Complex Multi-flares of GRB 250129A
Evidence of Successive Shock Interactions

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GRB 250129A - Diversity of the Team

Joint Project between GRANDMA and COLIBRI

- **Coordinators GRANDMA**: M. Pillas / **Coordinator COLIBRI** : N. Globus
- **Paper Writing Team (Main Contributors)**: D. Akl (lead); Supervised by S. Antier
- **Observations (17 Telescopes)**: GRANDMA + COLIBRI
- **Gamma-ray Prompt Swift**: Z. Wang
- **X-ray Data Reduction**: M. Molham, M. Pereyra
- **Optical Data Reduction**: D. Akl, S. Antier, S. Karpov, A. Klotz, with help of A. Watson
- **Line of Sight Extinction**: N. Rakotondrainibe
- **Galaxy Investigation**: R. Becerra
- **Empirical Fitting**: R. Strausbaugh, J. Mao
- **Afterglow Agnostic Injection**: P. Pang, H. Koehn

Lots of other contributors !

GRB 250129A - Prompt

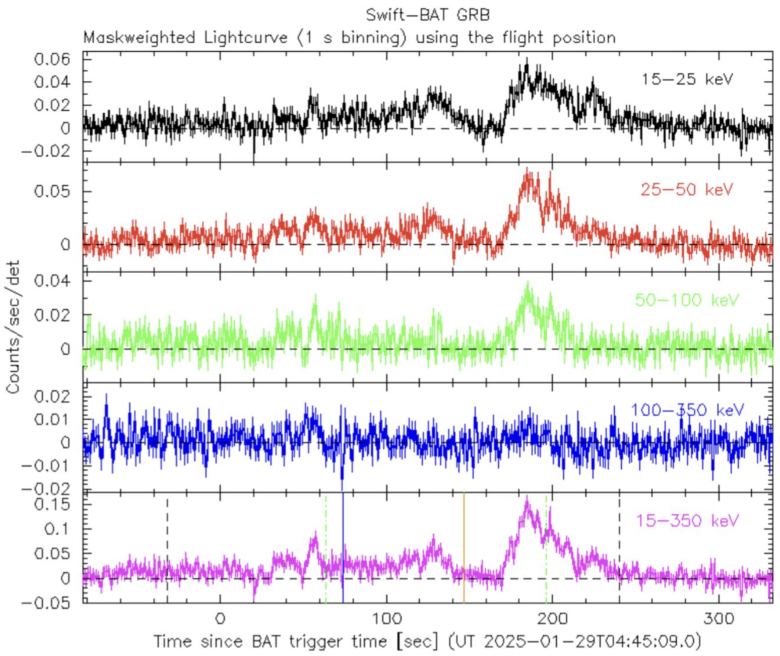


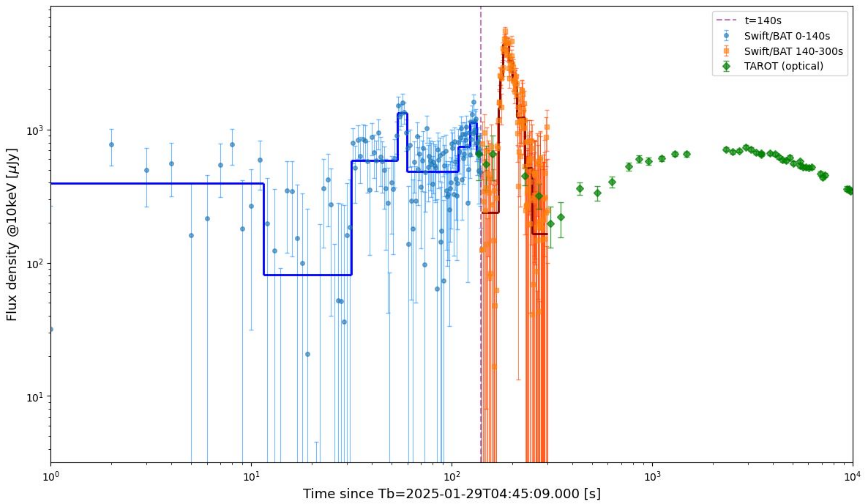
Fig. 1. *Swift*–BAT mask-weighted light curves (1-s bins) for GRB 250129A in the standard BAT energy bands.

Detected 2025-01-29 04:45:09 UTC

Classified as a LGRB

T90 = 262.25 ± 23.71 seconds in 15-350 keV

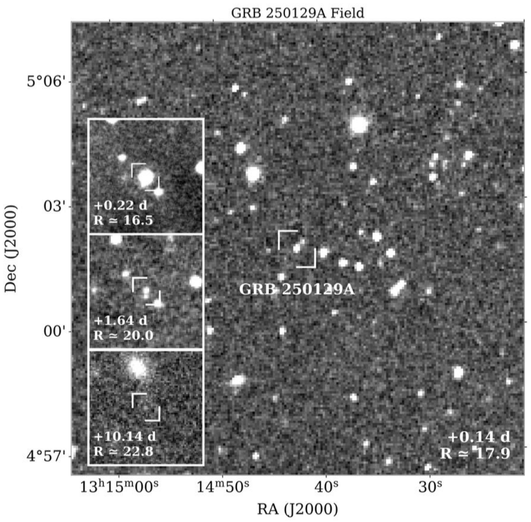
+ Konus-Wind



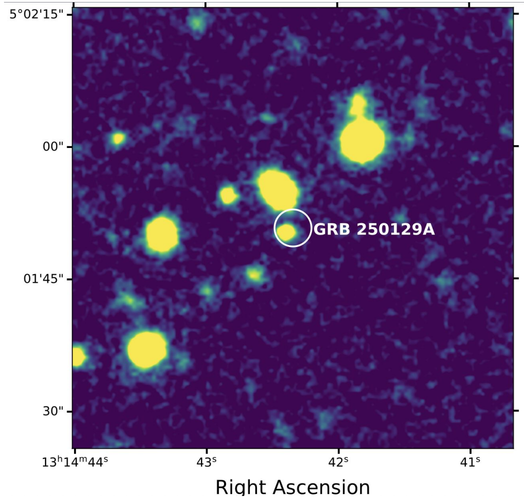
R-band and X-ray (15-350 keV)

X-ray / Optical Counterparts

TAROT
T+0.14d



COLIBRI
DDRAGO
T+6.0d

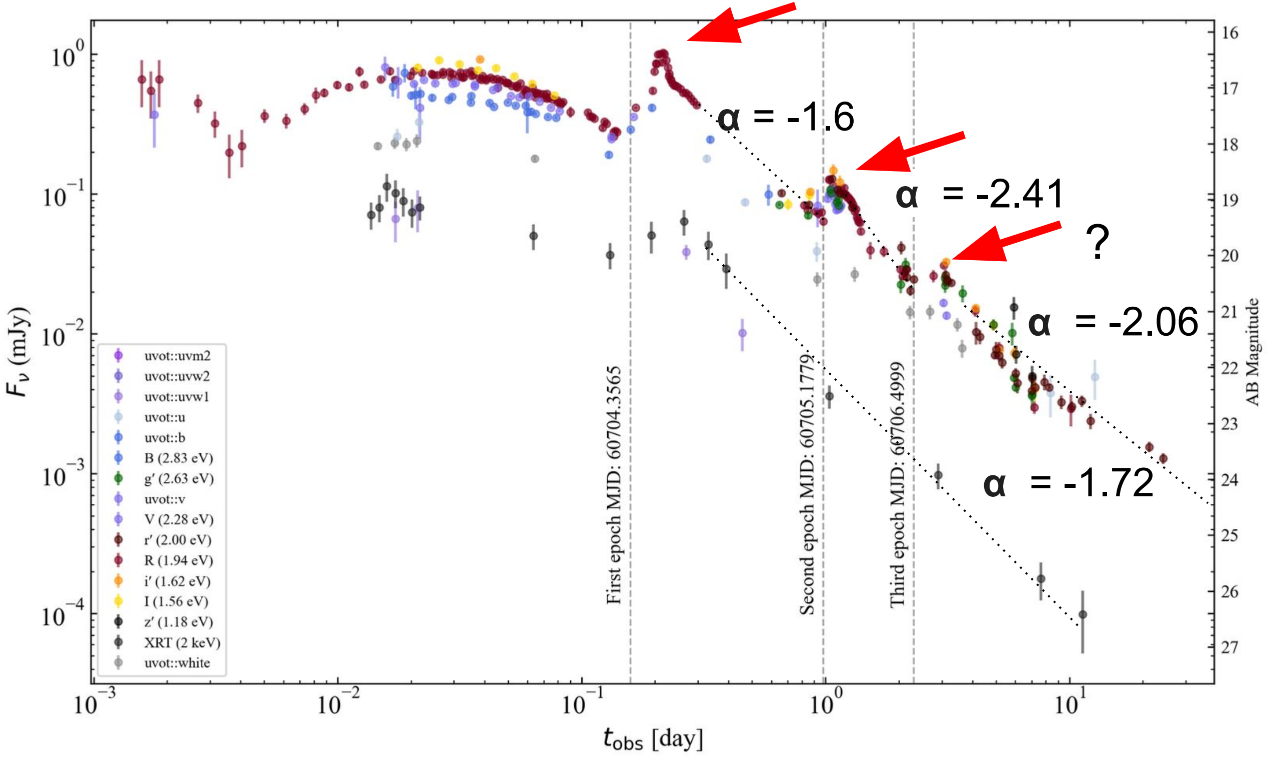


X-ray and optical counterparts were found.
Redshift of z = 2.151

Observed by 18 instruments :

- AbAO T-70
- ARTEMIS
- SPECULOOS
- Colibri
- C2PU
- Euler
- FRAM-Auger
- KAO
- KAIT
- MISTRAL
- NAO-2m
- OPD-0.6m
- Pic du Midi 1-m
- Skynet
- TAROT-TCA
- TAROT-TCH
- TNOT
- YAHPT/AST3-3.

GRB 250129A UVOIR Lightcurve



Observations Over 24 days revealed:

Multiple Rebrightening Episodes in the Optical and the X-ray

1. Very fast optical brightening at ~5 hr post-T0.
2. Second ~1 day post T0
3. Third ~3 d post T0

Environments

Line of Sight

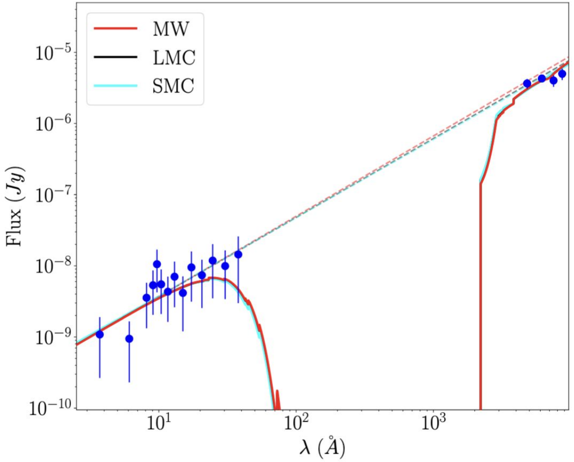


Fig. 5. X-ray-to-optical SED of GRB 250129A at t - t_0 ~ 7.04 days using the MW (red), LMC (black), and SMC (cyan) extinction curves. **Dashed lines**: intrinsic simple power law model of the afterglow. **Solid lines**: Best fits to the data, including the X-ray absorption and the optical extinction.

E (B-V) =0.05 (+0.12 −0.03) mag
Compatible with no host galaxy extinction

Host Galaxy

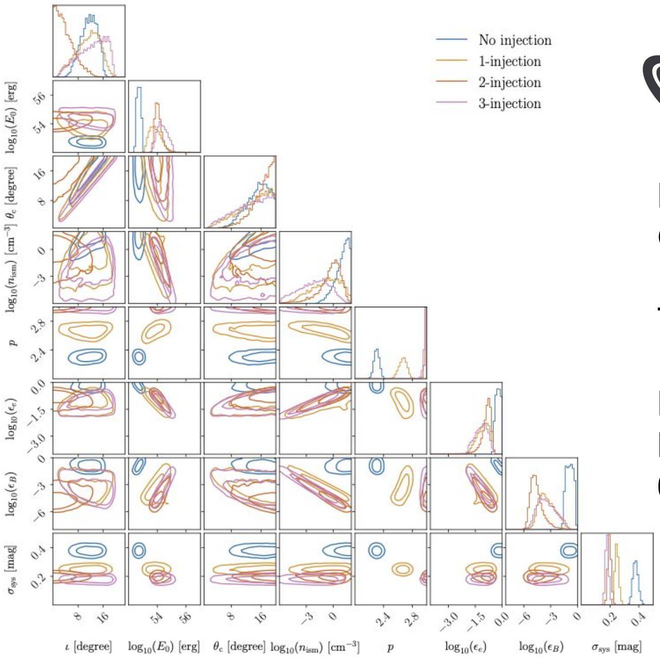
Table 2. Galaxies in the neighbourhood of GRB 250129A. Is described for each galaxy: label (see text), redshift (z), magnitude in m_r, the projected angular separation R_0 between the GRB and the galaxy, the offset, and the probabilities of chance alignment $P_{ch}(< R_0)$.The asterisk in the photometric value indicates that it is a photometric redshift.

	z	m_r	R_0 [″]	Offset [kpc]	$P_{ch}(< R_0)$
G1	0.42	20.30 ± 0.05	4.48	49.99	2.08
G2	0.26	21.00 ± 0.10	14.82	94.66	29.10
G3	0.69*	23.10	6.85	139.03	36.20
G4	0.64*	22.64	7.85	145.32	32.62

No Host Galaxy

First Scenario – Agnostique Energy Injection

- **Prolonged central-engine activity / slower shells with lower Lorentz factors continue to deposit energy into the FS.**
- Late-time addition of energy temporarily enhances the afterglow emission, producing plateaus or rebrightenings



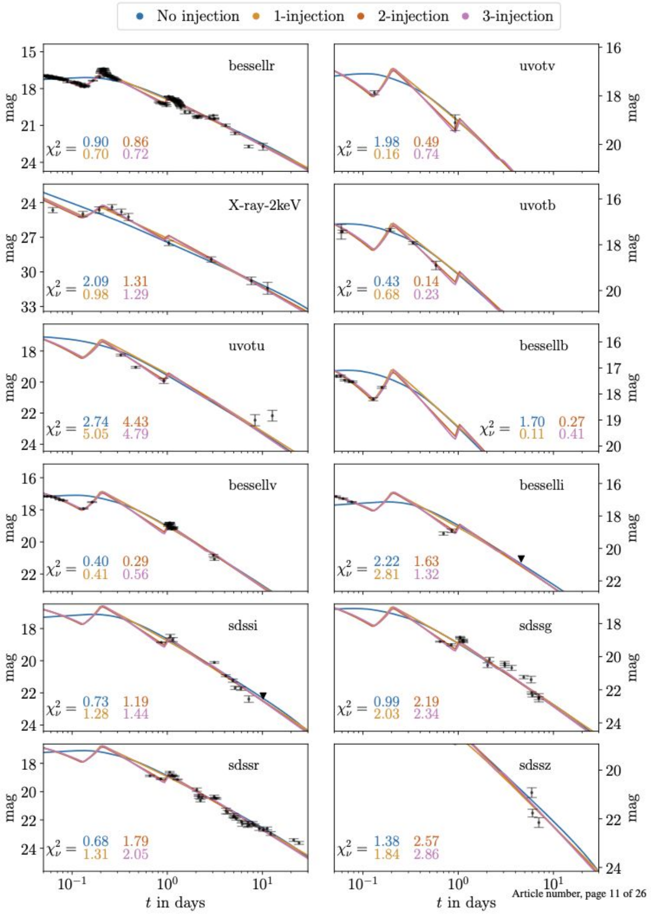
NMMA

Posterior of the GRB afterglow

Top-hat jet model

Prior z, Baseline 0.05 to 0.2 days

Best-fit LC of the GRB afterglow, together with the reduced $\chi2$ of each filter, for each model considered.



Parameters Employed in Bayesian inferences

- **Can reproduce each rebrightening shape individually:** consistency between model and data for each individual rebrightening

- **Derived physical parameters become inconsistent between the injections** (across the different epochs)

Parameter	No injection	1-injection	2-injection	3-injection
($\log_{10}$-) On-axis isotropic equivalent energy E_0 [erg]	$52.53^{+0.43}_{-0.02}$	$53.72^{+0.95}_{-0.58}$	$53.85^{+0.80}_{-0.18}$	$54.12^{+0.93}_{-0.36}$
($\log_{10}$-) Ambient medium's density $n_{\rm ISM}$ [cm^{-3}]	$-0.31^{+2.3}_{-0.22}$	$-0.32^{+2.32}_{-3.45}$	$0.82^{+0.81}_{-3.8}$	$-0.84^{+1.53}_{-4.65}$
($\log_{10}$-) Energy fraction in electrons ϵ_e	$-0.01^{+-0.0}_{-0.44}$	$-0.93^{+0.45}_{-0.84}$	$-0.61^{+0.14}_{-0.81}$	$-0.89^{+0.29}_{-0.96}$
($\log_{10}$-) Energy fraction in magnetic field ϵ_B	$-1.86^{+1.66}_{-0.35}$	$-3.71^{+2.21}_{-1.23}$	$-5.26^{+2.31}_{-0.48}$	$-4.25^{+2.78}_{-0.9}$
Electron distribution power-law index p	$2.29^{+0.09}_{-0.06}$	$2.68^{+0.09}_{-0.12}$	$3.00^{+0.00}_{-0.03}$	$3.00^{+0.00}_{-0.06}$
Viewing angle [degree]	$7.15^{+8.85}_{-0.5}$	$13.44^{+3.99}_{-9.94}$	$0.13^{+9.61}_{-0.13}$	$14.79^{+4.38}_{-10.59}$
Jet core opening angle $\theta_{\rm core}$ [degree]	$9.75^{+10.25}_{-0.2}$	$16.62^{+3.38}_{-10.76}$	$16.66^{+3.34}_{-5.88}$	$15.93^{+4.07}_{-10.92}$
Time of 1$^{\rm st}$ energy injection $t_{\rm inj,1}$ [day]	-	$0.128^{+0.021}_{-0.015}$	$0.126^{+0.012}_{-0.015}$	$0.129^{+0.011}_{-0.013}$
Duration of 1$^{\rm st}$ energy injection $\Delta t_{\rm inj,1}$ [day]	-	$0.070^{+0.024}_{-0.033}$	$0.075^{+0.019}_{-0.021}$	$0.075^{+0.014}_{-0.018}$
($\log_{10}$-) 1$^{\rm st}$ Fractional energy injected $\Delta \log E_{0,1}$	-	$0.51^{+0.057}_{-0.065}$	$0.512^{+0.059}_{-0.039}$	$0.515^{+0.059}_{-0.033}$
Time of 2$^{\rm nd}$ energy injection $t_{\rm inj,2}$ [day]	-	-	$0.974^{+0.031}_{-0.077}$	$0.926^{+0.074}_{-0.042}$
Duration of 2$^{\rm nd}$ energy injection $\Delta t_{\rm inj,2}$ [day]	-	-	$0.007^{+0.102}_{-0.006}$	$0.083^{+0.037}_{-0.082}$
($\log_{10}$-) 2$^{\rm nd}$ Fractional energy injected $\Delta \log E_{0,2}$	-	-	$0.166^{+0.008}_{-0.043}$	$0.204^{+0.013}_{-0.034}$
Time of 3$^{\rm rd}$ energy injection $t_{\rm inj,3}$ [day]	-	-	-	$2.55^{+0.301}_{-0.05}$
Duration of 3$^{\rm rd}$ energy injection $\Delta t_{\rm inj,3}$ [day]	-	-	-	$0.282^{+0.294}_{-0.281}$
($\log_{10}$-) 3$^{\rm rd}$ Fractional energy injected $\Delta \log E_{0,3}$	-	-	-	$0.053^{+0.02}_{-0.044}$
Systematic error $\sigma_{\rm sys}$ [mag]	$0.38^{+0.03}_{-0.04}$	$0.24^{+0.03}_{-0.02}$	$0.19^{+0.03}_{-0.01}$	$0.17^{+0.03}_{-0.01}$
(ln-) likelihood ratio $\ln \Lambda$	reference	87.17	128.52	144.15
(ln-) Bayes factor $\ln \mathcal{B}$	reference	78.88 ± 0.22	110.44 ± 0.24	116.95 ± 0.25

+30 +6

Conclusion: The two re-brightenings (T-at 0.12d, 0.5d) are statistically real

The 3rd one (at 2.55d) is less convincing

Origin of the rebrightenings: Refreshed Shocks Shell Collisions

- Multiple shells with different Lorentz factors were ejected during the prompt.
- Outer shell decelerates → later, faster shells catch up → collisions inject energy.
- Each collision launches new FS + RS leading to → rebrightenings.

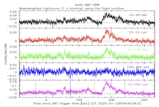


Fig. 1. *Swift*–BAT mask-weighted light curves (1-s bins) for GRB 250129A in the standard BAT energy bands.

Findings: Collision timings naturally match the three optical peaks

Numerical FS/RS modeling successfully fits: X-ray + optical light curves, rise/decay timescales, peak luminosities

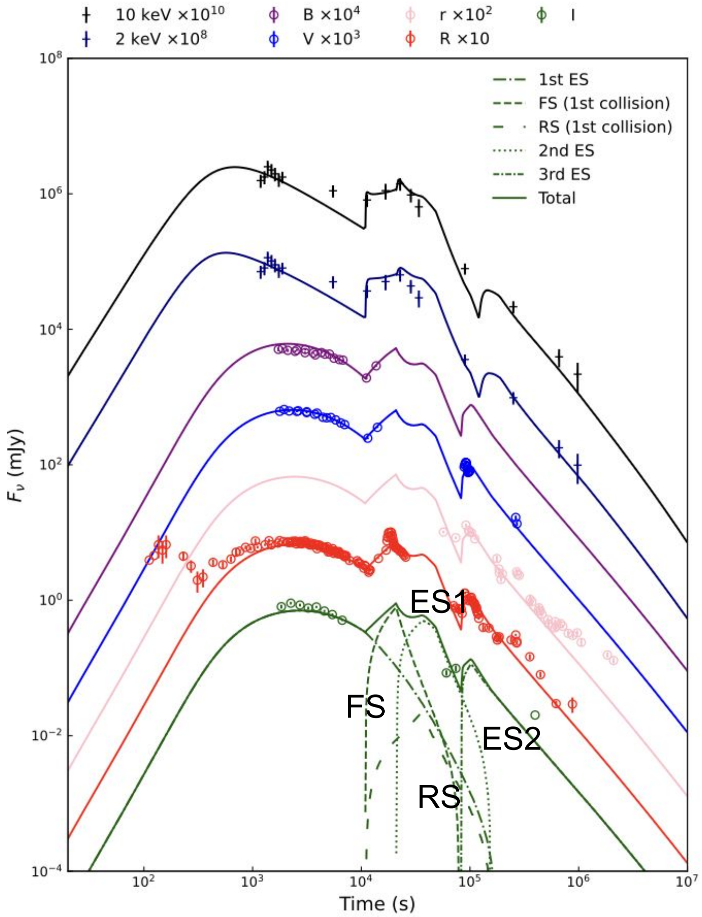
Fully consistent with fireball dynamics – Parameters are not fitting – We are taking resonabling values, consistent with table 4?

Parameters	First Shell	Second Shell	Third Shell	First Collision			Second Collision		
				FS	RS*	ES	FS	RS*	ES
$E_{\mathrm{k,iso}}$ (10^{53} erg)	$1.70^{+0.12}_{-0.11}$	10.0	8.0						
Γ_0	$97.72^{+2.28}_{-4.40}$	39.0	24.5						
θ_{j} (rad)			$0.10^{+0.02}_{-0.02}$						
n_{ISM} (cm^{-3})			$1.05^{+0.27}_{-0.16}$						
ϵ_{e}	$0.09^{+0.01}_{-0.00}$			0.18	0.10	0.11	0.10	0.10	0.12
ϵ_{B} (10^{-3})	$2.51^{+0.31}_{-0.32}$			10.0	10.0	2.0	10.0	10.0	2.0
p	$2.07^{+0.00}_{-0.00}$			2.3	2.3	2.3	2.3	2.3	2.4

Second Scenario: Refreshed Shocks Shell Collisions

- **Dash-dotted line** → emission of the external shock (ES) for the first outflow.
- **Dashed and loosely dashed line** → emission from the forward shock (FS) and the reverse shock (RS) during the collision,
- **Dotted line** → emission of the newly formed (second) ES after the shell merging, which is refreshed again to produce the third ES (**densely dashed-dotted lines**) by the second collision near 1 day.
- The total flux from all emission components is given by the **solid line** for each band.

Refreshed Shocks Shell Collisions is a plausible explanation



Stage of the paper

Before 11.12

Finalizing the cohrence on the various sections

Discussion needs to be finalized

Prompt emission physical parameters

Before 18.12

International reviews done

Before 28.12

Comments from collaborators

Questions ?