Infrared Observations of Novae with Subaru/COMICS and Gemini/T-ReCS

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Infrared Observations of Novae

Mid-infrared Imaging and Spectroscopic monitoring observations of Galactic dust forming novae

→ unique laboratories to study the process of dust formation and to understand the mass-loss history of the CO white dwarves from the chemical point of view

Infrared Spectral Evolution of CO Novae and ONeMg Novae

- Hot ejecta gas is initially seen as an expanding photosphere or "fireball"
- When the expanding material becomes optically thin, free-free and line emission dominate

1). CO Novae;

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

chemical evolution of the Nova ejecta over various physical phases is not fully understood

V1280 Scorpii

-Discovered on 2007 Feb 4.86 by Y. Nakamura and Y. Sakurai (Yamaoka et al. 2007)
- d = 1.6$\pm$0.4 kpc (Chesneau et al. 2008)
-Dust formation occurred at d~23days after discovery (Das et al. 2007)

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$\pm$0.03mas day^{-1}
-Expansion velocity of the nova ejecta; 500$\pm$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}

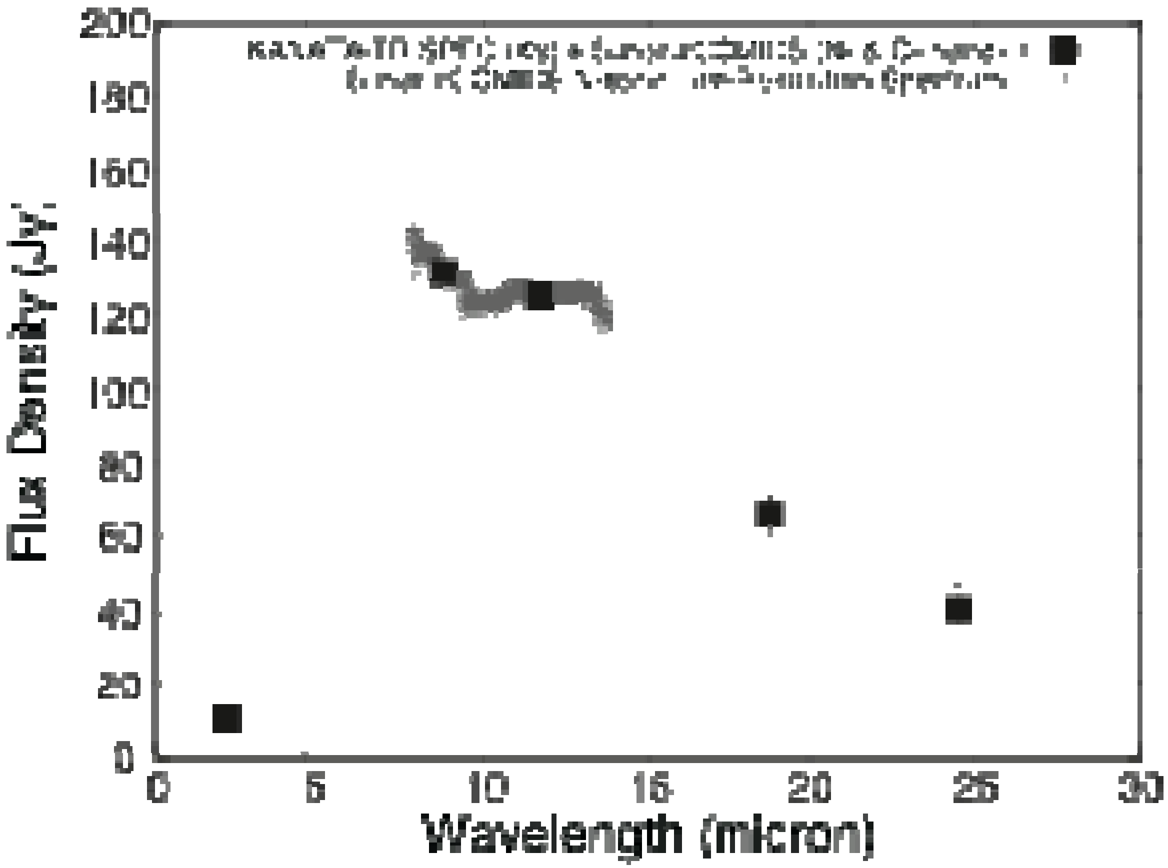
Late-epoch Observations of Dust Forming Nova V1280Sco

- <u>July 7, 2007 (epoch ~150 days)</u>
Subaru/COMICS; N-band spectroscopy (8-13.4μm)
N- & Q-band photometry (8.8μm, 11.7μm, 18.8μm, 24.5μm)
Kanata/TRISPEC (June 26, 2007; epoch ~140 days); Ks-band photometry (2.15μm)

- <u>September 8, 2009 (epoch ~940 days)</u>
AKARI/IRC; near-infrared spectroscopy (2.5-5μm)

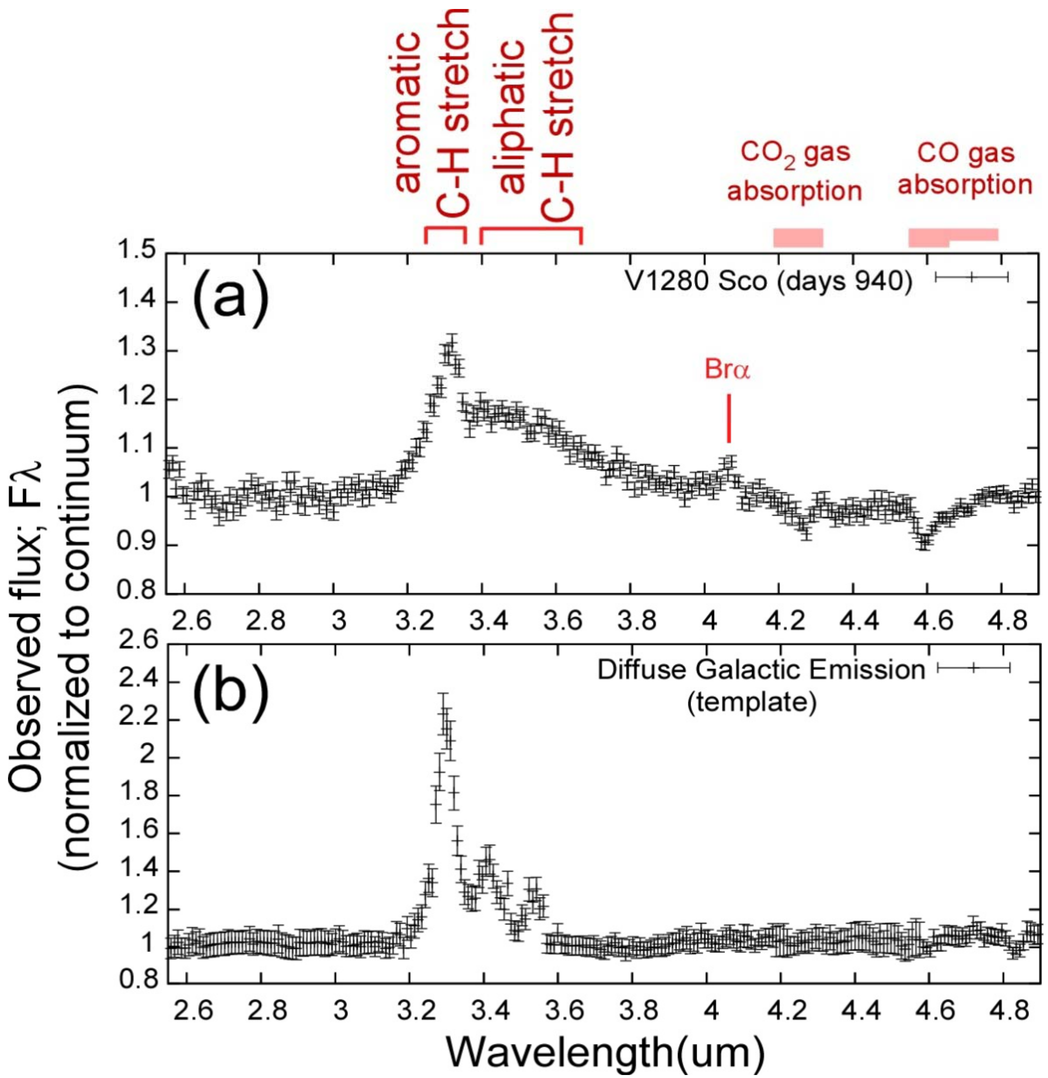
- <u>August 1, 2010 (epoch ~1270 days)</u>
Gemini-S/TReCS; N-band spectroscopy (7.7-13.2μm)
N- & Q-band photometry (7.8μm, 9.7μm, 11.7μm,18.8μm, 24.5μm)
Gunma (Aug 26, 2010; epoch ~1300 days);
J, H, Ks-band photometry (1.24, 1.66, 2.15μm)

Infrared Spectral Energy Distribution of V1280Sco at ~150 days with Subaru/COMICS



Possible Silicate Absorption Feature at ~10μm

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

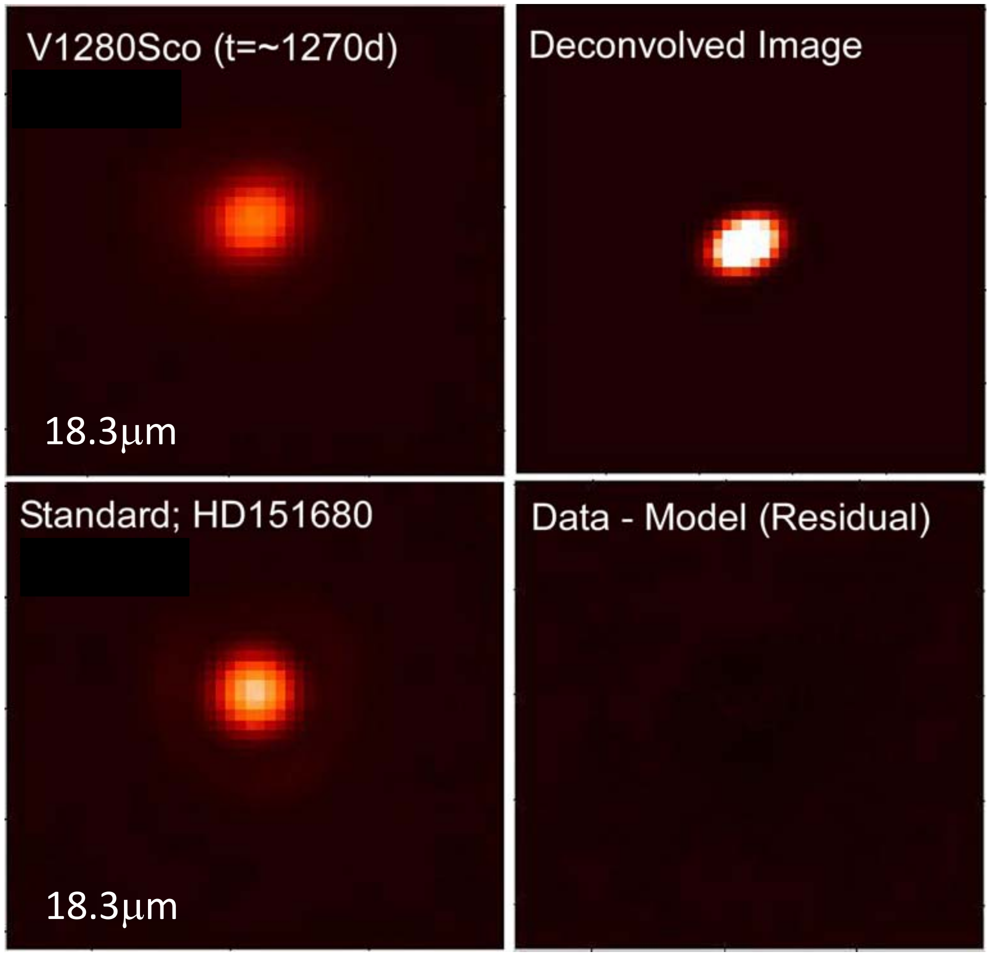


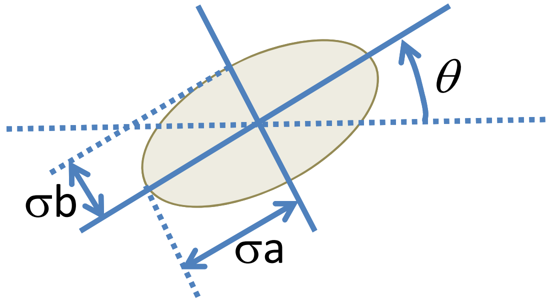
(a) Near-Infrared spectrum of V1280 Sco on the epoch 940 days after the discovery normalized to the continuum obtained with Infrared Camera (IRC) onboard AKARI.
A PAH 3.3μm feature with a strong redwing in 3.4-3.6μm was recognized.

(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.

Results of N- & Q-band imaging observations of V1280 Sco at t=~1270 days with Gemini-S/TReCS

Example; Qa band data of V1280Sco and HD151680





Intrinsic profile of the dust emission;
3D-Elliptical Gaussian

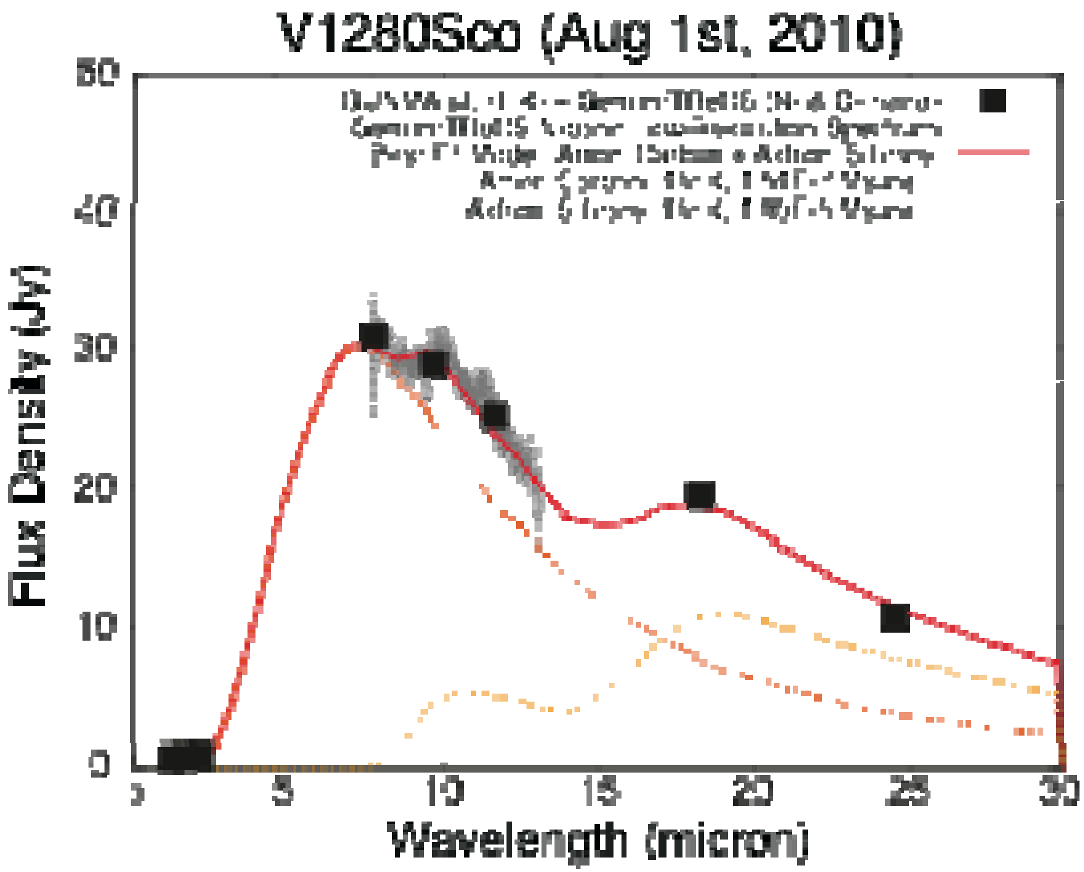
θ ; position angle for the major-axis
σa ; semi-major axis radius
σb ; semi-minor axis radius

The best-fit 3D-Elliptical Gaussian parameters

Band	λ(μm)	θ (deg)	σa (“)	σb (“)
Si-1	7.73	25	0.32±0.02	0.19±0.02
Si-3	9.69	25	0.30±0.02	0.18±0.02
Si-5	11.66	25	0.29±0.02	0.15±0.02
Qa	18.30	25	0.29±0.03	0.20±0.03
Qb	24.56	25	0.38±0.03	0.23±0.03

Non-spherical distribution of dust emission
Effective size of the dust shell; 7.2×10^{10} k (~500AU)
→ Much smaller than the size of the expanding Ejecta Shell with 500km/s at t~1300d; 2×10^{13} km

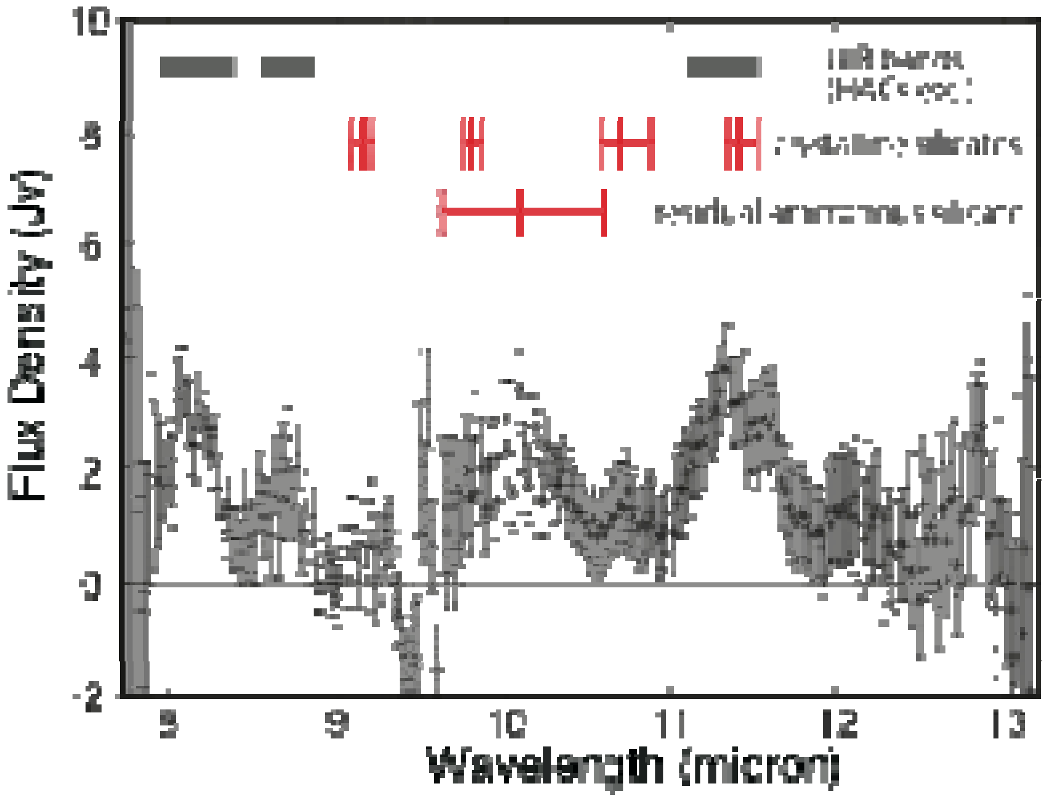
Spectral Decomposition of model fit to the Infrared Continuum Spectrum of V1280Sco at ~1300 days obtained with Gemini-S/TReCS



Amorphous Carbon; 485±5 (K), 1.54x10^{-7}Msun

Astronomical Silicate; 185±5 (K), 1.90x10^{-6}Msun

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



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)

Interpretations; IR observations of V1280Sco

-Near- to mid-infrared (1-25μm) spectrum at t = ~1270 day with Gemini-S/TReCS is well reproduced by Emission from warm (T~185±5K) astronomical silicate dust of $1.9 \times 10^{-6} M_{sun}$ and hot (T~485±5 K) amorphous carbon dust of $1.5 \times 10^{-7} M_{sun}$

→ presence of both carbonaceous dust and (pre-existing?) silicate dust

→ the emitting regions of both components are confined within ~500AU (within an expanding dust shell; 0.35mas/day).

-Strong 18-μm /10- μm silicate band ratio

→ presence of lower temperature astronomical silicate dust (T~185K) of $1.9 \times 10^{-6} M_{sun}$?

→Possible annealing effect? (evolution of circumstellar silicate) (Nuth & Hecht 1990) (consistent with the possible presence of crystalline silicate band emission.)

-Detection of 3.3μm feature with strong red-wing in AKARI/IRC NIR spectrum at t = ~940 days

-Detection of 8.1, 8.7 and 11.35μm features in the spectrum of of V1280 Sco at t=~1270 days with Gemini-S/TReCS

→ Formation of Hydrogenated Amorphous Carbons (HACs) in the nova ejecta

-Presence of silicate absorption in the N-band Low-resolution spectrum of V1280Sco at t = ~150 days with Subaru/COMICS

-CO gas absorption in the AKARI/IRC near-infrared spectrum of V1280Sco at t=~940 days

→ presence of rich circumstellar medium around the white dwarf

Summary

Mid-infrared Imaging and Spectroscopic monitoring of Galactic dust forming novae
→ unique laboratories to study the process of dust formation and to understand the mass-loss history of the CO white dwarves from the chemical point of view

- Late epoch observations t>1000 days are important to examine the chemical evolution of dust grains formed around novae in harsh UV radiation environment
-High spatial resolution achieved by 8-10m class telescopes in the mid-infrared is indispensable to resolve the dust shell structures at those late epochs

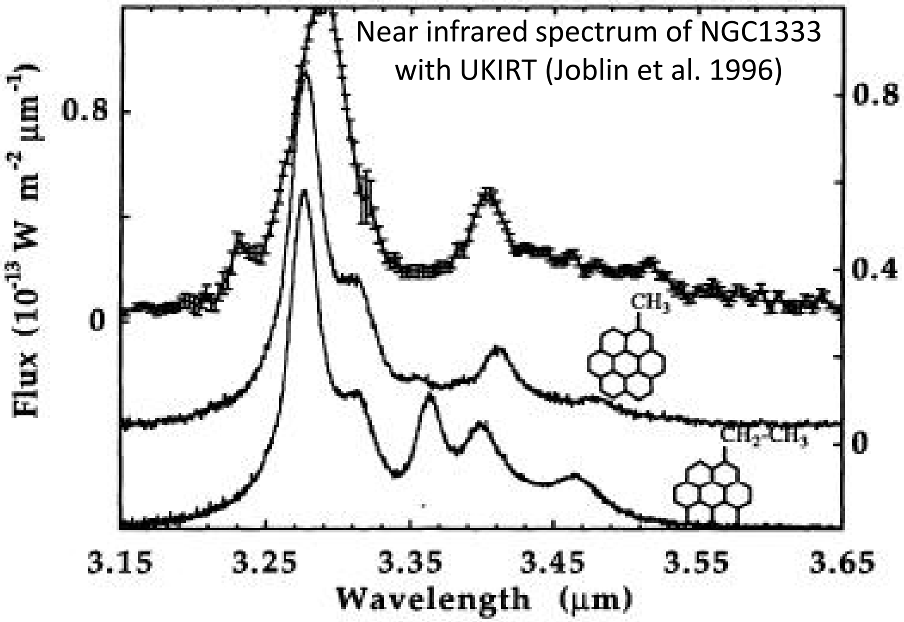
Excellent Performance of Gemini-S/TReCS, not just in N-band, but also in Q-band

Subaru/COMICS; Useful N-band, Q-band Spectroscopic capability with slit viewer
→ crucial to examine the distribution of each dust component by means of the spectral decomposition of the spatially resolved spectra

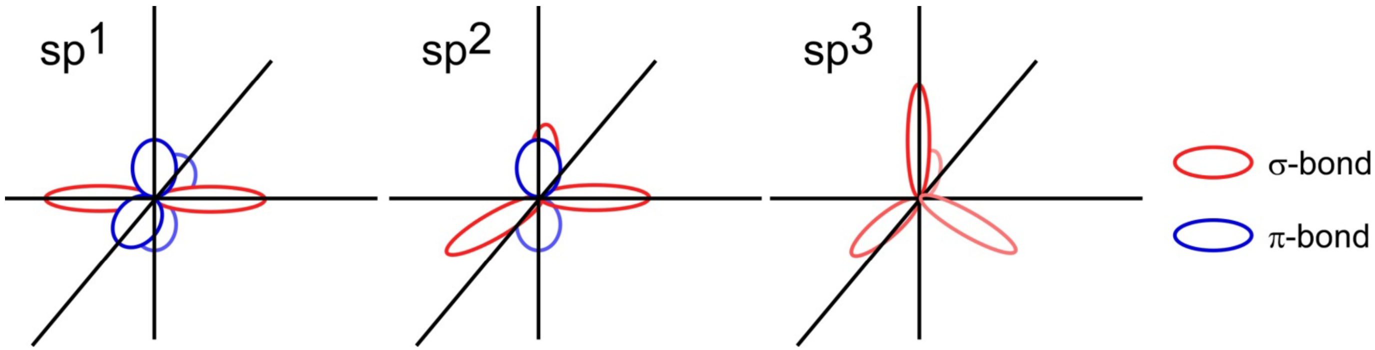
Whole sky coverage achieved by Subaru/COMICS and Gemini-S/TReCS
- Strong advantages in the chemical understanding of dust formation around evolved stars
- Good collaboration with Space Infrared missions (AKARI, SPICA, etc.)
- Observations of time varying phenomena with a timescale of several years;
  (novae, Wolf-Rayet +O-type binary stars, nearby supernovae, optical transients etc.)
- Continuous multi-epoch observations are indispensable

Polycyclic Aromatic hydrocarbons (PAHs) (Allamandola et al. 1989)

3.3μm feature; aromatic C-H stretch mode
3.4μm feature; aliphatic C-H stretch mode



Hydrogenated Amorphous Carbons (HACs) (Duley & Williams et al. 1990)
-contain PAH-like units weakly bounded by van der Waals forces
-consist of a mixture of aromatic hydrocarbons dominated by sp^2 bonds which can produce the polycyclic ring and aliphatic hydrocarbons including sp^1 bonds (like in acetylene) and sp^3 bonds (like in methane).



The “aromatic” to “aliphatic” ratio in HACs can be modified by the irradiance of UV fields.