Towards a 3D view of the Galactic interstellar medium with Planck, Herschel and Gaia

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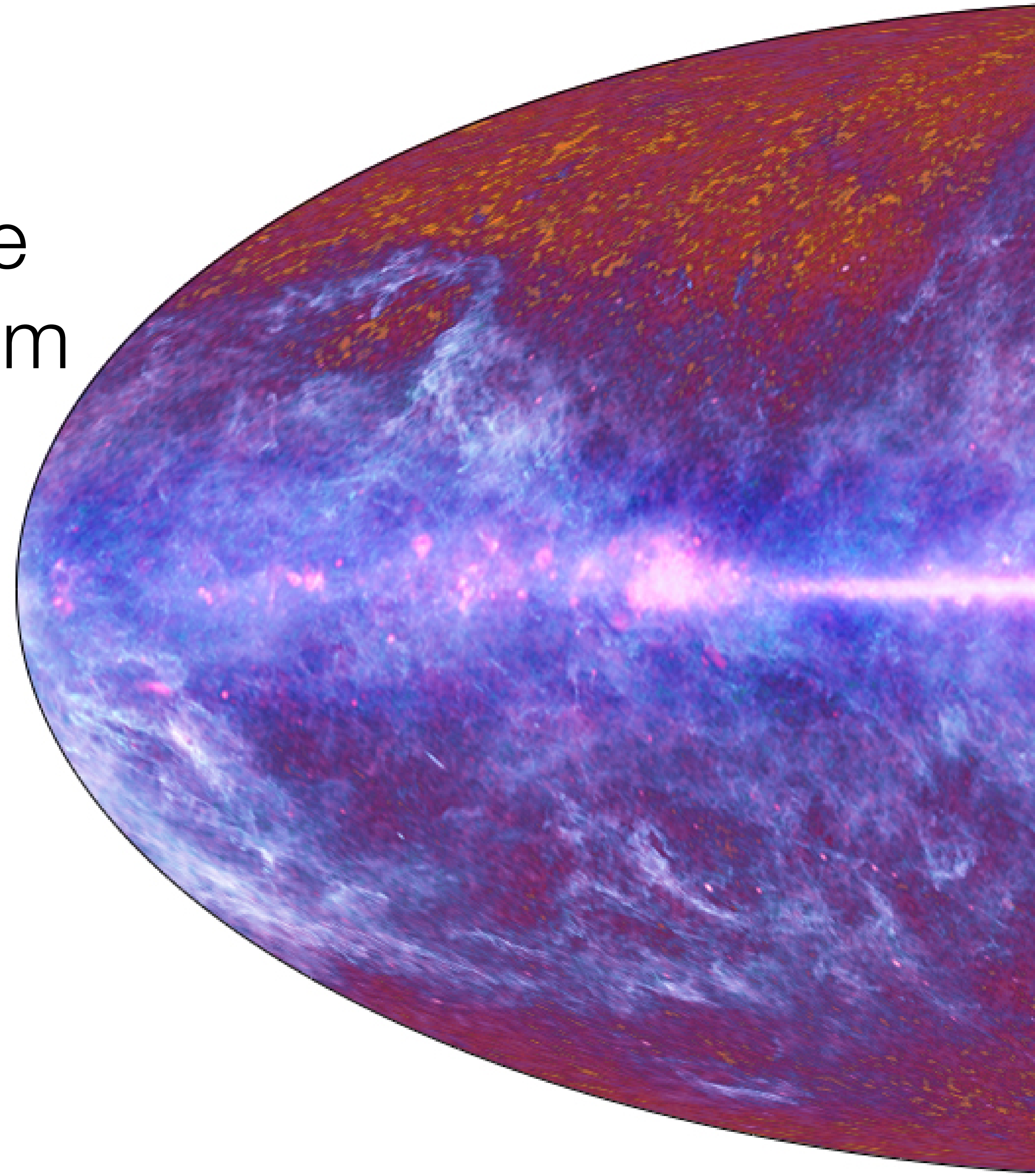
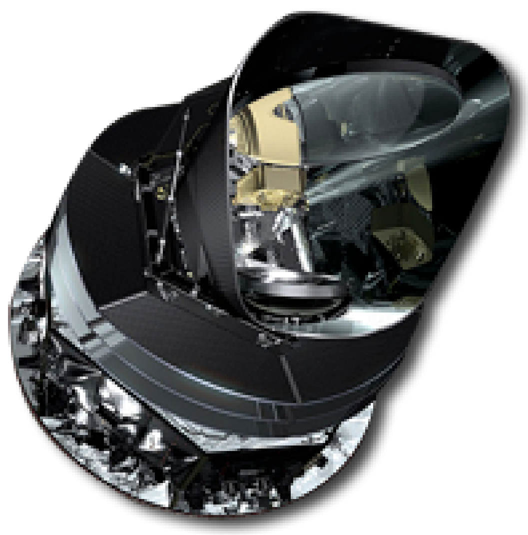


1. Planck and Herschel

Planck & Herschel

Launched together

- Over 2 yrs ago
- Point L2



Planck

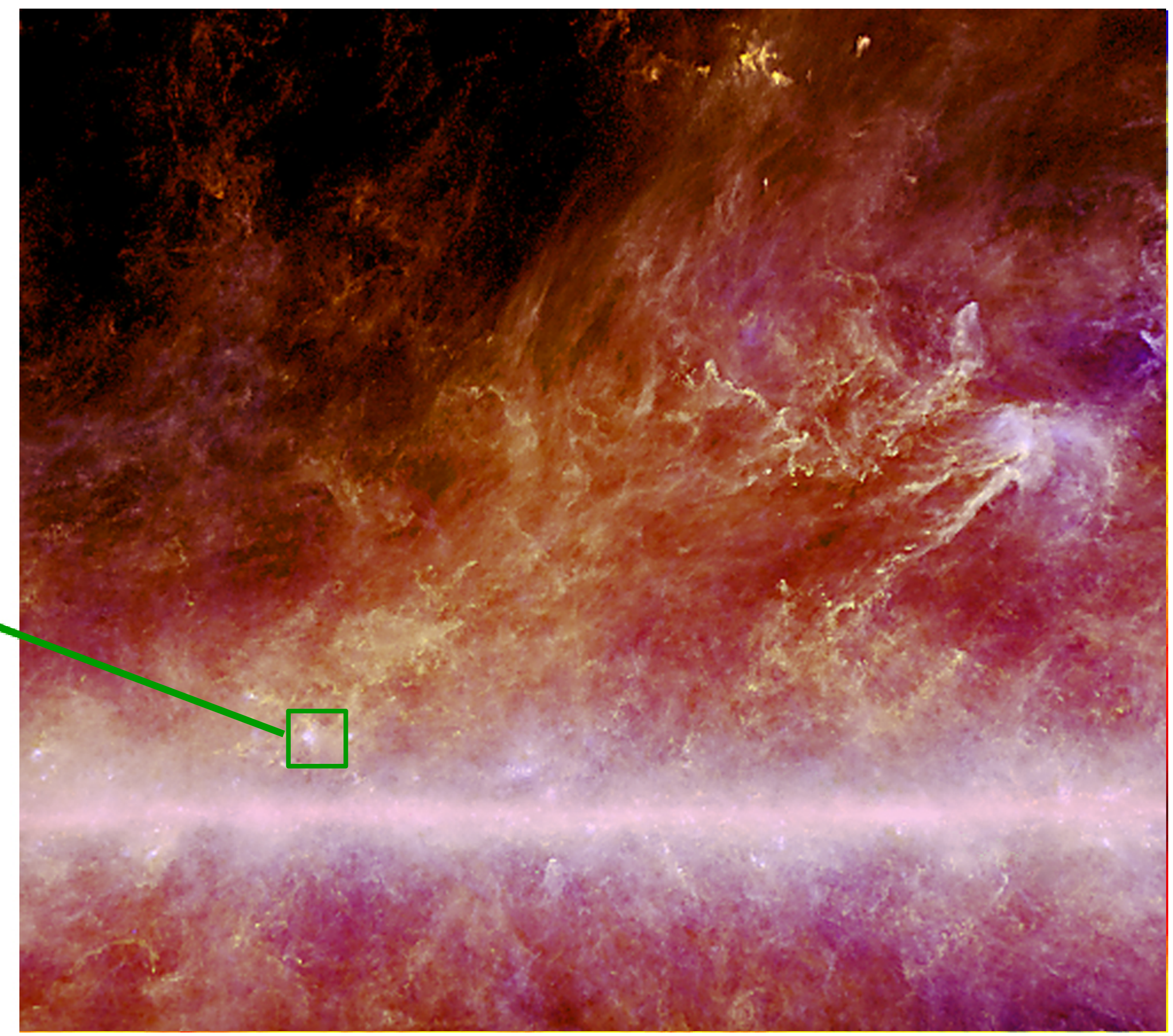
- Surveyor
- Photometry
  - HFI, LFI
- Photometry from 30 GHz (1cm) to 857 GHz (350 µm
- Angular resolution : 4’ to 30’

Herschel

- Observatory
- Photometry & Spectroscopy
  - PACS, SPIRE, HIFI
- Photometry from 70 to 500 µm
- Angular resolution : 6” to 36”
- Largest mirror (3.5m) ever sent into space !

Planck & Herschel

ESA, PACS & SPIRE Collaborations



ESA, Planck Collaboration

Planck & Herschel

ESA, PACS & SPIRE Collaborations

ESA, PACS & SPIRE Collaborations

ESA, Planck Collaboration

Dust emission

Big dust grains

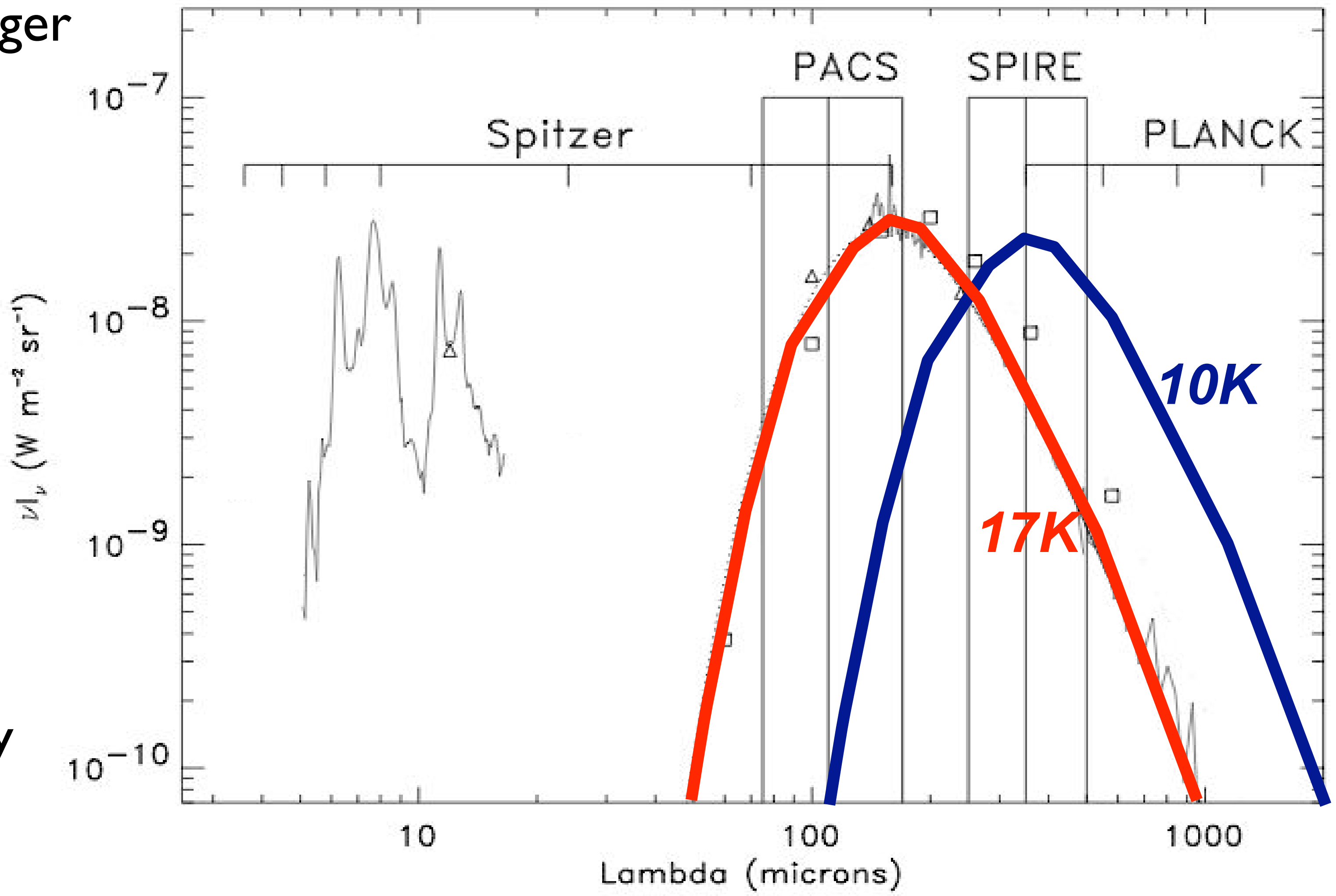
- •In thermal equilibrium with the ISRF
- •Colder dust has peak emission at longer wavelength

Advantage of Planck

- •Observations in the sub-millitmetre probe very cold ISM
- •Full sky!

Advantage of Herschel

- •High spatial resolution (3.5m primary mirror - largest ever sent into orbit)
- •Peak of dust SED emission



Dust extinction

Big dust grains

- Responsible for extinction in visible / near-infrared
- Energy absorbed re-emitted in far-infrared / sub-mm

Dust extinction

Big dust grains

- Responsible for extinction in visible / near-infrared
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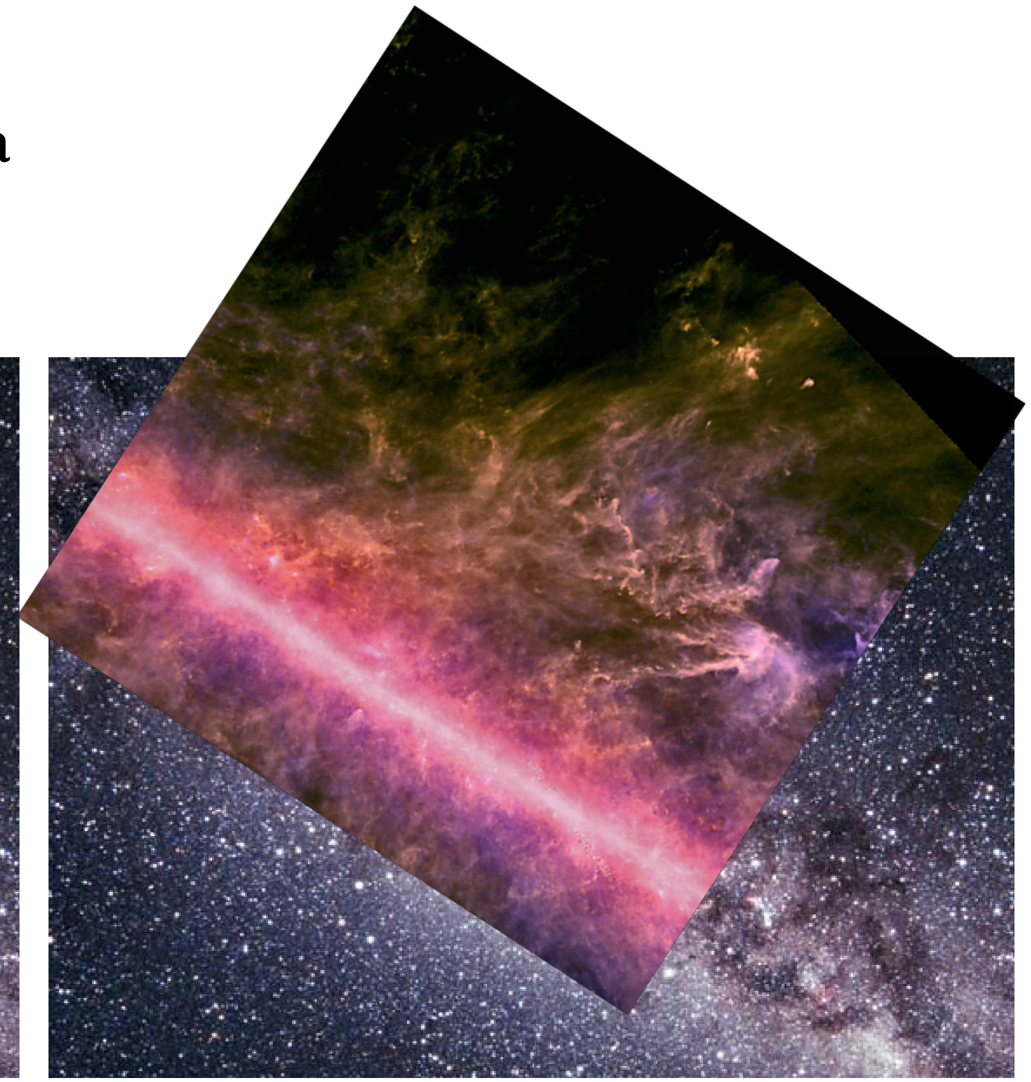
Same grains!!!

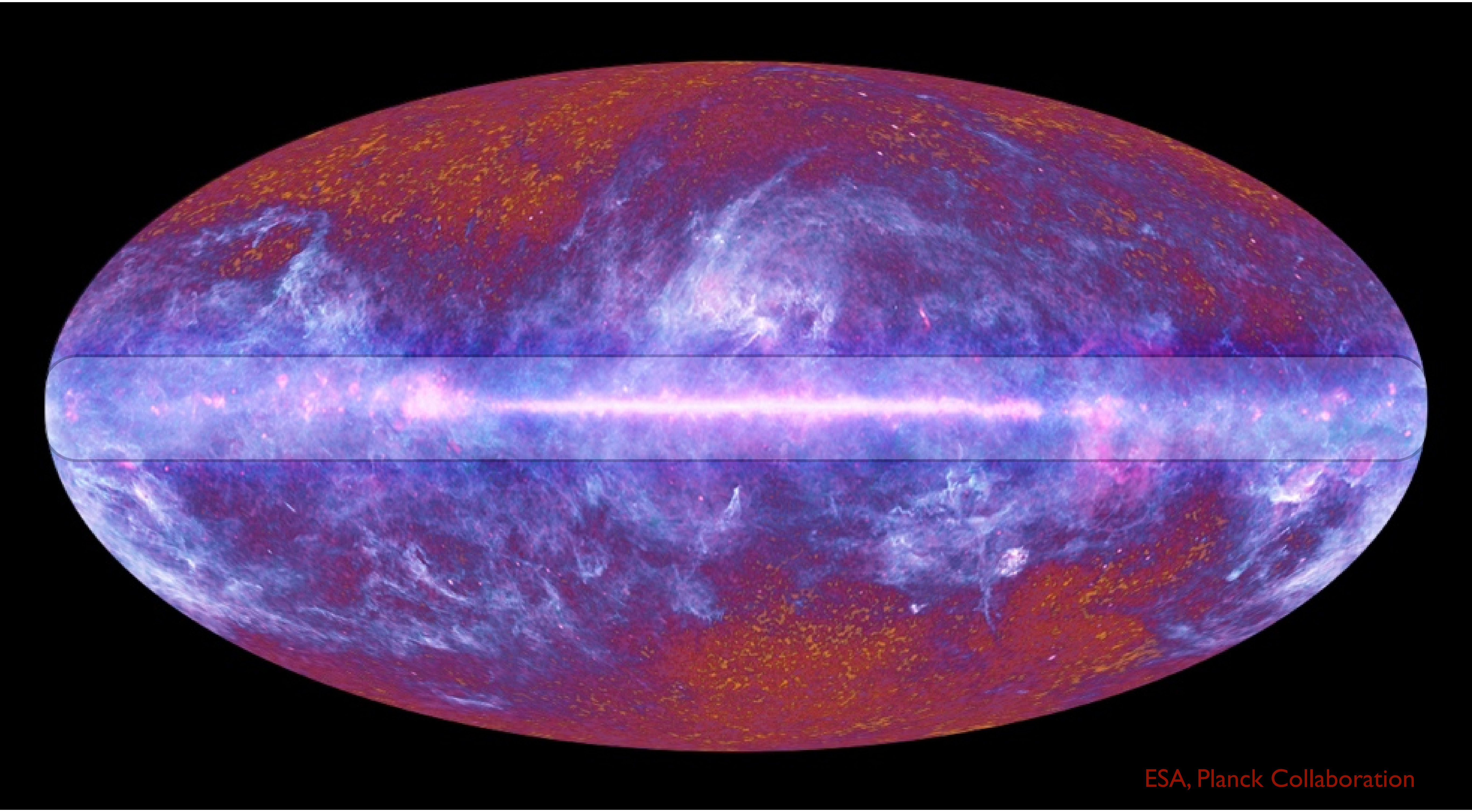
- Link between Planck / Herschel and Gaia
- Parallax + extinction measurement

  => new possibilities for ISM



- Distances crucial for proper interpretation
  - In the mean time ... gas kinematics, 3D Galactic models ....

2. Galactic Plane ISM



ESA, Planck Collaboration

Galactic plane decomposition

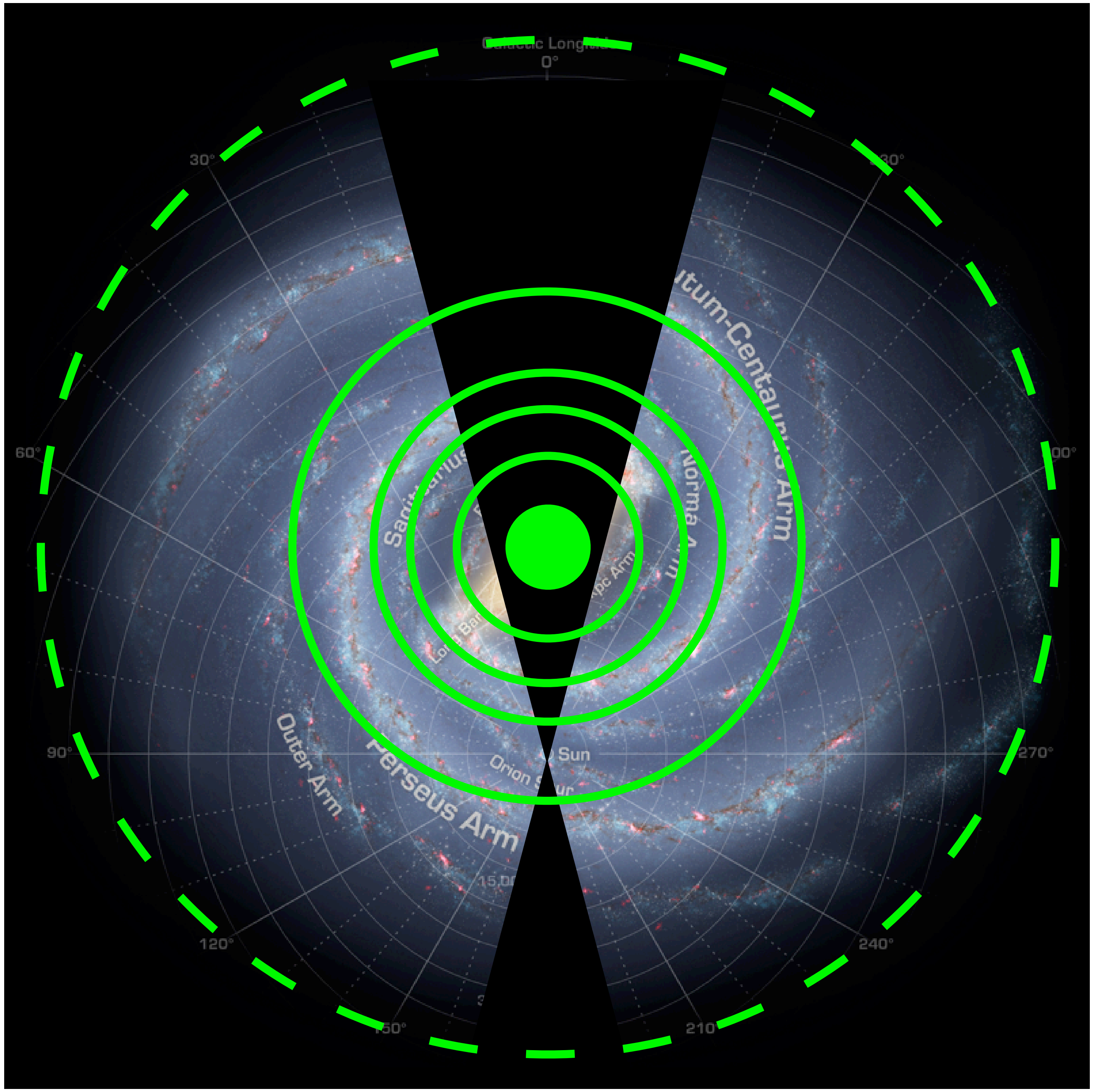
To study our home Galaxy, we need to investigate the Galactic plane

Observed emission sum of many different line of sight components

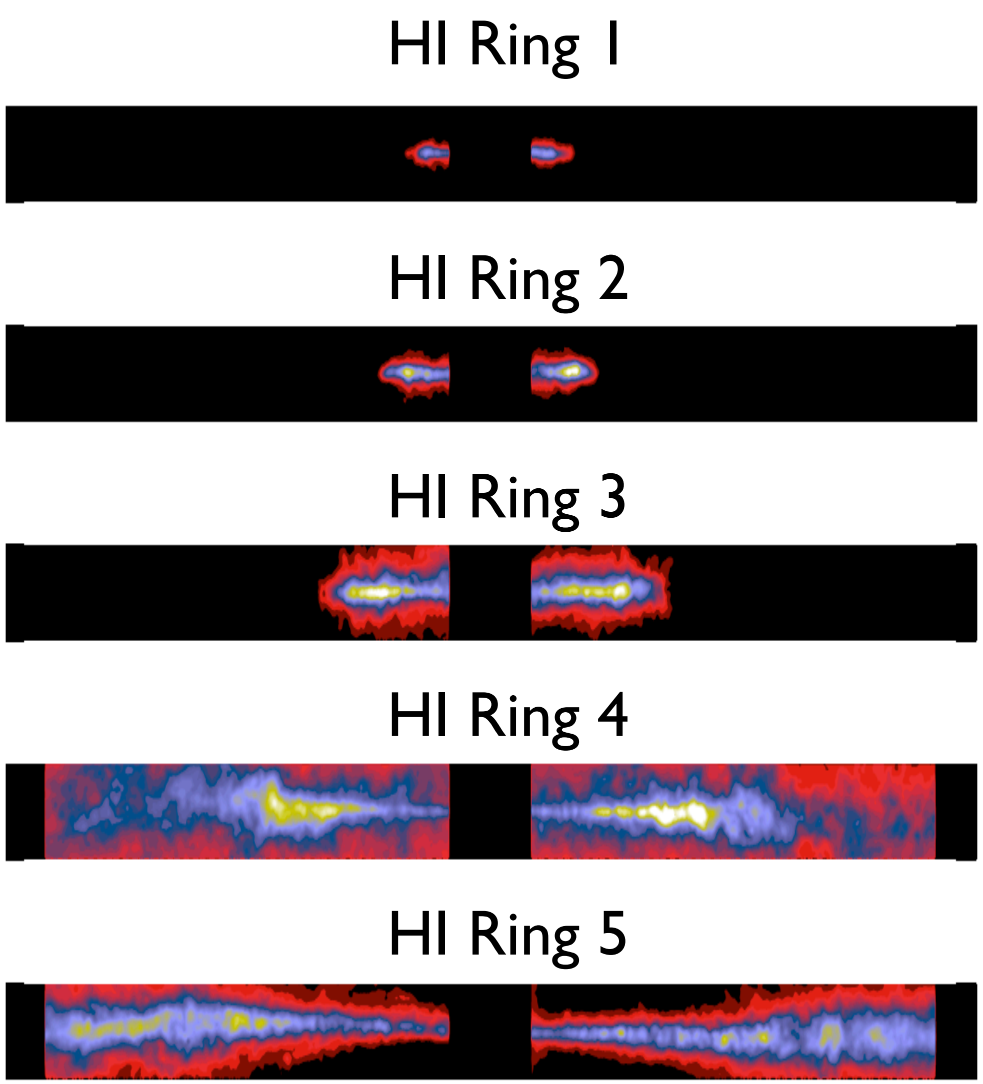
In this first analysis, we use kinematical tracers (HI, CO) to investigate radial variations

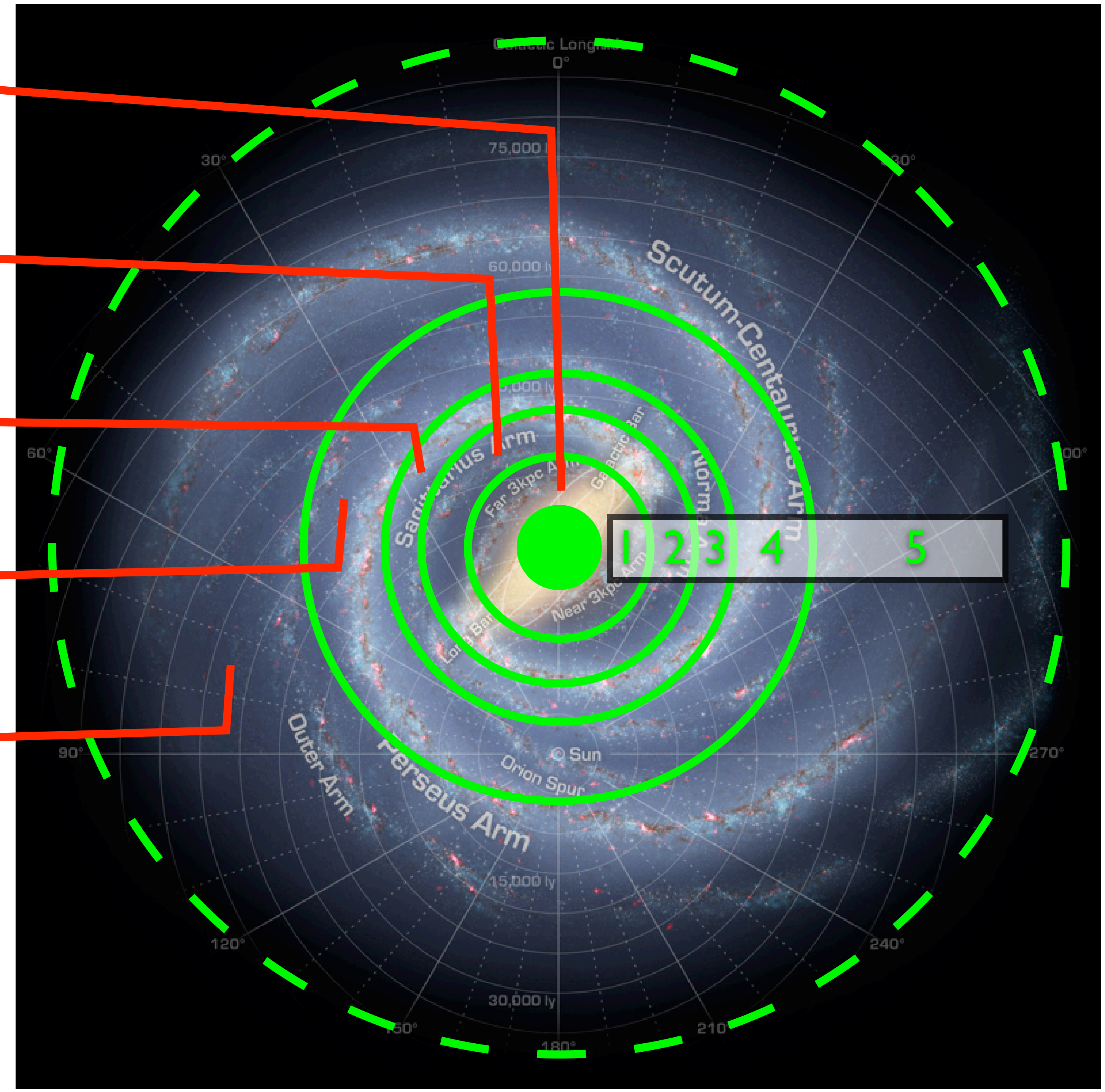
1) Assume circular velocity for gas
2) Radial velocity (V_{REL})provides **Galactocentric** distance
3) For centre and anti-centre V_{REL} = 0

(Planck collaboration 2011, contact author D. Marshall)



Galactic plane decomposition

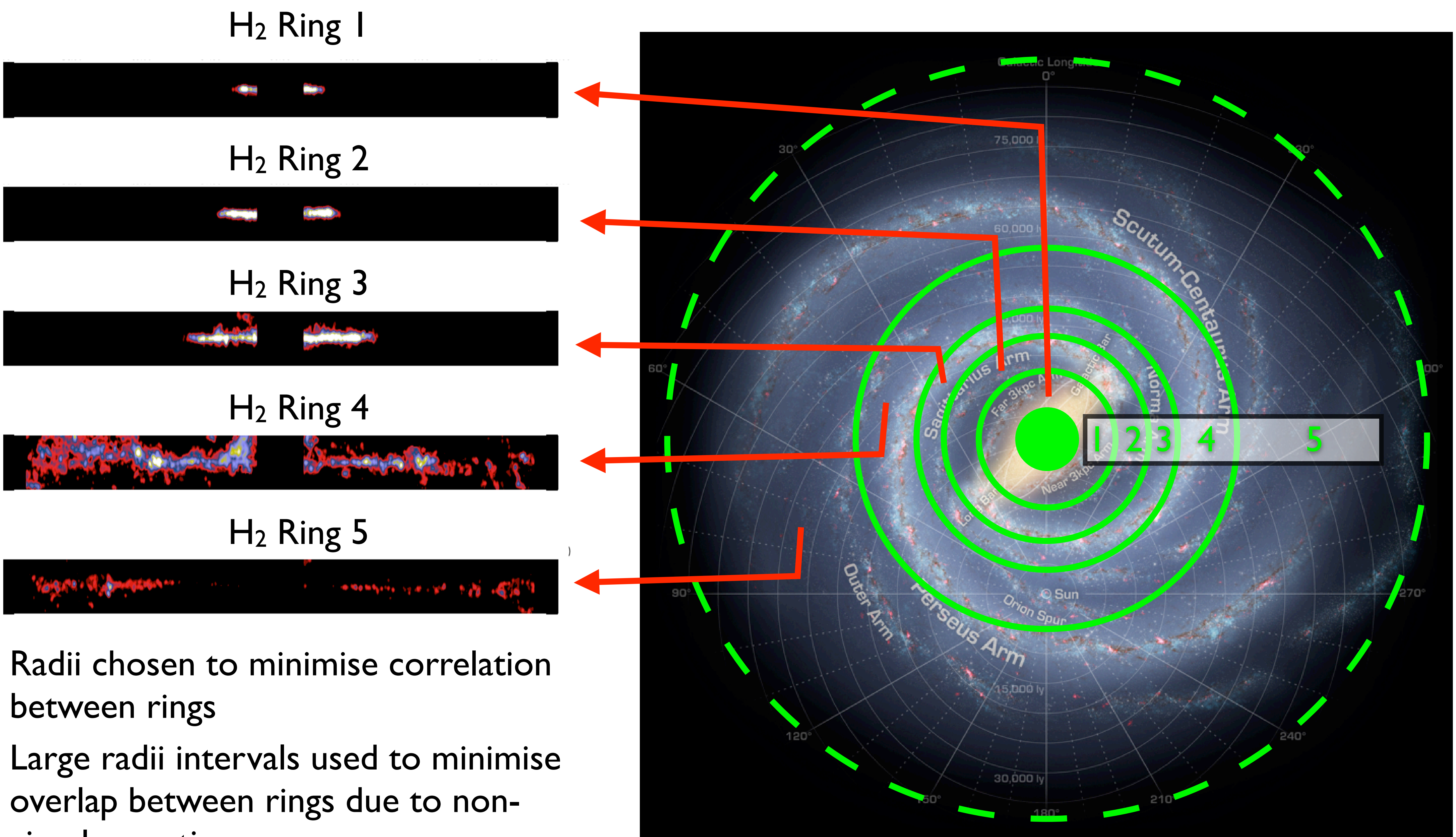




Radii chosen to minimise correlation between rings

Large radii intervals used to minimise overlap between rings due to non-circular motions

Galactic plane decomposition



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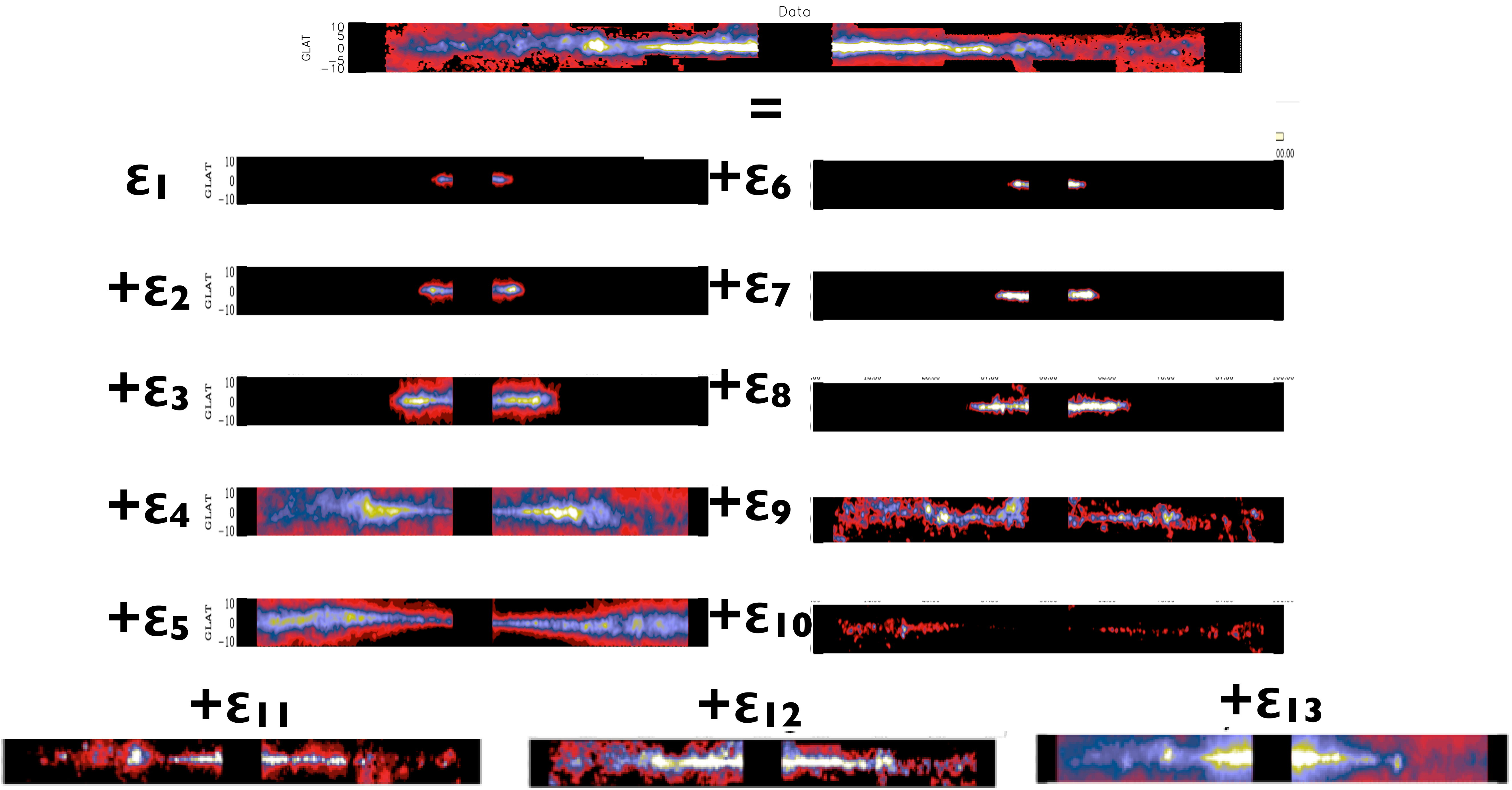
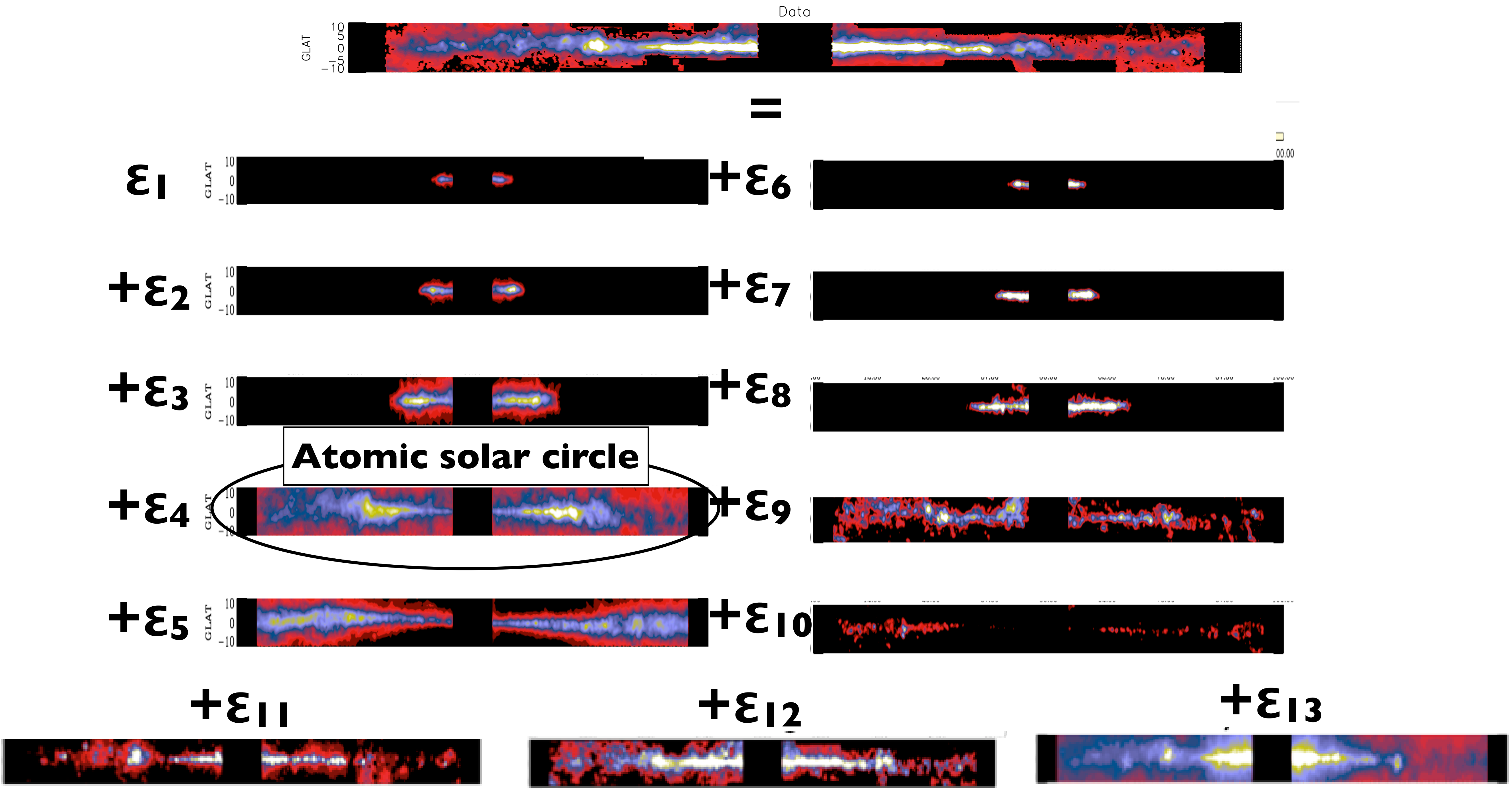
Example at 857 GHz



13 unknowns and ~7000 pixels

Example at 857 GHz



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Example at 857 GHz

Data

Model

$\varepsilon_1 \rightarrow \varepsilon_5$ HI

$\varepsilon_6 \rightarrow \varepsilon_{10}$ H_2

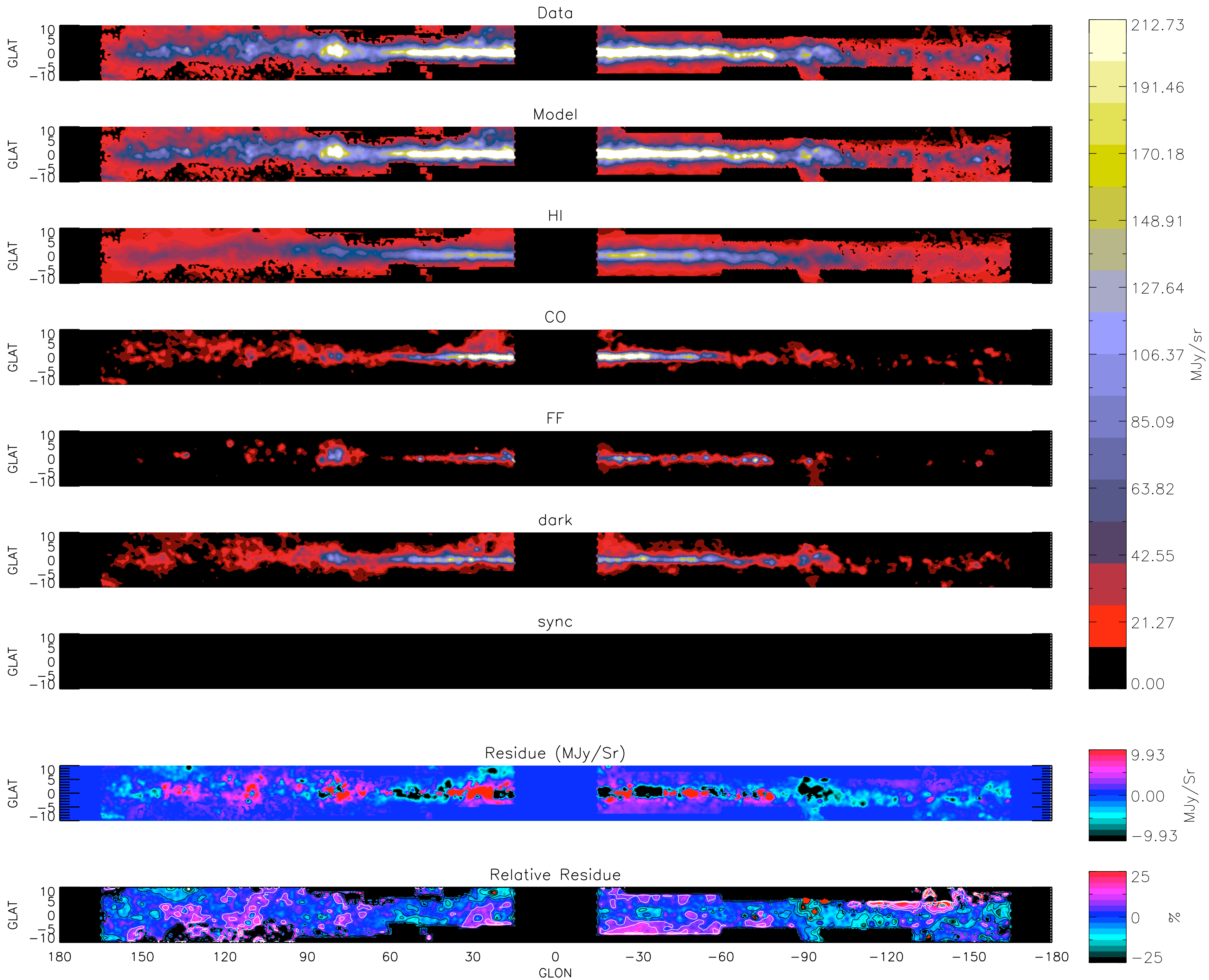
ε_{11} HII

ε_{12} Dark

ε_{13} Sync.

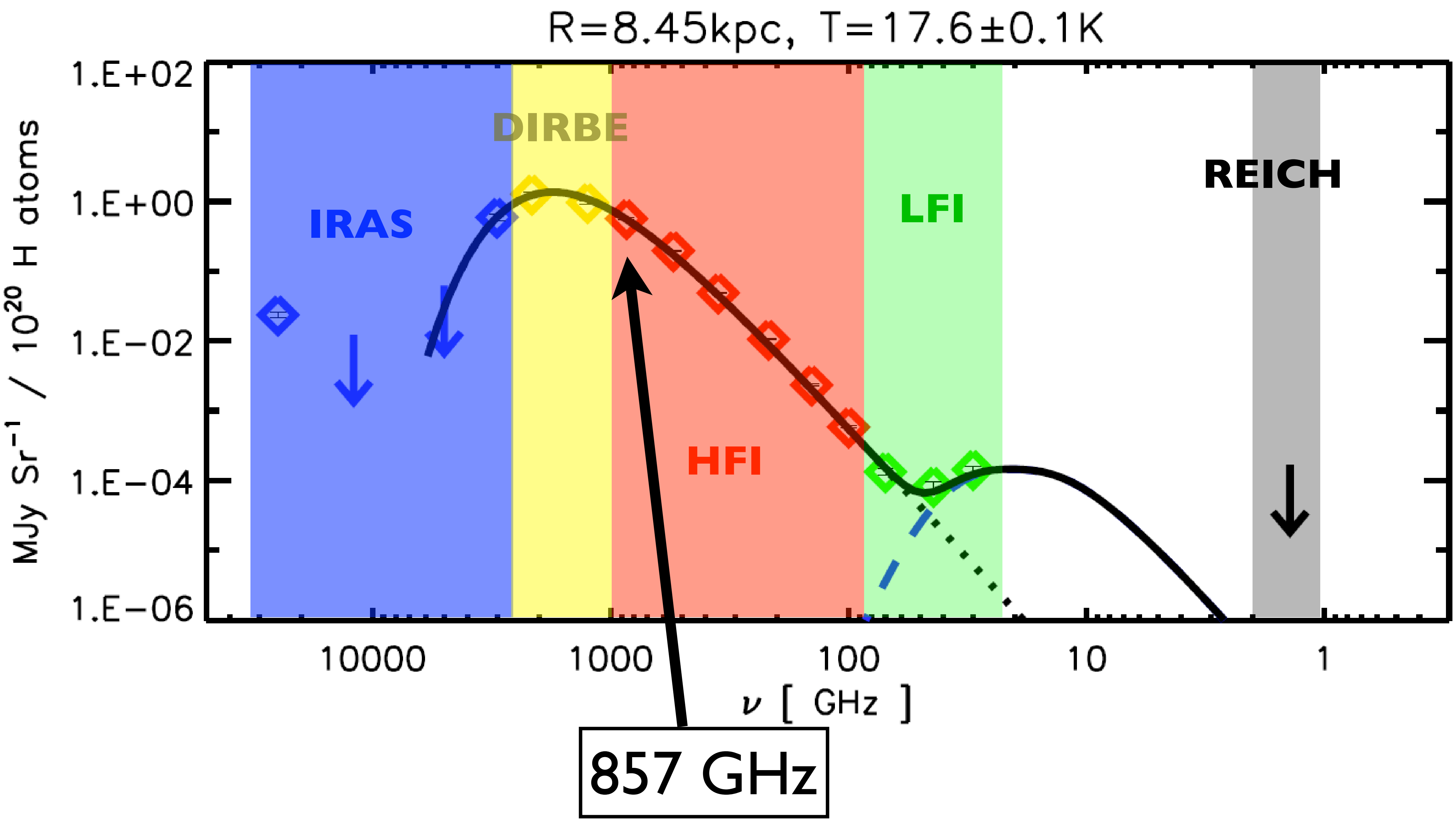
Residue

Relative Residue



Results - SEDs

Example SED for solar circle atomic medium (ε_4)

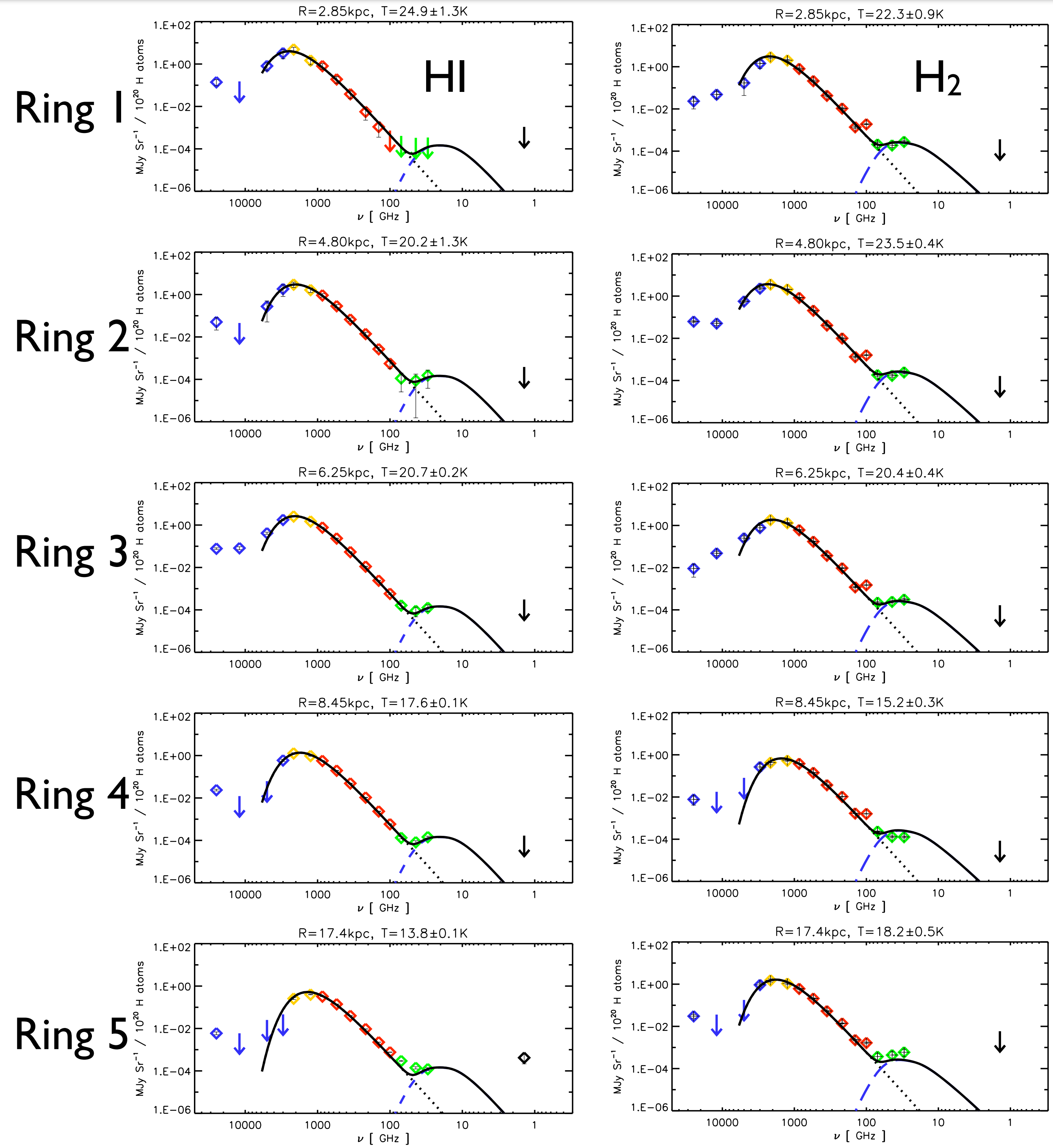


Atomic and molecular SEDs

Result of decomposition is one emissivity per phase and per ring (when available)

Combining emissivities over all frequencies allows us to construct SEDs for each phase and ring

SEDs are combination of thermal dust, free-free, synchrotron and spinning dust

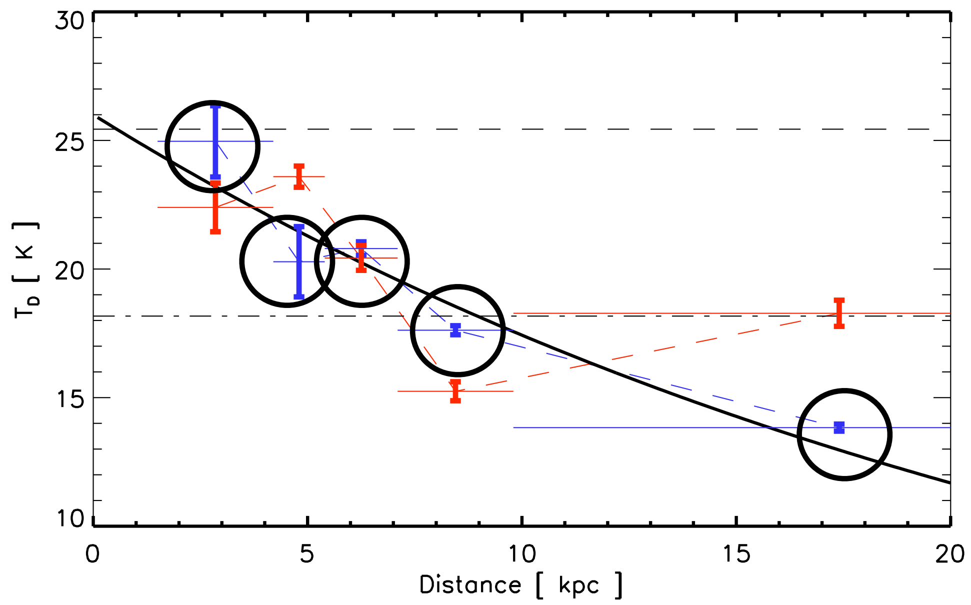


Thermal dust

Emission modelled with modified blackbody

$$I_\nu = B_\nu \nu^\beta = \frac{2h\nu^3}{c^2(e^{h\nu/kT}-1)}\nu^\beta ,$$

Dust spectral index ß = 1.8



Variation with Galactic radius

1) HI dust follows ISRF
2) CO dust follows star formation

Anomalous microwave emission (AME)

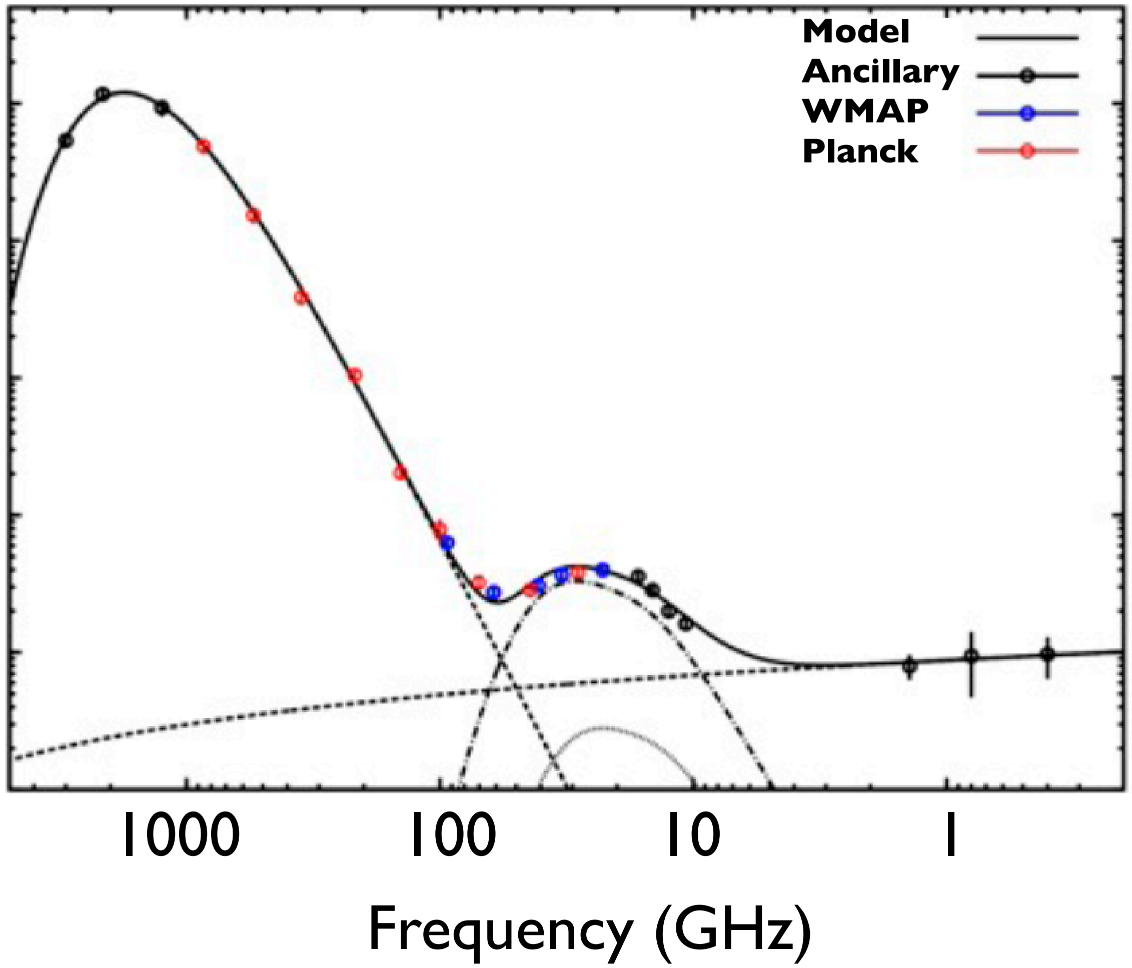
Anomalous microwave emission

Explored in detail in Planck collaboration (2011, contact: C.Dickinson)

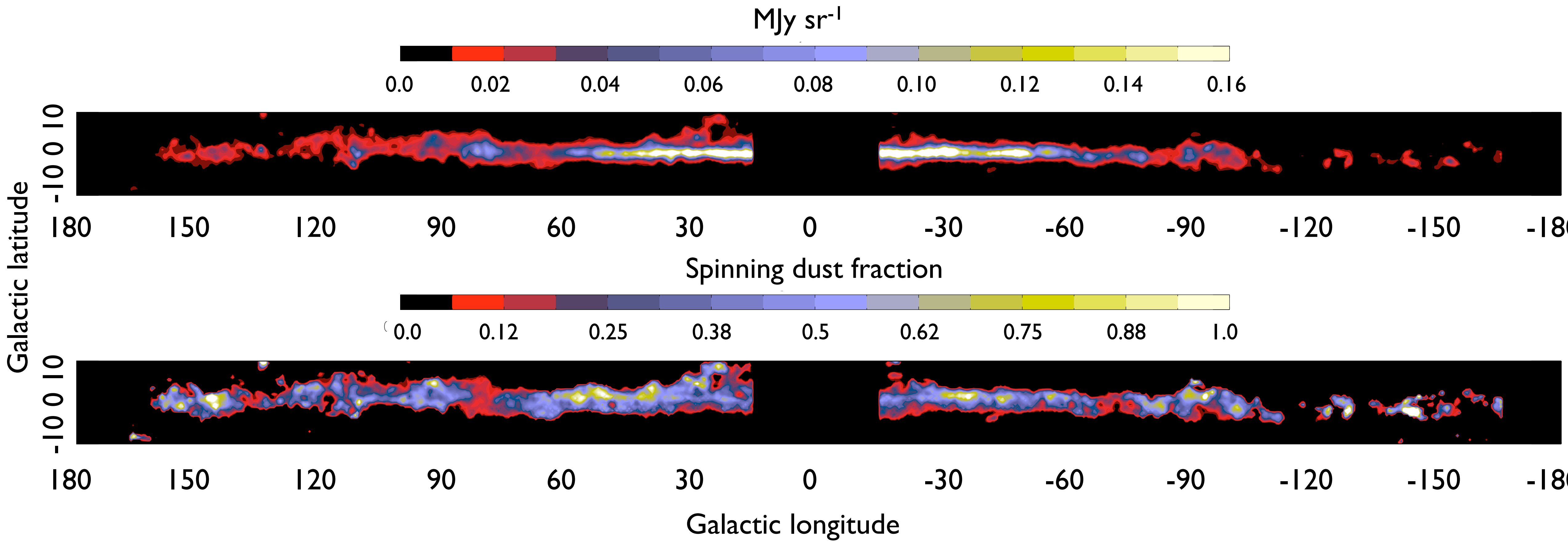
1) Too bright for free-free
2) Not polarised
3) Correlated with dust emission (PAHs)

One possibility is **spinning dust** as modelled by Silsbee et al. (2010)

1) Important for CMB work
2) New ISM constituent
3) New diagnostic (grain size, ISRF ...)



New AME regions?



AME regions in the Galactic plane

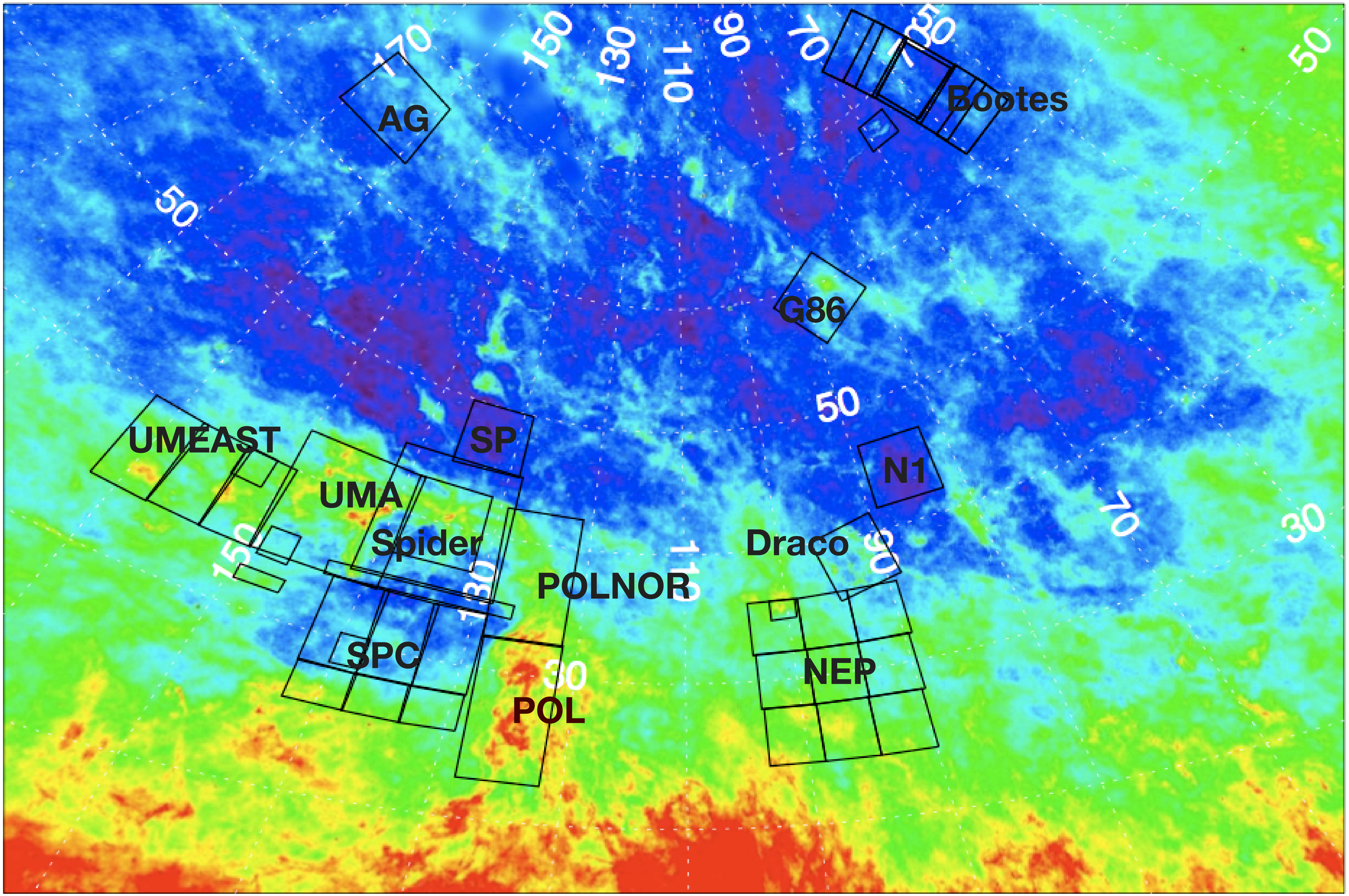
1) Assuming that 30 GHz emission associated with atomic, molecular and dark gas phases is 100 % due to spinning dust

2) No contribution from ionised regions

3) See also Planck collaboration (2011, contact C.Dickinson)

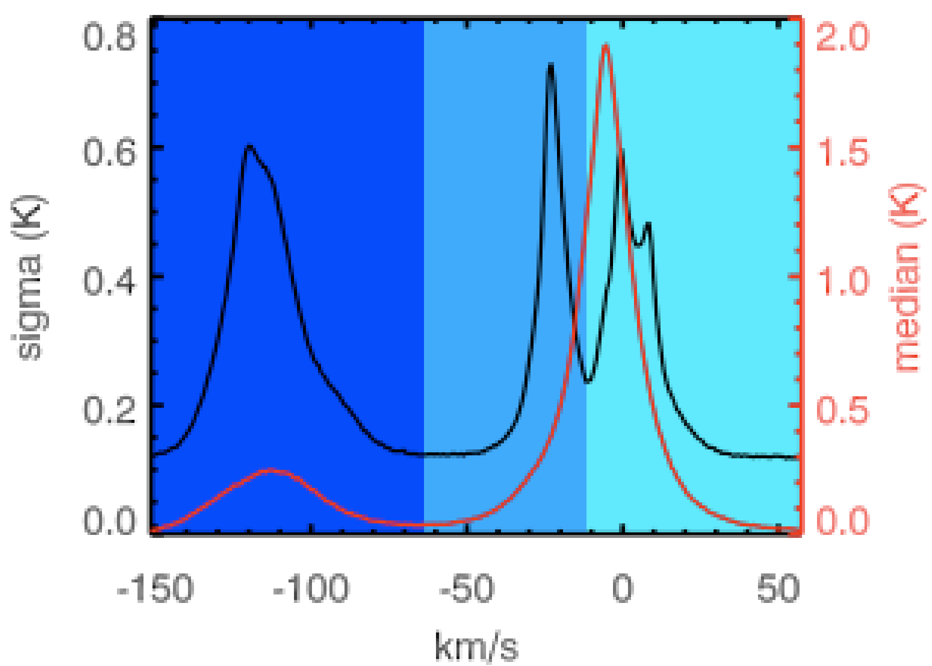
3. Dust in the Galactic Halo

Green Bank

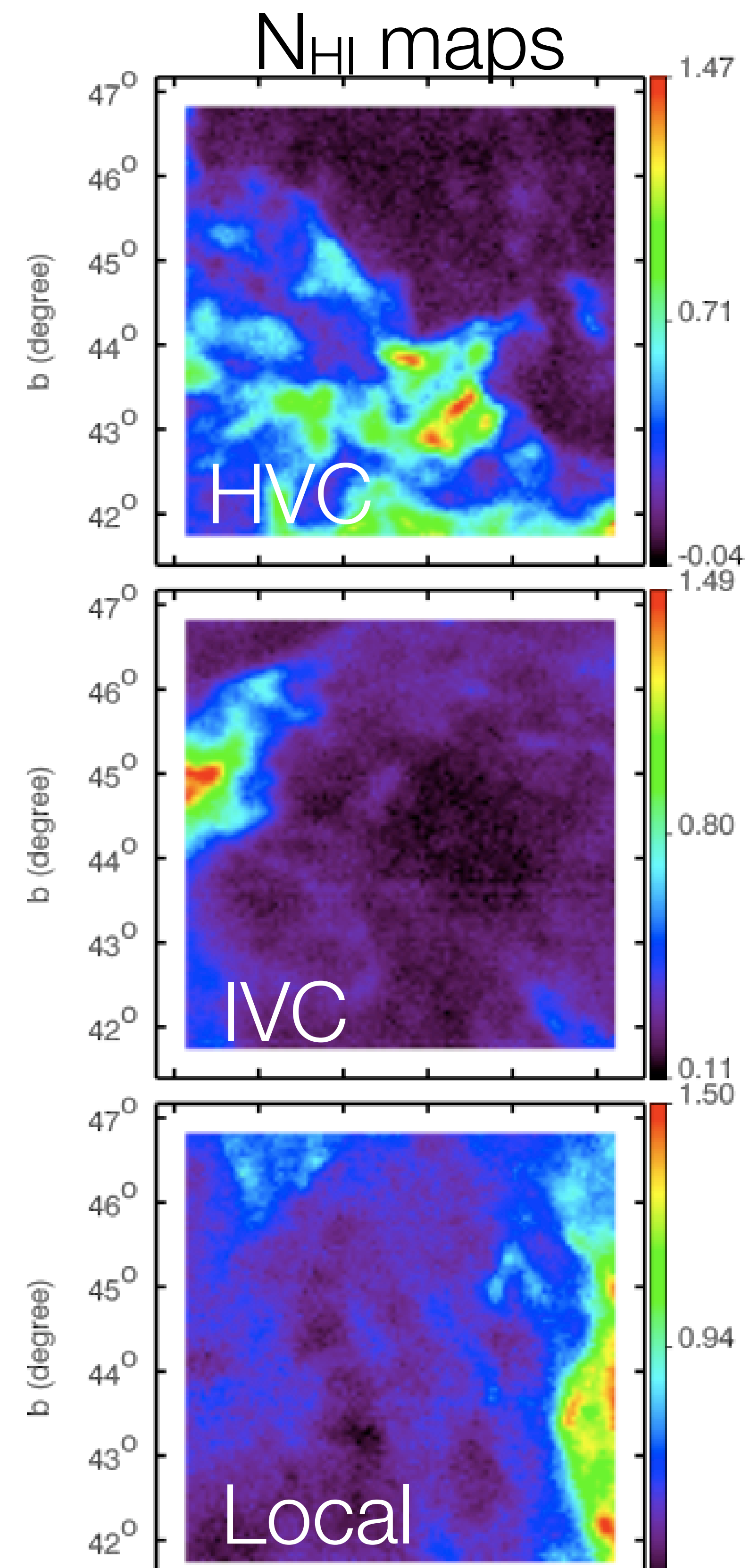


AG
Bootes
G86
SP
N1
UMEAST
UMA
Spider
Draco
POLNOR
SPC
NEP
POL

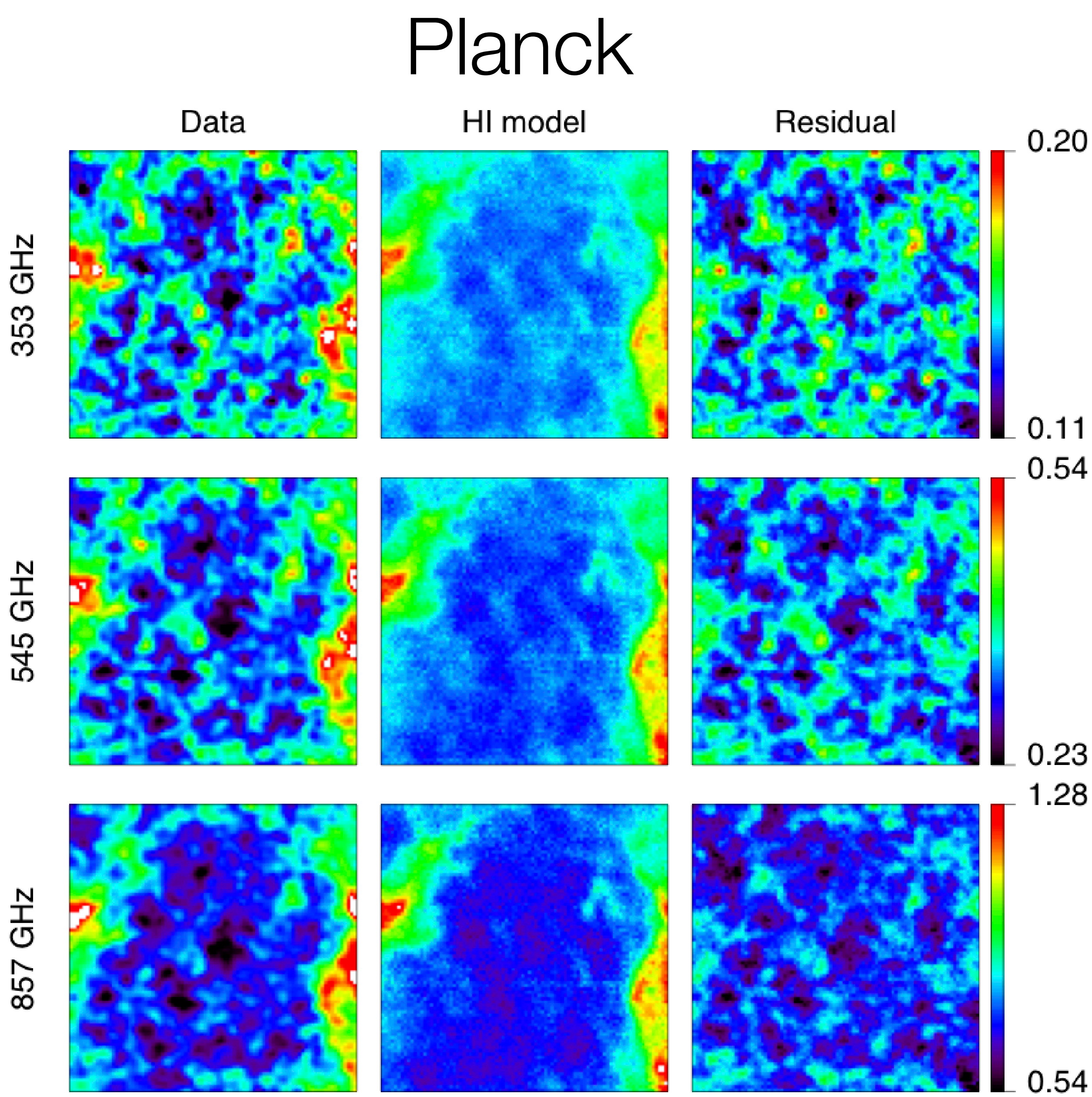
Estimating the HI components

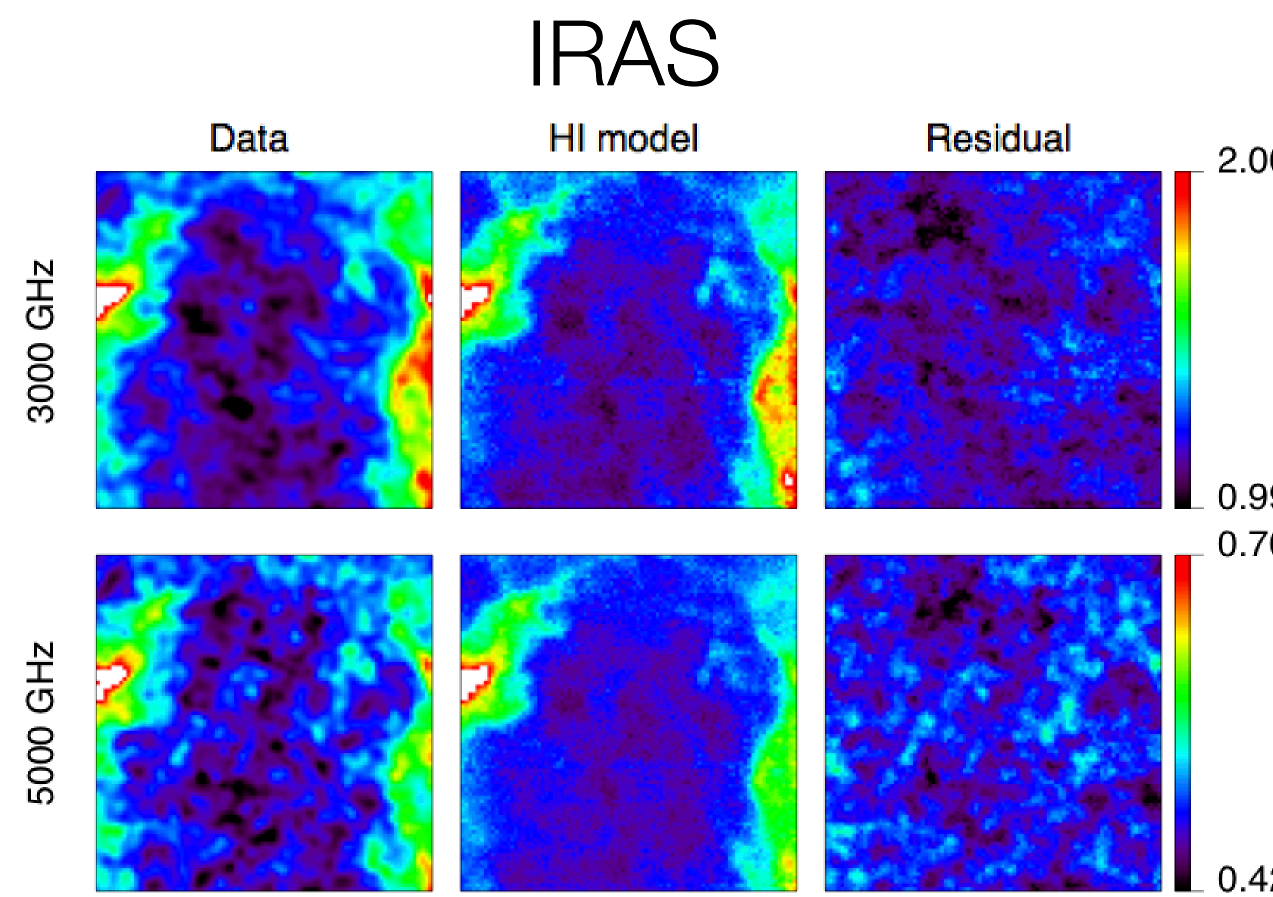


- Separating the 21 cm velocity channels in 3 : local, IVC and HVC
- Use of the median and rms spectrum to identify natural channel cuts
- Column density estimated assuming Tspin=80K



Dust-HI correlation: N1 field



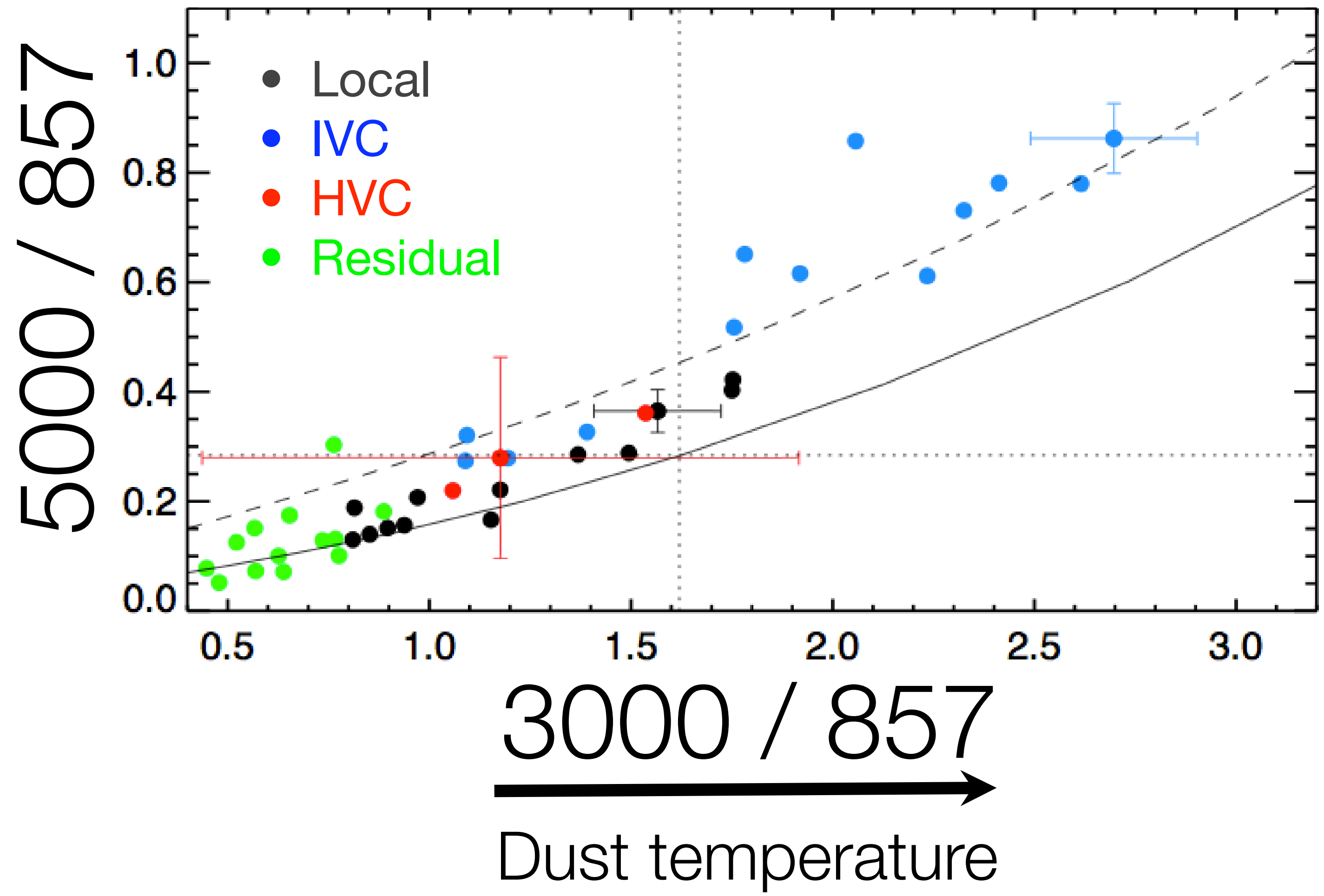


$$R_{\nu}(x,y) \equiv I_{\nu}(x,y) - \sum_{i=1}^{3} \epsilon_{\nu}^{i} N_{HI}^{i}(x,y) - Z_{\nu}$$

Dust properties in HI

- Evidence for grain processing in IVCs
    - 5000/857 ratio compatible with an abundance of VSG 4 times the local ISM value

- HVC have a significant lower 857 GHz emissivity in accordance with their low metallicity



4. Compact emission
"Cold Clumps"

Understanding star formation

- Cold dust is a tracer of dense, hidden regions of star-forming clouds

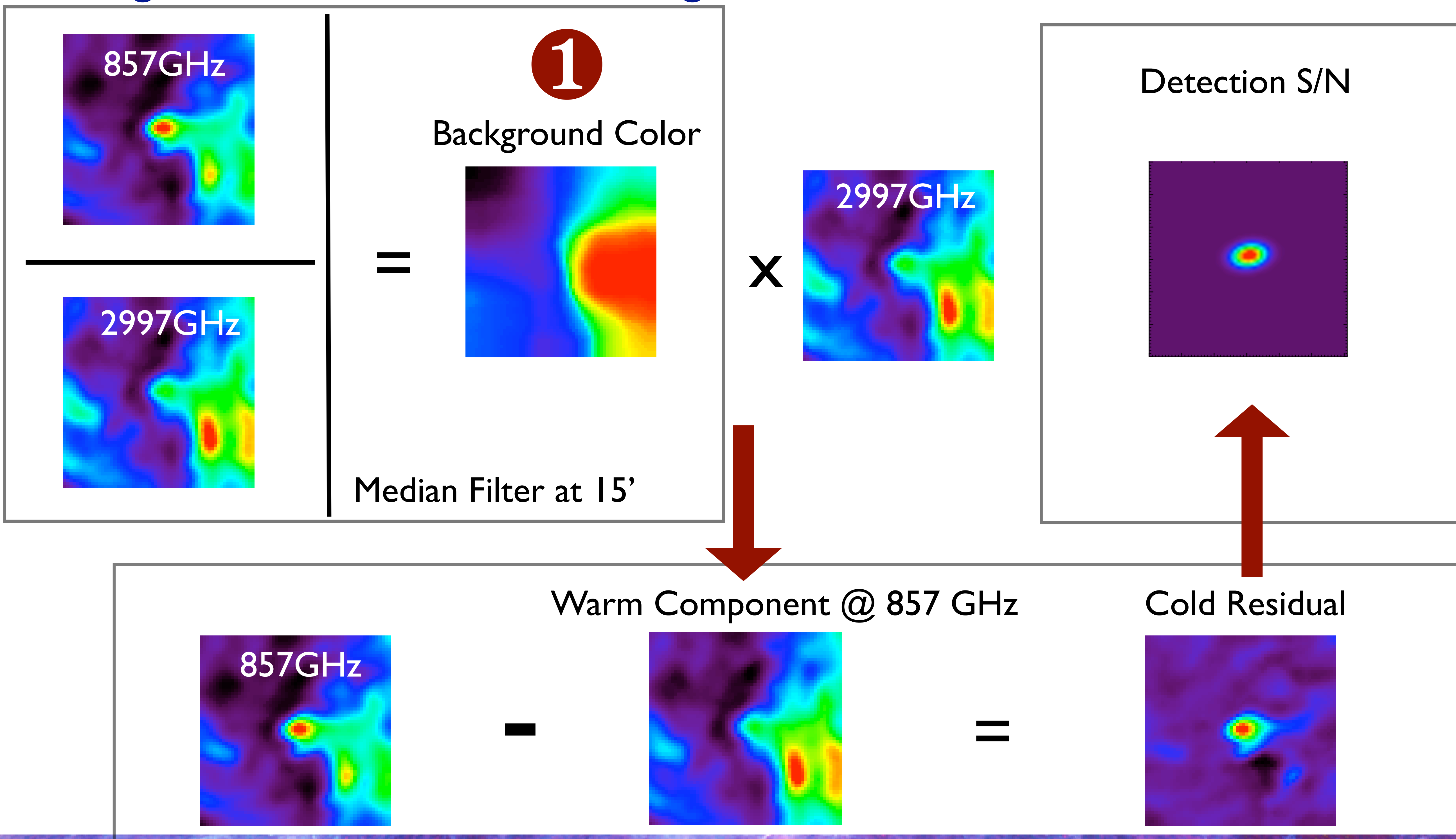
- Many questions are still open on the earliest phases of star formation:
    - What generates pre-stellar cores ?
    - What governs their evolution to protostars ?
    - What is the origin of the global initial mass function (IMF) ?

- *Planck* => resolution, sensitivity, frequency coverage (especially in HFI bands)

- Two catalogues :
  C3PO: Cold Core Catalogue of Planck Objects (Legacy)
  ECC: Early Cold Core Catalogue (part of the ERCSC) (planck2011c)

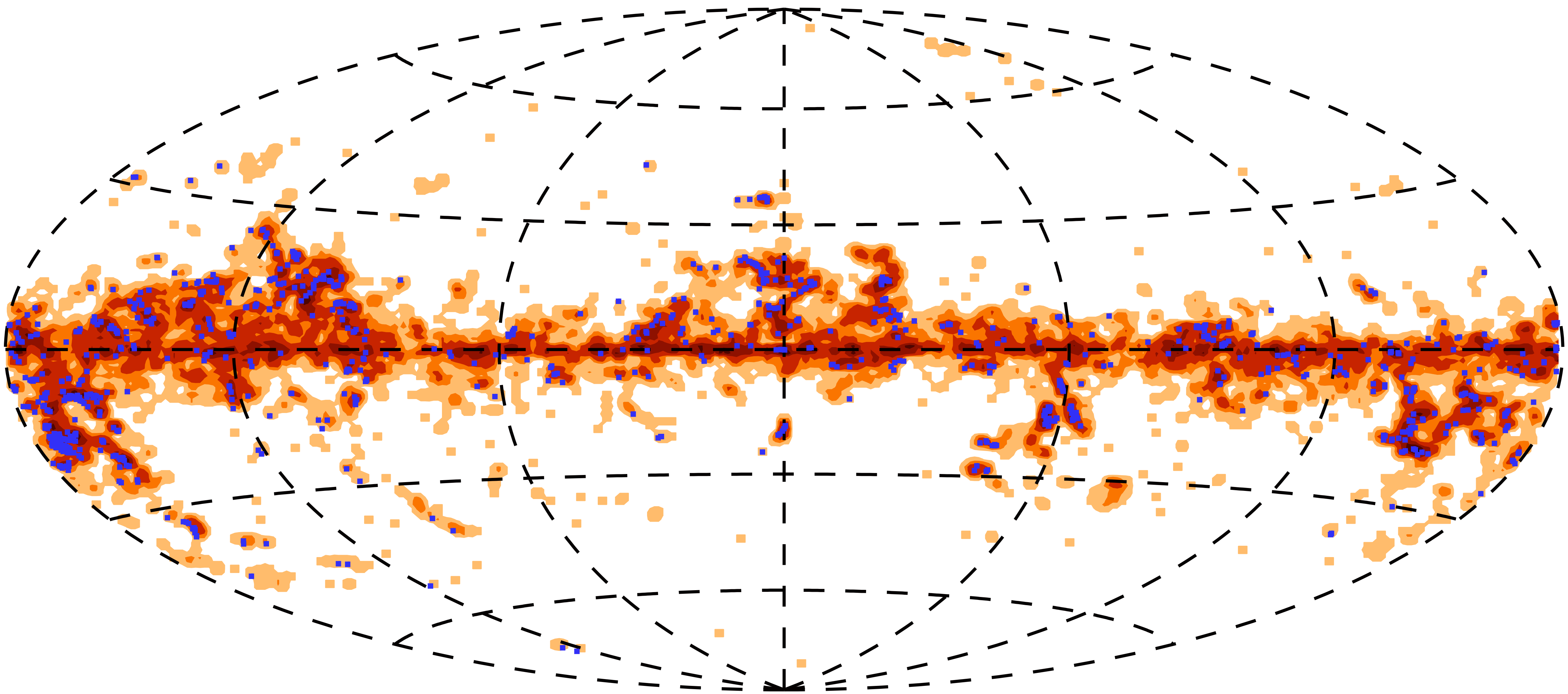
Building the C3PO

Algorithm of the Warm Background Subtraction (Montier et al., 2010)



X-Correlation with Ancillary Data

All-Sky Distribution



All-sky map of the number of C3PO objects per square degree (10783)

(Planck Collaboration, 2011 - Contact author L. Montier)

■ ECC Selection (915)

(Planck Collaboration, 2011 - Contact author R.Chary)

Spatial distribution

Distance Estimates

IR
Extinction Signature
(2MASS, GLIMPSE)

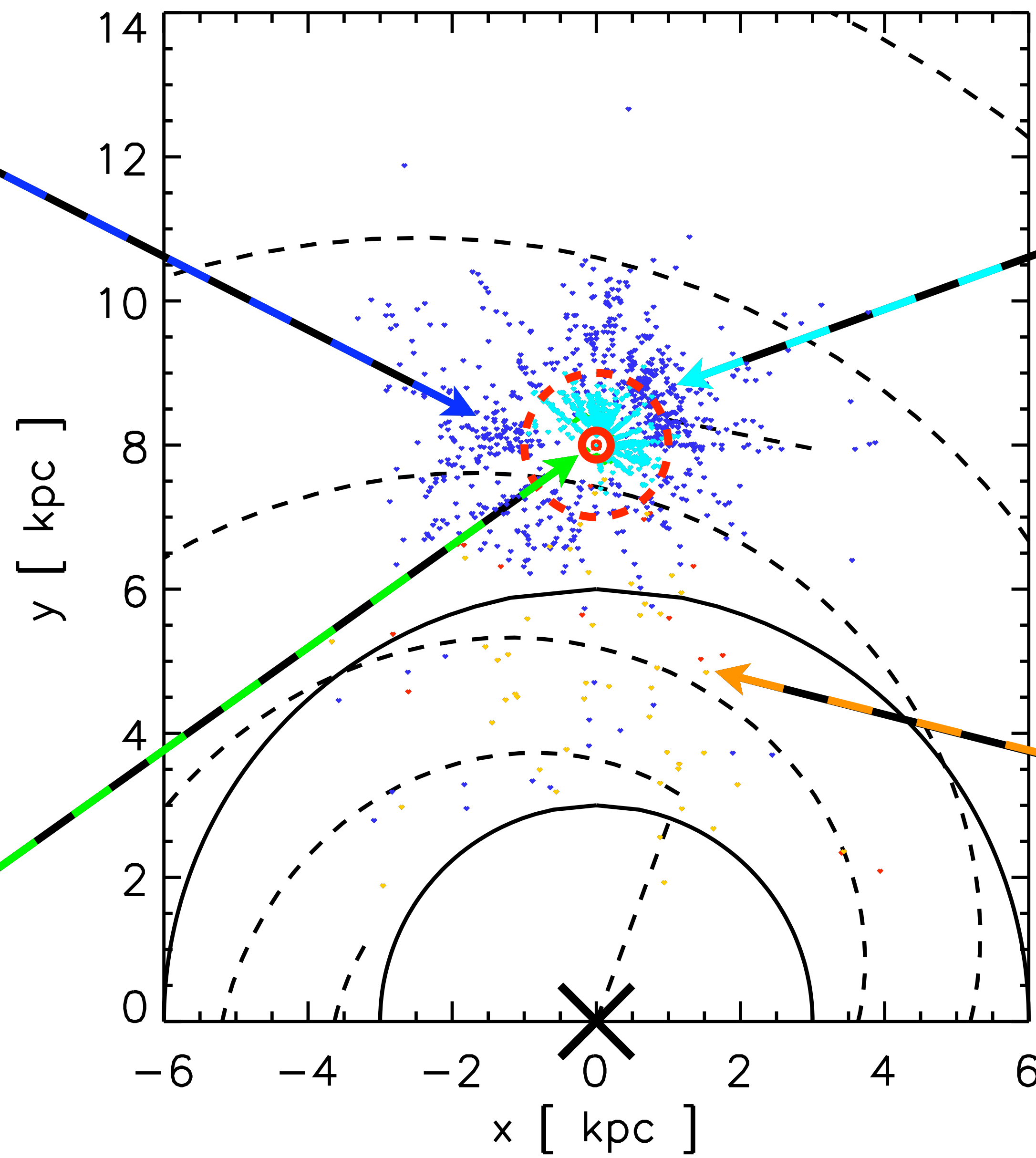
(Marshall et al. 2009)

(978)

Optical
Extinction Signature
(SDSS)

(Mc Gehee et al. 2011 in prep)

(1452)



Association with 14
known Molecular
Complexes

(1152)

Association with
IRDCs

(Simon et al. 2006b
Jackson et al. 2008,
Peretto et al. 2009)

(315)

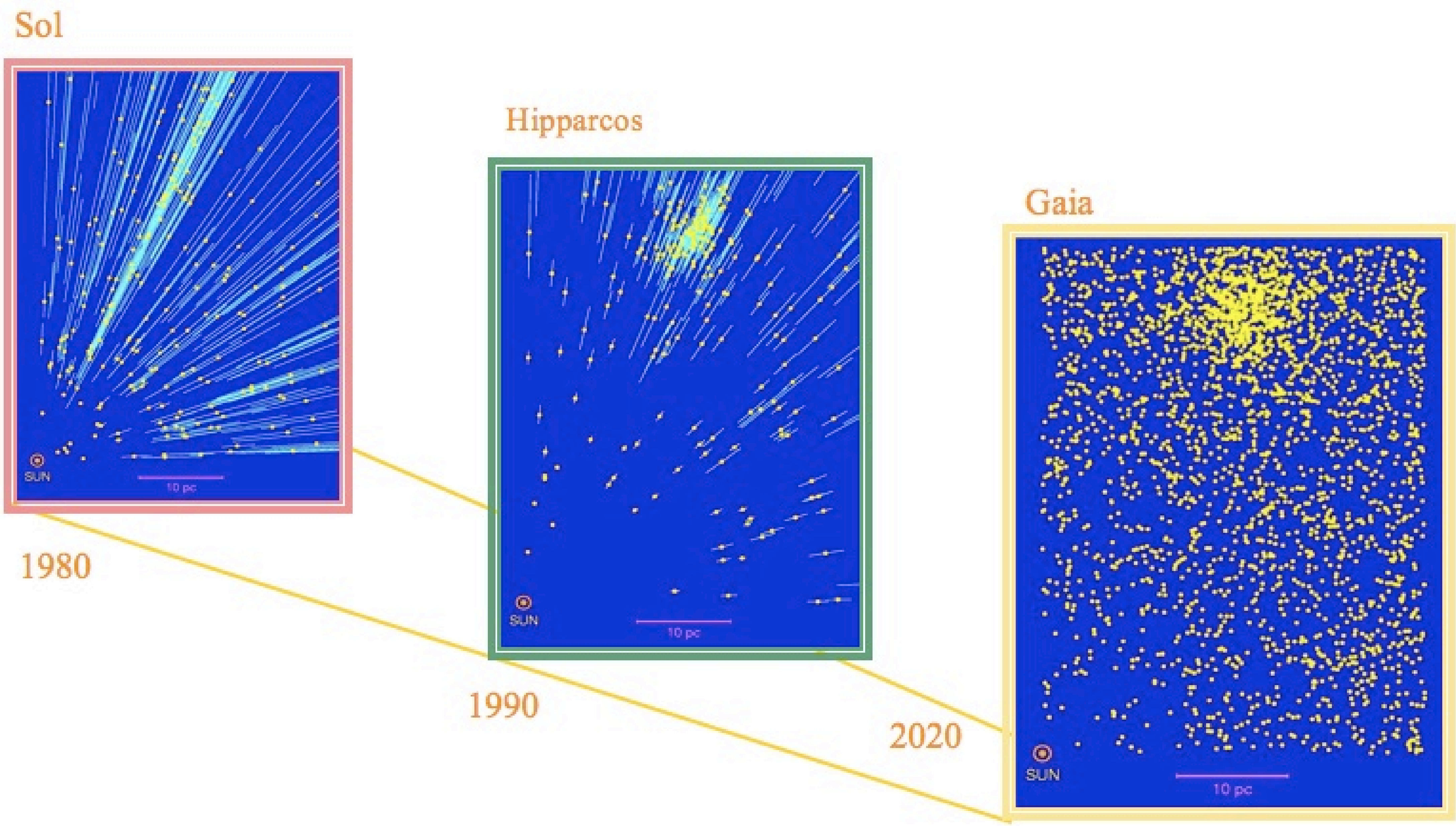
Spatial distribution

3D Distribution

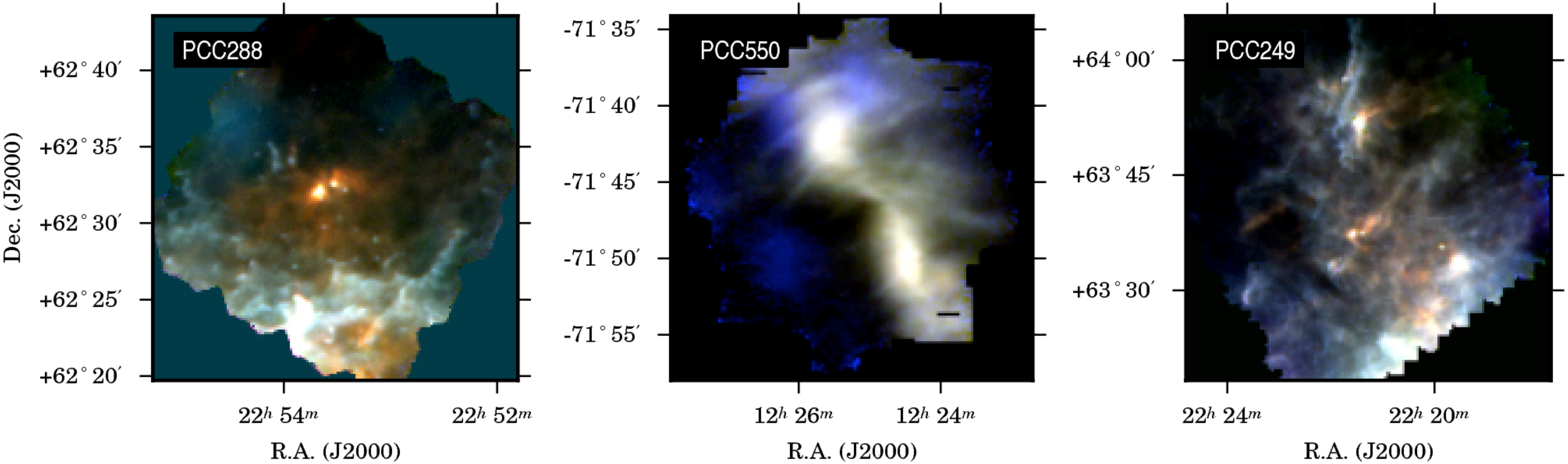
- Mainly Local Solar Neighbourhood (D<2kpc)
- A few objects at greater distance (D > 5kpc)
- Completeness of the sample is very difficult to probe.
- Heterogeneous due to the bias introduced by distance estimates

Spatial distribution

3D Distribution of Hyades cluster



Herschel follow-up



PCC288 at 800 pc

- ~14K clump in Cepheus with ~140 Msun
- Several compact objects with FIR/submm colour temperatures above 20K
- One Fu Ori type protostar with a molecular outflow
- Between a young stellar group and a molecular cloud – triggered SF?

PCC550 at 225 pc

- Piece of a long filament in Musca
- Two ~11K cores, both about 10 Msun
- Quiescent with density profiles similar to stable Bonnor-Ebert spheres

Juvela et al. (2010, 2011)
see also
Planck collaboration (2011),
contact I.Ristorcelli

PCC249 at 900 pc

- Very active star forming region
- Average temperature high, the Planck detections correspond to ~100 Msun regions at ~17K
- Colder smaller clumps (~13K) between the hot cores – possibly pre-stellar?

Conclusions

- Planck & Herschel provide unprecedented glimpse into cold interstellar medium
  - Dust powerful tracer of local environment
  - Important for understanding star formation
  - Distances crucial
- Gaia will provide three dimensional distribution of absorbing dust
  - Structure of the local bubble, halo
  - Galactic plane out to several kpc
  - Temperature independent measurement of dust column density