# Deflections of UHECRs from Cen A in the Galactic magnetic field

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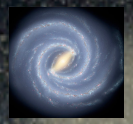
# Outline



## Galactic Magnetic Field

- Current Models
- JF12 Model

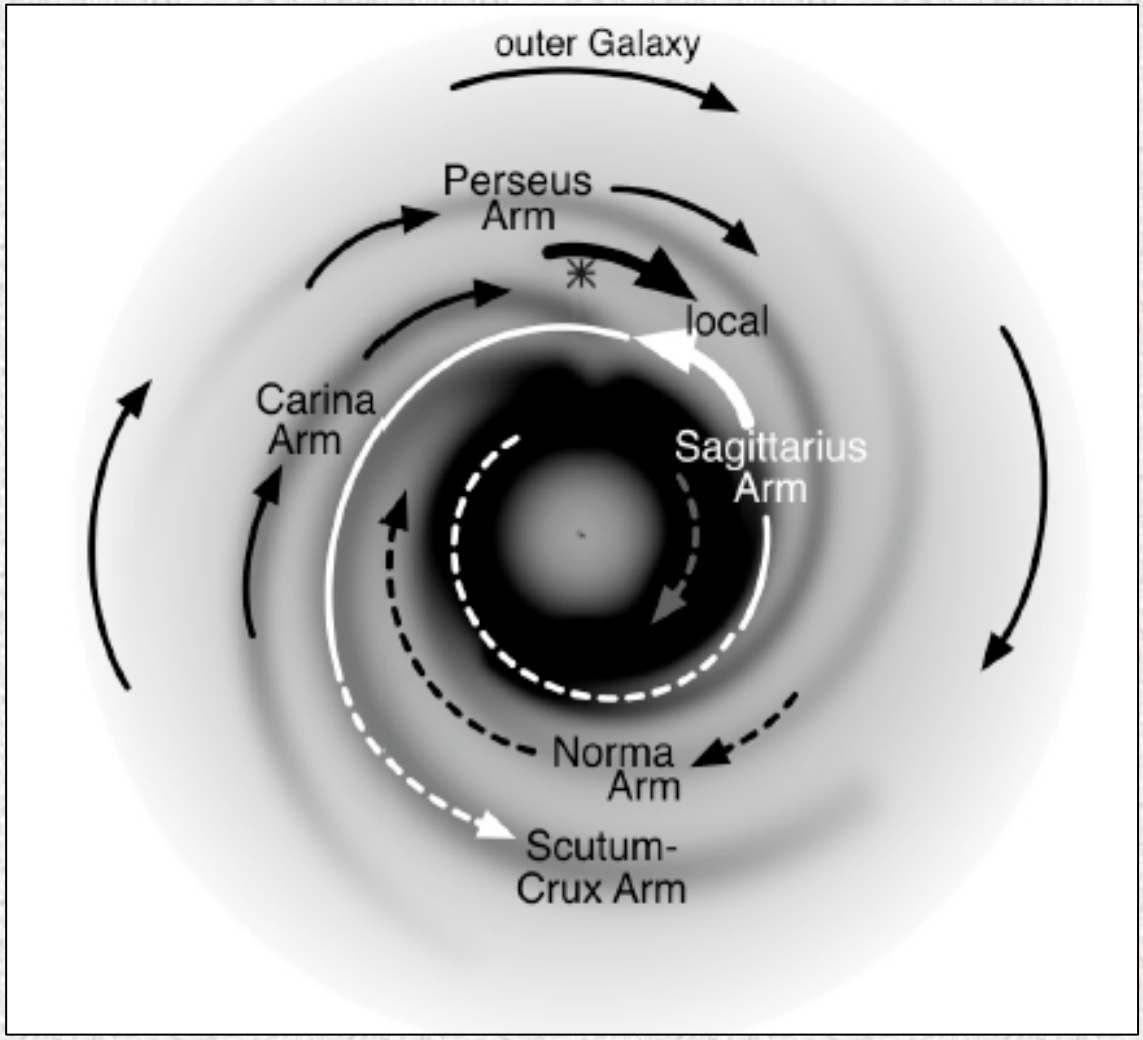
## Tracking UHECRs

- Centaurus A
- Method

## Summary

- What comes next

# Galactic Magnetic Field: Current Models




Van Eck, et al. (2010)

## Common properties:

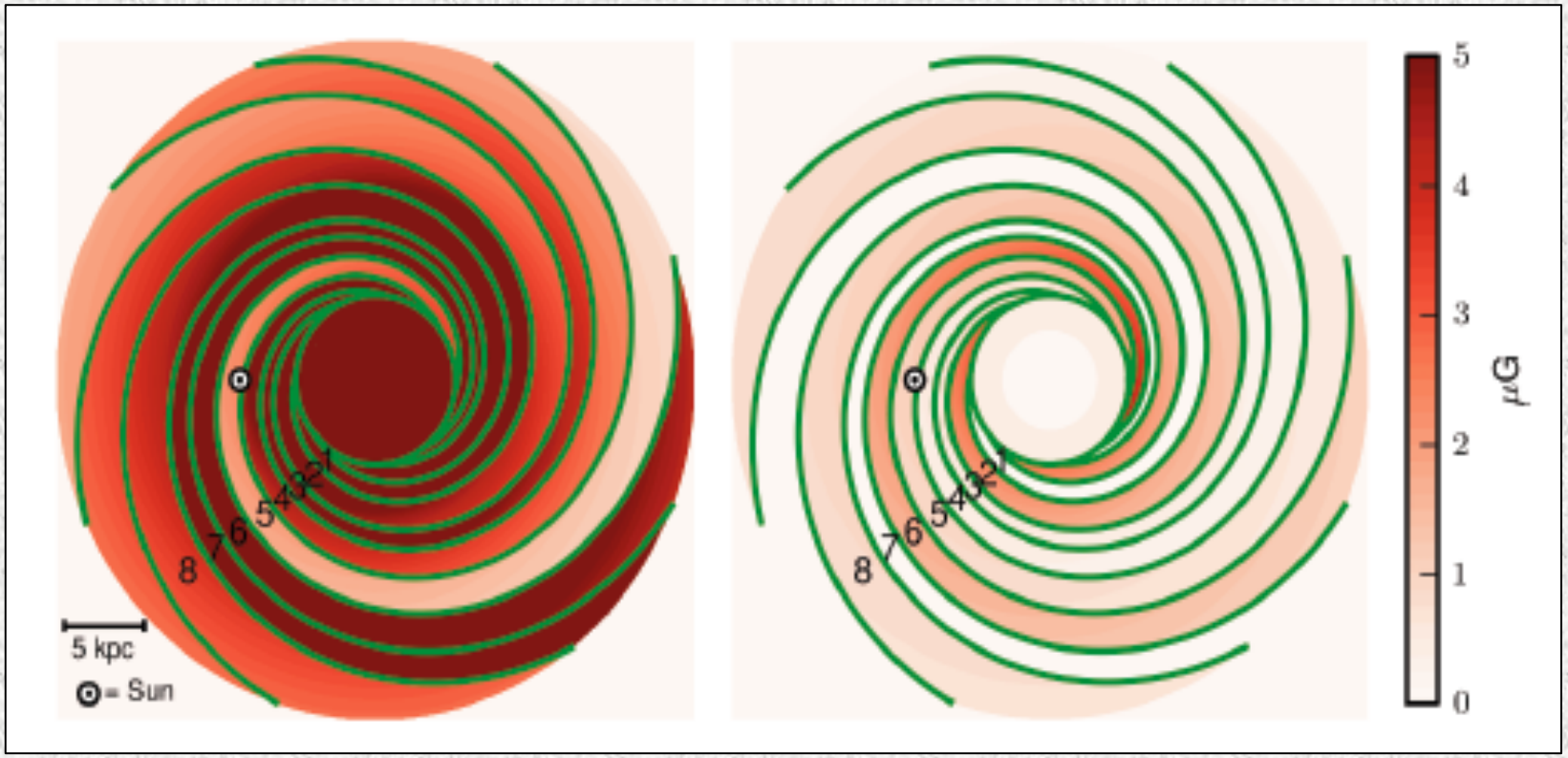
- Large-scale regular component
- Follow the spiral arms
- Turbulent component
- Local parameters

# Jansson-Farrar GMF Model (JF12)

## This model includes:

- Regular large scale component
- Random field component
- Striated random field component

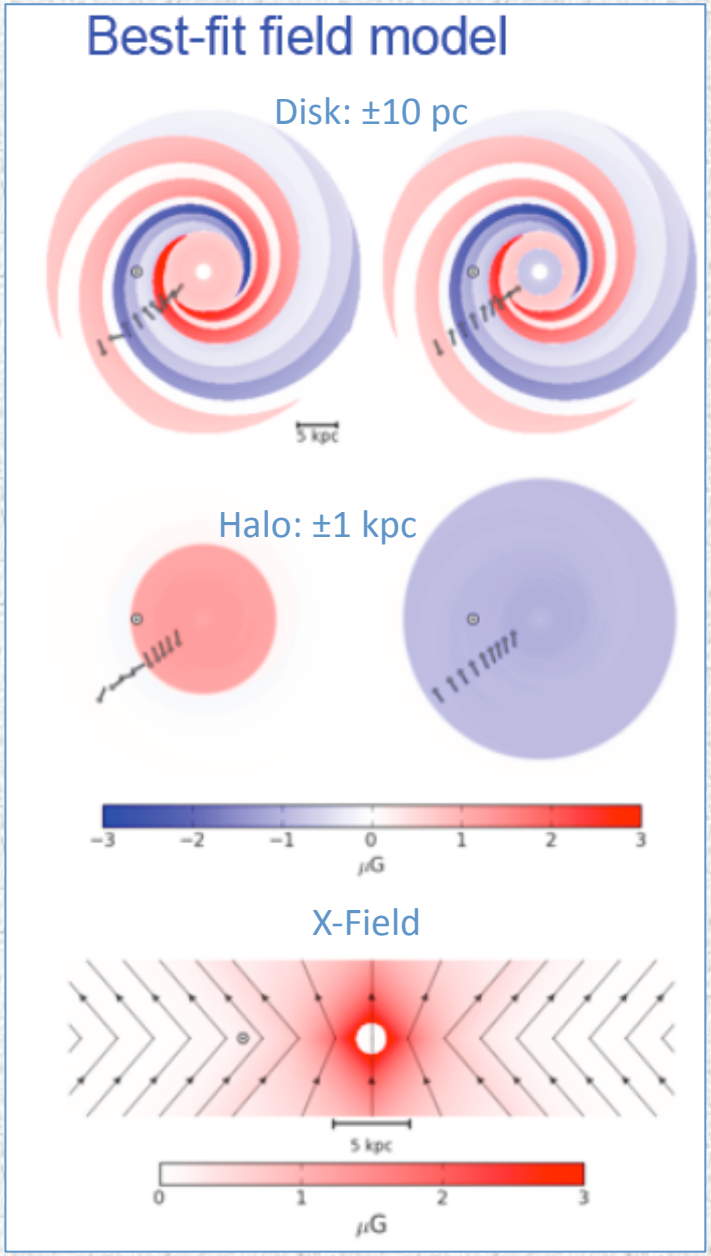
Fit to the observational data: More than 40k extragalactic RM and
the WMAP7 22 GHz polarized and total intensity synchrotron emission maps




R. Jansson and G. R. Farrar, ApJ 761 (2012)

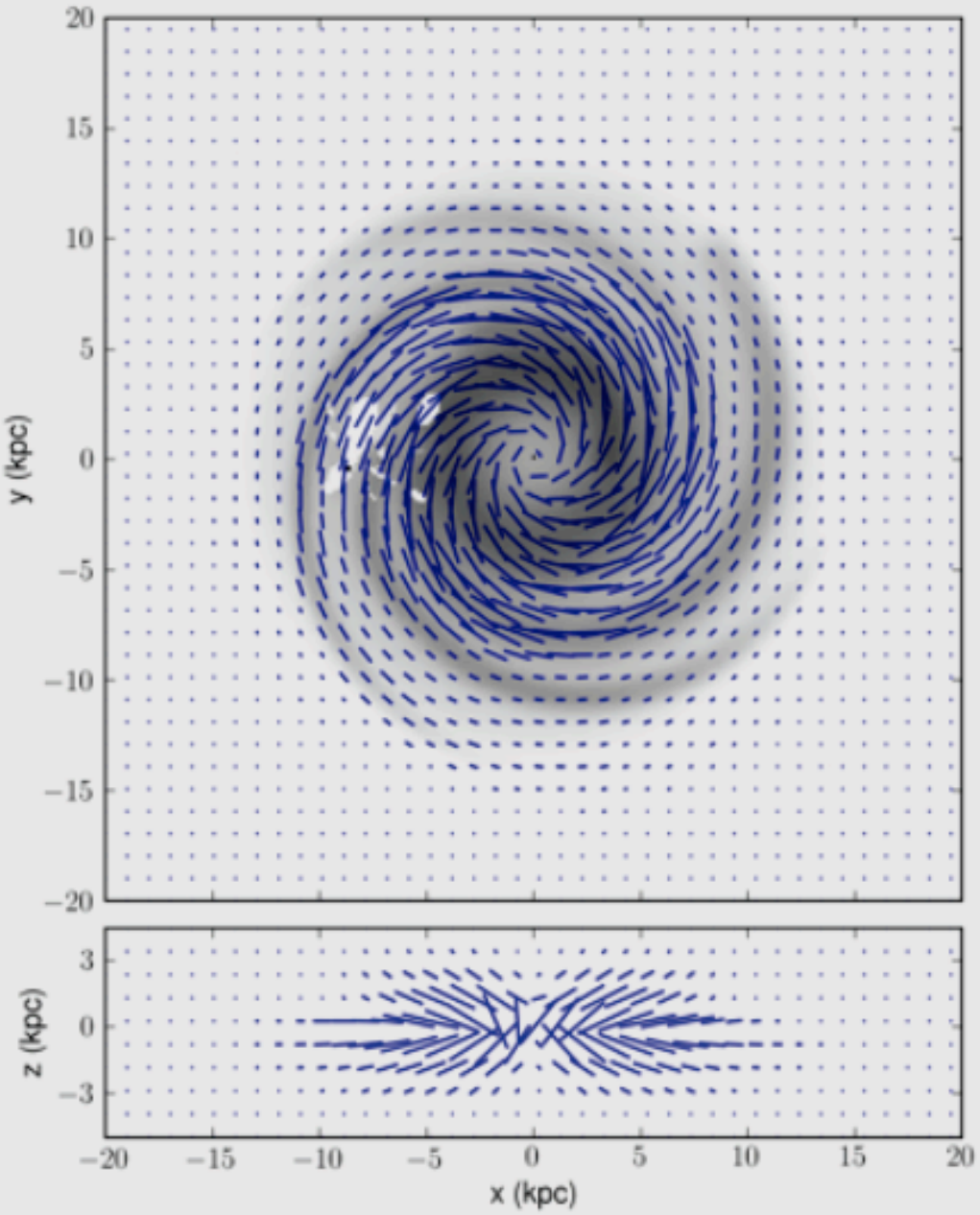
# JF12 Regular Component*

- 3 large scale and divergenceless components:
  - Spiral disk (generalized from Brown et al., 2007)
    - 8 field strengths for arms at r=5kpc
    - 1 field strength for ring (3kpc<r<5kpc)
    - Disk-halo transition
    - Transition width
  - Toroidal halo field
    - Northern/Southern halo strengths
    - Transition radius, north/south
    - Transition width
    - Vertical scale height
  - Poloidal out-of-plane field
    - Field strength at origin
    - Elevation angle at z=0
    - Radius where theta=theta0
    - Exponential scale length
- 22 free parameters



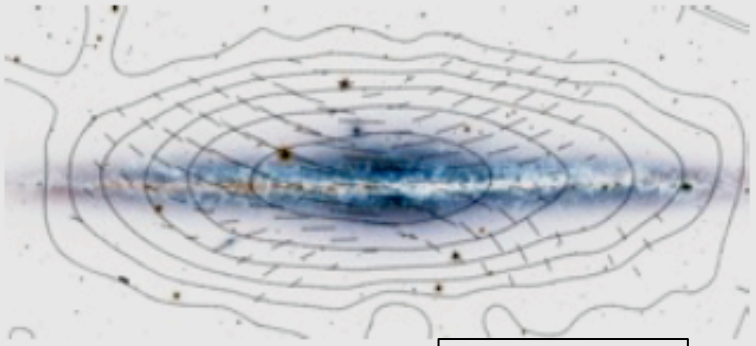

*R. Jansson and G. R. Farrar, ApJ 757 (2012)

# The Milky Way to an Extragalactic Radio Observer




Milky Way analogues:

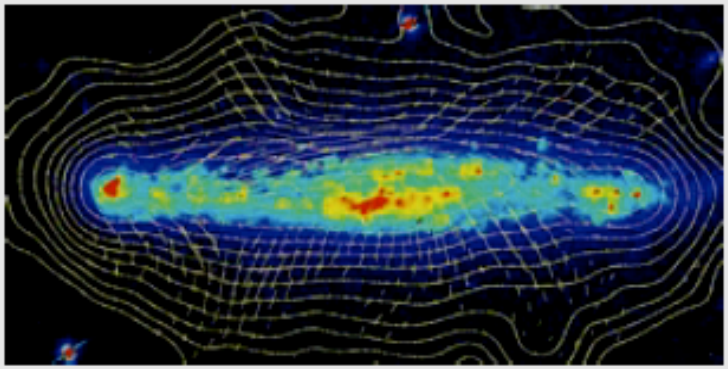
NGC 891



Krause (2009)

NGC 5775

Soida, et al (2011)



R. Jansson and G. R. Farrar, ApJ 757 (2012)

# JF12 Random* and Striated Field Components

- Superposition of a disk component and an extended smooth halo component
- ✧ 13 Free parameters
- Disk component:
  - 8 arms as in regular component; B≈1/r
  - Central region: constant Brms
  - Gaussian vertical profile
- Smooth extended component:
  - Vertical scale height: 3 kpc
  - Radial scale length: 10 kpc
  - Central value: Brms=3μG
- Using total synchrotron intensity map
- Coherence length of 100 pc or less

The data calls for a **striated component** to the random field:

Whose orientation is aligned with the regular component, having zero mean and RMS strength of ≈20% larger than the regular field

With this complete field model, a very good fit to more than 40k extragalactic RM and the WMAP7 22 GHz polarized and total intensity synchrotron emission maps is obtained.

*R. Jansson and G. R. Farrar, ApJ 761 (2012)

# Tracking UHECRs

Charged particles are deflected in magnetic fields

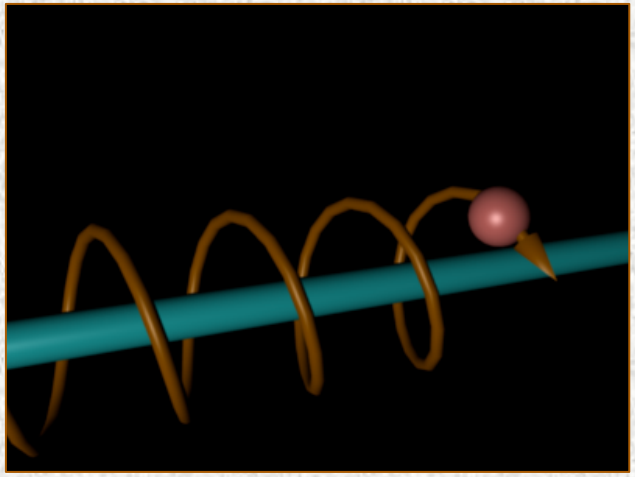
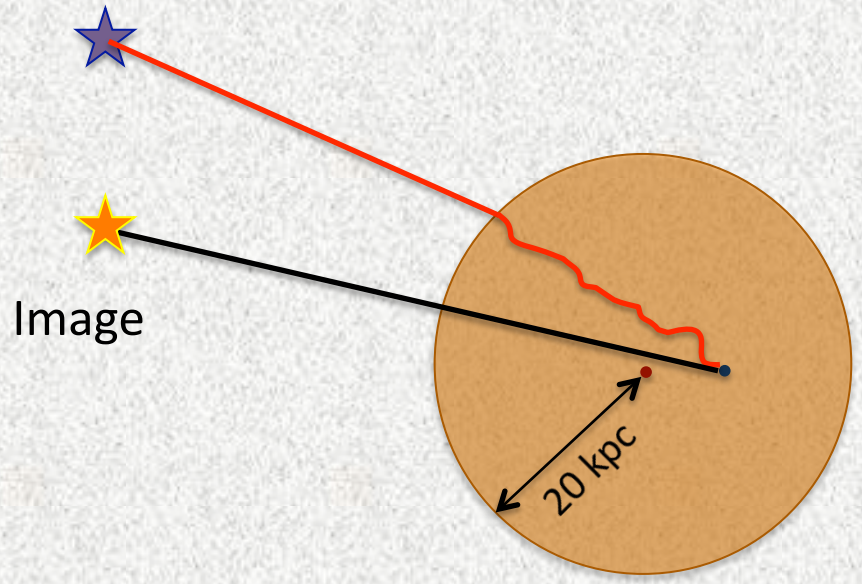


Image credit: scientopia.org

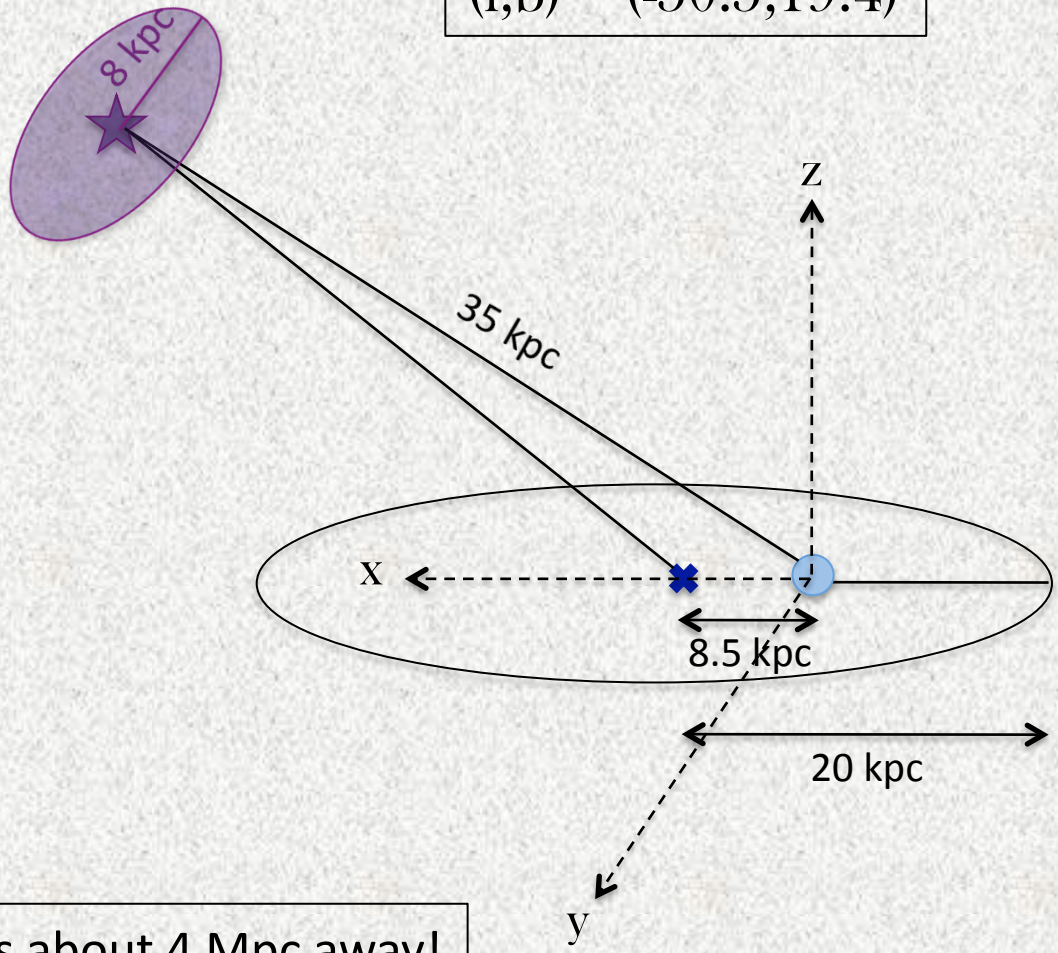
Real Source




We should consider the effect of the GMF to identify the sources of UHECRs

# Centaurus A


(l,b) = (-50.5,19.4)

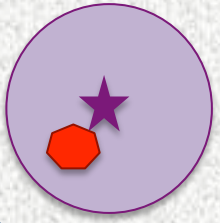



Cen A is about 4 Mpc away!

# Forward-tracking for Z up to Iron

✦ Use CRT Michael Sutherland, et al (2010)

1. Injection plane around center of Cen A (the first step)



2. Detect them on a sphere surrounded the Earth

3. Record the successful events

4. Inject particles to a smaller detector size (the second step)

5. This time from random positions inside the region of the successful events

The goal of this method is to reach to a small detector closer to reality

R = Rigidity=E/Z: 2, 8, 16, 22, 32, 45, 64 EV
detR = the radius of the detector: 0.4 → 0.002 kpc

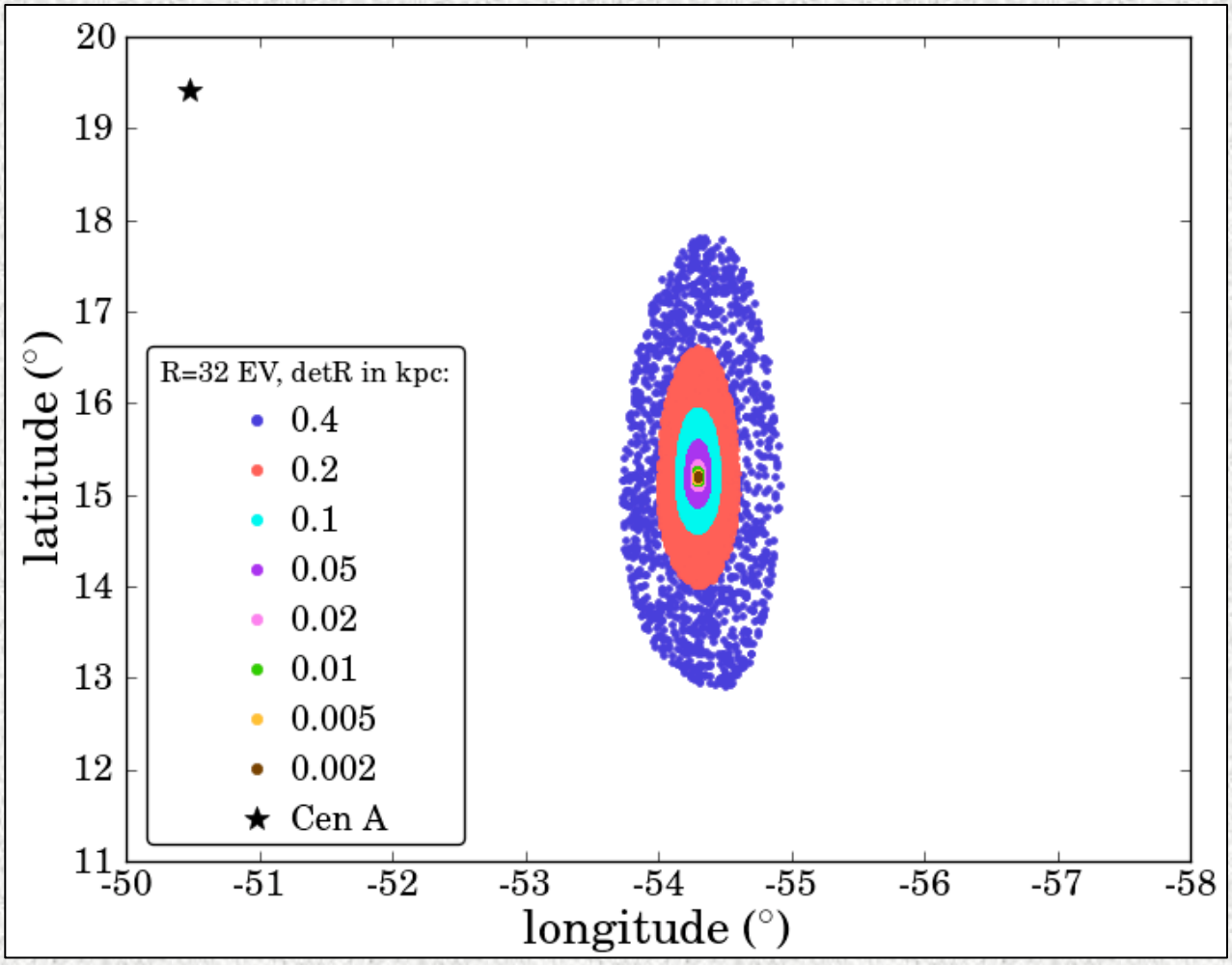
# No random field, R==E/Z=32 EV

## Observed Directions

Only a small region near Cen A is detected at Earth.

The smaller the detector size (detR), the more compact the starting region

Galactic coordinates

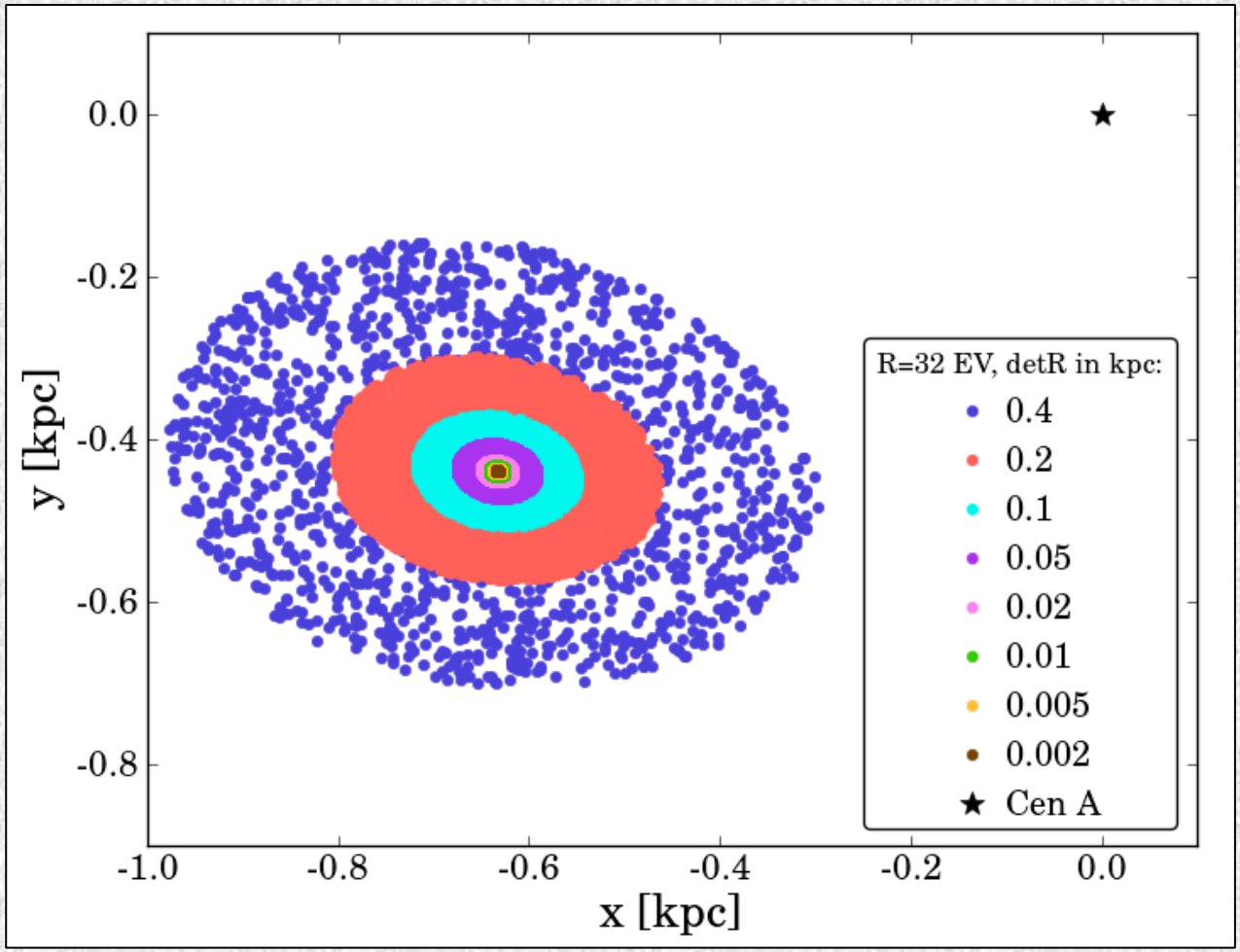


# No random field, R==E/Z=32 EV

## Injection Plane

The position of the successful particles on a disk around Cen A.

The image quantitatively shows a convergence as we go to smaller detR's.

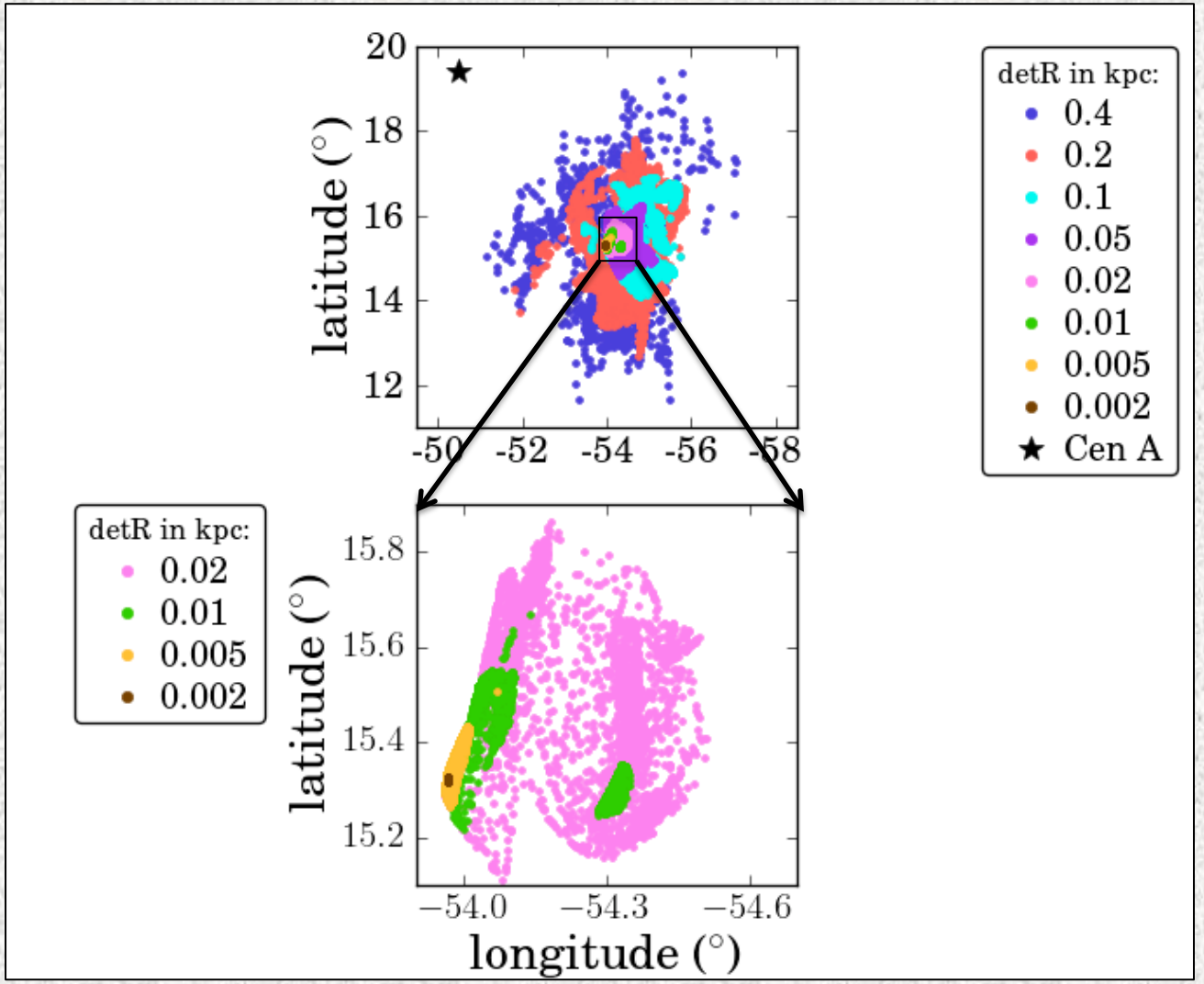


# Adding random and striated field, R==E/Z=32 EV

## Observed Directions

Adding the random field scatter the particles around.

The bottom is a zoomed in image of the last 4 detR's.

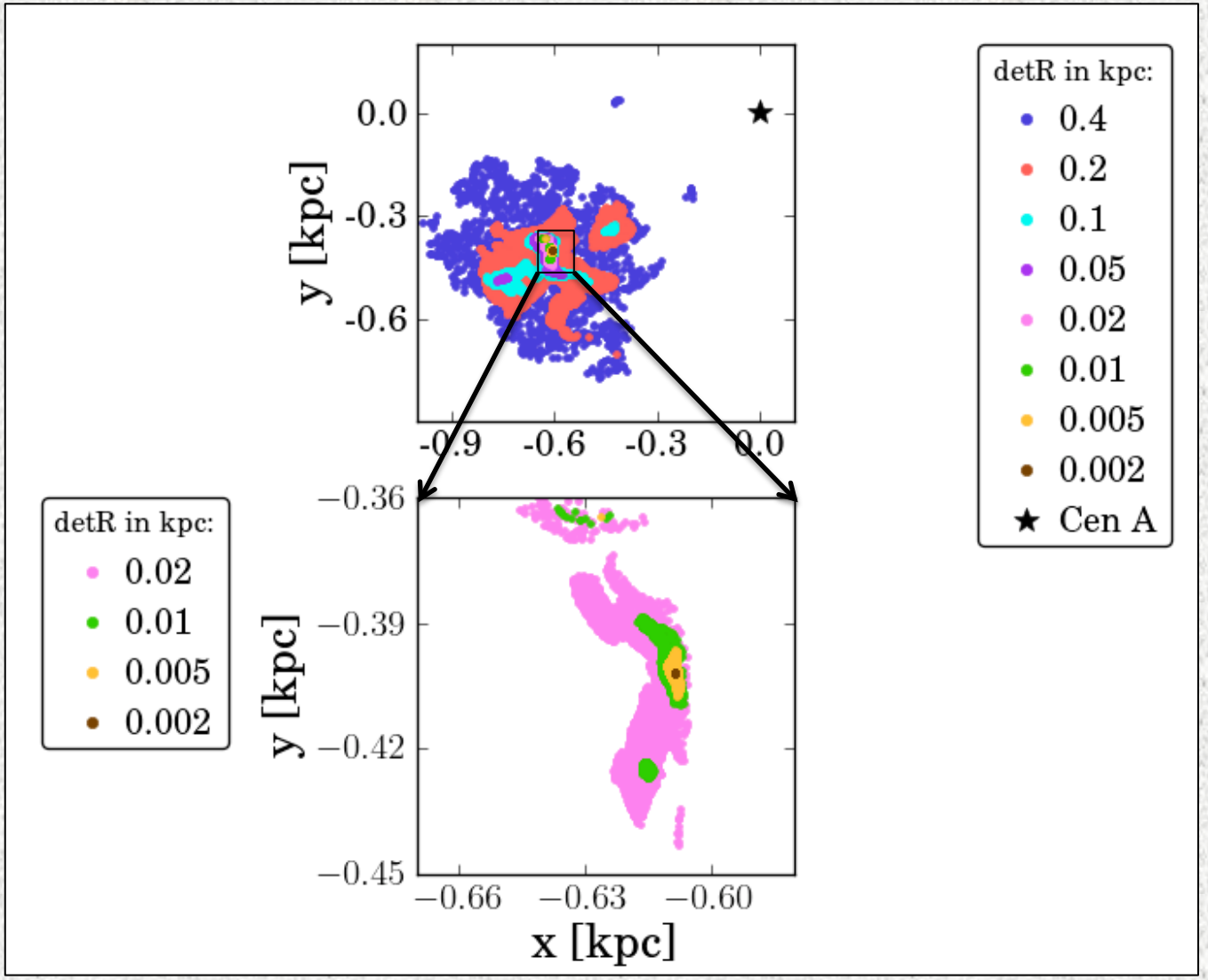


# Adding random and striated field, R==E/Z=32 EV

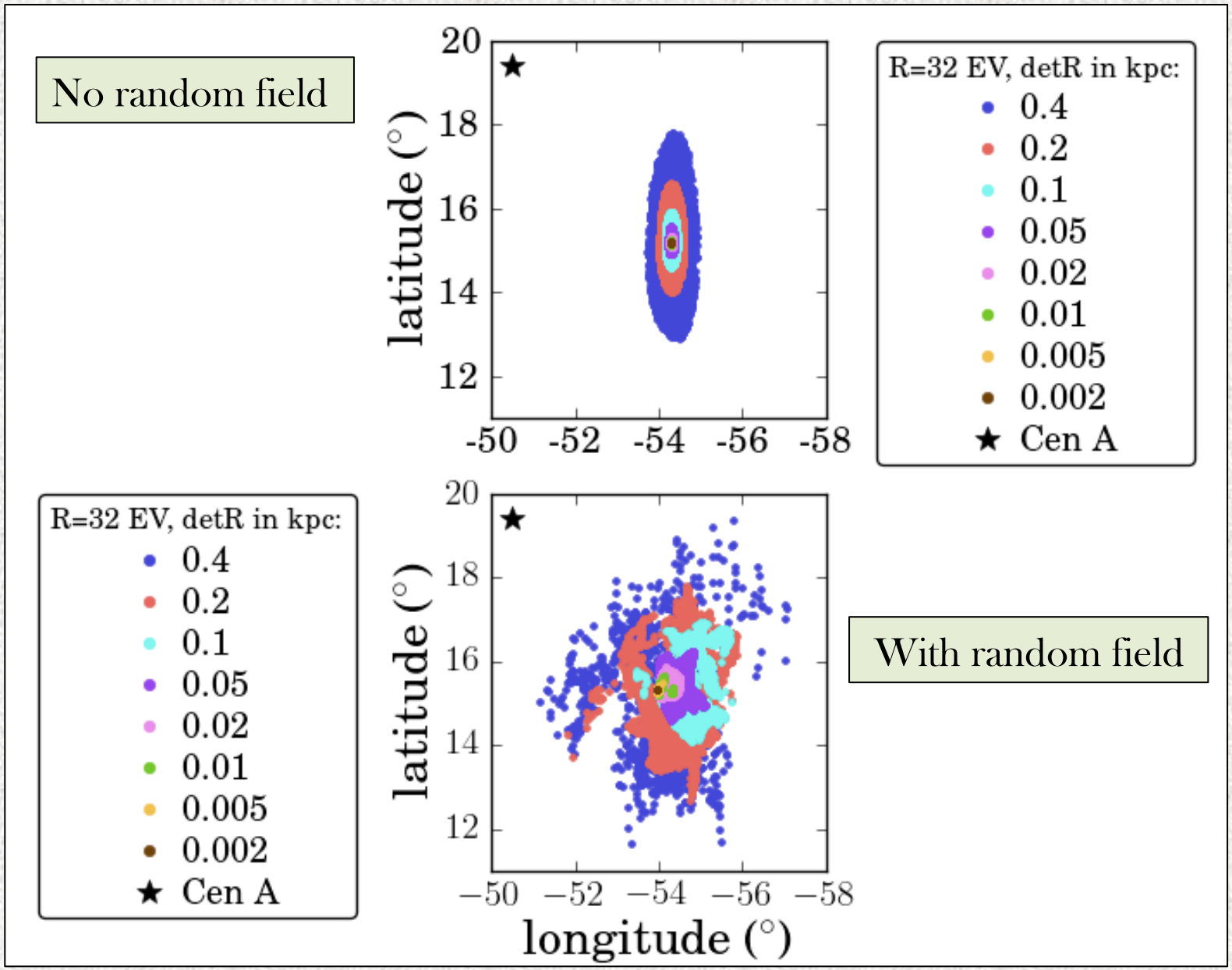
## Injection Plane

The position of the successful events on the injection disk.

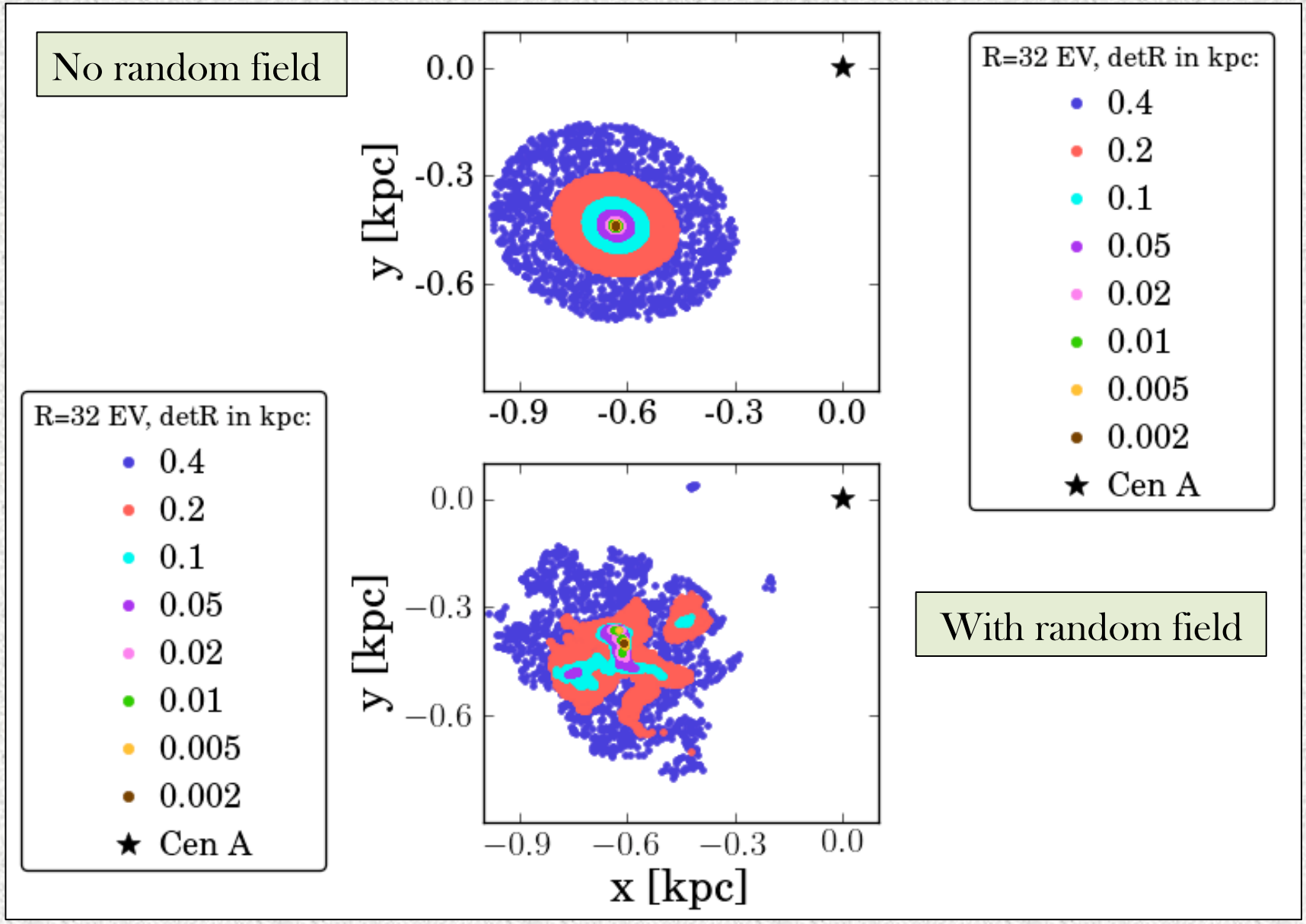
The bottom is a zoomed in image of the last 4 detR's.



# Comparing observed directions with and without random field, R=32 EV



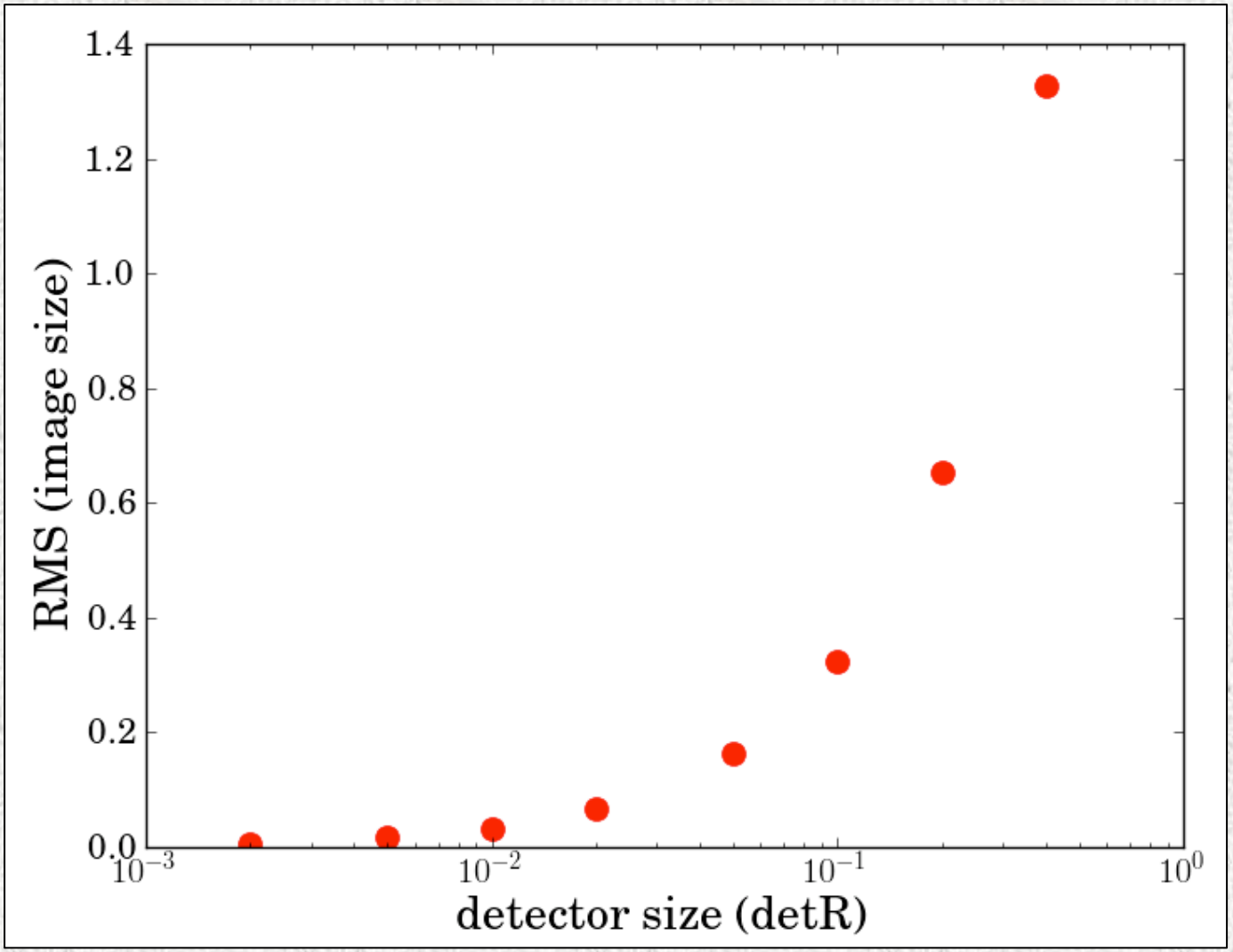
# Comparing injection planes with and without random field, R=32 EV



# Converged to smaller detr, R==E/Z=32 EV

We stop at a small detR.

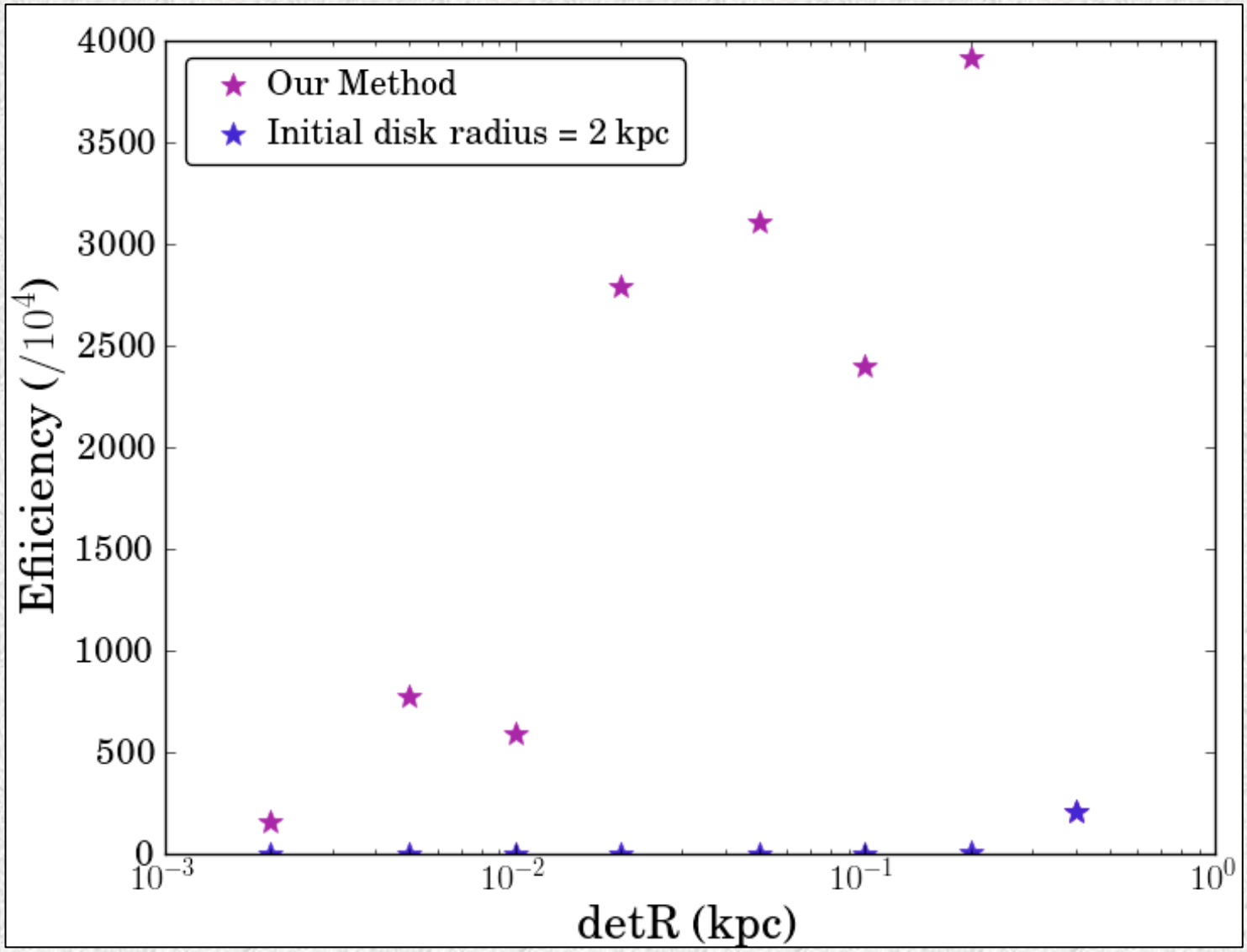
The image starts to converge at some detR.



# Efficiency of our method for R=32 EV

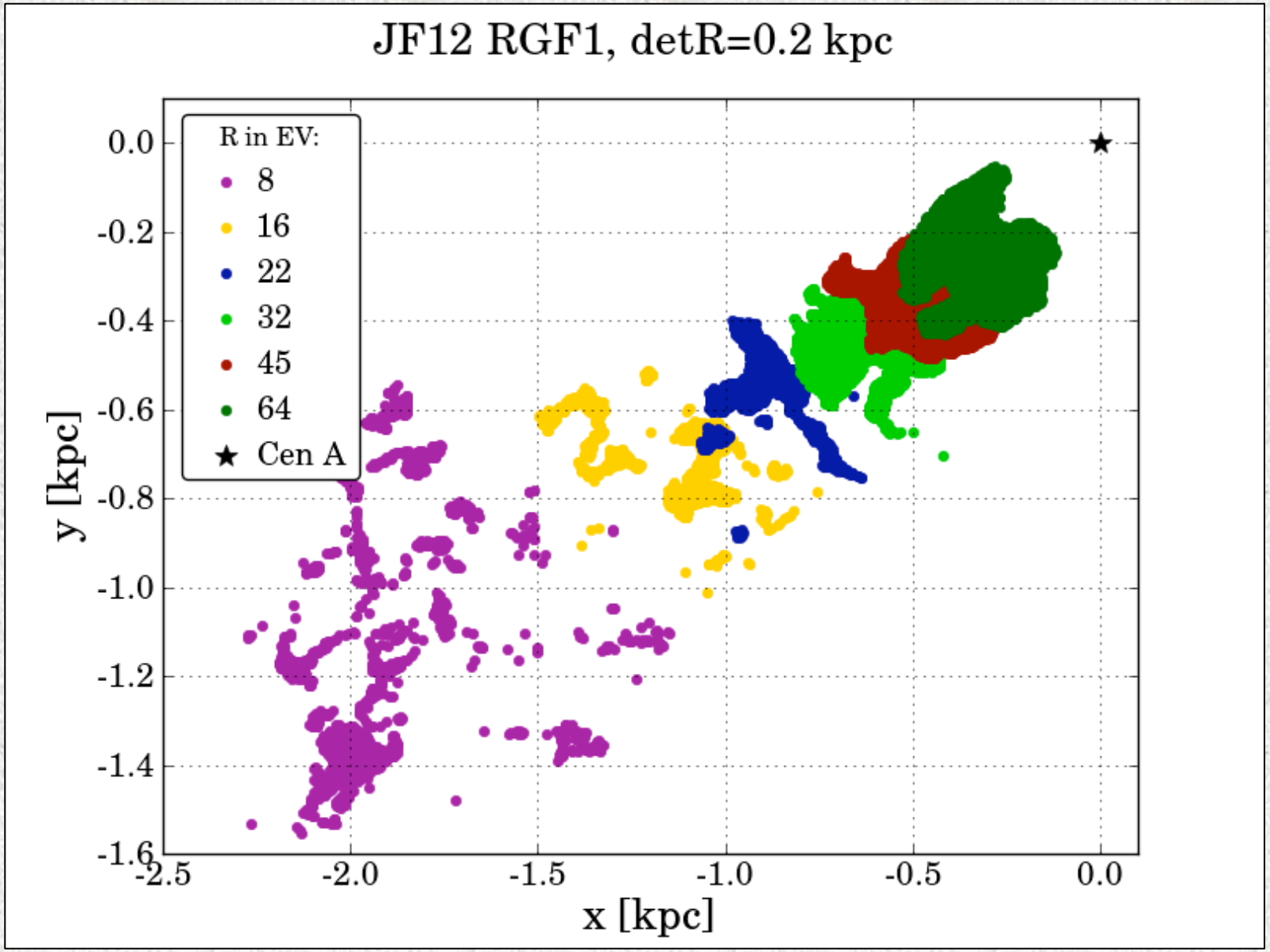
There is almost 0 detection at a small detector size, starting from a disk around CenA with radius of 2 kpc

Our method is a lot more efficient



# Particles from Cen A, 8<R<64

## Injection Plane



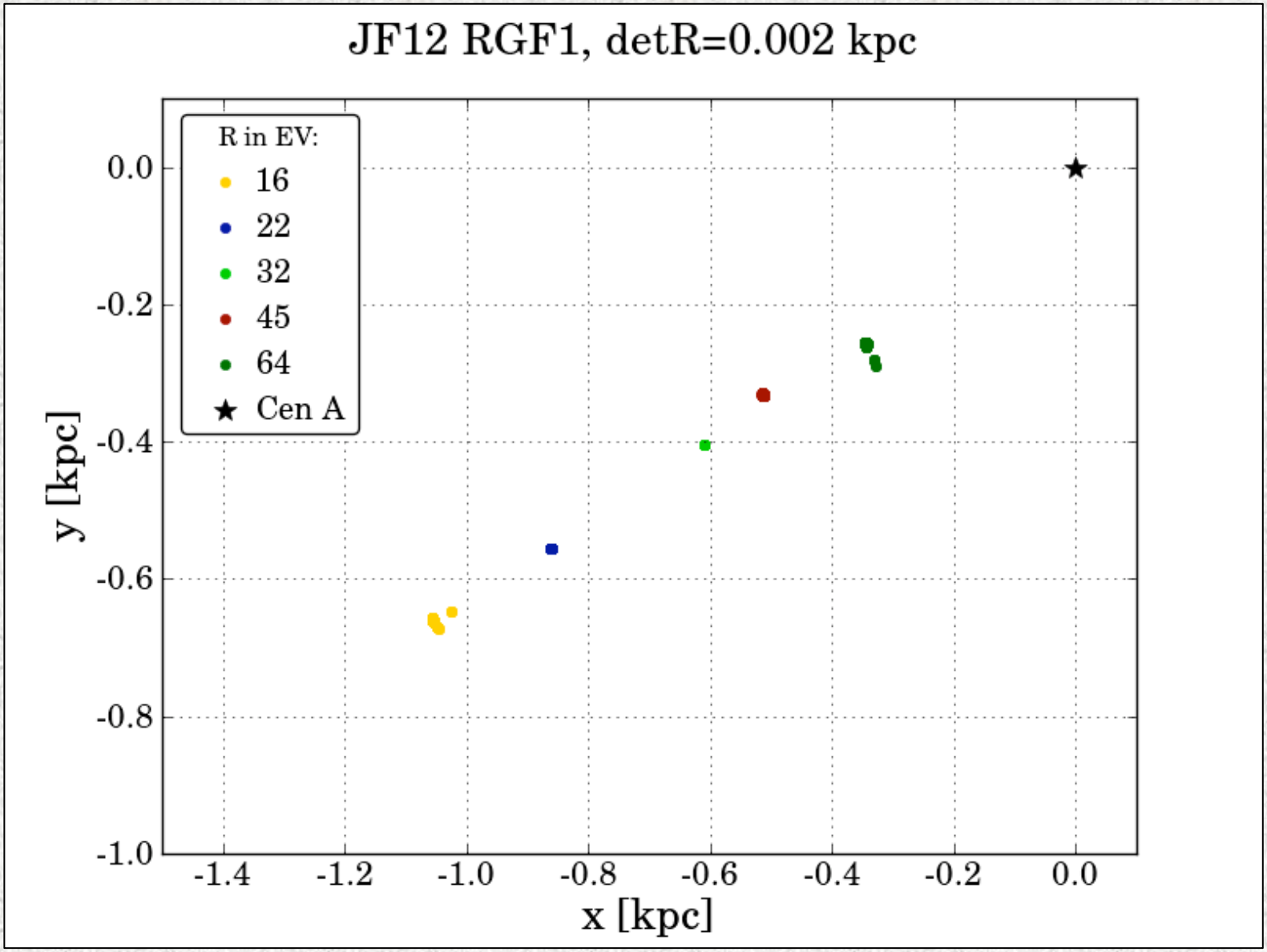

Different rigidities

A fairly large detR

Lower rigidities scatter more

# Particles from Cen A, 16<R<64

## Injection Plane



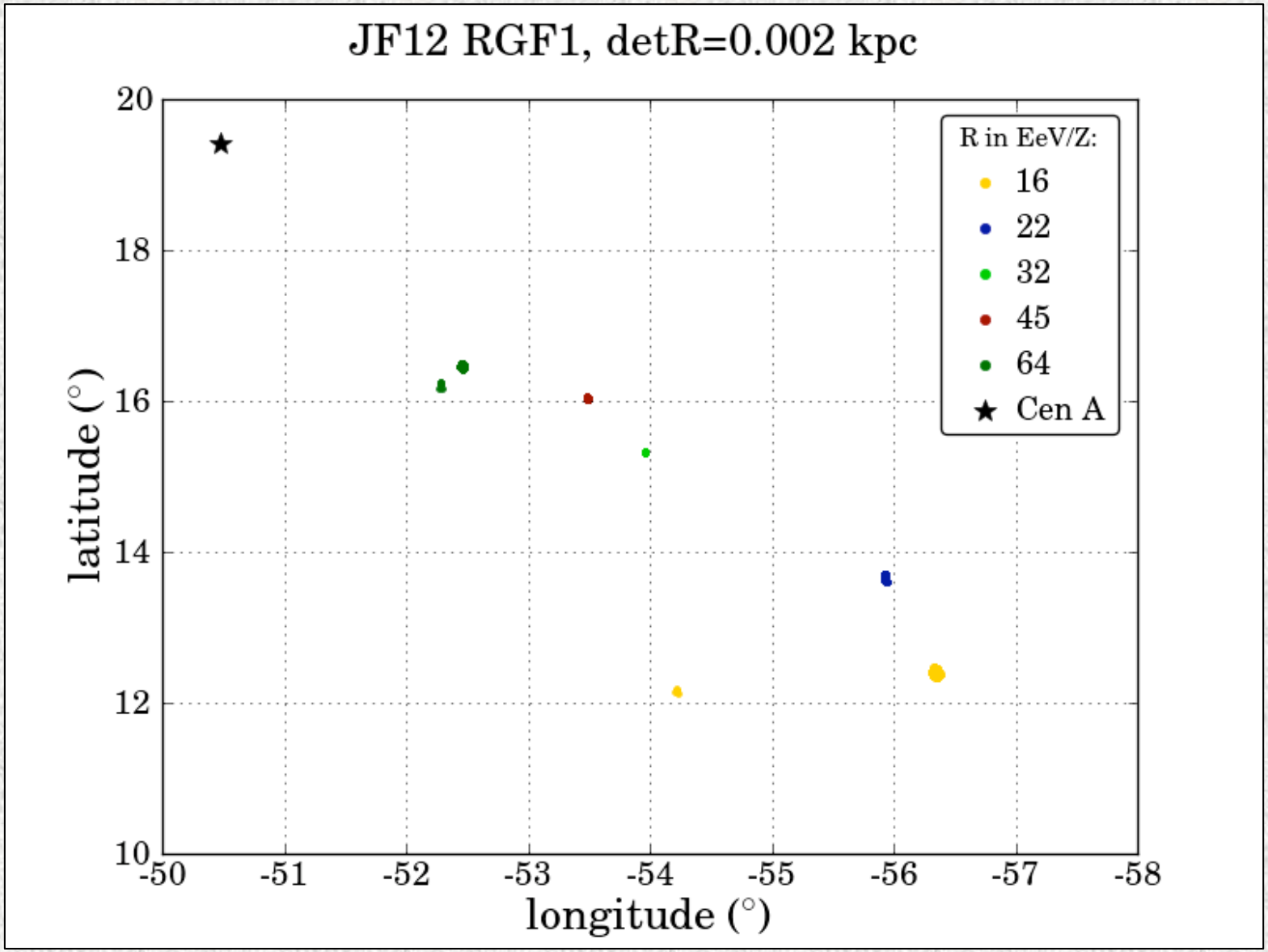

The smallest detR,

Compact regions,

Events lined up

# Particles from Cen A, 16<R<64

## Observed Directions




The smallest detR,

Compact regions,

Events lined up

# Simulated Events and Auger Data

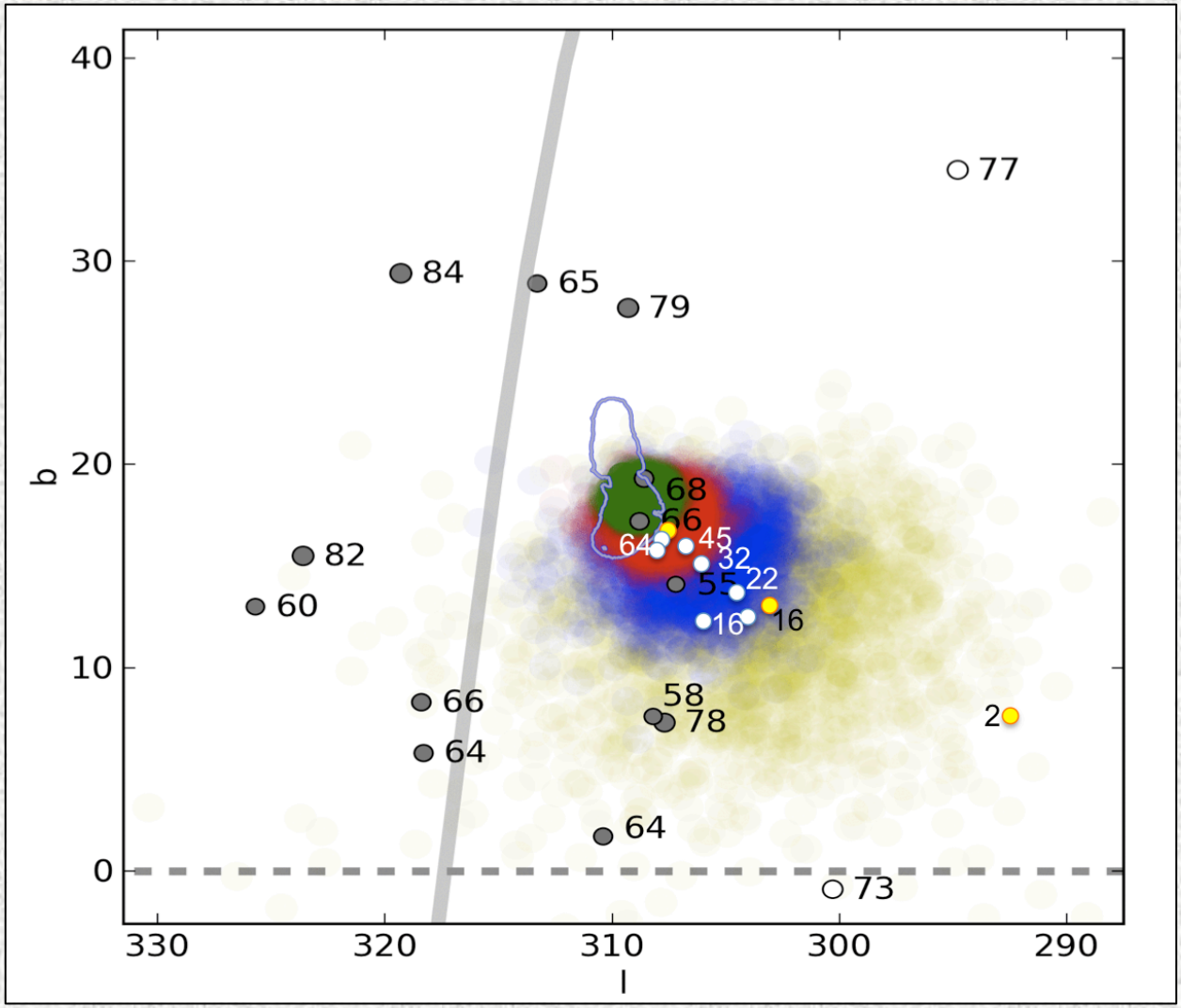
## Observed Directions

Added events on the original plot by Jansson and Farrar

Arcs of the simulated data are thin, Consistent with 6 events in data

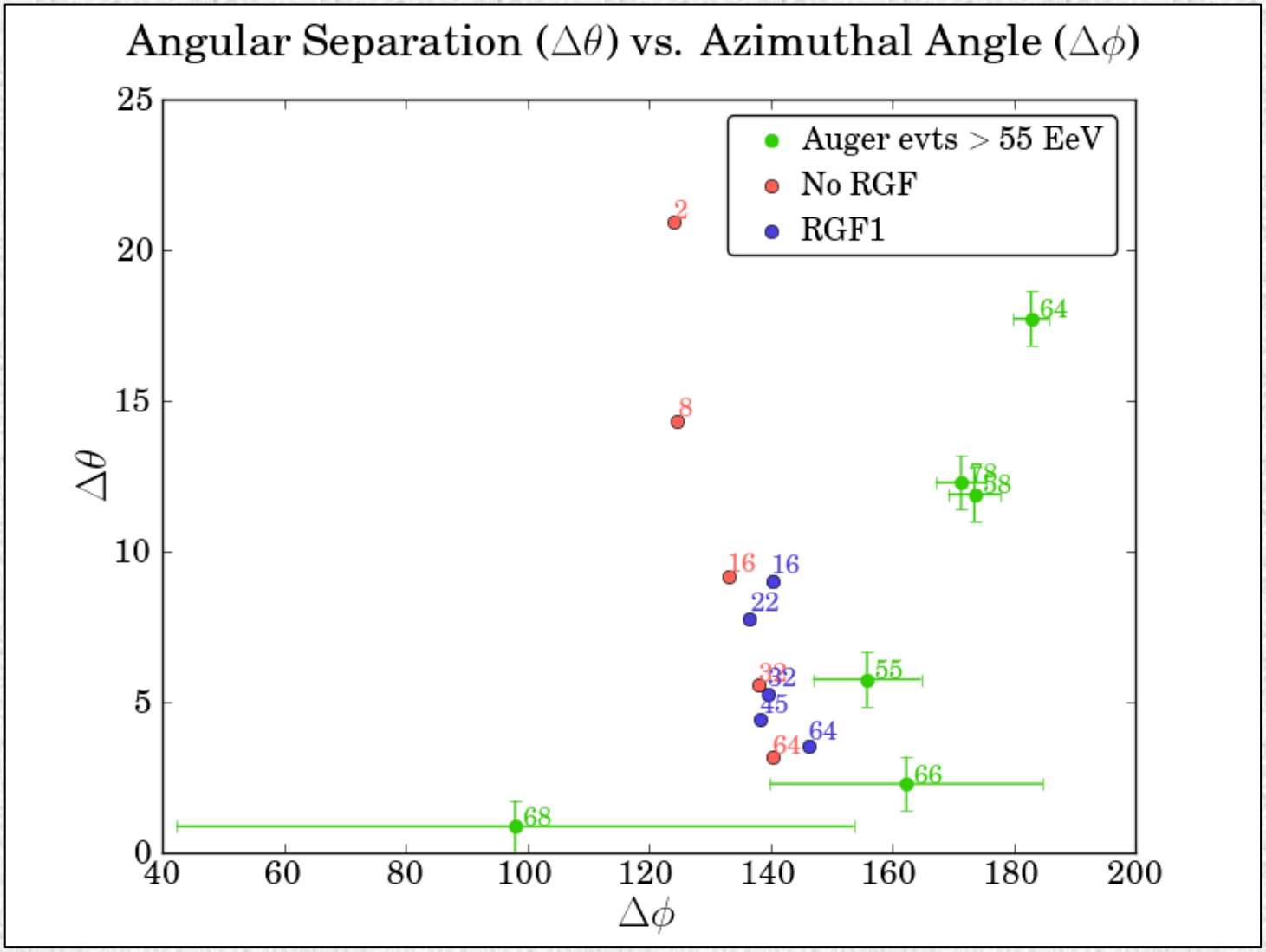
Signs of multiplets

Yellow circles: Coherent field
White circles: + Random field
Grey circles: Auger data



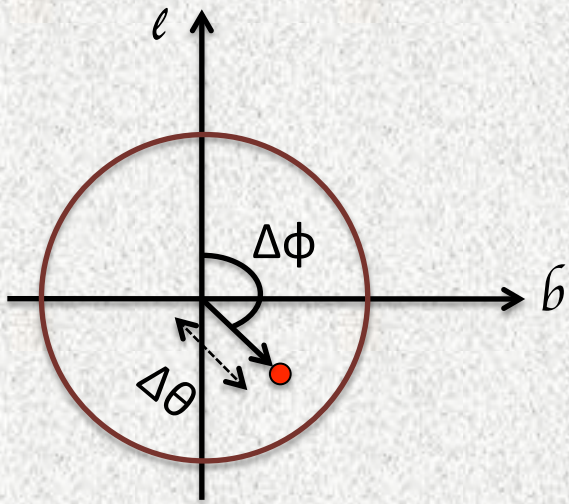
# Simulated Events and Auger Data

## Observed Directions relative to Cen A




An arbitrary coordinate centered on Cen A: showing relative locations of the events

Auger events could follow the simulations certain assigned charges




Events with E=58, 78, 64 EeV may be consistent with Cen A: Assign higher charge or in different realization of the RGF

# Summary: Preliminary Results

- We see the convergence when we get to smaller detectors
- No matter what the composition is, the region is more compact than anticipated
- It seems CenA in unlikely to be the source of more than a few cosmic rays above 55 EeV, assuming the correctness of JF12 GMF model

What we can do next:

Increasing the number of realizations of random field
Checking other similar sources
Going lower in the energy
Including the extragalactic field model

*Thanks for your attention*