# Gamma-Ray Burst Afterglows: Time-varying Extinction, Polarization, and Colors due to Rotational Disruption of Dust Grains

Hoang et al., 2020

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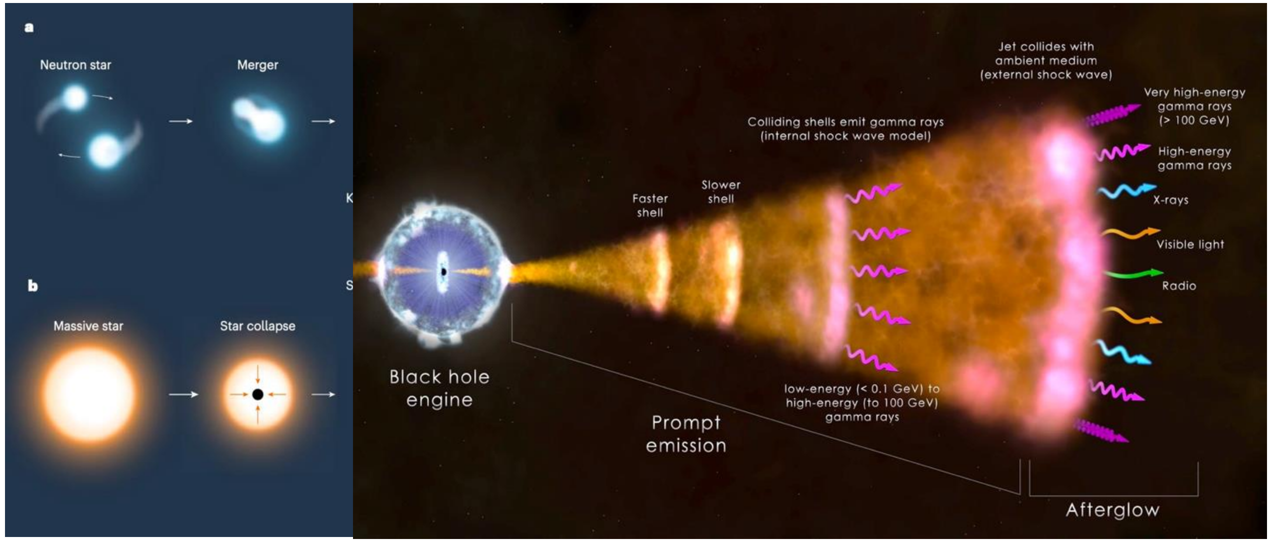
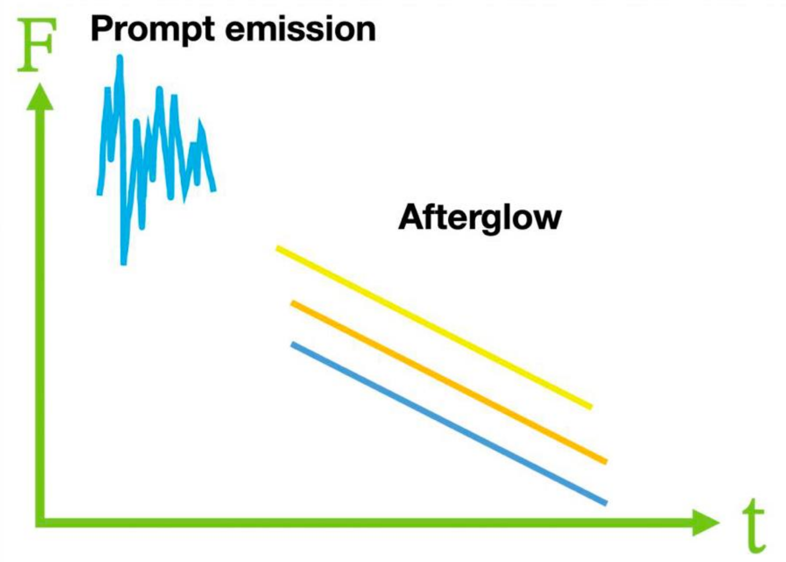
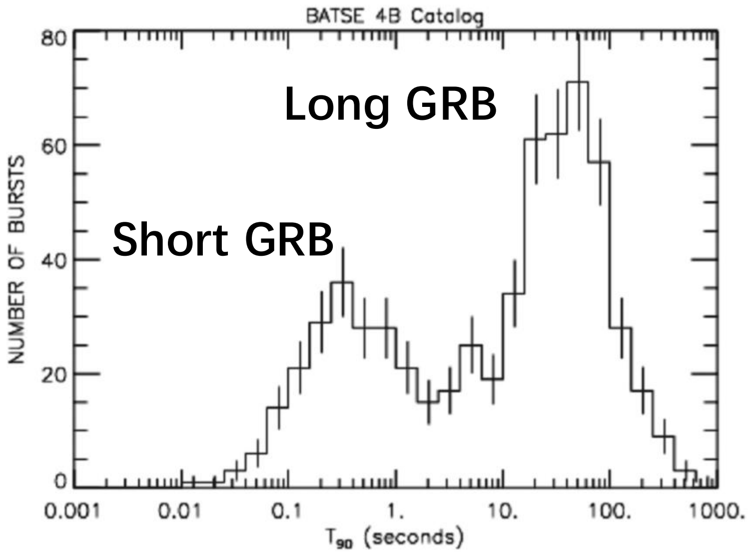
2025.4.18 @SWIFAR, YNU

# 1. Introduction

Merge /collapse          Central engine + relativistic jet



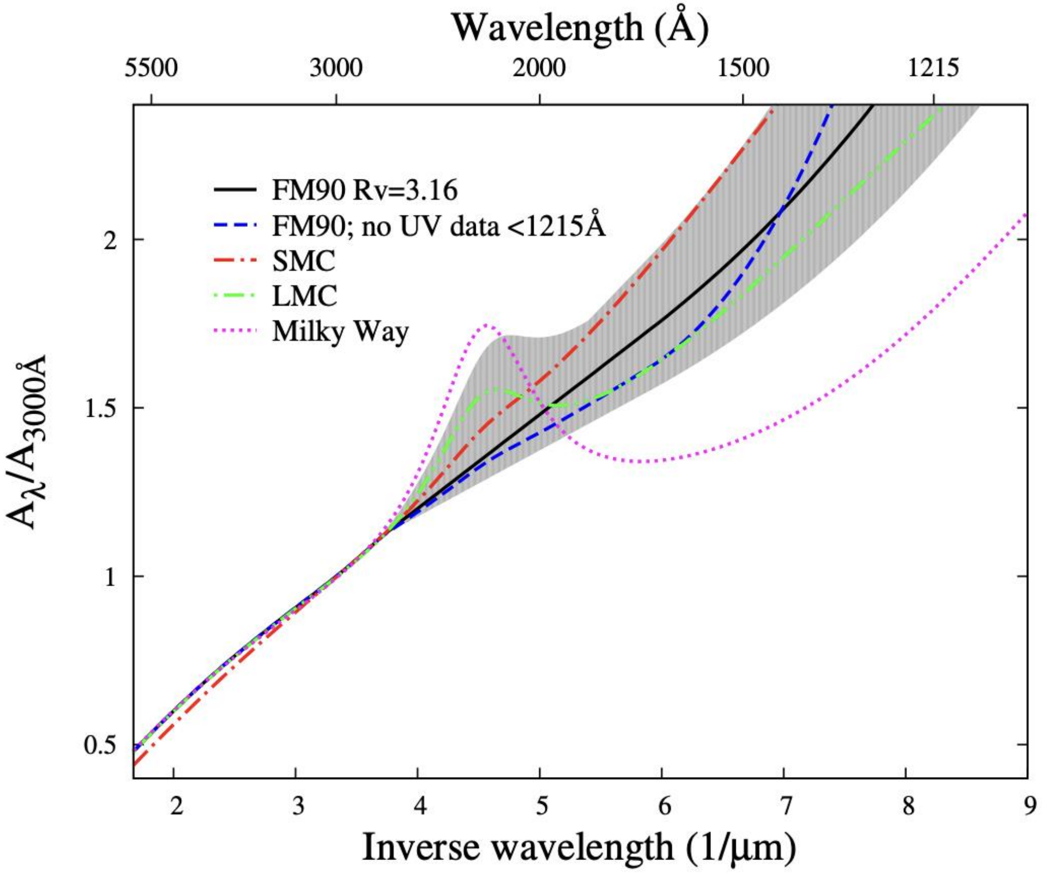

Swift GRBs:

- Detected in optical wavelengths : ~ 60%
- Detected in X-ray : > 95%
- ~40% of GRBs undetected in optical , so-called “dark” GRBs.

The leading reason for this lies in the attenuation of optical photons by intervening dust.

# 1. Introduction

- Extinction curve shows a steep far-UV rise, which suggests the predominance of small grains in the local environment.




Schady et al., 2012

## Previous studies:

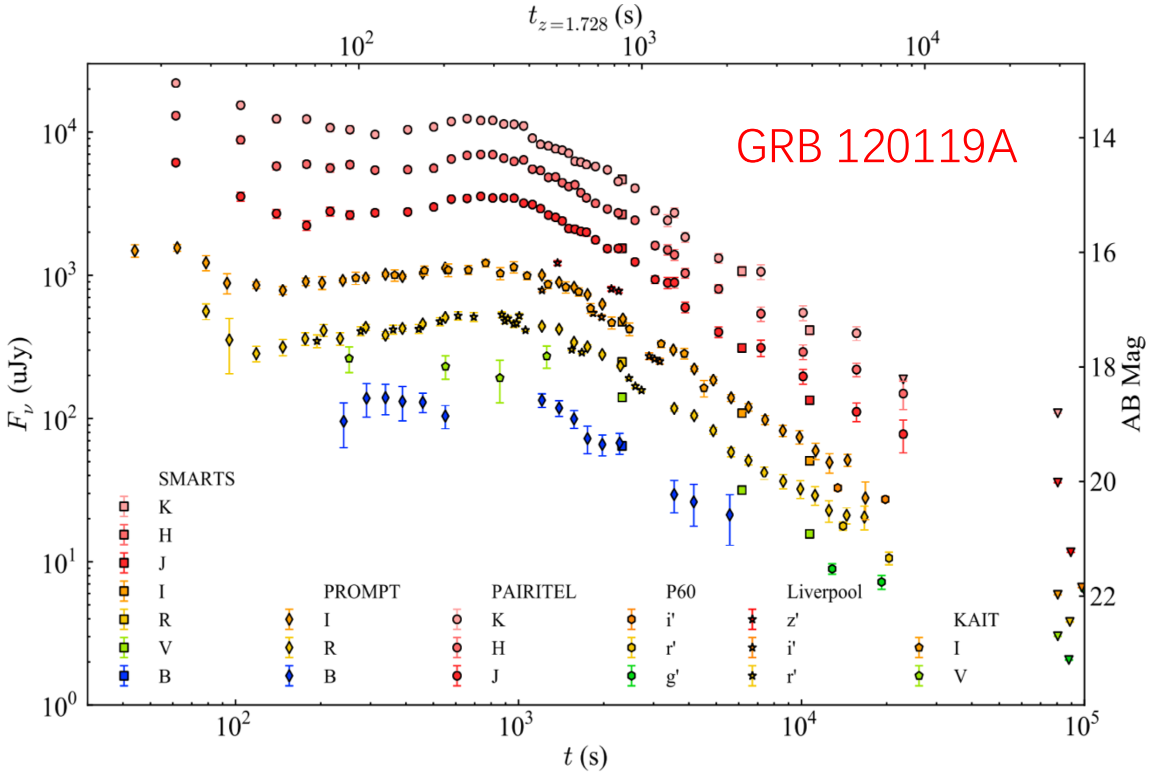
- dust grains within 10 pc can be sublimated (升华) within 10 s due to the effects of prompt optical-UV emission (Waxman+, 2000).

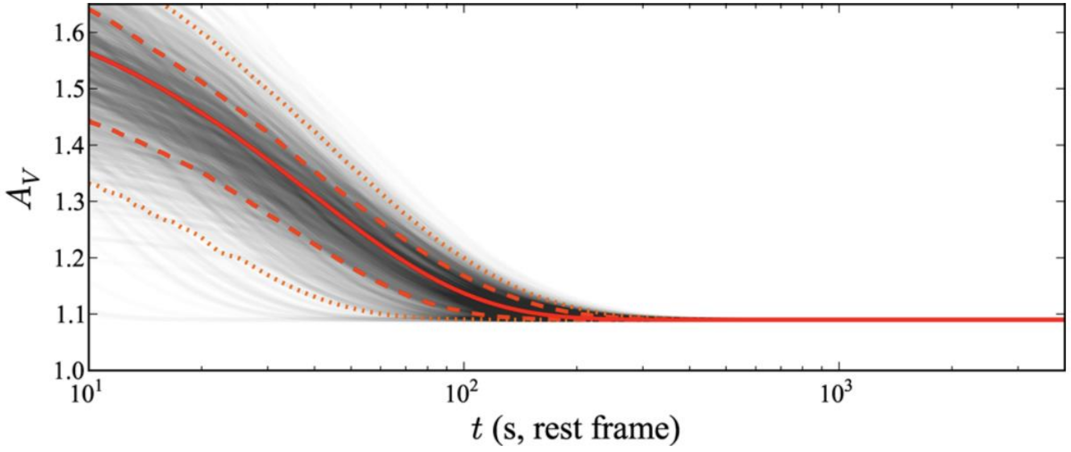
- Studies on the time-dependent dust extinction due to the thermal sublimation and ion-field emission by the optical-UV flash found that dust extinction decreases significantly by t~10 s from the start of the burst (Perna+,2003).

# 1. Introduction

Observations on GRB afterglows:

- GRB 111209A and GRB 120119A show a significant red-to-blue color change within t ~200–500 s.
- GRB 120119A show a significant decrease of visual extinction $A_V$ within t~10–100 s.
- Late-time observations usually reveal a rebrightening in the optical-NIR light curves.



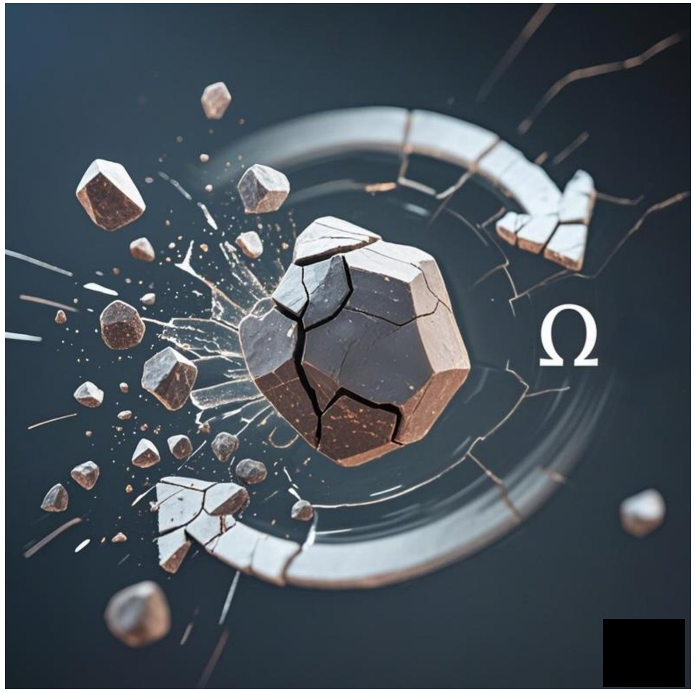




Morgan et al., 2014

# 2. RAdiative Torque Disruption (RATD)

**The RATD mechanism is based on the centrifugal force within rapidly spinning grains spun-up by radiative torques (RAT), which can break a large grain into numerous smaller fragments.**

**A dust grain spinning at angular velocity  is disrupted when induced centrifugal stress S exceeds the maximum tensile strength of grain material.**




**Disruption time :** $\boldsymbol{t_{dis}}$

**Grain disruption size ：** $\boldsymbol{a_{dis}}$

**Distance from the source :  d (pc)**

**Tensile strength :** $\boldsymbol{S_{max}}$

**Luminosity of afterglow: L**

**Tensile strength:**

$S_{max} = 10^{11}\ erg\ cm^{-3}$ for ideal materials, i.e., diamond;
$S_{max}{\sim}10^{9} - 10^{10}\ erg\ cm^{-3}$ for polycrystalline bulk solid
$S_{max}{\sim}10^{6} - 10^{8}\ erg\ cm^{-3}$ for composite grains.

$\boldsymbol{S_{max} = 10^{7}\ erg\ cm^{-3}}$ **was taken as a typical value for large grains in this work.**

# 3. Extinction of GRB Afterglows

## 3.1. Grain Disruption Size

Fig. 1

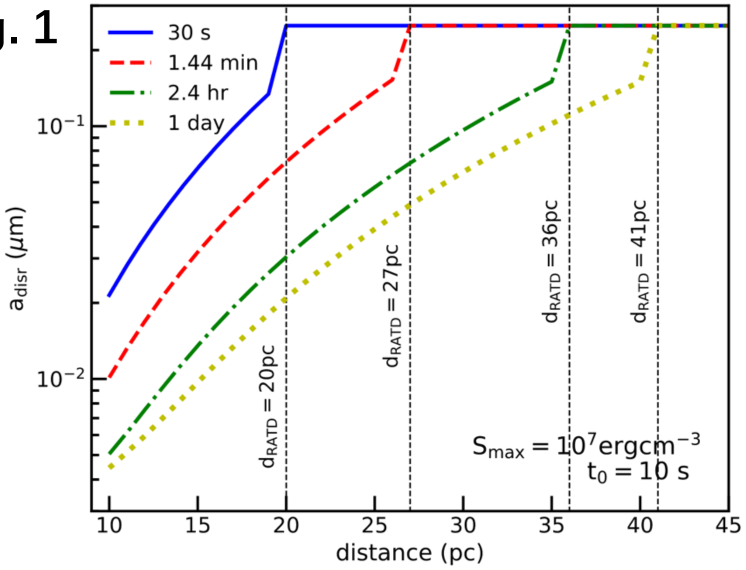



Fig. 2

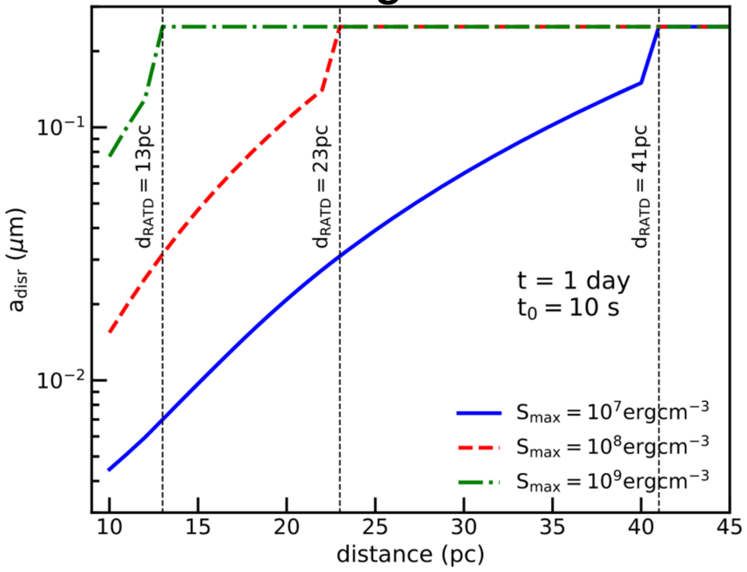



Fig. 3

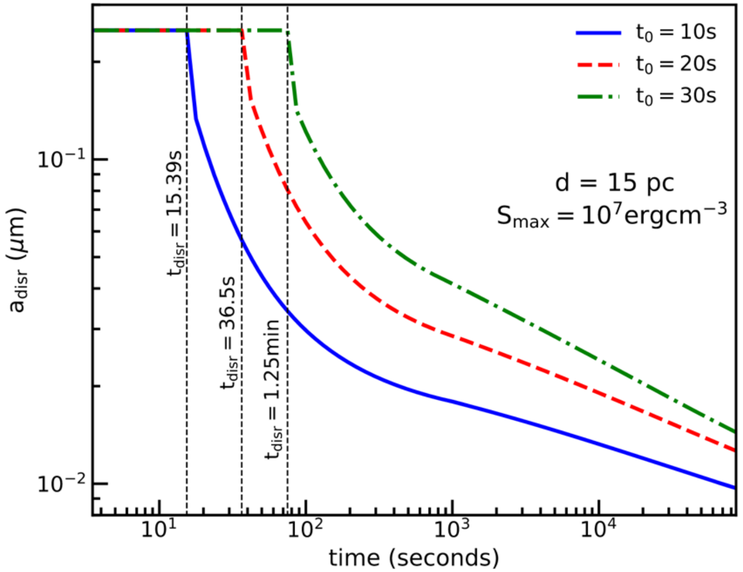



Fig. 4

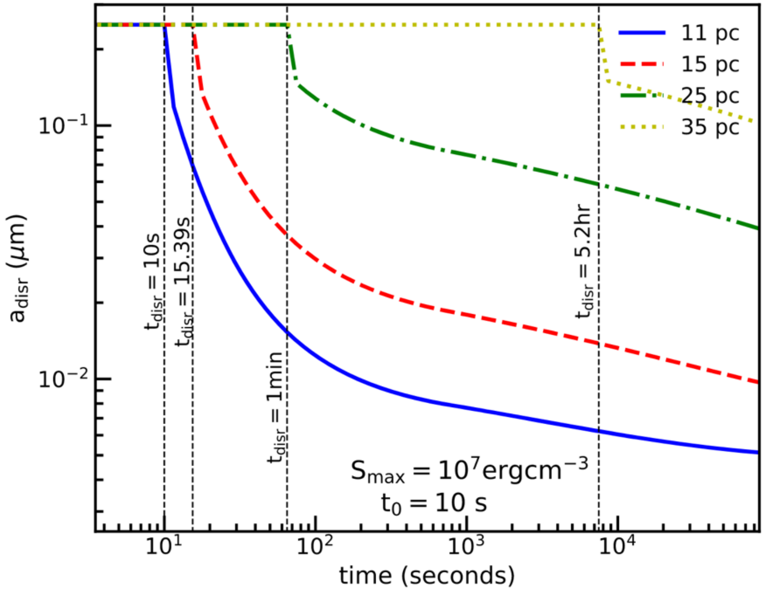
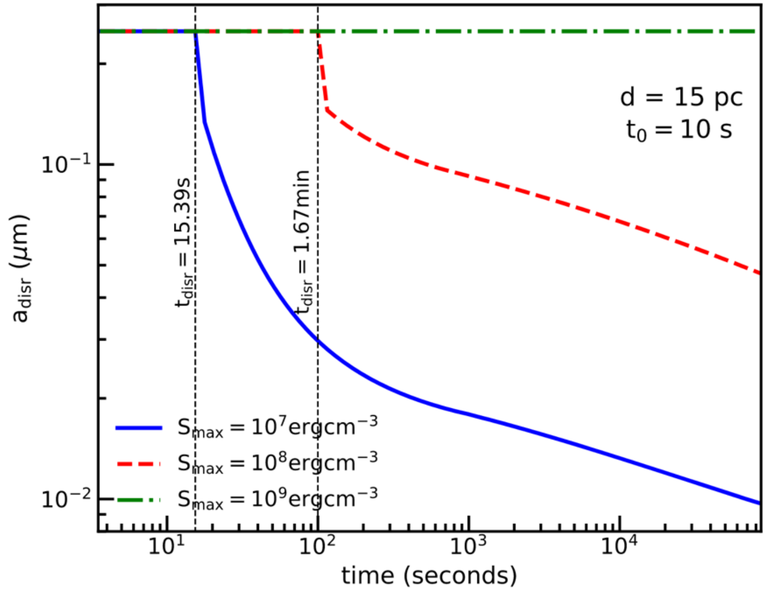
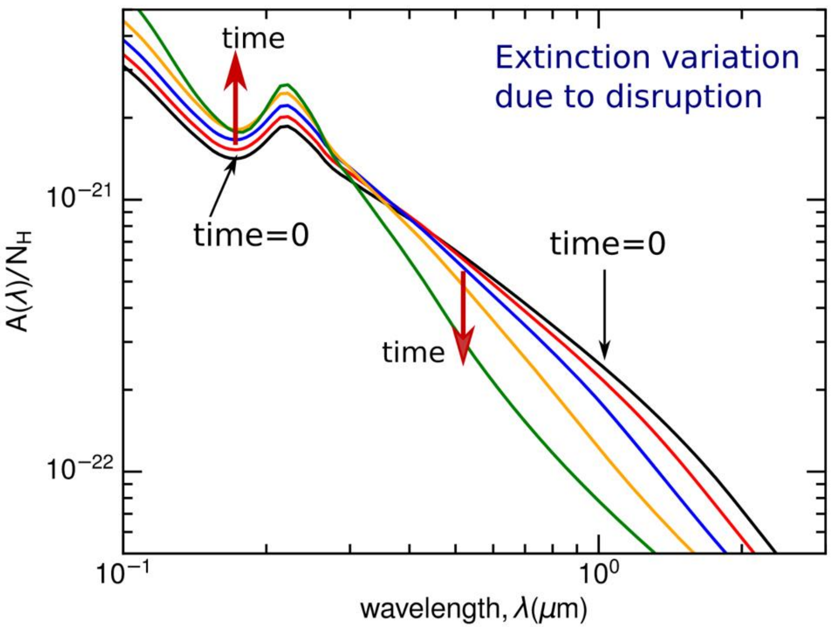



Fig. 5

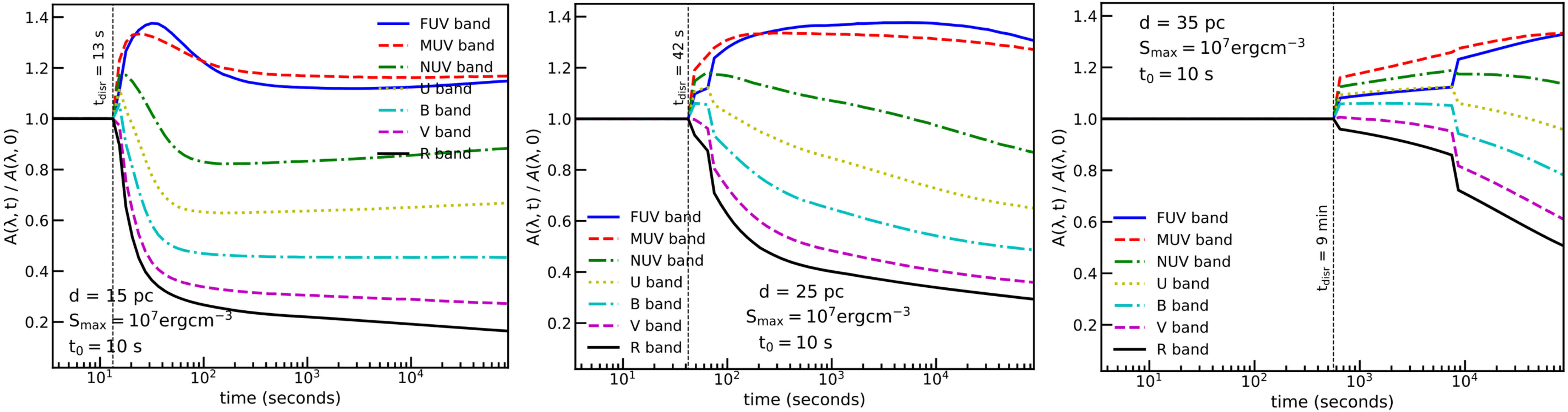


## 3.2. Extinction Curves

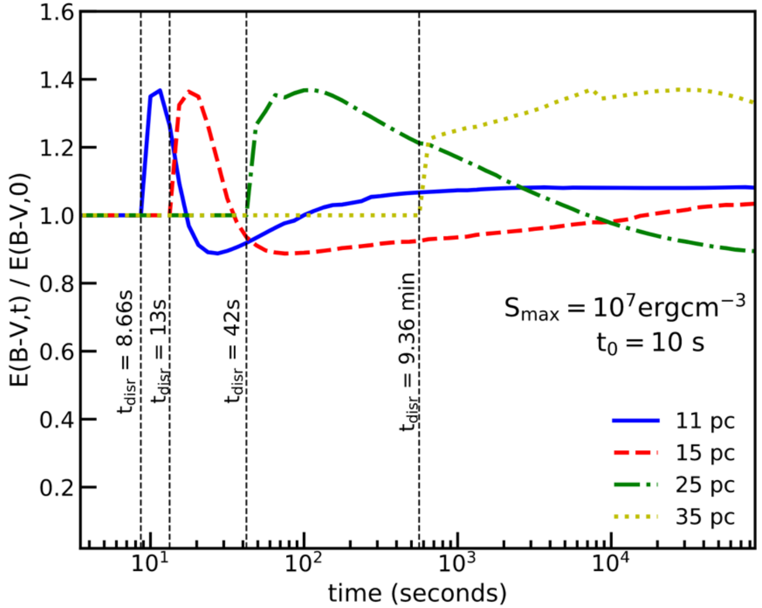



The optical to near-infrared (NIR) extinction is seen to decrease gradually with time due to the removal of large grains by RATD. In contrast, UV extinction increases due to the enhancement in the abundance of small grains with respect to larger ones.

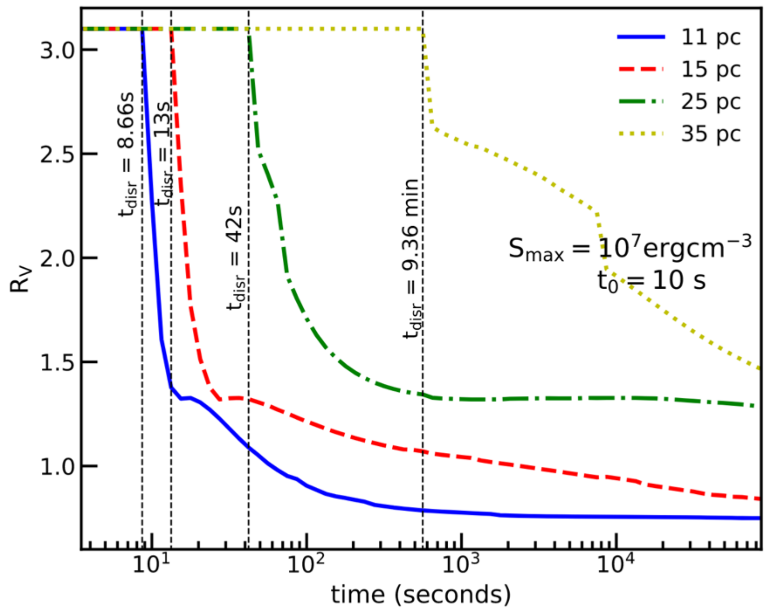
The optical-NIR extinction decreases immediately to smaller values because of the quick removal of large grains of size a ~0.1 μm by RATD. In contrast, the extinction value in other bands (U,B ,UV) first increases due to the enhancement of small grains then decreases later when these small grains are again fragmented into smaller ones.

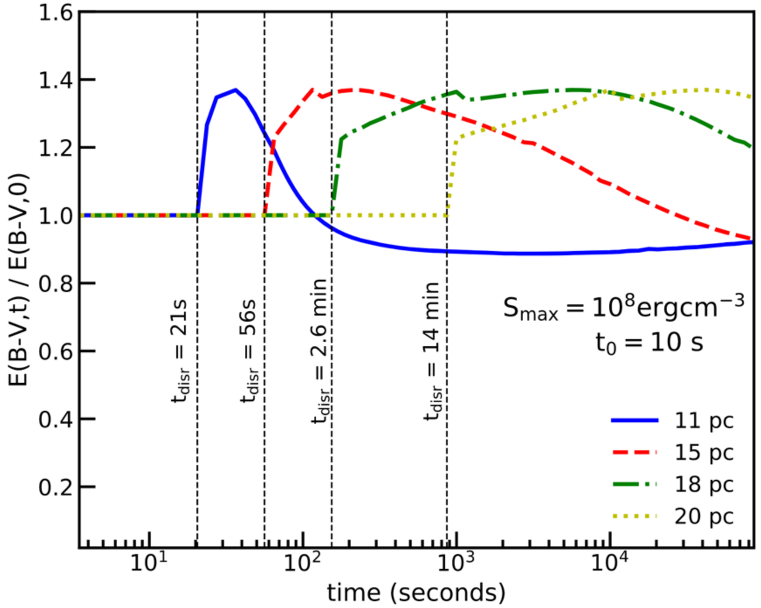


## 3.3. Time Variability of $E(B-V)$ and $R_V$

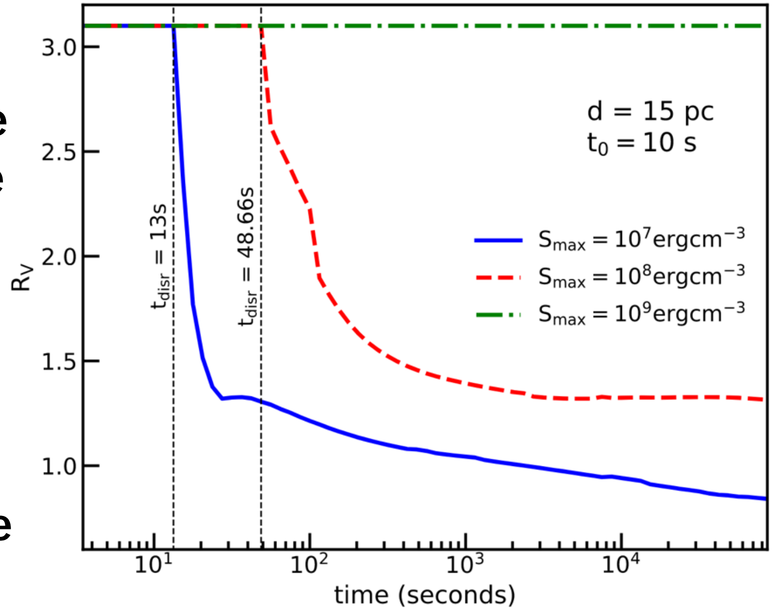



- For a given cloud distance, the color excess remains constant until grain disruption begins at $t \sim t_{disr}$. Subsequently, the ratio increases rapidly and then decreases to a saturated level when RATD ceases.

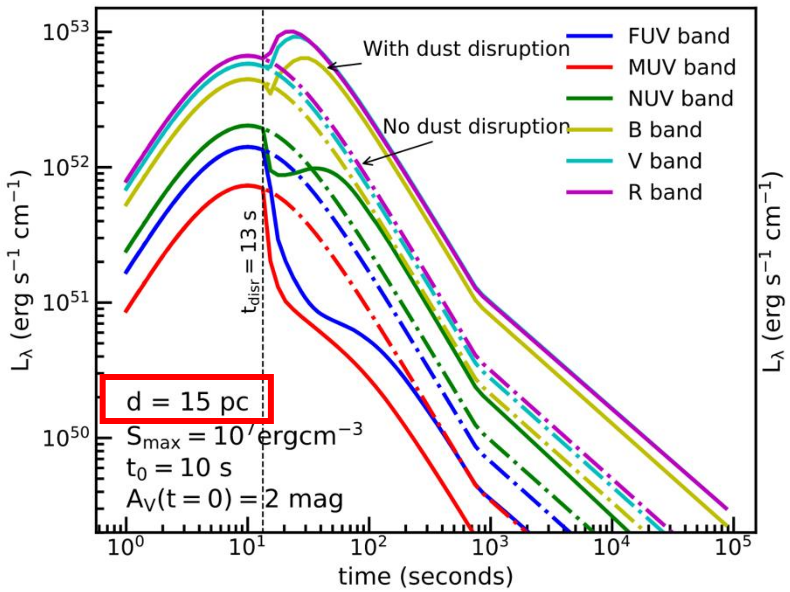


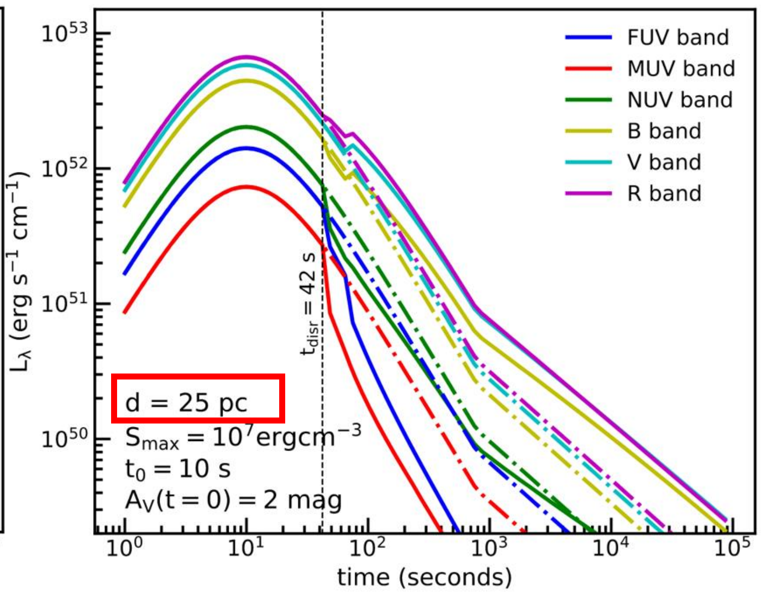




- For a given distance, one can see that $R_V$ begins to decrease rapidly from its original value of 3.1 given by standard dust in ISM at $t=t_{disr}<10$ min to smaller values of $R_V \sim 0.5$–$1.5$ due to RATD. The final value of $R_V$ is larger for grains located farther away from the source.

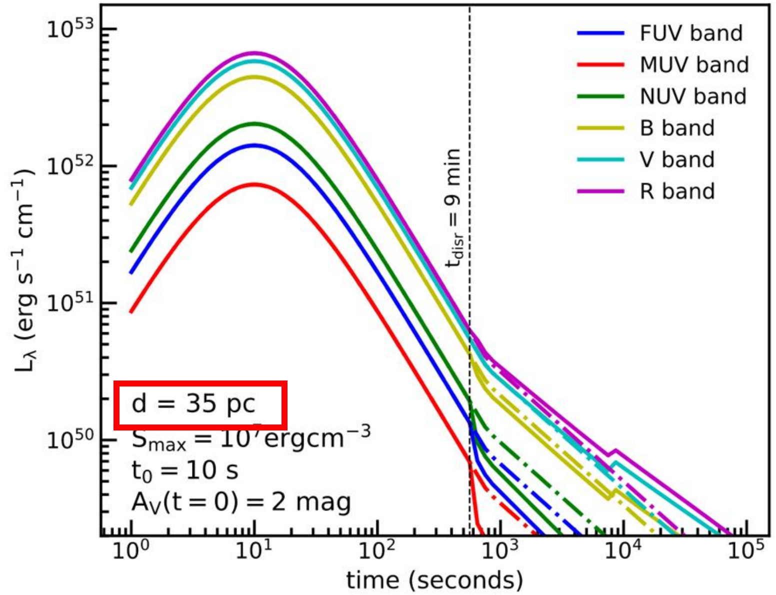


# 4. Effect of RATD on the Light Curves of GRB Afterglows

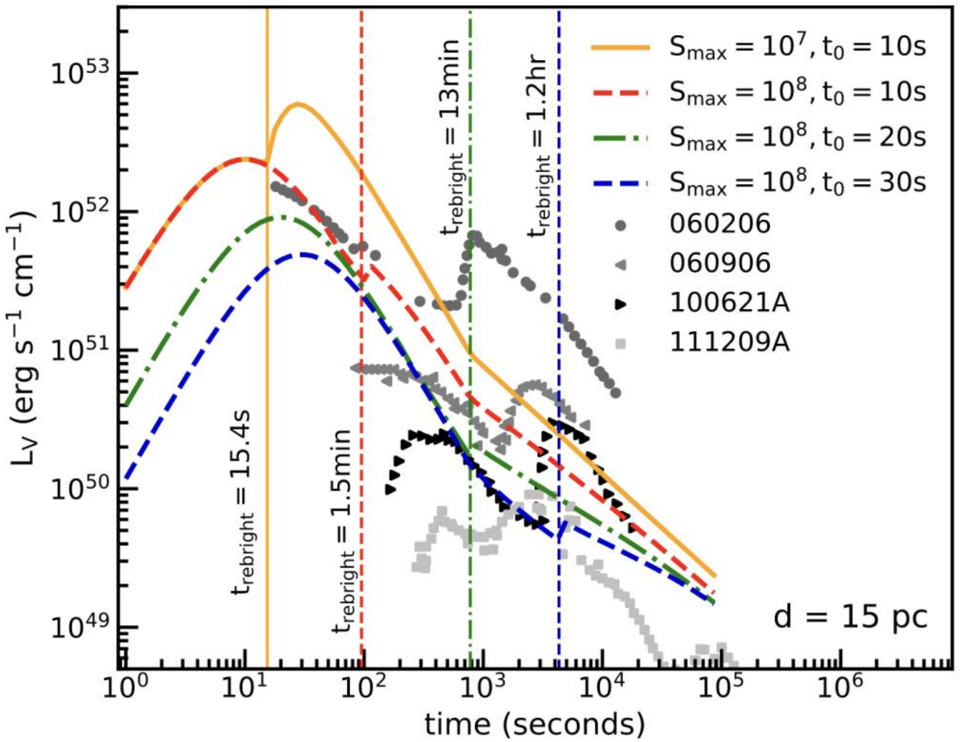



- **Models for a dust cloud of original visual extinction A(V, t = 0) = 3 can indeed reproduce the timing of optical rebrightening; although, the models yield a lower amplitude of the raebrightening than the observations.**
- **Increasing the original extinction A(V,t = 0) can increase the rebrightening amplitude and better fit the observational data.**




- **GRB afterglows suddenly rebrighten in the visible-NIR bands compared with the no grain disruption case.**
- **The reason is that the reduction of the visible NIR extinction will let more light escape from the dust, resulting in the increase of visible-NIR luminosity**



# 7. Summary

- 1. Large dust grains can be disrupted into smaller ones within one day up to 40 pc due to RATD.
- 2. The optical-NIR extinction decreases, whereas the UV and FUV extinction increase gradually until a day after the burst due to the enhancement of small grains by RATD. This causes the time variability of color excess E (B-V).
- 3. The optical-IR polarization first increases with time due to enhanced alignment by strong radiation fields and then decreases rapidly when grain disruption by RATD begins.
- 4. Our predictions are, in general, supported by observations, including SMC-like extinction curves and low values of RV of GRB afterglows. Grain disruption by RATD can partly contribute to the optical rebrightening of GRB afterglows at late times.

**Thanks .**