Photoluminescence by Interstellar Dust

And A Look at the Dust Characteristics in the LMC using the Spitzer Space Telescope

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Outline

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Dust Grains and Nanoparticles
Interstellar Extinction

- Interstellar dust grains span a wide range of sizes: $\sim$ few Å to few μm
- Interstellar nanoparticles form the smallest and the most numerous of these grains
- The structural building blocks of larger, composite grains
- Are in pristine form: retaining their chemical and structural characteristics
- Hold the key to understanding the nature of interstellar grains

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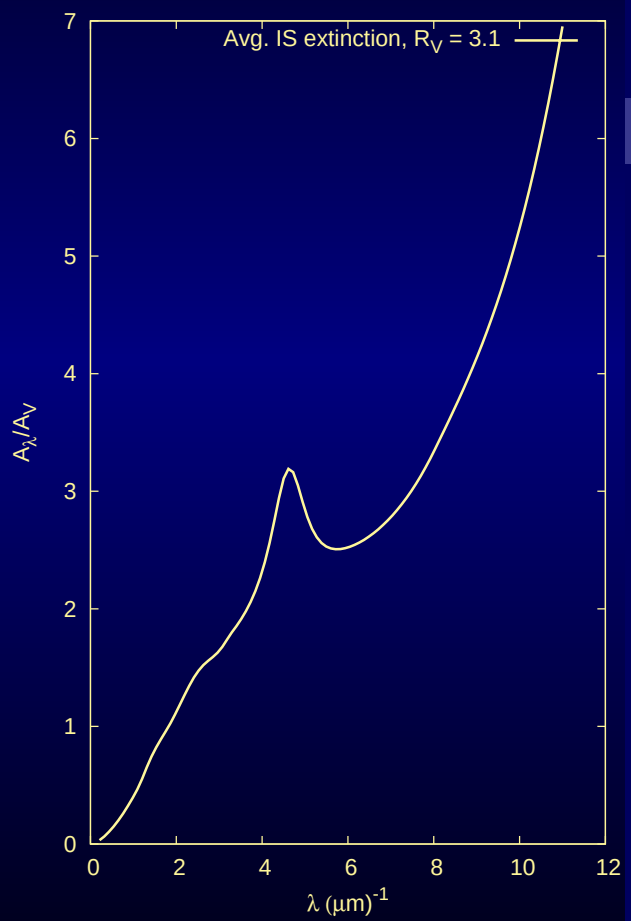

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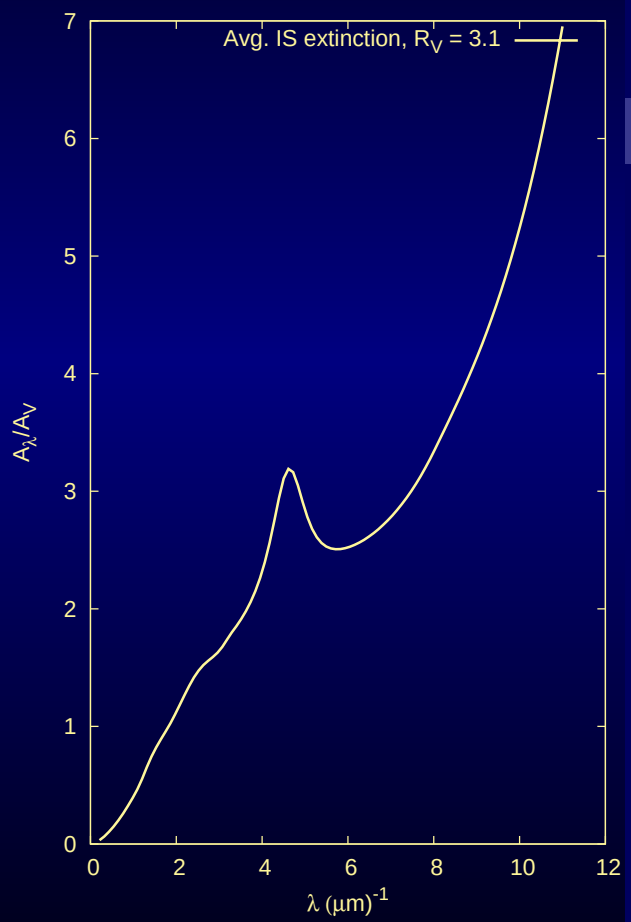

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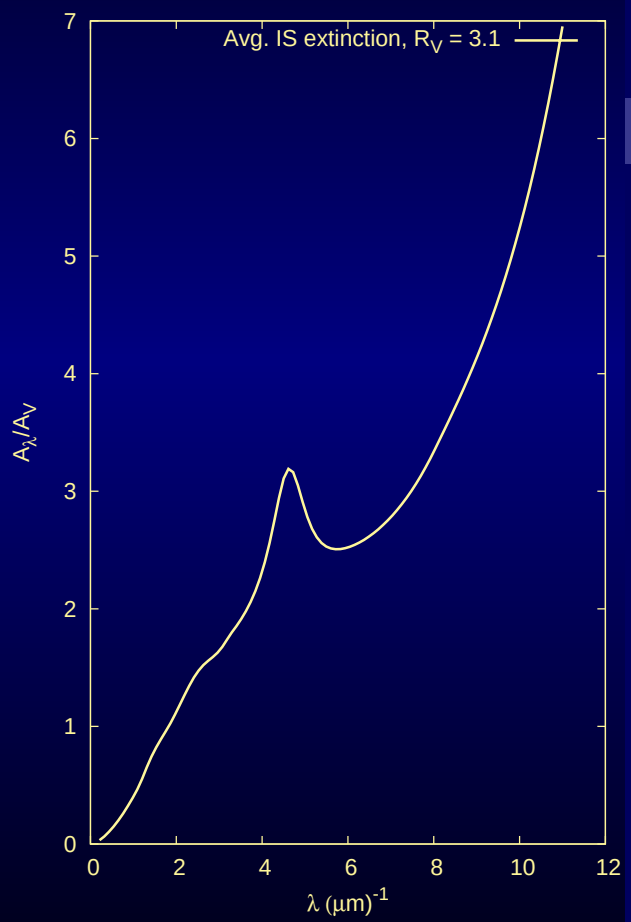

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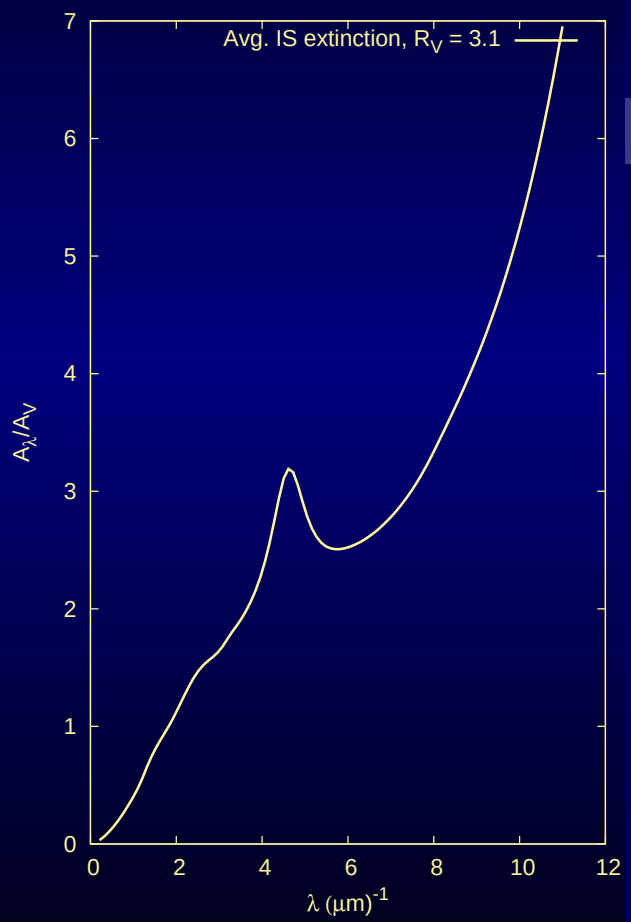
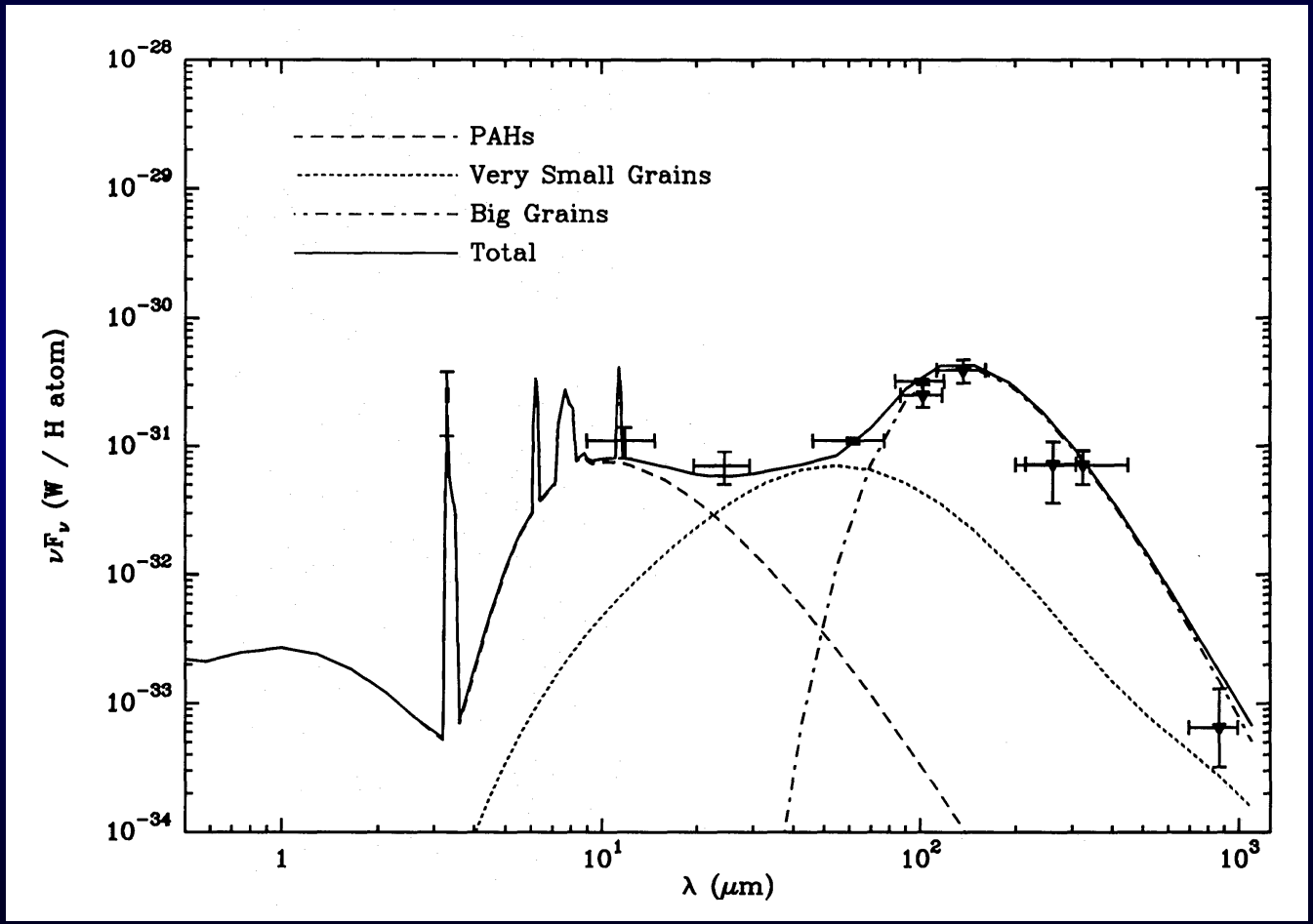


Dust Grains and Nanoparticles

Emission from IS Dust



(from Desert et al, 1990, A & A, 237, 215)

Dust Grains and Nanoparticles
Emission from IS Dust: Photoluminescence

- *Photoluminescence (PL)* is process in which absorption of UV/optical photons is followed by electronic transitions associated with the emission of photons
- Interstellar dust in nebulae, H II regions, planetary nebulae, external galaxies as well as in the diffuse ISM exhibits photoluminescence in the 500 nm to 1000 nm spectral range, known as *Extended Red Emission (ERE)*.

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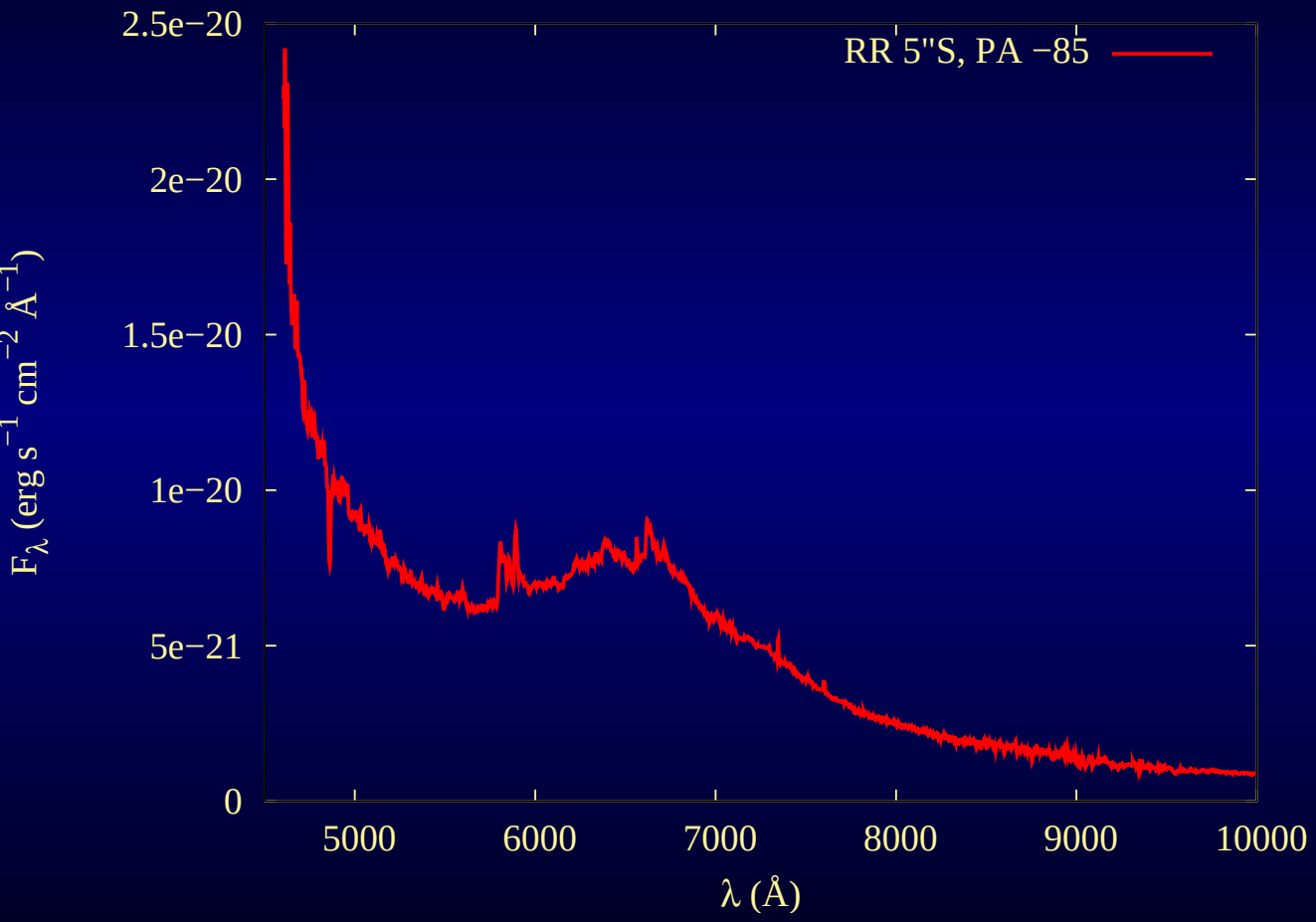

- Known now for over three decades, the carrier of the ERE is still unknown.

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Dust Grains and Nanoparticles
PAHs in the ISM
Blue Luminescence
Presence of Small PAHs in the ISM
The Excitation of ERE
Summary

PAHs in the ISM
Infrared Emission Bands

- PAHs are ubiquitous in space and form the class of largest known molecules in the ISM
- The IR spectra of many classes astronomical objects are dominated by emission features at 3.3, 6.2, 7.7, 8.6, 11.2 and 12.7 μm
- These features (called UIR or AEFs) coincide with the stretching and bending modes characteristic of aromatic materials

The ISO-SWS spectra of NGC 7027 and the PDR in the Orion Bar (From Peeters et al. 2004, in ASP Conf. Proc. 309, 141)

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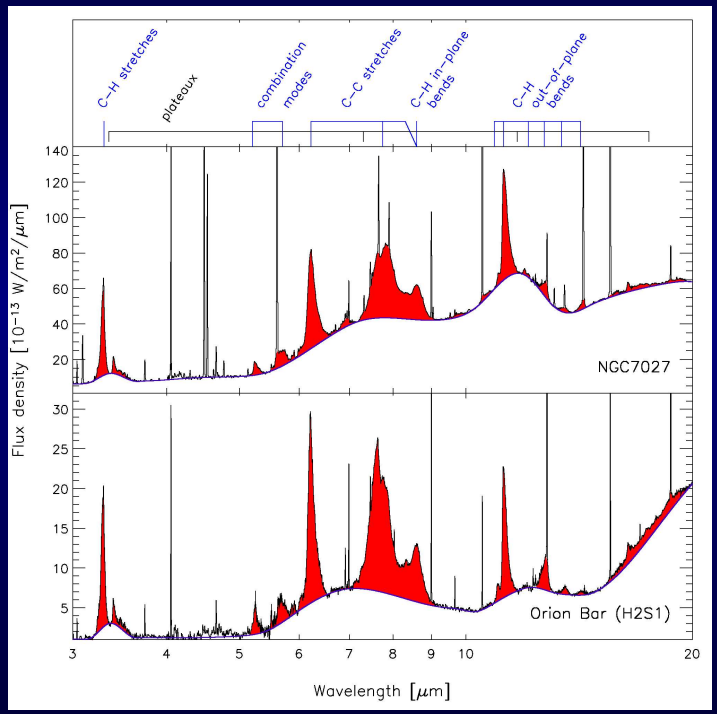

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PAHs in the ISM
Optical Fluorescence

- The vibrational transitions responsible for the AEFs are largely independent of size, structure and ionization state of the molecule. (Vijh et al. 2004, ApJ, 606, L65)
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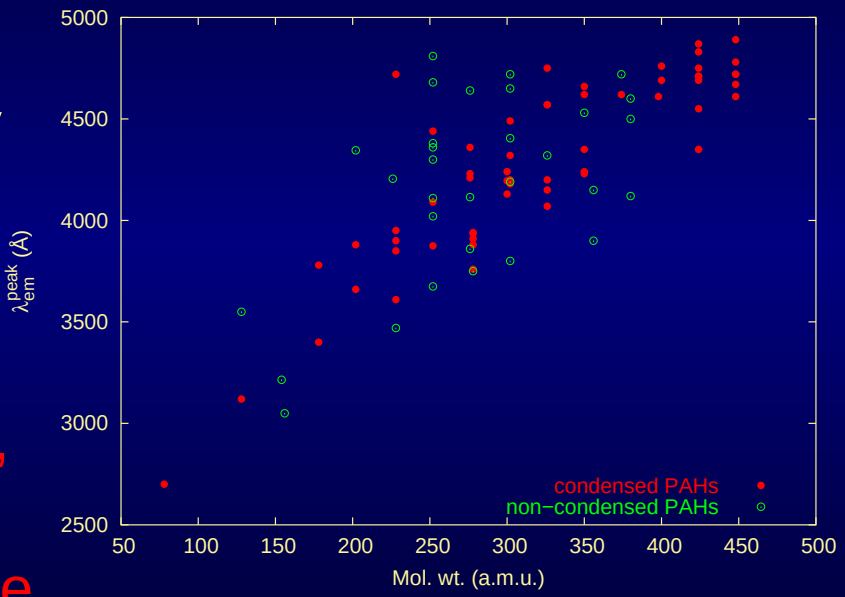

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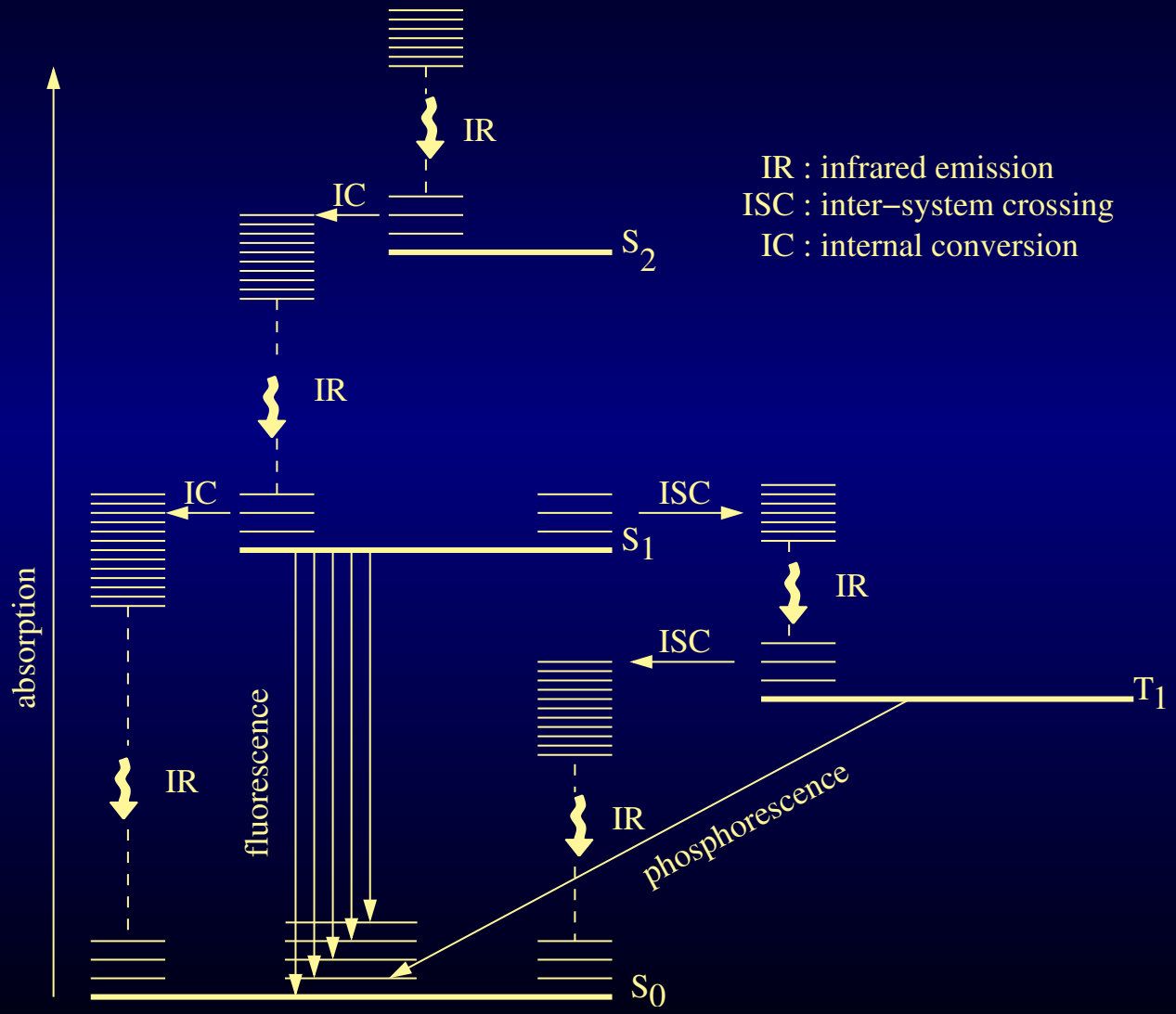

Jablonski diagram

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The Red Rectangle

- First identified by Cohen et al. 1975 and so named because of the distinctive appearance on the Palomar Sky Survey
- Unique, peculiar, proto-planetary nebula

HST WFPC2 (F622W + F467M)

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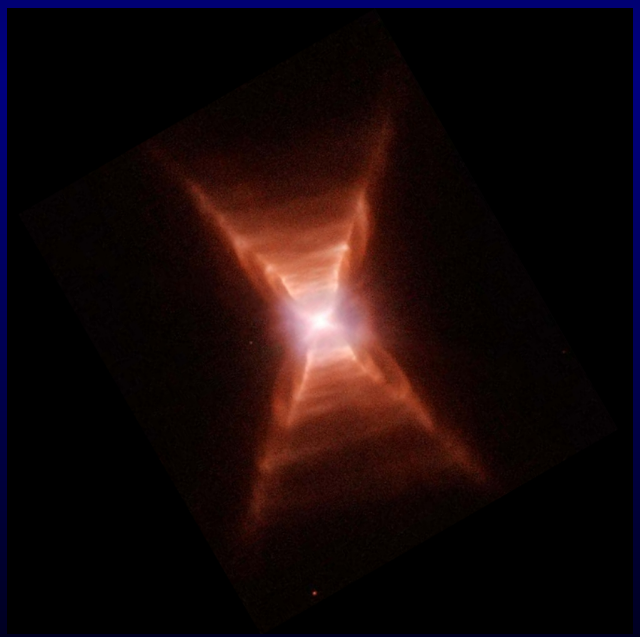

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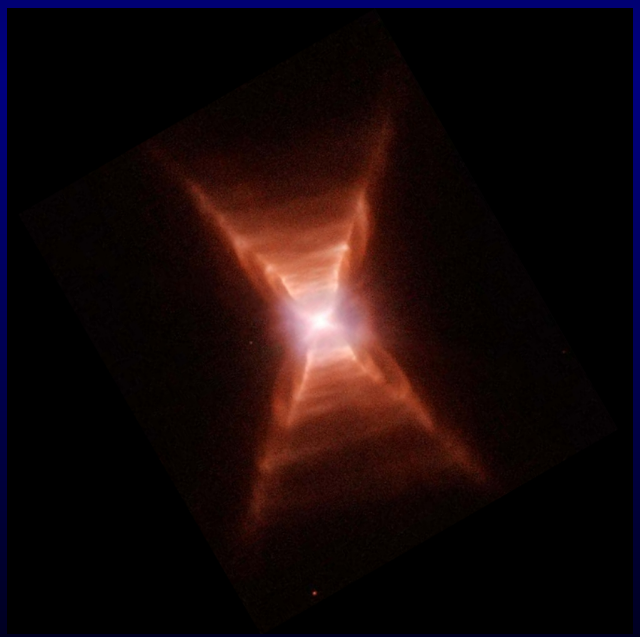

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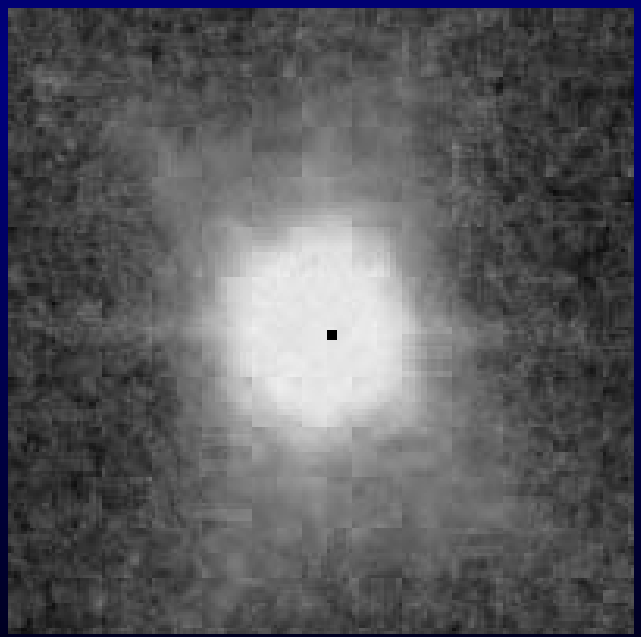

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Discovery of the BL
The Red Rectangle

- The central star HD44179 is a A III post-AGB star, in a stage of active dust production
- Close hot white dwarf companion ($T_{eff} \sim 60{,}000$ K)
- Optically thick circum-binary dust torus
- Outflow through polar openings produces bipolar structure
- Close-by, rare, short-lived stage of such a system
- Remarkable, favorable viewing geometry

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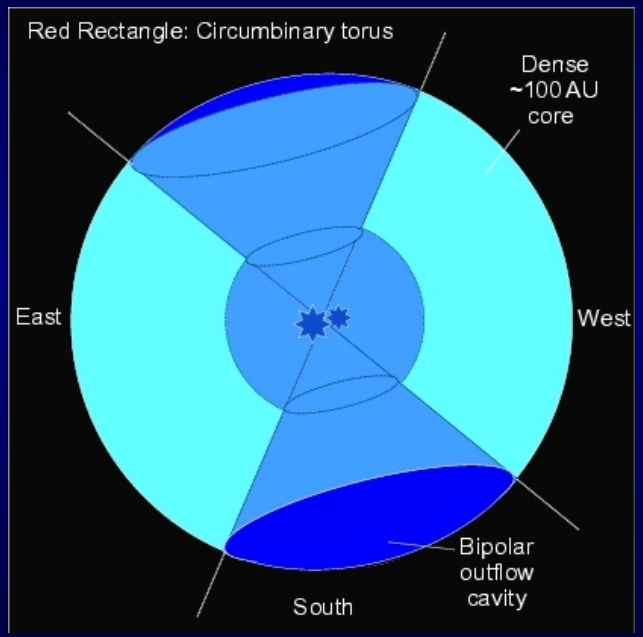

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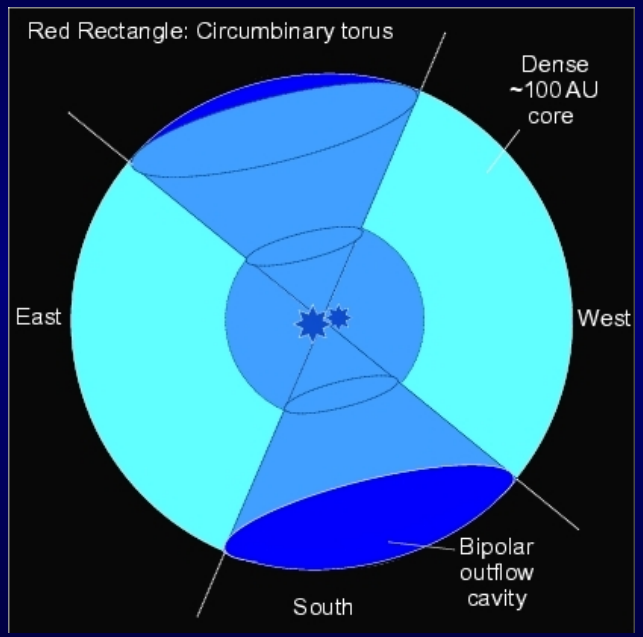

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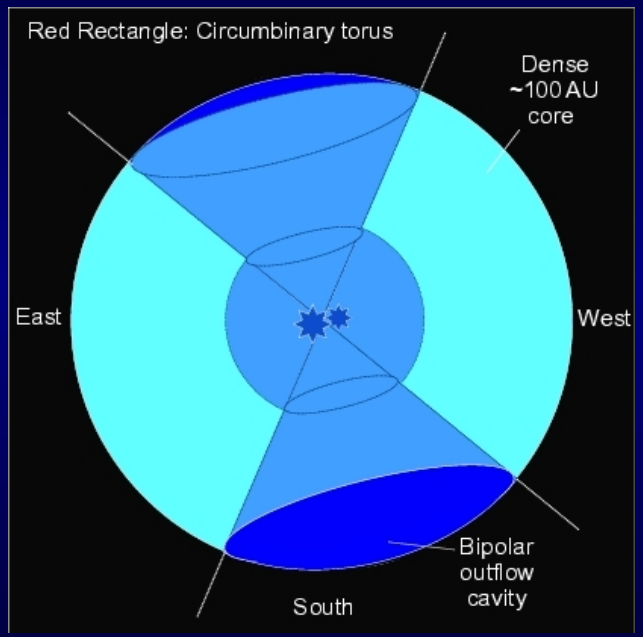

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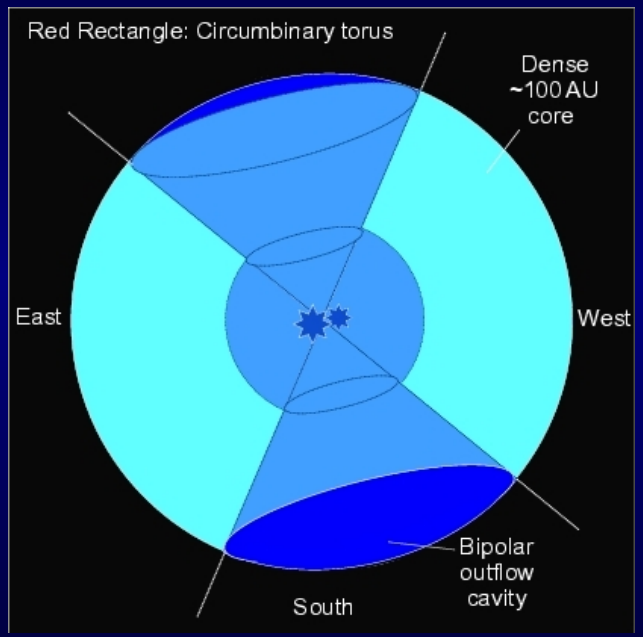

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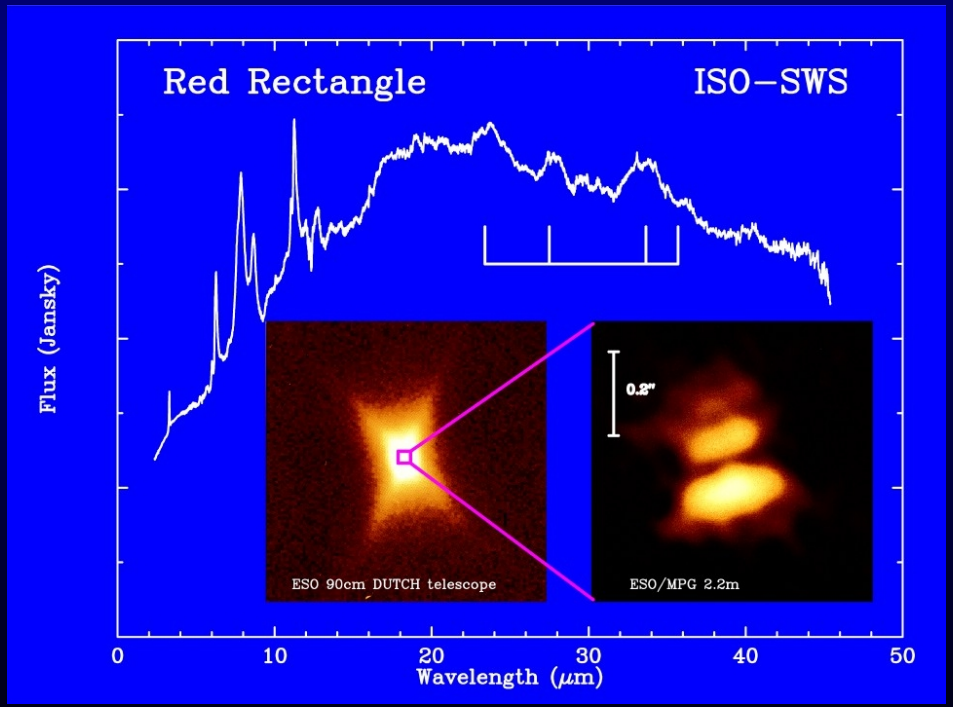
Discovery of the BL
The Red Rectangle

- Source of many dust-related emissions: ERE, UIR/AEF, BL
- First discovered source of the ERE, BL
- Brightest source of the UIR/AEF



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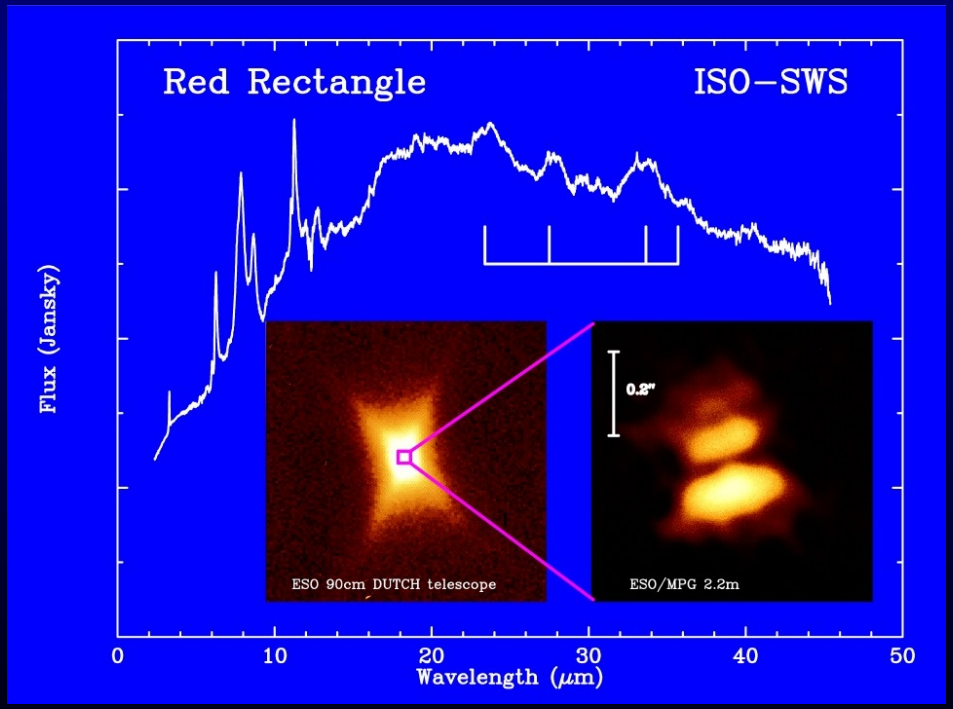

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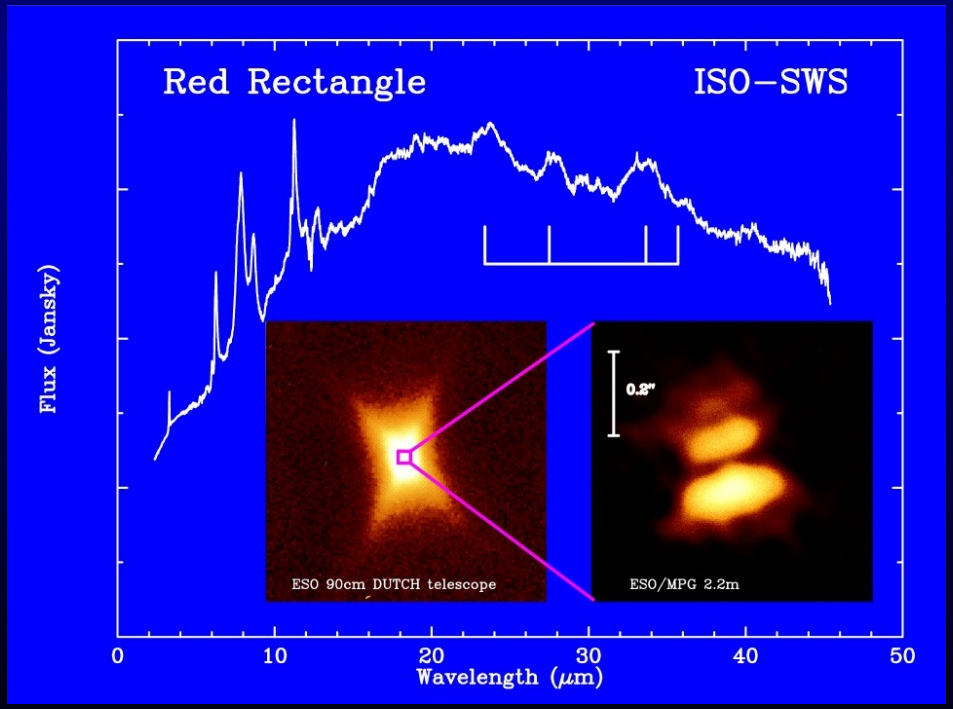

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Detection

- Blue emission band: asymmetrically peaked ($\lambda_{peak} \sim$ 375 nm, FWHM $\sim$ 45 nm)
- Long-slit spectra at two offsets from the central source: 2.5" south and 5" south
- Detected using line-depth technique

(Vijh et al. 2004, ApJ, 606, L65)

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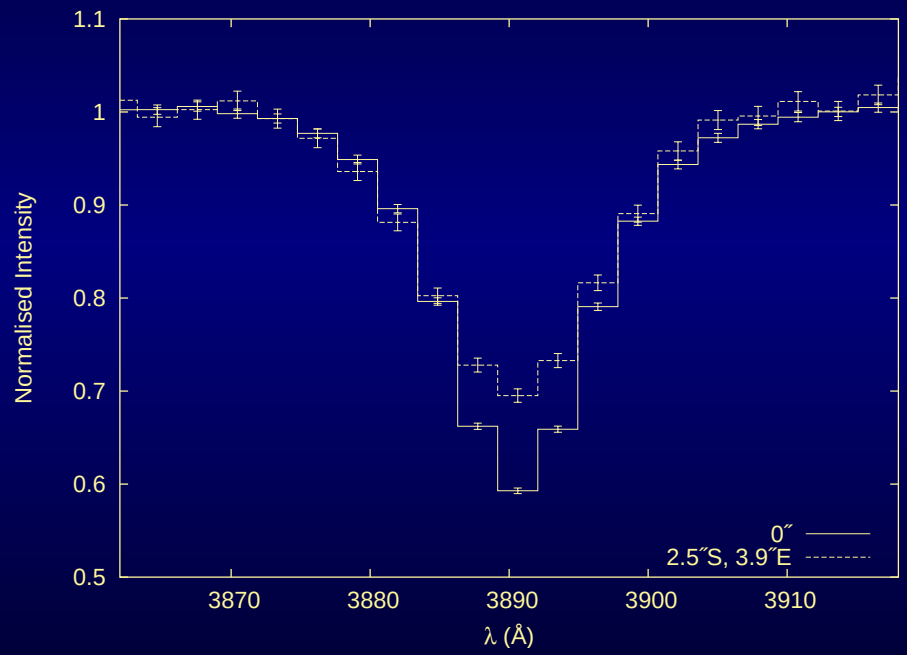

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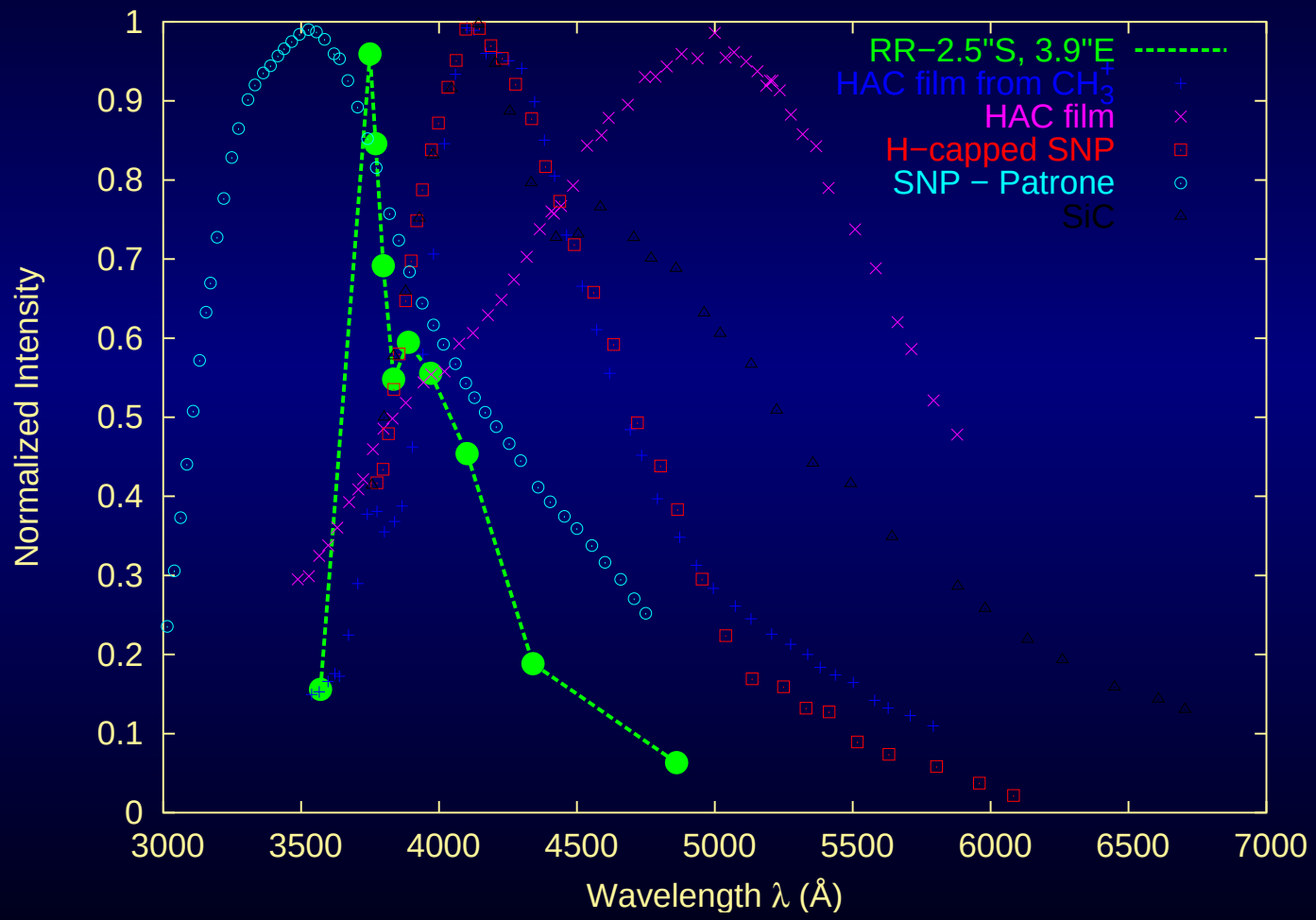
The BL Spectrum

Comparison with solid-state candidates



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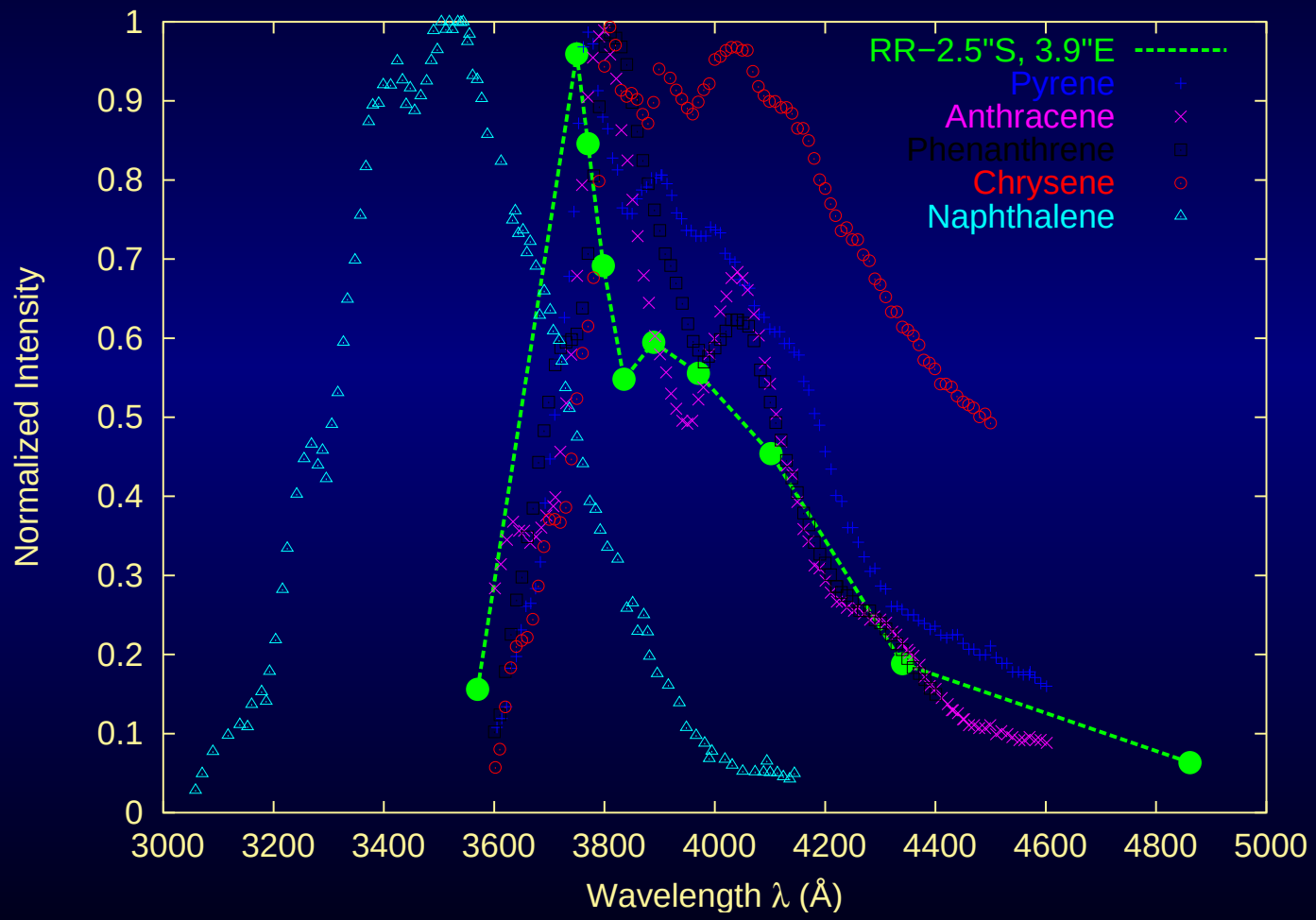

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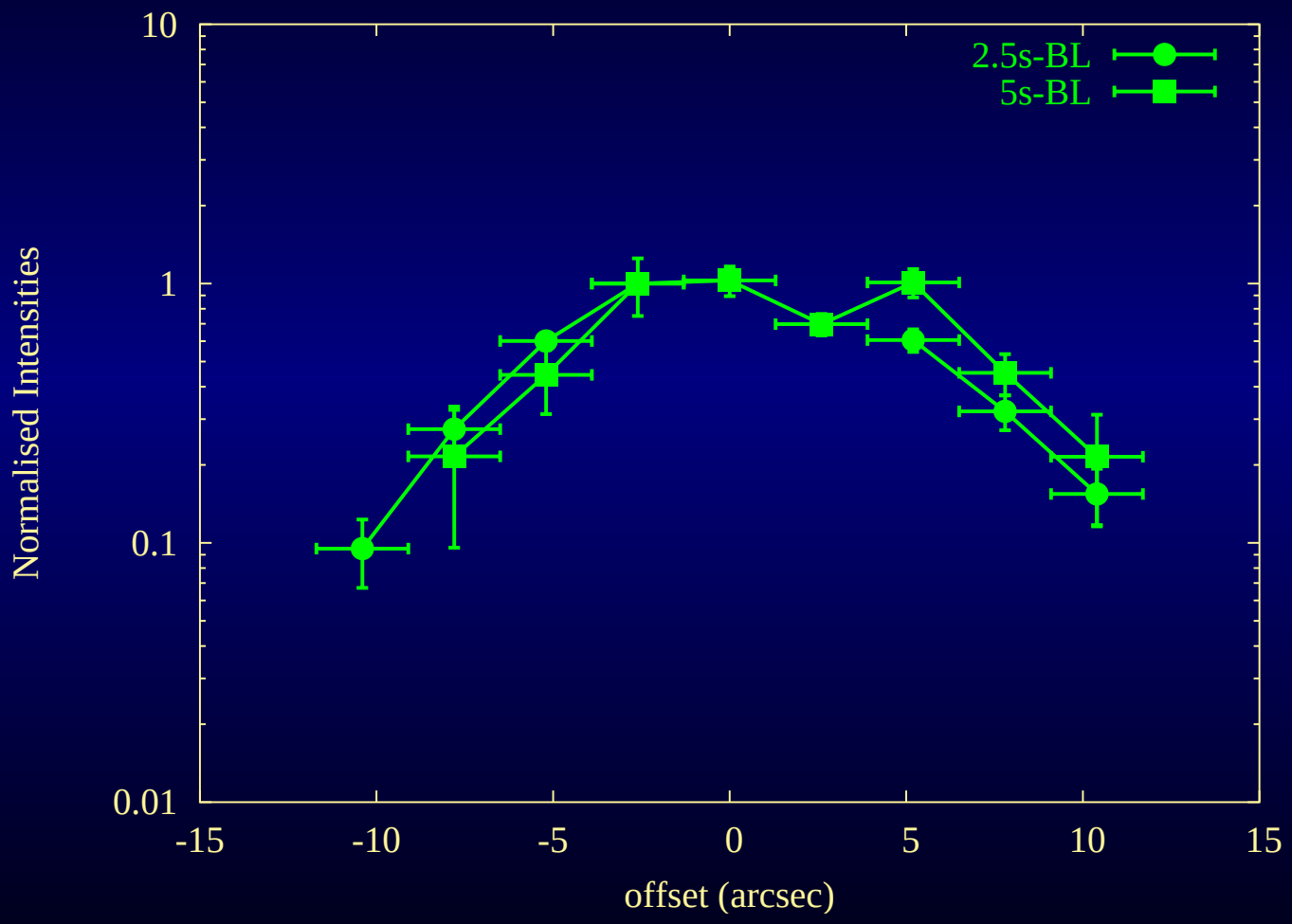

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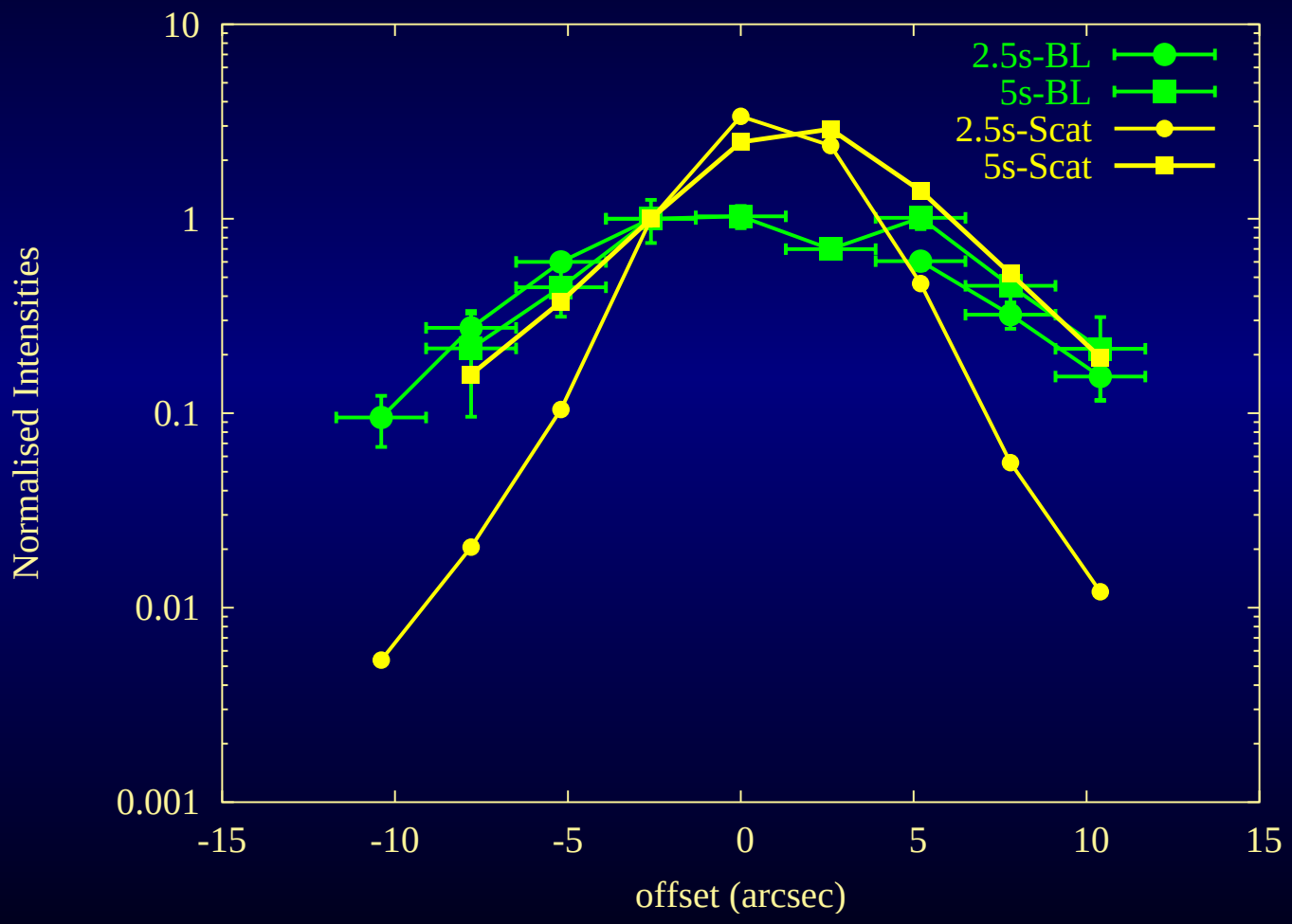

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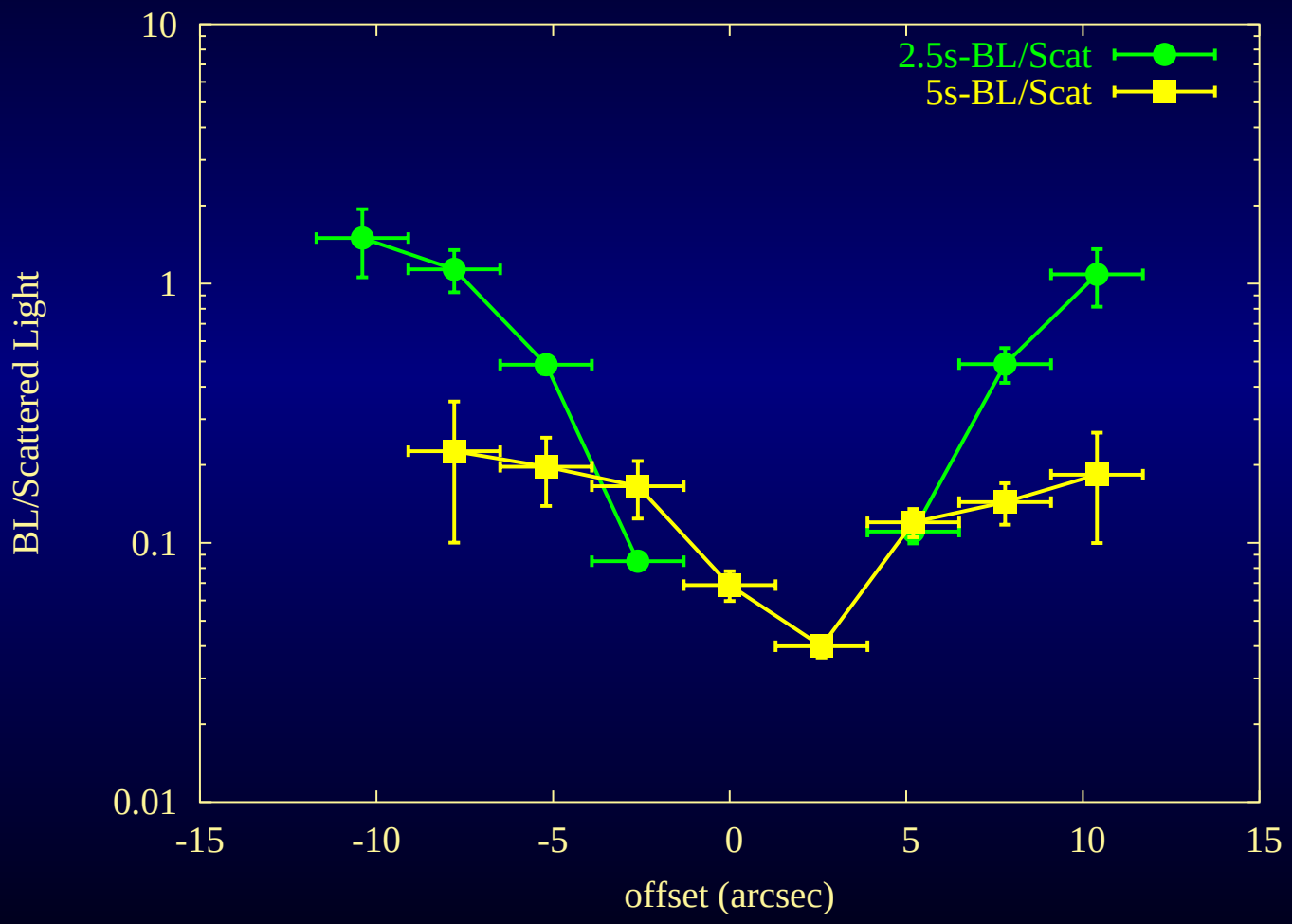

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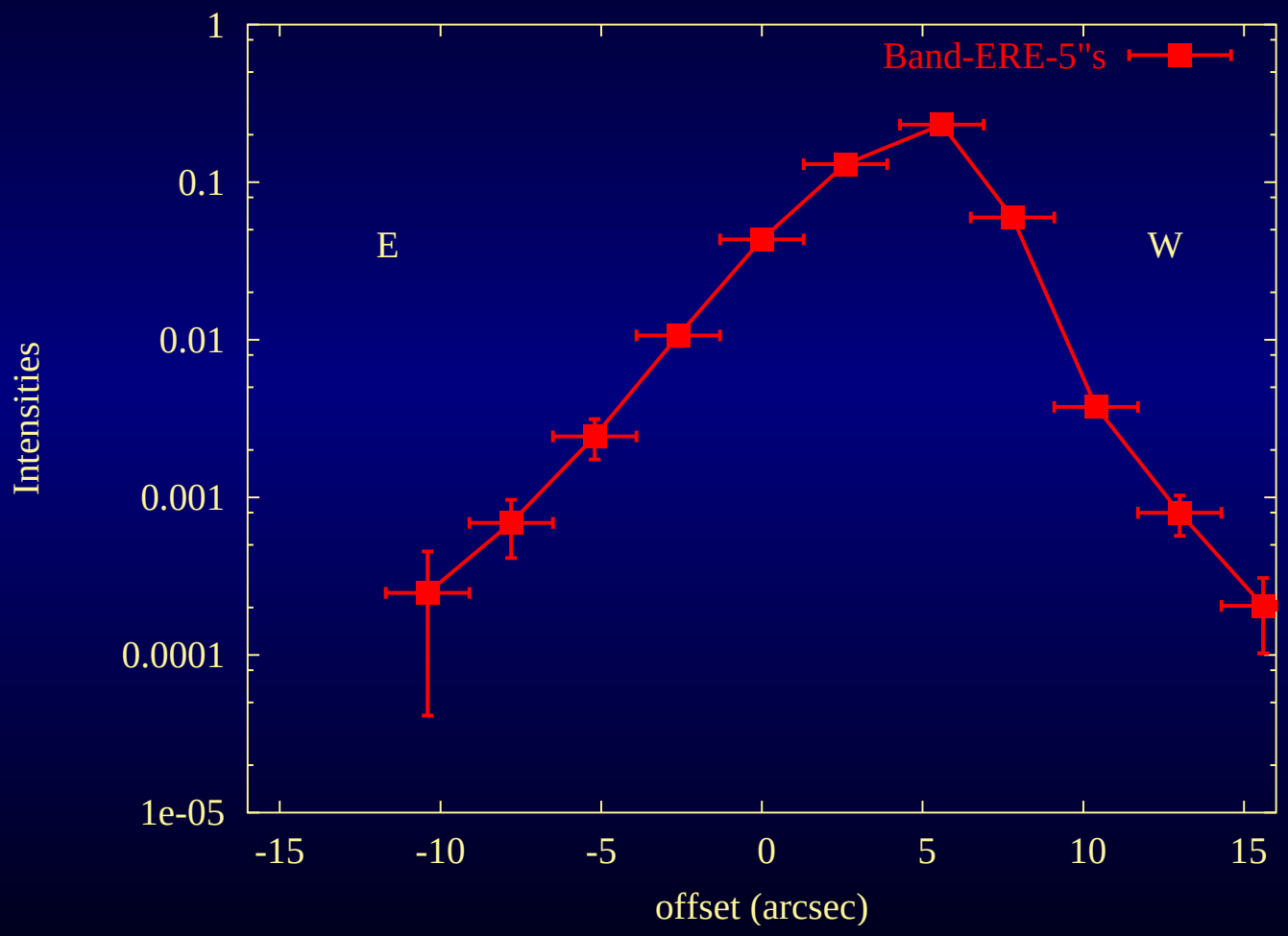

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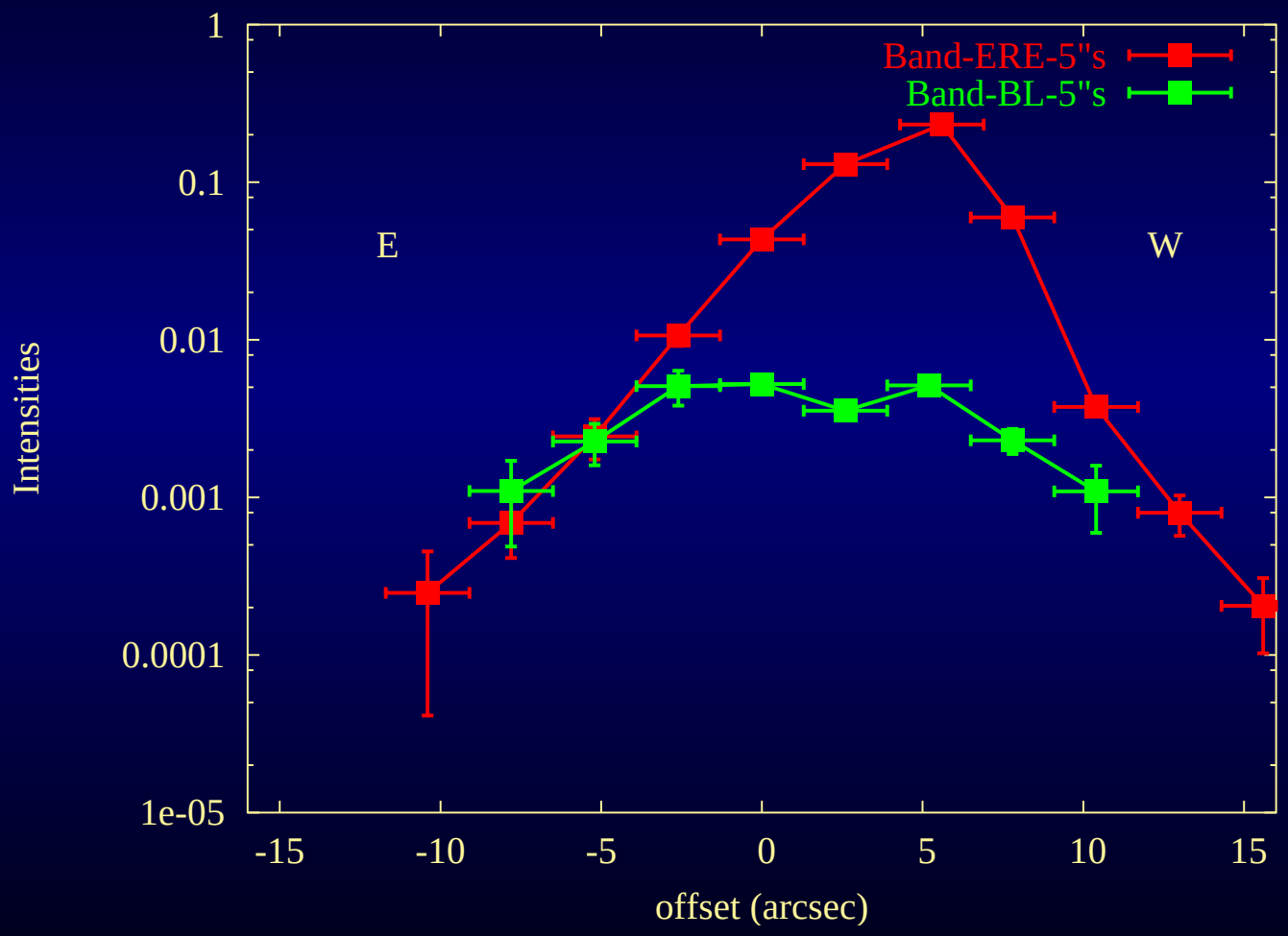

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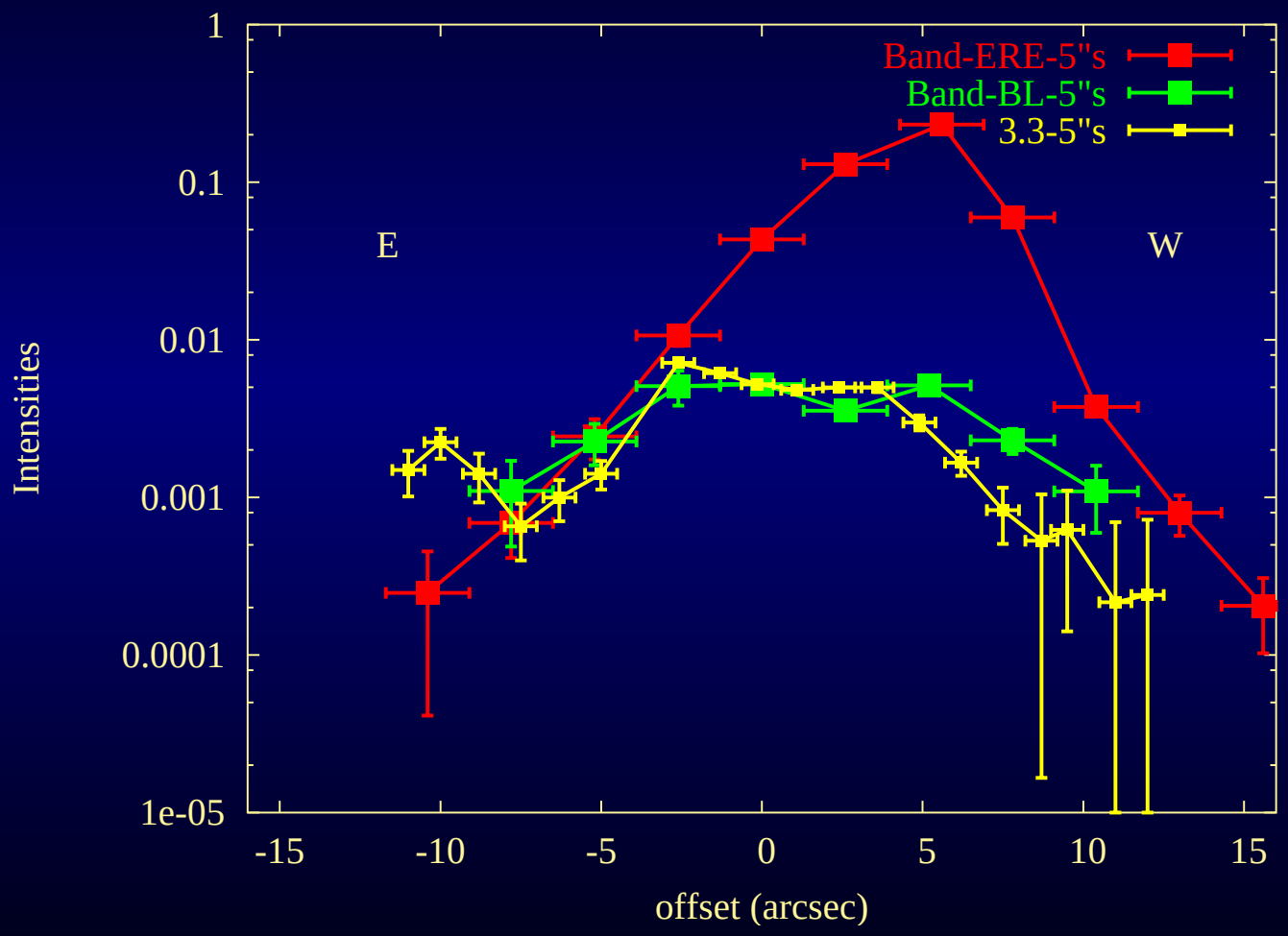

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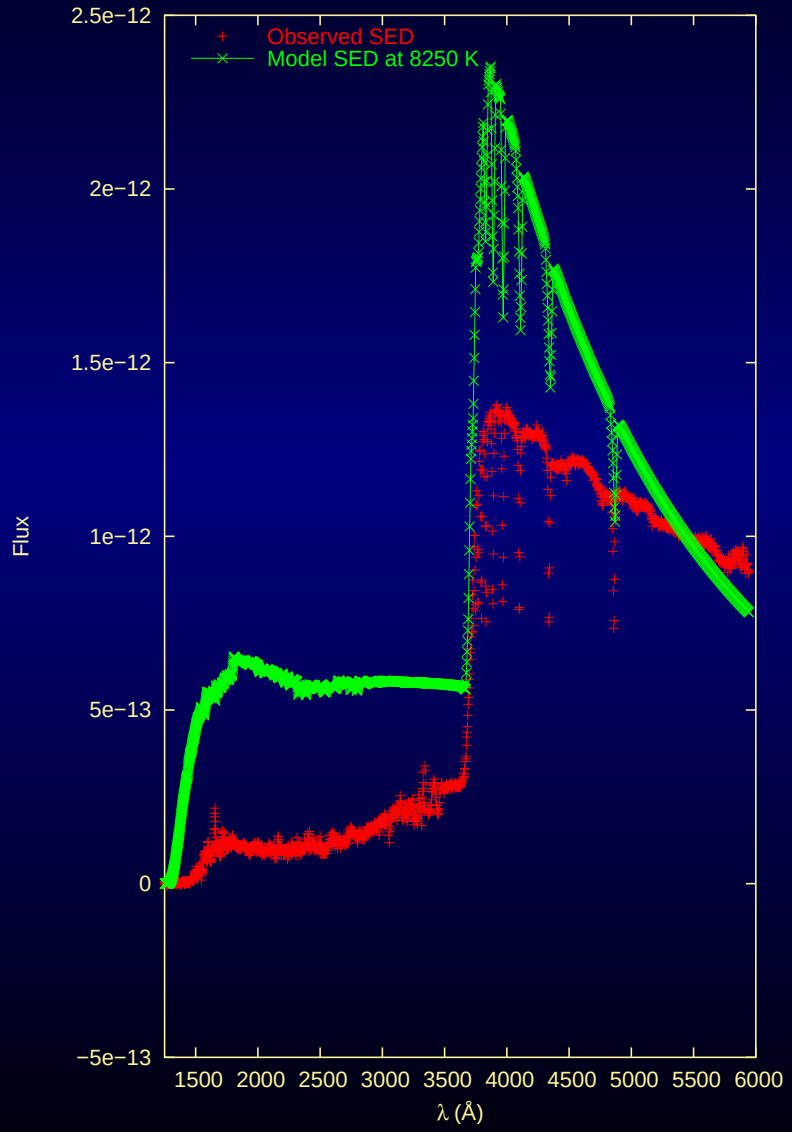

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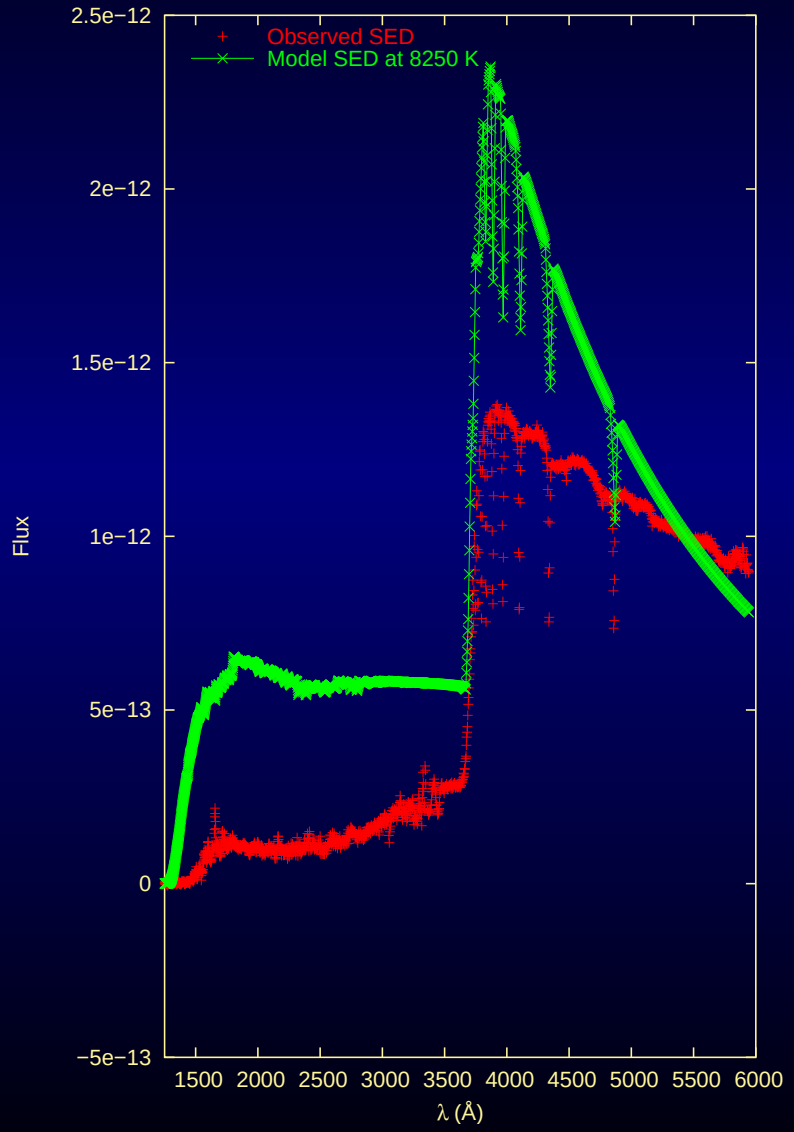

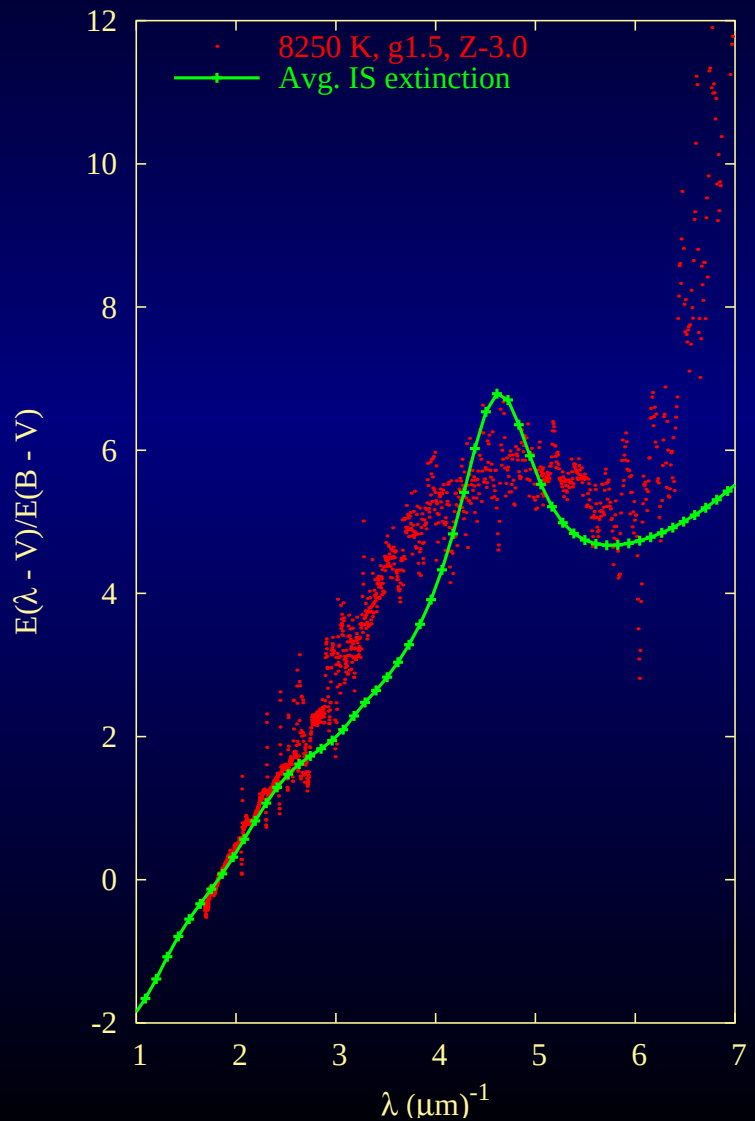

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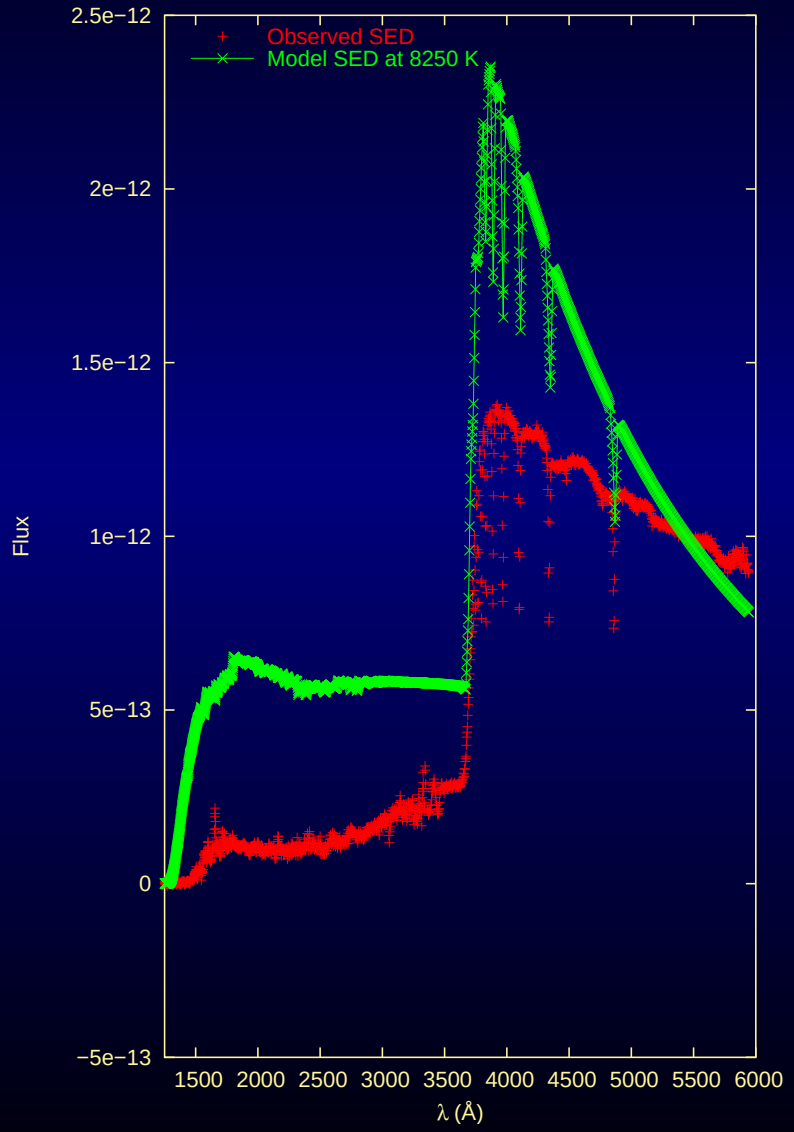

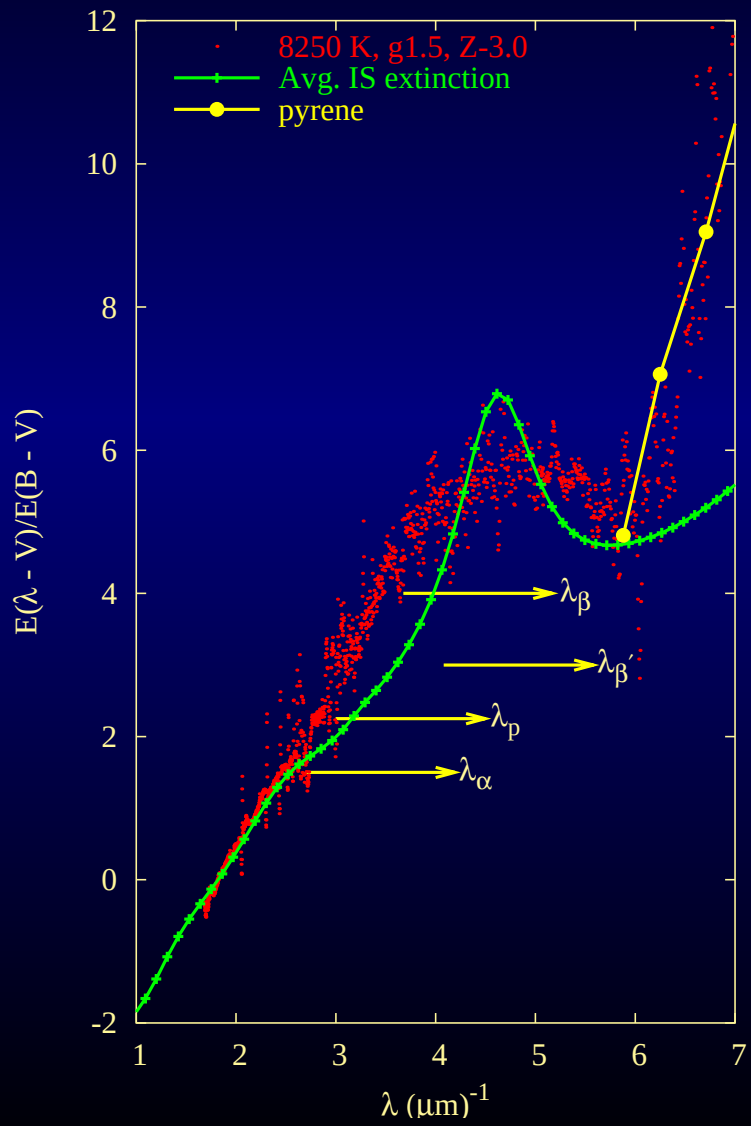

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Presence of Small PAHs in the ISM

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Detection of BL in Other Nebulae

- Do small PAHs survive? Are AEFs primarily produced by large PAHs?
- BL preferentially traces small, neutral PAHs
- BL was detected in several ordinary reflection nebulae illuminated by stars ($T_{eff} \sim$ 10,000 – 23,000 K)
- All these nebulae also exhibit AEFs
- Provides evidence for grain processing and possibly in-situ formation of small PAHs from larger aggregates
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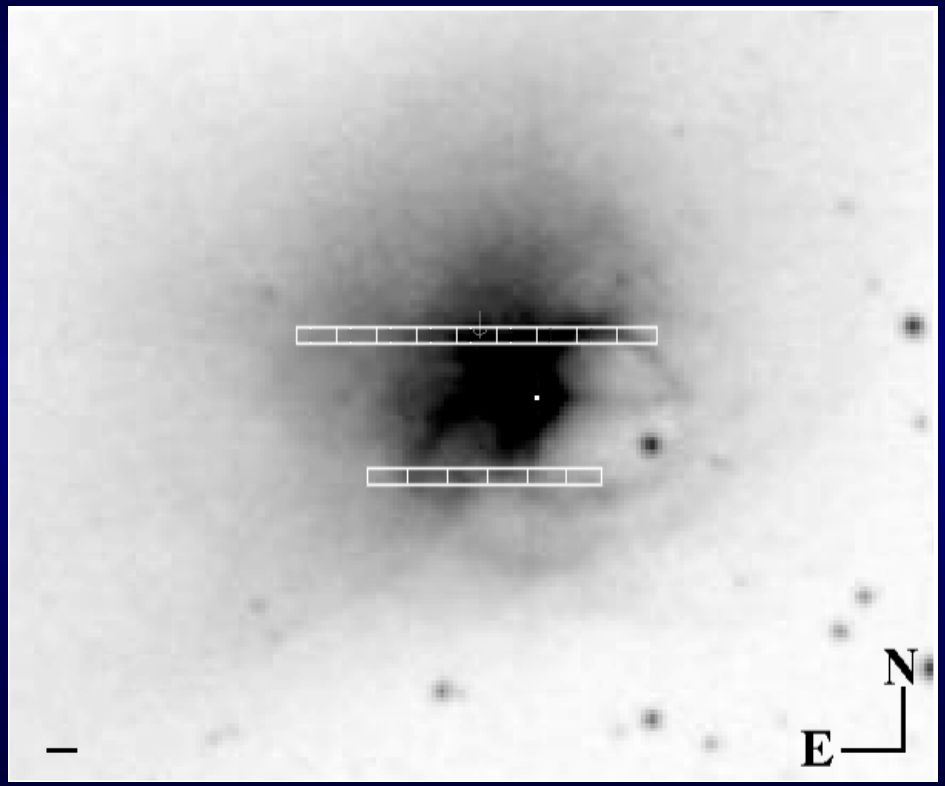
Detection of BL in Other Nebulae

Ced 201

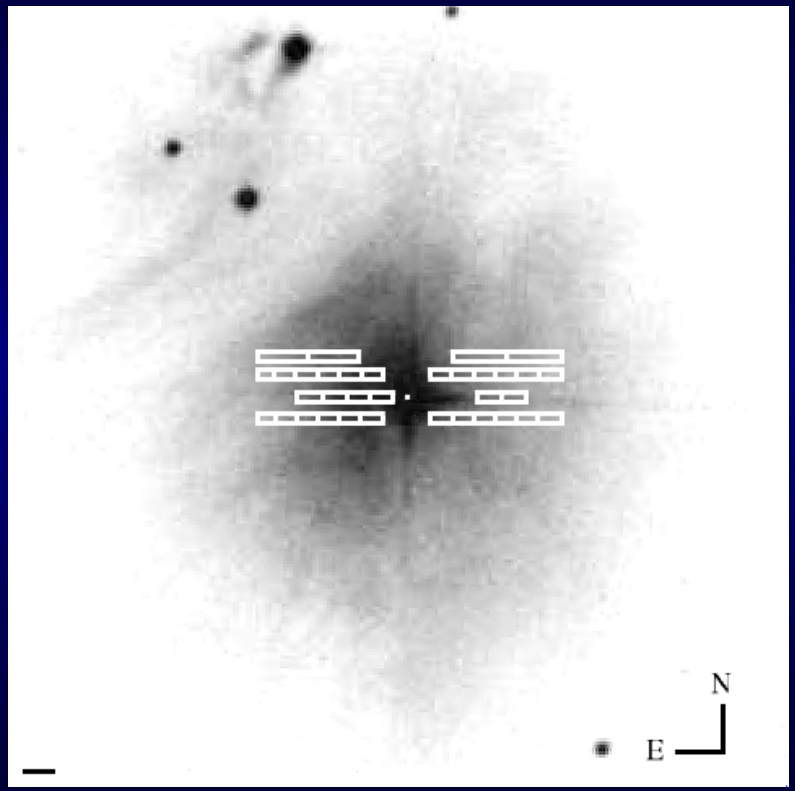


Central star: BD +69 1231, B9.5 V, $T_{eff} \sim 10{,}000$ K

(Vijh et al. 2005, ApJ, 633, 262)

Detection of BL in Other Nebulae

Ced 112

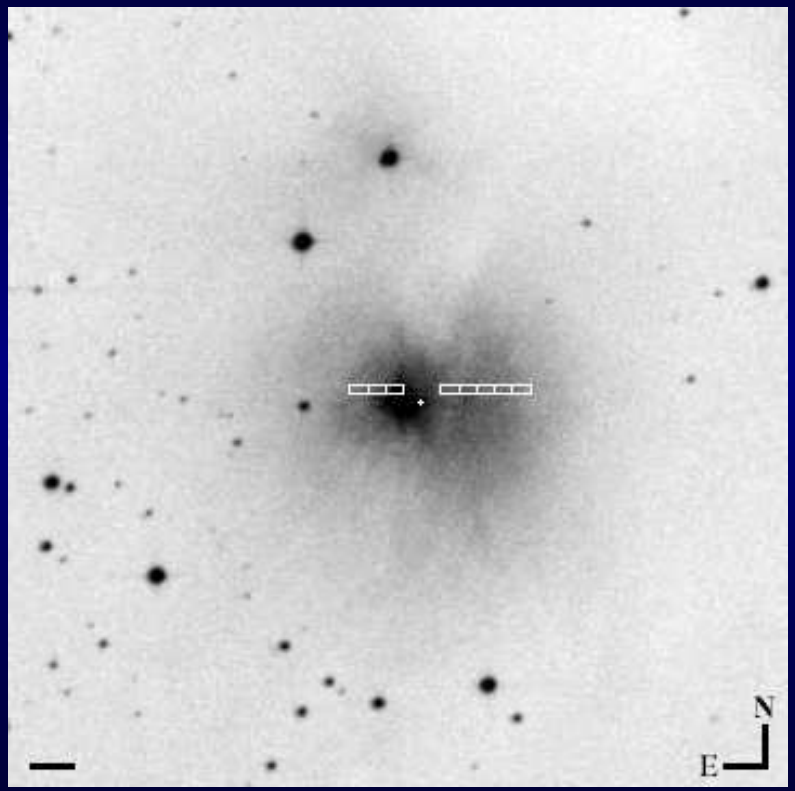


Central star: HD 97300, B9 V, $T_{eff} \sim 10{,}500$ K

(Vijh et al. 2005, ApJ, 633, 262)

Detection of BL in Other Nebulae

NGC 5367

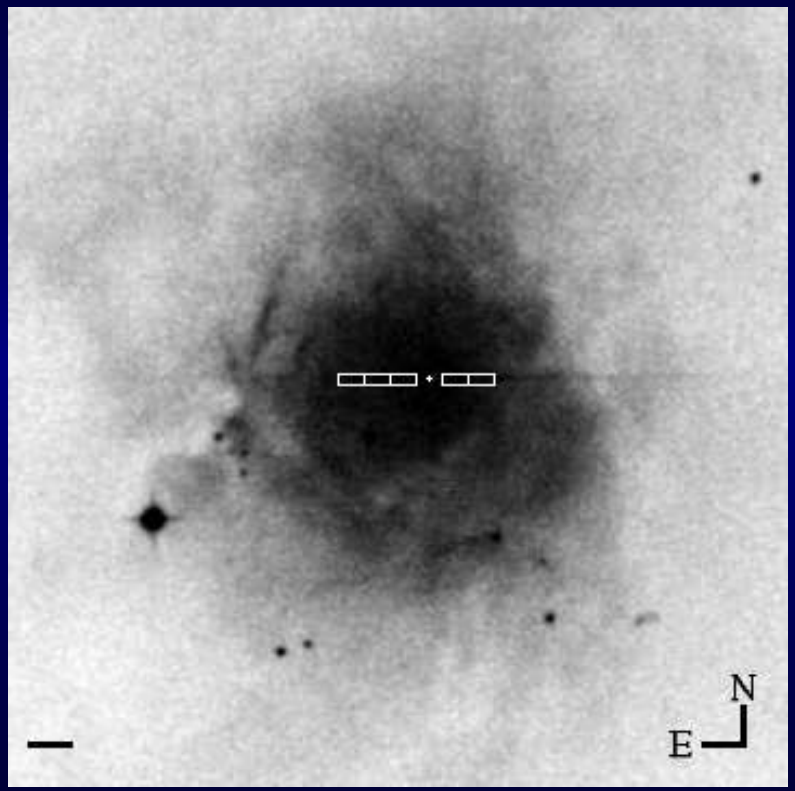


Central star: Her 4636, Herbig Ae/Be, $T_{eff} \sim 18{,}700$ K

(Vijh et al. 2005, ApJ, 633, 262)

Detection of BL in Other Nebulae

NGC 2023



Central star: HD 37903, B1.5V, $T_{eff} \sim 23{,}000$ K

(Vijh et al. 2005, ApJ, 633, 262)

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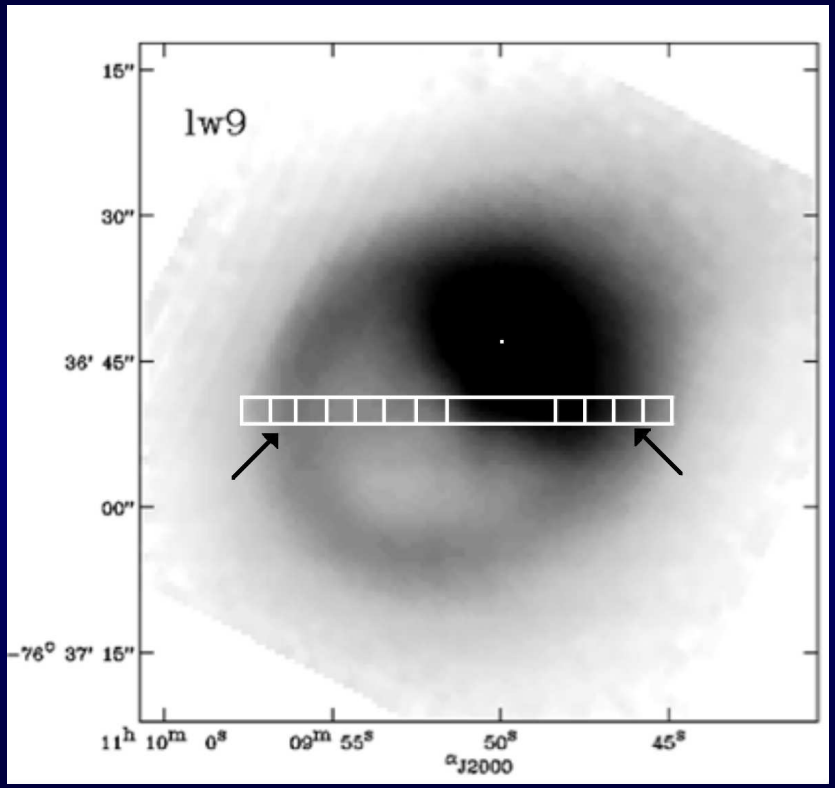
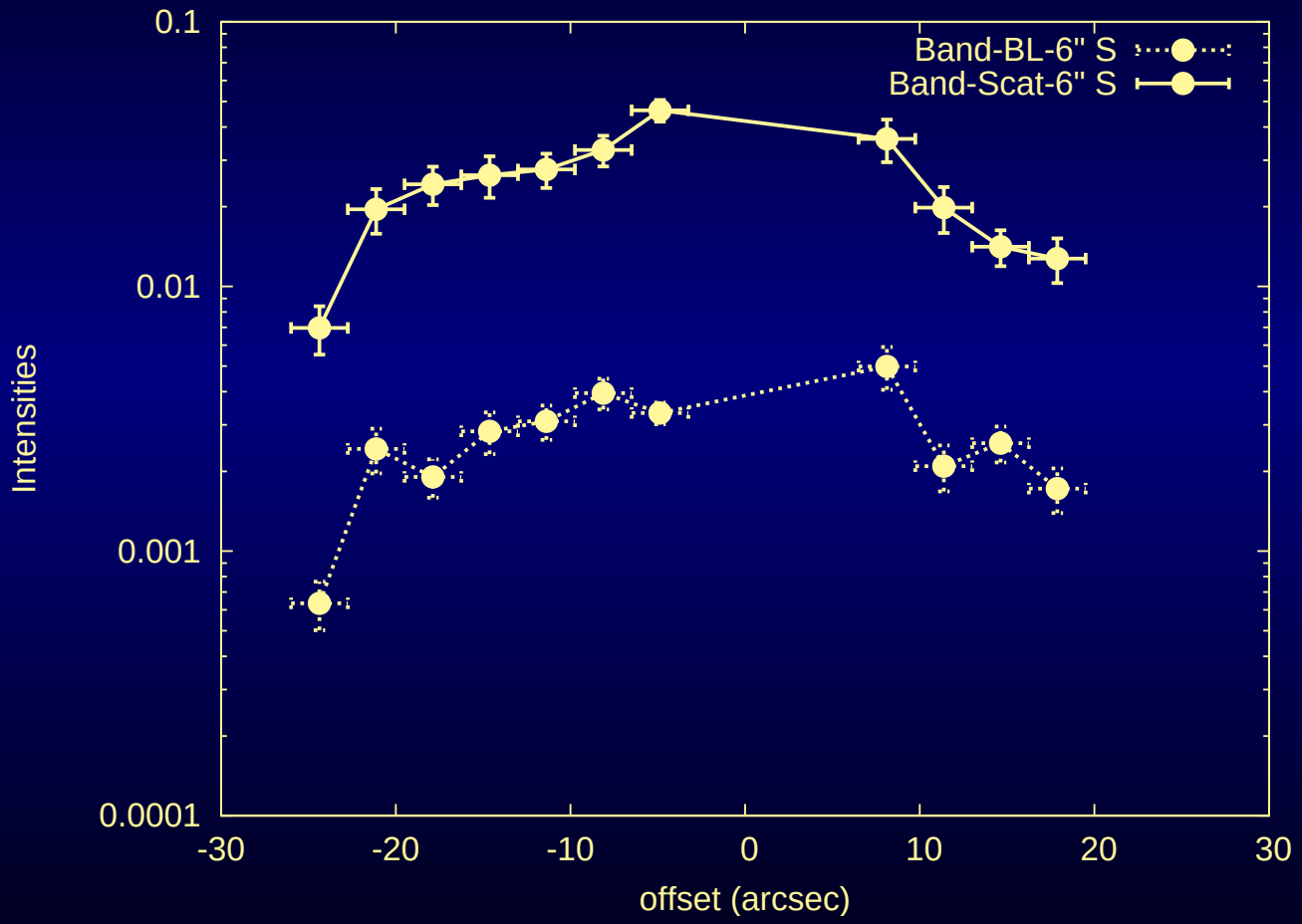


ISOCAM image (lw9) (from Siebenmorgen et al. 1998, A & A, 339, 134), overlaid with slit

(Vijh et al. 2005, ApJ, 633, 262)

Ced 112: Correlation with mid-IR emission



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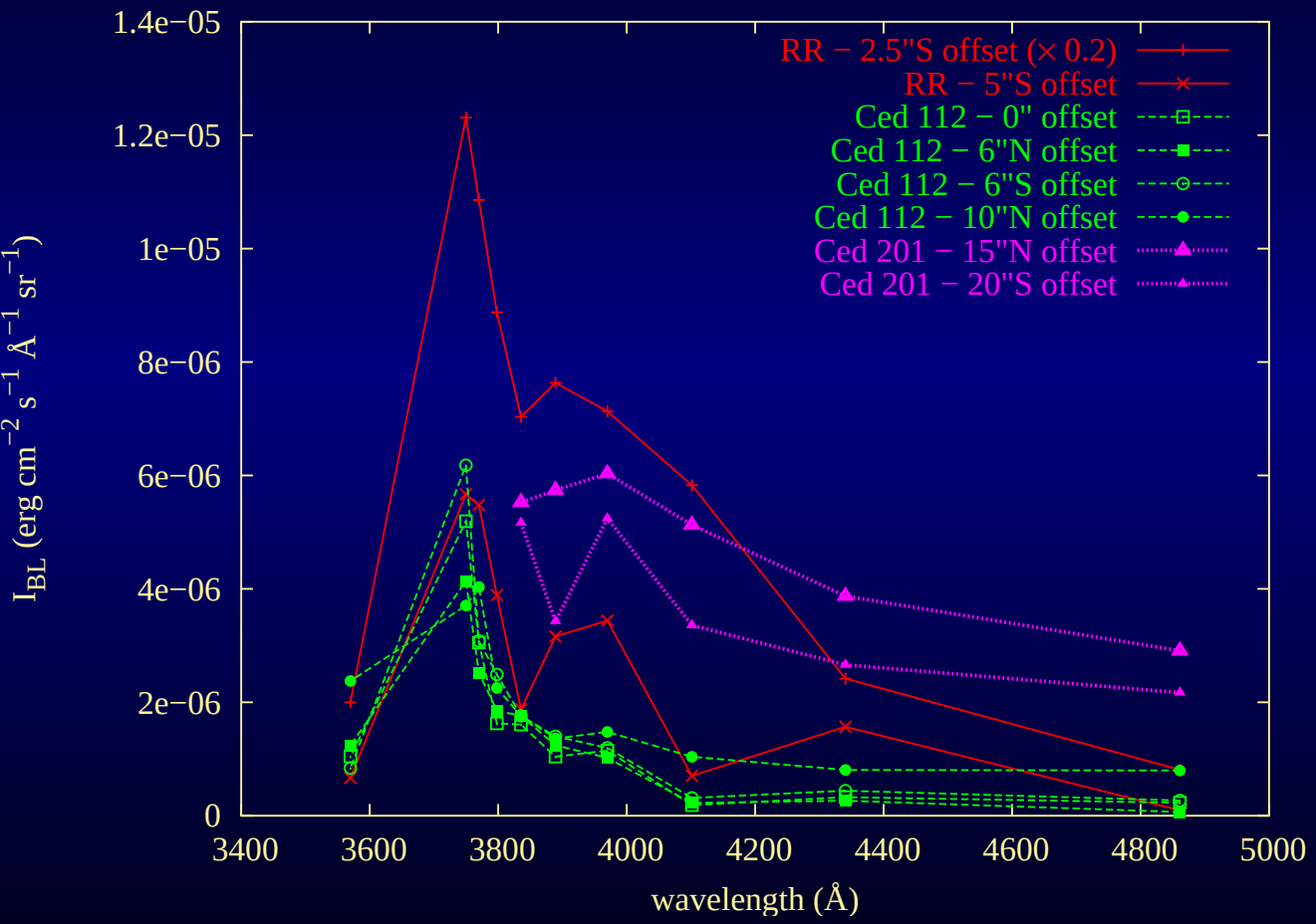
Average BL Spectra from Various Slits



(Vijh et al. 2005, ApJ, 633, 262)

Outline

The Excitation of ERE

- The determination of the exciting wavelength for ERE further constrains the ERE carrier
- Existing ERE models propose fluorescence/phosphorescence by organic molecules or photoluminescence by semiconductor nanoparticles
- For most such systems the Stokes shift is ≤ 1 eV
- However, ERE is observed only in sources with UV radiation: specifically photons with $7.3 < E < 11.2$ eV seem to required for ERE initiation (Darbon et al. 1999, A & A, 348, 990; Witt & Schild 1985, ApJ, 294, 225)
- The above implies a Stokes shift of 6 eV, if in fact UV photons required for initiation are also the exciting photons
- We determine this critical wavelength of ERE initiation using HST observations of ERE filaments in NGC 7023

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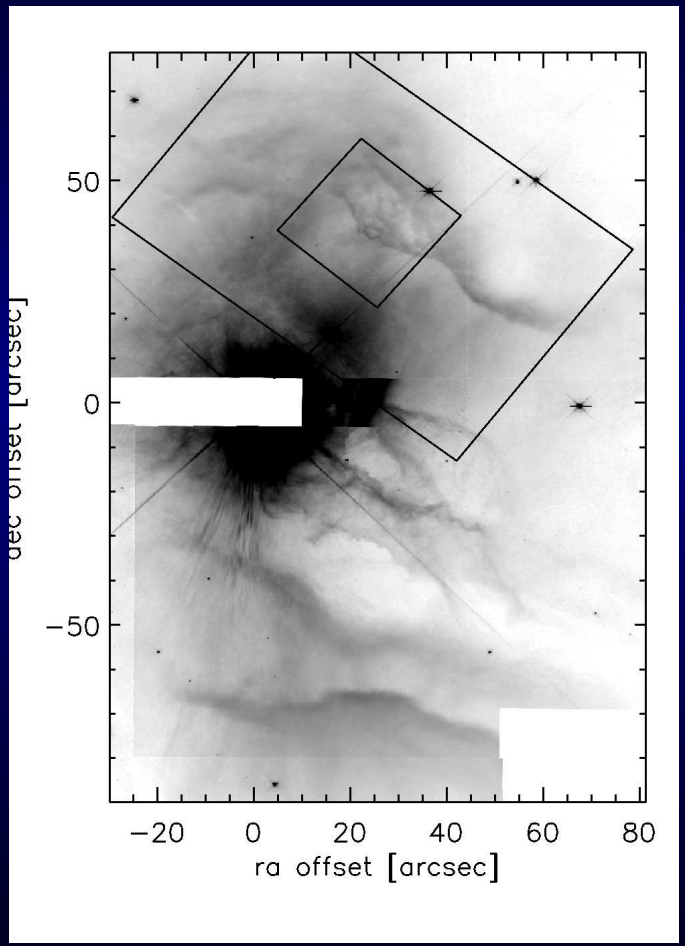

(Witt et al. 2006, ApJ, 636, 303)

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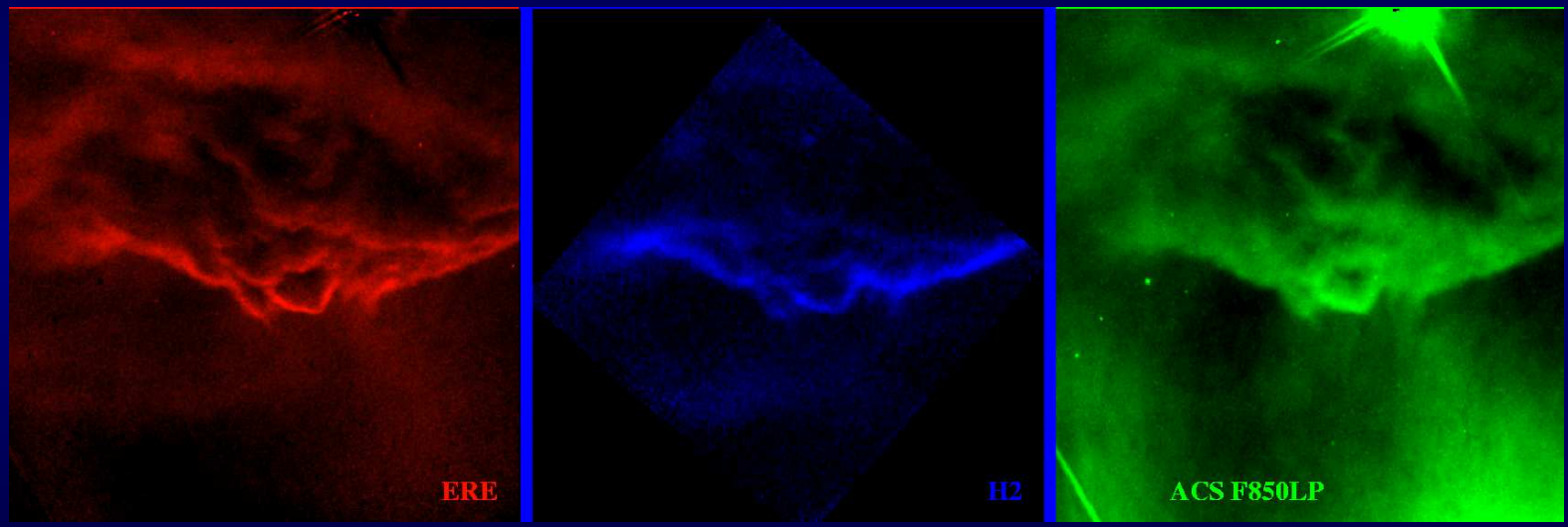

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The Excitation of ERE
Results

- ERE is initiated by photons with $\lambda < 118$ nm (~ 10.5 eV)
- None of the existing ERE models satisfies this condition
- UV photons with E $>$ 10.5 eV alone are insufficient to generate the required number of ERE photons
- ERE must therefore be a two-step process:
  1. Creation of the ERE carrier by far-UV photons with 10.5 eV $<$ E $<$ 13.6 eV, by photoionization or photodissociation
  2. Followed by pumping of this carrier by optical/near-UV photons
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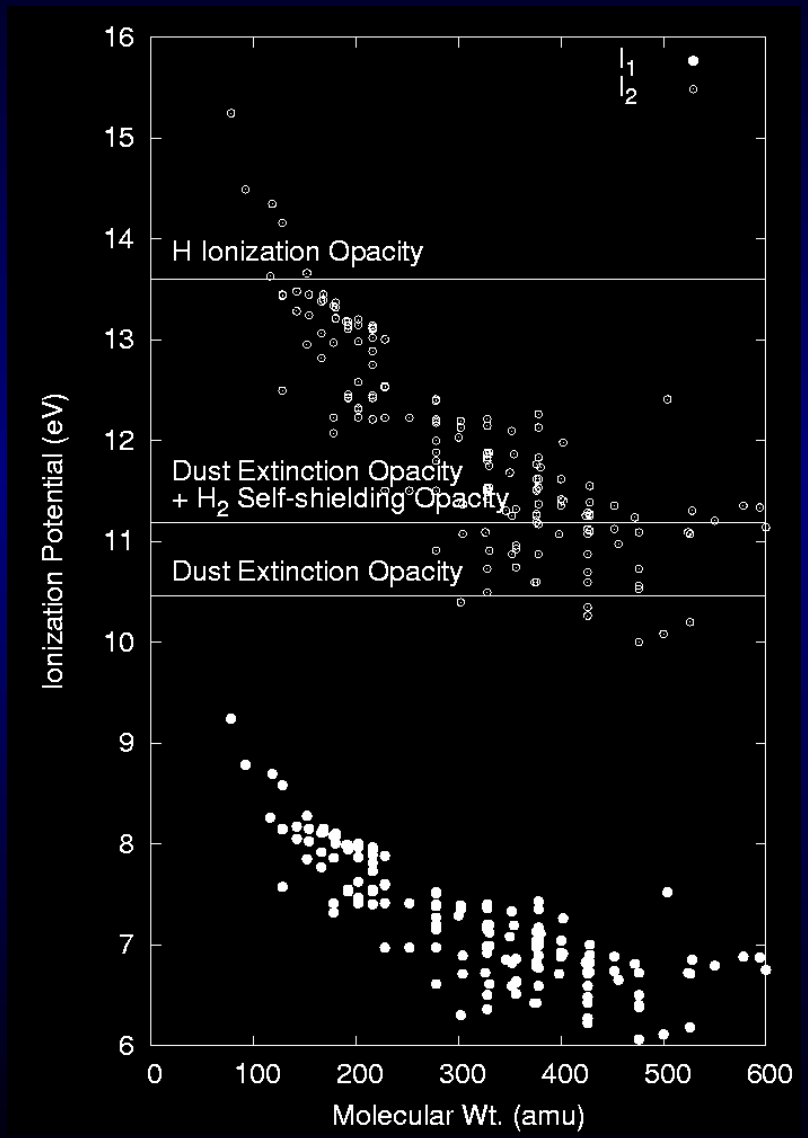
PAH Ionisation Potential



Witt et al. 2005, in prep.

Ellinger et al., 1999, TheoChem, 458,

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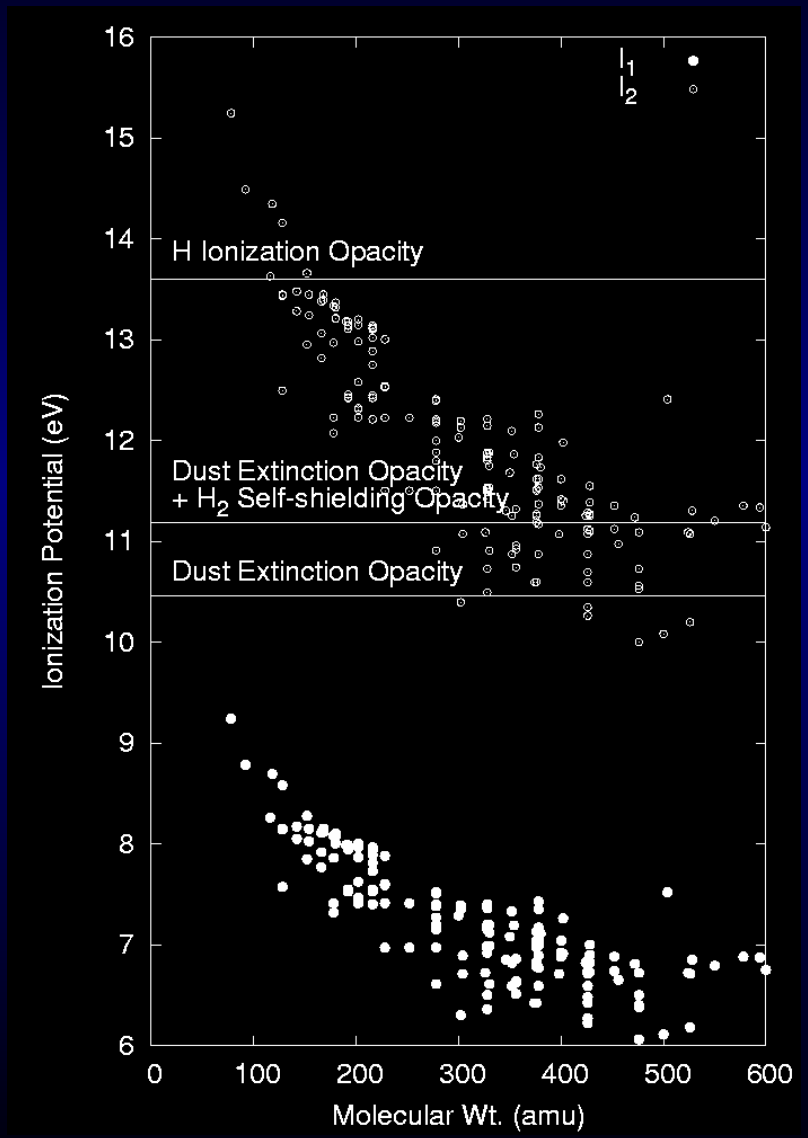

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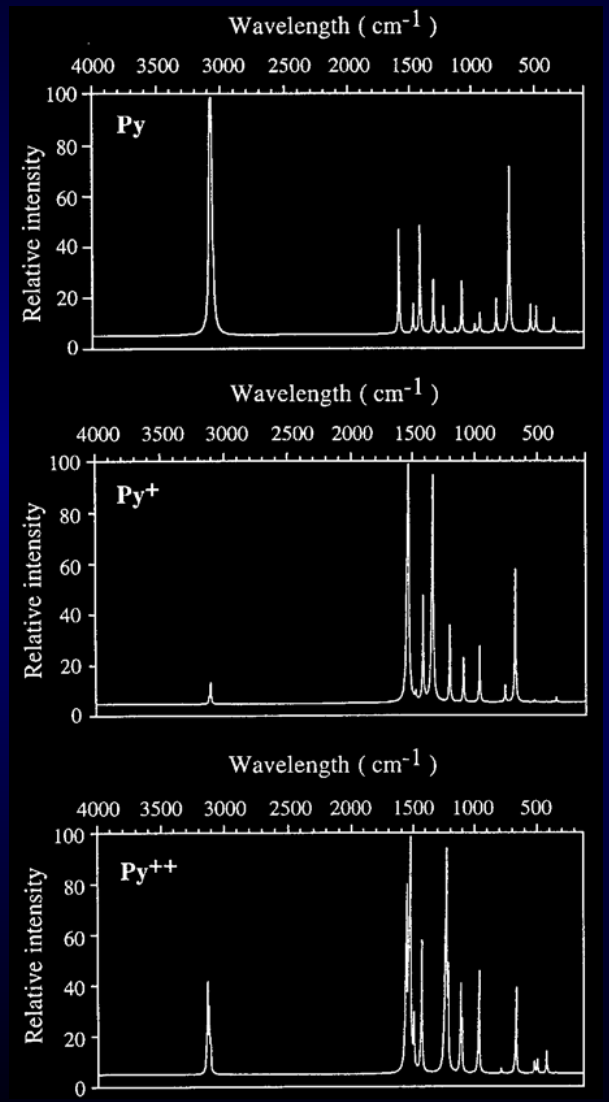

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Summary

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