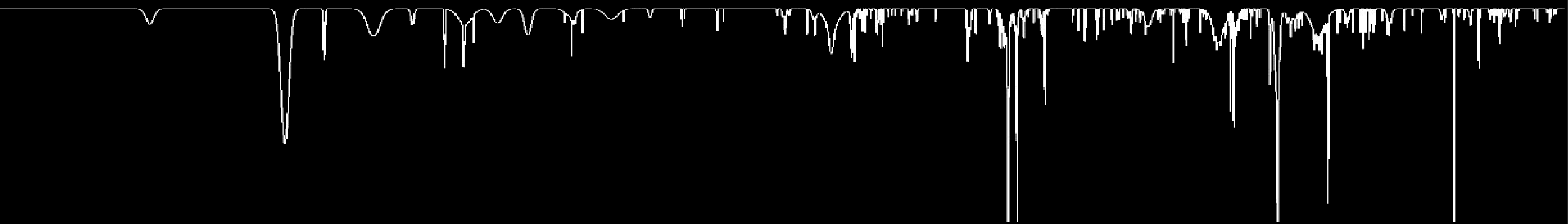


Diffuse Interstellar Bands:
an elderly astro-puzzle rejuvenated

Nick Cox*

[nick@ster.kuleuven.be]

K.U.Leuven

* With support from my collaborators throughout the years:
M. Cordiner, P. Ehrenfreund, P. Sarre, B. Foing, F. Salama, J. Cami, K. Smith, L. Kaper, M. Spaans, F. Patat, J. Sollerman, C. Thoene, D. Vos.

Contents

Chemical complexity of the (diffuse) ISM

Diffuse/translucent clouds: T ~ 50 - 200 K and n_H ~ 100-1000, A_V < 10 mag

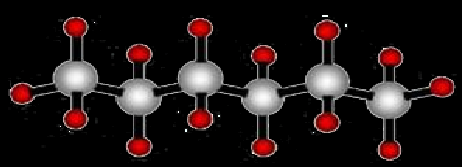
IDENTIFIED FEATURES:

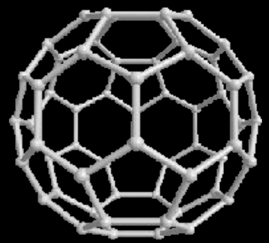
Ground level transition of neutral and ionised atoms (1904+);
UV-OPTICAL: NaI, CaI,II, TiII, KI, C, H, etc.

Posters 1.83 (Snow)
2.50 (Krelowski)

Transitions of simple molecules (1937+);
UV-OPTICAL-NIR: CH, CH^+, CN, H_3^+, H_2, C_2, C_3

Molecular lines (absorption);
far-IR/sub-mm/mm: HCO^+, C_2H, NH_3, C_3H_2

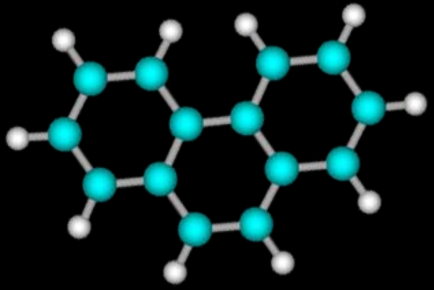




UNIDENTIFIED FEATURES:

Aromatic Infrared emission Bands (AIBs); 6.2, 7.7, 8.6, 11.2 micron

3.4 micron infrared absorption feature



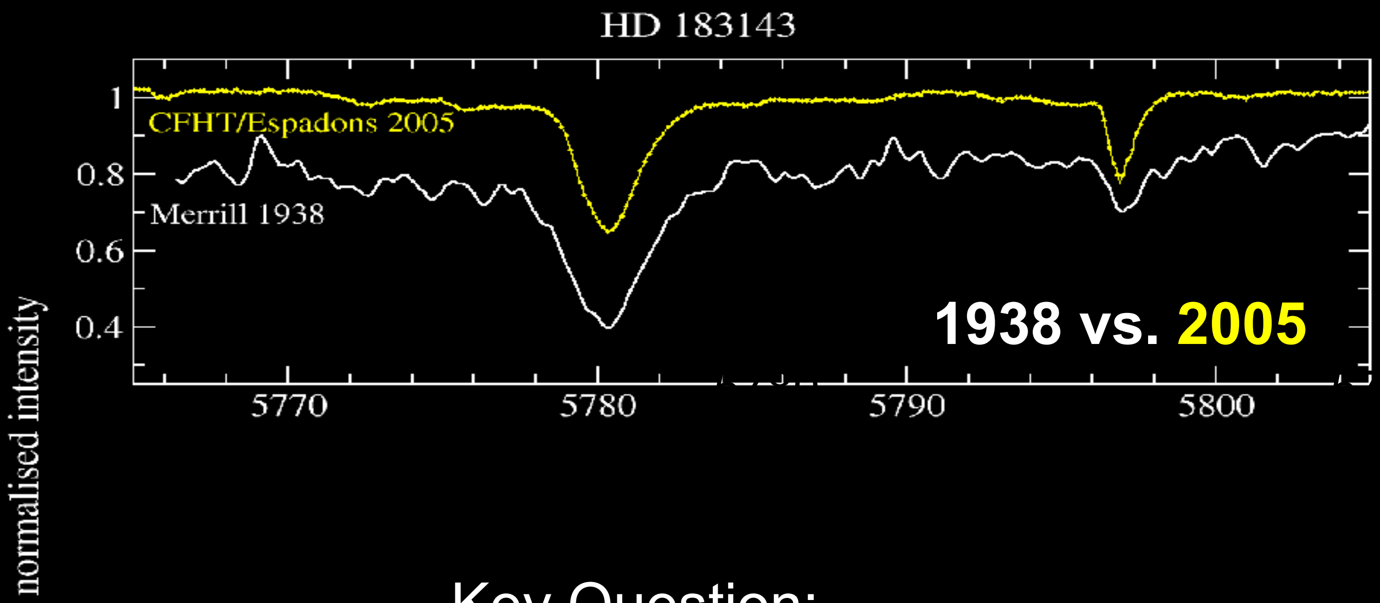
UV extinction bump (~1970); 2175 Å

Diffuse Interstellar absorption Bands (1922);
4,000-10,000 Å

[2 DIBs at ~1.1 & 1.3 micron → Poster 2.82: Rawlings]

Diffuse interstellar bands

"… first 2 noted by Canon (~1904), reported stationary by Lea Mary Heger (1921), identified as interstellar by Merrill (1937). Now >400 known (Hobbs 2010)."



Highest nr. DIBs around
6500 Å

FWHM distribution peak
0.7 Å

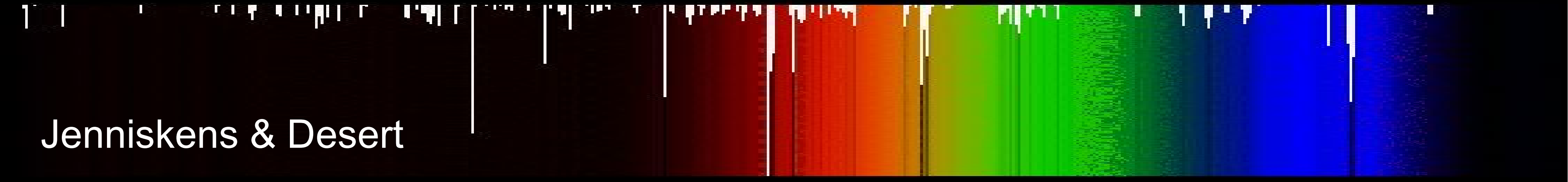
Total equivalent width:
~25-30 Å/E_{B-V}

Abundance (f=1):
10^{14} cm^{-2}

Fractional abundance:
10% of f_{PAH} (10^{-7})

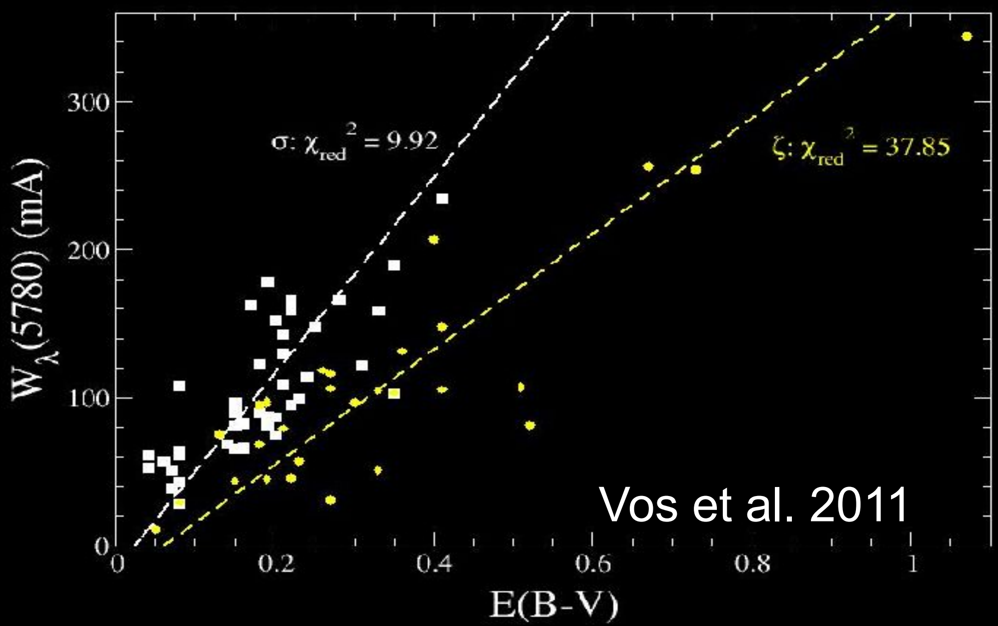
Key Question:

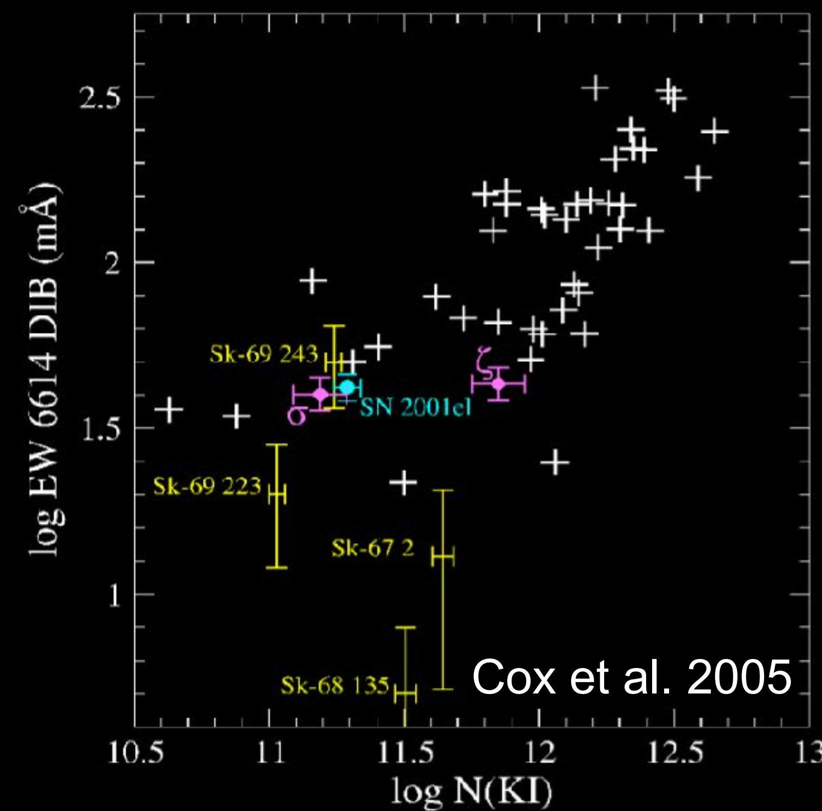
What are the carriers of these absorption bands?

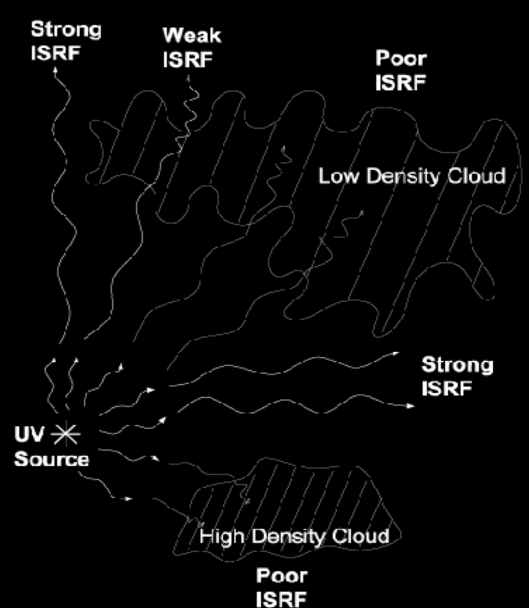


DIBs related to interstellar gas or dust?

DIBs correlate (roughly) with both amount of gas & dust (Merrill 1937)



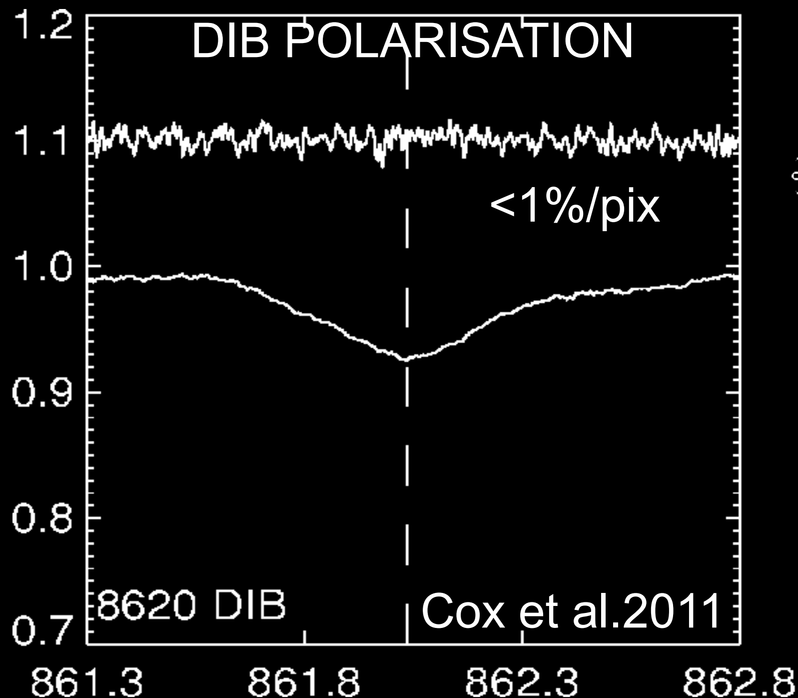




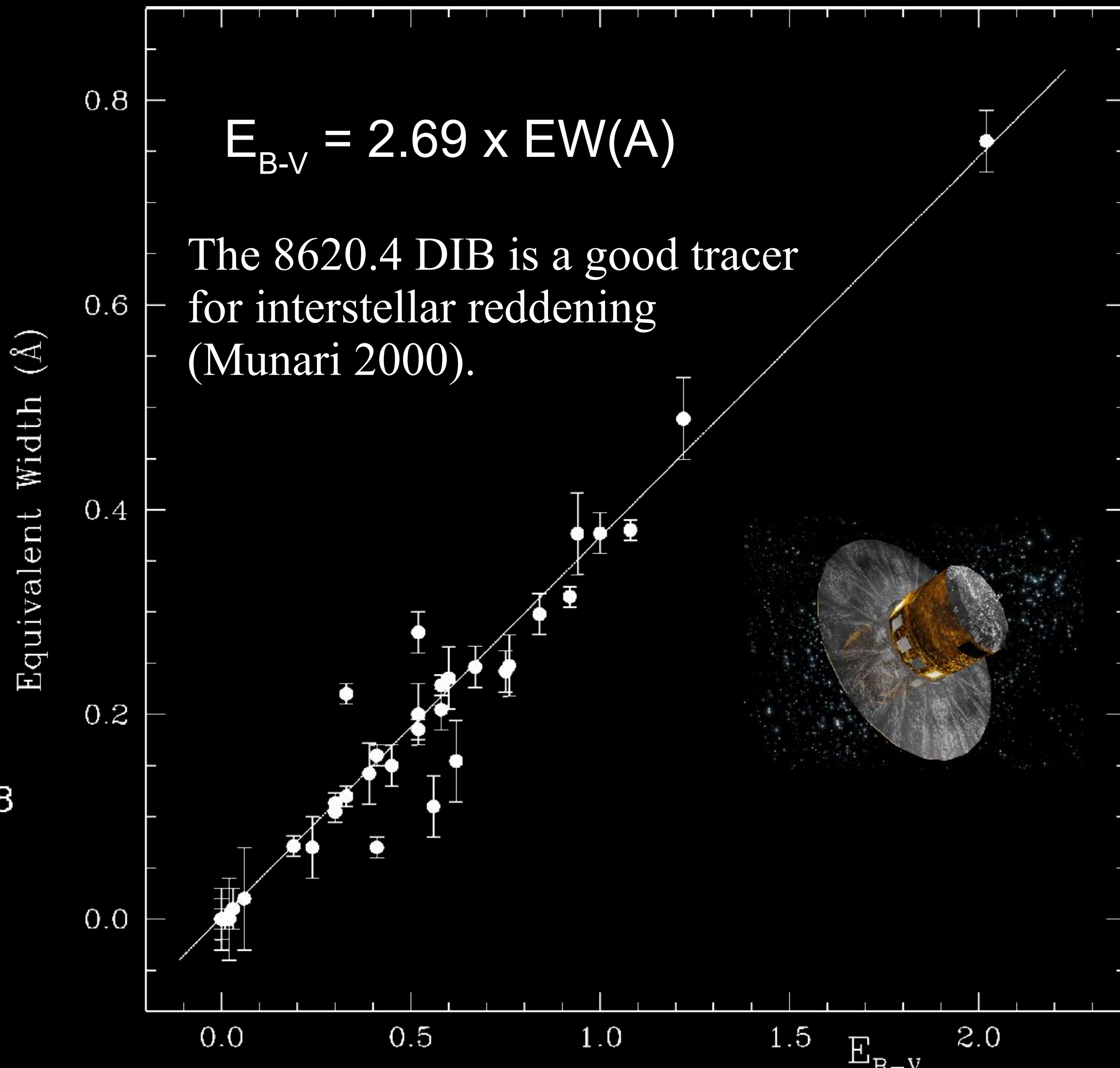
Strong dependence of DIB ratios on effective interstellar radiation field → **sigma / zeta effect**

8620.4 Å "Gaia" DIB – perfect dust tracer

Is this DIB related to dust grains!?

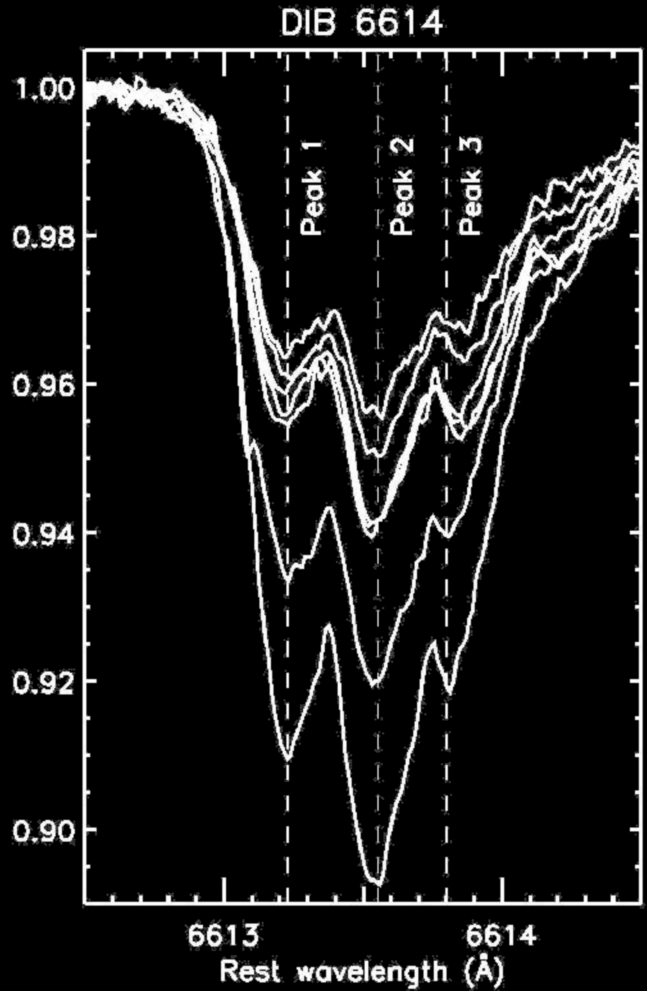


Understanding the behaviour of the 8620.4 DIB would be extremely useful, providing a tracer of the interstellar medium conditions.

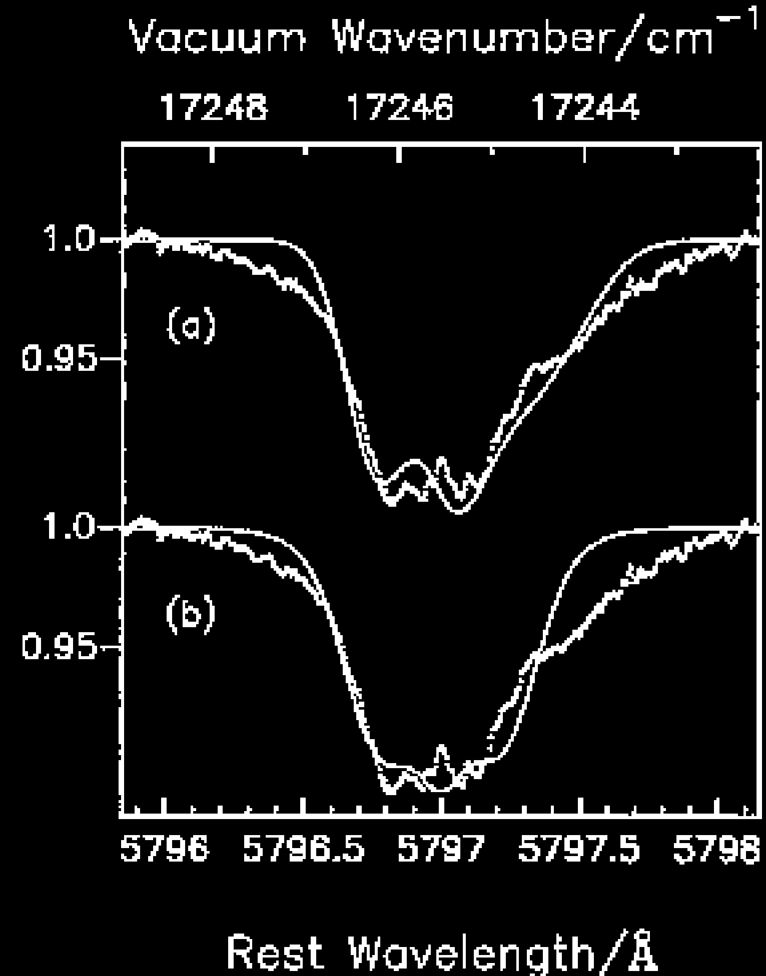


DIB SUBSTRUCTURE

evidence for large carbonaceous gas-phase molecule

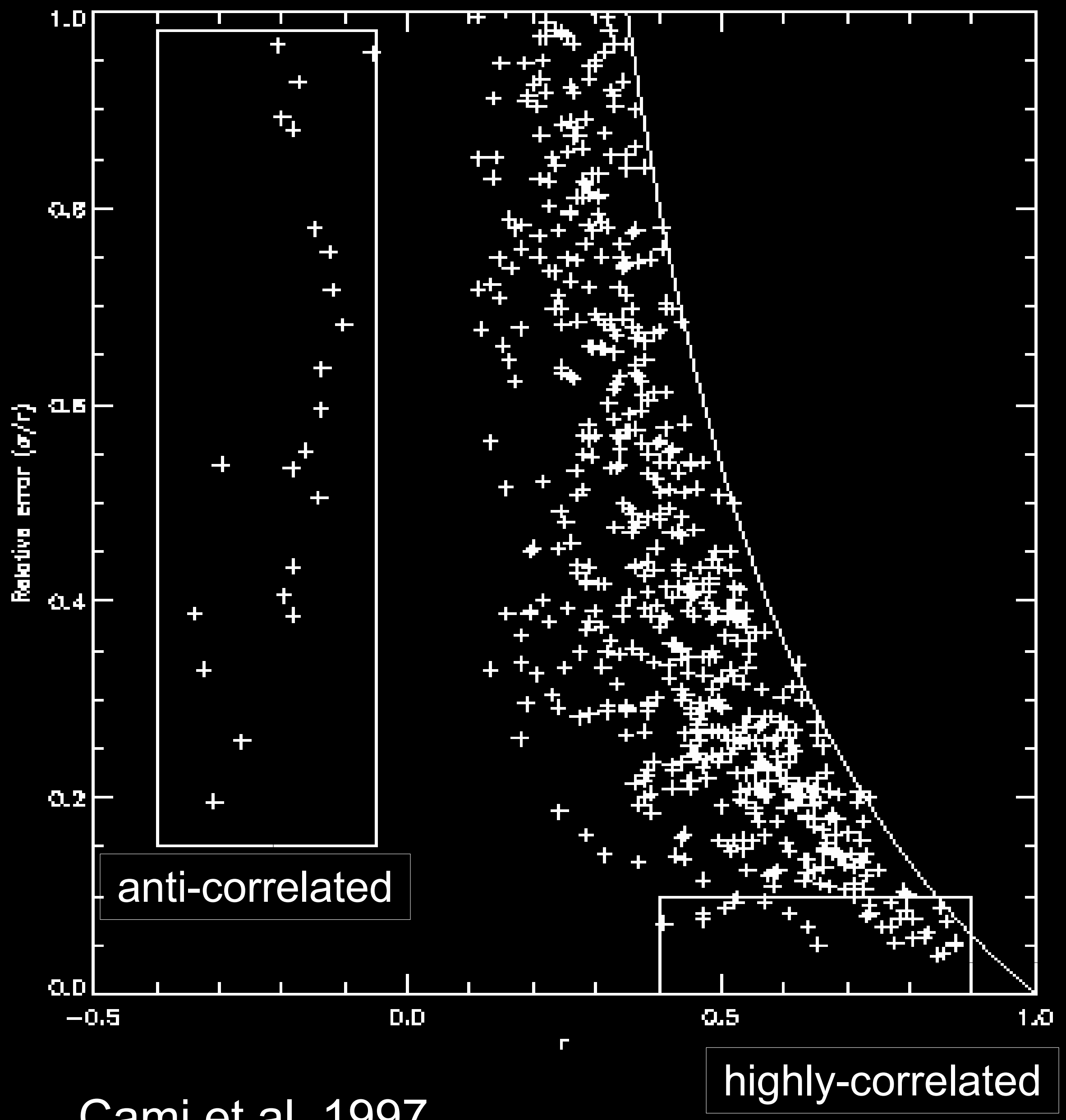


Cami et al. 2004



Kerr et al. 1996, Sarre 1995

DIB CORRELATION STUDIES



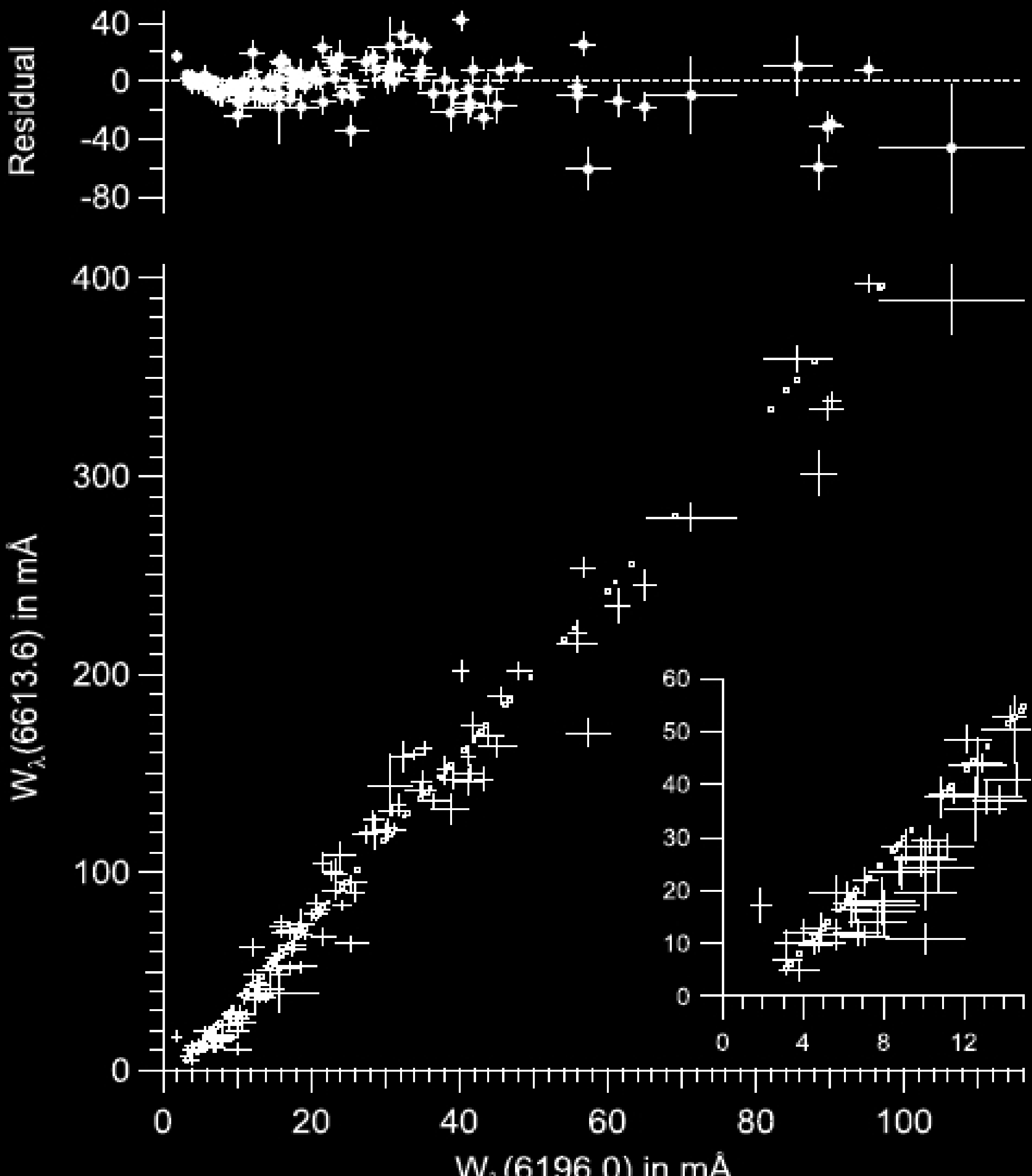
Cami et al. 1997

Weak correlation between most DIBs → strengths increases (roughly) with $E_{(B-V)}$ and NaI.

Thus unique, but many related, carriers. Related in sense of similar stability, size and/or ionization/hydrogenation levels.

1 DIB – 1 CARRIER HYPOTHESIS

DIB correlation studies



McCall et al. 2010

Strong correlation between **6196** and **6613** DIBs.

Pearson correlation coefficient **r=0.986**

Much better than between 5780 DIB and E(B-V) or N(HI) (r=0.82 & r=0.95) (Friedman et al. 2011).

Implications: same carrier!?

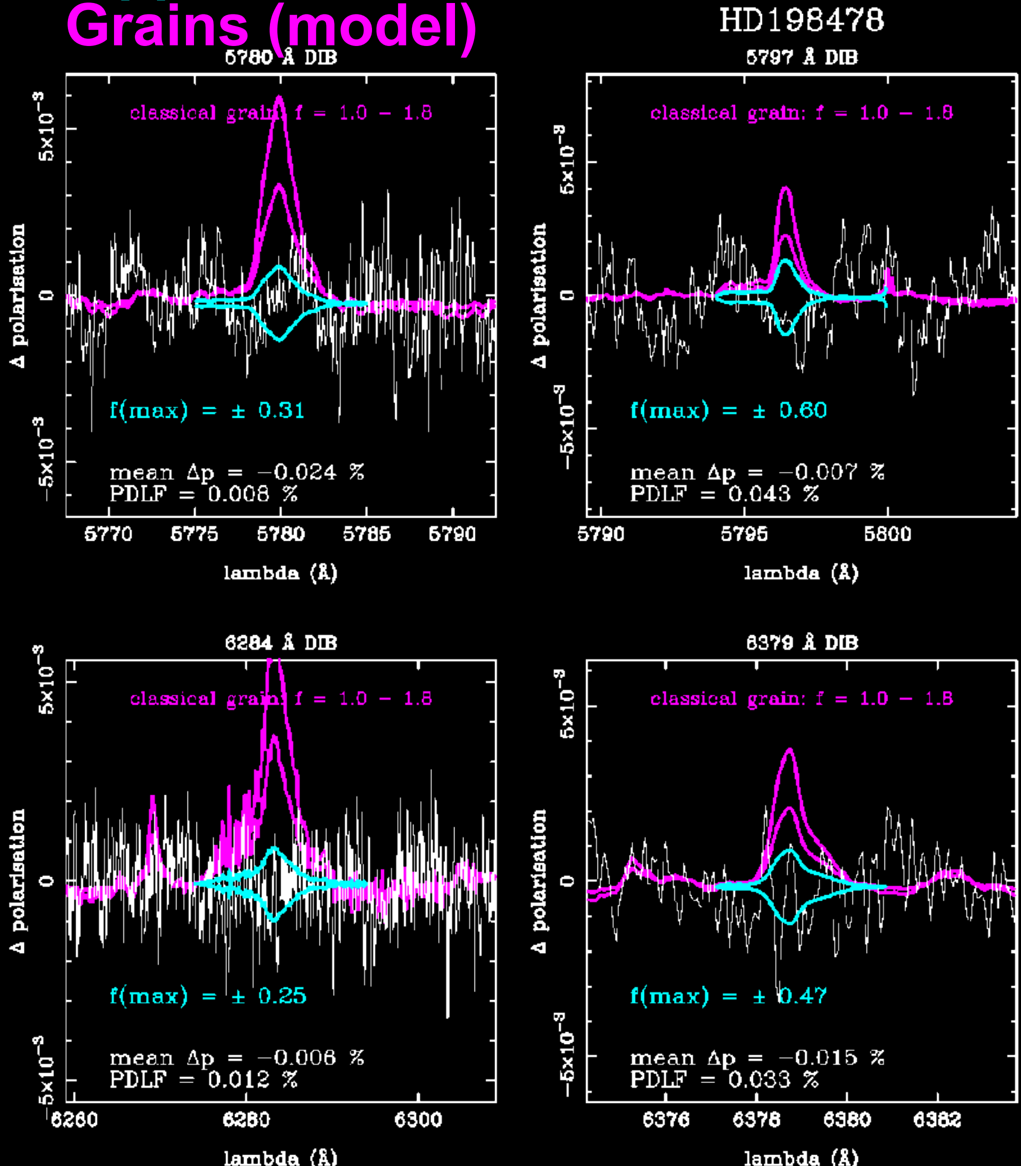
Problem: different line widths, shapes and strengths

Solution → strong constraints on molecular constants.

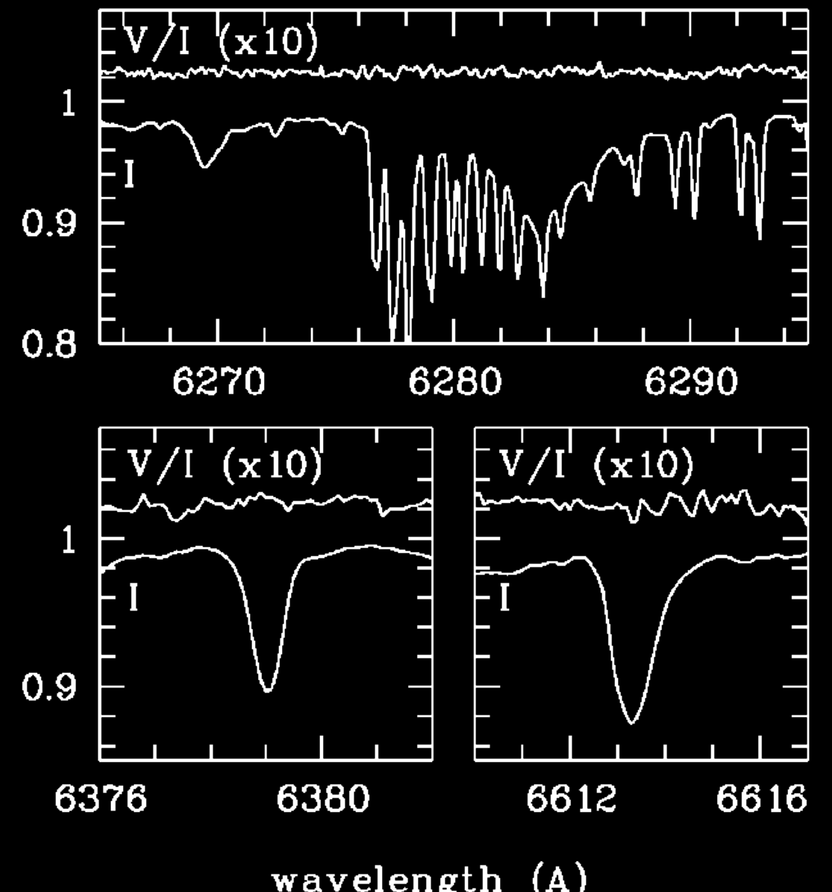
Scatter on perfect correlation or underestimated uncertainties?

Why not a grain? Lack of polarisation in DIBs.

Upper Limit - Observed
Grains (model)



40 DIBs (strong, weak, near-IR) show **no line polarisation**.



Lack of polarisation w.r.t. predicted polarisation for dust grains implies gas-phase molecules.

Cox et al. 2007 & 2011

Overview DIB properties & behaviour

See also reviews by Herbig (1995) and Sarre (2006) and reference therein.

- Variety of widths (narrow, broad, very broad – from ~0.5 to 30 Å or 2 – 80 cm^{-1}) **indicative of poly-atomics.**
- Stronger where there is more **interstellar dust (reddening) & gas (HI, NaI)**
- Band **strength ratios not constant**; affected by the effective UV field?
- Weak correlation between bands (except 6196+6613) → unique carrier each DIB?
- Chemical stable species! No temporal variation.
- Substructure -> **rotational contours** of complex **gas phase** molecules (depends on temperature)
- no polarisation signal in band profile -> **no 'large' grains nor grain-impurities**
- **Not correlated** with far-UV extinction (ie not small grains) nor UV bump (HACs)
- **absent/depleted** in circumstellar material of **evolved stars**
- **ubiquitously** present in diffuse Galactic ISM

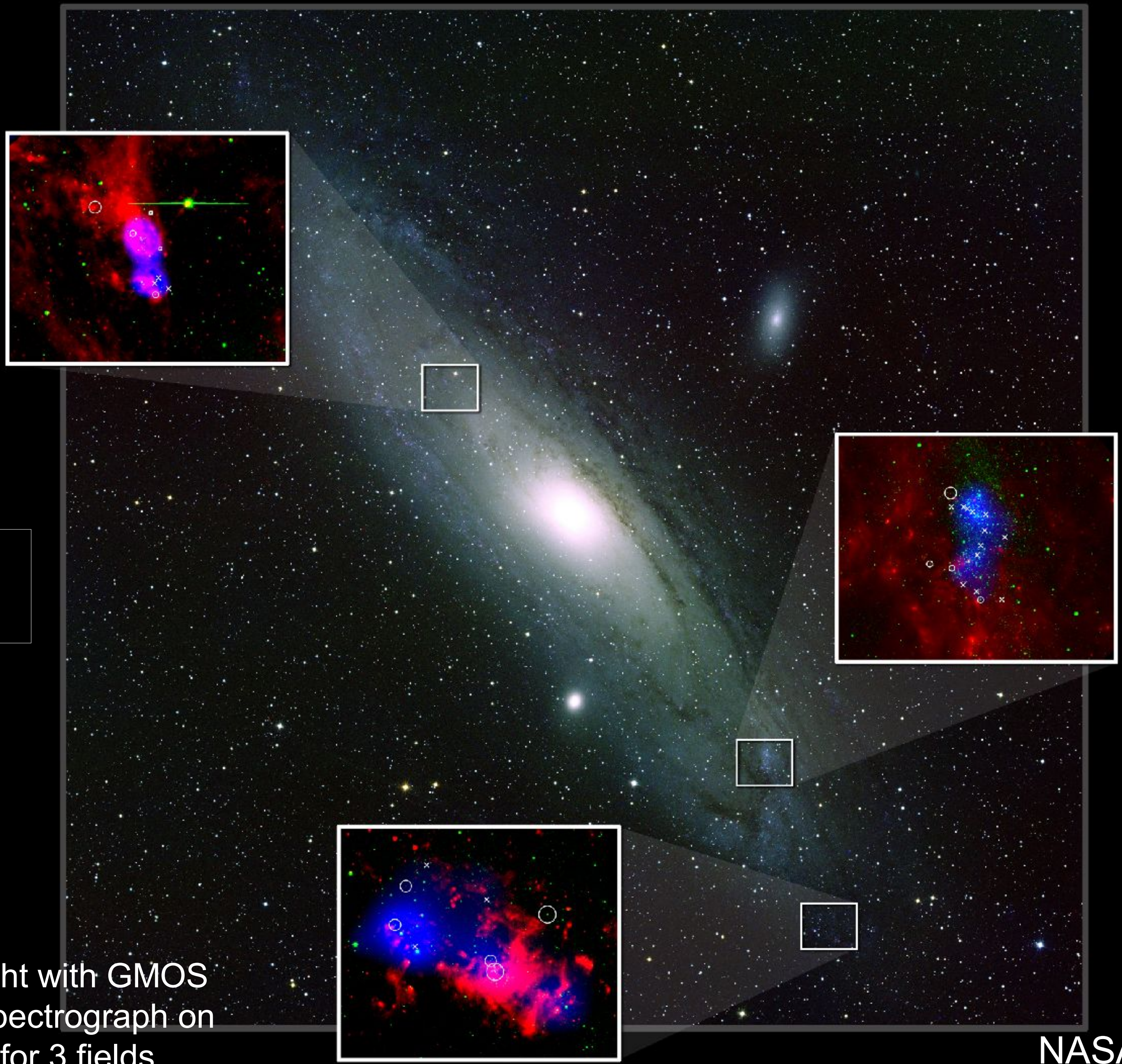
Beyond the MW: The Local Group

probing different interstellar environments

	Metalicity	Gas/dust	ISRF	Extinction
Milky Way	~1	~1	1-10	nominal
SMC	0.1-0.2	~5-10	>30	No UV bump
LMC	0.25 – 0.5	~2-5	>5	Weak UV rise, strong ISRF
Andromeda (M31)	~1	~1	<1	Weak UV bump, anomalous extinction curve
Triangulum (M33)	~1	~1	~1	?

* To probe larger range in global physical ISM condition
* To understand how common and widespread DIBs (organic matter) are throughout the history of the Universe
* To gain insight in formation & destruction of the DIB carriers
* To derive properties of the extra-galactic diffuse ISM

A case study for the Andromeda galaxy

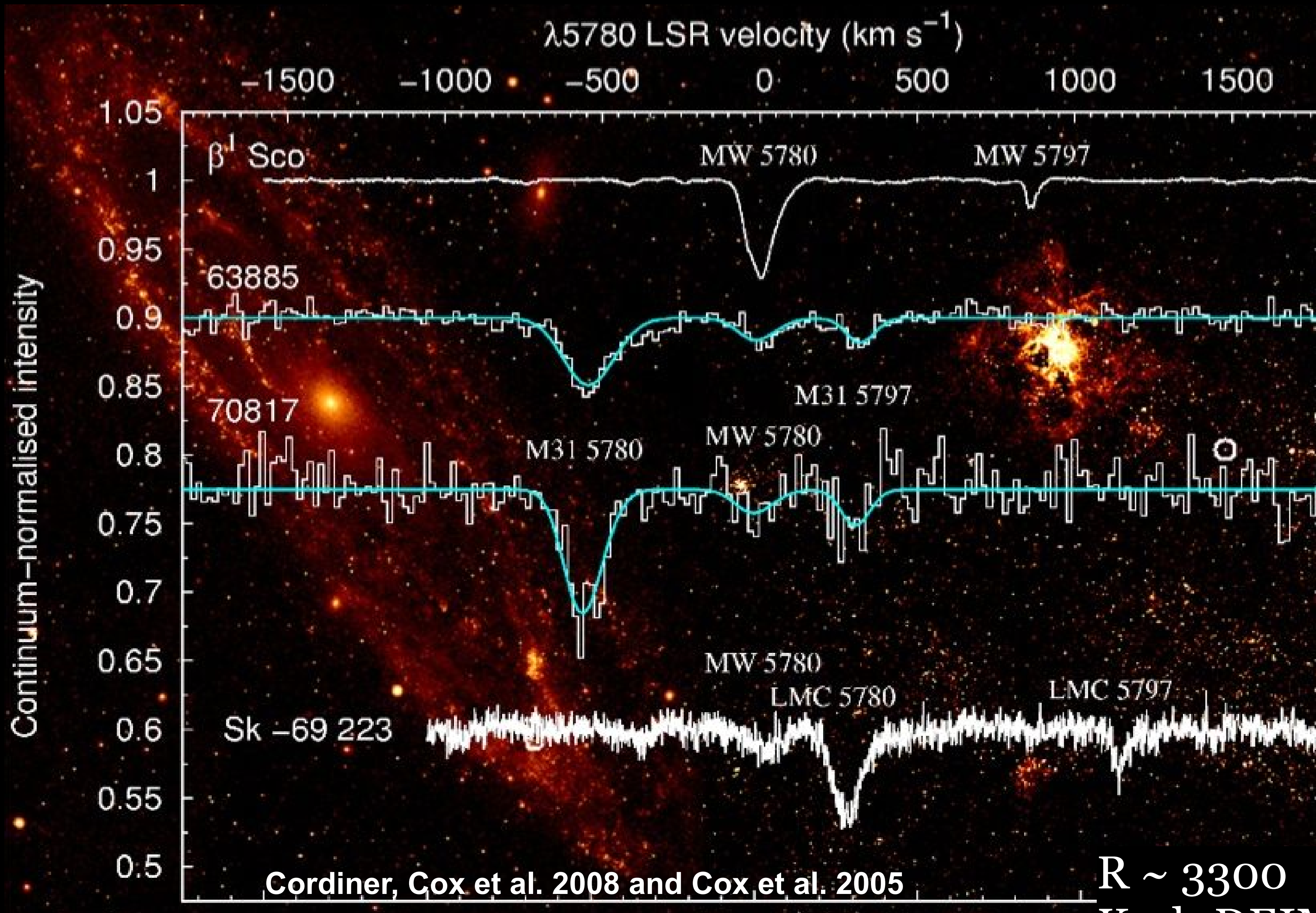


Poster: 2.21 (Cordiner)

33 lines-of-sight with GMOS multi-object spectrograph on Gemini-North for 3 fields.

NASA/Cordiner/Cox

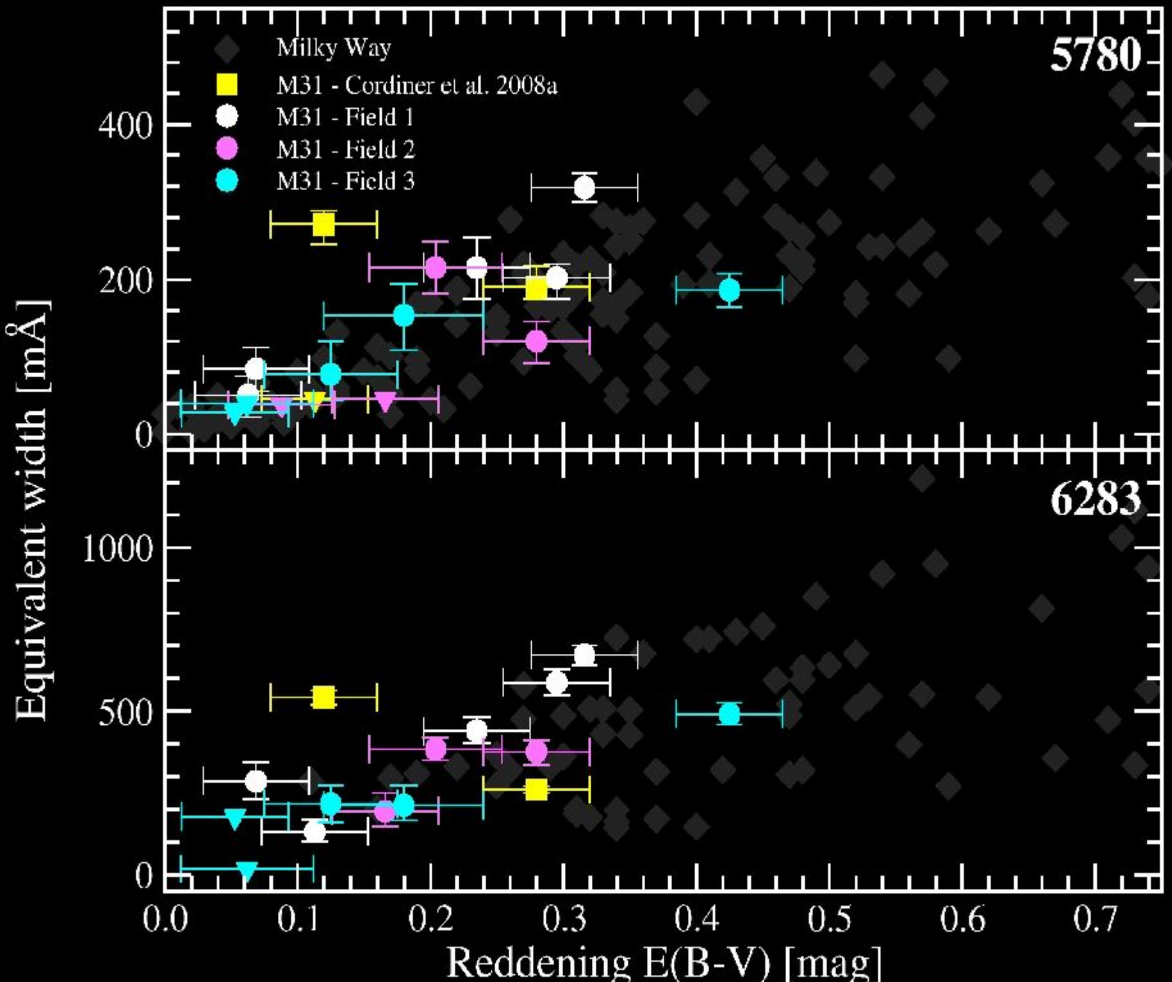
DIBs in MW, LMC & M31

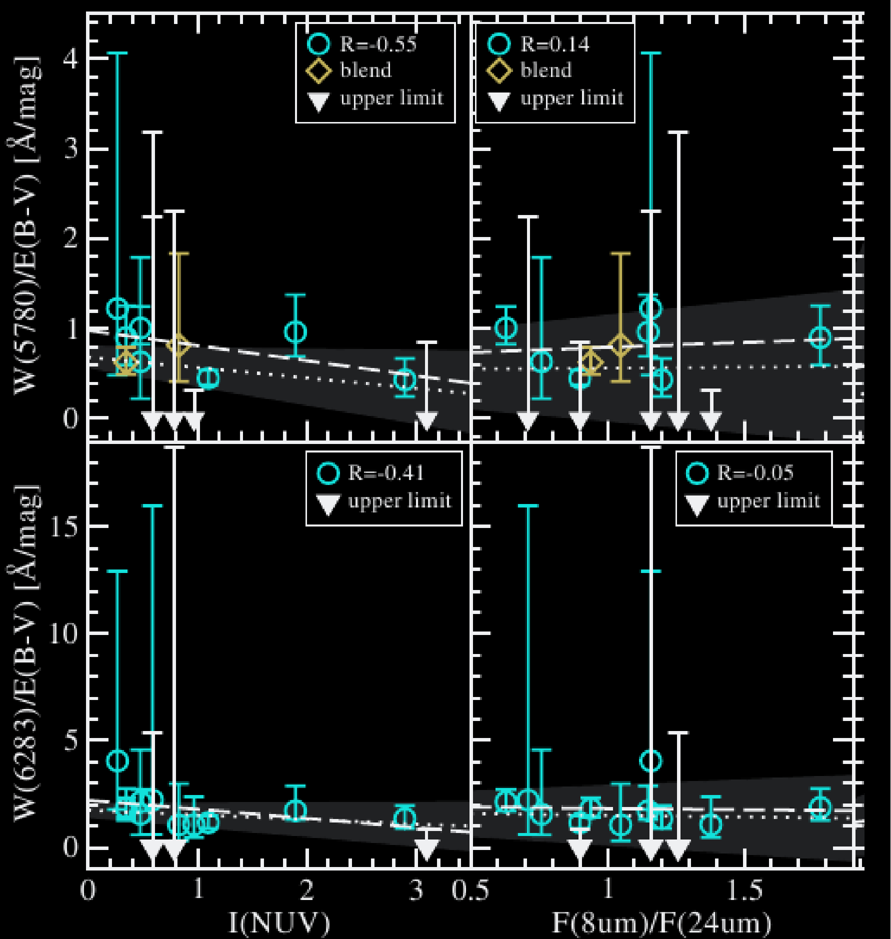


M31 DIBs, NaI and CO
at -560 km/s

R ~ 3300
Keck-DEIMOS
Novel DIB-FIT

DIBs & Dust in MW & M31

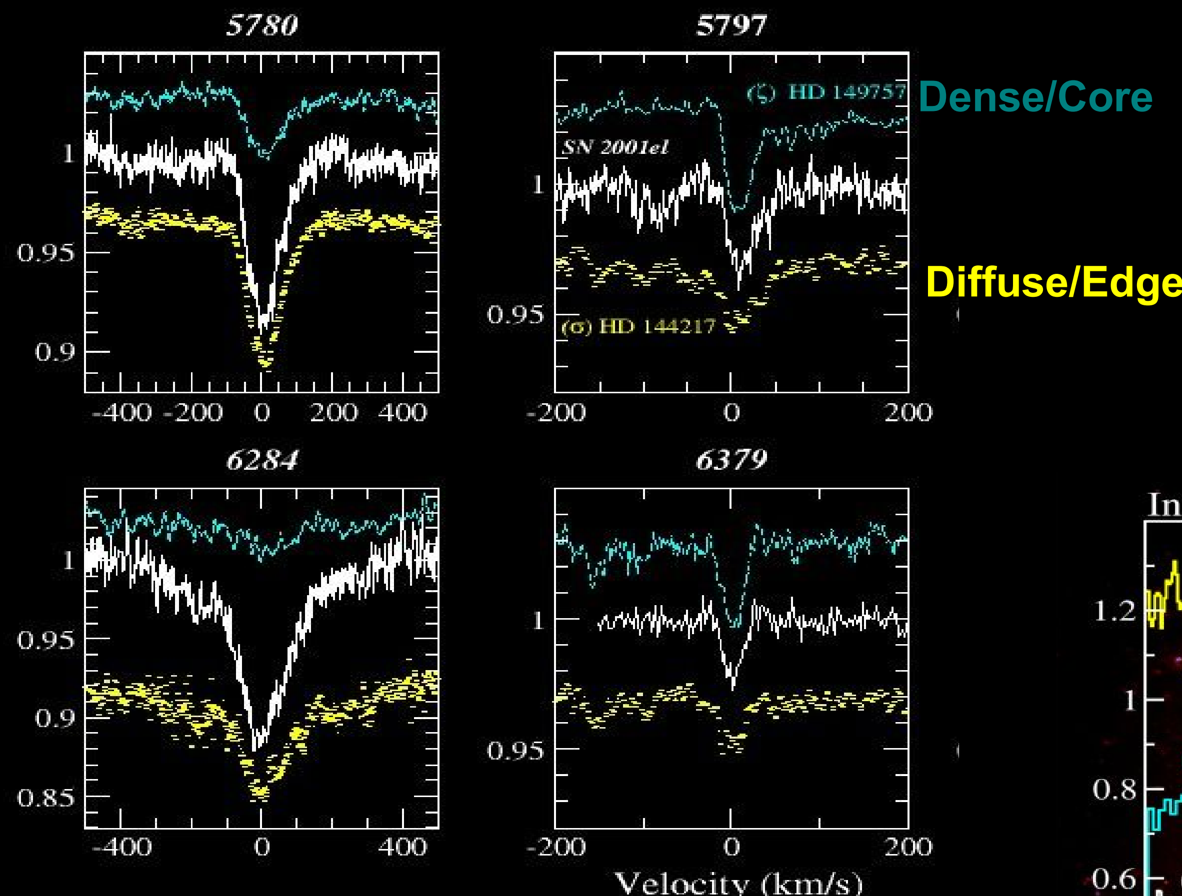




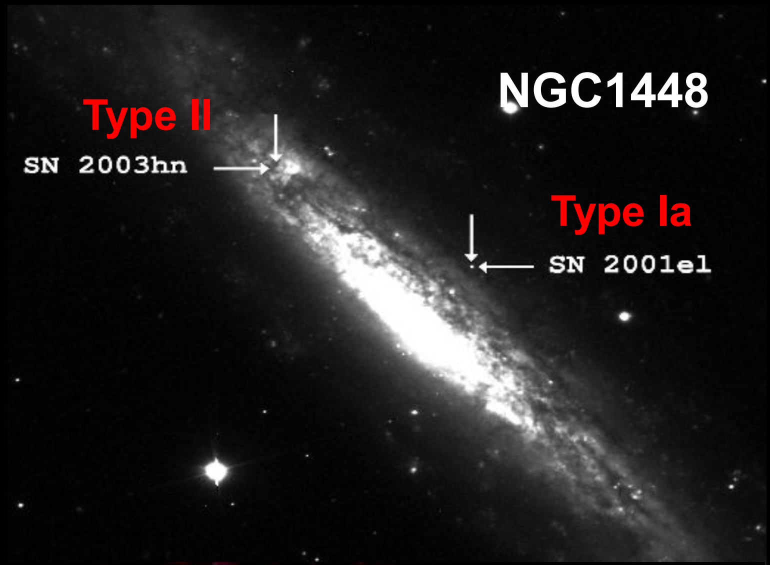
Cordiner, Cox et al. 2011

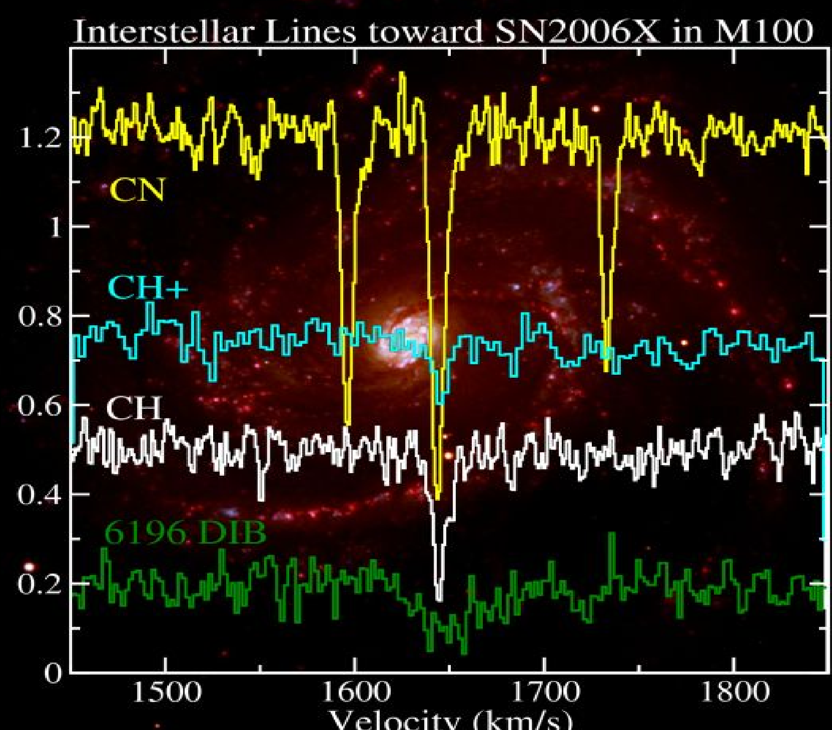
DIBs beyond the Local Group:

Probing supernova host galaxies



Sollerman, et al. 2005





Cox & Patat 2008

Extra-Galactic DIBs

* **Metallicity, Star Formation** (=>UV radiation field) and **dust size distribution** (=> extinction curve) are the most important differences between **Local Group** galaxies.

* The strength of DIB features is governed by the **balance between formation (incl. ionisation) and destruction** of interstellar organic molecules.

* There is an apparent positive **correlation** between the presence of the **UV-bump and DIB carriers**, further hinting at their carbonaceous nature.

* DIB formation / destruction depends on the **LOCAL physical and chemical conditions**. Similar conditions exist among galaxies.

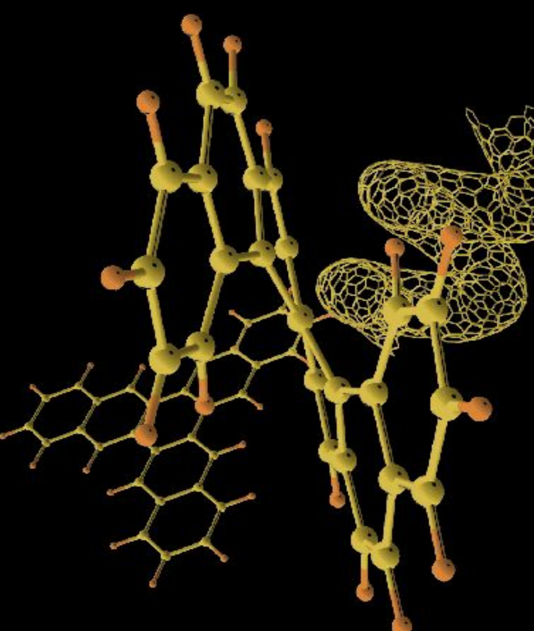
* DIBs (and thus large organics?) are **ubiquitously formed throughout space and time** (also DLAs at z ~ 0.5).

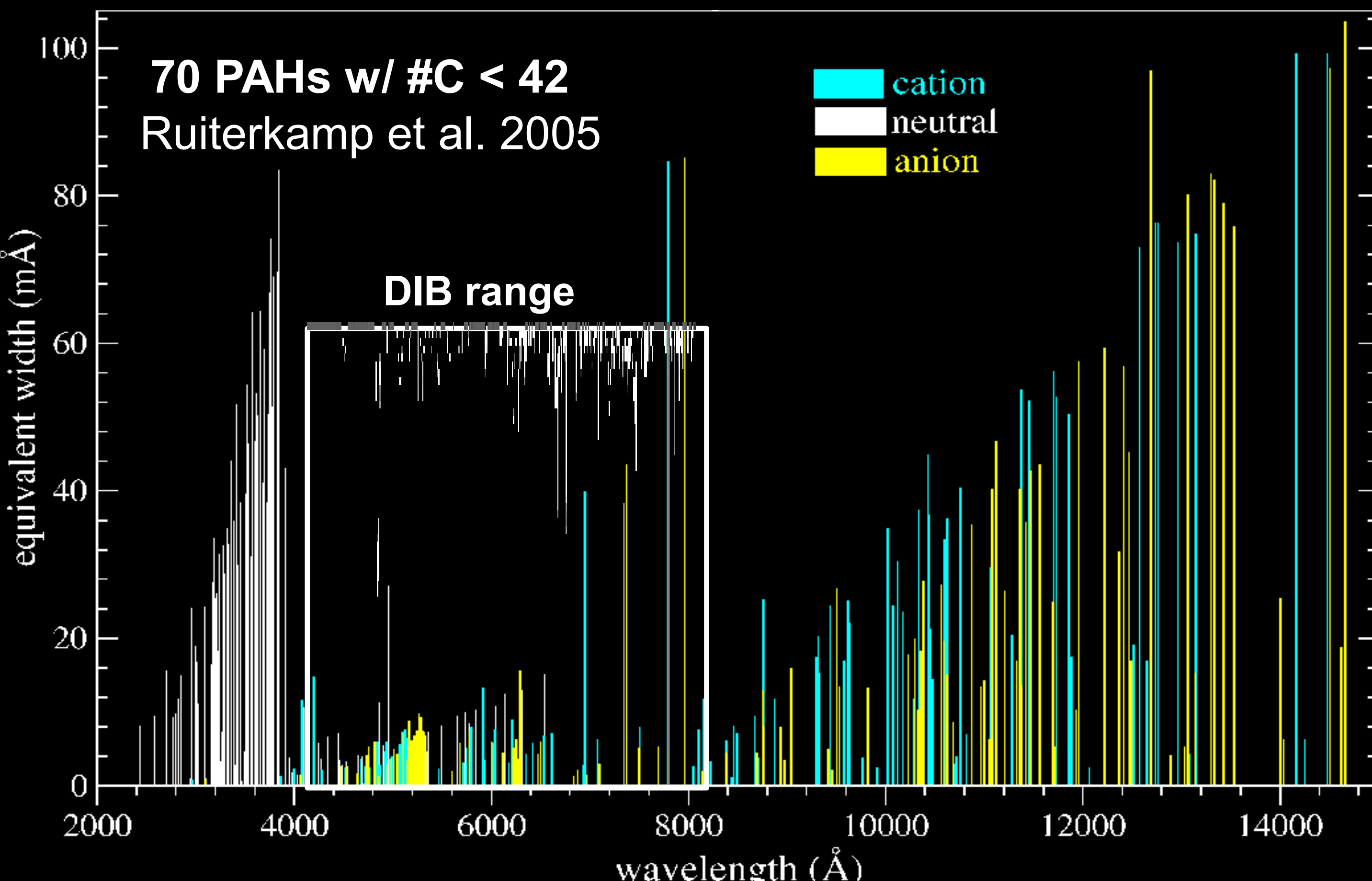
PAHs as DIB carriers?

- PAHs/aromatics in various forms are very abundant in space. Growing evidence from IR emission bands, narrow optical bands in RR, related carrier for UV bump.

- (compact) PAHs can be very stable against photo- and thermo-dissociation (for which formation/destruction mechanism is equilibrated) i.e. survive in harsh ISM.

- PAHs and its ions (cation or anion) absorb in the near-uv, visible to near-infared.

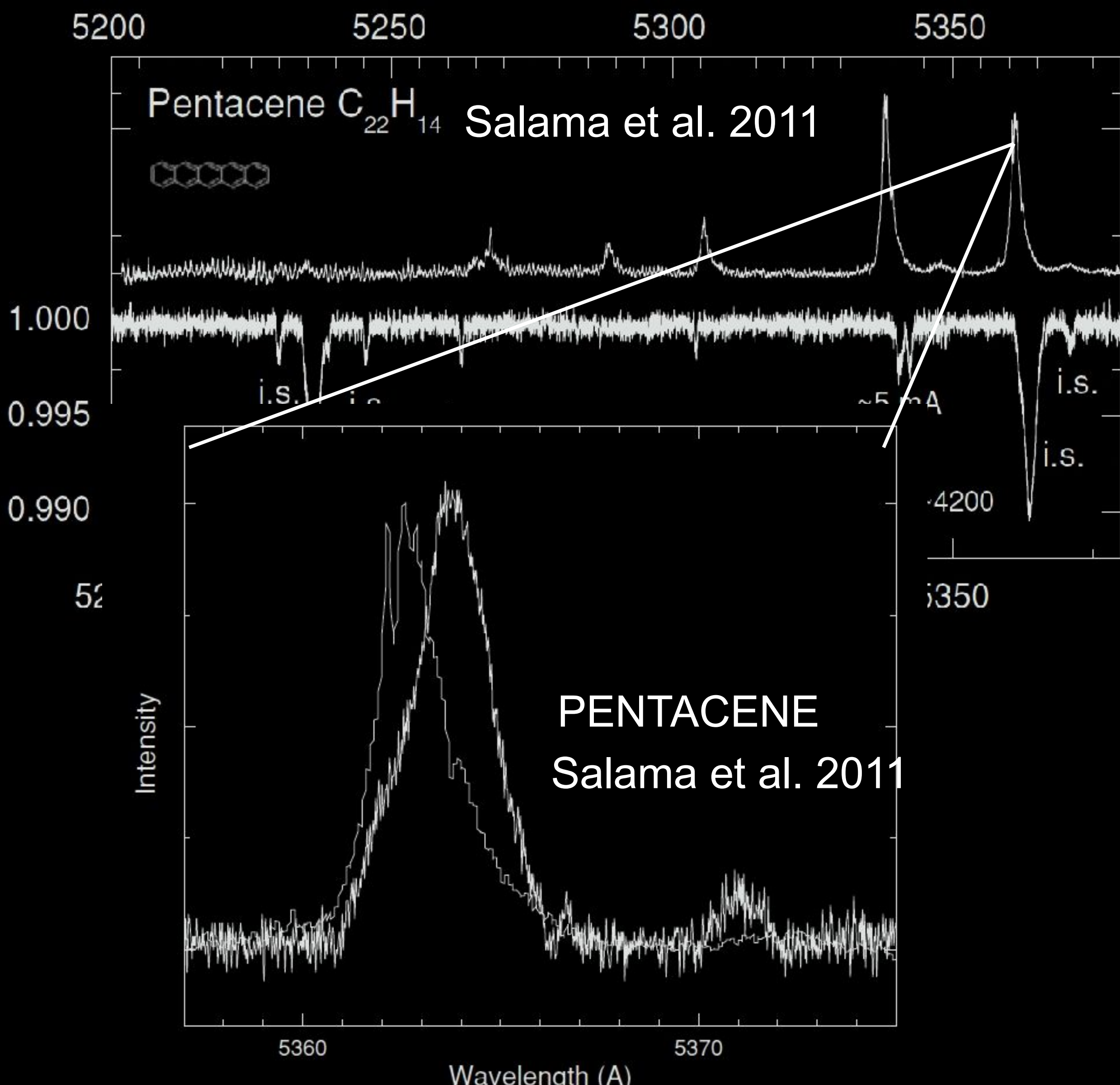




Similar results from lab & theoretical work by several groups.

Search for PAHs / DIB carriers...

Direct comparisons of observations with gas-phase spectra



Direct comparison with neutral PAHs measured in gas-phase

Salama et al. 2011:
7 PAHs: $C_{11}H_{10}$ to $C_{22}H_{14}$

Gredel et al. 2011:
6 PAHs: $C_{14}H_{10}$ to $C_{42}H_{18}$

$N_{PAH} < 10^{11}$ cm^{-2}
(fraction $< 10^{-10}$)

Posters 2.86 (Rouille) & 2.88 (Salama)

Search for DIB carriers…

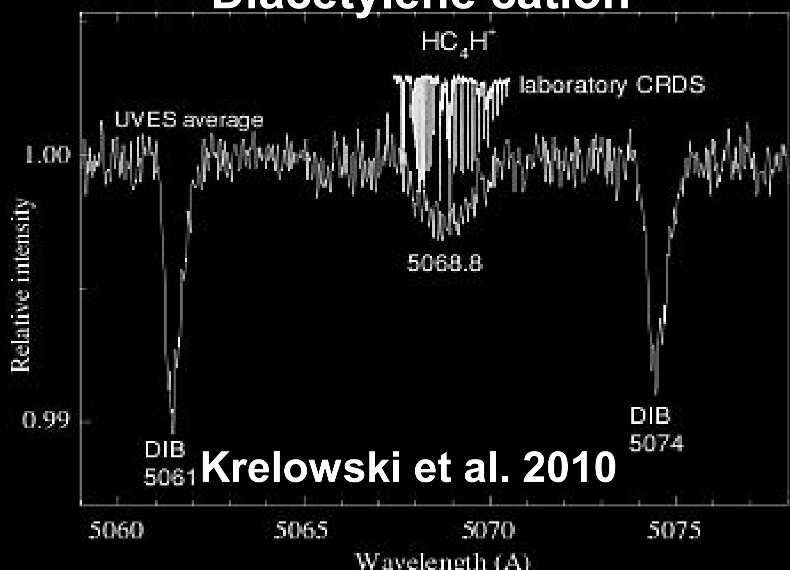
Direct comparisons with gas-phase spectra

Reilly et al. 2007: a radical species, produced by a discharge in benzene, absorbing coincident with the strong DIB at 4760Å.

Acetylene plasma - Band is due molecular transient consisting of C & H.

Temp independent & carrier specific broadening of profile.

Diacetylene cation



Poster 3.25 (Dietsche)

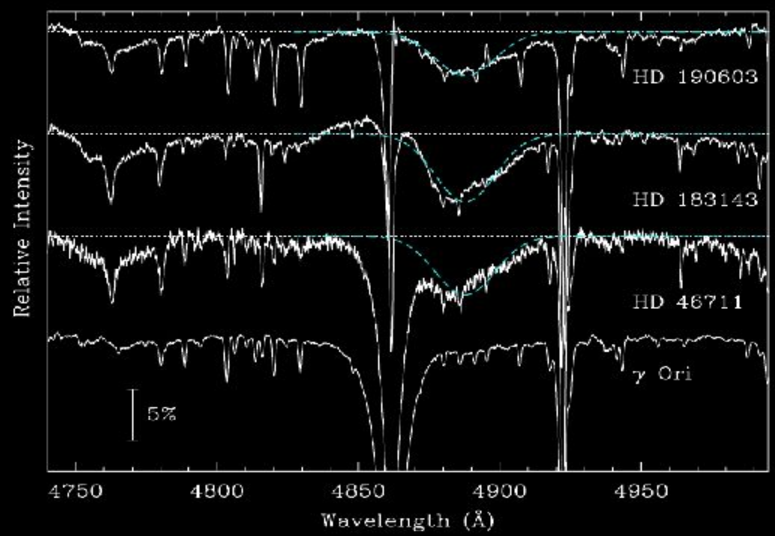
Iglesias-Groth et al. 2008, 2010

Tentative evidence for the **naphthalene+** (0.008% of carbon budget) and **anthracene+** in a region with anomalous microwave emission.

Refuted: Galazutdinov et al. 2011, Searles et al. 2011

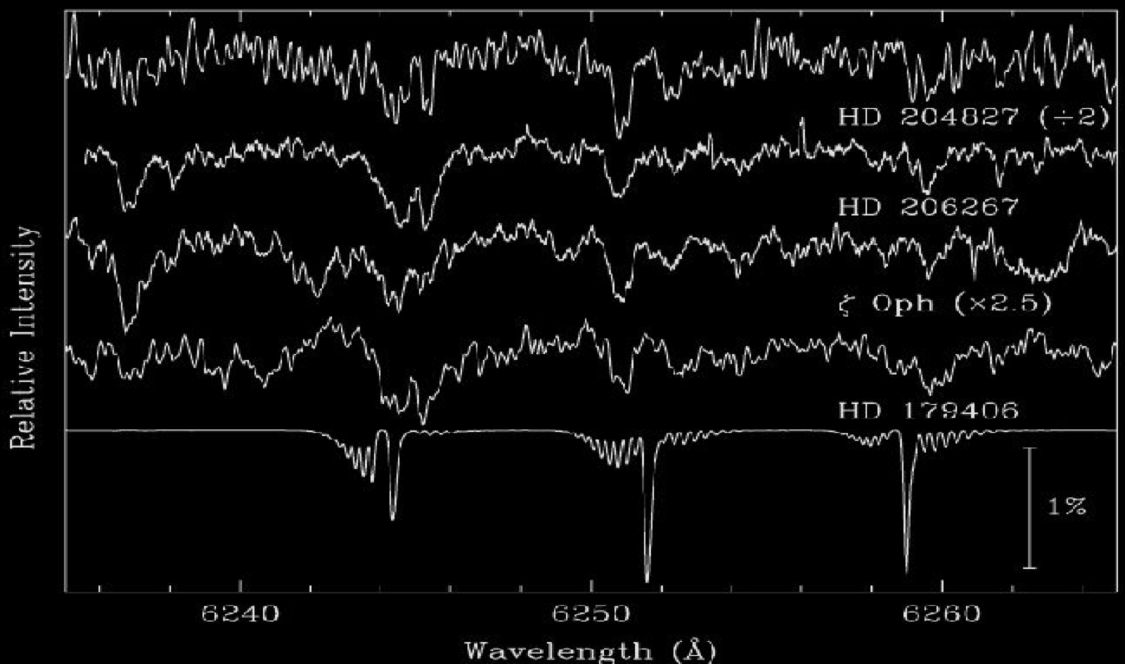
Search for DIB carriers...

Direct comparisons with gas-phase spectra cont'd



New candidate: H_2CCC (l-C_3H_2) (Maier et al. 2011)
Disputed by: Oka & McCall (2011), Krelowski (2011)

Laboratory gas-phase spectra show two broad features that correspond to 4883 and 5450 DIBs. Hint of narrow features matching lab spectra in 6200A range.



Criteria Carrier Identification:

* **2+ objects**
* absent in unreddened l.o.s.
* 1+ instruments confirmed
* stationary (in spec. binary)
* **2+ transitions (prefered)**
* **Match wavelength+profile**

N(l-C_3H_2) = 2 – 5 10^{14} cm^{-2} (for E(B-V)~1 mag).
Anti-correlated with N(C_3) in sightline.

Open questions & perspective

* Carbon molecules are currently most promising candidates for identifying the DIB carrier(s). **Alternative candidate carriers** can not be dismissed, although the carriers are very likely **large carbonaceous gas phase molecules** that are **stable, UV resistant,** but **sensitive** to the **local cloud conditions**, in particular the **UV radiation** field.

* **Multi-object** line-of-sight high-resolution studies of **Local Group** galaxies are needed.

* **Spectroscopic signatures** in both the **UV** and the **near-IR** are predicted for many (neutral/cation) **PAHs**.

* Explore **new environments** other than diffuse/translucent ISM → **Circumstellar** envelopes of **evolved stars** ("PAH" factories)?

* **Observational verification** of proposed candidates!
  - e.g. **naphtalene+** detected in only 1 (peculiar) sightline.
  - **DIB correlations**: intrinsic scatter or measurement uncertainties?