The “hidden phase”of the AGB to PN evolution as seen by AKARI and Spitzer

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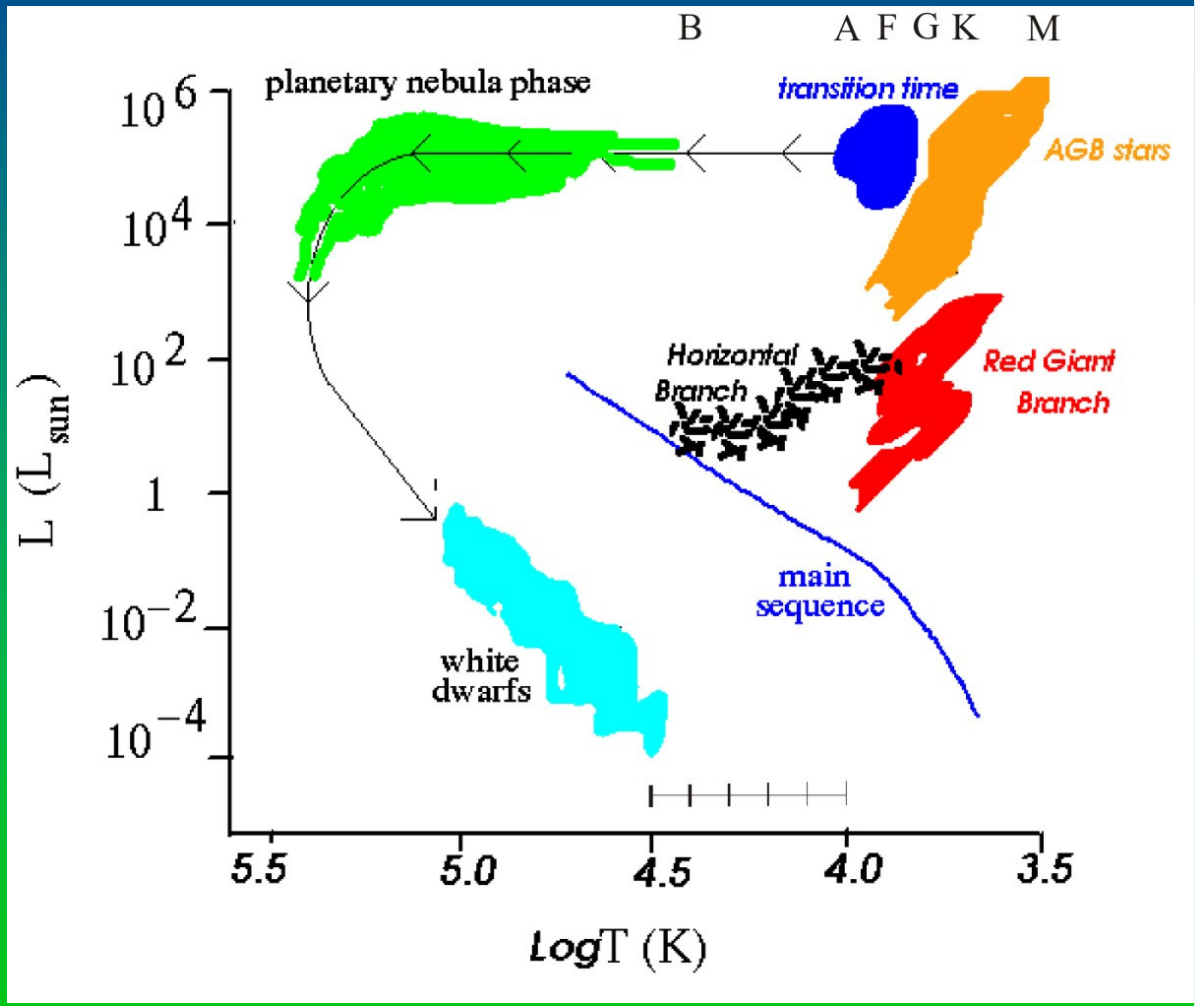
Stellar evolution: AGB stars

Asymptotic Giant Branch: late stage of evolution of low- to intermediate-mass stars ($1 \leq M \leq 8\ M_{\odot}$)

TP phase: strong mass loss enriches the ISM with radionuclides and circumstellar dust grains!



AGB stellar nucleosynthesis

- **Thermal Pulsing phase** $\Rightarrow$ ^{12}C production, s-element production (Rb, Zr, Sr, Nd, Ba, Tc, etc.)

- Low-mass ($M < 4\ M_{\odot}$) AGBs turn C-rich & s-process rich
- High-mass ($M > 4\ M_{\odot}$) AGBs remain O-rich (HBB & ^{22}Ne)

- High-mass AGBs produce $\neq$ elements (e.g. ^{87}Rb, ^{96}Zr, ^{13}C, ^{14}N, ^{17}O, $^{25,26}Mg$, etc.) than lower-mass AGBs (^{13}C) & SNe

The more massive C-rich & O-rich AGBs departure from the AGB phase when they are completely obscured!

Project Summary

- **Scientific Goal:** Characterization of the IR properties of the Galactic Population of heavily obscured transition sources (AGB–PN). Detailed study of the total obscuration phase (chemical & morphological changes)

- **The sample:** a complete flux-limited sample of ~80 hidden post-AGB candidates selected from the GLMP catalog (García-Lario 1992) according to their IRAS colors:
  - No OPC; many obscured also at NIR wavelengths
  - ~40 non-variable OH/IR + ~40 of unknown chemistry
  - Plus a few young PNe & variable TP-AGB stars

AKARI and Spitzer observations

- **The Spitzer observations:** 5–37 μm IRS spectra (SL+SH+LH when possible). S/N > 50 (two 6 s cycles) for all sources (88). Data reduction was done using the Spitzer tools SPICE and SMART

- **The AKARI observations:** 2–13 μm (NP, SG1, SG2) and 18–25 μm (LG2) IRC spectra for 13 sources. Short exposures were used in the data reduction, which was done by using the IRC Spectroscopy Toolkit Version 20080528

Project Status

- **88 spectra (~40 non-variable OH/IRs + ~40 unknown chemistry + a few PNe & variable AGBs) reduced and qualitatively analysed**
- **Here we present the first results and a qualitative analysis of these spectra (e.g. dominant chemistry, dust composition, identification of new young PNe and peculiar sources)**
- **The sources (13) also observed by AKARI, have been modelled using DUSTY (Ivezic et al. 99)**

Dominant chemistry

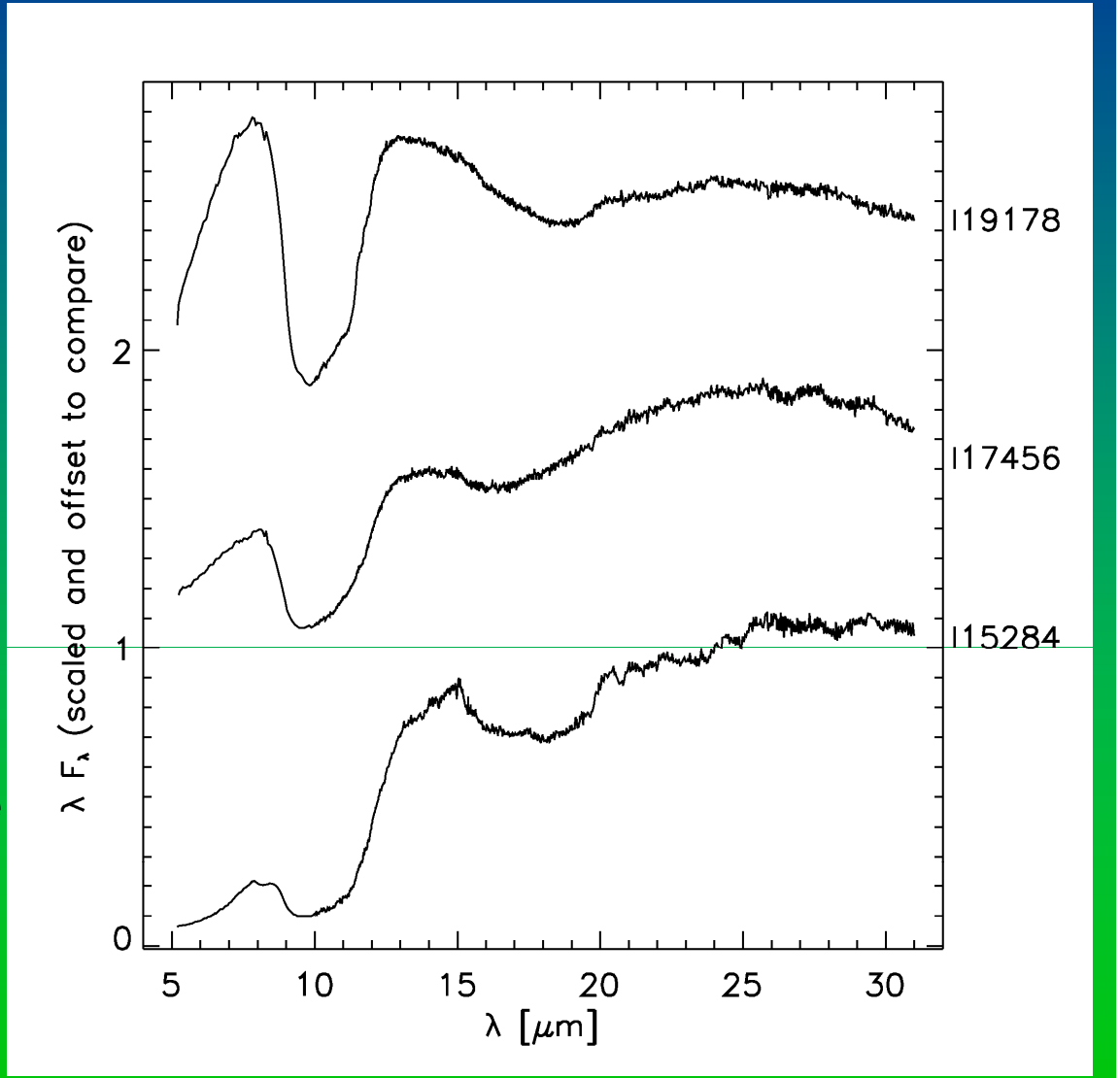
- The variety of the spectra found is amazing:

- Non-variable OH/IRs show strong O-rich solid state features as expected & a few are featureless
- Among the pAGBs with unknown chemistry we find O-rich, C-rich & featureless (20 C-rich!)
- We find some stars showing very clearly the moment of transition from amorphous (aliphatic) to crystalline (aromatic) dust features (in both chemical branches)
- We identify 1 new young PNe which is a possible double-dust chemistry (C-rich & O-rich) PN

O-rich PN precursors

Different strengths of the amorphous silicate absorption features at 9.7 and 18 μm

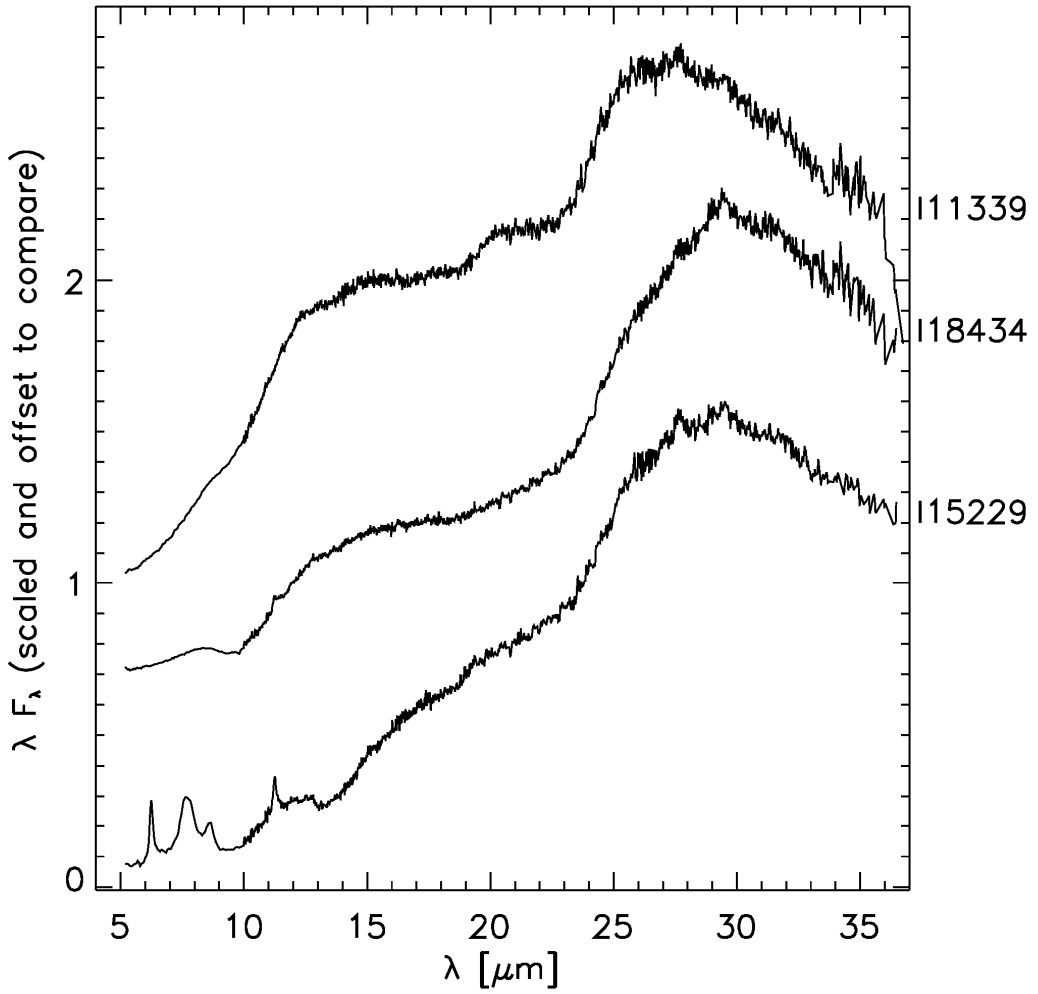
The crystalline silicates features at λ>15–20 μm are seen emerging from the underlying continuum while the amorphous silicate absorptions decrease in strength



C-rich PN precursors

Bumps at 11–15 & 15–20 μm, and sometimes strong and broad features centred at 21, 26 and 30 μm and the 'classical' set of PAH features (6.2, 7.7, 8.6 and 11.3 μm)

The 11–15 & 15–20 μm bumps dissapear while the PAH features emerge at shorter wavelengths

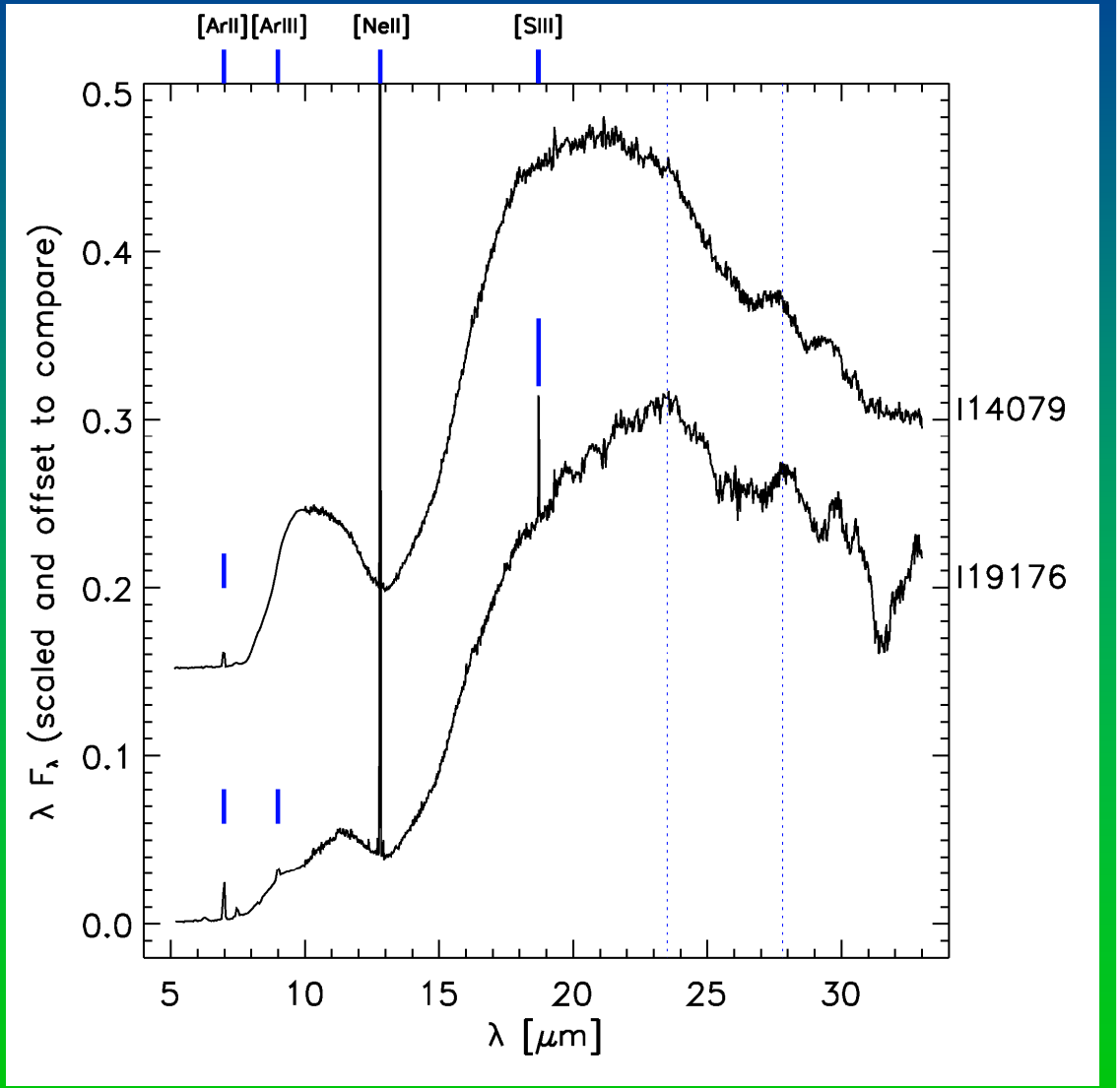


Young IR PNe

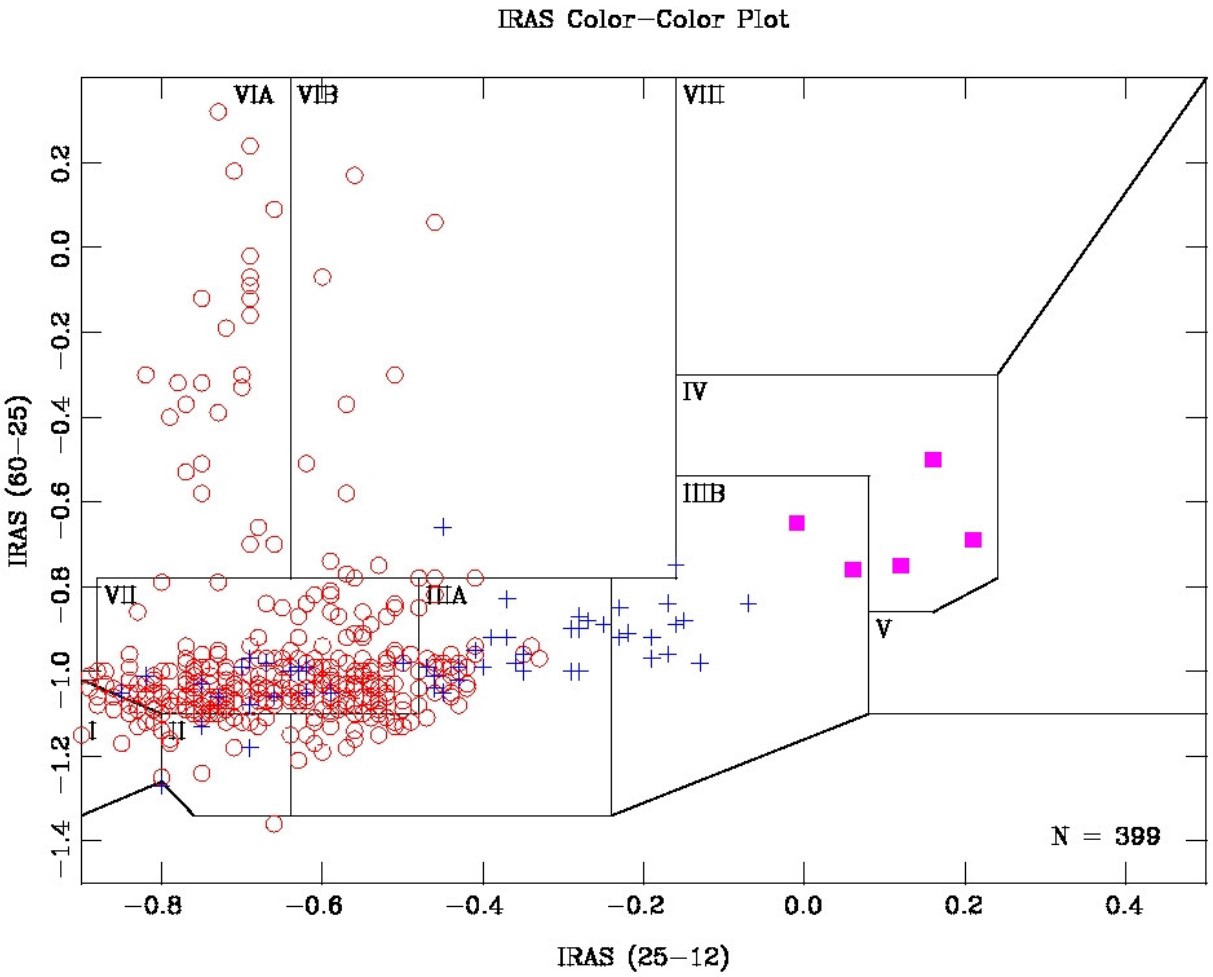
2 young IR PNe as indicated by the detection of nebular emission lines (e.g. [Ar II], [Ar III], [Ne II], [S III])

- I14079 is a poorly known young and dusty PN. It is O-rich showing amorphous and crystalline silicates

- I19176 is a new PN (possible double-chemistry) displaying crystalline silicates & 6.3 μm emission



Extremely red C-rich stars

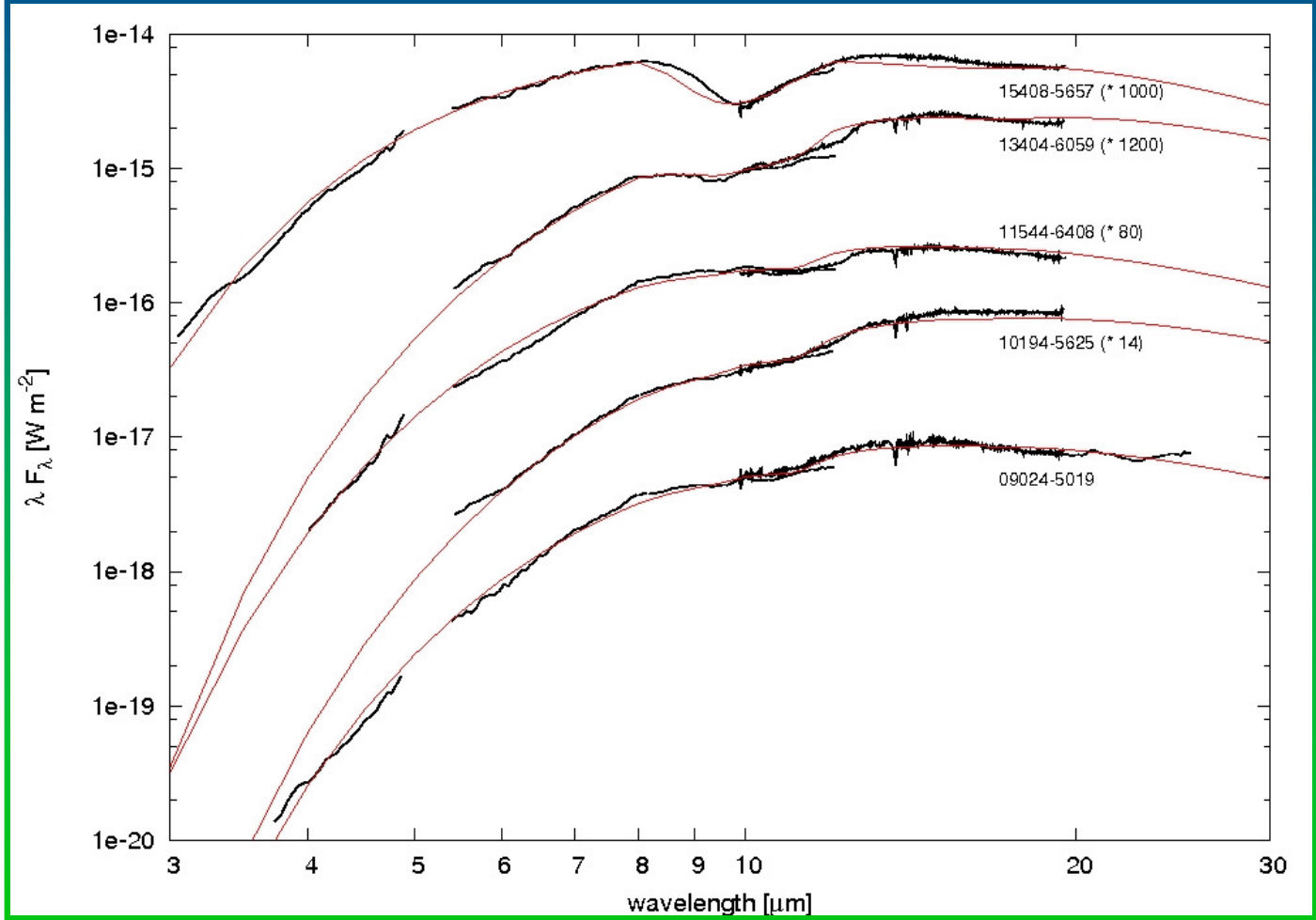


IRAS two-colour diagram:powerful tool to search for pAGB candidates

We find the reddest AGB/pAGB stars observed so far!

IRAS(25-12)≥0.0

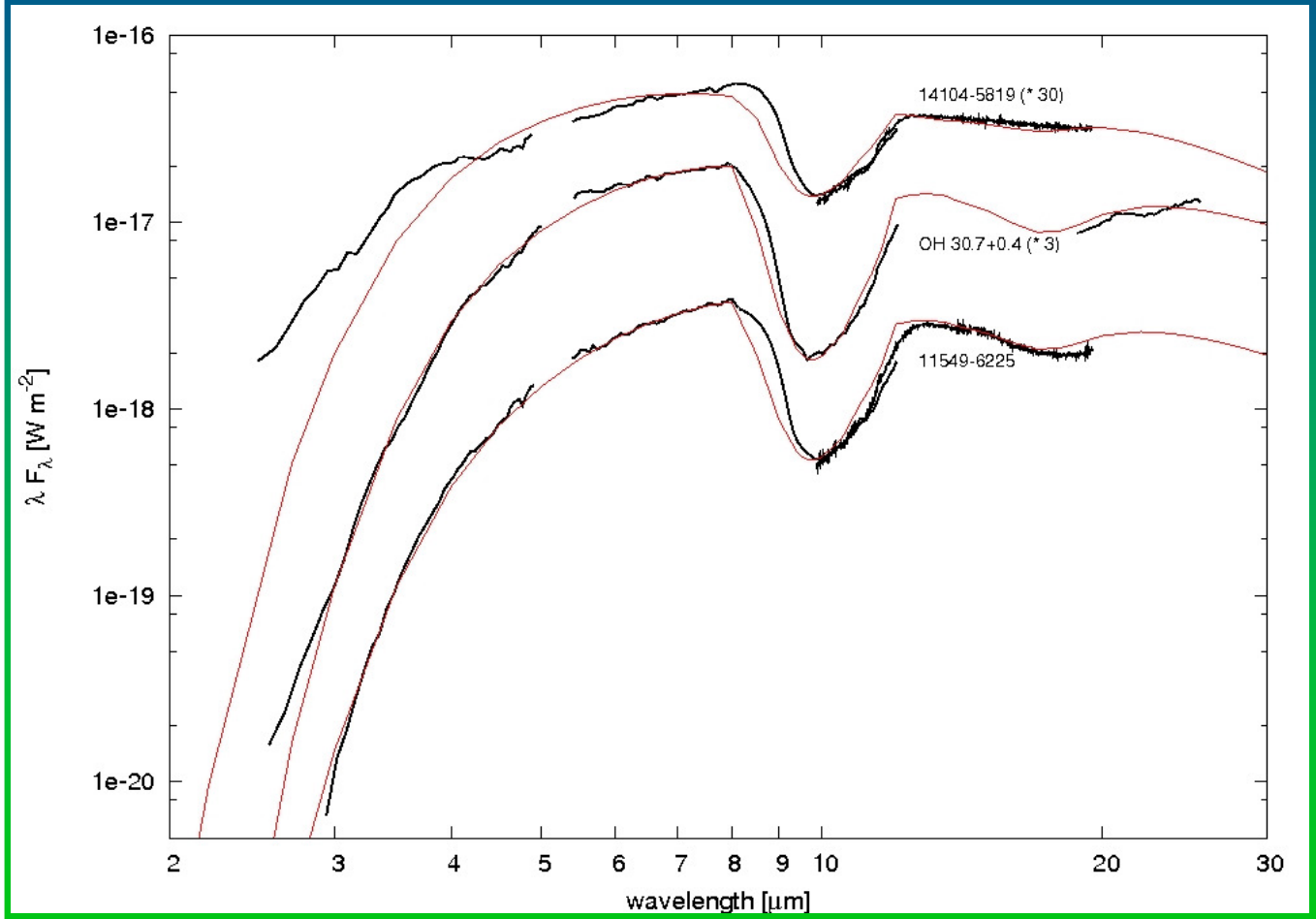
C-rich SEDs: DUSTY modelling



Extremely red AGB/pAGB stars are well modelled with amorphous carbon dust

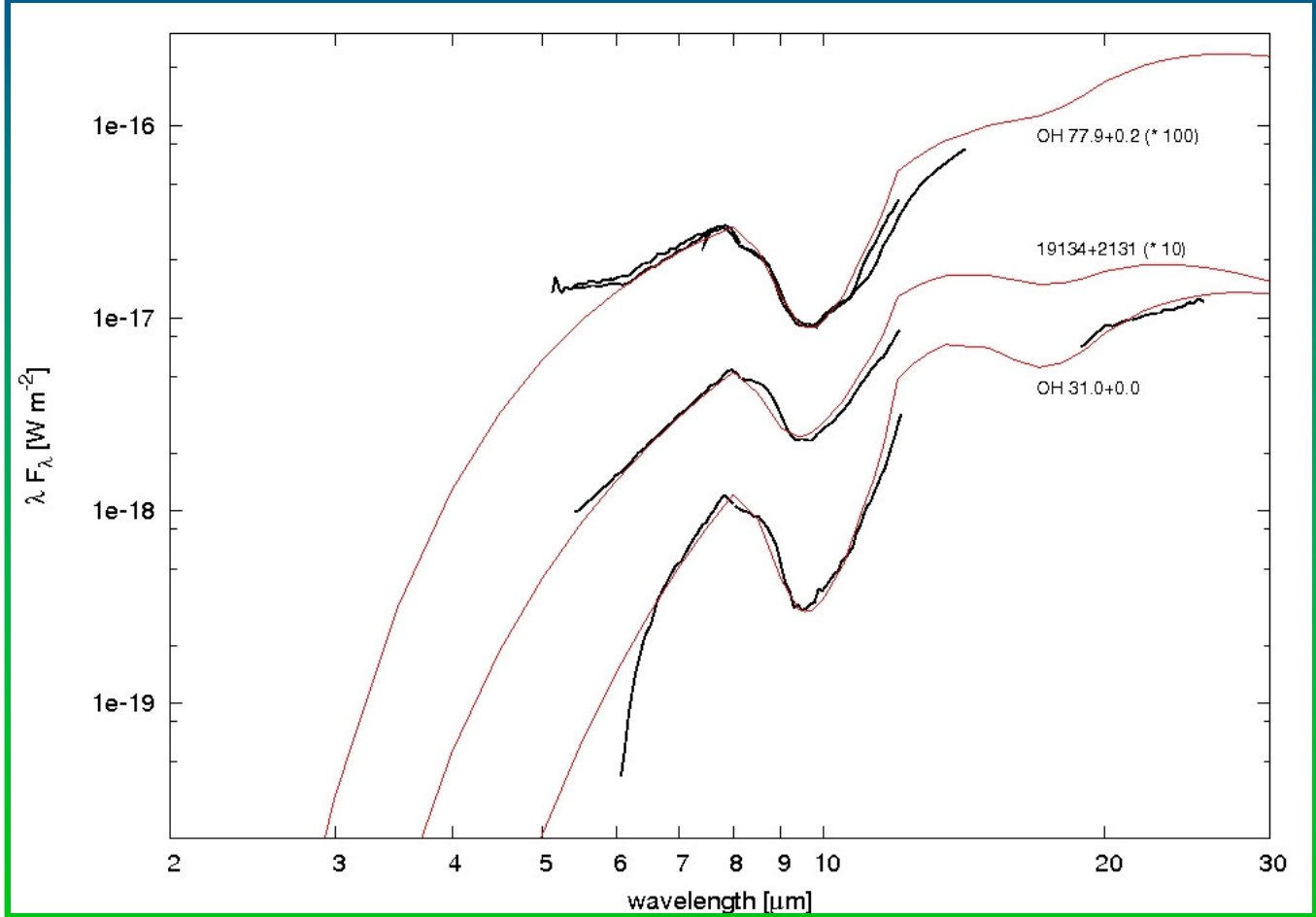
Their C-rich nature is confirmed by the detection of C_2H_2 molecular absorptions at 13.7 μm

O-rich SEDs: AGB stars



AGB stars are reasonably well modelled with silicate dust (O-rich)

O-rich SEDs: post-AGB stars

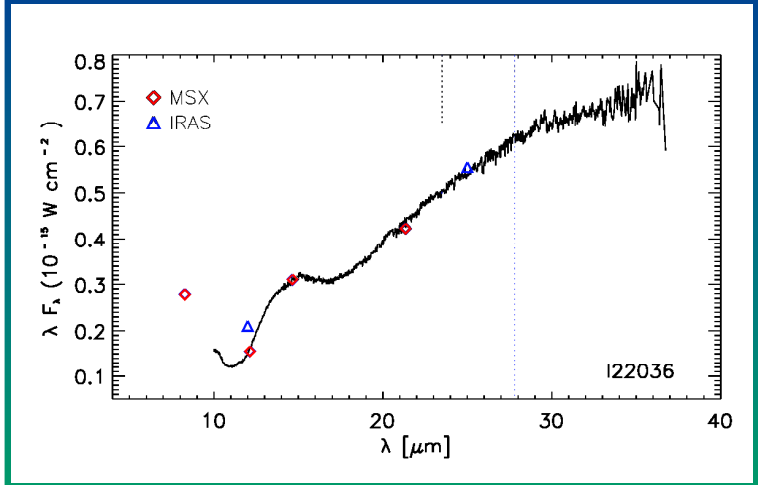


Preliminary SED fits of pAGBs require double shell dusty models (C-rich inner shell + mixed chemistry outer shell)

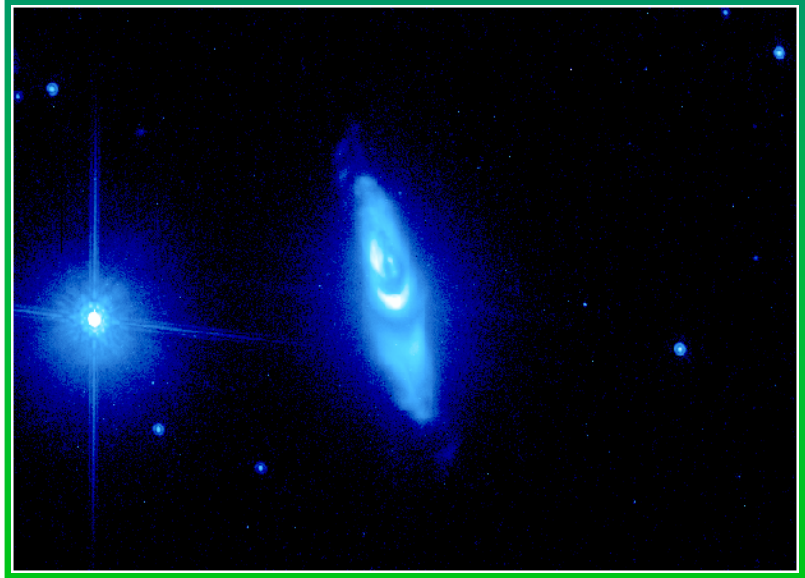
This is unexpected!

Possible reasons:
- ≠ grain properties and T_{dust}
- ≠ geometries (bipolar sources)

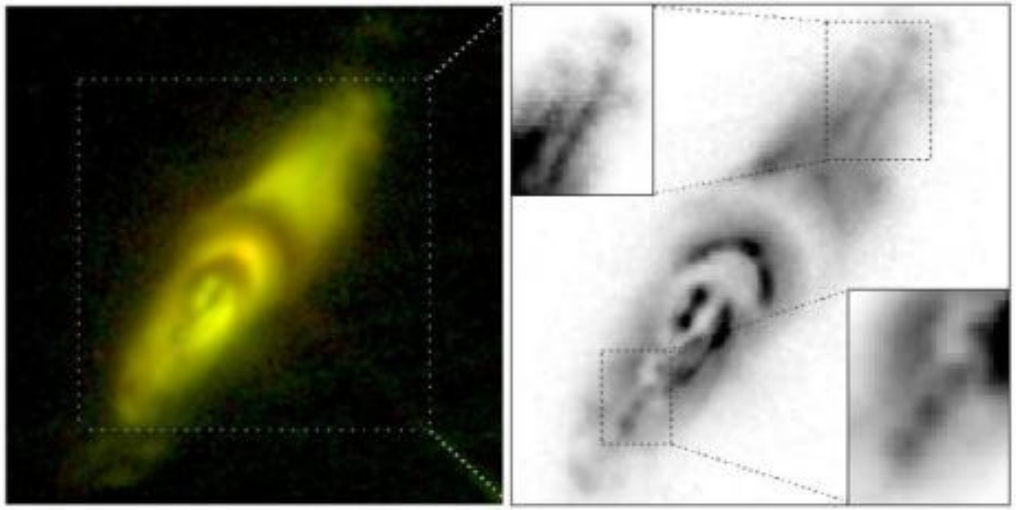
IRAS 22036+5306



Spitzer shows an O-rich chemistry, being consistent with previous ISO observations. HST images show a spectacular bipolar morphology (knotty & jetlike structures & a central disk). This suggest that I22036 may be a massive (>4–5 $M_{\odot}$) HBB PN precursor.



HST/ACS F814W (HST Data Archive)

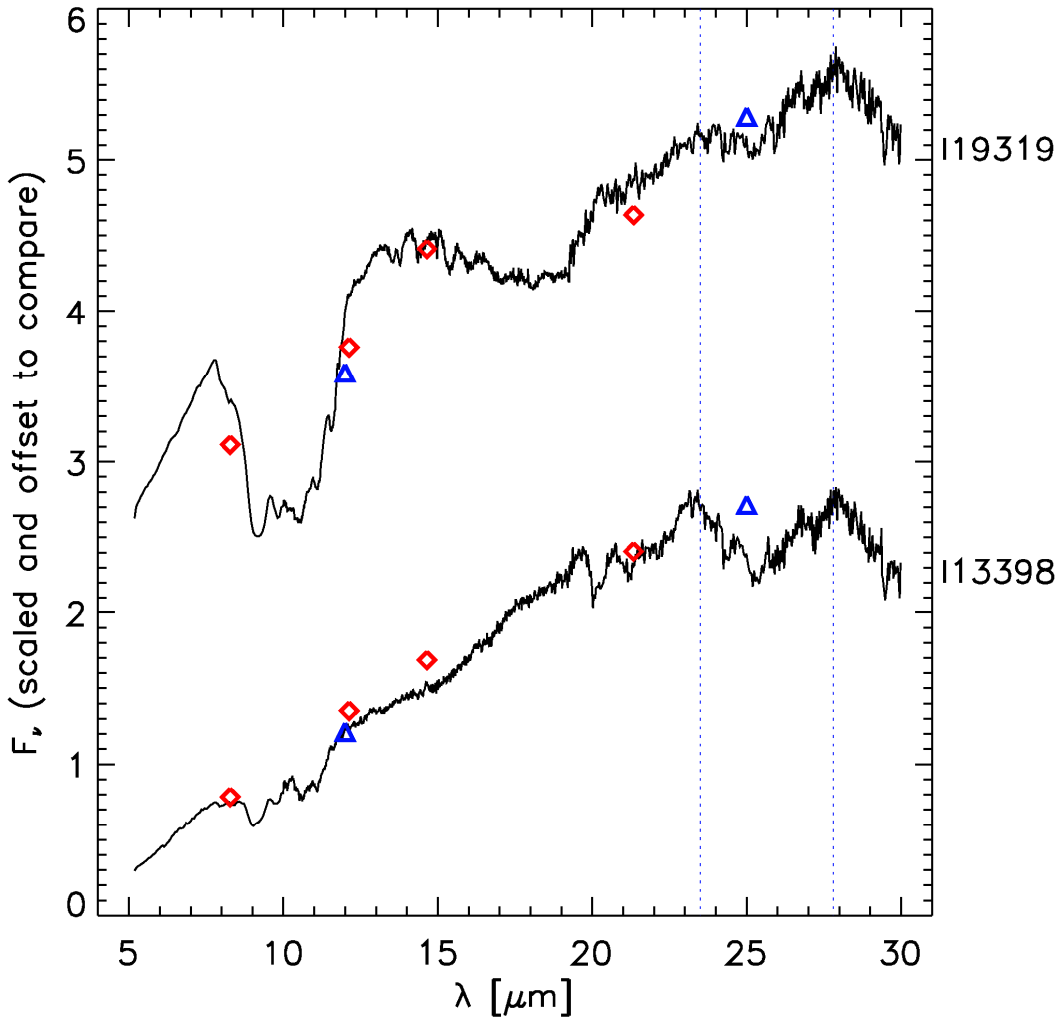


Sahai et al. 2003

O-rich transition sources

5 O-rich PN precursors where the transition from amorphous to crystalline dust structure is taking place

The crystalline silicate features are detected in emission inside the amorphous silicate absorptions at 9.7 & 18 μm

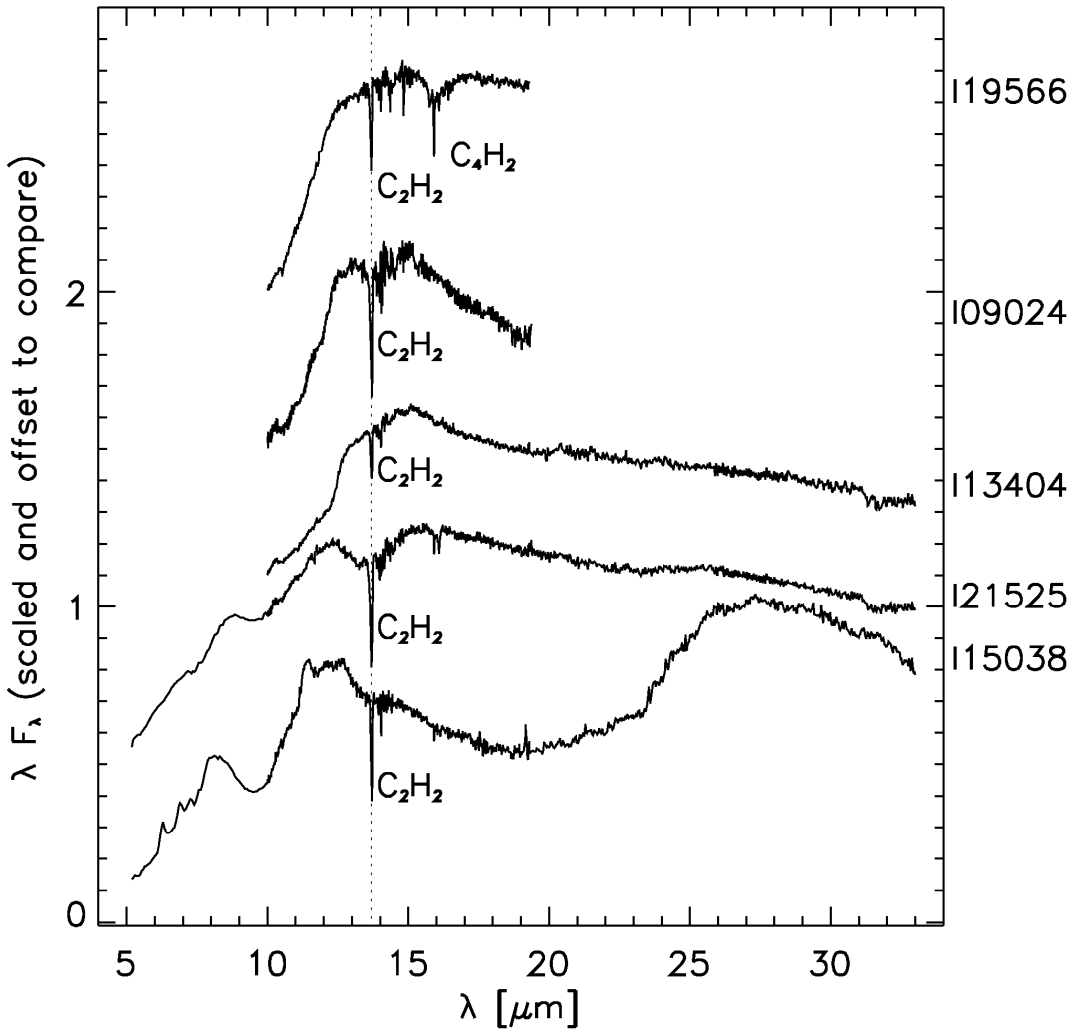


C-rich transition sources

10 sources displaying C_2H_2 at 13.7 μm and other molecular absorptions

I21525 and I15038 show a broad C-based feature (SiC?) at 11.3 μm but I15038 also displays C_2H_2, PAHs & the 26 and 30 μm features! Previously observed in some Galactic & MC pAGBs (e.g. MSX SMC 029; Kraemer et al. 2006)

Other C-rich molecular absorptions detected in the region 12–16.5 μm



Summary

- Spitzer/IRS & AKARI/IRC spectra of heavily obscured PN precursors have been qualitatively analysed
- Most of the non-variable OH/IRs are O-rich but both C-rich & O-rich sources are found among the pAGBs with unknown chemistry. Reddest C-rich pAGBs
- The IR spectra display a variety of dust compositions (amorphous and crystalline structures in both C-rich & O-rich environments)
- We identify for the first time O-rich PN precursors where the transition from amorphous to crystalline dust structure is taking place including the first clear detection of C_6H_6 in Galactic post-AGB stars

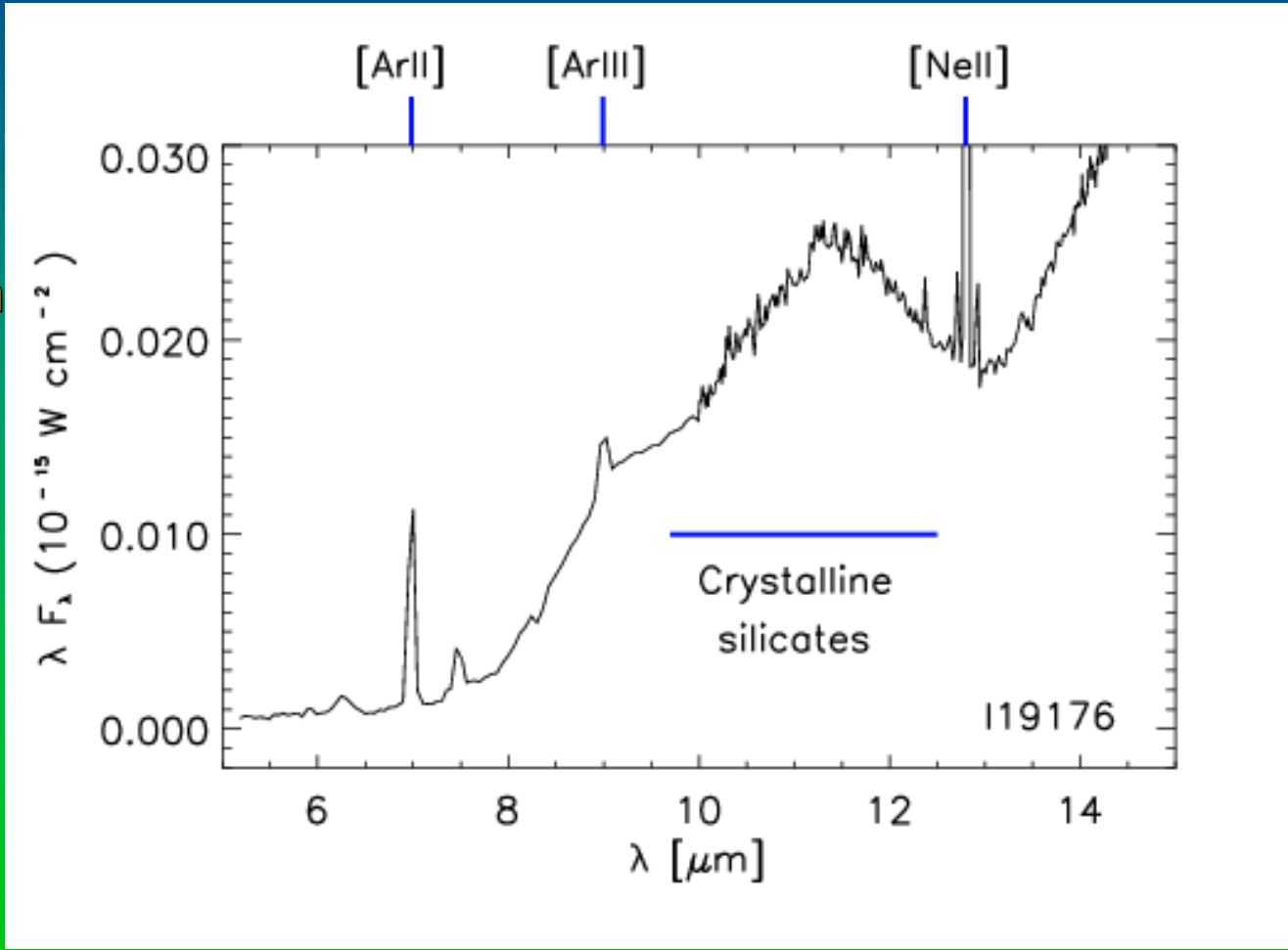
Work in progress

- **Dusty modelling of the rest of sources**
- **Classification of spectra into an evolutionary sequence for both chemical branches**
- **Detailed study of the transition sources (both C-rich and O-rich)**
- **The obtention of additional AKARI/IRC near-IR spectra (warm phase) to get some information of the inner shell in some pAGBs**

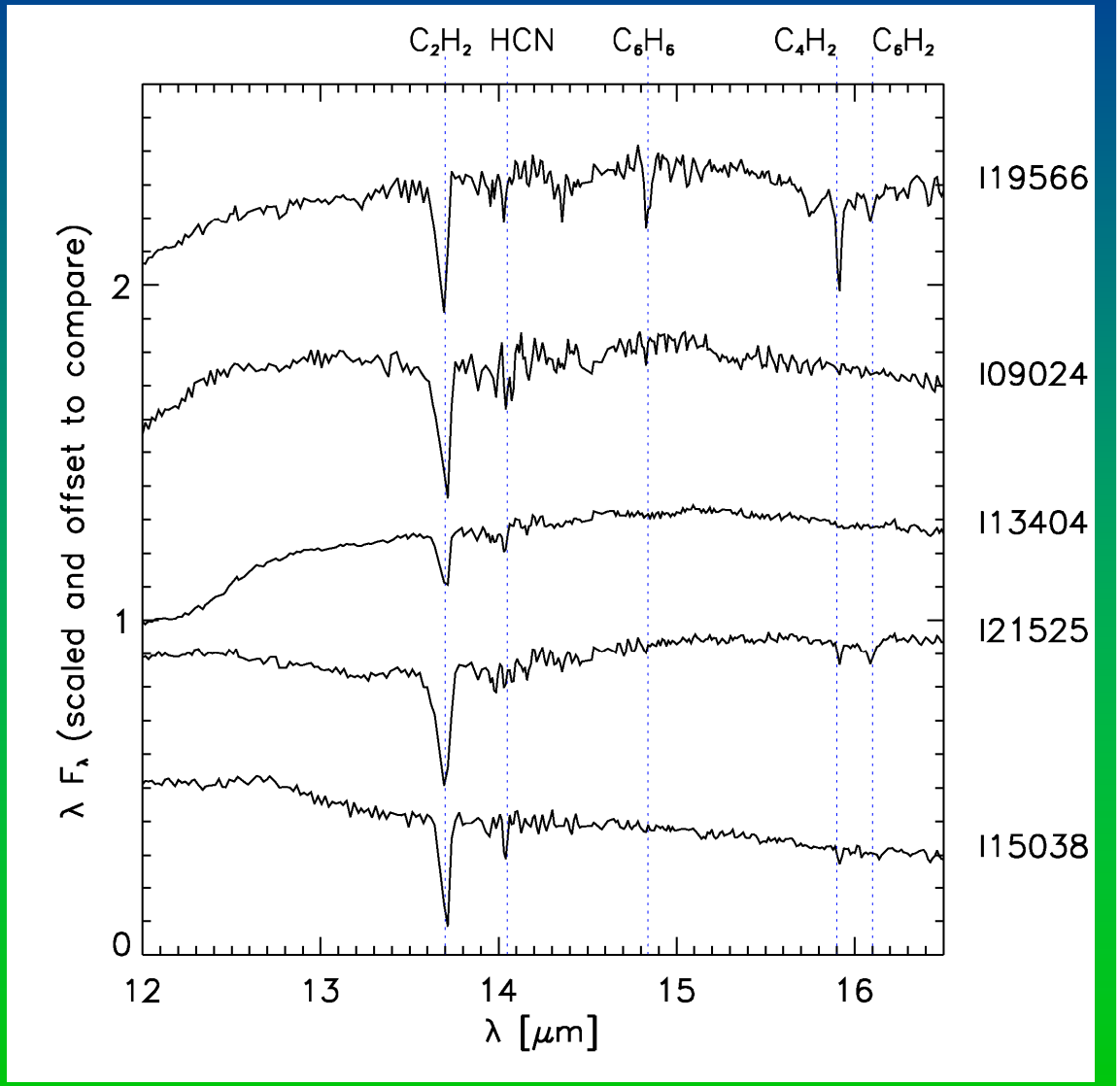
Many thanks to ESAC Faculty and Pedro García-Lario for doing this visit possible!

I19176: a double-chemistry PN?

Crystalline silicates in the 9–13 μm spectral range together with a 6.3 μm feature. A 6.4 μm feature has been attributed to C-C stretch transitions in extremely H-deficient carbonaceous grains (e.g. Abell 78; Harrington et al. 1998)



Molecular Absorptions

Molecular absorption of C_2H_2, HCN, C_4H_2, & C_6H_2: the building blocks of PAHs!

Benzene (C_6H_6) is clearly detected in I19566 (only two other detections reported by Cernicharo et al. 2001 in CRL 618 – tentative – and Bernard–Salas et al. 2006 in SMP LMC 11)