Multi-dimensional simulations of interaction-powered supernovae

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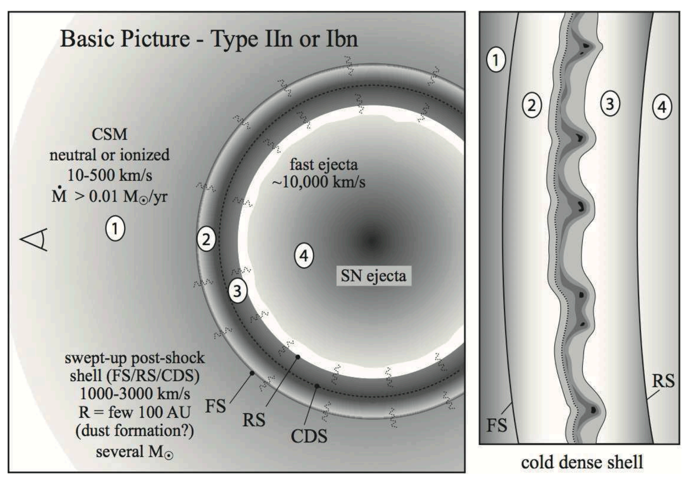
Abstract

Recent optical supernova surveys continue to discover populations of transients powered by the collision of the ejected materials with circum-stellar materials (CSMs). Nowadays, it has turned out that any spectral type of supernovae (SNe; both core-collapse and thermonuclear) can be interaction-powered or exhibit some spectral signatures of CSM interaction. Even CCSNe that look normal can also be powered by CSM interaction in their early stage, as is clearly observed in the recent nearby SN 2023ixf. Such CSMs are found in the vicinity of SN progenitors and therefore indicate their origin closely related to still mysterious mass-loss processes immediately before the explosion. Then, the central question is how exactly such CSMs could be created around exploding stars. Tackling this important problem requires detailed modelings of electromagnetic signals from interaction-powered SNe based on radiation-hydrodynamic simulations and comparisons with observations. In this pre- sentation, I introduce our 2D radiation-hydrodynamic models of SN ejecta colliding with spherical and aspherical CSMs. SN ejecta interacting with aspherical CSMs (e.g., disk-like) produces a variety of light curves depending on the viewing angle, which can be a powerful probe of CSM origins. I discuss what we can learn from multi-D modelings of interaction-powered transients.

1. Motivation

Circumstellar media (**CSM**) surrounding massive stars play important roles in core-collapse supernova explosions (**CCSNe**). Massive stars are thought to produce CSMs by shedding a part of their envelopes via several mechanisms, e.g., stellar winds and binary interactions. When a massive star undergoes the gravitational collapse, a CCSN happens and the bright emission illuminates the surrounding medium. CCSNe showing observational signature of dense CSMs are commonly found in SN observations and they make up a special spectral class, known as **type IIn SNe** (Schlegel 1990, Filippenko 1997)

One of the highly uncertain but important issues among interacting SNe is multi-dimensional effects. Deviations from spherical symmetry are expected even in cases where ejecta and CSM are both spherical because of the development of hydrodynamic instabilities, around the ejecta-CSM interface. In addition, the CSM itself can be asymmetric and/or clumpy (e.g., Chugai & Danziger 1994). In this work, we investigate the SN ejecta-CSM interaction by using **2D radiation-hydrodynamic simulations.** We especially focus on SN ejecta interacting with a CSM disk.

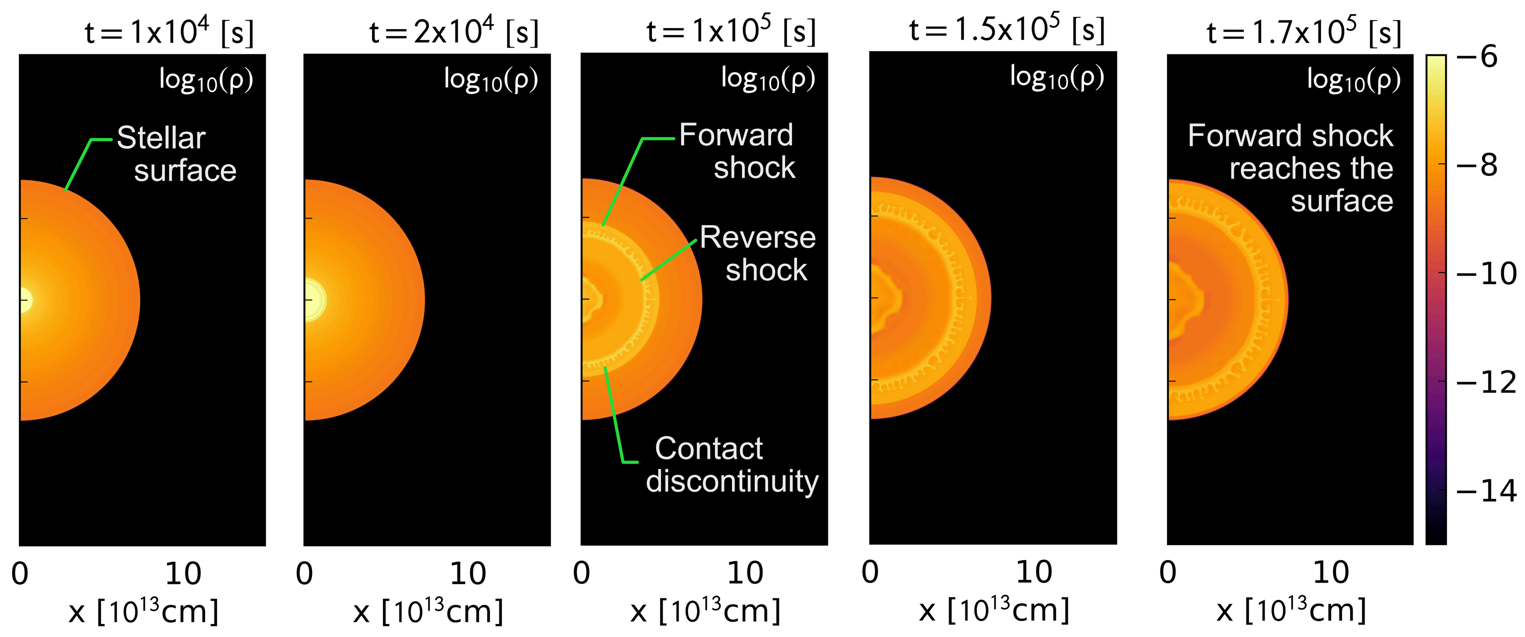


Smith (2016)

2. Exploding Red-supergiant

Firstly, we carried out simulations of an exploding red-supergiant until the shock breakout. We evolved a 18M_{sun} Red supergiant until core-clapse by using the public stellar evolution code MESA, and deposite an explosion energy of 10^{51}erg by hand. The simulation setups are as follows:

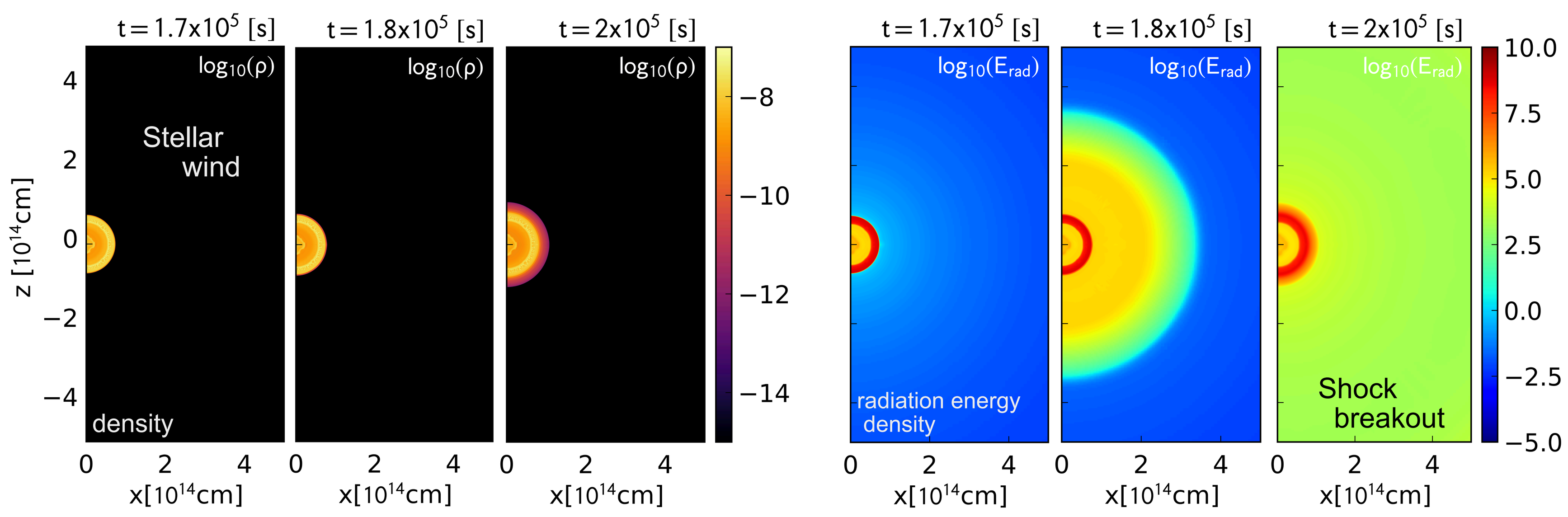
- **Progenitor mass: 18[M_{sun}]**
- **metallicity: Z=0.0142**
- **Pre-supernova mass: 12.6[M_{sun}]**
- **Pre-supernova radius: 1070[R_{sun}]**
- **Explosion energy: 10^{51}[erg]**



3. Ejecta-CSM interaction

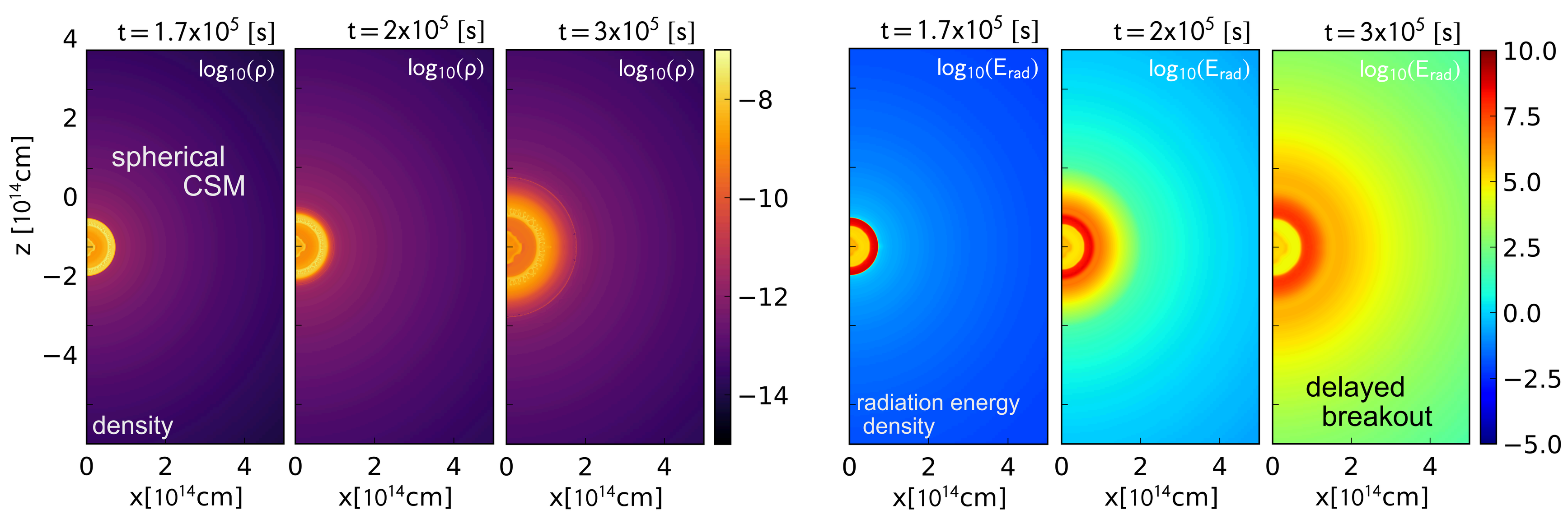
Three models with differnet CSM configurations are considered; no CSM model. spherical CSM model, and disk-like CSM model.

No CSM model: dM/dt= 10^{-5}[M_{sun}/yr]



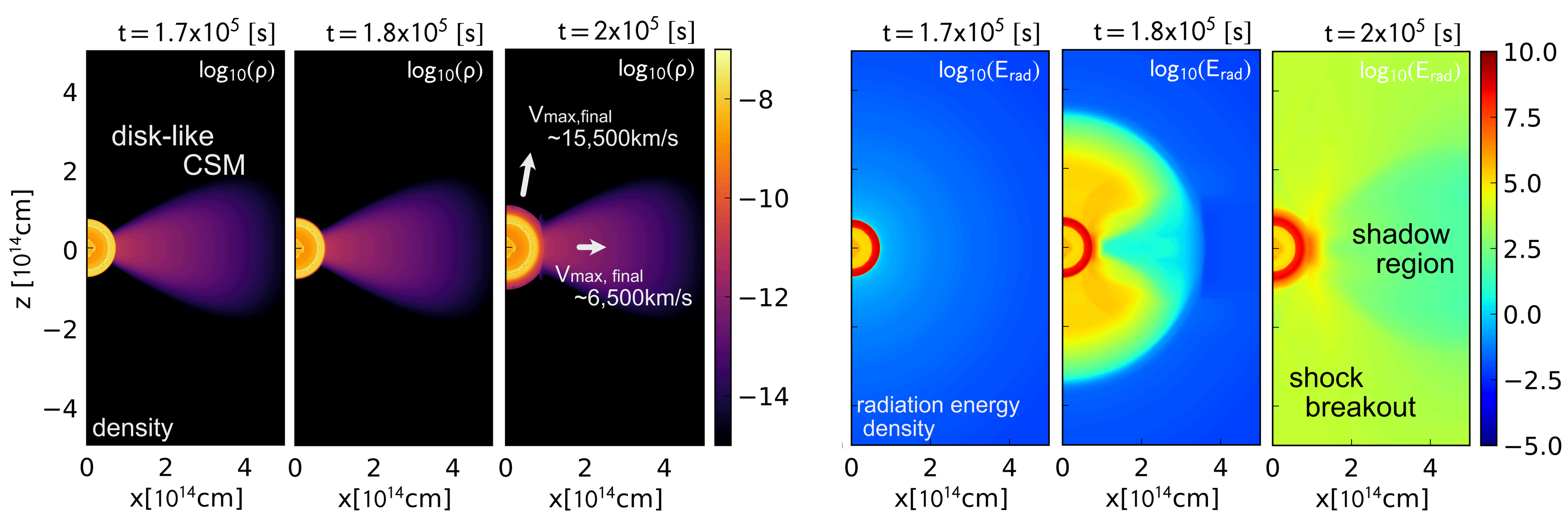
spherical CSM model:

$\rho \propto r^{-2}$, M_{csm}=0.05[M_{sun}], R_{csm}=6x10^{14}[cm]



disk-like CSM model:

θ_{disk}=20[deg], $M_{csm,iso}$=0.1[M_{sun}], R_{csm}=2x10^{14}[cm]

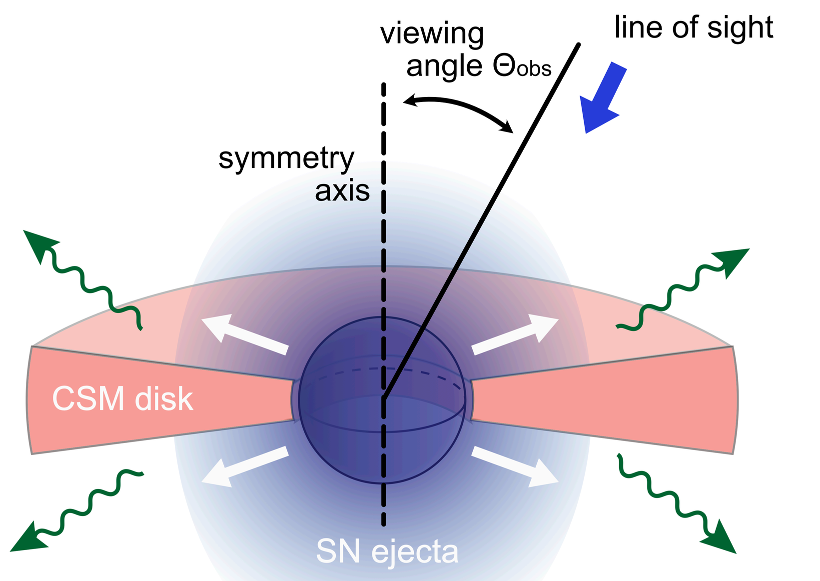


4. Light curves

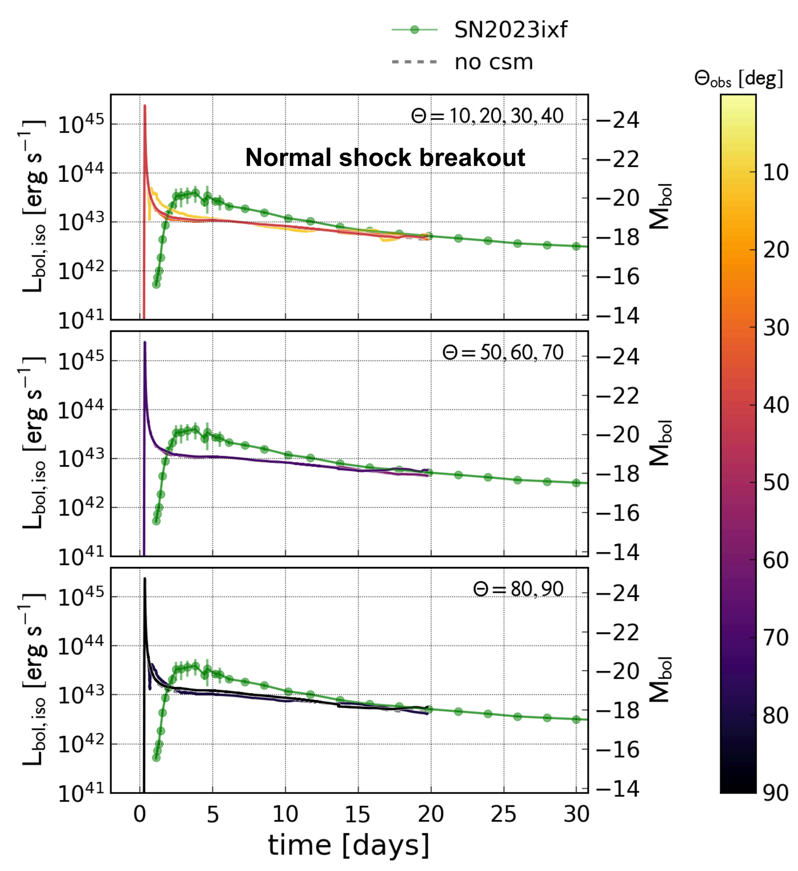
In the following, we compare the bolometric light curves of the 3 models with observations of the recnet nearby SN-II 2023ixf.

The light curve is depednet on the line of sight for the aspherical model.

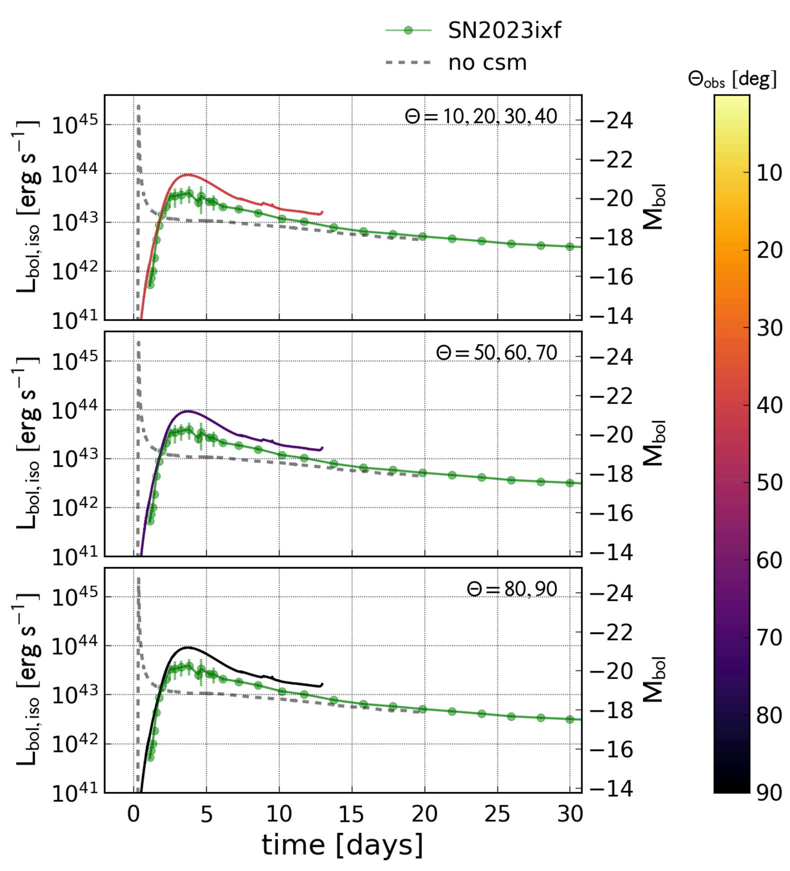
The viewing angle is defined as the angle between the line of sight and the symmetry axis.



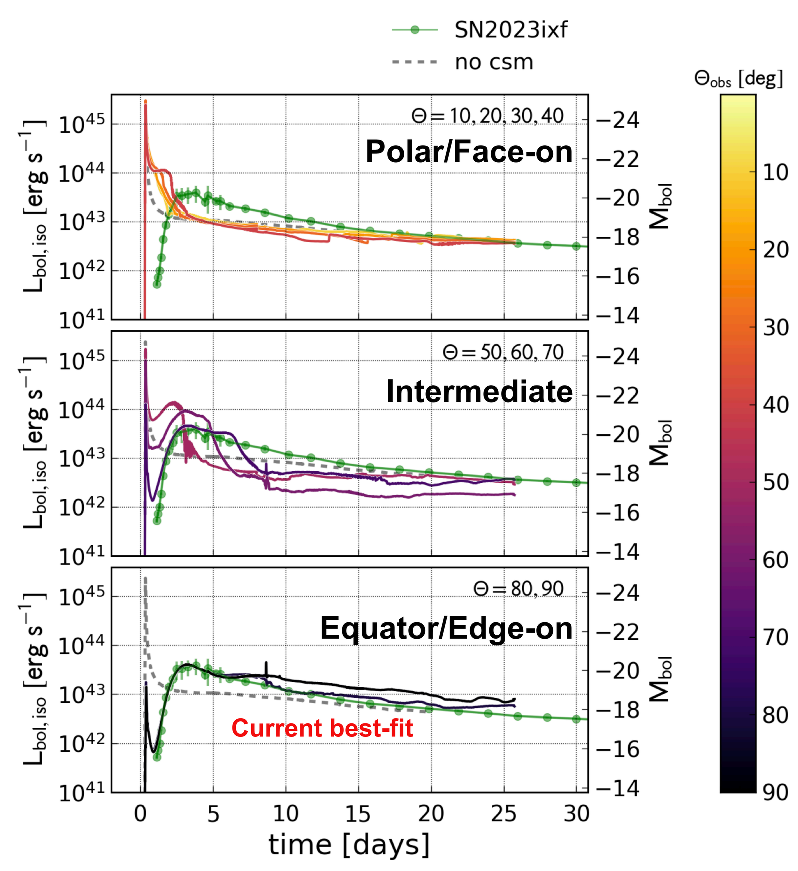
No CSM model:



spherical CSM model:



disk-like CSM model:



Our current conclusion is that SN 2023ixf is **an exploding RSG with disk-like CSM viewed from equatorial plane**. In the future, we will conduct further parameter survey and post-process calculations for polarization and H-alpha line profiles by using these radiation-hydrodynamic models.