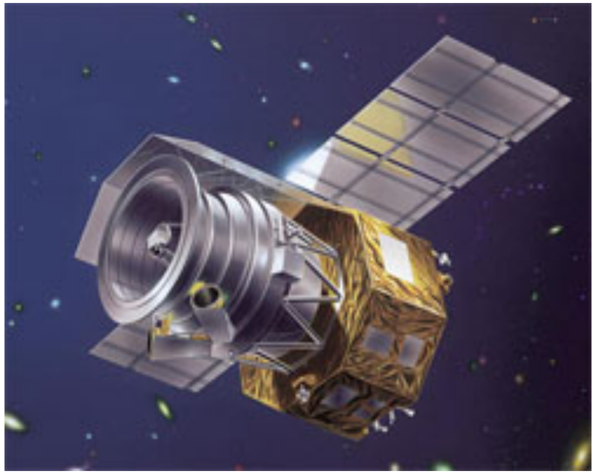
Dust Formation History in Nova V1280Sco



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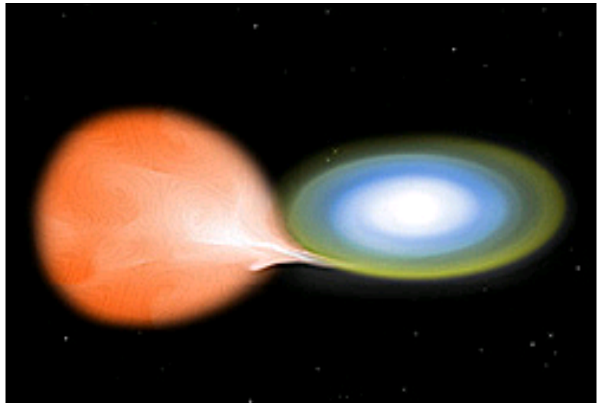
Classical Novae



Classification (Gehrz, Truran & Williams 1993; Gehrz et al. 1998)

1). CO novae

- Thermonuclear runaway (TNR) on the surface of relatively low-mass ($M_{WD}<1.1M_\odot$) white dwarves
- Dust formation after the free-free phase is seen for several CO Novae [e.g., V2362 CYGNI (Lynch et al. 2008), V705 Cas (Evans et al. 1997), etc.]
- Complicated dust compositions (both Silicates and Carbonaceous dust)

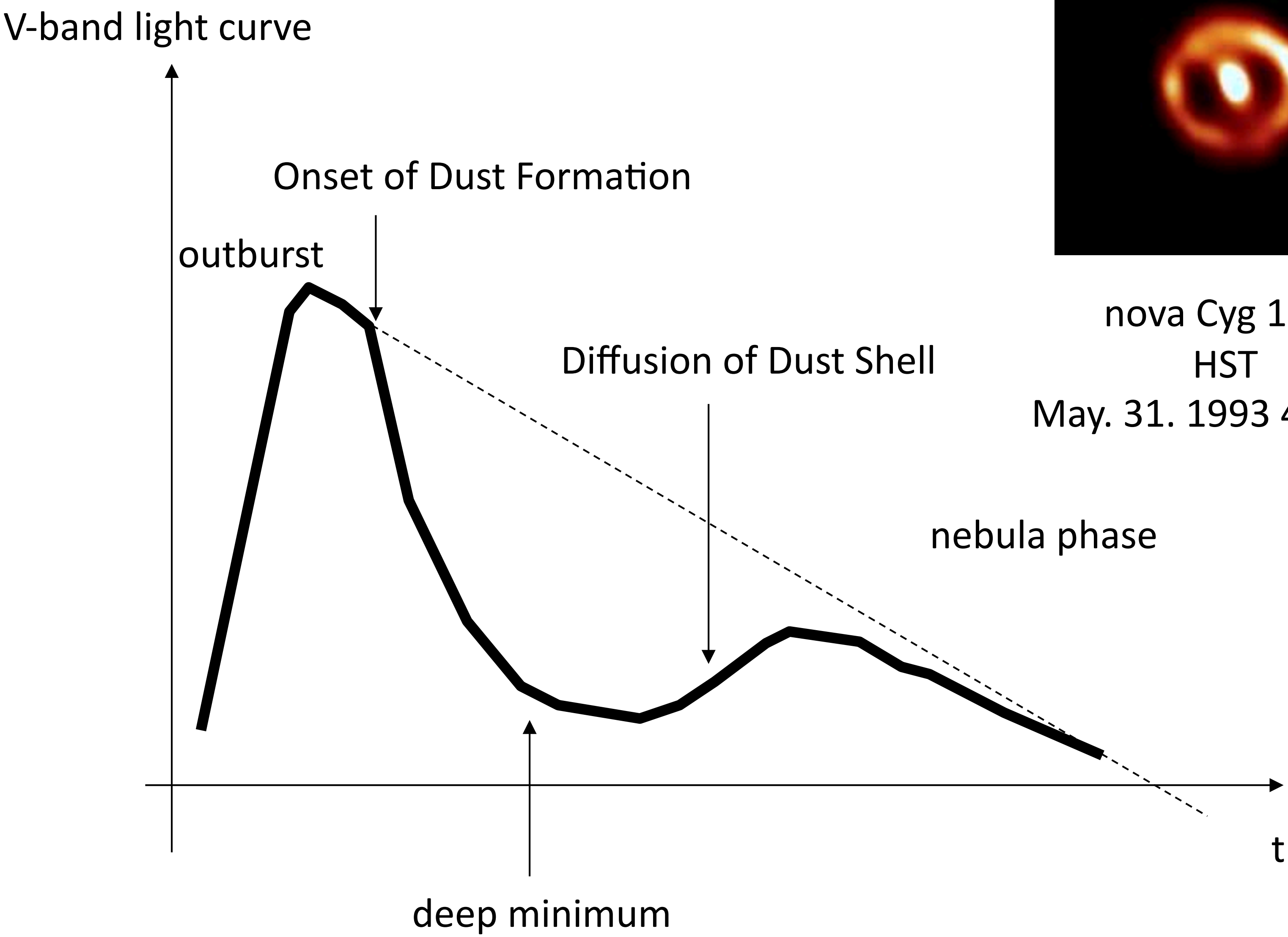
2). ONeMg Novae

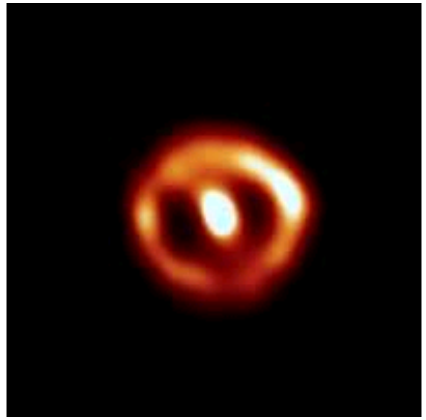
- Thermonuclear runaway (TNR) on the surface of relatively high-mass white dwarves ($M_{WD}>1.1M_\odot$)
- coronal emission-lines phase comes after the free-free phase
- No or little evidence of dust formation (cf., V1974 CYGNI; Woodward et al. 1995)

Dust Forming Novae (Gehrz et al. 1998)

Object	Year	Type of Dust	Object	Year	Type of Dust
FH Ser	1970	C	OS And	1986	C?
V1229 Aql	1970	C	V842 Cen	1986	C, SiC, HC
V1301 Aql	1975	C	V827 Her	1987	C
NQ Vul	1976	C	QV Vul	1987	C, SiO2, HC, SiC
V4021 Sgr	1977	C	LMC1998#1	1988	C?
LW Ser	1978	C	V838 Her	1991	C
V1668 Cyg	1978	C	V704 Cas	1993	C, HC, silicates
V1370 Aql	1982	C, SiC, SiO2	V1419 Aql	1993	?
PW Vul	1984	C	V1494 Aql	1995	C
QU Vul	1987	SiO2	V2274 Cyg	2000	?

Optical Light Curve Evolution of Dusty Novae





nova Cyg 1992
HST
May. 31. 1993 467days

V1280 Scorpii

- Discovered on Feb 4.86, 2007 by Y. Nakamura and Y. Sakurai (Yamaoka et al. 2007)
- d = 1.1±0.4 kpc (Naito et al. 2012)
- Dust formation occurred at d~23days after discovery (Das et al. 2007)
- Extremely slow light curve evolution → M_{WD}=0.6M_{sun} (Hounsell et al. 2010; Naito et al. 2012)

VLTI/AMBER and MIDI observations between t=23 d and 145 d (Chesneau et al. 2008)
-An apparent linear expansion rate for the dust shell; 0.35±0.03mas day^{-1}
-Expansion velocity of the nova ejecta; 500±100 km/s
-Dust production rate; 2-8x10^{-9} M_{sun} day^{-1} (a probable peak in production at t=36-46 days)
-The amount of dust in the shell; 2.2x10^{-7} M_{sun}

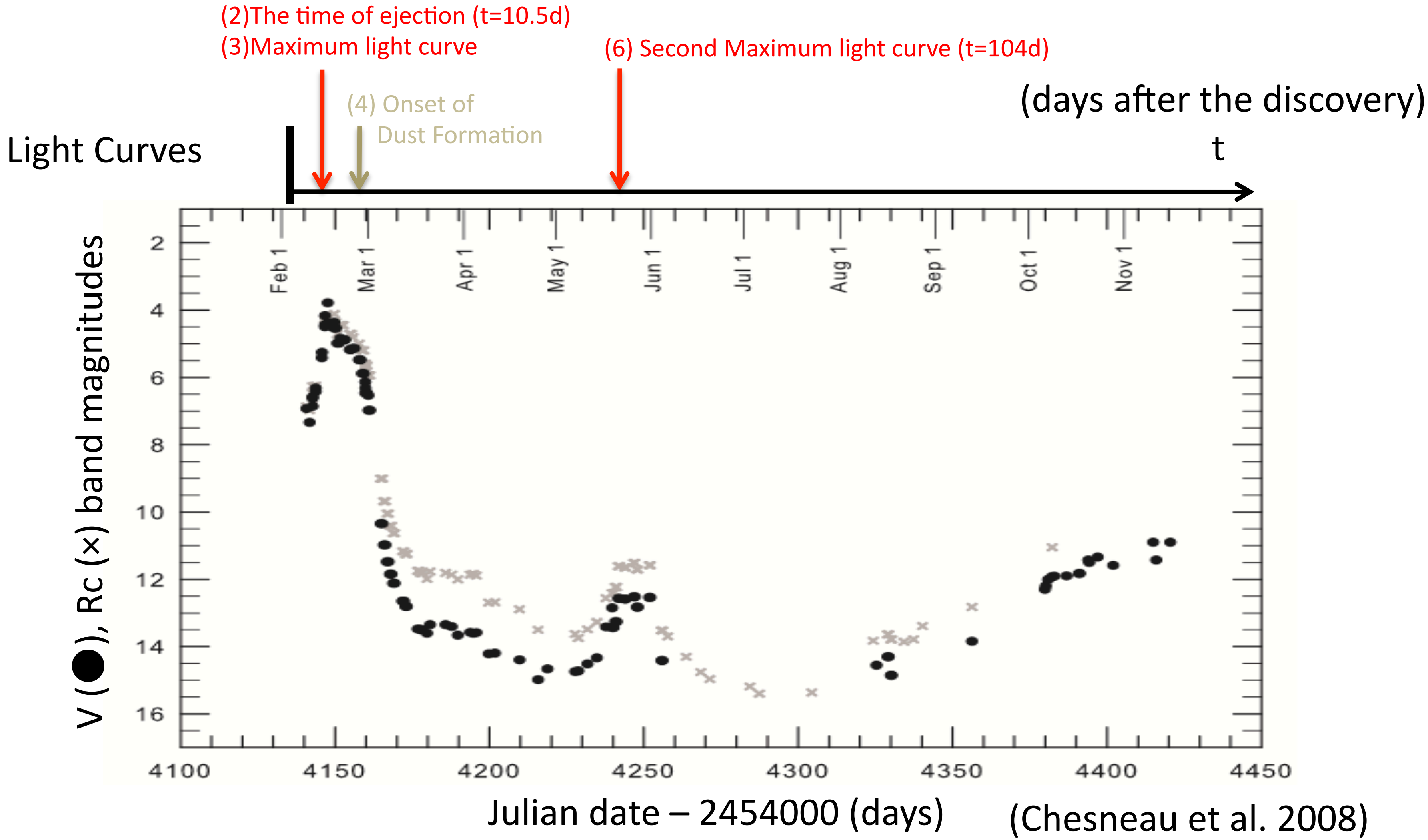
Late-epoch Observations of Dust Forming Nova V1280Sco

- July 7, 2007 (epoch ~150 days)
Subaru/COMICS; N-band spectroscopy (8-13.4μm), N- & Q-band photometry (8.8,11.7,18.8, 24.5μm)
Kanata/TRISPEC (June 26, 2007; epoch ~140 days); Ks-band photometry (2.15μm)
- Aug. 1, 2010 (epoch ~1272 days) [GS-2010B-C-7, PI; Sakon, I.]
Gemini-S/TReCS; N-band spectroscopy (7.7-13.2μm), N- & Q-band photometry (7.8, 9.7, 11.7,18.8, 24.5μm)
Gunma (Aug 26, 2010; epoch ~1300 days); J, H, Ks-band photometry (1.24, 1.66, 2.15μm)
- July 10, 2011 (epoch ~1616 days) [GS-2011B-C-4, PI; Sakon, I.]
Gemini-S/TReCS; N-band spectroscopy (7.7-13.2μm), N- & Q-band photometry (7.8, 9.7, 11.7,18.8, 24.5μm)
Gunma (Sep 8, 2010; epoch ~1670 days); J, H, Ks-band photometry (1.24, 1.66, 2.15μm)
-June 5, 2012 (epoch ~1947 days) [GS-2012A-C-5, PI; Sakon, I.]
Gemini-S/TReCS; N-band spectroscopy (7.7-13.2μm), N- & Q-band photometry (7.8, 9.7, 11.7,18.8, 24.5μm)

- Sep. 8, 2009 (epoch ~940 days) [AKARI phase 3-II Open Time program "SENNA", PI: Sakon I.]
AKARI/IRC; near-infrared spectroscopy (2.5-5μm)

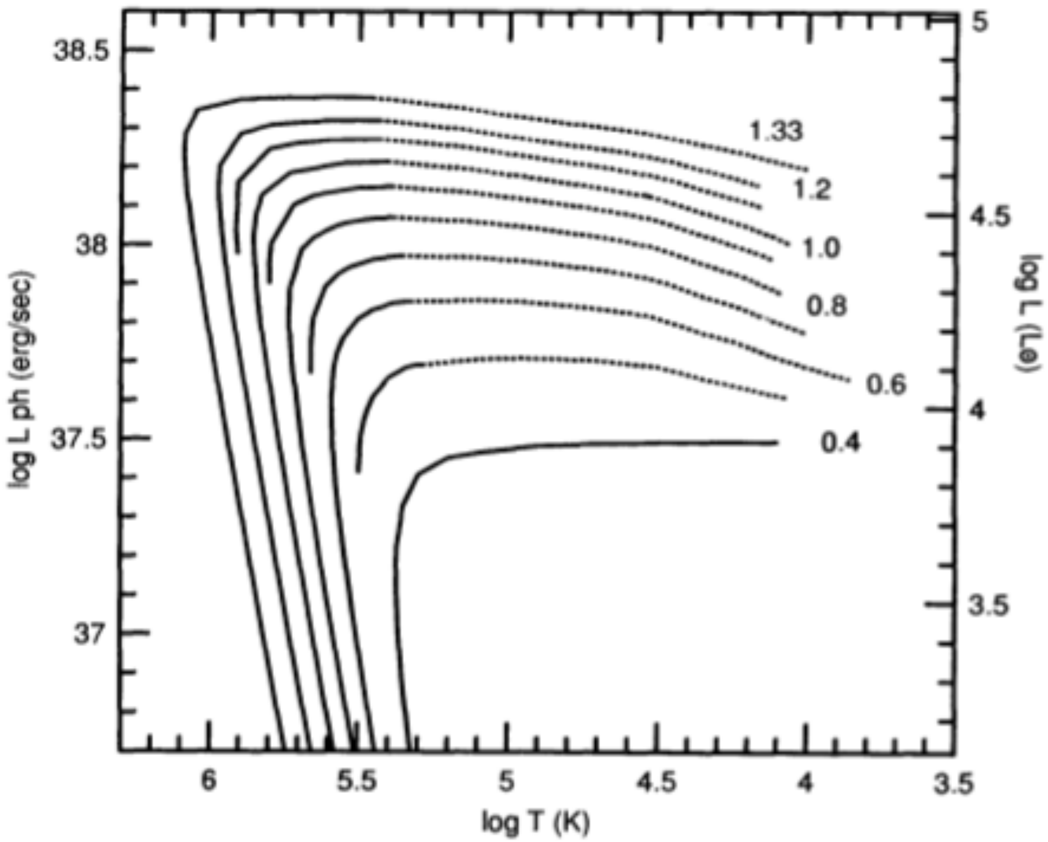
The Light Curve Evolution and the Mass loss History of V1280Sco

(1) DISCOVERY ; 2007,Feb.,4.85 [JD=2454136.85] (t=0 days; Yamaoka et al. 2007)
(2) THE TIME OF EJECTION ; 2007, Feb.,15 (t~10.5±7 days; Das et al. 2008; Chesneau et al. 2008)
(3) MAXIMUM LIGHT CURVE ; 2007, FEB., 16 (t=12 days after the discovery)
(4) ONSET OF DUST FORMATION ; 2007, FEB, 28 (t=23 days after the discovery)
(5) HIGHEST DUST FORMATION ; t=36-45 days 7.4×10^{-9} M_{sun}/day (Chesneau et al. 2008)
(6) SECOND MAXIMUM ; 2007, MAY, 20 (t=104 days after the discovery)



(Chesneau et al. 2008)

Luminosity and Temperature Evolution of M_{WD}=0.6$M_{\odot}$



(Kato & Hachisu 1994, ApJ, 437, 802)

Assuming X = 0.35, Y = 0.33, C+O= 0.30

Day 150;
T_{WD}=25,000K
M_{WD}=16,000$L_{\odot}$

Days 1272, 1616, 1947;
(close to nebular phase)
T_{WD}=100,000K
M_{WD}=18,000$L_{\odot}$

Expanding Dust Structures Around V1280Sco

1”

1” corresponds to the distance
at which the ejected materials
with 350km/s can travel in 5000 days

0.25”

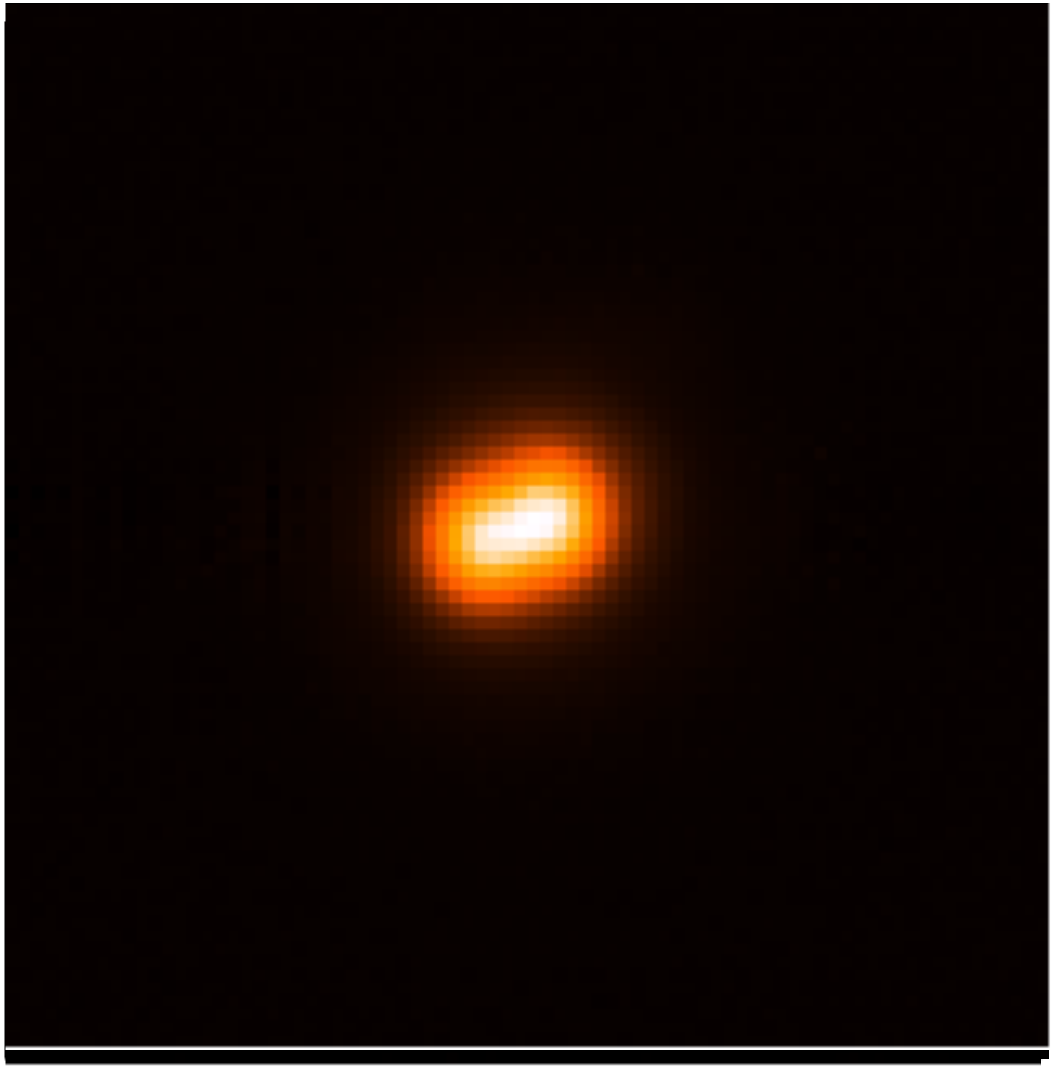
the distance at which the ejected materials
with 350km/s can travel in ~1250 days

0.32”

the distance at which the ejected materials
with 350km/s can travel in ~1600 days

0.40”

the distance at which the ejected materials
with 350km/s can travel in ~2000 days

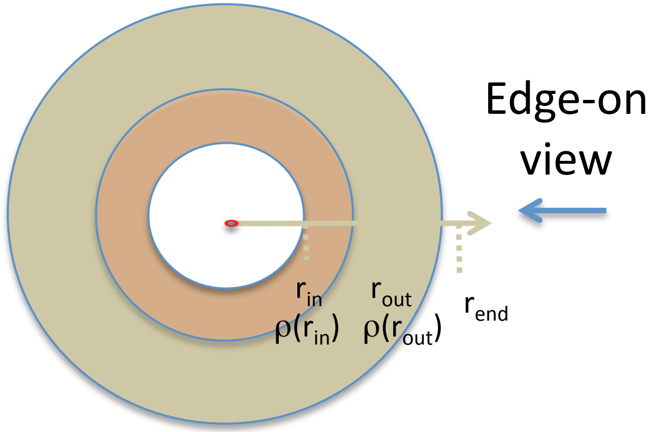


Day 1947 (5th Jun, 2012)

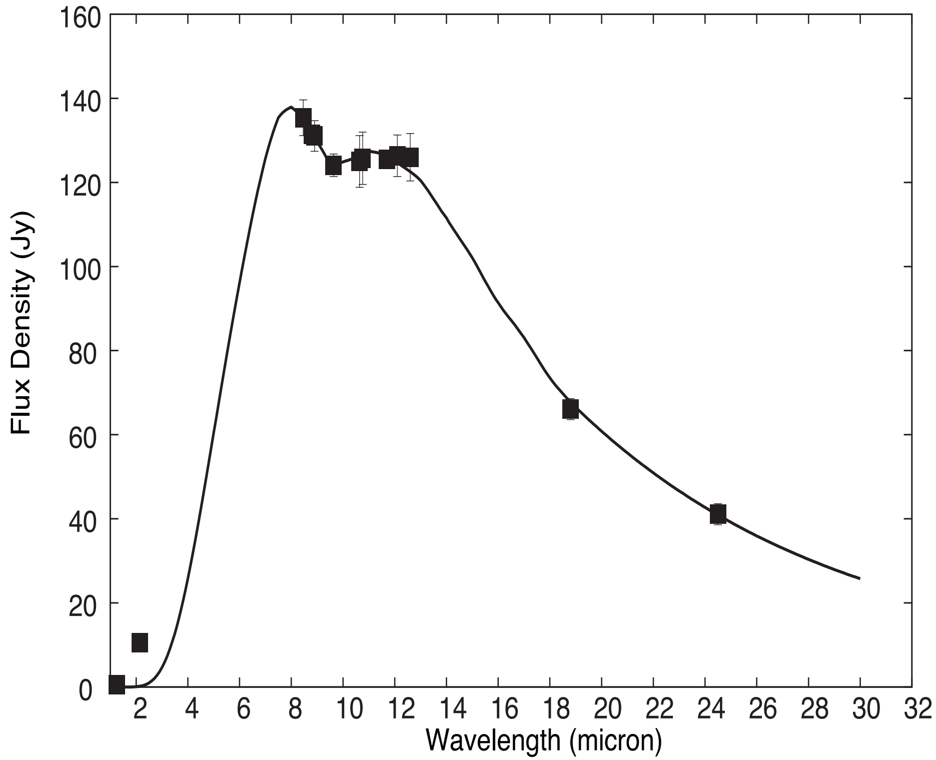
Day 1616 (10th Jul, 2011)

Subaru/COMICS N11.7, Gemini-S/TReCS Si-5 (11.7μm)

[Day 150] SED Analyses for Optically Thick Spherical Double Dust Shells Model



$$\rho(r)=\begin{cases}\rho_{in}\,(r/r_{in})^{-2} & (r_{in}<r<r_{out})\\ \rho_{out}\,(r/r_{out})^{-2} & (r_{out}<r<r_{end})\end{cases}$$



Composition of Dust;

Amorphous Carbon with $a=0.5\mu m$

$Q_{abs}(\lambda)$ for $\lambda<0.1\mu m$; Dwek & Smith (2006)

for $\lambda>0.1\mu m$; Zubko et al. (1996)

- - - - - - - - - - - - Stellar Parameters - - - - - - - - - - - -

White Dwarf Mass; $M_{WD}=0.6\,M_\odot$

Effective Temperature at Day 150; 25,000K

Total Luminosity at Day 150; $16{,}000L_\odot$

-- - - - - - - - - - - best-fit parameters - - - - - - - - - - - -

Radius of the Inner Dust Shell; r_{in}=0.007"

Radius of the Outer Dust Shell; r_{out}=0.035"

Radius of the Outer Disk Shell; r_{end}=0.056"

Initial Number Density at r_{in}; $\rho_{in}=0.32\ (m^{-3})$

Initial Number Density at r_{out}; $\rho_{out}=1.58\ (m^{-3})$

Extinction by Silicate; $\tau_{9.7}=0.24$

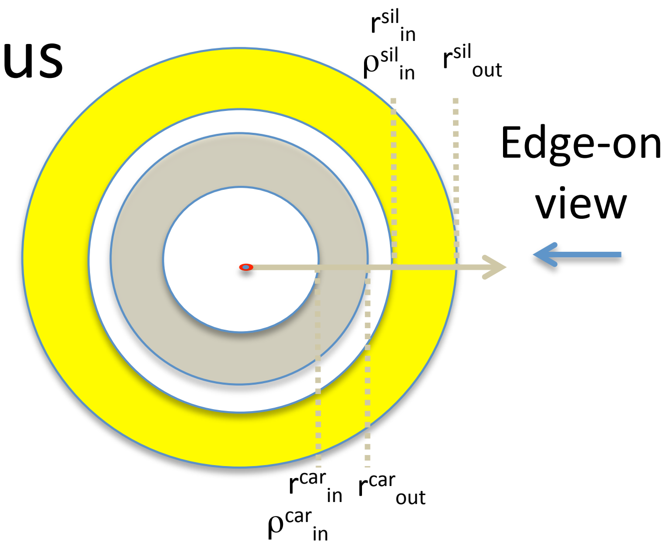
The outer disk shell can reside in a space enclosed by the two concentric spheres with radii of 0.024" and 0.046", where the initial nova ejecta ejected at t=10.5d with velocities from $320kms^{-1}$ to $620kms^{-1}$ can reach at t=150 d.

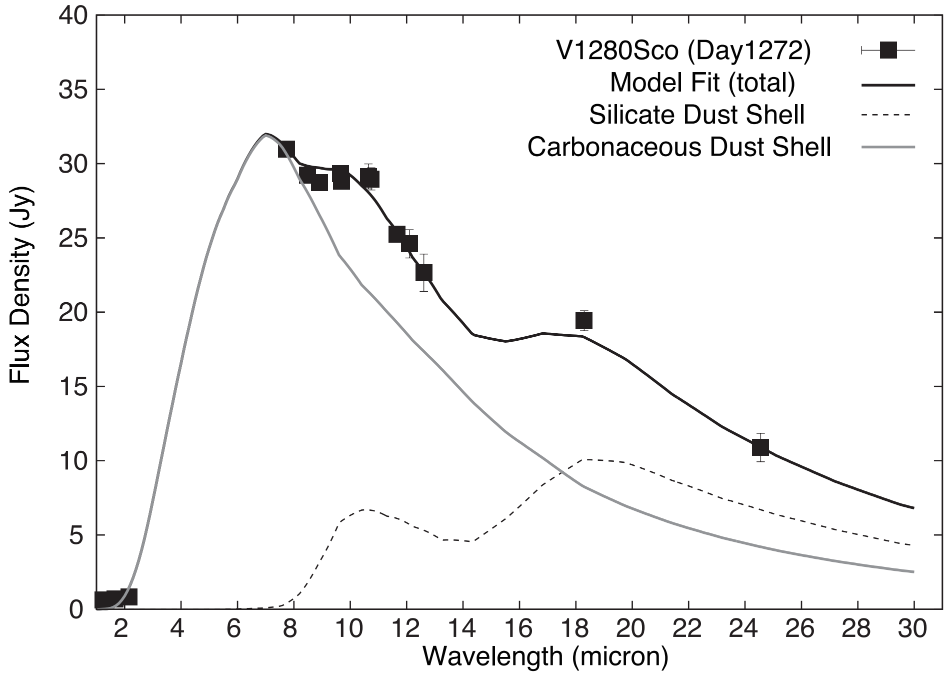
- Amorphous Carbons in the outer Shell are formed in the nova wind associated with the initial outburst at t~10.5d.
- Uniform spherical dust shell model fails in explaining the near-infrared excess emission

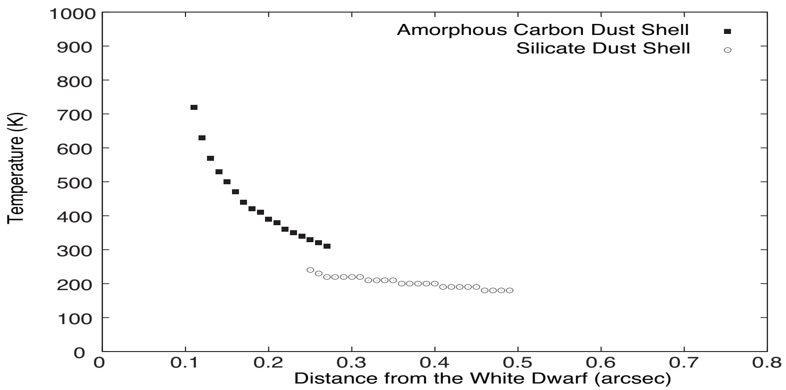
[Day 1272] SED Analyses for Carbonaceous and Silicate Dust Shells Model

$\rho^{car}(r) = \rho^{car}_{in} (r/r^{car}_{in})^{-2} \quad (r^{car}_{in}<r<r^{car}_{out})$

$\rho^{sil}(r) = \rho^{sil}_{in} (r/r^{sil}_{in})^{-2} \quad (r^{sil}_{in}<r<r^{sil}_{out})$







Composition of Dust;

Amorphous Carbon with a=0.01μm

Astronomical Silicate with a=0.1μm

$Q^{car}_{abs}(\lambda)$, $Q^{sil}_{abs}(\lambda)$ for λ<0.1μm; Dwek & Smith (2006)

$Q^{car}_{abs}(\lambda)$ for λ>0.1μm; Zubko et al. (1996)

$Q^{sil}_{abs}(\lambda)$ for λ>0.1μm; Draine et al. (1984)

----------- Stellar Parameters -----------

White Dwarf Mass; M_{WD}=0.6 $M_{\odot}$

Effective Temperature at Day 1272; 100,000K

Total Luminosity at Day 1272; 18,000$L_{\odot}$

----------- best-fit parameters -----------

Inner Radius of Carbon Dust Shell; r^{car}_{in}=0.11”

Outer Radius of Carbon Dust Shell; r^{car}_{out}=0.29”

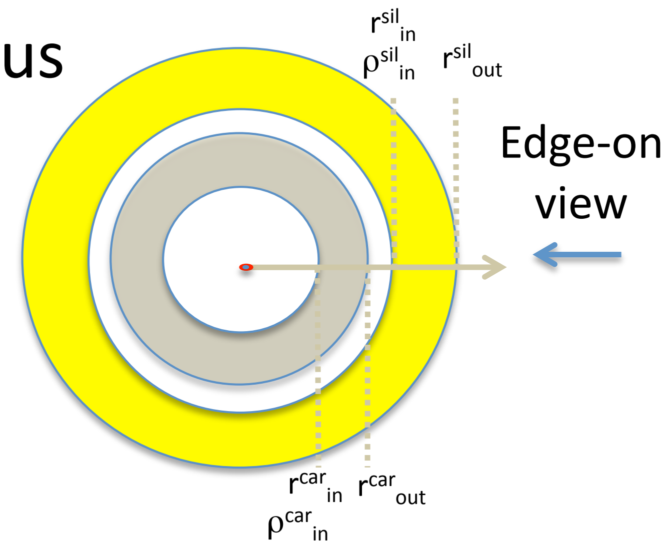
Inner Radius of Silicate Dust Shell; r^{sil}_{in}=0.25”

Outer Radius of Silicate Dust Shell; r^{sil}_{out}=0.50”

Initial Number Density at r^{car}_{in}; ρ^{car}_{in}=2.5x10^3 (m^{-3})

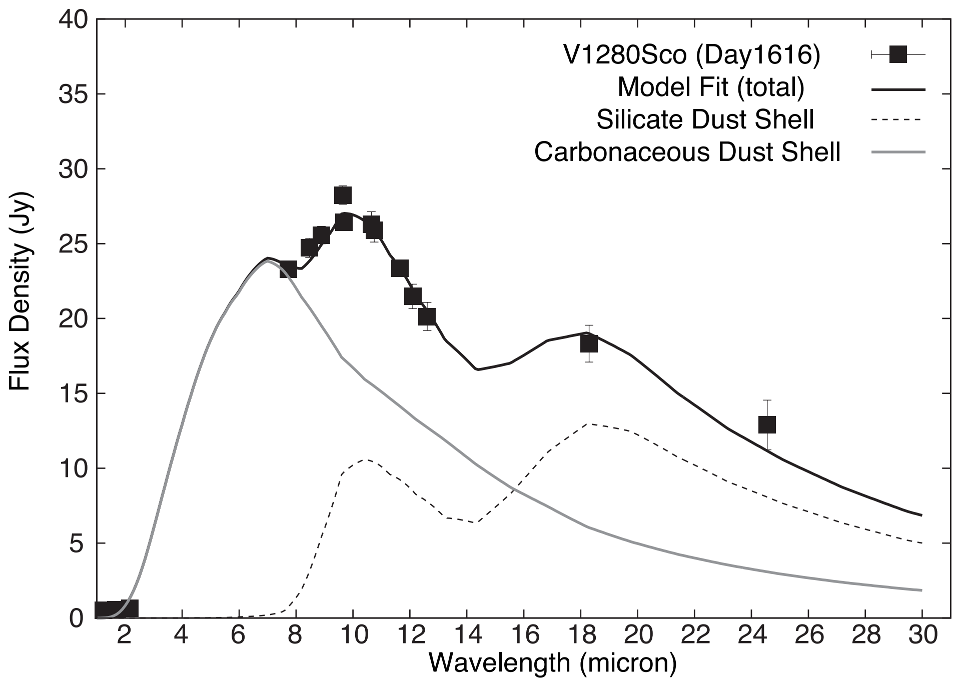
Initial Number Density at r^{sil}_{out}; ρ^{sil}_{out}= 1.0 (m^{-3})

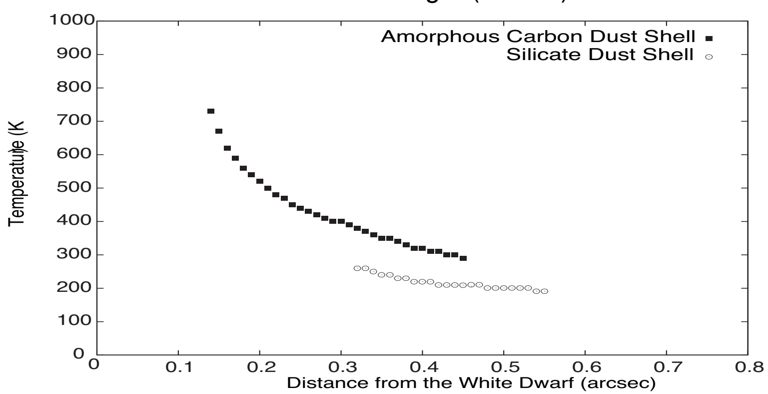
[Day 1616] SED Analyses for Carbonaceous and Silicate Dust Shells Model



$\rho^{car}(r) = \rho^{car}_{in} \, (r/r^{car}_{in})^{-2} \qquad (r^{car}_{in}<r<r^{car}_{out})$

$\rho^{sil}(r) = \rho^{sil}_{in} \, (r/r^{sil}_{in})^{-2} \qquad (r^{sil}_{in}<r<r^{sil}_{out})$





Composition of Dust;

Amorphous Carbon with a=0.01μm

Astronomical Silicate with a=0.1μm

$Q^{car}_{abs}(\lambda)$, $Q^{sil}_{abs}(\lambda)$ for $\lambda<0.1\mu m$; Dwek & Smith (2006)

$Q^{car}_{abs}(\lambda)$ for $\lambda>0.1\mu m$; Zubko et al. (1996)

$Q^{sil}_{abs}(\lambda)$ for $\lambda>0.1\mu m$; Draine et al. (1984)

- - - - - - - - - - - Stellar Parameters - - - - - - - - - - -

White Dwarf Mass; M_{WD}=0.6 $M_\odot$

Effective Temperature at Day 1272; 100,000K

Total Luminosity at Day 1272; 18,000$L_\odot$

-- - - - - - - - - - best-fit parameters - - - - - - - - - - -

Inner Radius of Carbon Dust Shell; r^{car}_{in}=0.14”

Outer Radius of Carbon Dust Shell; r^{car}_{out}=0.46”

Inner Radius of Silicate Dust Shell; r^{sil}_{in}=0.32”

Outer Radius of Silicate Dust Shell; r^{sil}_{out}=0.57”

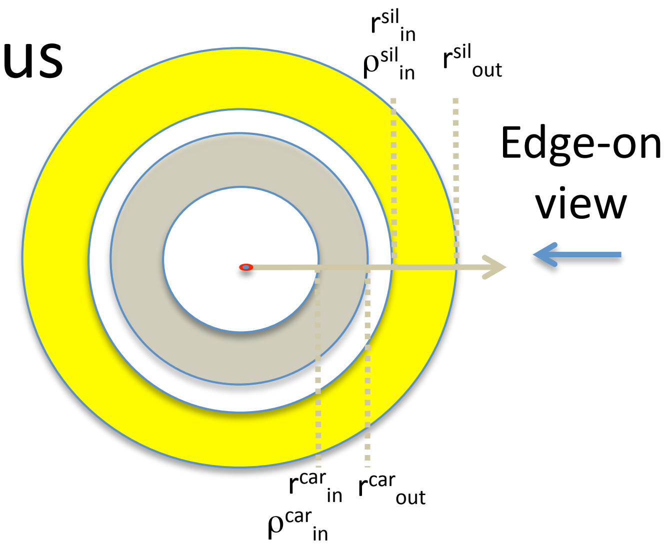
Initial Number Density at r^{car}_{in}; ρ^{car}_{in}=1.0x10^3 (m^{-3})

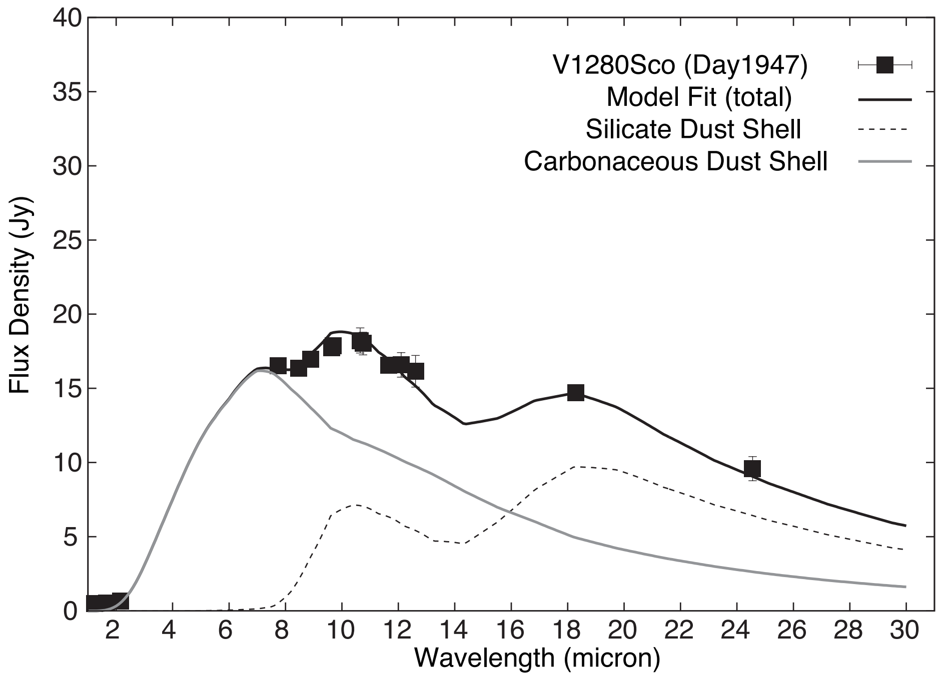
Initial Number Density at r^{sil}_{out}; ρ^{sil}_{out}=1.0 (m^{-3})

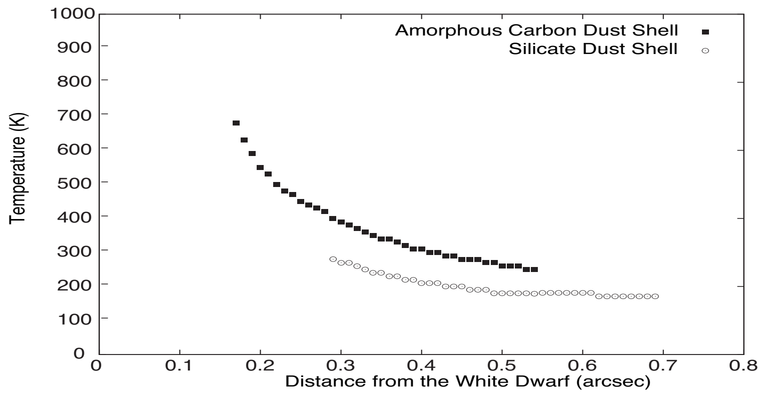
[Day 1947] SED Analyses for Carbonaceous and Silicate Dust Shells Model

$\rho^{car}(r) = \rho^{car}_{in}\,(r/r^{car}_{in})^{-2} \qquad (r^{car}_{in}<r<r^{car}_{out})$

$\rho^{sil}(r) = \rho^{sil}_{in}\,(r/r^{sil}_{in})^{-2} \qquad (r^{sil}_{in}<r<r^{sil}_{out})$







Composition of Dust;

Amorphous Carbon with a=0.01μm

Astronomical Silicate with a=0.1μm

$Q^{car}_{abs}(\lambda)$, $Q^{sil}_{abs}(\lambda)$ for $\lambda<0.1\mu m$; Dwek & Smith (2006)

$Q^{car}_{abs}(\lambda)$ for $\lambda>0.1\mu m$; Zubko et al. (1996)

$Q^{sil}_{abs}(\lambda)$ for $\lambda>0.1\mu m$; Draine et al. (1984)

----------- Stellar Parameters -----------

White Dwarf Mass; $M_{WD}=0.6\,M_\odot$

Effective Temperature at Day 1272; 100,000K

Total Luminosity at Day 1272; $18{,}000L_\odot$

----------- best-fit parameters -----------

Inner Radius of Carbon Dust Shell; r^{car}_{in}=0.17”

Outer Radius of Carbon Dust Shell; r^{car}_{out}=0.55”

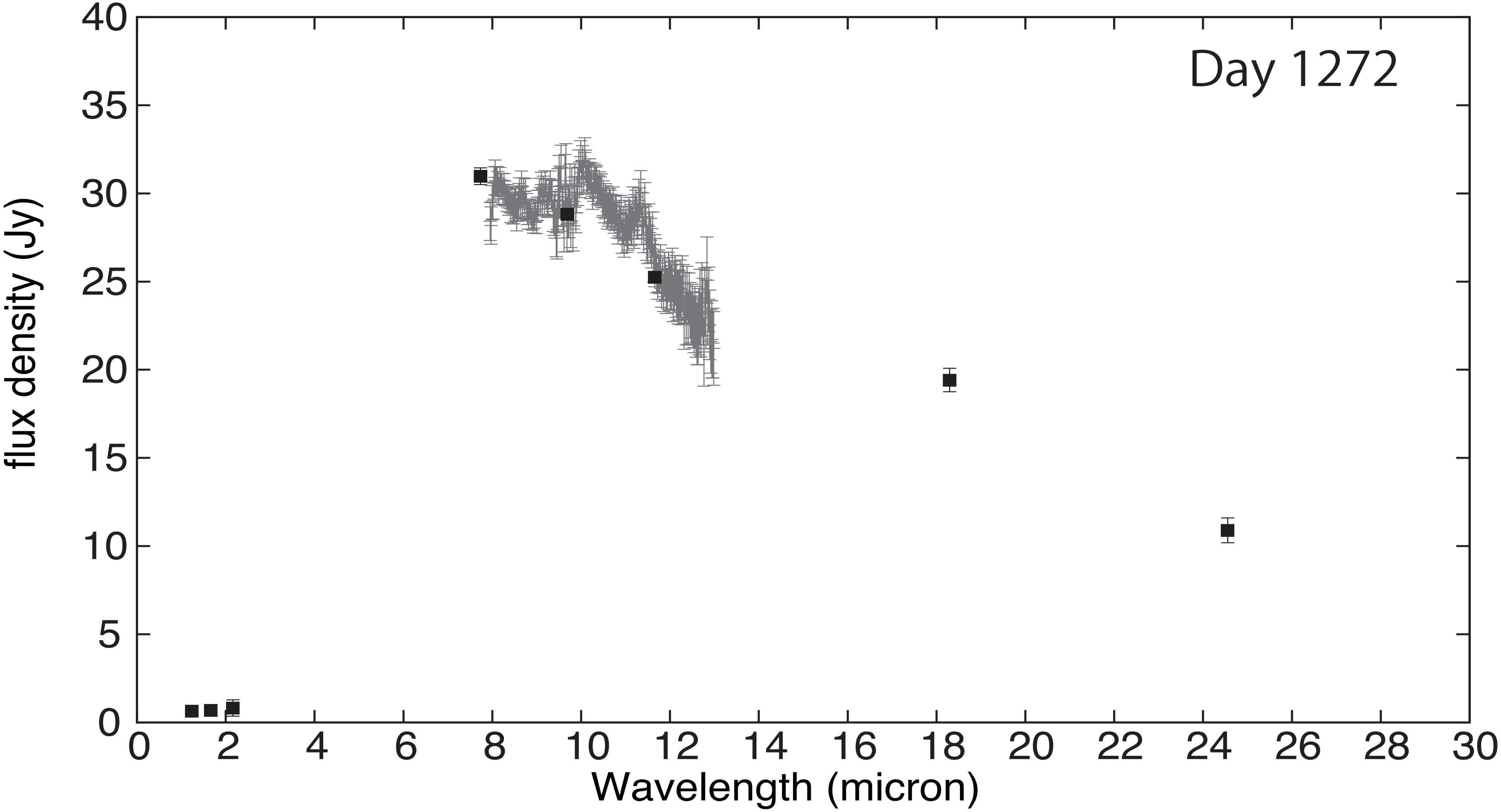
Inner Radius of Silicate Dust Shell; r^{sil}_{in}=0.29”

Outer Radius of Silicate Dust Shell; r^{sil}_{out}=0.70”

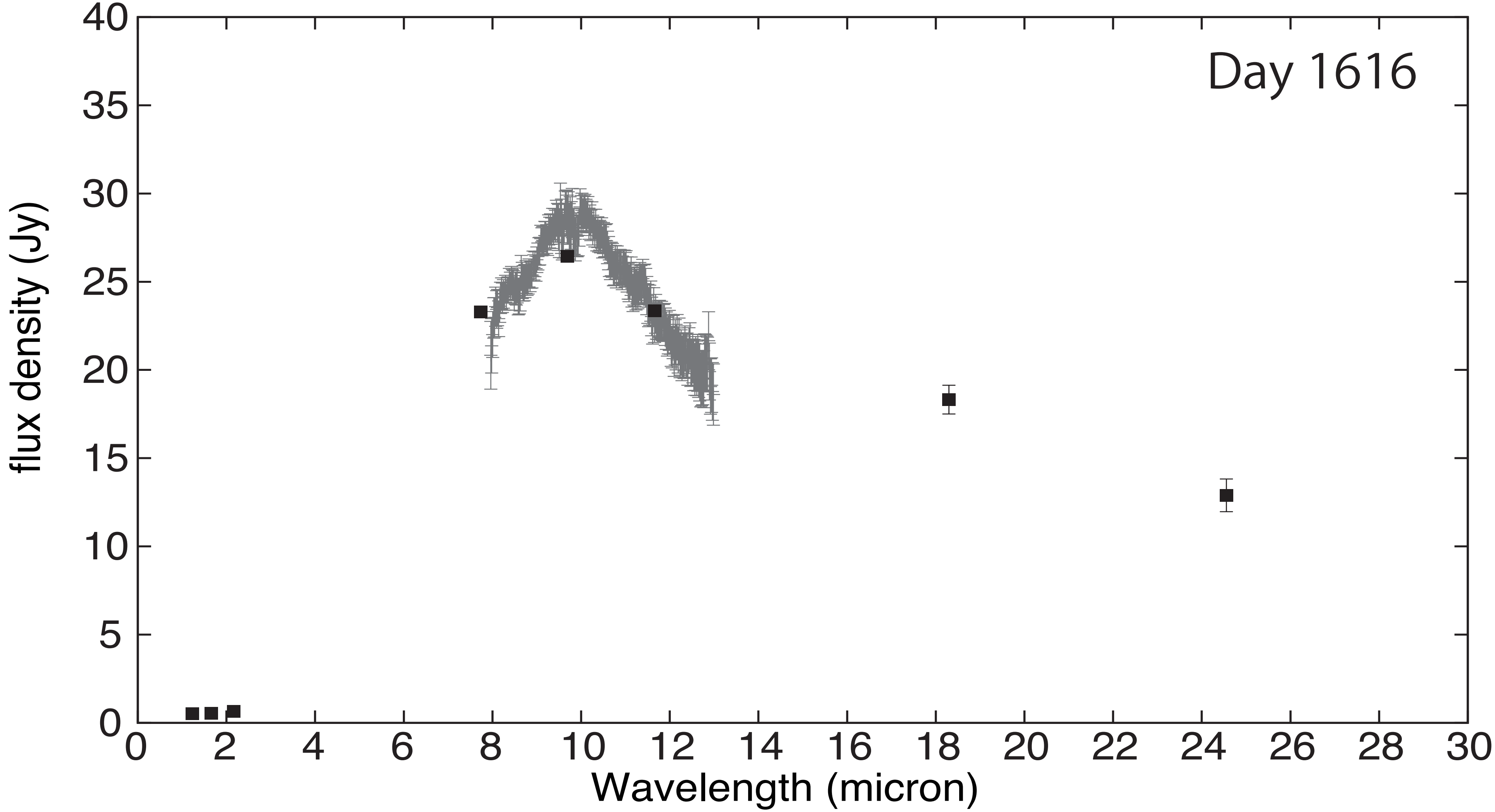
Initial Number Density at r^{car}_{in}; $\rho^{car}_{in}=1.0\times10^3$ (m^{-3})

Initial Number Density at r^{sil}_{out}; $\rho^{sil}_{out}=1.0$ (m^{-3})

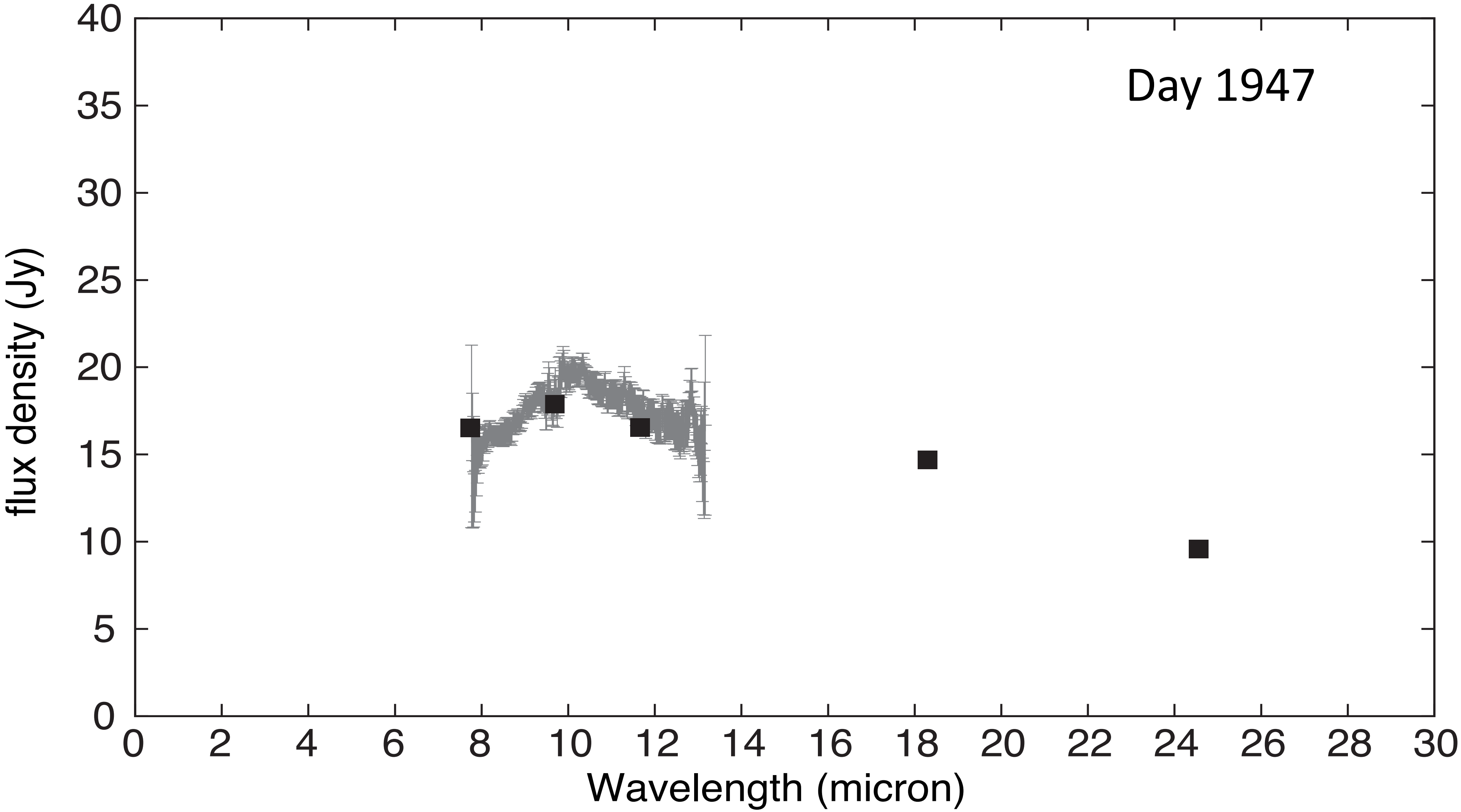
Spectral Energy Distribution of V1280Sco at ~1272 days obtained with Gemini-S/TReCS



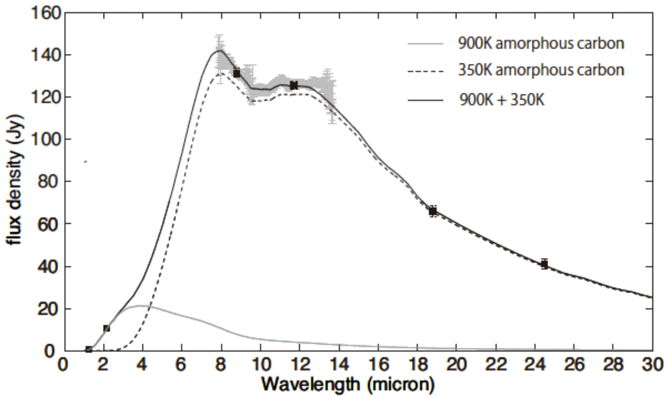
Spectral Energy Distribution of V1280Sco at ~1616 days obtained with Gemini-S/TReCS

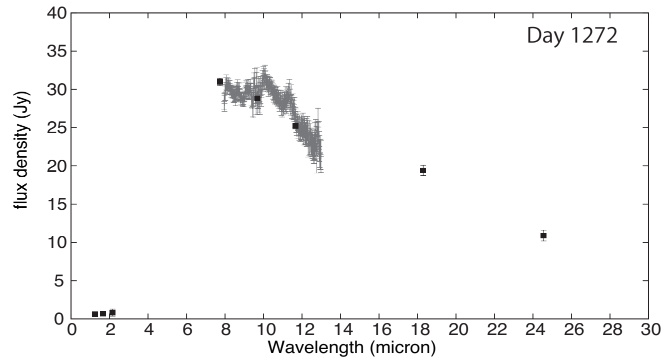


Spectral Energy Distribution of V1280Sco at ~1947 days obtained with Gemini-S/TReCS



Interpretation for the origin of Silicate Dust seen in V1280Sco

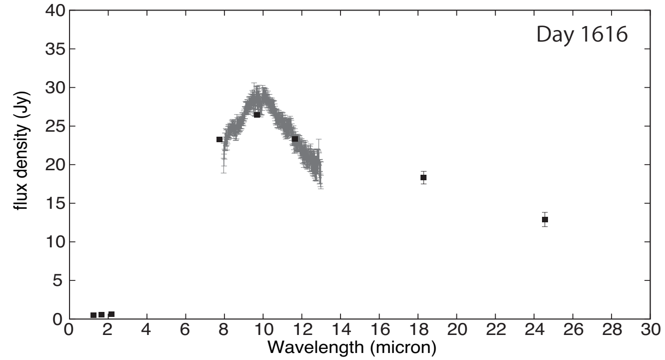


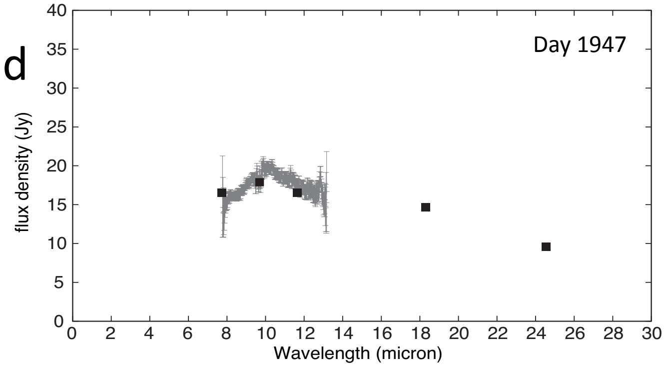


Bimodal Nature of Dust in V1280Sco

Amorphous Carbons
- formed in nova wind

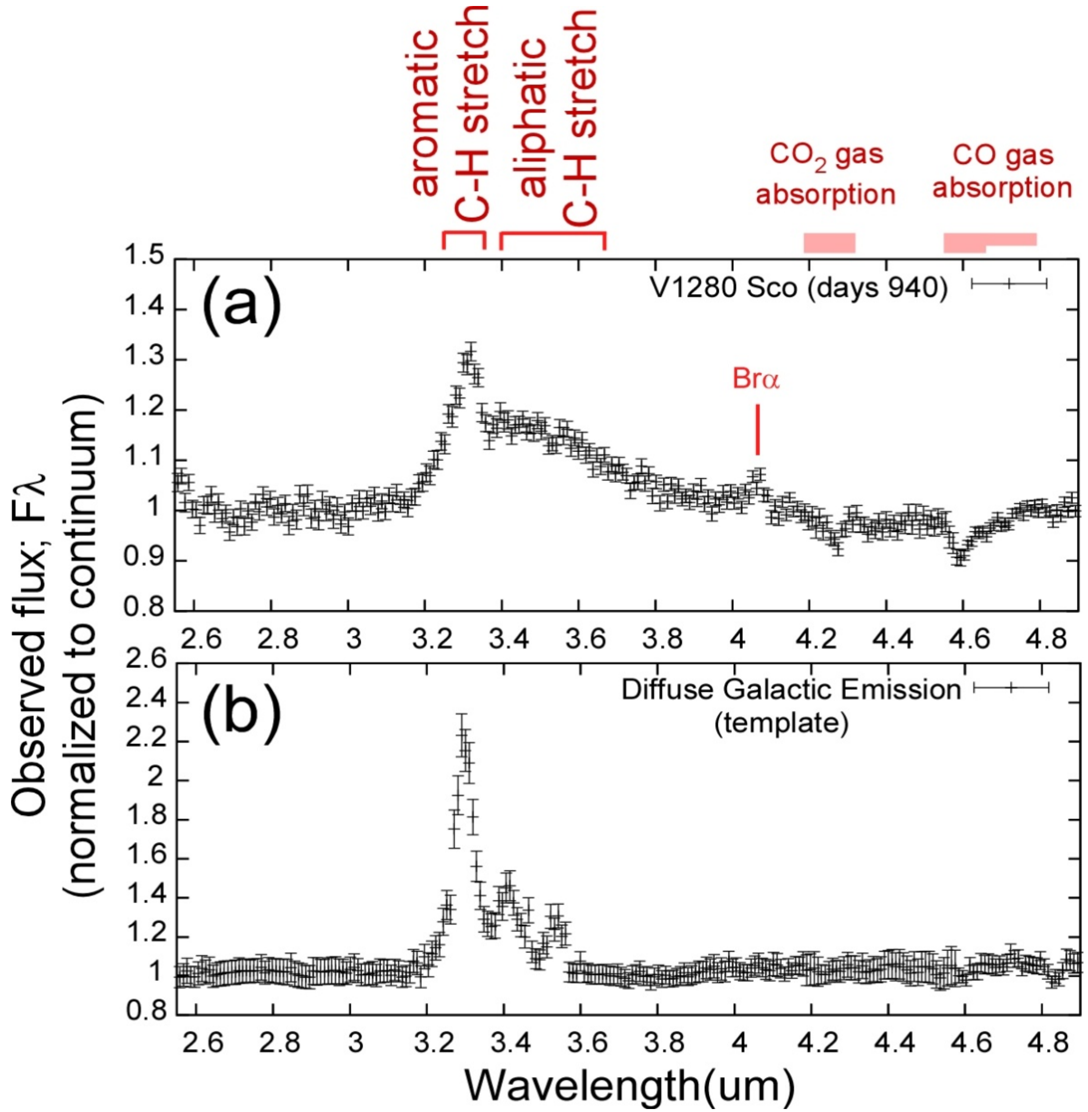
Silicate Dust
- Initially seen in absorption at t=150d
- seen in emission at later epochs at t=1272d, 1616d and 1947d





Higher 10μm/18μm was observed at t=1616 and 1947
→Geometry effect of amorphous carbon dust shell in screen

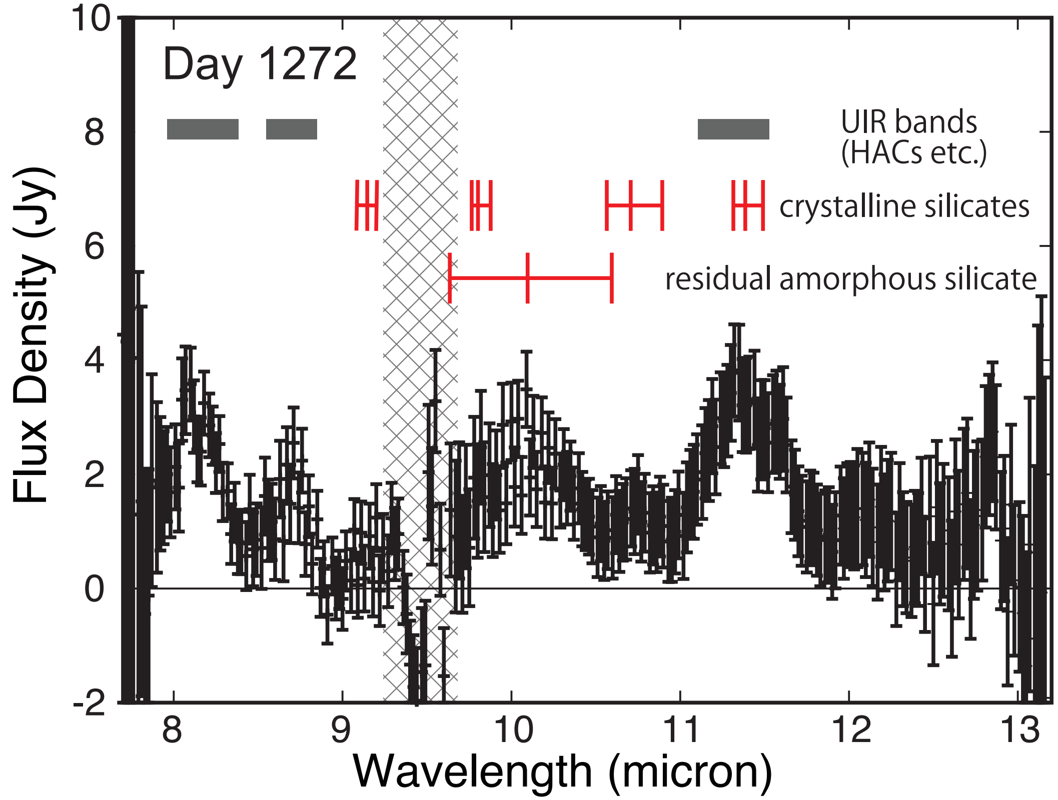
Near Infrared Spectrum of V1280Sco at ~940 days with AKARI/IRC



(a) Near-Infrared spectrum of V1280Sco obtained at 940 days after the discovery normalized to the continuum obtained with AKARI/Infrared Camera (IRC). The UIR 3.3μm feature with a strong redwing in 3.4-3.6μm was recognized.

(b) Near-infrared spectrum of Galactic ISM as an example of typical spectrum of PAH features with a normal inter-band ratios among 3.3, 3.4 and 3.5μm features obtained with AKARI/IRC.

Mid-Infrared Spectral Features over the Infrared Continuum modeled with amorphous carbon and astronomical silicate at 1272 days



Features at ~8.1μm, ~8.7μm, ~11.35μm;

Hydrogenated Amorphous Carbons (HACs), NH2-rocks (Grishko & Duley 2002)

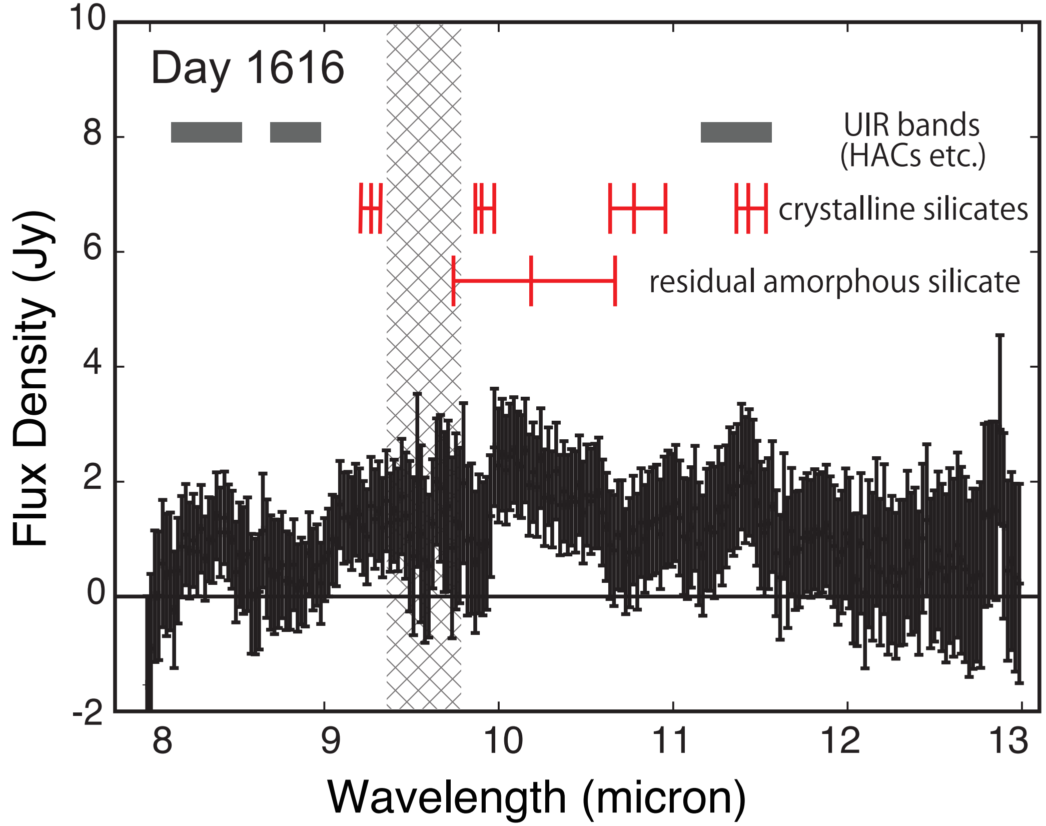
→ similar to those found in V704 Cas 1993 (Evans et al. 1997, 2005)

A Broad Feature at ~10.1μm; amorphous silicate

Features at ~9.2μm, ~9.8μm, ~10.7μm, ~11.4μm;

Possible contributions of forsterite, enstatite and diopside (Molster et al. 2002)

Mid-Infrared Spectral Features over the Infrared Continuum modeled with amorphous carbon and astronomical silicate at 1616 days



Possible HAC features at ~8.1μm, ~8.7μm, ~11.35μm have diminished at t=1616 days

Summary

Dust Formation and Evolution History of V1280Sco has been examined based on the multi-epoch mid-infrared observations of V1280Sco with Subaru/COMICS, Gemini-S/TReCS, and AKARI/IRC ;

- Amorphous carbon dust is formed in the major nova wind ejected at t=10.5d.
- Amorphous carbon dust is formed in the ejecta of second outburst at t=104d.
- Silicate features detected in the SED at t=1272, 1616, 1947 are expected to be carried by pre-existing circum-stellar silicate dust.

The dust formation and evolution scenario of V1280Sco obtained in this study may be common for some other classical novae showing both the silicate and carbonaceous features.