Planck's impact on interstellar medium science new insights and new directions

Peter Martin
CITA–ICAT
CITA, University of Toronto
On behalf of the Planck collaboration

esa

HFI PLANCK

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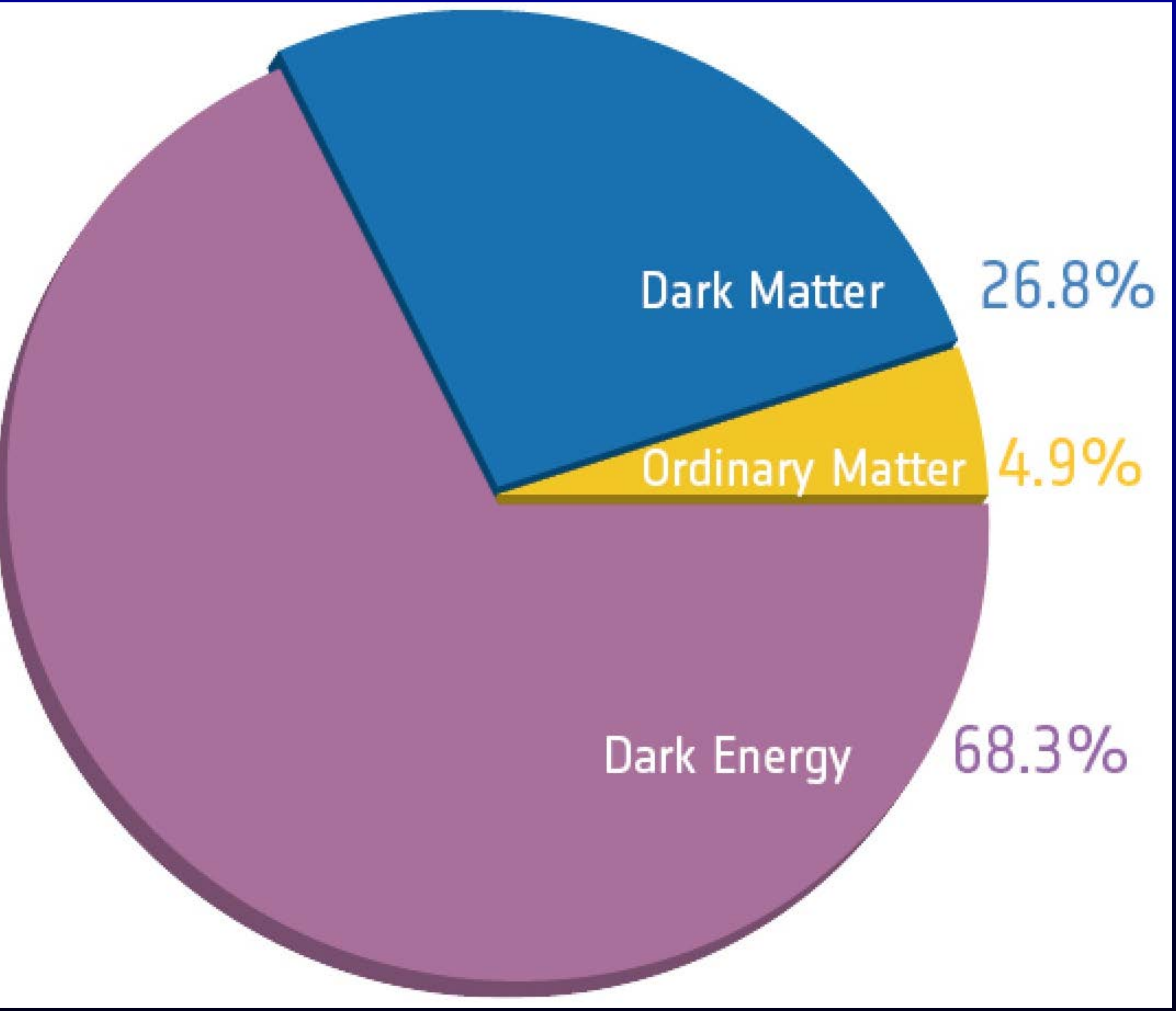
Perspective

Wasted opportunity

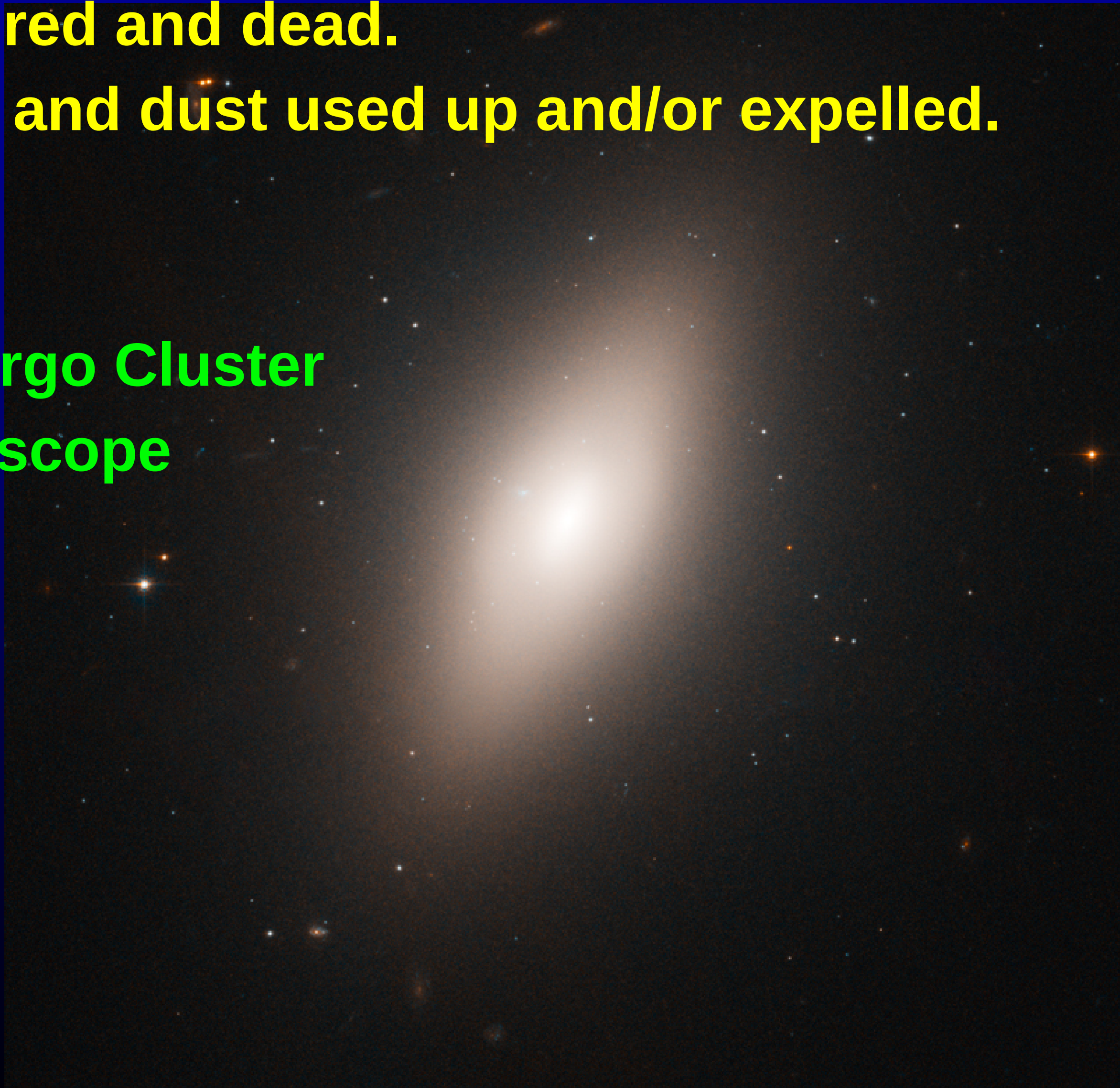


Fractionally, there are not many baryons, and even though Planck has given us a bit more, still most of these baryons are not in galaxies.

Extragalactic context: Ellipticals

Elliptical galaxies: red and dead.

Very little ISM: gas and dust used up and/or expelled.



NGC 4660 in the Virgo Cluster

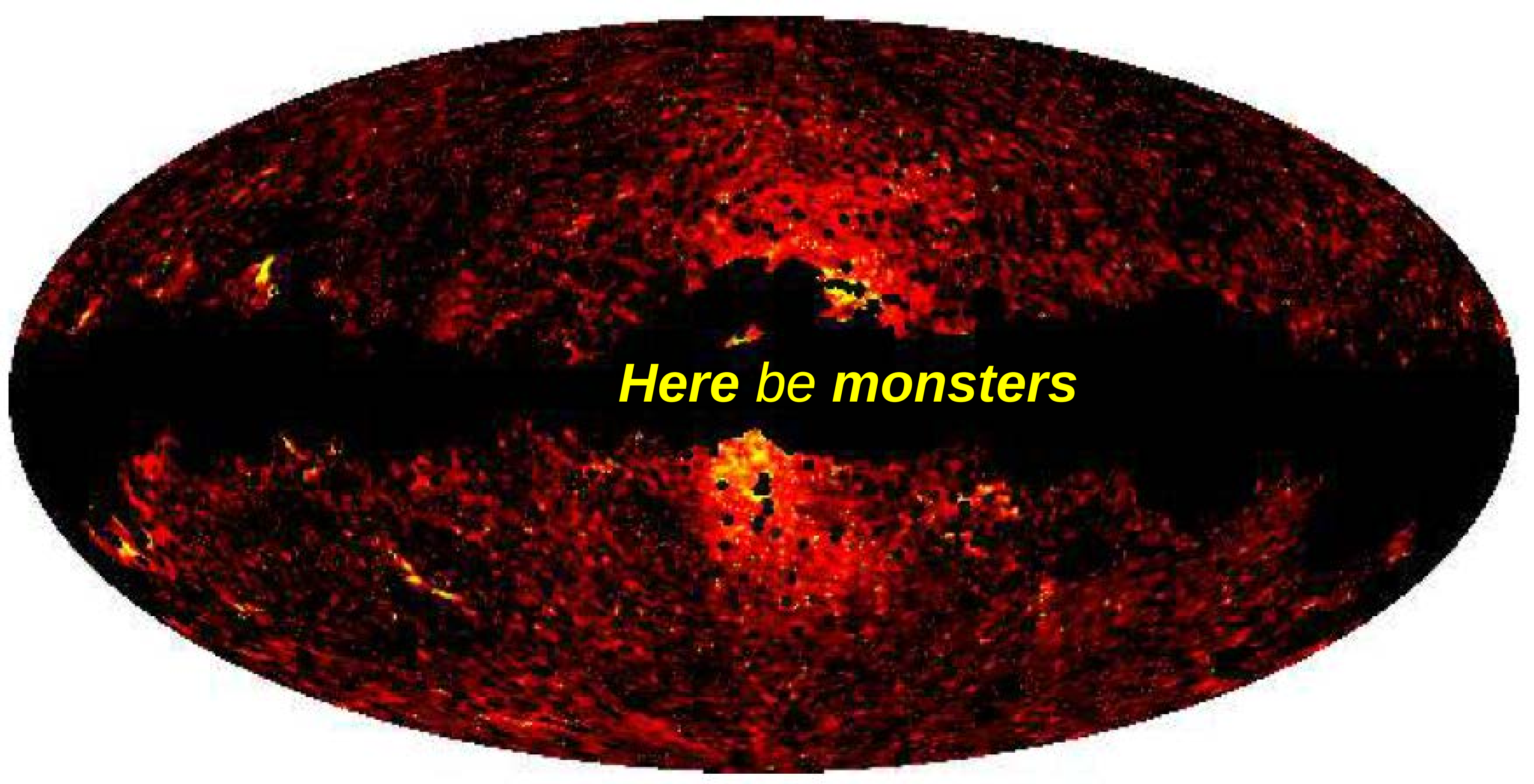
Hubble Space Telescope

Elliptical envy

With no ISM – no Galactic foregrounds – imagine the clear view of the CMB from inside such a galaxy!

Galactic centre microwave haze

Planck intermediate results. IX. Detection of the Galactic haze with Planck



Non-thermal emission. Relativistic particles.

Extragalactic context: Spirals

Spiral galaxies: gas and dust available in an ISM for ongoing star formation

NGC 3982
HST

Dusty disk – like we live in

Spiral galaxy:
edge on, dust lane

In our Galaxy, a foreground to the CMB.

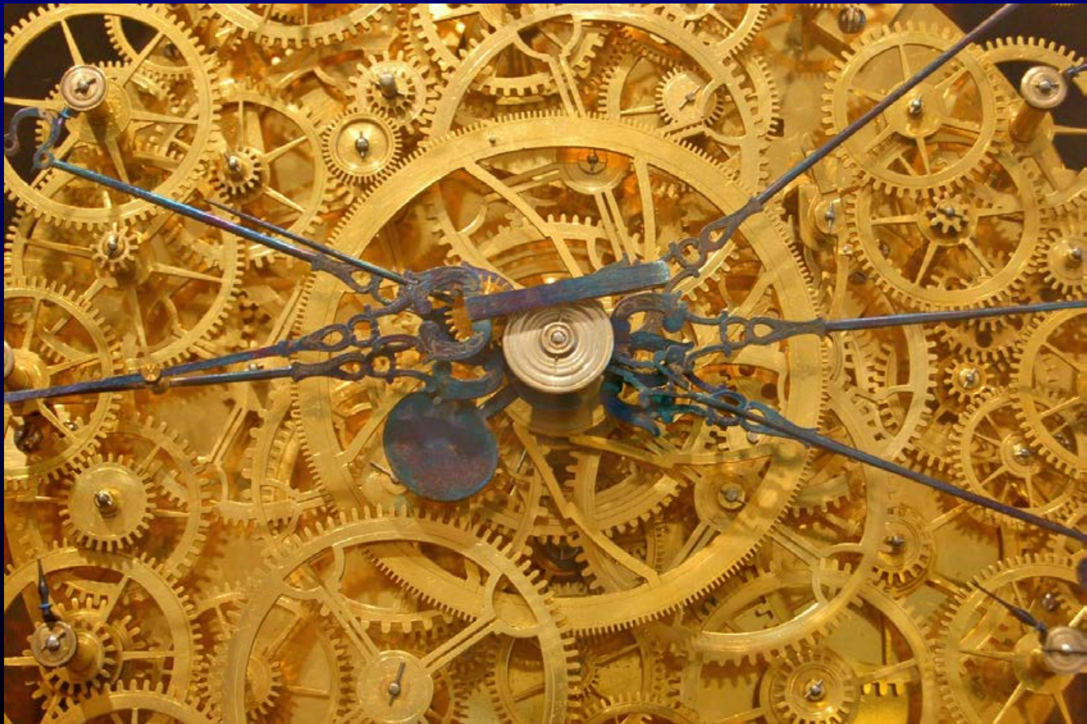
NGC 4565
CFHT

An overarching question in interstellar medium (ISM) science

Why is there still an ISM in the Milky Way in which stars are continually forming?

How does the Milky Way tick?

Curious Expeditions: Augustinian friar’s astrological clock.



Spirals: gratitude

Would we be able to figure out, ab initio and theoretically, how stars form, if we did not have an ISM “up close” in the Galaxy and so the empirical evidence and constraints?

Or more to the point, could we answer why star formation is so disruptive of the ISM and so inefficient?

Or would we have any fun at all?

An ISM research program

Galactic ecology: the cycling of the ISM from the diffuse atomic phase to dense molecular clouds, the sites of star formation/evolution, and back.

Because of feedback, recycling, and infall, current star formation is not all-consuming, and there still is an ISM.

Comprehending complexity in the Galactic ISM, from ethereal wisps to dense structures at the onset of star formation.

Details are intriguing too

Planck provides full sky coverage, for global analysis.

But Planck also enables regional analyses, to find evidence for astrophysically important processes.

Why Planck will impact ISM science

Planck Legacy Archive (PLA)

planck

The Planck Legacy Archive (PLA) contains all public products originating from the Planck mission. A graphical user interface accessible from this page allows to browse, display, inspect, select, and download these products.

As of March 21st 2013, the PLA provides public data products from the first 15.5 months of Planck operations. It notably includes full-sky intensity maps at all nine Planck frequencies, maps of foregrounds components at high resolution, and the Cosmic Microwave Background fluctuations at unprecedented angular resolution. Angular power spectra and cosmological parameter grids are also provided, as well as the Planck Catalogue of Compact Sources and the Planck Sunyaev-Zel'dovich clusters catalogue. Many additional data sets are provided as well.

Access to PLA

The PLA is freely accessible via the URL:

http://pla.esac.esa.int/pla/pla.jnlp

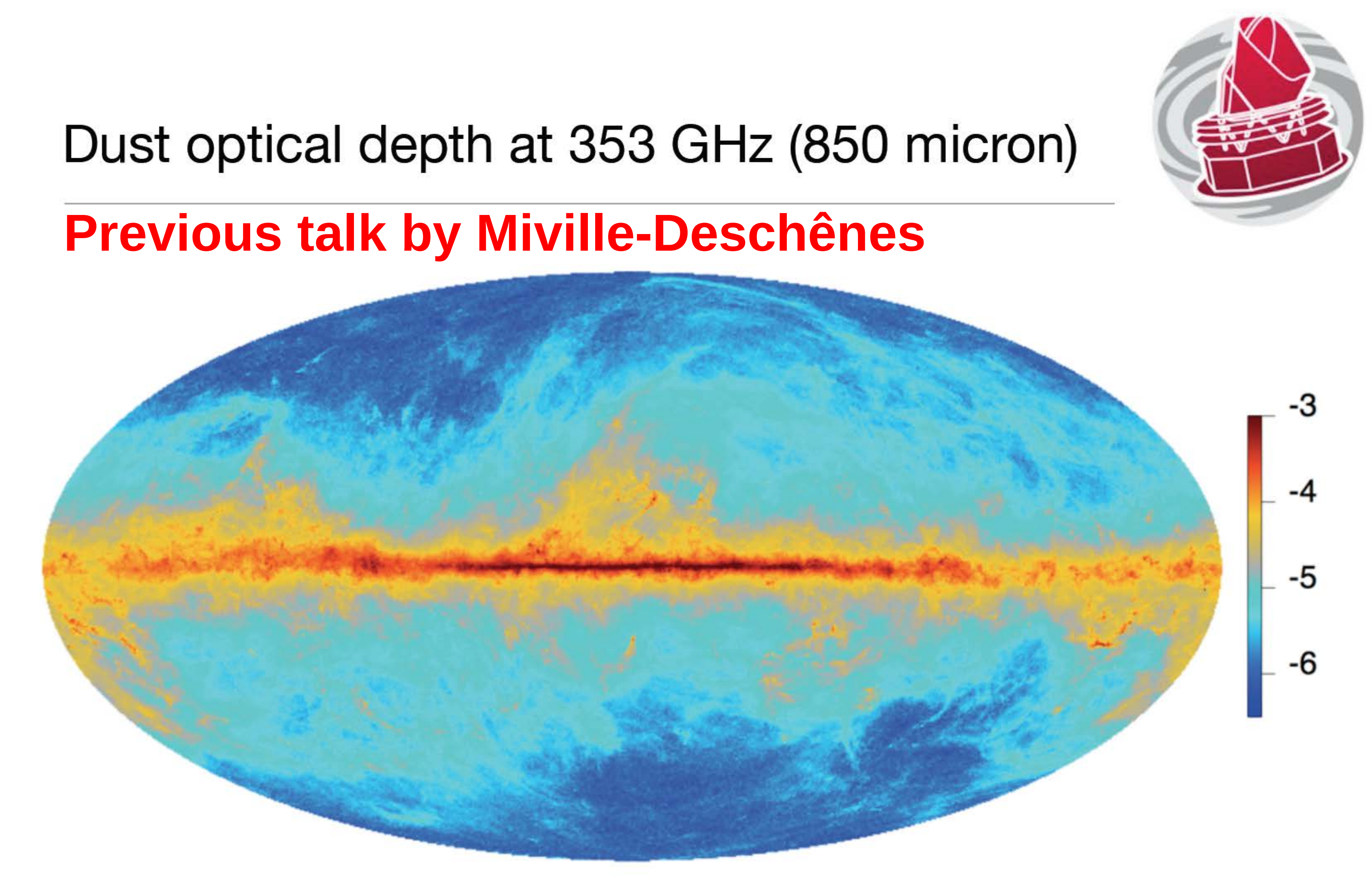
Frequently requested products **Explanatory supplement** **Planck publications**

Planck science team home

Use of Planck data

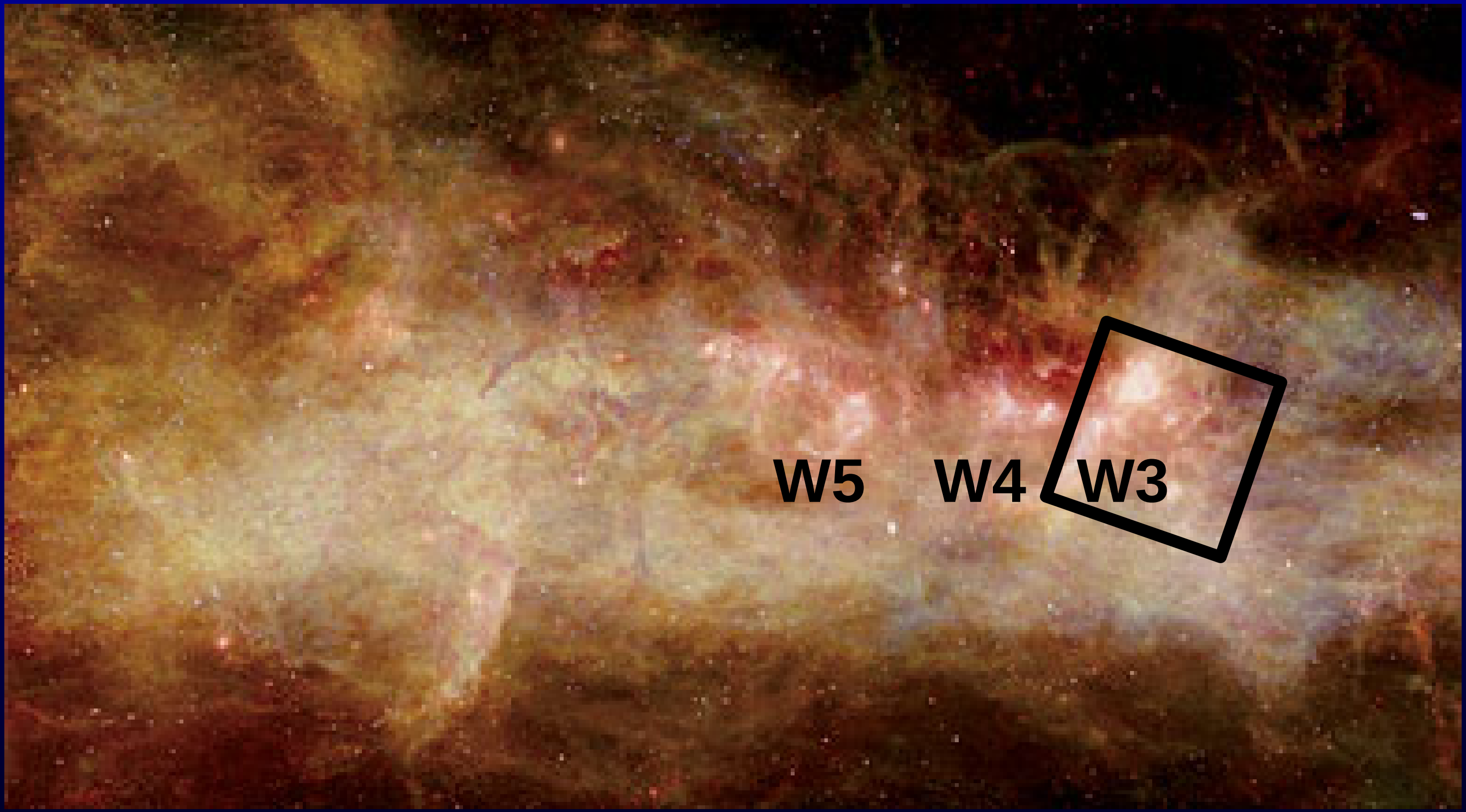
The reservoir for star formation

Planck measures the reservoir



Previous talk by Miville-Deschênes

W3: a star-forming Giant Molecular Cloud

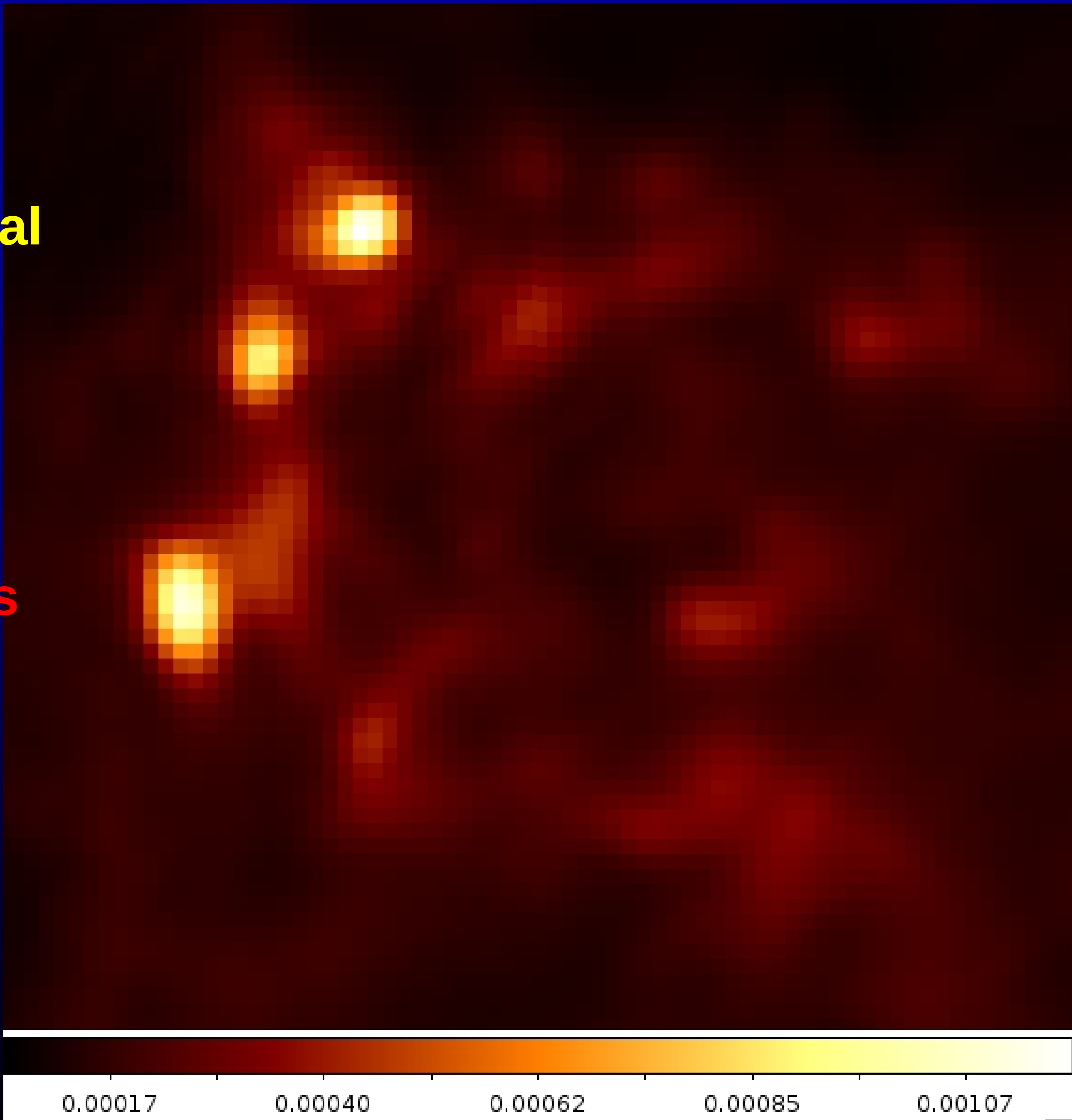


from Canadian Galactic Plane Survey: H I channels and radio continuum (J. English)

W3 GMC

Planck dust optical depth at 5' resolution ~ 2 degree field

Miville-Deschênes earlier talk



W3 GMC

Herschel:
Blue 70 µm
Green 160 µm
Red 250 µm
ESA enhanced rendition: see Herschel latest news

Rivera-Ingraham et al. 2013, HOBYS

Herschel KPs: surveys of known star-forming molecular clouds and the Galactic plane

Herschel studies at higher resolution in targeted molecular clouds:

Gould Belt GBS: Andre et al. 2010

High-mass stars HOBYS: Motte et al. 2010

Also a Galactic plane survey,

full 360 degrees in longitude, but |b| < 1 degree.

Hi-GAL: Molinari et al. 2010

Herschel image offsets

To measure total dust intensity (and ultimately study τ_ν and β) all Herschel images need a zero-point offset, as can be provided by a combination of Planck in the submillimetre and IRAS in the far infrared.

Bernard, Paradis, et al. 2010

P63: Schulz (implementation in SPIRE pipeline in HIPE 10)

Planck cold clumps blind survey

Blind all-sky survey (C3PO).
Compact regions colder than their surroundings;
possible early stages leading to star formation.

Planck early results. XXIII. The first all-sky survey of Galactic cold clumps

Follow-up with Herschel:
Planck early results. XXII. The submillimetre properties of a sample of Galactic cold clumps
Juvela, Ristorcelli, et al. 2012
Session 12 talk by Montier

Origin of this high density structure

Review: Hennebelle and Falgarone 2012

“Turbulent” structure

“Column density” maps reveal complex structure.

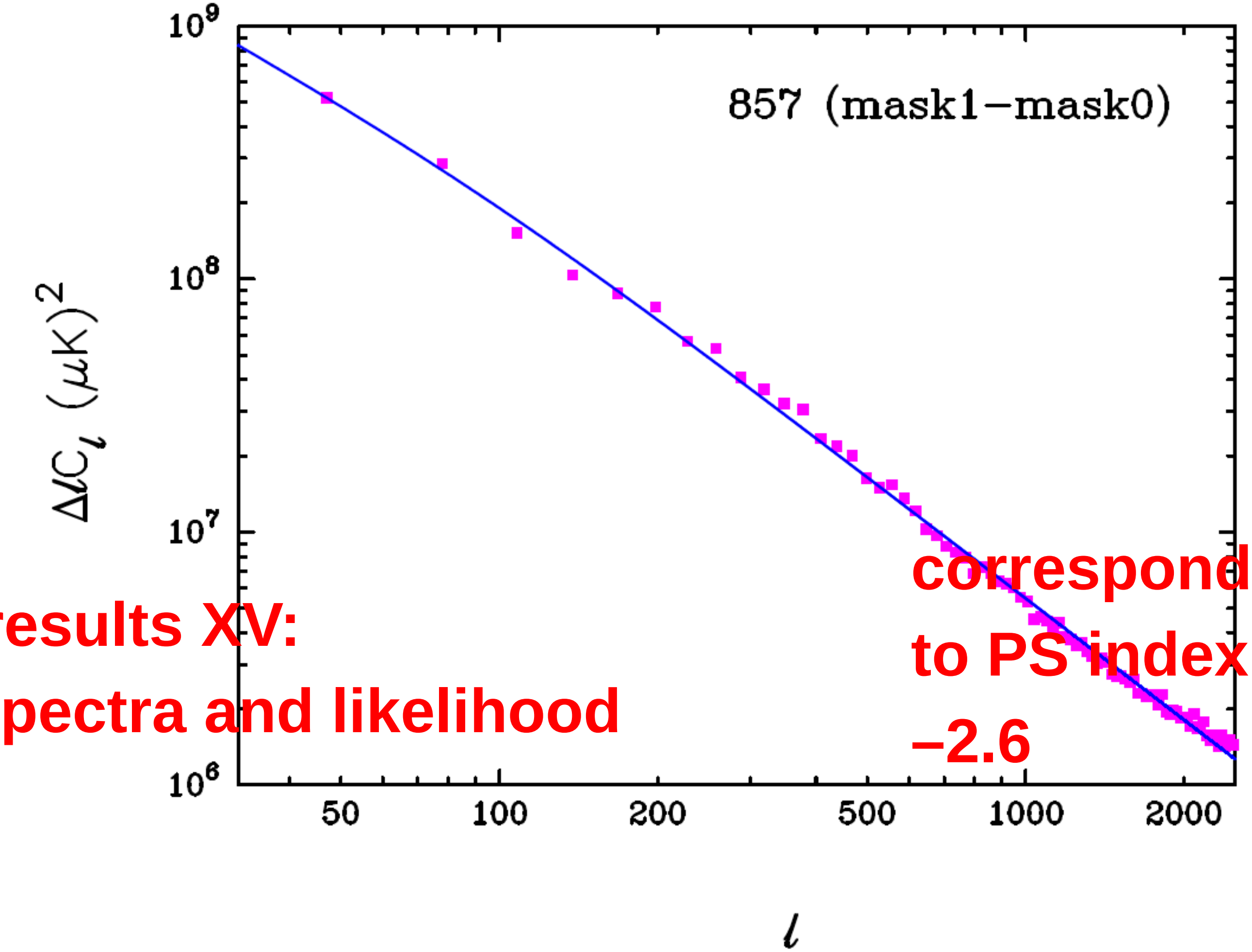
The 1-D power spectrum of the image is a power law, decreasing to high spatial frequency (small scales).

Broadly suggestive of a turbulent influence (with magnetic fields). Numerical simulations needed to follow the physics and chemistry.

Characterizing structure – dust

Mask power spectrum difference from dust emission.

Planck 2013 results XV: CMB power spectra and likelihood

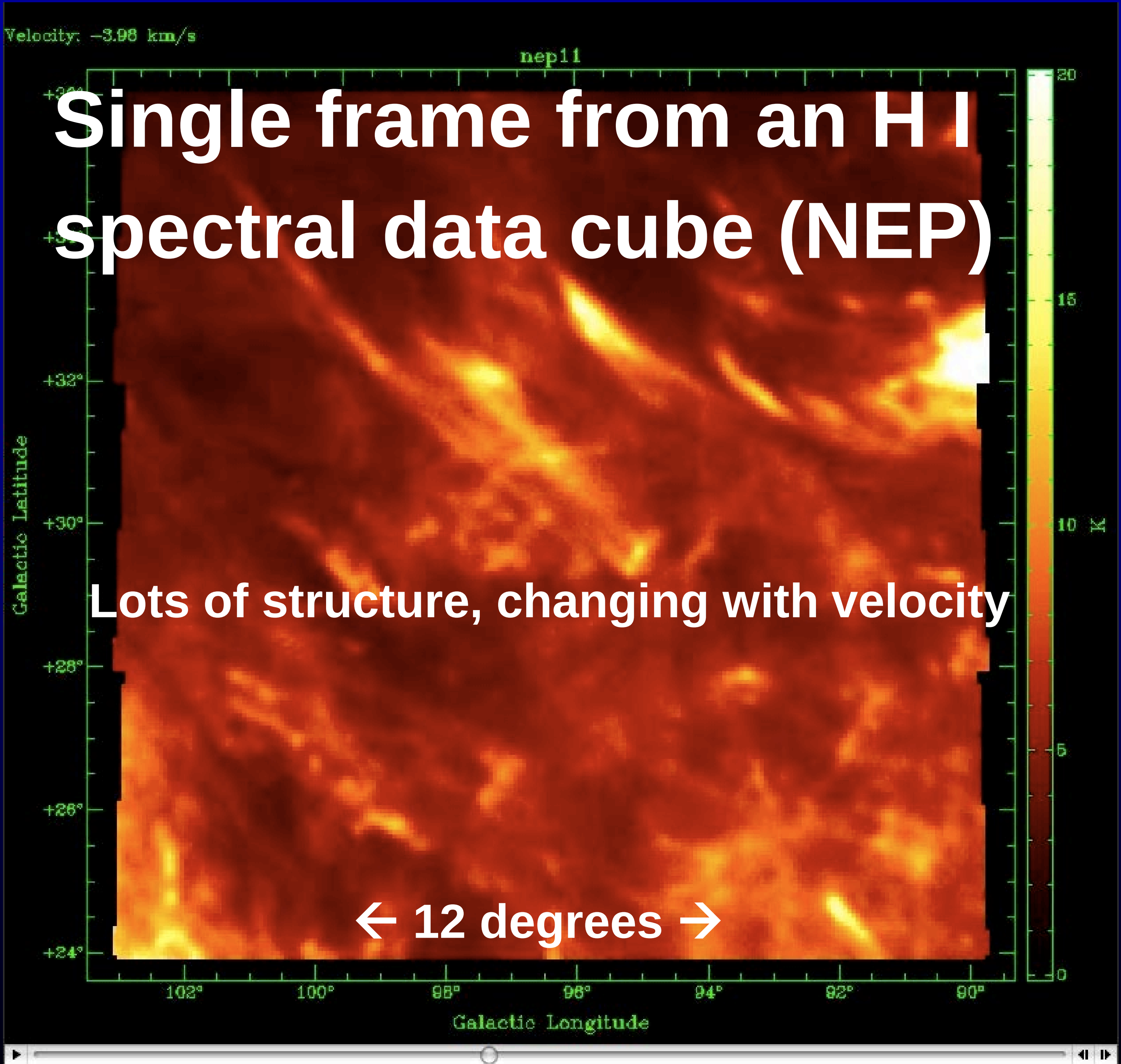


corresponds to PS index –2.6

Figure 4. 857 GHz mask-differenced power spectrum (points), interpreted as Galactic dust emission. The solid line shows the best-fit model defined by Eq. 9.

Check against power spectrum of gas

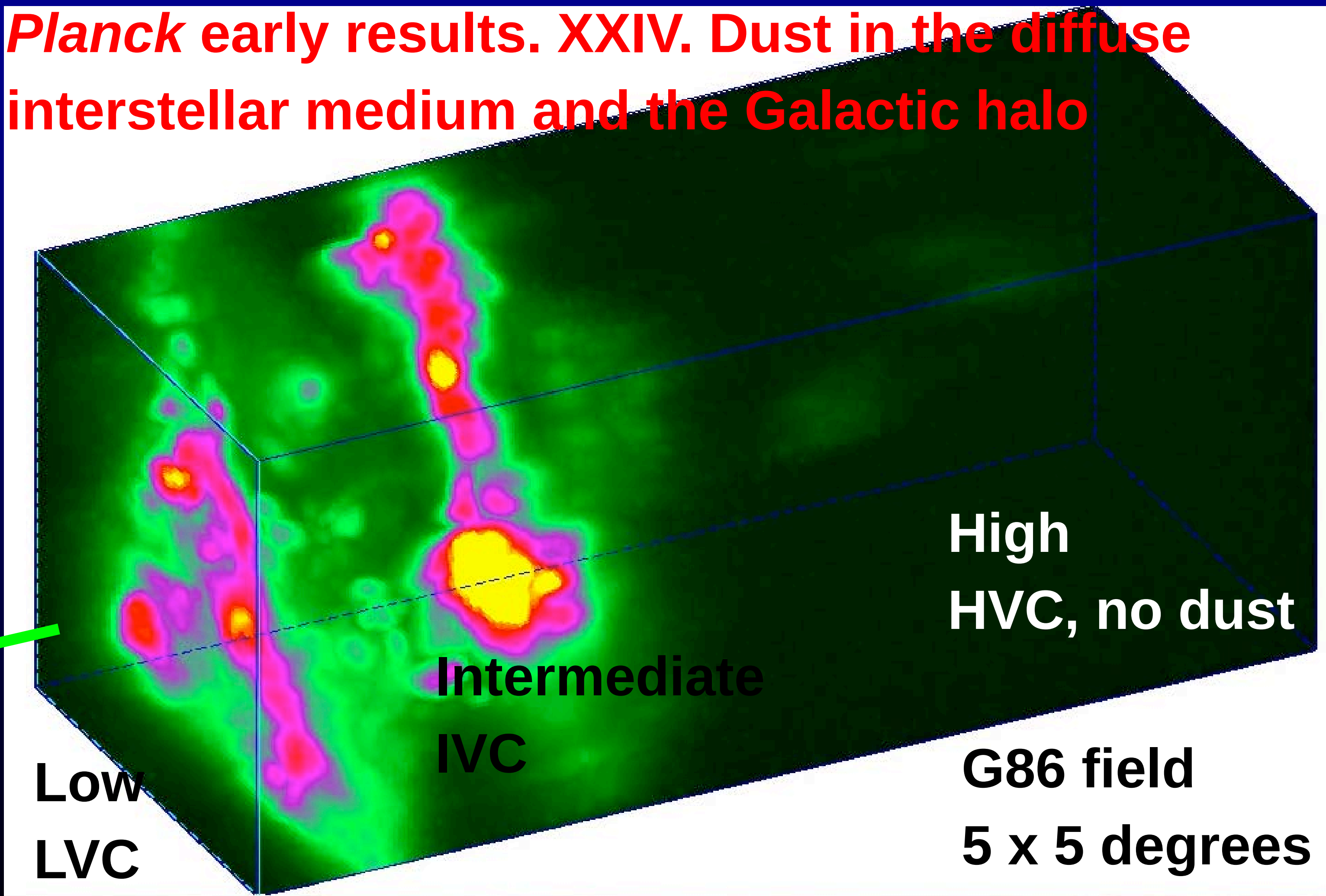
Single frame from an H I spectral data cube (NEP)



Rendered H I cube to show different LSR velocity ranges

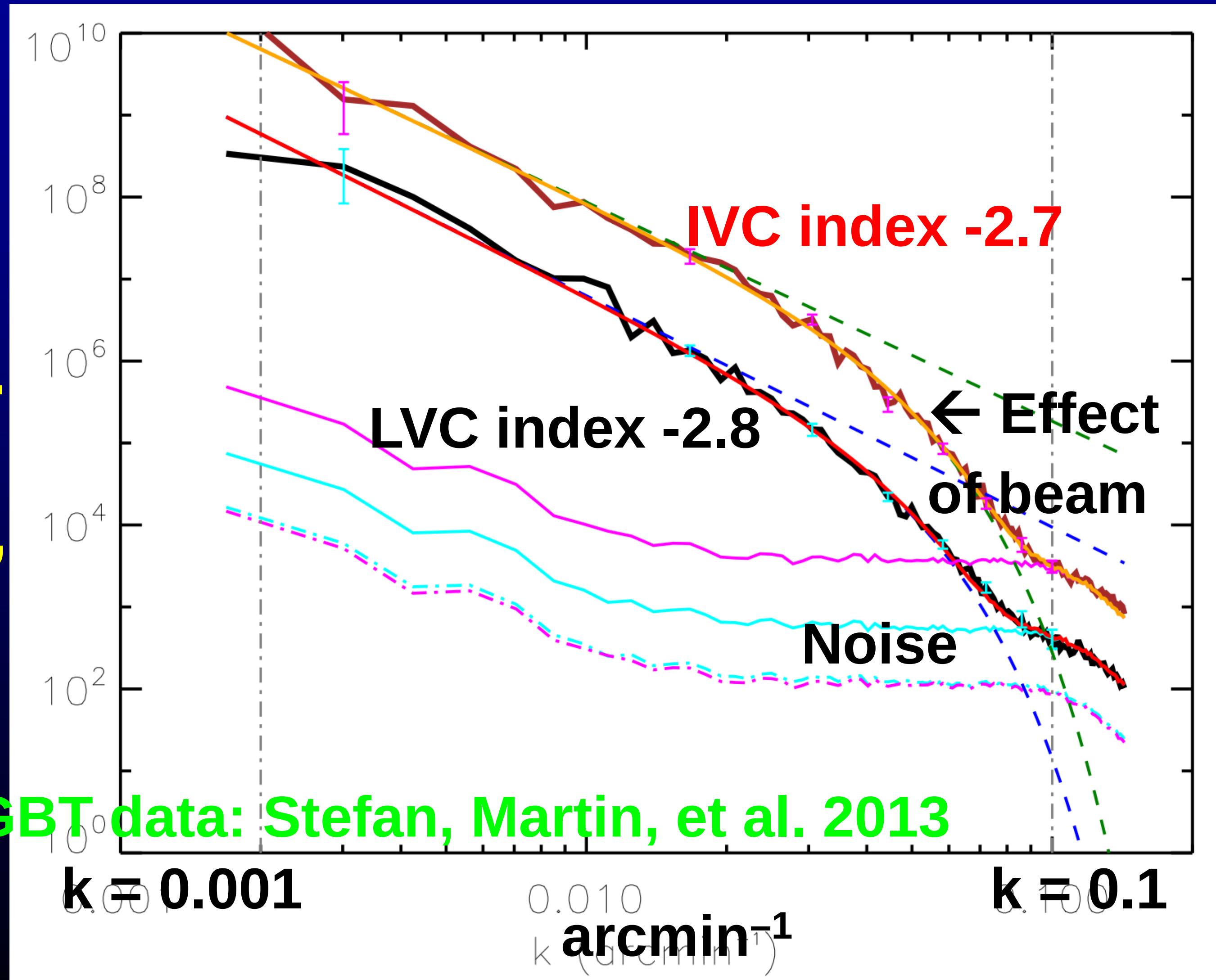
Dust is well correlated with the LVC and IVC gas:

***Planck* early results. XXIV. Dust in the diffuse interstellar medium and the Galactic halo**



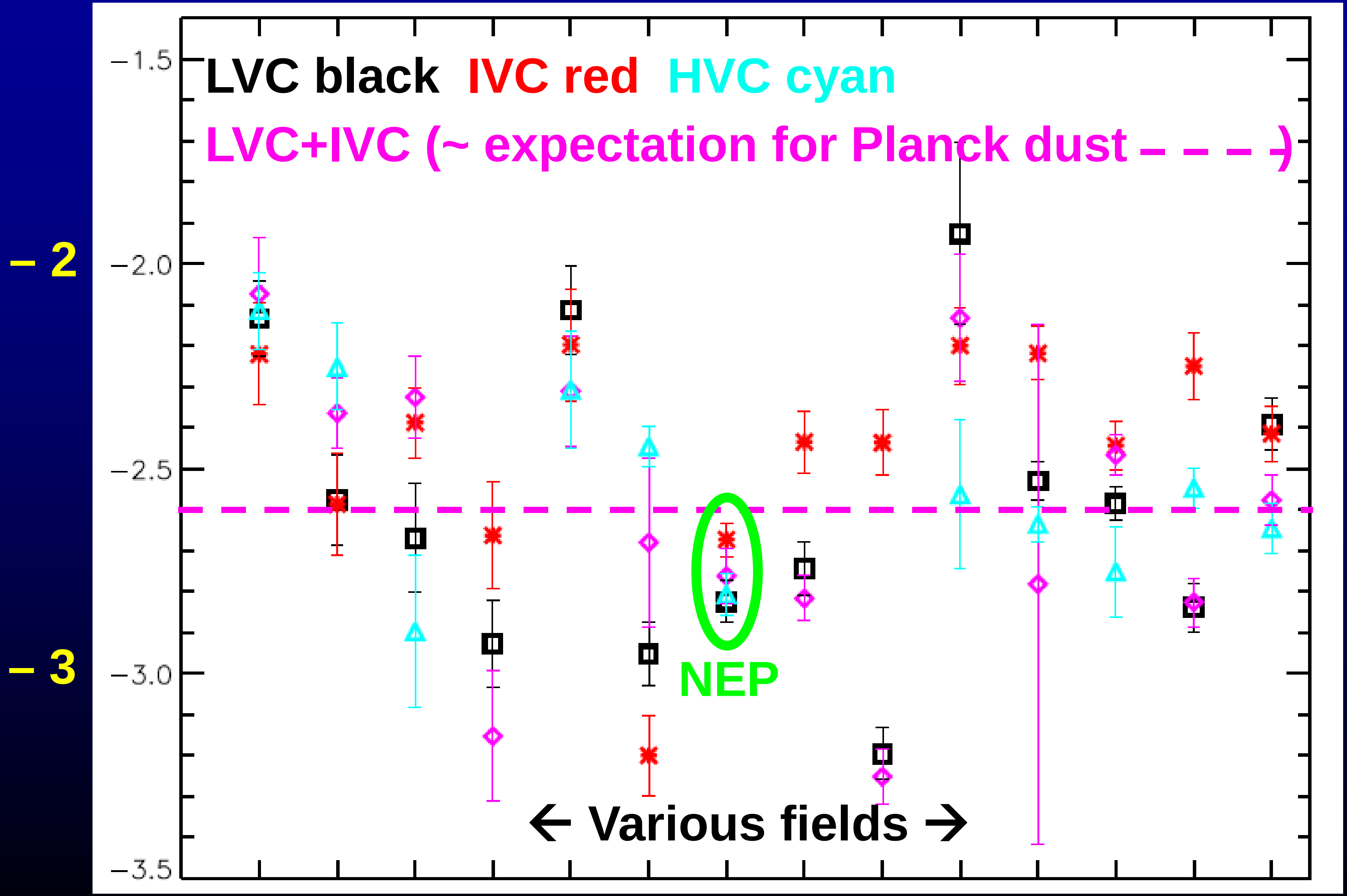
Characterizing structure – H I

Power spectrum of H I column density, LVC and IVC. North Ecliptic Pole, 12 x 12 deg.



Analysis of GBT data: Stefan, Martin, et al. 2013

Index for different parcels of gas, many different linear scales



From a diffuse medium to condensed structures

Two major transitions:

1) From warm neutral gas (WNM) to cold H I (CNM), via thermal instability. Study numerically to see what fraction is in each form and what conditions would give rise to the observed power spectrum index ~ – 2.6.

Saury, Miville-Deschênes, et al. 2013.

2) Atomic to molecular gas, with CO cooling to even lower temperatures. Planck CO.

What is the role of the magnetic field in determining the structure?

Planck all-sky CO product

CO emission integrated over velocity: W(CO).

Out of the Galactic plane, CO emission extends well beyond the known boundaries of molecular clouds, providing an opportunity to study the transition region where gas is becoming molecular. And the nature of the "dark gas."

Planck 2013 results. XIII. Galactic CO emission

Session 7 talk by Combet (including PIP #58)

“Dark gas” phenomenon

“Excess” dust emission, dust optical depth not correlated with detectable gas tracers, H I or CO.

Planck early results. XIX. All-sky temperature and dust optical depth from *Planck* and IRAS – constraints on the “dark gas” in our Galaxy. Also Session 12 Grenier.

Possible reasons for “excess:”

→ transition phase where H_2 (invisible) survives photodissociation but CO does not. → X(CO) is higher than assumed: CO-dim gas; more gas (dust) than traced.

→ atomic gas underestimated due to self-absorption of H I line in relatively cold gas; more dust than traced.

→ dust with higher opacity/H than standard assumed; no extra “dark” gas or dust.

Opacity: ability of a parcel of ISM material to emit

Intensity of optically thin dust emission:

$I_\nu = \tau_\nu B_\nu(T)$. Expand $\tau_\nu \rightarrow$

$I_\nu = \kappa_\nu$ [Dust/Gas] μm_H N_H $B_\nu(T)$.

where κ_ν is the opacity of the dust material, in cm^2/gm.

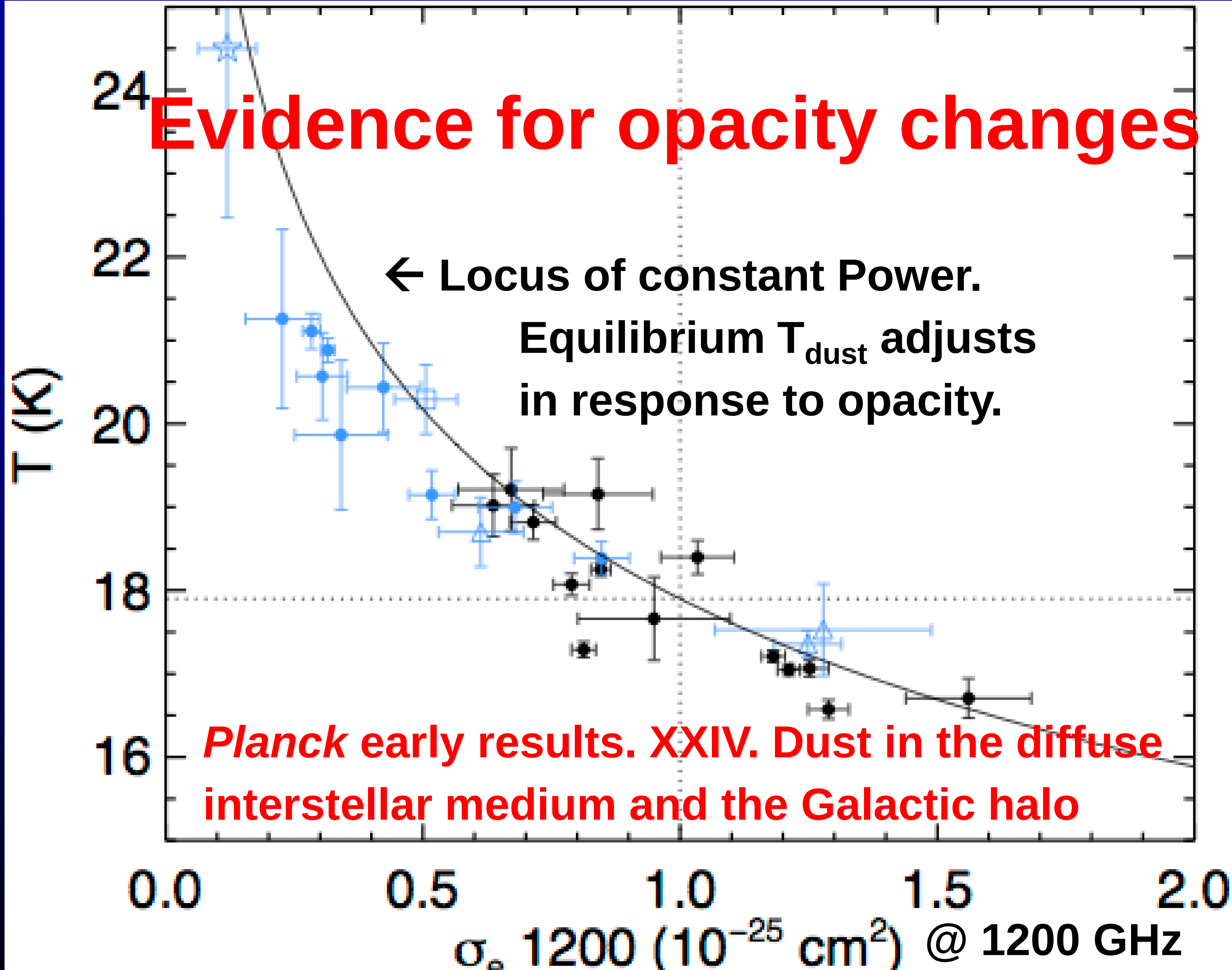
Dust is mixed with gas.

Define another opacity σ_ν, in different units cm^2/H, a property of the dust + gas mixture.

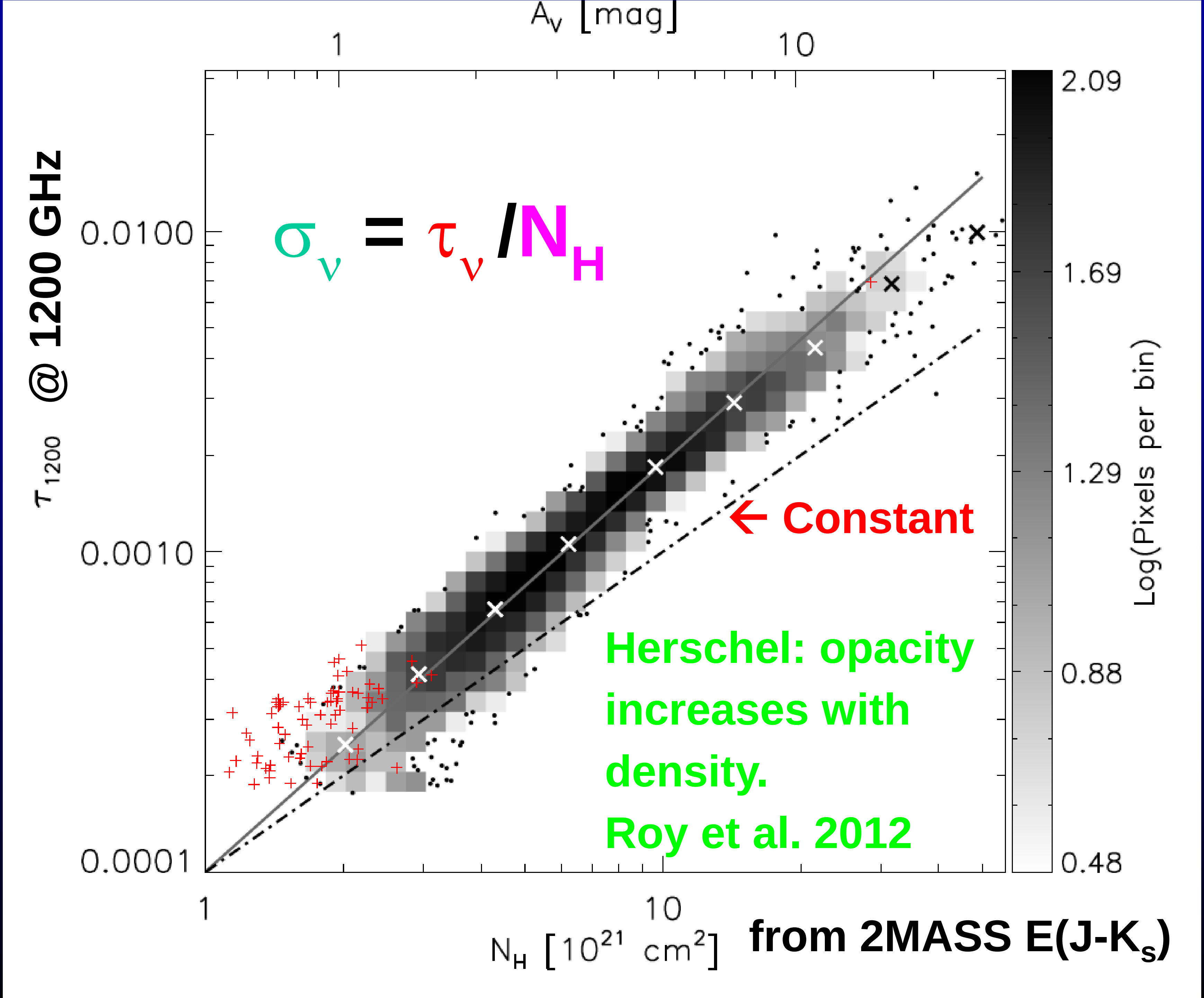
$\sigma_\nu = \kappa_\nu$ [Dust/Gas] $\mu m_H = \tau_\nu / N_H$.

Changes of dust opacity

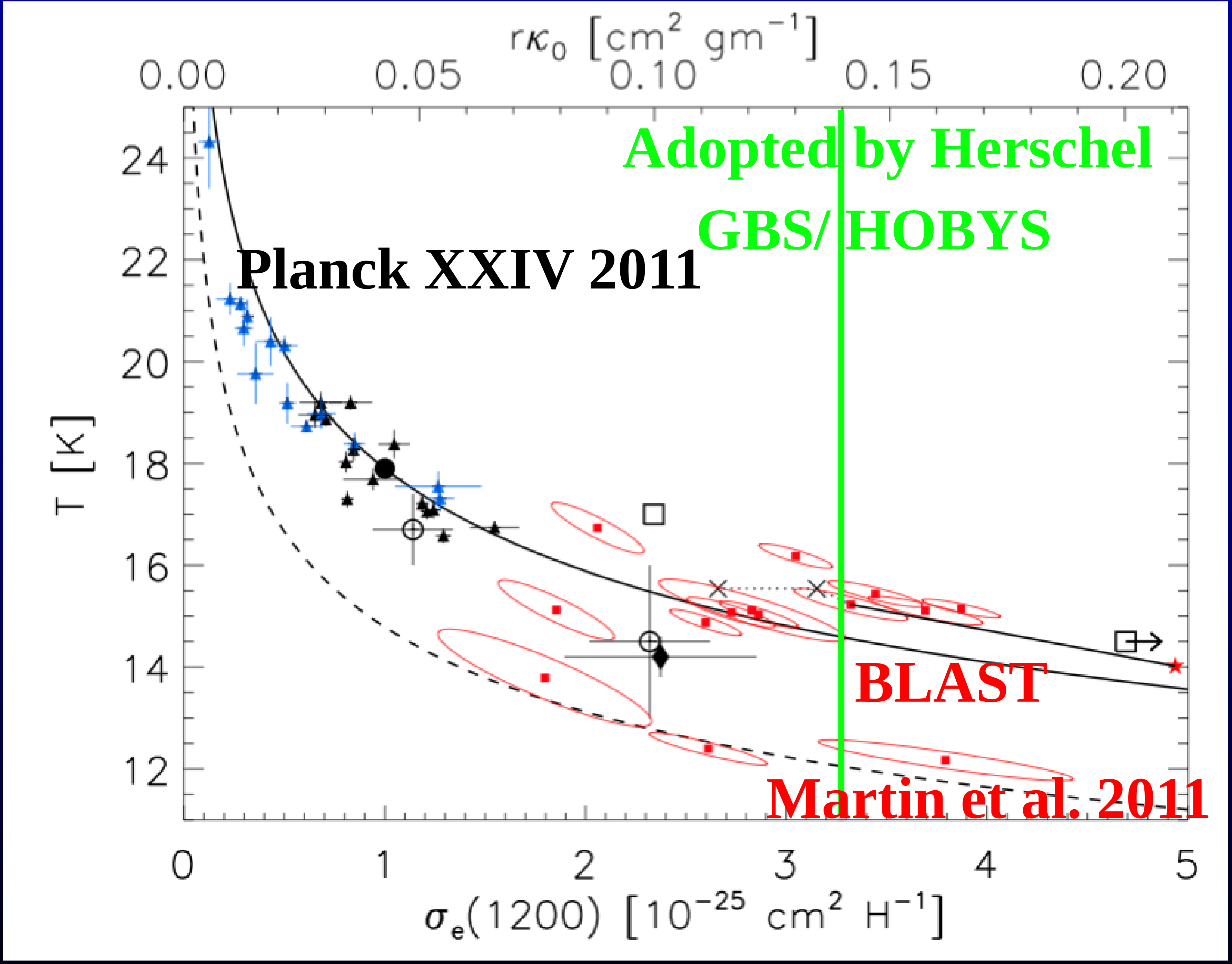
Evidence for opacity changes



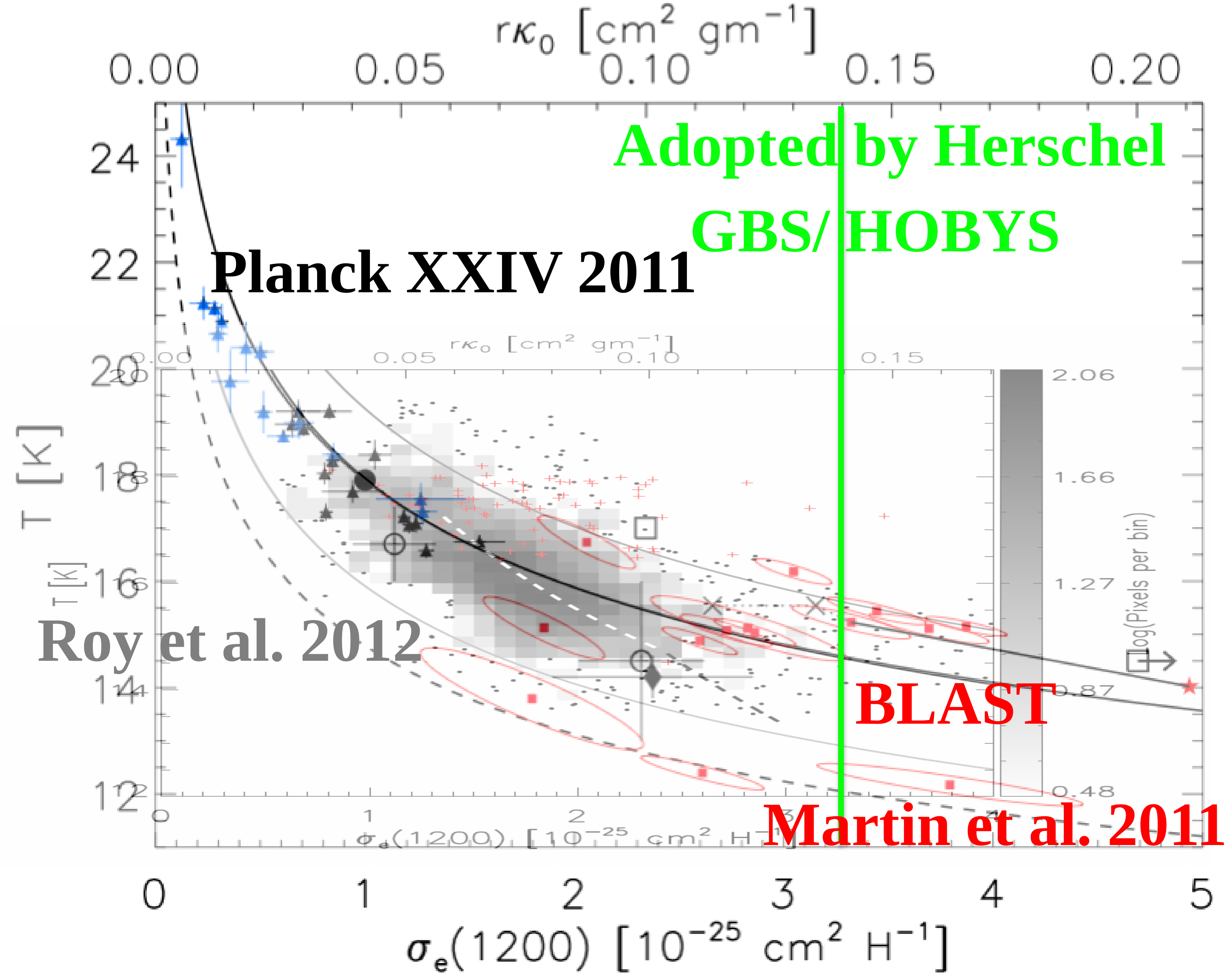
Planck early results. XXIV. Dust in the diffuse interstellar medium and the Galactic halo



$\sigma_\nu = \tau_\nu / N_H$
← Constant
Herschel: opacity increases with density.
Roy et al. 2012
A_V [mag]
1
10
τ_{1200} @ 1200 GHz
0.0100
0.0010
0.0001
1
10
N_H [10^{21} cm^2]
from 2MASS E(J-K$_s$)
2.09
1.69
1.29
0.88
0.48
Log(Pixels per bin)



rκ0 [cm2 gm-1]
0.00
0.05
0.10
0.15
0.20
Adopted by Herschel
GBS/ HOBYS
Planck XXIV 2011
24
22
20
18
16
14
12
T [K]
BLAST
Martin et al. 2011
0
1
2
3
4
5
σe(1200) [10-25 cm2 H-1]



$r\kappa_0$ [cm^2 gm^{-1}]
0.00
0.05
0.10
0.15
0.20
Adopted by Herschel
GBS/ HOBYS
Planck XXIV 2011
T [K]
24
22
20
18
16
14
12
Roy et al. 2012
BLAST
Martin et al. 2011
log(Pixels per bin)
2.06
1.66
1.27
0.87
0.48
0
1
2
3
4
5
$\sigma_e(1200)$ [10^{-25} cm^2 H^{-1}]

Impact on masses

Need to know the appropriate value of the opacity to convert dust optical depth to gas column density.

$N_H = \tau_\nu / \sigma_\nu$.

Masses of compact objects (cores, clumps, filaments) extracted from submillimetre maps, and thus our assessment of their gravitational state, are affected (depend inversely on adopted opacity).

Motivated by Planck: another probe of dust – scattered light in the optical

Light scattering by high-latitude dust

The integrated light from stars below in the Galactic plane illuminates the cloud (Sandage 1976).

The brightness is a fraction of a percent of the terrestrial night sky, but structure can now can be brought out easily with modern optimally-coated fast lenses in front of CCD detectors.

Scattered light: new horizons

Higher spatial resolution (3” to 6”) for studies of morphology.

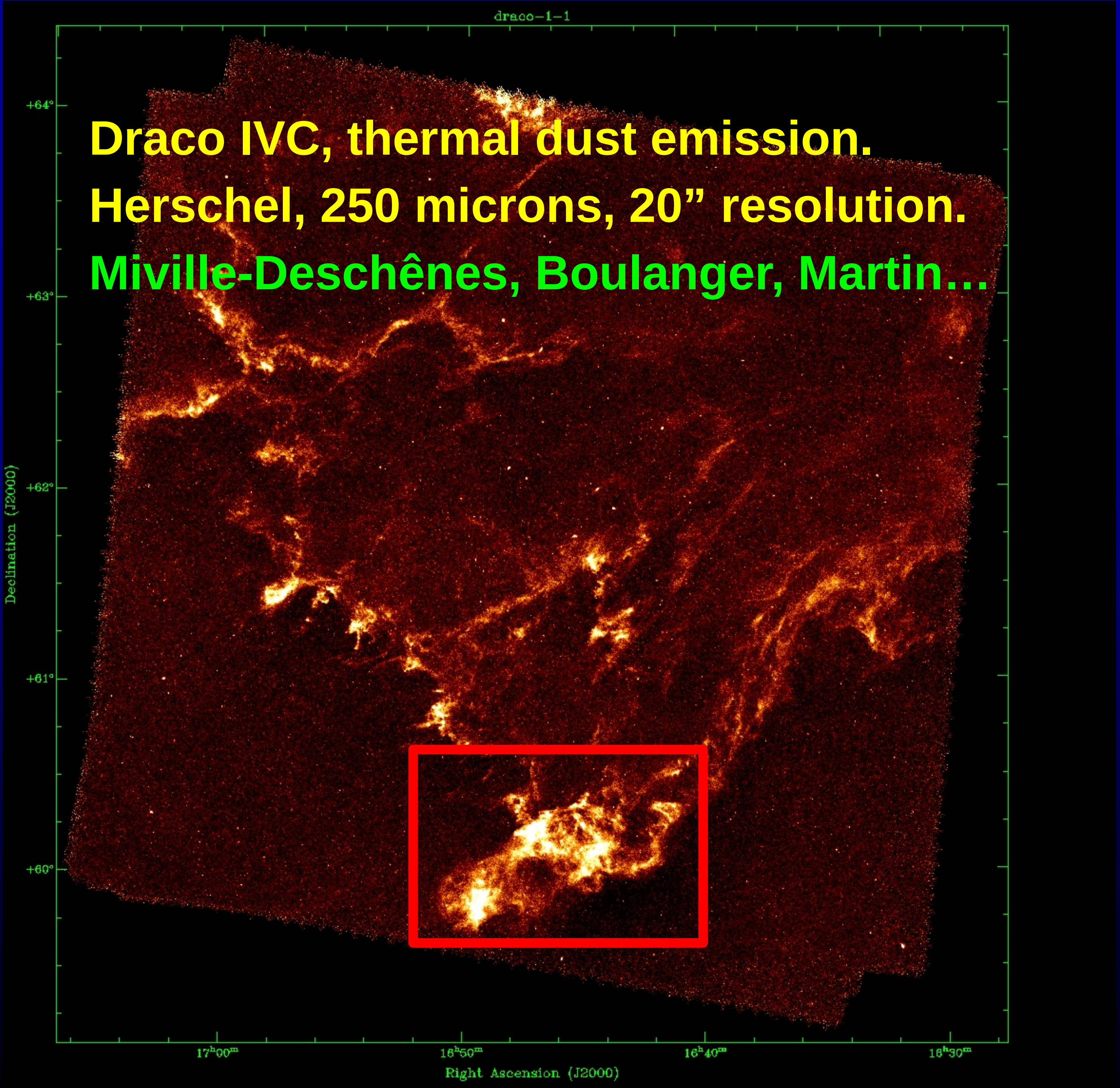
A consistency check on the strength of the interstellar radiation field that powers the dust emission.

Scattering is sensitive to the amount of dust and grain size and composition → a new handle on dust evolution in regions where we see opacity changes in the submillimetre (including dust in “dark gas” regions) but where we can’t get corresponding extinction data because column densities are so low.

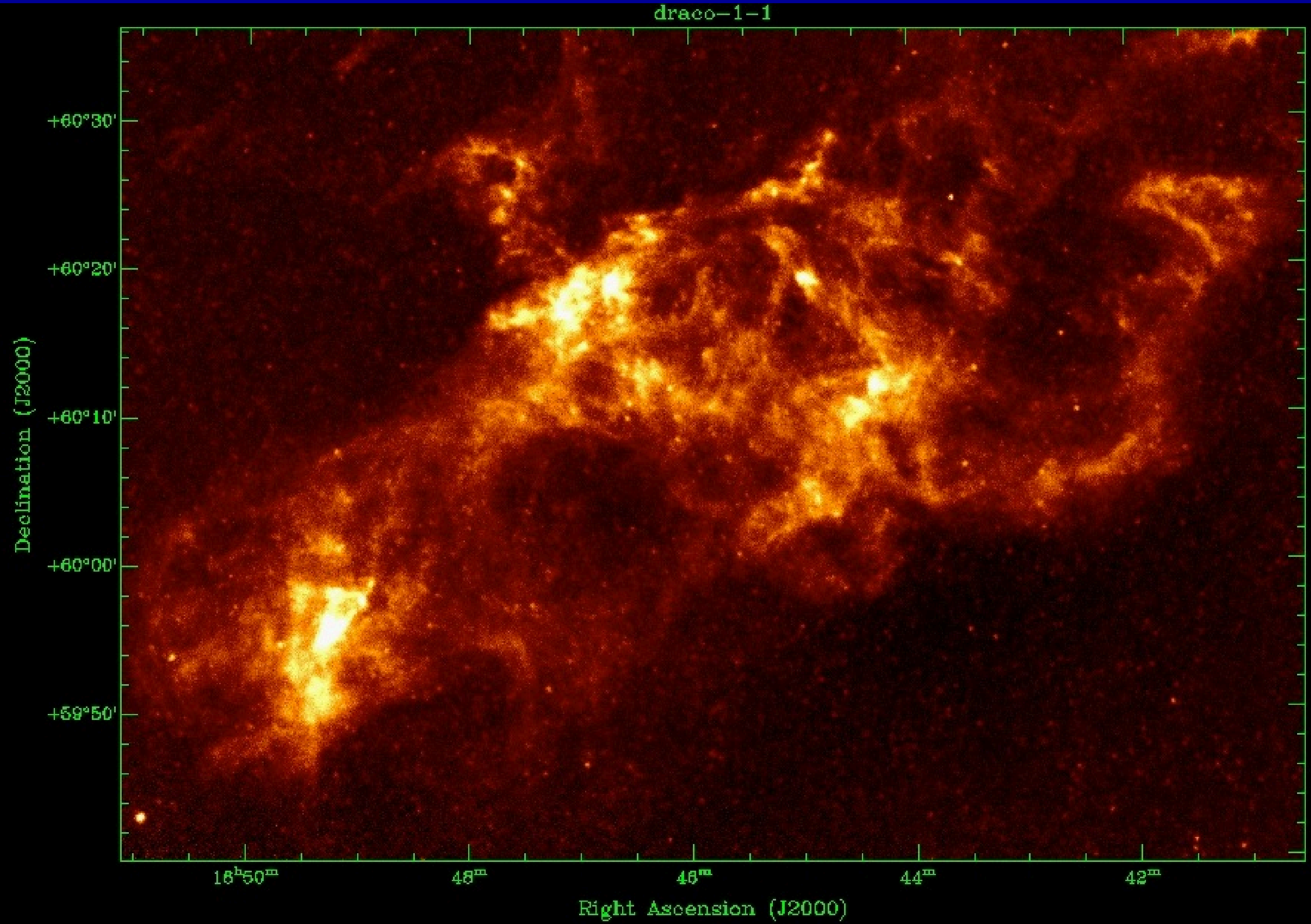
Trial target: an "IVC" crashing into the Galactic disk

DRACO nebula. Scattered light already detected: POSS and Witt 2008.
One of our Planck/GBT regions: Planck early results. XXIV.
See also poster P26 Lenz.

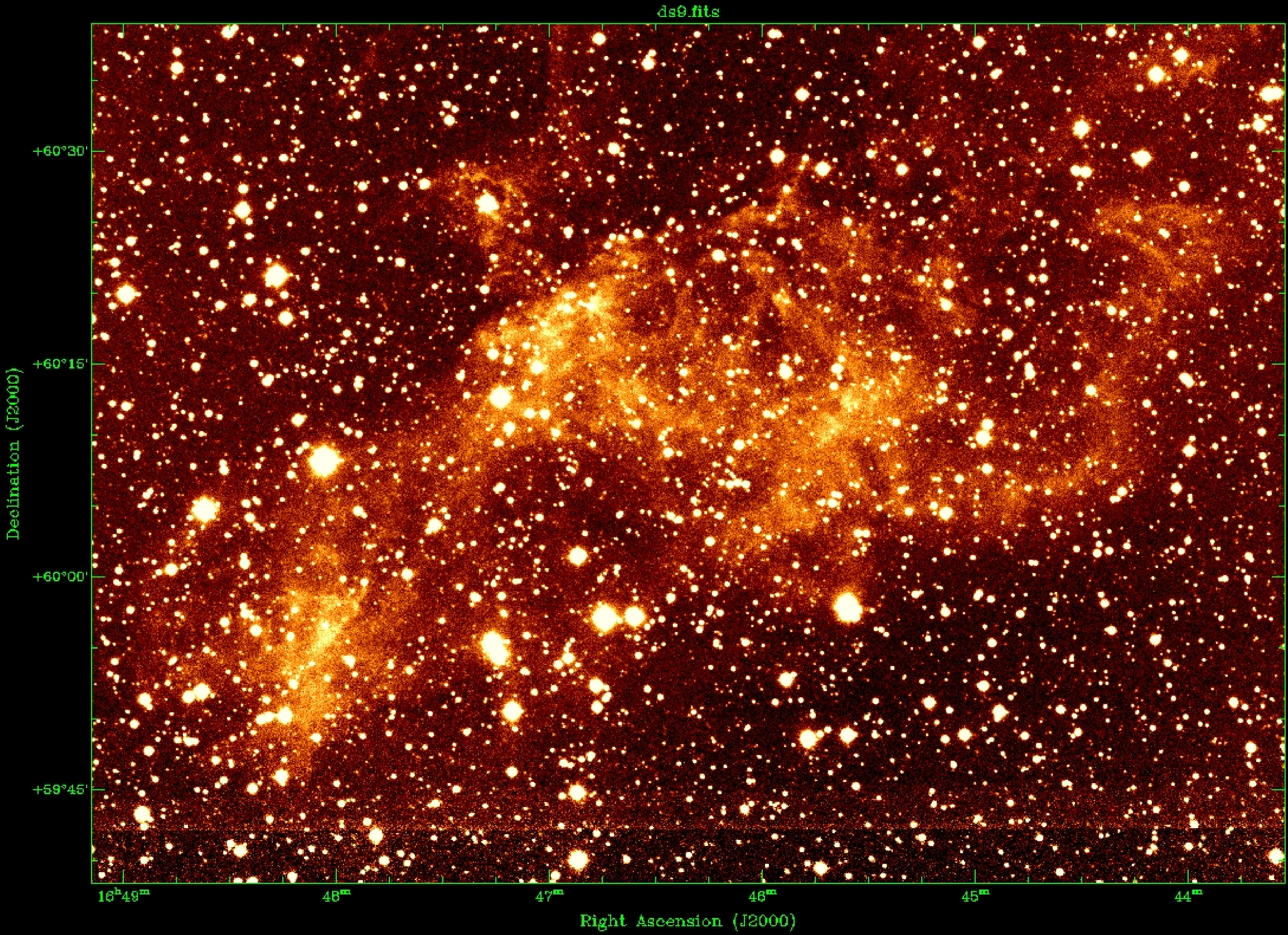
Herschel imaging offers higher resolution, an opportunity to examine the "working surface." Development of instabilities. Transition between atomic and molecular gas.


draco-1-1
Draco IVC, thermal dust emission.
Herschel, 250 microns, 20” resolution.
Miville-Deschênes, Boulanger, Martin…
+64°
+63°
+62°
+61°
+60°
Declination (J2000)
17h00m
16h50m
16h40m
16h30m
Right Ascension (J2000)

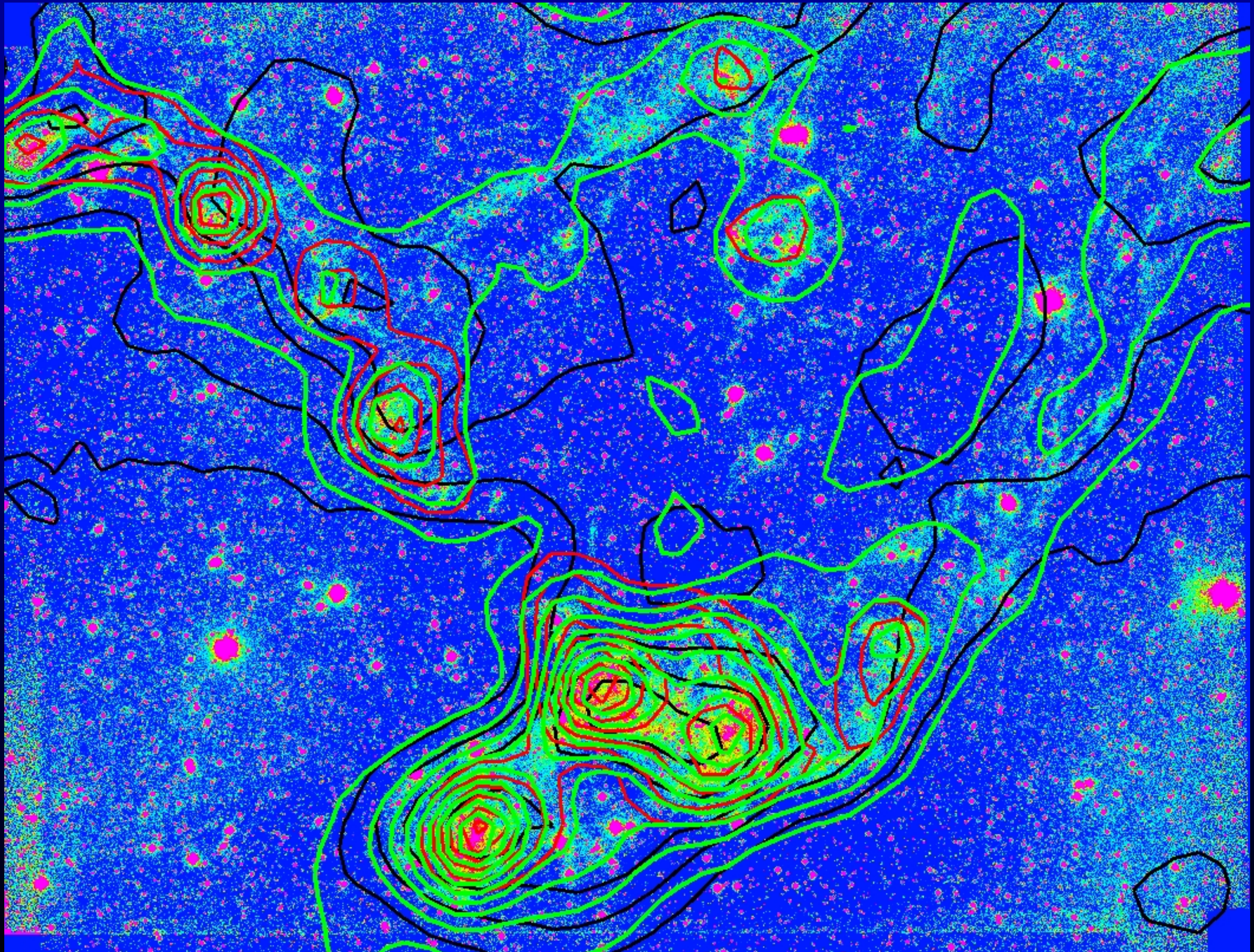
Herschel zoomed in for detail



Scattered light in quick Dragonfly test image



Scattered light coincides with Planck τ, with CO at peaks



← dust emission that signals "dark gas"

Contours:
Green τ
Red CO
Black H I (IVC)

Project Dragonfly

The above was a short trial exposure at poor elevation with a single prototype of Project Dragonfly (now ten systems).

Developed by Abraham (U Toronto) and van Dokkum (Yale), to search for the "cosmic web."

FOV 2 by 3 degrees.

Figure 1: R. Abraham with the 3-lens Prototype Dragonfly Array deployed at the New Mexico Skies telescope hosting facility. Three Canon 400/2.8 lenses are mounted at left, with a 200/2.8 wide-field patrol camera mounted at right for rapid monitoring of airglow variations.

Anomalous microwave emission (AME)

Anomalous microwave emission

New component of Galactic emission – S4: Davies

***Planck* early results. XX. New light on anomalous microwave emission from spinning dust grains**

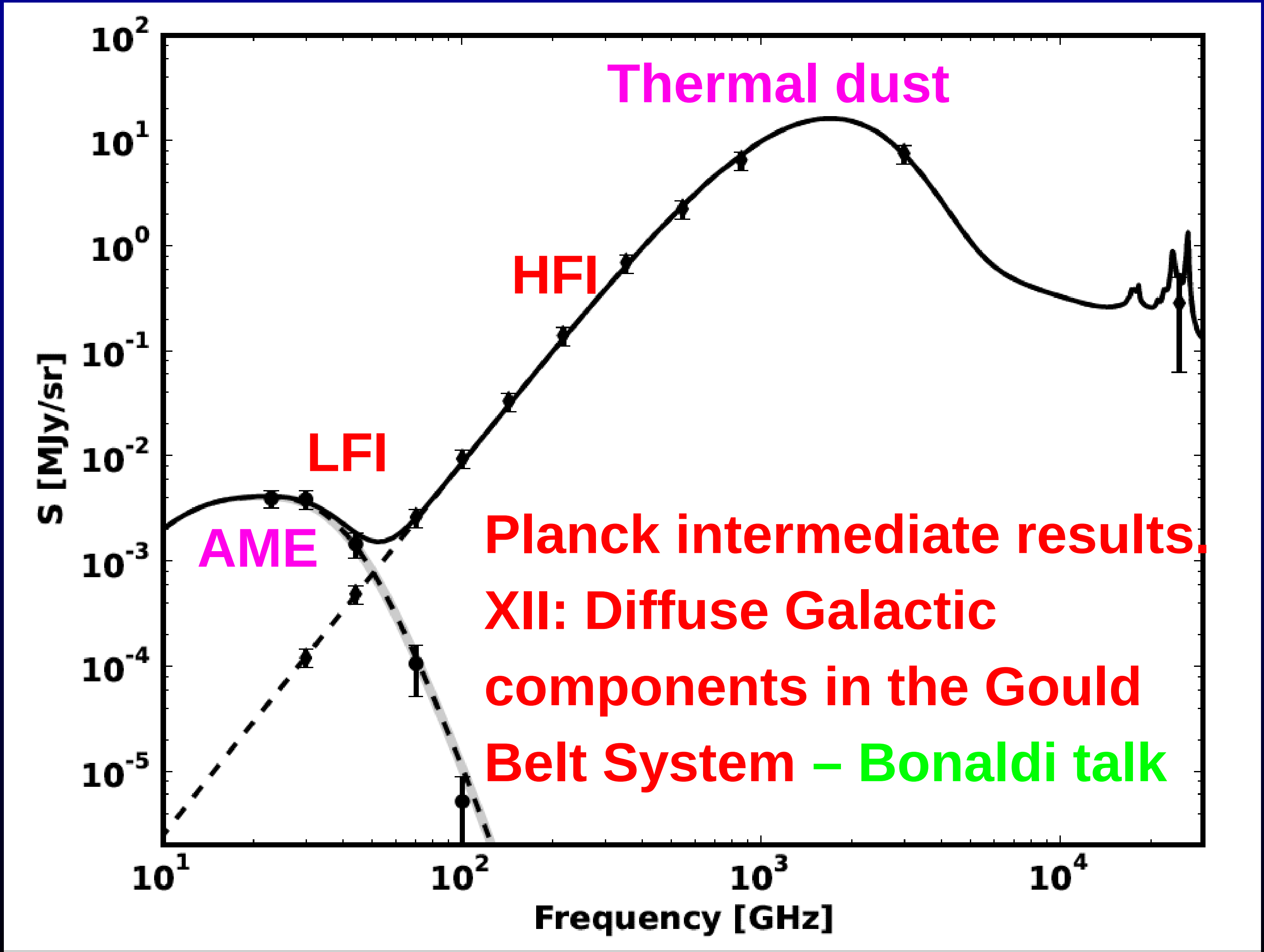
***Planck* early results. XXI. Properties of the interstellar medium in the Galactic plane**

***Planck* intermediate results. XII: Diffuse Galactic components in the Gould Belt System – S7: Bonaldi**

Session 7: Dickinson, A study of AME in Galactic clouds with Planck (PIP #77)

AME spectrum

Peaks at 25 GHz



Anomalous microwave emission

Correlated with thermal dust emission.

If spinning dust, very small particles possibly related to the carriers of the UIR near-IR emission bands.

- **UIR is pumped by ultraviolet (this absorption is part of the observed UV interstellar extinction).**
- **UIR carriers are identified as PAHs or, more generally, amorphous carbon nano-particles.**
- **From UV extinction curve, small particles disappear in molecular clouds outskirts. What about AME carriers?**

Polarization? – Session 7 Genova-Santos and Hoang

Why the interest in very small particles?

Thought to be important for heating the atomic gas, via their photoelectric emission.

Not much mass, but a lot of surface area.
Possibly important for molecule formation.

Planck dust polarization

Forthcoming Planck papers

Talk previously in Session 4 by Boulanger

Talks tomorrow in Session 7 by Bernard and Guillet and Session 9 by Aumont.

Posters: P31 Ghosh, P33 Levrier

Polarization goals

Verify the predicted amount of P/I in submm vs. p/tau in the optical.

Spectrum of polarized flux (like total intensity?).

Magnetic field orientation relative to structures.

Degree of alignment in high-density shielded regions.

Power spectrum.

→ A better understanding of this dusty polarized **foreground** to the CMB (and CIBA).

Future stratospheric balloon experiments with higher angular resolution: SuperBLASTPol, PILOT, … Also SCUBA2Pol on JCMT.

END

Thanks to Planck for the fantastic data and to the Canadian Space Agency for supporting my participation in this grand venture.

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.