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Modeling the Afterglow of GRB 221009A: Constraints from MeV-GeV-TeV Data

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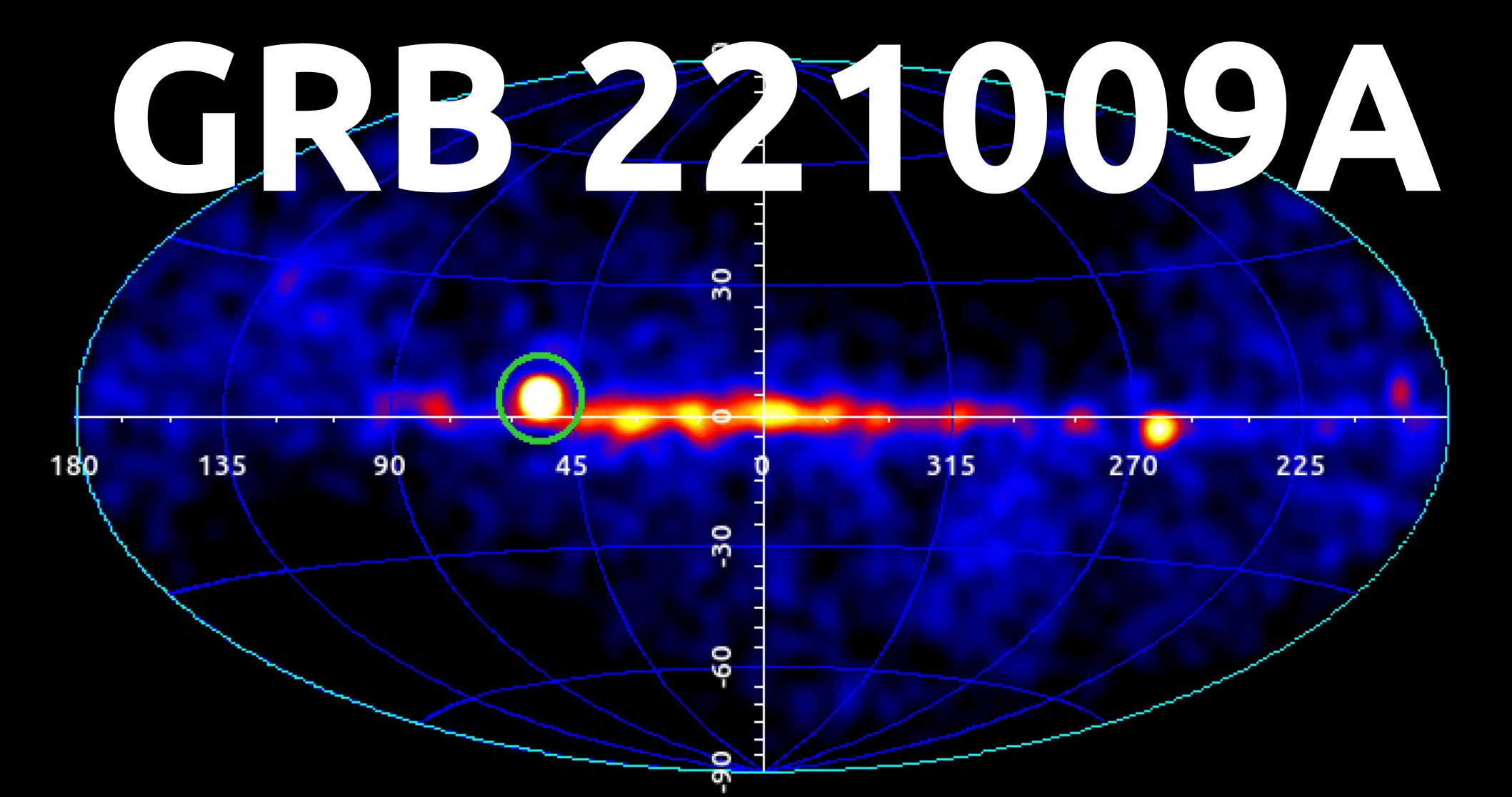
Overview

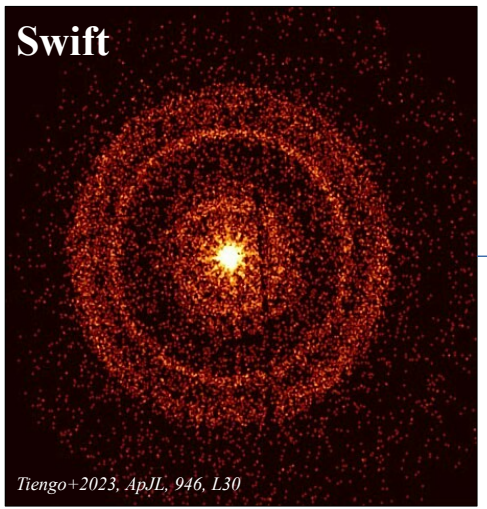
1. Datasets
2. Model
3. Results

GRB 221009A



AGILE gamma-ray sky during the GRB 221009A event

GRB 221009A: Extraordinary and Complex



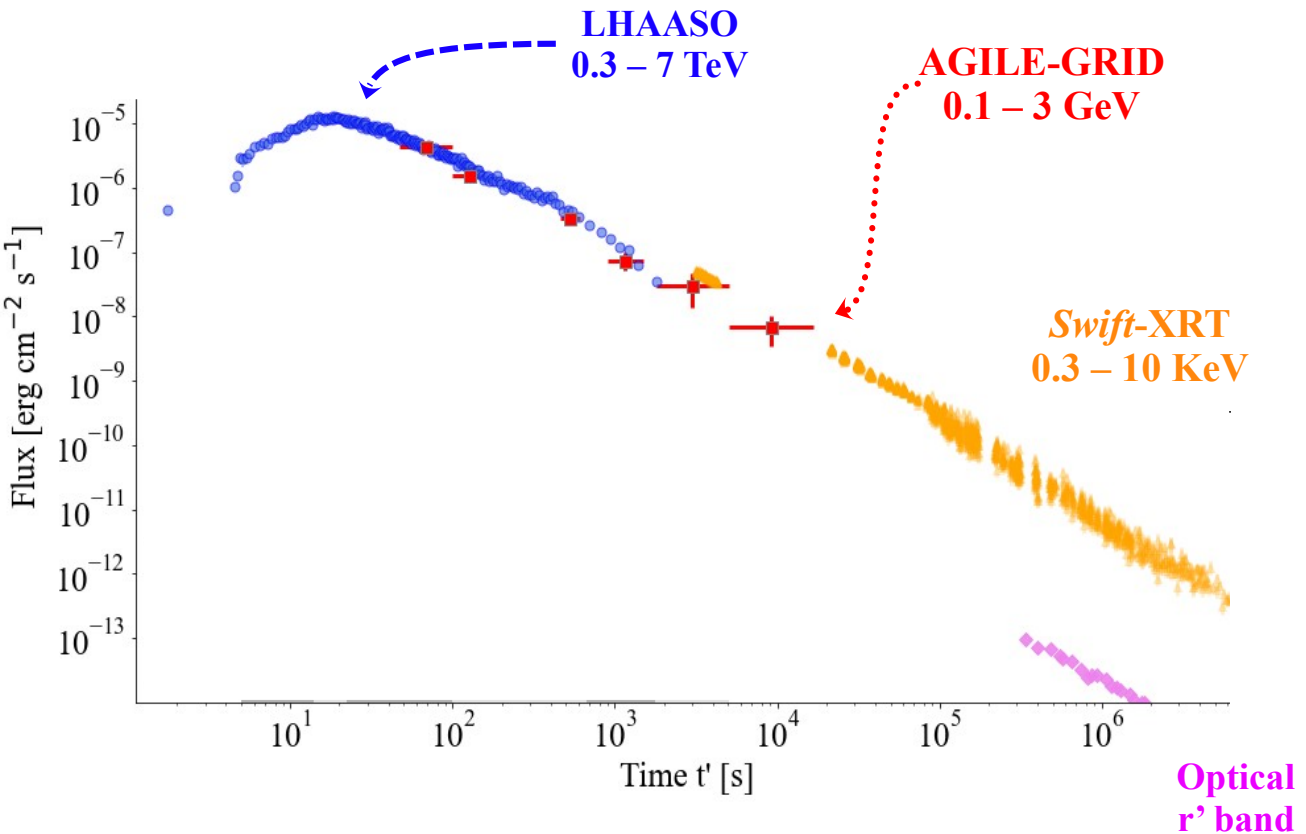
Challenge

Provide a **global fit** of all the spectral and flux data over a long-lasting event, not trivial for any standard GRB model in the case of GRB 221009A

Results

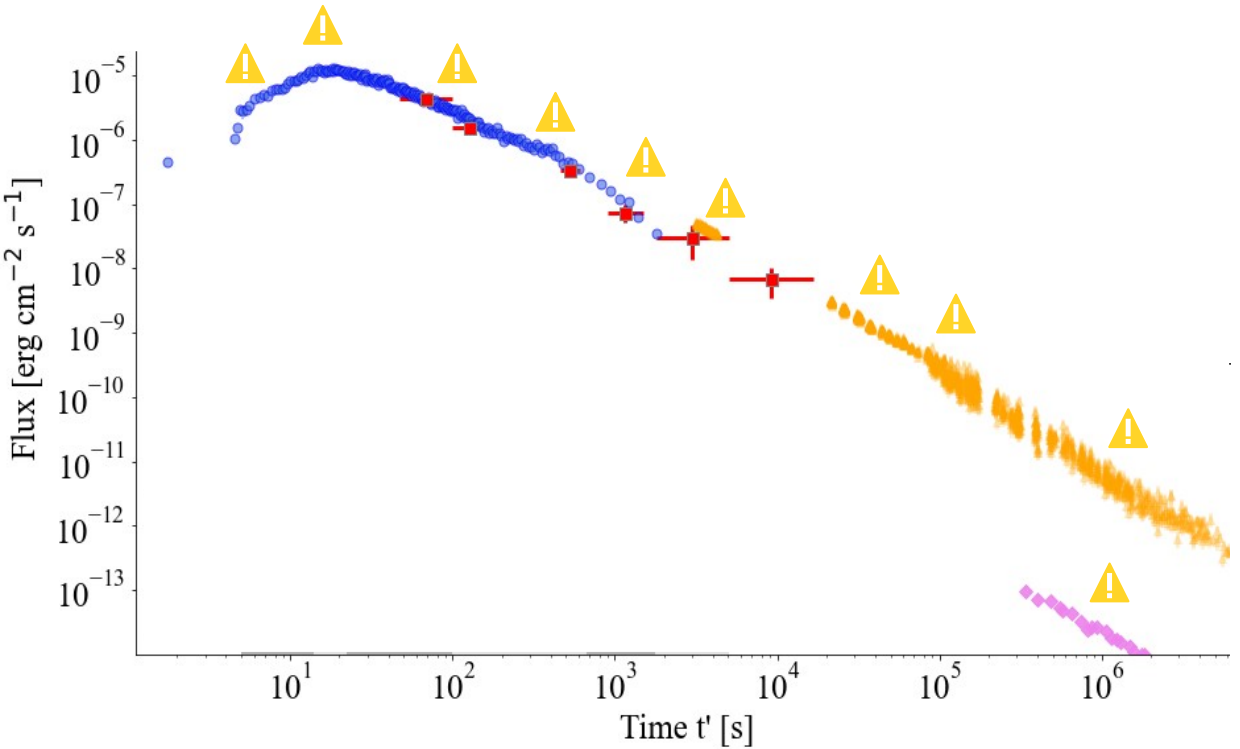
1) **Comprehensive interpretation** of GRB 221009A from very early to late times 10^6 s, describing most of the intensity and spectral features characterizing the real data
2) Interpretation within the **relativistic fireball** framework, with a fully adiabatic hydrodynamic evolution in a homogeneous external medium
3) **Time-evolving microphysical quantities**

Light curves of GRB 221009A



Time T' = T_0 + 226 s

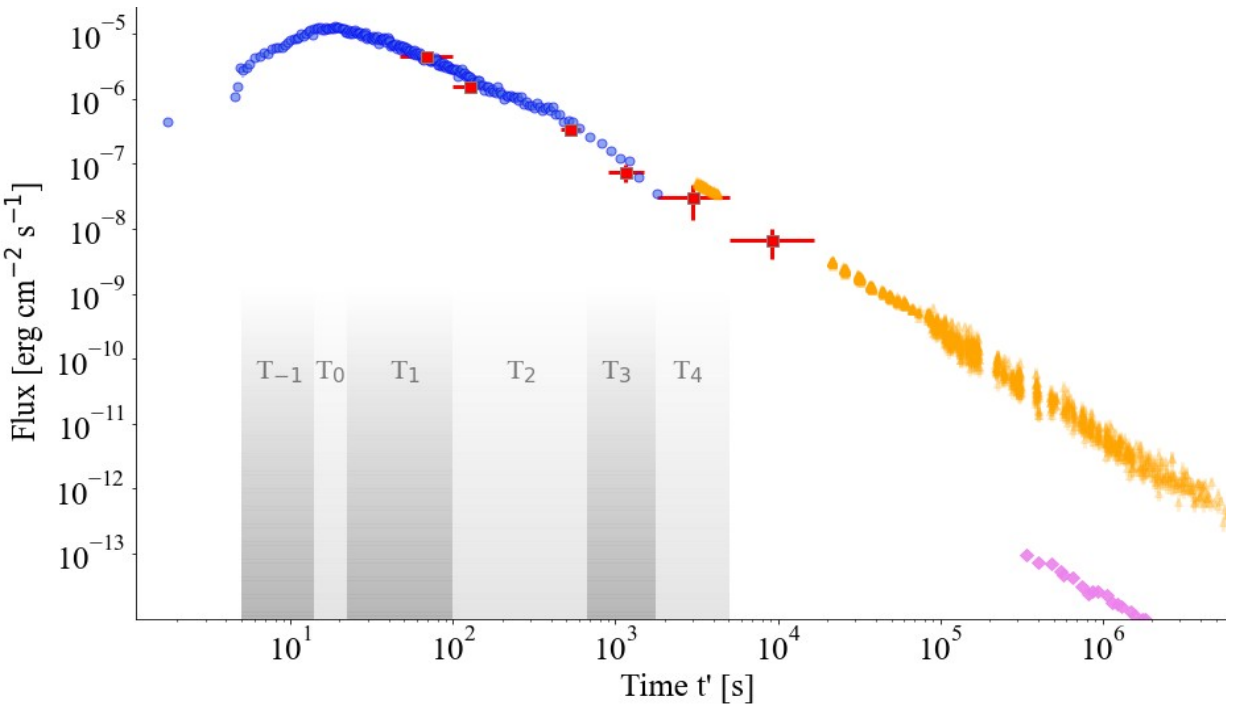
Light curves of GRB 221009A



Many experimental evidences to be globally interpreted by the model: time-evolution indices and flux breaks

Time T' = T_0 + 226 s

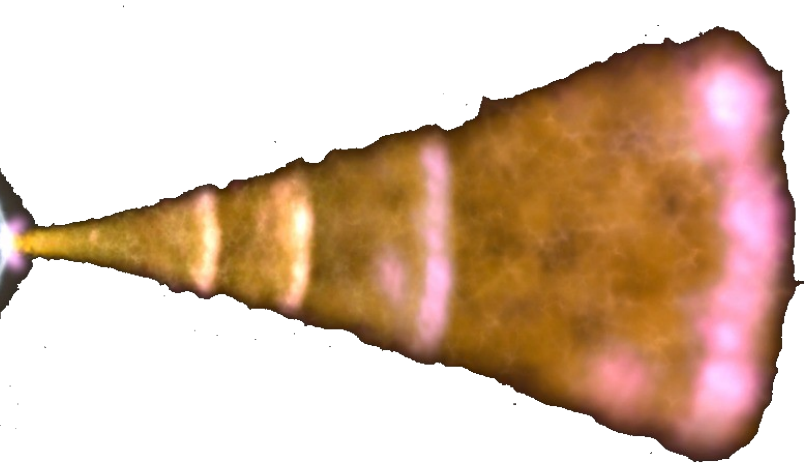
Spectral datasets of GRB 221009A



6 spectral data sets:

- 2 very early **TeV-only**
- 3 early **GeV**+**TeV**
  Crucial simultaneous AGILE + LHAASO datasets
- 1 late **X-rays** + **GeV**

Relativistic Fireball Model



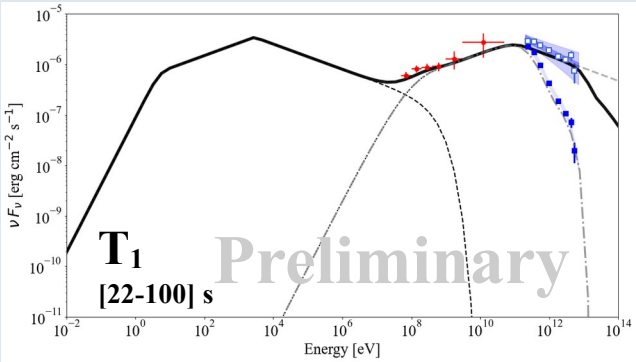
Modified from an image of NASA's Goddard Space Flight Center

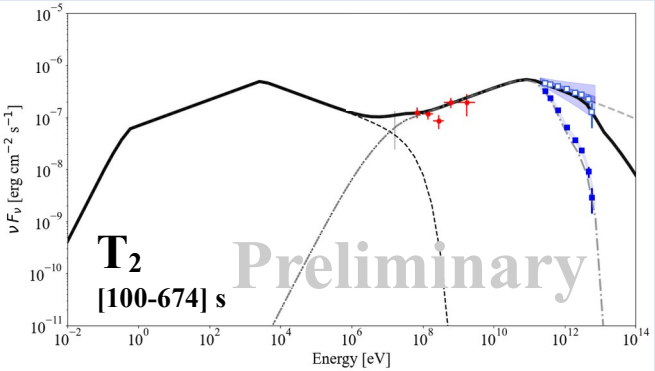
- **Relativistic fireball** model describing the expansion of a blast wave in a medium with **homogeneous** density profile
- Expansion governed by a fully **adiabatic hydrodynamic** evolution
- The shock front expanding with bulk Lorentz factor $\Gamma(r)$, accelerating e^-e^+ over a power-law energy distribution
- The GRB afterglow emission is due to **synchrotron** and **inverse Compton** radiation produced by accelerated particles

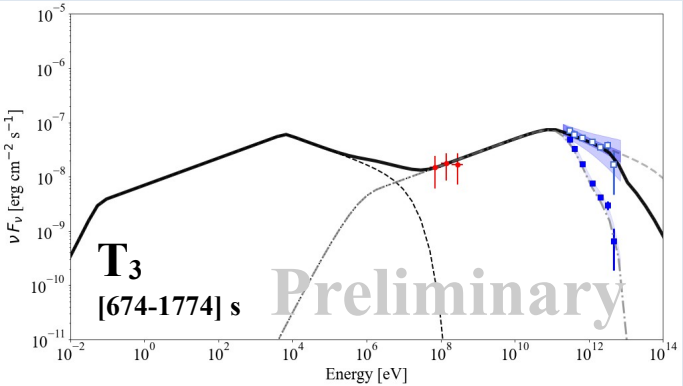
Results

Very Early Phase

Early Phase



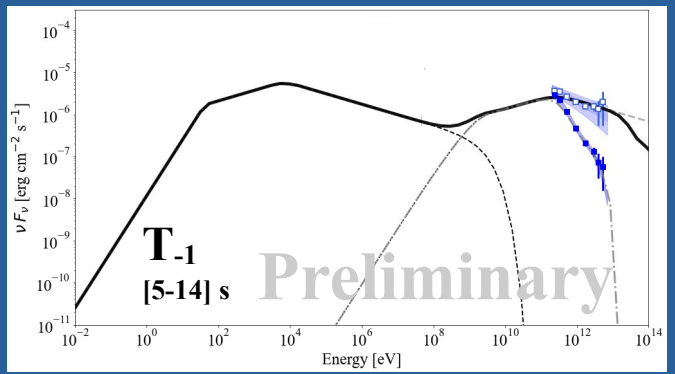


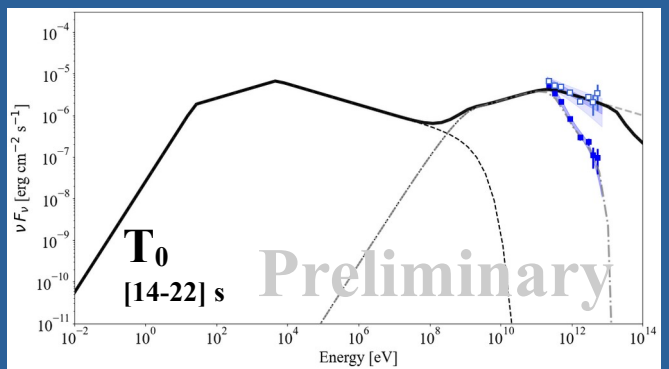


LF+2024,
ArXiv:2409.02859

Late Phase

Very Early Phase





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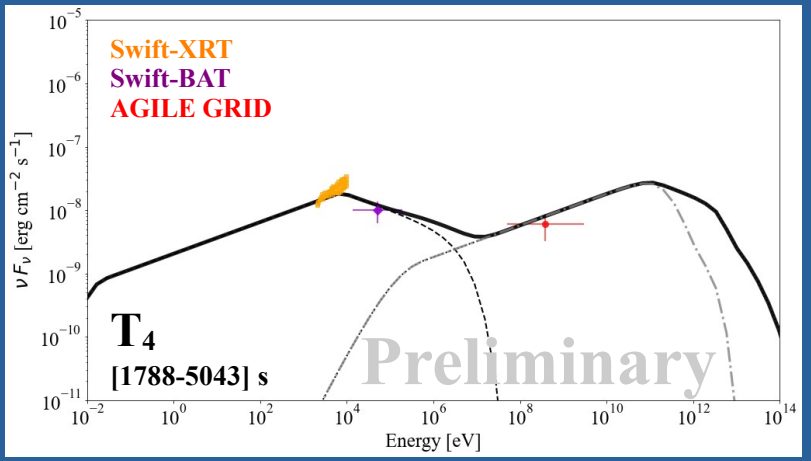
Early Phase

Late Phase

Very Early Phase

Early Phase

Late Phase



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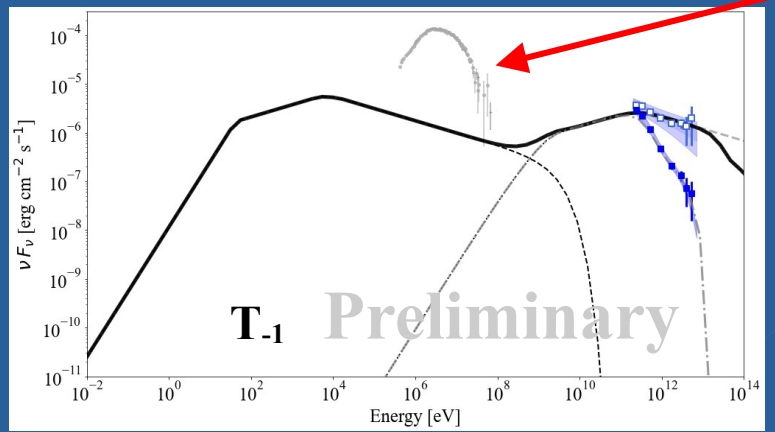
Very Early Phase

Prompt emission?



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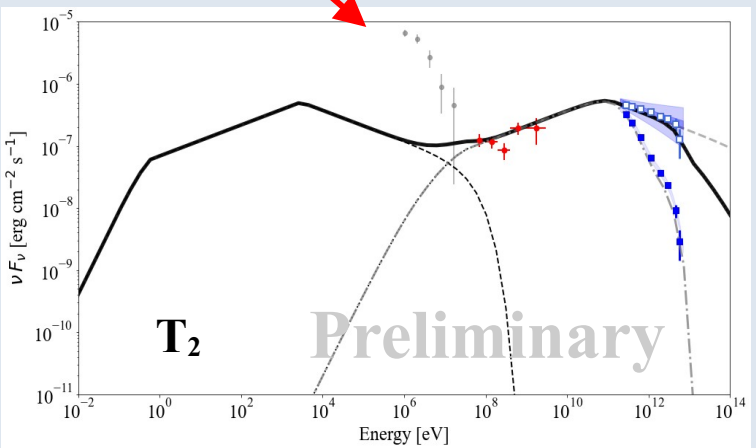
Early Phase

AGILE-MCAL
0.35 – 100 MeV



Late Phase

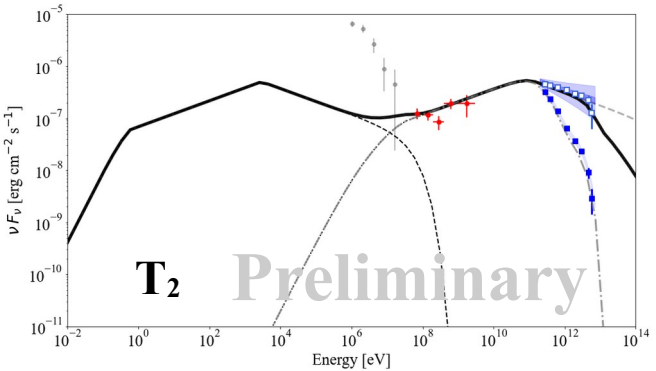
Physical indications from the spectral analysis

- GRB 221009A afterglow interpreted as Synchrotron and **SSC emission**
- Overall MeV-GeV-TeV datasets show the **transition** from a **prompt**-dominated phase to an **afterglow**-dominated phase
- Quasi **constant emission peaks** for a long time (rather than the standard behavior $\sim t^{-1/2}$)

  1) Time-evolving shock efficiencies

     → shock energy being progressively transferred to accelerated electrons with increasing efficiency

  2) Hydrodynamical effects due to losses wrt the fully adiabatic expansion?



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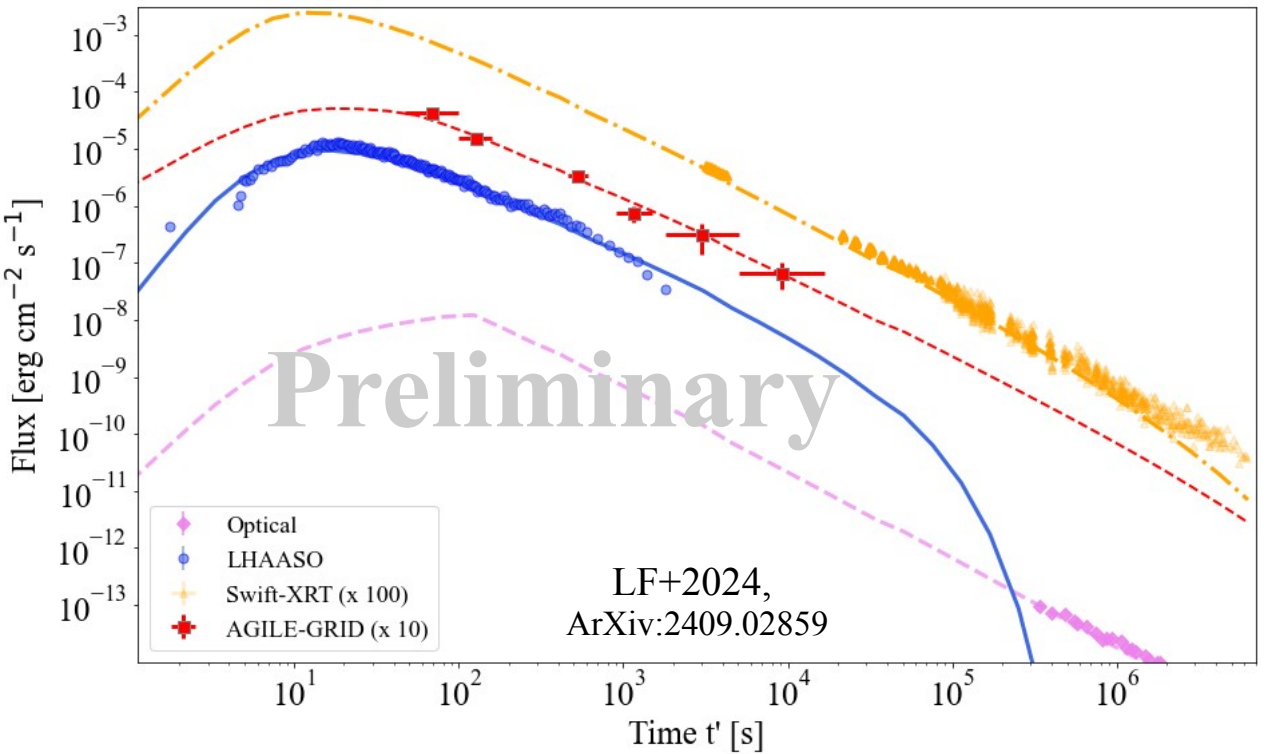
Light curve: Model and Data

Good agreement with the extensive datasets at TeV, GeV, X-ray, and optical energies over 5 orders of magnitude in time



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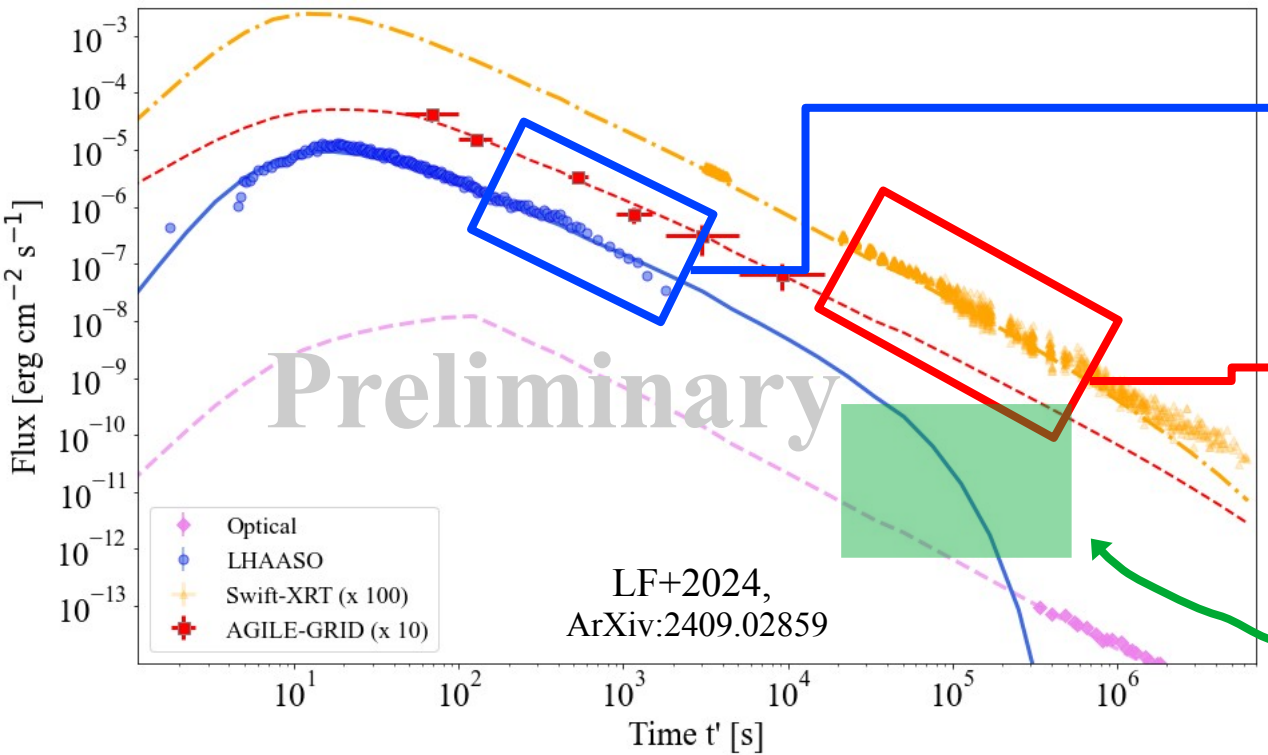

Jet break at t'~600 s **not supported** by the AGILE GeV data and by the model

Curvature of the X-ray lightcurve near t′∼10^5s interpreted as the intervening effect of a spectral break due a finite γ_{max}

→ without invoking a jet break

The model predicts **detectable TeV emission up to ~1 day** after the event

Conclusions

GRB 221009A was an extraordinary event!

- difficult to interpret in a global scenario
- not trivially described by any standard GRB models

We provide a **theoretical intepretation of the GRB 221009A afterglow** within a **global model evolution** from very early to late times:

- within the framework of a **relativistic fireball** expanding in an external homogeneous medium and producing the synchrotron self-Compton radiation of the afterglow
- adopting **time-evolving mycrophysical quantities** ε_B and ε_e

Crucial to our investigation are the early **simultaneous datasets at GeV – TeV gamma-ray energies** providing spectral and flux intensity information

Stay tuned! → New paper on theoretical interpretation of GRB 221009A: LF+2024, ArXiv:2409.02859