Comparing lightcurves of SN2014J to SN1987A between cooling phase and Nickel-56 peak

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1 Abstract

When a supernova explodes, the matter of the star is ripped apart with such force that even neutrons are ripped from protons. As the expanding cloud cools, the matter forms into ^{56}Ni, a relatively stable atom. ^{56}Ni decays over time into ^{56}Co, then ^{56}Fe. Each of step of this decay process releases gamma rays, which deposit energy into the surrounging gas, "propping up" the supernova's luminosity.

Preceding the peak of ^{56}Ni and thus luminosity in the supernova and after the drop in luminosity due to cooling, Type Ia supernovae like SN2014J and Type II-P supernovae like 1987A differ significantly. Here we compare example lightcurves from each category and discuss implications for how the supernovae explode and how we decide taxonomy.

2 Background and Data

The taxonomy of supernovae is, like that of planets, a system which has developed over many years as we creep intellectually through the cosmos. It is not based directly on progenitors, which we still can only feel towards in some cases, nor on explosion mechanism, the specifics of which continue to elude us. Instead, supernovae are categorized by what is simple to observe from our rock: their spectra.

First supernovae are split into Type I and Type II supernovae. Type I supernovae do not contain hydrogen – that is, we do not observe H's spectral lines in their photometry. Type II supernovae do exhibit H spectral lines.

Type I is further divided into Type Ia, Ib, and Ic. Type Ia supernovae have silicon spectral lines. Type Ib has no silicon or hydrogen, but helium. Type Ic has no silicon, no hydrogen, and no helium at all. Type II is divided into Type IIn, IIP, IIL, and IIb. Type IIn exhibits hydrogen, as all Type II's do, but their lines are narrowed, indicating that the hydrogen was moving slower than normal. Astronomers argue this is caused by the ejection of the hydrogen before explosion, which has been substantiated by some observation. Type IIP supernovae don't differ in ingredients, but they remain at their peak (plateau) before a gradual ^{5}6Ni-controlled descent longer than other supernovae. Type IIL have the normal ingredients, but drop rapidly and linearly after peak. Type IIb spectra change fundamentally over time: early in the explosion hydrogen can be observed, but later these spectral lines shrink and vanish from the spectra.

Spectra are our first and dearest friends in astronomical observation. To deduce how supernovae explode and what they explode from, lightcurves provide essential information to constrain computer models of the explosion. With this interest. we compare the pre-plateau lightcurves of two supernovae: 2014J, a Type Ia, and 1987A, a Type IIP. We plot magnitude vs. time for each band individually, all bands together, and compare linear fits for the rise from cooling trough to brightness plateau.

3 Type Ia Example: 2014J

The mechanisms of Type Ia supernovae are, like most other supernovae, only gestured at by modern astrophysics; we can guess some of what happens, but the exact mechanisms of the explosion and progenitors remain mysterious. What we do know is that Type Ia lightcurves are remarkably consistent. They have the steepest climb to the ^{56}Ni plateau of all the types, post-cooling. We plot this range here for SN2014J: first band by band, then with all the bands compared together.

4 TypeII-b Example: 1987A

Type II-P supernovae starkly contrast with the quick rise-and-drop in magnitude of other supernovae before ^{56}Ni beta decay takes hold of the magnitude. Type II-L supernovae exhibit lightcurves very similar to those of Type Ias, but II-Ps show unusual slow rises and relatively flat plateaus that can stretch to 100 days or more. Here we plot magnitude versus time for five bands of 1987A, the quintessential Type II-P supernova, with special attention to its pre-plateau shape.

5 Lightcurve Comparison

From these magnitude vs. time plots, we can calculate a linear fit to the climb between cooling trough and plateau. This provides a quick comparison for how quickly the brightness rises to the plateau in the first moments of the supernovae.

Below are plots of the U band of 1987A and 2014J with a linear fit. The U band has been selected because in both lightcurves, its rise is very linear and free of the "shoulder" observed in the 2014J spectrum. For both supernovae, a range has been selected to focus only on the specific, initial climb. For 1987A, this is 47400 through 47800 seconds. For 2014J, this is 56700 through 56720 seconds.

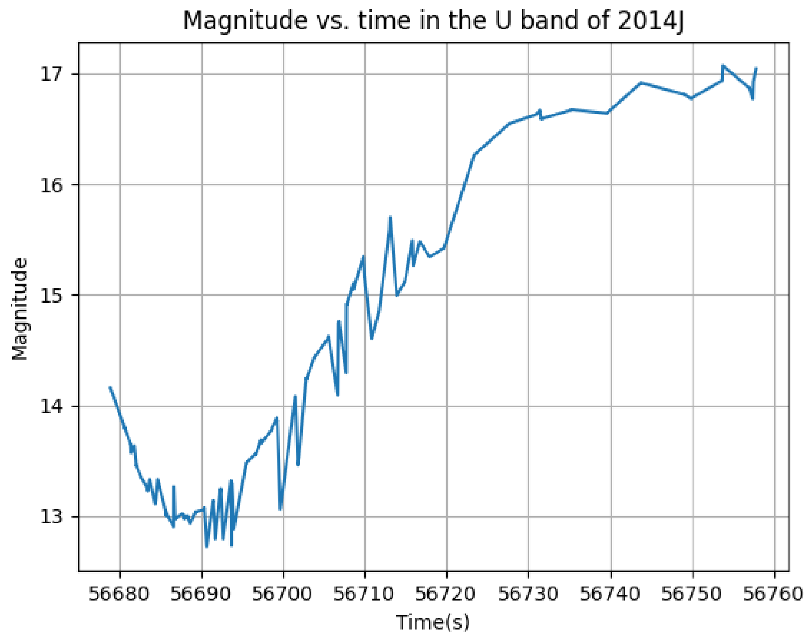

Figure 1: Change in brightness of SN2014J across time in the U band.

From these plots, we observe a slope of 0.0103319 for the U band of 1987A and a slope of 0.0975568 for the U band of 2014J. This difference fits our expectations based on the typical lightcurves of Type IIP and Type Ia supernovae: Type Ia tend to rise in brightness much more sharply at the start, while Type IIP climb more slowly. 1987A and 2014J are typical examples of this feature.

6 Summary

Our current system for the classification of supernovae can be cumbersome and inefficient as our understanding of these events increases. Type IIb, for example, exhibits features of multiple categories. Still, these categories generally describe features of supernovae that can be gathered at a glance: spectral features, plateau shape, or the steepness of the rise and fall of brightness. For now they are useful. Future discoveries about the explosion mechanisms and progenitors of supernovae may present a new, more direct and intuitive taxonomic system. The astronomy community must be willing to adapt our categories with our understanding as we explore the cosmos.

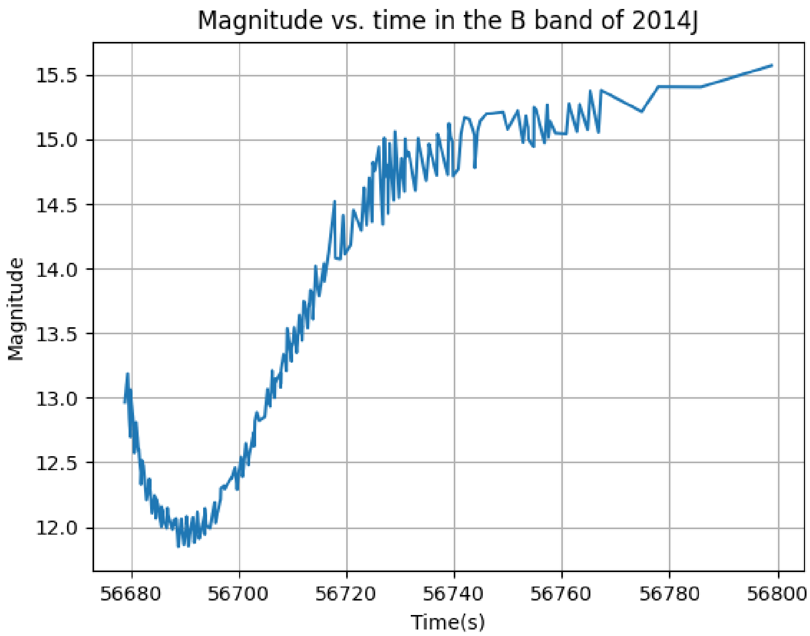

Figure 2: Change in brightness of SN2014J across time in the B band.

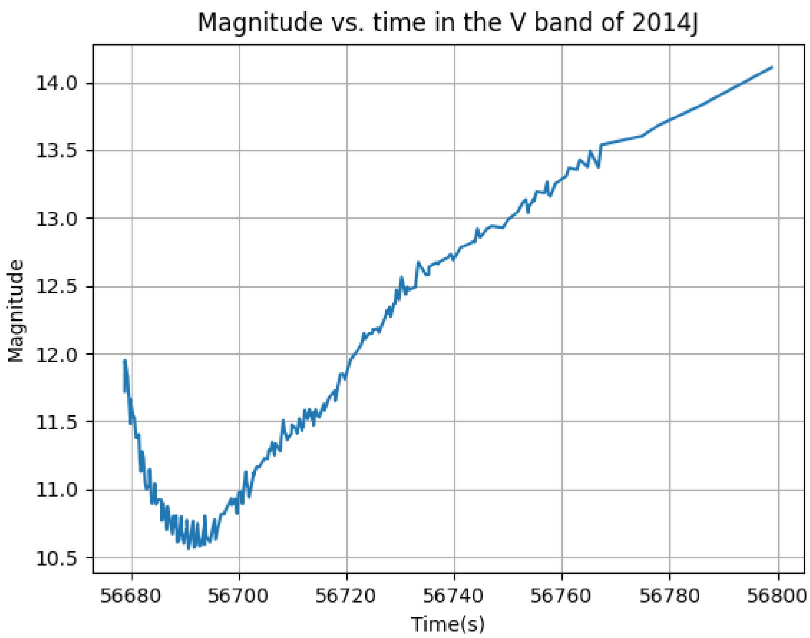

Figure 3: Change in brightness of SN2014J across time in the V band.

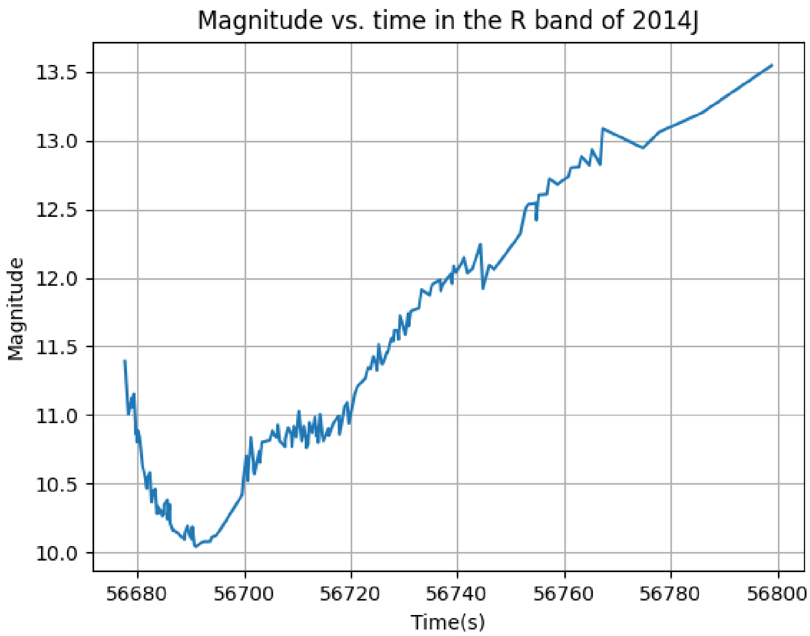

Figure 4: Change in brightness of SN2014J across time in the R band.

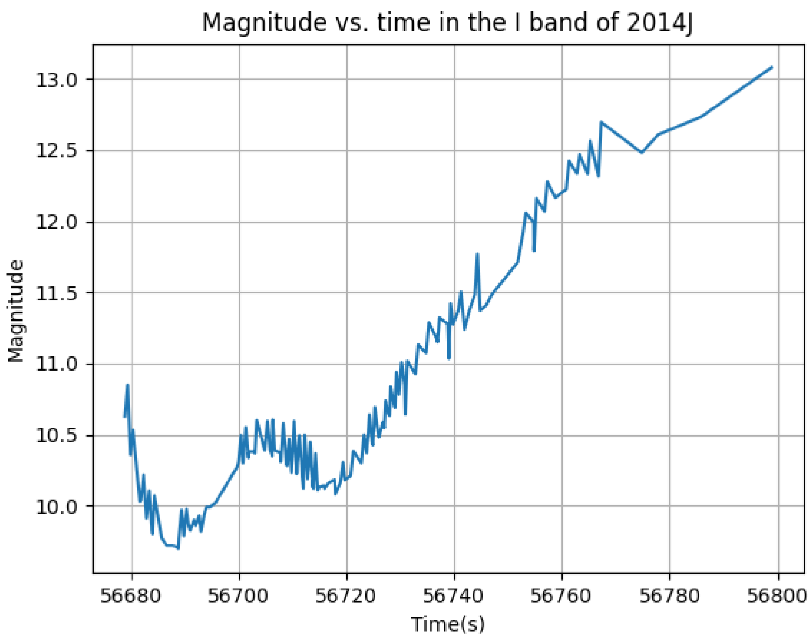

Figure 5: Change in brightness of SN2014J aross time in the I band.

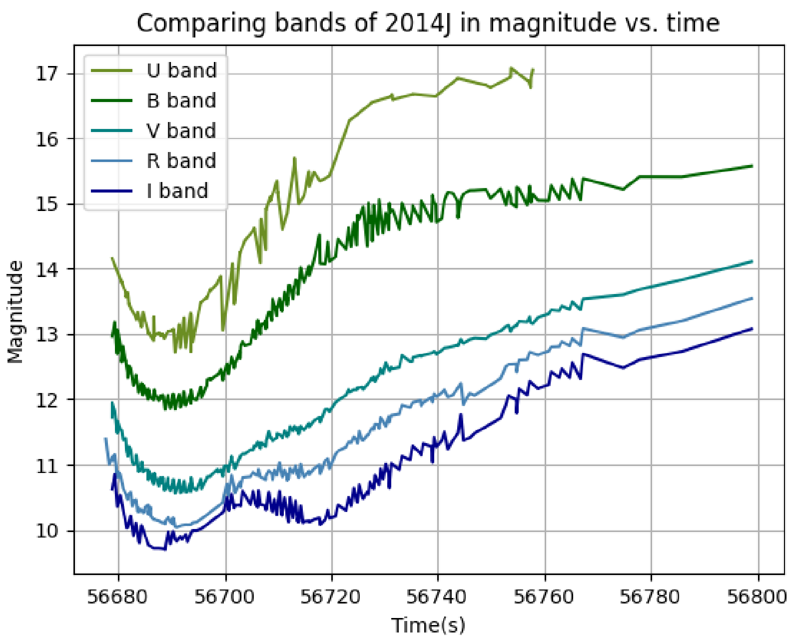

Figure 6: All bands of SN2014J together. Note especially the differences between the shape of the I band brightness over time compared to the bluer colors. Just before 56720 seconds, a "shoulder" is visible in the curve. Its beginnings show up in the R band as well.

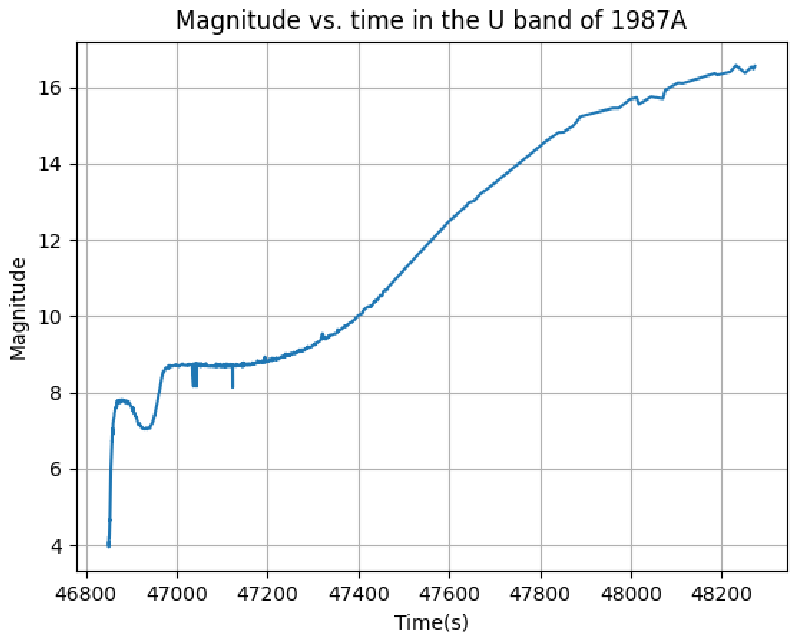

Figure 7: Change in brightness of SN1987A across time in the U band.

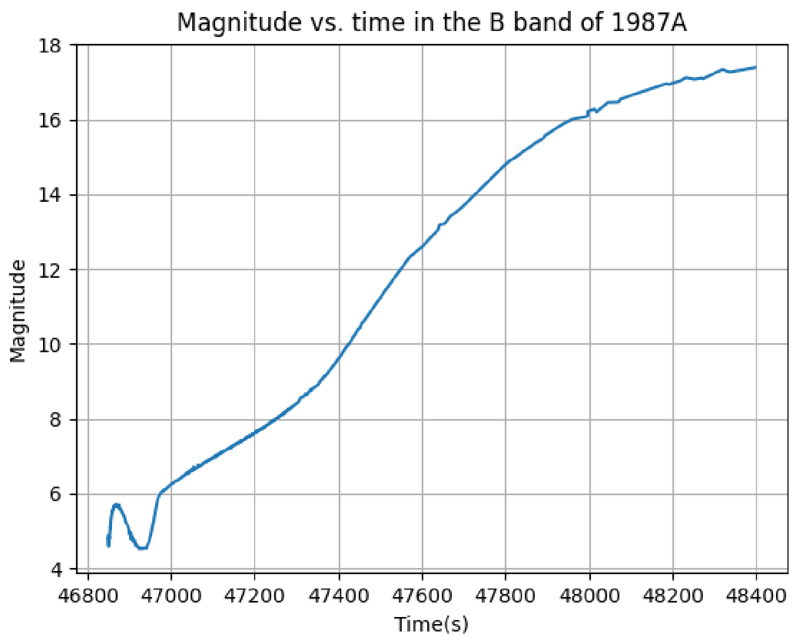

Figure 8: Change in brightness of SN1987A across time in the B band.

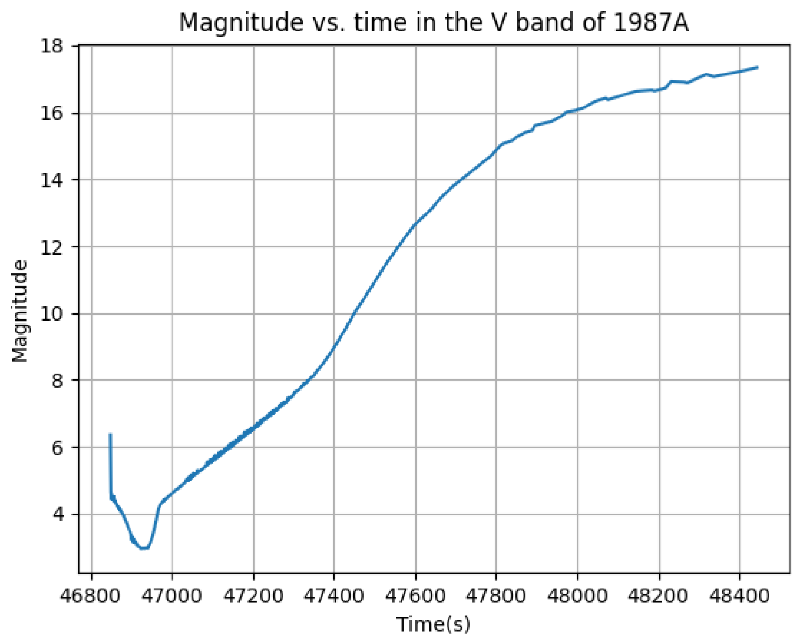

Figure 9: Change in brightness of SN1987A across time in the V band.

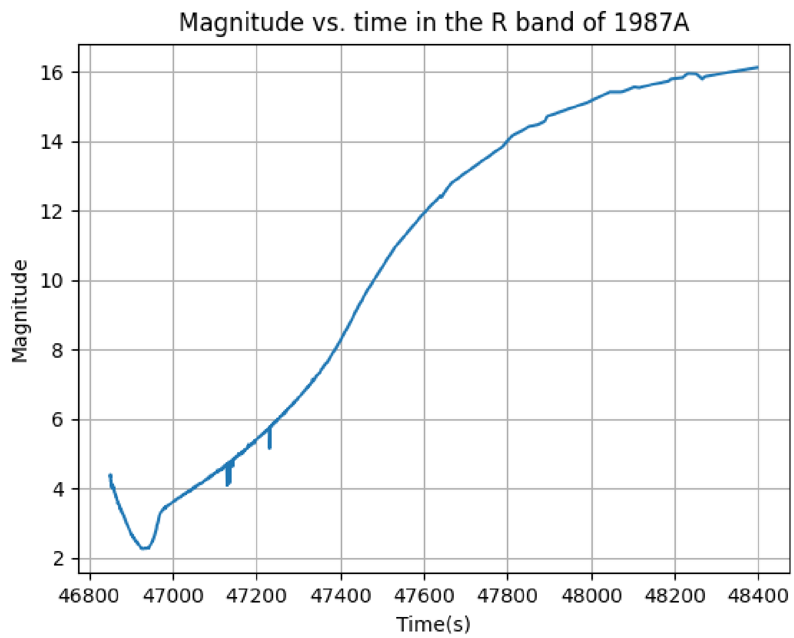

Figure 10: Change in brightness of SN1987A across time in the R band.

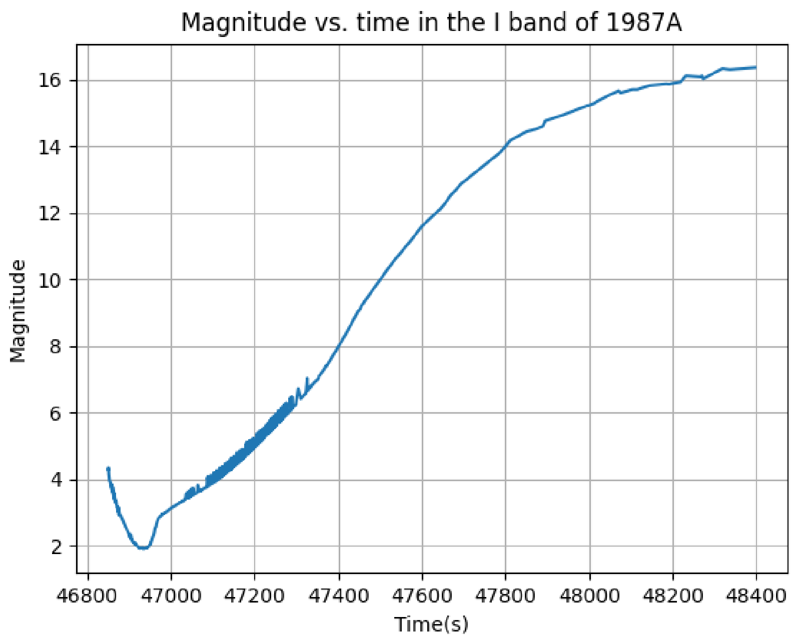

Figure 11: Change in brightness of SN1987A aross time in the I band.

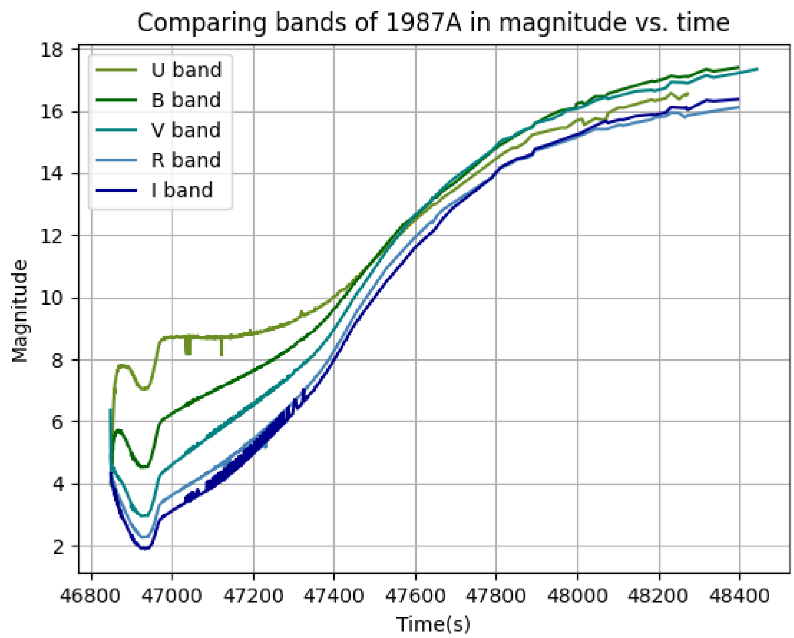

Figure 12: All bands of SN1987A together. Note the similarity in magnitude vs. time curve of each of the five bands, as opposed to the distinct differences between bands observed in 2014J.

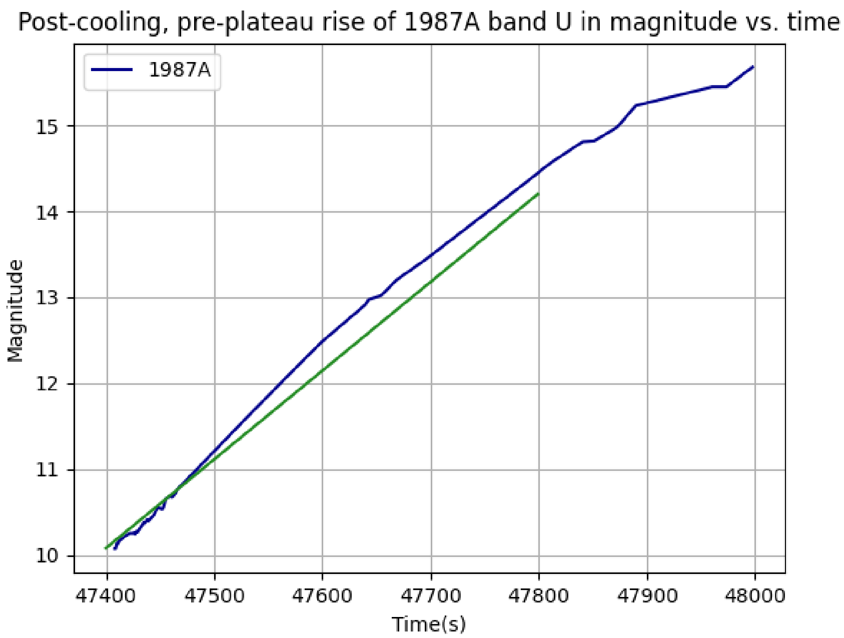

Figure 13: Linear fit to magnitude vs. time in U band of 1987A. Slope for 1987A = 0.0103319.

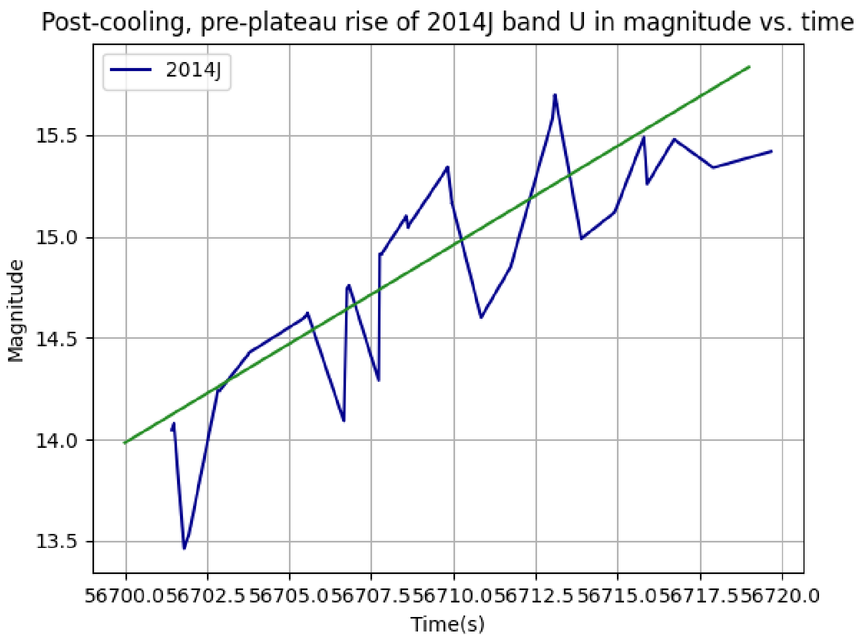

Figure 14: Linear fit to magnitude vs. time in U band of 1987A. Slope for 2014J = 0.0975568.