Status of the Diffuse Interstellar Band Problem

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APO DIB Collaboration:

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Discovery of the DIBs

- $\lambda\lambda 5780, 5797$ seen as unidentified lines
  - $\zeta$ Per, $\rho$ Leo (Mary Lea Heger, Lick, 1919)
- Six bands confirmed as “detached” lines
  - Merrill & Wilson, Mt. Wilson, 1938
- Broad (“diffuse”)
What are the DIBs?

• Reasonable correlation with dust extinction
  – but “level off” at high $A_V \rightarrow$ diffuse clouds only?
  – for a long time, solid state carriers favored

• Several characteristics argue against dust:
  – constancy of $\lambda$
  – lack of emission
  – fine structure!

• Present consensus:
  – gas-phase molecules
  – probably large
  – likely carbon-based
  – reservoir of organic material

• Greatest unsolved mystery in spectroscopy!

The APO DIB Survey

- Apache Point Observatory 3.5-meter
- 3,600–10,200 Å ; $\lambda/\Delta\lambda \sim 37,500$ (8 km/s)
- 119 nights, from Jan 1999 to Jan 2003
- S/N (@ 5780Å) > 500 for 160 stars (115 reddened)
- Measurements & analysis still very much underway
Search for a Common Carrier

- Assumptions:
  - gas phase molecules
  - DIBs are vibronic bands
  - low temperature
    - carriers all in \( v=0 \)
  - relative intensities fixed
    - Franck-Condon factors
    - independent of \( T, n \)

- Method:
  - look for DIBs with tight correlations in intensity

- Prospect:
  - identify vibronic spectrum of single carrier
  - spacings may suggest ID
DIB Correlations

$r=0.55$

“C$_7$- bands”

$r=0.985$

measurement errors could be causing deviations?

Still much work to do, especially on weaker bands!
Evaluation of Proposed DIB Carriers

- Need a laboratory spectrum
  - gas phase (avoid matrix shifts)
  - rotationally resolved (or profile resolved)
- Need to be able to simulate spectrum
  - interstellar temperatures, excitation conditions
- DIB, simulated spectra must match exactly
  - central wavelength & profile
  - relative intensities & correlation
  - all laboratory bands present


The “C$_2$ DIBs”

- First set of DIBs known to be correlated with a known species!

Tuairisg atlas

HD 183143

HD 167971

HD 179406

HD 206267

HD 34078

HD 147889

HD 172028

HD 204827

N(C$_2$) ($10^{12}$ cm$^{-2}$)

<3

<4

73

93

110

210

270

430

$E_{B-V}$

1.27

1.08

0.33

0.53

0.52

1.07

0.79

1.11

Carbon Chains as DIB Carriers?

- Some DIBs correlated with $C_2$
- $C_3$ widely observed in diffuse clouds
  - J. P. Maier 2001
- But, search for $C_4$, $C_5$ unsuccessful so far
- Conclusions:
  - Need high abundance, or
  - Large oscillator strength
    - Potential carbon chain DIB carriers must have $>15$ carbon atoms
    - $C_{2n+1}$ (n=7-15); $HC_nH$ (n>40); $C_{2n}$ (n>10); $C_nH$; $HC_nH^+$; $C_n$−
  - No lab spectra of long chains; very little of cations
PAHs as DIB Carriers?

• Polycyclic Aromatic Hydrocarbons
  – proposed by Leger & d’Hendecourt and by van der Zwet & Allamandola in 1985
• Would expect complex mixture
  – ionization stages (cation, neutral, anion?)
  – hydrogenation states
• So far, no spectroscopic match with DIBs
• Cation transitions observed so far in gas-phase are too broad!
• Still no convincing evidence

See poster 32.09, Salama et al.
• $\text{IP}(\text{C}_{60}) = 7.6 \text{ eV}$
  – Ionized in diffuse clouds
• $\text{C}_{60}^+$ in Ne matrix
  – two bands near 9600 Å
• Detection claimed in HD 183143
• Need gas-phase spectrum!
  – Experiment in preparation

Fulara, Jakobi, & Maier

Foing & Ehrenfreund
The Road to a Solution

• Laboratory spectroscopy is essential
• Blind laboratory searches unlikely to work
  ~$10^7$ organic molecules known on Earth
  ~$10^{200}$ stable molecules of weight < 750
    containing only C, H, N, O, S
• Observational constraints & progress are also essential!
• Computational chemistry will play an important role
• Close collaborations needed!
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