The formation and Evolution Processes of Circumstellar Dust

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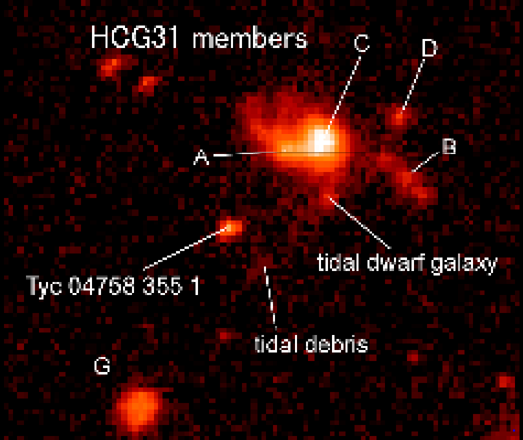
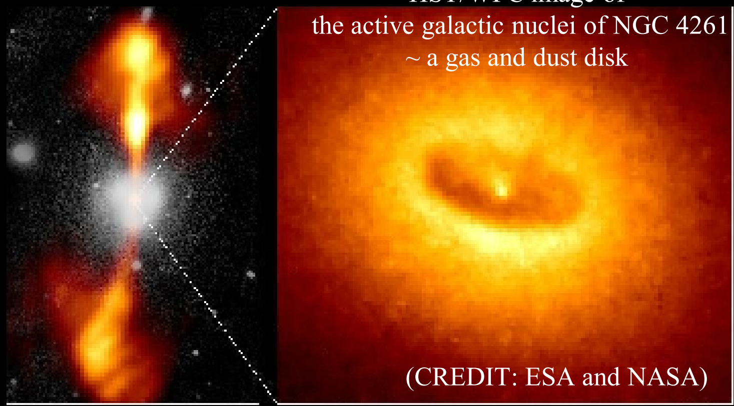
Life Cycle of Dust

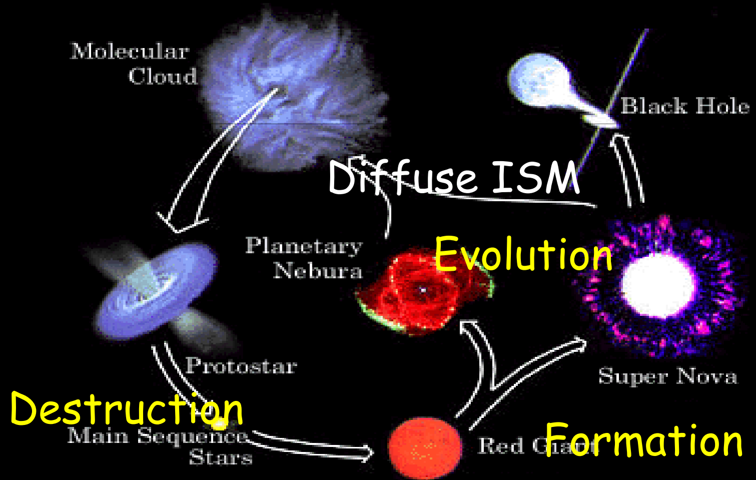
AKARI 9μm image of Hickson Compact Group 31 ~ the site of galaxy interactions and the Formation of Tidal Dwarf Galaxies



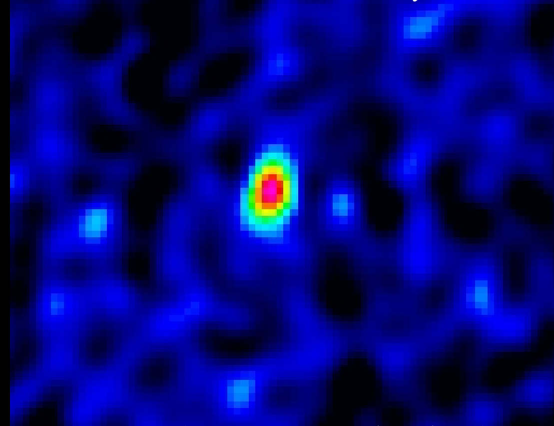
HST/WFC image of the active galactic nuclei of NGC 4261 ~ a gas and dust disk



(CREDIT: ESA and NASA)



VLA image of J1148+5251 ~the most distant quasar at z~6.4 One of the most interesting object to discuss the evolution of dust in the early universe



(CREDIT: NRAO/AUI/NSF)

-- how the dust is formed
-- how they are ejected into the interstellar space
-- how they evolve in the interstellar space in a galaxy
-- where and how the dust is destroyed
-- how they enrich the universe

1. Dust formation process by massive stars

SCIENTIFIC BACKGROUND

- Dust Formation in the ejecta of core-collapse supernovae (SNe)
  -> Important to explore the origin of dust in the early universe
  e.g., The amount of $0.1M_{solar}$/SN dust formation is needed to account for the dust content of high red-shift galaxies (Morgan & Edmunds 2003).
  The dust condensation in the ejecta of core-collapse SNe is theoretically suggested (Kozasa et al.1991; Todini & Ferrera 2001).

- Observational Evidence for the dust formation in SN ejecta
  - Type II SN2003gd; $0.02M_{solar}$ (Sugerman et al. 2006)
    -> $4\times10^{-5}M_{solar}$ (Meikle et al. 2007)
  - Type II SN1987A ; $7.5\times10^{-4}M_{solar}$ (Ercolano et al.2007)
  - Cas A ; $0.003M_{solar}$ (Hines et al. 2004) or 0.02-$0.054M_{solar}$ (Rho et al. 2004)
    → much smaller amount of dust formation

A gap still remains in produced dust mass in core-collapse SN ejecta between those observational results and theoretical prediction of 0.1 - $1M_{solar}$ (Nozawa et al. 2003)

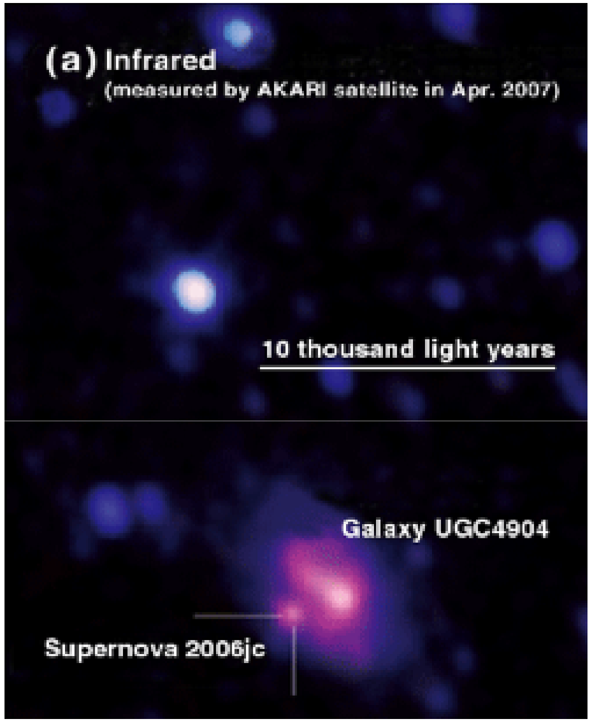
ISSUES TO BE SOLVED

-- How much amount of dust is formed in the SN ejecta and what fraction of it can survive to become the interstellar dust.

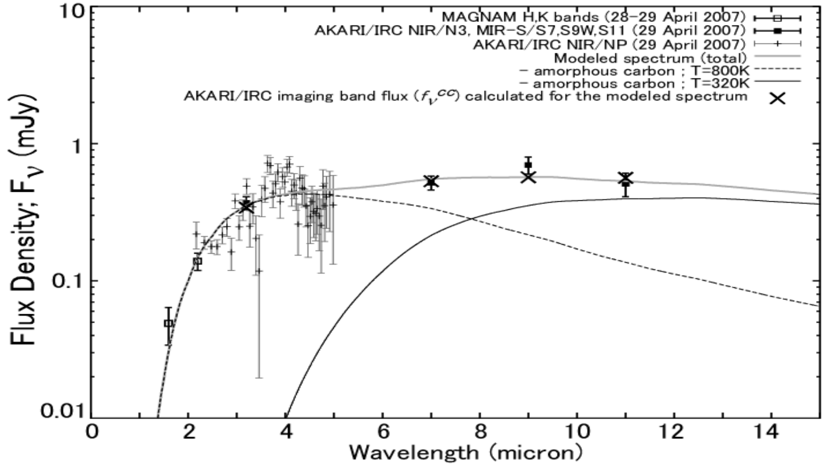
1. Dust formation process by massive stars

An Example of the Latest Results on the Dust Formation by Core-collapse SNe

<u>AKARI/Infrared Camera (IRC) observations of SN2006jc in UGC4904</u>



[3μm(blue), 7μm(green), 11μm(red)]



800K component; Newly formed dust in the ejecta of SN2006jc

$T_{hot.car.}$ = 800±10 (K)

$M_{hot.car.}$ = 6.9±0.5 x 10^{-5} M_{solar}

300K component; pre-existing circumstellar dust

$T_{warm.car.}$ = 320±10 (K)

$M_{warm.car.}$ = $2.7^{+0.7}_{-0.5}$ x 10^{-3} M_{solar}

→ The amount of newly formed dust is more than 3 orders of magnitudes smaller than the amount needed for a SN to contribute efficiently to the early-Universe dust budget

→ Dust condensation in the mass loss wind associated with the prior events to the SN explosion could make a significant contribution to the dust formation by a massive star in its whole evolutional history (Sakon et al. 2009, ApJ, 692, 546).

1. Dust formation process by massive stars

Dust Formation in the wind-wind collision of massive Wolf-Rayet binary systems

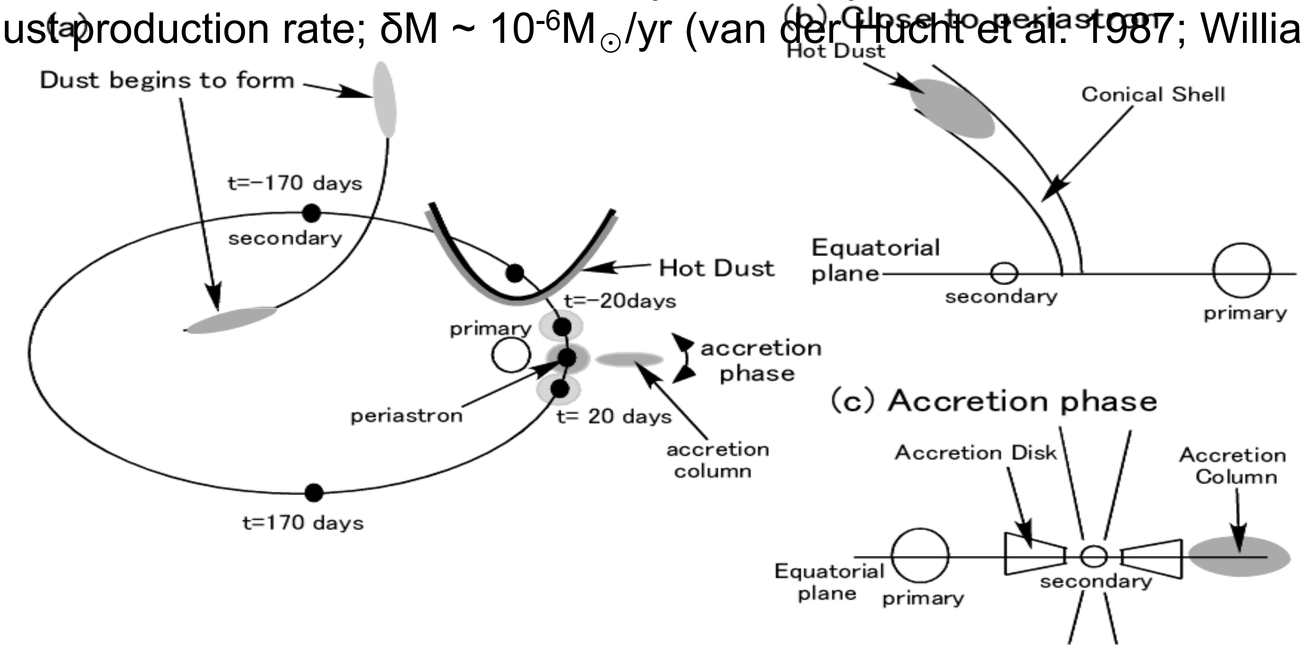
Wolf-Rayet stars; extremely luminous ($L>10^5 L_\odot$, $T_{eff} \gg 20,000K$)

average mass-loss rate ; $\delta M \sim 10^{-5} M_\odot$/yr

terminal velocity ; $v_\infty \sim$ 1,000 - 4,500km/s

Periodic dust formation in binary WC+O system with eccentric orbits

dust production rate; $\delta M \sim 10^{-6} M_\odot$/yr (van der Hucht et al. 1987; Williams 1995)



"spectroscopic event"

(a) Schematic view of dust formation in the colliding winds.
(b) Formation of hot dust in the colliding winds close to periastron.
(c) The accretion disk during the accretion phase and the formation of hot dust in the accretion column. (Kashi & Soker 2008a)

WR 'dusters' --- WR9, WR25, WR48a, WR76, WR80, WR95, WR98a, WR102e, WR106, WR121, WR125, WR137, WR140, etc (Marchenko & Moffat 2007; Wood et al. 2003)

2. Dust formation process by low-to intermediate-mass stars

SCIENTIFIC BACKGROUND

Chemical evolution models for dust budgets in the Milky Way (Dwek 1998)
Silicate dust; Type II SNe, red supergiants, O-rich AGB stars
Carbonaceous dust; mainly in low-mass (2-5$M_{\odot}$) C-rich AGB star
Metalic iron; Type Ia SNe

Observations (Waters 2004; Cohen & Barkiw 2005)

Asymptotic Giant Branch (AGB) stars with C/O<1 in their envelope
･･･presense of several silicate dust species
Asymptotic Giant Branch (AGB) stars with C/O>1 in their envelope
･･･presense of amorphous carbon, SiC, MgS, and in some cases PAHs

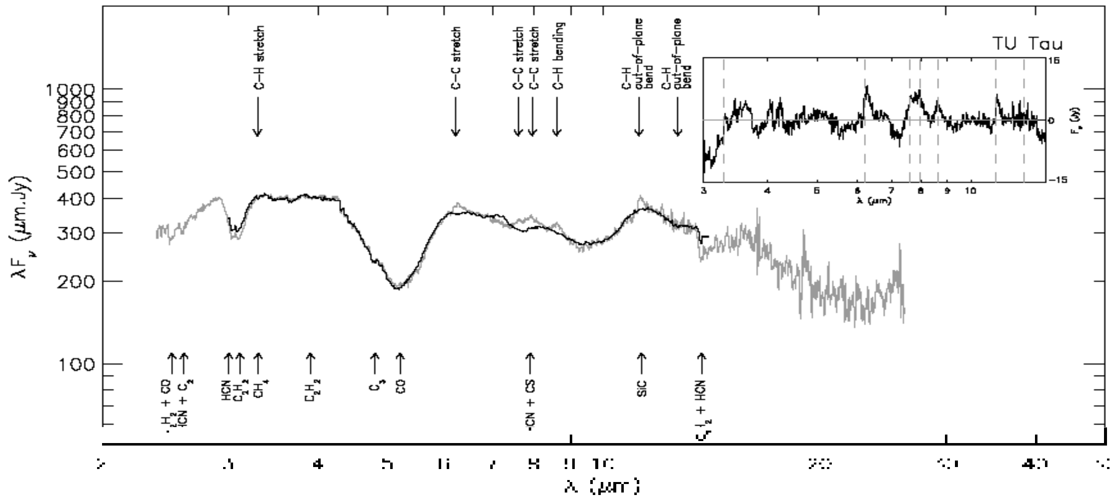
PAH features in the mid-infrared appear after the AGB phase and are observed in C-rich Planetary Nebulae

ISSUES TO BE SOLVED

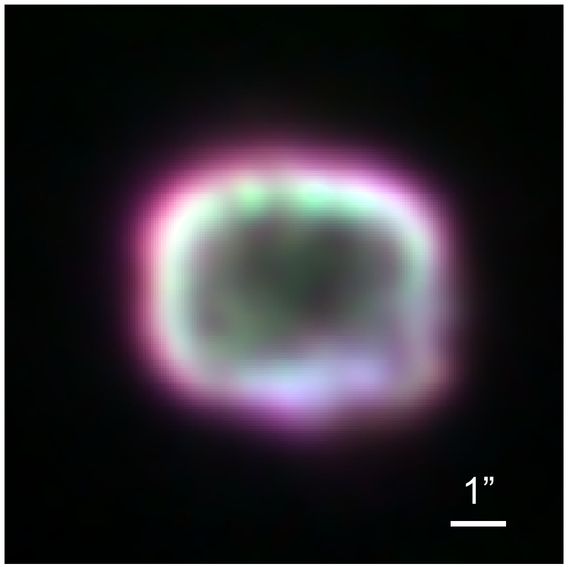
- Demonstrating how the dust is formed around the AGB stars and how it is ejected into the ISM at the evolutionary end phase of the AGB stars

2. Dust formation process by low-to intermediate-mass stars

UIR bands in the ISO SWS spectrum of carbon-rich AGB star TU Tauri (Boersma et al. 2006)



the presence of UIR bands in TU Tau
→ UV photons from the A2 companion



Subaru COMICS 11.7μm image of Galactic planetary nebula BD+30 3639. UIR 11.2μm (red), continuum at 12.4μm (green) Image size is 10”.64 x 10”.64. (Matsumoto et al. 2008)

The 11-13μm plateau and continuum; dominant in the shell
UIR 11.2μm band; extended towards the outside of the shell

No apparent changes in the profile of UIR features between the shell and its outside (Matsumoto et al. 2008)
･･･ in agreement with “Class B” in terms of the Peeters’s classification (Peeters et al. 2002)
･･･ possible changes in the profile of the UIR band from “class B” to “class A” take place outside of the nebula.

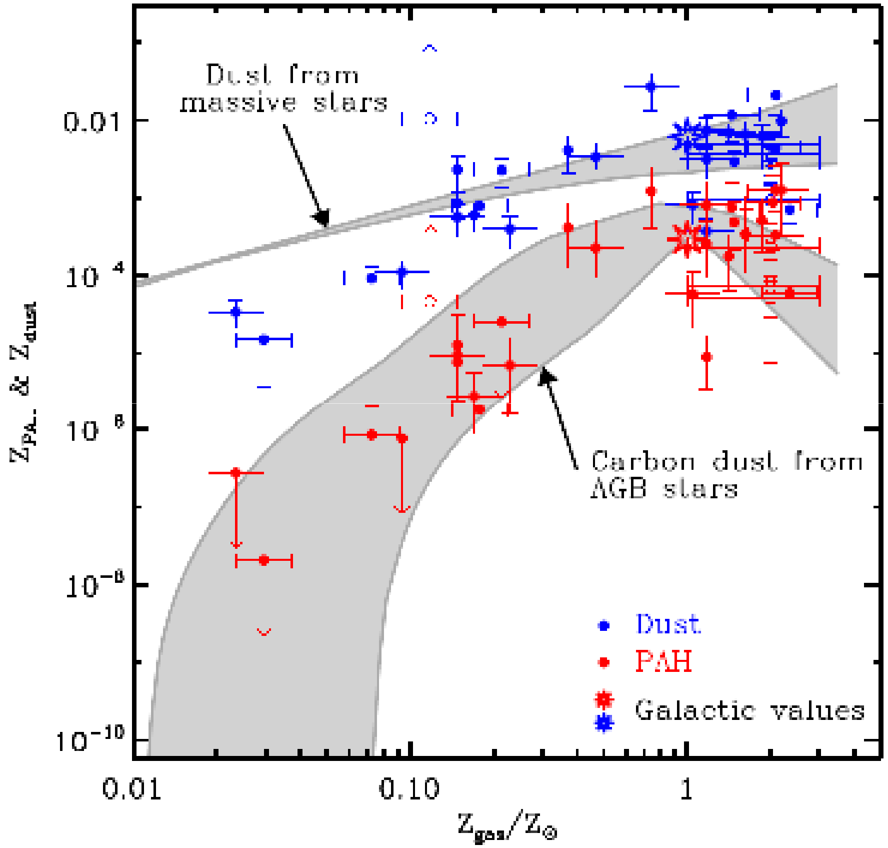
3. PAHs in external galaxies
~ PAHs-to-metallicity relations

Deficiency of PAH emission in low-metallicity galaxies
(Madden et al. 2006; Engelbracht et al. 2005)

-- destruction of PAHs by hard UV photons?
(Madden et al. 2006)

-- more efficient destruction of PAHs by interstellar shocks? (O'Halloran et al. 2006)

(Dwek et al. 2008)



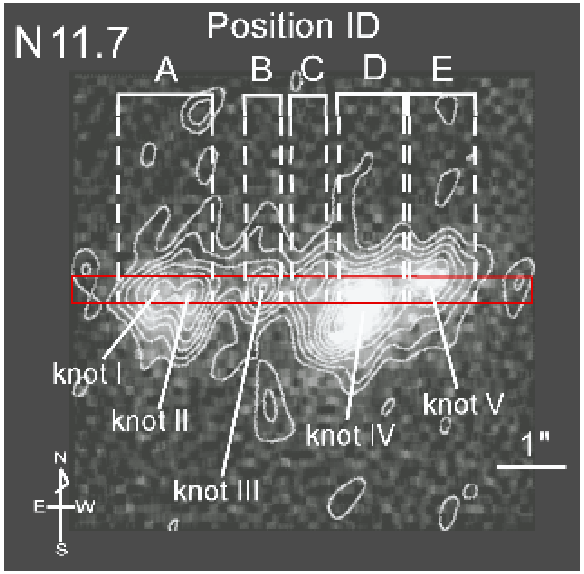
Plots of dust-to-gas mass ratios for PAHs (red) and for dust that carry the FIR thermal emission (blue) as a function of gas-metallicity for galaxy samples;

in good agreement with the evolutionary trends of AGB-condensed dust and SN II-condensed dust derived from the chemical evolution model
(Dwek et al. 1998)

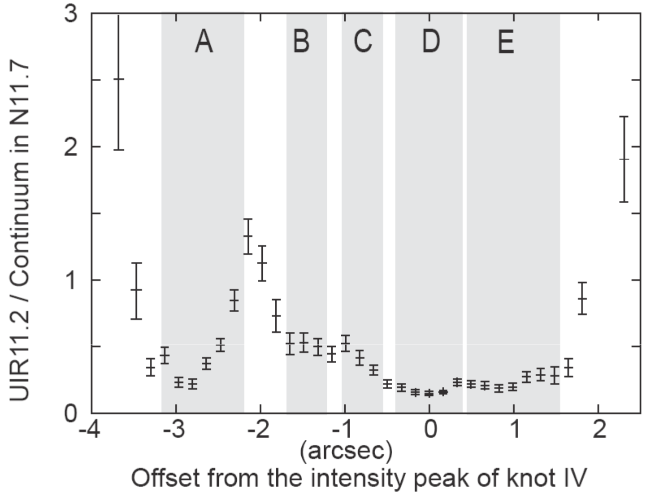
-- a trend of PAH abundance with galactic age (e.g., Most of the carbon dust injection occurs after ~400Myr); the delayed injection of PAHs and carbon dust into the ISM by AGB stars in their final phase of their evolution (Dwek et al. 2008)

3. PAHs in external galaxies
~ interstellar PAHs in blue compact dwarf galaxies based on observations with Subaru/COMICS

Henize 2-10
blue compact dwarf (BCD) galaxy at 9Mpc (Vacca & Conti 1992)
~ solar metalicity
contains embedded super-star clusters (SSCs); radio knots I-V (Kobulnicky and Johnson 1999)



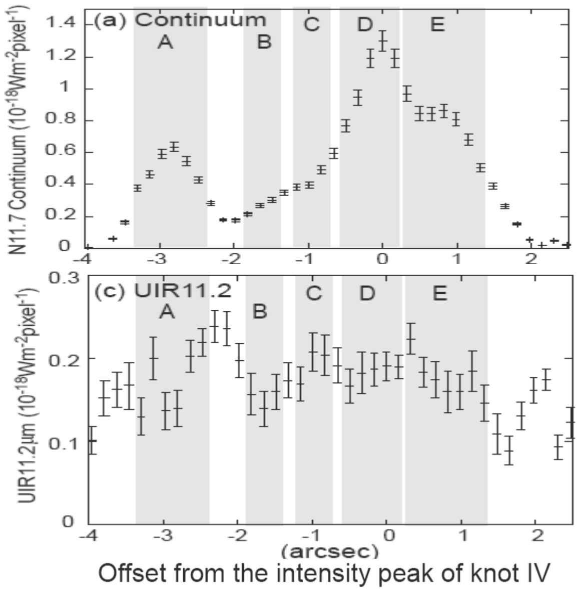
Low UIR/continuum ratio at the embedded SSCs



Embedded SSCs;

Each SSC contains several thousands O-type stars

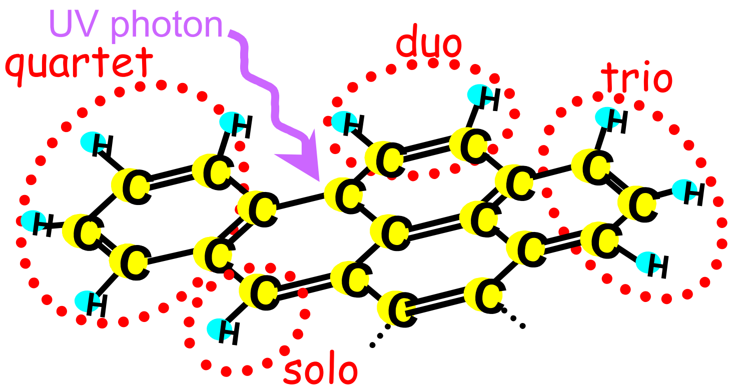
young (a few Myr) and massive (10^4-$10^7 M_\odot$)
absent from optical images and seen in radio & mid-infrared

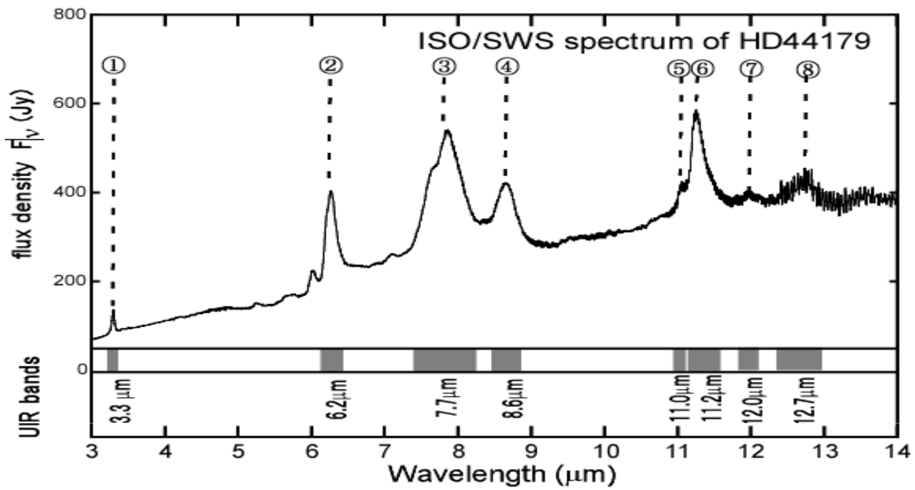


-> The intensity profile of hot dust continuum emission at 11.7μm shows peaks at the positions of embedded SSCs
-> The intensity profile of UIR 11.2μm band is rather flat over the Henize 2-10 showing little or no positional correlations with SSCs
(Sakon et al. 2009, in prep)

4. Evolution of circumstellar PAHs based on observations with Subaru/COMICS

Polycyclic Aromatic Hydrocarbons (PAHs)





<u>Ionization of PAHs</u>

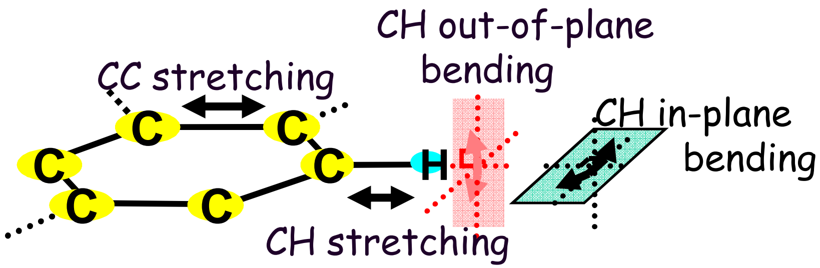
-> 6.2μm/11.2μm, 7.7μm/11.2μm, 8.6μm/11.2μm ratios

ionization degree ∝ $G_0 T^{0.5}/n_e$ (Bakes & Tielens 1994)

Ambient UV radiation field, G_0

Electron density; n_e

Gas temperature; T



<u>Size of PAHs and PAH clusters</u>

-> 3.3μm/11.2μm, 7.6μm/7.8μm component ratio, UIR feature/plateau

<u>Molecular Structures (Aliphatic <-> Aromatic)</u>

-> 3.4μm/3.3μm, 8.2μm feature

Further observations in collaboration with the laboratory experiments are needed to understand the evolution of circumstellar PAHs

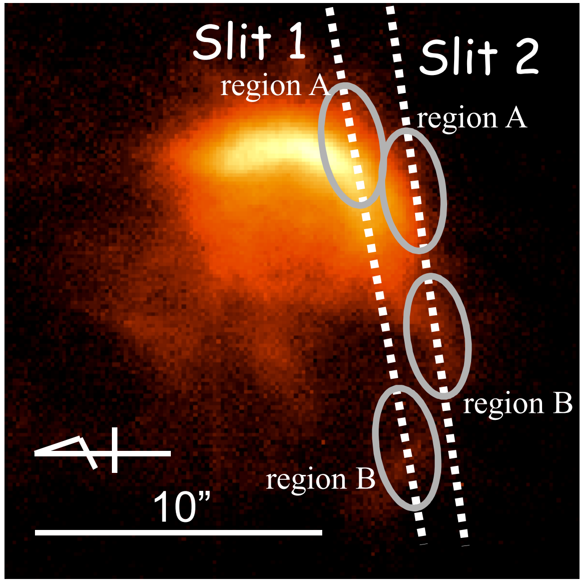
4.1. Dust Emission in IRAS18434-0242
based on observation with Subaru/COMICS

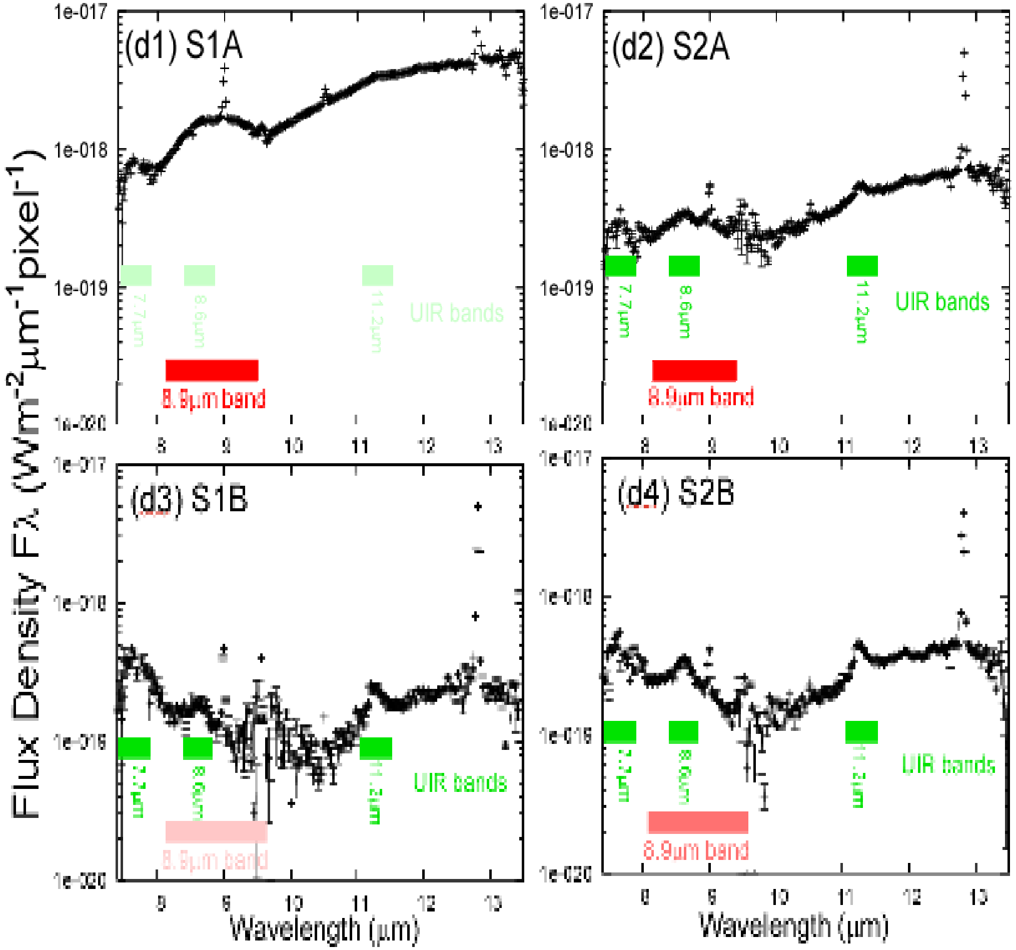
IRAS18434-0242; Massive star forming region
ionizing star: O5-O6 (Martin-Hernandez 2003), d=6kpc (Pratap et al. 1999)

New broad 9μm component in the core of HII region
-> firstly reported by Peeters et al. (2005) in four HII regions

PAH features are detected in diffuse nebulae located at the distant region from the HII region core

-> Possible changing in the nature of carbonaceous materials ?





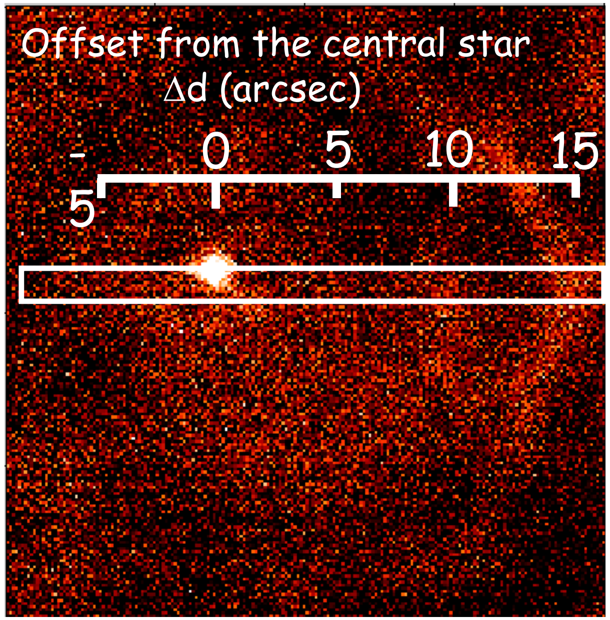
9μm component in M17 → Poster #E-16 (Y. Takahashi)

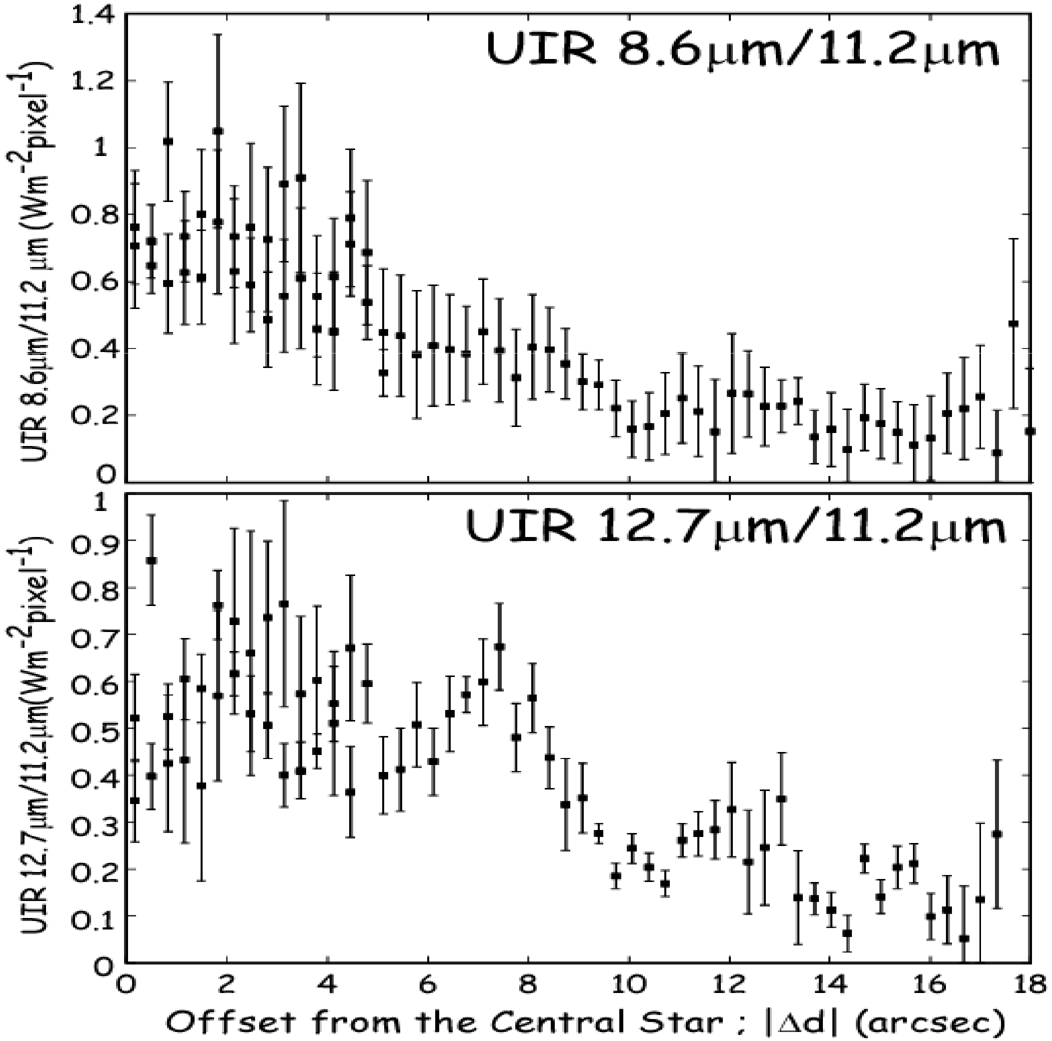
4.2. UIR bands in IRAS03260+3111
based on observation with Subaru/COMICS

IRAS03260+3111; Reflection nebulae illuminated by the central B6 star (SVS3) with $T_\star$= 13,000 K, L=360$L_\odot$ (Harvey, Wilking, & Joy 1984)

Ionization of PAHs

A plot of the ratio of 8.6/11.2 against the distance |Δd| from the central star
-> PAHs are positively ionized in the vicinity of the B6 star.
(Joblin et al. 1996, Bregman et al. 2005)

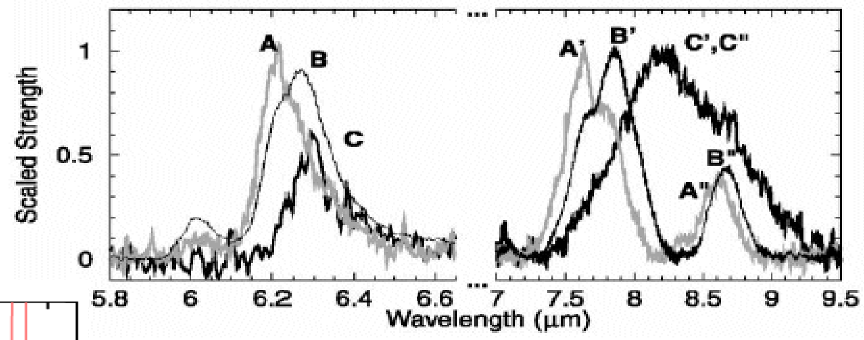




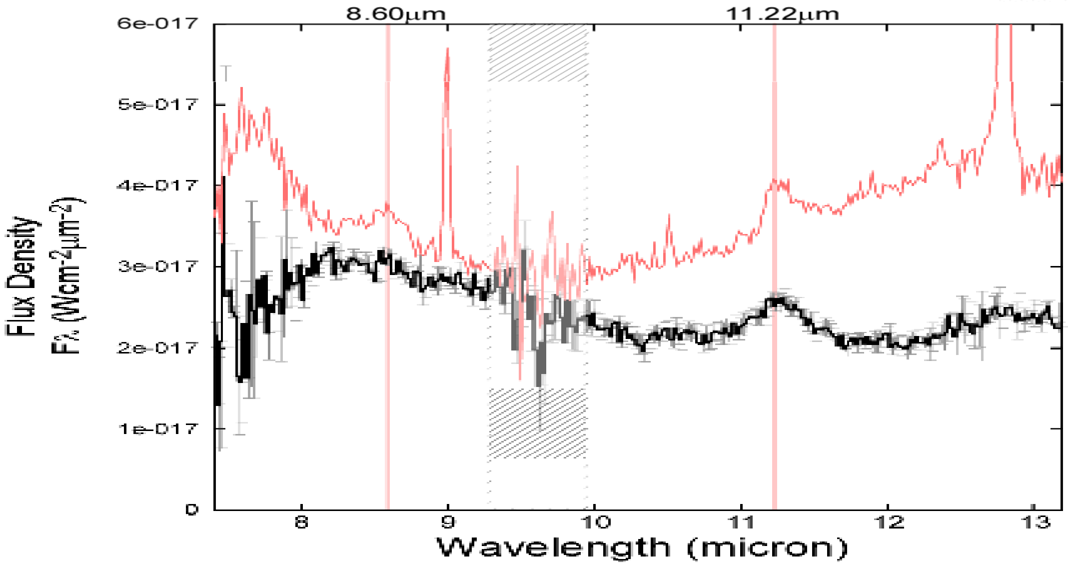
4.3. UIR bands in HD233517
based on observation with Subaru/COMICS

HD233517 Red giant
ionizing star: K2III (Fekel et al. 1996)
$T_{\star}$ = 4,475 K (Balachandran et al. 2000)
d = 617±80pc (Balachandran et al. 2000)

Classifications of interstellar PAH features
(Peeters et al. 2002)



N-band spectrum of HD233517
obtained with Subaru/COMICS



red line; nebulae in IRAS18434
consistent with "Class A" spectra

Black line; HD233517
consistent with "Class C" spectra
- broad 8.2μm feature
- no 7.7μm feature
- small sign of 8.6μm feature
-broad 11.3μm feature
with a peak at 11.30μm
[cf. 11.35μm from Sloan et al. (2007) with Spitzer IRS]

possible carriers of 8.2μm band
Hydrogenated amorphous carbon (HAC)
-> survival of aliphatic structures in soft radiation

Summary

Subaru/COMICS have been playing an important role in understanding the evolution of circumstellar and interstellar PAHs

Subaru/COMICS is expected to make a significant contribution towards understanding the formation process of circumstellar dust both around massive stars and low- to intermediate-mass stars