SOUL

Single Conjugated Adaptive Optics Upgrade for LBT

Presented by: E. Pinna[1]

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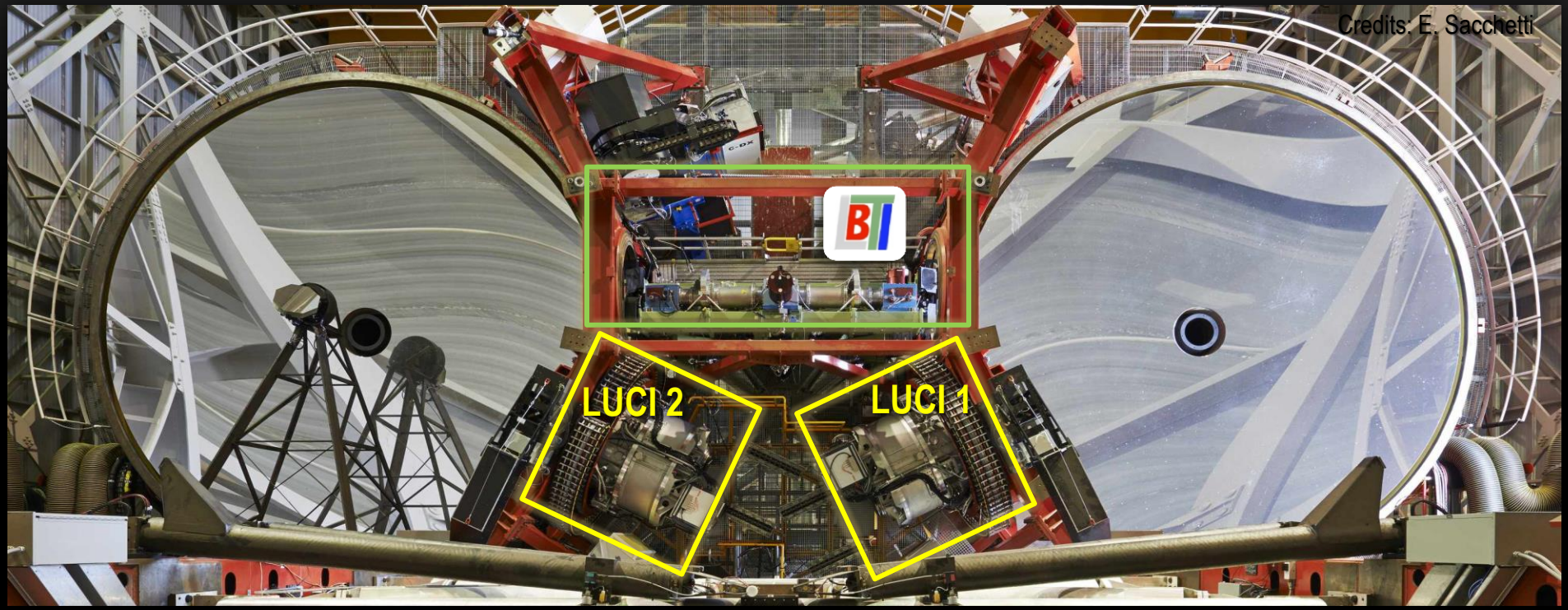
ADONI 2016 - L'Ottica Adattiva in Astronomia in Italia
Firenze 12-14 aprile, 2016

THE SCAO SYSTEMS ON THE LBT

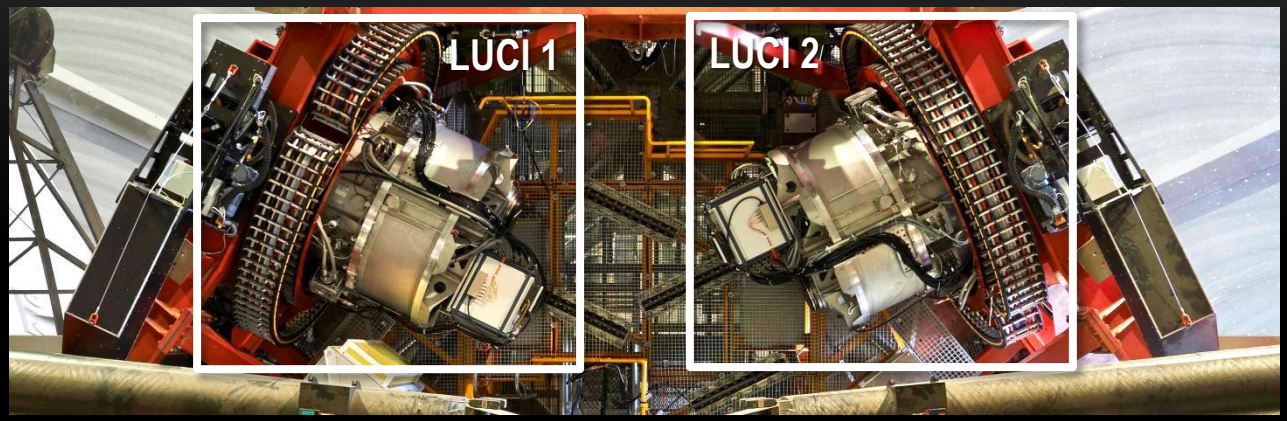


SCAO systems

2x systems (S. Esposito, PI)
+ LUCI (W. Seyfert, PI)
2x Spectro-imager J-H-K

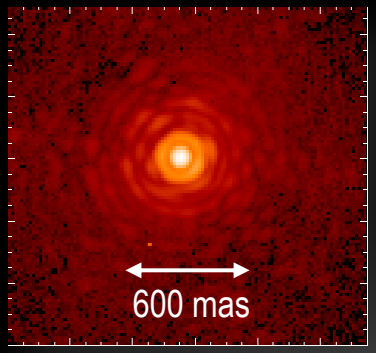
2x systems feeding LBTI (P. Hinz, PI)
Imager L' M' - Fizeau interferometer - Nulling interferometer
Soon feeding SHARK-NIR and V-SHARK

LUCI1 AND LUCI2 + AO COMMISSIONING NOW!



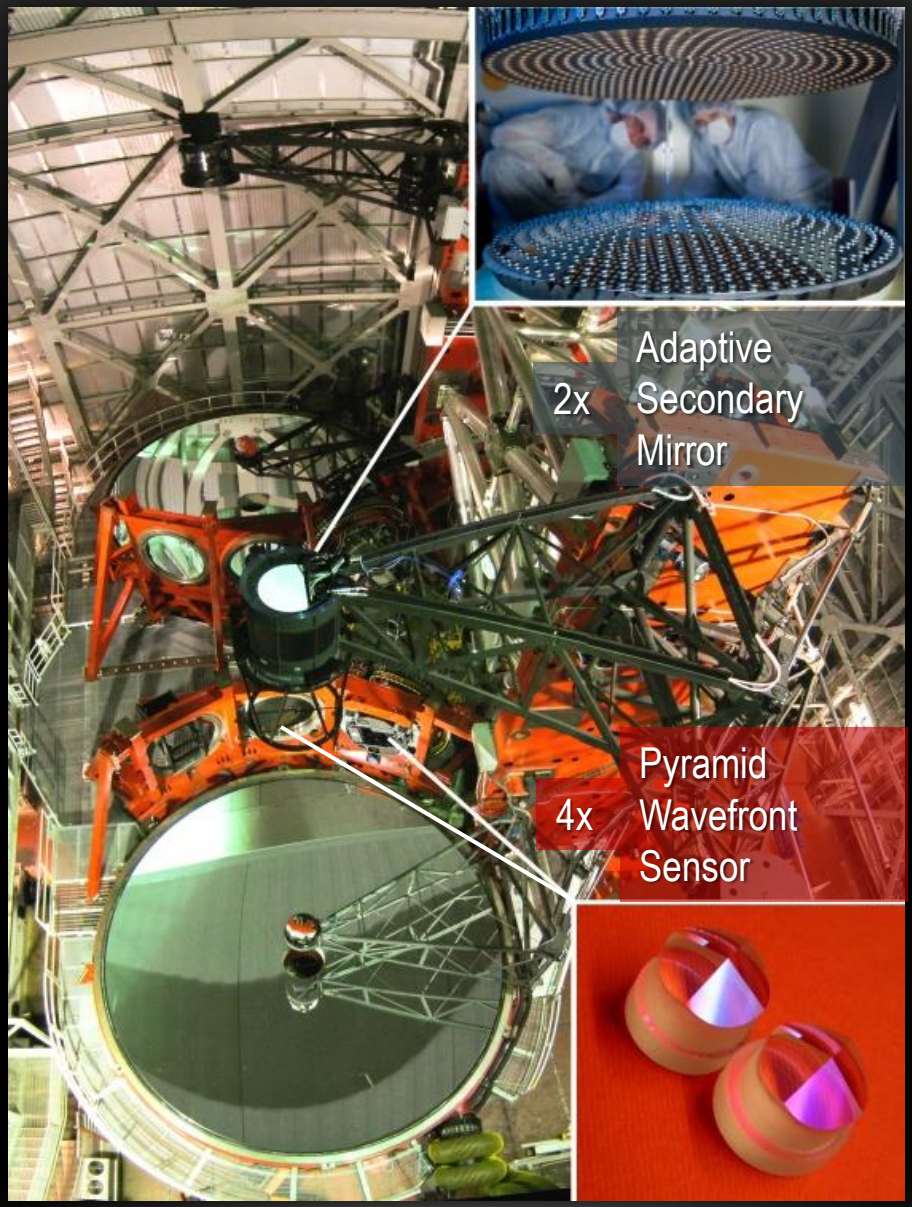
Spectro-imager J-H-K AO assisted offered to the coomunity in 2016B

LUCI Camera J-H-K		platescale		
N3.75	Imaging		0.12”/pix	GLAO Assisted with ARGOS (2016B)
N1.8	LSS + MOS	0.25”/pix		
N30	Imaging + LSS		0.015”/pix	XAO Assisted with FLAO (2016B)



ONSKY LUCI2-N30 + FLAO
SR (BrG) = 75%
Seeing = 0.86”

THE SCAO SYSTEMS ON THE LBT



SCIENCE WITH LBT (+MAGAO) SCAO SYSTEMS

FLAO + LUCI

2016...

2015

2014

2013

FLAO + PISCES

2012

1. **Rodigas**, Timothy J., et al.; MagAO Imaging of Long-period Objects (MILO). I. A Benchmark M Dwarf Companion Exciting a Massive Planet around the Sun-like Star HD 7449. ; ApJ , 818, 106.(2016)
2. **Schlieder**, Joshua E., et al.; The LEECH Exoplanet Imaging Survey: Orbit and Component Masses of the Intermediate-age, Late-type Binary NO UMa. ; ApJ , 818, 1.(2016)
3. **Skemer**, Andrew J., et al.; The LEECH Exoplanet Imaging Survey: Characterization of the Coldest Directly Imaged Exoplanet, GJ 504 b, and Evidence for Superstellar Metallicity. ; ApJ , 817, 166.(2016)
4. **Cesaroni**, R., et al.; Star and jet multiplicity in the high-mass star forming region IRAS 05137+3919. ; A&A , 581, A124.(2015)
5. **Conrad**, Albert, et al.; Spatially Resolved M-band Emission from Io's Loki Patera-Fizeau Imaging at the 22.8 m LBT. ; AJ , 149, 175.(2015)
6. **Morzinski**, Katie M., et al.; Magellan Adaptive Optics First-light Observations of the Exoplanet beta; Pic b. II. 3-5 um Direct Imaging with MagAO+Clio, and the Empirical Bolometric Luminosity of a Self-luminous Giant Planet. ; ApJ , 815, 108.(2015)
7. **Testi,** L., et al.; Hunting for Planets in the HL Tau Disk. ; ApJ , 812, L38.(2015)
8. **Monelli,** M., et al.; The Absolute Age of the Globular Cluster M15 Using Near-infrared Adaptive Optics Images from PISCES/LBT.. ; ApJ , 812, 25.(2015)
9. **Maire,** A.-L., et al.; The LEECH Exoplanet Imaging Survey. Further constraints on the planet architecture of the HR 8799 system (Corrigendum). ; A&A , 579, C2.(2015)
10. **Defrère,** D., et al.; First-light LBT Nulling Interferometric Observations: Warm Exozodiacal Dust Resolved within a Few AU of η Crv. ; ApJ , 799, 42.(2015)
11. **Rodigas,** Timothy J., et al.; On the Morphology and Chemical Composition of the HR 4796A Debris Disk. ; ApJ , 798, 96.(2015)
12. **Wu,** Ya-Lin, et al.; New Extinction and Mass Estimates of the Low-mass Companion 1RXS 1609 B with the Magellan AO System: Evidence of an Inclined Dust Disk. ; ApJ , 807, L13.(2015)
13. **Sallum,** S., et al.; Accreting protoplanets in the LkCa 15 transition disk. ; Natur , 527, 342-344.(2015)
14. **Sallum,** S., et al.; New Spatially Resolved Observations of the T Cha Transition Disk and Constraints on the Previously Claimed Substellar Companion. ; ApJ , 801, 85.(2015)
15. **Wu**, Ya-Lin, et al.; New Extinction and Mass Estimates from Optical Photometry of the Very Low Mass Brown Dwarf Companion CT Chamaeleontis B with the Magellan AO System. ; ApJ , 801, 4.(2015)
16. **Arcidiacono**, C., et al.; A high-resolution image of the inner shell of the P Cygni nebula in the infrared [Fe II] line. ; MNRAS , 443, 1142-1150.(2014)
17. **Bailey,** Vanessa, et al.; HD 106906 b: A Planetary-mass Companion Outside a Massive Debris Disk. ; ApJ , 780, L4.(2014)
18. **Skemer**, Andrew J., et al.; Directly Imaged L-T Transition Exoplanets in the Mid-infrared. ; ApJ , 792, 17.(2014)
19. **Males,** Jared R., et al.; Magellan Adaptive Optics First-light Observations of the Exoplanet β Pic B. I. Direct Imaging in the Far-red Optical with MagAO+VisAO and in the Near-ir with NICI. ; ApJ , 786, 32.(2014)
20. **Matthews,** Christopher T., et al.; Mid-infrared High-contrast Imaging of HD 114174 B: An Apparent Age Discrepancy in a "Sirius-like" Binary System. ; ApJ , 783, L25.(2014)
21. **Close,** L.~M., et al.; Discovery of Halpha; Emission from the Close Companion inside the Gap of Transitional Disk HD 142527. ; ApJ , 781, L30.(2014)
22. **Bonnefoy**, M., et al.; Characterization of the gaseous companion κ Andromedae b. New Keck and LBTI high-contrast observations. ; A&A , 562, A111.(2014)
23. **Bailey,** Vanessa, et al.; A Thermal Infrared Imaging Study of Very Low Mass, Wide-separation Brown Dwarf Companions to Upper Scorpius Stars: Constraining Circumstellar Environments. ; ApJ , 767, 31.(2013)
24. **Cesaroni**, R., et al.; A close-up view of a bipolar jet: Sub-arcsecond near-infrared imaging of the high-mass protostar IRAS 20126+4104. ; A&A , 549, A146.(2013)
25. **Close,** L.~M., et al.; Diffraction-limited Visible Light Images of Orion Trapezium Cluster with the Magellan Adaptive Secondary Adaptive Optics System (MagAO). ; ApJ , 774, 94.(2013)
26. **Esposito,** S., et al.; LBT observations of the HR 8799 planetary system. First detection of HR 8799e in H band. ; A&A , 549, A52.(2013)
27. **Follette,** Katherine B., et al.; The First Circumstellar Disk Imaged in Silhouette at Visible Wavelengths with Adaptive Optics: MagAO Imaging of Orion 218-354.; ApJ , 775, L13.(2013)
28. **Wu,** Y.-L., et al.; High Resolution Hα Images of the Binary Low-mass Proplyd LV 1 with the Magellan AO System. ; ApJ , 774, 45.(2013)
29. **Skemer,** Andrew J., et al.; First Light LBT AO Images of HR 8799 bcde at 1.6 and 3.3 μm: New Discrepancies between Young Planets and Old Brown Dwarfs. ; ApJ , 753, 14.(2012)
30. **Rodigas,** Timothy J., et al.; The Gray Needle: Large Grains in the HD 15115 Debris Disk from LBT/PISCES/Ks and LBTI/LMIRcam/L' Adaptive Optics Imaging. ; ApJ , 752, 57.(2012)
31. **Close,** L.~M., et al.; High-resolution Images of Orbital Motion in the Orion Trapezium Cluster with the LBT AO System. ; ApJ , 749, 180.(2012)

THE SOUL UPGRADE

Wavefront sensor detector

Early 2000 *Now available*

Spec/camera	CCD39	Ocam2k
Chip size [pix]	80x80	240x240
Pixel side [μm]	24	24
RON [e-]	10.5 @1kfps	0.37 @2kfps and G=400
Excess noise	NO	$\sqrt{2}$
Max. framerate [fps]	1000	3625 (ROI 128x128)
Min. read-out time [ms]	0.95	0.24 (ROI 128x128)

Techincal omprovement	Benefits on the system	Benefits on the correction
• Bigger frame	More corrected modes (higher pup sampl + less RON)	-> Better correction at shorter wavelength
• Less RON	Less aliasing (higher pup sampling)	-> Improve contrast at all wavelengths
	Lower noise	-> Improve sky coverage at all wavelengts
• Faster framerate	Faster loop (faster camera + less RON)	-> Better vibration rejection

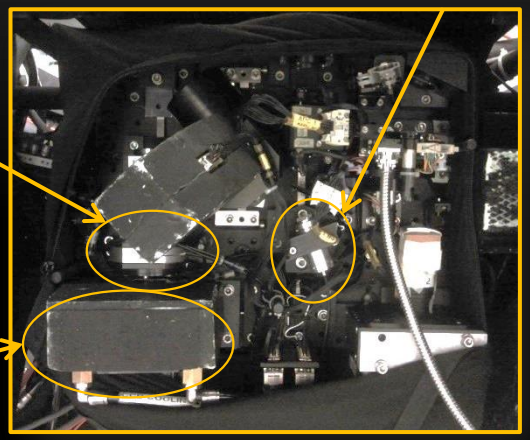
THE SOUL UPGRADE

RON	= 0.3 e-
Max samp.	= 40x40 Sub-Ap
Framerate	= 1.5kHz (2.0kHz goal)
Read Out Time	= 0.24ms

Wavefront Sensor board

Tip tilt mirror
Faster framerate

Camera lens
higher pupil sampling



New WFS camera

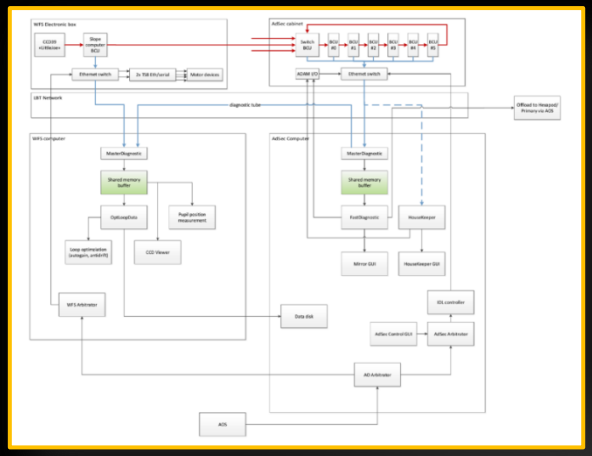
WFS electronics

Slope Computer
Higher #slopes
Different camera
Higher framerate

Adaptivie Secondary Mirror Corrector + RTC

No Hardware modification
Possible Firmware changes required for faster framerate

Control Software



# of slopes

Arbitrators
WFS control SW
ASM Control
Master diagnostic
Elaboration library

Preliminary Design Review
Approved on March 31st

THE TEAM

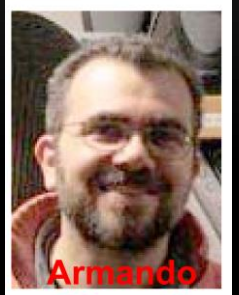
Simulations Control

Simulations

Opto-mechanics System

ASM Software

Management ASM



ASM WFS TTM

Management

Software

Management

Software

Opto-mechanics

Software ? Hiring!

Contact me: pinna@arcetri.astro.it

ERROR BUDGET: PARAMETER OPTIMIZATION

Fainter guide star

CCD39 – 30x30 SAs

GS Rmag	Samp.	Loop freq [Hz]	Corrected modes	gain	WF RMS [nm]
7.5	30.0	1000	663	0.55	91.8
8.5	30.0	1000	663	0.50	95.3
9.5	30.0	400	634	1.00	107.2
10.5	30.0	300	443	1.40	123.5
11.5	30.0	300	331	1.10	159.4
12.5	15.0	300	147	1.10	185.0
13.5	15.0	200	145	1.40	213.0
14.5	10.0	200	77	1.00	286.2
15.5	10.0	100	58	1.50	362.9
16.5	10.0	50	54	1.80	460.9
17.5	7.5	50	34	1.20	631.5
18.5	7.5	50	11	0.70	897.3

Seeing = 0.8asec
L0 = 40m
wind =16m/s

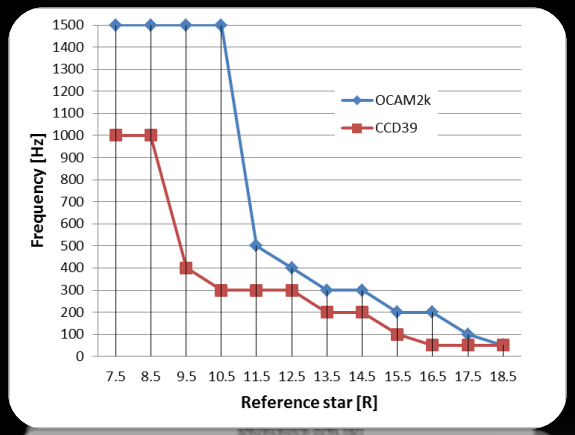
WFE sources

- Aliasing
- Noise
- Time
- Fitting

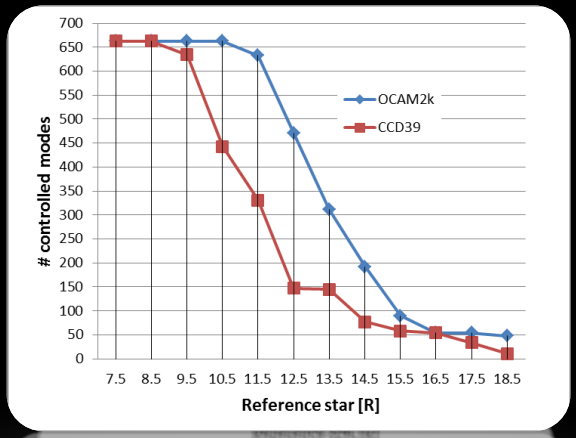
OCAM2k – 40x40 SAs

GS Rmag	Samp.	Loop freq [Hz]	Corrected modes	gain	WF RMS [nm]
7.5	40.0	1500	663	0.50	84.0
8.5	40.0	1500	663	0.50	85.6
9.5	40.0	1500	663	0.40	88.8
10.5	40.0	1500	663	0.35	96.0
11.5	40.0	500	633	0.90	112.0
12.5	40.0	400	471	1.00	133.9
13.5	40.0	300	312	1.20	170.3
14.5	20.0	300	192	0.90	218.1
15.5	13.3	200	90	1.00	290.3
16.5	10.0	200	54	0.70	374.5
17.5	10.0	100	54	0.90	463.4
18.5	10.0	50	48	1.20	636.8

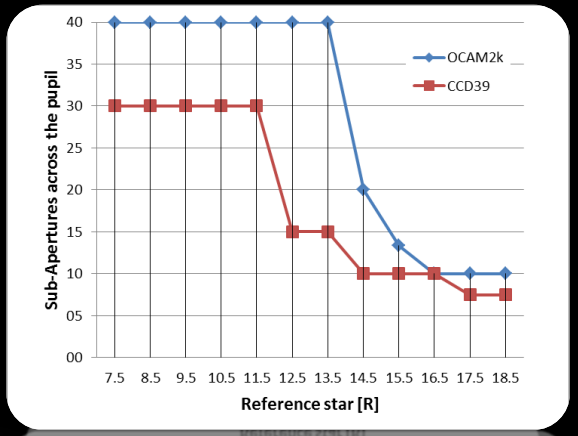
Loop frequency



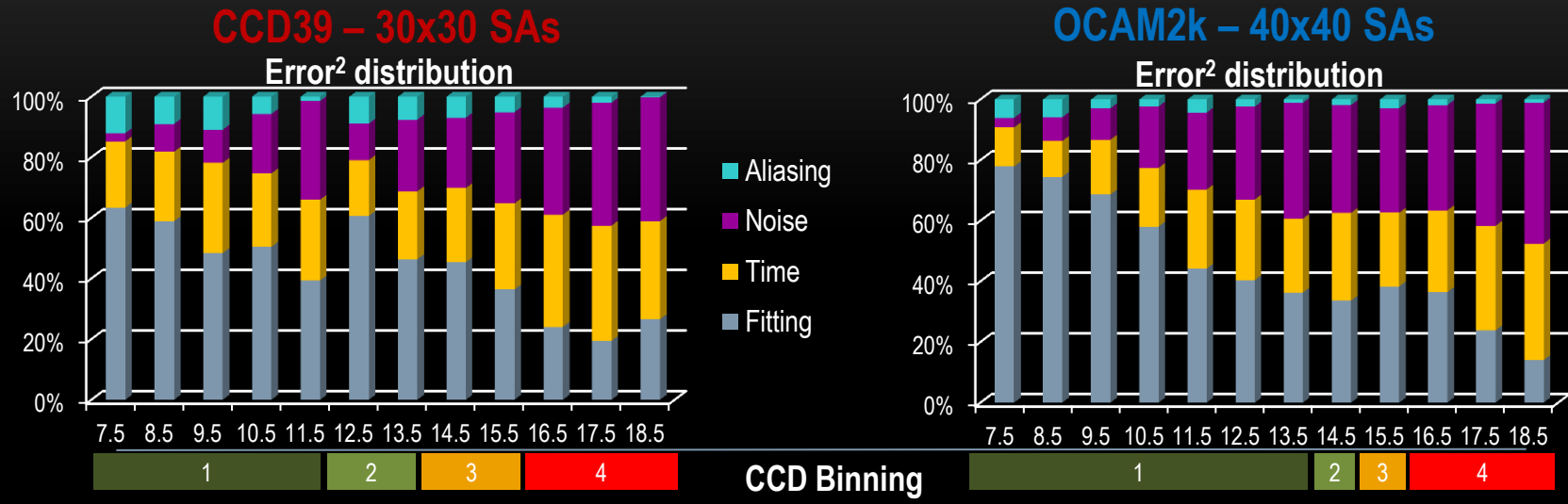
Controlled modes



Pupil sampling

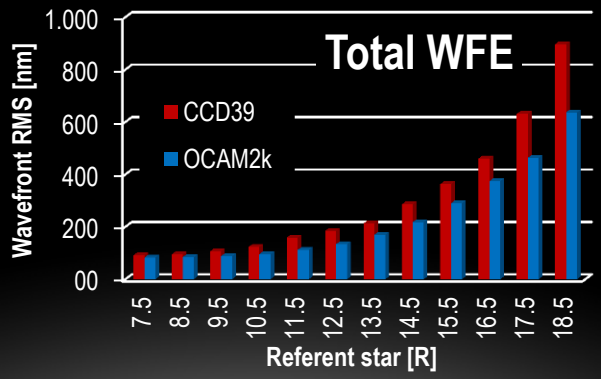


WAVEFRONT ERROR CONTRIBUTIONS



Bright end:

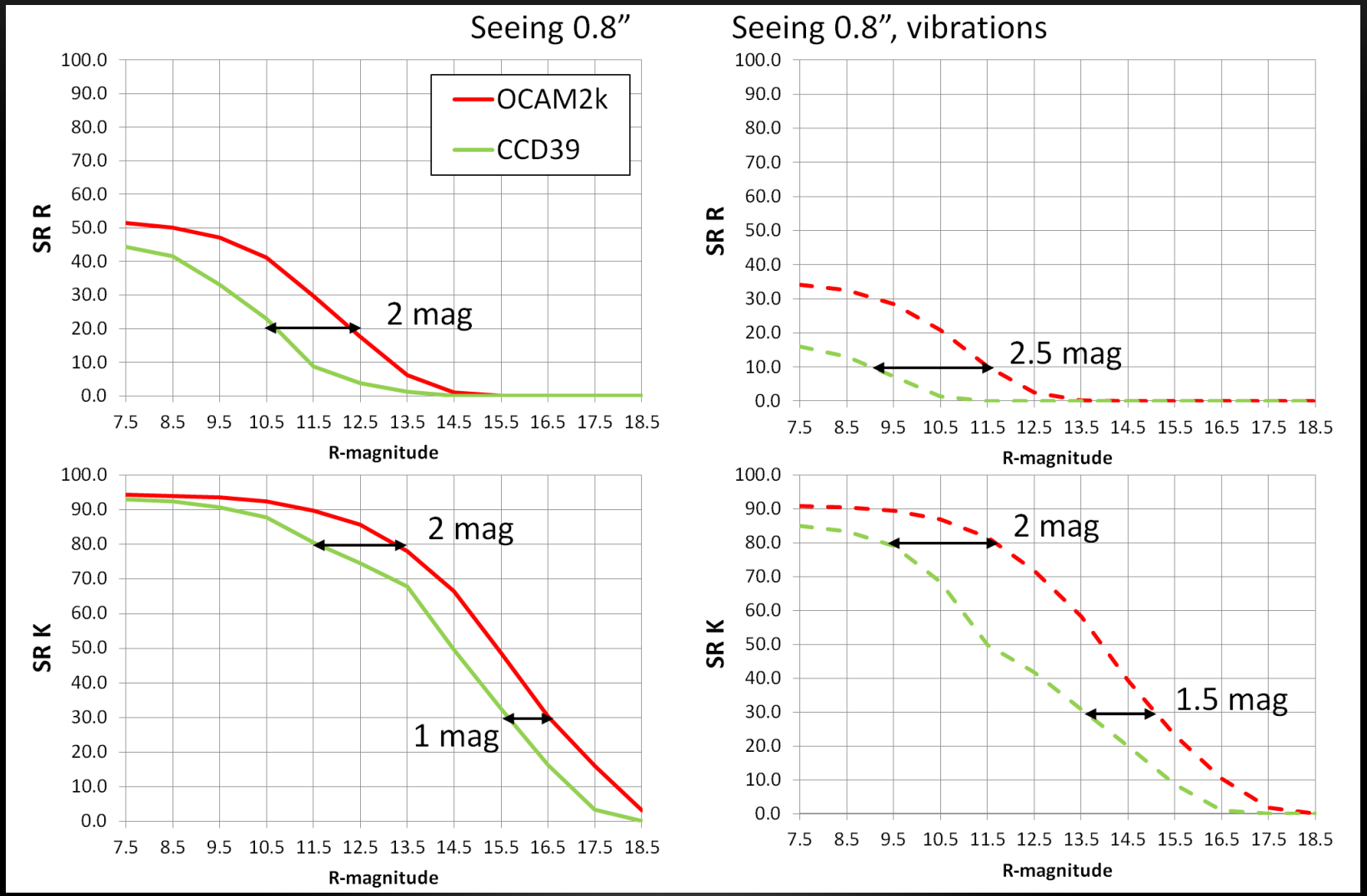
- Fitting error here considered constant (# of available actuators)
- RON not impacting performance (bright)
- Alising reduced (higher pup sampling)
- **Loop delay reduced from 2.74ms to 1.97ms**



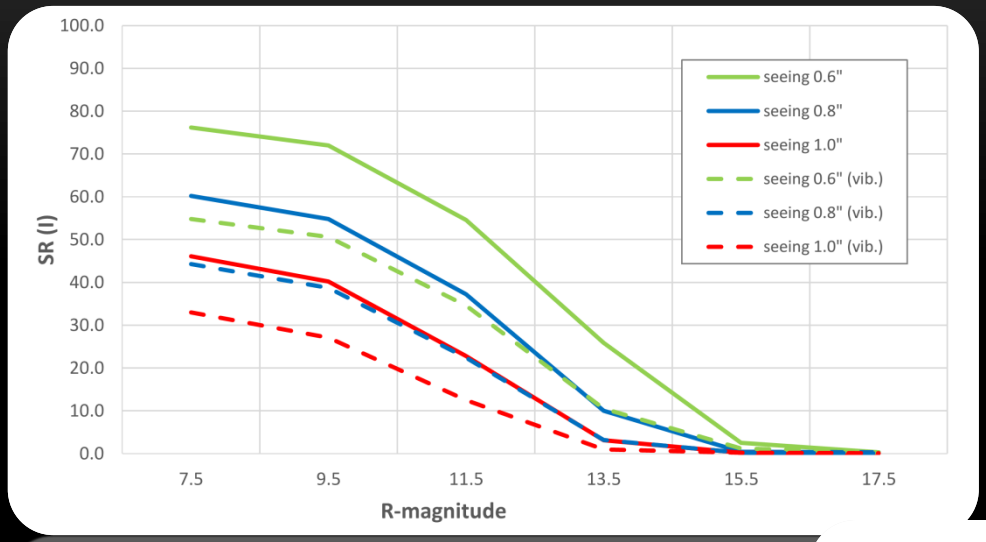
Fain end:

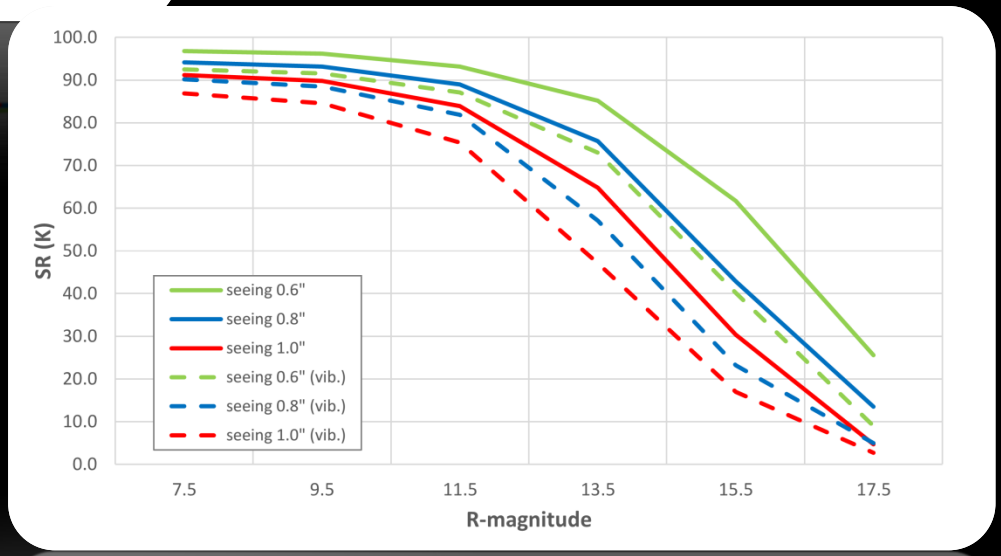
- Fitting error improved
- RON reduced to 0
- Alising reduced (higher pup sampling)
- Loop frequency always higher

STREHL RATIOS IMPROVEMENT (E2E)



PERFORMANCES VS. SEEING (E2E)



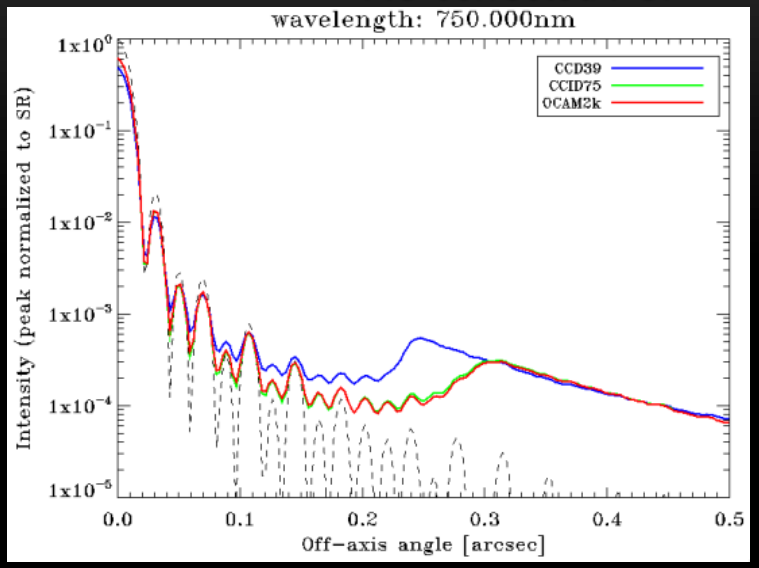


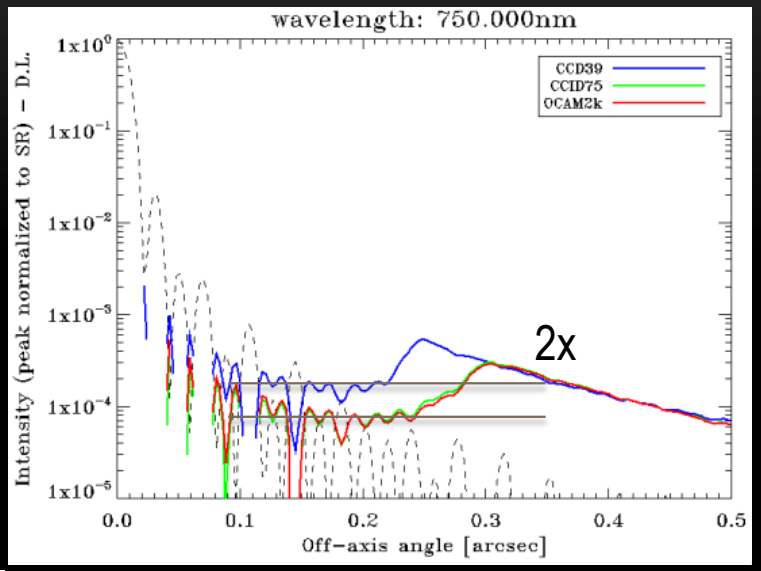
CONTRAST (E2E SIMULATION)

AO corrected PSF

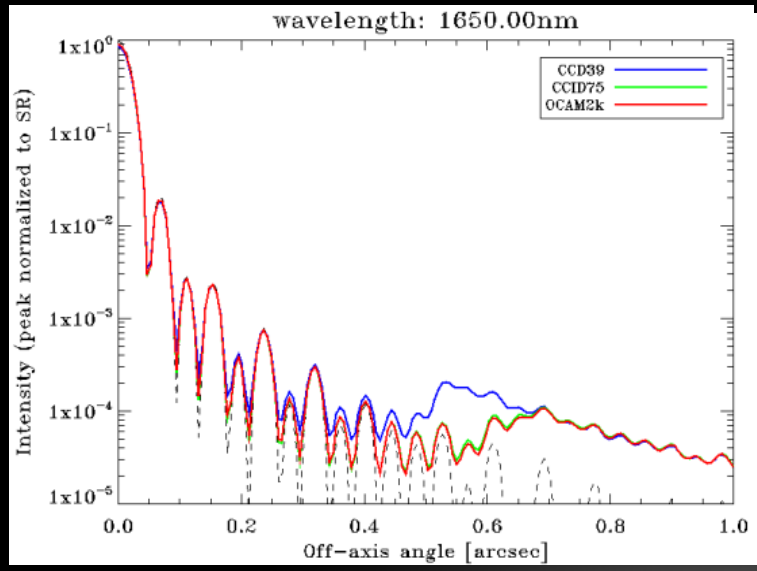
AO halo

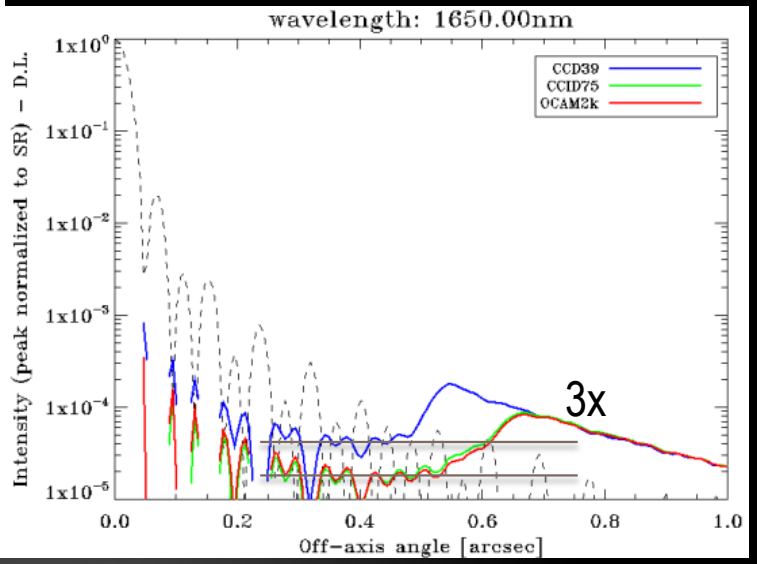
Wavelength = 750nm





Wavelength = 1650nm

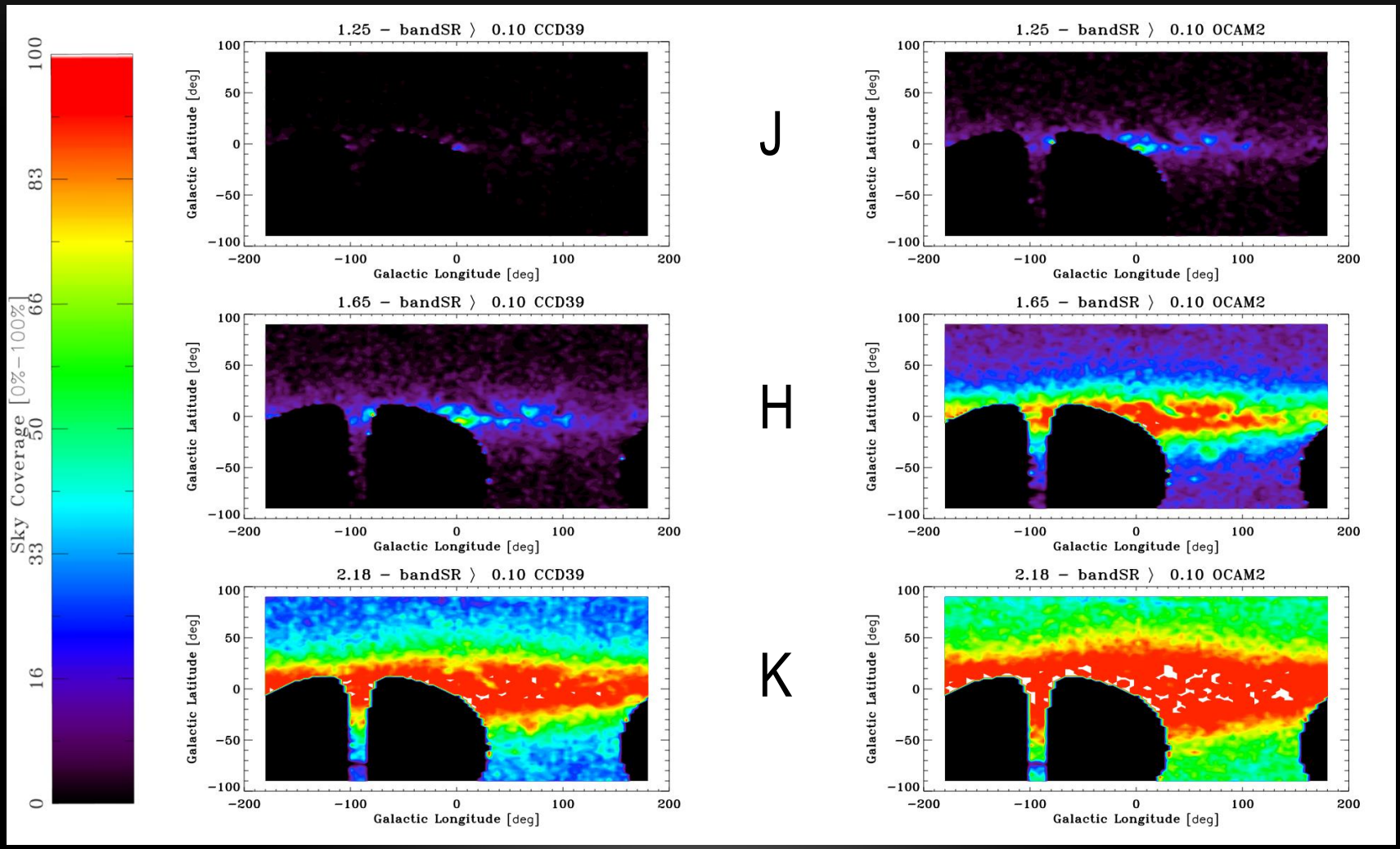




Bright end
Seeing=0.8”

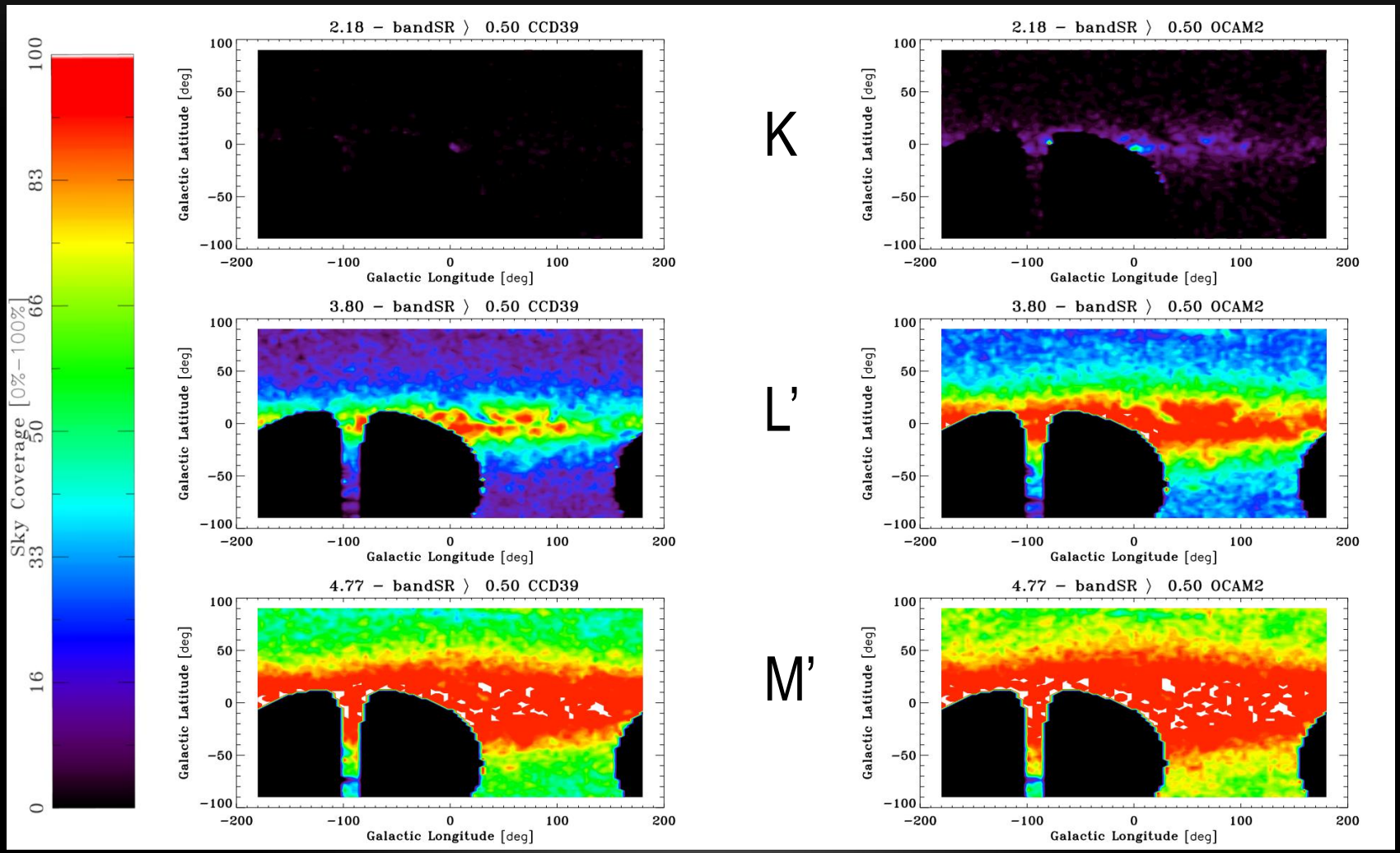
SKYCOVERAGE (E2E SIMULATION)

FLAO SR threshold = 10% SOUL



SKYCOVERAGE (E2E SIMULATION)

FLAO SR threshold = 50% SOUL

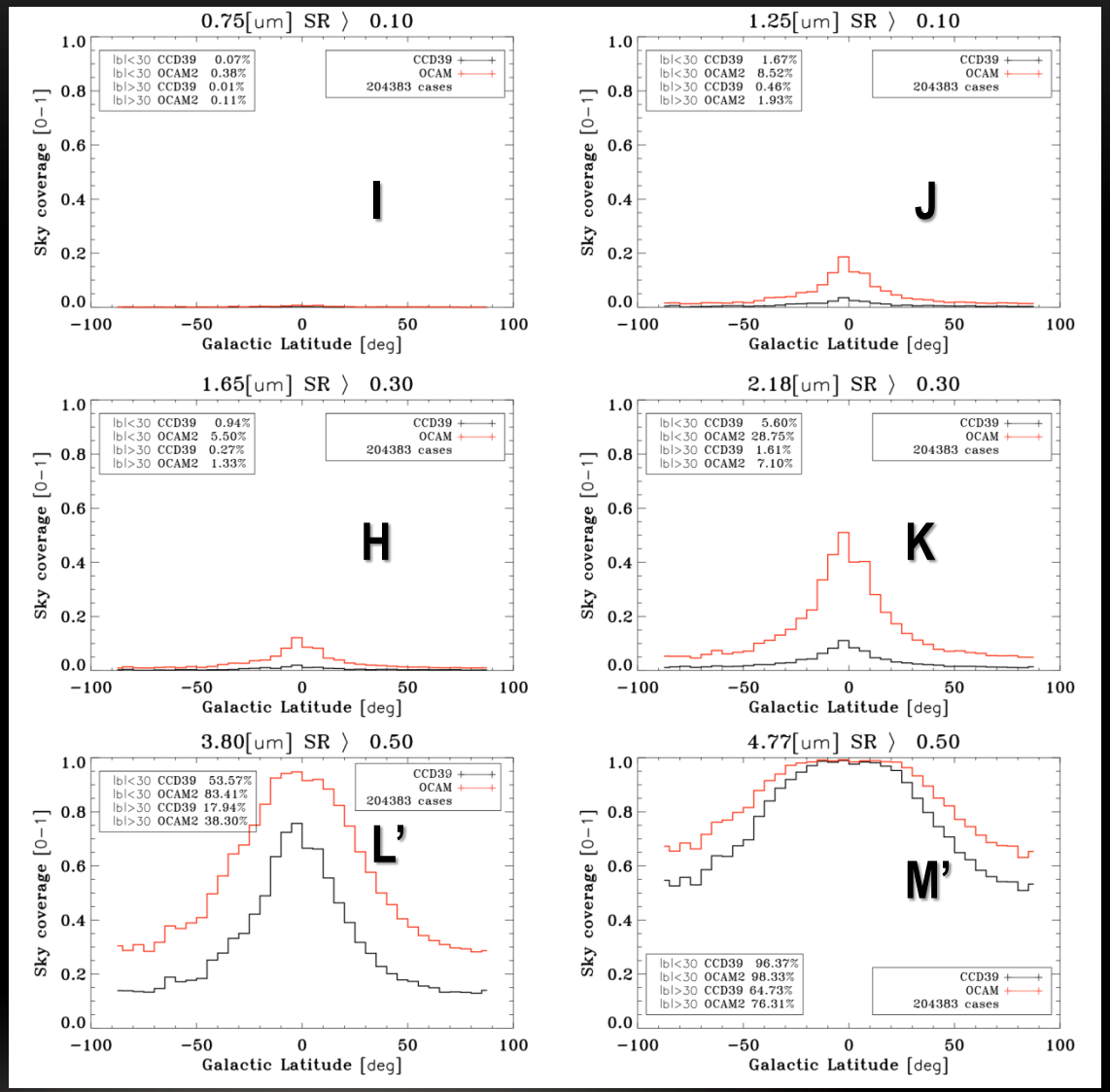


SKY COVERAGE LATITUDE PLOT

SR LIMIT 10% GAIN 5X

SR LIMIT 30% GAIN 2X

SR LIMIT 50% GAIN 1.15X @|b|>30°



SOUL SCHEDULE

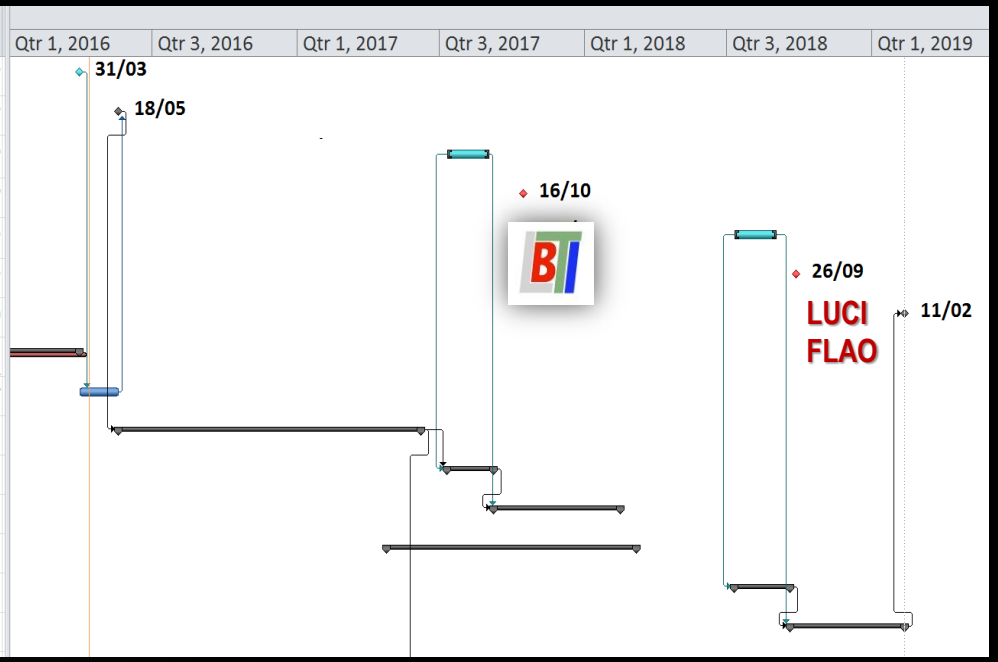
- WFS and ASM upgrade to be performed during the summer shutdown
- 1 WFS per summer shutdown drives to a 5 years project

→ **2 WFS per Summer shutdown**

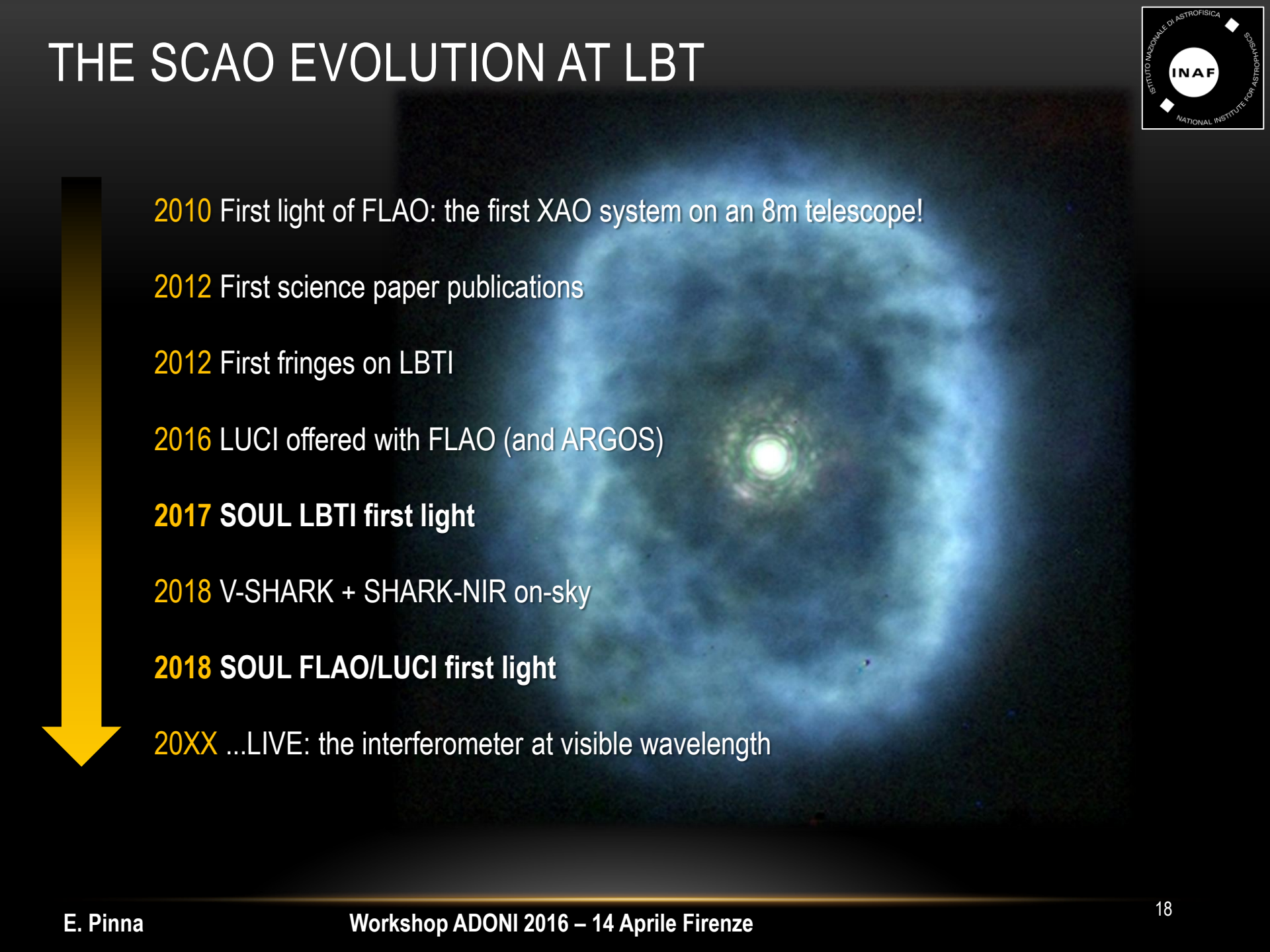
- LUCI1 and 2 + FLAO currently in commissioning
- SOUL is strategic for SHARK-NIR, V-SHARK and iLocater

→ **LBTI as first 2 systems to be upgraded**

Task Name	Start	Finish
Preliminary Design Review	*Thu 31/03/16*	*Thu 31/03/16*
M1 - AIT MoU signing	***Wed 18/05/16***	***Wed 18/05/16***
Summer shutdown 2017	*Mon 10/07/17*	*Fri 01/09/17*
Upgraded LBTIAO 1st Light	*Mon 16/10/17*	*Mon 16/10/17*
Summer shutdown 2018	*Tue 10/07/18*	*Sat 01/09/18*
Upgraded FLAO 1st Light	*Wed 26/09/18*	*Wed 26/09/18*
M4 - End of the project	***Mon 11/02/19***	***Mon 11/02/19***
Preliminary Design Study	**Fri 01/05/15**	**Wed 30/03/16**
AIT proposal and negotiation	*Thu 31/03/16*	*Wed 18/05/16*
AIT Part 1 (ASM + LBTI 1&2)	**Thu 19/05/16**	**Wed 07/06/17**
Integration and test at LBT Part 1	**Mon 10/07/17**	**Thu 07/09/17**
Commissioning Part 1	**Fri 08/09/17**	**Thu 15/02/18**
AIT Part 2 (FLAO 1&2)	**Tue 25/04/17**	**Wed 07/03/18**
Integration and test at LBT Part 2	**Tue 10/07/18**	**Tue 18/09/18**
Commissioning Part 2	**Wed 19/09/18**	**Mon 11/02/19**



THE SCAO EVOLUTION AT LBT



2010 First light of FLAO: the first XAO system on an 8m telescope!

2012 First science paper publications

2012 First fringes on LBTI

2016 LUCI offered with FLAO (and ARGOS)

2017 SOUL LBTI first light

2018 V-SHARK + SHARK-NIR on-sky

2018 SOUL FLAO/LUCI first light

20XX ...LIVE: the interferometer at visible wavelength