Structure of the Polaris flare revealed by SPIRE

Marc-Antoine Miville-Deschênes (IAS, Orsay, France)

on behalf of the SAG 4 “Evolution of Interstellar Dust”

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Outline

• Structure of the ISM and the Polaris flare
• How well does SPIRE restore diffuse emission ?
• Power spectrum analysis
Background and goal

• What governs the structure of the ISM? direct impact on the CMF and IMF.
  • Complex physics: turbulence, magnetic field, thermal instability
  • Need for direct comparison with numerical simulations
  • Importance of the density field (compare to the velocity field)
  • Power spectrum of column density --> power spec. of the 3D density field

• Need for a careful selection of fields and emission tracers

• Goal: use of long wavelength dust emission of cirrus clouds to study the 3D structure of the diffuse ISM.
  • Uniformly heated by the ISRF: no local source of UV photons
  • Extinction low enough to neglect radiative transfer
  • Dust temperature rather uniform: dust emission is a good tracer of the total column density.
  • Traces all phases (atomic, molecular)
View of the Polaris flare with IRAS

- R: 100 micron,
  G: 60 micron,
  B: 12+25 micron

- Dense cirrus cloud
  - 150 pc
  - significant CO emission
  - several proto-stellar cores but no star formed

- Ideal target to study the early phases of star formation
  - formation of molecular clouds
  - role of dust
  - structure of the ISM
...and here comes Herschel-SPIRE

- Spectacular increase of the angular resolution
- Provides, for the first time, a uniform view of the ISM structure at scales from 0.01 to 8 pc
IRAS (100 micron) - SPIRE correlation @ 5arcmin

- Global correlation between SPIRE (5 arcmin) and IRAS 100 micron reveals a dust spectrum in accordance with expectations (Bernard et al. 1999 - PRONAOS observations)
- Variations around the correlation much stronger than the noise levels
- SPIRE-SPIRE correlation extremely tight

\[ T = 14.5 \pm 1.6K \]
\[ \beta = 2.3 \pm 0.6 \]
How well does SPIRE map diffuse emission?

- R: 350 micron
- G: 250 micron
- B: IRAS (IRIS) 100 micron

- Dust properties variations
- Large scale systematic effect due to residual 1/f noise
How well does SPIRE map diffuse emission?

- Clear difference at large scales between IRAS and SPIRE
- Comparison with Planck at 350 and 500 micron would allow to confirm this result.
- Probably room for improvement on the removal of the 1/f noise (thermistor correlation)
Tentative restoration of the large scale emission
Power spectrum of the 250 micron Polaris map

\[ P(k) = \phi(k)[A_0 k^\gamma + S_0] + N(k) \]

- transfer function
- ISM
- sources/CIBA
- noise floor

modes affected by map-making
beam
noise floor
SPIRE beam power spectrum

Red: Gaussian beam
Black: beam measured on Neptune
Power spectrum modelling

\[ P(k) = \phi(k) [A_0 k^\gamma + S_0] + N(k) \]

<table>
<thead>
<tr>
<th>( \lambda (\mu m) )</th>
<th>( \gamma )</th>
<th>( S_0 (Jy^2 sr^{-1}) )</th>
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</thead>
<tbody>
<tr>
<td>250</td>
<td>(-2.65 \pm 0.10)</td>
<td>(5 \pm 2 \times 10^3)</td>
</tr>
<tr>
<td>350</td>
<td>(-2.69 \pm 0.13)</td>
<td>(4 \pm 2 \times 10^3)</td>
</tr>
<tr>
<td>500</td>
<td>(-2.62 \pm 0.17)</td>
<td>(1 \pm 1 \times 10^3)</td>
</tr>
</tbody>
</table>

- Power spectrum slope
  - Compatible with previous estimates using CO and 100 micron emissions
  - Typical of molecular clouds
- Detection of a white term compatible with the expected level of the Cosmic Infrared Background Anisotropies (CIBA)
Power spectrum modelling: Gaussian PSF

\[ P(k) = \phi(k)[A_0 k^\gamma + S_0] + N(k) \]

- Gaussian beam is a bad approximation for power spectrum analysis
- The use of the measured beam is crucial: secondary lobes impact on the power estimate at arcmin scales

IRAS 100  SPIRE 250

\[ k^{-\gamma} \left[ \frac{P(k) - N(k)}{\phi(k)} - S_0 \right] \]
What is the density power spectrum of diffuse ISM?

- A power spectrum of -2.7 is very different than subsonic, compressible turbulence (-3.7).
- **Supersonic** and/or **magnetic** turbulence can produce flatter (~ -3) density spectrum without a strong modification of the velocity spectrum.
- **Thermal instability**: the local production of stable cold structure modifies dramatically the density structure of the flow.
  - The many narrow features on top of a smooth broad line is the sign of cold, spatially disconnected structures moving in the same velocity field as the warm gas.
  - The warm and cold phases probably do not have the same power spectrum.
- Detailed comparison with gas phase (21 cm, CO), polarization (Planck) and numerical simulations is needed.

A 21cm spectrum of the Polaris flare cirrus
Miville-Deschenes et al. (in prep.)
21 cm observations of Polaris

- Green Bank Telescope (9’ - this figure)
- DRAO (1 arcmin)
Illustrative comparison with MHD simulations

- Preliminary study of MHD simulations including the HI thermal instability (collaboration with Hennebelle & Audit).

\[ \langle B \rangle = 5 \text{ microG}, \quad \gamma \approx -2.5 \]

\[ \langle B \rangle = 0 \text{ microG}, \quad \gamma \approx -3.5 \]
Conclusion

• First time the diffuse ISM is uniformly sampled from 0.01 to 8 pc: SPIRE provides an ideal opportunity to study the ISM structure which sets the initial conditions of the star formation.

• Global understanding of the power spectrum features:
  • SPIRE does not recover large scale diffuse emission perfectly yet but the quality of the data processing is excellent at such an early stage.
  • SPIRE beam is significantly different than a Gaussian.
  • Power spectrum slope (-2.7) seen in CO and 100 micron at large scales extends down to 30 arcsec (0.02 pc).
  • Marginal detection of the CIBA, in accordance with expectations.

• Comparison with numerical simulations and 21 cm observations is ongoing: preliminary results shows the importance of the magnetic field.
Filamentary structure of the diffuse HI: magnetic turbulence?

21 cm observations (DRAO)
Velocity channels only 2.6 km/s apart

Martin et al. (in preparation)
SPIRE-SPIRE correlation at 5 arcmin
- **Total(Beam)/total(Gaussian)**
  - 250 micron : 1.35
  - 350 micron : 1.31
  - 500 micron : 1.25