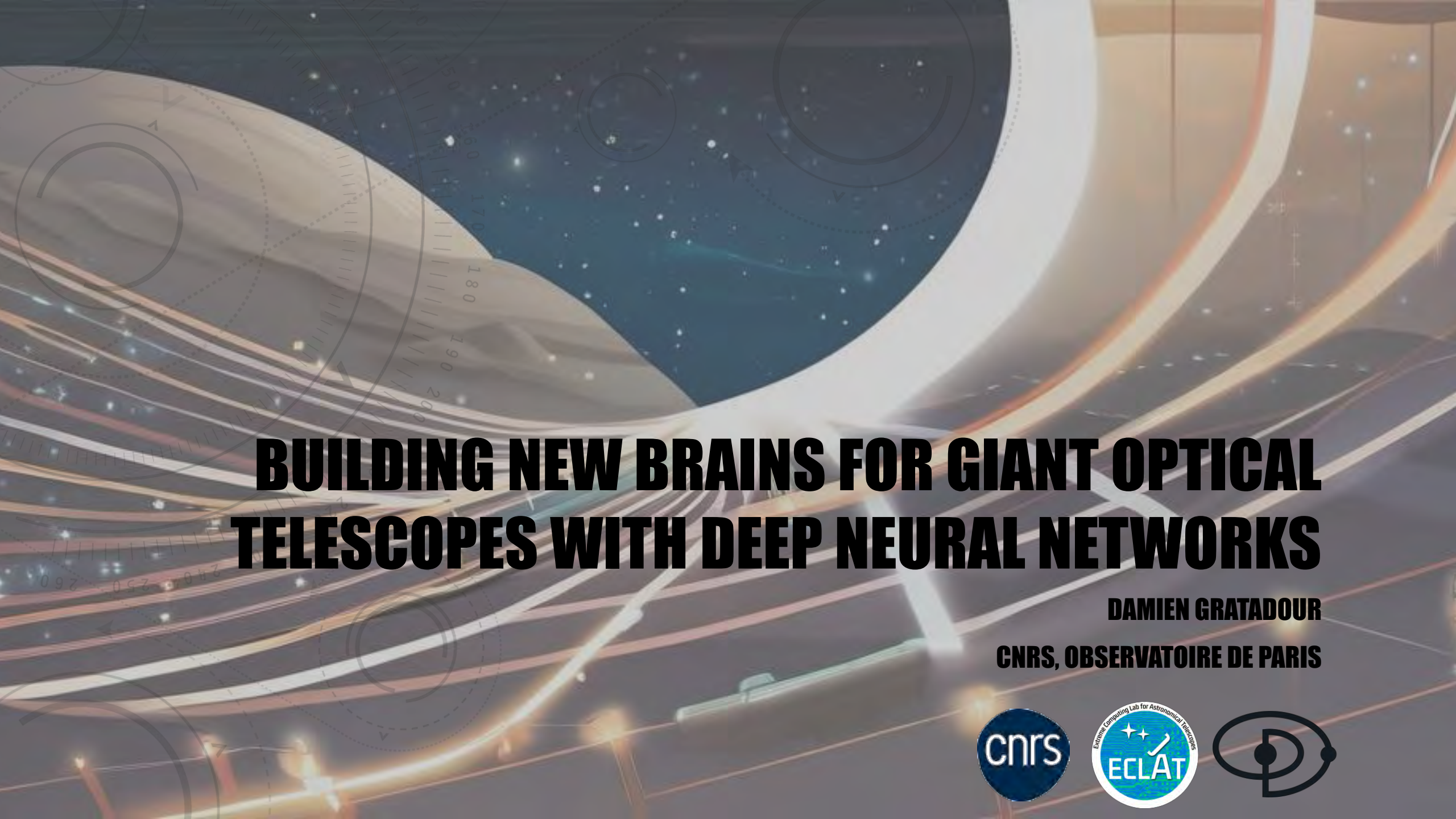


BUILDING NEW BRAINS FOR GIANT OPTICAL TELESCOPES WITH DEEP NEURAL NETWORKS

DAMIEN GRATADOUR

CNRS, OBSERVATOIRE DE PARIS

European Optical Telescopes

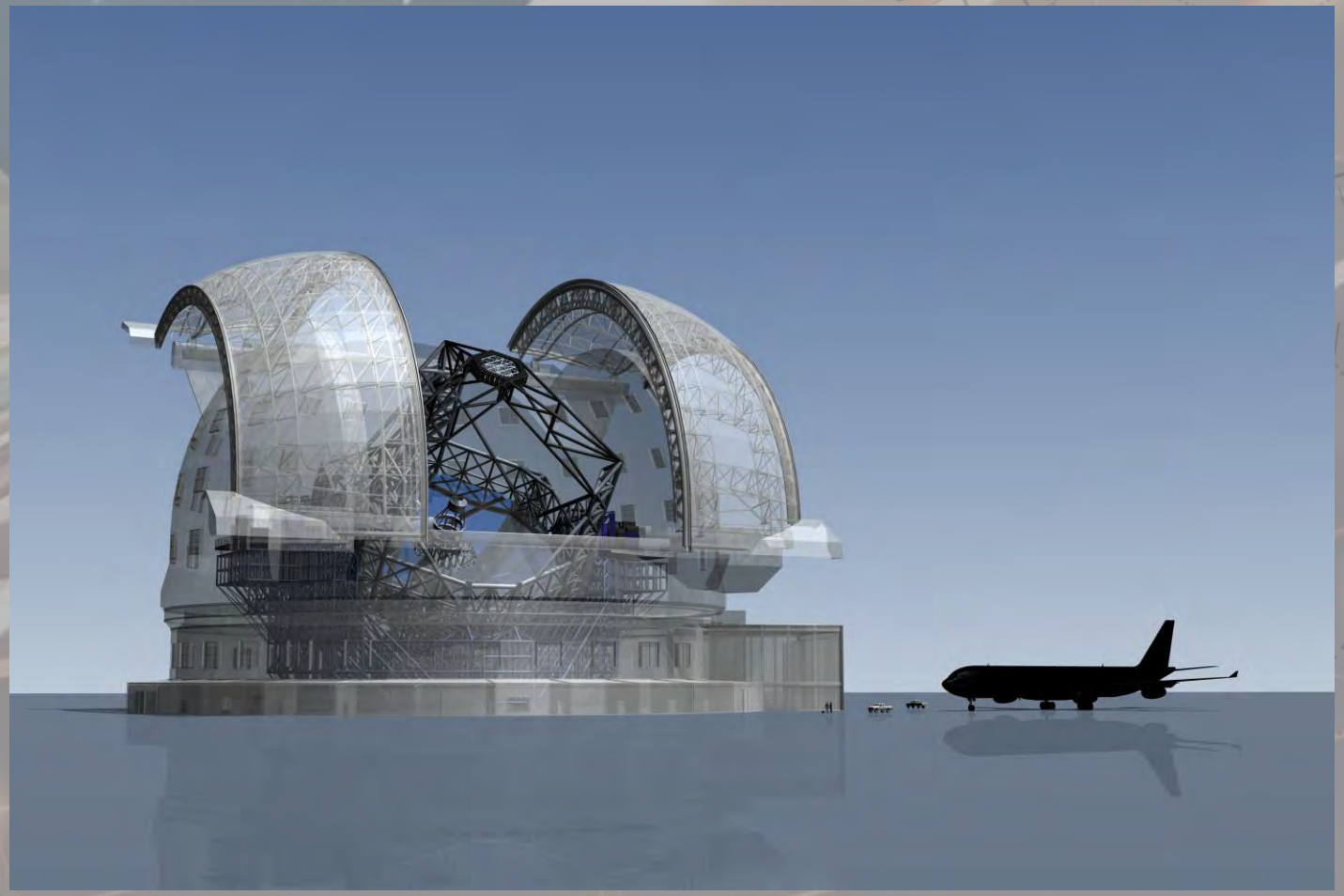
World Leadership in building and operating giant optical telescopes

- State-of-the-art: Very Large Telescope (VLT)
- Currently building the Extremely Large Telescope(ELT)

European Extremely Large Telescope

Largest Optical Telescope ever built (for decades)

- Primary mirror: 39m diameter
- 6100 tons rotating structure
- On top of a 3100m mountain in Chile
- “First light” circa the end of this decade
- Designed to make major breakthroughs: **e.g. observing rocky exoplanets**



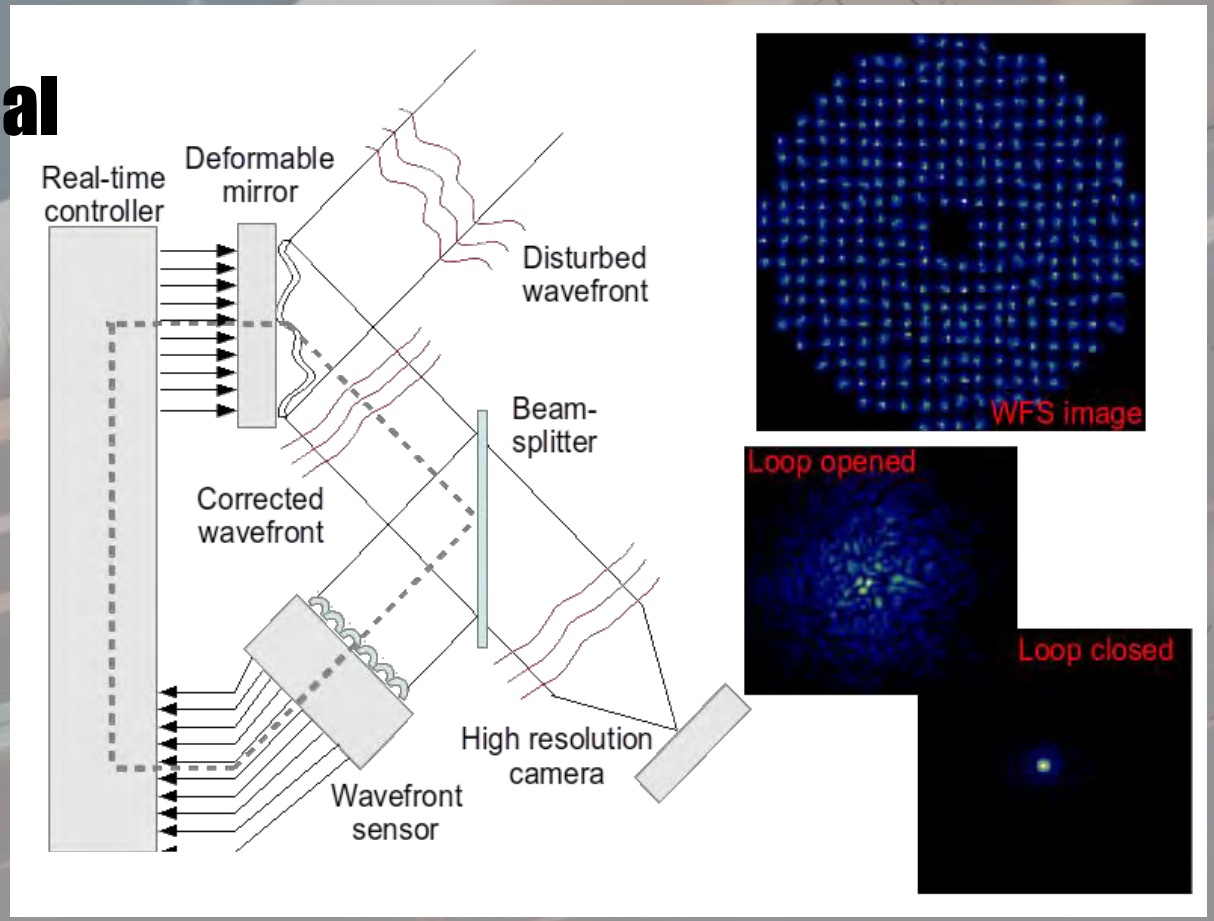
European Extremely Large Telescope

Adaptive Optics: enabling technology

Principles of Adaptive Optics

Control in real-time the shape of the incoming wavefront

- Sensors: cameras equipped with an optical device (lenslet array, pyramidal prism, etc...)
- **Thousands** of actuators to control
- Compute pipeline **latency below 1 millisecond**
- Stable time-to-solution is critical (**10s of µs of jitter**)



A new brain for Adaptive Optics

Complex, multi-physics problem: requires multiple flavors of AI mixed with HPC workloads

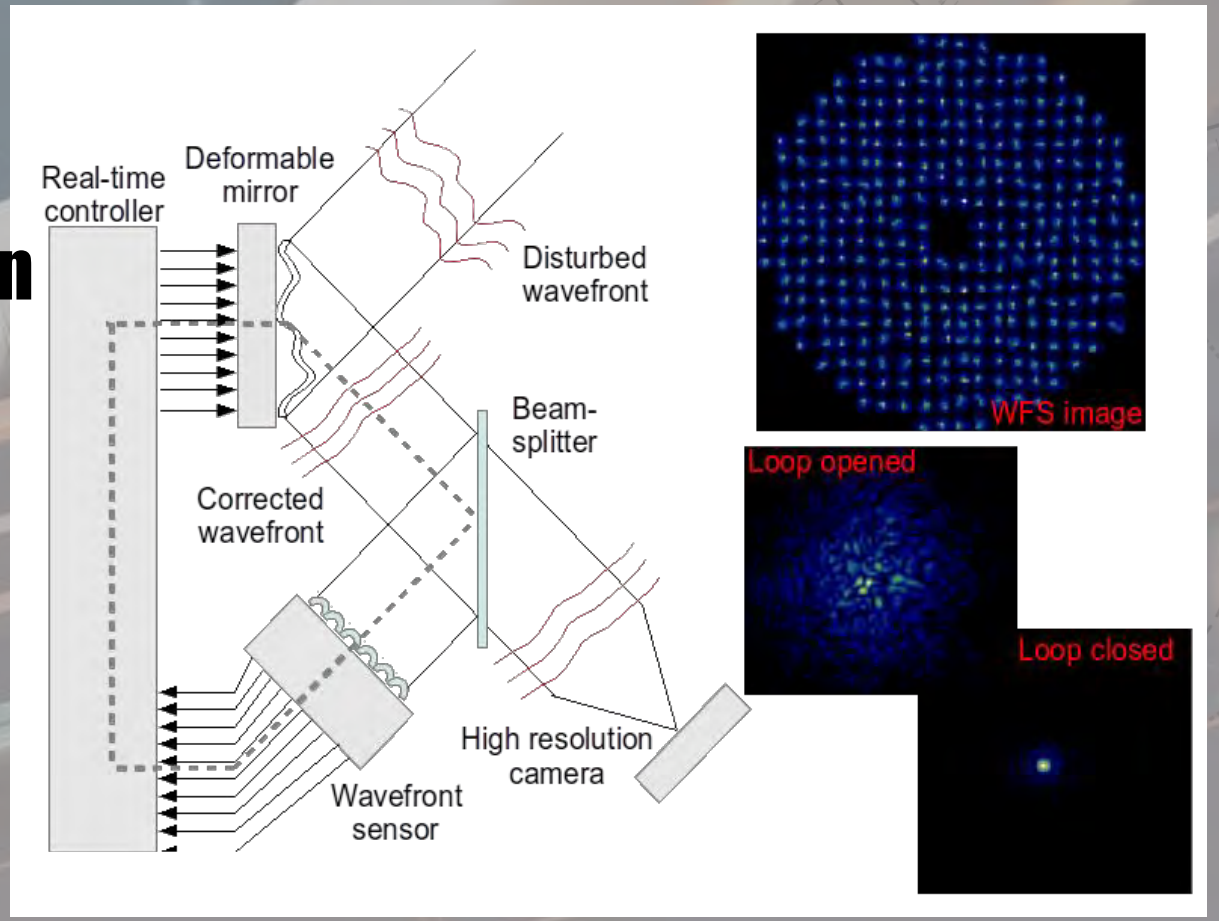
Sensors data: mitigate noise, improve linearity, merge multiple sensors

Deformable mirrors: improve resolution

Pipeline latency: enable predictive control

Variable conditions: self-adapting controller

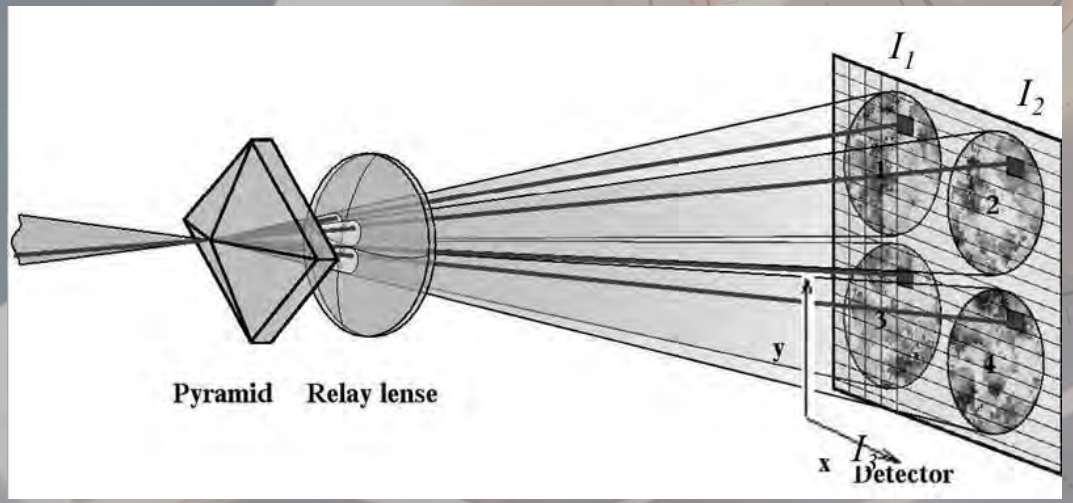
Stable time-to-solution: real-time inference



Planet hunting gear: Pyramid sensor

Based on the "Foucault's knife" principle: increased sensitivity

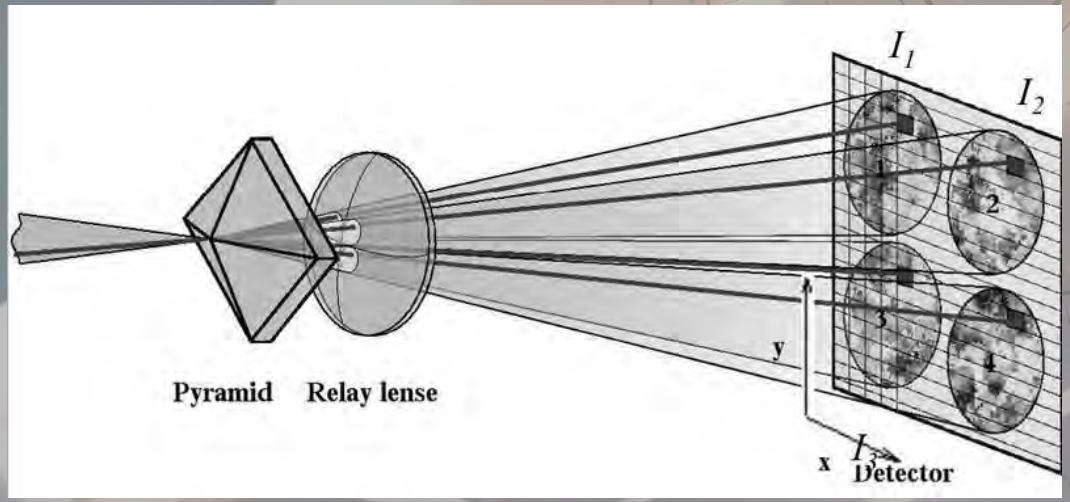
- **Highly non-linear response**
- **Becoming mainstream (especially for planet hunting !)**
- **Need to "linearize" response to make it actionable**

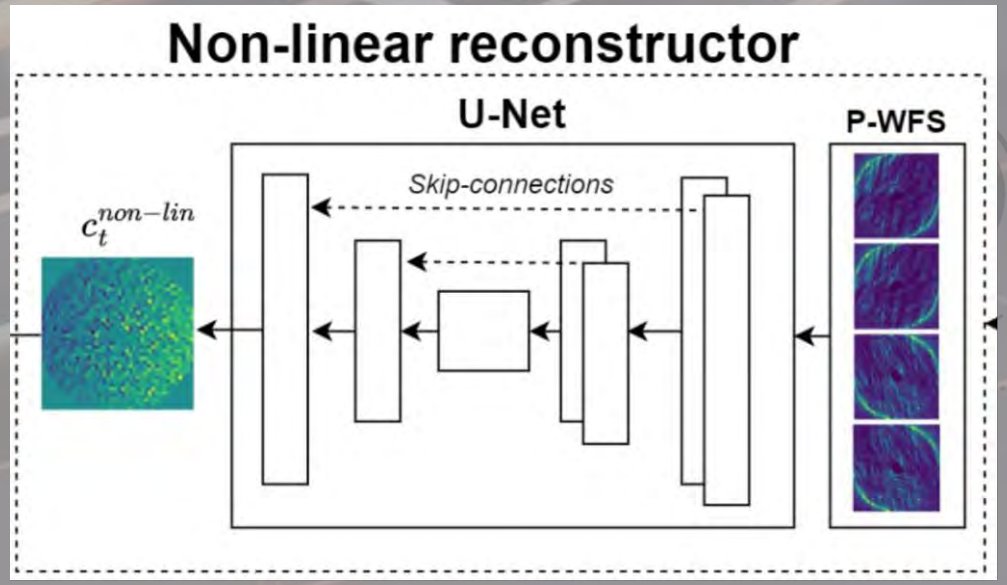


Planet hunting gear: Pyramid sensor

Increased sensitivity with pyramid wavefront sensors

- **Highly non-linear response**
- **Becoming mainstream (especially for planet hunting !)**
- **Need to "linearize" response to make it actionable**
  - **Idea: Use a U-Net to provide non-linear reconstruction**

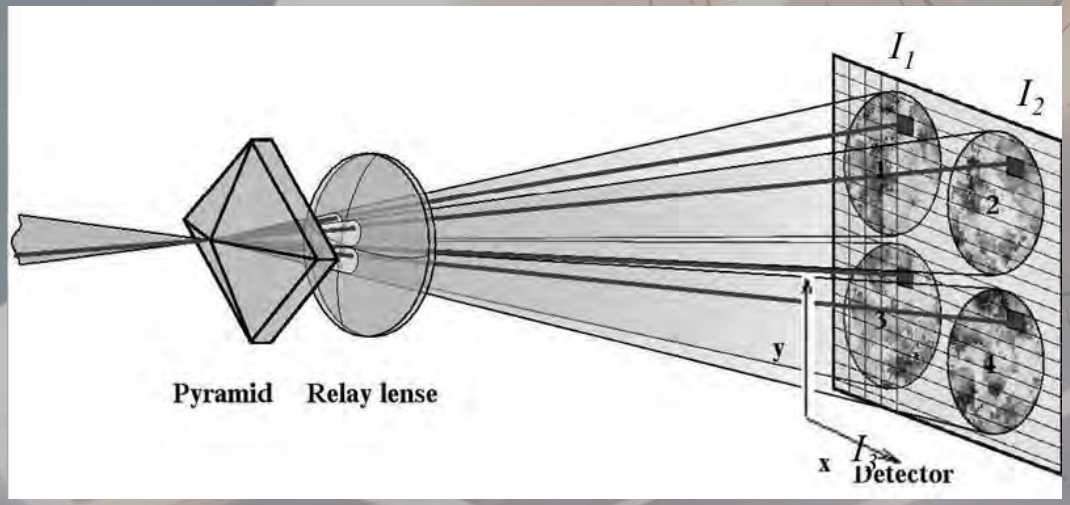


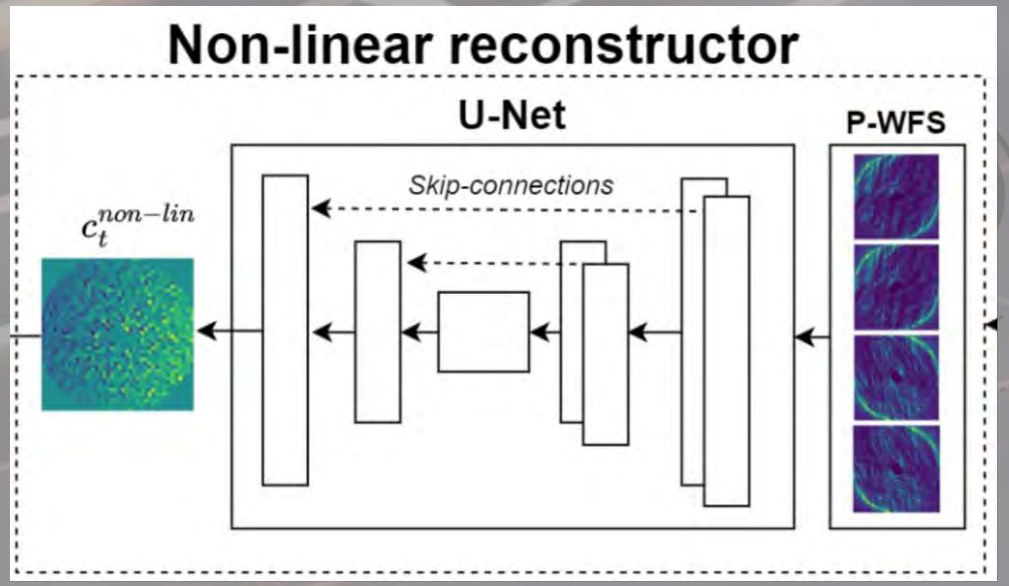


Training the U-Net efficiently …

This U-Net is used to build a "deterministic non-linear model" of the pyramid

- Integrate the perturbation statistics out of the problem
- Use a uniform distribution for training





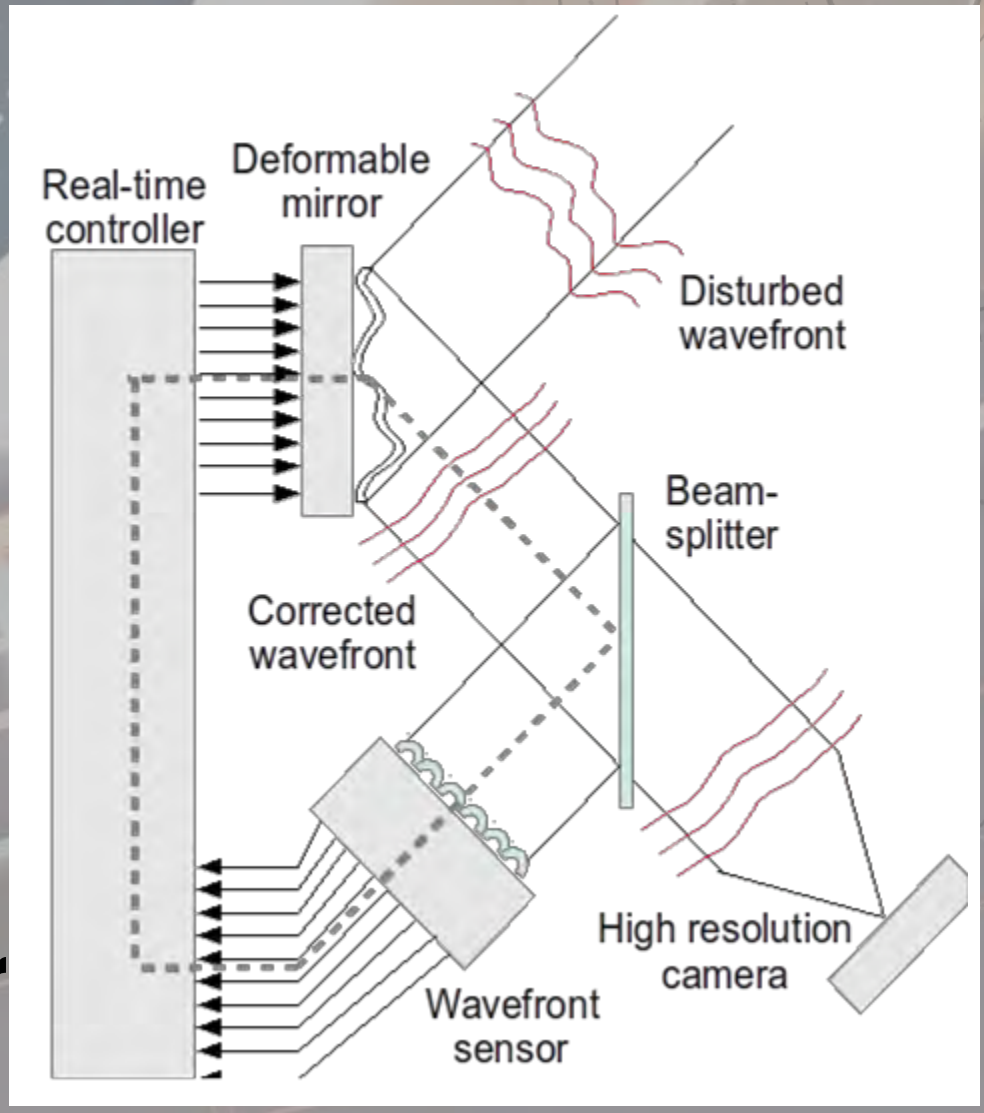
Training the U-Net efficiently …

This U-Net is used to build a "deterministic non-linear model" of the pyramid

- Integrate the perturbation statistics out of the problem
- Use a uniform distribution for training

This is a control problem:

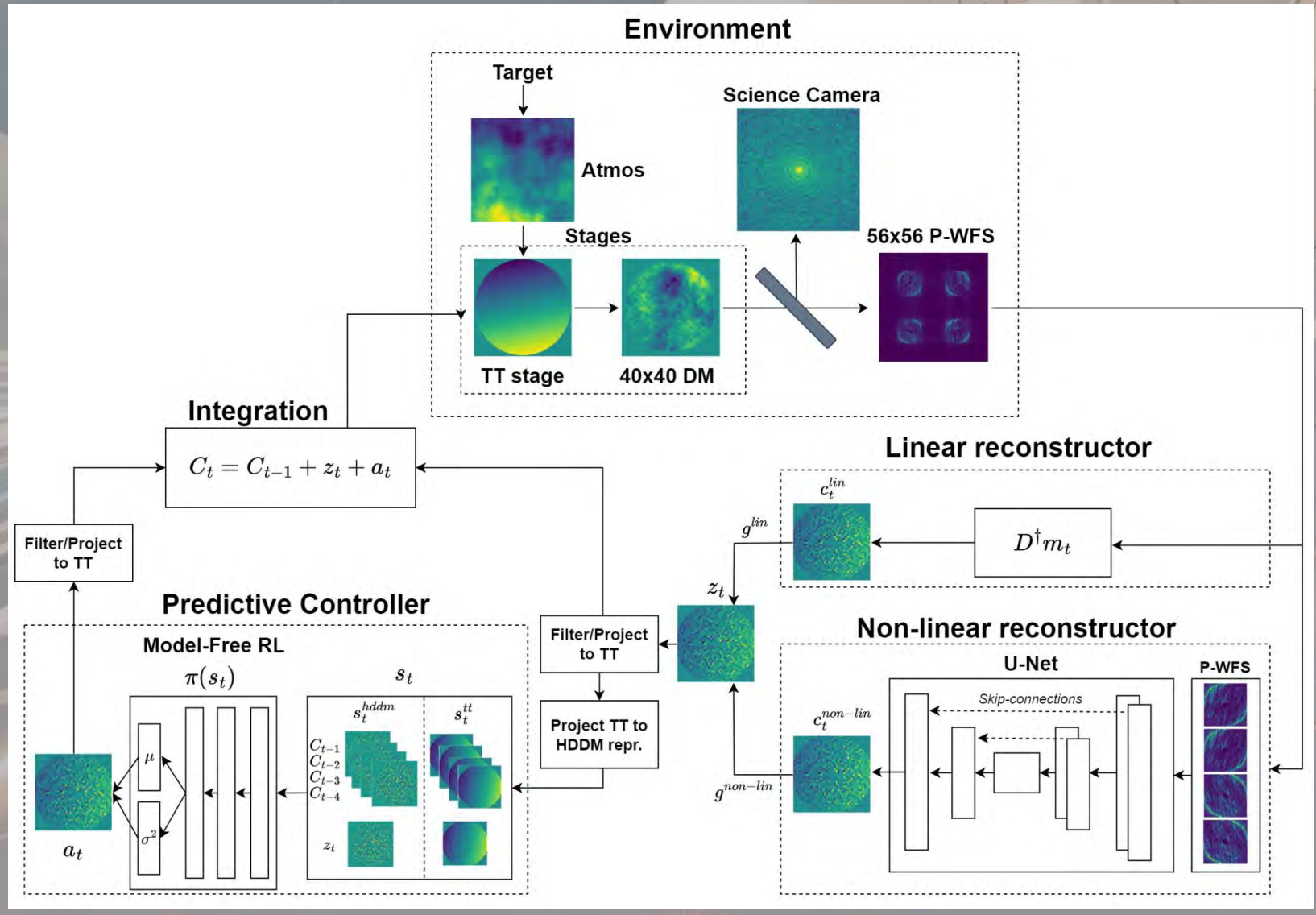
- Max resolution needed is the mirror's actuators pitch
- Leverage the closed loop: training under realistic conditions with the system's mirror



A new (trustworthy) brain for AO

A new (trustworthy) brain for AO

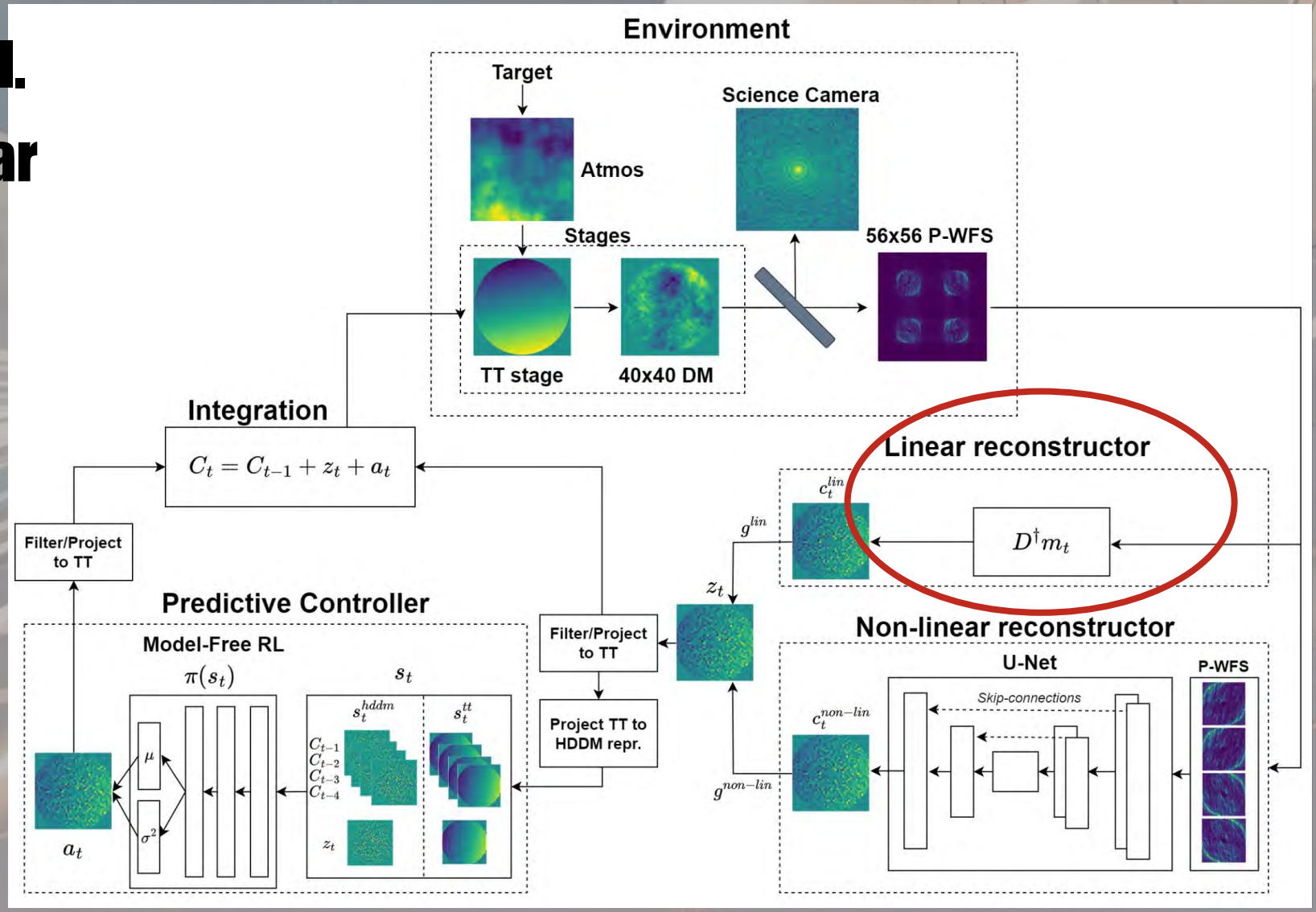
Multi-stage approach



A new (trustworthy) brain for AO

Multi-stage approach incl.

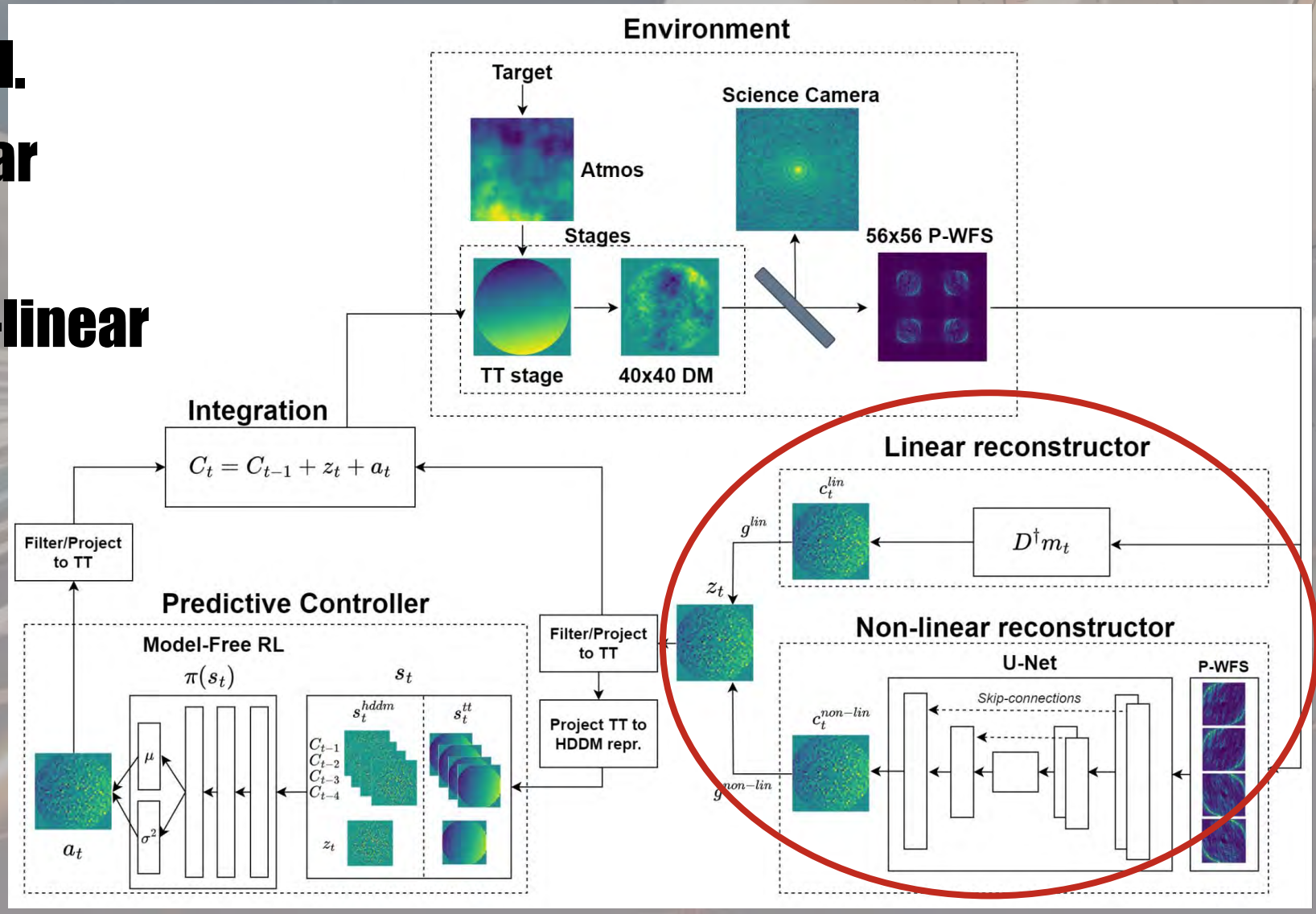
- High Performance Linear Algebra



A new (trustworthy) brain for AO

Multi-stage approach incl.

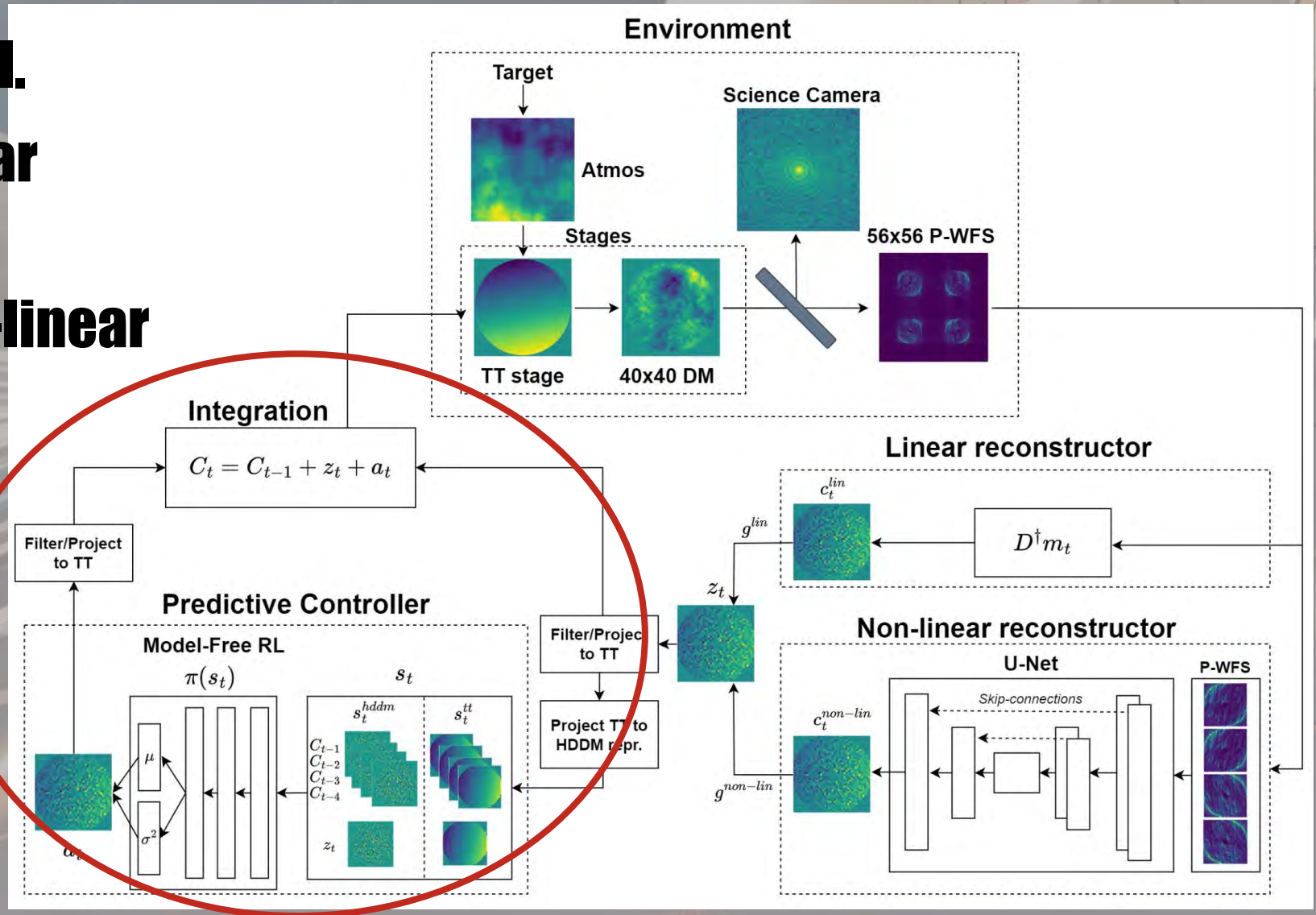
- **High Performance Linear Algebra**
- **Combined linear + non-linear reconstruction**



A new (trustworthy) brain for AO

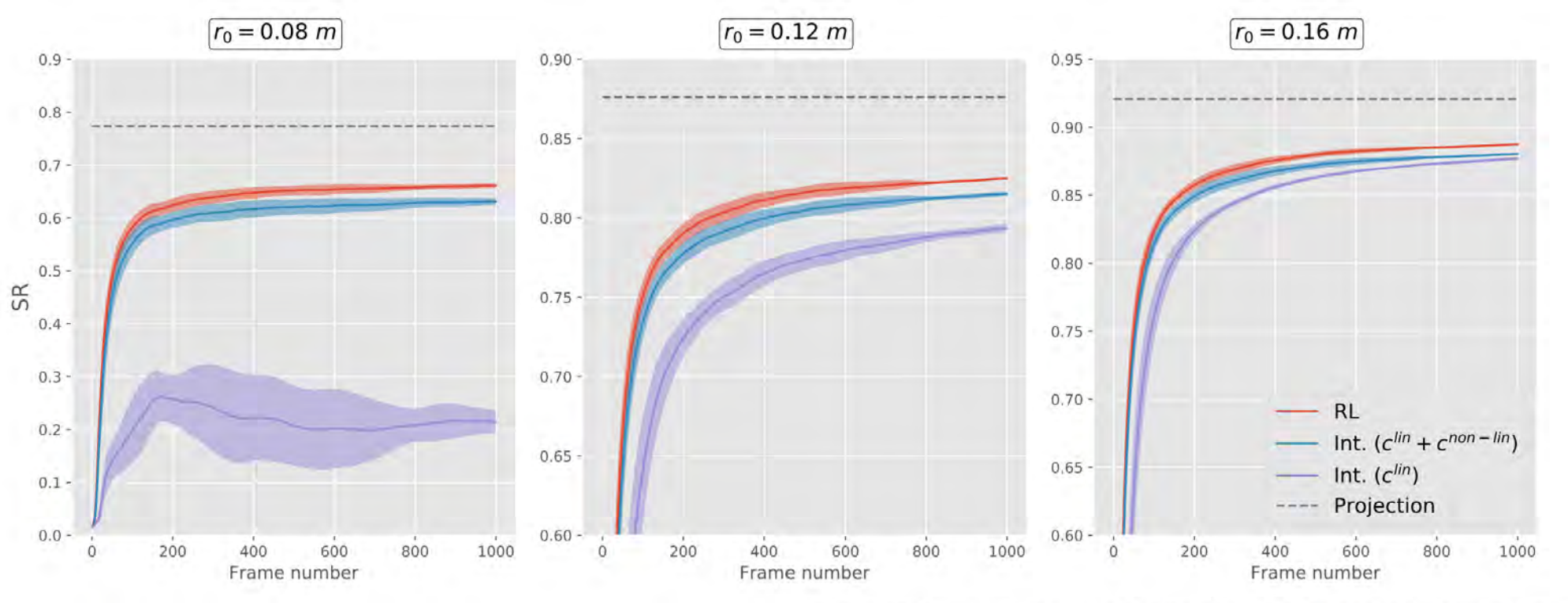
Multi-stage approach incl.

- **High Performance Linear Algebra**
- **Combined linear + non-linear reconstruction**
- **Combined linear + non-linear control**



Towards trustable operations

Provides optimal compensation level whatever operating conditions



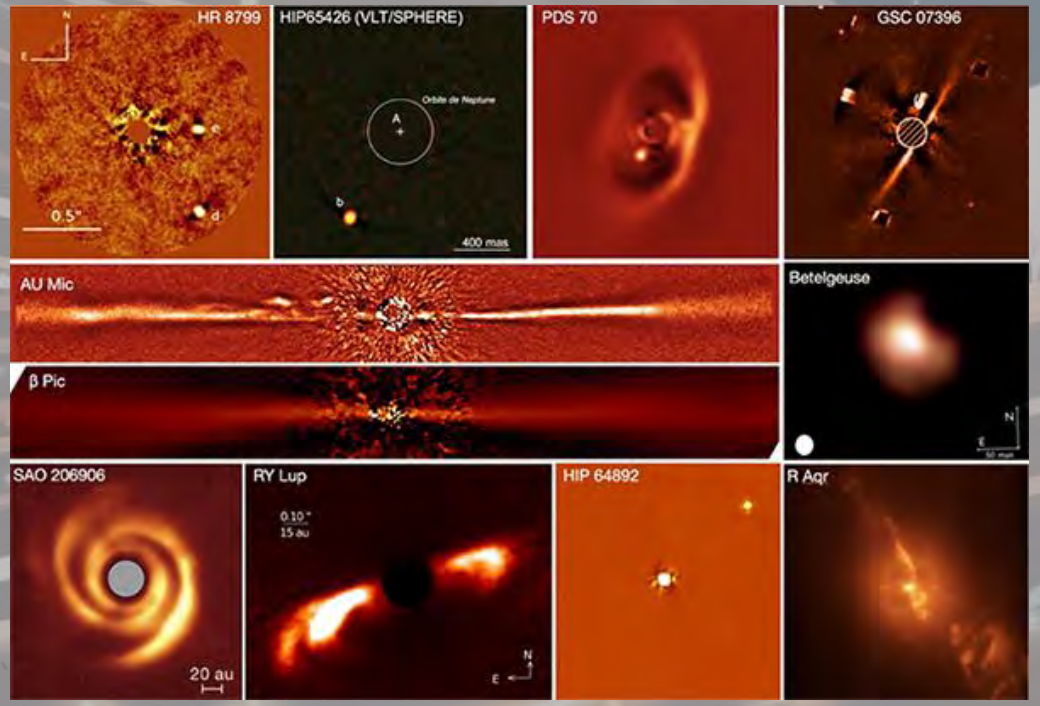
B. Pou, F. Ferreira, E. Quinones, **D. Gratadour,** and M. Martin, "*Adaptive optics control with multi-agent model-free reinforcement learning*," Opt. Express 30, 2991-3015, **2022**.

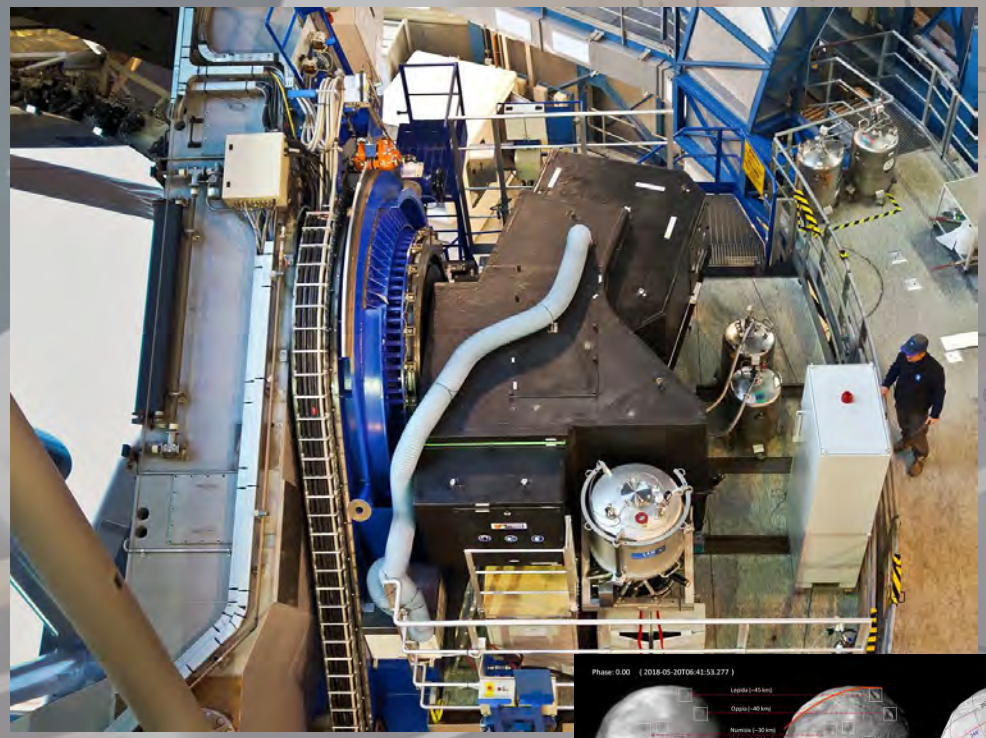
Stable & self-adapting without human intervention

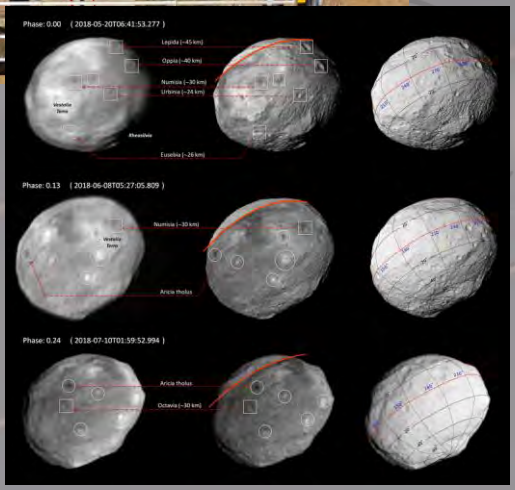
Towards an upgraded planet finder at the VLT

SPHERE+: imaging Jupiters at the snow line

- Capitalizing on success of SPHERE
- Enabling more discoveries with AI



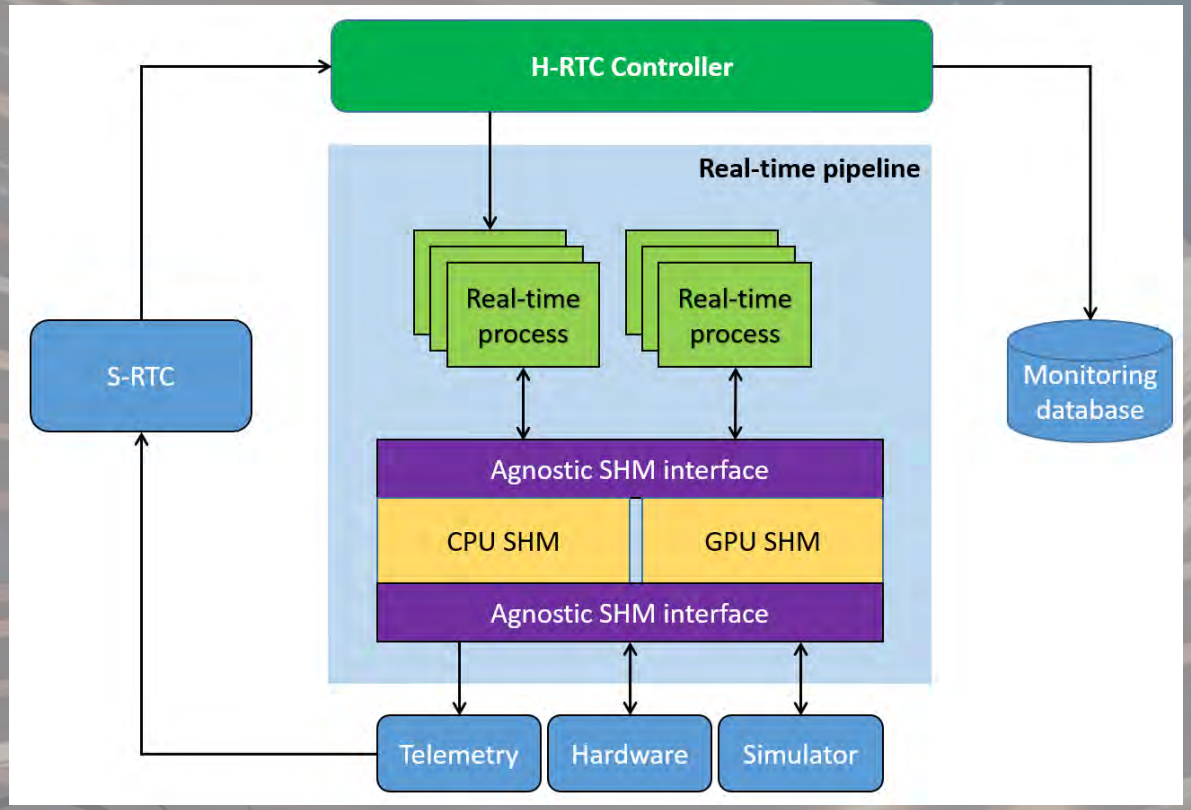


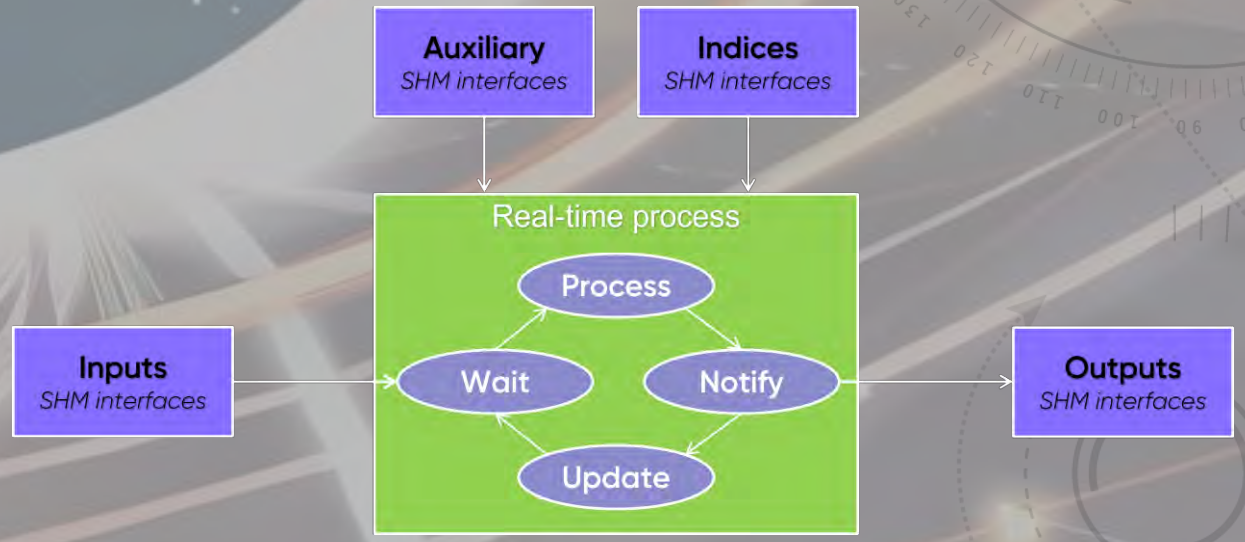


Fast-tracked project: first light in 2026.

Towards real implementation

The COSMIC platform: future-proof seamless real-time computing

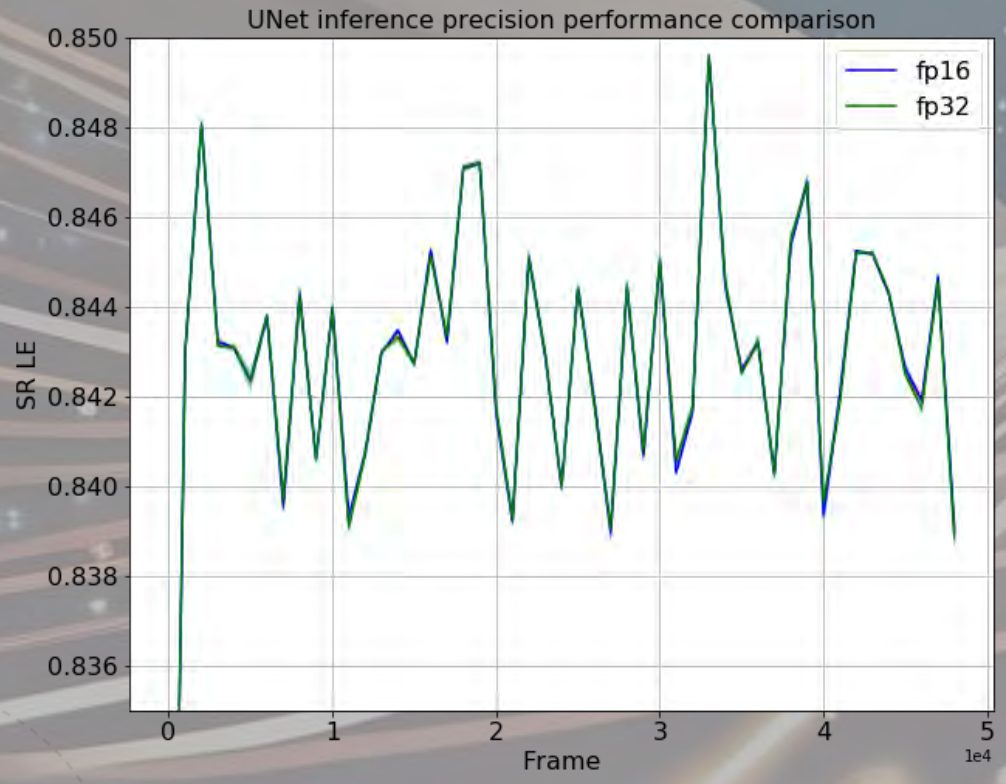


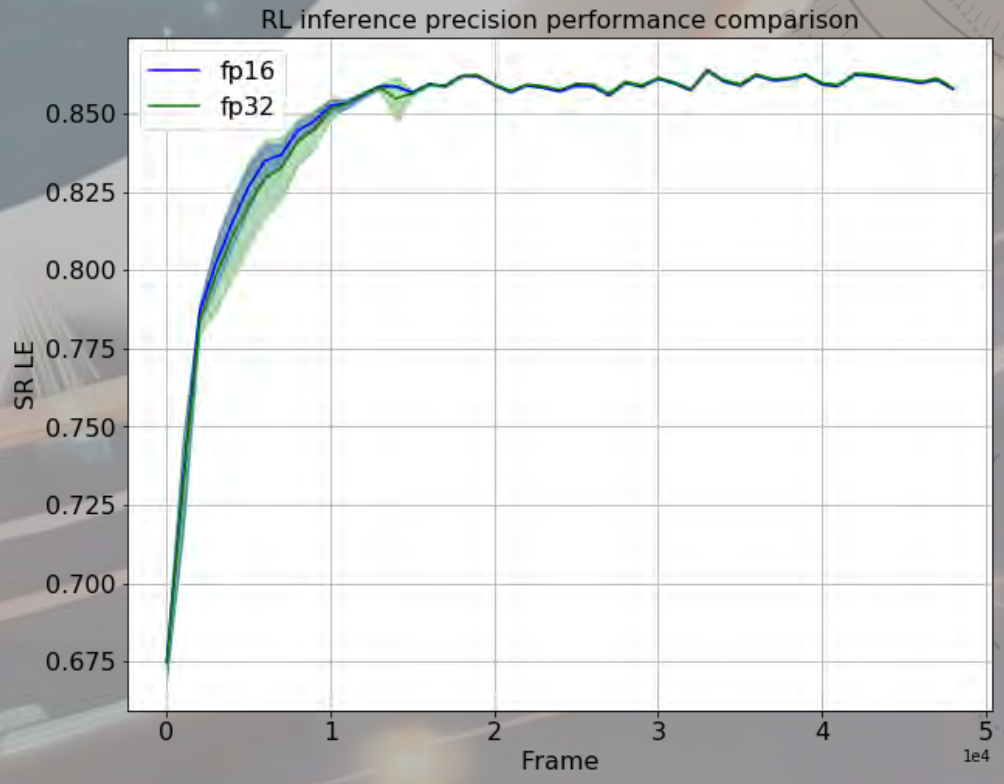


Modular & heterogeneous by design, baseline for several facility instruments

Towards practical implementation

Effect of quantization on U-Net and RL Inference





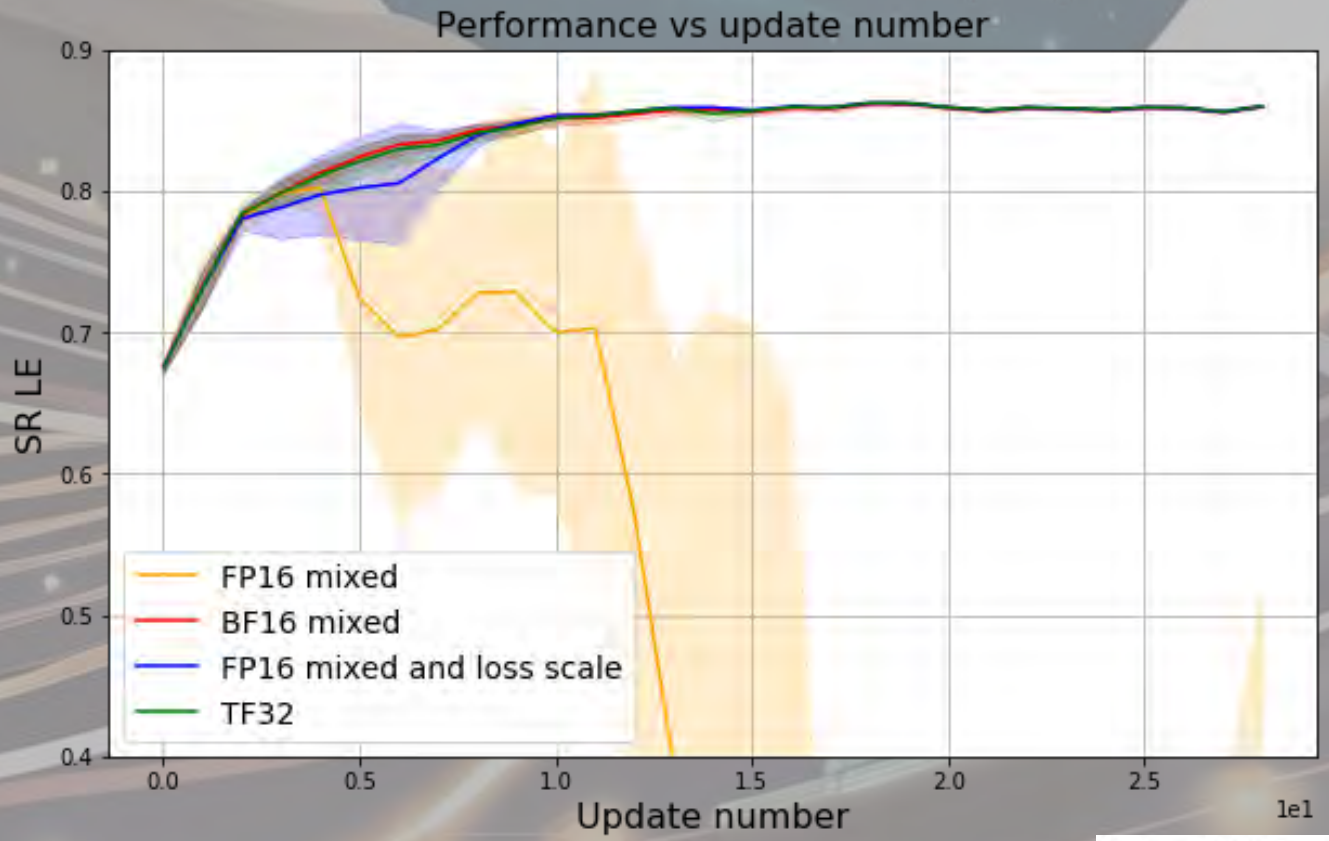
No significant effect from quantization

Integrating deep neural networks with COSMIC and CACAO on SCExAO for real-time control

B. Pou[a, b, c], F. Ferreira[c], V. Deo[d], K. Ahn[d], S. Vievard[d], J. Lozi[d], O. Guyon[d, e, f], E. Quinones[a], M. Martin[b], and D. Gratadour[c]

Towards practical implementation

Effect of quantization on RL training



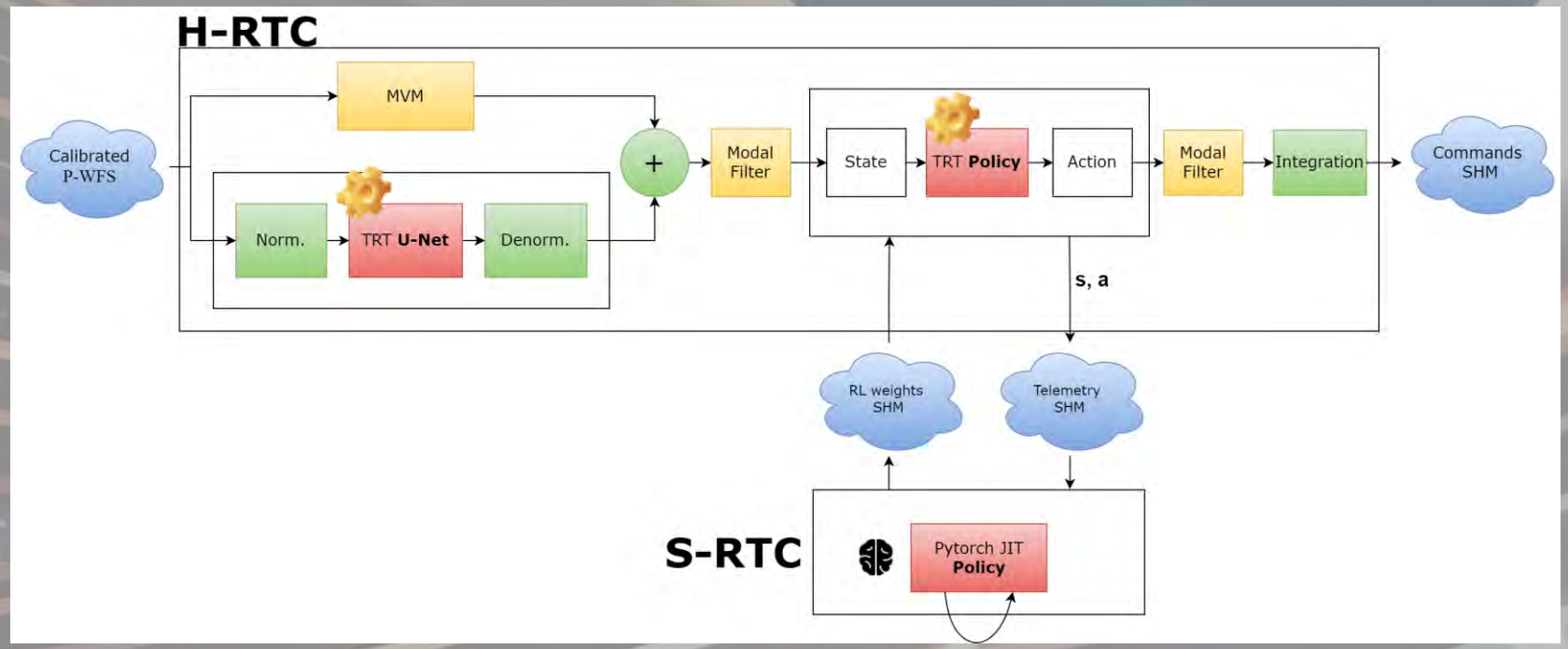
Stable with BF16, portability concerns ?

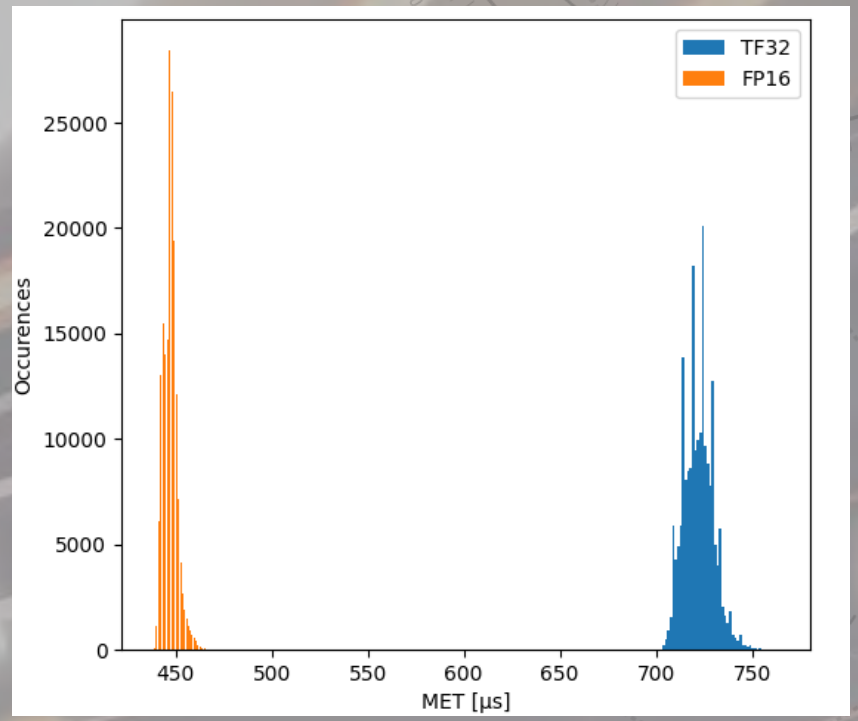
Integrating deep neural networks with COSMIC and CACAO on SCExAO for real-time control

B. Pou[a, b, c], F. Ferreira[c], V. Deo[d], K. Ahn[d], S. Vievard[d], J. Lozi[d], O. Guyon[d, e, f], E. Quinones[a], M. Martin[b], and D. Gratadour[c]

Towards practical implementation

Critical path inference time: full pipeline (HPC + AI) on A100 GPU





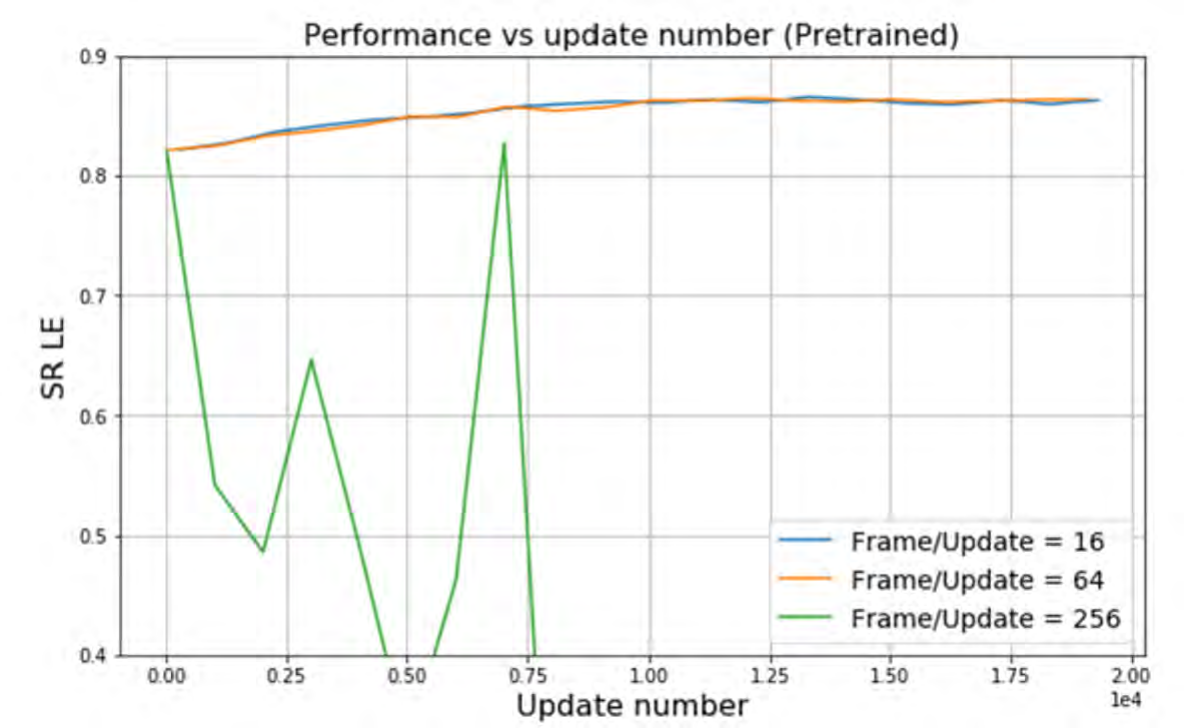
Pipeline	Mean latency [µs]	Mean jitter [µs]	Max. jitter [µs]	Jitter P2V [µs]
DSRL TF32	722	7	42	65
DSRL FP16	447	3	27	36

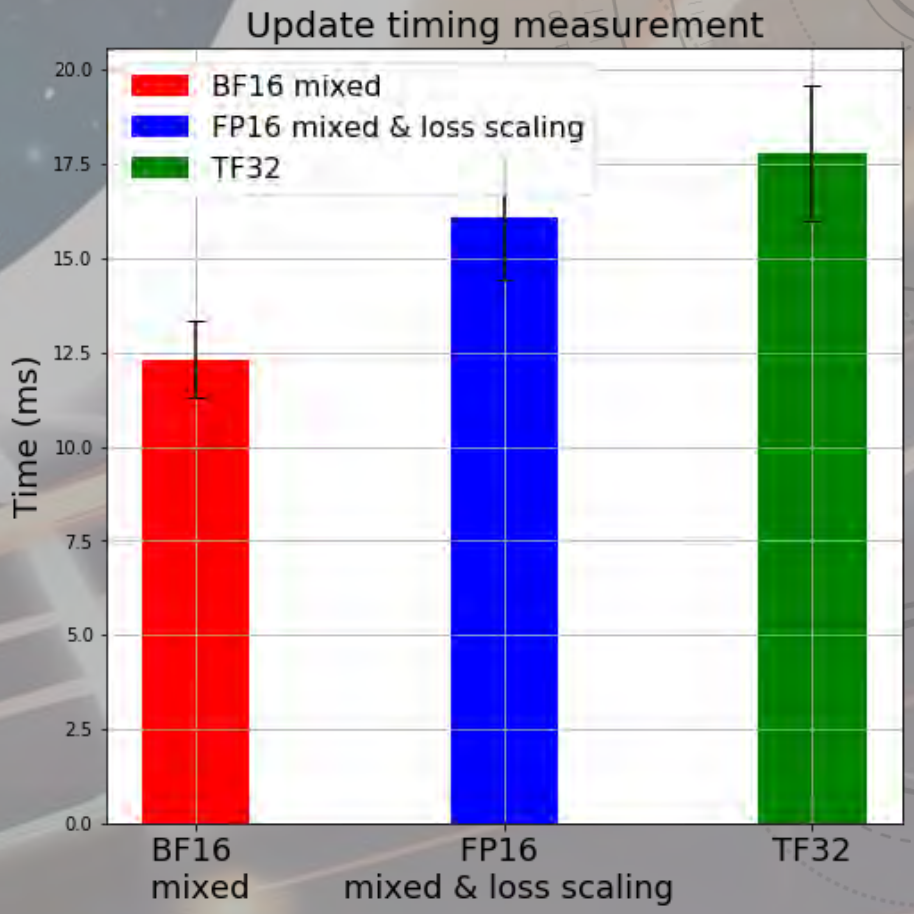
Integrating deep neural networks with COSMIC and CACAO on SCExAO for real-time control

B. Pou[a, b, c], F. Ferreira[c], V. Deo[d], K. Ahn[d], S. Vievard[d], J. Lozi[d], O. Guyon[d, e, f], E. Quinones[a], M. Martin[b], and D. Gratadour[c]

Towards practical implementation

Training requirements and update time

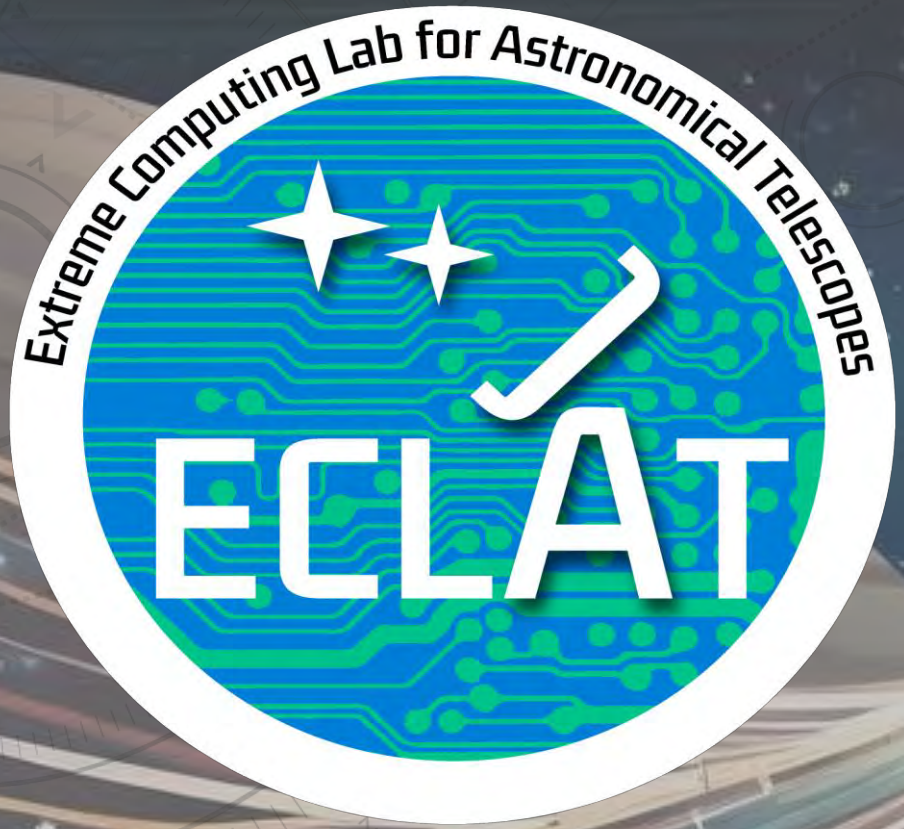




Compatible with specifications < 20ms on A100

Integrating deep neural networks with COSMIC and CACAO on SCExAO for real-time control

B. Pou[a, b, c], F. Ferreira[c], V. Deo[d], K. Ahn[d], S. Vievard[d], J. Lozi[d], O. Guyon[d, e, f], E. Quinones[a], M. Martin[b], and D. Gratadour[c]



cnrs Inria l'Observatoire de Paris | PSL OBSERVATOIRE DE LA CÔTE D'AZUR UNIVERSITÉ CÔTE D'AZUR EVIDEN

SUPPORTING INITIATIVES