THEMIS

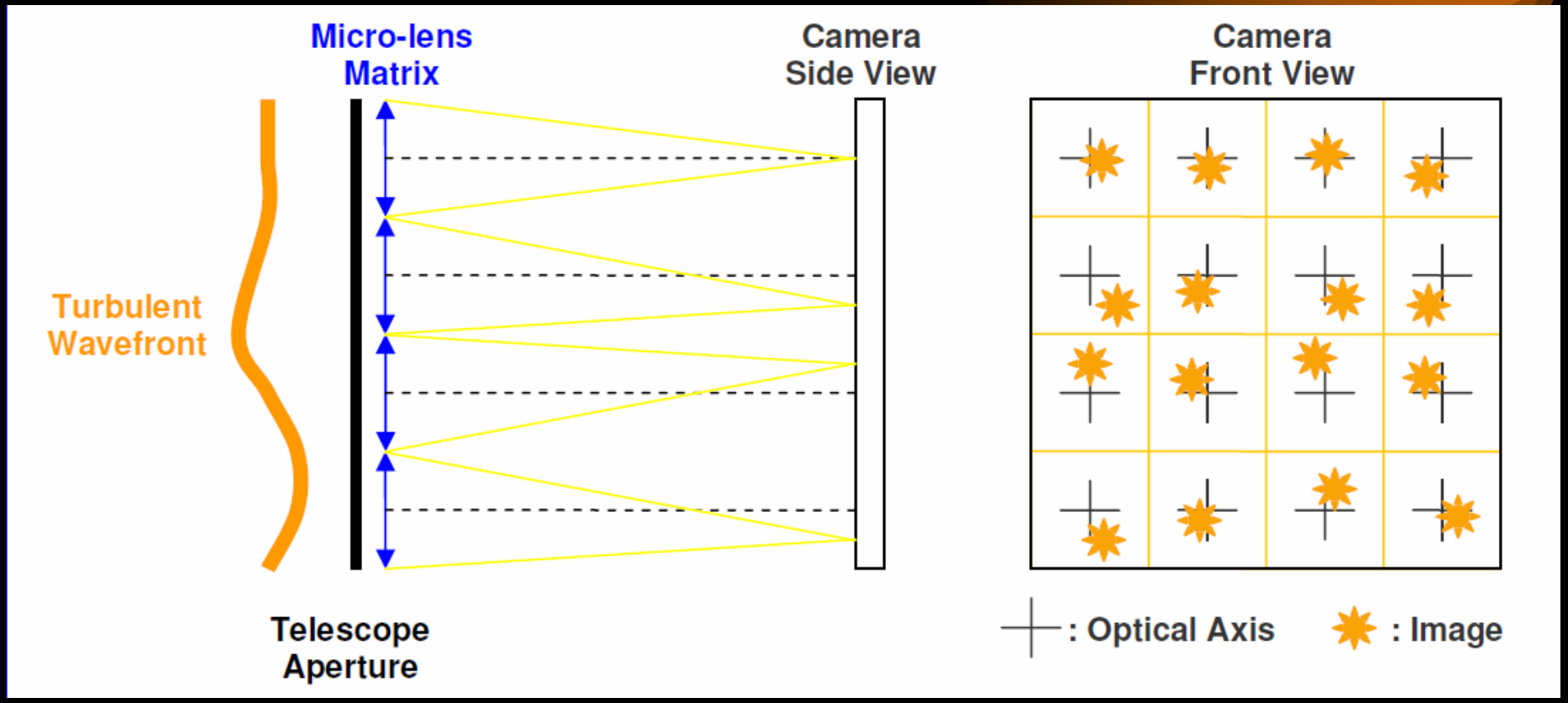
Polarimetric Wave Front Weak Sensor

« *Wavefront sensing in the absence of correlation features* »

C. Le Men (Themis - CNRS-UPS853)
A. Lopez Ariste (IRAP - CNRS-UMR5277)

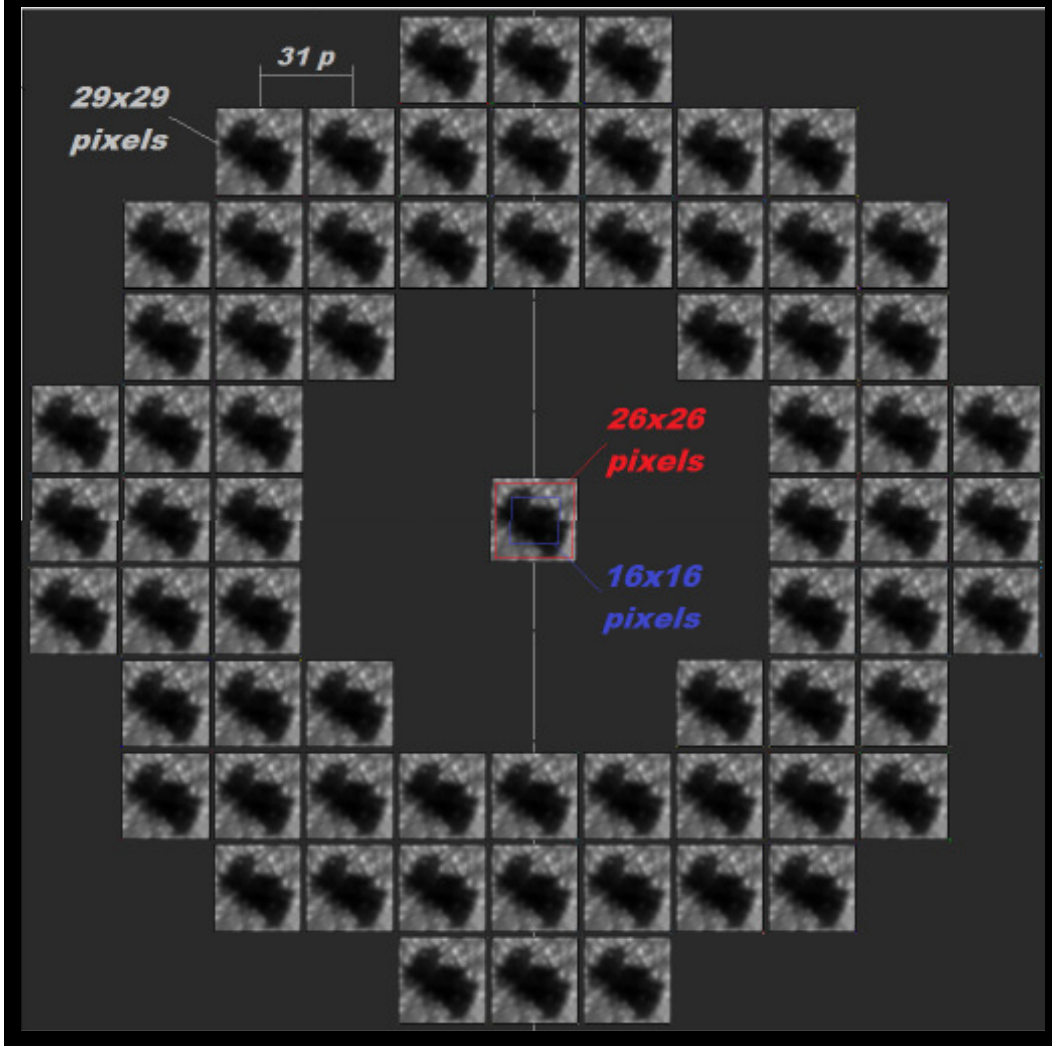
COST Meeting, Toulouse, November 4th ,2014

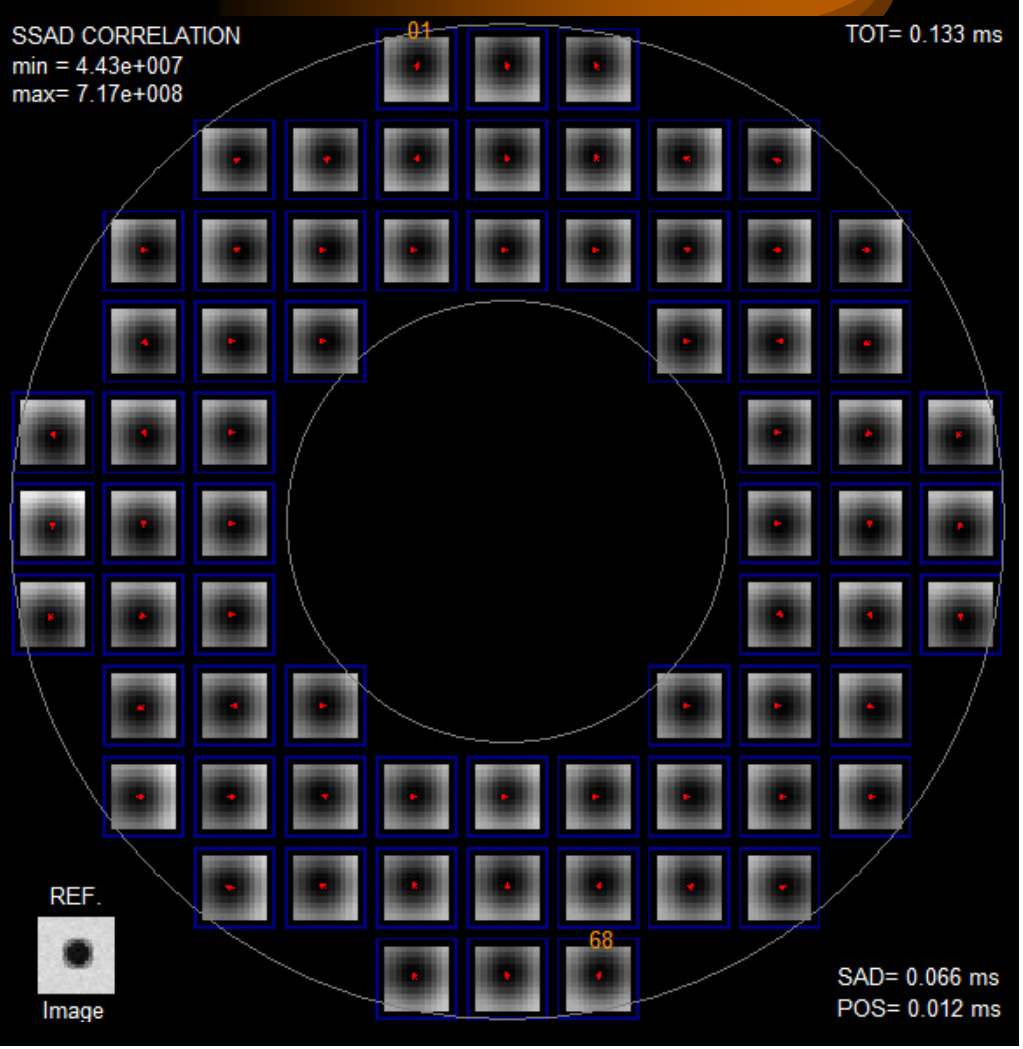
Introduction: The Shack-Hartmann WFS



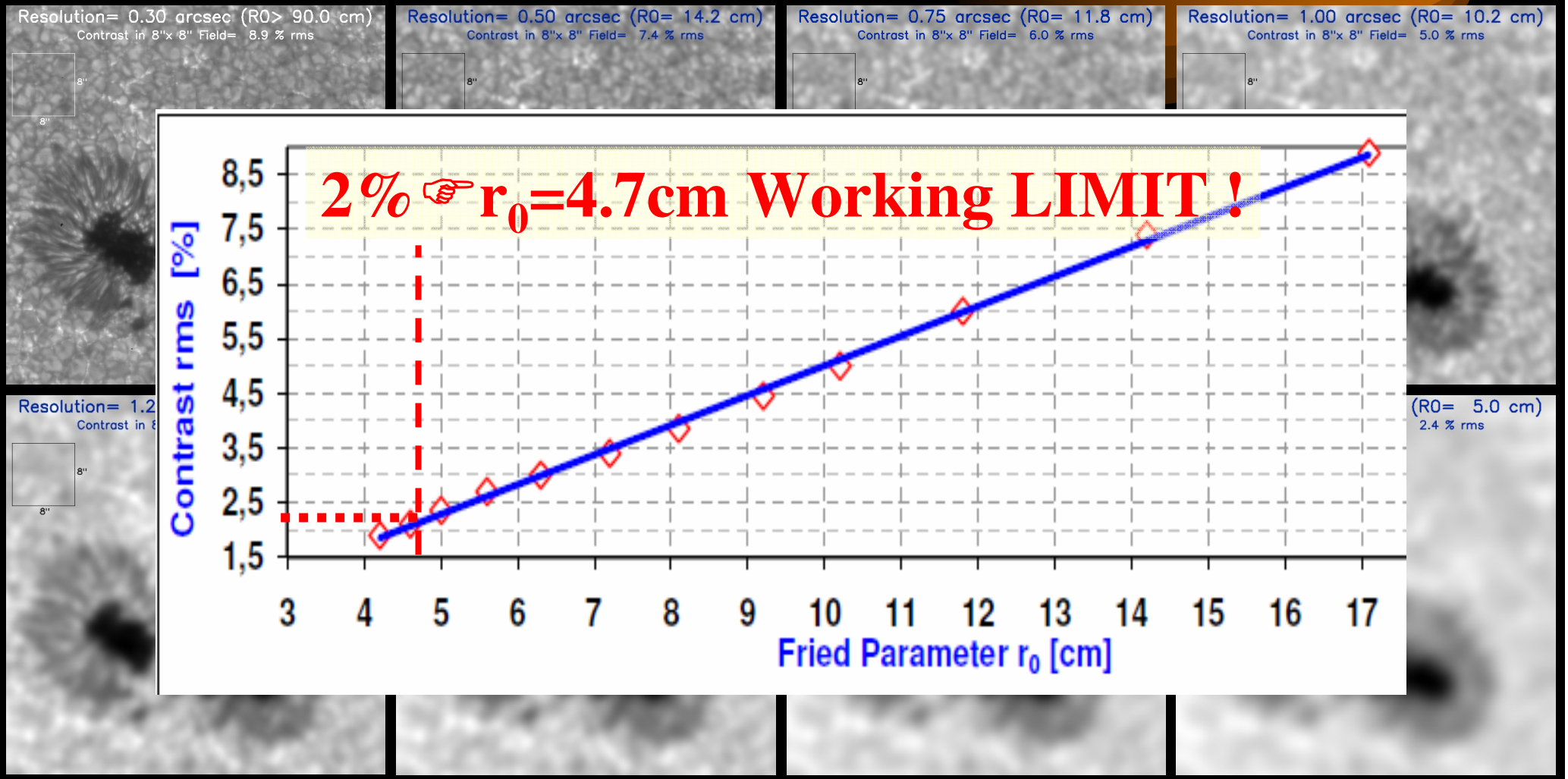
$$x_{slope} = \frac{\lambda}{2\pi S}\int_S \frac{\partial\phi}{\partial x} dS = \frac{dx}{fM} \quad and \quad y_{slope} = \frac{\lambda}{2\pi S}\int_S \frac{\partial\phi}{\partial y} dS = \frac{dy}{fM}$$

The SOLAR Correlating Shack-Hartmann WFS

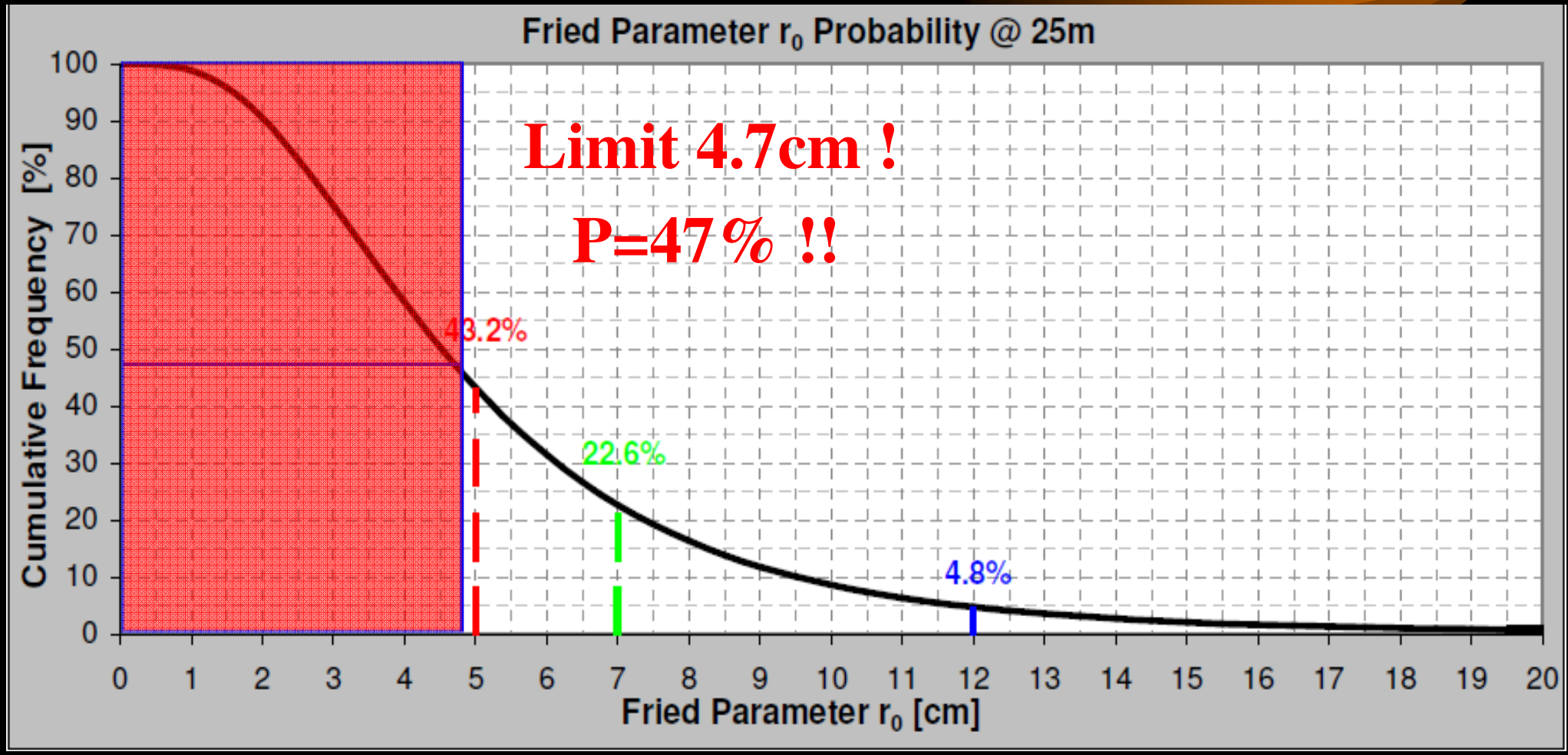




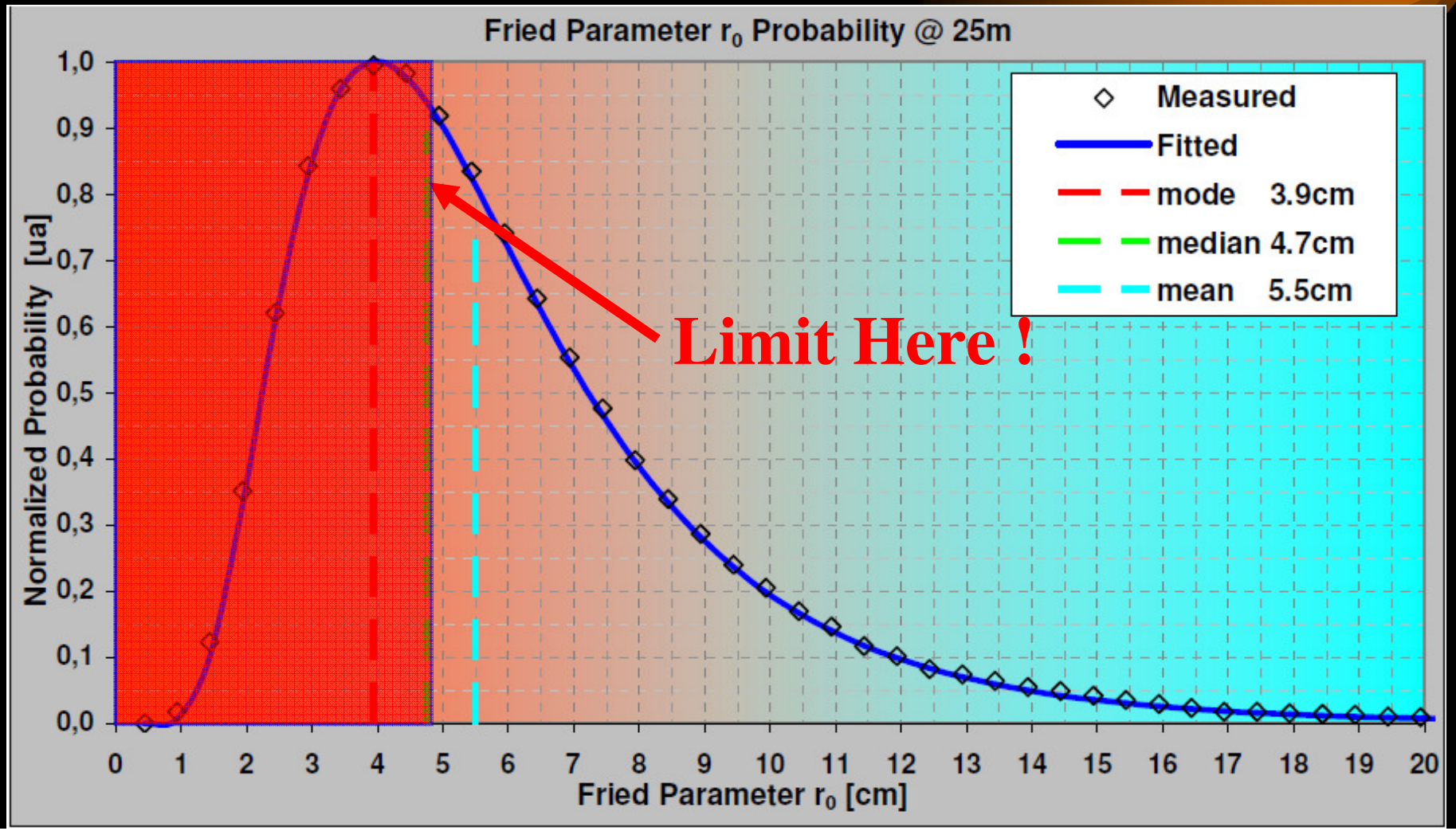
The SOLAR Correlating Shack-Hartmann WFS



Atmospheric Data of the Site: « Seeing » r_0 Statistics (La Palma)



Atmospheric Data of the Site: r_0 Probability Density Function



The SOLAR Shack-Hartmann WFS: DISADVANTAGES

1/ SH-WFS Strongly **DEPENDENT on FEATURES**

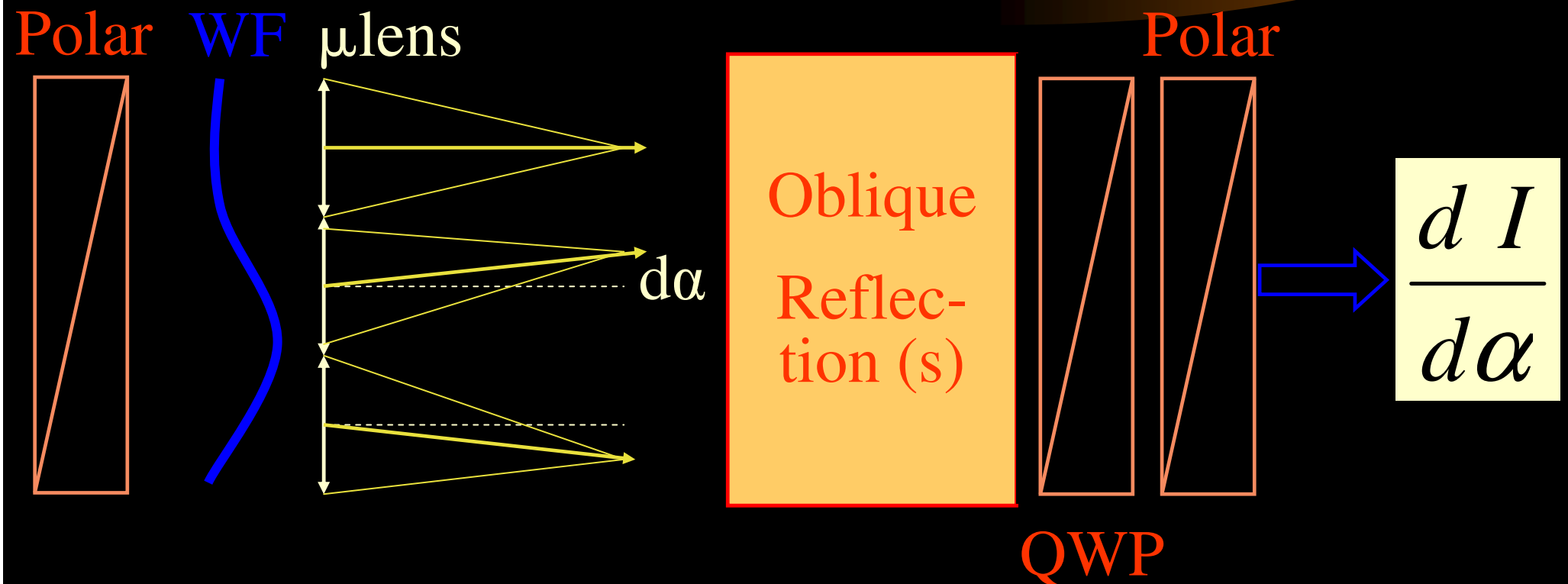
2/ Correlating SH **on FULL DISK** limited at $r_0 > 4.7$cm

3/ AO & Tip-Tilt IMPOSSIBLE out of the DISK on-axis

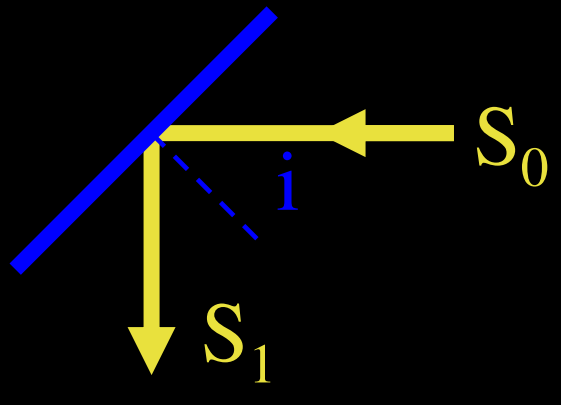
4/ AO & Tip-Tilt POSSIBLE out of the DISK **OFF-axis**

- 4-1 Prominences **IF** Features on Disk close to the Limb
- 4-2 Corona **IF** Features on Disk close to the Limb
- 4-3 **No Coronograph ! Anisoplanatism !! Seeing Limited**

The New POLAR-WFS: PRINCIPLE



The New POLAR-WFS: PRINCIPLE

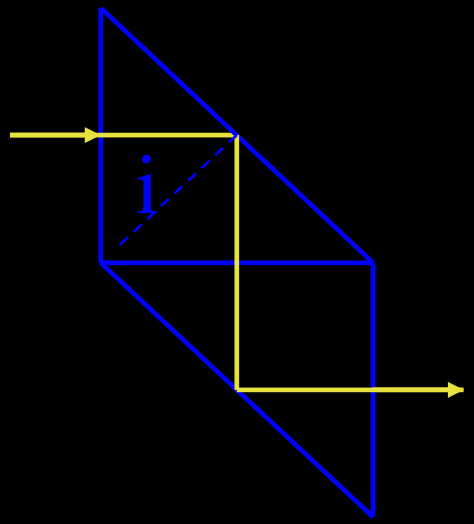


$$\begin{pmatrix} I_s \\ Q_s \\ U_s \\ V_s \end{pmatrix} = M_{\text{Reflection}} \cdot \begin{pmatrix} I_0 \\ Q_0 \\ U_0 \\ V_0 \end{pmatrix}$$

$$M_{\text{Reflection}} = \frac{1}{2}\begin{bmatrix} 1+X^2 & 1-X^2 & 0 & 0 \\ 1-X^2 & 1+X^2 & 0 & 0 \\ 0 & 0 & 2X\cos\Delta & 2X\sin\Delta \\ 0 & 0 & -2X\sin\Delta & 2X\cos\Delta \end{bmatrix} \quad \text{with } X = \frac{|r_P|}{|r_S|} \text{ and } \Delta = \phi_S - \phi_P$$

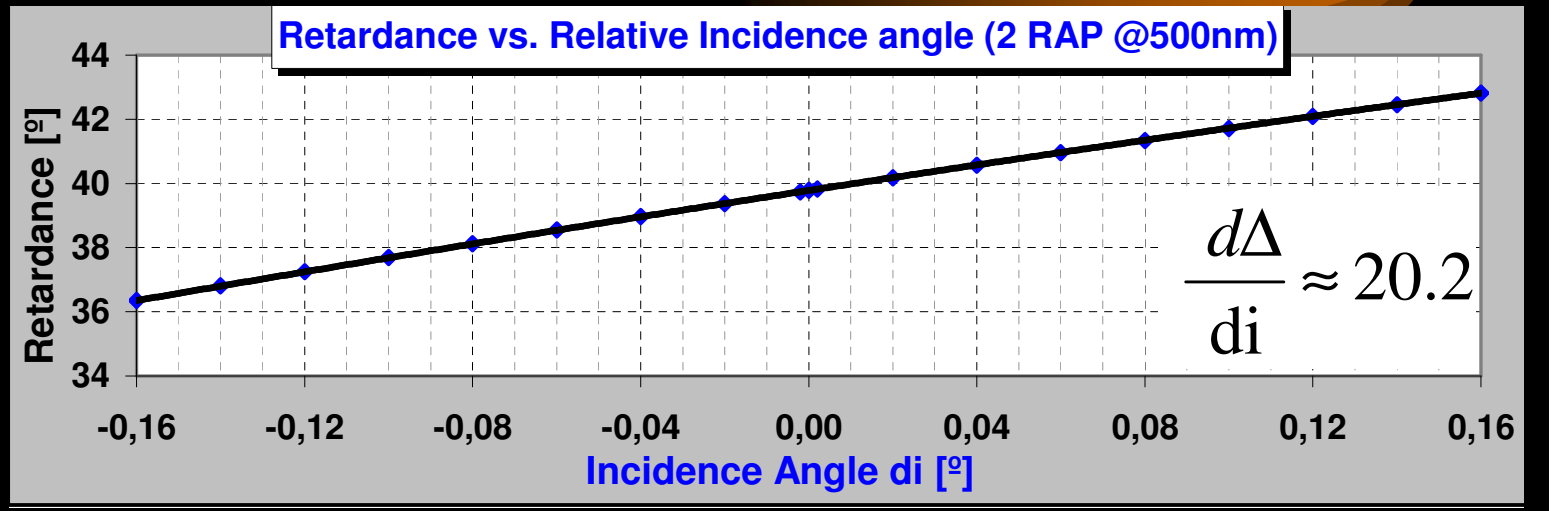
$$\text{Retardance } \Delta = f(\textit{Incidence } i)$$

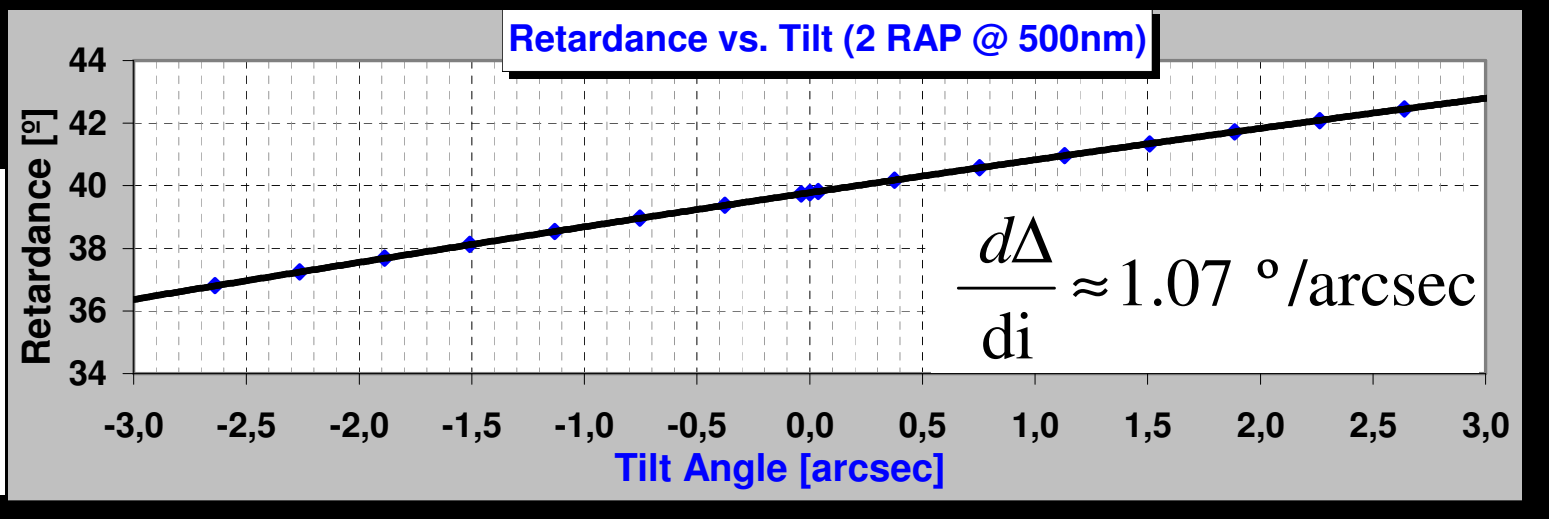
The New POLAR-WFS: Example of 2 RAP



$$i = 45^{\circ} + d\,\mathrm{i}$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos\Delta & \sin\Delta \\ 0 & 0 & -\sin\Delta & \cos\Delta \end{bmatrix}$$





The New POLAR-WFS: An Example of Set-Up

PolarWF μlens

U

dα

$$\begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} 1 \\ 0 \\ \cos\Delta \\ \sin\Delta \end{pmatrix}$$

$$\begin{pmatrix} 1 \\ \sin\Delta \\ \cos\Delta \\ 0 \end{pmatrix}$$

QWP 45°

Polar Θ

$|i\rangle$

$|f\rangle$

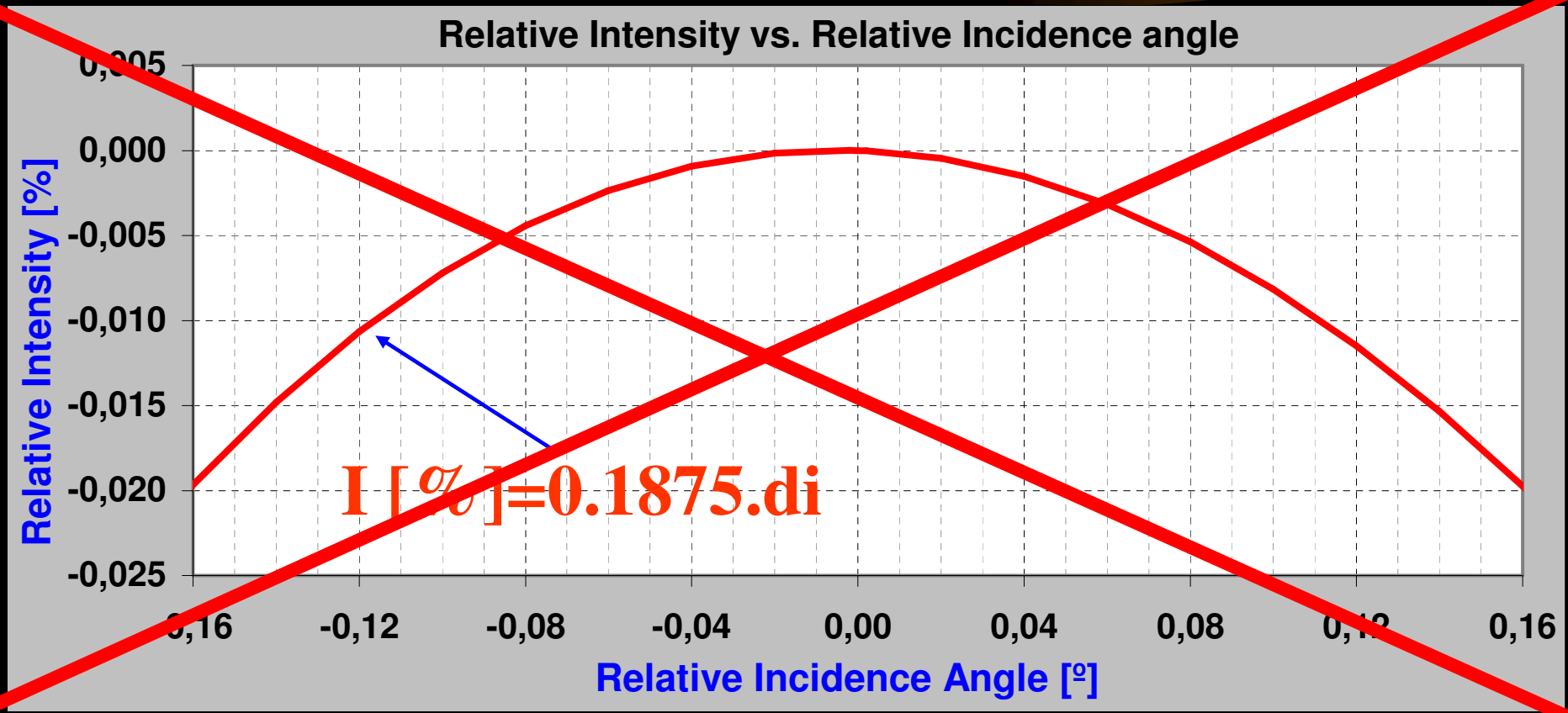
$$\frac{dI}{d\alpha}$$

Pre-selection: $|i\rangle$

Post-selection: $|f\rangle$

The New POLAR-WFS: 1st TRY: « Strong » Measurement

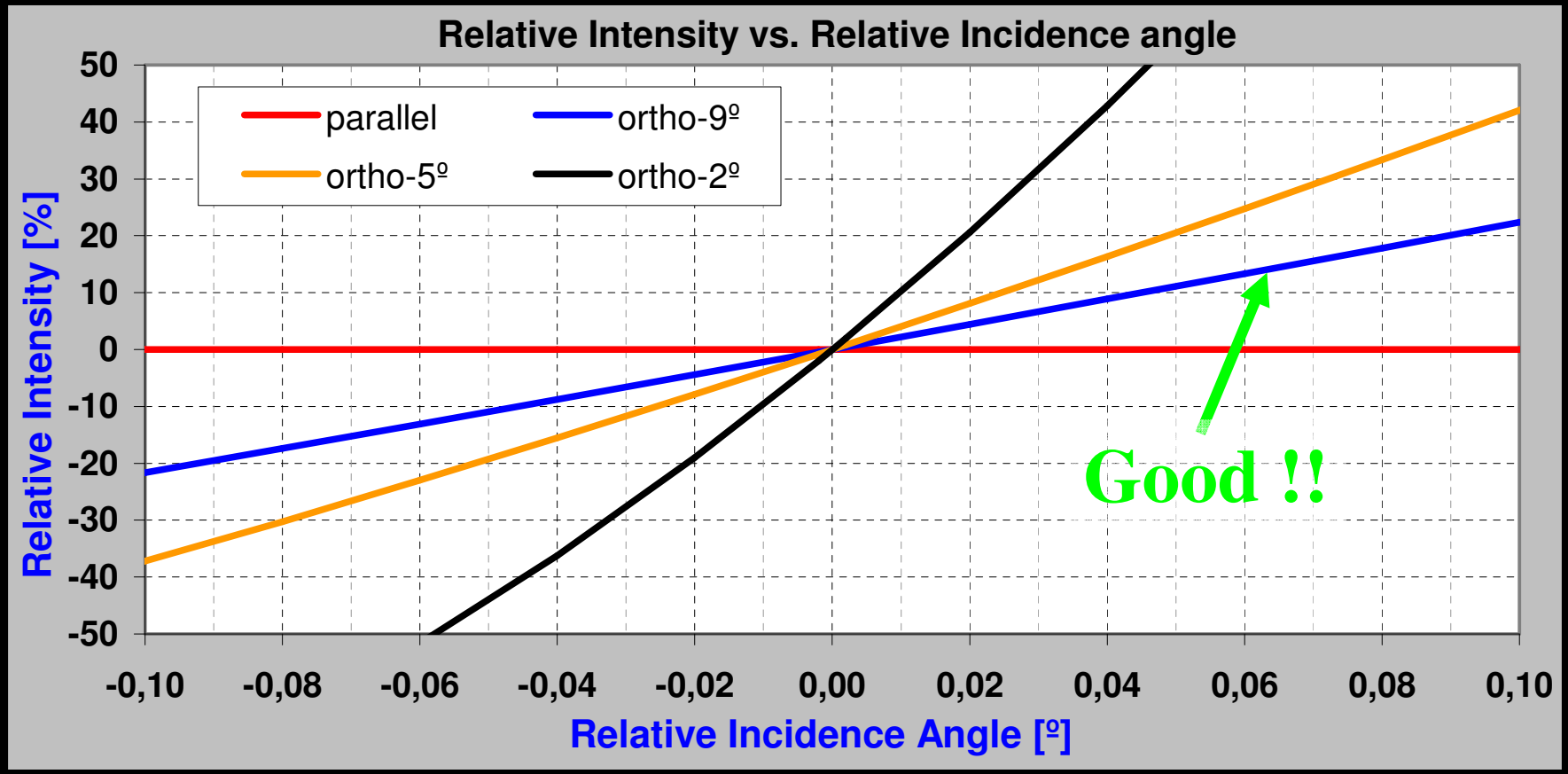
Post-selection = Pre-selection: $|f\rangle = |i\rangle$ $(\theta = 64.8^{\circ})$



The New POLAR-WFS:

2nd TRY: « WEAK » Measurement

Post-selection "⊥" Pre-selection: $|f\rangle \approx \perp |i\rangle$ $(\theta = -25.2^{\circ} \pm d\theta)$



The New POLAR-WFS: Really ?? A « WEAK » Measurement ?

Aharonov, Albert & Vaidman, 1988

« How the Result of a Measurement of a Component of the Spin of a Spin -1/2 Particle Can Turn Out to be 100 »

$f\rangle$

bation Û:

$$P_\varepsilon(i\neq 0^\circ)=\left|\langle f|\hat{U}(\varepsilon)|i\rangle\right|^{-}=\left|\langle f|\exp(-i\varepsilon\hat{A})|i\rangle\right|^{-}=\left|\langle f|(1-\varepsilon\hat{A}+\ldots)|i\rangle\right|^{-}=P+2\varepsilon\langle i|f\rangle\langle f|\hat{A}|i\rangle+\ldots$$

Relative Correction to a small Perturbation Û:

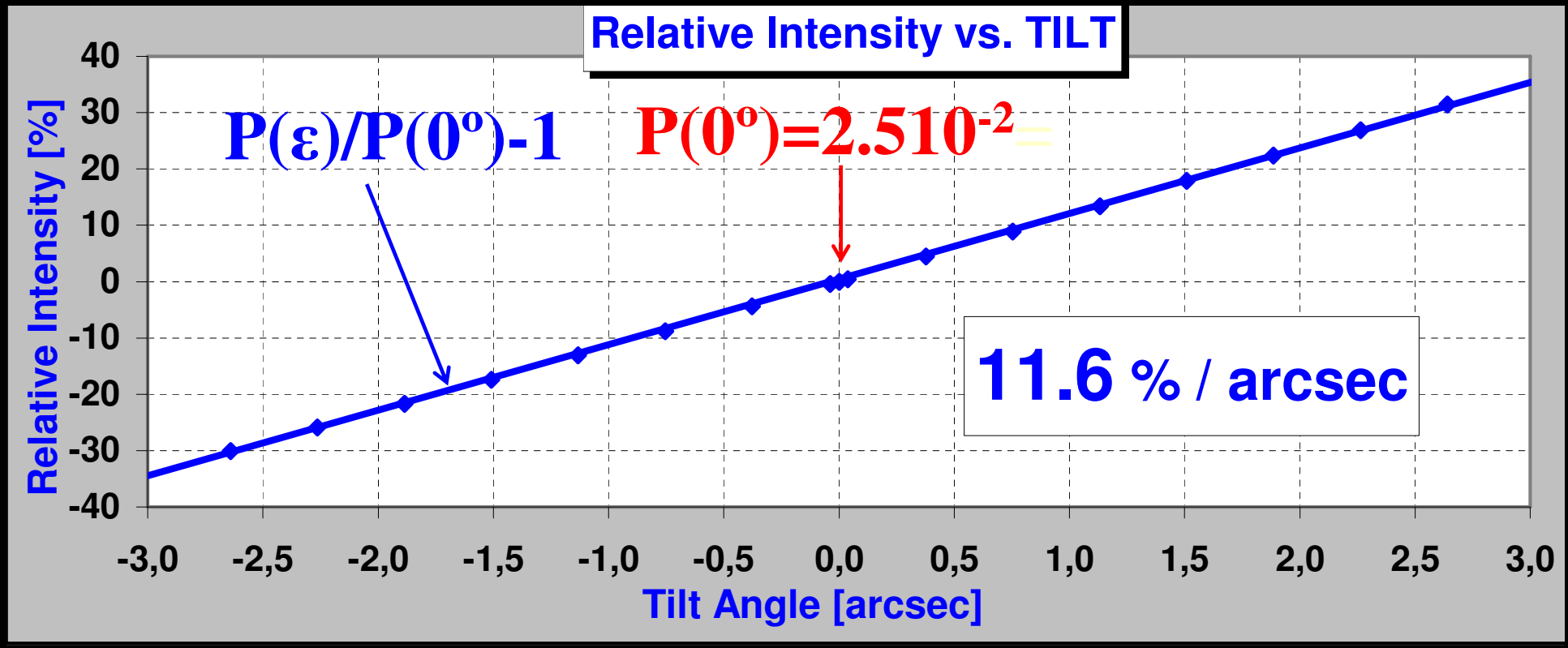
$$\frac{P_\varepsilon(i\neq 0^\circ)}{P(0^\circ)}=1+2\varepsilon\,\mathrm{Im}\frac{\langle f|\hat{A}|i\rangle}{\langle f|i\rangle}+\ldots=1+2\varepsilon\,\mathrm{Im}A_w+\ldots$$

Weak Value

The New POLAR-WFS:

OUR « WEAK » Measurement

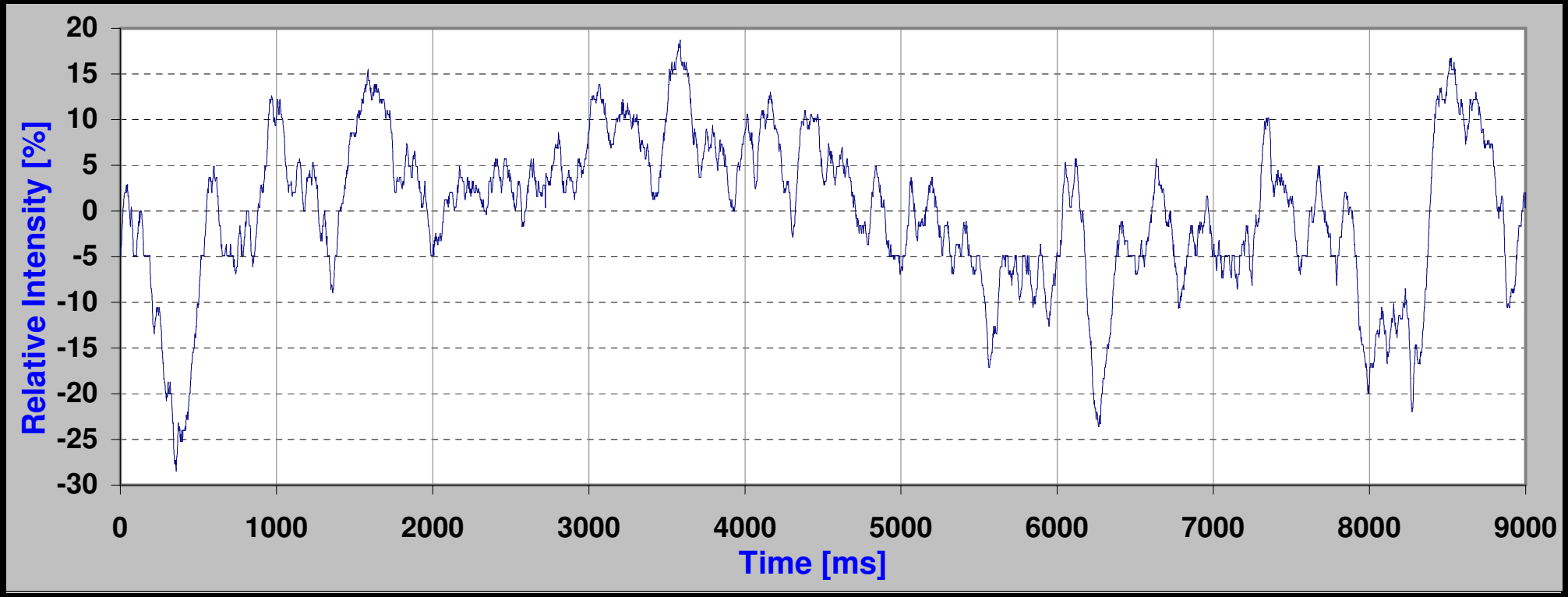
Post-selection "$\perp$" Pre-selection: $|f\rangle \approx \perp |i\rangle$ $(\theta = -25.2^{o} - 9^{o})$



The New POLAR-WFS:

THE « WEAK » Measurement

A REAL CASE … (Tip @ r_0=4.7cm)

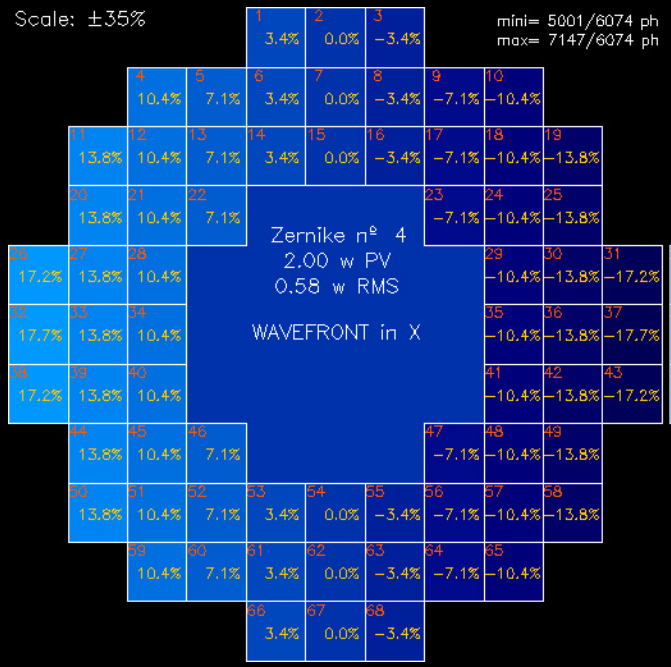


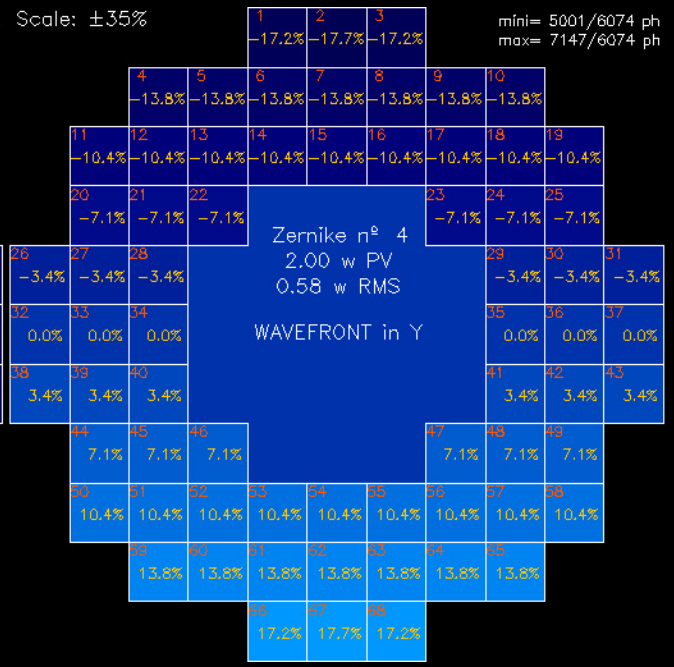
Possible Dynamic: ± 8.6 arcsec (r_0 about 2cm !)

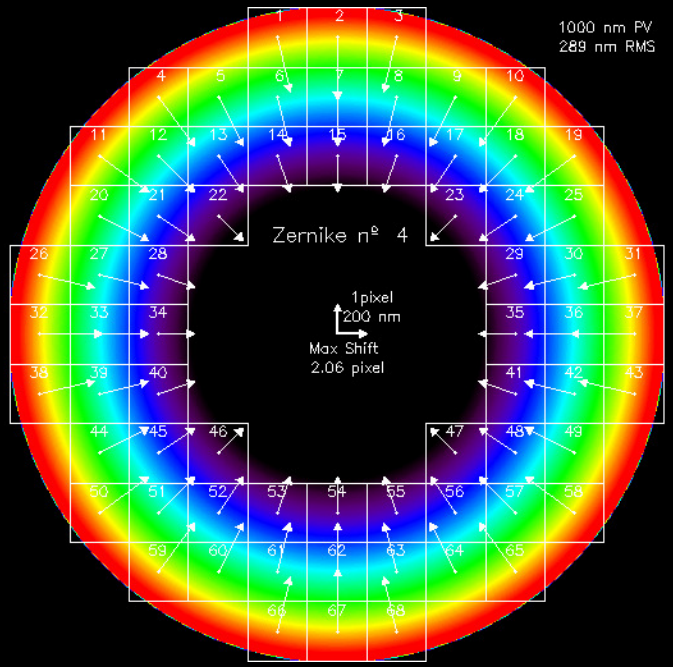
The New POLAR-WFS:

THE « WEAK » Measurement

A REAL CASE: WFS on a 2w Defocus (SR=0.8%)



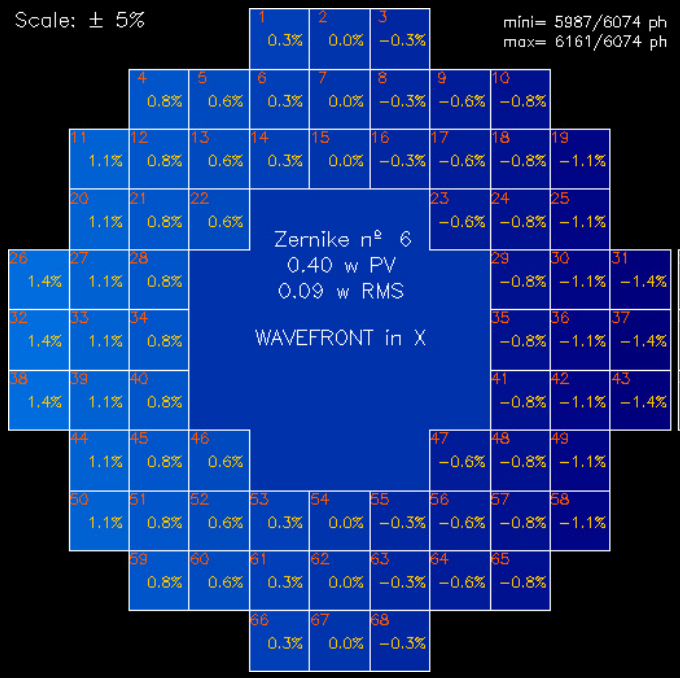


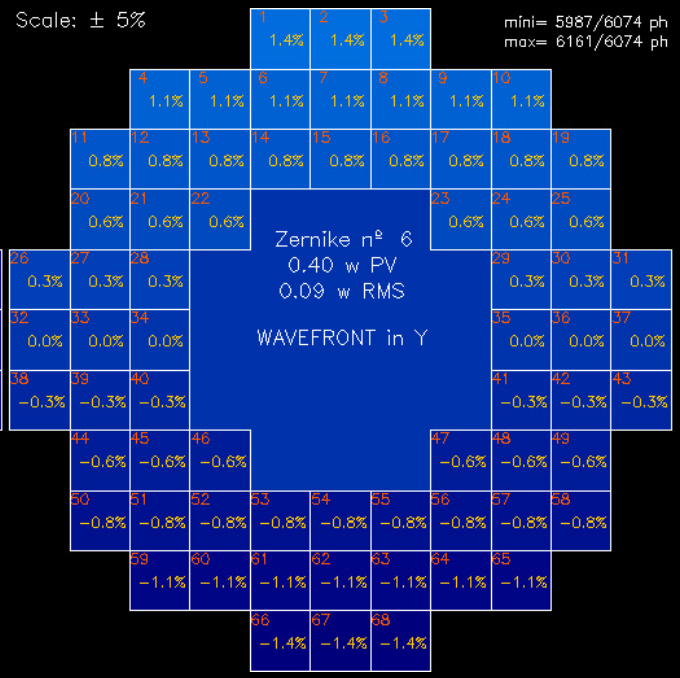


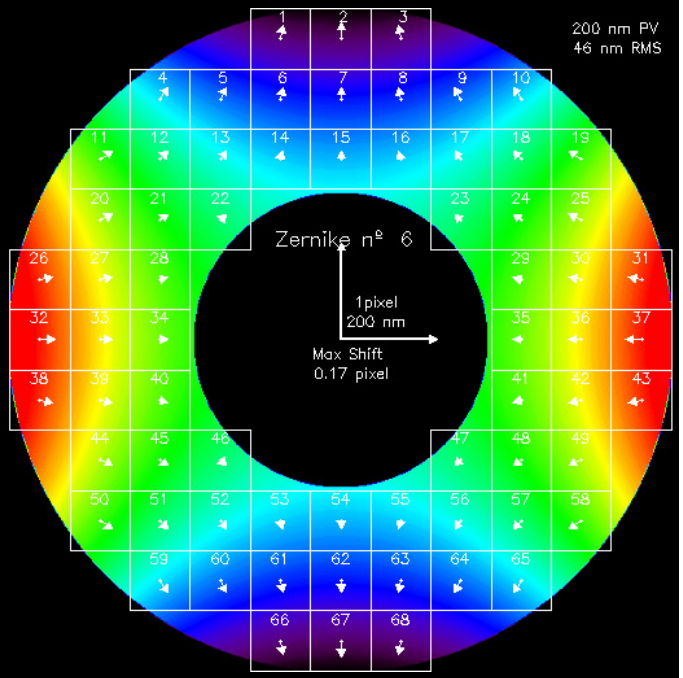
The New POLAR-WFS:

THE « **WEAK** » *Measurement*

A REAL CASE : WFS on a 0.4w Astigmatism (SR=72%)







The New POLAR-WFS: ADVANTAGES

1/ WFS **NOT DEPENDENT on FEATURES**

2/ WFS **on FULL DISK** **"unlimited" (r_0 > 2cm - 90%)**

3/ AO & Tip-Tilt **POSSIBLE** out of the DISK OFF-axis
(no limitation on target choice on the disk)

4/ AO & Tip-Tilt POSSIBLE out of the DISK **ON-axis**

→ 4-1 Prominences: **Tip-Tilt & AO (Limited)**

4-2 Corona: **Tip-Tilt ONLY**

The New POLAR-WFS: SUMMARY

1/ New WFS where Wavefront Slope $\propto$ **INTENSITY**

2/ SENSING through a **POLARIMETRIC Measure**

3/ SENSING through a Quantum **WEAK** Measurement

4/ NOT DEPENDENT on TARGETS
(No image Needed) !

5/ WFS **IMPROVING Solar AO & TT**
(On ALL Kind of Targets: Disk, Protu, Corona, …)

THANKS !

“A bove majore discit arare minor”