Giacomo Basile

Wavefront control in telescope projects based on active and adaptive optics

Tutor: Prof. Stefania Santini **Co-Tutor: Ing. Pietro Schipani**

Cycle:XXXVII **Year: First**

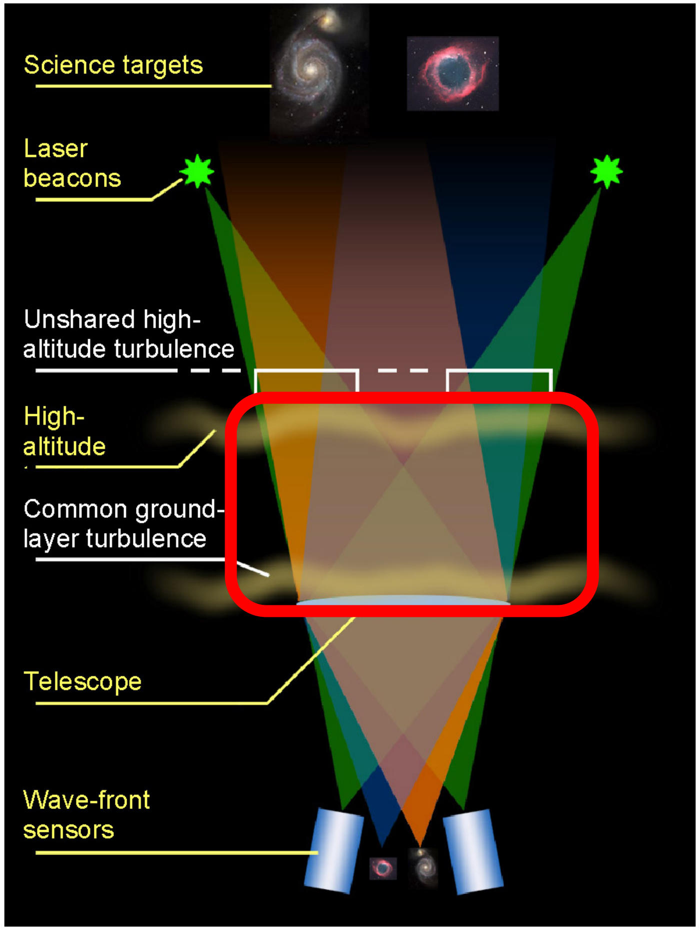
Academic Year 2021-2022

Background & Info

- **MSc degree in Automation Engineering, University of Naples Federico II**
- **Research groups: Inaf an DAiSY Lab**
- **Tutor: Prof. Stefania Santini**
- **Co-Tutor: Ing. Pietro Schipani**
- **PhD start date: 01/11/2021**
- **Scholarship type: UNINA**

Research Topic (1/2)

- **Considering a novel astronomic telescope, e.g. Very or Extremely Large Telescope (VLT, ELT), the design of a namely Adaptive Optic (AO) system is required in order to mitigate the atmospheric turbulence disturbance**

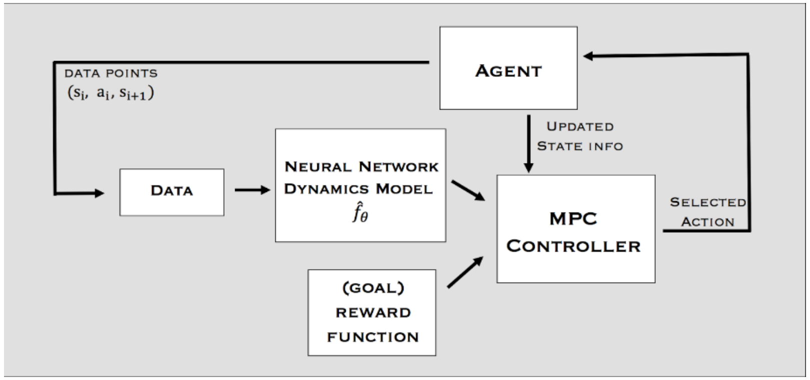


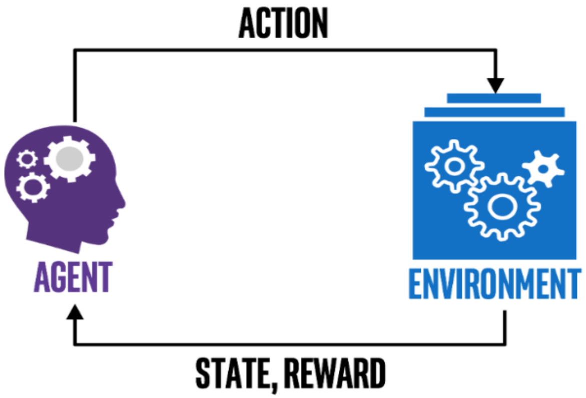
- **The AO system performance are intrinsically limited by:**
  - **Spatial and fitting error:** The controlled deformable mirror are segmented in finite number of parts.
  - **Temporal servo lag error:** The AO system present a physical delay due to the wave front sensor (WFS) computation, the actuation delay and the time necessary for receiving the wave front beam coming from the scientific target.
  - **Angular or Anisoplanatic error:** It is the error corresponding to the projection from a 3D volume (the turbulence) to a 2D space (the DM's pupil).

Research Topic (2/2)

- The above-mentioned intrinsic limitations of the AO systems involve in uncertainties in the control-oriented model needed for the design of the control action. This implies that, while the theoretical AO problem has been solved by classical model-based control techniques, the novel conceptualized of Multi Conjugate AO (MCAO) instruments, aiming to mitigate the whole atmospheric turbulence volume, suffers from unavoidable uncertainties which that have to be counteracted from the very beginning of the control design phase.

- So, the aim of the research is devising strategies that are robust and resilient w.r.t. the uncertainties and latencies that may arise. To this aim, control strategies fully driven by data, e.g., exploiting Deep Reinforcement Learning (DRL), or hybrid strategies, e.g., extended DRL-based Model Predictive Control (MPC), are investigated in order to achieve the MCAO's objective.





My First Year: Study & Training Activities (1/2)

- **The main focus of my first-year activity is to deepen theoretical knowledge related to the state-of-the-art about architectures and strategies exploited to solve the AO control problem. Moreover, some effort has been also dedicated to the studying of RL and Deep Reinforcement Learning (DRL) techniques, as well as hybrid strategies for solution of optimal control problems**

Attended to project team for the novel Multi-conjugate adaptive Optics For ELT Observations, MORFEO (known as MAORY).

A. Bemporad, et al. "Learning affine predictors for MPC of nonlinear systems via artificial neural networks." *IFAC-PapersOnLine* 53.2 (2020): 5233-5238.

Z. Mario, Sébastien Gros, and Alberto Bemporad. "Practical reinforcement learning of stabilizing economic MPC." *2019 18th European Control Conference (ECC)*. IEEE, 2019.

Landman, Rico, et al. "Self-optimizing adaptive optics control with reinforcement learning for high-contrast imaging." *Journal of Astronomical Telescopes, Instruments, and Systems* 7.3 (2021): 039002.

My First Year: Study & Training Activities (2/2)

- Attended courses are listed as follows:

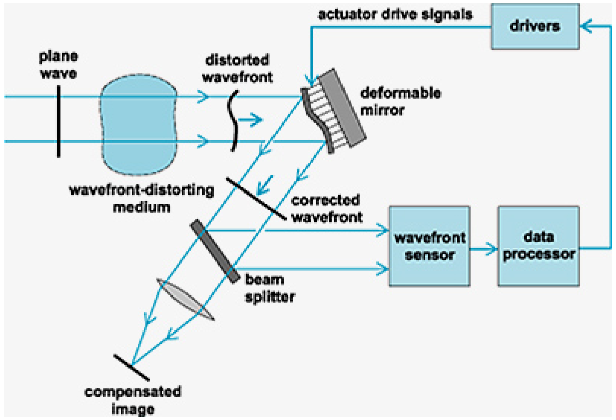
- **Matrix Analysis for Signal Processing with MATLAB Examples.**
- **Data Science for Patient Records Analysis**
- **Machine Learning for Science and Engineering Research**
- **Operational Research: Mathematical Modelling, Methods and Software Tools for Optimization Problems**
- **Sustainable Ship for the Energy Transition of Maritime Transport**

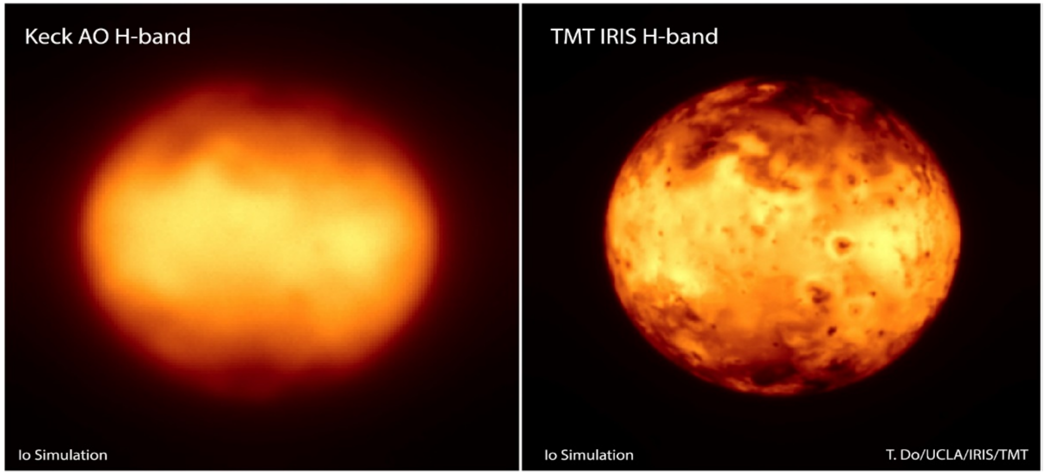
- Some of the attended seminars are listed as follows:

- **Using Delays for Control, Prof. Emilia Fridman**
- **Data-Driven methods in engineering, Prof. Ricardo Vinuesa**

Research activity: Problem Statement

- **Research activities aim designing of DRL-based actions or Hybrid control strategies for the MCAO. The fundamental issue is to provide robustness to the control of the Deformable Mirrors tracking the scientific target while mitigate the atmospheric turbulence.**





My Product

- **Basile, G., Lui, D. G., Petrillo, A., & Santini, S. (2022).** ***"ACC Fuzzy-Based Control Architecture for Multi-body High-Speed Trains with Active Inter-cars Couplers".*** **In European Dependable Computing Conference (pp. 126-138). Springer, Cham. (Published)**

- **Basile, G., Petrillo, A., & Santini, S. (2022).** ***"DDPG Based End-To-End Driving Enhanced With Safe Anomaly Detection Functionality for Autonomous Vehicles".*** **In IEEE Metrology For Extended Reality, Artificial Intelligent And Neural Engineering. (Accepted)**

- **Basile, G., Lui, D. G., A., & Santini, S. (2022).** ***"Deep Deterministic Policy Gradient-based Virtual Coupling Control For High-Speed Train Convoys".*** **In 2022 IEEE International Conference on Networking, Sensing and Control. (Accepted)**

Next Year

- **The main objective is to design hybrid control architectures, e.g., MPC + DRL, and/or data-driven control strategies, e.g., via DRL, in order to deal with delayed and uncertain control loops and then, to apply those methodologies to the AO systems. The idea is to provide resilience and robustness w.r.t.:**

  I. **External disturbances and unmodelled, uncertain, or unknown dynamics**

  II. **Time-varying parameters**

  III. **Lags, e.g., propagation delay of the wave front beam and servo delays**

- **Testing and validation on realistic benchmark configurations are the final goals. The ESO standard test systems will be examined for the applicability of the proposed model.**

1^{th} Year Credits

- **The first-year activities and the outlook on the first year can be summarized as:**

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	4.1	5.9	0	10
Bimonth 2	0	0.9	9.1	0	10
Bimonth 3	2	0.4	7.6	0	10
Bimonth 4	5	0	4.8	0.2	10
Bimonth 5	0	0	10	0	10
Bimonth 6	13	0	2	0	15
Total	20	5.4	39.4	0.2	65
Expeted	min20-max40	min5-max10	min10-max35	min0-mx1.6	

Thank for your time!

Contact:
giacomo.basile@unina.it/@inaf.it
Room 4.03 – building 3/A – via Claudio 21