Cosmographic model of the astroparticle skies

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ICRC 2021 / UHECR sources

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The near-infrared sky & extragalactic astroparticles

Wide field-of-view astroparticle physics

TeV-PeV neutrinos

$M_\star$ ↔ **stellar explosions, GRBs**

• Bounds on ν source density

Antares, IceCube(-Gen2), KM3NeT

EeV-ZeV cosmic rays

$M_\star$ ↔ **stellar explosions, GRBs**

• Bounds on CR source density

Pierre Auger Obs., Telescope Array

GeV gamma-rays

$M_\star$ ↔ **baryonic or dark matter**

• Extragalactic ɣ-ray background

Fermi Large Area Telescope

Gravitational waves (GW)

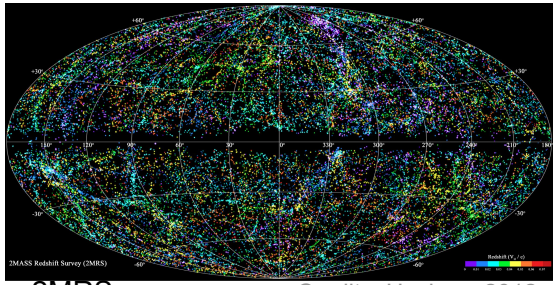
$M_\star$ ↔ **binary mergers**

• Galaxy targeting, Hubble's H_0

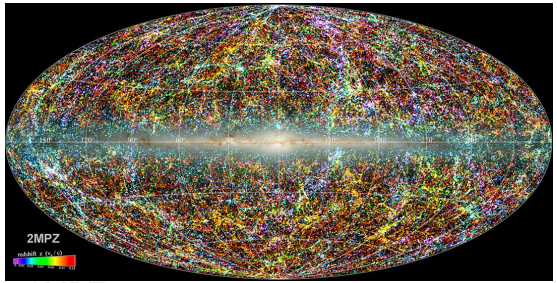
LIGO, Virgo, KAGRA

Full-sky astronomy

Galactic coordinates



2MRS Credits: Huchra+ 2012



2MPZ Credits: M. Bilicki & T. Jarret 2014

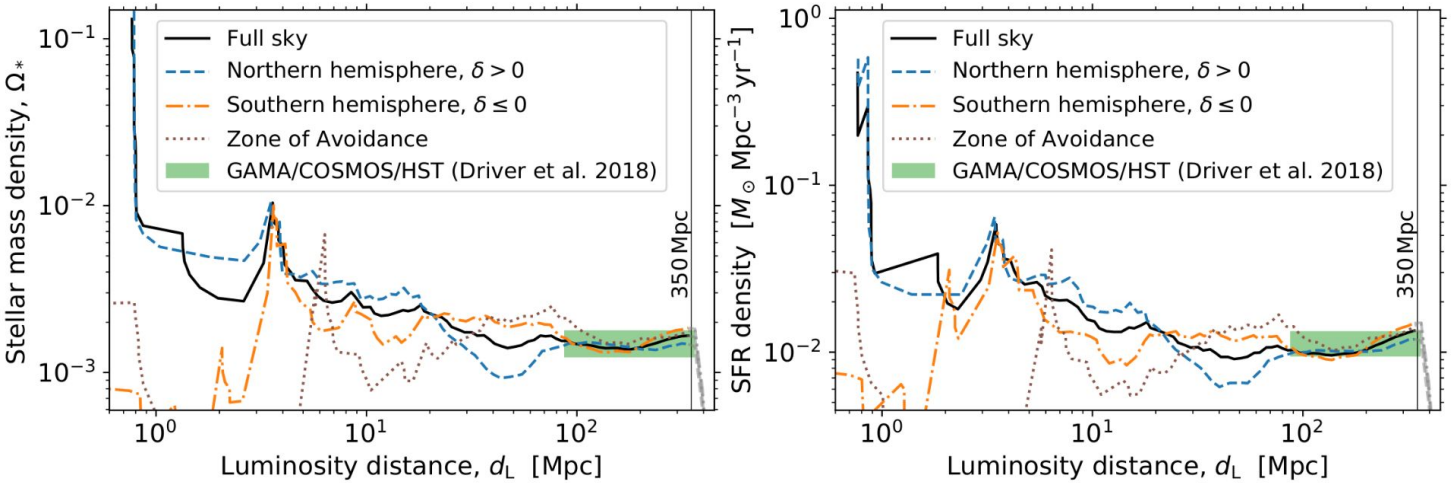
2MASS Redshift Survey (2MRS): Spectroscopy of the brightest ones, $d(\sum M_{obs} = 0.5\ M_{tot}) =$ **140 Mpc**

2MASS Photometric Redshift (2MPZ): Photo-z with $\sigma(d) = 12\%$ of fainter ones, $d(\sum M_{obs} = 0.5\ M_{tot}) =$ **350 Mpc**

A catalog of $M_\star$ and SFR within 1 Gyr

Revised MANGROVE catalog (Biteau 2021, based on MANGROVE, Ducoin+ 2020, & GLADE, Dálya+ 2018)

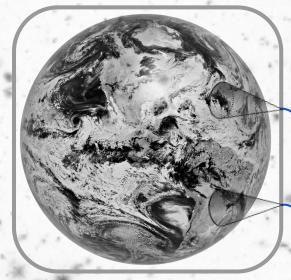
- Cross-match with HyperLEDA distance database: **400,000 galaxies at d < 350 Mpc**, spectro-z for ~50% (× 4)
- $M_\star$ and star-formation rate (**SFR**) estimate for each galaxy
- **Incompleteness correction factors** vs distance (sensitivity threshold) & Galactic latitude (Zone of Avoidance)



pre-print: arXiv:2105.11345 (ApJS, in press)

online catalog, **3D visualization**, **code**: DOI|10.5281/zenodo.4783406

Application: UHECR transients

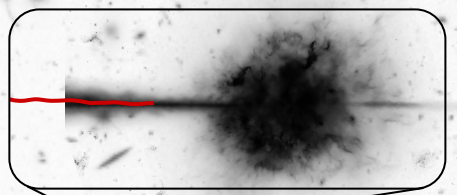


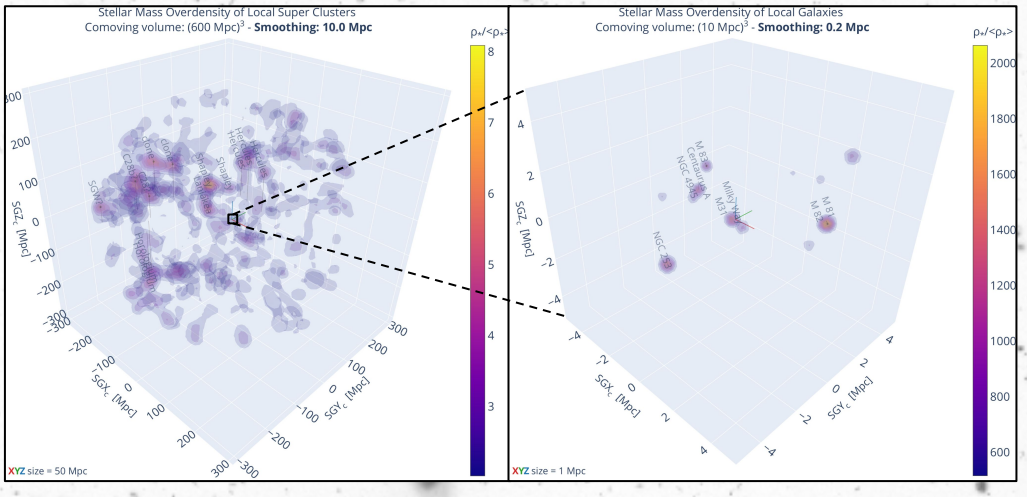
CMB
meV photons

EBL
eV photons

EeV-ZeV
cosmic rays

Transient with rate ∝ SFR





Key modeling points

Catalog tracing 3D SFR density

isotropy assumed at $d > 350$ Mpc

Peters' cycle injection, with free

$(A, Z)_{inj}$ norm, index p, $R_{max} = (E_{inj}/Z_{inj})_{max}$

UHECR propagation (EBL, CMB)

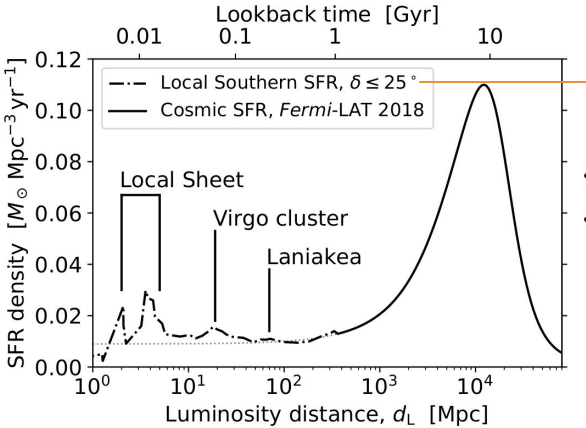
SimProp v2.4 → npy 5D tensor, T

T: E_{inj}, $(A, Z)_{inj}$, z_{inj} → E_{obs}, $(A, Z)_{obs}$

If UHECR production rate ∝ SFR > 1 Mpc...

Model of Auger public spectrum and composition

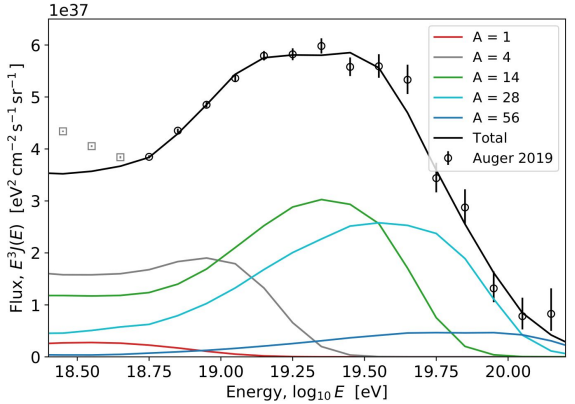
- Efficient use of 5D transport tensor based on SimProp output (Aloisio+ 2017)
- Source distribution from **SFR density in Auger field of view**

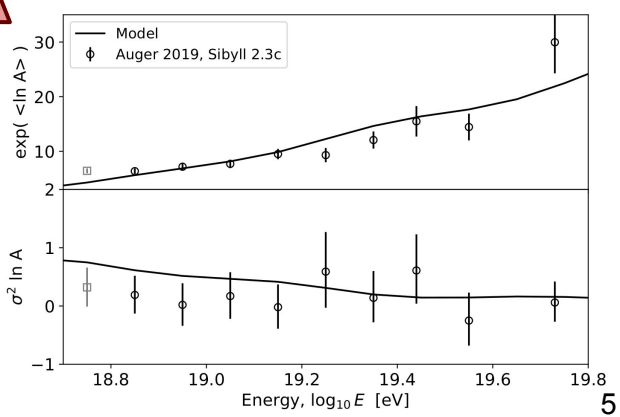


Best-fit parameters

$p \approx -1.4$, $R_{max} = 10^{18.2}$ V
(Sybill 2.3c composition)

vs $p \approx -1.5$, $R_{max} = 10^{18.3}$ V
in Auger 2017 (Sybill 2.1)





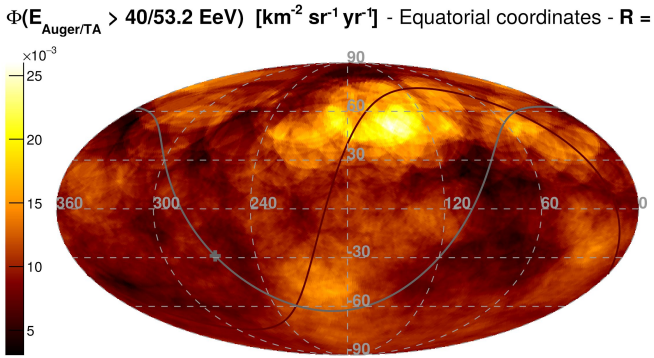
Results of the fit

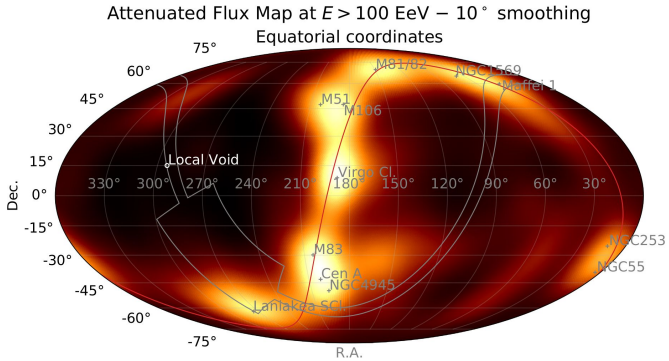
- **Good fit** of UHECR spectrum and ln *A* moments (X_{max} to be investigated)
- **Spectral variations at *E* > 10s EeV vs declination** (data agreement?)

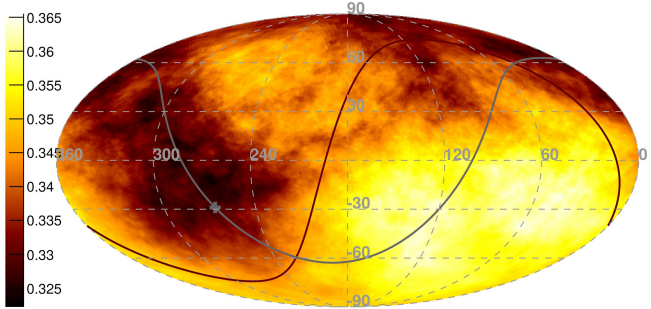
UHECR data *vs* skymaps from 1–350 Mpc

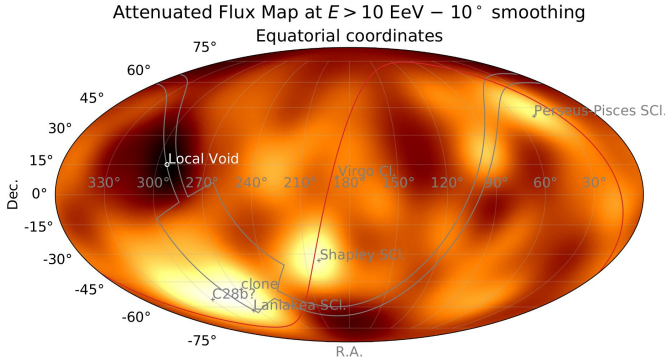
Model smoothing on a 10° angular scale

Observed UHECR skymaps
(Biteau+ [Auger + Telescope Array], 2019)









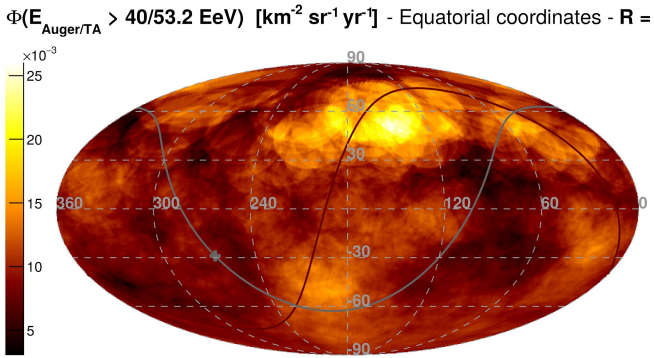
Model UHECR skymaps

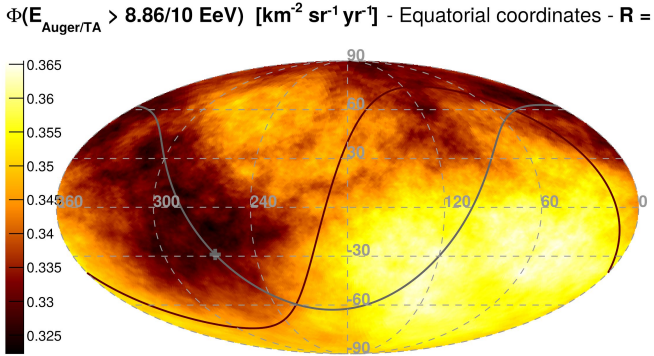
N.B.: Galactic *B*-field and extragalactic *B*-field (fG < *B* < nG) not taken into account

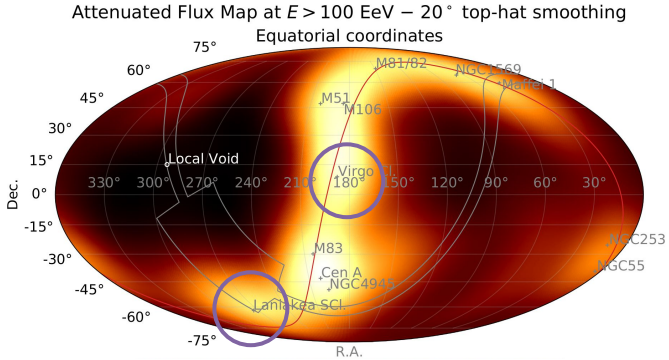
UHECR data *vs* skymaps from 1–350 Mpc

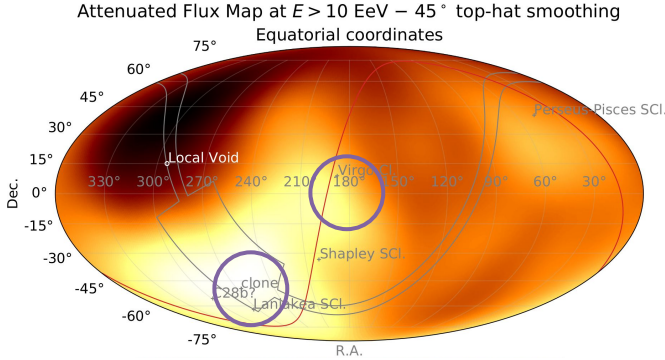
Model smoothing on a data-based top-hat scale

Observed UHECR skymaps
(Biteau+ [Auger + Telescope Array], 2019)









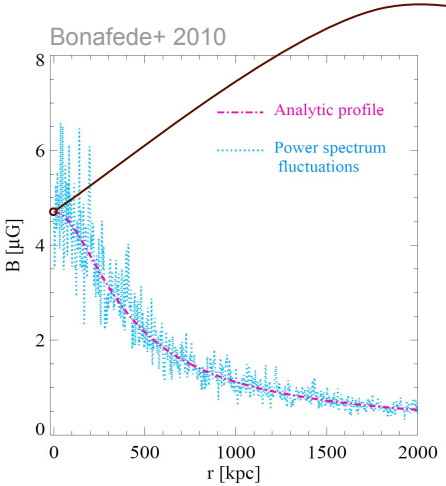
Model UHECR skymaps

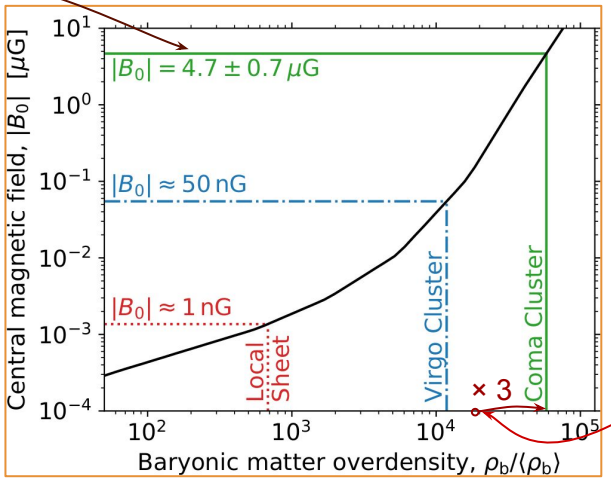
N.B.: Galactic *B*-field and extragalactic *B*-field (fG < *B* < nG) not taken into account

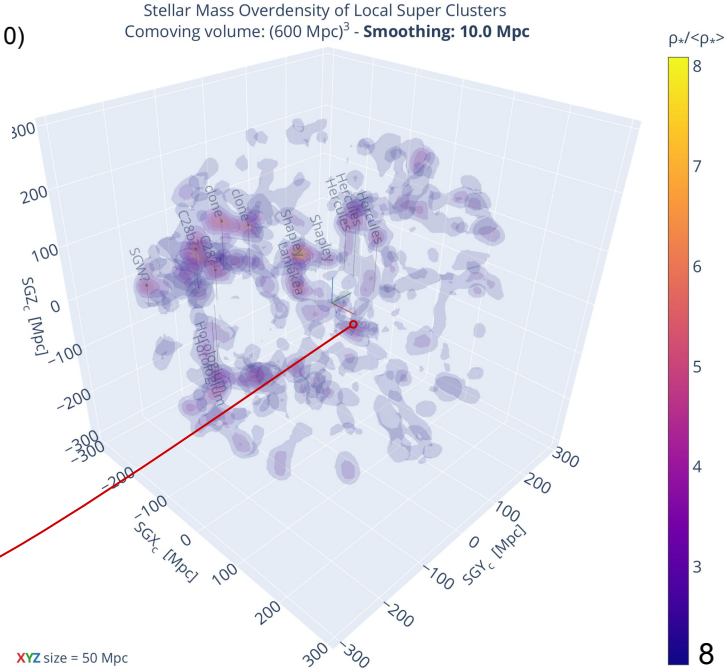
Should we see the Virgo cluster and other clusters?

Inferring *B*-fields on cluster scales from our catalog

- ***B*-field scales with baryon overdensity** based on MHD cosmological simulation (Donnert+ 2018)
- **Baryon mass scales with $M_\star$** of galaxies through halo mass (Gonzales+ 2013)
- **Recalibration of overdensity to match Coma's *B*-field** (Bonafede+ 2010)



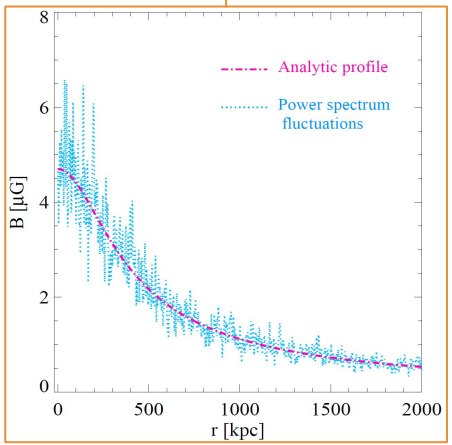


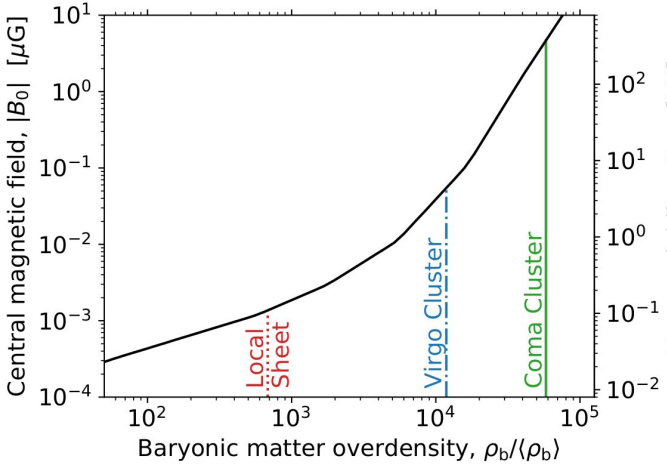


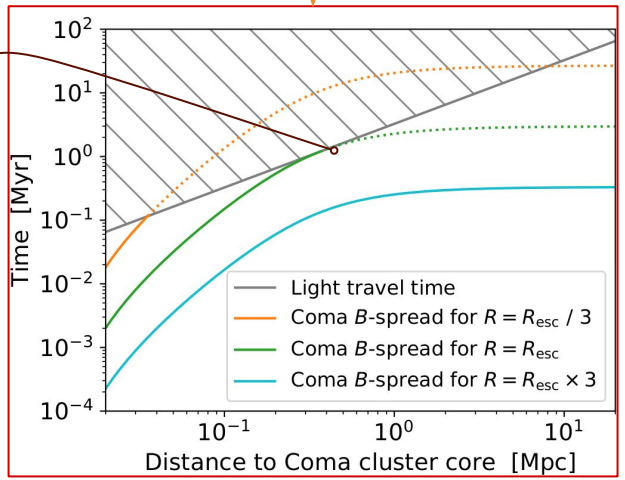
Should we see the Virgo cluster and other clusters?

Inferring *B*-fields on cluster scales from our catalog

- Temporal spread vs rigidity from Coma's observed ***B*-field coherence length and extent**
- **Escape rigidity of Coma from its magnetic horizon**: light-travel time = *B*-field temporal spread
- **Escape rigidity of Virgo ($\propto B_0$) from overdensity**, assuming (1st order) same *B*-field geometry as Coma







Should we see the Virgo cluster and other clusters?

Escape Rigidity, R_{esc}, vs Maximum Rigidity, R_{max}

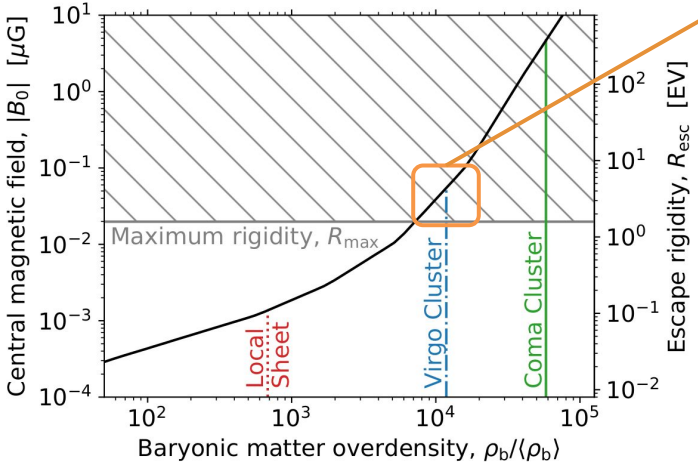
- **Coma, Virgo clusters**: $R_{esc} > R_{max}$ ⇒ no UHECRs can escape
- No escape + background screening ⇒ **expected UHECR blind spots**

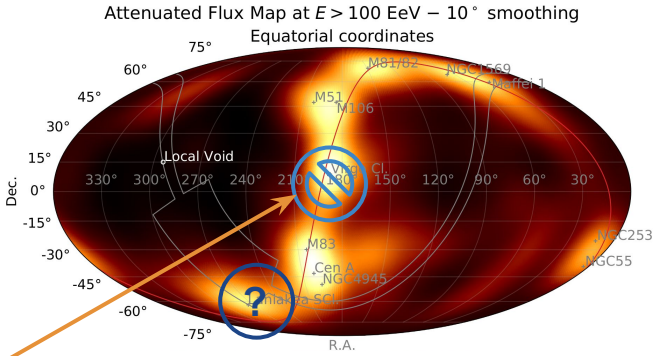
Impact on UHECR spectrum at escape from environment

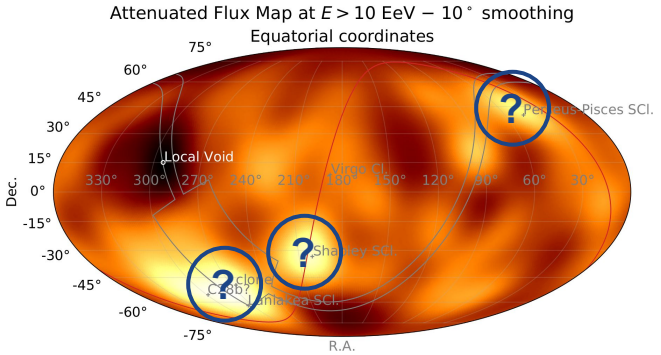
- **Hard observed index** ($p < 0$) ⇔ **narrow rigidity range**
- Strenghtened by B-shielding at entrance in Local Sheet/Group?

Next steps

- Confirm $R_{esc}(B)$ with dedicated simulations
- Provide realistic model of **flux and composition vs energy and direction**







Summary

A catalog of $M_\star$ and SFR within 350 Mpc (Biteau+ 2021, arXiv:2105.11345)

- Nearly half a million galaxies: 2MRS × 10
- Significant improvement on distance & completeness estimates
- Realistic data-driven model of $M_\star$ and SFR 3D distribution

UHECR studies opened by this catalog

- Impact of the local overdensity on the combined-fit vs declination
- Consistent modeling of foreground and background $M_\star$ and SFR
- Over/under-density mapping on the sphere vs *E*

A tentative investigation of *B*-fields on cluster scales

- Exploiting the link between baryonic overdensity and central *B*-fields
- No UHECR escape from most magnetized clusters

⇒ Simple *B*-horizon argument used here, to be checked against sims

⇒ Extended sources of secondary ν and γ ? (see e.g. Fang & Murase 2018 in 1D)