Long baseline interferometry in the visible: FRIEND project achievements and prospects

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Outline

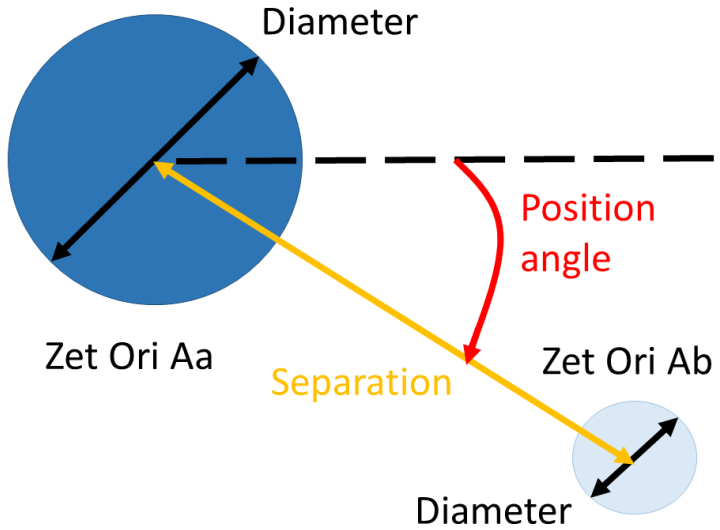
I. Observations
II. On-sky validation of FRIEND *(martinod 2018, submitted)*
III. Injection into optical fibers with AO *(martinod 2018, submitted)*
IV. Conclusion

Observations

Date	Telescopes	R0 (cm)(@550nm)	Target	Comments
March (4 nights)	S1-S2	5-12	Sirius Regulus	Test AO (CHARA meeting 2017)
May (1 night)	S2-W2-W1	10	Theta Aql	Instrumental issues
June (2 nights)	S1-W2-W1	7-10	Theta Aql	Instrumental issues
October-12	S2-S1-W2	10	Zet Ori A	Fringes
October-14	S2-S1-W2	9	Zet Ori A	Fringes
October-16	S2-S1-W2	11	Capella	AO and injection

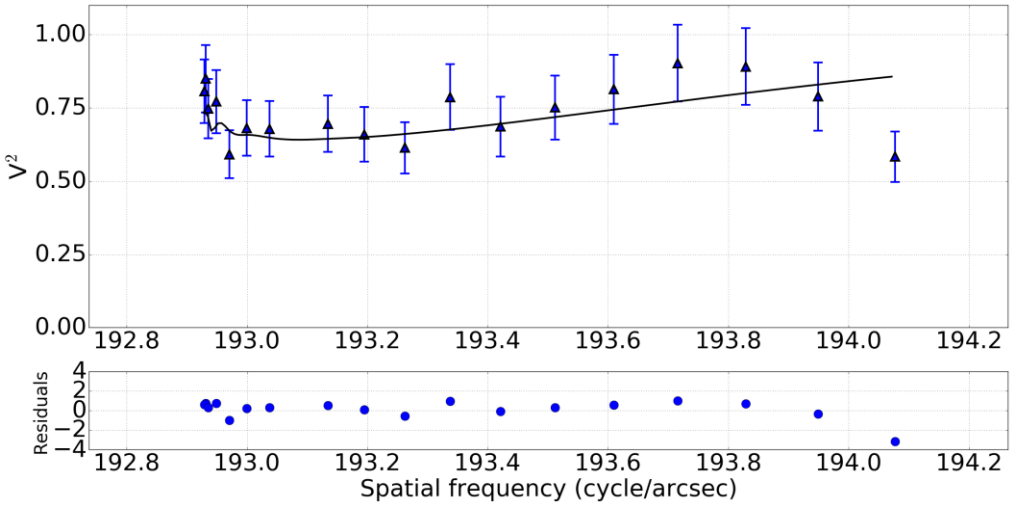
On-sky validation of FRIEND

- Target: Zeta Ori A (mR=1.89), known binary system *(Hummel et al. 2013)*
- Cal: Kap Ori (mR=2.09)
- Use of LABAO
- 1st night (2017-10-12): calibrated V^2 and CP
- 2nd night (2017-10-14): calibrated CP but no V^2 (instrumental issue on Cal star)
- Model fitting using LITpro : 2 Uniform Disks
  - Diameter Aa (mas)
  - Diameter Ab (mas)
  - Visual magnitude difference
  - Seperation (mas)
  - Position Angle (°)
- In *Martinod et al. 2018 (submitted)*



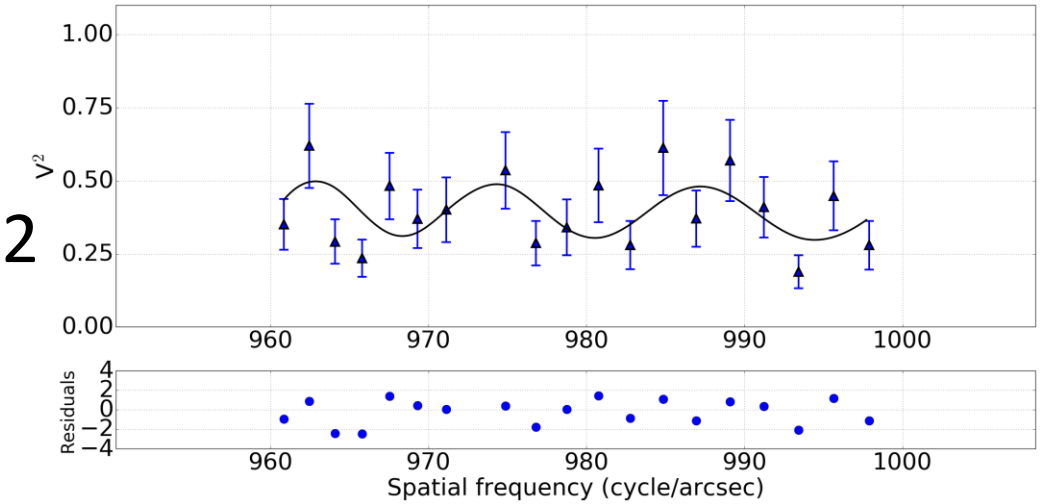
On-sky validation of FRIEND

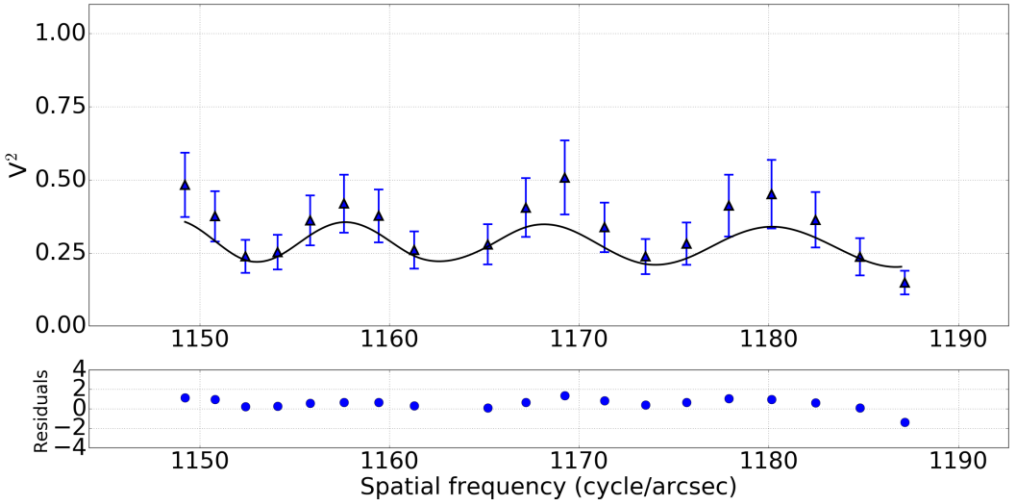
Calibrated V²



S1S2

S2W2





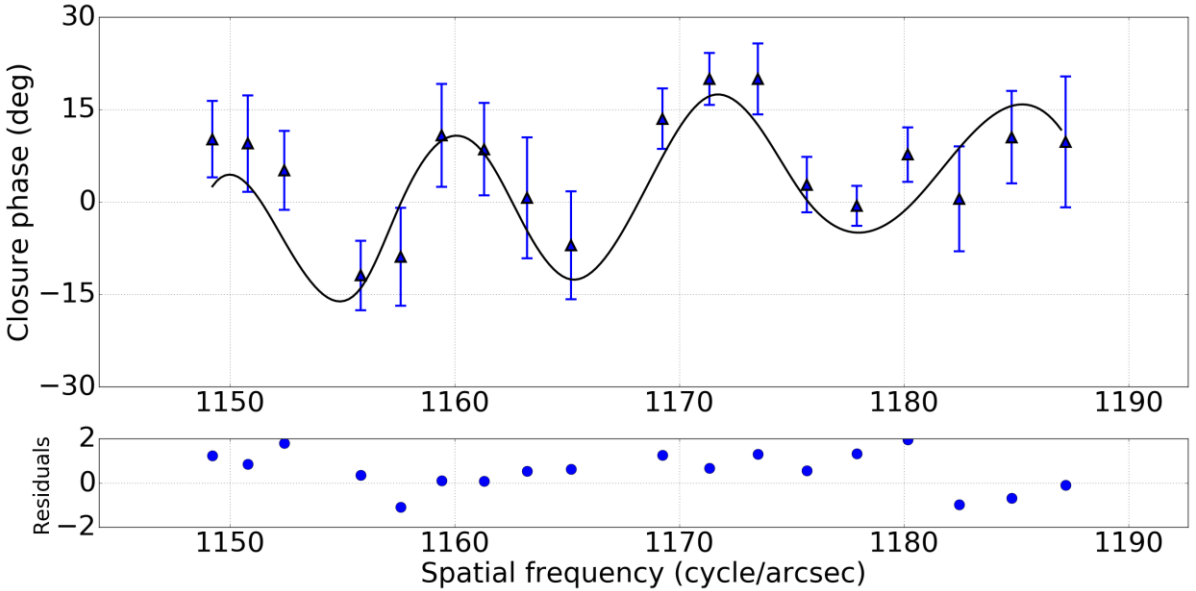
S1W2

Data of night of 2017-10-12

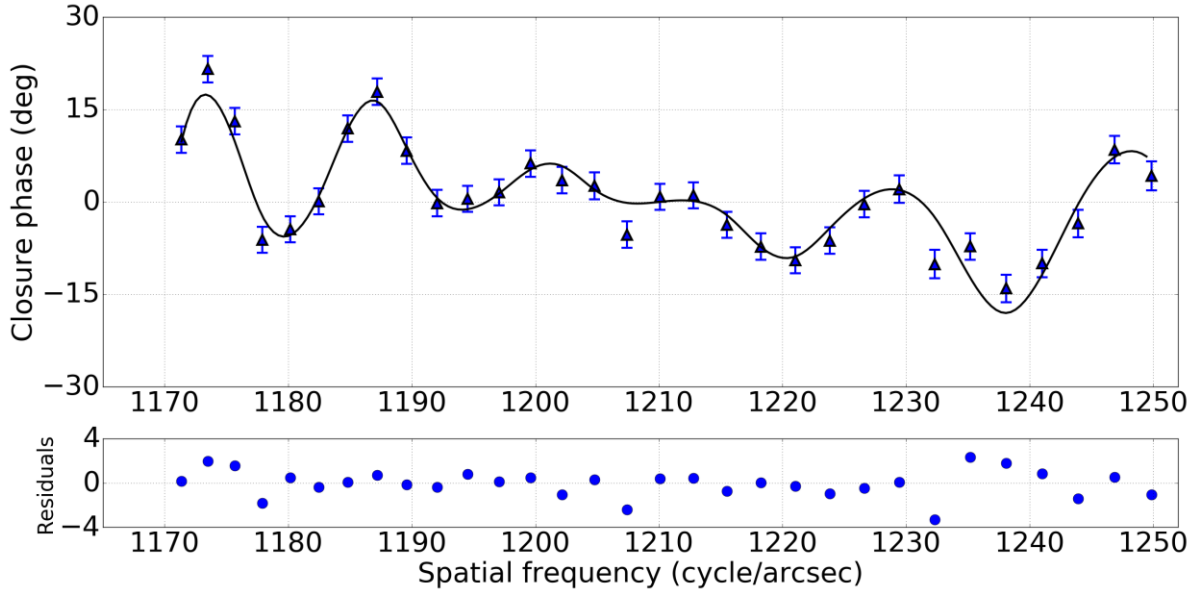
1 point = 6000 frames = 2min

On-sky validation of FRIEND

Calibrated CP



2017-10-12



2017-10-14

1 point = 6000 frames = 2min

Average uncertainty: 2.2°
Median of residuals = 1.2°

} Good fit

On-sky validation of FRIEND

- Results of model fitting

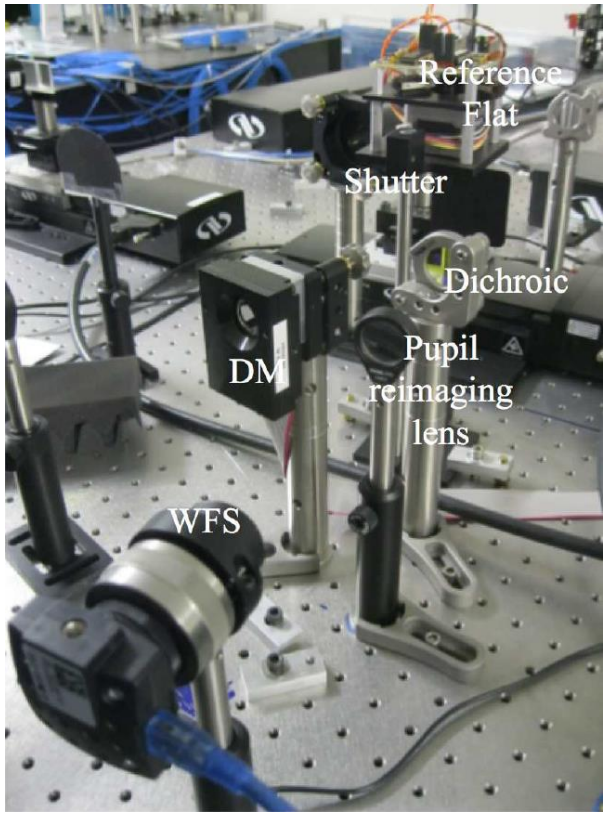
Parameters	Hummel et al. 2013	2017-10-12	2017-10-14
Diameter Aa (mas)	0.48 ± 0.2	0.54 ± 0.01	-
Diameter Ab (mas)	0.48 ± 0.2	0.45 ± 0.12	-
Visual magnitude difference	2.2 ± 0.1	2.4 ± 0.1	-
Separation (mas)	24.1 ± 0.15 / 24.07 ± 0.15	23.89 ± 0.44	24.23 ± 0.15
Position angle (°)	80.5 ± 0.45 / 80.1 ± 0.46	81.42 ± 0.33	81.00 ± 0.15
Reduced χ^2	-	1.14	1.59

- Results consistent with expected values:

⇨ V^2 and CP estimations validated and **new diameters**

Injection into optical fibers with AO

- Use of LABAO only
- DM 37 actuators
- WFS: Shack-Hartmann
  32 subapertures
- Correct WF at 40 Hz
- $\lambda = 500\ nm$
- Compute 8 first Zernike
- Save average on 4 values

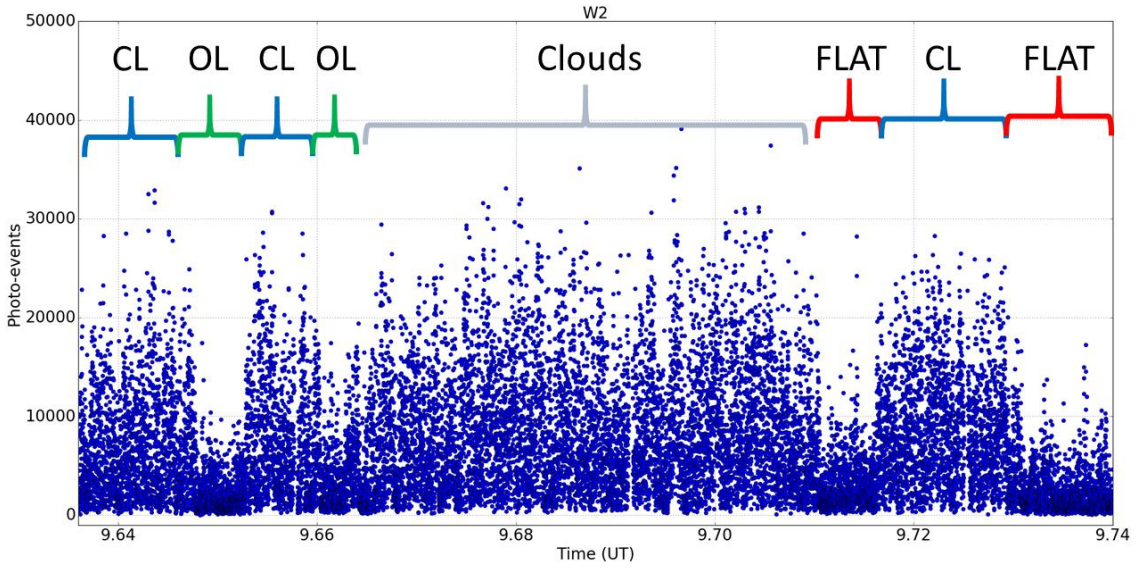


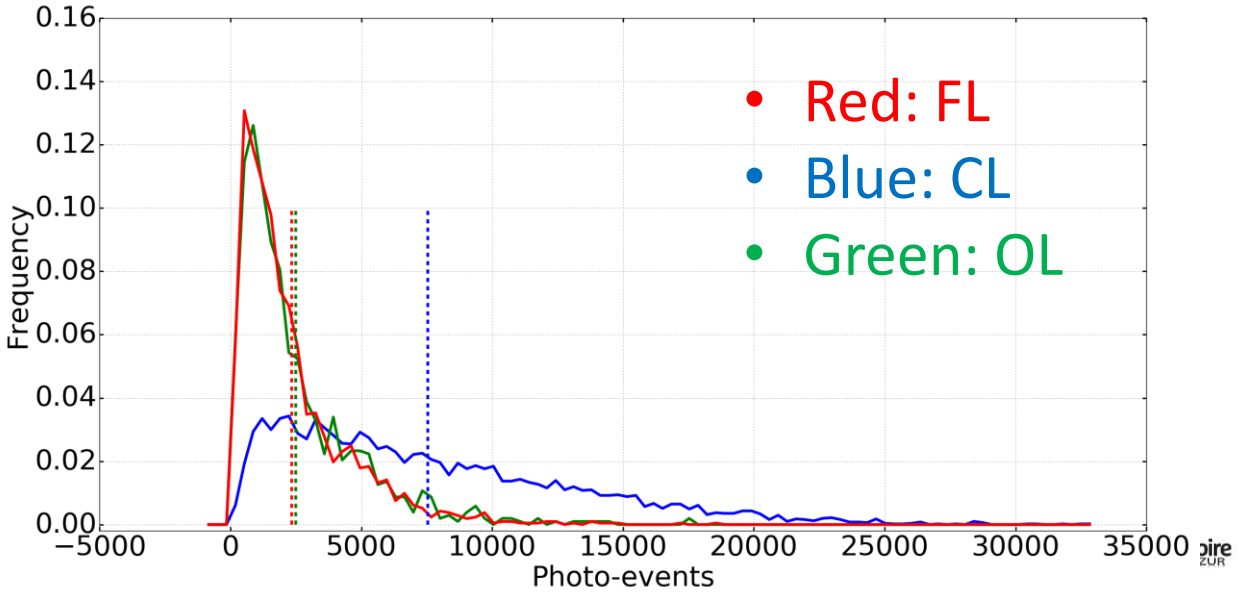
Injection into optical fibers with AO

- Use of: S2, S1 and W2
- 3 modes:
  - Closed loop (CL): correction of turbulence
  - Open loop (OL): servo stopped, DM keeps last shape
  - Flat (FL): reinitialization of DM shape
- Target: Capella (m_R = -0,52), bright enough for LABAO and FRIEND
- Some clouds disturbing photometry and servo

Injection into optical fibers with AO

Statistical analysis on W2



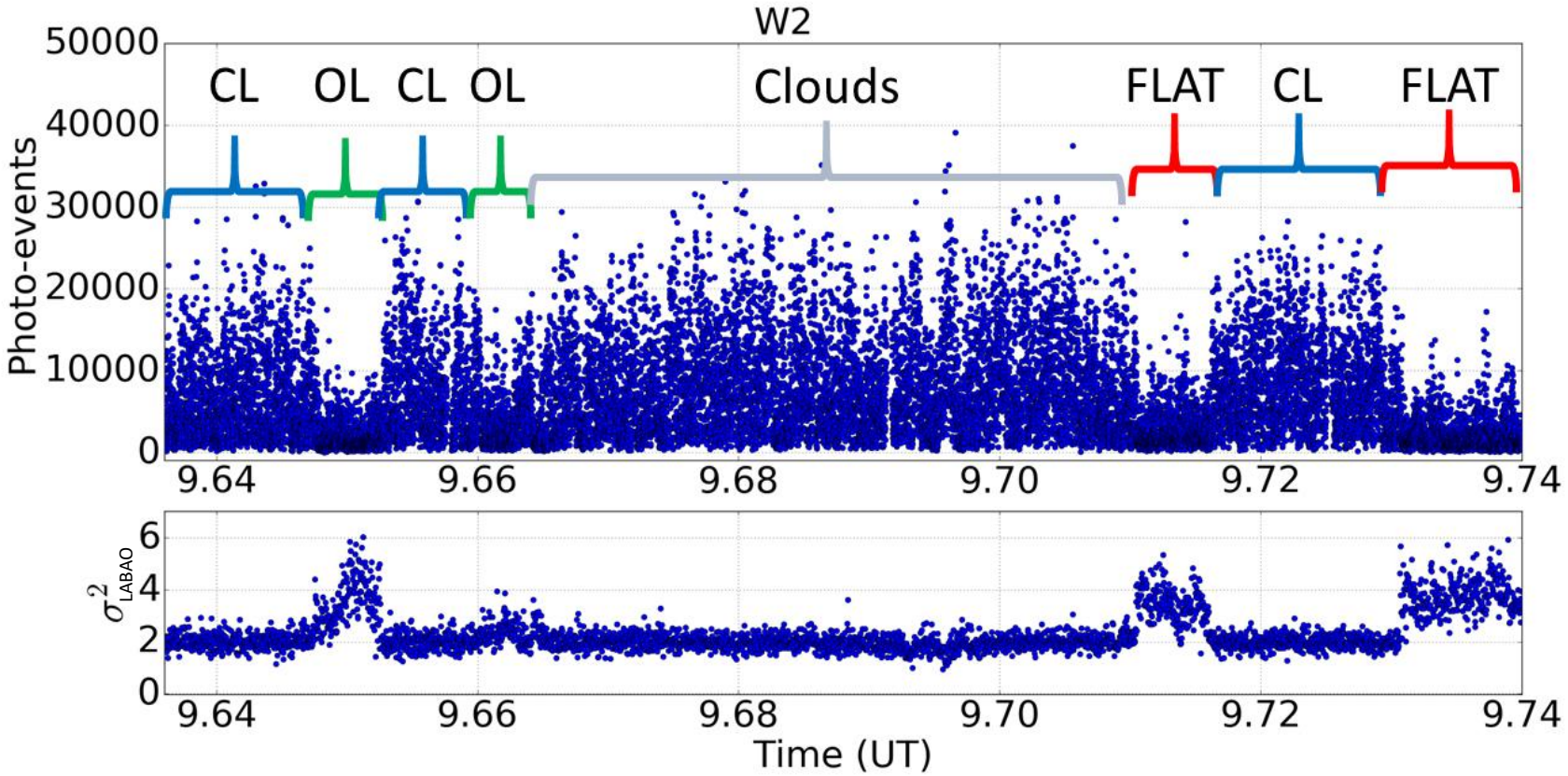


<ρ>
Closed Loop 3.8 ± 2.8 %
Open Loop 1.26 ± 1.18%
FLAT 1.19 ± 1.09%

$\rho \times$ 3 with AO
+1 mag !

Injection into optical fibers with AO

Observation of coupling and variance of phase variations



- σ^2 variance of phase fluctuations
- $\sigma^2 = \sum_{i=2}^{\infty} a_i^2$
- $\sigma^2_{LABAO} = \sum_{i=2}^{8} a_i^2$
- a_i^2 : Zernike coeff.

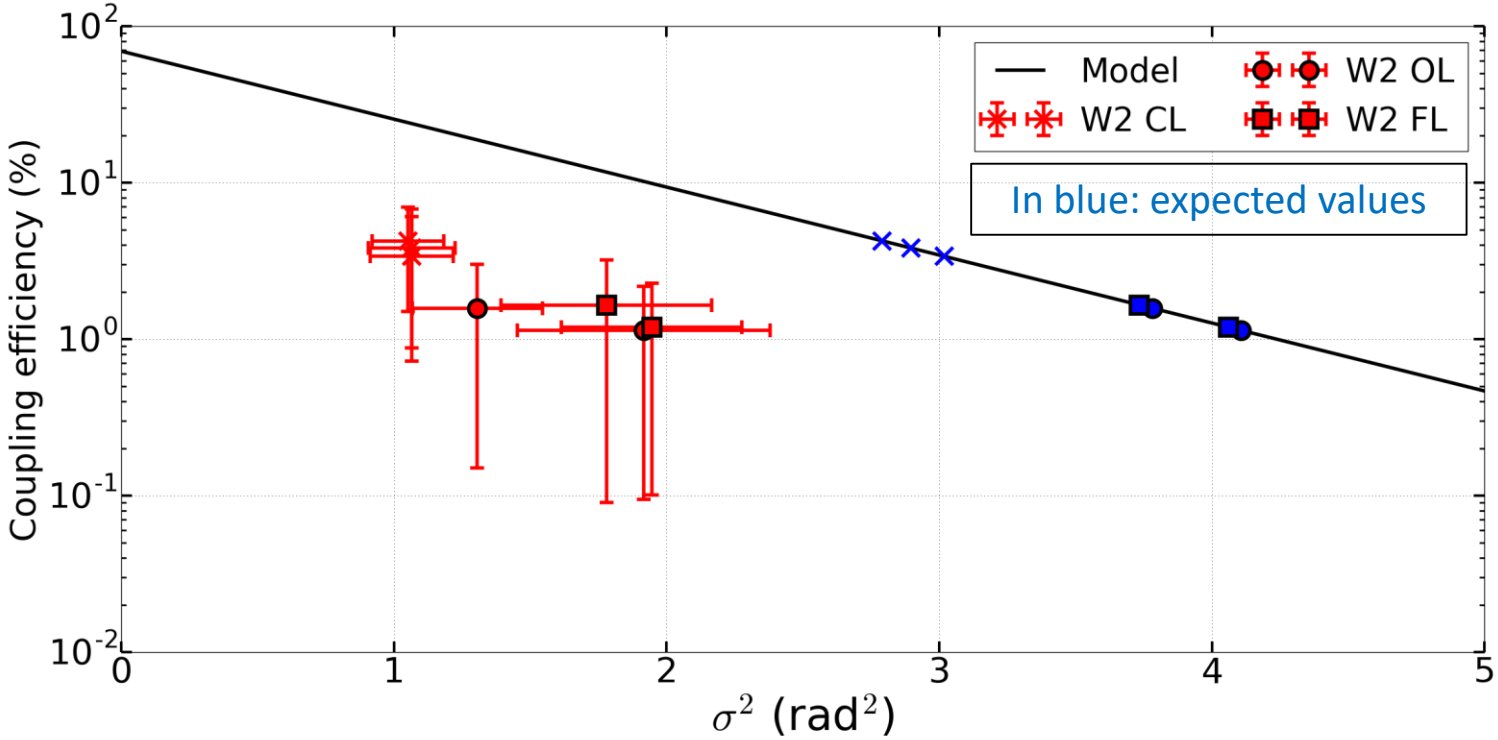
Injection into optical fibers with AO

Correlation between ρ and LABAO data

- $\rho = \rho_0 \, Sr$ (Coudé du Foresto 2000)
  $\rho_0 = 0.69$ (Ruilier 1998)
- $Sr = e^{-\sigma^2}$ (Marechal approximation)
- Even if $Sr \simeq 1.7\%$
  (Fig.1, Ross 2009, App. Optics)

$$\rho = \rho_0 e^{\sigma^2}$$

$$\ln(\rho) = \ln(\rho_0) - \sigma^2 (\text{model})$$



- σ^2 from LABAO biased?
- Residuals and/or scale factor
- $\sigma^2 = \sigma^2_{LABAO} + b$ or $\sigma^2 = a\,\sigma^2_{LABAO} + b$

Injection into optical fibers with AO

Study of additive bias hypothesis

- Additive bias: $\sigma^2 = \sigma^2_{\mathrm{LABAO}} + \mathrm{b}$
- Assuming calibrated Zernike
- $b = 1.8\, rad^2$
- Noll's residuals errors at 8th order:

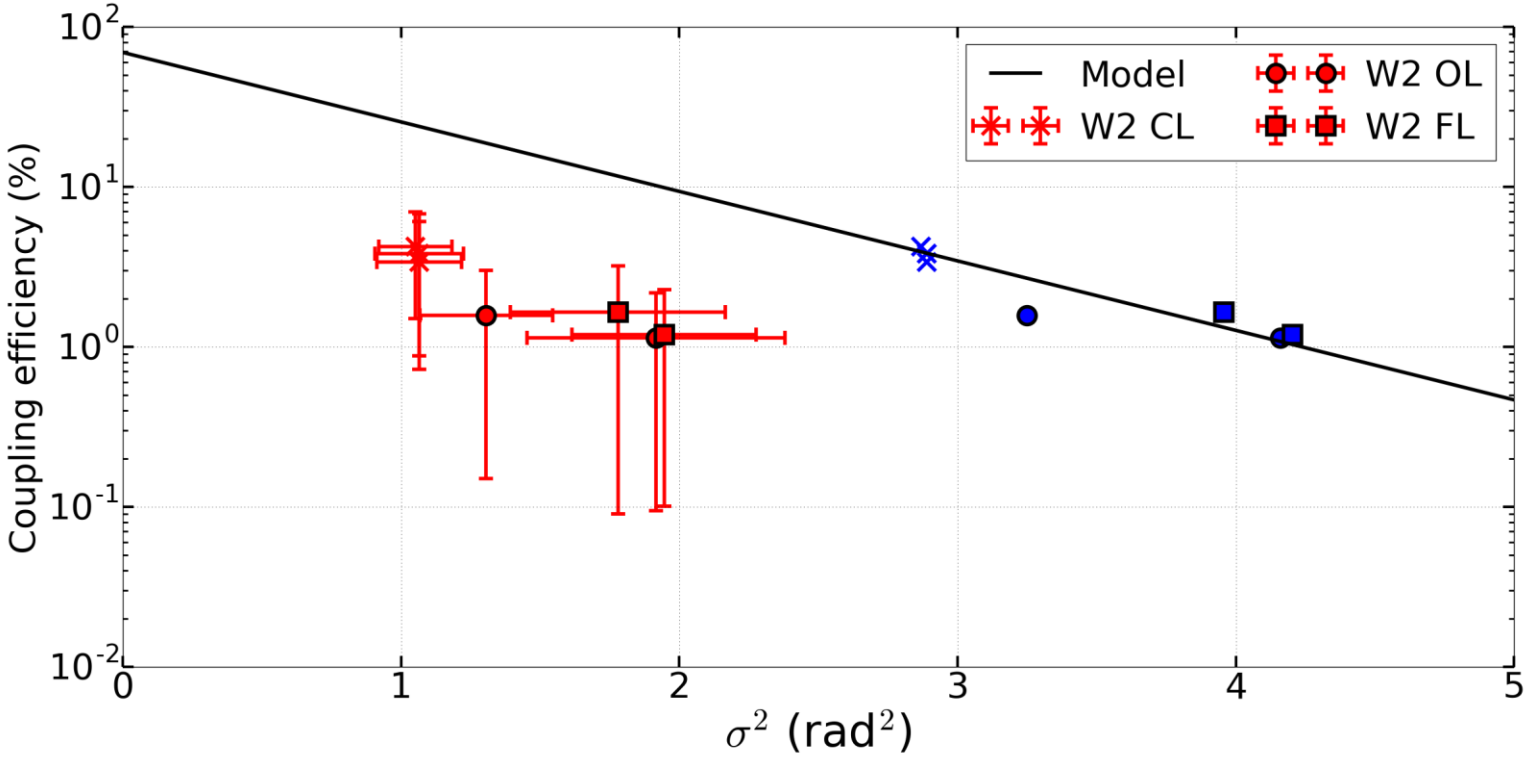
$$\Delta_8 = 0.0525 \left(\frac{D}{r_0}\right)^{\frac{5}{3}} = 1.3\, rad^2$$

- Other sources:
  - Subsampling of saved data
  - Temporal error ?

Injection into optical fibers with AO

Study of scale factor + additive bias hypothesis

- Scale factor bias : $\sigma^2 = \mathrm{a}\ \sigma^2_{\mathrm{LABAO}} + \Delta_8$
- Model to fit : $\ln(\rho) = \ln(0.69) - a\ \sigma^2_{LABAO} - \Delta_8$



$a = 1.49 \pm 0.23$

Reduced $\chi^2 = 0.08$

- Scale factor
- But:
  - χ^2 very low
  - Uncertainties too large
  - $b = \Delta_8$?

Real value of scale factor ?

Conclusion

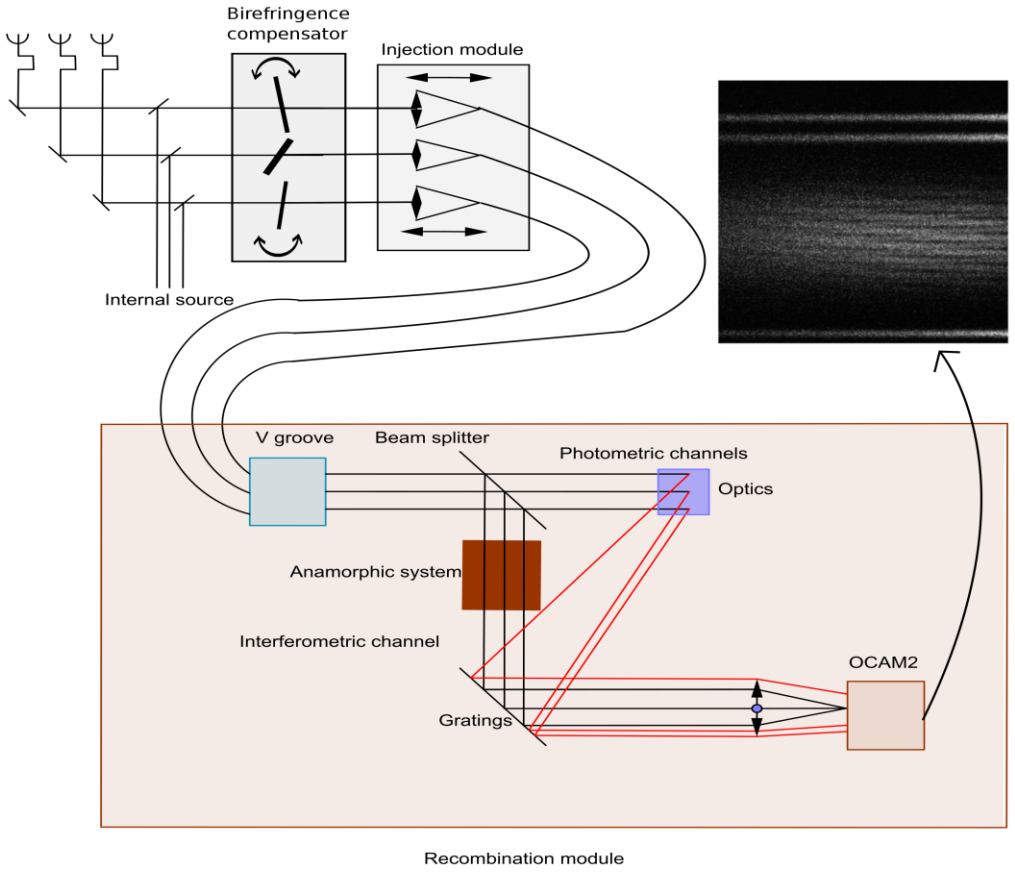
- FRIEND, prototype of SPICA, does the job
  - Study of instrumental effects and signal processing
  - Reliable V^2 and Closure Phase measurements
  - Study of the injection in optical fibers with partial correction in the visible

- Next : increase and stabilize injection
  - Simulation studies
  - CESAR project (Coupling Efficiency Statistical Analysis and Recording)
  - Better know-how on calibration of AO data

Thank you for your attention

Bonus slides

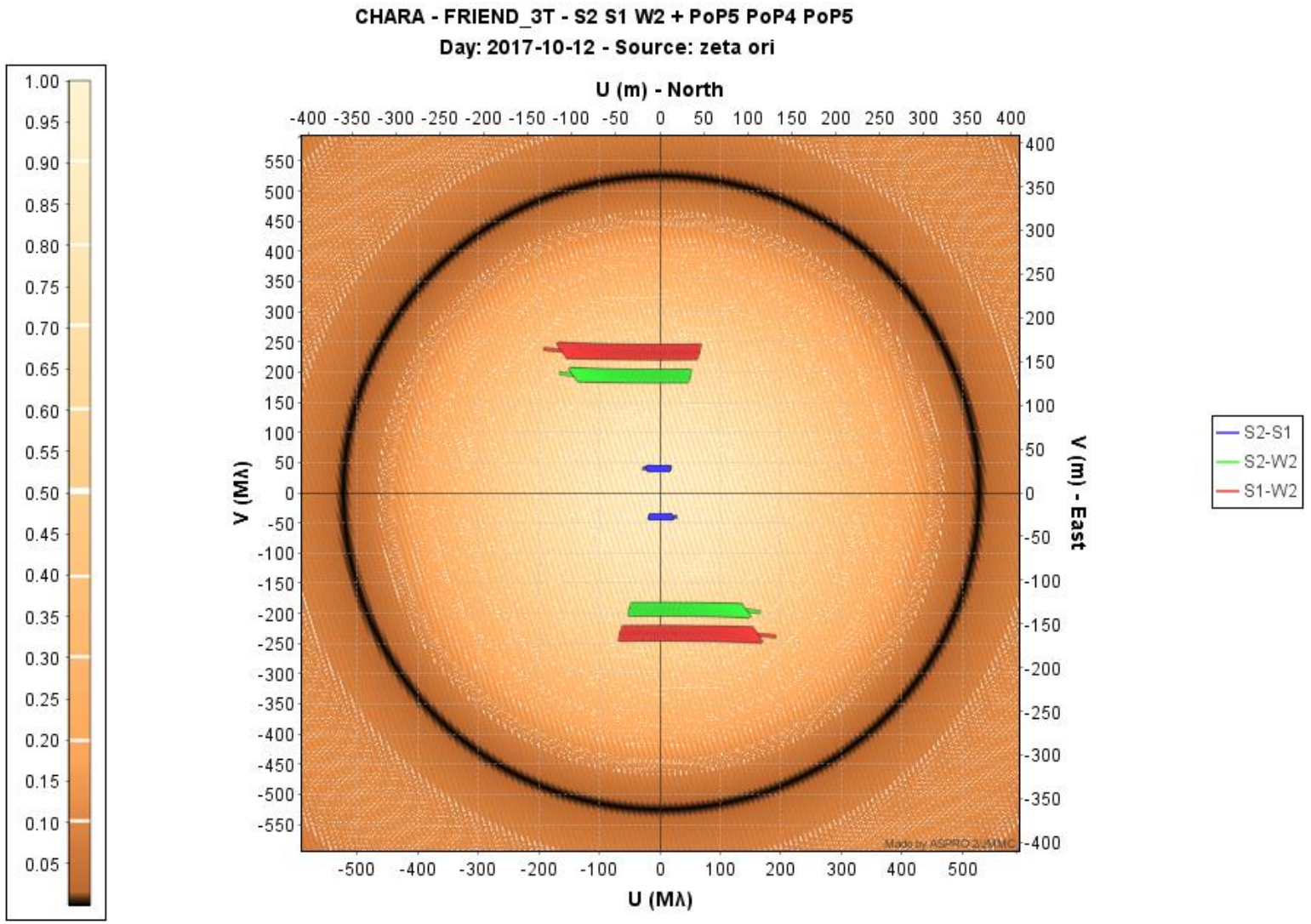
Short presentation of FRIEND prototype



$$< |V|^2 >= \frac{< E_{HF} >}{\int_{\Delta\lambda} \kappa(\lambda) \int_{\Delta x} < P_1(\lambda, x) P_2(\lambda, x) > dx d\lambda}$$

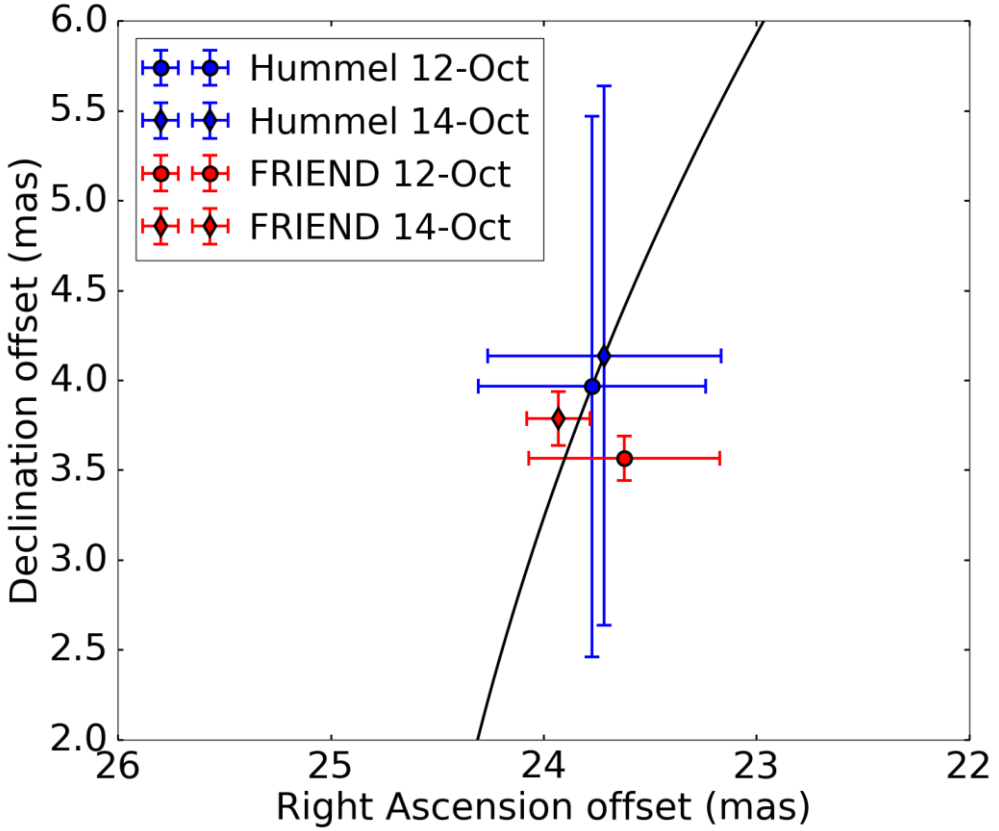
$$< B_{0,u,v} >=< B_{1,u,v} > -\alpha < \left(|C_u|^2 + |C_v|^2 + \left|C_{u,v}\right|^2 \right) > +\beta N$$

On-sky validation of FRIEND

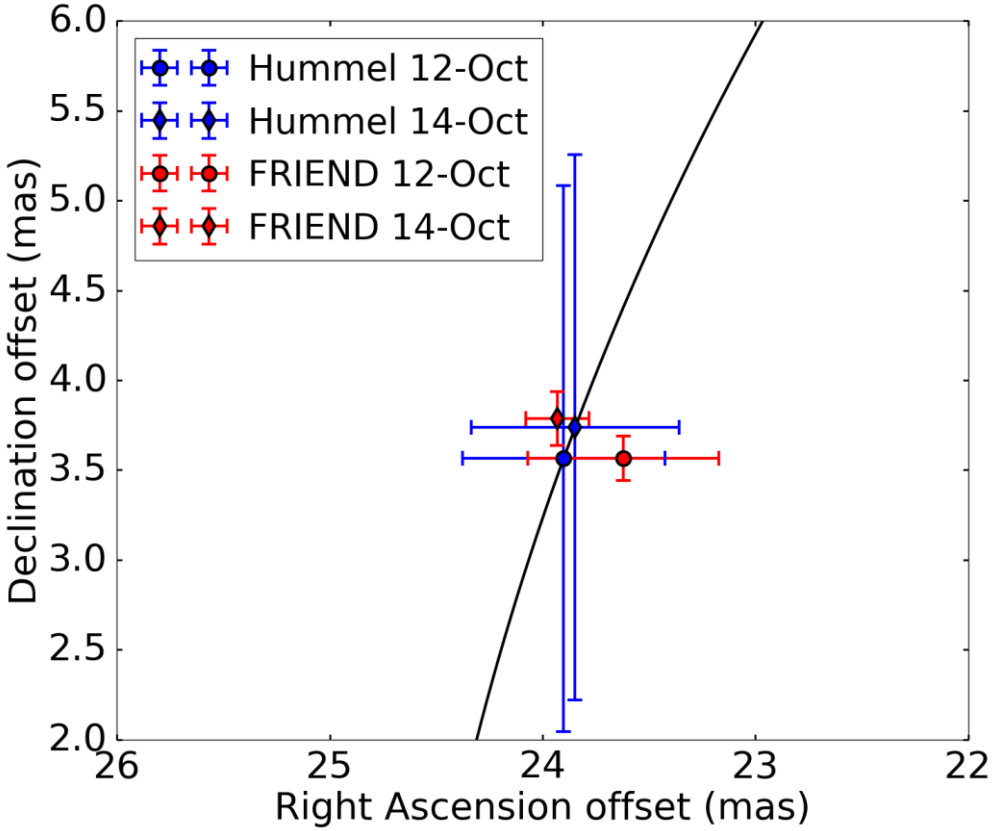


On-sky validation of FRIEND

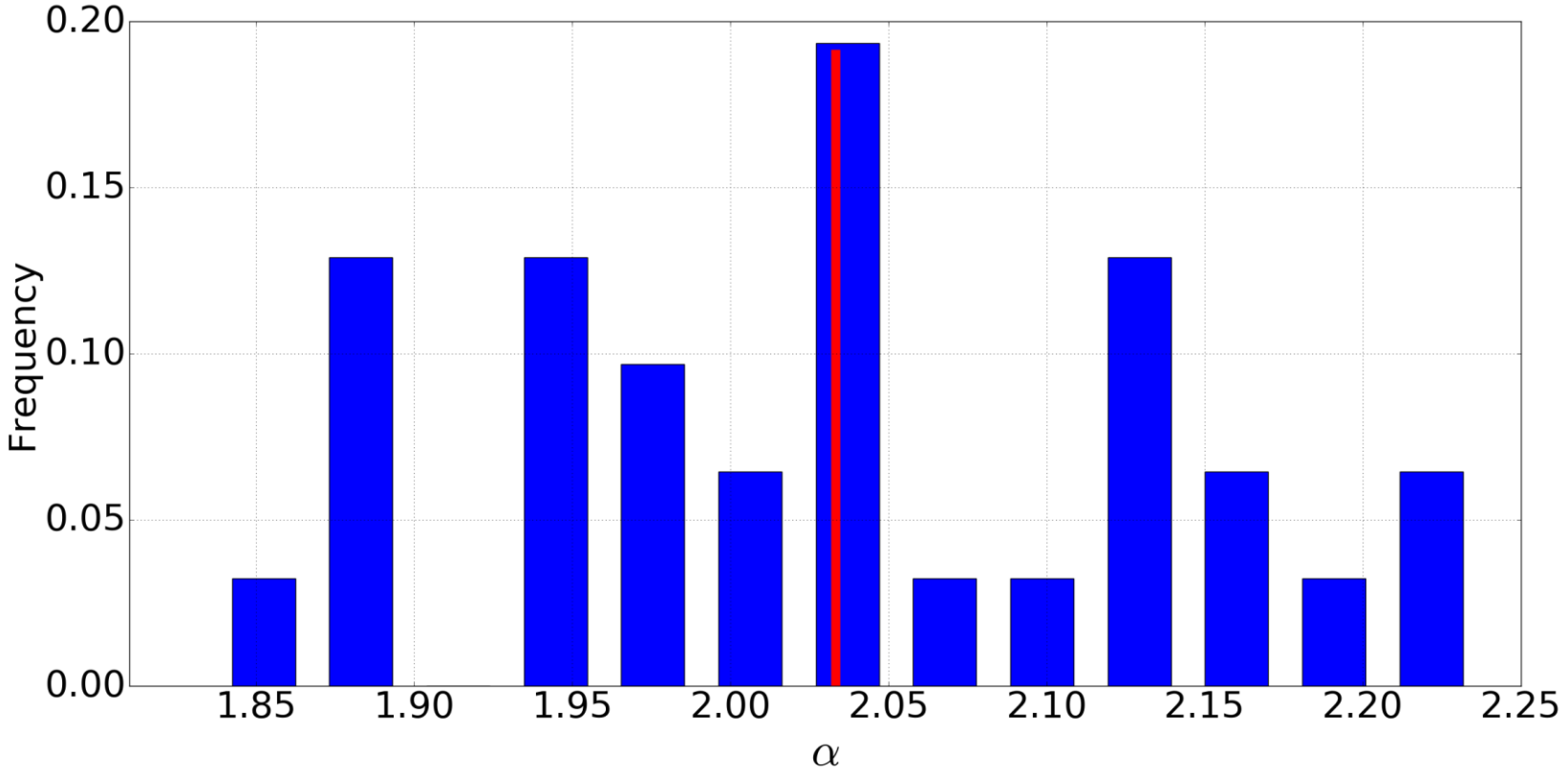
- Old period P = 2687.7 ± 7.0 d
- Old epoch (JD) T0 = 2452734.2 ± 9.0



- New period P = 2688.9
- New epoch (JD) T0 = 2452735.8



$$< B_{0,u,v}>=< B_{1,u,v}> -\alpha < \left(|C_u|^2 + |C_v|^2 + \left|C_{u,v}\right|^2\right) > +\beta N, \alpha = 2$$ (Basden&Haniff 2004)

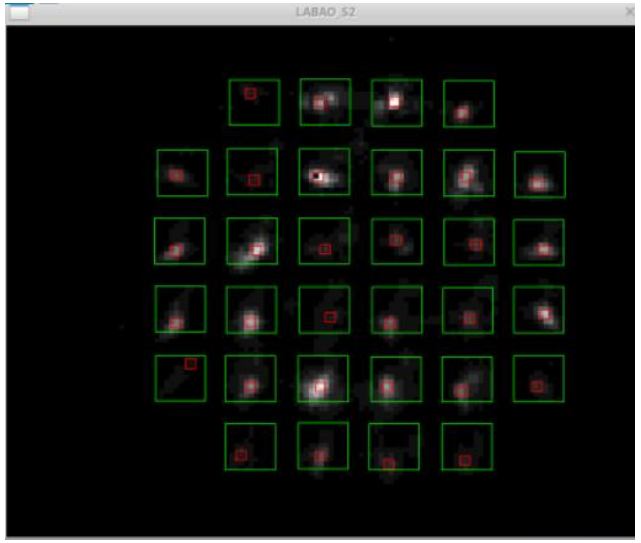


Injection into optical fibers with AO

Measuring coupling efficiency

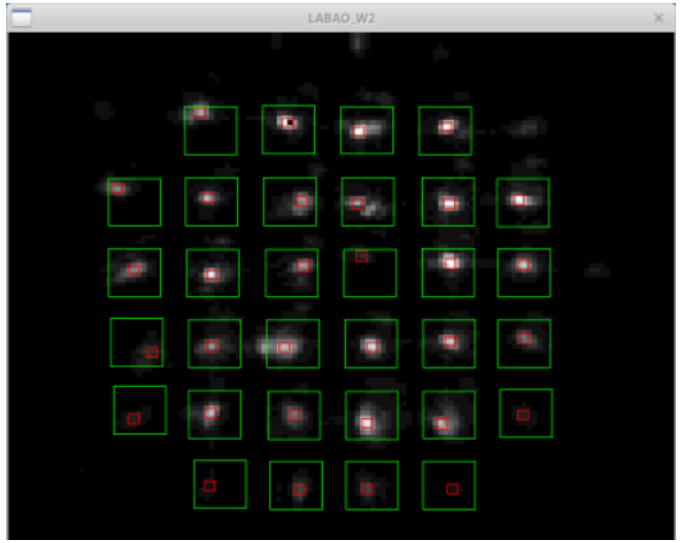
- Measuring photometry on FRIEND ($\lambda = 690\ nm$) for W2
- $N_{W2} = QE\ S_{tel}\ \delta\lambda\ DIT\ \phi_0\ 10^{-0.4mag}\ t_{FRIEND}\ t_{OA}\ \boldsymbol{t_{CHARA,W2}}\ \boldsymbol{\rho}$
- $\boldsymbol{t_{CHARA,W2}}$?
  - $\rho = \rho_0 Sr, \rho_0 = 0.69$ (Ruillier 1998)
  - OL, r_0 = 14 cm @690 nm => $S \simeq 2\%$ => $\rho \simeq 1.4\%$
  - $\boldsymbol{t_{CHARA,W2}} = 2.1\%$
- Deduce coupling efficiency (CE) $\boldsymbol{\rho}$

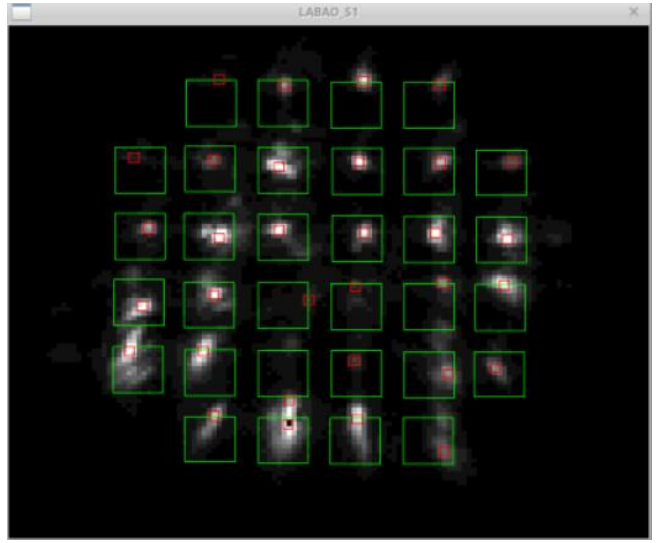
Injection into optical fibers with AO



S2
(lack of pupils)

W2
(aligned)





S1
(misaligned)