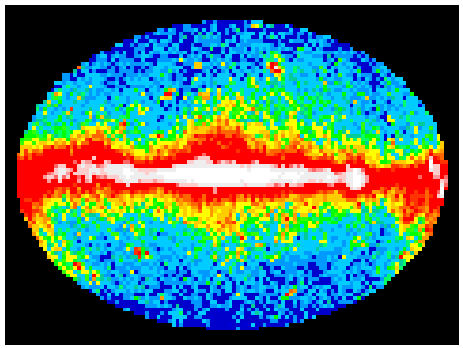
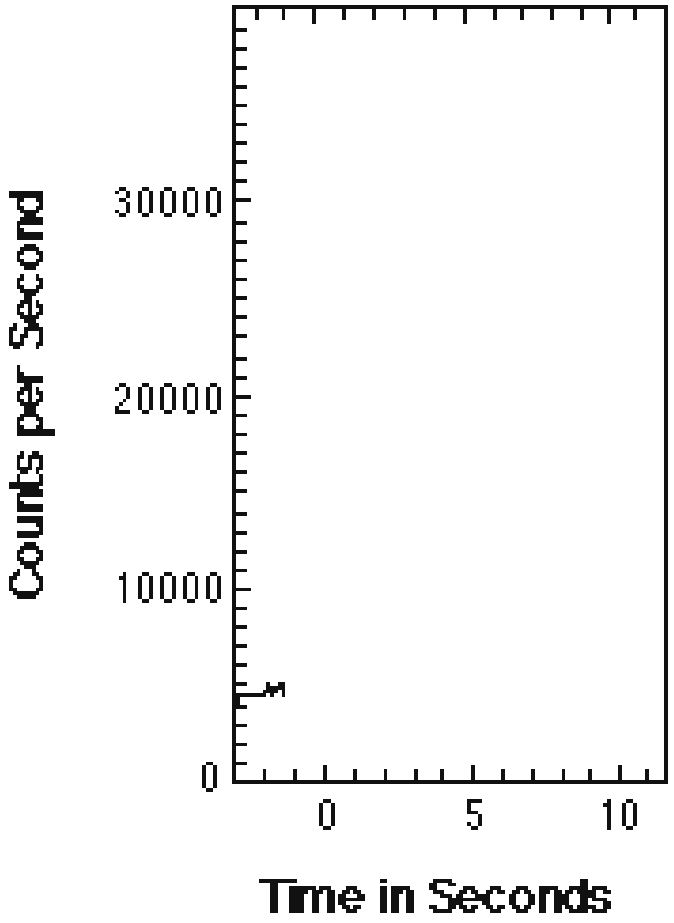
Gamma-ray Bursts & SVOM

Frédéric Daigne (Institut d'Astrophysique de Paris)

+ Robert Mochkovitch

GRBs: observations

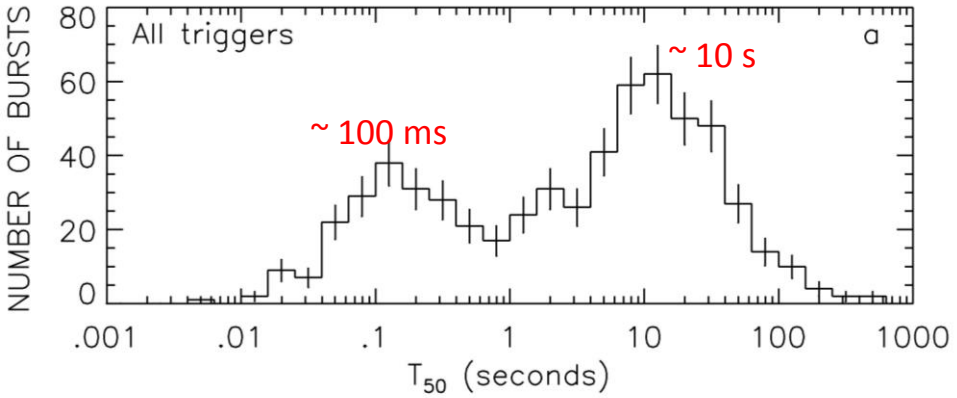




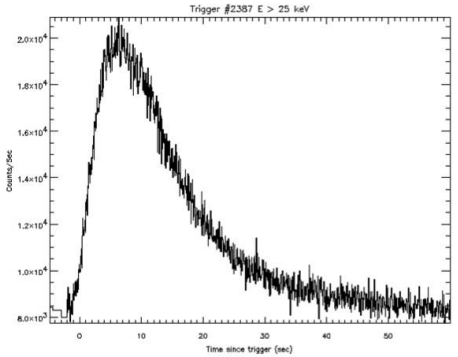
Gamma-ray bursts: prompt emission

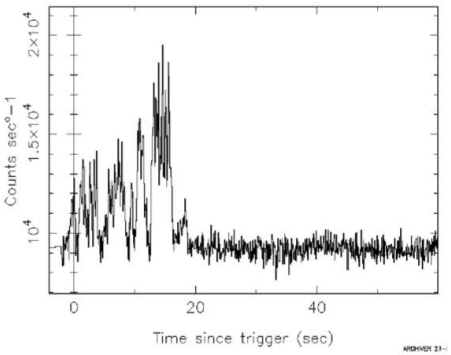
CGRO/BATSE

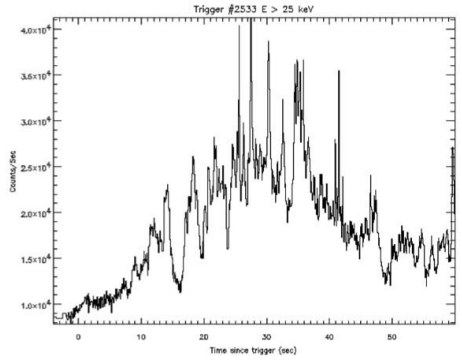
- Apparent rate:
  ~ 1 GRB / day
- Duration:
  two groups



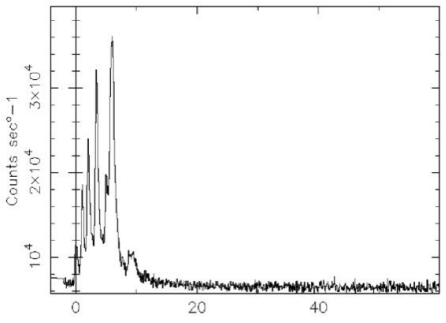
- Lightcurves : variability & diversity



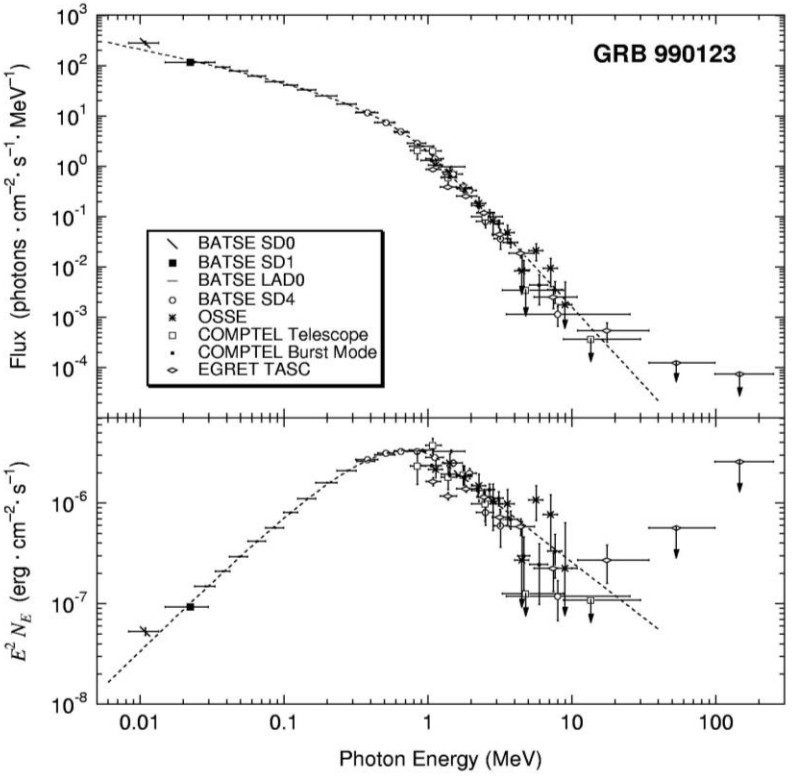




Trigger # 1425 E > 25 keV

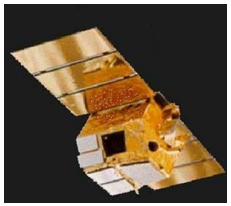


- Spectrum: non-thermal

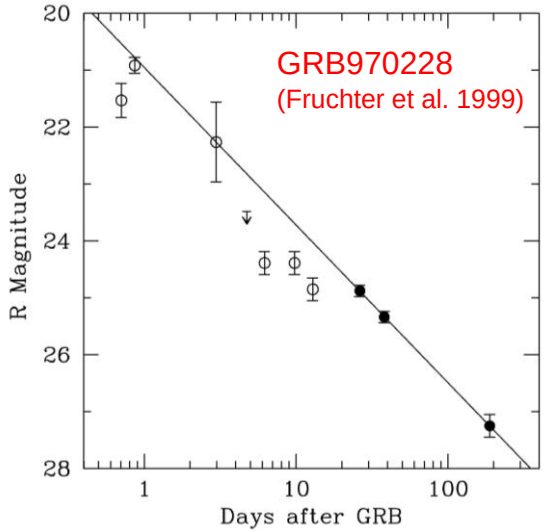


Gamma-ray bursts: afterglow

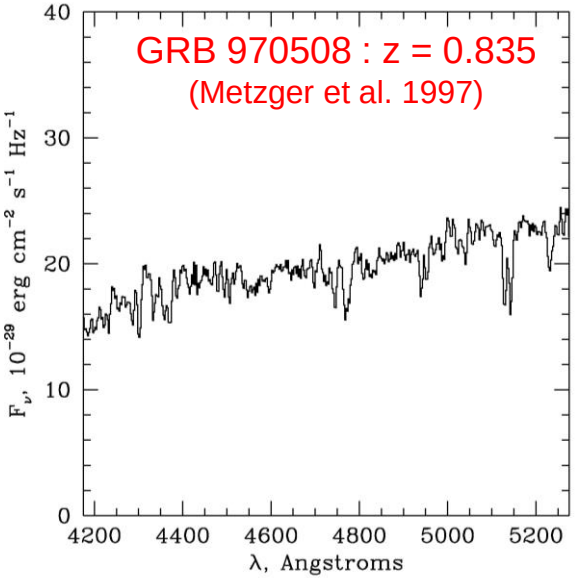
Beppo-SAX



- Discovery: 1997 (X-rays: Beppo-SAX ; V: van Paradijs et al. 1997)
- Flux: power-law decay
- Non-thermal spectrum
- Spectral evolution: X-rays → V → radio



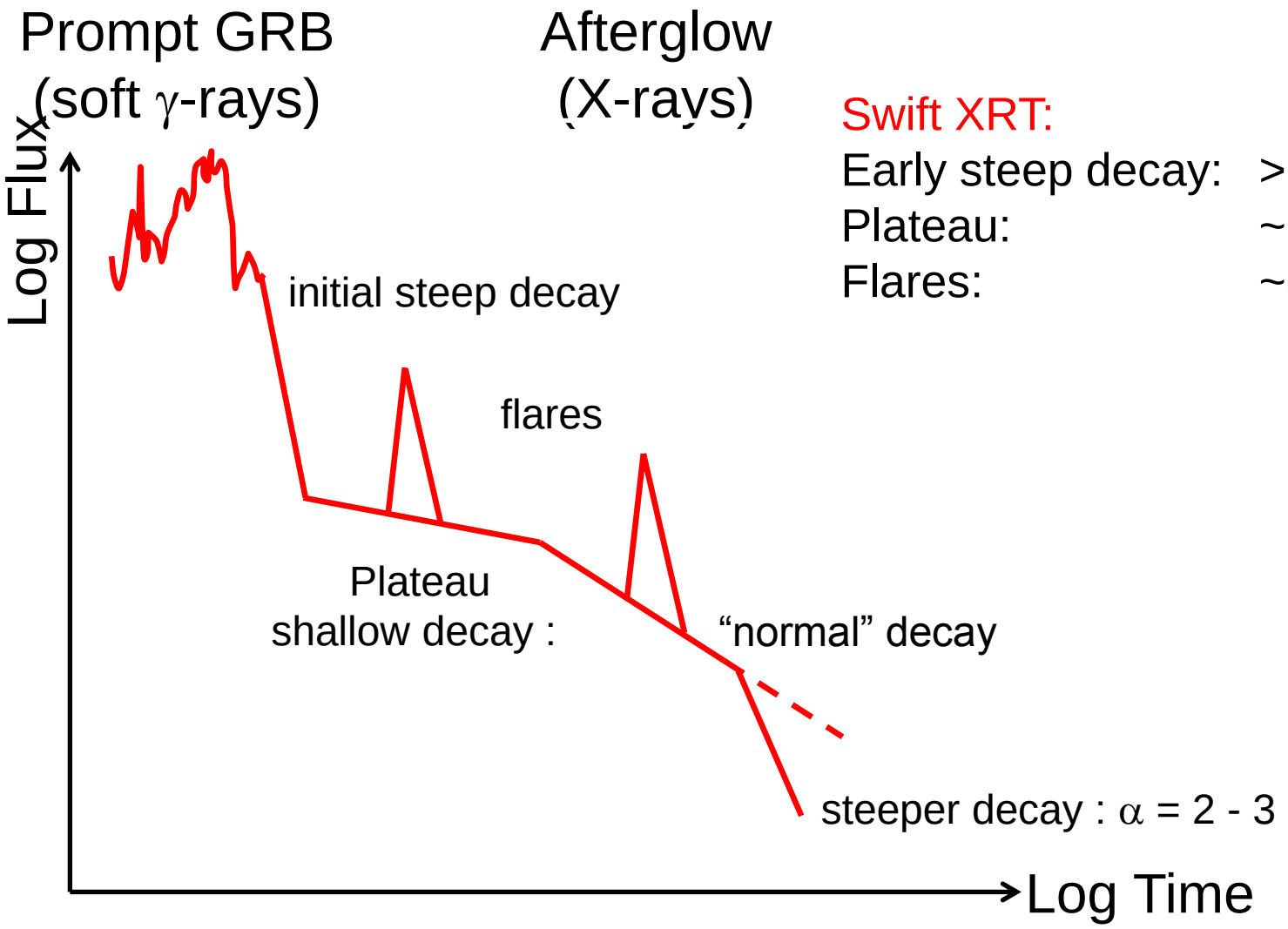
- Follow-up: redshift & host galaxy



- High redshift ($z_{max,obs} > 9$):

  huge luminosity and radiative energy
  $E_{iso,\gamma} \sim 10^{51} – 10^{54}$ erg

Observed emission: prompt → afterglow



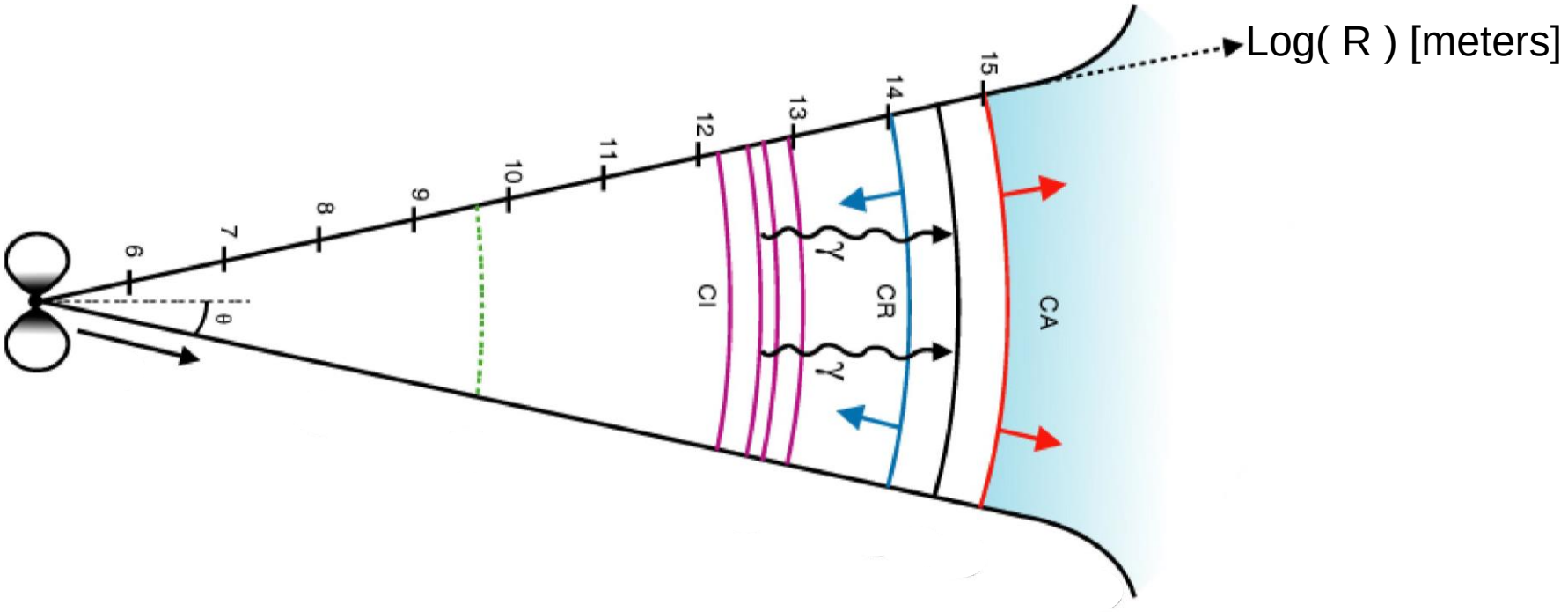
Swift XRT:

Early steep decay:	>90%
Plateau:	~60%
Flares:	~30%

Also: prompt optical, GeV

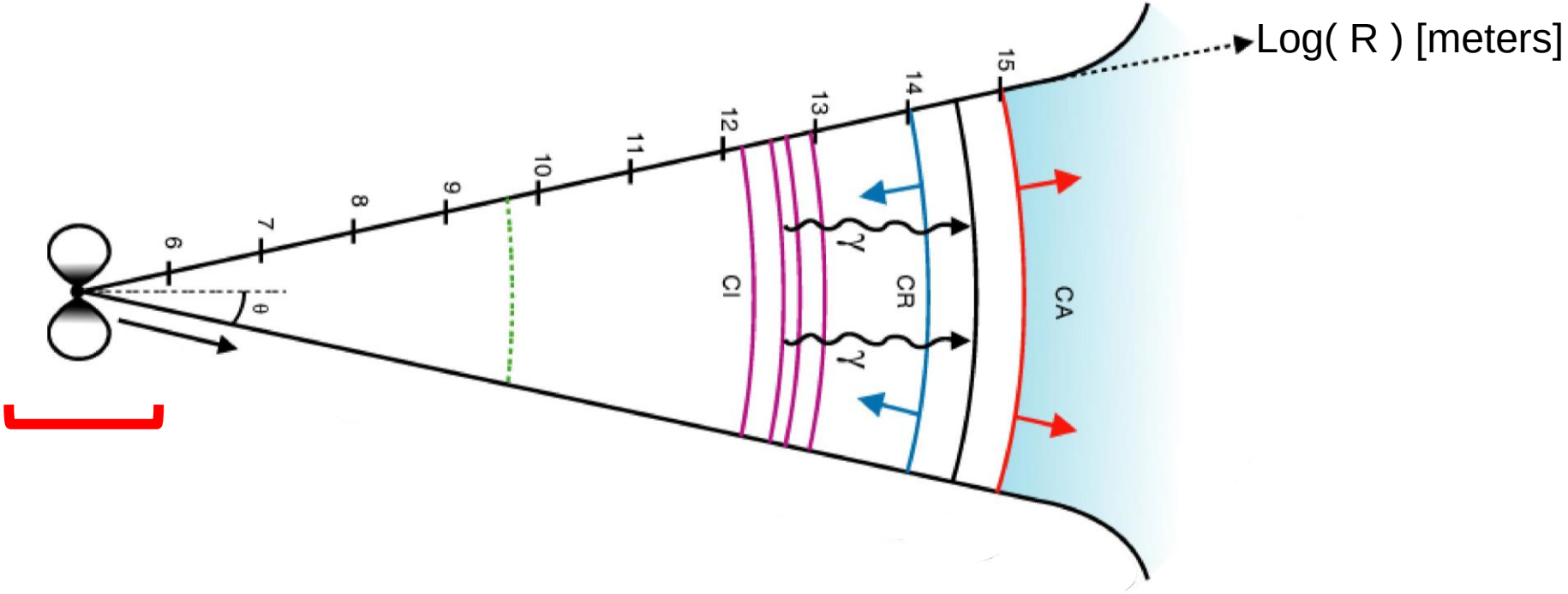
Also: optical, radio afterglow

GRB physics

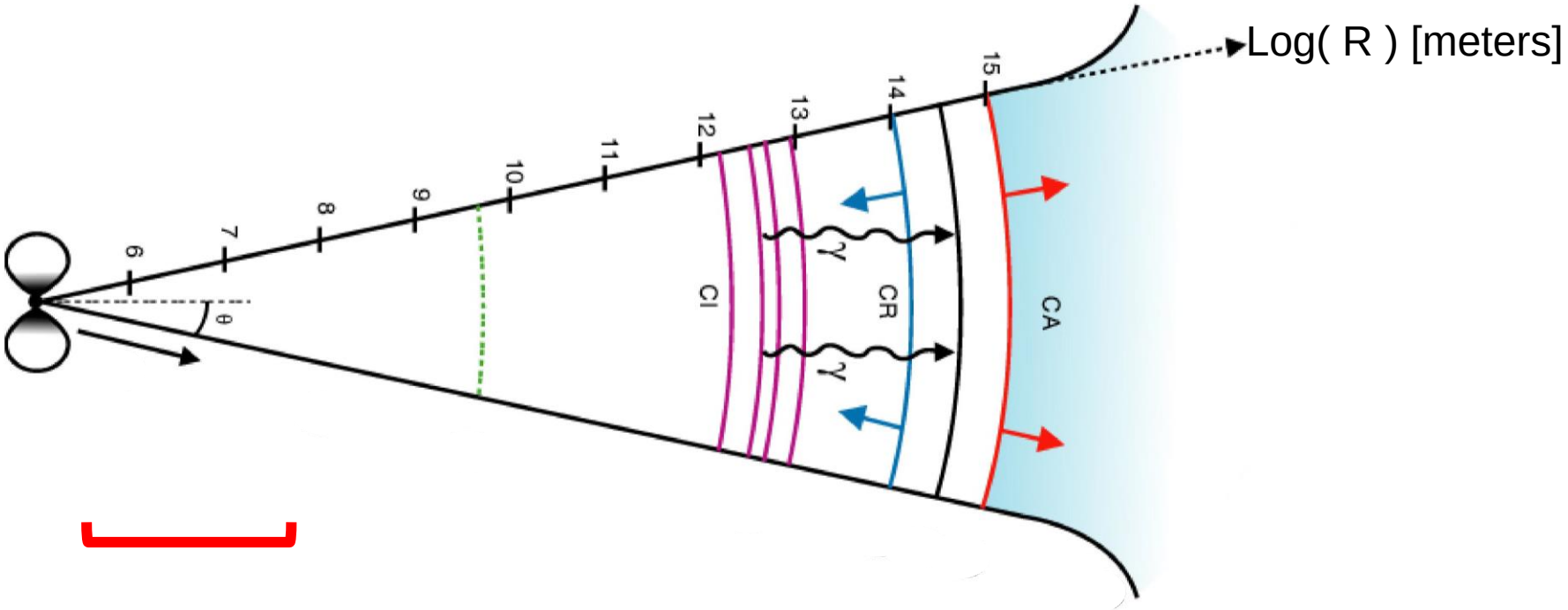


- Cosmological distance: huge radiated energy ($E_{iso,\gamma}$ ~ 10^{50}-10^{55} erg)
- Variability + energetics: violent formation of a stellar mass BH

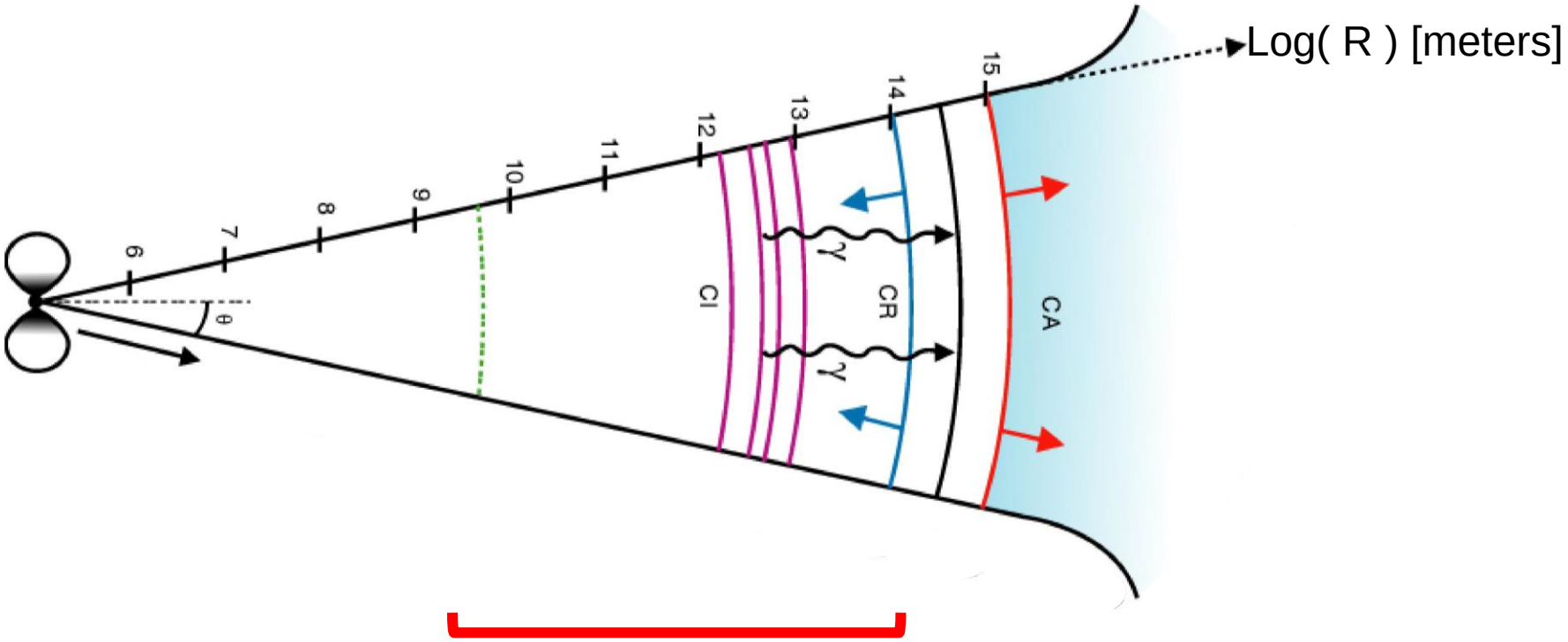
Long GRBs: collapse of a massive star
Short GRBs: NS+NS/BH merger? (link with GW)



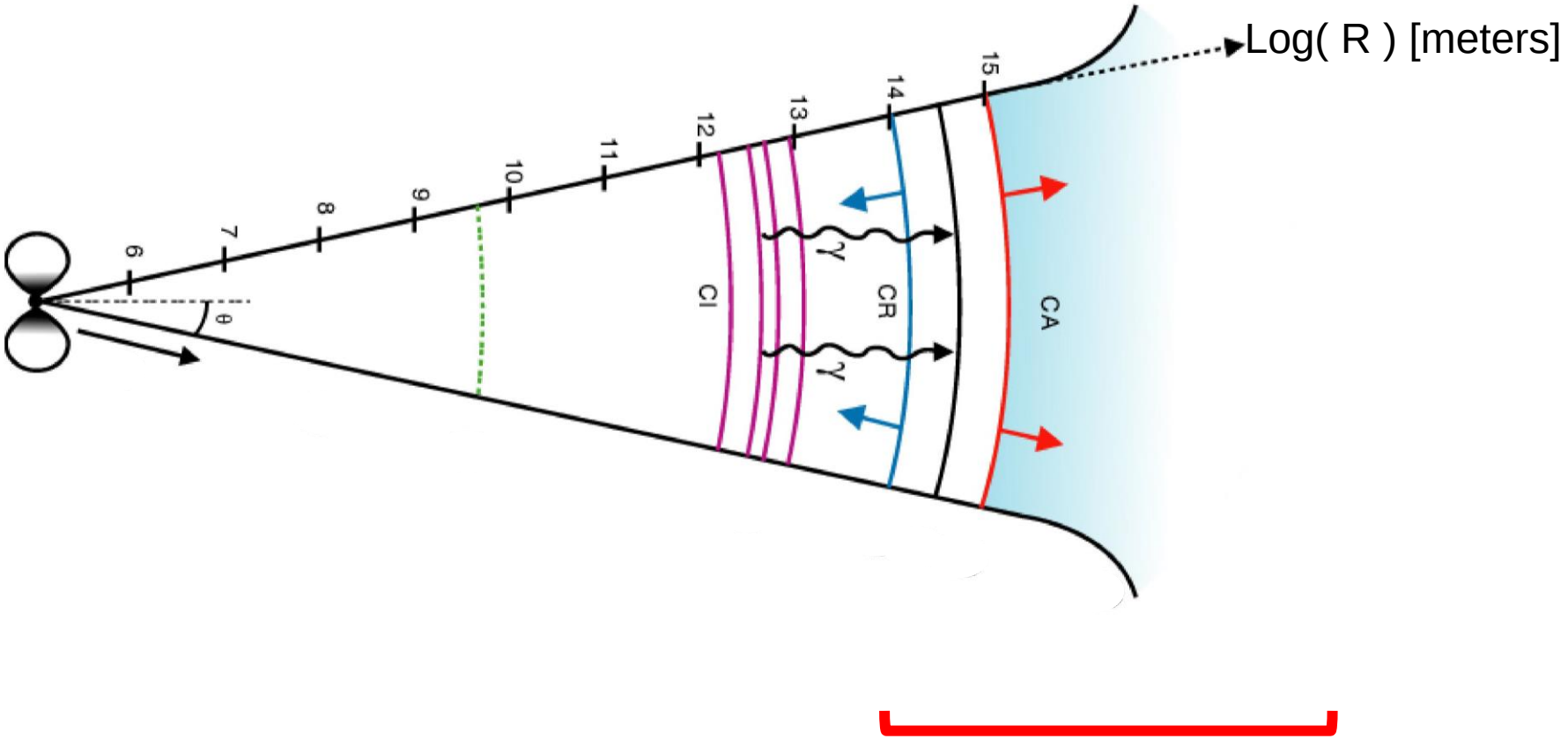
- Variability + energetics + gamma-ray spectrum: relativistic ejection



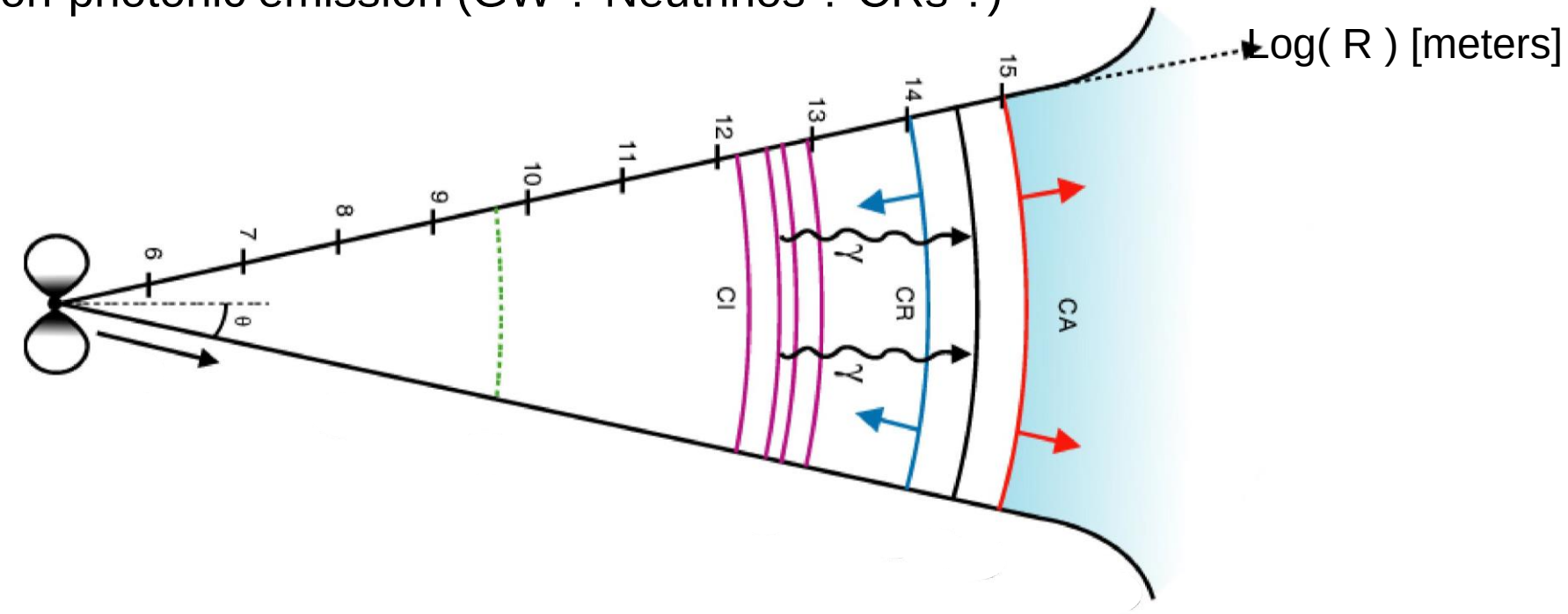
- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt emission: internal origin in the ejecta



- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt emission: internal origin in the ejecta
- Afterglow: deceleration by ambient medium



- Final state of massive stars
- Compact objects
- Relativistic ejecta
- Particle acceleration, non-thermal emission
- Non-photonic emission (GW ? Neutrinos ? CRs ?)



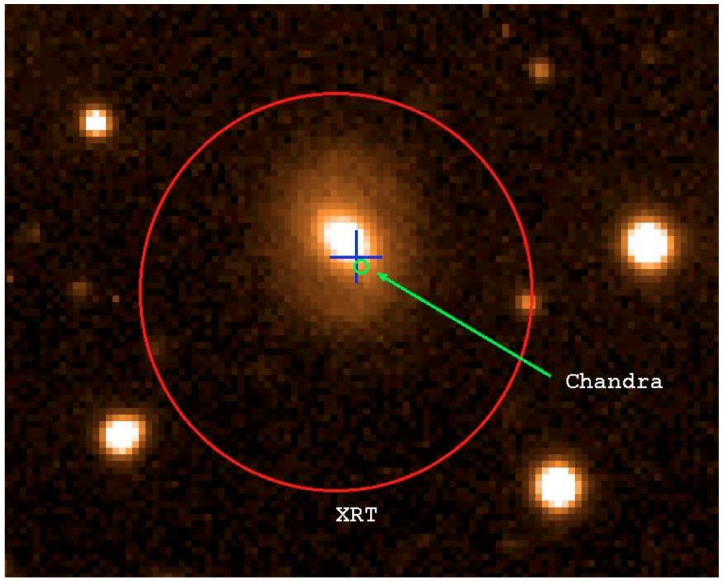
GRB activities at IAP

- Modelling: prompt & afterglow emission (F. Daigne & R. Mochkovitch)
  - internal shock model (prompt phase)
  - photospheric emission
  - gamma-gamma annihilation, constraints on the Lorentz factor
  - long-lived reverse shock (afterglow phase)
  - comparison to Fermi data

  (collaboration with GSFC Washington: GBM & LUPM Montpellier: GBM/LAT)
- Shock acceleration, possible link with UHECRs (M. Lemoine)
- Population models, cosmic rates, link with SFR (F. Daigne J.Palmerio)
  Short GRB rates vs mergers/kilonovae (E. Vangioni, F. Daigne & collab.)
- Host galaxies (J. Palmerio with S. Vergani (GEPI & IAP) ; D. Leborgne)
- Afterglow spectroscopy (P. Petitjean & P. Noterdaeme)

Shorts GRBs

Merger scenario ? Indirect evidence = host galaxies



GRB 050724 @ VLT

Barthelmy et al. 2005

Short GRBs: no correlation with star formation

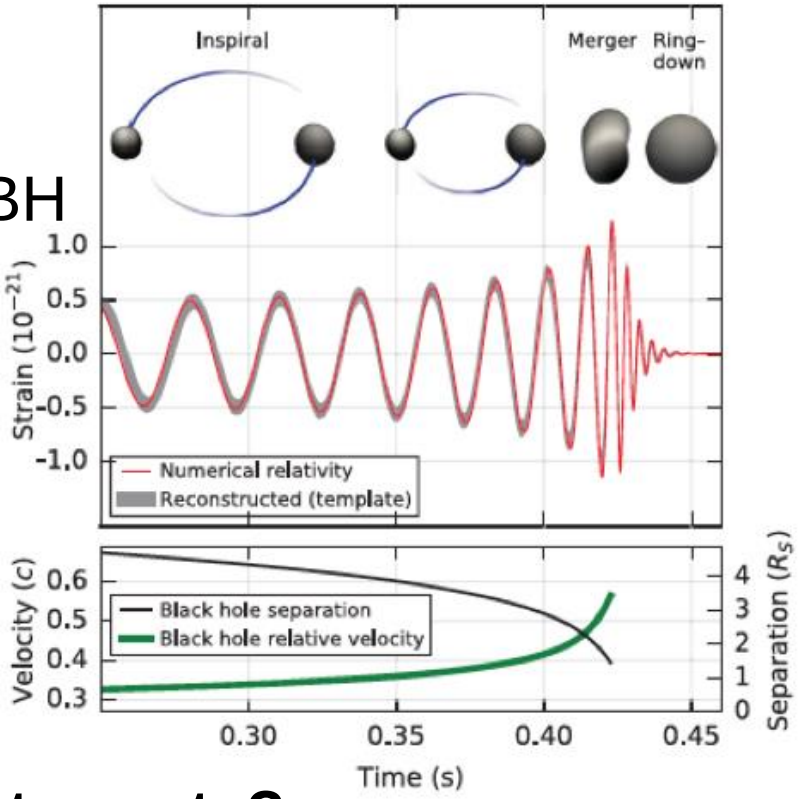
good agreement with the merger scenario

Long GRBs: star forming galaxies

good agreement with the collapsar scenario

A new challenge: short GRBs in the GW era

- First detection: GW150914 = BH+BH
- Advanced Ligo/Virgo:
  NS+NS NS+BH mergers are
  expected soon.

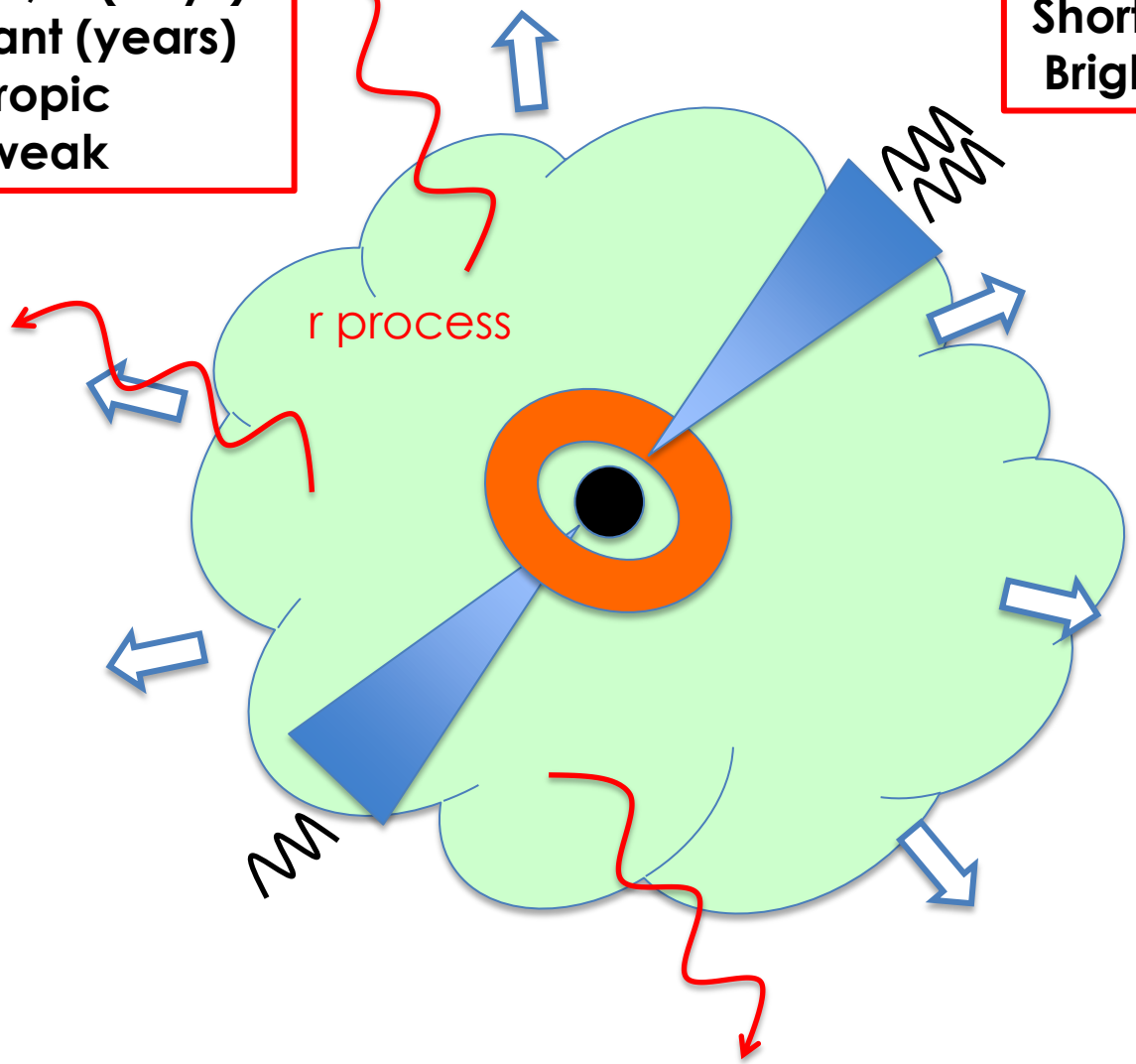


- **Next step: electromagnetic counterparts?**

Final state of a merger

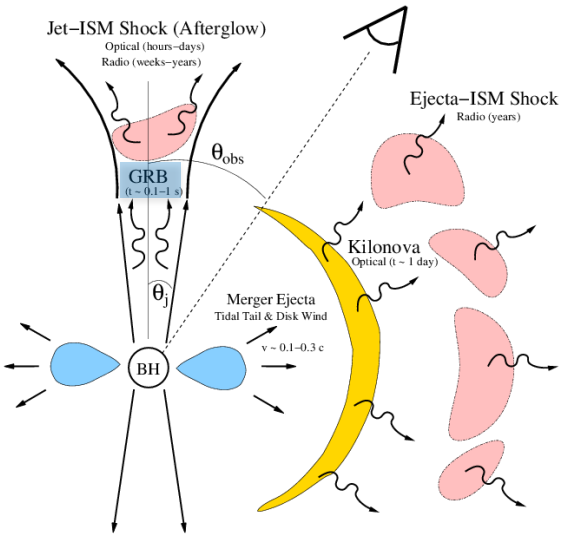
Kilonova: NIR, V (days)
Radio remnant (years)
~isotropic
BUT weak

Short GRB: hard γ-rays
Bright BUT collimated



Detection rate: GW+GRB

OAG



$$R_{GW+GRB} = R_{GW} \times f_\gamma \times \left(\frac{\theta_j^2}{2}\right) \times \left(\frac{\Omega}{4\pi}\right) \times DC$$

source detector

$f_\gamma = 1$?

$\theta_j = 0.1 - 0.3$?

$\Omega \gtrsim 8$ sr (Fermi, GRM); 2 sr (Swift, Eclairs)

DC (duty cycle) $\gtrsim 50\%$

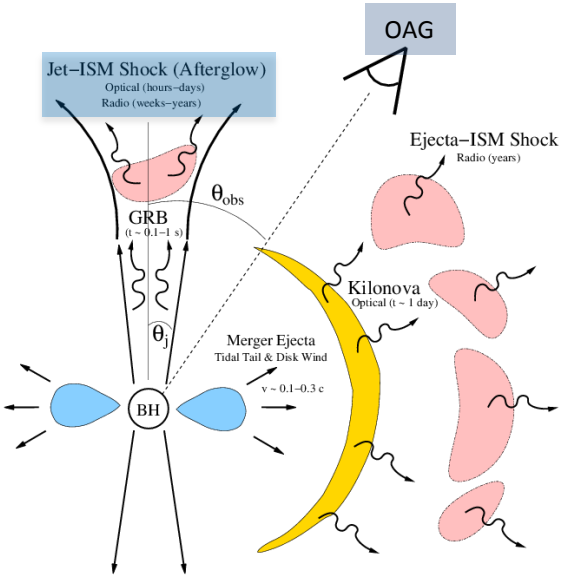
$\rightarrow R_{GW+GRB} = 6\ 10^{-3}\ R_{GW}$ (8 sr + "standard values" of f_γ, θ_j)

What will be the observed rate R_{GW} in O2, O3?

In case of simultaneous detection:

→ confirmation of the link NS + NS/BH mergers and short GRBs
→ new measure of H_0 if the burst redshift is known
→ delay GW – GRB : constraint on dissipation radius in GRBs

Detection rate: GW+afterglow



Search of GW error box in X-rays, visible

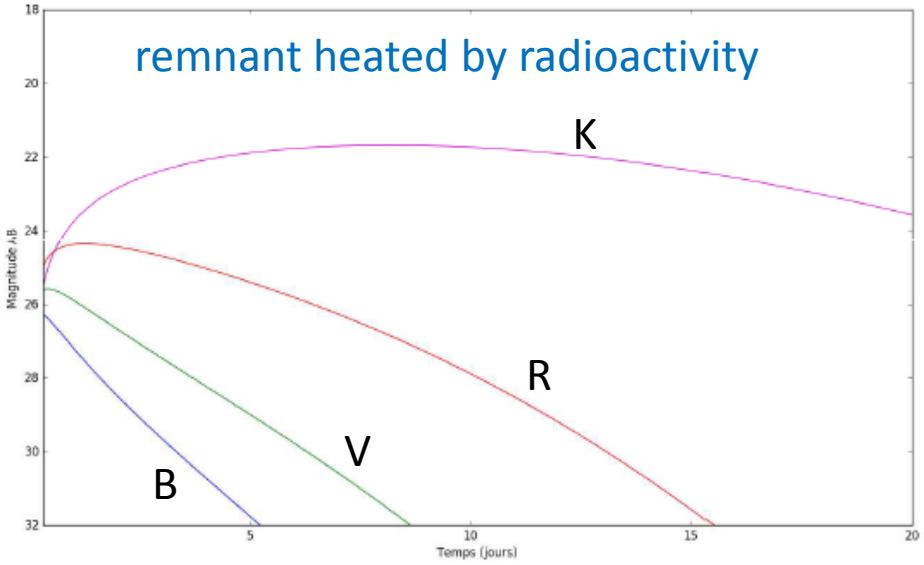
$$R_{GW+AG} = R_{GW} \times f_{\gamma} \times \left(\frac{\theta_j^2}{2} \right) \times SE(D, E_{kin}, n, \text{delay/loc.})$$

Orphan afterglow:

$$R_{GW+OAG} = R_{GW} \times f_{\gamma} \times SE(D, E_{kin}, n, \theta_{\text{obs}}, \text{delay/loc.})$$

At later times: kilonova (days) and radio remnant (years)

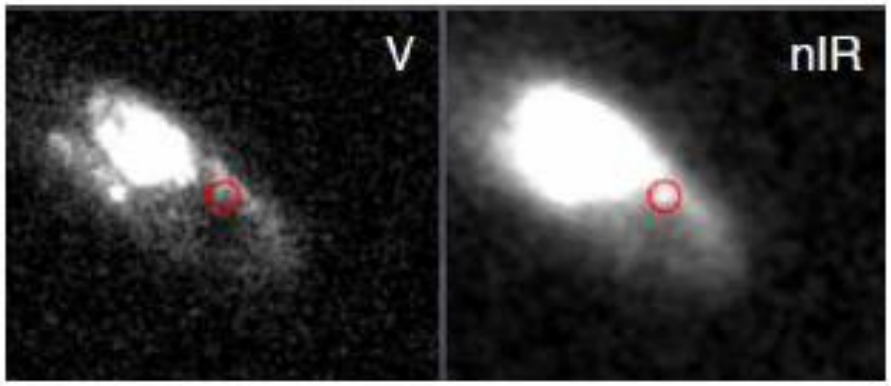
$M = 10^{-2}\ M_o$, v = 0.1c , $\kappa = 10\ cm^2/g$; $D = 100$ Mpc



$$t_{pic} = t_{dec} = 15\, E_{K,50}^{1/3}\, n^{-1/3}\, \mathrm{v}_{.1c}^{-5/3}\ \mathrm{ans}$$

$$F_\nu^{\max} = 25\, E_{K,50} n^{0.83} \varepsilon_{e,-1}^{1.3} \varepsilon_{B,-2}^{0.83}\, \mathrm{v}_{.1c}^{2.3}\, f_{GHz}^{-0.65}\ \mu\mathrm{Jy}$$

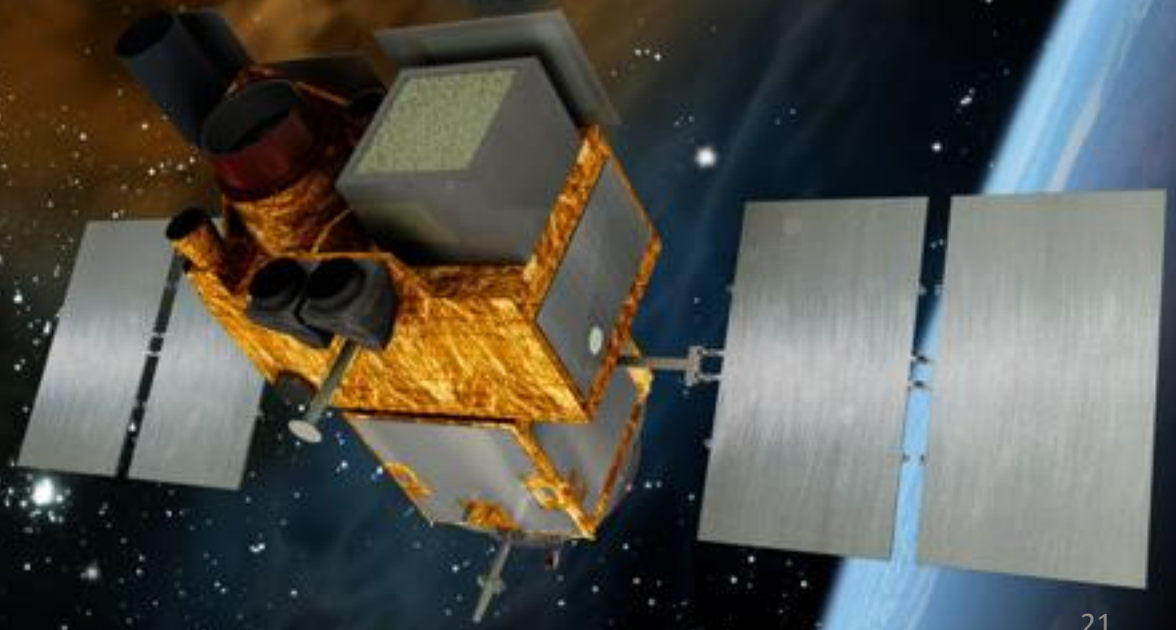
Isotropic but weak…



GRB 130603B Tanvir et al. 2013

SVOM

SVOM



NAOC, Beijing
XIOPM, Xi'an
NSSC, Beijing
CEA-Irfu, Saclay
APC, Paris
LAM, Marseille
CPPM Marseille
GEPI Meudon
U. of Leicester
CNES, Toulouse

IHEP, Beijing
SECM, Shanghai
IRAP, Toulouse
IAP, Paris
LAL Orsay
LUPM Montpellier
Obs. Strasbourg
MPE, Garching

SVOM in context

- SVOM = Space-based multiband astronomical Variable Objects Monitor

- SVOM is a multi-wavelength Chinese-French mission dedicated to the transient sky.
- SVOM is a mission deployed on the ground and in space.
- The space segment of SVOM is planned to be launched early in the next decade (2021), for a 3 year nominal mission.
- SVOM is currently in phase C (budget accepted for phase D, E1 (post-launch)

SVOM science:

- Core program: GRB physics + GRB as a tool for cosmology
- Multi-wavelength observation of transient phenomena
- Follow-up: GW, HE neutrinos, but also: radio, V/IR, HE gamma-rays (CTA)
- Observatory program
- See white paper

SVOM at IAP:

- GRB science + contribution to the ground-segment (GRB pipeline)
- 3 co-Is: F. Daigne, R. Mochkovitch, P. Petitjean
- [M. Dennefeld ; M. Lemoine ; D. Leborgne ; P. Noterdaeme ; E. Vangioni]
- 2 engineers: L. Domisse (40%) + 3 years CDD UPMC (recruitment in progress)

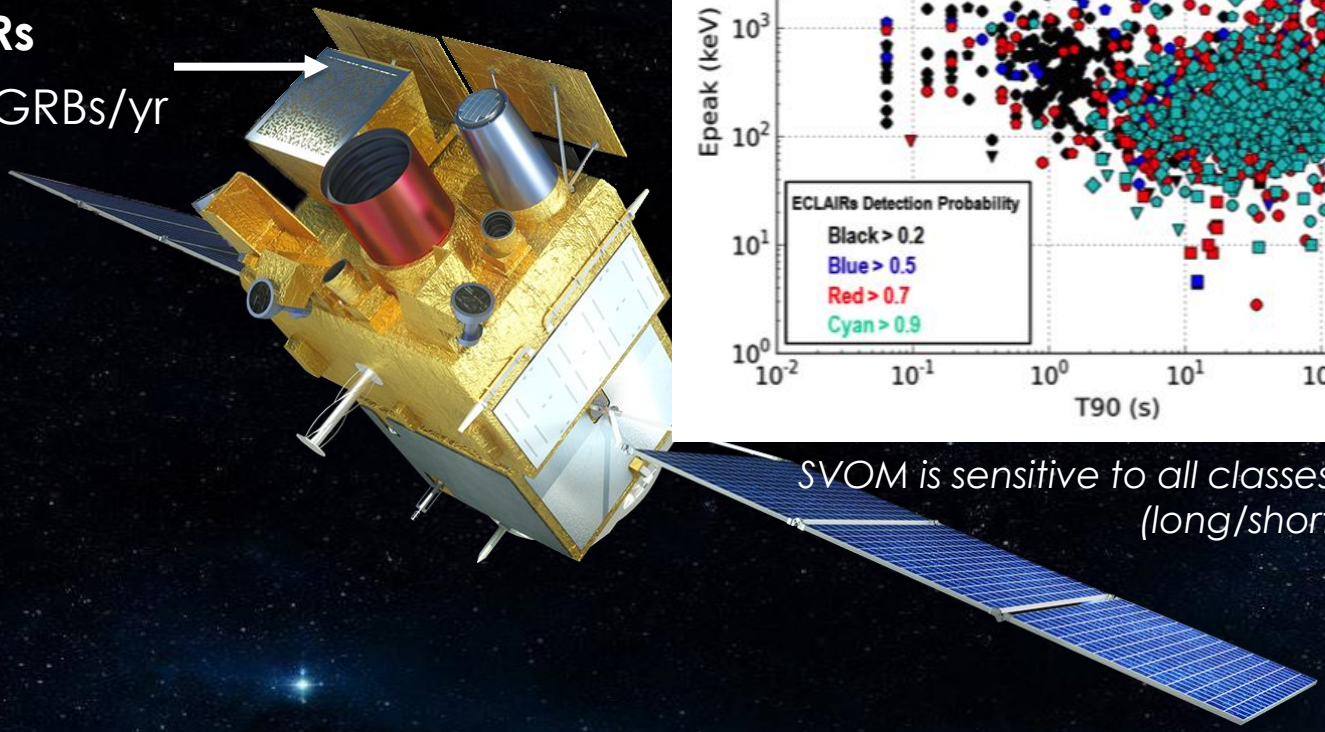

MXT
1 deg², 0.2-10 keV, loc. < 1'
Satellite ~ 930 Kg
Payload ~ 450 kg
26² arcmin²,
visible, loc. < 2''
VT
ECLAIRs
2 sr, 4-150 keV, loc. < 13'
GRM
2x3 sr, 15 keV-5 MeV
GFT-2
visible & NIR
GWAC
5000 deg²
visible
GFT-1
visible

A unique GRB sample

GRB trigger

ECLAIRs

42-80 GRBs/yr



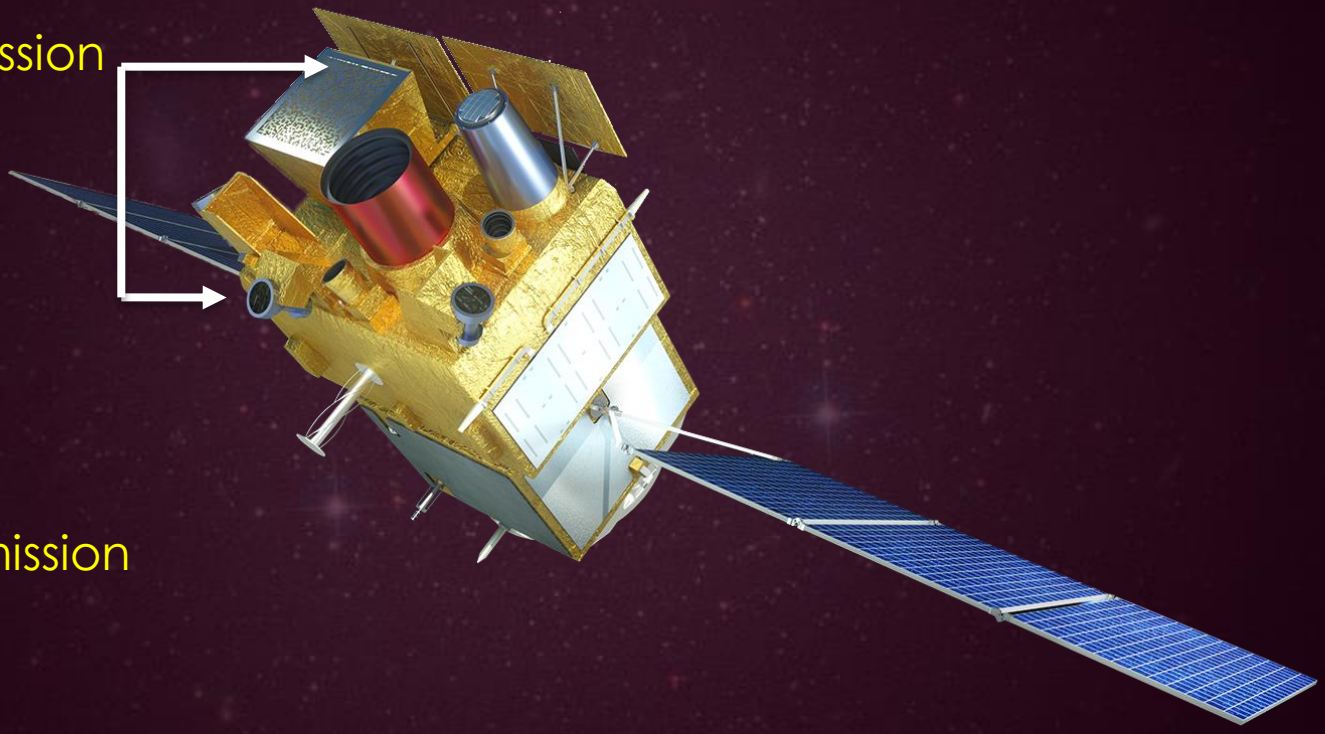
SVOM is sensitive to all classes of GRBs (long/short/soft/…)

A unique GRB sample

Prompt emission

ECLAIRs+GRM

Prompt GRB emission
over 3 decades
(4 keV-5.5 MeV)



GWAC

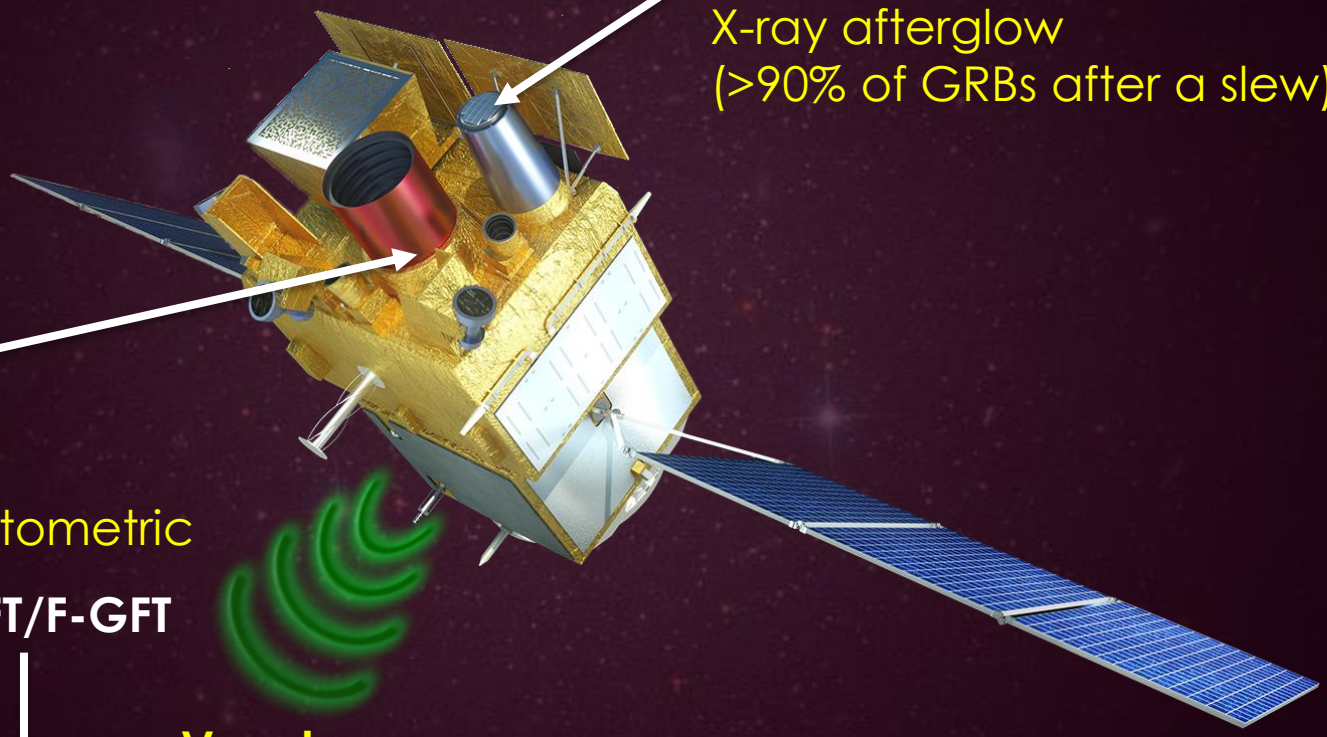
prompt visible emission
in ~16% of cases

The multi-component spectrum of the Fermi/GBM burst GRB 100724B simulated in ECLAIRs+GRM.

A unique GRB sample

Afterglow & distance

slew request: 36-72 GRB/yr



MXT

X-ray afterglow
(>90% of GRBs after a slew)

VT

Visible and NIR
afterglow+photometric
redshift

GWAC

C-GFT/F-GFT

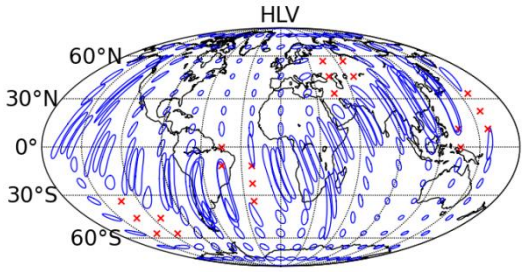
Very large telescopes

Redshift in ~2/3 of cases

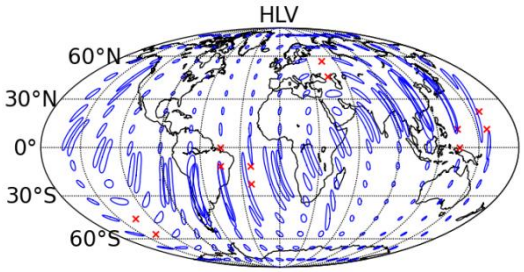
The X-ray afterglow of the Swift burst GRB 091020 simulated in MXT.

SVOM and the Gravitational Waves at the beginning of the next decade

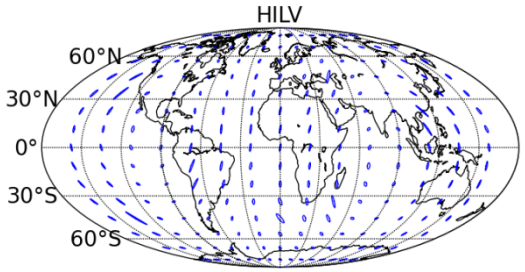
GW observations in 2020+



2015



2019



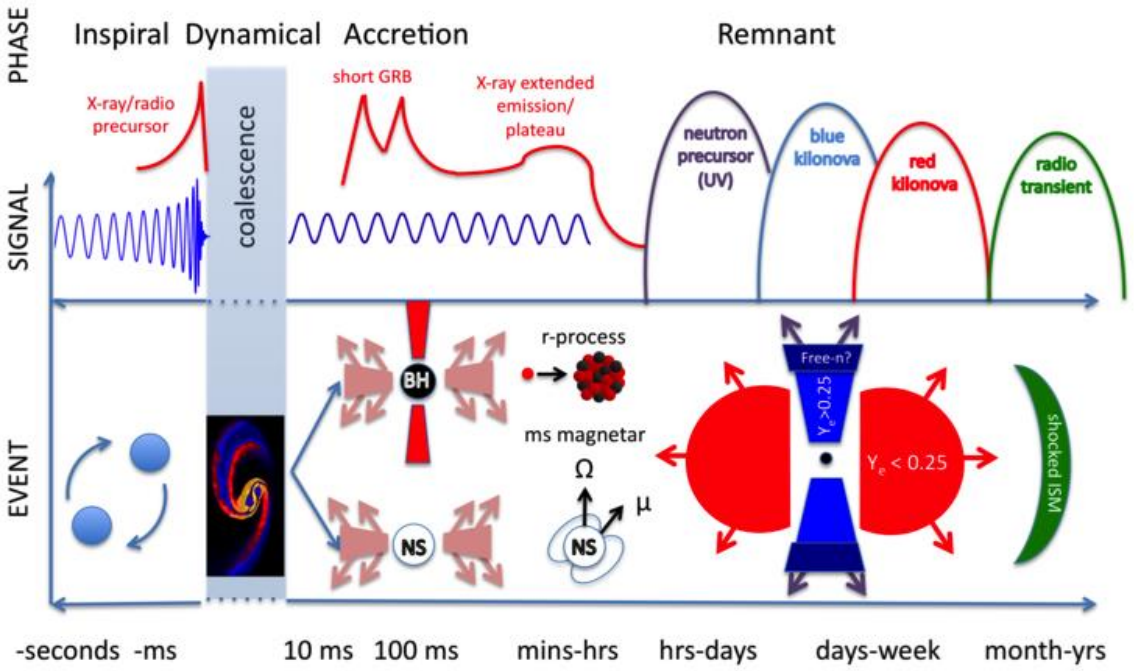
2022

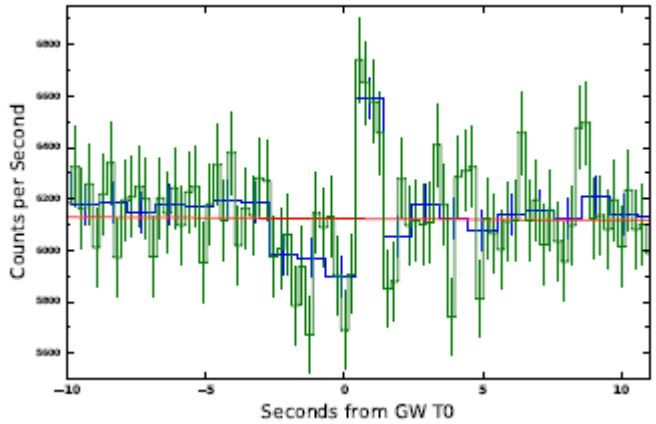
- In 2020+ the network should be able to detect NS+NS/BH mergers within an error box of a few deg^2.
- Expected NS-NS mergers detection rate: about 40/year within 445 Mpc (z~0.1)
- Expected BH-NS mergers detection rate: about 10/year within 927 Mpc (z~0.2)

(Abadie et al. 2010: large uncertainties)

- SVOM launch: end of 2021

Conclusion (in two figures)





How does (will) a GW +GRB association look like ?
GW 150914 and GRB 150914
(Connaughton et al, 2016)