Dust Scattering: Effects on the Light Curves and Polarization Evolution of SNe Ia

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Hu+ 2020 in prep

Overview

Xiaofeng's paper

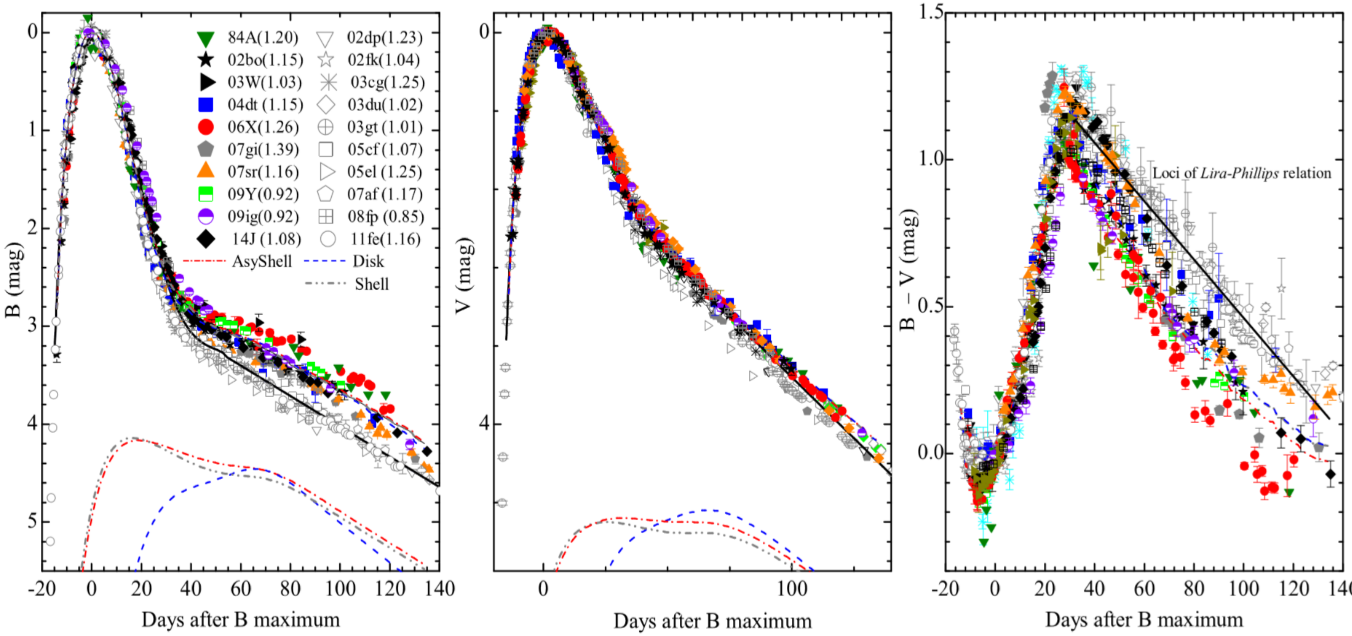
The geometric distribution of the CSM
Statistical results of fitting the LCs of HV SNe Ia

Mattia's paper

Predictions on color evolution
Cases of SN 2006X and 2014J
Predictions on polarization evolution
Case of SN 2014J

Wenxiong's paper

Kernel distribution of the intensity due to dust emission
Case of SN 2017cbv



Wang et al. 2019

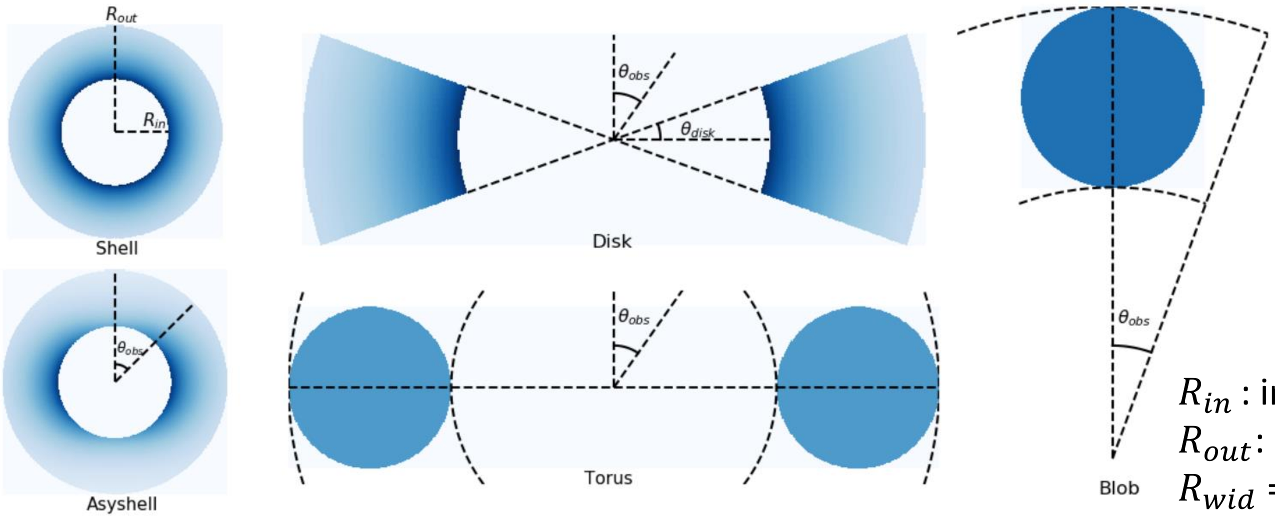
Template : NV SNe Ia

CSM : Shell
Disk
Asymmetric shell
(Asyshell)

$R_{inner} \sim 1 \times 10^{17} cm \quad R_{outer} \sim 2 \times 10^{17} cm$

$\tau(shell) = 0.12 \quad \tau(asyshell) = 0.15 \quad \tau(disk) = 0.7$

$\dot{M}_w(shell) \sim 9 \times 10^{-7} M_\odot yr^{-1} \quad \dot{M}_w(asyshell) \sim 8 \times 10^{-7} M_\odot yr^{-1} \quad \dot{M}_w(disk) \sim 6 \times 10^{-6} M_\odot yr^{-1}$

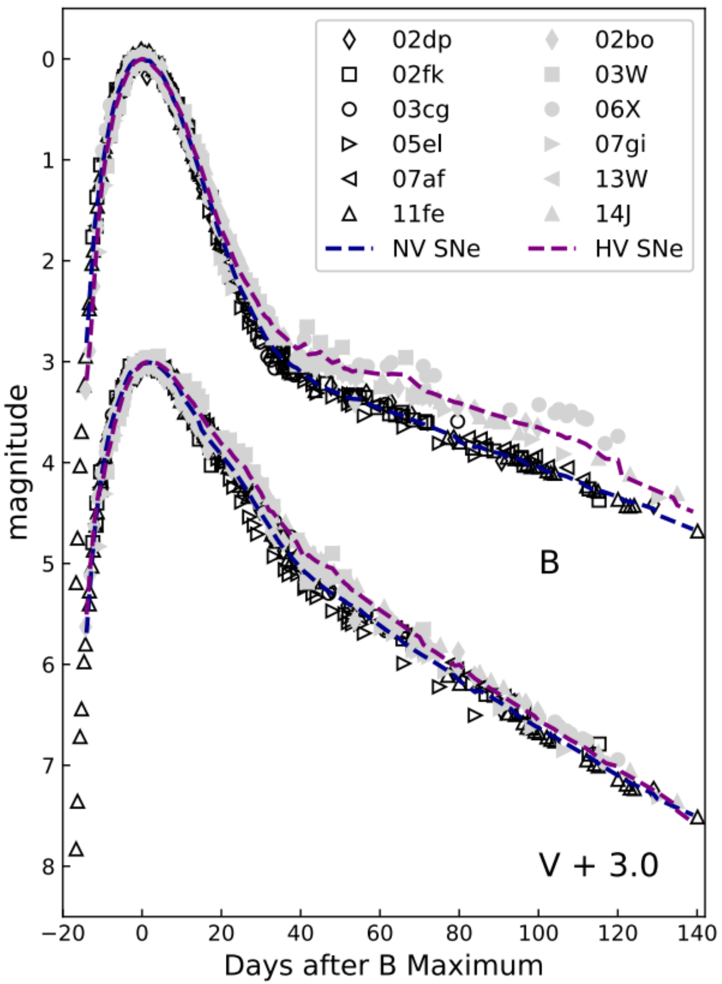


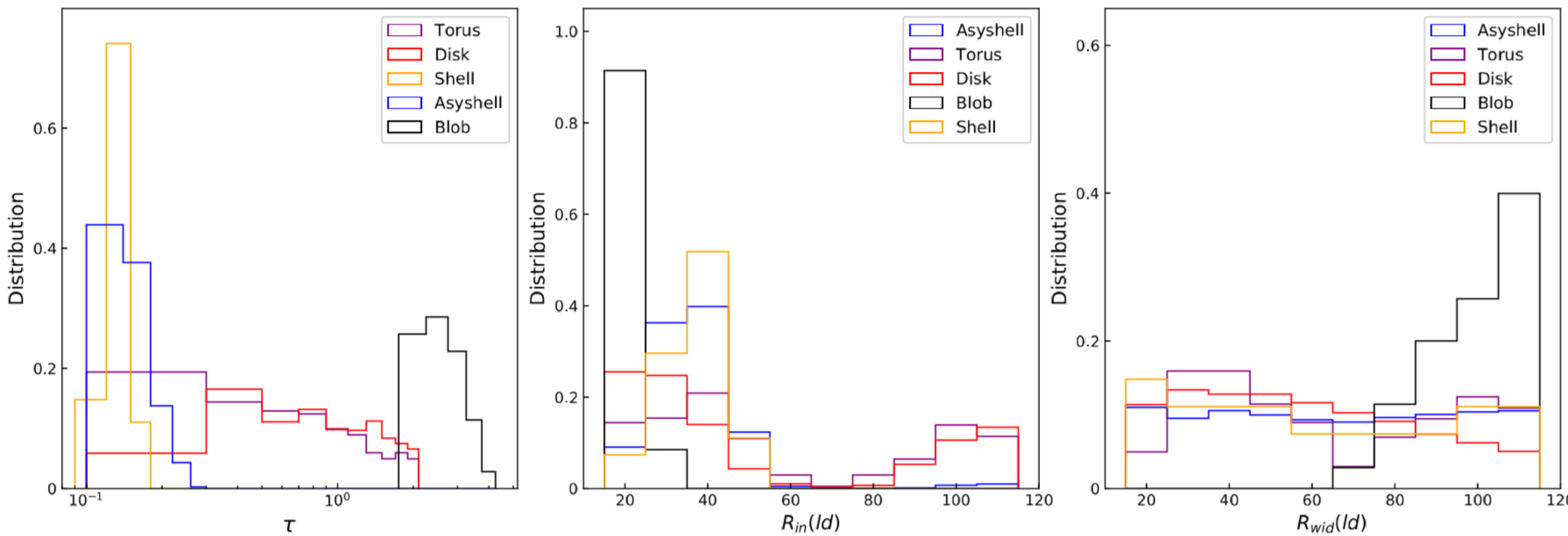
R_{in} : inner radius of CSM
R_{out}: outer radius of CSM
R_{wid} = R_{out} - R_{in}
τ : optical depth
θ_{disk}: opening angle of the disk structure
θ_{obs} : observing angle
(m,s0): the degree of asymmetry for AsyShell structure

$n(R) = A/R^2$: the radial distribution for Shell, Disk
$n(R) = (s0 \ * sin^m\theta + 1 - s0) \ * \ A/R^2$: distribution for AsyShell
$n(R) = const$: for Blob and Torus

	Range and Interval (Δ)	
R_{in}	$[20, 110]$ $\Delta = 10ld$	All structures
R_{wid}	$[20, 110]$ $\Delta = 10ld$	All structures
τ	$[0.2, 2.0]$ $\Delta = 0.2$	Disk, Torus
τ	$[0.03, 0.3]$ $\Delta = 0.05$	Shell
τ	$[0.04, 0.4]$ $\Delta = 0.05$	Asyshell
τ	$[0.5, 5.0]$ $\Delta = 0.5$	Blob
θ_{disk}	$[6°, 30°]$ $\Delta = 6°$	Disk
m	$[0.5, 1, 2, 3, 4]$	Asyshell
$s0$	$[0.1, 0.9]$ $\Delta = 0.2$	Asyshell
θ_{obs}	$[10, 180]$ $\Delta = 10°$	Blob
θ_{obs}	$[10, 90]$ $\Delta = 10°$	Disk, Torus, Asyshell

Shell : 1000 simulations
Blob : 1000 simulations and 18 observing angles
Torus: 1000 simulations and 9 observing angles
Disk : 5000 simulations
Asyshell : 25000 simulations

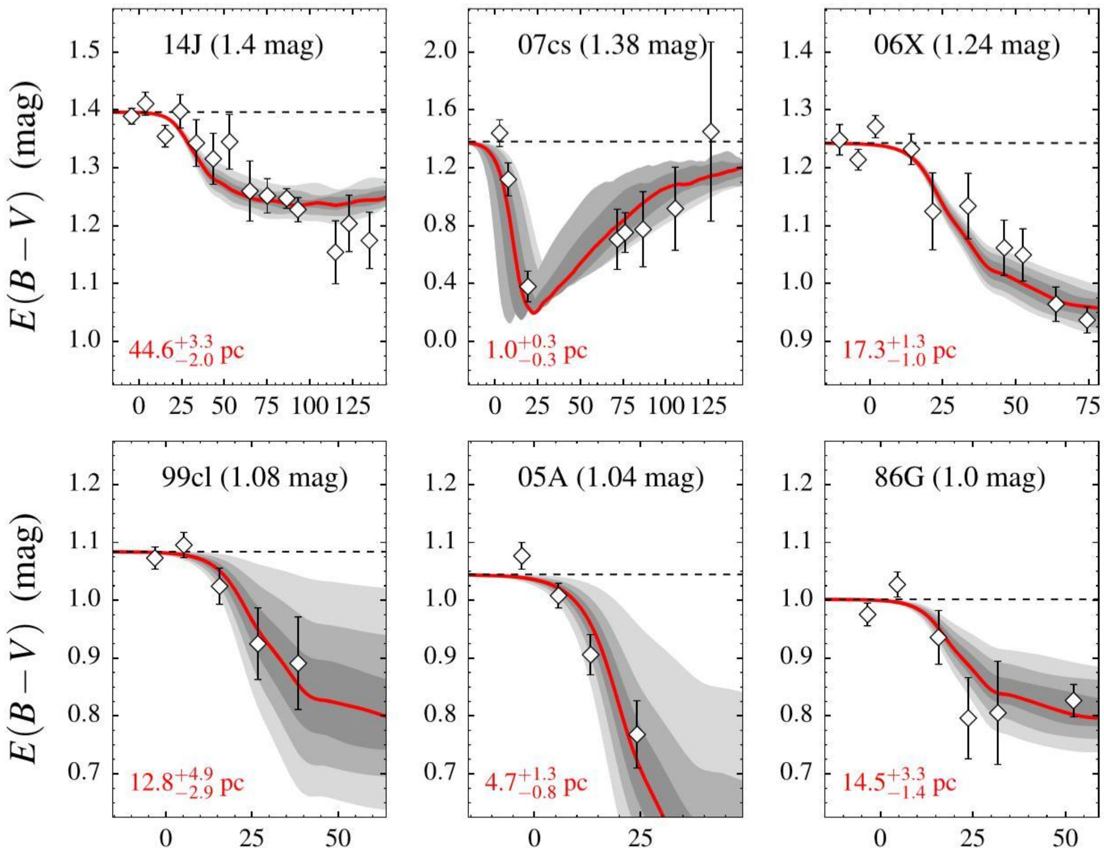




The parameter distributions with RMSE less than 0.07.

Hu et al. in prep

Blob : be abandoned due to its extreme values of parameters.
Tours and disk : similar distributions
Shell and asyshell : similar distributions



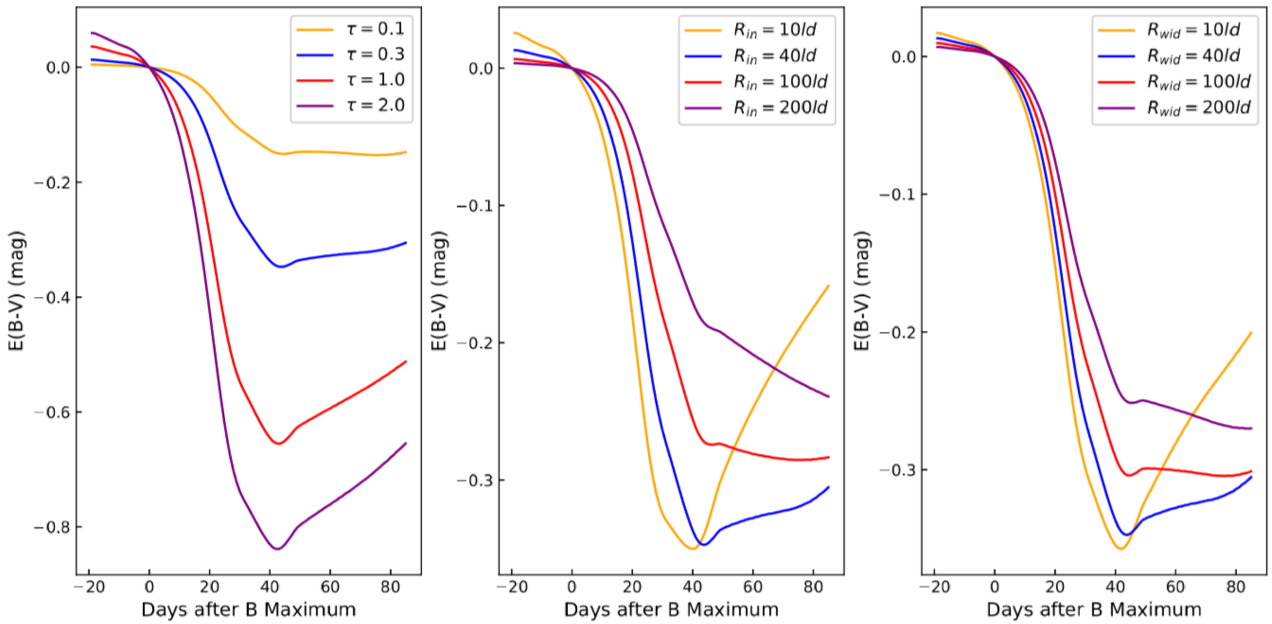
Bulla et al. 2018

CSM : Spherical shell
$R_{inner} = 0.95R_{outer}$
(Thin)

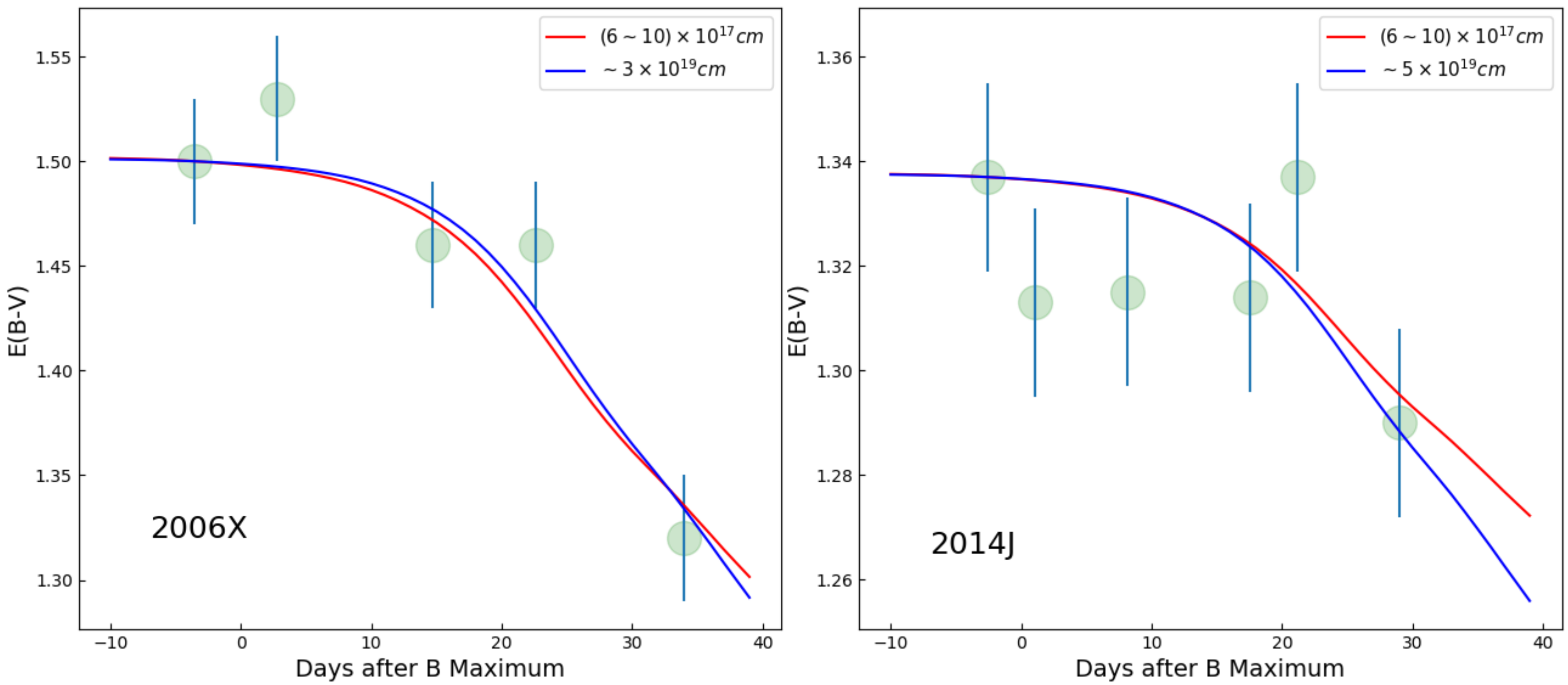
Template : From Hsiao 2007

Distance : almost ISM

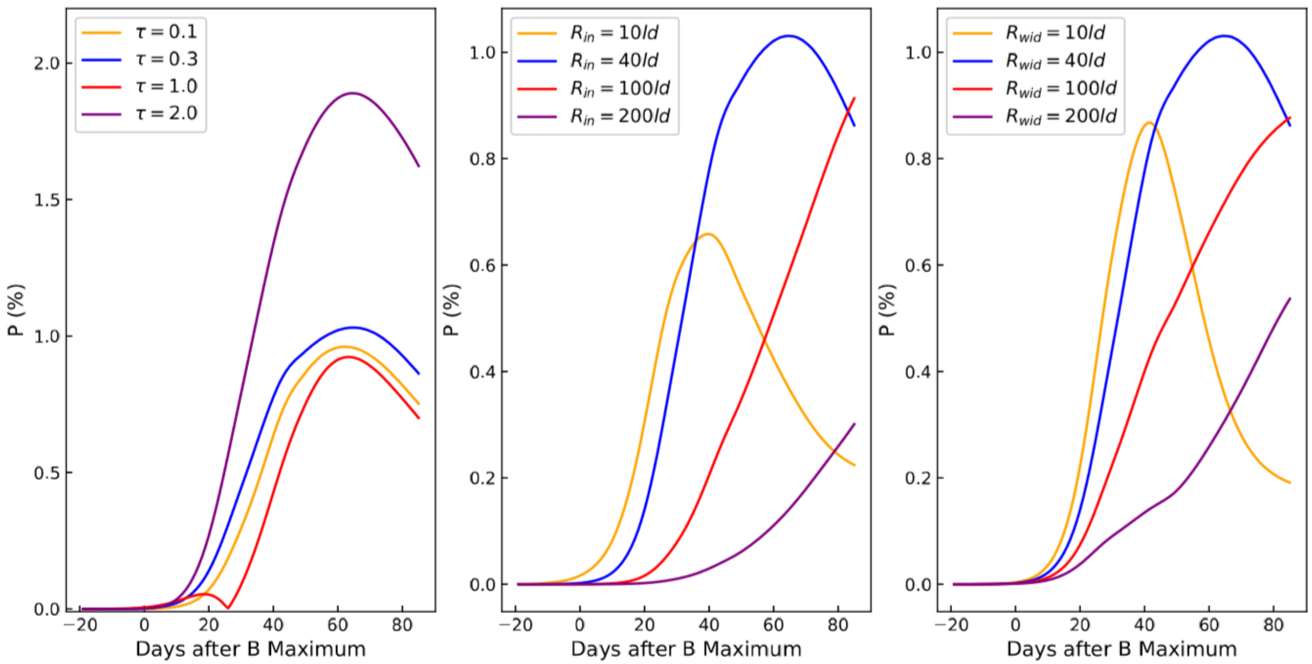
Characteristic values :
$R_{in} = 40\ ld$
$(\sim 10^{17} cm)$
$R_{wid} = 40\ ld$
$R_{out} = R_{in} + R_{wid}$
$\tau = 0.3\ (B\ band)$



In middle and right panels, the yellow lines can be regarded as the close or thin shell (10ld to 50 ld, and 40 ld to 50 ld). The color curves have large deviation from 06X and 14J.



Blue lines : $\sim3\times10^{19}cm$ (Thin shell, which is similar with the situation in Bulla et al. 2018).
Red lines : $6\sim10\ \times\ 10^{17}cm$ (Extended shell, the situation in my work and Li's, Wang's papers).

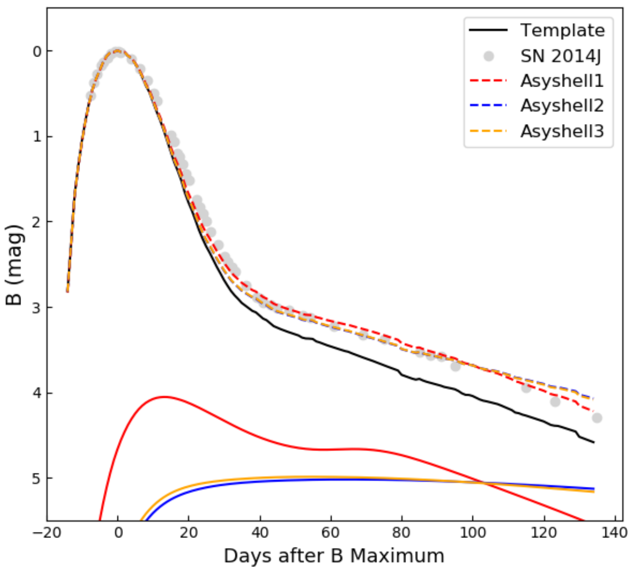


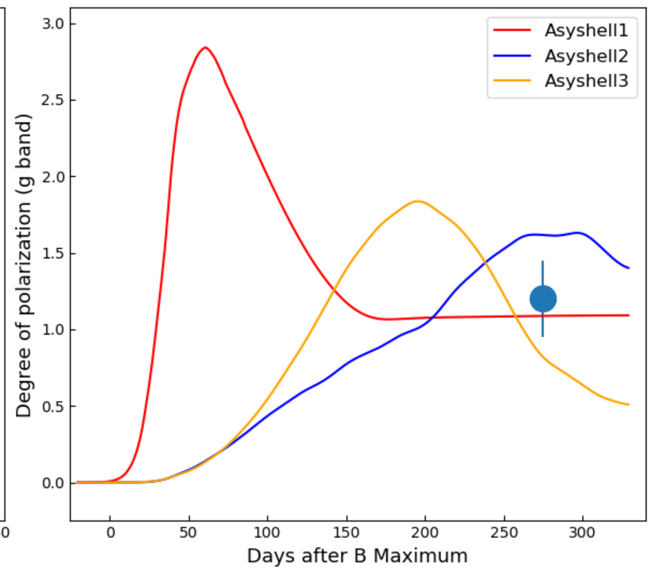
Asymmetric shell

Template : from Hsiao

$\tau = 0.3$
$R_{in} = 40\ ld$
$R_{wid} = 40\ ld$
B band
$(m, s0) = (3, 0.8)$
$\theta_{obs} = 45^{\circ}$

Shell, ISM, or CSM with large distance : zero degree of polarization.
Different positions produce different profiles of polarization evolution.





Polarimetry from Yang et al. 2018

Hu+ in prep

	τ	$R_{in}(ld)$	$R_{out}(ld)$	m	$s0$	θ_{obs}
Asyshell1	0.2	35	90	3.0	0.8	60°
Asyshell2	0.4	140	280	3.0	0.8	30°
Asyshell3	0.4	200	250	3.0	0.8	40°

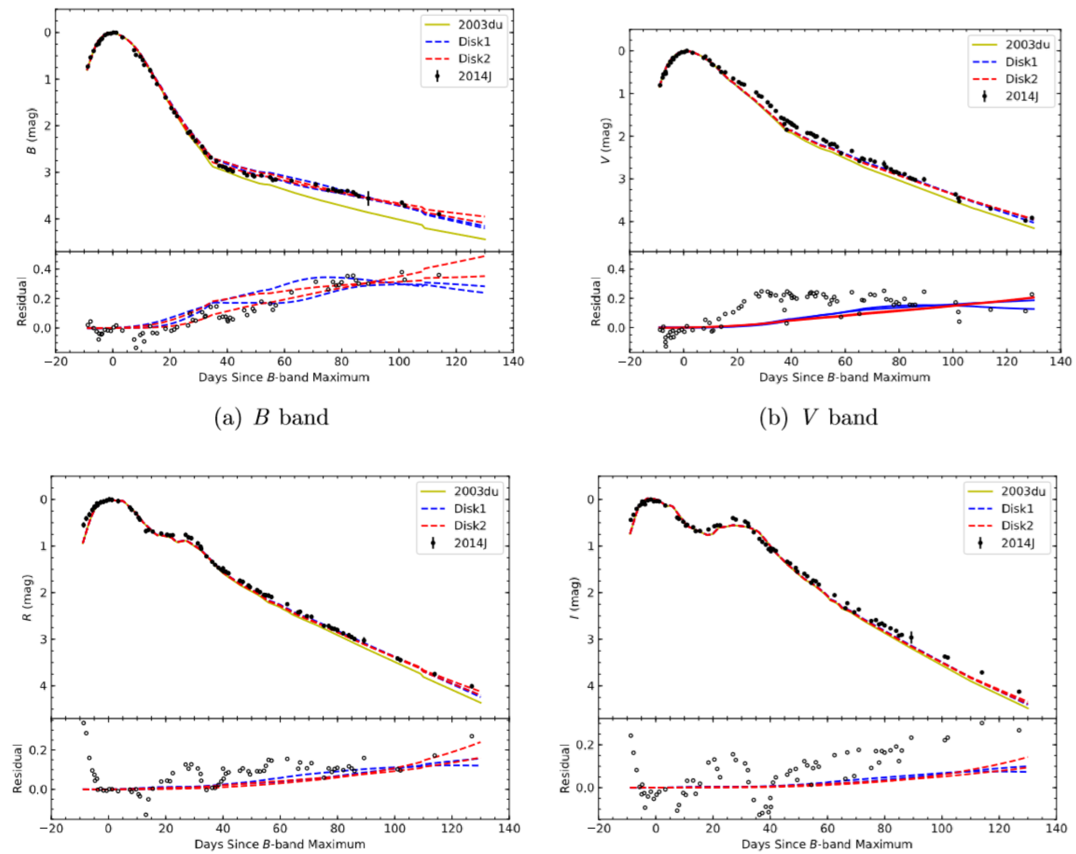
Li et al. 2019

Template : SN 2003du (NV)

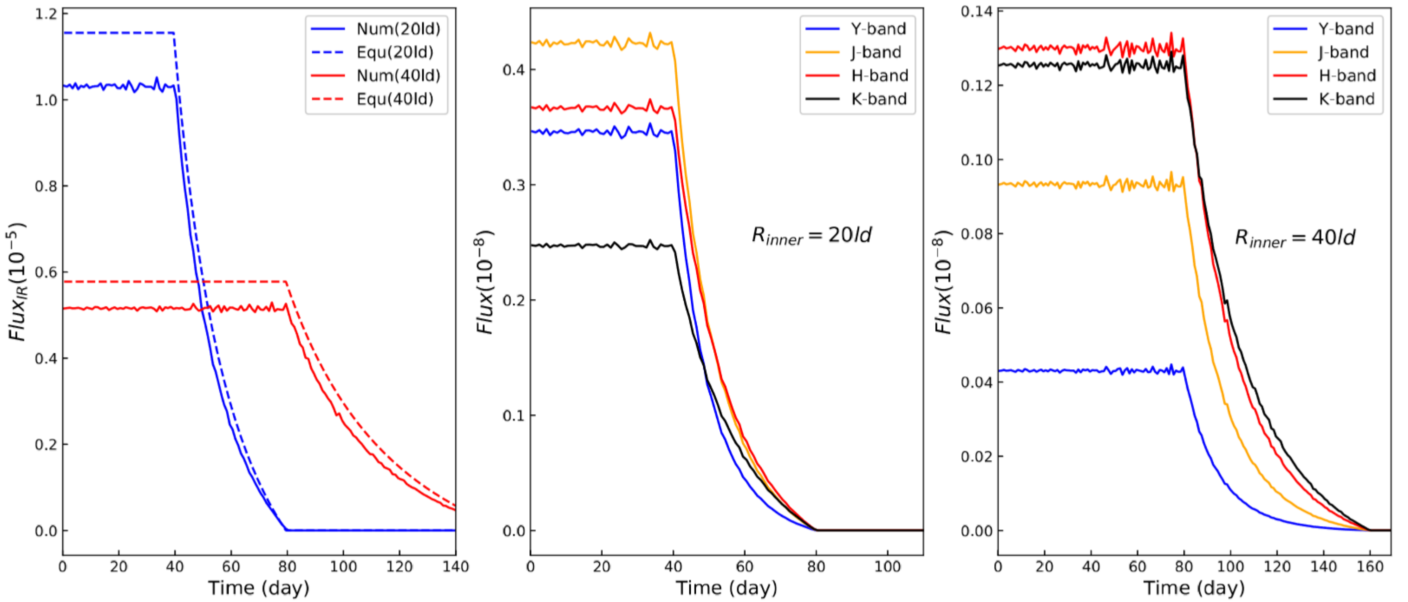
Disk1 : $\theta_{disk} = 15^{\circ}$
Disk2 : $\theta_{disk} = 30^{\circ}$

$\theta_{obs} = 30^{\circ} \quad or \quad 60^{\circ}$

Significant scattering effect in B band due to relatively small dust grains.
Almost no scattered intensity in R and I bands.



(a) B band (b) V band (c) R band (d) I band

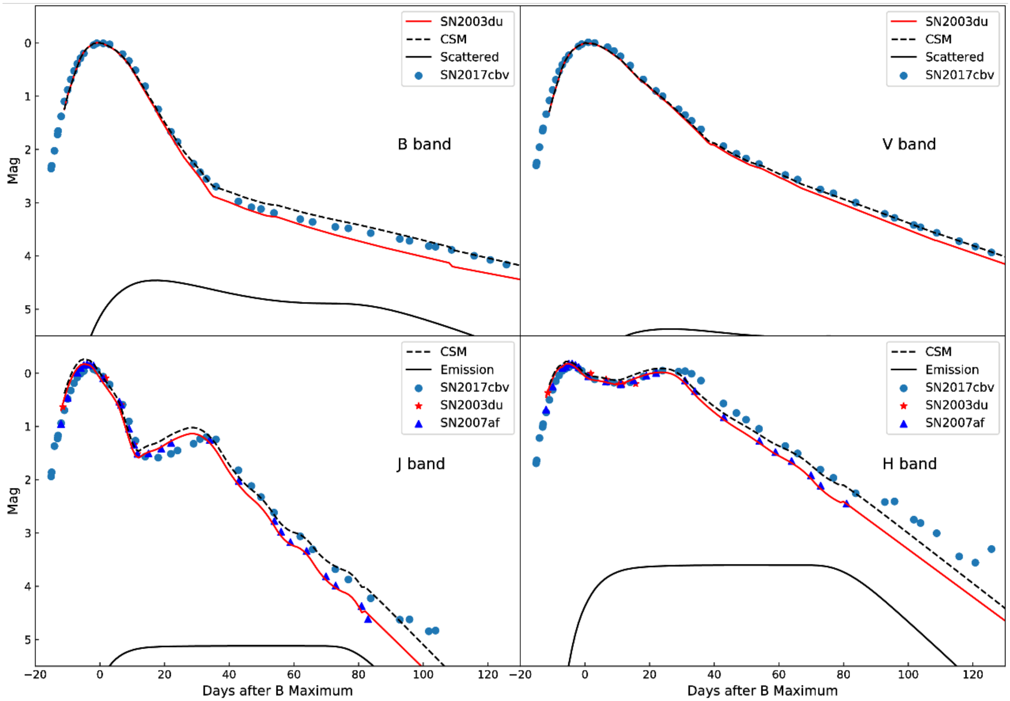


Shell only

Thermal emission of dust grains relating to the B-band maximum light.

(20ld to 40ld) (40ld to 80ld)

Equation from Chevalier 1986



Data from Lingzhi's paper (in prep)

SN 2003du : templates of B and V bands
SN 2007af : templates of J and H bands

Shell
$R_{in} = 40\ ld$
$R_{out} = 40\ ld$
$\tau = 0.1$

B and V bands : dust scattering only
J and H bands : thermal emission only

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The thermal emission of dust grains can explain part of the flux excess of J and H bands. However, more observations are needed to cover the infrared LCs of late phases.

Summary :

Either extended shell or thin shell can fit the color evolution of SNe Ia with different distance. ($10^{17} cm$ or 10^{19} cm)

The data of B- and V-band light curves only can not constrict the geometric distribution of the CSM (shell, disk, torus, and asyshell are all potential structures).

The polarization signals can provide clues to reveal either the configuration or the distance of the CSM.

The thermal emission of dust grains provides another view to investigate the distance of the CSM.