Gamma-ray bursts
& Electromagnetic Counterparts to Gravitational Waves

Frédéric Daigne, Institut d'Astrophysique de Paris

Focus on mergers
of stellar mass compact objects

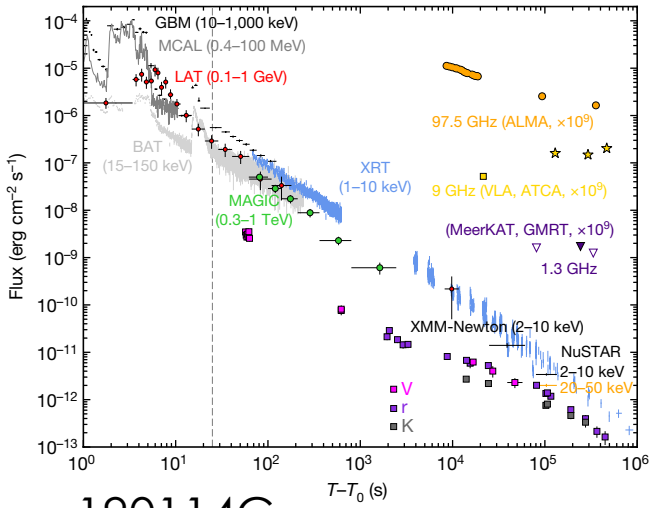
Réunion générale du PNHE – 14, 15, 16 septembre 2021

A very dynamic subject, with rapid progress:

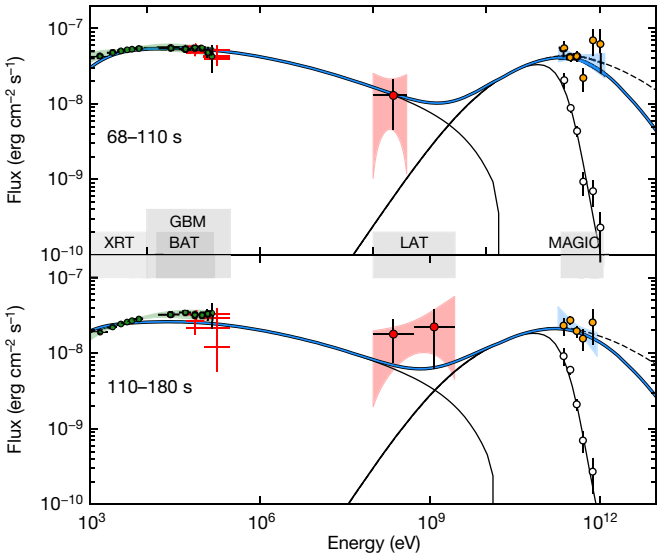
A few examples of recent observations:

- **Three GRBs recently detected at VHE (afterglow):**

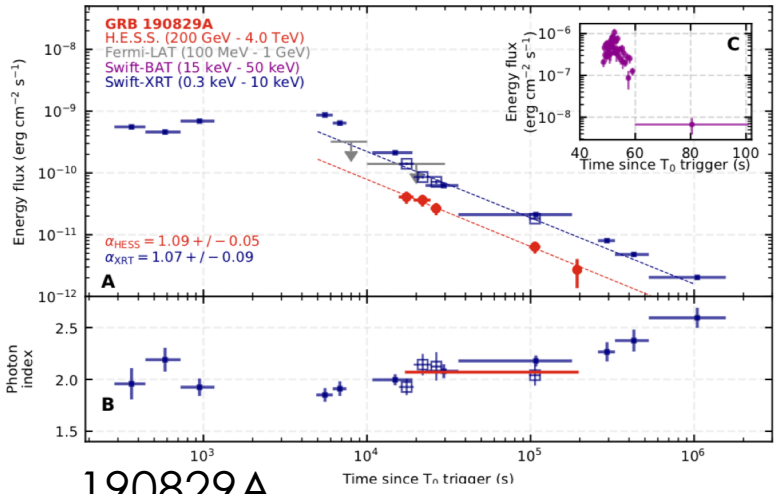
180720B (HESS)
190114C (MAGIC)
190829A (HESS)



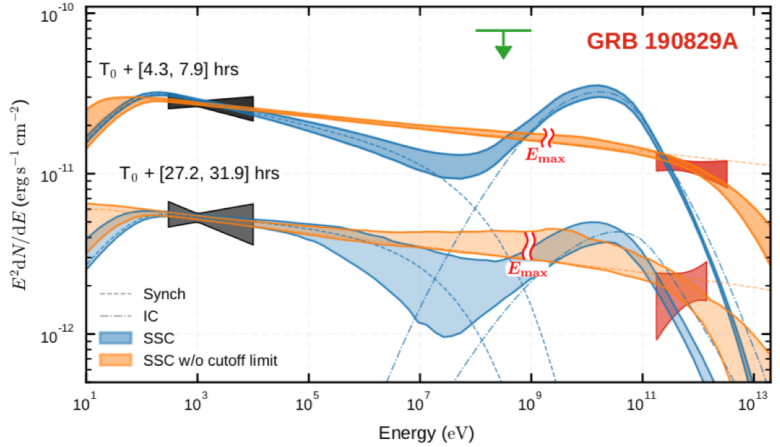
190114C



MAGIC collab.



190829A

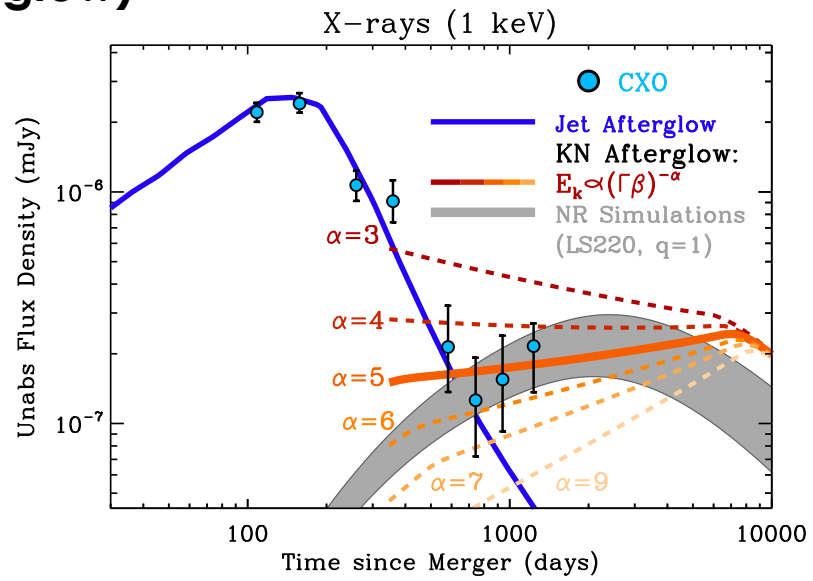


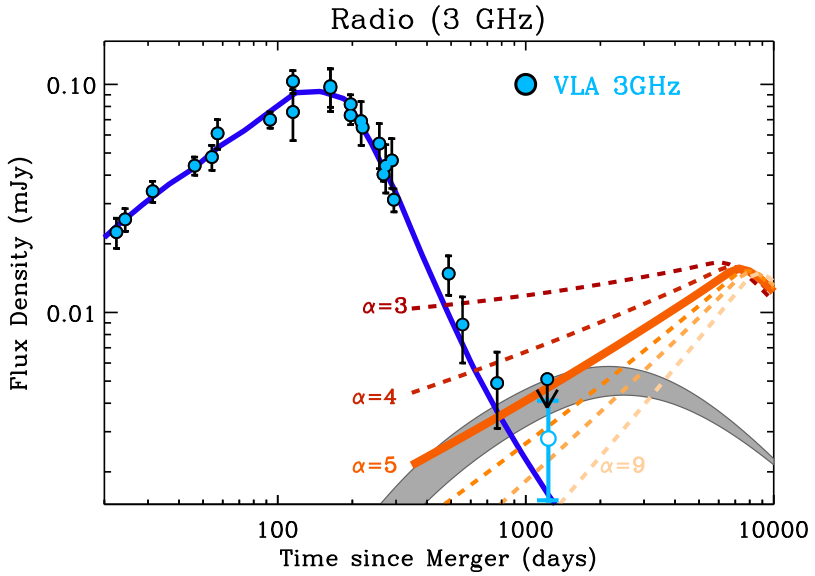
HESS collab.

A very dynamic subject, with rapid progress:

A few examples of recent observations:

- **Three GRBs recently detected at VHE (afterglow)**
- **Late observations of 170817 @ 3.5 years (KN afterglow?):**





Hajela et al. 2021

A very dynamic subject, with rapid progress:

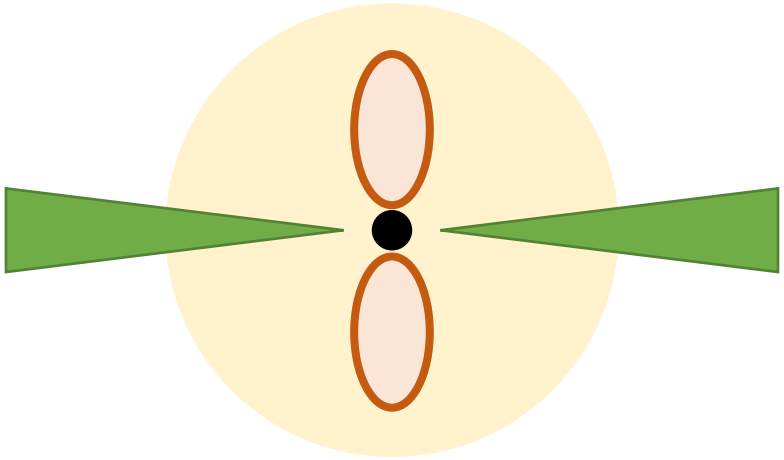
A few examples of recent observations:

- **Three GRBs recently detected at VHE (afterglow)**
- **Late observations of 170817 @ 3.5 years (KN afterglow?)**
- **Results of the LVK O3 run:**

190425 BNS
190814 NSBH? or BBH
200105 NSBH
200115 NSBH
(Ed Porter's talk)

A second BNS, at least two NSBH, but no new em counterpart.

A common physics:



Gravitational collapse
(core-collapse / merger)

Formation of a stellar mass
compact object

Non/midly-relativistic ejection
(SN, KN)

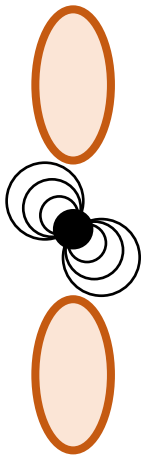
Ultra-relativistic ejection
(internal dissipation: prompt,
interaction with ext. medium: afterglow)

Particle acceleration,
non-thermal emission

Etc.

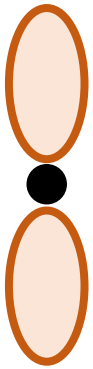
Nature of the central engine?

Accreting hypermassive NS/magnetar



OR

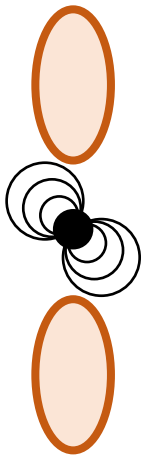
Accreting BH



OR one and then the other…

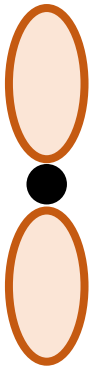
Nature of the central engine?

Accreting hypermassive NS/magnetar



OR

Accreting BH



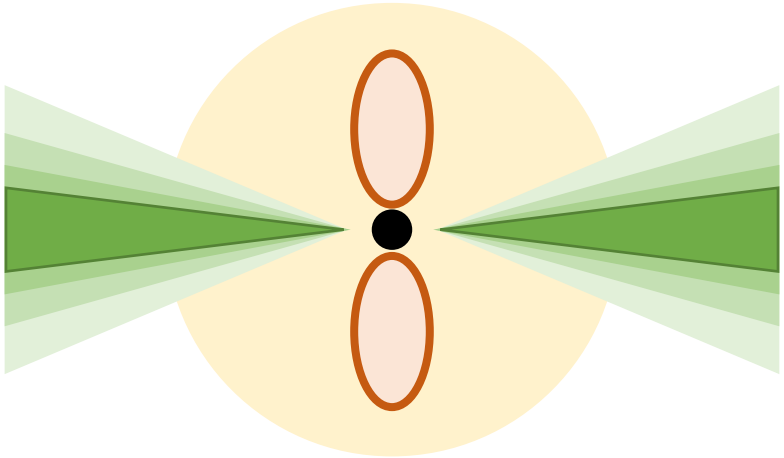
OR one and then the other…

Many questions:

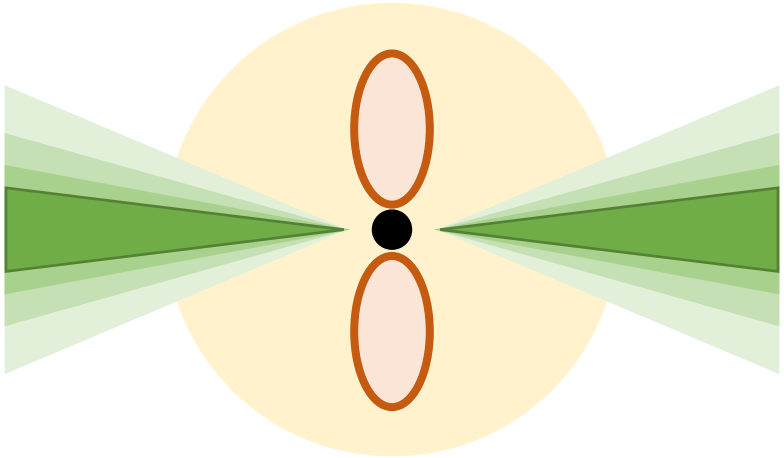
- **Extreme core-collapse:** magnetar or BH? (Jérôme Guilet's talk)
  -Numerical modelling
  -Neutrino/GW signal?

- **Mergers:** post-merger evolution?
  -Depends on several factors, including the E.O.S (Micaela Oertel's talk)
  -Indirect constraints from em (mainly KN: only one case): new observations and more modeling are needed.
  -Direct GW signal? Wait for ET? (Ed Porter's talk)

Jet launching, acceleration & early propagation:



Jet launching, acceleration & early propagation:



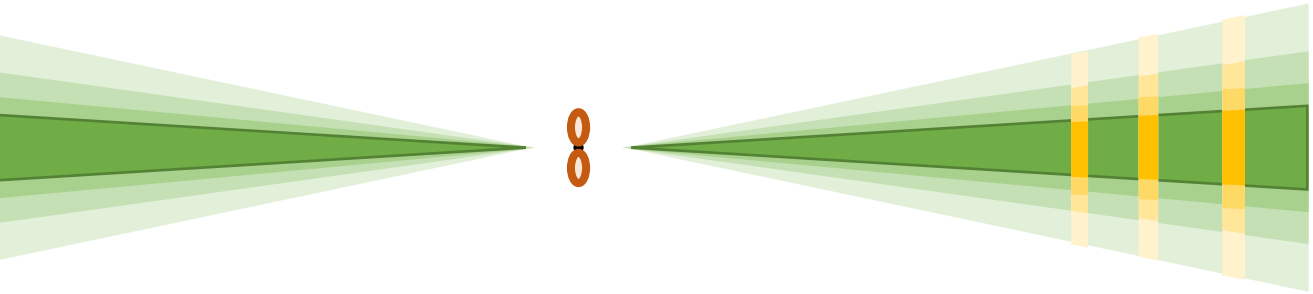
Many questions:

- 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?
  (collapsar: infalling enveloppe, merger: dynamical ejecta, neutrino wind)
  Choked/successful jets?
- Jet geometry, orientation, structure, composition?
- Etc.

- Observations: indirect from prompt & afterglow (the beautiful case of 170817)
  Needs models for the analysis.
- Numerical modelling
- Neutrino signal? (KM3net, IceCube)

(Damien Dornic's talk)

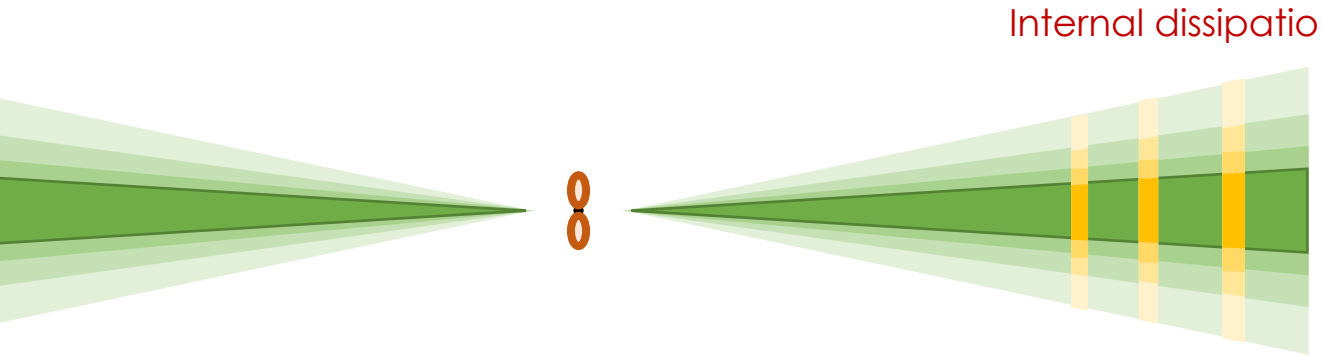
Prompt emission:



- High variability, strong spectral evolution
- Internal dissipation in the relativistic ejecta

- Shock breakout, dissipative photophere, internal shocks, reconnection, …
- Particle acceleration
- Non-thermal emission

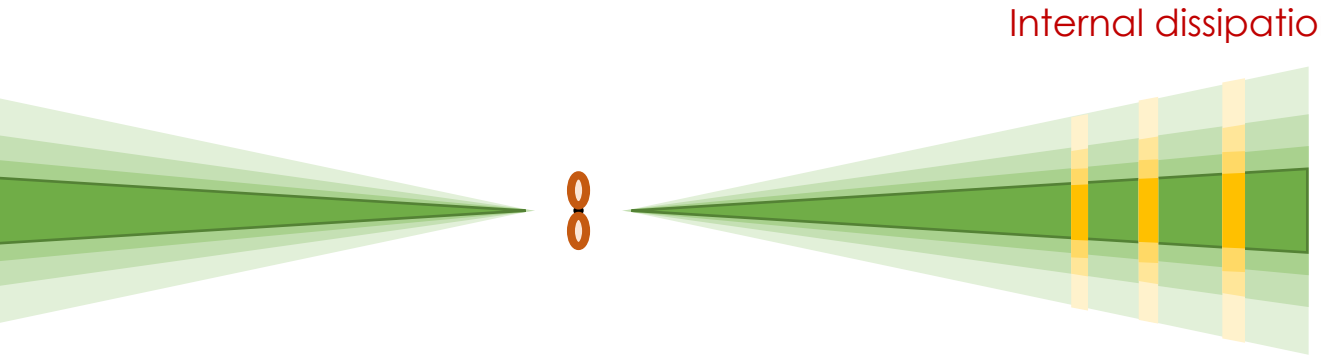
Prompt emission:



Many questions:

- Structured jet: same mechanism in the core jet and in the lateral structure?
- Role, signature of the shock breakout?
- Signatures of the different mechanisms (shocks, reconnection, …)?
- Microphysics? Acceleration of hadrons?

Prompt emission:

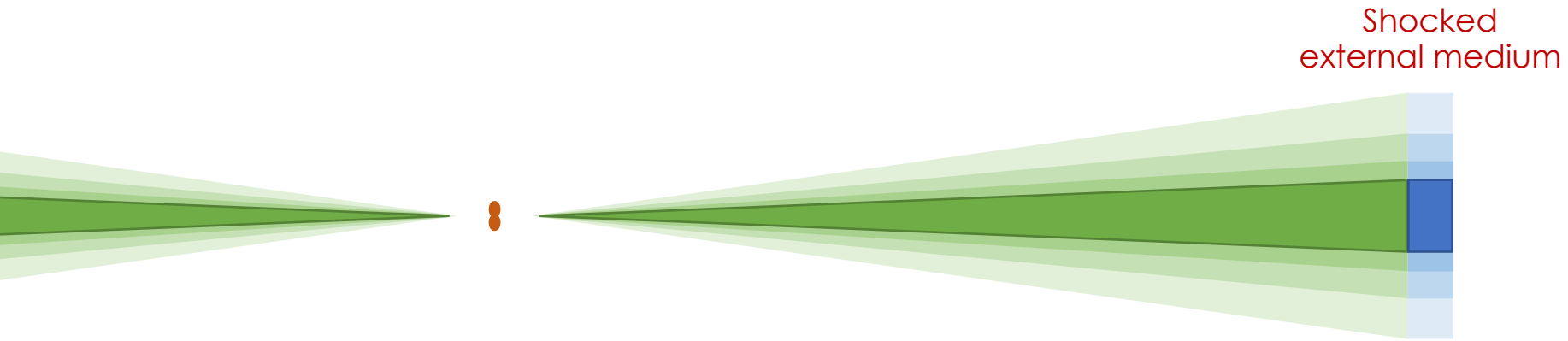


Many questions:

- Needed observations: synergy SVOM-Fermi-CTA
  - needs a good spectral coverage in gamma-rays + distance
  - prompt optical emission? (Bertrand Cordier's talk)
  - VHE prompt emission? (Luigi Tibaldo's talk)
  - neutrinos? (KM3NET, IceCube) (Damien Dornic's talk)

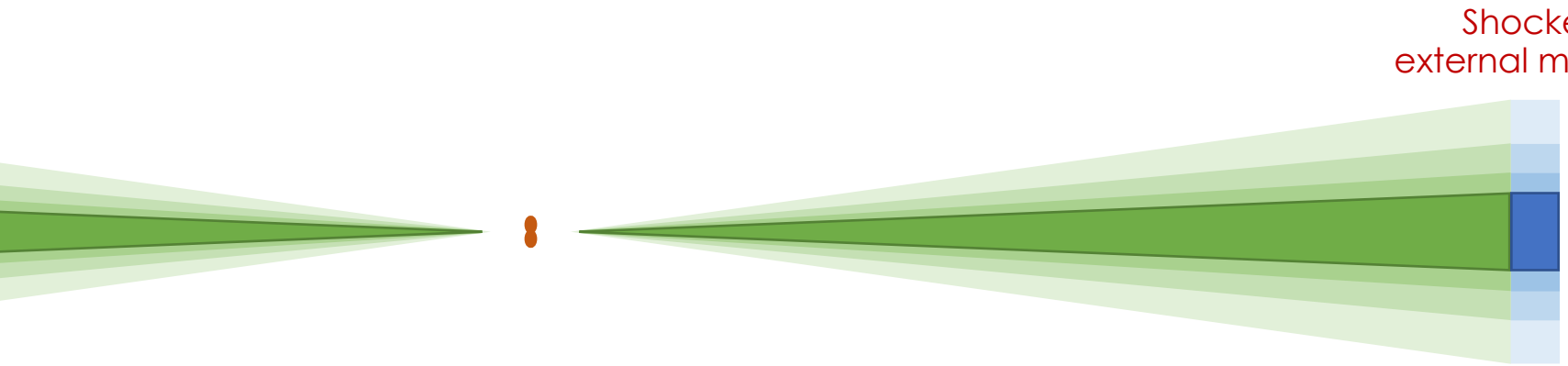
- Needed numerical simulations/models:
  - Microphysics (Benoît Cerutti's, Arno Vanthieghem's talks)
  - Dynamics
  - Time-dependent Radiative codes
  - Etc.
- Needed new tools to the data/model comparison
  (see e.g. Yassine, Piron, Daigne, Mochkovitch et al. 2020)

Afterglow:



- Long lived
- Multi-wavelength
- Less variable
- Reverse shock, Forward shock
- Again: particle acceleration, non-thermal radiation

Afterglow:

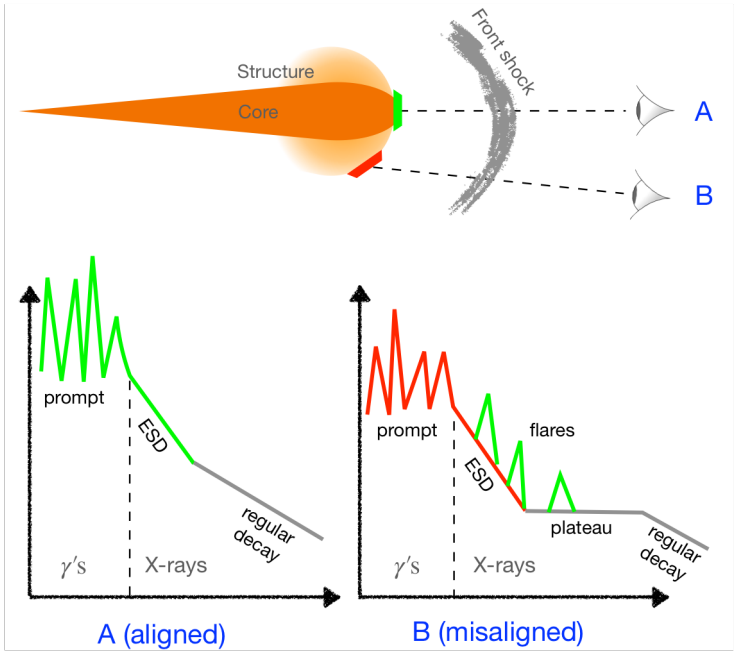


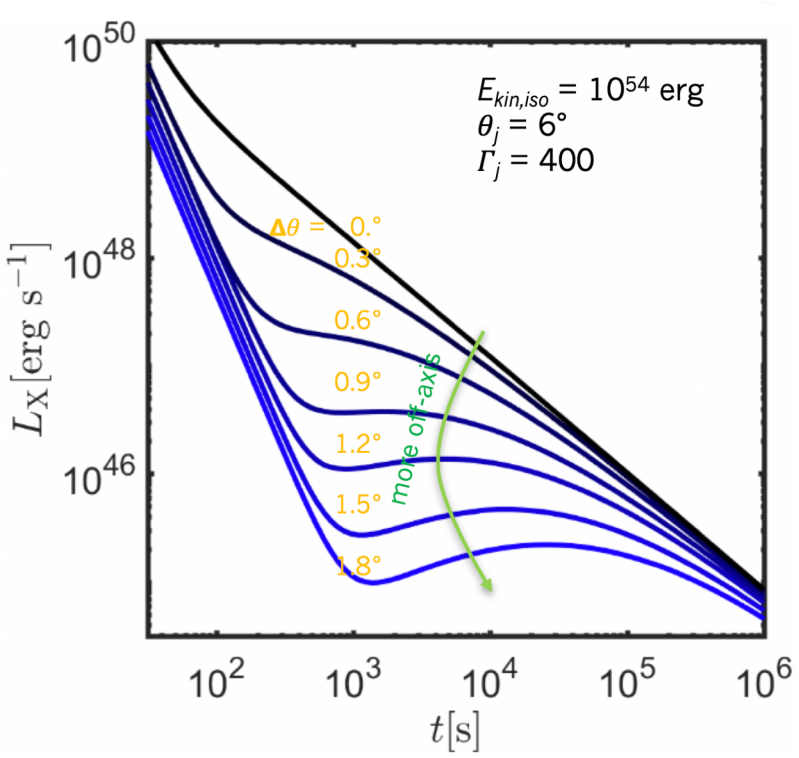
Many questions:

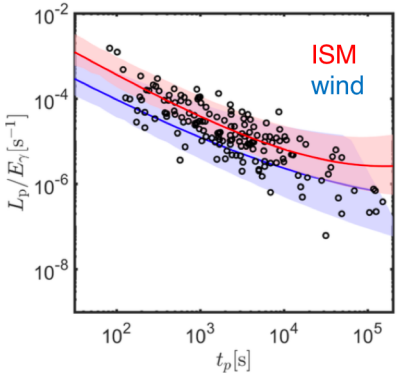
- Signature of the reverse shock? (always present?)
- Consequences of the lateral structure? (see e.g. Beniamini, Duque, Daigne & Mochkovitch 2020)
- Late evolution: lateral expansion, non-relativistic transition) (late 170817 obs.)
- Constraints on external medium?
- Microphysics, radiative processes

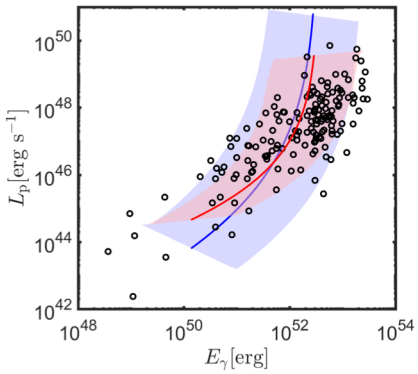
- Observations:
  - Multi-wavelength + distance (SVOM) (Bertrand Cordier's talk)
  - More VHE observations (CTA) (Luigi Tibaldo's talk)
  - More radio observations (SKA/precursors) (Stéphane Corbel's talk)
  - More GW+EM observations of mergers under different viewing angles (see e.g. Duque, Daigne & Mochkovitch 2019) (Ed Porter's, talk)
- Models/ numerical simulations (see e.g. Lamberts & Daigne 2018 ; Ayache, van Eerten & Daigne 2020)

Afterglow:







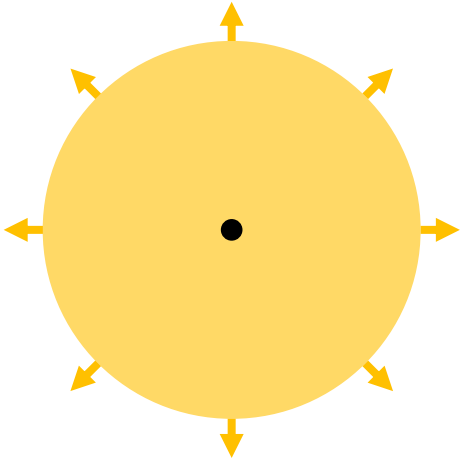


- Slightly misaligned line of sight to structured jets allows a geometrical interpretation of plateaus.
- Observed correlations arise naturally.
- Flares can be produced in the same scenario.

Beniamini, Duque, Daigne & Mochkovitch 2020 ; Duque, Beniamini, Daigne & Mochkovitch in preparation

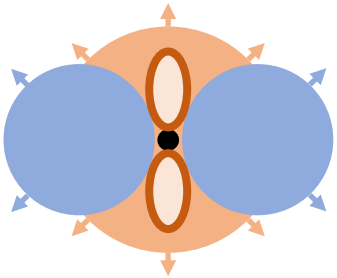
Supernova/Kilonova:

Massive stars:
Core-Collapse



Supernova

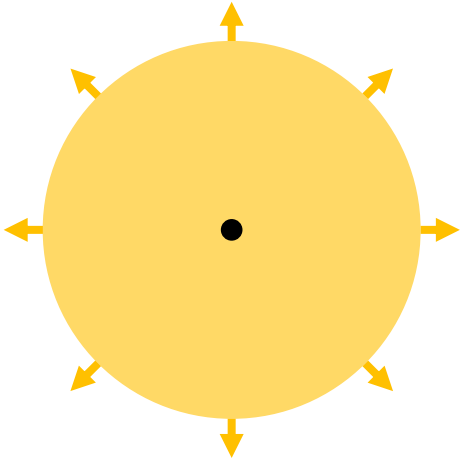
Mergers:



Red/Blue KN

Supernova/Kilonova:

Massive stars:
Core-Collapse

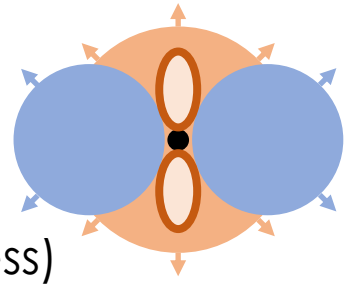


Supernova

Many questions:

- Physics of SNae associated to GRBs? (Jérôme Guilet's talk)
- Better understand the SN/GRB connection, the diversity, …

Mergers:



Red/Blue KN *(only one case!)*

Dynamical ejecta + v wind

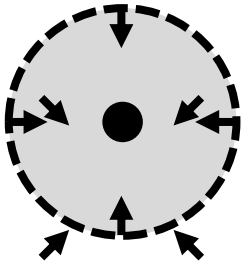
Many questions:

- Nuclear uncertainties (r process) (Jérôme Margueron's talk)
- Atomic uncertainties (opacity, lines of highly ionized heavy elements)
- Geometry of each component, v wind always present?
- Robustness of the ejected mass measurement
- Interpretation of spectra, etc.

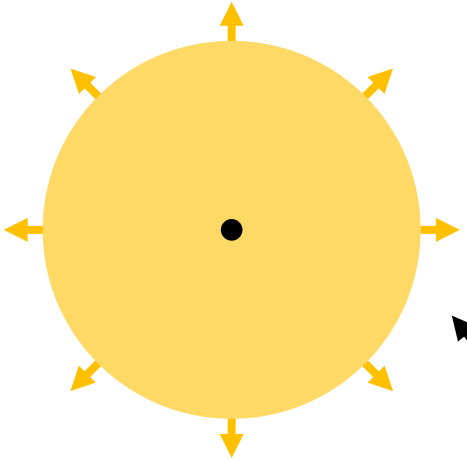
- Needs more observations + models/numerical simulations…
  (see e.g. Mochkovitch, Daigne, Duque & Zitouni 2021)

Progenitors?

Massive stars: Core-Collapse



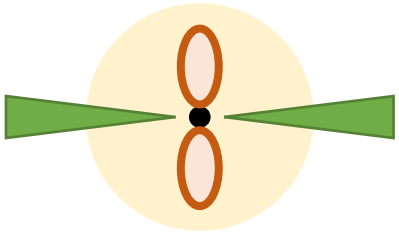
Mass? Metallicity? Rotation? Binarity?



Supernova

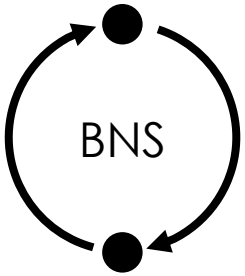
AND/OR

Continuum of events?
Low-L GRBs, XRFs, XRRs, etc.



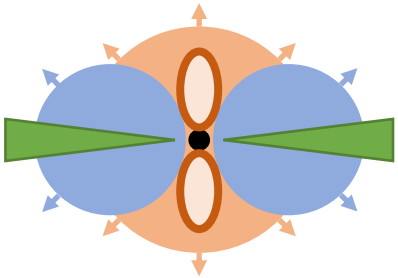
Long GRB (with or w/o SN?)

Mergers:

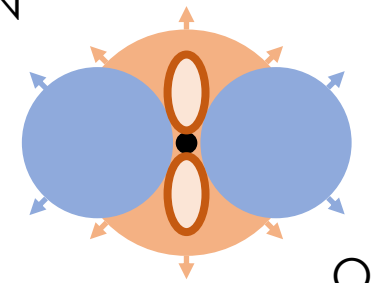


BNS

Red/Blue KN

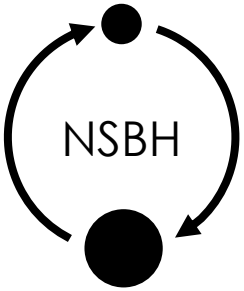


OR

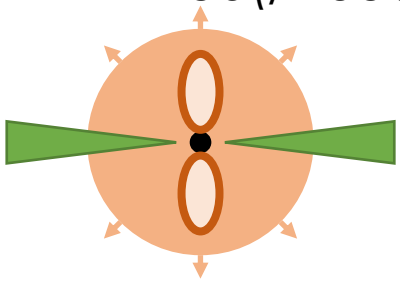


OR?

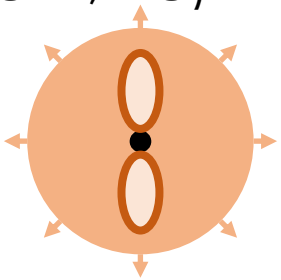
Red(/Blue?) KN + Jet? (GRB, AG)



NSBH



OR



Or nothing for a large mass ratio… (« just GW »)

Progenitors?

- Need more observations of individual events to explore the diversity
  SVOM (Bertrand Cordier's talk)
  GW+EM BNS/NSBH (Ed Porter's talk)
  LSST (Anais Möller's talk)

- Host galaxies

- Population models
  (Long GRBs: see e.g. Palmerio & Daigne 2021 ; BNS: see e.g. Duque, Beniamini, Daigne & Mochkovitch 2020)

- Indirect constraints (e.g. chemical evolution, bkgs, …) (I. Dvorkin's talk)
  (see e.g. Dvorkin, Daigne, Goriely, Vangioni& Silk 2021)

- Important not only for understanding the physics of these phenomena, but also for other applications
  (e.g. constraining the cosmic star formation rate,
  constraing the stellar evolution in binaries, etc.)

A common challenge: rapid follow-up on alert

- GRB/merger studies need the best multi-λ/multi-messenger coverage
- Many important signatures are short duration and happen very early.

- Many challenges:
  - Initial alert: localization
  - Accurate initial localisation: rapid follow-up at all wavelength (especially challenging for the late prompt/early afterglow emission)
  - Large error boxes: very challenging
    detection of candidates, classification, identification, …
    Needs photometric + spectroscopic follow-up.
  - Etc.

- **How prepared is the French community for this challenge?**
  See talks by
  Bertrand Cordier (SVOM),
  Pierre Duverne (FINK, GRANDMA),
  Sarah Antier (TS2020+, SNO « alertes » ?),
  Chiara Caprini (GDR GW) ,
  and probably the discussion led by Susanna Vergani on MMA…

Thanks!

Comments? Questions?