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Spatial structure of the Galactic ISM obtained with the analysis of prominent DIBs

Stars without borders
A galaxy in crisis

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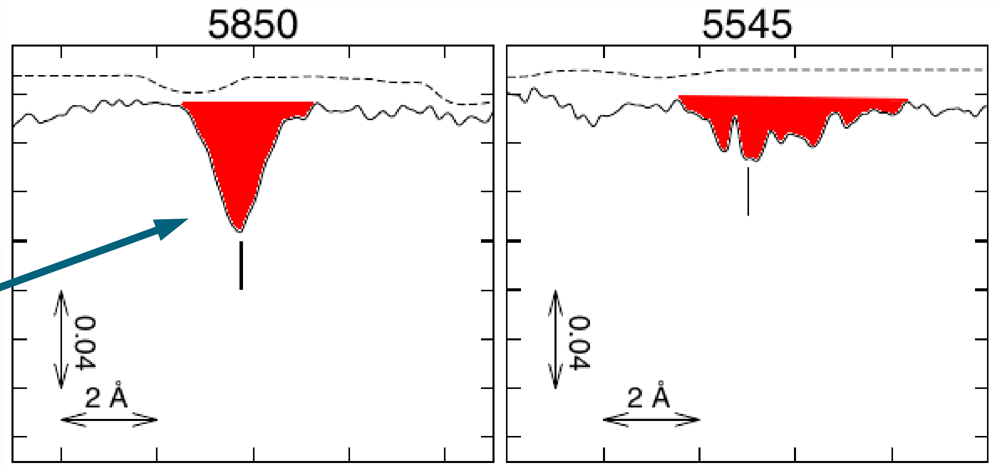
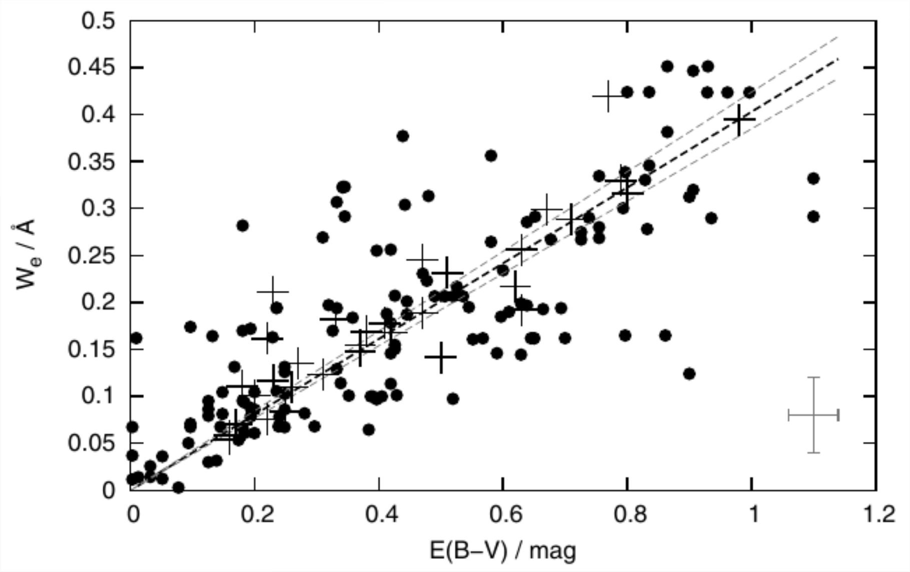
Introduction – The Diffuse Interstellar Bands (DIBs)

- Weak non-stellar absorption features of unknown origin.
- Annie J. Cannon, 1890, DIB 4430.
- With known **oscillator strength** one can deduce a column density of atoms/molecules.
- **Equivalent width**.
- Strength increases with degree of reddening.
- > 400 in optical (400-900 nm), ~30 NIR, 0 in near-UV.
- DIBs are mostly observed in our Galaxy.

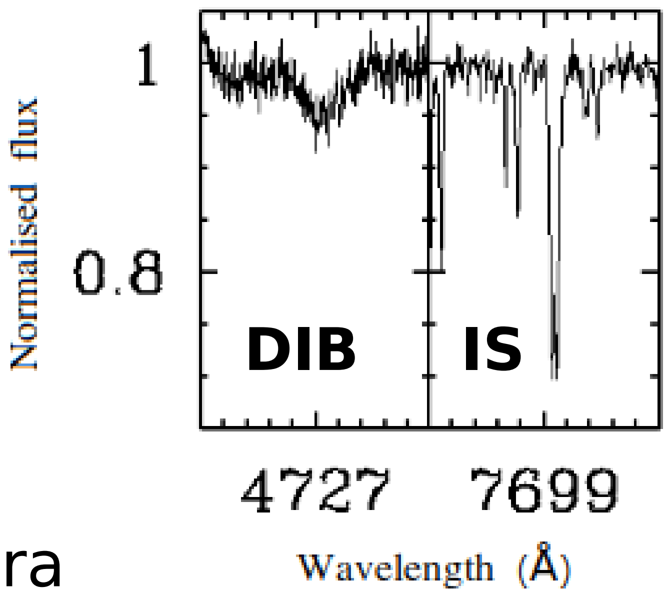


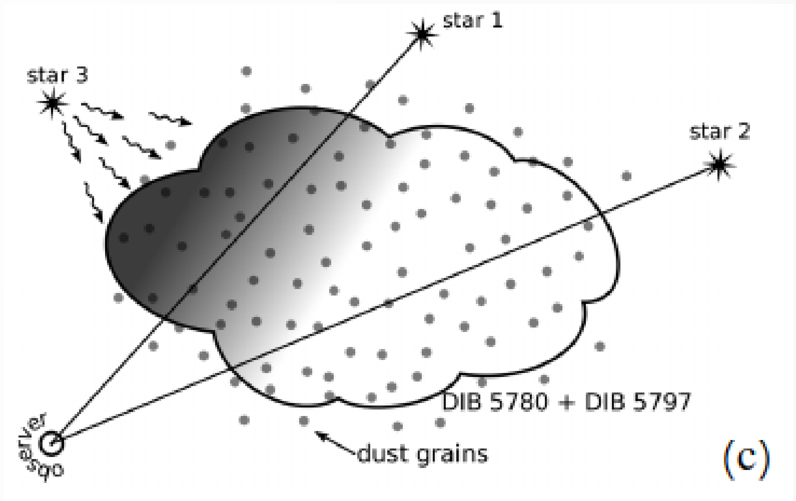


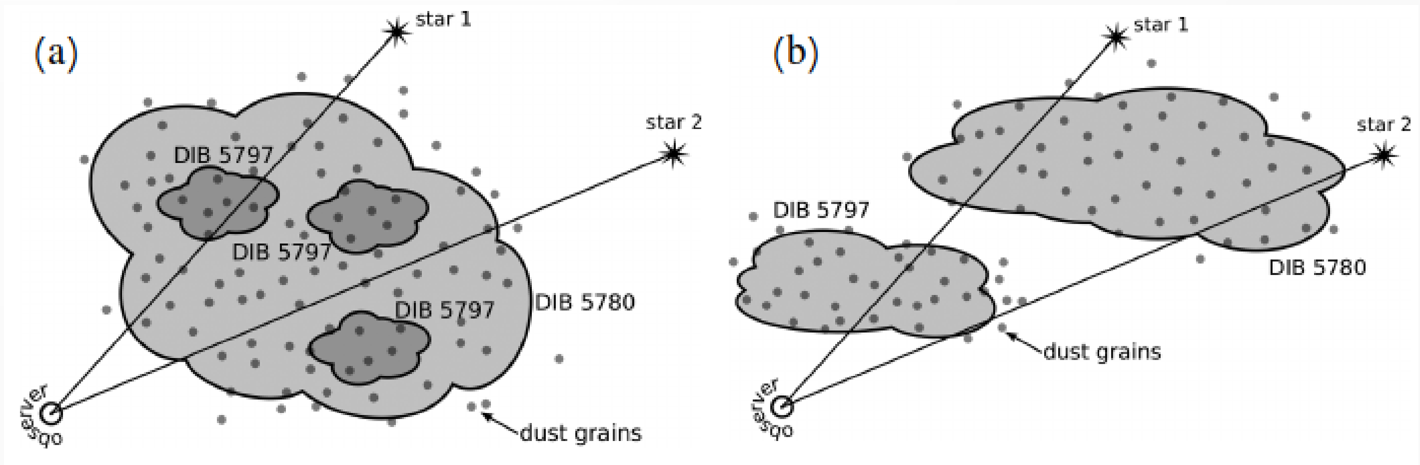
Source: (top) J. Kos, T. Zwitter, 2013, Properties of diffuse interstellar bands at different physical conditions of the interstellar medium, **(bottom)** J. Kos et al., 2013, Diffuse interstellar band at 8620 Å in RAVE: A new method for detecting the diffuse interstellar band in spectra of cool stars.

Introduction – The Diffuse Interstellar Bands (DIBs)

- Broader than atomic interstellar lines, wide range of intensities and widths.
- Non-saturated.
- Asymmetric.
- Rotational-vibrational spectra (gas-phase molecular nature).
- Mutually do not correlate well ⟶ molecular diversity.
- **EW(5780)/EW(5797) ratio.**
- σ-type < 0.35 ≤ ζ-type.



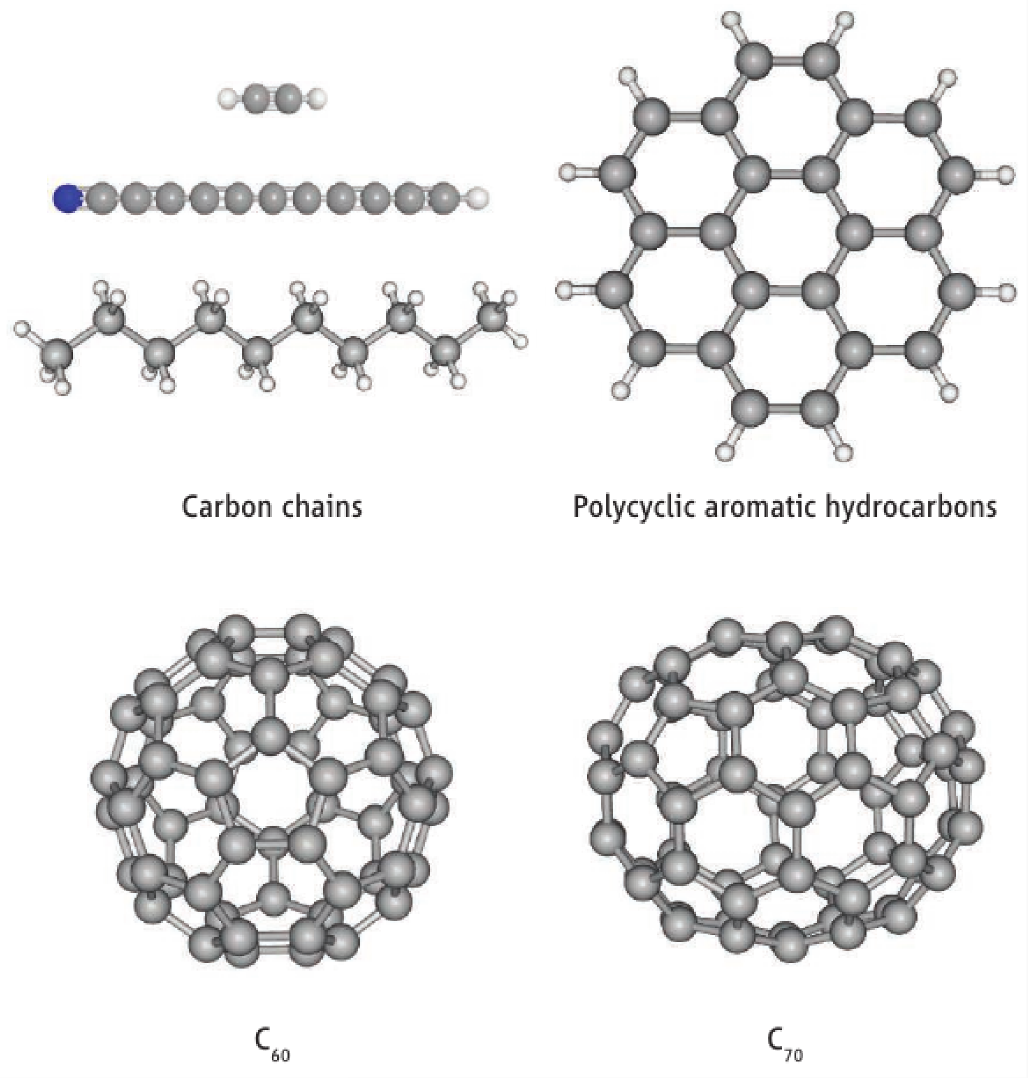




Source: (a, b, c) J. Kos, 2017, Spatial structure of several diffuse interstellar band carriers; **(top left)** De Silva et al., 2015, The GALAH Survey: Scientific Motivation.

Introduction – The Diffuse Interstellar Bands (DIBs)

- **Who's responsible?**
  - Carbon chains (ions and neutrals)
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Fullerenes (C_{60}^{+} **confirmed**)
- **Why not solid-phase hypothesis?**
  - Absorption due to impurities
  - No polarization of the DIBs ⟶ not attached to dust grains
  - Sub-structures of DIBs similar to rotational-vibrational molecular lines
  - Electronic transitions in large molecules
- **PAHs?** Vibration modes of C-H, C-C.
- **Fullerenes?** C_{60}^{+} in gas-phase, T = 5.8 K, exhibits transitions near 9580 Å and 9630 Å (9020 Å, 9210 Å, 9260 Å).
- Identification debated (ISM ~ 10^{6} m^{-3}), telluric contamination ⟶ **solution?**



Source: P. Ehrenfreund and B. H. Foing, 2010, Fullerenes and Cosmic Carbon, Science, 1159-1160.

Goals

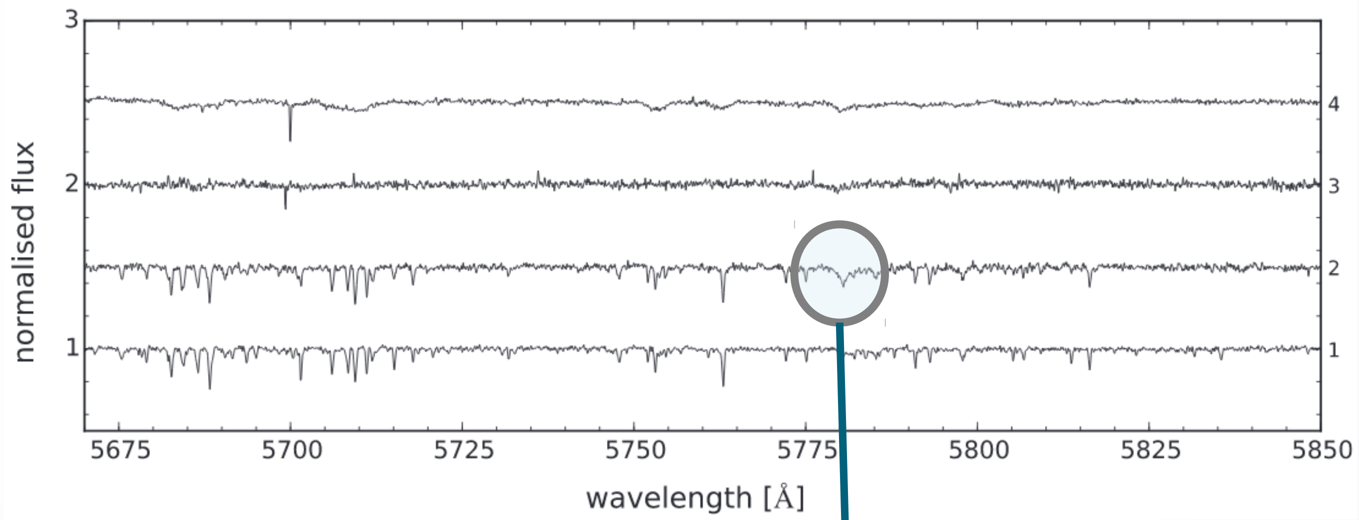
- To obtain a **spatial structure** of the Galactic ISM
- To find **physical properties** of carrier molecules responsible for DIBs
- To study **gas dynamics**
- To look for relationship between the DIBs distribution in the interstellar gas and young stellar clusters

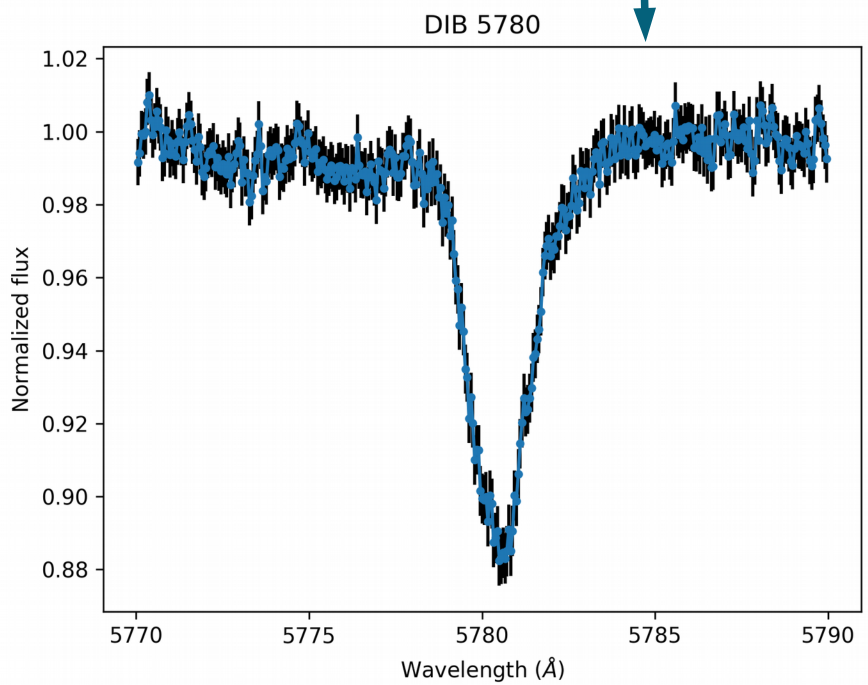
- **I require**:
  - Number of high-resolution, high SNR spectra in the red and NIR wavelengths, with many lines of sight
  - Large sample of stars at different distances and at different reddening

GALAH + Gaia

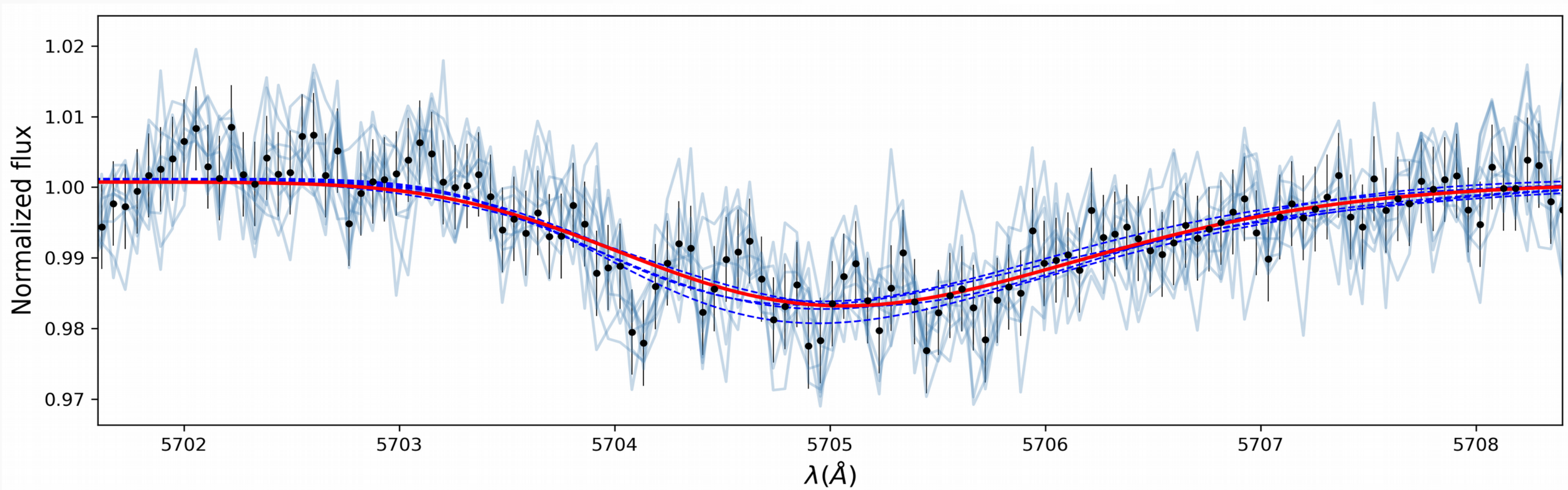
Goals

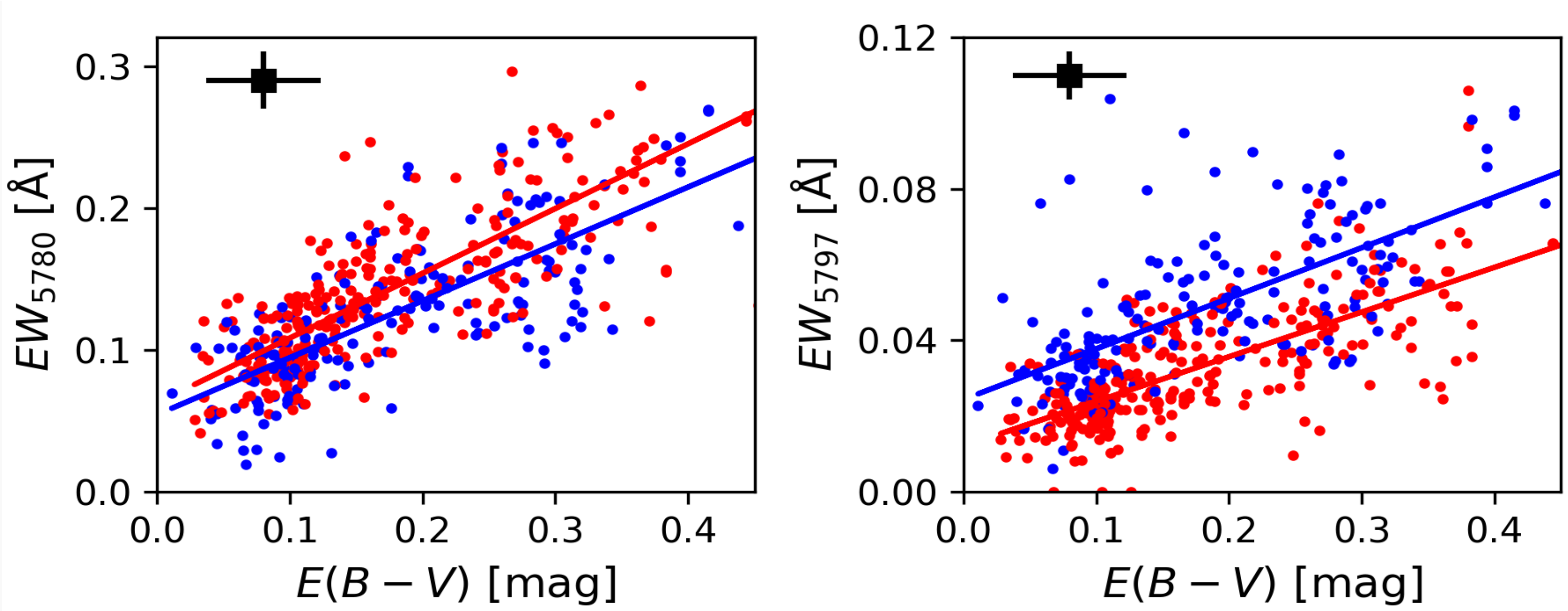
- **Gaussian processes**
  - To accurately measure profiles of interstellar absorption lines
  - Weak DIBs with amplitudes of order of 1% below the continuum
  - To fit **correlated noise** from data reduction and stellar spectral features
  - DIBs at low resolution can be approximated with **asymmetric Gaussian** function





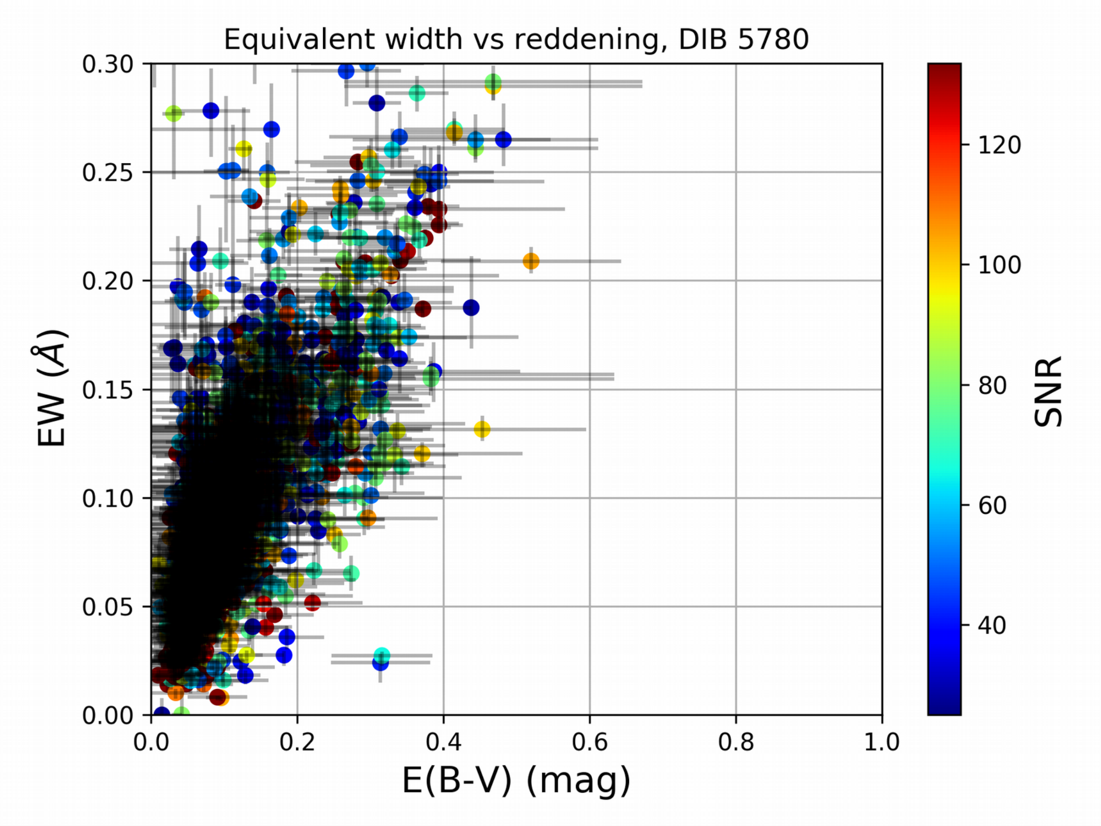
Results



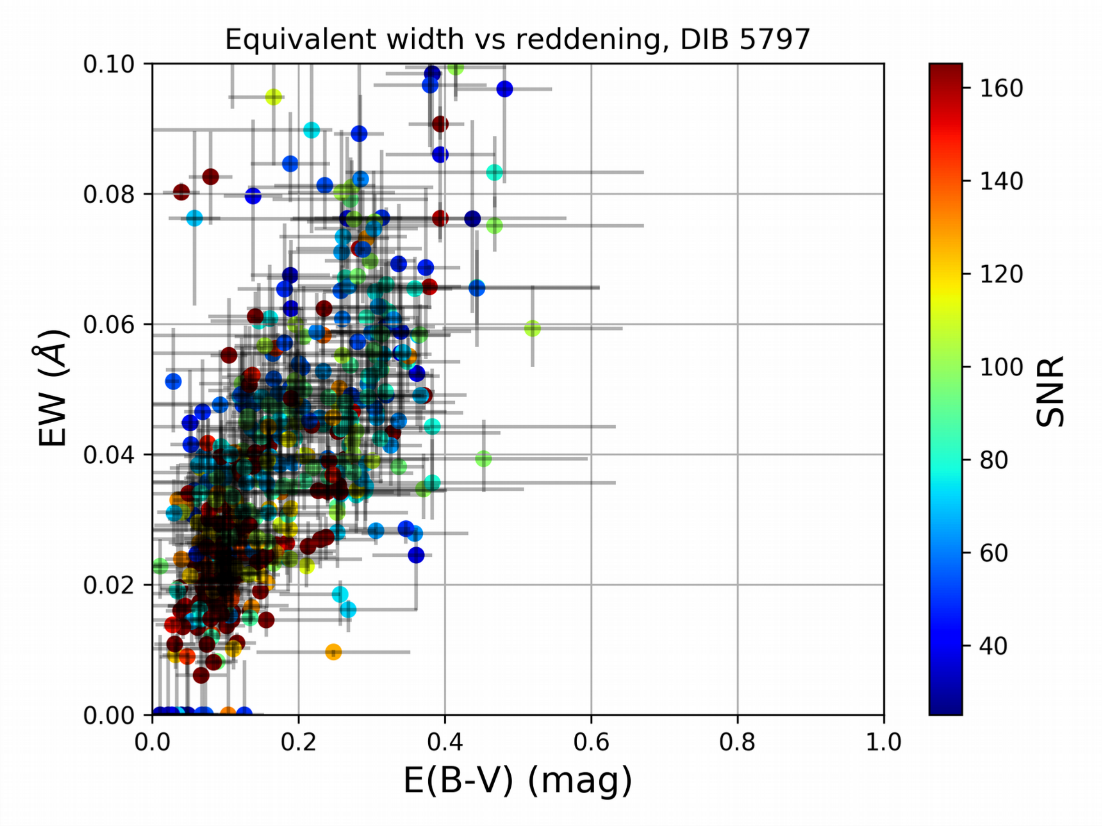


- Linear relation for ζ (blue) and σ (red) sightlines.
- Non-zero EW.
- Type I (left) and type II (right) DIBs.
- UV-shielding.
- DIB 5797 is sensitive to UV light.

Results

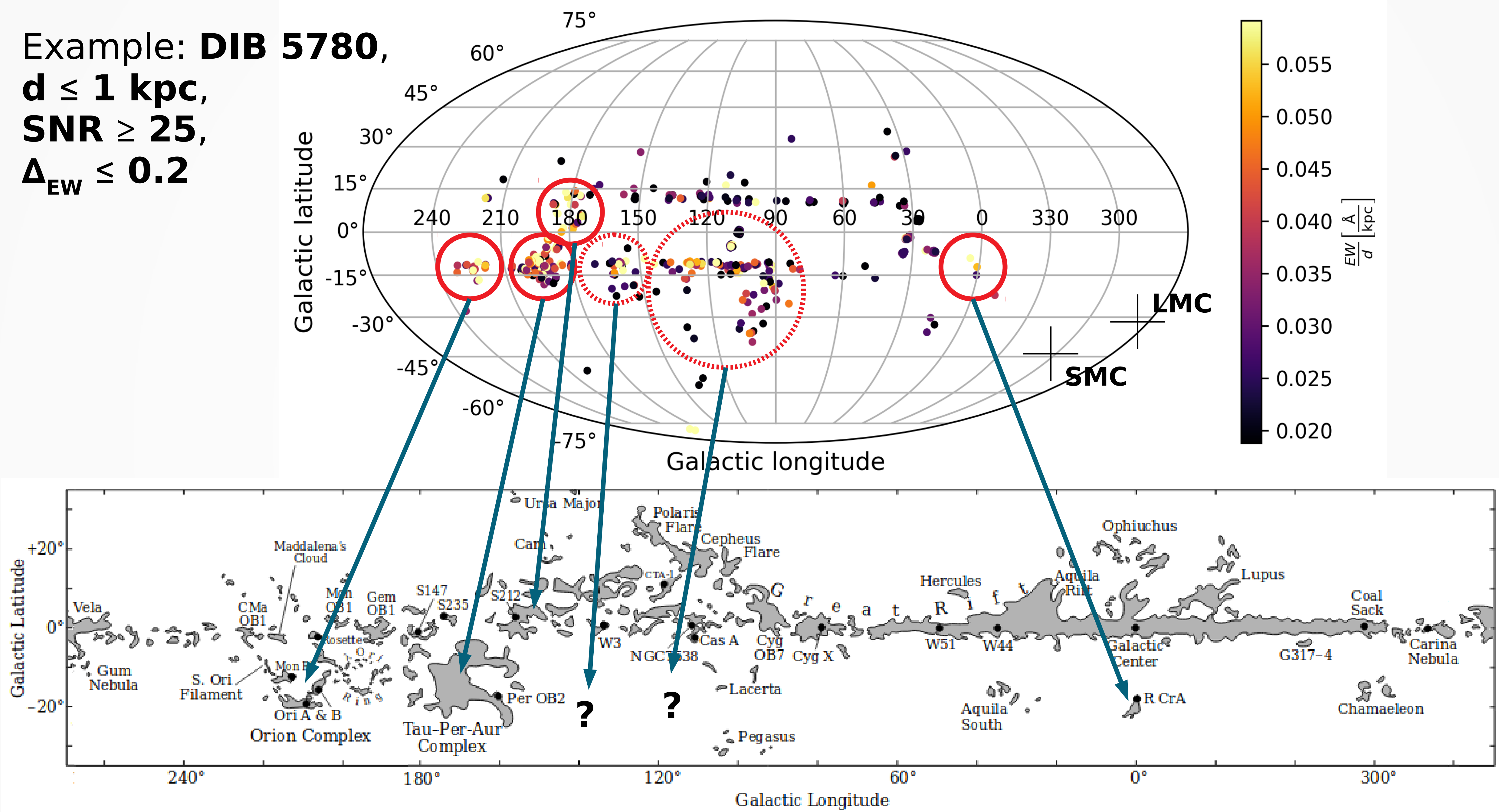


Equivalent width vs reddening, DIB 5780
EW (Å)
E(B-V) (mag)
SNR
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.2
0.4
0.6
0.8
1.0
120
100
80
60
40

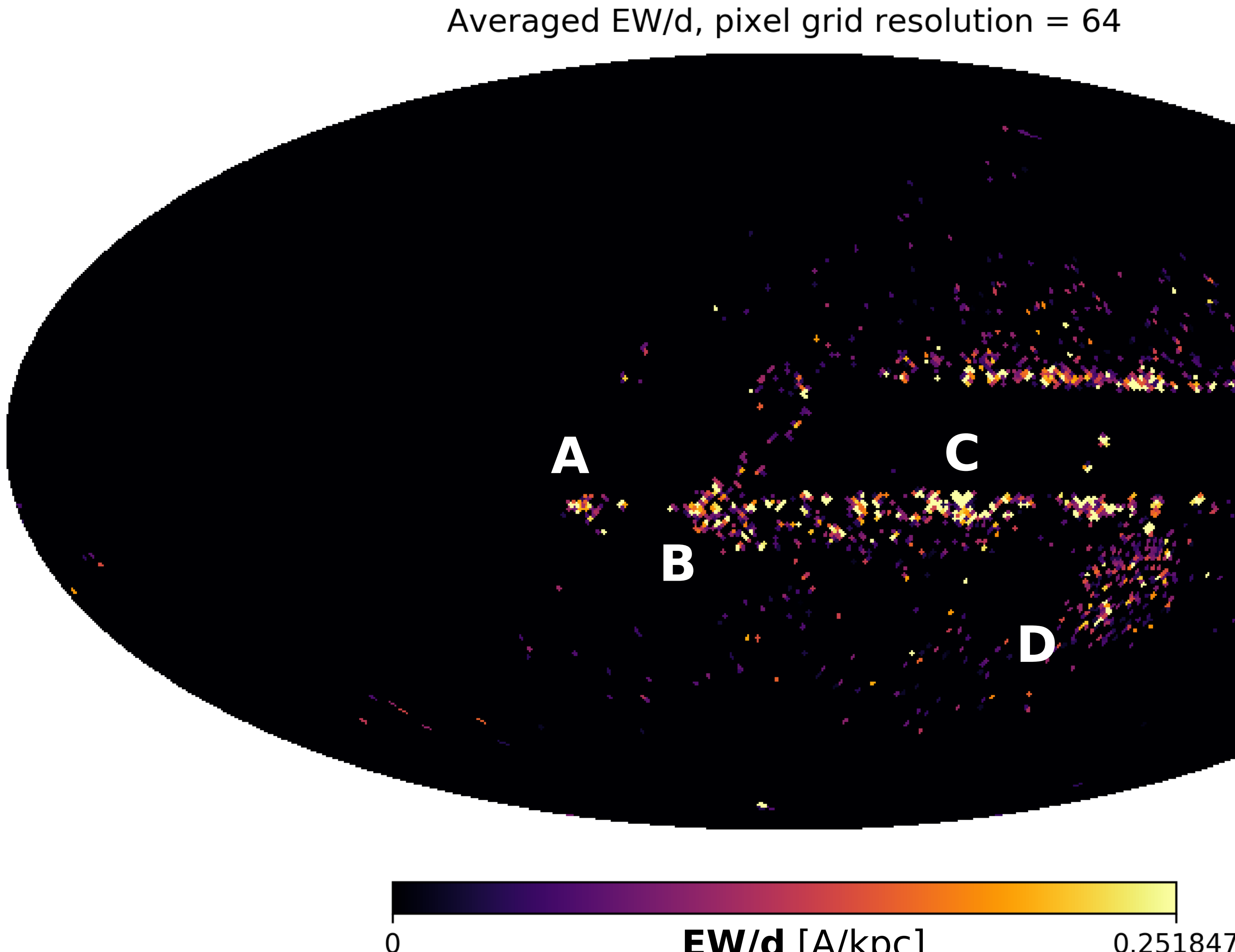


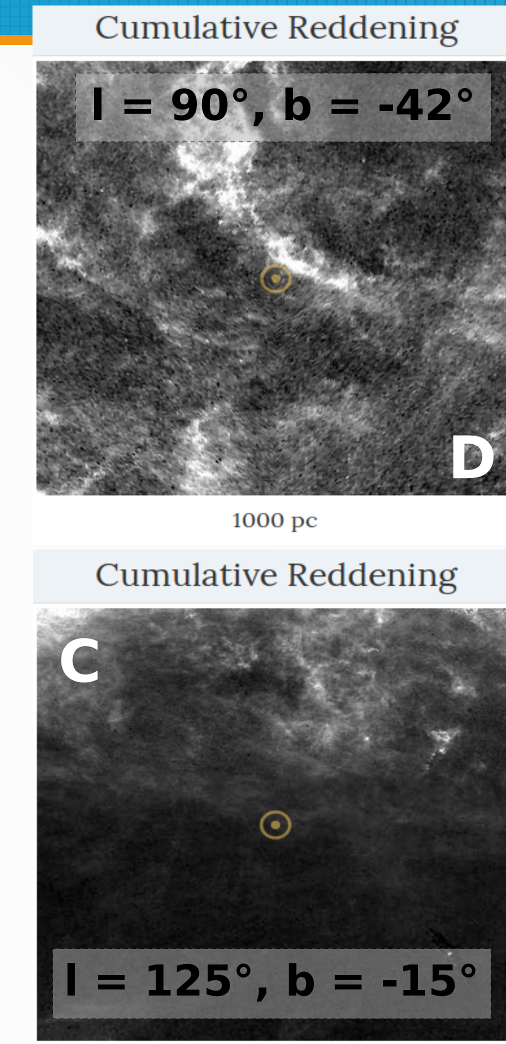
Equivalent width vs reddening, DIB 5797
EW (Å)
E(B-V) (mag)
SNR
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.2
0.4
0.6
0.8
1.0
160
140
120
100
80
60
40

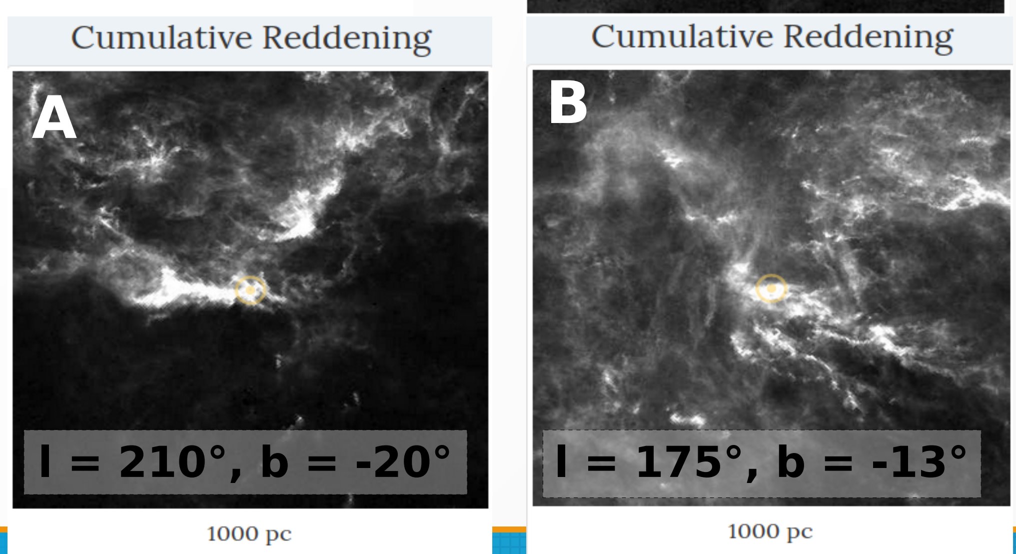
Example: **DIB 5780**, **d ≤ 1 kpc**, **SNR ≥ 25**, **Δ_{EW} ≤ 0.2**



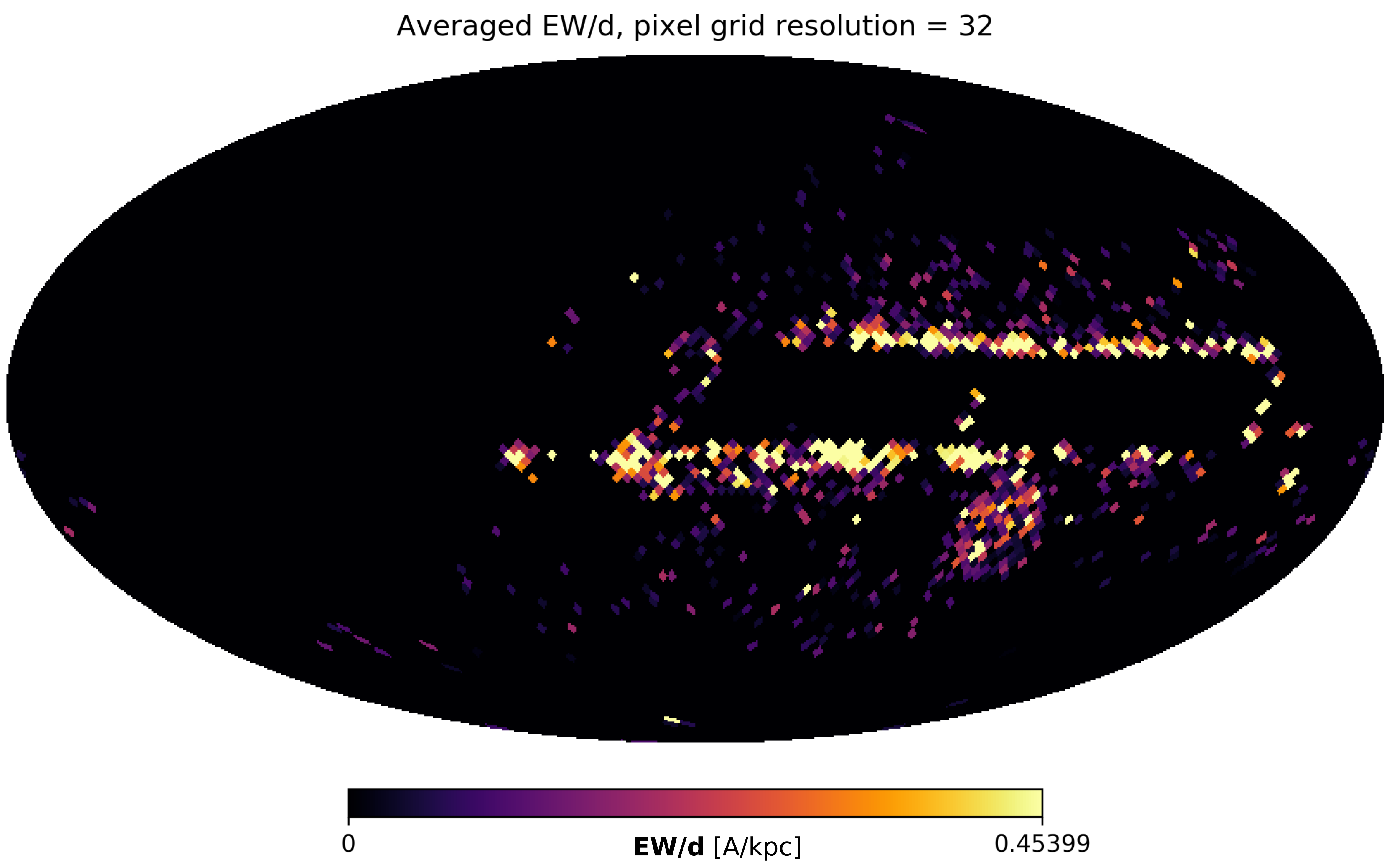
Source: (bottom) T. M. Dame et al., 2000, The Milky Way in Molecular Clouds: A New Complete CO Survey, pg.35



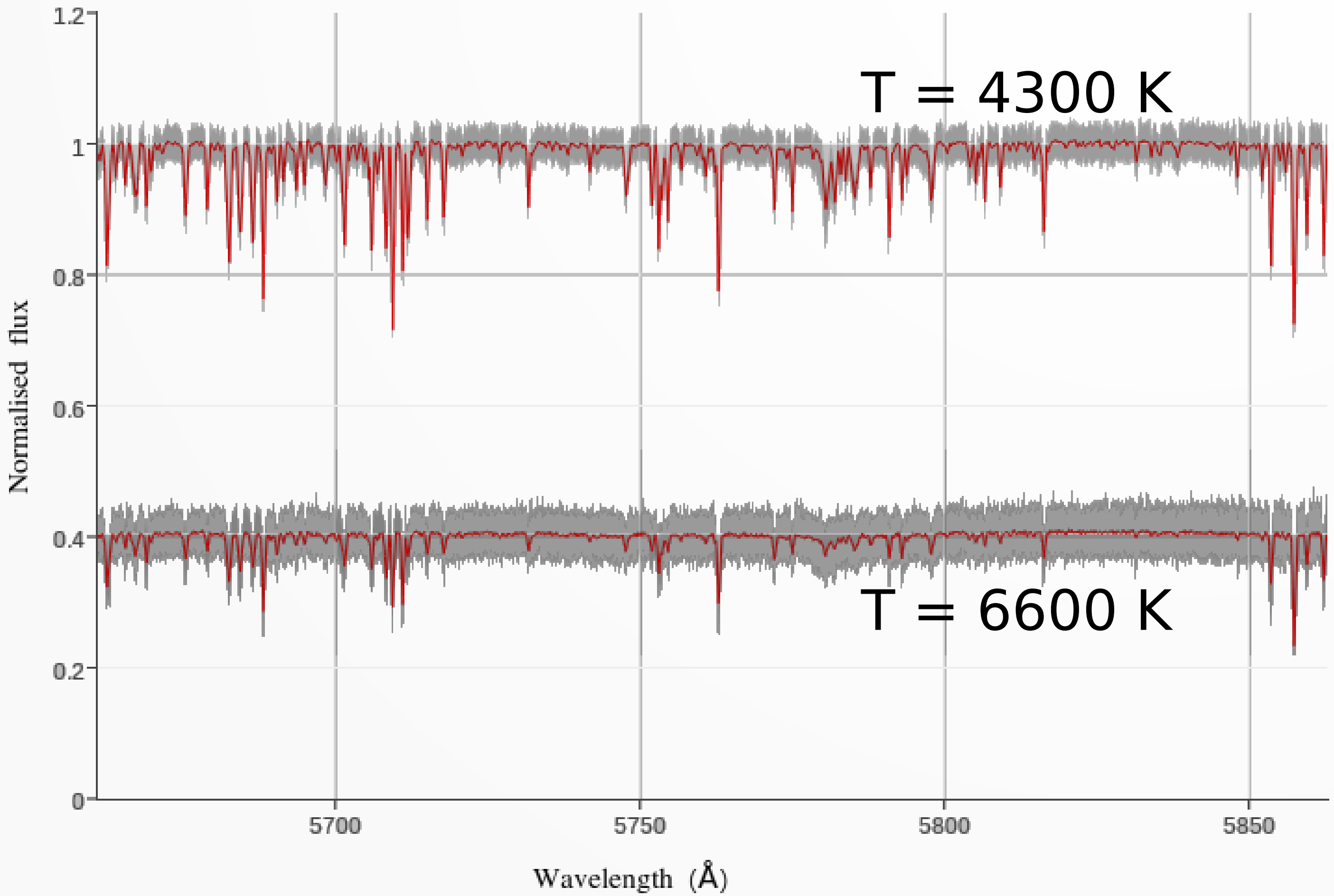




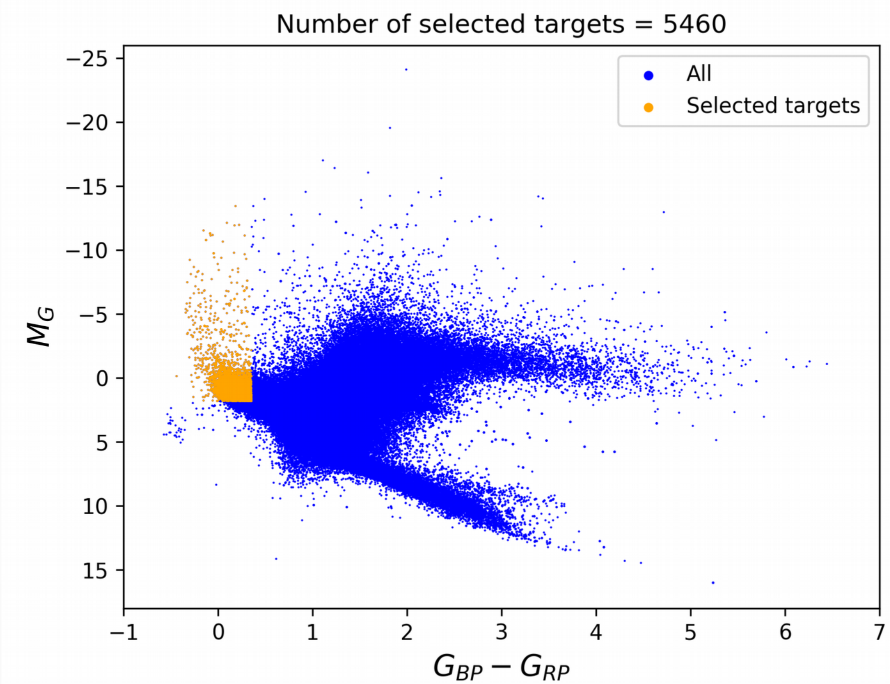
(top) 2943 LoS, 1532 bins, max. @ 84th percentile
(right) Bayestar 2019, 23° × 23° field, 1 kpc cumulative reddening
source: http://argonaut.skymaps.info


Averaged EW/d, pixel grid resolution = 32
0
EW/d [A/kpc]
0.45399

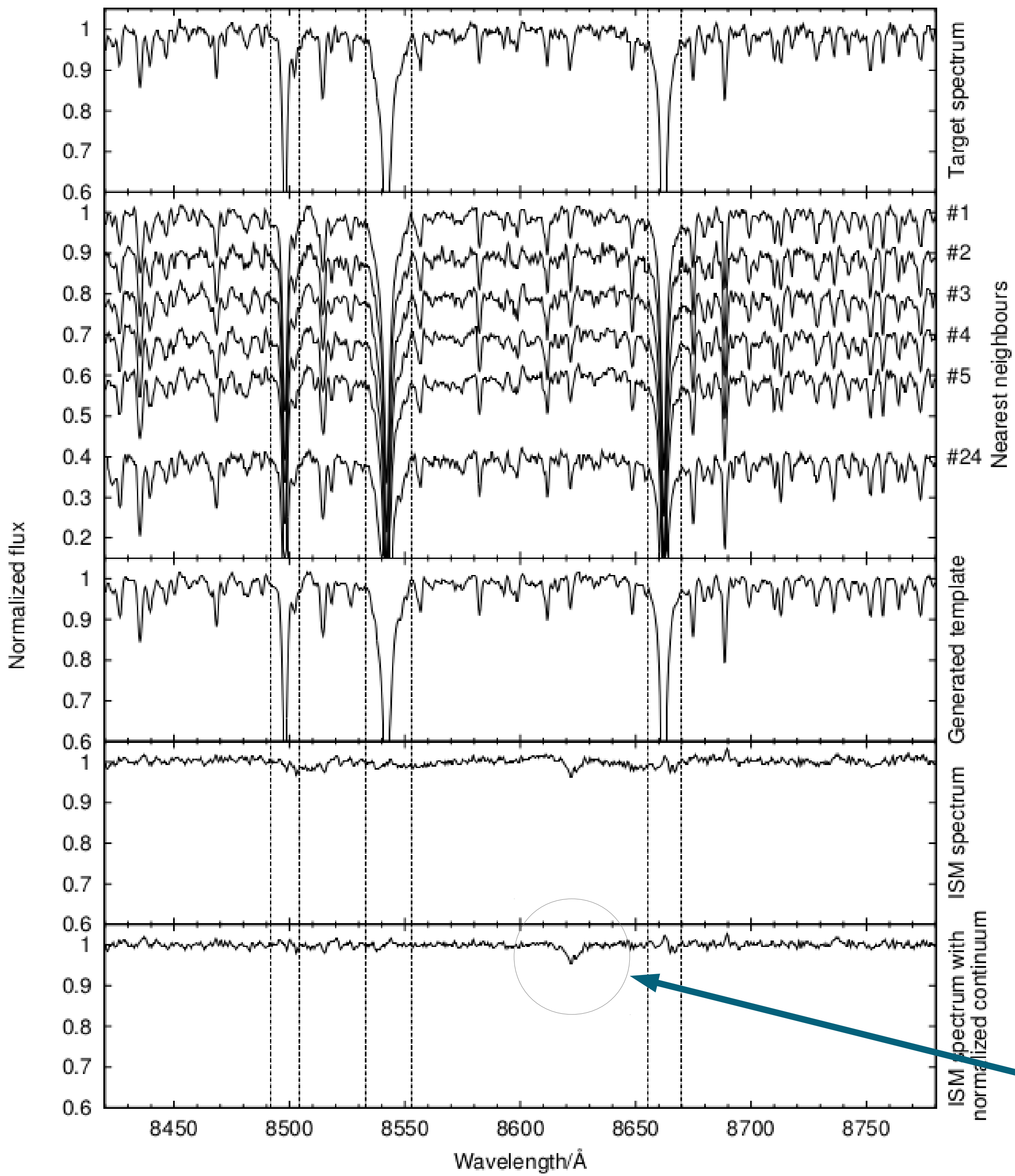
Results - Current work



- Measure strength of 9 DIBs and 1 atomic interstellar line KI in many sightlines.
- Extend analysis to investigate cooler stars.
- Problem with stellar absorption lines.

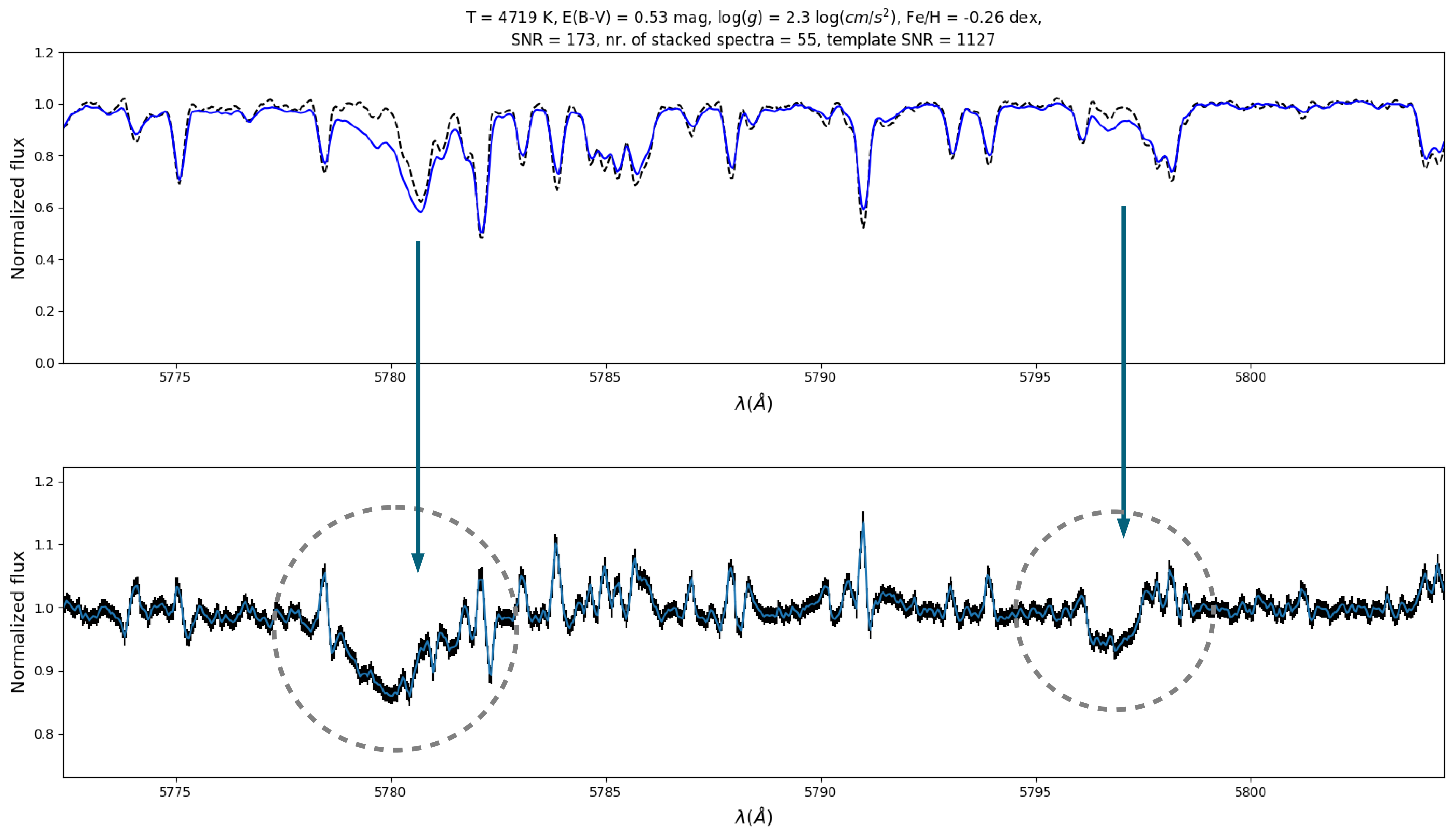


Source: (top) t-SNE Explorer, Projection of 587154 datapoints. Galah P30 dr52 new all noIR, Credit: G. Traven



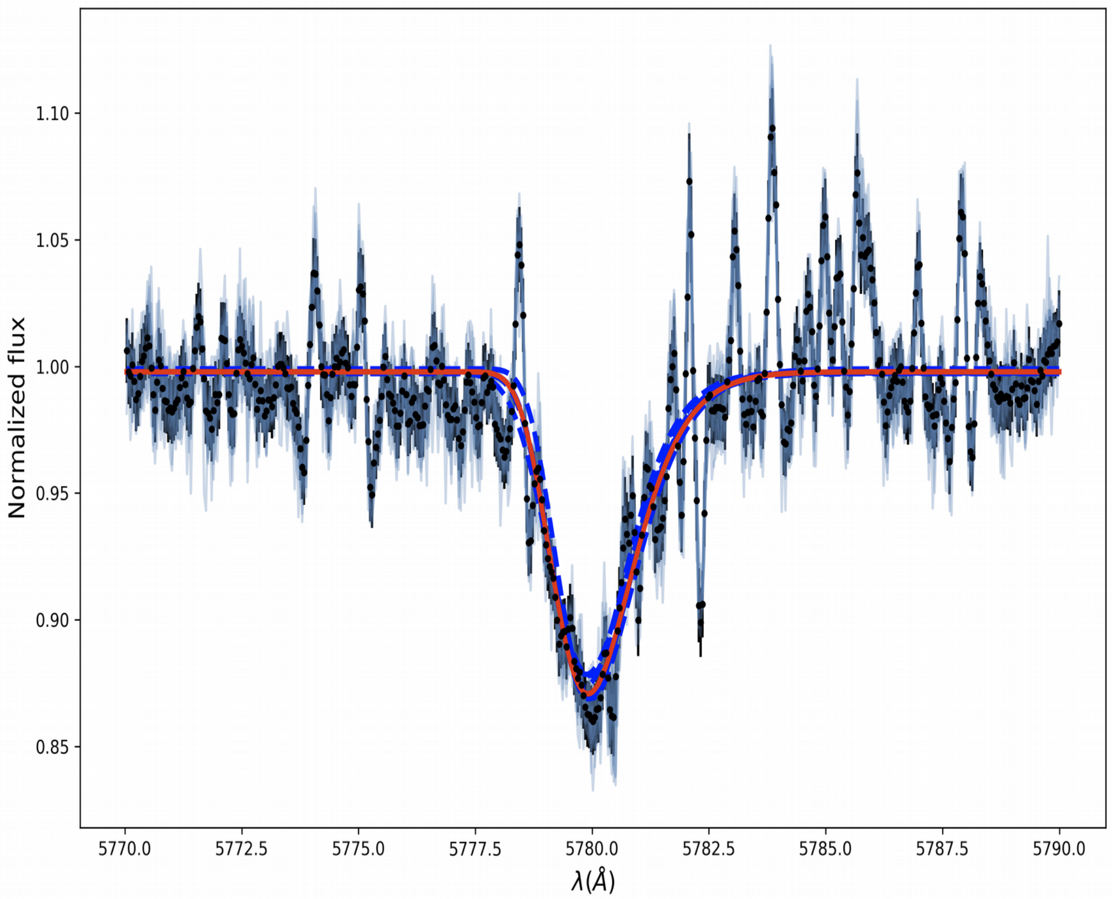
- Select one observed spectrum for which we want to extract the ISM spectrum.
- Use a table of stellar parameters to find similar stars.
- Create a list of nearest neighbours (T, log(g), Fe/H, SNR > 15, E(B-V) < 0.1).
- Combine most similar spectra into a template.
- Divide the spectrum in question with the template to obtain the ISM spectrum.
- Measure IS lines.

Source: J. Kos et al., 2013, Diffuse interstellar band at 8620 Å in RAVE: A new method for detecting the diffuse interstellar band in spectra of cool stars.

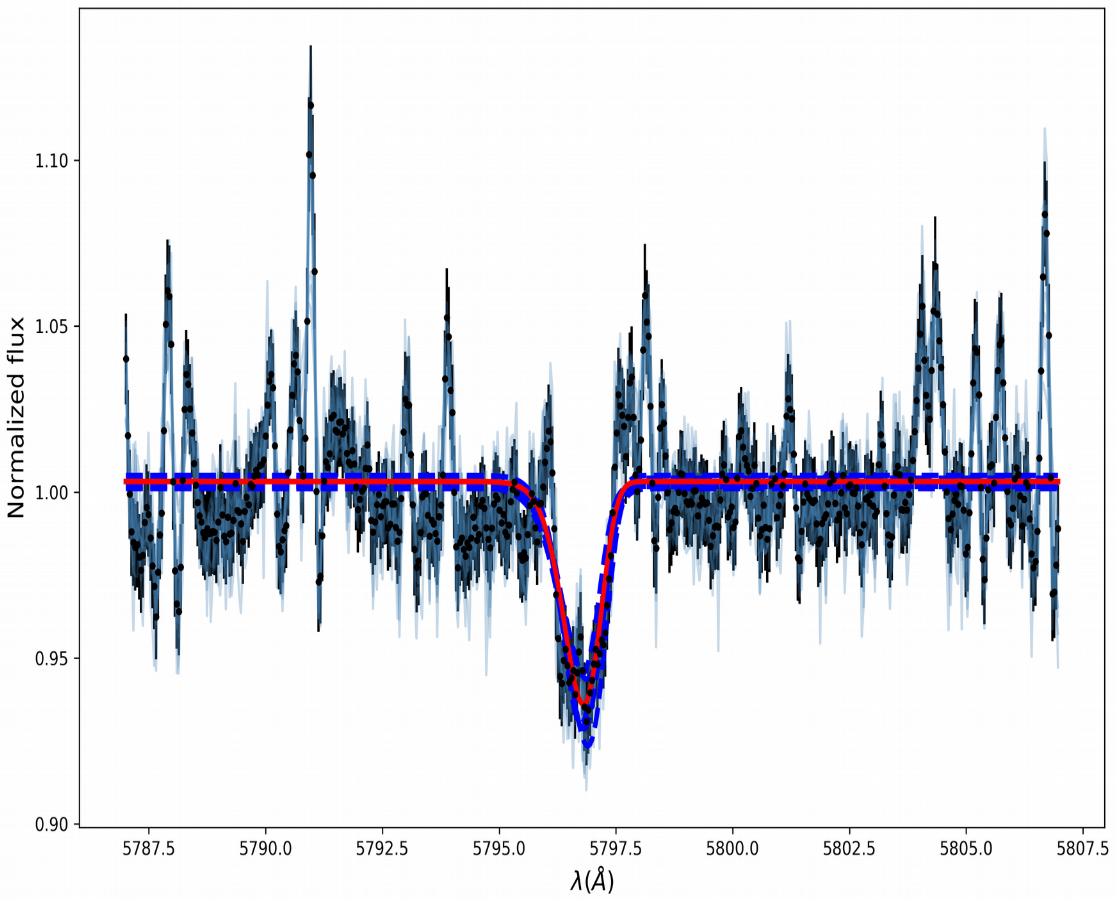


T = 4719 K, E(B-V) = 0.53 mag, log(g) = 2.3 log(cm/s²), Fe/H = -0.26 dex,
SNR = 173, nr. of stacked spectra = 55, template SNR = 1127
Normalized flux
λ(Å)
5775
5780
5785
5790
5795
5800

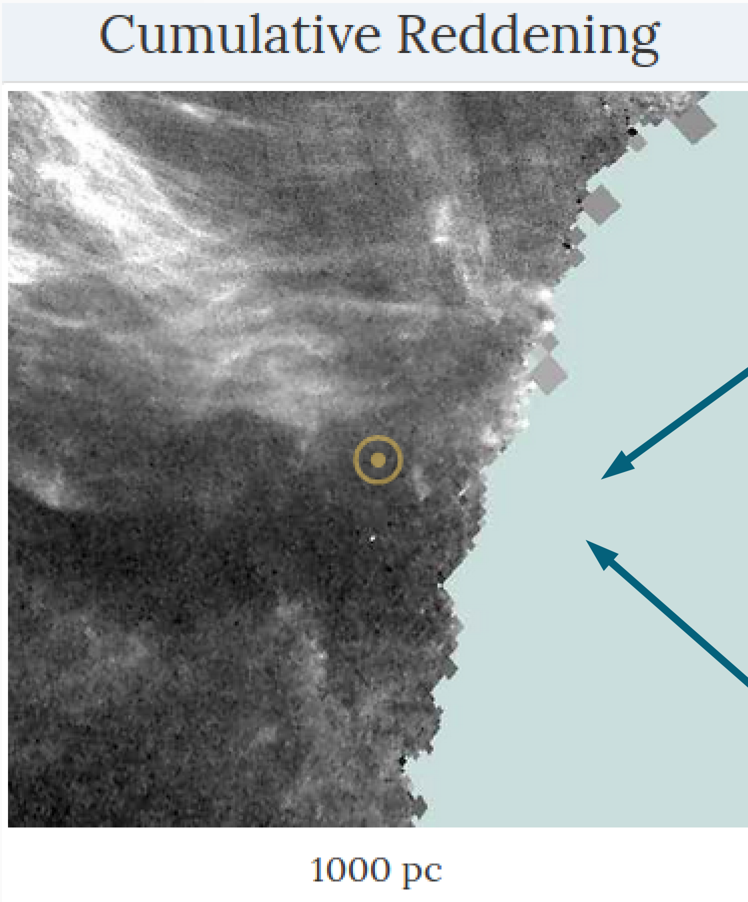
DIB 5780

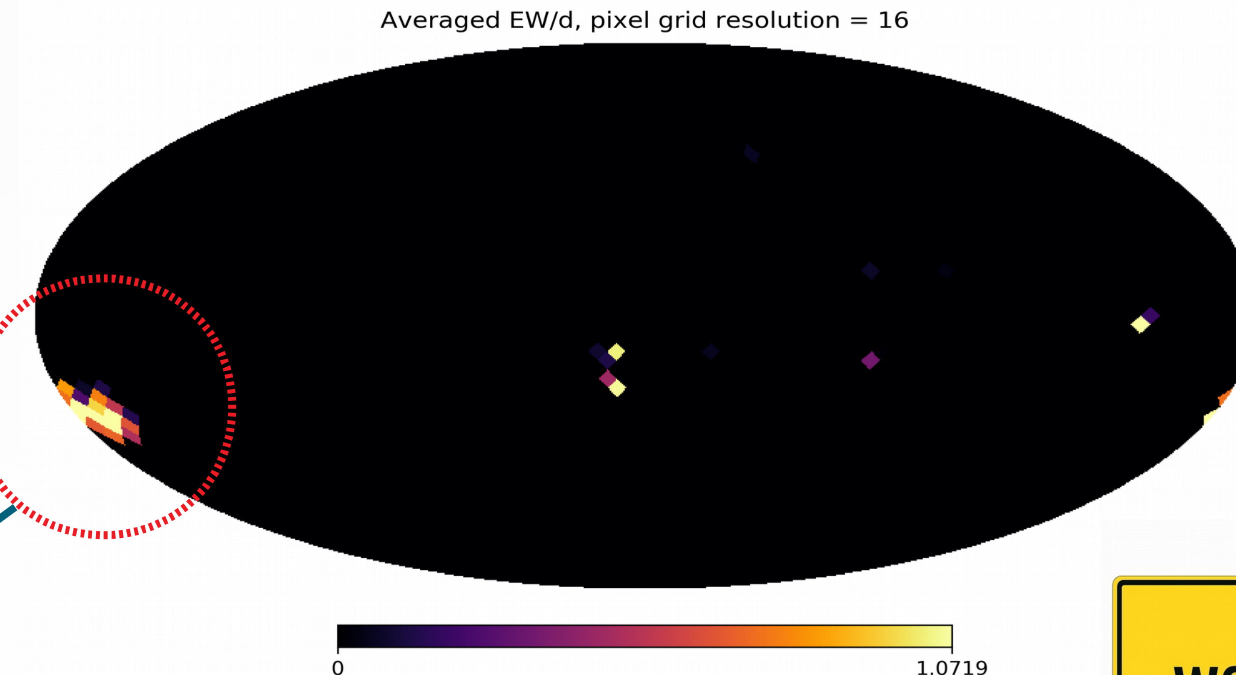


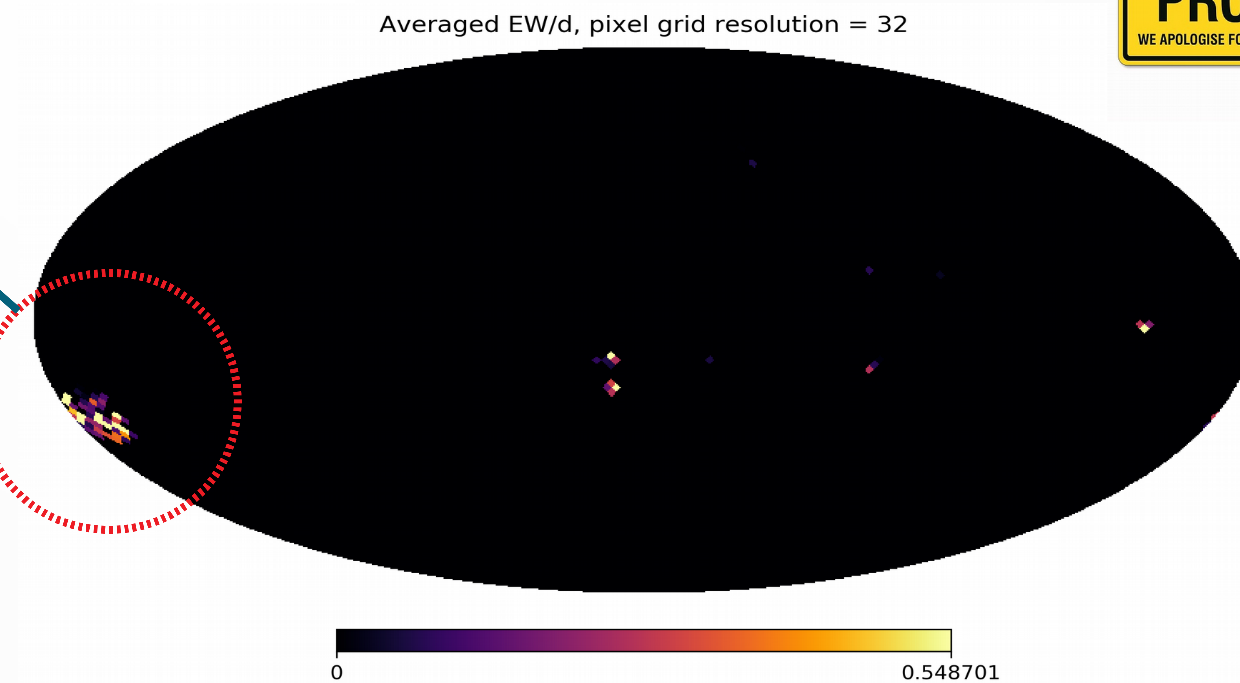
DIB 5797



l = 15°, b = -30°

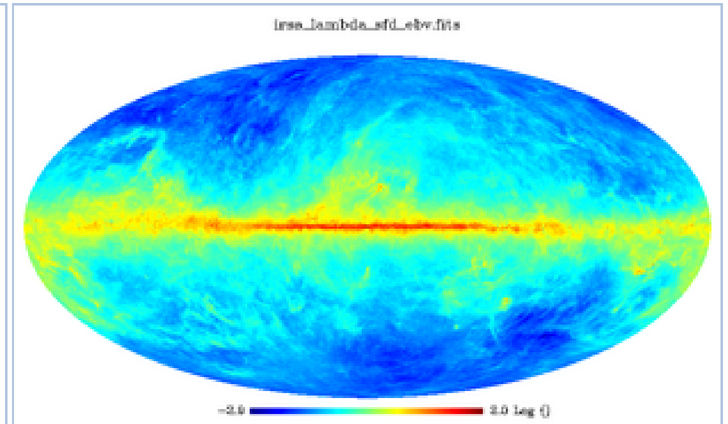




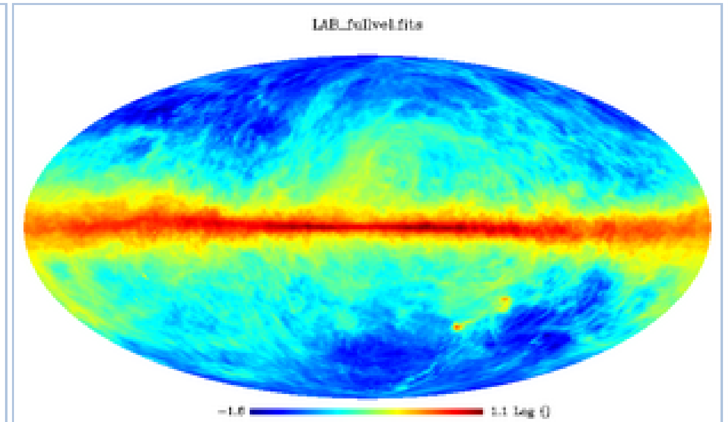


360 LoS, 32 bins (top), 65 bins (bottom),
max. @ 84th percentile

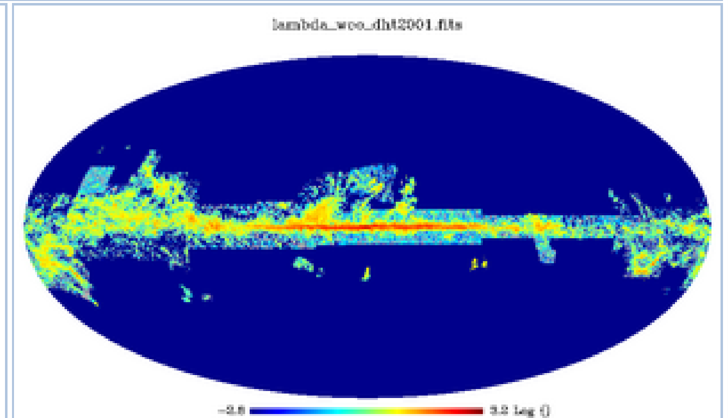
FIR-derived maps of Galactic interstellar reddening.
Map band: E(B-V)
Map units: Magnitudes
Schlegel, D.J., Finkbeiner, D.P. and Davis, M. 1998 ApJ 500 525
Download



Neutral hydrogen (21 cm) emission from the Leiden/Dwingeloo HI survey and the Instituto Argentino de Radioastronomia survey.
Map band: 21 cm [1420 MHz]
Map units: K
Kalbera, P.M.W. et al. 2005 A&A 440 775
Product Description and Download Page

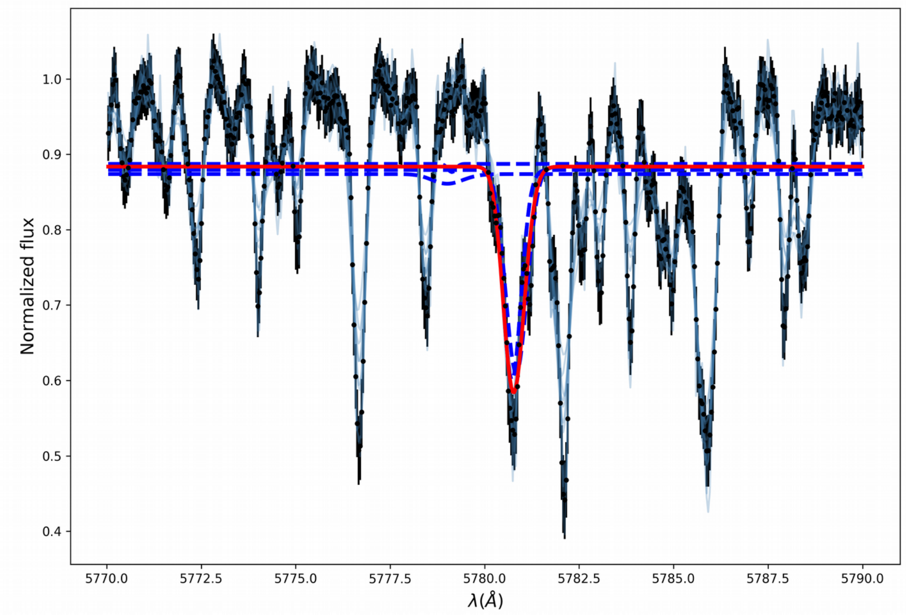


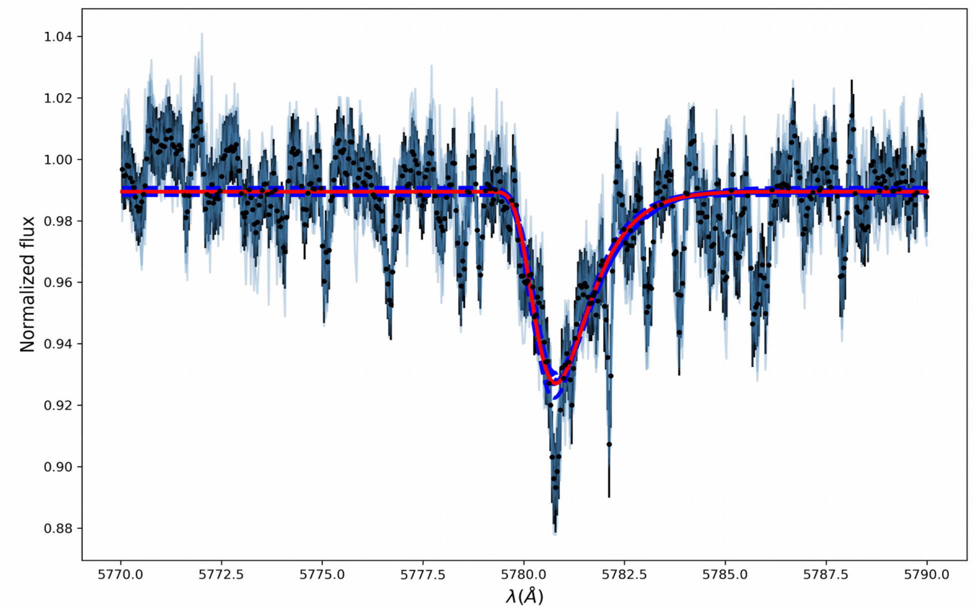
Dame CO(1-0) survey.
Map band: 115 GHz
Map units: Velocity integrated main beam T_B, W(CO), K km s^{-1}.
Dame, T.M., Hartmann, D. & Thaddeus, P. 2001 ApJ 547 792
Product Description and Download Page

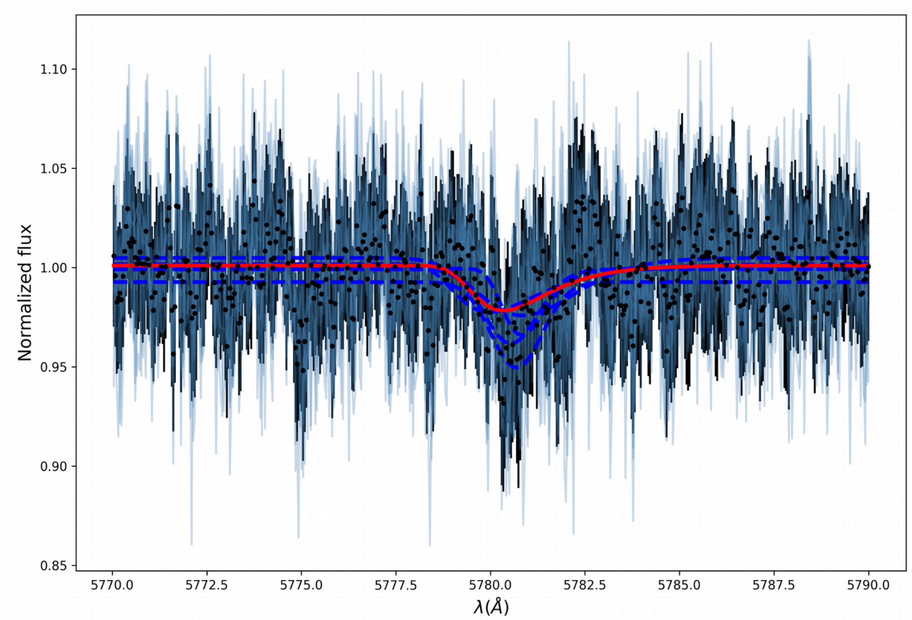


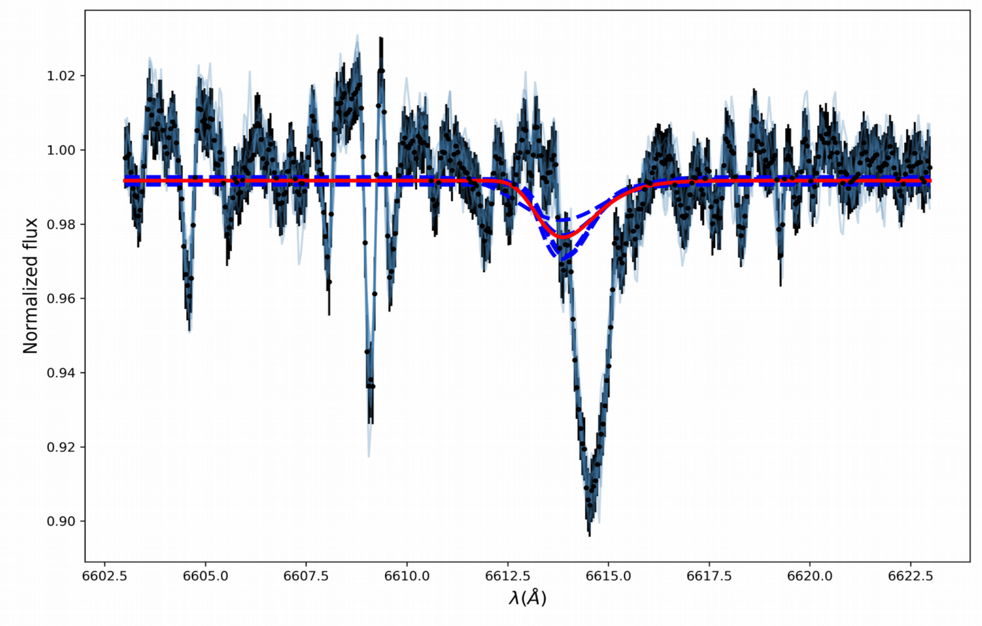
Source: https://irsa.ipac.caltech.edu/data/Planck/release_1/external-data/external_maps.html

Results - Problems









Conclusion

- Requirement for number of high-resolution, high SNR spectra in the red and NIR wavelengths, with many lines of sight (reddening).
- Correlate between different DIBs's spatial distribution of EW; compare with similar surveys.
- Investigation of cool stars via template spectra.
- Detailed 3D maps of carrier molecules.
- Strengths of DIBs and their physical properties.
- Evolution of the Galaxy.

Thank you for your attention!