

Development of a very high-contrast wavefront control method for the detection of exoplanets with the Nancy-Grace-Roman space mission

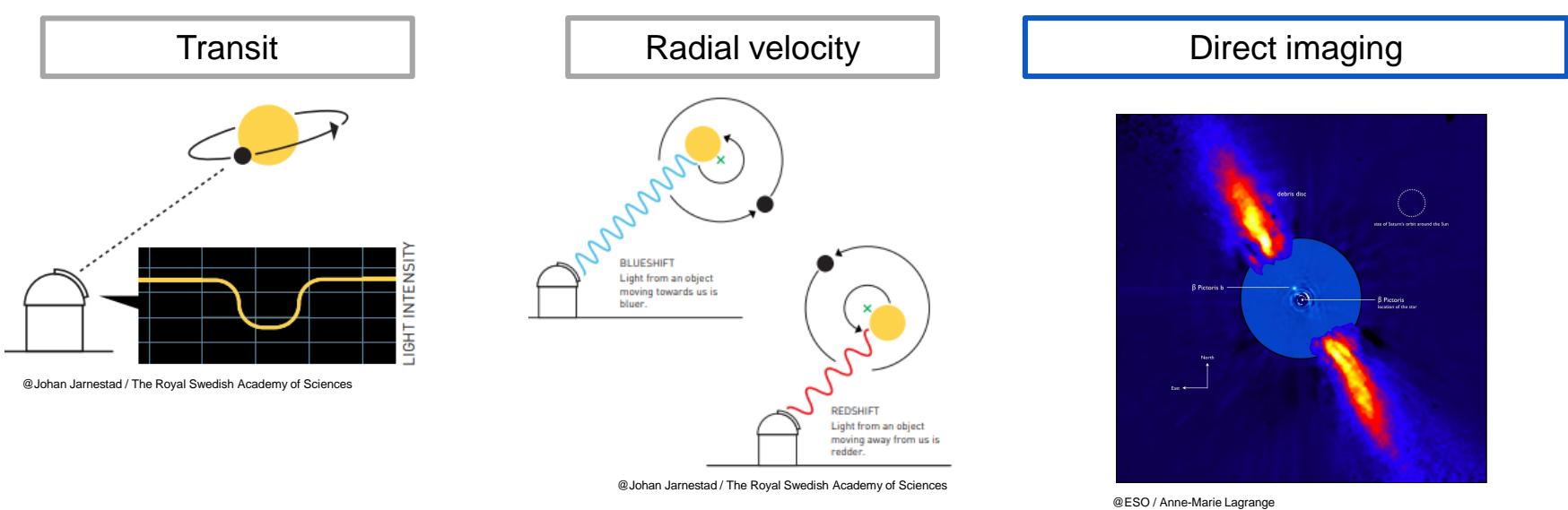
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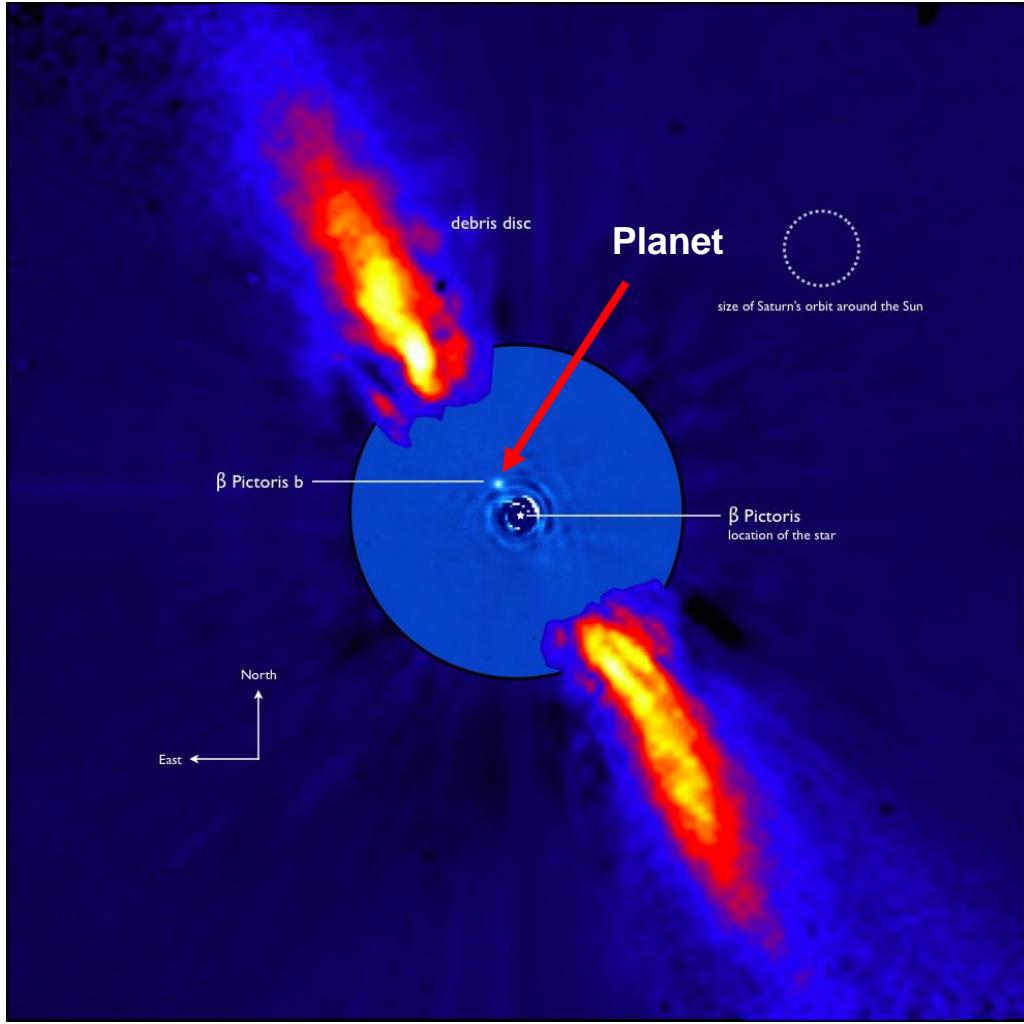
Supervisors: Laurent MUGNIER (ONERA), Raphaël GALICHER (LESIA)

Scientific context

- Context : Exoplanets imaging
- 4500~ Exoplanets confirmed (2021)
- 1st detection : 1995, (Nobel Prize in Physics 2019)
- Different methods:



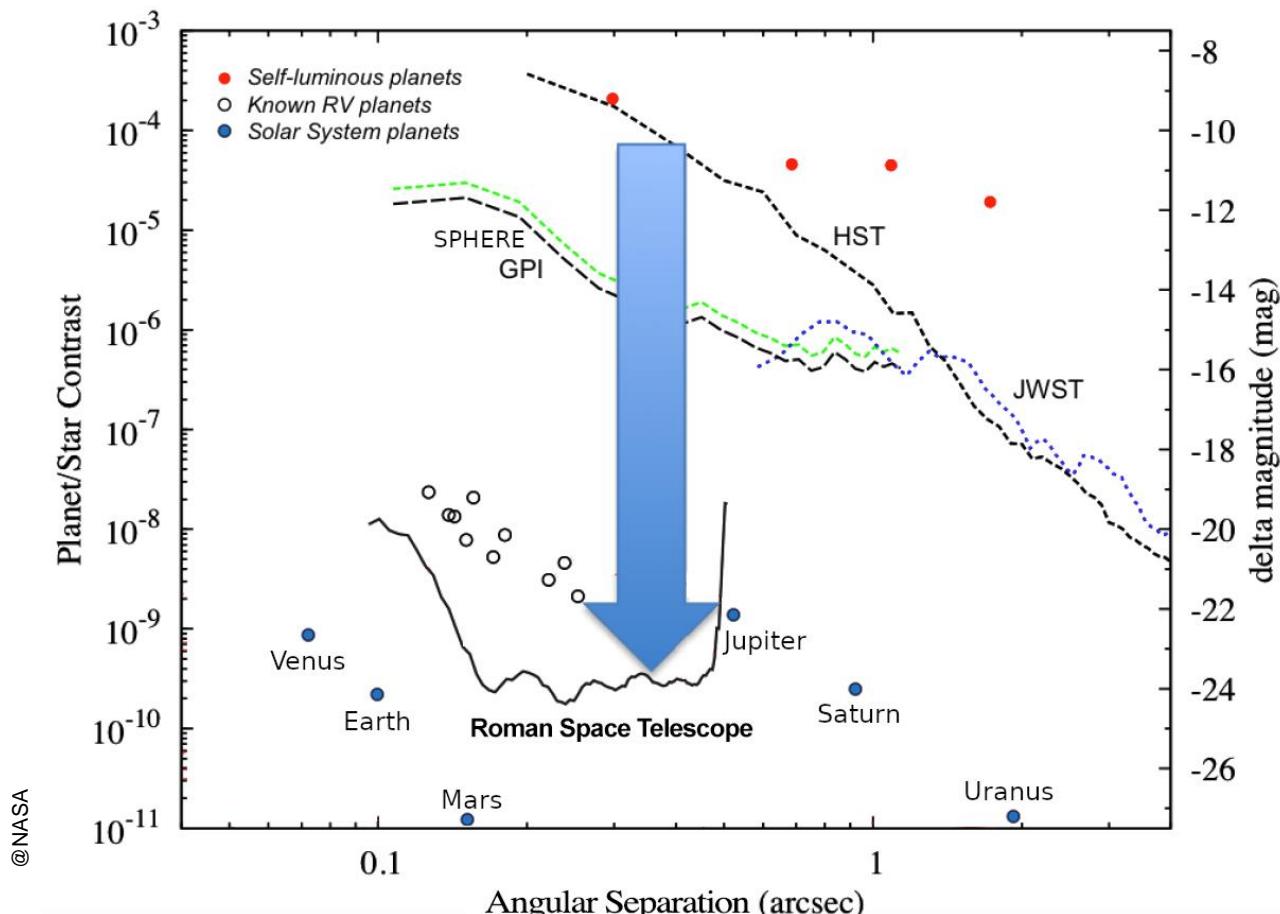
Direct imaging



- **A dynamic field: Roman, HabEx, LUVOIR, JWST**
- **Instrumental challenge**
- **Contrast : flux ratio between the star and the planet**
 - Visible and near-infrared:
 - Jupiter at 10 pc : 10^{-9} at 0,5 arcsec
 - Terre at 10 pc : 10^{-10} at 0,1 arcsec

@ESO / Anne-Marie Lagrange

State of the art



Ground telescopes:

around 10^{-6}

Laboratory :

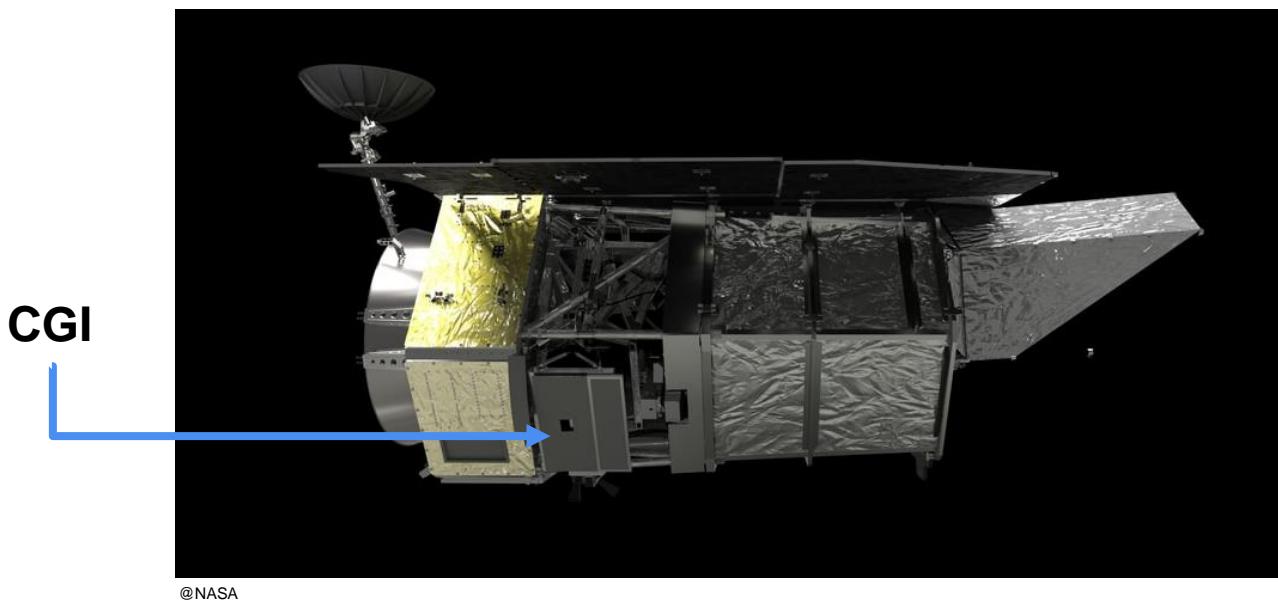
around $10^{-9} - 10^{-10}$

NGRST Goal :

around 10^{-9}

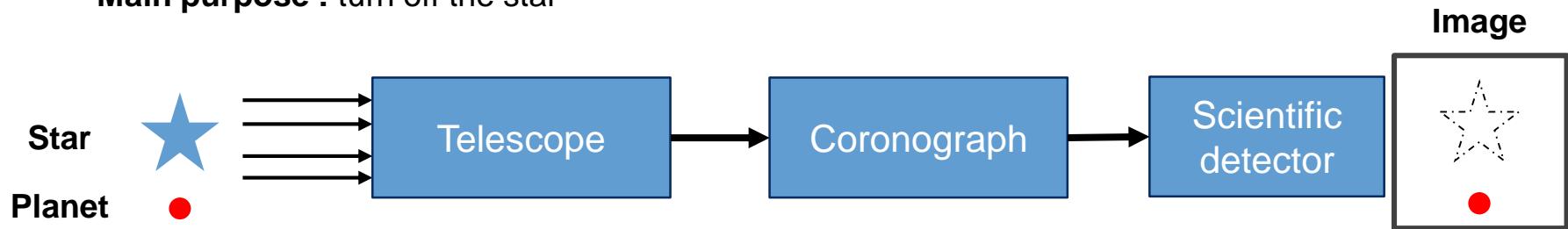
Instrumental context

- The Nancy-Grace-Roman Space Telescope (NGRST), NASA mission planned for 2025
- 1 french contribution for « Dark-Hole » algorithms
- **CGI** (Coronagraph Instrument)
 - **Demonstrator** for exoplanets direct imaging
 - **Goal** : exo-Jupiter imaging

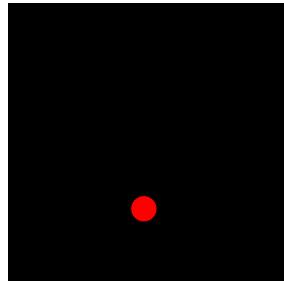


Coronograph and active correction

- **Main purpose :** turn off the star



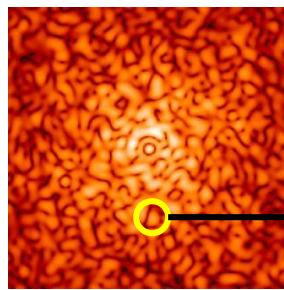
- **Perfect case :**



SPHERE

50 nm rms

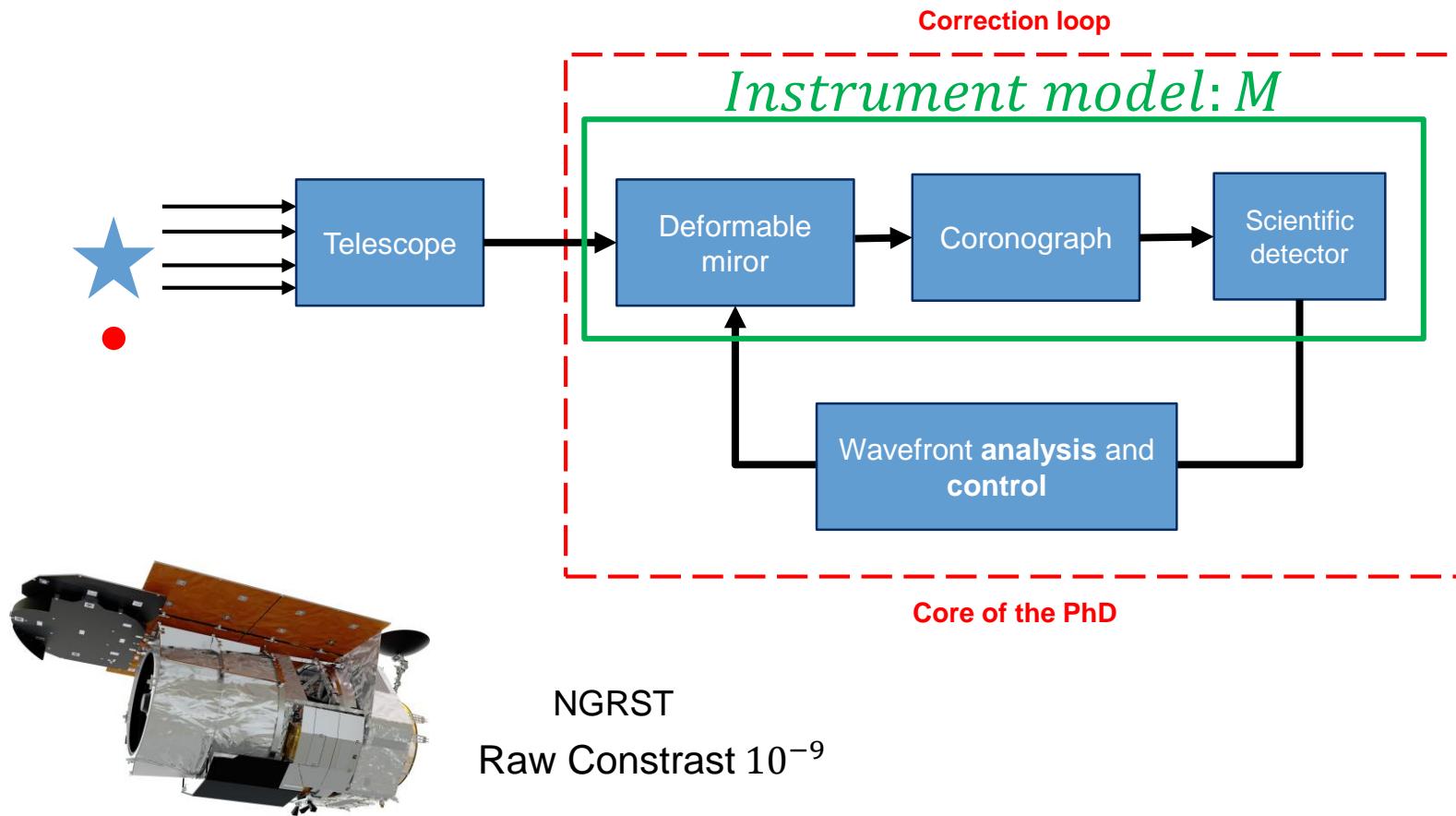
Raw contrast 10^{-5}



@Baptiste PAUL - Onera

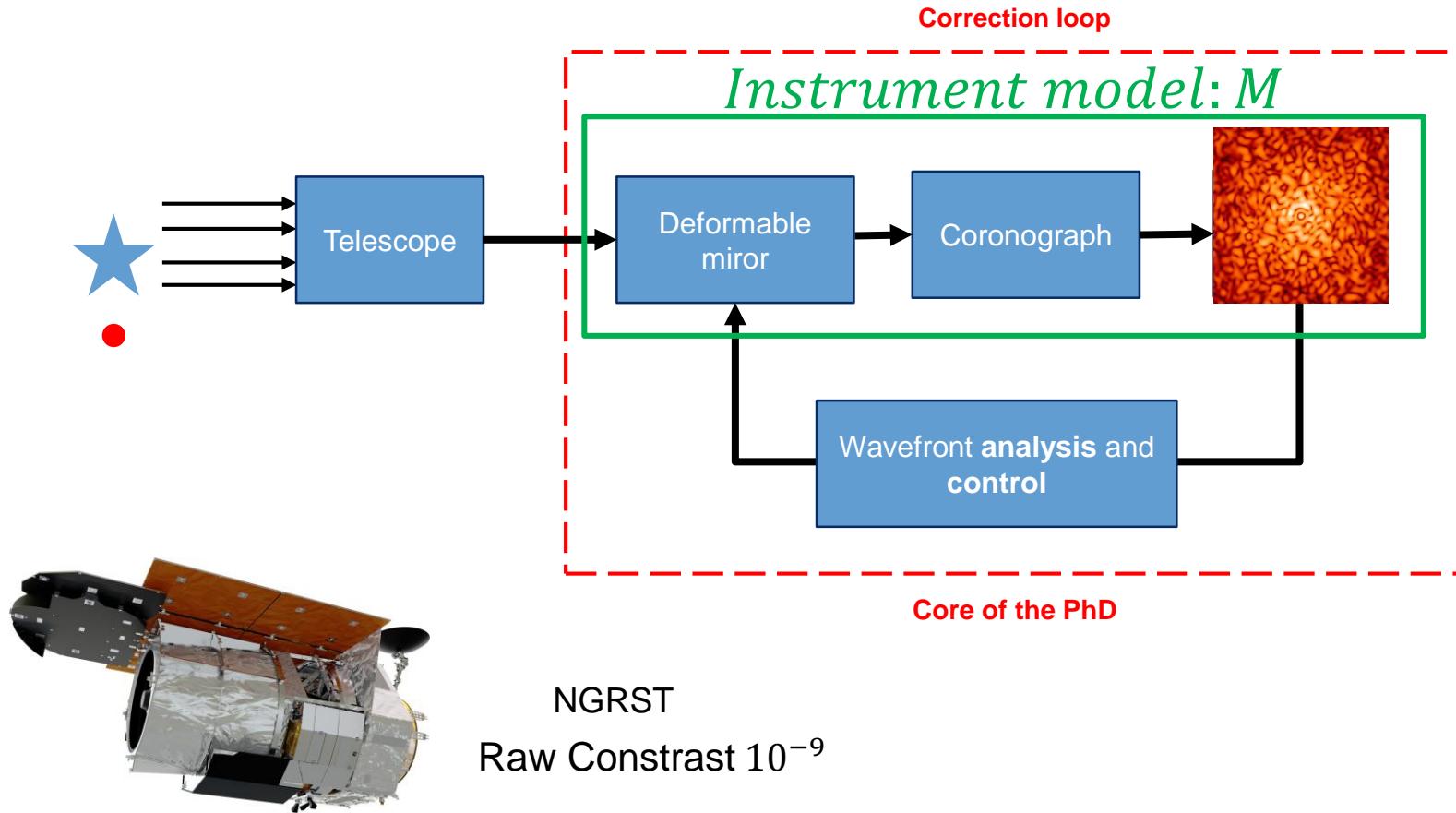
Coronograph and active correction

- Focal plane wavefront analysis



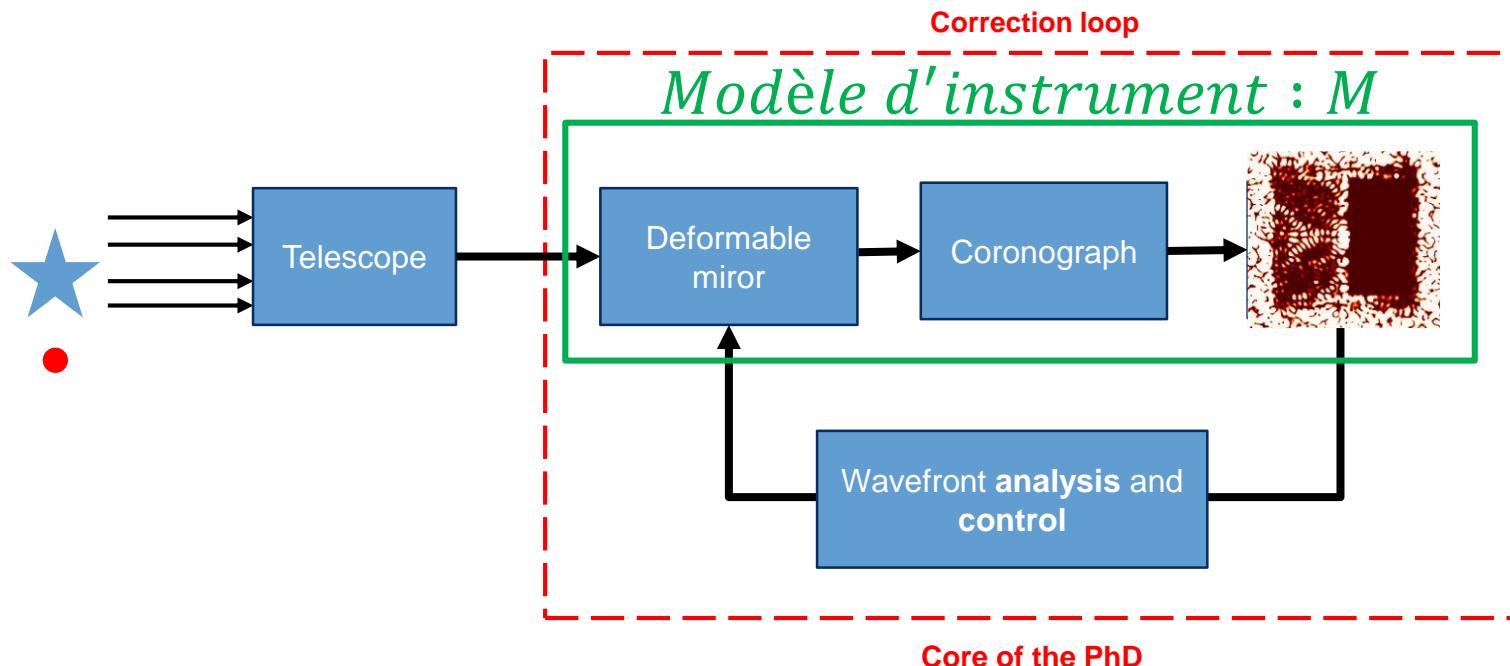
Coronograph and active correction

- Focal plane wavefront analysis

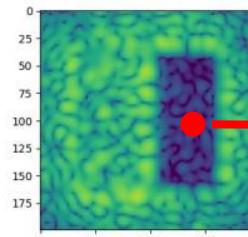
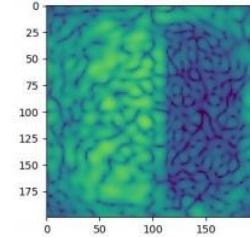
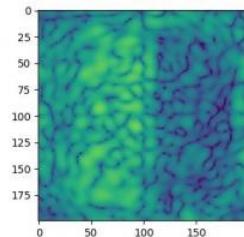
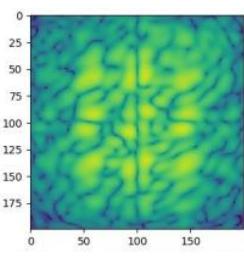


Coronograph and active correction

- Focal plane wavefront analysis



Iterations



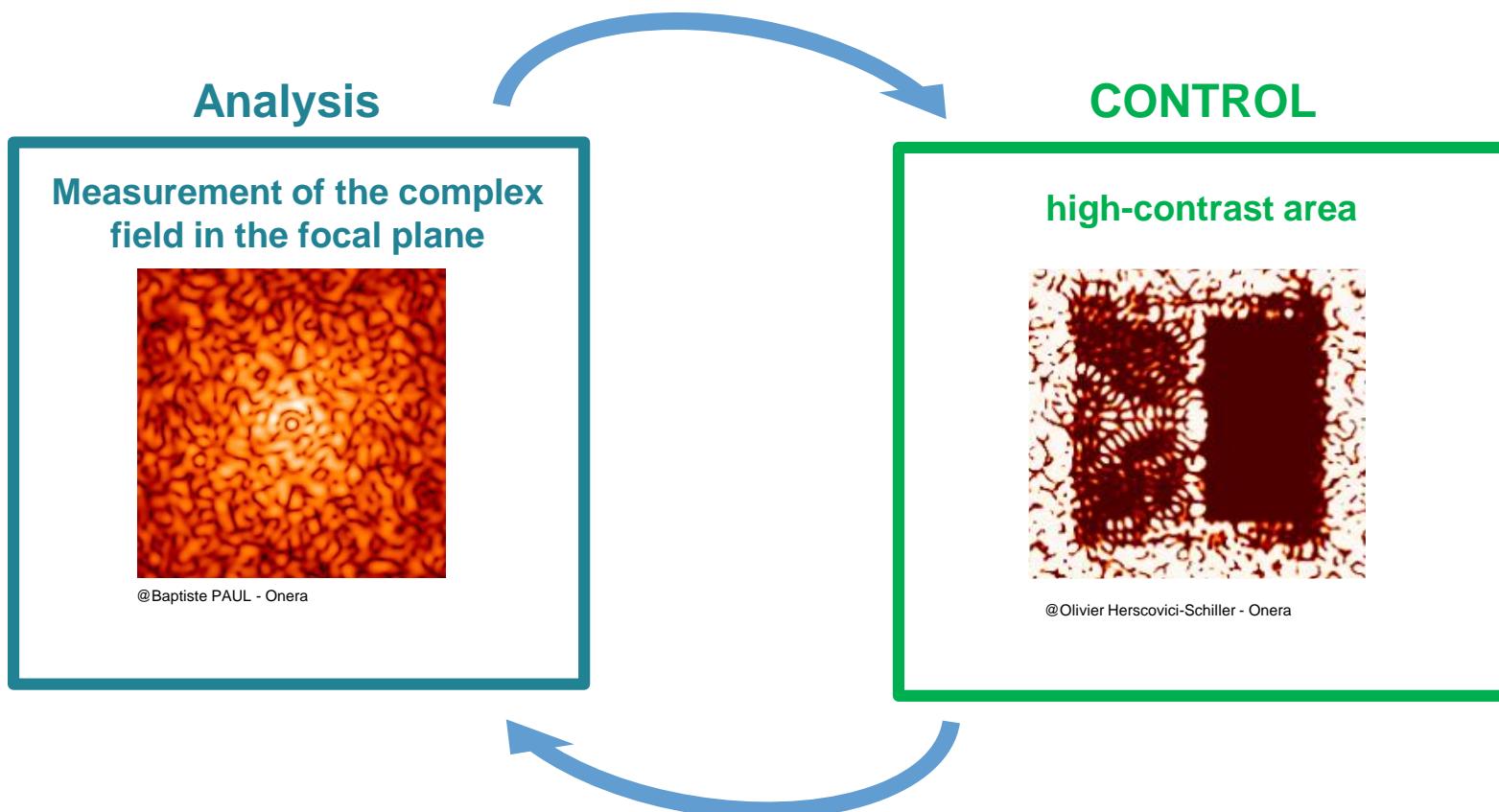
Dark Hole
Detection
area

@Axel Potier - LESIA

LESIA l'Observatoire de Paris | PSL

Method

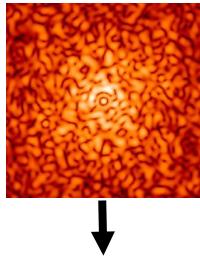
- How to delete the speckles to detect a planet?



Measure

Analysis

Direct problem :



$$I_{\text{Speckles}} = M(\text{aberrations}) + \text{noise}$$

Inverse problem (our case) :

$$\text{aberrations} = "M^{-1}(I_{\text{Speckles}})"$$

The estimate of the aberrations → minimisation of J_a :

$$J_a = \min \| I_{\text{Tavelures}} - M(\text{aberrations}) \|^2$$

Measure

Analysis

COFFEE *

- Non-linear model
- No hypothesis on the amplitude of the aberrations
- 3 images

Pair-Wise

- Linear model
- Low aberrations hypothesis
- 4 images

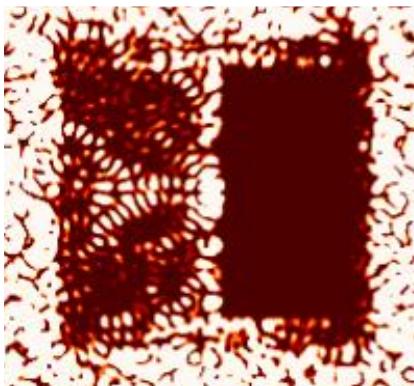
*COFFEE : COronographic Focal-plane wave-Front Estimation for Exoplanet detection

Correction

CONTROL

Electric Field Conjugation

Minimisation : $J_{Dark-Hole} \longrightarrow M(aberrations + a_{deformable mirror})$



@Olivier Herscovici-Schiller - Onera

Objectives and schedule

Provide a **powerful**, **fast** and **robust** wavefront control method

- **Powerful** : high contrast (exo-Jupiter)
- « **Fast** » : observation time
- **Robust** : sensitivity to disturbances

How ?

- **Analyse / Compare / Optimize measurement** : Pair-Wise, COFFEE
- **... and control methods (Dark-Hole)** : Electric field conjugation, Non-linear Dark Hole
- **Technical resources** : *Très Haute Dynamique 2* (THD2) optical bench at LESIA

Year 1

- Bibliography
- Simulations
- Get familiar with THD2

Year 2

- Experiments
- Limitations of methods
- Conferences / publications

Year 3

- Astrophysics perfs
- Writing

THANKS FOR YOUR ATTENTION

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- **Travaux antérieurs :**
 - **Baptiste Paul**, « Mesure de front d'onde post-coronographique à haute précision pour l'imagerie à haut contraste ».
 - **Olivier Herscovici-Schiller**, « Analyse et correction de surface d'onde post-coronographique pour l'imagerie d'exoplanètes ».
 - **Axel Potier**, « Comparaison des techniques d'analyse de surface d'onde en plan focal dédiées aux missions spatiales d'imagerie directe et de spectroscopie des planètes extrasolaires ».
 - **Johan Mazoyer**, « Haut contraste pour l'imagerie directe d'exoplanètes et de disques : de la self coherent camera à l'analyse de données NICI »