Gaia

and

3D mapping of the ISM

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Latmos/IPSL, CESR, ACRI-ST, LGIT

Outline

- 3D distributions of the ISM : methods and past results

=> The Gaia context: a unique opportunity to progress

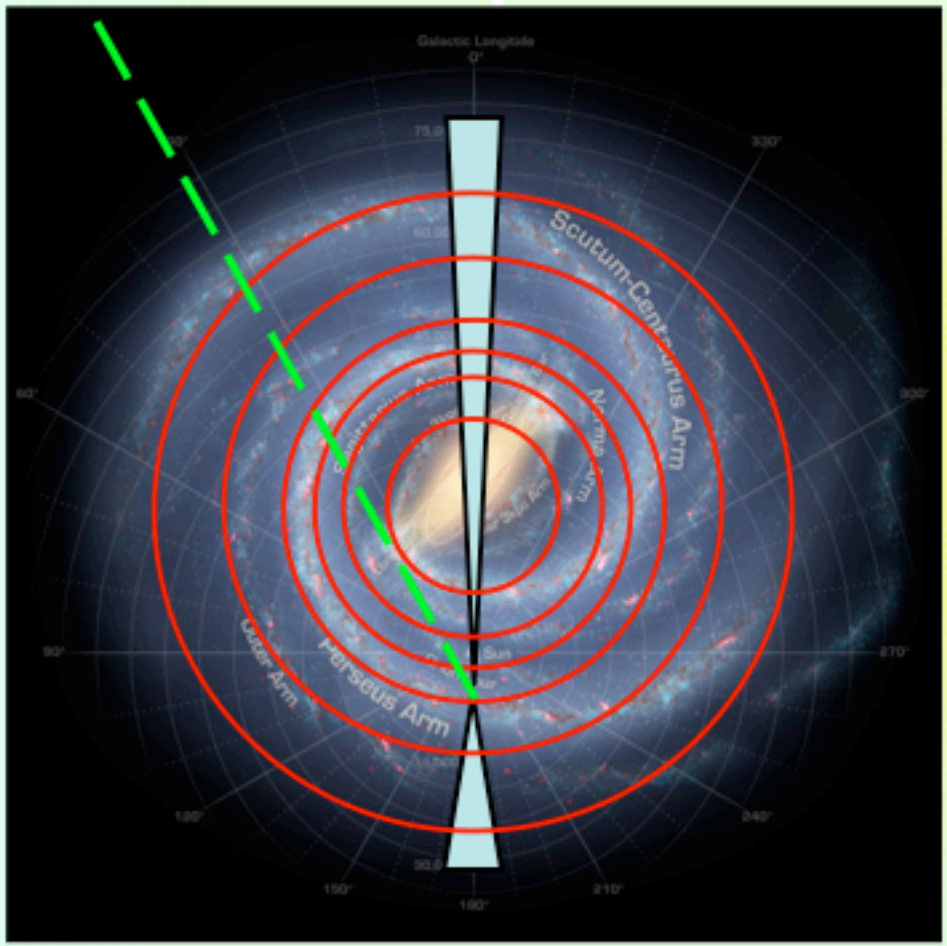
- The increasing needs for three-dimensional maps of the galactic ISM: gas and dust

3D mapping ingredients

- -gas/dust line-of-sight data:
  - -individual: colour excess, absorption or emission line
  - -photometric surveys: statistics
- -distances (kinematic, photometric ,parallax)
- -a way to link distances and data



1) **Using kinematic distances**: model rotation curves



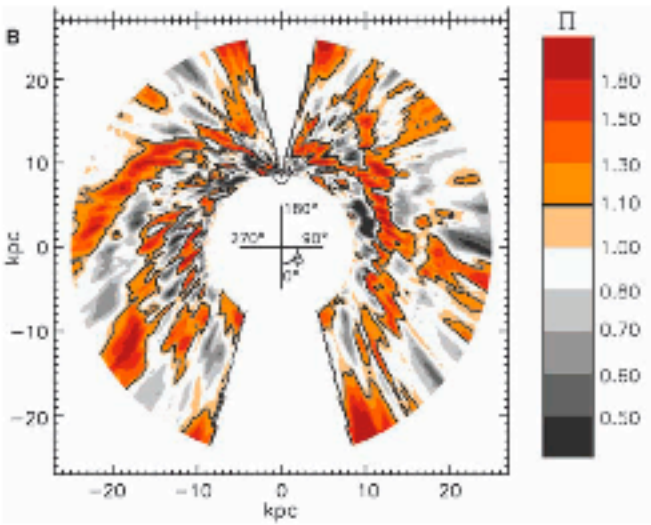
Appropriate to **spectral cubes**: **l, b, V**

(e.g. HI) , large distances

- Assume orbits (circular)
- Given line of sight, max radial velocity along tangent

Known limitations

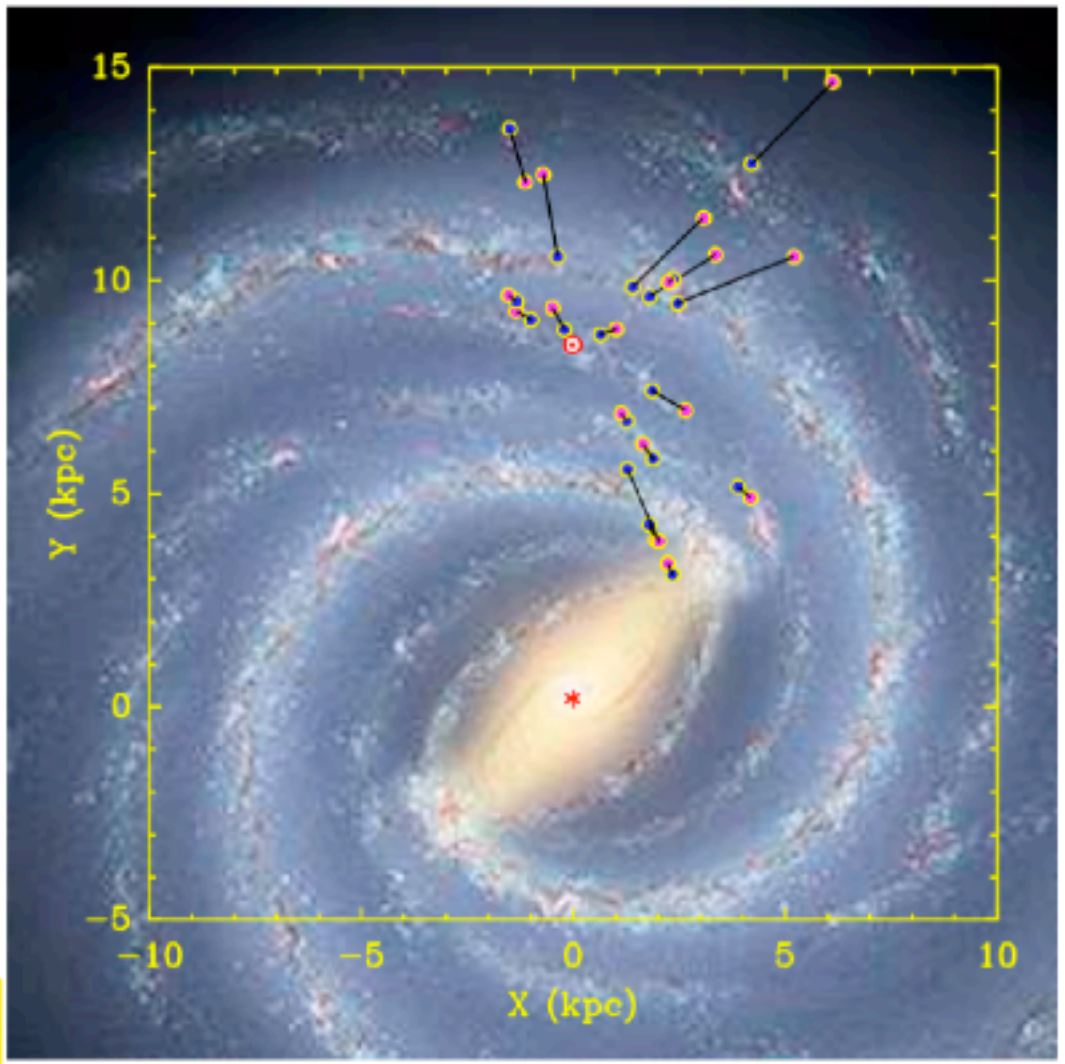
- Can be (very) wrong near spiral arms, Galactic bar
- Inner Galaxy, LOS crosses all orbits twice: near/far ambiguity
- Cannot be applied :
  - -out of plane
  - - in centre and anti-centre directions
  - -Not accurate for the local ISM



HI results

Levine et al. (2006)

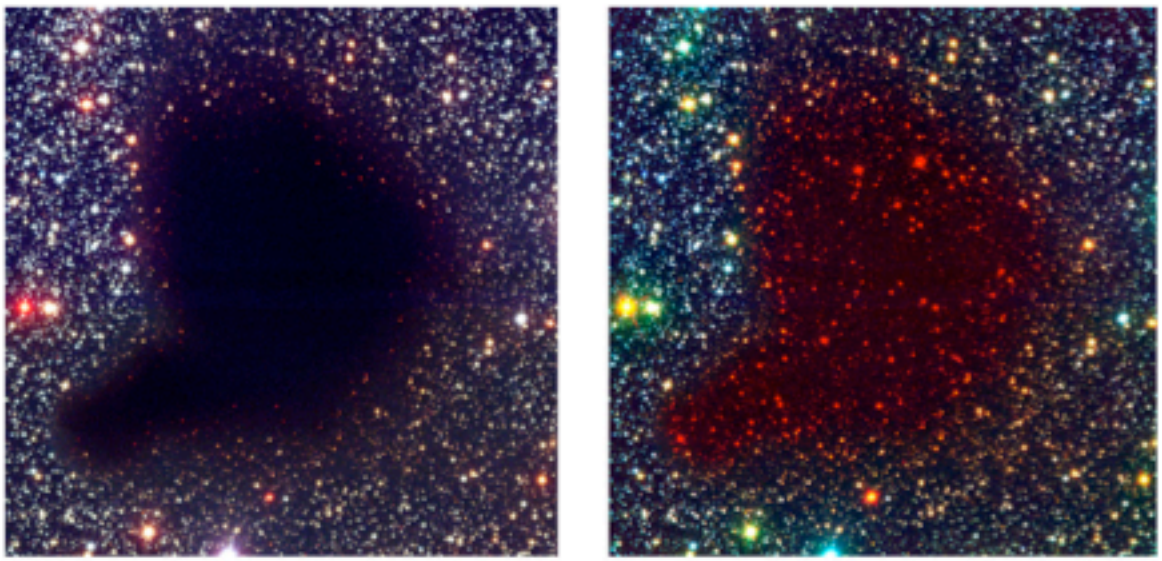
BUT :



Parallax (blue), Kinematic (red)

Reid et al. (2008)

2 Using stellar surveys - interstellar reddening



B, V, I

B, I, K

Pre-Collapse Black Cloud B68 (comparison)
(VLT ANTU + FORS 1 - NTT + SOFI)

ESO PR Photo 02c/01 (10 January 2001)

© European Southern Observatory

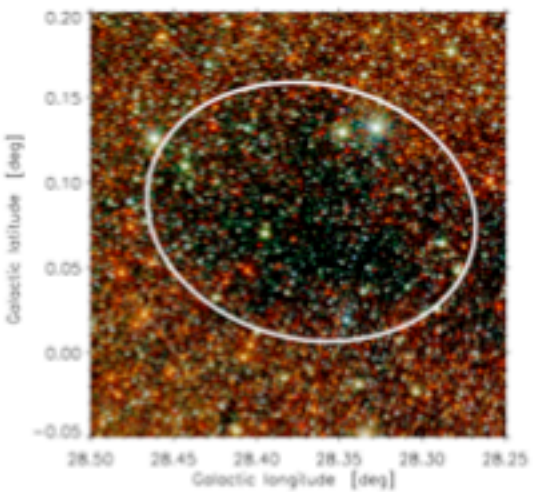
Interstellar extinction:

- **Infrared observations allow us to go deeper than vis or uv**
- **Use of the 2MASS catalog (IJK)+ Besancon galactic model**
-

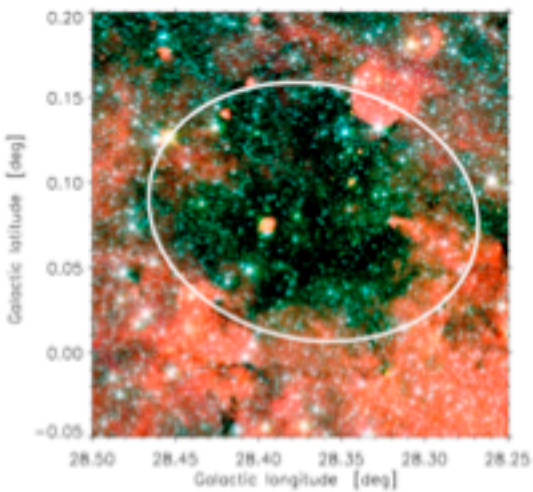
(Marshall et al, 2006,2009)

Distance from extinction signature

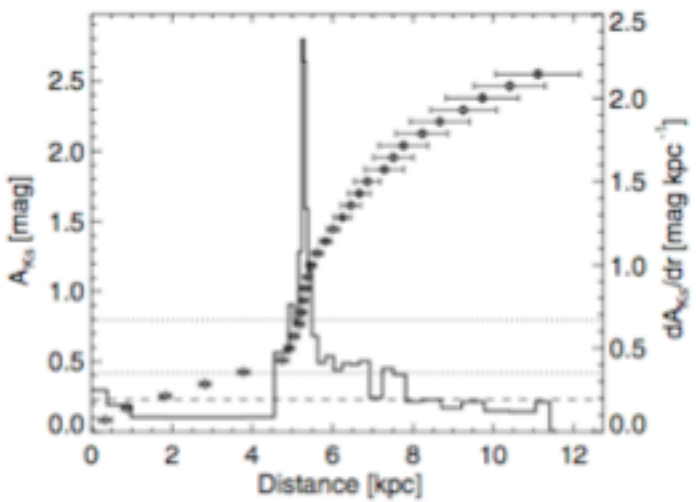
From Marshall et al. (2009), applied to Infrared Dark cores :



2MASS NIR stars



GLIMPSE (Spitzer)
8 µm extinction

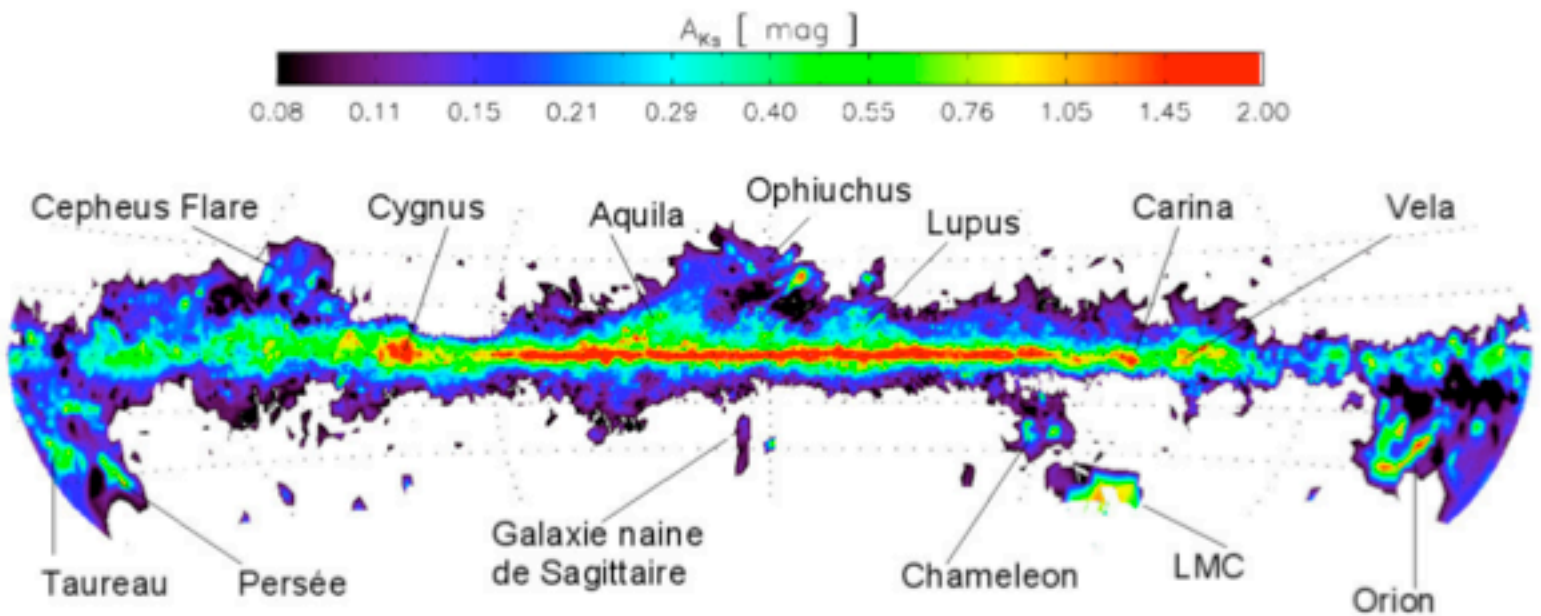


In a nutshell:

- Observe reddened stars
- Create 3D simulation of (unreddened) stars in the same field
- **Find extinction vs distance that minimises differences between model and observations**
- Use only stellar colour not the number of stars

Integrated extinction map

Many structures identifiable in recovered extinction map

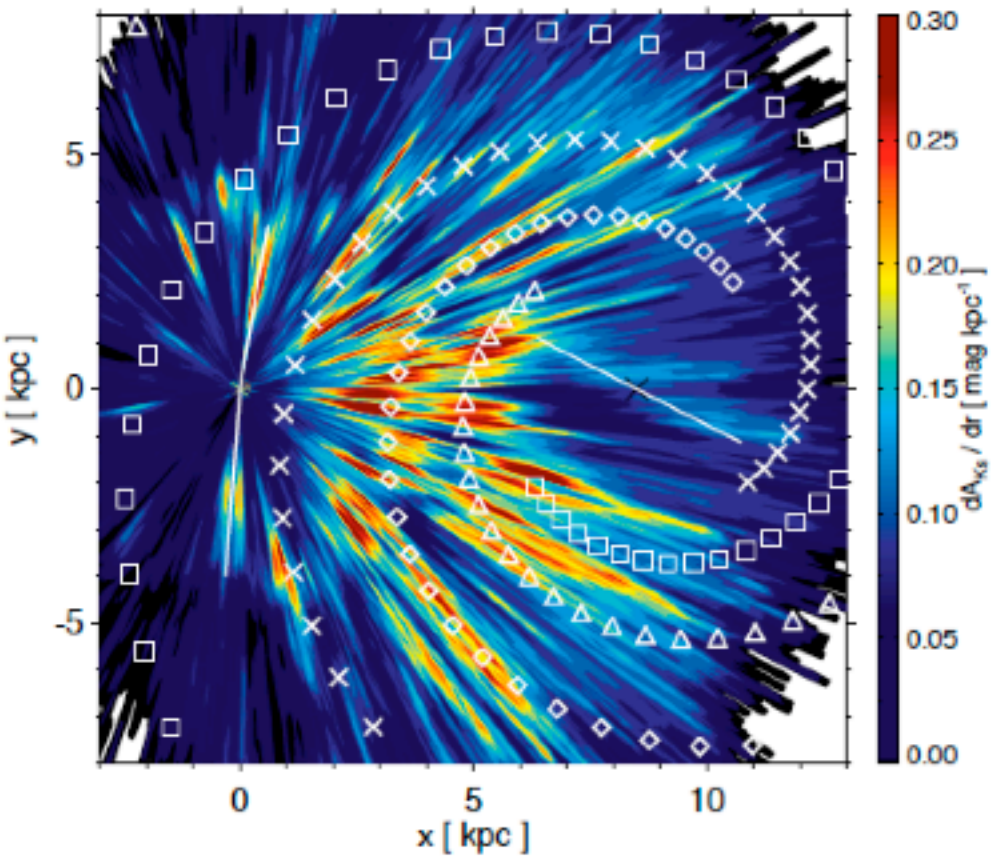


-based on 65,000 objects

Marshall et al, 2006

Extinction mapping

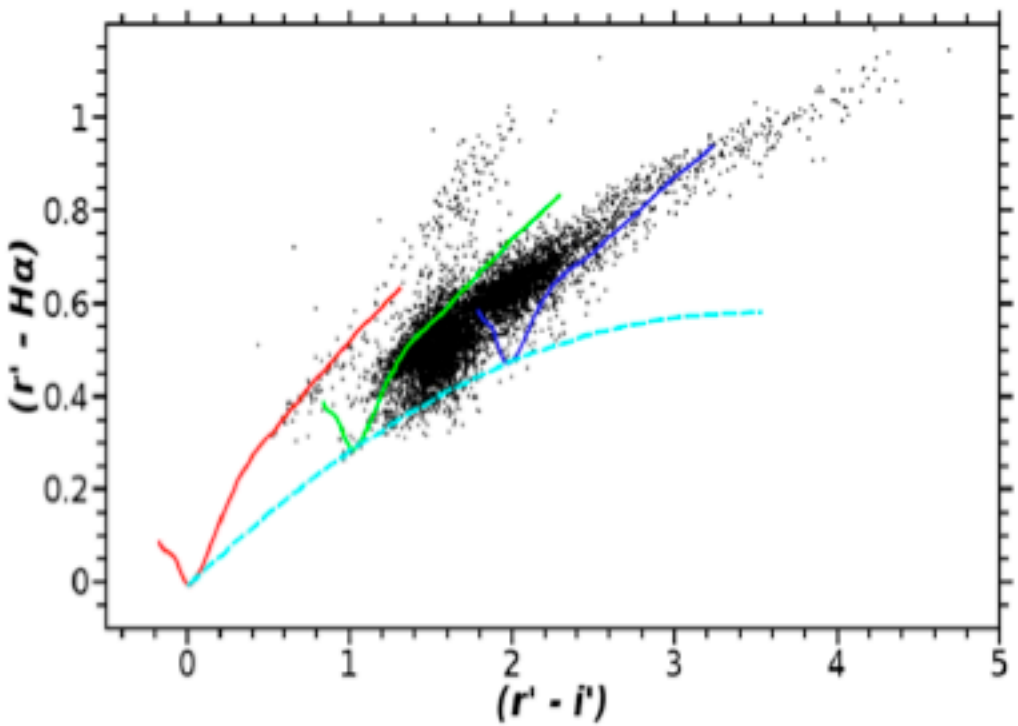
Spiral tangents very obvious



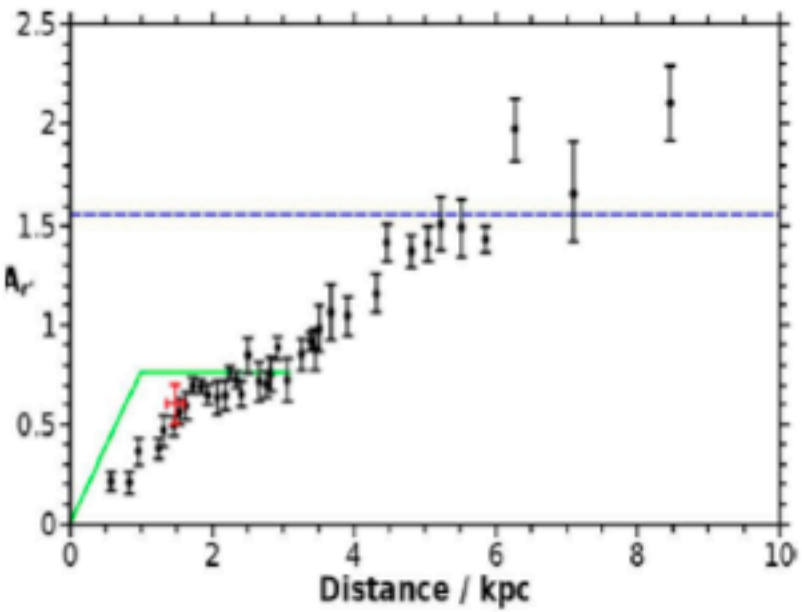
3) Matching to synthetic stellar spectra: IPHAS survey

IPHAS: The INT/WFC Photometric Hα Survey of the Northern Galactic Plane (200 millions objects)

Find distance, extinction to match stellar spectra to synthetic spectra

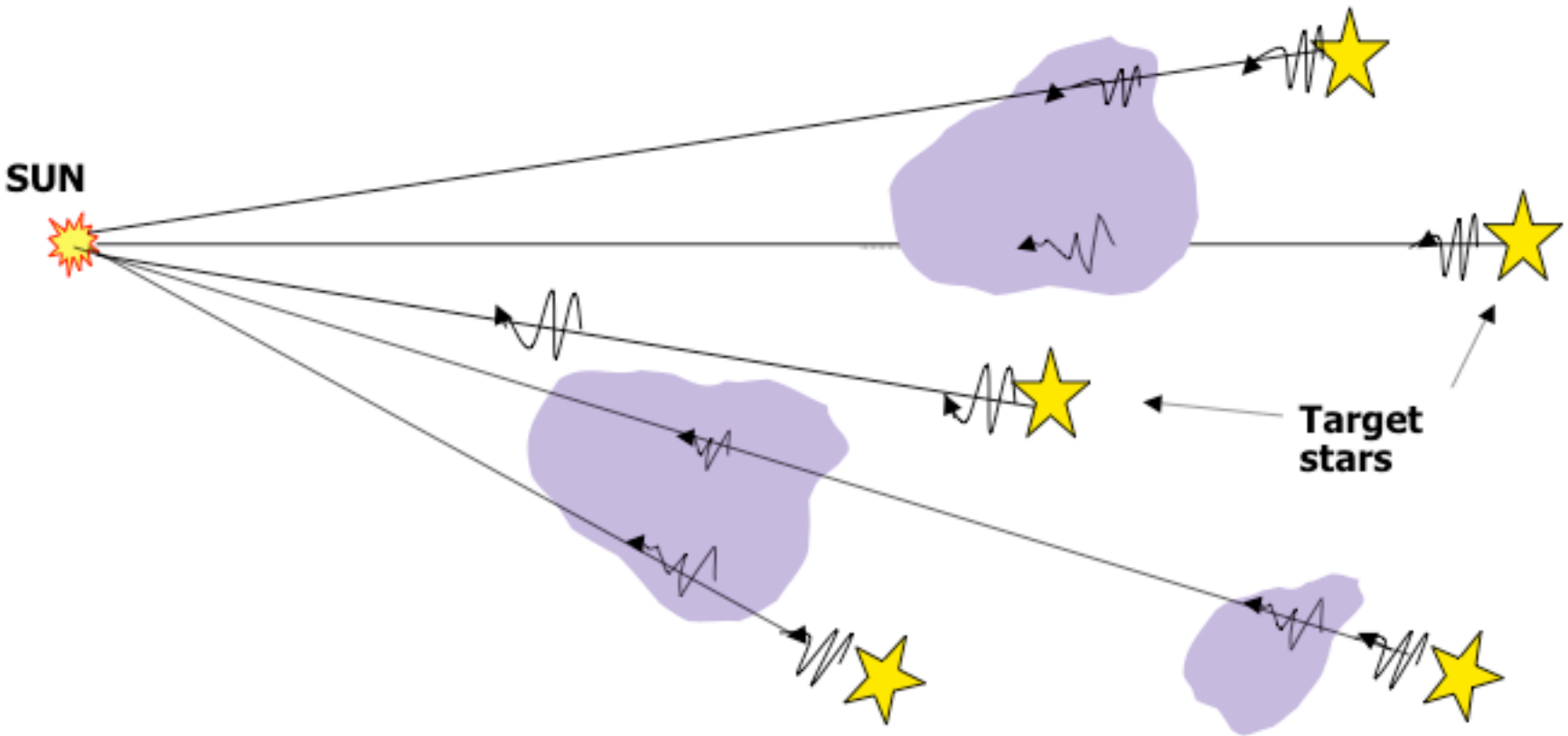


A0V Av=0 red,4 green,8 blue



Sale et al. (2009)

- 4) Parallax distances and inversion of line-of-sight distributed quantities



-Not enough objects to reconstruct extinction vs distance (or gas column)=> needs precision on each individual measurement

-Limited (until Gaia) to short distances <300pc

Inversion method applied to reddening data and interstellar NaI , CaII

Principle: given a series of total absorbing columns, solving for the **nonlinear least squares inverse problem**

(Tarantola & Valette, 1980)

-the volume density (of dust opacity , or of gas) is a continuous function in space

-densities at two neighbouring points are linked by a correlation kernel (otherwise the problem is under-constrained)=> equivalent to smearing IS matter in a volume larger or equal than the chosen correlation length

-the solution is obtained by iteration and expressed as the least squares minimization of departures from a « prior » solution

Inversion of neutral sodium columns

- About 1700 lines-of-sight up to 400 pc
- High resolution spectra: NaI 5893A doublet

Lallement et al, 2003
Welsh et al, 2010

Inversion of interstellar extinctions

-About 6500 lines-of-sight up to 300 pc

-Strömgren photometry

Vergely et al, 2010

HPPARCOS PARALLAXES

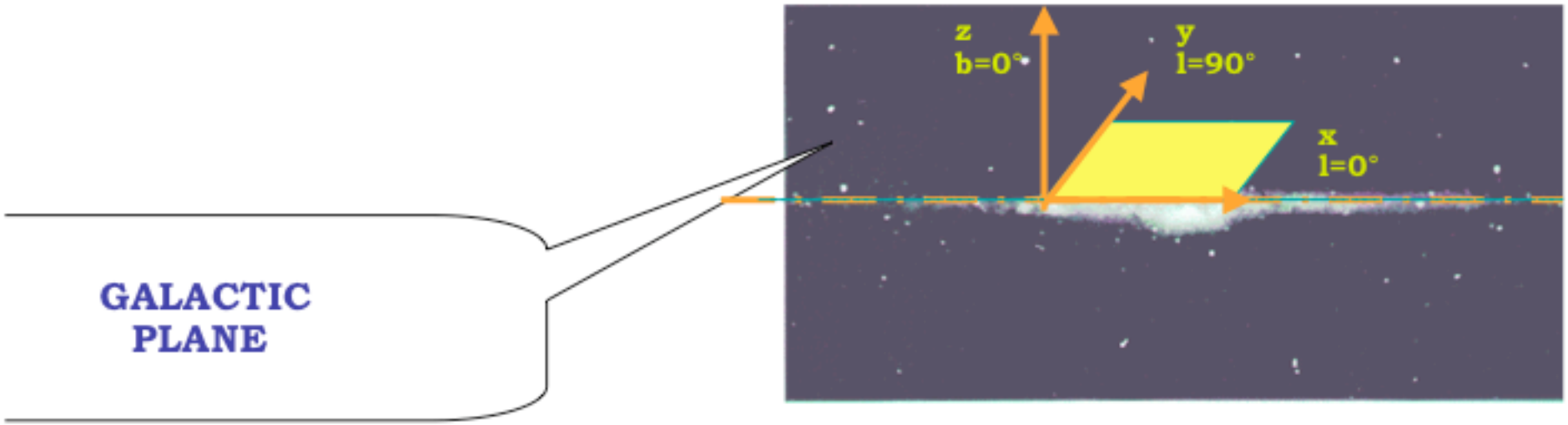
-Double correlation kernel adapted to 15 and 5 pc wide clouds

-Initial distribution depending of the distance to the plane only: exponential decrease with h=200 pc

OUTPUT

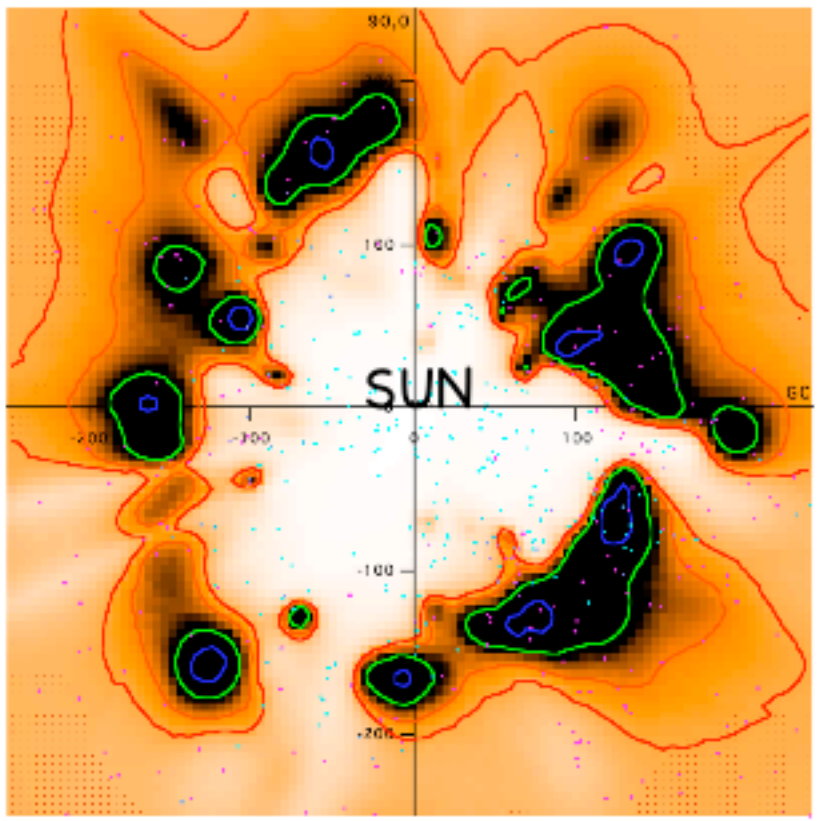
-101x101x101 volume density cubes 250x250x250 pc

-averaging index cube: provides the degree of constraints from the dataset at each location

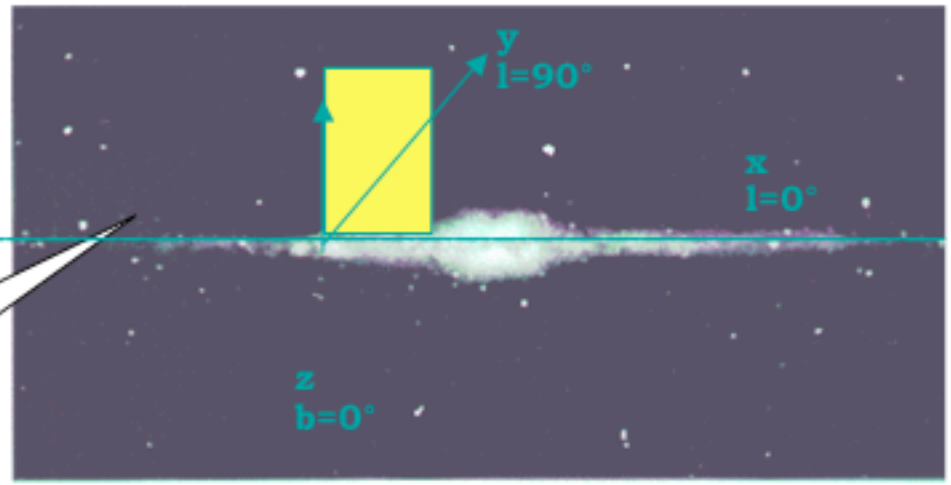


CUT
IN THE 3D
NaI CUBE

250 pc x 250 pc

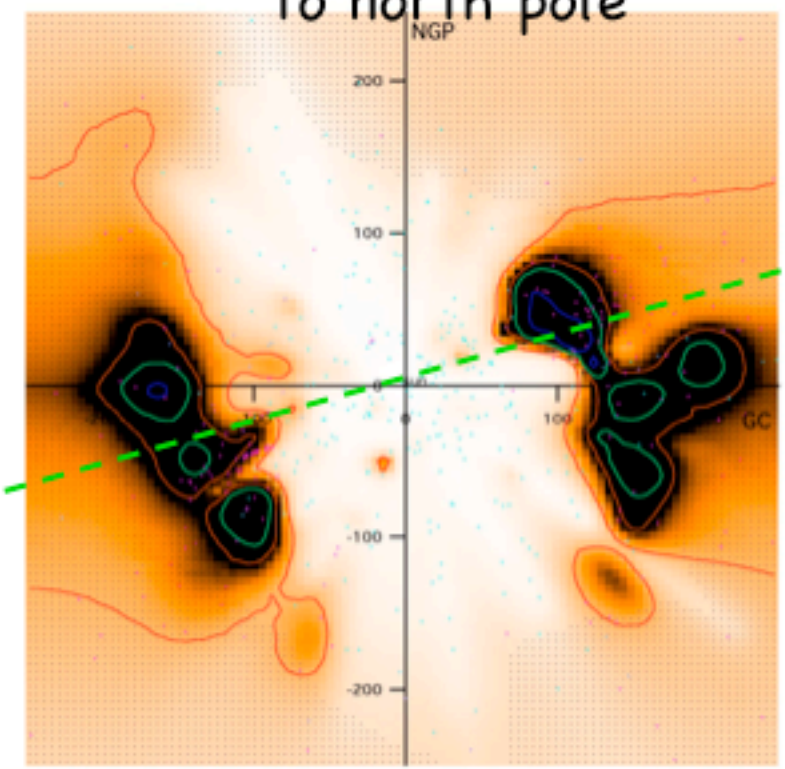


to galactic
center



MERIDIAN PLANE

to north pole

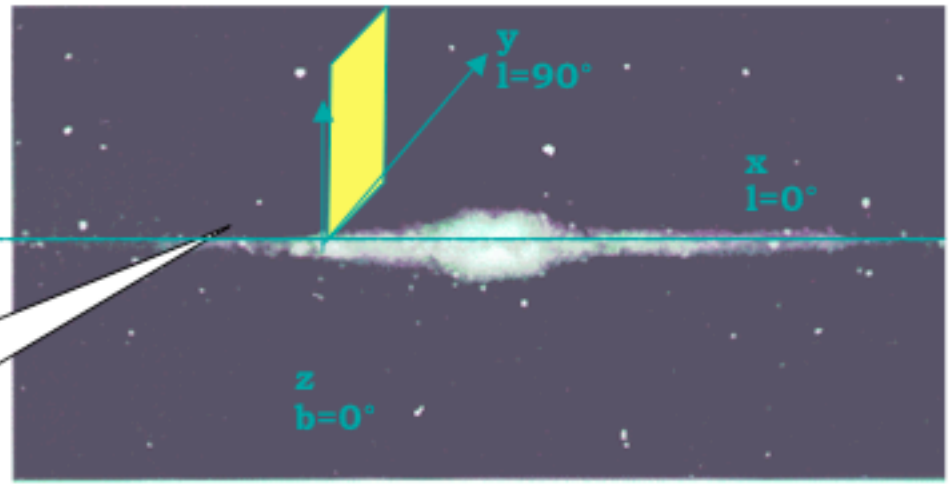


GOULD BELT PLANE

to galactic center

CUT
IN THE 3D
NaI CUBE

250 pc x 250 pc

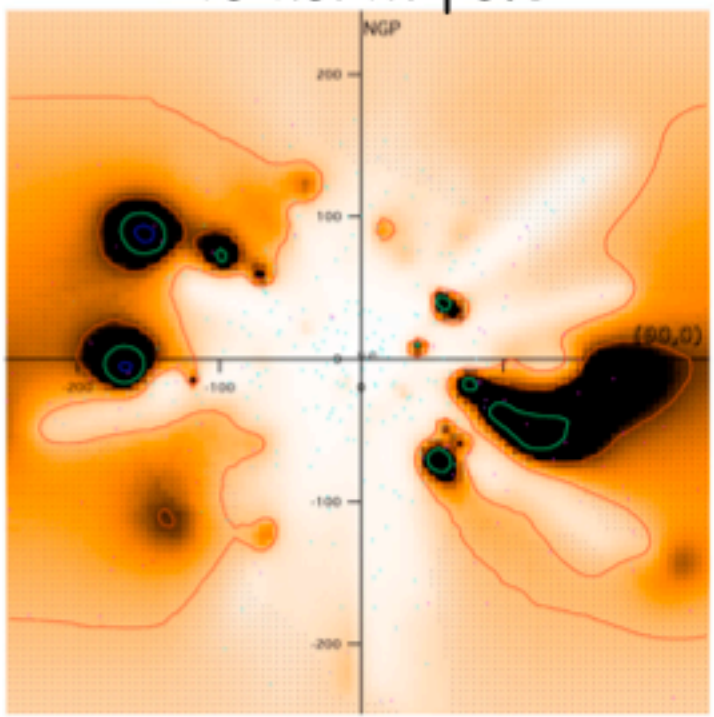


ROTATION PLANE

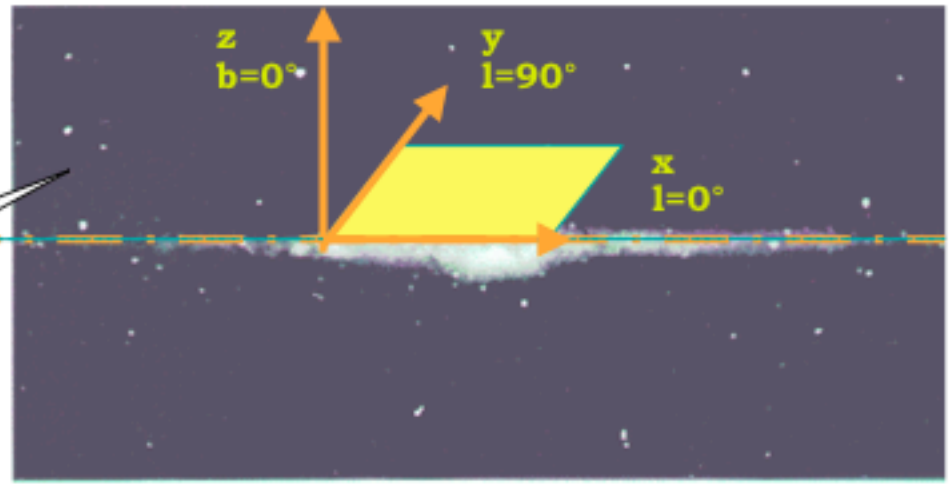
to north pole

CUT
IN THE 3D
NaI CUBE

250 pc x 250 pc



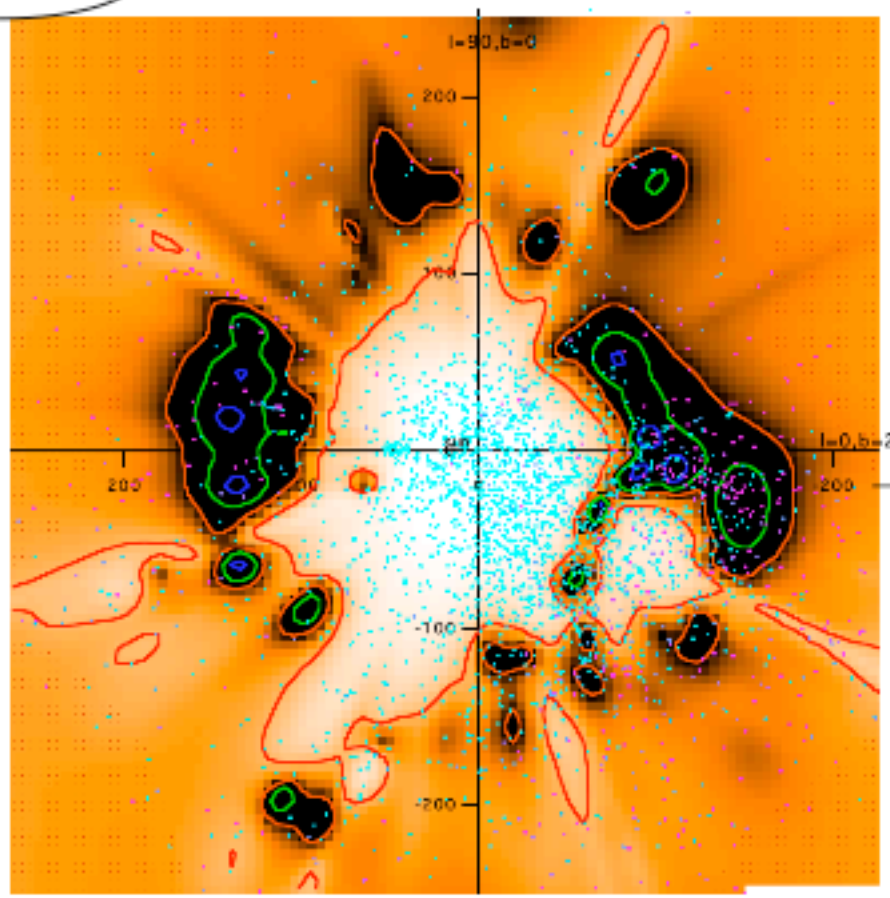
to l=90°



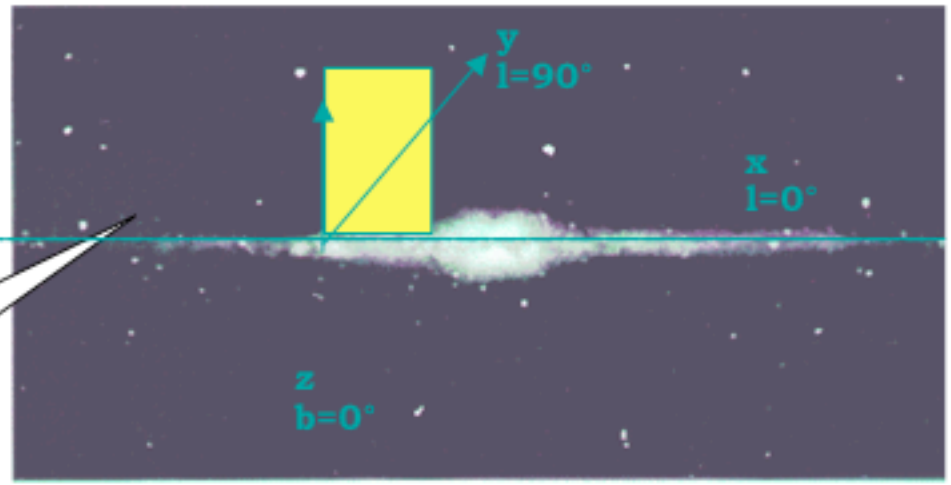
GALACTIC PLANE

CUT
IN THE 3D
NaI CUBE

250 pc x 250 pc



to galactic center

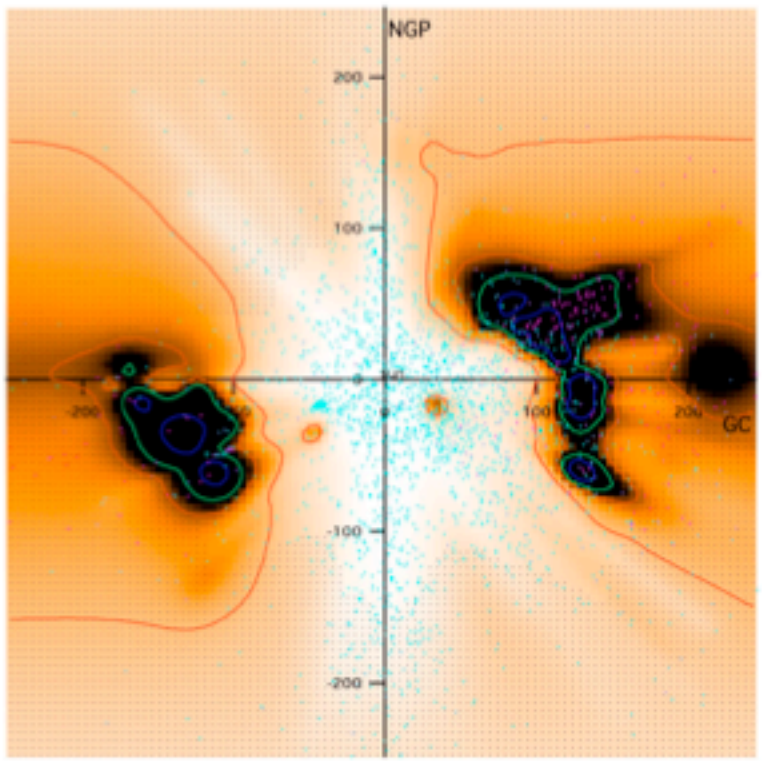


MERIDIAN PLANE

to north pole

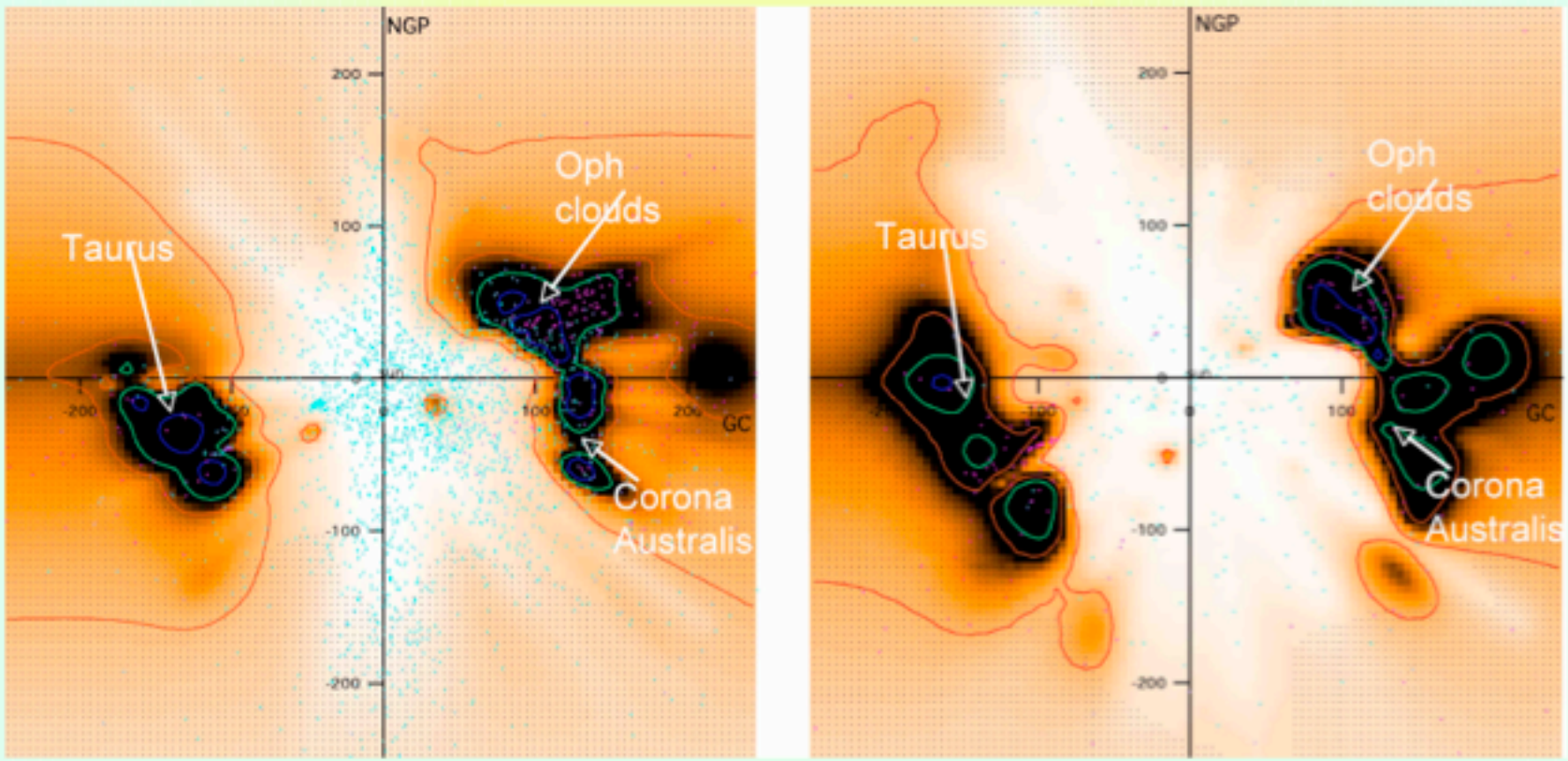
CUT
IN THE 3D
NaI CUBE

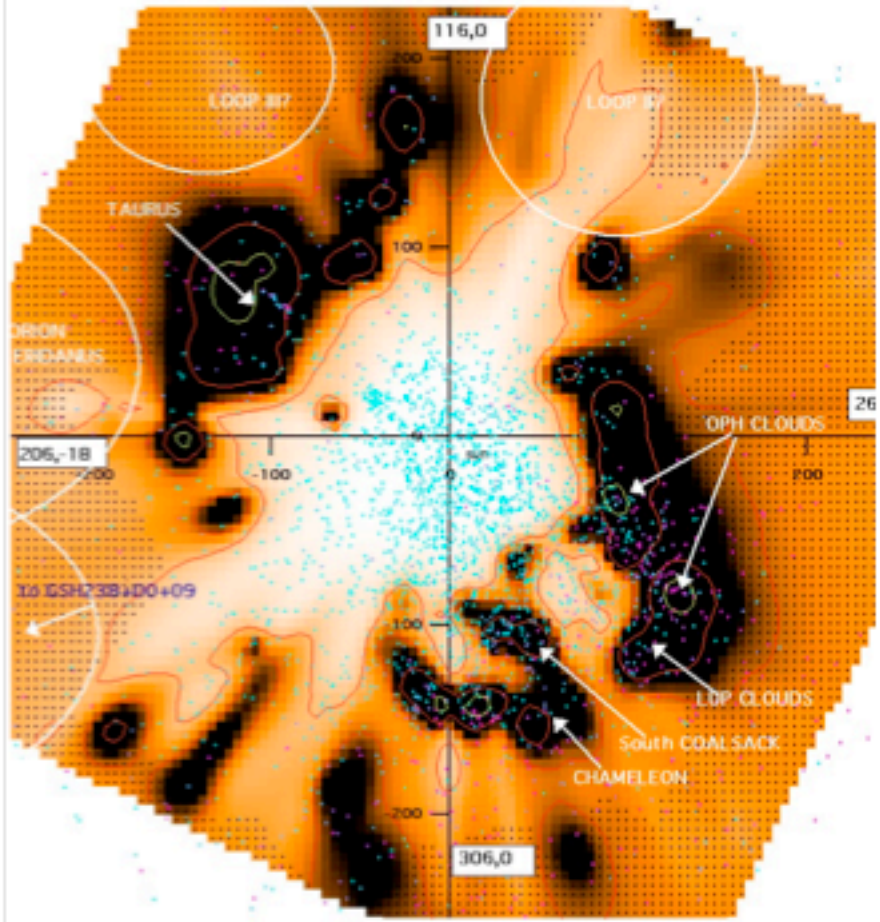
250 pc x 250 pc

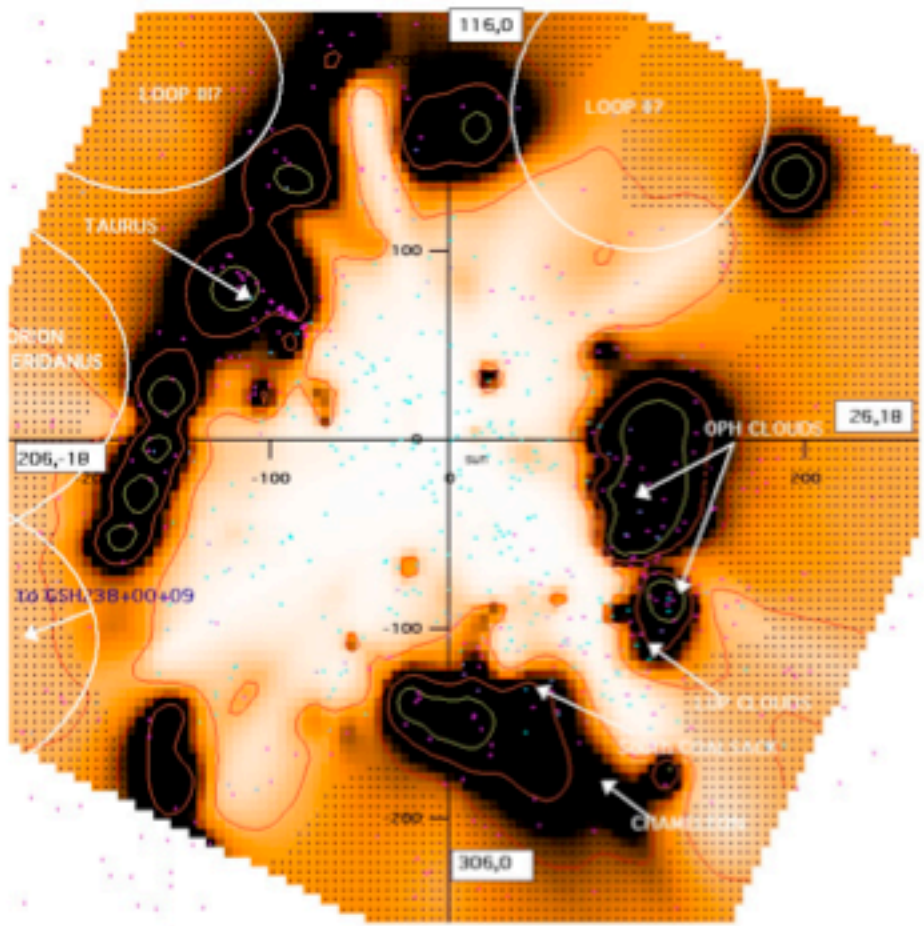


to galactic center

Dust and gas in the meridian plane







GOULD belt PLANE

20° inclination w.r.t. the Plane

max inclination at 26° gal. longitude

Gas - Dust comparisons

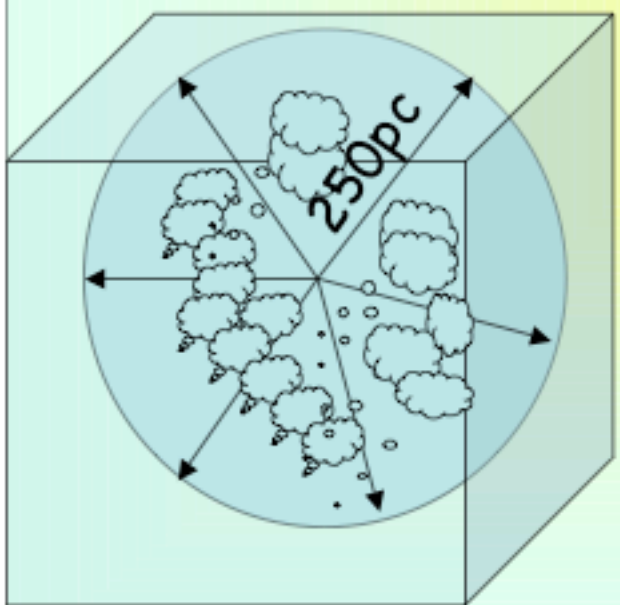
Test on integrated sodium columns and extinctions

Method:

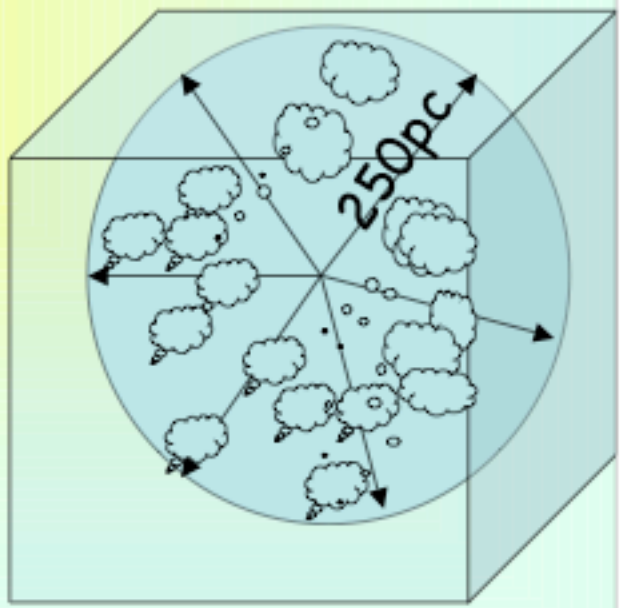
-start with the 3D distributions resulting from the line-of-sight inversion (cubes)

-integration within the cube between the Sun and 250 pc

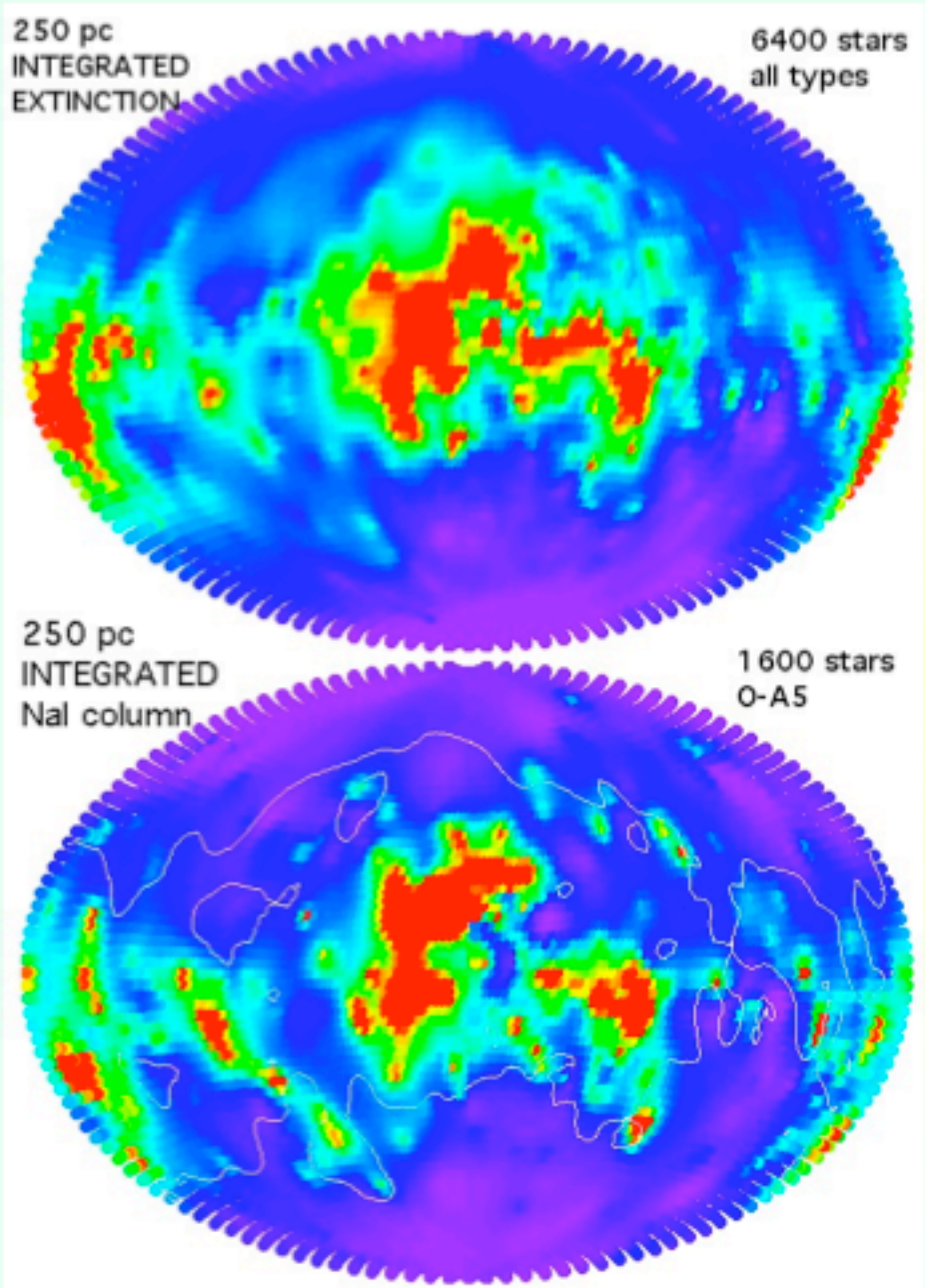
-building of 2D maps of these 0-250pc integrated dust and gas



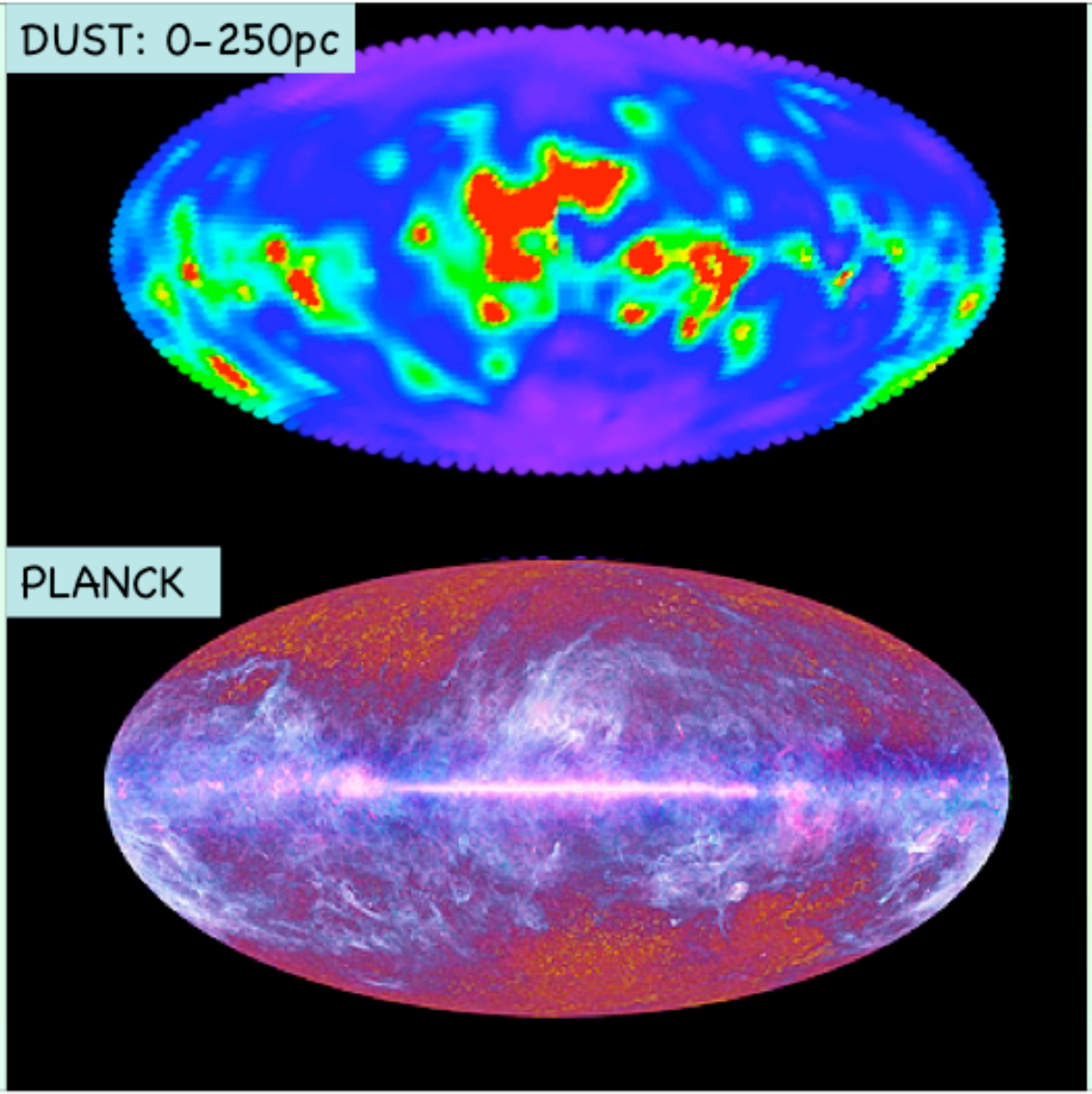
OPACITY CUBE

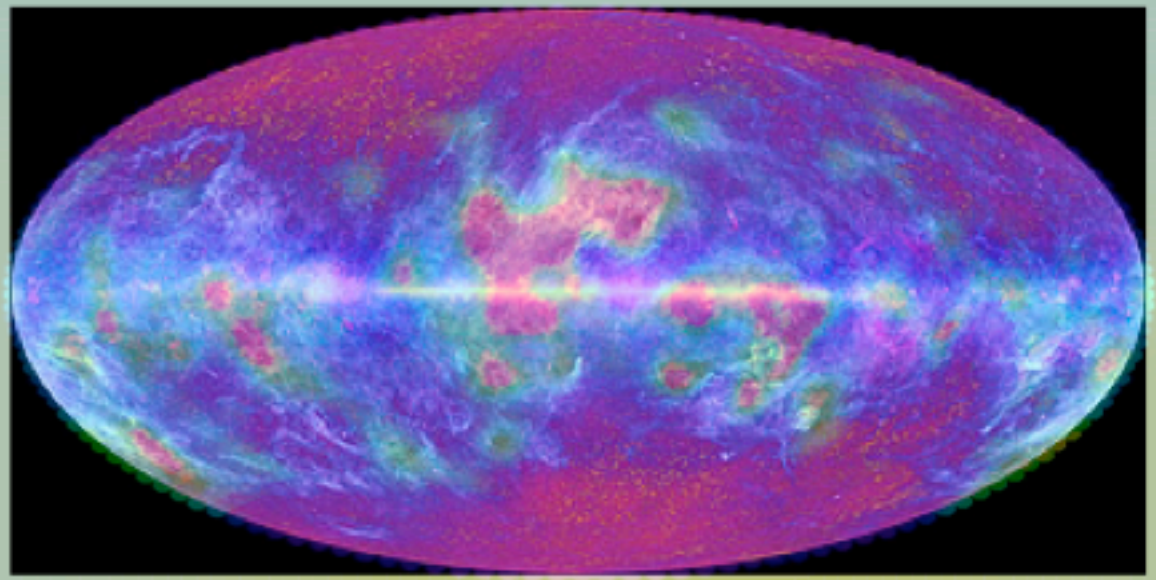


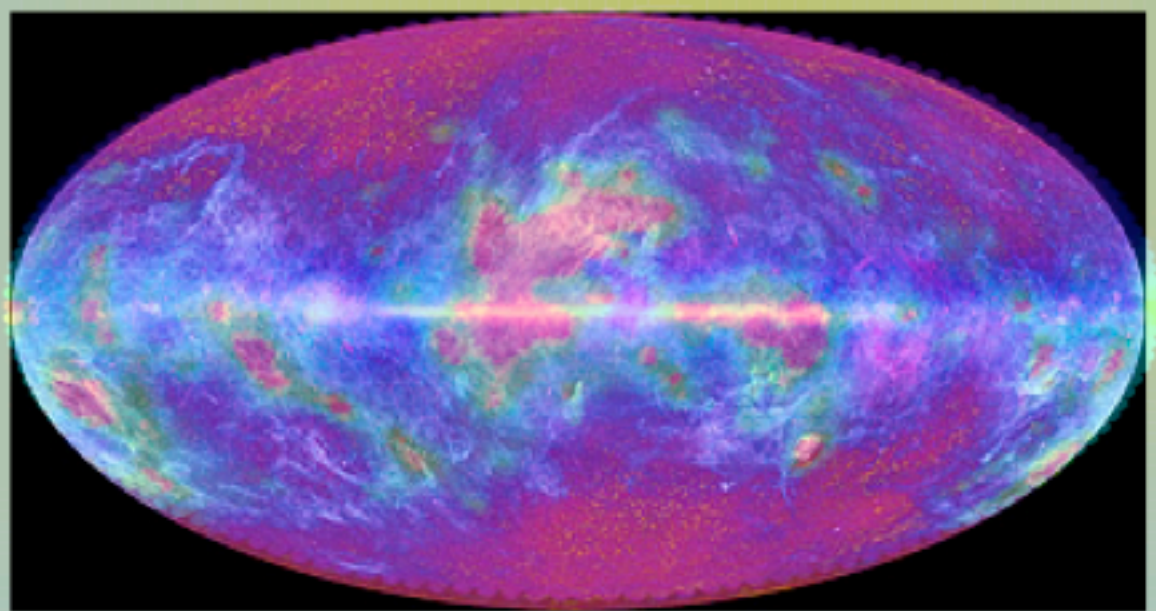
GAS CUBE



Despite the very different datasets, and the limited number of targets, there is a strong similarity between the two maps.
This demonstrates the validity of the inversion method


DUST: 0-250pc
PLANCK





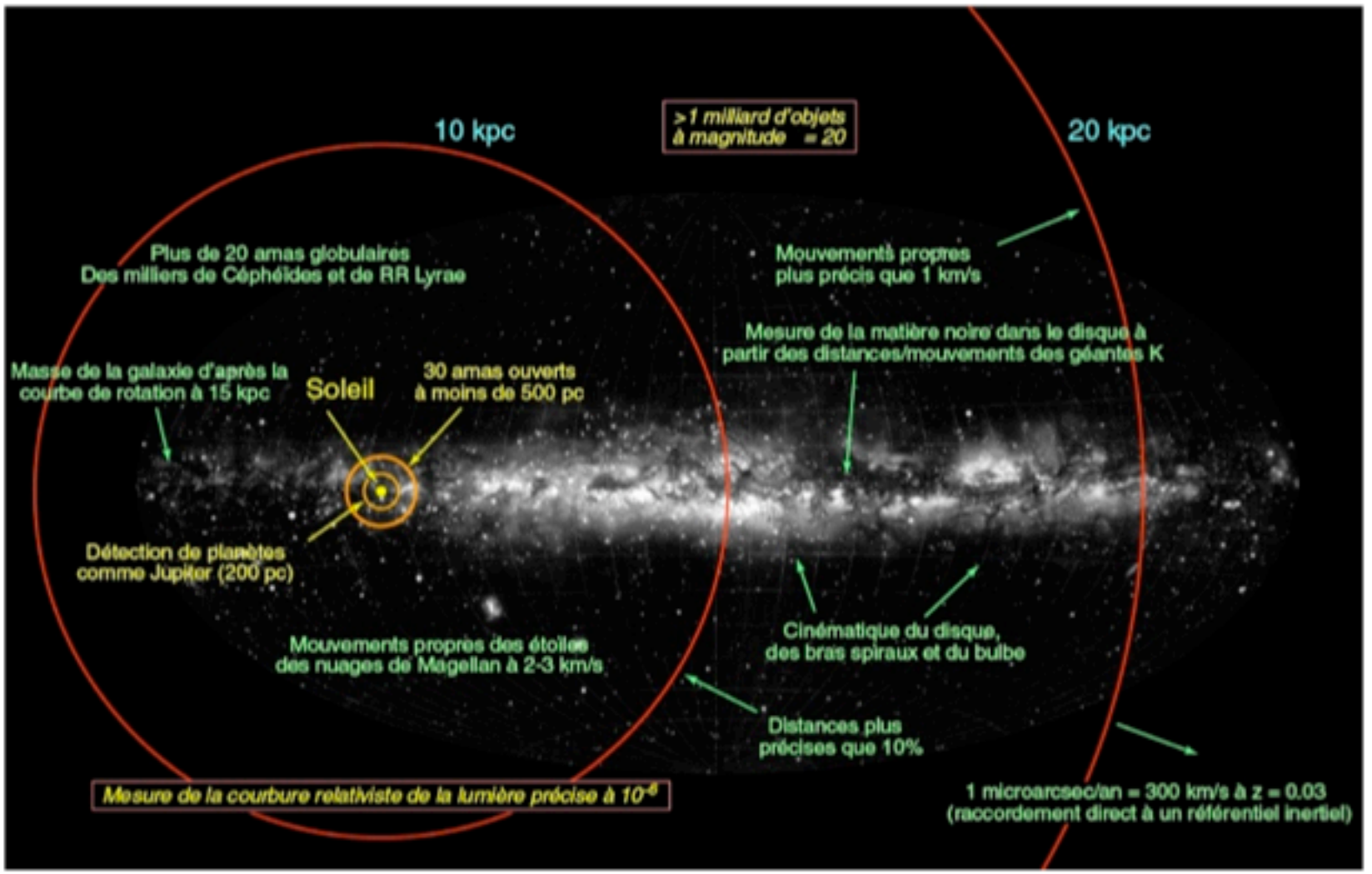
BUT:

CURRENT MAPS HAVE A POOR RESOLUTION

- number of targets too small
- errors on parallaxes too large beyond 300pc
- ACQUIRING LARGE NUMBERS OF HIGH RESOLUTION SPECTRA IS TIME-CONSUMING



III. The promise of Gaia



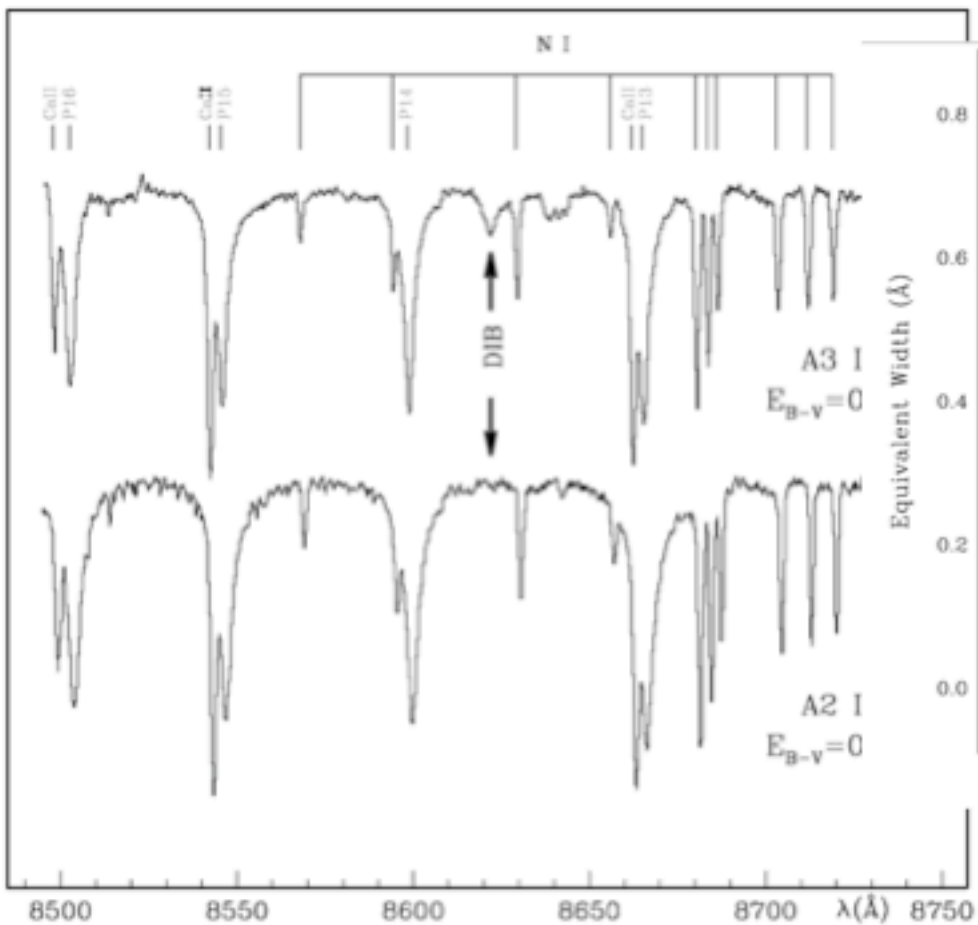
Gaia data and the 3D mapping extension

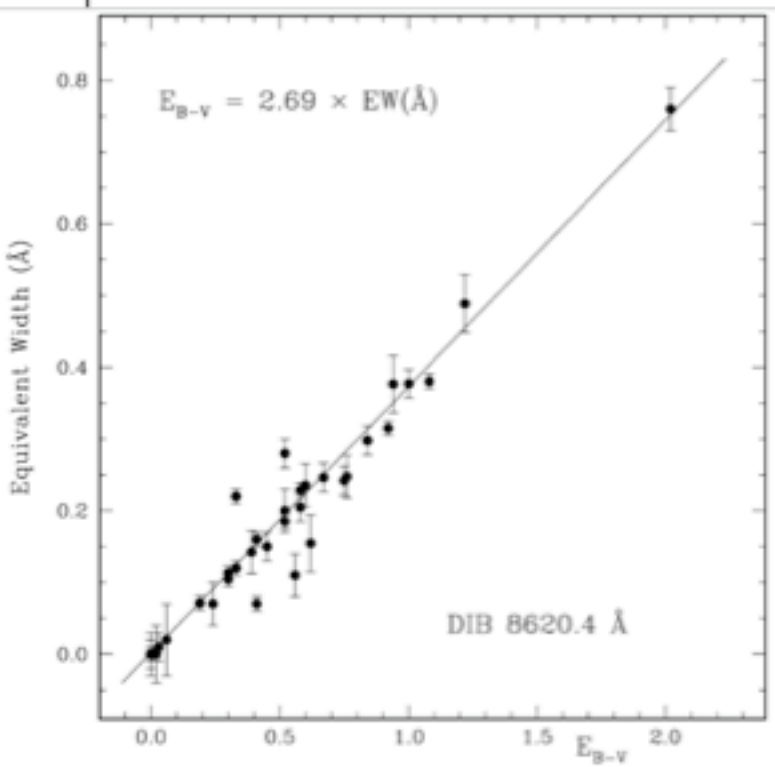
-Direct inversion of all combined measurements of Parallax + Extinction

-Direct inversion of all DIB measurements

Extinction via DIB @ 8620 angstroms

Munari (2000)





Gaia data and the 3D mapping extension

-Direct inversion of all combined measurements of Parallax + Extinction

-Direct inversion of all DIB measurements

-Simultaneous inversion of extinction and DIB equivalent width => derivation of E(B-V)-DIB relationship variability (if any?)

ISM <-> Gaia stellar science

-At large distances of for faint objects degeneracy remains between extinction and absolute luminosity:
Simultaneous self-consistent building of the 3D opacity distribution and determination of stellar parameters!

•Ground-based spectroscopic surveys complementary to **Gaia: gas and kinematics**

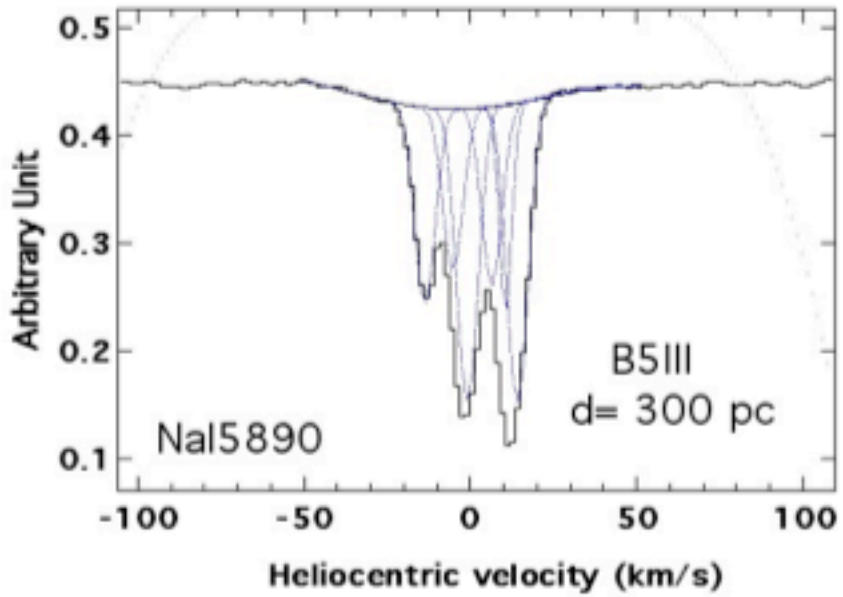
-requirements: at least one interval contains a strong IS absorption line (ideally NaI 5890-6A, CaII 3934A)
(UVES only NaI or NaI +DIB)

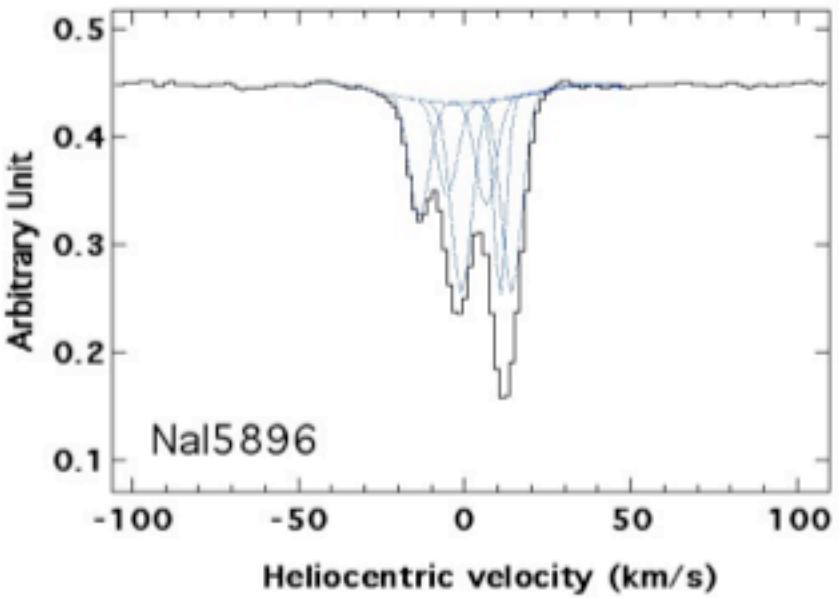
Compared with the existing:

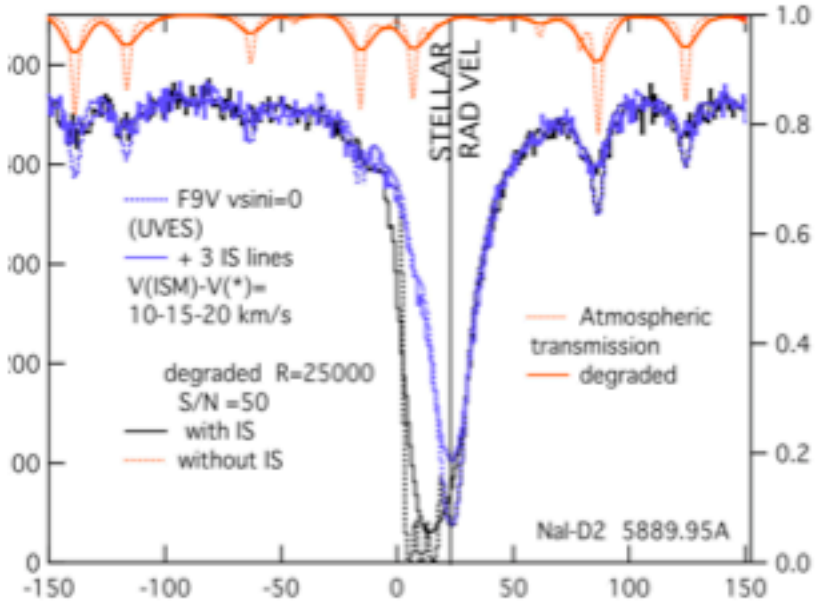
- multi-fibre => massive data sets
- high throughput= > faint and distant objects

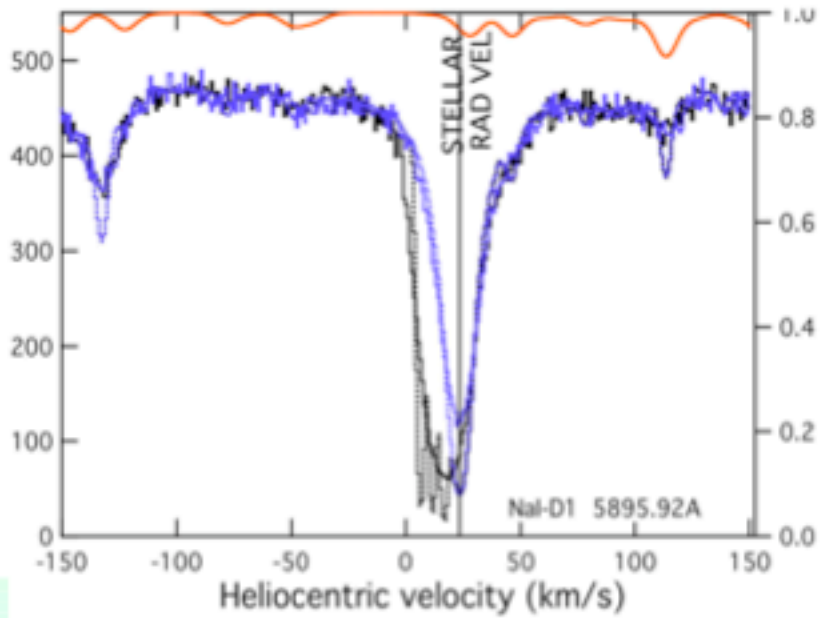
Possibility to get much more detailed gas maps at short distance and to extend the 3D maps to large distance

Simultaneous inversion of gas column-densities, velocities, extinction, DIB EW
Dust, gas, DIB relationships


Arbitrary Unit
0.5
0.4
0.3
0.2
0.1
NaI5890
B5III
d= 300 pc
-100
-50
0
50
100
Heliocentric velocity (km/s)


Arbitrary Unit
0.5
0.4
0.3
0.2
0.1
NaI5896
-100
-50
0
50
100
Heliocentric velocity (km/s)


STELLAR
RAD VEL
F9V vsini=0
(UVES)
+ 3 IS lines
V(ISM)-V(*)=
10-15-20 km/s
degraded R=25000
S/N =50
with IS
without IS
Atmospheric
transmission
degraded
NaI-D2 5889.95A
1.0
0.8
0.6
0.4
0.2
0.0
-150
-100
-50
0
50
100
150


STELLAR
RAD VEL
NaI-D1 5895.92A
500
400
300
200
100
0
0.8
0.6
0.4
0.2
0.0
-150
-100
-50
0
50
100
150
Heliocentric velocity (km/s)

- **The needs** for three-dimensional maps of the galactic ISM

various, very different and more and more numerous!!!!!

At least 3 general classes:

A-structure and evolution of the ISM: links with stars

B-context, foreground, background for specific objects, **optimization** of observations

HST,Spitzer,GALEX, etc
+ high resolux from ground

C-mutual influences of

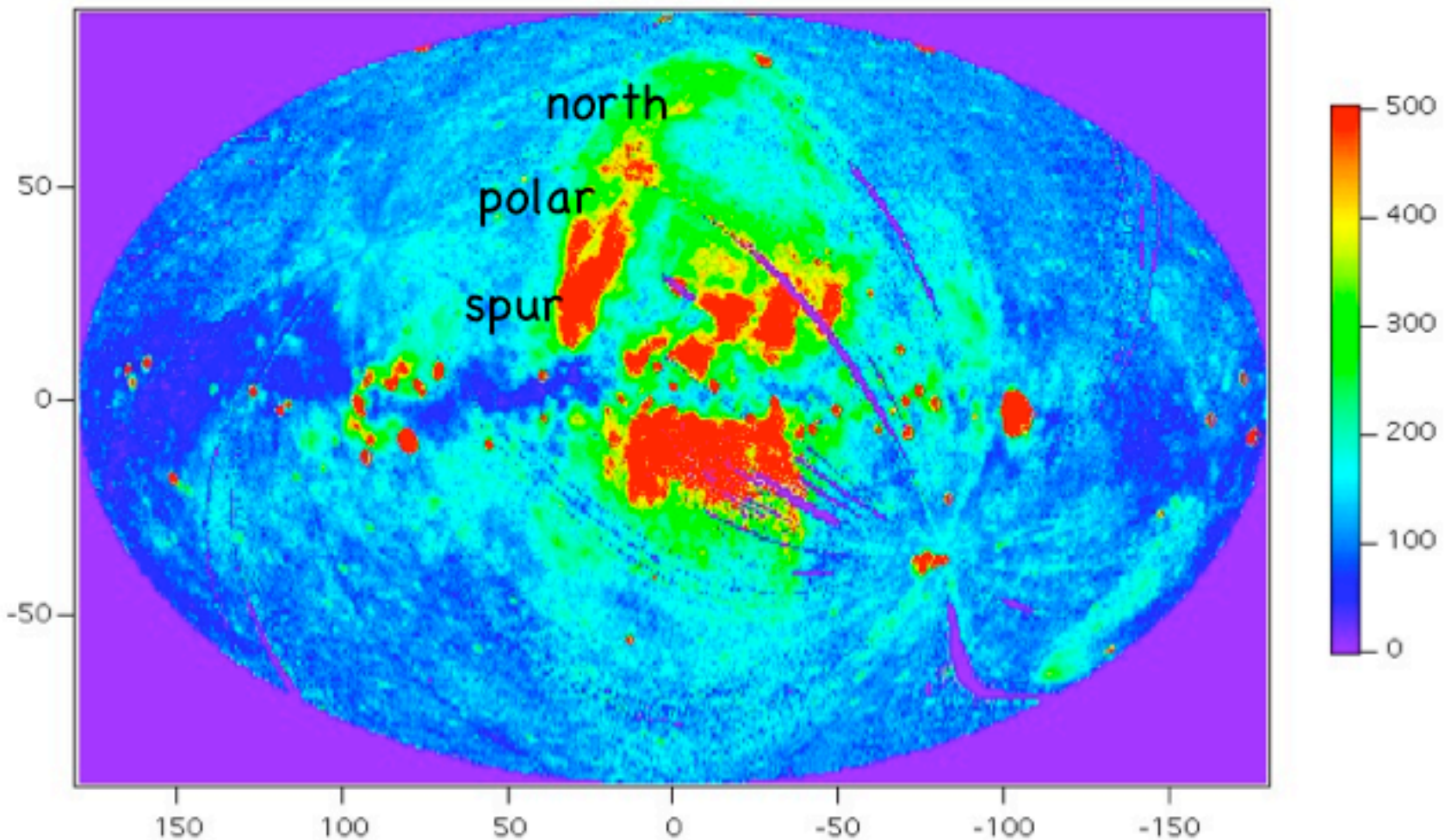
-gas and dust 3D distribution and properties

-radiation field

-cosmic rays

Planck, Herschel, Fermi...

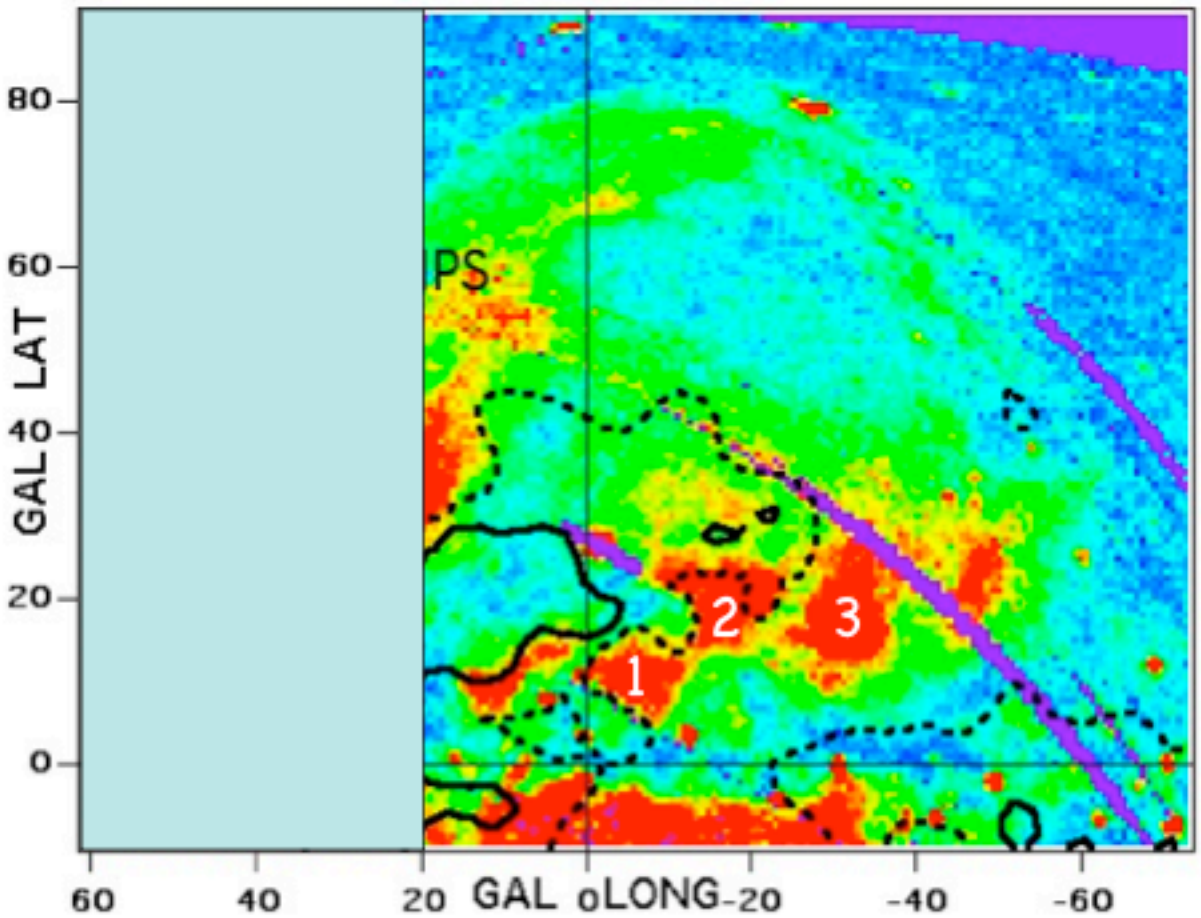
A-structure and evolution of the ISM example: nearby hot (coronal) IS gas



ROSAT SOFT X-RAYS 0.75 keV band

path length $\tau \approx 10^{21}$ cm^{-2}

Snowden et al, 1990

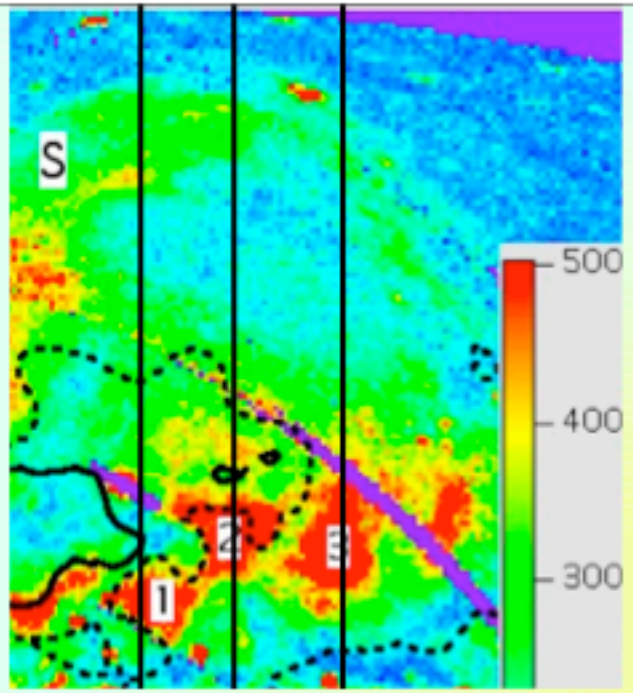


Soft X-rays

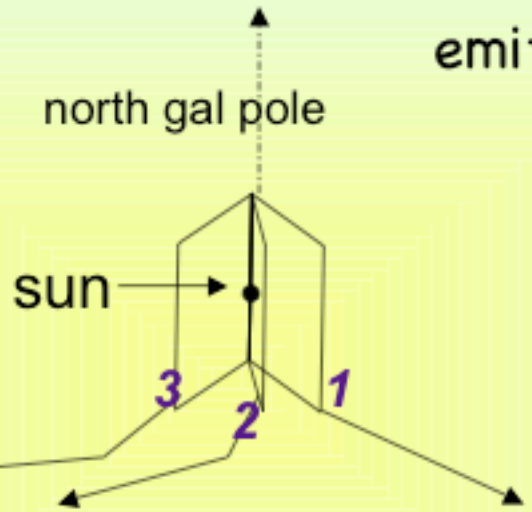
+iso-NaI column densities 0 to 250 pc

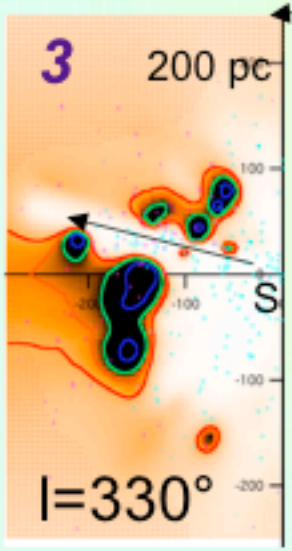
_ 70% absorption --- 30% absorption

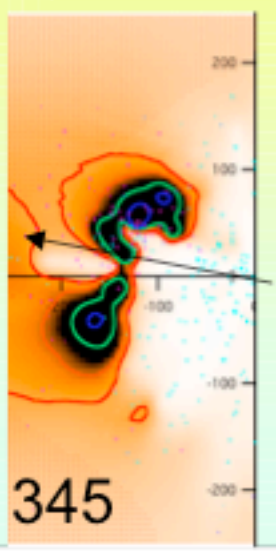
Columns computed from 3D maps

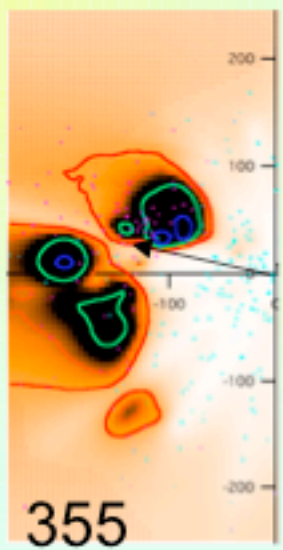


The 3-D structure sheds light (and reveals anomalies) on the X-ray emitting gas



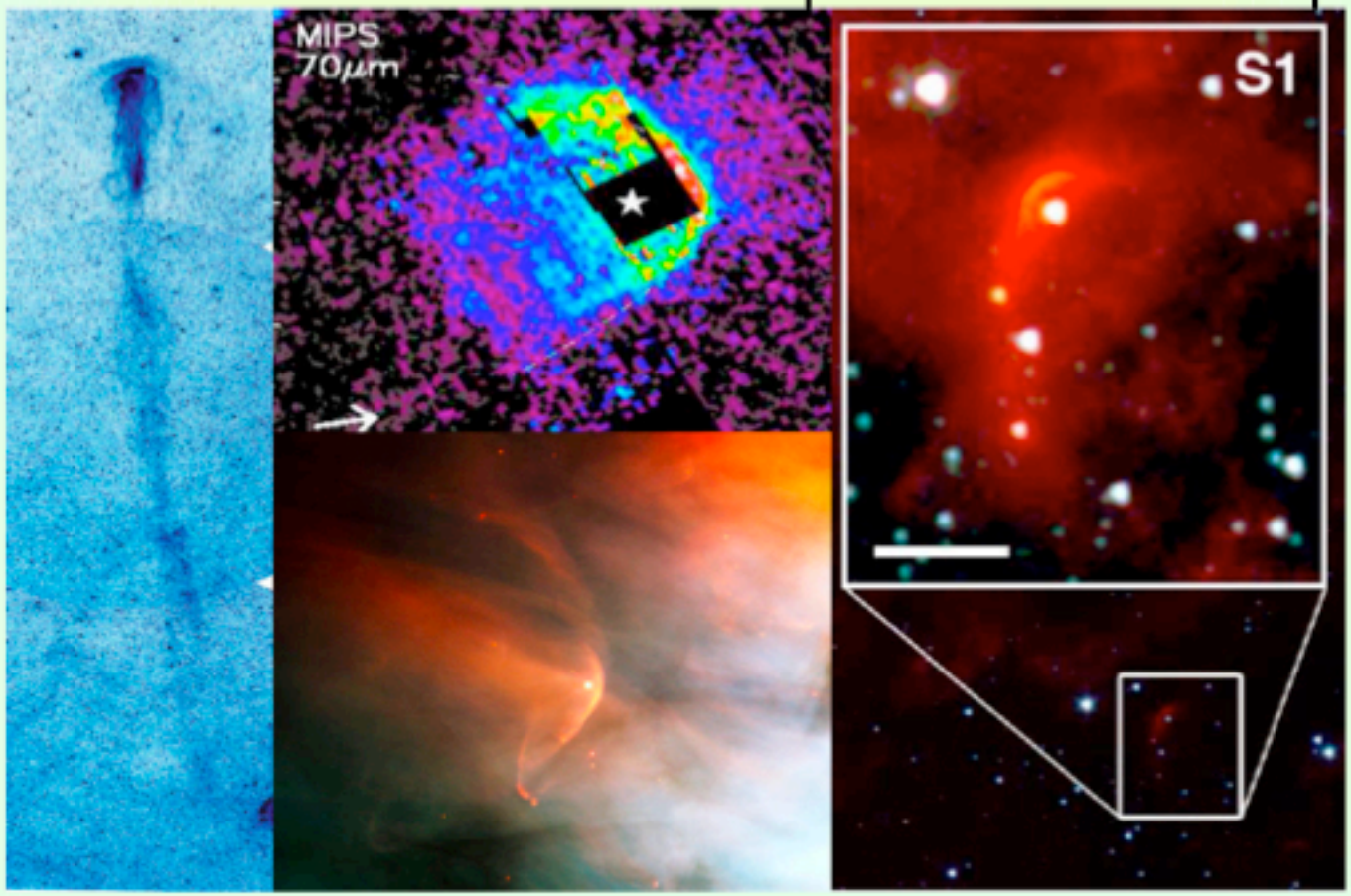




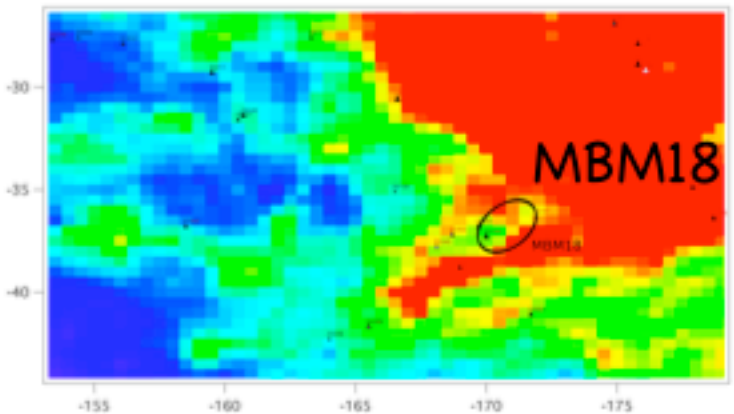


B-context, foreground, background for specific objects, optimization of observations

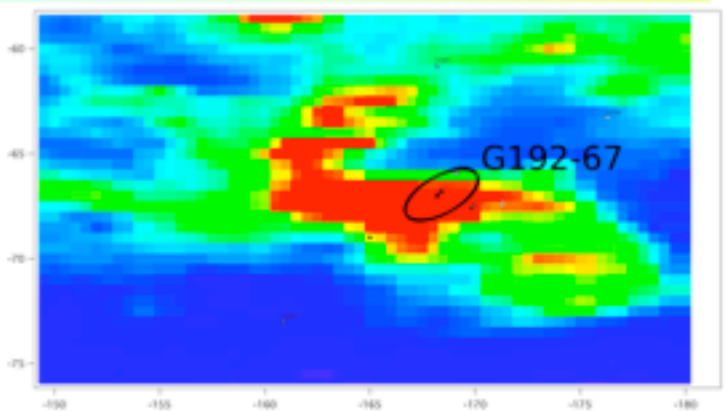
-models of star-ISM interfaces require ambient ISM properties

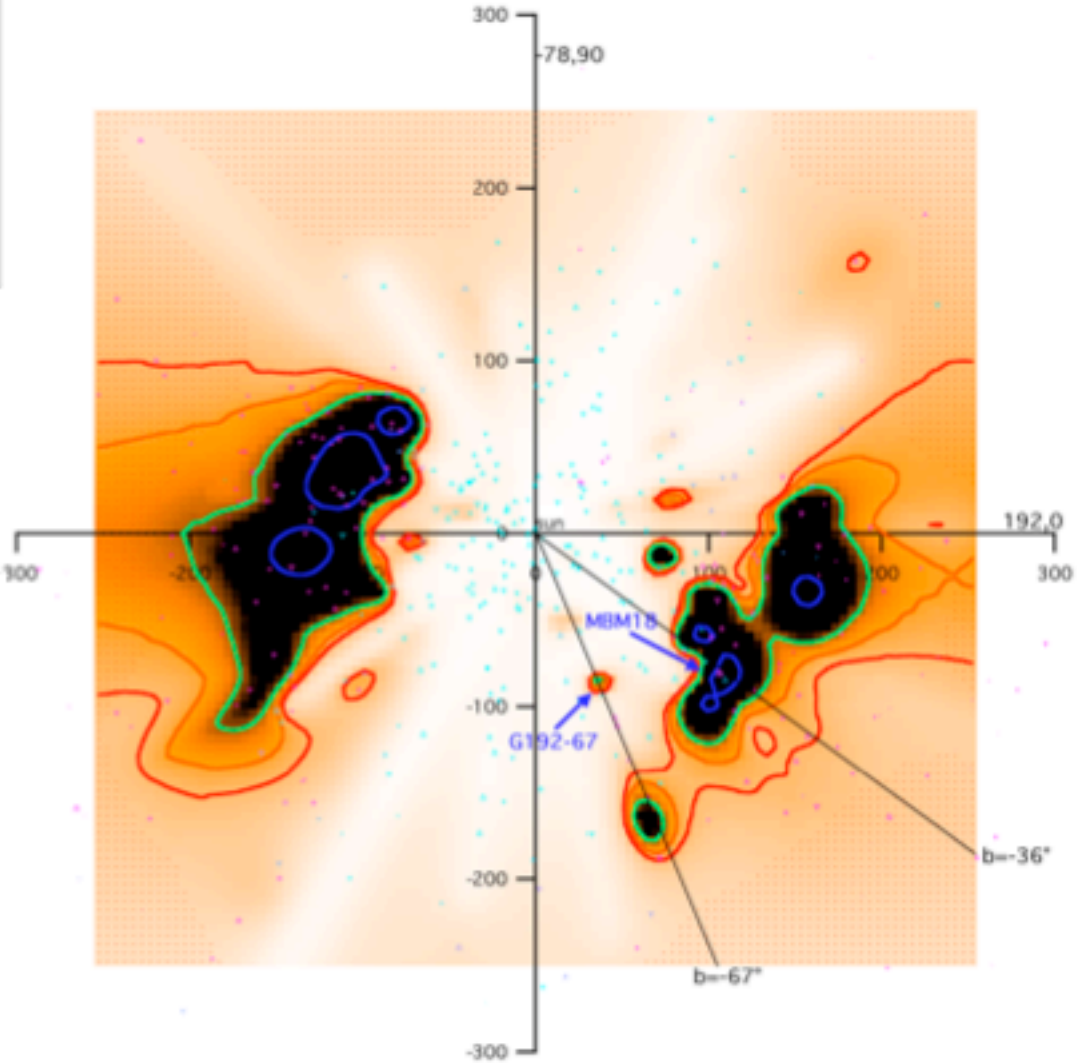


HST,Spitzer,GALEX, etc
+ high resolux from ground



HI 21 cm





Environment of nearby molecular clouds

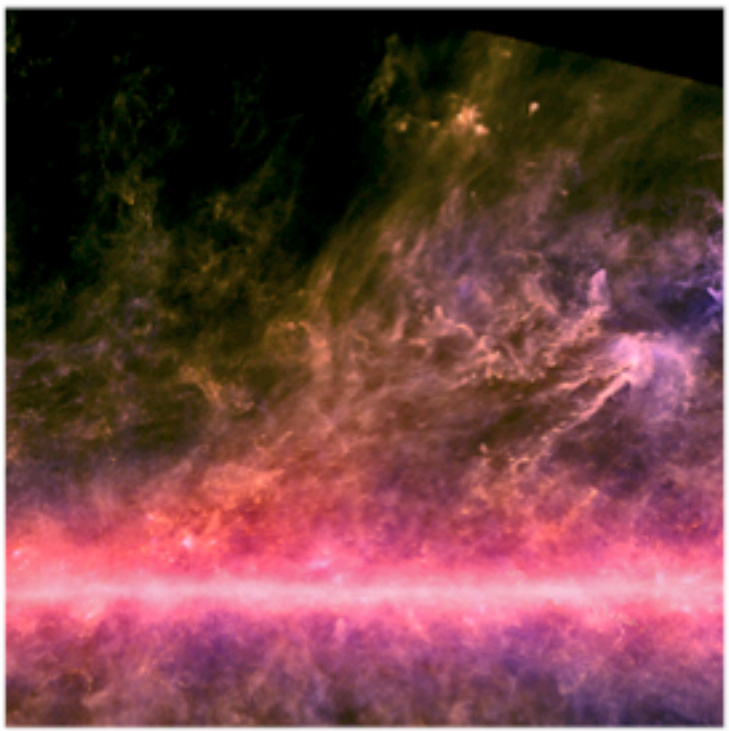
C-mutual influences of

-gas and dust 3D distribution and properties

-radiation field

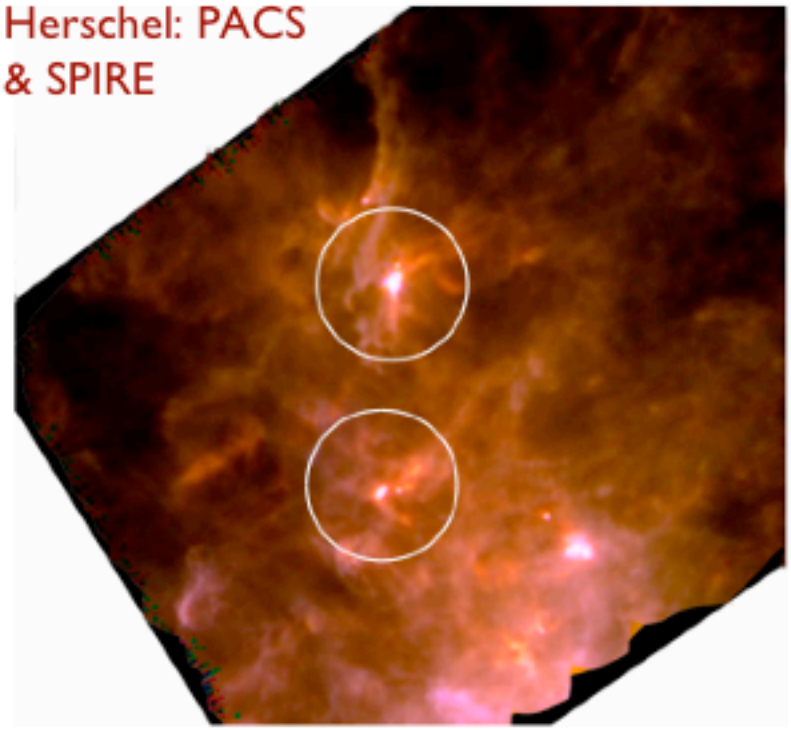
-cosmic rays

Planck & IRIS



50 degrees (but full sky)

Herschel: PACS & SPIRE



20 arc mintues

Ex: Cold Core Project

Thank you