Improving Interferometric Null Depth Measurement with statistics : theory and first results with the Palomar Fiber Nuller

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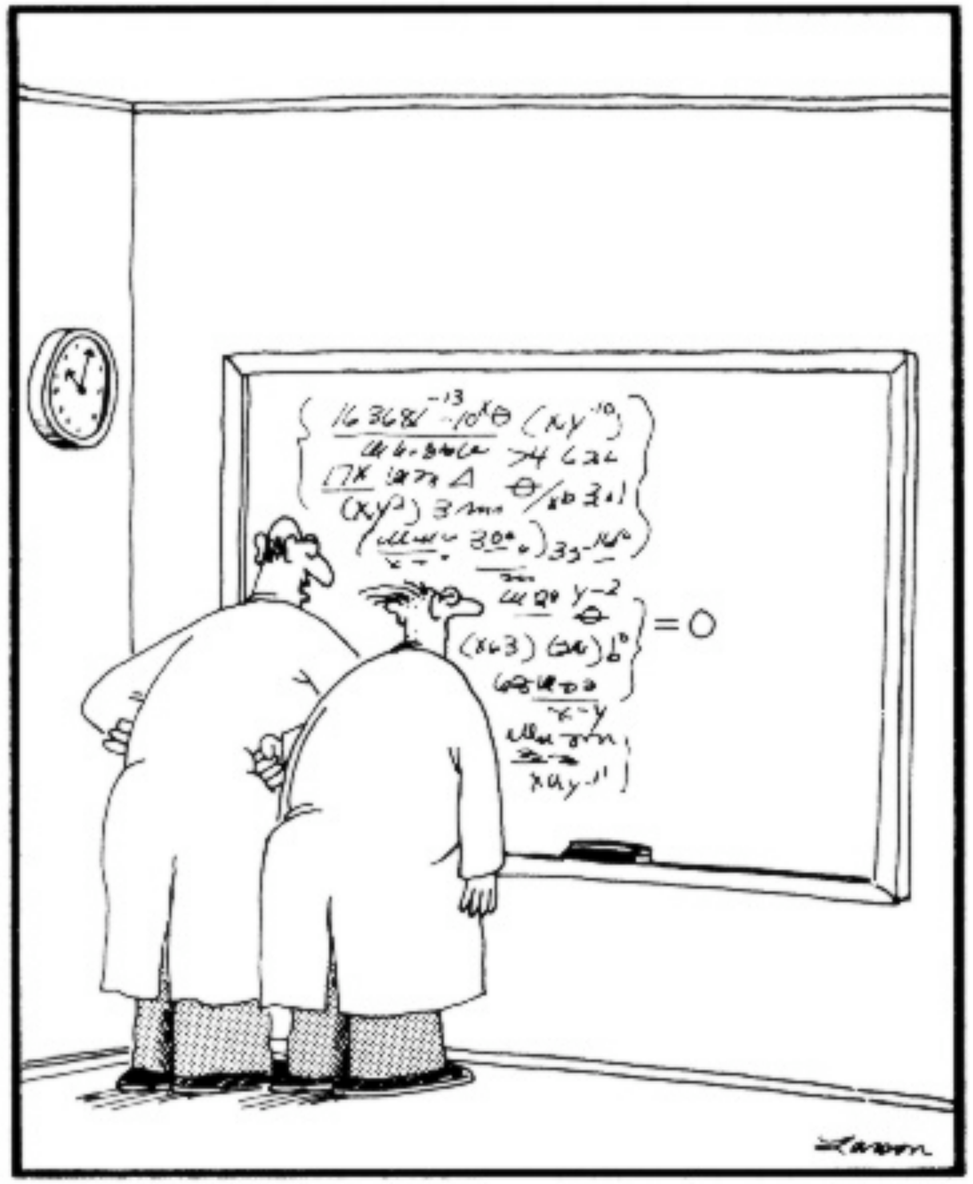
If you sometimes wonder:

Why do we spend so much time on calib. ?

or

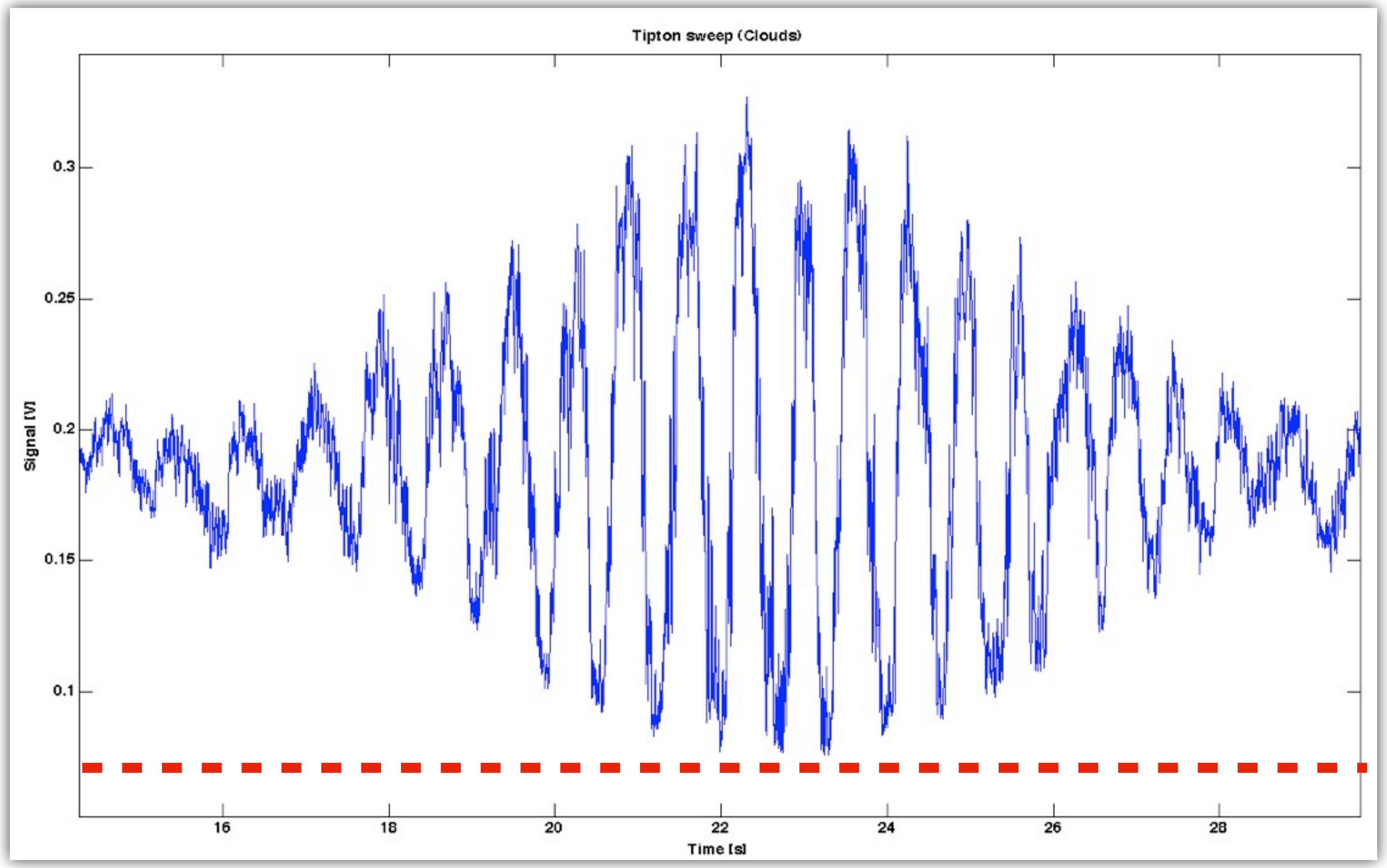
Why is this data reduction so tricky ?

Please, have a seat !



"No doubt about it, Ellington—we've mathematically expressed the purpose of the universe. Gad, how I love the thrill of scientific discovery!"

What is the Null Depth ?



$$N = \frac{I_{min} - I_{Bkg}}{I_{max} - I_{Bkg}}$$

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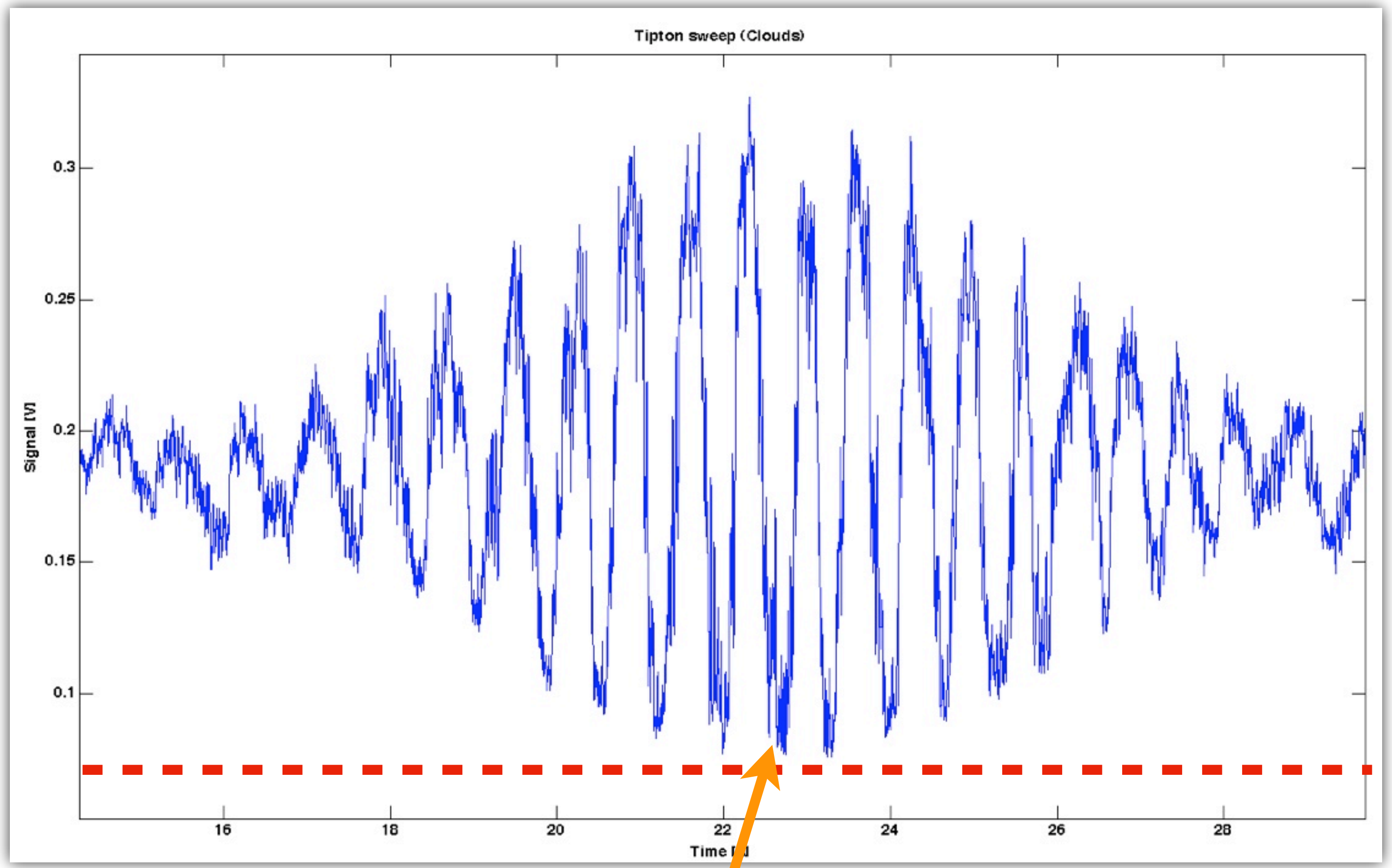

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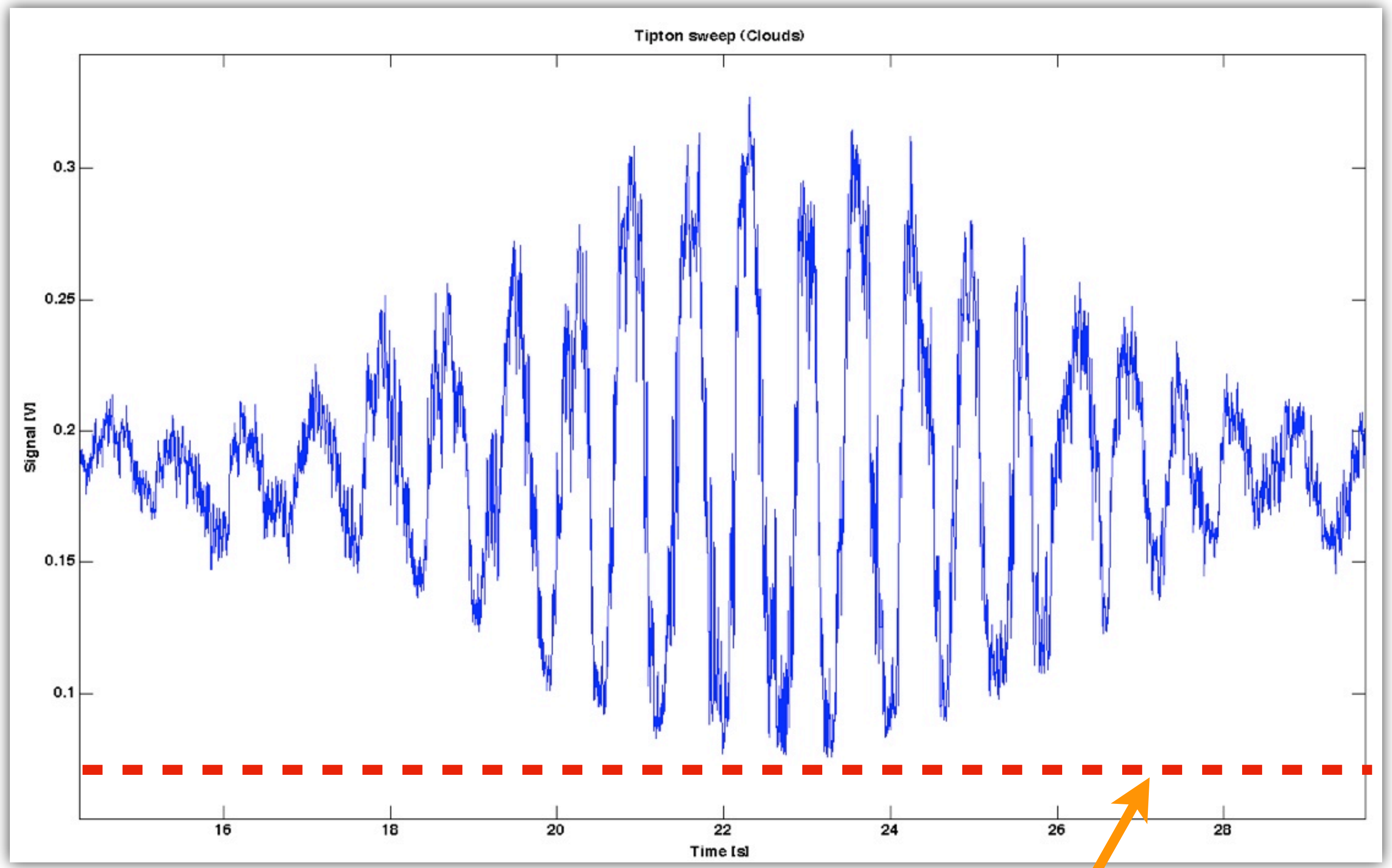

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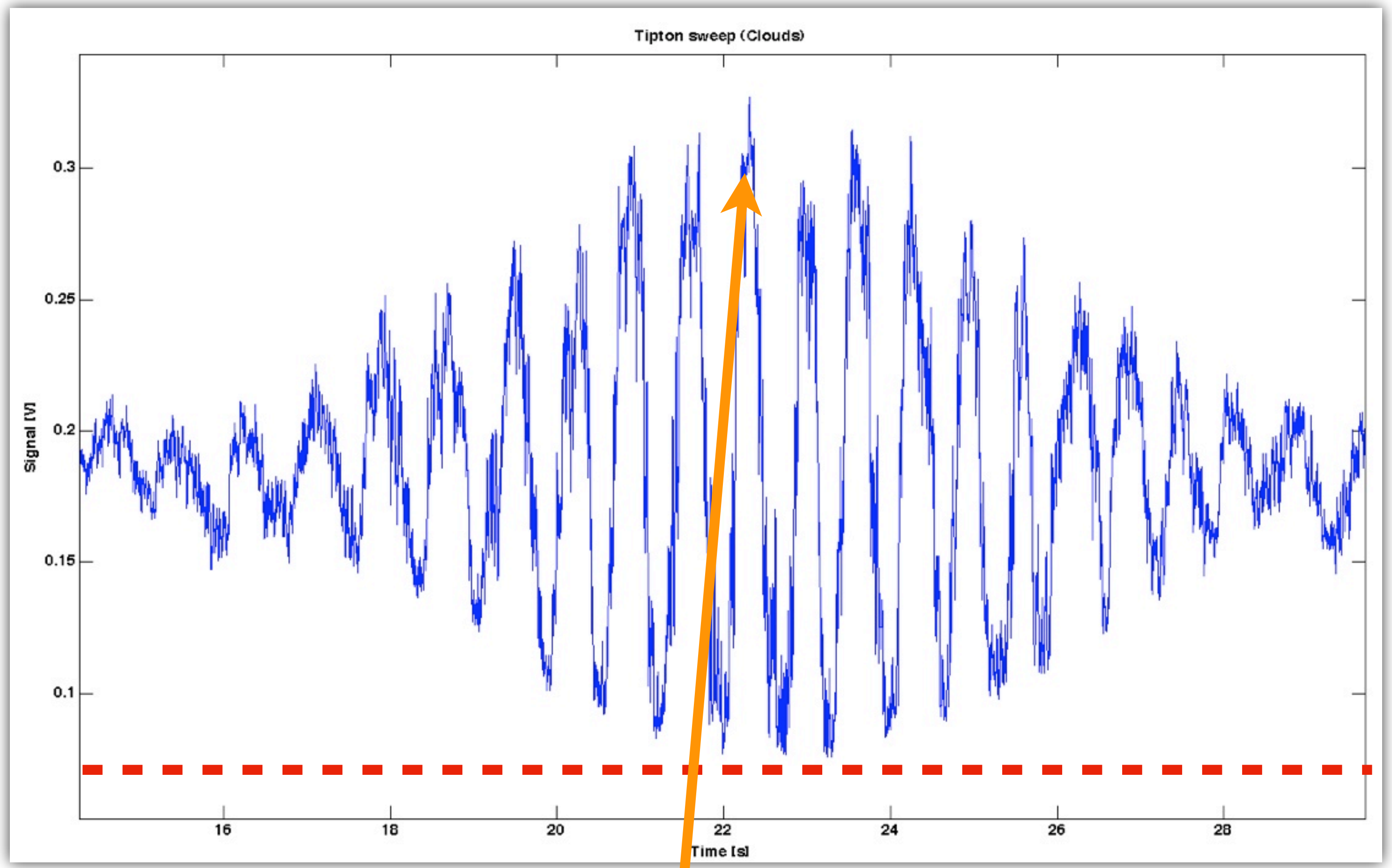

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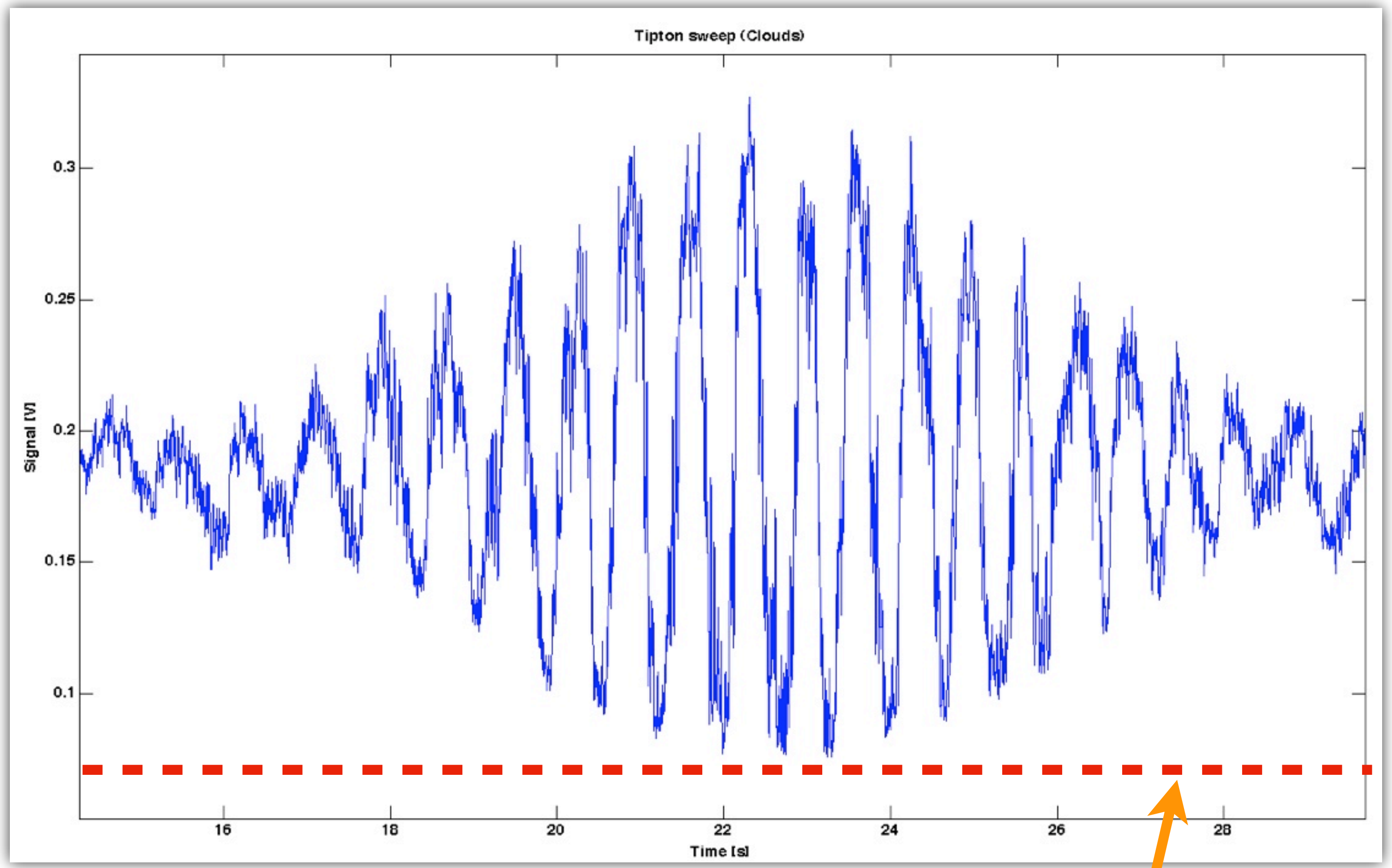

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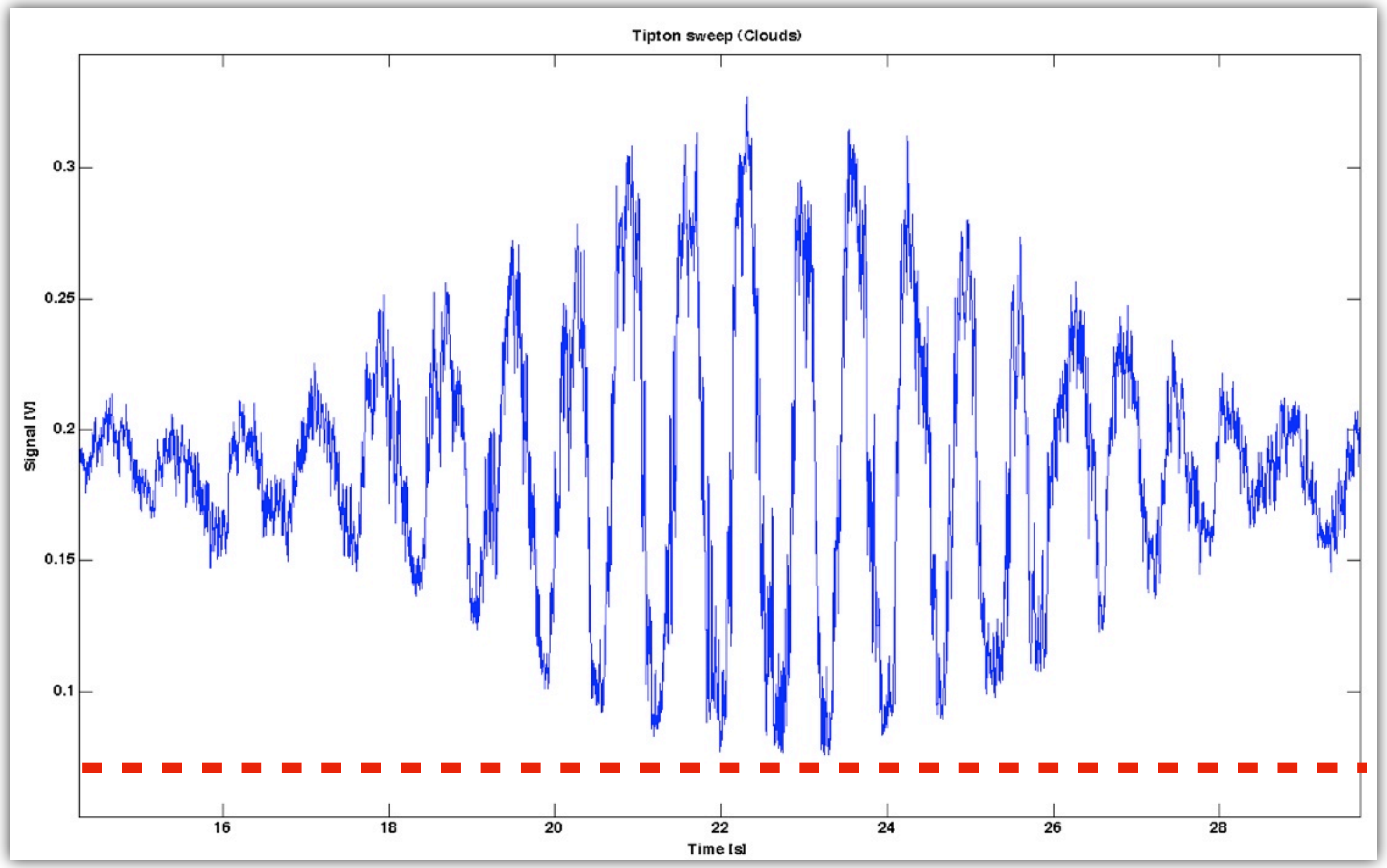
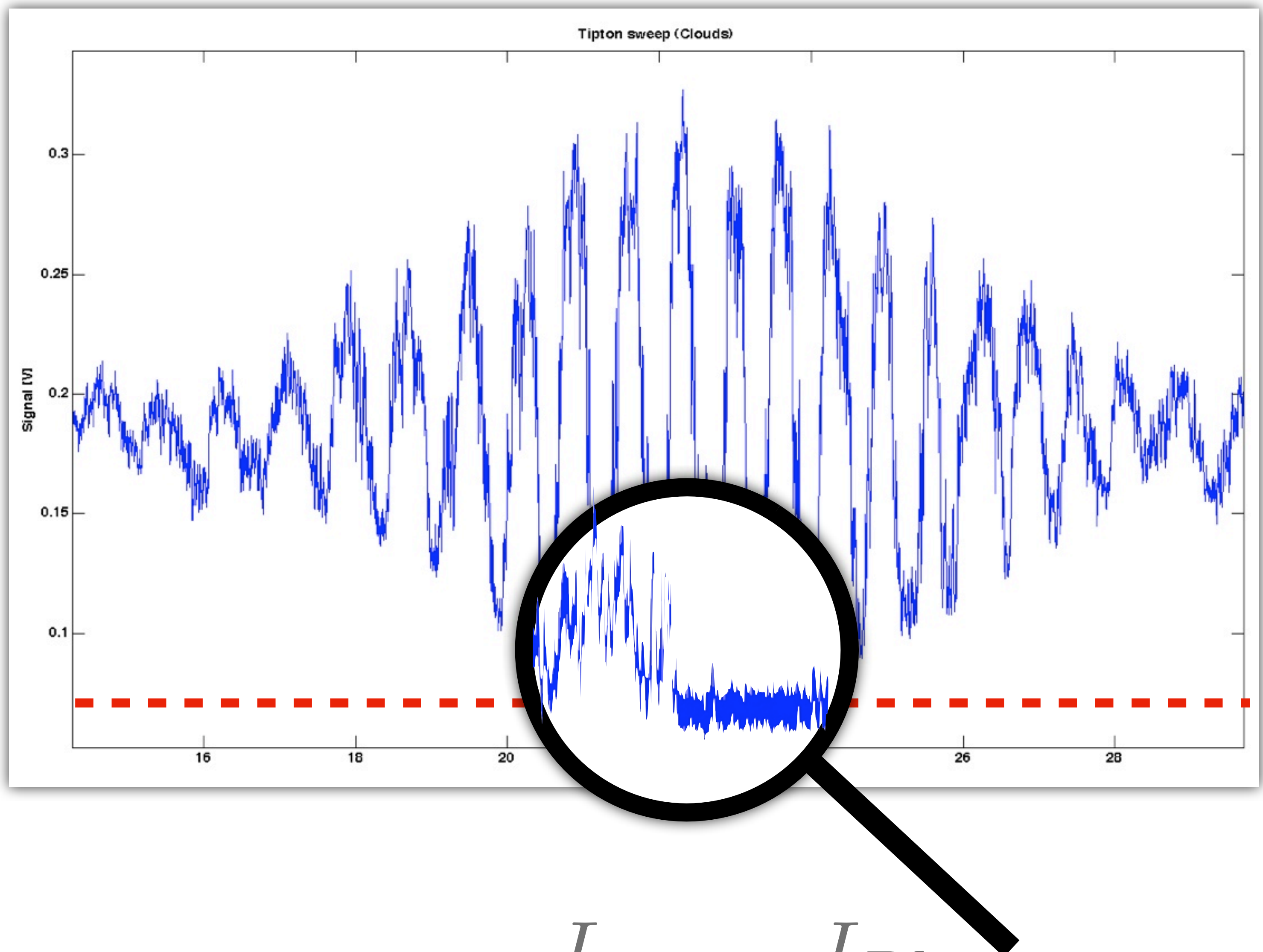


$$N = \frac{I_{min} - I_{Bkg}}{I_{max} - I_{Bkg}}$$

Problem : How to measure Null Depths ?



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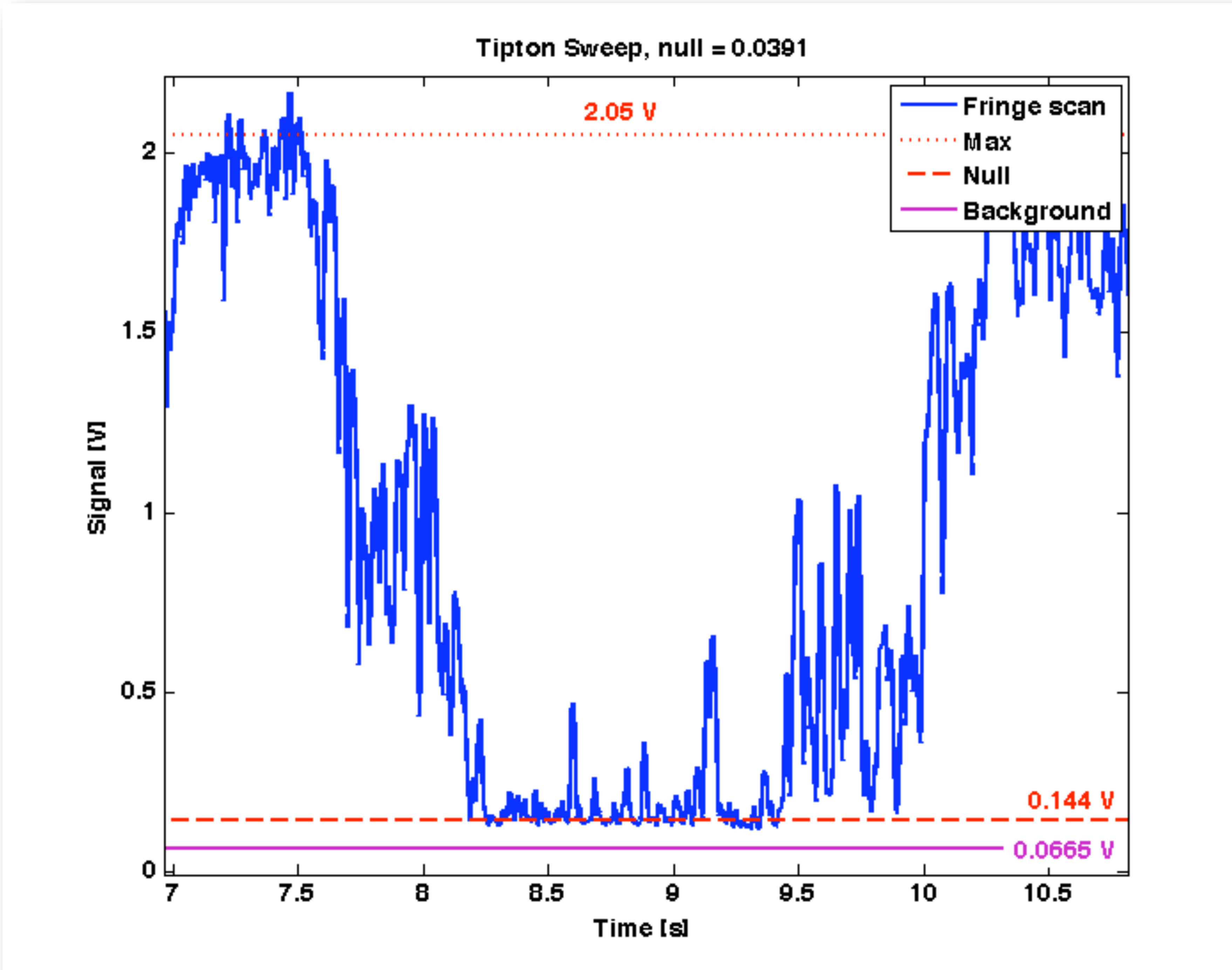

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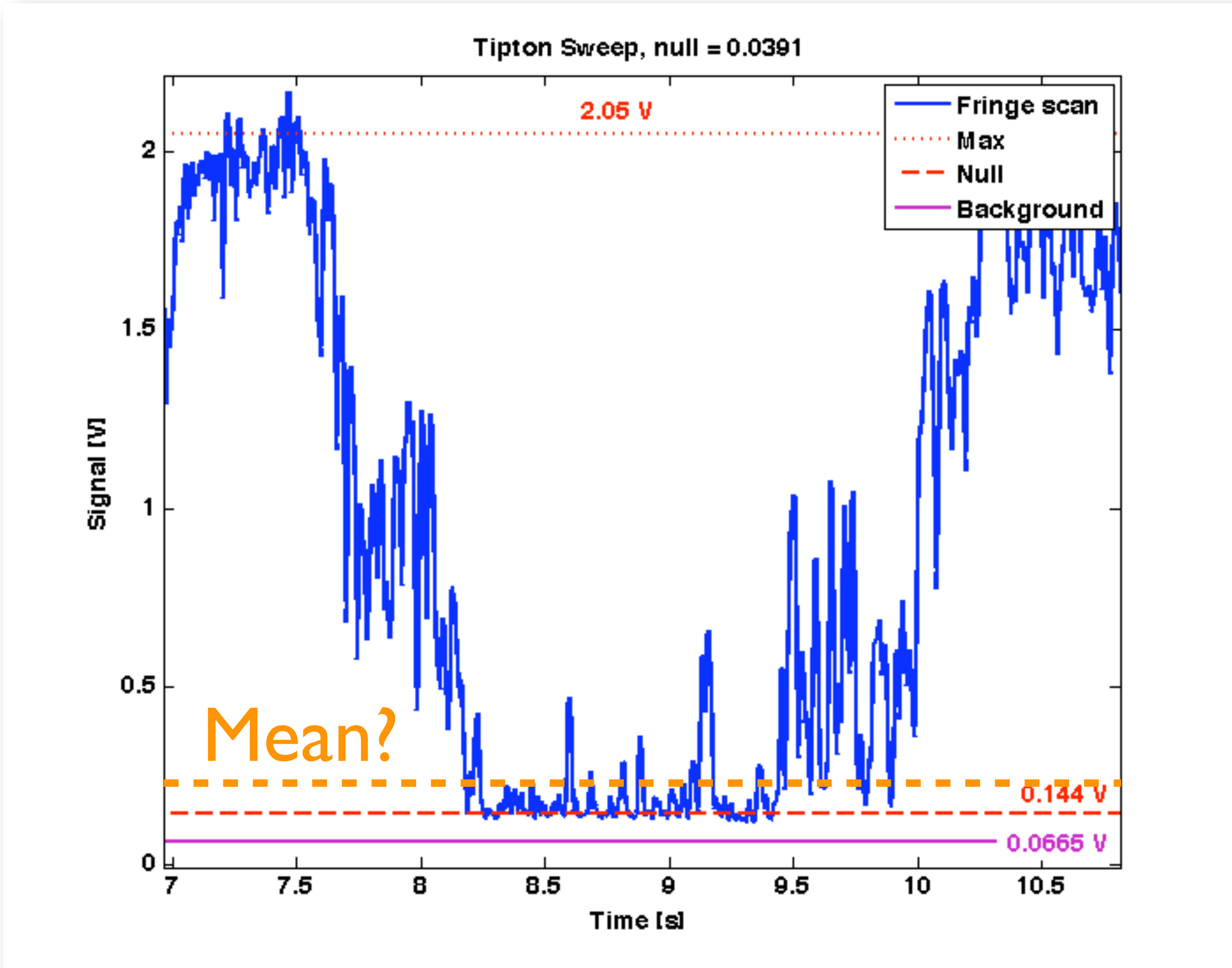

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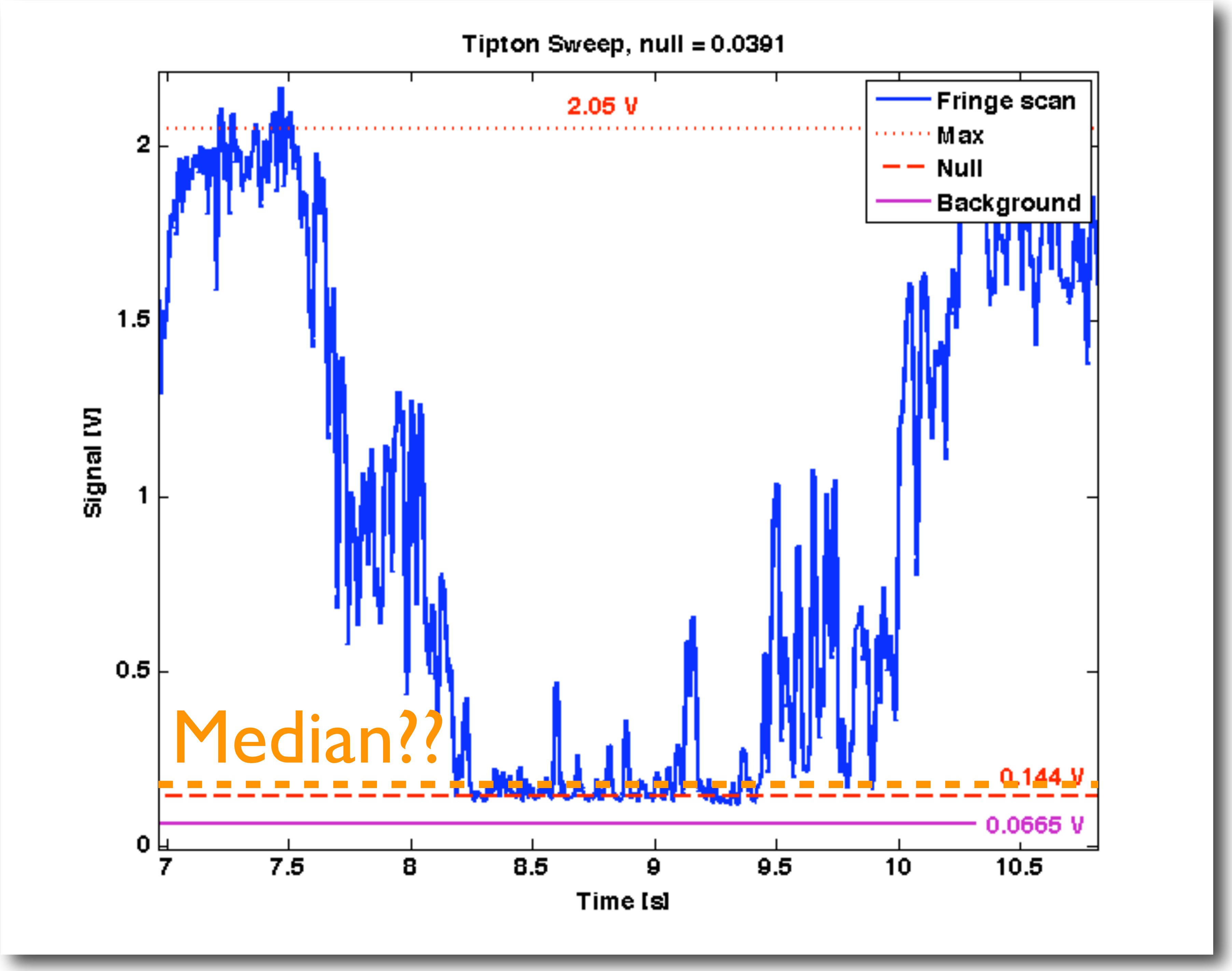

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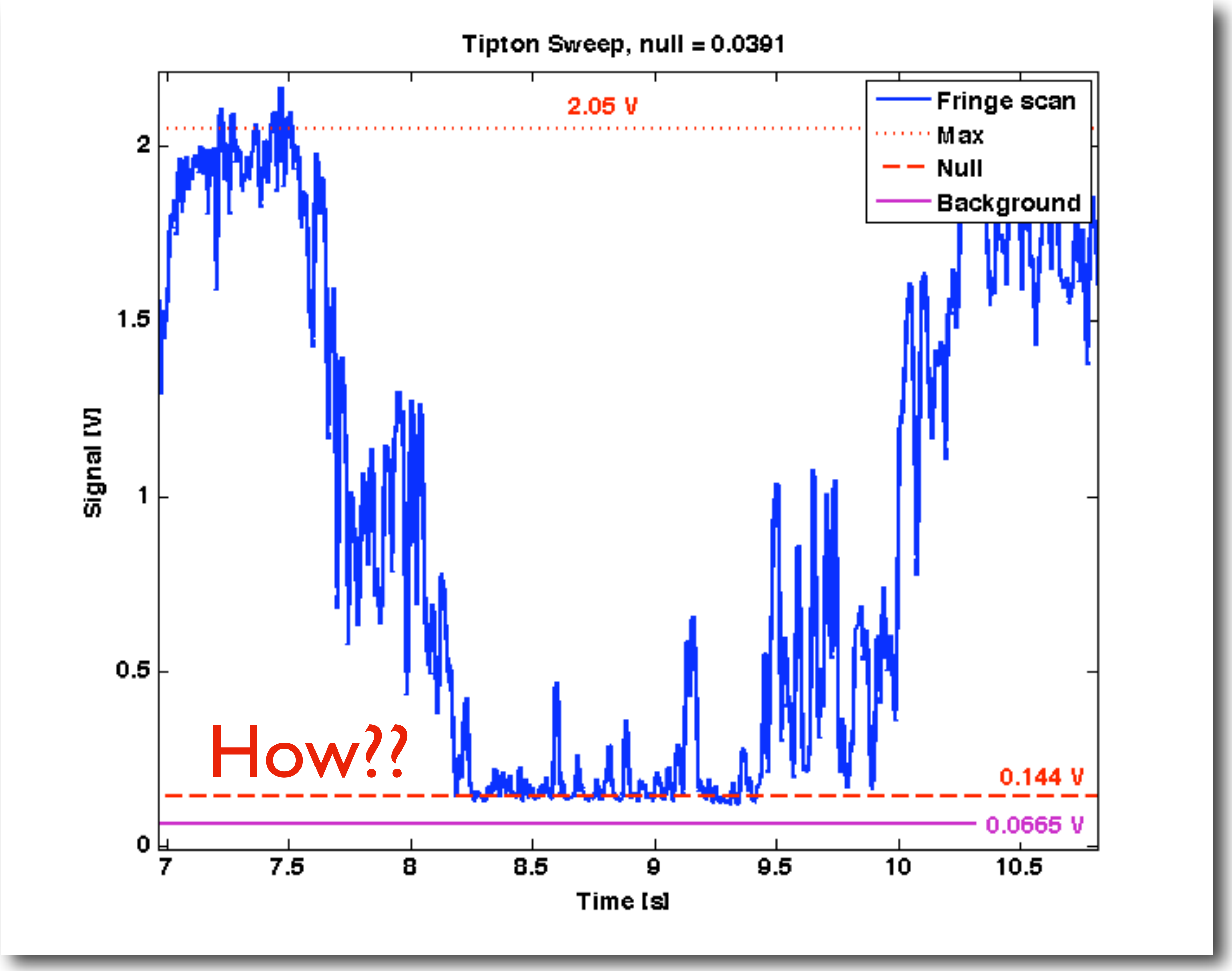
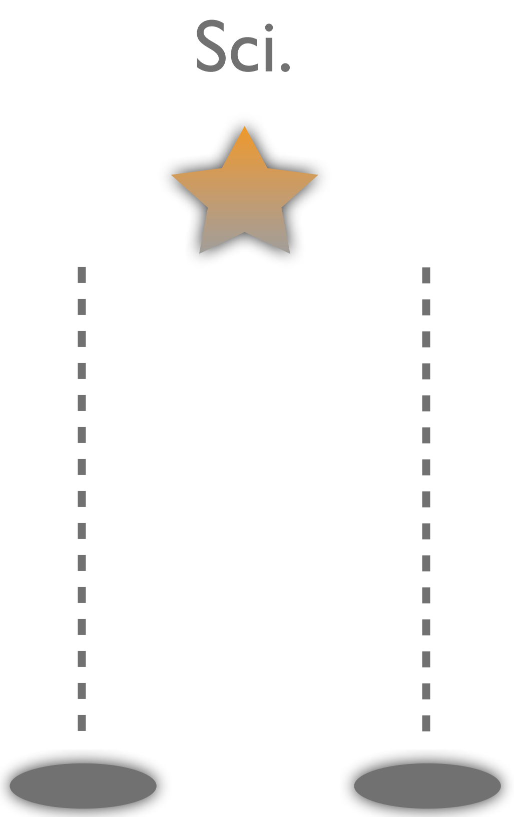


Classical method

- Non-calibrated ND

$$\langle N(t_1)\rangle = N_a + \langle N_{Ins}(t_1)\rangle \longrightarrow \text{Science target}$$



Classical method

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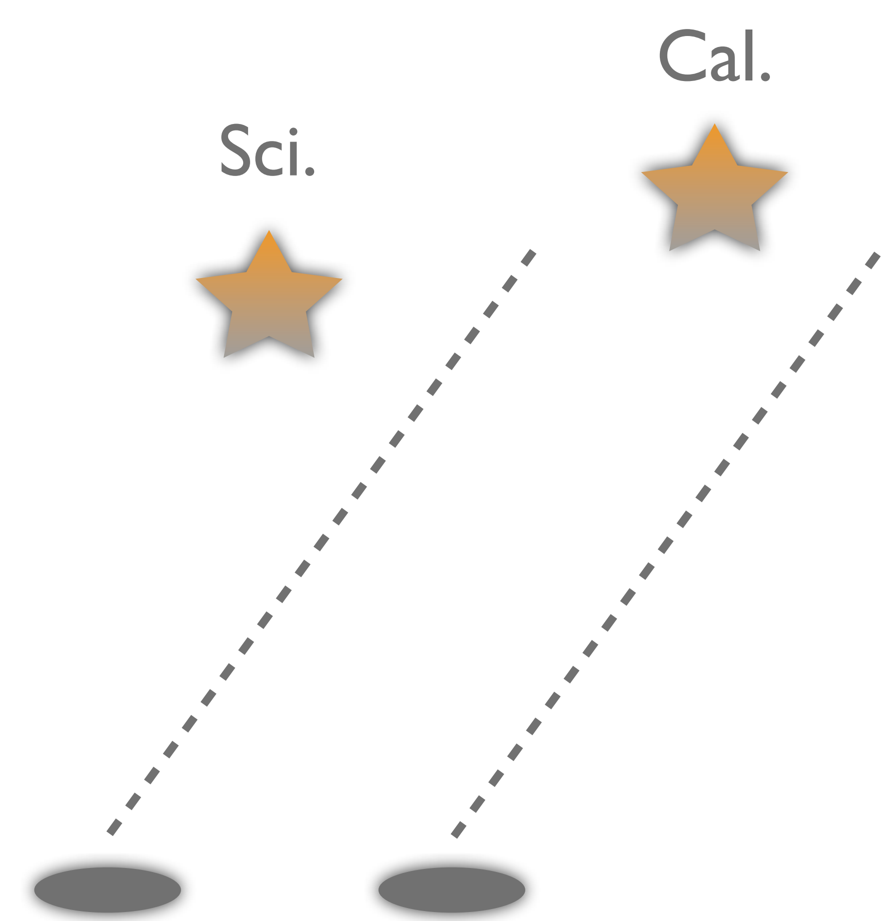
$$\langle N(t_1)\rangle = N_a + \langle N_{Ins}(t_1)\rangle \longrightarrow \text{Science target}$$

$$\langle N_{cal}(t_2)\rangle = N_{a,\,cal} + \langle N_{Ins,\,cal}(t_2)\rangle \longrightarrow \text{Calibrator star}$$



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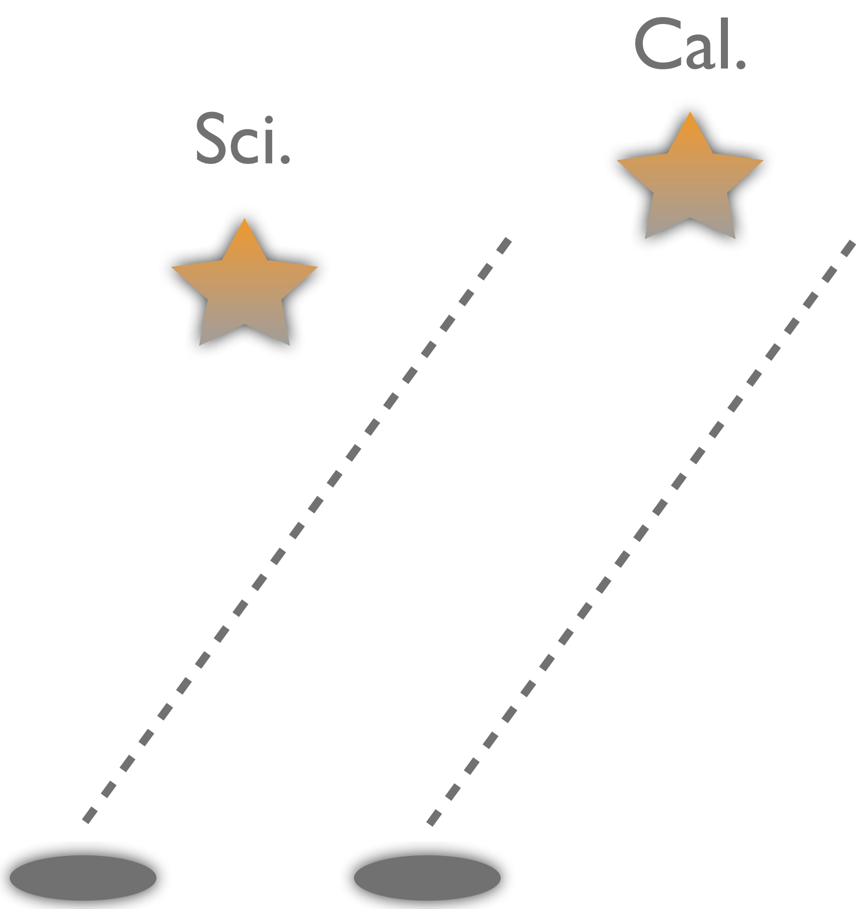
- Calibrated ND

$$N_a = N_{a,\,cal} + \langle N(t_1)\rangle - \langle N_{cal}(t_2)\rangle$$



Classical method

Advantages

+ Easy to process
+ Used for centuries

Drawbacks

- Duty cycle
- Require lots of observations
- Limited by fluctuations
- $N_{a,cal}$ dependent

Statistical Method

$$N(t) \approx I_r(t)(\delta I(t)^2+\Delta\phi(t)^2+\alpha_{rot}{}^2+N_a)+N_{Bkg}(t)$$

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Astrophysical leakage

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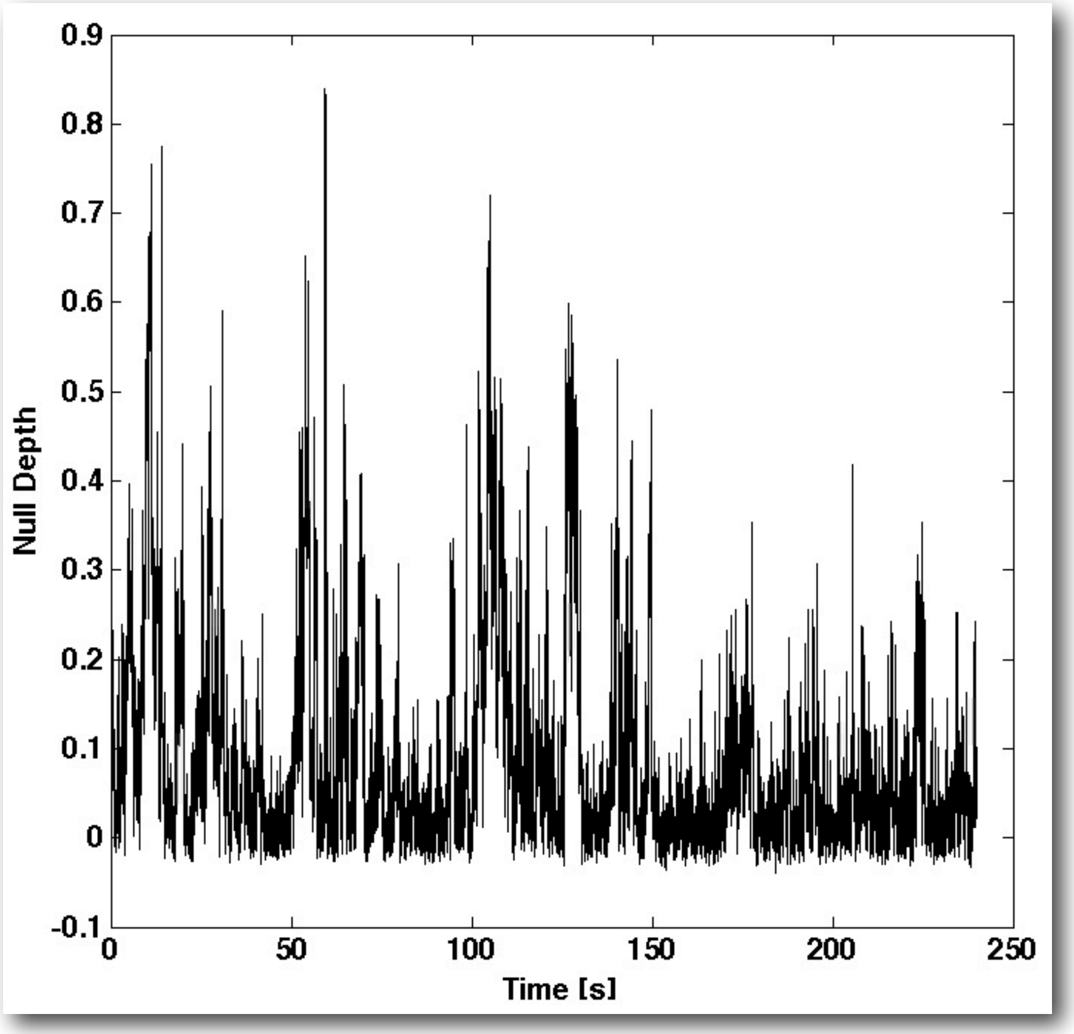

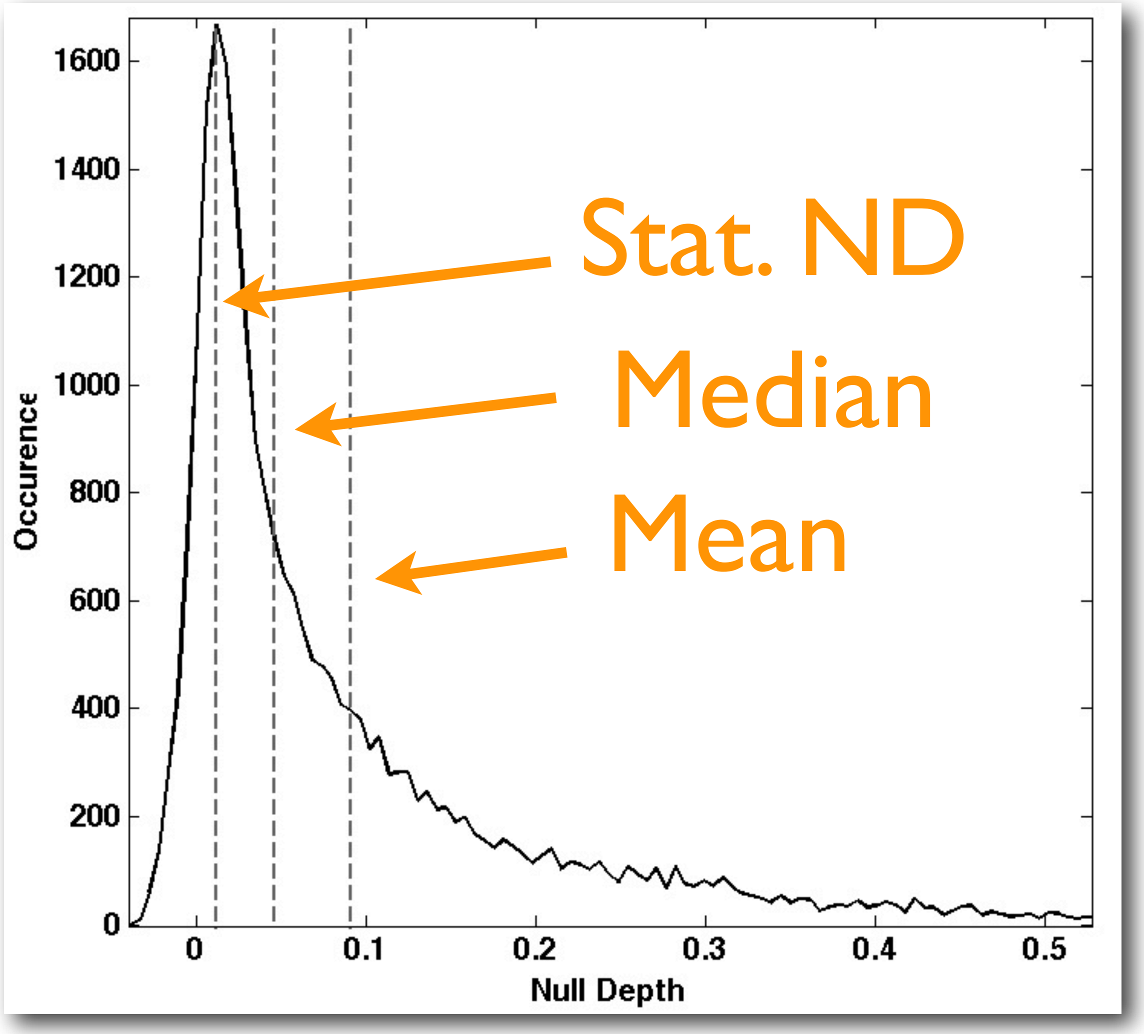

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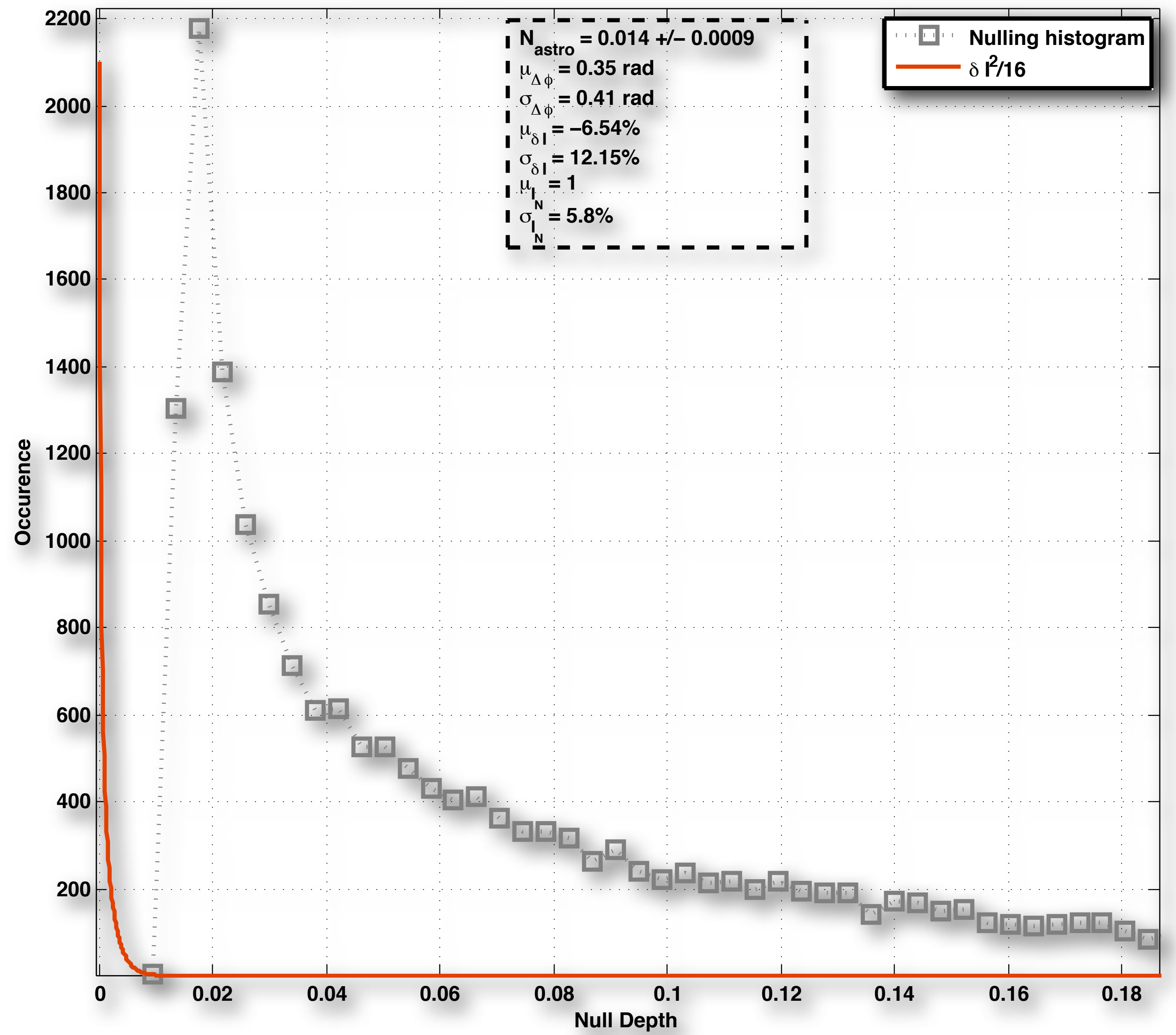

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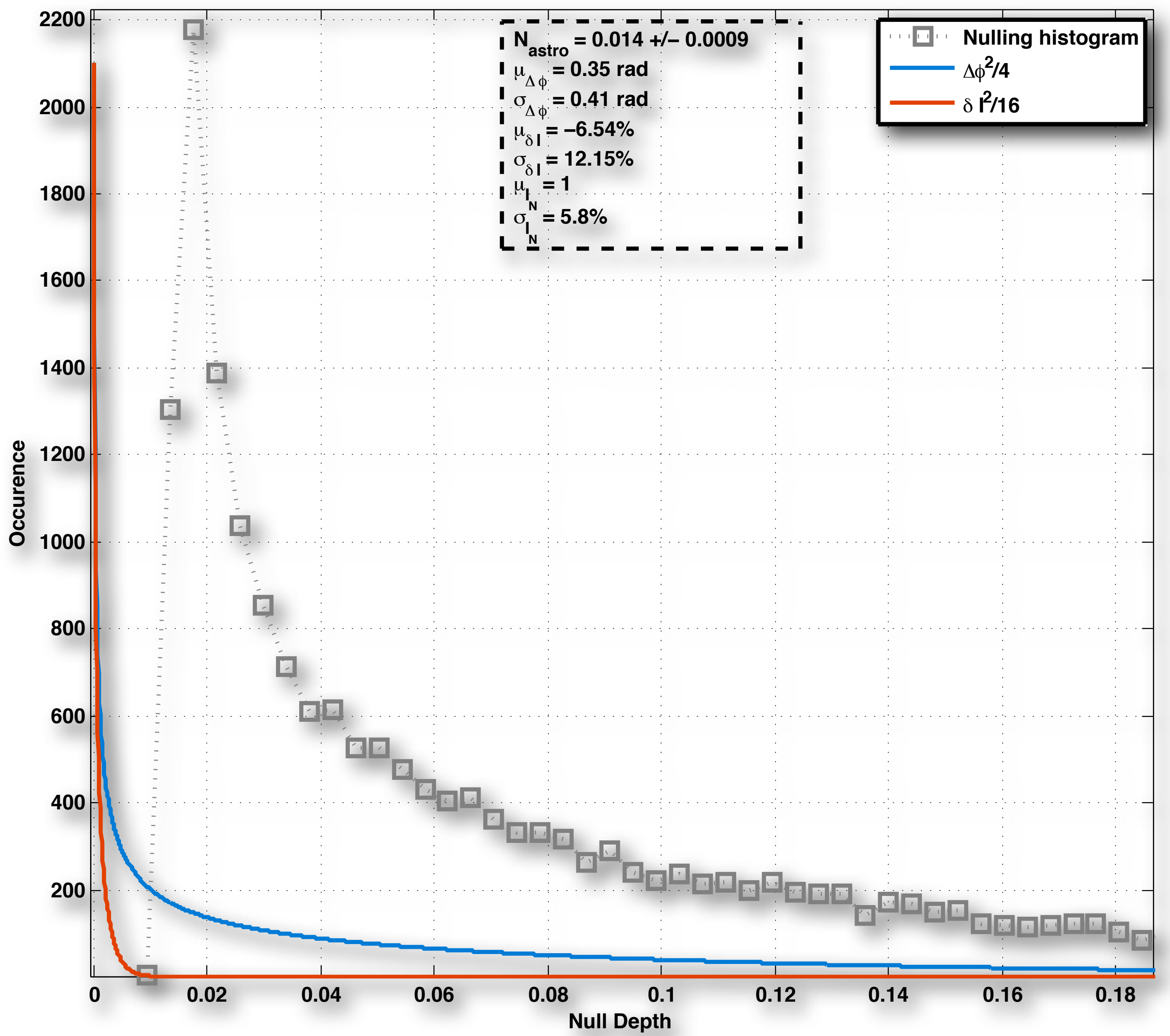

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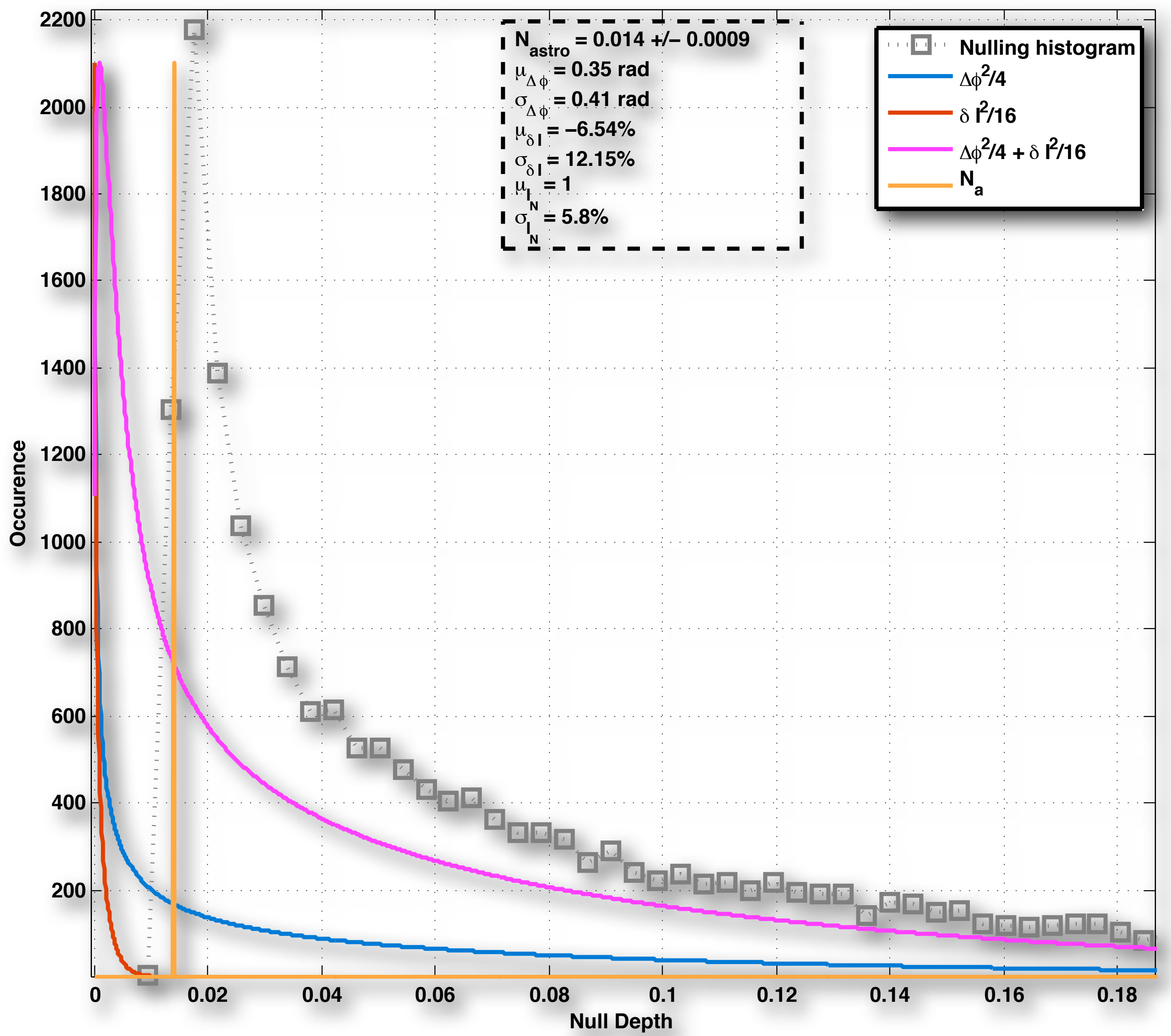

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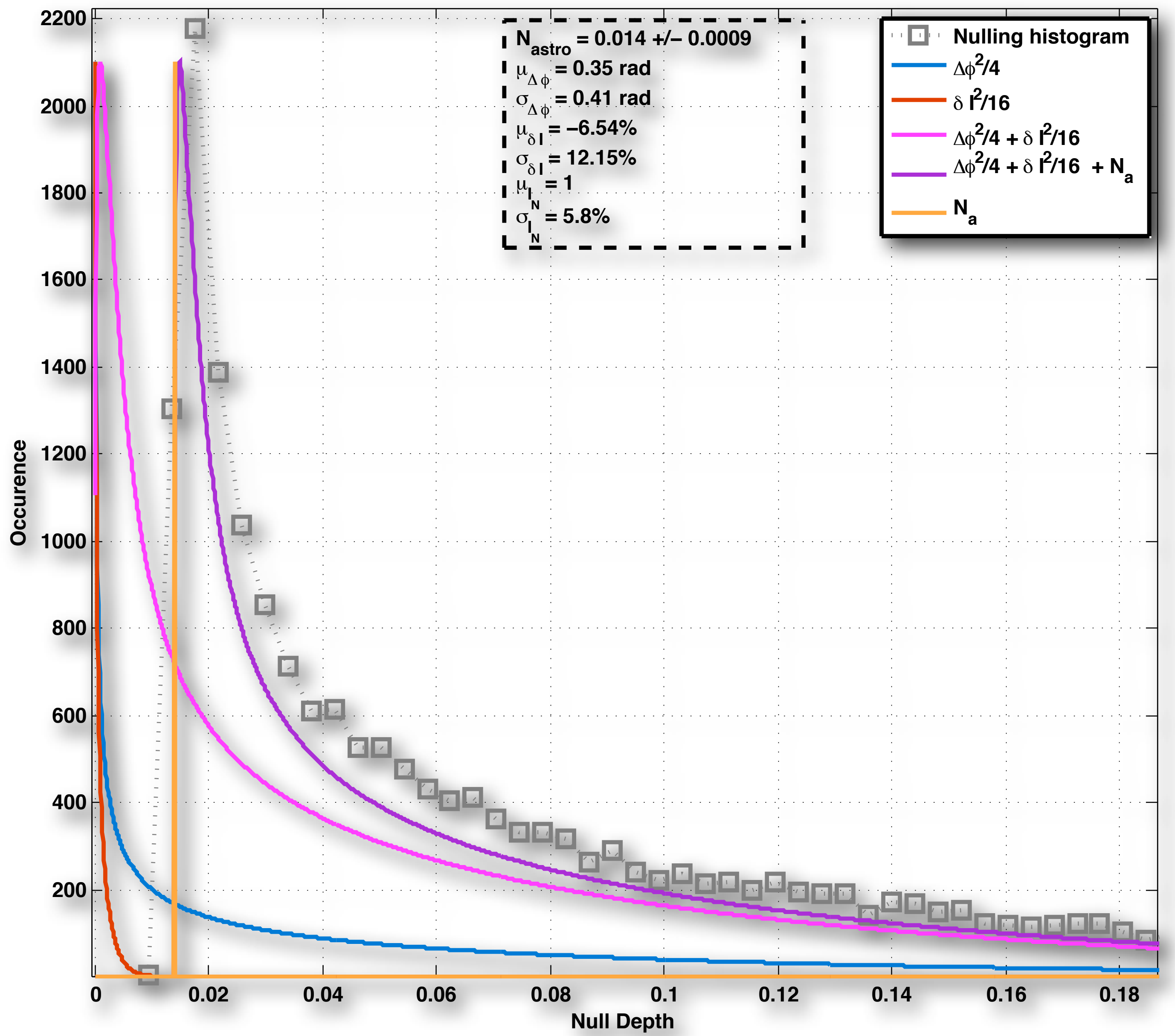

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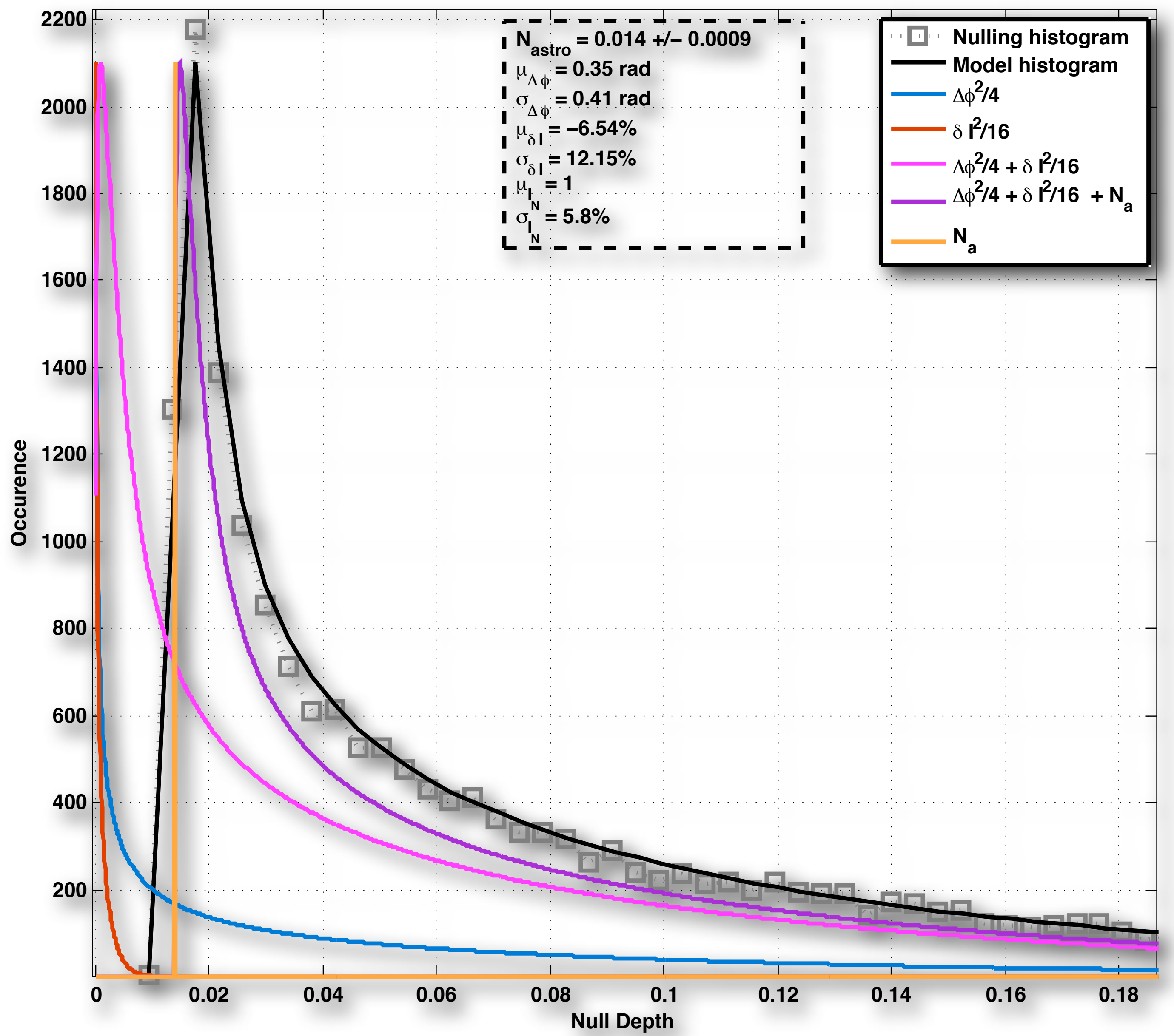


Is the solution unique?

$$N(t) \approx I_r(t)(\delta I(t)^2+\Delta\phi(t)^2+\alpha_{rot}^2+N_a)+N_{Bkg}(t)$$

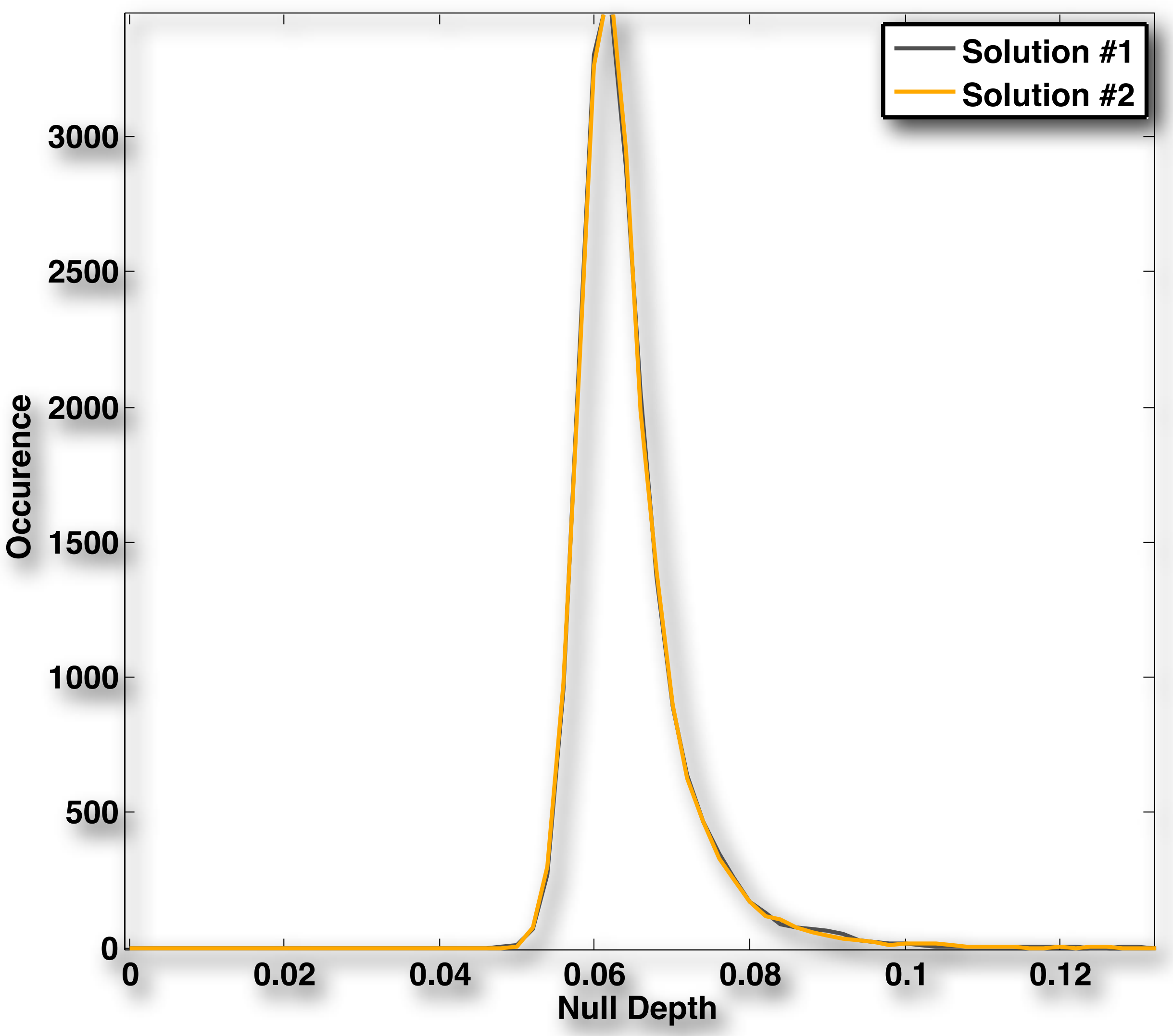
Case #1 : No fluctuation

- $\Delta\phi(t)^2 \rightarrow \Delta\phi^2$
- Infinite num. of solutions

ANSWER: NO!!!

- $N_a = 0.06$
- $\mu_\phi = 0$ rad
- $\sigma_\phi = 0$ rad

- $N_a = 0.02$
- $\mu_\phi = 0.4$ rad
- $\sigma_\phi = 0$ rad



Is the solution unique?

$$N(t) \approx I_r(t)(\delta I(t)^2+\Delta\phi(t)^2+\alpha_{rot}{}^2+N_a)+N_{Bkg}(t)$$

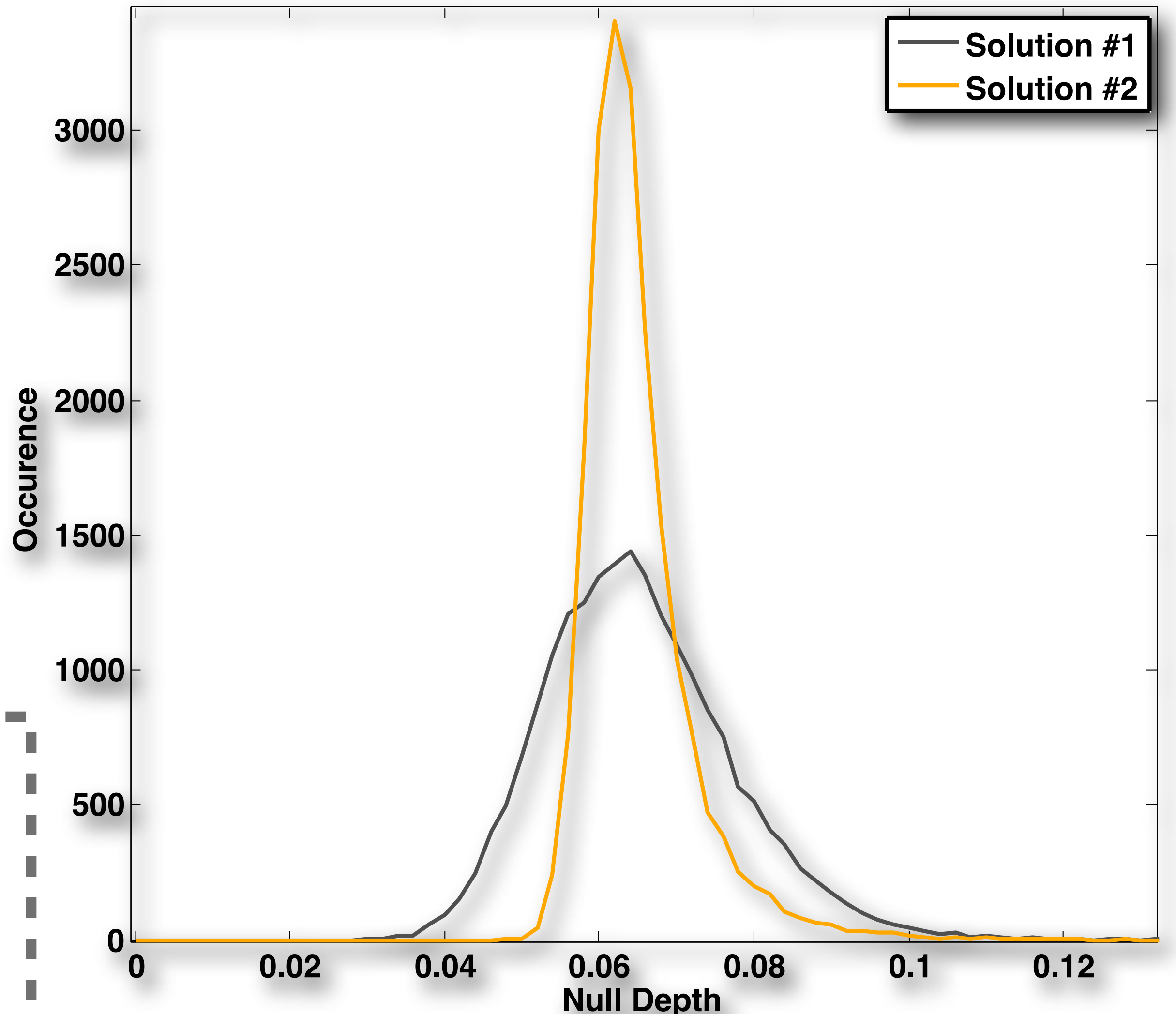
Case #2 : Fluctuations

- Can be small fluctuations
- Only one solution

ANSWER: YES!!!

- $N_a = 0.06$
- $\mu_\phi = 0$ rad
- $\sigma_\phi = 0$ rad

- $N_a = 0.02$
- $\mu_\phi = 0.4$ rad
- $\sigma_\phi = 0.05$ rad



Classical method

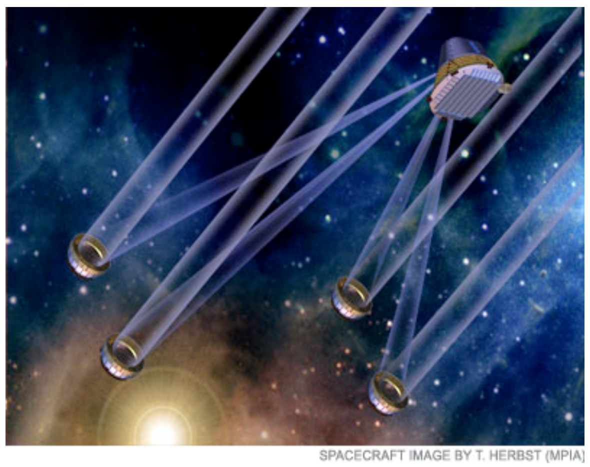
Advantages

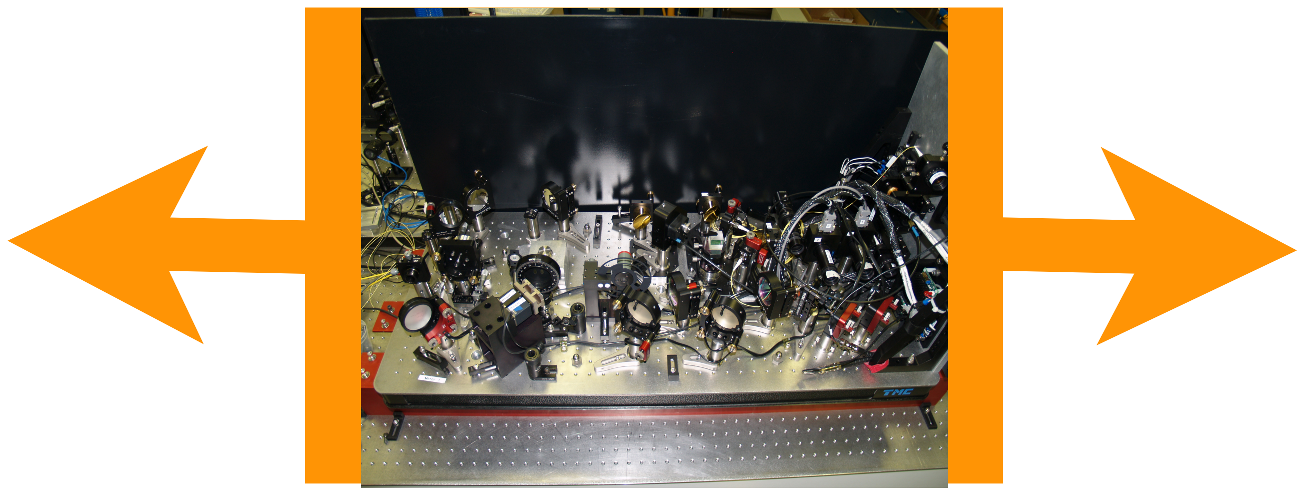
+ Easy to use
+ Fast
+ No calibration!
+ Better accuracy
+ Better sensitivity

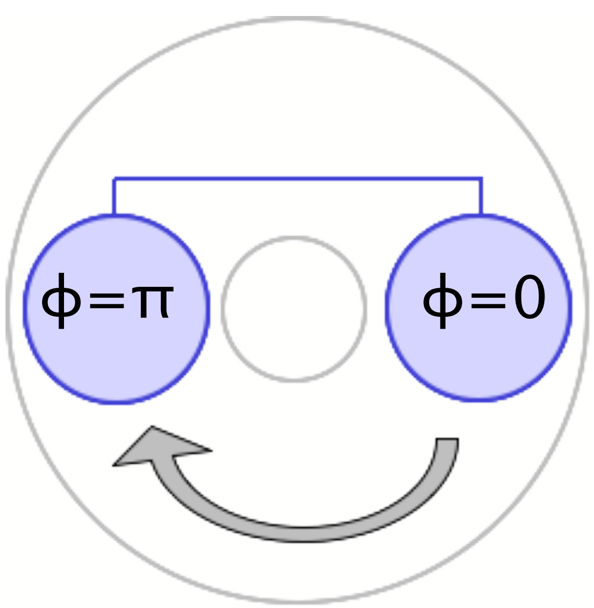
Application #1

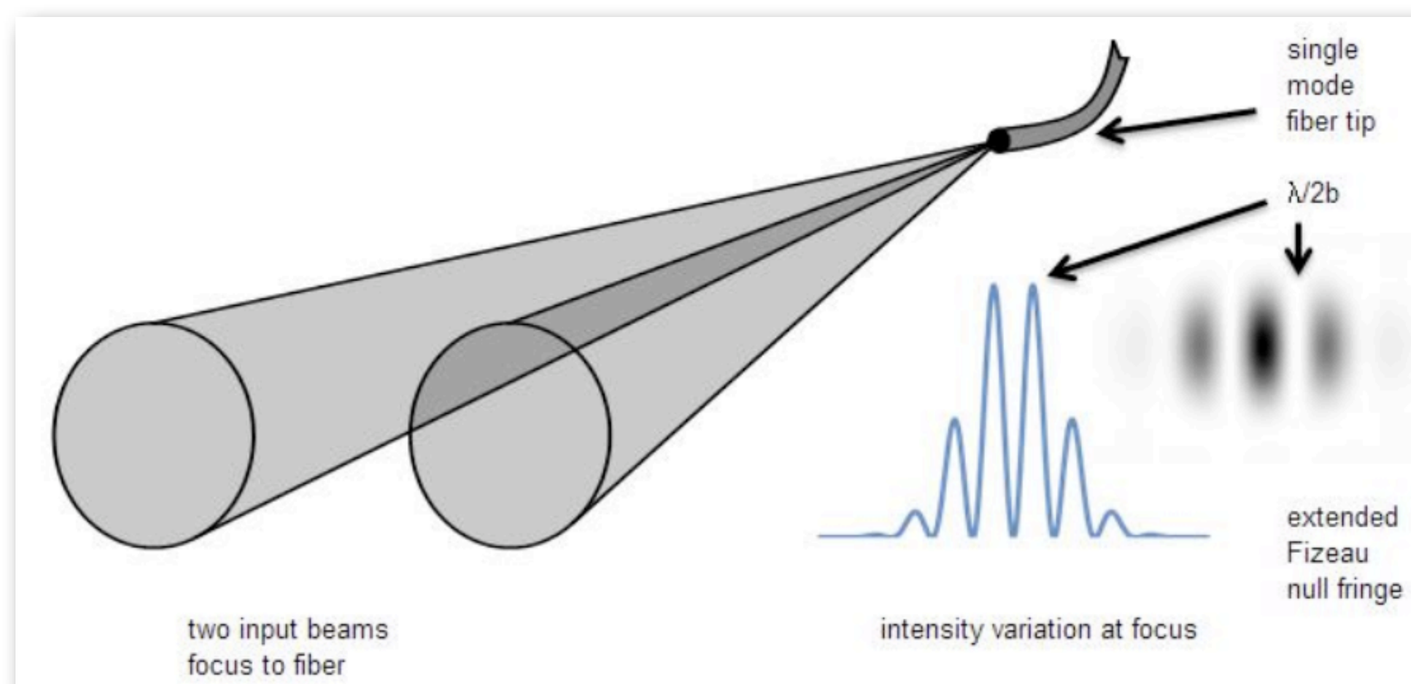
The Palomar Fiber Nuller (PFN)

Palomar Fiber Nuller

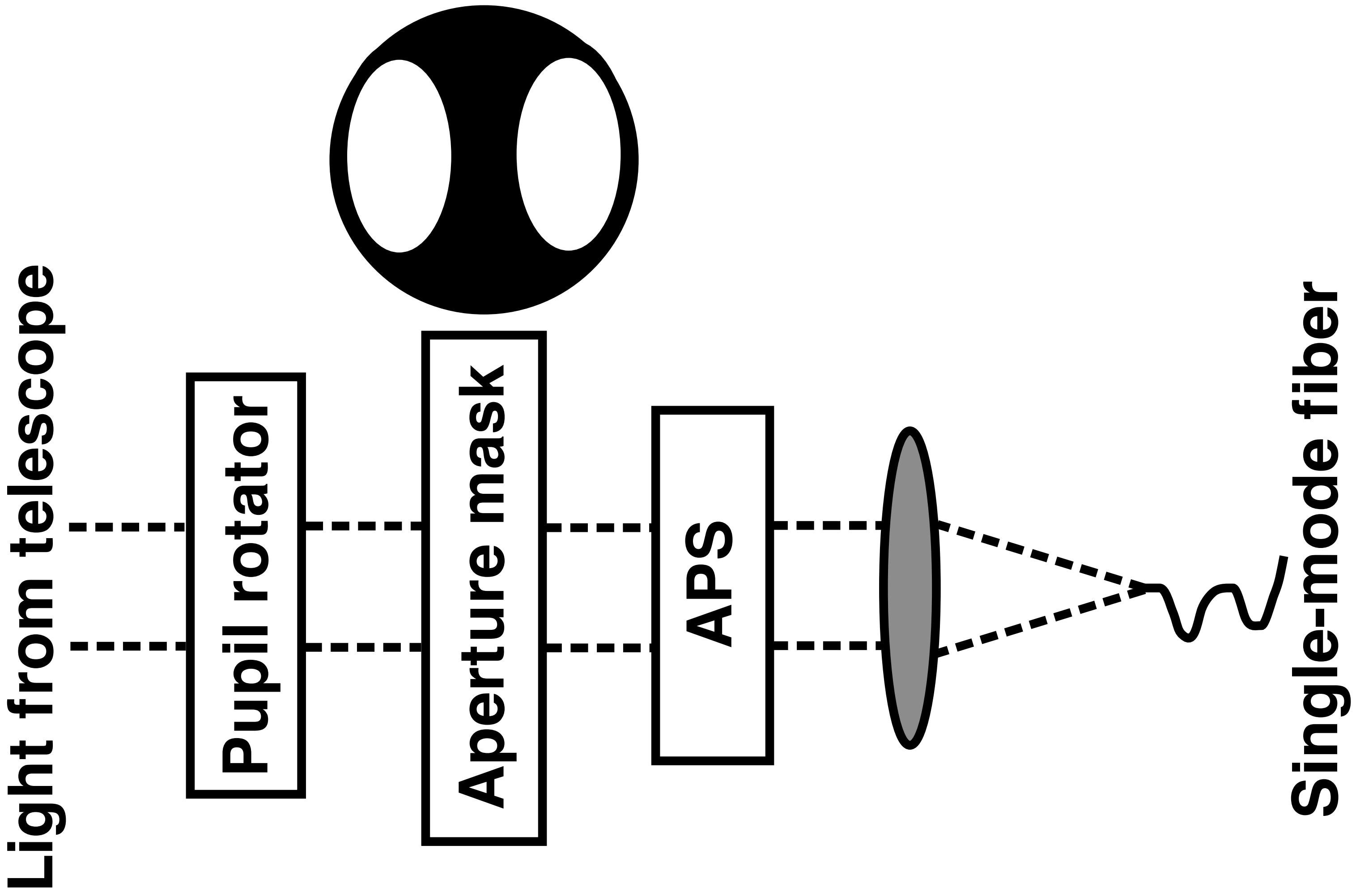








Palomar Fiber Nuller



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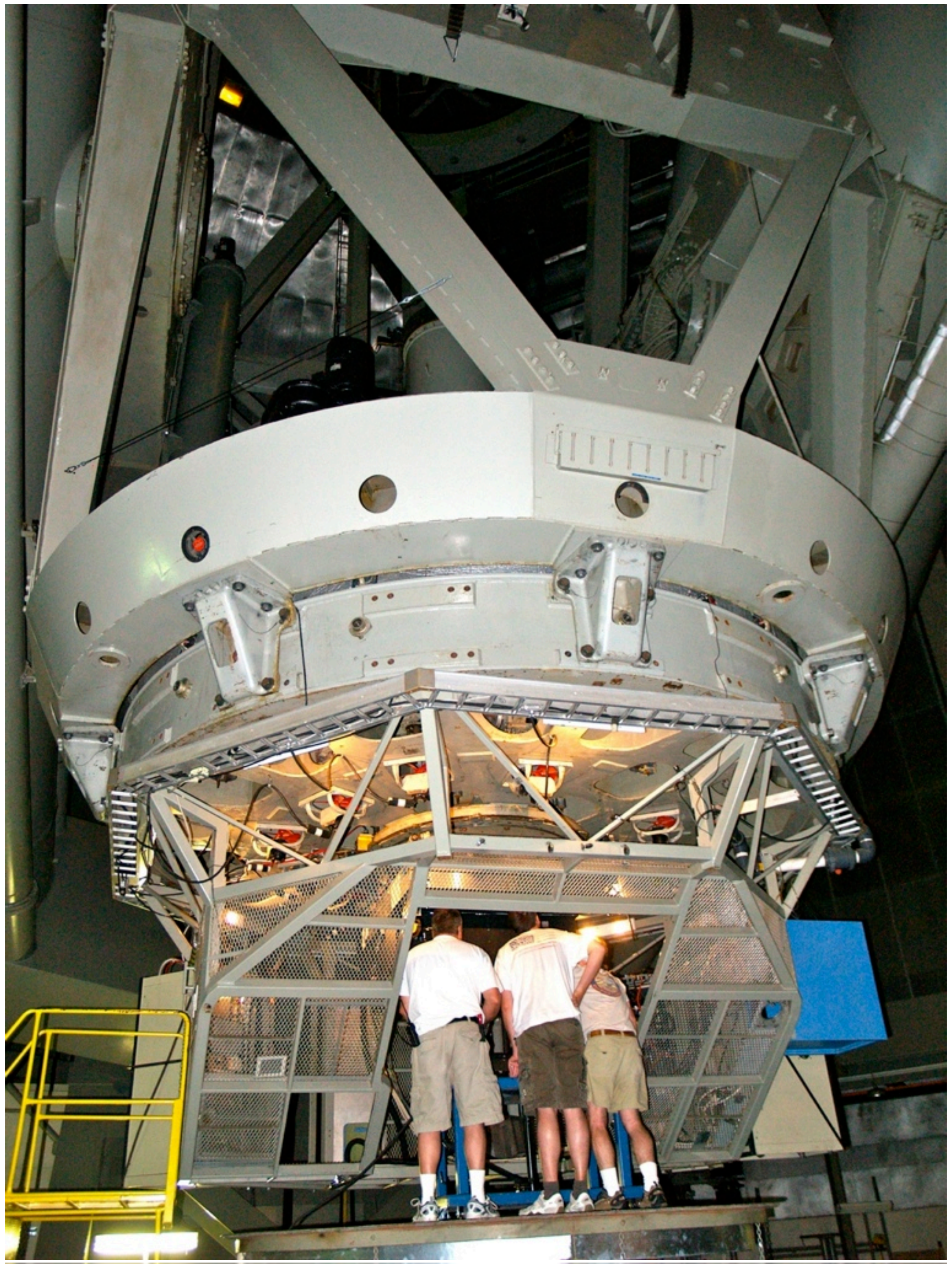
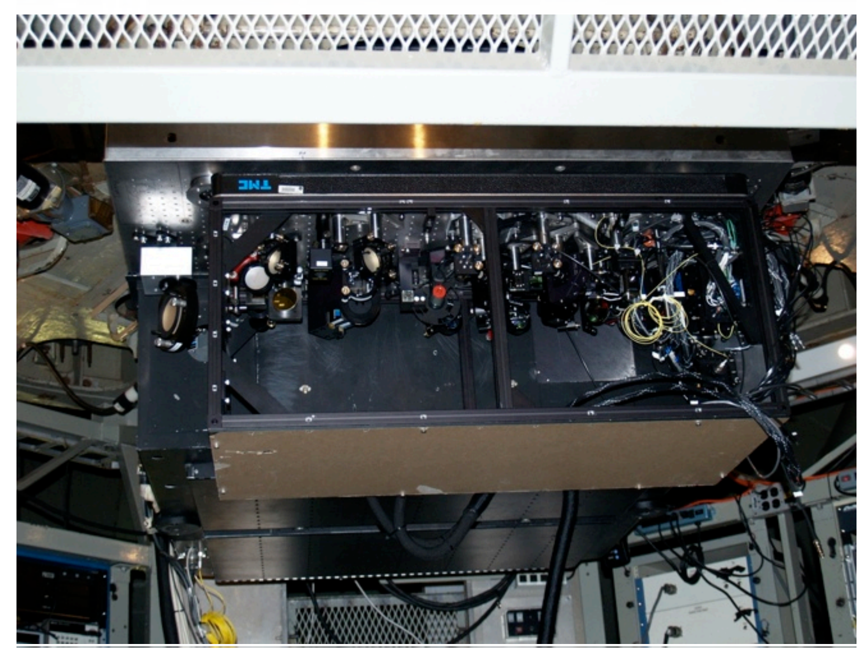


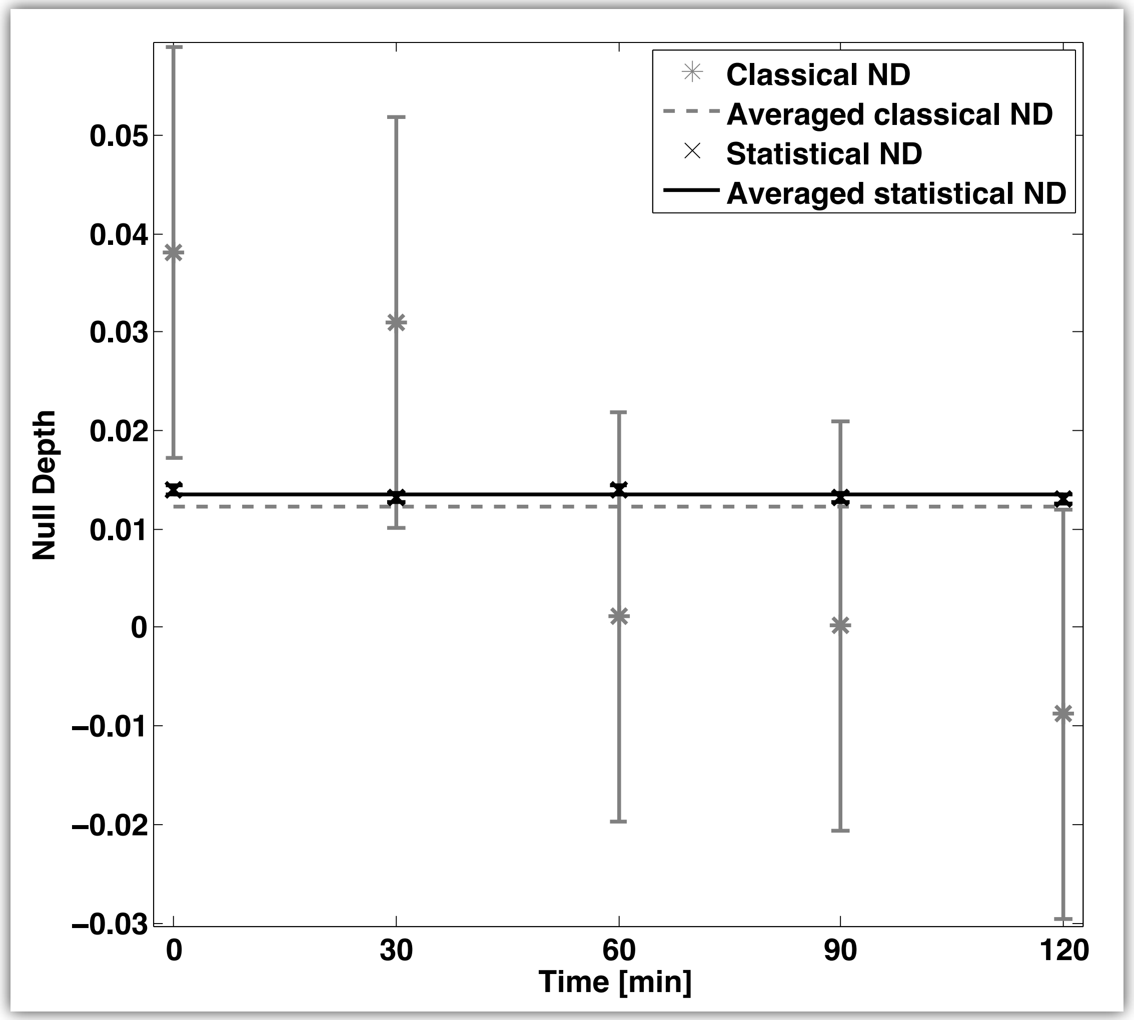


Comparison classical vs statistical

Alpha Boo

- LBI: Na = 1.35% ± 0.01%
- Class. : Na = 1.23% ± 0.4%
- Stat. : Na = 1.35% ± 0.004%

Alpha Boo

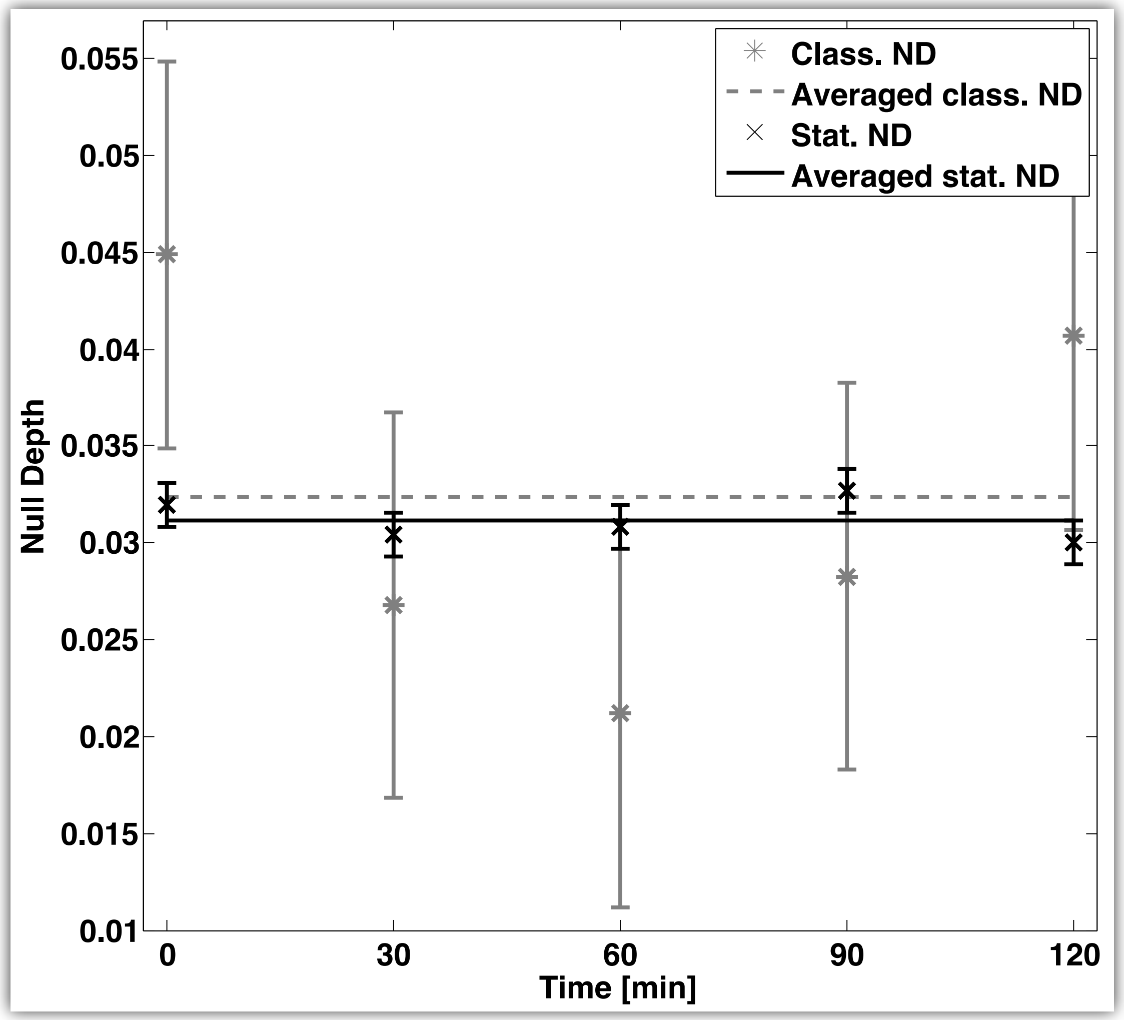


Comparison classical vs statistical

Alpha Her

- LBI: Na = 3.25% ± 0.15%
- Class. : Na = 3.24% ± 0.4%
- Stat. : Na = 3.12% ± 0.04%

Alpha Her

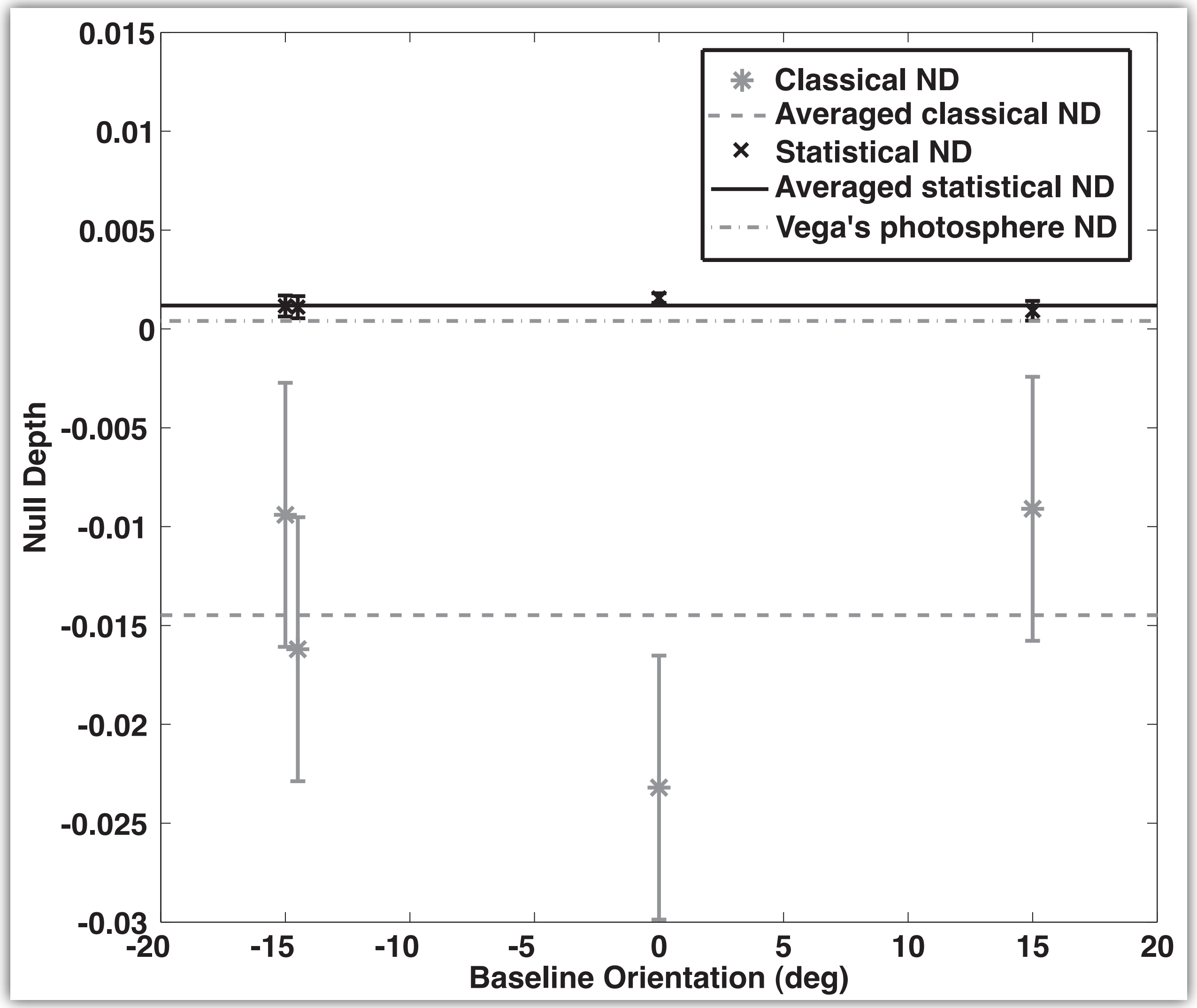


Comparison classical vs statistical

Alpha Her

- Excess = 0.11% ± 0.05%
- Class. : bad calibration

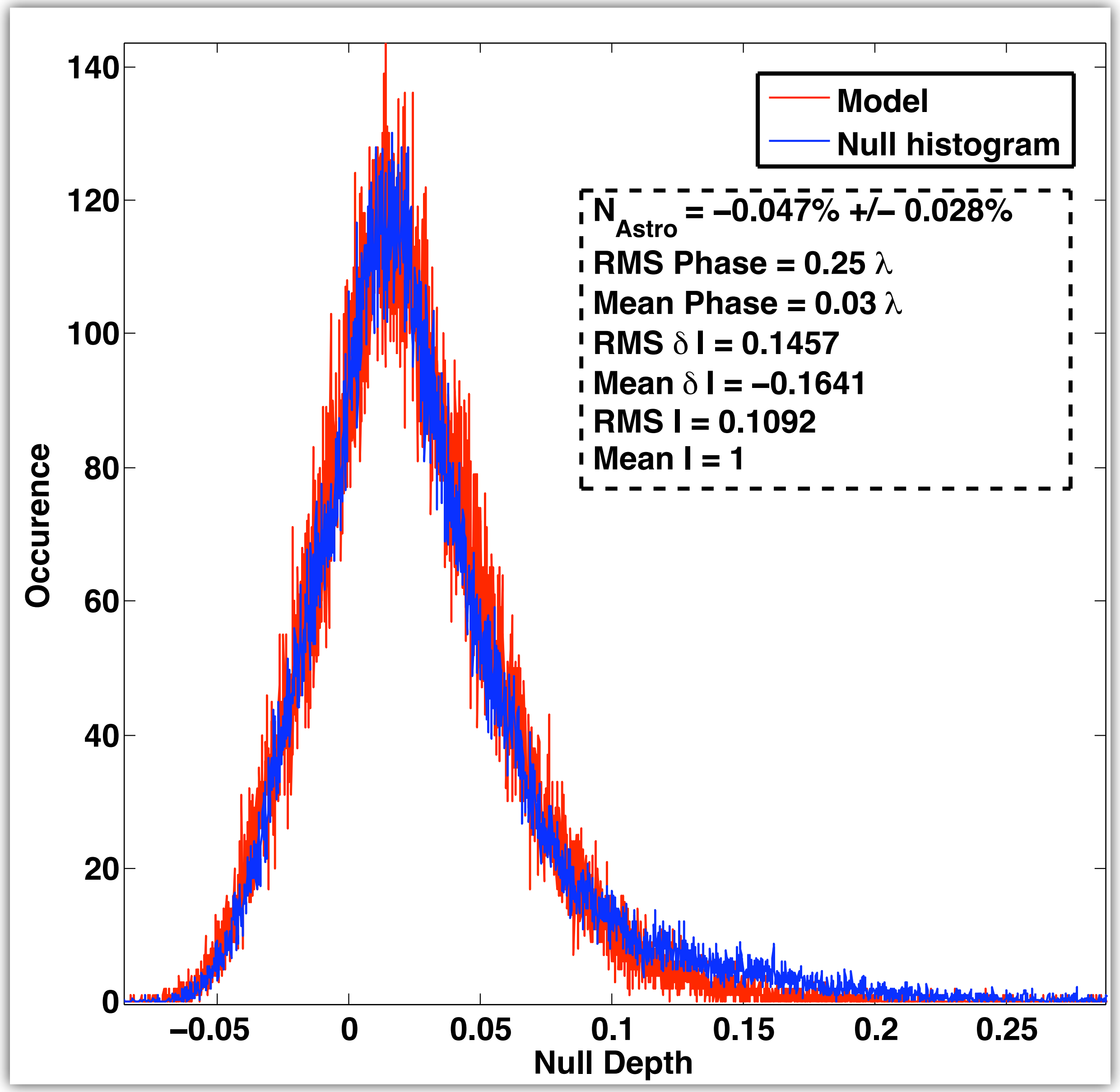
Vega



Reaching High contrasts

Eta Peg

- ND excess : 4.7 x 10^{-4}
- Theo. excess : 3.5 x 10^{-4}
- Bias : 1.2 x 10^{-4}



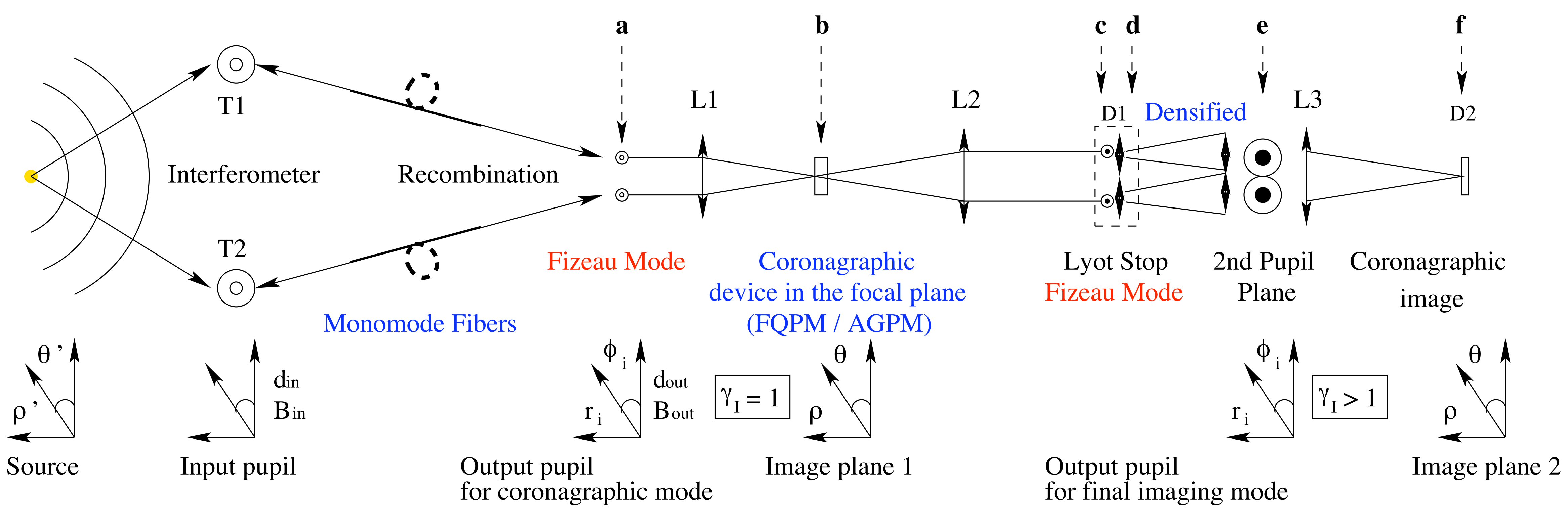
Application #2

Measurement of stellar diameters

Measurement of stellar diameters

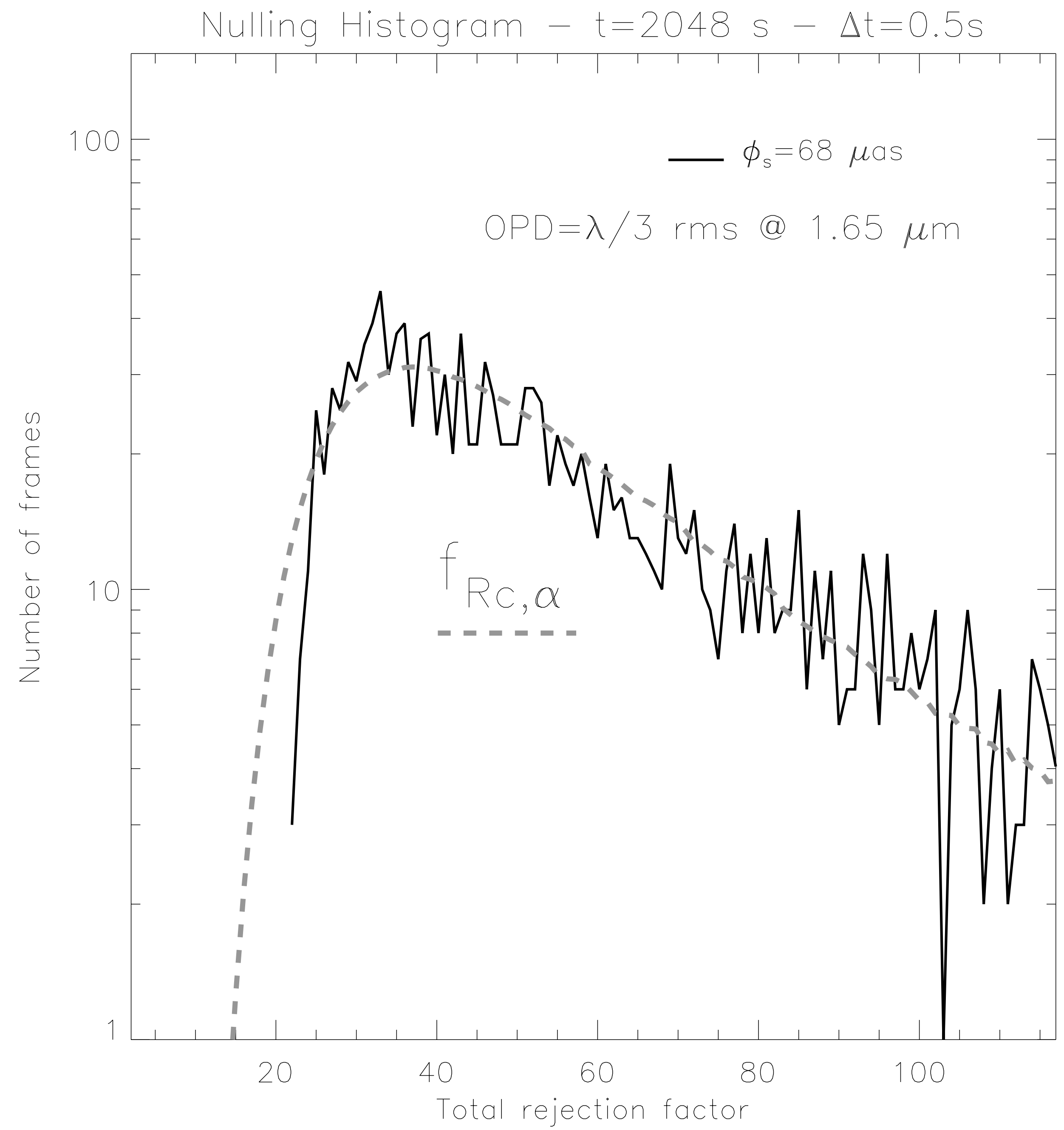
Method:

Combining coronagraphy and interferometry



Measurement of stellar diameters

Stel. Diam. (μas)	68	72	75	78
$\mu_{\Delta\phi}$ in wave	0.308	0.365	0.41	0.46
$\sigma_{\Delta\phi}$ in wave rms	0.076	0.064	0.071	0.08
μ_{di} in %	8	9	10	6.5
σ_{di} in % rms	2	3	10	6.5
σ_I in % rms	2	2	2	2
Retreived Diam. (μas)	68.4	71.6	75	78



Conclusion

- A new data reduction method for interferometry
- Better stability and accuracy of the measurements
- Better sensitivity
- Best ND ever achieved on the sky
- Not restricted to a particular instrument