# X-ray observations of GW 170817/GRB 170817A

Maria Grazia Bernardini

LUPM, Montpelleir, France
INAF-OAB, Merate, Italy

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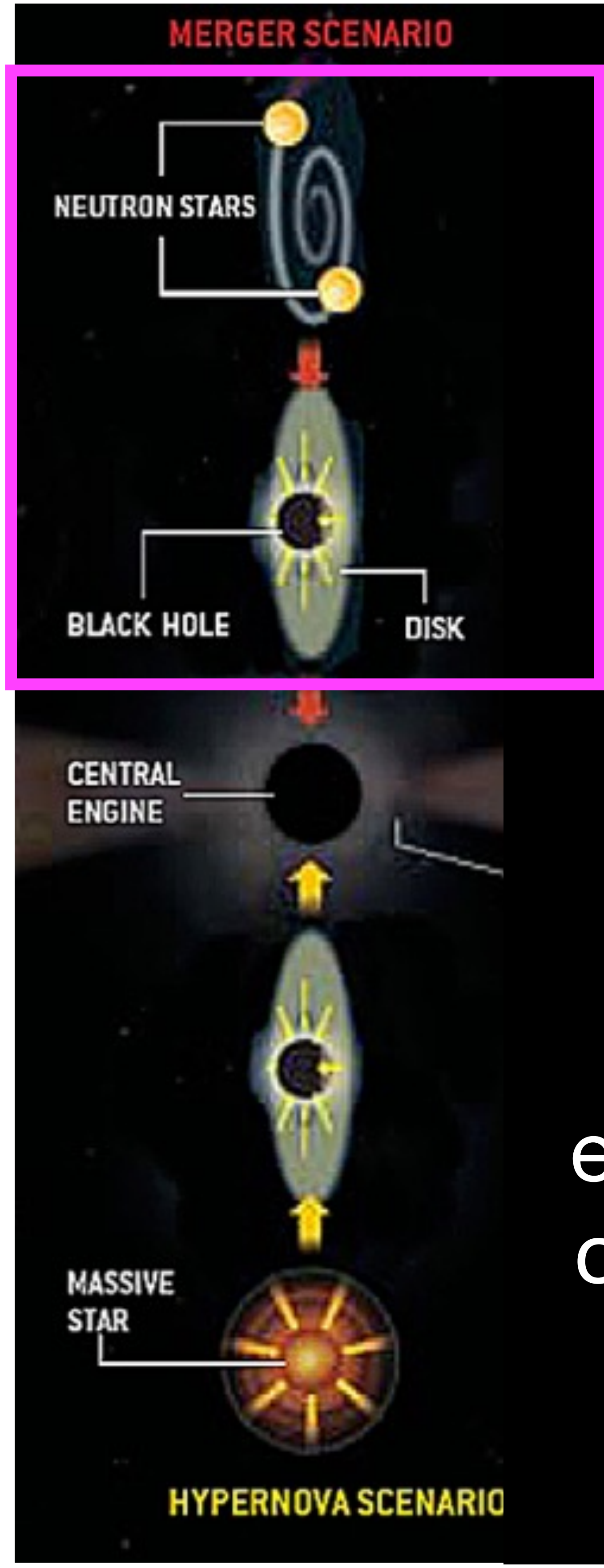
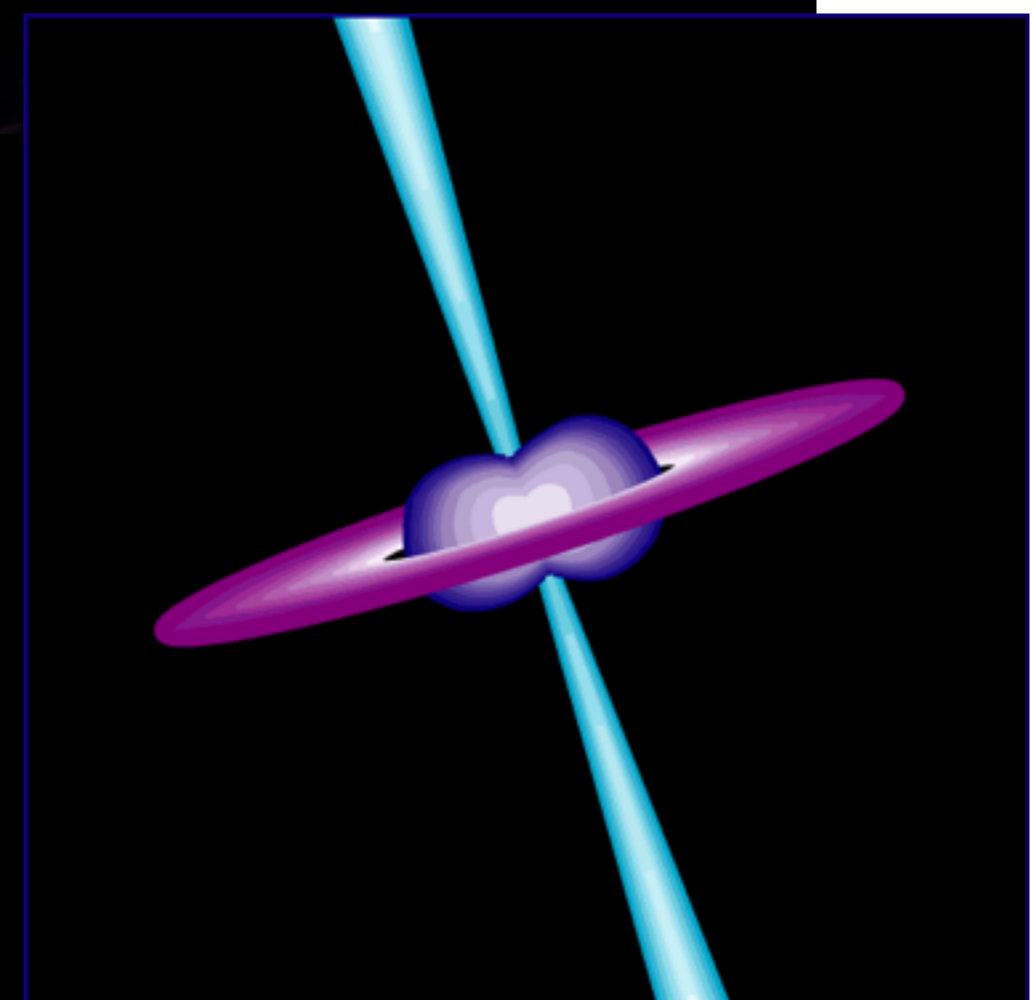
# Gamma-ray bursts (GRBs)

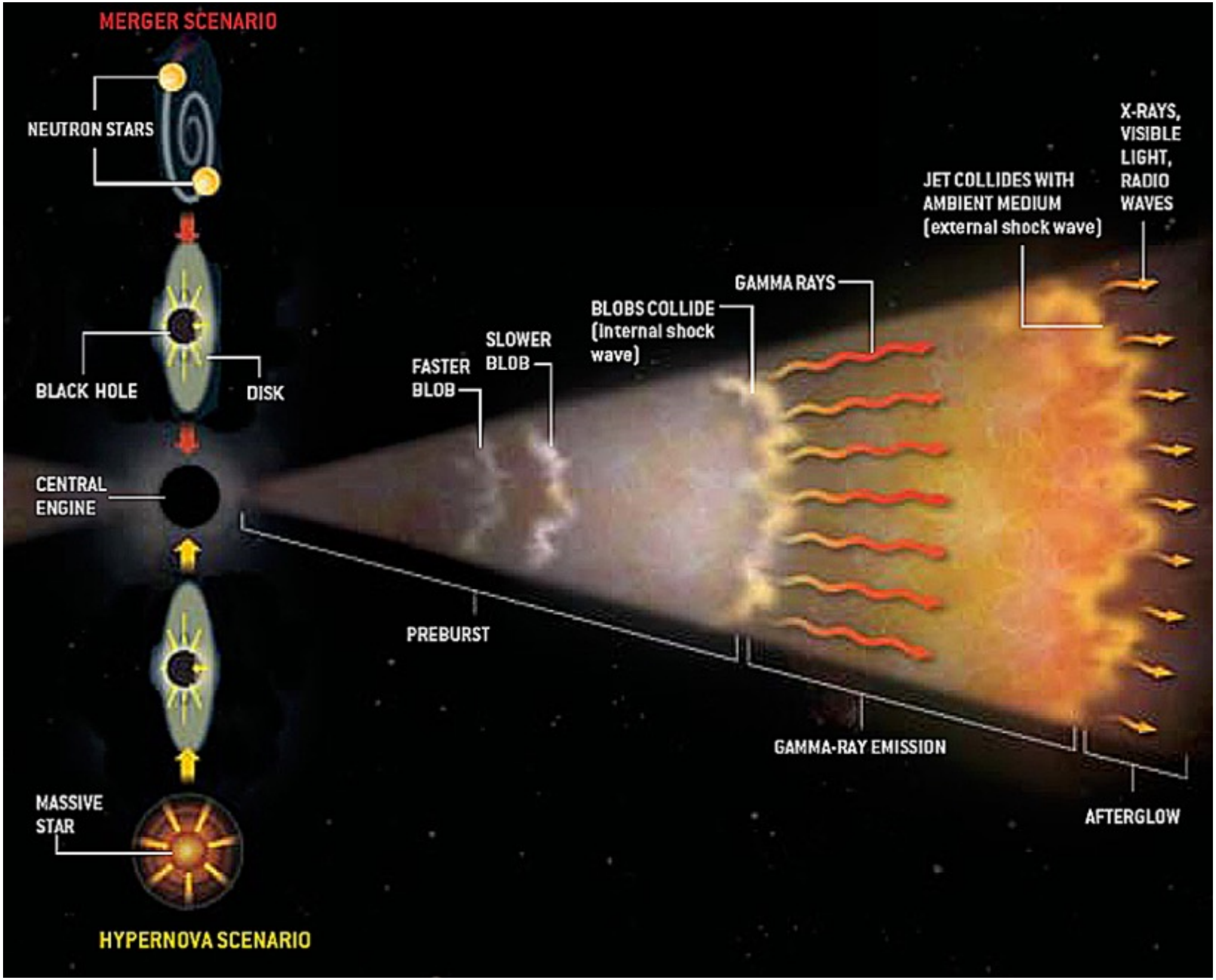
Short



SGRBs: most promising elettromagnetic counterparts of GWs

# Gamma-ray bursts (GRBs)



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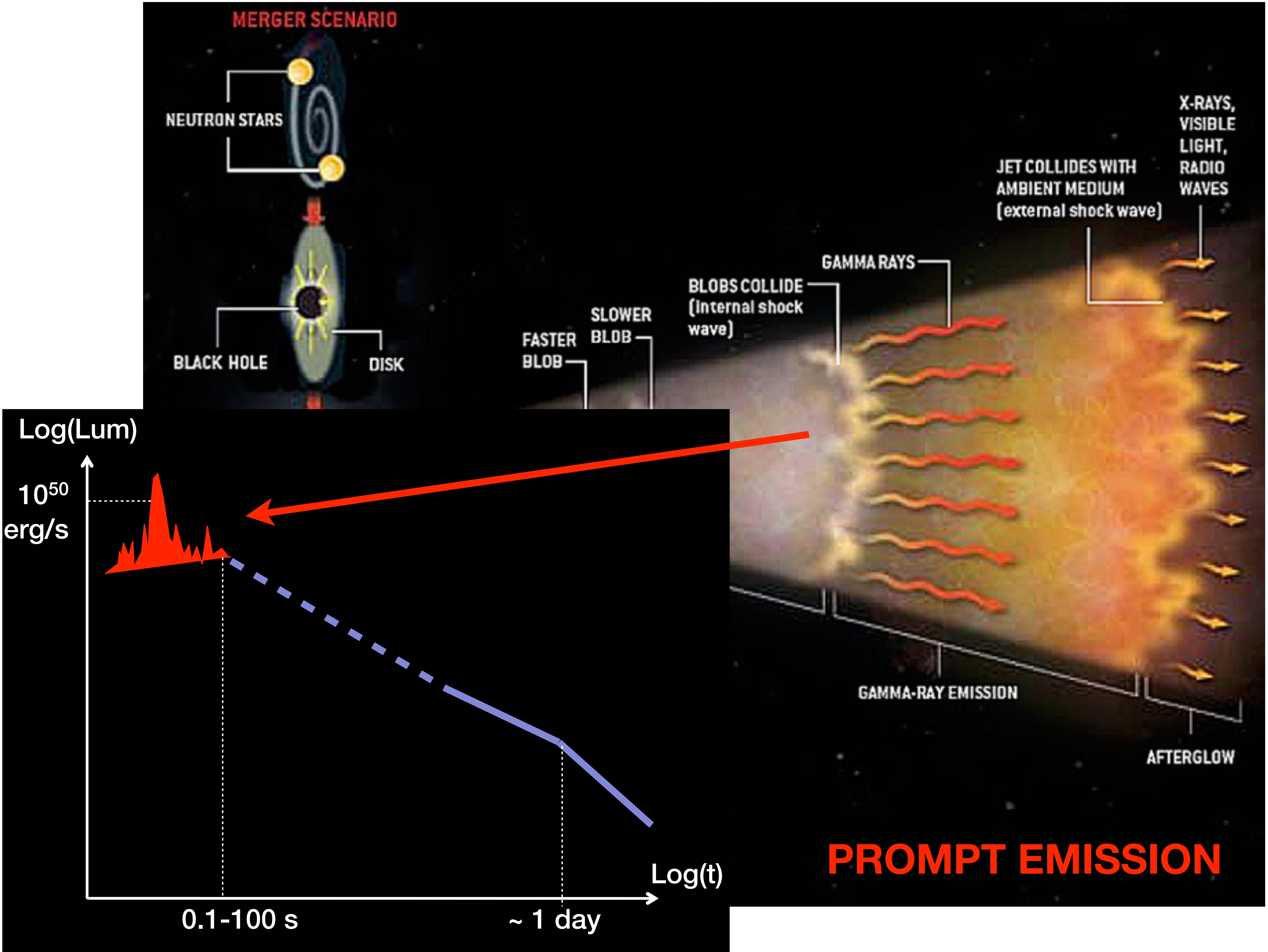

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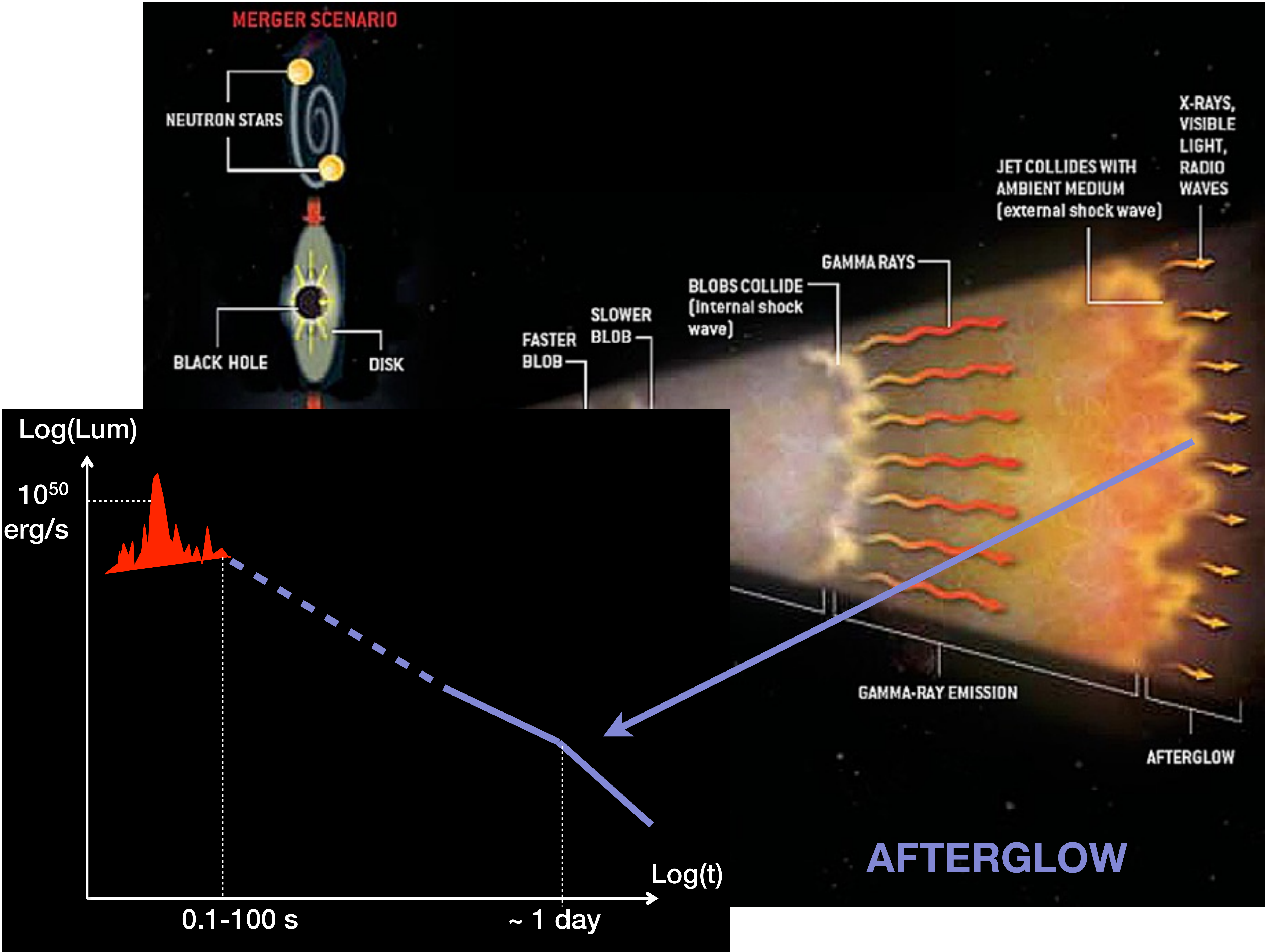
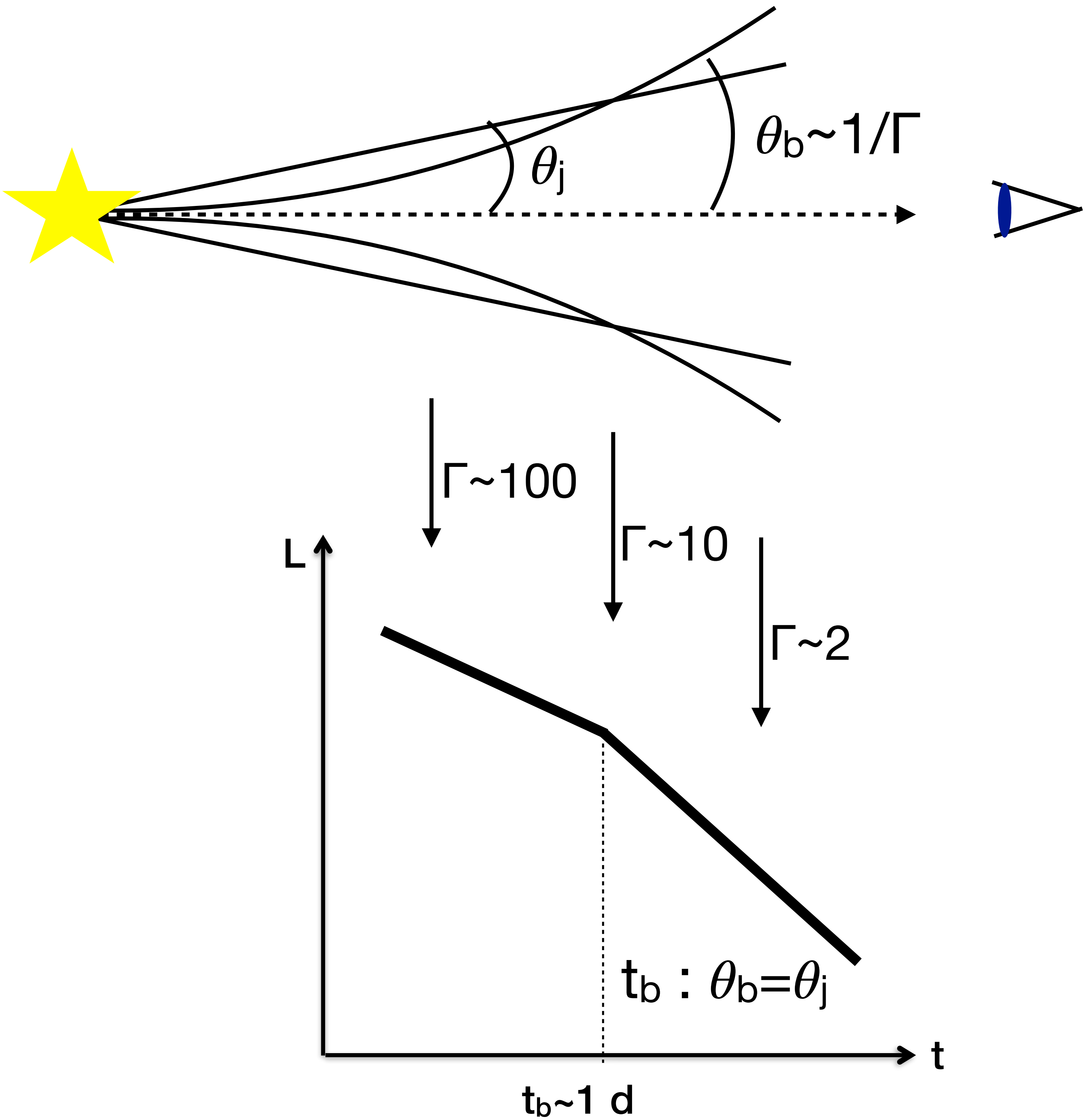


# On-axis SGRB afterglow



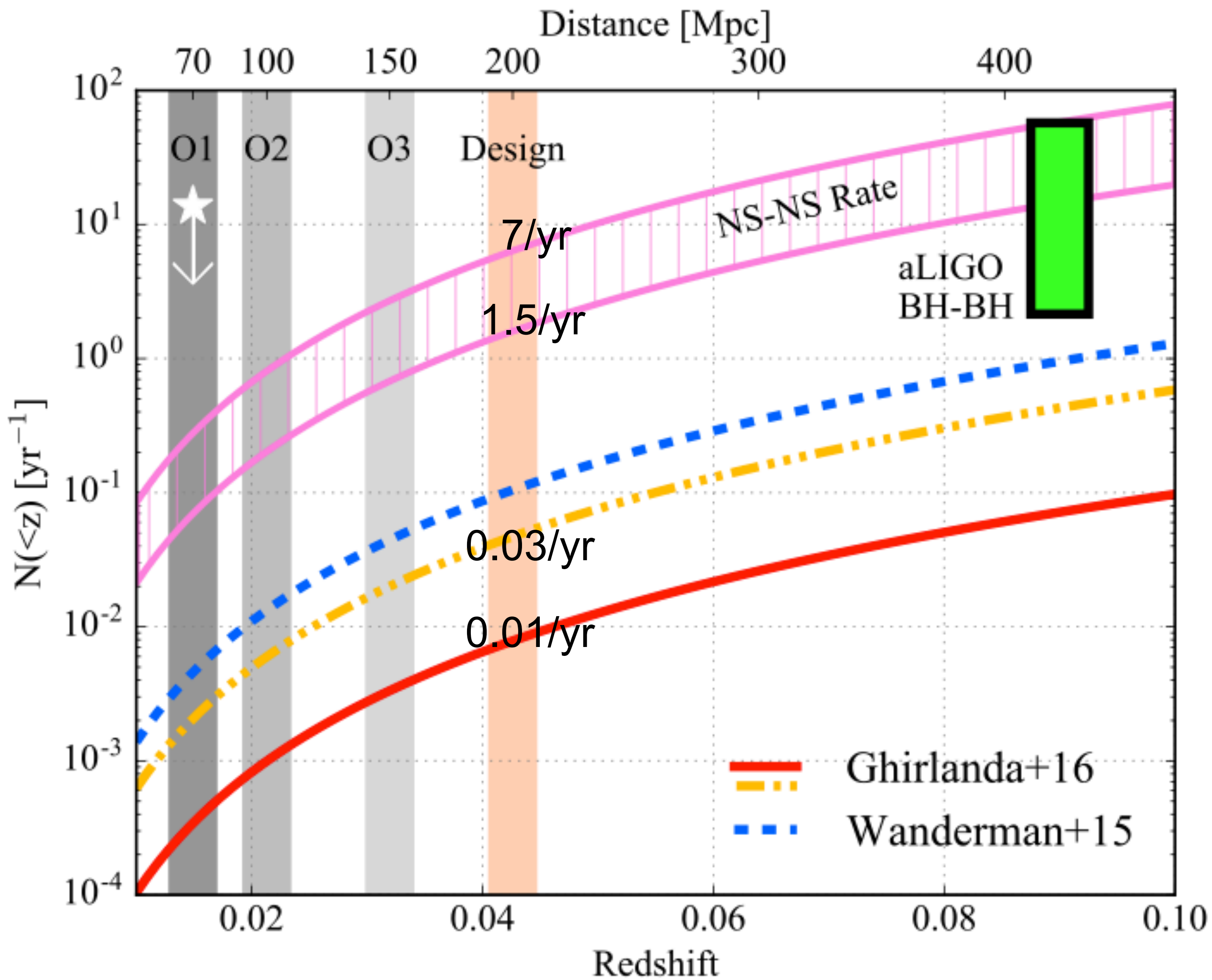

$\theta_j$ inferred from detection of the jet break

Short GRB Opening Angles

| GRB | Band[a] | $\theta_j$ (deg) | $\delta t^{b}_{\rm last}$ (days) | Reference |
|---|---|---|---|---|
| 050709 | O | $\gtrsim 15°$ | 16.2 | 1 |
| 050724A | X | $\gtrsim 25°$ | 22.0 | 2 |
| **051221A** | X | $6-7°$ | 26.6 | 3 |
| **090426A** | O | $5-7°$ | 2.7 | 4 |
| 101219A | X | $\gtrsim 4°$ | 3.9 | 5, This work |
| **111020A** | X | $3-8°$ | 10.2 | 6 |
| 111117A | X | $\gtrsim 3-10°$ | 3.0 | 7, 8 |
| 120804A | X | $\gtrsim 13°$ | 45.9 | 9, This work |
| **130603B** | OR | $4-8°$ | 6.5 | 10 |
| 140903A | X | $\gtrsim 6°$ | 3.0 | 11, This work |
| 140930B | X | $\gtrsim 9°$ | 23.1 | This work |

Typical jet angles for SGRBs: $\theta_j$ ~5°-15° (Fong+15)

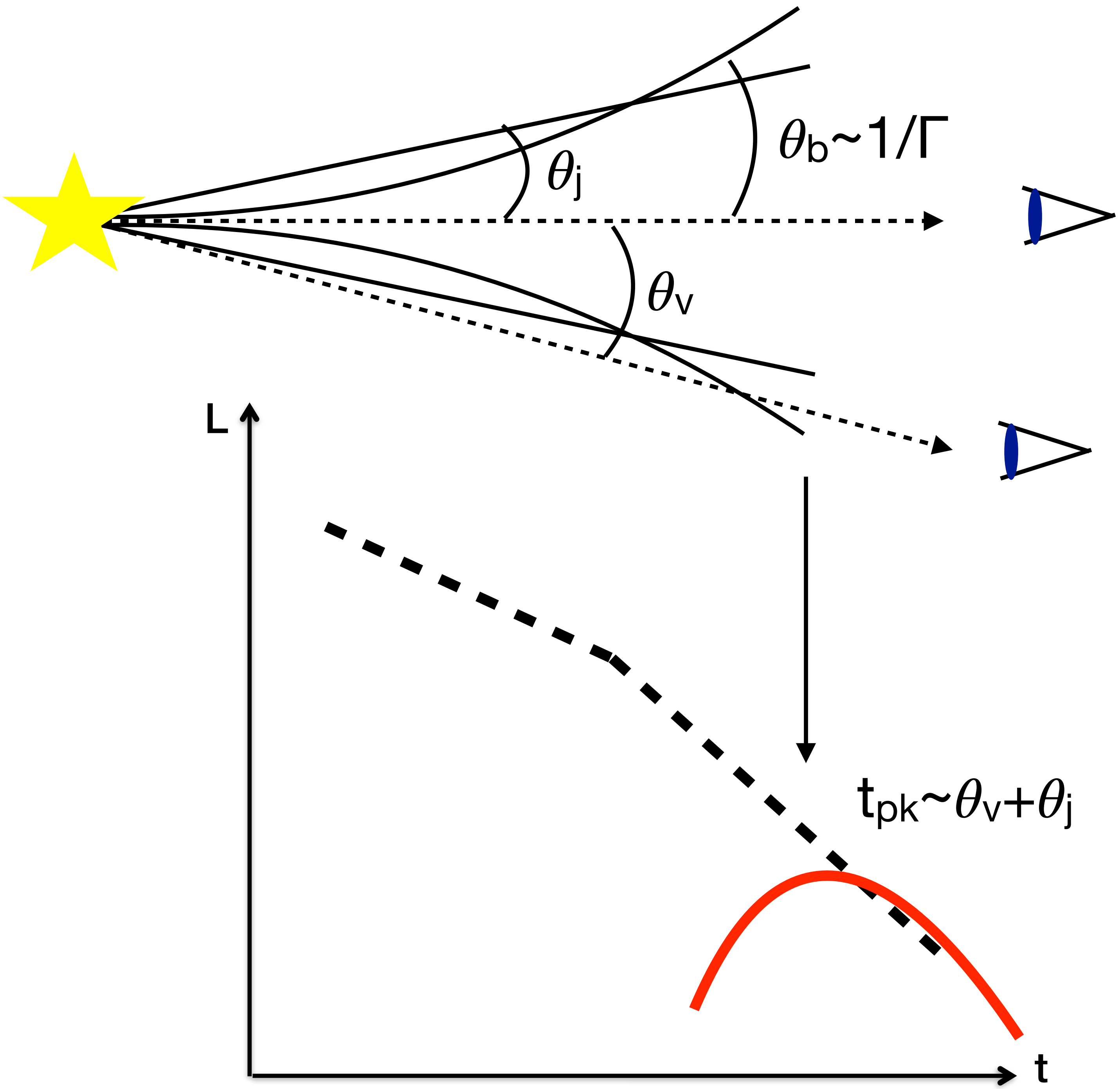
# Prospects for detection of on-axis SGRBs

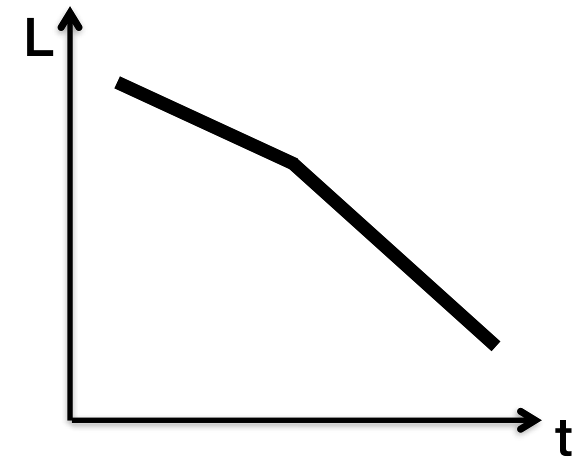



On-axis short GRB rate inferred form the luminosity function and redshift distribution (Ghirlanda+16)

➡ detection of on-axis SGRBs not very promising: better prospects for "orphan" afterglows

# Off-axis "orphan" SGRB afterglow




**Orphan afterglows:**

✓more numerous,
$N_{off} \sim N_{on}(1-\cos\theta_j)^{-1} \sim 200\ N_{on}$

- dimmer and delayed

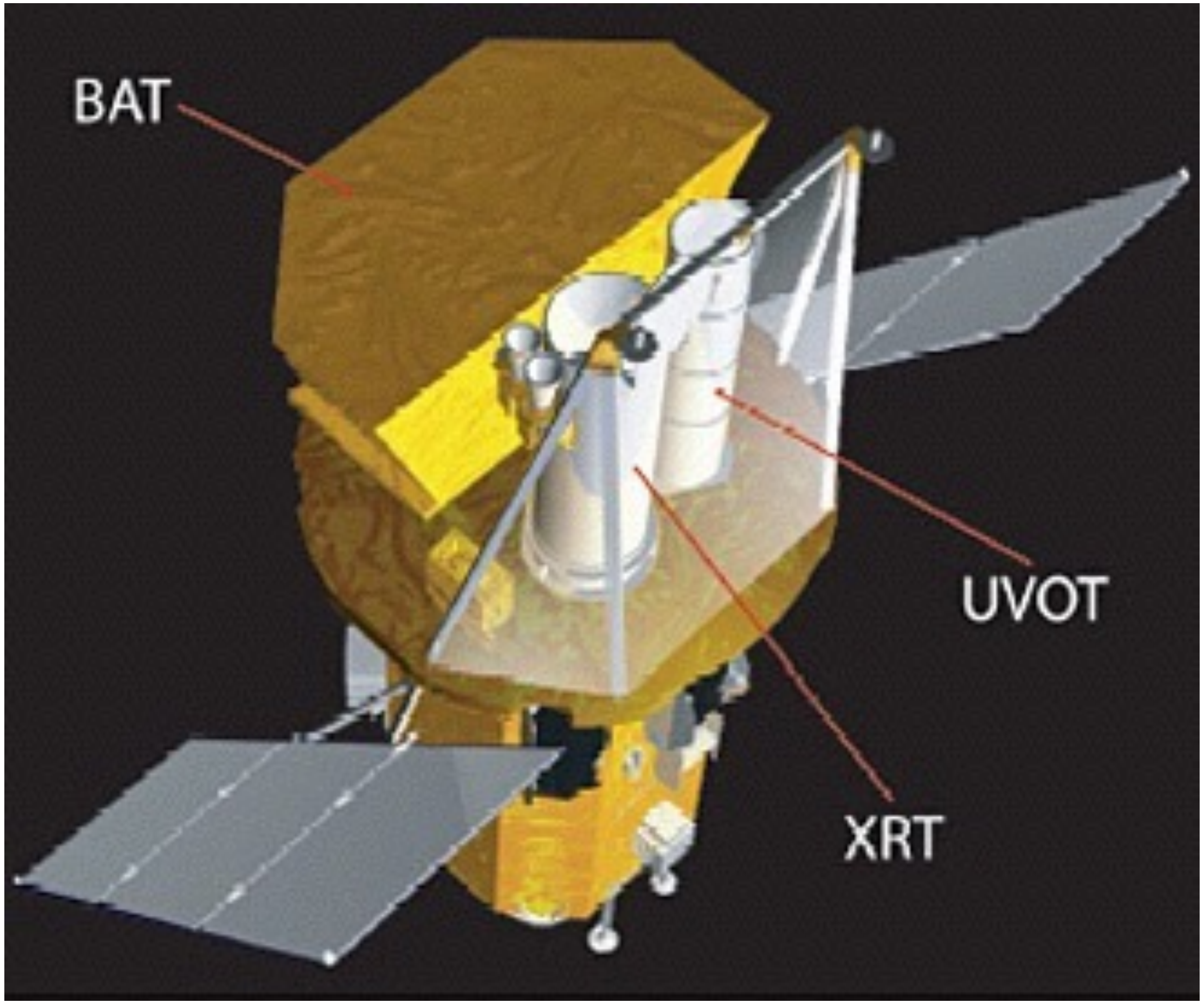
- no gamma-ray trigger

No orphan afterglows detected so far (up to 170817)

# The search for GW counterparts in X-rays

**Neil Gehrels Swift Observatory**

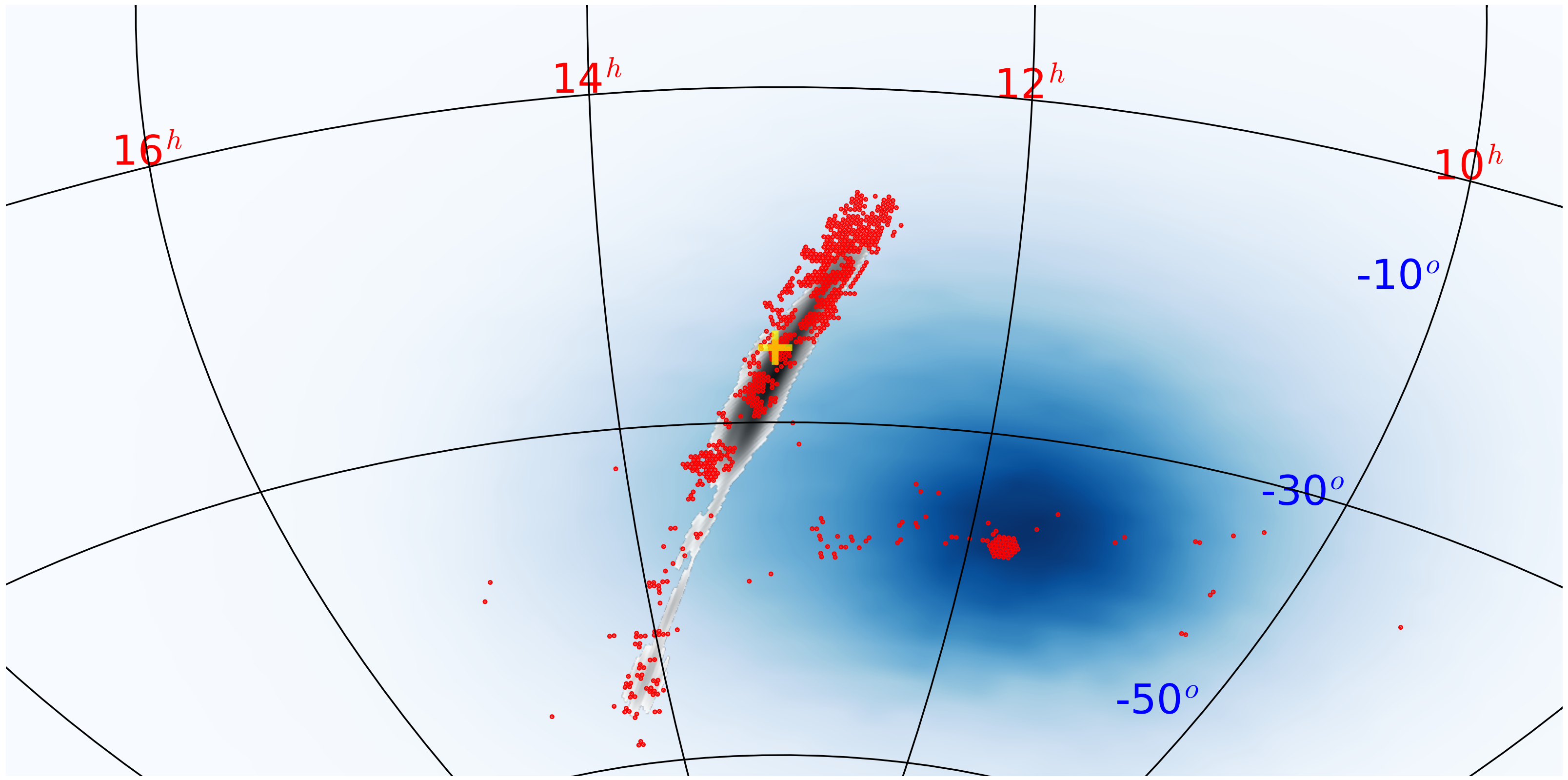
- **BAT**: coded mask, 15-150 keV, ~2 sr fov, transients detection and localisation
- **XRT**: 0.3-10 keV, rapid slew (~ 1 min) and accurate localisation (5”)
- **UVOT**: 6 filters (170-600 nm), 24th mag sensitivity (1000 s), centroid accuracy 0.5”




**Challenge**: scan wide region of the sky with XRT, if no trigger from BAT Evans+15,16

# GW 170817/GRB 170817A: Swift observations

Evans+17

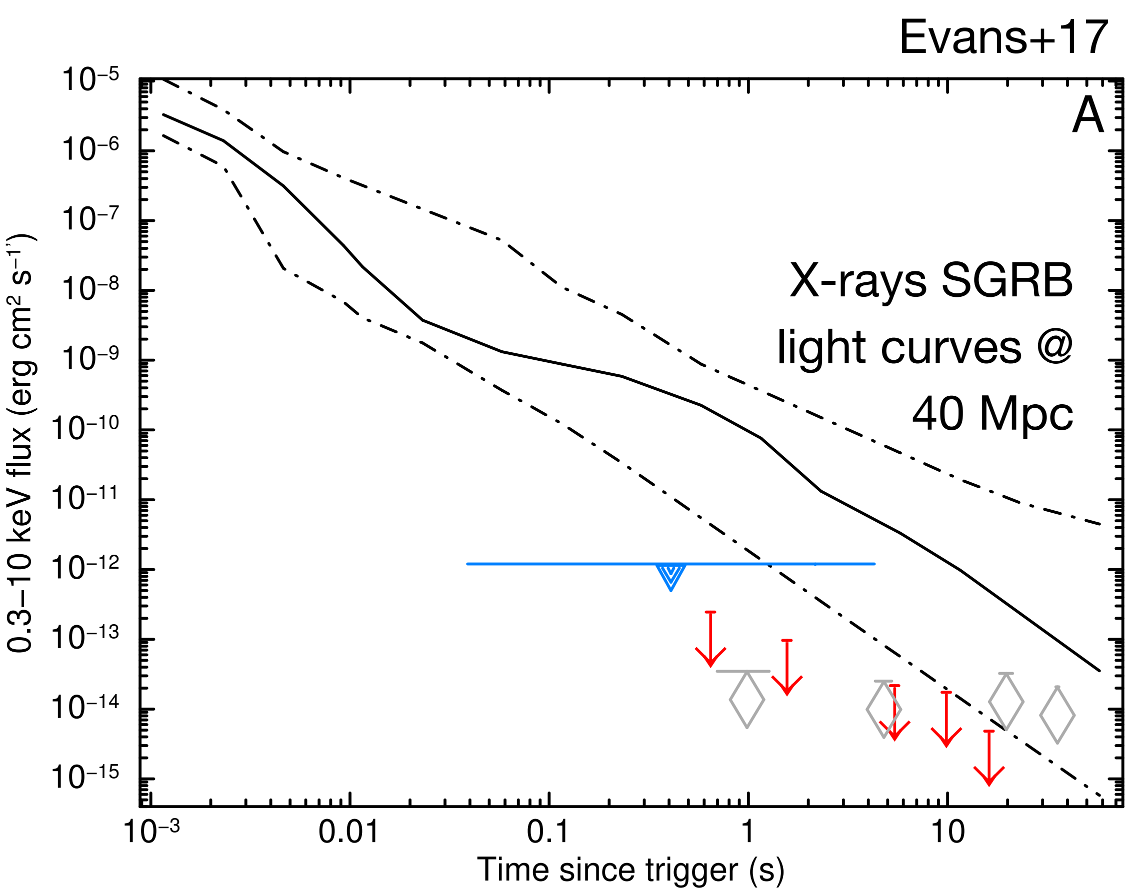



- trigger LIGO/Virgo and Fermi/GBM, no BAT detection (Earth occultation):
  - ➡scan of the GBM region (t=0.04 d) and later of the smaller LIGO/Virgo region (t=0.2 d): short (120 s) exposure centered in the known galaxies
  - ➡no new X-ray source detected ($f_X < 10^{-12}$ erg/cm$^2$/s, 0.3-10 keV)

- candidate optical counterpart reported (t=0.5 d):
  - ➡follow-up with Swift/XRT and UVOT (t=0.6 d) and with NuSTAR (t=0.7 d)
  - ➡UV counterpart detected by UVOT
  - ➡still no X-ray emission detected by XRT ($f_X < 2.7 \times 10^{-13}$ erg/cm$^2$/s, 0.3-10 keV) and NuSTAR ($f_X < 2.6 \times 10^{-14}$ erg/cm$^2$/s, 3-10 keV)

Evans+17

# GW 170817/GRB 170817A: Swift observations

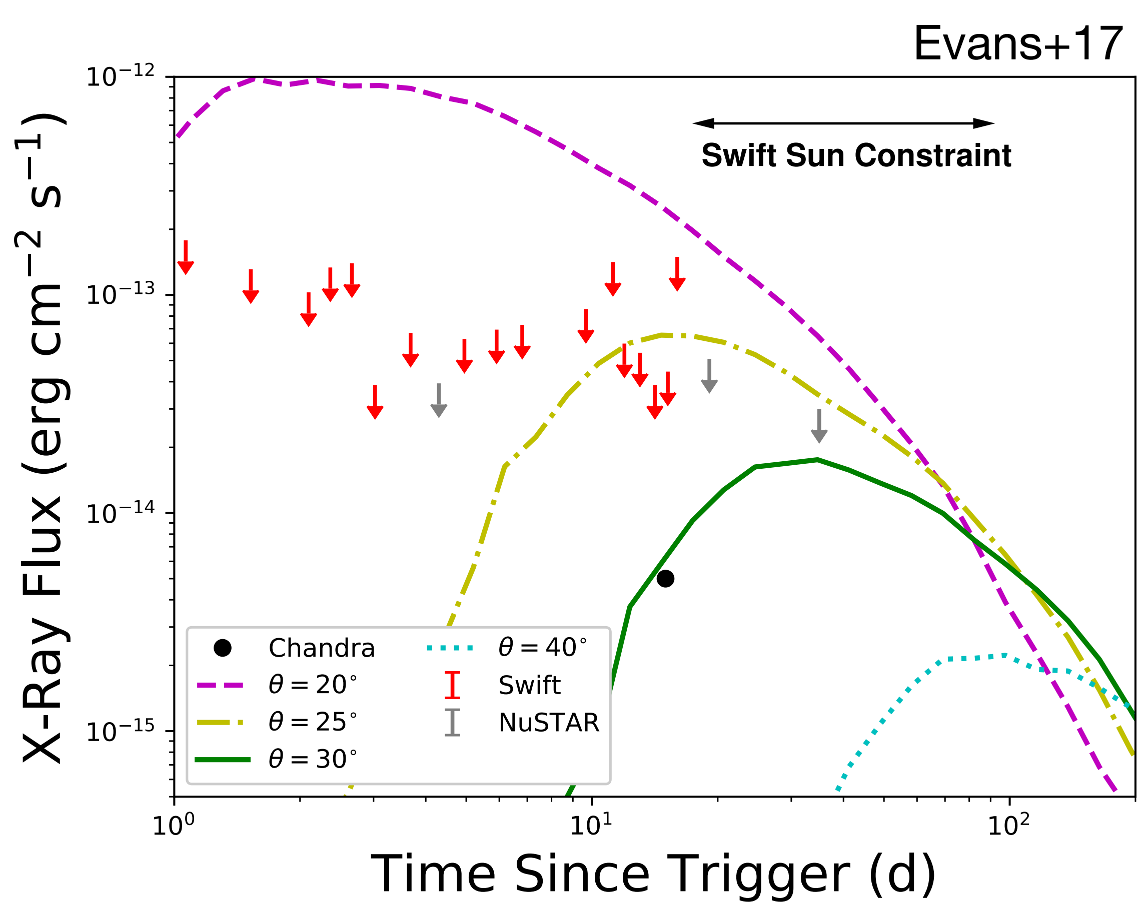



X-ray (and radio) emission not expected to be related to the kilonova but to the GRB itself

➡information on the SGRB afterglow

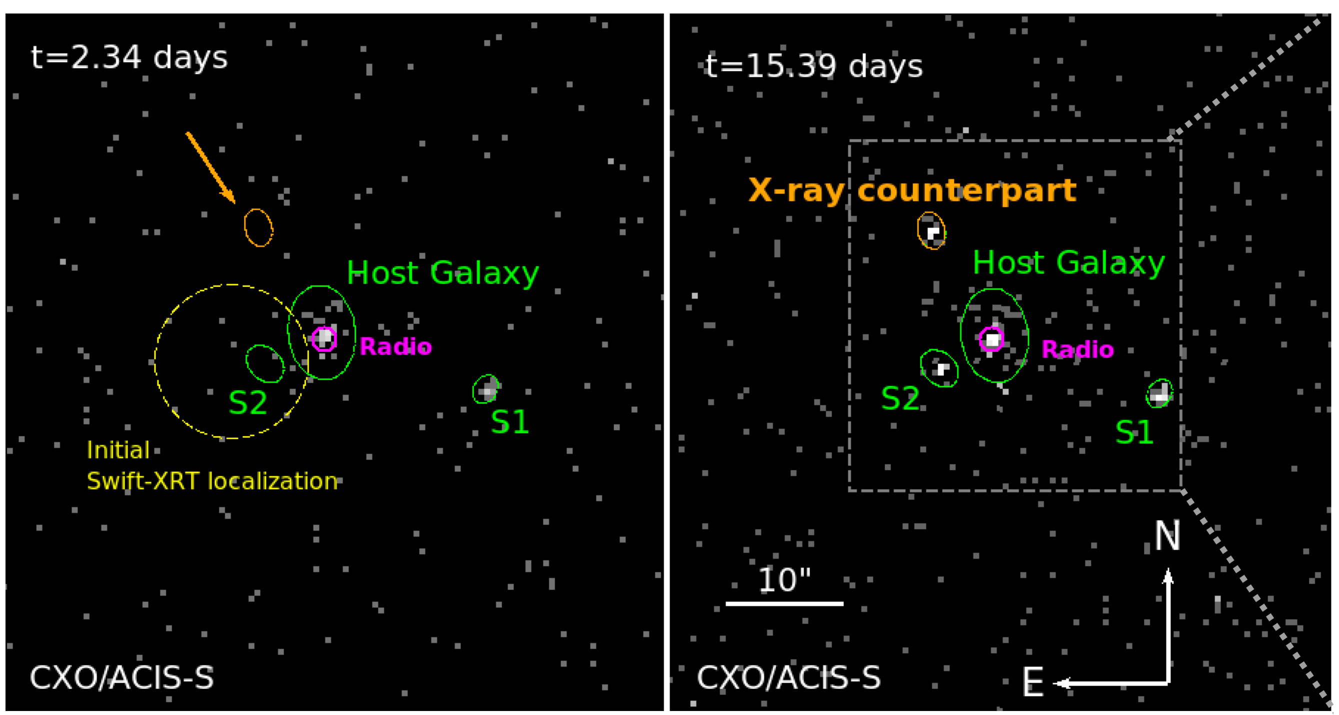
Upper limits with Swift/XRT and NuSTAR:

- X-ray afterglow of GRB 170817A dimmer than for typical SGRBs (D'Avanzo+14)
- possibly consistent with the orphan afterglow scenario
- supported by Chandra observations



# GW 170817/GRB 170817A: search for the X-ray counterpart

- **MAXI**: no detection at t=0.19 d ($f_X$<8.6x10$^{-9}$ erg/cm$^2$/s, 2-10 keV) Sugita+17
- **Super-AGILE**: no detection at t=0.53 d ($f_X$<3x10$^{-9}$ erg/cm$^2$/s, 18-60 keV) Verrecchia+17
- **INTEGRAL/JEM-X**: no detection at t~6 d ($f_X$<2x10$^{-11}$ erg/cm$^2$/s, 3-10 keV) Savchenko+17
- **XMM-Newton**: source in Sun constraint
- **Chandra**: source observed from t=2.2 d up to Sun constraint:



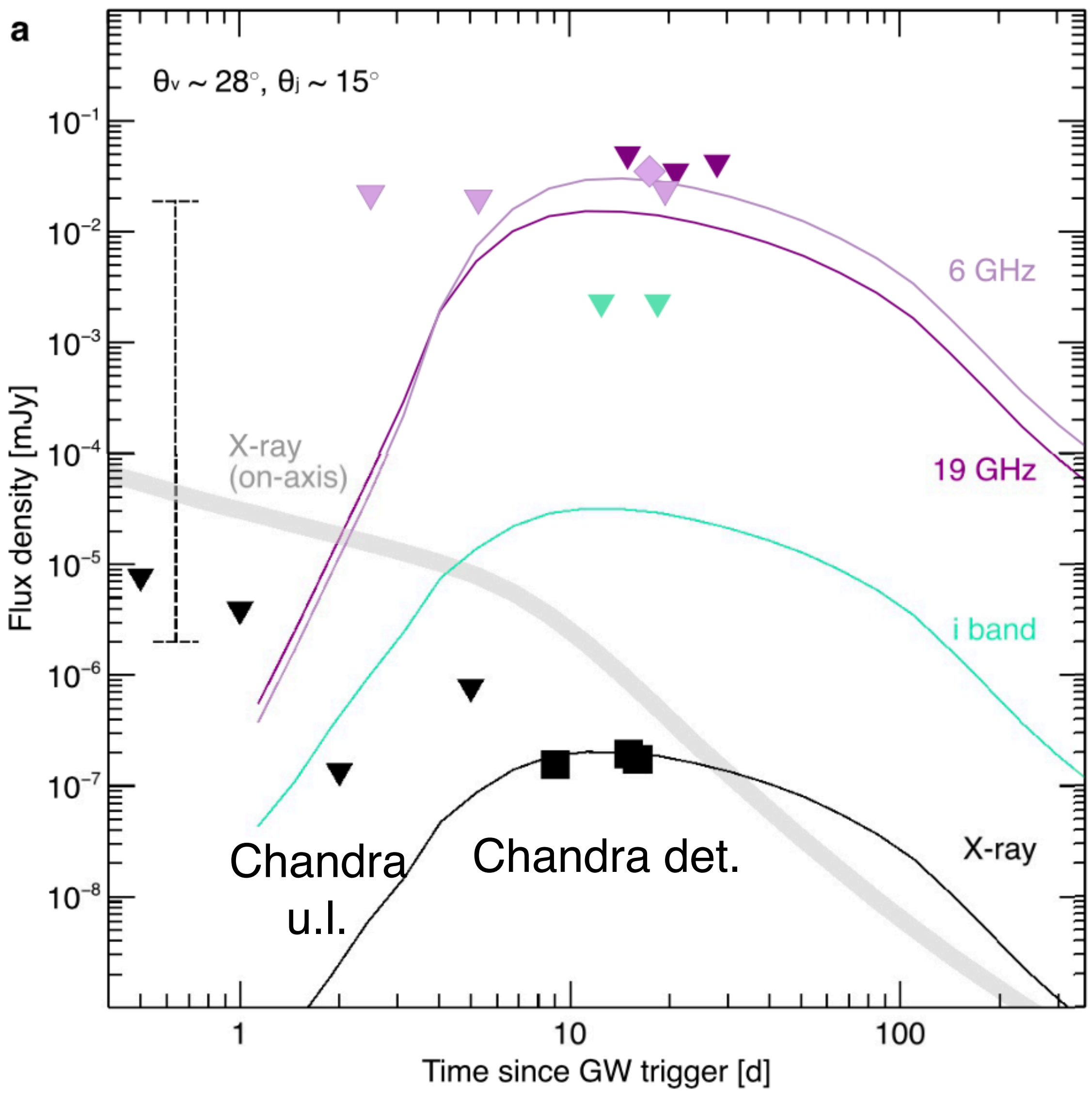

Margutti+17

➡initial non detection at t=2 d (expo 25 ks, $f_X$<1.4x10$^{-15}$ erg/cm$^2$/s, 0.3-10 keV) Margutti+17

➡detection of an X-ray counterpart at t=9 d (expo 50 ks) consistent with the OT/IR counterpart Troja+17

➡X-ray source confirmed by other observations Margutti+17, Troja+17, Fong+17, Haggard+17

# GW 170817/GRB 170817A: early Chandra observations




- initial non-detection at t=2.2 d (expo 25 ks) Margutti+17
- detection of X-ray emission at t=9 d (expo 50 ks) with $f_X$=4x10$^{-15}$ erg/cm$^2$/s (0.3-10 keV) Troja+17
- several detections reported at t=15-16 d (expo ~50 ks, $f_X$=5x10$^{-15}$ erg/cm$^2$/s, 0.3-10 keV) Margutti+17, Troja+17, Haggard+17

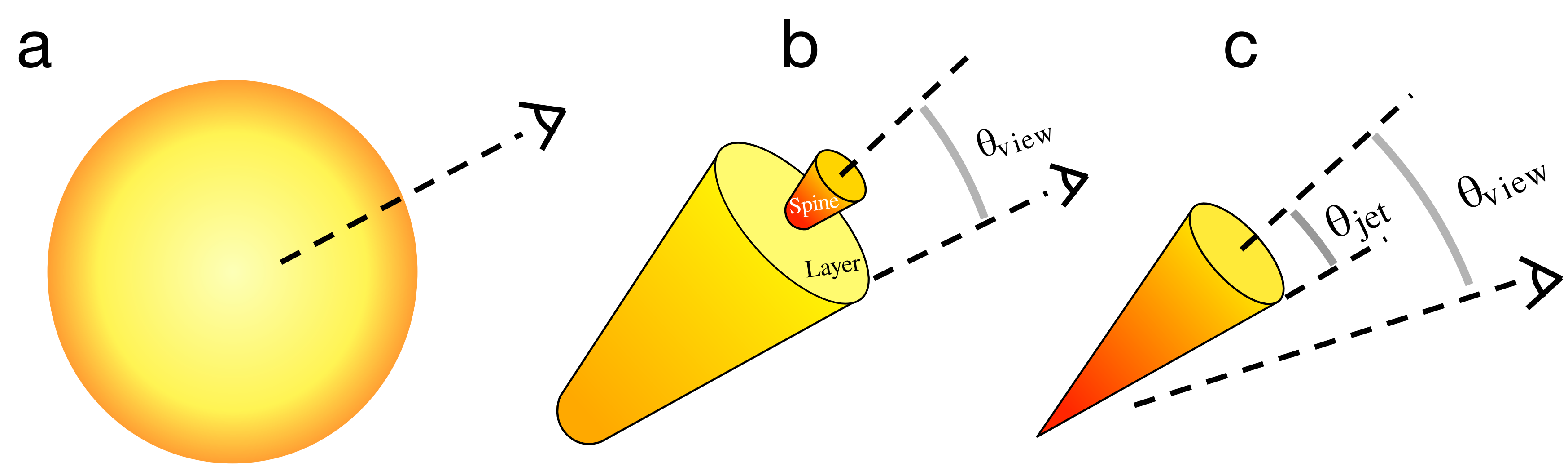
➡on-axis GRB afterglow is ruled out

➡off-axis afterglow with $\theta_v$~20$^o$-40$^o$ and $\theta_j$~15$^o$

➡central engine origin of X-ray emission is disfavoured

The source entered in Sun constraint until December 2017…

# How X-ray observations can constrain theoretical models




Salafia+17

Different scenarios are still consistent with early X-ray observations:

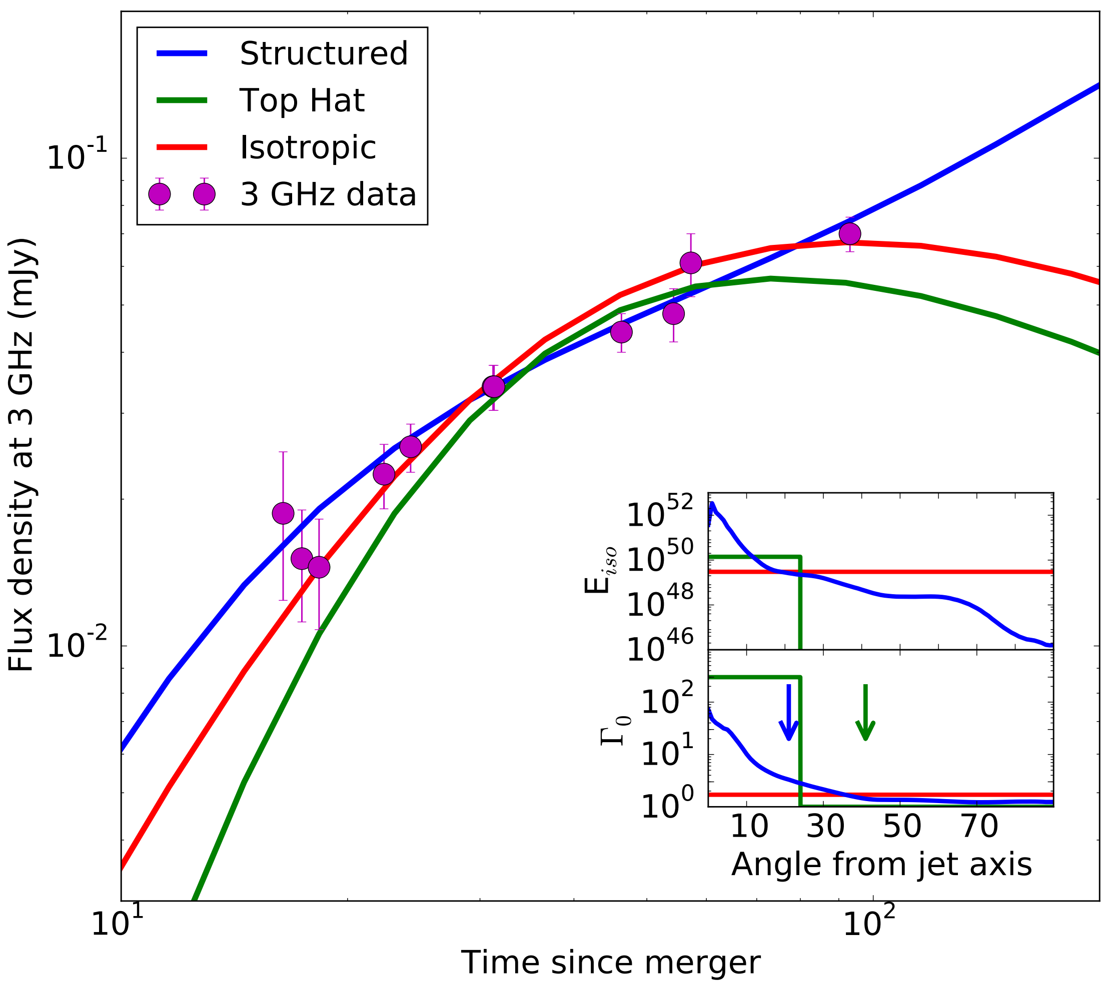
a. isotropic fireball Salafia+17 or hot cocoon from a failed jet Mooley+17

b. structured jet: standard jet+less energetic cocoon/layer Lazzati+17, Kathirgamaraju+17, Gottlieb+17, Lyman+18, Margutti+18, D'Avanzo+18

c. uniform (top-hat) jet with unusually low Lorentz factor Pian+17

# How X-ray observations can constrain theoretical models

Lazzati+17




- Radio observations up to t=107 d Mooley+17

  ➡the emission is rising

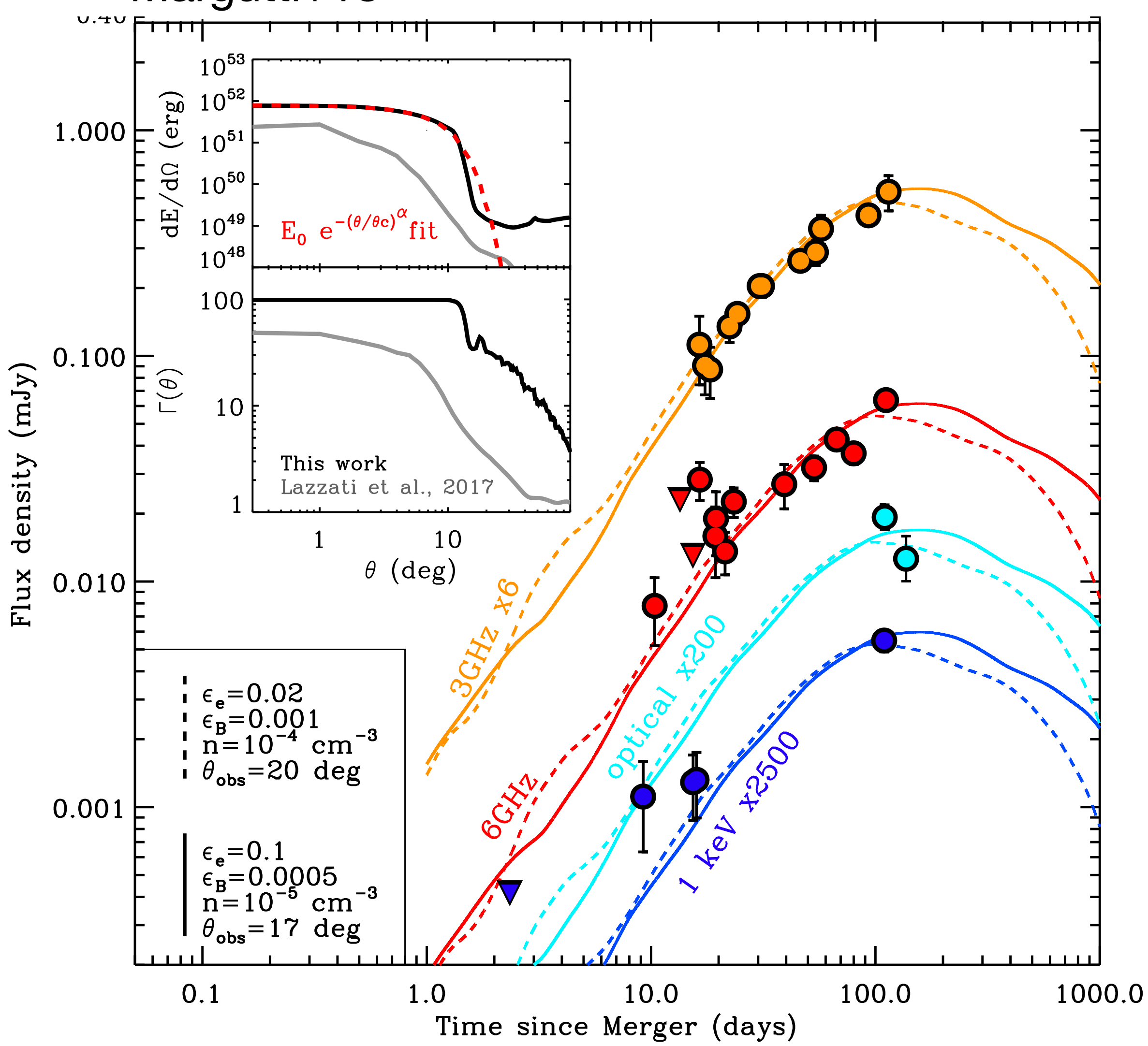
Different scenarios are still consistent with early X-ray observations:

a. isotropic fireball Salafia+17 or hot cocoon from a failed jet Mooley+17

b. structured jet: standard jet+less energetic cocoon/layer Lazzati+17, Kathirgamaraju+17, Gottlieb+17, Lyman+18, Margutti+18, D'Avanzo+18

c. ~~uniform (top-hat) jet with unusually low Lorentz factor Pian+17~~

# GW 170817/GRB 170817A: late X-ray observations

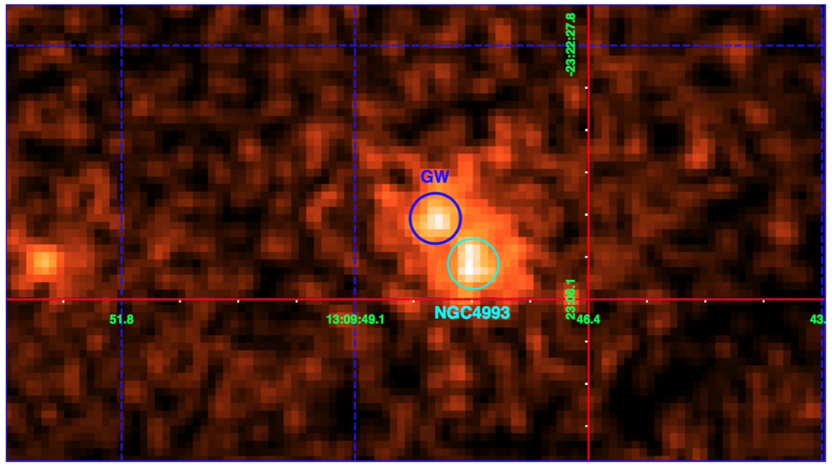



- Further observations with Chandra once the source exit the Sun constraint (t=107 d Margutti+18 and t=109 d Ruan+18)
  - ➡the X-ray emission substantially rised
- OT observations at t=110 d Lyman+17 and t=137 d Margutti+18
  - ➡unrelated to the kilonova, likely associated to GRB 170817A
  - ➡consistent with radio and X-ray behaviour

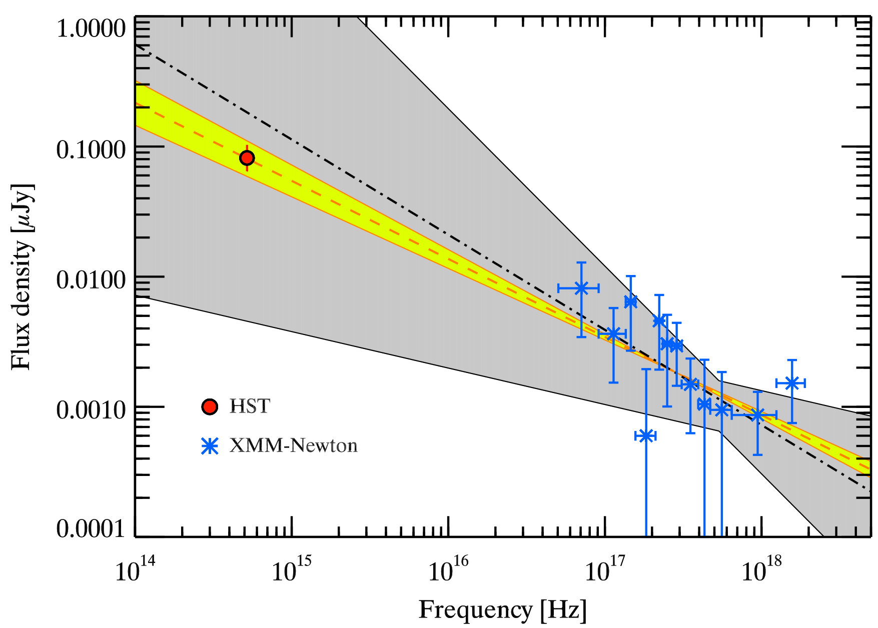
- constraints on the nature of the emission process (synchrotron emission)
- no constraints on the nature of the relativistic ejecta (both scenarios still valid)

# GW 170817/GRB 170817A: late X-ray observations

D'Avanzo+18

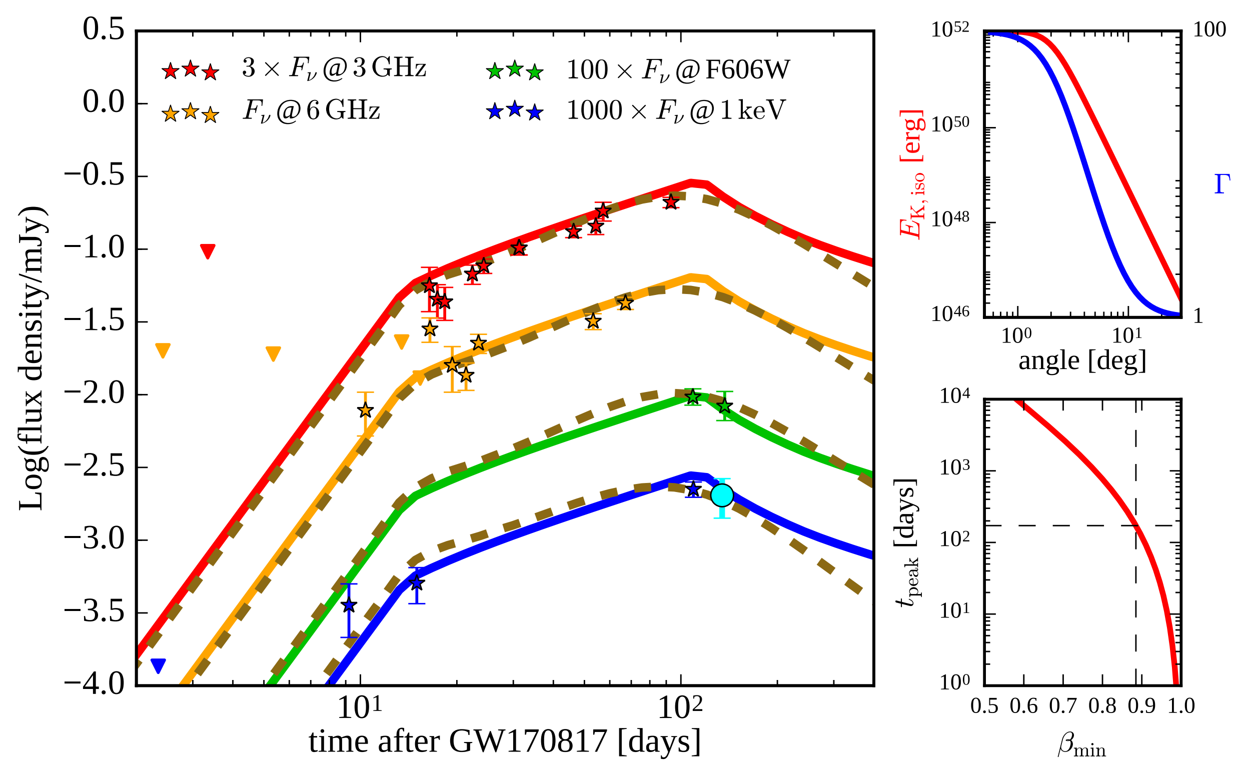



D'Avanzo+18




- XMM detection at t=135 d (PI:D'Avanzo)
  - ➡OT-X-ray spectral slope unchanged form previous epochs: no passage of the cooling frequency
  - ➡evidence of a change in the temporal slope: likely geometrical effect
- Chandra detection at t=153, 156 and 164 d Haggard +18, Troja+18
  - ➡possible change in the slope Troja+18

D'Avanzo+18




- still not possible to distinguish between the structured jet and the isotropic fireball

# Conclusions

- X-ray (and radio) emission directly from the SGRB afterglow: first direct observations testing the structure of the jet
- SGRB and kilonova spatially coincidents, further proof of their direct connection
- observations at $t \leq 200$ days are unlikely to settle the outflow geometry as in both scenarios the observed emission is effectively dominated by radiation from mildly relativistic material
- continuous monitoring of the source will possibly provide the first proof of the geometry of the ouflow of SGRBs