FITS MAPS: A MULTIMESSENGER APPROACH FOR ANTARES AND KM3NET

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DATA FILES TYPES. MAIN CATEGORIES

CLASSIC TABLES

PRO: Readable with text editor, excel, etc.
CON: Subjected to the original format
CON: Difficult to store metadata
CON: Slow, large
CON: Must read the whole file

BINARY BASED

CON: Looks weird as first sight
PRO: Can be easily manipulated
PRO: Made to store metadata
PRO: Fast, small
PRO: Can read just what you want

WHY FITS?

Standard format in Astronomy

Used by all Telescopes!

Many platforms to read these files:

astropy

Aladin

FITS4WIN2

NASA FITS

...

BINARY BASED

One of this is the **FITS** format

Flexible
Image
Transport
System

WHY FITS?

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astropy

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NASA FITS

...

ADVANTAGES:

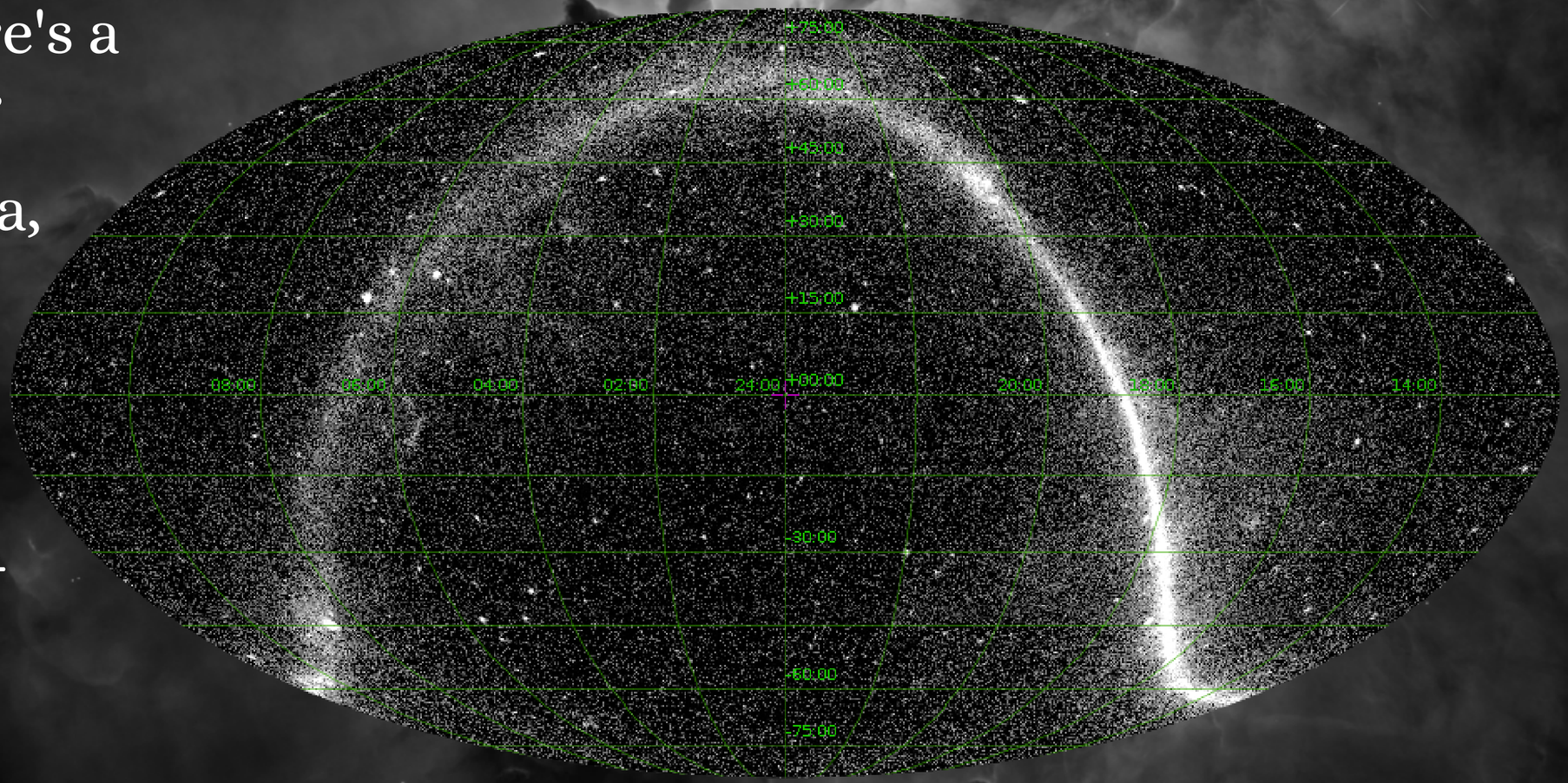
- Quicker targeted statistical analysis
- Faster comparisons
- Fast and easy visual checks between complete and partial skymaps

ALADIN...

Tried this, there's a huge library of maps in gamma, UV, X-rays...

Stars, nebula, galaxies, LIGO-VIRGO maps, Fermi, etc...

From Fermi Telescope.

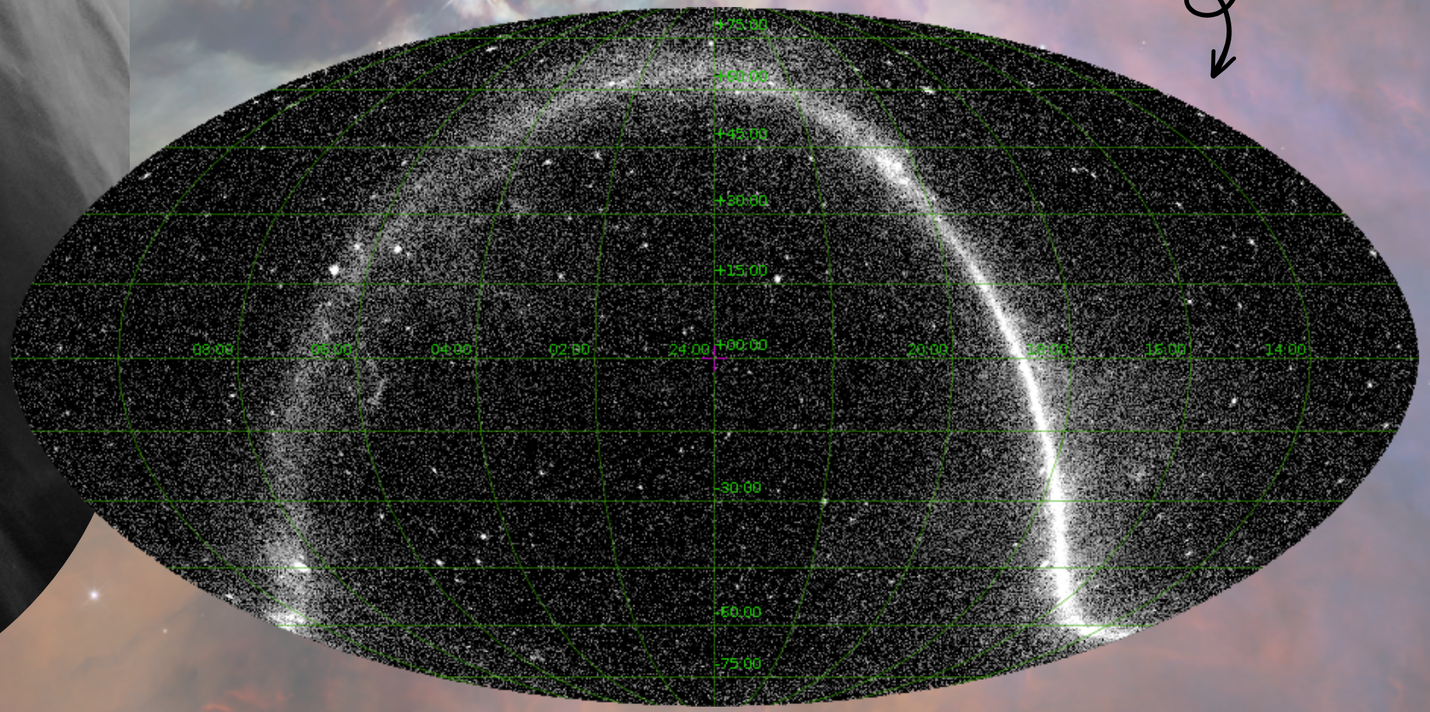


FIRST STEP

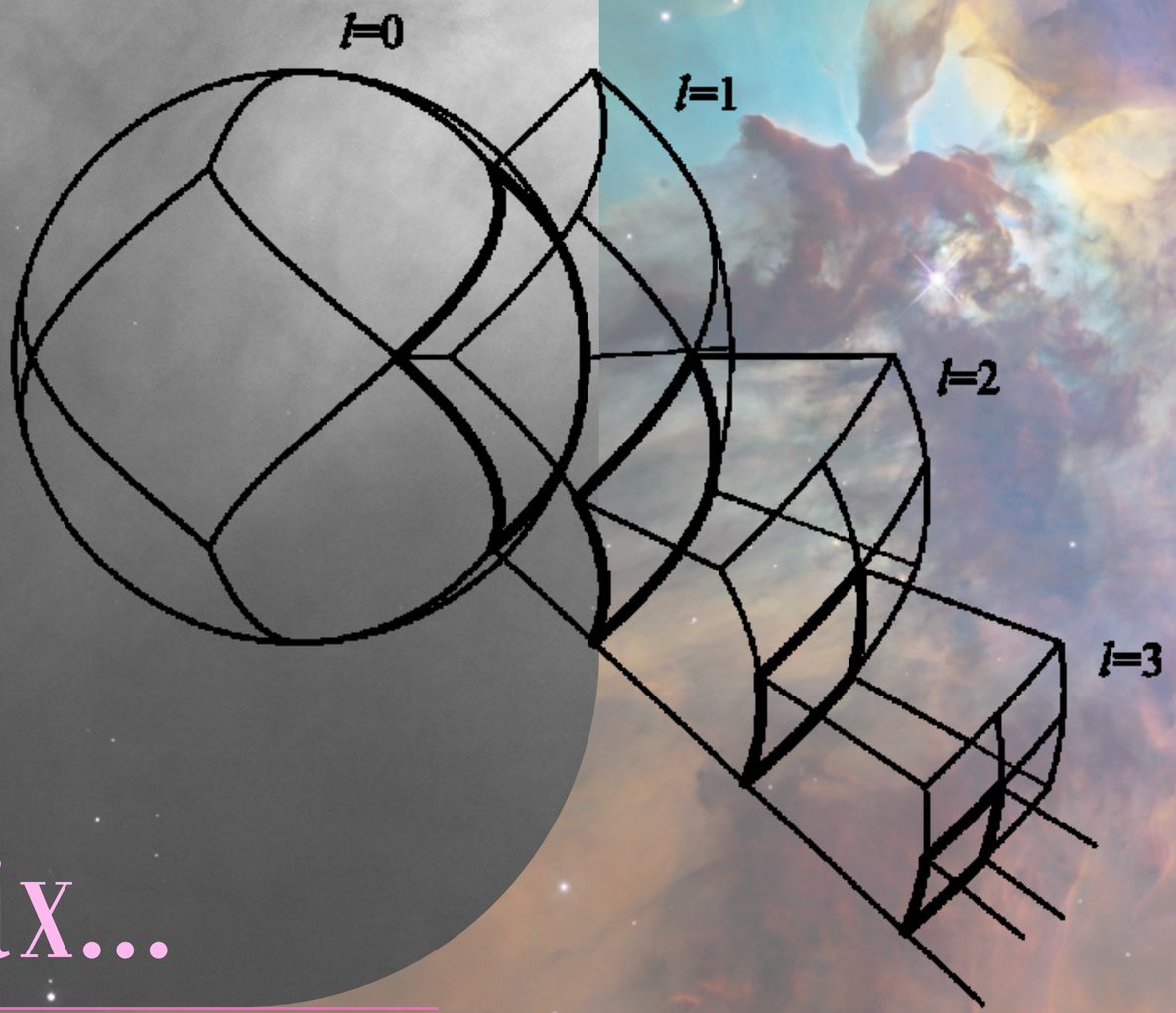
Convert data to the FITS format

HEALPix to the Rescue!!

FERMI used HEALPix for this!



Hierarchical **E**qual-**A**rea and iso**L**atitude **Pix**elization

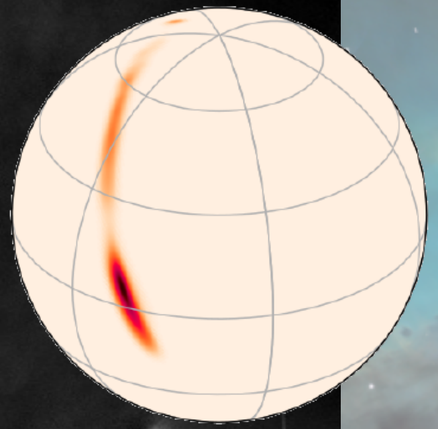


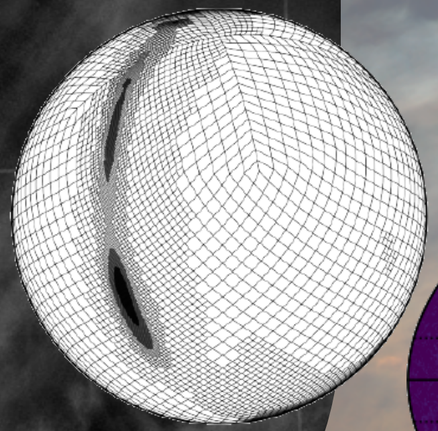
Is an **all-sky map projection** and a **spatial indexing method**. Divides and covers the unit sphere with equal-area tiles.

May be thought of as a tree in which each node except for the root node has four children.

HEALPix...

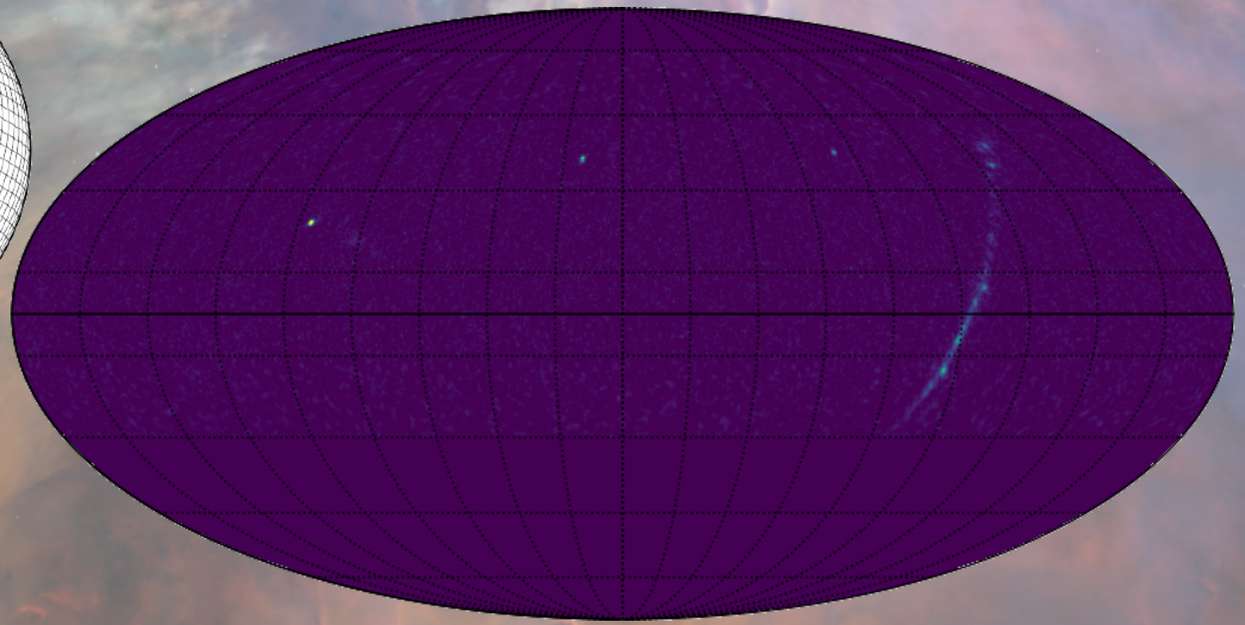
HEALPix...





Pixel density roughly proportional to probability density

HAWC FITS file map:
Flux & Significance.



FROM DATA TO FITS

- **We know what we want to do.**
- **We know how a FITS should be.**
- **We might know how to do it.**
- **Can we?**

First try:
ANTARES public data
https://antares.in2p3.fr/publicdata2017.html

dec RA nhit beta time

Need more info to get a map!

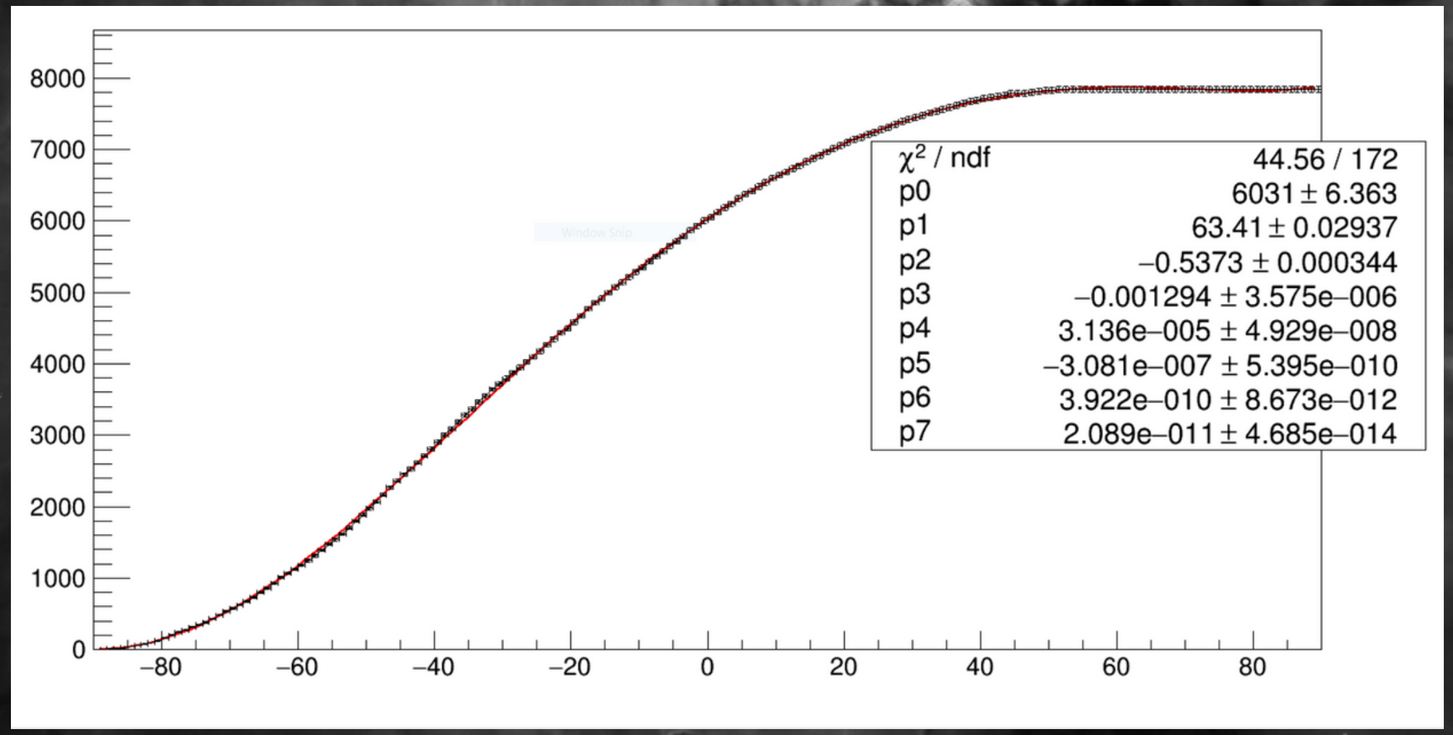
HANDS ON!

To have a map that can be used in multimessenger astronomy, we need information such as the Flux of the detected events

Using some information contained in the public data table (**declination**, number of hits **nhit** and **beta**)

A "cumulative" function of **nhit** (using **beta** as error bars) as a function of the **declination** was fit with a 7 degree polynomial function.

HANDS ON!

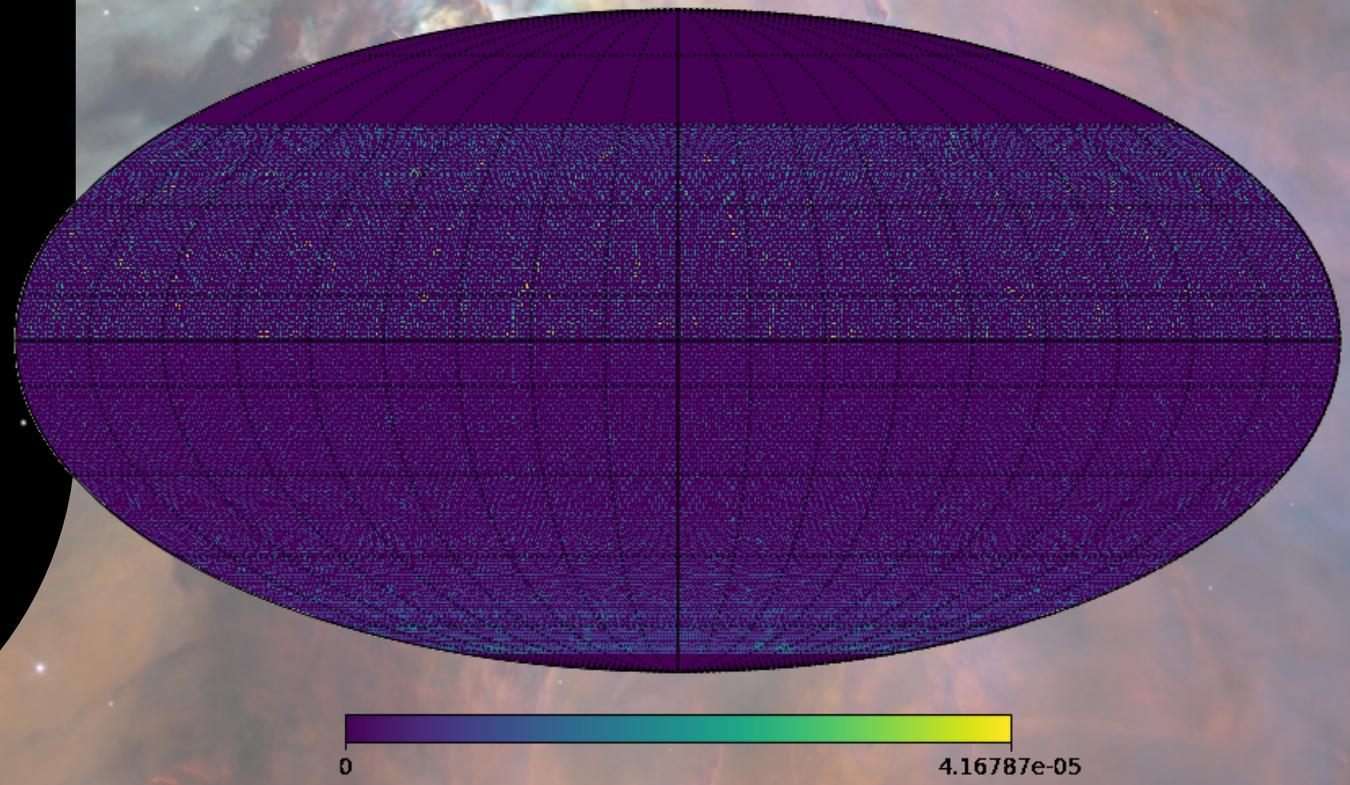


Using the fit parameters and ANTARES script (based on Feldman Cousins statistical approach), we computed:

Background
Observed events
Flux Upper Limit

FITS FILE PRODUCTION...

Using Healpix, Matplotlib, Numpy, Astropy, Healpy and a lot of other pys
A FITS file was prepared, written and read



FITS FILE PRODUCTION...

We are now able to produce FITS files with whatever information we want to show/share

Partial or complete!

What can we modify?

Nside (resolution of pixelization)

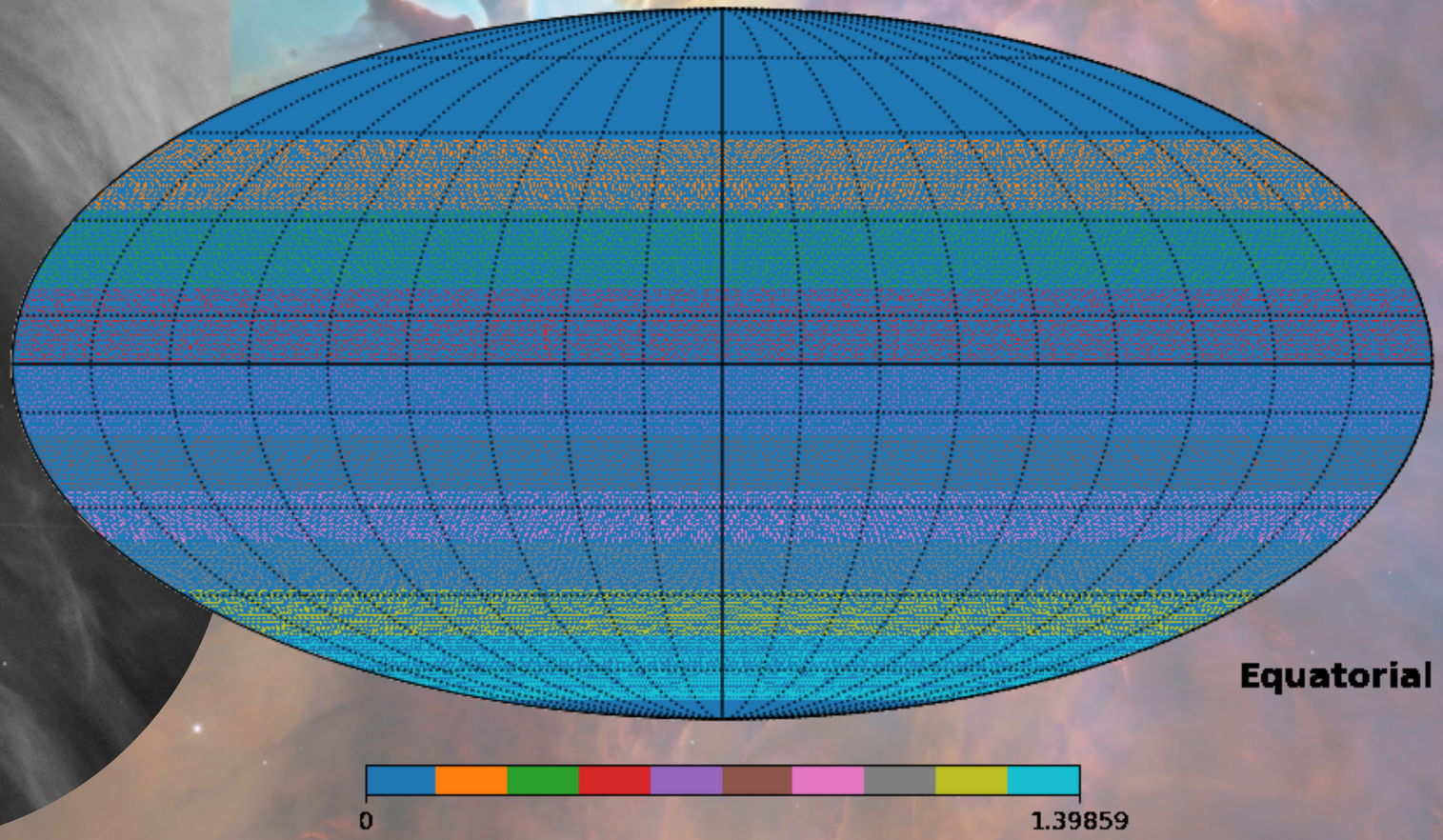
Ordering (way of writing a map)

Coordinate system

BACKGROUND

Different skymaps for all the information available

nside=128

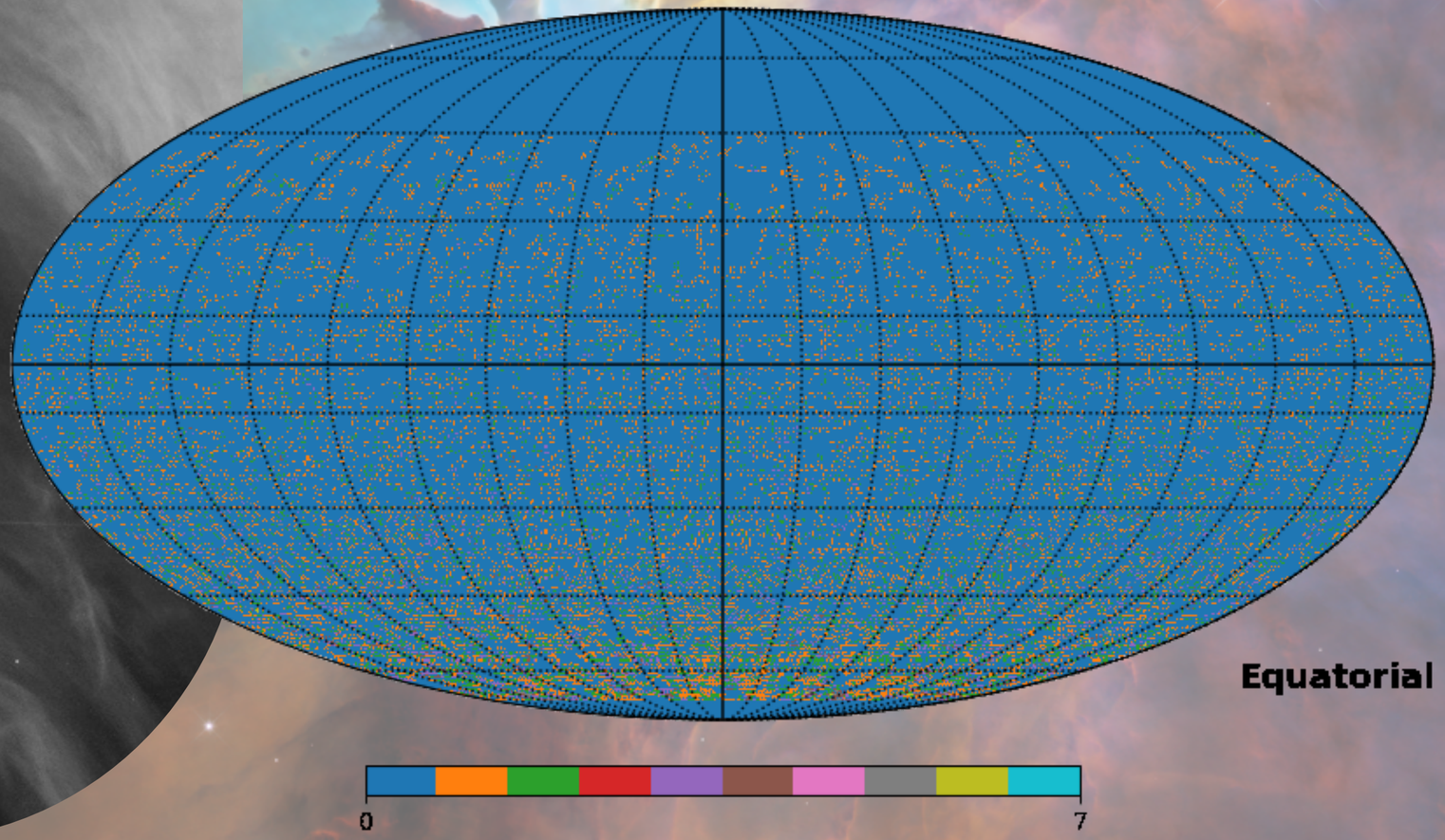


ANTARES 2017 DATA ANALYSIS

EVENTS OBSERVED

Different skymaps for all the information available

nside=128

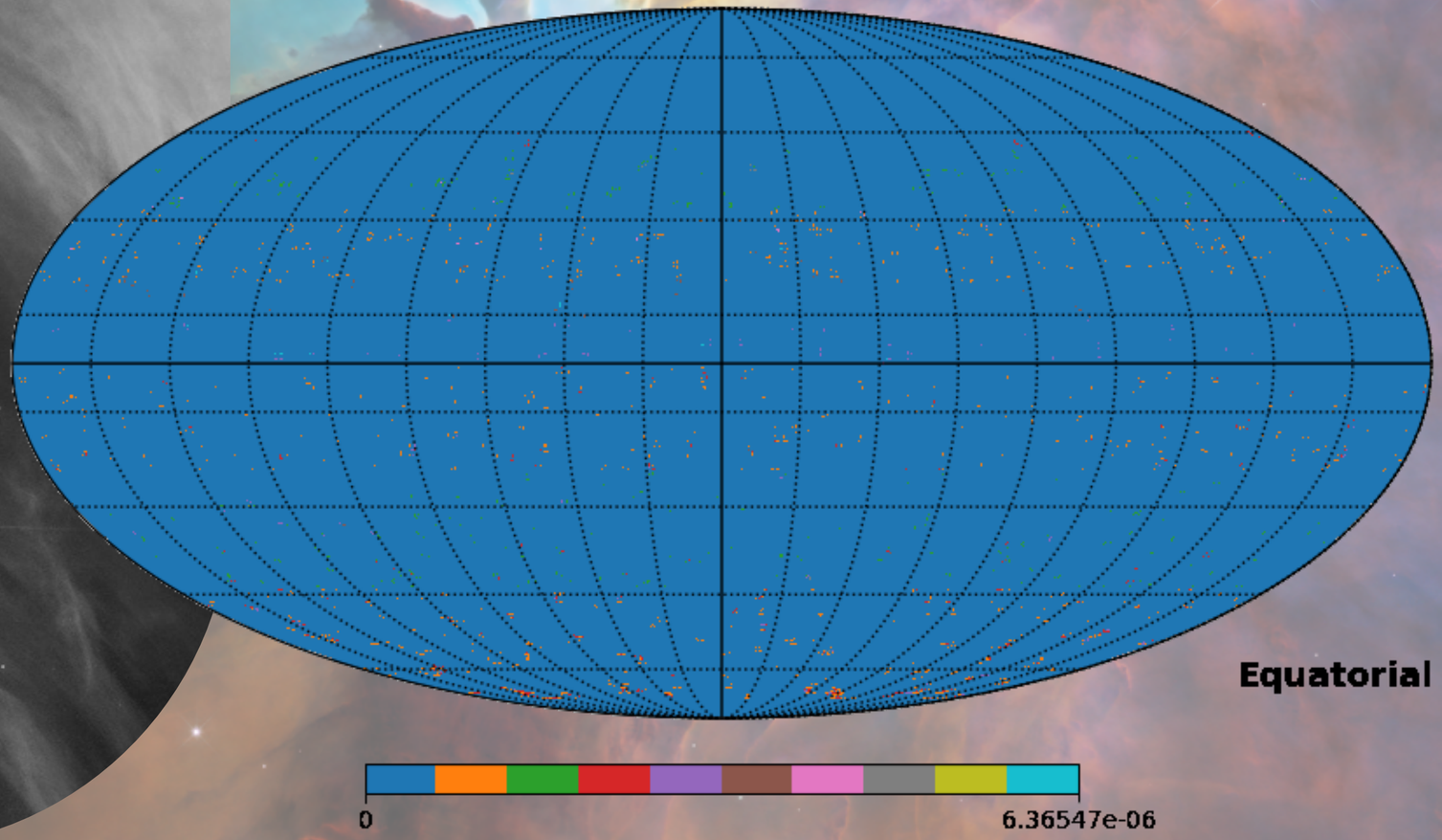


ANTARES 2017 DATA ANALYSIS

FLUX LOWER LIMIT

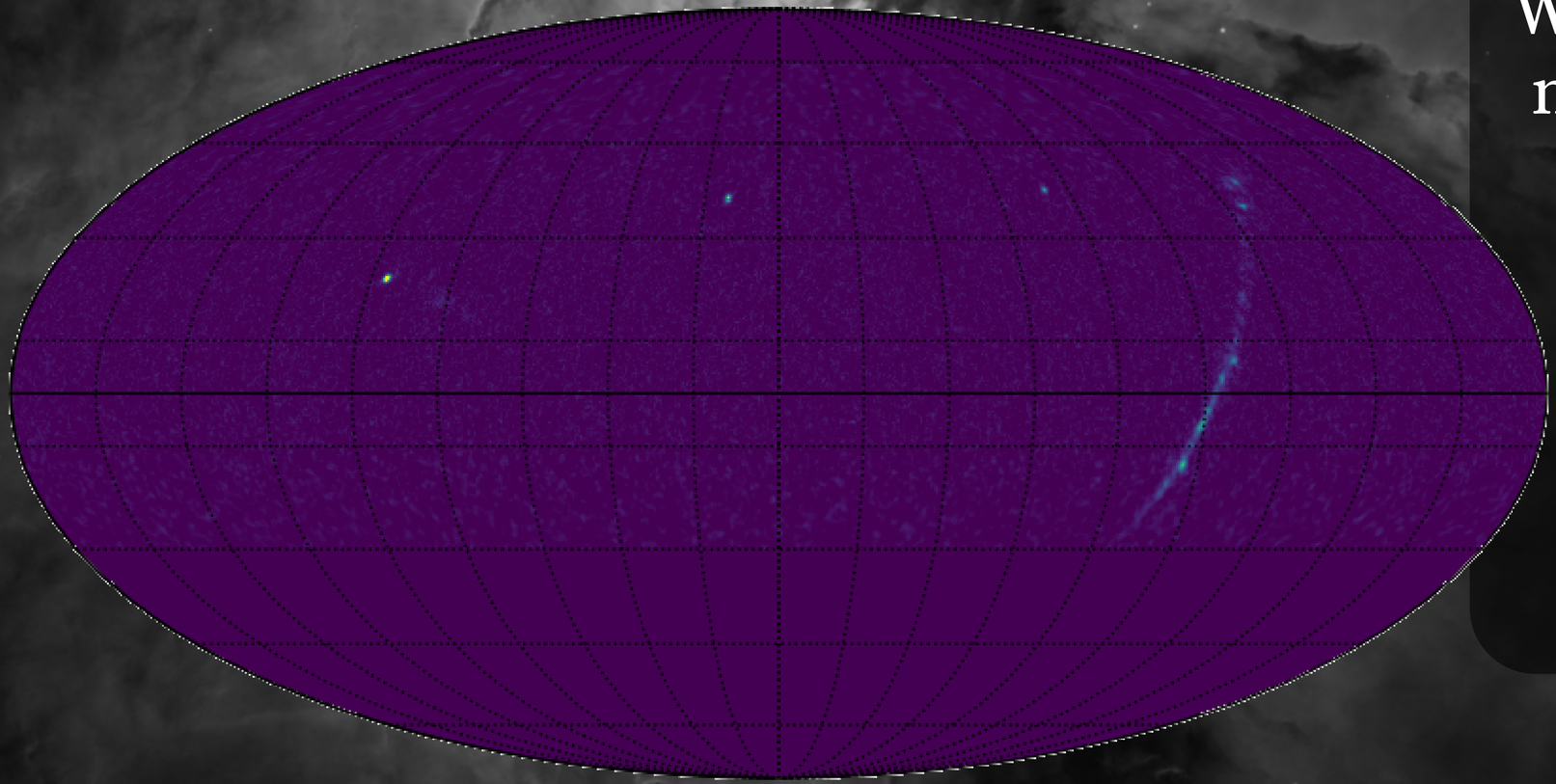
Different skymaps for all the information available

nside=128



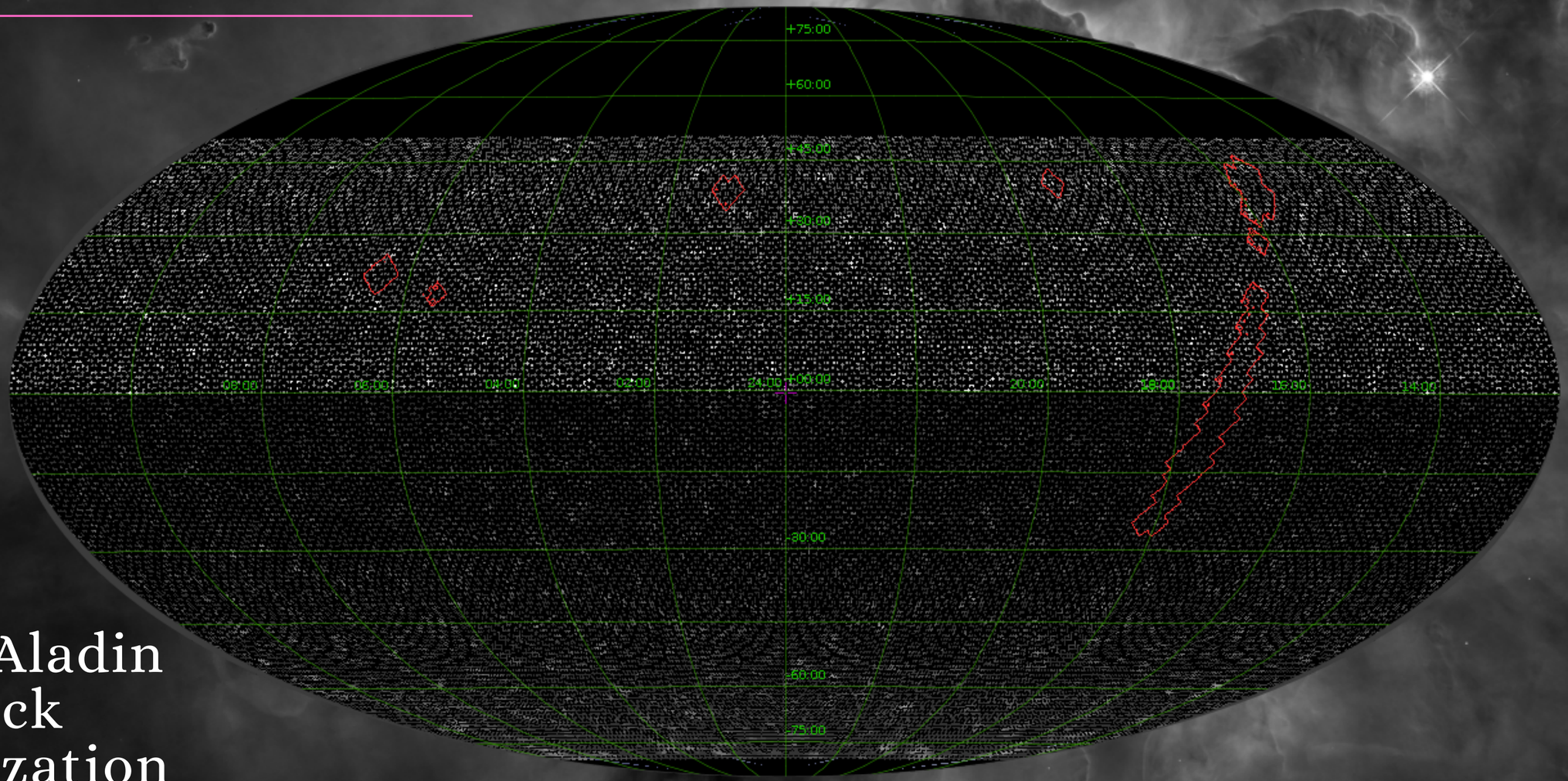
ANTARES 2017 DATA ANALYSIS

READY FOR MULTIMESSENGER ASTRONOMY!



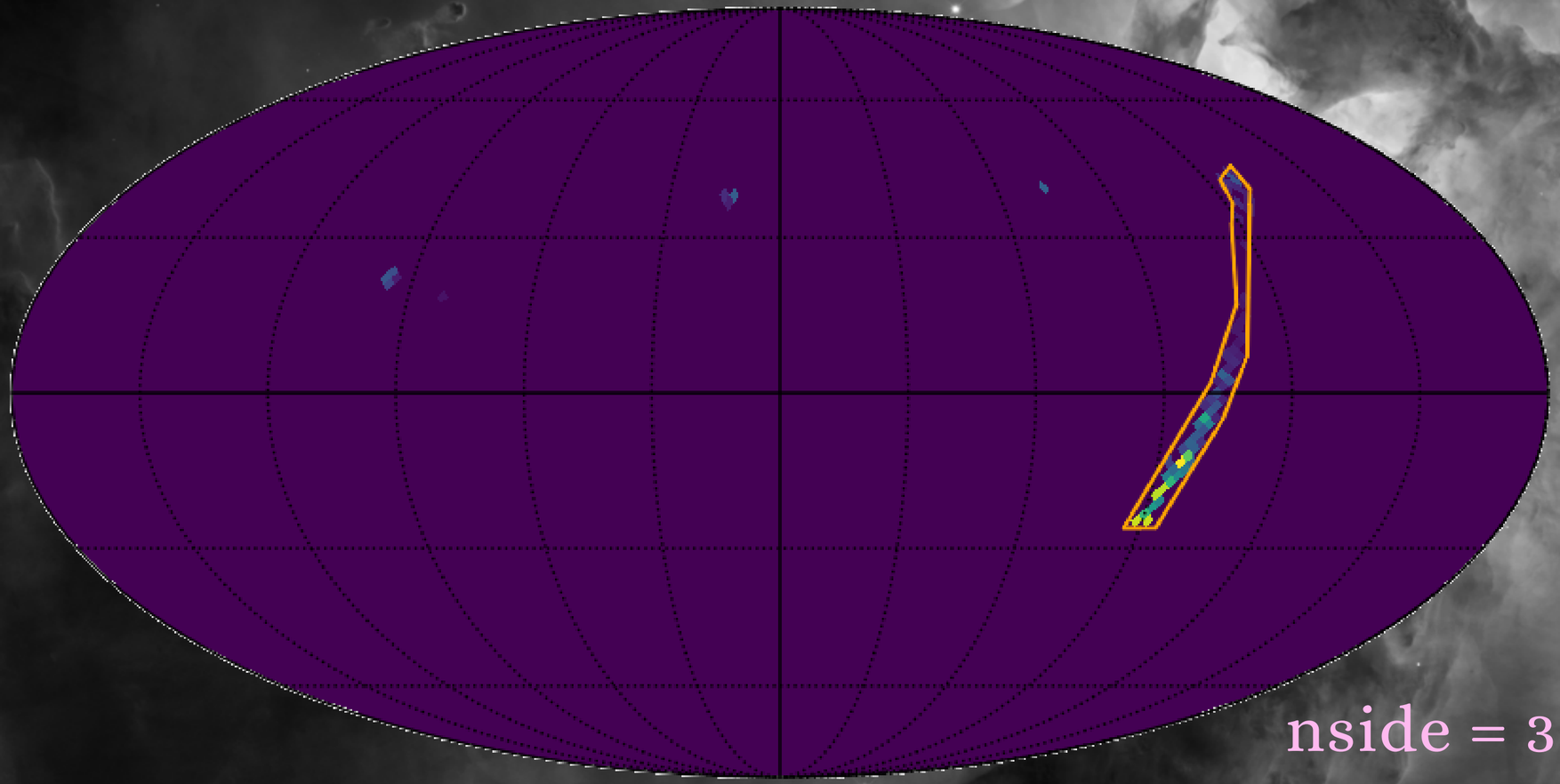
We don't know how much of this FLUX is actual signal. Need to compare with some real signal.
Used HAWC's for this

ASTRO SOFTWARE



Using Aladin for quick visualization

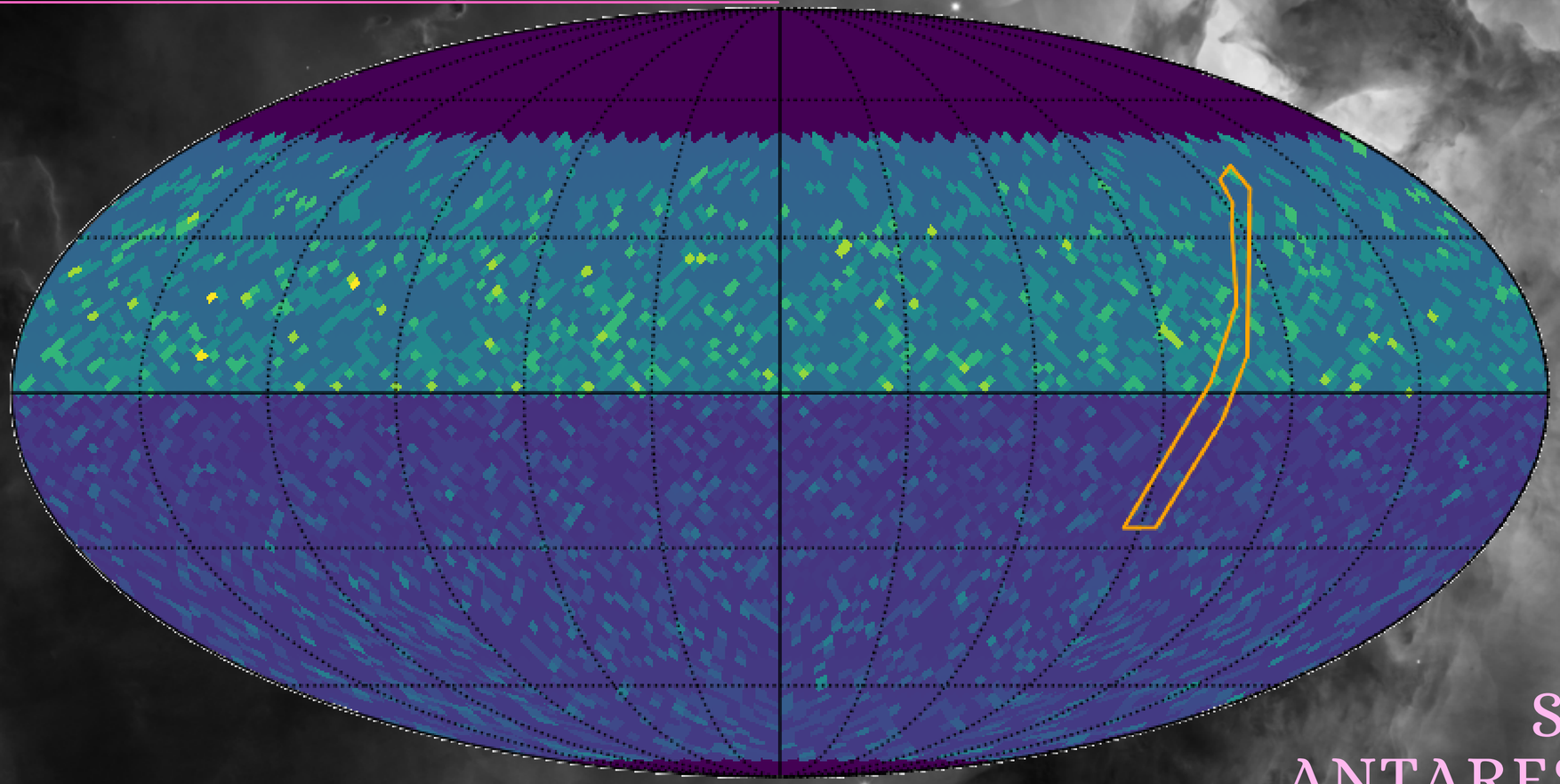
QUANTITATIVELY...



HEALPix again!
nside = 32 for semplicity

Step 1: Identify HAWC'S position

QUANTITATIVELY...



Step 2: Integrate ANTARES flux e^gamma within HAWC's position

QUANTITATIVELY...

WARNING: This has to be done after careful conversion of coordinates to pixels.

Two tests (100 TeV):
gamma=2.7 INT=3.66e-17 $[\text{GeV cm}^2\text{s}]^{-1}$
gamma=2.0 INT=1.25e-16 $[\text{GeV cm}^2\text{s}]^{-1}$

This information -> Energy spectrum

...WORK IN PROGRESS...

WHAT'S NEXT?

FITS files carry so much information that a quick comparison between different telescope data can be made (using HEALPix)

Also, the FITS format can put KM3NeT under all other telescopes' light which can lead to many new collaborations (and papers!) thanks to its simplicity and versatility

THANKS!

INFN
NAPOLI
Istituto Nazionale di Fisica Nucleare
Sezione di Napoli
KM3NeT
arca&orca

UNIONE EUROPEA
Fondo Europeo di Sviluppo Regionale

Ministero dell'Università
e della Ricerca

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