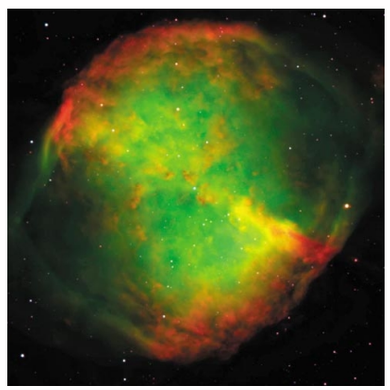
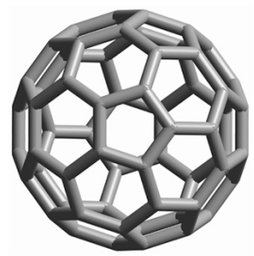
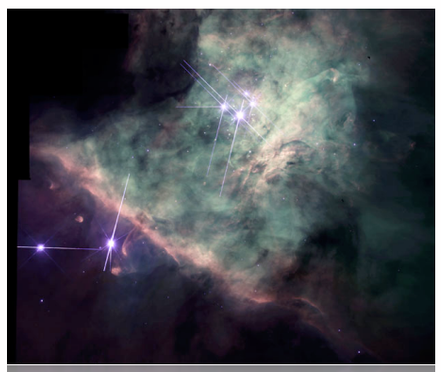
Interstellar & Circumstellar Fullerenes

Jeronimo Bernard-Salas

J. Cami, E. Peeters, A.P. Jones, E.R. Micelotta, M. Otsuka, C. Kemper, M. Groenewegen, G.C. Sloan







Images credit: JK group (Cambridge), ESO, O'Dell & Wong

Taiwan, Nov. 2013

The Open University

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POSTERS

Sloan, P7-9

Otsuka, P7-8

Micelotta, P7-6

Kemper, P7-3

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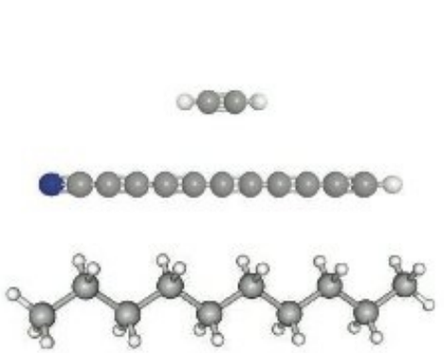
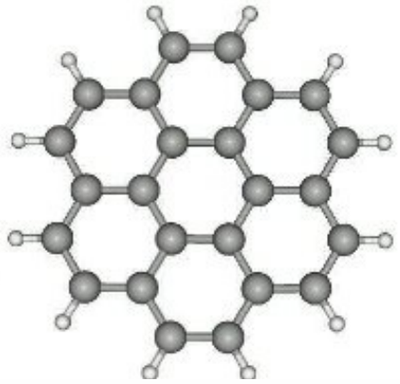
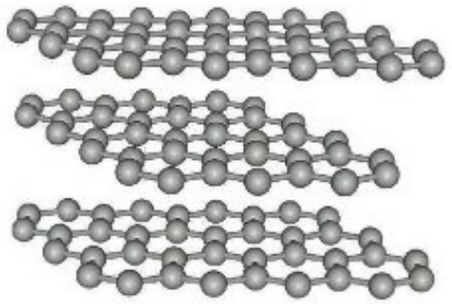
Fullerenes



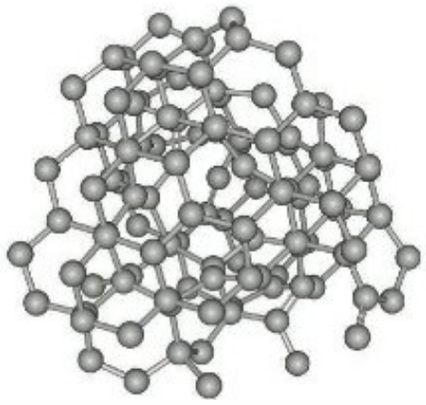
Carbon Chains



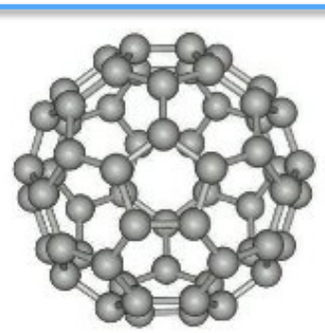
PAHs



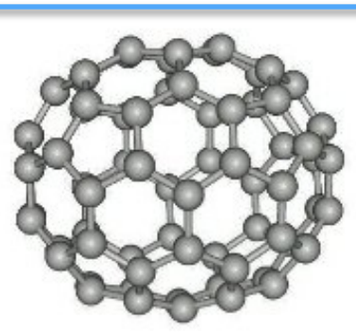
Graphite



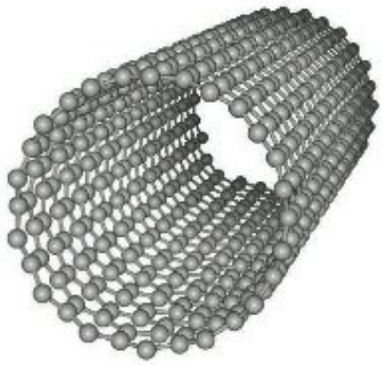
Am. Carbon



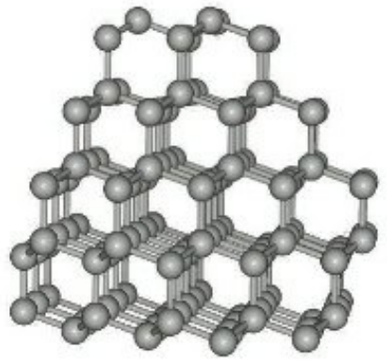
C60



C70

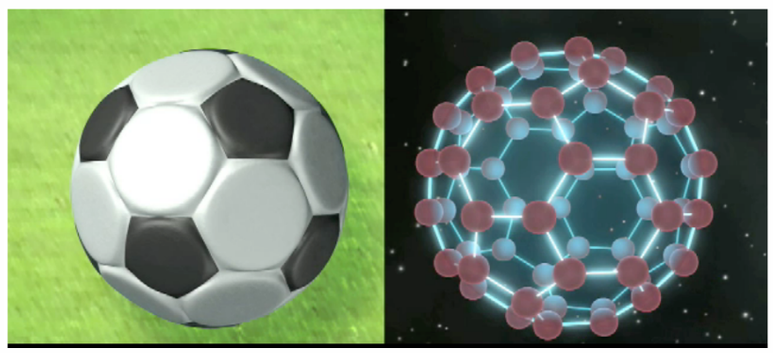


Nanotubes



Nanodiamond

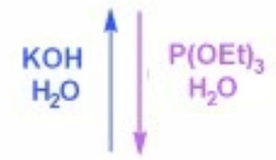
- Hollow molecule made of carbon
- Discovered by Sir H. Kroto et al. in 1985
- Most popular C60 (soccer ball)

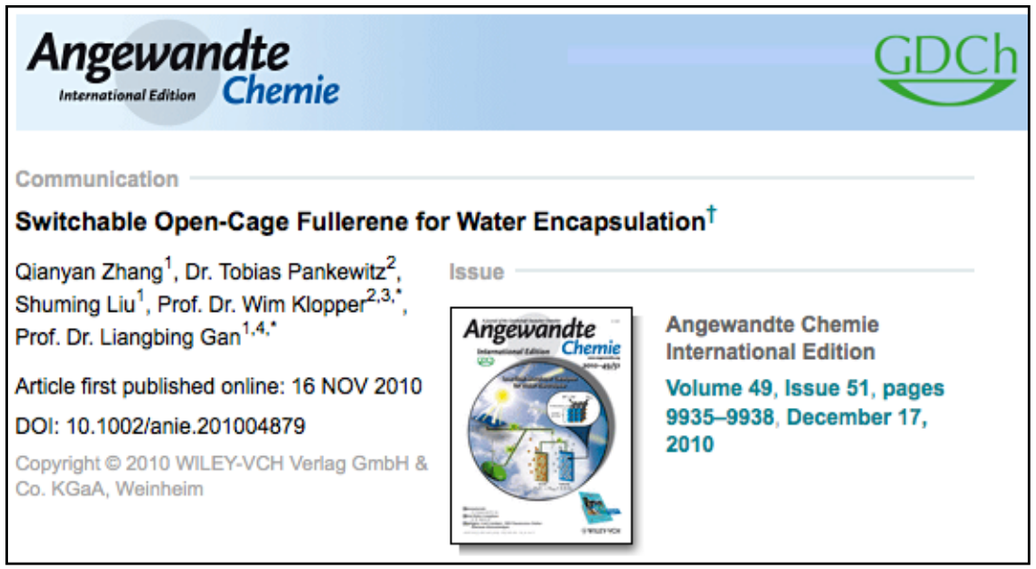


Images credit: Science 2010, NASA, JPL, Caltech

Importance

- Nanotechnology: heat resistance and super-conductivity (18 K)
- Material sciences: electronics (promotes e^- transfer)
- Medicinal: use as targeting drug delivery (e.g. cancer melanoma)





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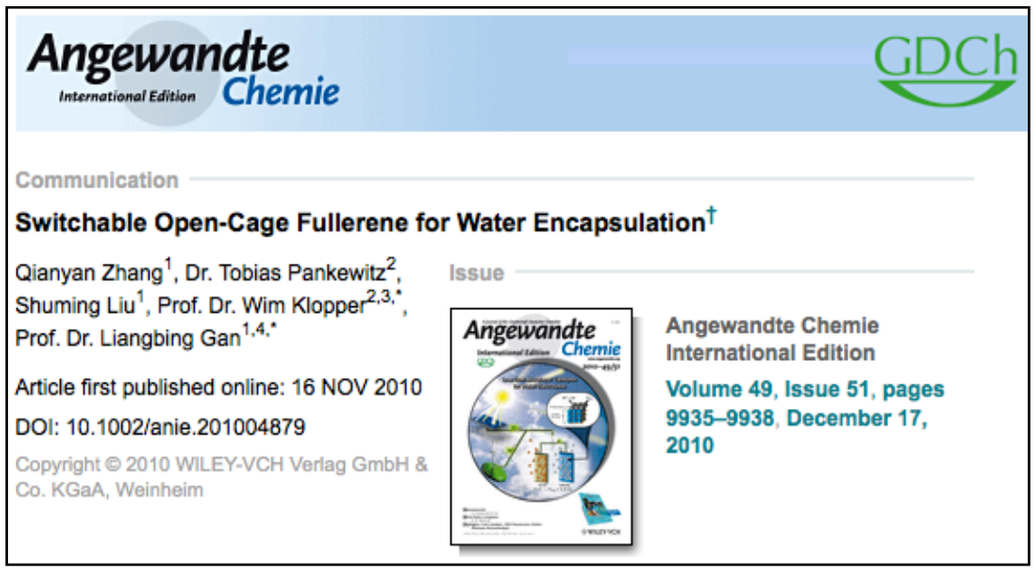
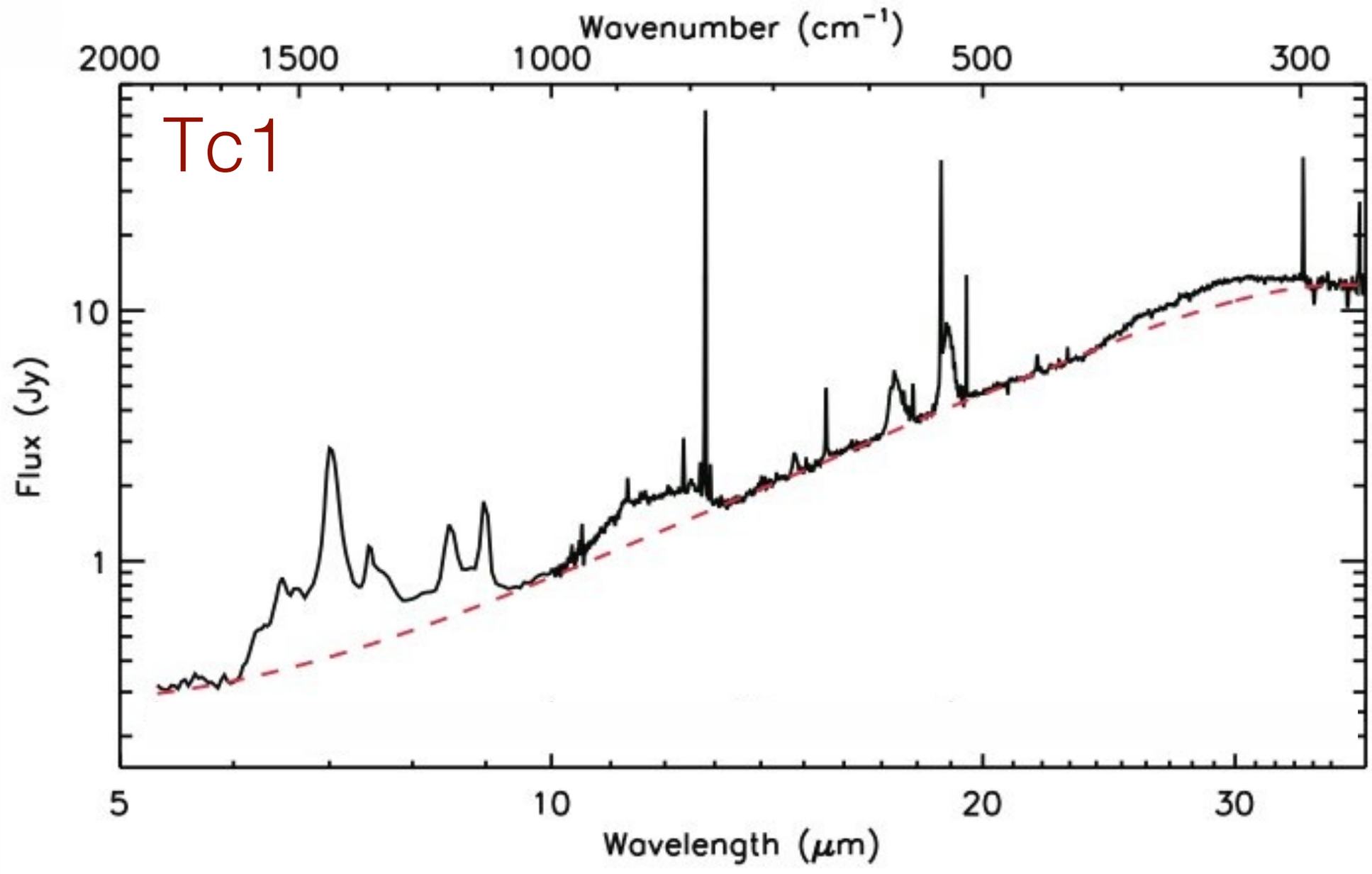


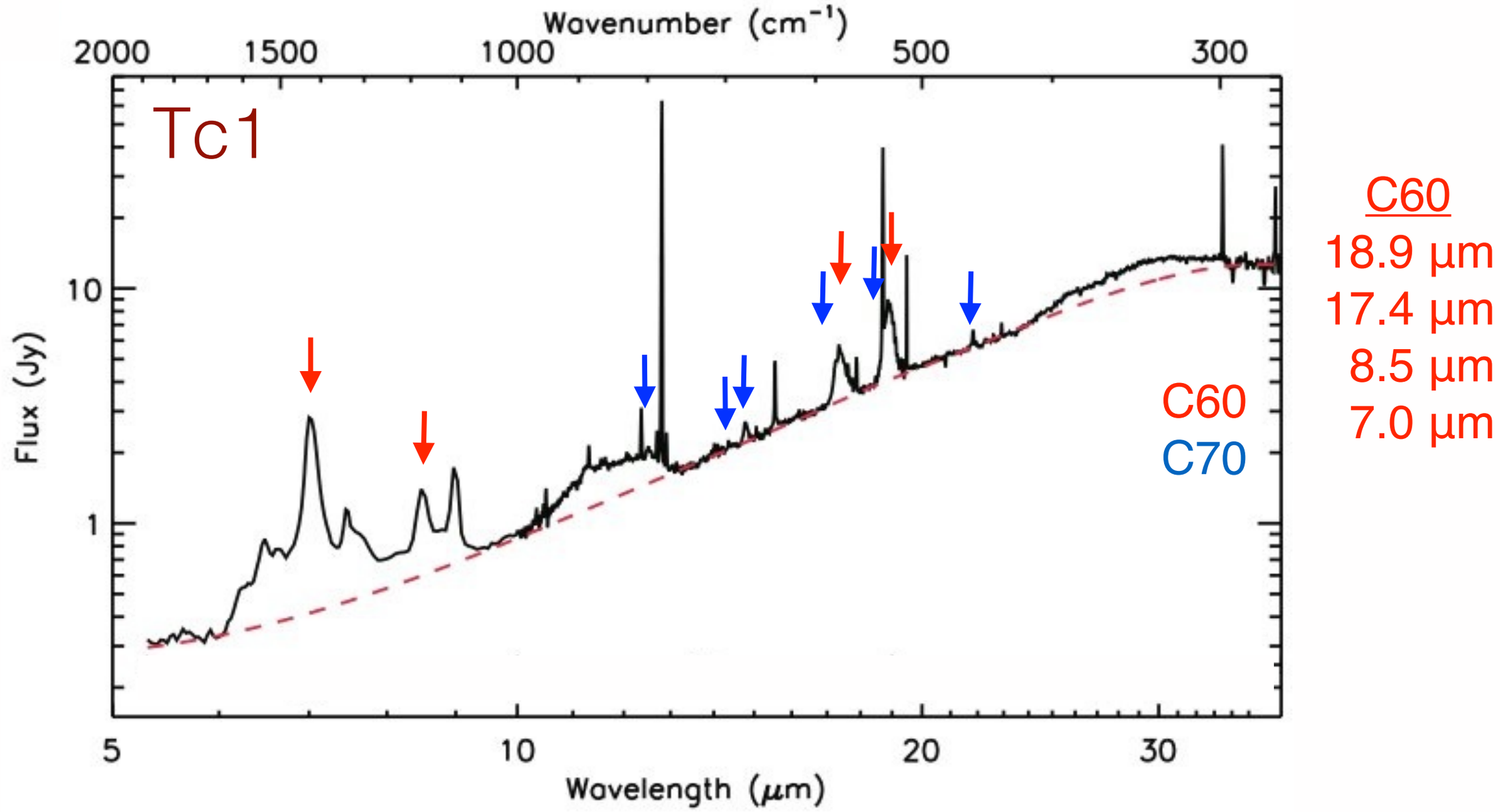
➡ Very stable molecule: survive conditions of the ISM

Discovery



Cami, Bernard-Salas et al. (2010, Science)

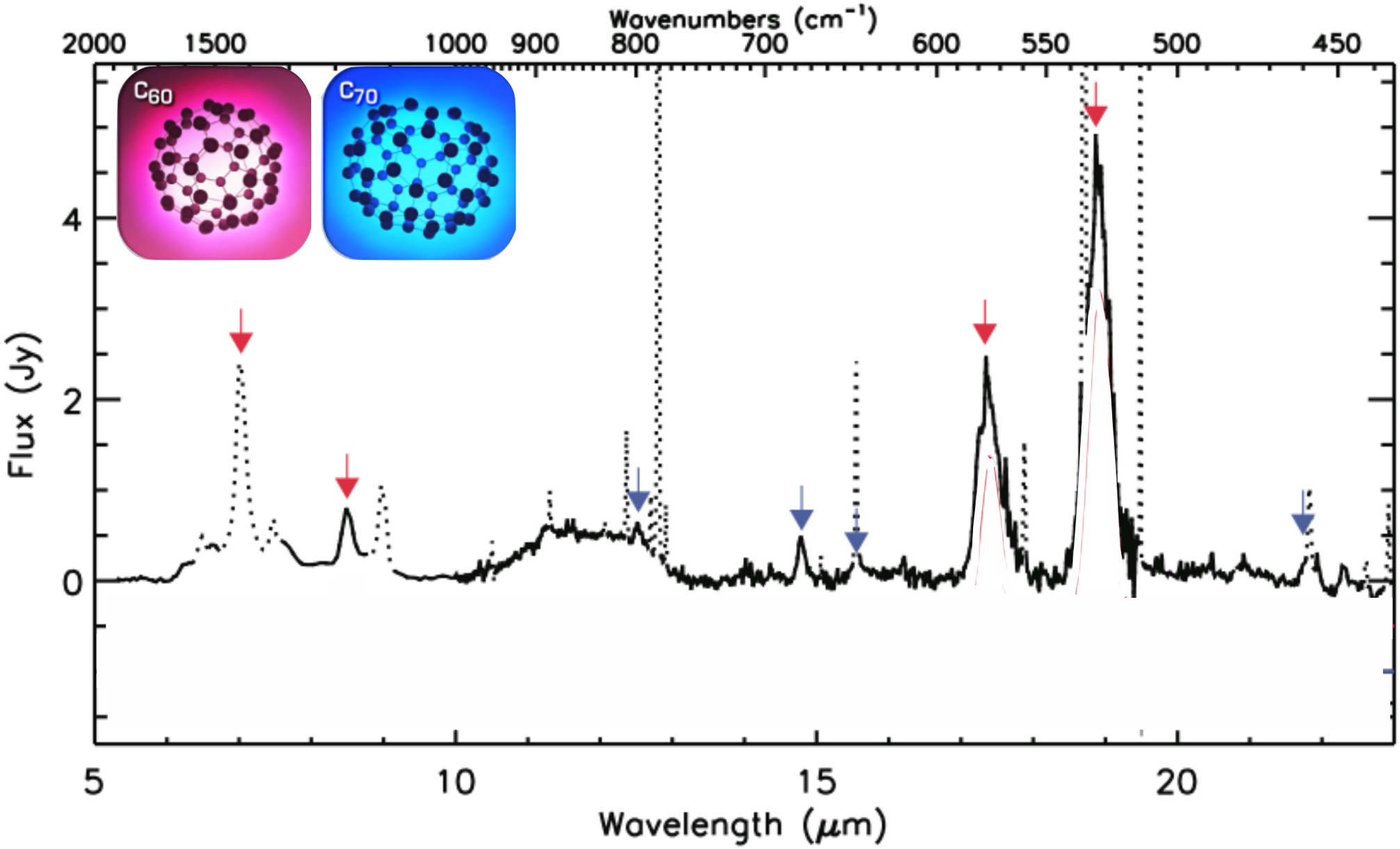
Discovery



C60
18.9 μm
17.4 μm
8.5 μm
7.0 μm

Cami, Bernard-Salas et al. (2010, Science)

Discovery



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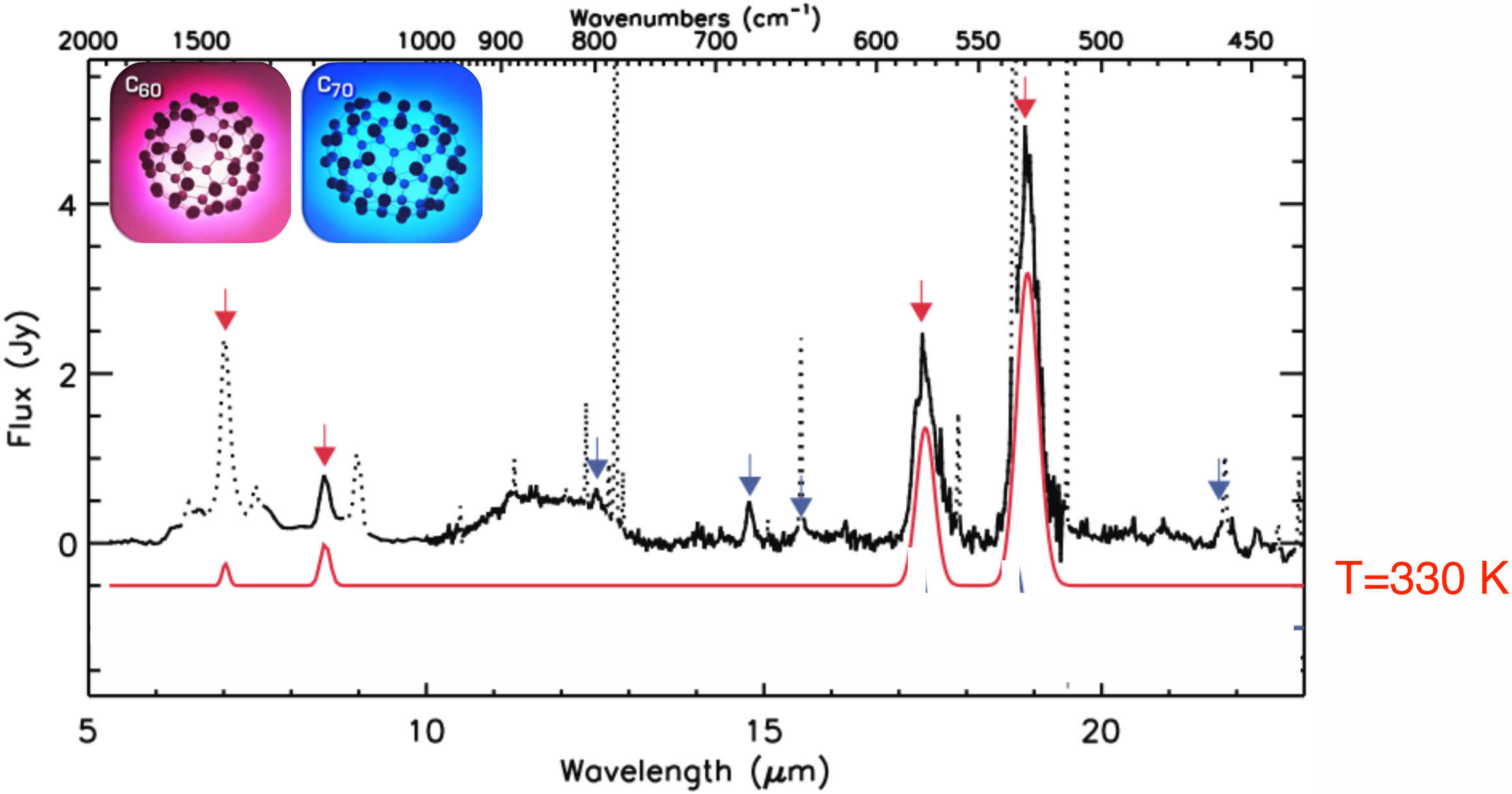
Discovery



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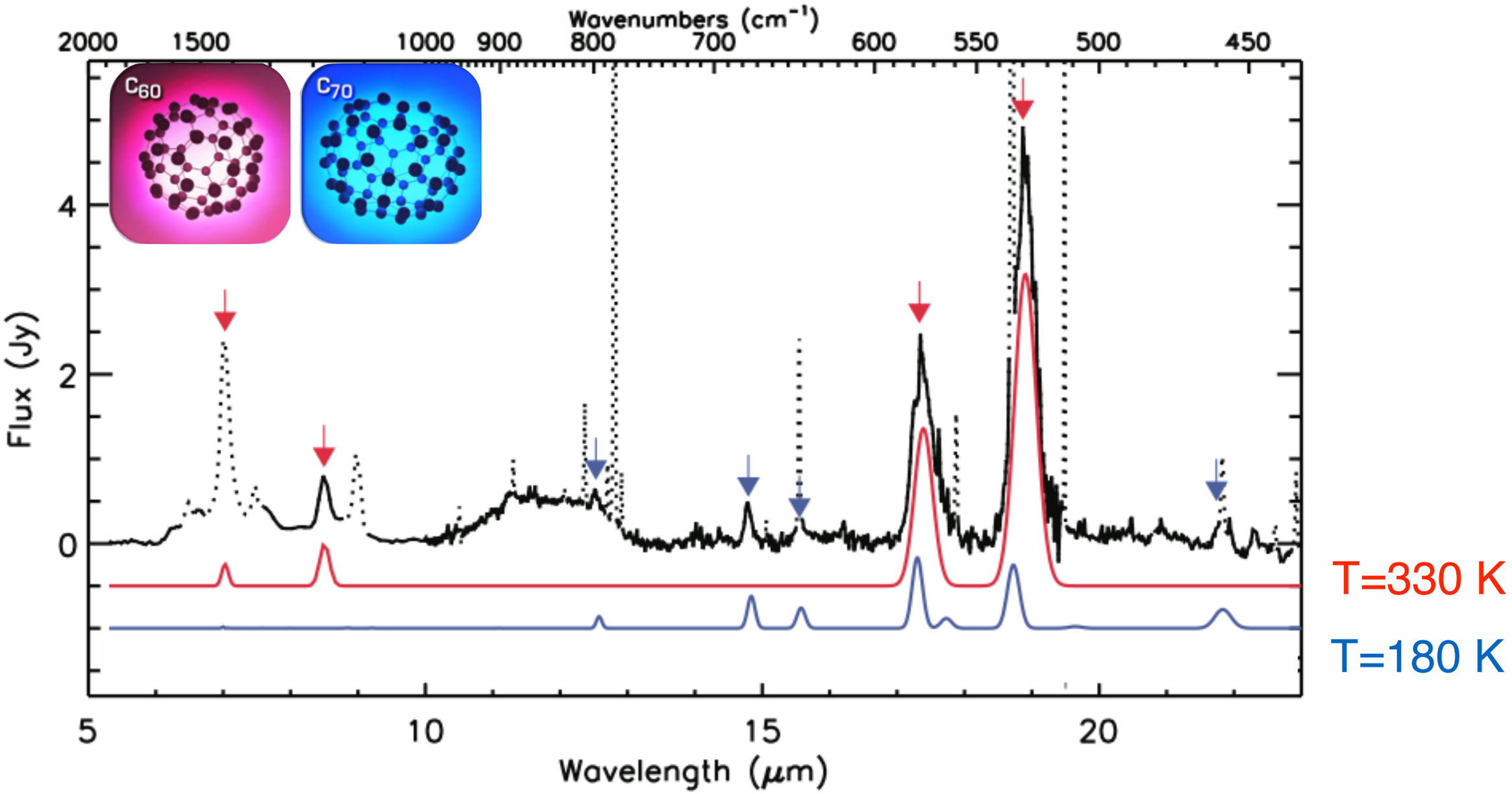


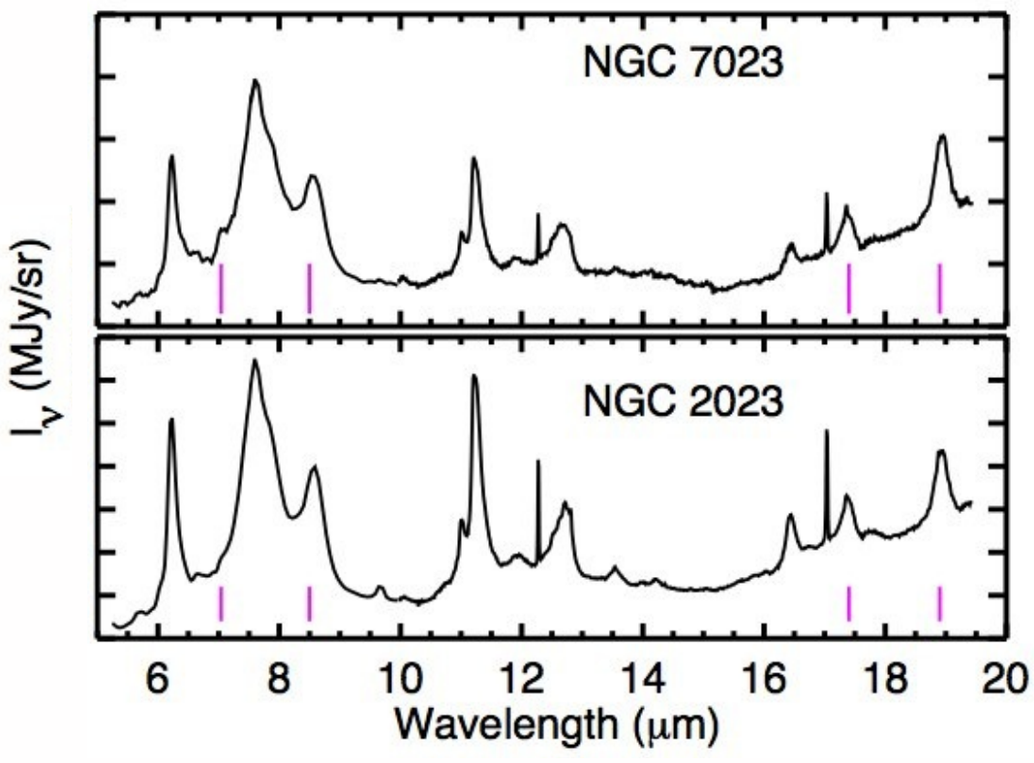
Cami, Bernard-Salas et al. (2010, Science)

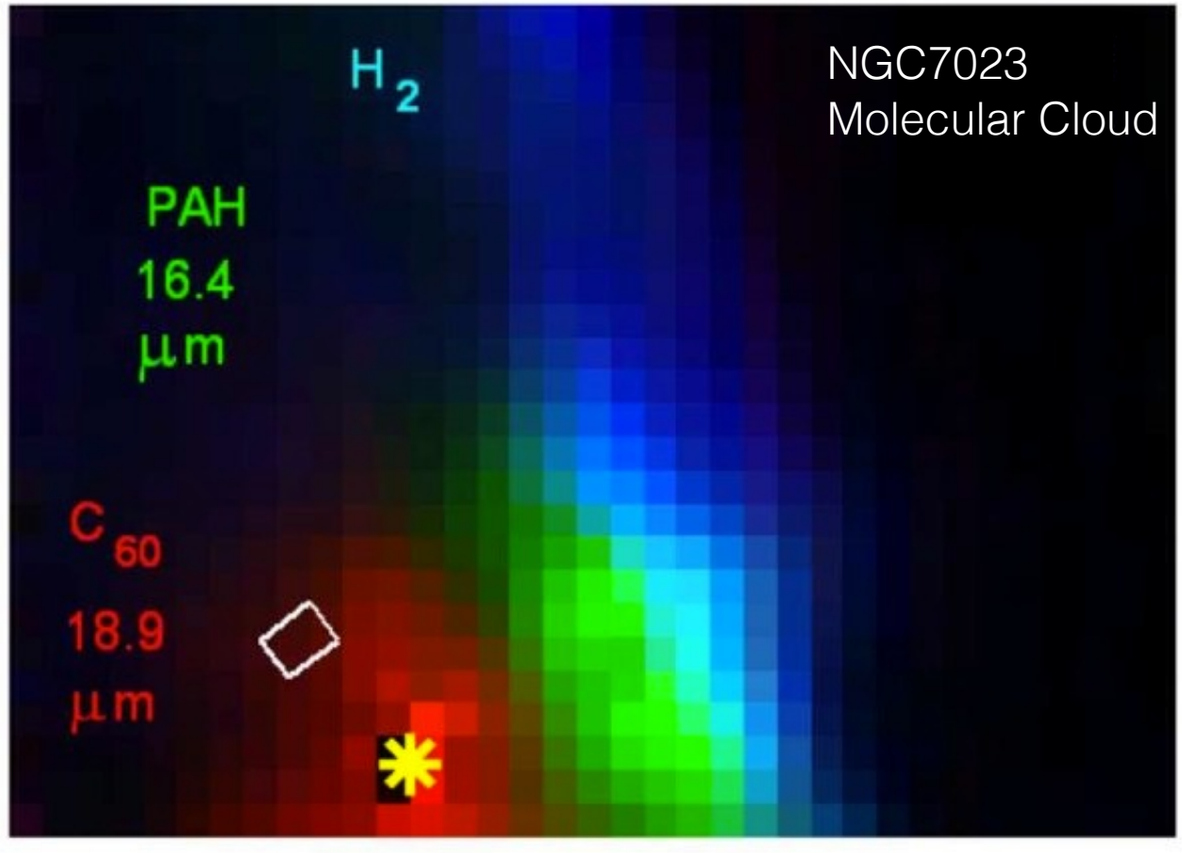
C_{60} in Diverse Environments

post-AGBs, pPNe, PNe, HII regions, Reflection Nebulae, Stars, YSOs

➡ Fullerenes formed in the post-AGB to PN phase

➡ Fullerenes survive the harsh conditions of the ISM





Sellgren et al. (2010)

Importance in Space

- Very large Molecule (60-70 atoms!) (before just 13)
  Crucial to understand formation & evolution of large organics

- Share many physical properties with PAHs
  Understand one of the largest reservoirs of organic material in space

- Very stable, survives the harsh conditions in the ISM
  Contribute interstellar extinction, heating, complex chemical reactions?

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Excitation - Formation - Environment

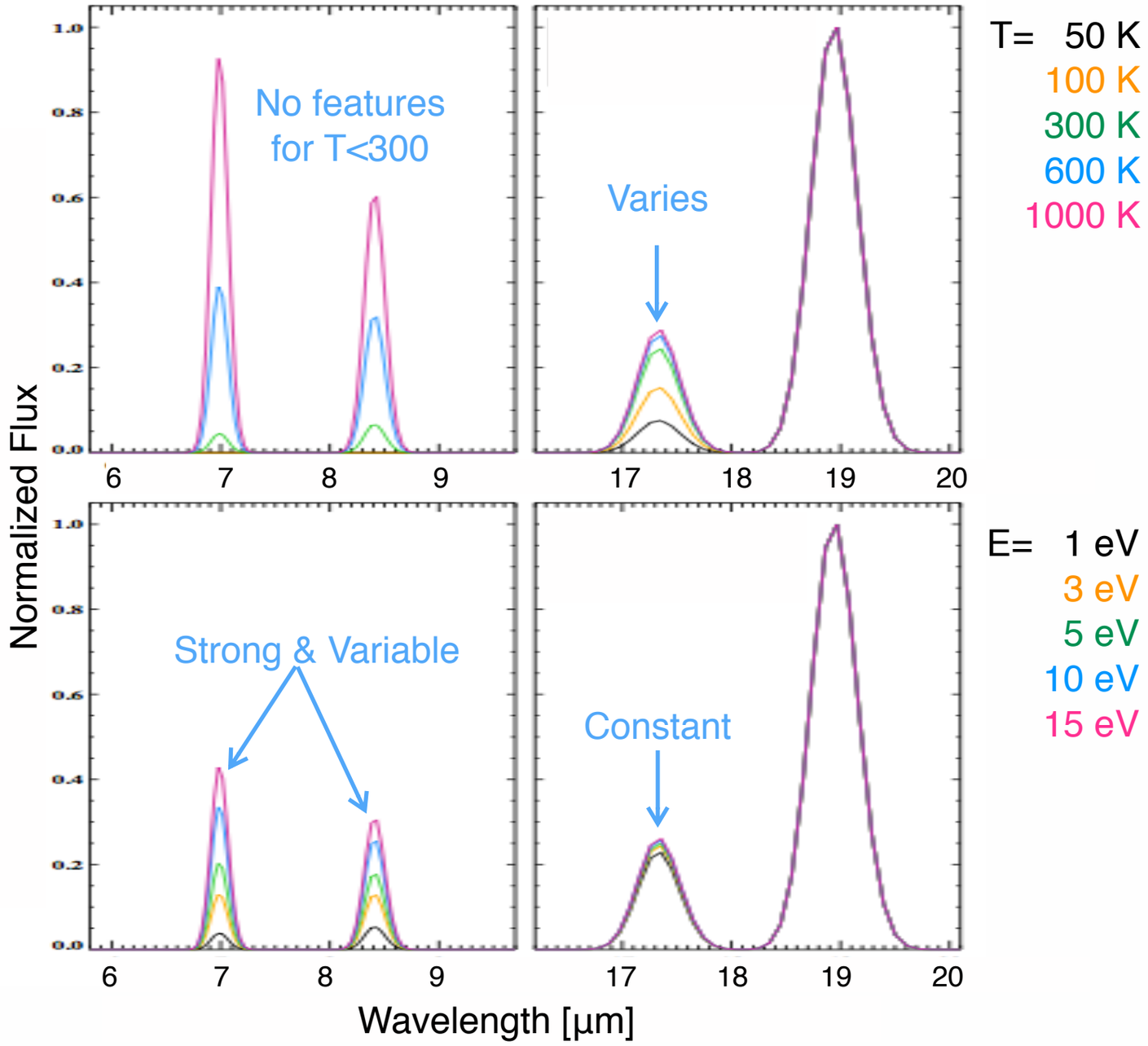
Excitation: Thermal vs Fluorescence

<u>Fullerene rich objects show:</u>

- Constant 17.4/18.9 μm ratio
  (Otsuka et al. 2013) ➔ POSTER P7-8
- Weak or no 7.0 and 8.5 μm bands

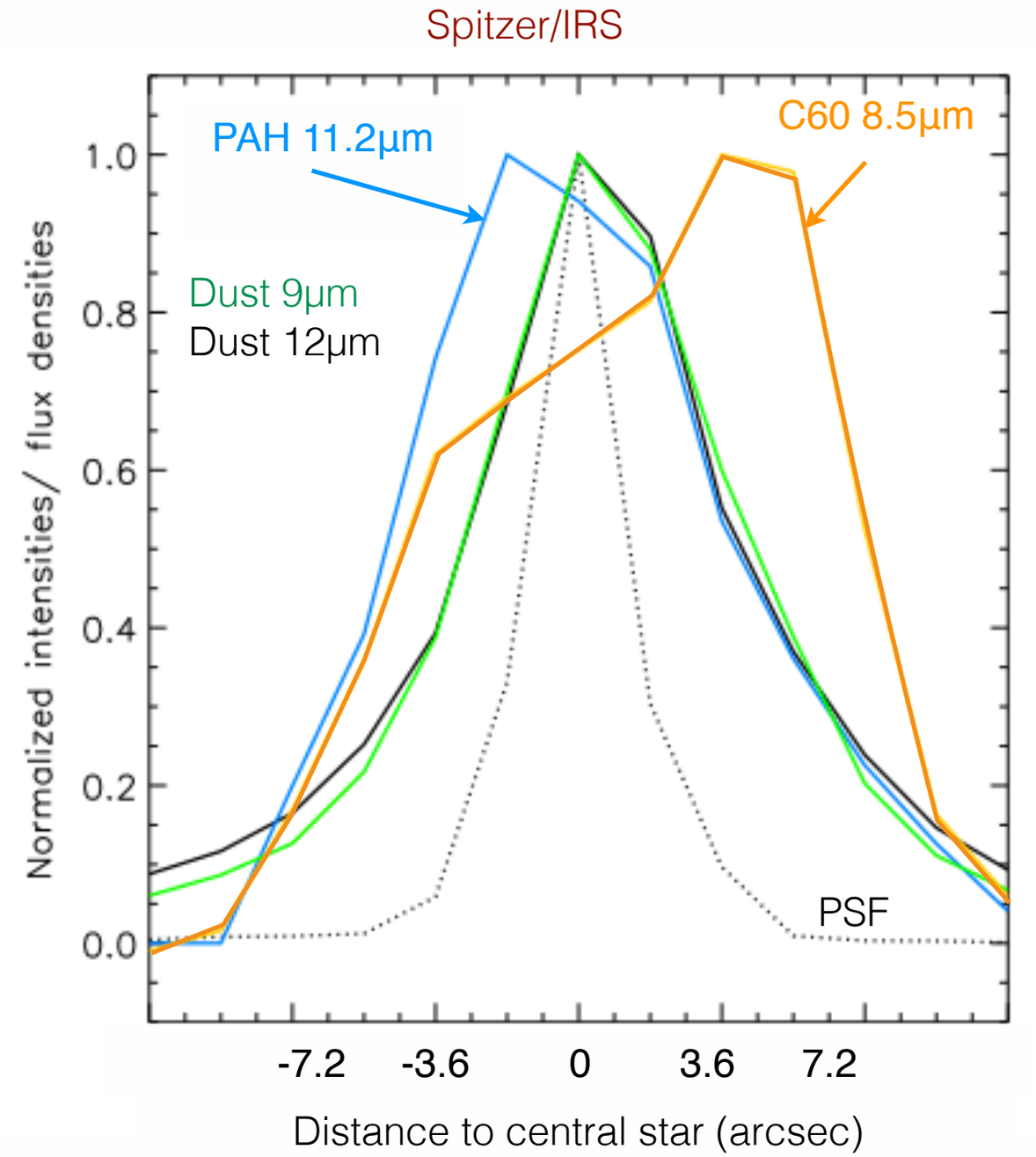
➡ Difficult to reconcile observations with thermal models

➡ But fluorescence predicts too high 7.0 μm bands



Bernard-Salas et al. (2012), Cami et al. (2011)

Spatial Distribution, Tc1

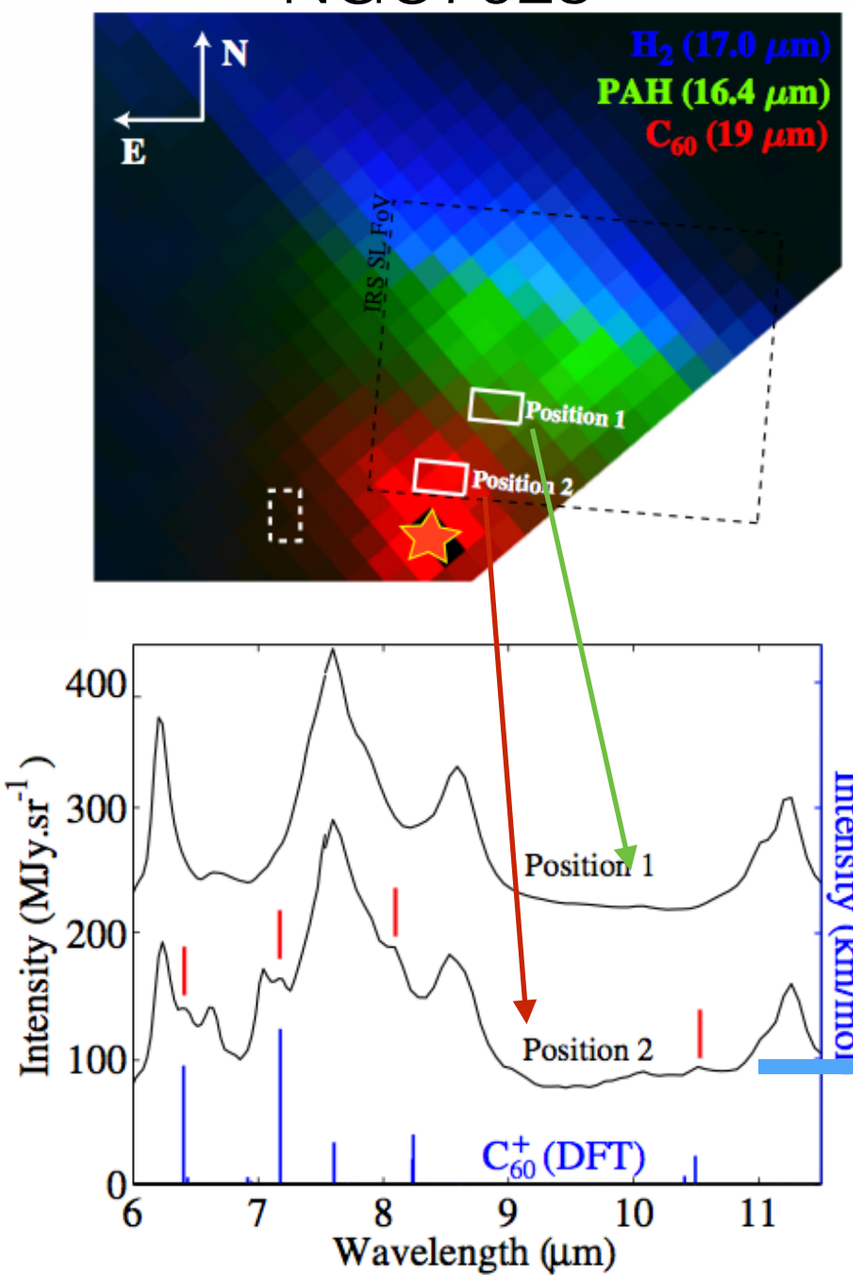


Bernard-Salas et al. (2012)

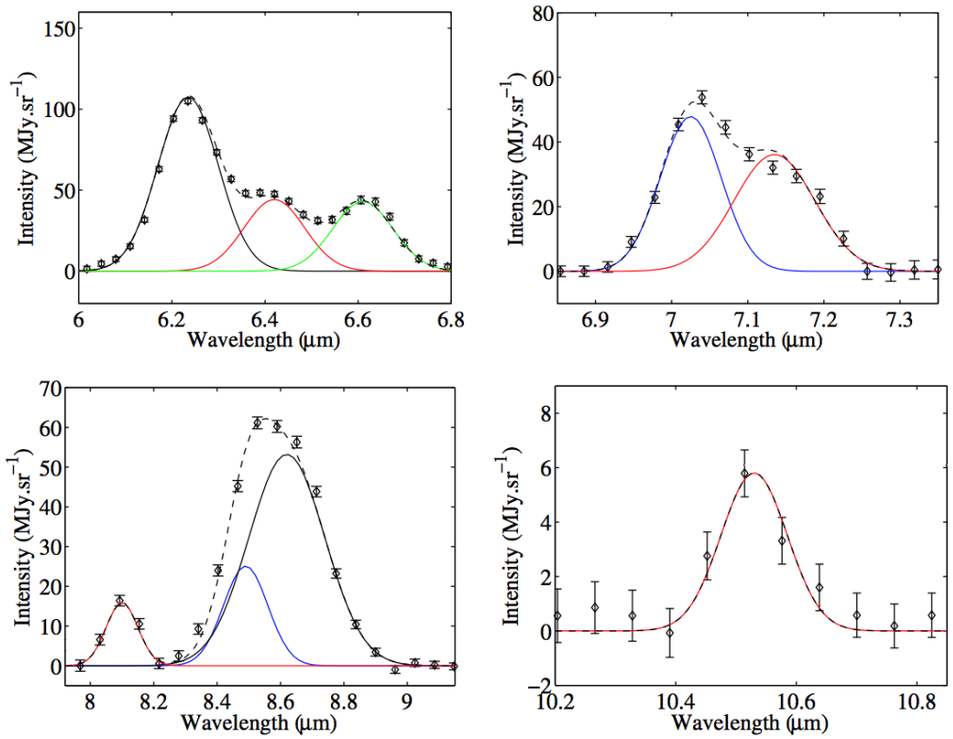
- Not consistent with thermal ➔ Fluorescence

Detection of C_{60}^+

NGC7023

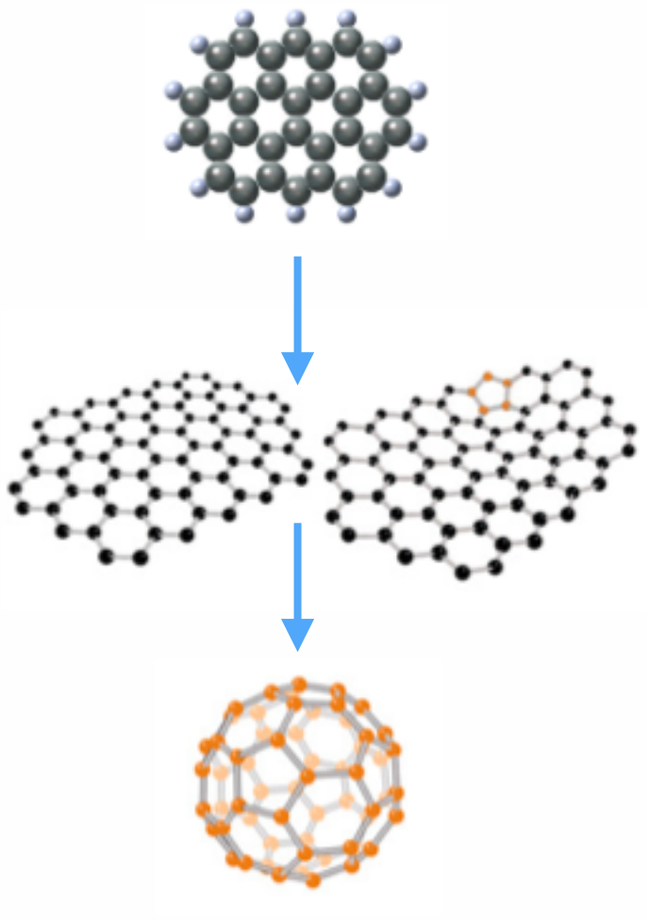


- Detection in NGC7023 (Berné et al. 2013)
- Tentative detection in Tc1 (Zhang & Kwok 2013)



Formation Routes

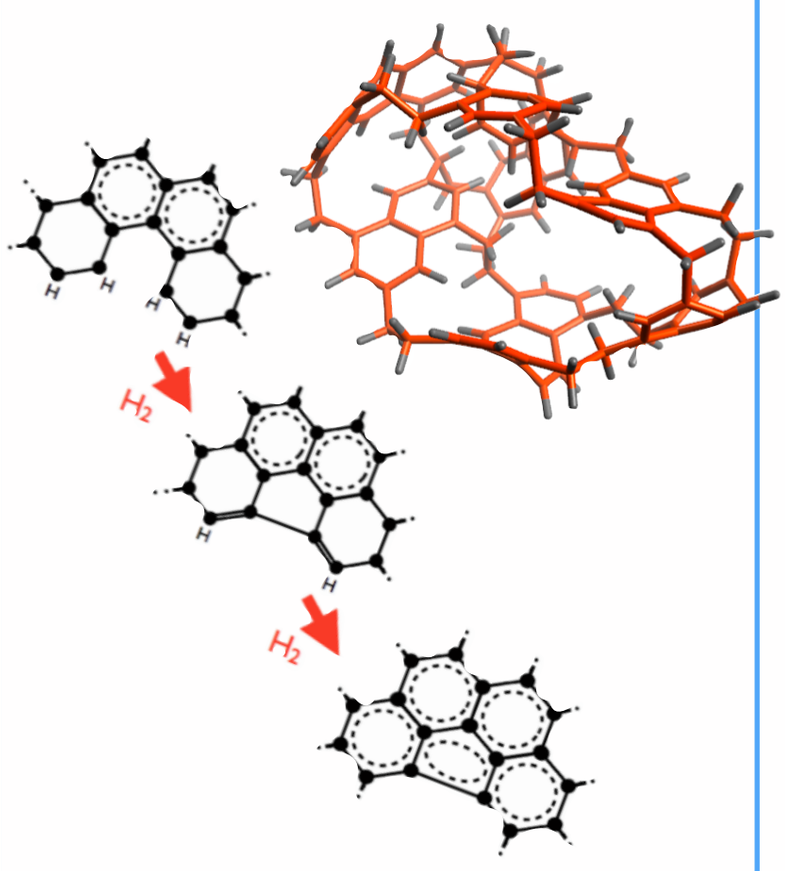
PAH processing
(Berné & Tielens 2011)



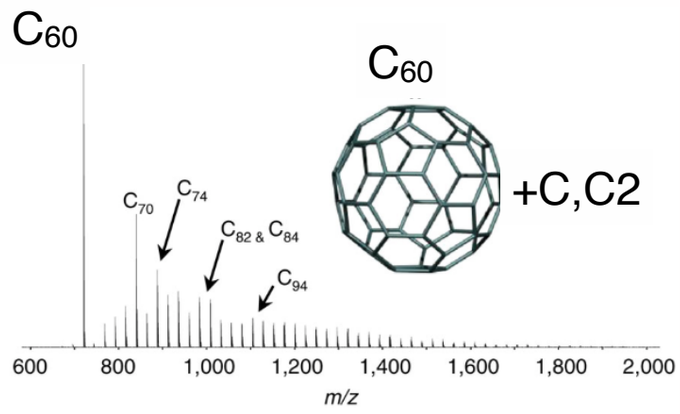
- Timescales not consistent
  (Micelotta et al. 2012)

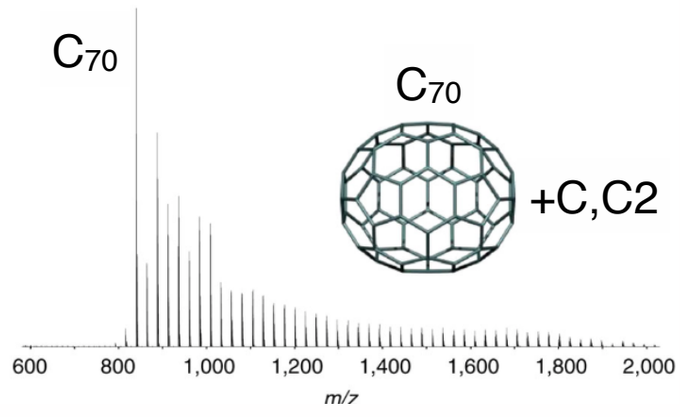
HAC processing
(García-Hernández et al. 2010)

Shrinking
(Micelotta et al. 2012)

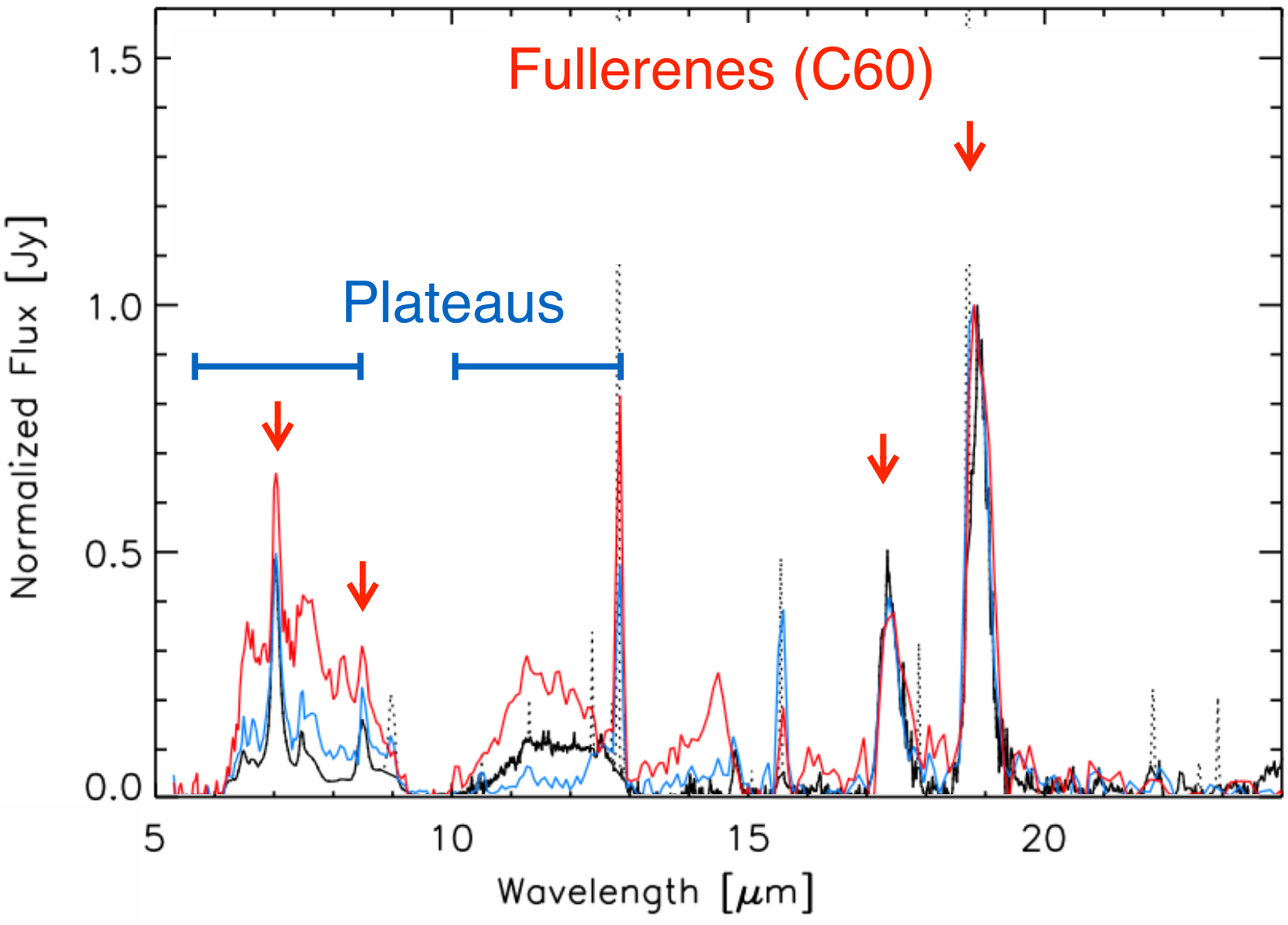


Closed Network Growth (CNG)
(Dunk et al. 2012, 2013)





6-9μm plateau - HAC



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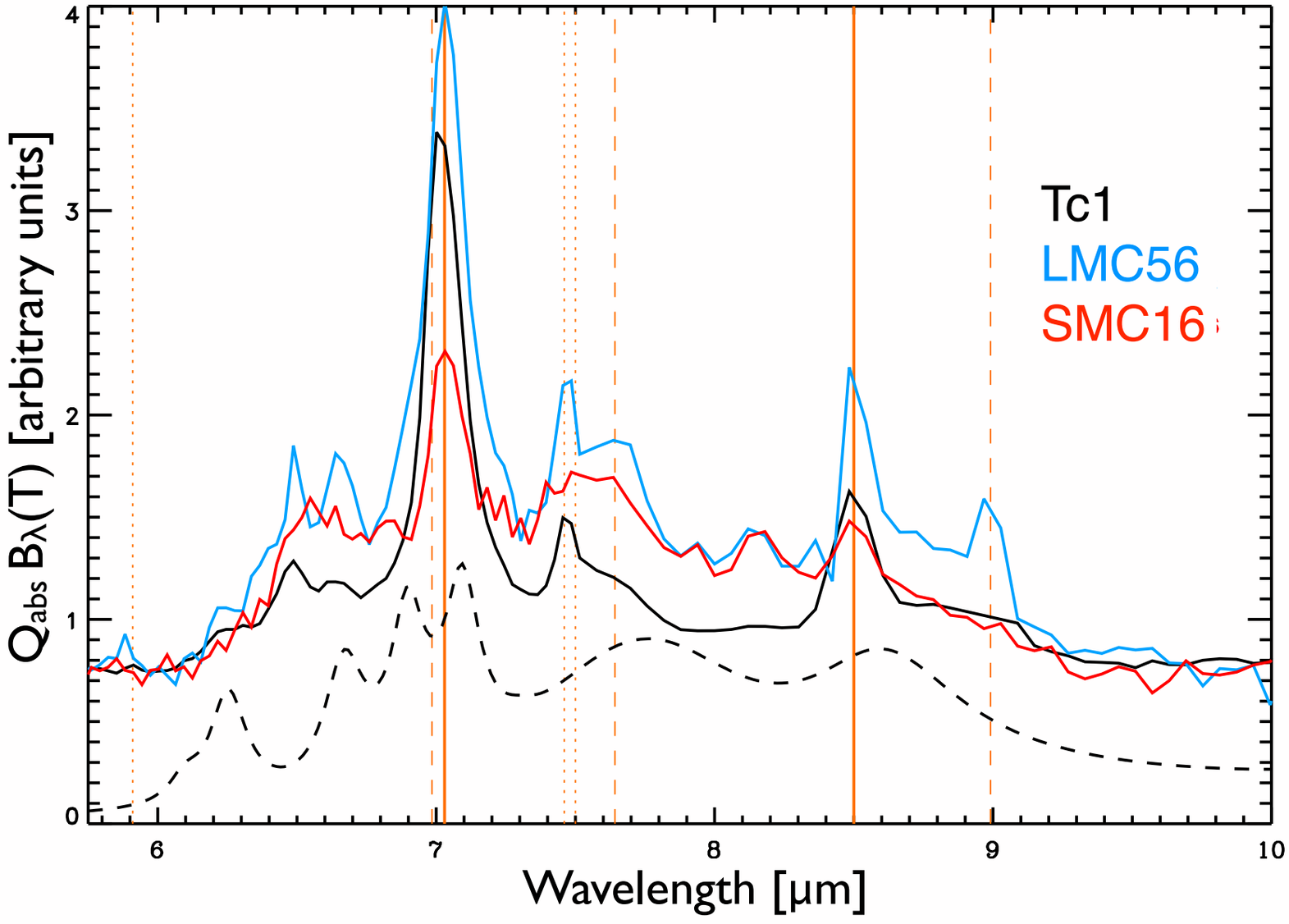
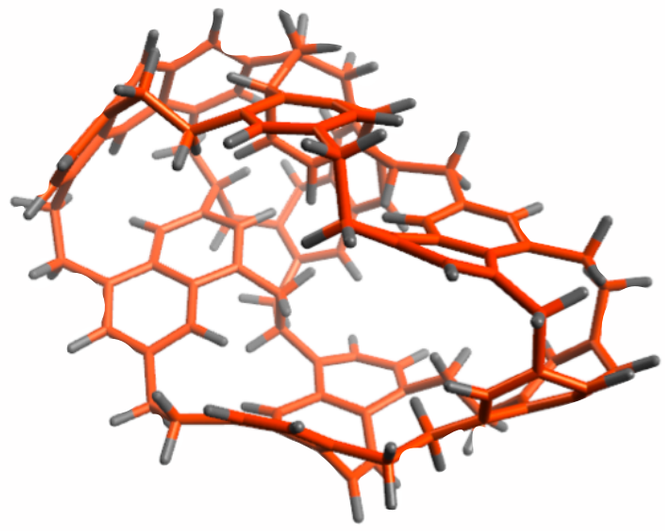


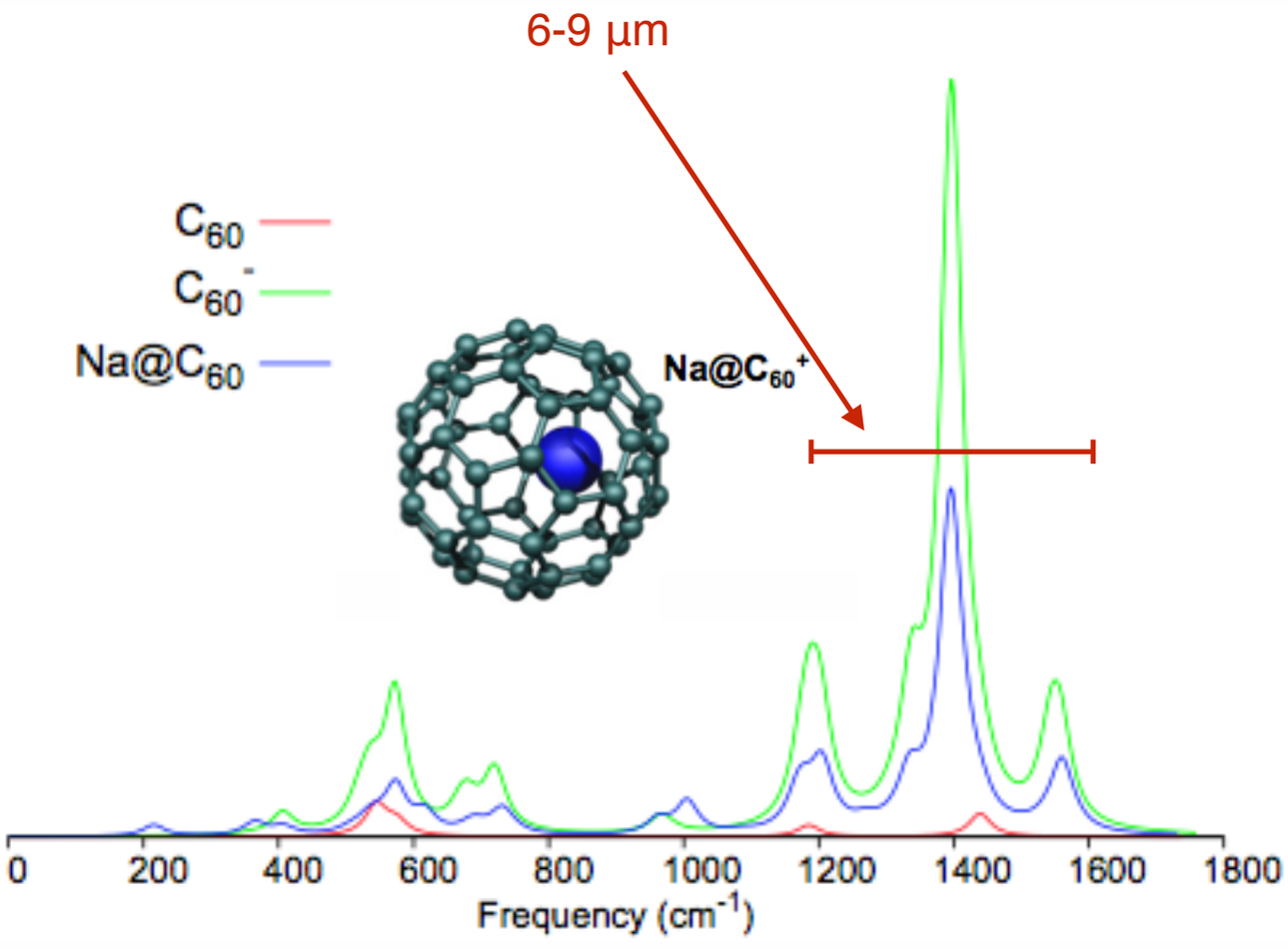


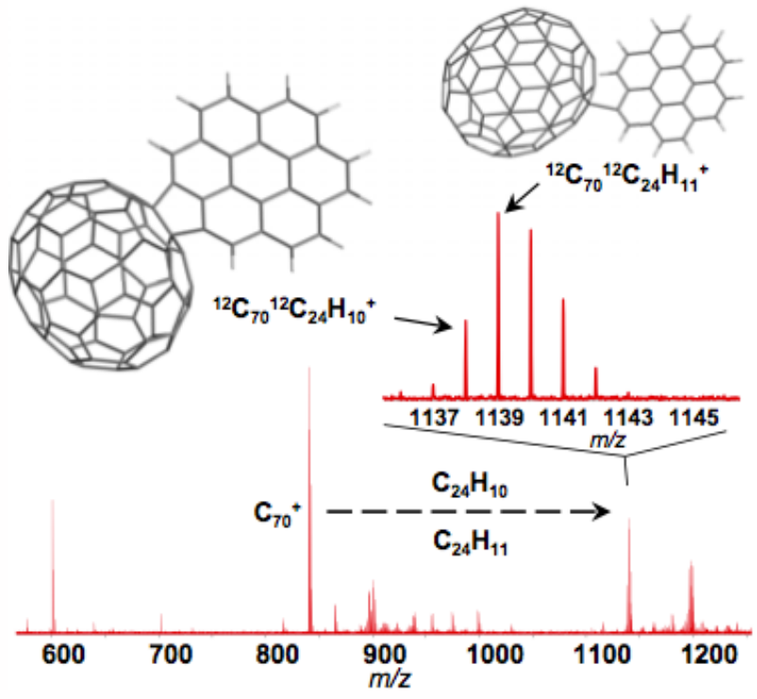
Micelotta et al. (2012)
Poster P7-6

- Plateau consistent with model of HAC nano-particles
  (Bernard-Salas et al. 2012, Jones et al. 2013)

Closed Network Growth

- Metallofullerenes: Symmetry breaking activates silent modes, e.g. 6-9μm



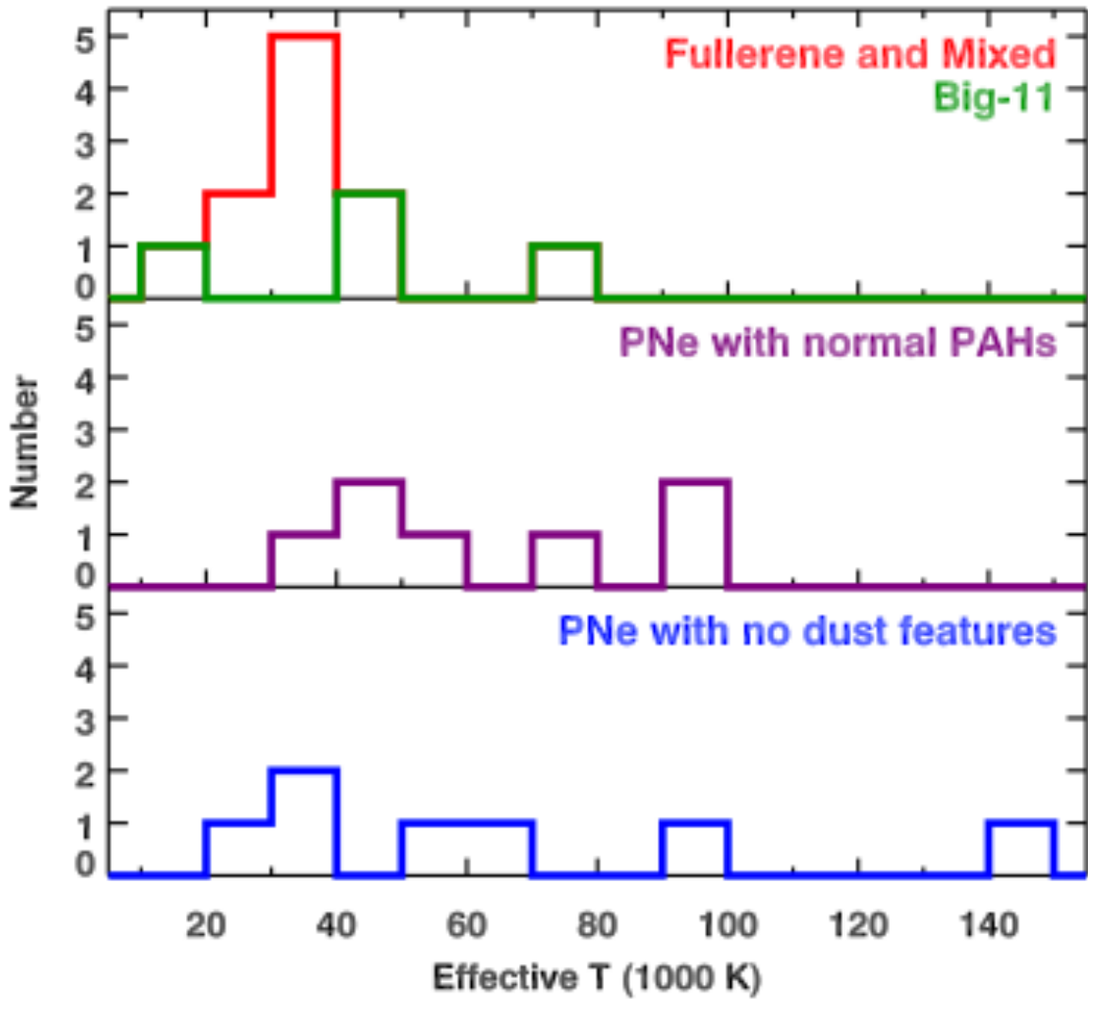


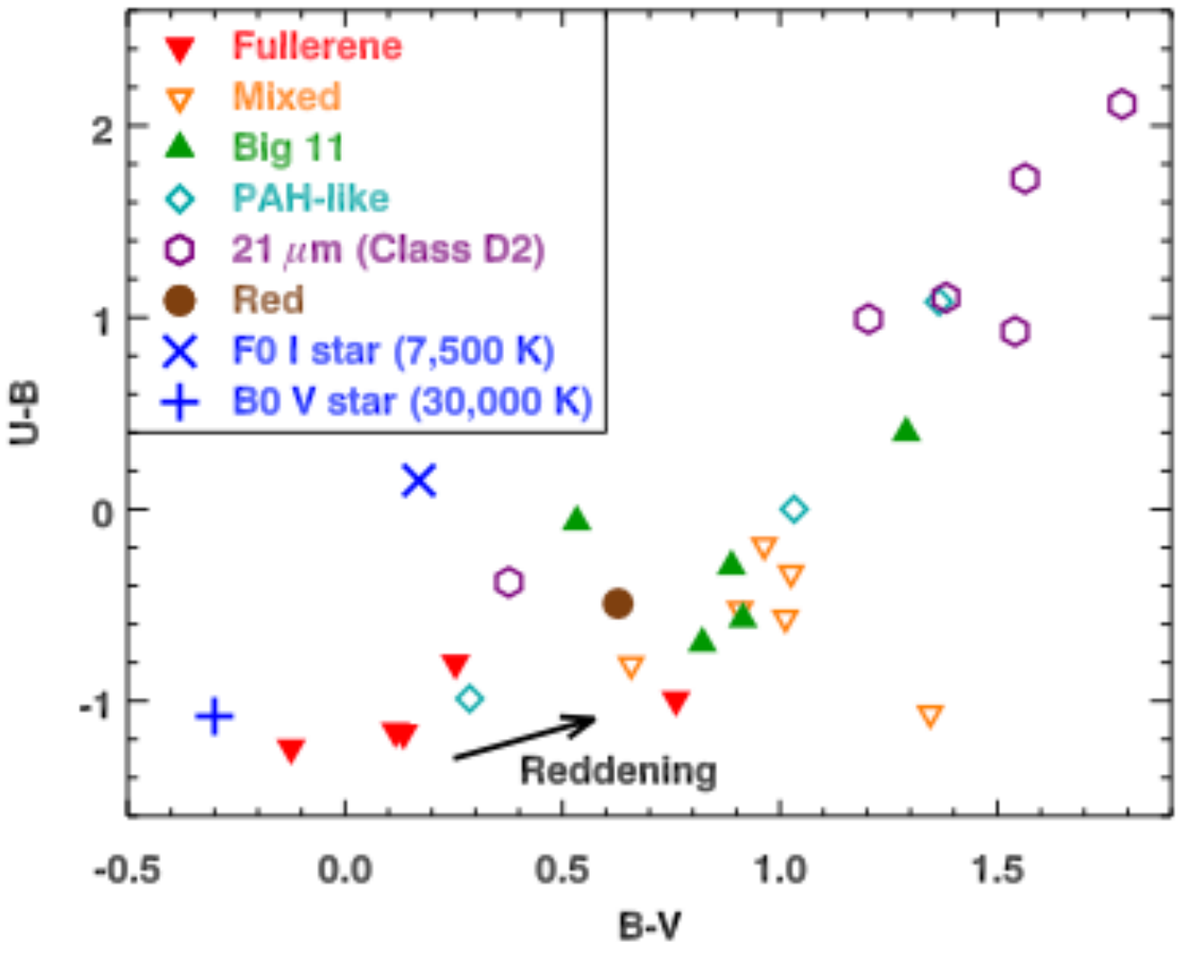
- Reaction PAHs-Fullerenes: insight on how fullerenes aggregate in c-grains

Dunk et al. (2012, 2013)

Fullerenes in Evolved Stars

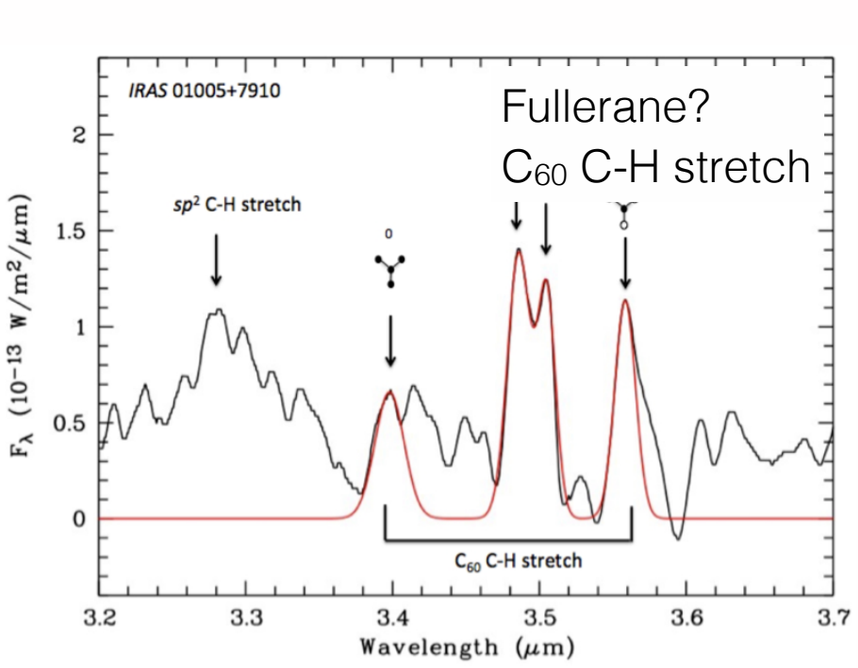
- Not common: 3% of Galactic C-rich PNe (Otsuka et al. 2013 ➔ P7-8)
- Do not require strong UV fields and are bluer (Sloan et al., sub. ➔ P7-9)
- Mostly in C-rich environments, but also O-rich! (Gielen et al. 2011)



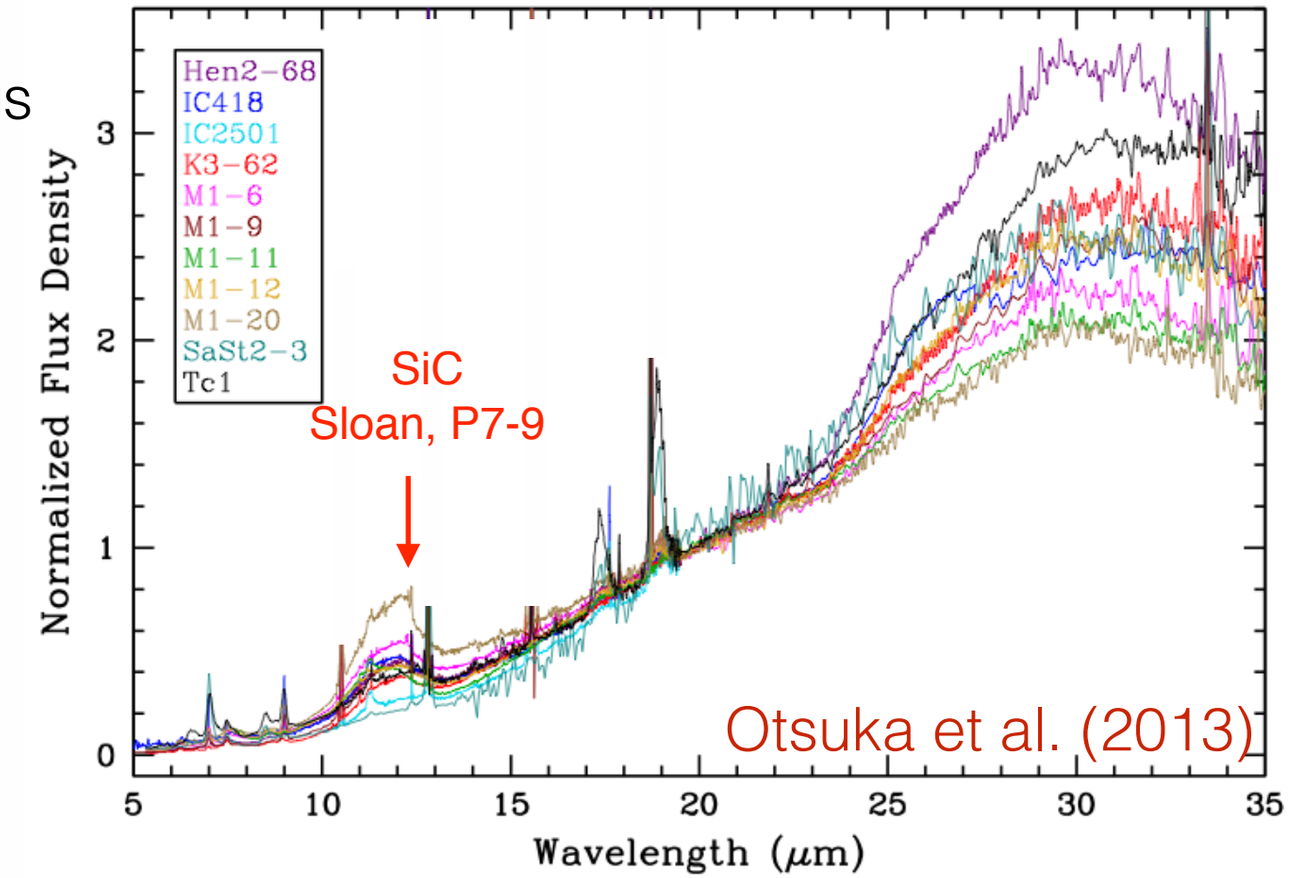


Carbon-rich evolution?

- Strong fullerenes ➔ weak PAHs, plateaus
- Weak fullerenes ➔ PAHs
- All show 30μm feature! Correlates with dust (Kemper et al. **P7-3**)



Zhang & Kwok (2013)



Otsuka et al. (2013)

We need a consistent picture for carbon-rich evolution

Summary

- Fullerenes detected in many circumstellar & interstellar environments:
  - Formed in the post-AGB to PNe phase
  - Survive the ISM

- Excitation due to fluorescence (mixture of species?)

- Formation is still debated:
  - Photo-chemical processing of HACs /Arophatic
  - Closed Network Growth

➡Evolution of organic material

- Role in the ISM?
  Extinction, chemistry, molecular to solid state physics,…

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