Tenerife 2017

L4AO

Lasers for AO

Workshop Review

Presented by Céline d'Orgeville

With contributions from:

Frédéric Vogt, Felipe Pedreros-Bustos, Joshua Hellemeier, Noelia Martínez, Gustavo Rahmer, Cristian Moreno/Eduardo Marin, Julio Castro-Almazán, Andrew Reeves, Ron Holzlöhner, Céline d'Orgeville/François Rigaut

12th Workshop on Laser Technology and Systems for Astronomical AO

12th L4AO Workshop 2017 *Instituto de Astrofísica de Canarias (La Laguna, TENERIFE, CANARY ISLANDS)*

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09:00 – 09:15	Registration and Welcome coffee	10 **G1 - Julio Castro-Almazán (IAC)** *The Natrium pipeline for absolute Na profiling*
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21:00		Conference dinner – 'El Bistró de Gamonal' - Calle Viana, 34, La Laguna

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Detection and Implications of

Laser-Induced Raman Scattering at Astronomical Observatories

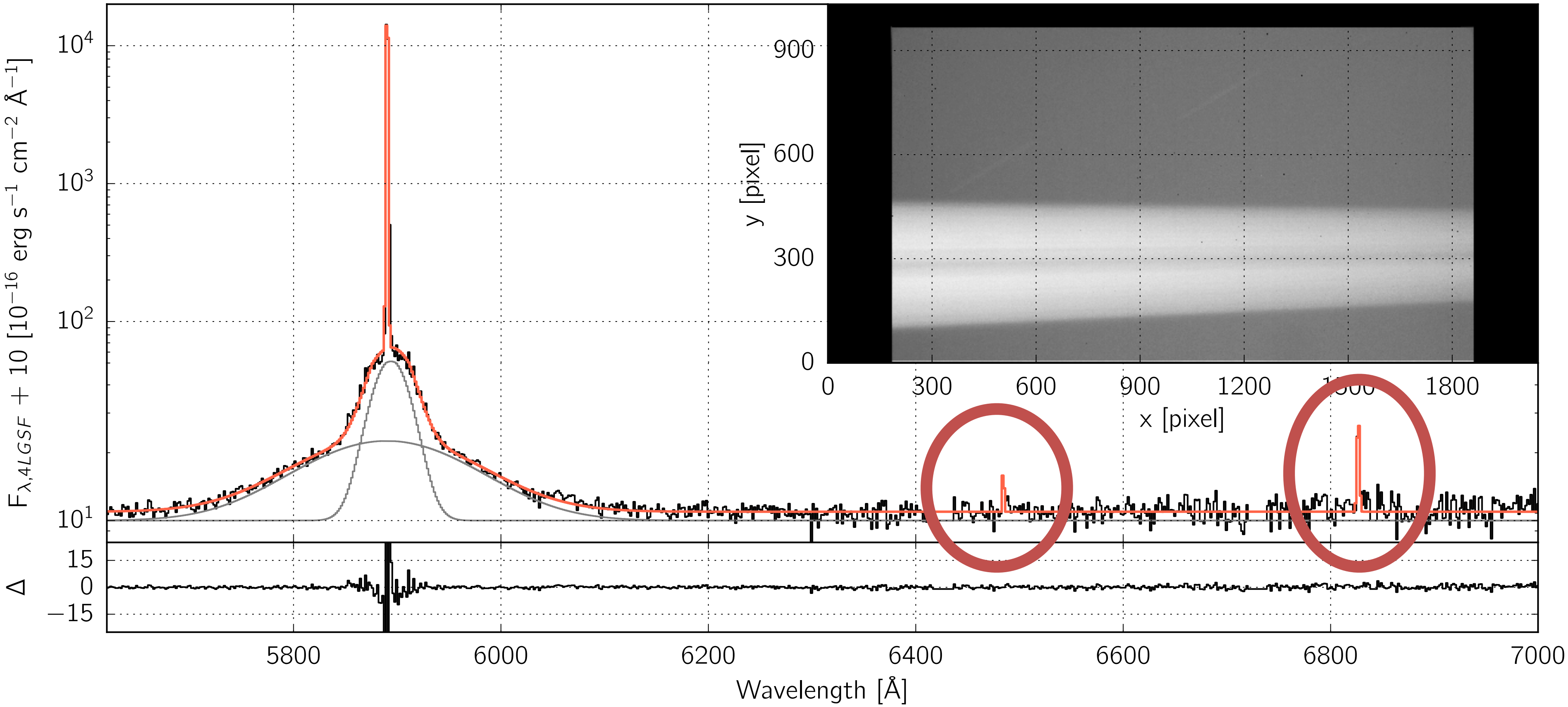
Frédéric Vogt[1] - ESO Fellow - **fvogt@eso.org**

with
D. Bonaccini Calia[2], W. Hackenberg[2], C. Opitom[1], M. Comin[2], L. Schmidtobreik[1], J. Smoker[1], I. Blanchard[1], M. Espinoza Contreras[1], I. Aranda[1], J. Milli[1], Y. L. Jaffe[1], F. Selman[1], J. Kolb[1], P. Hibon[1], H. Kuntschner[2], and P.-Y. Madec[2]

1. European Southern Observatory, Vitacura, Chile.
2. European Southern Observatory, Garching, Germany.

UT1-FORS2 view of UT4-4LGSUx

589 nm **648 nm** **683 nm**



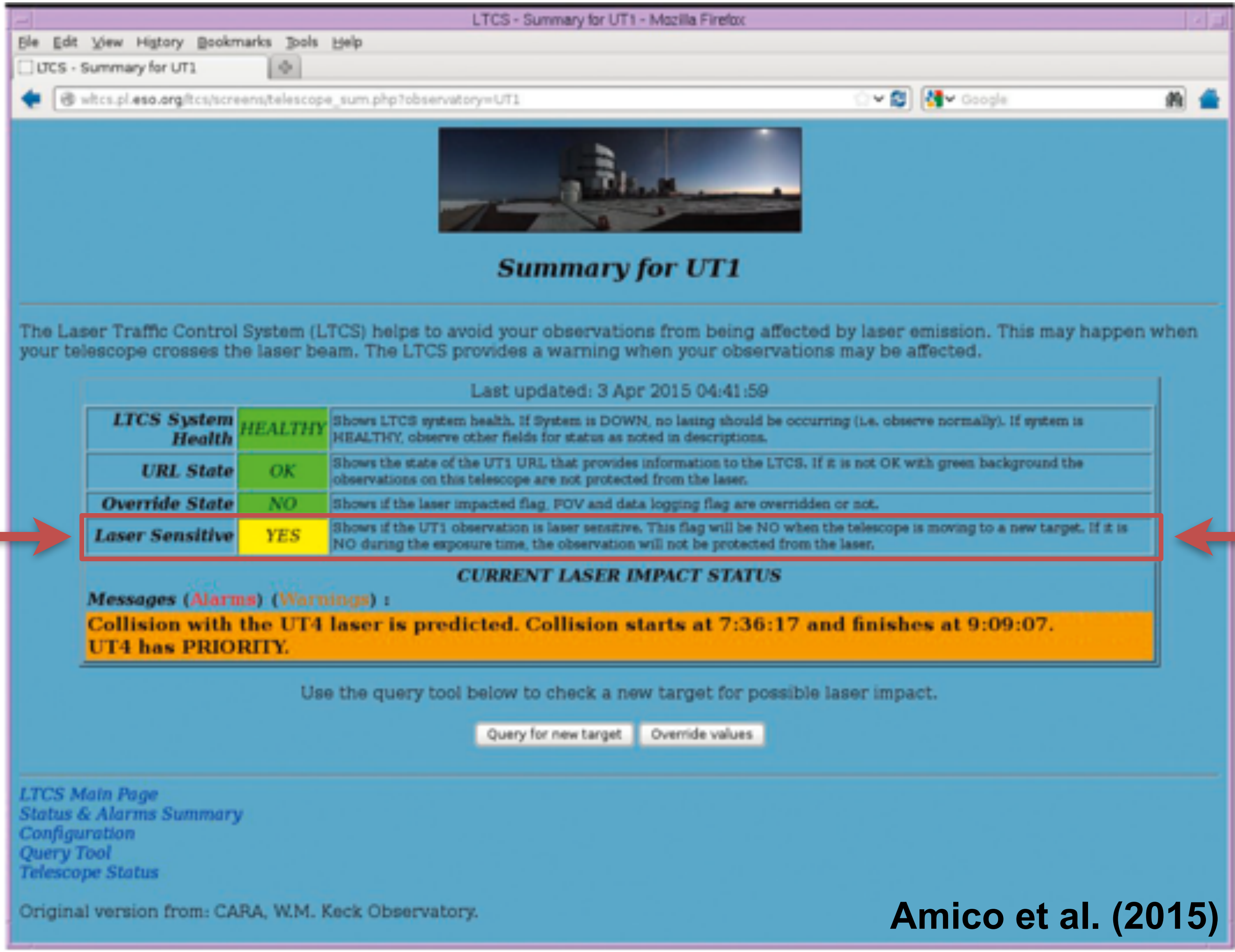
! Possible impact on laser collisions !

Laser wavelength dependant !

Table II. Wavelength of the main atmospheric, laser-induced Raman scattering lines as a function of the LGS exciting wavelength at different astronomical telescopes.

Telescope	LGS system	λ_{LGS} [nm]	CO_2 [nm]	CO_2 [nm]	$O_2(\nu_{1\leftarrow0})$ [nm]	$N_2(\nu_{1\leftarrow0})$ [nm]	CH_4 [nm]	$O_2(\nu_{2\leftarrow0})$ [nm]	H_2O [nm]	$N_2(\nu_{2\leftarrow0})$ [nm]
Gemini North	ALTAIR [8, 9]									
Gemini South	GeMS [10–12]									
W. M. Keck	LGSAO [6, 7]									
Lijang 1.8-m Telescope	LGS-AOS [65]									
Shane 3-m Telescope	ShaneAO [66, 67]									
Subaru	AO188 [13, 14]	589	637	641	648	683	711	720	750	810
VLT (UT4)	4LGSF [16, 20]									
VLT (UT4)	PARLA [15]									
Thirty Meter Telescope	LGSF [68, 69]									
Giant Magellan Telescope	GMT AO [70]									
Extremely Large Telescope	ATLAS & MAORY [71–74]									
Large Binocular Telescope	ARGOS [75, 76]	532	571	574	580	607	630	637	660	706
William Hershel Telescope	GLAS [77]	515	552	555	560	585	606	612	634	676
Hale 5-m Telescope	PULSE [78]									
Southern Astrophysical Research Telescope	SAM [79]	355	372	373	376	387	396	399	408	425

Laser collision tool "update"



Amico et al. (2015)

See Frederic's presentation on Friday morning

Take-home messages:

$$\text{Rayleigh scattering} \Leftrightarrow \text{Raman scattering}$$

$$\text{Raman scattering} \propto P_{\text{LGS}}$$

$$\lambda_{\text{Raman}} = f(\lambda_{\text{LGS}})$$

"Raman" **laser collisions**

LGS + optical instrument

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Mesospheric magnetometry with LGS at Observatorio Roque de los Muchachos

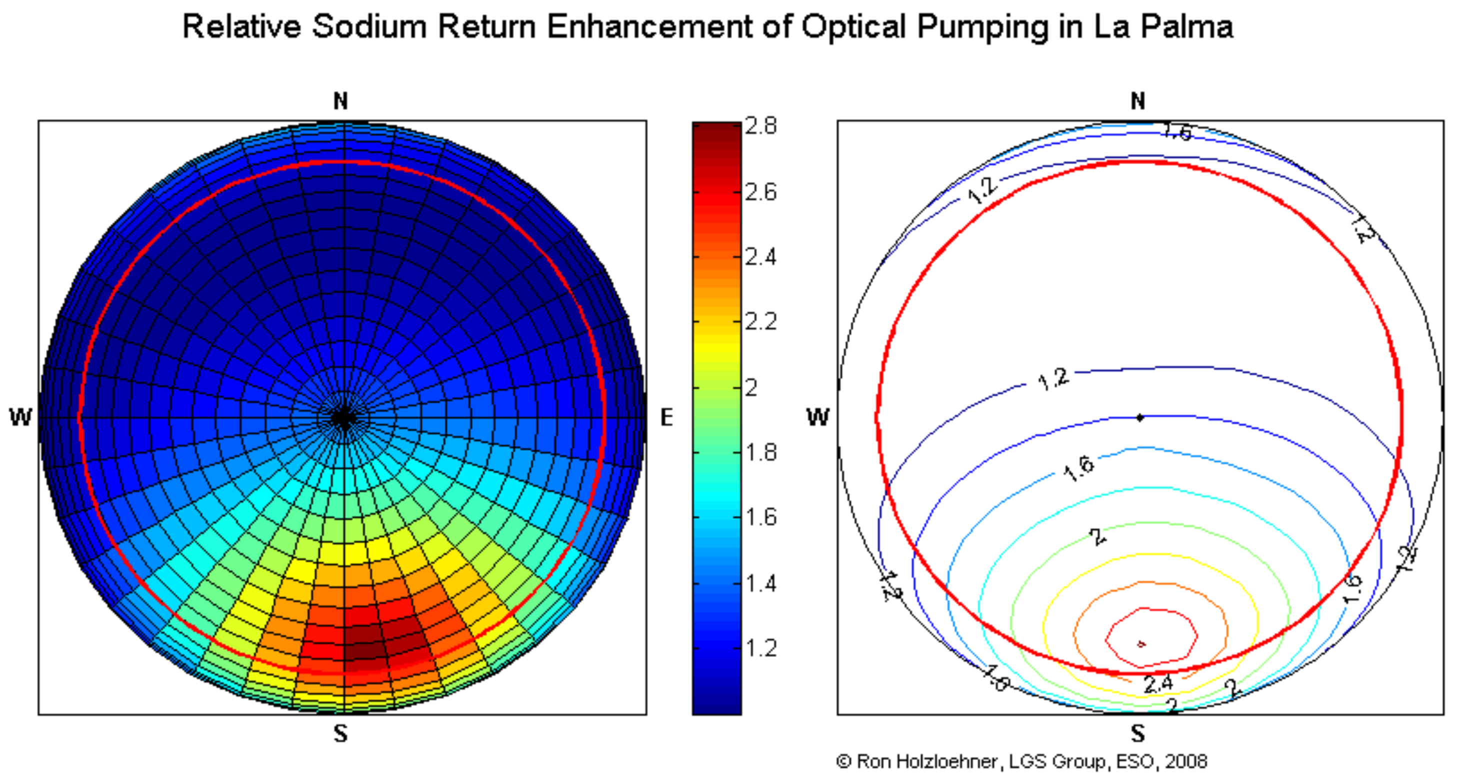
Felipe Pedreros Bustos, Domenico Bonaccini Calia, Dmitry Budker, Mauro Centrone, Joschua Hellemeier, Paul Hickson, Ronald Holzlöhner, Thomas Pfrommer, Simon Rochester

12th Annual Workshop on Laser Technology and Systems for
Astronomical Adaptive Optics, 2017

Scientific motivation

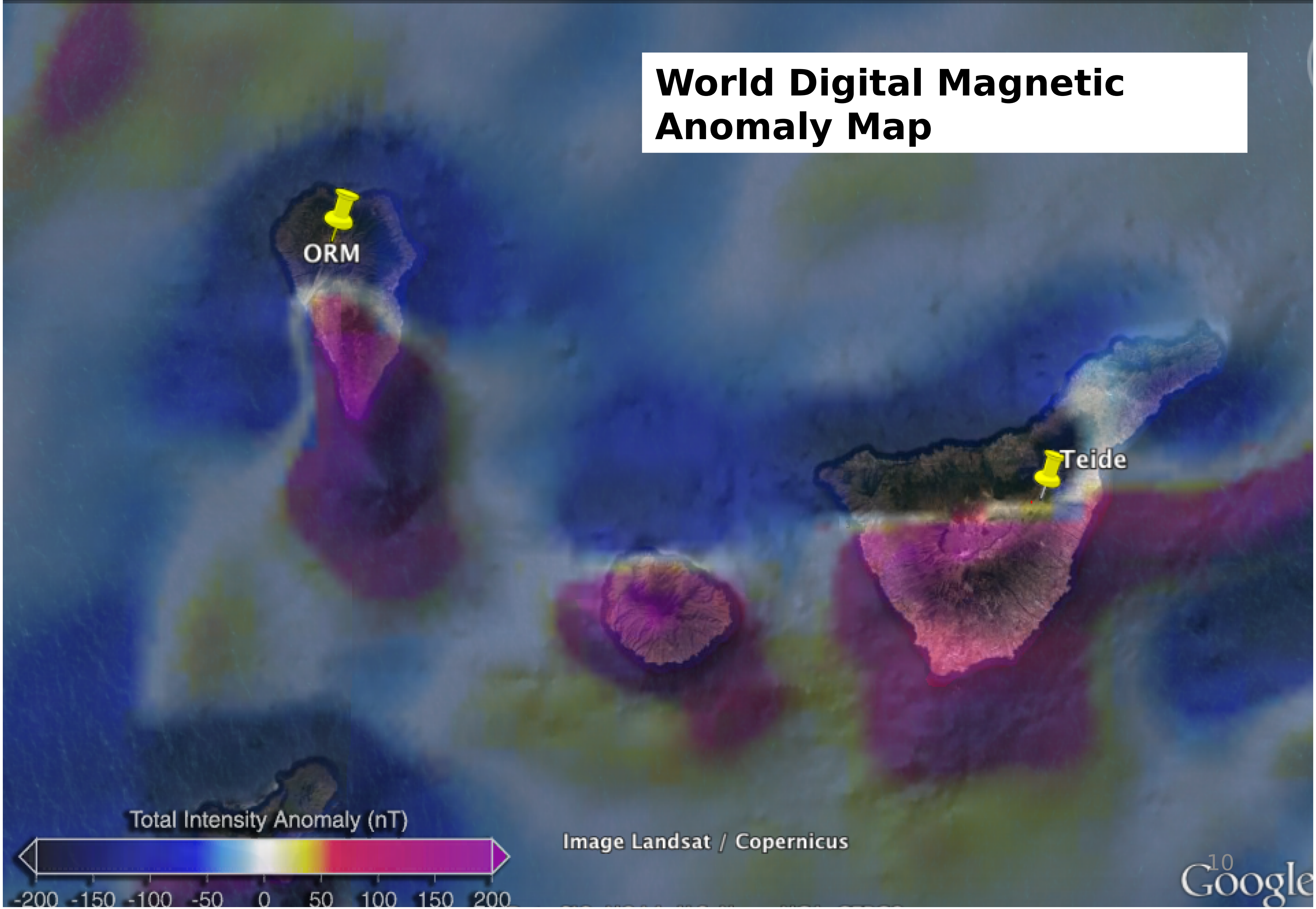
- **Experiment no. 1:** Remote detection of the Geomagnetic field in the mesosphere

- **Experiment no.2**: Exploration of LGS return flux enhancement methods, for cases when the laser propagation is not parallel to the geomagnetic field lines (optical pumping gets less efficient)



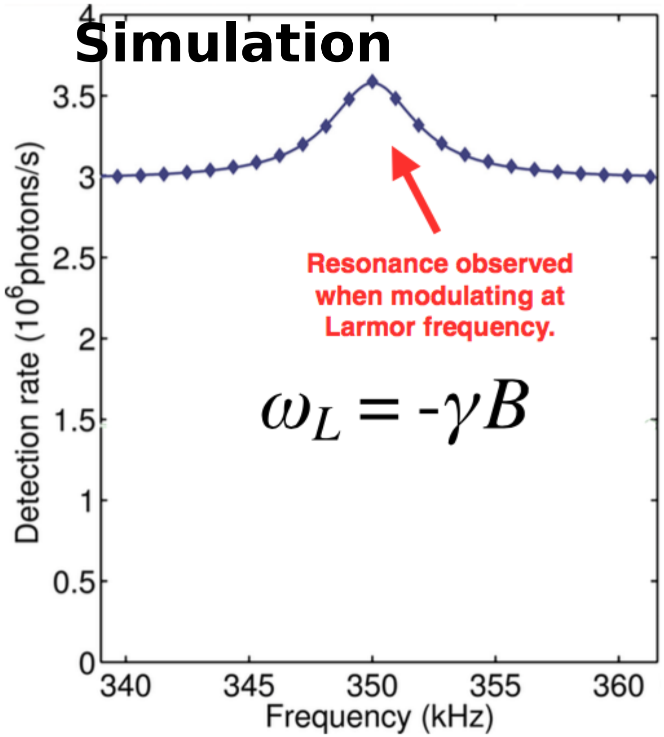
Geomagnetism near Canary Islands

Geomagnetism near Canary Islands

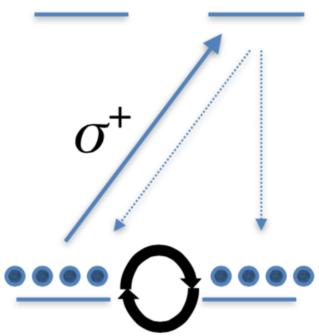


Remote mesospheric magnetometry

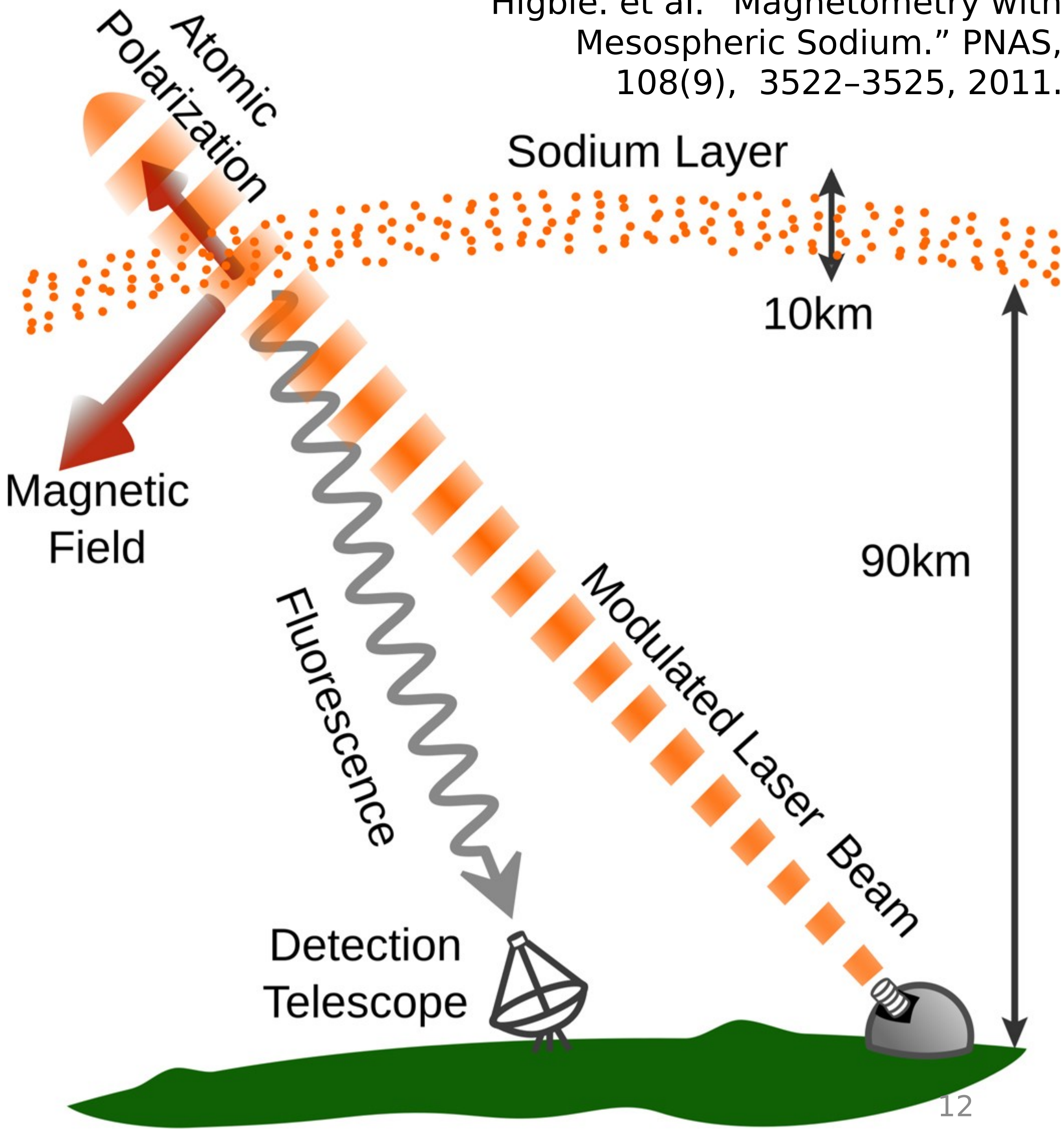
Higbie. et al. “Magnetometry with Mesospheric Sodium.” PNAS, 108(9), 3522–3525, 2011.



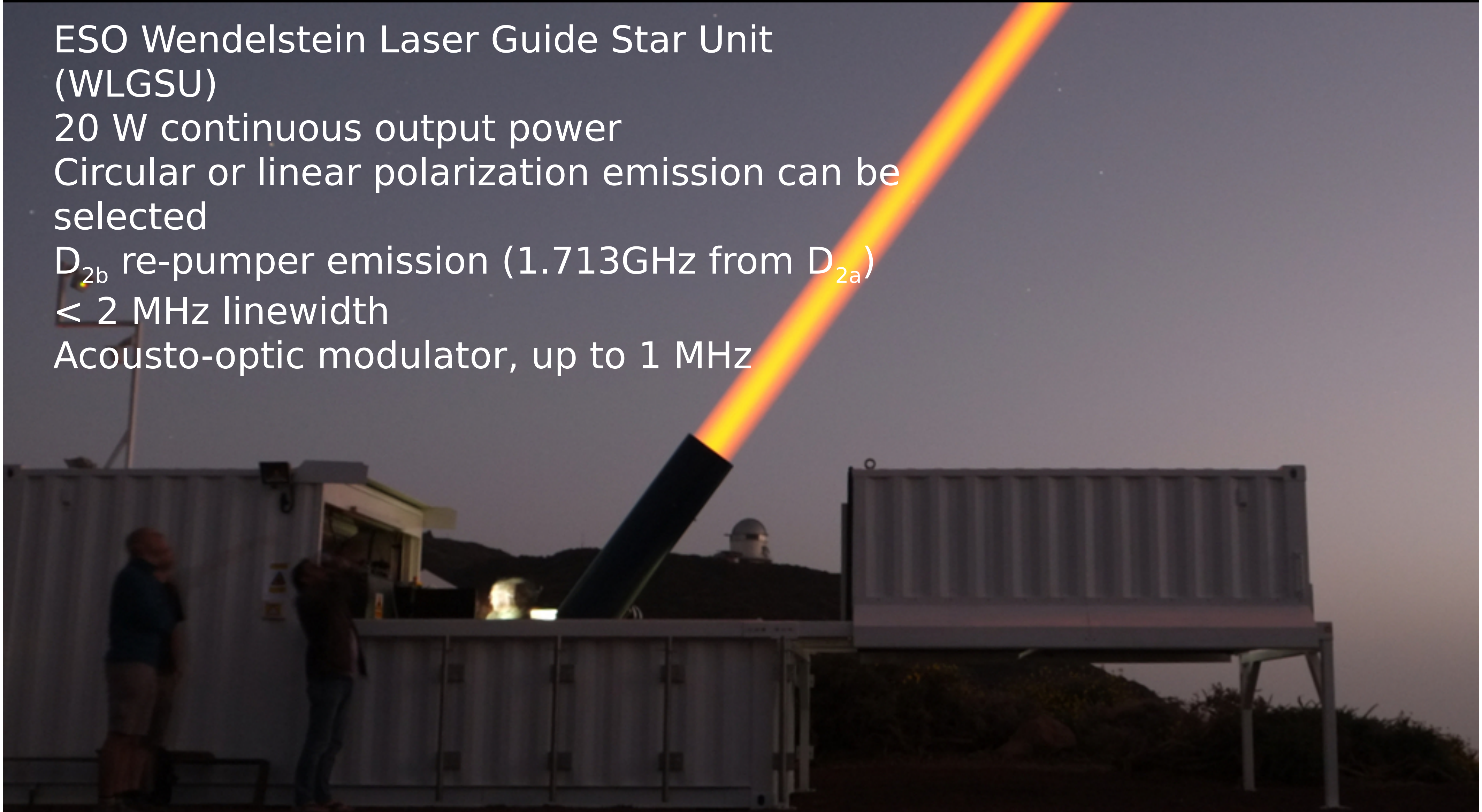
$$B = B_{meso}$$



$$\omega_m = \omega_L$$

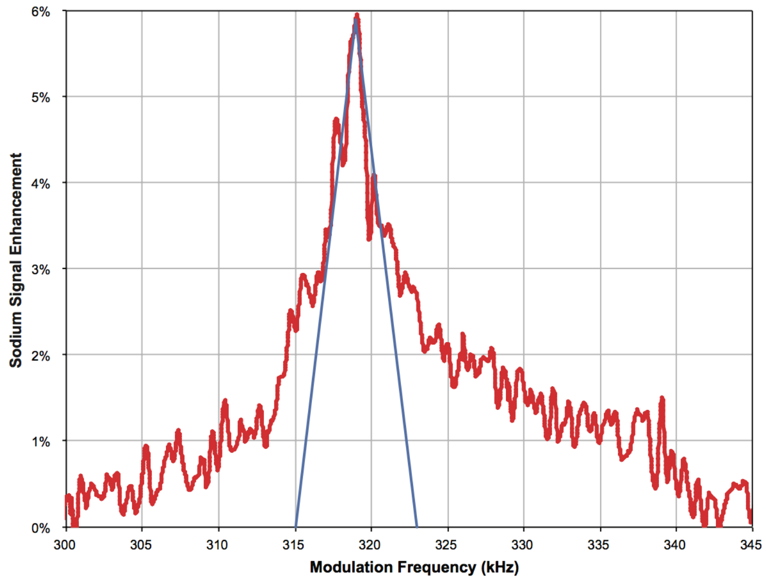


Site at Observatorio Roque de los Muchachos



ESO Wendelstein Laser Guide Star Unit (WLGSU)
20 W continuous output power
Circular or linear polarization emission can be selected
D_{2b} re-pumper emission (1.713GHz from D_{2a})
< 2 MHz linewidth
Acousto-optic modulator, up to 1 MHz

Resonance observed at Kuiper Observatory (Kane et al, 2016)



- 6 % amplitude resonance reported by Kane et al. “Laser remote magnetometry using mesospheric sodium”, arXiv:1610.05385 [astro-ph.IM], 2016.

Summary

- **Upcoming**: first remote mesospheric magnetometry experiment in La Palma (very excited!)
- Technique based on all-optical atomic magnetometer
- Expecting to find a ~10% amplitude Larmor resonance
- Frequency modulation approach will be used to “freeze” LGS from scintillation

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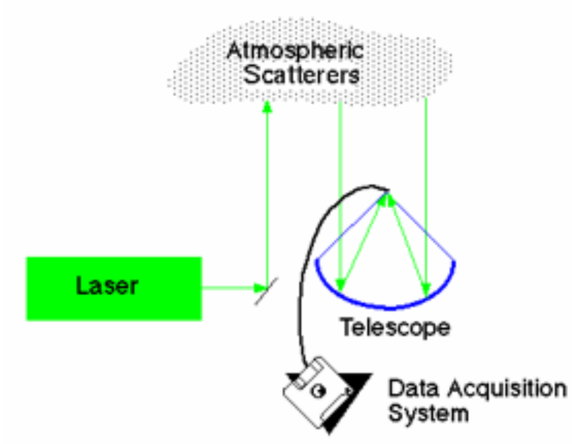
Modelling the response of mesospheric sodium to pulsed-laser excitation

L4AO Workshop 2017

Joschua Hellemeier, Paul Hickson, Lucas Labadie

Setup of the simulation

- aim: relate specific energy density to photon return from one sodium atom
- developed for lidar data from the Large Zenith Telescope (LZT)
- LZT has been used for studies of the mesospheric sodium layer
- simulation can be generalized to nanosecond-pulsed lasers (4-20 ns)

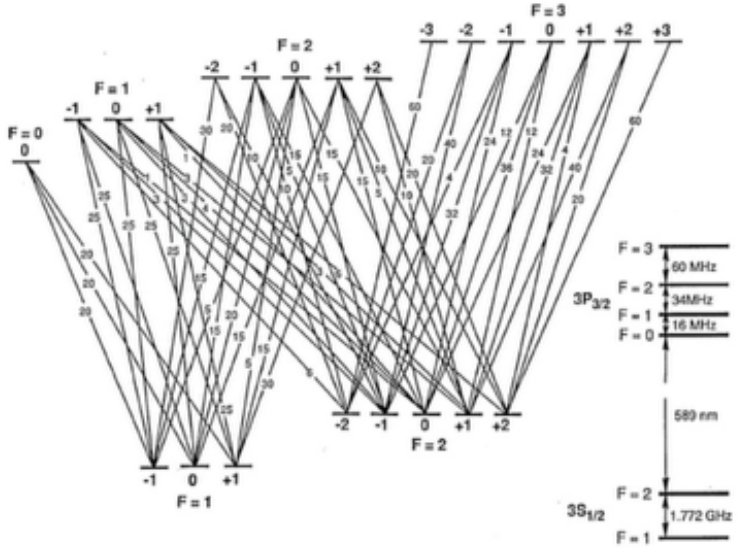


copyright: http://pcl.physics.uwo.ca

copyright: P. Hickson

- sodium D_2 line transitions
- occupation numbers of 21 relevant hyperfine states
- rate equation:

$$\frac{d\mathbf{n}}{dt} = (\mathbf{A} + u_\nu \mathbf{B})\mathbf{n}$$



Ungar et al.1989

assumptions:

local thermodynamic equilibrium before each pulse

only dipole transitions

Larmor precision effects not implemented

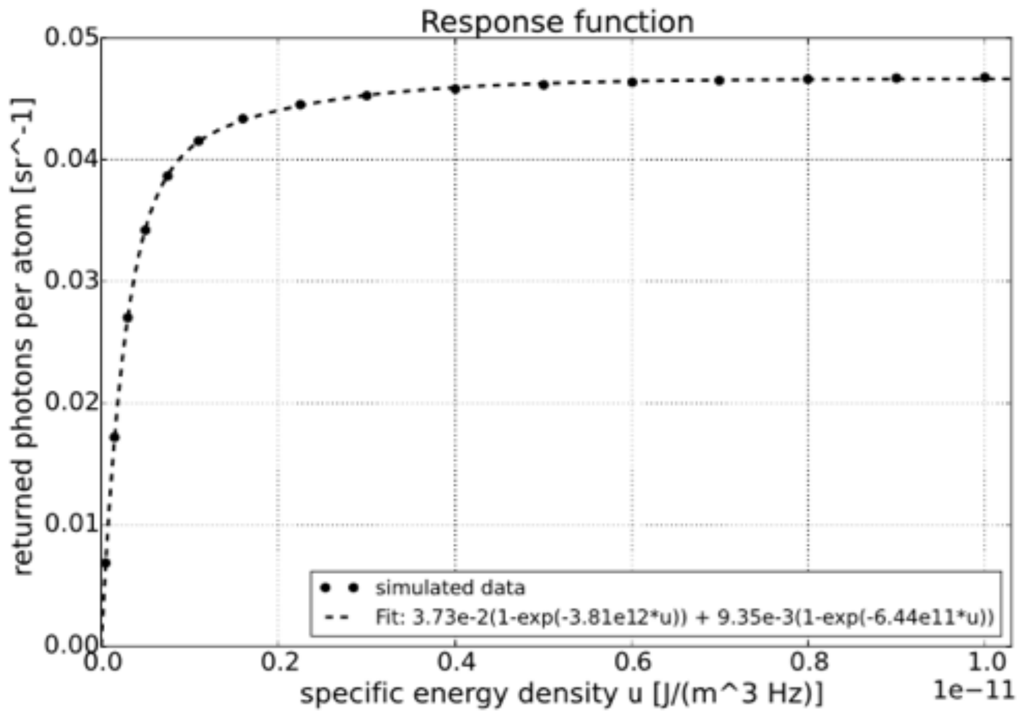
Rabi-oscillations effectively cancel out

no change in atom velocity during pulse
—> velocity classes need to be implemented in later analysis

critical value for π-pulses:

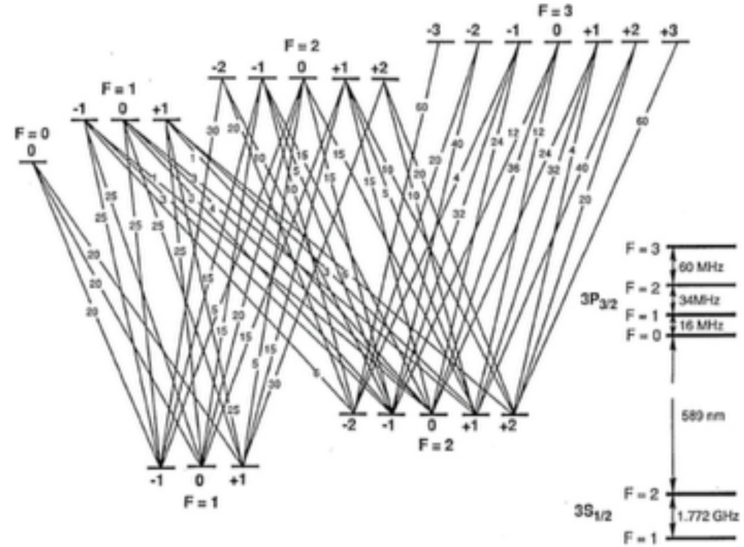
$$It_p^2 = 8 \cdot 10^{-18}\ \mathrm{Ws^2/cm^2}$$

LZT

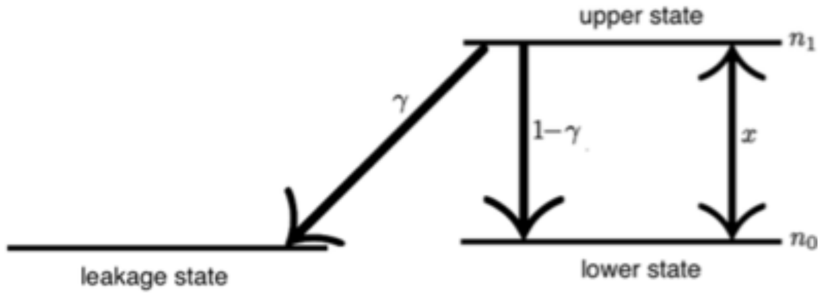


- return photons from spontaneous emission for the LZT towards Earth
- pulse rate: 50/s, t = 6 ns, $\theta = 19.68°$, π-polarized

Analytical three-level model



Ungar et al.1989



$$\frac{dn_1}{dt} = -(1+x)n_1 + gxn_0$$

$$\frac{dn_0}{dt} = [(1-\gamma)+x]\,n_1 - gxn_0$$

$$g = B_{01}/B_{10}$$

$$x = (1/3)u_\nu B_{10}/A_{10} = (1/3)u_\nu \lambda^3/(8\pi h)$$

$$n_1 = \frac{gx}{D}e^{-Ct}\sinh(Dt)$$

$$C = 1 + (g+1)x/2$$

$$D = \sqrt{(1+(g+1)x)^2 - 4\gamma gx}/2$$

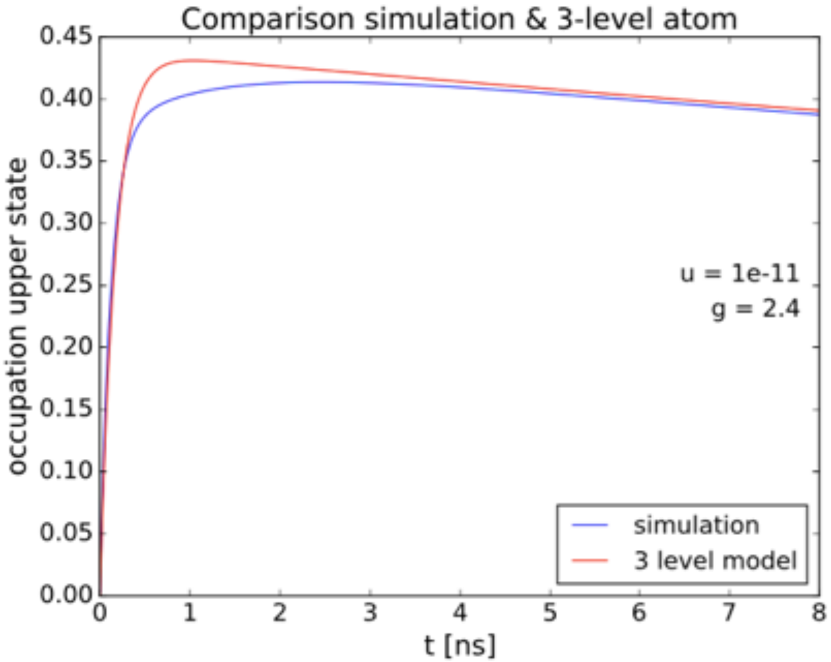
$$n_{sp}(t) = \int_0^t A\, n_1(t')\, dt'$$

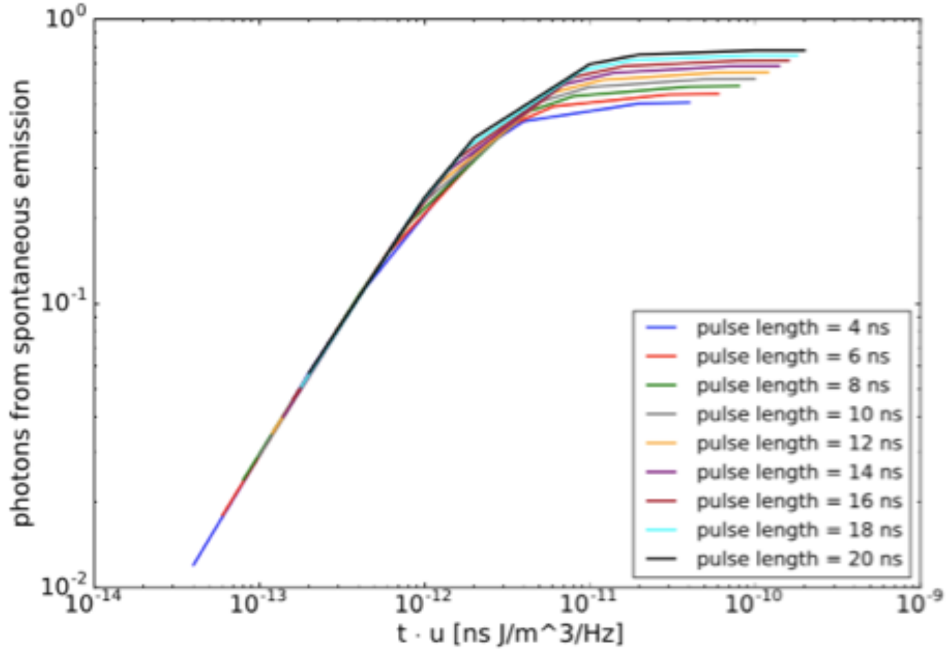
$$n_{sp}(t) = \frac{gx}{D^2 - C^2} e^{-Ct} \left[\cosh(Dt) + \frac{C}{D}\sinh(Dt)\right] - \frac{gx}{D^2 - C^2}$$

See Joschua's poster this afternoon

number of photons per pulse:

$$N(t_p) = n_{sp}(t_p) + n_1(t_p)$$





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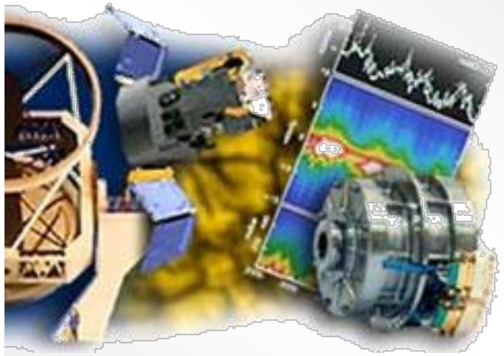

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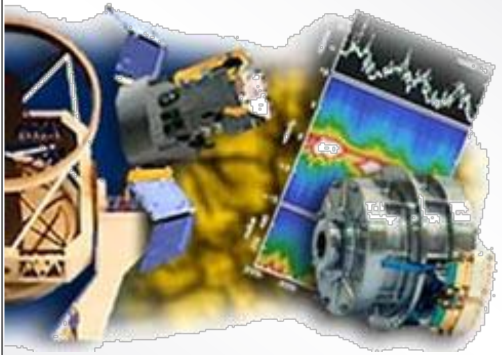
TOWARDS THE UPLINK CORRECTION

Performance assessment of uplink correction in FSOC

Noelia Martínez
Instituto de Astrofísica de Canarias

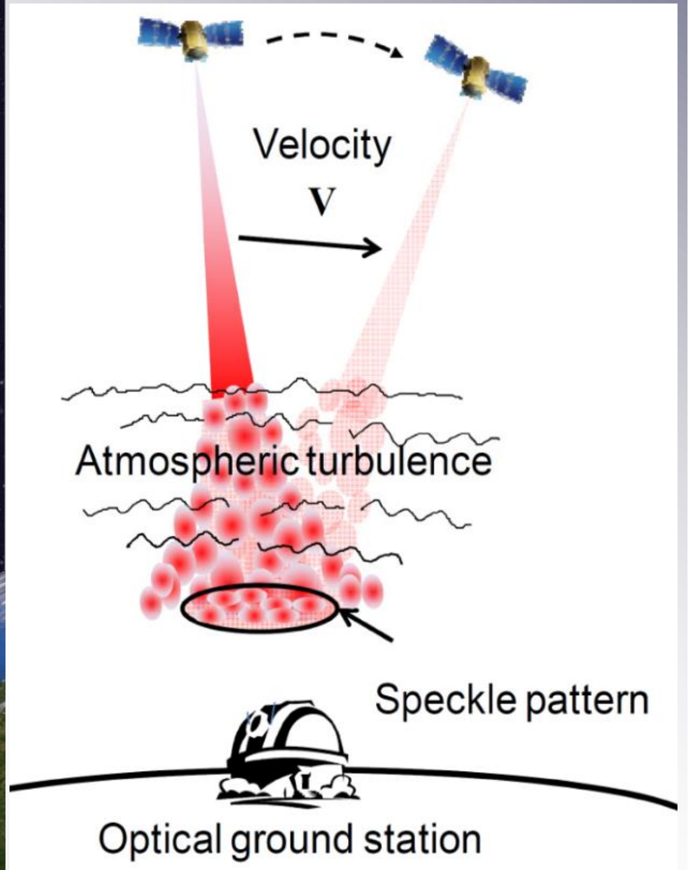
Instrumentation Division



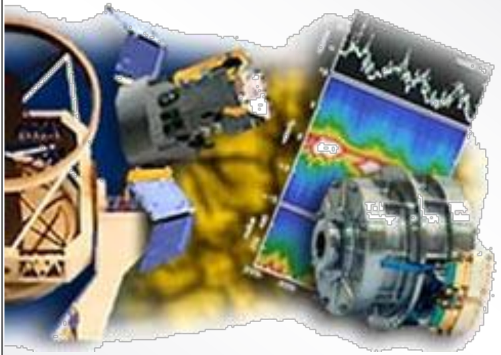
1. Uplink Wavefront Corrector System

UWCS — OOMAO Simulations — OGS Hawk Test — Future Tasks

Goal 1: Performance improvement of FSOC links through the atmosphere



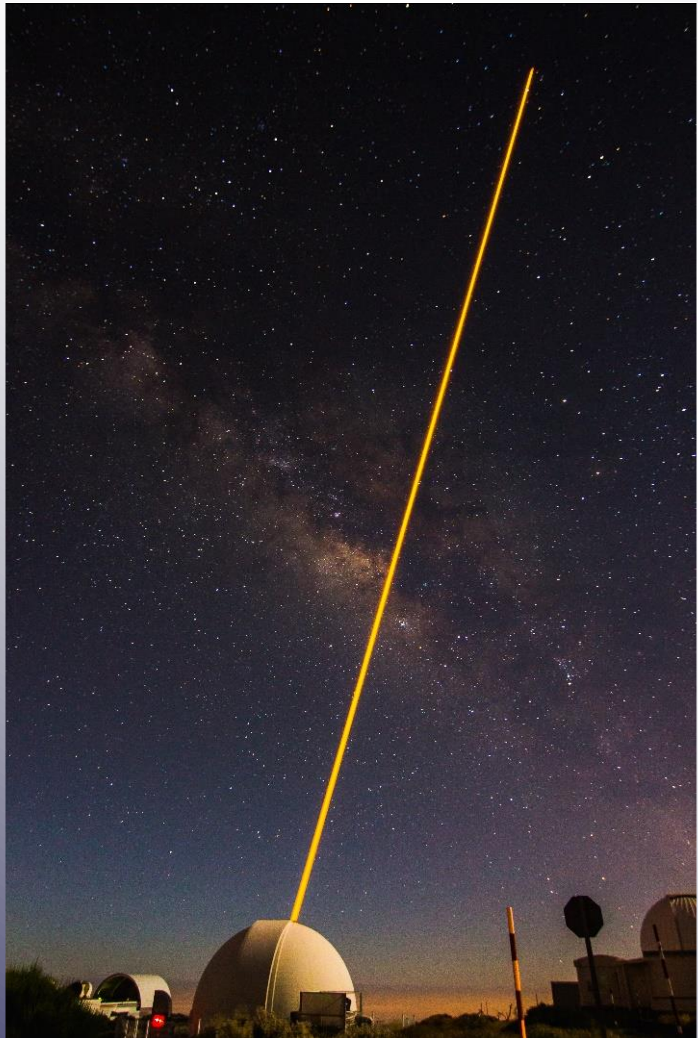
Toyoshima et al, 2011



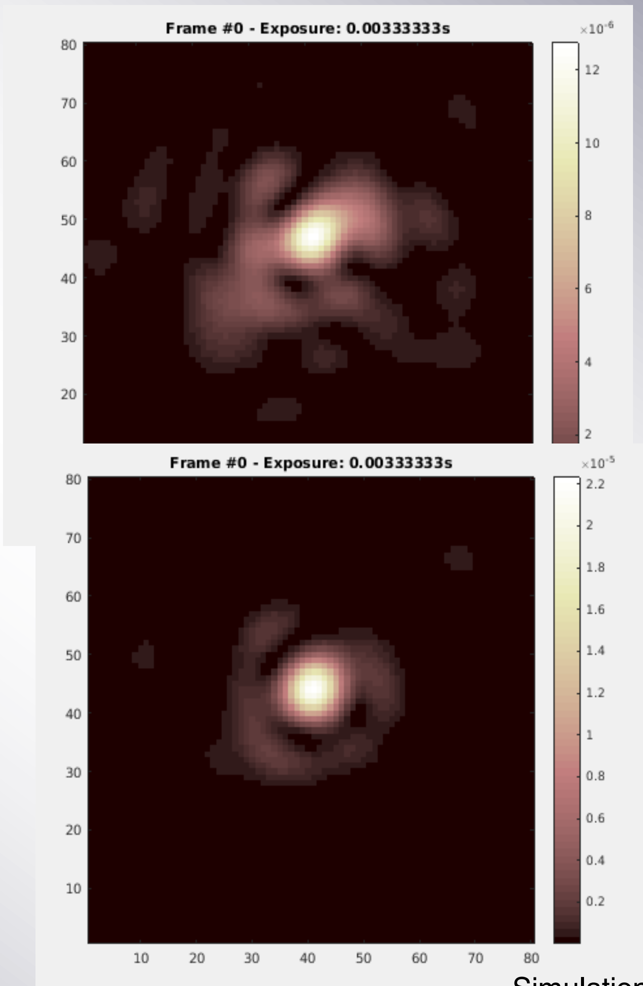
1. Uplink Wavefront Corrector System

UWCS — OOMAO Simulations — OGS Hawk Test — Future Tasks

Goal 2: Spot size reduction in Laser Guide Stars



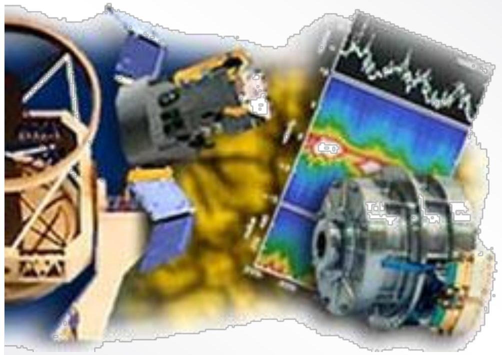
Copyright Oscar Casanova



Simulation Images

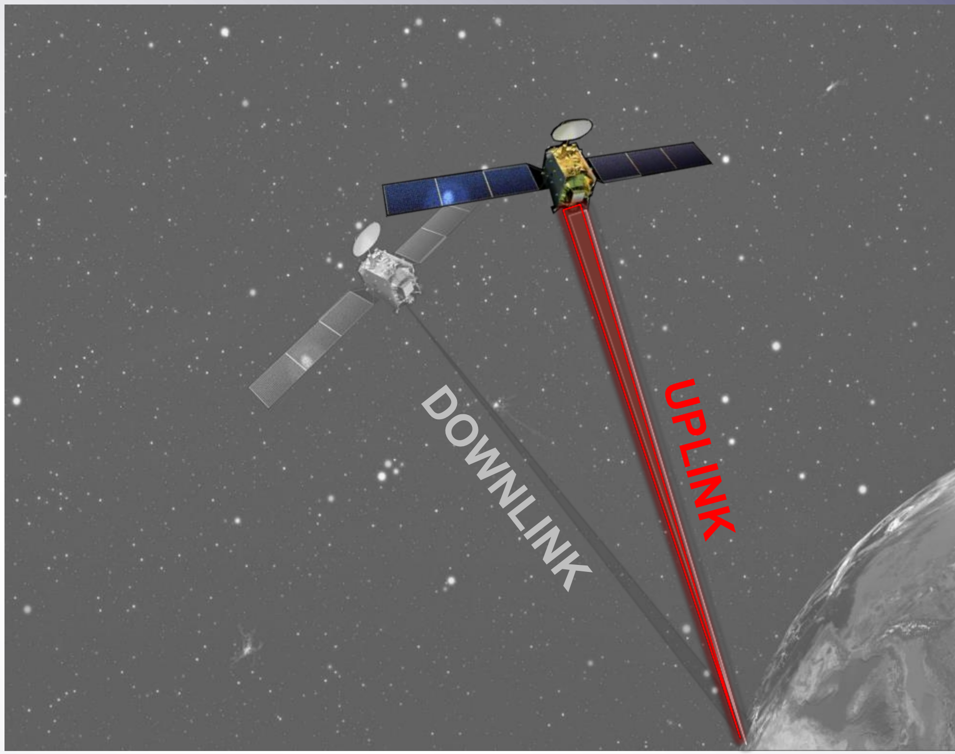
Noelia Martínez
Instituto de Astrofísica de Canarias

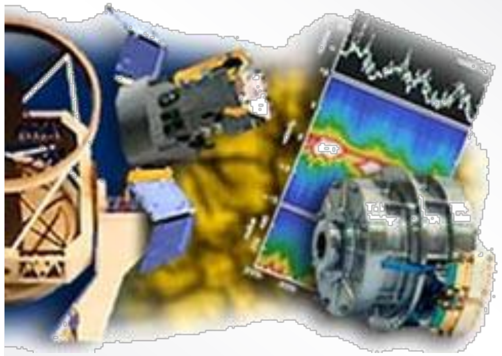
Instrumentation Division



1. Uplink Wavefront Corrector System

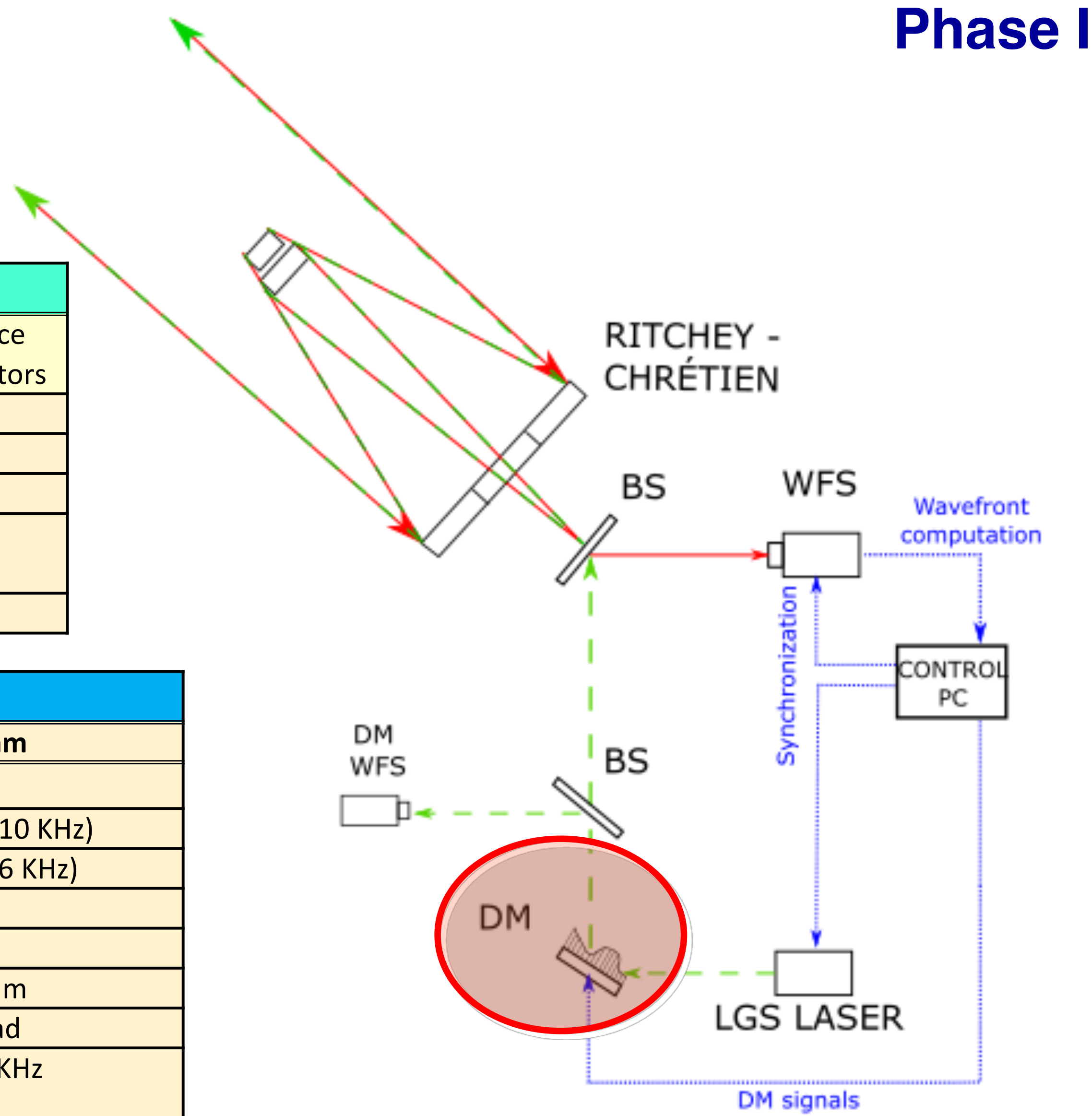
Optical Ground Station (OGS)	
Telescope diameter	1 m
Central obstruction	20 %
Field-of-view	2.5 arcmin
Optical configurations	RC F/13.3
	Coudé F/38.95





1. Uplink Wavefront Corrector System

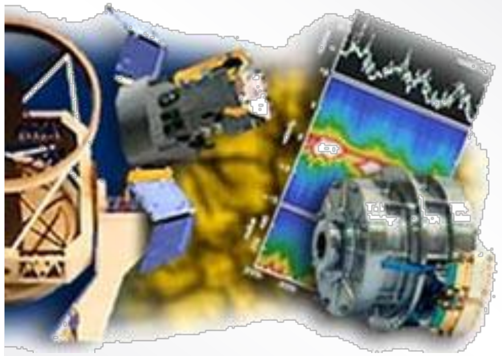
Phase I



DM: ALPAO DM241	
DM type	Continuous reflective surface motioned by magnetic actuators
Number of actuators	241
Pupil diameter	37.5 mm
Wavefront tip/tilt stroke (PV)	40 µm
Wavefront higher modes (inter actuator)	Up to 5 µm
Settling time	1.6 ms

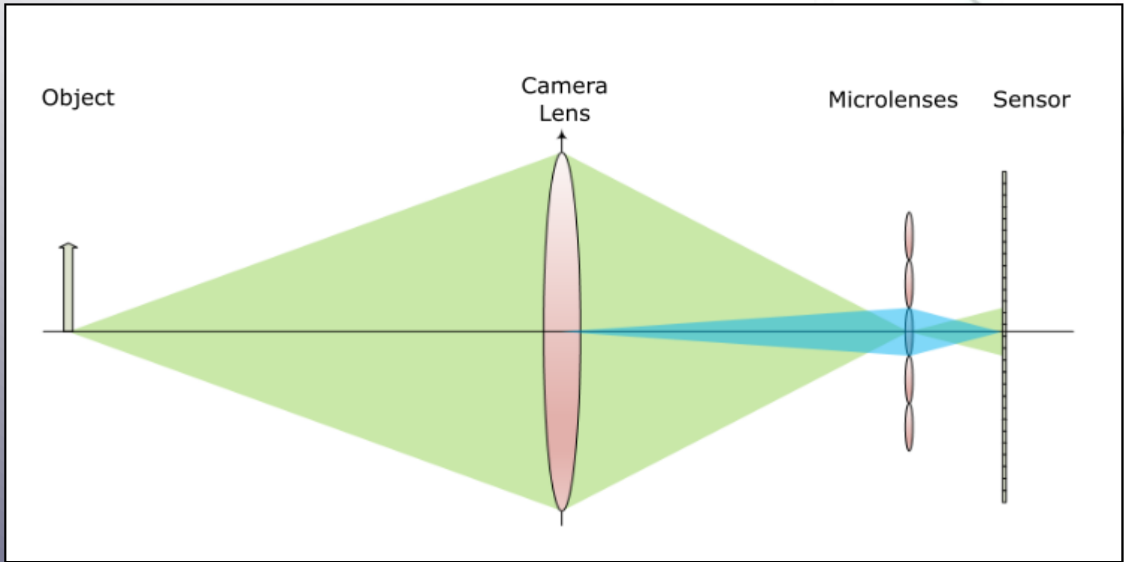
LGS LASER: Hawk-II-1064-25-0/532-8-0		
Wavelength	**1064 nm**	**532 nm**
Average Power	25 W (CW)	-
	20 W (10 KHz)	8 W (10 KHz)
	17 W (6 KHz)	7 W (6 KHz)
Pulse Width (6 KHz)	140 ns	90 ns
Beam Quality –M-	1.2	1.2
Beam Diameter at window	0.55 mm	0.8 mm
Beam Divergence Angle	3 mrad	1 mrad
Pulse Repetition Frequency (PRF)	1-90 KHz	1-40 KHz

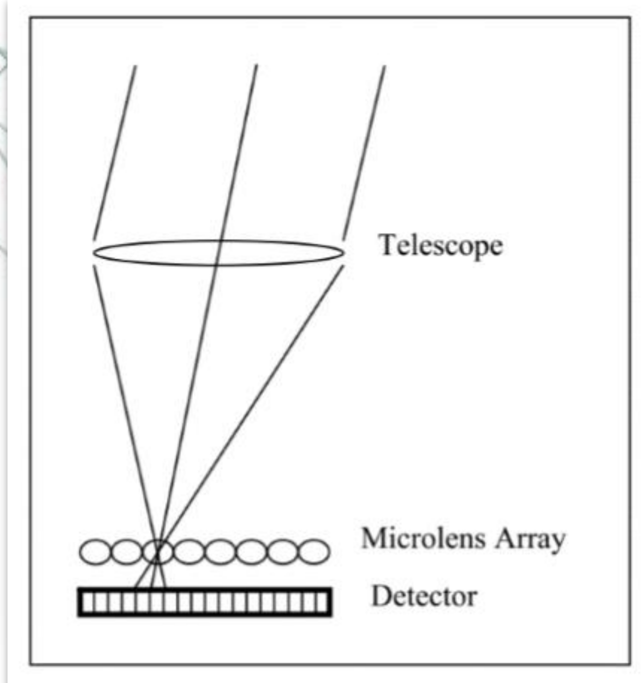
Noelia Martínez
Instituto de Astrofísica de Canarias



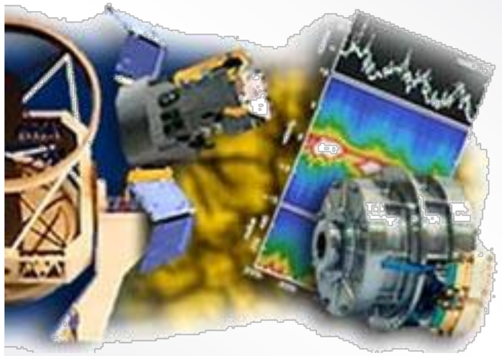
1. Uplink Wavefront Corrector System

The Plenoptic Camera





Noelia Martínez
Instituto de Astrofísica de Canarias



2. OOMAO Simulations

Object- Oriented Matlab Adaptive Optics Toolbox (OOMAO)

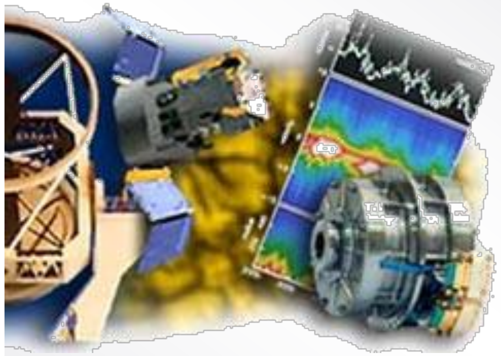
Conan and Correia, 2014

FSOC

A. Isoplanatic area at the OT
B. Uplink correction performance

LGS

C. Uplink correction performance



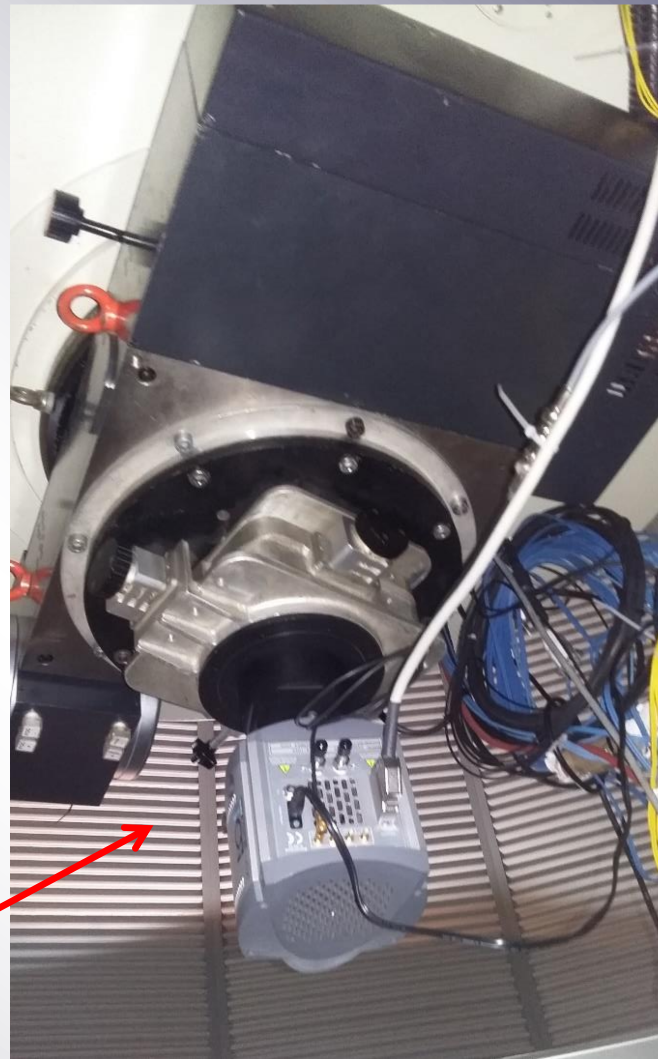
3. OGS Hawk Laser Test

UWCS — OOMAO Simulations — **OGS Hawk Test** — Future Tasks

Goal: Test the Hawk laser as a Rayleigh LGS and analyse the photon flux return

Setup Description:

- Laser: Hawk-II-1064-25-0/532-8-0 + beam expander
- Camera: ANDOR DV885
- Synchronizer: Tektronix Arbitrary Waveform generator AWG2021



Have you seen Noelia's posters on Monday & Tuesday?

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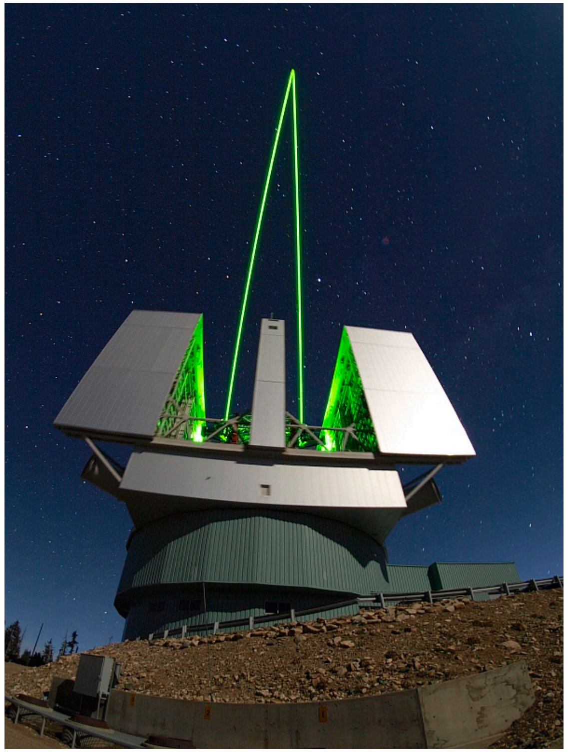
ARGOS

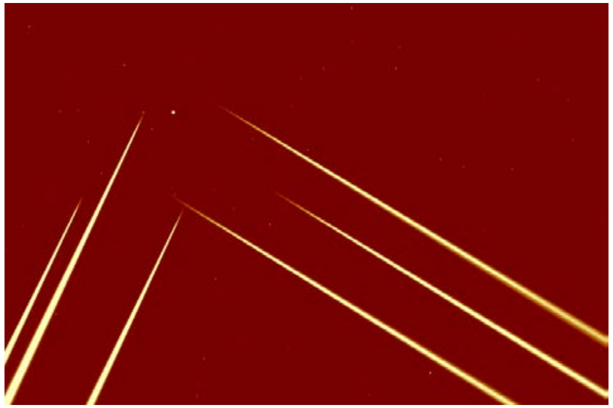
Operational Challenges

Gustavo Rahmer (LBTO/University of Arizona) for the ARGOS Collaboration

What is ARGOS

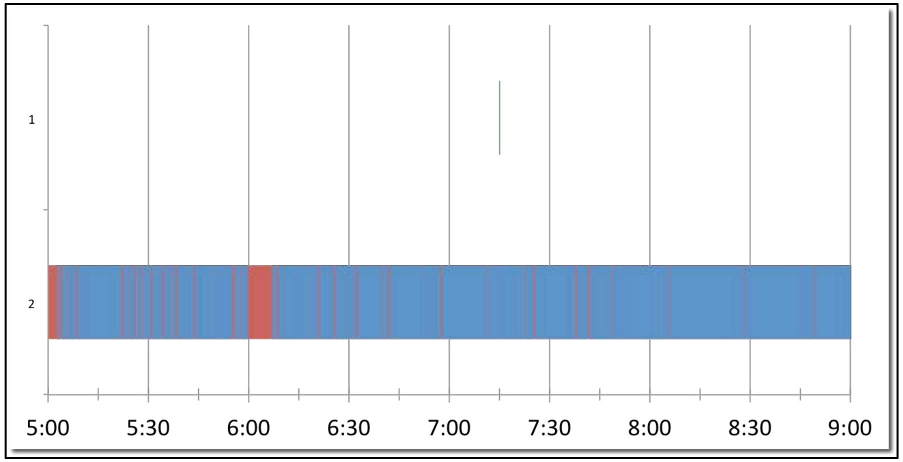
- Ground-layer AO for wide-field corrections (4x4 arcmin) ➔ Correction factor of 2-3
- 3 "Rayleigh beacons" at 12 Km (above each mirror)
- Each laser: Nd:YAG, 18 W, pulsed @10KHz, 532 nm
- Designed to work with the two LUCI instruments (near-IR multimode)
- **Working in binocular mode**
- **Demonstrated 2-3 seeing improvement**
- **Started shared-risk science last December**



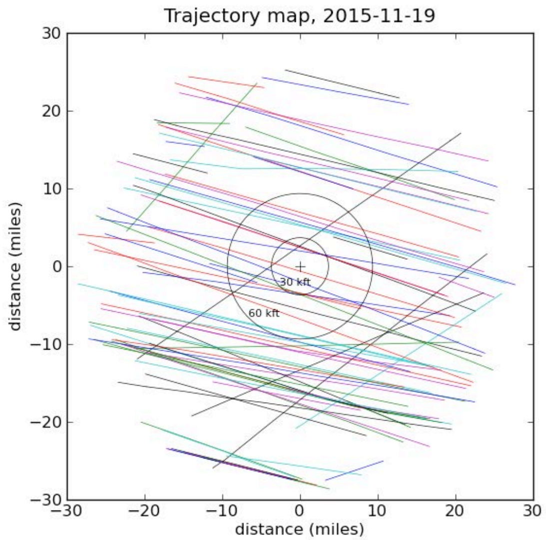


Laser Operations Challenges

- Satellites

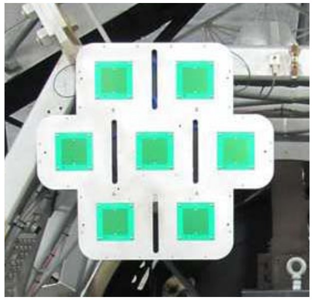


- Airplanes

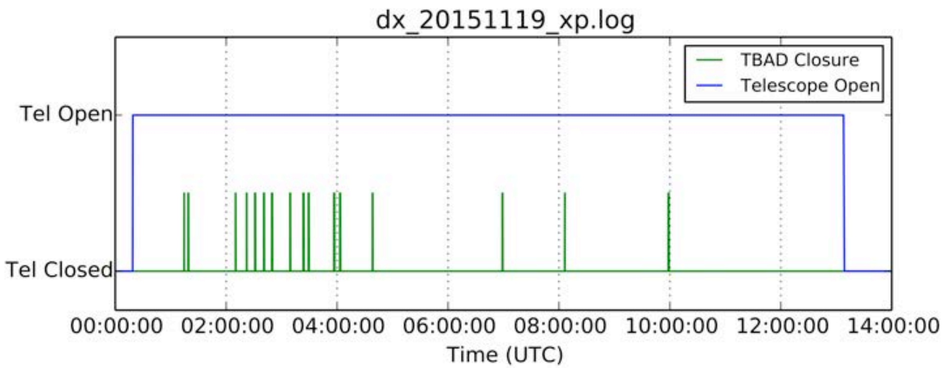


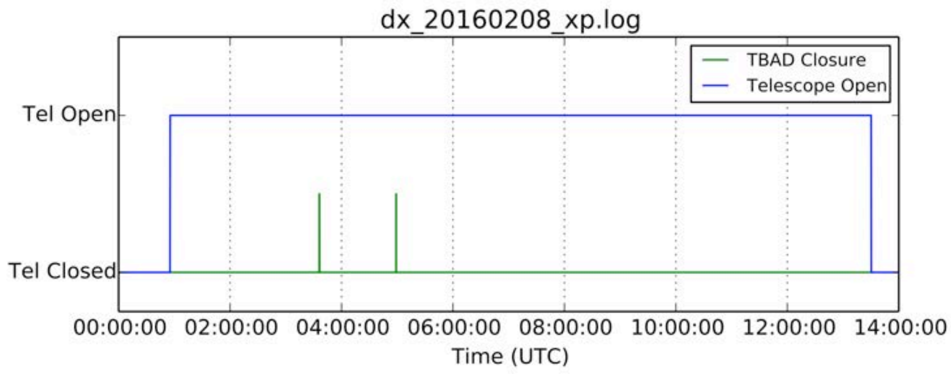
Our Airspace Problem

TBAD @LBTO

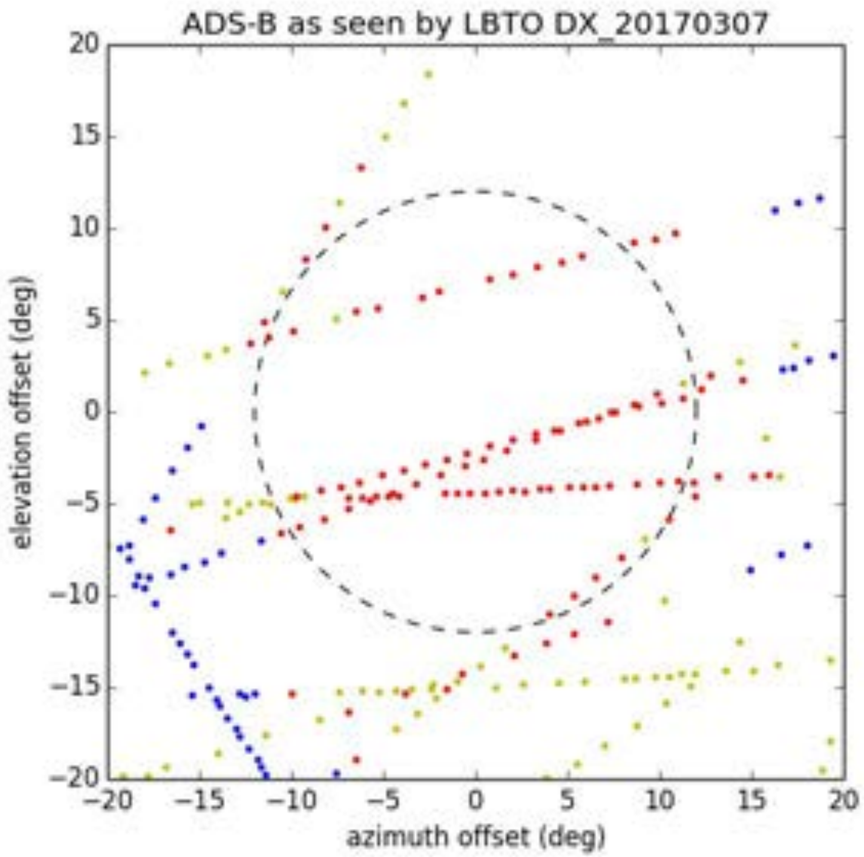


- Two systems (one per side).
- Antennas mounted on each M2 swingarm.
- Trigger from any side stops propagation on both sides.
- Continuous logging every night, even when not lasing.
- Lots of air traffic:
  - 6.37 +/- 3.2 detections per night (N = 143, Max = 16, Min = 2).





1 Night in March (laser run) for DX via ADS-B(*)



Red: “in-beam,” shuttered

Yellow: shuttered

Blue: not shuttered

Self-assessment based on transmitted lat/lon and TBAD disposition to that transmission

(*) Automatic Dependent Surveillance – Broadcast

See Gustavo’s poster this afternoon

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GeMS Next Generation Laser Facility

Cristian Moreno

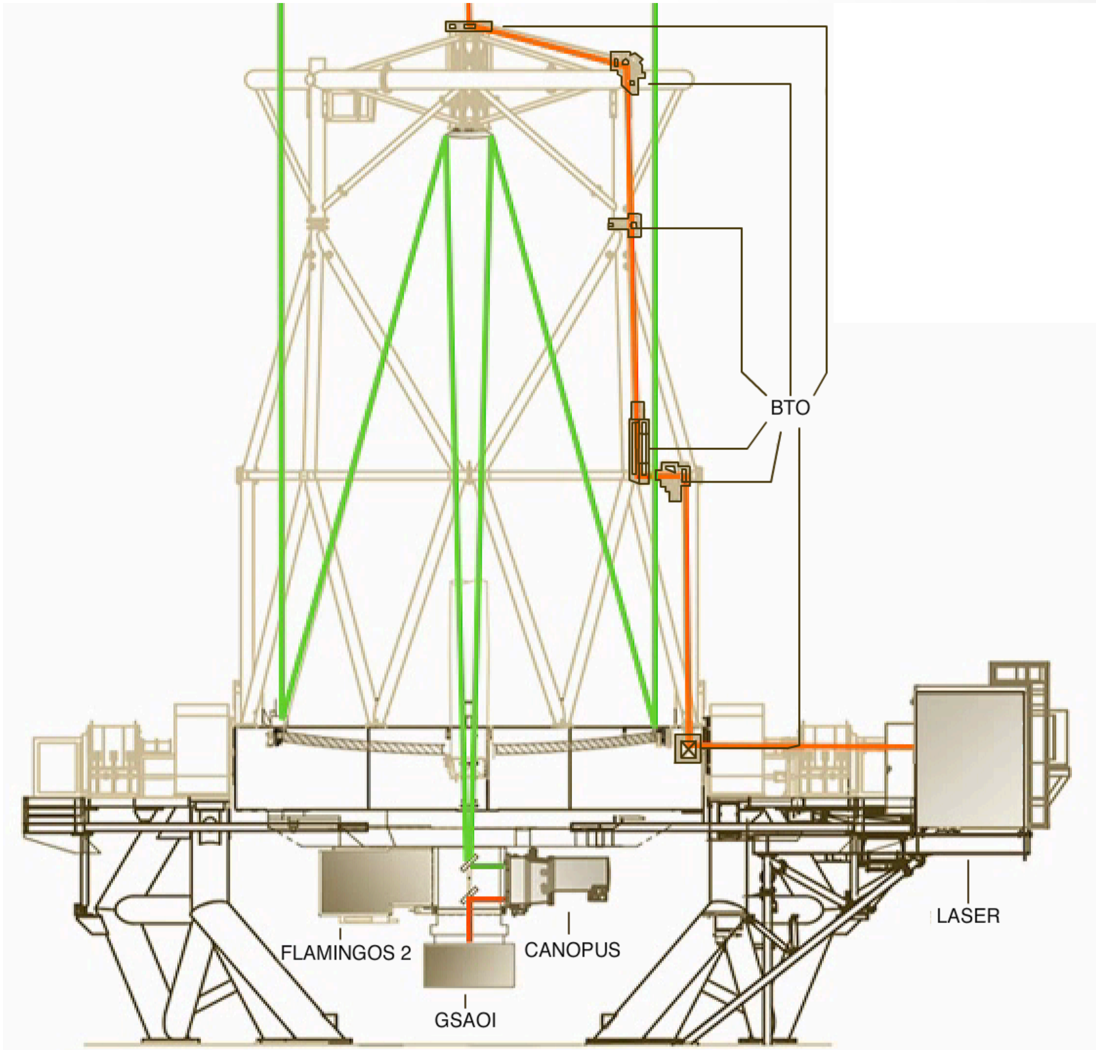
Gemini South Observatory

Emmanuel Chirre, Gabriel Pérez, Pablo Díaz, Vicente Vergara, Paul Collins, Angelic Ebbers, Gaetano Sivo, Eduardo Marin, Manuel Lazo

GeMS

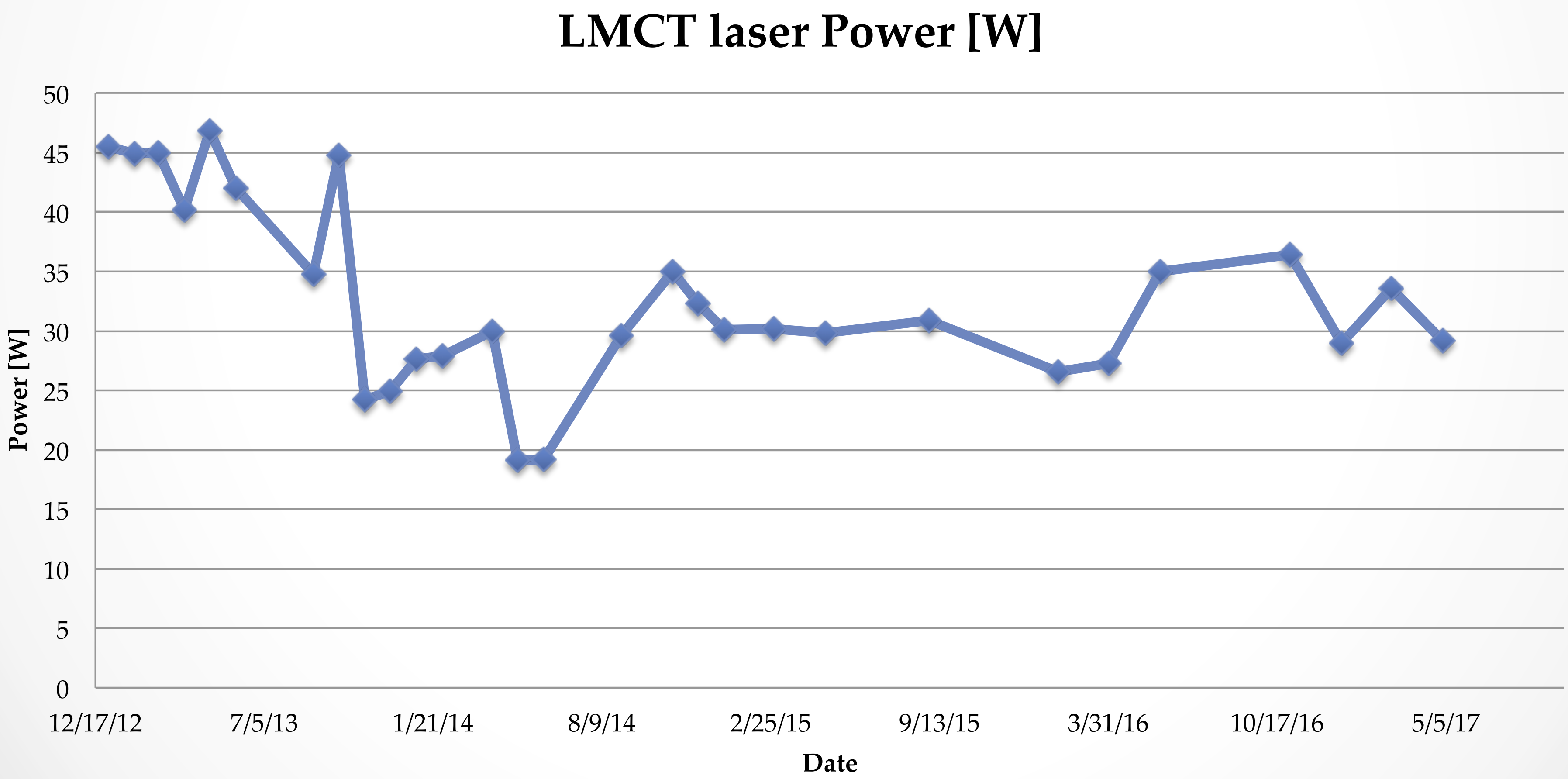
GeMS is the Gemini Multi-Conjugate Adaptive Optics system and consist of three subsystems:

- The Laser
- The Beam Transfer Optics (BTO)
- Canopus (the Adaptive Optics bench)

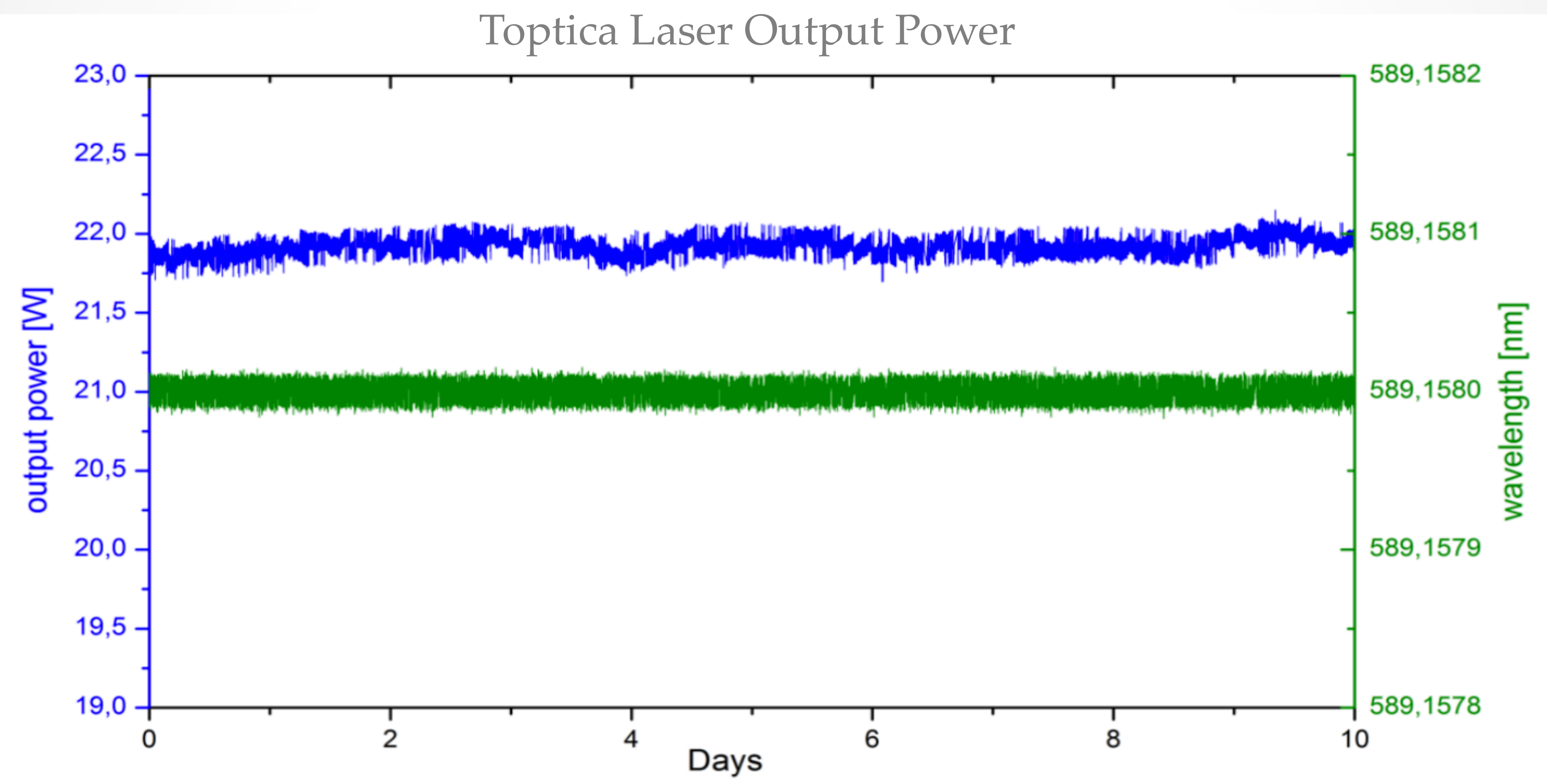


LMCT laser

- The power from last 5 years can be seen below:

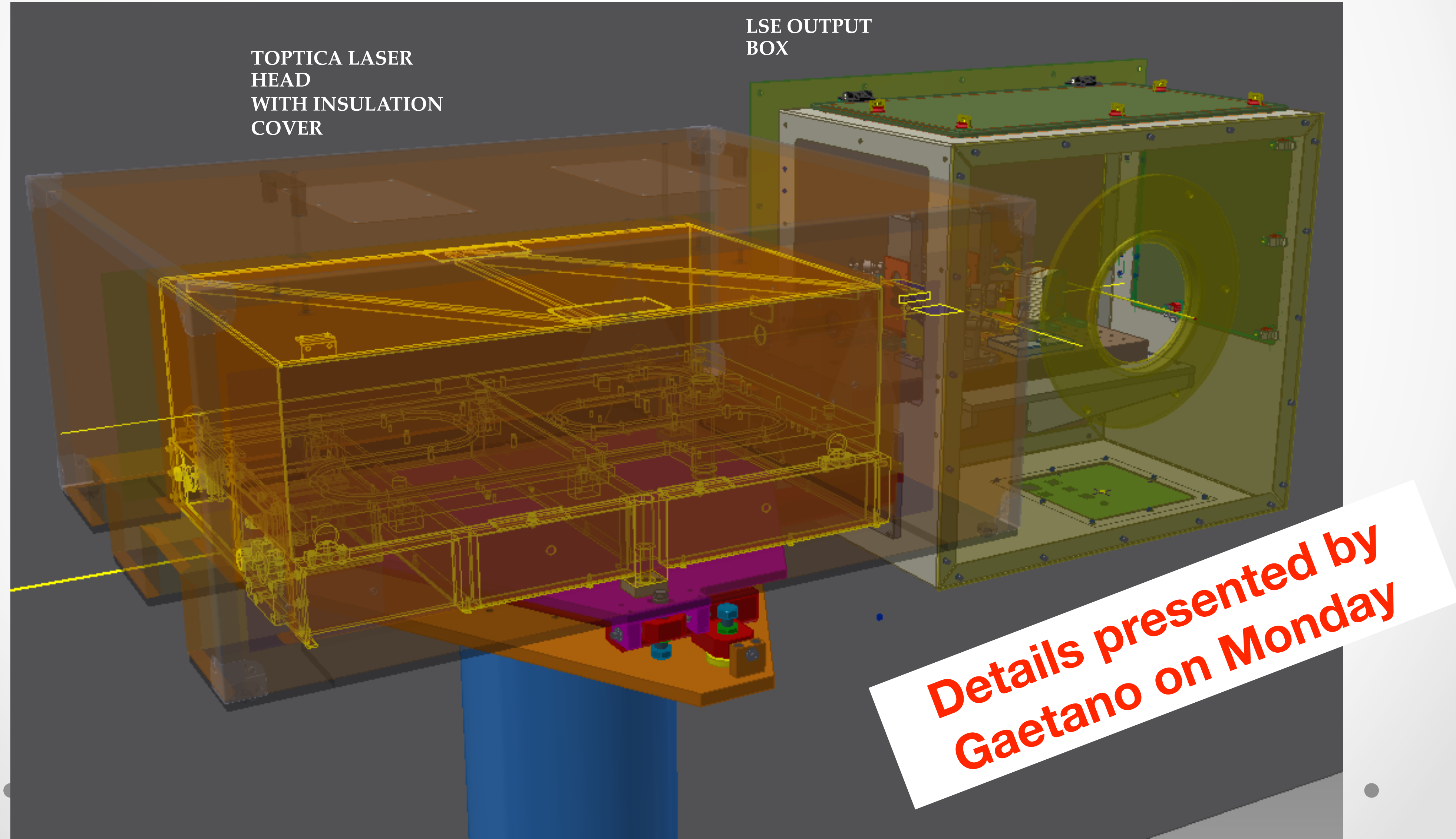


Laser Upgrade



Output power and wavelength measurement of laser unit SN #6 over a period of 10 days showing excellent stability without any long-term drifts, at Toptica lab.

Laser Head Mounted and Beam Injector



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The natrium pipeline for absolute Na profiling

Julio Castro-Almazán
Instituto de Astrofísica de Canarias

In colaboration with :

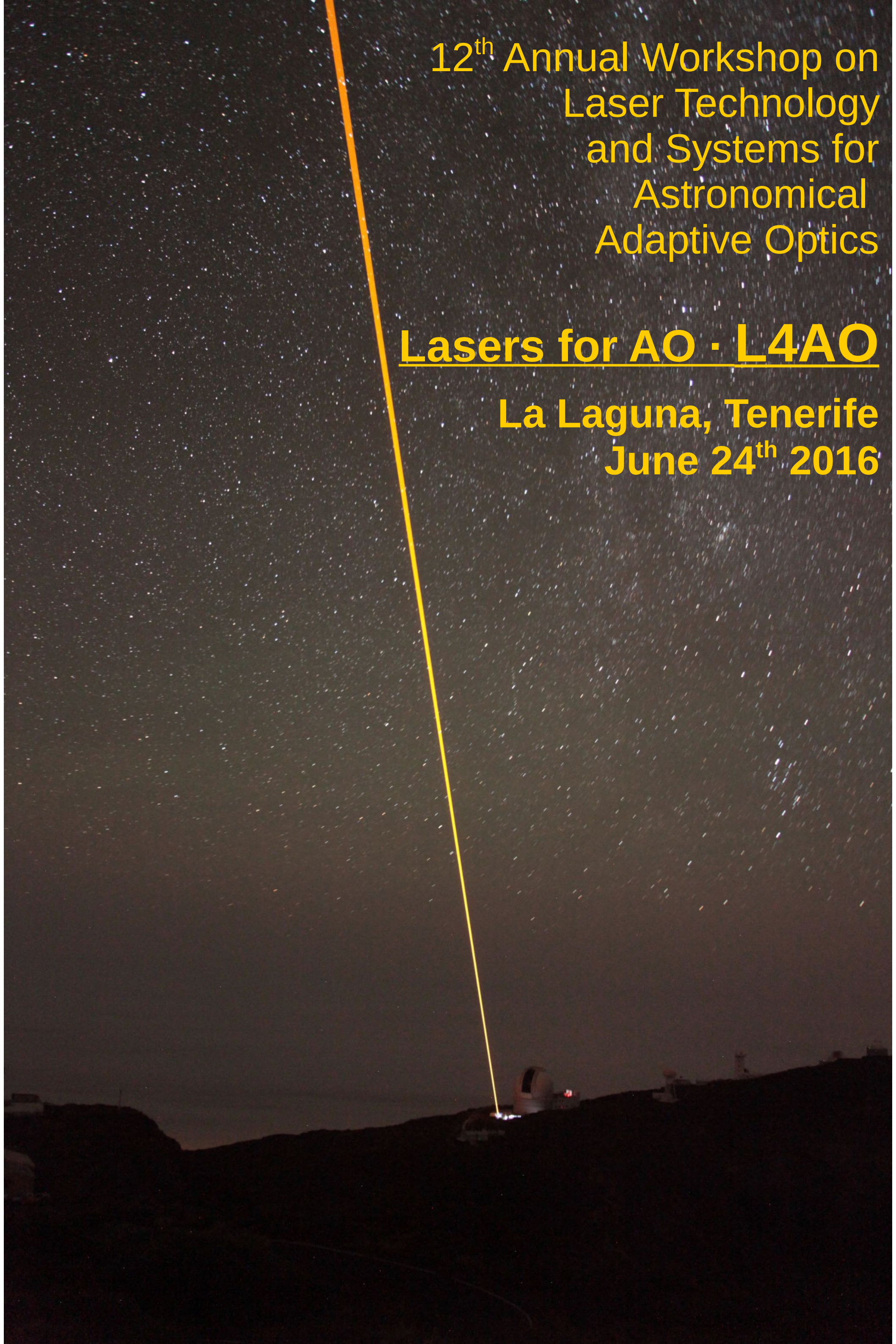
***Instituto de Astrofísica de Canarias*:**
Ángel Alonso
Marcos Reyes García-Talavera
Iciar Montilla

***Durham University*:**
Matthew J. Townson
James Osborn

***European Southern Observatory*:**
Domenico Bonaccini Calia

***INAF-Osservatorio Astronomico di Roma*:**
Mauro Centrone

***Gran Telescopio Canarias*:**
Gianluca Lombardi



The

natrium

pipeline for absolute Na profiling

retrieval of Na absolute height profiles

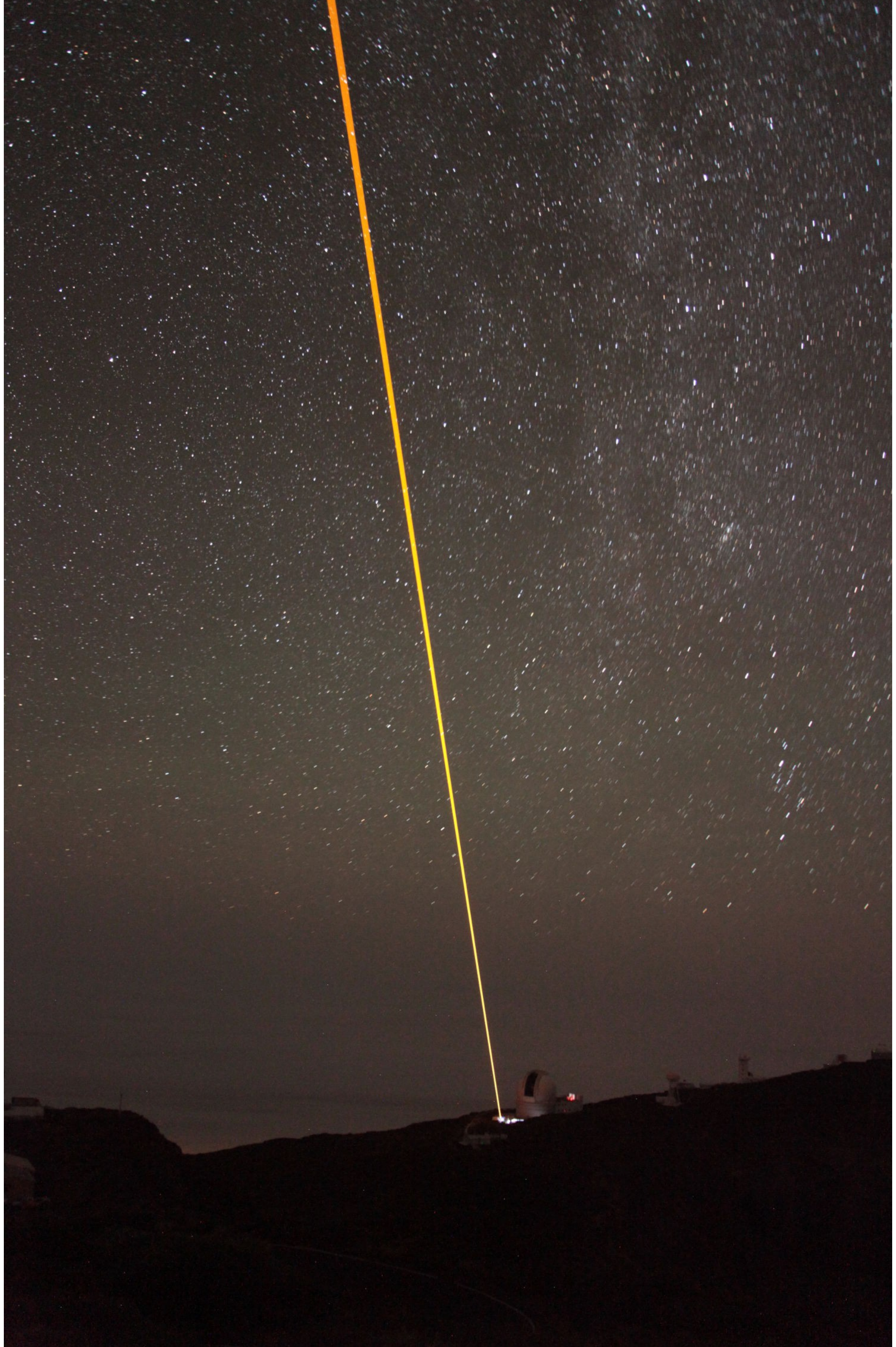
goals:

Real time feedback for AO with elongated LGS:

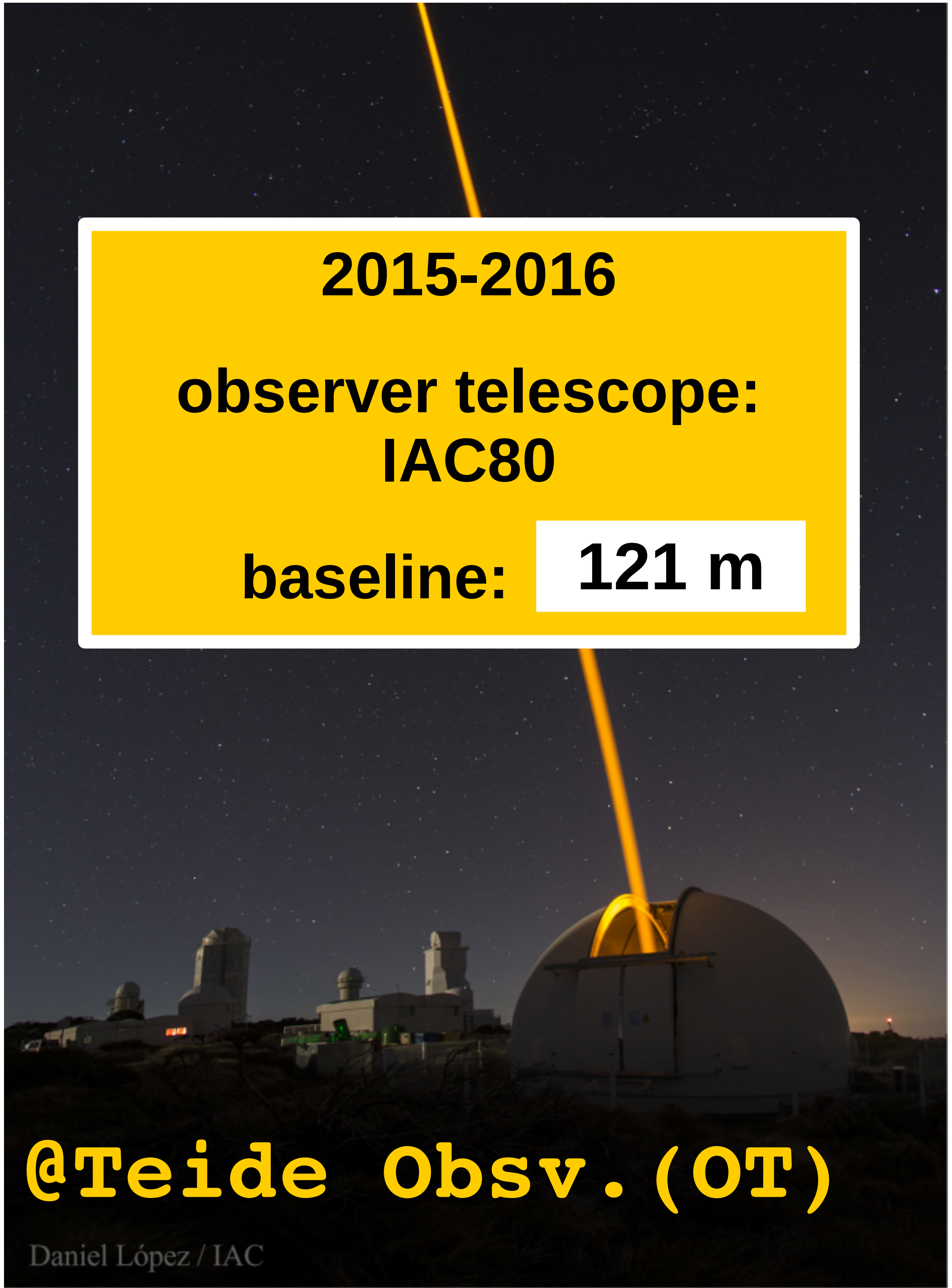
- -Total flux calibration in WFS
- -Laser waist/focus adjust
- -WFS focus adjust

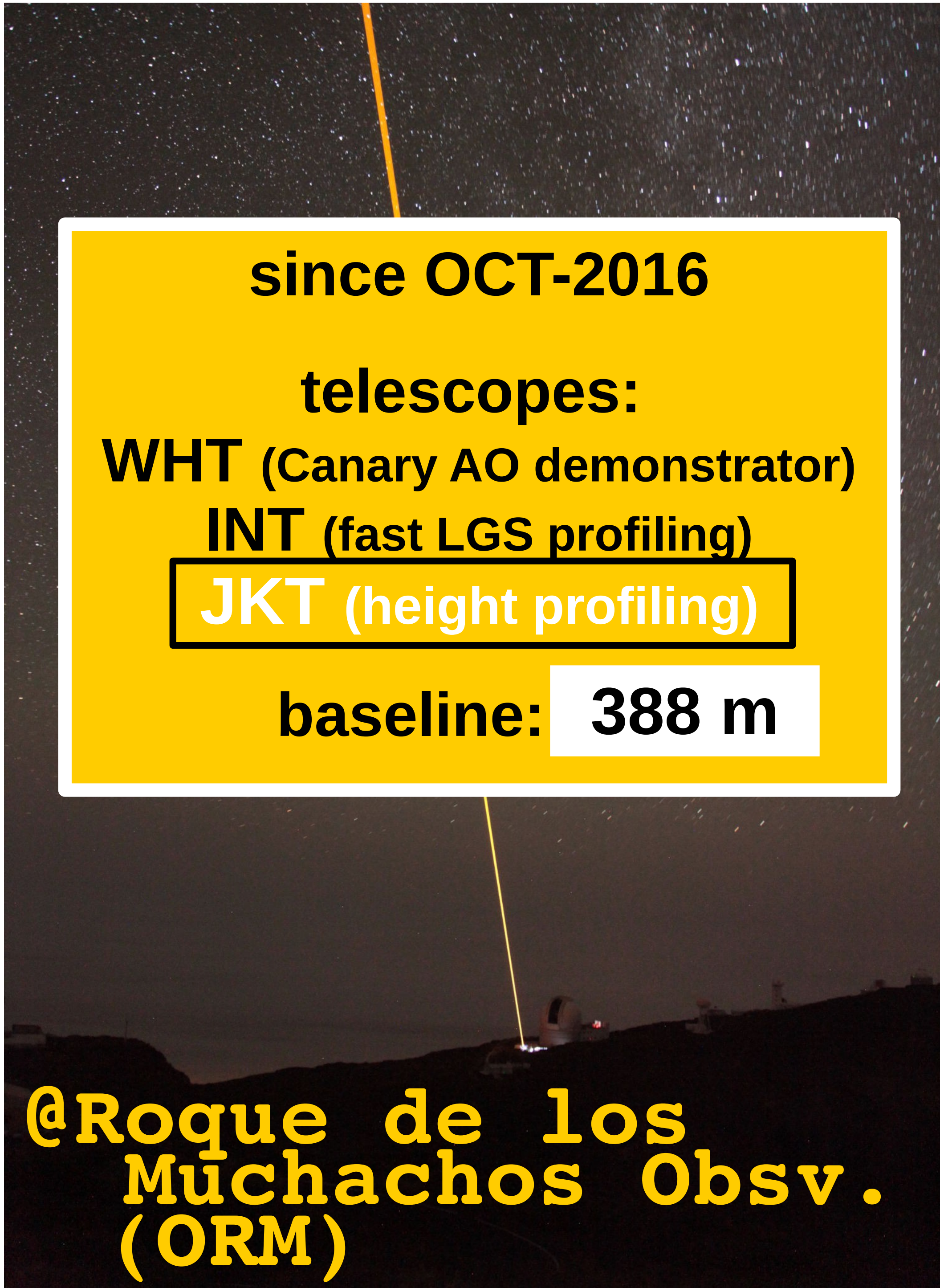
Na layer site characterization:

- -AO simulations
- -Design specifications



ESO Wendelstein LGS Unit (WLGSU)

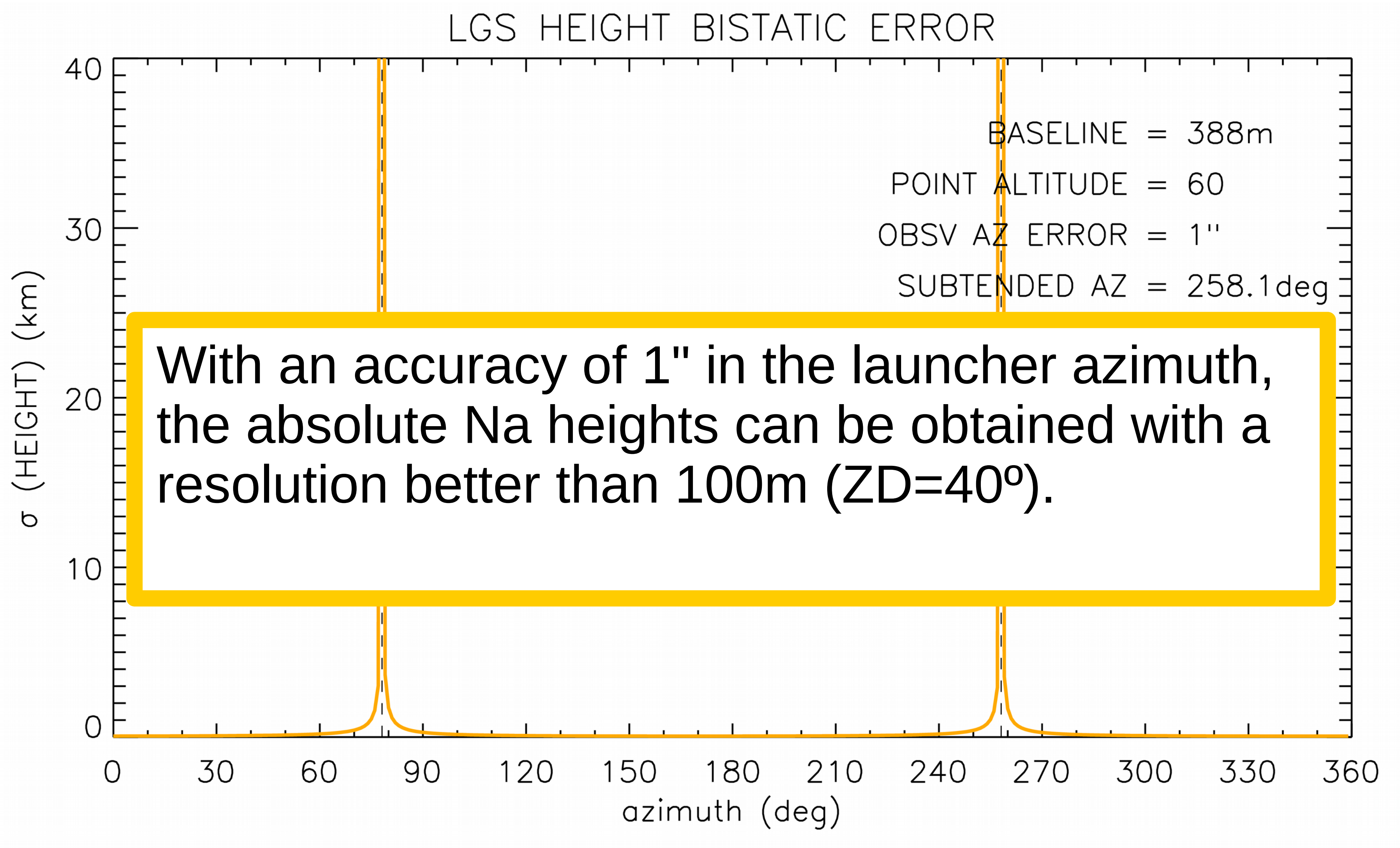




The **natrium** pipeline for absolute Na profiling

montecarlo simulation

general behaviour:

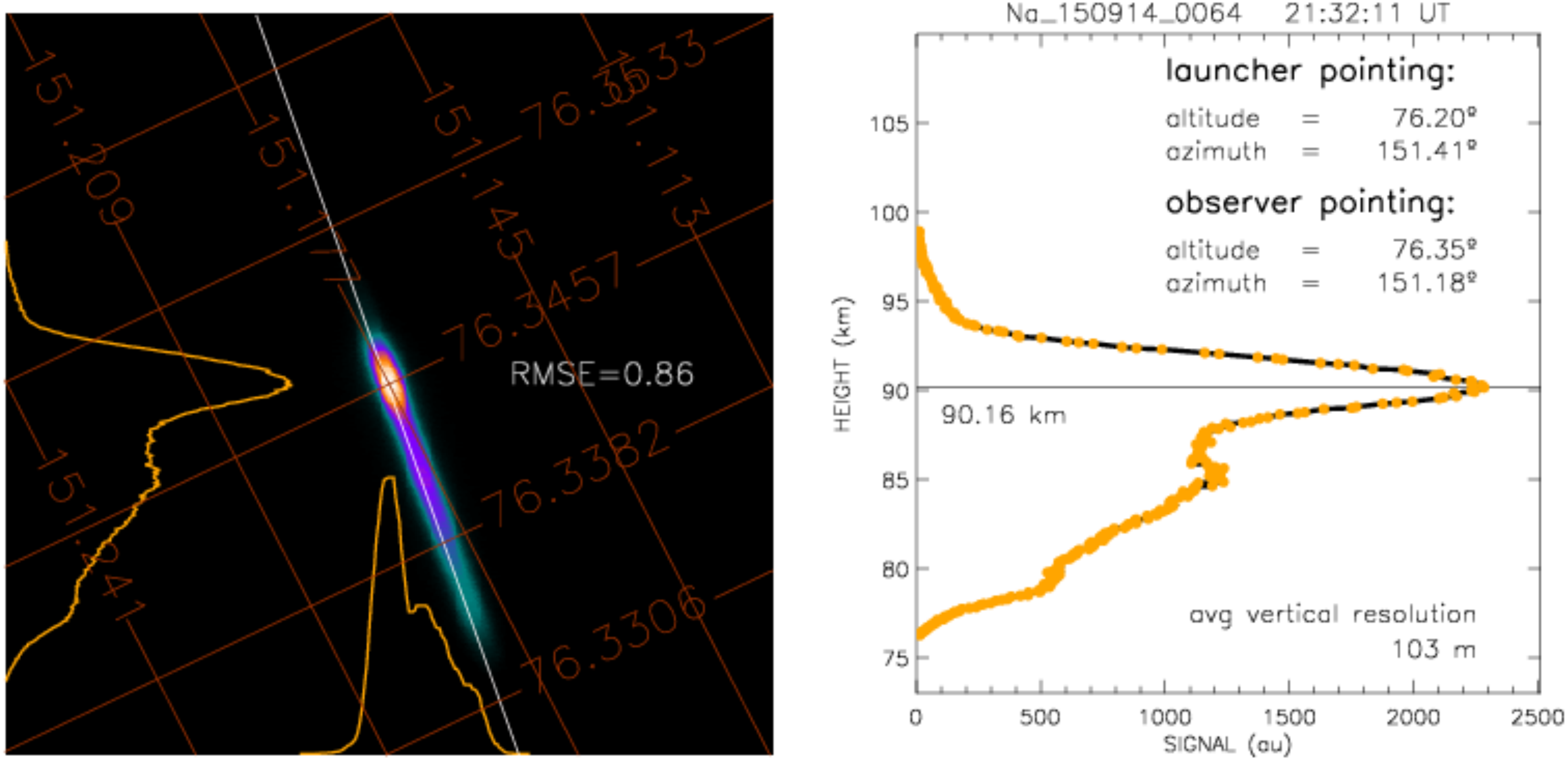


With an accuracy of 1'' in the launcher azimuth, the absolute Na heights can be obtained with a resolution better than 100m (ZD=40º).

The **natrium** pipeline for absolute Na profiling

natriumdos

4



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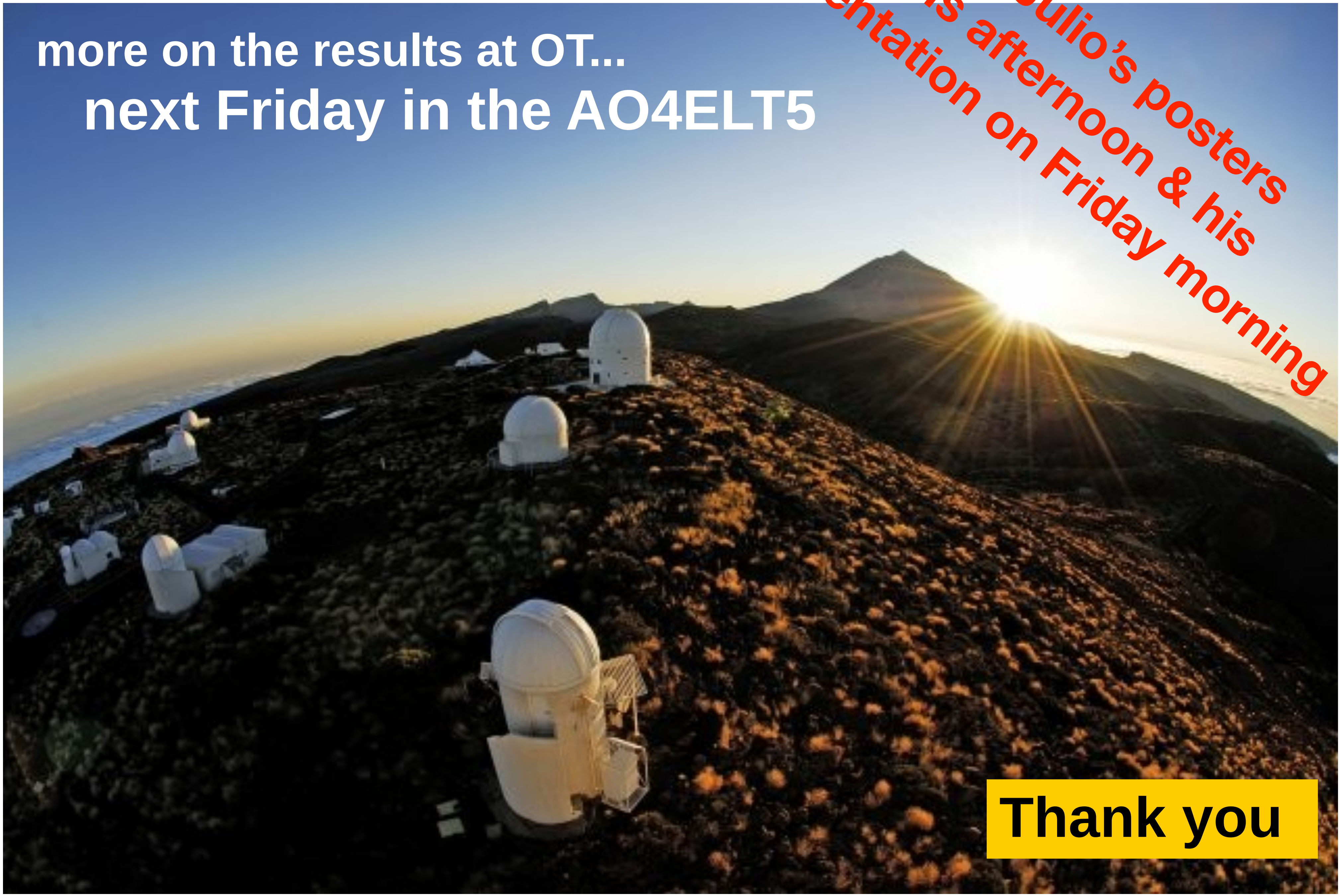

more on the results at OT...

next Friday in the AO4ELT5

See Julio's posters this afternoon & his presentation on Friday morning

Thank you

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Canary Phase D
Testing the ELT LGS configuration On-sky

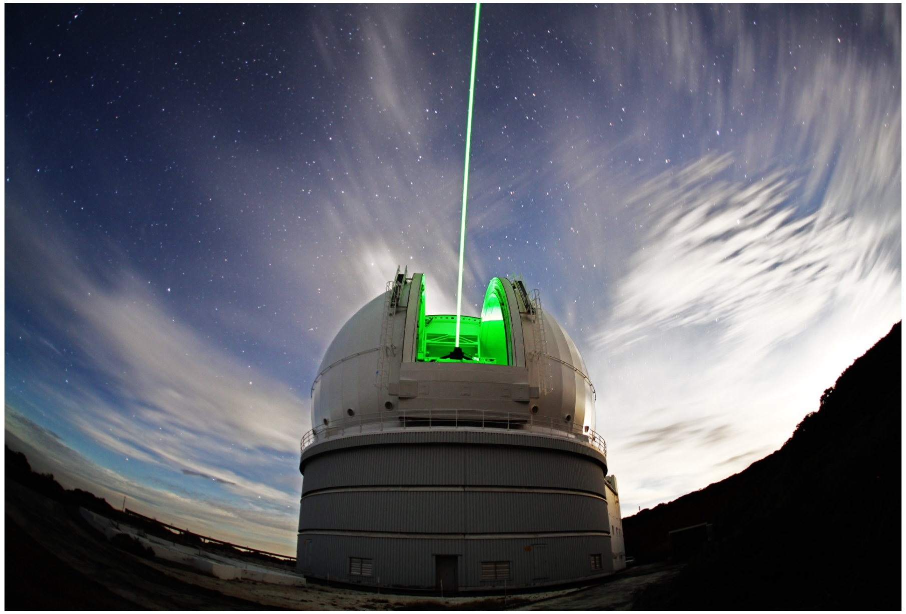
Andrew Reeves
Durham University

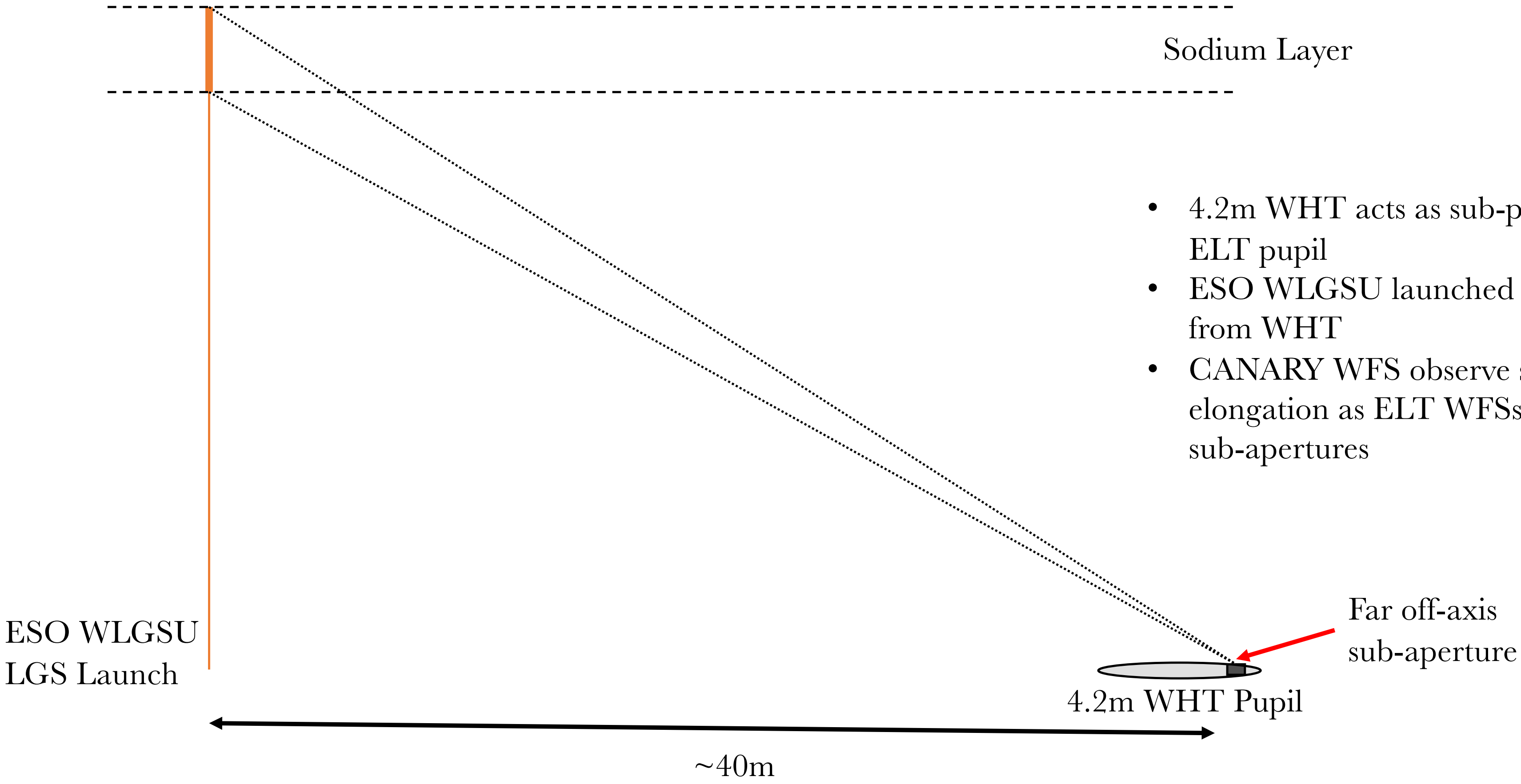
Canary Phase D - Goals

- Mitigate the risks of the ESO ELT LGS configuration by emulating it on-sky
- Investigate optimal centroiding schemes for highly elongated LGS WFS
- Investigate effects of dynamic sodium layer density profile on various centroiding algorithms and potential mitigation strategies
- Gather high time and vertical resolution statistics on the sodium layer altitude and density profile

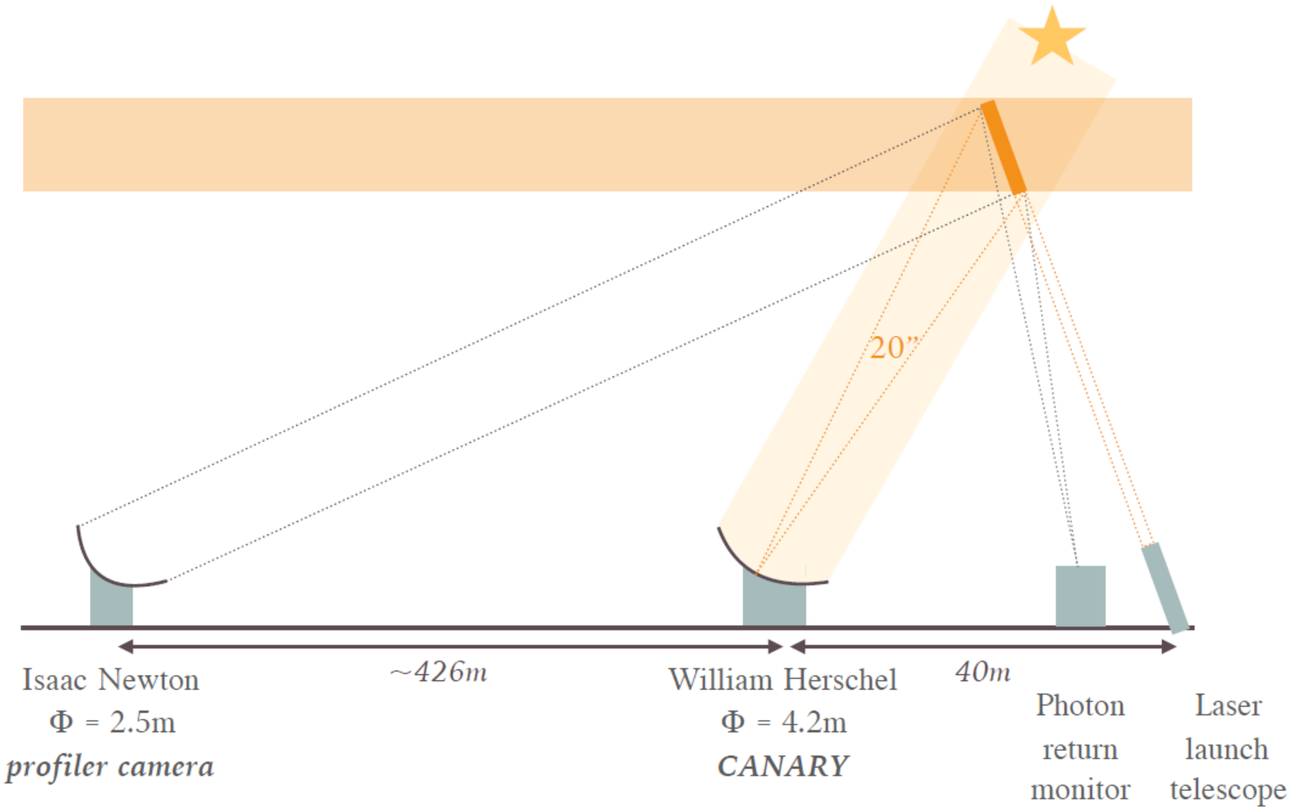
Canary

- On-sky AO demonstrator for ELT issues at the 4.2 m WHT
  - Multi-Object AO (Phases A & B)
  - Laser Tomographic AO (Phase C)
  - **Sodium LGS with extreme elongation (Phase D)**
- Multiple DMs
  - CILAS ADONIS Low Order DM (closed loop of all WFSs)
  - 241 actuator ALPAO High-Order DM (open or closed loop of all WFSs)
- Multiple WFSs
  - 3 off-axis NGS – 7x7 Shack-Hartmann WFSs
  - 1 on-axis "truth" NGS – 14x14 Shack-Hartmann WFSs
  - Previously 4 Rayleigh LGS – 14 x 14 Shack-Hartmann WFSs
  - **New for Phase D: Sodium LGS – 7x7 Shack-Hartmann WFS**
- Comprehensive "Telescope Simulator"
  - **New for Phase D: Elongated Sodium LGS**

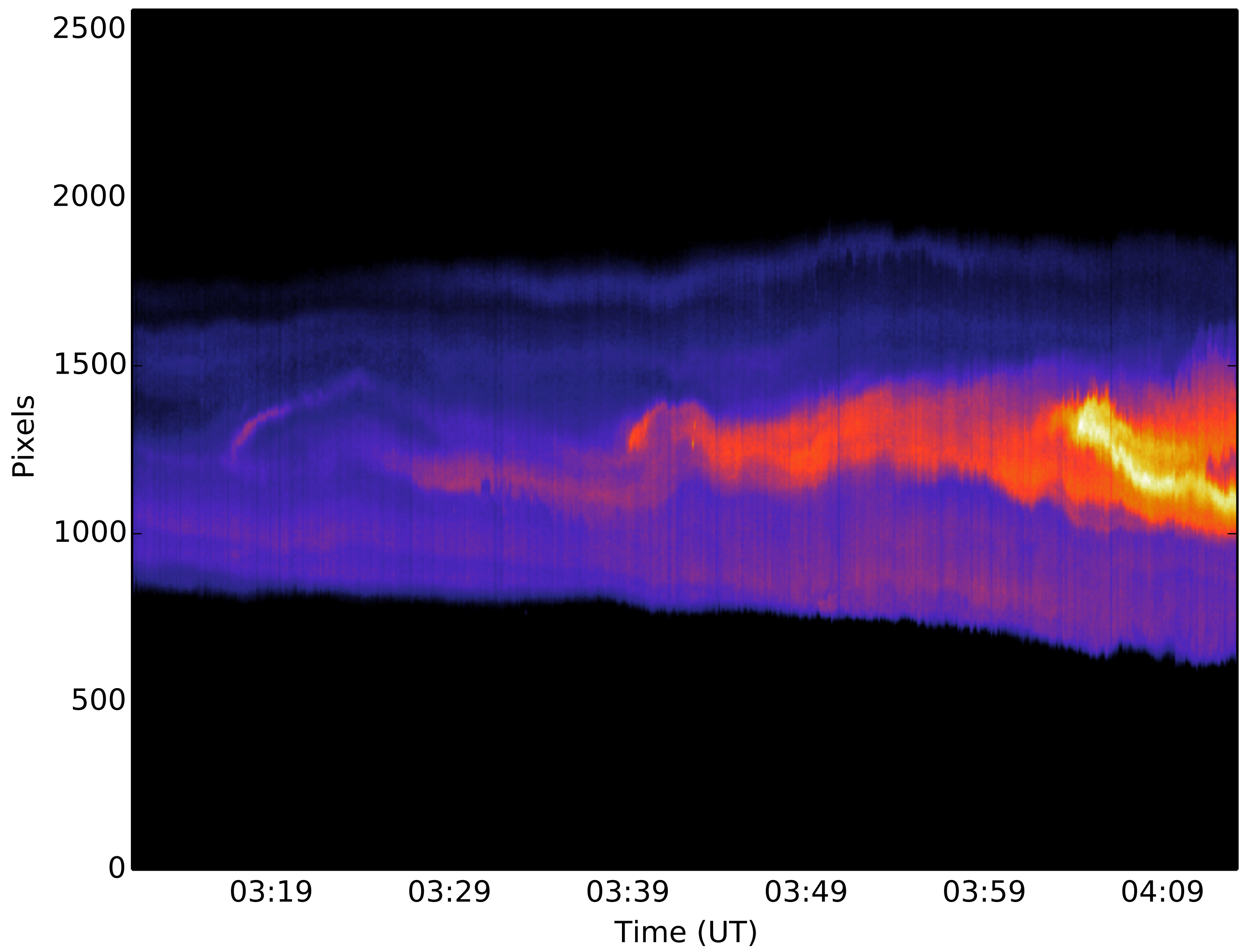




- 4.2m WHT acts as sub-pupil of ELT pupil
- ESO WLGSU launched ~38m from WHT
- CANARY WFS observe same elongation as ELT WFSs edge-sub-apertures



20"
~426m
40m
Isaac Newton
Φ = 2.5m
profiler camera
William Herschel
Φ = 4.2m
CANARY
Photon
return
monitor
Laser
launch
telescope



See Andrew's poster this afternoon

12th L4AO Workshop 2017 *Instituto de Astrofísica de Canarias (La Laguna, TENERIFE, CANARY ISLANDS)*

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TOPICS

- **A** Sodium and Rayleigh return modeling and measurements
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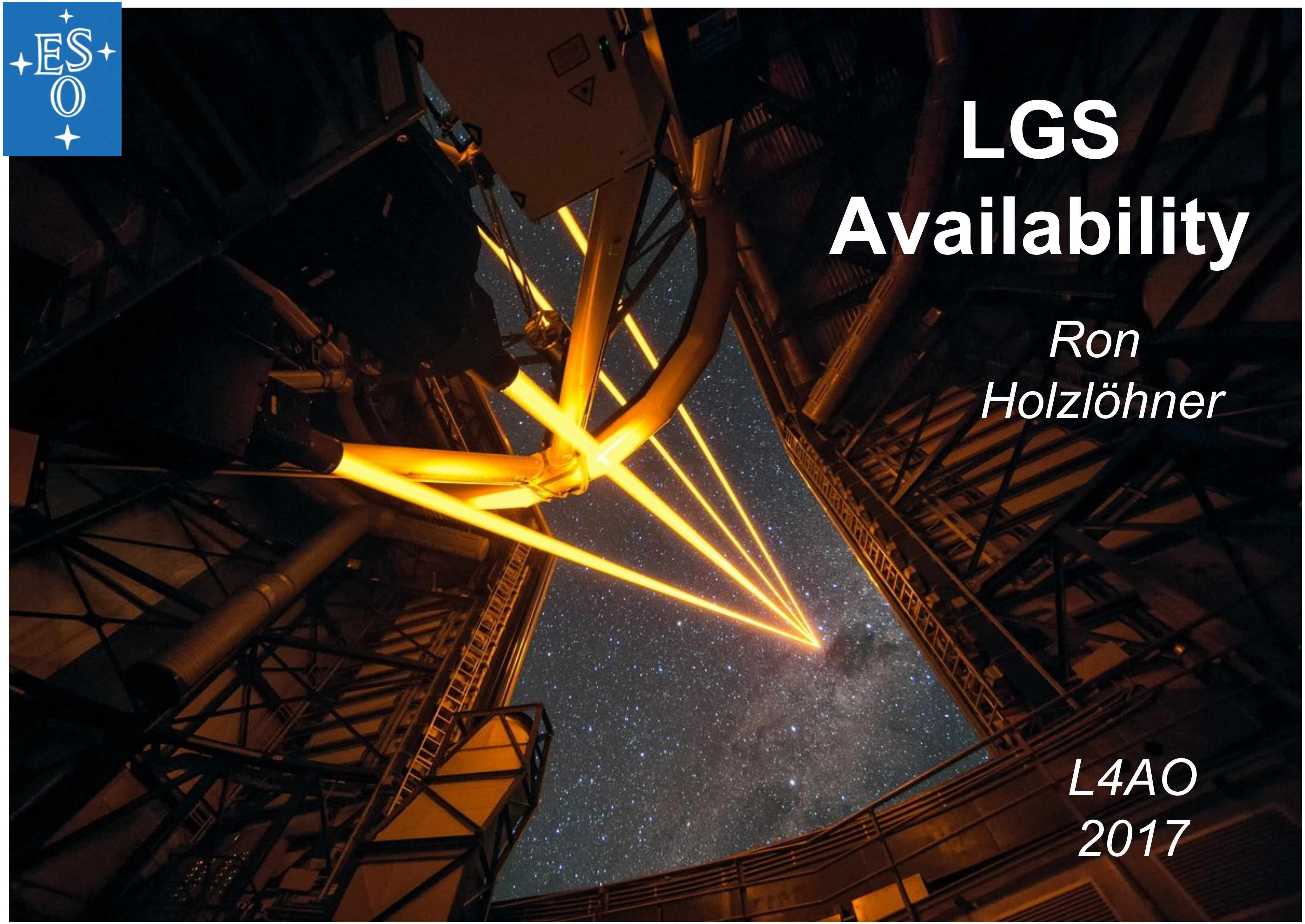
LGS Availability

Ron Holzlöhner

L4AO 2017



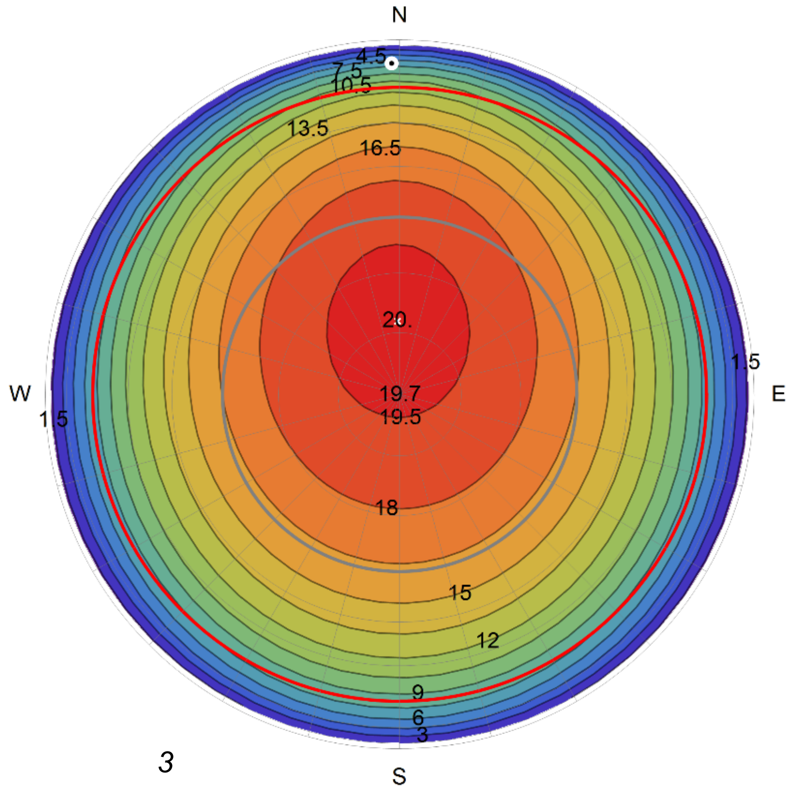
What does Availability Mean?

- A (single) laser guide star is available when
  1. The laser is working and can be projected/pointed
  2. Aircraft safety is cleared
  3. There are no clouds (cirrus!)
  4. The return flux is sufficient → sodium abundance
- Will focus on items 1 and 4
- Item 4 depends on pointing (altitude)
- An LGS ensemble is available when *k* LGS out of *n* are available
  - Degraded modes ($k < n$) can strongly raise ensemble availability

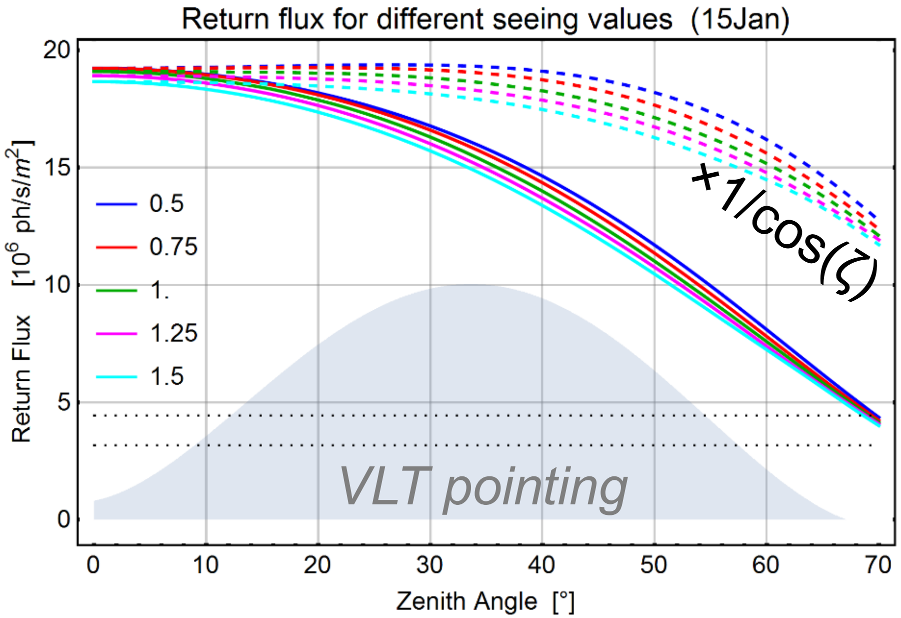
Return Flux Availability

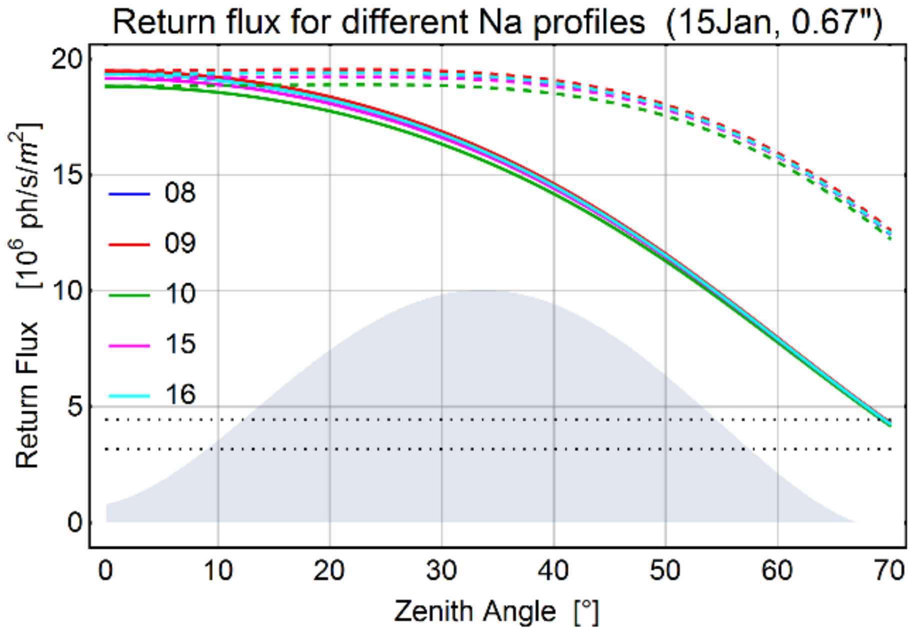
- Extensive simulations
  - Return flux across whole sky
  - Physical optics simulation to take into account laser irradiance pattern (divergence, speckling → SPIE 2008)
  - Measured sodium profiles (Pfrommer/Hickson)

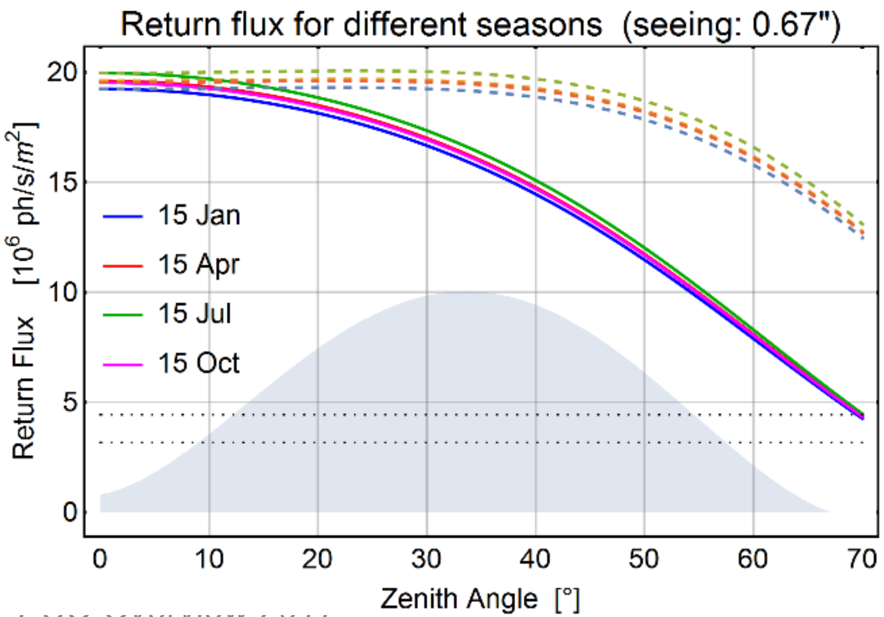
Parameter Name	Value
Launched laser power (D2a+D2b)	20 W
Power(D2b) / Power(D2a)	0.1
Polarization ellipticity angle χ	39°
Polarization azimuth	45°
B-field magnitude at 92 km	0.228 G
Geomagnetic inclination	–21.0°
Geomagnetic declination	–1.4°
Telescope altitude	2560 m
Launched Gaussian beam FWHM	127 mm
Reference sodium abundance	4×10^{13} atoms/m^2
Atmospheric throughput (589nm, one-way, zenith)	0.895



Seeing, Na Profiles, Season







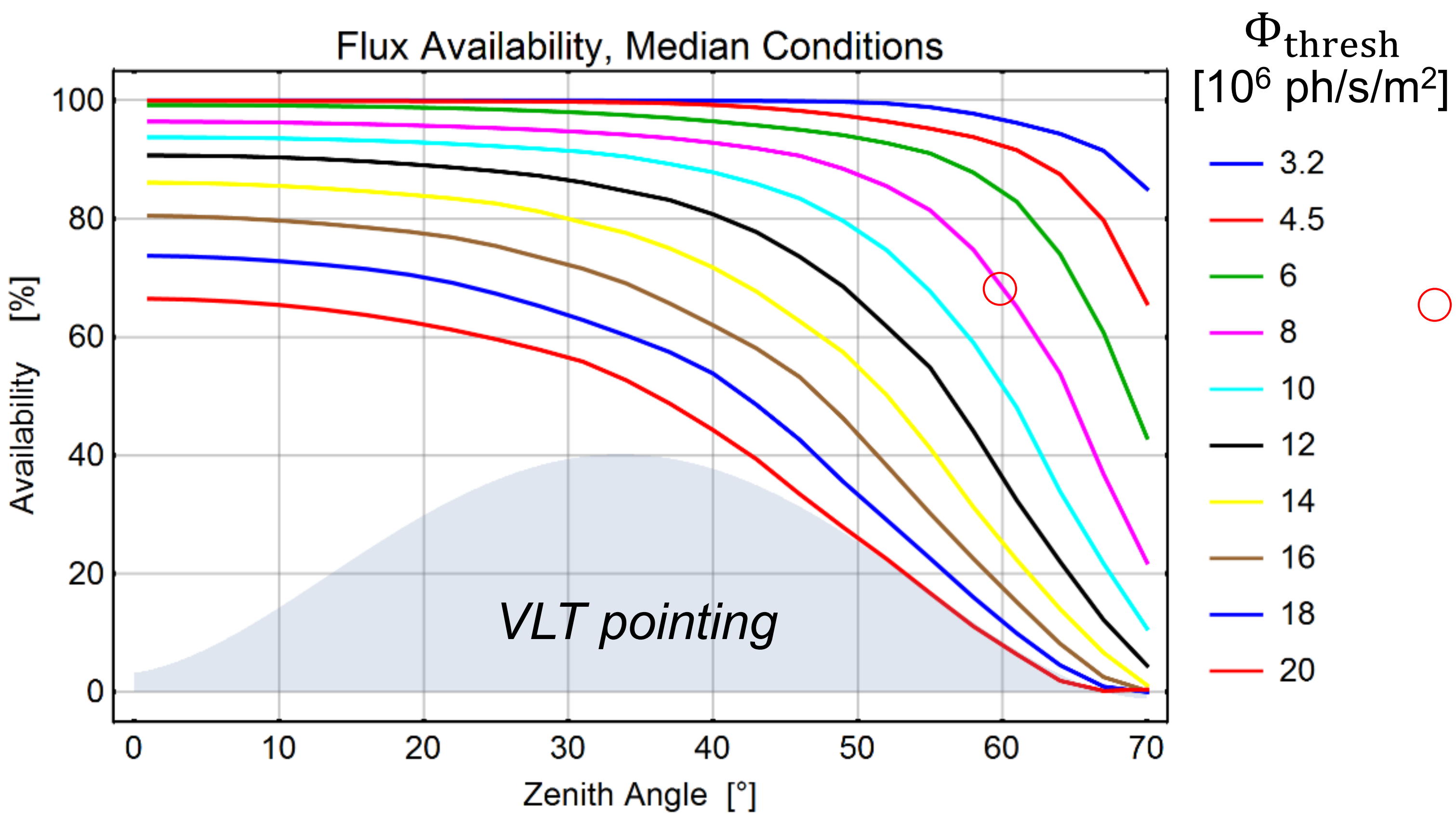
Spot elongation scales like cos(ζ)

In practice, the variations of return flux with seeing, Na profile and season are dwarfed by the fluctuations of C_{Na}, which can easily reach a factor 2 or more during a night.

Flux Availability

- How often do we achieve the return flux Φ_{thresh}?

Compute $P\left(C_{\text{Na,ref}} \frac{\Phi_{\text{thresh}}}{\Phi_{\text{sim}}}\right)$



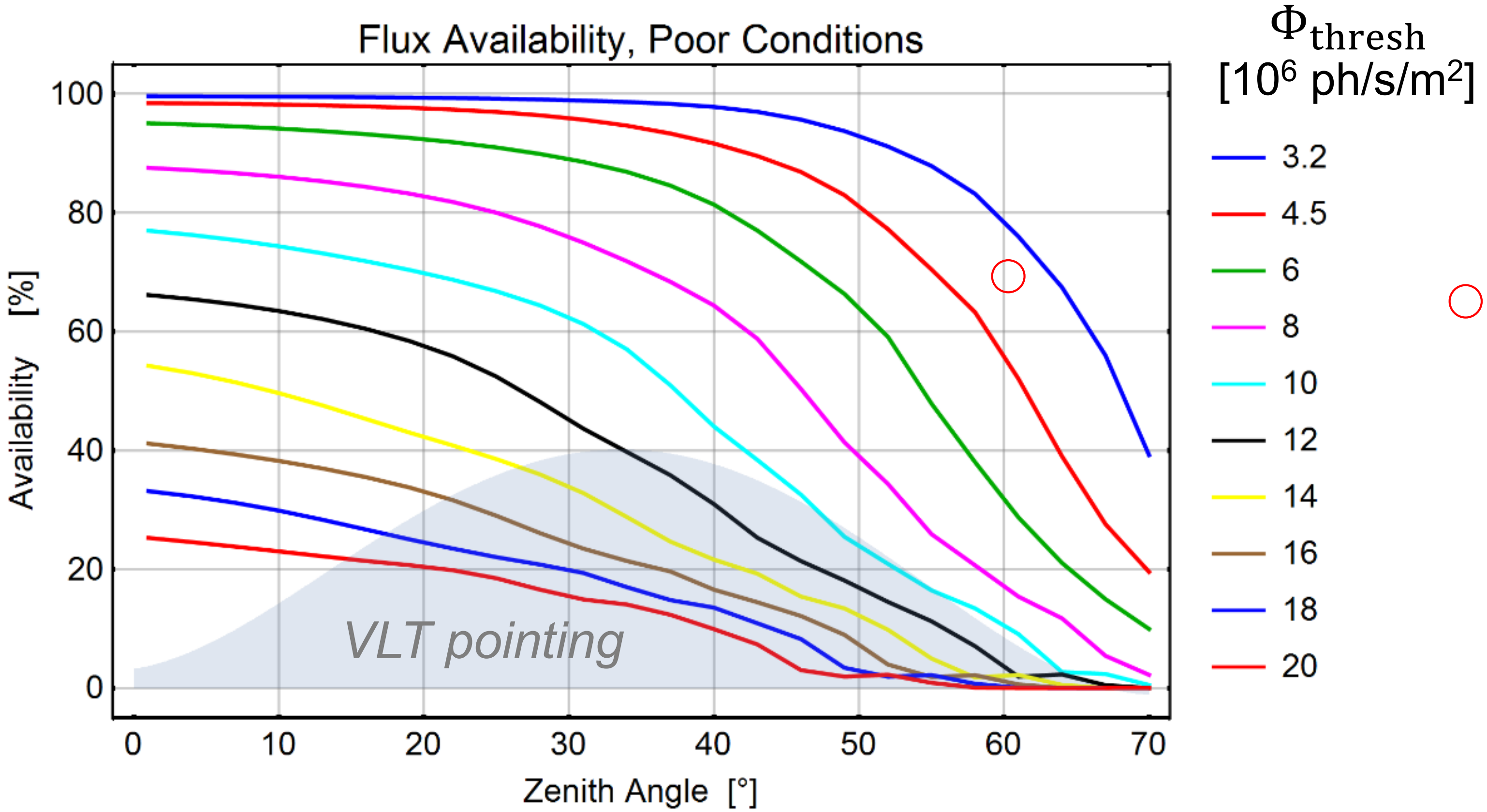
Example:
8×10^6 ph/s/m^2 available 70% of the time at ζ=60°

averaged through the year; median conditions, seeing: 0.67”

Flux Availability (II)

- Low sodium season and pessimistic assumptions

(Dec–Feb), worst azimuth, 15% power loss, seeing: 1.5”



○ *Example:*
3.7×10^6 ph/s/m^2 available 70% of the time at ζ=60°

Downtime

- Mean DownTime (MDT): The mean time from the indication of a failure to the moment the unit becomes available again
- Define unit nonavailability: ε = MDT/MTBF ➔ The probability that all *n* LGSUs out of *n* installed LGSUs *work* at a given time equals

$$P_{n|n} = (1 - \varepsilon)^n = 1 - n\,\varepsilon + O(\varepsilon^2)$$

- Probability that *at least* any combination of *n*–1 LGSUs out of *n* works

$$P_{n-1|n} = P_{n|n} + n\,\varepsilon\,(1-\varepsilon)^{n-1} = 1 - (n^2 - n)\,\varepsilon^2/2 + O(\varepsilon^3)$$

- Any combination of *n*–2 LGSUs out of *n* works:

$$P_{n-2|n} = P_{n-1|n} + n(n-1)\varepsilon^2\,(1 - \varepsilon)^{n-2}/2 = 1 - (n^3 - 3n^2 + 2n)\,\varepsilon^3/6 + O(\varepsilon^4)$$

- Numeric example for $n = 6$ and ε = 1.0% :

$$P_{6|6} = 93.95\% \;\rightarrow\; \text{SDT} = (1-0.9395) \times 365 \text{ days/year} = 22 \text{ days/year},$$

$$P_{5|6} = 99.84\% \;\rightarrow\; \text{SDT} = (1-0.9984) \times 365 = 6.8\text{h/year} \;\; (1 \text{ day} = 12\text{h})$$

- 4LGSF Technical SDT is 2 days/year for ≥ 2 LGSU unavailable out of 4

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Australian National University

Semiconductor Guidestar Laser for Astronomy, Space, and Laser Communications

C. d'Orgeville, G. Fetzer, F. Bennet, A. Bouchez, Y. Gao, M. Goodwin, A. Lambert, J. Mason, F. Rigaut, S. Ryder, D. Shaddock, R. Sharp

Acknowledgements

This work is supported by the Australian Research Council Linkage Infrastructure Equipment and Facilities (LIEF) grant #LE170100004 and associated LIEF partners. Additional funding is provided by the Australian National University via Major Equipment Committee (MEC) program grant #17MEC35.

Presented by Assoc. Prof. Céline d'Orgeville
Advanced Instrumentation Technology Centre
Research School of Astronomy & Astrophysics
Australia National University

Sodium Guidestar Laser Technology

Australian National University

- Three generations of sodium guidestar lasers
  - Dye lasers (~1990s)
  - Solid-state lasers (~2000s)
  - Fiber lasers (~2010s)

ALFA CW dye laser @ Calar Alto Observatory (Spain)

50W CW mode-locked solid-state laser @ Gemini South (Chile)

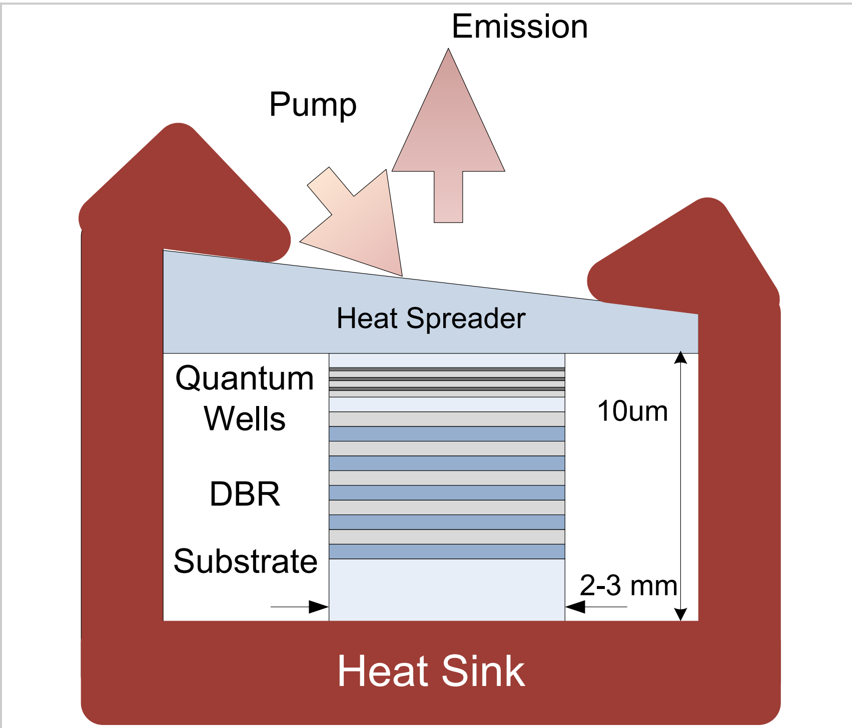
20W Toptica SodiumStar fibre laser @ Keck Observatory (Hawaii, USA)

- Review paper: *d'Orgeville & Fetzer, Proc. SPIE 9909, 99090R, 2016*

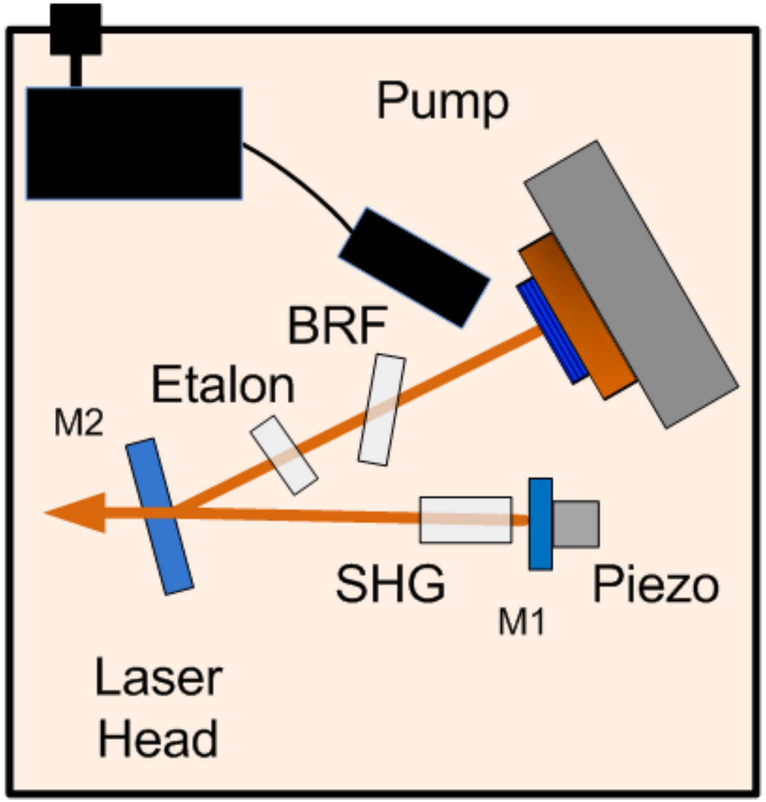
Semiconductor Laser Technology

Australian National University

- Fourth generation sodium guidestar laser (~2020s)
- Based on semiconductor laser technology
  - a.k.a Vertical External-Cavity Surface-Emitting Lasers (VECSEL)
  - a.k.a Optically Pumped Semiconductor Lasers (OPSL)



Semiconductor Laser Chip (Credit: Areté Associates)

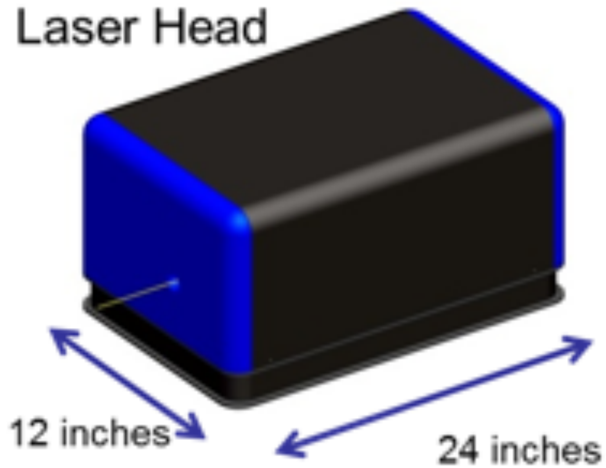


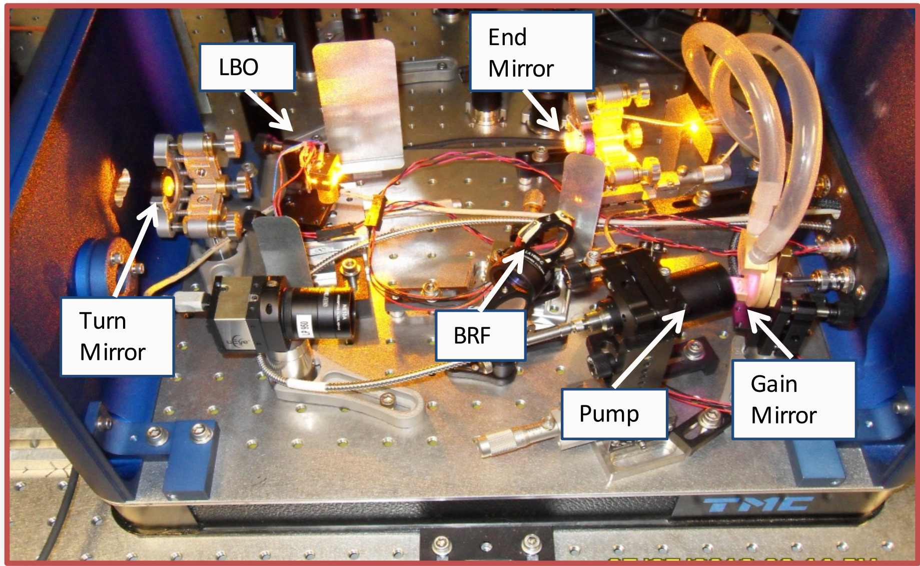
Semiconductor Guidestar Laser Cavity Layout (Credit: Areté Associates)

Semiconductor Laser Technology

Australian National University

- Early efforts by US laser manufacturer Areté Associates to produce 589 nm output with semiconductor laser technology have yielded highly promising results, including:
  - 20 W multi-mode operation near 589 nm (sodium resonance wavelength)
  - Low power single longitudinal mode operation
  - Cavity locked to the sodium D2a line resonance feature
  - Continuous tuning over sodium D2a and D2b lines





589nm Semiconductor Laser Demonstrator (Credit: Areté Associates)

ARC LIEF Grant

Australian National University

Australian Government
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Laser guide star within reach

Home » Media Centre » Research News » Feature Articles

The creation of a new laser system for the first Australian laser guide star that will have important and far-ranging uses in astronomy, satellite tracking and mitigation of the threat of space debris will soon be possible, following the award of a $502,453 grant from the Australian Research Council (ARC).

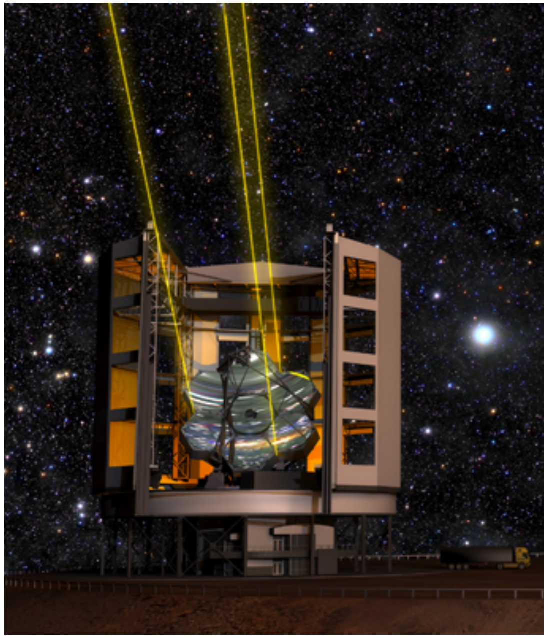
Associate Professor Celine d'Orgeville, from The Australian National University (ANU), will lead the successful ARC Linkage Infrastructure, Equipment and Facilities (LIEF) project announced as part of the ARC Major Grants Announcement on 1 November 2016. The ARC is providing $28.6 million for 48 new LIEF projects.

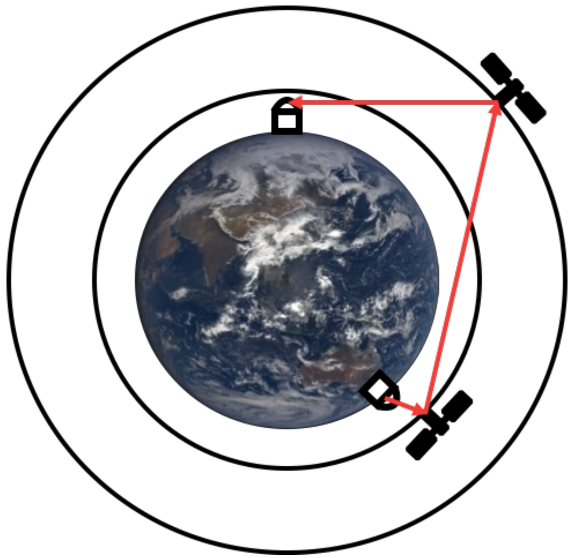
The new project, to commence in 2017, will use semiconductor laser technology as a cost-effective, highly reliable and compact alternative to expensive, inefficient, bulky laser systems that are currently used.

The new infrastructure will enable the production of the first sodium laser guide star in Australian skies, and will secure Australia's position as the premier provider of commercial-grade laser guide star adaptive optics systems for civil and defence telescopes around the world. This laser has wide scientific appeal for research with telescopes in astronomy, and for satellite tracking and mitigation of the threat of space debris.

Applications in Astronomy, SSA & Laser coms

- Following its successful demonstration at Mount Stromlo Observatory in late 2018/early 2019, the Semiconductor Guidestar Laser prototype will become available for use by ANU and their academic and industry partners for LGS AO research projects in astronomy, space situational awareness, and ground-to-satellite laser communications.
- Commercialisation of the Semiconductor Guidestar Laser technology by US and/or Australian vendors is expected in the longer term.





See Celine's poster this afternoon

Discussions and Conclusions

- Beware of Raman scattering (plan ahead)
- Sodium profile data sharing
- Guidestar lasers are now used beyond AO for astronomy
  - Exciting new laser developments
  - Uplink laser correction (guidestar lasers and laser comms)
  - DMs for high power laser compensation
  - Should coordinate approach to laser propagation approvals
- Venue and time for next Laser Workshop?

Thank you to the L4AO Organizers for a wonderful 2017 Laser Workshop in beautiful Tenerife!