Disentangling possible dust components of core-collapse supernovae within a Bayesian framework

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Abstract

Core-collapse supernovae (CCSNe) have long been considered one of the essential stellar sources of dust, as they could explain the observed dust content of high-redshift galaxies and a crucial part of the cosmic dust content of the Universe. However, only a small number of young extragalactic SNe show direct observational evidence for dust condensation, and several questions remain unanswered regarding the dust parameters and their sources.
The dust components could be traced by modeling both the emerging infrared (IR) excess and the red-blue asymmetries in optical and near-IR emission-line profiles of SNe. By applying both modeling approaches simultaneously, it is possible to determine the grain properties and the location of dust formation and, therefore, successfully disentangle possible pre-existing and newly formed SN dust components.

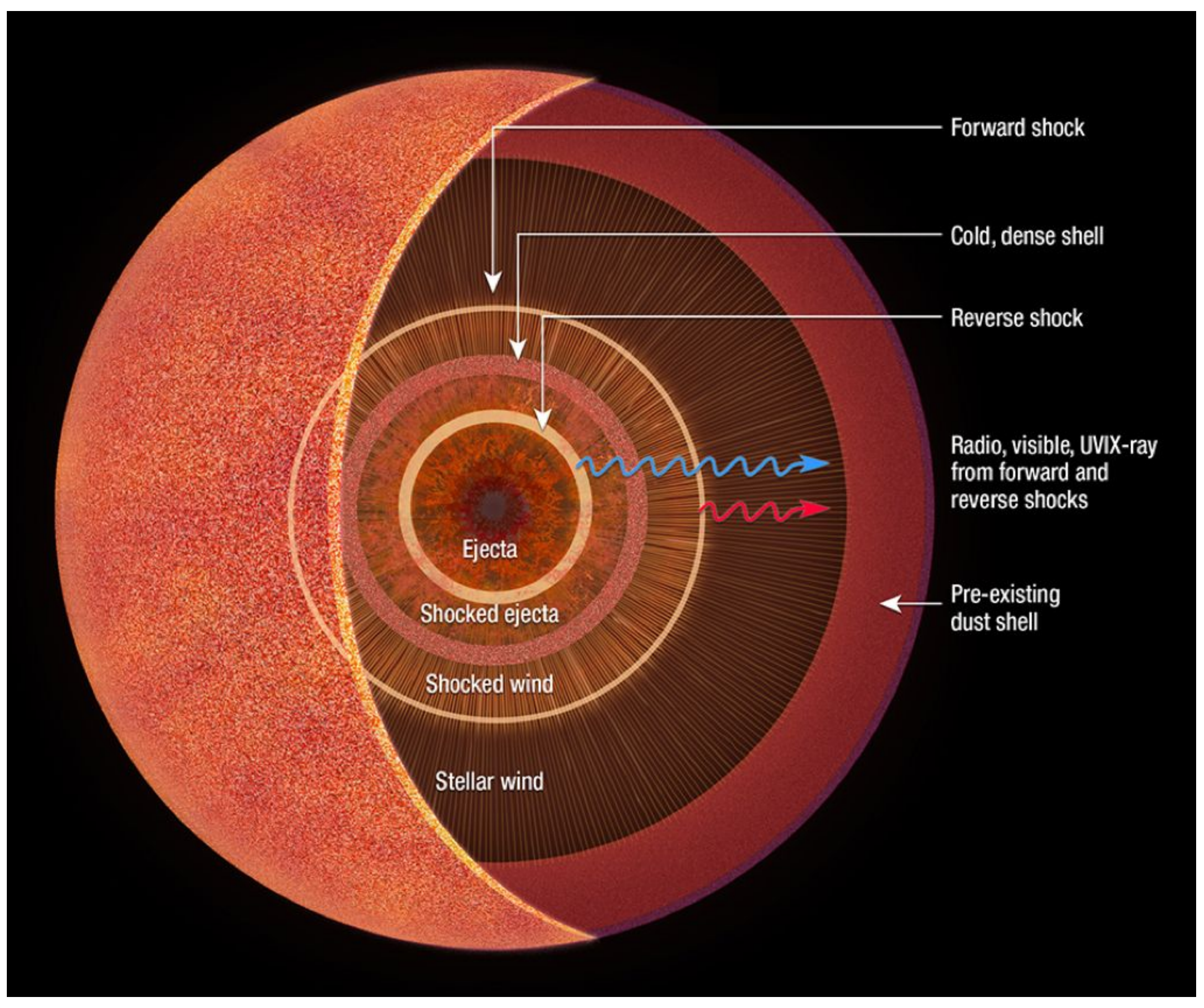


Fig. 1. Schematic model of dusty core-collapse supernova environments, illustrating different locations of dust grains (©Dr. Ori D. Fox, STScI). Dust grains in the environment of CCSNe could be either newly formed (in the ejecta or the cold dense shell) or pre-existing and heated due to the SN explosion.

Work in progress & outlook

We aim to analyze different types and ages of CCSNe (~20) using this consistent methodology based on the most precious measurements available to date, including data from the **James Webb Space Telescope** (GO 2666, GO 3921, GO 5290, GO 6049 programs) and the **Keck I Telescope**.

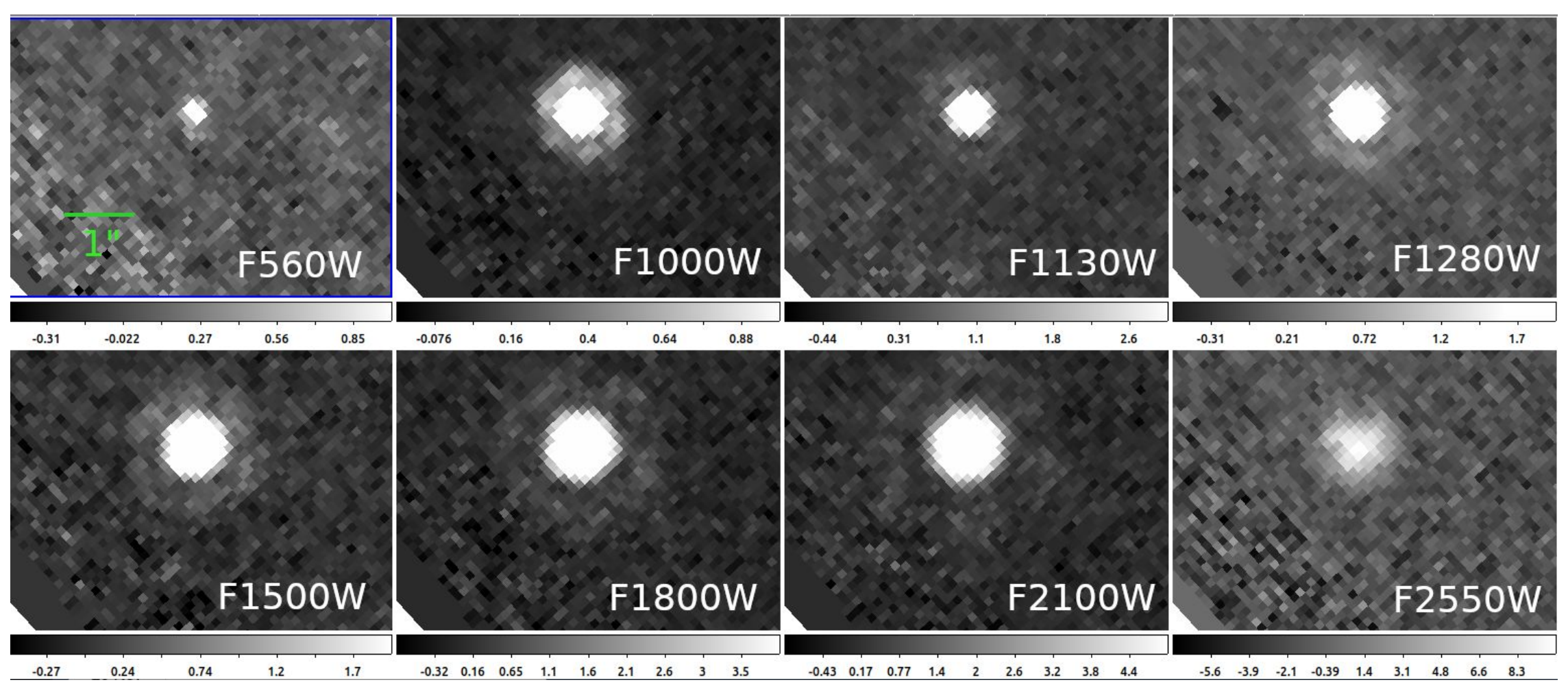


Fig. 6. The SN 1980K on all JWST/MIRI images (Zsíros et al., 2024). The sensitivity of JWST allows capturing faint extragalactic SNe even at late times.

- ★ It will enable us to constrain the location and timing of dust formation for a statistical sample of SNe;
- ★ provide observational limitations across a large sample of diverse SNe, which will establish a benchmark for future modeling efforts on SN dust condensation.

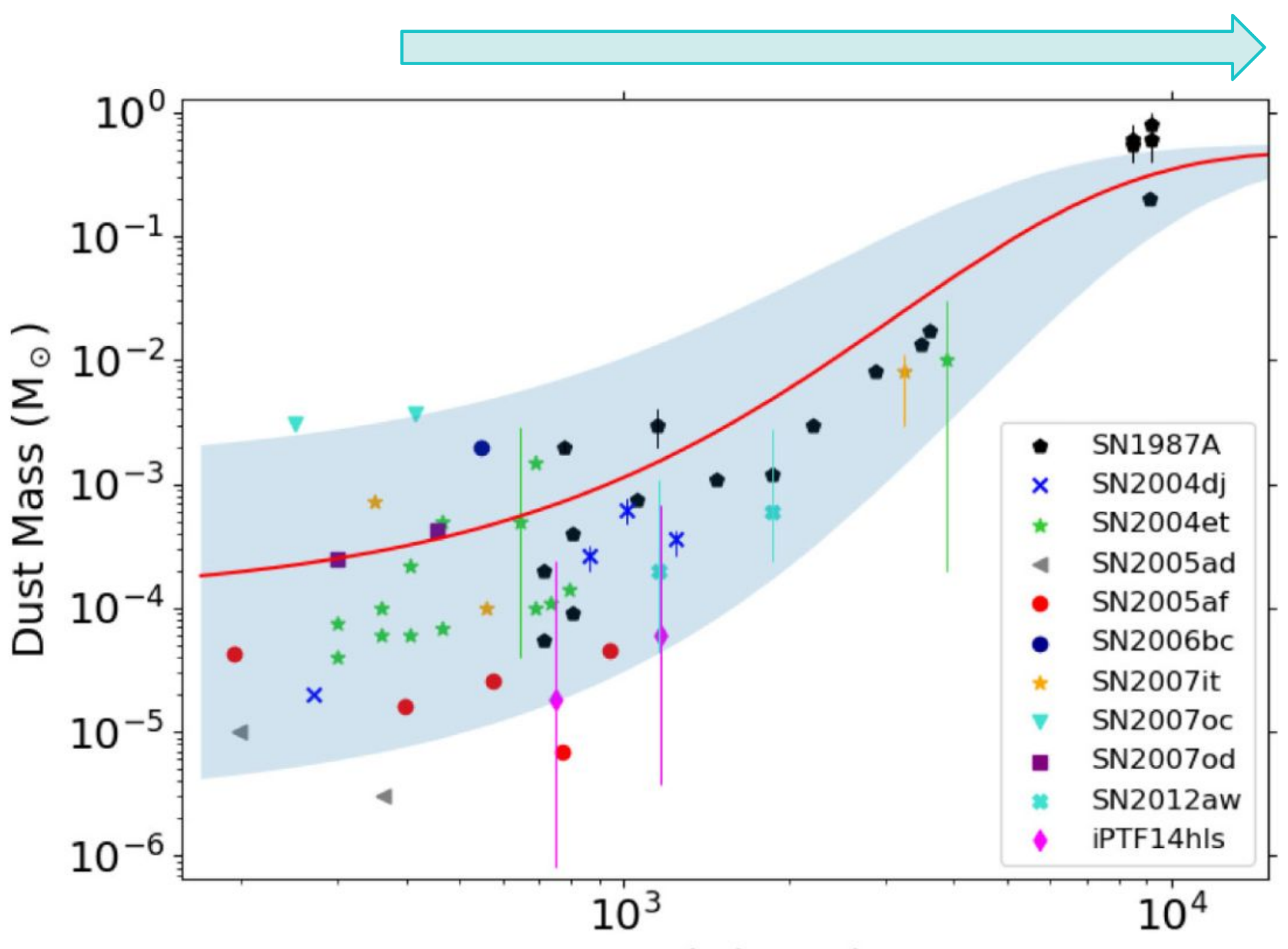


Fig. 7. The dust mass formed as a function of time post-explosion (Niculescu-Duvaz et al., 2023) with a blue arrow indicating the range that will be covered by the new observations. We plan to add data extending beyond 10^4 days post-explosion for various types of SNe (including many new objects and revisiting some old ones) in order to understand the scatter in this diagram.

Methodology: Modeling Dust Grains in the Environment of CCSNe

1. Fitting **analytical dust models** to the spectral energy distributions to provide a foundation for the advanced models. Deriving the composition, size, mass, and temperature of the dust grains.

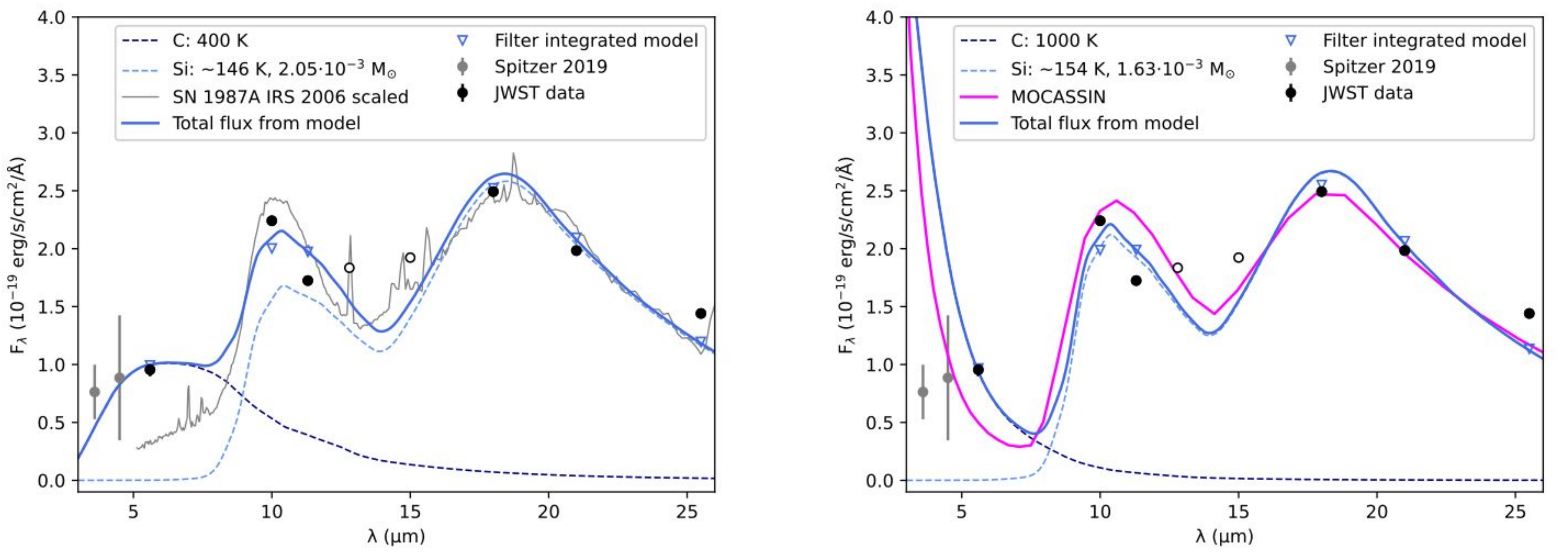
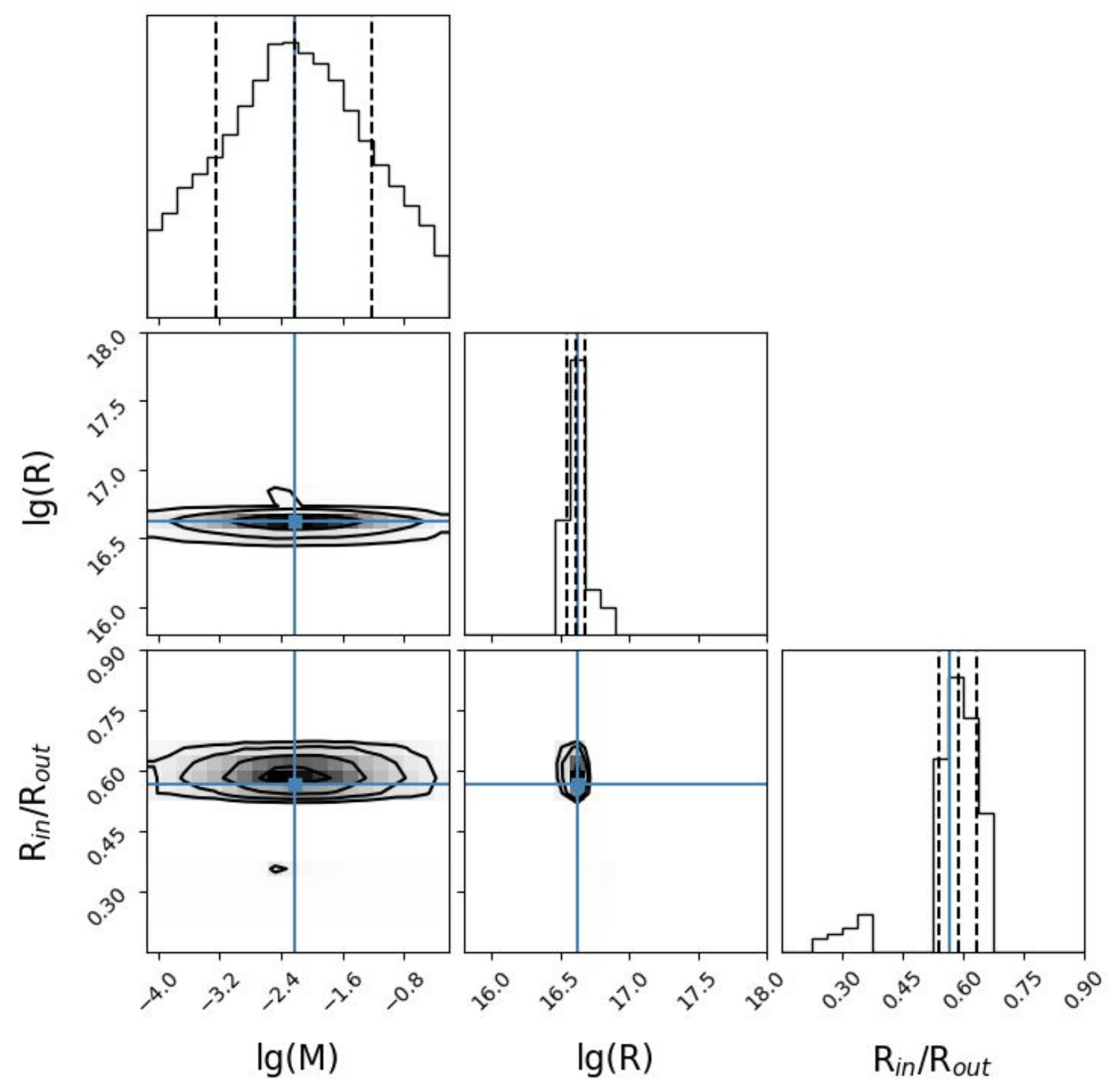


Fig. 2. The best-fit analytical dust models and best MOCASSIN model of SN 1980K with the JWST/MIRI data (Zsíros et al., 2024). These results confirm that JWST photometric data alone can effectively constrain the dust composition.

2. Compute **numerical dust models** with MOCASSIN (Ercolano et al., 2003, 2005, 2008) and follow the possible light-matter interactions. The code enables simulations of the radiation propagating through dusty media with arbitrary geometry, grain density distribution, and composition. We assume a radiation field originating from a single point source.
We interpret our models within a Bayesian data inference framework linked to an MCMC method, allowing us to explore the parameter space of complex models efficiently and describe the relationship of given parameters.



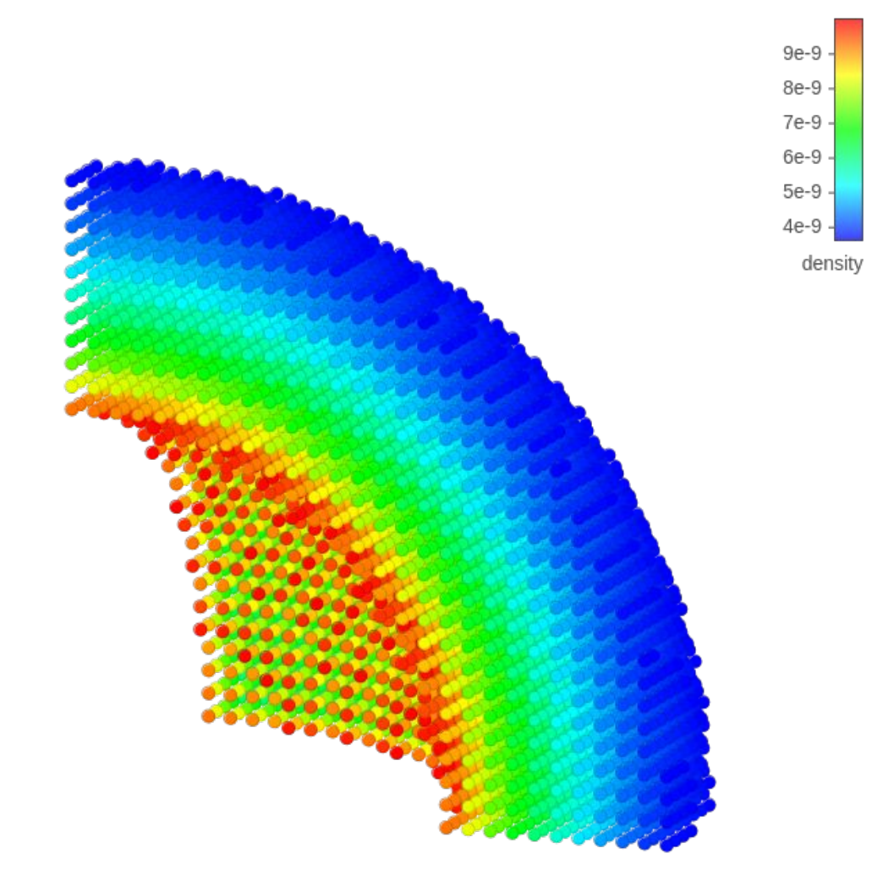


Fig. 3. A model grid describing the geometry of a dusty shell used in the case of MOCASSIN models. (https://nebulousresearch.org/codes/gridmaker/, Dr. Roger Wesson).

Fig. 4. A corner plot obtained from late-time mid-IR numerical dust models of the SN 1980K. The plot describes the relationship between specific parameters through different projections (e.g., dust mass, the outer shell radius, and the ratio of the inner and outer radii).

3. Model the **optical line emission** of CCSNe with DAMOCLES (Bevan & Barlow 2016, Bevan 2018) to constrain the possible location of dust grains in the SN ejecta and to gain further insight into the properties of SN dust.

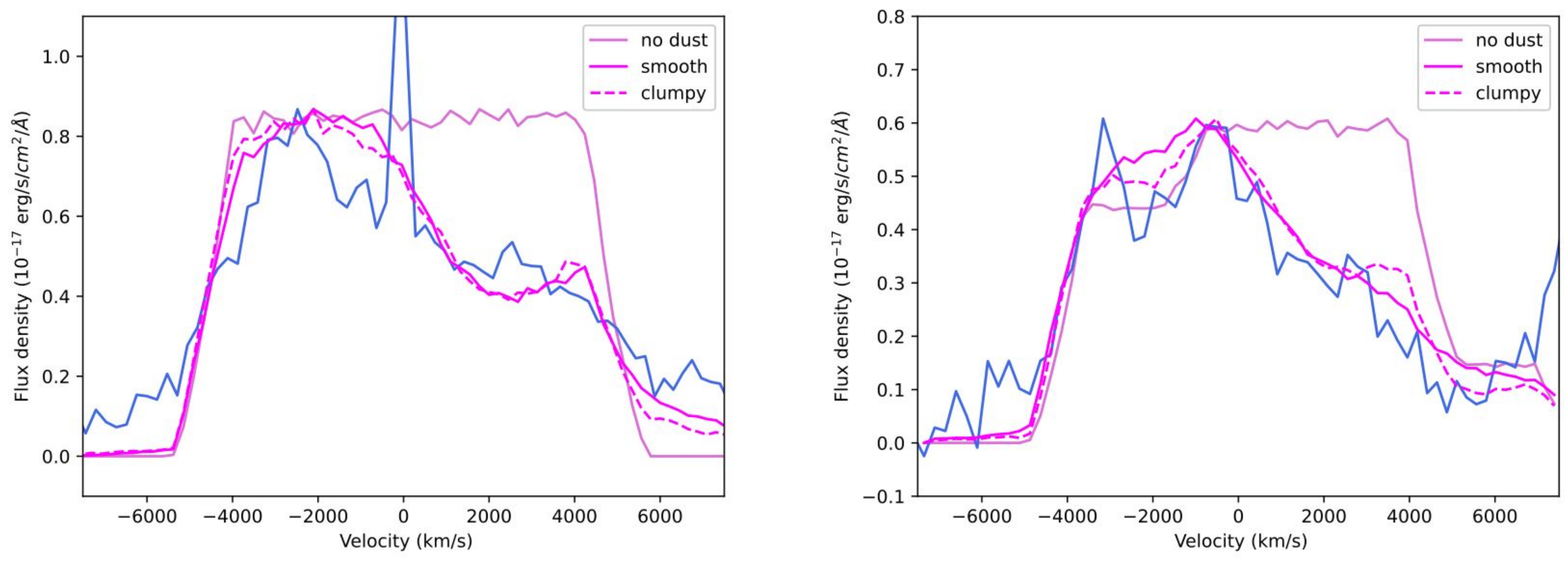


Fig. 5. The best smooth and clumpy DAMOCLES models of Hα and [OI] 6300, 6363 Å lines in the late-time Keck spectrum of SN 1980K indicate a significant amount of dust in the ejecta (Zsíros et al., 2024).

References:

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