TITAN
ARTIFICIAL INTELLIGENCE
IN ASTROPHYSICS

HORIZON-WIDERA-2022-TALENTS: ERA Chairs

TITAN:
Frugal Artificial Intelligence and Application in Astrophysics

ERA CHAIR: Jean-Luc Starck

Project Overview

Panagiotis Tsakalides

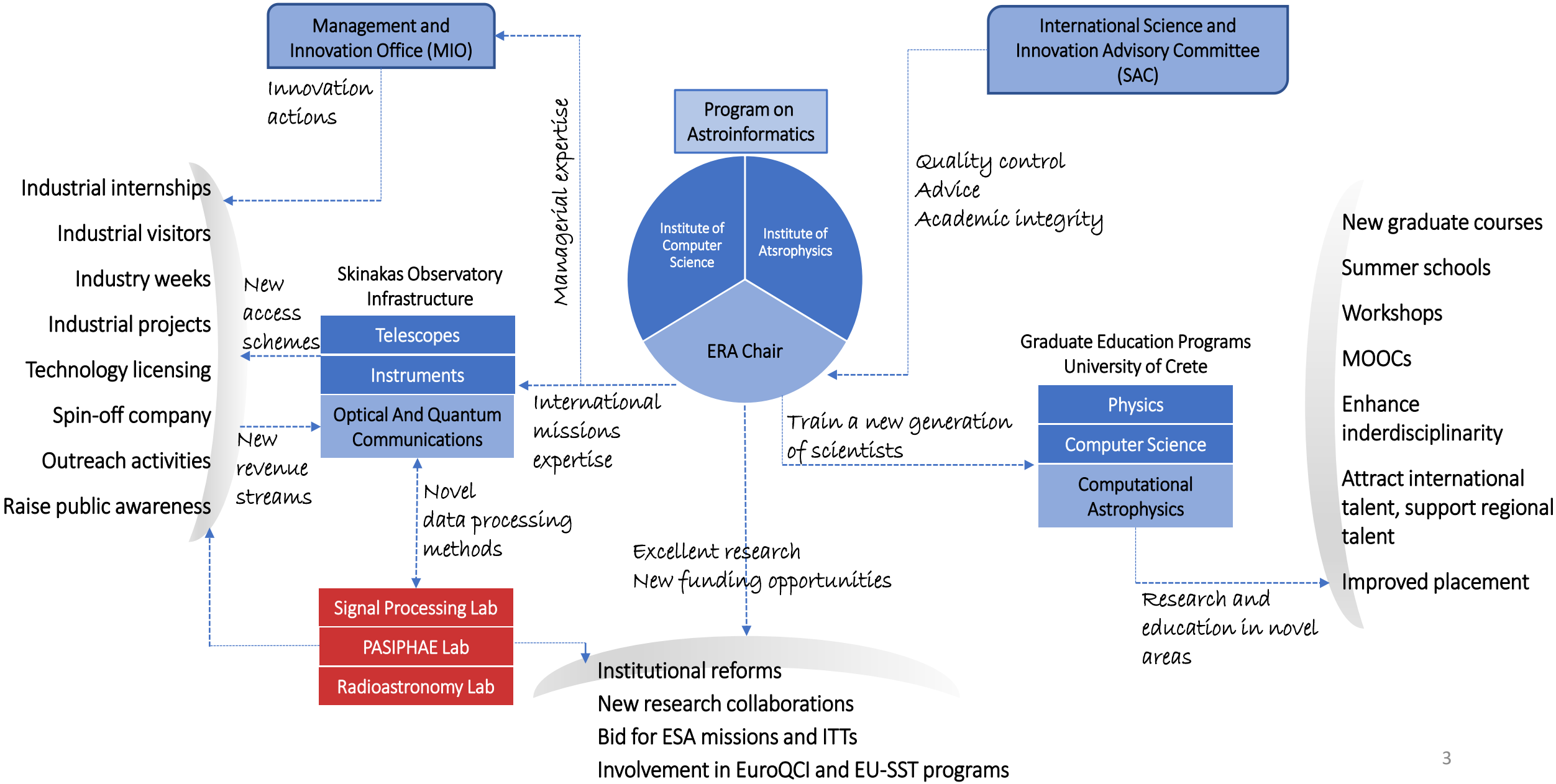
Institute of Computer Science (ICS)
Foundation for Research and Technology Hellas (FORTH)

The TITAN ERA Chair Project

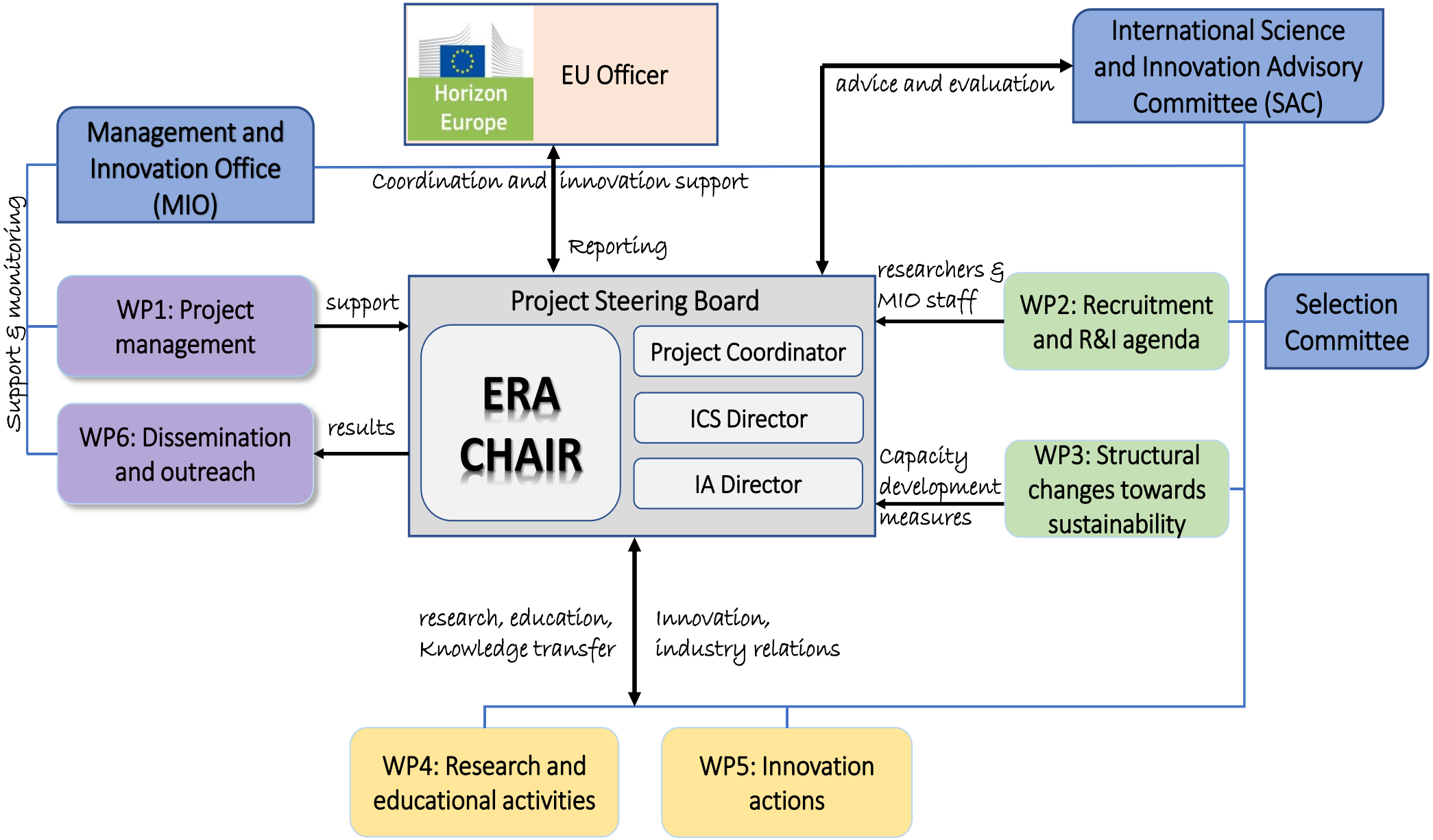
- **Scope**: Establish a collaborative **Astroinformatics Program** at FORTH in Crete. Form a high-caliber research team specializing in statistical data science and machine learning for astrophysics, accompanied by relevant educational initiatives.

- **Expected impact**: Unlock the potential of FORTH through the implementation of a set of measures geared towards capacity building; institutional development and structural change; intersectoral and international partnership activities bolstering a research and innovation culture.

The TITAN project concept



The TITAN project structure



The TITAN Team

Jean-Luc Starck

ERA CHAIR

Panos Tsakalides

PROJECT COORDINATOR

Greg Tsagkatakis

SENIOR RESEARCHER

George Tzagkarakis

SENIOR RESEARCHER

Samuel Farrens

SENIOR RESEARCHER

Anastasia Aidini

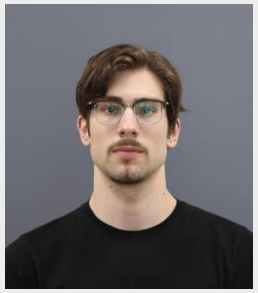
POSTDOCTORAL FELLOW

Athanasia Gkogkou

POSTDOCTORAL FELLOW

Victor Bonjean

POSTDOCTORAL FELLOW



Andreas Tersenov

PHD STUDENT

Pauline Gorbatchev

PHD STUDENT

Arnab Lahiry

PHD STUDENT

Ioannis Gavalas

MANAGEMENT AND INNOVATION OFFICER

Marian Papadaki

ADMINISTRATIVE ASSISTANT

Stelios Roubakis

RESEARCH ENGINEER

Jan. 2023

05 Senior Researchers	03 Post-doc Researchers
03 PhD Students	03 Administrative/Technical Personnel

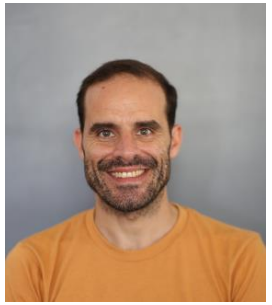
EU

2.5M€

The TITAN Collaborators

Vassilis Charmandaris

FORTH-IA DIRECTOR



Tanio Diaz-Santos

IA SENIOR RESEARCHER

Kostas Tassis

IA SENIOR RESEARCHER

John Antoniadis

IA SENIOR RESEARCHER

Stefano Camera

PROF. UNIVERSITÀ DEGLI STUDI DI TORINO

Martin Kilbinger

EUCLID SCIENTIST
CEA - COSMOSTAT

Klea Panayidou

EUROPEAN UNIVERSITY CYPRUS

The TITAN Science and Innovation Advisory Committee

Christina Giannopapa

EUROPEAN SPACE AGENCY

Carola-Bibiane Schönlieb

UNIVERSITY OF CAMBRIDGE

Emmanuel Candès

STANFORD UNIVERSITY

Sune Toft

NIELS BOHR INSTITUTE

Frédéric Courbin

EPFL

TITAN Research Challenges (1)

- **Challenge 1 - Develop a robust Deep Learning (DL) framework.** Use a *physics-driven approach* that: (i) generalises well; (ii) provides uncertainties quantification; and (iii) is frugal.

- **Challenge 2 - Unlock the application of DL to higher dimensional data**. Assimilate *high-dimensional (3D and 4D) observations* from different sensing modalities.

- **Challenge 3 - Enhance radio-interferometry image reconstruction**. Take advantage of SKA's *widefield imaging capabilities*, *high angular resolution*, and *instantaneous sensitivity*, to find and characterize radio emission from sources.

TITAN Research Challenges (2)

- **Challenge 4 - Develop robust weak lensing methods for both optical and radio weak lensing**. Develop new *weak lensing tools* for image reconstruction, and *galaxy shape and mass mapping methods* for both Euclid and SKA.

- **Challenge 5 - Promote frugality in Astrophysics**. Introduce a *likelihood-free cosmological parameter inference framework*.

- **Challenge 6 - Develop cutting-edge technologies**. Novel imaging systems including *AI-powered sensing platforms*, *distributed camera networks* for space asset tracking, and space mission designs for *astrophysical research and Earth Observation*.

TITAN Research: 3 intellectual themes and 3 target applications

IT-1: A robust DL approach

- Quantify uncertainties
- Ensure good generalization and trustworthiness

IT-2: Towards higher dimensions

- New 4D representations
- Sparse decompositions in a DL framework
- Extension of learnlets to 3D and 4D

From models to technologies

- Integration of physics-driven analytical models and data-driven ML approaches
- Resource-efficient ML considering appropriate hardware (FPGA/GPU)

TA-1 Time Domain Astrophysics

- Reconstruct high dimensional radio-interferometry data
- SKA will provide a gain in resolution, sensitivity and survey speed

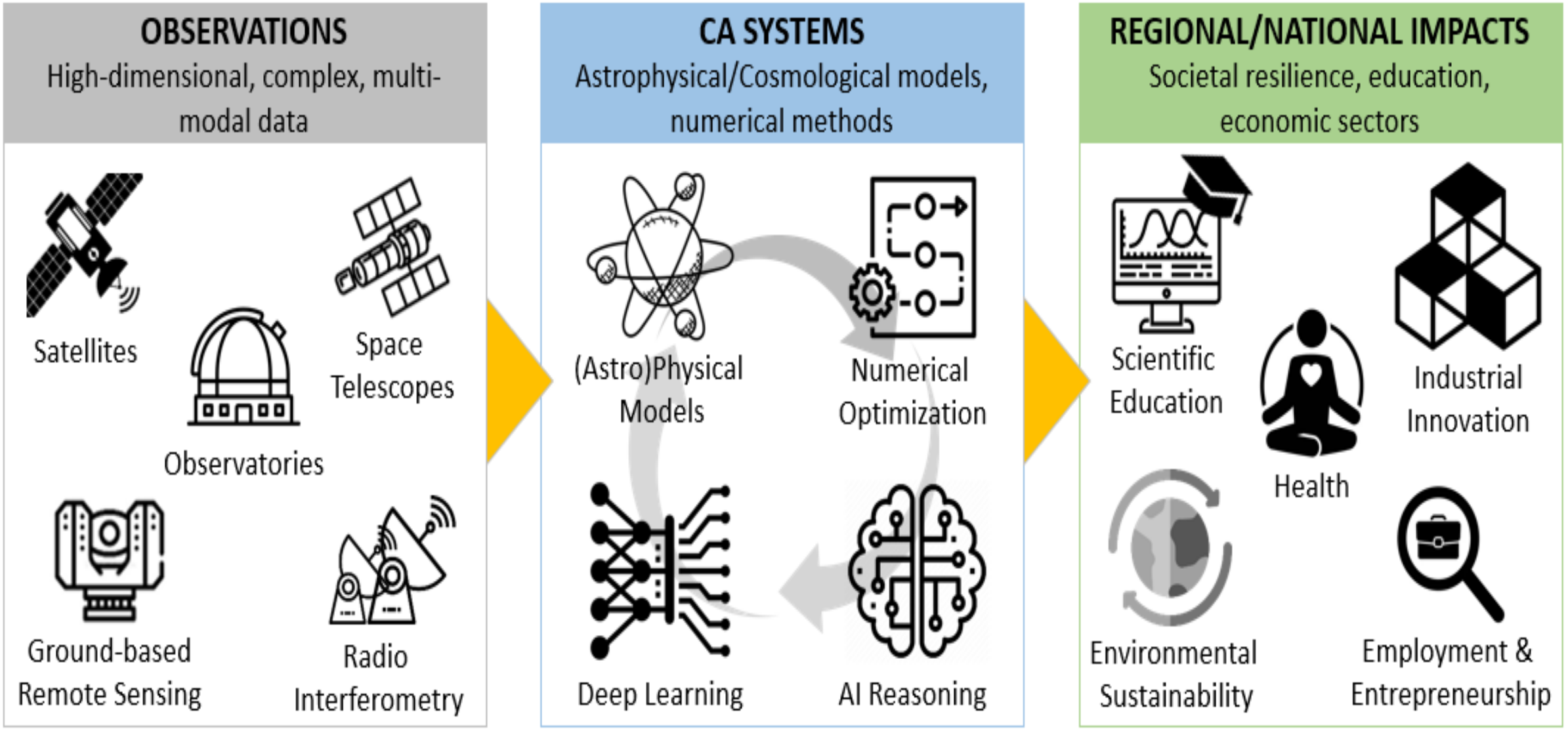
TA-2: Weak Lensing

- Measuring galaxy shapes from radio interferometric measurements
- Couple deep learning priors with geometrical shape regularization

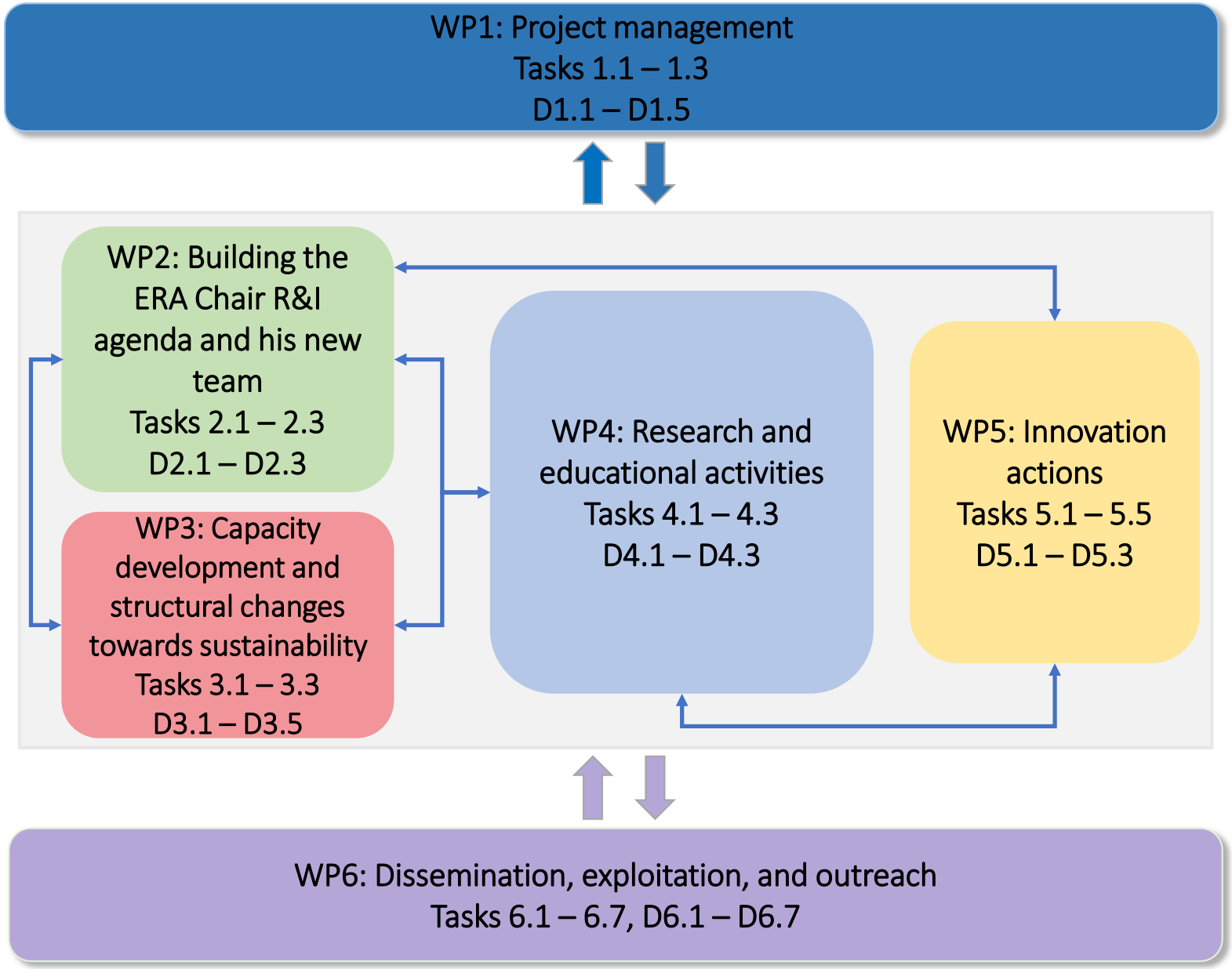
TA-3: Frugal Cosmological Parameters Estimation

- Likelihood-free cosmological parameter inference based on high-order statistics
- Reduce computational (CPU/GPU) resources

TITAN will create scientific/technological/societal impact



The TITAN project Pert Chart



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IN ASTROPHYSICS

European Commission

TITAN YEAR 1 ACHIEVEMENTS

FORTH
INSTITUTE OF COMPUTER SCIENCE

DE LA RECHERCHE À L'INDUSTRIE
cea

CosmoStat

Team Recruitment

03 Post-doctoral Researchers

Anastasia Aidini

SPARSE SIGNAL PROCESSING AND DEEP LEARNING FOR DATA ANALYSIS

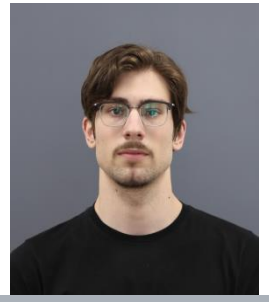
Athanasia Gkogkou

DEEP-LEARNING-BASED IMAGE PRIORS WITH GEOMETRIC SHAPE REGULARIZATION

Victor Bonjean

WEAK LENSING & HIGH ORDER STATISTICS

03 PhD Students



Andreas Tersenov

DATA-DRIVEN APPROACHES FOR WEAK LENSING MASS MAPPING

Pauline Gorbatchev

HIGHER-ORDER STATISTICS FOR NEUTRAL HYDROGEN INTENSITY MAPPING

Arnab Lahiry

MORPHOLOGY AND SPATIAL DISTRIBUTION OF THE DUST EMISSION USING DL METHODS

03 Administrative/Technical Personnel

Ioannis Gavalas

Marian Papadaki

Stelios Roubakis

7/23

Dr. Stefano Camera

University of Turin

Synergies Across the Spectrum for Cosmology and Astroparticle Physics

Galaxy Cluster Cosmology with fgas

CosmoStat

Dr. Lucie Baumont

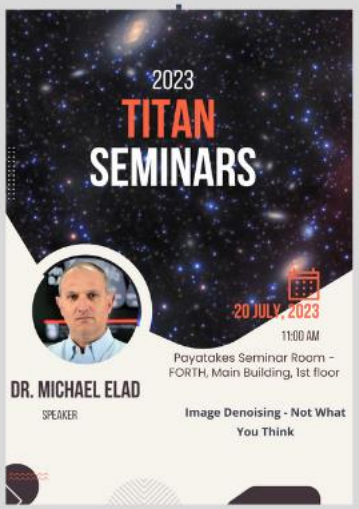
6/23

6/23

Dr. Grigorios Tsagkatakis

ICS - SPL

Machine Learning for Big Science Data Analysis



Dr. Michael Elad

Technio - Israel Institue of Technology

Image Denoising - Not What you thing

7/23

9/23

Dr. Stephane Mallat

Collège de France

From Deep Network Mysteries to Physics

Dr. Sergio Verdu

Princeton University

Recent Research Results on the Cauchy Distribution in Information Theory

9/23

1/24

Prof. John Baras

Maryland University

Robust Machine Learning, Reinforcement Learning and Autonomy: A Unifying Theory via Performance and Risk Tradeoff

7/23

Dr. Stefano Camera
University of Turin

CosmoStat
Dr. Lucie Baumont

6/23

6/23

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ICS - SPL

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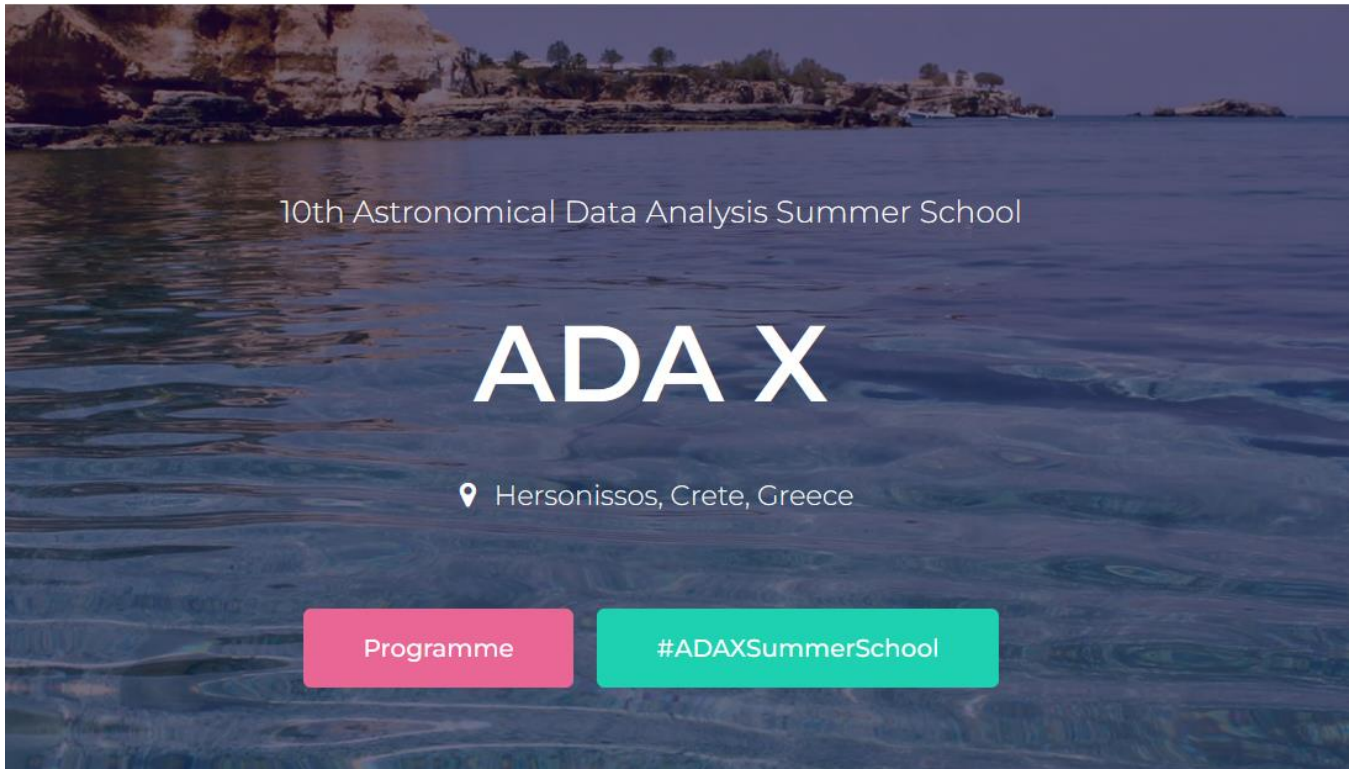
Maryland University

ADA X Summer School



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Artificial Intelligence in Astrophysics

ARGOS

FORTH

cea

CosmoStat

Speakers

Stéphane Mallat
Collège de France

Frosso Doutsi
FORTH-ICS

Samuel Farrens
CosmoStat, CEA Paris-Saclay

Organizers

Jean-Luc Starck
CosmoStat, CEA Paris-Saclay

Grigorios Tsagkatakis
FORTH-ICS

Samuel Farrens
CosmoStat, CEA Paris-Saclay

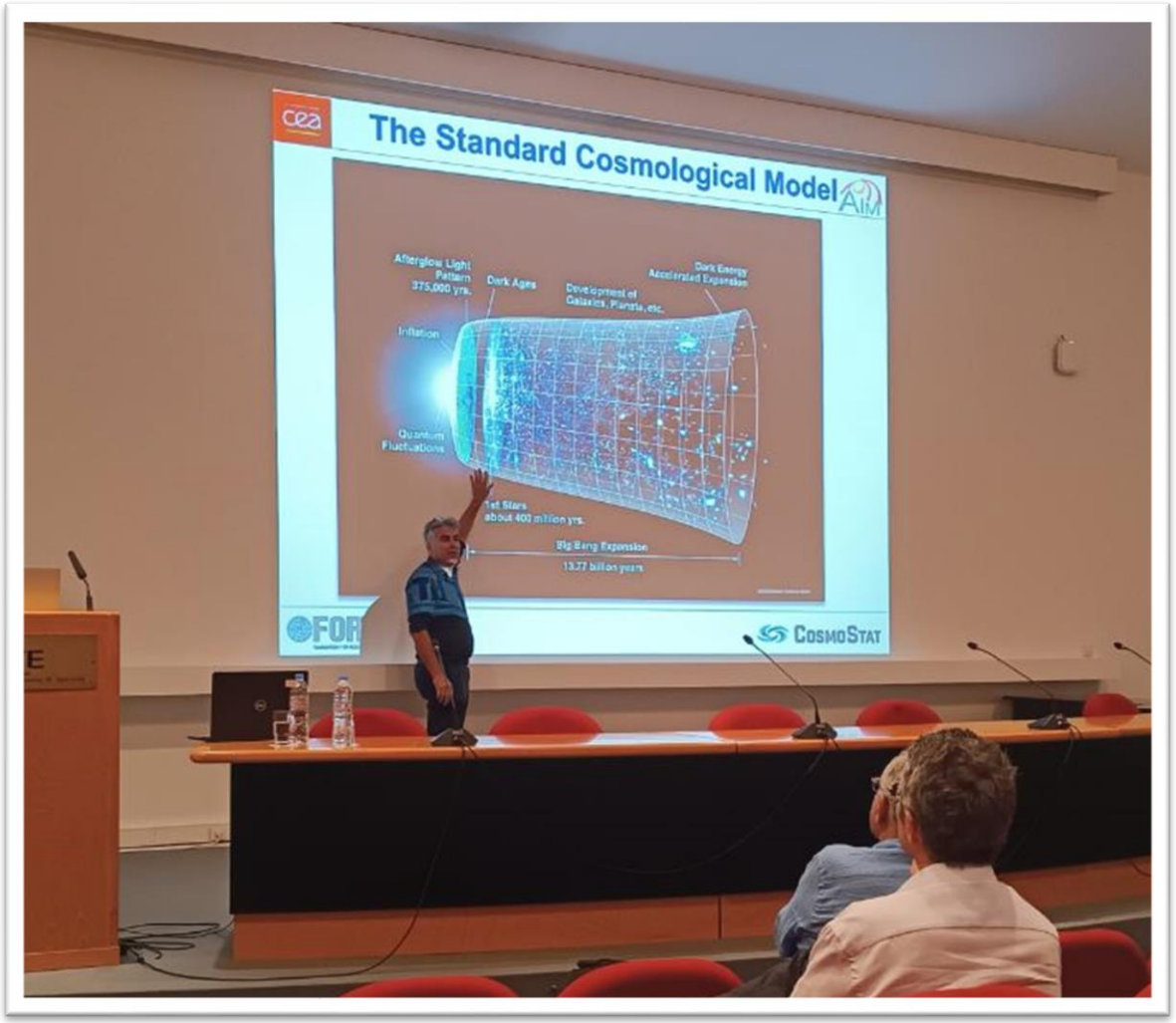
Anna Bonaldi
SKAO project

Alan Heavens
Imperial College London

Elena Sellentin
Leiden University

François Lanusse
CosmoStat, CEA Paris-Saclay

Greek ERA Chairs Day



Upcoming Event: COSMO21

20 – 25 May, 2024

Chania, Greece

80 - 100

cea

CosmoStat

Imperial College London

FORTH
FOUNDATION FOR RESEARCH AND TECHNOLOGY - HELLAS

TITAN
Artificial Intelligence in Astrophysics

ARGOS

TOSCA
Weak lensing for optical and radio surveys

Upcoming Event: COSMO21

20 – 25 May, 2024

Chania, Greece

80 - 100

Invited Speakers

- Justin Alsing, Oskar Klein Centre for Cosmoparticle Physics, Stockholm University, Sweden
- Chihway Chang, Department of Astronomy and Astrophysics, University of Chicago, USA
- Sihao Cheng, Institute for Advanced Study, Princeton, USA and Perimeter Institute, Canada
- David Donoho, Statistics Department, Stanford University, USA
- Jia liu, Kavli, IPMU, Japan
- Bhuvnesh Jain, Penn Center for Particle Cosmology, Pennsylvania School of Arts & Sciences, USA
- Luisa Lucie-Smith, Max Planck Institute for Astrophysics (MPA), Garching, Germany
- Simone Mastrogiovanni, Department of Physics, Sapienza University of Rome, Italy
- Annalisa Pawlosky, Google Accelerated Science Biochemistry and Molecular Biology Laboratory, Switzerland
- Marta Spinelli, Nice Observatory, France

TITAN Deliverables (Due by 1st project review in June 2024)

WP No	Del No	Title	Description	Person Responsible
WP1	D1.1	**Project management and quality assurance plan**	A report outlining the project technical and financial management structure and the quality assurance workflow.	George Tzagkarakis
WP1	D1.2	Report on **MIO's organization plan**	Report on the organization of the Management and Innovation Office (MIO): identification of funding opportunities; assistance with proposal writing, networking and interacting with the industry.	Giannis Gavalas
WP2	D2.1	Report on **R&D trends, best practices and future missions**	A comprehensive uptake of the current and forthcoming research and innovation agenda, within Europe and internationally, in the field of Astroinformatics.	JL Starck, Greg Tsagkatakis, P. Tsakalides
WP2	D2.2	Move of the **ERA Chair to FORTH**, outline of r**esearch group structure**, and **timeline of recruitment**	Detailed description on the move of the ERA Chair to the host institution confirming the move and the arrangements in place. Initial planning phase of the structure and the size of the ERA Chair group, preparation of job descriptions and advertisement of positions worldwide. Selection and appointment of the members of the research group.	P. Tsakalides
WP3	D3.1	**Capacity development plan**	The plan will describe the Program's education/research/innovation targets, it will outline capacity development objectives such as administrative policies and procedures, it will define capacity development indicators, and it will describe a sustainability strategy.	P. Tsakalides

TITAN Deliverables (Due by 1st project review in June 2024)

WP4	D4.1	Report on **research and educational activities** and associated material for the period M1-M15	Report and demos on the Astrophysics signal processing research, the educationsl activities (workshops, summer schools, tutorials, etc.).	Emma Soultatou, P. Tsakalides
WP6	D6.1	**Dissemination, exploitation and communication strategy** and action plan, 1st edition	A report on the dissemination of the project activities and results and the exploitation of its outcomes.	George Tzagkarakis
WP6	D6.4	**Website** of the project	Set-up and maintenance of the project's website. The website will promote the objectives, activities, achievements, and the events to be organised.	Stelios Roubakis
WP6	D6.5	Report on the **outreach activities and mass media material** for the period M1-M15	Report on the dissemination activities to academic audience (workshops, summer schools, etc.) Outreach activities to non-academic audience including presentations of the ERA Chair at exhibitions, industrial fora, etc.	Stelios Roubakis
WP6	D6.8	**Data Management Plan / OSCeP platform,** 1st edition	A detailed Data Management Plan where the access and use of all data collected or generated by the Program will be clearly defined. We will also develop an Open Science Collaboration e-Platform (OSCeP) for sharing data, computational tools, and mathematical models with the academic and industrial communities.	Greg Tsagkatakis

Topics for discussion

- Facilitate the interaction between astrophysicists and computer scientists
- Specify 1-2 “grand challenges”
  - Classification vs Inverse problems
  - Identify ML aspects (robustness, imbalance, recovery, etc.)
- Specify and generate TITAN datasets
  - Access to Simulations or Observations
  - Dimensions, Characteristics, Storage, Open-access
- Define performance metrics
  - State-of-the-art solutions (codes & papers)
  - State-of-the-art datasets

Next major TITAN milestone

- *1st TITAN project review meeting*
  - June or July, 2024
  - On location(?), with the participation of the project PO and external evaluators

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https://spl.ics.forth.gr/titan