# Finding the Fermi Bubble in the microwave bands and the CMB map

*For the workshop:*
*"Three elephants in the gamma-ray sky: Loop I, the Fermi bubbles, and the Galactic center excess"*

Hao Liu and the CMB Group in NBI, Copenhagen

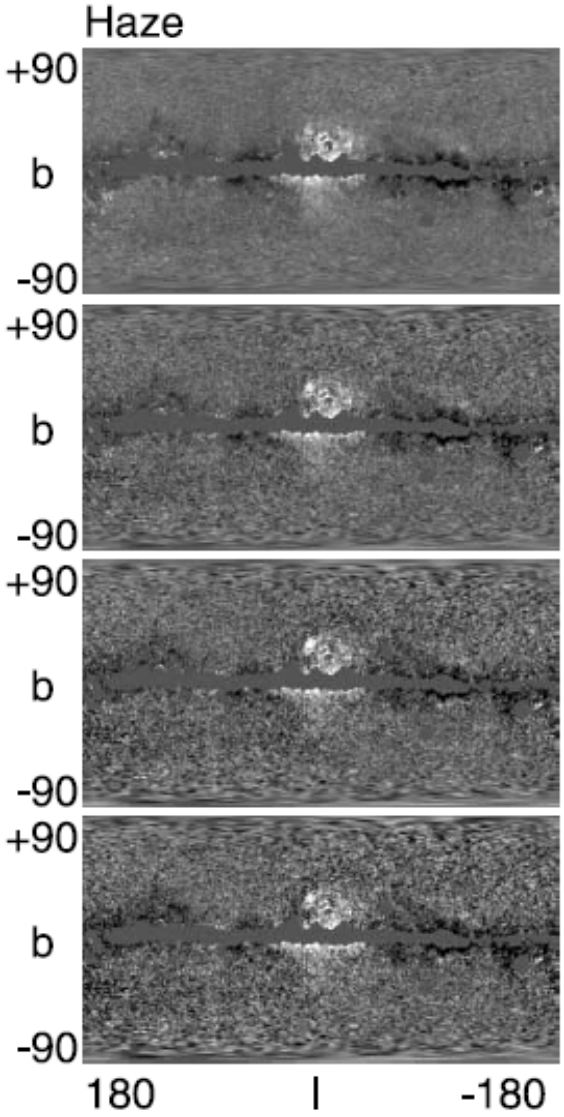
Oct-2017, Garmisch-Partenkirchen

# Fermi Bubble: real “Bubbles”

However, the microwave counterpart is a little bit “naughty”

# The Fermi Bubble and the Microwave Haze

Finkbeiner 2004, APJ 614, 186



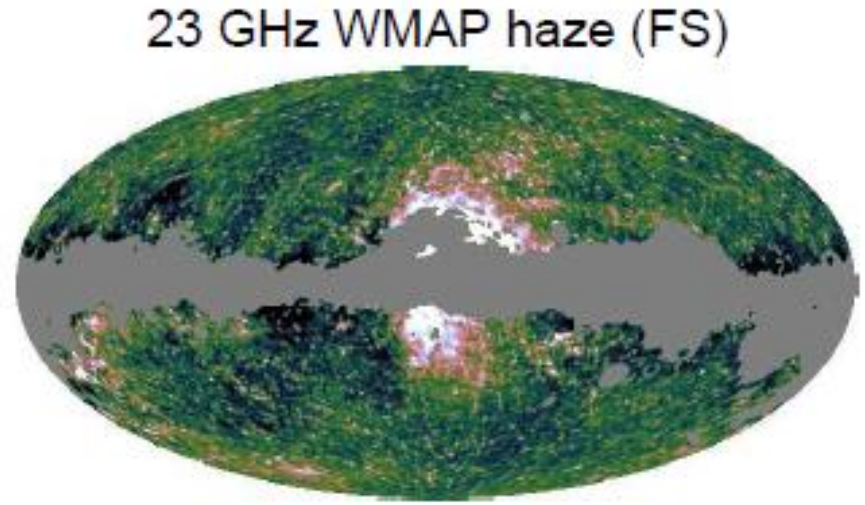

In microwave bands, we see haze/sphere/bar, but not Bubble

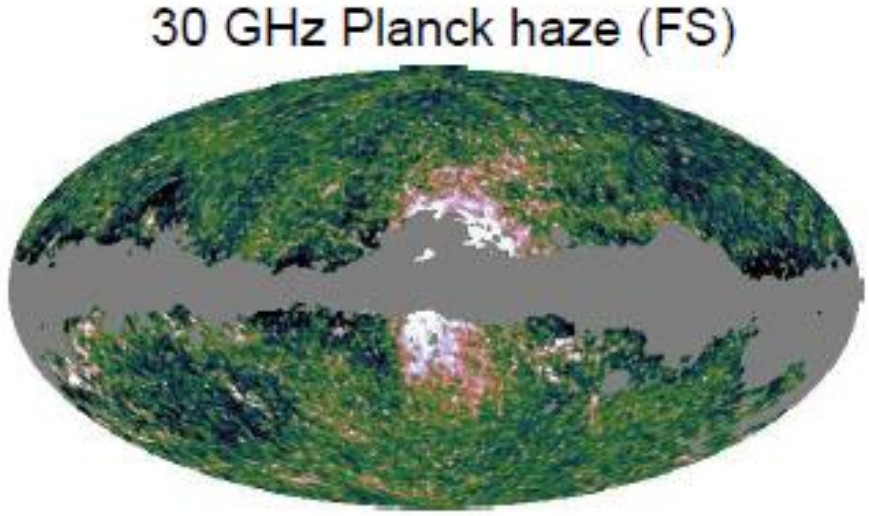
The morphology really matters:

Dark matter annihilation? (Dan Hooper et al., 2007)

A bubble-like morphology will reject this

Planck Intermediate Results. IX. Detection of the Galactic haze with Planck

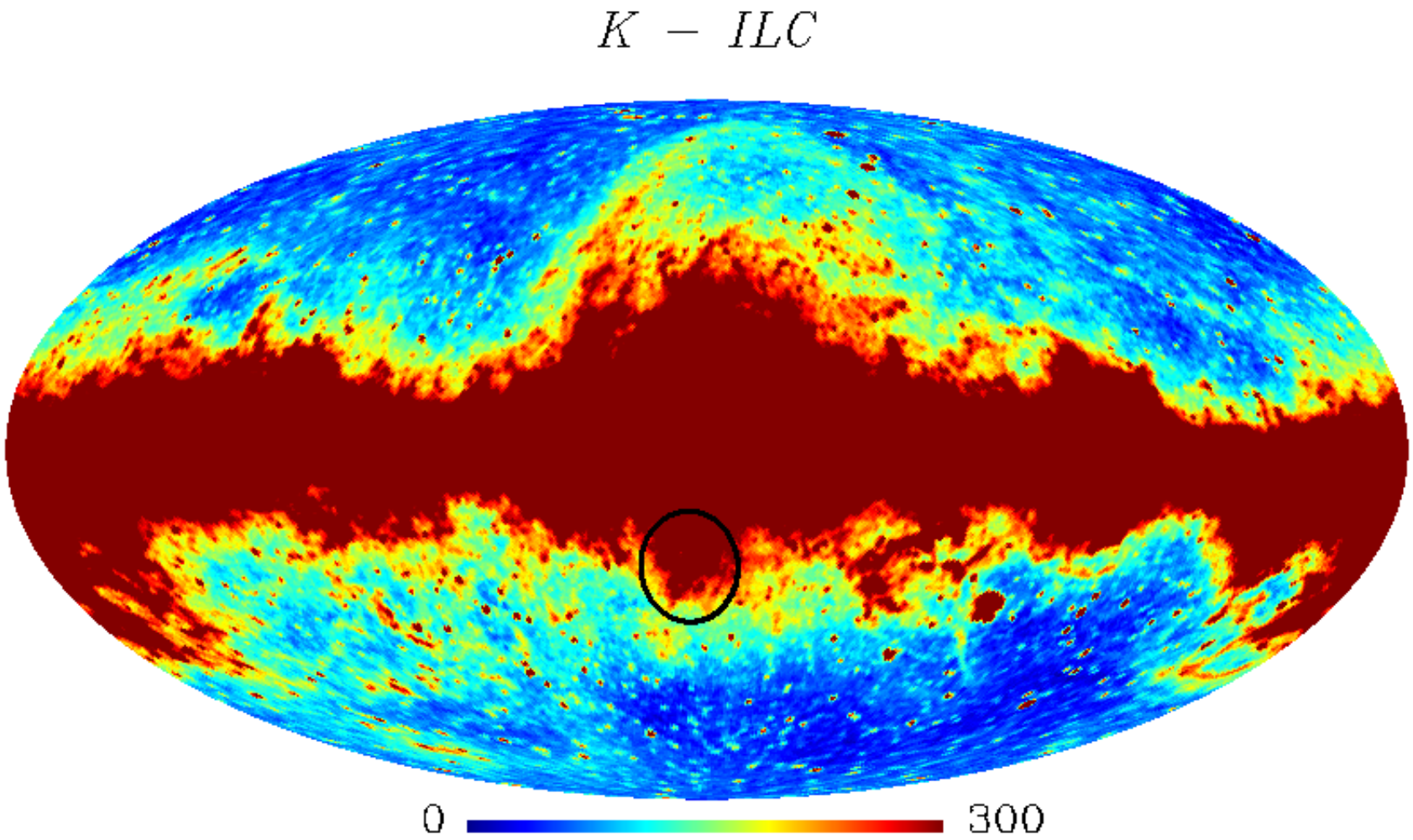


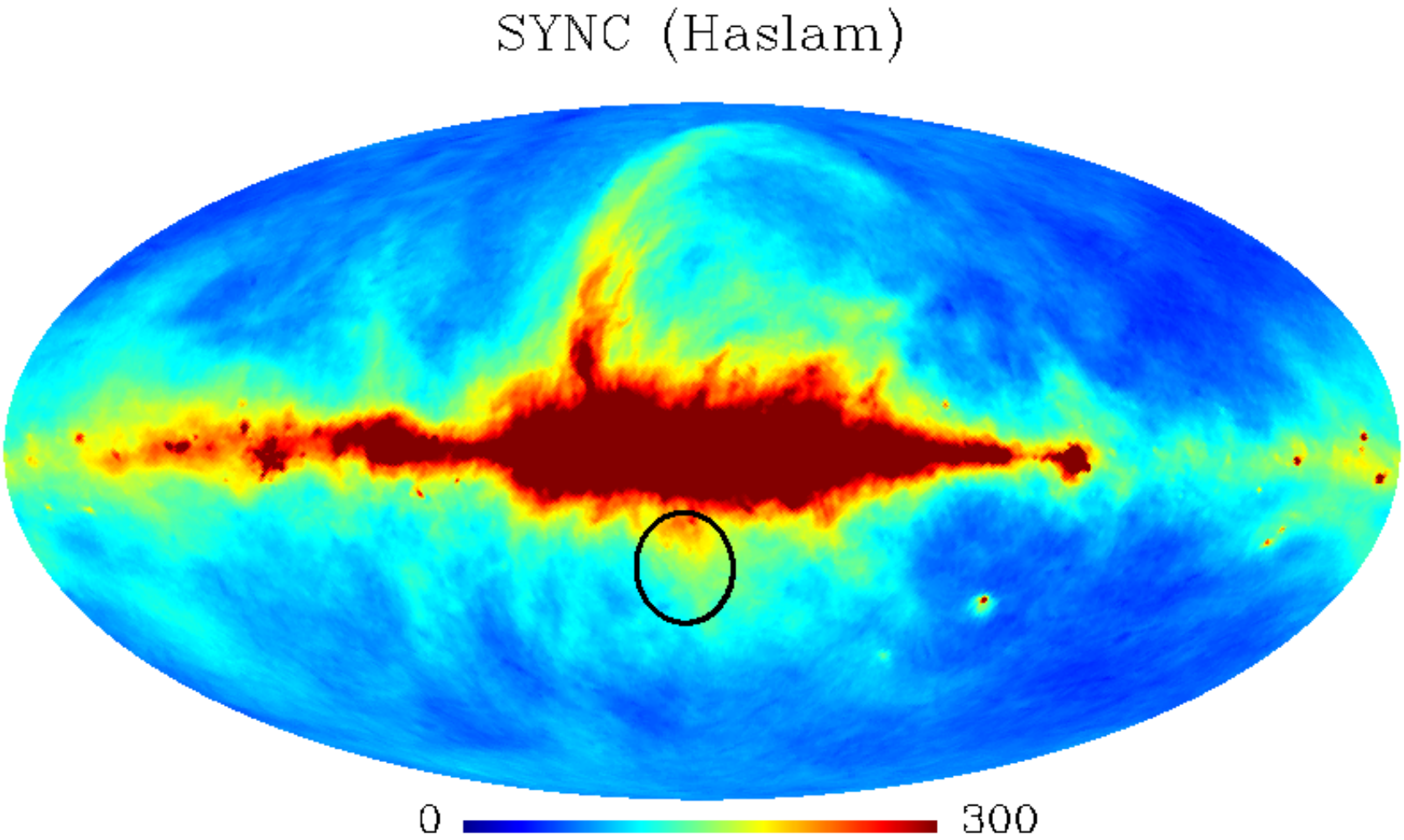
# To get an estimation of the microwave Haze:

- Microwave map at low frequency (20-50) Hz
- Foreground templates
  - Dust, free-free, sync, and others (?)
  - Variation of the spectrum for each one
- A model for Bubble or Haze
  - Fermi $D^3PO$ model
  - Others
- Mask
- There are many, many variants…
- A convenient fact:
  - If there is nothing, then we can not fabricate one out by template fitting
  - If we see “something”, then most likely this is for real

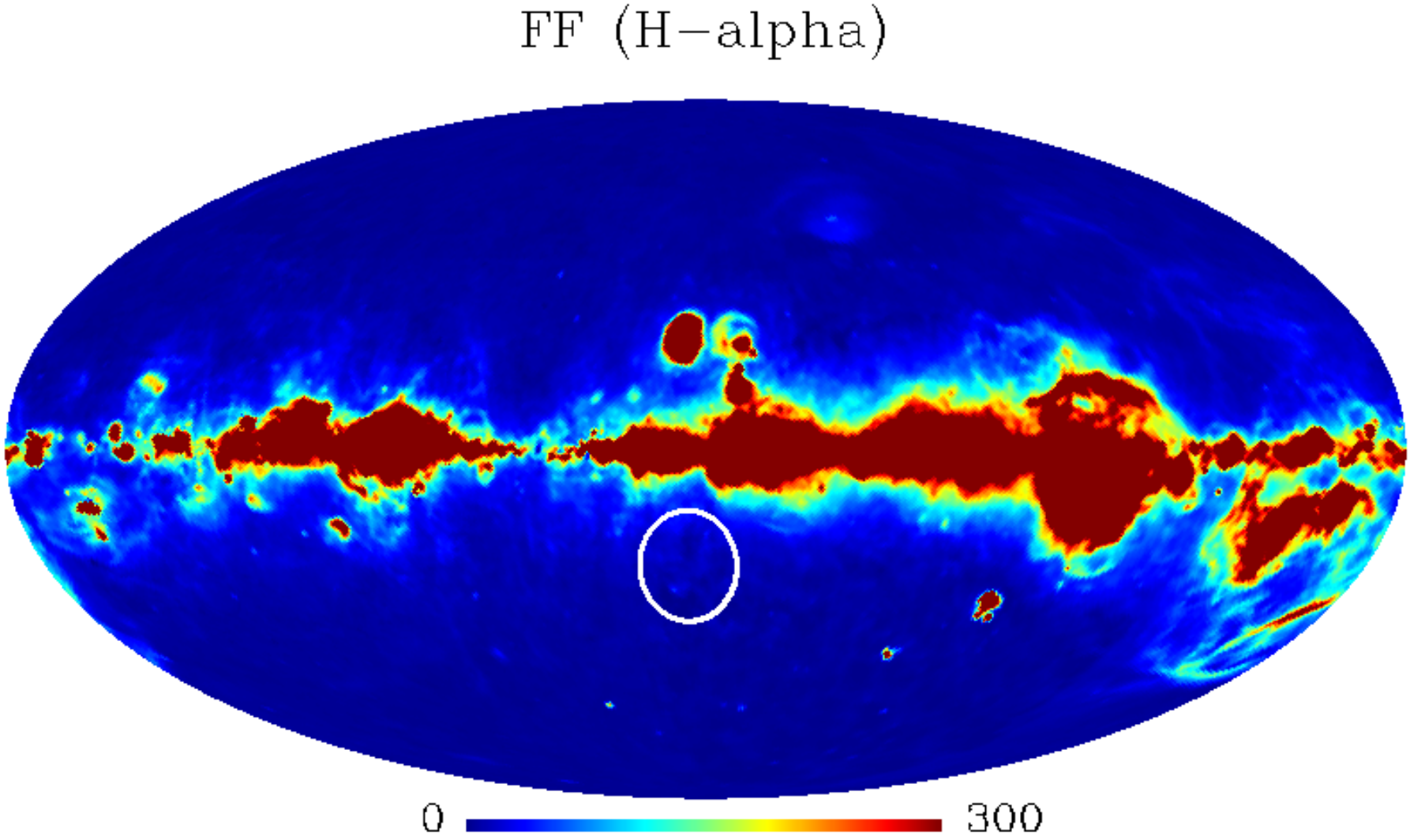
# The K-band sky map (23 Hz)



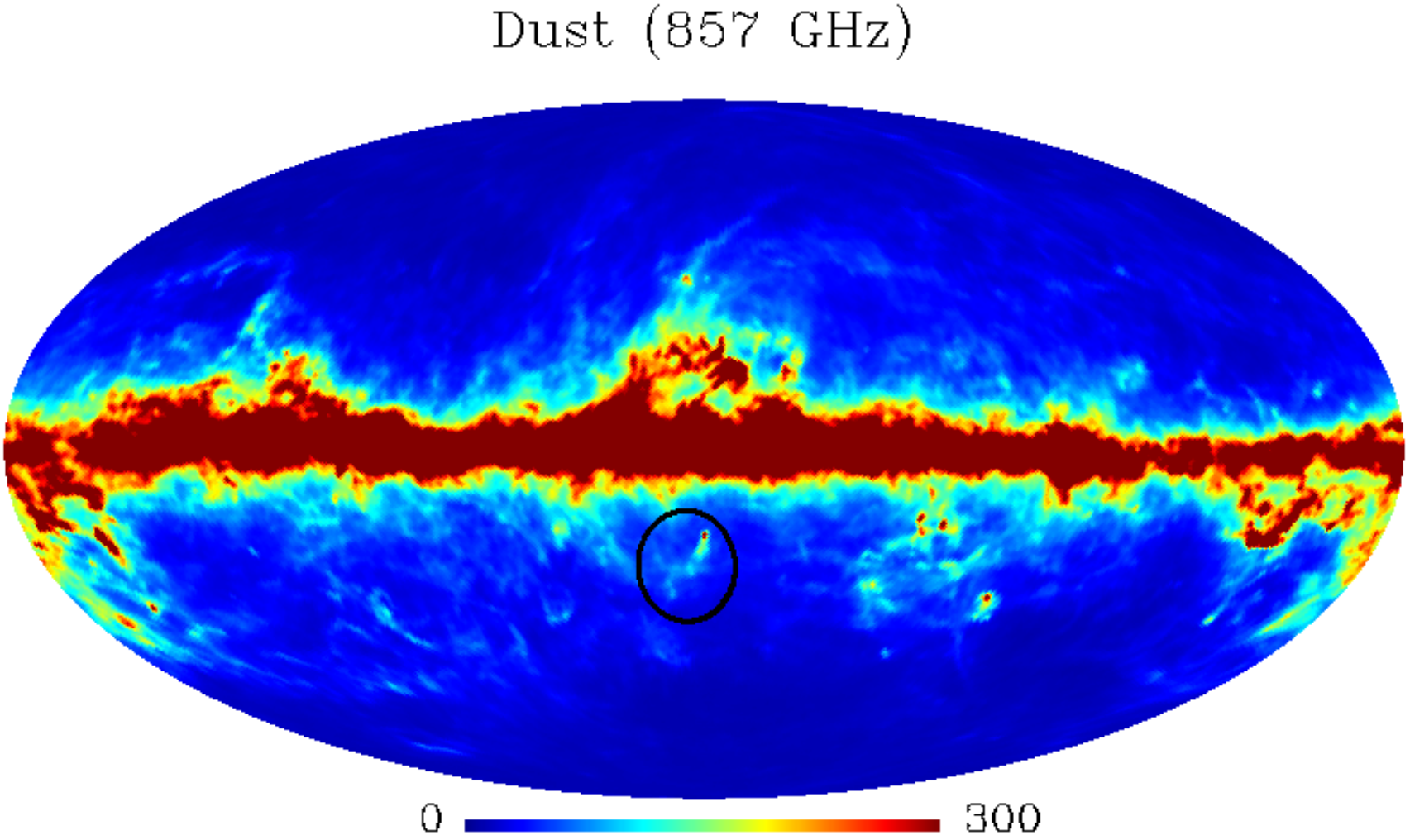
# In SYNC template

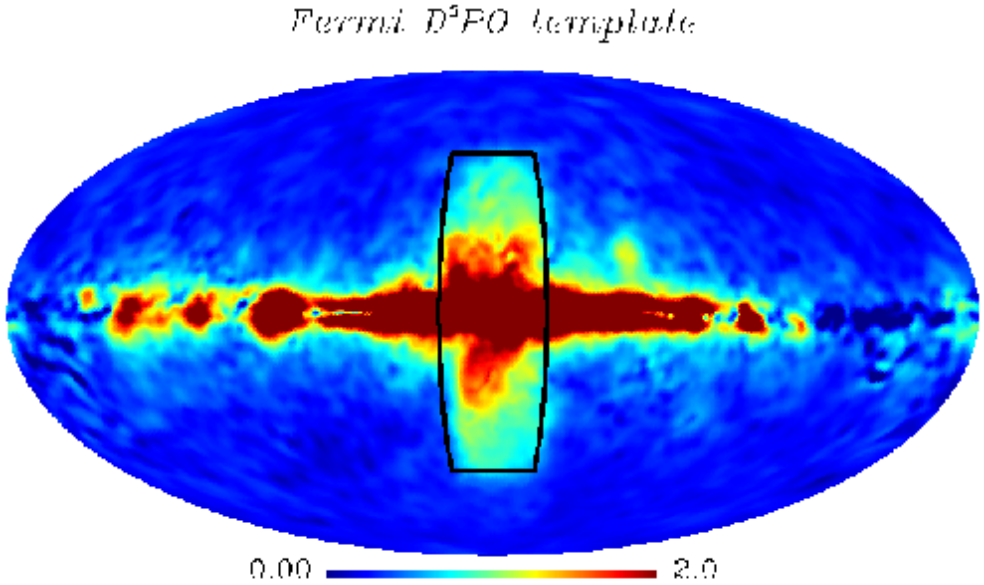


# In free-free template



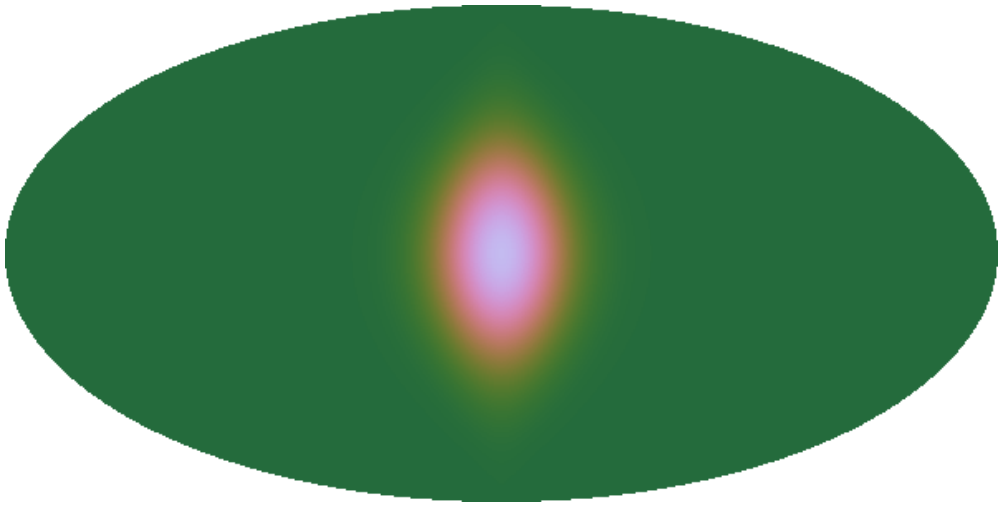
# In the dust template






The Bubble

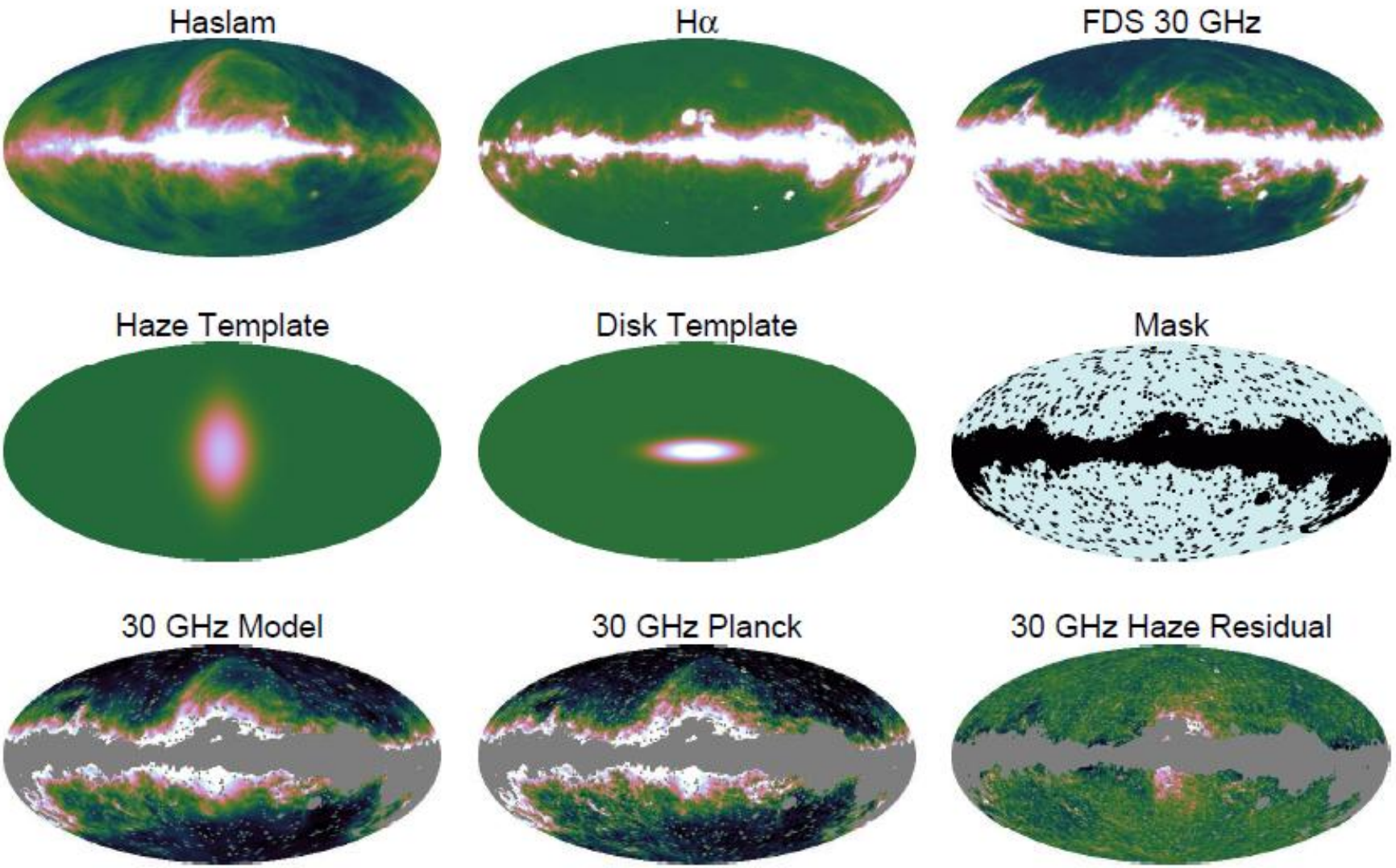
Planck Haze template



## Variants of the templates

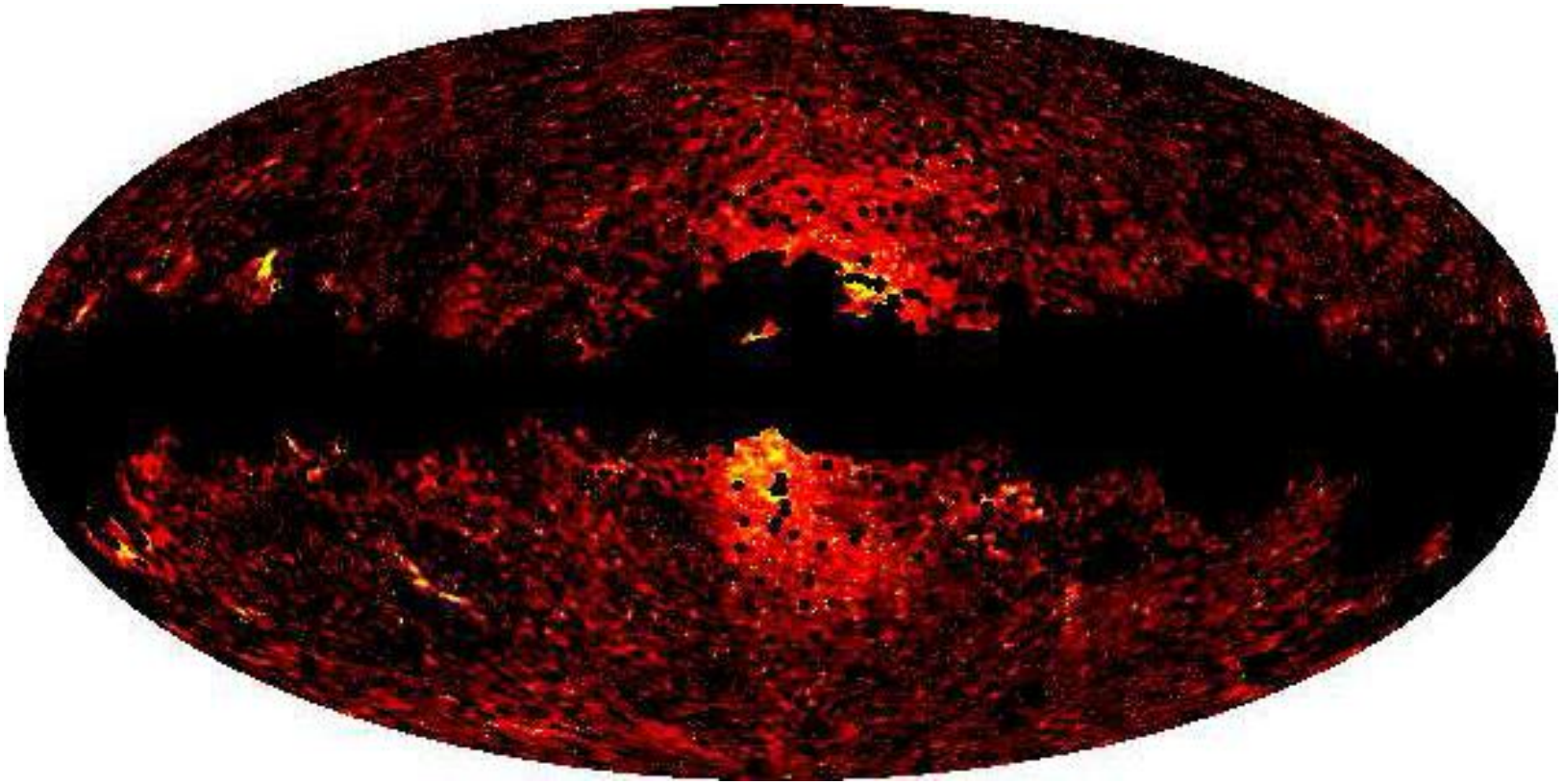
# The Haze template by Planck

Planck Collaboration: Detection of the Galactic haze with *Planck*



# The result from Planck work

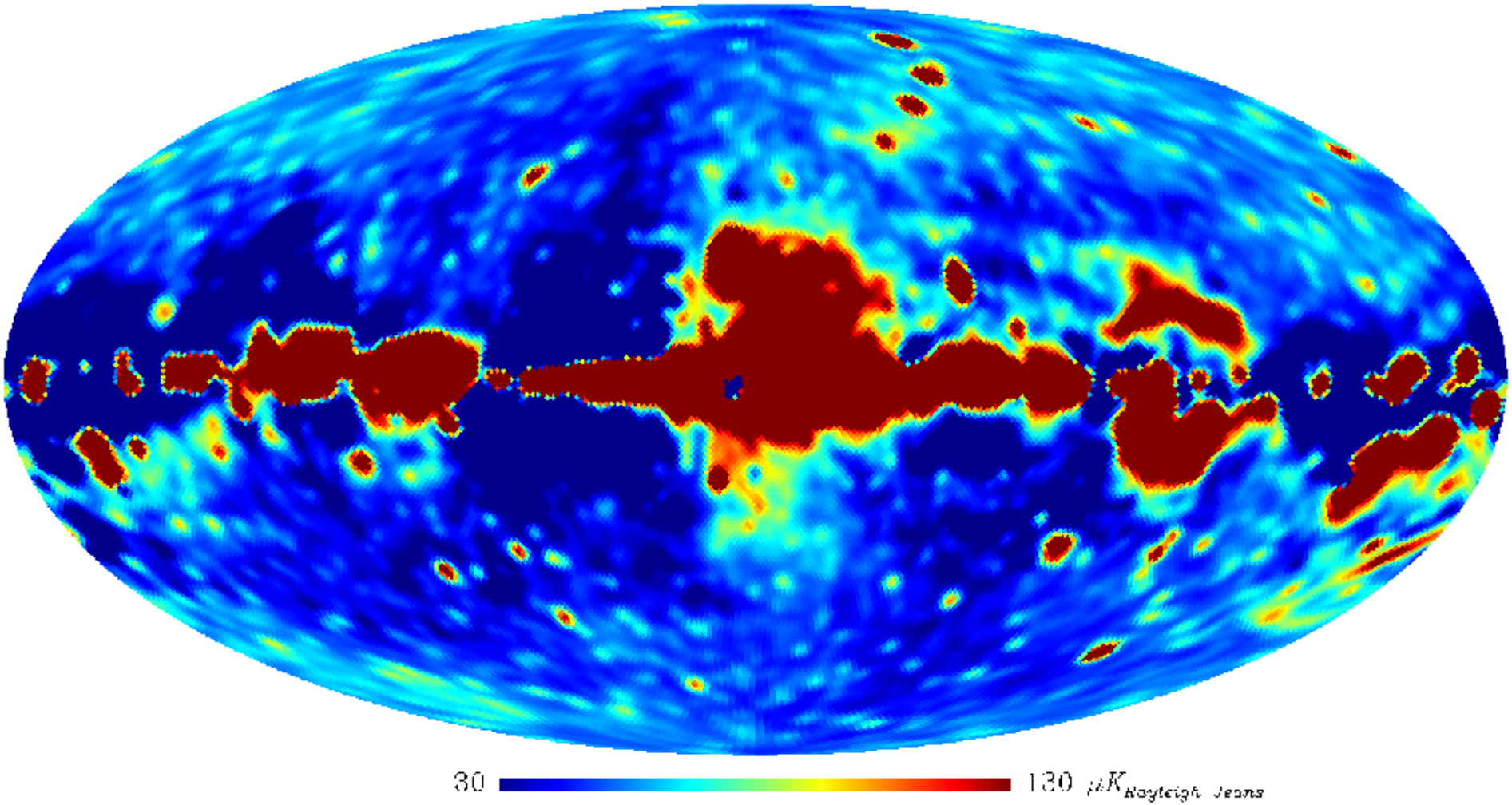
-Planck Intermediate Results. IX. Detection of the Galactic haze with Planck



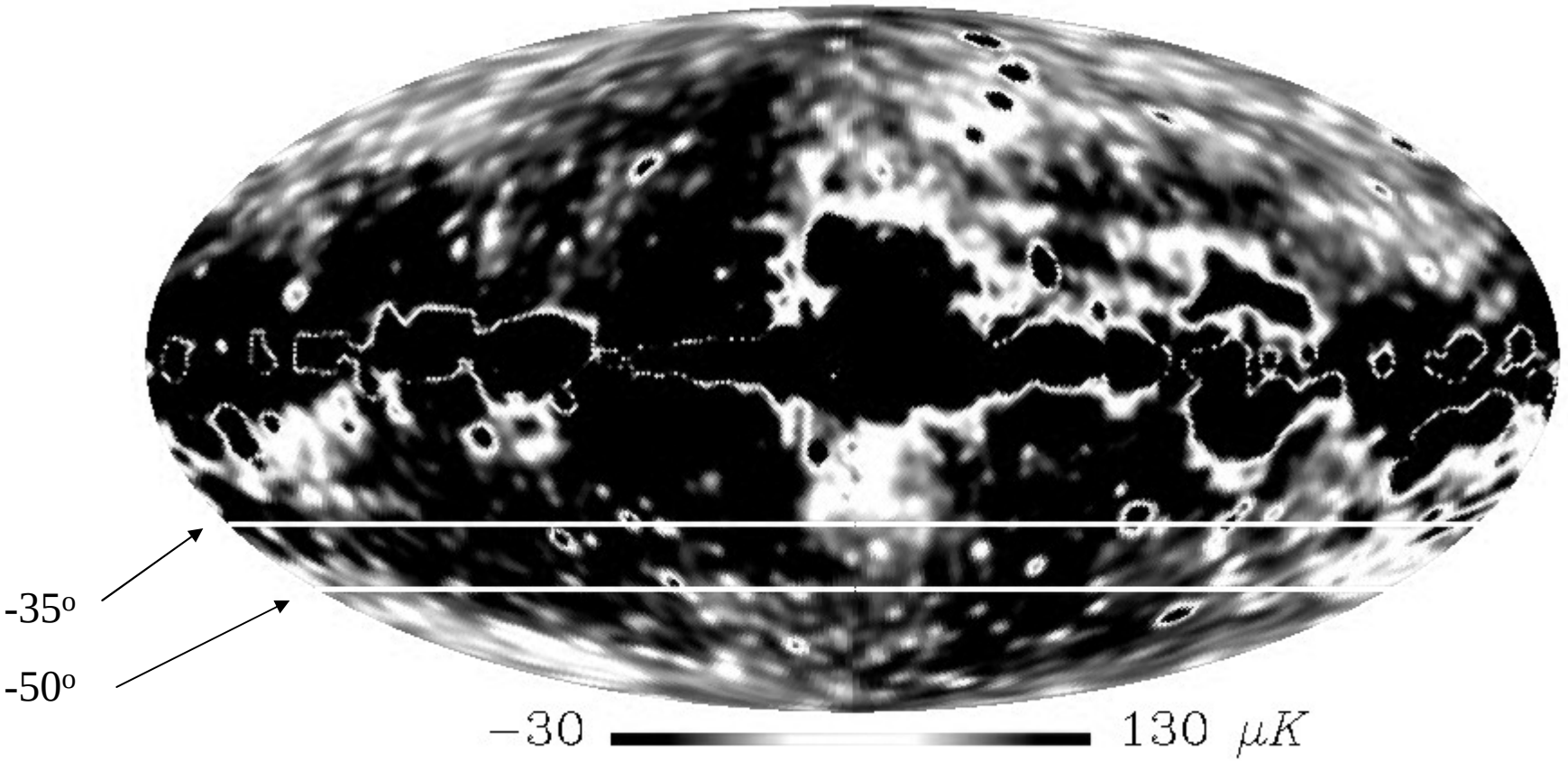
# A more simple approach

*similar to KISS in Iris Gebauer's talk*

- WMAP K-band map
- Dust (857 GHz) + FF (H-alpha) + SYNC (Haslam 408 MHz)
- Mask: 20% brightest FF sky (FF has hard spectrum)
- No need for FB-model
- Linear regression
- That gives:

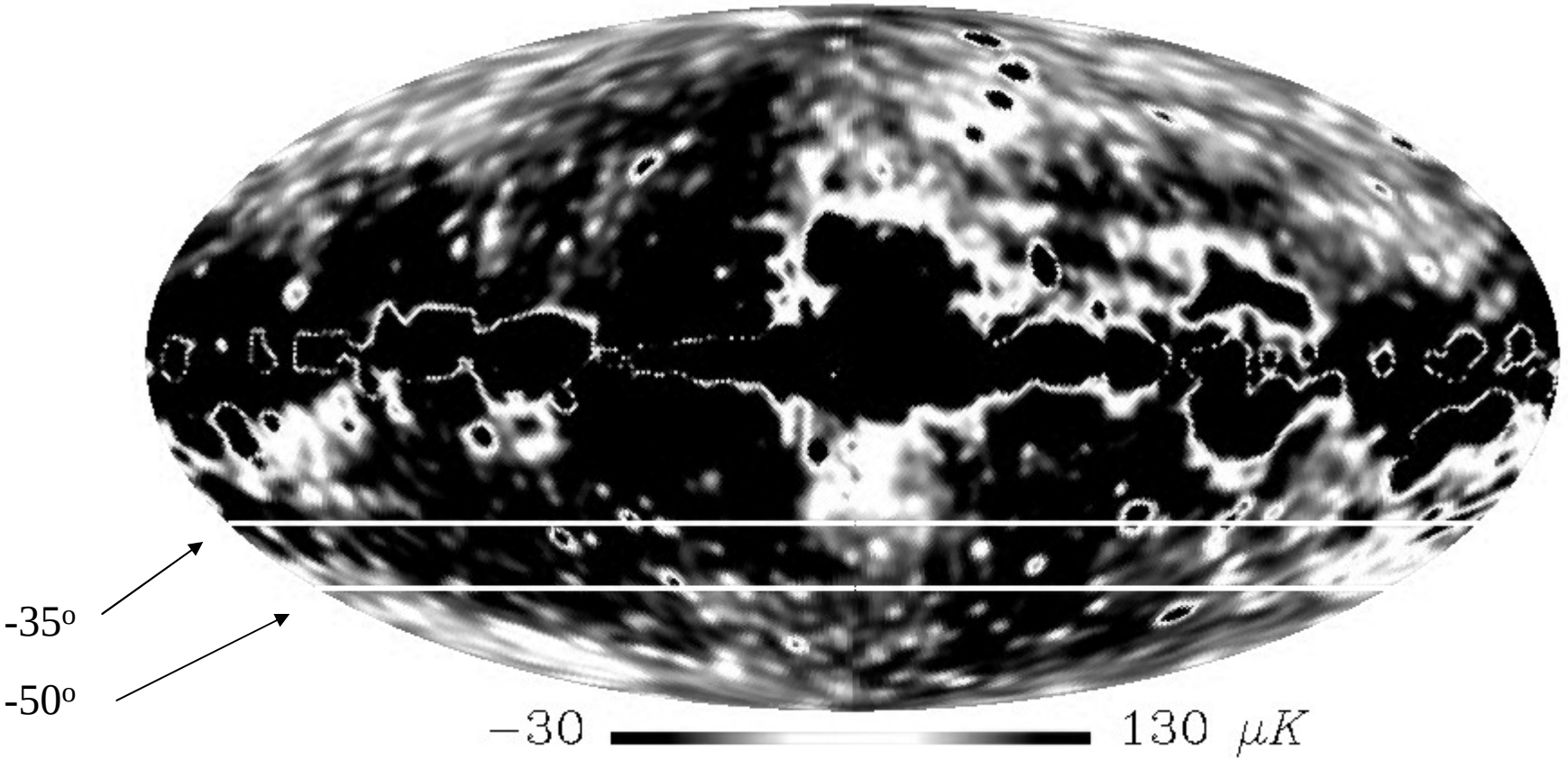

30
130 $\mu K_{Rayleigh\ Jeans}$

# Enhanced image



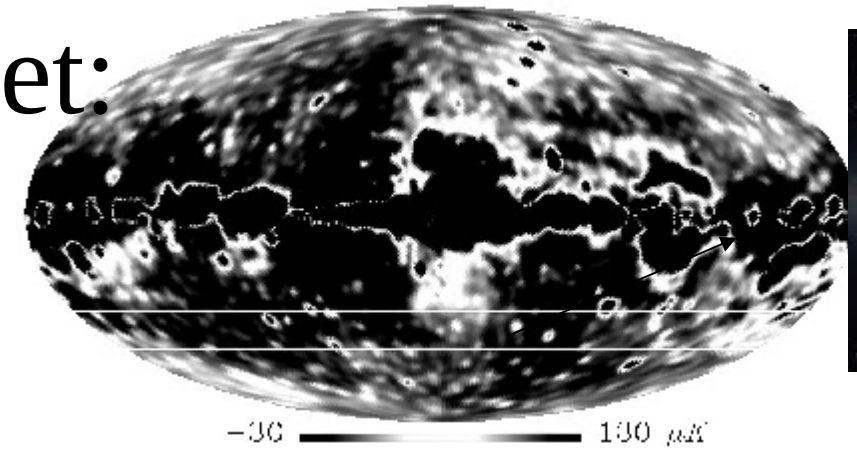

Same figure, take only the green channel
Will enhance the intermediate bump

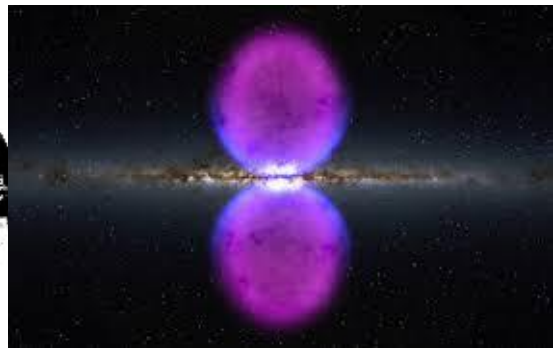
# Enhanced image



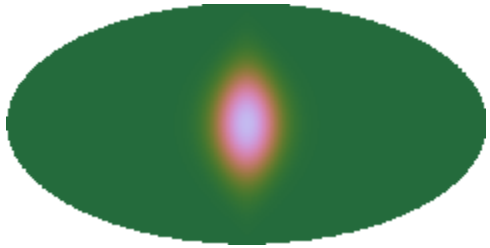

- All templates have **positive** weight (Dust ,SYNC, FF)
- Subtraction **à** The shape is **not** from any foreground template

# What we get:



- There is really a bubble, not Haze!
  - Not stick
  - Not ellipsoid

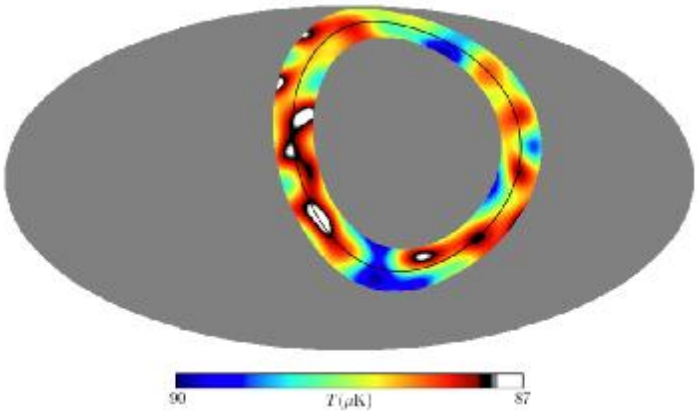


- Not from Dust, FF, SYNC
- Has intermediate amplitude

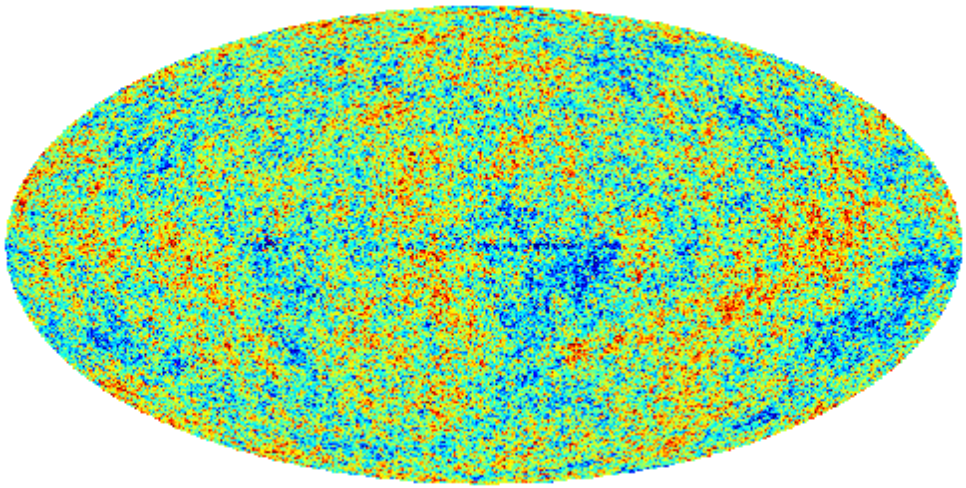
Refers only to ordinary templates

# Can we see the Fermi Bubble in the CMB map?

- The CMB map (especially Planck) has been very carefully cleaned for the foreground.
- There can be no “apparent” foreground residual
- However: *“Fingerprints of Galactic Loop I on the Cosmic Microwave Background”*, Hao Liu, Philipp Mertsch, Subir Sarkar, 2014
  - Residual on CMB
  - Magnetic dust in Loop I
- What about the Fermi Bubble?



# Can we see the Fermi Bubble in the CMB map?



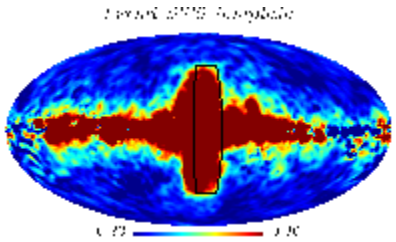
This is impossible by direct visual inspection

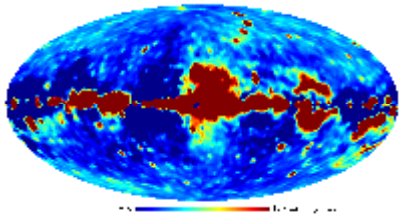
How about the following?

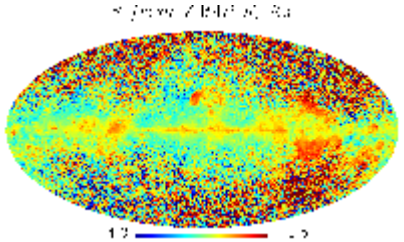
The Fermi D$^3$PO model

Microwave Haze template

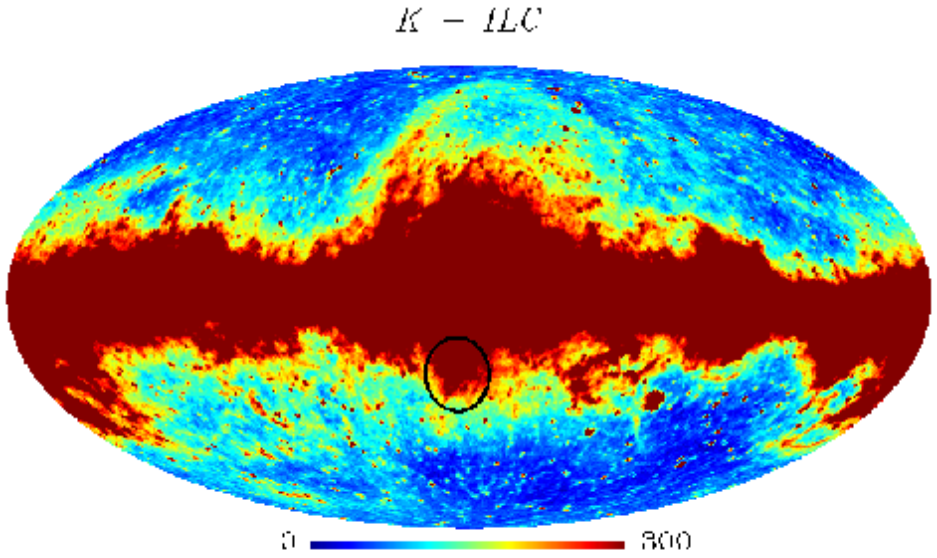
The spectrum index map



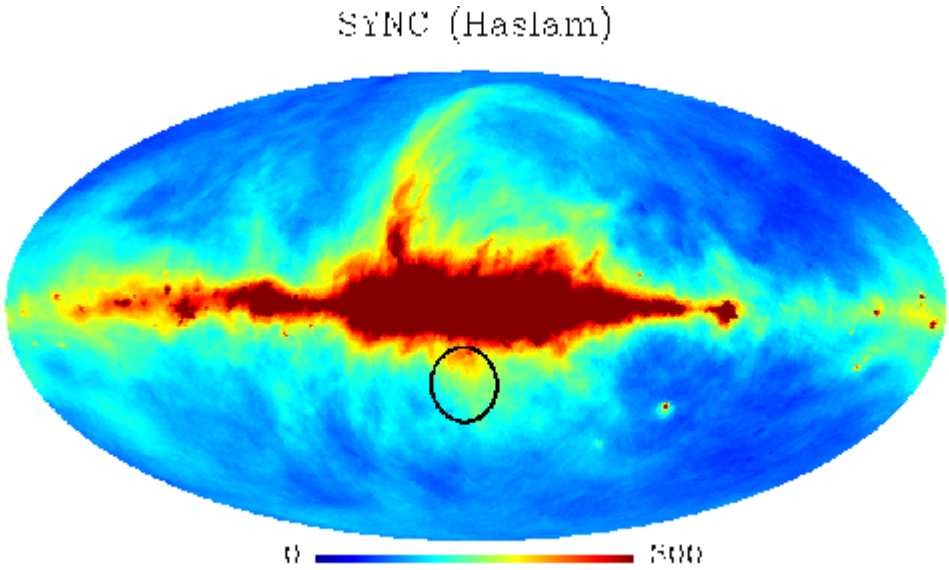




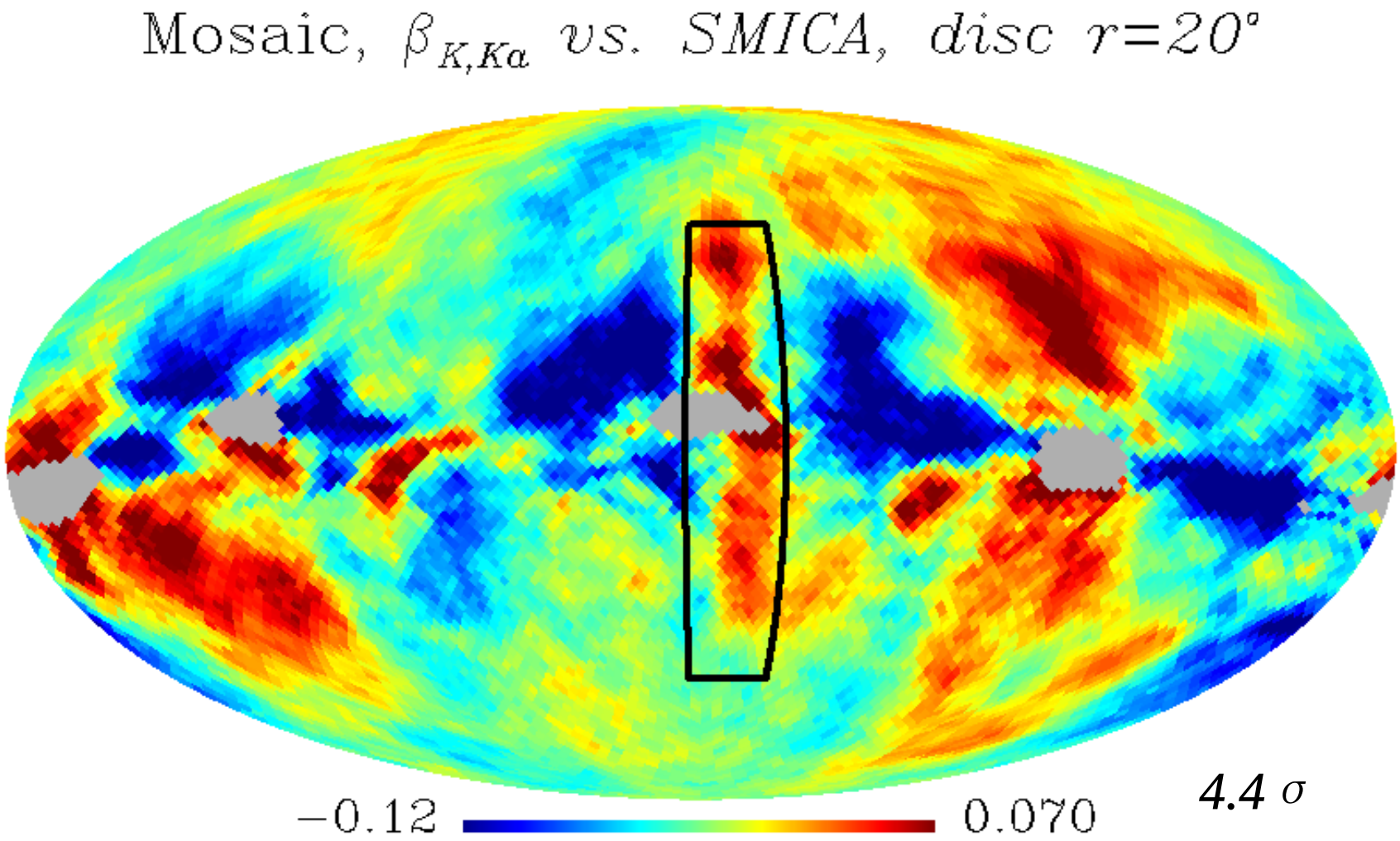
# Mosaic correlation




For example:



# Mosaic correlation

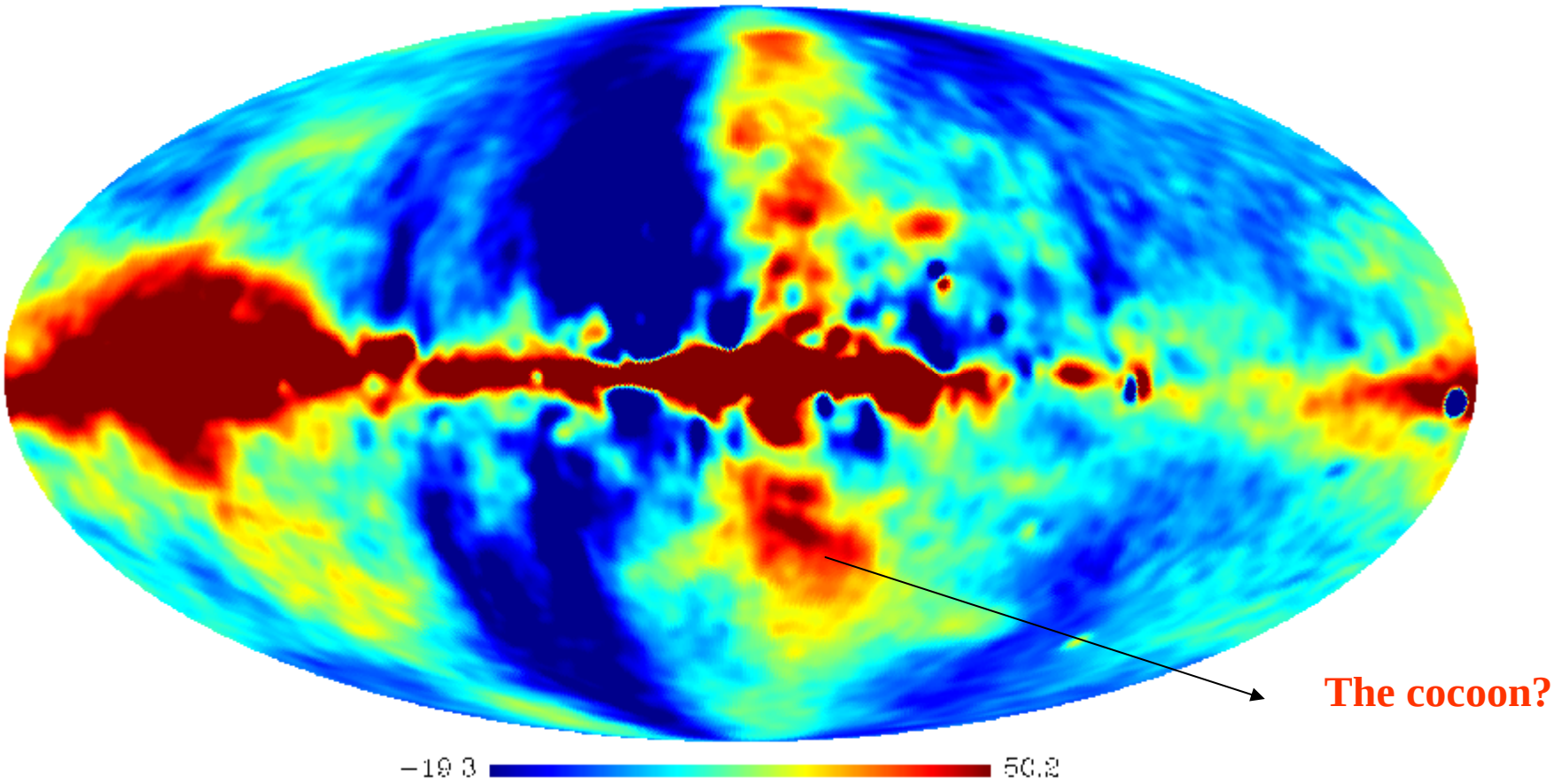


# Fermi bubble in polarization? 3D model?

- Integration along the LOS
- Component separation or
- Component determination
- Q-stokes or U-stokes or both?

# Fermi Bubble and polarization

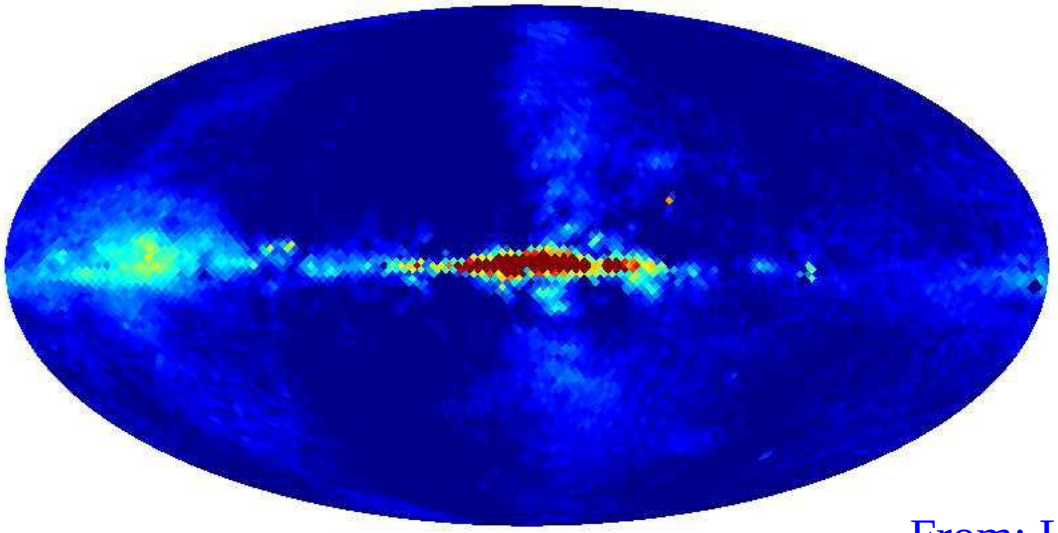
WMAP K-band Q-stokes




Note: the connection to Fermi Bubble is not finally confirmed

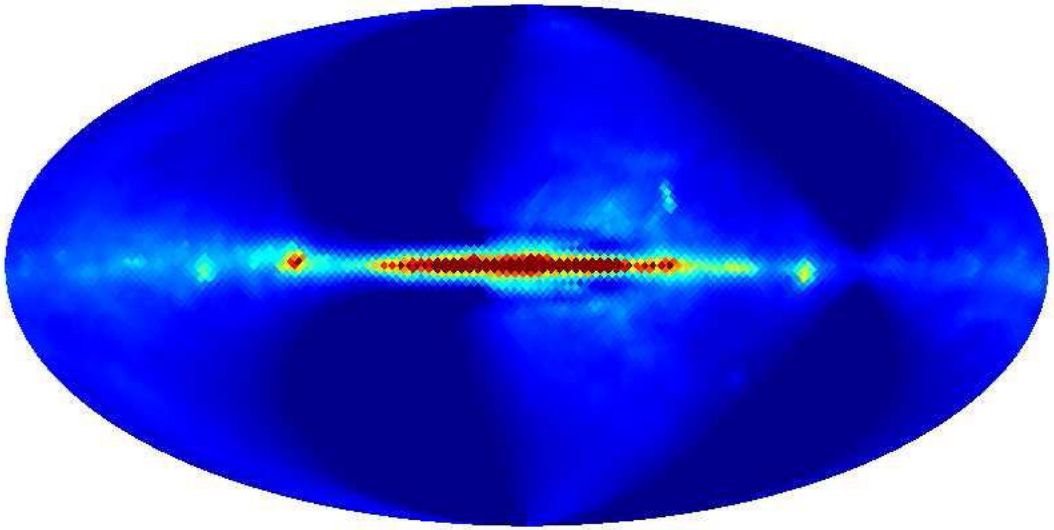
# The 3D model for sync-pol

The first guess should be sync



Data (WMAP K-band)

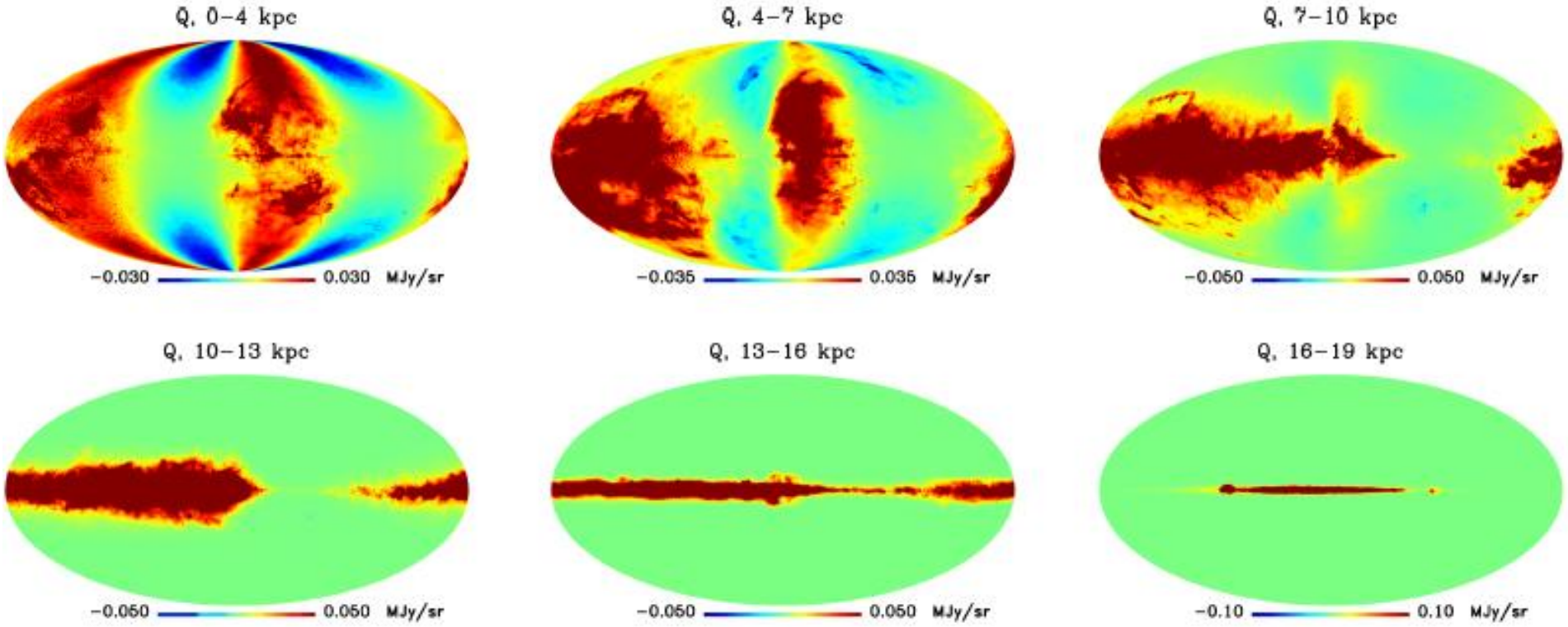
From: L. Fauvet et al, Arxiv 1003.4450



3D Model, considering the Modified Logarithmic Spiral (MLS) magnetic field model for our Galaxy

# The 3D model for Dust-pol

Galactic center~8 kpc

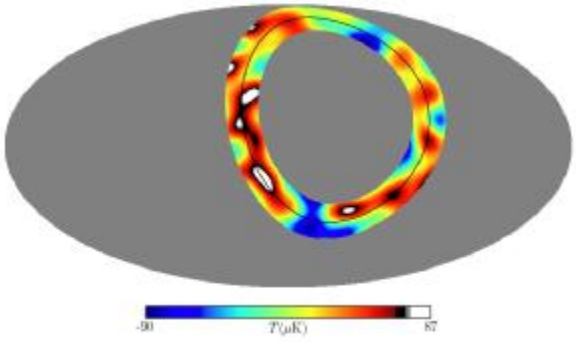



From Gines et al, “A 3-D model of polarised dust emission in the Milky Way ”1706.04162

Based on the 3D dust work (Green G. M., et al., 2015, ApJ, 810, 25, FINKBEINER’s talk)

# Connection to Loop I and Magnetic dust

- K-band polarization “stick” is connected to dust but not sync?
  - This can not be an ordinary thermal dust emission.
- What emission can shine from ~800 GHz to 20 Hz?
  - Possibly: Magnetic dust emission
- What emission can leave stronger residual on the CMB map?
  - Possibly: Magnetic dust emission
- *“Fingerprints of Galactic Loop I on the Cosmic Microwave Background”*, Hao Liu, Philipp Mertsch, Subir Sarkar, 2014
  - Magnetic dust in Loop I
  - Residual on CMB



# The three elephants

- Loop I and Fermi Bubble: they are brothers in some sense.
  - Odd spectrum
  - Polarization
  - Residual on CMB
  - Magnetic dust
- Galactic center excess
  - This huge shining guy is definitely the mother elephant (in the microwave bands)

*“Three elephants in the gamma-ray sky: Loop I, the Fermi bubbles, and the Galactic center excess”*