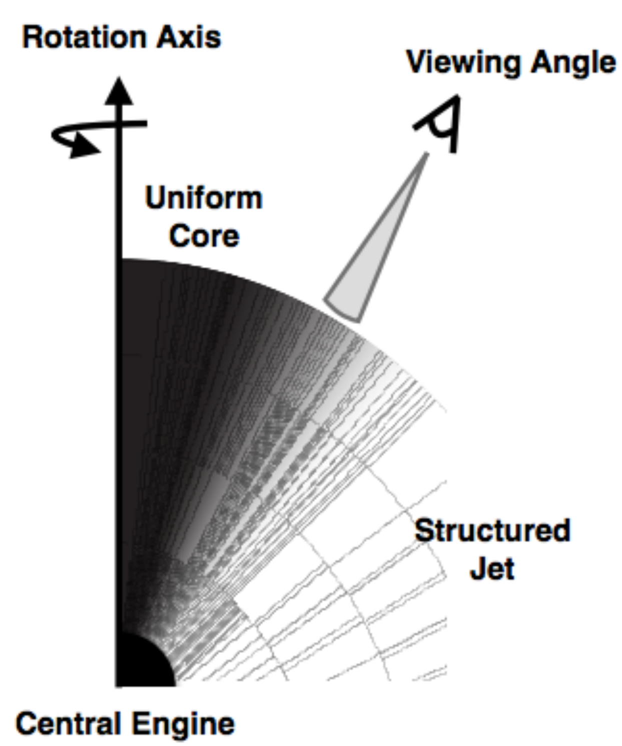
GW observations break the degeneracy between energetic burst far away Vs weak burst near by.

# Structure of the Jet?

## *Top hat vs Structured Jet*

$$\{z, \theta_v, \theta_j, E_{\rm iso}, \Gamma, \epsilon_E, \epsilon_B, n\}$$




- Strongly degenerate parameter space, it is difficult to say which is favoured.
- GW information will be crucial in future.

LVC+ Fermi + Integral, arXiv:1710.05834

# Projections for future

| Source | O3(1yr) | Designed (1 yr) |
| --- | --- | --- |
| BNS | 1-50 | 6-120 |
| BNS+GRB | 0.1-1.4 | 0.3-1.7 |

LVC+ Fermi + Integral, arXiv:1710.05834

# Future prospects

- *Understanding of the central engine.*
- *Constraining the jet structure.*
- *Do NS-BH mergers produce SGRBs too?*
- *GW+EM+Neutrino observation!*

We dedicate this *Letter* to the memory of Neil Gehrels. His pioneering work in gamma-ray astronomy and his vision for multimessenger astrophysics were instrumental to our discoveries.

LVC+ Fermi + Integral, arXiv:1710.05834