

Some Types of Carbon-Rich Star

Type	C(N, late R)	C(J, early R)
Incidence	85%	15%
Chemistry	C/O > 1; CN, C ₂ . <i>s</i> -pr. enhanced, often Tc.	C/O > 1; CN, C ₂ , ¹³ C isotopic species; not <i>s</i> -pr. enhanced, often Li-rich
L/L_{\odot}	6×10^3 to 7×10^4	$< 10^3$ (some higher)
CSE	CO, dust	CO, dust
$\dot{M}(M_{\odot} \text{ yr}^{-1})$	10^{-7} to 10^{-5}	$\sim 10^{-7}$
Evol. state	AGB	pre-AGB?

Barnbaum 2000, in *Allen's Astrophysical Quantities*, 4th ed., A. N. Cox ed., p. 415

The Problem with J Stars¹

AGB models give C-rich, ¹³C-rich, Li-rich envelopes

- He-shell flashes and third dredge-up episodes
- Hot bottom burning at base of convective envelope: CNO cycle & ${}^7\text{Be} + e^- \rightarrow {}^7\text{Li} + \nu_e + \gamma$
- High masses, $> 4M_{\odot}$

But:

- Evidence points to $M \lesssim 3M_{\odot}$ for J stars
- HBB converts C to ¹⁴N, ends C star phase
- There should be *s*-process enhancement:
 ${}^{13}\text{C}(\alpha, n){}^{16}\text{O}$

¹Abia & Isern 2000, *Ap. J.*, **536**, 438

Hydrocarbons in Interstellar Dust

Outline

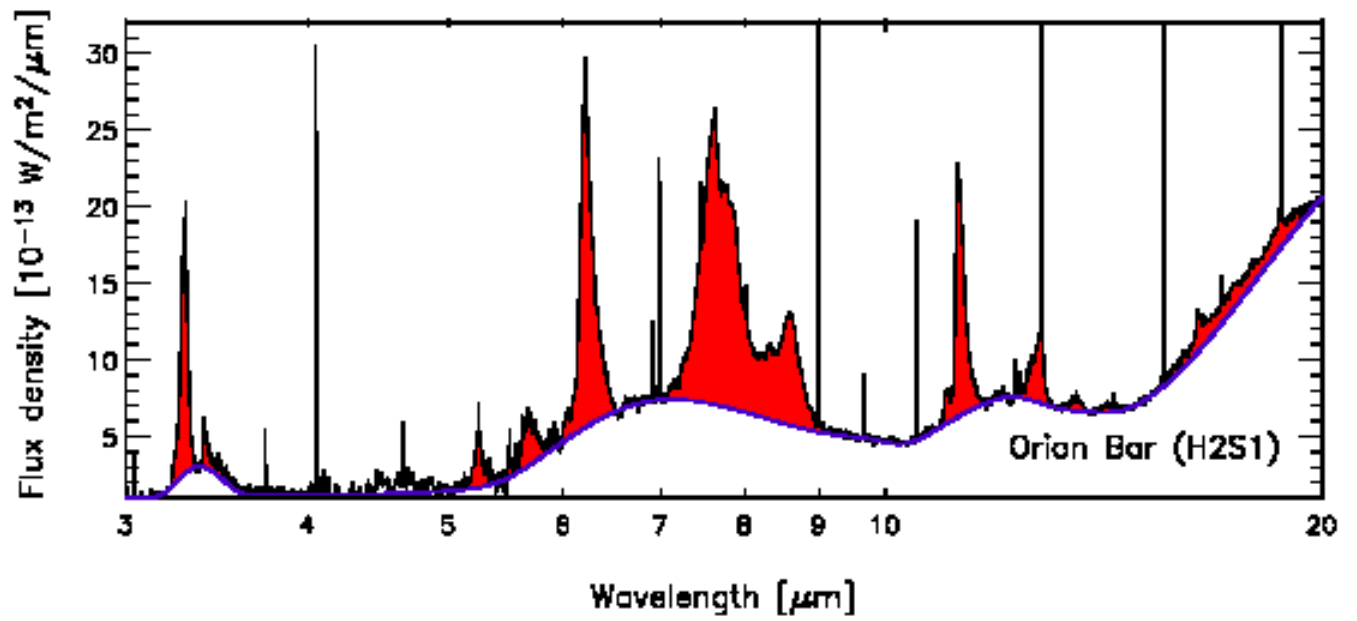
- Observables in the diffuse ISM
 - The absorption spectrum
 - The emission spectrum (Unidentified Infrared Bands)
- Organic chemistry & spectroscopy basics
- Constraints on the composition of the diffuse ISM
- The Unidentified Infrared Bands in various environments near stars

Observables in the diffuse ISM

Absorption in long sight lines (Pendleton & Allamandola 2002)

- Cyg OB2 No. 12 (B5 Ia⁺, $r = 1.7 \pm 0.2$ kpc, $A_V = 10.2$)
- Galactic Center IRS 6E. Even the strongest feature, $3.4\mu\text{m}$, is weak; max. optical depth is 0.2.
- Weakness of other features is significant

Unidentified Infrared Bands (Peeters et al. 2004)



In the diffuse ISM (Onaka 2004)

Organic chemistry & spectroscopy basics

In large molecules, chemical subgroups produce characteristic vibrational spectra, independent of the rest of the molecule. [Large molecules vs. small](#)

Types of vibration, each with its own frequency

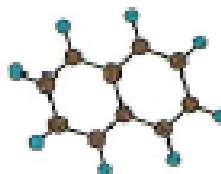
- Stretch
- In-plane bend
- Out-of-plane bend

Some important subgroups

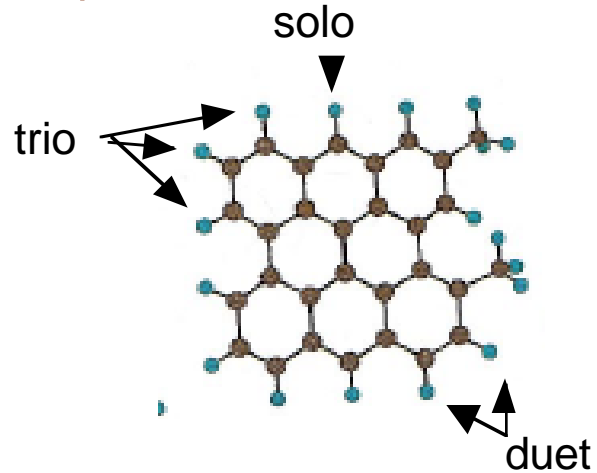
- Aliphatic groups: CH_3 , CH_2 (form chains)
e.g., pentane, $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$
- Aromatic groups (based on benzene rings), e.g.:

● Carbon

● Hydrogen



- Classify aromatic rings according to number of adjacent CH groups



Example mode identifications (Pendleton & Allamandola 2002)

Bending mode identifications (out of plane)
(Hony et al. 2001)

How the composition of the hydrocarbon molecules is constrained

Band strength ratios give relative numbers of different types of group or bond

- Measured band positions and strengths for various hydrocarbons
- Construct synthetic spectra for various mixtures
- Compare with observed spectrum

Another method: acquire spectra of various materials in the lab, accept those that match as candidate materials

Pendleton & Allamandola 2002

- Plasma processed carbon-rich materials work
- *E. coli* (doesn't work)
- Murchison meteorite hydrocarbon extract (works at $3.4\mu\text{m}$, but other parts of the spectrum don't match)
- Other materials that failed have spectral features due to O, N components that are not present in the diffuse ISM

Conclusions

- Little O or N is present
- Ratio of CH stretch ($3.4\mu\text{m}$) to deformation bands at 6.85 and $7.35\mu\text{m}$ is consistent with maximum alkane chain lengths of about 4 mixed with aromatic groups
- The most successful laboratory analogs have clear aliphatic character and a comparably strong aromatic component.
- A molecule that is consistent with all observations

Likely structure of interstellar grains (Bakes, Bauschlicher, and Tielens 2004)

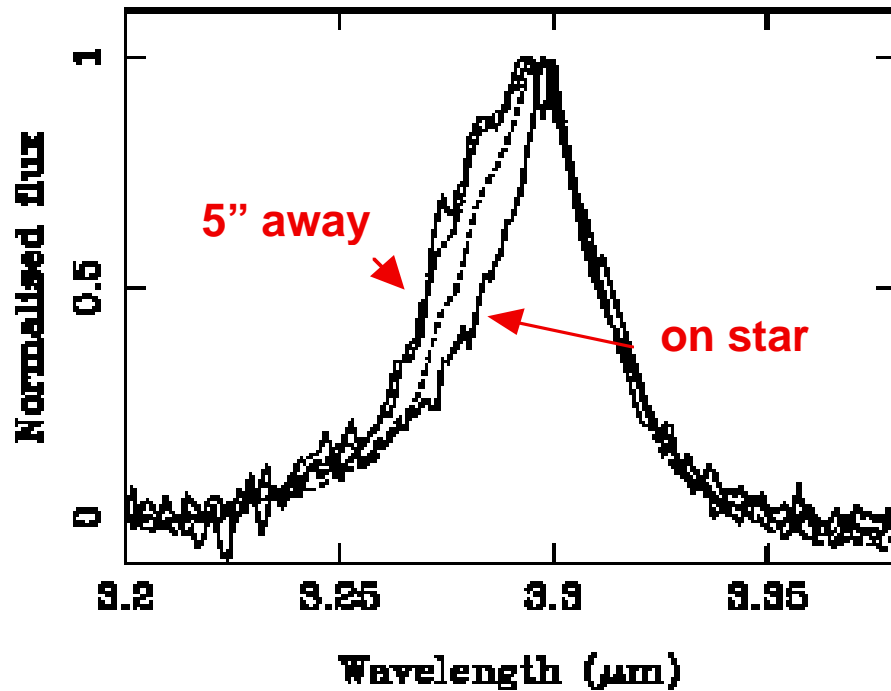
The Unidentified Infrared Bands (Peeters et al. 2004)

Generally recognized due to PAHs

Variations in spectrum from source to source

- Class A is like the diffuse ISM
- The CC modes vary in wavelength and correlate with each other more than the CH modes

Variations within individual sources: systematic change in **Red Rectangle** spectrum with distance from star; approaches diffuse ISM profile



Radiation produced in cold environments: mechanism

- Grain absorbs single UV photon from star
- May eject an electron (10% probability)
- Or photon energy redistributed among many vibrational degrees of freedom, excites vibrational states
- Fluorescence when states decay

Implies

- Molecules are small, perhaps 50 to 100 C atoms
- Properties should depend on local radiation energy density

But many sources with different radiation fields have similar profiles

- Grain heating independent of radiation field
- Hotter stars have larger particles; same amount of energy per bond
- Particle size controlled by photodissociation; smallest stable size increases with stellar temperature

Conclusion: the UIR bands are a probe of physical conditions in interstellar and circumstellar space.

Ground truth: Titan (Bakes and Tielens 2004)

Lack of $3.4\mu\text{m}$ feature suggests ionized PAHs in haze in outer atmosphere

Importance of PAHs

- Diagnostic of interstellar conditions
- Among the cosmically most abundant molecules after H_2 and CO
- PAHs with 15 to 500 carbon atoms contain 1 to 10% of all the carbon in the Galaxy.
- Significant in heating & cooling the ISM
- Significant in interstellar chemistry, e.g., catalytic formation of H_2

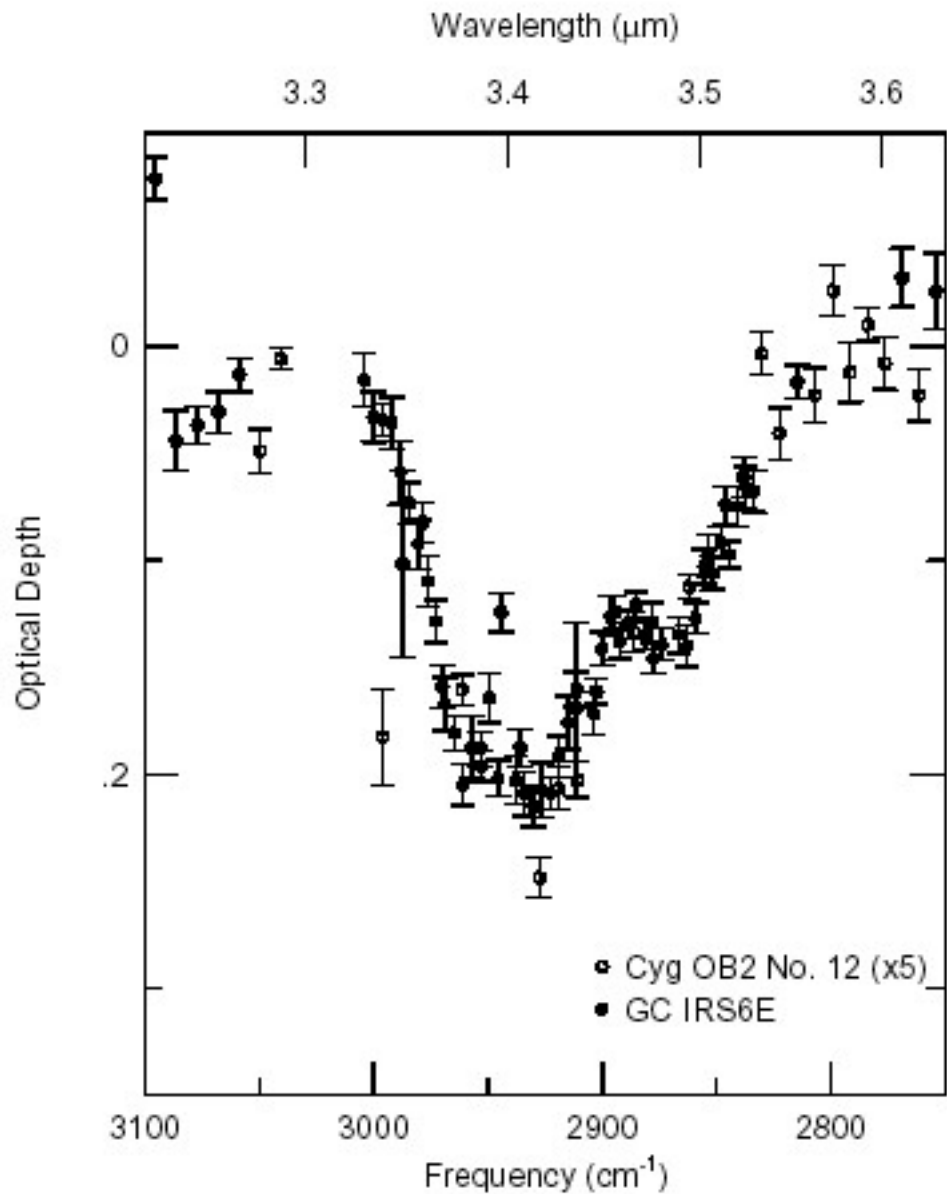
References

From [Astrophysics of Dust](#), ASP Conference Series, Vol. 309, 2004, Adolf N. Witt, Geoffrey C. Clayton, & Bruce T. Draine, eds. —

- E. L. O. Bakes, C. Bauschlicher, and A. Tielens, “Models of the Unidentified Infrared Emission Features”
- T. Onaka, “Unidentified Infrared Bands in the Diffuse Interstellar Medium”
- E. Peeters, L. J. Allamandola, D. M. Hudgins, S. Hony, and A.G.G.M. Tielens, “The Unidentified Infrared Features after ISO”

Y. J. Pendleton and L. J. Allamandola 2002, ApJS, 138, 75

S. Hony, C. VanKerckhoven, E. Peeters, A. G. G. M. Tielens, D.M. Hudgins, and L. J. Allamandola 2001, A&A, 370, 1030



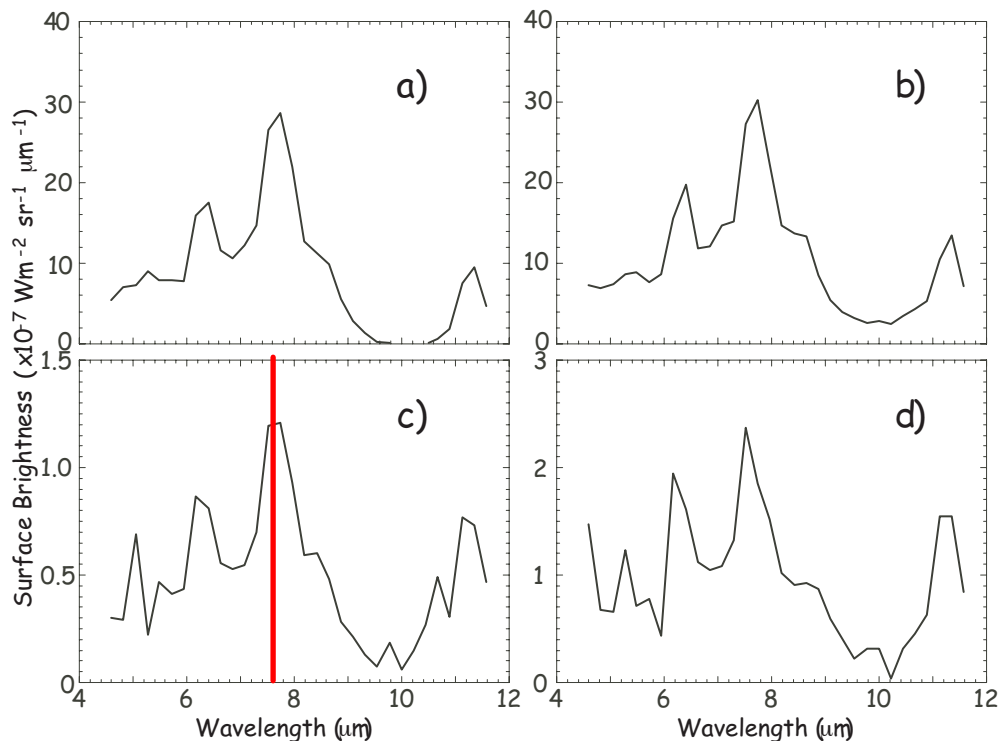
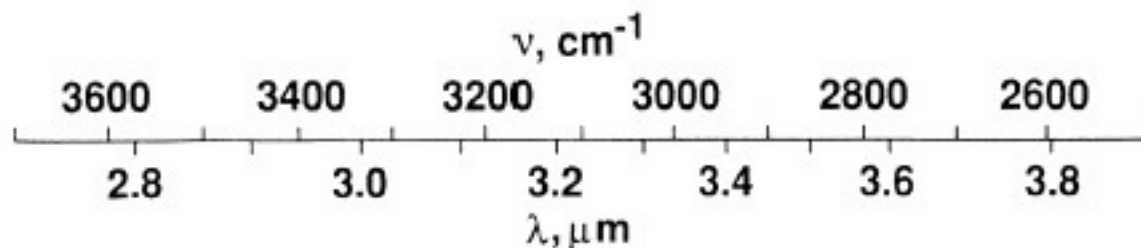


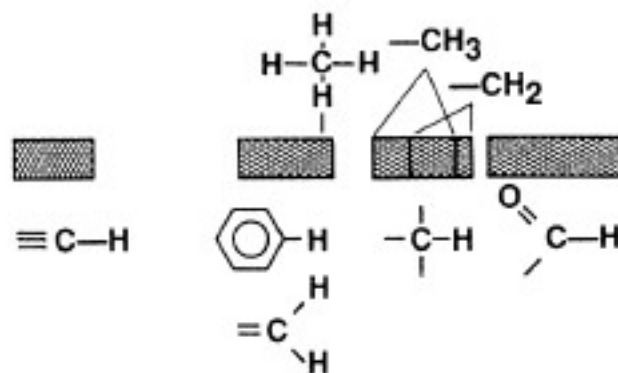
Figure 6. Typical MIRS spectra of the Galactic plane. a) Area I ($l \sim -10^\circ$), b) Area II ($l \sim 50^\circ$), c) Area III ($l \sim 170^\circ$), and d) Area IV ($l \sim 230^\circ$). The zodiacal emission has been subtracted (see text).

Figure 6 shows typical MIRS spectra of the four areas. The zodiacal emission was estimated in the surrounding regions and has been subtracted. The spectra were averaged over regions of $8' \times 8'$ or $16' \times 16'$ for Areas I and II, or III and IV, respectively. The MIRS aperture size was $8' \times 8'$. The spectrum shape does not show appreciable variations within each area and the distribution of the UIR bands appears very similar to that of the IRAS $100 \mu\text{m}$ intensity also in the outer Galaxy. The spectra in Areas I and II seem to be similar to each other as suggested by Fig. 5. The Area I spectrum shows a slightly deeper valley around $10 \mu\text{m}$ than that of Area II, which can be attributed to larger silicate absorption. The presence of the emission in the $10 \mu\text{m}$ region is well demonstrated by the variation with the galactic latitude in Area II (Onaka et al. 1996), while that in the Area I spectrum is difficult to confirm partly due to the silicate absorption and partly to the uncertainty in the zodiacal emission subtraction. Note that Area I is located very close to the ecliptic plane. ISOPHOT-S spectra do not confirm the presence of the emission around $10 \mu\text{m}$ in the diffuse emission, but their uncertainties are compatible with the intensity level of the MIRS spectrum (Kahanpää et al. 2003). In the spectra of Areas I and II there seem to be faint features present around 5.5 and $7.0 \mu\text{m}$, which may be weak companions of the UIR bands (e.g. Allamandola et al. 1989).

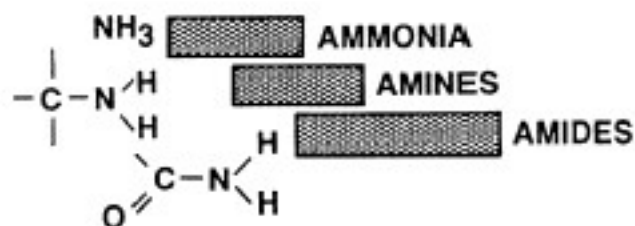
H-X STRETCHING FREQUENCIES



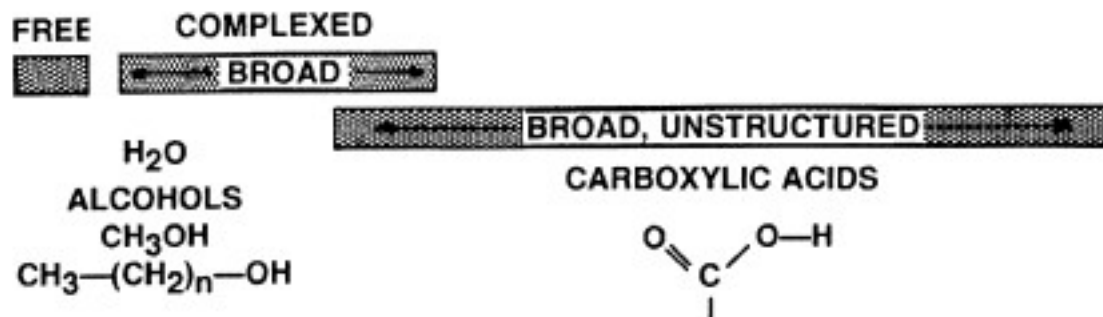
C-H STRETCH



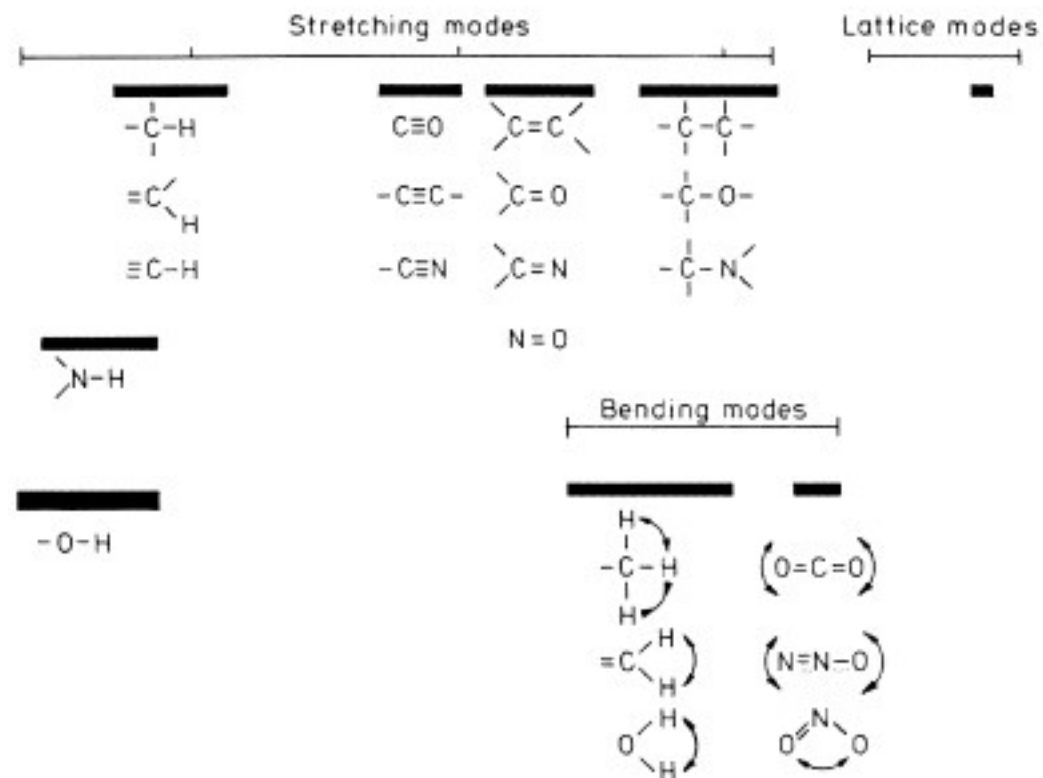
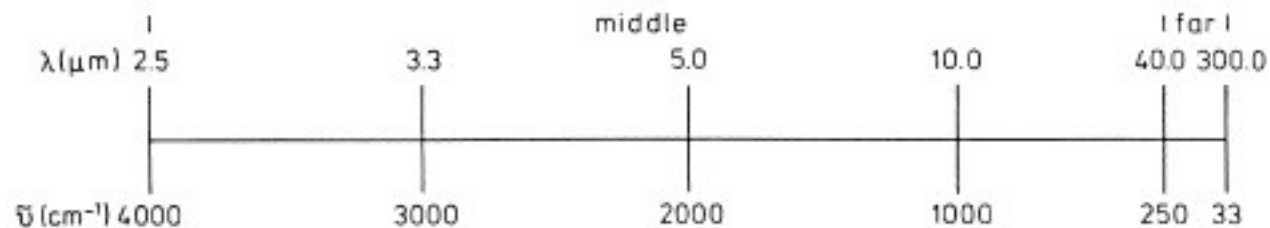
N-H STRETCH

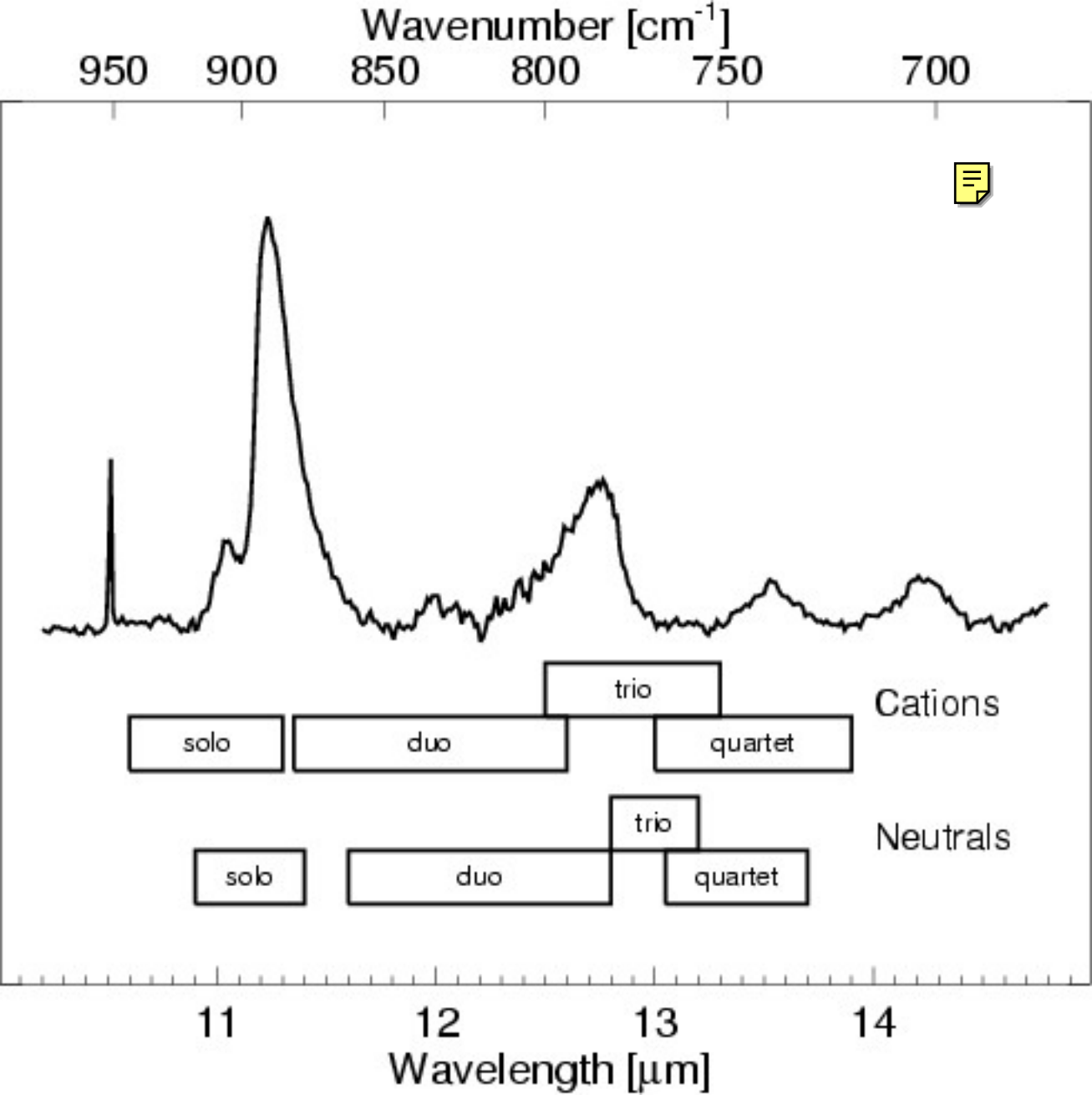


O-H STRETCH

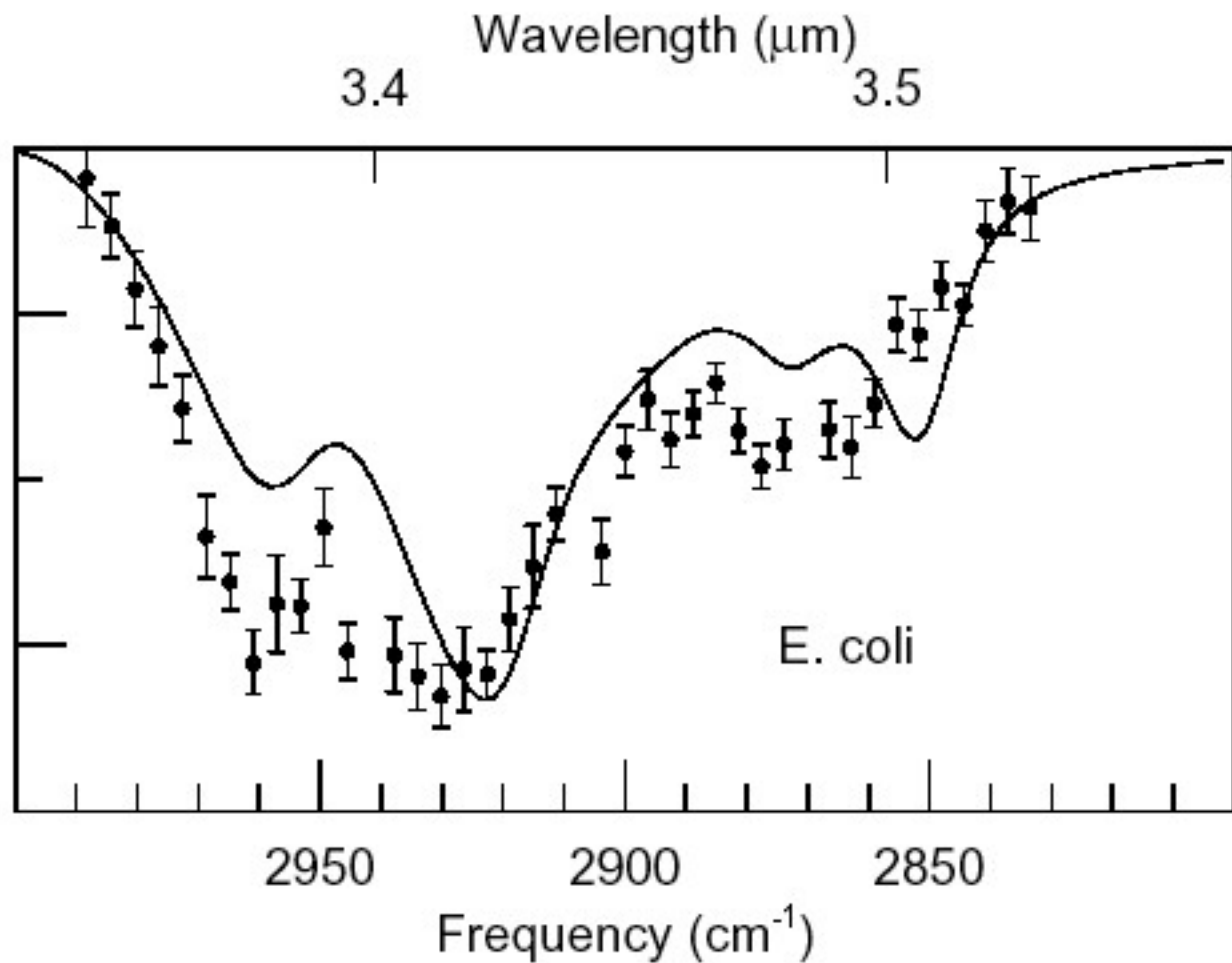


INFRA-RED

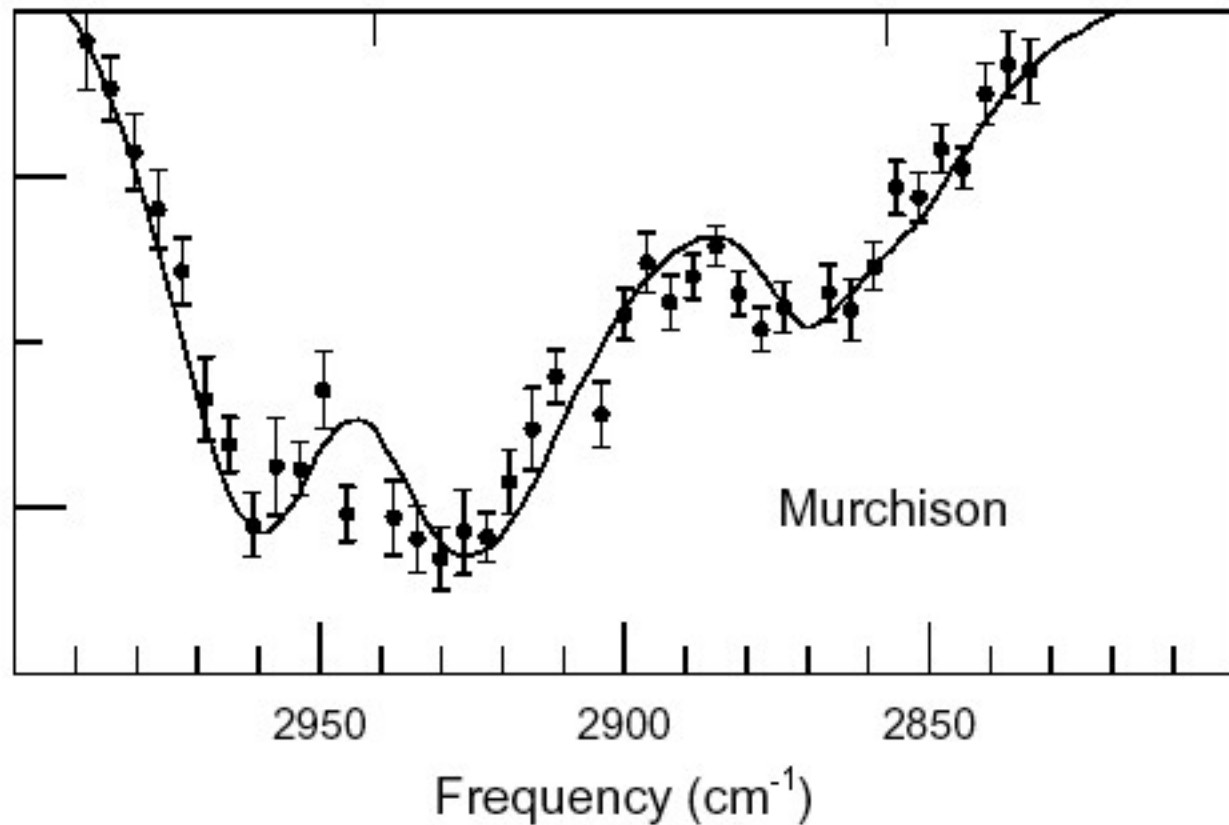




Normalized Optical Depth

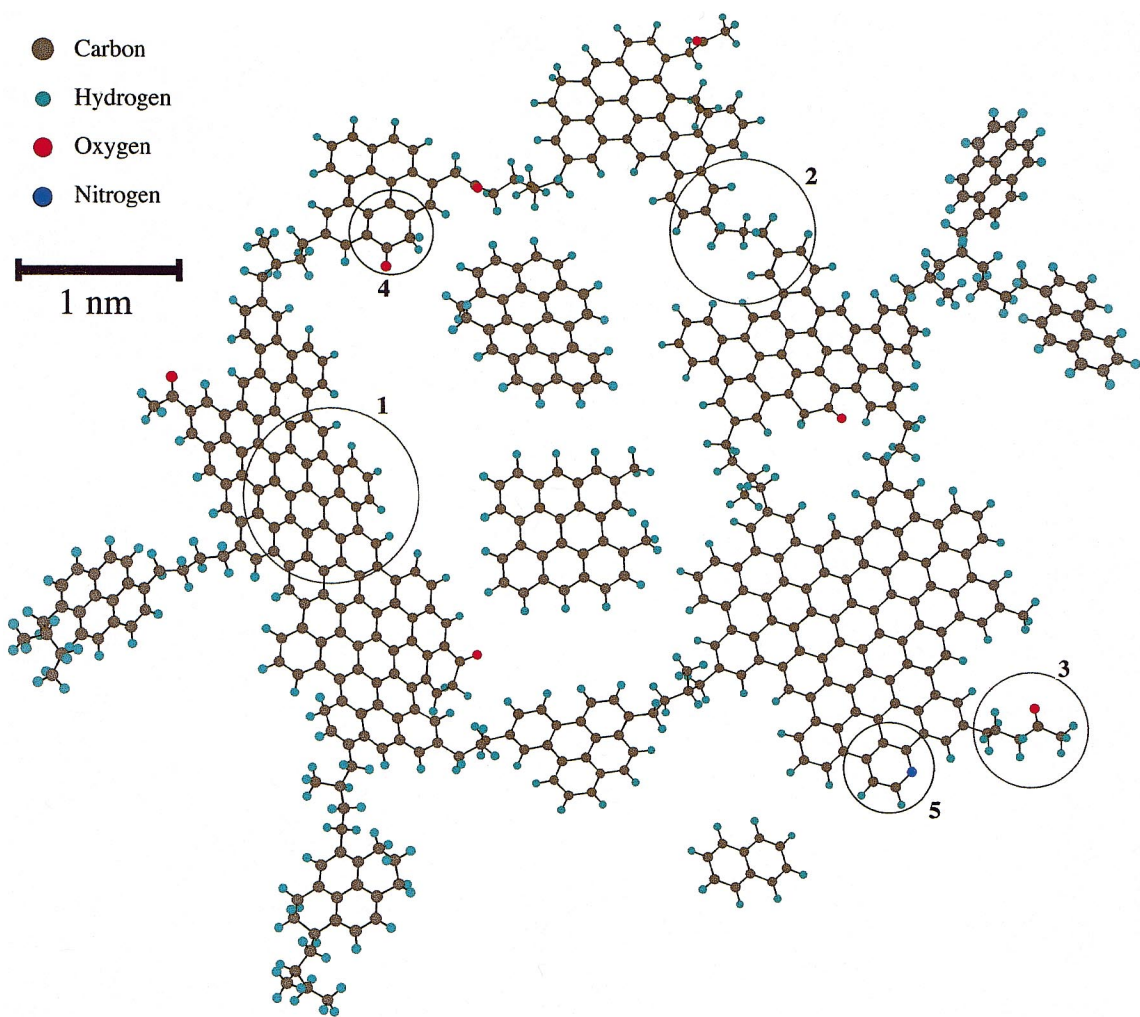


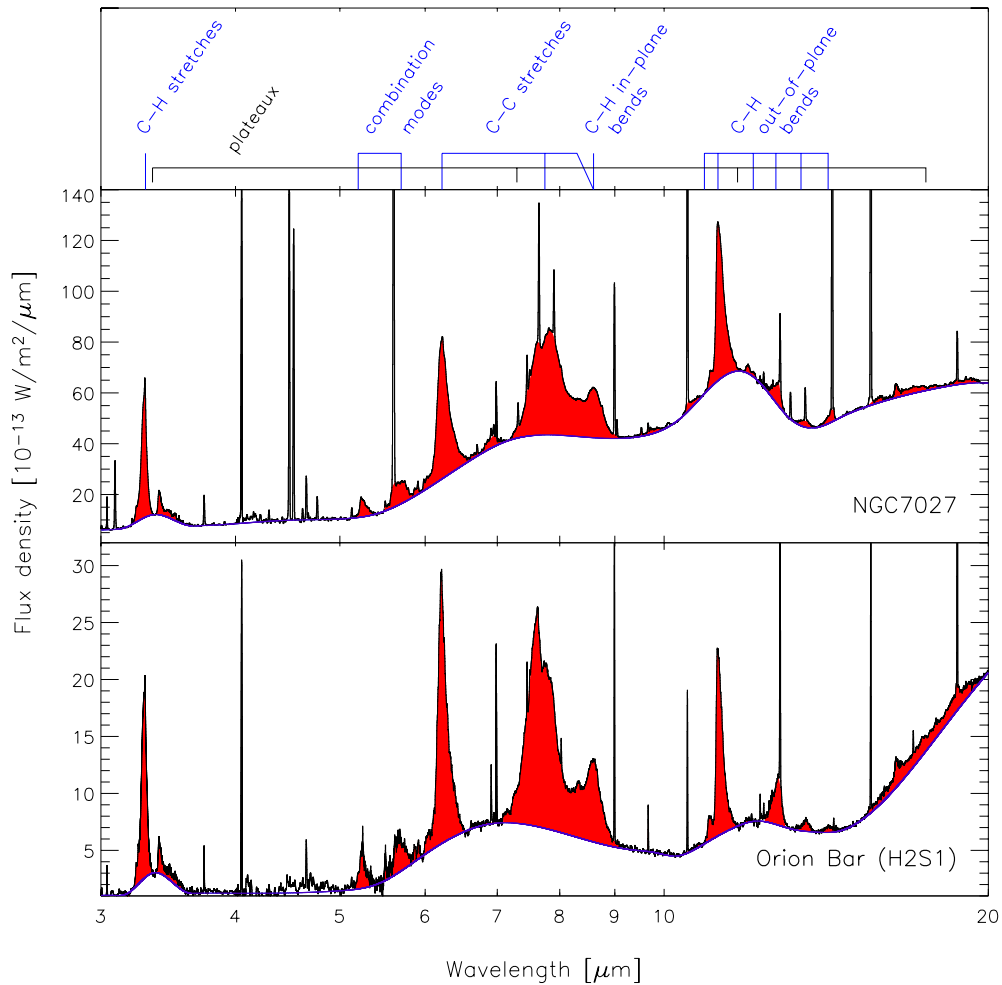
Normalized Optical Depth

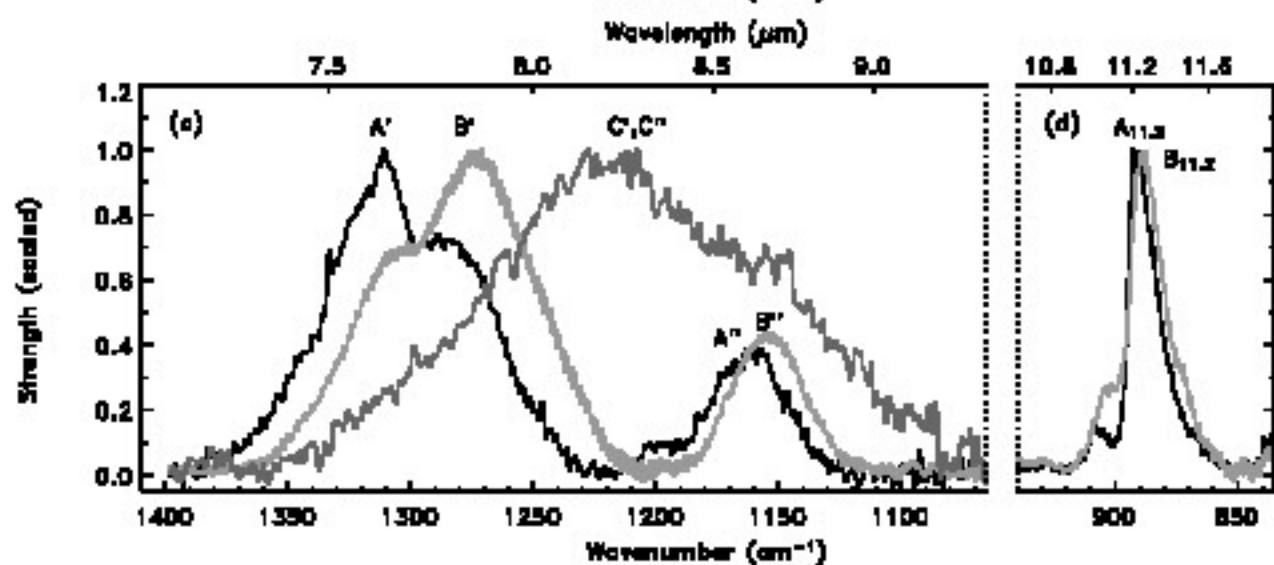
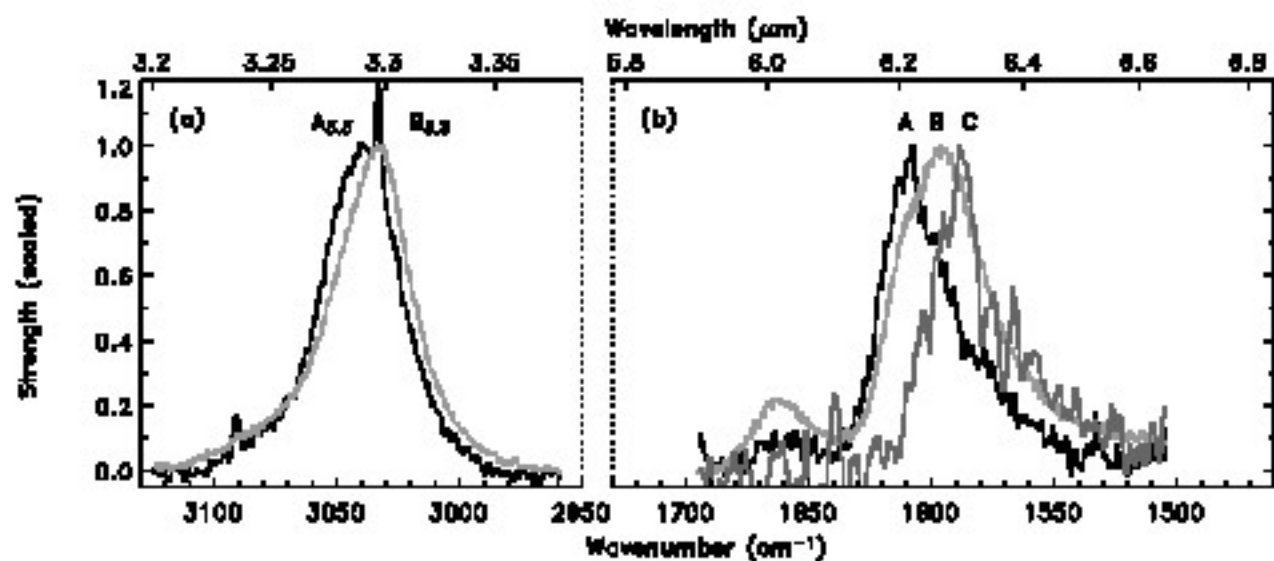


- Carbon
- Hydrogen
- Oxygen
- Nitrogen

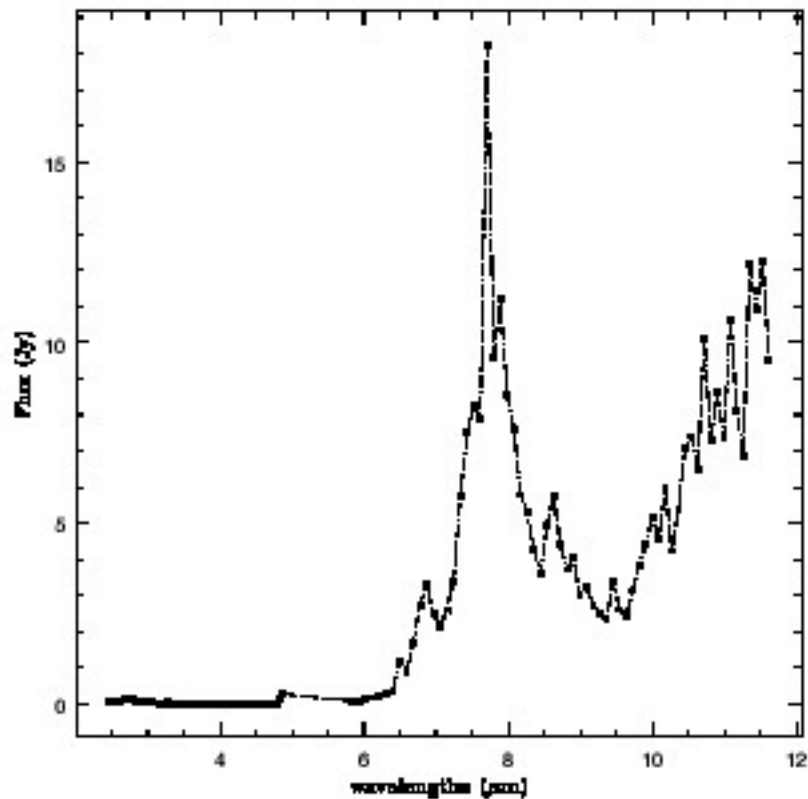
1 nm

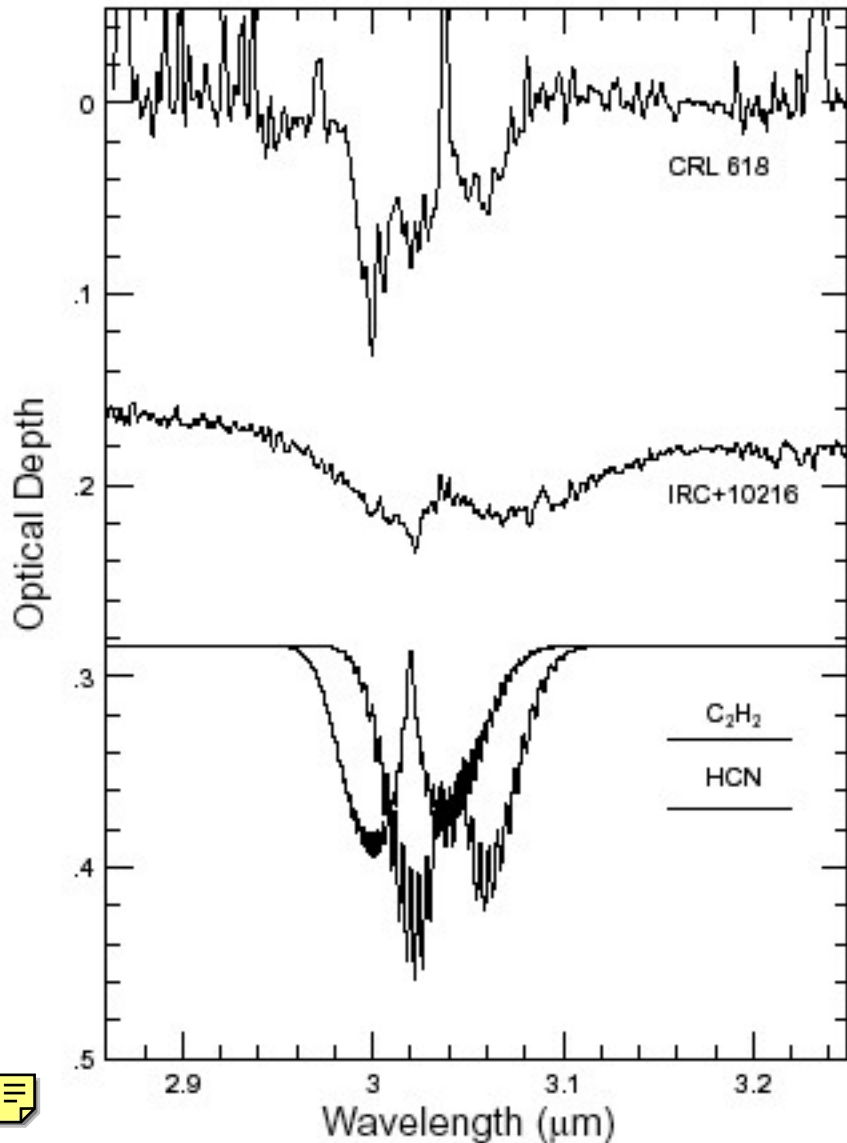






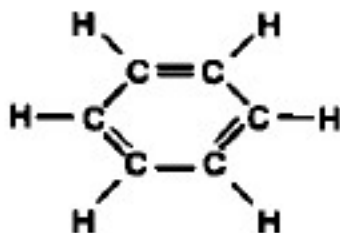
UIR Emission Features from Titan Haze







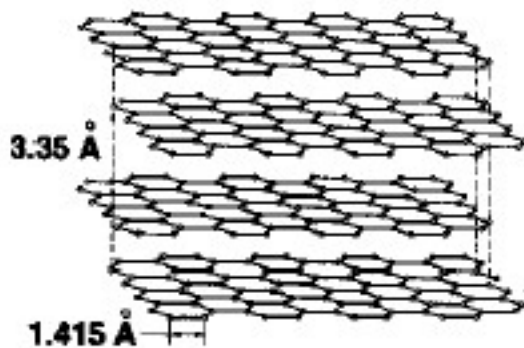
ACETYLENE



BENZENE



**POLYCYCLIC
AROMATIC
HYDROCARBON**



PLATELET



SOOT PARTICLE