A millimeter rebrightening in GRB 210702A

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Introduction

GRB 210702A is a long gamma-ray burst discovered by *Swift*. Our ALMA 3 mm (97.5 GHz) light curve shows a **significant rebrightening** beginning at 8.2 days post-burst. This is the first such rebrightening seen in a GRB millimeter light curve. Our extensive multi-wavelength dataset spanning 8 orders of magnitude in frequency (1 keV—700 MHz) and almost 5 orders of magnitude in time (0.001—86 days) allows us to test forward shock (FS) afterglow models and scenarios that give rise to the millimeter rebrightening.

Based on de Wet S., Laskar T., Groot P. J., et al. 2024, ApJ, 974, 279

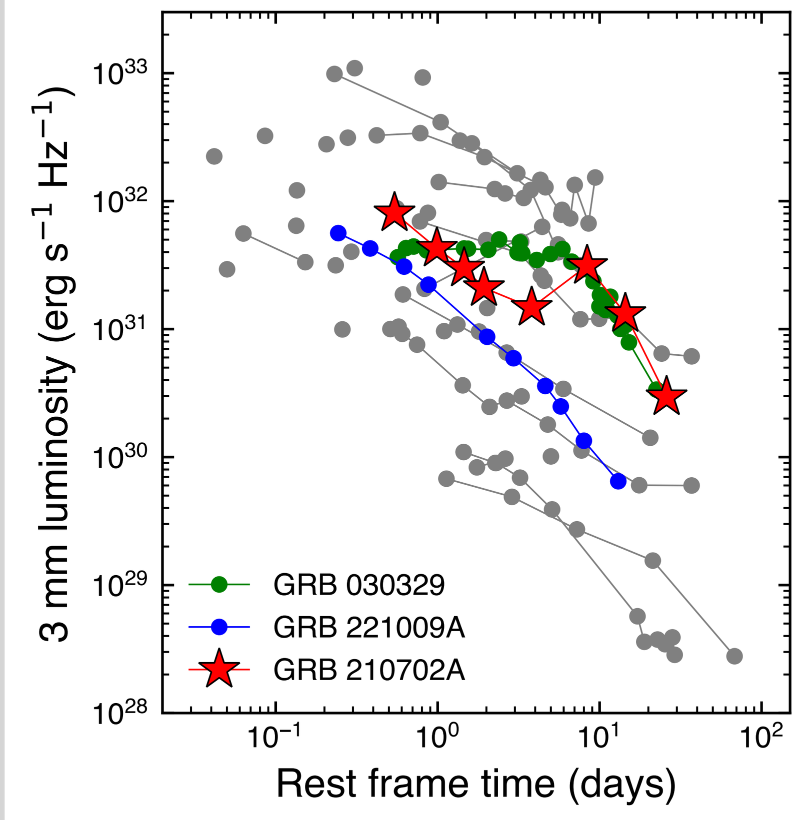


Fig.1: Spectral luminosity at 3 mm for GRB 210702A compared to a sample of long GRB millimeter light curves from [1]. We highlight two extremely bright and nearby bursts: GRB 030329 (z=0.1685) and GRB 221009A (z=0.151).

An extensive multi-wavelength dataset

GRB 210702A was first discovered by *Swift*/BAT with a duration of 138 s. VLT X-shooter spectroscopy pinned down the redshift to z=1.16. The MeerLICHT telescope in Sutherland, South Africa, responded automatically to the Swift trigger and started observing 16 minutes post-trigger. The afterglow was bright in the optical, with the first UVOT u-band exposure having a brightness of 12.34 AB mag. Due to the optical brightness, we triggered a number of radio follow-up programs with ALMA, ATCA, MeerKAT and the GMRT (PIs Laskar).

The optical and X-ray light curves (Fig. 2) appear to show typical afterglow behaviour with similar decay indices. The early millimeter decay rate prior to the rebrightening also agrees with the early optical decay rate. Using a closure relation analysis, we found that the X-ray, optical and early millimeter data can be explained by a standard FS model in a stellar wind medium.

The lower frequency radio data, on the other hand, is challenging to interpret (Figs. 3+4). The first SED shows a rising segment that is suggestive of optically-thick synchrotron emission, allowing us to constrain the self-absorption spectral break. However, no standard FS model can accommodate such a high self-absorption frequency. The sharp jumps in our SEDS might be explained by interstellar scintillation, which is expected to be strongest at 5.5 and 9 GHz.

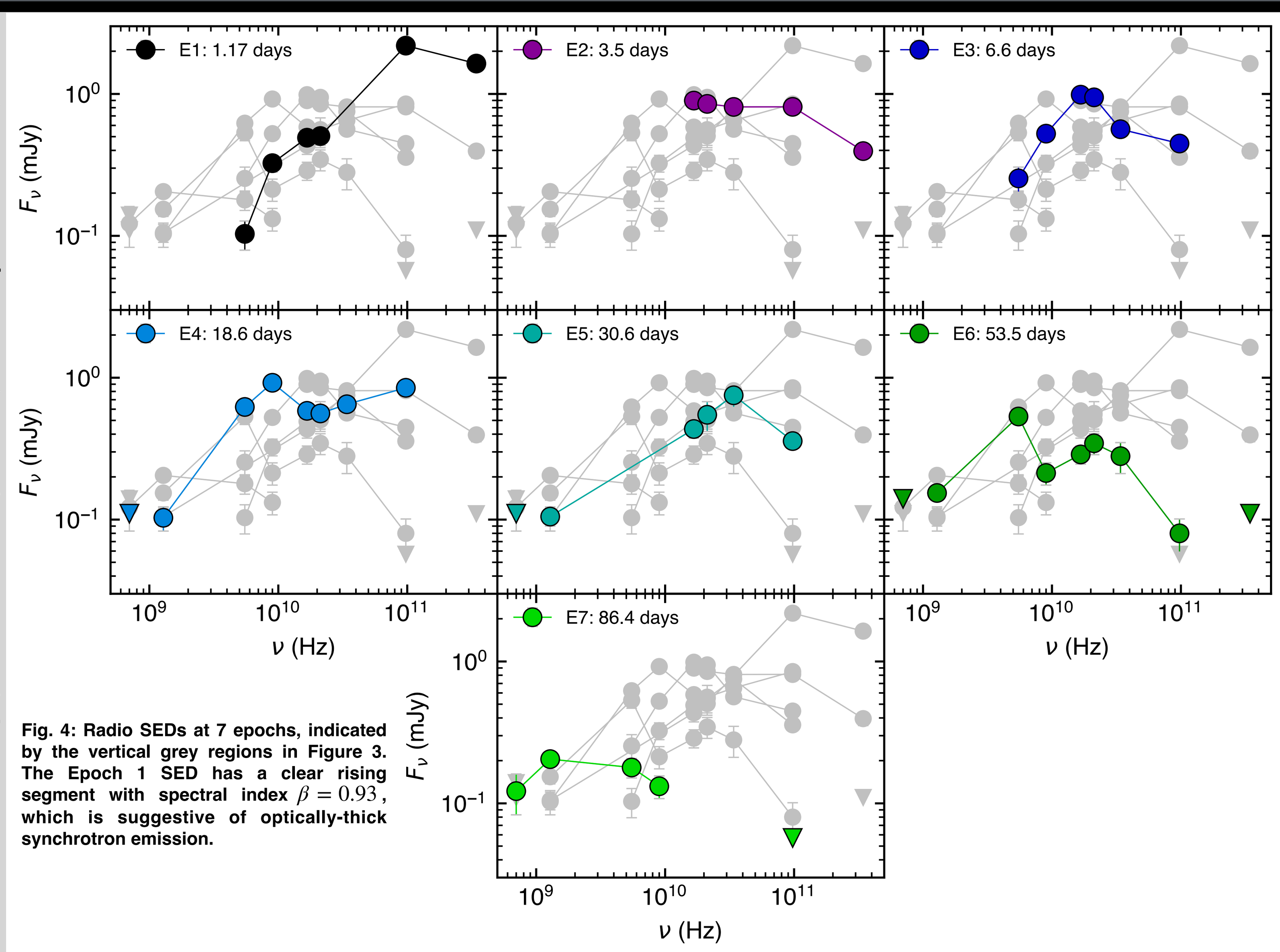


Fig. 4: Radio SEDs at 7 epochs, indicated by the vertical grey regions in Figure 3. The Epoch 1 SED has a clear rising segment with spectral index $\beta = 0.93$, which is suggestive of optically-thick synchrotron emission.

Fig. 2: X-ray, optical and 3mm light curves with power-law fits indicating the decay rate for individual segments.

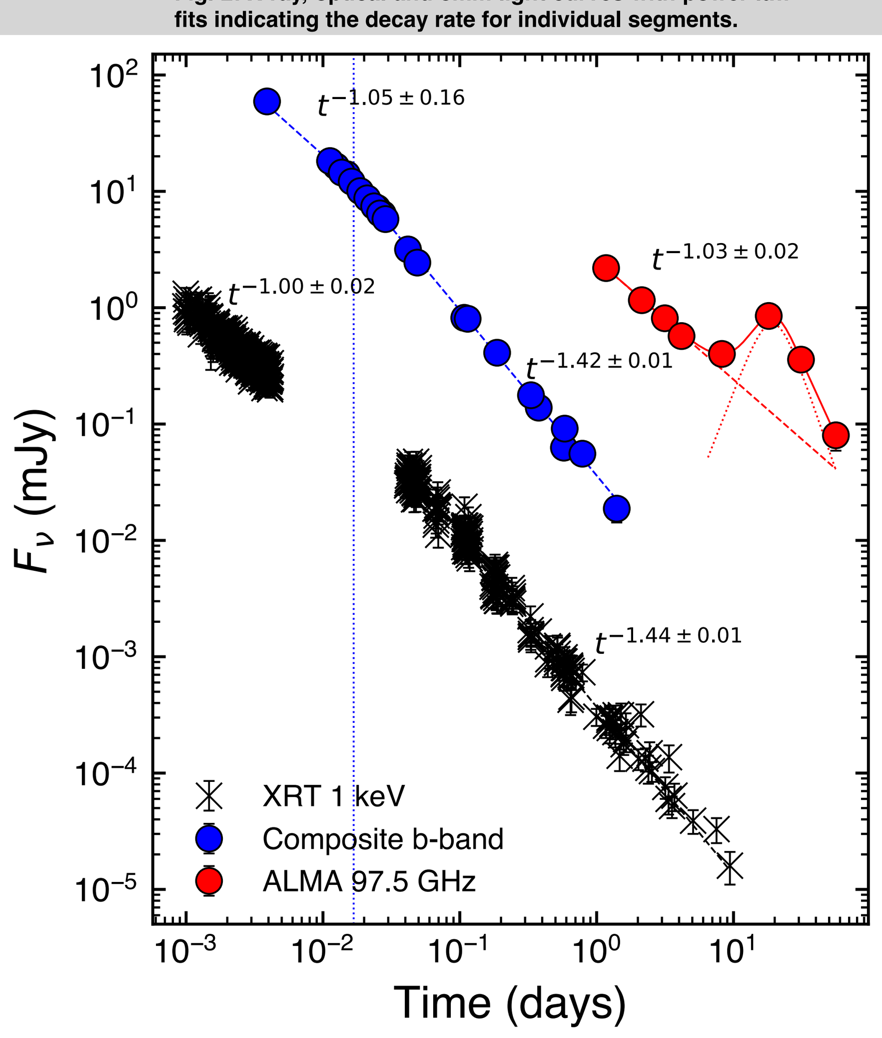
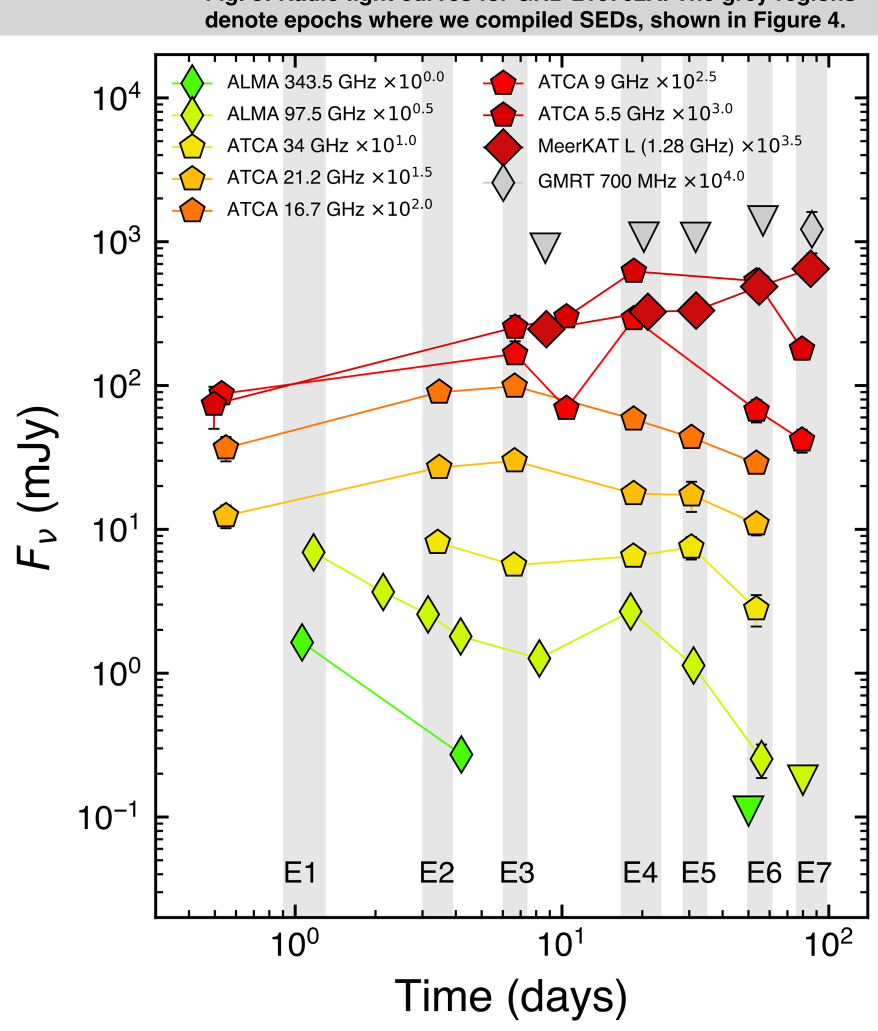


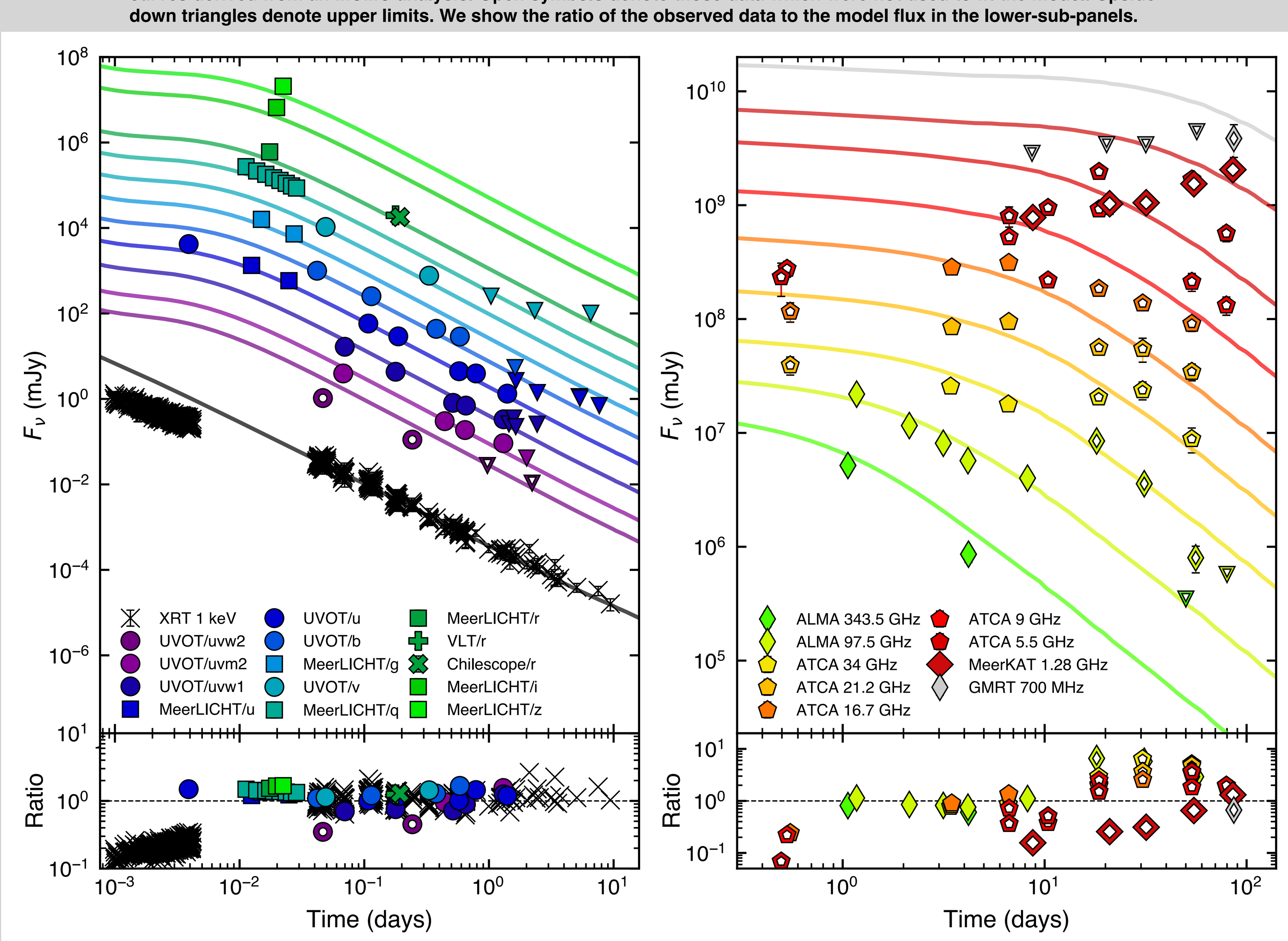
Fig. 3: Radio light curves for GRB 210702A. The grey regions denote epochs where we compiled SEDs, shown in Figure 4.



Afterglow modelling

We used the ScaleFit software package [2] to model our data prior to the millimeter rebrightening. We exclude the first epoch of ATCA data at 6.6 days and lower frequency (<16.7 GHz) data since we know that no standard FS model can accommodate these data. We also exclude the early (t<0.01d) X-ray data since these also cannot be explained by a standard FS model. We attribute this to a period of energy injection. Our FS parameters are typical for long GRBs, and we are able to place a lower limit on the jet opening angle due to the lack of an observed jet break. The shallower decline seen in the optical and early millimeter bands is due to the proximity of the synchrotron peak to the observing band.

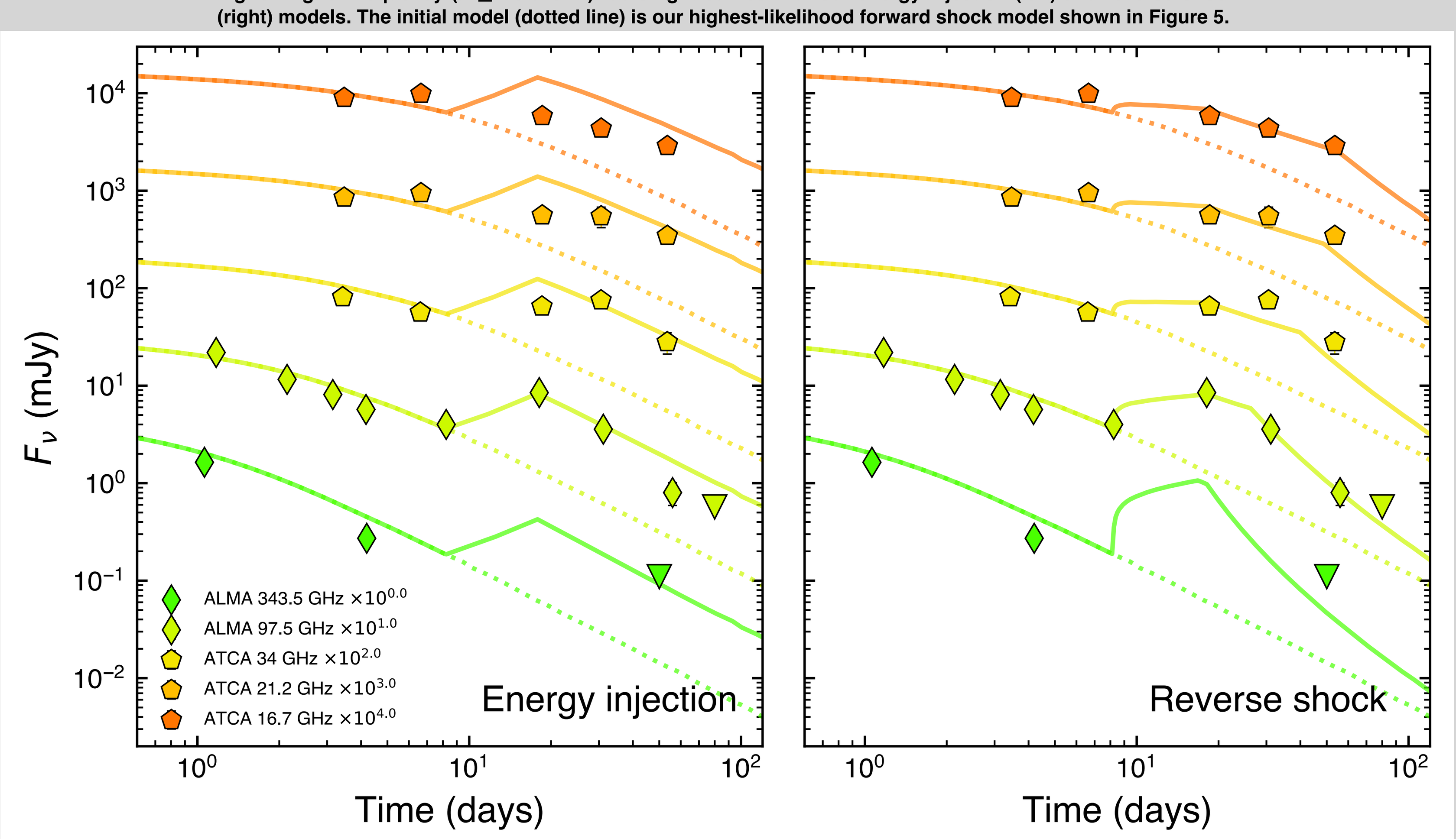
Fig. 5: All afterglow data associated with GRB 210702A along with our highest-likelihood forward shock model light curves derived from an MCMC analysis. Open symbols denote those data which were not used to fit the model. Upside-down triangles denote upper limits. We show the ratio of the observed data to the model flux in the lower-sub-panels.



Explanations for the millimeter brightening

We considered a number of scenarios to explain the millimeter rebrightening, but the two most promising were energy injection (Fig. 6 left) and a reverse shock from a late-time shell collision (Fig. 6 right). A period of energy injection between 8.2 and 18.1 days in which the blast wave energy increases by a factor of 10 can explain the rise in the millimeter light curve, but does not perfectly match the lower-frequency radio bands. A relativistic reverse shock produced by the collision of two ejecta shells can adequately describe our higher frequency radio data. We note, however, that the spectral breaks are not well-constrained and the model presented here merely demonstrates that a reverse shock is a possible explanation for the millimeter rebrightening.

Fig. 6: Higher frequency ($\nu \geq 16.7$ GHz) radio light curves with our energy injection (left) and reverse shock (right) models. The initial model (dotted line) is our highest-likelihood forward shock model shown in Figure 5.



Conclusions

GRB 210702A is remarkable for being the first GRB with a clear rebrightening in its millimeter light curve, clearly demonstrating that millimeter light curves can show some of the complex features more commonly seen in optical and X-ray light curves. The rebrightening can be explained by energy injection or a reverse shock. Similar to other GRBs with extensive radio datasets, our radio data shows incompatibilities with standard FS models and may require alternative scenarios such as a structured jet or thermal electron population to explain the data.

References

[1] Eftekhari, T., Berger, E., Metzger, B. D., et al. 2022, ApJ, 935, 16
[2] Ryan, G., van Eerten, H., MacFadyen, A., & Zhang, B.-B. 2015, ApJ, 799, 3