Active and Passive Surface Wave Testing: Addressing Uncertainty using Open-Source Tools

Inversion of Site 1

With Multi-Mode and f_0

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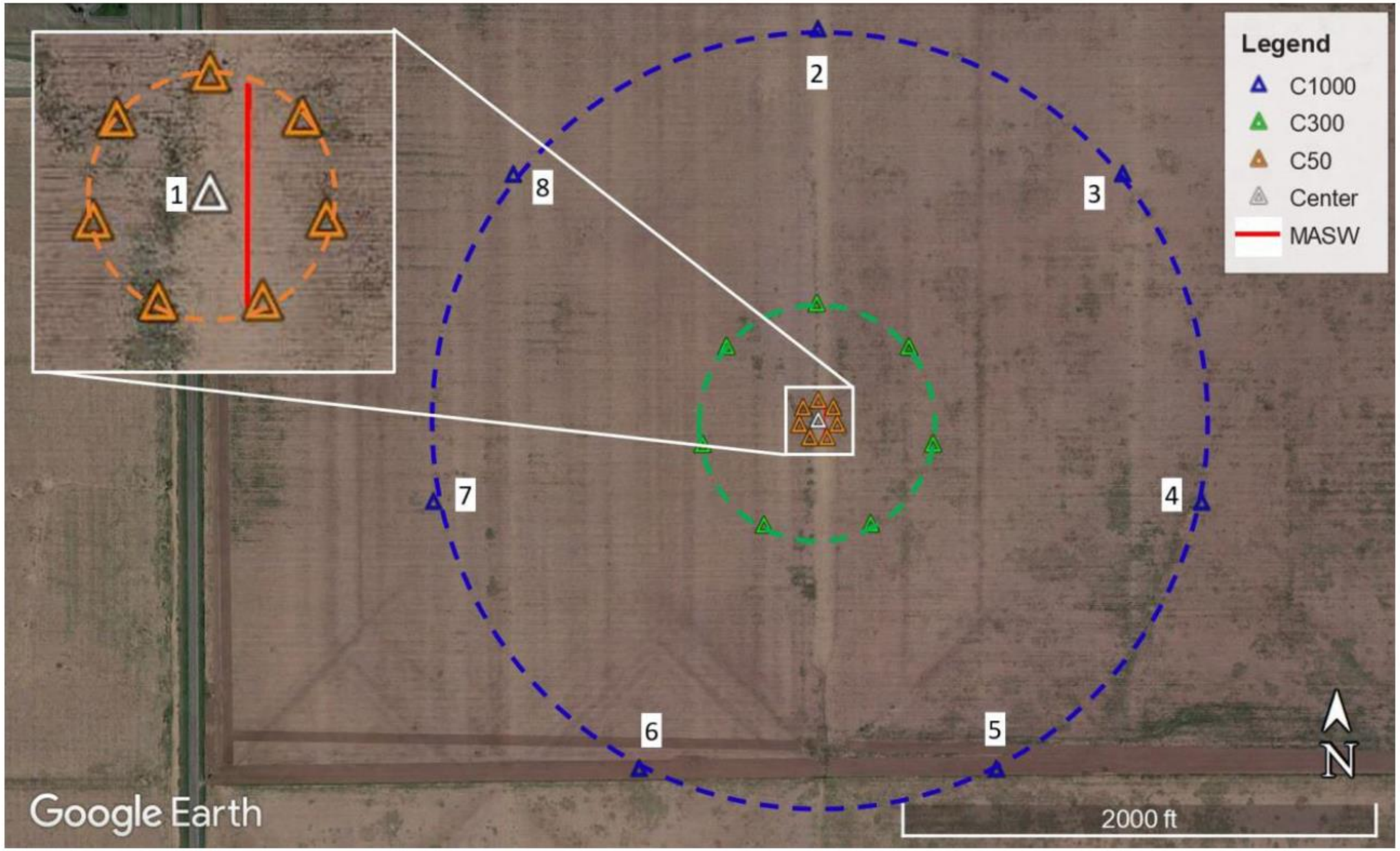
Utah State University, Logan, Utah; 29 July – 1 August 2024

Site 1

One MASW Array
Three MAM Circular Arrays



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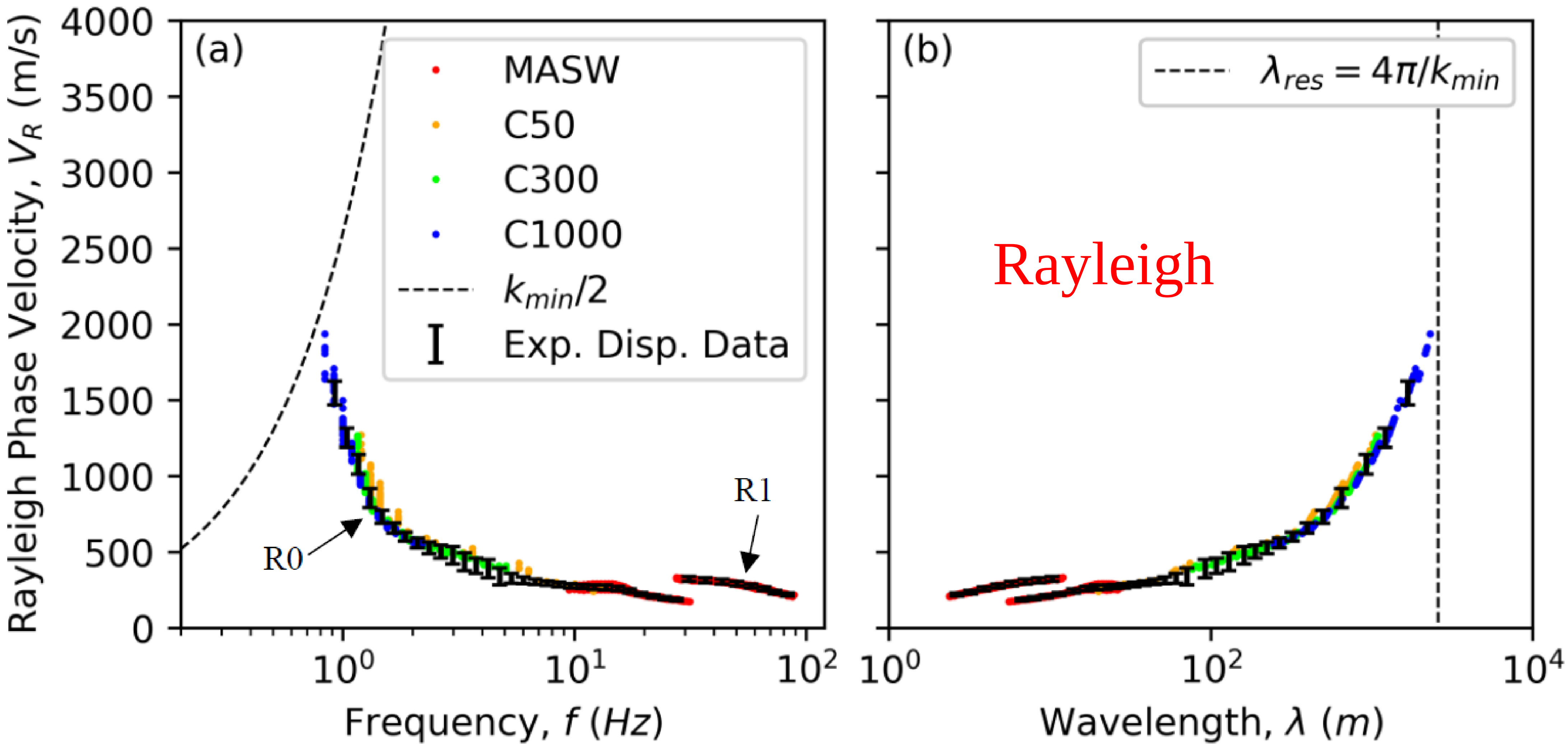
Site 1

Will be skipping processing and solely focus on inverting the experimental dispersion data.



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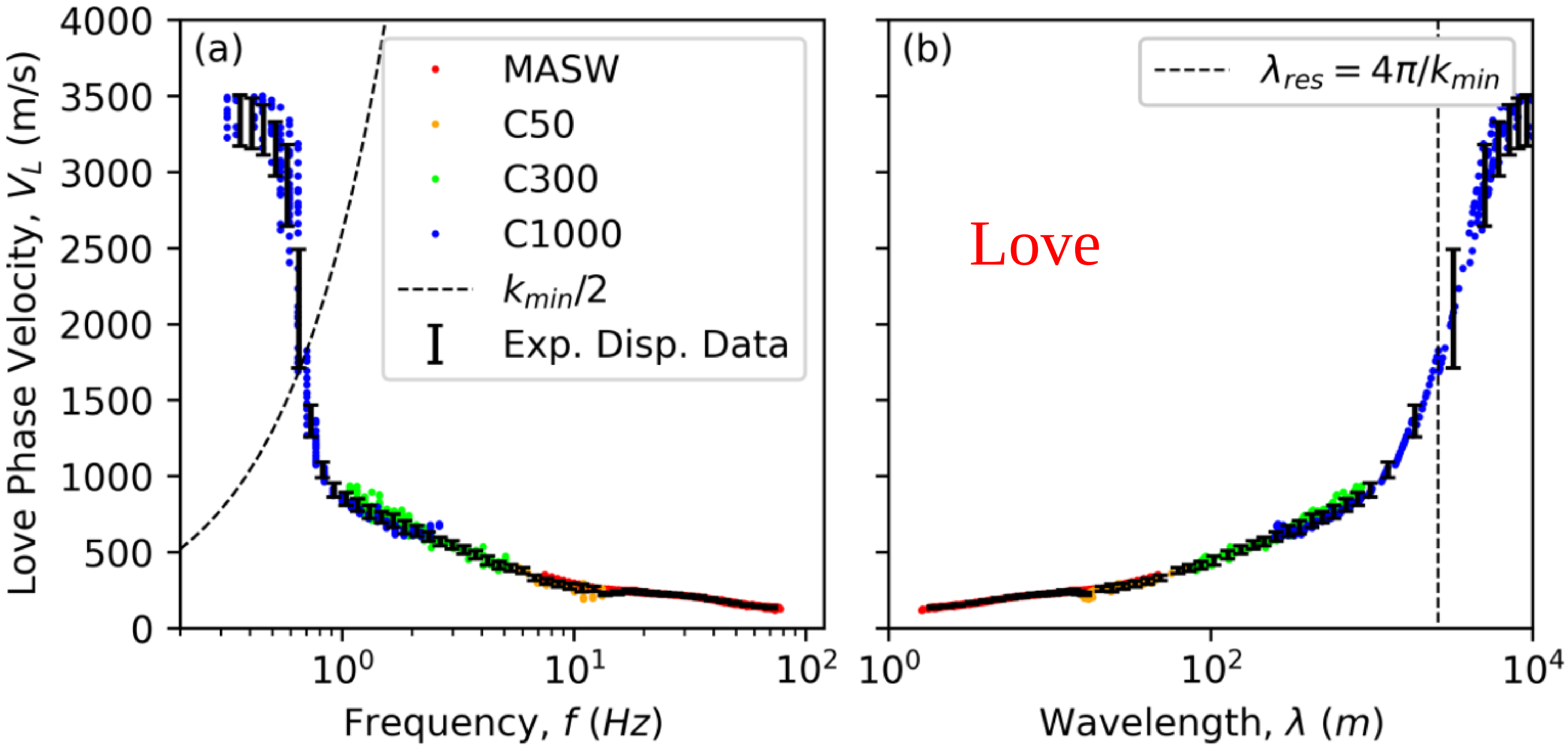
Site 1

Will be skipping processing and solely focus on inverting the experimental dispersion data.



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Will be skipping processing of HVSR and focus solely on using the f_0 resonance.

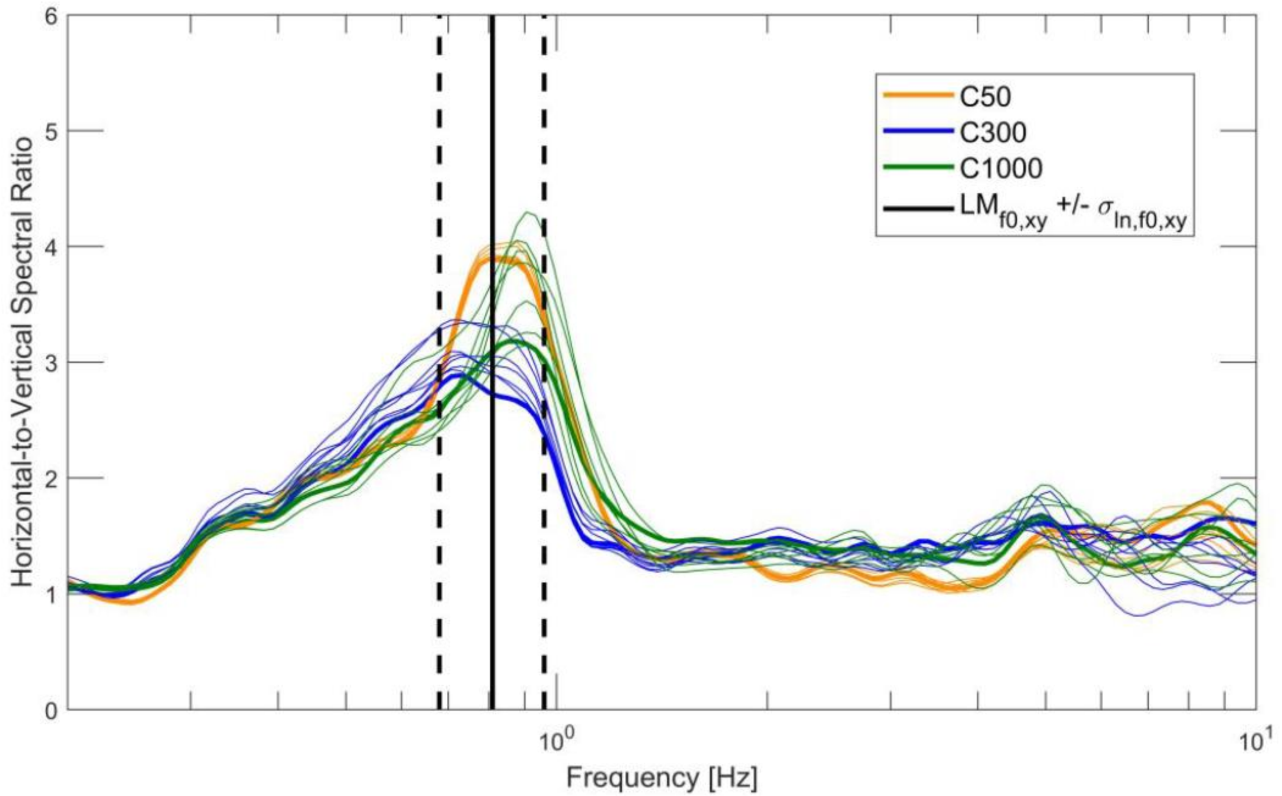

Figure 6: Lognormal-median H/V spectral ratio curves considering azimuthal variability derived from all single station seismometer recordings for the MAM arrays at **Site 1**. The fundamental frequency for the site is statistically represented by the spatial median fundamental frequency **($LM_{f0,xy}$ = 0.81 Hz)** and its associated standard deviation in natural log space **($\sigma_{ln,f0,xy}$ = 0.17)**.

Note the original analysis used lognormal spatial statistics, however Dinver requires normal statistics.

So we need to make an approximation.

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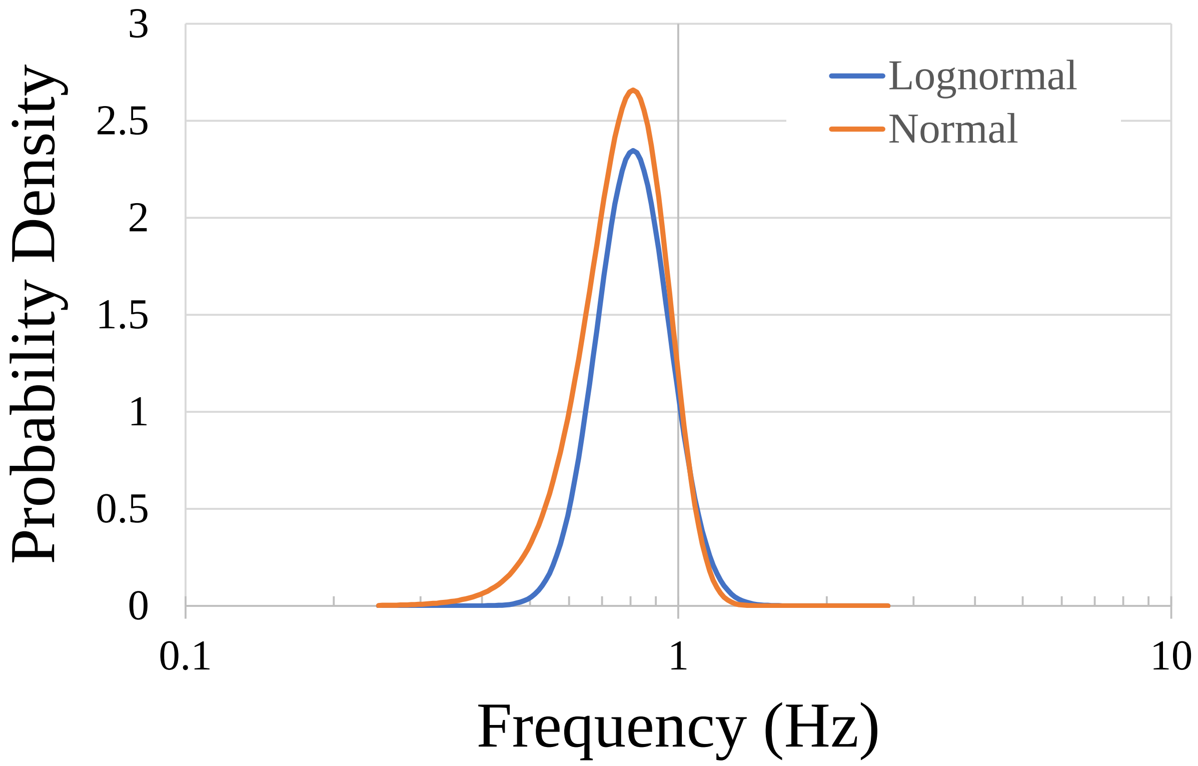

We will use:

$$\mu_{f0,xy} = 0.81\ Hz$$

$$\sigma_{f0,xy} = 0.15\ Hz$$

For input into Dinver.

Approximately match the implied probability distribution.*

*Ideally you would reprocess the HVSR data and have *hvsrpy* provide normal statistics, however that was not possible in this case.

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Defining the Inversion Target

Importing the Experimental Dispersion Data

1. Select the desired approach by commenting/uncommenting the appropriate line in the cell below.
2. Review the figure to ensure your data has loaded correctly, then proceed to the next cell.

Back to top

[2]:

```
# Approach 1: Import from comma seperated text file (see swprepost documentation for details).
# target = swprepost.Target.from_csv("example.csv")

# Approach 2: Import from version 2.X.X dinver-style text file (see swprepost documentation for details).
target_l0 = swprepost.Target.from_txt_dinver("site1_l0.txt", version="2.10.1")
target_r0 = swprepost.Target.from_txt_dinver("site1_r0.txt", version="2.10.1")
target_r1 = swprepost.Target.from_txt_dinver("site1_r1.txt", version="2.10.1")

# Approach 3: Import from version 3.X.X dinver-style text file (see swprepost documentation for details).
# target = swprepost.Target.from_txt_dinver("example_dv3.txt", version="3.4.2")

fig, axs = plot_target(target_l0)
for ax in axs:
    ax.set_ylim(0, 3600)
plt.show()

fig, axs = plot_target(target_r0)
target_r1.plot(x="frequency", y="velocity", ax=axs[0])
target_r1.plot(x="wavelength", y="velocity", ax=axs[1])
for ax in axs:
    ax.set_ylim(0, 3600)
plt.show()
print("Import successful, you may proceed.")
```

Files are in the Geopsy v2.10.1 format.

Will use *swprepost* to convert; so we can load all of the targets into Dinver.

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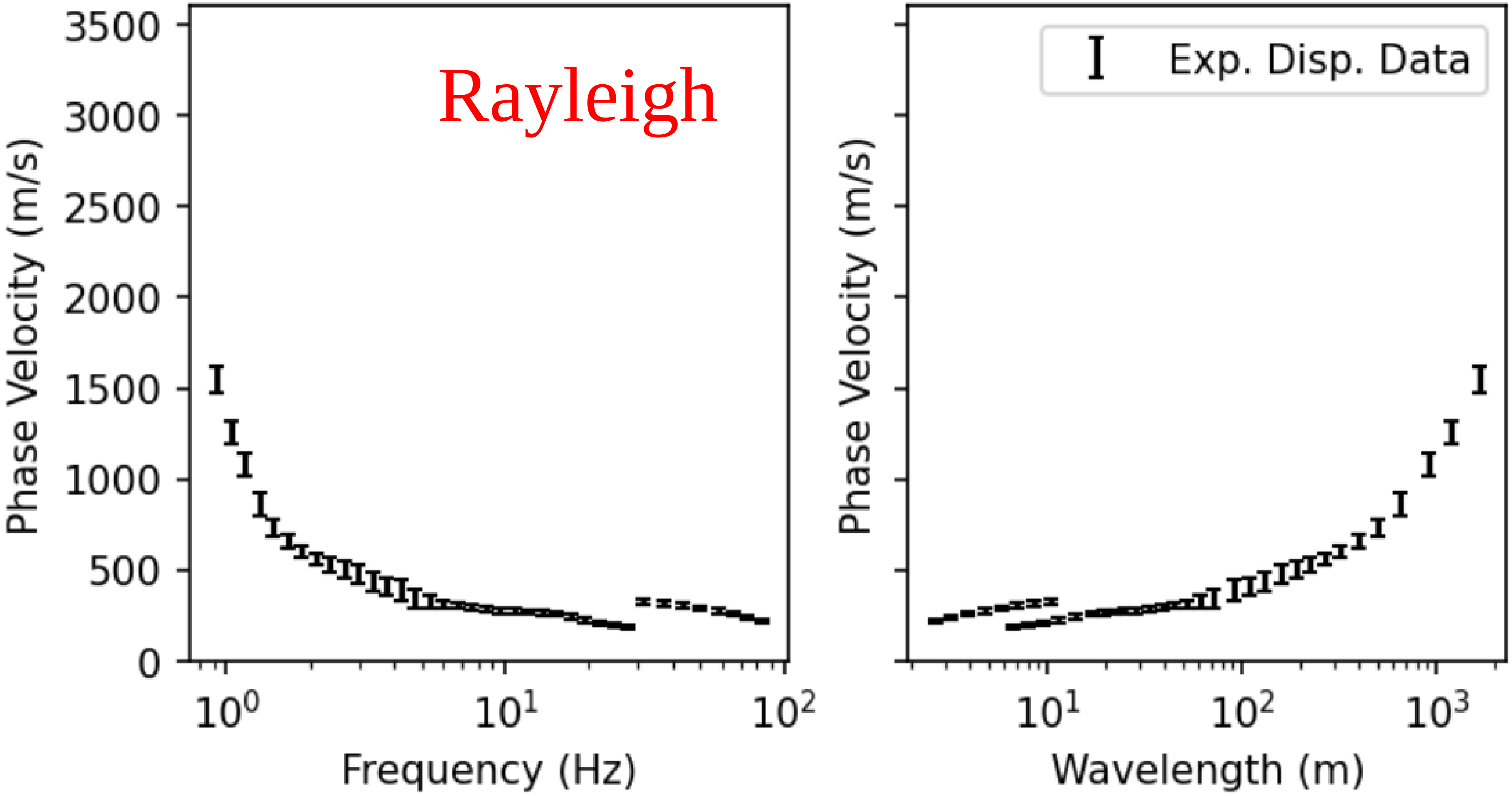
$\lambda_{min} = 2.5 \text{ m} \quad \lambda_{max} = 1670 \text{ m}$



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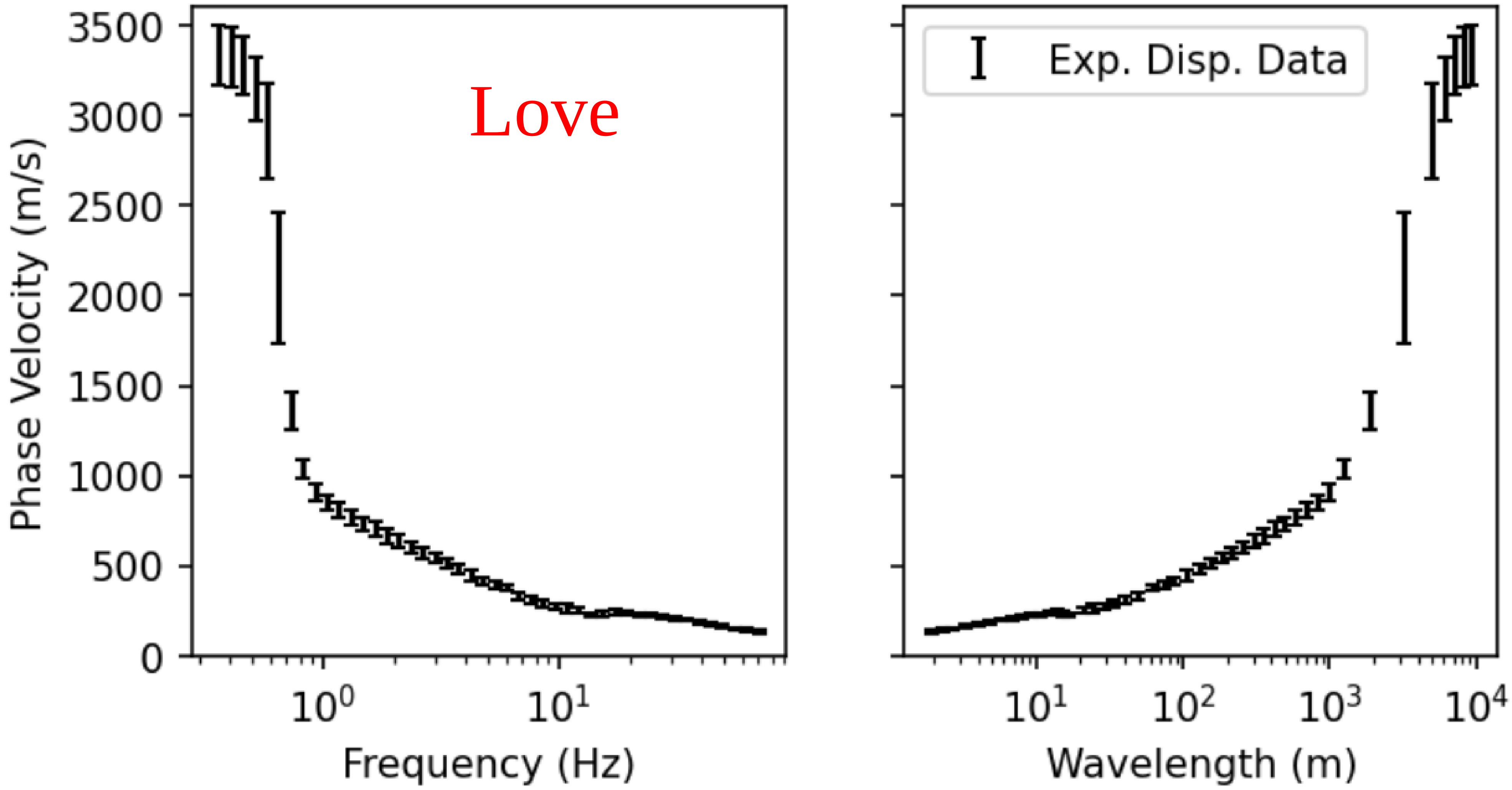
$\lambda_{min} = 2\text{ m} \quad \lambda_{max} = 9200\text{ m}$



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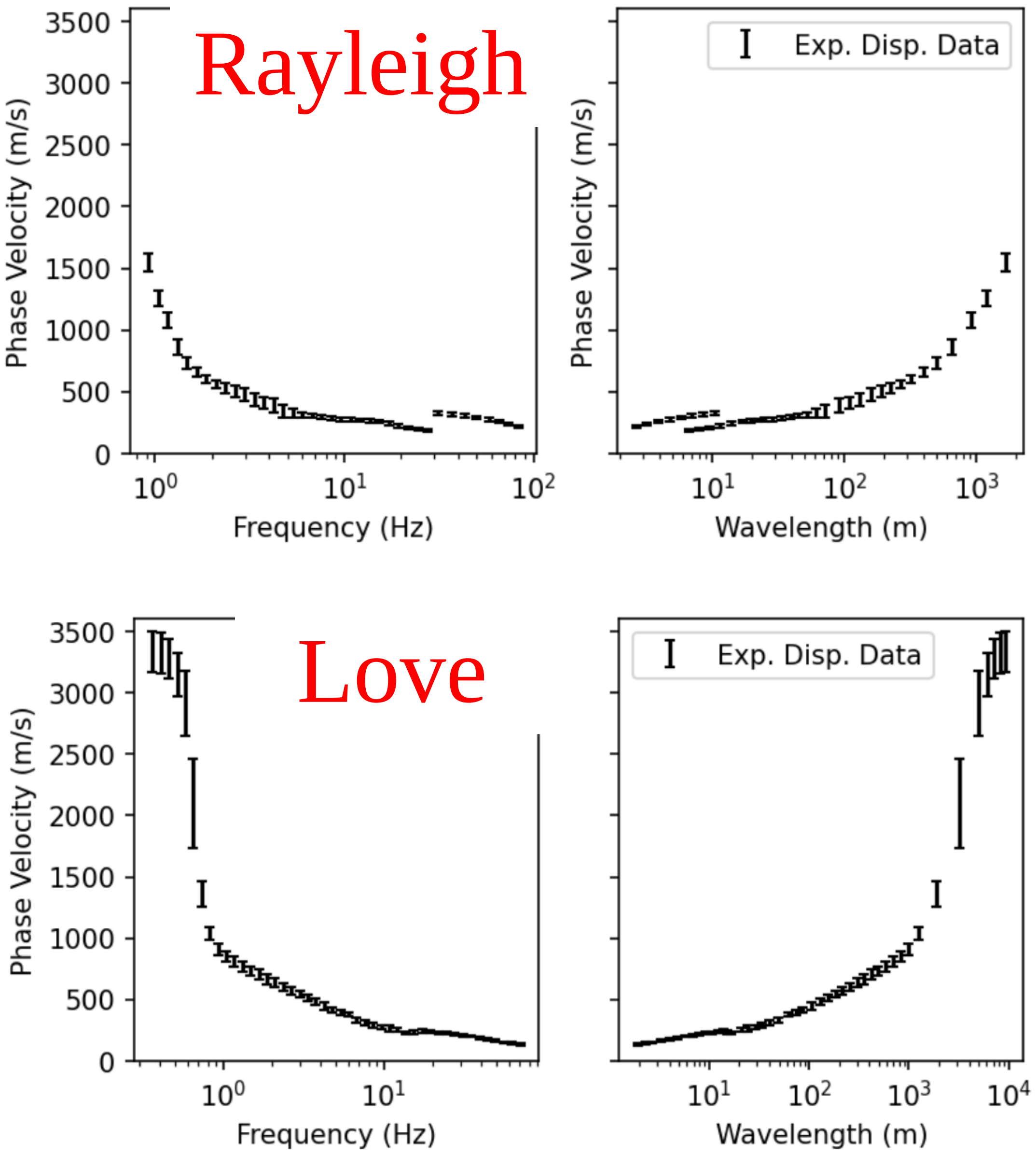

Overall for the joint inversion

$$\lambda_{min} = 2 \text{ m}$$

$$\lambda_{max} = 9200 \text{ m}$$

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Save Target to Disk

After importing your experimental dispersion data and completing any desired resampling, use the cell below to create the `0_targets` directory (if it does not exist) and write your `.target` file. You can confirm that the write was sucessful by examining the created `.target` file using the Dinver graphical user interface.

```
[4]:
# combine all targets together
target_r0.description = (("rayleigh", 0),)
target_r1.description = (("rayleigh", 1),)
target_l0.description = (("love", 0),)
target = swprepost.TargetSet([target_r0, target_r1, target_l0])

target_name = "tar1"        # Name of target file (no .target suffix)
version = "3.4.2"           # Version of Geopsy "2.10.1" or "3.4.2"

# Save to Disk
if os.path.isdir("0_targets/")==False:
    os.mkdir("0_targets/")
target.to_target(f"0_targets/{target_name}", version=version)

# Confirm file exists.
if os.path.exists(f"0_targets/{target_name}.target"):
    print(f"{target_name}.target exists, you may proceed.")
```

```
tar1.target exists, you may proceed.
```

Update descriptions of targets so *swprepost* can write the .target file for us.

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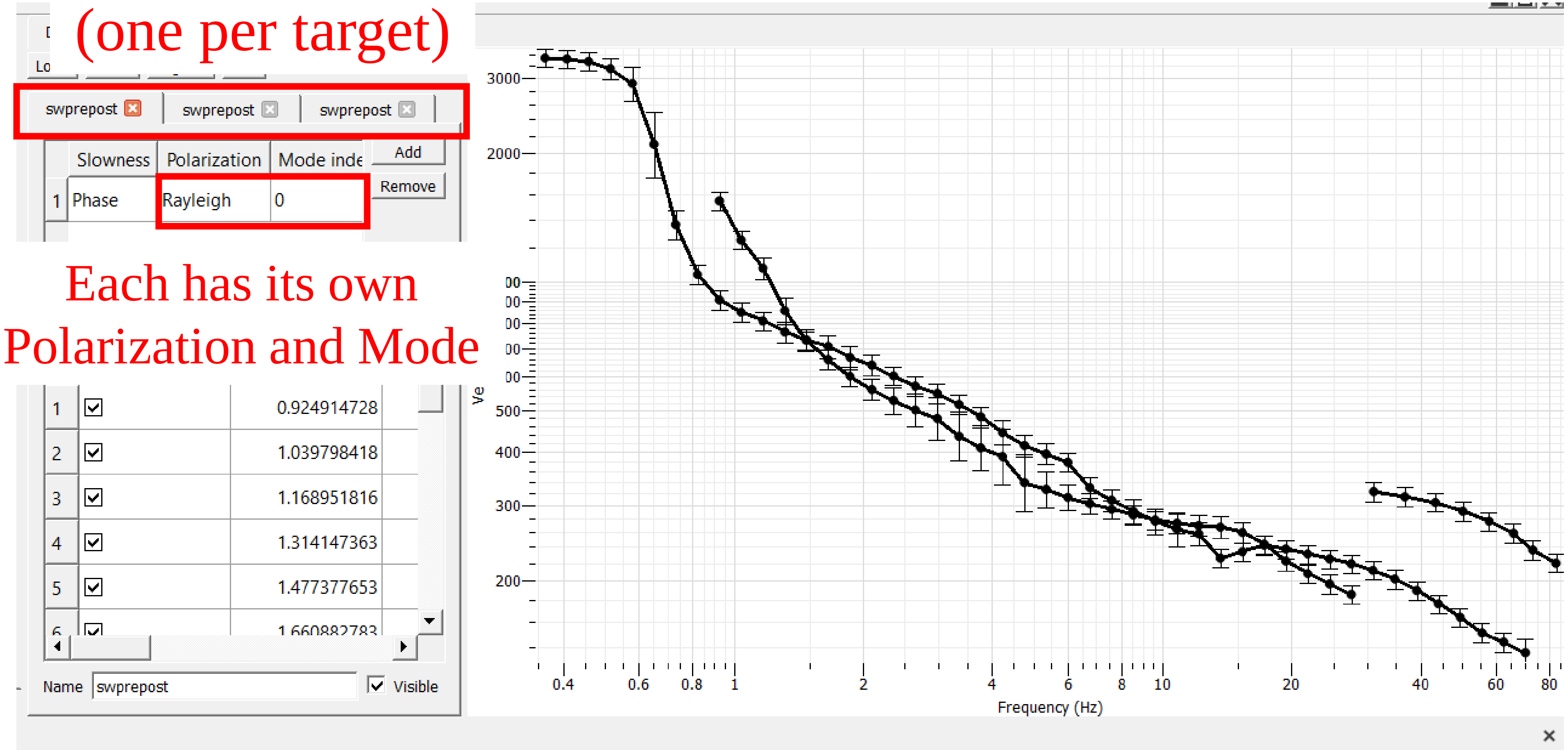
Three Tabs
(one per target)



Each has its own
Polarization and Mode

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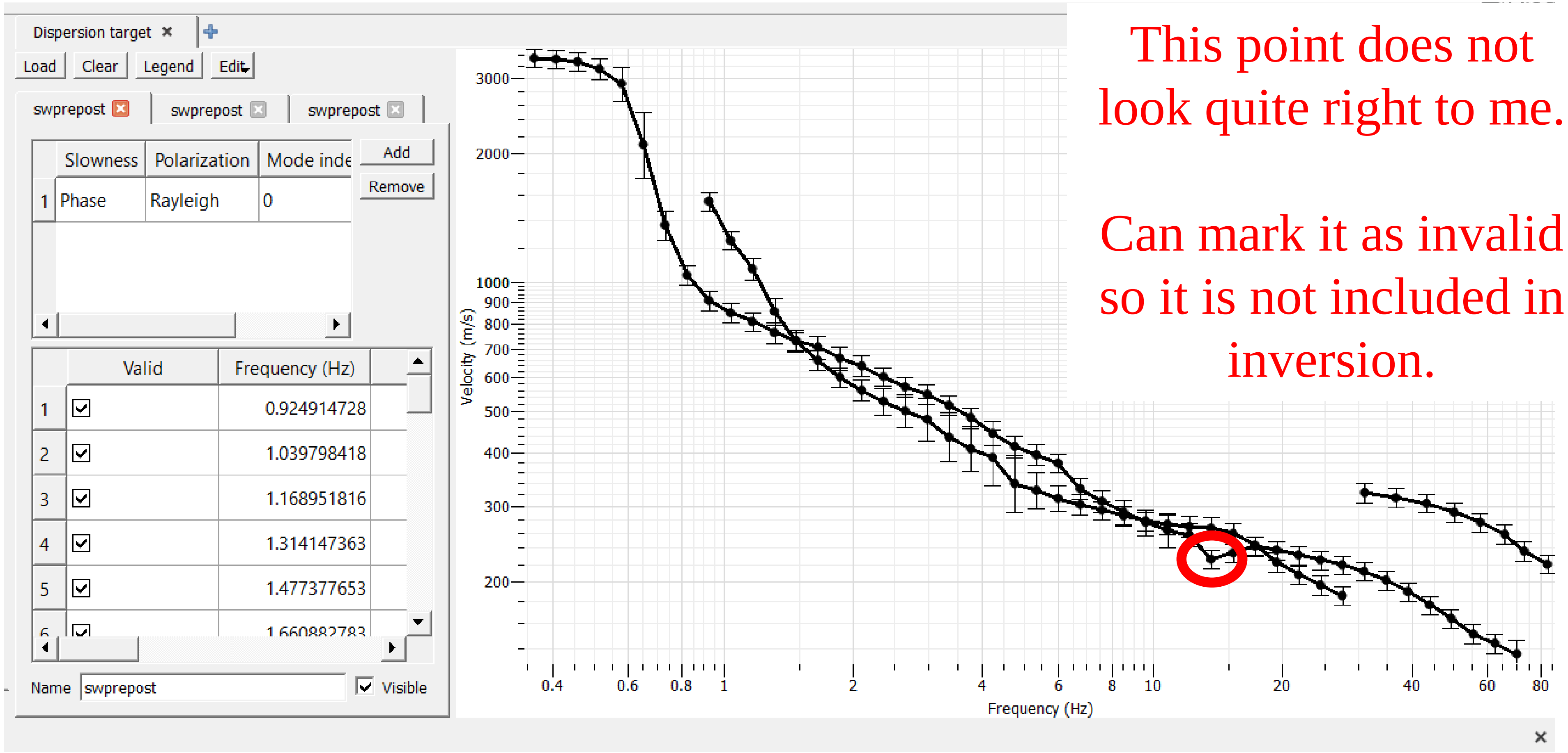

This point does not look quite right to me.

Can mark it as invalid so it is not included in inversion.

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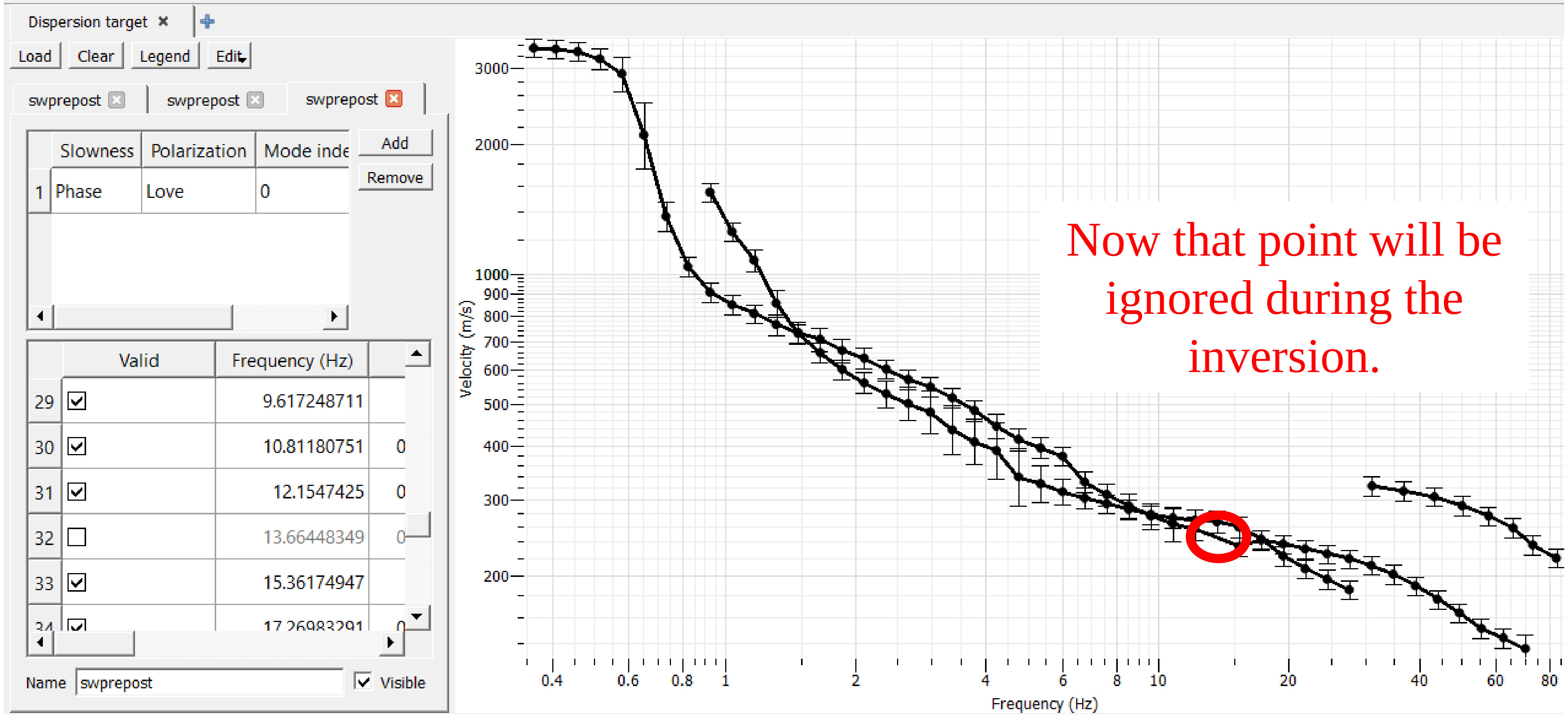

Now that point will be ignored during the inversion.

In general you want to make these checks during dispersion processing, but that was not possible here.

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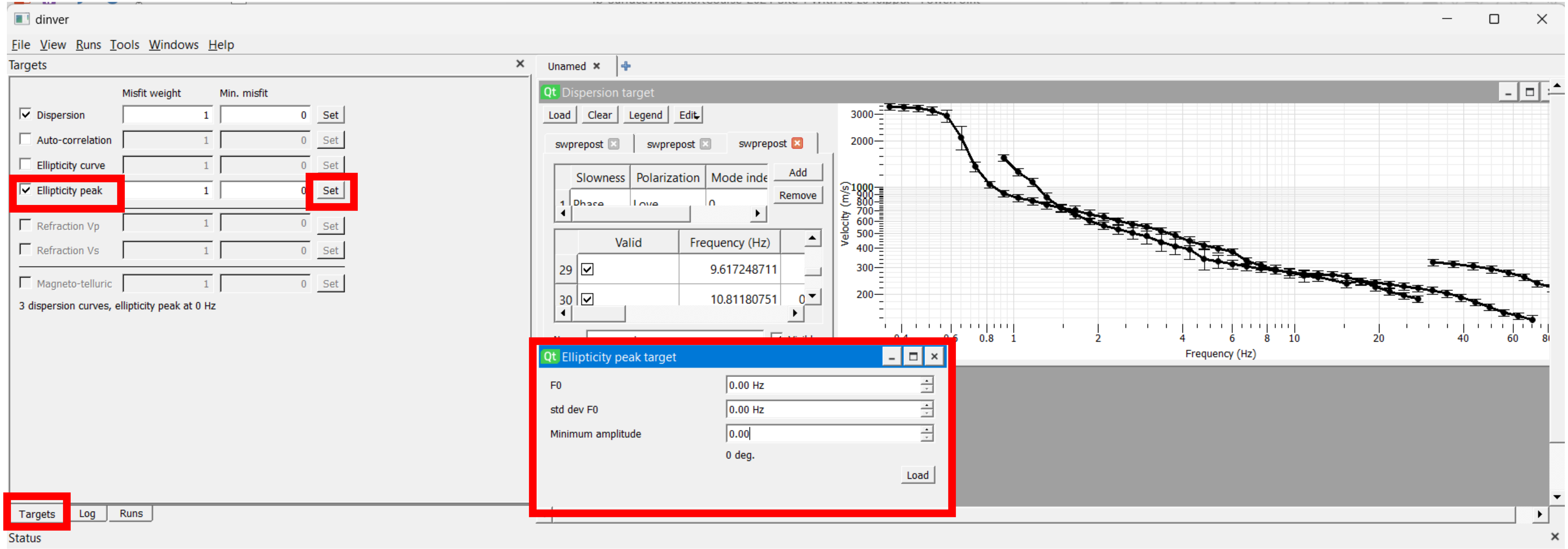
Now we need to include f_0.

Targets > Ellipticity Peak > Set



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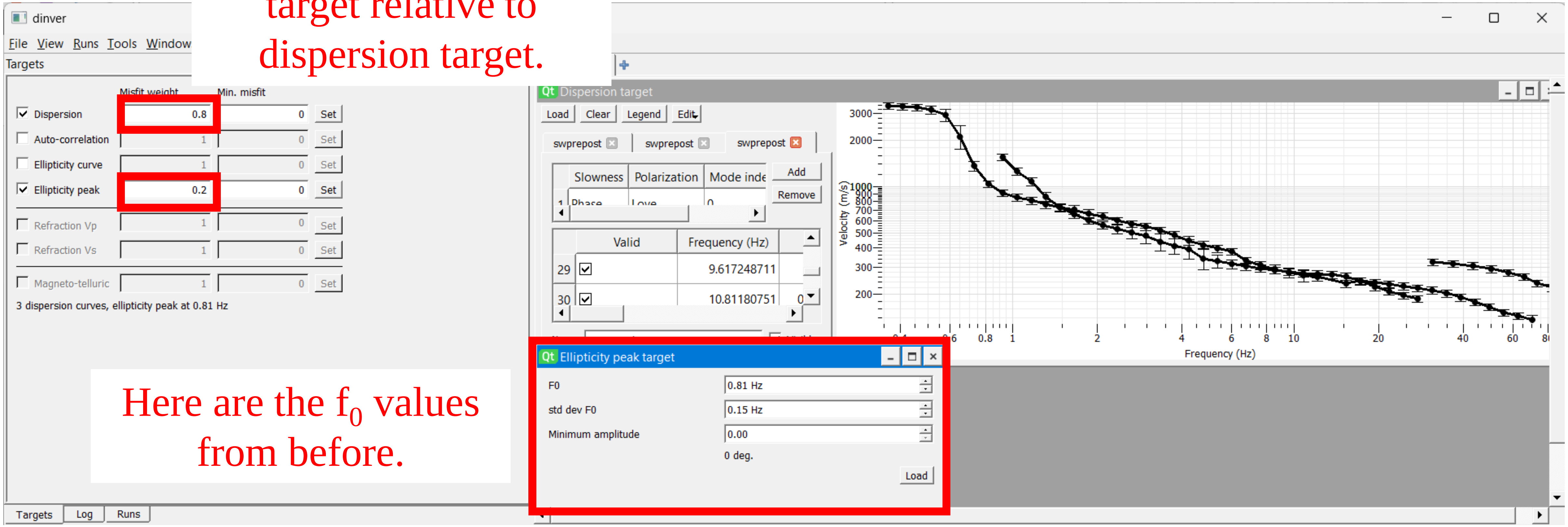
Also want to weight the ellipticity peak target relative to dispersion target.



Here are the f_0 values from before.

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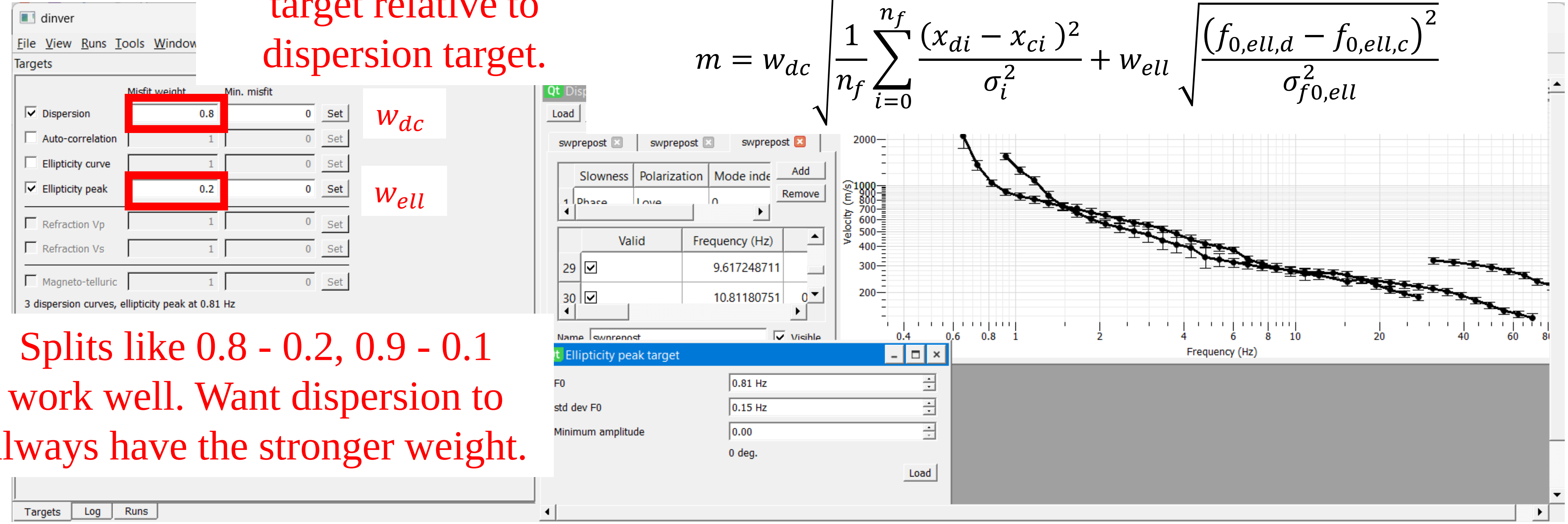
Misfit with Rayleigh Ellipticity
(Wathelet et al., 2004; Teague et al., 2018)

$$m = w_{dc}\, m_{dc} + w_{ell} m_{ell}$$

$$m = w_{dc}\sqrt{\frac{1}{n_f}\sum_{i=0}^{n_f}\frac{(x_{di} - x_{ci})^2}{\sigma_i^2}} + w_{ell}\sqrt{\frac{\left(f_{0,ell,d} - f_{0,ell,c}\right)^2}{\sigma_{f0,ell}^2}}$$

Also want to weight the ellipticity peak target relative to dispersion target.



Splits like 0.8 - 0.2, 0.9 - 0.1 work well. Want dispersion to always have the stronger weight.

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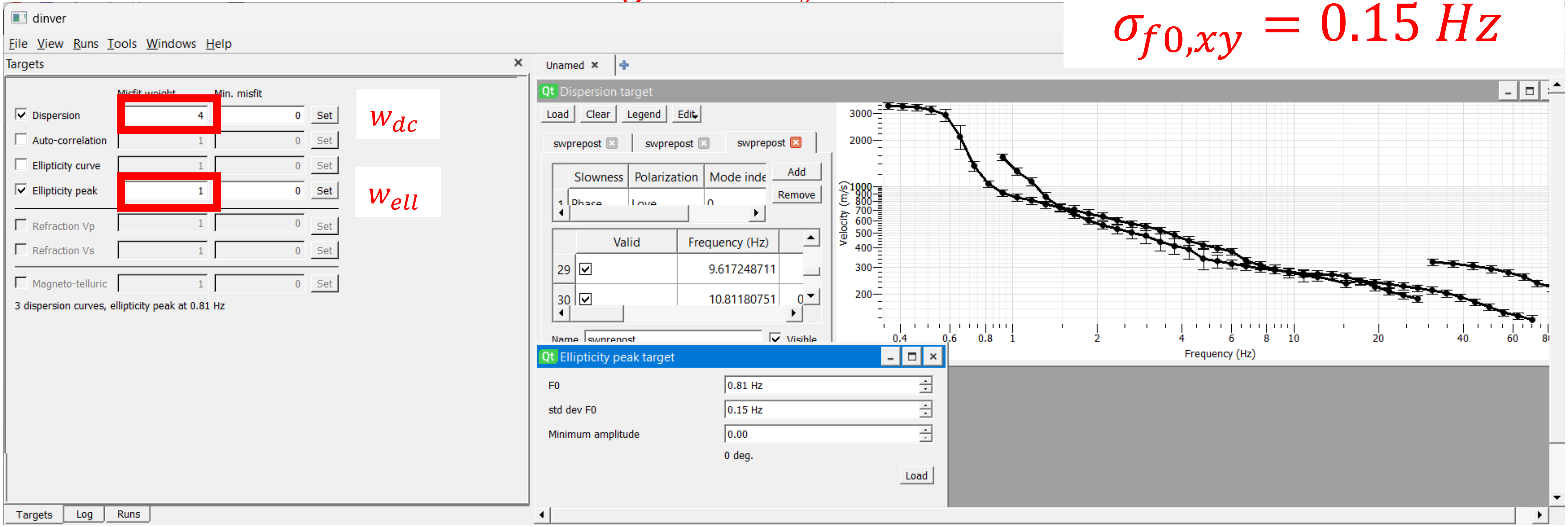
However, there is a bug in v3.4.2 that the ellipticity weight can only be 1. So we just scale Dispersion accordingly. Dinver scales the weights so they sum

$$\mu_{f0,xy} = 0.81\ Hz$$
$$\sigma_{f0,xy} = 0.15\ Hz$$



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Be cautious when making your selections as they can strongly bias your inversion results.

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•[5]:
```
# Minimum and maximum for all parameters. Refer to detailed instr
vp_min, vp_max, vp_dec = 200., 6000., False
vs_min, vs_max, vs_dec = 100., 3800., False
pr_min, pr_max = 0.1, 0.5
rh_min, rh_max = 2000., 2000.

# Layering by Number (LN) parameterizations to consider. Add or r
# See Vantassel and Cox (2021) for details.
lns = [5, 7, 9, 12]

# Layering Ratios (LRs) parameterizations to consider. Add or remove as desired.
# See Vantassel and Cox (2021) and Cox and Teague (2016) for details.
lrs = []

# Depth factor, typically 2 or 3.
depth_factor = 2

# Minimum and maximum wavelength, selected from experimental
# wmin, wmax = min(target.wavelength), max(target.wavelength)
wmin, wmax = 2, 9200
```

Set broad limits informed by dispersion data

Will use LNs for this example.

Will set minimum and maximum wavelength manually.

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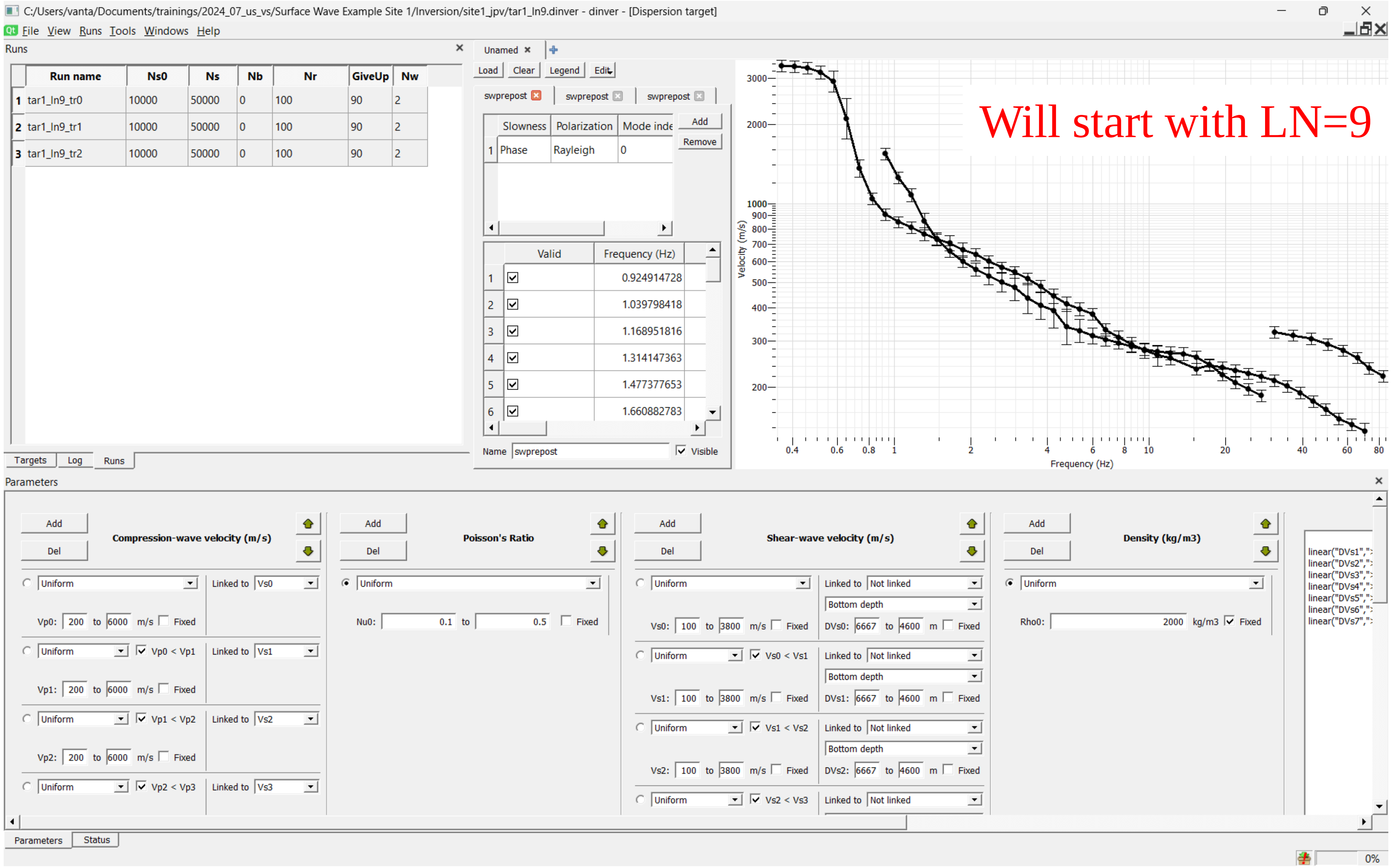

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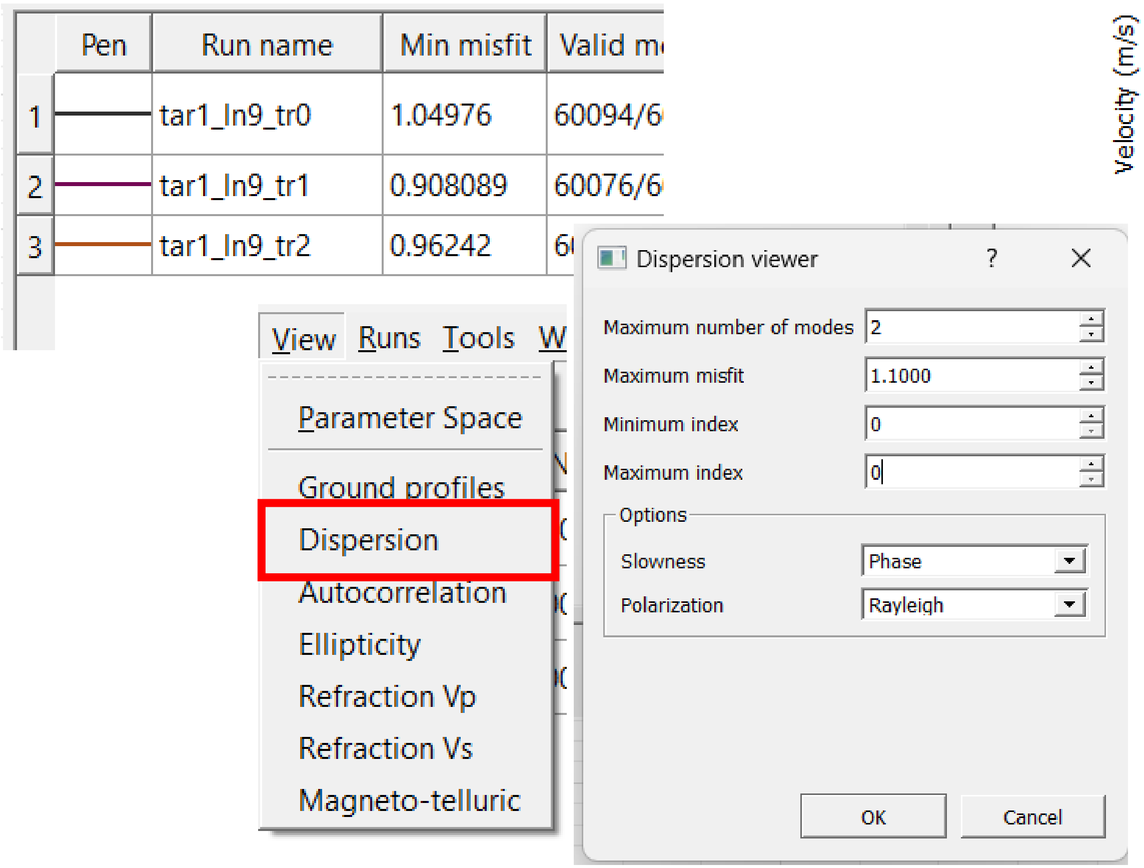
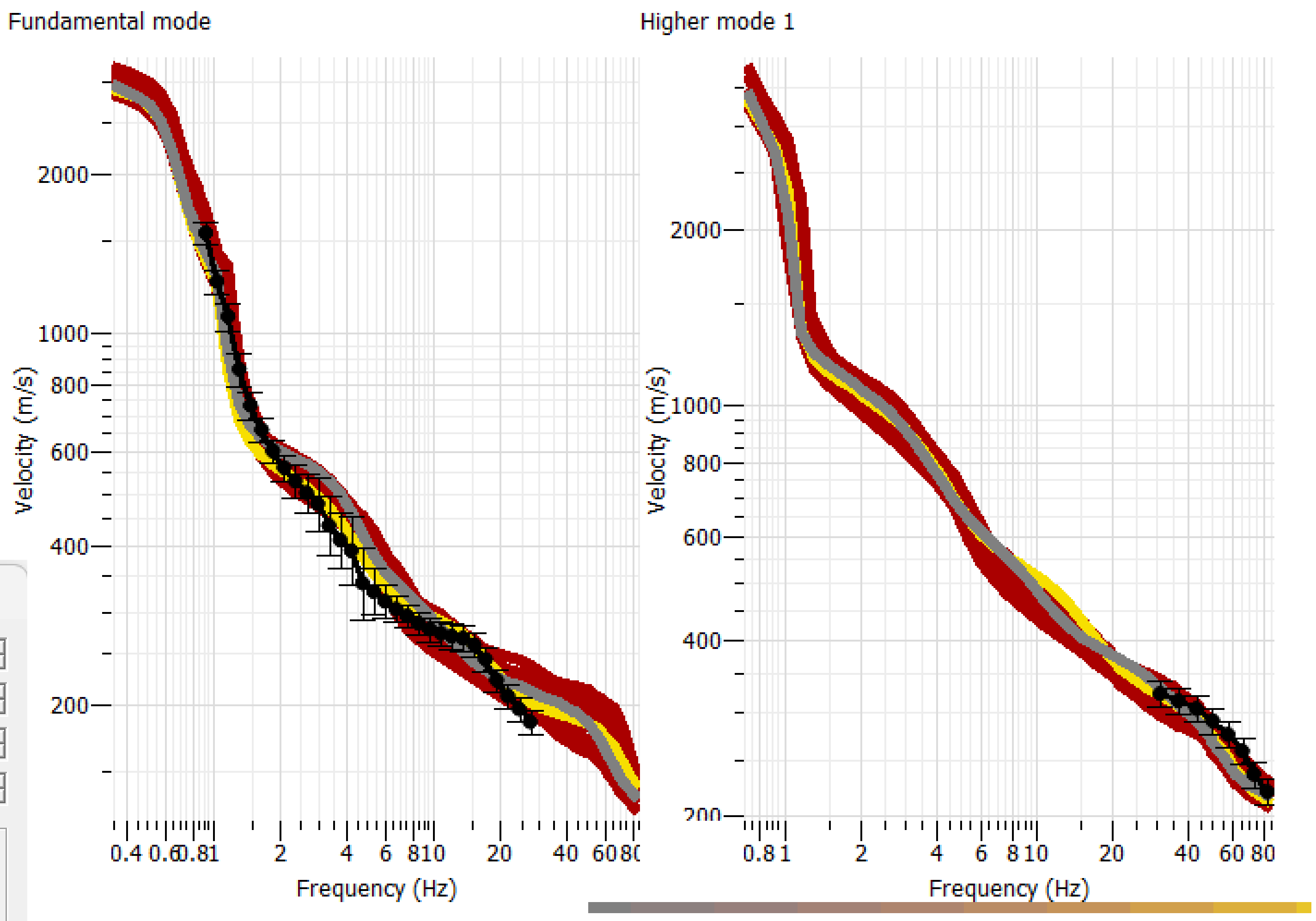
Will start with LN=9

Misfits are high; want to see why.





Two Rayleigh modes.

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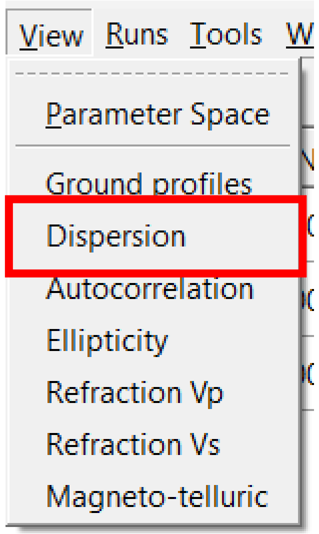
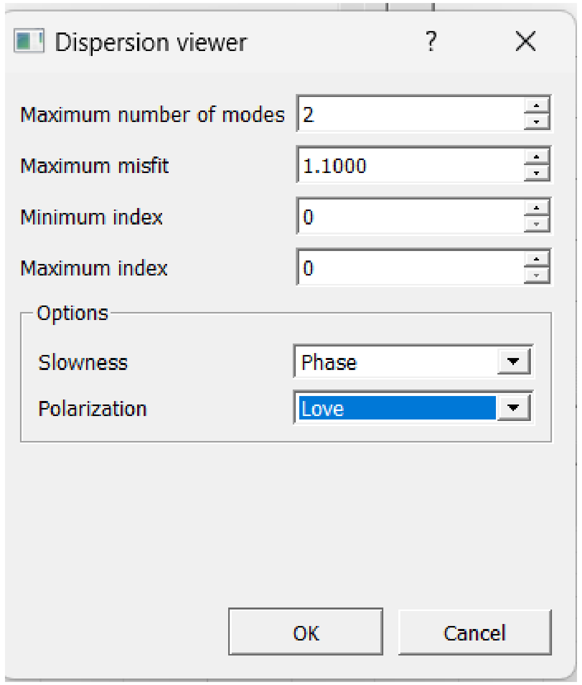
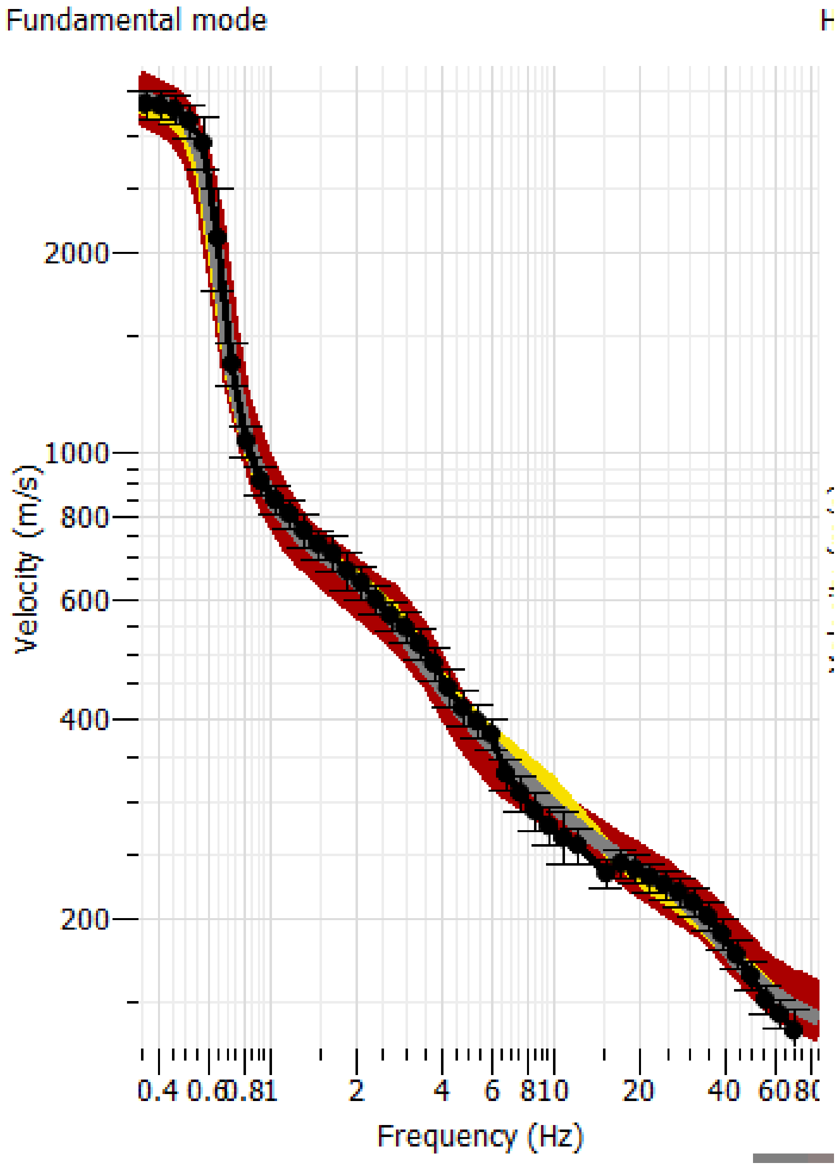
One Love mode.

	Pen	Run name	Min misfit	Valid m
1		tar1_In9_tr0	1.04976	60094/6
2		tar1_In9_tr1	0.908089	60076/6
3		tar1_In9_tr2	0.96242	60102/6







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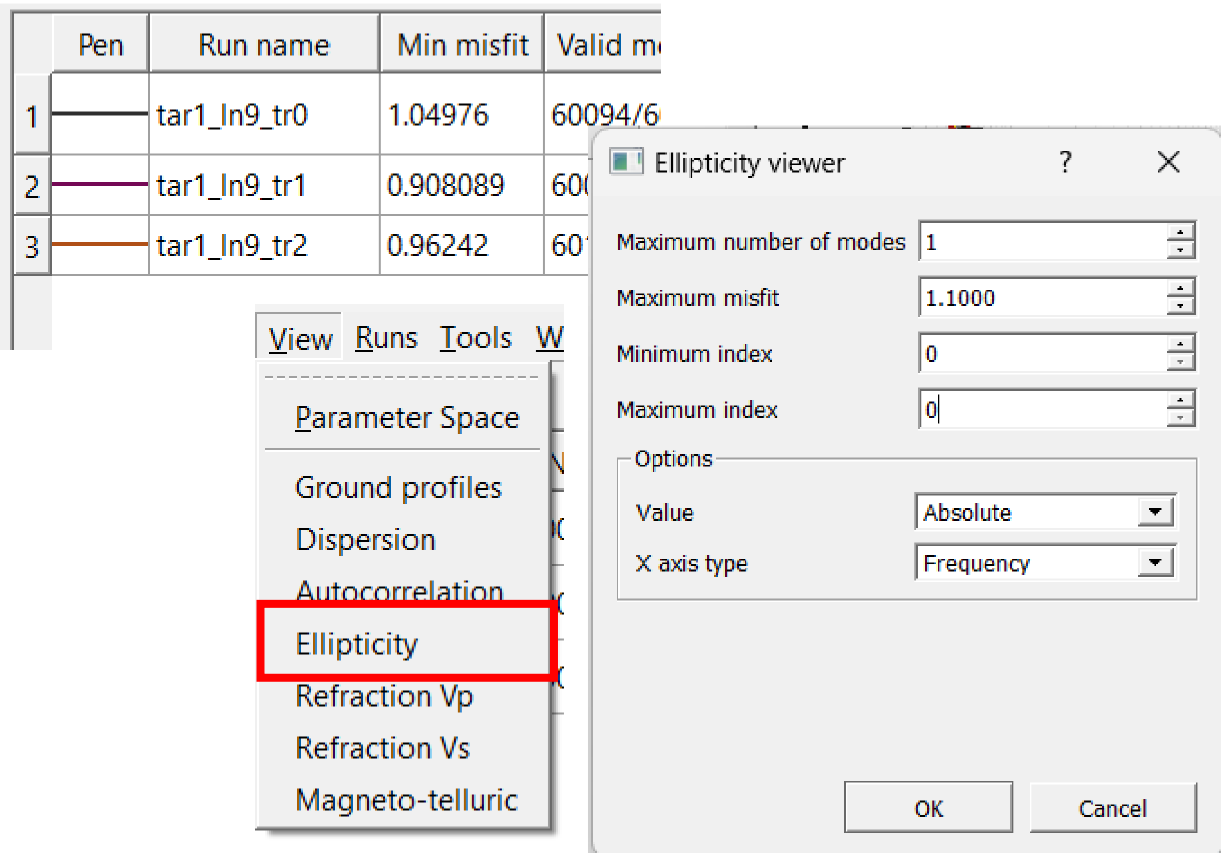
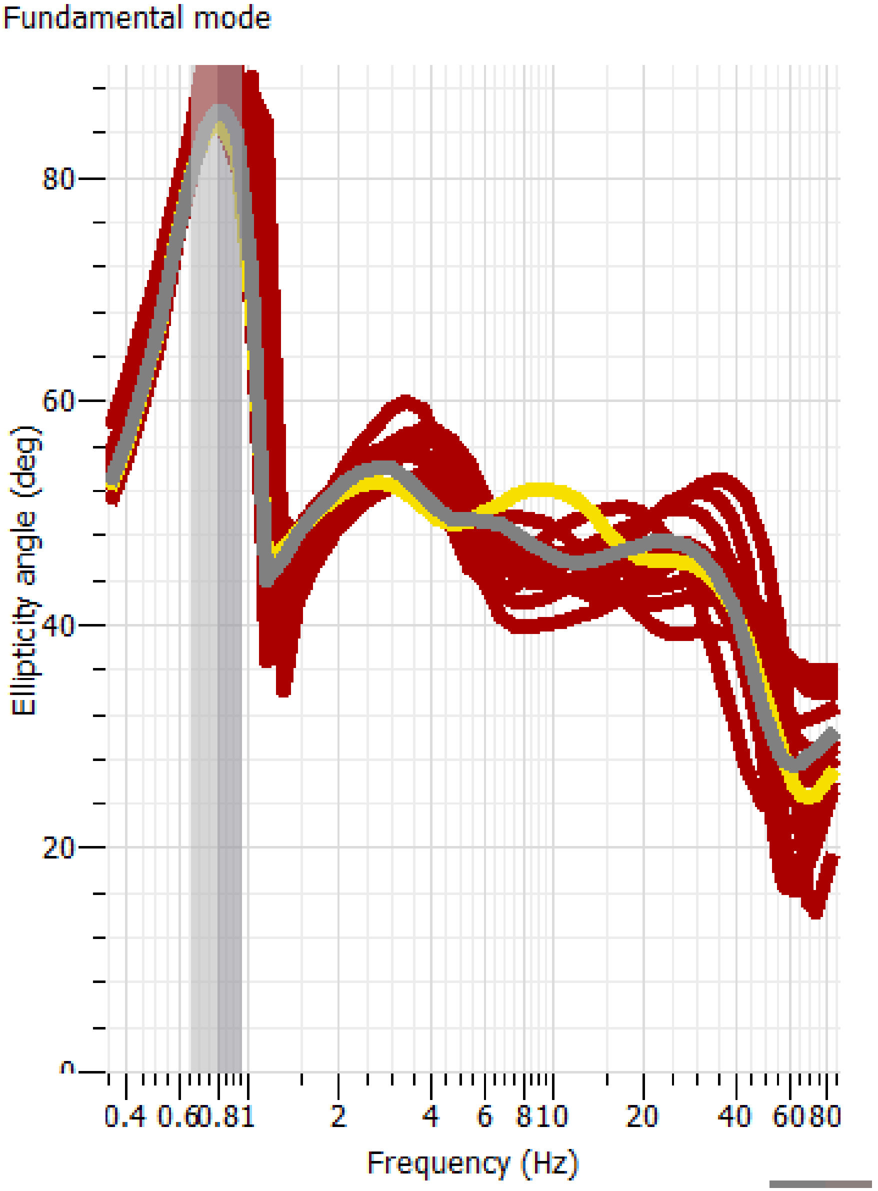
Rayleigh Ellipticity.





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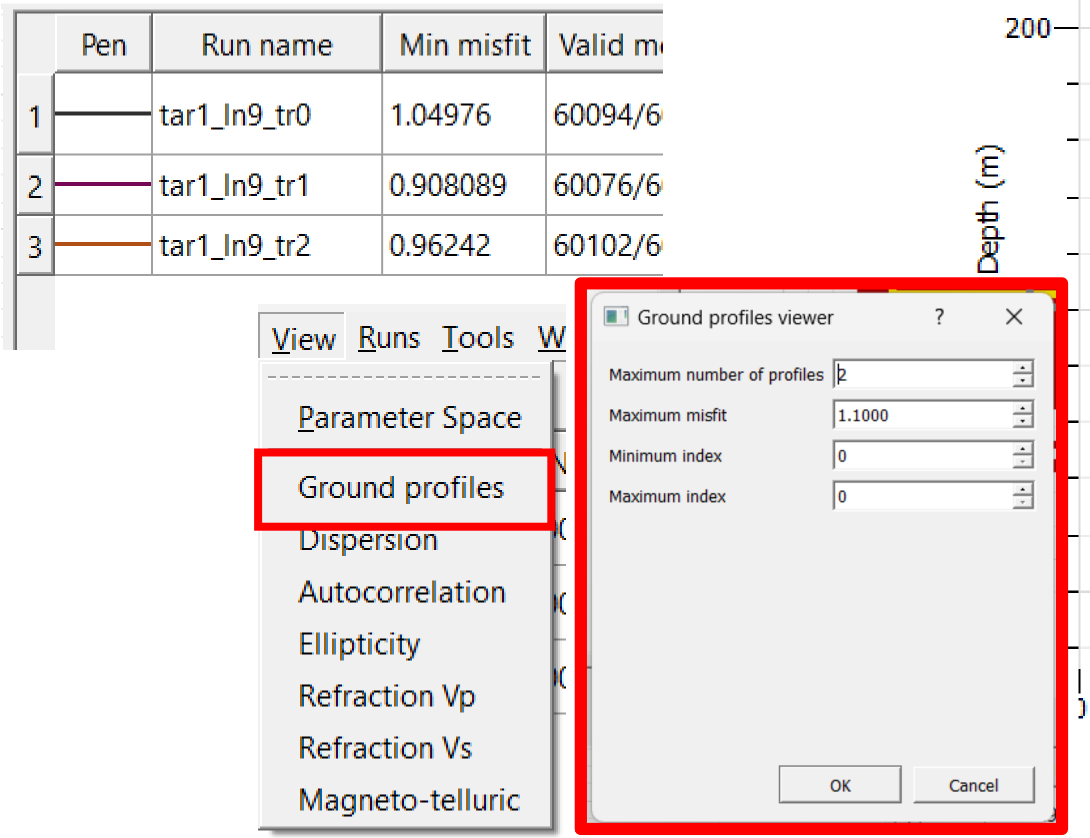
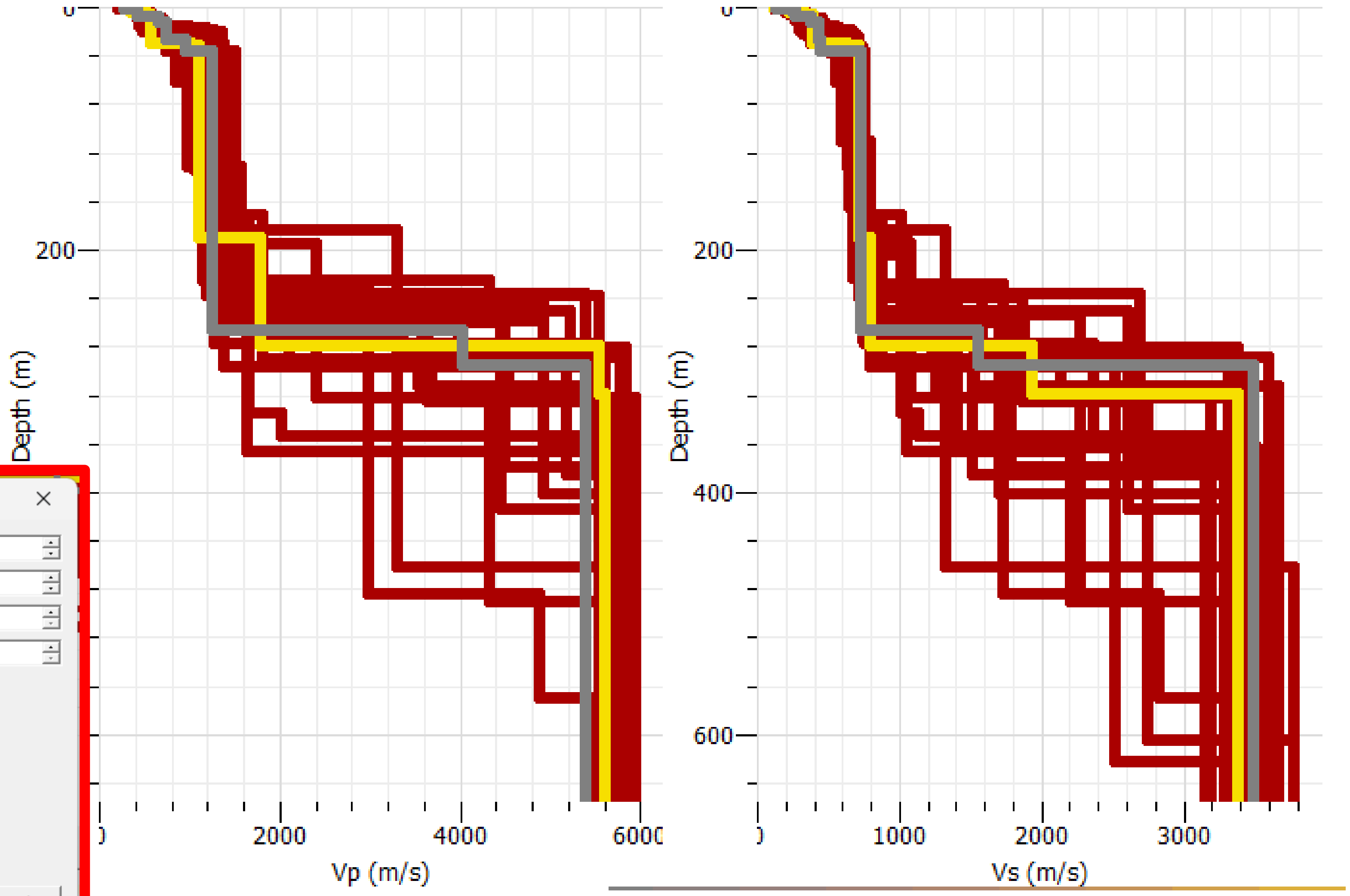
Ground Profiles





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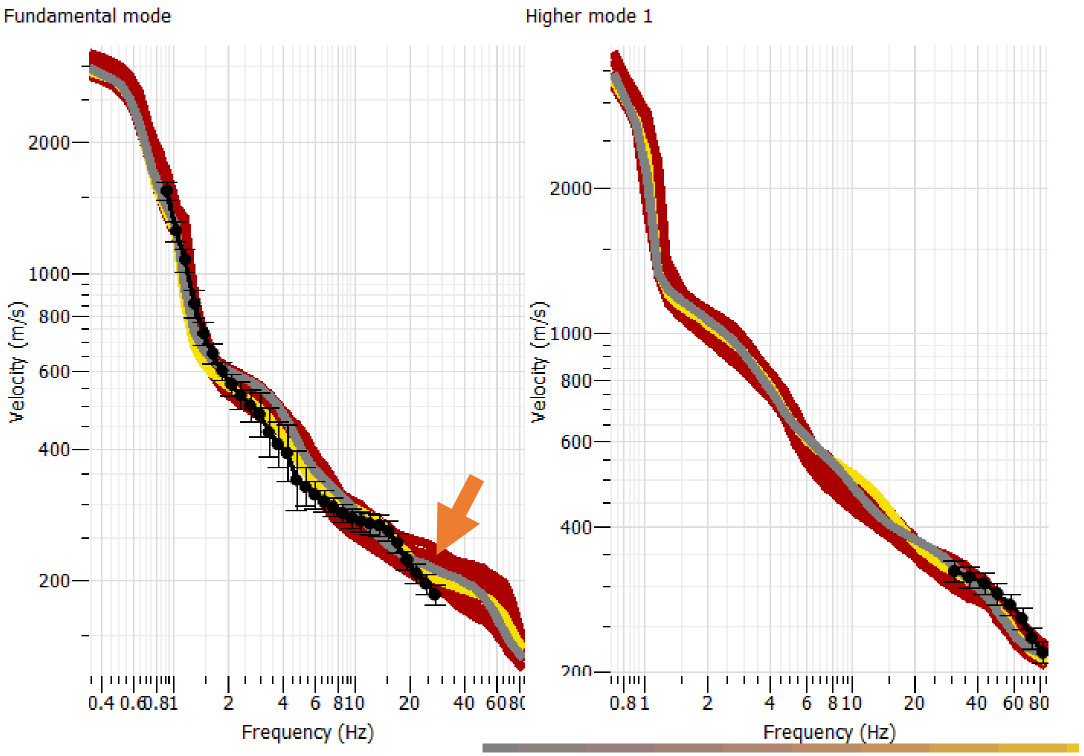
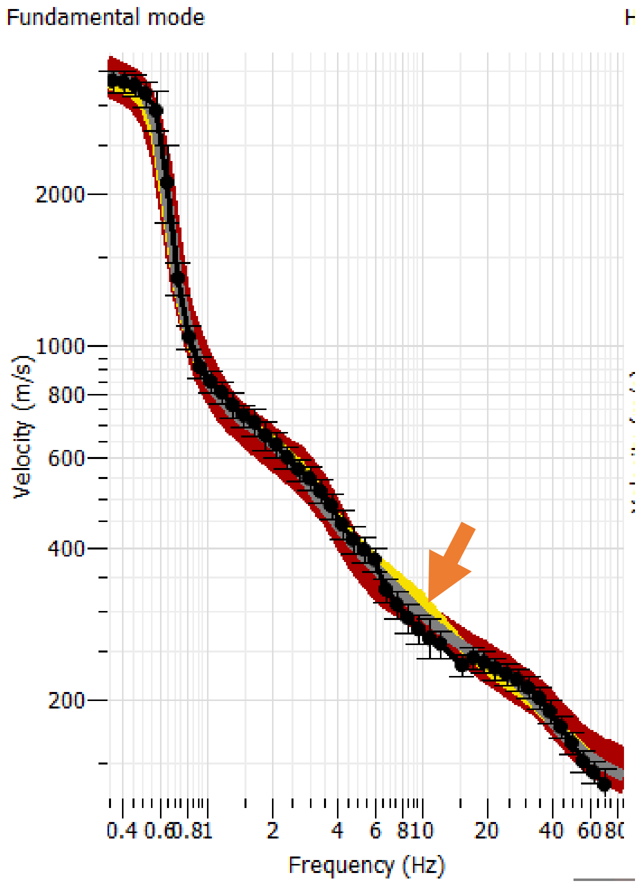
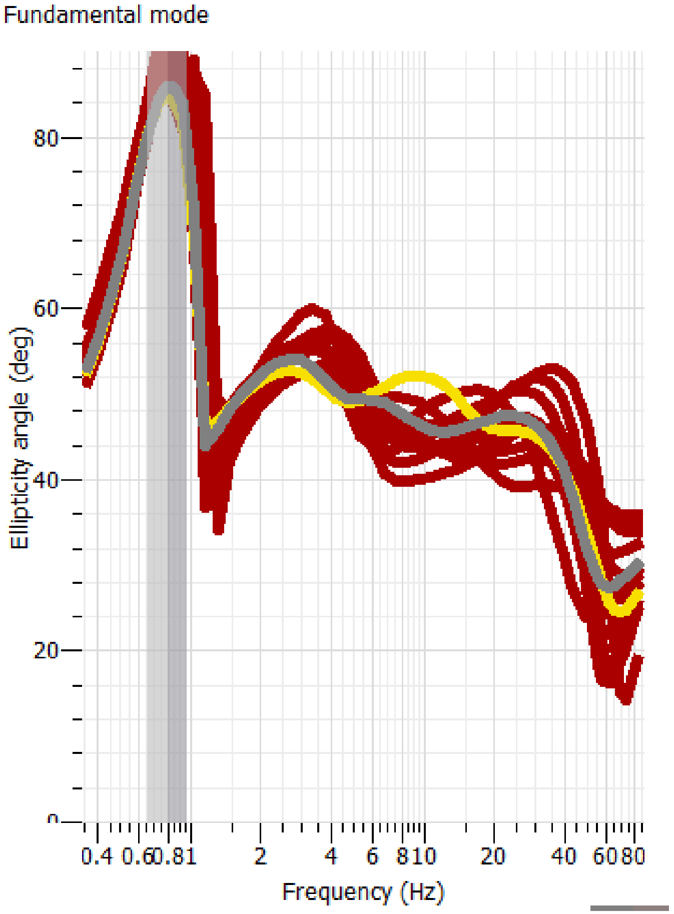
Two Rayleigh modes.



One Love mode.



Rayleigh Ellipticity.



No single major issue with targets.

In general, misfits will be higher when you have multiple targets,

but we know that using multiple targets results in more robust characterization.

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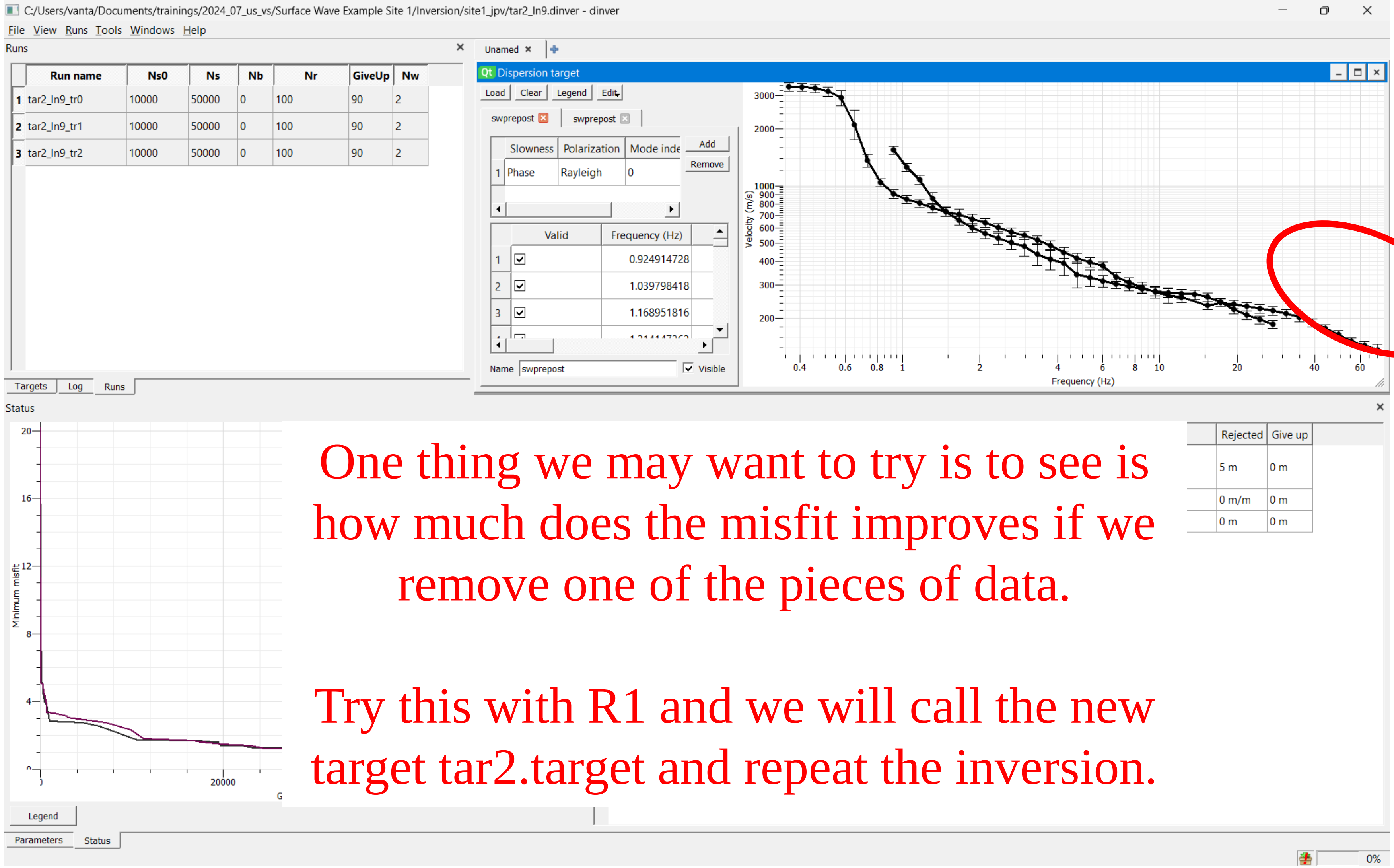

One thing we may want to try is to see is how much does the misfit improves if we remove one of the pieces of data.

Try this with R1 and we will call the new target tar2.target and repeat the inversion.

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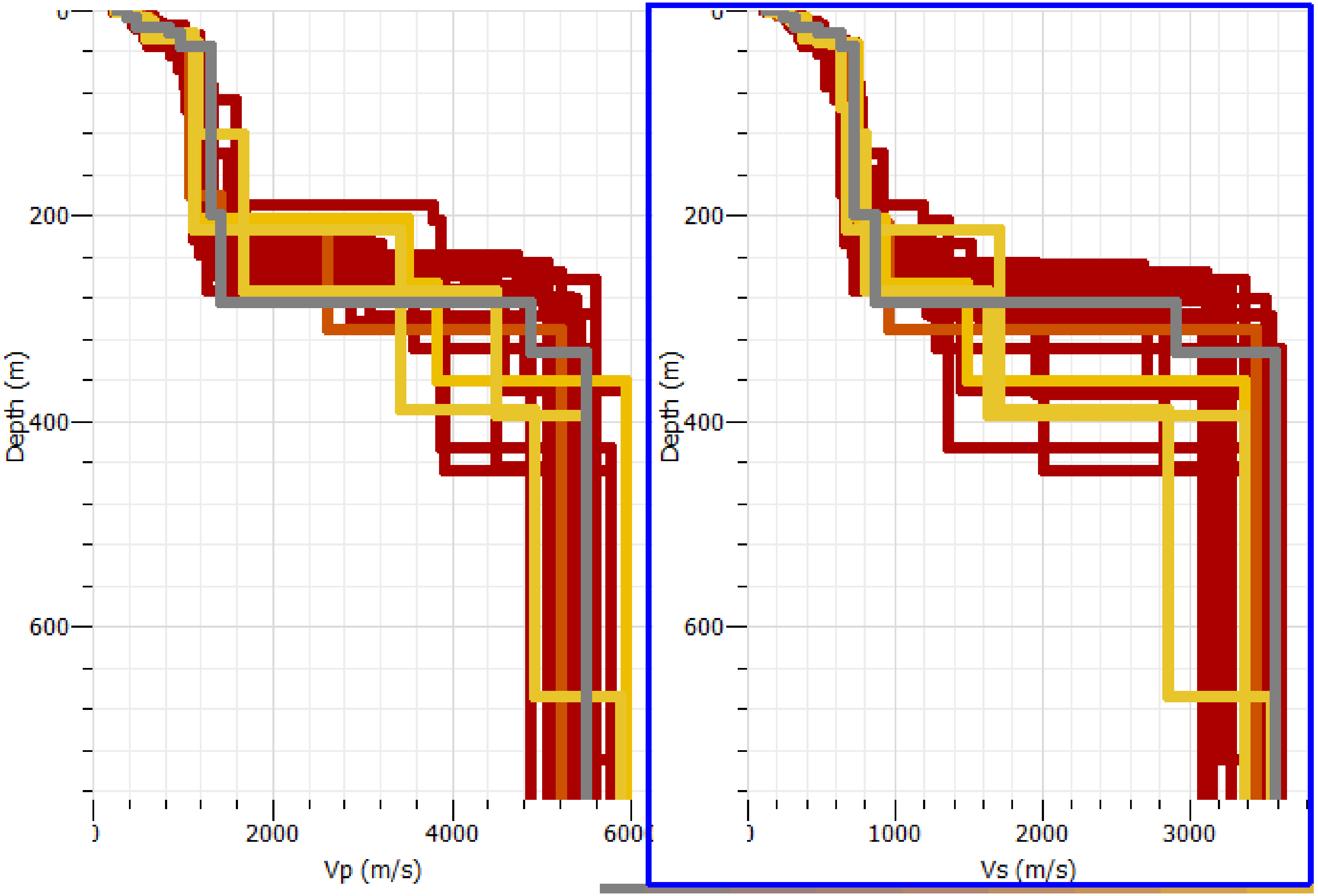
No substantial improvement

	Pen	Run name	Min misfit	Valid models	Activ
1		tar2_ln9_tr0	1.01885	60090/60037	60090
2		tar2_ln9_tr1	0.96541	60081/60030	60081
3		tar2_ln9_tr2	1.07522	60053/60041	60053



Very similar velocity profiles

Indicates model is well-constrained with the R0, R1, L0, f0 interpretation.

Will move forward with tar1.target

Site 1

Inversion Results Extraction Details

•[7]:

```
# Number of ground models/dispersion curves/ellipticity curves to export
number_of_models_to_export = 100

# Number (positive integer) of Rayleigh and Love wave modes to export.
# If no dispersion curves are desired set both the number of Rayleigh and
# Love modes to 0. (1 is recommended)
number_of_rayleigh_modes_to_export = 2
number_of_love_modes_to_export = 1

# Number (positive float) for minimum amd maximum frequency of exported
# dispersion curve(s) in Hz. Selecting a value slightly less than the
# minimum frequency and a value slightly greater than the maximum frequency
# of your experimental dispersion data is recommended.
minimum_dispersion_frequency = 0.1
maximum_dispersion_frequency = 100.

# Number (positive integer) of frequency points in the exported dispersion
# curve(s). (30 is recommended)
number_of_dispersion_frequency_points = 30

# Number (positive integer) of Rayleigh modes to include in exported ellipticity.
# If no ellipticity curves are desired set this value to 0
number_of_rayleigh_ellipticity_modes_to_export = 1

# Number (positive float) for minimum amd maximum frequency of exported
# Rayleigh wave ellipticity curve(s) in Hz. Selecting a value less than and
# greater than the site's resonant frequency is recommended.
minimum_ellipticity_frequency = 0.2
maximum_ellipticity_frequency = 20.

# Number (positive integer) of frequency points in exported Rayleigh wave
# ellipticity curve(s). (64 is recommended)
number_of_ellipticity_frequency_points = 64
```

Export 2 Rayleigh and 1 Love mode

Broaden Frequency Range

1 Mode of Rayleigh Ellipticity

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Site 1

Imports and Function Definitions

[2]:
```
import glob, re, os

import numpy as np
import matplotlib.pyplot as plt

import swprepost
from ellipticitytools import EllipticitySuite
from dispersiontools import DispersionSuite

def plot_target(target):
    fig, axs = plt.subplots(nrows=1, ncols=2, sharey=True, figsize=(6, 3), dpi=150)
    target.plot(x="frequency", y="velocity", ax=axs[0])
    target.plot(x="wavelength", y="velocity", ax=axs[1])
    axs[1].set_ylabel("")
    axs[1].legend()
    return (fig, axs)

print("Imports successful, you may proceed.")
```

```
Imports successful, you may proceed.
```

Modified codes
(new features not yet available publicly).

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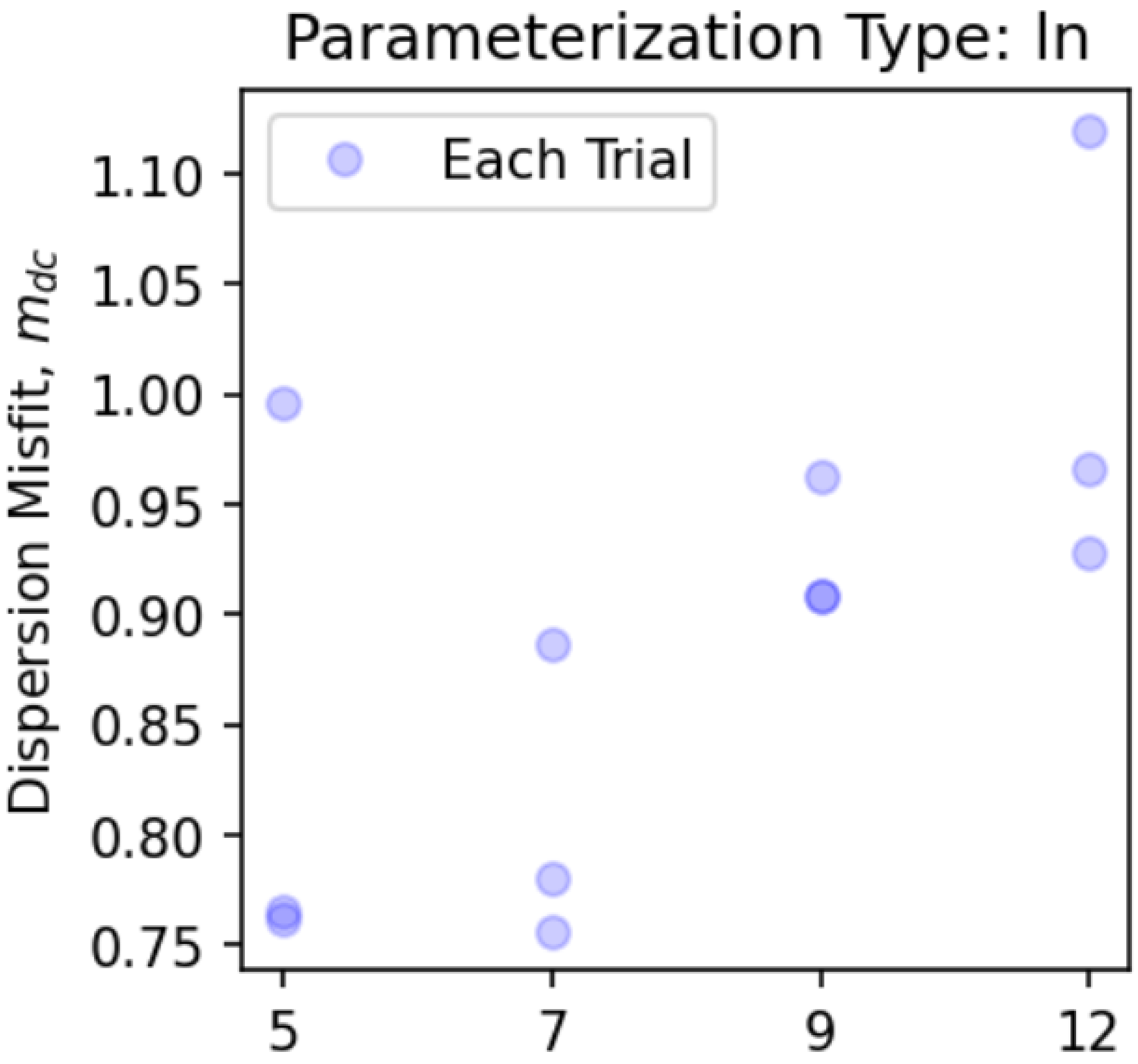

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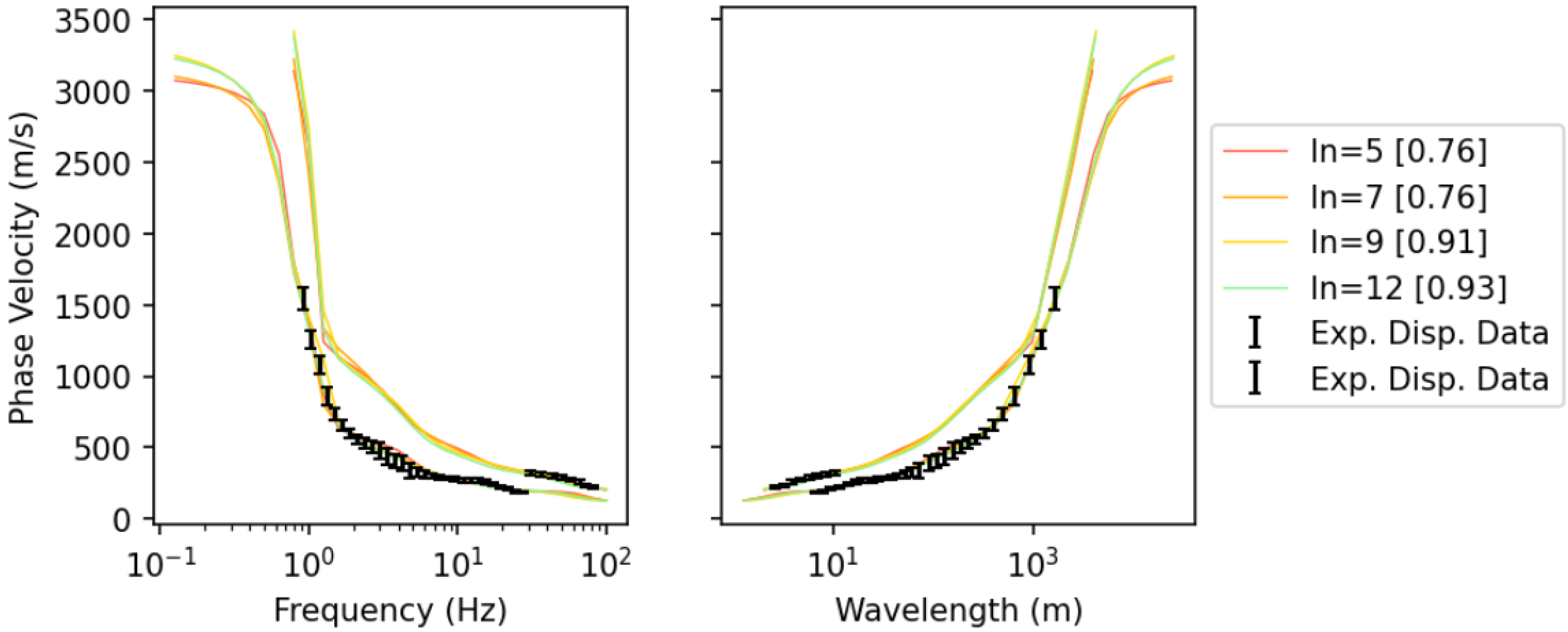
Rayleigh Dispersion (Single Best Model)



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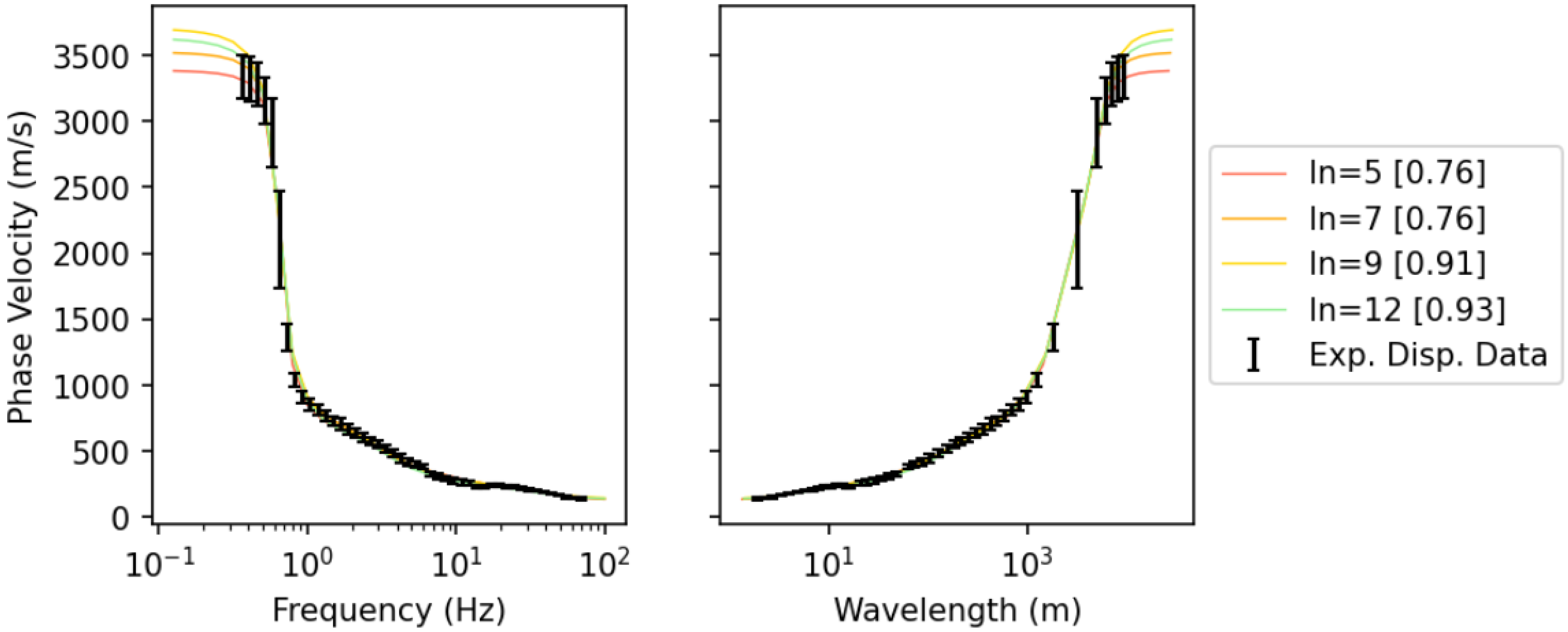
Love Dispersion (Single Best Model)



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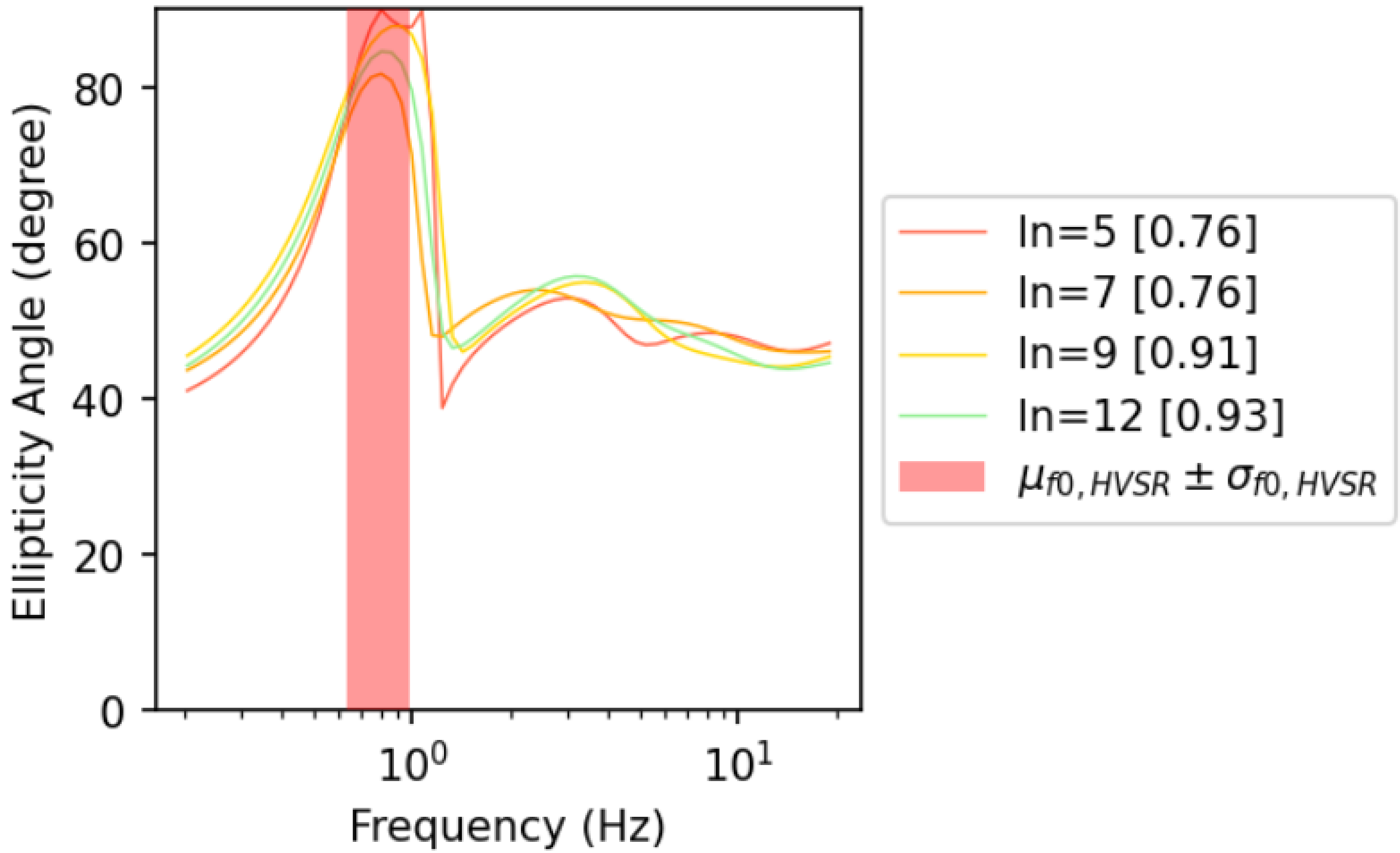
Ellipticity (Single Best Model)



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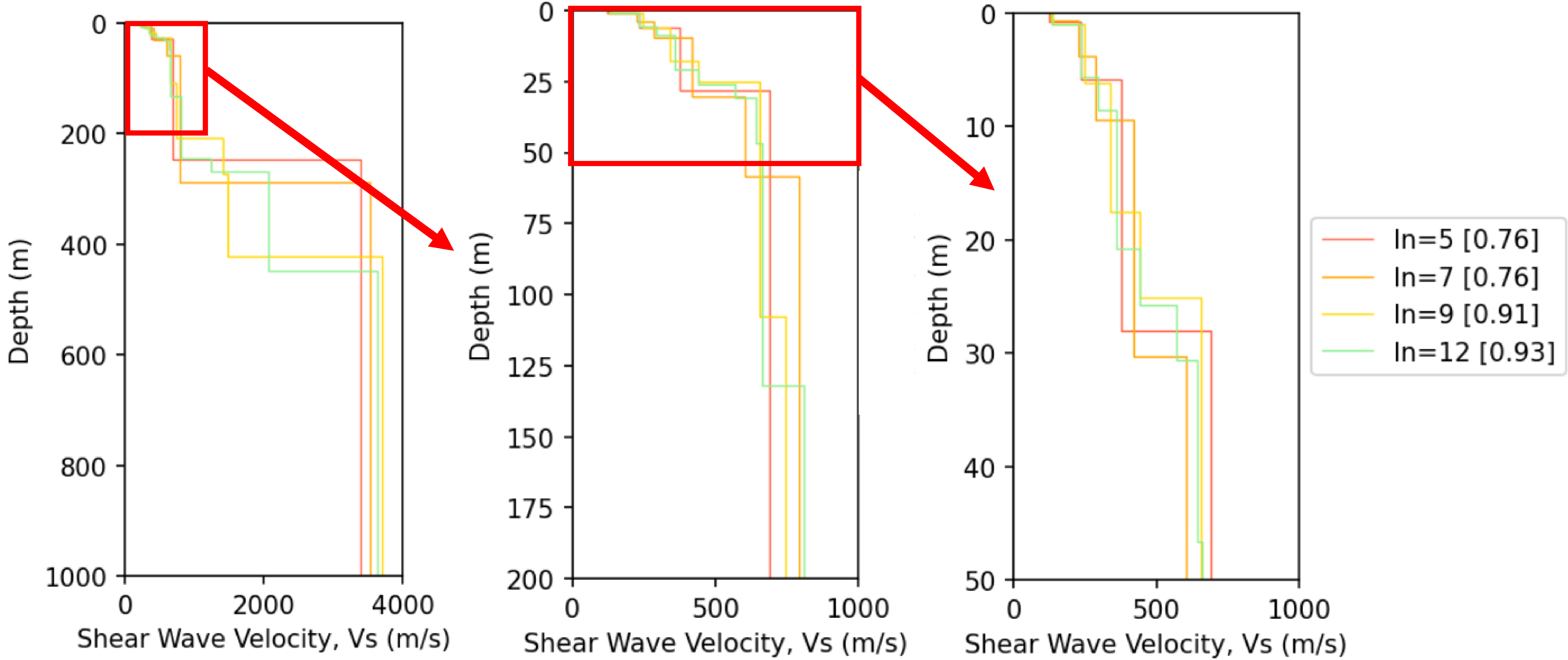
Ground Models (1 best) at three different scales.

Which one would you pick?



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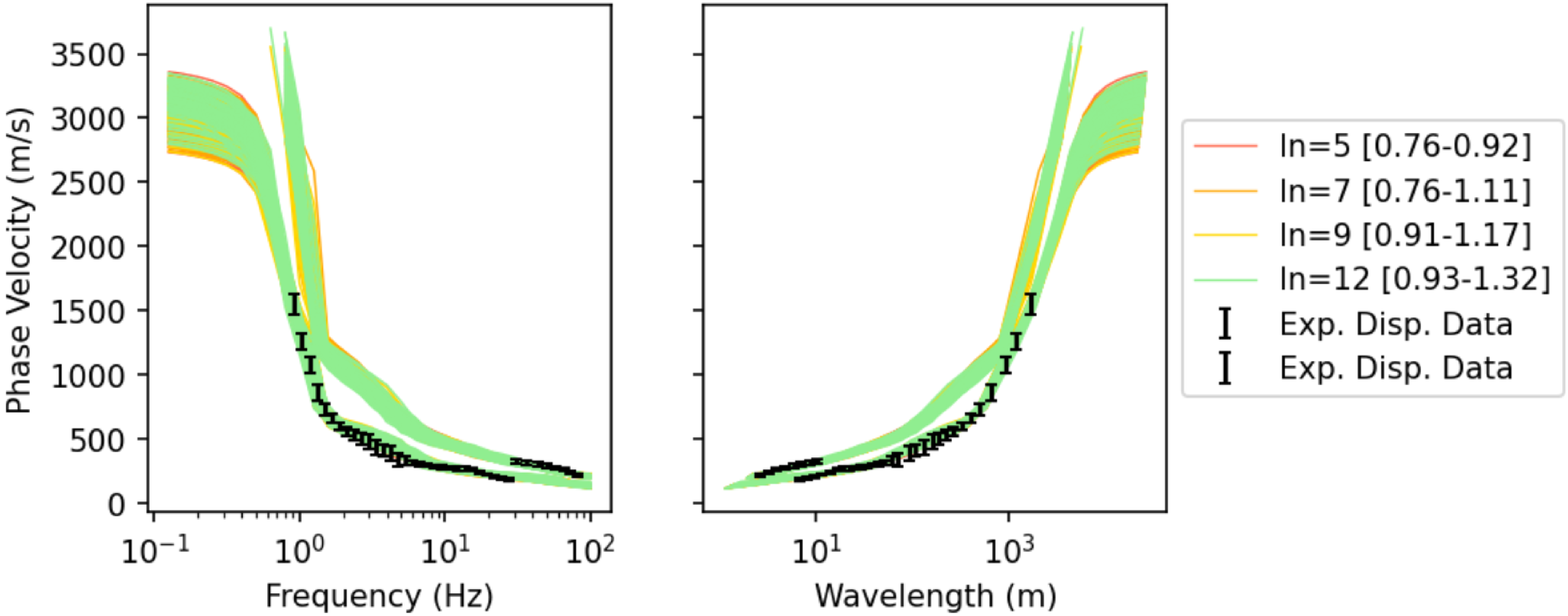
Rayleigh R0 and R1



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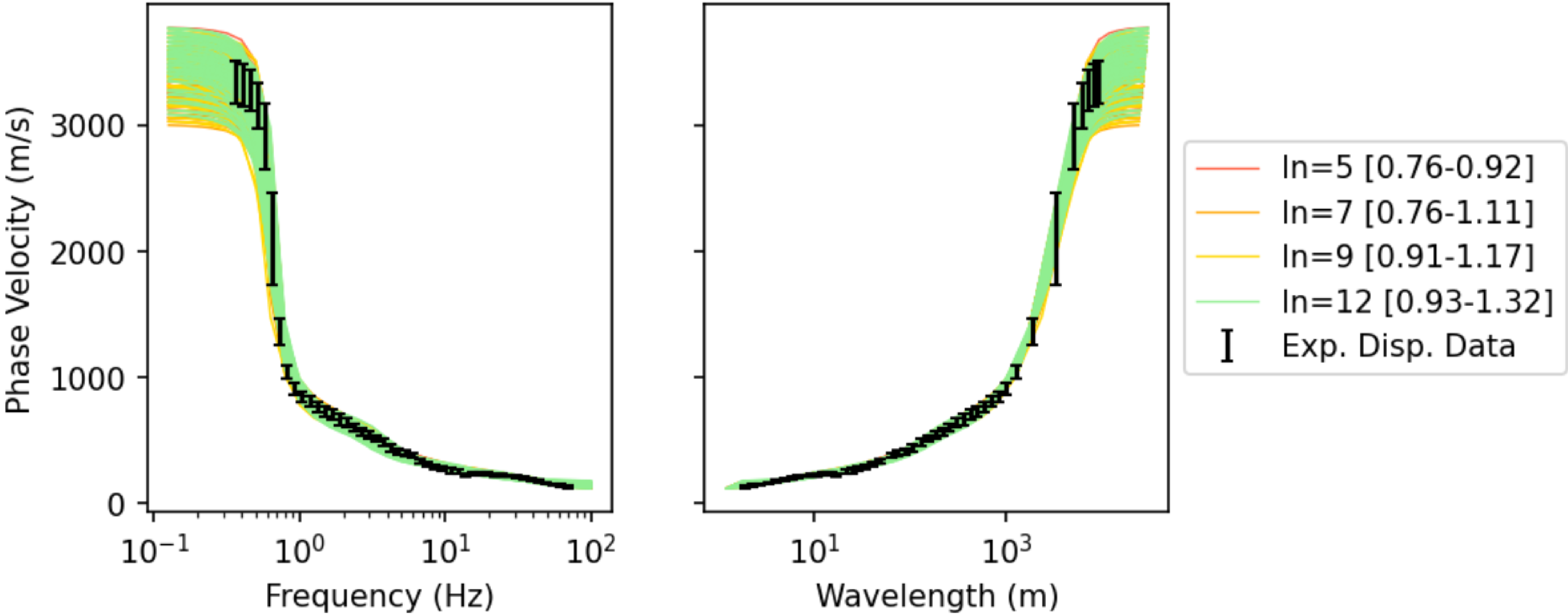
Love L0



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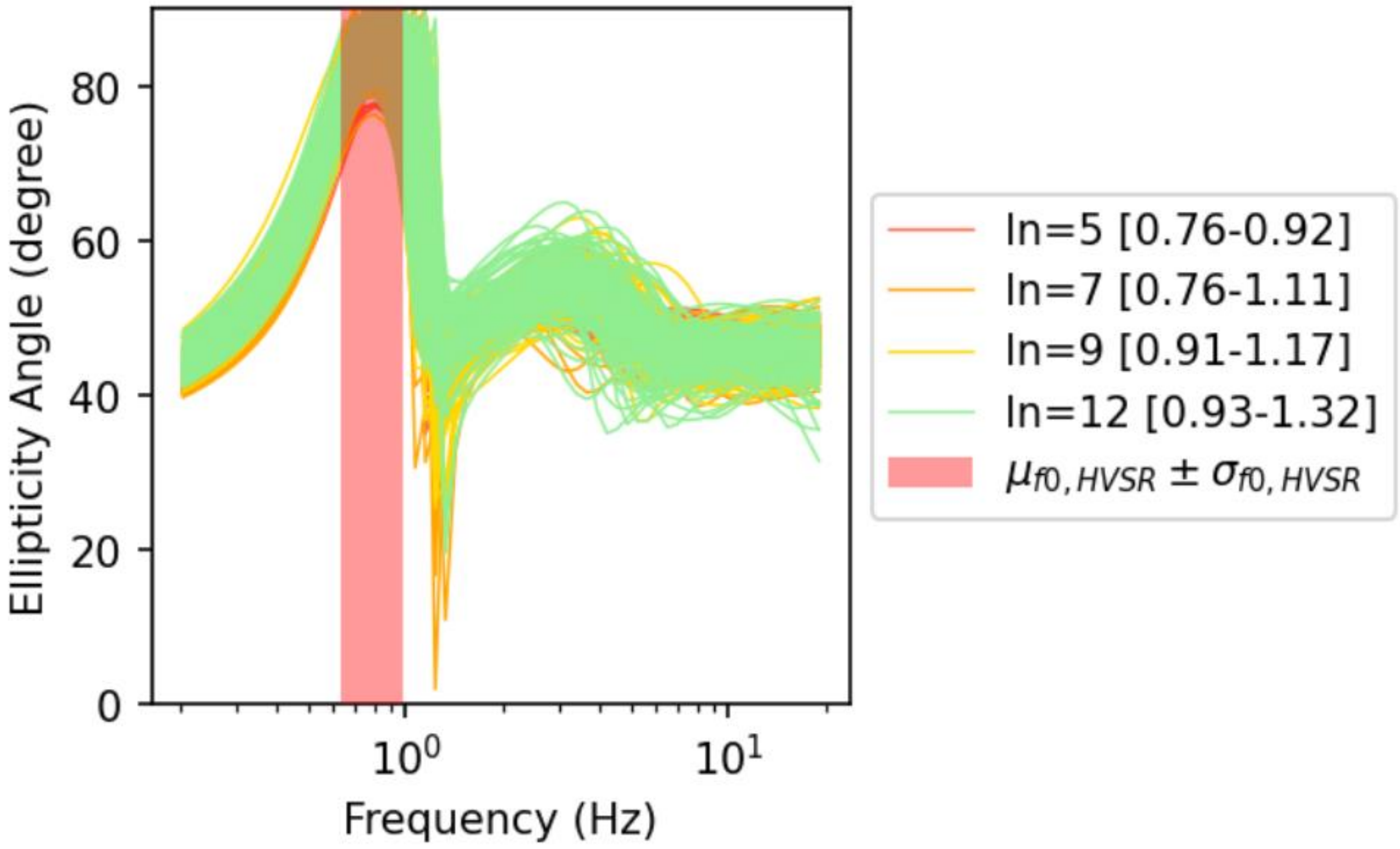
Rayleigh Ellipticity with f_0 from HVSR



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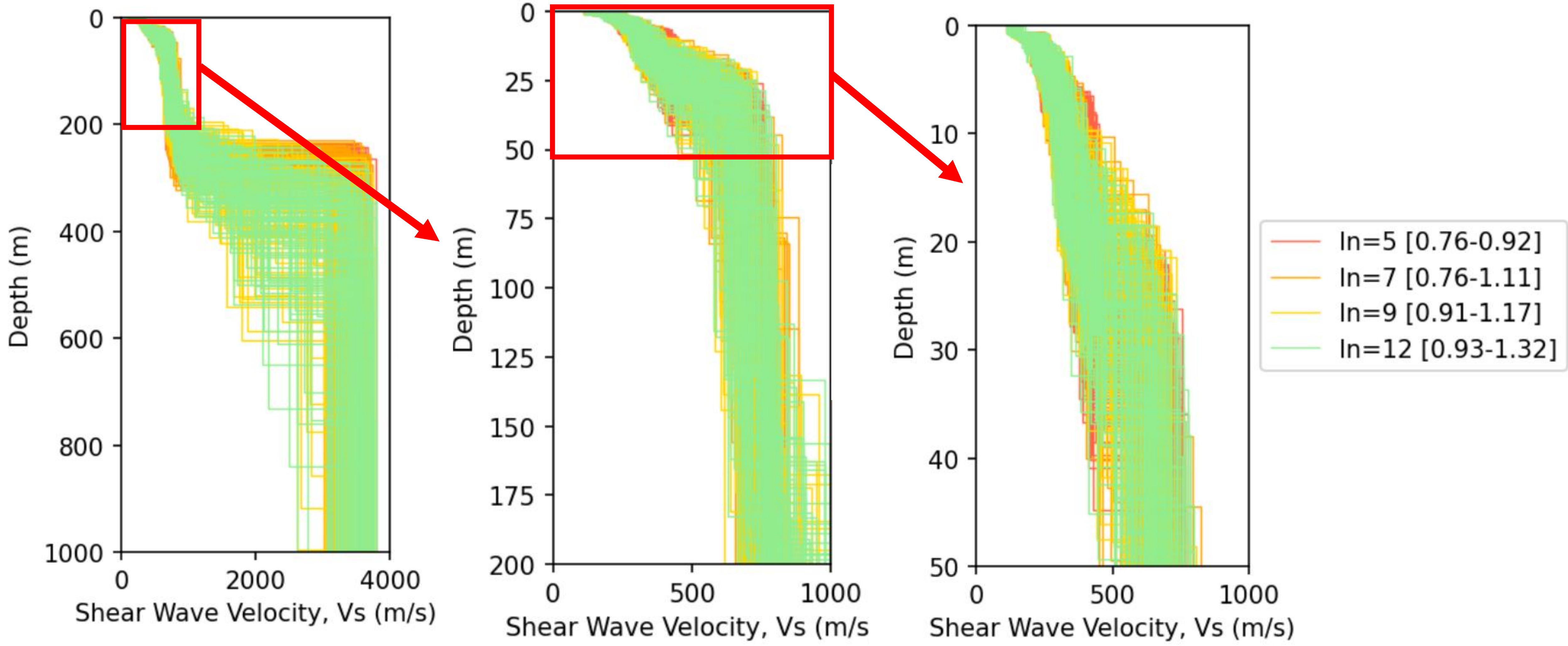
Site 1

Ground Models (100 best) at three different scales.



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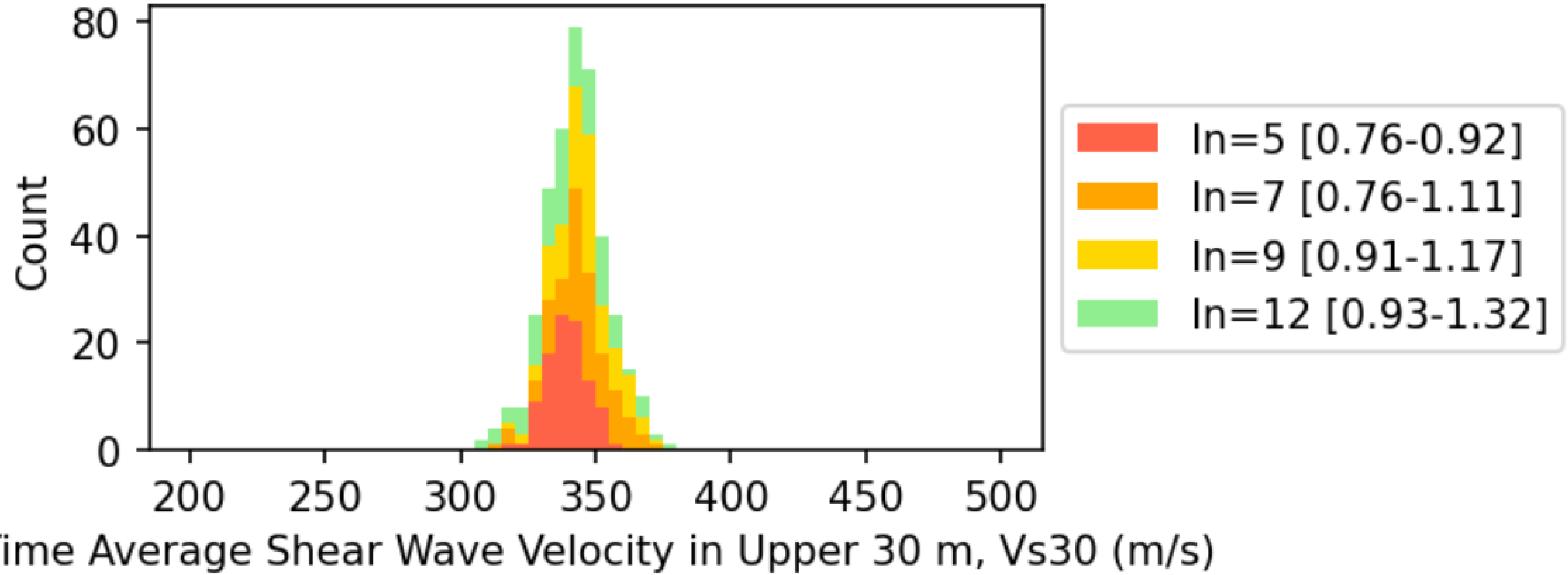
Site 1

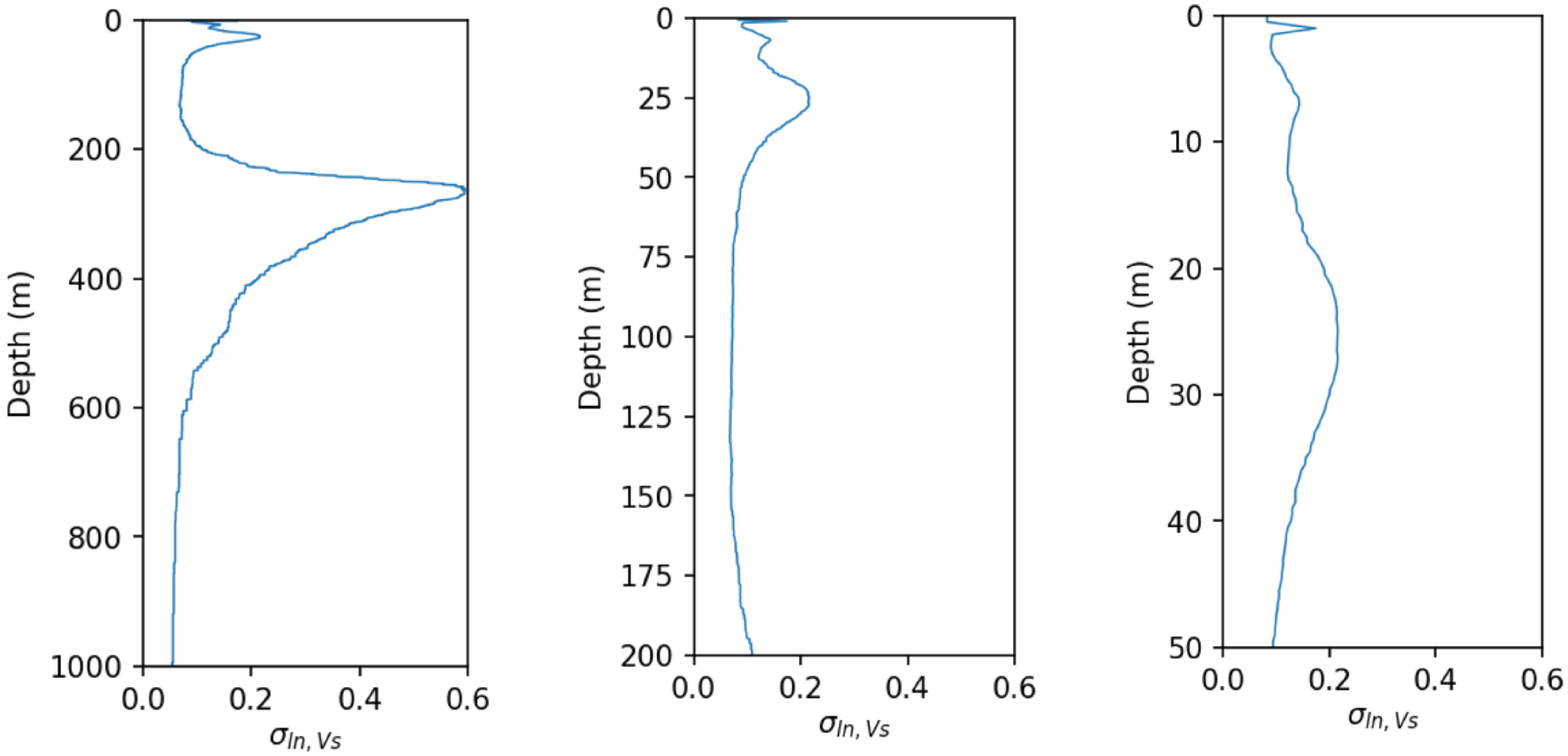
Vs30




```
Mean Vs30: 343 m/s
Standard Deviation of Vs30: 12 m/s
```

Site 1

Uncertainty in Vs at three different depth scales.



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