Dynamical ISM with Gaia and ground-based massive spectroscopic stellar surveys

Tomaž Zwitter
University of Ljubljana

In a nutshell:

I. Line absorption along one line of sight.
II. Line absorption along many lines of sight.
III. 3-dimensional placement of absorptions.
IV. Radial velocity adds another dimension.
V. Complete 6-dimensional information for special morphologies (absorption sheets..).
Completed and ongoing spectroscopic stellar surveys with $R>5000$: GCS, RAVE, Galah, Gaia-ESO, Apogee, Gaia
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V magnitudes of RAVE, Galah and Gaia-ESO
## Dynamics of the interstellar medium

<table>
<thead>
<tr>
<th></th>
<th>Bands/lines in optical</th>
<th>3-D position</th>
<th>Radial velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust absorptions</td>
<td>≥ 1</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Interstellar emission lines</td>
<td>a few</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Interstellar absorption lines</td>
<td>a few</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Diffuse interstellar absorption bands (DIBs)</td>
<td>up to ~400</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

**Diagram:**

- **Stellar spectroscopic surveys** (Hermes/GALAH, Gaia-ESO)
- A million sight-lines out of the Galactic plane
- Three-dimensional interstellar medium
- Radial velocities and shapes of diffuse interstellar bands
- Dynamic interstellar medium in four dimensions

- Discovery of up-to 1Myr old supernova shells seen in DIBs out of the Galactic plane
- Date and spatial position of supernovae witnessed by our ancestors
- Properties of galactic fountains, their entraining of gas from the halo
- Membership test for stars in clusters
- Patchiness of DIB distribution
- Distribution of young stars away from known star clusters
- Recent dynamics in Solar neighbourhood
- Spatial distribution of individual diffuse interstellar band carriers
- Relative mass or charge of individual DIB carriers
ISM in the wavelength range of Gaia's Radial Velocity Spectrometer

Resonant lines of metallic ions abundant in ISM are absent in the 850-875 nm range. But a medium intensity diffuse interstellar band at 862 nm is present. Its existence and a good correlation with reddening was among reasons to choose this wavelength interval for Gaia (Munari 1998).
DIB @ 862 nm in RAVE spectra of hot stars (Munari et al. 2008)
DIBs in: RAVE, Gaia-ESO, GALAH

- **RAVE**: ~500,000 spectra, one strong DIB at 8620 Å.

- **Gaia-ESO**: 5 strong DIBs, some of them with multiple components.

- **GALAH**: 12 strong DIBs plus the K I absorption at 7699 Å.
Measuring DIBs in spectra of cool stars

- **Modelling** the stellar contribution (Chen et al. 2013; talk by Zasowski)

- **Self-calibrating** the stellar contribution (Kos et al. 2013)

Kos, et al. (2013)
Radial velocity measurement from complex profiles

The observed normalized stellar spectrum can be written as:

\[ F(\lambda) = S(\lambda) \prod_{i=1}^{D} \prod_{j=1}^{C} \prod_{k=1}^{P} [1 - G(A_{ijk}, \lambda_{ik}, \sigma_{ik}, v_{ij})(\lambda)] \]

where \( S(\lambda) \) is the intrinsic stellar spectrum (plus telluric lines), and the products go over \( D \) DIBs, \( C \) interstellar clouds with distinct radial velocities along the line of sight, and \( P \) components of the profile of each DIB.

\( G \) is the adopted shape of the DIB absorption component, e.g. a Gaussian with a given amplitude \( A \), rest wavelength \( \lambda_c \), width \( \sigma \), and radial velocity \( v \). Here we assume that only radial velocity and amplitudes of individual components of a given DIB change from cloud to cloud, while the relative position of components stays fixed (which is true if components are partially resolved branches in the electronic transition of a large molecule).

Concept of 3-D position + radial velocity measurement

Fig. 1. Concept of 3-D position and radial velocity measurement of diffuse interstellar band (DIB) absorptions in a dynamic interstellar medium (ISM).
DIBs close to the Galactic plane

Puspitarini et al. (2015)
Dynamics in the plane (Apogee)

Galactic longitude-velocity diagram of the DIB @ 1.5272\(\mu\)m (Zasowski et al. 2014).

Gray points are individual measurements and red circles are medians in 10° steps. Velocity curves for different Galactocentric radii are over-plotted.
Cluster membership of a star can be questioned if a discordant strength and/or radial velocity of DIBs is seen. 

Red: likely members according to standard membership tests.
RAVE – the first (quasi) 3-D map of a DIB

Vertical scale-height larger for the diffuse interstellar band than for dust.

Kos et al. (2014, Science, 345, 791)
Quasi 3-D maps of DIB macromolecules (left) and dust (right)

Asymmetric explosions of supernovae

Evolution of gas column density (a), dust column density (b) and magnetic field structure (c) at $t = 2; 7; 11; 15$ Myr after start of simulation in meridional projection. Panel (d) is the distribution of gas (left) and dust grains of different sizes ($a = 10^{-4}; 10^{-5}; 10^{-6}$ cm — from left to right) at $t = 15$ Myr. From Khoperskov & Shchekinov (2014).

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GALAH – a preliminary intensity and radial velocity map

Radial velocity and equivalent width of the DIB @ 6613 Å in GALAH spectra. LSR is removed from the radial velocity map. A rest wavelength of 6613.7 Å is assumed. Spectra within 0.25 square degrees were averaged to measure the position of the DIB. From Kos (2015).
Dynamics in and out of the plane

- **In the Galactic plane:** complicated dynamics, head-on collisions.

- **Away from the plane:** motion largely perpendicular to the plane, formation of Galactic fountains.
Into the future

6-dimensional dynamics of recent events in the interstellar medium through diffuse interstellar bands

DIB distribution is different on either side of the Galactic plane, a witness to asymmetries in placement of recent explosions of supernovae and to incomplete vertical mixing.

With DIBs we can identify dynamic voids, shells and Galactic fountains blown away by these SNe.

Possibly it can place and date them by modelling of dynamics.

Such explosions sustain star formation in the disk by entraining fresh gas from the halo.