Overview of the Planck Sky Model

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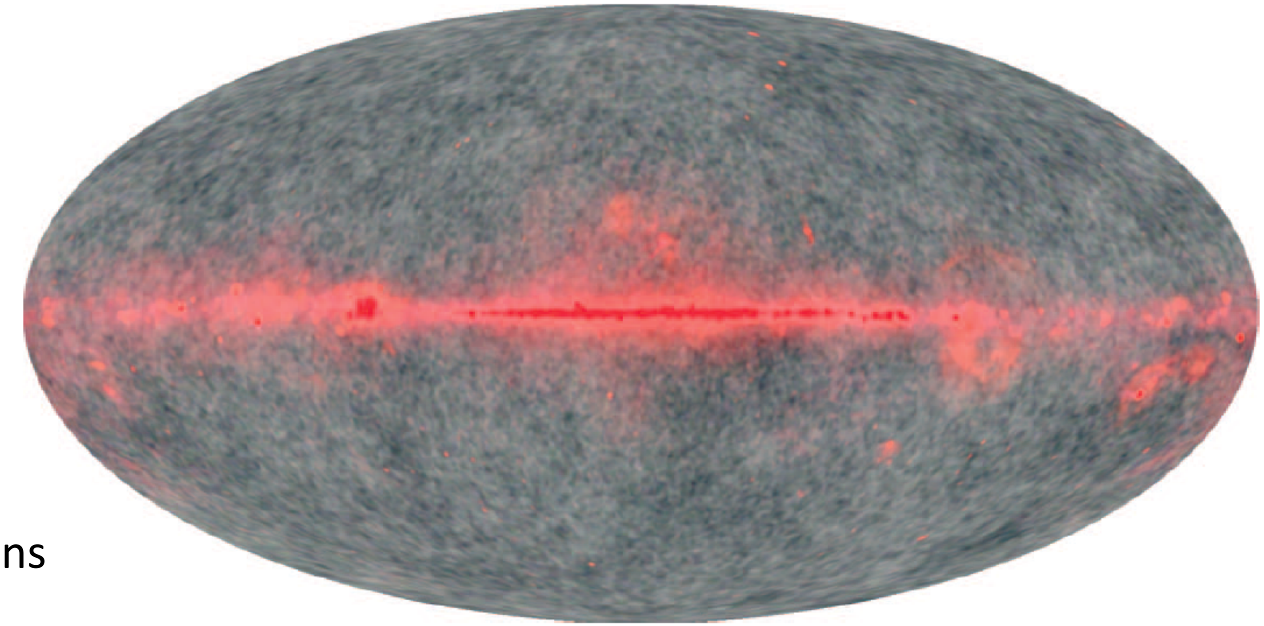
The multi-component sky

- The sky emission, at a given frequency, is a superposition of emissions from different sources
  - Different emission processes (thermal, synchrotron, Bremsstrahlung, …)
  - Different media/objects (Milky way ISM, CMB, clusters of galaxies)
  - Has always been a worry for CMB observations

- The sky in color

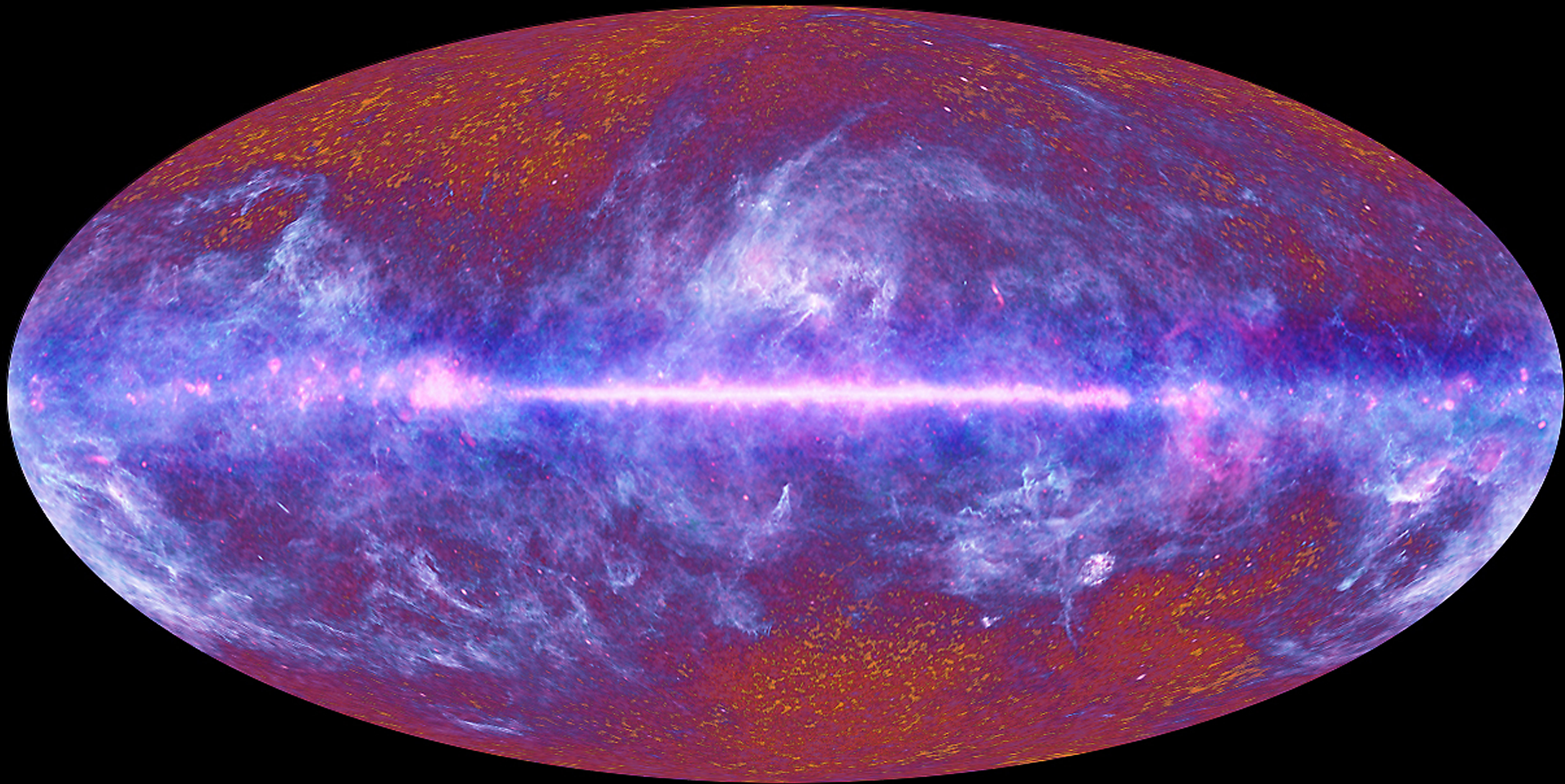
WMAP observations



Bennett et al., ApJSS Volume 148, Issue 1, pp.97-117 (2003)

The sky in color

Planck observations

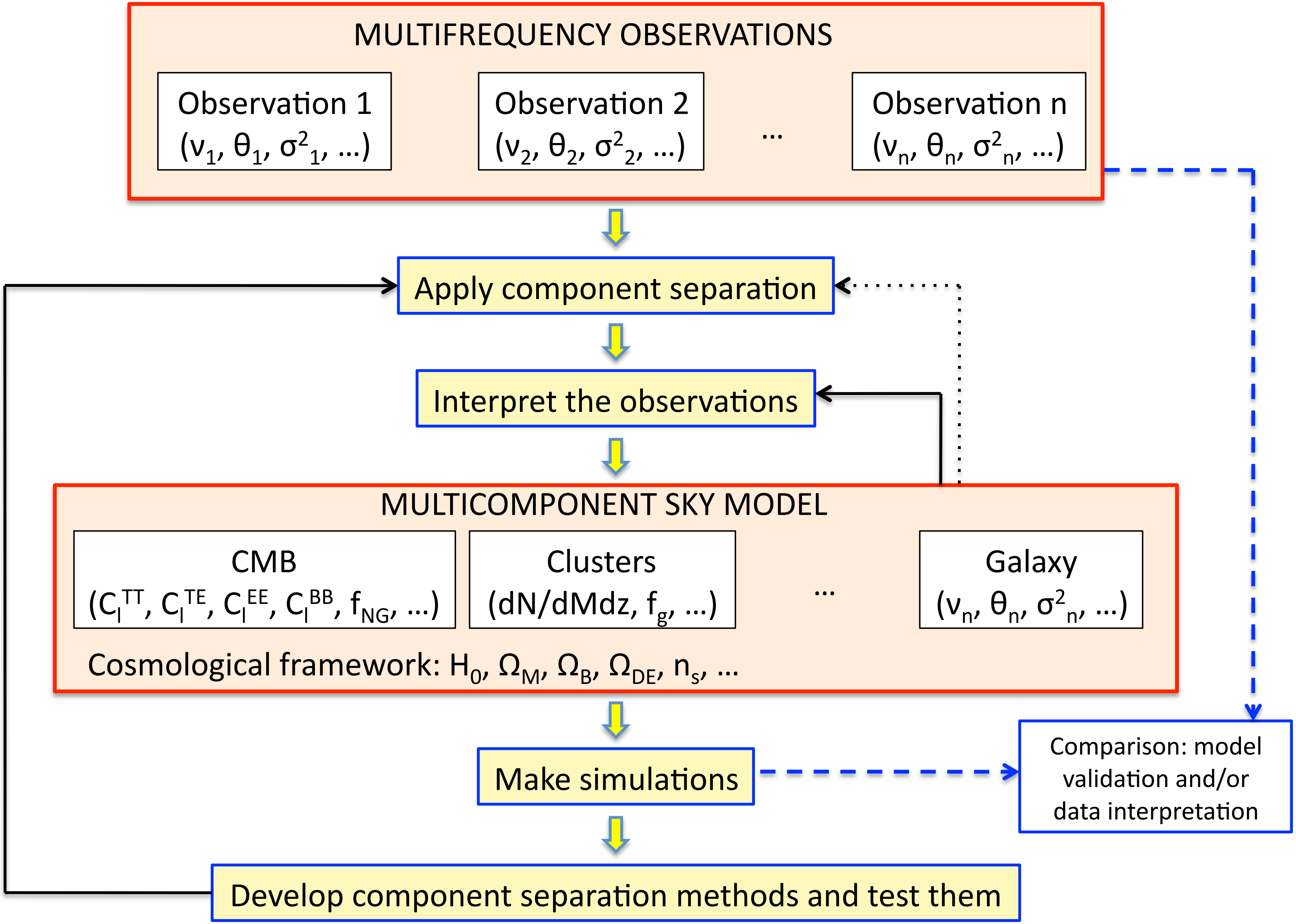


A multi-component model of sky emission

- The ultimate objective of all of our observations!
  - Our understanding of any emission is summarised in a model
  - The model can be physical, descriptive, parametric…

- The Planck Sky Model (PSM) is a global ***model*** of multi-component sky emission, in intensity and polarisation, over the frequency range ≈ 3GHz to ≈ 3THz, currently being developed in the Planck collaboration.

- It comprises
  - An underlying cosmological model (standard Big-Bang scenario) with associated cosmological parameters H_0, Ω_M, Ω_B, Ω_{DE}, n_s, …
  - A model of CMB emission and growth of structure (density contrast in the linear regime);
  - A model of Sunyaev-Zel'dovich emission from the hot gas in clusters of galaxies;
  - Models for the emission of the galactic ISM: Synchrotron, Dust (thermal and spinning), Free-free, some molecular lines (CO);
  - A model for some galactic compact sources (ultra-compact H-II regions)
  - Models for (extragalactic) emission from compact sources (IR galaxies and CIB, radio galaxies).


MULTIFREQUENCY OBSERVATIONS
Observation 1 (ν_1, θ_1, σ^2_1, …)
Observation 2 (ν_2, θ_2, σ^2_2, …)
…
Observation n (ν_n, θ_n, σ^2_n, …)
Apply component separation
Interpret the observations
MULTICOMPONENT SKY MODEL
CMB (C_l^{TT}, C_l^{TE}, C_l^{EE}, C_l^{BB}, f_{NG}, …)
Clusters (dN/dMdz, f_g, …)
…
Galaxy (ν_n, θ_n, σ^2_n, …)
Cosmological framework: H_0, Ω_M, Ω_B, Ω_{DE}, n_s, …
Make simulations
Comparison: model validation and/or data interpretation
Develop component separation methods and test them

The PSM in practice

- DATA
  - Maps of observed or simulated diffuse components (CMB, synchrotron intensity, synchrotron spectral index, CO-line emission…)
  - Constraints on model parameters (e.g. cosmological parameters and errors)
  - Catalogues of known clusters of galaxies
  - Catalogues of know point sources

- SOFTWARE
  - Implements the model in a (hopefully) user-friendly way
  - *Input*: choice for global parameters (e.g. cosmological parameters, choice among alternate options for modelling each component) in the form of a configuration file
  - *Output*: maps and catalogues of modelled (simulated or predicted) sky emission for each component
  - *Output*: sky emission in user-defined frequency channels (total emission, and emission per component, in intensity and polarisation)

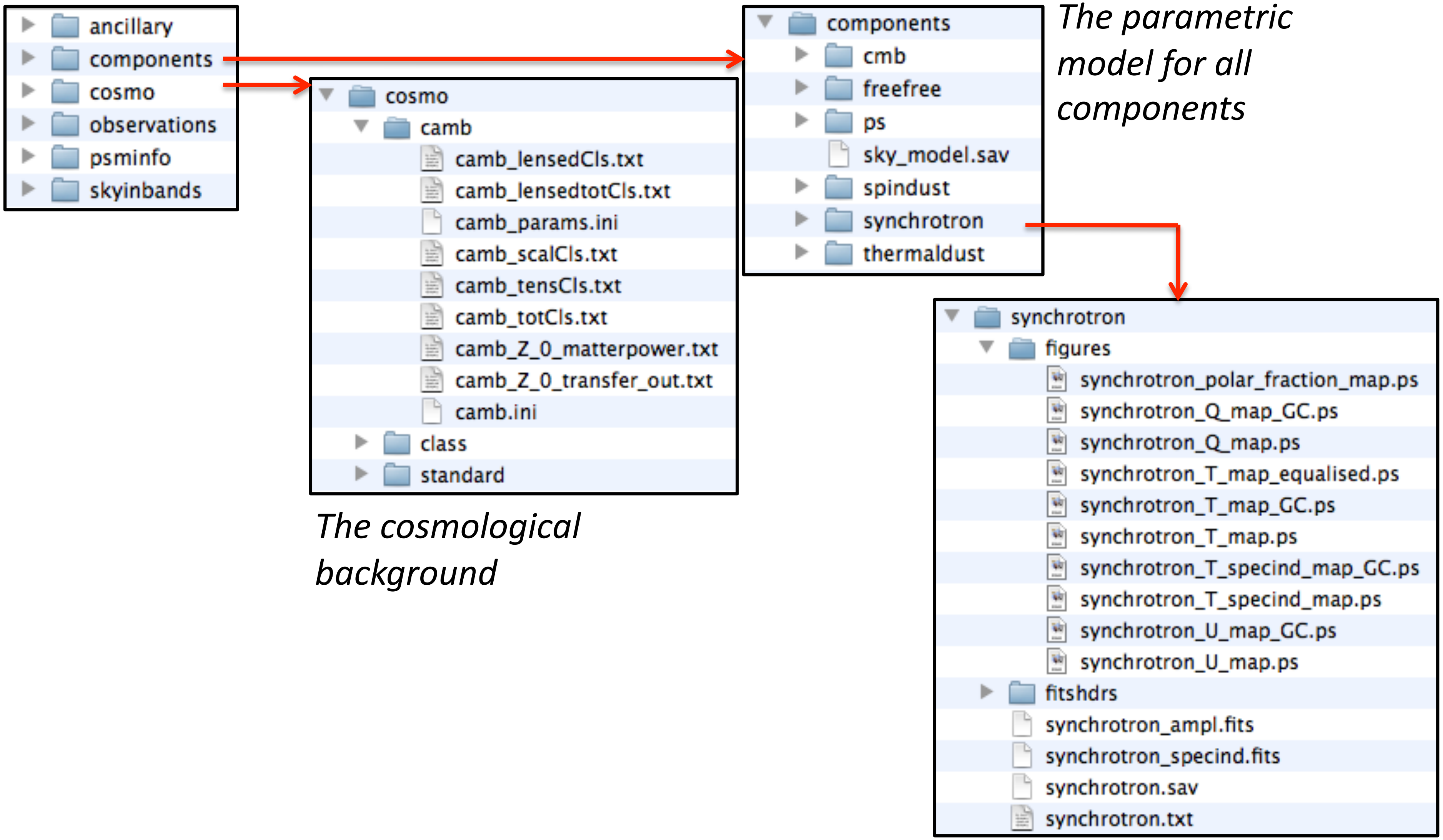
The PSM in practice

- More than a simulation tool, the PSM software is a framework for investigating multi-component sky emission
  - Parametric
  - Easy to add emissions, change their properties (e.g. emission law)
  - Easy to change templates describing galactic components
- Today: ~53.000 lines of code in the PSM release version 1.7.7 (excluding comment lines)
  - IDL: code ~33.000
  - C: CLASS software, ~17.000
  - F90: ilens software, ~2.300
- Input parameters passed via a single configuration file

Flexible, Evolutive

(price to pay: somewhat complex software)

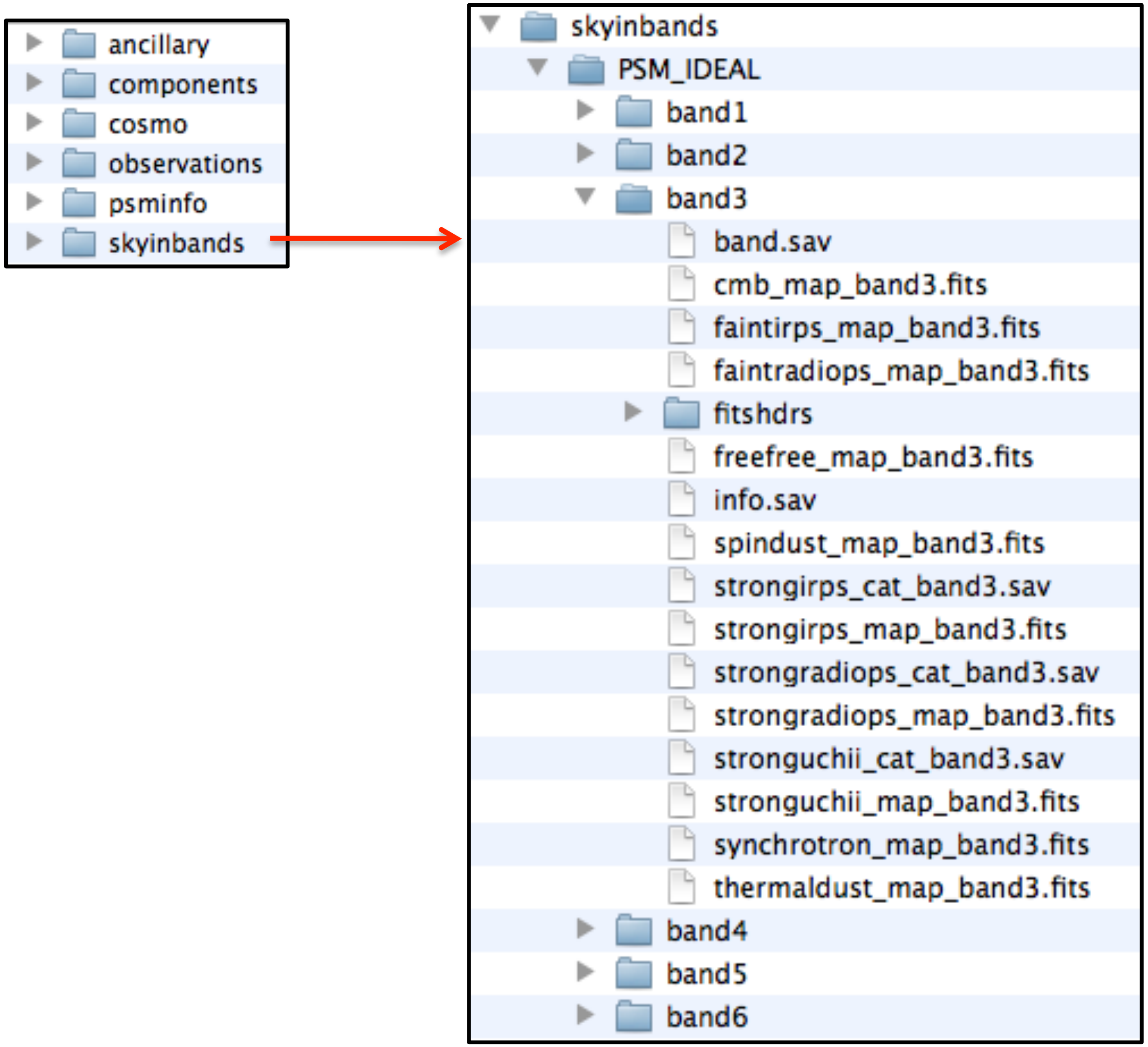
PSM outputs



The parametric model for all components

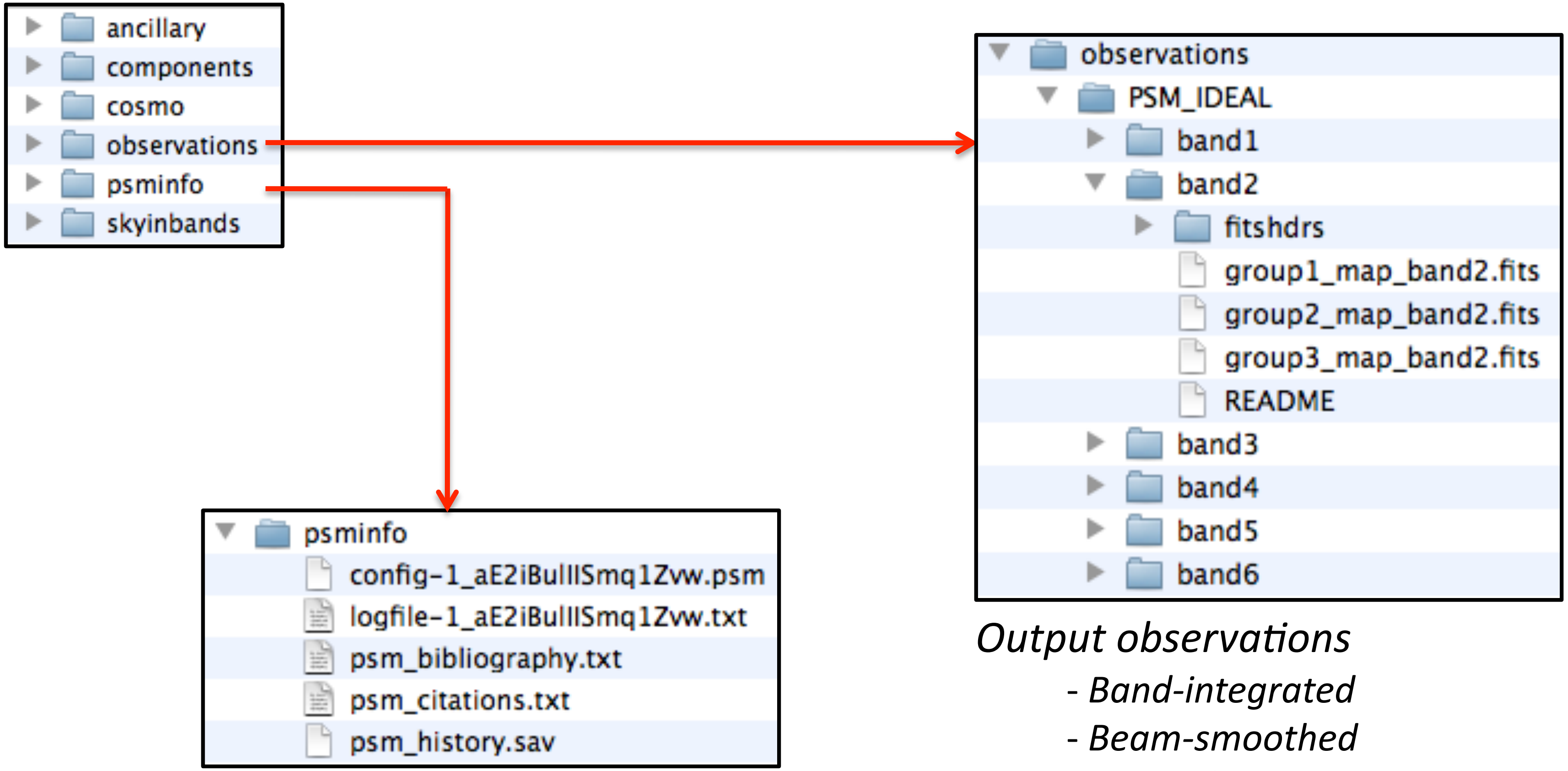
The cosmological background

PSM outputs



Maps and/or catalogues of band-integrated emission for all components

PSM outputs



For traceability

Output observations

- *Band-integrated*
- *Beam-smoothed*
- *Re-pixelised*
- *Polarised or not*
- *Instrumental noise included*

The PSM website

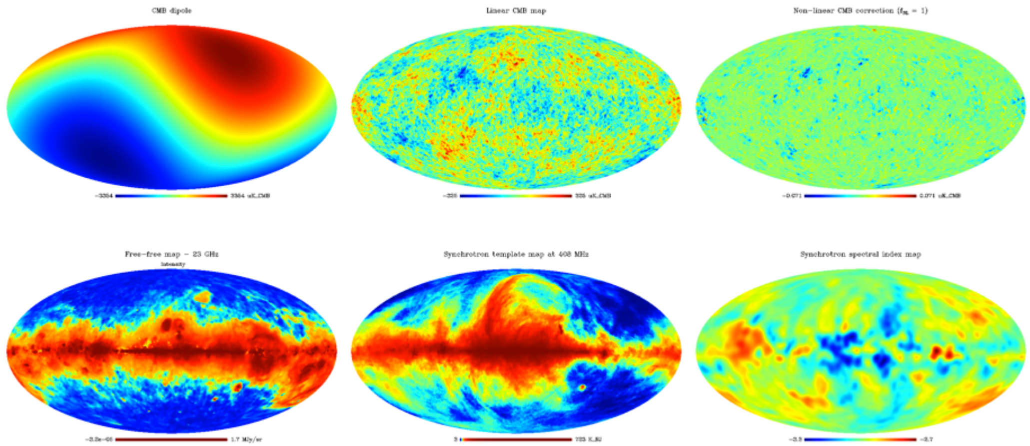
http://www.apc.univ-paris7.fr/~delabrou/PSM/psm.html

Apple Yahoo! Google Maps YouTube Wikipédia Informations Divers

A website with the official release of the Planck final PSM product is foreseen at ESA

THE PLANCK SKY MODEL

Welcome to the PSM website!



The project

The Planck Sky Model (PSM) is a complete and versatile set of programs and data, to be used for the simulation or the prediction of sky emission in the frequency range of typical CMB experiments, and in particular of the upcoming Planck sky mission. It has originally been developed as part of the activities of Planck component separation Working Group (or 'Working Group 2' - WG2), and of the ADAMIS team at APC.

The PSM software is developed with two main objectives in mind:

- The primary objective is the ability to simulate plausible sky emission maps, to be used as inputs for the development and testing of data processing and analysis techniques. It includes a basic set of tools to simulate observations taken with a particular instrument.
- The second objective is the availability of a tool which summarizes our present knowledge of the GHz sky. For this, the PSM is meant to allow predicting the sky emission in any direction of the sky, and at any frequency in the GHz range, based on an interpretation of presently existing and publically available data sets.

A model that does not use yet Planck observations

The pre-launch *Planck Sky Model*: a model of sky emission at submillimetre to centimetre wavelengths

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(Affiliations can be found after the references)

arXiv:1207.3675

ABSTRACT

We present the *Planck Sky Model* (PSM), a parametric model for the generation of all-sky, few arcminute resolution maps of sky emission at submillimetre to centimetre wavelengths, in both intensity and polarisation. Several options are implemented to model the cosmic microwave background, Galactic diffuse emission (synchrotron, free-free, thermal and spinning dust, CO lines), Galactic H ɪɪ regions, extragalactic radio sources, dusty galaxies, and thermal and kinetic Sunyaev-Zeldovich signals from clusters of galaxies. Each component is simulated by means of educated interpolations/extrapolations of data sets available at the time of the launch of the *Planck* mission, complemented by state-of-the-art models of the emission. Distinctive features of the simulations are: spatially varying spectral properties of synchrotron and dust; different spectral parameters for each point source; modeling of the clustering properties of extragalactic sources and of the power spectrum of fluctuations in the cosmic infrared background. The PSM enables the production of random realizations of the sky emission, constrained to match observational data within their uncertainties, and is implemented in a software package that is regularly updated with incoming information from observations. The model is expected to serve as a useful tool for optimizing planned microwave and sub-millimetre surveys and to test data processing and analysis pipelines. It is, in particular, used for the development and validation of data analysis pipelines within the *Planck* collaboration. A version of the software that can be used for simulating the observations for a variety of experiments is made available on a dedicated website.

Key words. Cosmology: cosmic background radiation – Interstellar medium (ISM), nebulae – Galaxies: clusters: general – Galaxies: general – Infrared: diffuse background

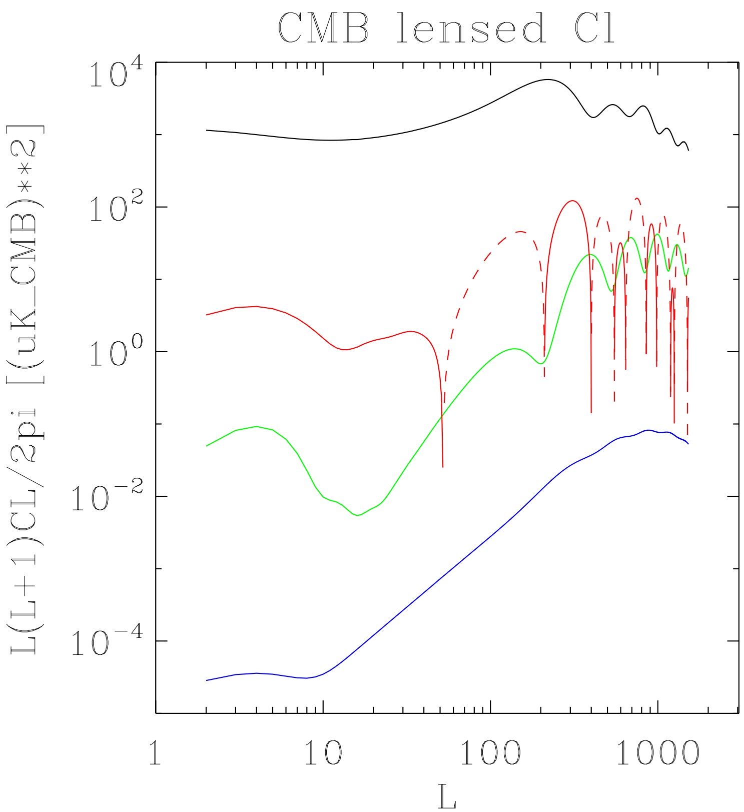
Cosmological background

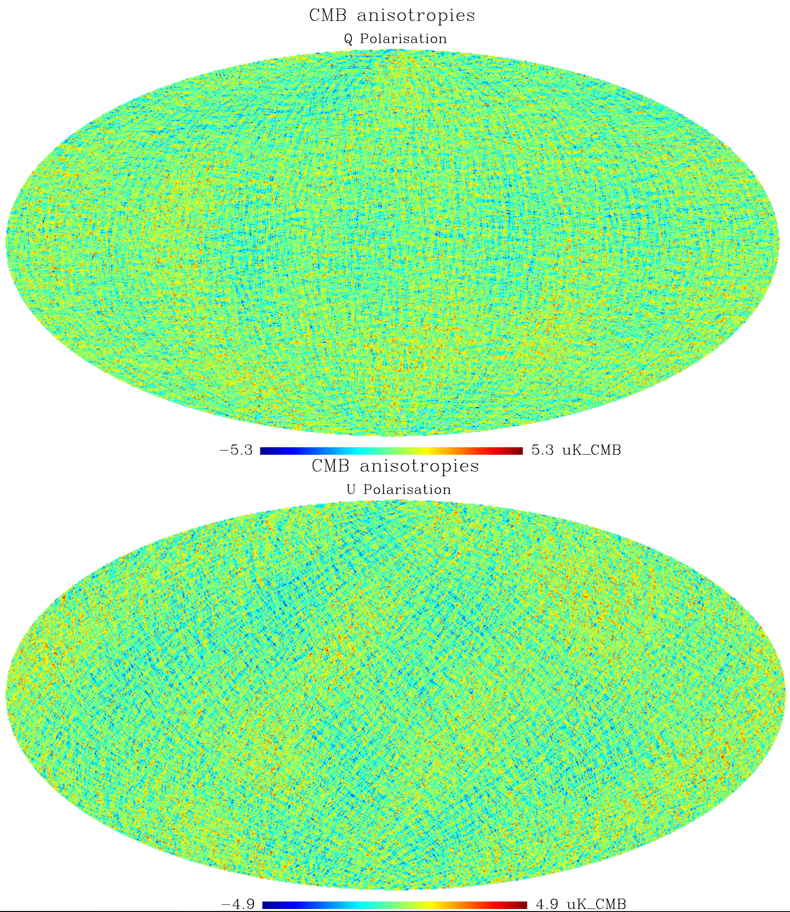
- GENERAL PHILOSOPHY
  - It should be possible to model all the "cosmological" emissions in a coherent way
  - CMB anisotropies, SZ effect, LSS should all use the same cosmological background
  - It should be possible to generate cosmological components compatible with observations, within errors: constrained random generation.

- IMPLEMENTATION
  - Cosmological parameters are set by the user
  - *CLASS and/or CAMB* are run to compute CMB Cl (and matter power spectra)
  - These outputs are written in the output directory.
  - *Output*: sky emission in user-defined frequency channels (total emission, and emission per component, in intensity and polarisation)

Polarisation: CMB

- CMB
  - CMB Cls from CLASS or CAMB (interfaced), or current best fit (read from file);
  - Accurate lensing with ilens [basak, Prunet, Benabed] (alternatively, CMB from lensed Cls)

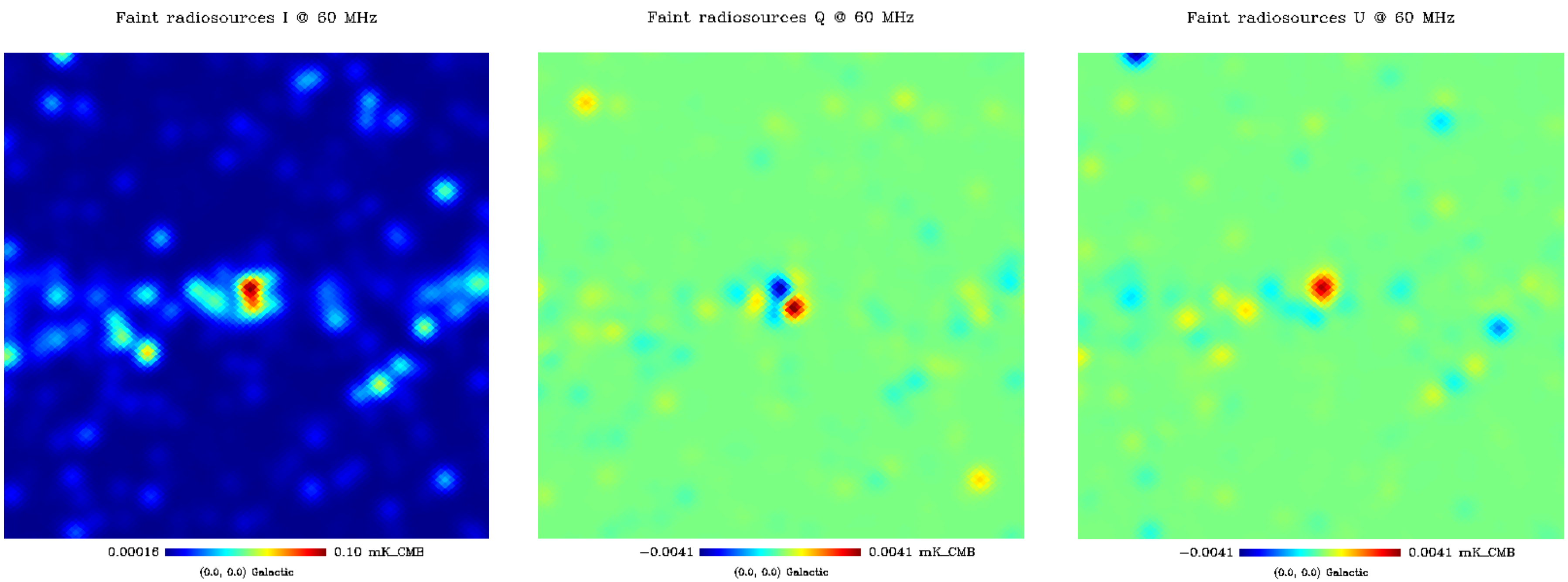




Polarisation: point sources

G. De Zotti, J. Gonzalez-Nuevo

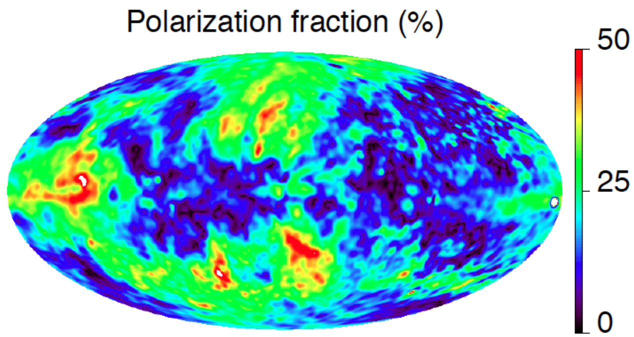
- POINT SOURCES
  - Polarisation direction at random between 0 and π;
  - Infrared sources: degree of polarisation random, with average polarisation set among the input parameters (1% on average by default);
  - Radio sources: degree of polarisation randomly drawn according to the distribution observed for steep-spectrum and for flat-spectrum sources (average about 6%)



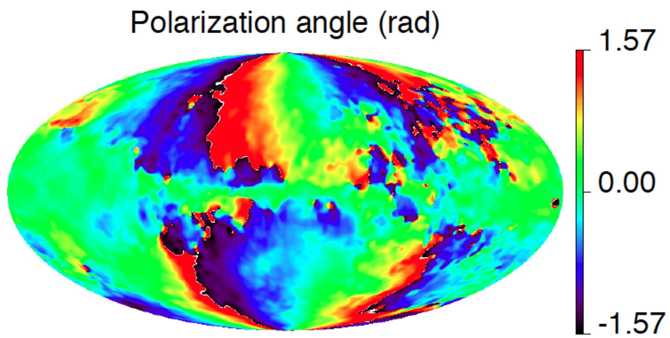
Polarisation: synchrotron

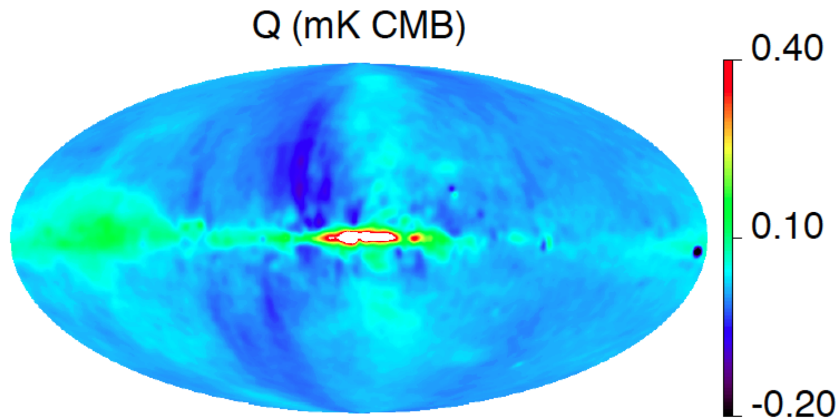
M.-A. Miville Deschênes

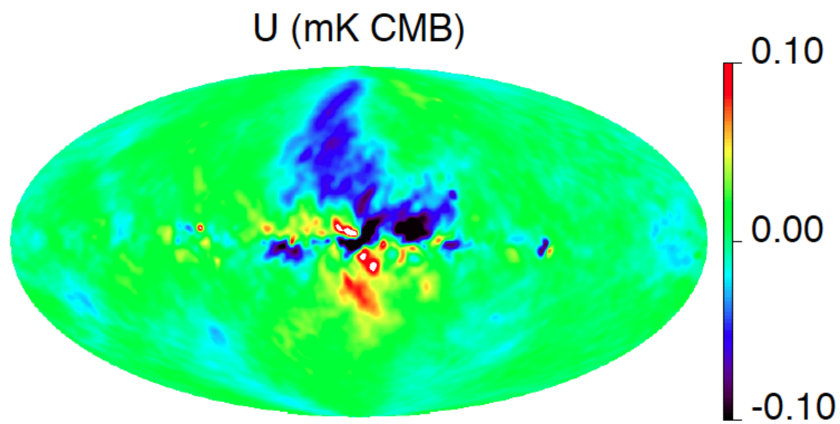
- GALACTIC SYNCHROTRON
  - Electron energy spectral index p implies
    - Synchrotron spectral index $\beta = -(p+3)/2$
    - polarisation fraction $3(p+1)/(3p+7)$
  - p = 3 implies intrinsic polarisation of 75%
  - p = 1 implies polarisation of 60%



Average 18%





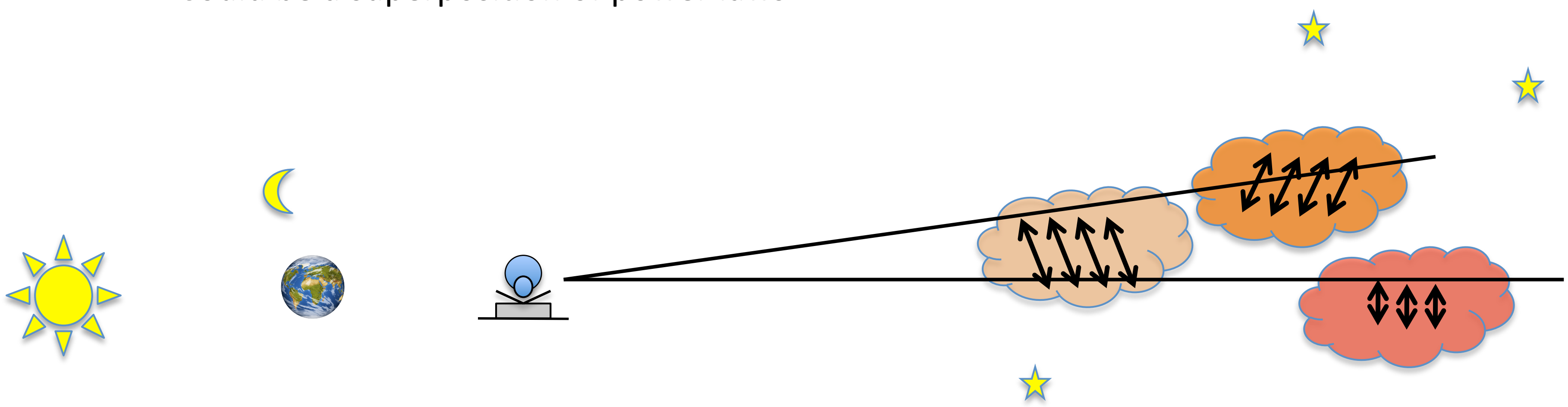


Synchrotron at 23 GHz

Synchrotron frequency scaling

- SAME EMISSION LAW FOR POLARISATION AND TEMPERATURE
  - This cannot be strictly true

- ONE SINGLE EMISSION LAW PER PIXEL
  - Power law or curved powerlaw (electron ageing)
  - Could be a superposition of power laws



Synchrotron frequency scaling

- SAME EMISSION LAW FOR POLARISATION AND TEMPERATURE
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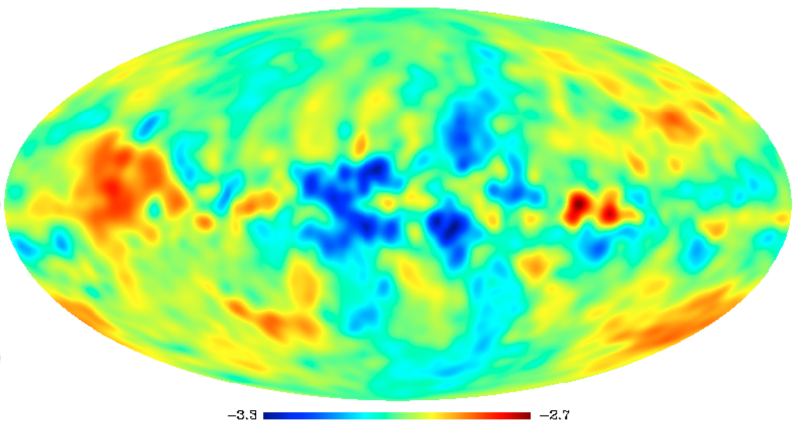
```
#---- Synchrotron emission law {powerlaw, curvpowerlaw}
#---- [default = powerlaw]
SYNCHROTRON_EMISSION_LAW = powerlaw

#---- Synchrotron emission index {giardino2002, mamd2008, uniform}
#---- [default = mamd2008]
SYNCHROTRON_INDEX_MODEL = mamd2008

#---- Reference frequency for synchrotron curvature (if any)
#---- in GHz [default = 23]
#---- For the moment has to be uniform on the sky (one single number)
SYNCHROTRON_CURV_FREQ = 20

#---- Amplitude of synchrotron curvature [default -0.3]
#---- For the moment has to be uniform on the sky (one single number)
SYNCHROTRON_CURV_AMPL = -0.3
```



Polarisation: dust

- GALACTIC DUST
  - Data is scarce…
  - Archeops; BICEP; QUAD

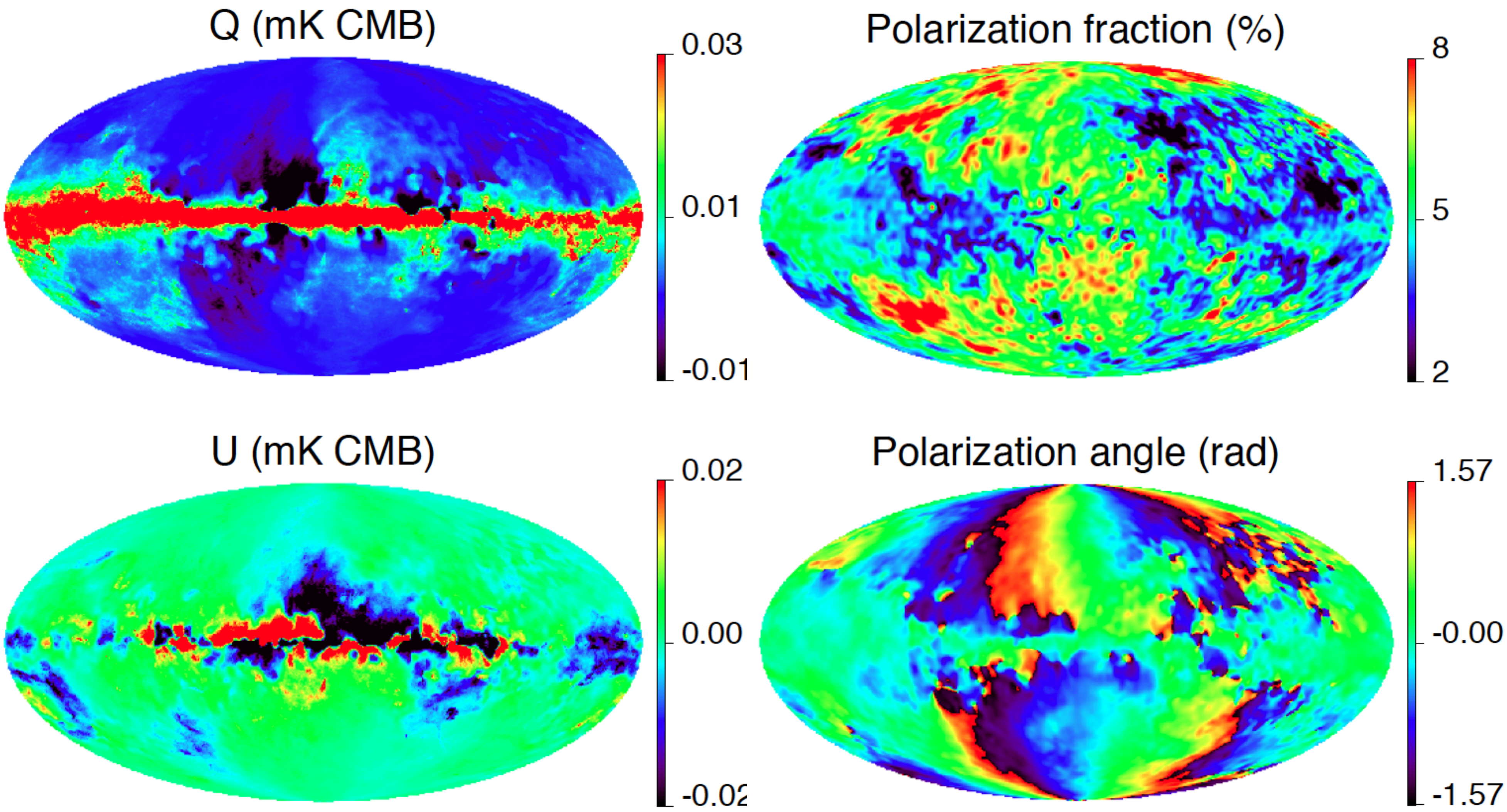
Polarisation angle

$$Q_\nu(p) = f_{\rm d}\, g_{\rm d}(p)\, I_\nu(p)\, \cos(2\gamma_{\rm d}(p)),$$
$$U_\nu(p) = f_{\rm d}\, g_{\rm d}(p)\, I_\nu(p)\, \sin(2\gamma_{\rm d}(p)).$$

Intrinsic polarisation
[default 15%]

Geometric depolarisation
[assumes a 3D model]

- FREQUENCY SCALING: two modified blackbodies (T varies)



Dust at 200 GHz

Polarisation: comparison

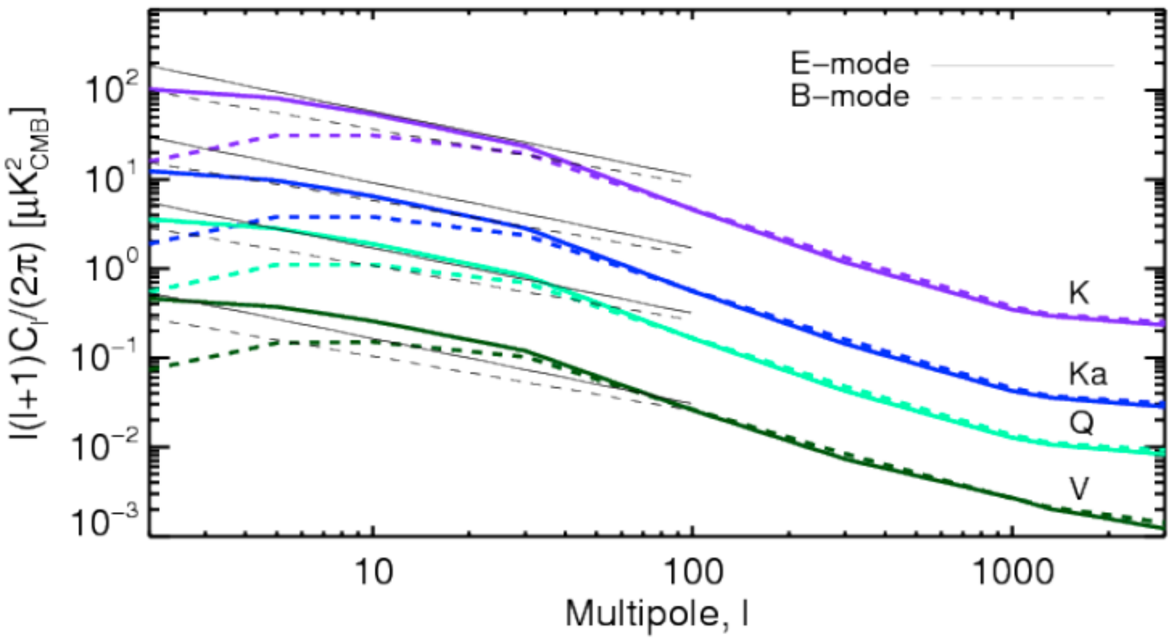


Fig. 16. *E* and *B* power spectra of diffuse Galactic emission simulated with the model at *WMAP* central frequencies (solid and dashed thick lines respectively). The P06 Galactic mask is used. The *WMAP* derived foreground levels from Gold et al. (2011) are also shown (thin lines).

Generally good Agreement with WMAP.

Comments and Summary

- HOW REPRESENTATIVE IS THE MODEL
  - It depends on the parameters – there is not a *single* Planck Sky Model
  - Polarised power spectra are in rough agreement with existing observations, but that's only the first order.
  - The default model may be too simple: one single synchrotron component, a very simple dust component. Does that hold down to relative precisions of 10^{-5} in power?

- A FRAMEWORK FOR INVESTIGATING THE MULTI-COMPONENT SKY
  - Parametric
  - Meant to be global and coherent
  - Investigate impact of changing the parameters, adding new components…

- MODEL AVAILABLE (as much as possible)
  - Use it, give feedback
  - Collaborators welcome