

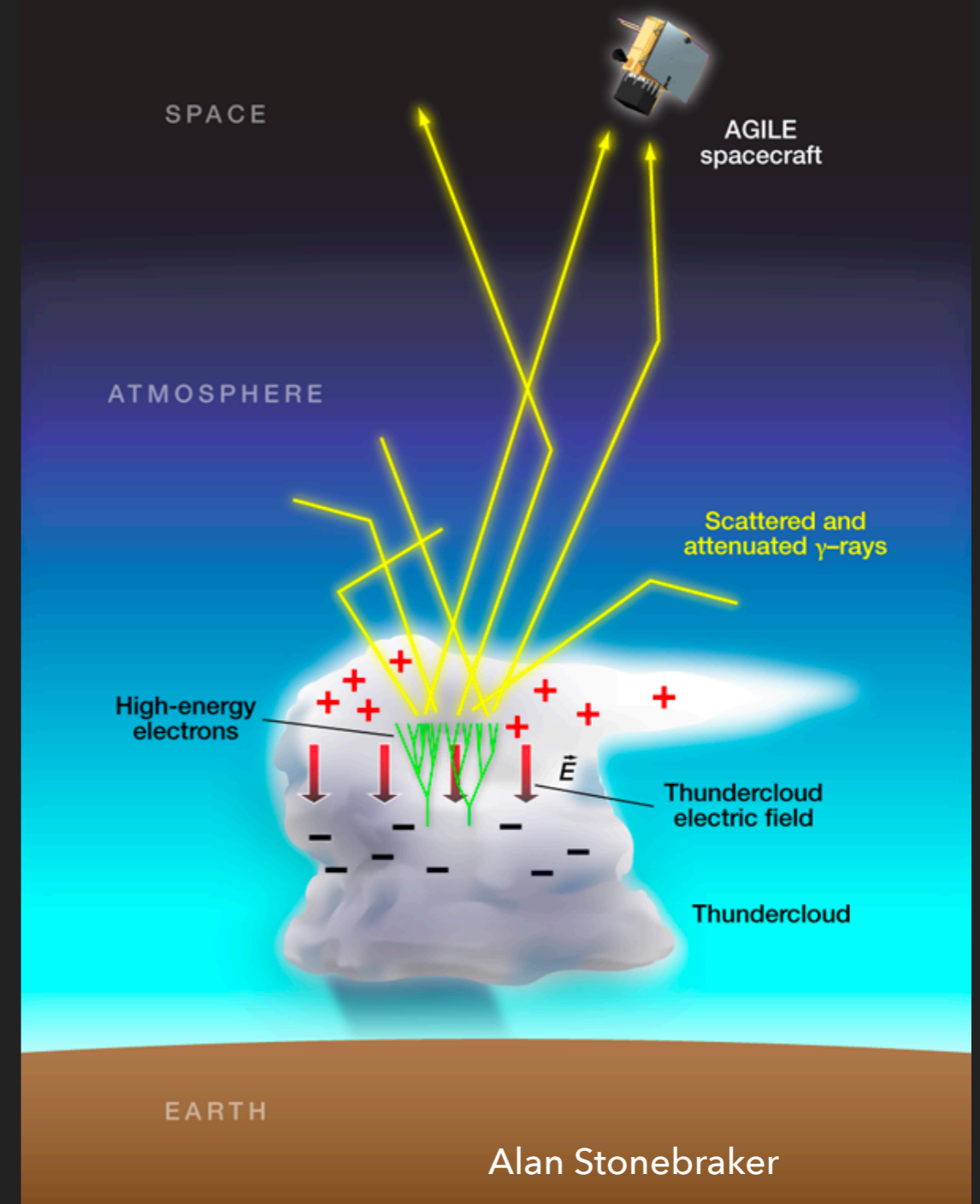
# A TGF WITH AZIMUTHAL ASYMMETRY AT THE PIERRE AUGER OBSERVATORY

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John Ortberg, Roberta Colalillo, David Smith,  
Joseph Dwyer

# DEFINITION AND MOTIVATION

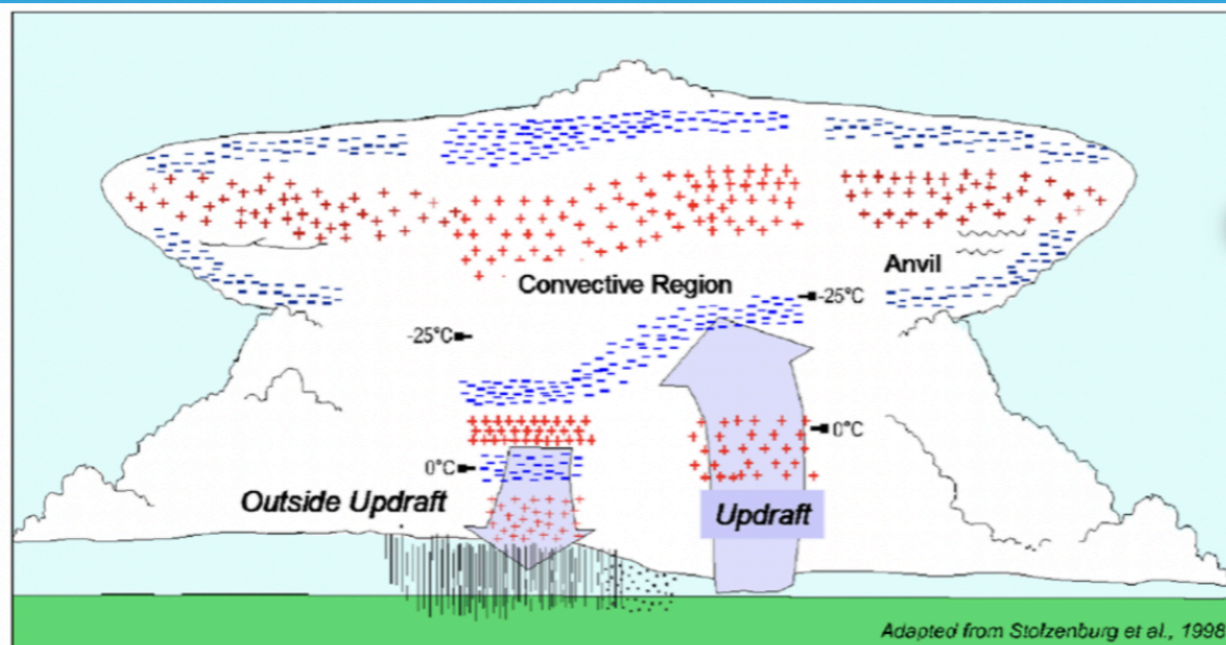
- ▶  $\sim 10^{17}$  gamma rays above 1 MeV
- ▶ 10-1000  $\mu\text{s}$  duration
- ▶ Estimates of frequency  $\sim 0.01\%$  to  $1\%$  of flashes
- ▶ Predicted in 1929, eluded detection until 1994



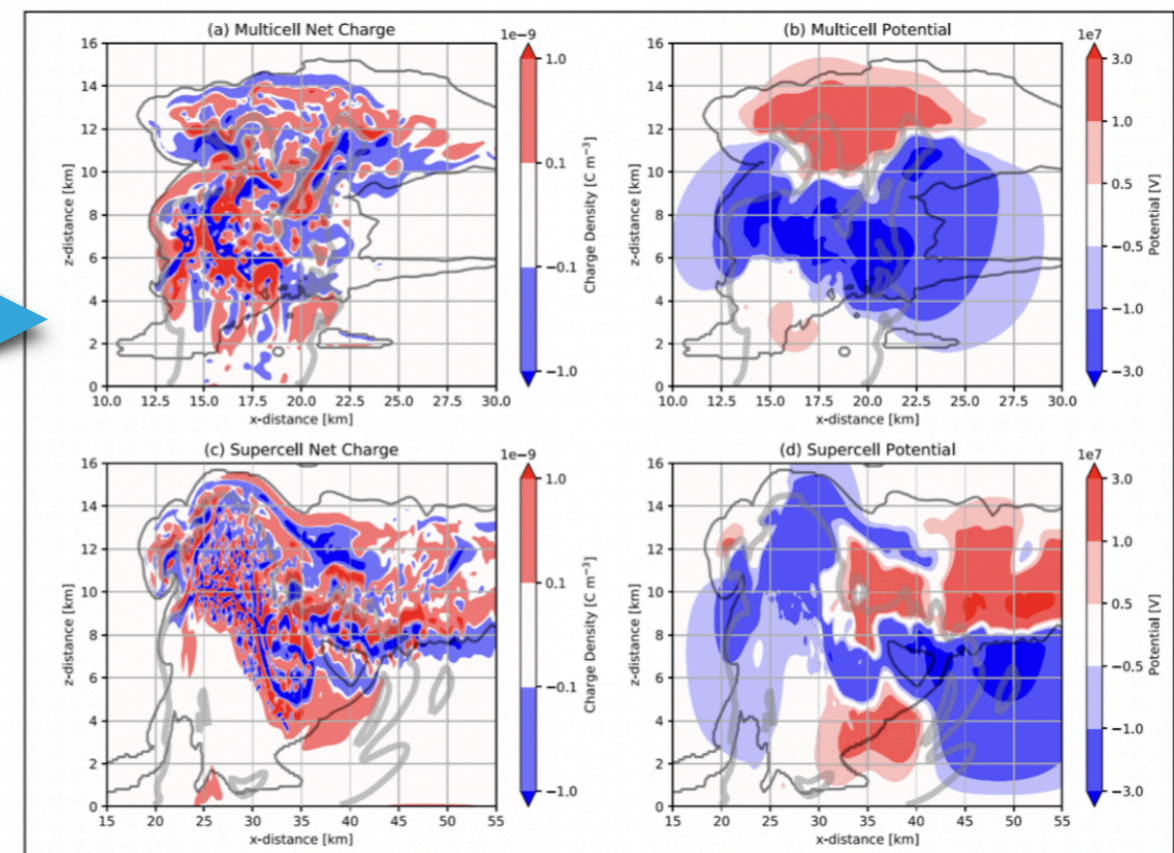
# DEFINITION AND MOTIVATION

- ▶ The charge structure and potentials inside thunderclouds has proven to be increasingly complex
- ▶ There are several competing theories for the mechanism of TGFs

STOLZENBURG 1998

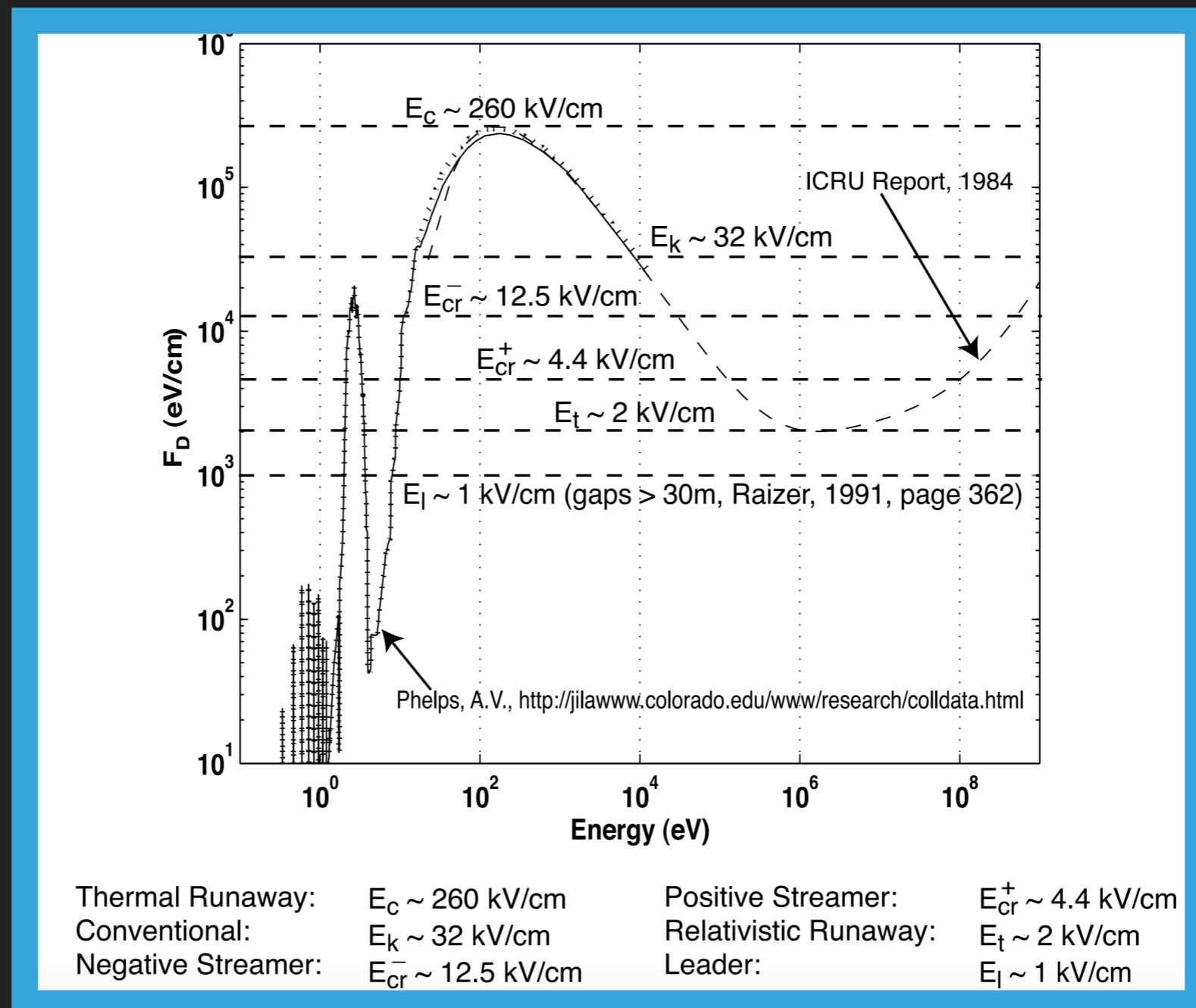


BROTHERS 2018



# DEFINITION AND MOTIVATION

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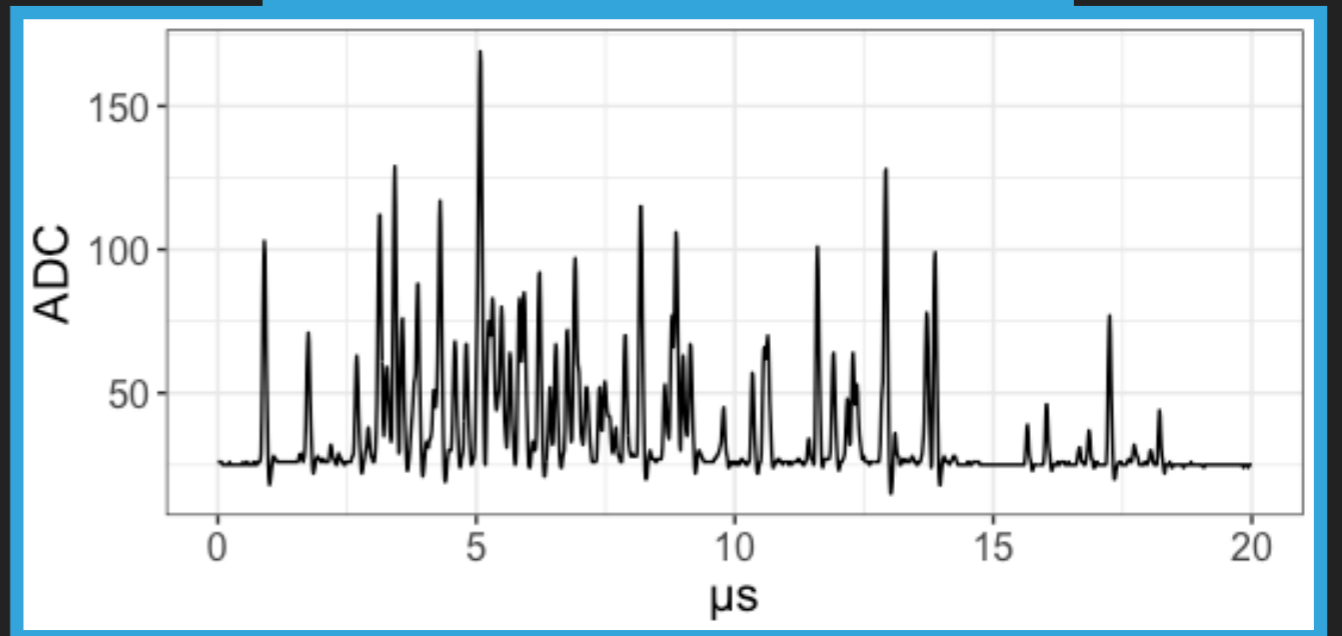


# WHAT'S SPECIAL ABOUT AUGER?

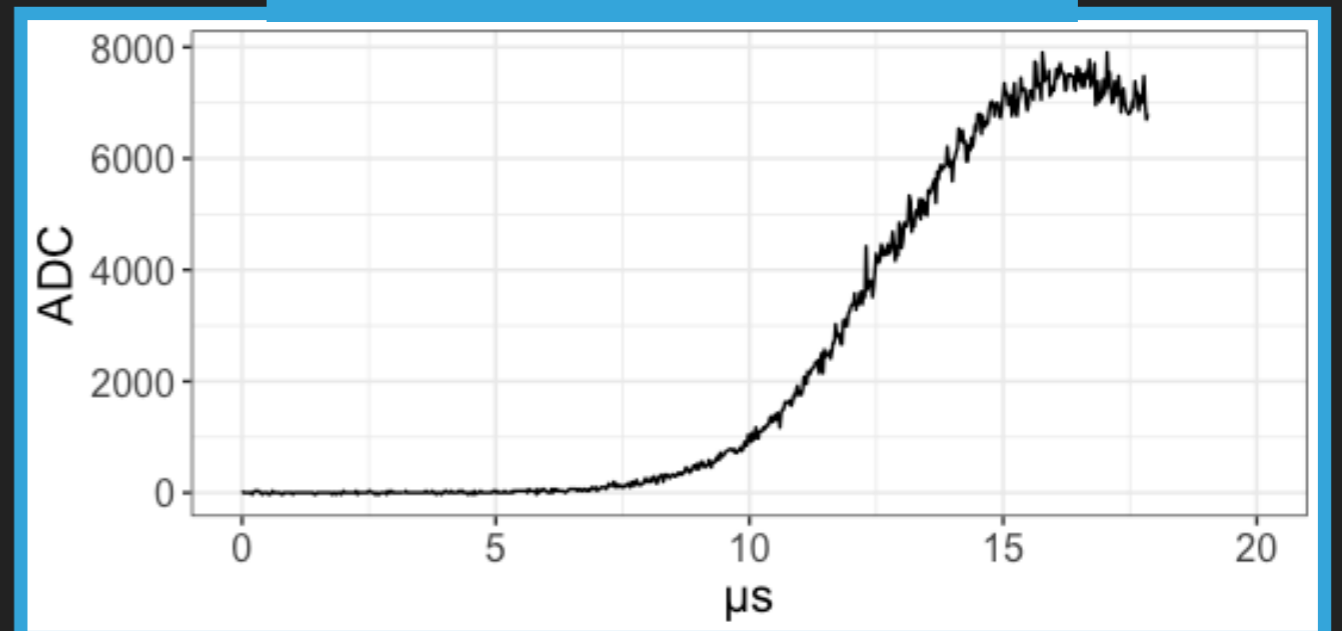
## Time Resolution

- ▶  $10^6$  cm<sup>3</sup> Cherenkov tanks at Auger
- ▶  $10^2 - 10^3$  cm<sup>3</sup> scintillators on satellites/ground
- ▶ High dynamic range = smooth time profile

4000 CM<sup>3</sup> SCINTILLATOR



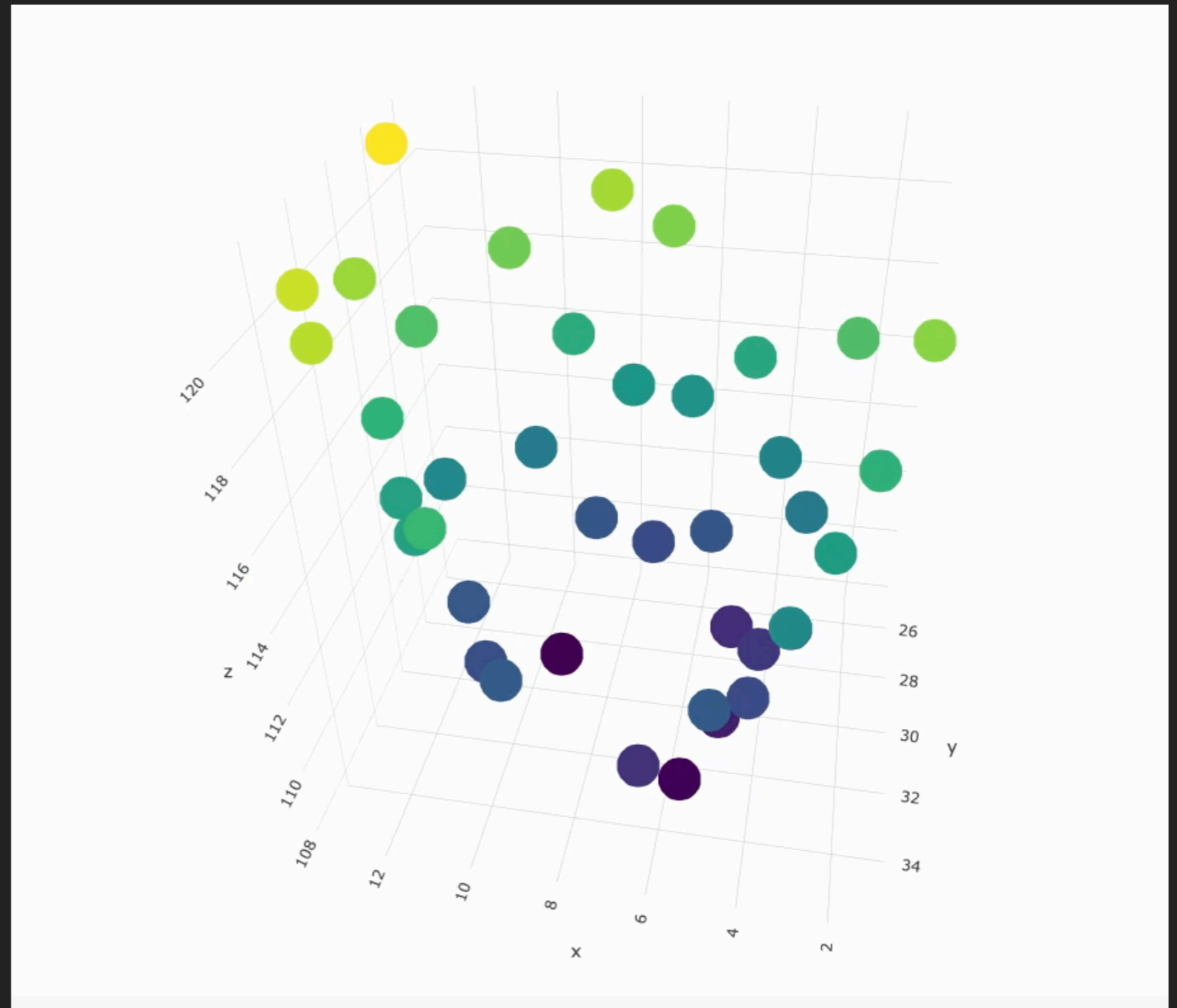
AUGER SD



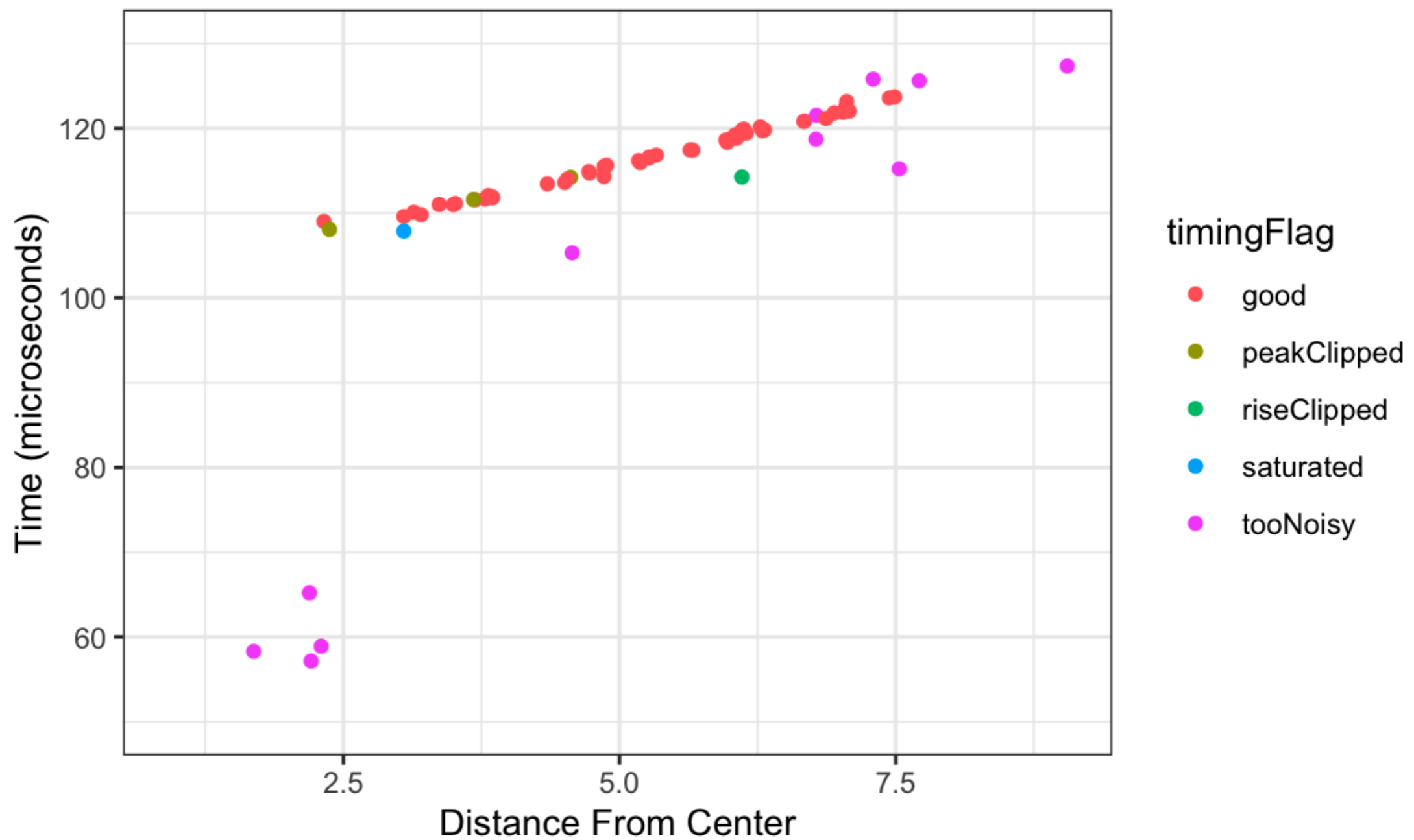
# WHAT'S SPECIAL ABOUT AUGER?

## Triangulation

- ▶ Auger allows direct triangulation of gamma ray source!
  - ▶ Previously only lightning channel
  - ▶ Similar method at TA, Utah (Remington 2023)

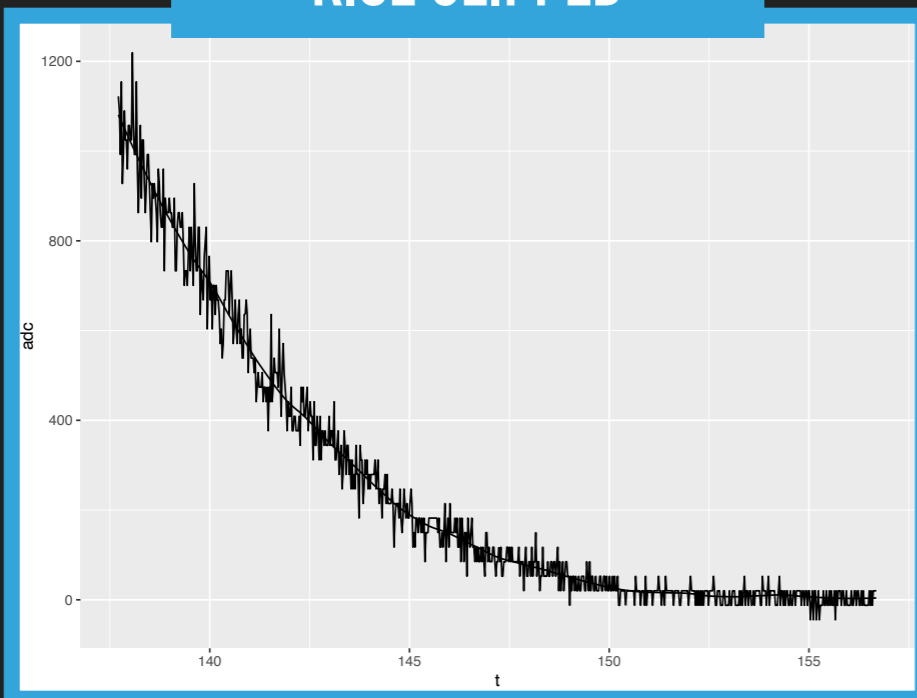


# WHAT'S SPECIAL ABOUT AUGER?

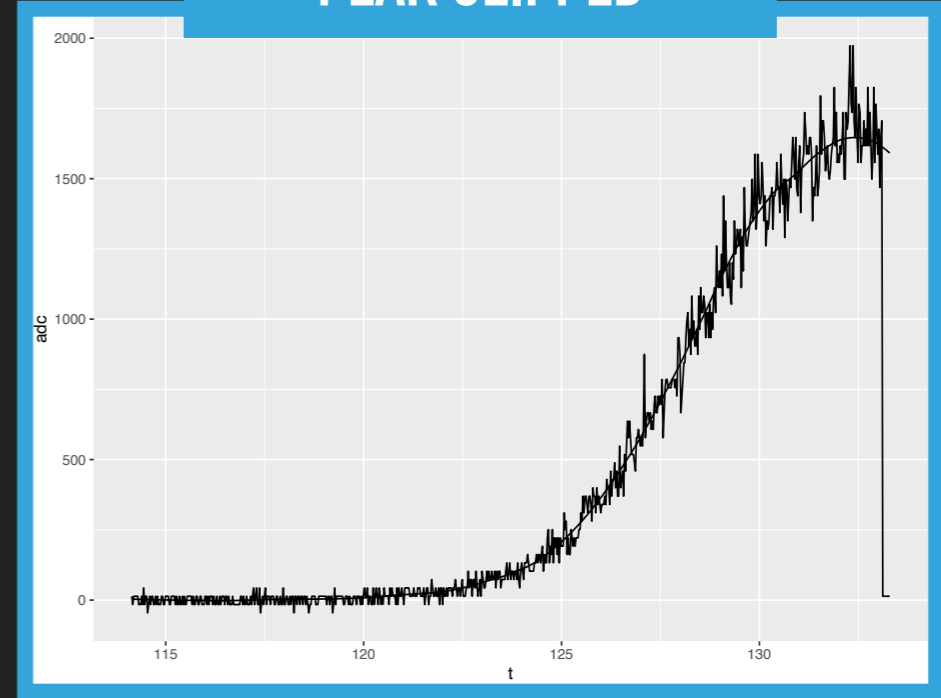


# WHAT'S SPECIAL ABOUT AUGER?

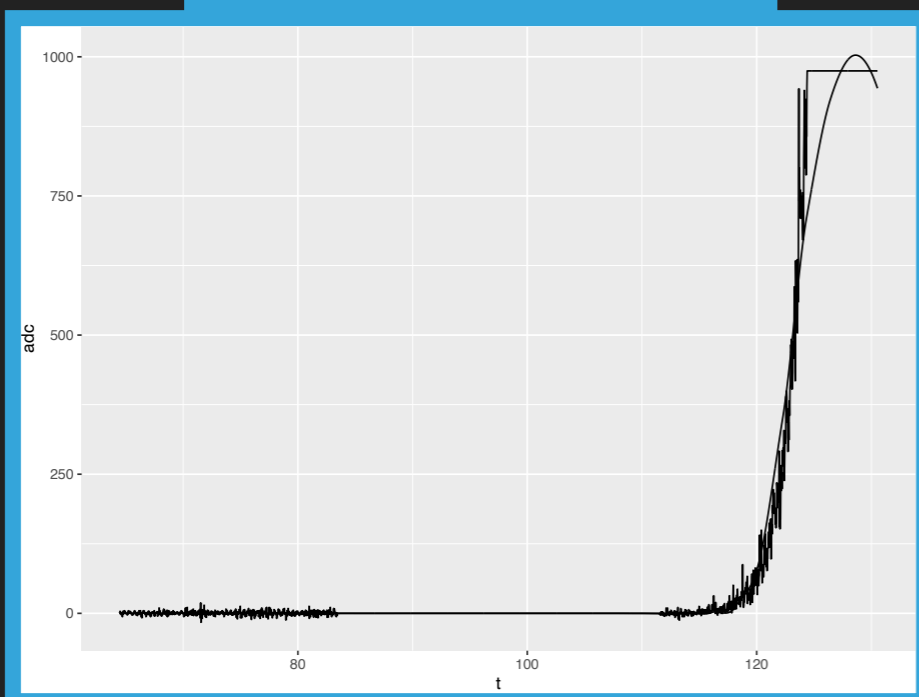
## RISE CLIPPED



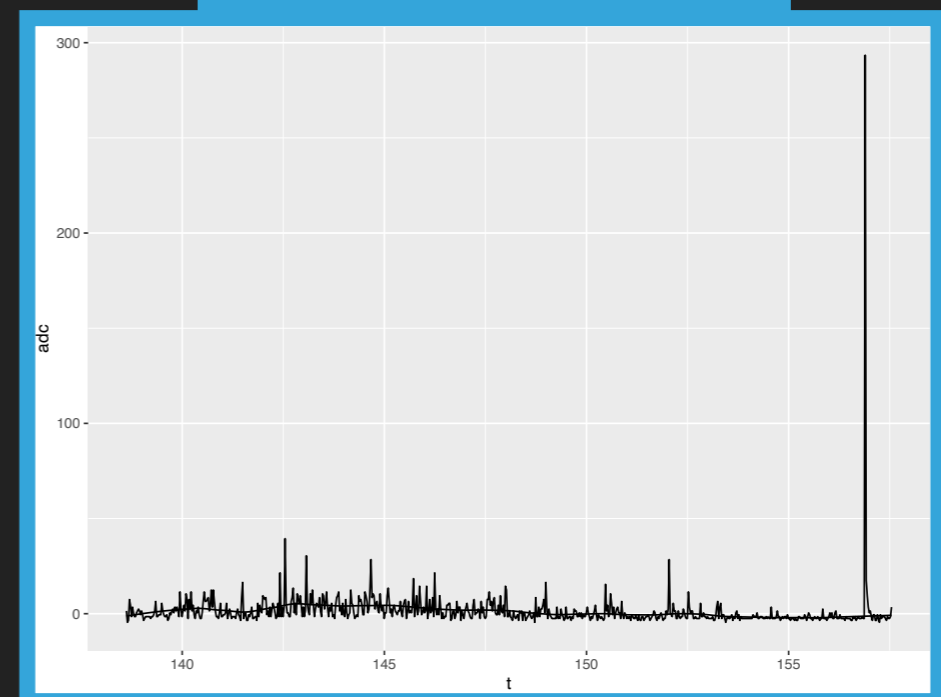
## PEAK CLIPPED



## SATURATED



## TOO NOISY

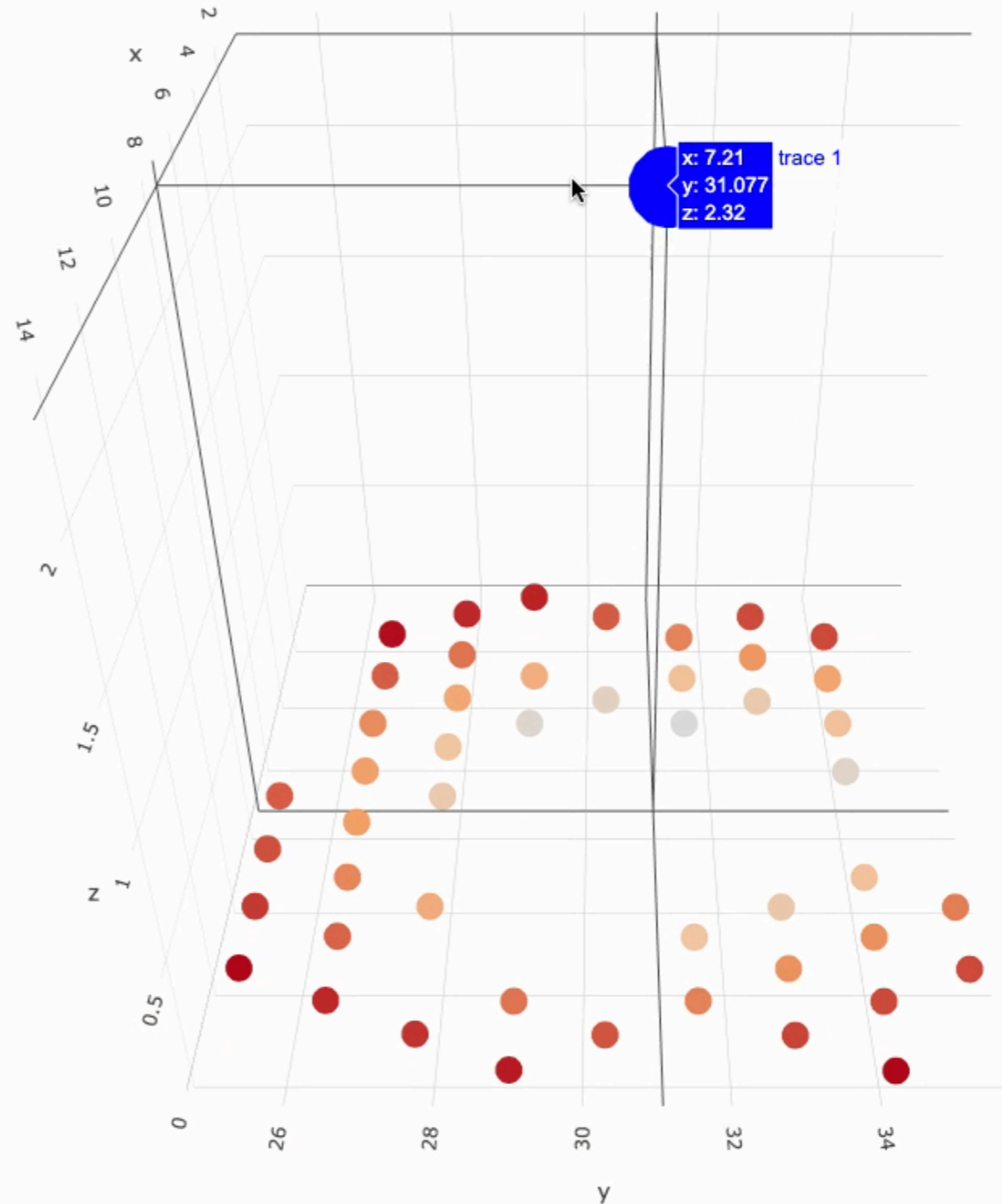




# WHAT'S SPECIAL ABOUT AUGER?

## TGF Source

- ▶ x-y: +/- 100m
- ▶ z: +/- 300m
- ▶ Finding the center allows analysis of:
  - ▶ Tilt/Asymmetry
  - ▶ Angular distribution



# WHAT'S SO SPECIAL ABOUT AUGER?

## History of Detections Since 1994

# of spatial data points

# of TGFs

1

~10,000

2

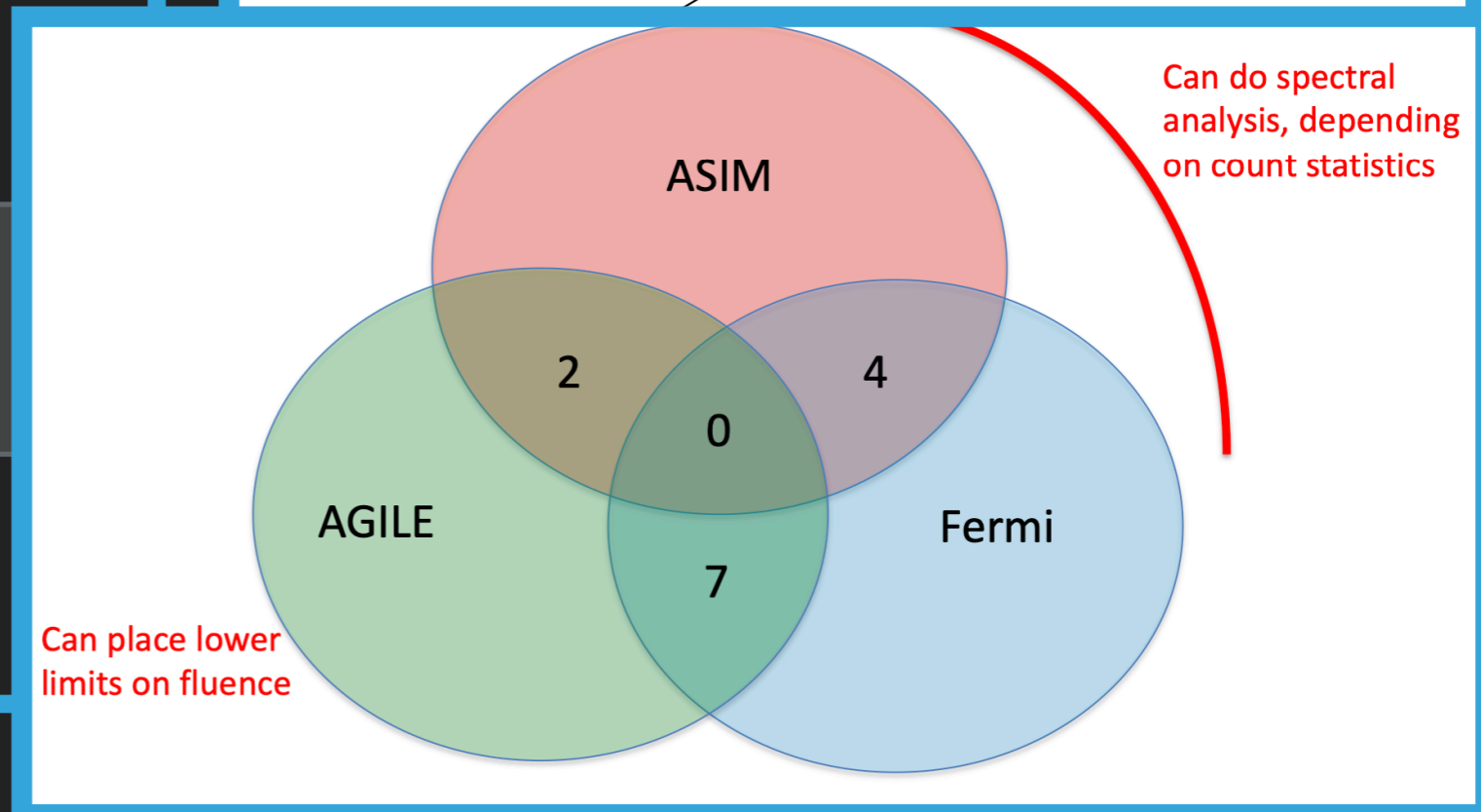
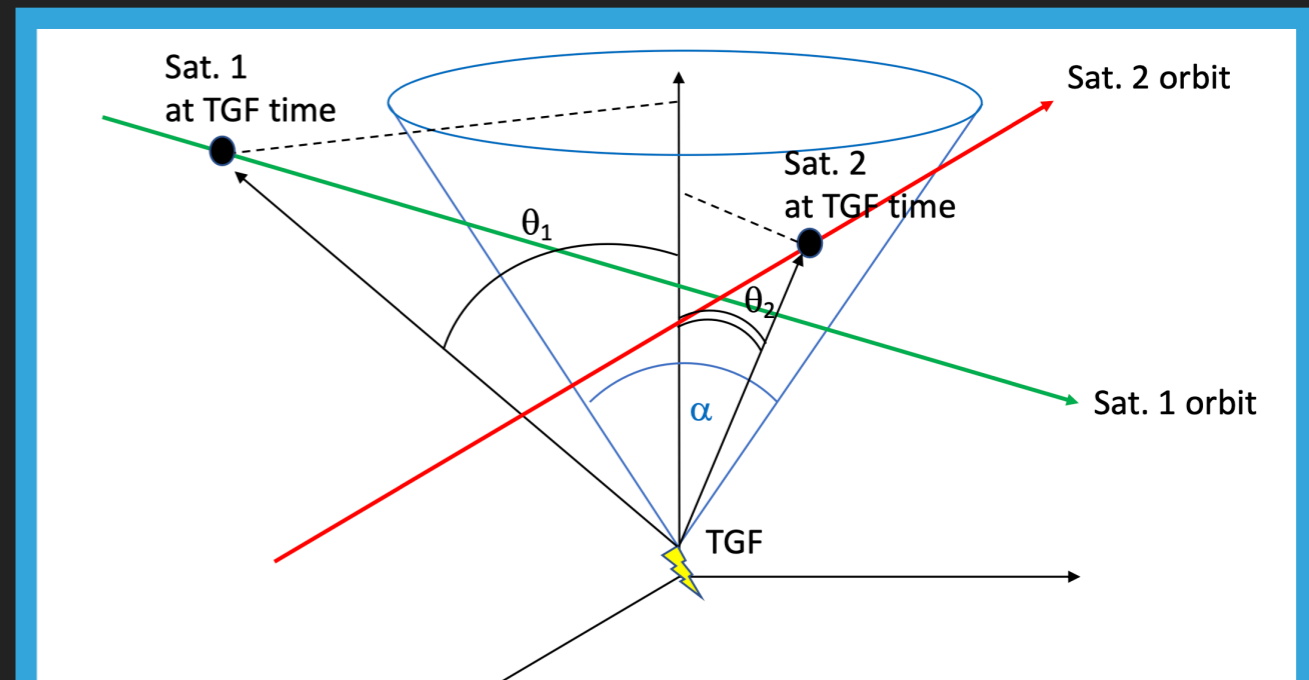
13

3

0

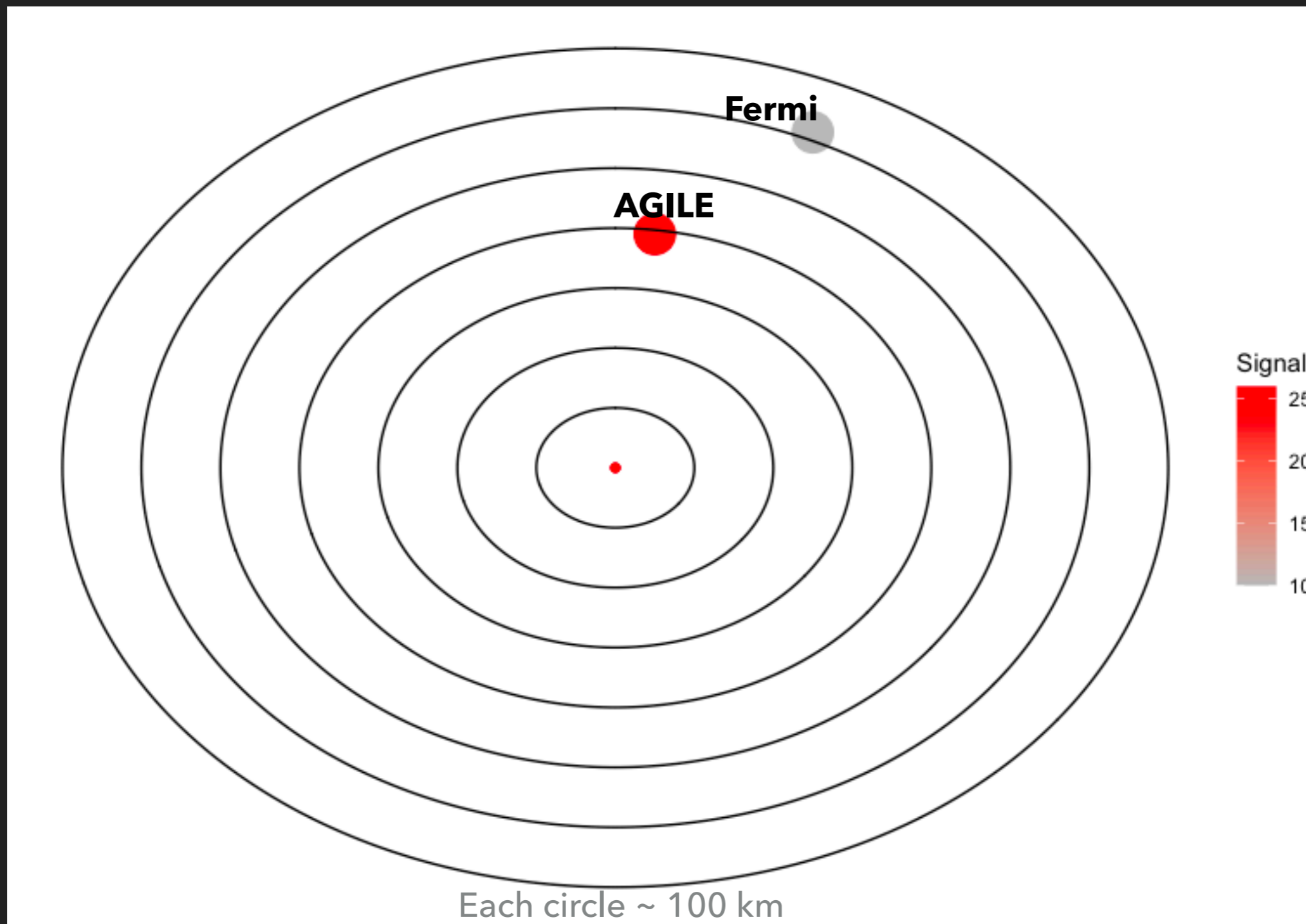
48

1



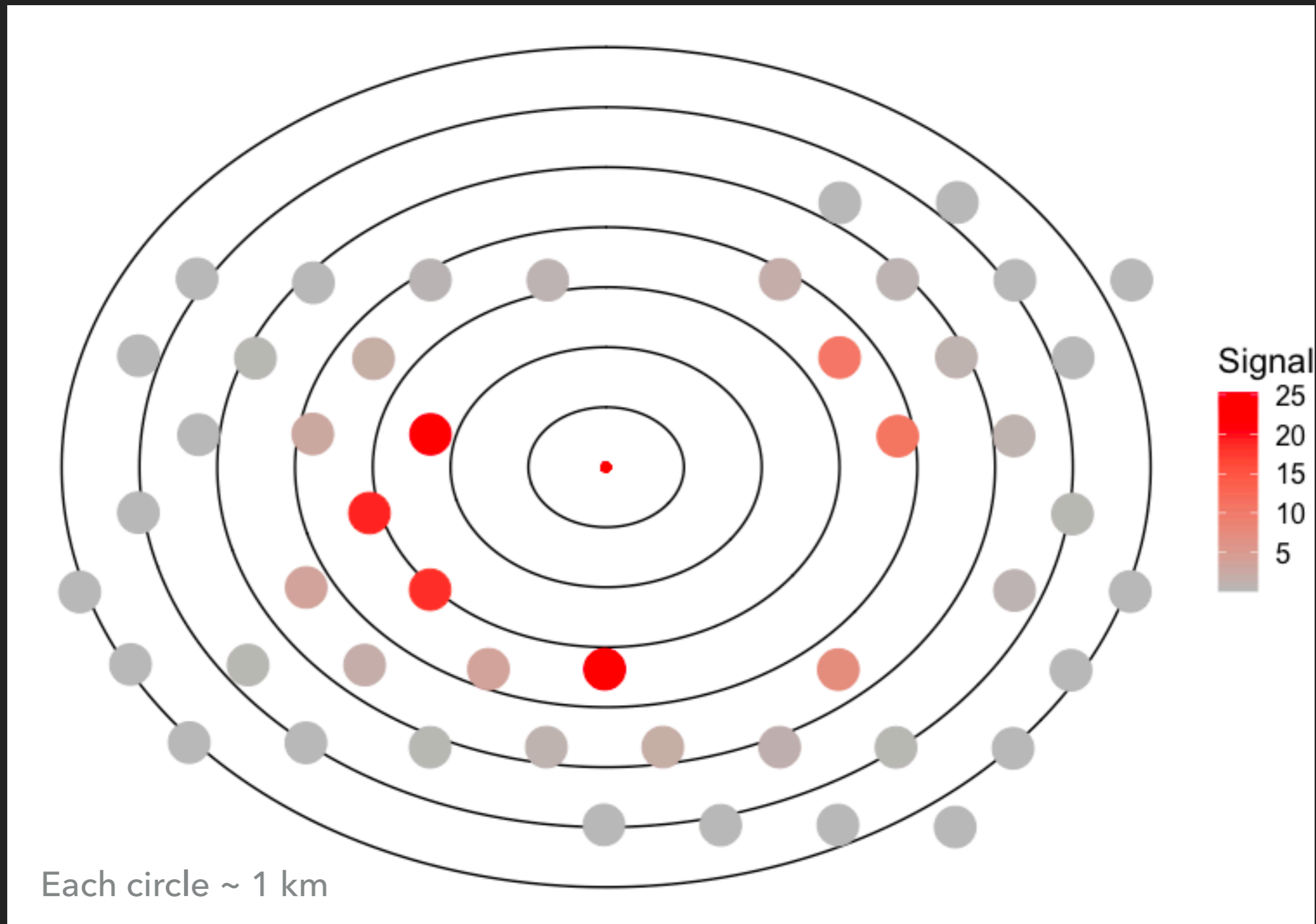
# WHAT'S SO SPECIAL ABOUT AUGER?

Greatest Spatial Resolution Prior to Auger



# WHAT'S SO SPECIAL ABOUT AUGER?

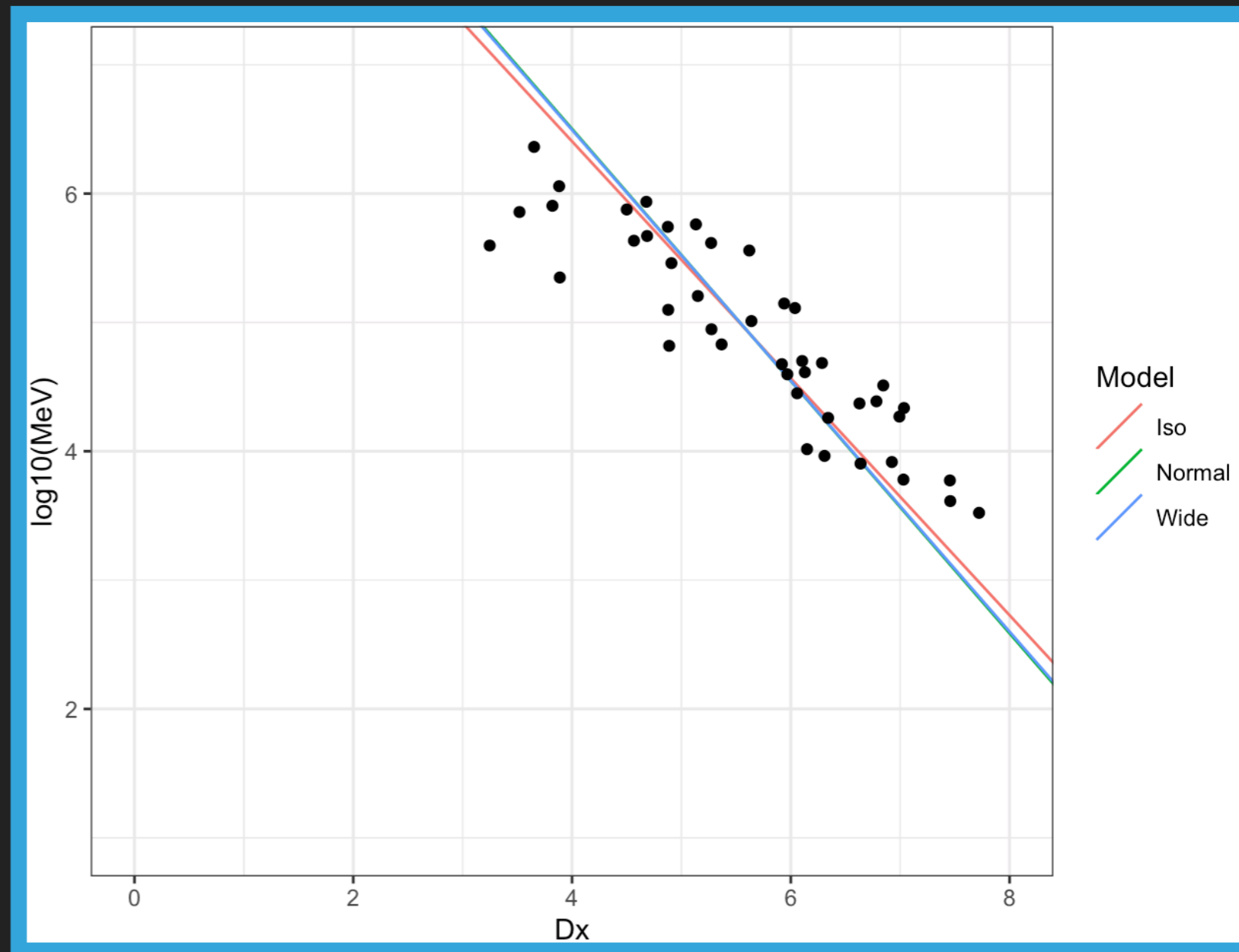
## Greatest Spatial Resolution at Auger



# TGF SOURCE PROPERTIES

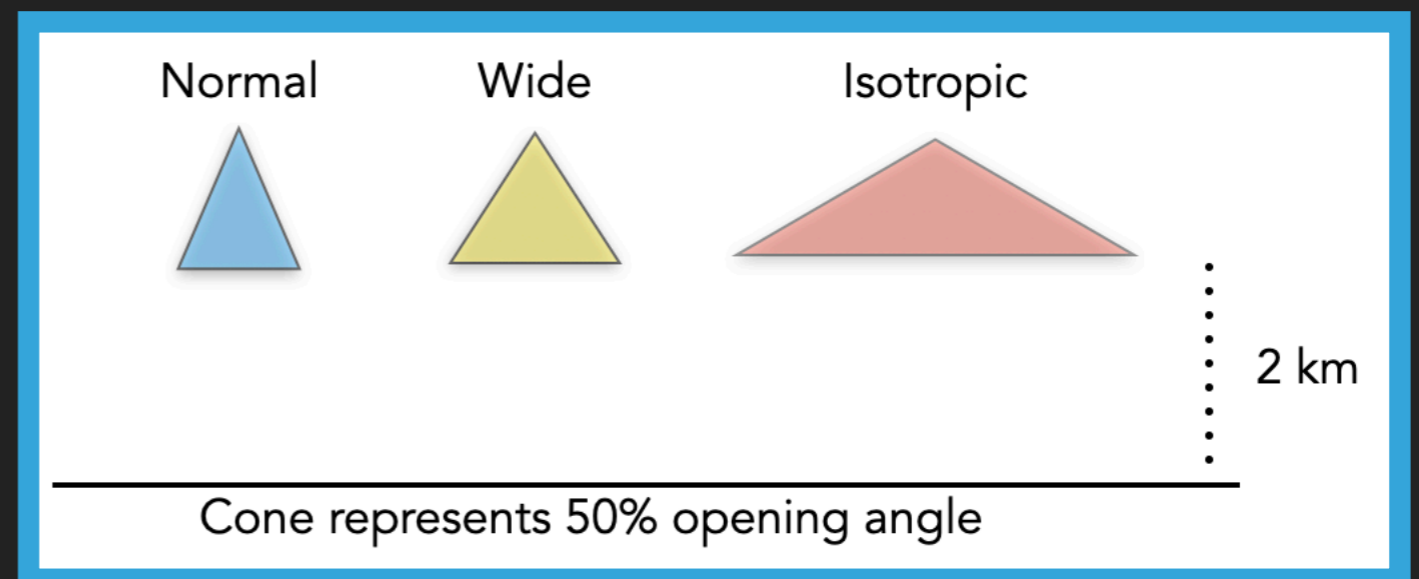
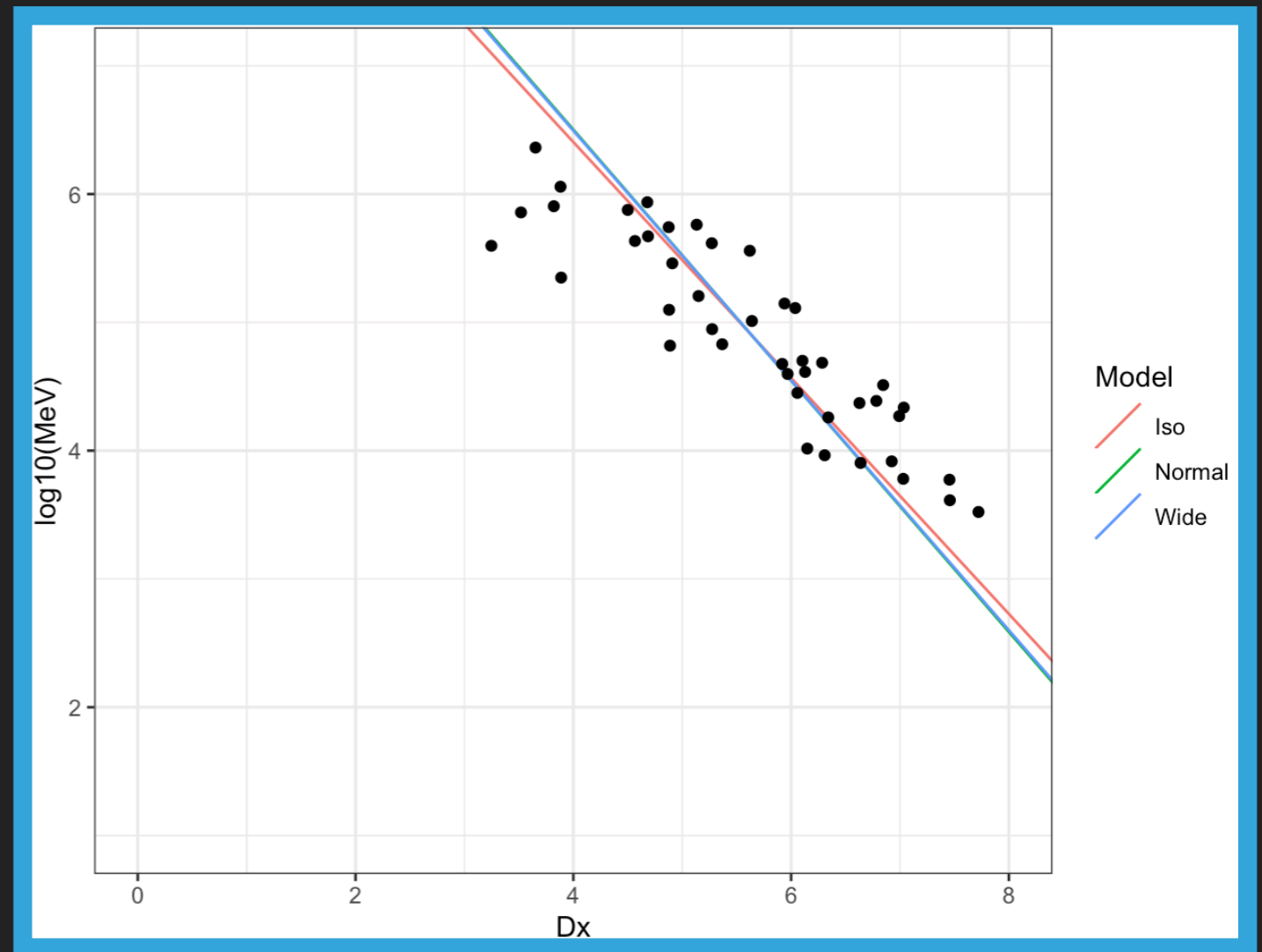
- Models from Dwyer 2012, simulated with Geant4

Beam Type	Best fit brightness $N_0$
Normal	$10^{18.7}$
Wide	$10^{18.2}$
Isotropic	$10^{17.4}$



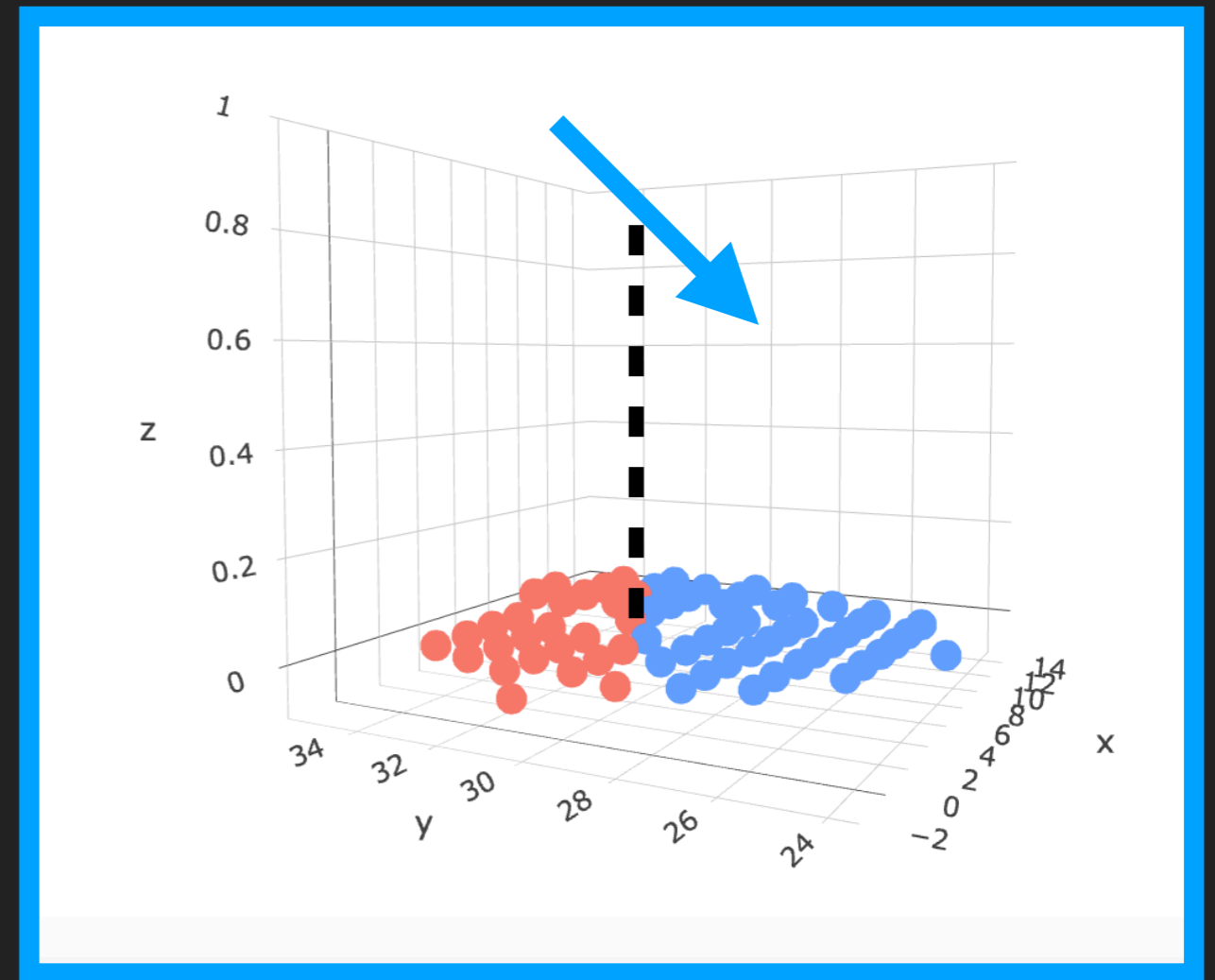
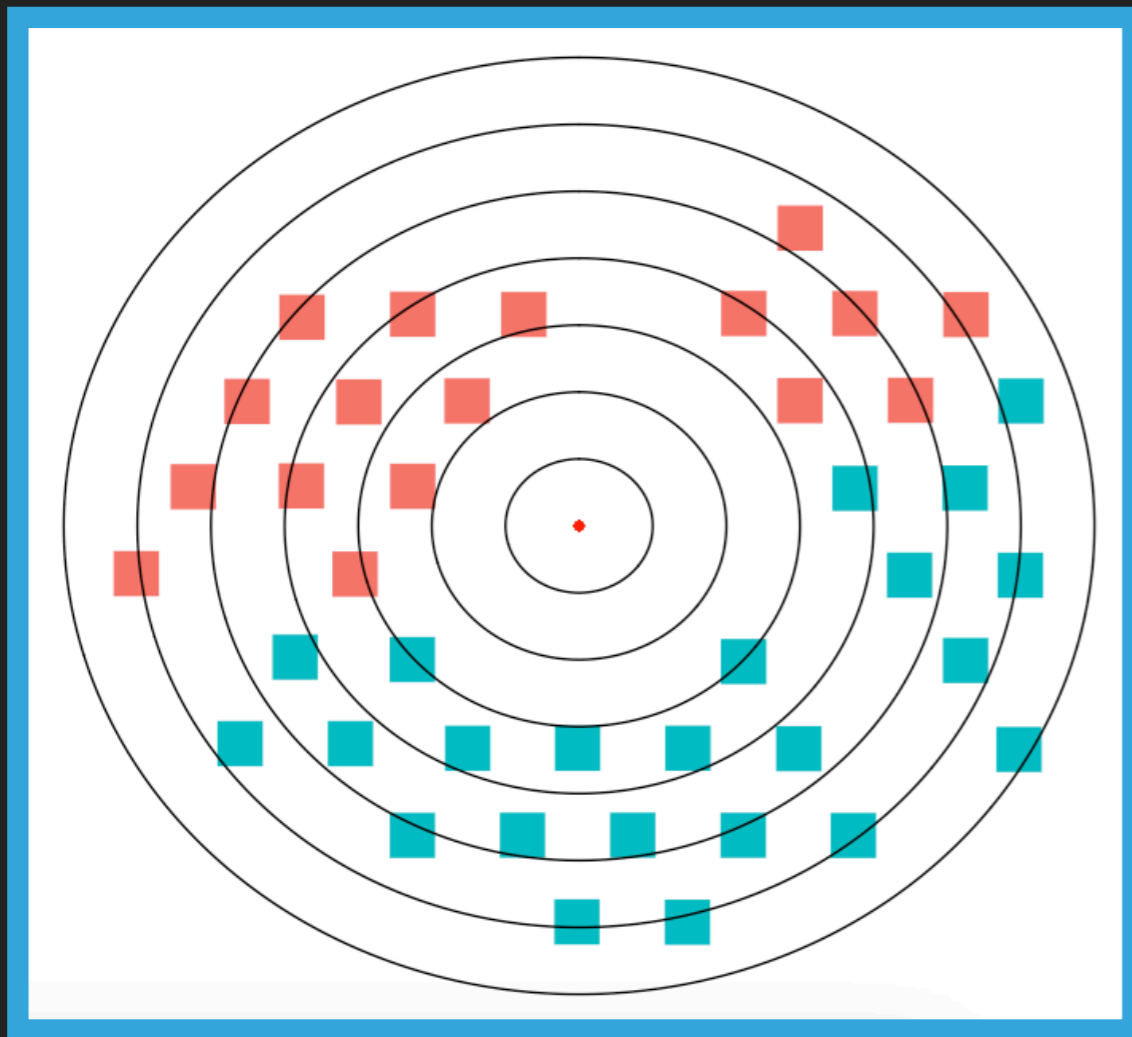
# TGF SOURCE PROPERTIES

- ▶ Brightness similar to TGFs seen from space
- ▶ Downward TGFs predict more decay with distance, regardless of beam width.



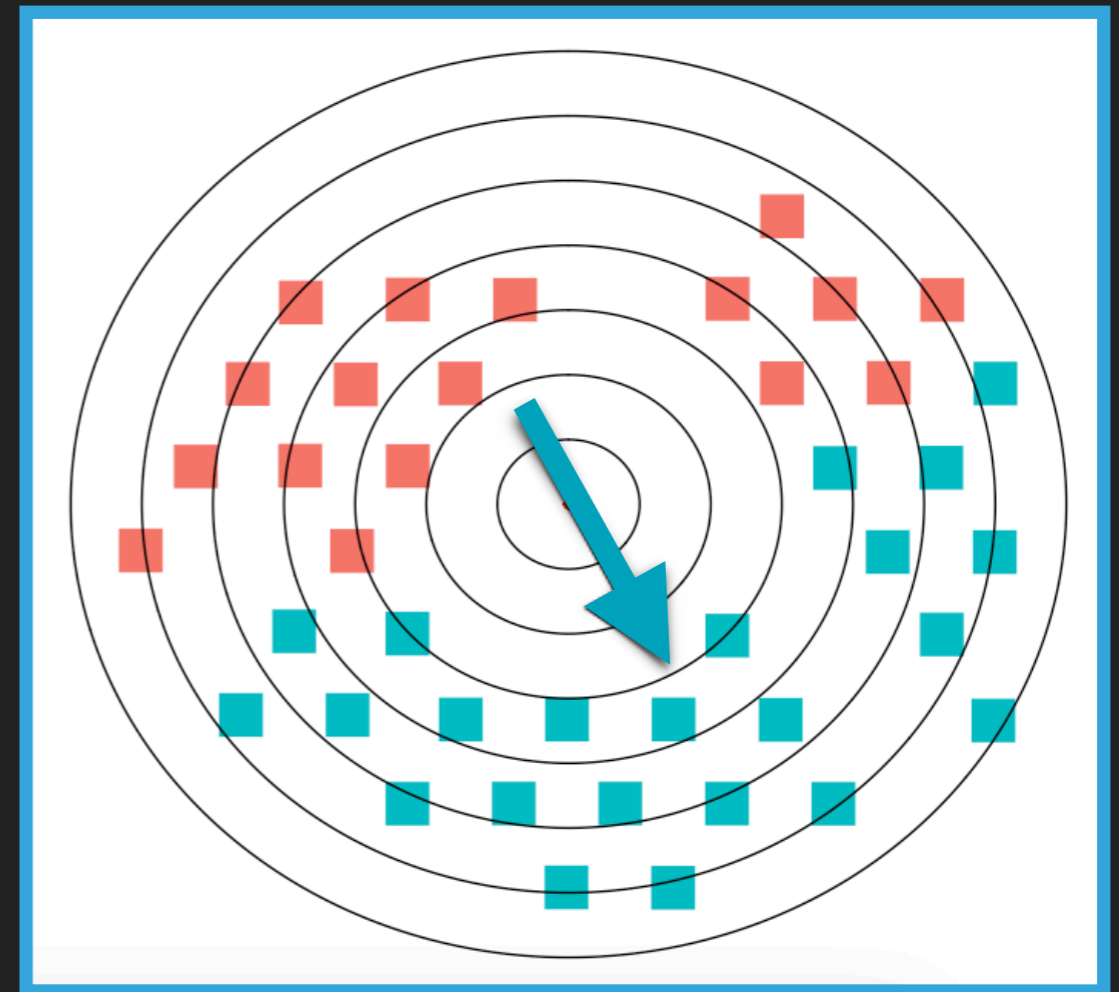
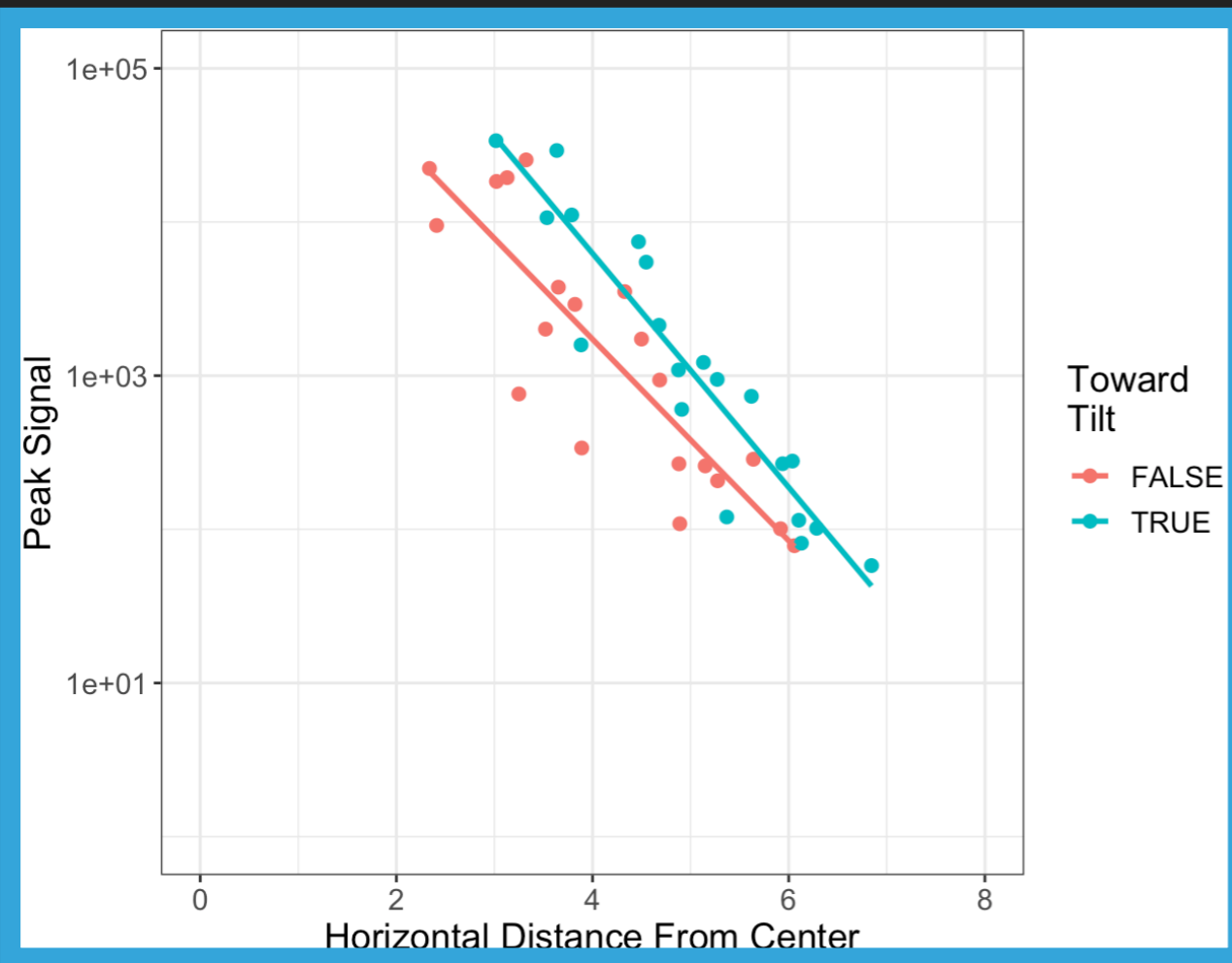
# TGF SOURCE PROPERTIES

Searching for Asymmetry: Is one side brighter than the other?



# TGF SOURCE PROPERTIES

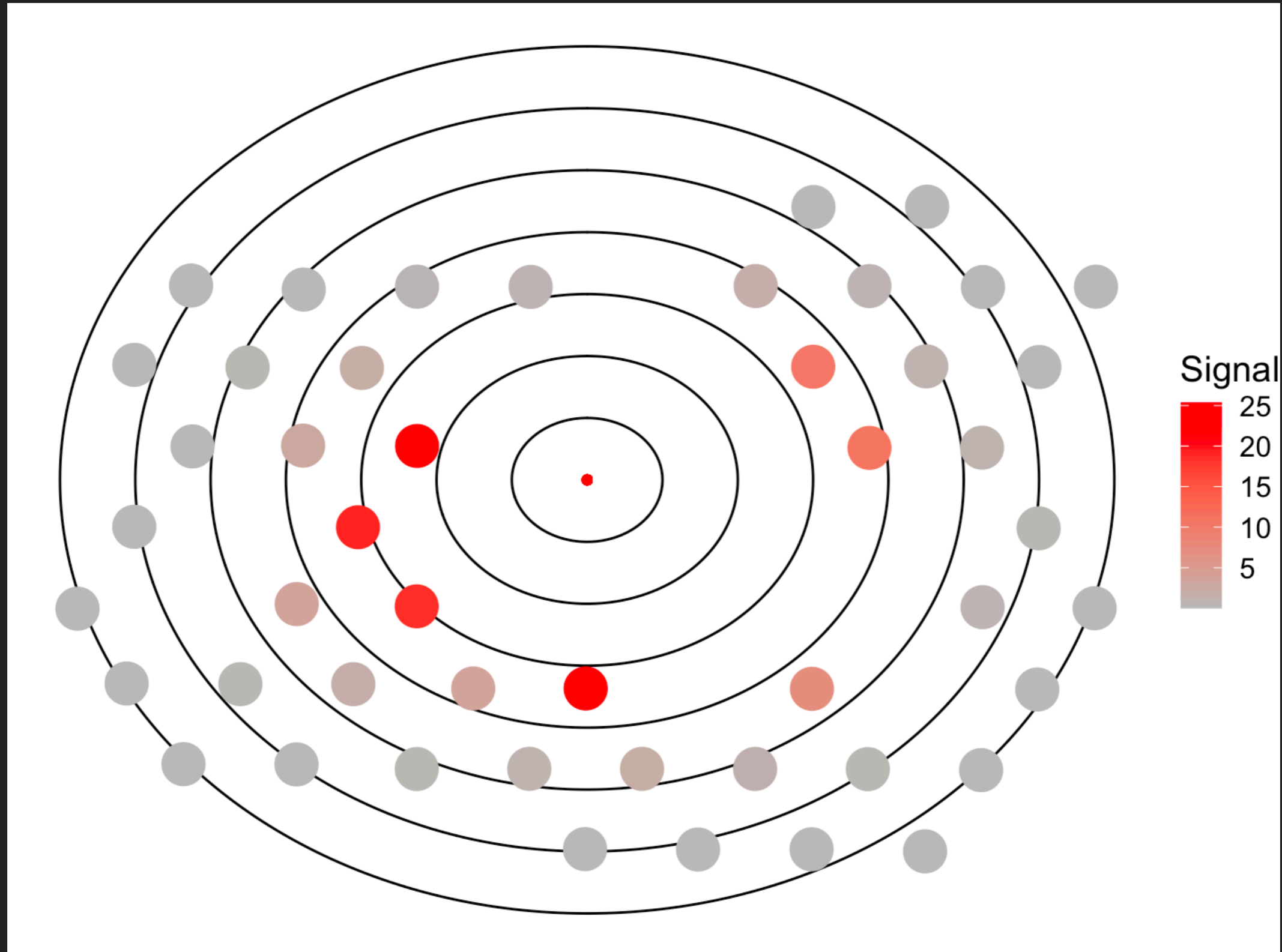
Clearest asymmetry when you assume a tilt toward the SE





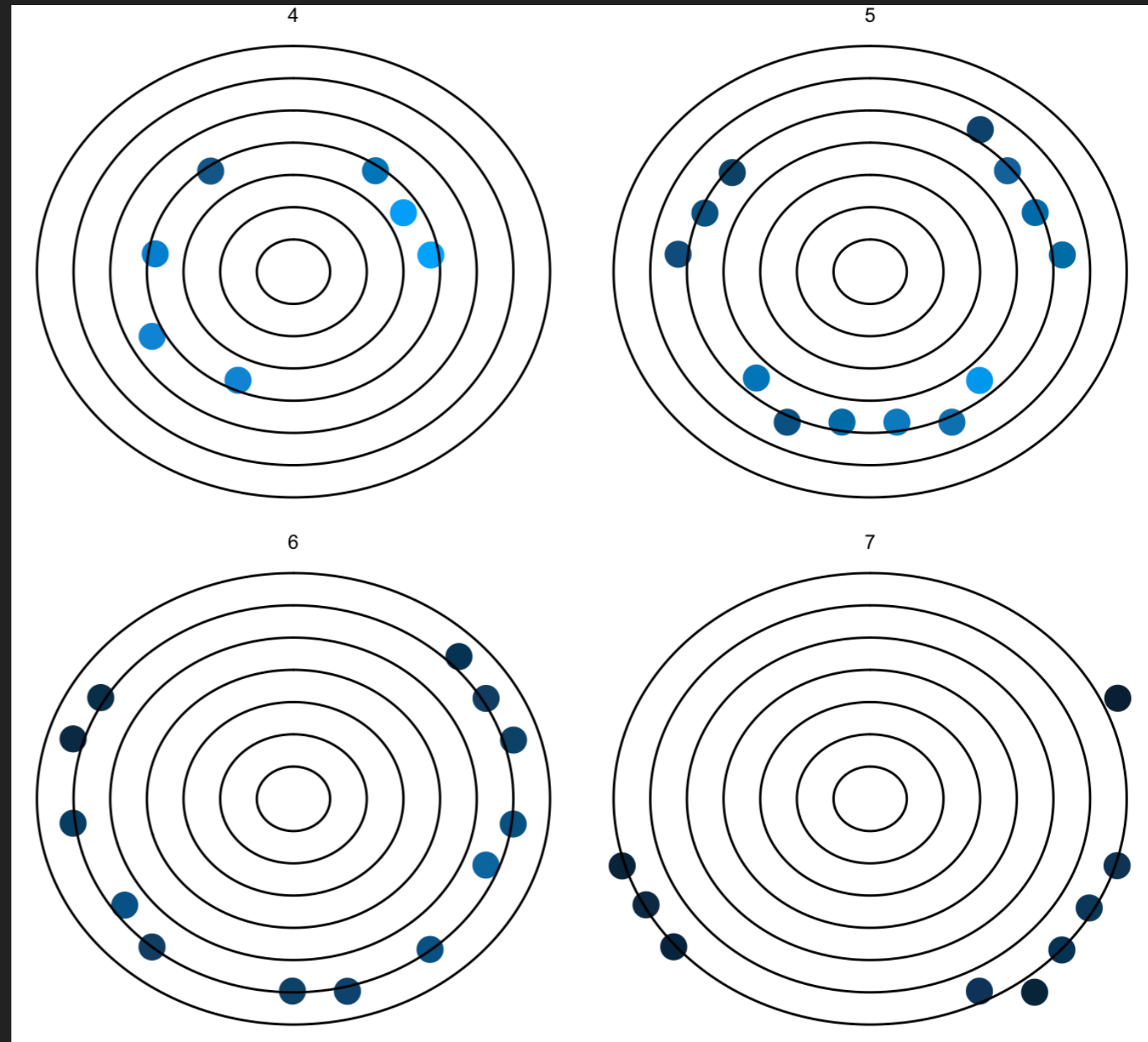
# TGF SOURCE PROPERTIES

But there's more...

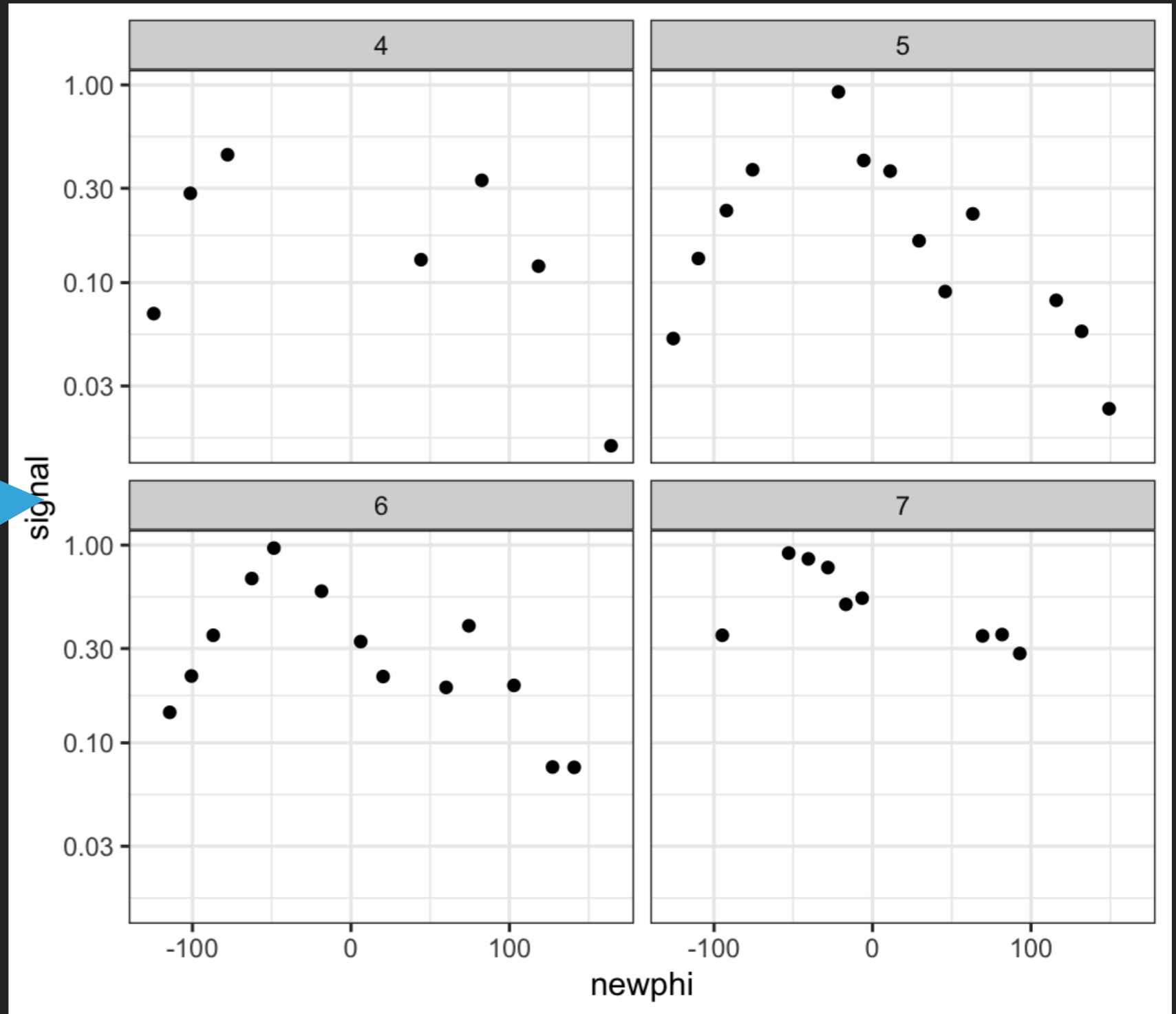
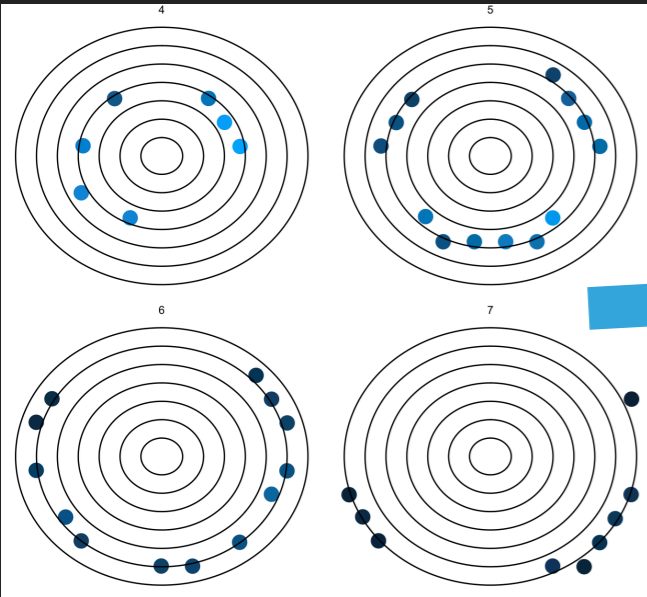


# TGF SOURCE PROPERTIES

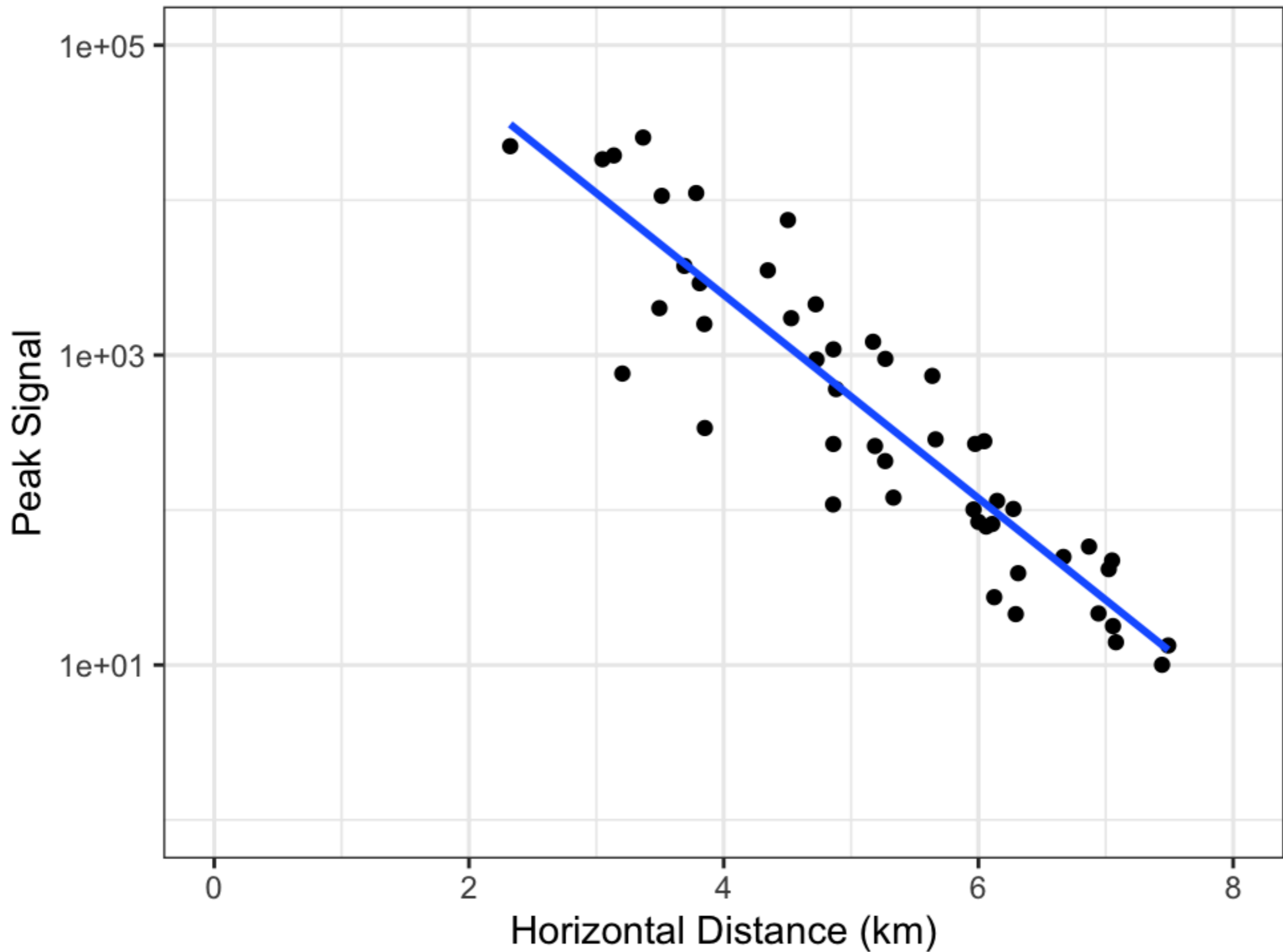
- ▶ Compare flux vs. azimuthal angle for constant distance
- ▶ Bin stations by 1 km increments from center



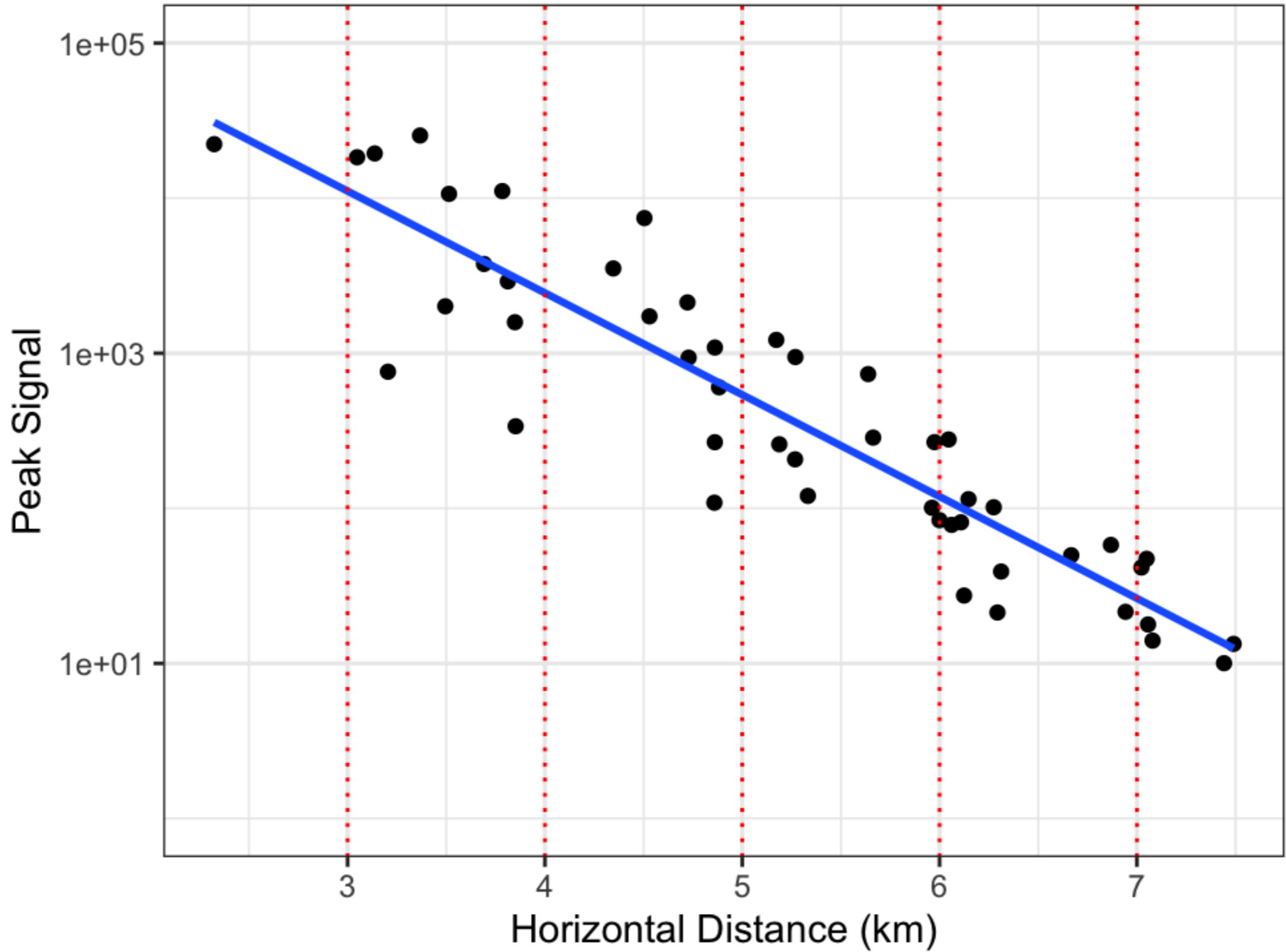
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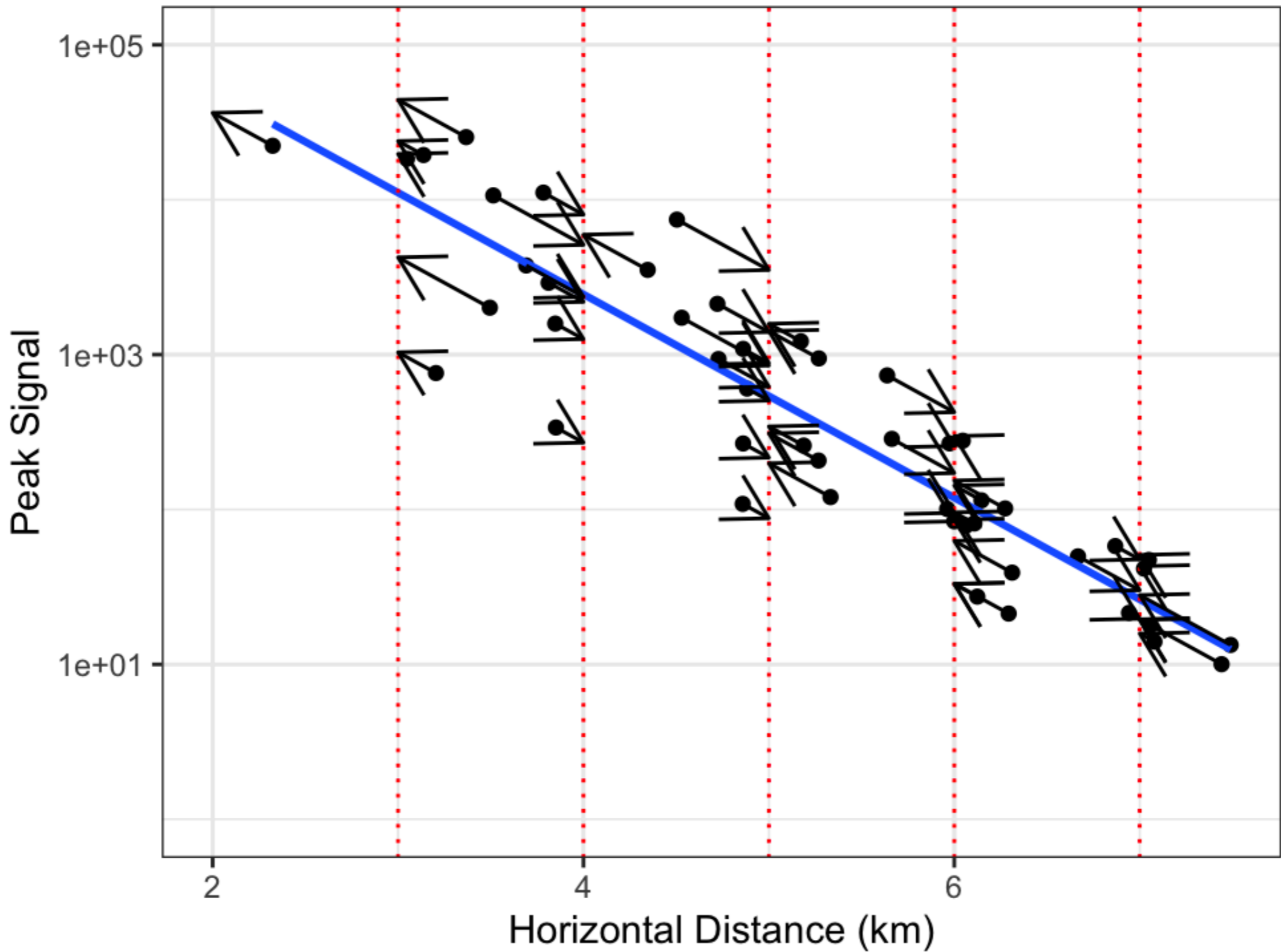
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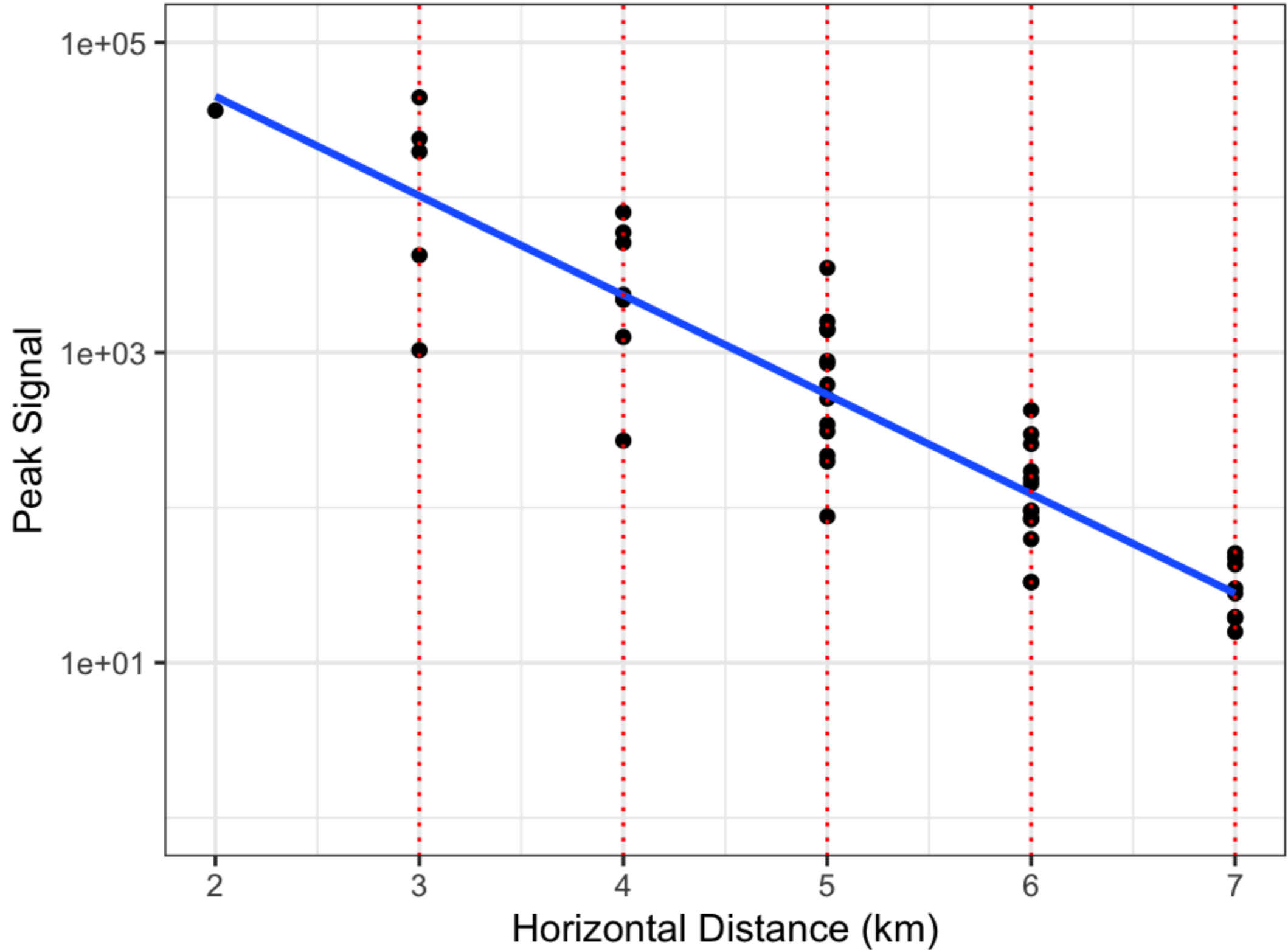
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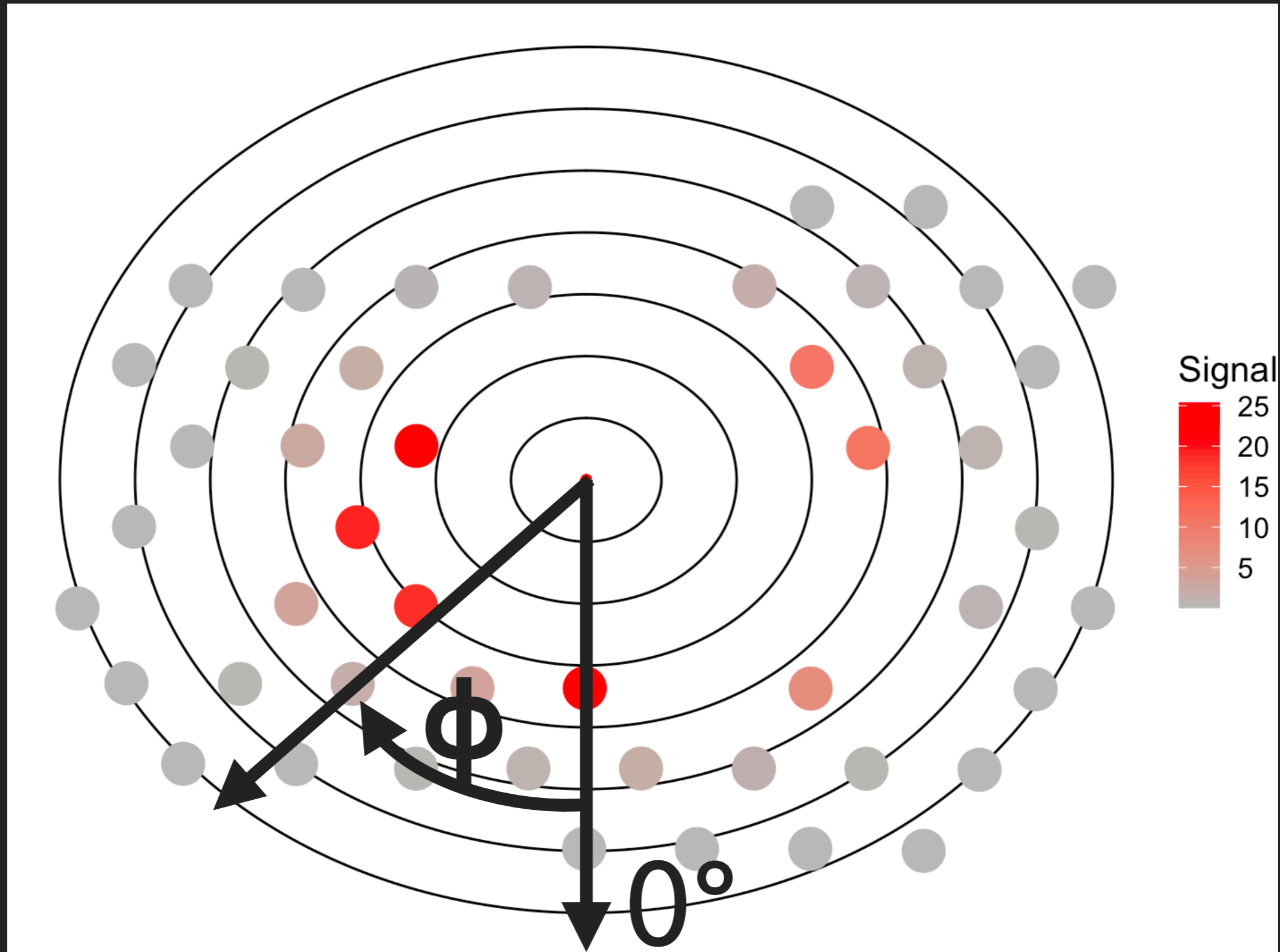


# TGF SOURCE PROPERTIES



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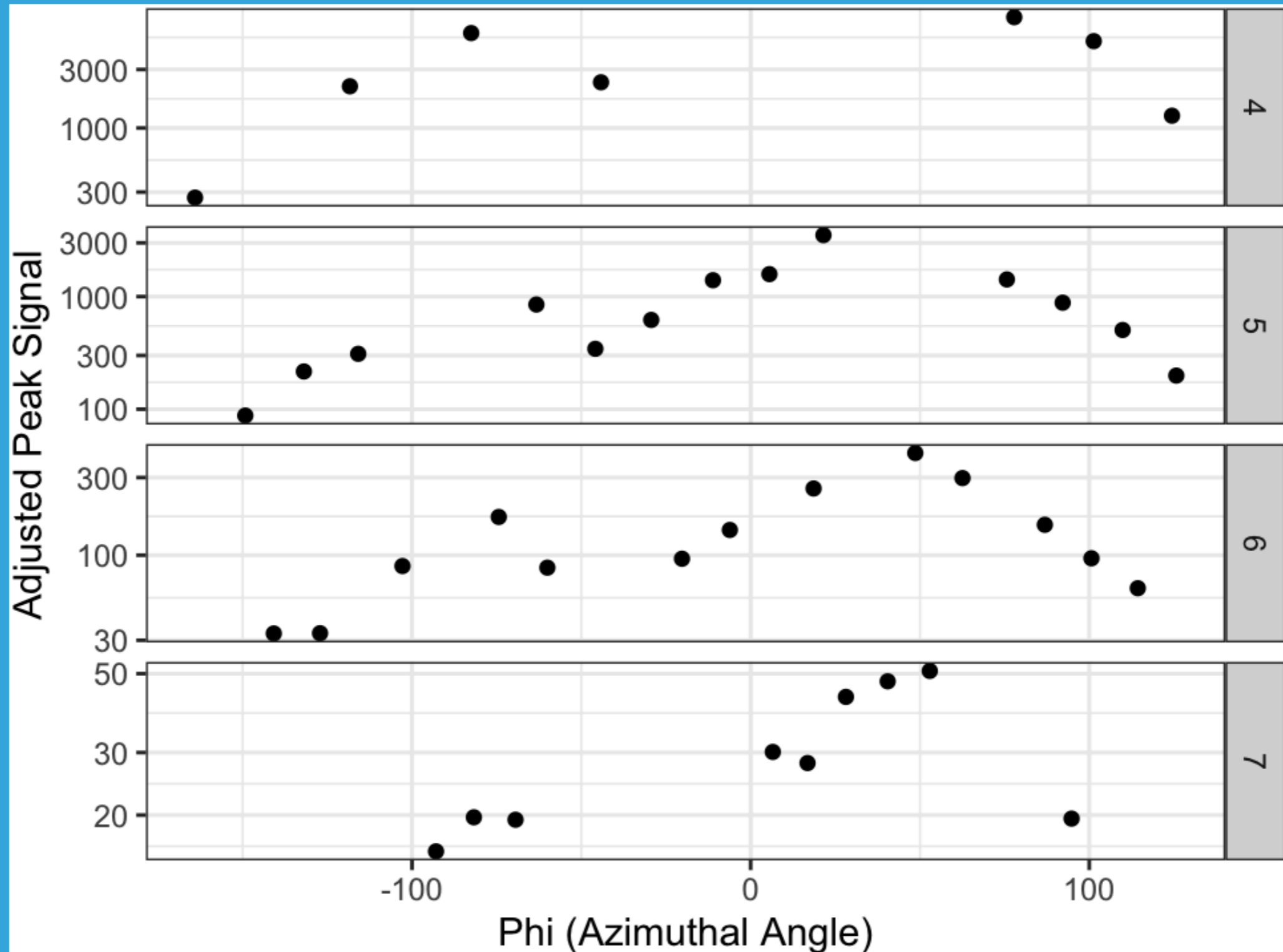
Now plot peak vs. azimuthal angle





# TGF SOURCE PROPERTIES

Now plot peak vs. azimuthal angle

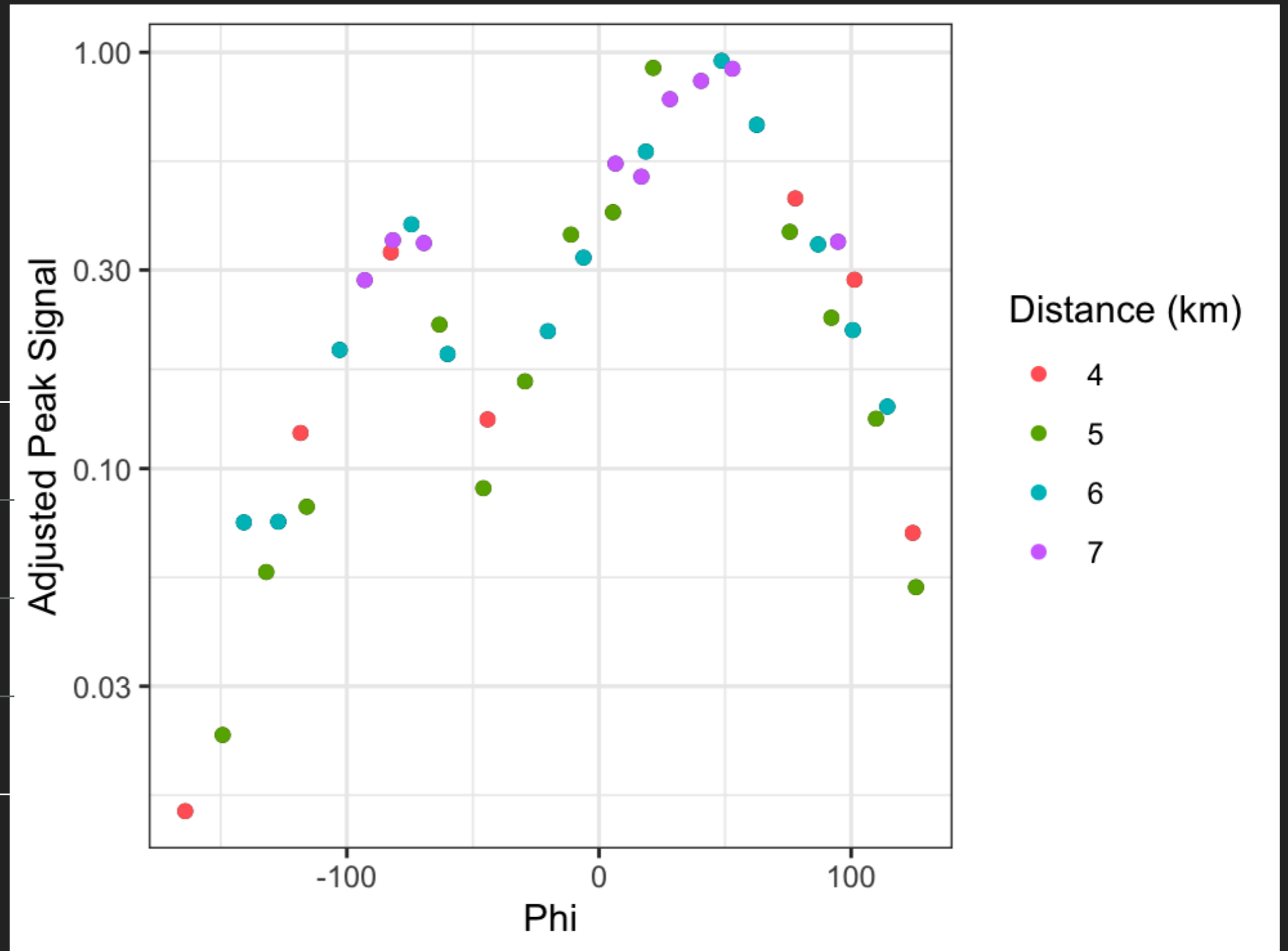


# TGF SOURCE PROPERTIES

Apply a scaling factor to each distance

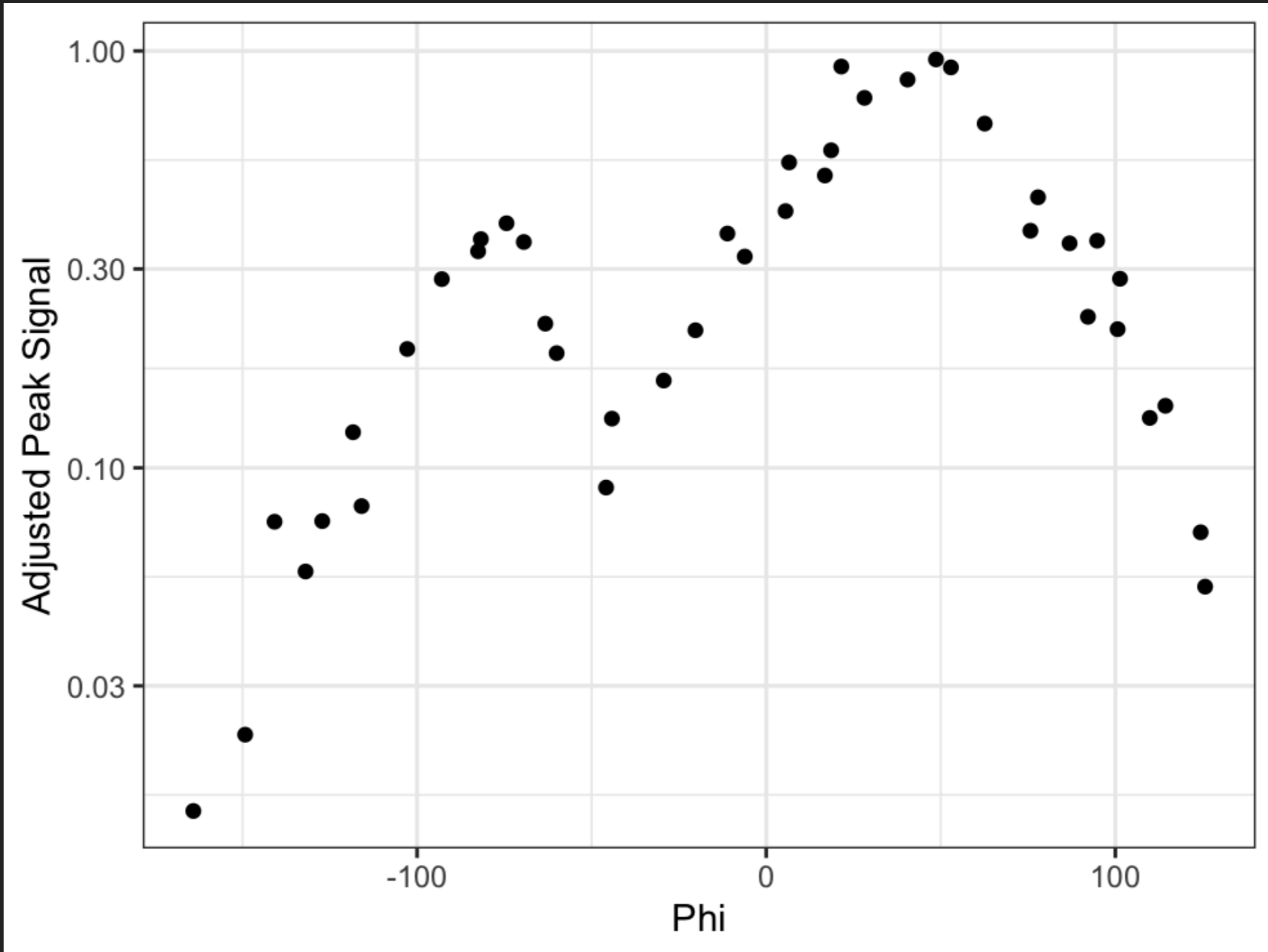
## SCALING FACTORS

4 km	1
5 km	4.7
6 km	41.1
7 km	323.5



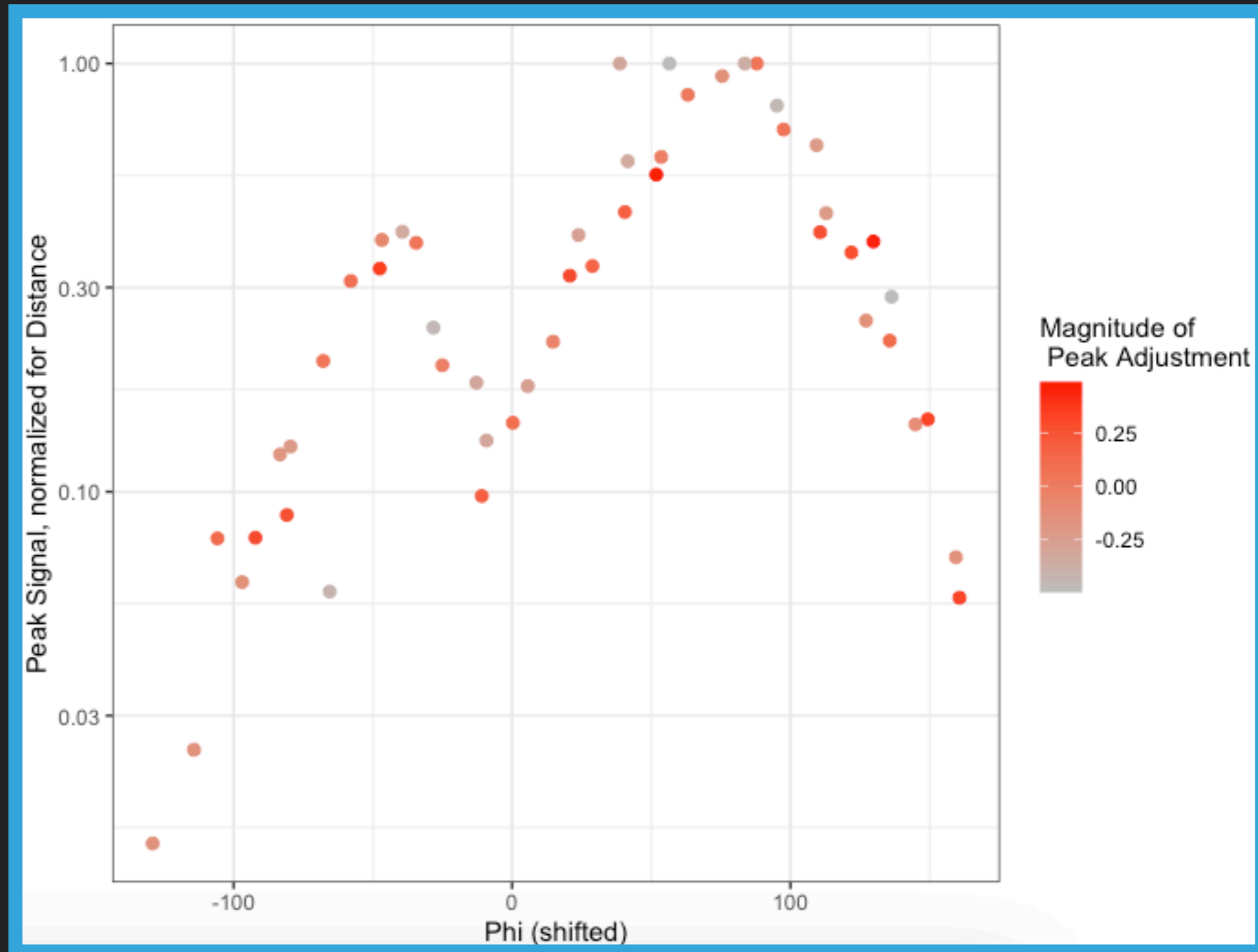
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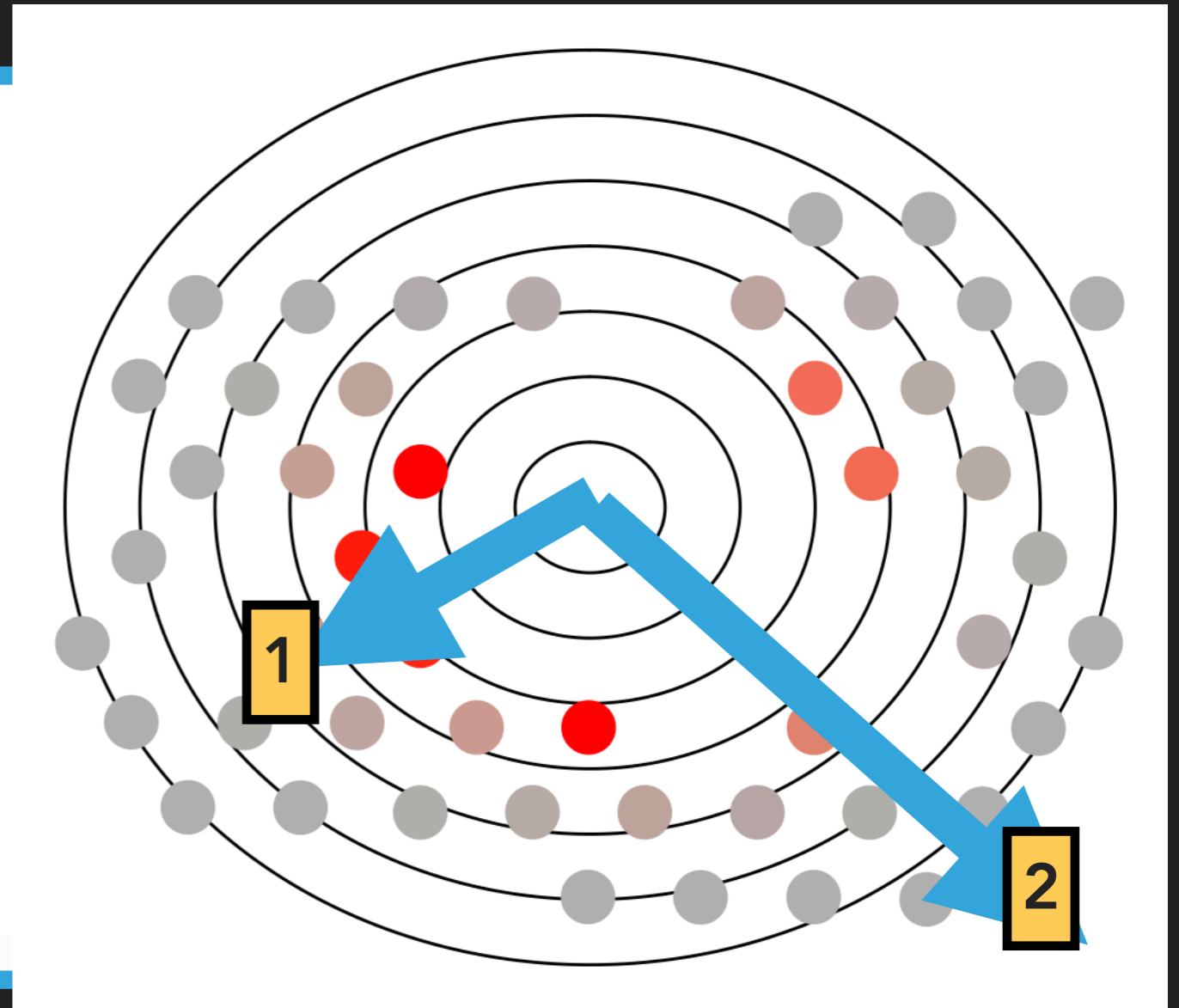
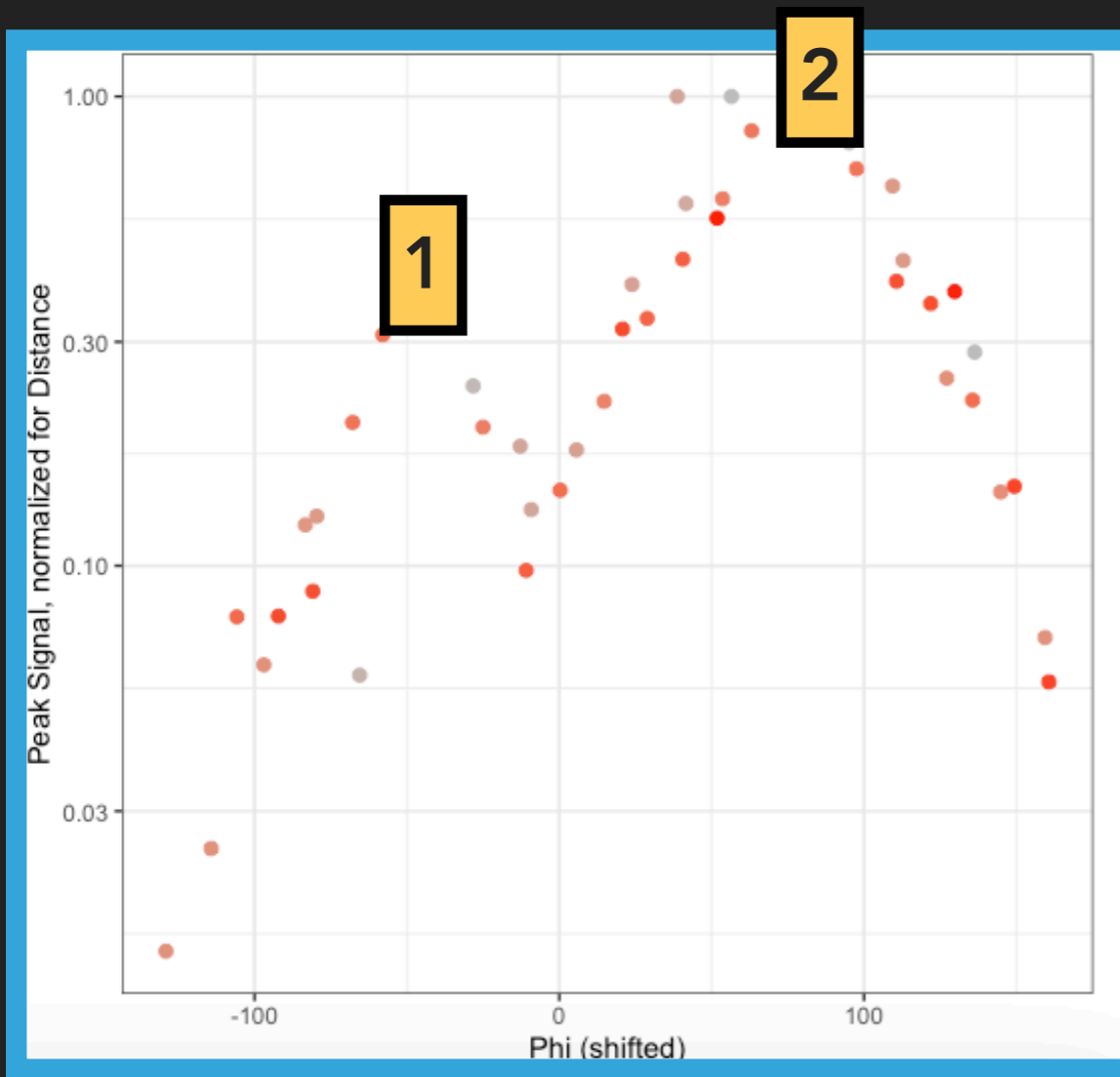


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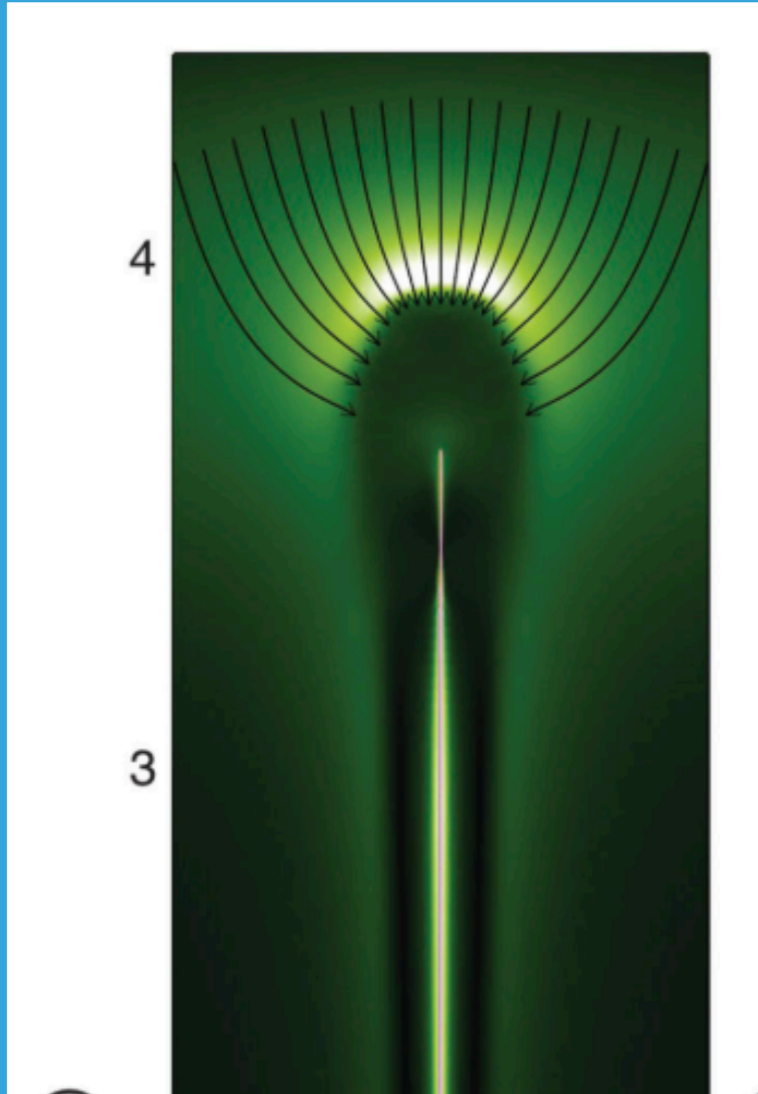
- ▶ Never before seen asymmetric structure.
- ▶ Possible theoretical roots in Dwyer 2008, Stadnichuk 2021
- ▶ Publication forthcoming 2024



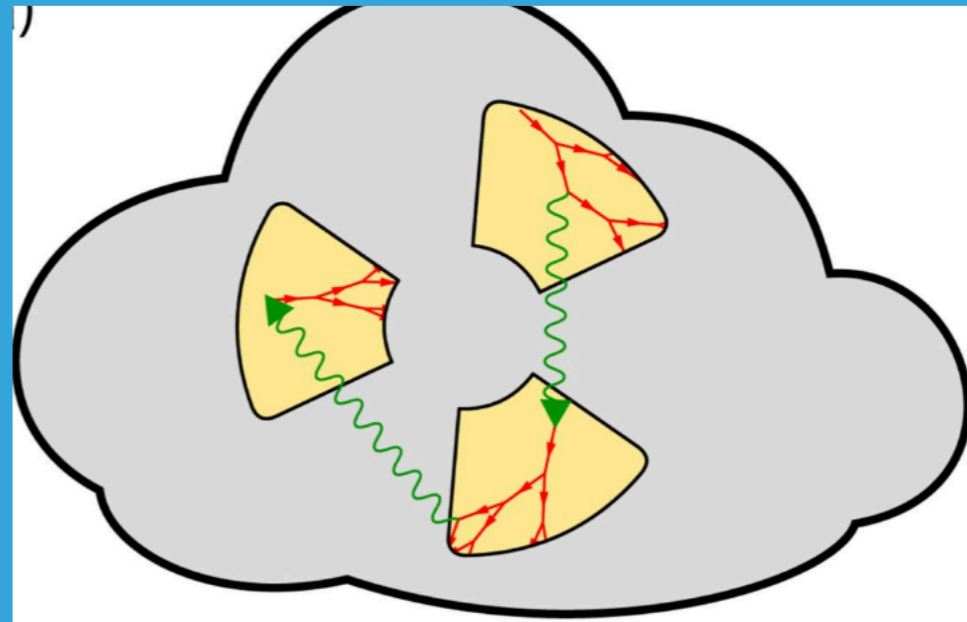
# TGF SOURCE PROPERTIES



# TGF SOURCE PROPERTIES



DWYER 2021



STADNICHUK 2021

# SUMMARY

- ▶ First direct evidence of TGF asymmetry
  - ▶ Surprise first evidence of azimuthal structure
- ▶ Unique ability to locate gamma ray source
  - ▶ Adding radio data would allow unprecedented comparison of lightning channel vs. gamma-ray source location

Observatory	Events
HAWC	None
TA (Utah)	Short, dimmer TGFs
Auger	~20 bright, med/long TGFs