Radiometer results

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Note from the start

- This represents “the” characterization of the radiometer analysis as far as I’m concerned
  - Not sure how much farther we can go characterizing our ability to this method for our the array
  - There are a few more things on the that aren’t presented/are in process that I’ll mention

Systematic characterization

- On the right is process we do for solving radiometer
- M = “model resolution matrix”
    - Ideally would be identity
    - Depends upon how we create pseudo-inverse matrix

$$Y = \gamma S_{true}$$

$$S_{model} = (\gamma^{\dagger}\gamma)^{-1}\gamma^{\dagger}Y$$

$$S_{model} = \gamma^{+}Y$$

$$S_{model} = \gamma^{+}\gamma S_{true}$$

$$\mathcal{M} = \gamma^{+}\gamma$$

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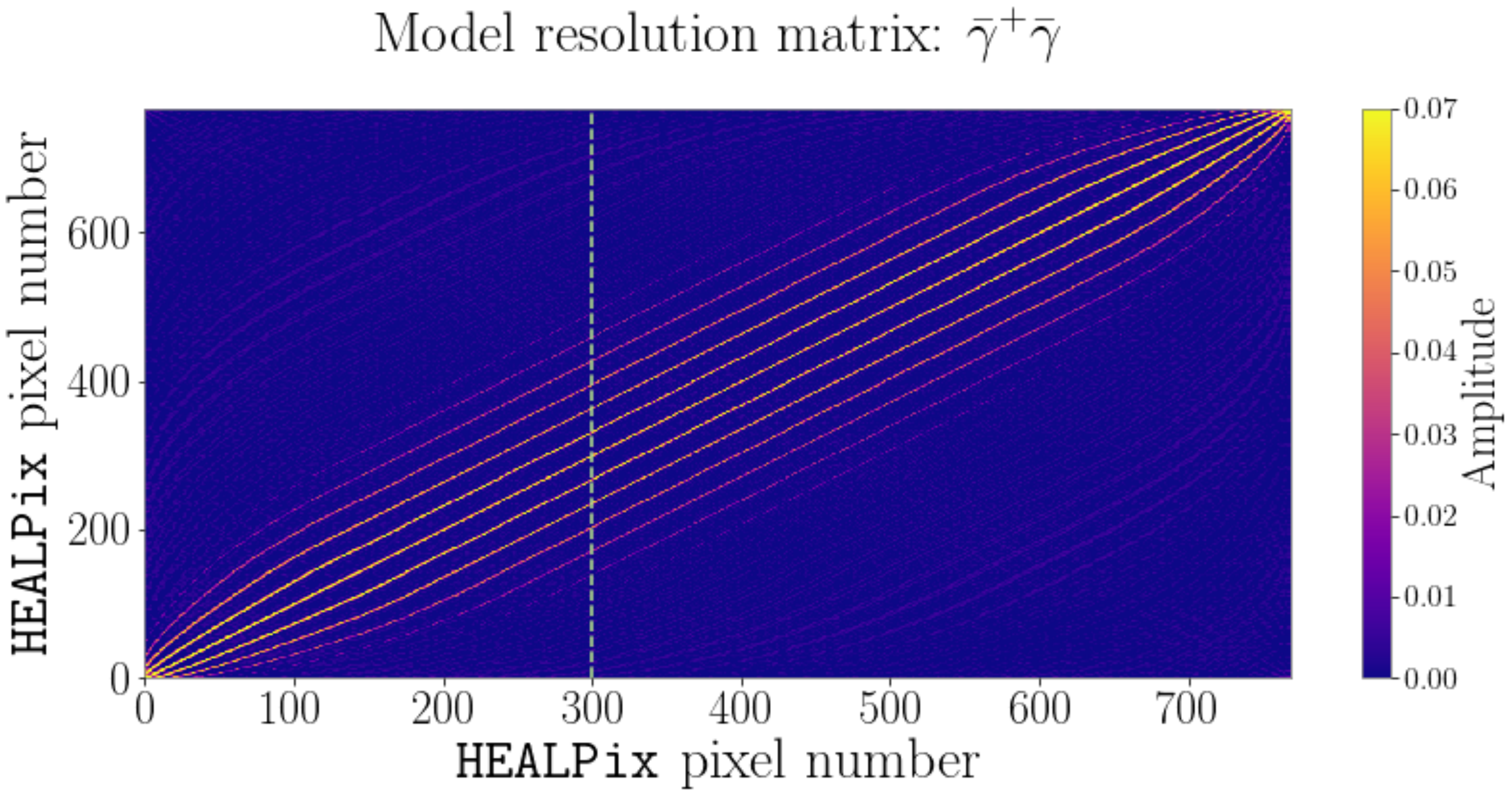
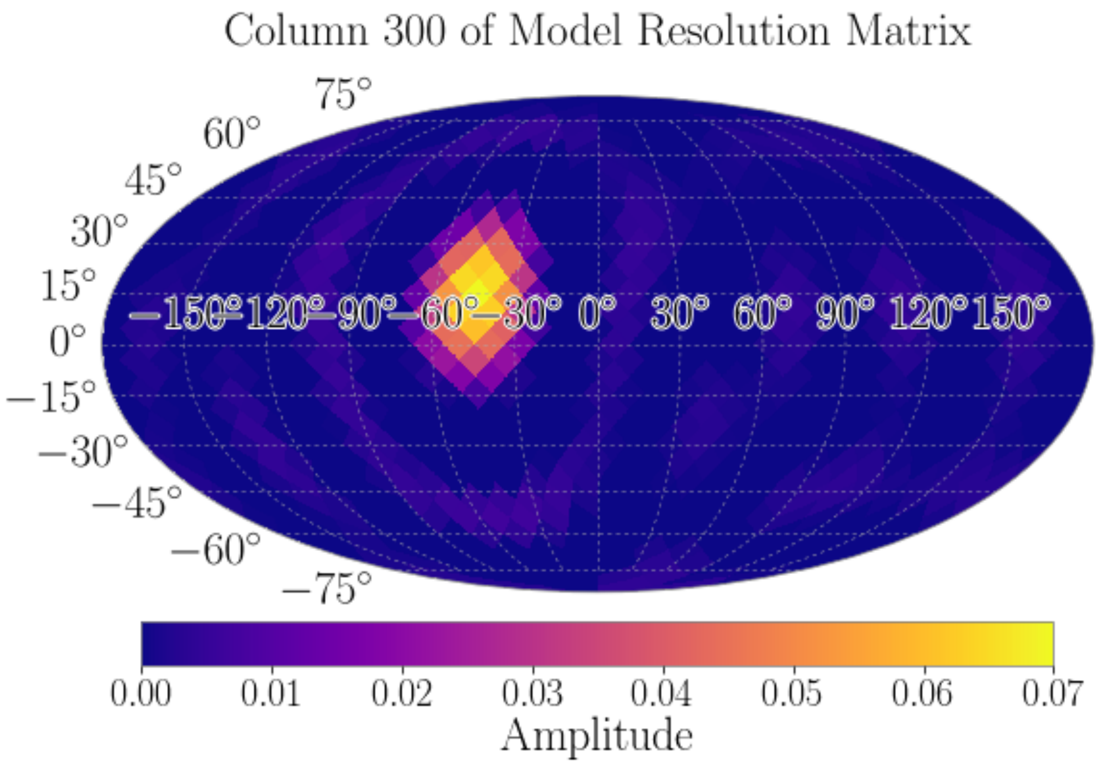
P-wave model resolution matrix





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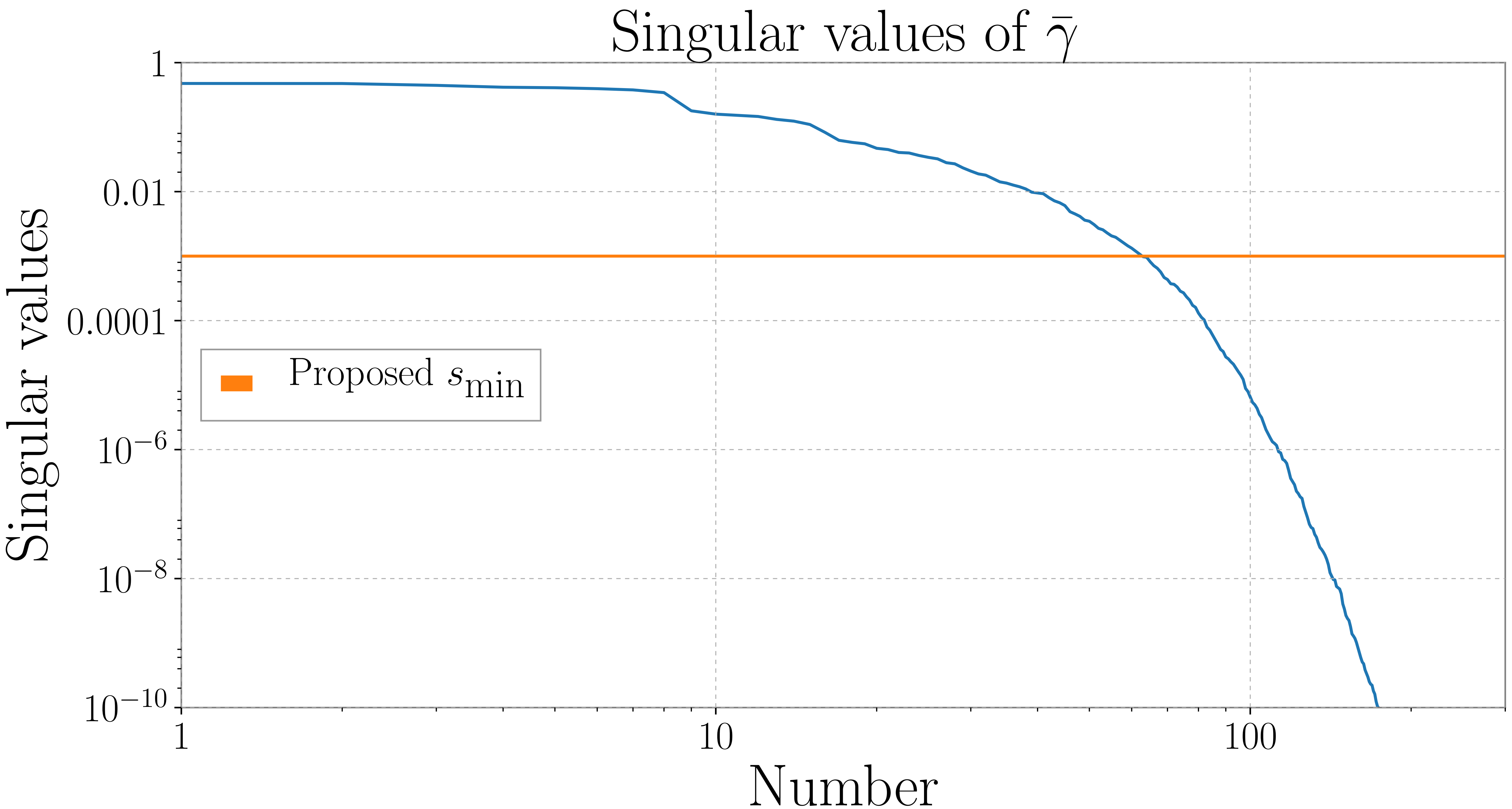
Creating pseudo-inverse

- Take singular value decomposition of gamma
  - cut off at some minimum value
  - create pseudo-inverse
  - Get model parameters
  - Small minimum => better resolution, higher covariance
  - large minimum => worse resolution, lower covariance

Singular values: P-wave gamma matrix



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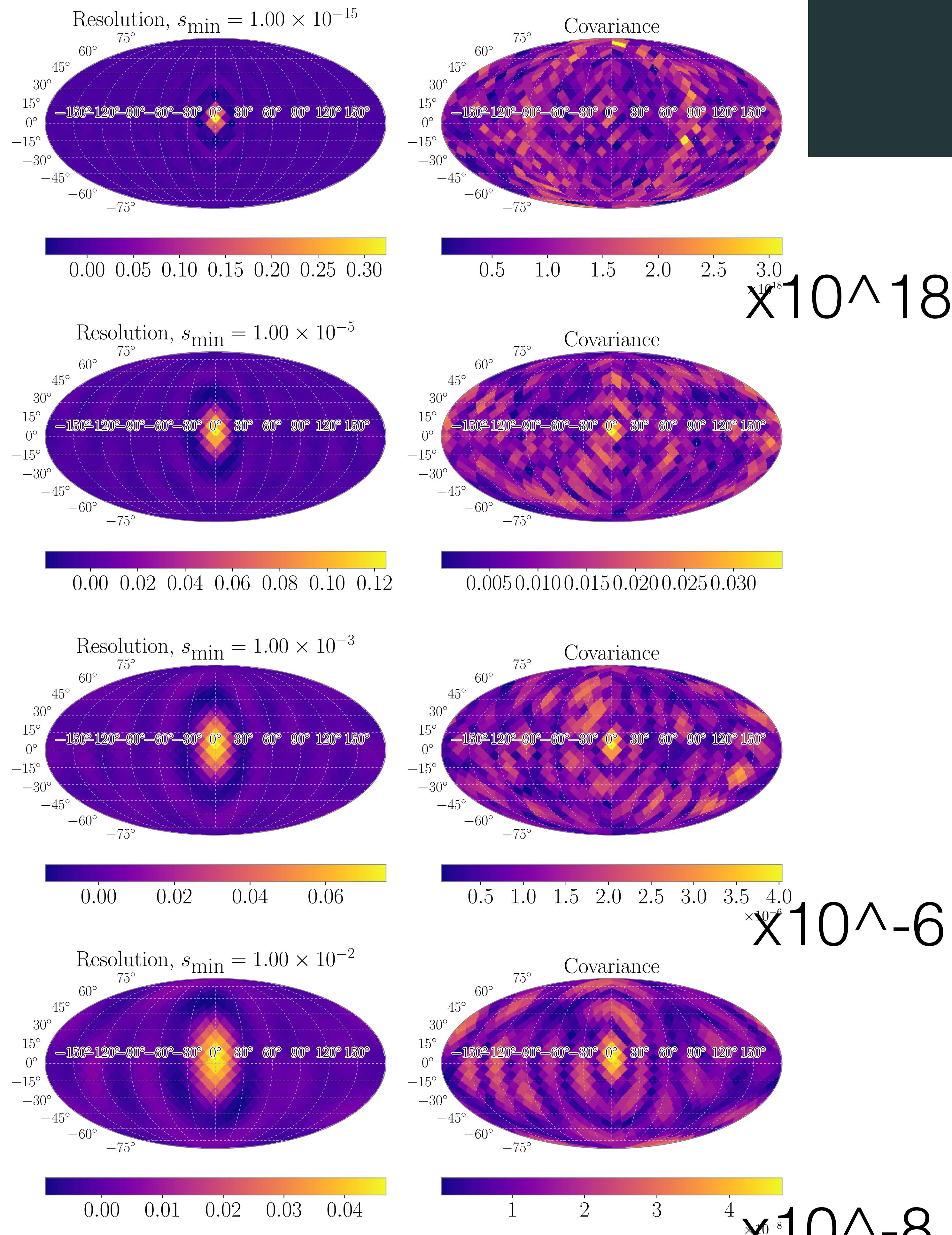

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Choosing best s_min

- Create injected map: single pixel with amplitude = 1, all others 0
- Get recovered map using s_min
- take map coherence
- maximize map coherence over s_min

$$\mathcal{C} = \frac{\frac{1}{2}(\mathbf{M}_1\mathbf{M}_2^\dagger + \mathbf{M}_2\mathbf{M}_1^\dagger)}{\sqrt{(\mathbf{M}_1\mathbf{M}_1^\dagger)(\mathbf{M}_2\mathbf{M}_2^\dagger)}}$$

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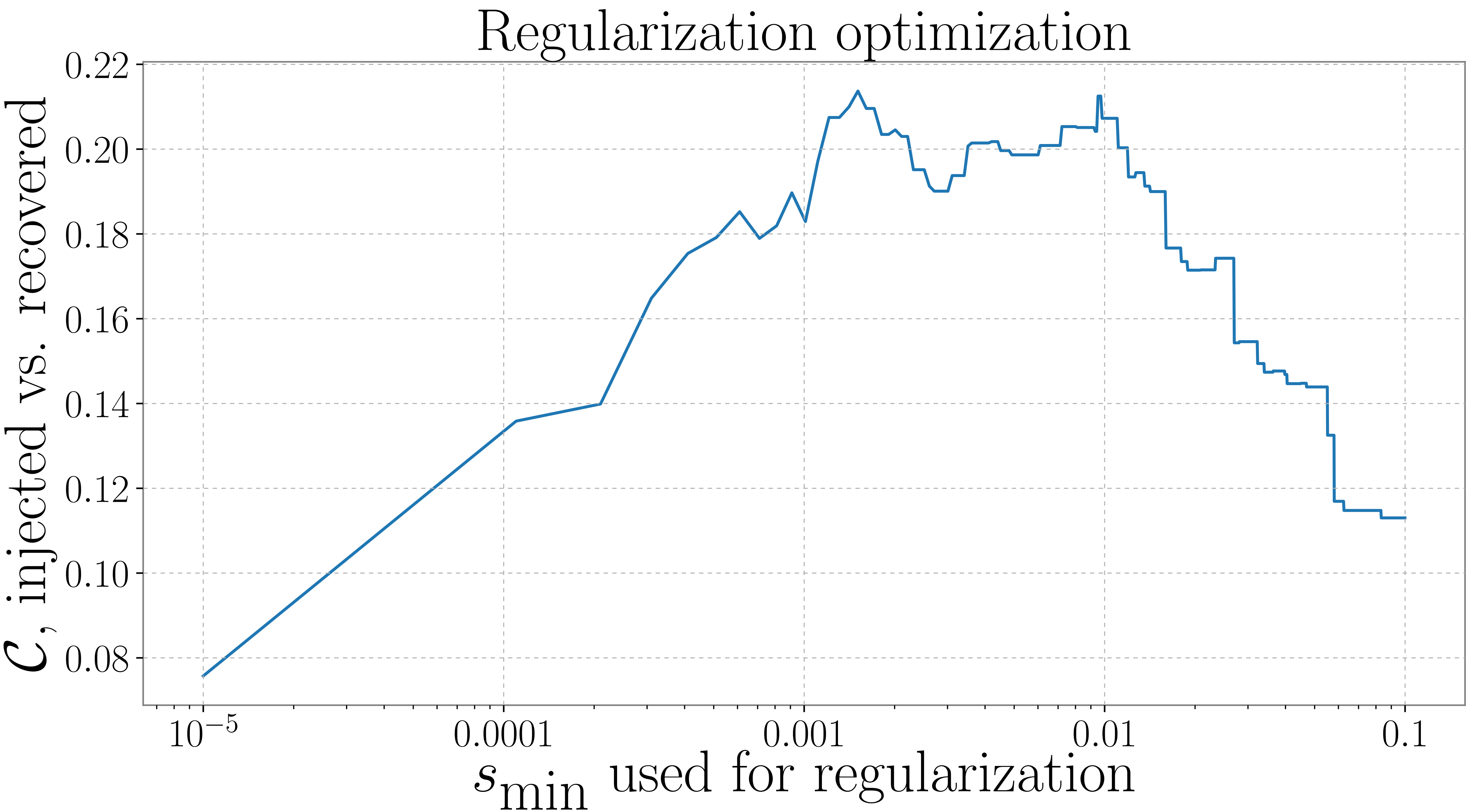
Maximization subtleties

- In theory, maximization needs to be re-run for different injection types and different recovery types (i.e. if we want to recovery P, S, or R-waves

P-wave, coherence maximization



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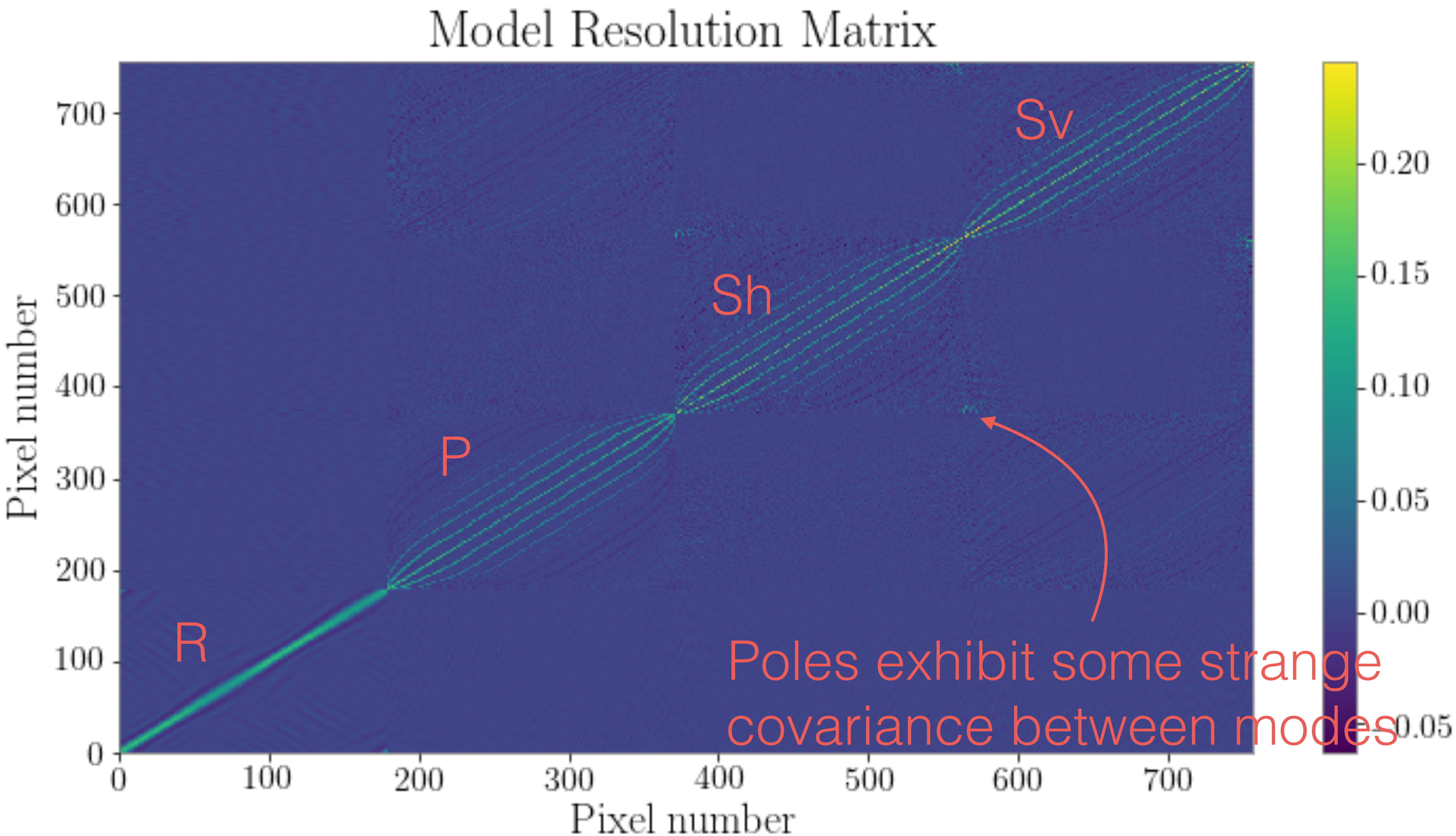
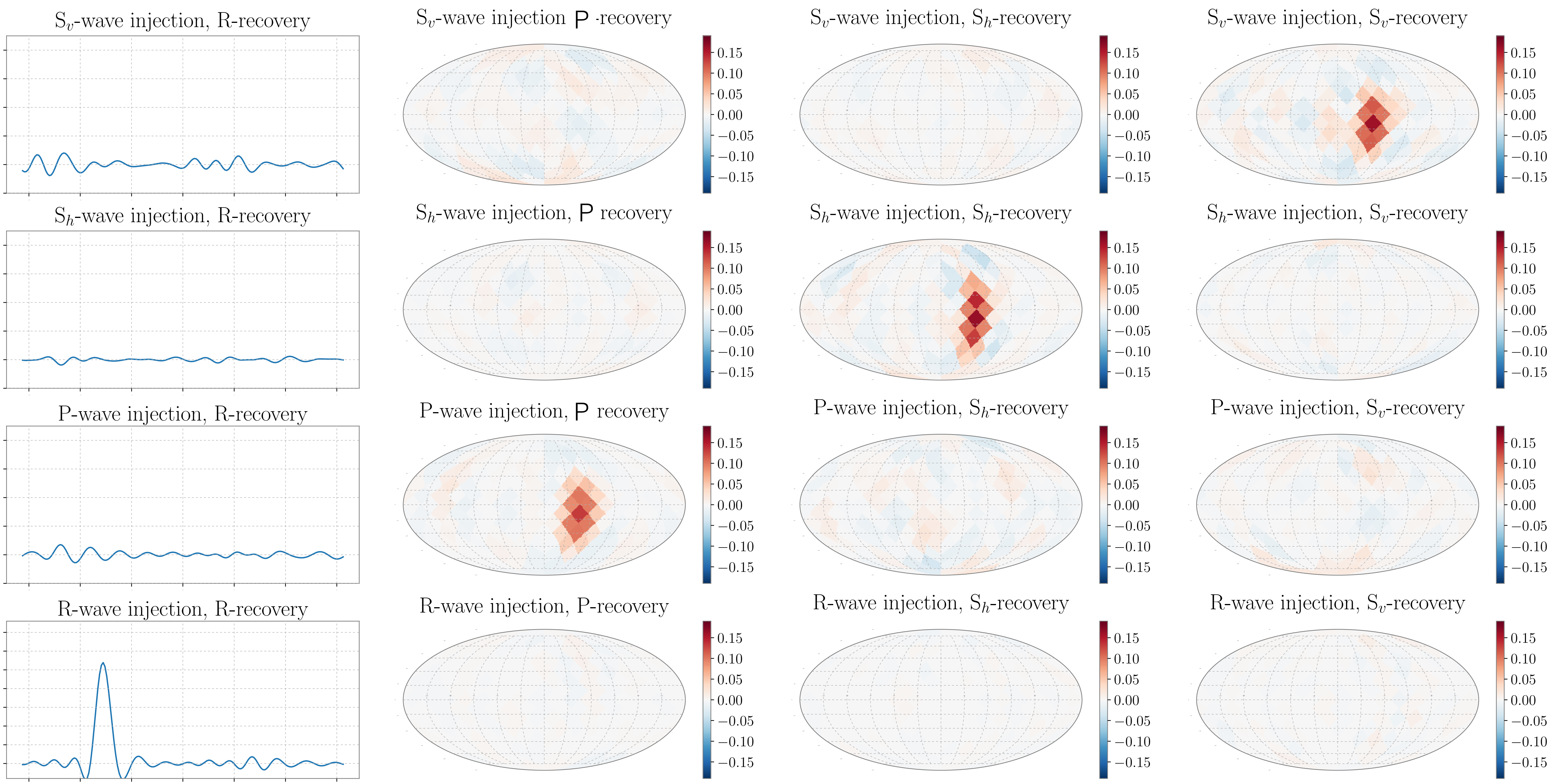
MRM for all recovery types



MRM for all recovery types (one column from each block)



MRM for all types (conclusions)

- Things tend to be fairly independent using our array.
  - In the end, I ran into some issues with covariance being large when trying to recover injections of three different types at once, though

Last characterization study in progress

- Angular resolution vs. wavelength for each mode
  - For each mode and for each wavelength, maximize map coherence for East-pointing injection over s_min
  - Take angular spot size from MRM column plot
  - Plot spot size vs. lambda
  - Plot column rank of pseudo-inverse vs. lambda as well (number of singular values larger than s_min)

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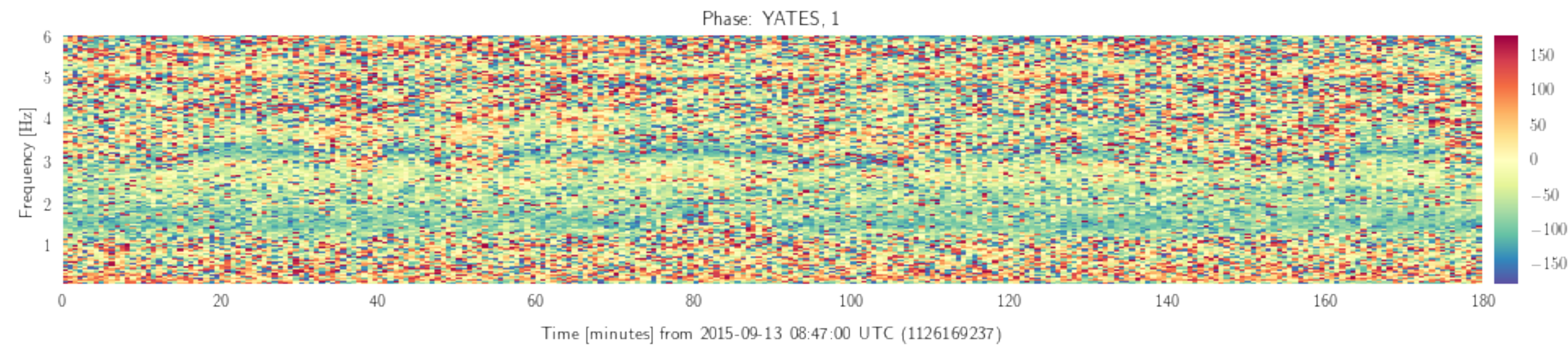
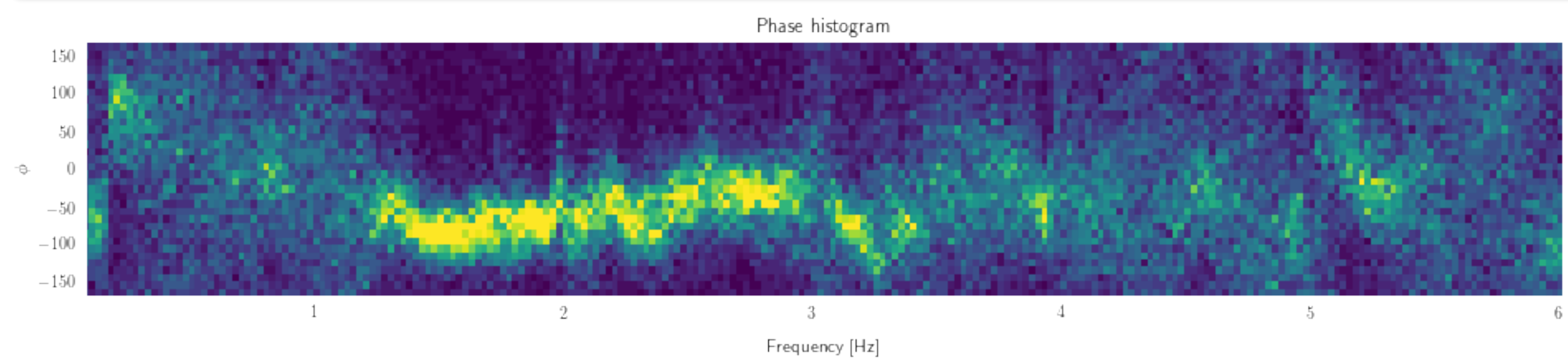
Persistent source example

- Top: Phase difference between vertical and east channel
- Bottom: Histogram over time segments
- NOTE: This source isn't really seen in the North channel at all



confusing information so I've covered up these plots



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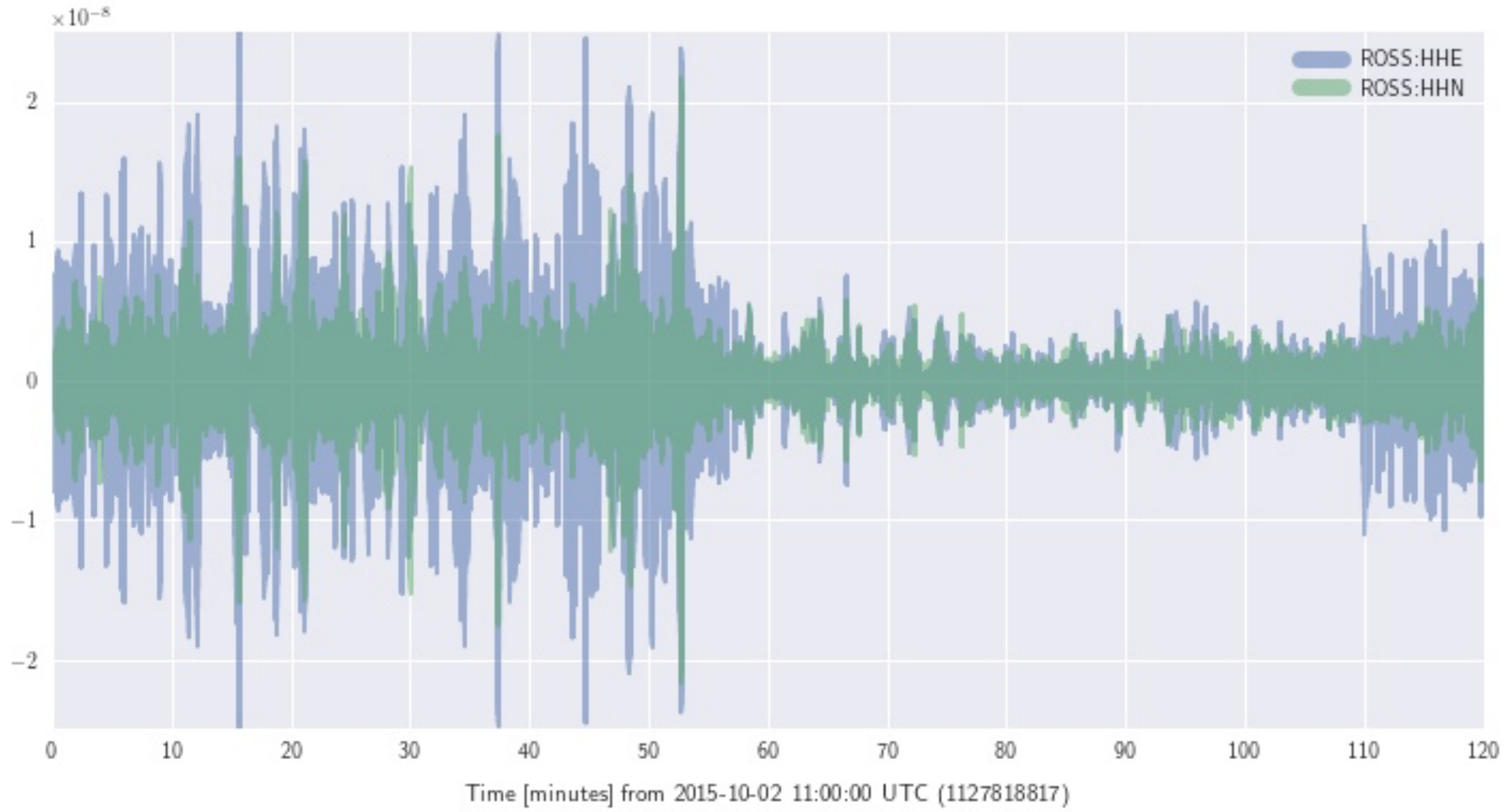
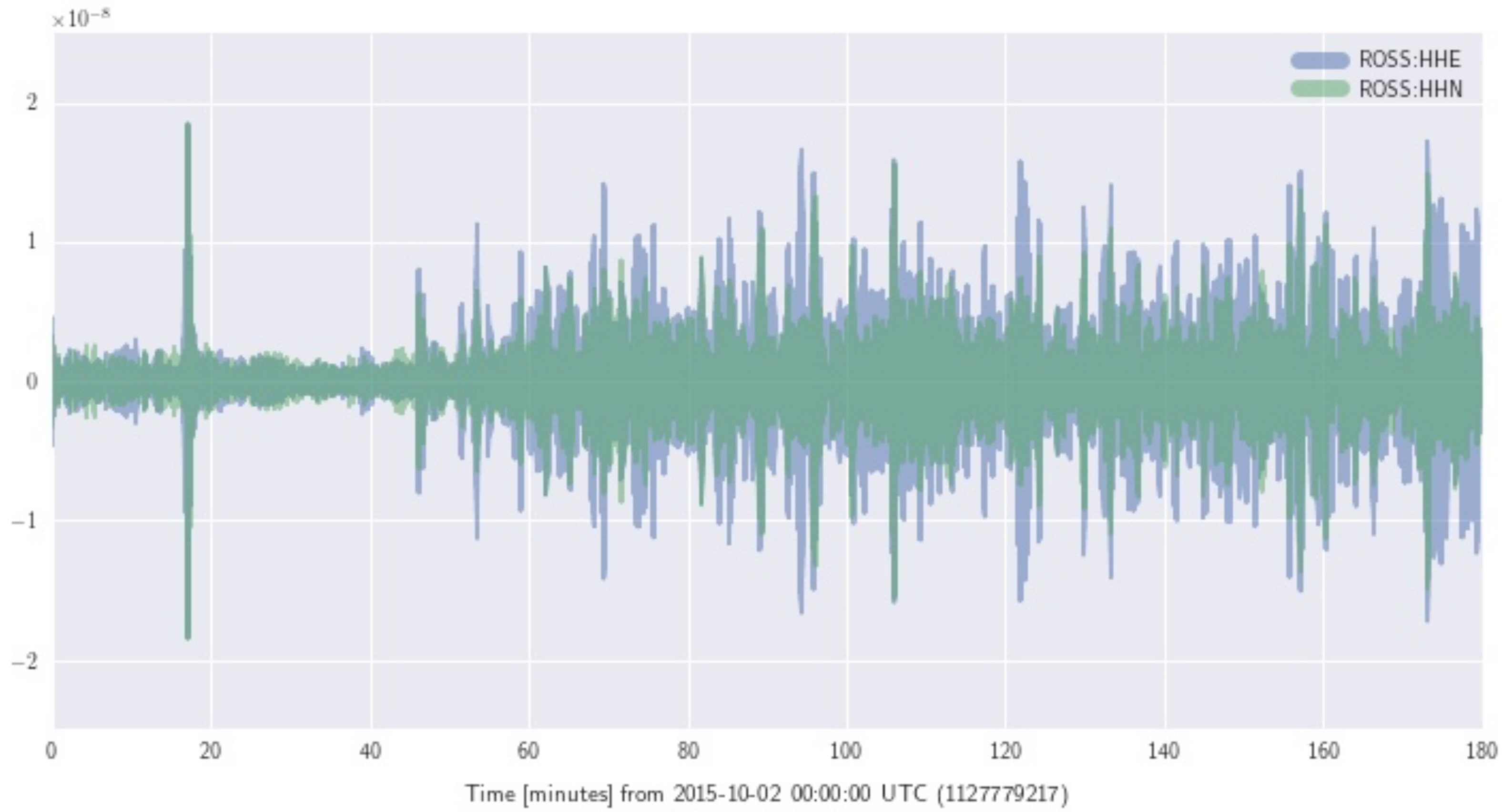
This source turns on and off?

- Band-pass filter from 1.4 - 1.6 Hz, look at time series

- See it turn off at 00:00 - 00:30 and 12:00 - 12:30 UTC *every day* for some reason





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Quick timing analysis

- Use only phase delay between stations to estimate direction and velocity
- Assume coming in along surface
- Basically this is a "surface plane-wave" hypothesis that uses no polarization information

Likelihood

- Use a student's t-distribution over inter-site phases
- i = pairs of channels at different seismometers, m_i = number of phase measurements for that pair

$$p(\{\vartheta\}\,|\hat{\Omega}, v) = \Pi_{i=1}^{N_{pairs}} \frac{\Gamma(m_i/2-1)}{2\pi^{m_i/2-1}} \left(\sum_{k=1}^{m_i} \left| \vartheta_{i,k} - \frac{2\pi f \hat{\Omega}\cdot\Delta\vec{x}_i}{v} \right|^2 \right)^{-m_i/2},$$

Phase measurement

theoretical phase between stations

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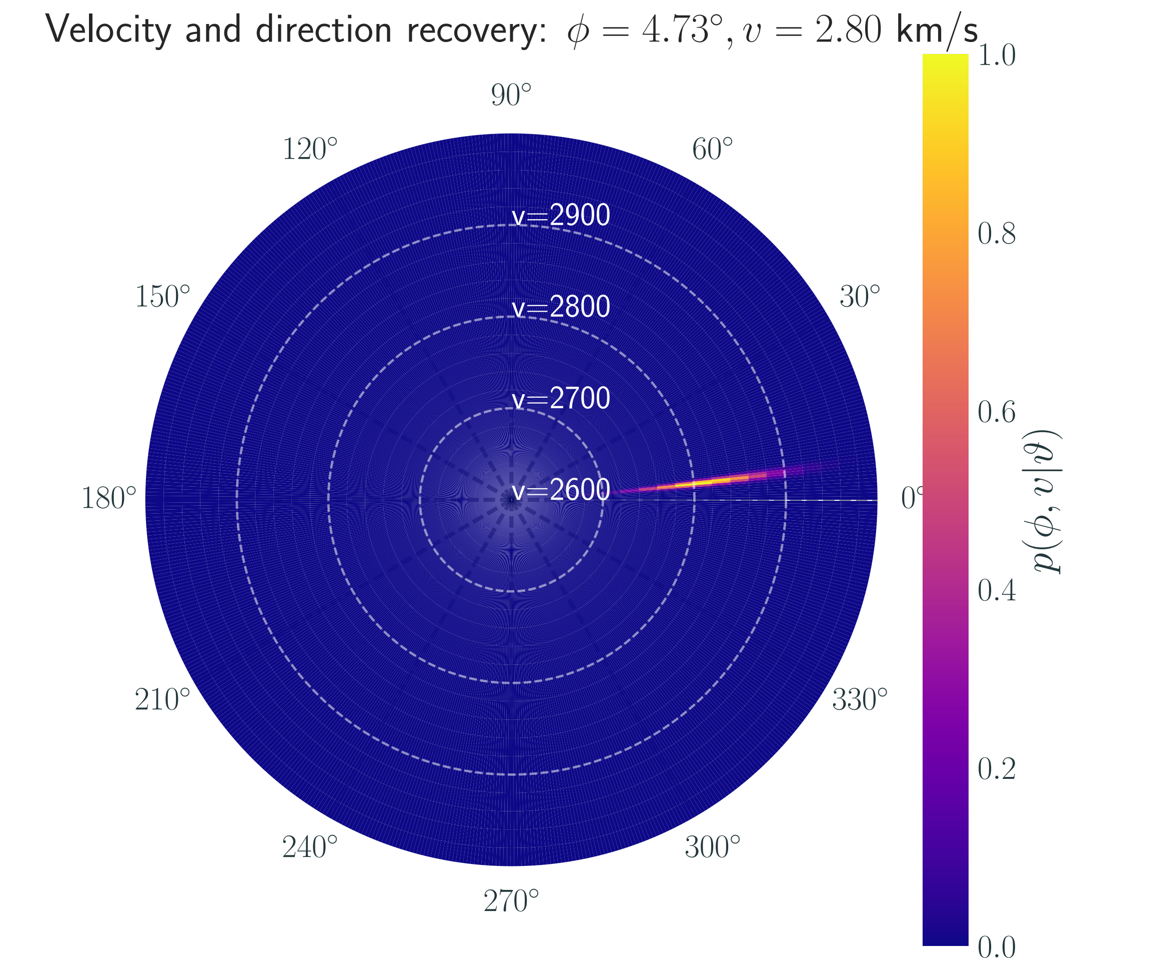
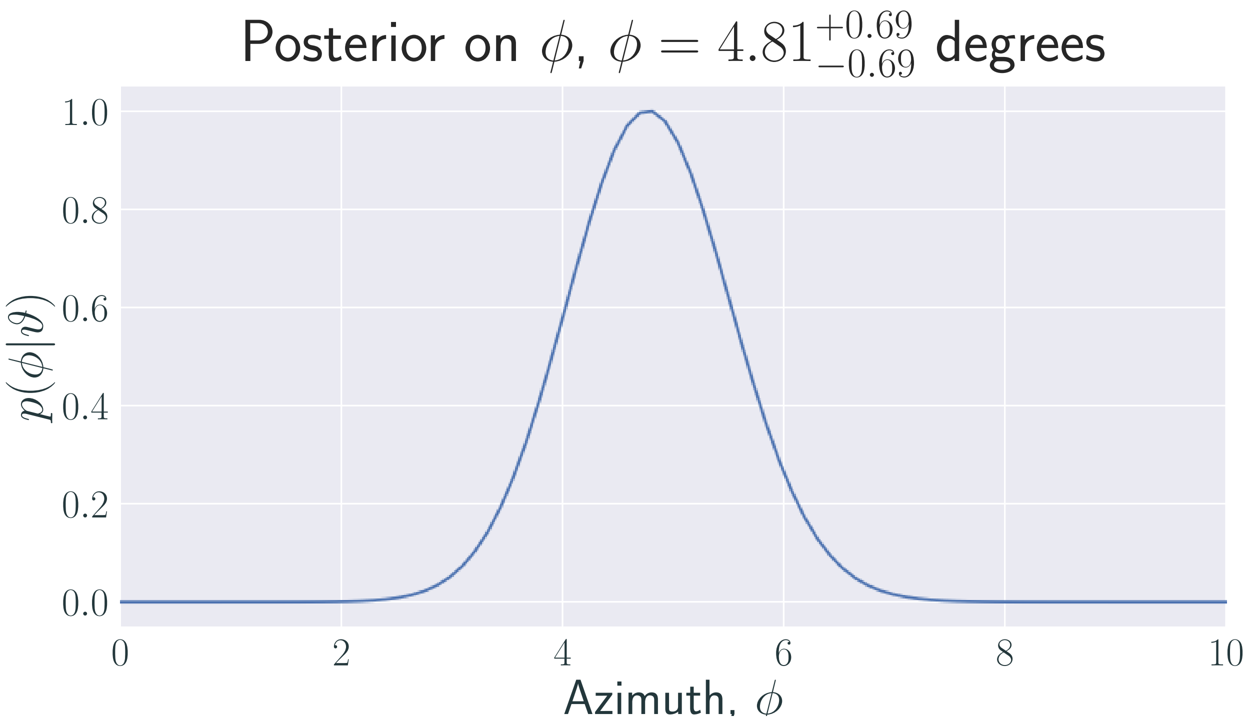
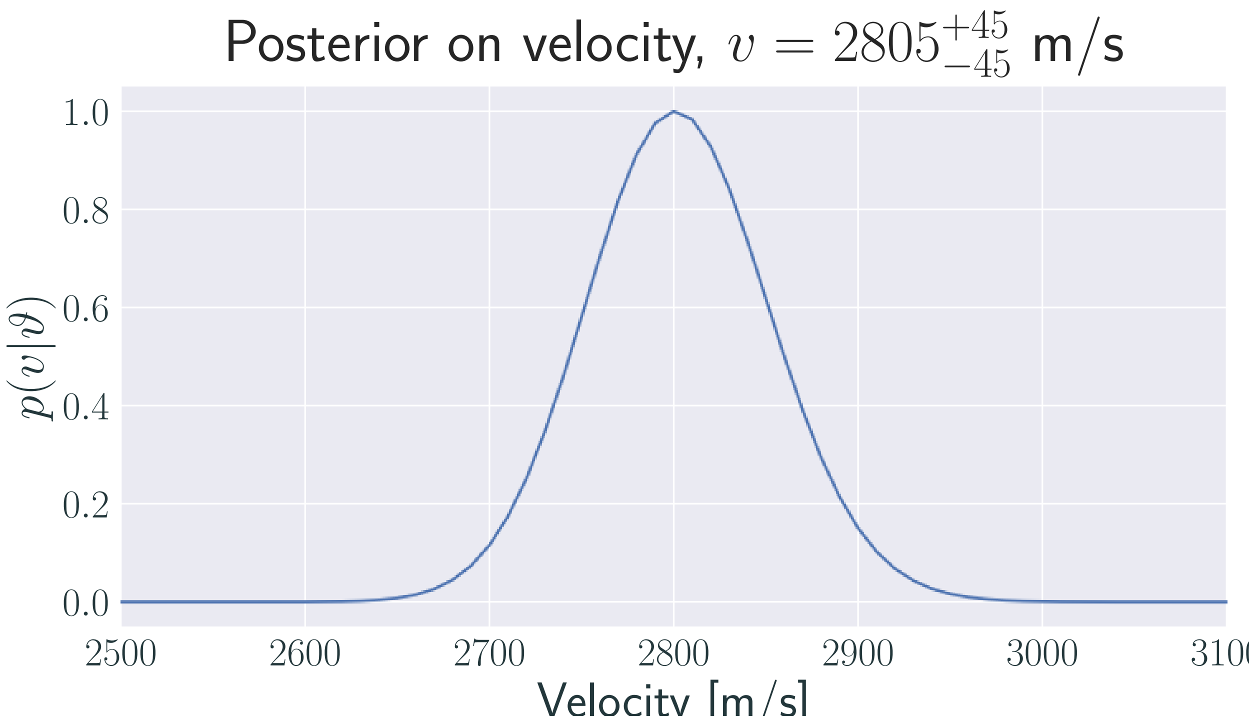
Results

- Bayes factor between random phases and surface plane-wave assumption is ~250





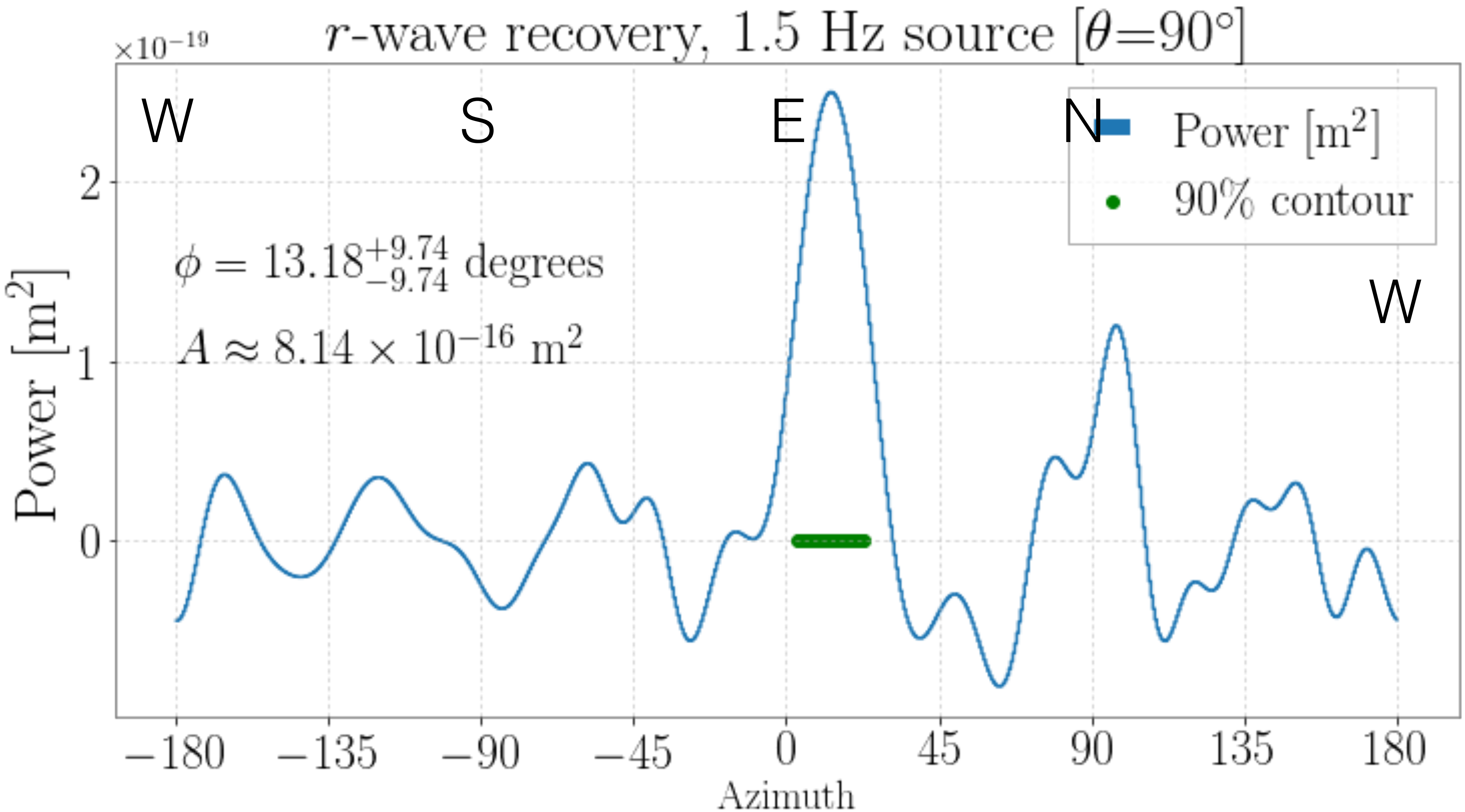


p

Radiometer results

- Run radiometer on same time-frame
- Only use surface stations (don't have a completely reliable eigenfunction yet to go to depth, plus it's not obviously seen at depth)
- Recover with many velocities within range of possible values, take average

R-wave map



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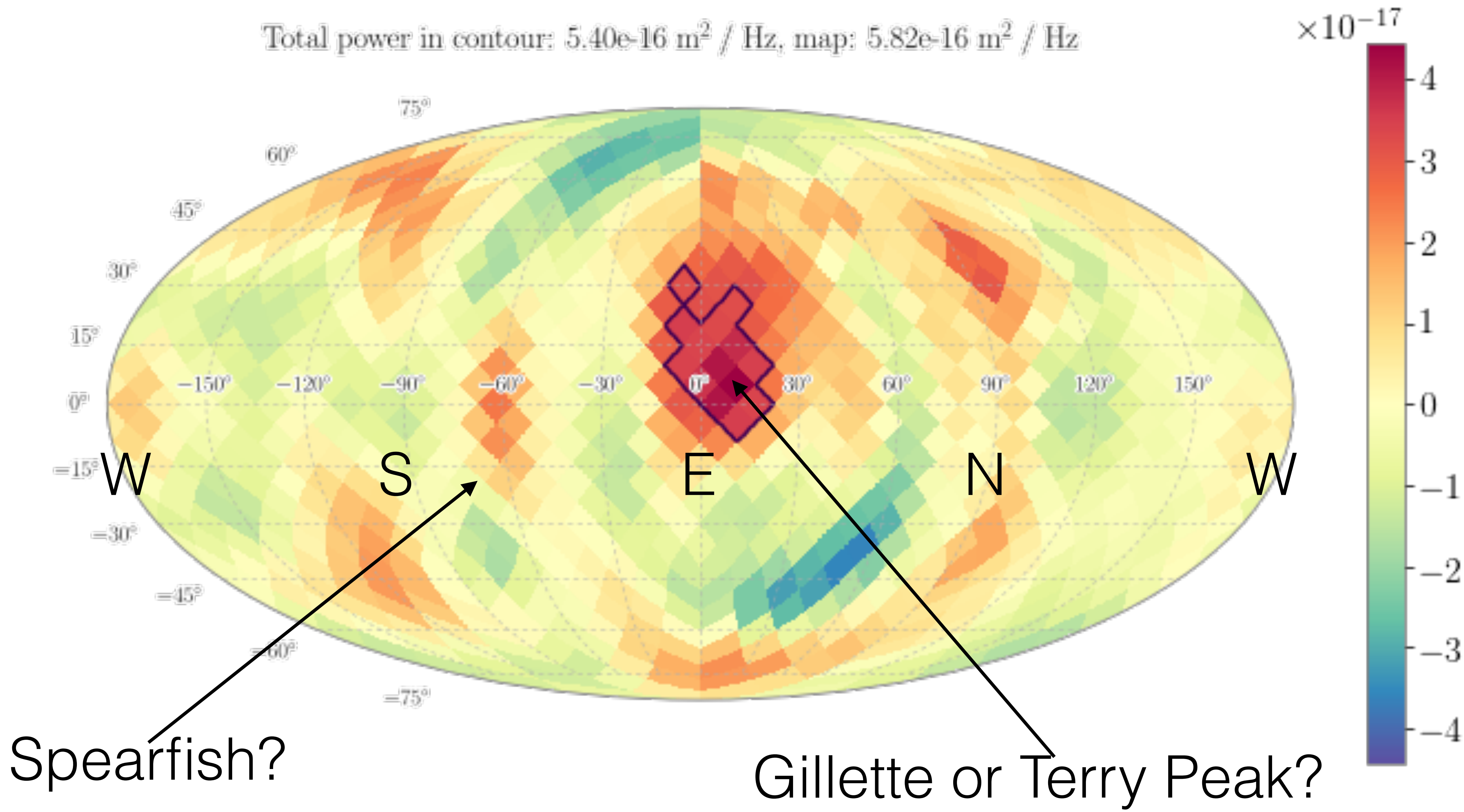
R-wave map with polar angle



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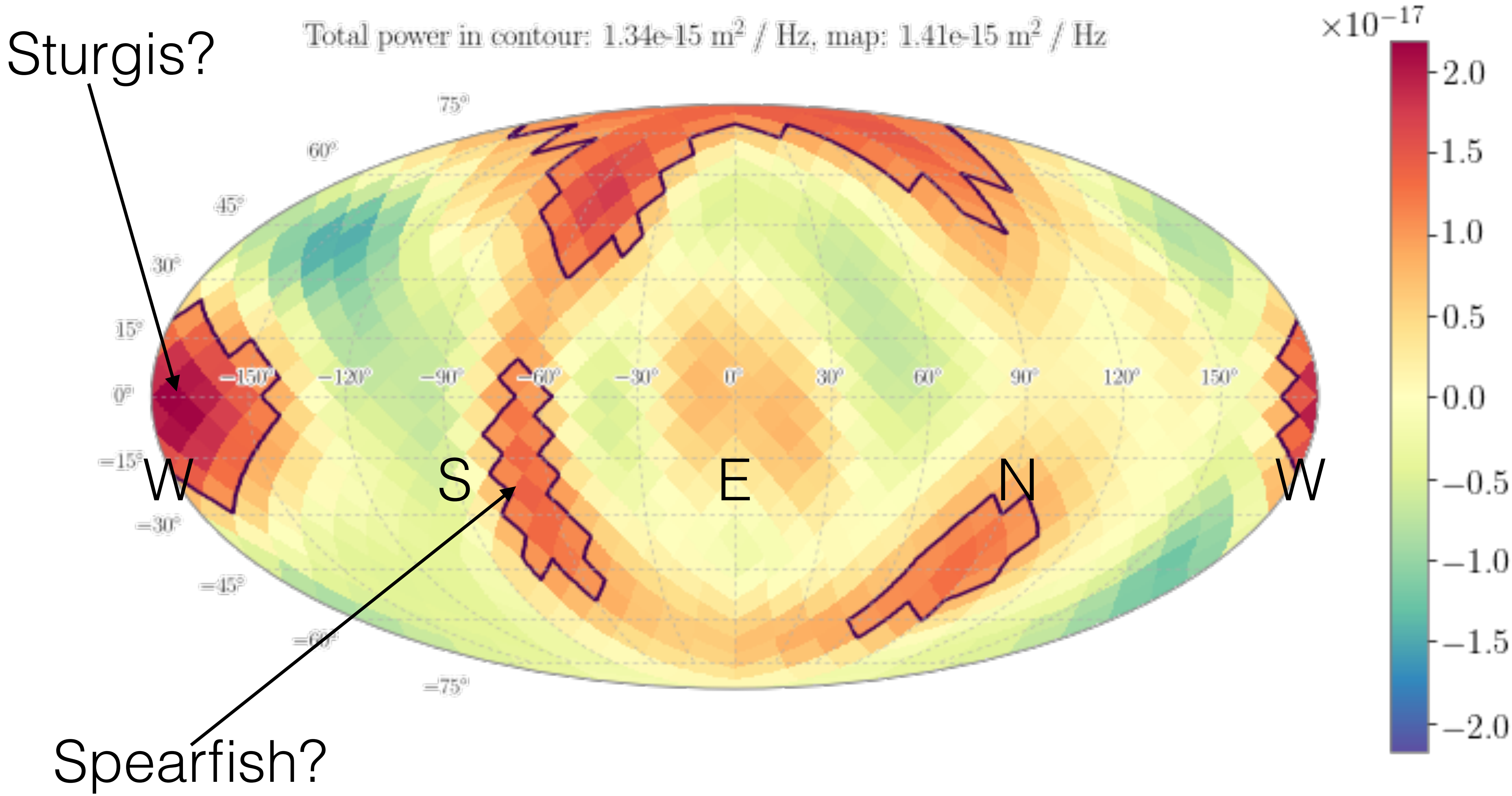
P-wave map with polar angle



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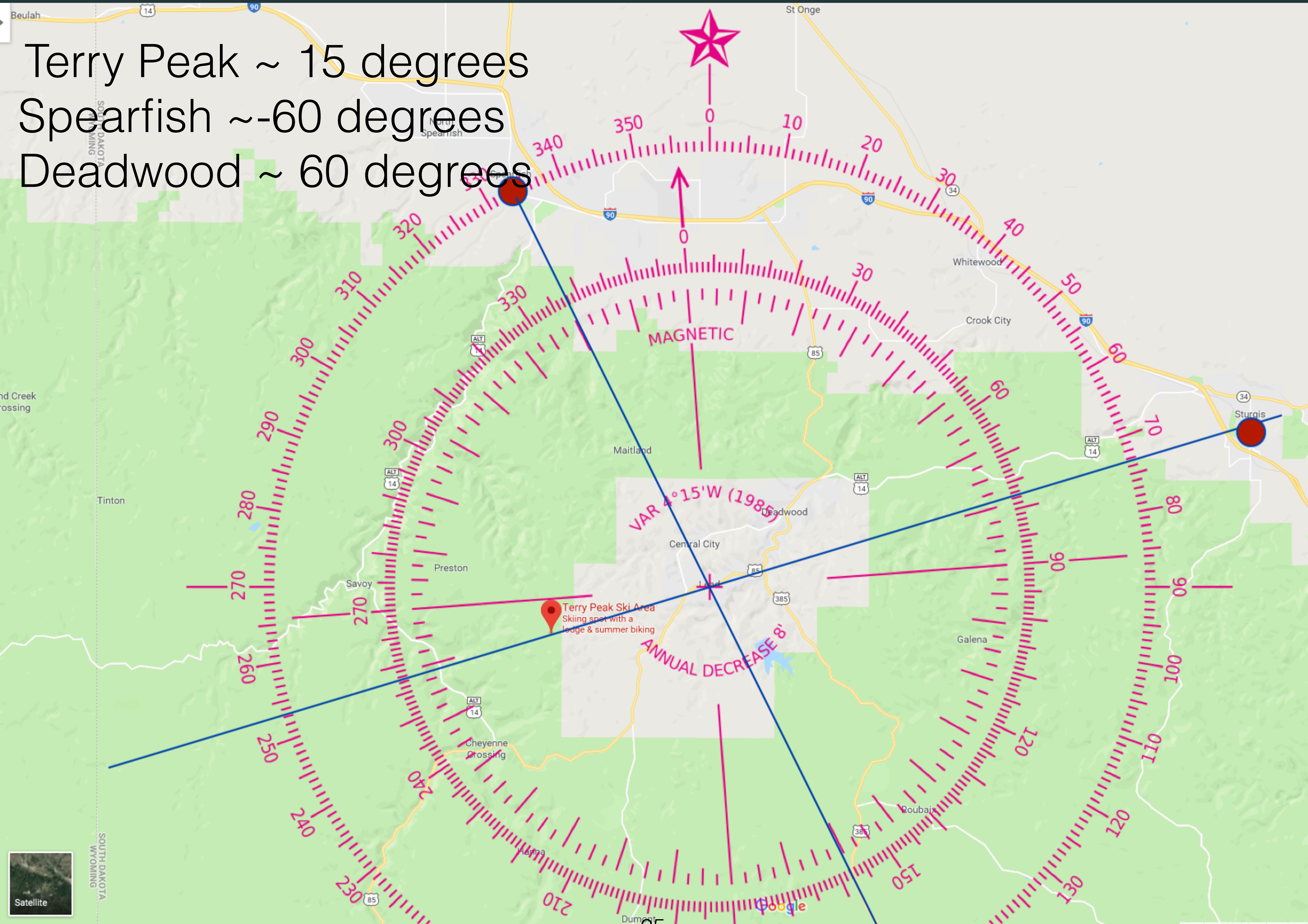
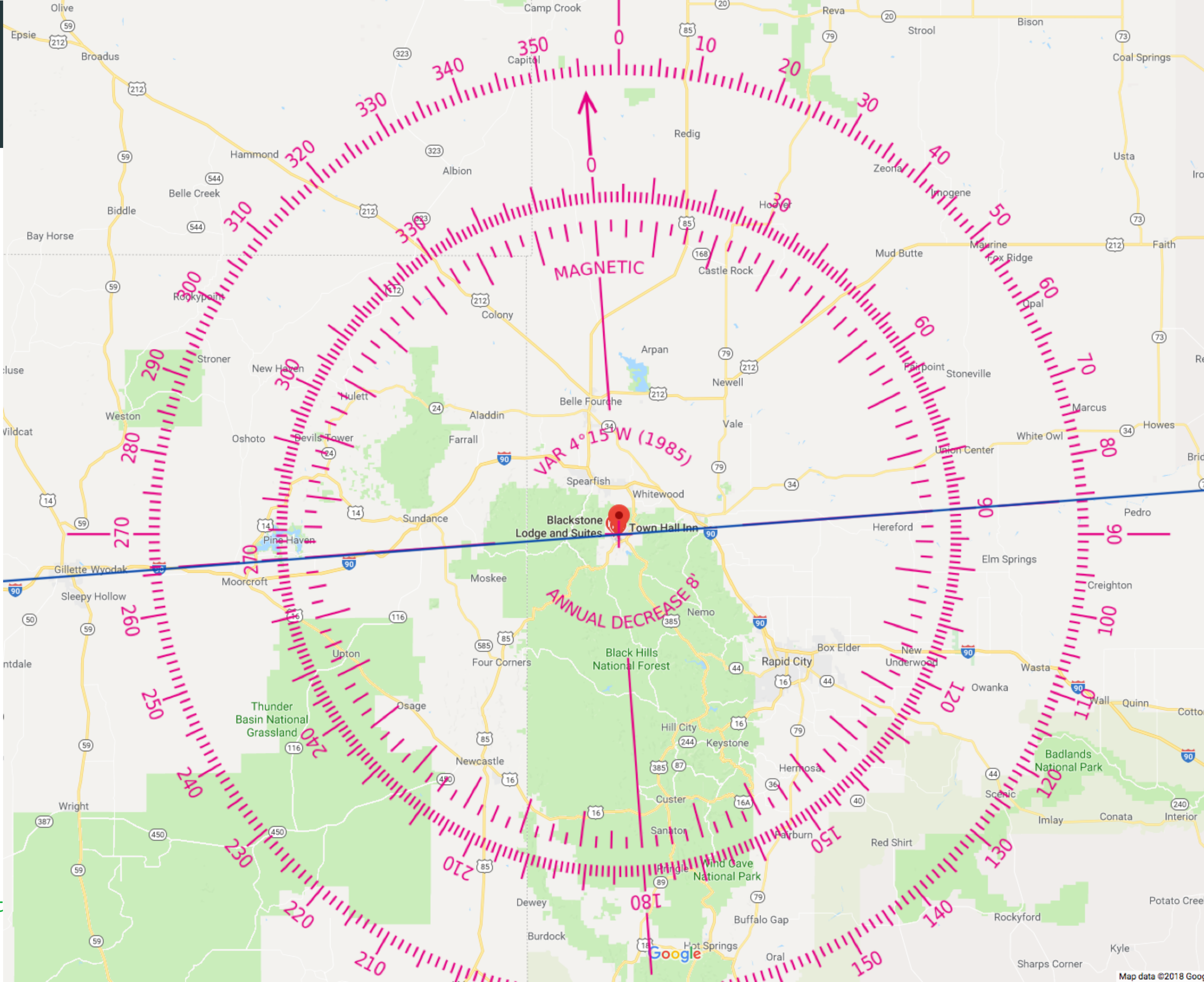
So…what is it?

- No clue! It's propagating in the East direction (that's not source direction…)
- => It's coming almost directly from the west.
- Terry Peak is roughly in the correct direction!
  - Might violate plane-wave assumption, though
- Gillette, Wyoming is in roughly the correct direction as well.

Terry Peak ~ 15 degrees
Spearfish ~-60 degrees
Deadwood ~ 60 degrees





MAGNETIC
VAR 4°15'W (1985)
ANNUAL DECREASE 8'
Blackstone Lodge and Suites
Town Hall Inn
Belle Fourche
Spearfish
Whitewood
Rapid City
Black Hills National Forest
Thunder Basin National Grassland
Badlands National Park
Wind Cave National Park
Sundance
Devils Tower
Hulett
Aladdin
Colony
Newell
Vale
Sturgis
Box Elder
New Underwood
Wasta
Wall
Hill City
Keystone
Custer
Hermosa
Hot Springs
Newcastle
Upton
Osage
Moorcroft
Pine Haven
Gillette Wyodak
Sleepy Hollow
Wright
Broadus
Hammond
Alzada
Belle Creek
Biddle
Bay Horse
Camp Crook
Capitol
Albion
Redig
Reva
Strool
Bison
Coal Springs
Usta
Zeona
Imogene
Maurine
Fox Ridge
Mud Butte
Castle Rock
Opal
Faith
Fairpoint
Stoneville
Marcus
White Owl
Howes
Union Center
Hereford
Elm Springs
Creighton
Pedro
Owanka
Quinn
Scenic
Interior
Conata
Imlay
Red Shirt
Buffalo Gap
Oral
Rockyford
Potato Creek
Kyle
Sharps Corner
Dewey
Burdock
Fairburn
Sanator
Pringle
Four Corners
Moskee
Farrall
Oshoto
Stroner
New Haven
Weston
Rockypoint
Arpan
Nemo
Map data ©2018 Google

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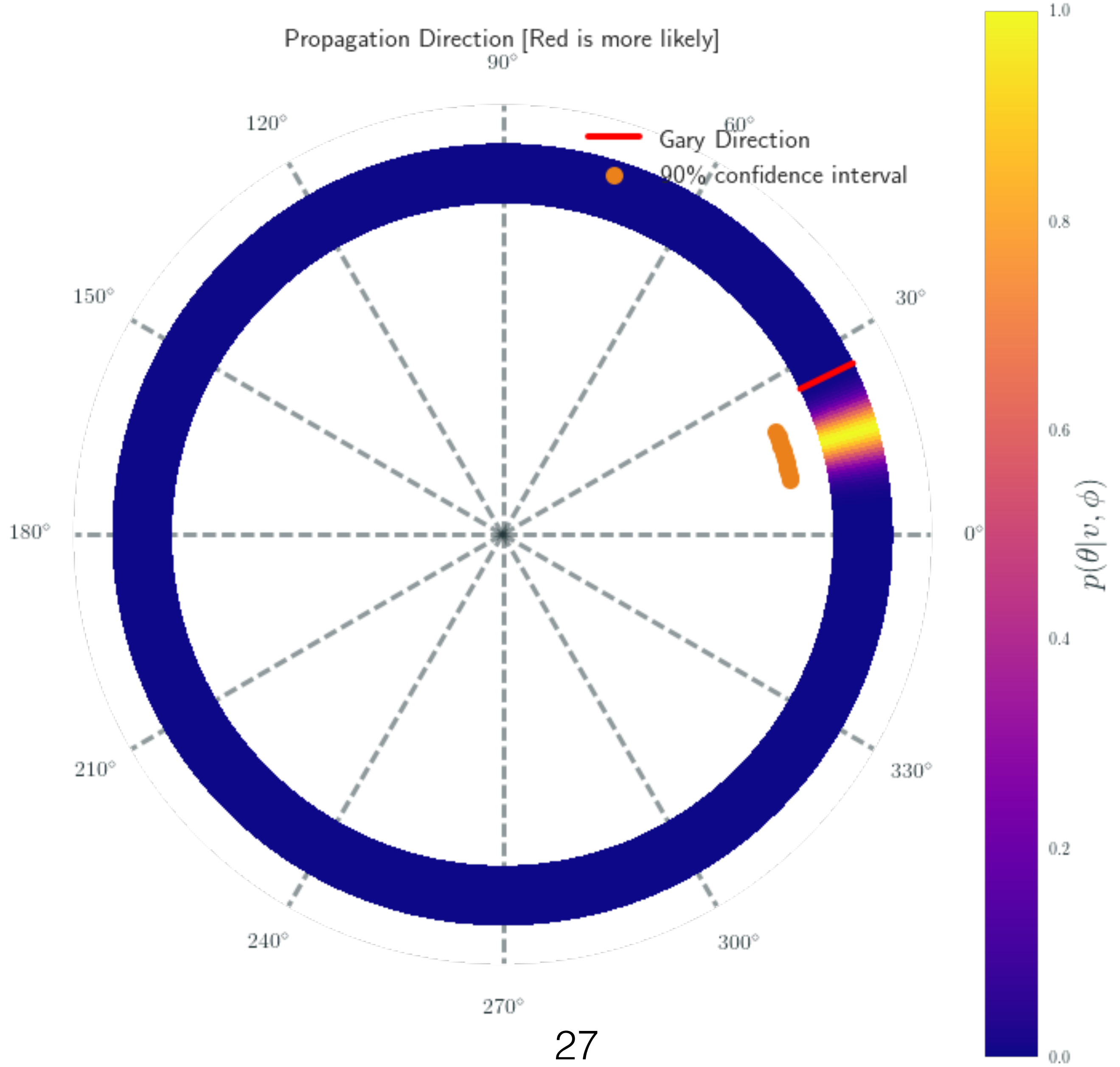
(Direction check on Gary’s event)

- Timing analysis check of whether we’re getting propagation direction or source direction using one of Gary’s events



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Next steps

- Calculate Newtonian noise from these maps
- Try to use R-wave eigenfunction so that we can include stations at several depths…although we won't have a measurement at this frequency
- Maybe try to measure R-wave eigenfunction using this as well?