An Investigation of Dust in OH 231.8 + 4.2

using subarcsec mid-IR Imaging

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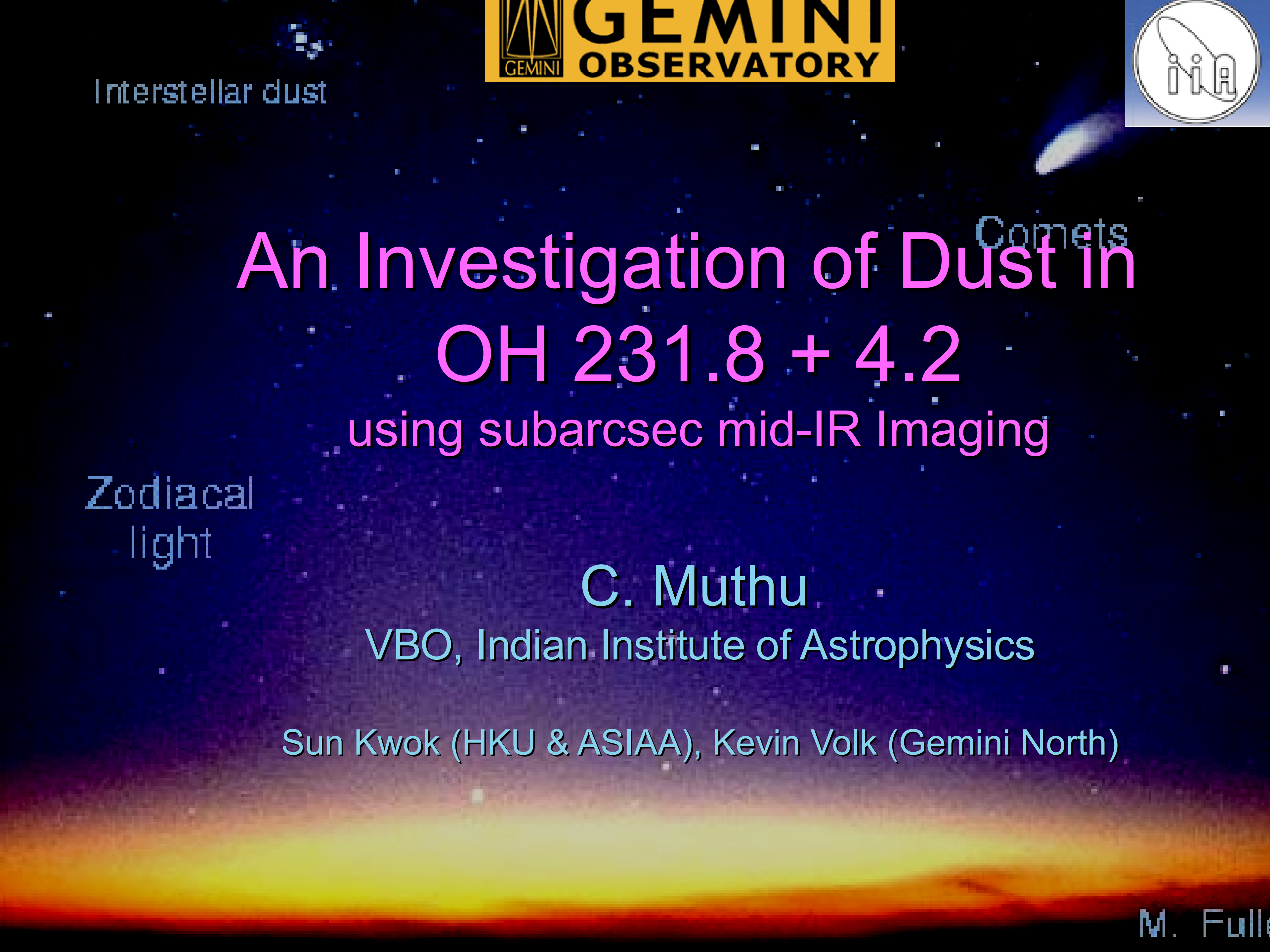
VBO, Indian Institute of Astrophysics

Sun Kwok (HKU & ASIAA) Kevin Volk (Gemini North)



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Reflection Nebulae

Circumstellar envelopes of gas and dust illuminated by the central star

Usually bipolar in shapes

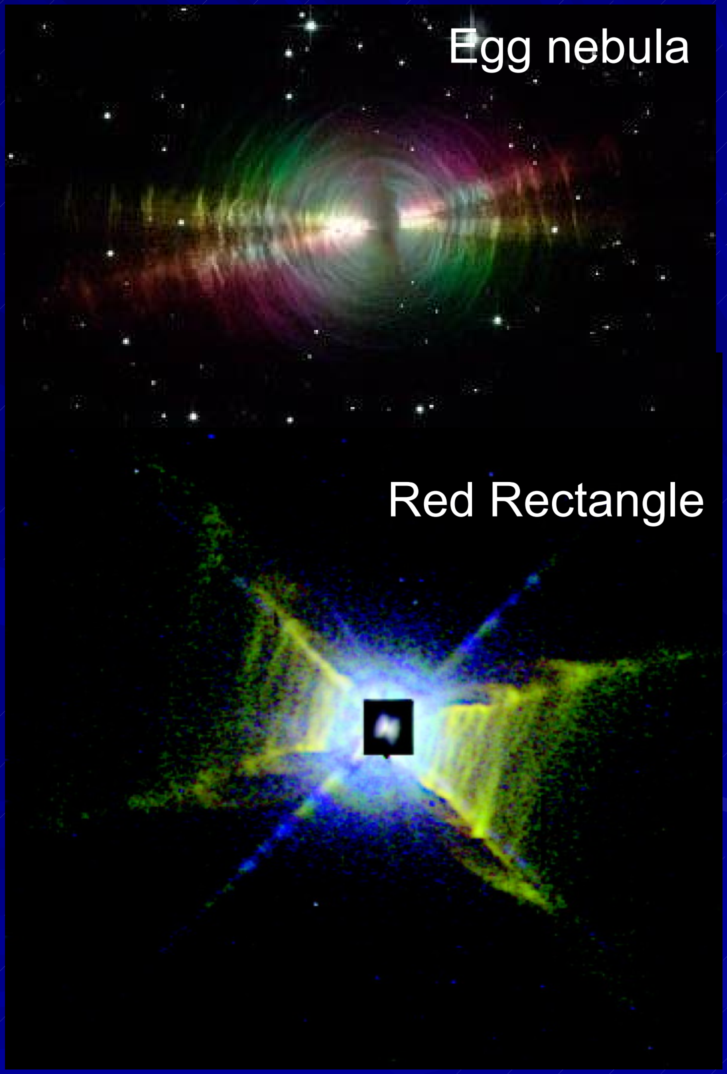
Shows large IR excess emission

Seen in dust scattered starlight in UV, Optical and near-IR

Dust emission peaks at mid to far IR

Either seen in star forming regions or in around evolved stars

Important laboratories to study cosmic dust



Proto-planetary Nebulae

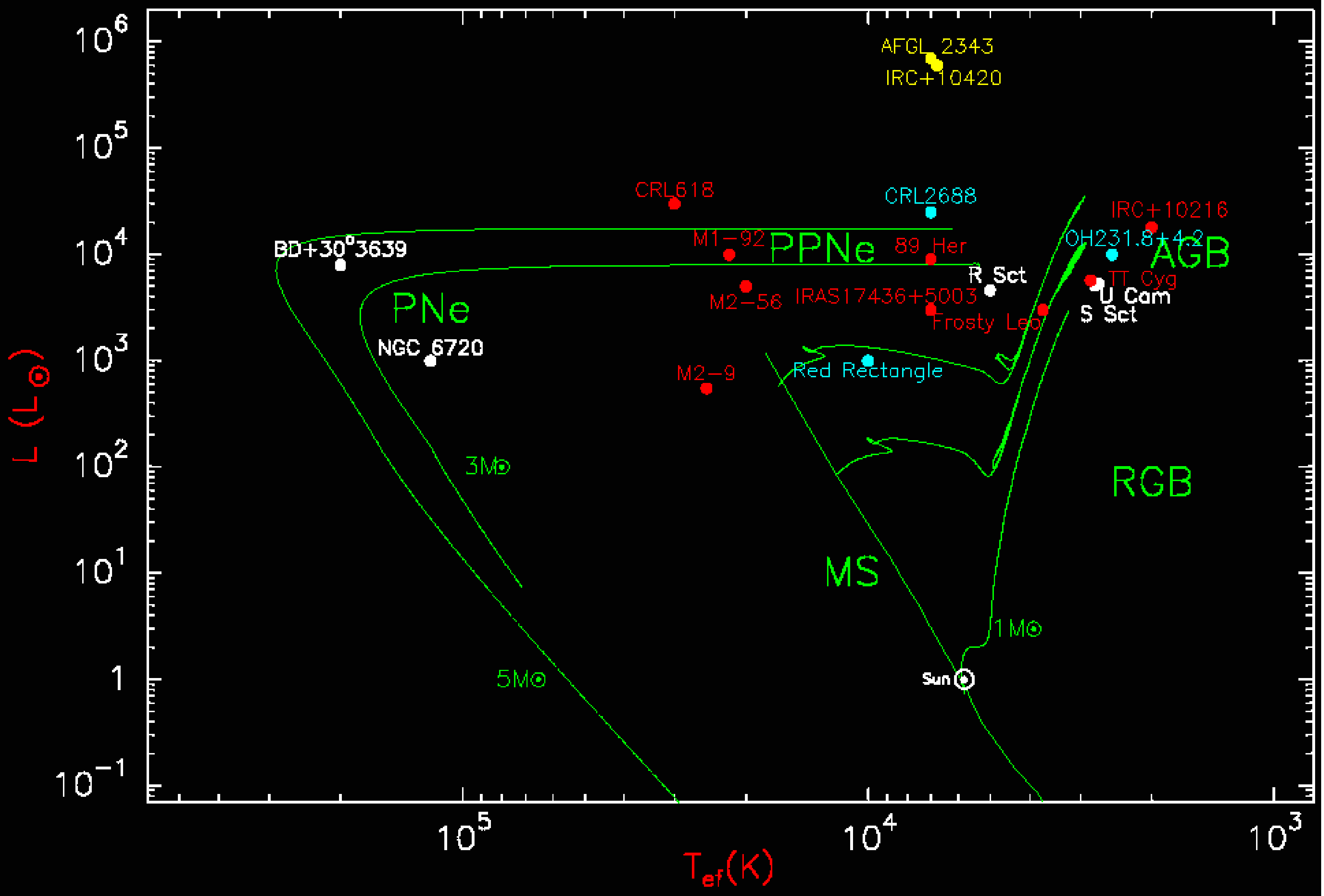
- A class of objects which are in the transition phase (1000 yr) from AGB to PNe (mass loss stopped, photoionization not yet begun)

  Detached Circumstellar envelopes

  Colour temperature between 150 to 300K

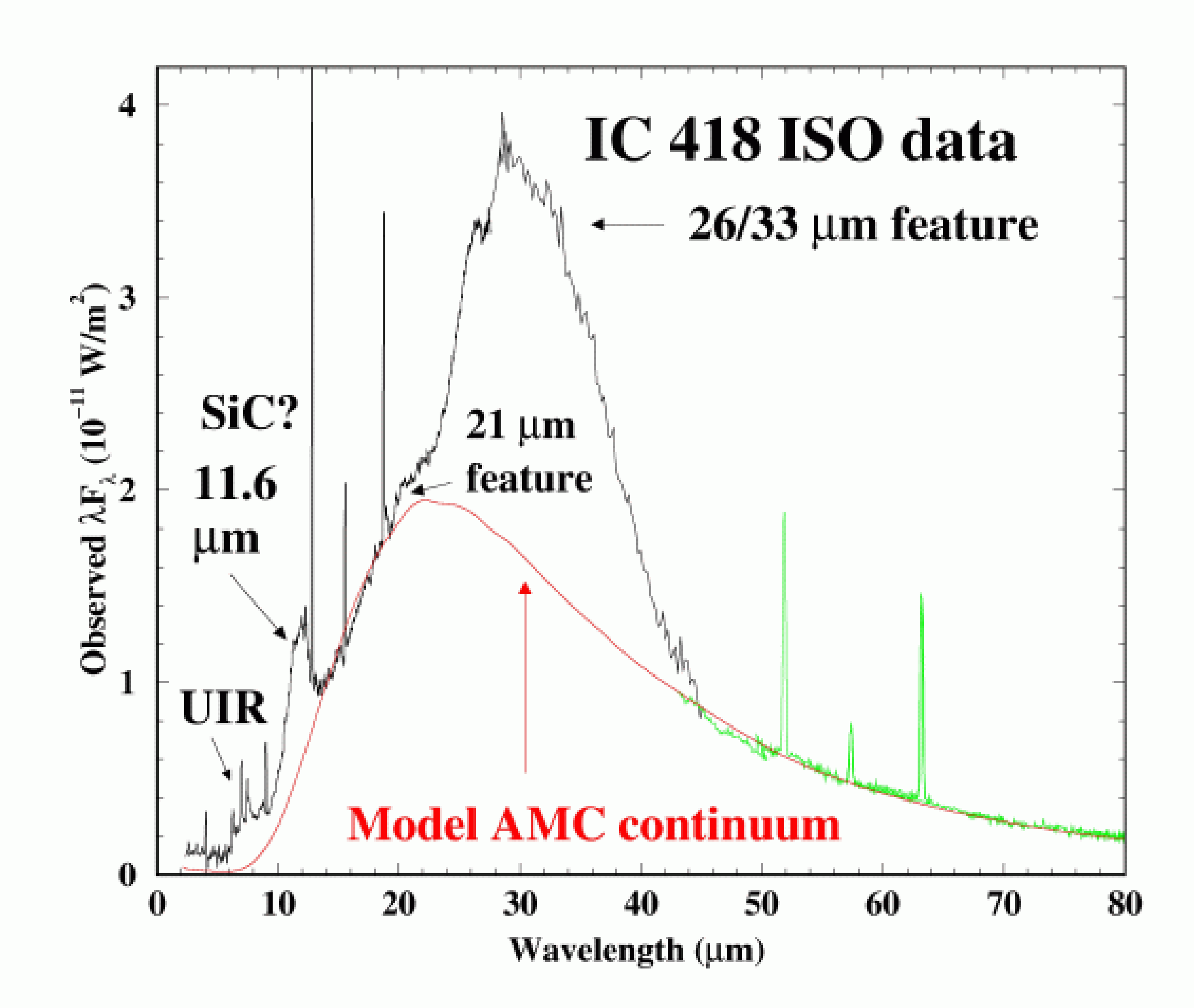
  Central star spectral type are B to G with luminosity class I

(see Kwok S. 1993, ARAA, 31, 63)

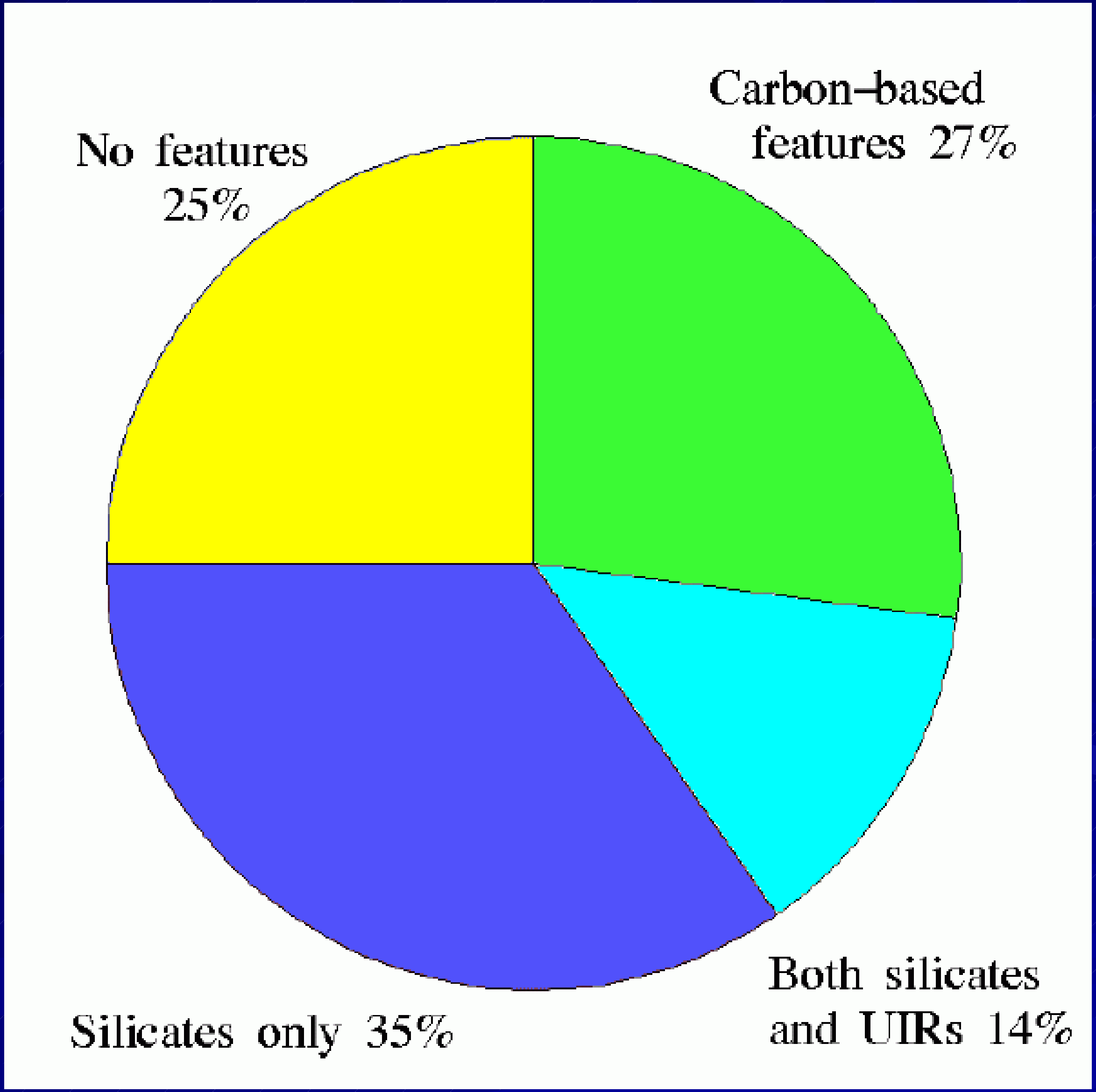


AFGL 2343
IRC+10420
CRL618
CRL2688
IRC+10216
OH231.8+4.2
BD+30°3639
M1−92
PPNe
89 Her
AGB
R Sct
TT Cyg
U Cam
S Sct
M2−56
IRAS17436+5003
Frosty Leo
PNe
NGC 6720
M2−9
Red Rectangle
3M⊙
RGB
MS
1M⊙
Sun
5M⊙
L (L⊙)
Tef(K)

ISO spectrum of young PN IC418



ISO spectroscopy of p-PNe



Why proto-PNe ?

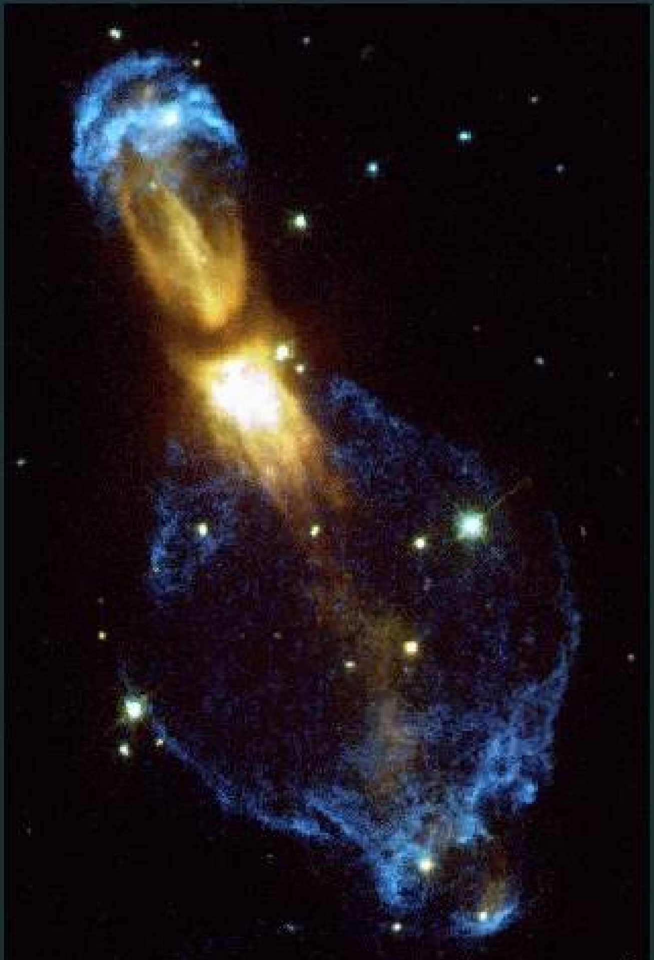
- UIR features are formed at this phase
- Envelope is not yet influenced by ionization & wind interaction
- Easy to solve radiative transfer problem

  Optically thin in most cases (by geometrical dilution)

  Needs to consider only stellar radiation field
- Physical conditions and the time scales are well constrained in circumstellar environment

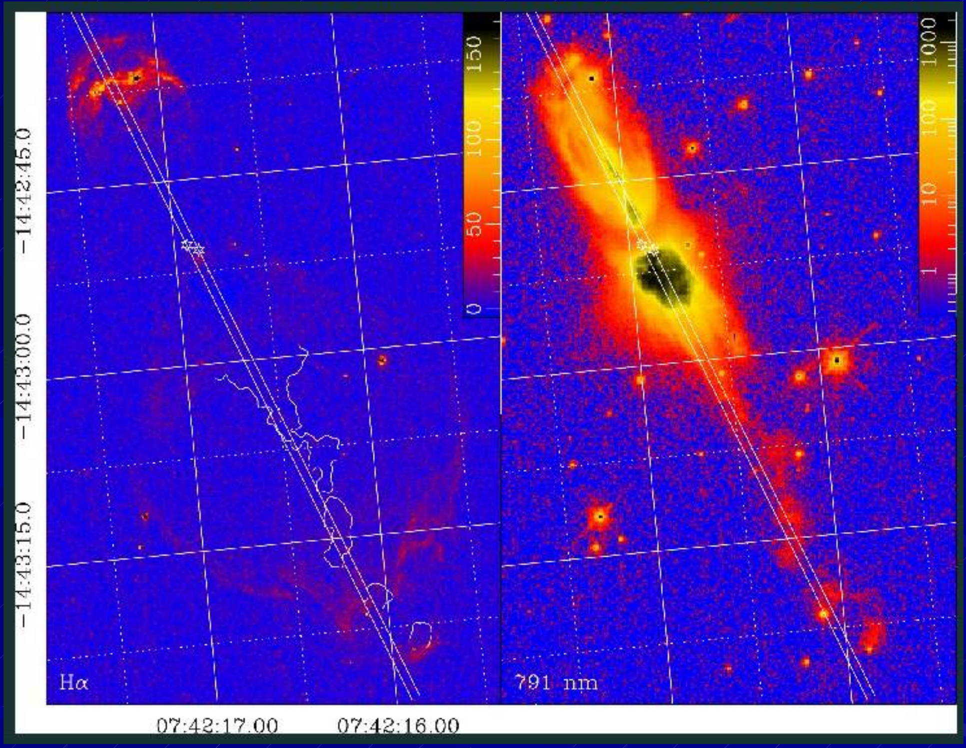
OH 231.8 + 4.2

- The bipolar nebula has four main components
  - A very dense/thick disk/torus of dust and gas, seen as an obscuring waist dividing the two lobes, and containing at least 0.6 $M_{\odot}$
  - A dense but cool one, seen in dust scattered light & mm-wave molecular lines (e.g. ^{12}CO). It is very elongated & contains $\approx 0.3\,M_{\odot}$
  - A hot but diffuse one, seen in Hα & forbidden lines, which traces the presence of shocks in a diffuse medium: two bow shocks & the corresponding forward shocks ($\approx 0.002\,M_{\odot}$)
  - A rounded halo, seen in deep NIR images, which traces of the order of 0.01 $M_{\odot}$ lost 5,000 — 10,000 yr. ago, extending 25″ in Ø


From Bujarrabal et al. 2002 (A&A 389, 271)

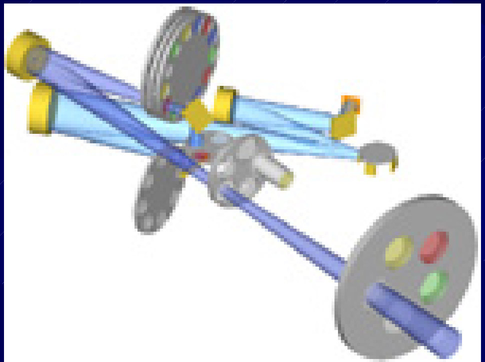
OH 231.8 + 4.2

- Reflection nebula in open cluster M46
- Outflow velocity > 400 km/s
- Central star with long period variability (700 days)
- Undergone an unexpected evolutionary path (Mira, PPN, Herbig Haro co-exist)
- Shows OH, SiO maser and 3.1μ ice feature, no AIB
- Distance 1.5 kpc



The Gemini Observatories

- 8m-class telescopes, optimized for thermal infrared observations (imaging and spectroscopy)
- Nearly diffraction limited images system (0.365´´ at 10μ, 0.700´´ at 25μ), high thermal-IR performance
- Together they can see the entire sky

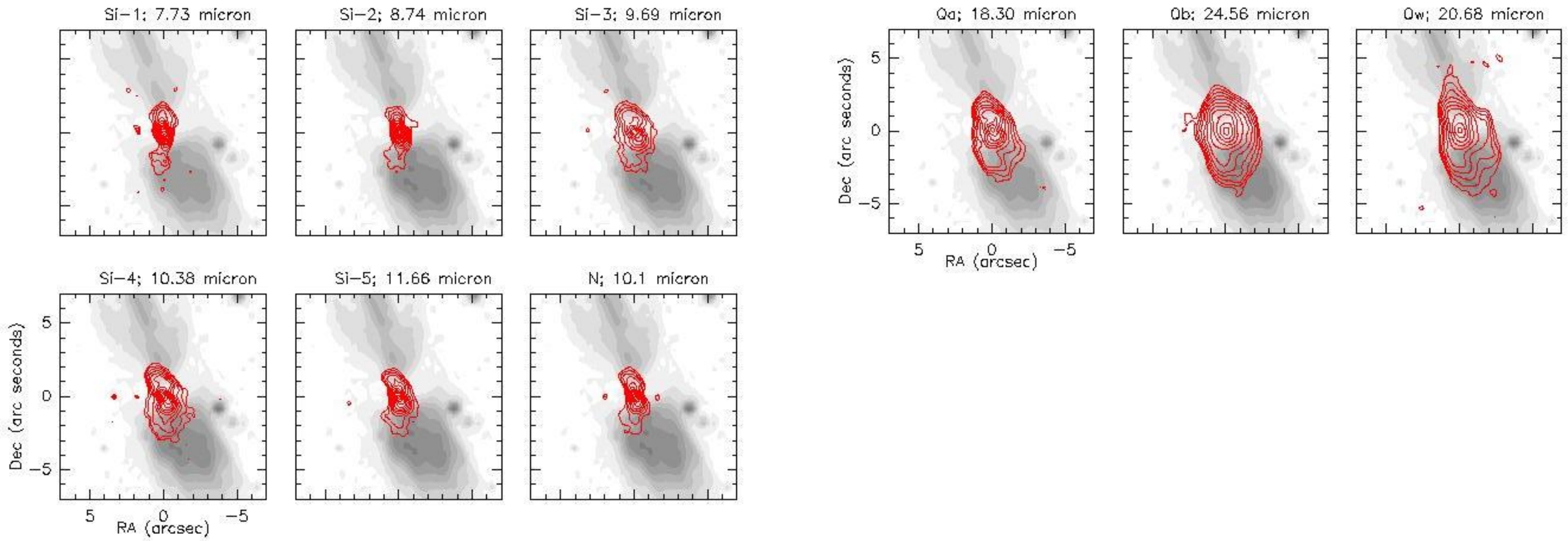


Thermal-Region Camera Spectrograph (TReCS)

- Broad and narrow band filter imaging, low and medium resolution spectroscopy in N and Q bands
- Optimized for 8-26 µm imaging (also 1-5 µm window)
- Raytheon 320×240 pixel Si:As IBC array
- Pixel size = 0.09" (fixed) Field of view = 28.8"×21.6"
- low thermal background, high throughput, excellent image quality

TReCS Images (narrow & broad band)

Images deconvolved with PSF; Spatial resolution 0.18''

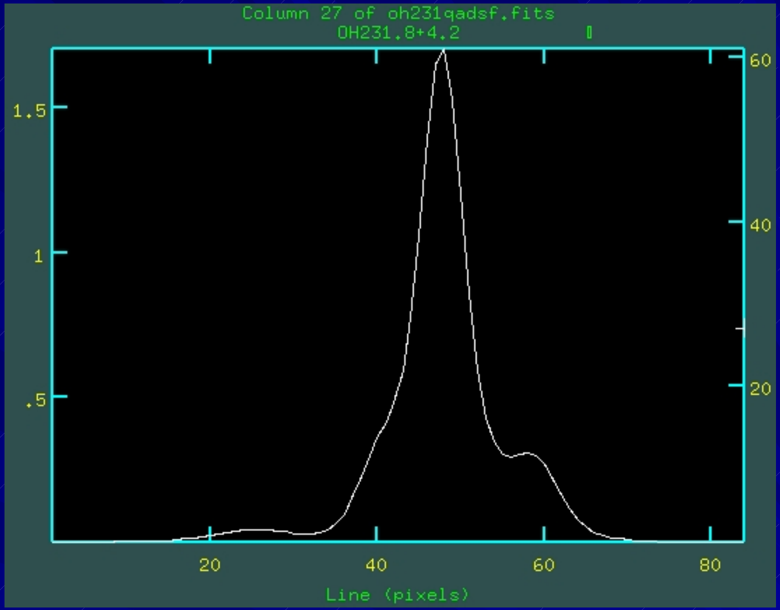


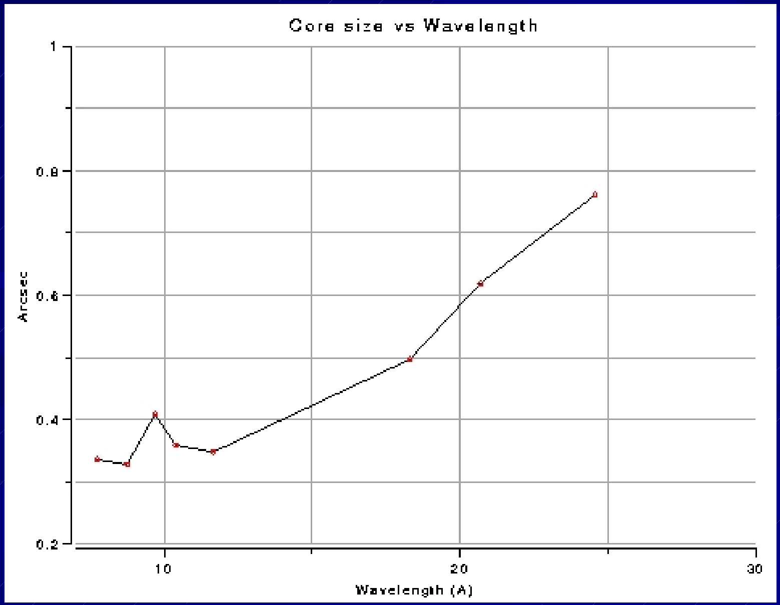
TReCS (contours) images superposed with HST 675W image (grey jumps)

Nature of the Core

Dust emission is seen in the dense core & extended along lobes

A bright region at the center of 0.52´´ diameter FWHM at 25μ
(48% of flux at 10μ, 38% at 20μ)





The size of the core increases with wavelength => stable PSF, steep temperature gradiant

Average temperature of the core 145K

Disk at the core?

$$F(_1\nu / (F(_2\nu\ B = ((_1\nu\ T)/ B,(_2\nu\ T)\ X,(_2\nu/_1\nu(^{\alpha}$$

fitting this function for 10.38, 18.3, 20.68μ fluxes results, index α = 0.5 for the core

typical value for spherical cloud of silicate dust
(for a flat disk α = - 0.3, flared disk α = -1.6)

- core is a spherical distribution of dust (no disk as proposed by Jura et al. 2002)

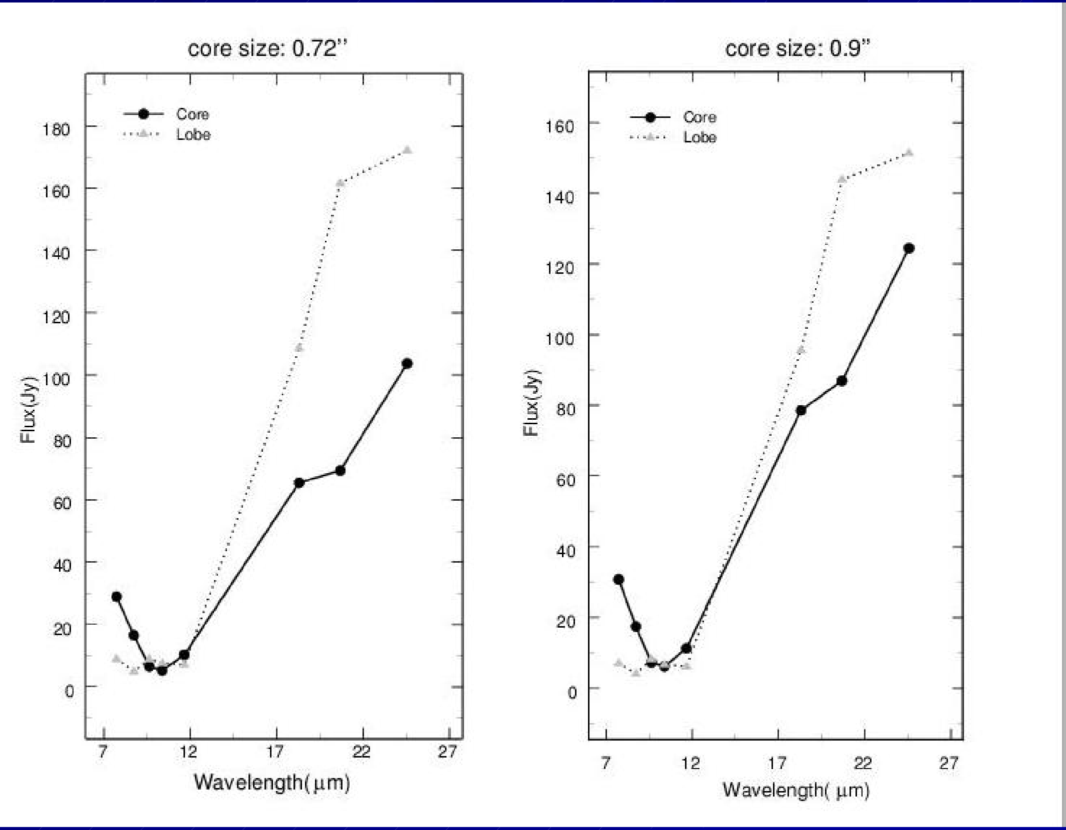
SED of the Core

i) excess opacity at 10μ and 18μ bands

ii) large opacity ratio between 10 and 18μ

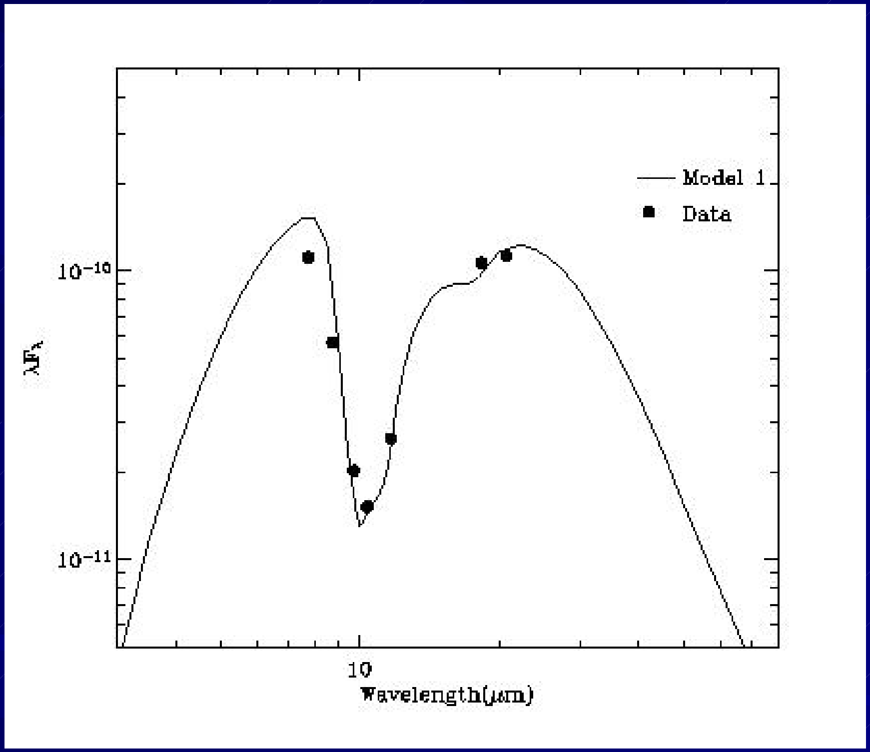
iii) opacity increases towards center

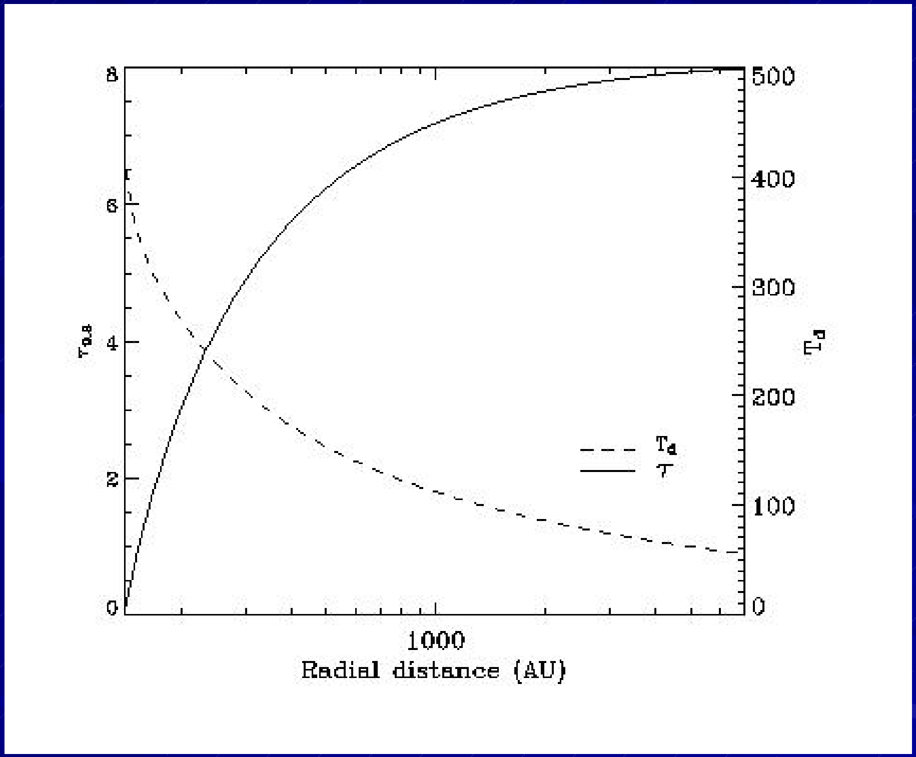
iv) featureless smooth 10μ absorption



RT model for Core

Dust species: cool silicate, amorphous alumina, $\tau_{9.8}$ = 8.5, MRN





Radiatively driven wind models, $\rho(r) = 1/r^2$, v_t =10km/s

Very similar to O rich dust shells around Miras

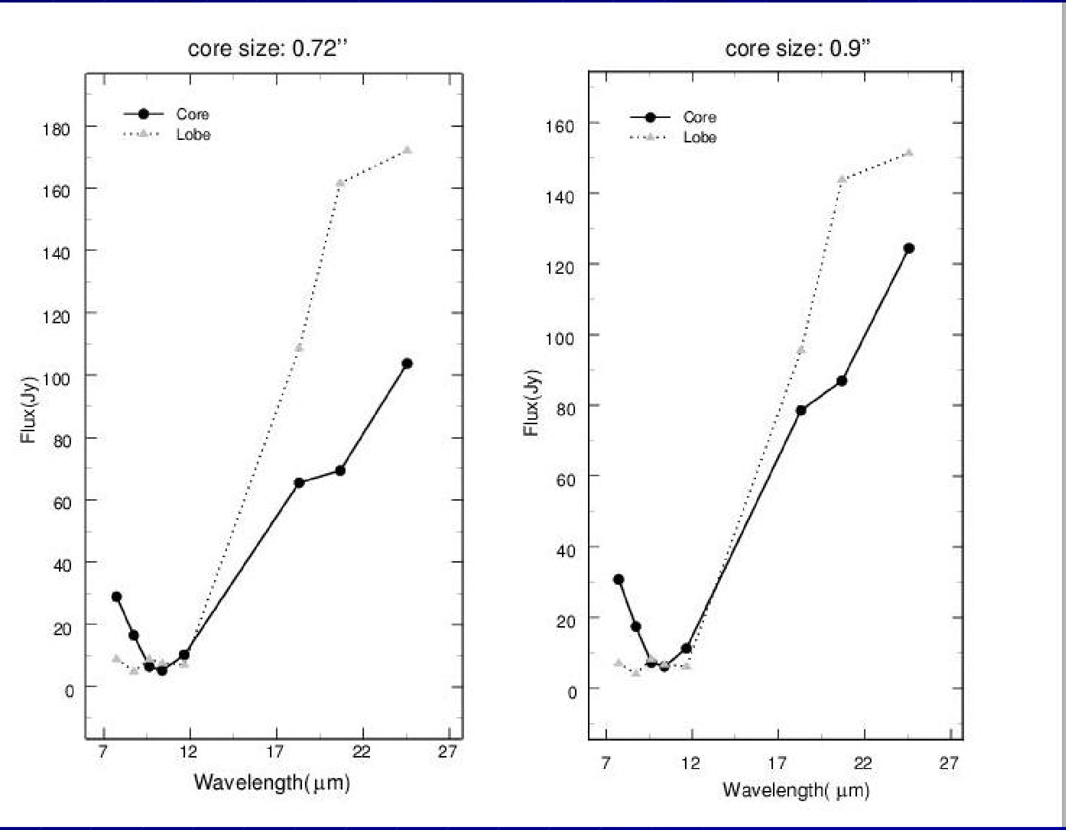
SED of the Lobes

i) no excess opacity at 10 and 18μ bands

ii) 10 and 18 μ bands are narrower than for the core

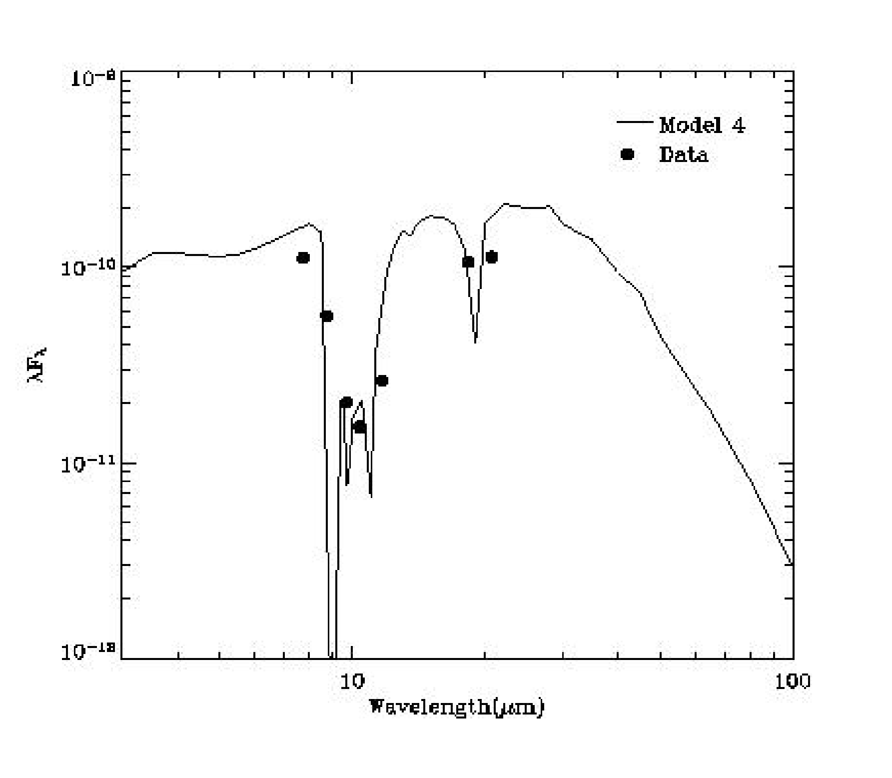
iii) sharp bottom end features at 10μ band

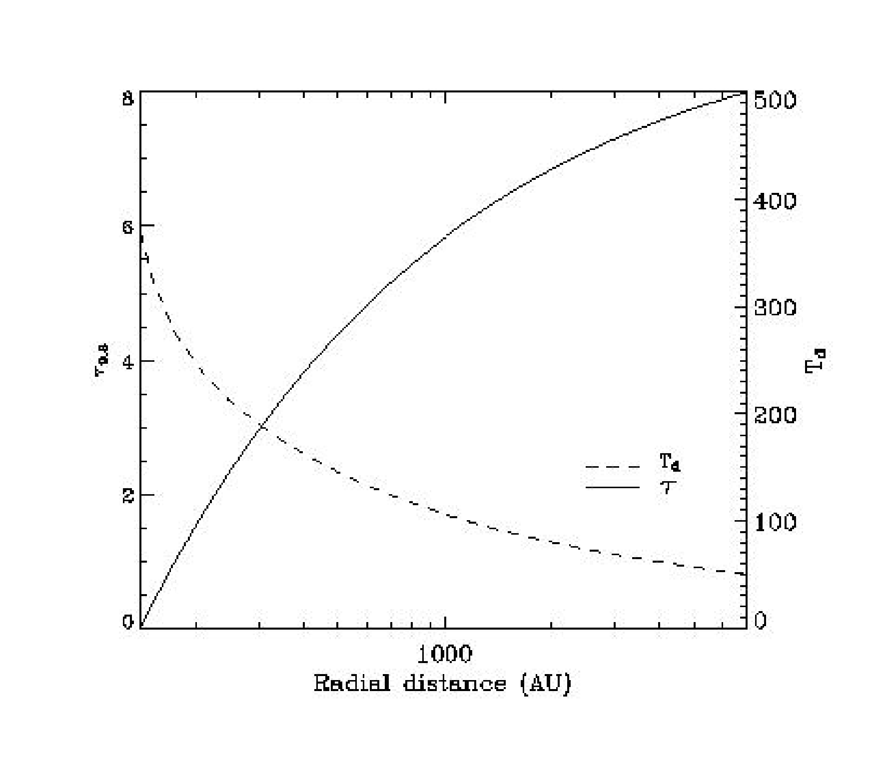
iv) features seen in IRAS spectra is due to lobes



RT models for Lobes

Dust composition: cool silicate, crystalline enstatite, amorphous alumina





$\rho(r) = 1/r^{1.5}$ $\tau_{9.8} = 6.5$ MRN

Not a radiatively driven wind

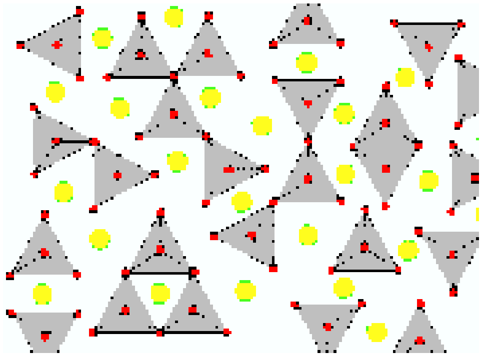
Nature of Silicates

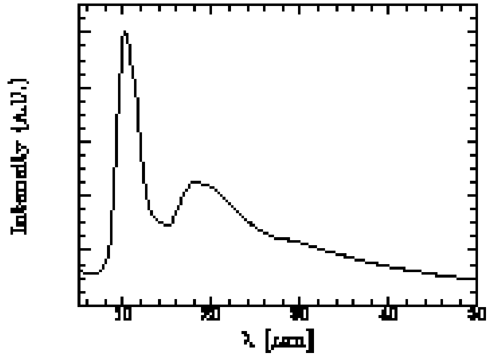
- Silica tetrahedras (SiO_4) combined with metal cations (Mg, Fe, Ca) in amorphous or crystal forms
- Ordered lattice structure tetrahedras share their nearby oxygen atom
- Olivines, pyroxenes, diopsides, quarts crystals
- Show resonance absorption at 9.8μ (Si-O stretching) and 18μ (O-Si-O bending)
- Lattice modes of crystals exist > 25μ

Most commonly seen in amorphous state

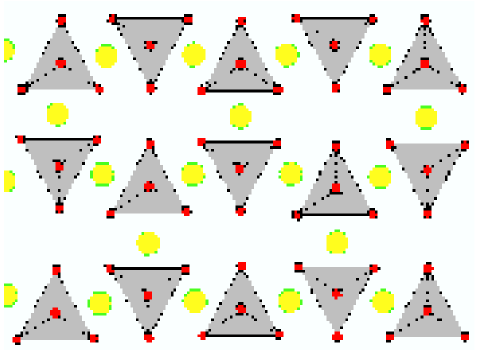
Silicates Structure

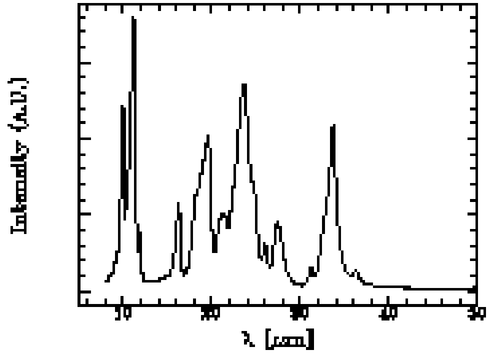
Amorphous structure





Crystalline structure





Tetrahedras:

4 Oxygen atoms around 1 silicon

Metal atoms are Inclusion (Mg, Fe, etc.)

Crystalline Silicates: importance

- Formation temperature, gas pressure & temperature
- Energetically most favoured state
- Colder, and less opaque than amorphous
- Can also be formed by annealing amorphous grains (shocks, radiation)

It traces the occurrence of high energy processes and physical conditions of its place of origin

Crystalline silicates: importance

- Wavelength & strength of feature are very sensitive to the chemistry

$100 \times (x/\Delta k) = -1.8$ for olivines $Mg_{(2-2x)}Fe_{2x}SiO_4$

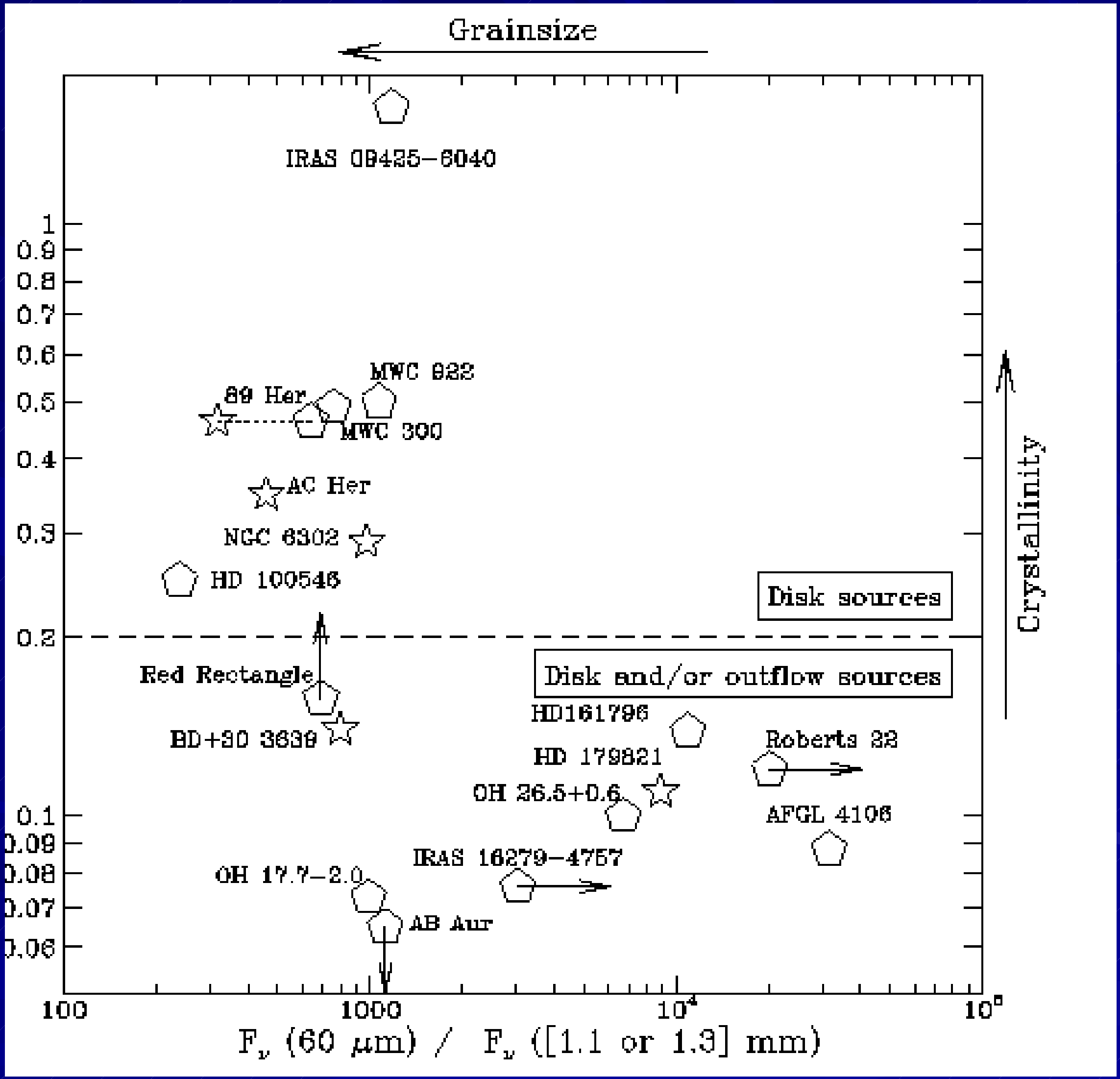
$100 \times (x/\Delta k) = -1.5$ for pyroxenes $Mg_{(1-x)}Fe_xSiO_3$

$\Delta k = kx - k0, \quad 0 < x < 1$

Chemical compositions can be directly measured

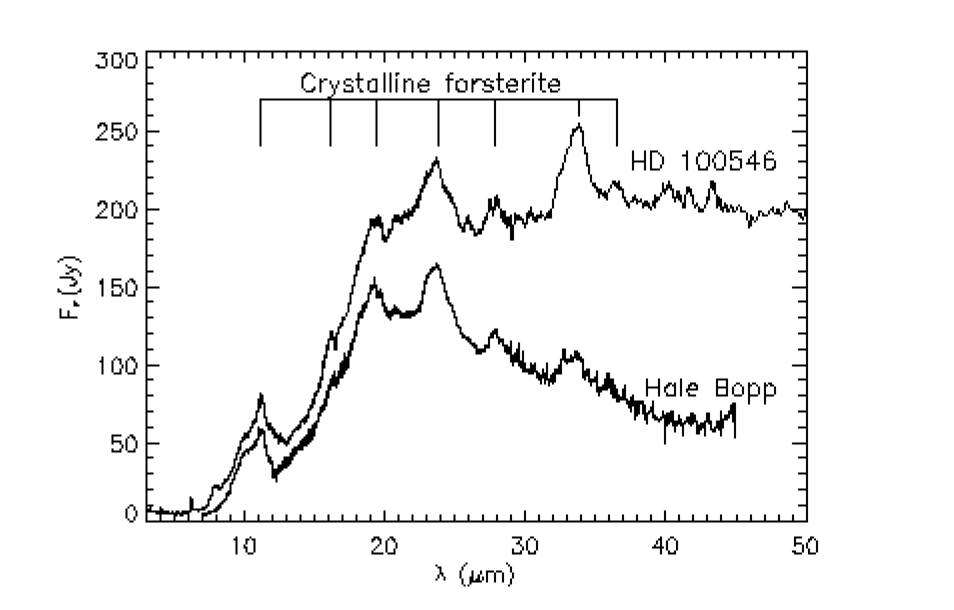
Crystalline Silicates: importance

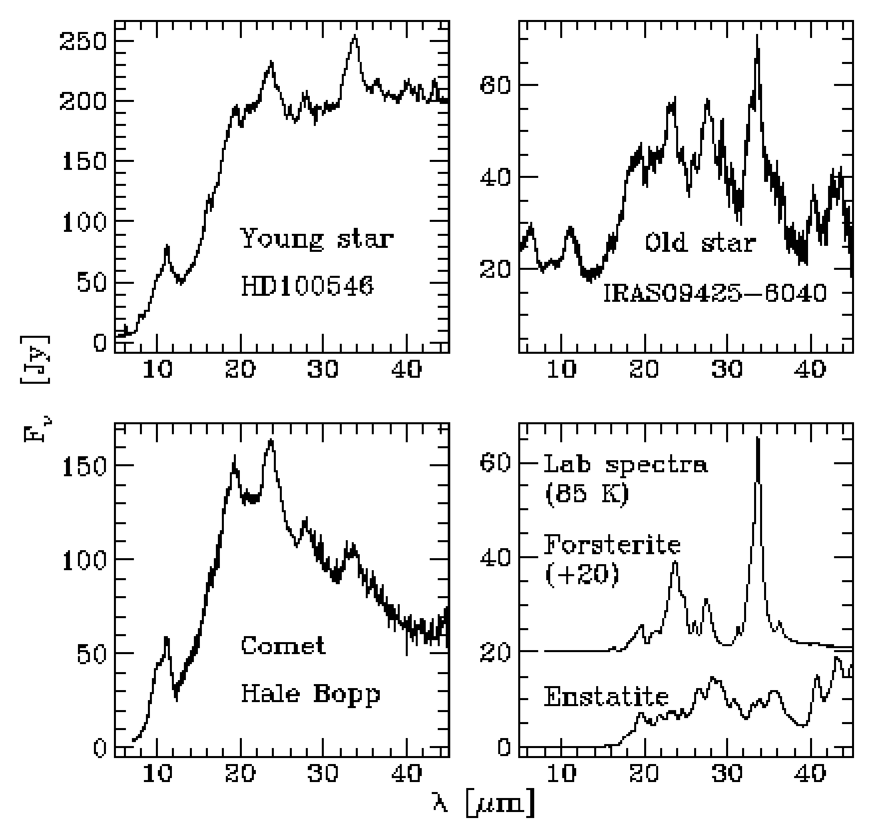
- Geometry of the system
- Grain coagulation
- Disks with more evolved planetary systems



Crystalline Silicates

15% of the silicates ejected to the ISM are crystalline





Seen in many astronomical objects, but absent in the ISM?

Grain Chemistry

	Core	Lobes
Cool silicate	70 %	> 65 %
Alumina	30 %	< 10 %
Crys.enstatite	--	25 %
" mass	--	10^{-6} M
Density function	$1/r^2$	$1/r^{1.5}$
Grain size	0.05 - 0.1μ	do
Mass loss	1.4×10^{-5} M /yr	--

Optical depth at 9.8μ implies a visual extinction of 120 mag; and only 2 mag is interstellar origin

Chemistry of OH 231.8

- Distinct chemistries between core and lobes
- Broad 10μ absorption in the core is attributed to the amorphous alumina (first dust species to condense and nucleation seed for silicate)
- Sharp featues in the lobe is due to the exisitence of (warm) crystelline silicate
- Shocks have played crucial role in crystal formation
- Crystals in lobes but not in the core => Crystal formation is two step process

Dust Mass & Age

Core:

$\alpha = 0.5$, $T_d = 140K$, $F_{18.3} = 65.5$ Jy, D = 1.5 kpc

$M_d = 2.2 \times 10^{-4}$ Age = 300 yrs

Crystalline Silicates:

2.5×10^{-6} M (from shock entrained gas mass); Age 650yrs:

Total:

$\alpha = 0.5$, $T_d = 95K$, $F_{60} = 548.3$ Jy

$M_d = 4.8\ 10^{-3}$ M Age = 1000 yrs

Massive cold dust (unseen in mid-IR) present at larger distance !

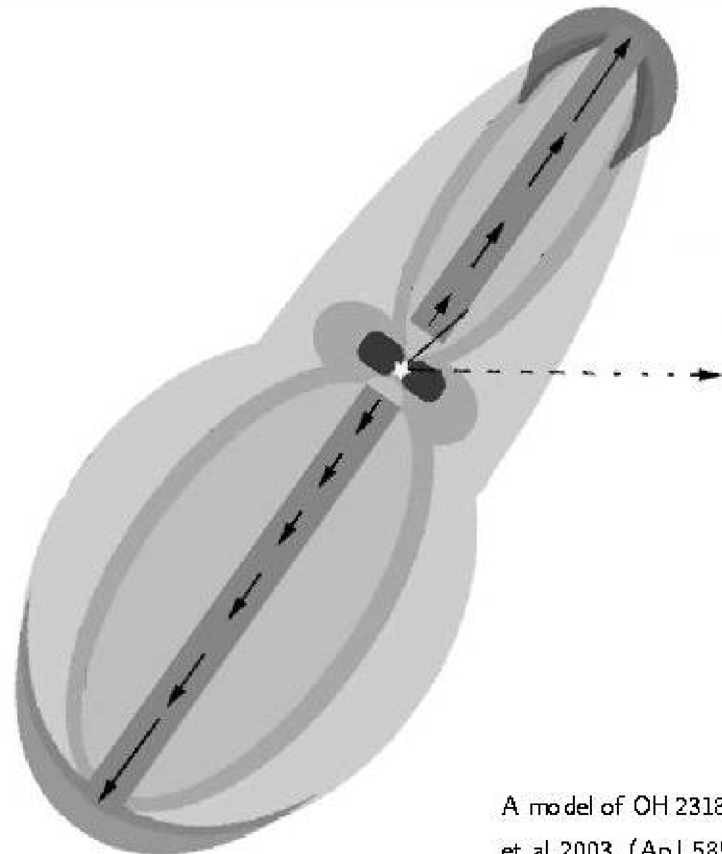
$M_{gas} = 0.72M$; M_{gas} from CO = 0.9M

Evolutionary status of OH 231.8

- Our finding (core is spherical, is due to recent mass loss and is younger than lobes) constrains its long debated nature
- We propose the source entered to ´born again´ AGB evolution triggered by a late thermal pulse (LTP)
- Envelope, disk, outflow formed when the star was on its first AGB stage, nearly 1000 yrs back
- Core was formed < 200 yrs before, where dust formation is still going on (shown by the presence of alumina)

High velocity collimated outflows can manipulate significantly the dust formation process !!

Schematic Model



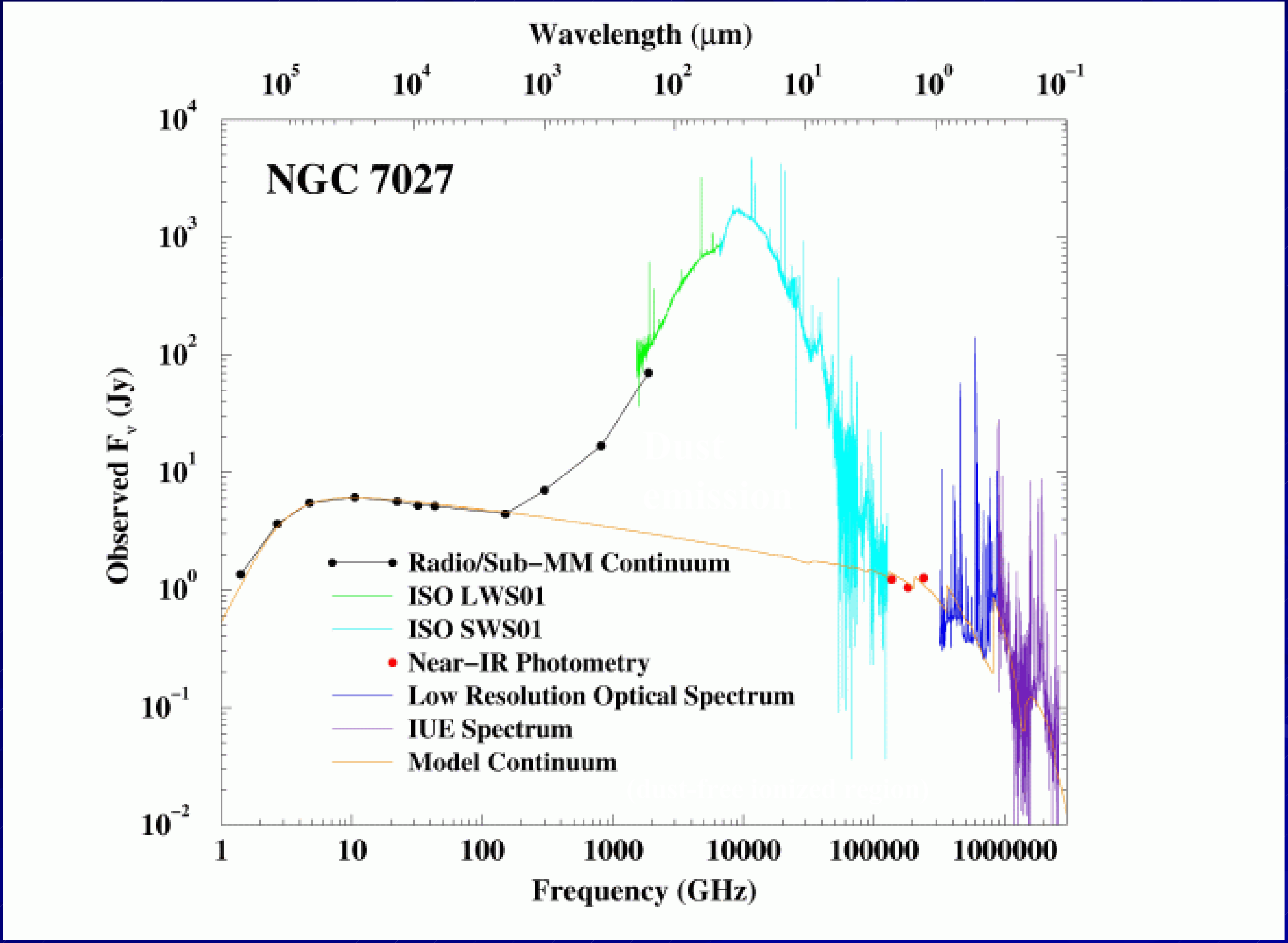
A model of OH 2318+4.2 by Meakin et al 2003. (ApJ 585, 482)

Concluding Remarks

- High spatial resolution observations on the dust shells around evolved stars are now possible with mid-IR telescopes like Gemini

They play a potential role in studying the origin and nature of dust as well as the physical properties of the sources

An example from recent observations



Cosmic Dust : Origin

- Evolved Stars condense copious amounts of dust in their cool circumstellar shells (Larimer 1979)
- Different grains were produced according to the details of the stellar outflows
- Grains are carbon based or oxygen based
- Processed grains are ejected to ISM where they can evolve further

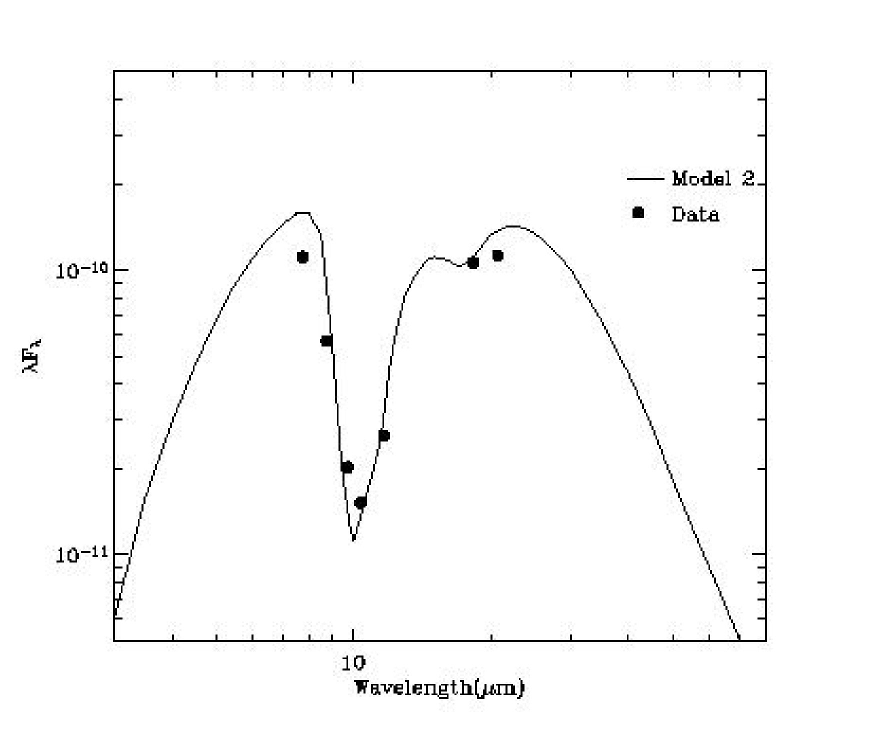
AGB stars eject 5 M of dust to ISM in every 1000yrs!

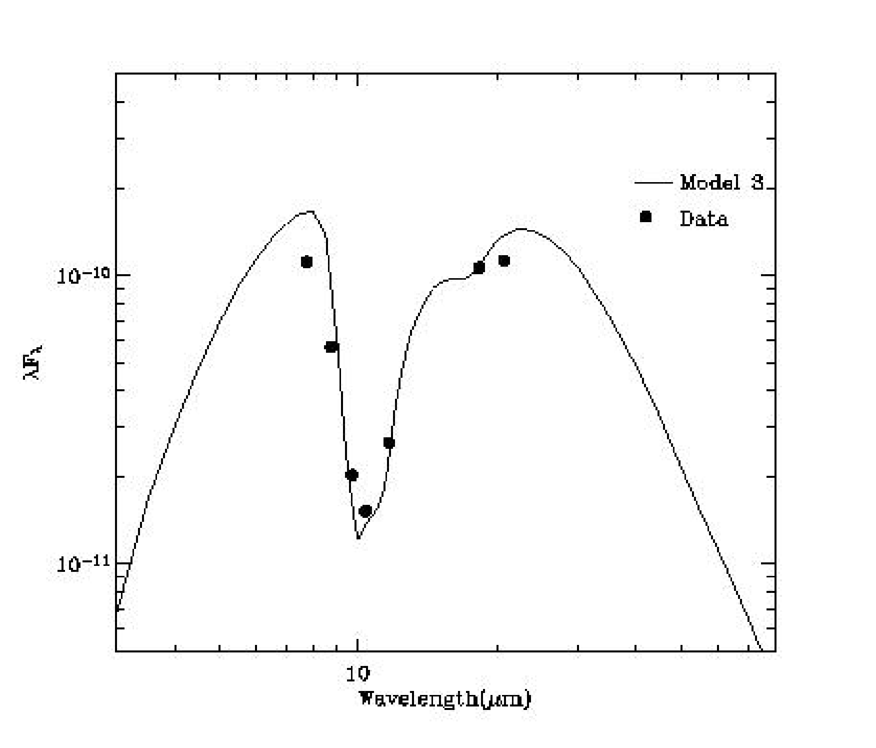
The Nature of Dust

- High and low temperature minerals
- Organic compounds
- Grains can have core mantle structure
- They can be either amorphous or crystals
- Dust may have different geometry and a variety of sizes (upto several mm)

Some exmples: silicates, graphites, SiC, PAH, water ice, alumina, olivine, pyroxene, metal Fe, diamonds

Other models for the core:





$\rho(r) = 1/r^2$

MRN size distribution

$\rho(r) = 1/r^2$ (r< 0.5 arcsec)
$\rho(r) = 1/r$ (r > 0.5 arcsec)

Dust composition: cool silicate and amorphous alumina, $tau_{9.8} = 8.0$