SN 2022ffg: an interacting Type II SN with an Ultraviolet Plateau

Avinash Singh[1,2] · R. Teja[3] · T. Nagao[4] · K. Maeda[5] · D.K. Sahu[3] · J. Sollerman[1] et al.

[1]Department of Astronomy, Oskar Klein Center, Stockholm University, Sweden, [2]Hiroshima Astrophysical Science Center, Hiroshima University, Japan
[3]Indian Institute of Astrophysics, Bengaluru, India, [4] University of Turku, Finland [5]Kyoto University, Japan

Introduction

Core-Collapse Supernovae (CCSNe) exhibiting circumstellar matter (CSM) interactions and dynamic signatures provide critical insights into the mass-loss histories of massive stars. The presence of CSM is not uncommon in massive stars; however, early spectral observations of hydrogen-rich (Type II) SNe often reveal highly-ionized narrow feature (flash lines) indicative of an extended dense wind-like environment (Yaron et al. 2017). These observations are suggestive of a CSM that is highly dense and indicates a much higher mass-loss rate than steady winds (Dessart et al. 2022). We investigate one such event described below.

SN 2022ffg, a Type II SN discovered in its infancy and classified with a spectrum displaying flash-ionized features. The optical light curve (LC) is typical of a Type II with a rise time of 25 d, however, the **UV LC peaked within 4 d, subsequently settling into a rare 2-week long plateau**, which is unprecedented among Type II/IIn SNe. The same is reflected in the double-peaked bolometric LC curve, which peaked at 4 and 25 d. Spectroscopic observations show a **flash-phase which lasted for over a week**, indicating interaction with an inner dense circumstellar matter (CSM) and ongoing interaction evident in the boxy Hα profile visible until 45 d. Polarimetric observations indicate two components with different Polarization Angle (PA). Hydrodynamical LC modeling across UV-Optical-Near Infrared (NIR) wavelengths suggests a complicated CSM structure with mass-loss rate of up to 0.01 $\mathrm{M_\odot\,yr^{-1}}$ and an explosion energy exceeding 1 foe.

Multi-wavelength Photometric Observations

- Ultraviolet-Optical-Infrared-band light curves from **SWIFT**, Kanata, Seimei, ZTF and ATLAS, spanning up to 400 d from estimated date of explosion.
- **V-band** : Peaks at -18.5 mag, Rise Time of 25 d, typical Type II LC with a single peak
- **UVW2**: Peaks at -19.2 mag, Rise Time of 4 d, LC peak followed by a 2-week plateau
- **Importance of UV Coverage** - Such disparity between Opt/UV LCs not seen in literature.

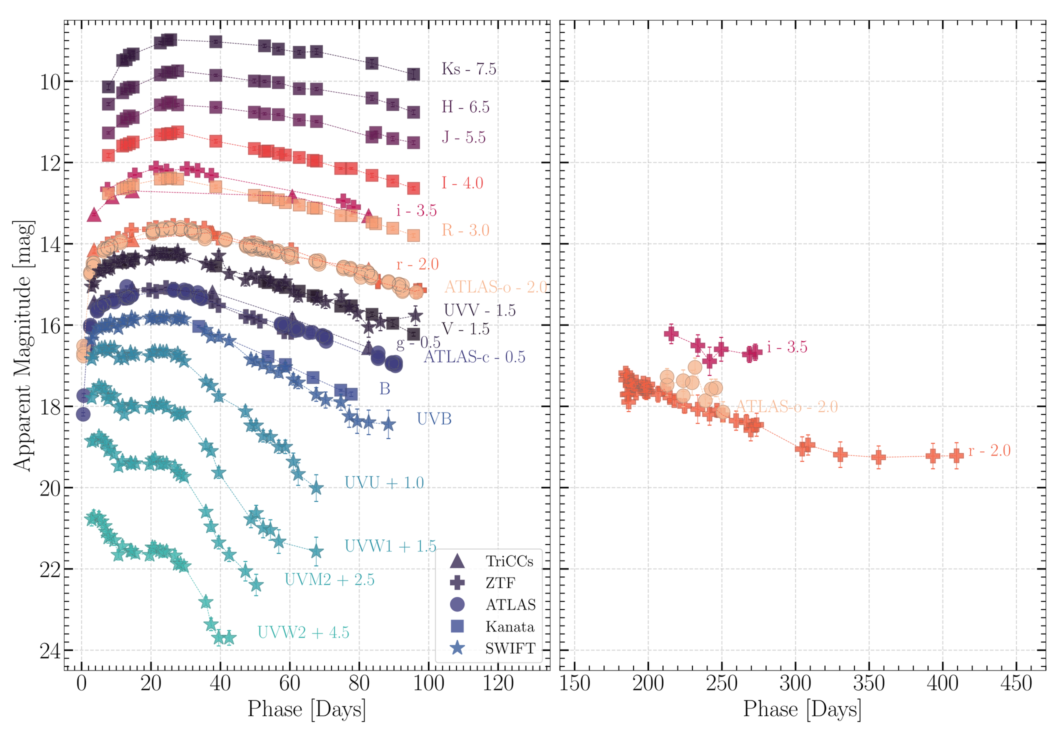

Figure 1. Multi-wavelength light curves of SN 2022ffg.

Comparison of SWIFT UV Light Curves

- **Optical LCs took typical of Type IIP/L, whereas the UV LC stands out due to its 2-week plateau.**
- Type IIn SNe do show flat-evolution in UV, but the UV LC shape is typically mirrored in optical bands unlike in SN 2022ffg.

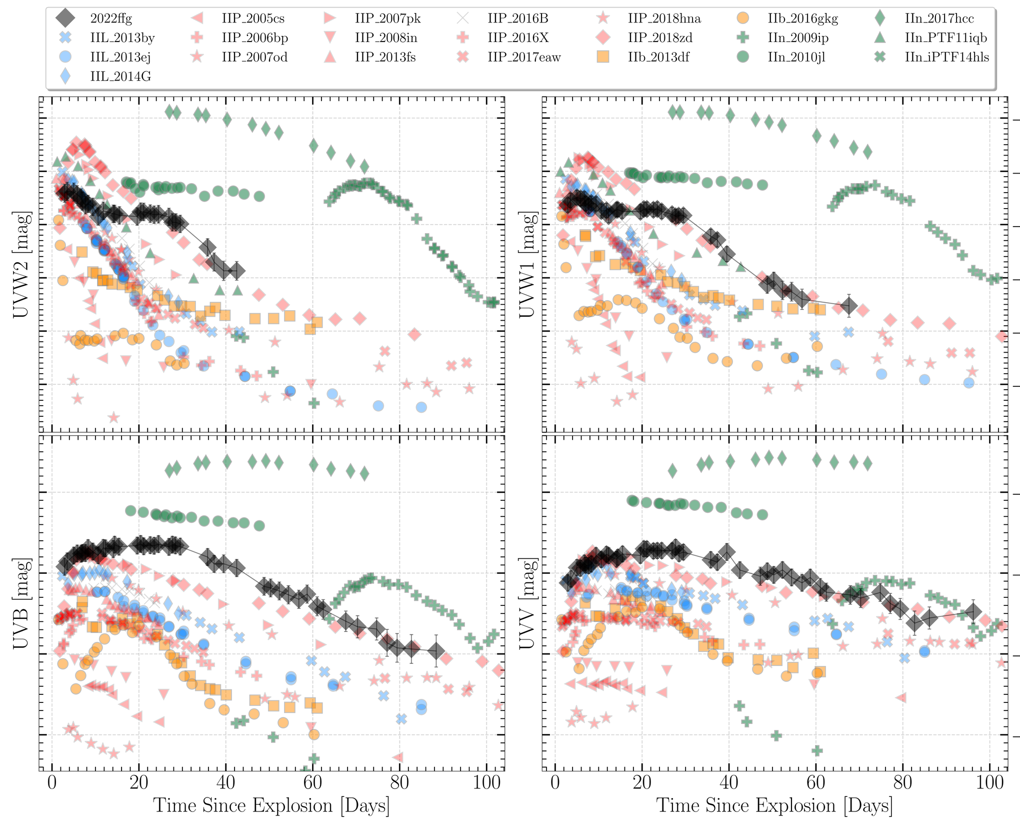

Figure 2. **SWIFT** LCs of SN 2022ffg compared with observed Type IIP/L/b/n.

Hydrodynamical Light Curve Modelling

- Hydrodynamical LC modelling performed using STELLA
- **Modelling the V-band LC: Indicates the need of a weak wind :** $10^{-5}\,M_\odot\,yr^{-1}$ curve confirmation with a stellar wind from an RSG.
- **Modelling the UVW2/W1 band LCs: Indicates the need of a strong wind :** $0.01\,M_\odot\,yr^{-1}$, indicating unsteady modes of mass-loss.
- Extent of the CSM is roughly 2–4e14 cm.

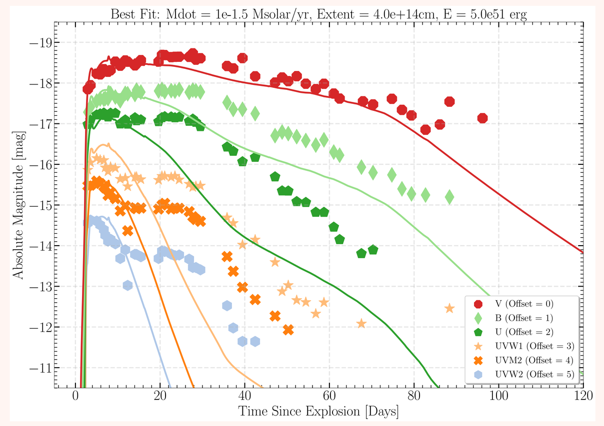

Figure 3. Hydrodynamical light curve model fits using V-Band. The UV peak and Optical LC is well predicted by a high-energy explosion with a typical stellar wind.

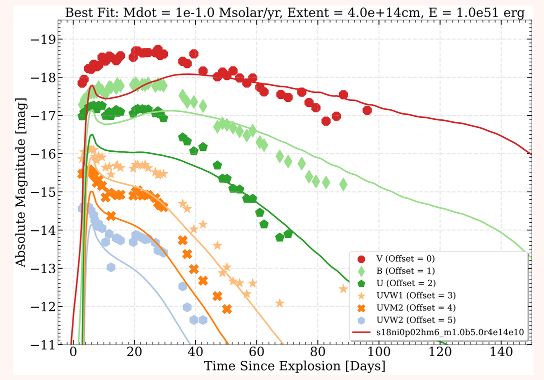

Figure 4. Hydrodynamical light curve fits using UV LCs> 10 d, reproducing the UV-plateau requires a strong stellar wind.

Spectroscopic Observations

- SN 2022ffg shows strong **"flash"** features lasting up to 8 d, indicating presence of **nearby dense CSM - Early Interaction**
- Photospheric phase shows a **broad boxy Hα P-Cygni profile** up to 45 d, indicating an **extended shell-like CSM - Late Interaction**

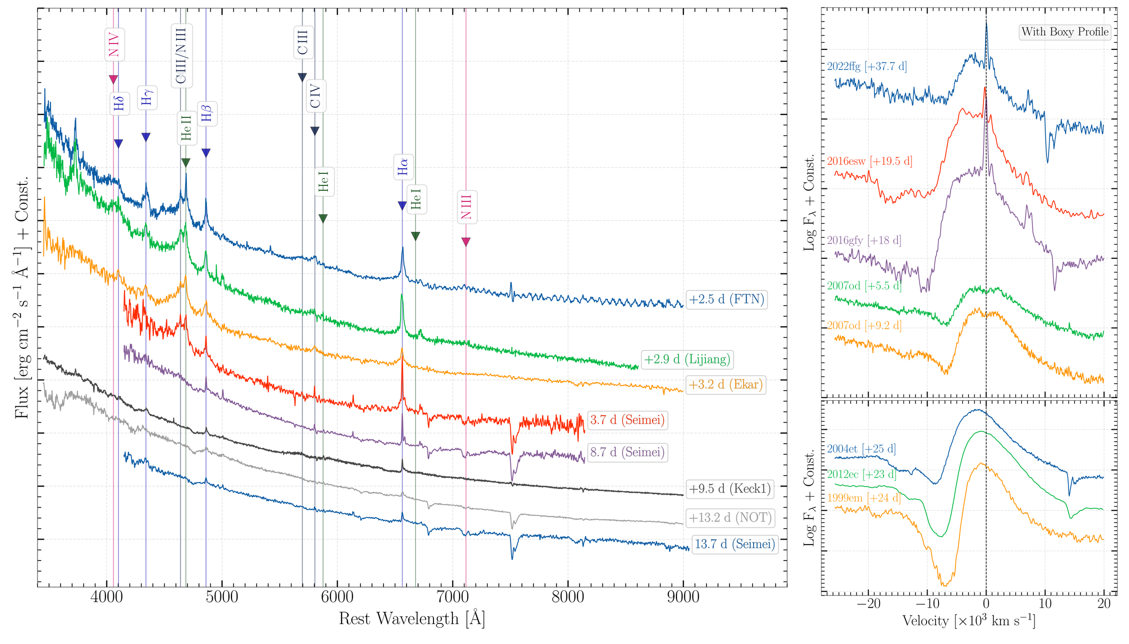

Figure 5. Spectroscopic sequence of SN 2022ffg

Polarimetric (and Bolometric Flux) Evolution

- We observe **two components with different polarization angles** ($\sim$1% with PA $\theta\sim$110 deg, and $\sim$0.75% with PA $\theta\sim$30 deg).
- Likely results from an aspherical CSM structure, followed by signature of an aspherical explosion (Needs further investigation).

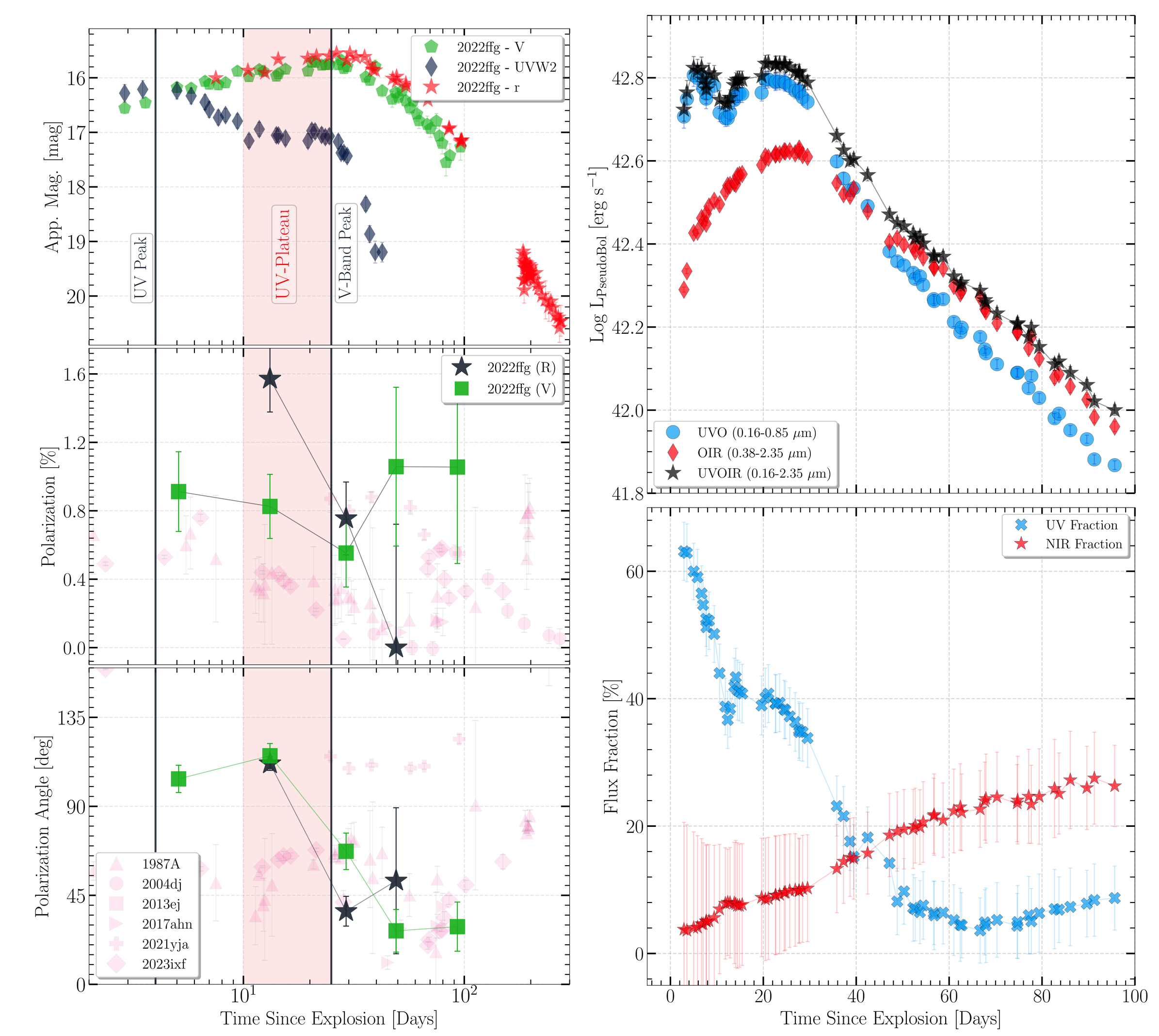

Figure 6. Time evolution of polarisation (left) and the bolometric flux (right).

Summary

Light Curves

- SN 2022ffg shows a Ultraviolet LC peaking at 4 d followed by a drop to a unique 2-week long plateau, in contrast to its smooth optical LC.
- Light curve comparisons with archival SWIFT observed SNe, highlights the **unusual UV plateau**.
- Hydrodynamic LC modelling : The long rising Optical LC and the first UV-peak could be modelled by an energetic explosion 5e51 erg, and a prototypical RSG stellar wind.
- UV-plateau requires a strong stellar wind of 0.01 $\mathrm{M_\odot yr^{-1}}$.
- The extent of the CSM is roughly compact at 2–4 e14 cm.

Spectroscopy

- Spectroscopically, SN 2022ffg showed flash features for roughly 8 d, indicating dense CSM.
- The photospheric phase spectra depicted **boxy** $H\alpha$ until 40 d, indicating an extended shell-shaped CSM.

Polarimetry

- Polarimetric observations revealed the presence of 2 components in the temporal evolution
- Interaction with an aspherical CSM, followed by signs of an aspherical ejecta during the recombination dominant phase.

Forthcoming Work

- Investigate the presence of redder-colors in the UV-peak but bluer colors during the UV-plateau.
- Need for a multi-component CSM structure to explain the complex mutli-wavelength light curve.
- Does the estimate of ejecta emanating out of the dense CSM agrees in velocity with the hydrodynamical models?
- Did the SN show a plateau drop during solar conjunction and constrain 56Ni-mass estimate from the > 200d LC.
- Inferring the kinematic structure of the ejecta based on the spectral decomposition of the late nebular phase line profiles.
- Interpretation of why the polarisation angle changed as the SN dropped from the UV-plateau (and not the UV-peak)? Implication that UV-peak and plateau are originating from the same emission region?
- Does the asphericity in SNe drive light curve peculiarities, especially in complex ejecta-CSM geometries.

References

[1] L. Dessart and D. John Hillier. Modeling the signatures of interaction in Type II supernovae: UV emission, high-velocity features, broad-boxy profiles. *A&A*, 660:L9, April 2022.

[2] W. V Jacobson-Galan et al. SN 2023ixf in Messier 101: Photo-ionization of Dense, Close-in Circumstellar Material in a Nearby Type II Supernova. *ApJL*, 954(2):L42, September 2023.

[3] W. V Jacobson-Galán et al. Final Moments. II. Observational Properties and Physical Modeling of Circumstellar-material-interacting Type II Supernovae. *ApJ*, 970(2):189, August 2024.

[4] O. Yaron et al. Confined dense circumstellar material surrounding a regular type II supernova. *Nature Physics*, 13(5):510–517, February 2017.