Transmigration of dust grains in the universe

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on behalf of ISM SWG

1. Dust formation in massive stars
2. Dust formation in low- to intermediate-mass stars
3. Dust formation/growth in dense interstellar clouds
4. Dust formation/destruction in SNe/SNRs
5. Material circulation in galaxies
6. Material circulation in the Galaxy

SWG

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Task Force

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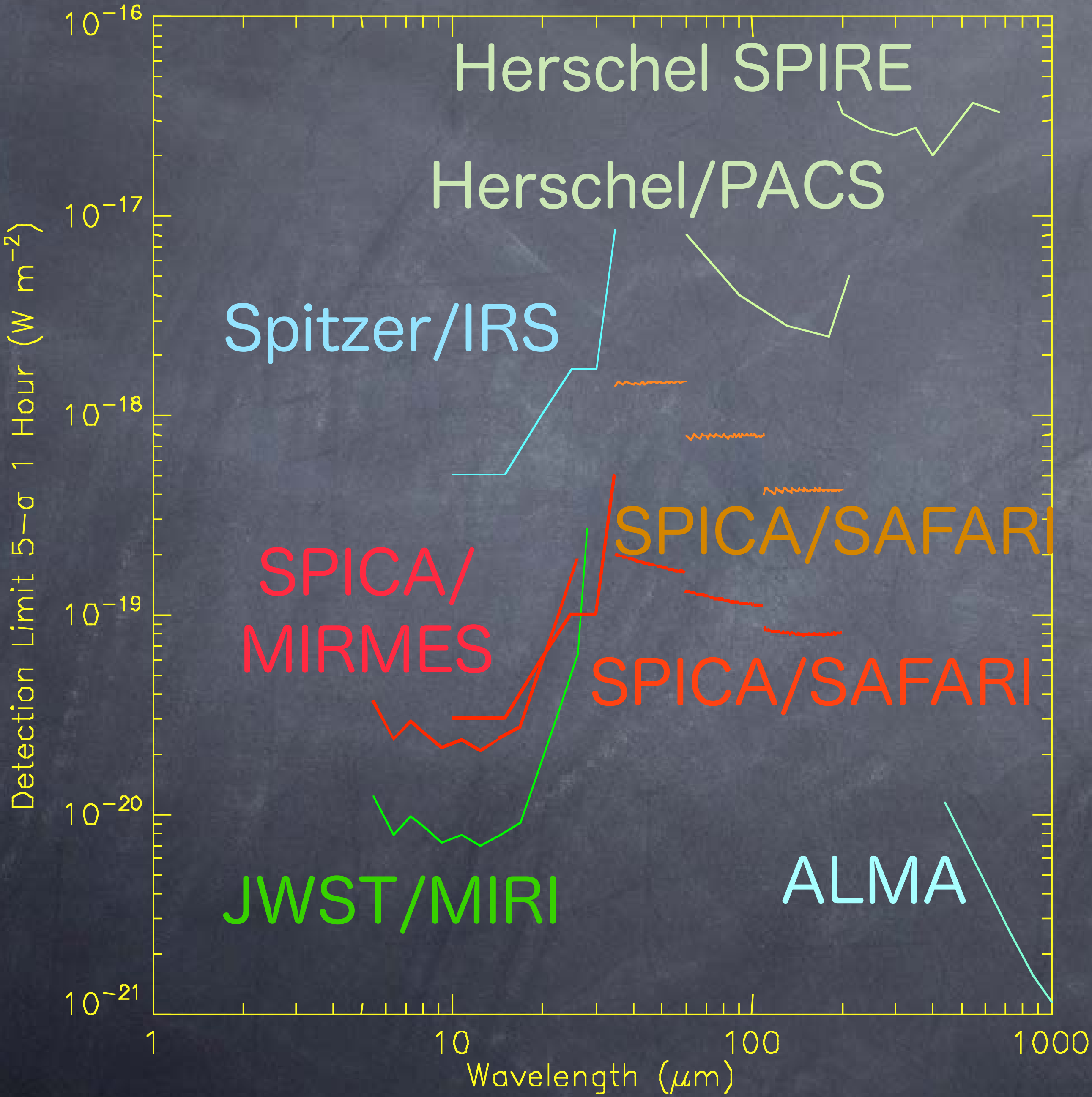
European Consortium

J. Goicoechea (CSIC), A. Jones (IAS), ...

SPICA Spectroscopic sensitivity



Unique to SPICA

Unparalleled sensitivity for λ>20μm particularly for diffuse emission

For λ>30μm high sensitivity spectroscopy has never been carried out

A General View of Dust Formation, Processing, & Destruction in the ISM

SPICA

Dust processing in a galactic scale is important for material evolution in the Universe

SNe important both for dust formation & destruction

Metal supply rate: SNe > AGB stars

Destruction rate by SN shocks

> Supply rate from stellar sources

-> most interstellar dust is formed in dense clouds

Issues

1. Dust formation efficiency and species formed in SNe
2. Destruction and processing in SN shocks and ISM
3. Dust formation in interstellar clouds

1. Dust formation in SNe

SPICA

Major dust source in the early universe

0.1-1$M_\odot$ per SN is required and theoretically predicted

But ....

Only a few SNe show evidence of dust formation

& they are all less than 0.1 $M_\odot$

Much smaller than theoretical predictions

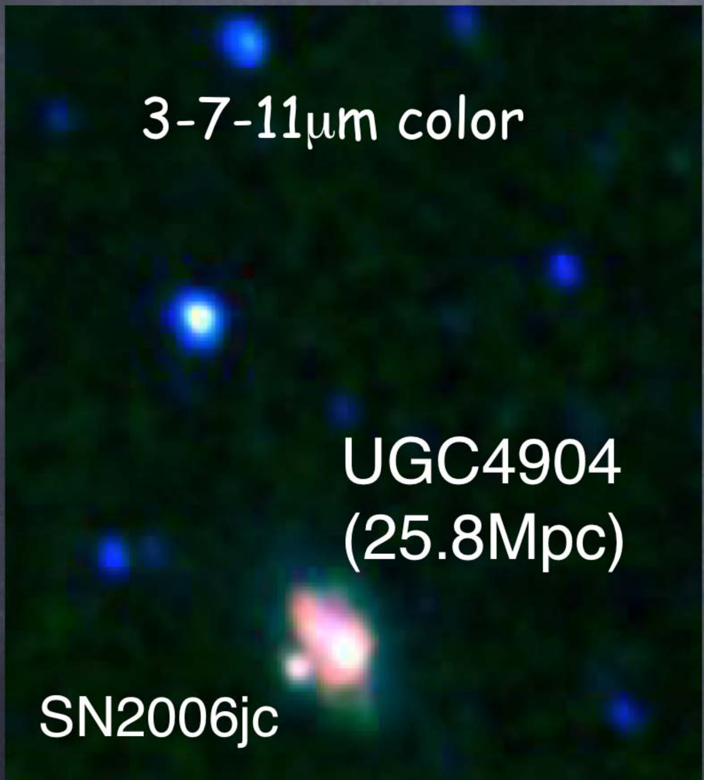
SN1987A 7.5×10^{-4} $M_\odot$ (Ercolano et al. 2007)

SN2003gd 0.02 $M_\odot$ (Sugerman et al. 2006)

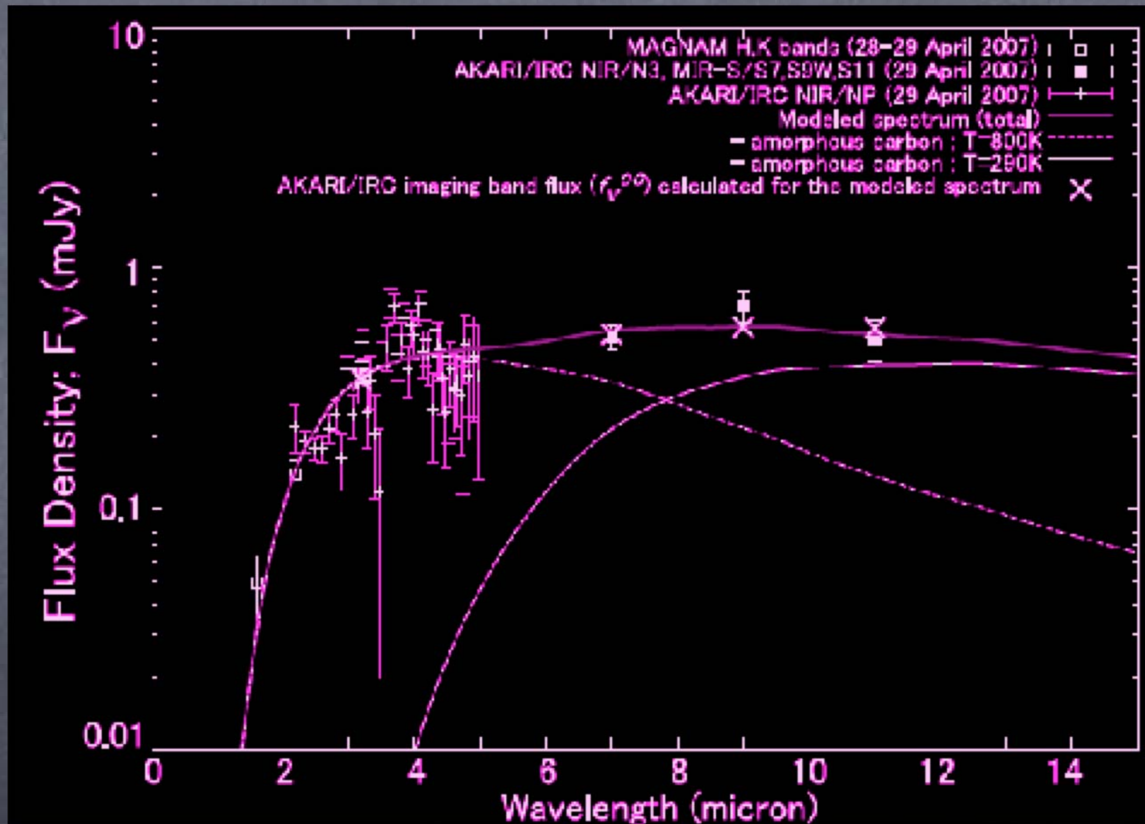
4×10^{-5} $M_\odot$ (Meikle et al. 2007)

Multi-component nature of IR emission from SNe

Emission from formed dust & circumstellar dust
A wide spectral coverage (>10μm) is important



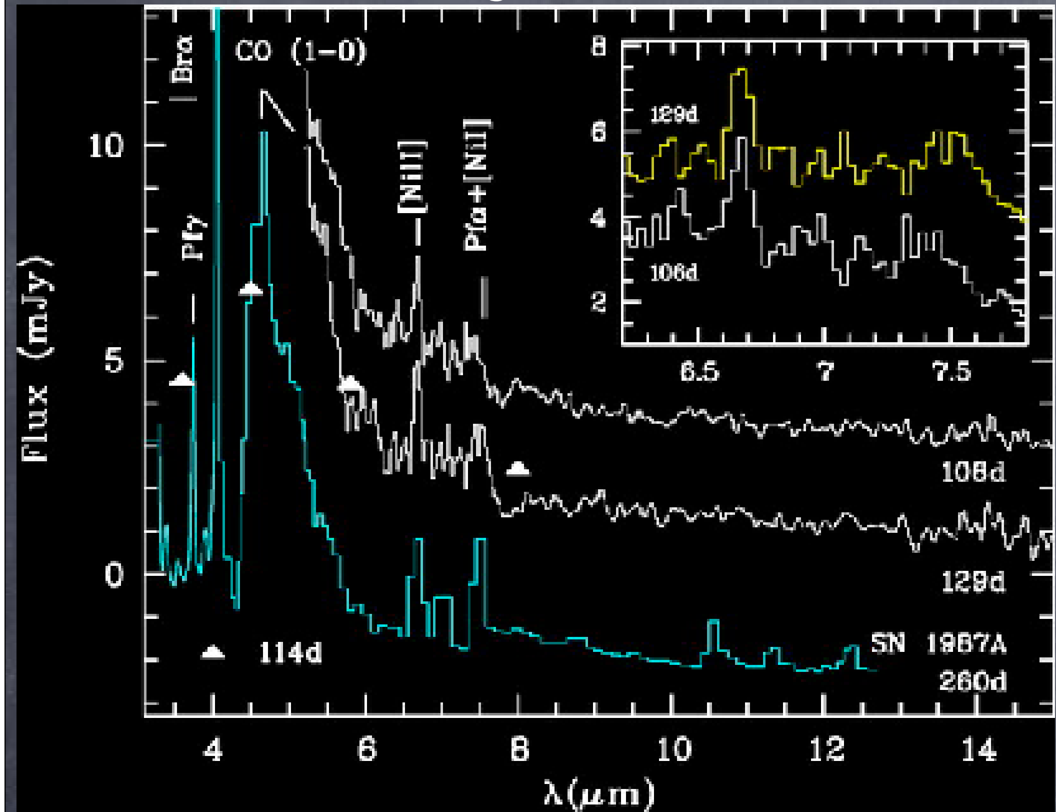
Sakon et al. (2009)



Again only $<10^{-4}M_\odot$ dust (carbon grains) detected for SN2006jc

MIR spectroscopy and chemical process in ejecta

SN 2004dj (Kotak et al. 2005)



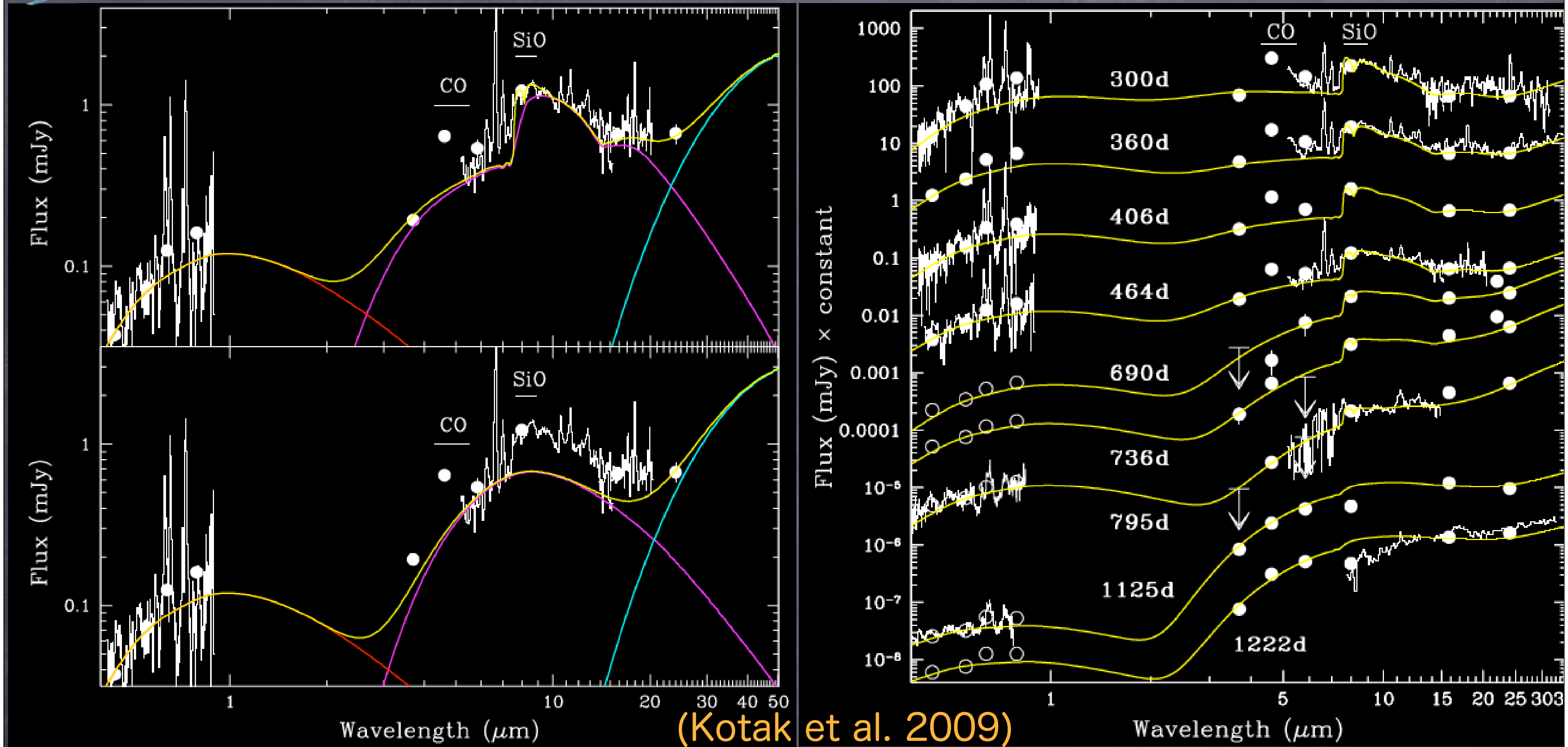
Formation of CO reduces the condensate mass (cf. CO may not be stable in SNe? (Clayton et al. 1999, 2001))

^{58}Ni mass can be derived from [NiII]6.64μm line to constrain SN models independently on gas T

MIR spectroscopy (4 - 20μm) is important for the study of dust formation in SNe

R>500 is required to separate [FeII]26.0μm from [OIV]25.9μm

Silicate dust formation in SN2004et



(Kotak et al. 2009)

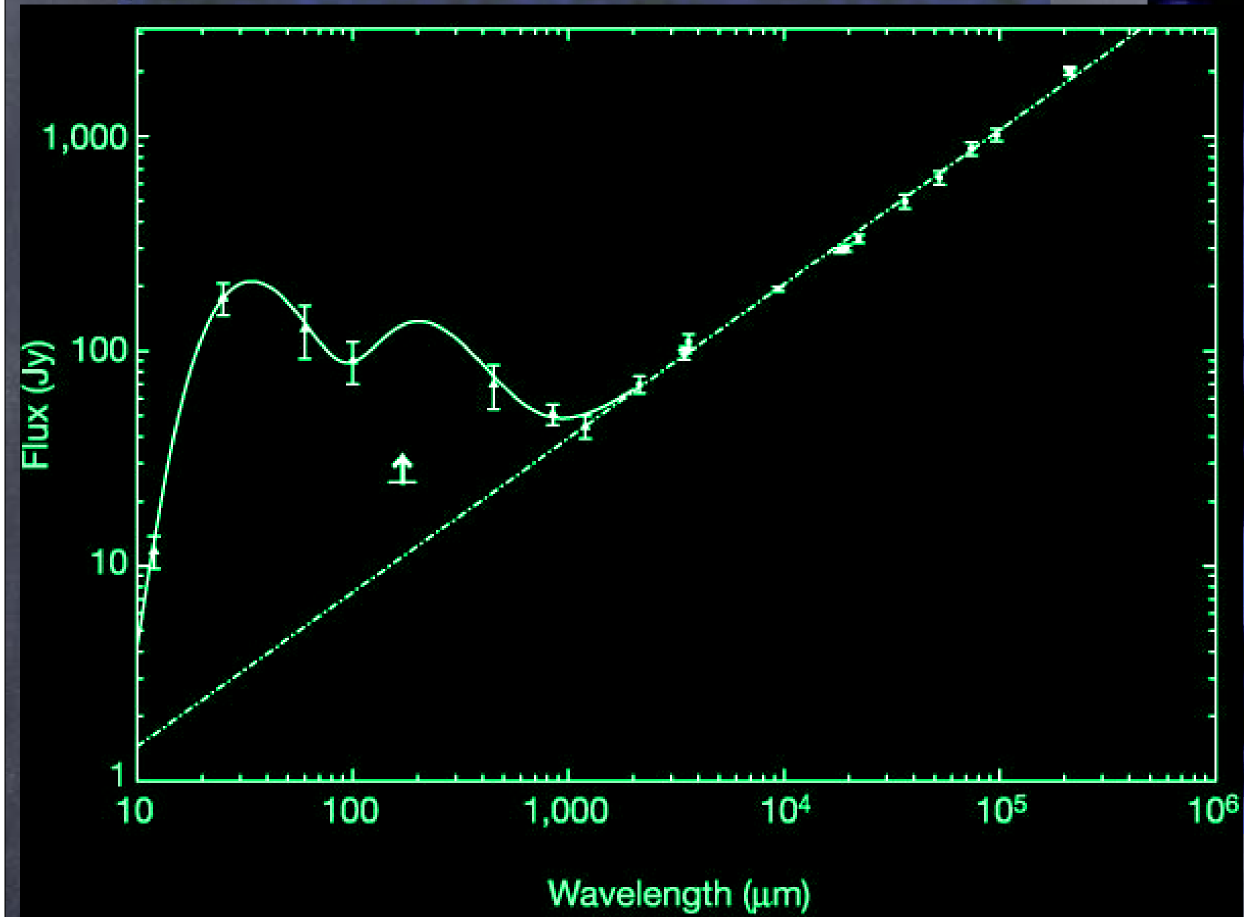
First detection of SiO (& its decrease)

& silicate dust at 10μm feature

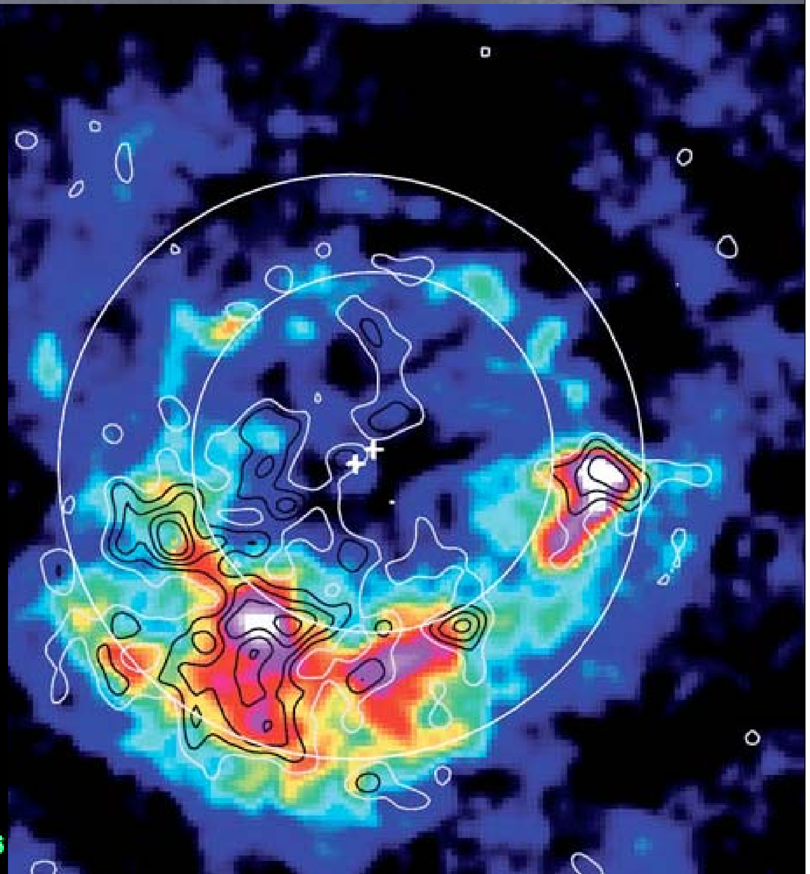
Detected dust mass is still small ($<10^{-4} M_{\odot}$)

FIR observations important to estimate warm/cool dust

4. Supernova remnants



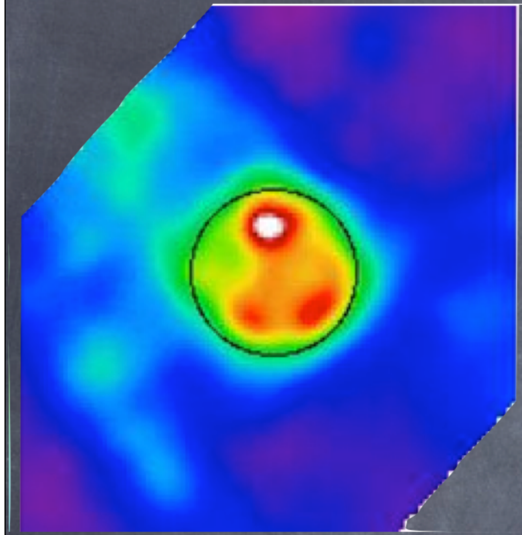
Dunne et al. (2003)



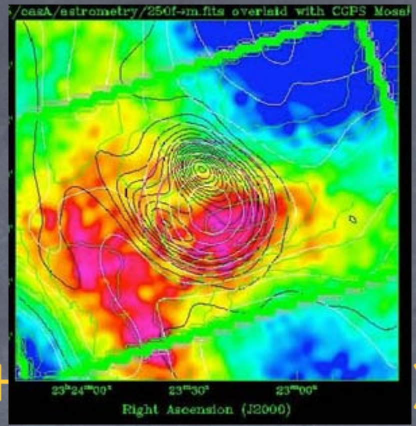
Synchrotron subtracted 850μm image

Detection of cold dust of 2-4M⊙ in Cas A

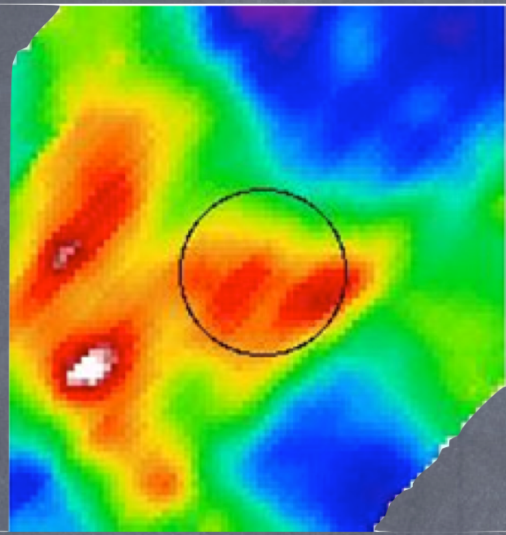
No cold dust in Cas A



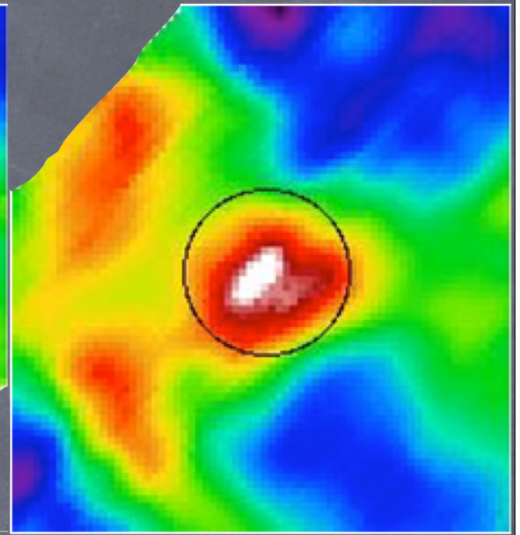
AKARI/FIS
90μm



Spitzer/MIPS
70μm

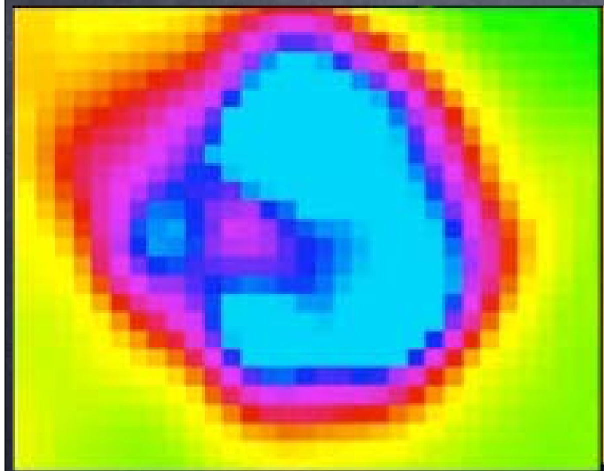


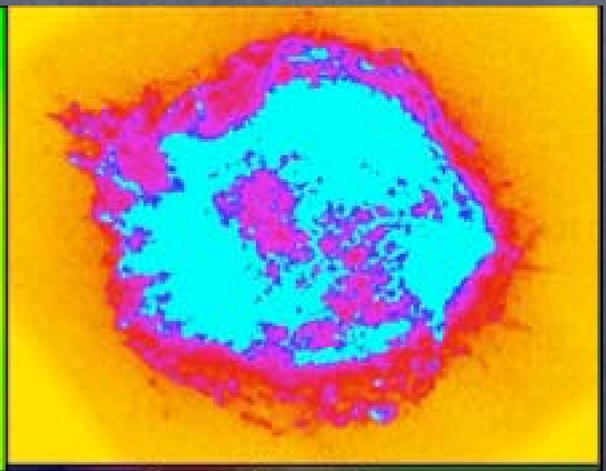
AKARI/FIS
160μm



AKARI/FIS
140μm

Koo, Sibthrope, Moon, Martin et al.


AKARI 65 micron


Chandra X-ray

Warm dust (@ 65μm) is associated with SNR, but cold dust is foreground

SNR dust mass < 0.1$M_\odot$

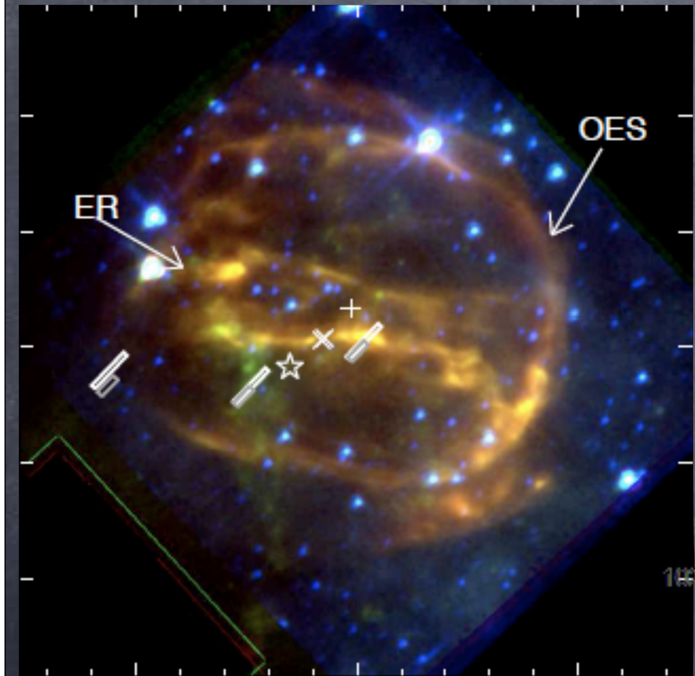
MIR spectroscopy of SNR: Dust

Composition of dust grains formed in ejecta still unknown

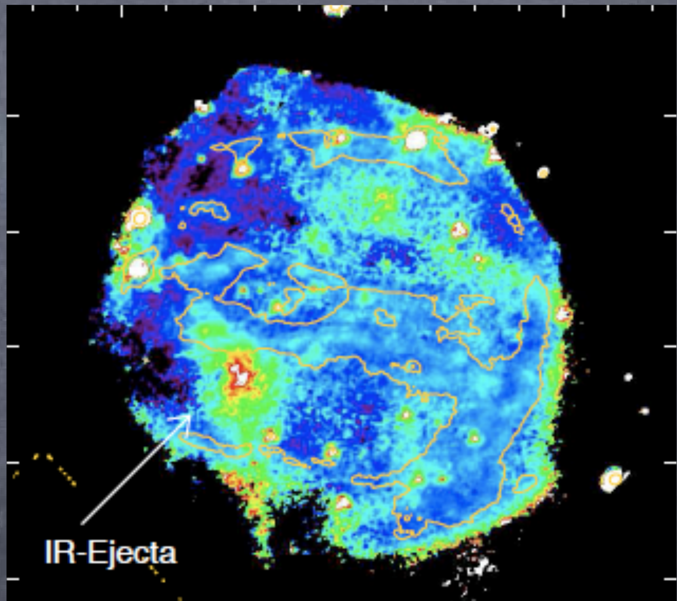
Only a few SNRs show IR emission from dust in ejecta

SNR G292.0+1.8

7, 15, 24μm color

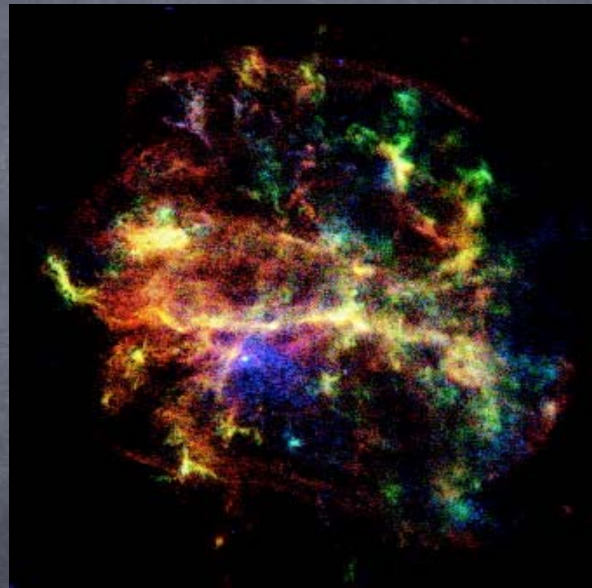


15/24μm ratio



Lee et al. 2009

Chandra

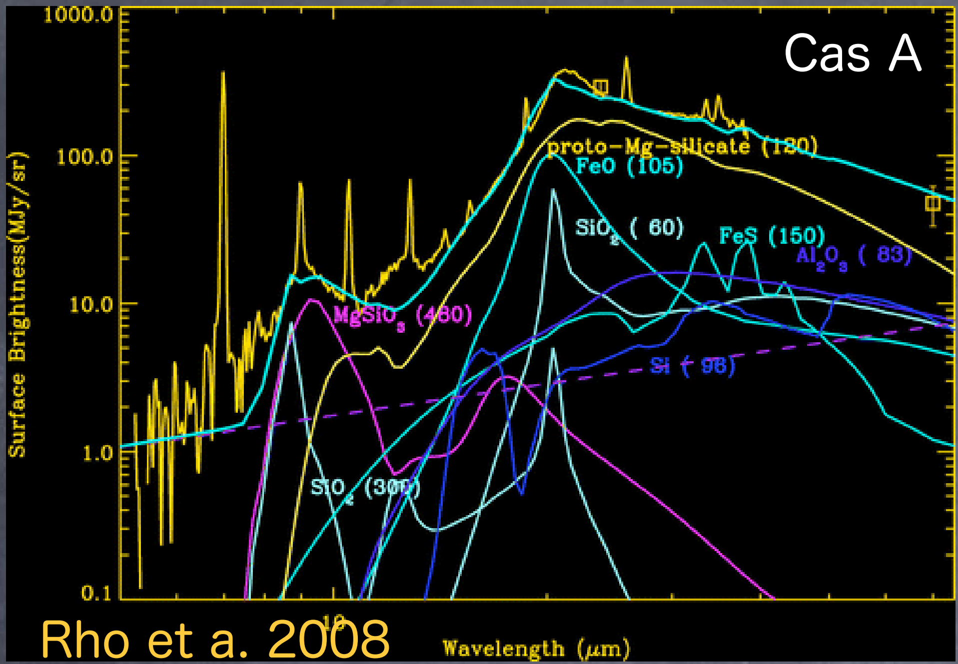


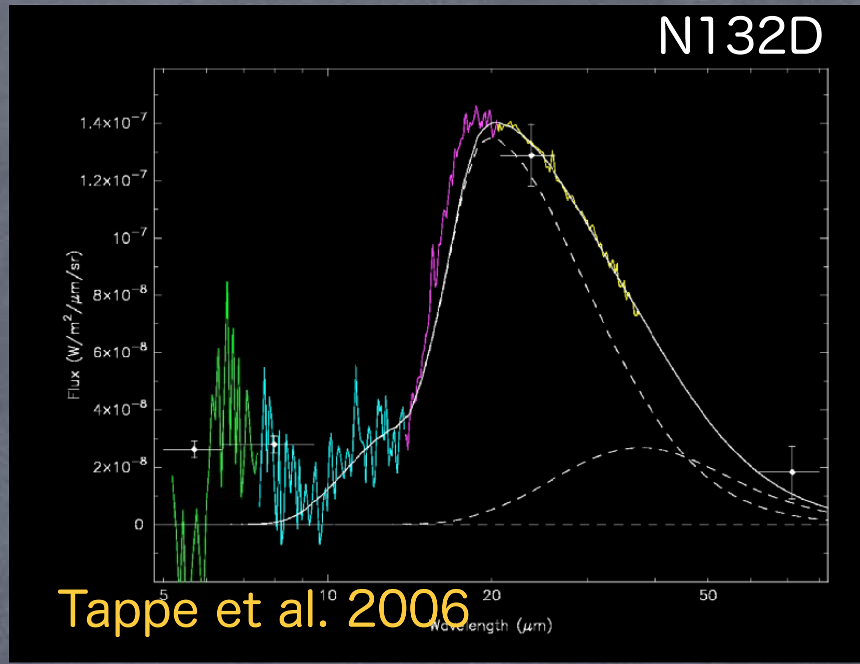
Park et al. 2002

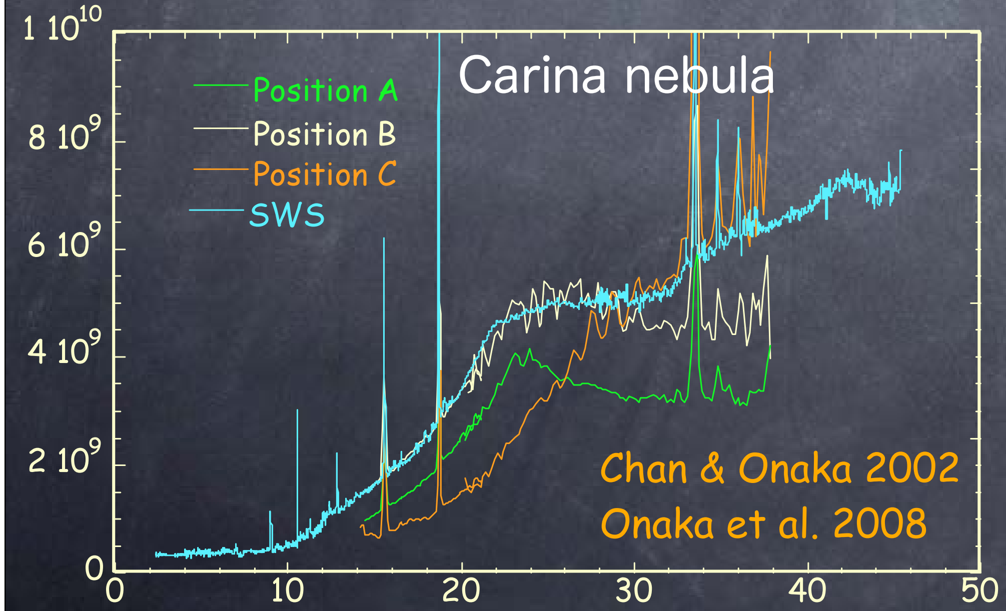
IR emission from the SN ejecta is clearly detected ($M_{dust} < 10^{-4}\ M_{\odot}$) together with emission from CSM

Dust feature in SNRs

IR spectra of dust in ejecta are available for a handful of SNRs



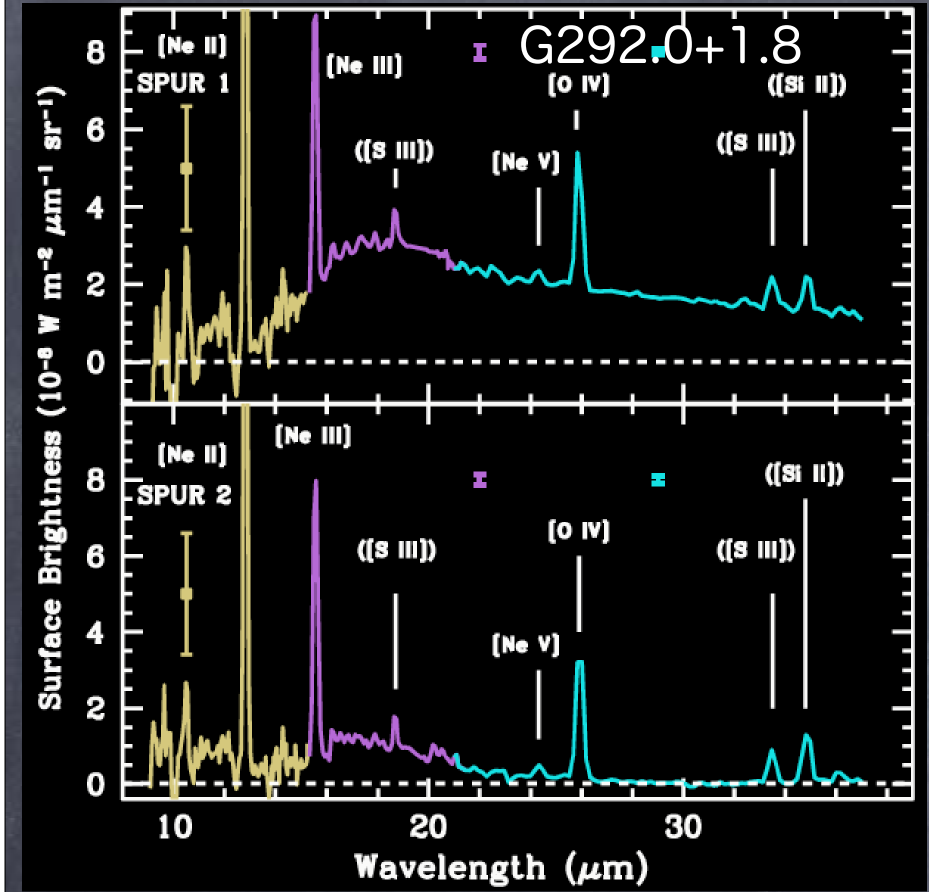




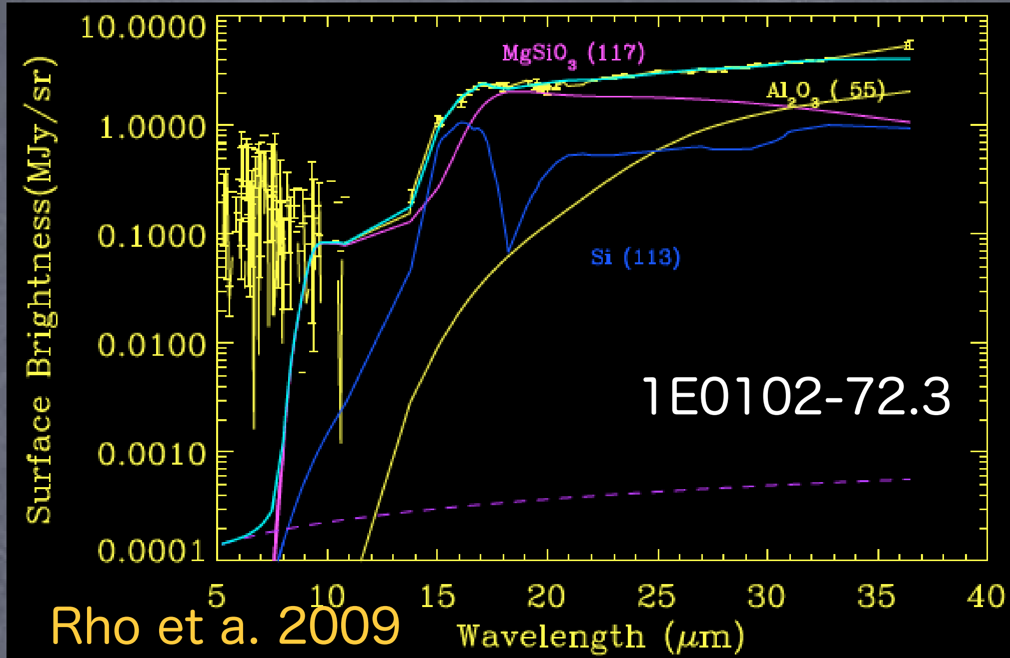
Features around 20-23μm may be common for ejecta dust

A similar feature also seen in massive star-forming regions

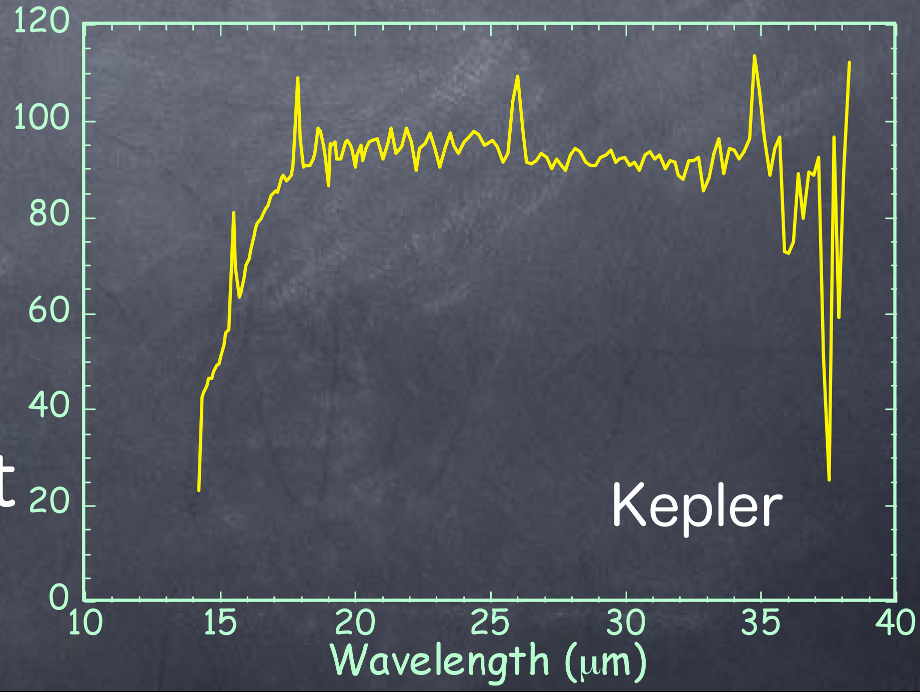
A bit more SNR spectra



Ghavamian et al. 2009



Rho et a. 2009



Spatially resolved spectra from MIR to FIR are important to separate components

SPICA Observations of SNe & SNRs

Monitoring observations of nearby (<25Mpc) SNe to investigate the dust formation and chemistry in ejecta

High spatial & spectral resolution observations of (~50) SNRs in the Galaxy and galaxies that show IR emission to study the nature of dust formed in SN ejecta

A wide spectral coverage (4 - 200μm) in a medium spectral resolution with sufficient spatial resolution is a key combination to investigate the contribution of each component and line emission

High spectral resolution in 4 - 8μm is important for the study of chemistry (CO & SiO)

High spatial resolution in FIR is crucial for the study of SNRs in external galaxies

2. AGB stars and PNe

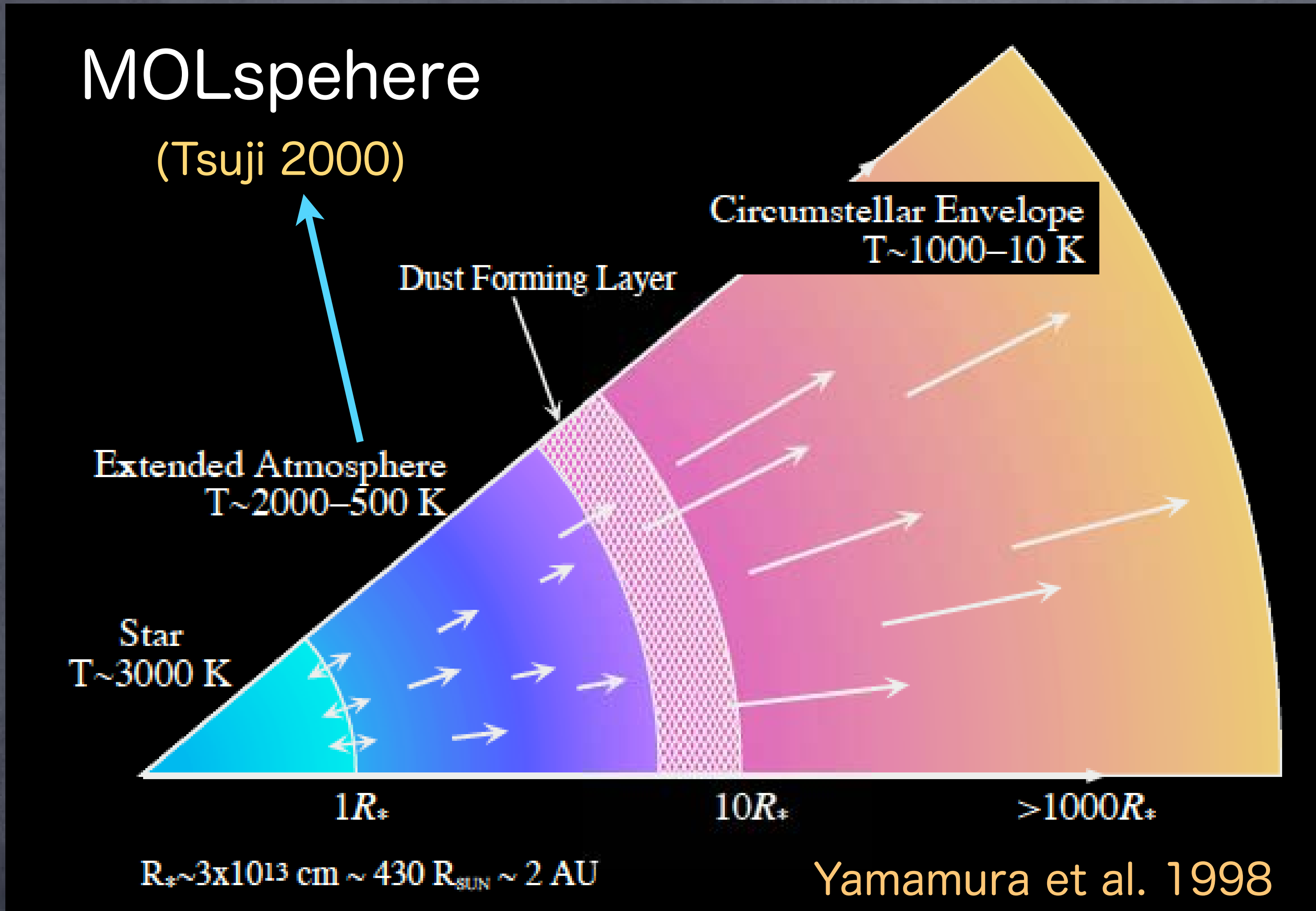
Low- to intermediate-mass evolved stars are an important dust source in the ISM

Dust formation process there are an excellent natural laboratory for dust formation in the Universe

Interplay of the dynamics of the atmosphere and dust formation is important for mass-loss

1. Chemistry and dynamics of MOLsphere and its role in the formation of dust grains
2. Mass loss history and mechanism of AGB stars
3. Carbonaceous dust/PAH formation and processing in AGB and PNe

MOLsphere

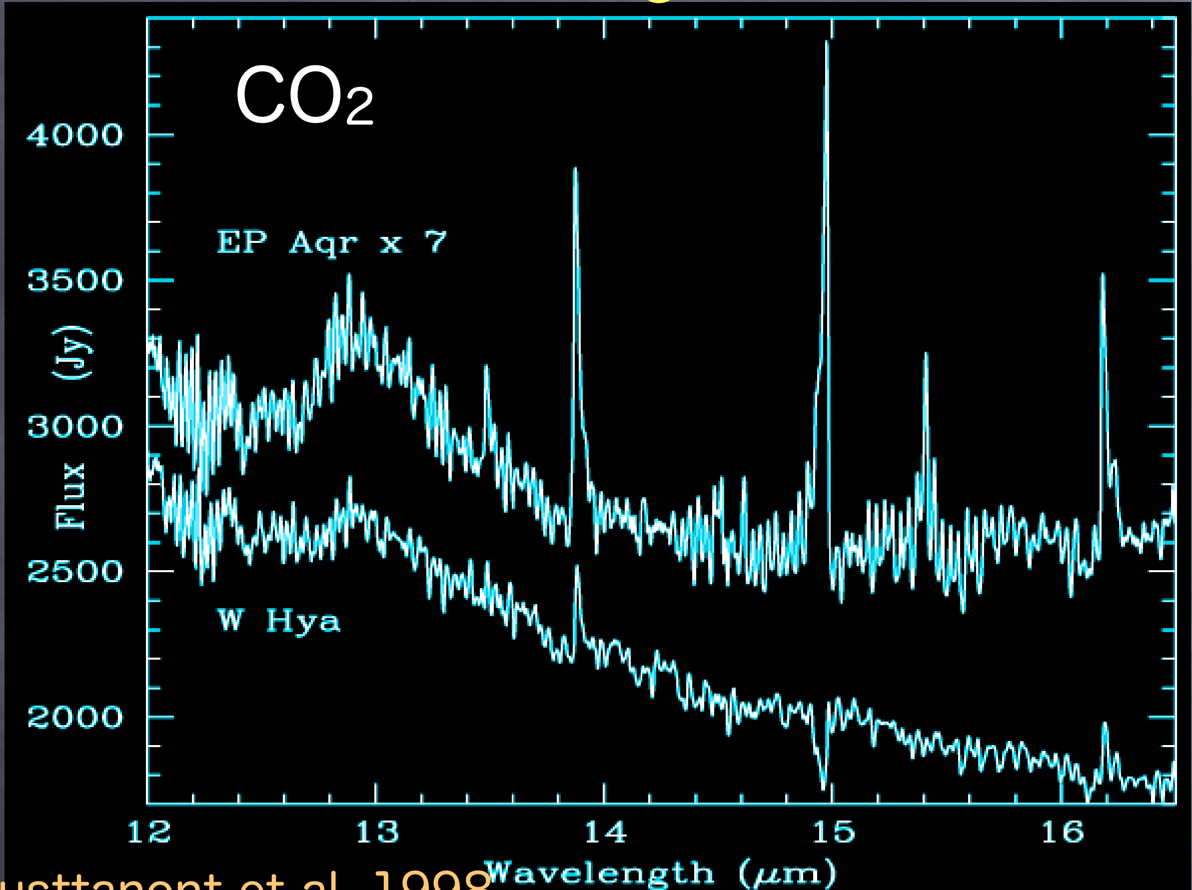


MOLsphere detected in red giants by ISO spectroscopy

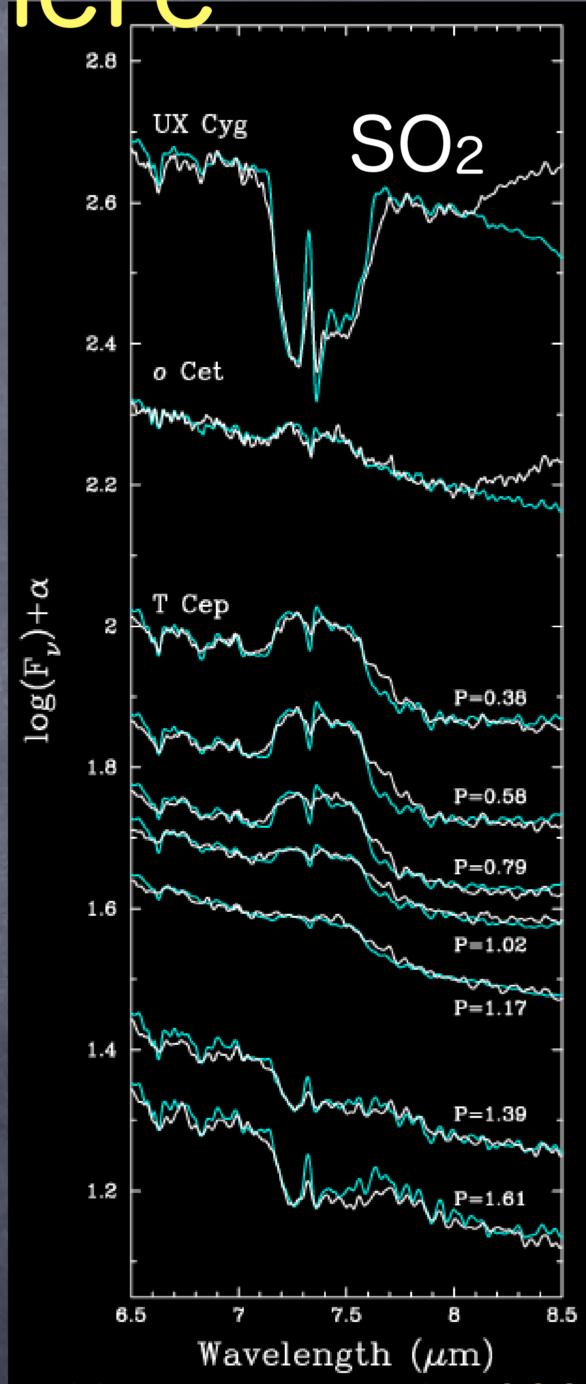
but no significant progress since ISO

A key region for dust formation and mass-loss

Chemistry in MOLsphere



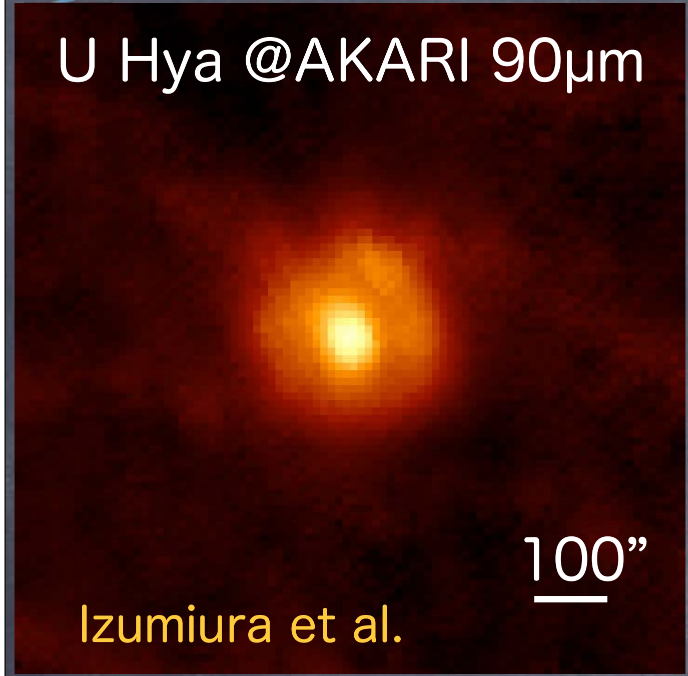
Justtanont et al. 1998



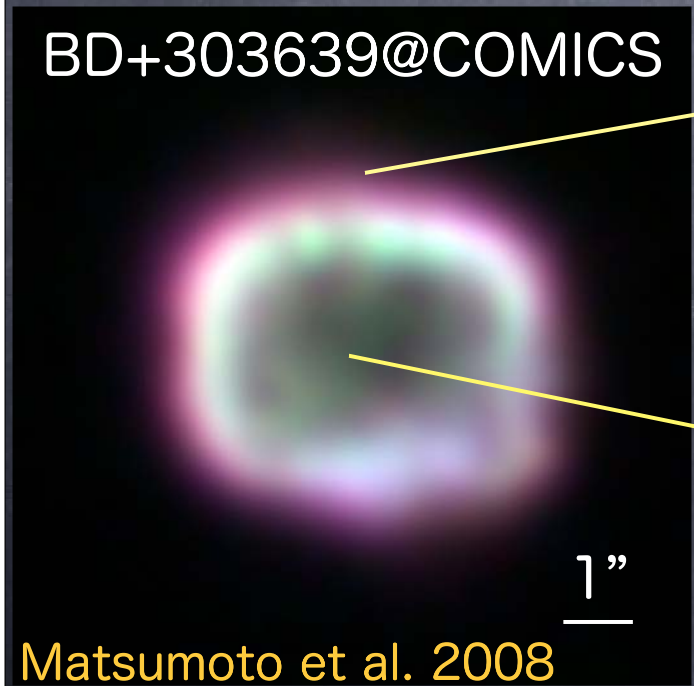
Yamamura et al. 1999

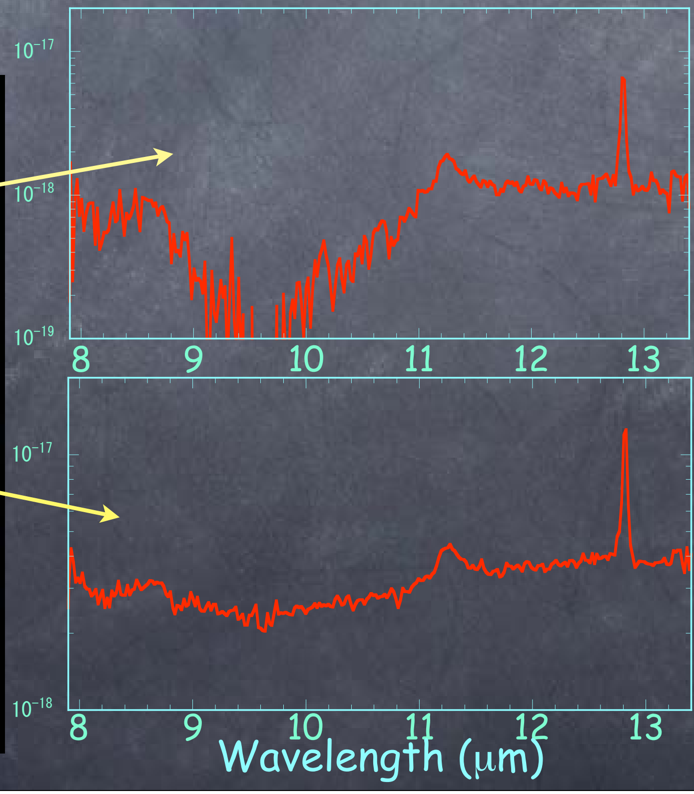
High spectral resolution (R ~ 30000) in 4 - 20μm is important to understand detailed chemistry and dynamics in MOLsphere

Mass loss history



FIR imaging of multi-band with high sensitivity and high spatial resolution enables detailed study of mass-loss history and chemical evolution (e.g. C/O<1 to C/O>1) in the circumstellar dust shell





High spatial resolution MIR spectroscopy indicates silicate dust around C-rich object

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SPICA Observations of AGB and PNe

High spatial resolution observations of ~30 AGB stars and PNe in MIR to FIR to study mass-loss history, dust formation, and chemical evolution of the CSM

Search for weak UIR bands in C-stars to investigate the origin of the band carriers and the processing in the ISM

Origin of carbonaceous grains is important for the study of dust in the early Universe

High spatial resolution and high sensitivity for diffuse emission from MIR to FIR are a key for this study

High spectral resolution capability in MIR (4-20μm) is important for the study of gas in MOLsphere

3. Search for dust formed in the ISM

Theoretical studies indicate:

(i) stellar dust sources (SNe, AGB stars, ..) replenish interstellar dust in 5×10^9 yr

and

(ii) SN shocks destroy dust in $<1 \times 10^9$ yr

Interstellar dust must be formed in the ISM

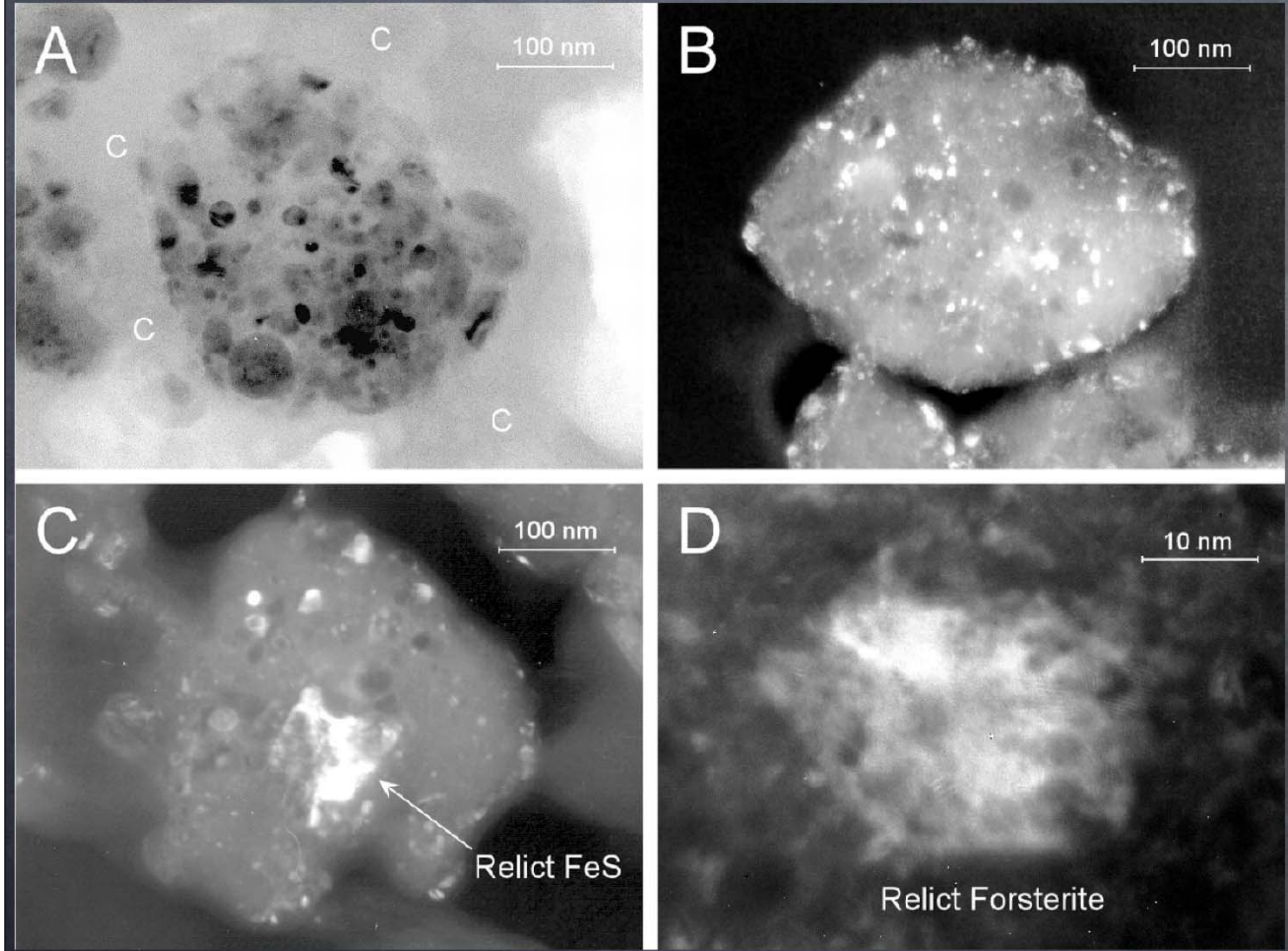
Significant dust processing in the ISM also expected

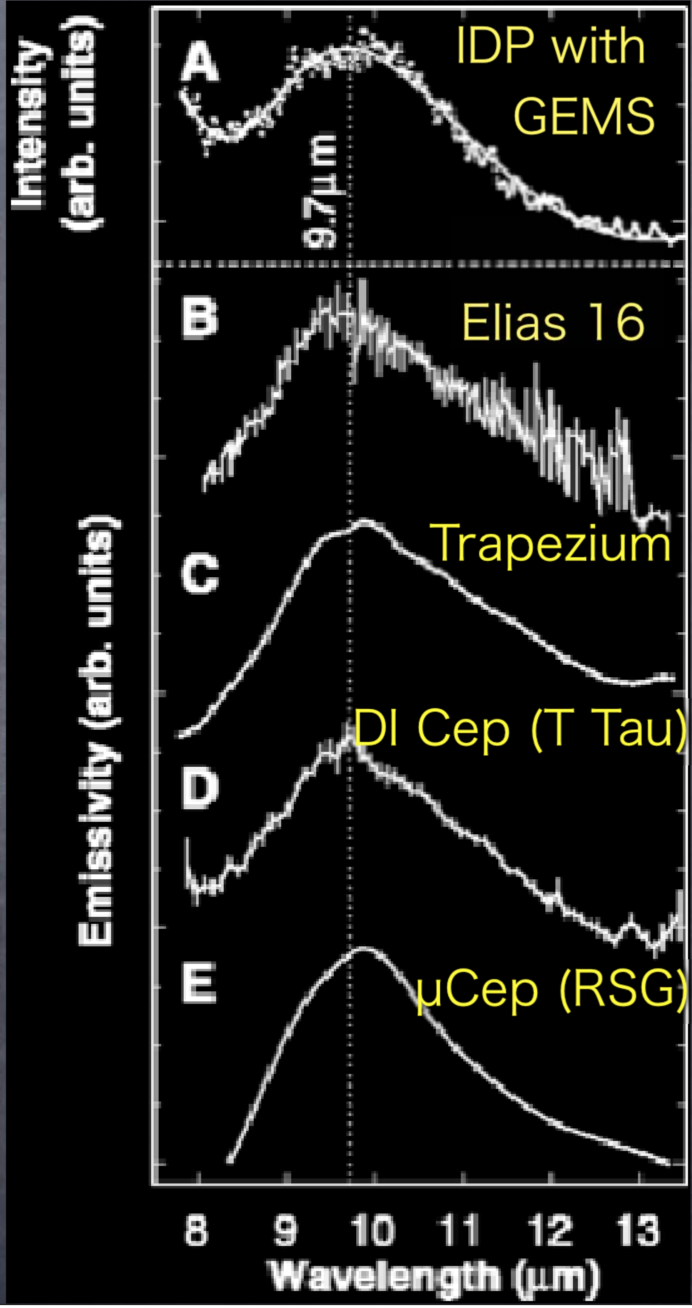
Up to now a systematic variation in the UIR band is observed in the halo of galaxies and elliptical galaxies

No systematic variation in the silicate feature (e.g. crystallization) reported in the galaxy scale (except for crystalline silicate in ULIRGs)

GEMS (Glass with Embedded Metals & Sulfides)

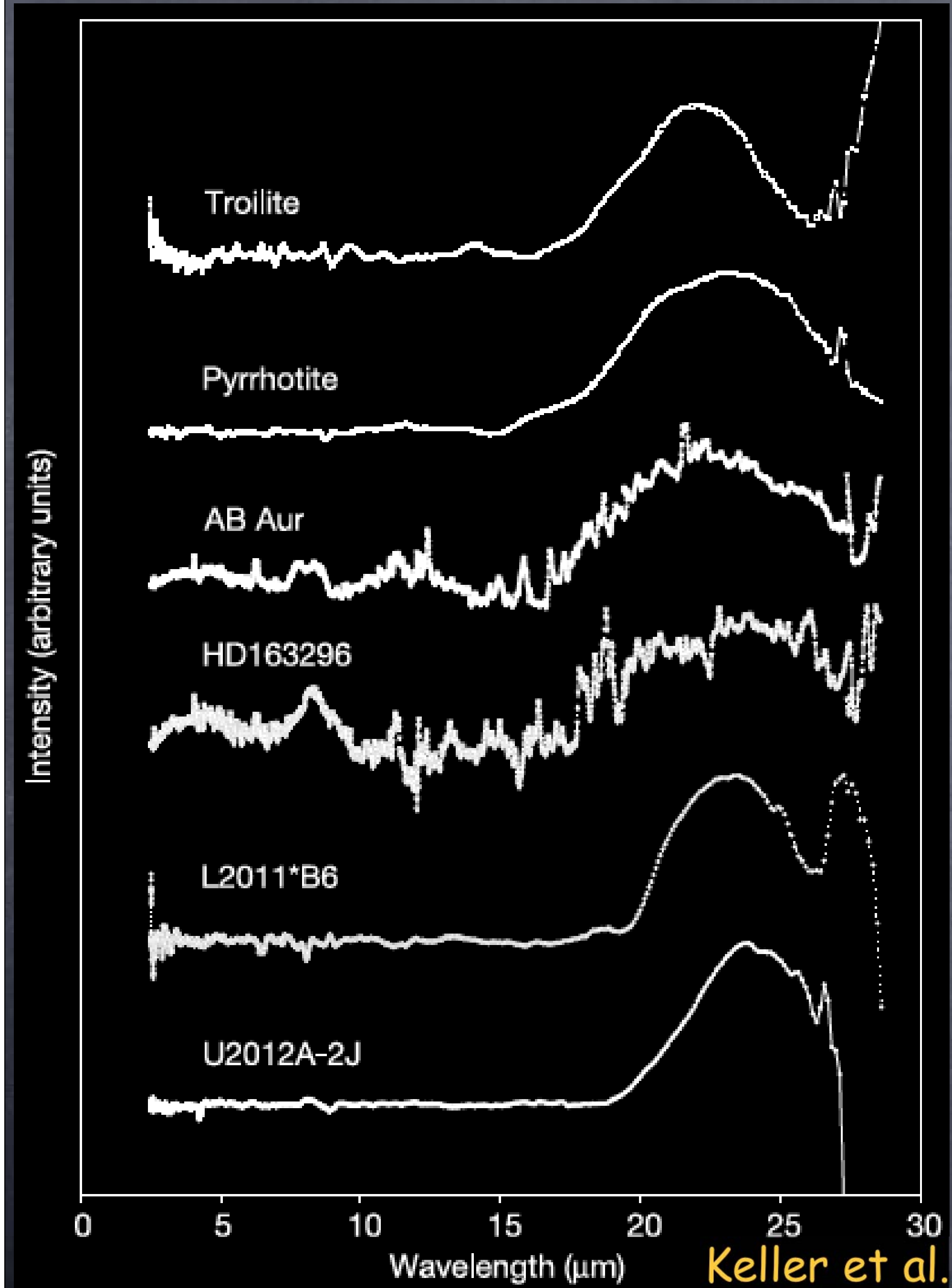
Good interstellar dust analog found in IDPs





Bradley et al. (1999)

IR Spectra of metal sulfides

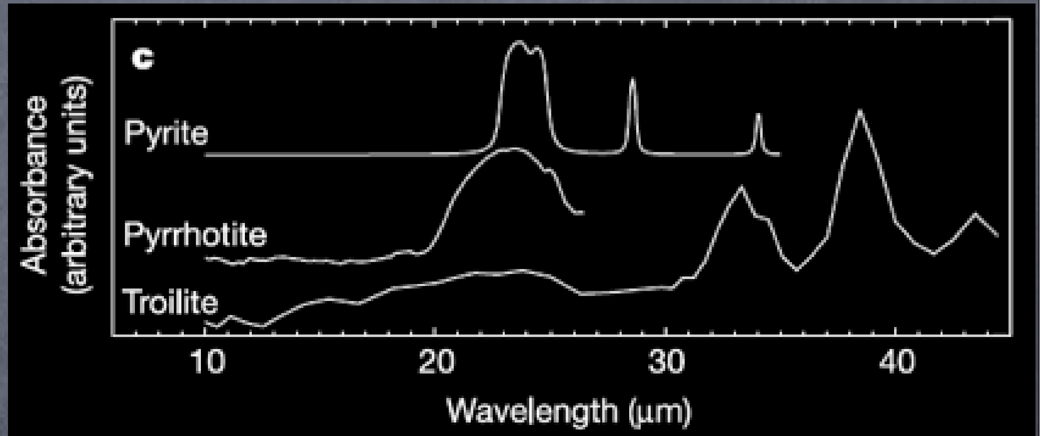


Keller et al. (2002)

FeS

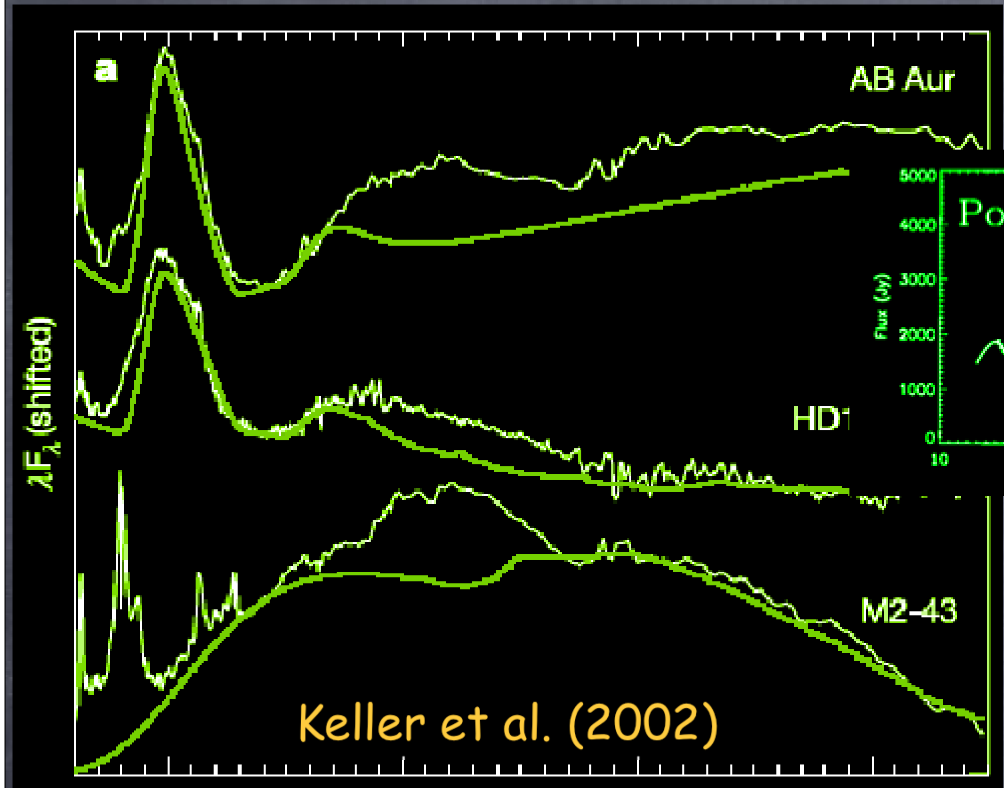
$Fe_{1-x}S$

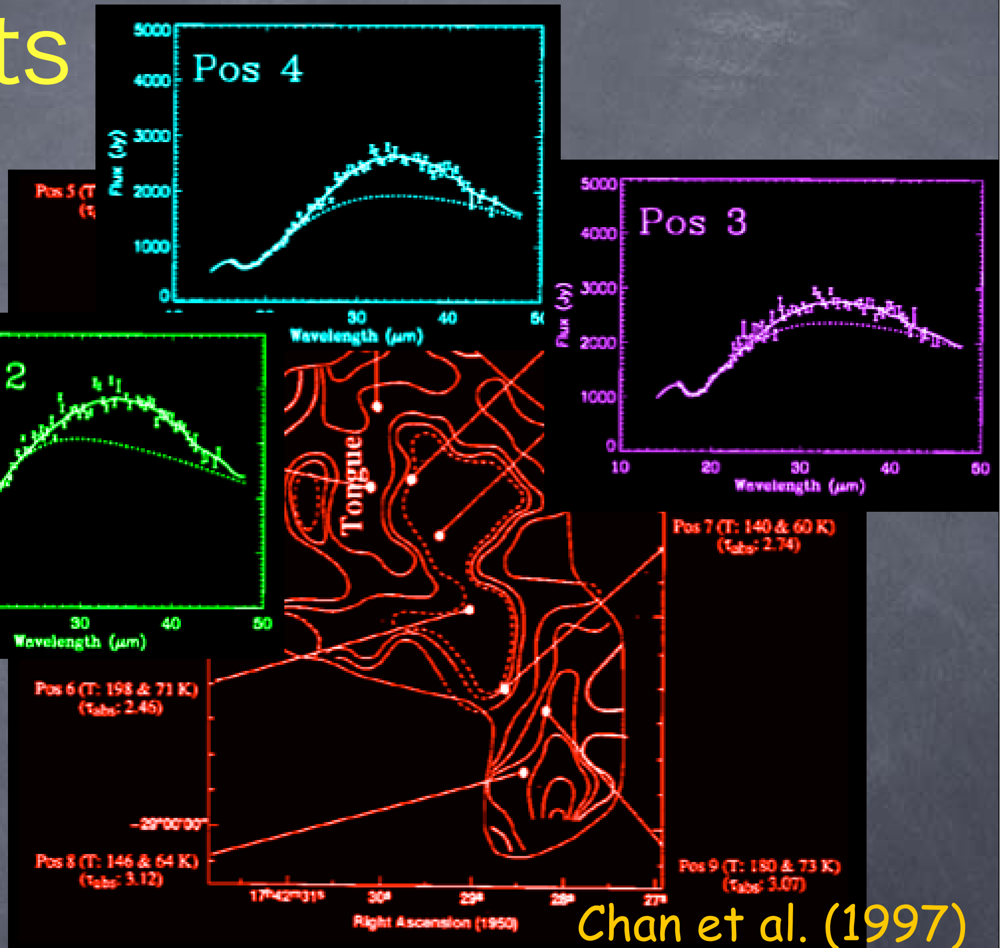
Metal sulfides have band features in 20-30μm



Sulfide-rich IDPs

Metal sulfide features in celestial objects



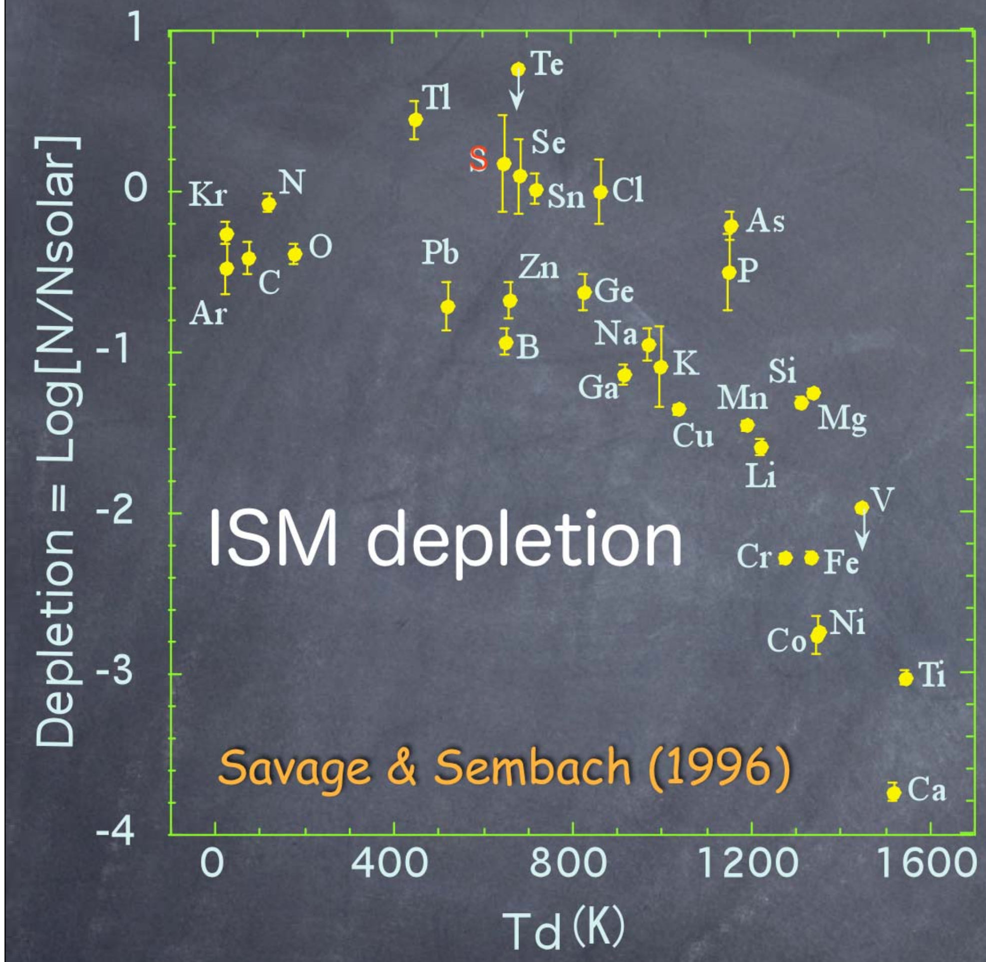


C stars have a feature around 30μm (MgS?)

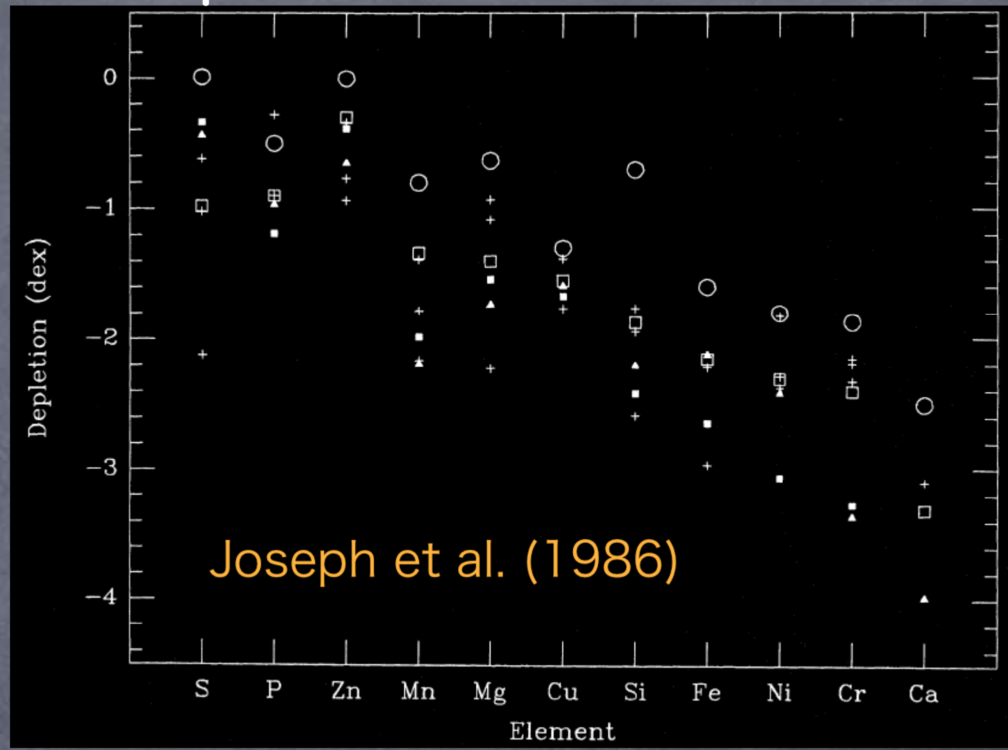
~20-30μm feature is seen in YSOs

and the Galactic Center

Depletion of sulfur



Depletion in dense clouds



Sulfur is not depleted in the ISM, but largely depleted in dense clouds

Sulfur may be incorporated in GEMS in dense clouds

SPICA observations of dust formation and processing in the ISM

Spectroscopic observations of dense clouds in 10-200μm with medium spectral resolution to search for new dust features (e.g. sulfides)
and study grain formation and processing in the ISM

Gas abundance can also be derived in dense regions by spectroscopy of forbidden lines in MIR to FIR ([FeII]26, [SiII]35, [OI]63, 145, [CII]158, ...)

Same aperture size for different lines is important in deriving physical parameters (n_e, T, ..)

Medium spectral resolution with high sensitivity spectroscopy for >20μm is required

Dust in galaxies

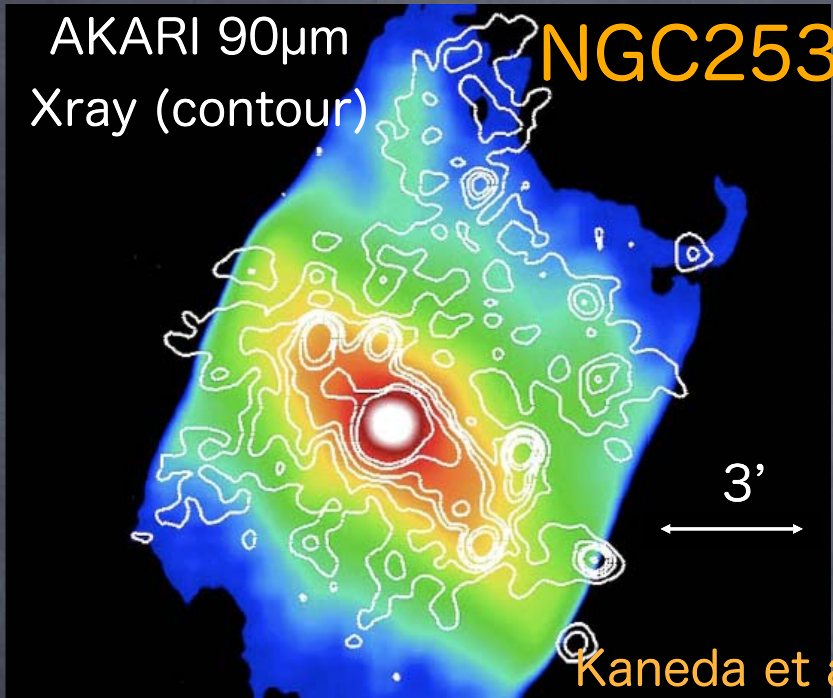
Spatially resolved spectra are indispensable to understand the properties of gas and dust in regions with different physical conditions in a galaxy

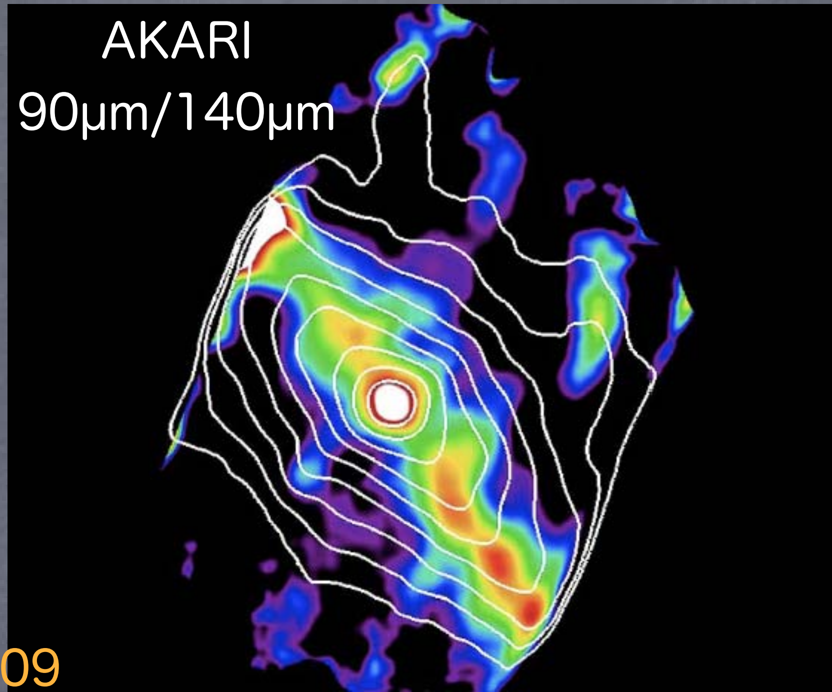
Key information of the physical conditions of each region can be derived from the study of gas

Dust circulation scenario in our Galaxy should be tested with the study of external galaxies that have a wide range of physical conditions

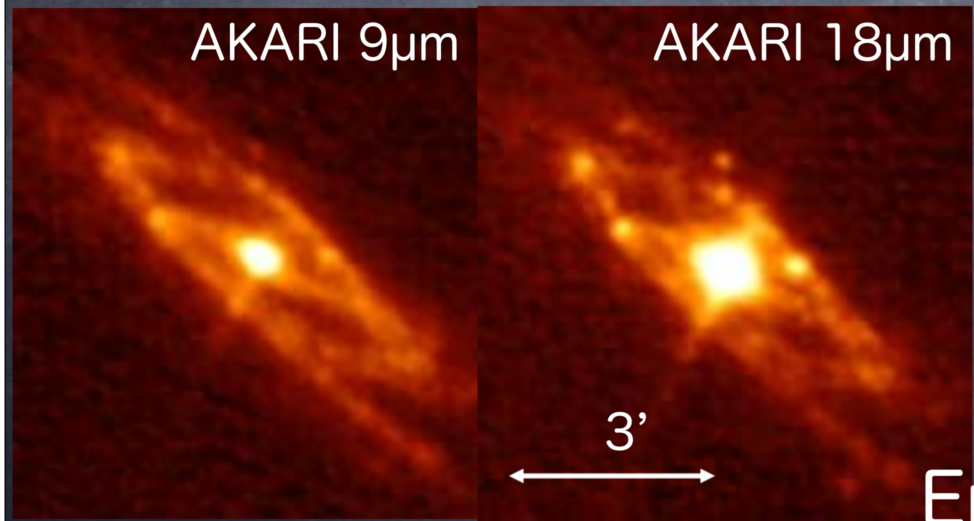
Dust survival and processing under harsh conditions, e.g., plasma environment in the halo, can only be studied with instruments of high sensitivity for diffuse emission

Dust in halo entrained by outflow





Kaneda et al. 2009



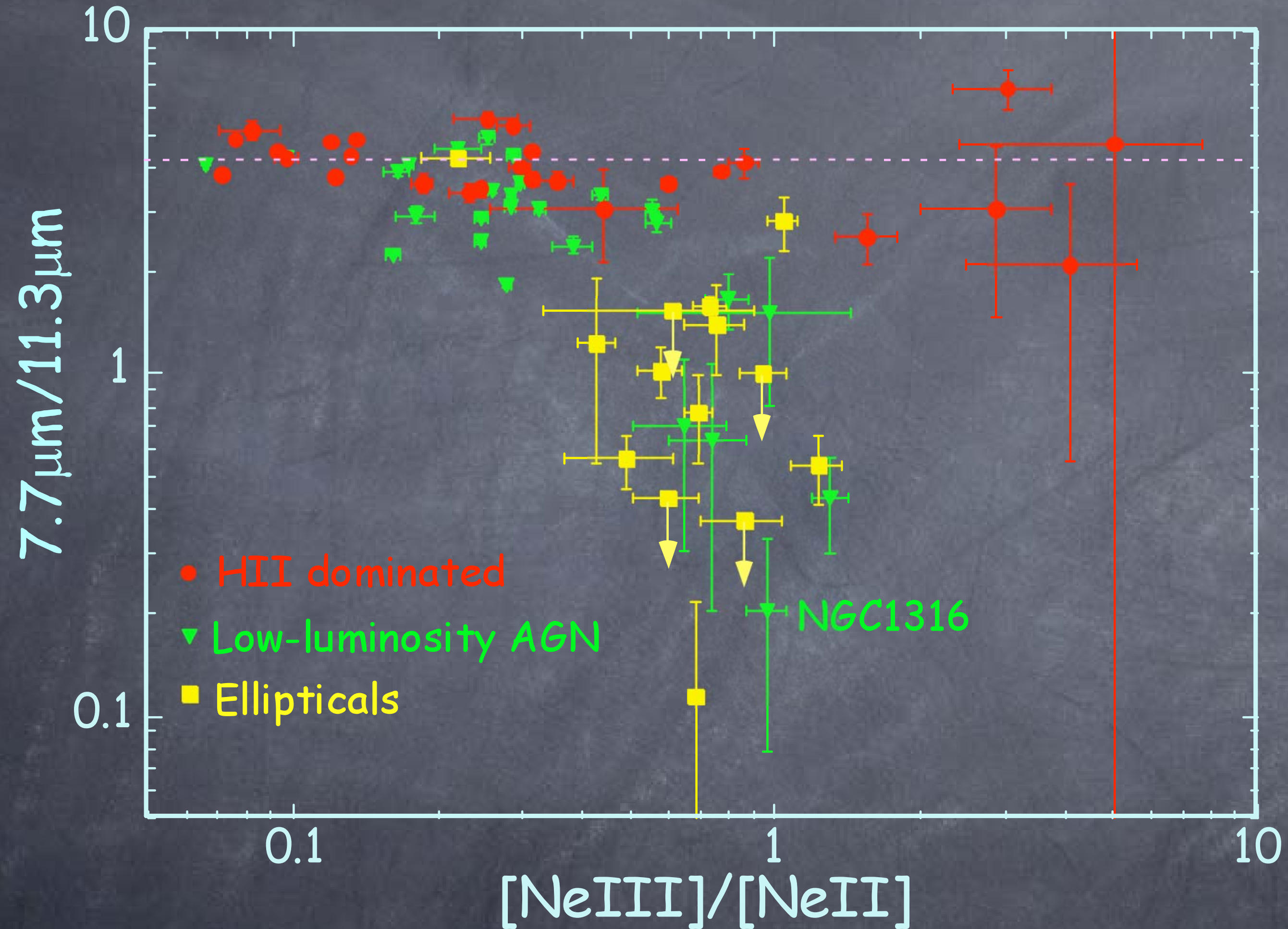
FIR emission seen in the halo well matched with X-ray

Dust must survives in the outflow and reaches the halo

Energy source of the emission?

Origin and processing of UIR band carriers in galaxies

SPICA

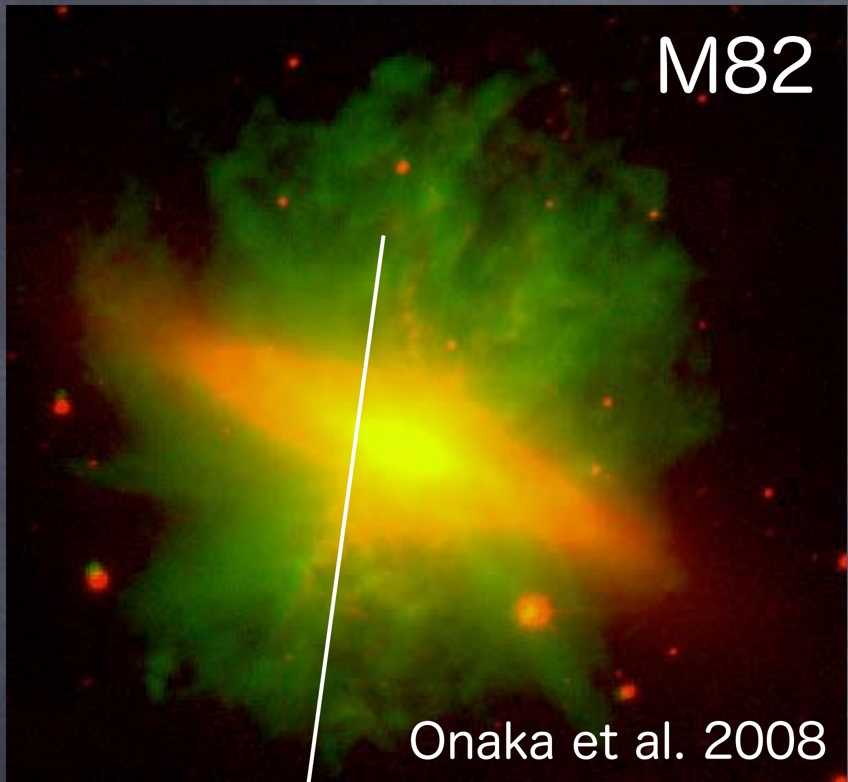


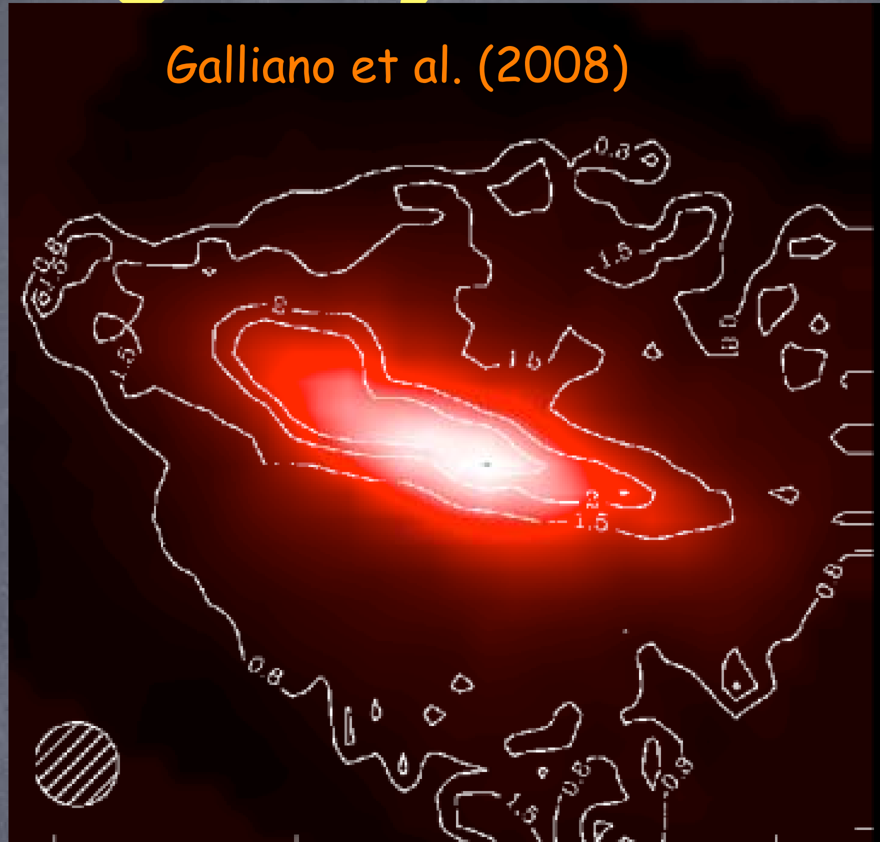
J.D. Smith et al. 2007;
Kaneda et al. 2008;
Onaka et al. 2008

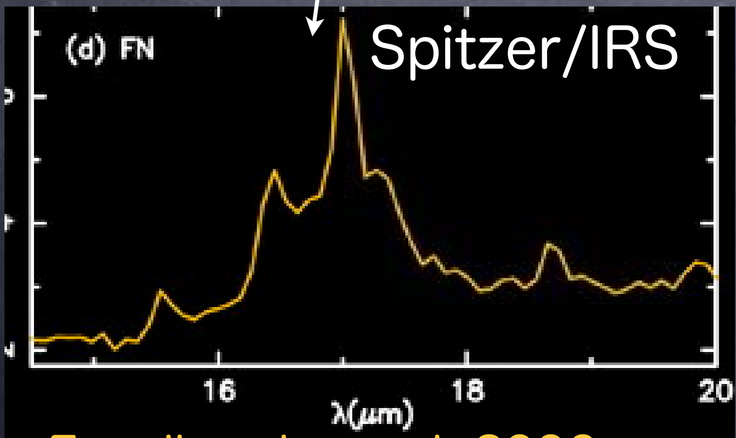
7.7/11.3μm band ratio is smaller in elliptical galaxies
Neutral carriers in elliptical galaxies
or carrier processing in a plasma environment?

UIR bands in the galaxy halo

Hα (red) + AKARI 7μm







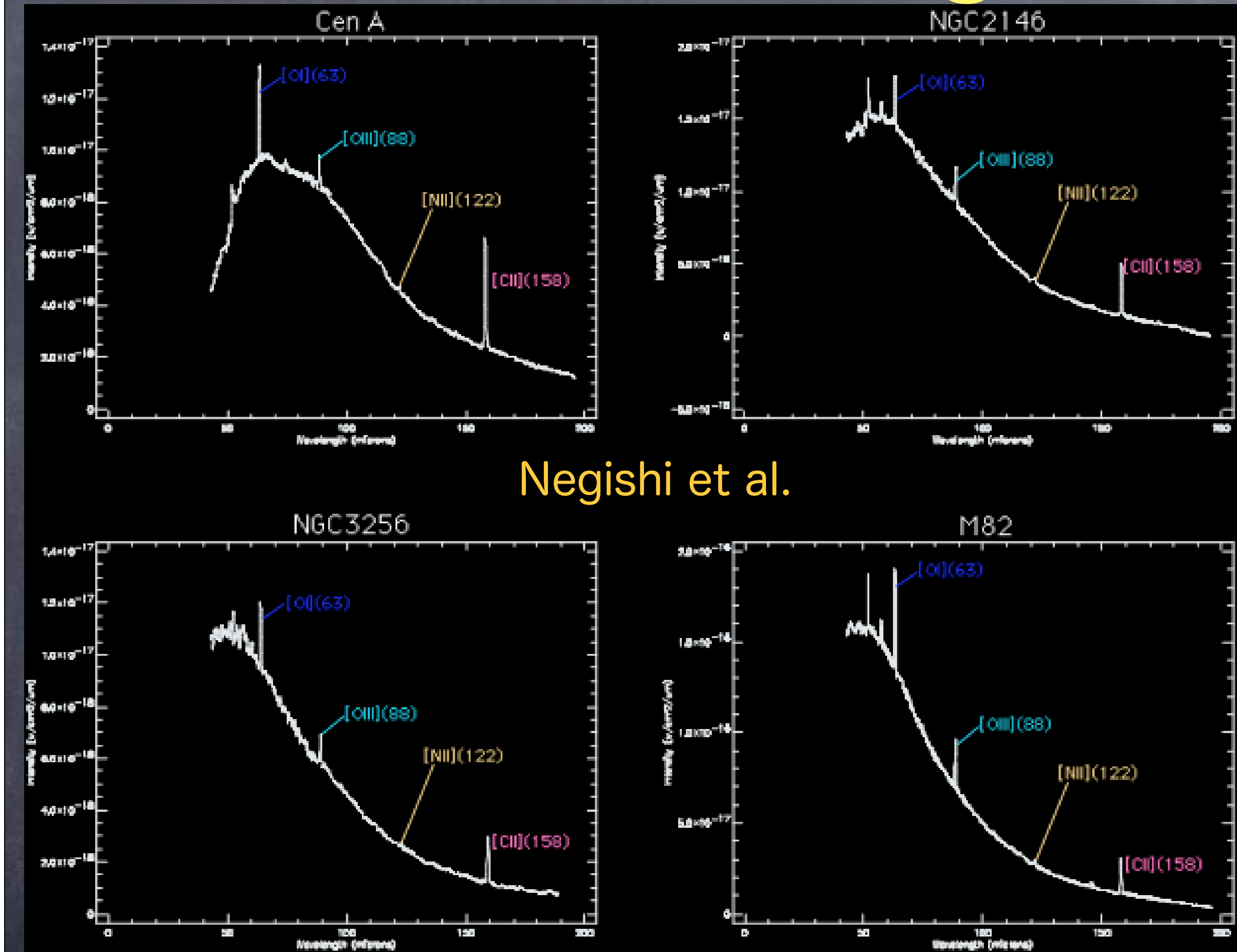
Engelbracht et al. 2006

UIR band detected in the halo region extended more than Hα

6.2/11.3 ratio smaller in the halo

Carbonaceous dust survival and processing in the halo region need further study

IR lines in galaxies



Neutral (PDR) gas
[OI]63, 145μm
[CII]158μm
[SiII]35μm
[FeII]26, 35μm

HII regions
[OIII]52, 88μm
[NIII]57μm
[SIII]18, 33μm
[NeIII]16, 36μm

Diffuse ionized gas
[NII]122, 204μm
[NeII]13μm
[CII]158μm
[SiII]35μm, [FeII]

Contributions from each phase must be separated spatially
Same aperture size observations important to derive physical parameters

SPICA observations of nearby galaxies

Imaging spectroscopic observations of ~50 nearby galaxies in MIR to FIR to study physical conditions of individual regions, e.g, HII regions, galactic center, molecular clouds, and halo in galaxies and investigate dust formation, processing, and destruction in a galactic scale, including feedback from nuclear activities, effects of merging on material evolution, origin and evolution of carbonaceous and silicate grains

High spatial resolution and medium spectral resolution spectroscopic capability together with high sensitivity for diffuse emission in MIR and FIR (10 - 200μm) are crucial

Mapping capability is also important