XXI Workshop di Geofisica | Tra geologia e geofisica 2024
Rovereto 6/12/2024

# SmartRefract a free and open source software for seismic refraction

Simone Pittaluga

Istituto di Matematica Applicata e Tecnologie Informatiche
Sede secondaria di Genova

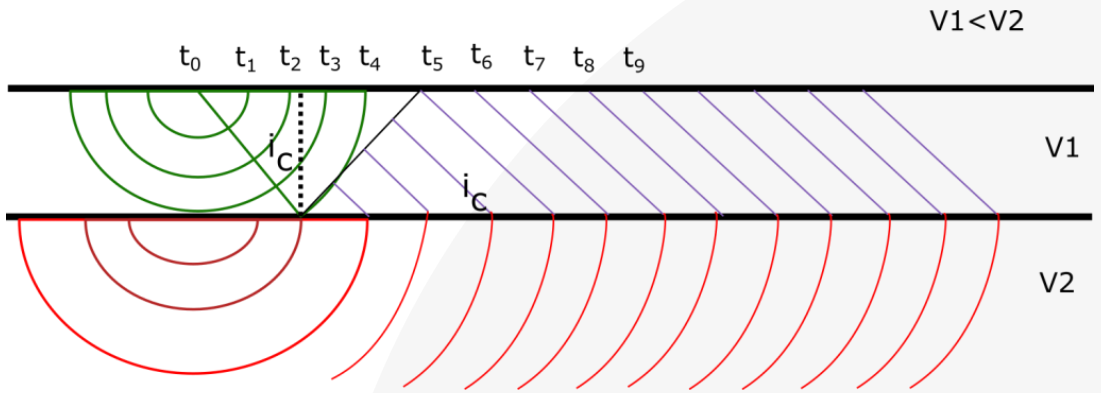
Consiglio Nazionale delle Ricerche

# The Challenge:

- Determining the depth and the shape of bedrock, where ***significant velocity contrasts*** between the top-soil, the weathered layer and the underlying bedrock exists

# What is a refraction event?

- **A refraction event** occurs when a seismic wave encounters an interface between two materials with different seismic velocities.
- **Critical refraction:** When the angle of incidence exceeds a critical angle, the seismic wave is refracted along the interface.



# Does smartRefract fit any kind of “refraction”?

# The Right Data for the Right Tool

- **Correct Data, Accurate Results:** Requires seismic **refraction** data to provide reliable results.
- **Correct geometry**: Requires the right setup of shots and geophones
- **Correct geology**: Requires the right velocity configuration

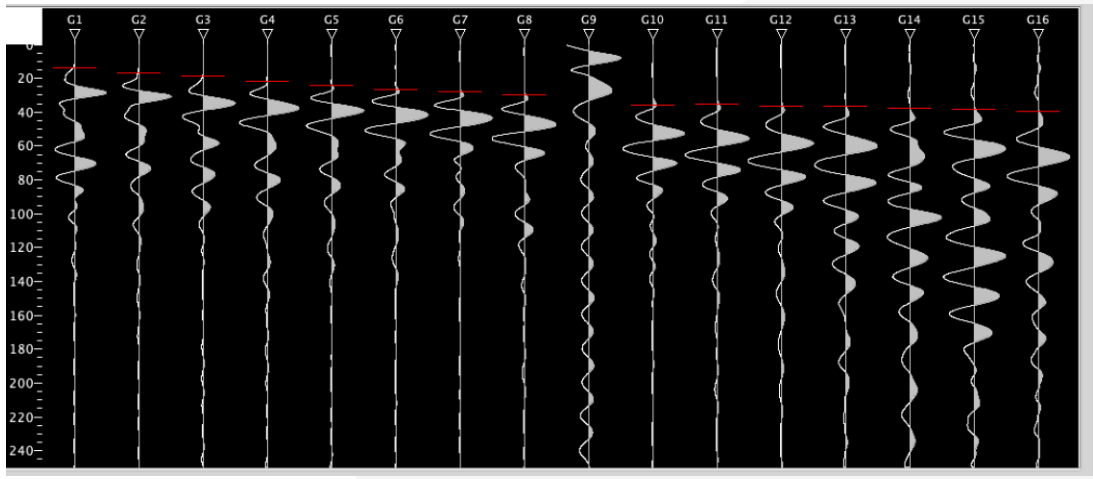
# The Right Data for the Right Tool

- **Correct Data, Accurate Results:** Requires seismic **refraction** data to provide reliable results.
- **Correct geometry**: Requires the right setup of shots and geophones
- **Correct geology**: Requires the right velocity configuration

- Correct survey setup
- Correct picking
- Correct travel time parametrization

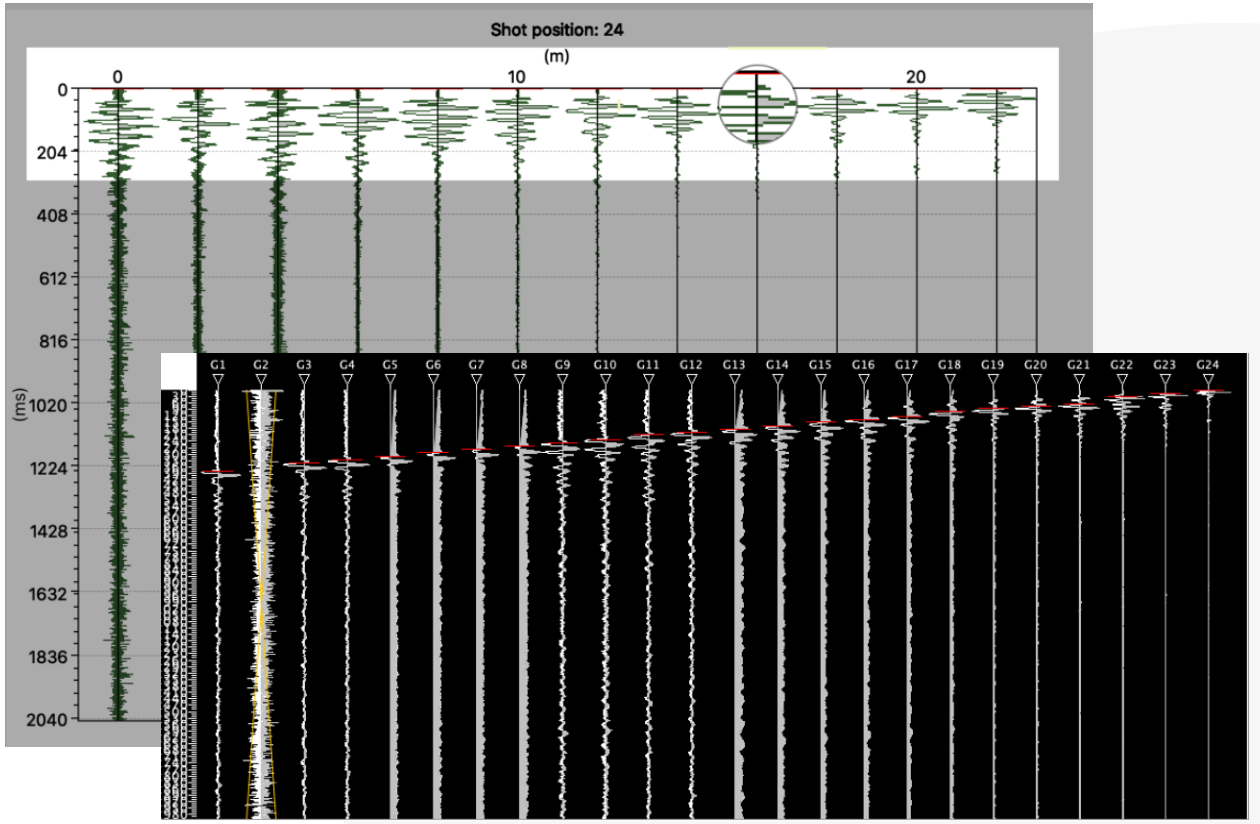
# Picking the first breaks

- **First break picking** is a crucial step in seismic data processing, particularly for seismic refraction surveys. It involves identifying the arrival time of the first seismic wave at each geophone.
- **Challenges in First Break Picking:**
  - **Noise Interference:** Noise from various sources, such as wind, traffic, and electronic interference, can obscure the first arrival.
  - **Complex Waveforms:** In some cases, the first arrival may be difficult to distinguish from later arrivals or noise.



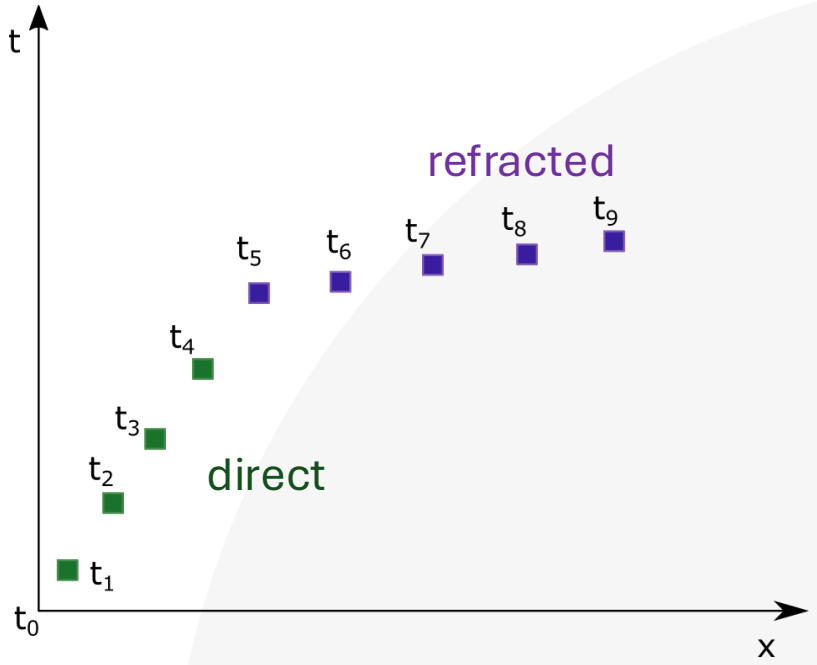
# Picking the first breaks

- **Avoid record echo from the other side of the Earth:** set recording time short enough
- **Avoid measure sound speed in air again:** there is a lot of papers about this



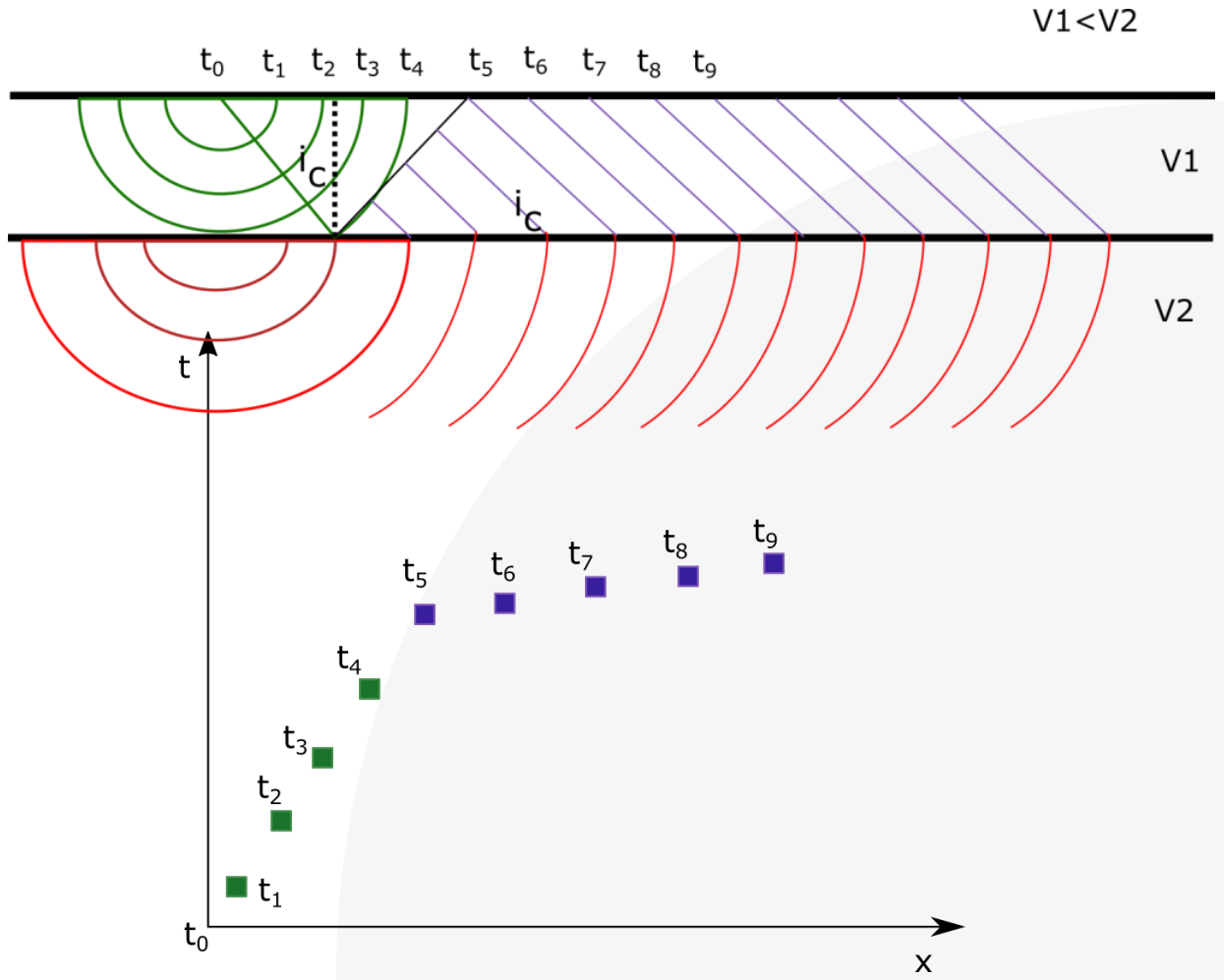
# Travel Times Plot Anatomy

- The arrival times of the first seismic waves at each geophone are plotted against their distance from the source.
- The resulting plot is typically a curve with two distinct segments:
  - **Direct Wave Segment:** Represents the wave traveling directly through the upper layer.
  - **Refracted Wave Segment:** Represents the wave that refracts along the interface between the two layers.

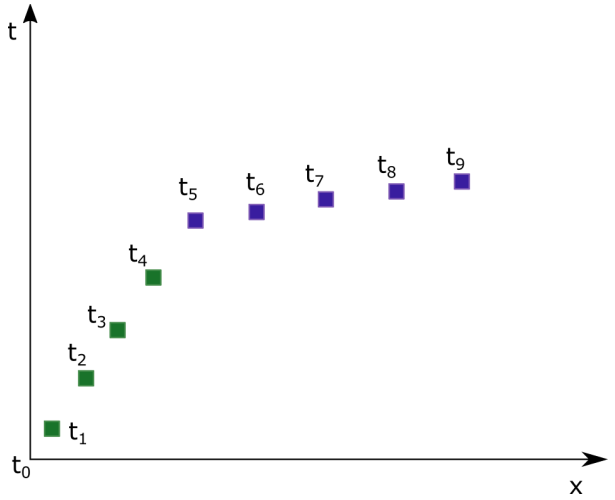


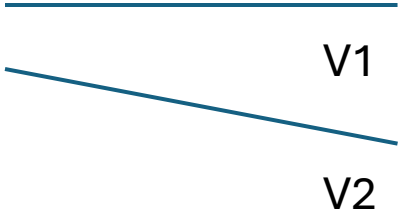
# Identifying Refraction Events on Travel Time Plots

- **Refraction Events on Travel Time Curves:** Refraction events are characterized by a distinct change in slope on a travel time curve.
- **Key Indicators:**
  - **Break in Slope:** A sudden change in the gradient of the curve indicates the onset of a refracted wave.
  - **Linear Segment:** The refracted wave typically forms a linear segment on the plot.

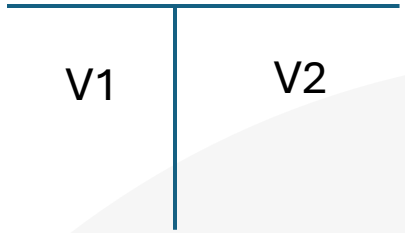


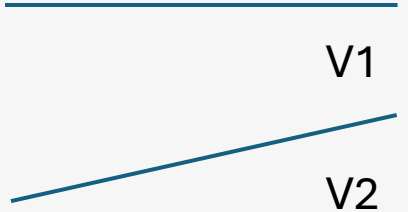
# Ambiguity of travel times plot



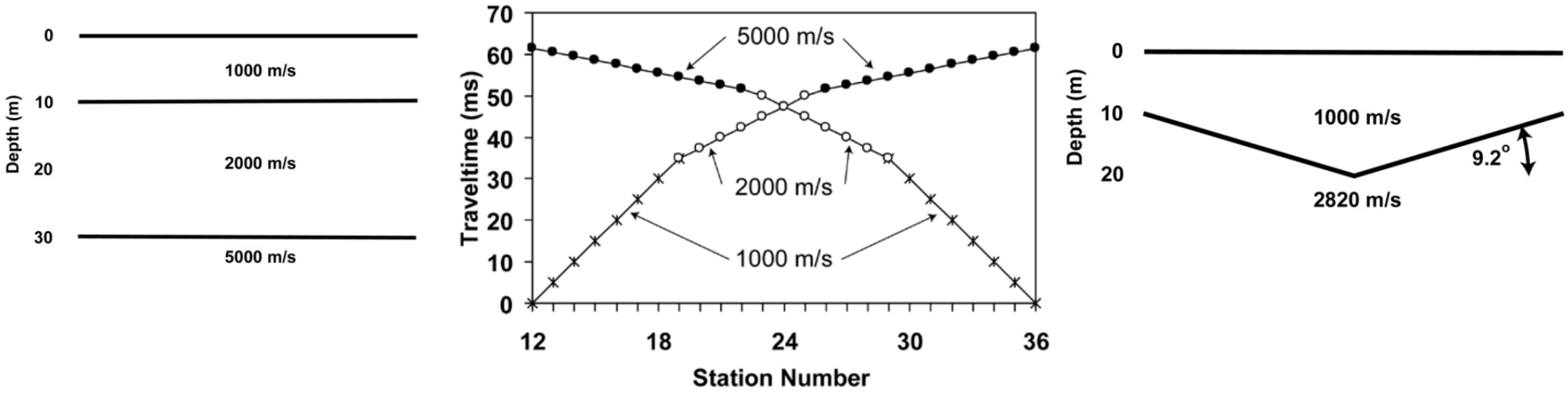





With V1<V2

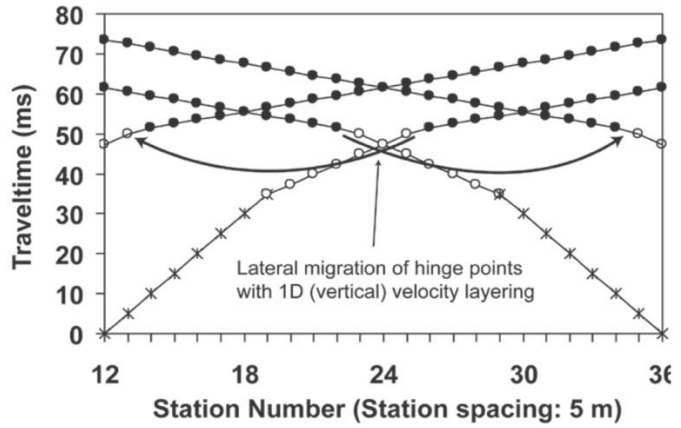
# Ambiguity of travel times plot

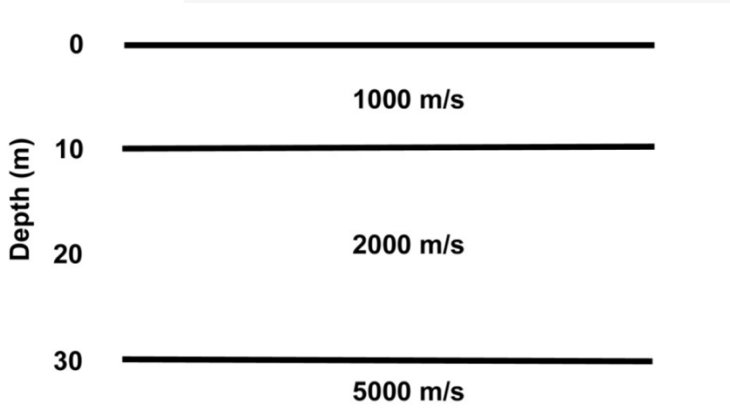



From D.Palmer – The Mt Bulga Tutorial 2011

# Fix the ambiguity of travel times

- **Multiple Perspectives:** By acquiring data from various shot points, you can observe subsurface layers from different angles.
- **Improved Resolution:** This approach helps to reduce uncertainty and improve the resolution of the subsurface model.
- **Reduced Interference:** Moving the shot point can help to minimize the impact of near-surface noise and interference.
- **Enhanced Depth Penetration:** By increasing the shot-geophone distance, you can probe deeper into the subsurface.

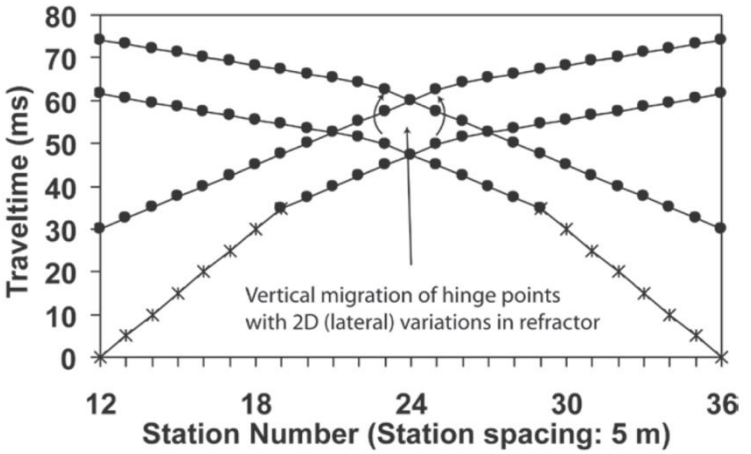


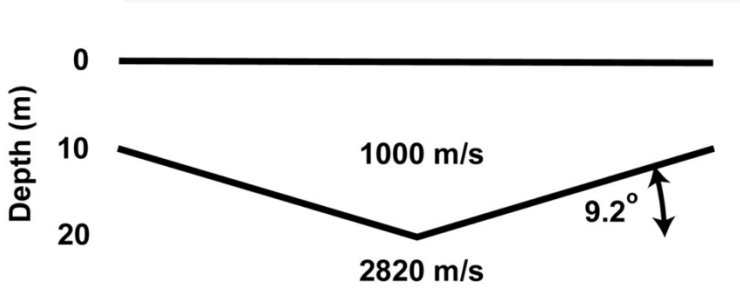




From D.Palmer – The Mt Bulga Tutorial 2011

# Fix the ambiguity of travel times

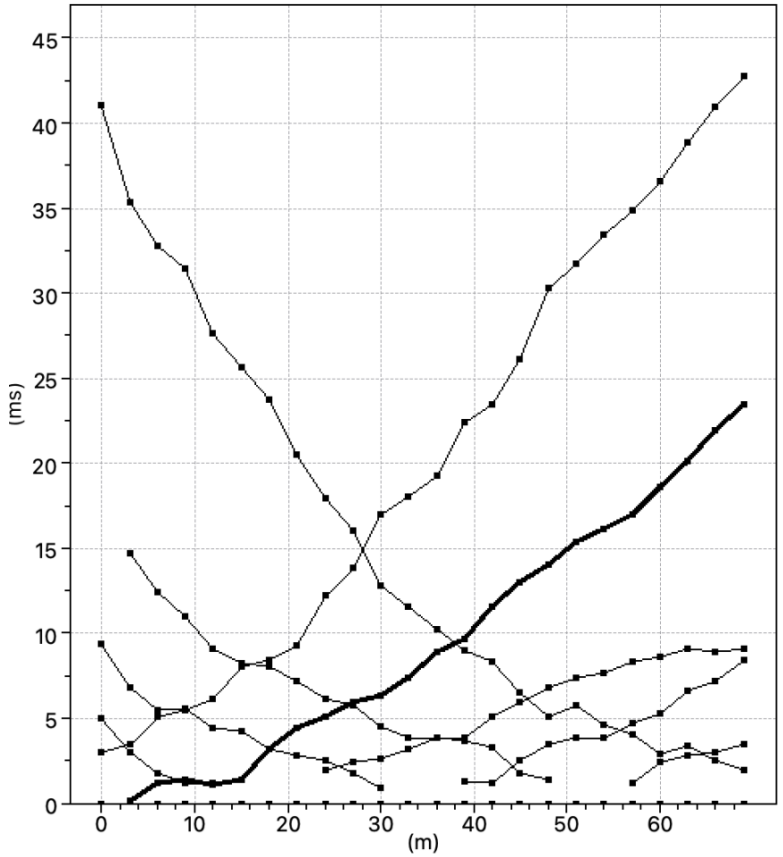
- **Multiple Perspectives:** By acquiring data from various shot points, you can observe subsurface layers from different angles.
- **Improved Resolution:** This approach helps to reduce uncertainty and improve the resolution of the subsurface model.
- **Reduced Interference:** Moving the shot point can help to minimize the impact of near-surface noise and interference.
- **Enhanced Depth Penetration:** By increasing the shot-geophone distance, you can probe deeper into the subsurface.



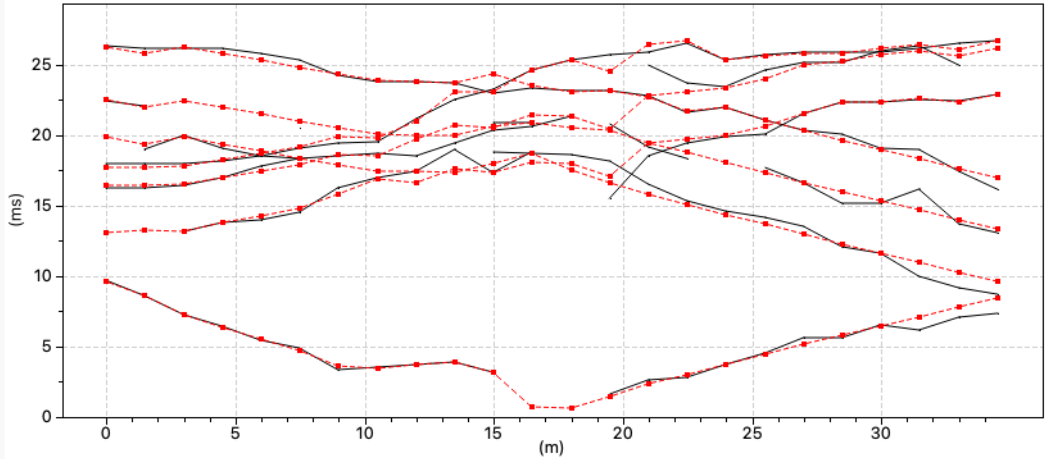

From D.Palmer – The Mt Bulga Tutorial 2011

# ”Simone, smartRefract doesn’t work at all”



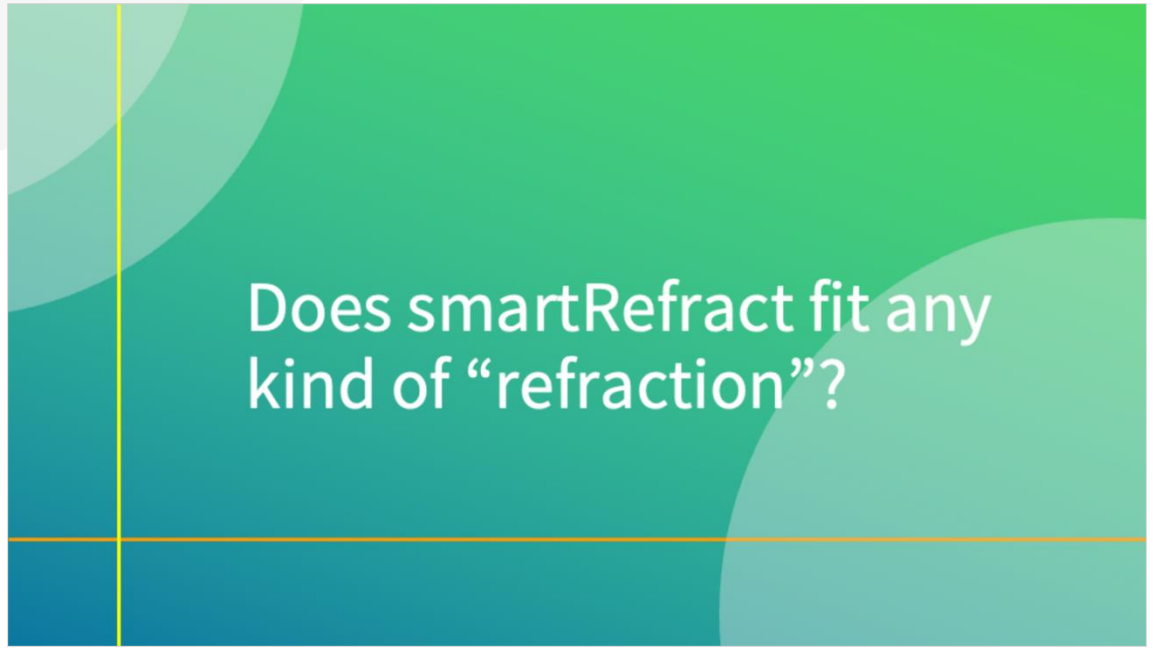

“Where is my refraction?”

# ”Simone, smartRefract doesn’t work at all”




Where my endline shots are?

# The answer

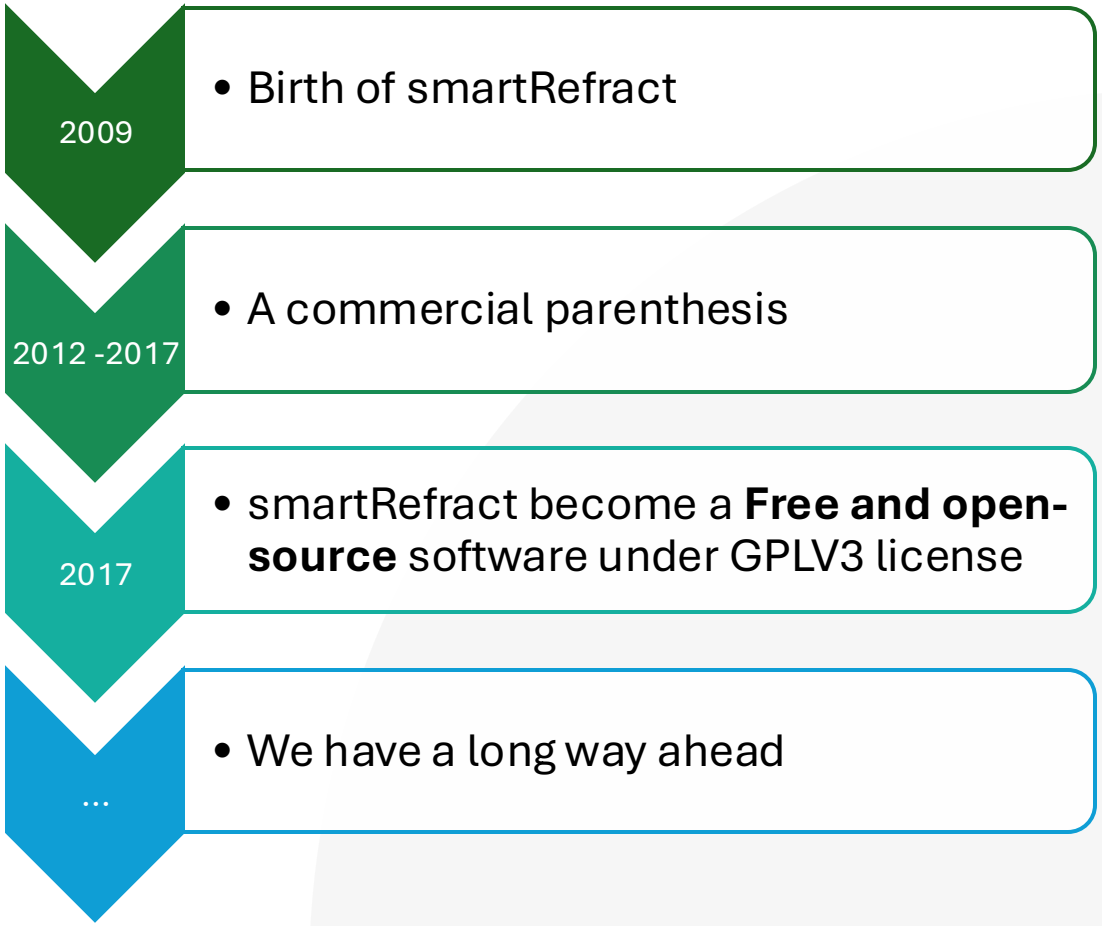



- Shortly: no
- SmartRefract needs:
  - At least 2 end line shots (forward and reverse shots)
  - A refractor, of course

# The birth of smartRefract

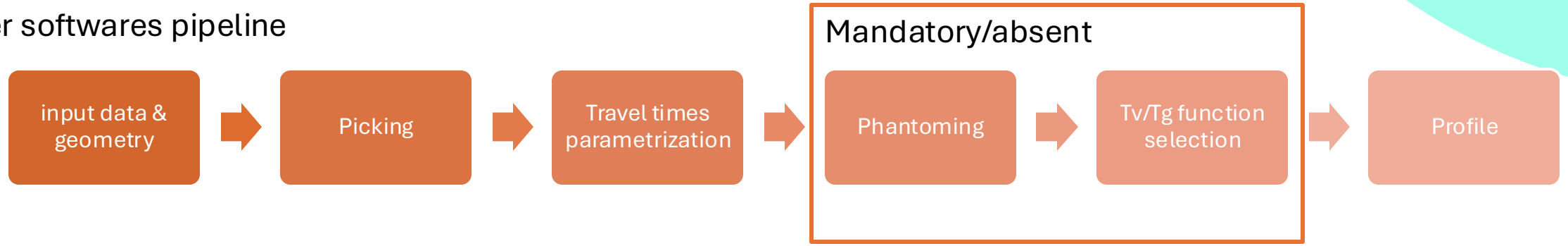
# A journey from Personal Project to Open Source

- **Filling a Gap:** Existing software was either too complex or lacked stability.
- **A Personal Project:** SmartRefract was born as a personal endeavor to address these limitations.
- Developing SmartRefract has provided me with **hands-on experience** and a deeper understanding of seismic refraction

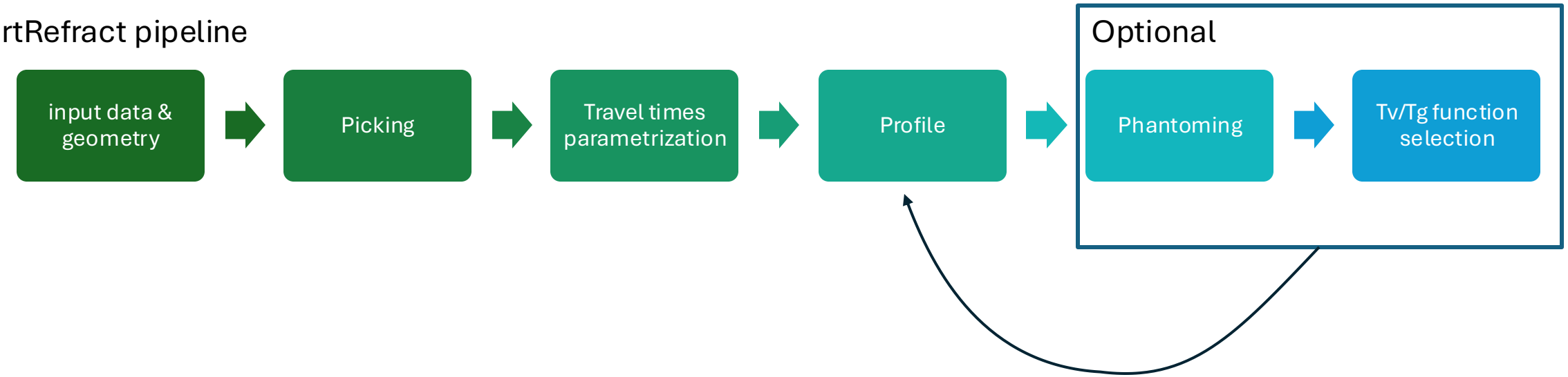


# The workflow

Other softwares pipeline




smartRefract pipeline

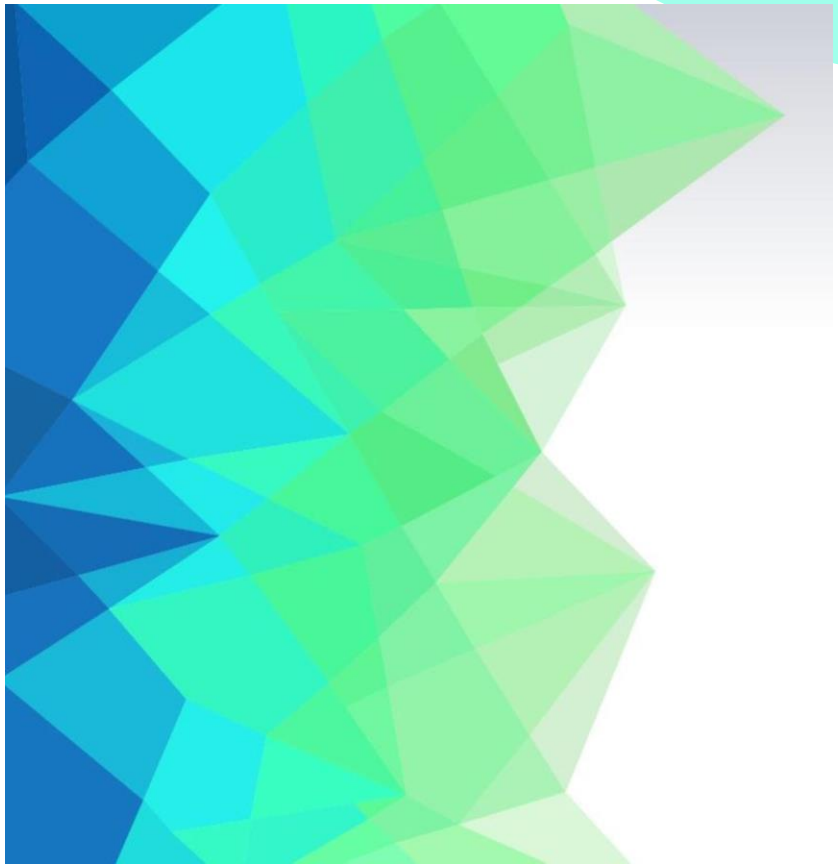


# SmartRefract: A Cross-Platform Application Built on Java and NetBeans

- **Developed in Java:** SmartRefract is built using the Java programming language.
- **Powered by NetBeans:** The NetBeans platform provides the development environment for SmartRefract.
- **Cross-platform compatibility:** Thanks to Java, SmartRefract can run seamlessly on Windows, macOS, and Linux.
- **Benefits of Netbeans platform development:**
  - **Installer** for each supported OS.
  - A built-in **updater** for free.

# The Double-Edged Sword of Java and NetBeans

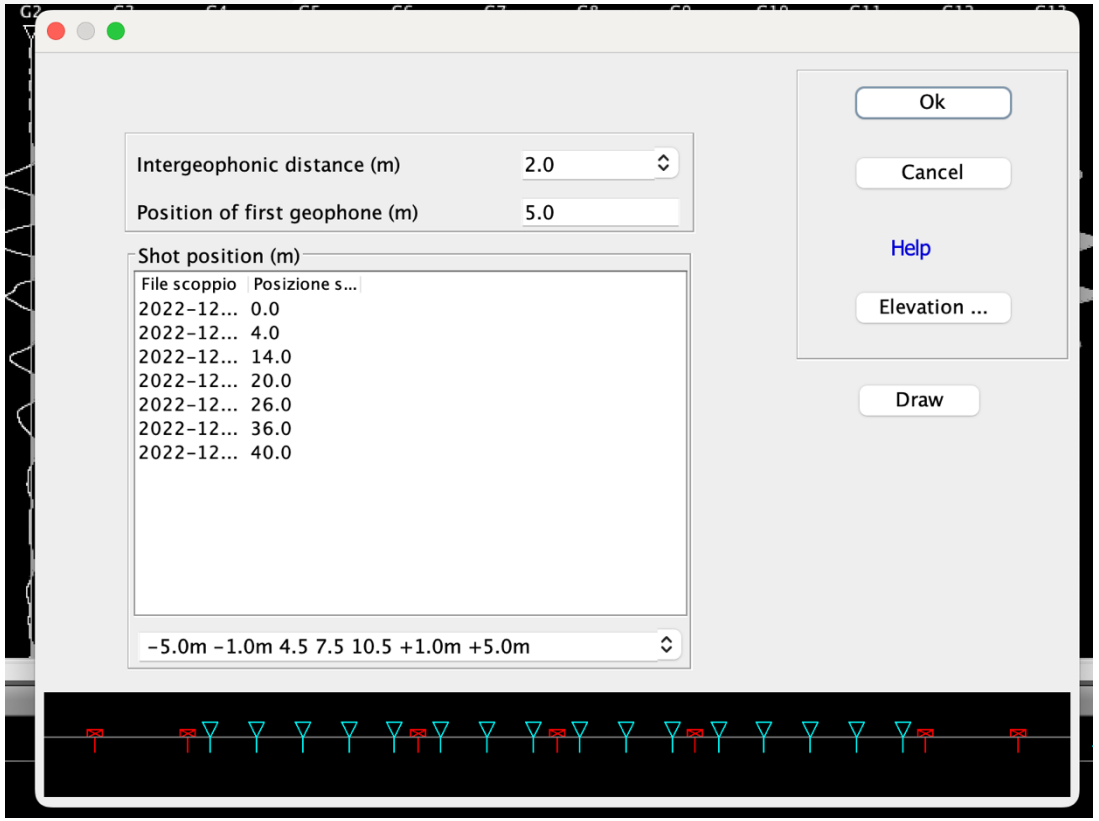
- **Advantages: Cross-platform compatibility:** As mentioned, Java and NetBeans make it easy to create applications that can run on multiple platforms.
- **Challenges: Development complexity:** Keeping up with the evolving Java and NetBeans ecosystems can be challenging.
- **Maintenance overhead:** Maintaining a large Java (and Netbeans) codebase can be time-consuming.
- **Potential performance issues:** In some cases, Java applications may not perform as well as those written in lower-level languages.



# The smartRefract approach

A quick dive into UI and algorithm

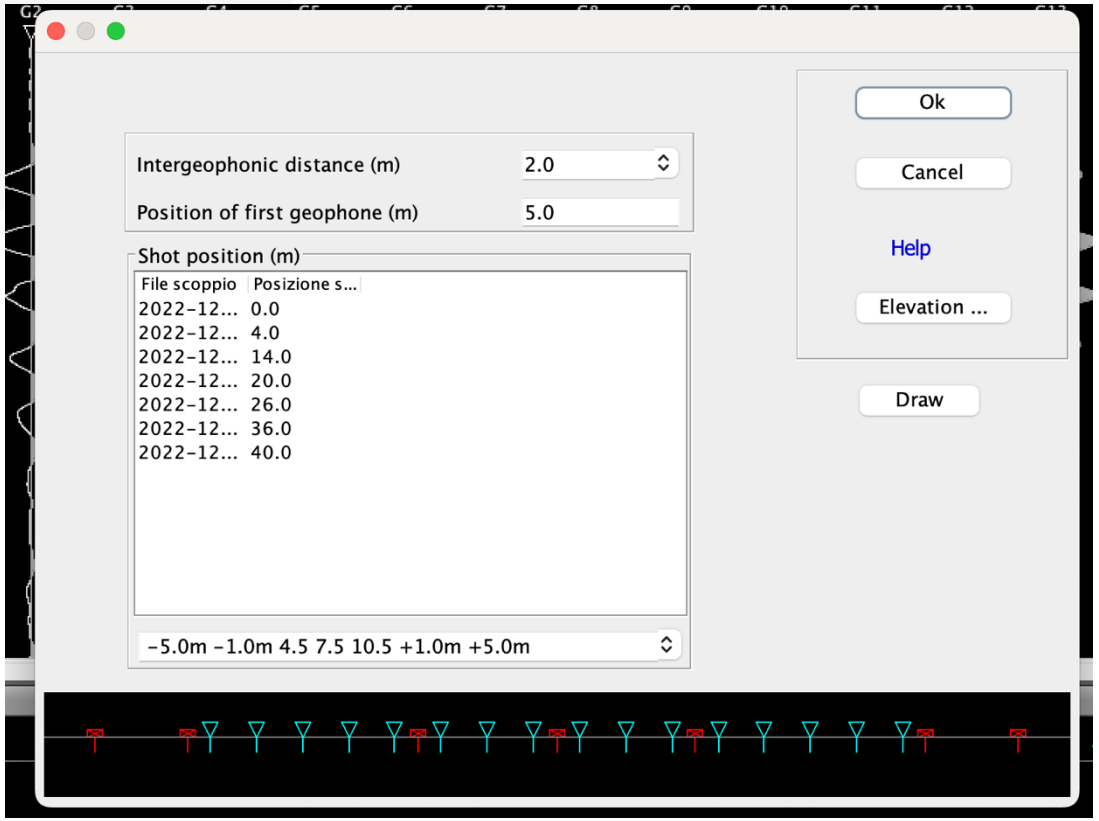
Input data & geometry → Picking → Travel times parametrization → Profile → Phantoming → Tv/Tg function selection




- The geophones must be equally distanced
- Shots position can be inserted using two different ways:
  - By editing the shot position table;

  or
  - By insert or select a string in the combo box below the table

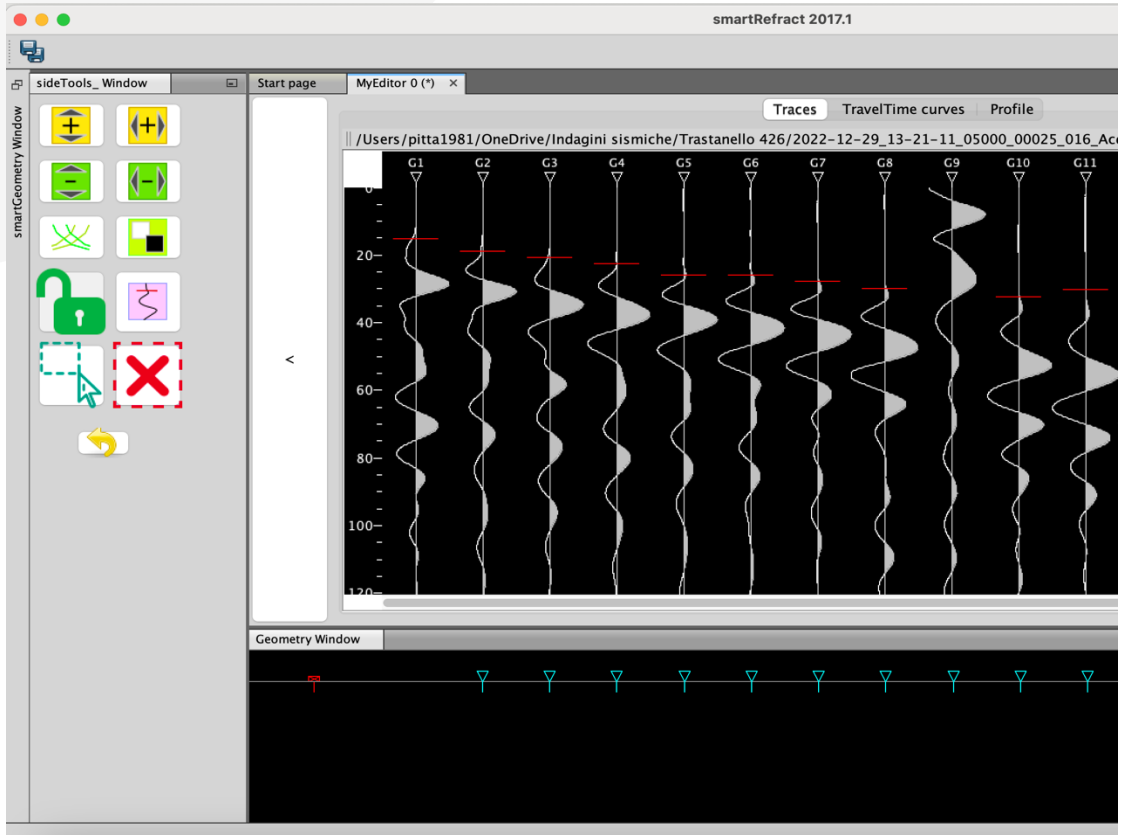
Input data & geometry → Picking → Travel times parametrization → Profile → Phantoming → Tv/Tg function selection



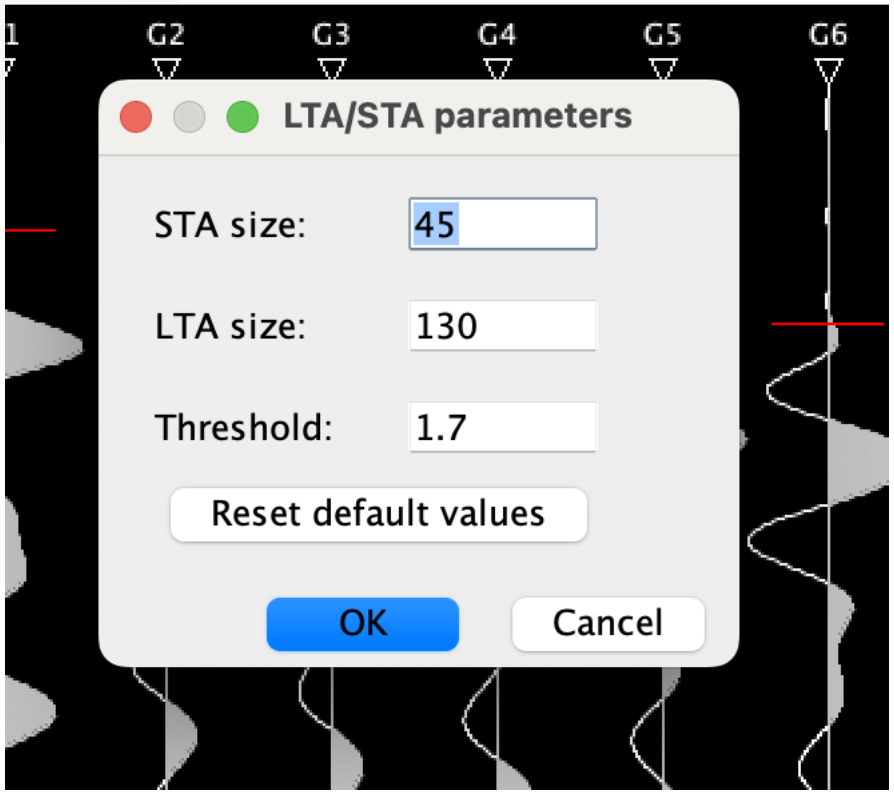

## Shot geometry syntax:

- Numbers followed by m mean distance before or after the first geophone or last geophone;
  - A shot with an offset of -5m is located 5 meters before the first geophone.
  - A shot with an offset of +10m is located 10 meters after the last geophone.
- Number without m are expressed as geophones number starting from 0;
  - A shot placed at 4.5 is between the 5$^{th}$ and 6$^{th}$ geophones

Input data & geometry → Picking → Travel times parametrization → Profile → Phantoming → Tv/Tg function selection

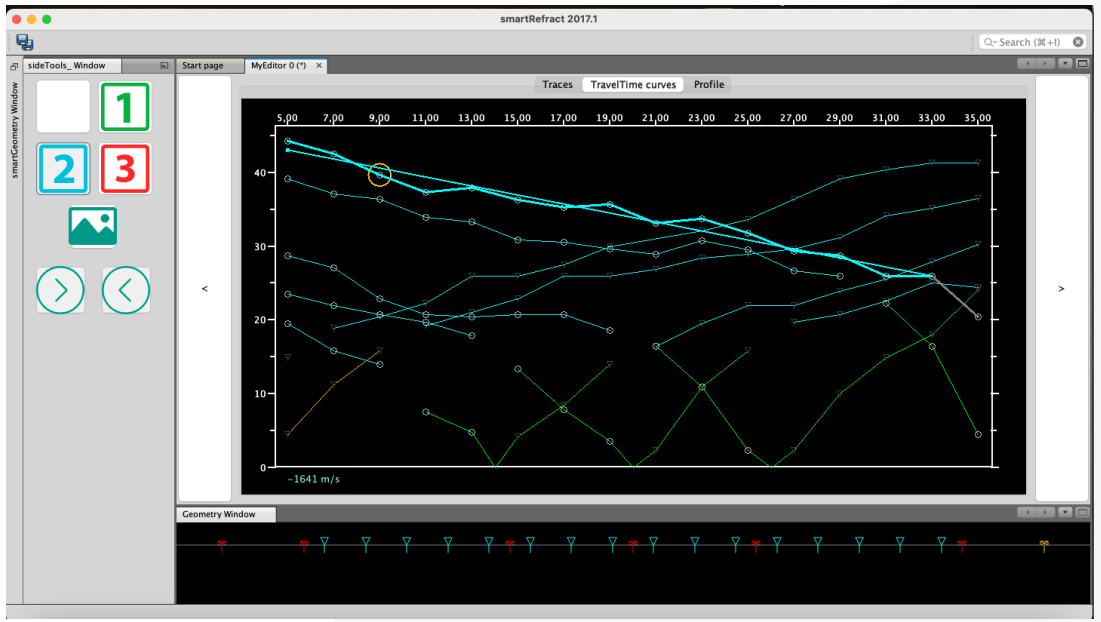


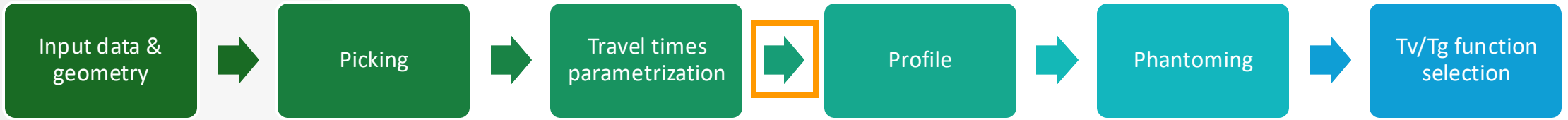

- SmartRefract offers both automatic and manual picking options to suit your workflow:
  - Automatic Picking:
    - Utilizes a robust STA/LTA algorithm to identify first breaks efficiently.
    - Ideal for large datasets and routine processing.
  - Manual Picking:
    - Provides precise control over first break identification.
    - Enables fine-tuning for complex waveforms and challenging data conditions.




- STA/LTA Algorithm for Precise First Break Picking
  - **Short-Term Average (STA):** Calculates the average amplitude of a short time window.
  - **Long-Term Average (LTA):** Calculates the average amplitude of a longer time window.
  - **STA/LTA Ratio:** The ratio of the STA to the LTA is calculated.
  - **First Break Detection:** When the STA/LTA ratio exceeds a predefined threshold, it indicates a significant increase in signal amplitude, likely corresponding to the first arrival.

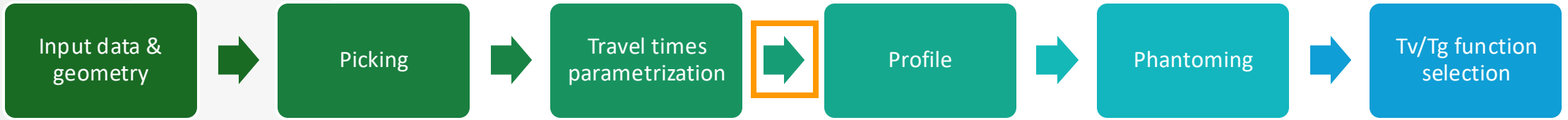
- Assigning travel times to layers is quite straightforward:
  - Click and drag on the plot to select the portion of travel time graph belongs to the selected (number in the sidebar) layer
  - Be careful: no check on layer consistency; **V1 must be lesser then V2 and V2 lesser then V3**



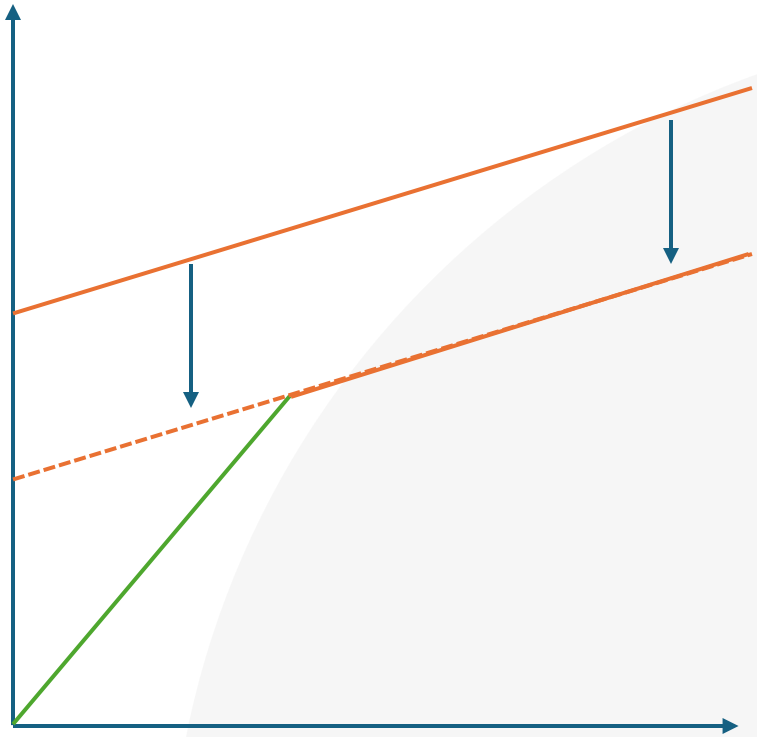


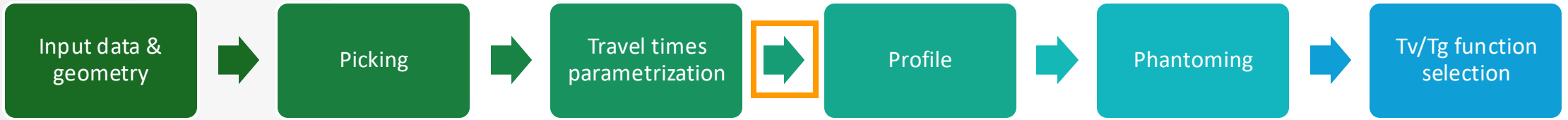

- What's behind profile plotting?

- smartRefract select the endline shots that map first and second layer
- smartRefract try to build a phantom travel time where layers are non mapped to real travel times
- smartRefract compute the depth profile exploitng GRM

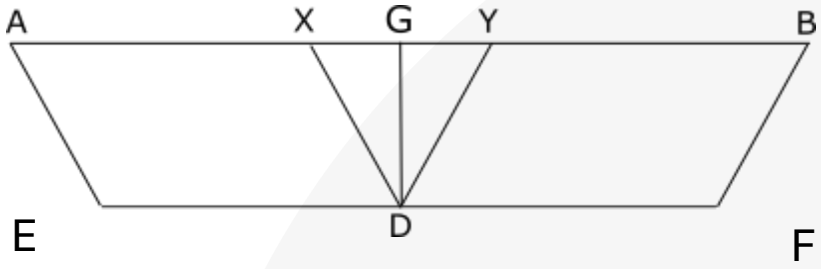



- Phantoming travel times:
  - Reconstruct travel times where not mapped by moving and interpolate data towards selected endline shots



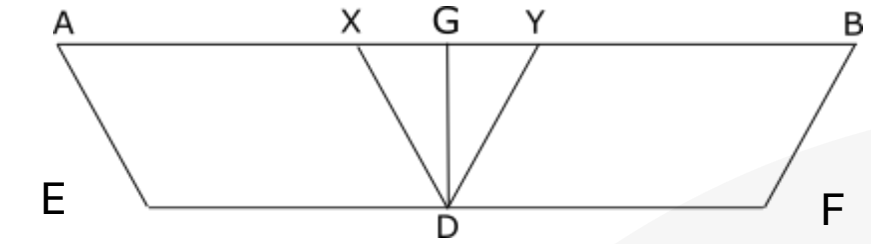


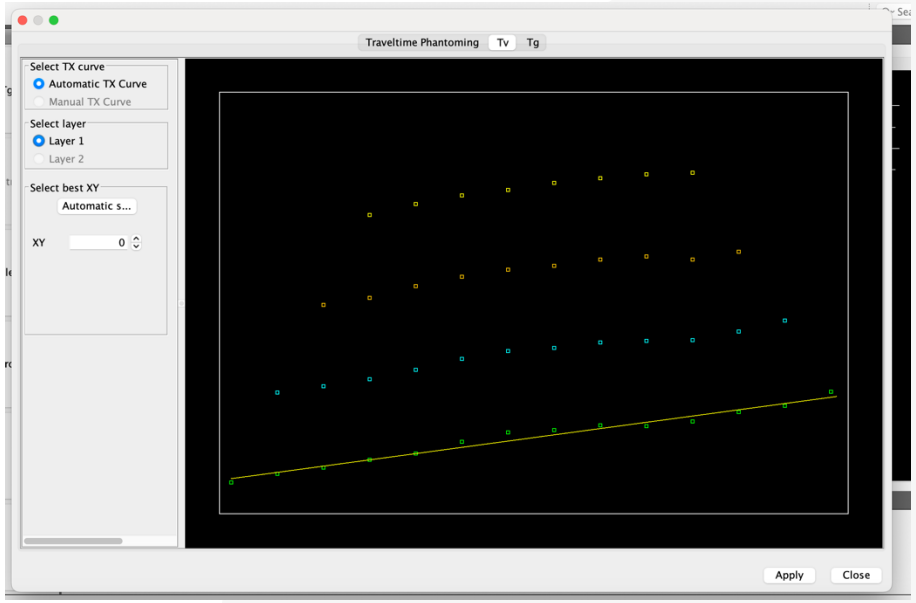

- The Generalized Reciprocal Method (GRM):
  - **Reciprocal Measurements:** The GRM utilizes both forward and reverse travel time data, providing a more robust analysis.
  - **Optimum XY Spacing:** The method involves finding the optimal spacing between geophones (XY) to maximize the accuracy of the depth and velocity estimates.



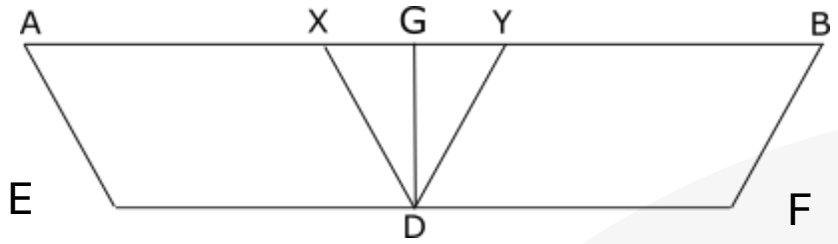
- **Definition:** The TV function (Time-Velocity function) relates the travel time of a seismic wave to its distance from the source.
- **Role in GRM:** The TV function is used to determine the optimal XY spacing for the GRM analysis.
- **Interpretation:** The slope of the TV function represents the reciprocal of the seismic velocity in a particular layer.

$$t_v = T_{AEDY} - T_{BFDX} + T_{AEDFB}$$



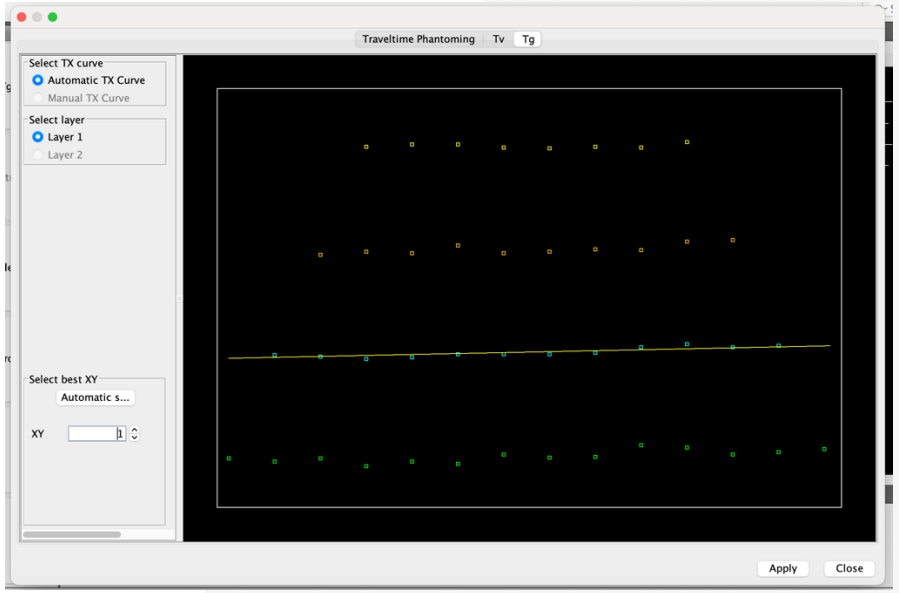



- **Definition:** The TG function (Time section) is a profile in travel time before migration.
- **Optimum XY Spacing:** The TG function can be used to determine the optimal XY spacing for the GRM analysis

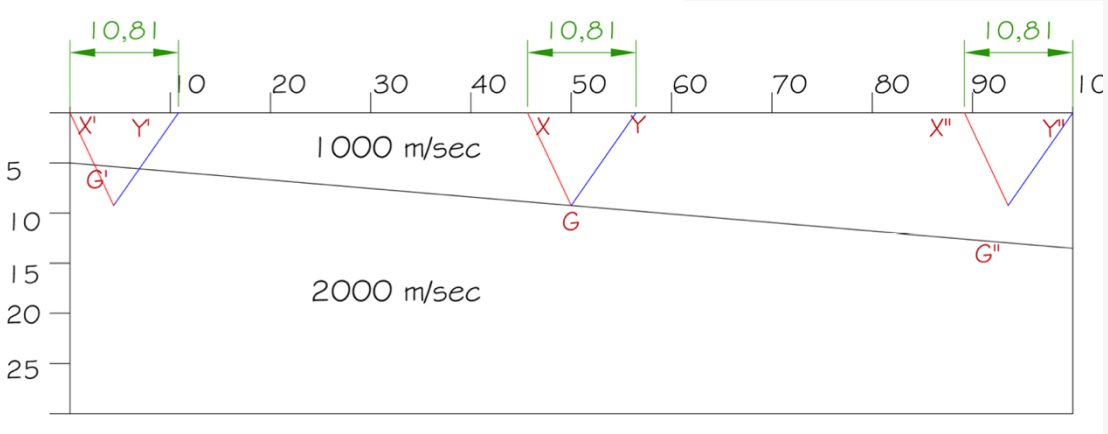



$$t_G = \frac{1}{2}(TAEDY + TBFDX - TAEDFB - XY/V_n)$$

$$Z_1 = T_{G1}\frac{V_2 V_1}{\sqrt{V_2^2 - V_1^2}}$$



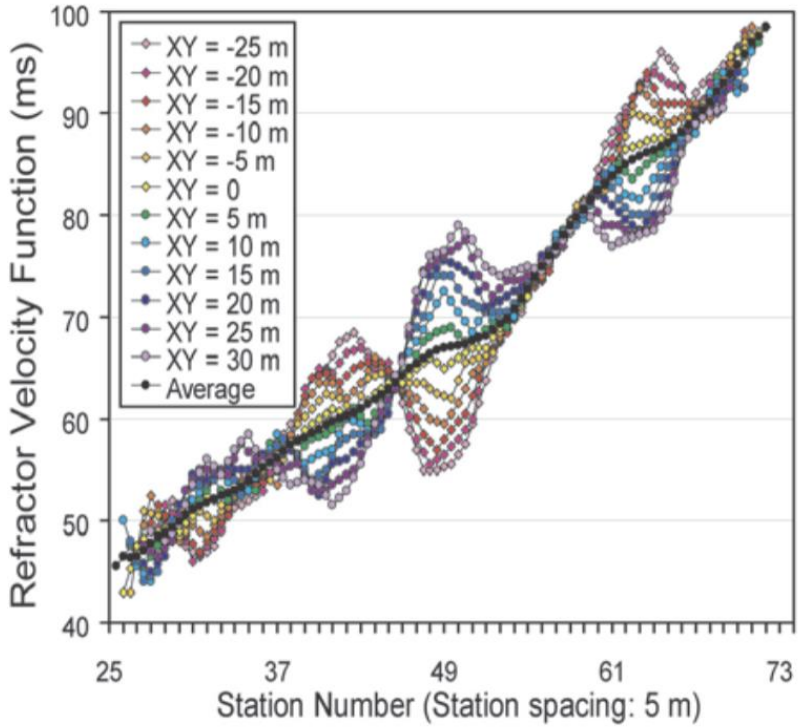
- Optimum XY values (Palmer 1981):
- **Smoothness of TV Function:** The optimum XY value is chosen to make the TV function as smooth as possible.
- **Roughness of TG Function:** The optimum XY value also maximizes the roughness of the TG function.
- **Automated Optimization:** SmartRefract automates the process of finding the optimal XY spacing



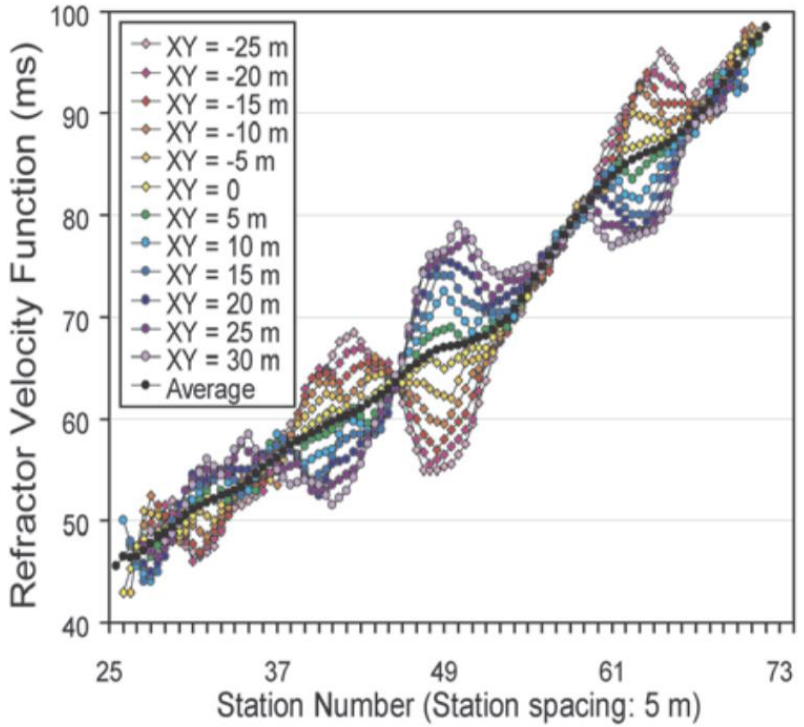

Non uniqueness of XY value

Source of image: https://rayfract.com/pub/XY@26.pdf

- **Palmer's 2011 Approach:**
  - **Computing TV and TG for Multiple XY Values:** Calculate TV and TG functions for a range of XY values.
  - **Averaging Functions:** Average the TV and TG functions obtained for different XY values to create a more robust and reliable estimate.



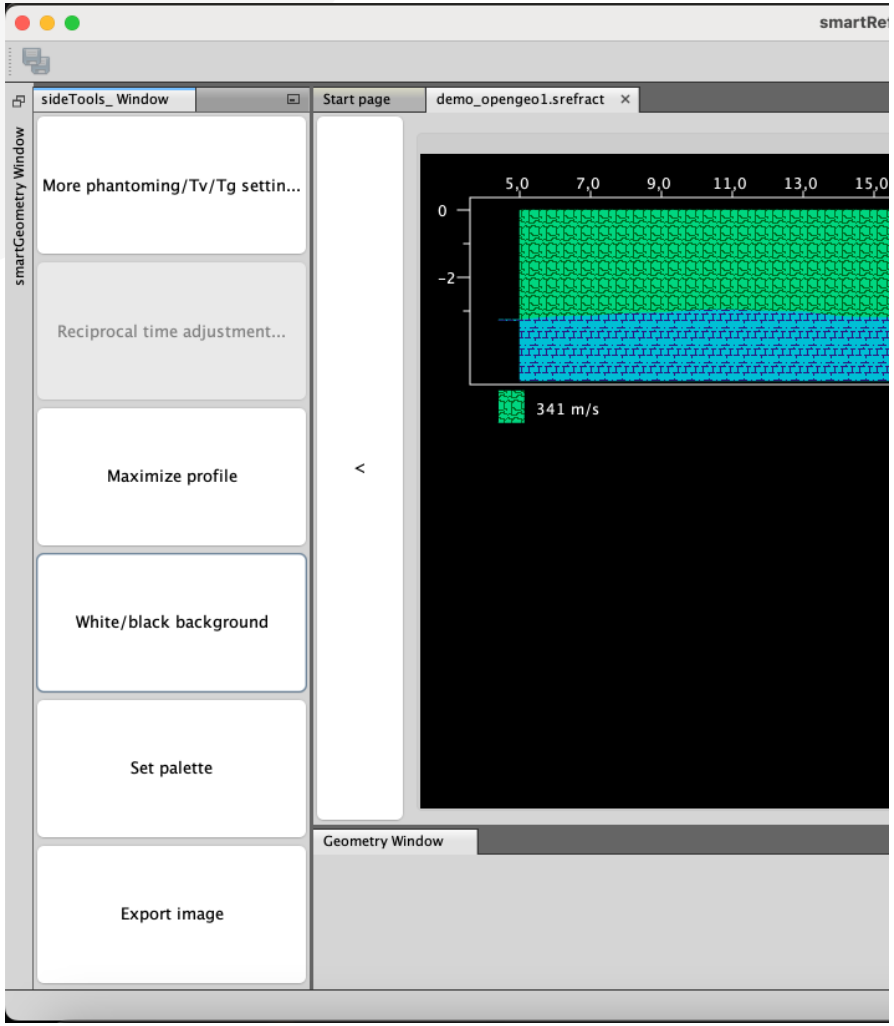

From D.Palmer – The Mt Bulga Tutorial 2011




# Any volunteers?

From D.Palmer – The Mt Bulga Tutorial 2011

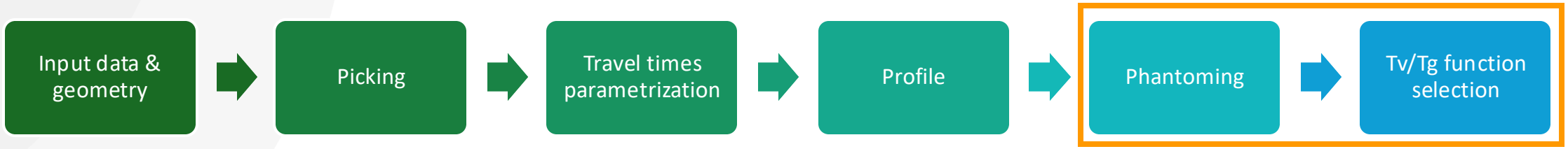
Input data & geometry → Picking → Travel times parametrization → **Profile** → Phantoming → Tv/Tg function selection




- SmartRefract offers different option to personalize profile:
- Proportional/maximized profile
- Changing color and pattern
- Exporting image

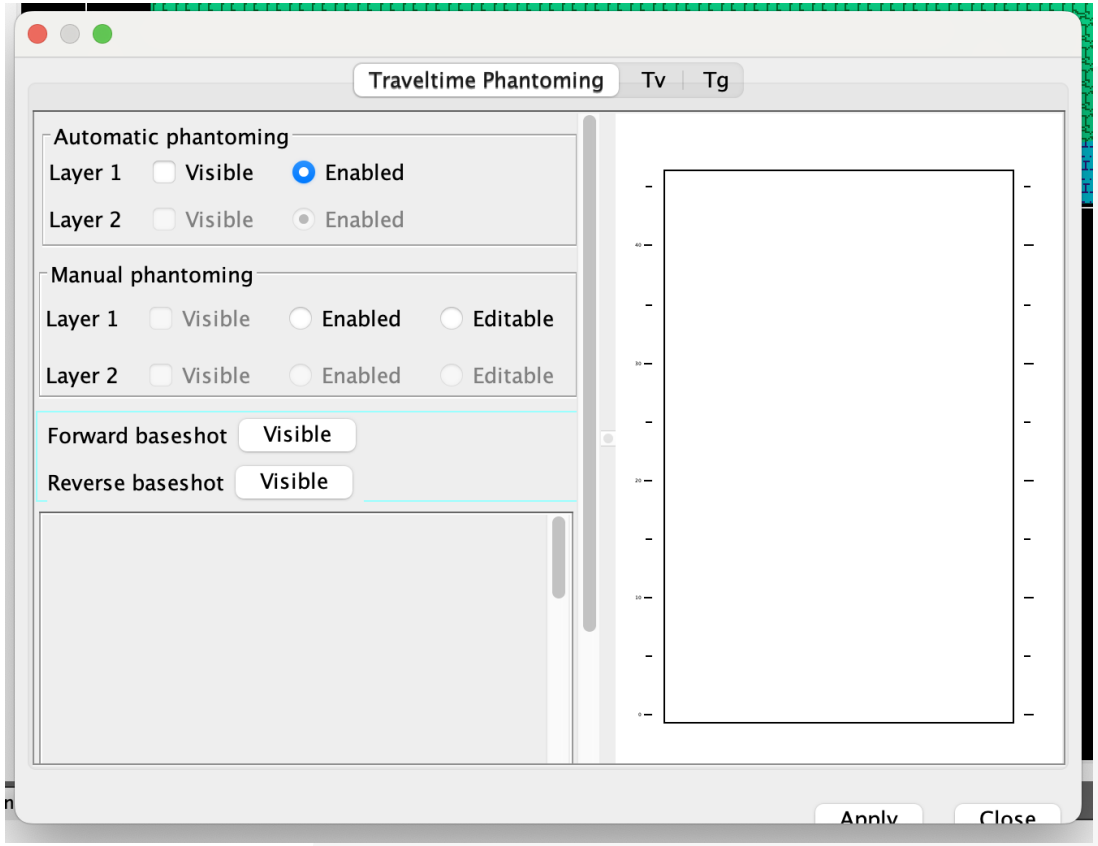
And….

**Phantoming options**



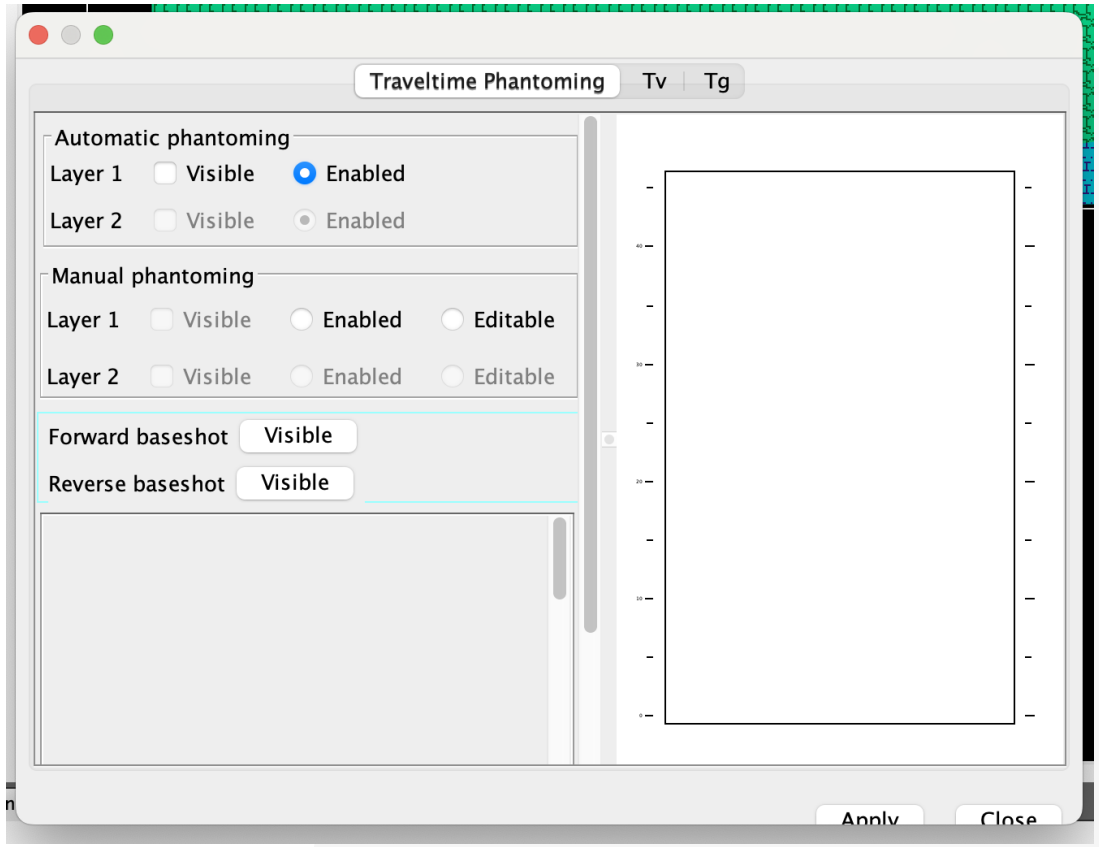

- Welcome to the hell of the worst but useful smartRefract dialog:

The **More phantoming/Tv/Tg settings** dialog

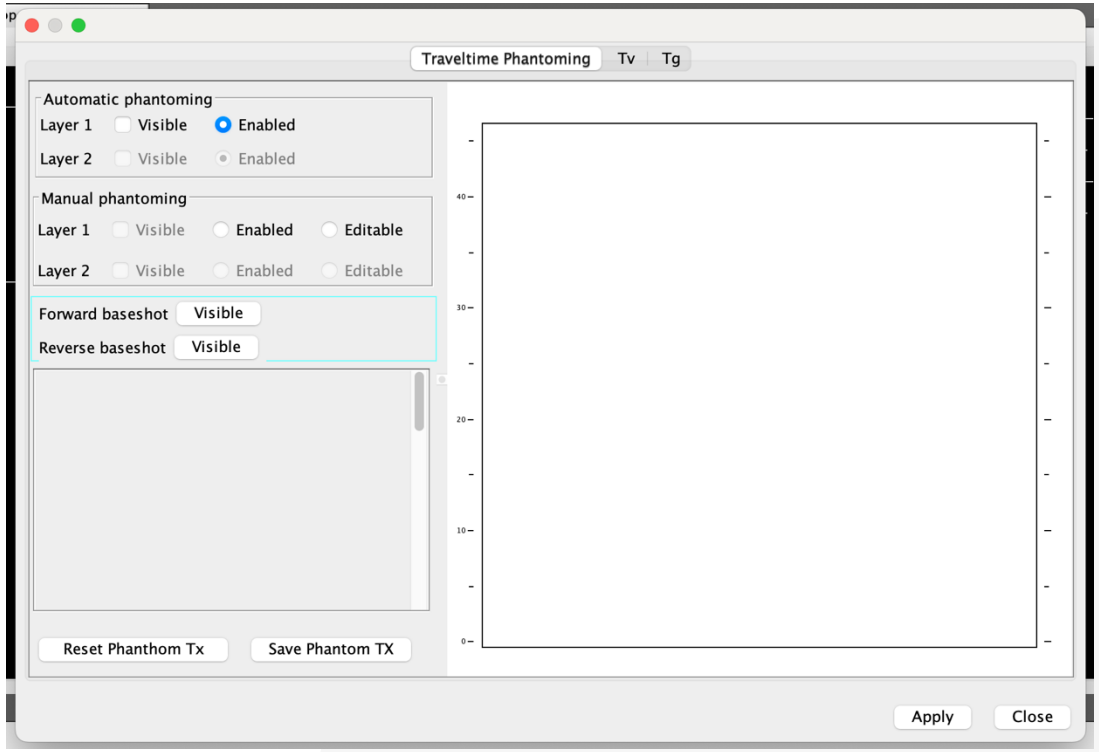


The **More phantoming/Tv/Tg settings** dialog.

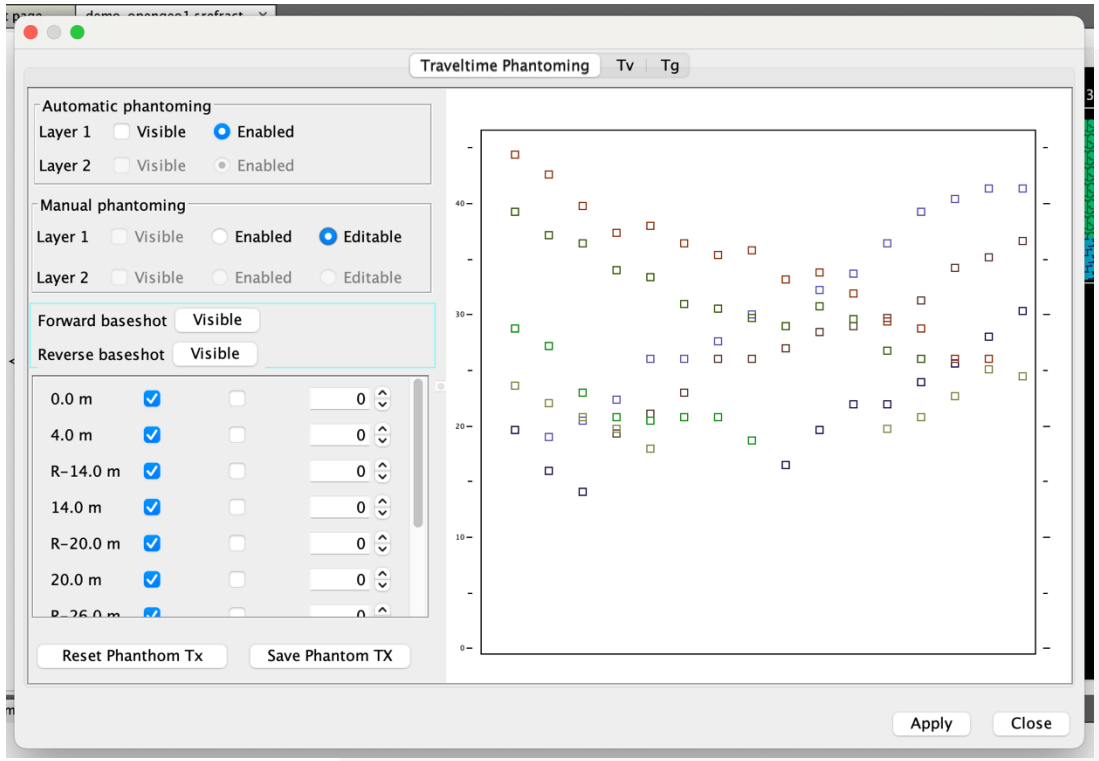
- From this dialog you can fix error in the reconstruction of travel times before and after hinge points
- Correct the reciprocal times
- Select manually a value of XY

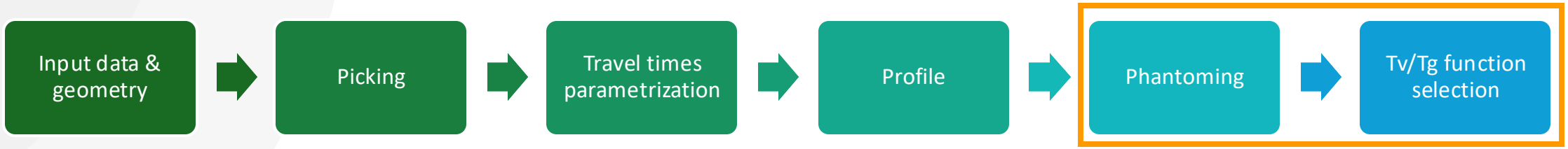


- Glossary:
- Baseshots are the two reciprocal travel times selected as reference by the software
- Enabled is the reconstructed traveltime actually used in profile building
- Editable allow or not to manually reconstruct travel times

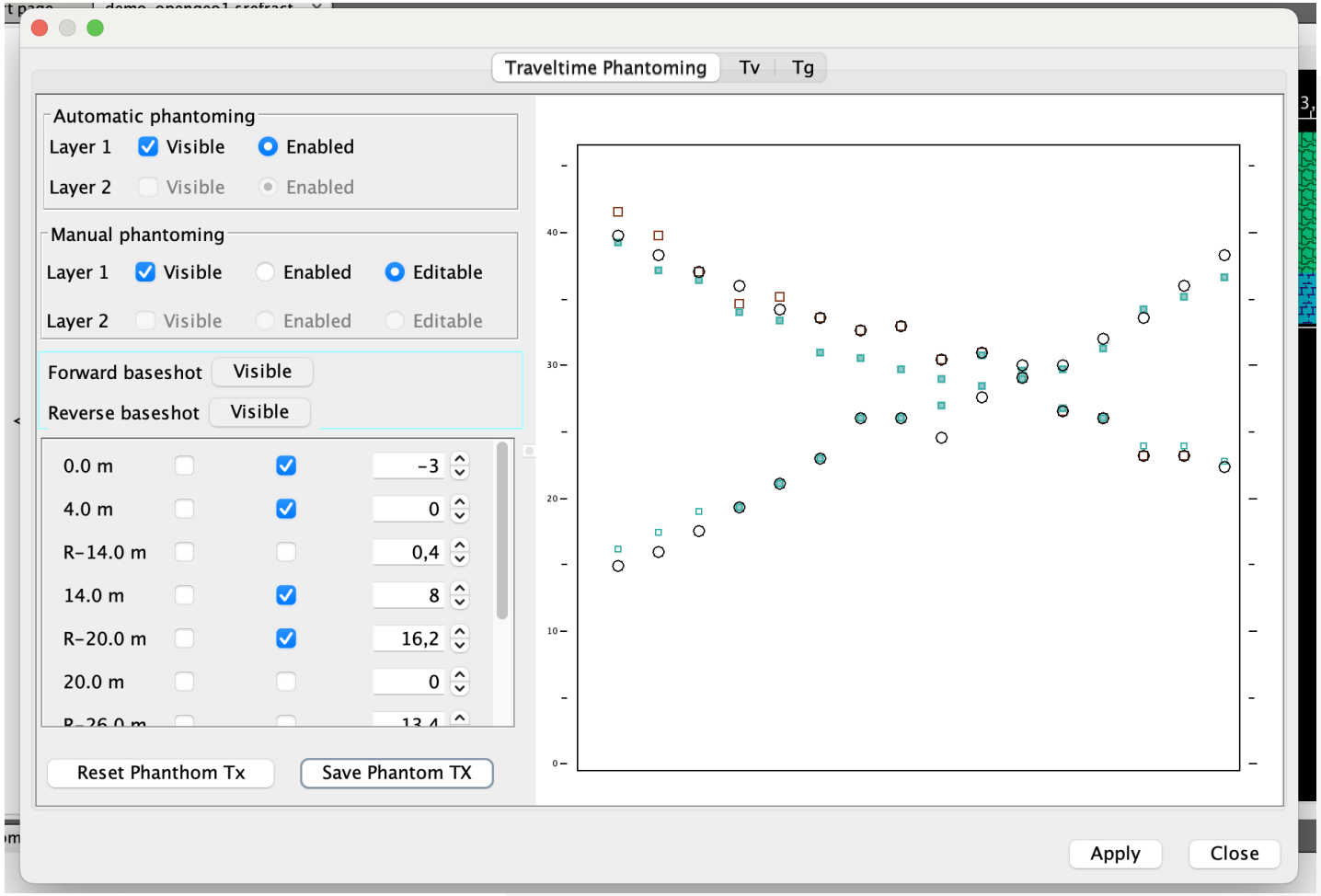


- Remember to press save phantom TX before applying






- Red circles shows manually reconstructed traveltimes
- Sky Filled squares are the baseshots t.t.
- Red empty squares are automatic travel times



# Live demo

(crossed finger)

# Conclusion & future works

# Conclusion

- The open-source nature make the software available to a wide range of users
- Benefits from feedback from users to improve usability
- One man band project: high risk of no time to update
  - Needs to build up a community of contributor

# Future works (& dreams)

- Implement a check of reciprocal travel times consistency
- Implement an automatic mapping of travel times to layers

---

Dreams

- AI powered first break picking
- AI powered mapping of travel times to layers
- Realtime profile during surveys

# Thank you

smartRefract, these slides and the demo datasets are available for download from: https://www.vs30.it

Email: simone.pittaluga@cnr.it