From the Combined Fit to arrival direction in a transient scenario

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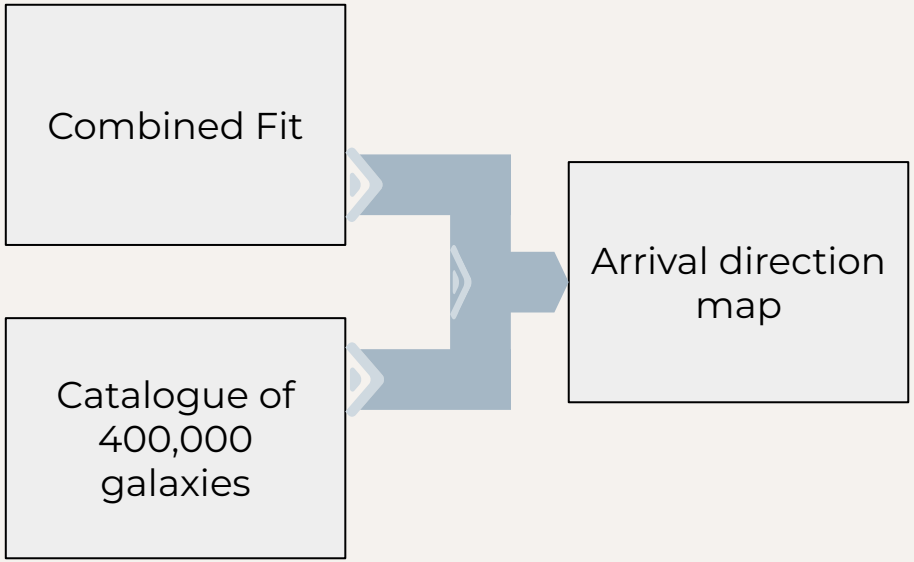
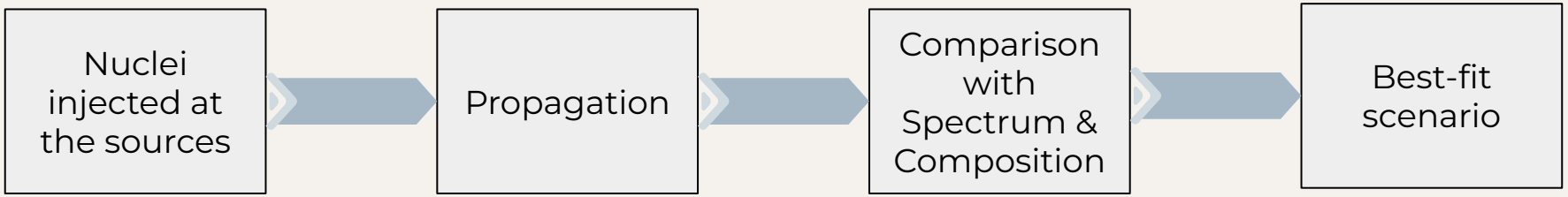
From Combined Fit to arrival direction

Idea:

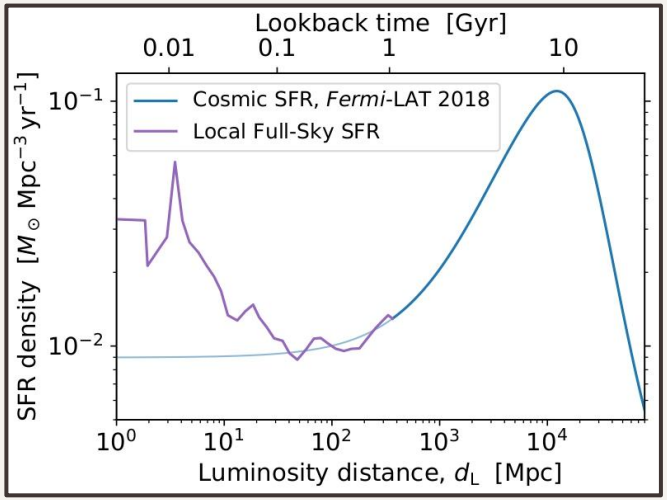
- ➔ Combined Fit gives us best-fit scenario using spectrum and composition data
- ➔ Associate to each galaxy a flux from the best-fit scenario of the CF



Combined Fit



- ➔ 5 representative masses injected at the sources: **H**, **He**, **N**, **Si**, **Fe**
- ➔ 7 parameters for the injection
  - 5 for the masses
  - 2 for the shape of the spectrum
- ➔ Assume the source to follow the Star Formation Rate Density

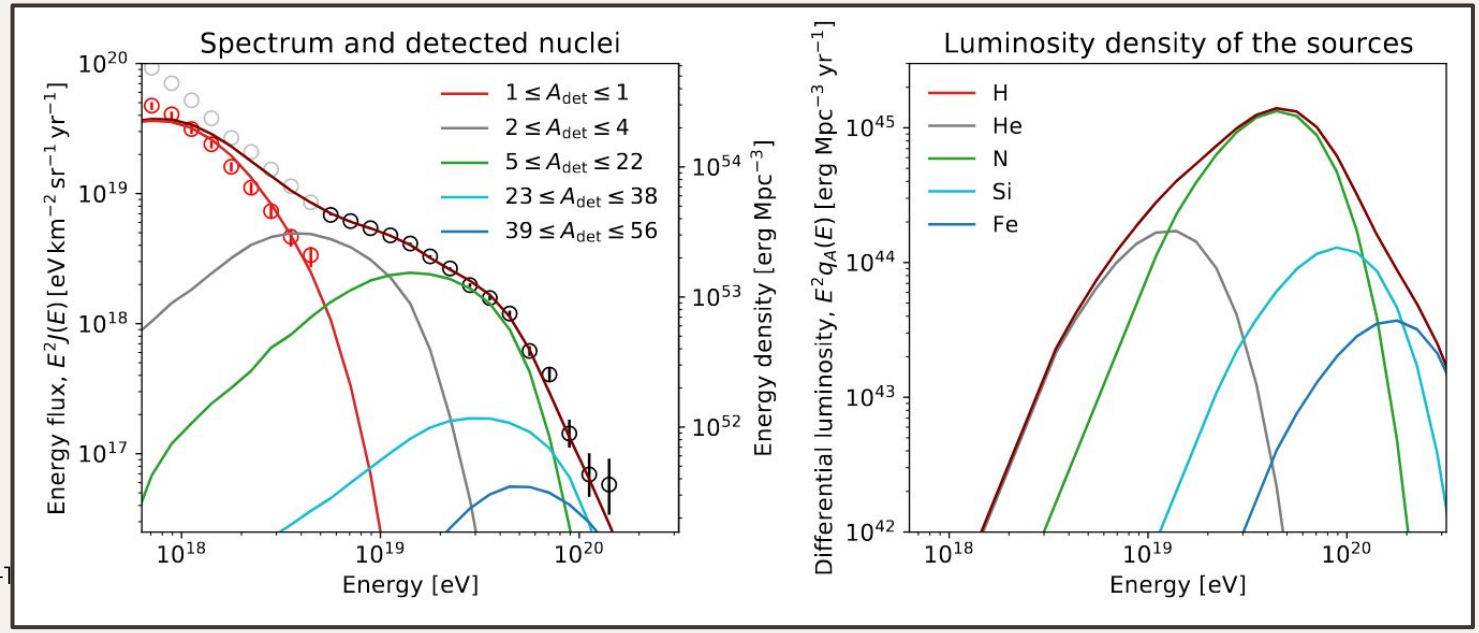


Result of the Combined Fit

Goodness of fit:
D_{tot}/ndf ~ 320/138

Parameters :
$E^{p}_{max} = 10^{18.2}$ eV
$\gamma = -1.7$

Emissivities ($E>10^{17.8}$ eV):
$L_{tot} = 2\ 10^{45}$ erg Mpc^{-3} yr^{-1}



Nuclei injected at the sources → Propagation → Comparison with Spectrum & Composition → Best-fit scenario

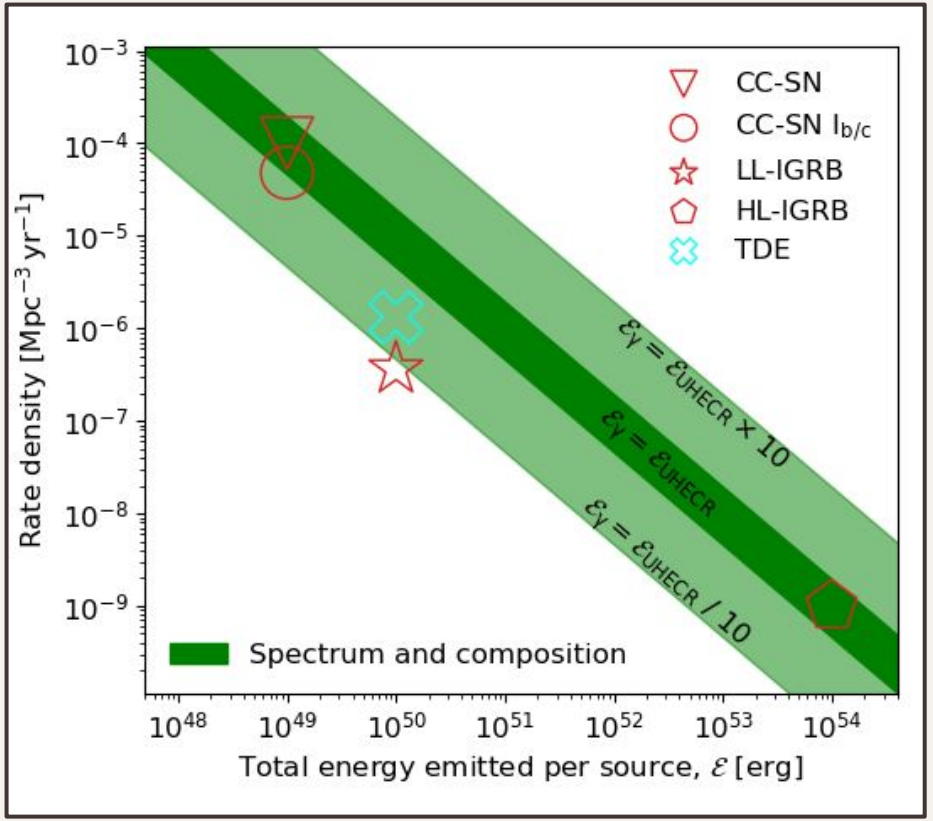
➔ Dominated **N**

➔ Protons are secondaries produced *en route*

Constraint on emissivity

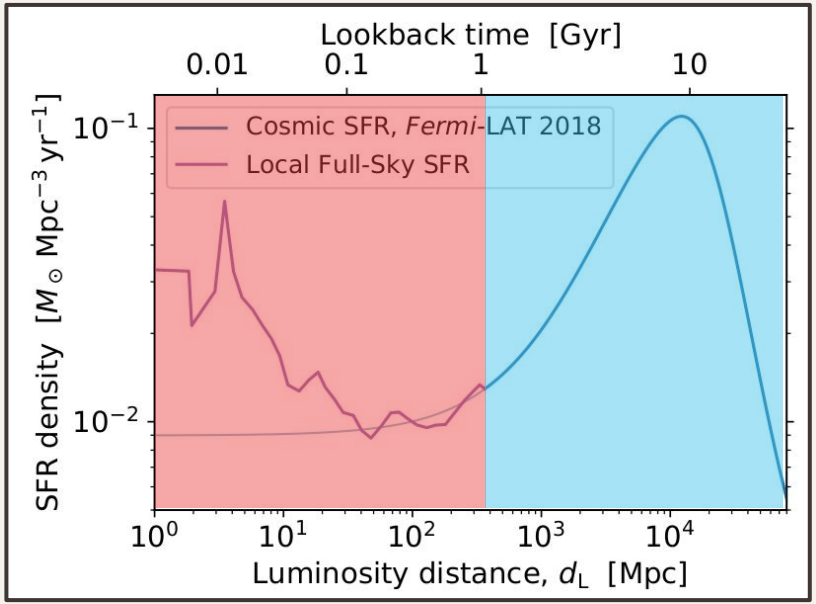
- Constraint on emissivity:
  - Green band
- Energy **per event and rate of occurrence** for different sources
  - Bolometric EM energy
- **Sources :**
  - Core Collapse supernova (CC-SN)
  - CC-SN type Ib/c
  - Low luminosity lGRB (LL-lGRB)
  - High luminosity lGRB(HL-lGRB)
  - Tidal Disruption Event (TDE)*

*Considering a stellar mass density evolution of sources



Catalogue of galaxies & arrival directions

- ➔ Catalogue of ~400,000 galaxies *(Biteau(2021) Astrophys.J.Suppl. 256)*
- ➔ Minimum distance of injection $\mathbf{D_{min} = 1\ Mpc}$
- ➔ Qualitative comparison



- ➔ **Discrete:** Compute the flux for **each galaxy** from the catalogue (~400 000) proportional to their SFR
- ➔ **Continuous:** Compute the flux as before, from z=0.08 to z=2.5 **(isotropic background)**

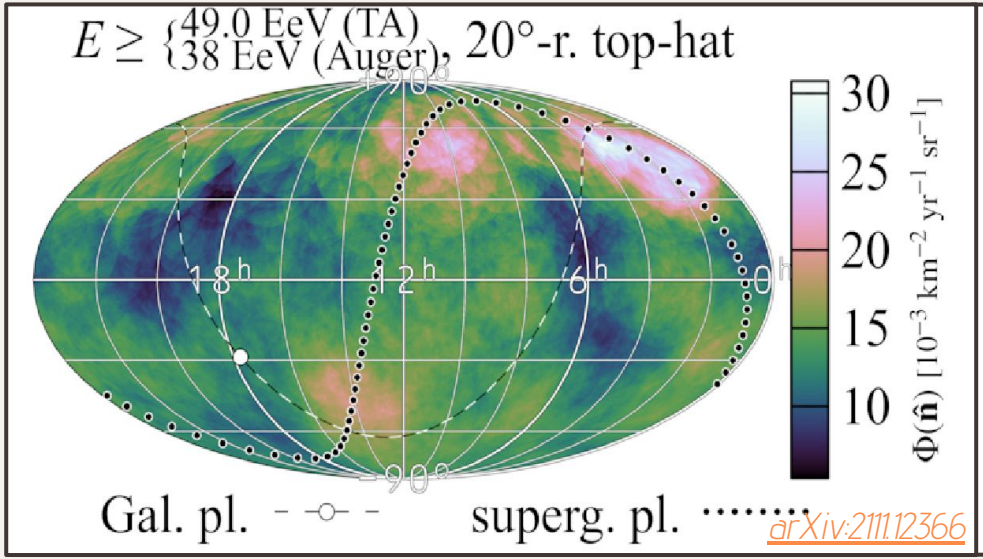
- ➔ **Arrival direction map:**
  Sum the contributions of all galaxies and isotropic background within one pixel

- ➔ Angular smoothing

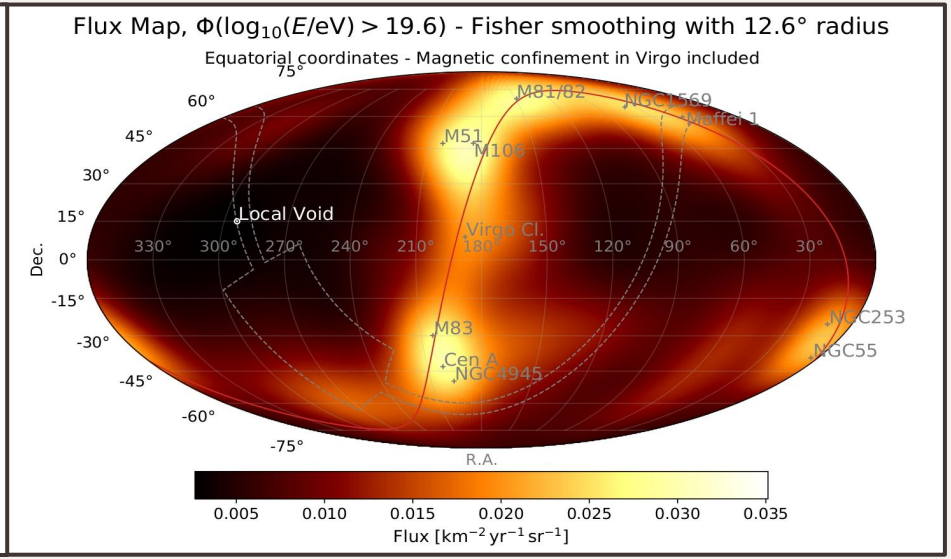
Sky map

- ➔ Sky map above **40 EeV**
- ➔ Consider confinement of UHECRs in Virgo's cluster
- ➔ Dominated the Council of Giants (~4 Mpc)

Data



Model

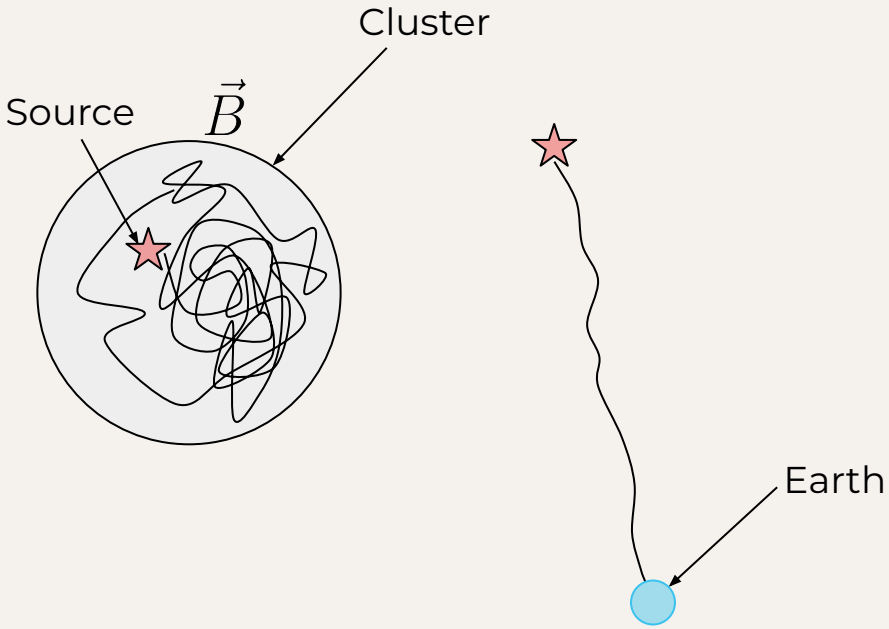


Cluster confinement

➔ Cluster magnetic fields could trap cosmic rays

➔ **Simplified approach:**
- Virgo cluster is considered
- UHECRs with a delay equal to the ballistic time are confined.

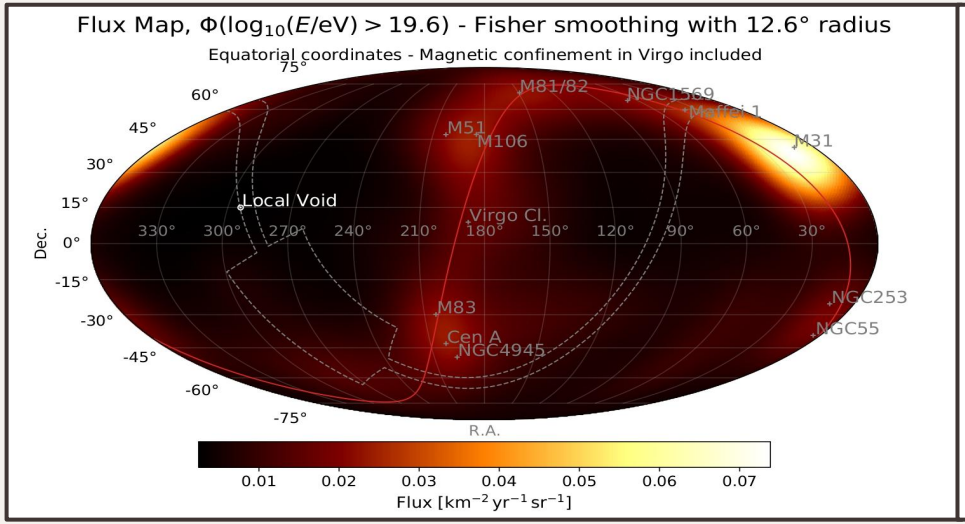
➔ **Future approach:**
- Full approach considering interactions (hadrons and photons)
  - *Harari D., Mollerach S. and Roulet E., JCAP 08 (2016) 010*
  - *Condorelli A., Adam R., Biteau J. (in prep.)*



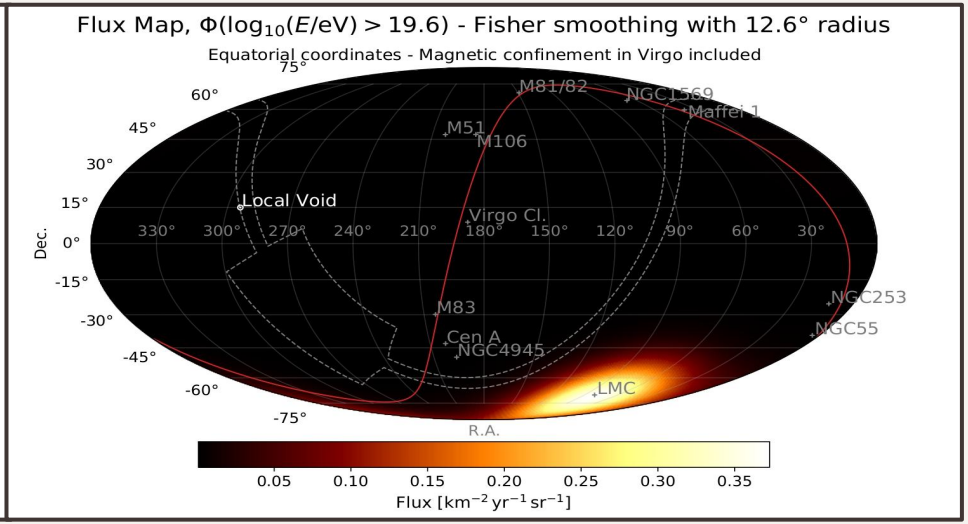
Impact of minimum distance of injection

- ➔ Since the beginning, D_{min} = 1 Mpc.
  - ◆ No reason for that
- ➔ If D_{min} is smaller
  - ◆ Sky is dominated by M31/M33, Magellan's clouds, or the Milky Way.

D_{min} = 0.50 Mpc



D_{min} = 0.01 Mpc

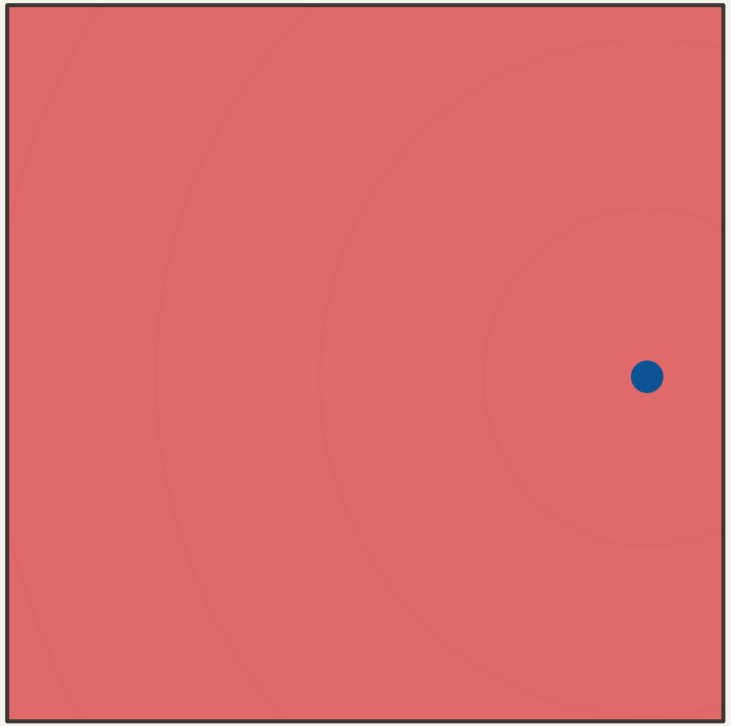


Up to now, stationary scenario

- Stationary scenario
  - UHECRs are continuously emitted

Source

UHECRs



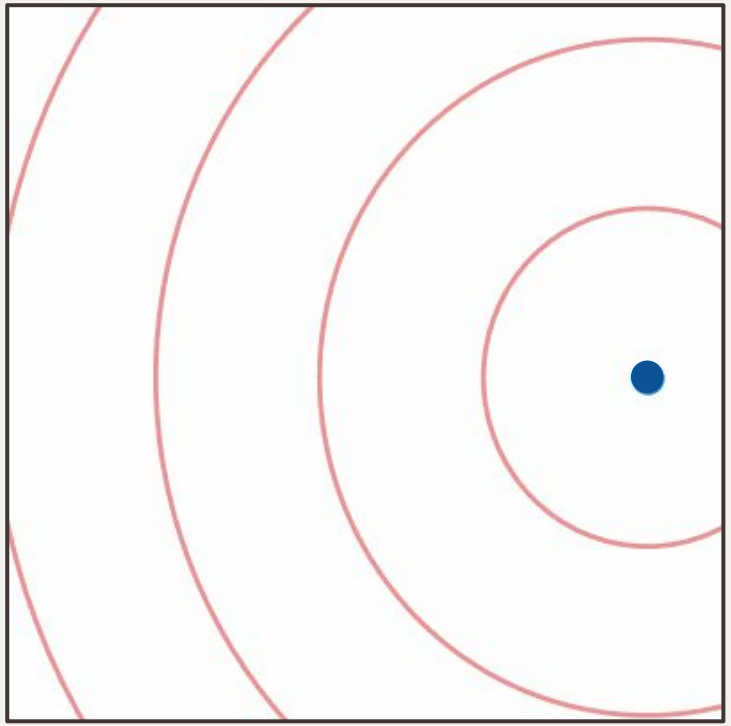
Consequence of transient scenario

- Stationary scenario
  - UHECRs are produced through bursts

Source

UHECRs

- No magnetic field
  - Each burst is of constant width



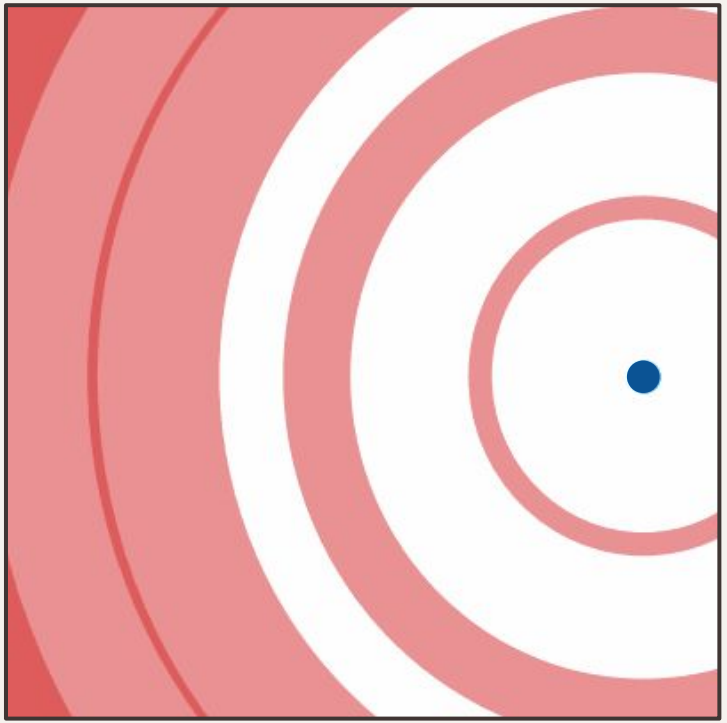
Consequence of transient scenario

- Stationary scenario
  - UHECRs are produced through bursts

Source

UHECRs

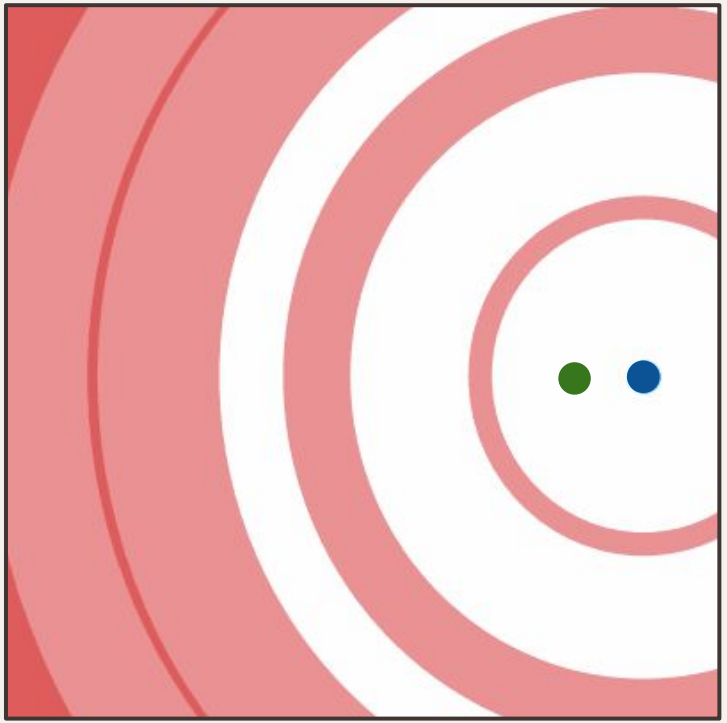
- Magnetic field
  - The width of burst increases with time



Consequence of transient scenario

Close source

- Source
- UHECRs
- Detector (Earth)

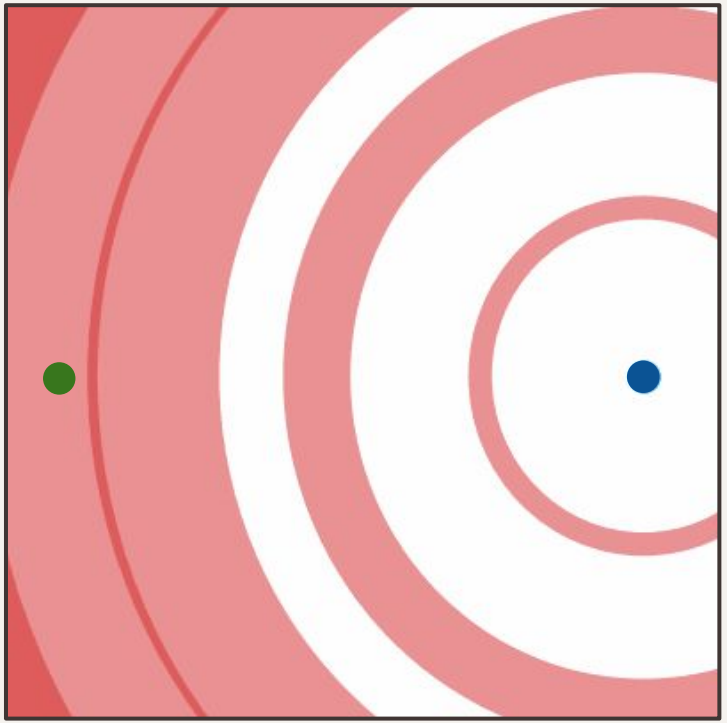


➔ Low probability to observe the source

Consequence of transient scenario

Faraway source

- Source
- UHECRs
- Detector (Earth)



➔ High probability to observe the source

Transient scenario : quantification

➔ The probability to observe a source is given by a Poisson distribution of parameter:

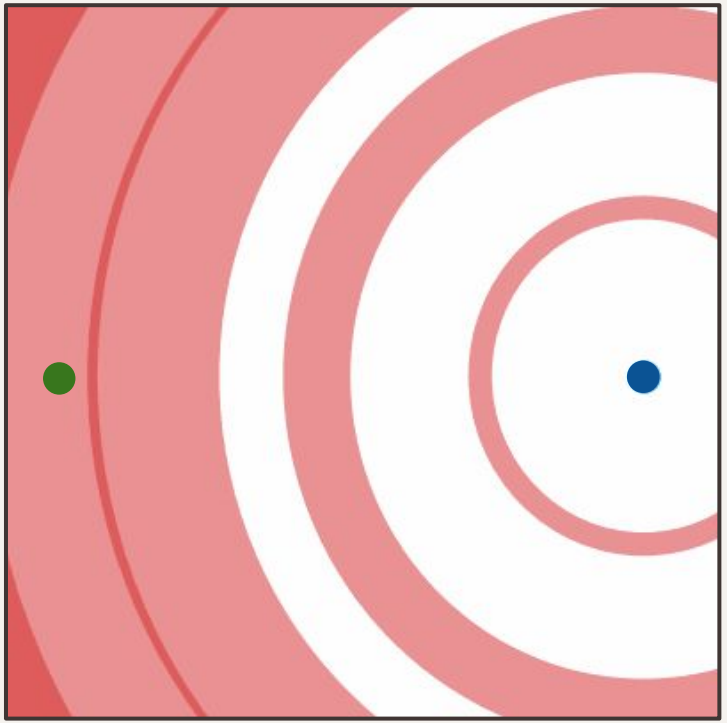
$$\mathbf{N = k \times \Delta T \times s_{Gal}}$$

➔ Poisson parameter:

- ΔT is the time spread (magnetic field)
- s_{Gal} is the star formation rate of the galaxy
- ***k* is a new parameter**
- $k \times s_{Gal}$ is the burst rate
- $[k] = \mathbf{M_{\odot}^{-1}}$

➔ Need to characterize **ΔT**

- What kind of magnetic fields matter ?



Magnetic field & time spread

➔ The time spread is computed assuming small-angle scattering

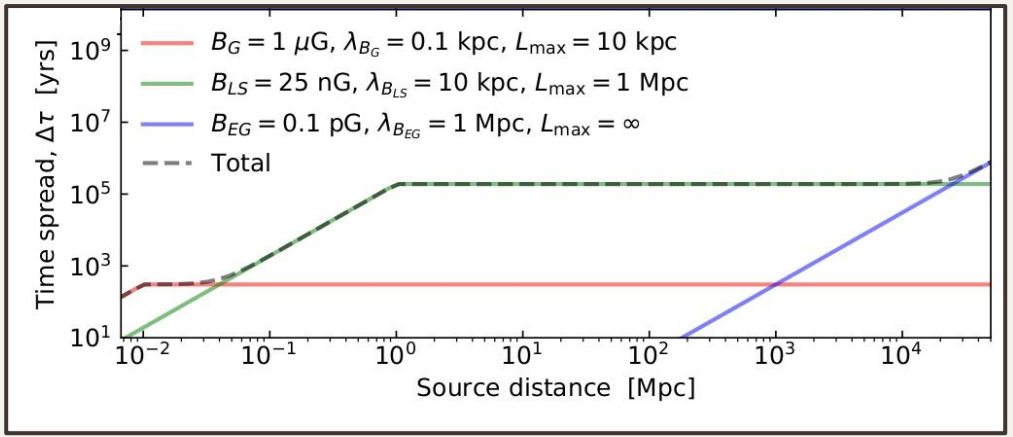
$$c\Delta\tau \simeq 4.4\times10^{3}\left(\frac{B}{10\,\mathrm{nG}}\right)^{2}\left(\frac{R}{10\,\mathrm{EV}}\right)^{-2}\left(\frac{D}{1\,\mathrm{Mpc}}\right)^{2}\left(\frac{\lambda_{\mathrm{B}}}{10\,\mathrm{kpc}}\right)\ \mathrm{yrs}$$

➔ **Galactic magnetic field**

➔ **Local sheet magnetic field**

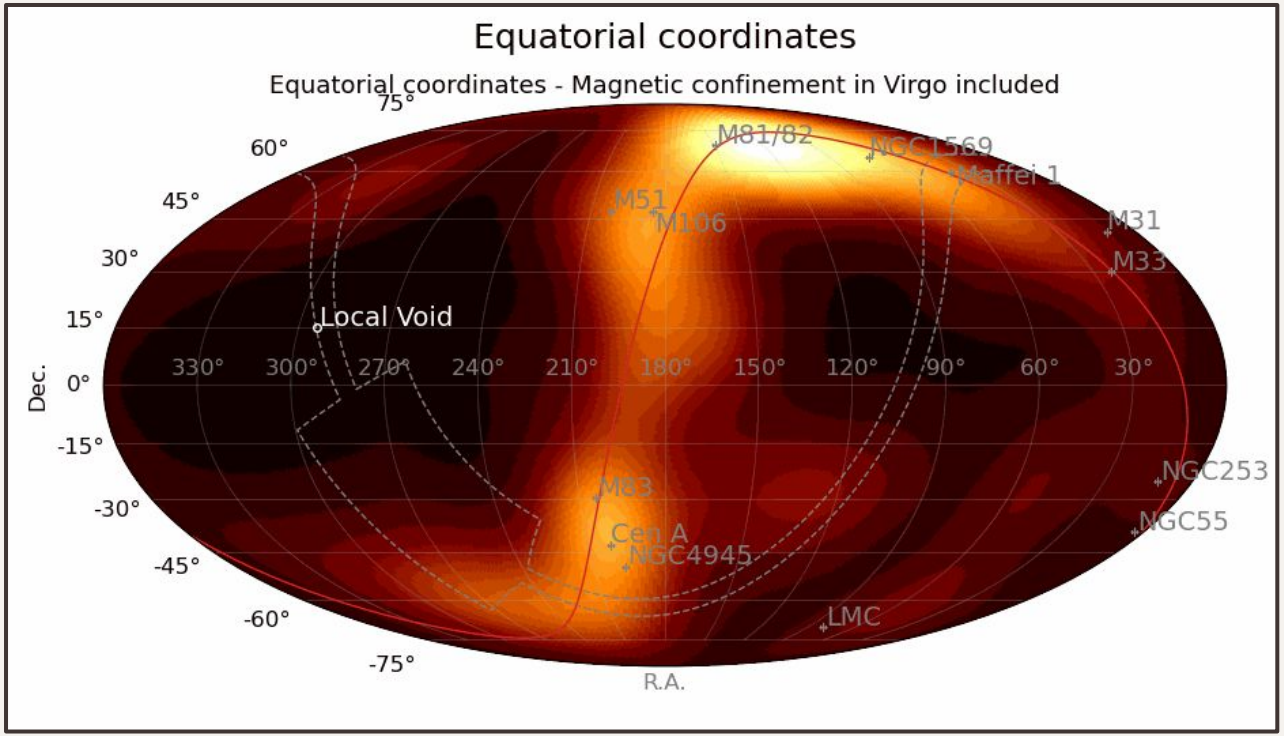
- Strength B_{LS} = [10; 25] nG (**consistant with MHD simulation** of magnetic fields)
- Coherence length λ_G = 10 kpc
- Size L_{max} = 1 Mpc

➔ **Extragalactic magnetic field**



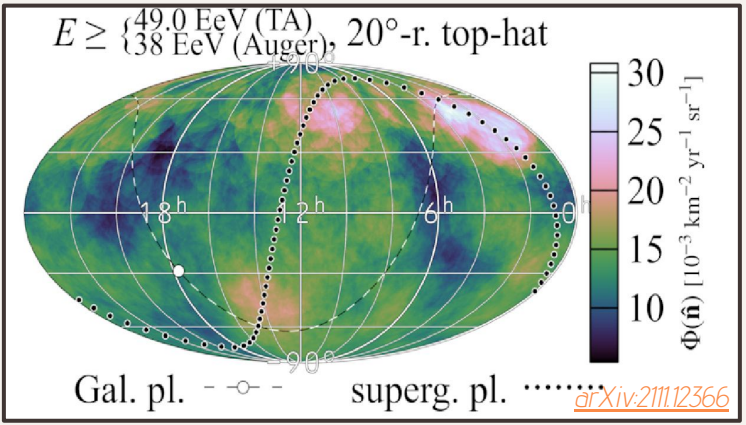
Skymap in a transient scenario

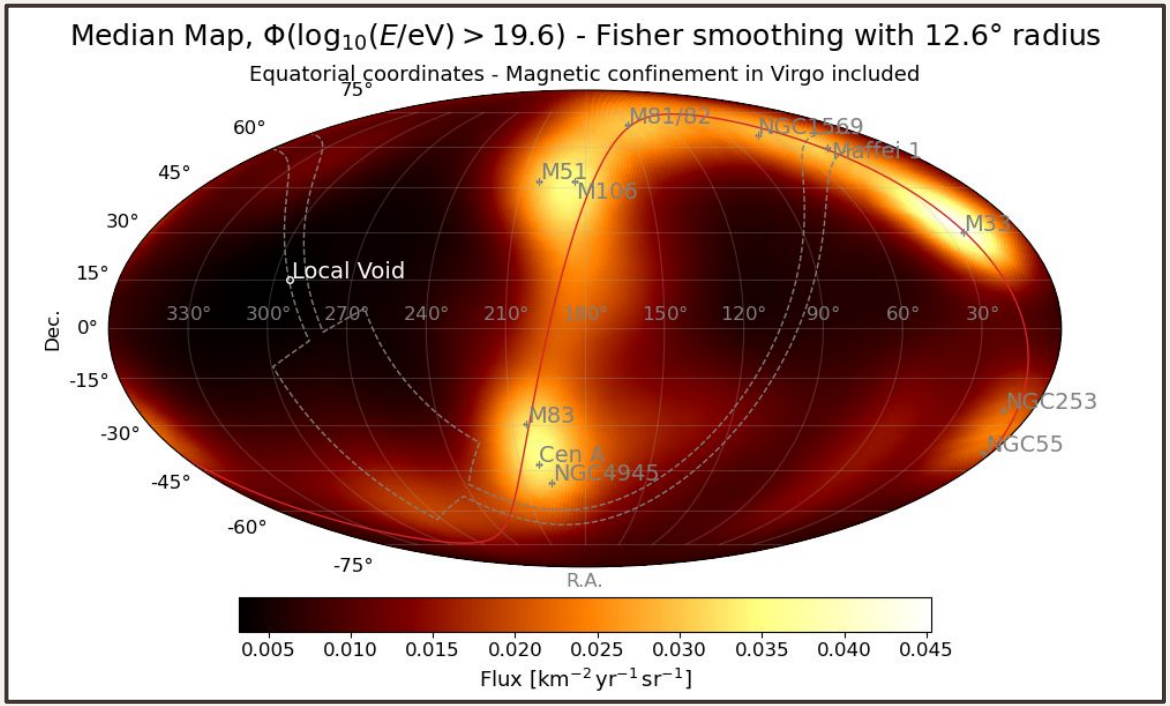
- **N** (number of bursts) is drawn at random for each galaxy
- 100 maps are produced
- Here, $k_{SFR} = 10^{-5}\ M_{\odot}^{-1}$



Median map - Best k

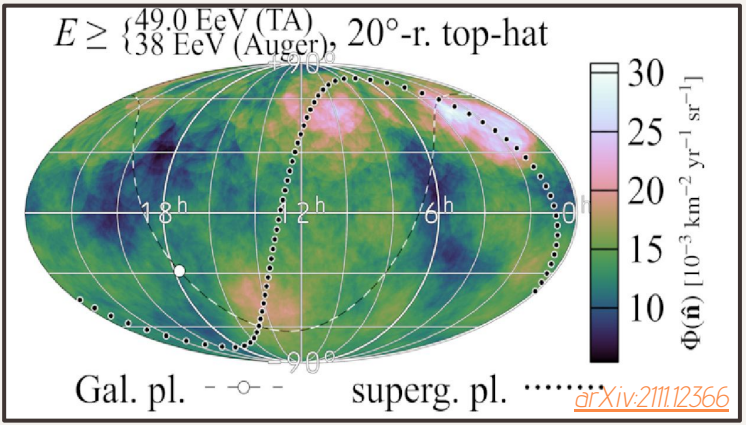
- ➔ k_{SFR}= 2 10^{-5} $M_{\odot}^{-1}$
- ➔ **Contribute:**
  - Council of Giants ✓
- ➔ **Do not contribute:**
  - Very nearby galaxies ✓

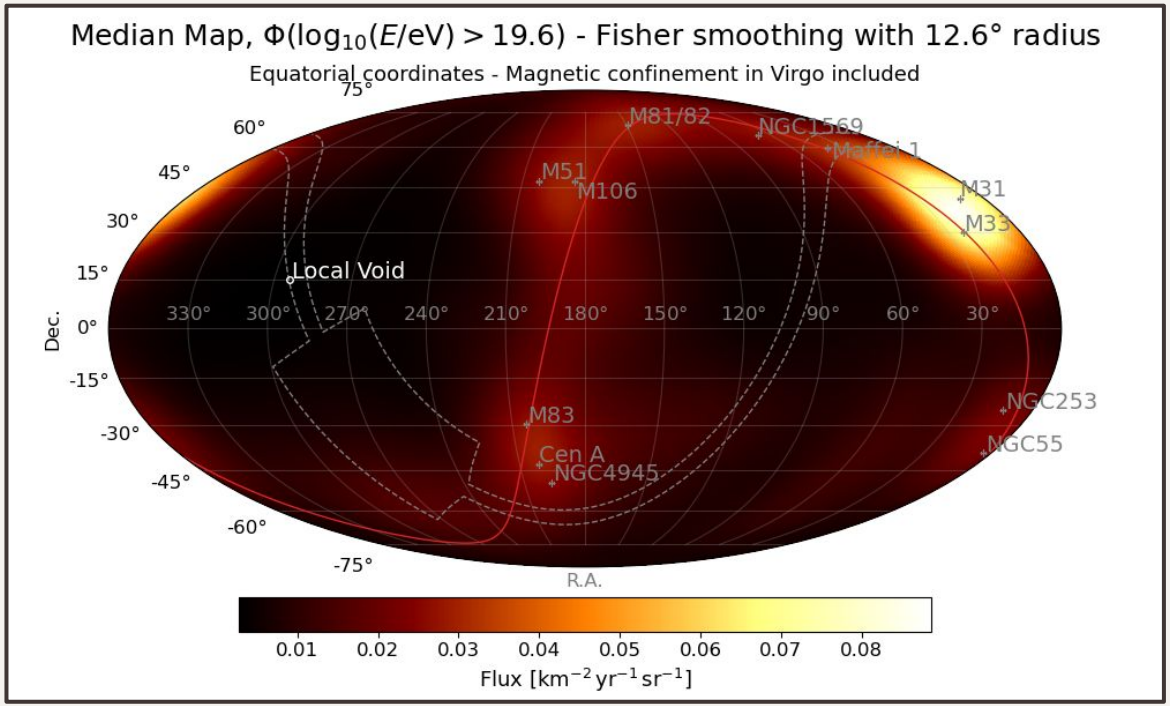




Median map - Big k

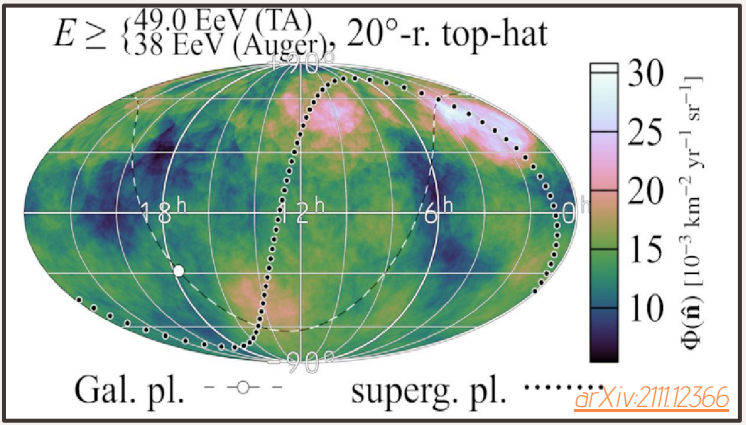
- ➔ $k_{SFR} = 10^{-4}\ M_{\odot}^{-1}$
- ➔ **Contribute :**
  - Council of Giants ✓
  - Very nearby galaxies ✗



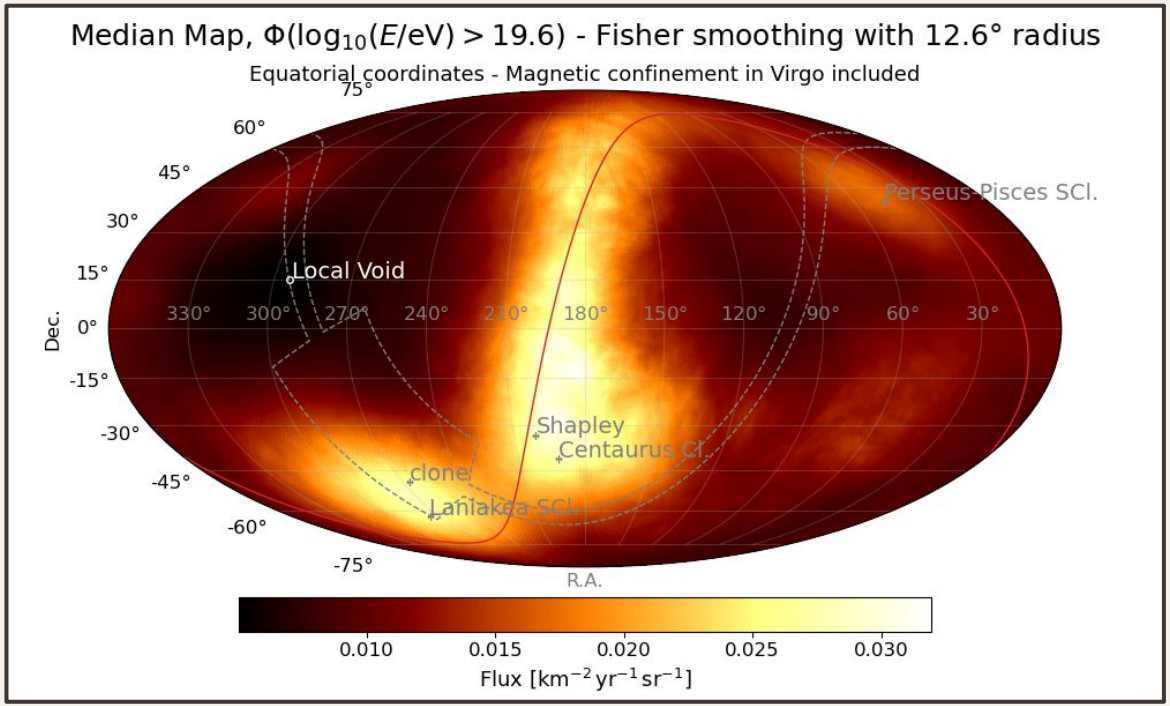


Median map - Small k

- ➔ $k_{SFR} = 10^{-7}\ M_{\odot}^{-1}$
- ➔ **Do not contribute :**
  - Council of Giants
  - Very nearby galaxies

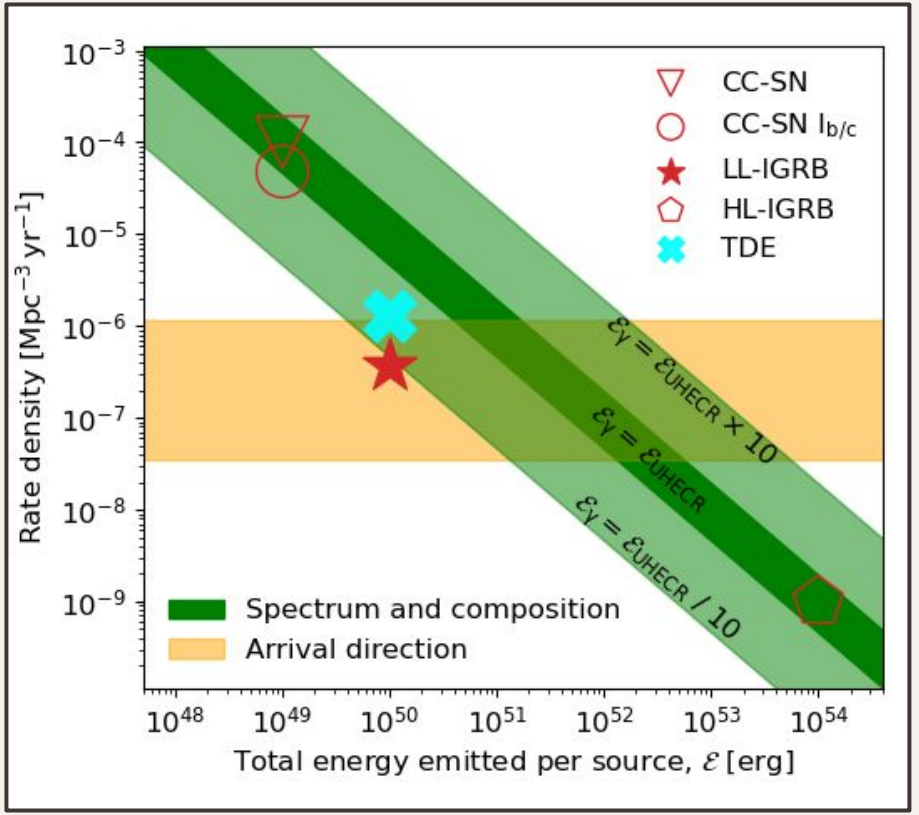


arXiv:211112366



Constraints on k

- The presence of the Council of Giants
  - Lower limit on k
- The non-presence of very nearby galaxies (ex. LMC)
  - Upper limit on k
- Constraints :
  - **Yellow band**
- Two candidates :
  - LL-lGRB
  - TDE

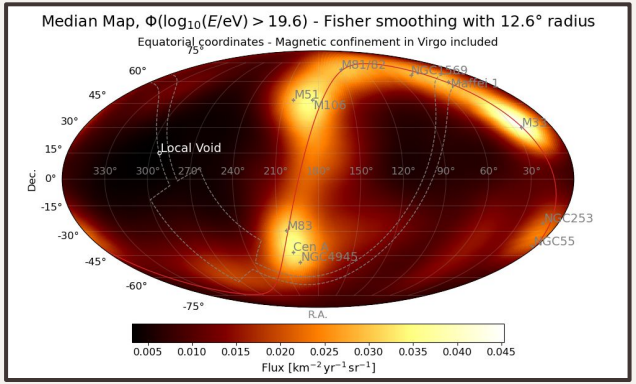


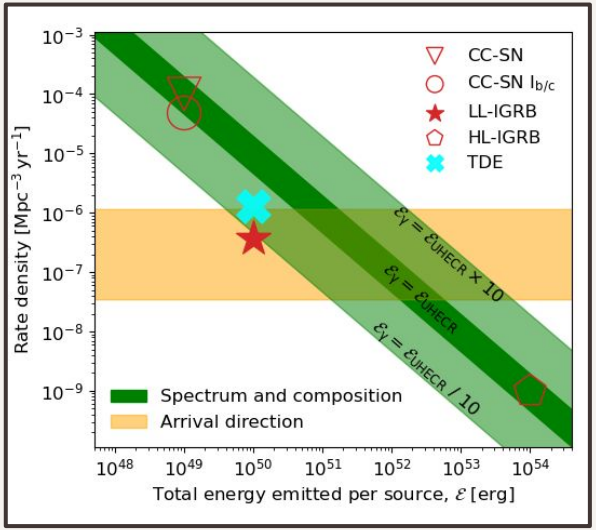
Conclusion and perspectives

- ➔ We are able to reproduce the AD map starting from the Combined Fit scenario
- ➔ Introduce a new parameter k
  - Transient scenario
- ➔ Constraining the sources
  - Constraint on k
  - Constraint on emissivity

Next?

- ➔ Take into account all clusters considering hadronic/photonic interactions (cf. A. Condorelli's talk)
- ➔ Quantify the constraints on k & B_{LS}





Merci !

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