Dusty Foregrounds at Intermediate to High Galactic Latitudes

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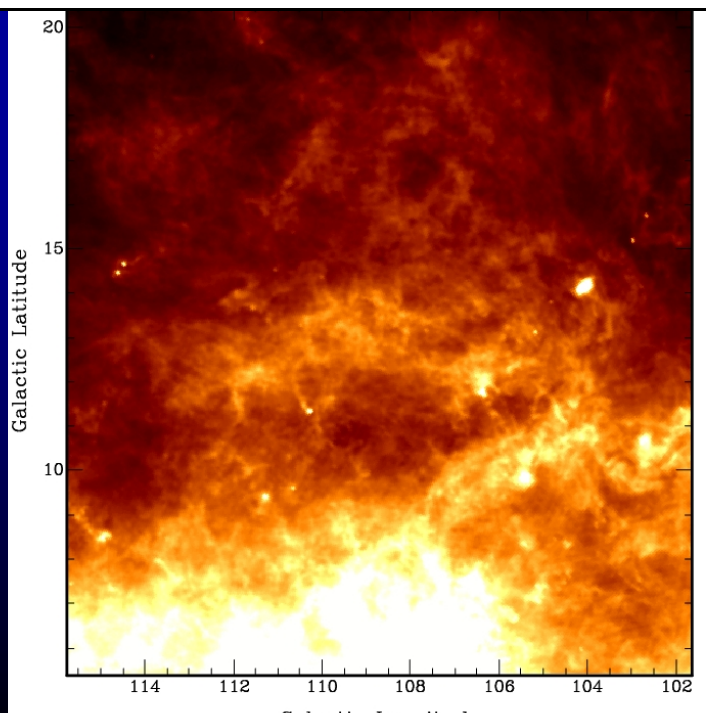
Cirrus



Faint Cirrus

Made famous by IRAS, but previously known also from extinction of galaxies and high latitude reflection nebulae. But low column density and so harder to characterize (e.g., by extinction curves).

Cirrus will produce foreground emission in the 100's of GHz range and is not so dim as to be able to ignore (wide sky coverage being needed for precision cosmology, for example).

Strategy: mask out regions of known cirrus.

Only 20% of the sky has H I column density below 10^20 cm^-2. Even that produces a non-negligible foreground. But this is so dim that we don't know a lot about this Galactic emission, certainly not with significant angular resolution.

Perspective

Have been carrying out Galactic Plane surveys.

Multiwavelength approach to cover emission from all main constituents (relevant too to component separation).

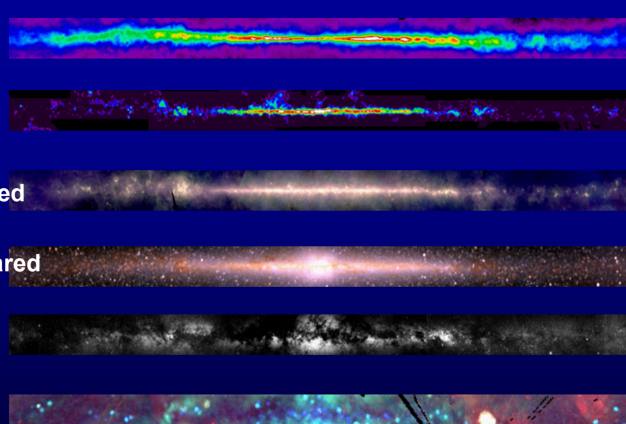
Data from all-sky surveys like WMAP and Planck will be useful complements, though of lower angular resolution.

Can our surveys (or adjuncts thereof) be useful for CMB studies? (masking; component separation).

A Multiwavelength Approach

The Galactic Plane looks different at different wavelengths, because of the different physics going on at the site of emission of the radiation and along the line of sight.

Disk of our Galaxy at Different Wavelengths



Radio	Neutral gas
Radio	Ionized gas
Far-infrared	Cool dust
Near-infrared	Stars (unobscured)
Visible	Stars (dust obscuration)
X-ray	Very hot gas

The Galaxy will look different at higher latitudes as well.

CGPS/VGPS (parts of IGPS)

H I and radio continuum observations are obtained using aperture synthesis telescopes.

• Originally DRAO ST. VLA used where Galactic plane crosses low declination, since it has north-south antenna spacings.

• Zero-spacing (low spatial frequency) data provided by surveys using large single antennae.

CO surveys at FCRAO using focal-plane array.

IR from IRAS (HiRes) and MSX.

DRAO Synthesis Telescope

9-m dishes on 600-m baseline

2 degree field

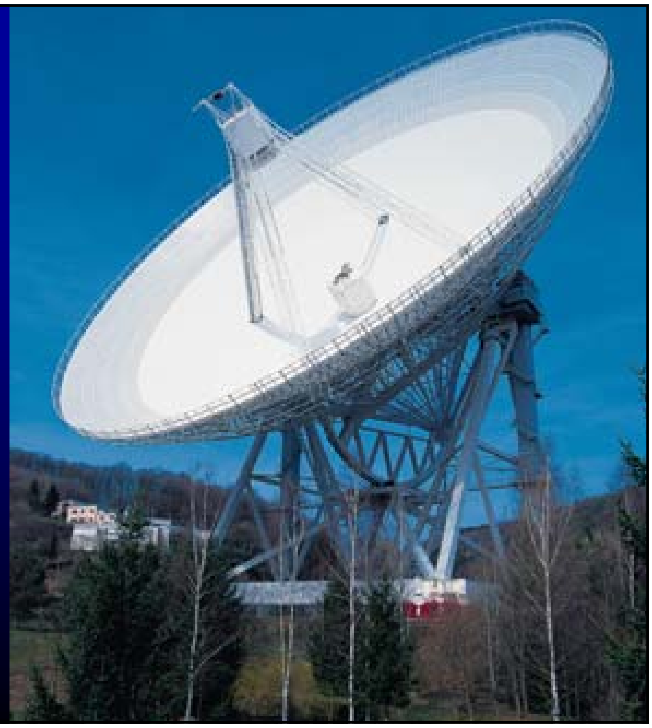
1’ resolution

DRAO 26 m for H I

36’ resolution

Effelsberg 100 m for continuum

9’ resolution

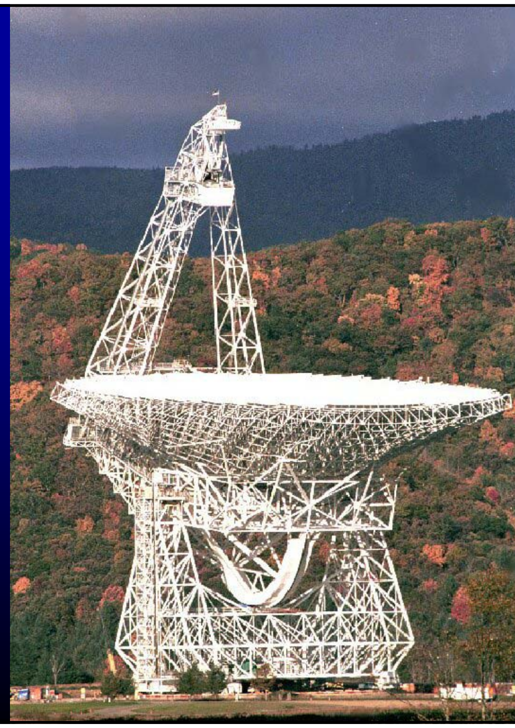


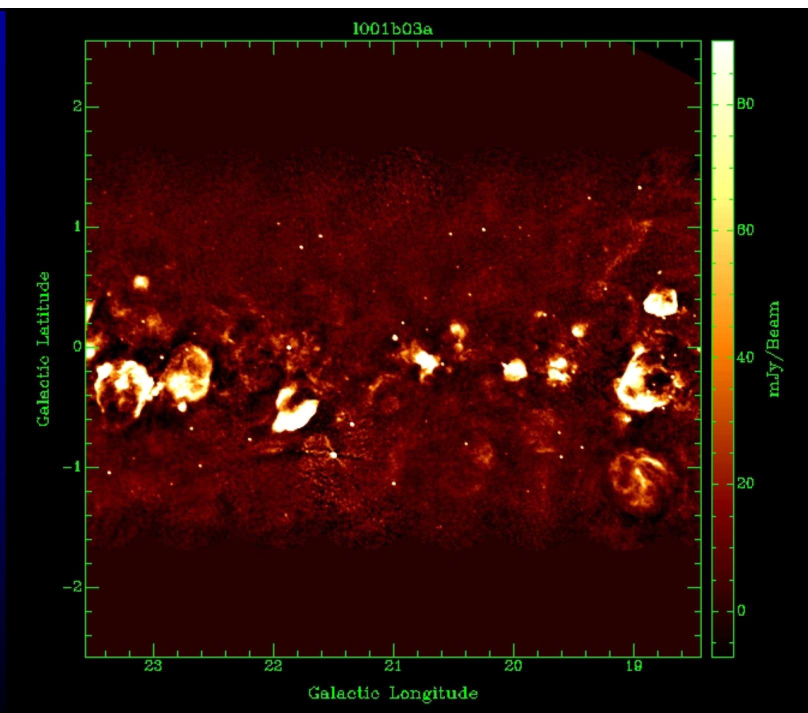
VLA D array

1’ resolution

GBT 100 m for H I

9' resolution





VGPS radio and infrared

Cirrus: Friend or Foe?

For a CMB audience probably the latter.

At least might “know the enemy.” At high latitudes one is looking at largely local material which therefore might be expected to share some properties with material studied in the local Galactic disk and at intermediate latitudes.

(see Intermediate and High Velocity Clouds later)

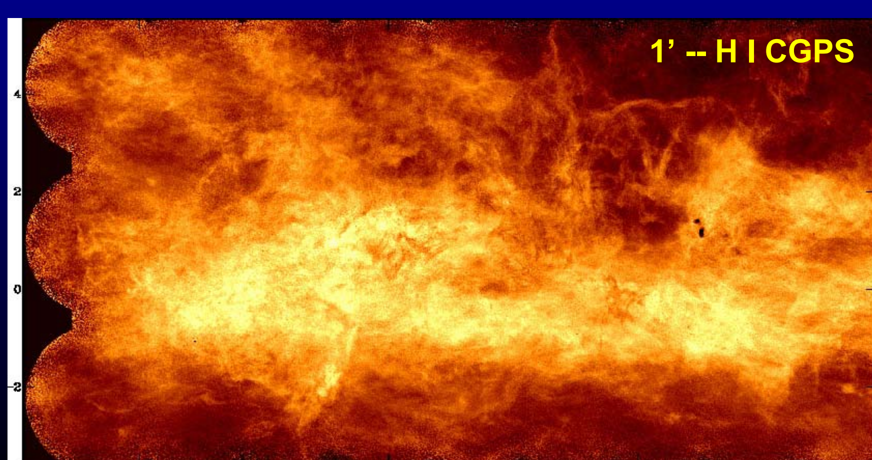
Perspective

Dilemma: it is counter-intuitive for those interested in Galactic phenomena to look where there is little signal!

Have been exploring what can be done, including “pilot” projects at increasingly higher latitudes.

Resolution Matters

36’ -- H I Leiden-Dwingeloo



Planck HFI – Frequencies and Resolution

Table: Goal Characteristics and Sensitivity of the HFI

Center Frequency (GHz)	857	545	353	217	143	100
Center Wavelength (mm)	0.35	0.55	0.85	1.38	2.1	3.0
Detector Temperature (K)	0.1	0.1	0.1	0.1	0.1	0.1
Bandwidth (%)	0.25	0.25	0.25	0.25	0.25	0.25
Bandwidth (GHz)	214	136	88	54	36	36
Number of unpolarised bolometers	6	0	6	4	3	4
Number of polarised bolometers	0	8	0	8	9	0
Angular Res. (FWHM, arcmin)#	5	5	5	5.5	8	10.7

Archeops: 545, 353, 217, 143 GHz; 10’ to 20’

Planck LFI – Frequencies and Resolution

Table 1: Goal Characteristics and Sensitivity of the LFI

Center Frequency (GHz)	30	44	70	100
Wavelength (mm)	10.0	6.8	4.3	3.0
Detector Temperature (K)	20	20	20	20
Bandwidth (%)	0.2	0.2	0.2	0.2
Bandwidth (GHz)	6.0	8.8	13.0	20.0
Number of Detectors	4	6	12	34
Angular Res. (FWHM, arcmin)	33	23	14	10

WMAP (GHz)	**23**	**33**	**41**	**61**	**94**
WMAP (Arcmin)	**51**	**37**	**29**	**20**	**12**

Boomerang/BLAST frequencies

Table 1: Data

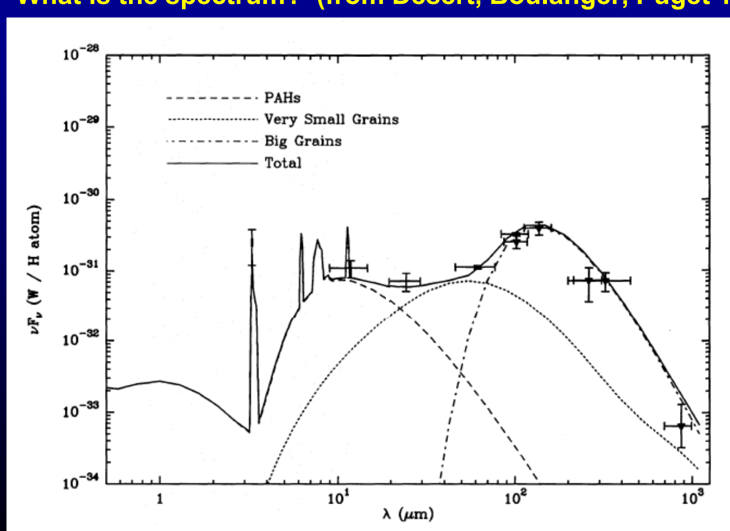
Experiment	Frequency	Wavelength	Polarization
BOOMERanG 1998	90GHz	3.3 mm	no
	150 GHz	2.0 mm	no
	240 GHz	1.25 mm	no
	400 Ghz	0.75 mm	no
BOOMERanG 2003	150 Ghz	2.0 mm	yes
	240 GHz	1.25 mm	yes
	345 Ghz	0.86 mm	yes
BLAST	545 GHz	0.55 mm	maybe
	857 GHz	0.35 mm	maybe
	1200 GHx	0.25 mm	maybe

BLAST resolution with 2-m mirror is better than 1' of the CGPS: 59", 44", 30: respectively.

Best Boomerang resolution is about 7'

Cirrus Emission: Lessons from IRAS and ISO

What is the spectrum? (from Desert, Boulanger, Puget 1990)



Emission mechanisms

What is the origin of the emission?

100 microns: thermal emission by larger grains

60 and 25 microns: non-equilibrium emission by small grains

12 microns: non-equilibrium emission by tiny grains/PAHs

UIRs: PAHs

All of these components of course radiate at longer wavelengths too (in predictable proportions).

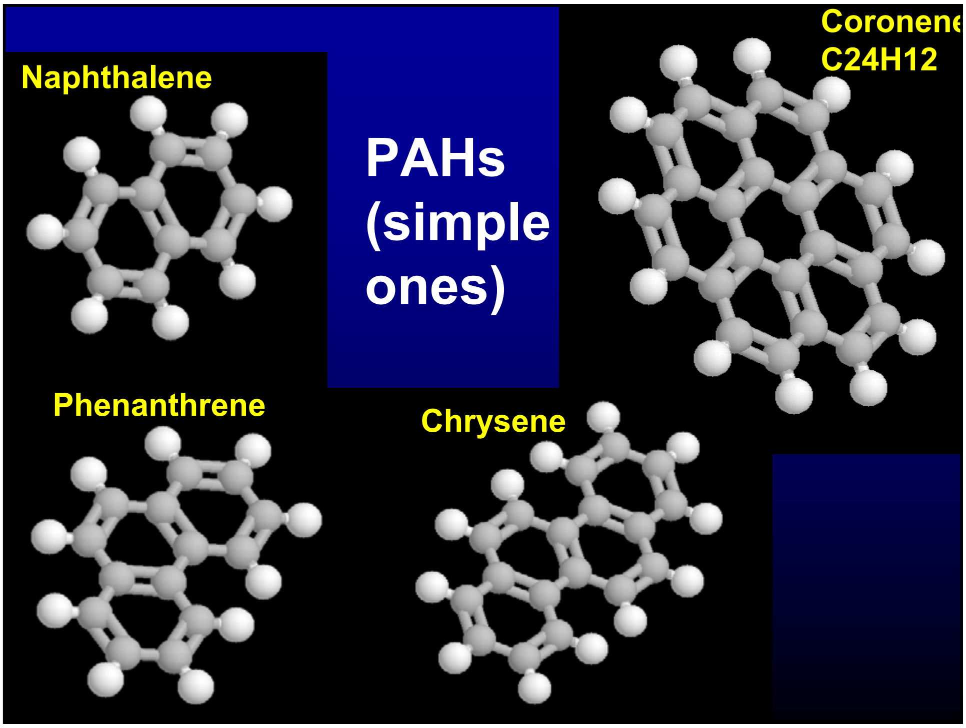
Tiny grains could also spin rapidly and emit microwave emission (significant? revived by Draine and Lazarian).

Range of Particle Sizes

Already known from the shape of the optical-UV interstellar extinction curve: continue rise of extinction into UV requires smaller particles.

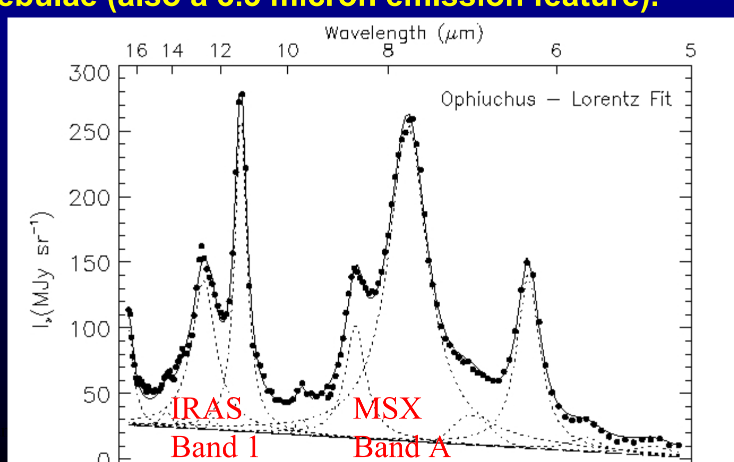
Number of small grains relative to large grains varies from line of sight to line of sight (quantified by Kim and Martin). Largest effects in dense dark cloud regions. Less evolution of the large grain size distribution.

Clearly there are consequences for (shorter wavelength) infrared emission (and emission from spinning grains), but hard to predict for faint cirrus because for those lines of sight the extinction cannot be measured.



PAH mid-infrared spectrum

Common emission spectrum appears in many ISM environments, from diffuse cirrus to dense reflection nebulae (also a 3.3 micron emission feature).



PAH model

(Verstraete et al.)

- features well fit by Lorentz profiles

- a psuedo-continuum from overlapping Lorentz profiles plus an underlying continuum.

- emission excited by single sub-ionizing UV photons. UV absorption signature not seen (Clayton et al.)

- broad mid-IR features and continuum produced by particles/large molecules with a few 100 atoms, heated to several 100 degrees.

- 3.3 micron feature and continuum requires particles as small as 50 atoms (not much larger than coronene).

IR Surrogates

What is then the best short-wavelength surrogate for long-wavelength emission?

Probably the larger grains dominate, because they comprise the most mass.   Hence use 100 micron emission. (At the next order, want to account for the emission by the smaller grains as well; and ratio of small to large grains can change.)

Except of course for emission from spinning grains. Would 12-micron emission be better? (3.3 micron would be better.)

Templates

Finkbeiner, Davis, Schlegel: COBE-normalized IRAS 100 microns and then colour-corrected (to produce temperature T and optical depth tau) using DIRBE data at 160 and 240 microns.

Should represent the large grain emission (see comments above re small grains).

Caveat: DIRBE resolution is only 40’ and we think that there is probably structure in T on finer angular scales.

New templates now available at all IRAS frequencies (see MAMD).

Power Spectra

One can also look at the power spectrum (and Cls) instead of the image itself.

e.g., this approach has been used to argue for the existence of a cosmic infrared background in ISO 170 micron data (several fields, including N1 to be discussed later).

Issues are the spectral index and the absolute power. How do they change with intensity at these brightness levels?

Does the cirrus power spectrum actually flatten at low intensities? (see MAMD).

(Same issues for synchrotron)

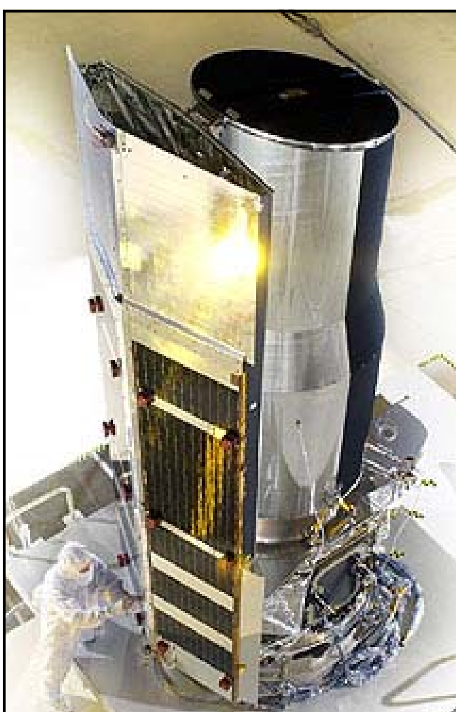
Spectrum evolution

IRAS/ISO/PRONAOS show there is spatial variability in the amount of short-wavelength to long-wavelength emission, presumably related to evolution of the grain size distribution, and perhaps composition (not just dark clouds but faint cirrus; no extinction curves). Relevant to spinning grains.

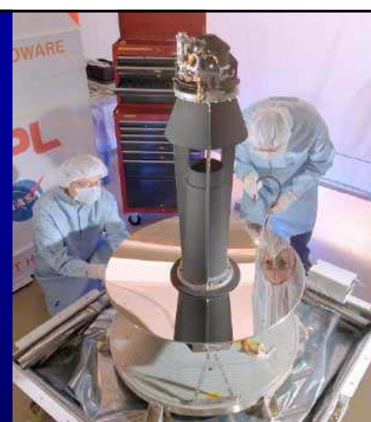
Understanding the evolution is the goal of the SEDI program on SIRTF (Boulanger et al.: Structure and Evolution of the Dusty ISM).

- high resolution (38”) mosaics in multiple passbands
- maps of large spatial extent that can be tied to DIRBE
- emphasis on relatively faint regions which can be observed with MIPS at 160 microns

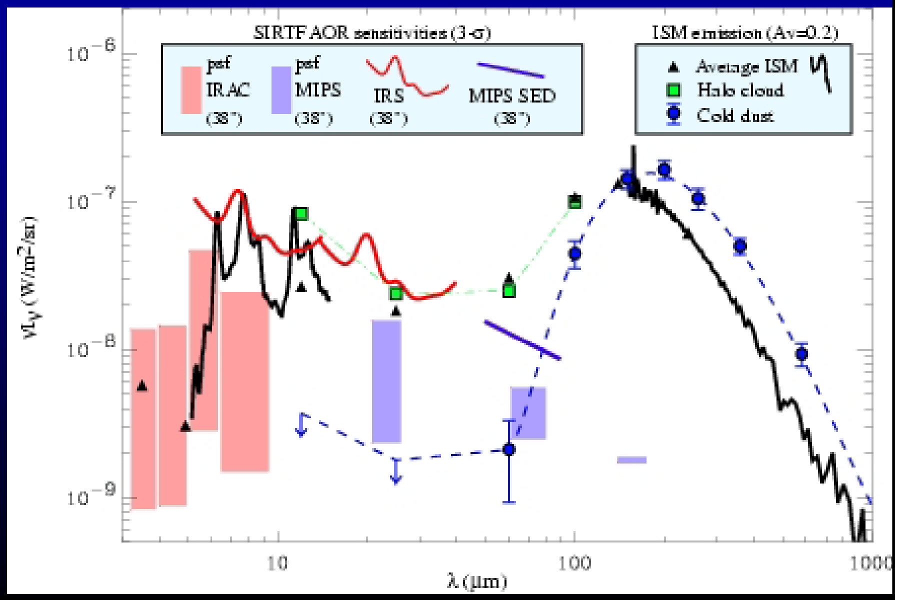
We are beginning with Early Release Observations (Dole) and MIPS GTO data (Rieke: aimed at detecting faint galaxies, for which cirrus is a foreground).



S I R T F



IR spectrum



Submillimetre spectrum

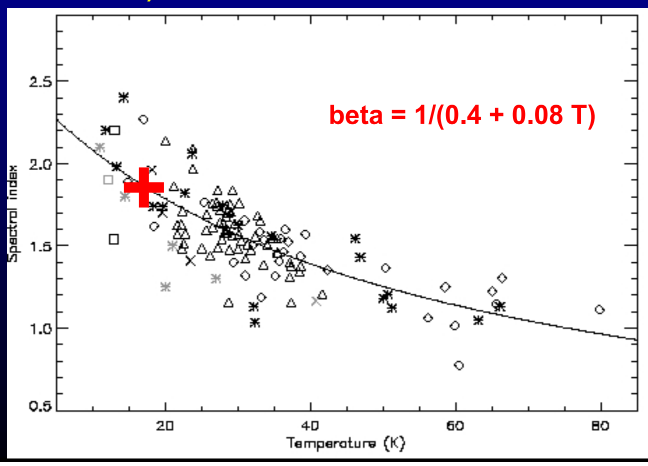
For submillimetre thermal emission, characterized by T and beta, the spectral index of the emissivity.

$$I_\nu = \epsilon_0 \; B_\nu(\lambda, T) \; (\lambda/\lambda_0)^{-\beta}$$

Is beta constant with wavelength? Is epsilon_0 constant?

Spectral Index Variations with T: the evidence

From addition of PRONAOS submillimetre data, 200 to 580 microns (Dupac et al 2003)



Spectral Index Variations: why?

Not causal. Three distinct effects may play a role:

- the grain sizes change in dense environments
- chemical composition of the grains is not the same in different environments
- an intrinsic dependence of beta on the T due to quantum processes (2-level tunneling in amorphous solids)

High T environments can be masked out?

Spectral Index Variations: Archeops

Bernard et al. Possible evidence for excess emission at 217 GHz (1.5 mm), which had been attributed to very cold dust (5 – 7 K).

Comments:

- Cold dust is unphysical
- Effect is seen everywhere (so a property of dust, not environment)
- beta is not constant with wavelength:
  - 1.8 for lambda < 600 microns
  - 0 at 1 mm
  - 2.2 at lambda > 2 mm

Conclusion: due to intrinsic processes in amorphous grains.

"Calibration" via cross-correlation

If spectral index and/or normalizing factor epsilon_0 is not known, then one can look at the cross-correlation between a dust template and the long-wavelength emission.

e.g., strong correlation between the 100 micron emission and the WMAP microwave K-band (23 GHz) emission. But does correlation imply causality? Related to flattening of synchrotron spectral index toward plane?

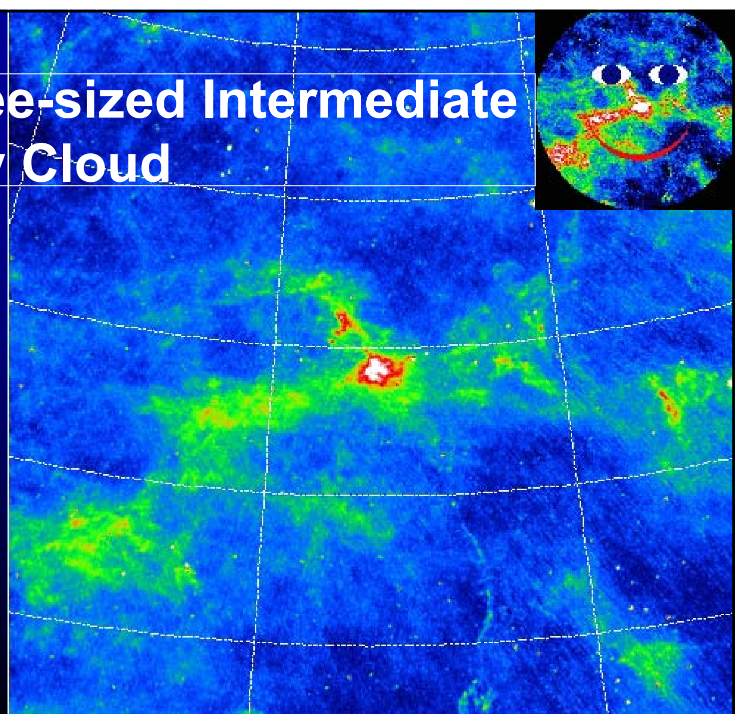
H I as a surrogate

Alternatively, one might want to make some cross-checks or even ab initio predictions of submillimetre emission, using another surrogate like H I (dust and gas being well mixed).

Caveat: there can be dust in the WIM (warm ionized medium) too.

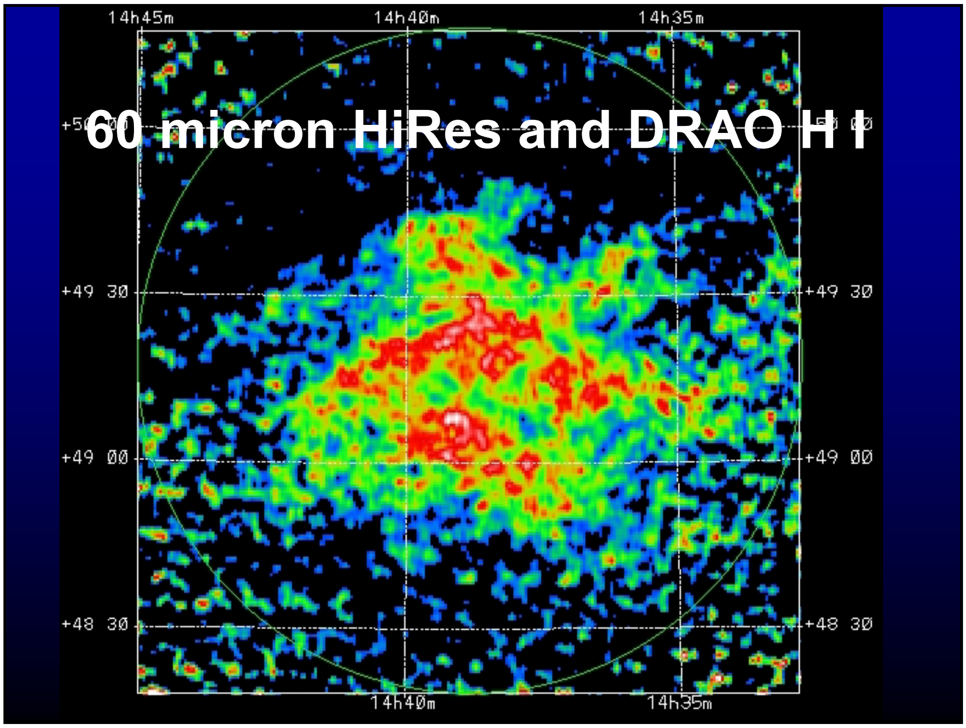
Useful at high latitudes, where sensitive H I observations are possible.

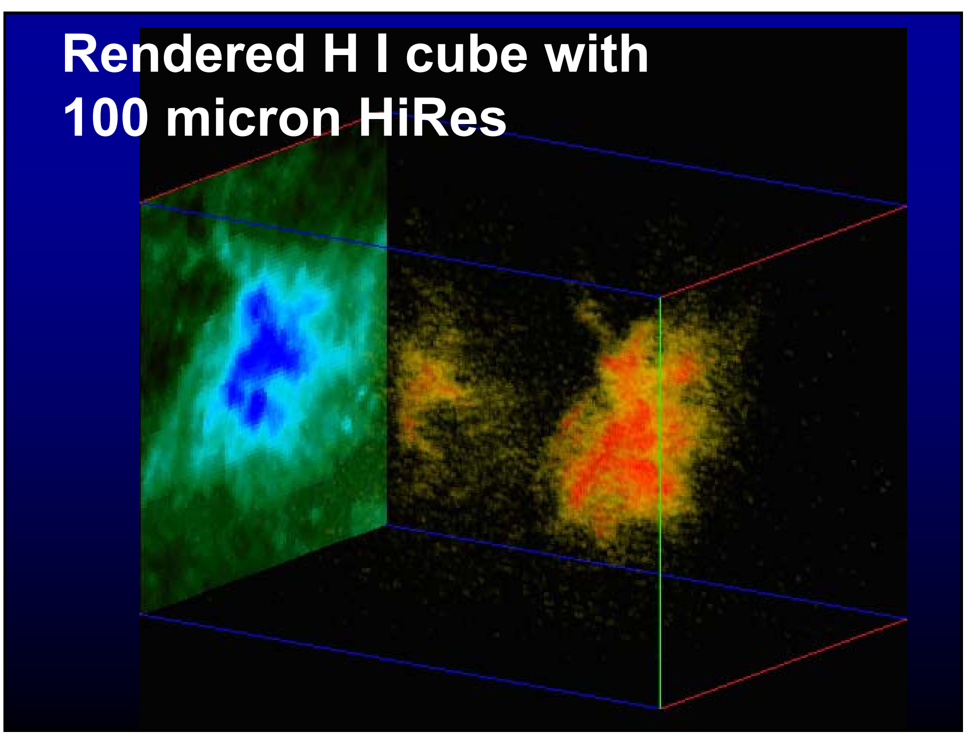
A Degree-sized Intermediate Velocity Cloud



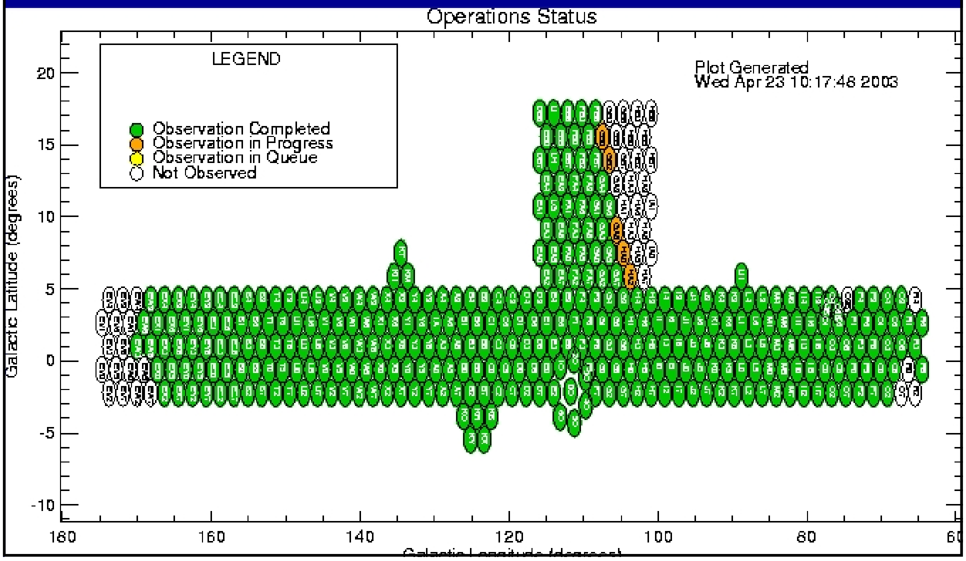
100 micron image

Showed that there is dust emission associated with the IV component.

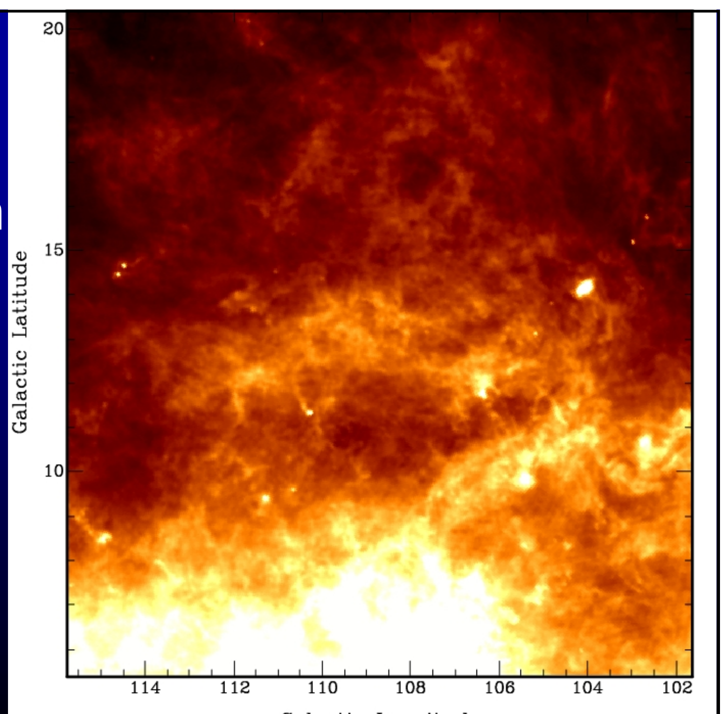

60 micron HiRes and DRAO H I
14h45m
14h40m
14h35m
+49 30
+49 00
+48 30

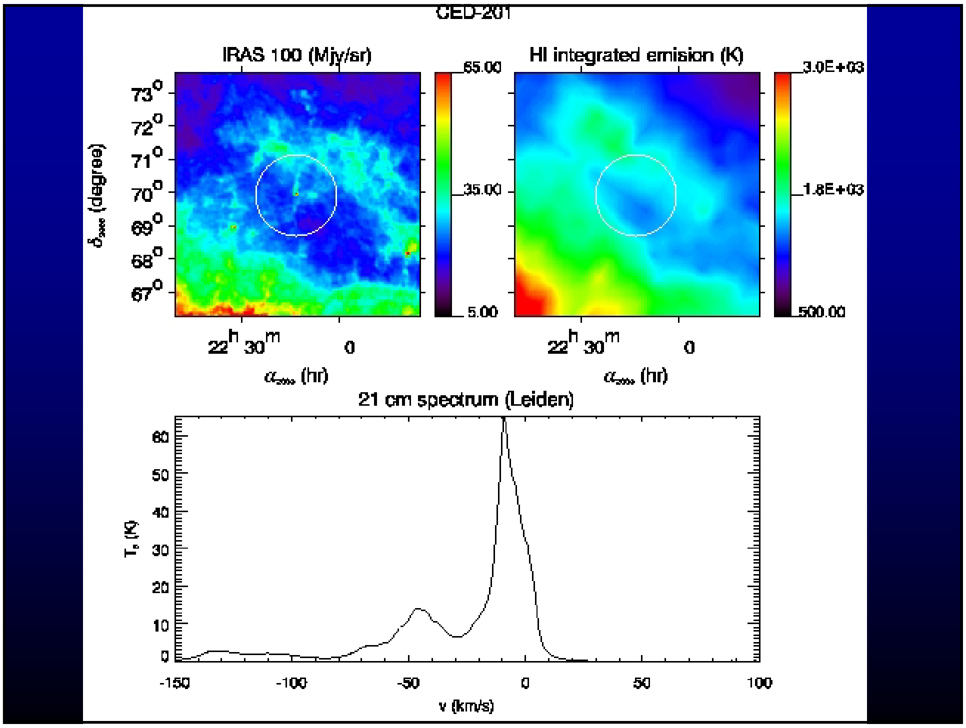

Rendered H I cube with
100 micron HiRes

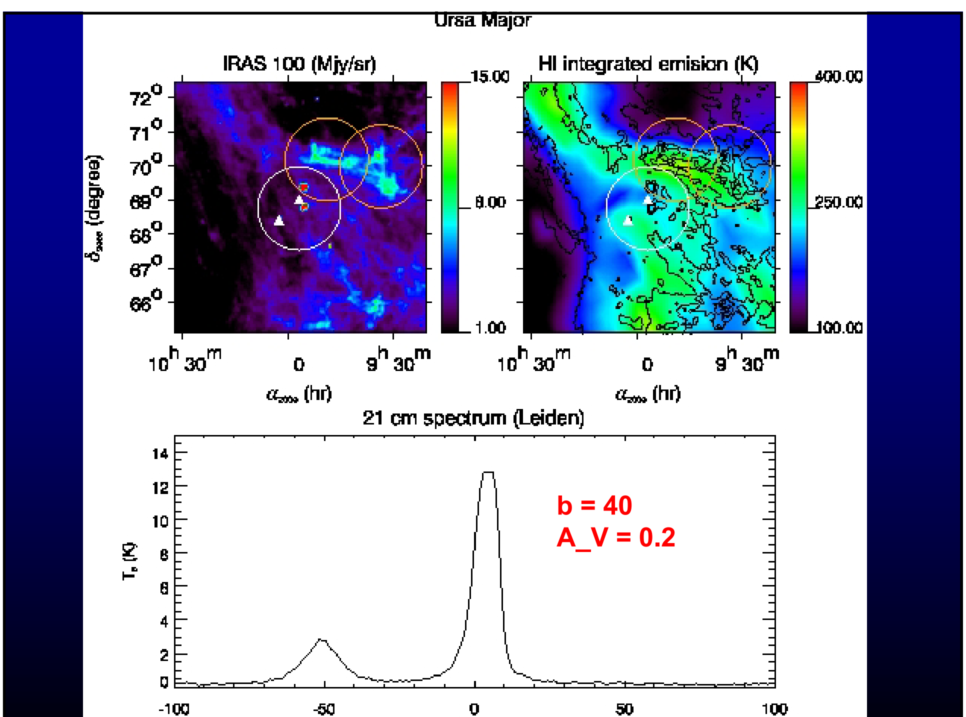
CGPS II – Extension to higher b



Cirrus in the CGPS II Region




CED-201
IRAS 100 (Mjy/sr)
HI integrated emision (K)
65.00
35.00
5.00
3.0E+03
1.8E+03
500.00
73°
72°
71°
70°
69°
68°
67°
δ2000 (degree)
22h 30m
0
α2000 (hr)
21 cm spectrum (Leiden)
T_b (K)
v (km/s)
-150
-100
-50
0
50
100

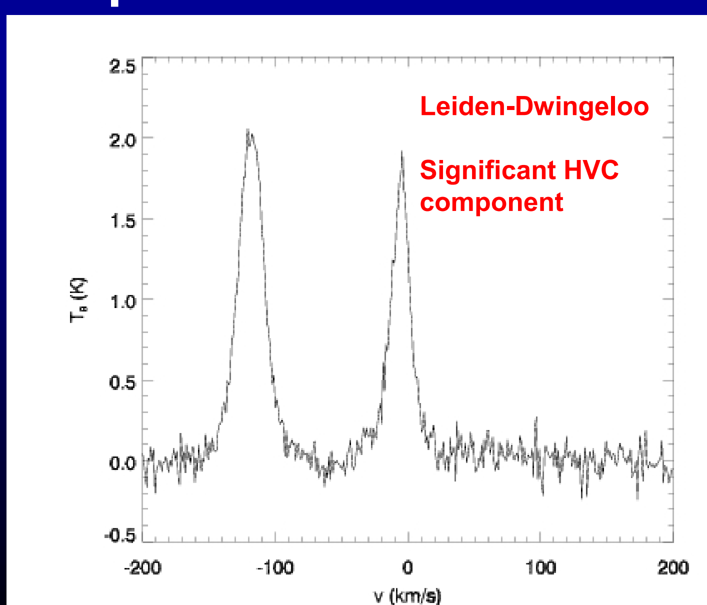

Ursa Major
IRAS 100 (Mjy/sr)
HI integrated emision (K)
15.00
8.00
1.00
400.00
250.00
100.00
72°
71°
70°
69°
68°
67°
66°
δ2000 (degree)
10h 30m
0
9h 30m
α2000 (hr)
21 cm spectrum (Leiden)
T_b (K)
b = 40
A_V = 0.2
-100
-50
0
50
100

The N1 Field

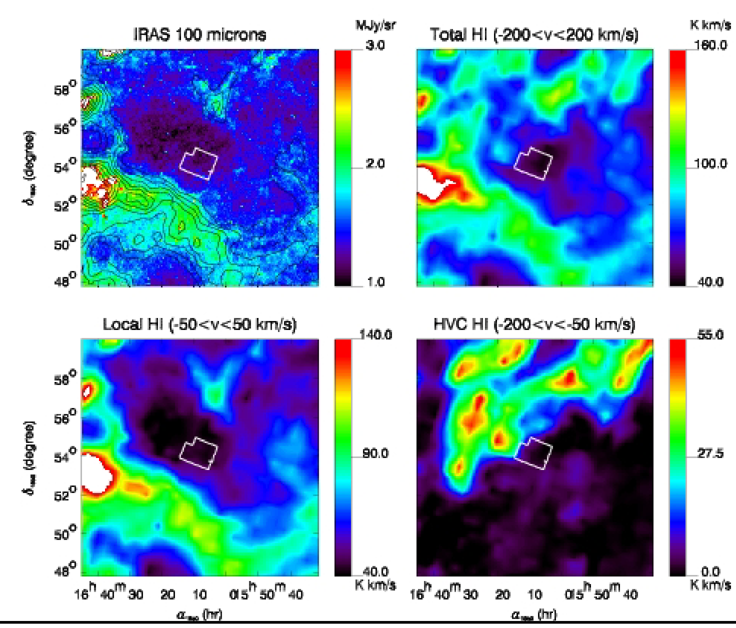
Faintest cirrus studied to date (with Jay Lockman and MAMD).

Example of the type of field leading up to the DRAO Deep Field.

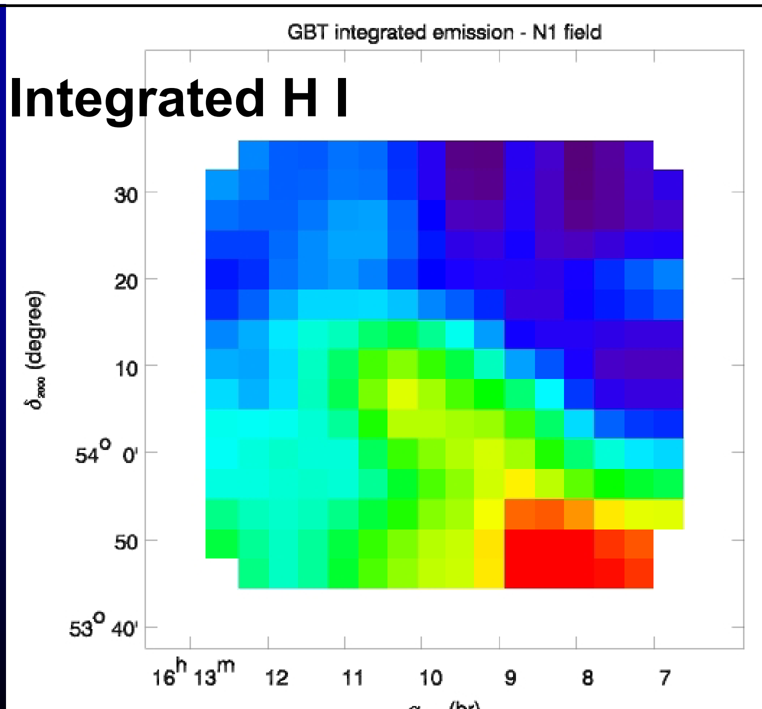
HI Spectrum



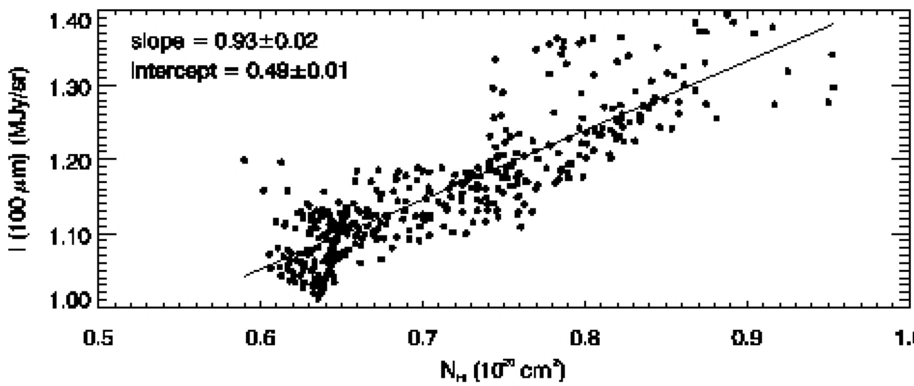
NI Environment: L-D H I and IRAS



GBT: Integrated H I



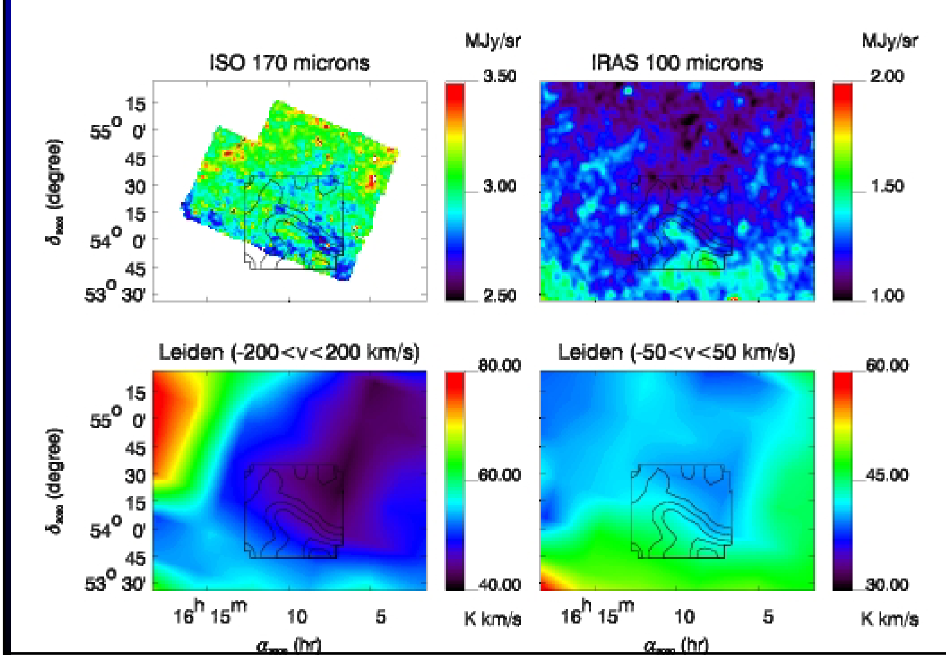
H I vs IR in the N1 (GBT) field



Characteristic tight correlation for low column density fields (this is really low!). Slope is the desired scale factor.

Intercept measures the Cosmic Infrared Background (caveats).

N1: ISO and GBT H I



CGPS III

Further high latitude fields with increasingly lower H I column densities, leading up to a "DRAO Deep Field."

Will produce interesting radio continuum data (including polarization) as well (see ART).

Being proposed by the CGPS consortium to NSERC under the SRO program.

DRAO Deep Field

"Heroic" attempt to obtain high resolution (1' to 2') data on H I and radio continuum.

Uses the mosaicing techniques developed in the Canadian Galactic Plane Survey.

With some infrastructure improvements to lower the noise temperature plus brute force (observing spaced over three years), a high sensitivity can be obtained in H I, about 0.1 K over 10 square degrees at arc minute resolution (c.f. current GBT surveys reaching 0.2 K in 7 hours).

Column density sensitivity for 10 km/s components [but beware HVCs] is 3 X 10^18 cm^-2.

10 square degrees, so spatial dynamic range about 10^2.

Dusty Polarization

Aligned aspherical grains produce UV, optical, near IR polarizaiton via differential extinction (dichroism).

Only the large grains are aligned (Kim and Martin).

Same grains should produce polarized emission. Theoretically (with empirical constraints!) can expect up to 10 –15% polarization in the submillimetre.

Polarized emission seen (at substantial column densities) in the:

- Infrared (10 microns)
- Mid-infrared (100 microns)
- Submillimetre (Archeops)

Should also be present at high latitudes. Very little is known about spectrum or power spectrum. (Planck; preview by Boomerang03? BLAST?).

Template

Template