Correlations among Diffuse Interstellar Bands, Atoms, and Small Molecules

Ben McCall

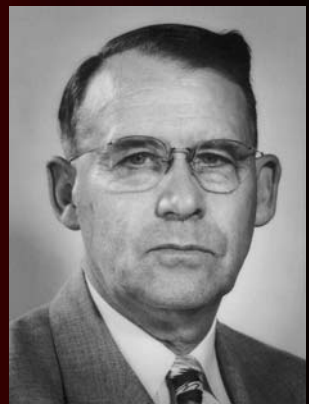
Department of Chemistry and Department of Astronomy

University of Illinois at Urbana-Champaign

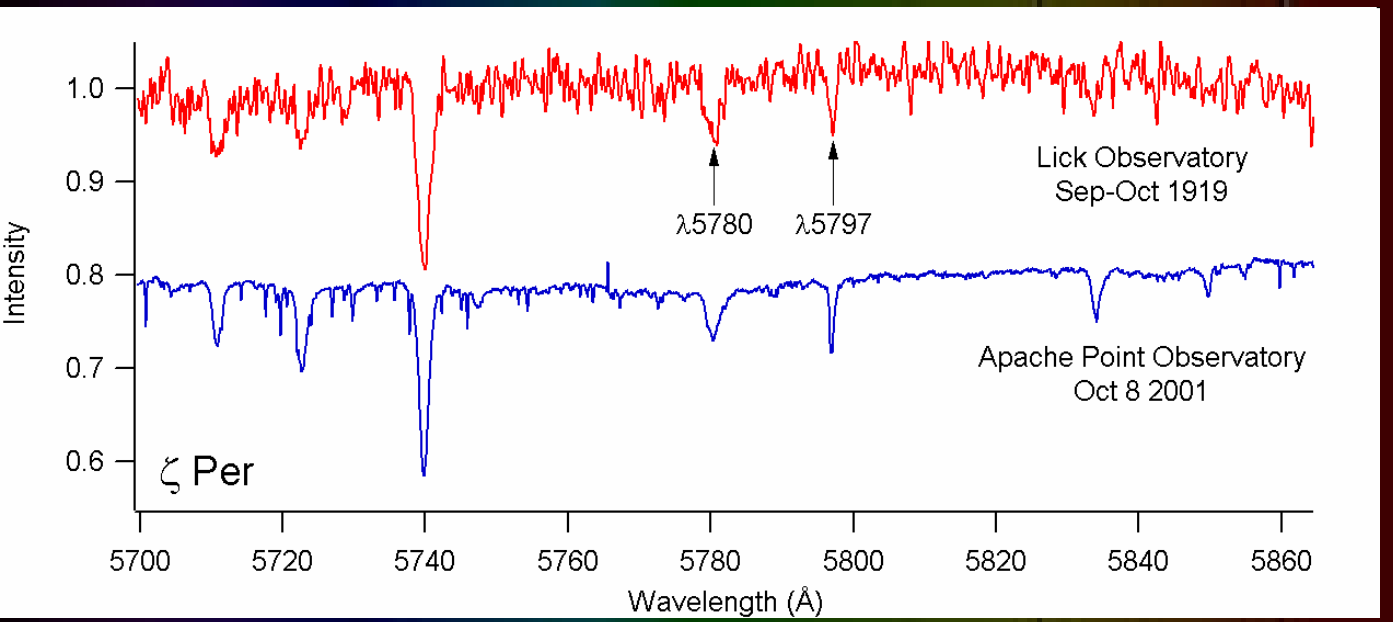
APO DIB Collaboration:

Máté Ádámkovics (Berkeley), Tom Fishman (Chicago), Scott Friedman (STScI), Lew Hobbs (Yerkes), Ben McCall (UIUC), Takeshi Oka (Chicago), Brian Rachford (Carleton), Ted Snow (Colorado), Paule Sonnentrucker (JHU), Julie Thorburn (Yerkes), Dan Welty (Chicago), Don York (Chicago)

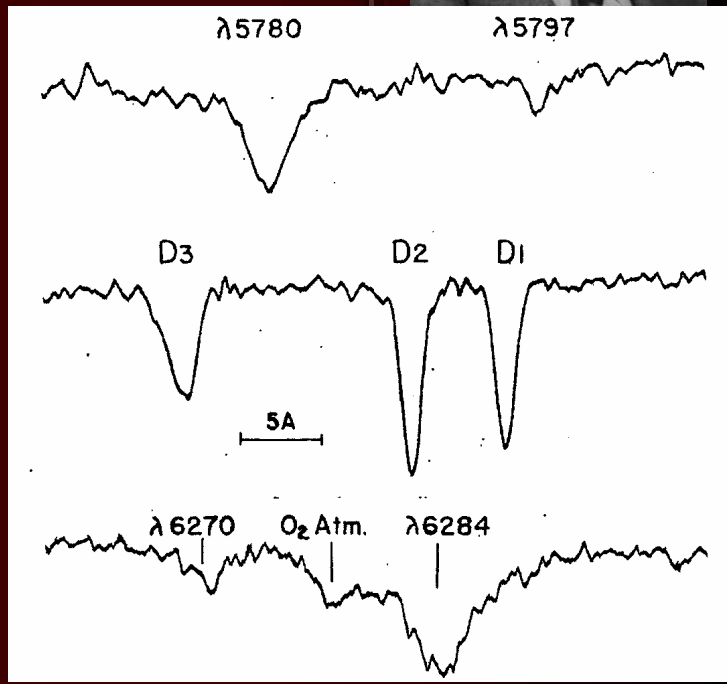
Discovery of the DIBs



- λλ5780, 5797 seen as unidentified lines
  - ζ Per, ρ Leo (Mary Lea Heger, Lick, 1919)
- Six bands confirmed as "detached" lines
  - Merrill & Wilson, Mt. Wilson, 1938
- Broad ("diffuse")



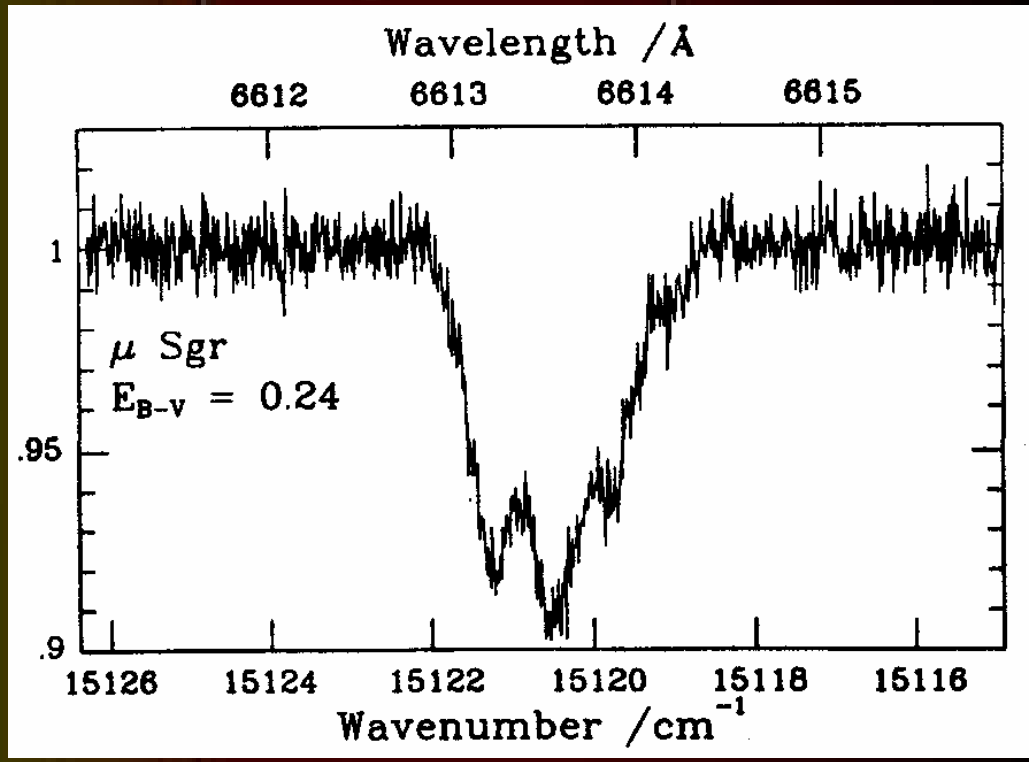
B. J. McCall, in preparation



Merrill & Wilson, ApJ 87, 9 (1938)

What are the DIBs?

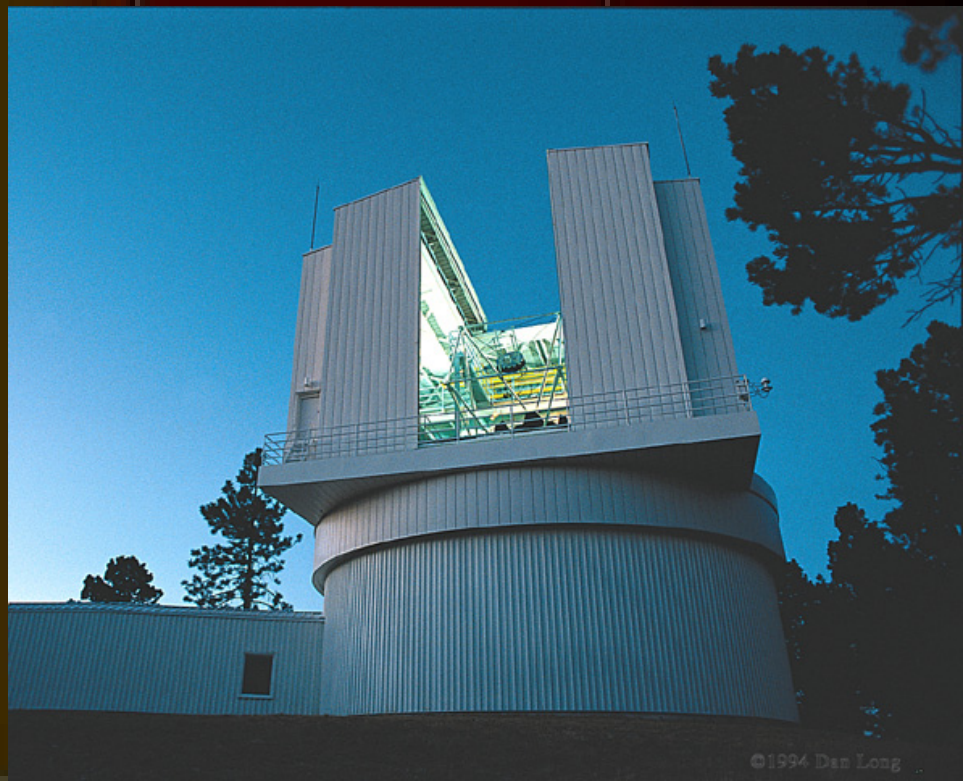
- Reasonable correlation with dust extinction
  - but "level off" at high $A_V \rightarrow$ diffuse clouds only?
  - for a long time, solid state carriers favored
- Several characteristics argue against dust:
  - constancy of λ
  - lack of emission
  - fine structure!
- Present consensus:
  - gas-phase molecules
  - probably large
  - likely carbon-based
  - reservoir of organic material
- Greatest unsolved mystery in spectroscopy!



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

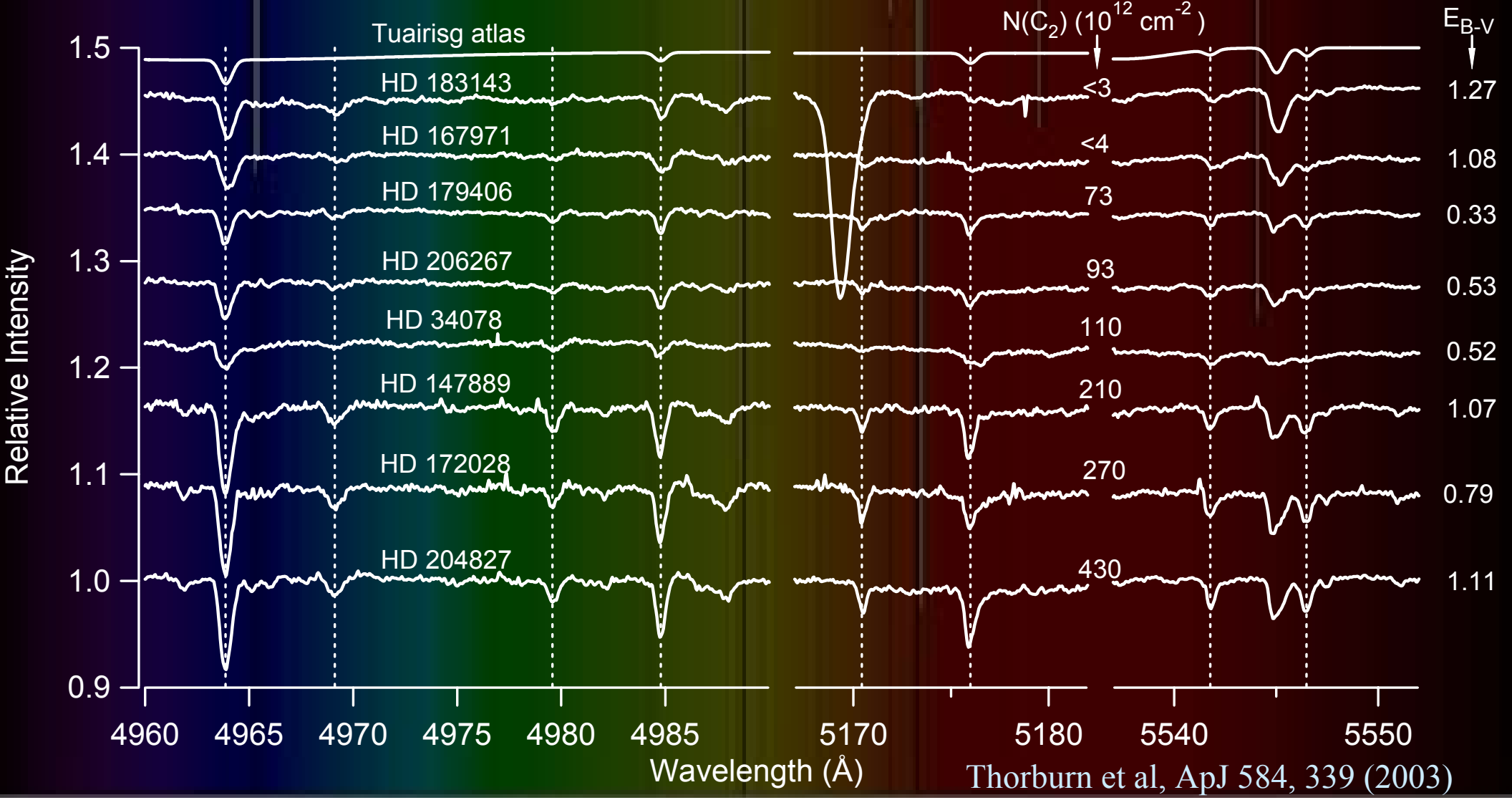
The APO DIB Survey

- 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



The "C_2 DIBs"

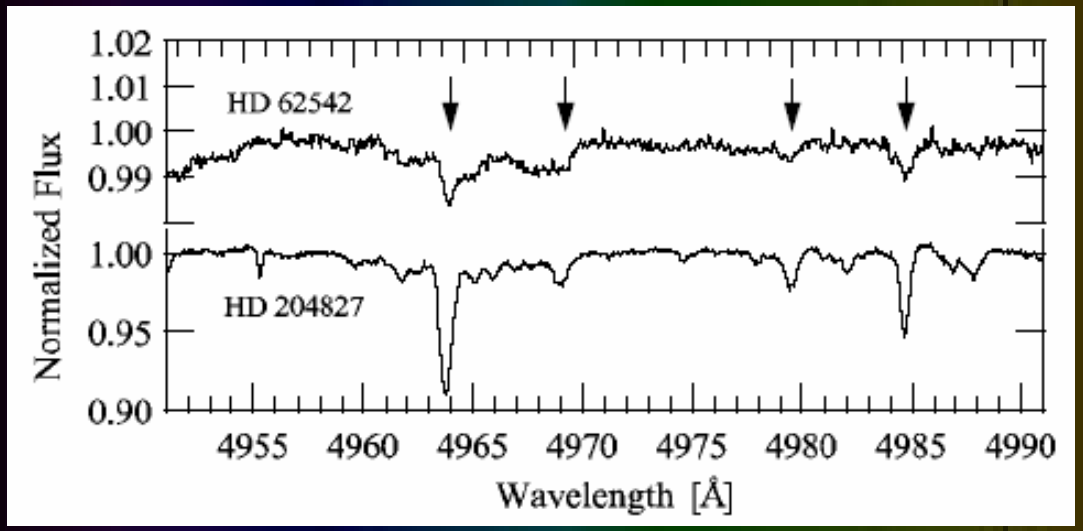
- First set of DIBs known to be correlated with a known species!



Thorburn et al, ApJ 584, 339 (2003)

C_2 DIBs toward HD 62542

- Unusual sightline with only diffuse cloud "core"
  - outer layers stripped away by shock (?)
  - DIBs undetected [Snow et al. ApJ 573, 670 (2002)]
- Recent Keck observations (higher S/N)
  - Classical DIBs (e.g. λ5780) very weak
  - C_2 DIBs among the few DIBs observed
- C_2 DIBs evidently form in denser regions

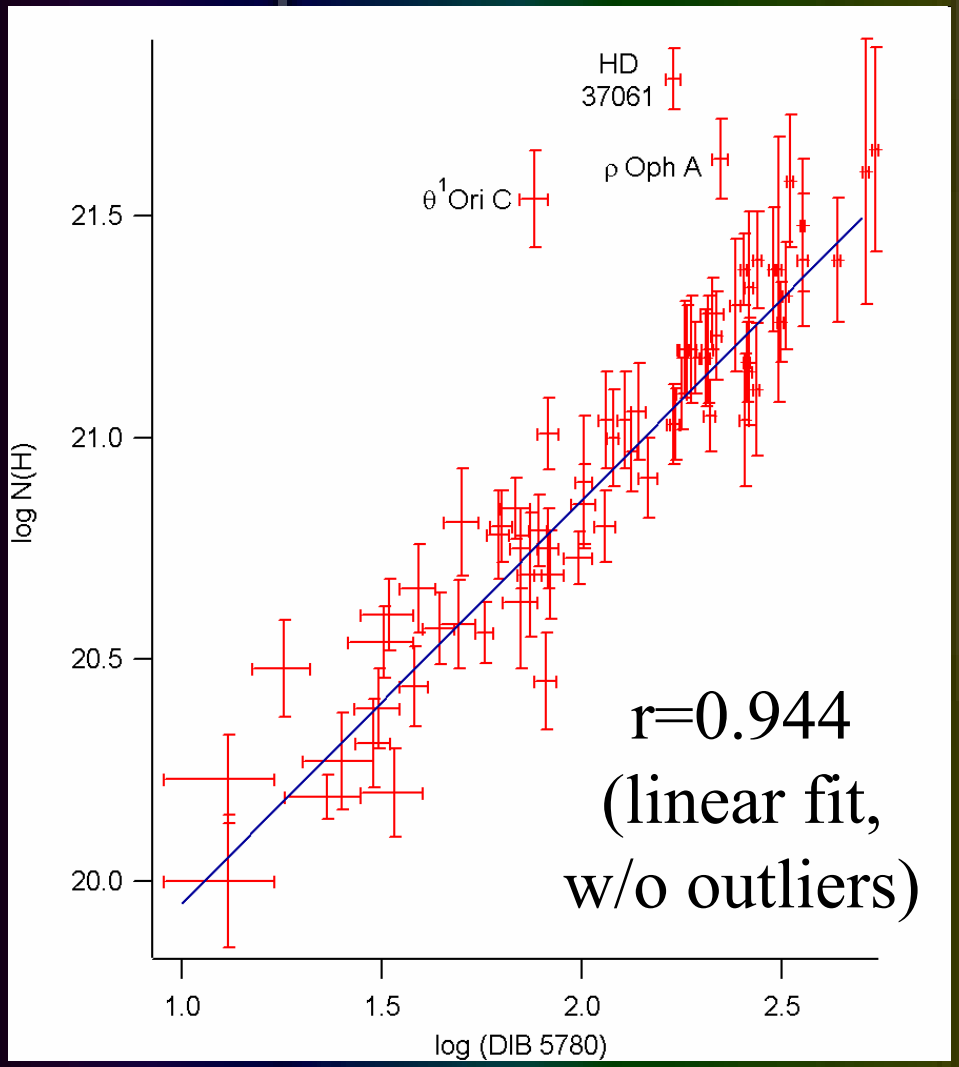


Ádámkovics, Blake, & McCall ApJ 625, 857 (2005)

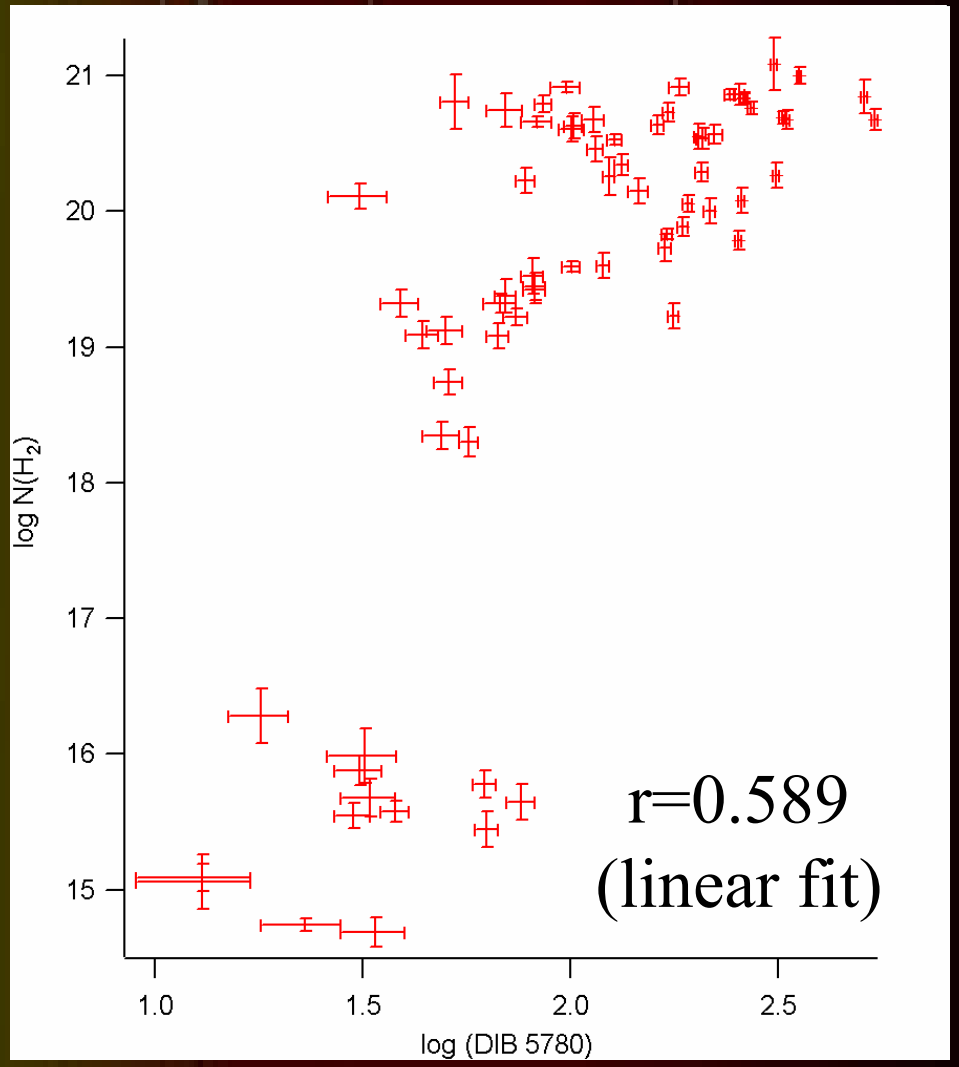
λ5780 and N(H)

well correlated with H

[a la Herbig ApJ 407, 142 (1993)]



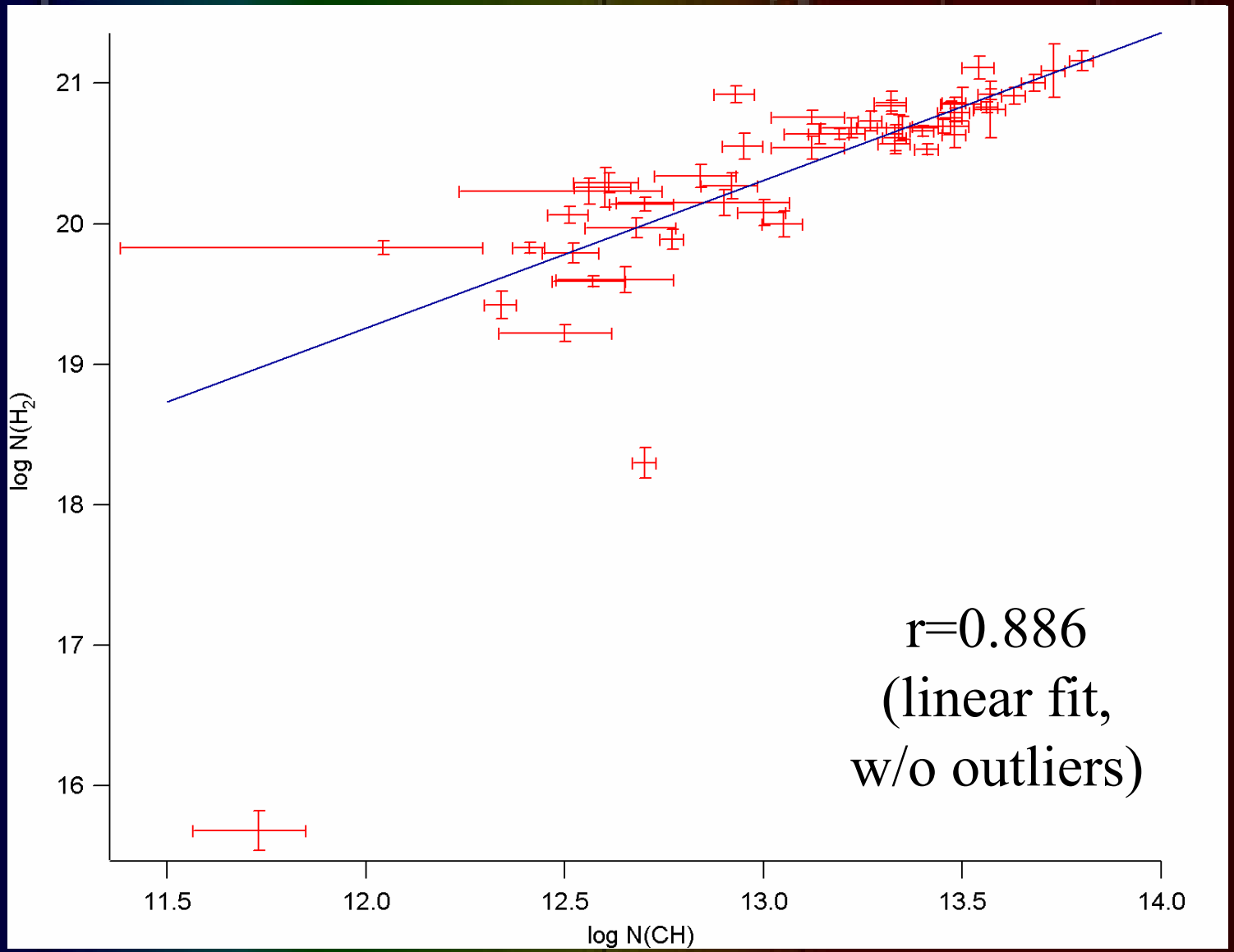
no correlation with H_2



York et al., in preparation

N(CH) and $N(H_2)$

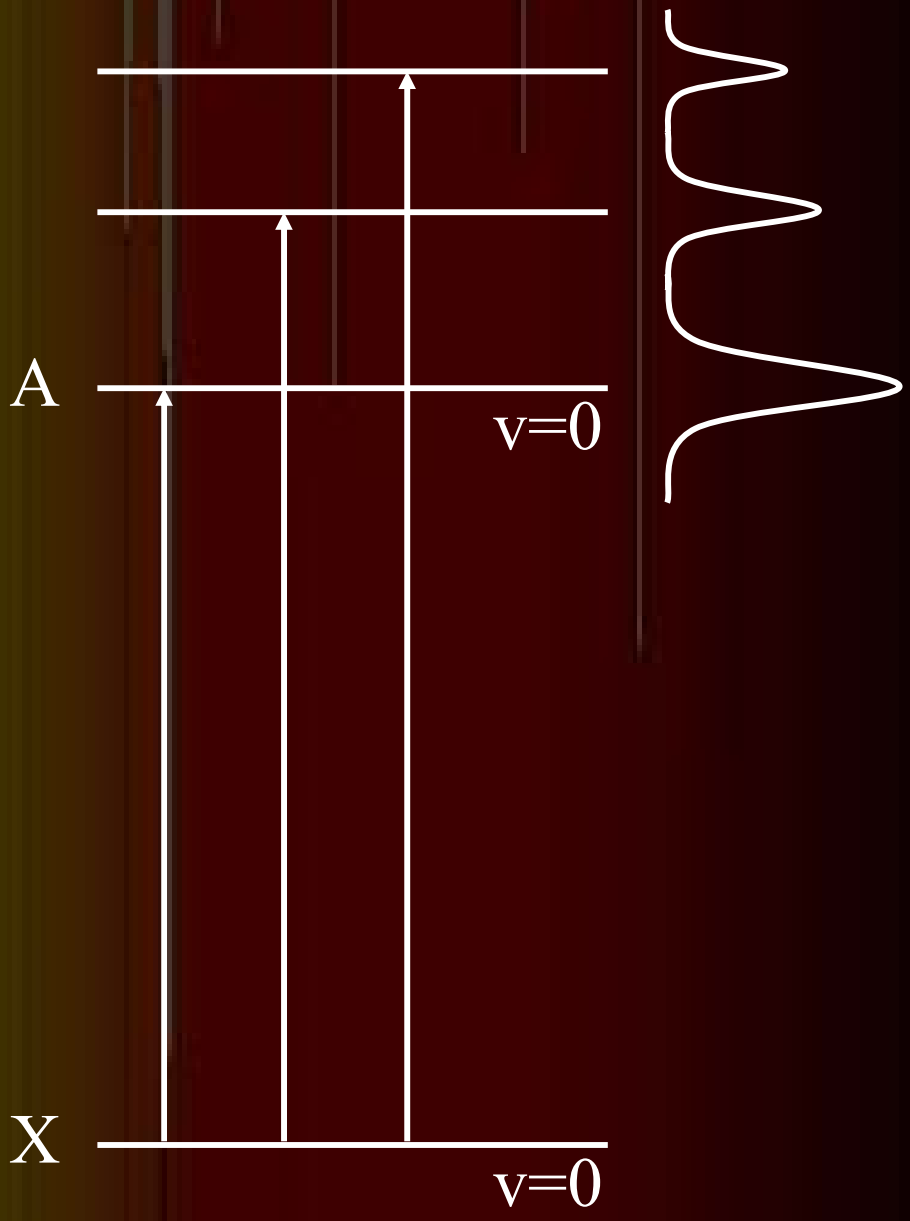
reasonable correlation [a la Federman et al. ApJ 287, 219 (1984)]



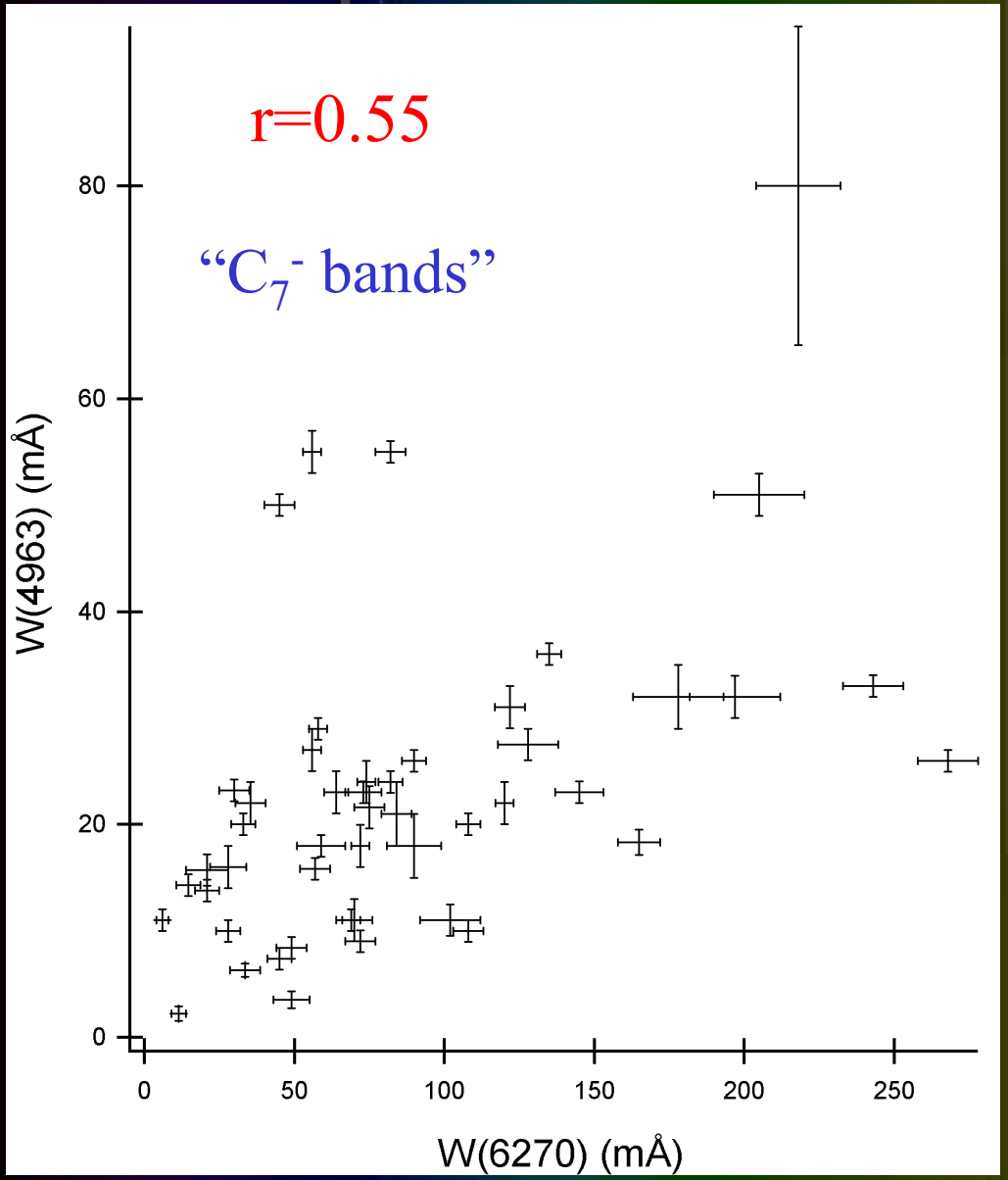
Visible spectroscopy can pinch-hit for UV spectroscopy?

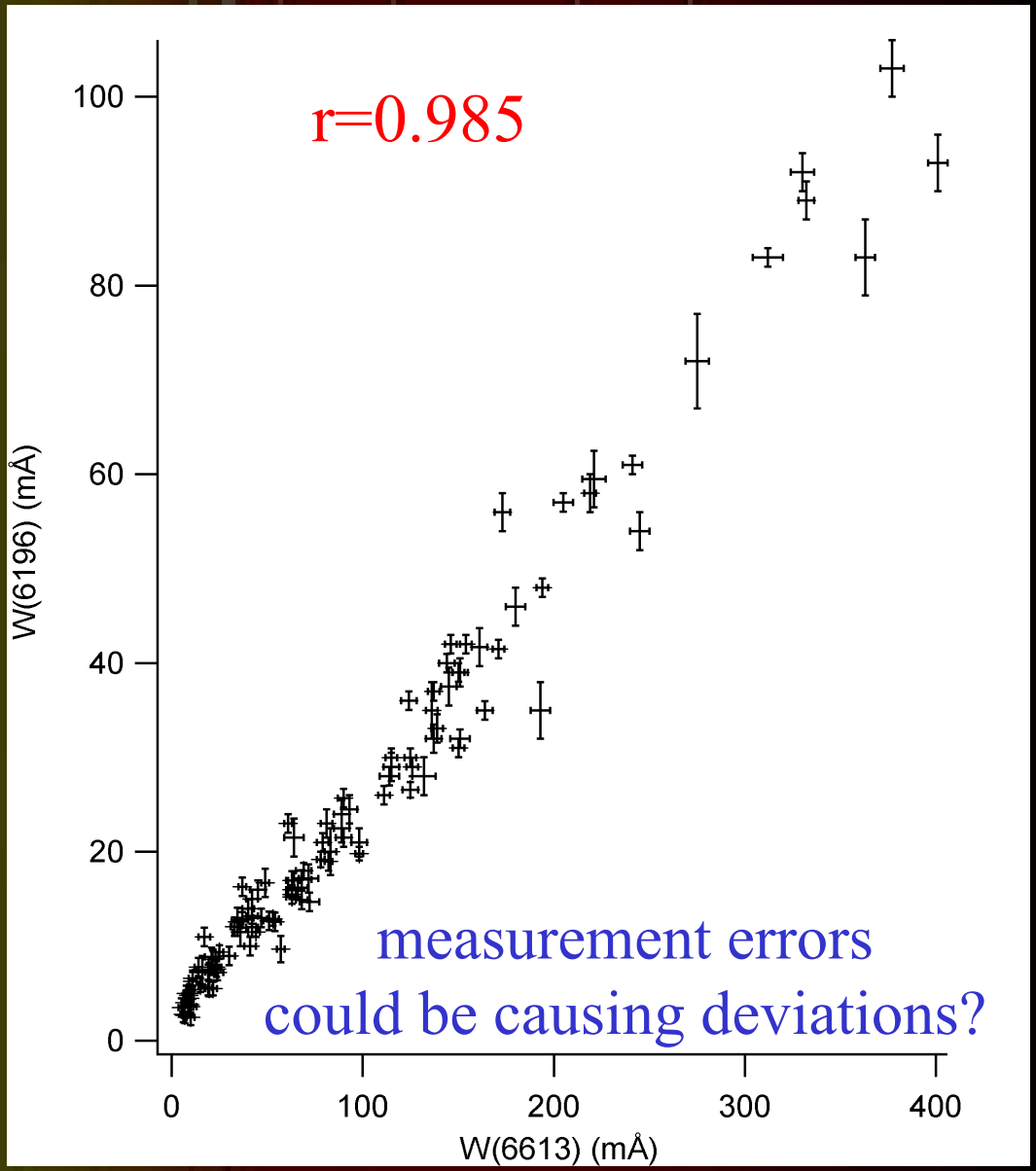
Search for a Common Carrier

- 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

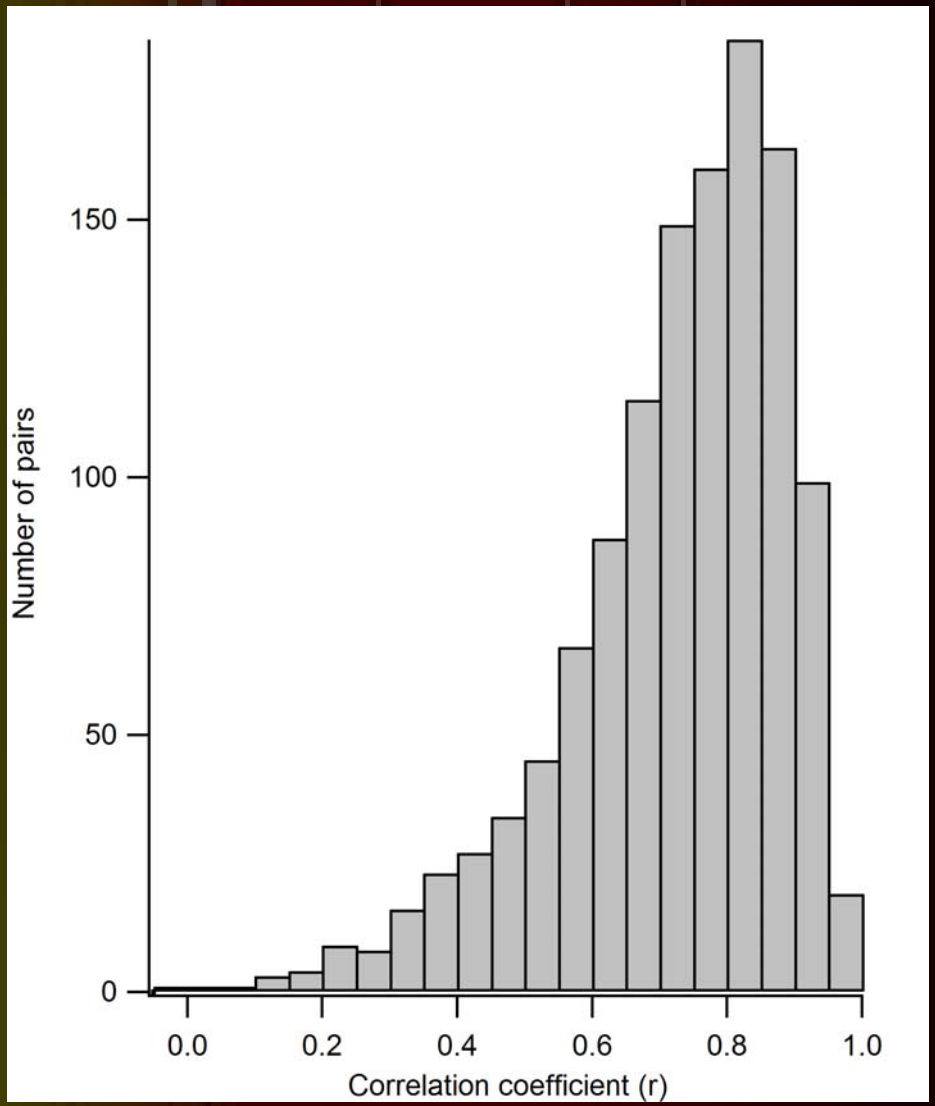




Still much work to do, especially on weaker bands!

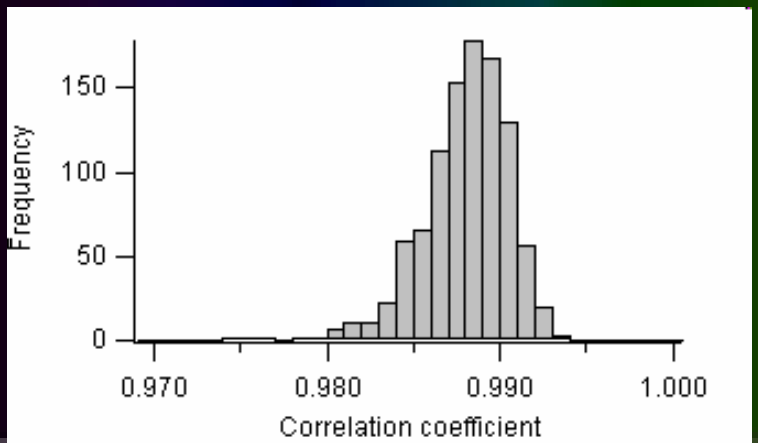
Statistics of Correlations

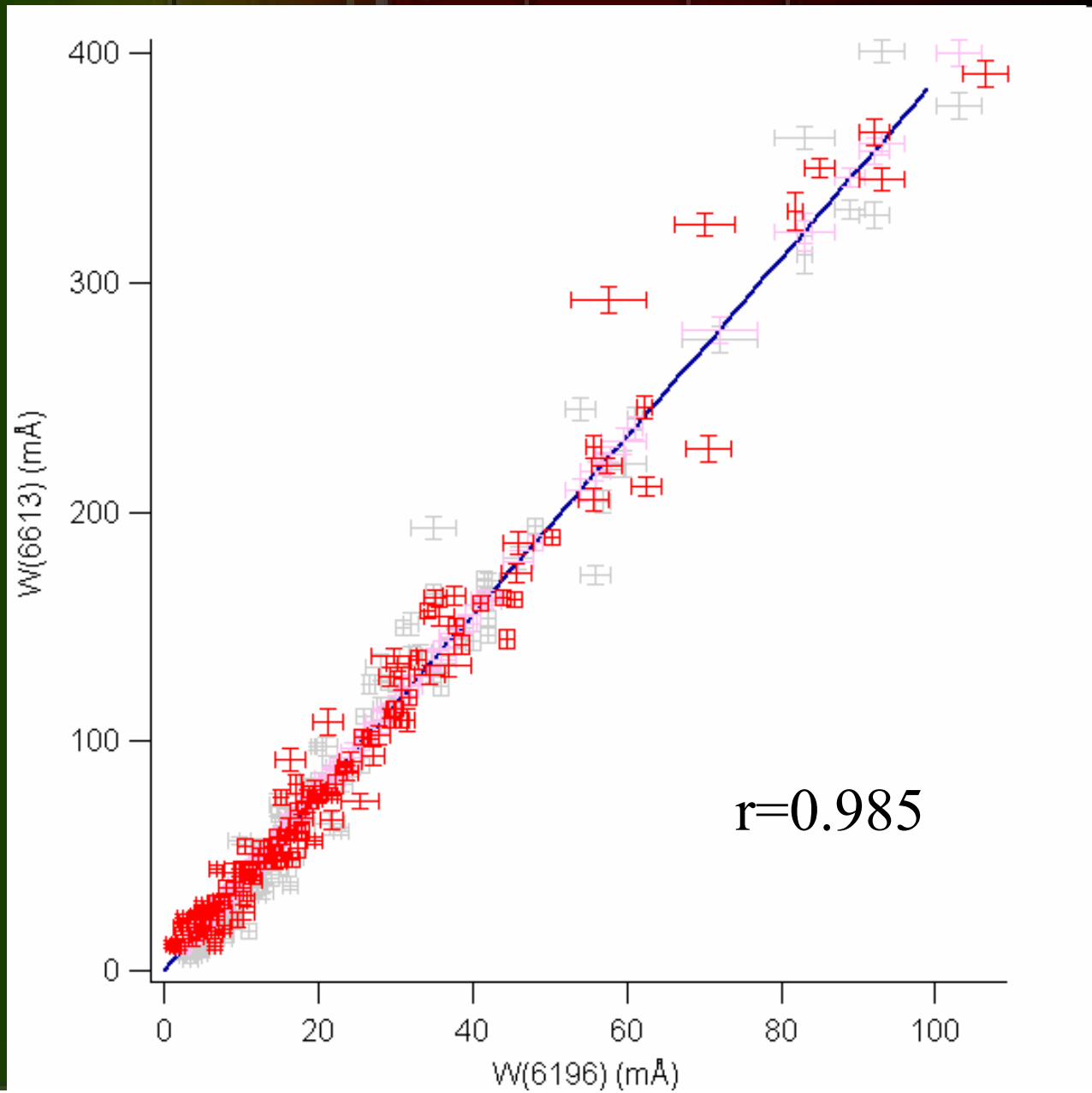
- 1218 pairs of DIBs observed in >40 stars
- 58 DIBs included
- Histogram of r
- Few very good correlations
  - 19 with r > 0.95
- Most strong DIBs have distinct carriers



Decorrelation Bias from Error

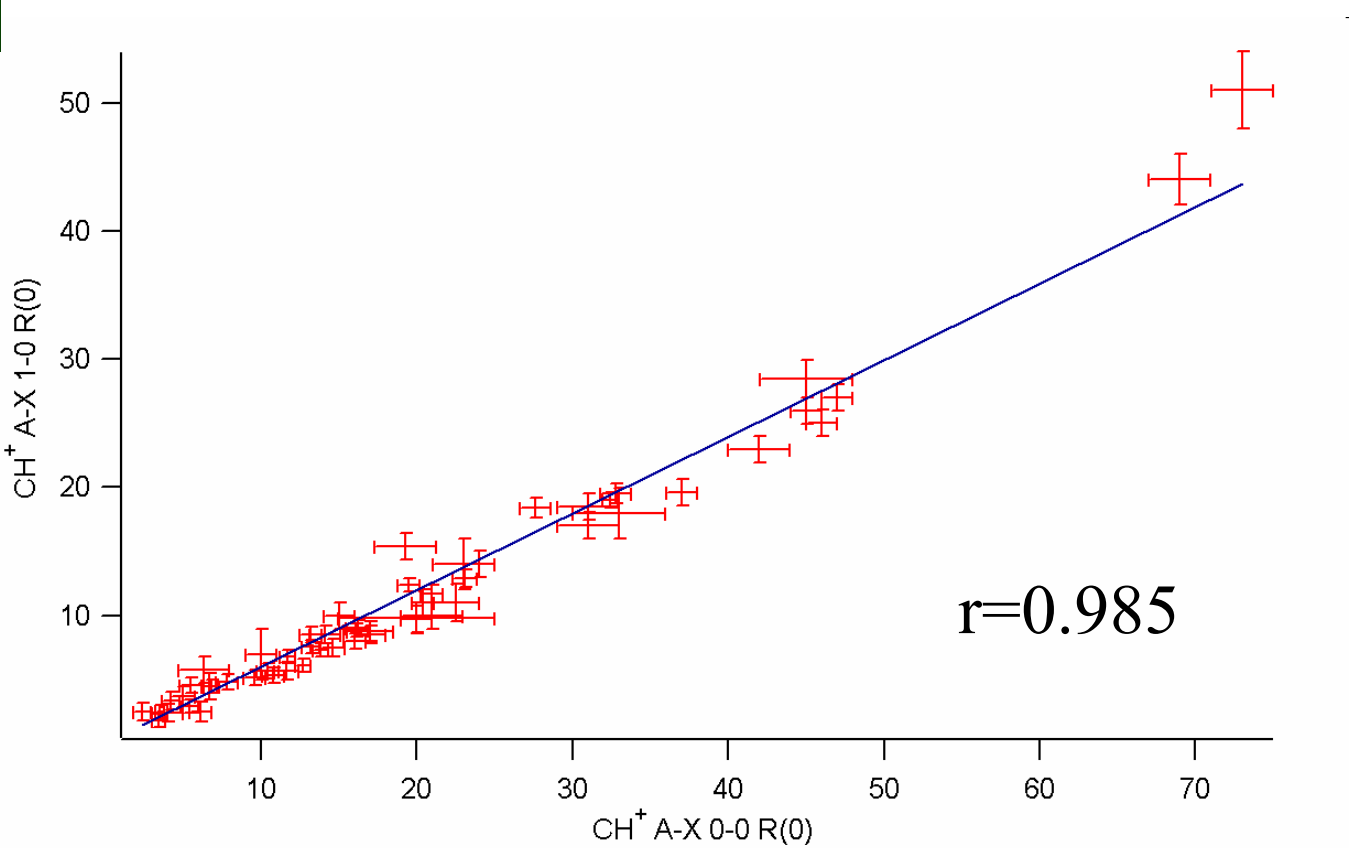
- Observed r=0.986
- Assume perfection
- Add Gaussian noise
- 1000 M.C. trials
- Double the noise
- 1000 M.C. trials
- Statistically OK if we underestimated errors





Measurement Errors

- Is doubling the error estimate reasonable?
- Error sources include:
  - finite S/N
  - unexpected structure
  - interfering DIBs?
  - continuum placement
- Agreement not always perfect!
  - CH^+ A-X band
- Hard to say; but it's certainly a very good correlation!



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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