Bayesian analysis on the origin of ultra-high energy cosmic ray events collected by the telescope array experiment

Anatoli Fedynitch

Research Results Presentation Meeting of the ICRR Inter-University Research Program FY2022

ICRR (online), 2023/02/20

People involved

Keito Watanabe

- BSc @ University of Alberta, Canada
- Now MSc cand @ Cologne U. (Germany)
- **Twice at ICRR** in summers 2020 and 2021
- Invited via my KAKENHI (JSPS) grant

Dr. Francesca Capel

- **Astroparticle physicist/Astrostatistician**
- Non-tenured staff scientist at Max-Planck (MPP) Munich
- **Visited ICRR** in 2019 before COVID
- Invited via my KAKENHI (JSPS) grant

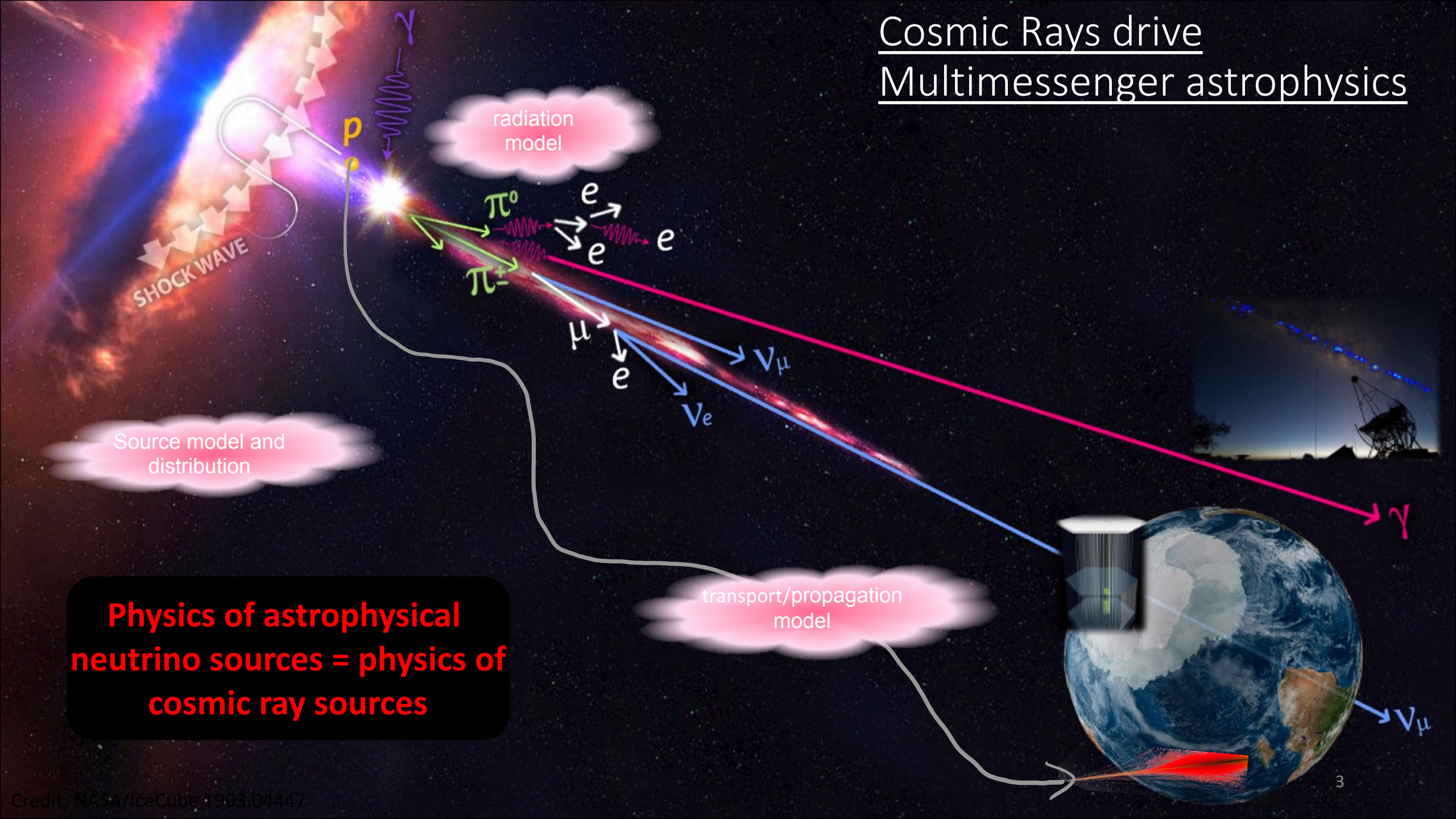
Dr. Anatoli Fedynitch

- **JSPS Fellow in TA group from 2019-2021**
- Now tenure-track faculty at Academia Sinica, Taipei
- PI of this project

Prof. Hiroyuki Sagawa

- **Host Professor**
- TA group leader
- Steering of scienfic outcome

Cosmic Rays drive Multimessenger astrophysics



Physics of astrophysical neutrino sources = physics of cosmic ray sources

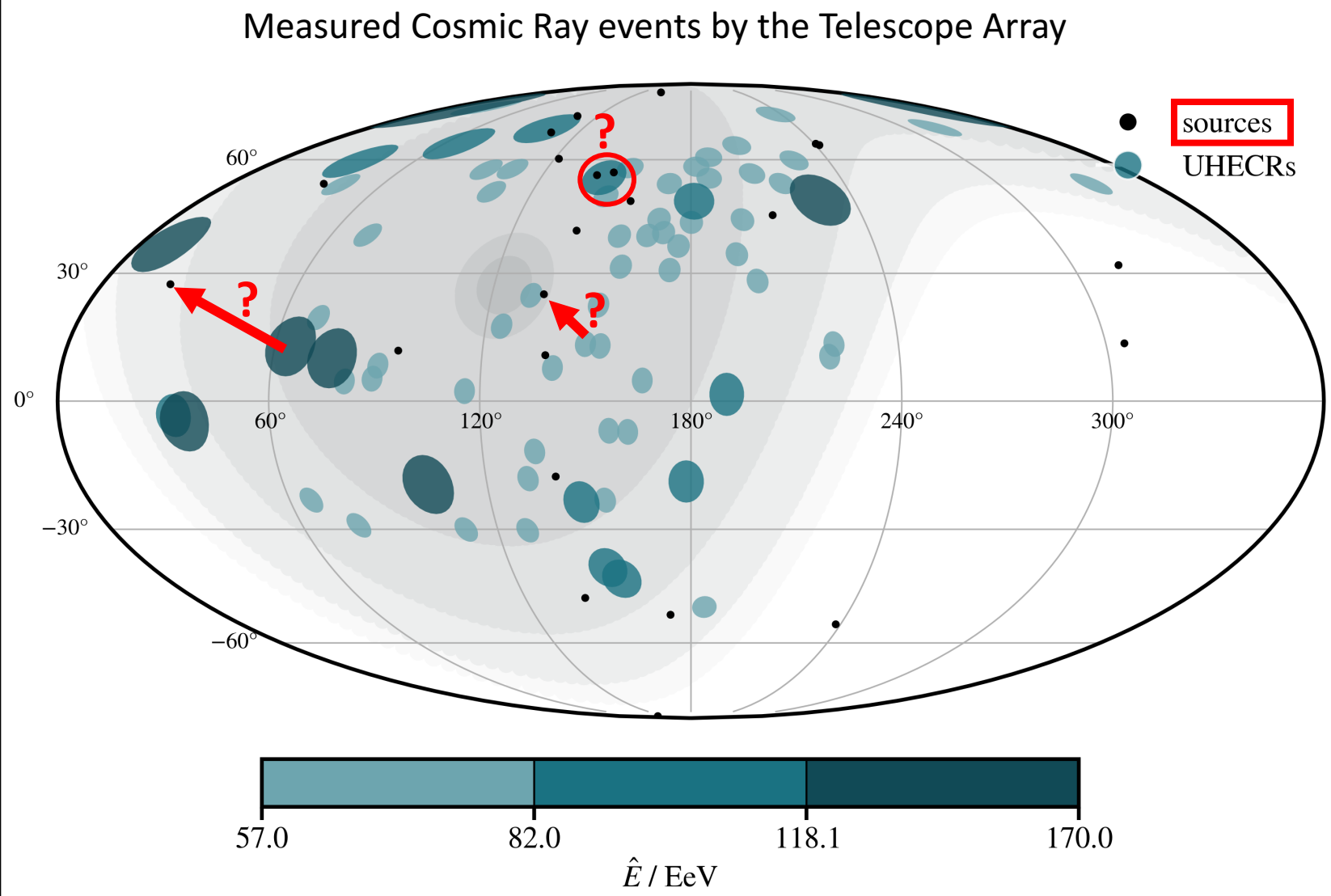
Credit: NASA/IceCube 1903.04447

Telescope array observes Cosmic Rays by looking at particle showers in Utah

Fluorescence detector (FD)

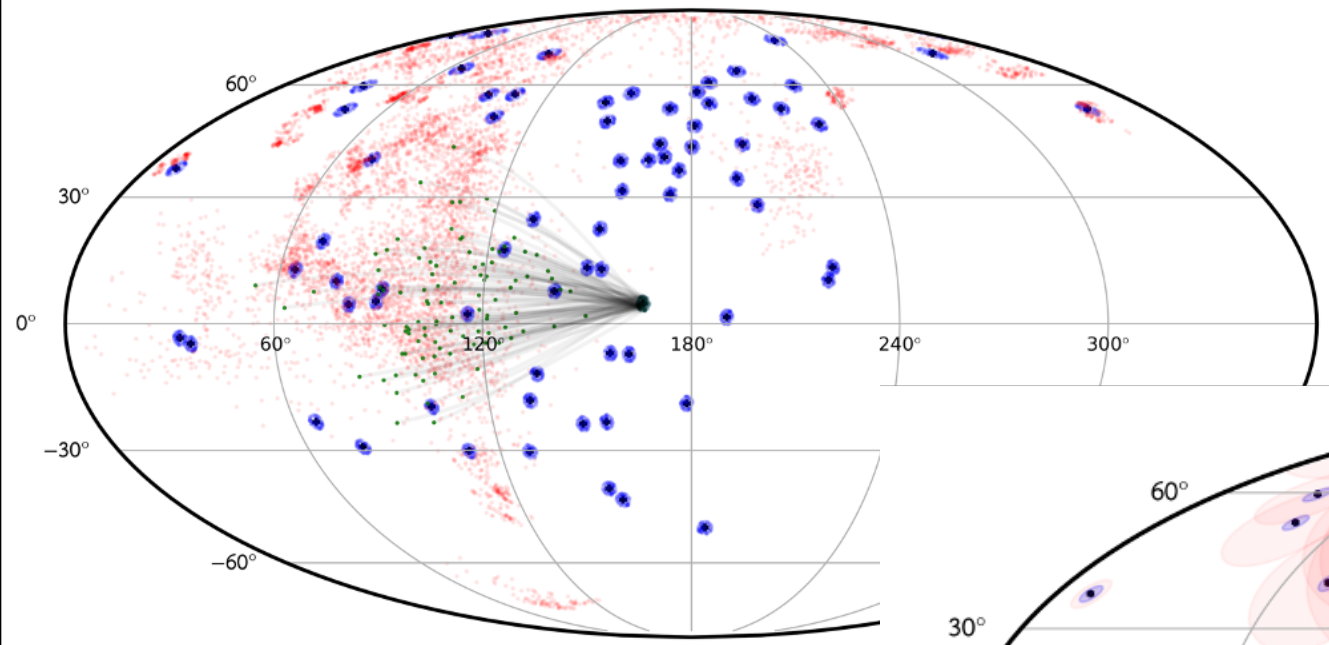
Surface detector (SD)

Research goals

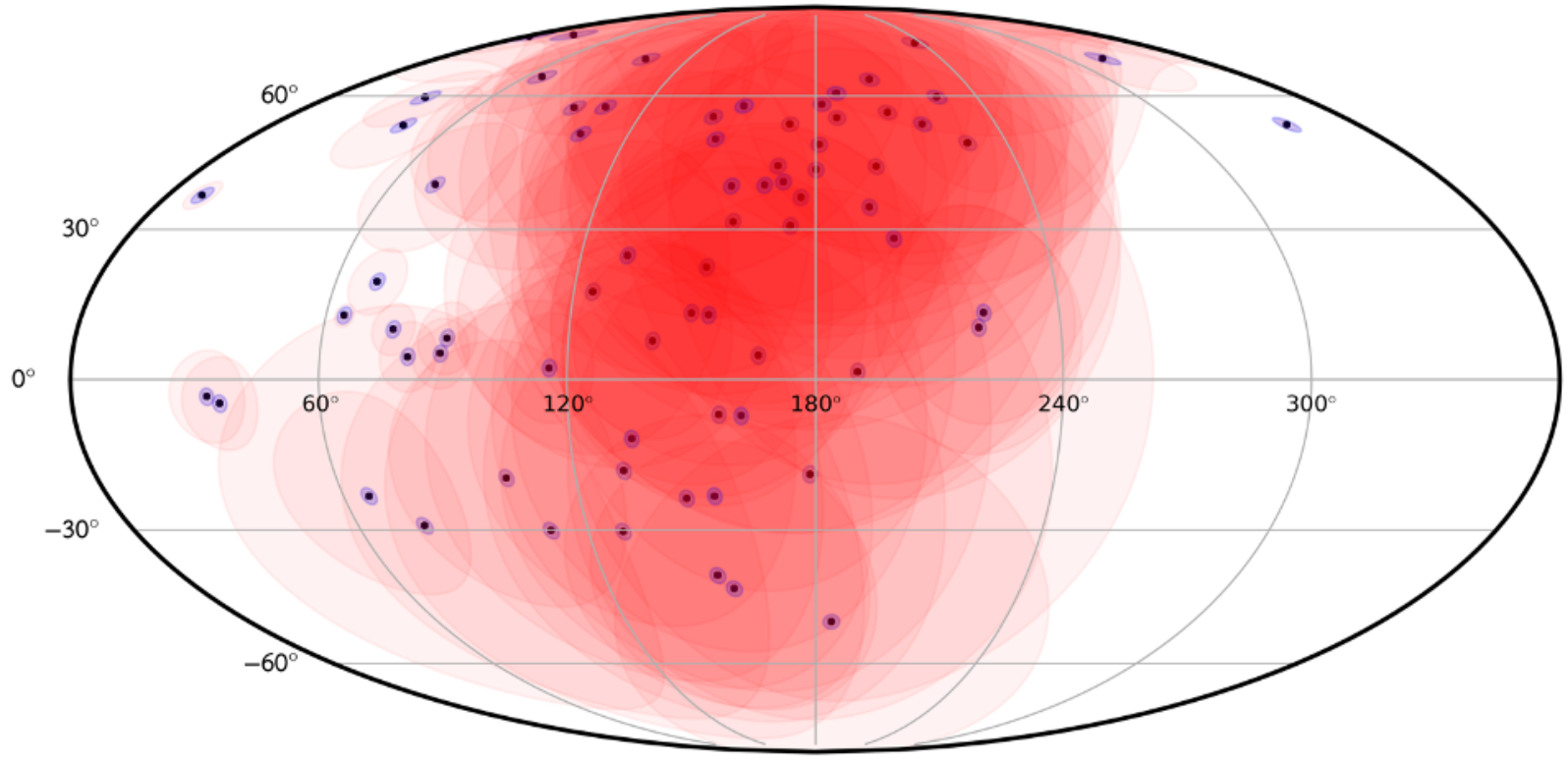


- How can the observed **cosmic rays** be **attributed** to potential **sources**?
- …as a **statistically viable**, robust answer?
- Can we incorporate **the knowledge of the physics** between the Earth and the sources into this statement?

Incorporate deflections in Galactic Magnetic Fields



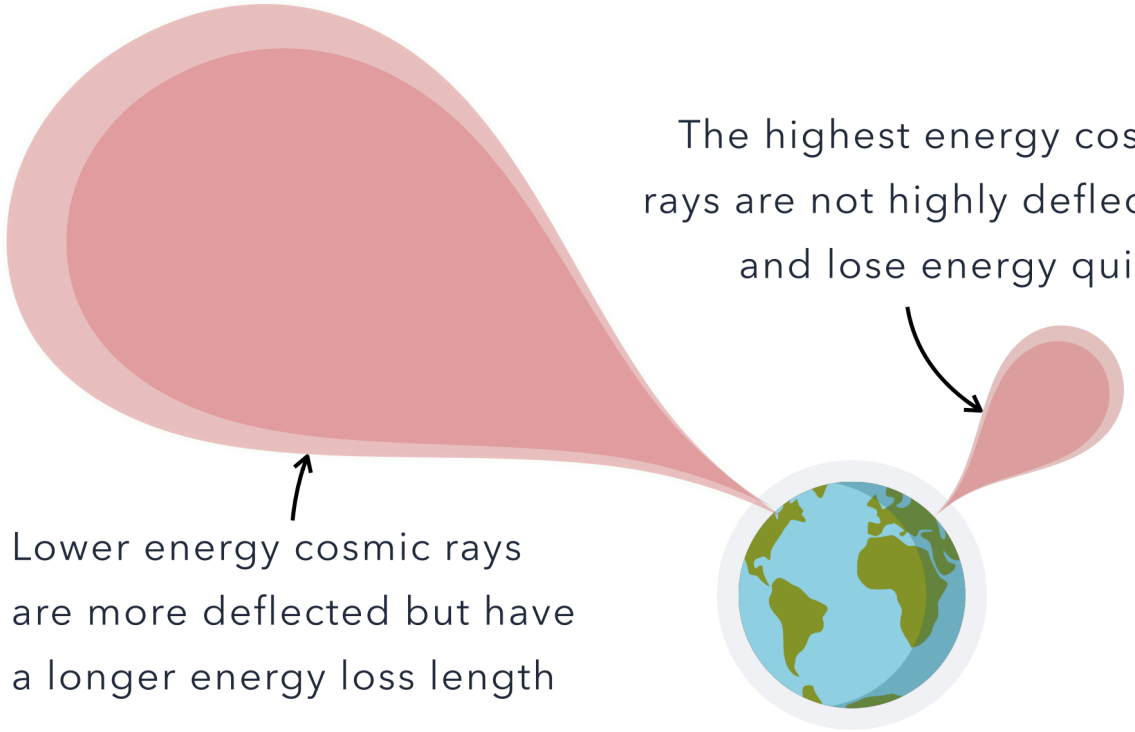
TA 2015 data, nitrogen assumption, JF12



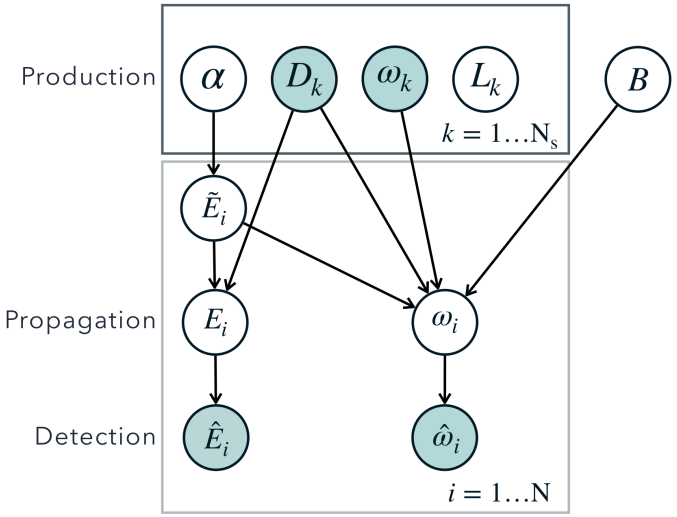
Keito Watanabe, Francesca Capel, AF, Hiroyuki Sagawa, UHECR2022, in prep.

Use detailed modeling and Bayesian inference

Francesca Capel & Mortlock, 1811.06464

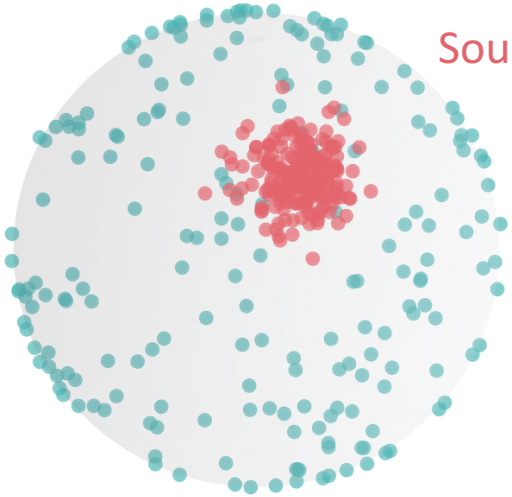


Bayesian Hierarchical Model
(implemented in Python + STAN)



Source fraction:

$$f = \frac{F_s}{F_0 + F_s}$$

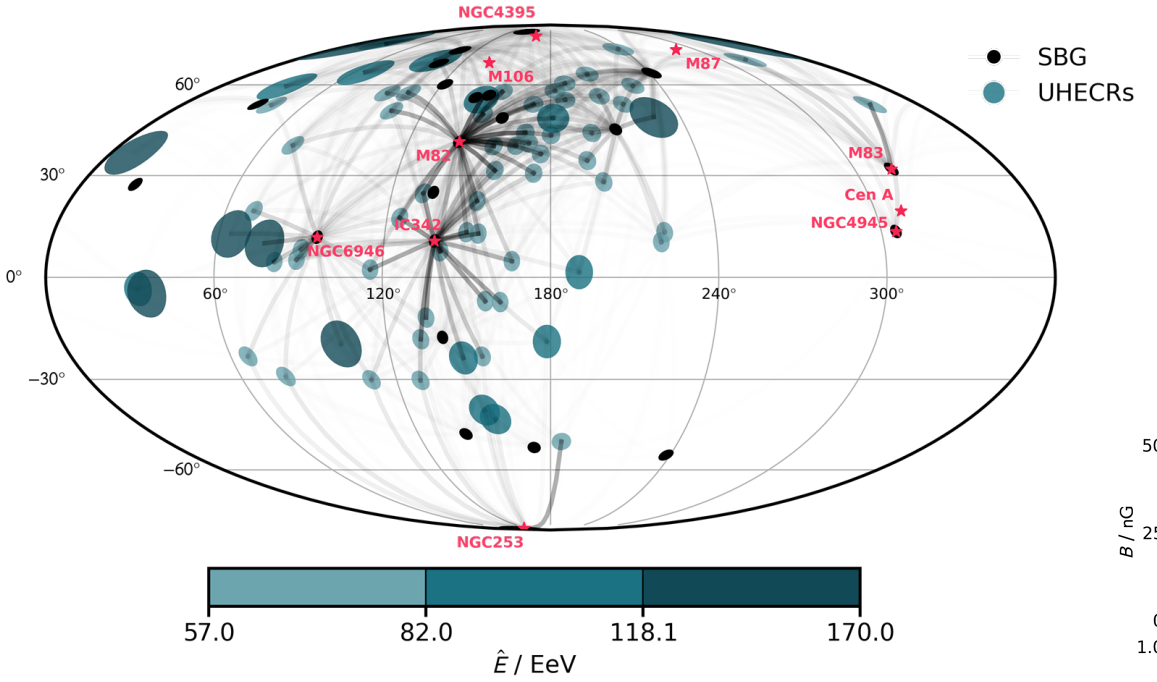


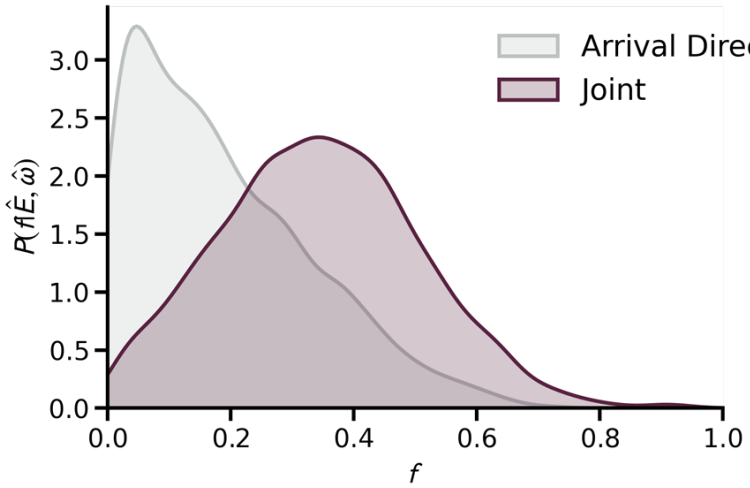
Evolution of:

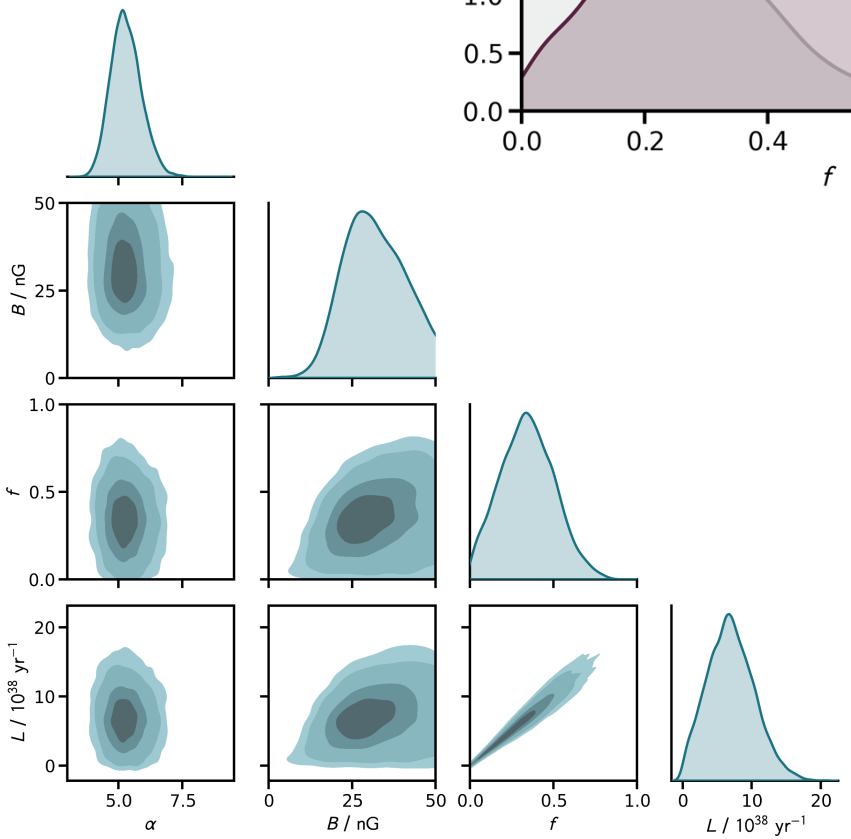
Watson+2012
Soiaporn+2013
Khanin+2016

Keito Watanabe, Francesca Capel, AF, Hiroyuki Sagawa, UHECR2022, in prep.

Current results for TA sky and “Auger” starburst catalog



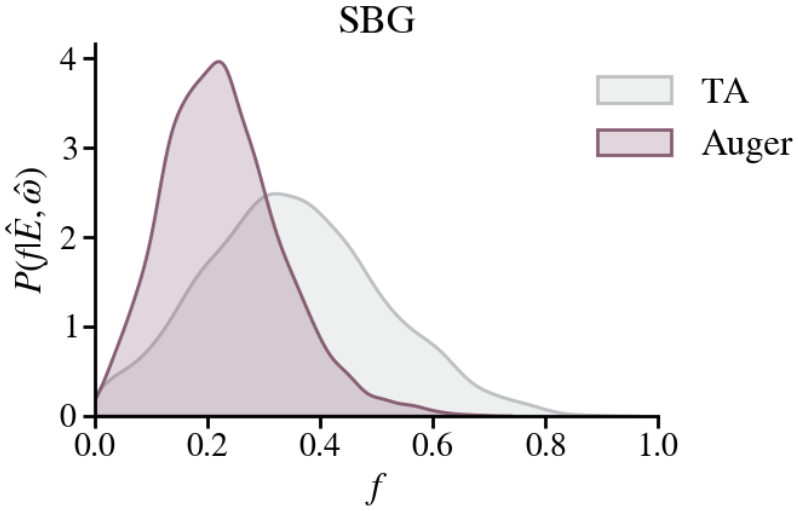




Top-3 sources (>10%)

1. M82 (3.5 Mpc)
2. IC342 (3.3 Mpc)
3. NGC6946 (7.7 Mpc)

One of the current results show that in TA more sources should be “visible” (gray bands)

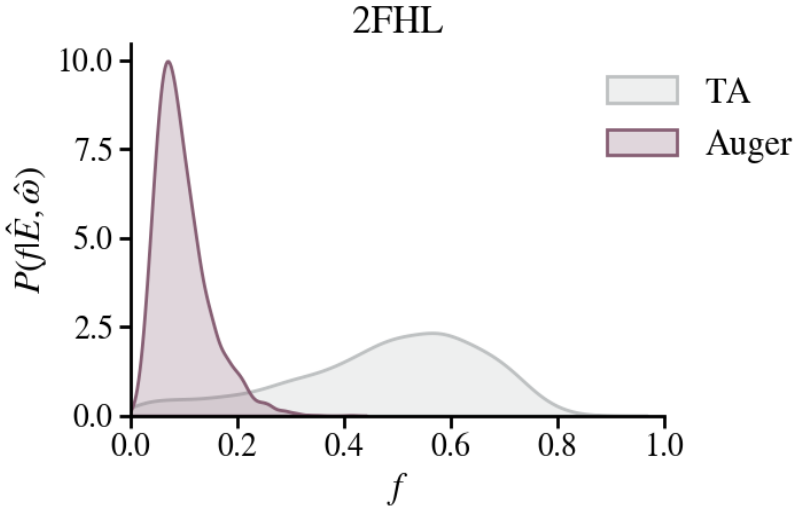


Top-3 TA

1. M82 (3.5 Mpc)
2. IC342 (3.3 Mpc)
3. NGC6946 (7.7 Mpc)

Top-3 Auger

1. NGC253 (3.5 Mpc)
2. NGC4945 (3.6 Mpc)
3. M83 (4.5 Mpc)

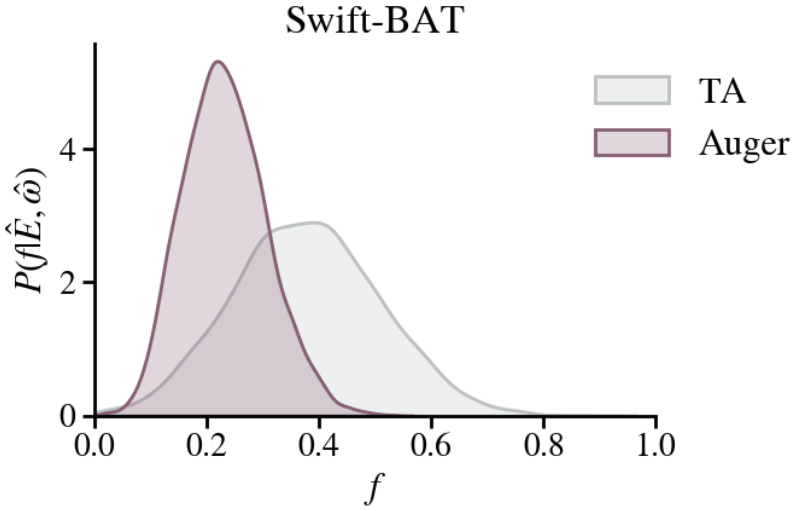


Top-3 TA

1. M87 (16.4 Mpc)
2. Centaurus A (3-5 Mpc)

Top-3 Auger

1. Centaurus A (3-5 Mpc)



Top-3 TA

1. NGC4395 (4.2 Mpc)
2. M106 (7 Mpc)

Top-3 Auger

1. Circinus (4.3 Mpc)
2. Centaurus A (3.5 Mpc)
3. NGC4945 (3.6 Mpc)

Project status and summary

1. Project somewhat delayed:
    - Keito and Francesca could not come to Japan because the borders were closed until Oct 2022 and prices increased shortly after
    - Finding a semi-analytical energy loss parameterization for nuclei was a challenge and it we recently (~1 month ago found a solution)
    - I could visit ICRR and collaborate with Sagawa-sensei due to close distance to Taiwan
    - **Everything in place to complete the project around ICRC 2023**
2. (Tentitatively) Invited Keito and Francesca to ICRR who both will come to the ICRC, so the proposed mini-workshop including other TA members and students can be conducted around this time
3. I will continue to collaborate with Sagawa-sensei beyond at the end of FY2022, who continues as Senior Fellow. Also, I will continue collaborating with Ogio-sensei and Sako-sensei on other topics regarding the data analysis methods