EXOPLANET DIRECT IMAGING:
DR WHO

ON SKY
NCPA CORRECTION
THROUGH
THE **PYRAMID** WAVEFRONT SENSOR **REFERENCE UPDATE**

NOUR SKAF
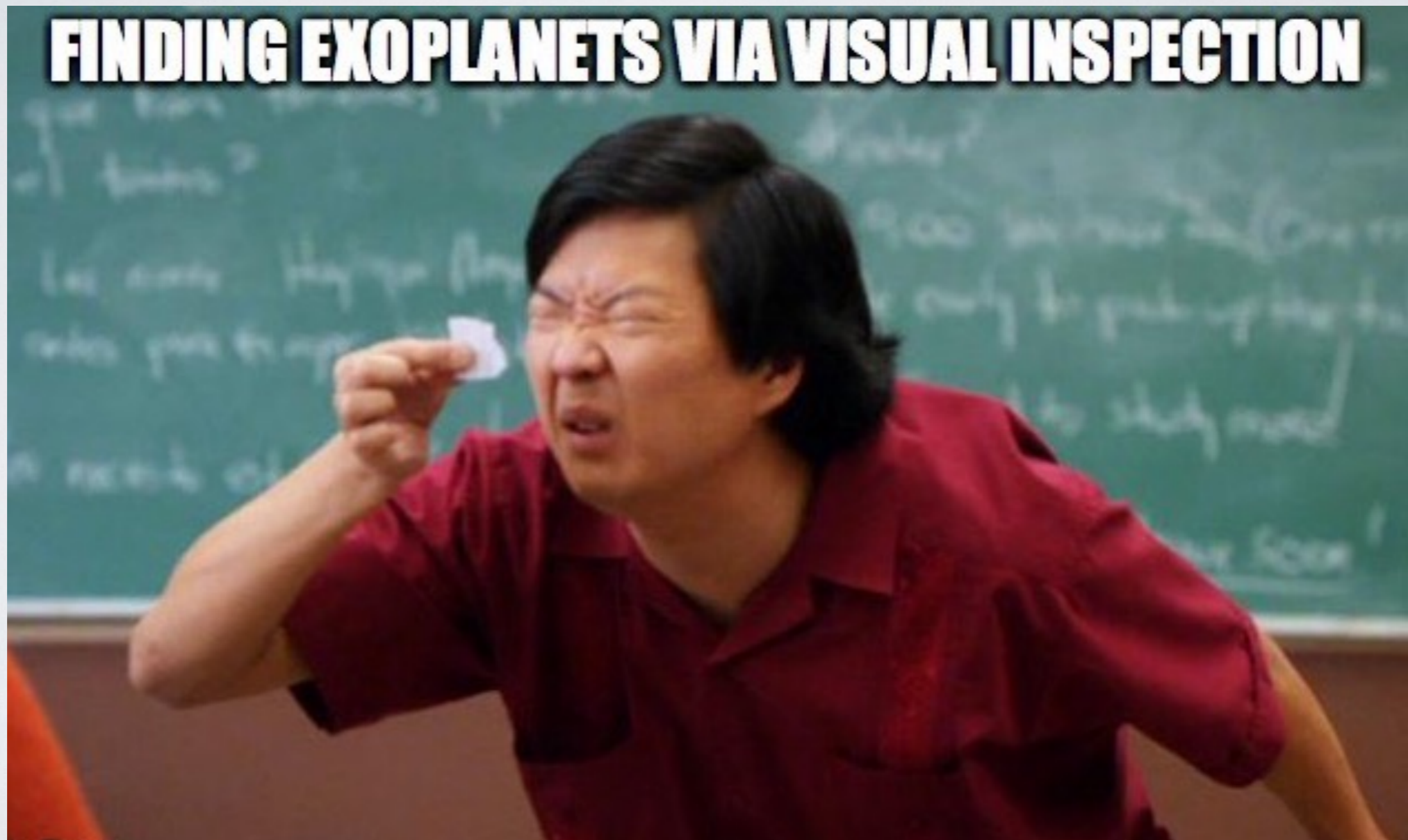
Supervisors:
Olivier Guyon
Anthony Boccaletti

WFS 2020 - Online
14 October 2020

LESIA l'Observatoire | PSL ★
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique
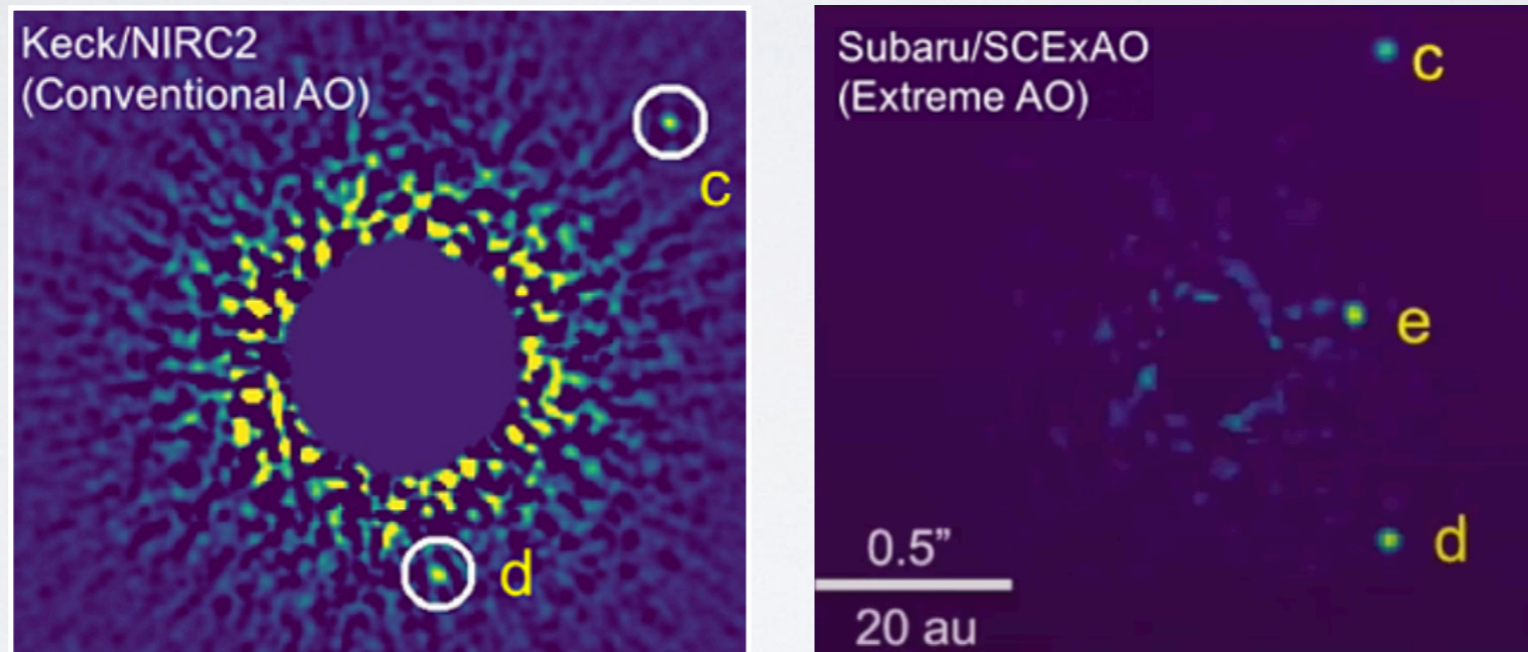
SCExAO
Subaru Coronagraphic Extreme Adaptive Optics
すばるコロナグラフ極限補償光学装置

DIRECT IMAGING …

Credit: Billy Edwards
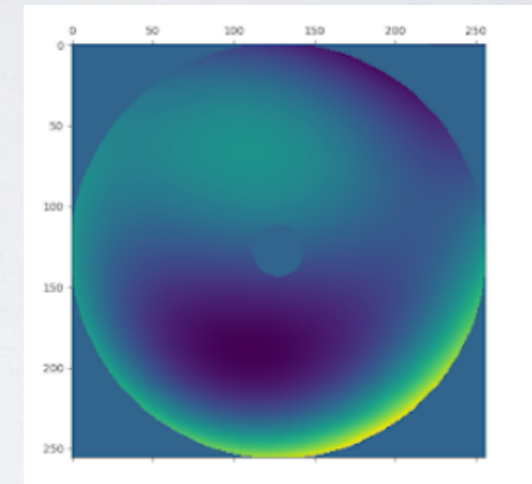
Speckle subtraction

Currie et al. 2019

Speckles = atmospheric residuals + NCPA

TECHNICAL CHALLENGES

Several kinds of NCPA…

Static
Quasi static (<0.01 Hz)
Dynamic (>0.01 Hz)

Each kind having low and high spatial frequencies

Several ways to deal with NCPA…

Can partially be solved by changing the gain

➡ in xAO, the modes are **coupled** …

DR WHO

Direct Reinforcement Wavefront Heuristic Optimisation

Problematic : what is the pyramid reference ?

i.e what gives a "flat" wavefront

The WFS reference is measured with an internal source, before the observations

BUT, this reference is constantly evolving, and is different on-sky than with the internal source.

→ Essential need of a continuous way to measure the WFS reference

WFS reference ≠ ideal reference

Goal : find what is the closest from it

★ special difficulty bonus for a PyWFS and all its tricky lovely annoying non-linearities ★

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Problematic : what is the pyramid reference ?

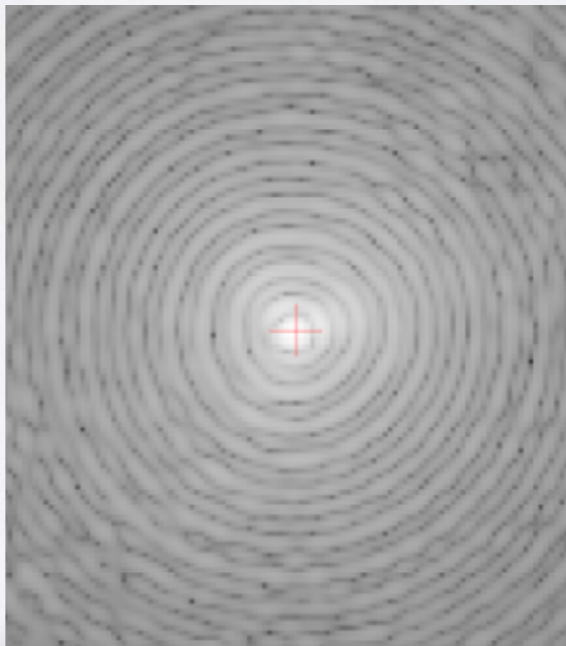**While the AO loop is running : live update of the pyramid reference**

DR WHO

Problematic : what is the pyramid reference ?

While the AO loop is running : live update of the pyramid reference

**1- On a 30 sec timescale, the algo identifies the best 10% Strehl Ratio
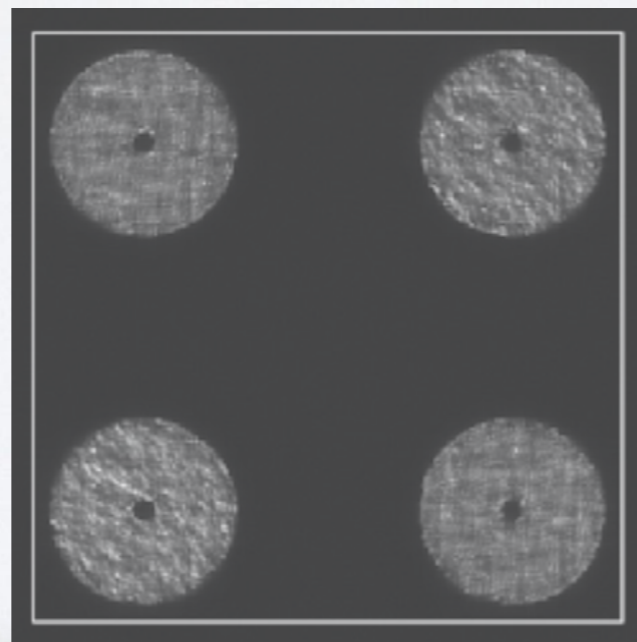(SR = reward - could be contrast, sharpness, minimum intensity etc)**

DR WHO

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While the AO loop is running : live update of the pyramid reference

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2- Take the corresponding WFS measurements

DR WHO

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**4- The resulting WFS frame replaces the WFS reference
(with an integrator filter)**

DR WHO

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5- As the algo proceeds, it is continuously rewarded for high quality PSF
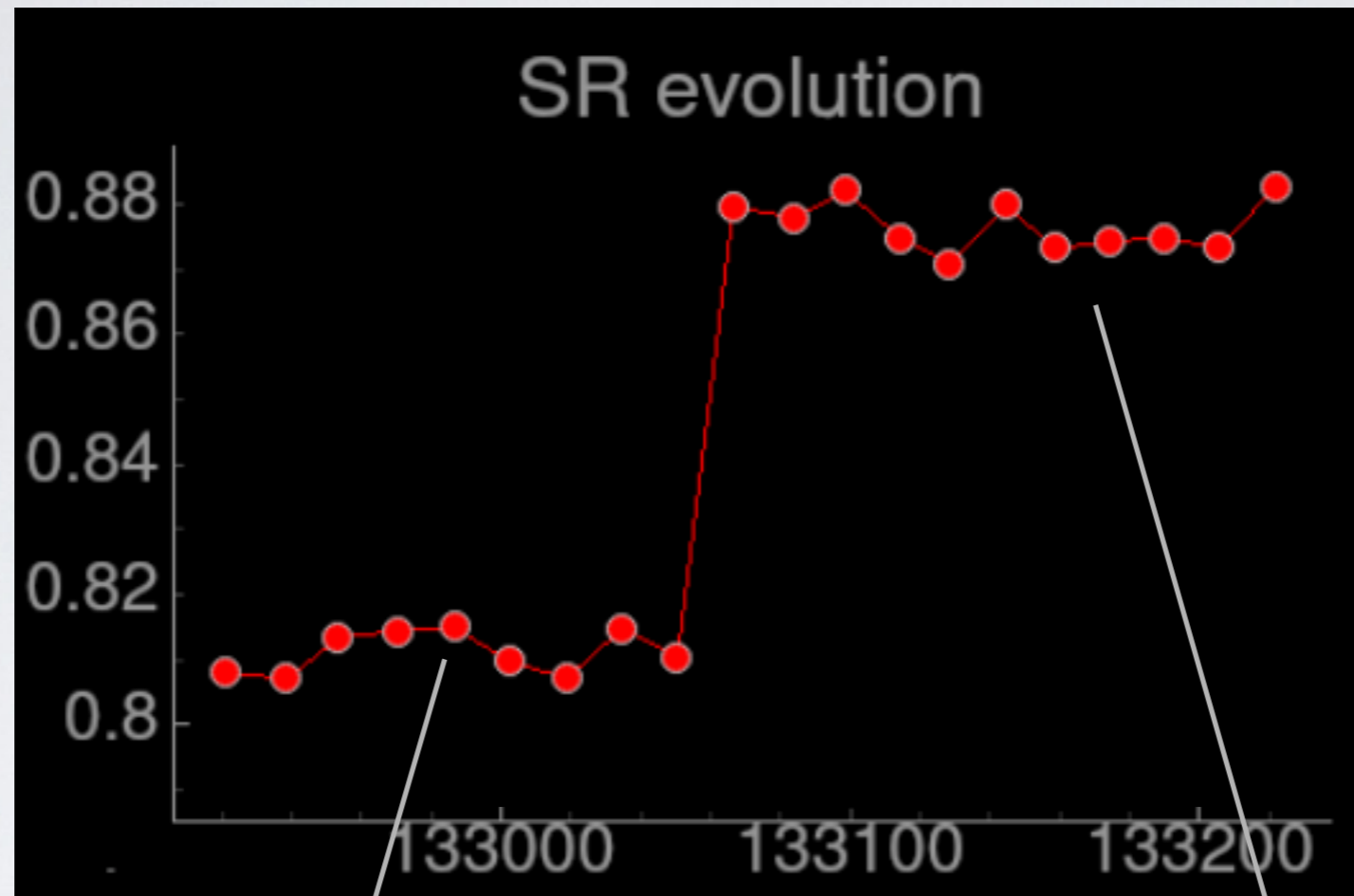
Results
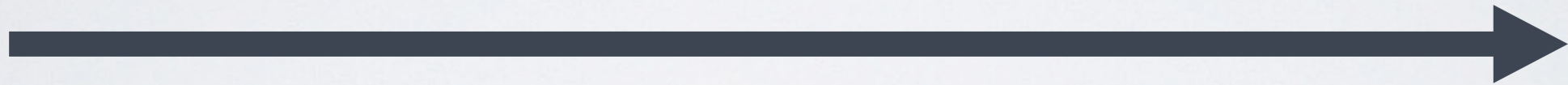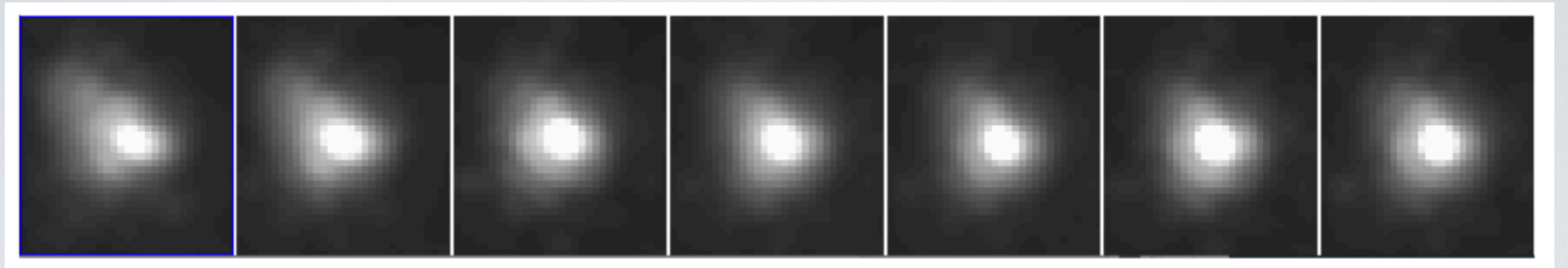
Evolution of the PSF quality, on sky (SCExAO), over a 21 min period

750 nm on Vampire
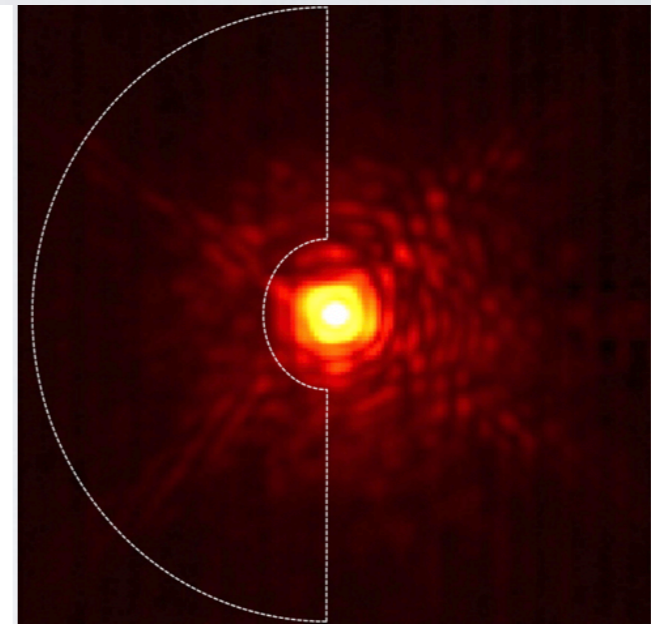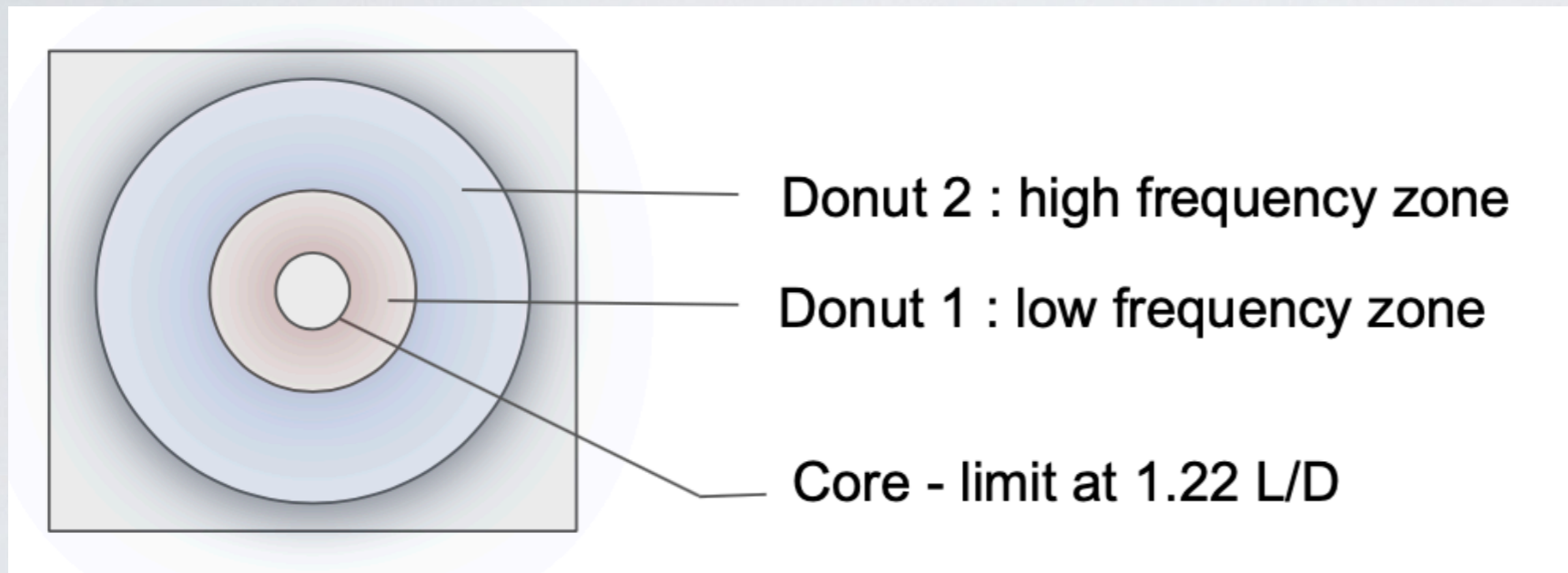
Results   Compass simulation

Loop with Initial Reference

Loop with update reference after Dr WHO

Without NCPA = 93%

Dr WHO 2.0

Take advantage of the difference in spatial frequency in the PSF

Donut 2 : high frequency zone

Donut 1 : low frequency zone

Core - limit at 1.22 L/D

PSF SE

the inner donut has a lower spatial frequency than the outer donut
> we can **select** part of the image corresponds to some spatial frequency

> 2 (N) loops Dr WHO for each donut and **separate lower and higher frequencies**
to correct each **independently**.

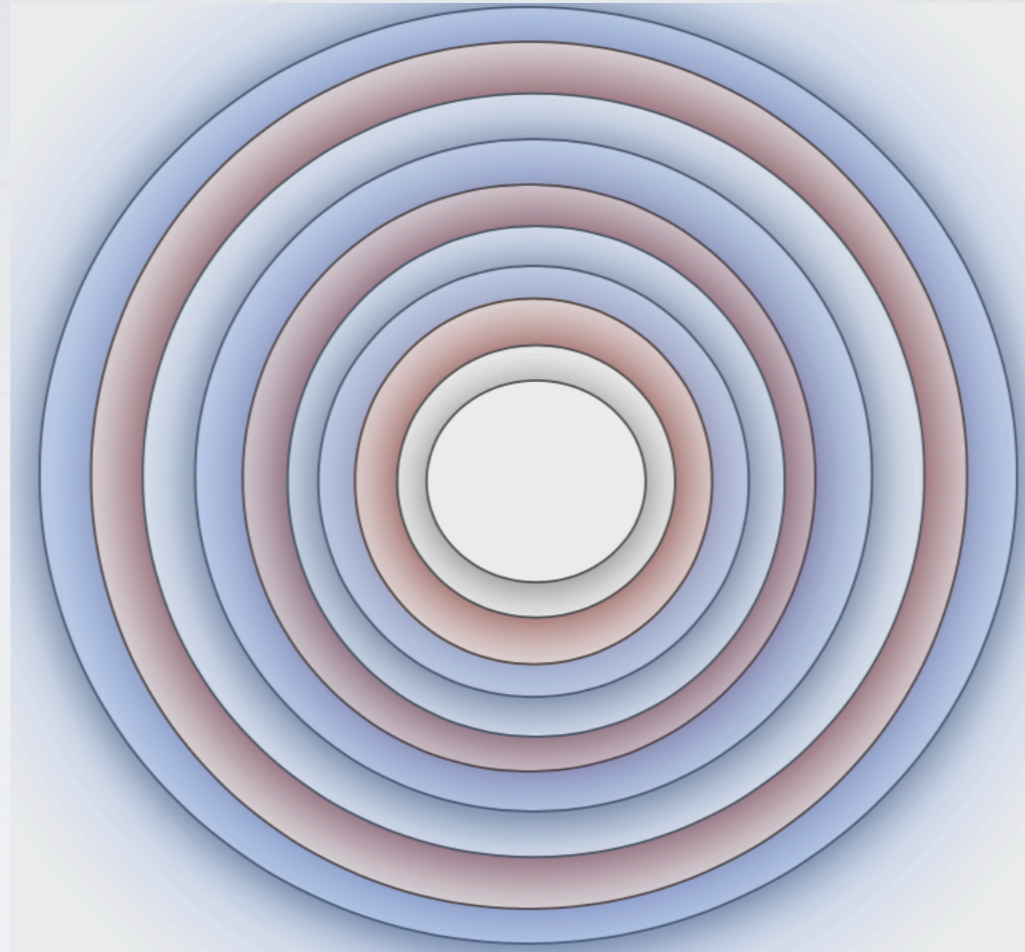then, sum up the 2 references found on the WFS

LET'S MAKE MORE DONUTS!
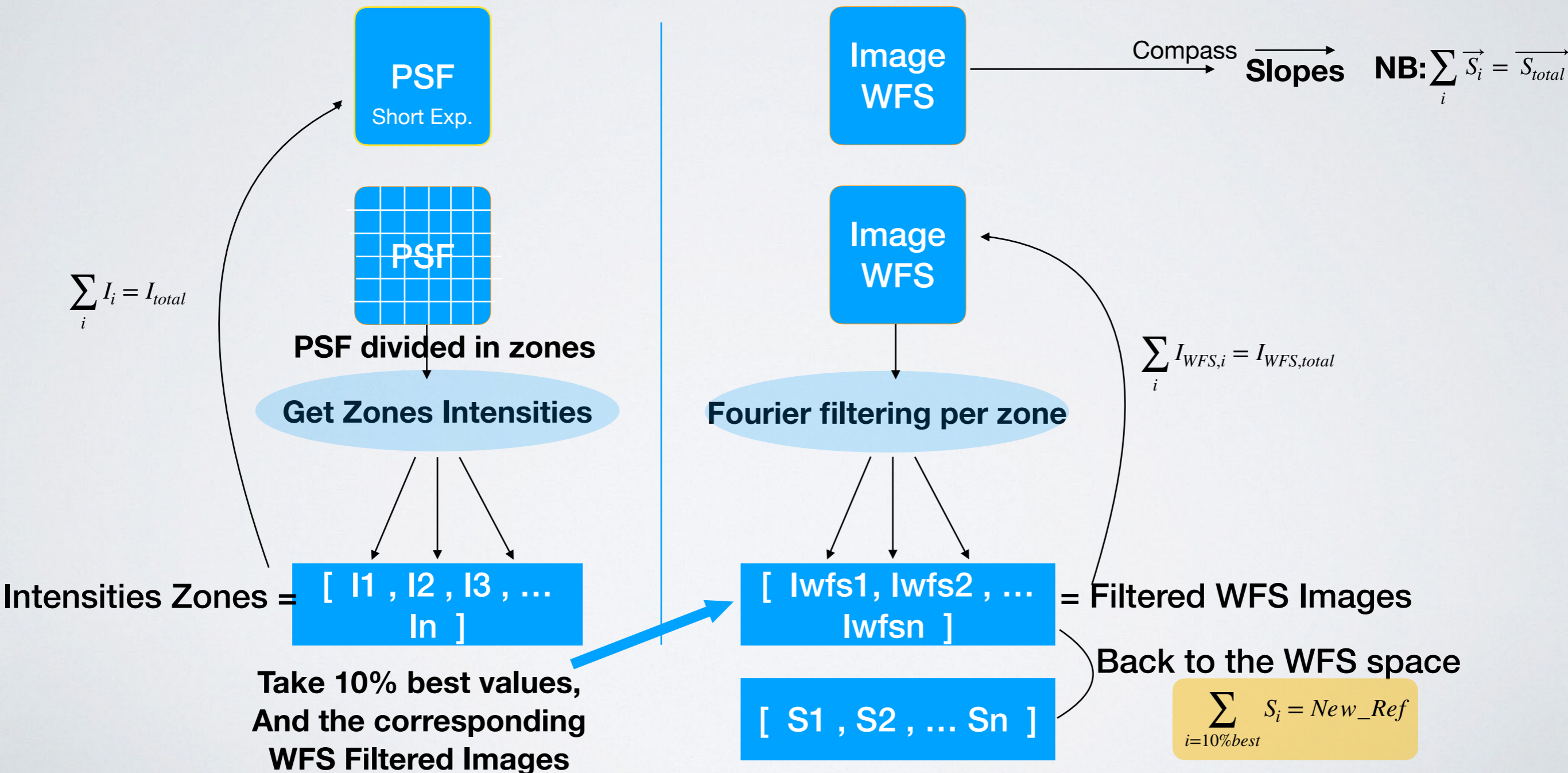
LET'S MAKE MORE DONUTS!

Nour post-lockdown

As many donuts as we want to separate in spatial frequencies

➜ To have an accurate quantification of NCPAs
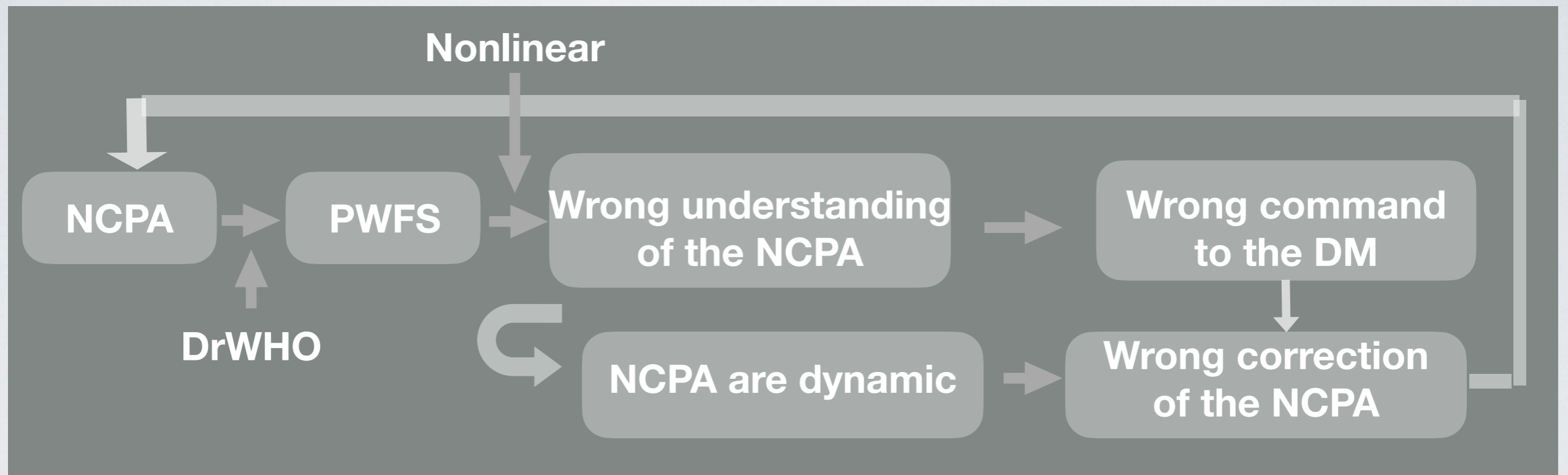And project the NCPA on the modal basis

(Gendrinou modal basis - Gendron et al 202x)

Dr WHO 3.0 : through Fourier spatial filtering of the WFS images via zones in the PSF

Schematic view

PSF
Short Exp.

PSF

PSF divided in zones

$$\sum_i I_i = I_{total}$$

Get Zones Intensities

Intensities Zones = [I1 , I2 , I3 , … In]

Take 10% best values, And the corresponding WFS Filtered Images

Image WFS

Compass

Slopes   **NB:** $\sum_i \vec{S_i} = \vec{S_{total}}$

Image WFS

$$\sum_i I_{WFS,i} = I_{WFS,total}$$

Fourier filtering per zone

[Iwfs1, Iwfs2 , … Iwfsn] = Filtered WFS Images

[S1 , S2 , … Sn]

Back to the WFS space

$$\sum_{i=10\%best} S_i = New\_Ref$$

Summer-y -I

Summer-y - II

- **Parallelisation** of the optimisation:
Each **area / donut / squares** runs optimally in //,
Each working on separate modes / spatial frequencies

- **Flexible** in the choice of optimisation :
  - kind of **zones** and their sizes
  - **frequency filtering** (modal basis / Fourier …)
  - **quantity** to optimise : local contrast, Strehl, etc.
  - Dr WHO algo time setting, lucky imaging setting, etc
  - SH, PyWFS…

- Possible extension to use DL as an **empirical** approach through the telemetry to learn the multiple **non-linear relationships** would be powerful.
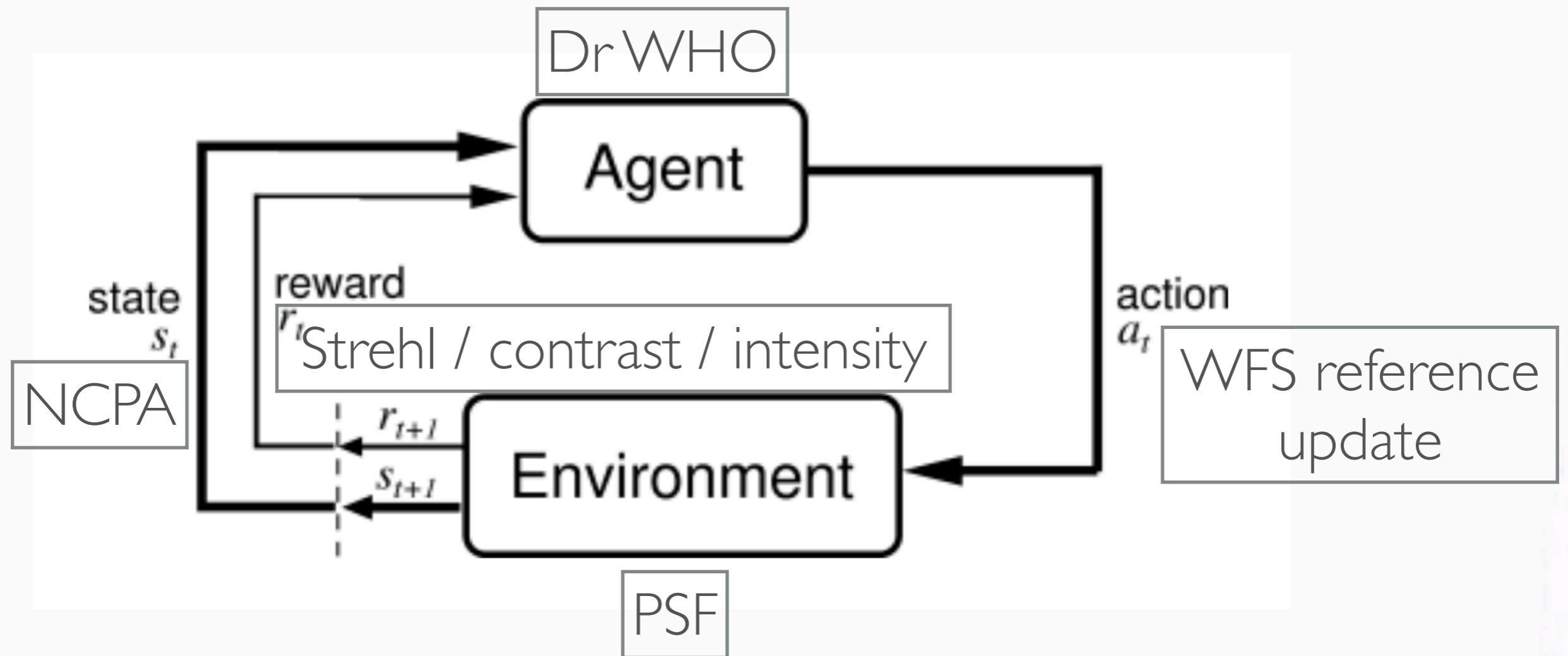
Next step: on SCExAO !
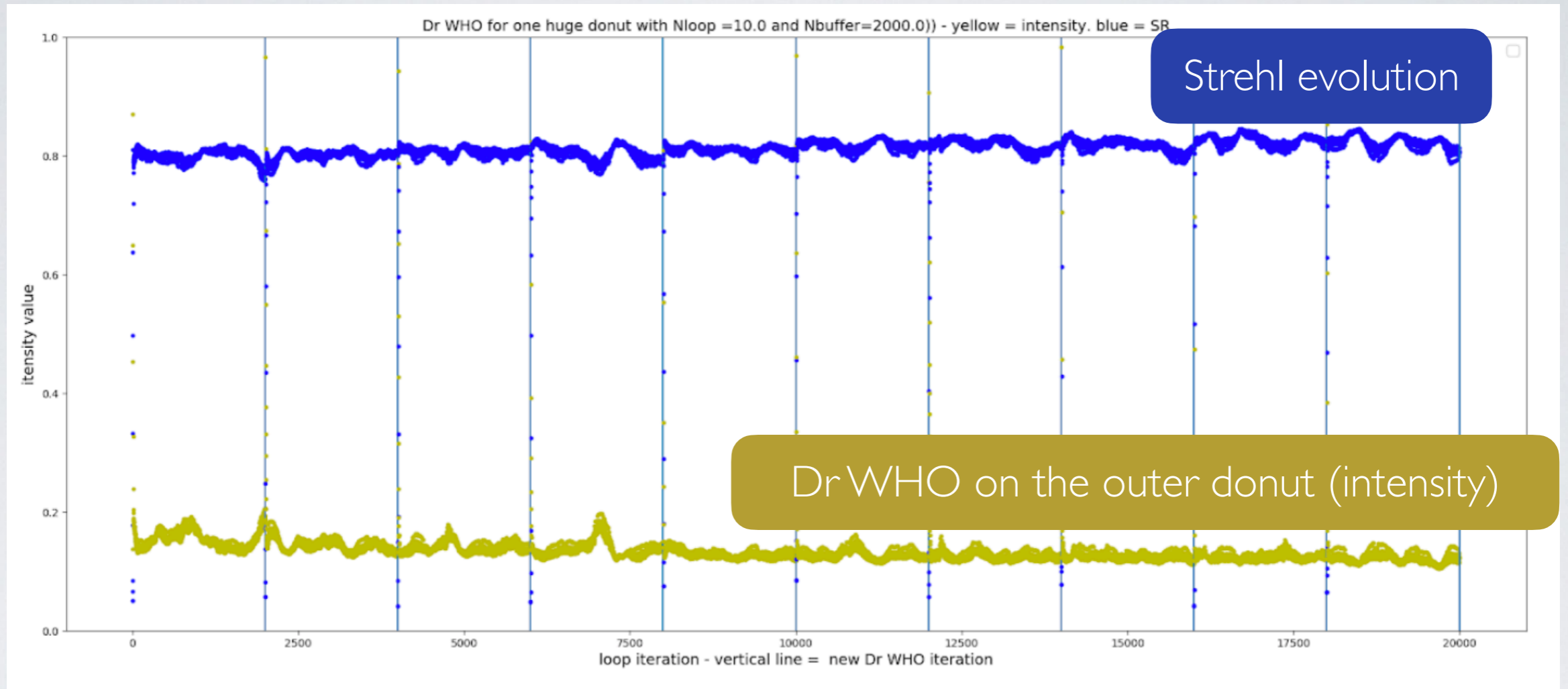
Thank you :)

Back up slides

DR WHO

Model-based Reinforcement Learning approach

Policy: binary selection of the PSF - "lucky imaging"

Compass simulation…

Dr WHO for one huge donut with Nloop =10.0 and Nbuffer=2000.0)) - yellow = intensity. blue = SR

Strehl evolution

Dr WHO on the outer donut (intensity)

itensity value

loop iteration - vertical line = new Dr WHO iteration

10 seconds of loop iterations
➡ SR improvement ~ 4%