The Diffuse Interstellar Bands and Carbon Chains

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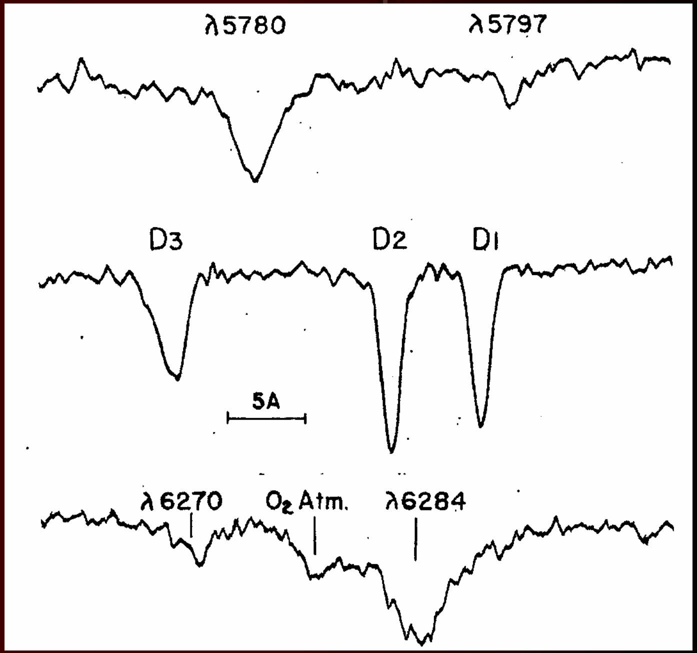
Discovery of the DIBs

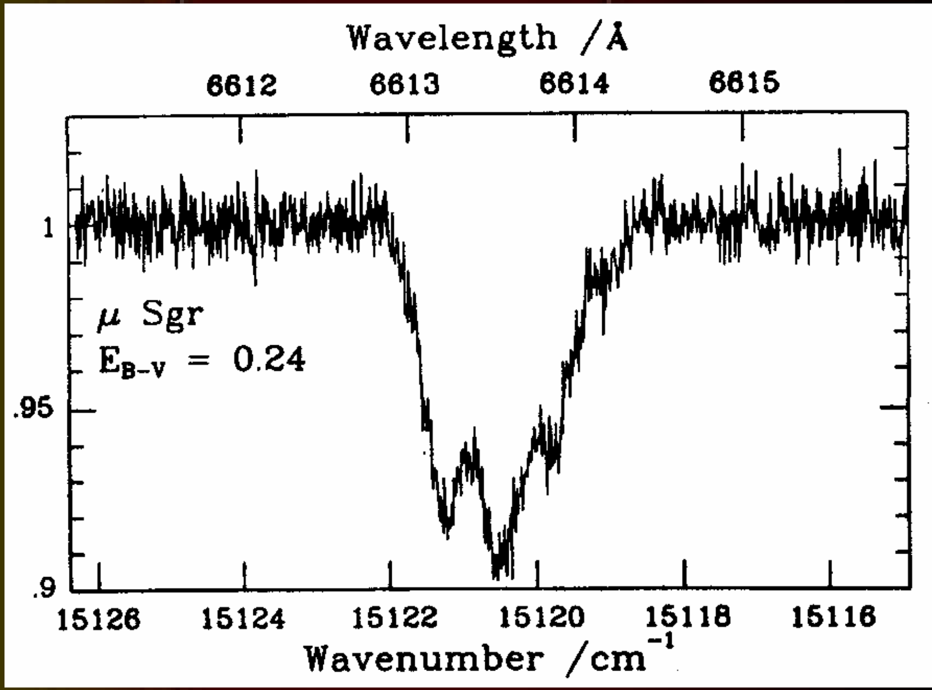
- λλ5780, 5797 noticed as unidentified lines
  - ζ Per, ρ Leo (Mary Lea Heger, Lick, 1920)
- Six bands confirmed as "detached" lines
  - Merrill & Wilson, Mt. Wilson, 1938
- Broad ("diffuse")
- Associated with interstellar neutral atomic gas
- With CCD detectors, hundreds of DIBs found



Merrill & Wilson, ApJ 87, 9 (1938)

What are the DIBs?

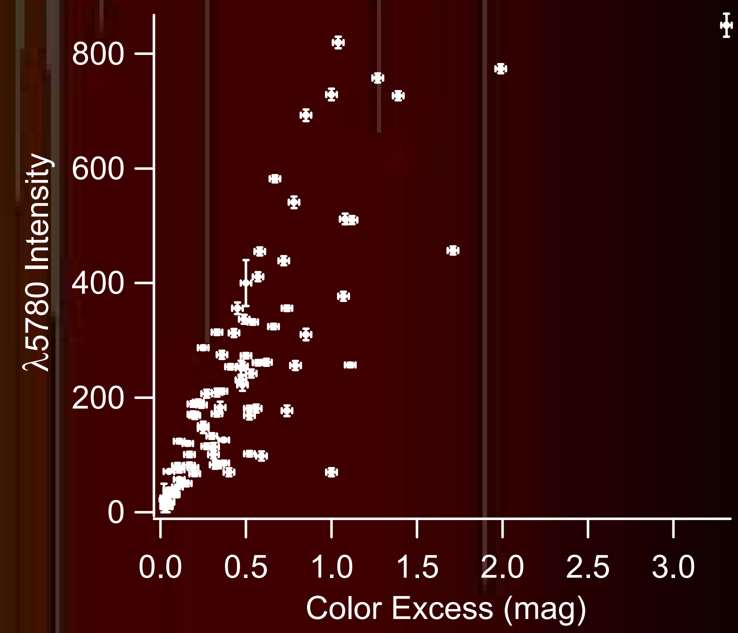
- Reasonable correlation with dust extinction
  - for a long time, solid state carriers favored
- But, several characteristics argue against dust:
  - constancy of λ
  - lack of emission
  - fine structure!
- Present consensus:
  - gas-phase molecules
  - probably large
  - likely carbon-based

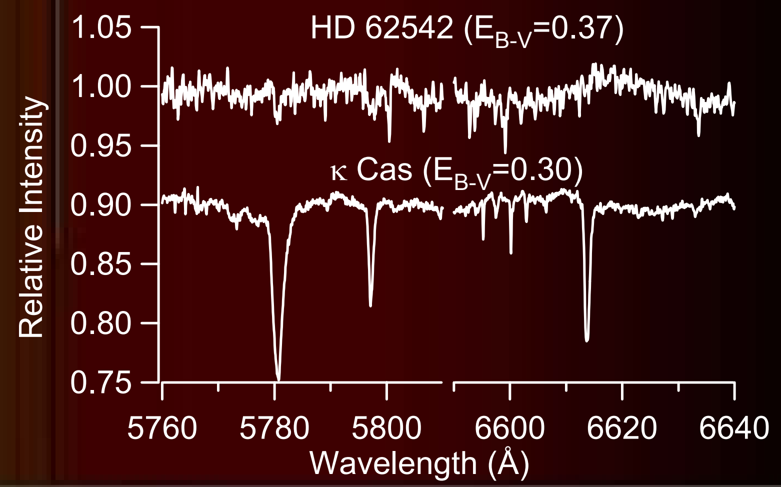


Sarre et al., MNRAS 277, L41 (1995)

Where Do the DIBs Live?

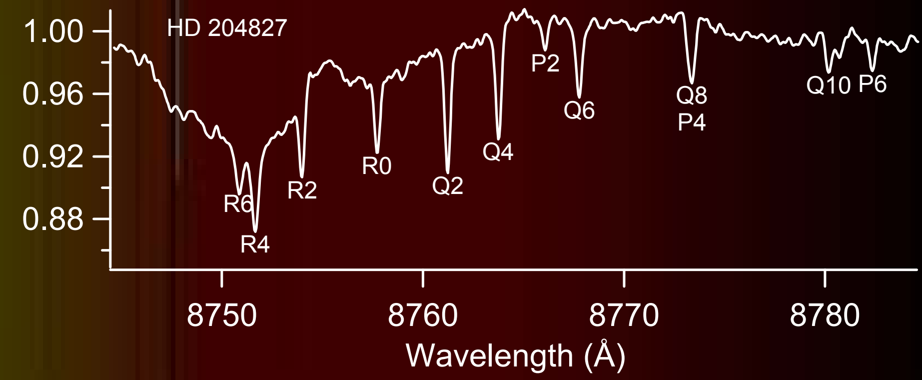
- Plot of DIB vs. E_{B-V} shows "saturation"
- Dense cloud sightlines show very weak DIBs
- DIBs in diffuse clouds
- UV flux seems important
  - – not enough: HD 62542
  - – too much: θ^1 Ori C
- Cations??





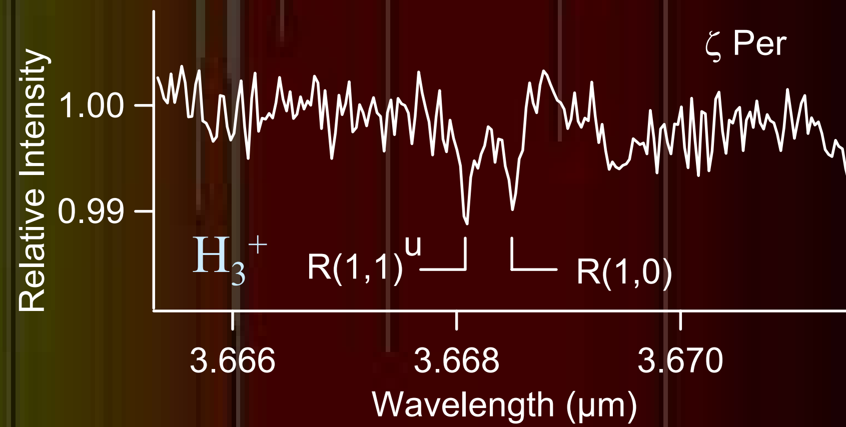
Diffuse Cloud Conditions

- Low dust extinction → high UV field
  - $N(H) \sim N(H_2)$
  - $C \rightarrow C^+ + e^-$
- Low density ($n \sim 100\ cm^{-3}$), temperature (~30 K)
- Electrons quench ion-neutral chemistry
- Predominantly diatomic molecules
  - OH, CH, CN, CH^+
  - C_2 yields n, T estimates
- Chemical models fail

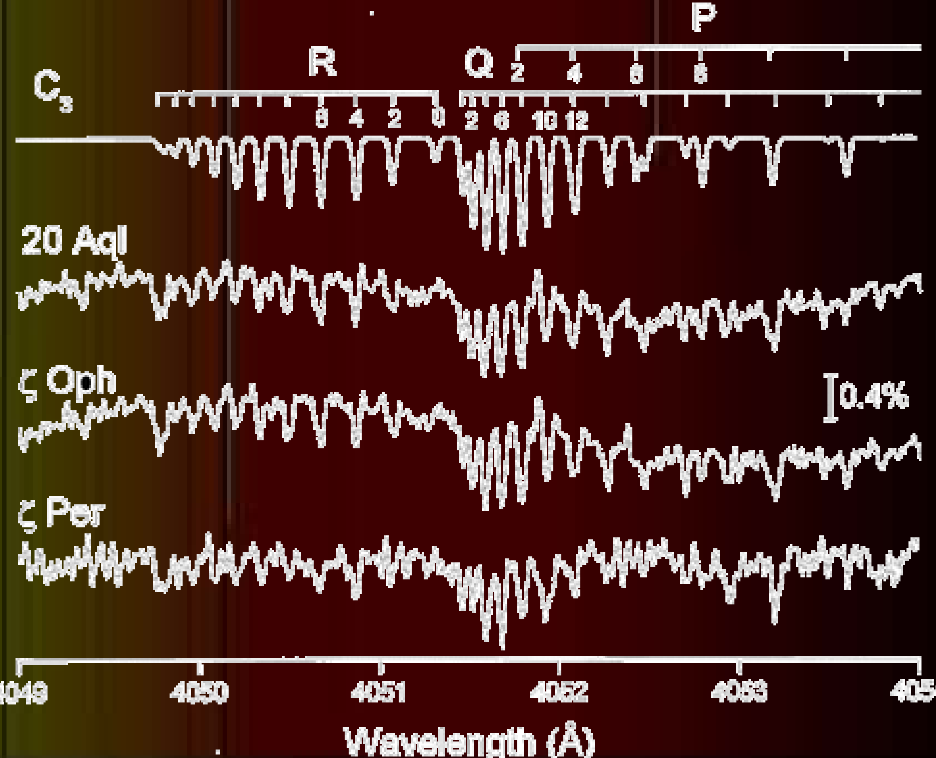


Polyatomic Molecules

- H_3^+ detected in 1998
  - chemical mystery
  - now in ζ Per!
- C_3 detected in 2001
- Survey of C_3
  - Oka et al., ApJ 2003
  - 15 sightlines
  - C_2:C_3 ~ 40
- Search for C_4 & C_5
  - negative so far



McCall et al., submitted



Maier et al., ApJ 553, 267 (2001)

How to Identify DIB Carriers?

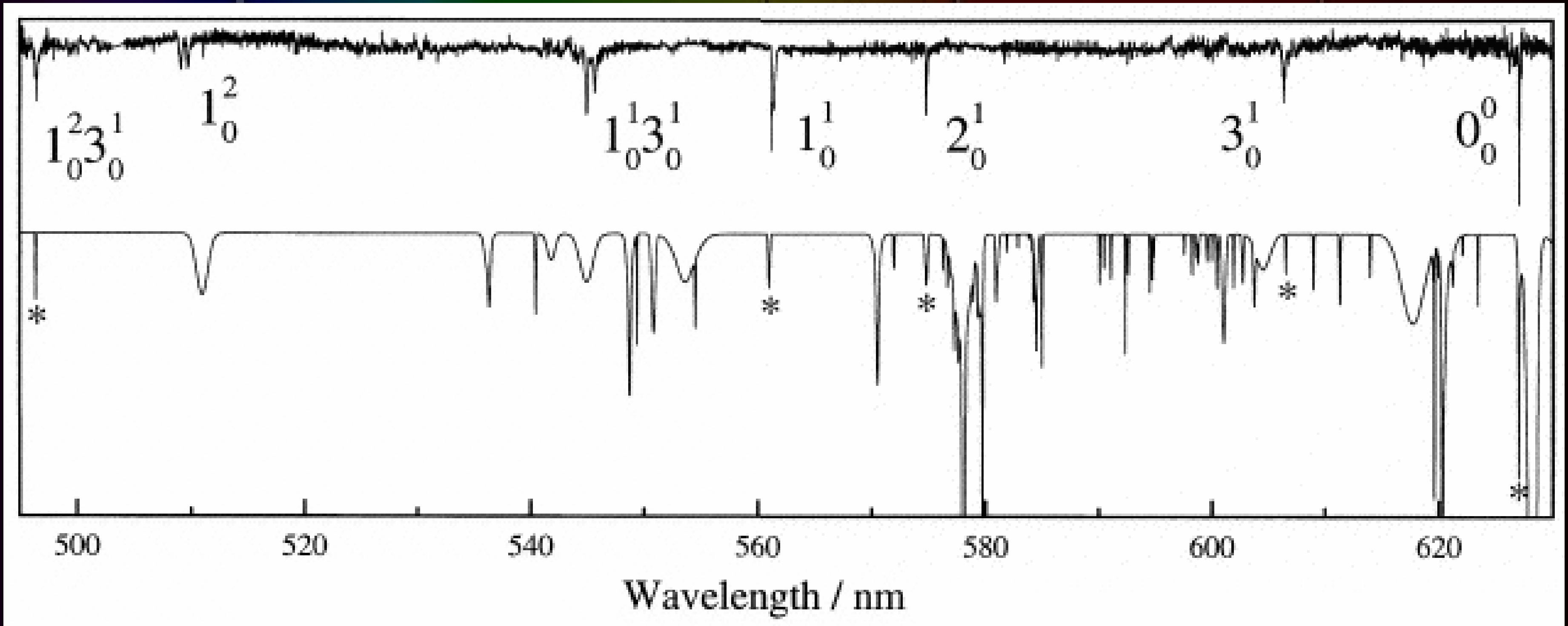
- Detailed comparison with laboratory spectra
  - rare-gas matrix spectra insufficient
  - need gas-phase spectra of (unstable) molecules
  - serious challenge for laboratory spectroscopists
- Criteria for evaluation:
  - match all ground-state laboratory bands
    - relative intensities, widths
    - 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_6H, C_8H, $C_{10}H$, $C_{12}H$
- HC_4H^+, HC_6H^+, HC_8H^+
- HC_7H, HC_9H
- NC_4N^+, NC_6N^+
- l-$C_3H_2^-$
- several PAH^+
- C_{60}^+ (?)

The Case of C_7^-

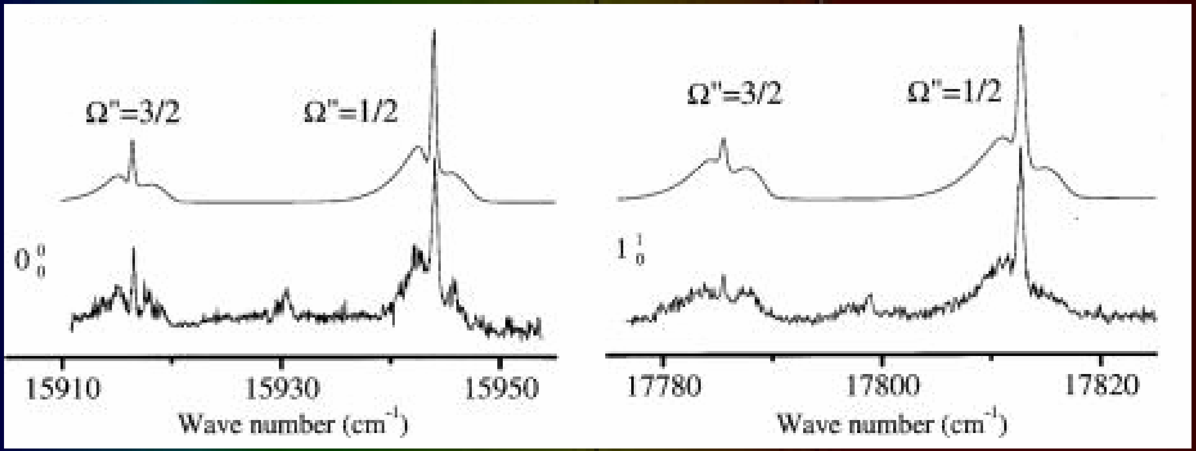
- 1997: Neon matrix spectrum
- 1998: Low-resolution gas-phase spectrum
  - "Striking matches with narrow DIBs"



Tulej, Kirkwood, Pachkov, & Maier, ApJ 506, L69 (1998)

Better Laboratory Data

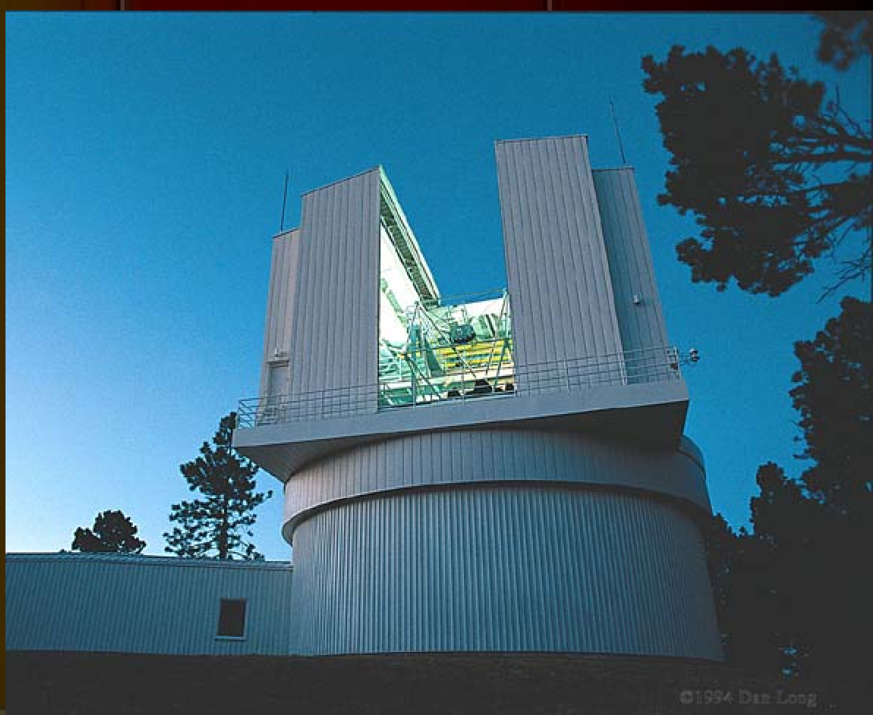
- Problems with assignment:
  - laboratory uncertainties ~ 0.5 Å
  - bands unresolved, temperature dependence unknown
  - available astronomical data of poor quality
- 2000: Higher resolution lab spectrum
  - permitted determination of molecular constants



Lakin et al., J. Chem. Phys., 113, 9586 (2000)

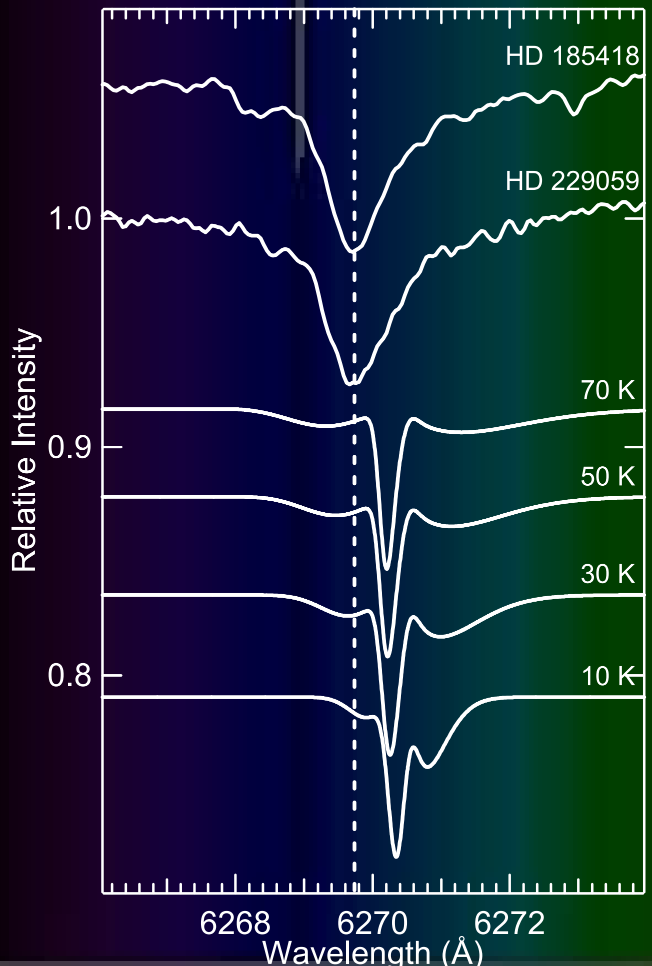
The APO DIB Survey

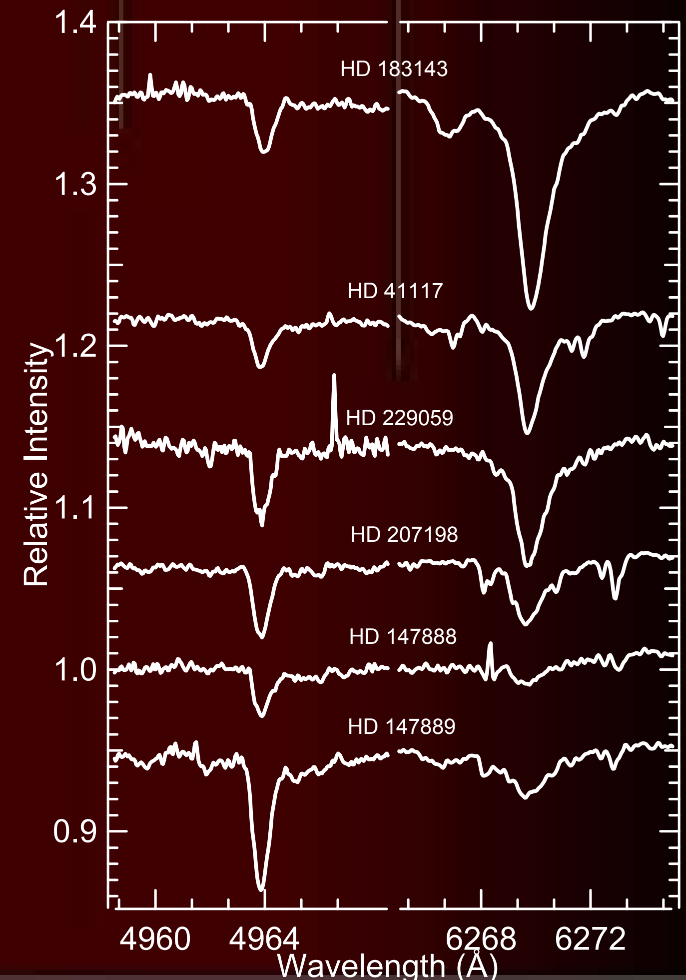
- Apache Point Observatory 3.5-meter
- 3,500–10,200 Å ; λ/Δλ ~ 37,500 (8 km/s)
- S/N (@ 5780Å) > 500 for >140 stars
- Comparison with lab data; empirical study



Rejection of C_7^-

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

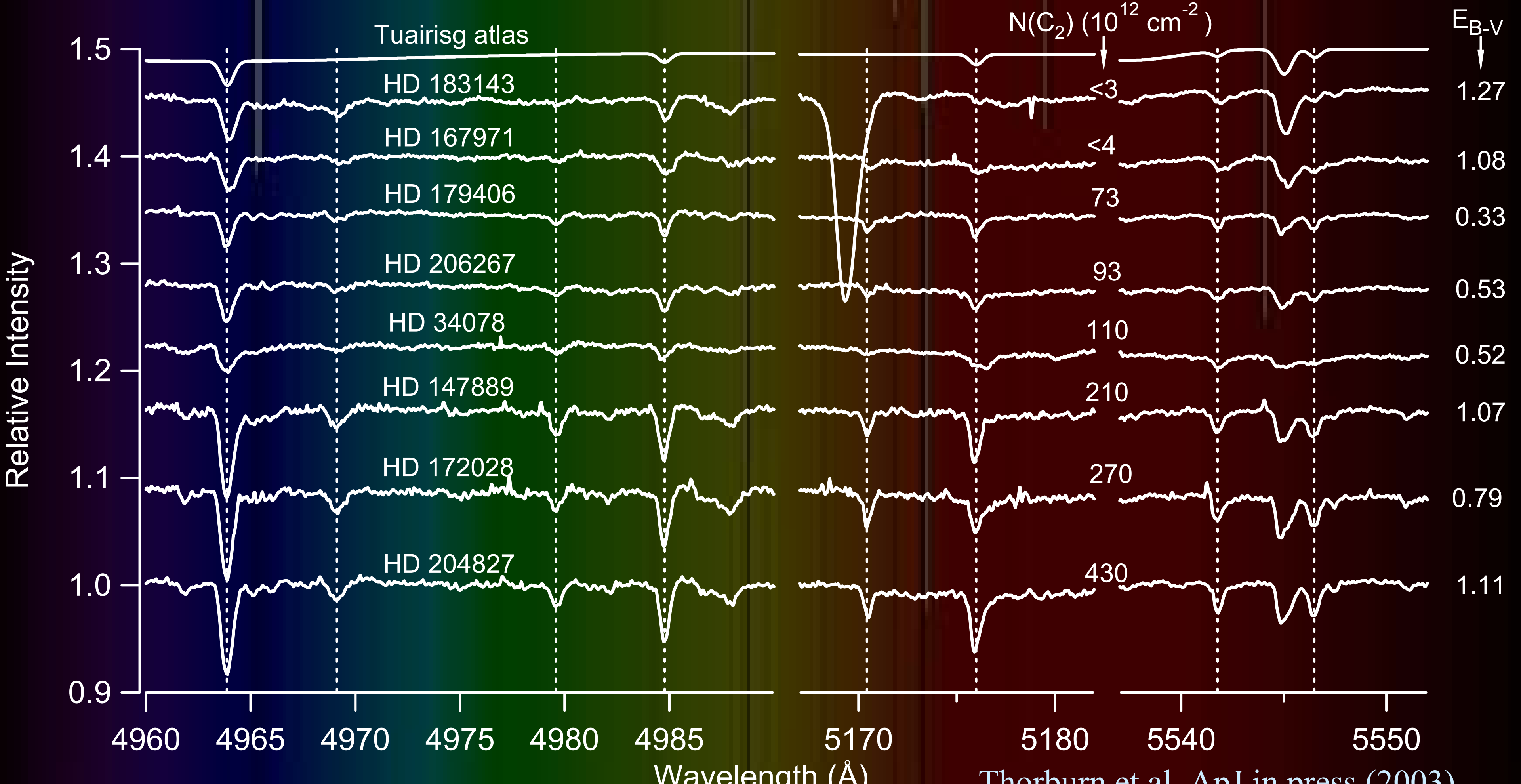




McCall et al., ApJ 559, L49 (2001)

The "C_2 DIBs"

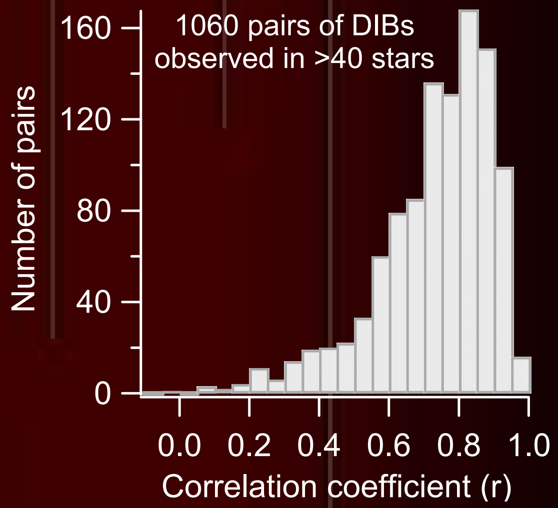
- First set of DIBs known to be correlated with a known species!

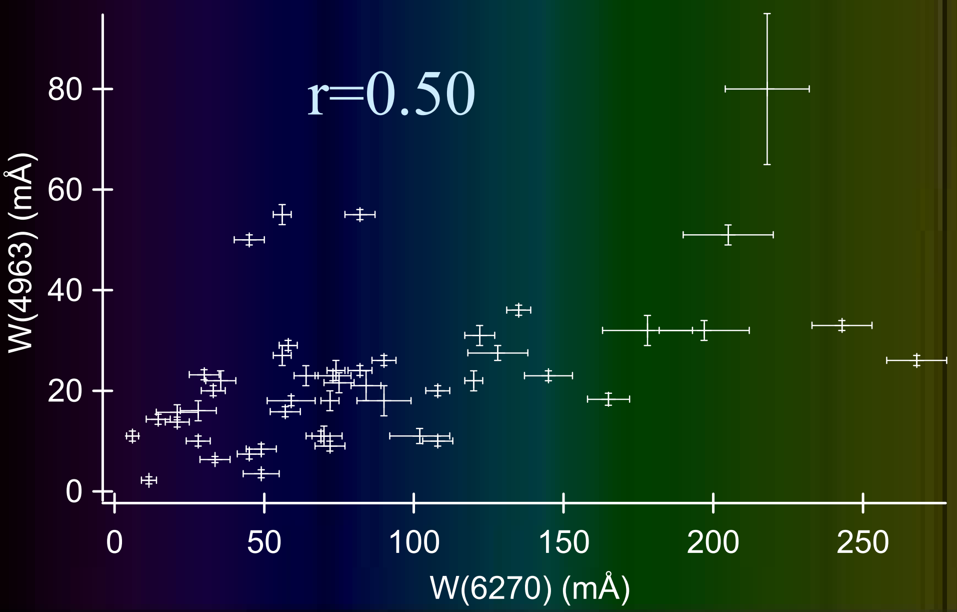


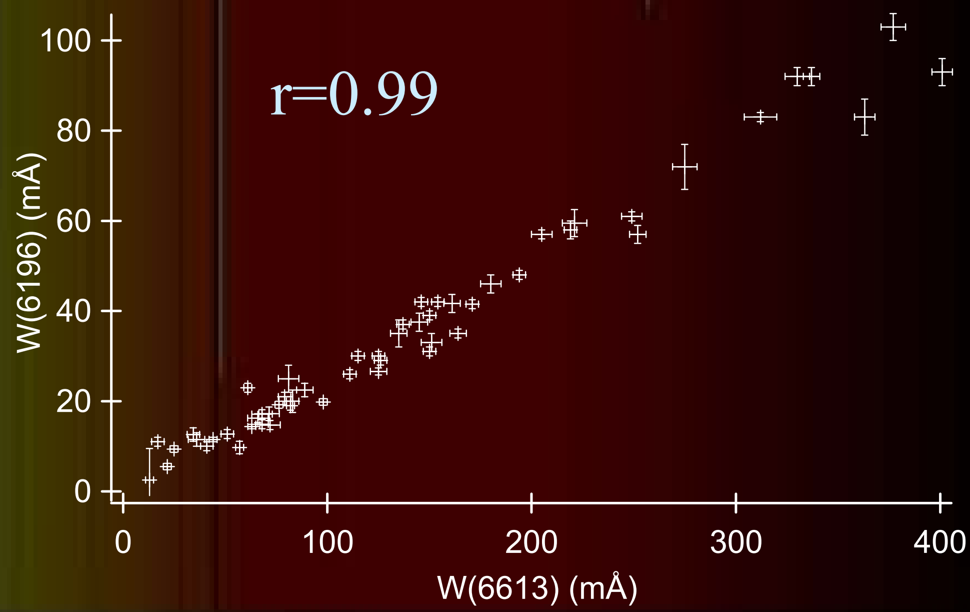
Thorburn et al, ApJ in press (2003)

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







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?