Interaction-Powered Supernovae as Probes of the High-Redshift Universe

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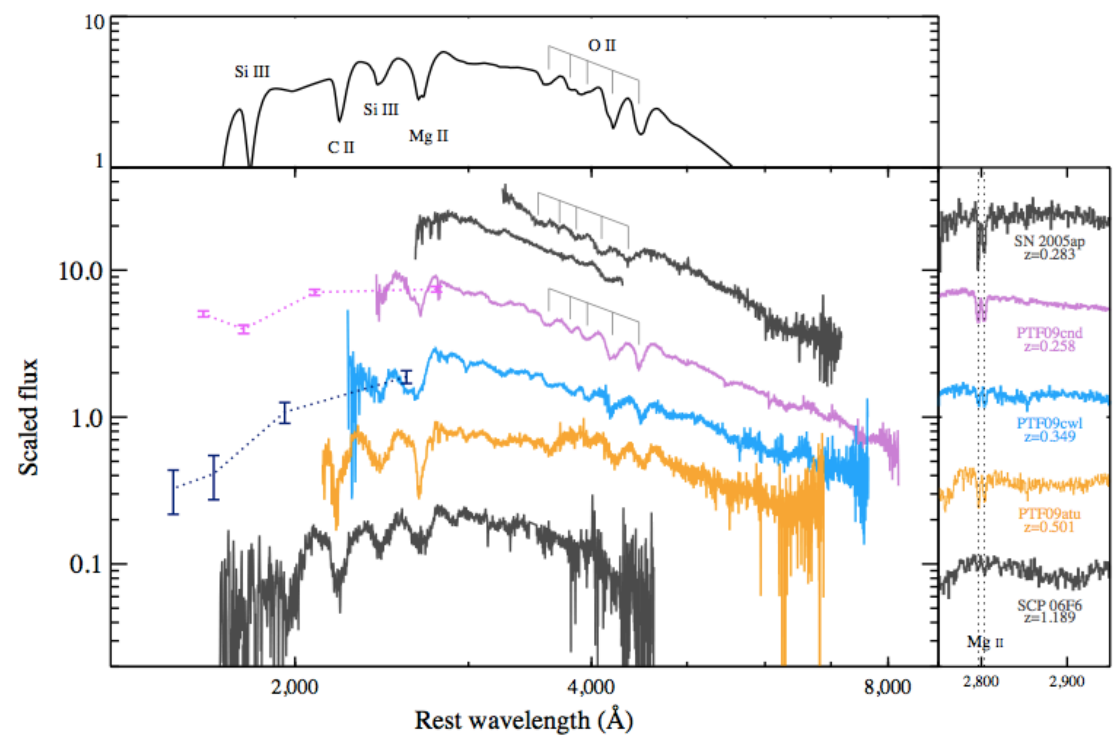
A supernova (SN) becomes as bright as a galaxy, and it is a powerful tool for probing the high-redshift universe. In particular, extremely luminous SNe (M_R < -21) were suggested to be detectable at z > 2, which is difficult for type Ia SNe to reach. Some luminous SNe are believed to be powered by the interaction of the SN ejecta with the circumstellar medium. For example, type IIn SNe, a typical type of luminous SNe, show evidence of this interaction. One of the interesting features of such interaction-powered SNe is the fact that they are bright in UV. With their intrinsic brightness in UV, interaction-powered SNe could unveil the properties of stars at high redshift and probe the primordial universe. We performed multigroup light curve calculations of interaction-powered SNe using STELLA code. Based on the synthetic multicolor light curves, we estimate the detectability of interaction-powered SNe at high redshifts with several telescopes.

Interaction-powered supernovae

If a SN is occurred in a dense CSM, the ejecta interacts with the CSM and this interaction converts kinetic energy of the ejecta to radiation energy. This makes the SN very bright and blue, which means that we can detect it even if it occurs in the high-z Universe.

- examples of interaction-powered SNe:
  Type IIn, pulsational pair-instability SNe, etc...

Observations of interaction-powered SNe from PTF (Quimby et al. 2009)



Models

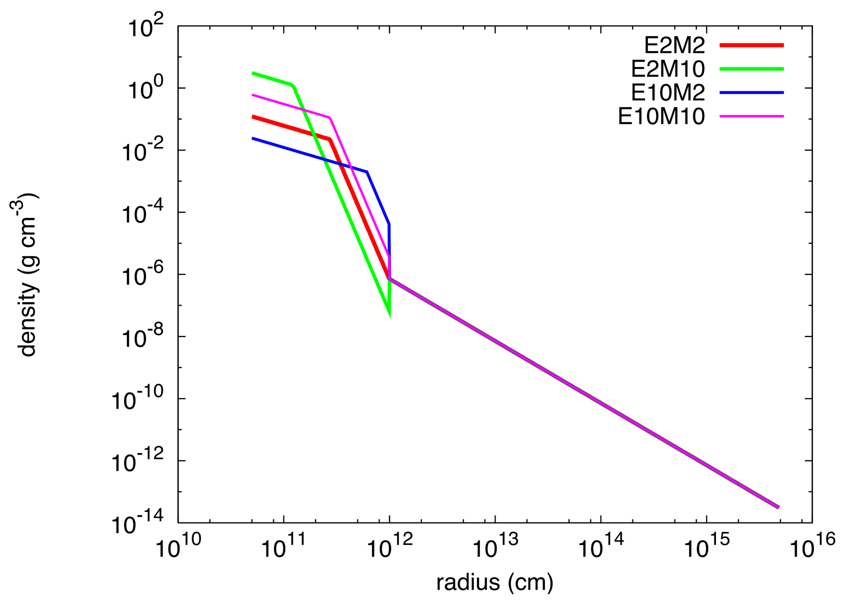
- Ejecta: Power-law density + homologous
  $\rho \propto r^{-1}$ inside, $\rho \propto r^{-8}$ outside (Chevalier & Soker 1989)
- CSM: steady wind, outer boundary= 5×10^{15} cm
  mass loss rate: $0.1\ M_\odot/\mathrm{yr}$ (eta Car-like), $\rho \propto r^{-2}$
- Ejecta hit CSM at 10^{12} cm (weak dependance on the results)

ejecta models

name	$E_{\rm kin}$	$M_{\rm ej}$
E2M2	2	2
E2M10	2	10
E10M2	10	2
E10M10	10	10

units : 10^{51}erg, $M_\odot$

density structure at the beginning of interaction

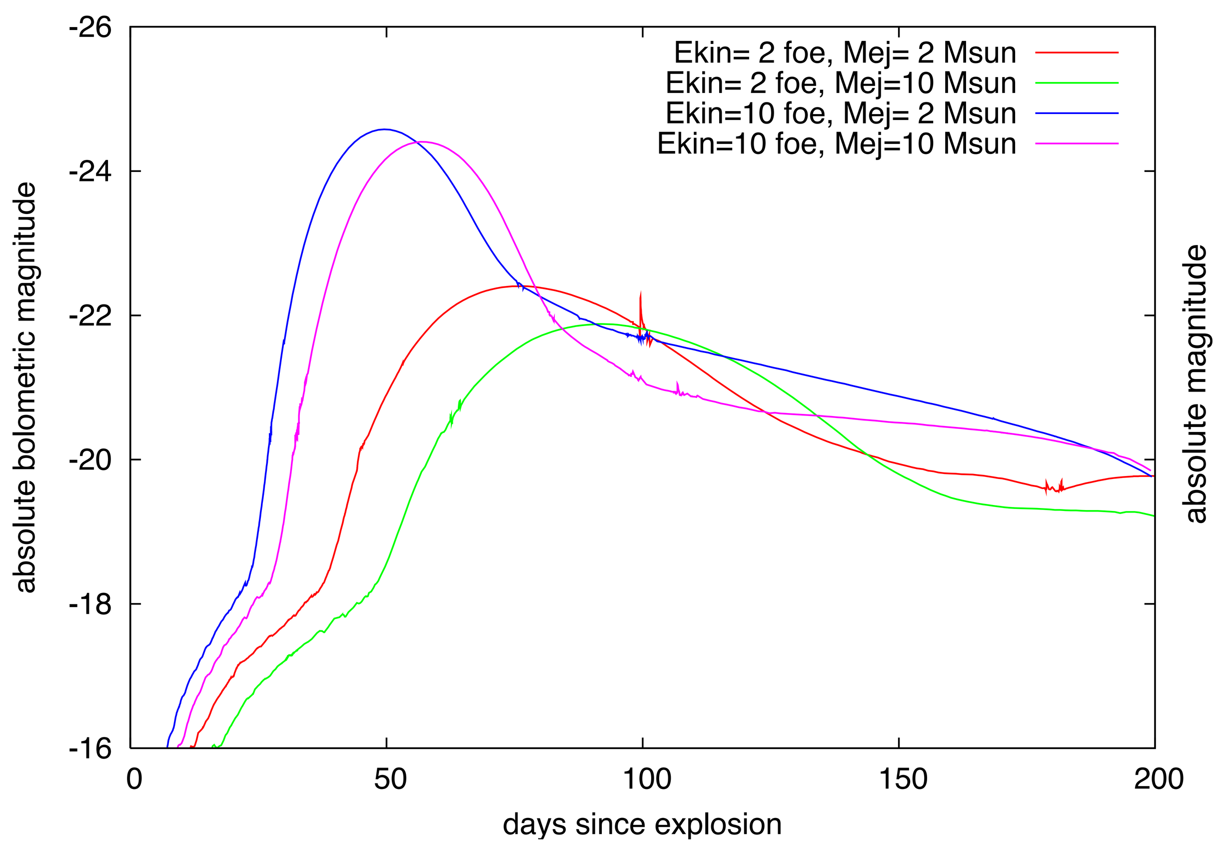


Numerical calculations of light curves

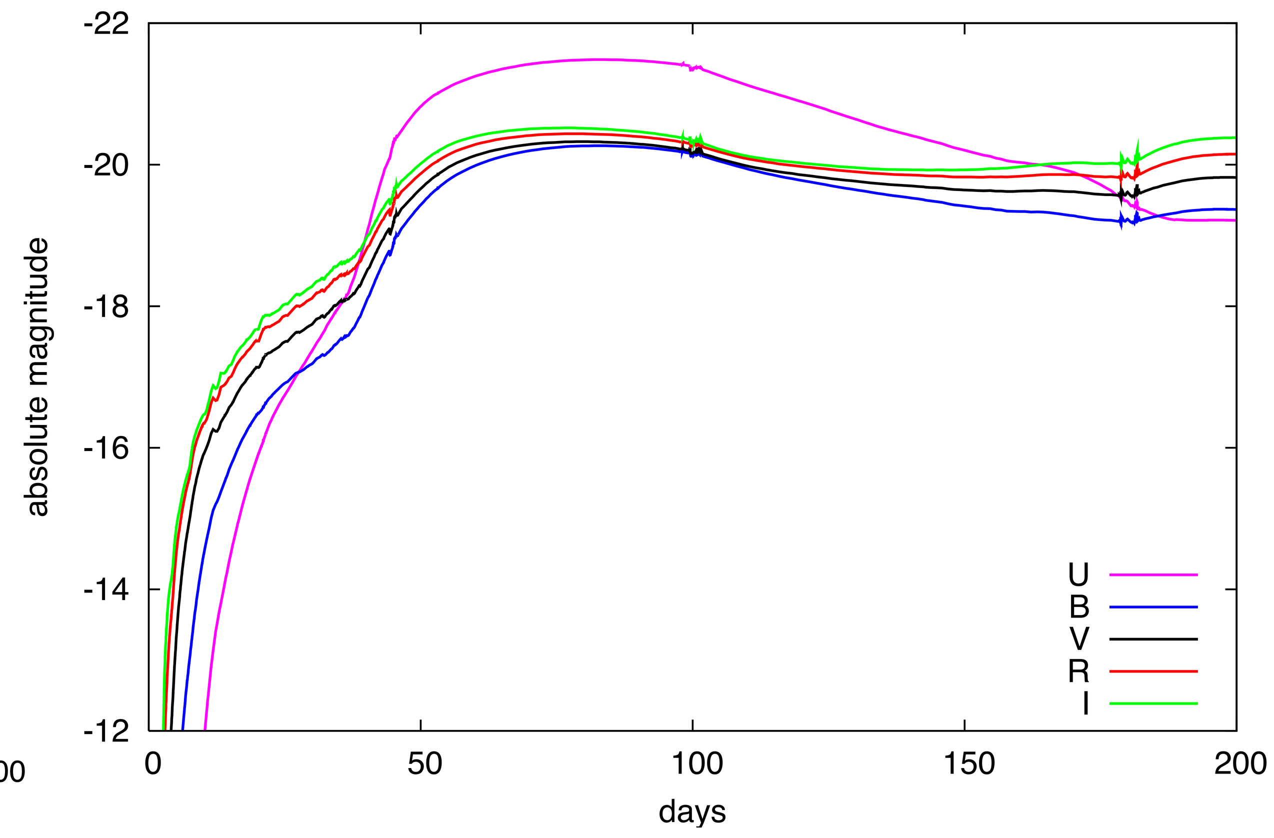
- STELLA code for the LC calculations
  one-dimensional multi-frequency radiation hydrodynamics
  (e.g., Blinnikov & Bartunov 1993, Blinnikov et al. 1998)

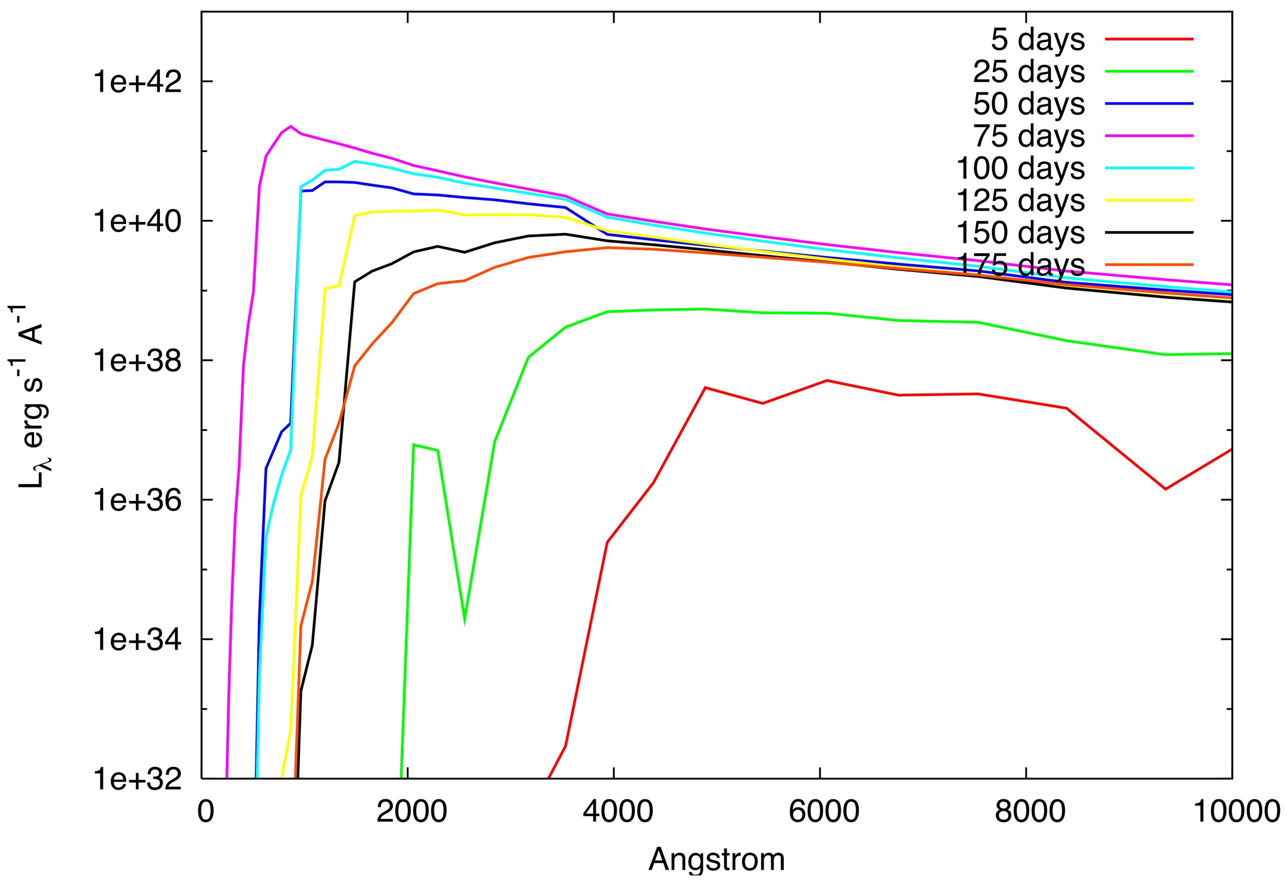
Results

- bolometric LCs



- multicolor LCs and SED of E2M2 ($\mathbf{E_{kin} = 2 \times 10^{51} erg,\ M_{ej} = 2\ M_\odot}$)





Detectability (model E2M2)

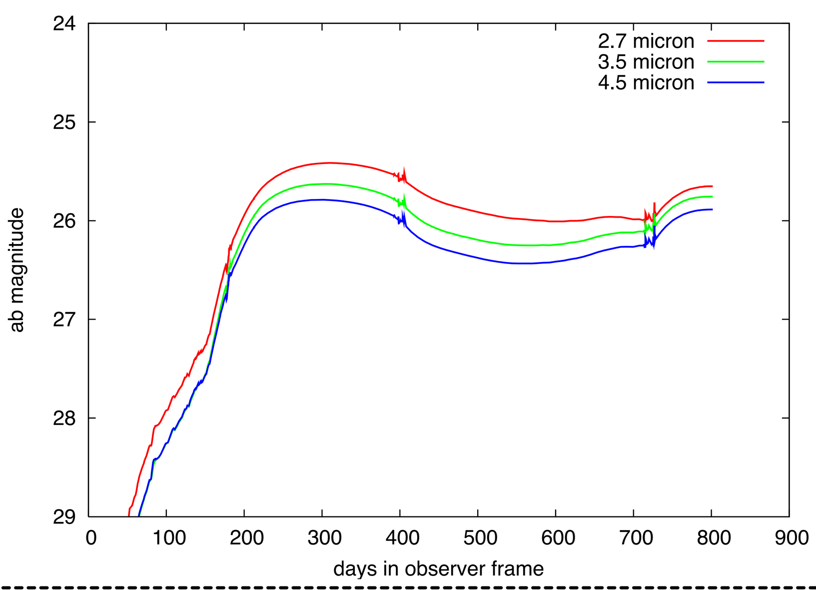
- assumptions $\Omega_\Lambda = 0.7,\ \Omega_M = 0.3,\ H_0 = 70$ km/s/Mpc
progenitor: $M_{\rm MS} > 100\ M_\odot$ (rough estimate), Salpeter IMF (Salpeter 1955), SFR by Hopkins & Beacom (2006)

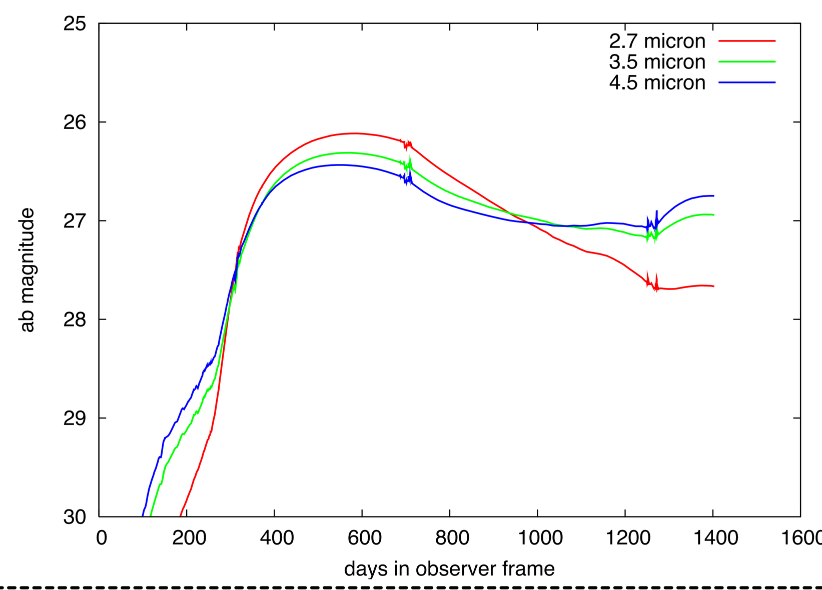
z=3 rate: $1,400\ \mathrm{yr^{-1}\ deg^{-2}}$ | **z=6** rate: $70\ \mathrm{yr^{-1}\ deg^{-2}}$ | **z=10**

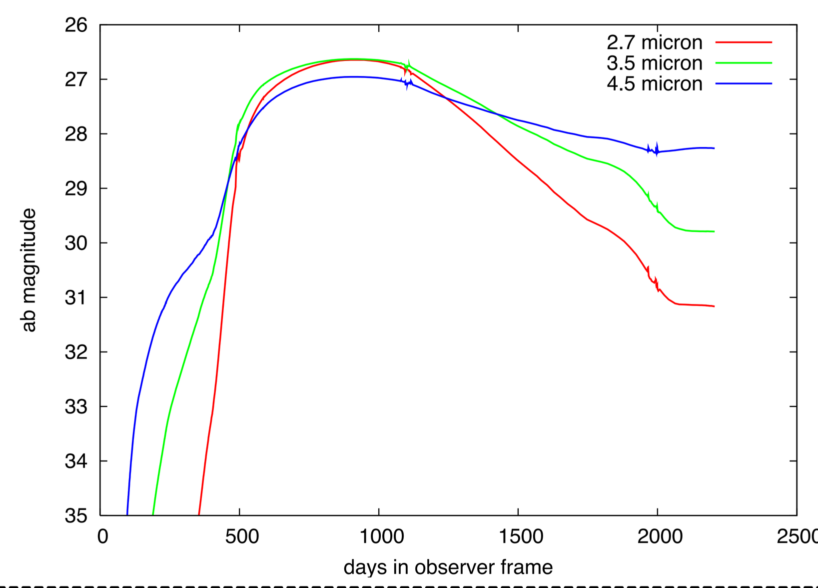
- JWST/NIRCam

LCs of wide band filters of 2.7, 3.5, and 4.5 microns

detection limit: ~ 29 mag (10-sigma, 10000 sec)



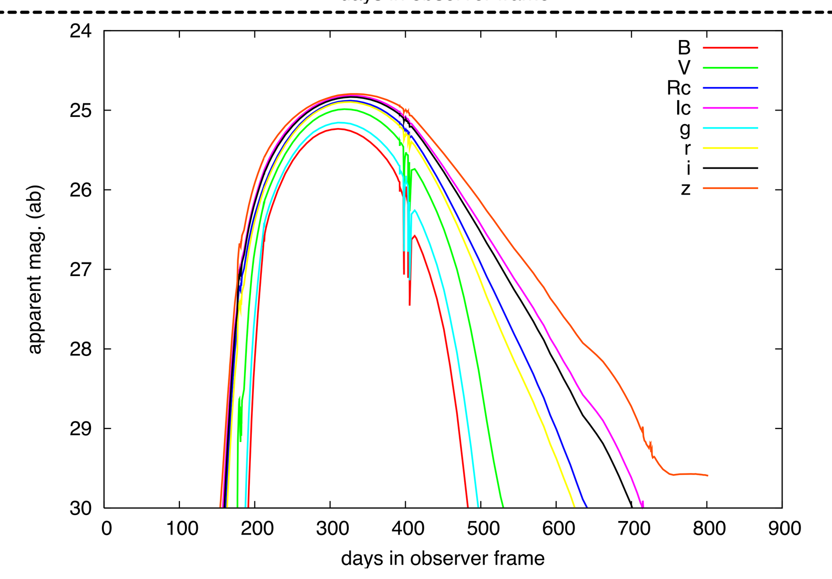


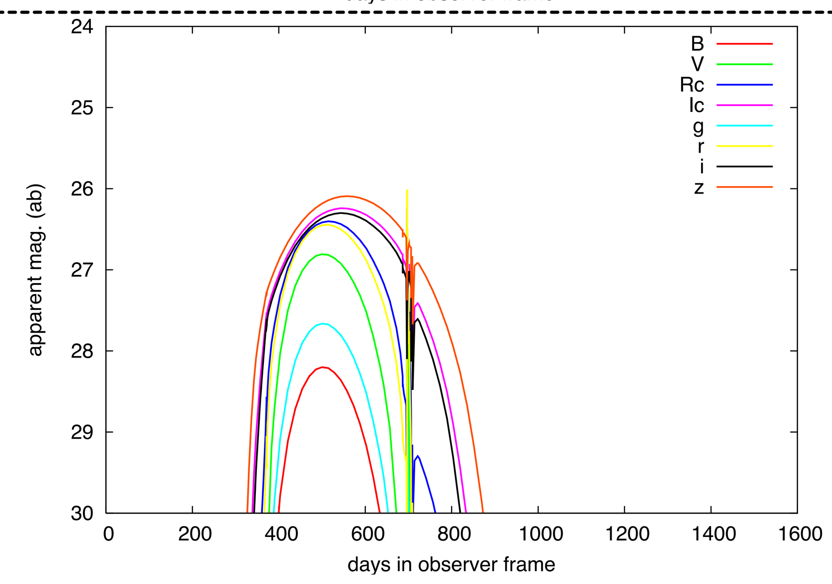


- Subaru/Suprime-Cam

LCs of wide band filters

detection limit: ~ 25 mag (5-sigma, 1 hour)





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- References
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Blinnikov, S. I. & Bartunov O. S., 1993, A&A, 273, 106
Blinnikov, S. I., et al., 1998, ApJ, 496, 454
- Filters and sensitivity of NIRCam (JWST)
http://ircamera.as.arizona.edu/nircam/features.html
- Filters and sensitivity of Suprime-Cam (Subaru)
http://www.naoj.org/Observing/Instruments/SCam/sensitivity.html