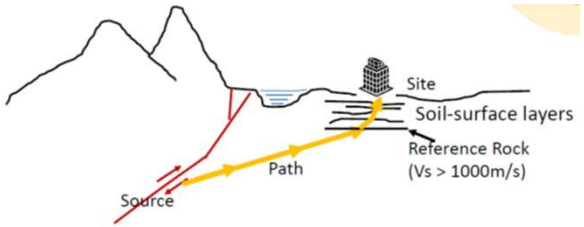

Regional-**S**cale **E**arthquake Ground Motion Predi**C**tions Thro**U**gh Pyhsics-based and Empi**R**ical Approach**E**s: A Case study Central Italy (**SECURE**)

Aybige Akinci

Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

PIANETA DINAMICO
WORKING EARTH

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SECURE
REGIONAL-SCALE EARTHQUAKE **GROUND MOTION PREDICTIONS**
THROUGH PYHSICS-BASED AND EMPIRICAL APPROACHES:
A CASE STUDY CENTRAL ITALY

Final Meeting of the INGV–SECURE Project, Pianeta Dinamico 2023–2025,
11–12 March 2026
INGV, Via di Vigna Murata 605, Rome – Sala del Consiglio
Online link: https://meet.google.com/kox-kyfs-nuc

----------11 March 2026 ----------

14:30 – Opening, Project Coord. Akinci A.

WP1 – Enhancements of Existing Crustal Velocity Models and Seismic Datasets WP Leader: De Gori P.

14:40 WP1 De Gori P. *3D velocity models across the three SECURE project target regions*

14:55 WP1 Burrato P. F. *Shallow geological models of Quaternary intermountain basins in Central Apennines*

WP2 – Characterization of Earthquake Source and Seismic Wave Propagation in the Central Apennines WP Leader: Calderoni G.

15:10 WP2 Calderoni G. *Multi-Method Stress Drop Estimation and Uncertainty Analysis for the 2016–2017 Amatrice–Visso–Norcia Seismic Sequence.*

15:25 WP2 Cirella, A., *Linking Stress Drop and Slip Heterogeneity to Assess Source Rupture Directivity for Earthquakes in Central Italy.*

15:40 WP2 Gabrielli, S., *Spectral Corrections for Propagation and Site Effects: Implications for Stress Drop Estimation in the 2016 Mw 6.0 Amatrice Earthquake.*

15:55 WP2 Colavitti, L. *Data-Driven Empirical Modeling of Source Directivity Effects in a Ground Motion Model for Central Italy*

16:10 - Coffee break

WP3 – Ground Motion Predictions using Innovative Approaches WP Leader: Sgobba S.

16:30 WP3 Sgobba, S., *Beyond Ergodicity and Stationarity: Advanced Approaches for capturing Spatio-Temporal Variability in Ground Motion Models*

16:50 WP3 Antonucci, A., *Intensity Prediction Equations: Performance and Developments*

17:05 WP3 - Artale Harris, P./Cuius, A., *Advancing Physics-Based Ground Motion Simulations through 1D and 3D approaches in central Italy.*

WP4 – Testing the Performance of Ground Motion Models and Empirical Relationships WP Leader: Taroni, M.

17:25 WP4 - Taroni, M., *New methods for the evaluation of the Ground Motion Models.*

17:45 – Discussion Q/A - End of Day 1

----------12 March 2026 ----------

10:00 – Keynote Lecture Bindi, D. (GFZ, Germany), *Bridging Spectral Decomposition and Ground-Motion Models: Results from SECURE and Perspectives.*

10:30 – Keynote Lecture, Gallovič, F., (Charles University in Prague, Czech Republic), *Constraining kinematic and dynamic rupture models for broadband strong-motion simulations.*

11:00 Coffee break

11:30 – Keynote Lecture, Askan, A., (METU, *Türkiye*), *From Simulations to Safety: Interdisciplinary Approaches for Urban Seismic Resilience in Türkiye.*

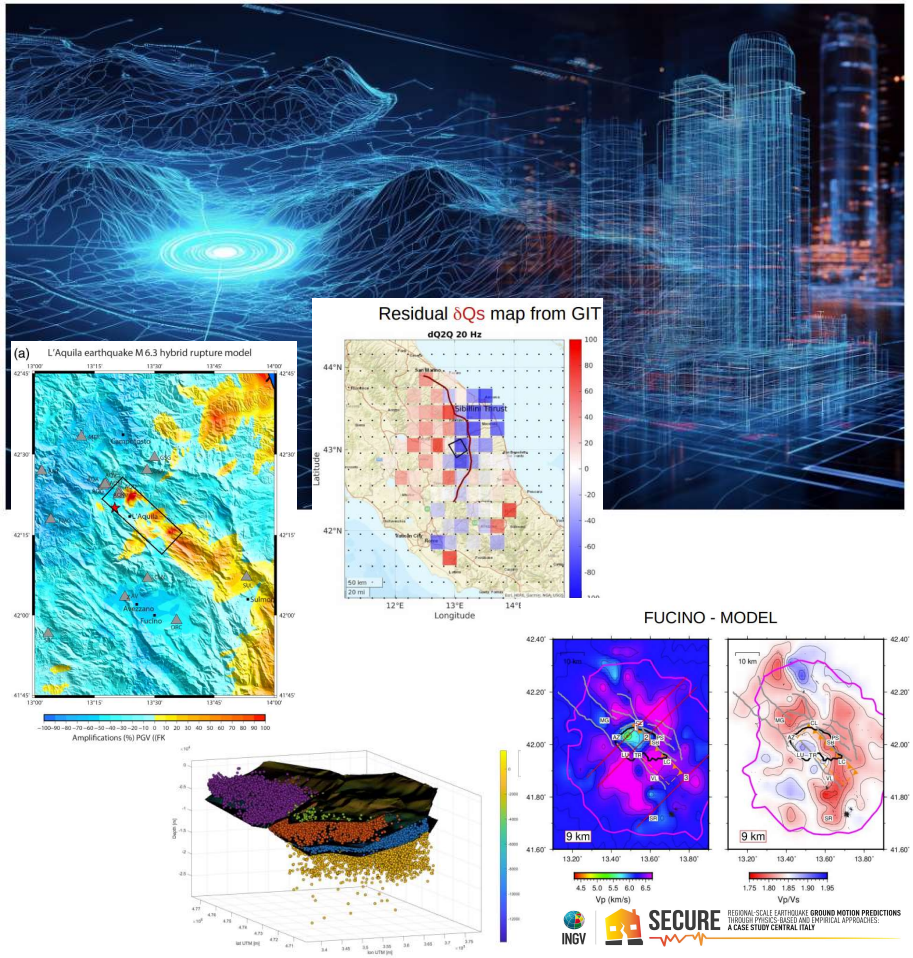
12:00 – Keynote Lecture Pitarka, A., (LLNL, USA), *Engineering use of recent physics-based ground motion simulations.*

12:30 – 13:00 Round Table and Closing

The main goals, activities, and outcomes of this research effort

The SECURE project — *"Regional-Scale Earthquake Ground Motion Predictions Through Physics-based and Empirical Approaches: A Case Study in Central Italy"* — was designed to address one of the central challenges in seismology and seismic hazard assessment:

- ✓ **How to improve the reliability of ground-motion predictions** in complex tectonic regions.
- ✓ Accurate quantification of earthquake ground motion as a function of magnitude, distance, and frequency is fundamental for **seismic hazard analysis, engineering applications, and civil protection strategies**, including rapid response and early warning systems.
- ✓ The Central Apennines provide an exceptional natural laboratory for this type of research, given the large amount of high-quality data produced by recent seismic sequences and the complex geological structures that strongly influence wave propagation.



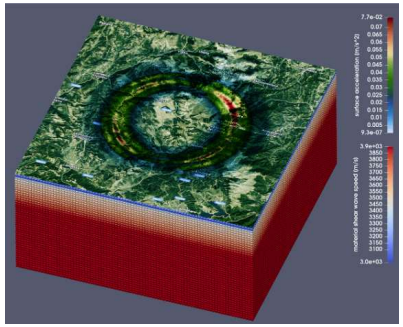
Project Vision and Scientific Objectives

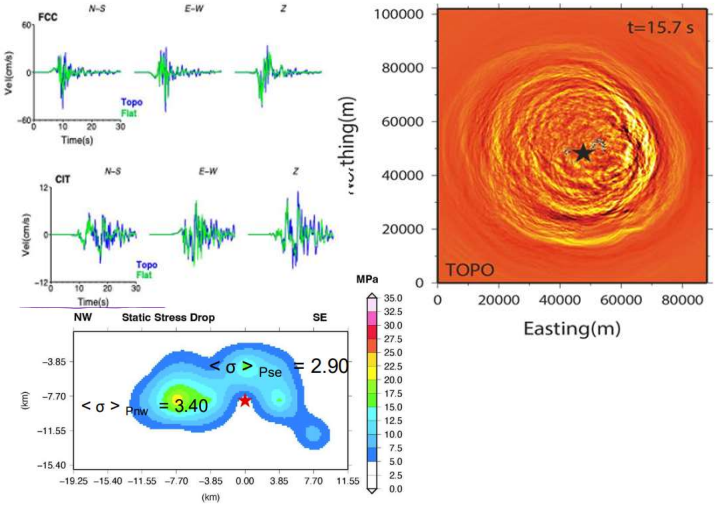
The main objective of SECURE was to **study earthquake ground motion characteristics using innovative techniques**, integrating empirical observations with advanced physics-based modeling approaches. In particular, the project focused on improving our understanding of the relationships between:

earthquake **source processes** (directivity effects, rupture velocity), **wave propagation** (attenuation/quality factors) through the crust, and **local site conditions** (such as basins, topography, and near-surface structures).

By investigating these elements together, SECURE aimed to better quantify the **spatial and temporal variability of ground shaking** during seismic sequences and to reduce uncertainties in ground-motion predictions.

Another key goal was the development of **data-driven non-ergodic and physics-based ground-motion models**, capable of capturing regional characteristics and temporal variations before, during, and after major earthquakes.





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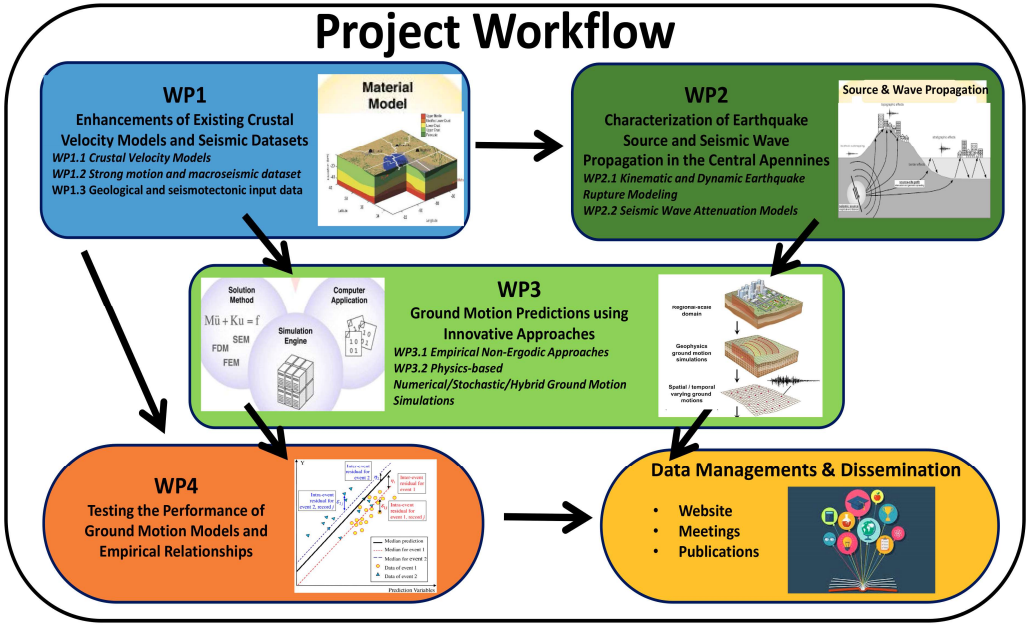
Research Activities

To achieve these objectives, the project implemented a multidisciplinary workflow.

First, we worked on the **construction of improved crustal velocity models** for the Central Apennines using tomographic analyses and geological constraints. We developed **comprehensive databases of earthquake recordings**, integrating accelerometric and velocimetric data together with macroseismic intensity observations.
(WP1, Resp. De Gori)

Second, we focused on the characterization of earthquake **source properties** and **seismic attenuation** (*moment magnitude, stress drop, apparent stress, and radiated energy*) using different approaches, while the spatial and temporal variability of **S-wave attenuation** was investigated to better understand its influence on **ground-motion variability** in the Central Apennines **(WP2, Resp. Calderoni).**



Third, we development of **data-driven non-ergodic and** generated **physics-based ground-motion models** and performed **broadband 3D ground-motion simulations** at thousands of sites. These simulations provide synthetic ground motions that complement the empirical data and are particularly useful in **near-fault regions** where recordings are limited (**WP3 Resp. Sgobba**).

Finally, the project **evaluated the performance** of different ground-motion prediction approaches through systematic validation against observed seismic recordings and macroseismic data (**WP4 Resp. Taroni**).

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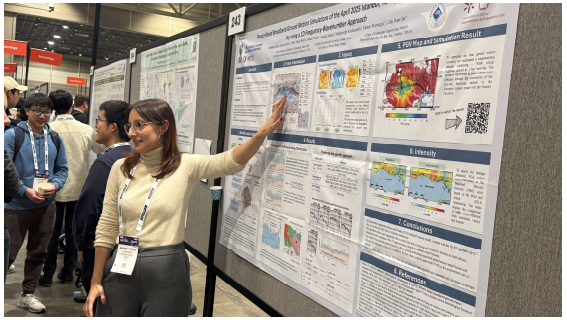
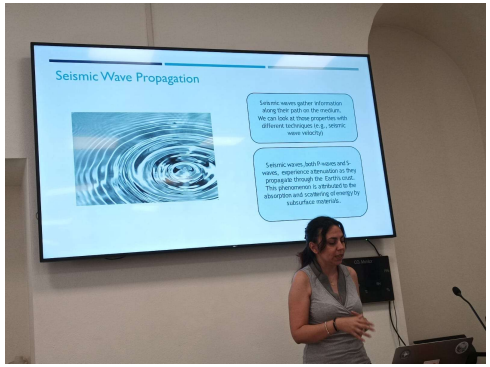
Collaboration and Team

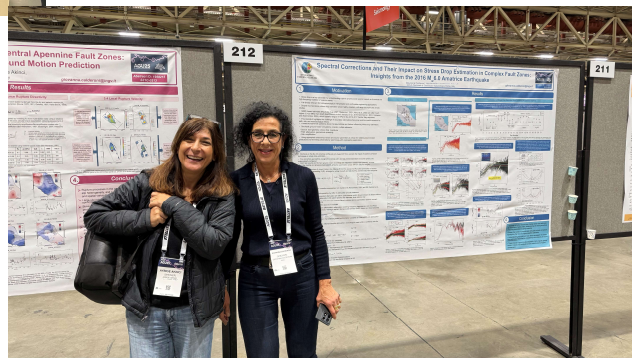
SECURE has been a collaborative effort.

The project involved **29 researchers from INGV and about ten external scientists** from national and international institutions, including universities and research centers in Europe and the United States.

This **collaboration** allowed us to combine **expertise** in seismology, earthquake physics, numerical modeling, and engineering seismology, and to **connect SECURE** with other **ongoing international** research **initiatives.**







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Key Outcomes and Impact

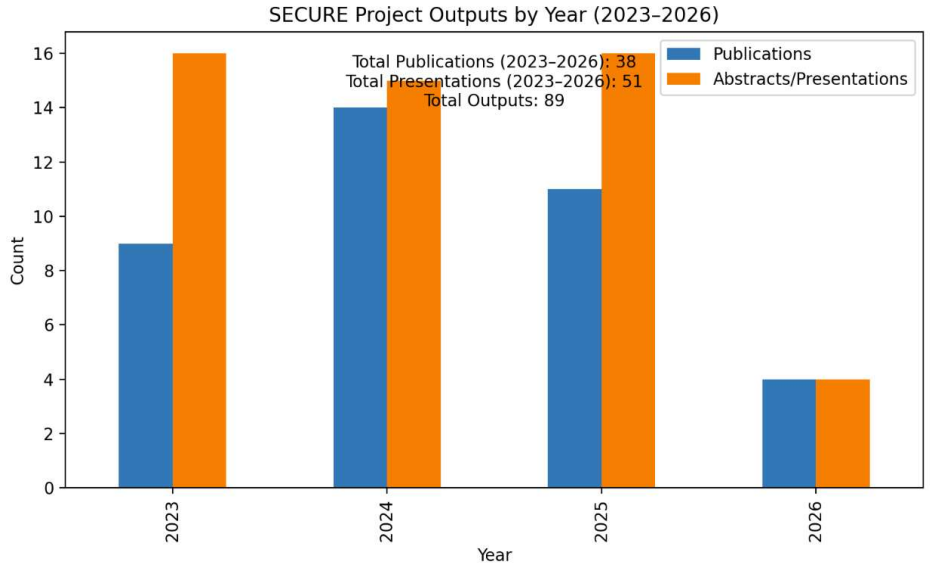
The main outcomes of SECURE can be summarized in three points:

1. **Improved physical understanding of ground-motion variability** in the Central Apennines.

2. **Development of advanced modeling frameworks** combining empirical and physics-based approaches.

3. **Generation of synthetic ground-motion scenarios and datasets** that can support engineering applications and seismic hazard assessments.

These results contribute to advancing **seismic hazard** assessment and **risk mitigation**.



BORSE DI STUDIO E ASSEGNI DI RICERCA PIANETA DINAMICO 2024 (non sono rendicontabili BS - AdR da altri progetti)			
Nominativo (Nome e Cognome)	**SEZIONE**	**Tipologia**	**TEMA**
Rossella Fonzetti	RM1	Professionalizzante	ST_SECURE
Genny Giacomuzzi	RM1	Post Dottorale	ST_SECURE
Simona Gabrielli	RM1	Professionalizzante	ST_SECURE
Edlira Xhafaj	MI	Post Dottorale	ST_SECURE
Leonardo Colavitti	MI	Professionalizzante	ST_SECURE
Arianna Cuius	RM1	Professionalizzante	ST_SECURE

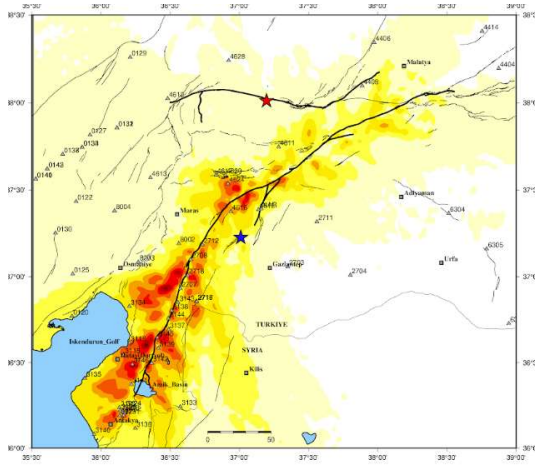
Final Remarks

SECURE represents an important step toward bridging the gap between **observational seismology, numerical simulations, and engineering applications**.

The methodologies and datasets developed within this project are not limited to Central Italy:

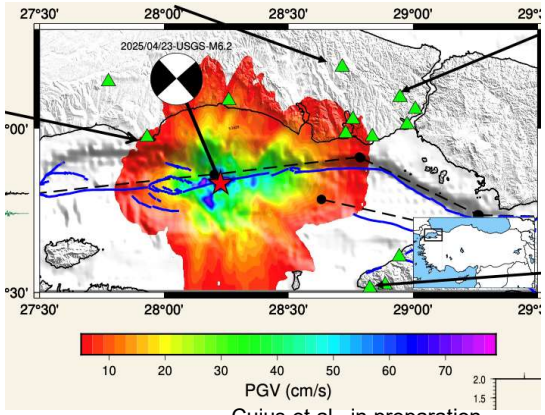
they can be **transferred to other seismically active regions**, helping to improve ground-motion predictions worldwide.

I would like to thank all the researchers, collaborators, and institutions that contributed to the success of this project.



Akinci et al., in preparation

Gabrielli et al., submitted



Cuius et al., in preparation

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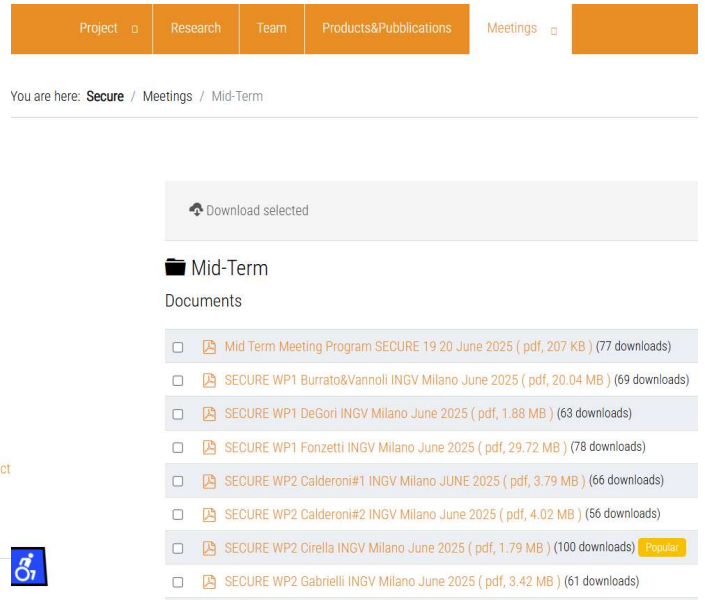

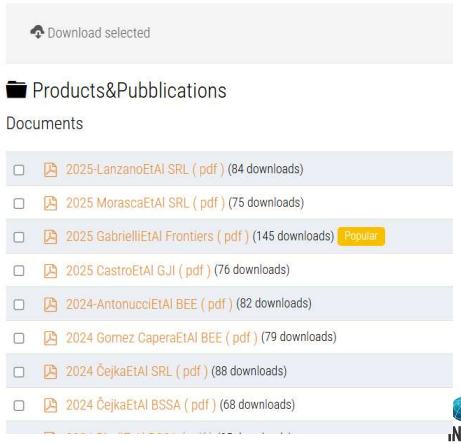

Key Scientific Questions to be addressed in the Project:

- How should we improve the **ground motion predictions** in central Italy?
- What is the **impact** of earth structure, basins, topography, source rupture heterogeneity (kinematic, dynamic, and geometrical), and seismic wave attenuation on the **estimated ground motions** at a given site?
- Can **non-ergodic ground-motion models**, accounting for spatial and temporal variability, improve the predictive capability of ground shaking, particularly during a seismic sequence?
- To what extent can **physics-based ground-motion simulations** be considered a reliable framework for ground-motion prediction?
- Is it possible to reduce the variability in ground-motion estimates by **calibrating temporally non-stationary GMMs** that implicitly incorporate parameters describing rupture dynamics (e.g., stress drop or apparent stress)?
- Can the empirical relationships between **macroseismic intensity and recorded ground motion** be validated using robust statistical testing?
- Can we develop **validation tests for Ground Motion Models (GMMs)** specifically designed to assess their performance in engineering applications?
- Do **regionalized hybrid GMMs,** derived from the physics-based simulations and non-ergodic modeling approaches, outperform existing GMMs currently used for Central Italy?

Riunione Plenaria SECURE (Progetto Pianeta Dinamico 2023-25), 30 Gennaio 2024, Roma

9:15	**Opening**	Akinci A.
9:30	**WP1. Miglioramenti dei Modelli Esistenti di Velocità della Crosta e Dati Sismici**	Resp. De Gori P.
9:30	Modelli di tomografia sismica locale /Vp, Vp/Vs) nelle tre aree studio del progetto SECURE: stato dell'arte e lavori in preparazione.	De Gori P.
9:45	Nuovo catalogo sismico della sequenza dell'Aquila 2009 determinato attraverso l'applicazione di tecniche di Machine Learning.	Fonzetti R.
10:00	Vincoli geologici superficiali e profondi per lo sviluppo dei modelli tomografici nelle tre aree studio del Progetto SECURE.	Burrato P.F.
10:15	Costruzione e analisi di dataset di registrazioni e dati macrosismici per le attività di ricerca del progetto SECURE.	Lanzano G.
10:30	**Discussione Q/A**	
10:45	**Pausa**	
11:00	**WP2 - Caratteristiche della Sorgente dei Terremoti e Propagazione delle Onde Sismiche nell'Appennino Centrale**	Resp.CalderoniG.
11:00	Risultati preliminari del confronto dei parametri di sorgente stimati applicando diversi metodi.	Calderoni G.
11:15	Alcune tecniche per la stima dei parametri di sorgente in Centro Italia	Morasca P.
11:30	Evoluzione temporale dell'attenuazione coda/S waves in funzione della frequenza nell'Appennino Centrale.	Gabrielli et al.
11:45	Variabilità spazio-temporale del parametro di attenuazione in alta frequenza (κ) e parametrizzazione ingegneristica degli effetti di direttività di sorgente.	Colavitti et al.
12:00	**Discussione Q/A**	
12:15	**Invited Talk:** Seismic Source Characteristics and Ground-Motion Variability in Central Italy: a bridge between WP2 and WP3.	Bindi D.,Picozzi, M.,Spallarossa,D.
13:00	**PAUSA PRANZO**	
14:30	**WP3 - Previsioni del Moto del Suolo Utilizzando Approcci Innovativi**	Resp. Pacor F.
14:30	Risultati preliminari dell'analisi della variazione spaziale e temporale del moto sismico osservato in Italia.	Pacor F., Sgobba S., Lanzano, G.
14:45	Simulazioni numeriche 3D del moto del suolo per il terremoto di Amatrice e Norcia.	Akinci A.
15:00	Simulazioni basate sul metodo 1D-FK deterministico per i terremoti dell'Appennino centrale.	Artale Harris, P.
15:15	Modelli di attenuazione dell'intensità macrosismica calibrati in Mw per l'Italia.	Gomez-Capera,A.
15:30	**Discussione Q/A**	
15:45	**WP4. Prestazioni dei Modelli di Moto del Suolo e delle Relazioni Empiriche**	Resp. Taroni M.
16:00	Caratteristiche dello scuotimento sismico negli Appennini Meridionali	Zimmaro P.
16:15	Nuovi metodi per confrontare e testare i Ground Motion Models: applicazione al caso studio dell'Appennino Centrale in Italia.	Taroni et al.
16:30	**Pausa**	
17:00	Tavola Rotonda	Tutti Partecipanti

Mid-Term Meeting SECURE (Dynamic Planet Project 2023–25)
June 19–20, 2025 – Milan -Italy

11:30 Opening & Overview, *Regional-**S**cale **E**arthquake Ground Motion Predi**C**tions Thro**U**gh Pyhsics-based and Empi**R**ical Approach**Es**: A Case study Central Italy*, **SECURE,** *Akinci A.*

WP1. Improvements to Existing Crustal Velocity Models and Seismic Data

ResponsibleWP & Convener, *De Gori P.*

11:45 Vp and Vs Velocity Models in the three Target Areas, *De Gori P.*

12:00 Application of Machine Learning Techniques to Fucino Seismic Data for the Detection of Local Earthquakes *Fonzetti R.*

12:15 Shallow Geological Models of the Aterno Valley (Target Area #2) and the Fucino Basin (Target Area #3), *Burrato P. and P. Vannoli*

12:45
Lunch Break

WP2. Earthquake Source Characteristics and Seismic Wave Propagation in CA

ResponsibleWP & Convener, *Calderoni G.*

14:15 Spectral Correction for Propagation and Site Effects: Impact on Stress Drop Estimation, *Calderoni G. et al.*

14:30 Analysis of stress drop variations in the strongest earthquakes of the AVN 2016-2017 Seismic Sequences, *Calderoni G., Morasca P., Bindi, D.*

14:45 Linking Slip Heterogeneity and Stress Drop–Directivity Effect to Near-Source Ground Motion: Application to the 2009 L'Aquila Earthquake and to the 2016 Central Italy Seismic Sequence, *Cirella et al.*

15:00 GITpy: A Python-based tool for Generalized Inversion Technique, *Morasca P. et al.*

15:15 Analysis of the Impact of Attenuation Variations on Ground Motion in Central Apennines, *Gabrielli et al.*

15:30 Modeling Seismic Source Directivity Effects from Apparent Source Spectra: A GIT-Based Approach for Small Earthquakes, *Xhafaj E. et al.*

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