The Diffuse Interstellar Bands and Carbon Chains

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Discovery of the DIBs

• $\lambda\lambda 5780, 5797$ noticed as unidentified lines
  – $\zeta$ Per, $\rho$ Leo (Mary Lea Heger, Lick, 1920)
• Six bands confirmed as “detached” lines
  – Merrill & Wilson, Mt. Wilson, 1938
• Broad (“diffuse”)
• Associated with interstellar neutral atomic gas
• With CCD detectors, hundreds of DIBs found

What are the DIBs?

- Reasonable correlation with dust extinction
  - for a long time, solid state carriers favored

- But, several characteristics argue against dust:
  - constancy of $\lambda$
  - lack of emission
  - fine structure!

- Present consensus:
  - gas-phase molecules
  - probably large
  - likely carbon-based

Where Do the DIBs Live?

- Plot of DIB vs. $E_{B-V}$ shows “saturation”
- Dense cloud sightlines show very weak DIBs
- DIBs in diffuse clouds
- UV flux seems important
  - not enough: HD 62542
  - too much: $\theta^1$ Ori C
- Cations??
Diffuse Cloud Conditions

- Low dust extinction $\rightarrow$ high UV field
  - $N(\text{H}) \sim N(\text{H}_2)$
  - $\text{C} \rightarrow \text{C}^+ + e^-$
- Low density ($n \sim 100 \text{ cm}^{-3}$), temperature ($\sim 30 \text{ K}$)
- Electrons quench ion-neutral chemistry
- Predominantly diatomic molecules
  - OH, CH, CN, CH$^+$
  - $\text{C}_2$ yields $n$, $T$ estimates
- Chemical models fail
Polyatomic Molecules

• H$_3^+$ detected in 1998
  – chemical mystery
  – now in ζ Per!
• C$_3$ detected in 2001
• Survey of C$_3$
  – 15 sightlines
  – C$_2$:C$_3$ ~ 40
• Search for C$_4$ & C$_5$
  – negative so far
How to Identify DIB Carriers?

• Detailed comparison with laboratory spectra
  – rare-gas matrix spectra insufficient
  – need gas-phase spectra of (unstable) molecules
  – serious challenge for laboratory spectroscopists

• Criteria for evaluation:
  – match all ground-state laboratory bands
    • relative intensities, widths
    • exact wavelength agreement
    • reasonable profile (based on molecular constants)
  – all bands correlate in intensity from star to star
Recently Rejected DIB Carriers

- H$_2$
- C$_6^-$, C$_7^-$, C$_8^-$, C$_9^-$
- C$_6$H, C$_8$H, C$_{10}$H, C$_{12}$H
- HC$_4$H$^+$, HC$_6$H$^+$, HC$_8$H$^+$
- HC$_7$H, HC$_9$H
- NC$_4$N$^+$, NC$_6$N$^+$
- 1-C$_3$H$_2^-$
- several PAH$^+$
- C$_{60}^+$ (?)
The Case of C$_7^-$

- 1997: Neon matrix spectrum
- 1998: Low-resolution gas-phase spectrum
  - “Striking matches with narrow DIBs”

Better Laboratory Data

• Problems with assignment:
  – laboratory uncertainties \( \sim 0.5 \text{ Å} \)
  – bands unresolved, temperature dependence unknown
  – available astronomical data of poor quality

• 2000: Higher resolution lab spectrum
  – permitted determination of molecular constants

The APO DIB Survey

• Apache Point Observatory 3.5-meter
• 3,500–10,200 Å ; \( \lambda / \Delta \lambda \sim 37,500 \) (8 km/s)
• S/N (@ 5780Å) > 500 for >140 stars
• Comparison with lab data; empirical study
Rejection of C$_7^-$

- Higher quality lab and astronomical data
  - Fails wavelength, profile, correlation tests

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

DIB Correlation Studies

- For each pair of DIBs
  - plot intensity in many stars
- Few pairs very well correlated
- Plan to extend to weaker DIBs
  - may find vibronic progressions

\[
\begin{align*}
&\text{Number of pairs} \\
&\text{Correlation coefficient (r)} \\
&1060 \text{ pairs of DIBs observed in } >40 \text{ stars}
\end{align*}
\]

\[
\begin{align*}
r &= 0.50 \\
r &= 0.99
\end{align*}
\]
The Future of the DIB Problem

• APO DIB survey nearly complete
  – lots of data to sift through
  – may be nearing the end of observational progress

• Solution depends on laboratory spectroscopy
  – extremely high sensitivity techniques
  – very high resolution
  – low temperature, gas-phase spectra
  – larger molecules?