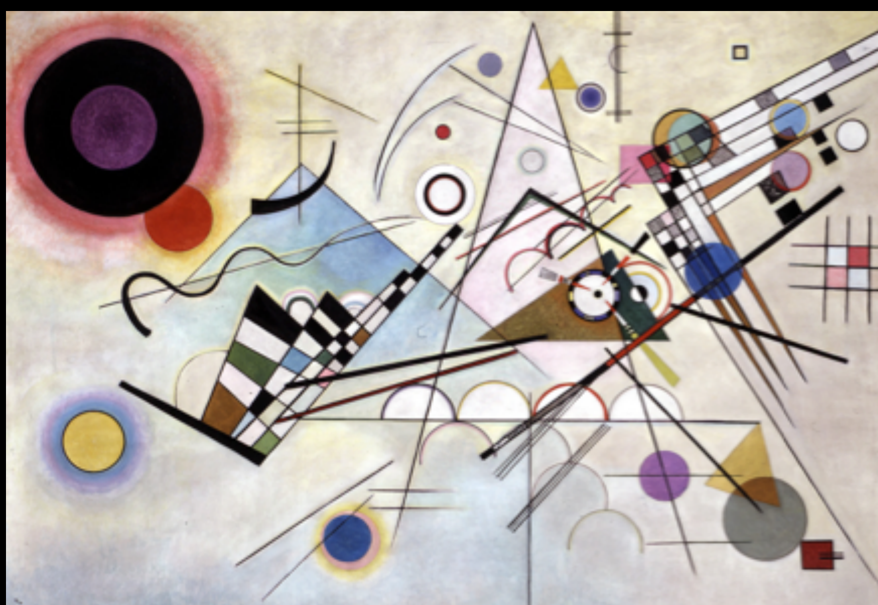
GAMMA-RAY BURSTS: PERSPECTIVES WITH THE SVOM MISSION

Frédéric Daigne
(Institut d'Astrophysique de Paris; Sorbonne University)



Kandinksy – Composition 8- 1923
Guggenheim Museum, New-York

Kandinksy - Curves and sharp angles - 1923
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Paris Saclay ISAPP School « Astrophysical sources of cosmic rays » – 2022, April 4

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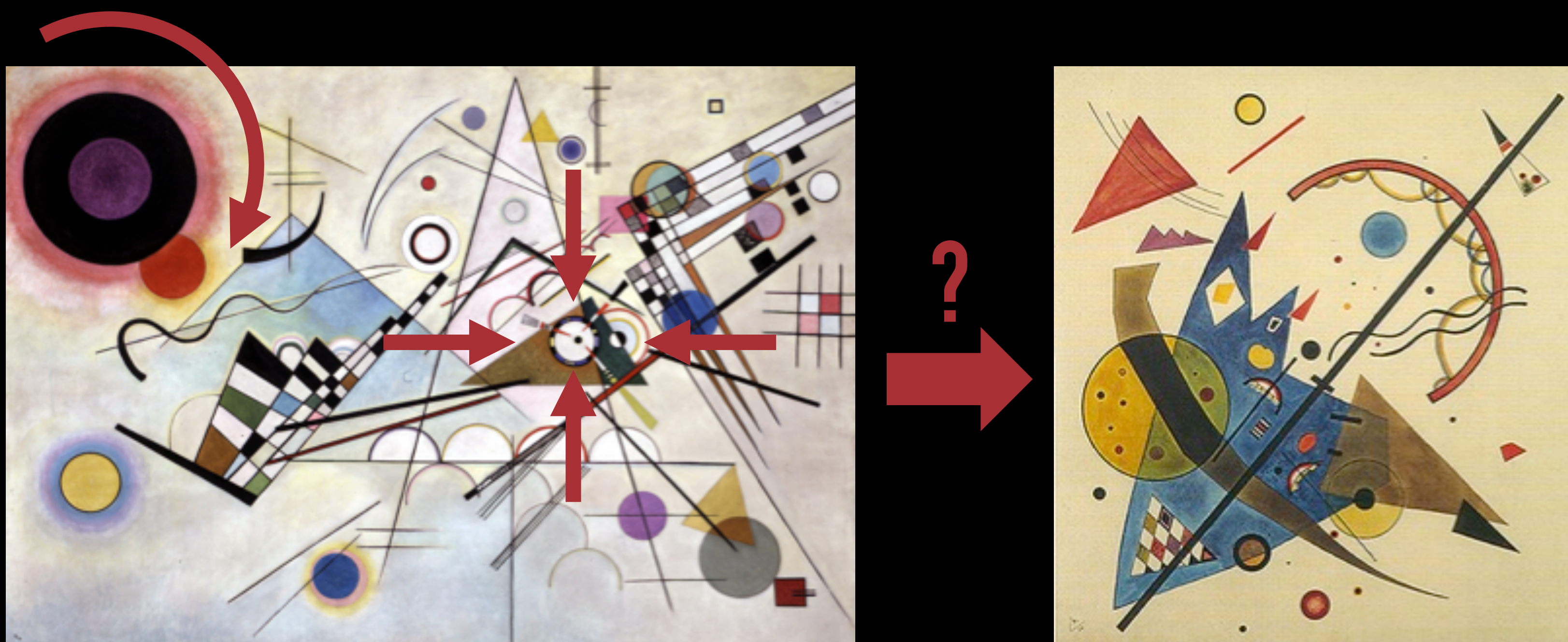

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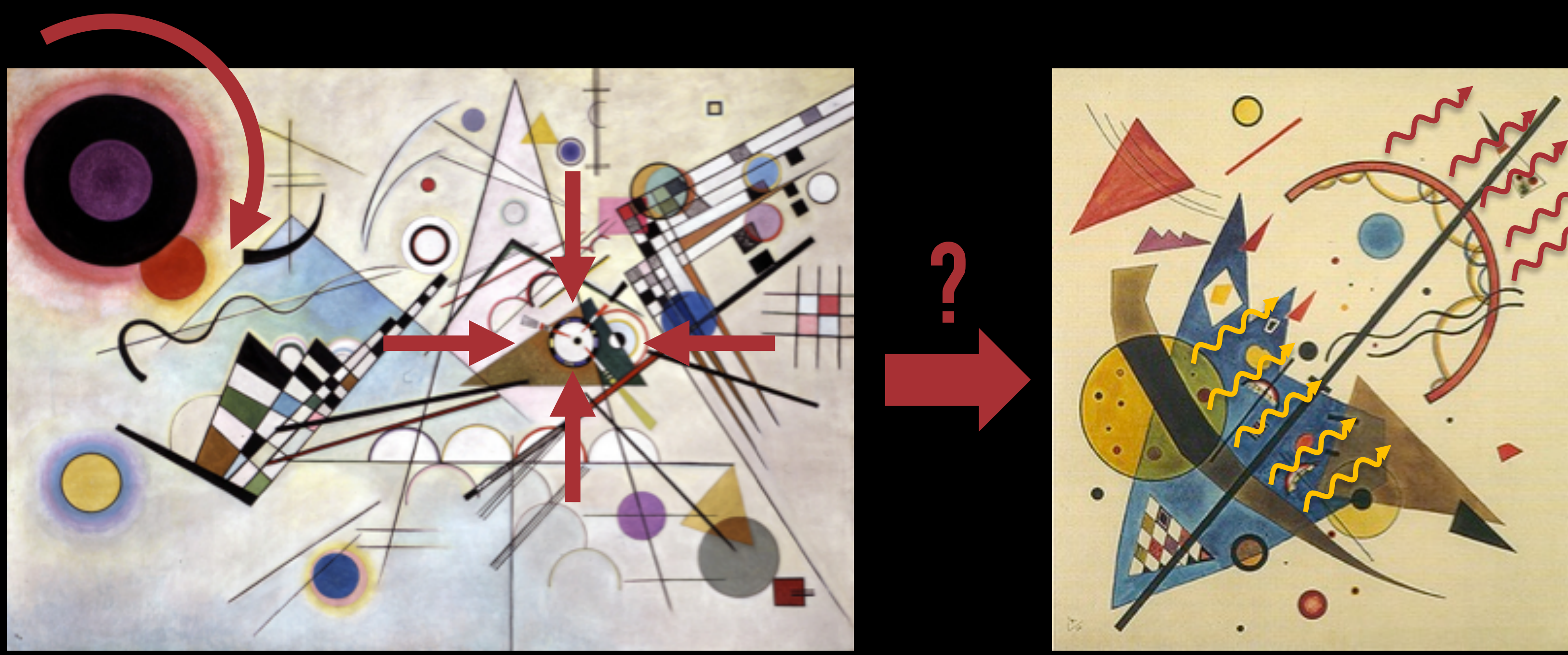

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Paris Saclay ISAPP School « Astrophysical sources of cosmic rays » — 2022, April 4 institut universitaire de France

SORBONNE UNIVERSITÉ

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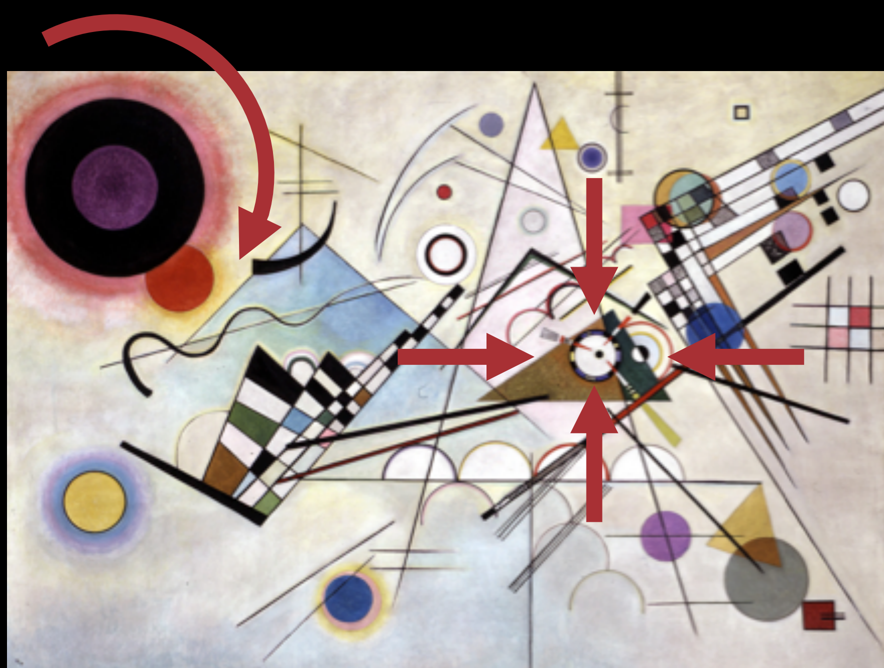

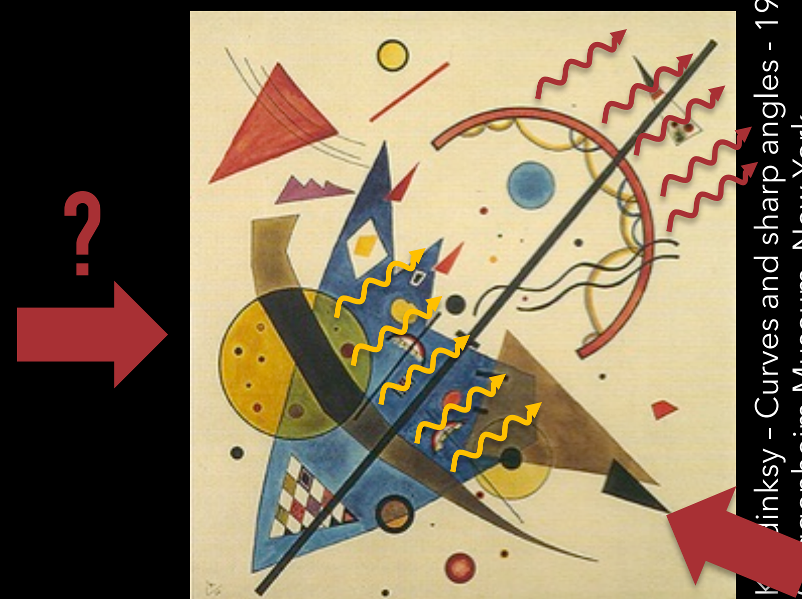

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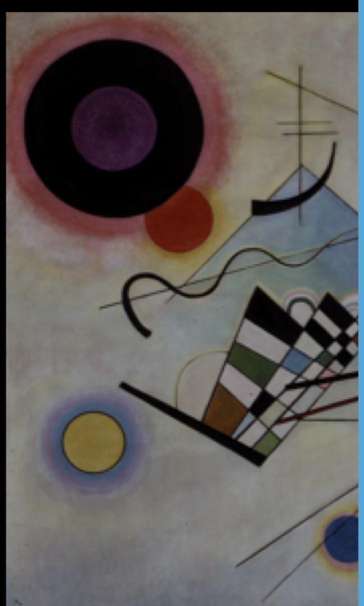
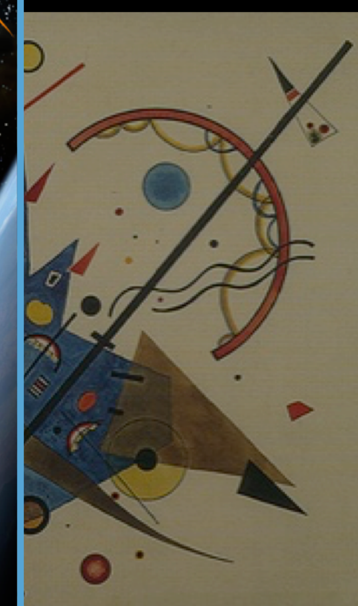




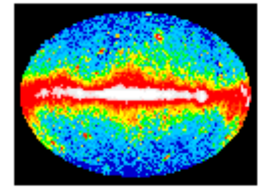
Kandinksy - Curves and sharp angles - 1923
Guggenheim Museum, New-York

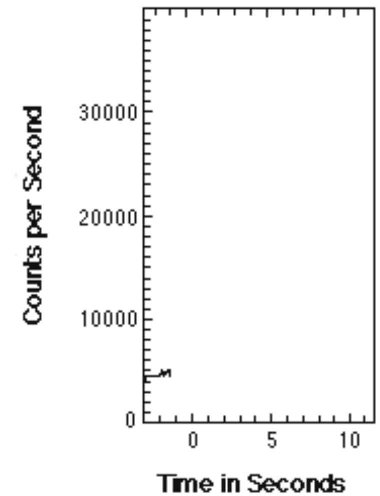
University of Leicester, Department of Physics and Astronomy – 2022, March 24

INTRODUCTION

GAMMA-RAY BURSTS

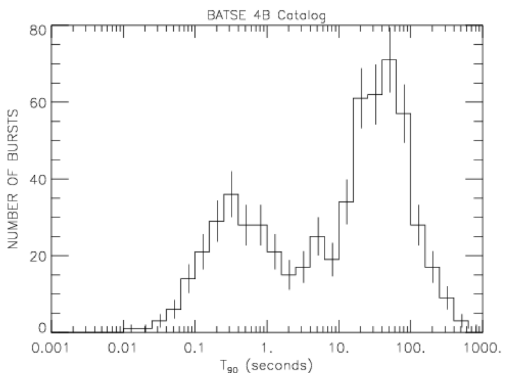
MAIN OBSERVATIONAL FACTS (1) PROMPT EMISSION

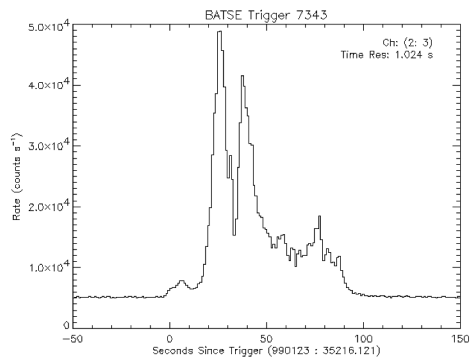


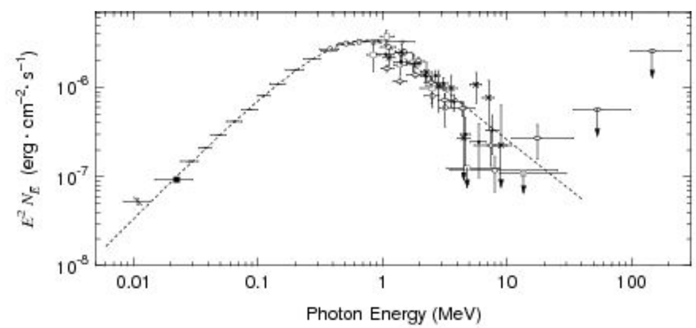


- **High variability :** ms ⟶ 100 ms
- **Short duration:** a few ms to a few min
- **Two classes: short & long GRBs**

BATSE



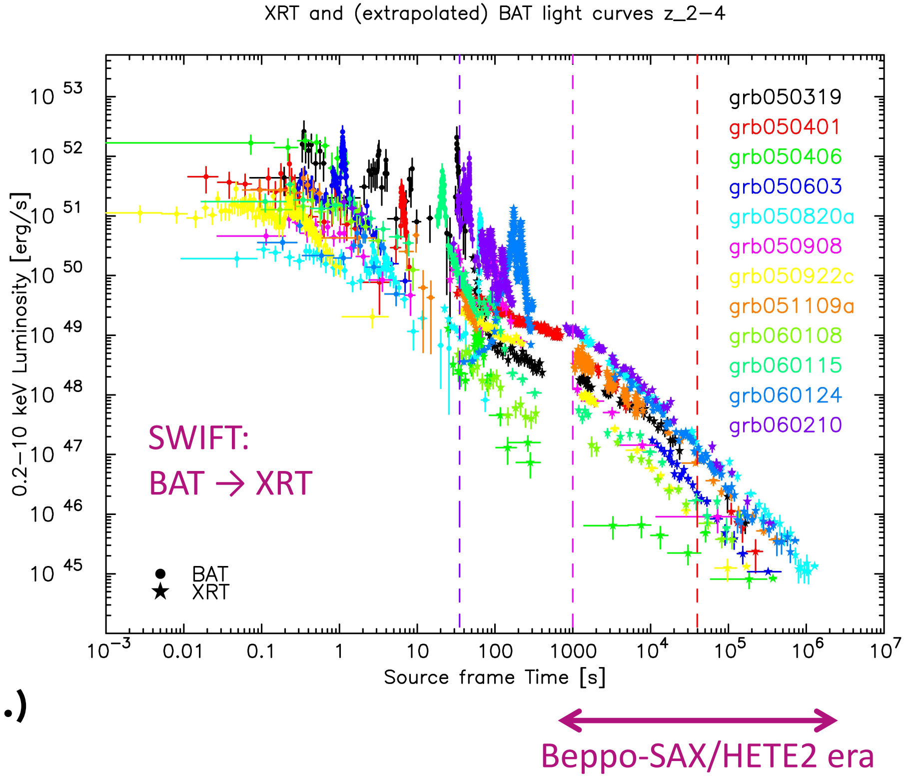




- **Great diversity of lightcurves ; Pulses:** 100 ms ⟶ 10 s
- **Non-thermal spectrum:** peak energy 100 keV → 1 MeV
- **Spectral evolution**
- **Spectral diversity:** classical GRBs, X-ray rich GRBs, X-ray Flashes, etc.

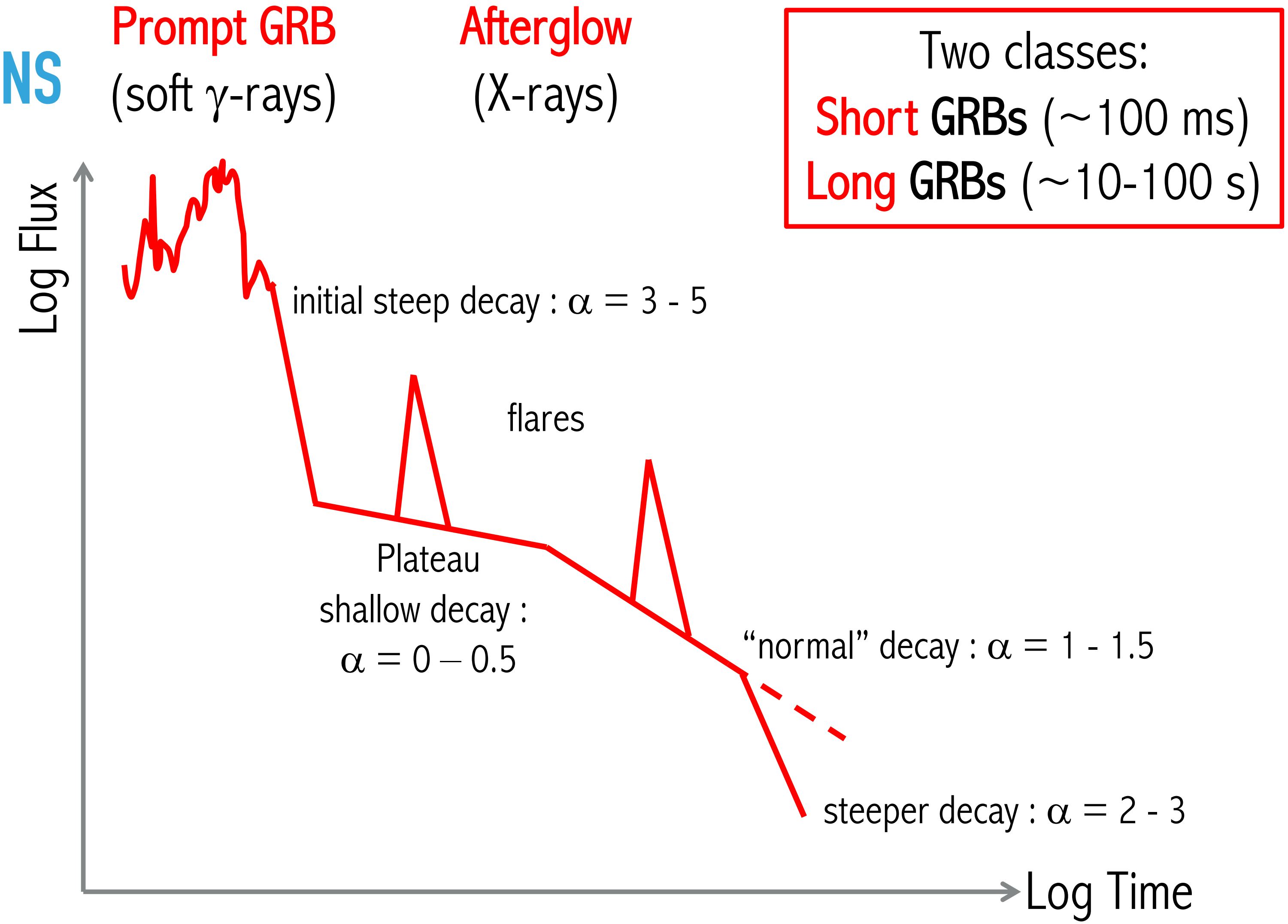
MAIN OBSERVATIONAL FACTS (2) AFTERGLOW

- **Lightcurves: power-law decay, breaks, variability**
  (flares, plateaus)
- **Spectral evolution:** X-rays to radio
- **Redshift**
  - Mean redshift above 2 for long GRBs
  - Maximum : GRB 090423 at z = 8.2
    GRB 090429B at z = 9.3
  - **E_{iso} ~ 10^{51} to 10^{54} erg**
    (some under-luminous ; some monsters…)



- **Host galaxy**
  - Clear difference between short & long bursts
  - Different progenitors

OBSERVATIONS

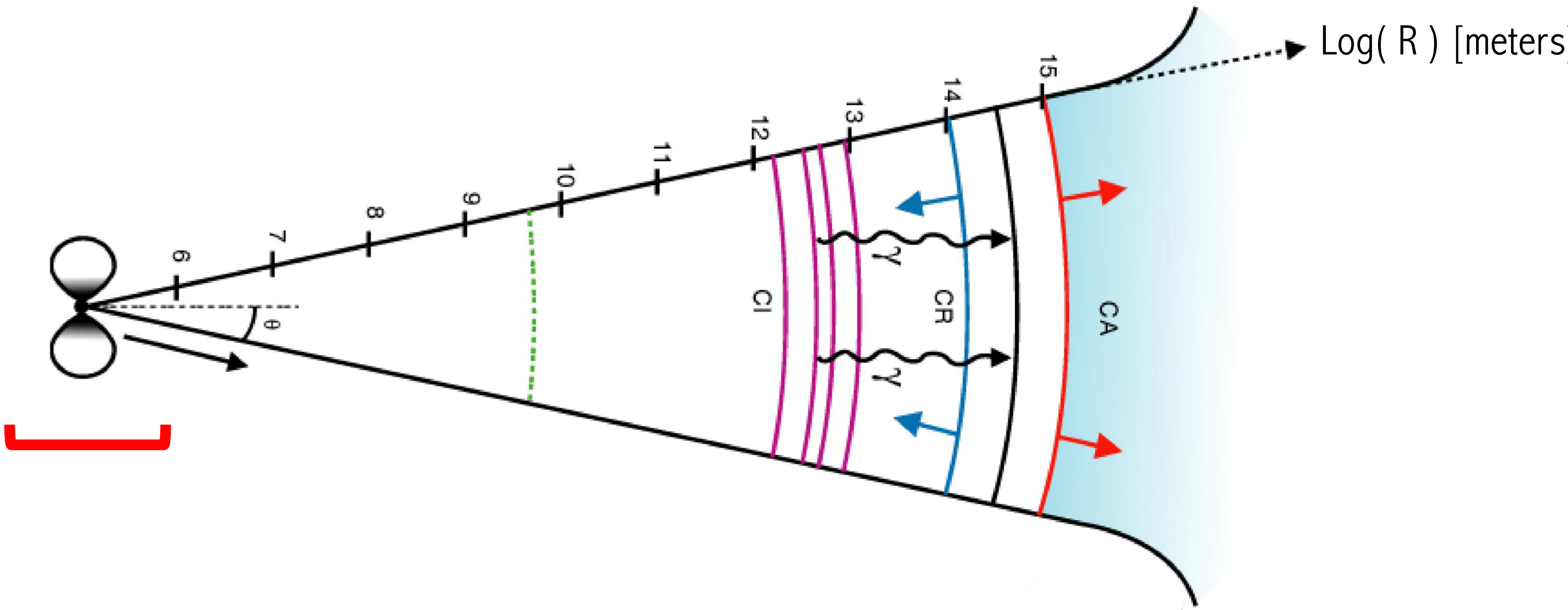


Also: prompt optical, GeV, TeV?

Also: optical, radio afterglow HE/VHE gamma-rays (Fermi/LAT; HESS/MAGIC)

THEORY

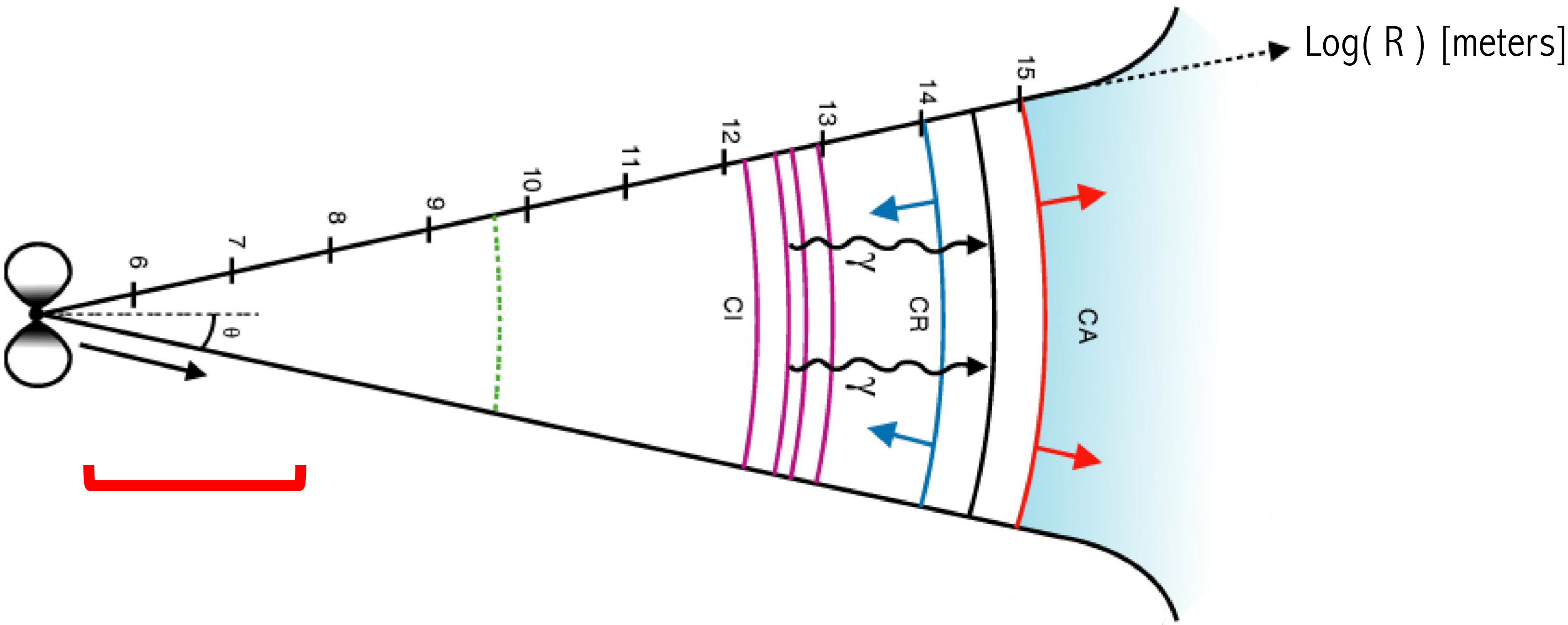
- Cosmological distance: huge radiated energy ($E_{iso,\gamma} \sim 10^{50}$-$10^{55}$ erg)
- Variability + energetics: violent formation of a stellar mass BH/magnetar



Progenitors: Long GRBs: collapse of some massive stars / probable diversity
Short GRBs: NS+NS(/BH ?)merger

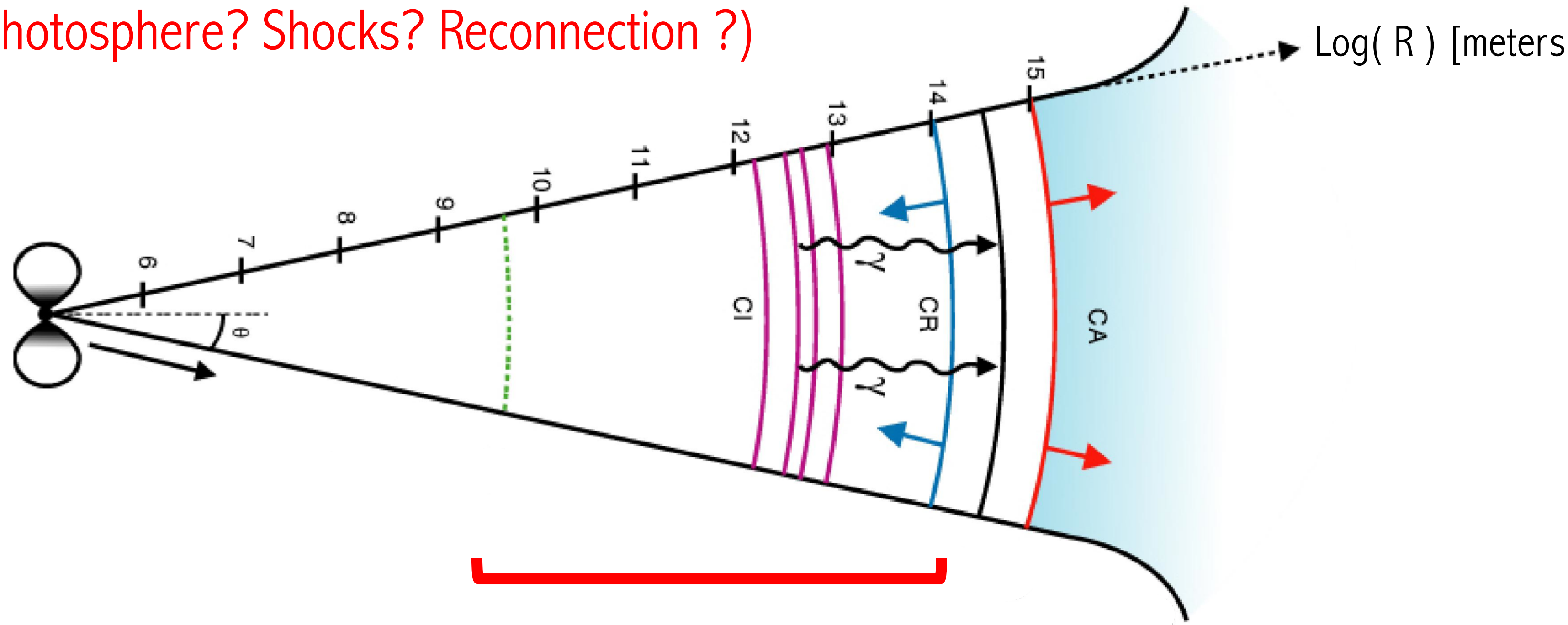
THEORY

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



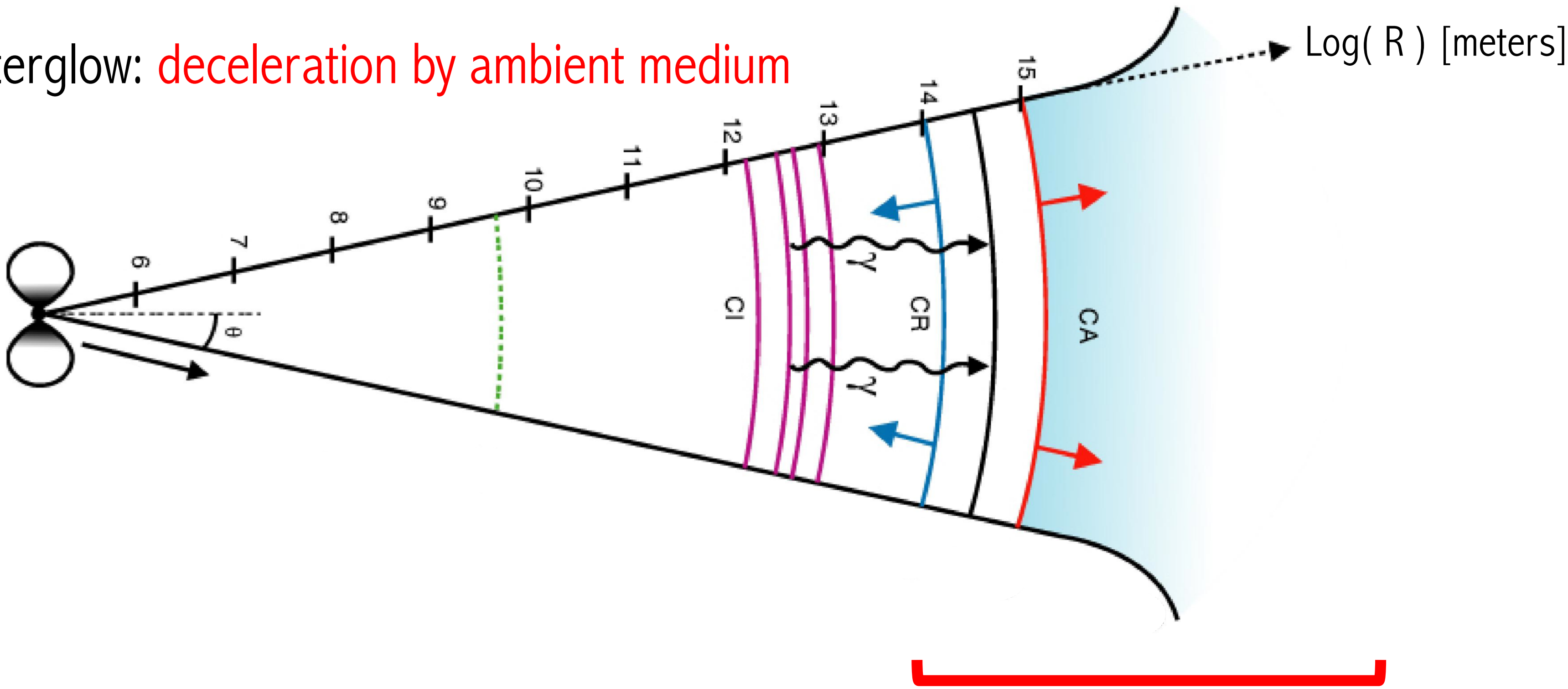
THEORY

- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta (photosphere? Shocks? Reconnection ?)



THEORY

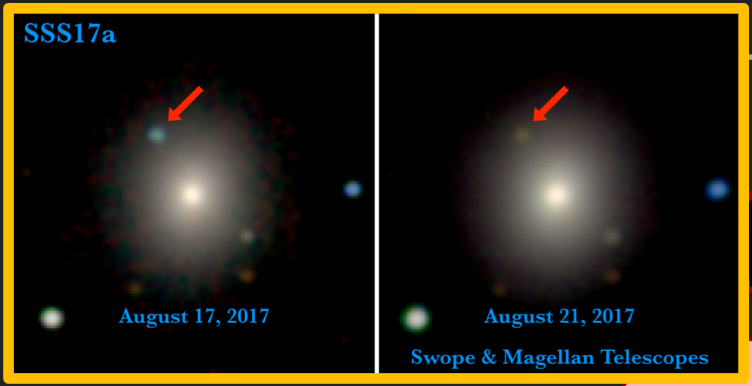
- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta
- Afterglow: deceleration by ambient medium



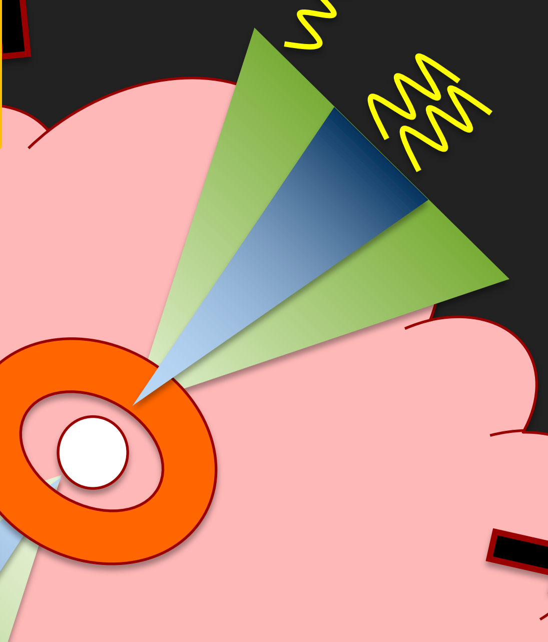
INTRODUCTION: GAMMA-RAY BURSTS

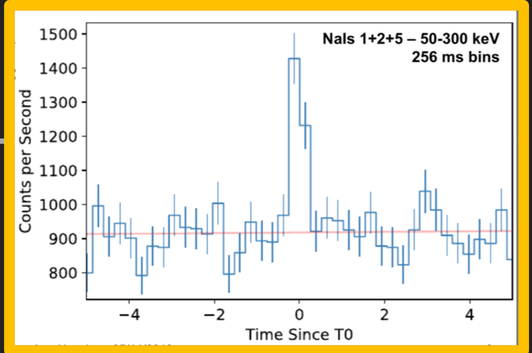
A FEW RECENT RESULTS

GW170817 AND GRB170817A



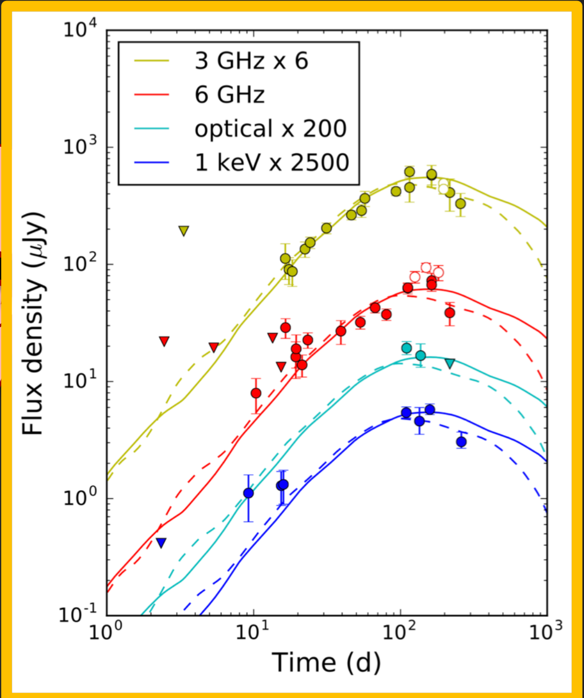
Kilonova: red and blue components

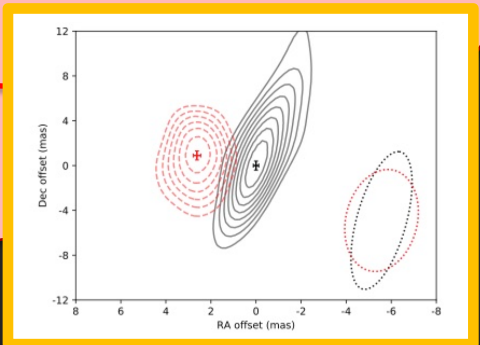




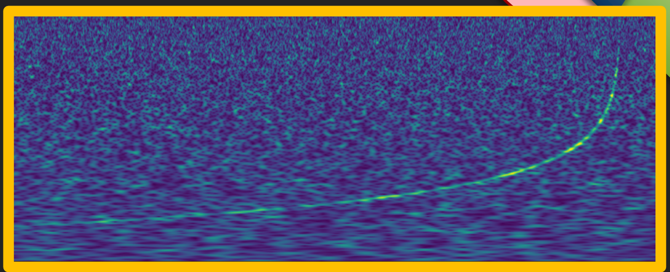
Short gamma-ray burst: physical origin?

A bright GRB for an on-axis observer?





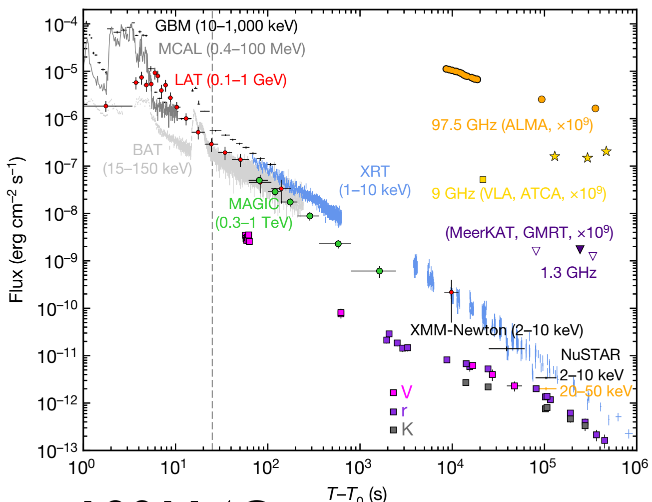
Afterglow: radio to X-rays + VLBI



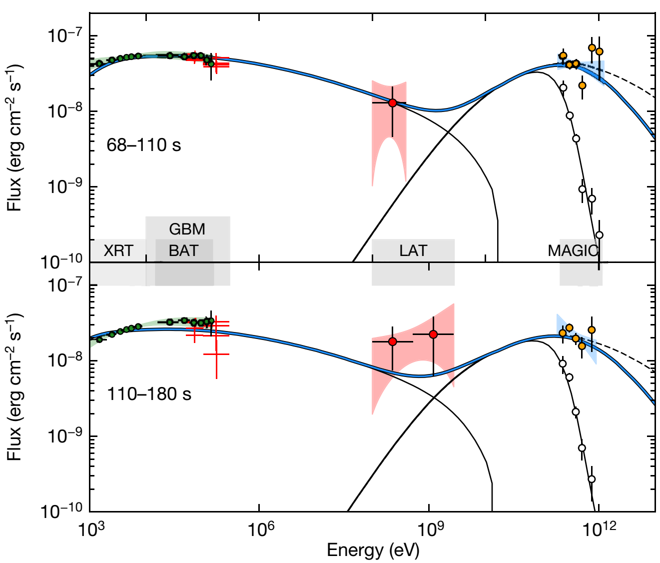
Gravitational waves

LONG GRBS: AFTERGLOWS AT VHE

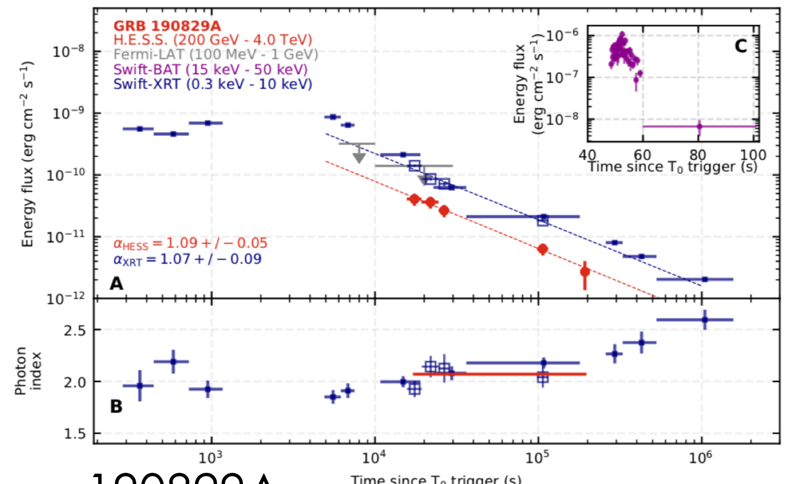
Already at least three GRBs detected at VHE (afterglow): 180720B (HESS) ; 190114C (MAGIC) ; 190829A (HESS)



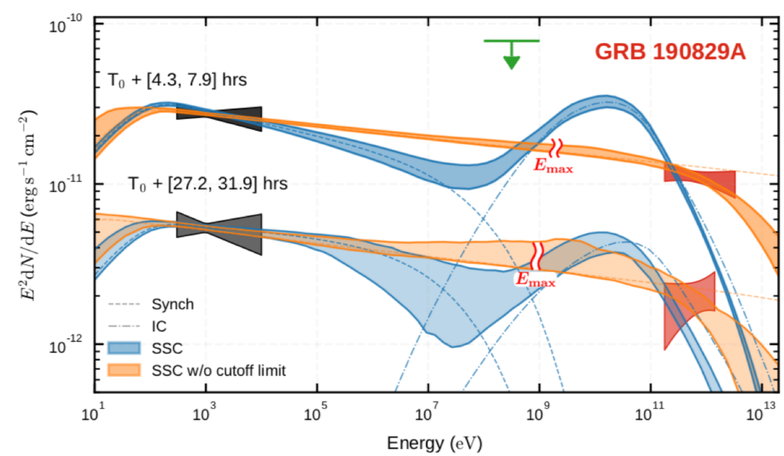
190114C



MAGIC collab.



190829A

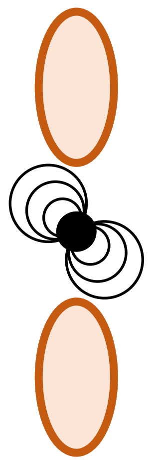


HESS collab.

MANY OPEN QUESTIONS

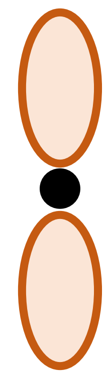
CENTRAL ENGINE

Accreting hypermassive NS/magnetar



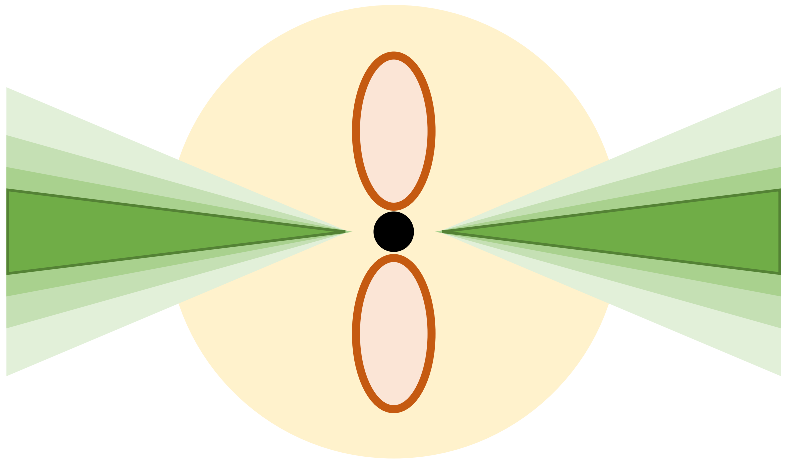
OR

Accreting BH



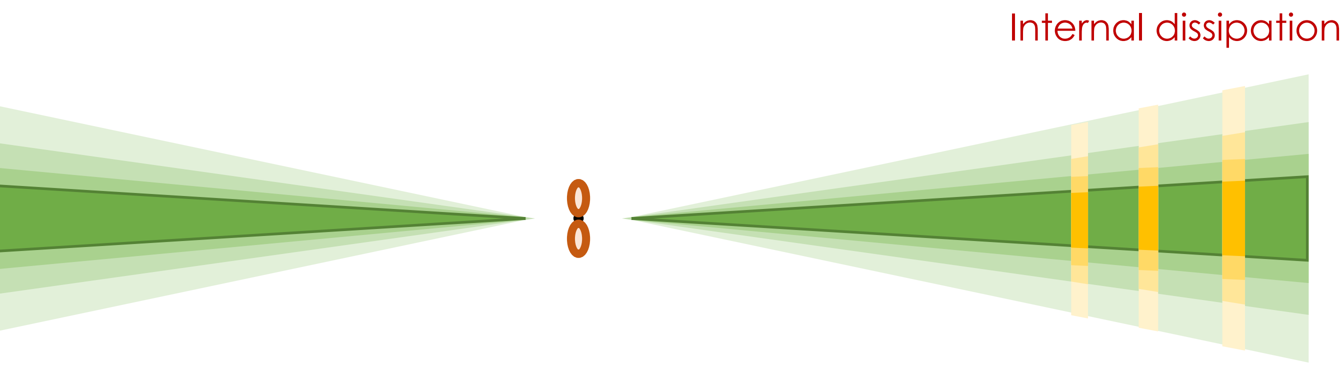
OR one and then the other…

JET LAUNCHING, ACCELERATION & EARLY PROPAGATION:



- Is a relativistic ejection possible either with a NS or a BH? Differences?
- Initial magnetization? Efficiency of the acceleration? Final magnetization?
- Effect of the interaction with the local medium?
  Choked/successful jets?
- Jet geometry, orientation, structure, composition?
- Neutrino signal?
- Etc.

PROMPT EMISSION

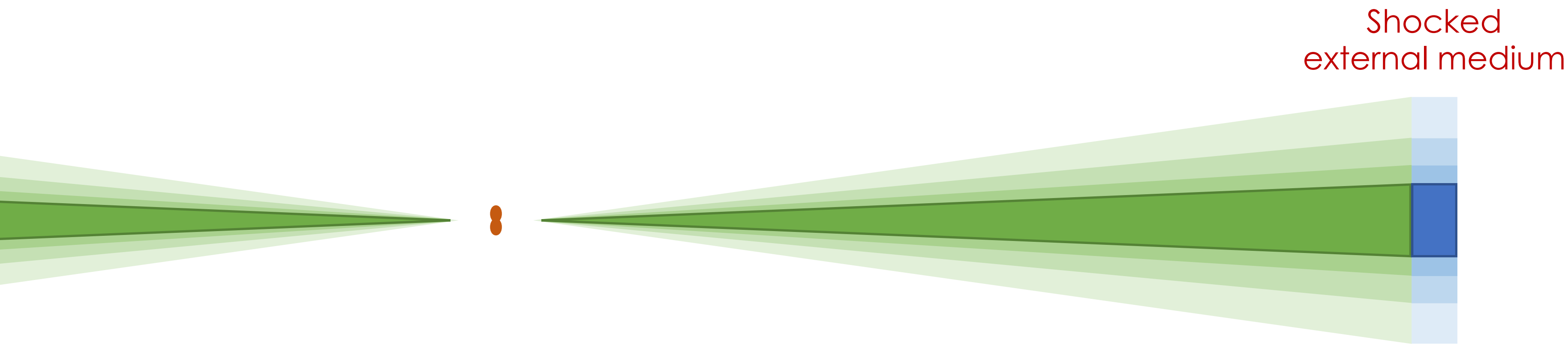


- Role, signature of the shock breakout?
- Signatures of the different mechanisms (shocks, reconnection, ...)?
- Microphysics? Acceleration of hadrons? Neutrino emission?

- Prompt optical emission? VHE emission ? Radio emission?

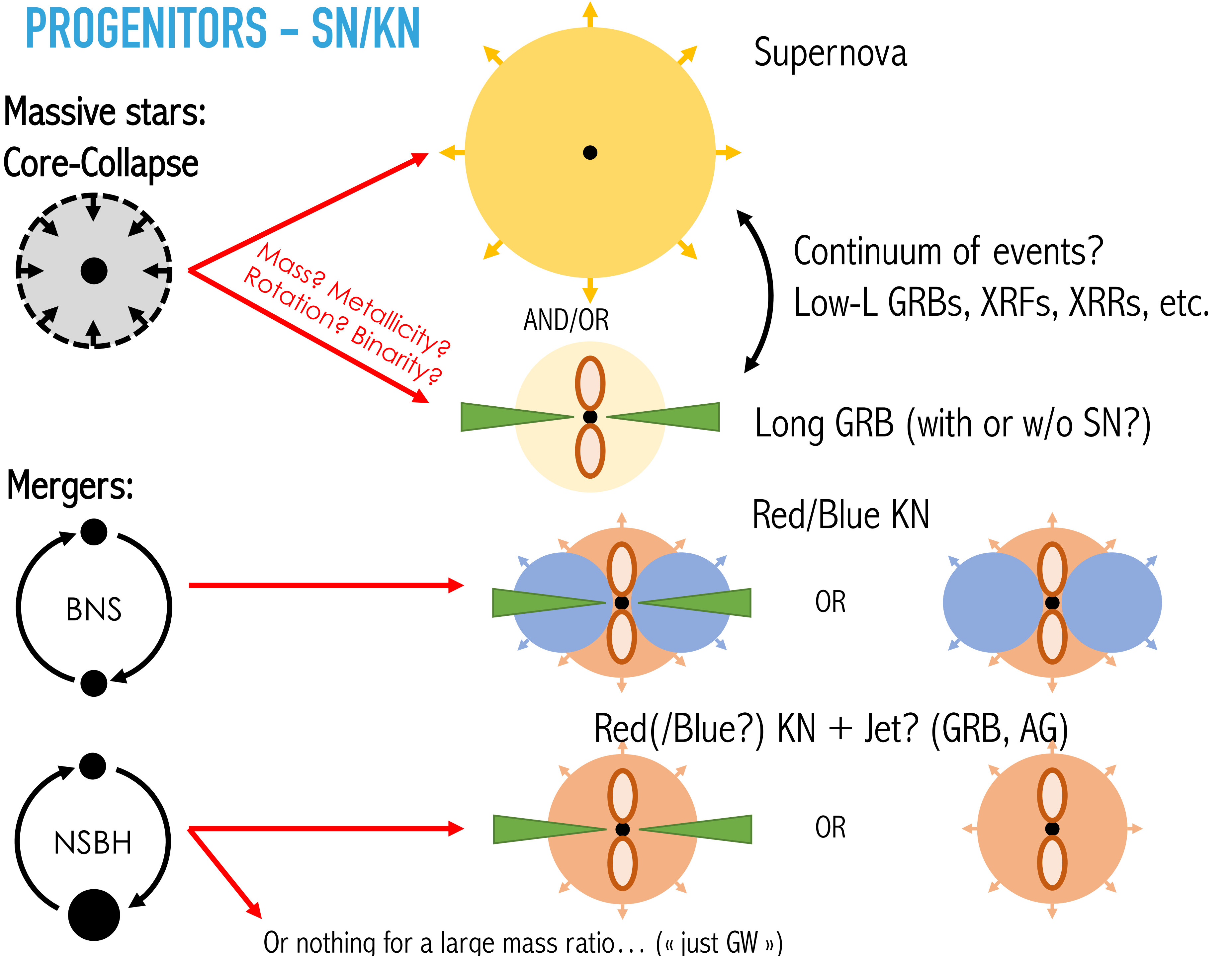
- Structured jet: same dissipation mechanism in the core jet & in the lateral structure?

AFTERGLOW



- Constraints on external medium?
- Microphysics, radiative processes
- Signature of the reverse shock? (always present?)
- Consequences of the lateral structure?
- VHE emission ? Neutrinos ?
- Late evolution: lateral expansion, non-relativistic transition) (late 170817 obs.)

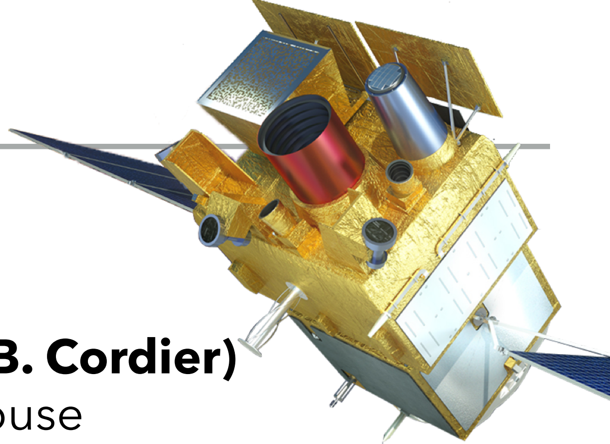
PROGENITORS – SN/KN



A NEW SPACE MISSION FOR THE MULTI-WAVELENGTH OBSERVATIONS OF GRBS

THE SVOM MISSION

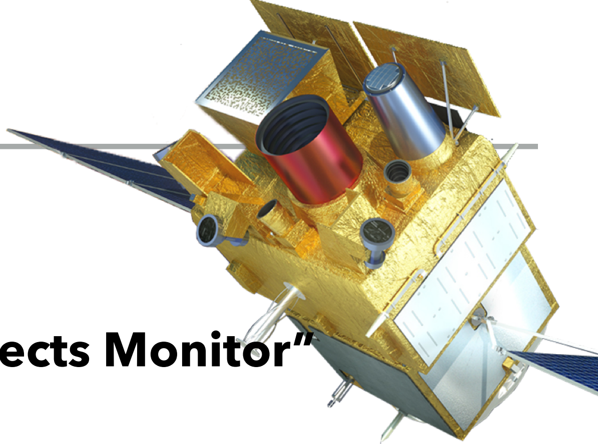
THE SVOM CONSORTIUM



- **China (P.I. J. Wei)**
  SECM Shangai
  NSSC Beijing
  NAOC Beijing
  IHEP Beijing
  GuangXi University

- **France (PI B. Cordier)**
  CNES Toulouse
  APC Paris
  CEA Saclay
  CPPM Marseille
  GEPI Meudon
  IAP Paris
  IJCLab Orsay
  IRAP Toulouse
  LAM Marseille
  LUPM Montpellier
  ObAS Strasbourg
  OCA Nice

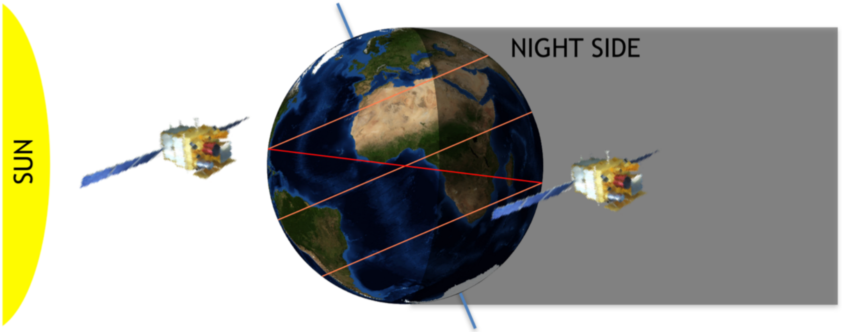
- **Mexico, UNAM (Colibri)**
- **UK, University of Leceister (MXT)**
- **Germany, MPE Garching & IAAT Tübingen (MXT)**



THE SVOM MISSION

- **"Space-based multi-band astronomical Variable Objects Monitor"**
- **Launch: mid-2023 ; for 3+2 years(+extension)**
- **A spacecraft with 4 instruments (ECLAIRs, GRM, MXT, VT) and rapid slewing capabilities**
- **A VHF alert network for near-real time alerts**
- **A ground segment for a rapid follow-up (GWAC, C-GFT, F-GFT=Colibri)**

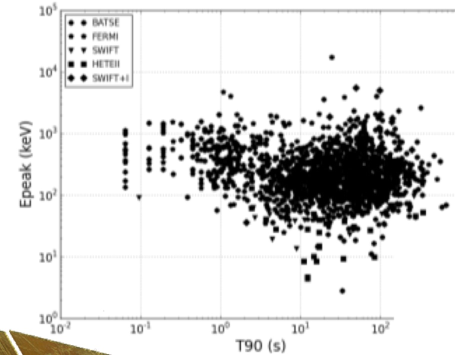
- **A nearly anti-solar pointing for optimizing the follow-up of GRBs**



- **Core Program: GRB science**
  (25% of time, GRB observation have the highest priority)
- **Other programs: MM follow-up (GW, neutrinos)** – General program

THE EXPECTED SVOM GRB SAMPLE

GRB TRIGGER



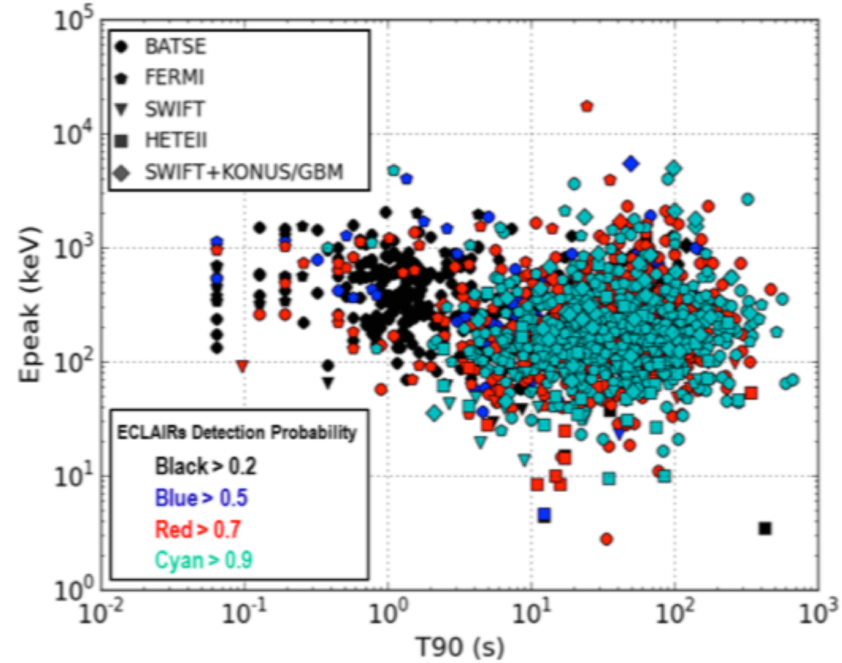
Original catalogs

Simulation in ECLAIRs

ECLAIRS

(4 -150 keV)
~ 2 sr
Loc. < 12′

42-80 GRBs/yr



ECLAIRs is sensitive to all classes of GRBs

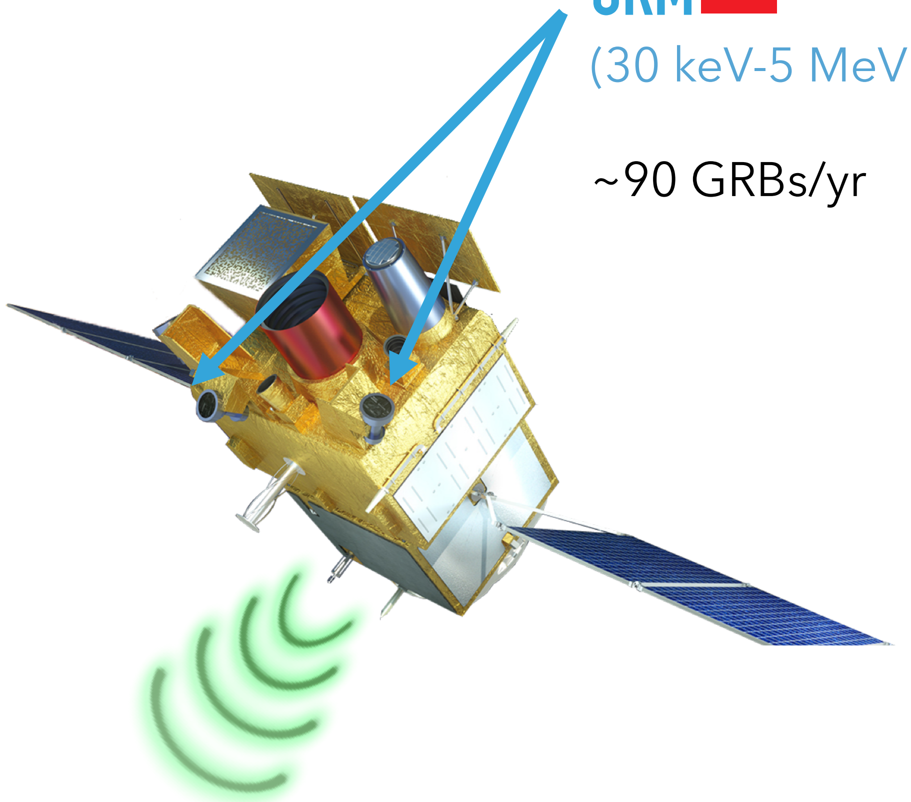
Classical long GRBs

Soft GRBs (XRR, XRF)

Short GRBs
(but with a moderate efficiency)

Detection probability by ECLAIRs
(simulations by S. Antier)
(Wei, Cordier et al. « Scientific prospects of the SVOM mission », arXiv:1610.06892)

GRB TRIGGER

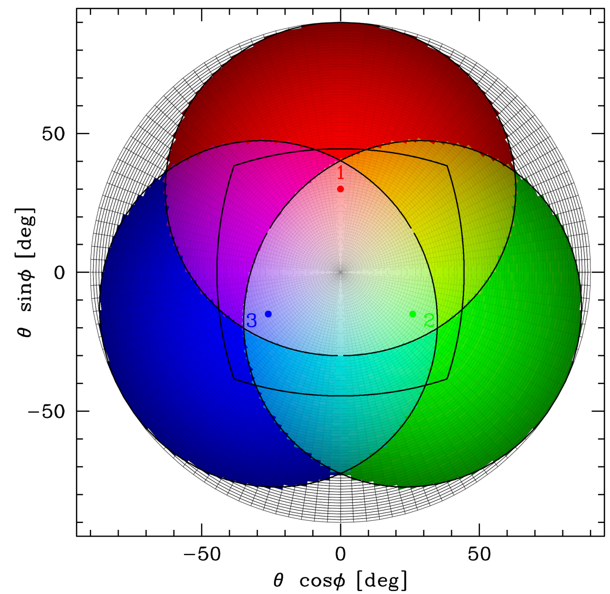


GRM

(30 keV-5 MeV) ~ 5.6 sr Loc.: 5-10° (3 GRDs)

~90 GRBs/yr

GRM field of view:



GRM has a larger field of view than ECLAIRs

ECLAIRs sensitivity to short GRBs can be improved by combining ECLAIRs+GRM

GRB TRIGGER

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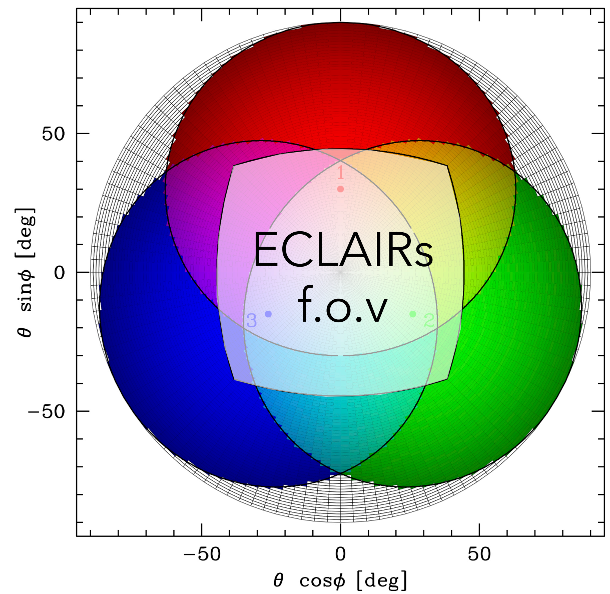
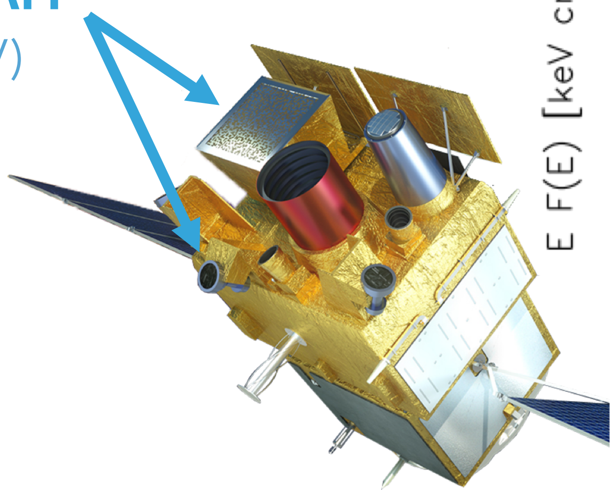


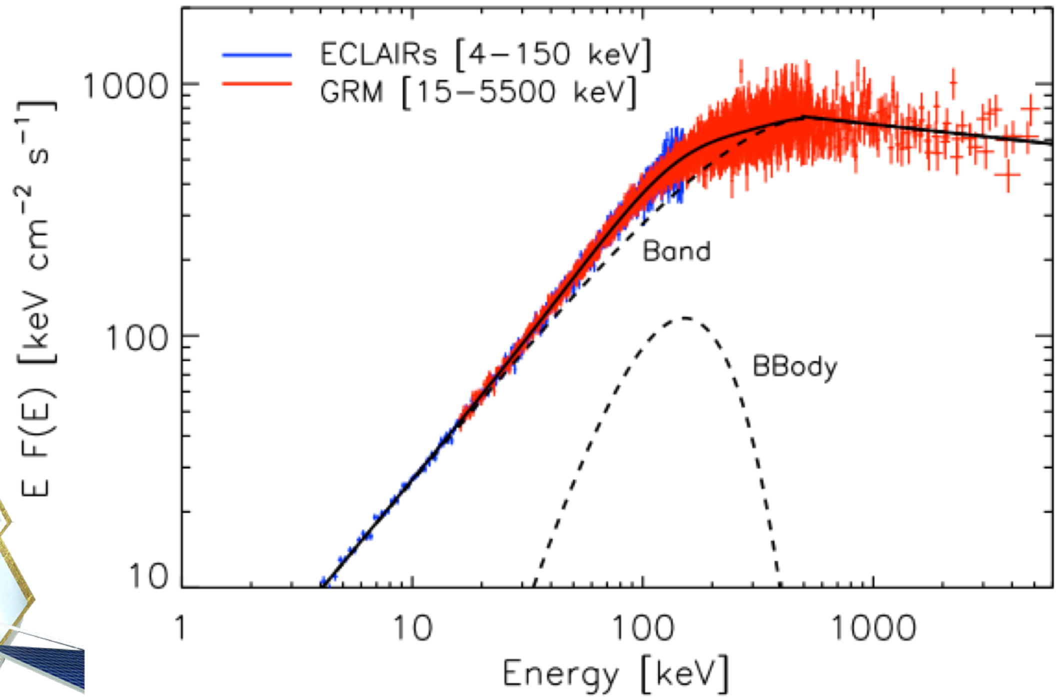
GRM has a larger field of view than ECLAIRs

ECLAIRs sensitivity to short GRBs can be improved by combining ECLAIRs+GRM

PROMPT EMISSION

ECLAIRS+GRM
(4 keV-5 MeV)





Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs+GRM. (Bernardini et al. 2017)

GWAC

2×5000 deg^2 – 500-800 nm
m_{lim} ~ 16-17 (10 s exposure)

prompt visible emission in ~16% of cases

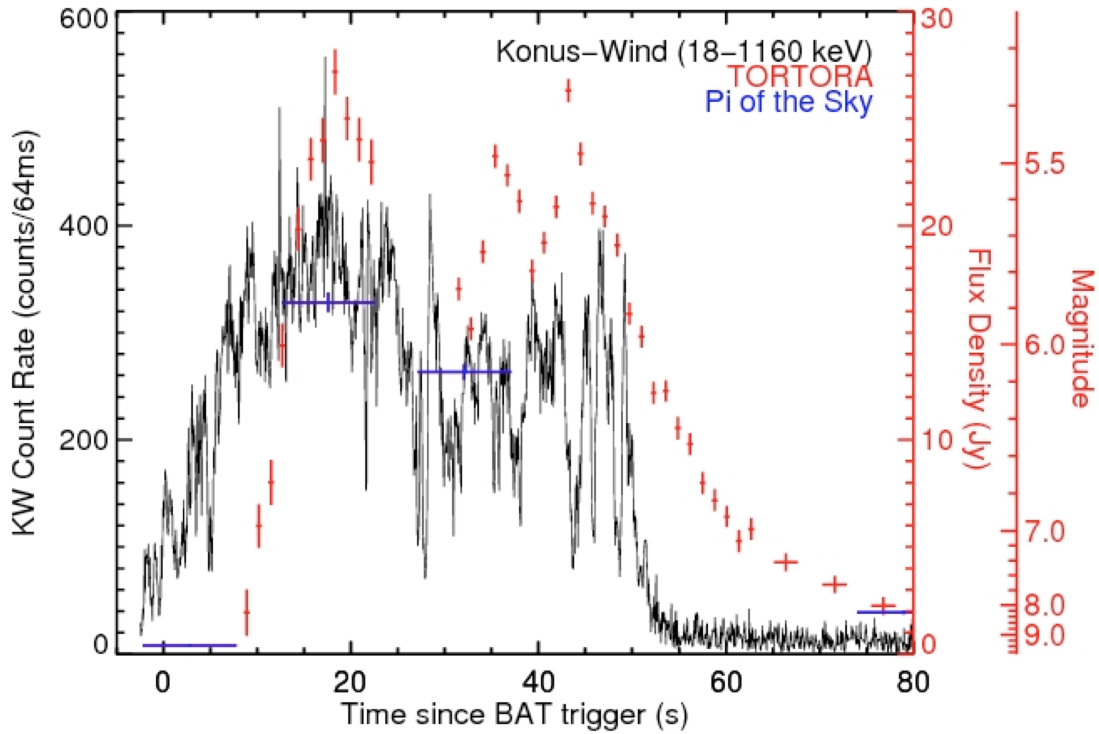
ECLAIRs+GRM can measure the prompt spectrum over 3 decades in energy

GWAC will add a constraint on the associated prompt optical emission in a good fraction of cases.

PROMPT OPTICAL EMISSION?

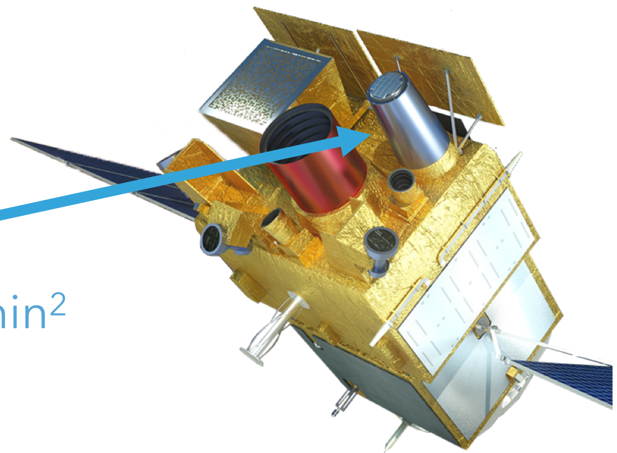
Present status: rare detections, great diversity.
GWAC: detection/upper limit in 16% of the ECLAIRs sample.

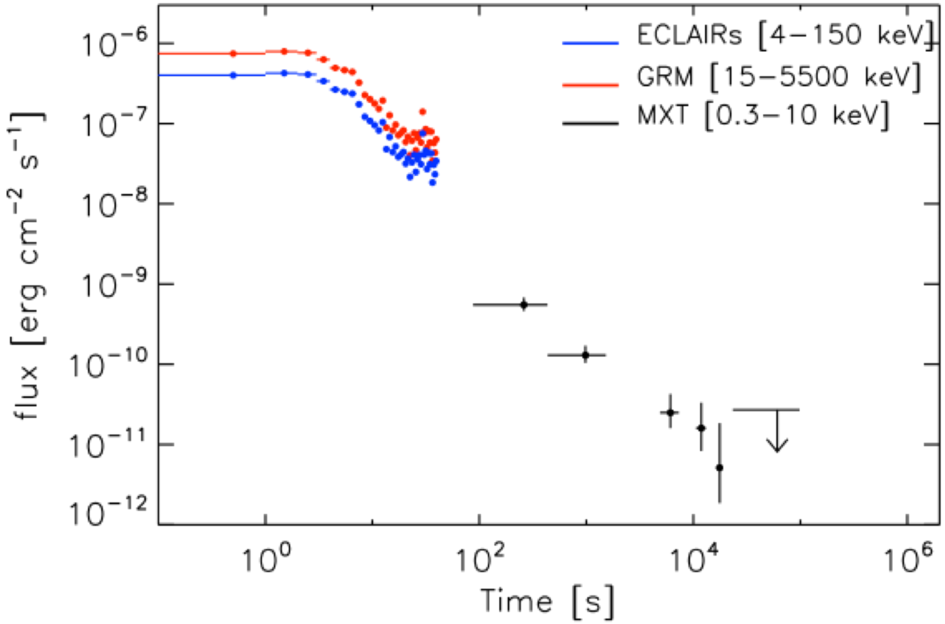
Sometimes, the prompt optical emission is very bright and variable



Naked Eye Burst (GRB 080319B @ z = 0.937) (Racusin et al. 2008)

AFTERGLOW





MXT

64 x 64 arcmin^2
0.2-10 keV
Loc.: <13″

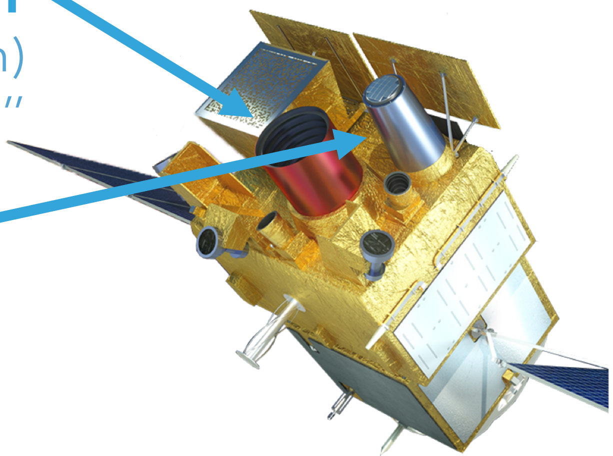
The X-ray afterglow of the Swift burst GRB 091020 simulated in MXT.
(Wei, Cordier et al. « Scientific prospects of the SVOM mission », arXiv:1610.06892)

MXT can detect and localize the X-ray afterglow in >90% of GRBs after a slew.

AFTERGLOW & DISTANCE

VT
(400-1000 nm)
Loc.: <1″

MXT
(0.2-10 keV)
Loc.: <13″



VT, C-GFT and F-GFT will detect, localize and characterize the V-NIR afterglows (lightcurve+photo-z).

Early observation by large telescopes are favored by SVOM's pointing strategy.

Redshift measurement is expected in ~2/3 of cases

GWAC
2x4000 deg^2
m_{lim} ~ 16-17

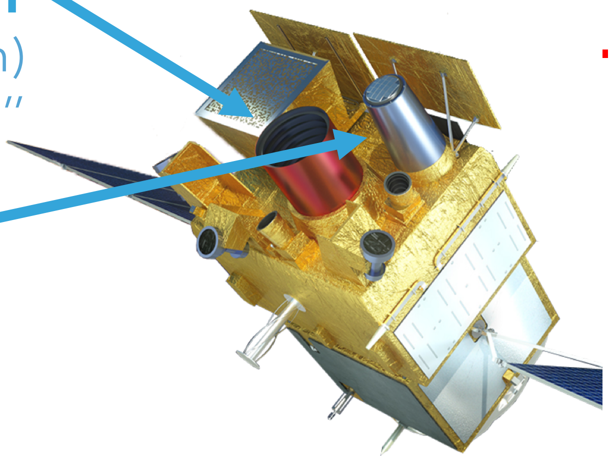
C-GFT
1.2 m
400-950 nm

F-GFT (COLIBRI)
1.3 m
400-1700 nm
multi-band

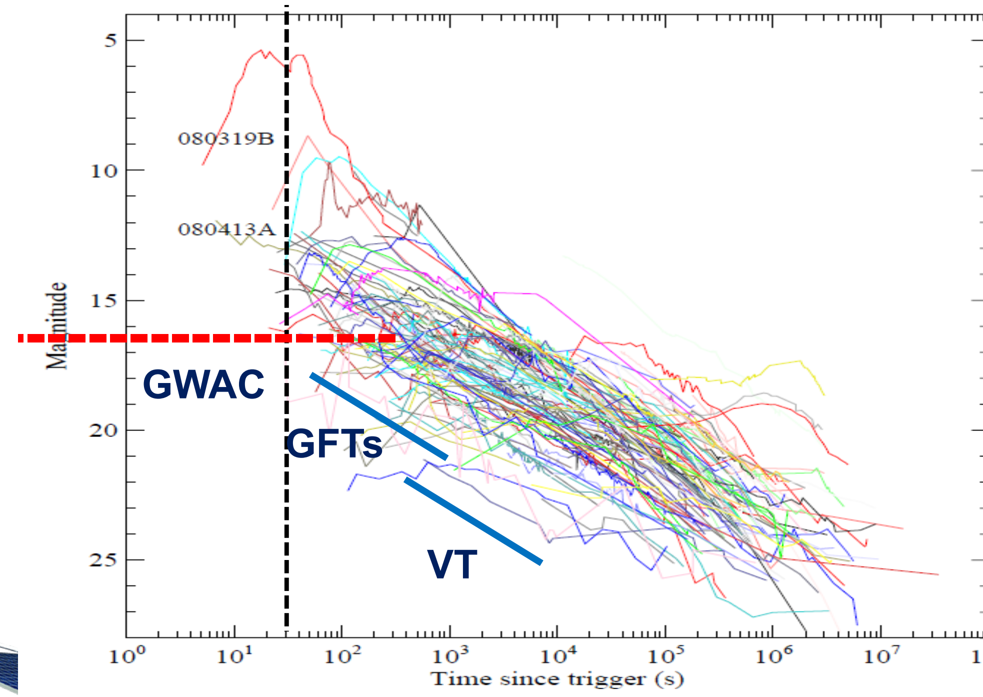
(Very) Large telescopes

AFTERGLOW & DISTANCE

VT
(400-1000 nm)
Loc.: <1″



MXT
(0.2-10 keV)
Loc.: <13″



(Wang et al. 2013)

GWAC
2x4000 deg^2
m_{lim} ~ 16-17

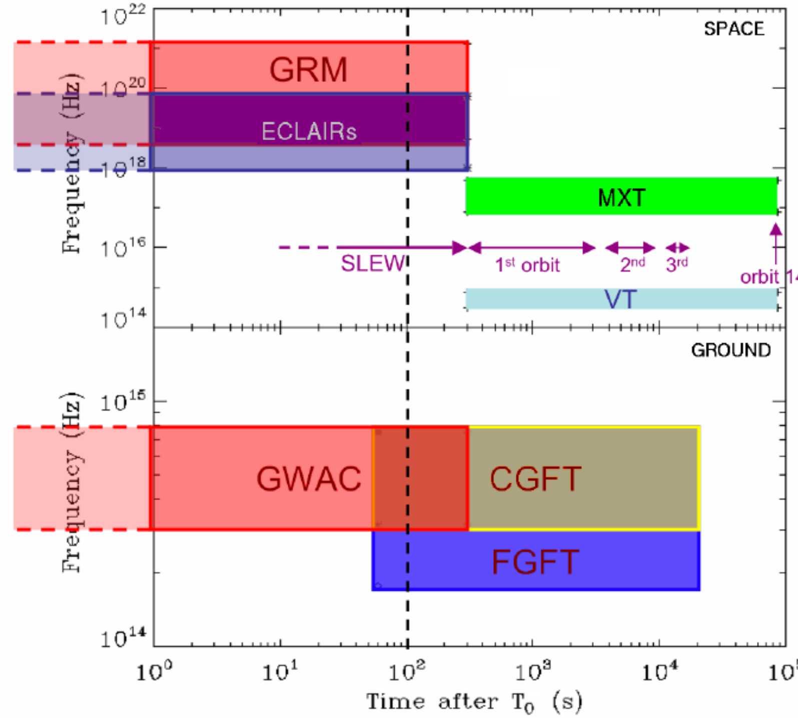
C-GFT
1.2 m
400-950 nm

F-GFT (COLIBRI)
1.3 m
400-1700 nm
multi-band

(Very) Large telescopes

A GRB SAMPLE WITH A COMPLETE DESCRIPTION

A unique sample of 30-40 GRB/yr with
- **prompt emission over 3 decades (+ optical flux/limit: 16%)**
- **X/V/NIR afterglow**
- **redshift**



	Swift	Fermi	SVOM
Prompt	Poor	Excellent 8 keV -100 GeV	**Very Good 4 keV - 5 MeV**
Afterglow	Excellent	> 100 MeV for LAT GRBs	**Excellent**
Redshift	~1/3	Low fraction	**~2/3**

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Physical mechanisms at work in GRBs

Nature of GRB progenitors and central engines
Acceleration, composition, dissipation & radiation process of the relativistic ejecta

Diversity of GRBs: event continuum following the collapse of a massive star

Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow
GRB/SN connection

Short GRBs and the merger model

GW association / Short GRBs with extended soft emission

GRBs as a tool to study the distant Universe

Host galaxies
Fraction of very high-z GRBs similar to Swift, better fraction of redshift measurements expected

SVOM CORE PROGRAM

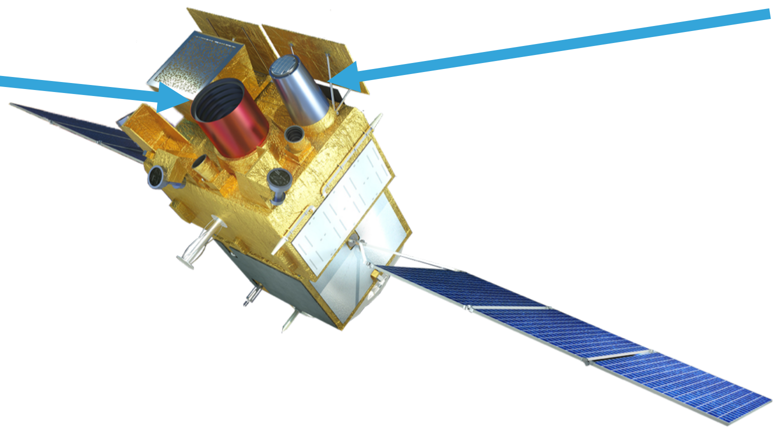
SVOM IN THE MULTI-MESSENGER ERA

GRBS IN THE MULTI–MESSENGER ERA

SVOM instruments with small f.o.v. in space

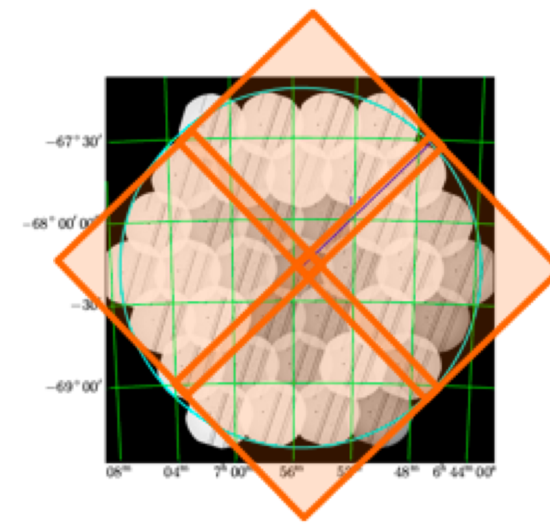
VT

400-1000 nm
26^2 arcmin^2
Loc: < 1 arcsec



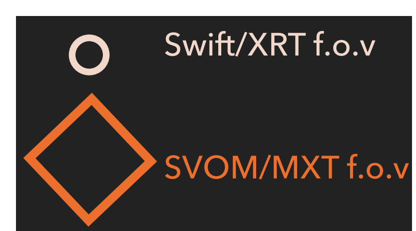
MXT

0.2-10 keV, 64^2 arcmin^2
Loc: <13 arcsec



- **Search for X-ray/V counterparts to MM events** (e.g. GW: large error boxes – KN/AG expectations depend on the viewing angle, HE neutrino: ~deg^2)
- Requires a **slew** of the satellite
- Large error boxes: requires a **tiling strategy**

MXT vs XRT: very competitive to rapidly cover large error boxes with only a slightly reduced sensitivity thanks to its large field of view (1 deg2).



GRBS IN THE MULTI-MESSENGER ERA

SVOM instruments with small f.o.v. on ground

C-GFT

(1.2 m, Changchun) 400-950 nm, 21^2 arcmin^2

F-GFT « COLIBRI »

(1.3 m, San Pedro Martir) 400-1700 nm, 26^2 arcmin^2
multiband photometry

- Search: galaxy targeting with error box
- **Characterize V-NIR counterparts to MM events: photometric follow-up** (e.g. a kilonova associated to a BNS)
- Needs an identified counterpart with an accurate localization (<30 arcmin)

GRB STUDIES

LONG GRBS IN THE LOCAL UNIVERSE
SHORT GRBS & THE MERGER CONNECTION

A GRB SAMPLE WITH A COMPLETE DESCRIPTION

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LONG GRBS IN THE LOCAL UNIVERSE

Dissipation mechanisms / Acceleration & Radiation processes in GRB jets

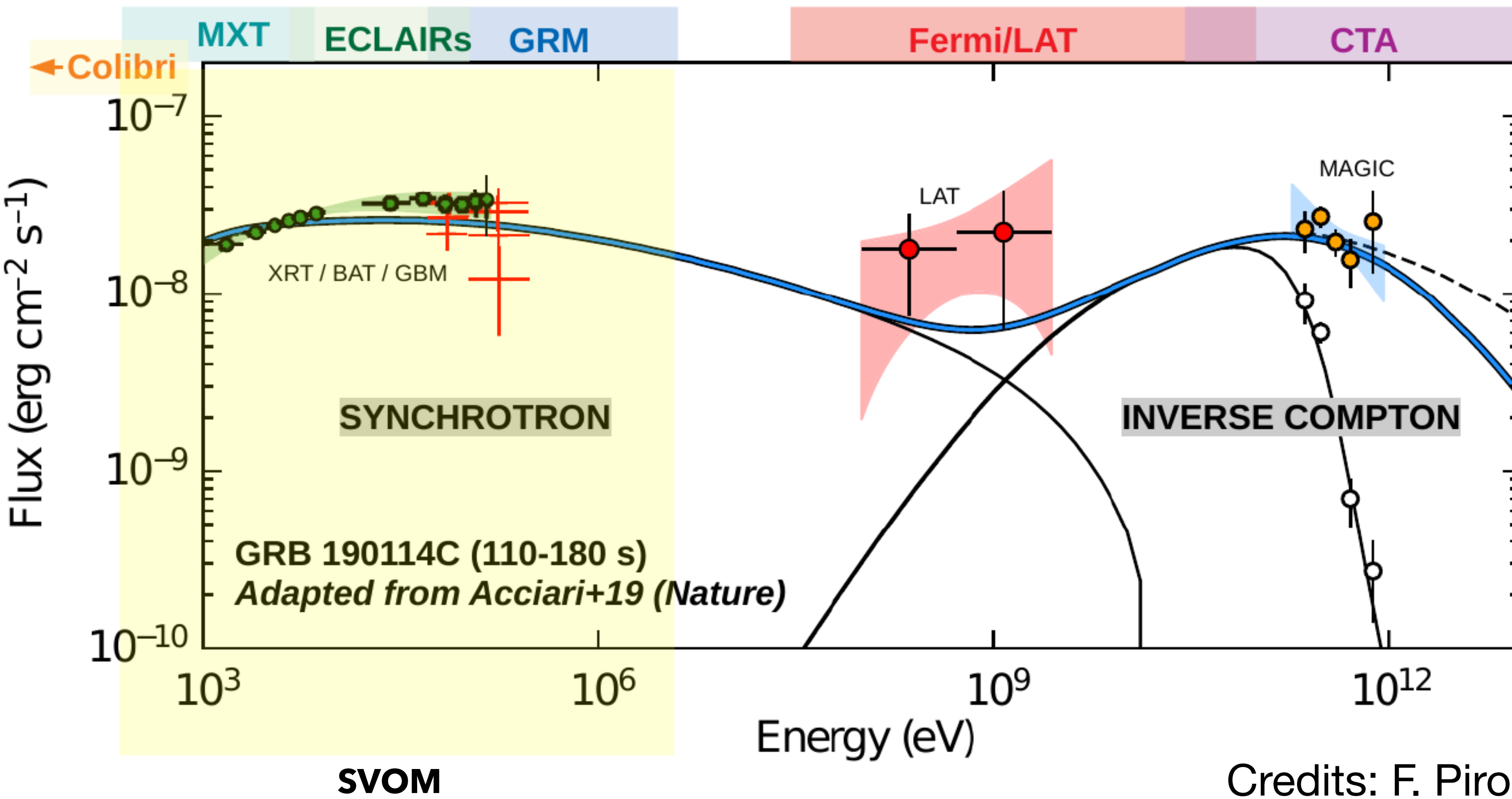
SVOM GRB sample

- **Probes the diversity of the GRB population in the local universe**
  - LGRBs (classical/low-L/XRR/XRF/…)
  - SGRBs
- **Redshift measurement in ~2/3 of GRBs**
- **Fast identification of low-z GRBs**
- **GWAC: detection/upper limit on prompt optical emission in ~16% of cases**

- **Synergies with CTA: more favorable at low z (intrinsic flux/EBL)**
- **Synergies with neutrino observatories**

SYNERGY WITH FERMI/LAT AND CTA

Multi-wavelength observations of promt and afterglow emission, in many cases with redshift.



Credits: F. Piron

LONG GRBS AT VHE: AFTERGLOW

Afterglow

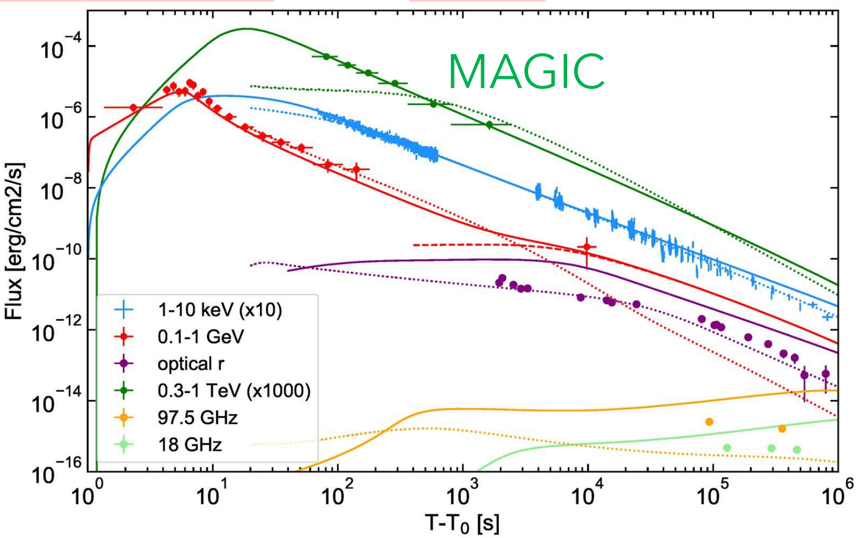
- Synchrotron + SSC from shock-accelerated electrons at the FS
- **HE: LAT extended emission**
- **VHE: a few cases since 2018!**

GRB 190114C (MAGIC) @ z=0.14
(MAGIC collab. 2019a,b)

detailed modeling:
new constraints on afterglow physics,
some puzzling results

(see also:
Yamasaki & Piran 2021, arXiv:2112.06945)

$s=0, \varepsilon_e=0.07, \varepsilon_B=8\times10^{-5}, p=2.6, n_0=0.5$ and $E_k=8\times10^{53}$ erg



LONG GRBS AT VHE: AFTERGLOW

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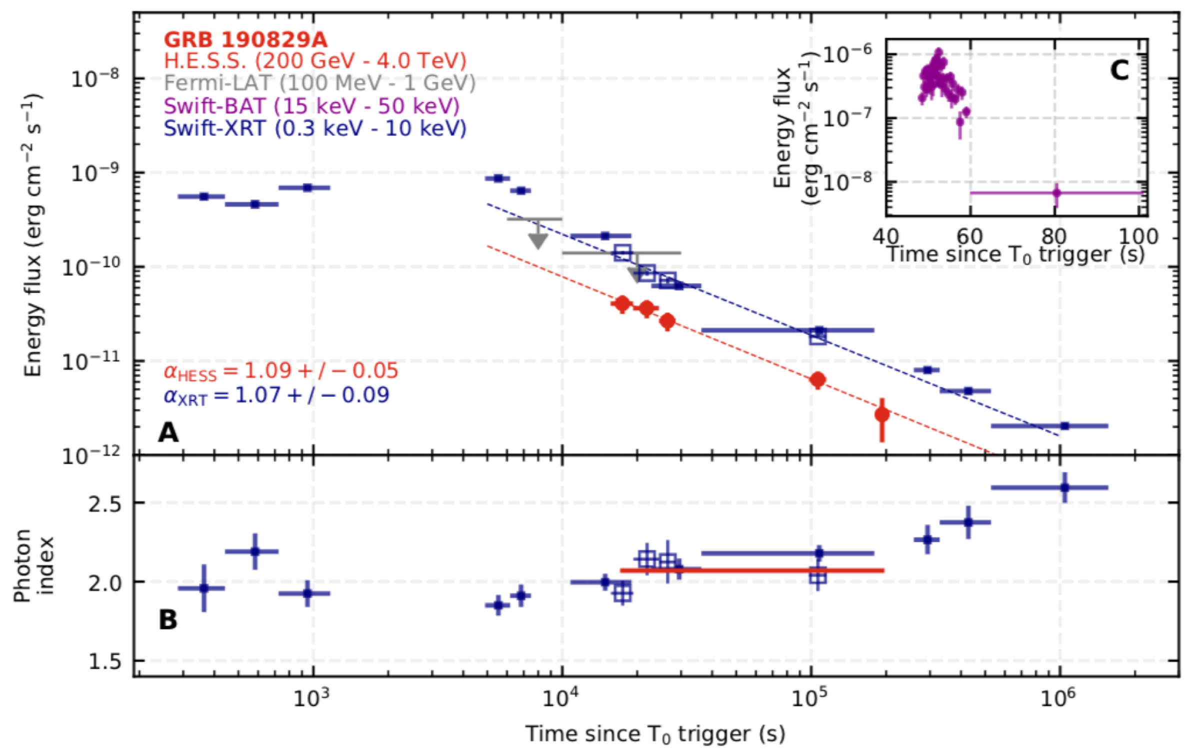
GRB 190829A (HESS)
z = 0.0785 ; D = 360 Mpc
(HESS collab. 2021)

Local low-luminosity GRB!



LONG GRBS AT VHE: AFTERGLOW

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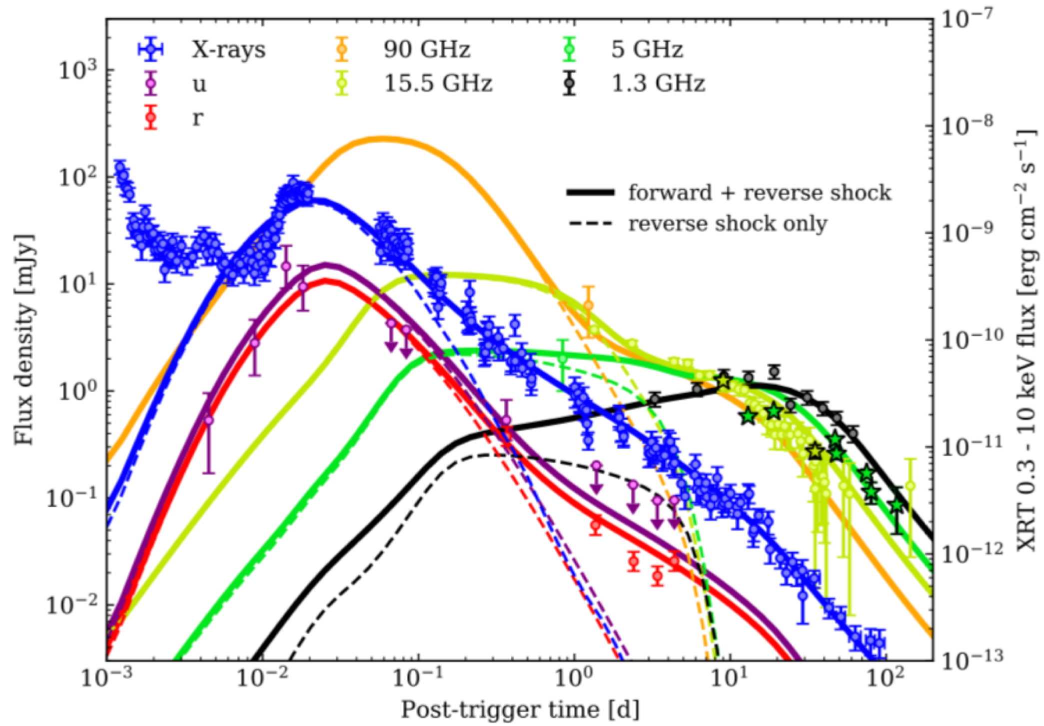
z = 0.0785 ; D = 360 Mpc
(HESS collab. 2021)

Local low-luminosity GRB!
Detailed AG model
Salafia et al. 2021
(includes VLBI constraint)



New constraints on electron acceleration at FS

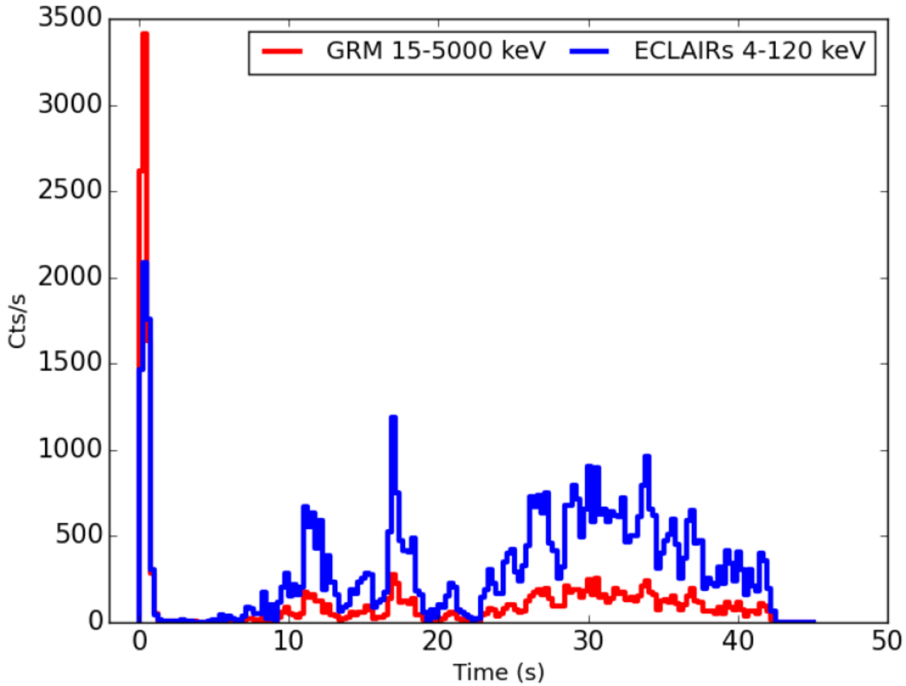
SHORT GRBS

- **A major target for MMA: the BNS/NSBH? merger-SGRB association**
- **Current limitation:**
  - On-axis observation: GW-limited
    (**2^{nd} gen. GW det.: z~0.2 at final sensitivity** ; 3^{rd} gen. GW det.: z~2-3)
  - Off-axis observation (e.g. 170817): gamma-ray limited

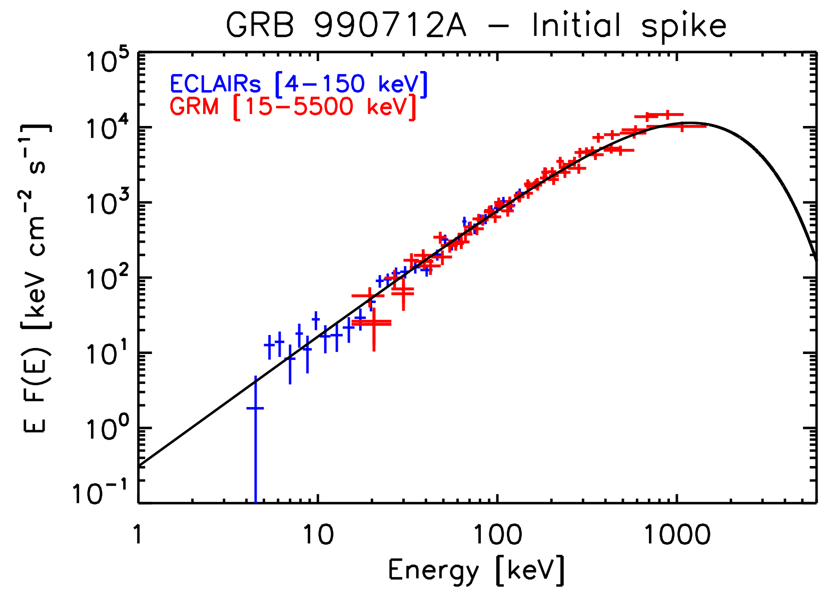
- **On-axis SGRBs:**
  - ECLAIRs (4-120 keV) alone: less sensitive to SGRBs than to LGRBs
  - **ECLAIRs+GRM (30 keV-5 MeV): good sensitivity to SGRBs**

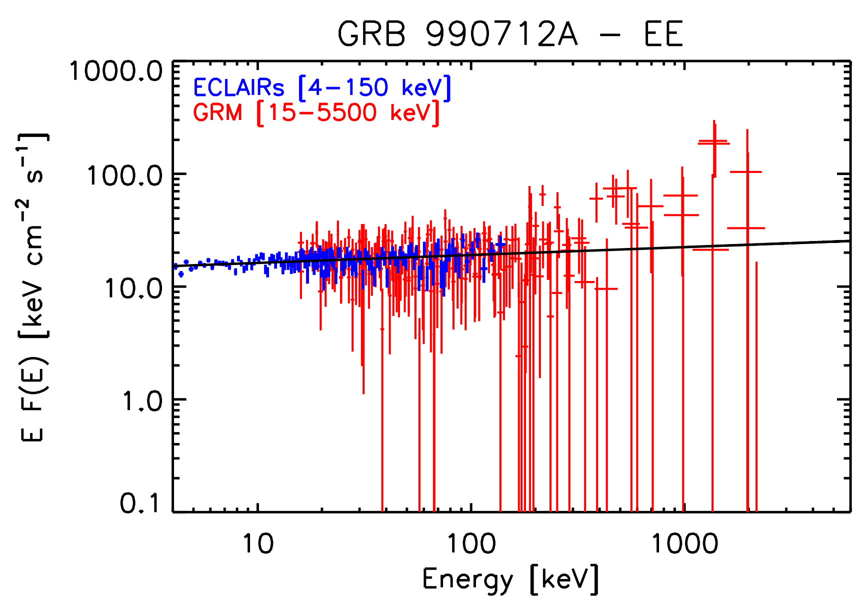
- **Off-axis SGRBs:**
  - Very faint signal (GRB170817A@40Mpc detected at ~6σ by Fermi/GBM)
  - Detection is possible in the local Universe only

ECLAIRS + GRM OBSERVATION OF A SHORT GRB



Simulation of a short GRB with a soft tail in ECLAIRs+GRM (990712A)
Simulation
by S.Antier, M.-G. Bernardini, F. Xie et al.





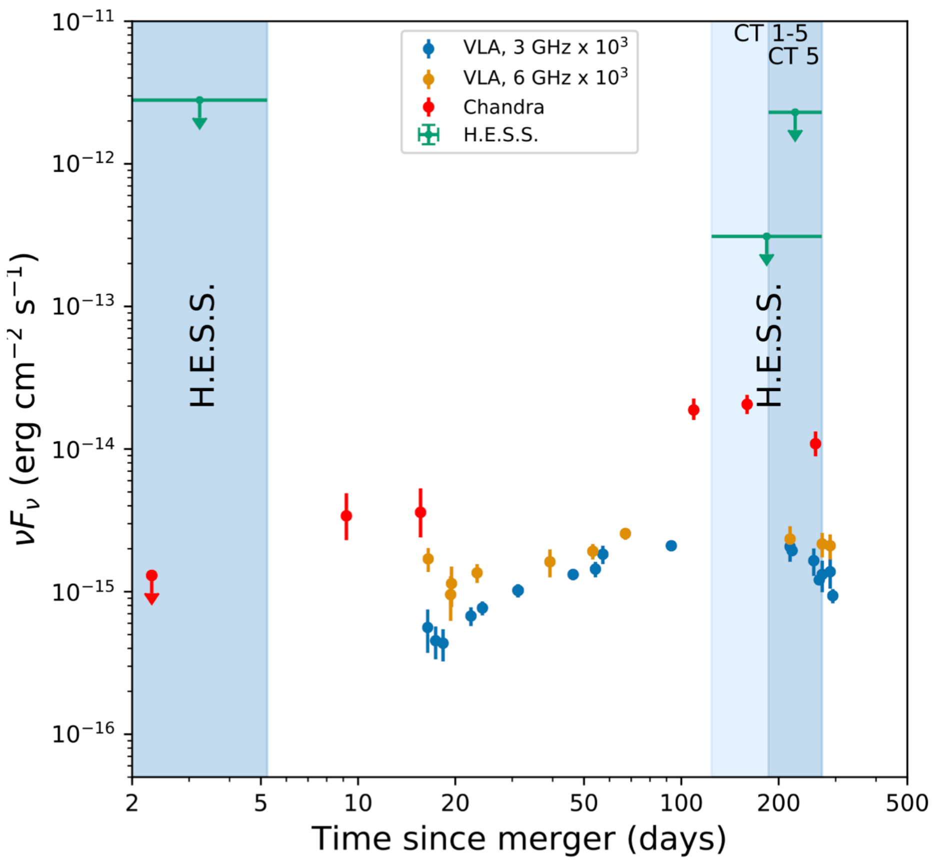
(Bernardini et al. 2017)
(Wei, Cordier et al. « Scientific prospects of the SVOM mission », arXiv:1610.06892)

SHORT GRBS AT VHE?

Afterglow

- **BNS/SGRBs?**
- **170817: upper limit by HESS** (HESS collab 2020)
- **Theoretical predictions?**

Low VHE emission expected due to KN

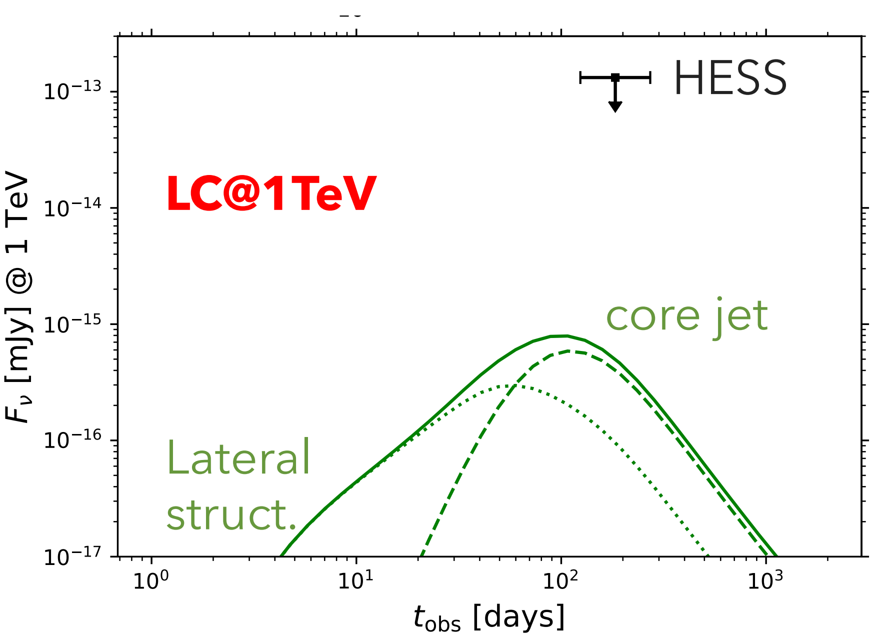


SHORT GRBS AT VHE?

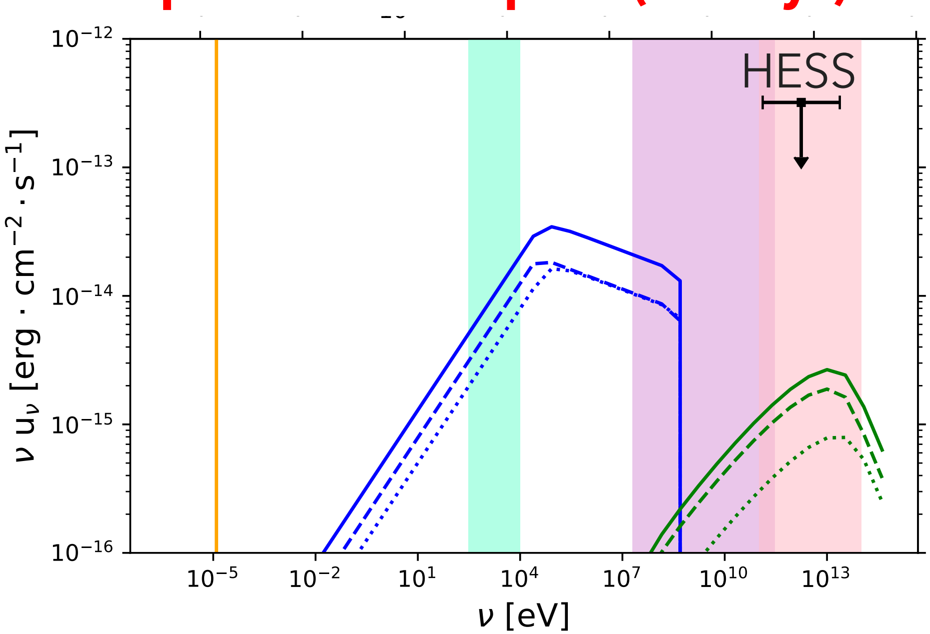
Afterglow

- **BNS/SGRBs?**
- **Simulation: structured jet seen off-axis**
  (Pellouin et al. [FD] in preparation)

170817 AG@1TeV peaks two orders of magnitude below HESS limit.



Spectrum@VHE peak (99 days)



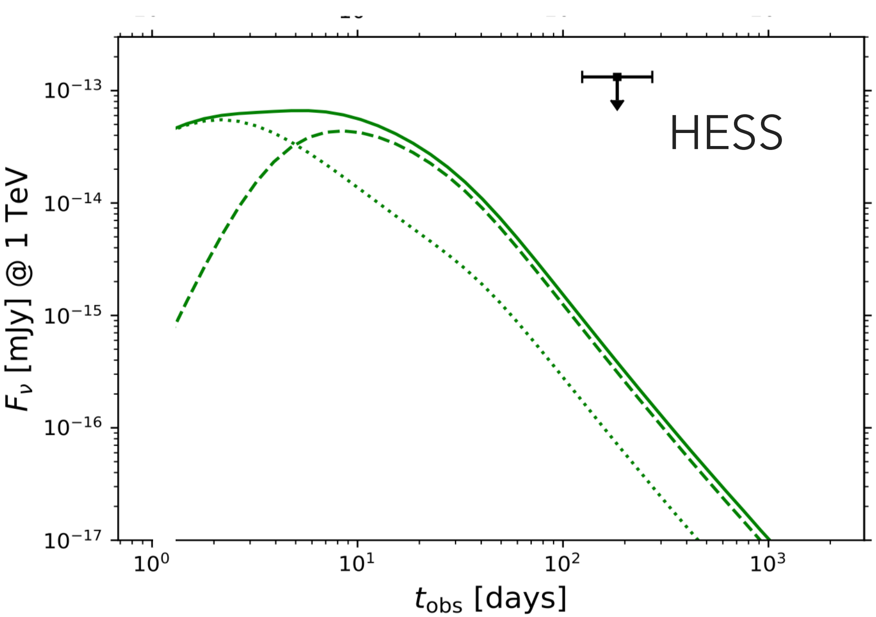
SHORT GRBS AT VHE?

Afterglow

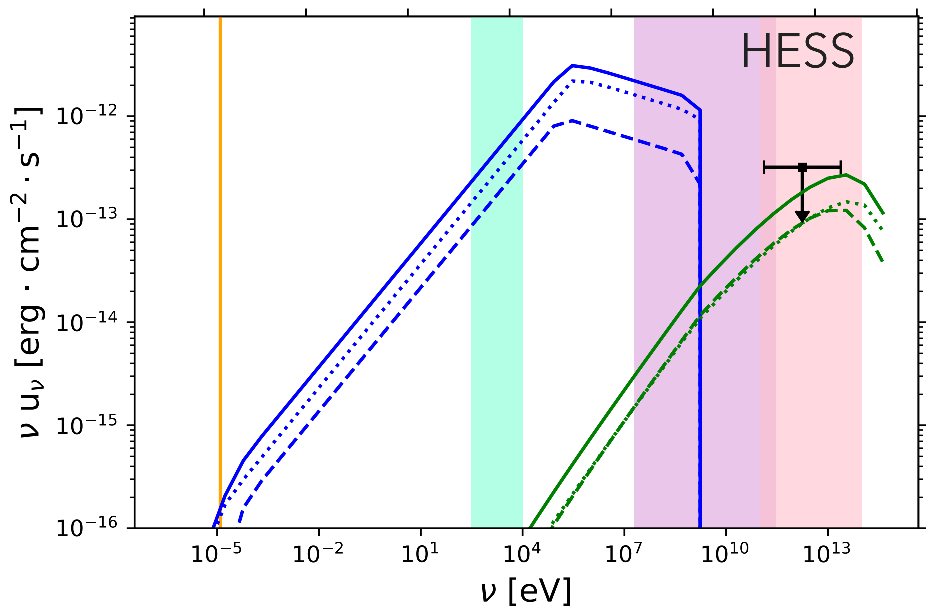
- **BNS/SGRBs?**
- **Simulation: structured jet seen off-axis**
  (Pellouin et al. [FD] in preparation)

Same GRB seen less off-axis (~10°)
Detectable by HESS
Could be detected by the CTAO >100Mpc

LC@1TeV – 10°



Spectrum@VHE peak (5 days)



SHORT GRBS AT VHE?

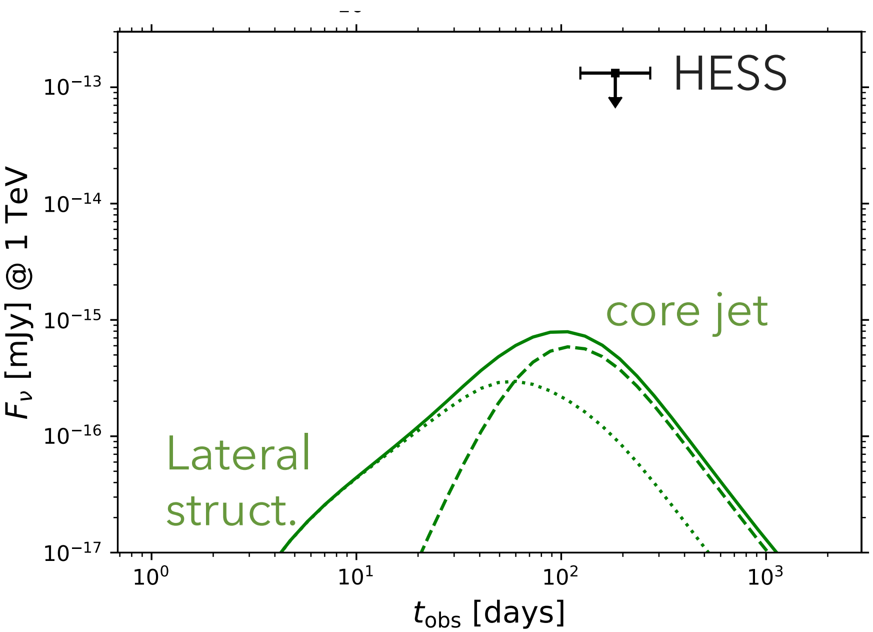
Afterglow

- **BNS/SGRBs?**
- **Simulation:**
  structured jet seen off-axis
  (Pellouin et al. [FD] in preparation)

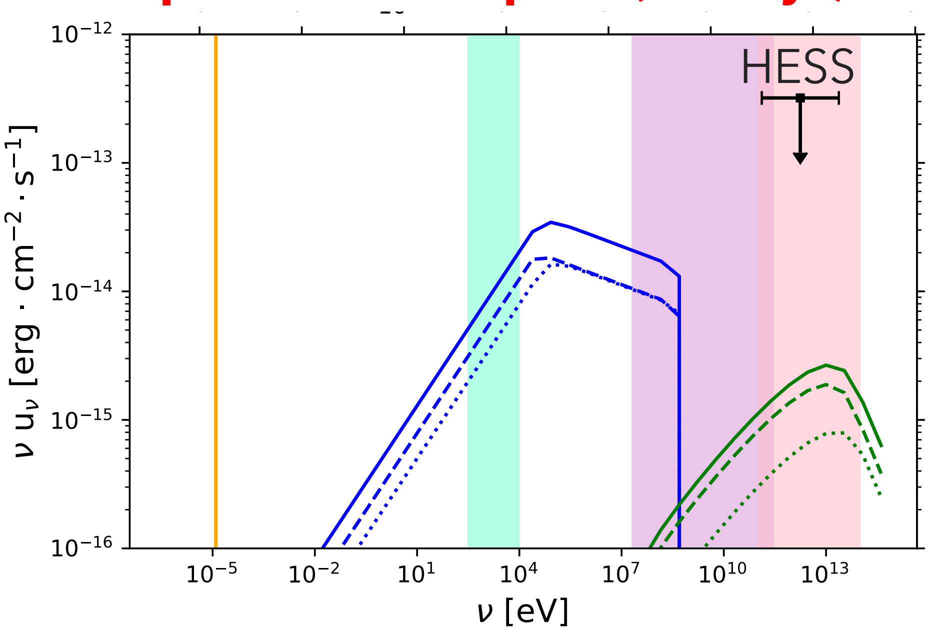
Same GRB with a denser environment

Much brighter at VHE!

LC@1TeV – 3 10^{-3} cm^{-3}



Spectrum@VHE peak (99 days)



SHORT GRBS AT VHE?

Afterglow

- **BNS/SGRBs?**
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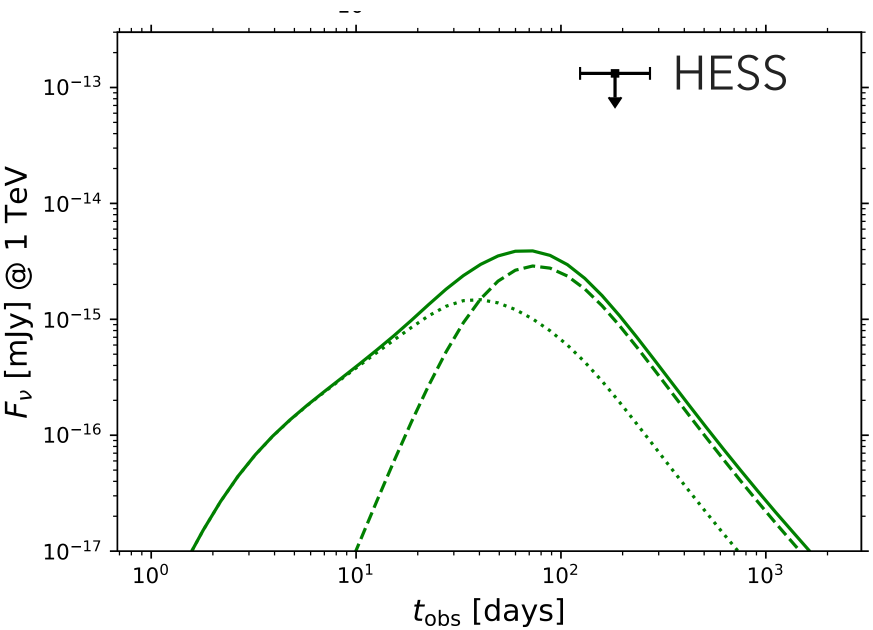
  structured jet seen off-axis
  (Pellouin et al. [FD] in preparation)

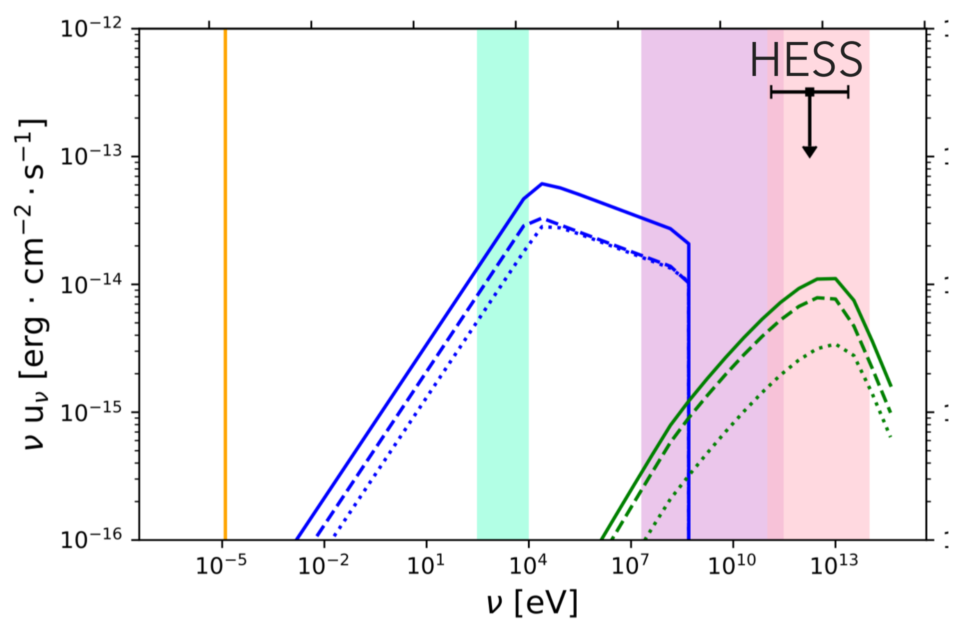
Same GRB with a denser environment

Much brighter at VHE!

LC@1TeV – 10^{-2} cm^{-3}



Spectrum@VHE peak (67 days)



SHORT GRBS AT VHE?

Afterglow

- **BNS/SGRBs?**
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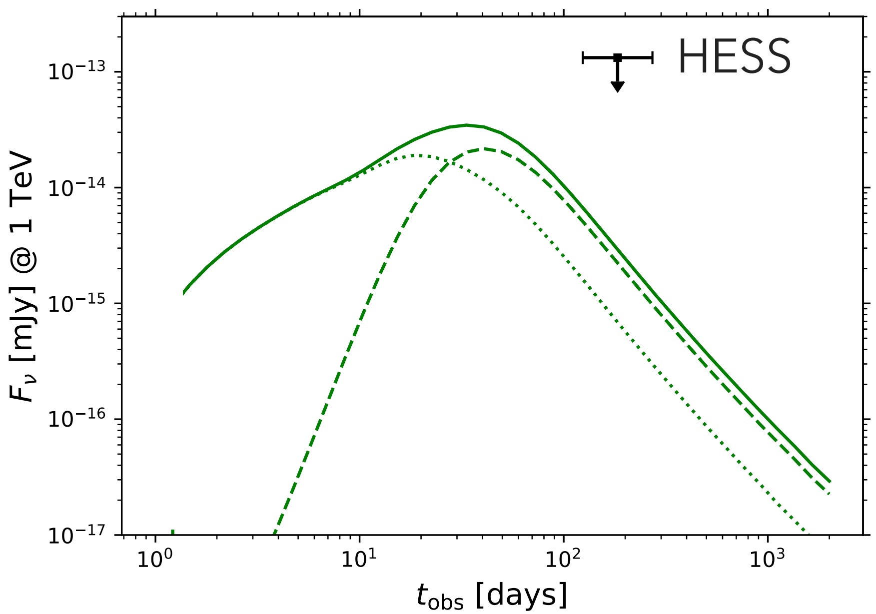
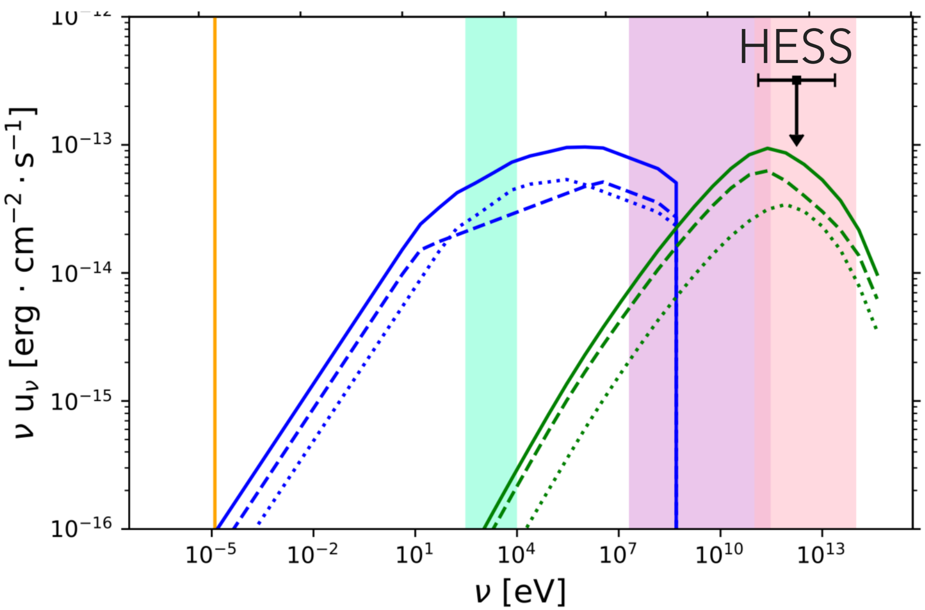
Same GRB with a denser environment

Much brighter at VHE!

LC@1TeV - 10^{-1} cm^{-3}



Spectrum@VHE peak (34 days)



SHORT GRBS AT VHE?

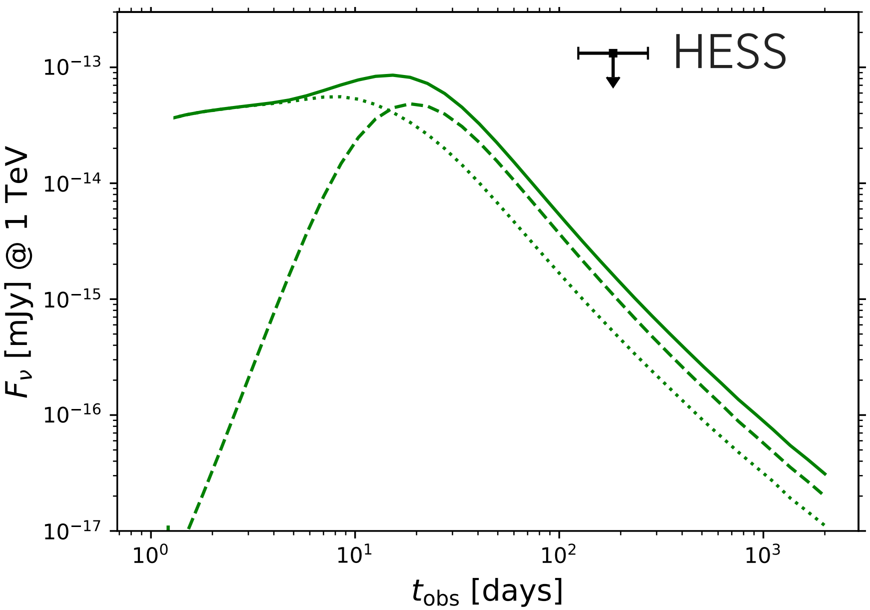
Afterglow

- **BNS/SGRBs?**
- **Simulation:**
  structured jet seen off-axis
  (Pellouin et al. [FD] in preparation)

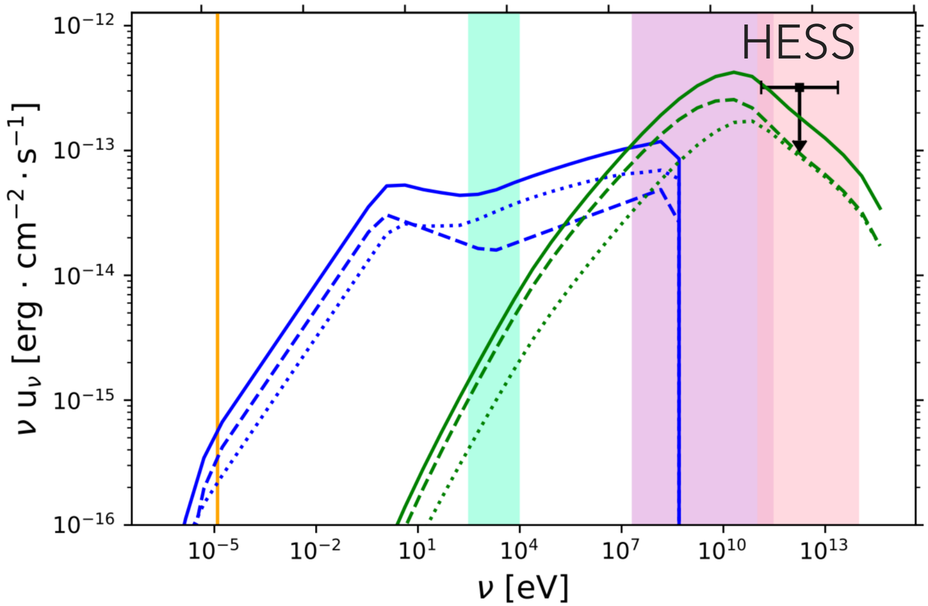
Same GRB with a denser environment

Much brighter at VHE!

LC@1TeV - 1 cm^{-3}



Spectrum@VHE peak (15 days)



SHORT GRBS AT VHE?

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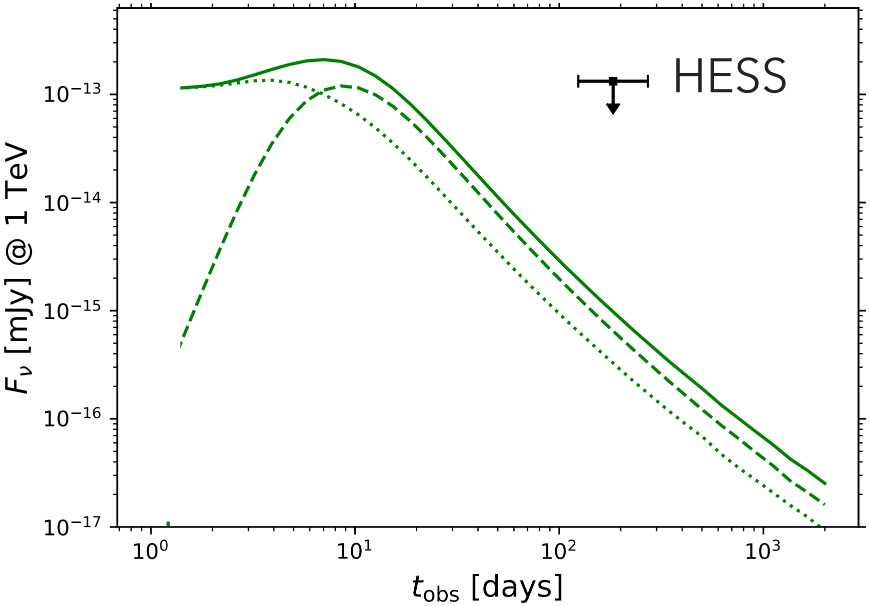
- **Simulation: structured jet seen off-axis** (Pellouin et al. [FD] in preparation)

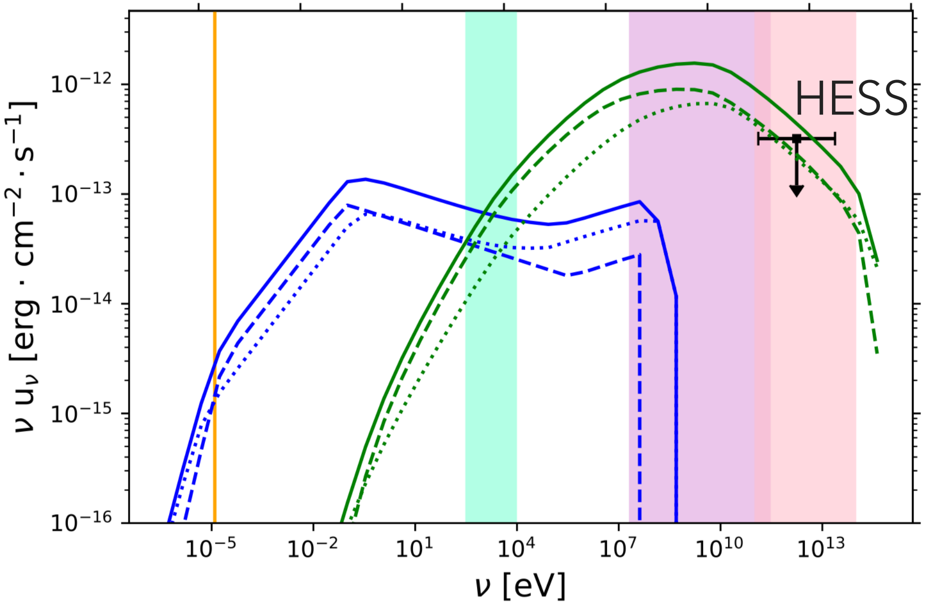
Same GRB with a denser environment

Much brighter at VHE!

LC@1TeV - 10 cm^{-3}



Spectrum@VHE peak (7 days)



SHORT GRBS AT VHE?

Afterglow

- **BNS/SGRBs?**
- **Simulation: structured jet seen off-axis** (Pellouin et al. [FD] in preparation)

Same GRB with a denser environment

Much brighter at VHE!

- If a possible of fast-mergers exist, they should be over-represented in the GW-AG sample, due to brighter afterglows (Duque et al. [FD] 2020)
- **These systems may be the only ones detected at VHE: direct signature of high density environment**
- Many arguments in favor of such systems:
  some SGRB afterglow fits, some SGRB low offset in host galaxy,
  early r-process enrichment, etc.

SVOM

A unique sample of GRBs with a complete description:

prompt (γ-rays: 3 decades; optical) + afterglow (X, V, NIR) + redshift.

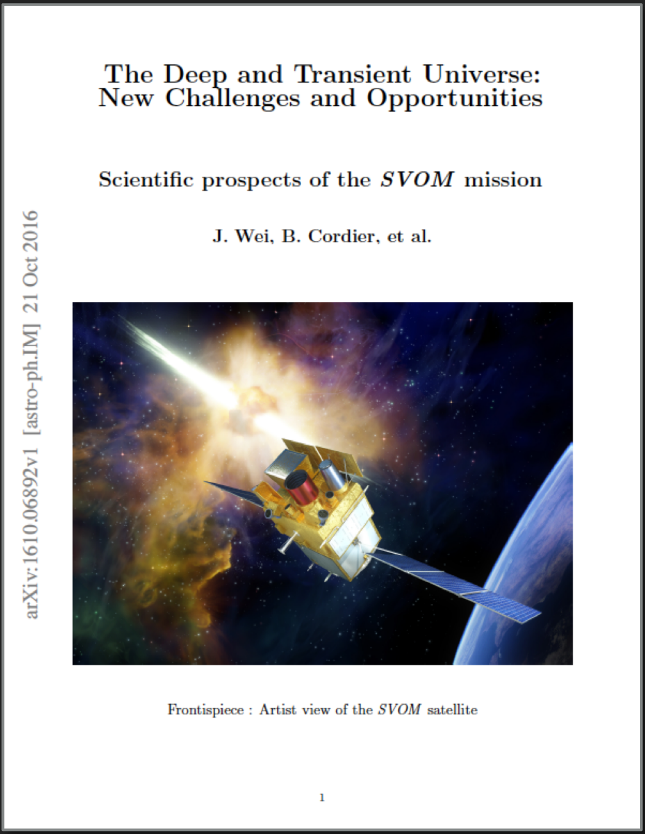
Exploration of the diversity of the GRB population.

Excellent synergy with other instruments (including Fermi+CTA, GW/ν detectors).

SVOM will be launched in early 2023 (mid-Feb): be ready!

SOME REFERENCES ON THE PERSPECTIVES FOR GRB STUDIES WITH SVOM

- Arcier, B., Atteia, J. L., Godet, O., et al. (2020) Detection of short high-energy transients in the local universe with SVOM/ECLAIRs, Astrophysics and Space Science, 365, 185
- Wang, J., Qiu, Y.-L., & Wei, J.-Y. (2020) A pilot study of catching high-z GRBs and exploring circumburst environment in the forthcoming SVOM era, Research in Astronomy and Astrophysics 20, 124
- Dagoneau, N., Schanne, S., Atteia, J.-L., Götz, D., & Cordier, B. (2020) Ultra-Long Gamma-Ray Bursts detection with SVOM/ECLAIRs, Experimental Astronomy 50, 91
- Bernardini, M. G., Xie, F., Sizun, P., et al. (2017) Scientific prospects for spectroscopy of the gamma-ray burst prompt emission with SVOM, Experimental Astronomy 44, 113
- Wei, J., Cordier, B., Antier, S., et al. (2016) The Deep and Transient Universe in the SVOM Era: New Challenges and Opportunities - Scientific prospects of the SVOM mission, arXiv e-prints arXiv:1610.06892


The Deep and Transient Universe:
New Challenges and Opportunities

Scientific prospects of the *SVOM* mission

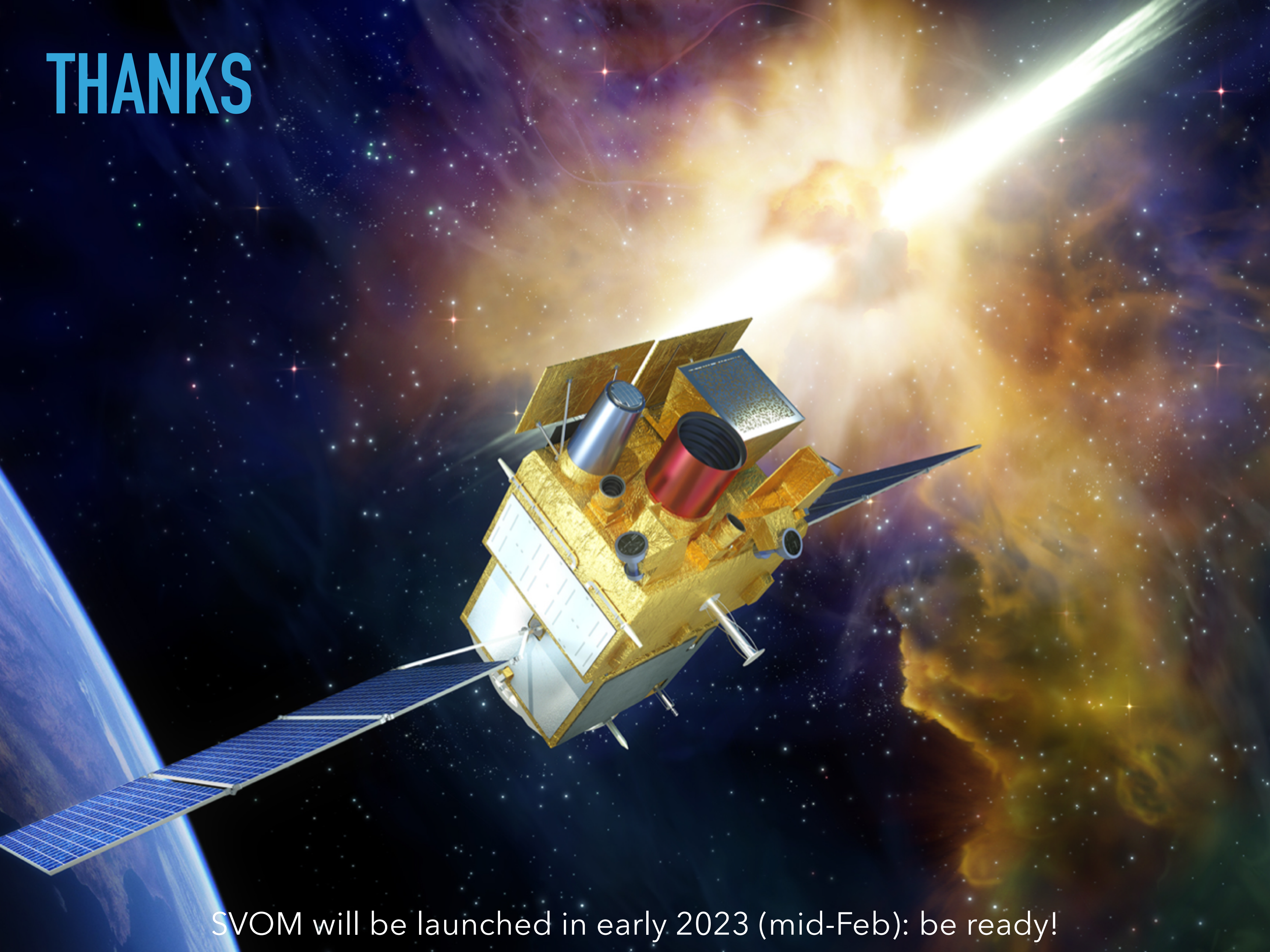
J. Wei, B. Cordier, et al.

arXiv:1610.06892v1 [astro-ph.IM] 21 Oct 2016

Frontispiece : Artist view of the *SVOM* satellite

1

THANKS



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