Hotspot update and a new excess of events on the sky seen by the Telescope Array experiment

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University of Utah

for the TA collaboration

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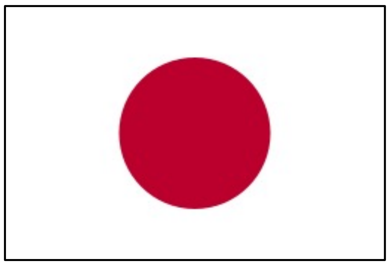
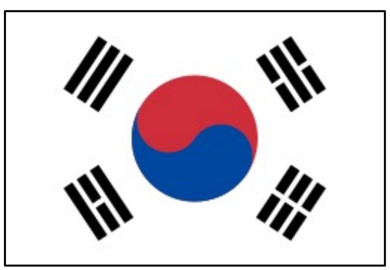
Telescope Array Collaboration

USA



Japan



Korea

R.U. Abbasi,[1] M. Abe,[2] T. Abu-Zayyad,[1] M. Allen,[1] R. Azuma,[3] E. Barcikowski,[1] J.W. Belz,[1] D.R. Bergman,[1] S.A. Blake,[1] R. Cady,[1] B.G. Cheon,[4] J. Chiba,[5] M. Chikawa,[6] A. di Matteo,[7,*] T. Fujii,[8] K. Fujisue,[9] K. Fujita,[10] R. Fujiwara,[10] M. Fukushima,[9,11] G. Furlich,[1] W. Hanlon,[1] M. Hayashi,[12] Y. Hayashi,[10] N. Hayashida,[13] K. Hibino,[13] R. Higuchi,[9] K. Honda,[14] D. Ikeda,[15] T. Inadomi,[16] N. Inoue,[2] T. Ishii,[14] R. Ishimori,[3] H. Ito,[17] D. Ivanov,[1] H. Iwakura,[16] H.M. Jeong,[18] S. Jeong,[18] C.C.H. Jui,[1] K. Kadota,[19] F. Kakimoto,[3] O. Kalashev,[20] K. Kasahara,[21] S. Kasami,[22] H. Kawai,[23] S. Kawakami,[10] S. Kawana,[2] K. Kawata,[9] E. Kido,[9] H.B. Kim,[4] J.H. Kim,[10] J.H. Kim,[1] M.H. Kim,[18] S.W. Kim,[18] S. Kishigami,[10] V. Kuzmin,[20,†] M. Kuznetsov,[20,7] Y.J. Kwon,[24] K.H. Lee,[18] B. Lubsandorzhiev,[20] J.P. Lundquist,[1] K. Machida,[14] K. Martens,[11] H. Matsumiya,[10] T. Matsuyama,[10] J.N. Matthews,[1] R. Mayta,[10] M. Minamino,[10] K. Mukai,[14] I. Myers,[1] S. Nagataki,[17] K. Nakai,[10] R. Nakamura,[16] T. Nakamura,[25] Y. Nakamura,[16] Y. Nakamura,[16] T. Nonaka,[9] H. Oda,[10] S. Ogio,[10,26] M. Ohnishi,[9] H. Ohoka,[9] Y. Oku,[22] T. Okuda,[27] Y. Omura,[10] M. Ono,[17] R. Onogi,[10] A. Oshima,[10] S. Ozawa,[28] I.H. Park,[18] M.S. Pshirkov,[20,29] J. Remington,[1] D.C. Rodriguez,[1] G. Rubtsov,[20] D. Ryu,[30] H. Sagawa,[9] R. Sahara,[10] K. Saito,[9] Y. Saito,[16] N. Sakaki,[9] T. Sako,[9] N. Sakurai,[10] K. Sano,[16] L.M. Scott,[31] T. Seki,[16] K. Sekino,[9] P.D. Shah,[1] F. Shibata,[14] T. Shibata,[9] H. Shimodaira,[9] B.K. Shin,[10] H.S. Shin,[9] J.D. Smith,[1] P. Sokolsky,[1] N. Sone,[16] B.T. Stokes,[1] S.R. Stratton,[1,31] T.A. Stroman,[1] T. Suzawa,[2] Y. Takagi,[10] Y. Takahashi,[10] M. Takamura,[5] M. Takeda,[9] R. Takeishi,[18] A. Taketa,[15] M. Takita,[9] Y. Tameda,[22] H. Tanaka,[10] K. Tanaka,[32] M. Tanaka,[33] Y. Tanoue,[10] S.B. Thomas,[1] G.B. Thomson,[1] P. Tinyakov,[20,7] I. Tkachev,[20] H. Tokuno,[3] T. Tomida,[16] S. Troitsky,[20] Y. Tsunesada,[10,26] Y. Uchihori,[34] S. Udo,[13] T. Uehama,[16] F. Urban,[35] T. Wong,[1] K. Yada,[9] M. Yamamoto,[16] H. Yamaoka,[33] K. Yamazaki,[13] J. Yang,[36] K. Yashiro,[5] M. Yosei,[22] H. Yoshii,[37] Y. Zhezher,[9,20] and Z. Zundel[1]

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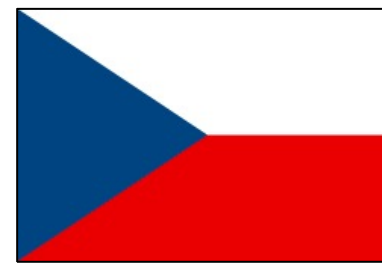
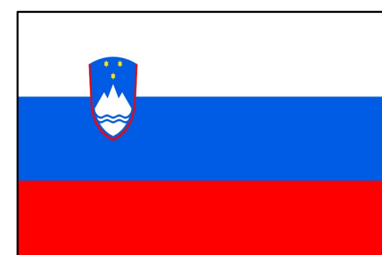
Russia

Belgium



Czech Republic

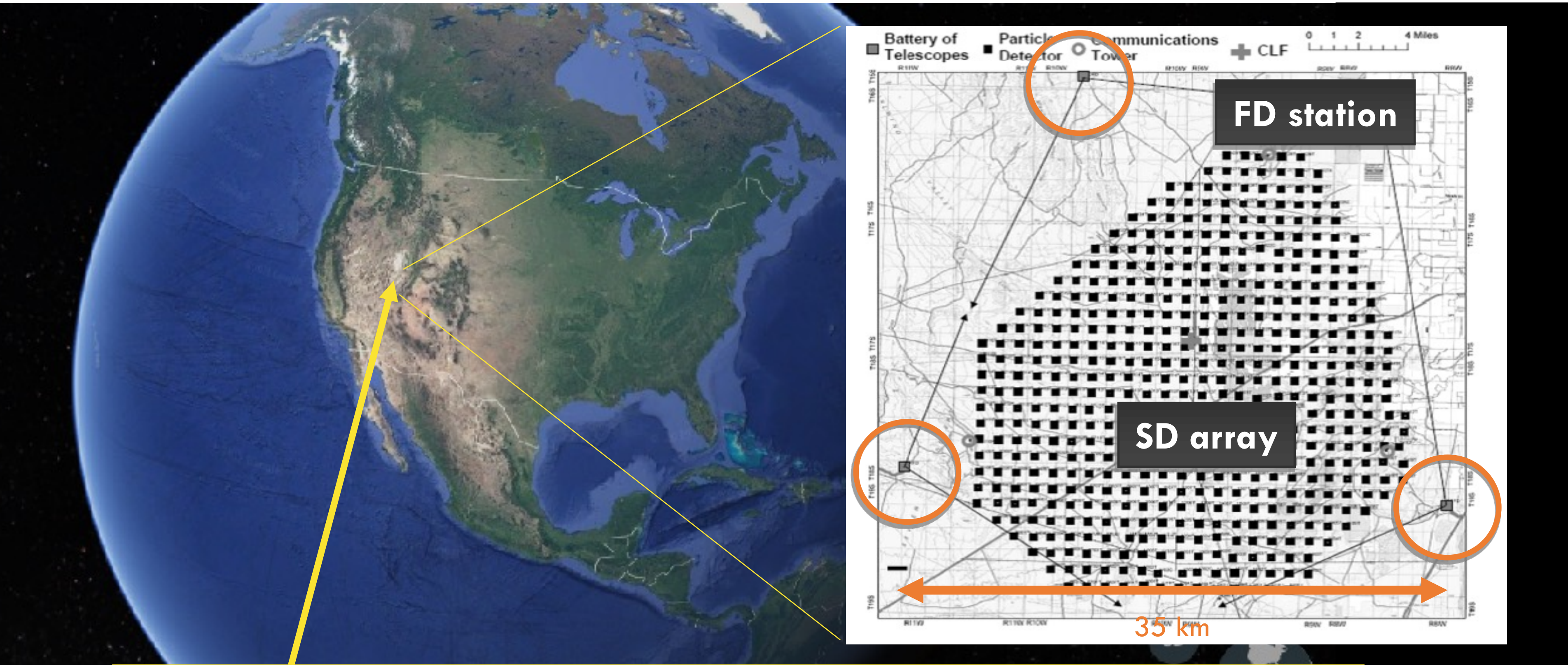


Slovenia

157 members , 36 institutes, 6 countries

Telescope Array (TA) experiment

- The largest cosmic ray observatory in the northern hemisphere



Telescope Array

Delta, Utah, USA. ~1400 m a.s.l.

TA surface detector covers ~700 km^2.

Excess of events: Hotspot Abbasi et al., ApJL 790, L21 (2014)

72 events with E > 5.7×10^{19} eV → Li-Ma sig.: 5.1σ, post-trial sig.: 3.4σ

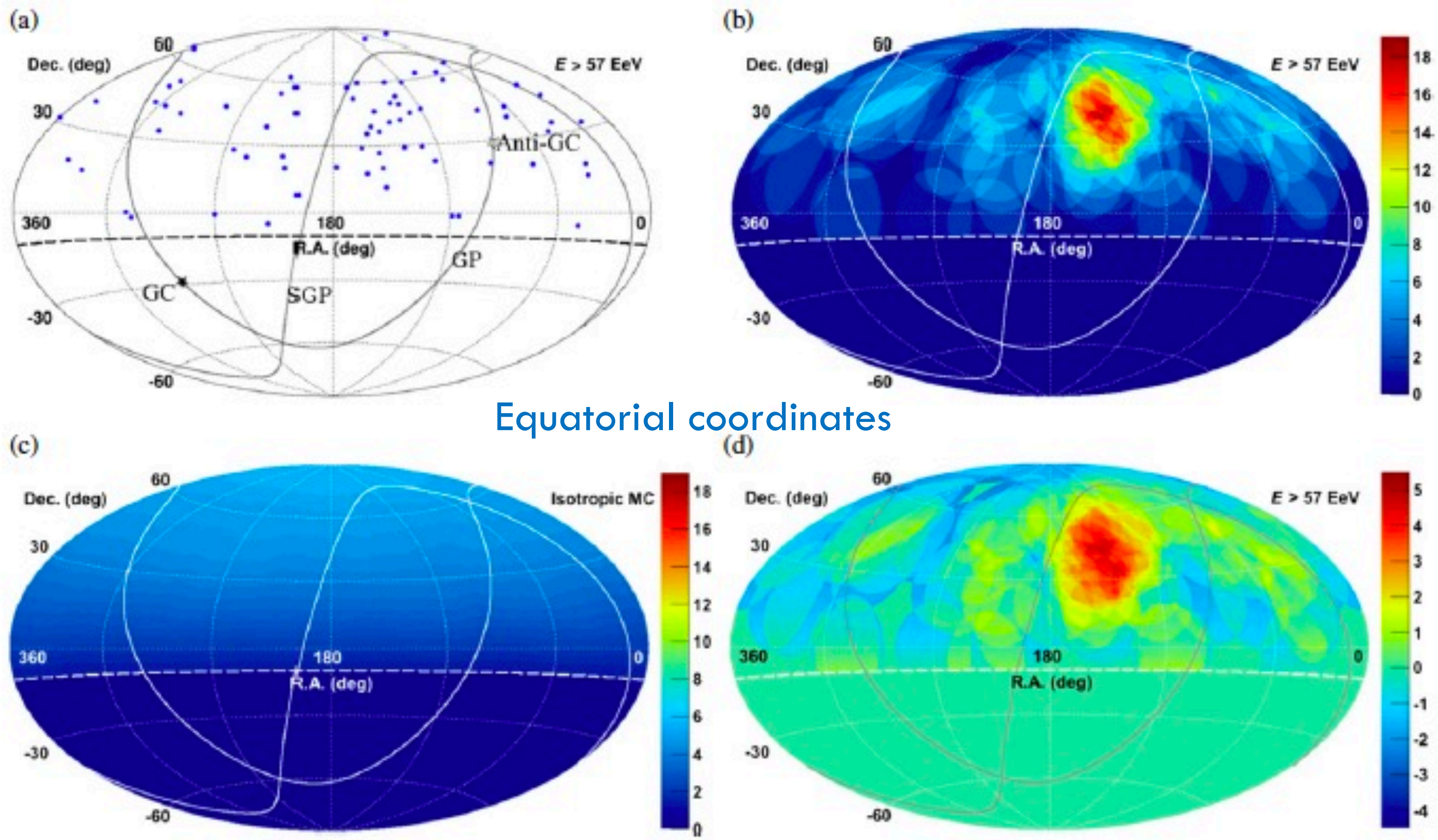
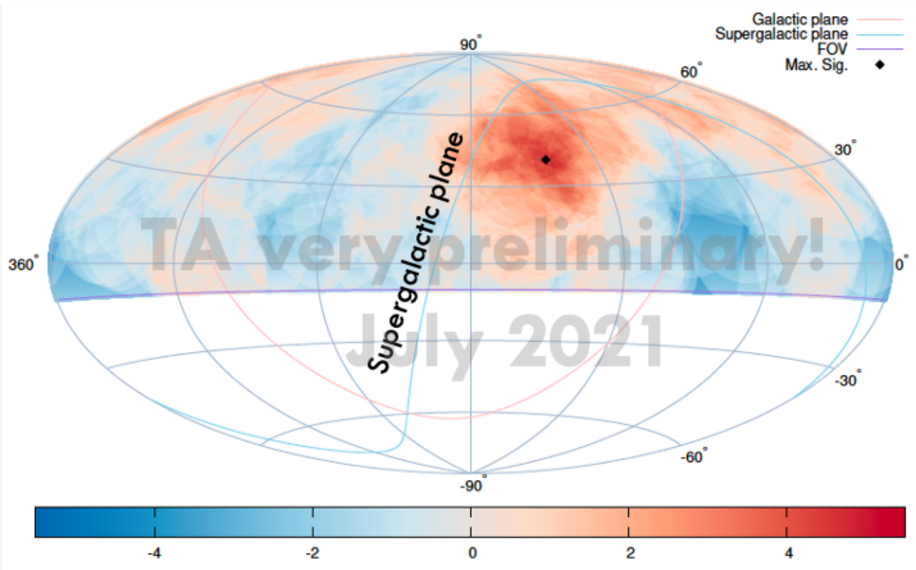


Figure 1. Aitoff projection of the UHECR maps in equatorial coordinates. The solid curves indicate the galactic plane (GP) and supergalactic plane (SGP). Our FoV is defined as the region above the dashed curve at decl. = −10°. (a) The points show the directions of the UHECRs $E > 57$ EeV observed by the TA SD array, and the closed and open stars indicate the Galactic center (GC) and the anti-Galactic center (Anti-GC), respectively; (b) color contours show the number of observed cosmic-ray events summed over a 20° radius circle; (c) number of background events from the geometrical exposure summed over a 20° radius circle (the same color scale as (b) is used for comparison); (d) significance map calculated from (b) and (c) using Equation (1).

Update on the hotspot: 12-year data

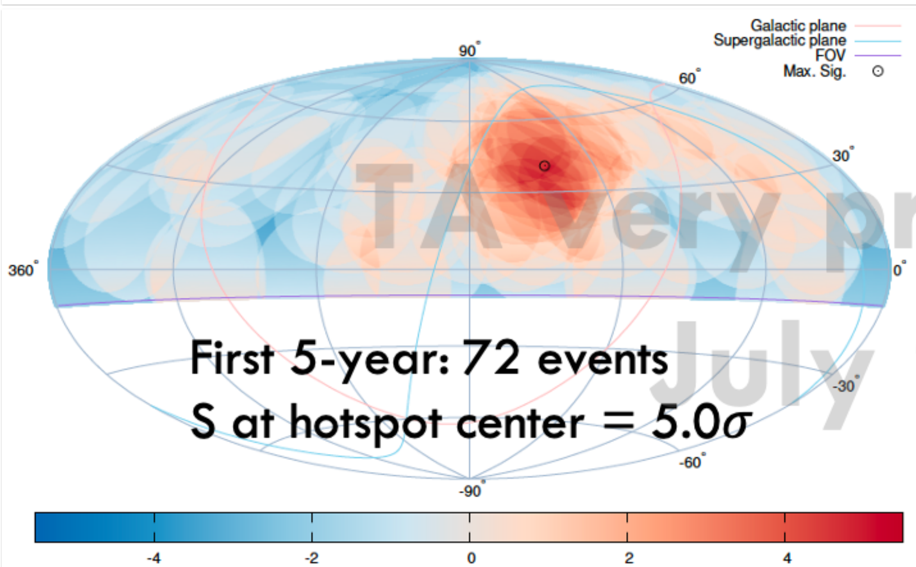
Significance map in the equatorial coords.

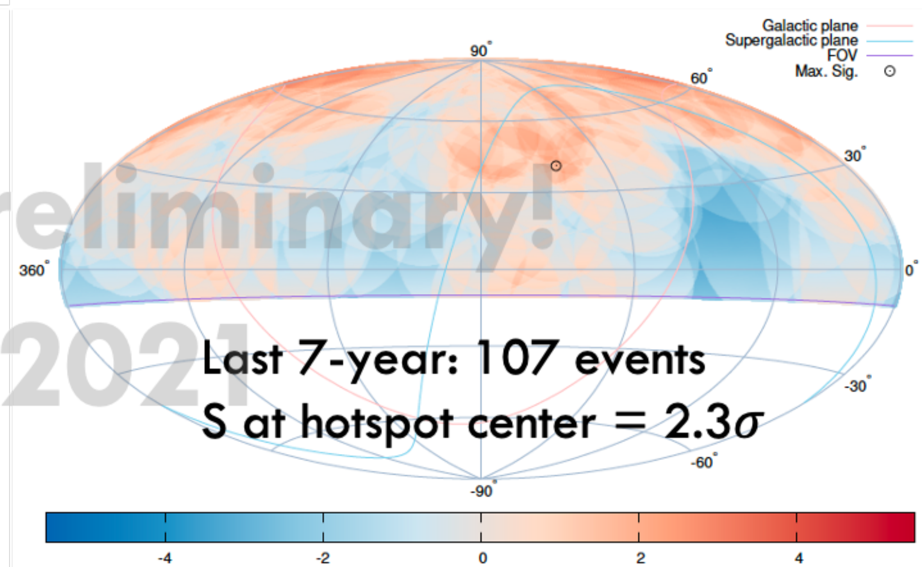


12-year SD data:

179 events with E > 5.7×10^{19} eV

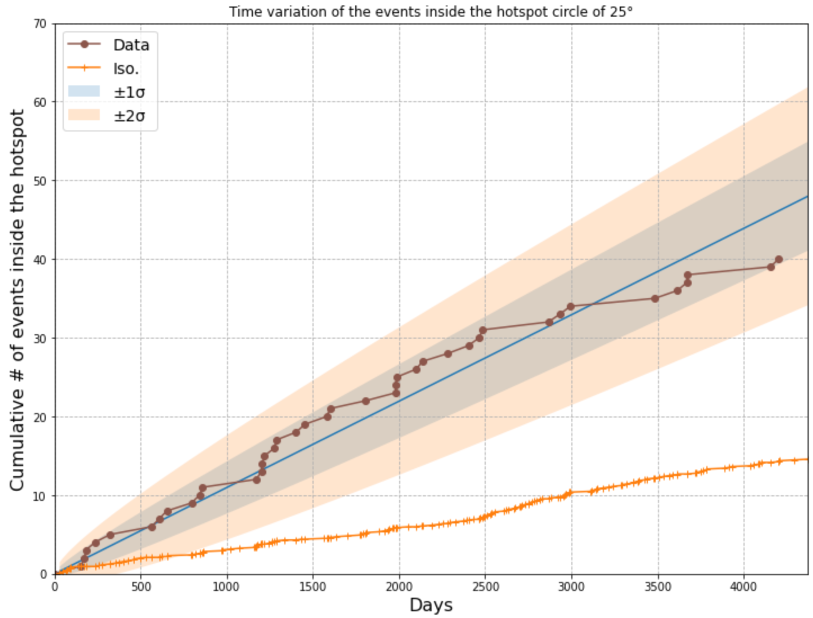
→ **5.1σ** with 25° oversampling





TA very preliminary!
July 2021

Update on the hotspot: 12-year data



- Time variation of the hotspot

The increase rate of the events inside the hotspot circle is **consistent with the linear increase within ~1σ.**

- 179 events with E > 5.7×10^{19} eV (12-year TA SD data)
- Maximum local significance: 5.1σ at (144.0°, 40.5°)

  Observed: 40 events

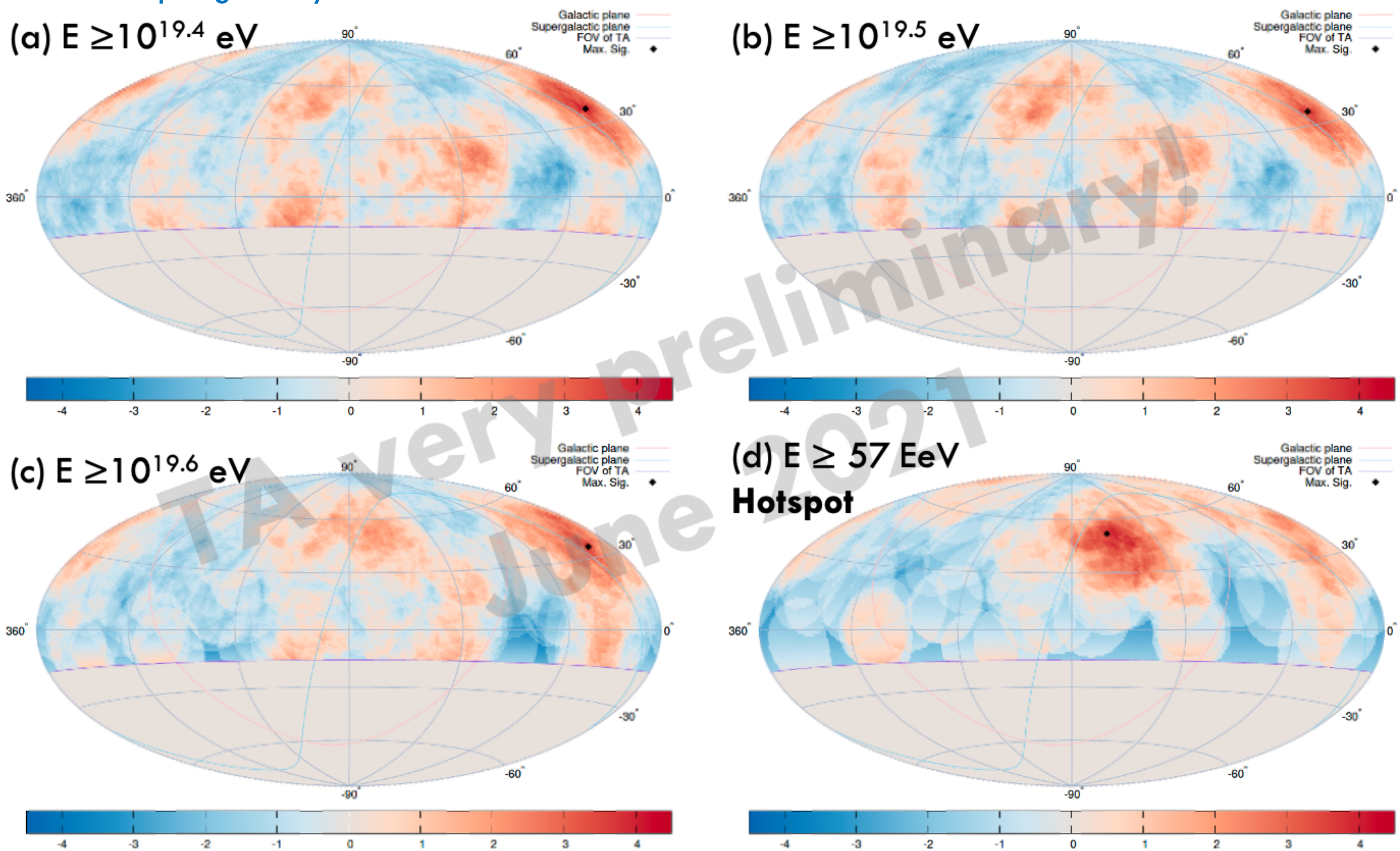
  Expected from isotropy: 14.6 events

  ~170% excess to the isotropy

- **Post-trial probability: $P(S_{MC} > 5.1\sigma) = 6.8\times10^{-4}$ → 3.2σ**

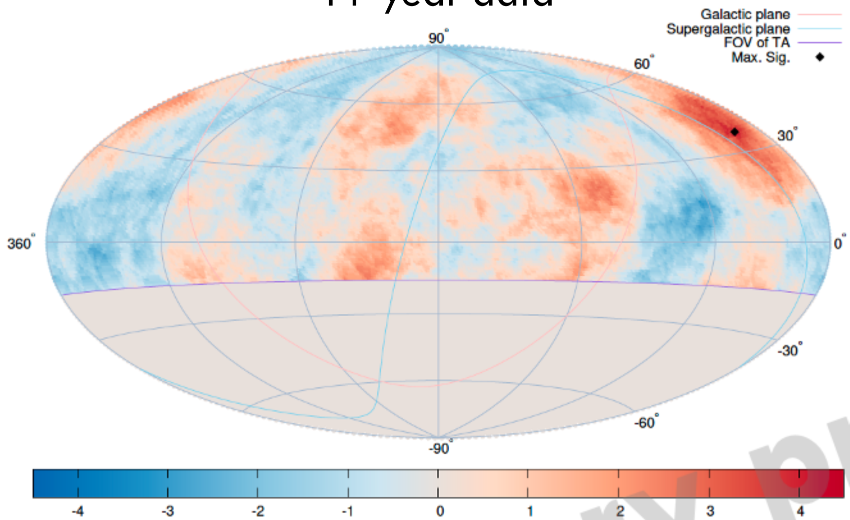
New excess of events at slightly lower energy: 11-year data

20°-oversampling analysis

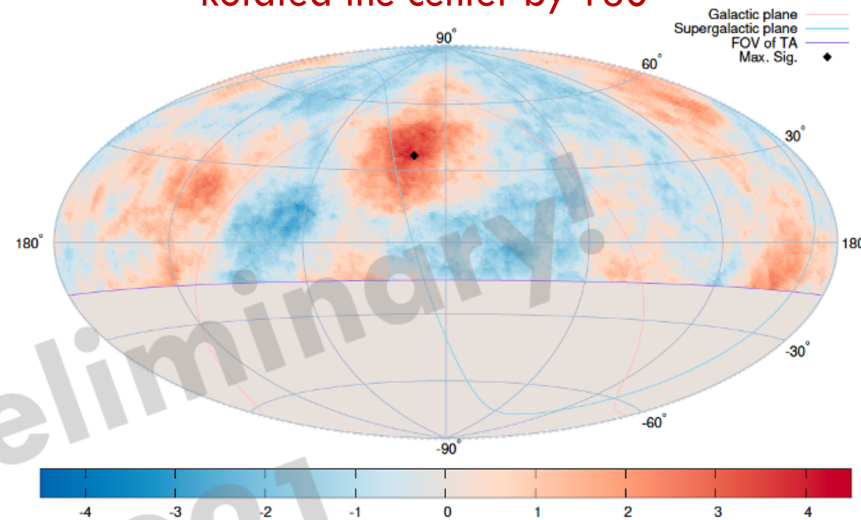


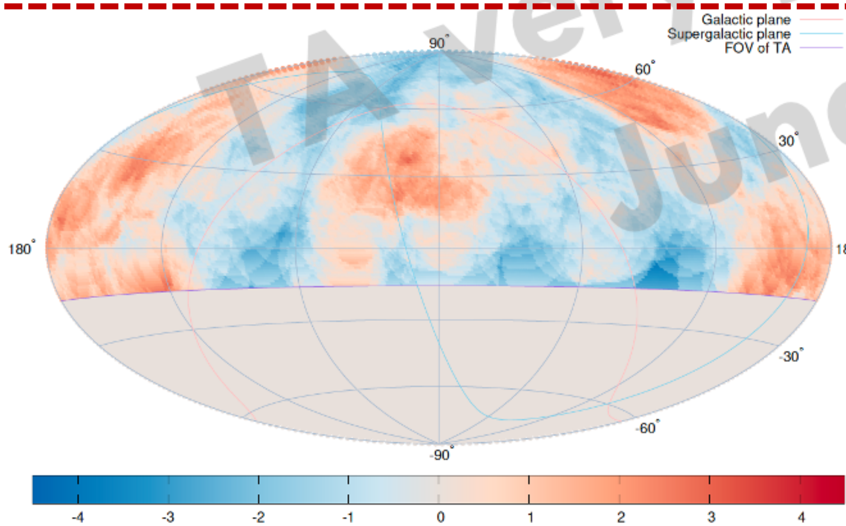
First 5- and last 6-year data, E $\geq 10^{19.4}$ eV

11-year data

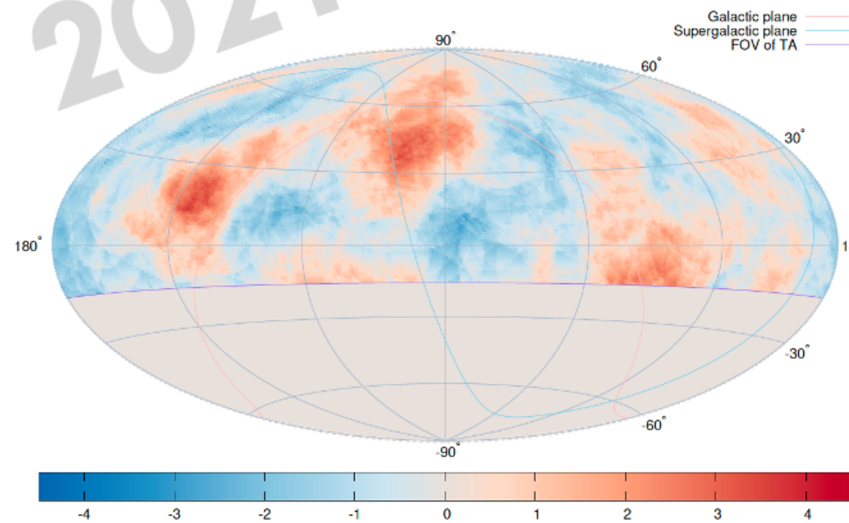


Rotated the center by 180°



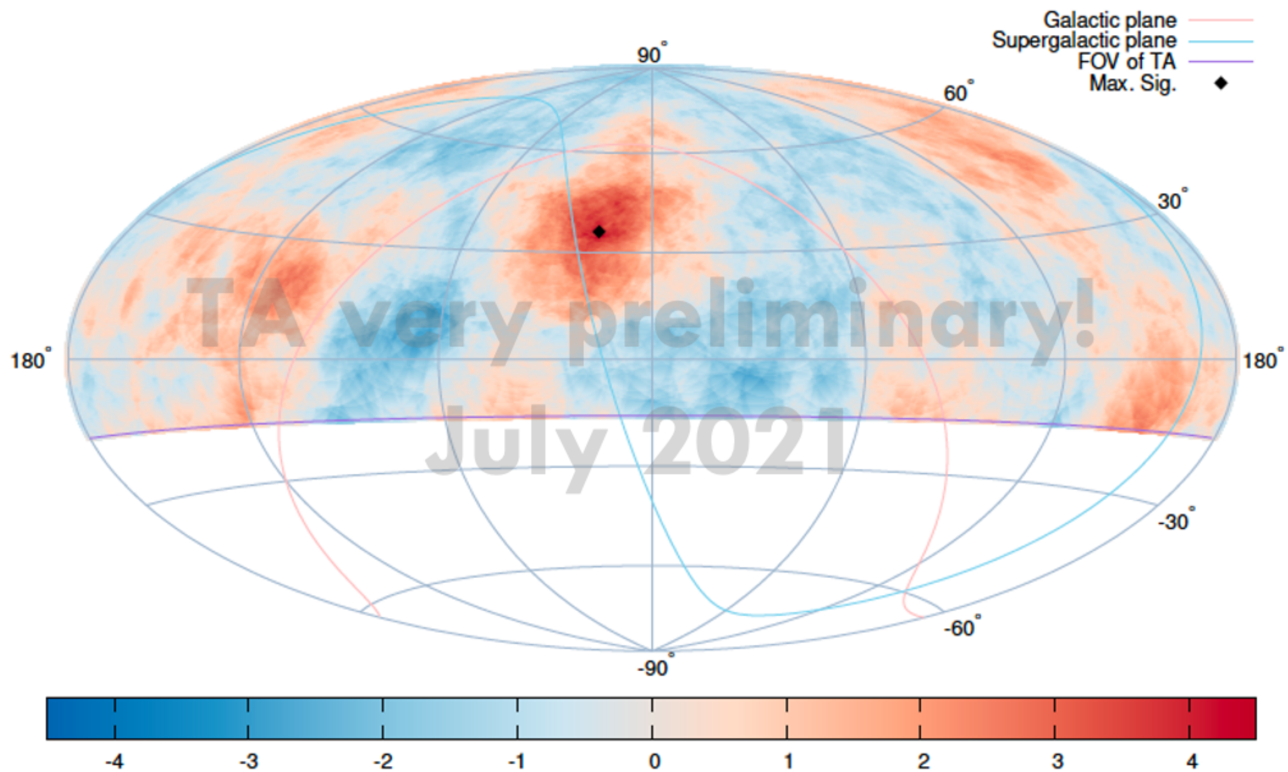


First 5-year data



Last 6-year data

New excess of events with E $\geq 10^{19.4}$ eV



Skymaps in the equatorial coordinates

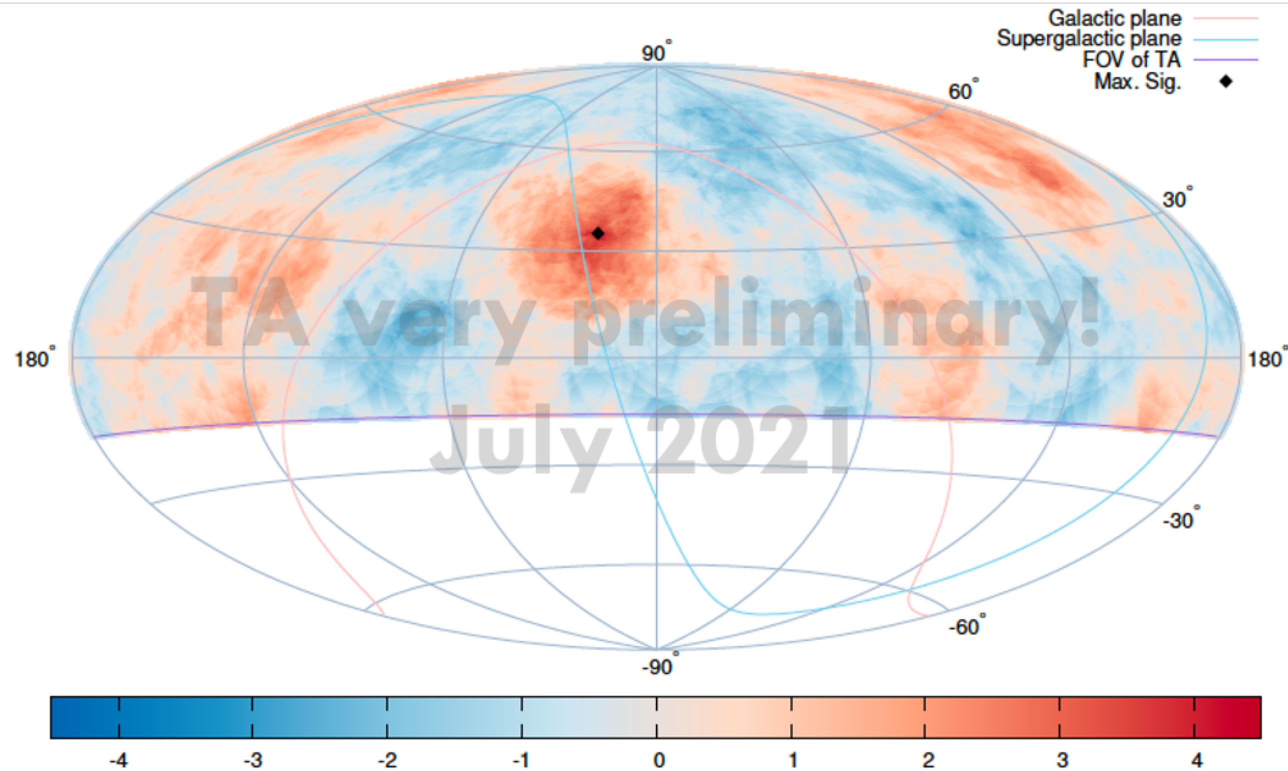
- 864 events with E $\geq 10^{19.4}$ eV (11-year TA SD data)
- Maximum local significance: 4.4σ at (17.4°, 36.0°)

Observed: 85 events

Expected from isotropy: 49.5 events

~72% excess to the isotropy

New excess of events with E $\geq 10^{19.5}$ eV



Skymaps in the equatorial coordinates

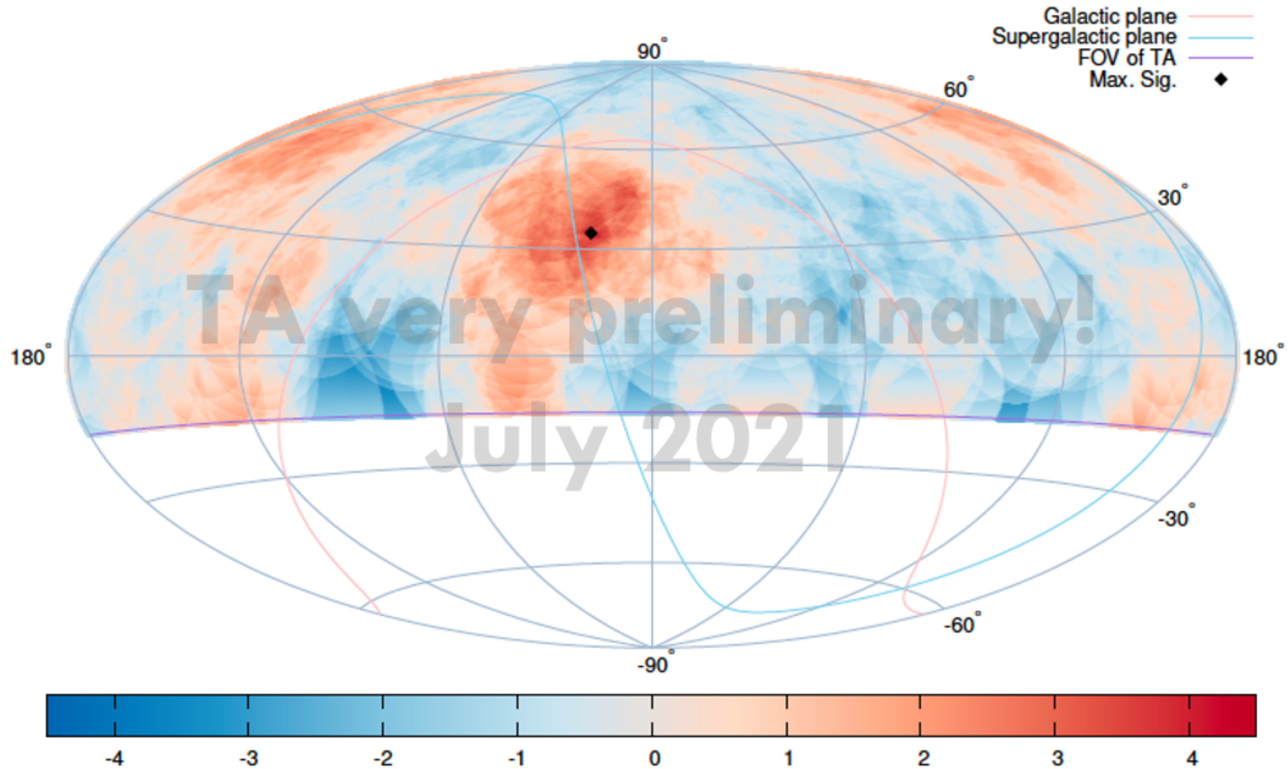
- 558 events with E $\geq 10^{19.5}$ eV (11-year TA SD data)
- Maximum local significance: 4.2σ at (19.0°, 35.1°)

Observed: 59 events

Expected from isotropy: 31.5 events

~87% excess to the isotropy

New excess of events with E $\geq 10^{19.6}$ eV



Skymaps in the equatorial coordinates

- 335 events with E $\geq 10^{19.6}$ eV (11-year TA SD data)
- Maximum local significance: 4.0σ at (19.7°, 34.6°)

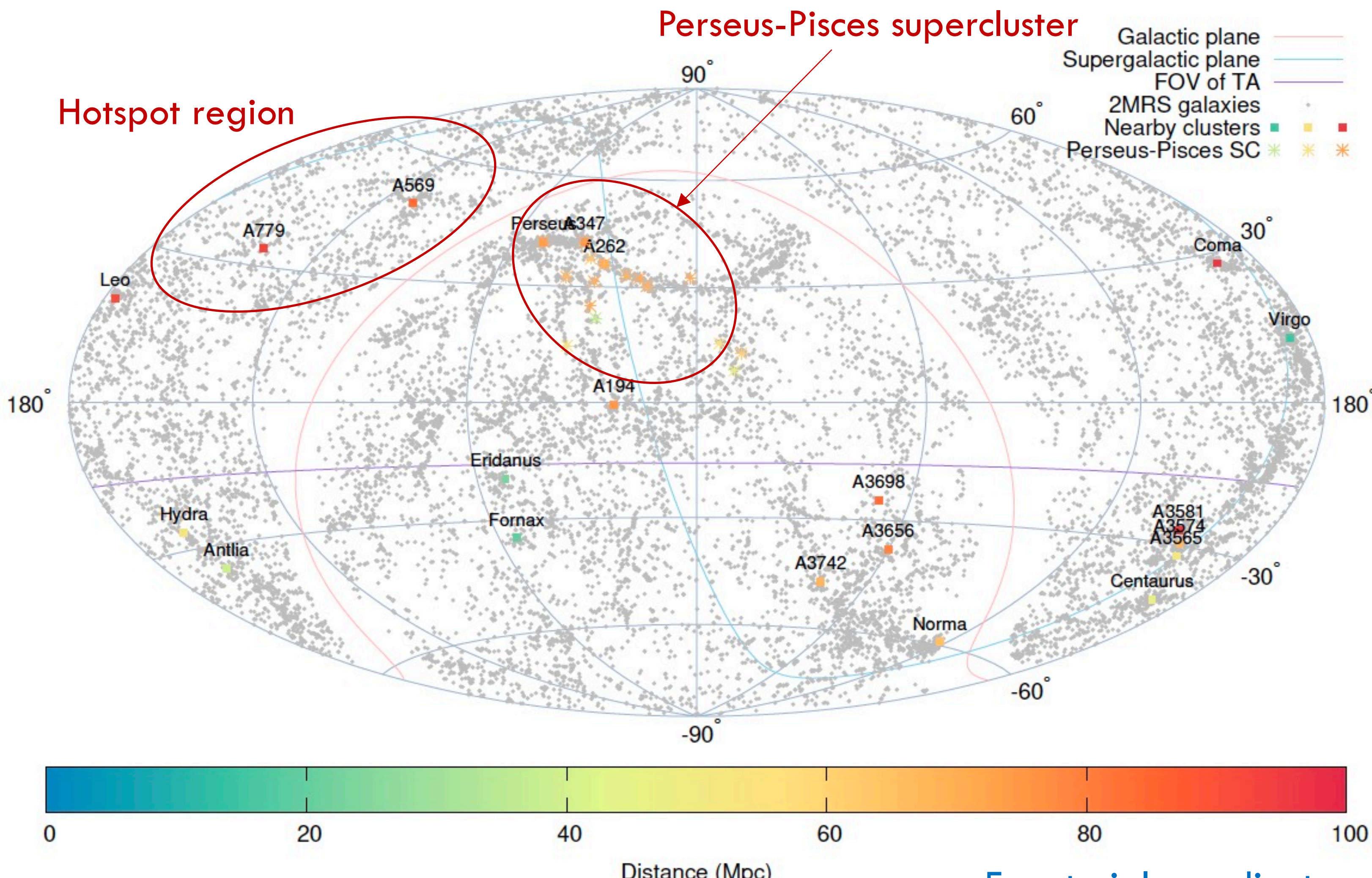
Observed: 39 events

Expected from isotropy: 18.6 events

~110% excess to the isotropy

What is behind the new excess?

Sky map with nearby galaxies and clusters of galaxies



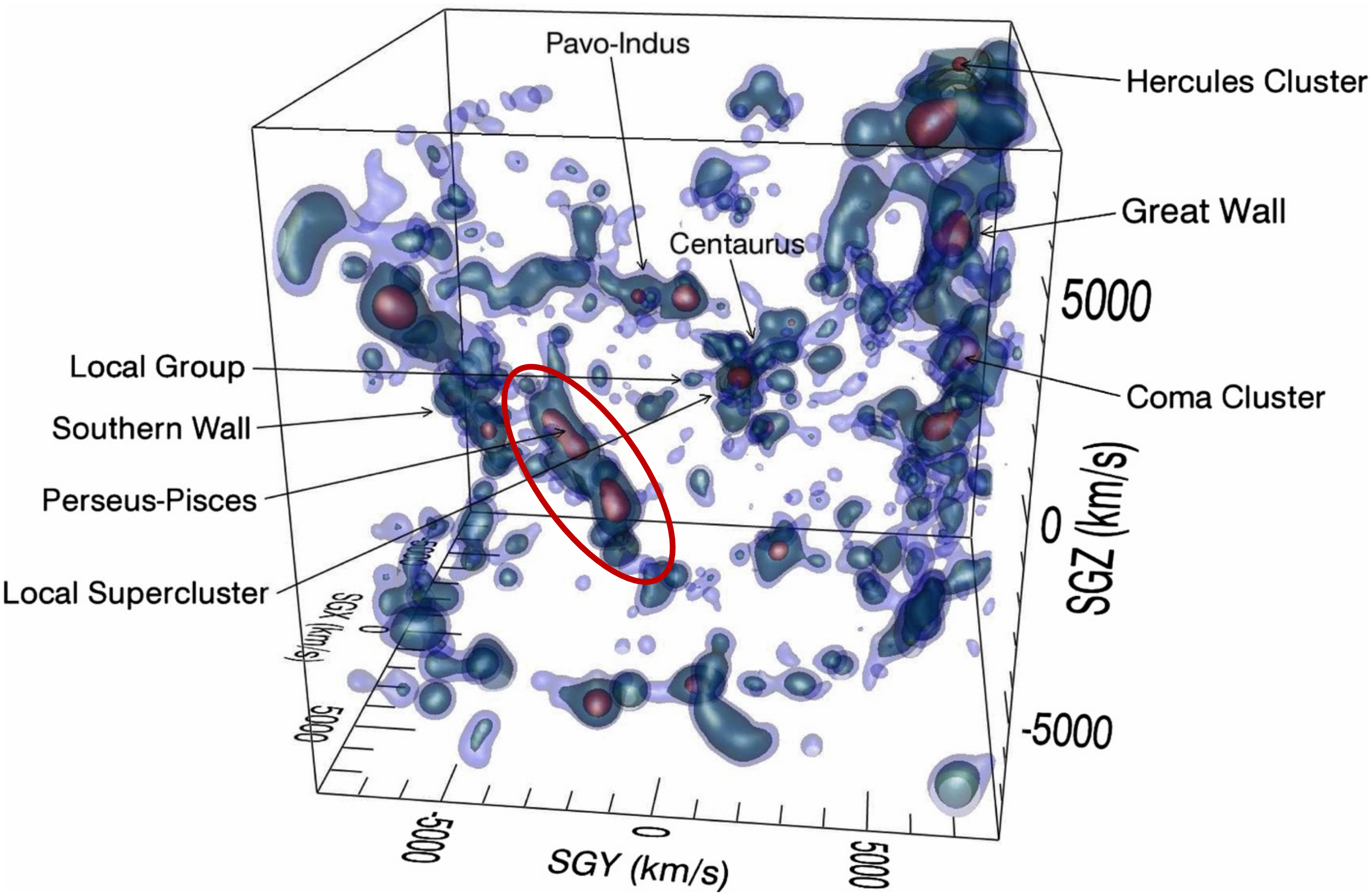
Equatorial coordinates

RA=0 at the center

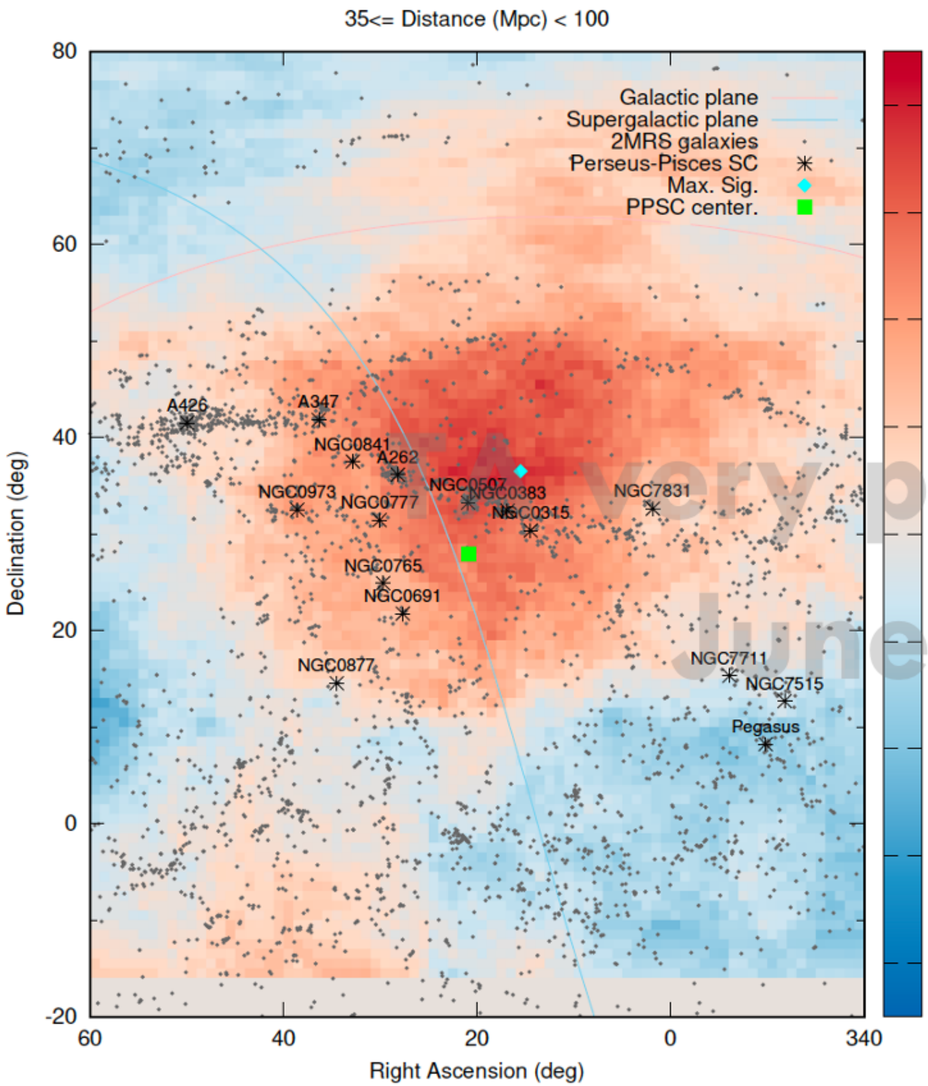
Perseus-Pisces supercluster (PPSC)

Courtois et al., Astronomical Journal 146, 69 (2013)

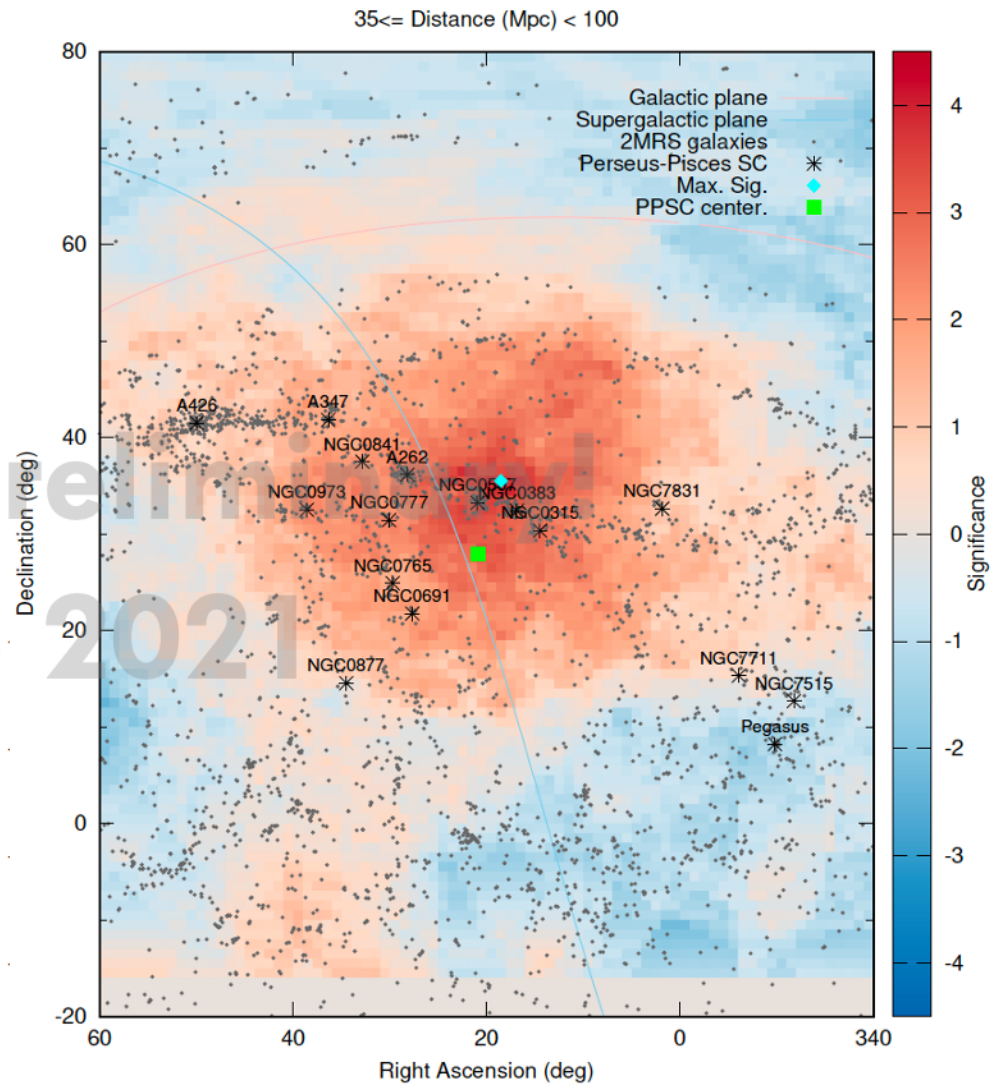
Density contour maps after making corrections for incompletion



New excess with the Perseus-Pisces supercluster

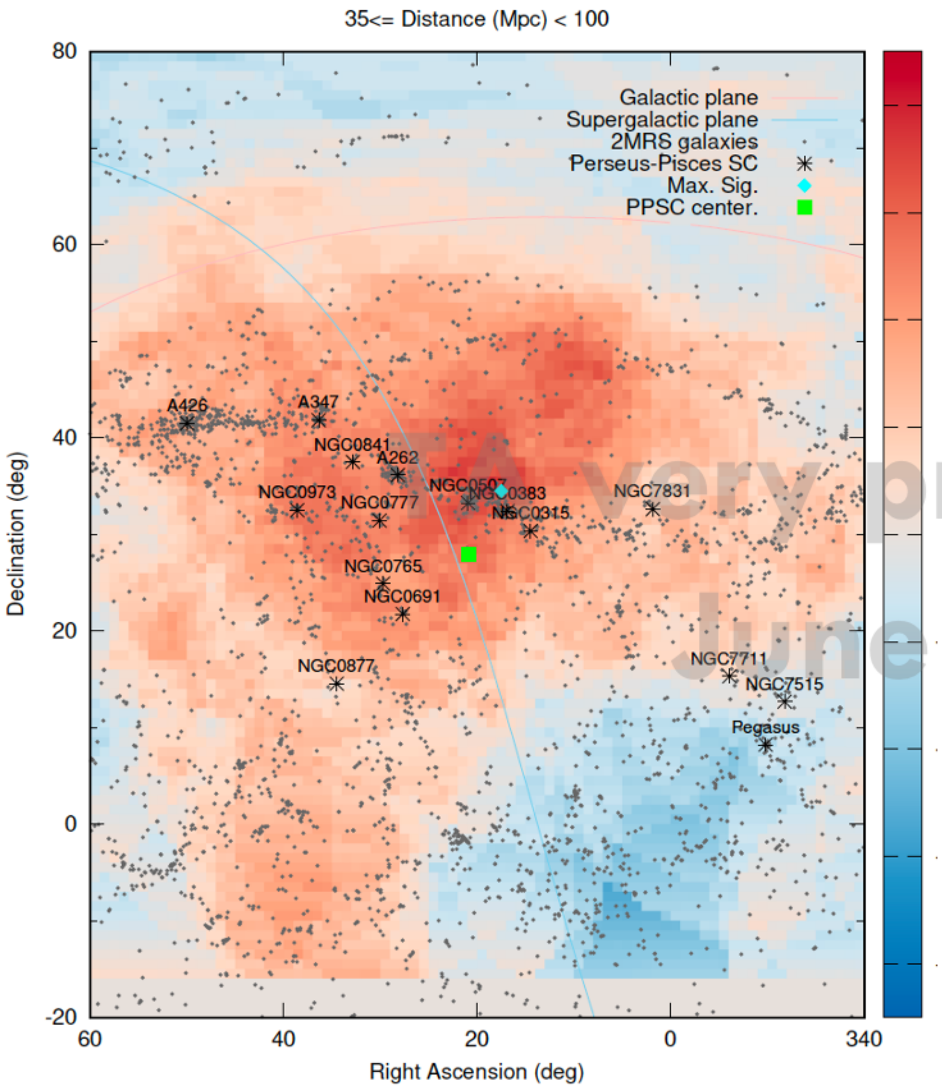


$E \geq 10^{19.4}$ eV

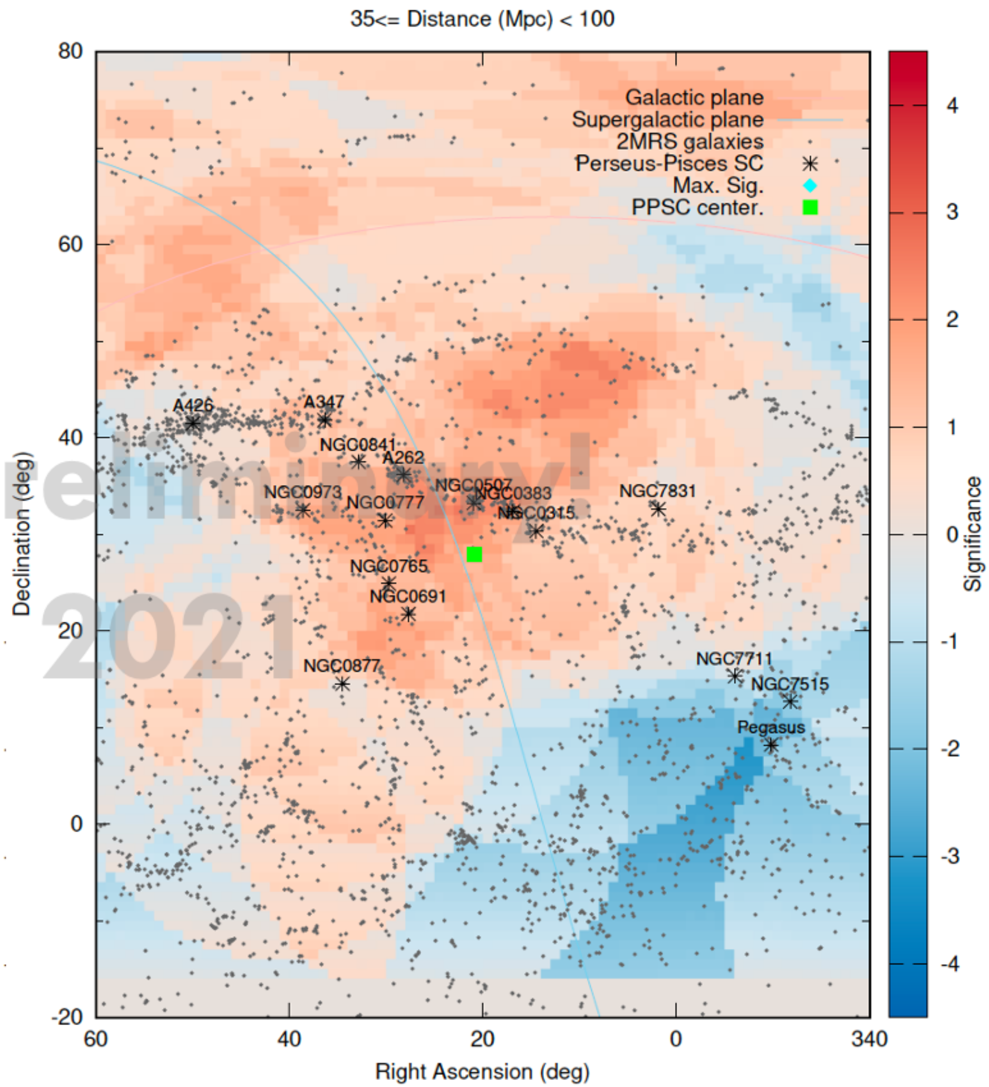


$E \geq 10^{19.5}$ eV

New excess with the Perseus-Pisces supercluster



$E \geq 10^{19.6}$ eV



$E \geq 57$ EeV

Chance prob. of having an excess on top of the PPSC

- At each energy, $10^{19.4}$ eV, $10^{19.5}$ eV, and $10^{19.6}$ eV, find the angle, θ_{obs}, between the max Li-Ma significance of the data and the PPSC center of (20.9°, 27.9°).
- Throw MC trials with the same statistics as the data and perform a Li-Ma analysis of each trial.
- Count as successes those within angle θ_{obs} of the PPSC with a higher significance than the data with PPSC.
- Calculate the probability of having an excess on top of the PPSC by chance.
- For $E \geq 10^{19.4}$ eV (S_{obs}=4.4σ and θ_{obs} = 8.6°),
  - MC successes ($S_{mc} \geq S_{obs}$) with $\theta_{mc} \leq \theta_{obs}$: 49 / 5x$10^5$ MC trials, **3.7σ**
- For $E \geq 10^{19.5}$ eV (S_{obs}=4.2σ and θ_{obs} = 7.4°),
  - MC successes ($S_{mc} \geq S_{obs}$) with $\theta_{mc} \leq \theta_{obs}$: 52 / 5x$10^5$ MC trials, **3.7σ**
- For $E \geq 10^{19.6}$ eV (S_{obs}=4.0σ and θ_{obs} = 6.8°),
  - MC successes ($S_{mc} \geq S_{obs}$) with $\theta_{mc} \leq \theta_{obs}$: 134 / 5x$10^5$ MC trials, **3.5σ**

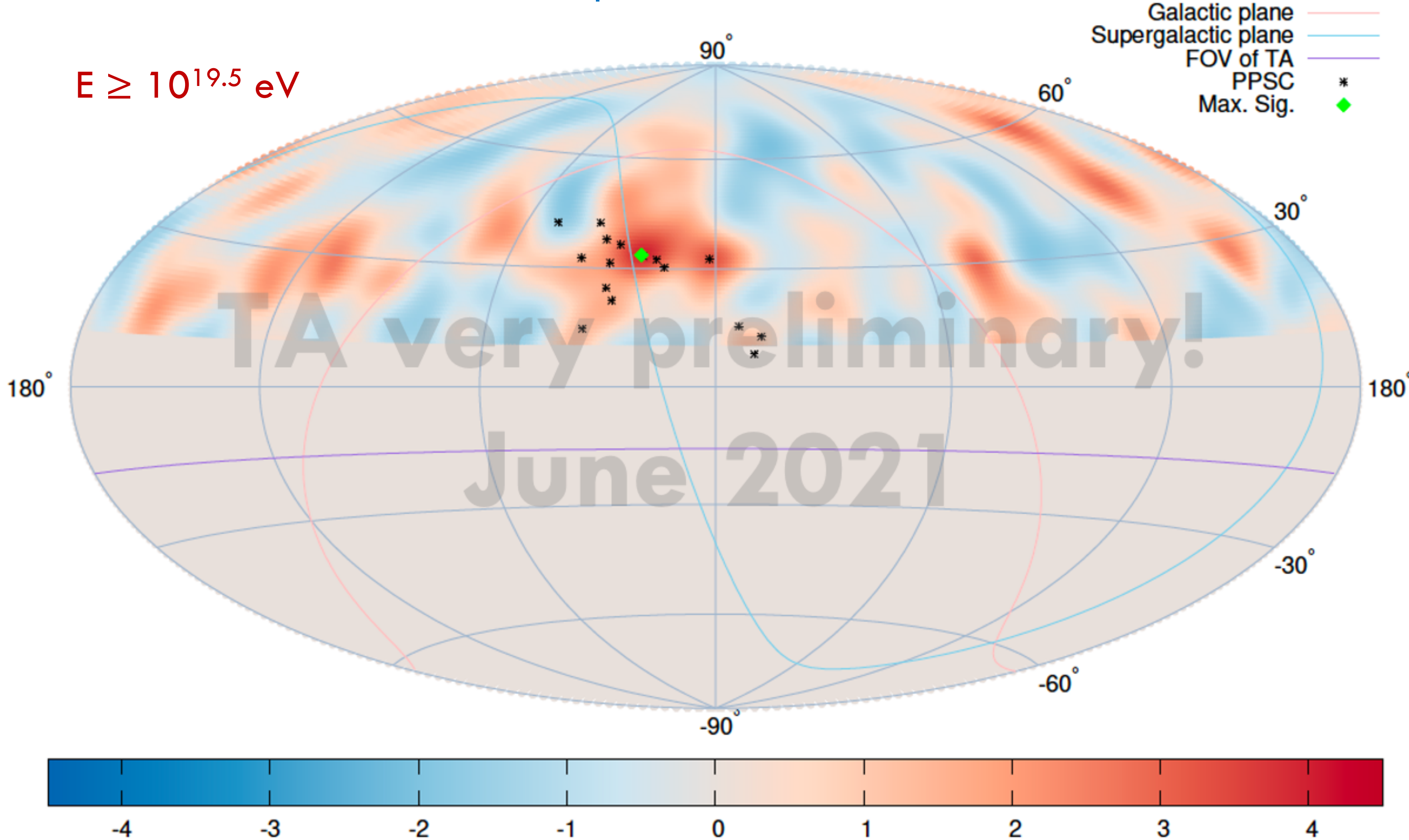
Summary

- We have persistent hints of intermediate angular scale anisotropies, the **hotspot**, at the highest energies, $E \geq 5.7 \times 10^{19}$ eV, near the Ursa Major group. (**S_{post} ~3.2σ**)
- A **new excess** appears in slightly lower energy events with the local Li-Ma significance of $\sim 4.2\sigma$.
- Behind the new excess, there is **the Perseus-Pisces supercluster**.
- Having an excess on top of the Perseus-Pisces supercluster by chance is rare (~**3.6σ**).
- More analyses, such as cross-correlation analysis between the data and the Perseus-Pisces supercluster, are underway.

Looking ahead…

Kernel density estimation, von Mises-Fisher distribution with 5° angular scale

New excess toward the Perseus-Pisces supercluster



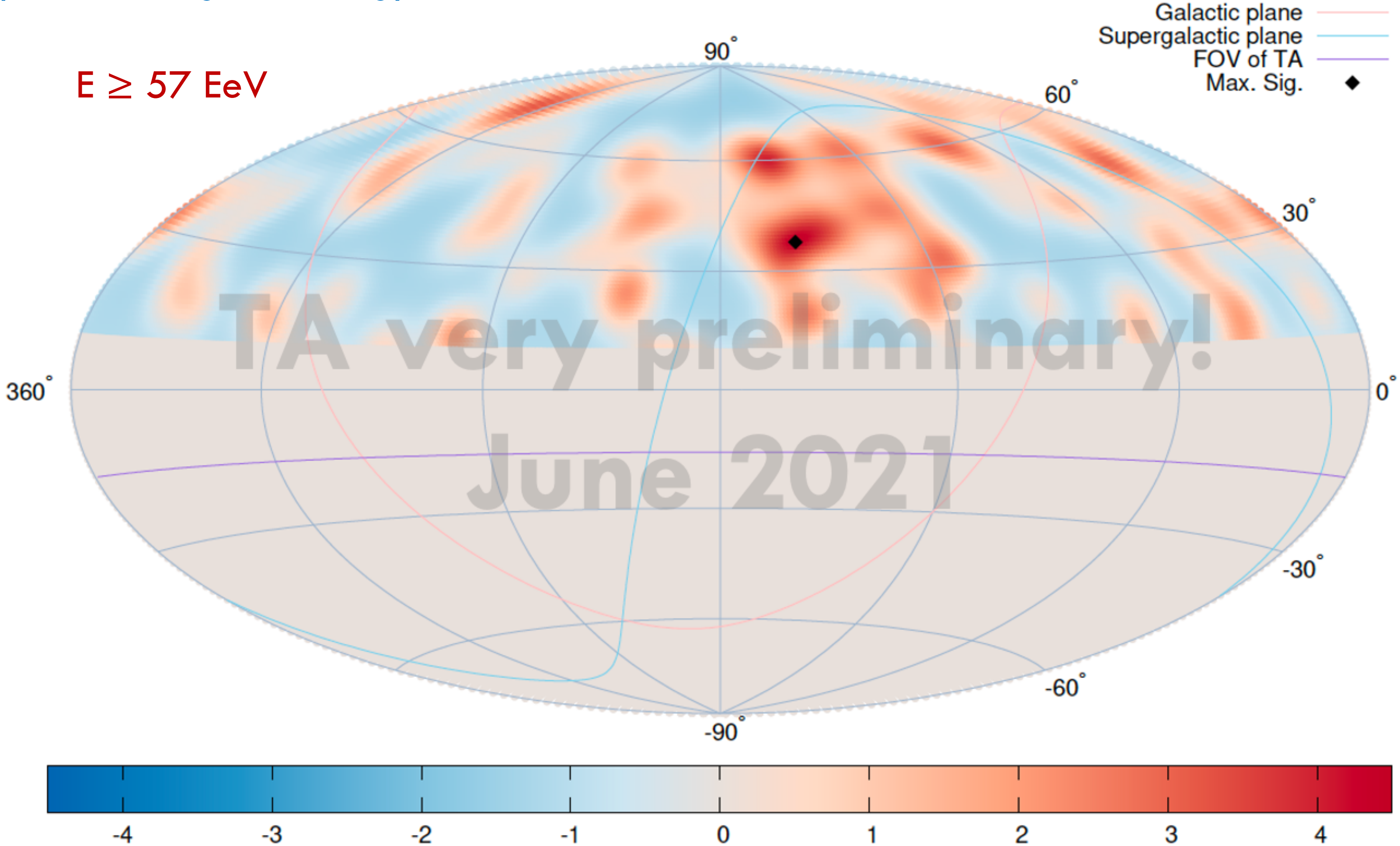
Equatorial coordinates

RA=0 at the center

One more interesting thing…

Kernel density estimation, von Mises-Fisher distribution with 5° angular scale

Hotspot in the highest energy events



Equatorial coordinates