The best skies for Astronomy

CASIANA MUÑOZ-TUÑÓN
&
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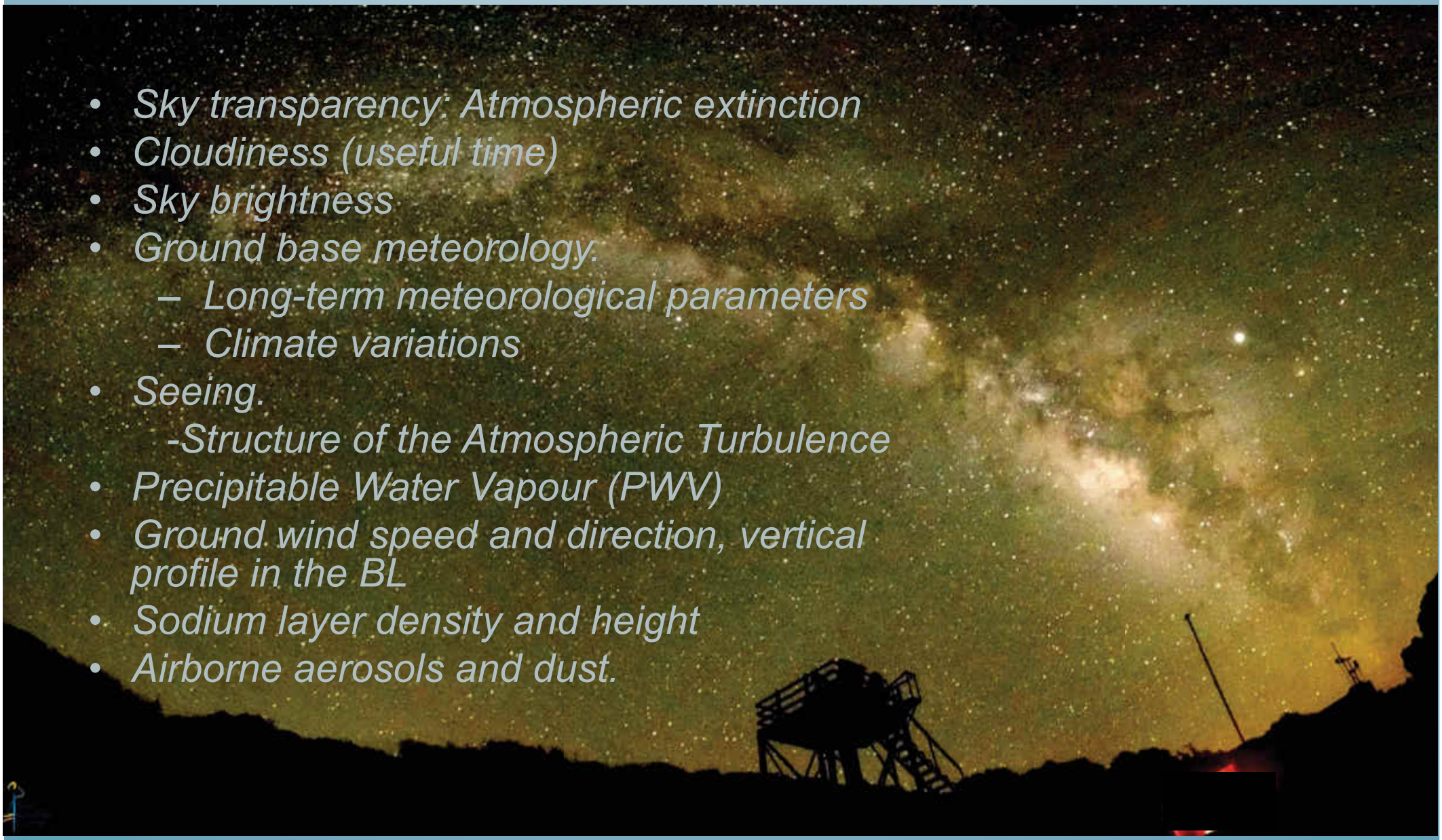
(SKYTEAM@IAC.ES)

Jean Vernin,
Jesus J. Fuensalida
Begoña García-Lorenzo
and many others

Cielos despejados, transparentes, nítidos y oscuros

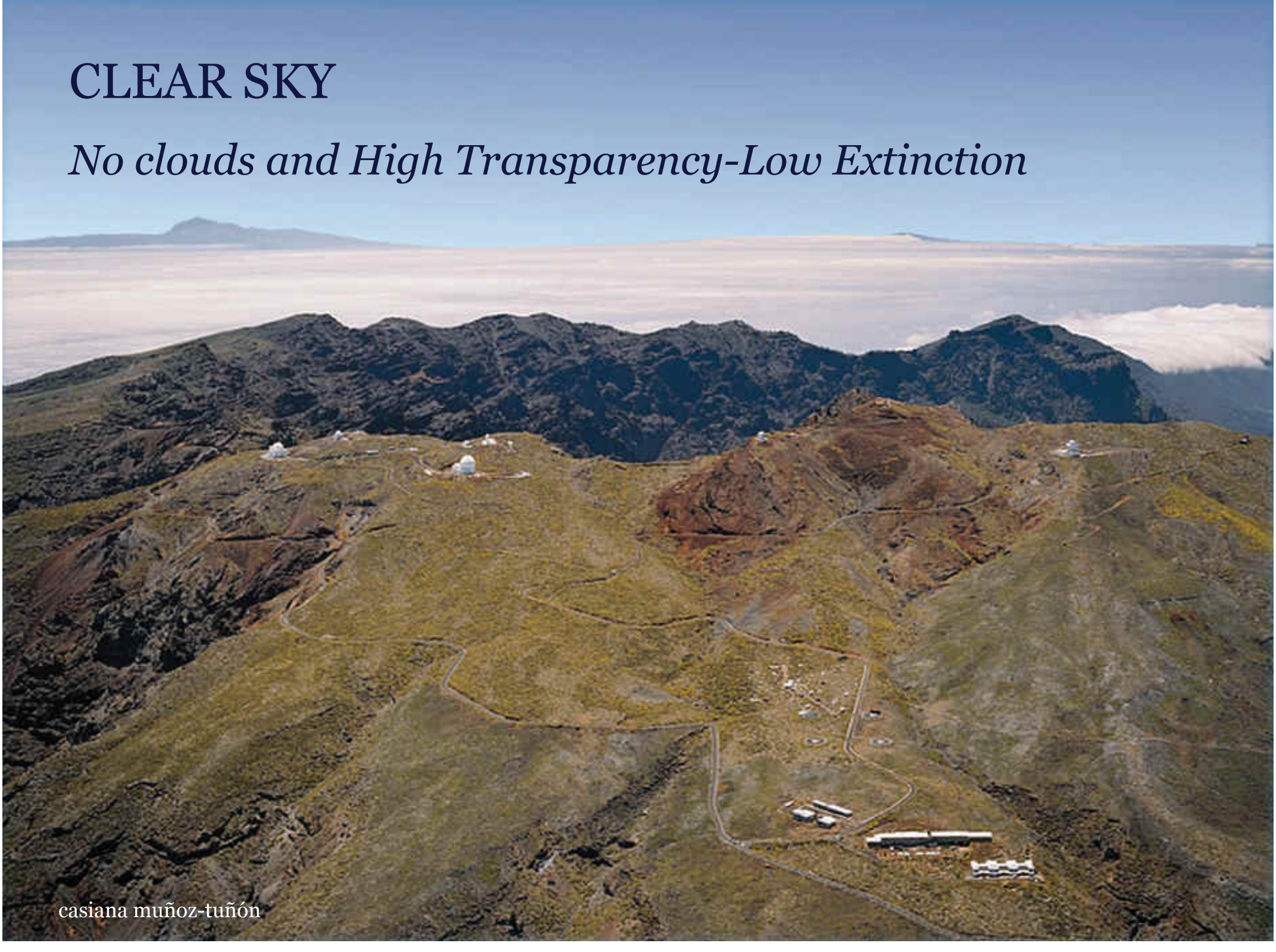
Parameters for Site Characterization



- *Sky transparency: Atmospheric extinction*
- *Cloudiness (useful time)*
- *Sky brightness*
- *Ground base meteorology.*
  - *Long-term meteorological parameters*
  - *Climate variations*
- *Seeing.*
  - *-Structure of the Atmospheric Turbulence*
- *Precipitable Water Vapour (PWV)*
- *Ground wind speed and direction, vertical profile in the BL*
- *Sodium layer density and height*
- *Airborne aerosols and dust.*

CLEAR SKY

No clouds and High Transparency-Low Extinction

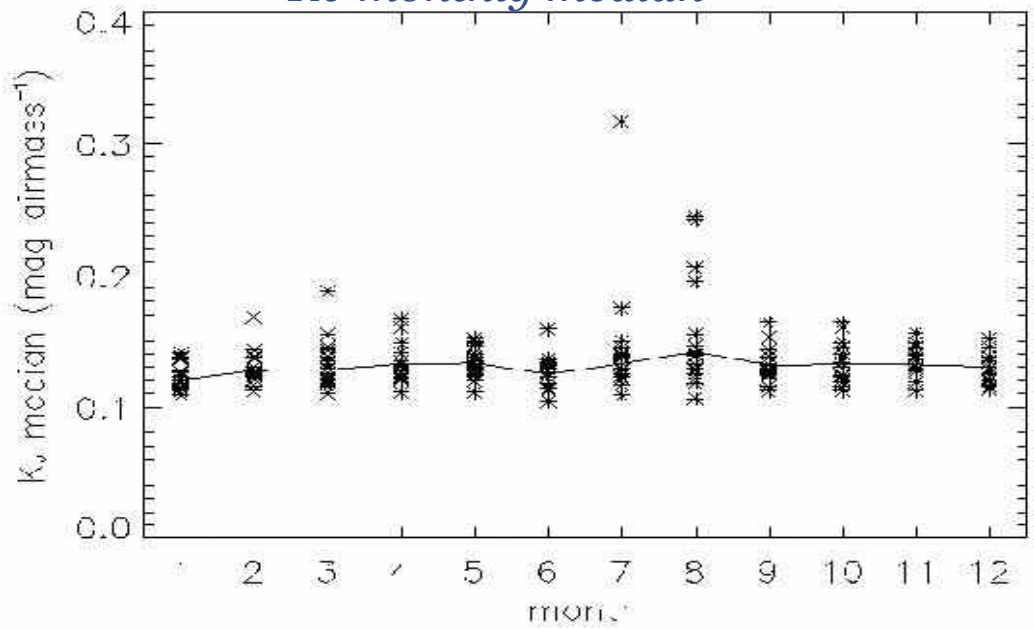


casiana muñoz-tuñón

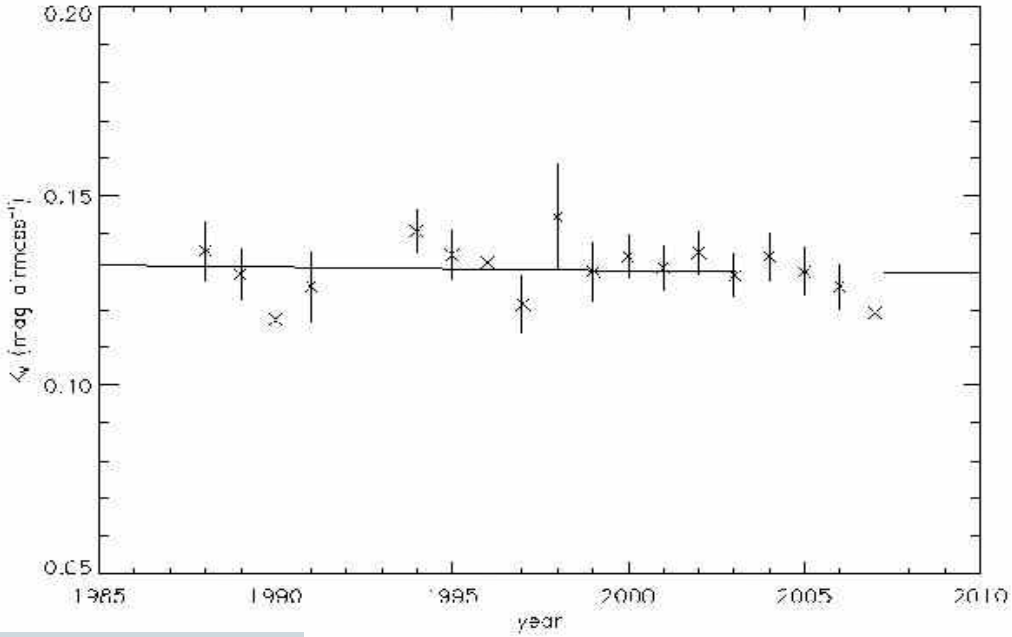
Useful time and extinction

The Carlsberg Meridian Telescope at the ORM since 1984 (http://www.ast.cam.ac.uk) providing nightly values of atmospheric extinction coefficient in V and r' Sloan filters

Kv monthly median

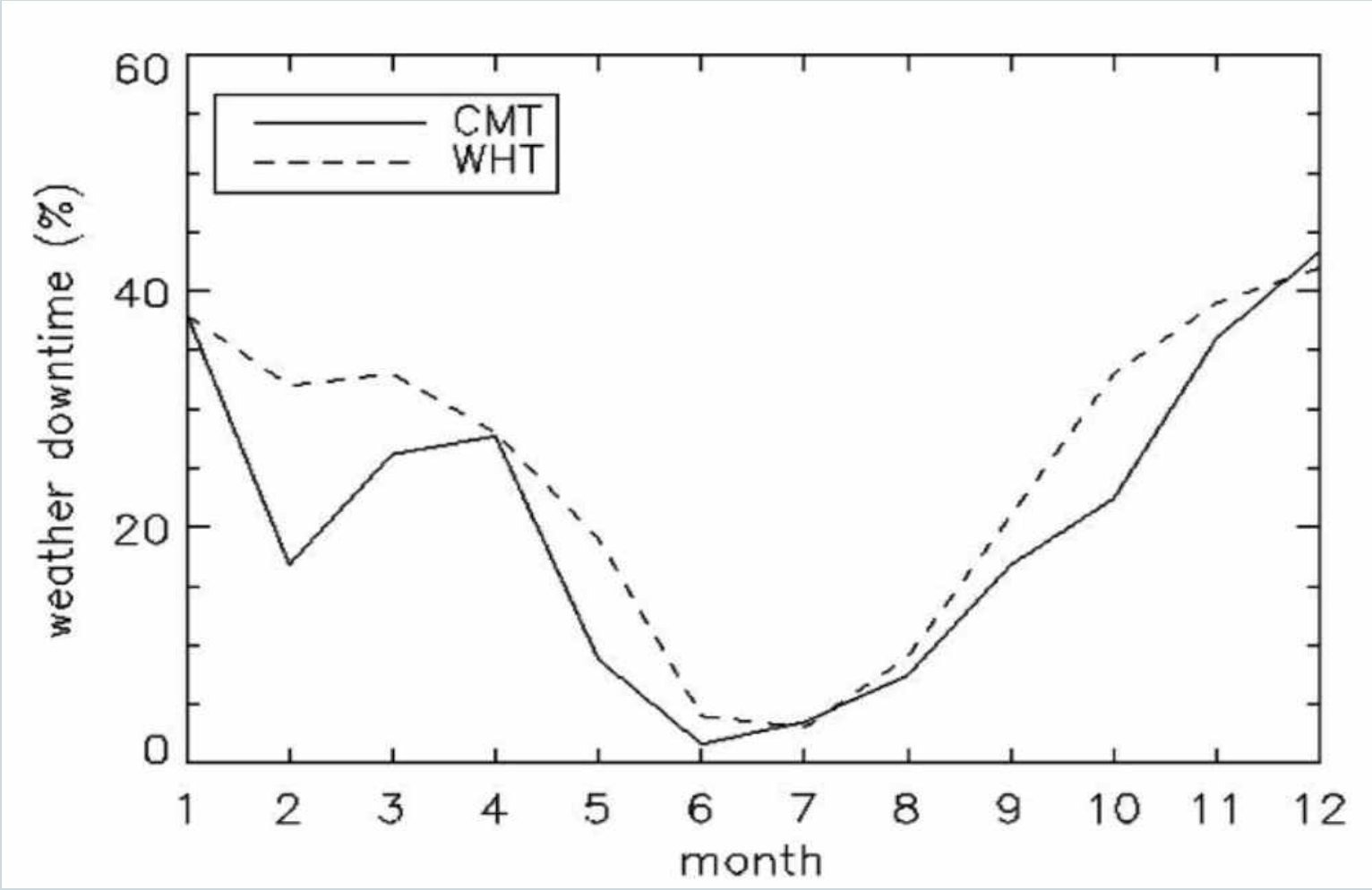


Kv yearly median fit=0.13



García-Gil, Muñoz-Tuñón & Varela, PASP, 122 , 1109 (2010)- 20 yr data.

Weather downtime



Average weather downtime : 23% (from a sample of 21 years)

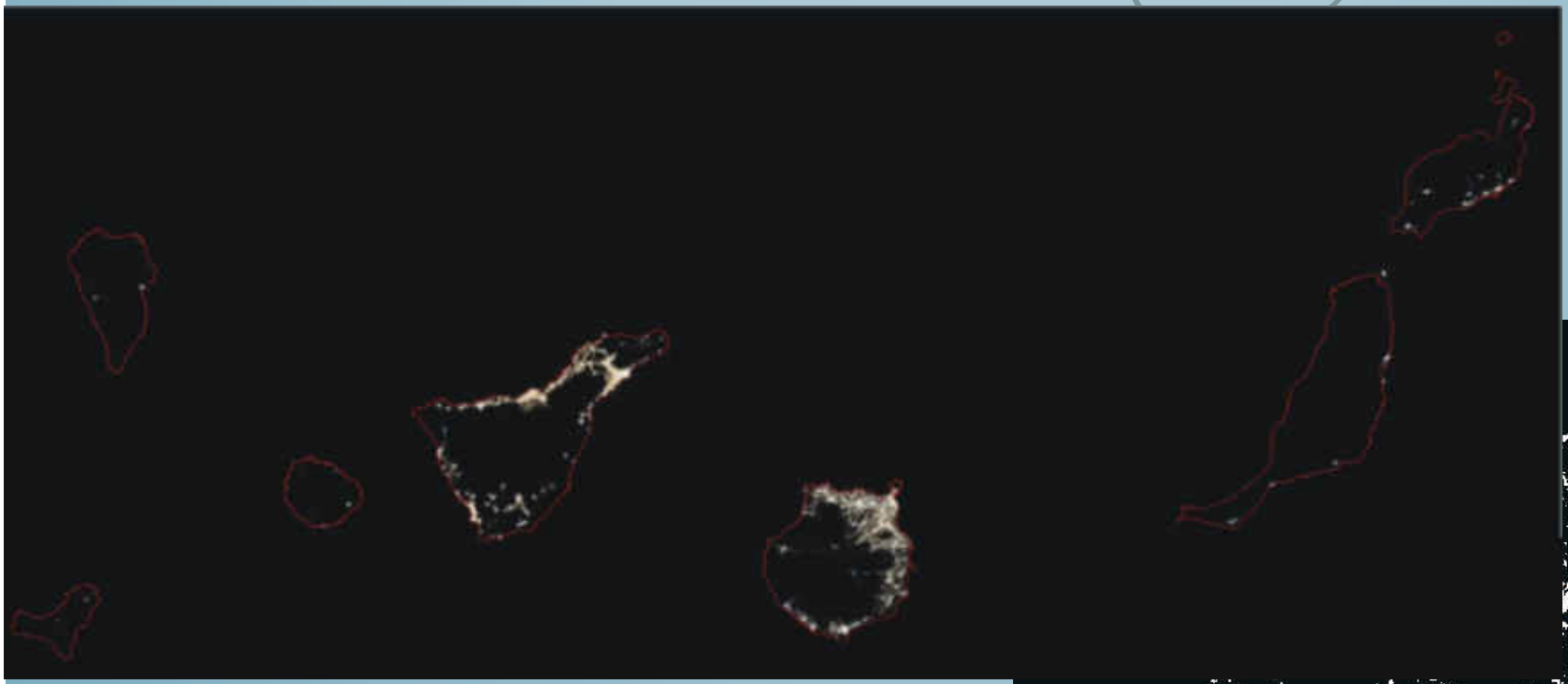
18 yr WHT logs 26.33%

García-Gil, Muñoz-Tuñón & Varela, PASP, 122 , 1109 (2010)- 20 yr database baseline

Canarian Observatories (OT&ORM) Astronomical reserves protected by law.

DARK SKY

SKY BRIGHTNESS- SKY LAW (OTPC)



The Sky Quality Protection Technical Office (OTPC) was set up by the IAC in January 1992 to provide advice on the application of the Sky Law (Law 31/1988), [*http://www.iac.es/otpc*](http://www.iac.es/otpc)

SKY BRIGHTNESS
Results @ ORM & OT

Sky brightness using Photomultipliers tubes (185-830 nm) @ ORM&OT for six different elevations// protocol to detect and control contaminating sources. (see more at http://www.iac.es/site-testing/ and www.iac.es/OTPC)

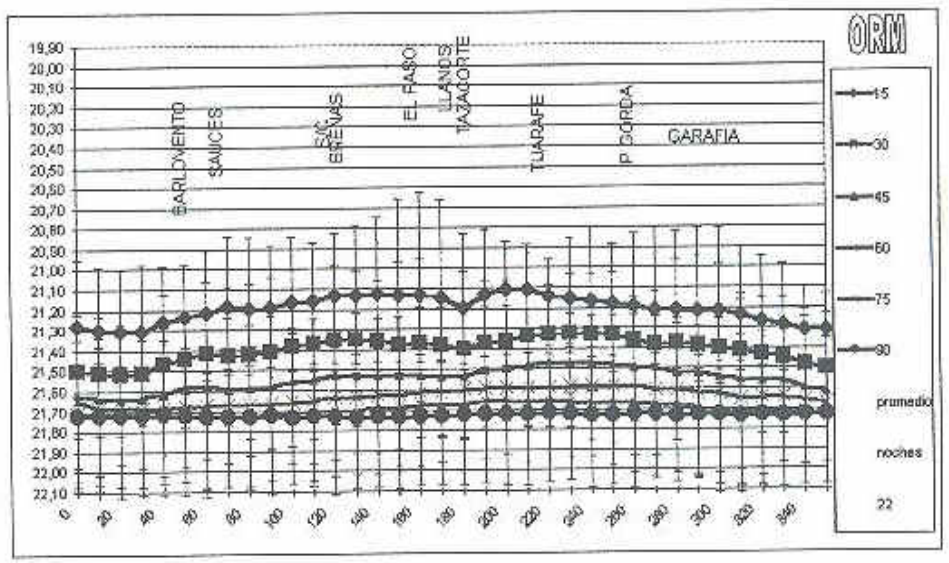


Fig. 2. Sky brightness at the ORM in *V* (mag arcsec^{-2}).

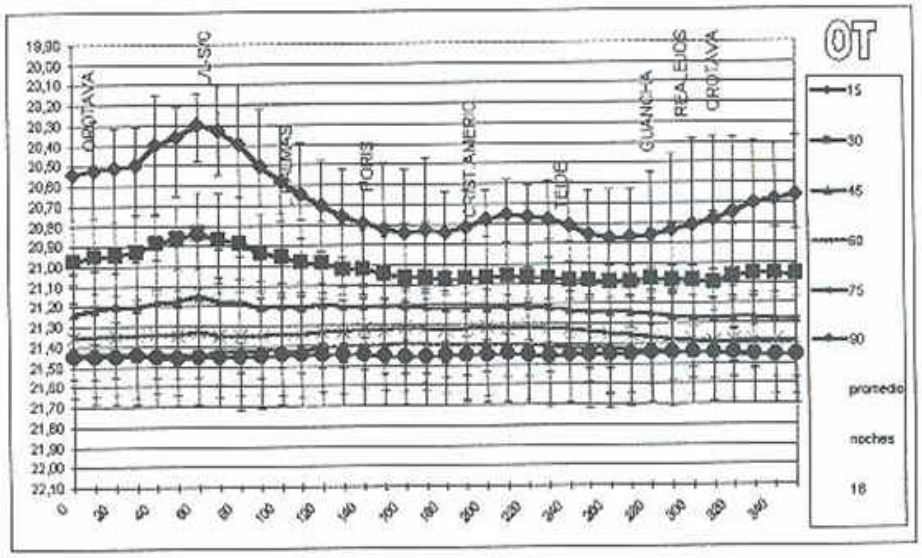
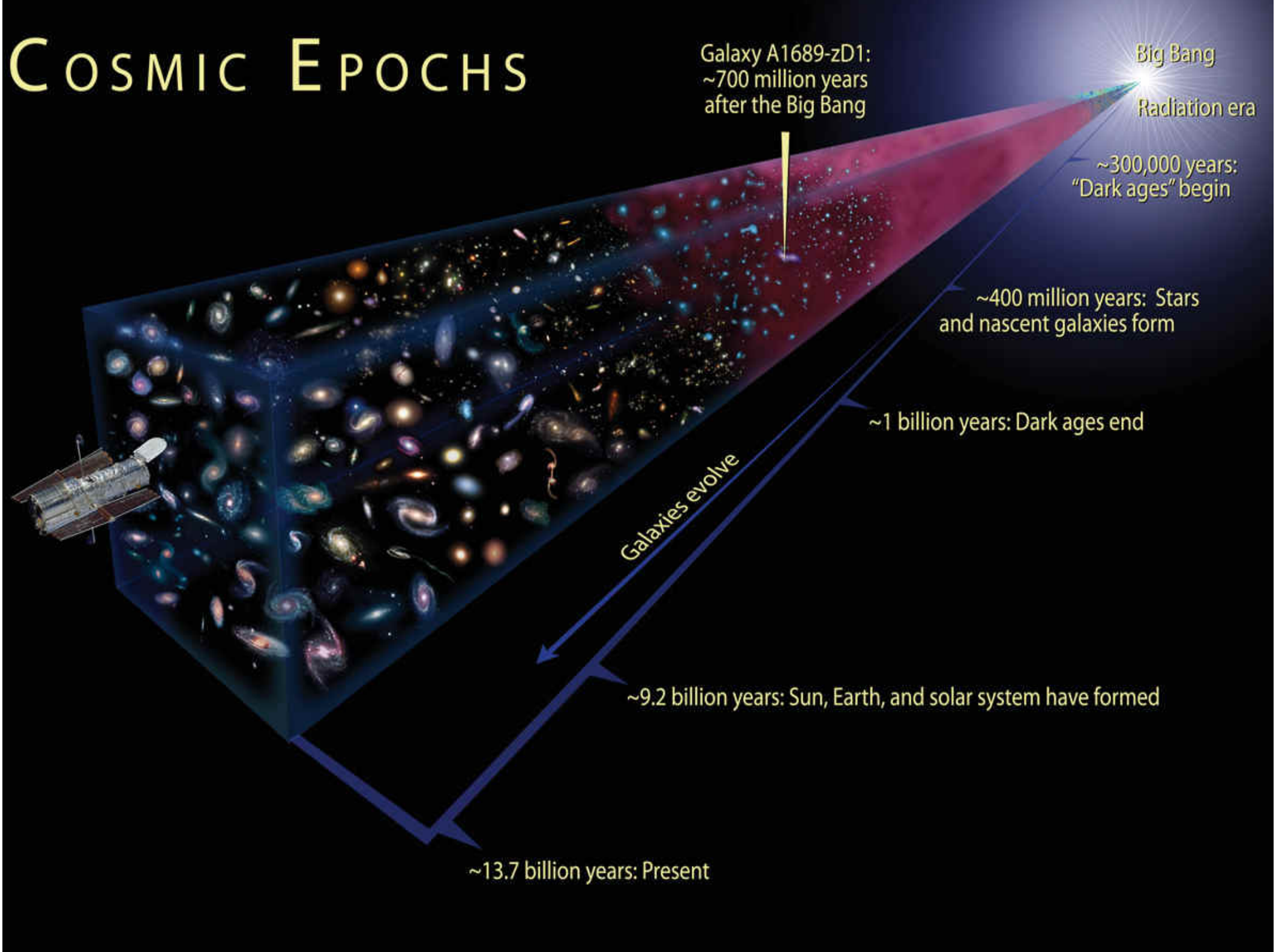
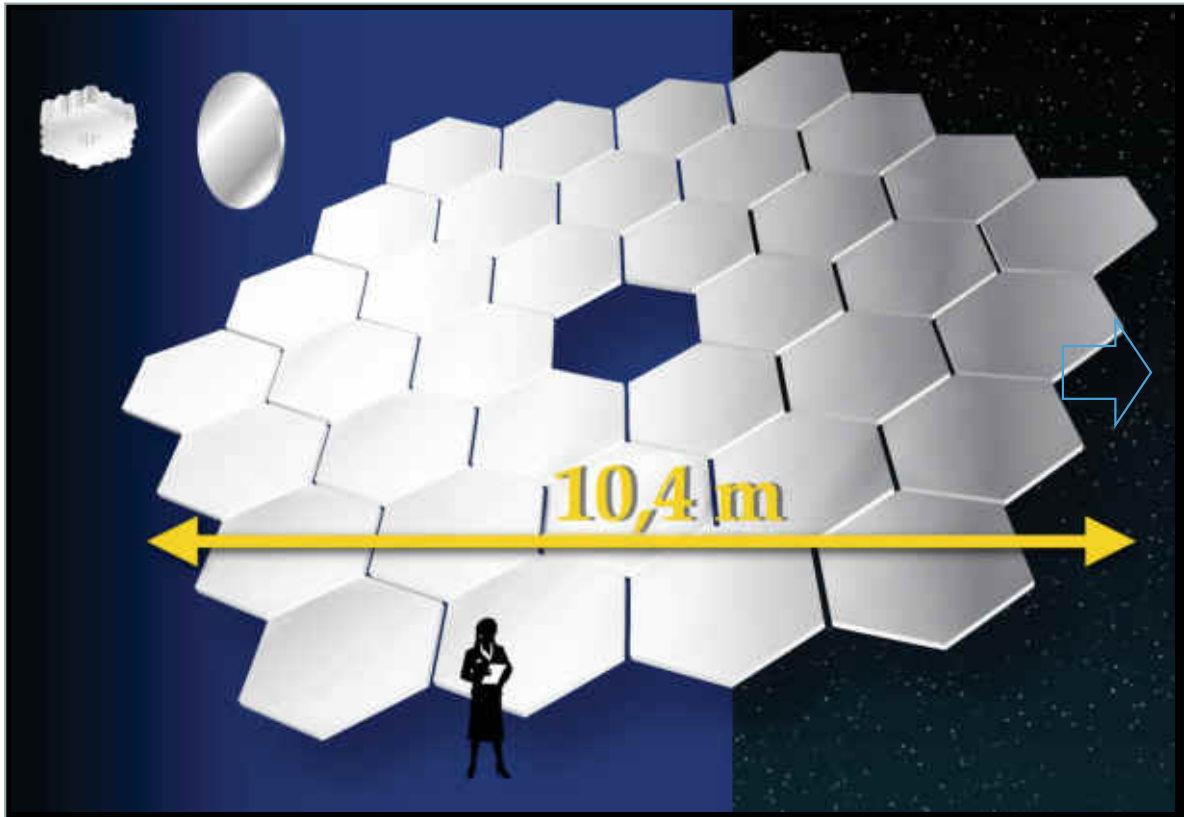


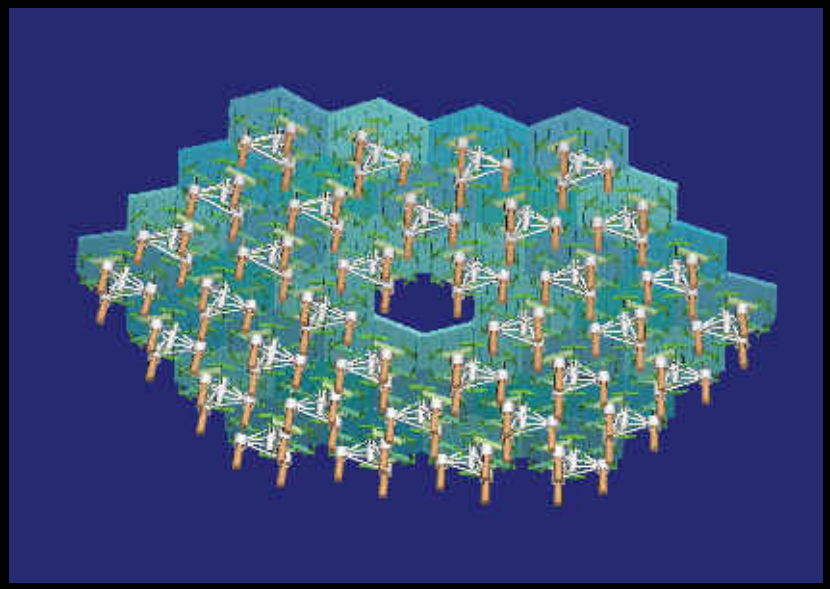
Fig. 3. Sky brightness at the OT in *V* (mag arcsec^{-2}).

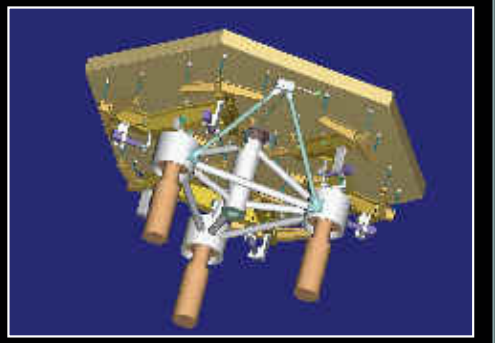
New Astronomy Reviews, 509-513, 42 (1998), F.J. Díaz-Castro

ASTMOSCOPES- the new devices for measurements.


Cosmic Epochs
Galaxy A1689-zD1:
~700 million years
after the Big Bang
Big Bang
Radiation era
~300,000 years:
"Dark ages" begin
~400 million years: Stars
and nascent galaxies form
~1 billion years: Dark ages end
Galaxies evolve
~9.2 billion years: Sun, Earth, and solar system have formed
~13.7 billion years: Present





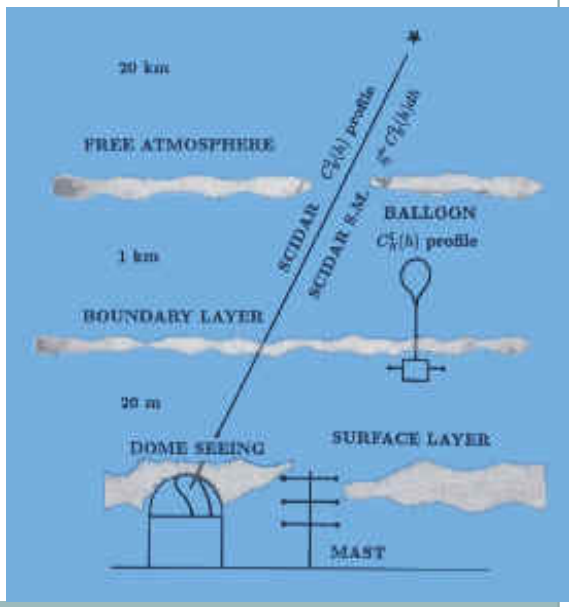


Necesitamos... grandes espejos, imágenes nítidas, que se pueden mejorar... (AO)

Vernin & Muñoz-Tuñón, A&A, 1992, 1994.

Instrument/Layer	D(Dome)	SL(Surface Layer)	BL(Bound. Layer)	FA(Free Atmos.)
Scidar	nothing			C_N^2(h,t)profile
Scidar SM			$\int C_N^2(h)dh;r0(t)$	
Ballon	nothing	less reliable profile	profile from 50 m to 20 km	
Mast	nothing	C_T^2 profile	nothing	

Turbulence	SL	BL	FA	Total
$\int C_N^2(h)dh10^{-13}$	0.11	2.10±0.6	1.53	3.74
ε_{fwhm}(arcsec)	0.08	0.50±0.2	0.40	0.69
%	3	56	41	100
Instrument	Mast	Balloons	Scidar	



Differential Image Motion Monitors

(accurate, absolute and reproducible data)

Sarazin & Roddier, 1990, A&A, 227, 294. (ESO DIMM)
Vernin & Muñoz-Tuñón, 1995, PASP, 107, 265 (DA/IAC DIMM)

Tower designed by the Galileo team

Used by, GTC, TNG, O. Sierra Nevada, Calar Alto, ING, INAOE (la Negra, Cananea), UNAM(Spedro M)...

Used in the FP6 site selection WP

Integrated seeing (ε) statistics

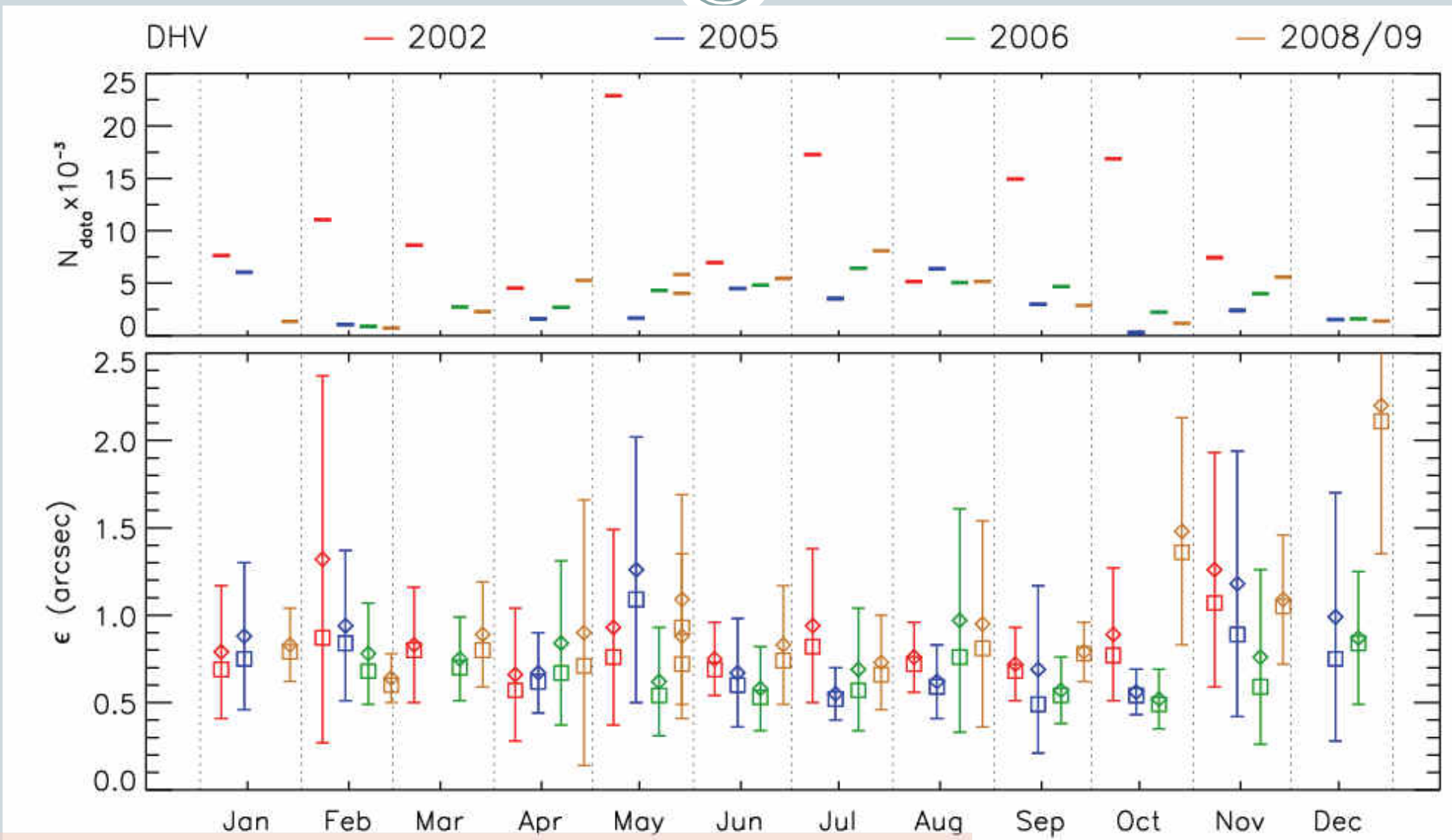
Muñoz-Tuñón, Vernin & Varela, 1997, A&A Supp. S, 125, 183-193.

mean	**0.76”**
median	0.64” (0.54” in summer)
std	0.17”
< 0.3”	7%

On-line seeing data available
@ORM www.iac.es/site-testing/DIMMA_ORM
@OT www.iac.es/site-testing/DIMMA_OT

Integrated seeing (ε)- measured since 1995

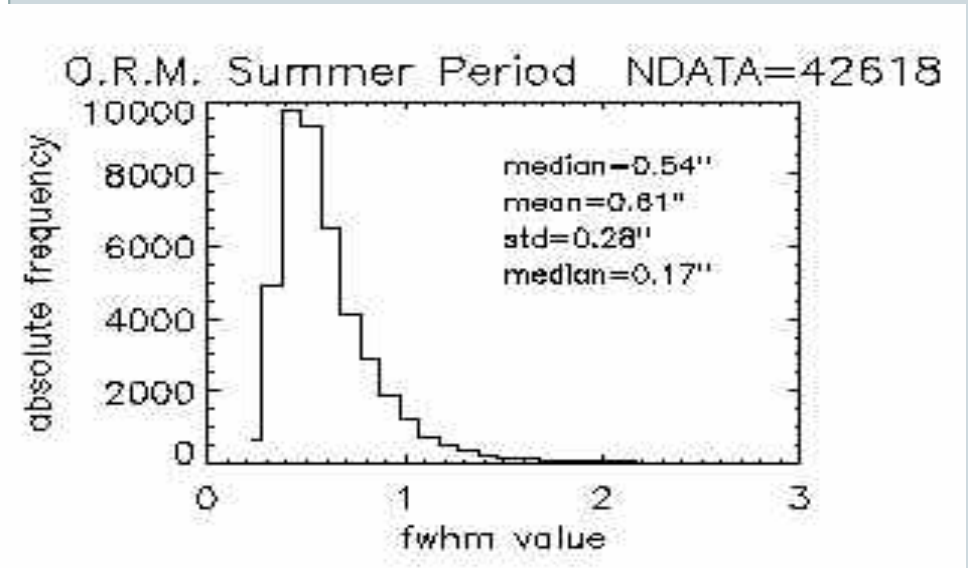
(*DIMM- Vernin & Muñoz-Tuñón, 1995, PASP,107, 265*)

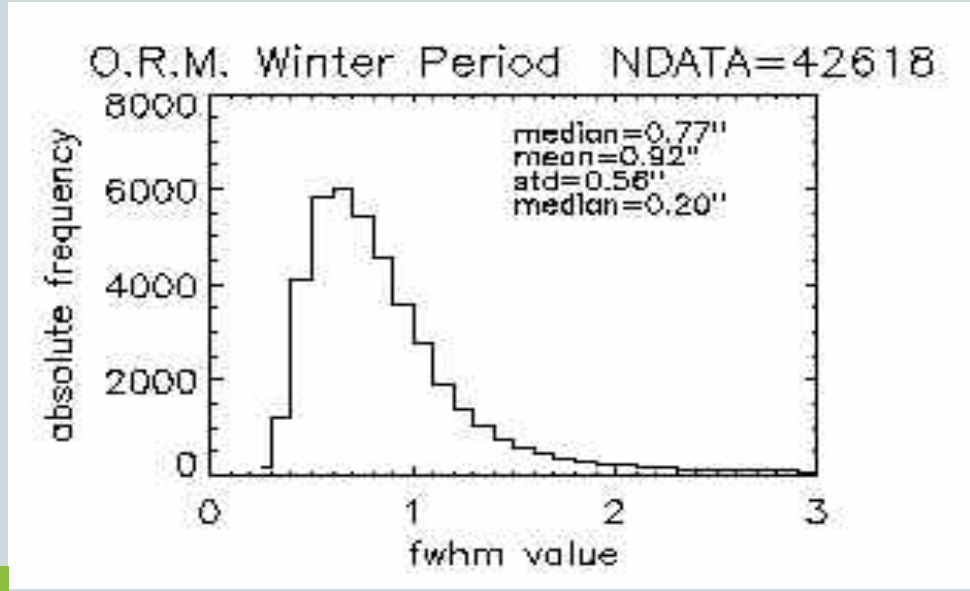


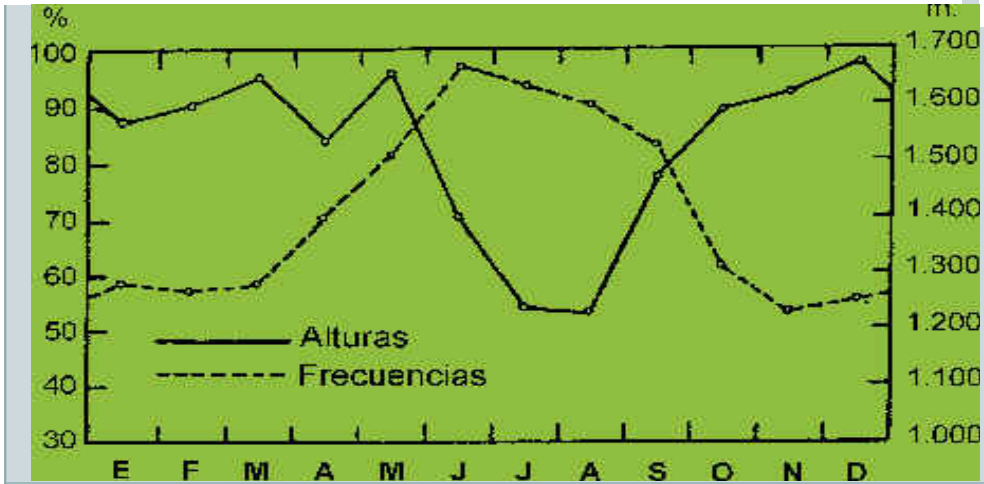
Squares: median values; Diamonds: mean values; Error bars STD of the mean.
Upper plot, Ndata for every month every year (color code)

Seasonal trend - seeing (ε)

Muñoz-Tuñón, Vernin & Varela, 1997, A&A Supp. S, 125, 183-193.



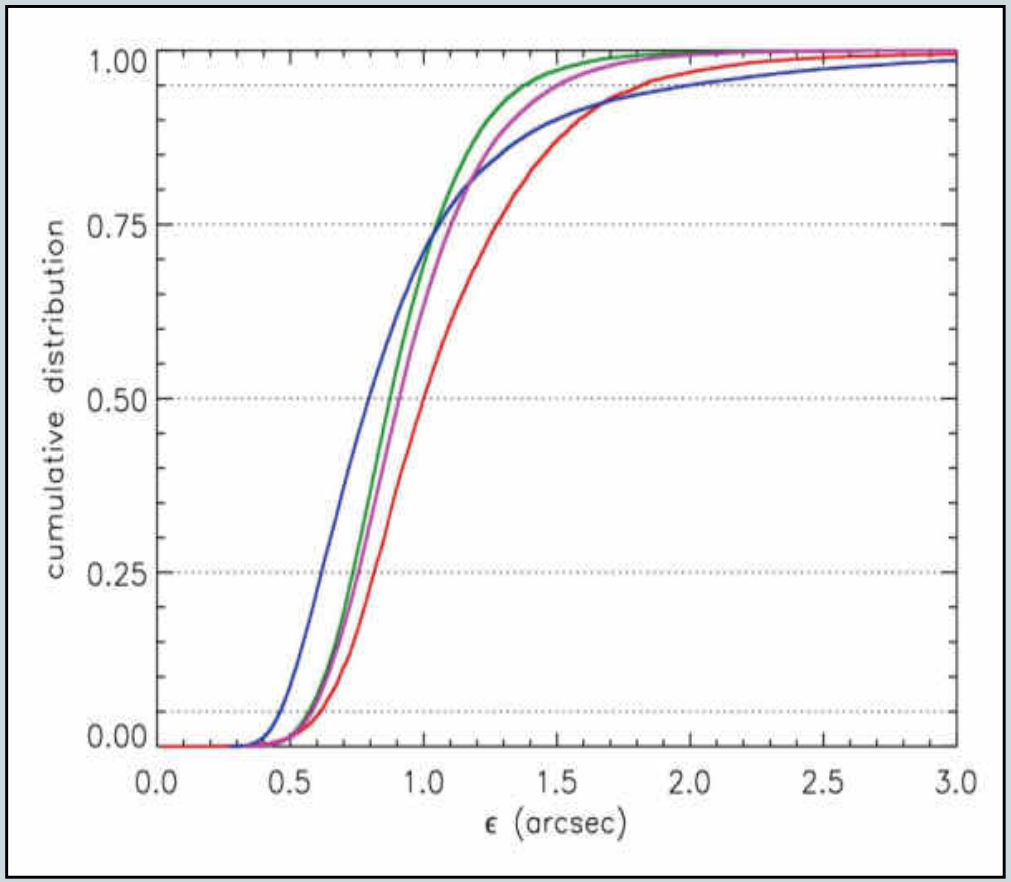




Behaviour coincident with the annual variation of the scale height and frequency of the inversion layer (Font-Tullot, 1956)

Competition for hosting the E-ELT

Cumulative frequency of ε //E-ELT FP6 EECC (2008/2009)



site	med	mean	stddev	min	max	h_{obs}
Aklim	1.00	1.09	0.45	0.02	10.54	250
Macon	0.87	0.91	0.26	0.38	3.16	1246
ORM	0.80	0.94	0.55	0.27	7.59	790
Ventar.	0.91	0.96	0.29	0.33	3.40	2214

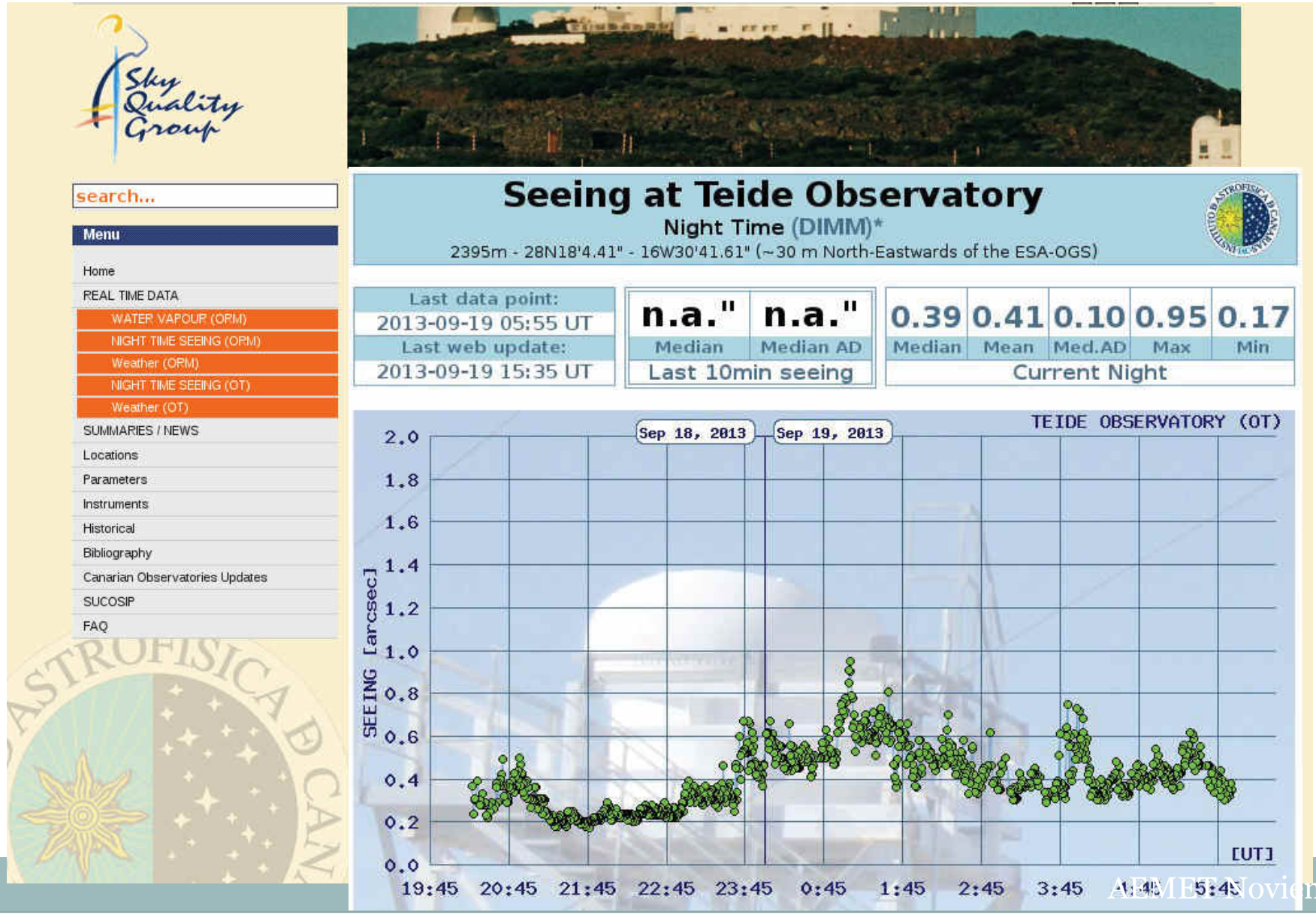
site	5%	25%	75%	95%	nacc	%rej
Aklim	0.61	0.81	1.28	1.82	13983	21.4
Macon	0.57	0.74	1.05	1.38	29723	24.4
ORM	0.46	0.62	1.06	2.00	47328	11.3
Ventar.	0.58	0.76	1.10	1.50	56547	8.8

Vernin & EELT team, PASP, 2011
Vázquez-Ramió & EELT team, PASP, 2012

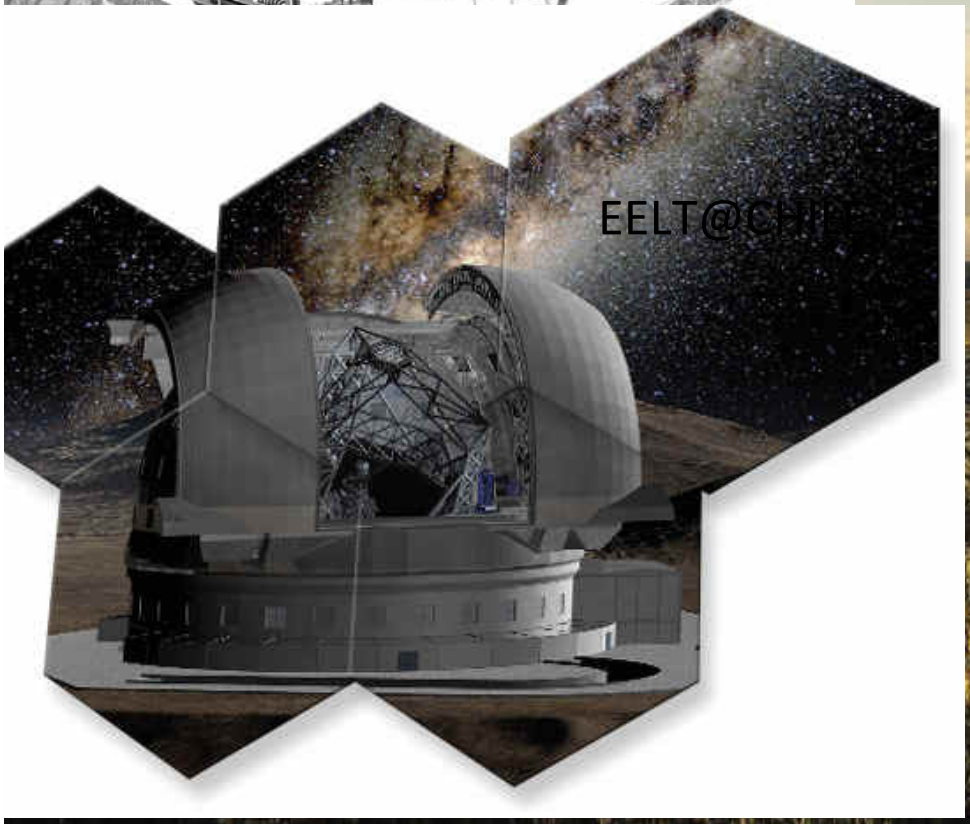
DIMM @ OT & ORM

Sarazin & Roddier, 1990, A&A, 227, 294.
Vernin & Muñoz-Tuñón, 1995, PASP, 107, 265

/www.iac.es/site-testing/DIMMA_OT

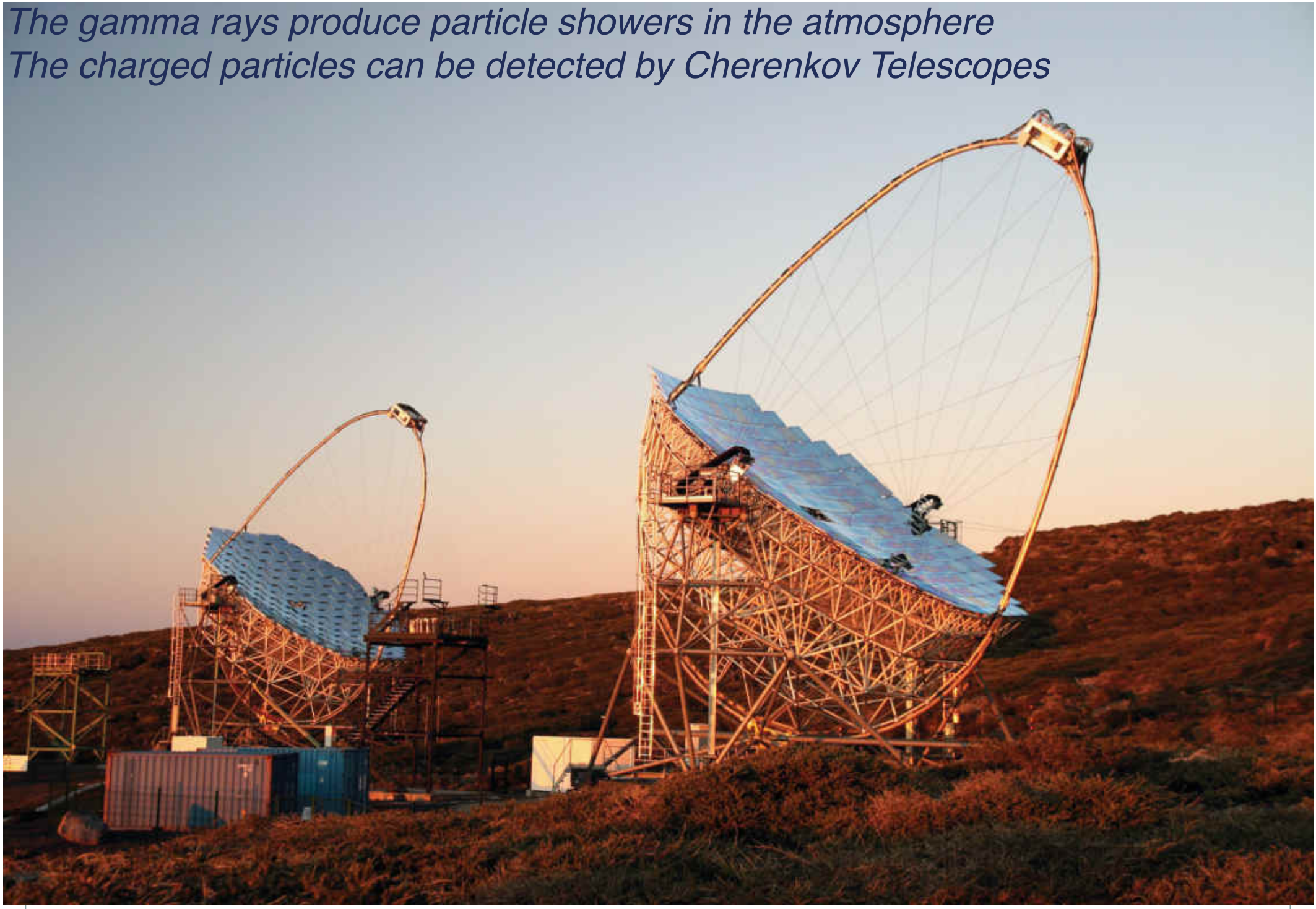


ATST @HAWAII



AEMET Noviembre 2016

The gamma rays produce particle showers in the atmosphere
The charged particles can be detected by Cherenkov Telescopes



CTA: Un esfuerzo a nivel mundial
cobertura de todo el cielo: dos observatorios

- *5 continentes*
- *32 países*
- *91 grupos*
- *200 institutos*
- *1270 miembros*

The technique works so we want bigger and better! Cherenkov Telescope Array (CTA)

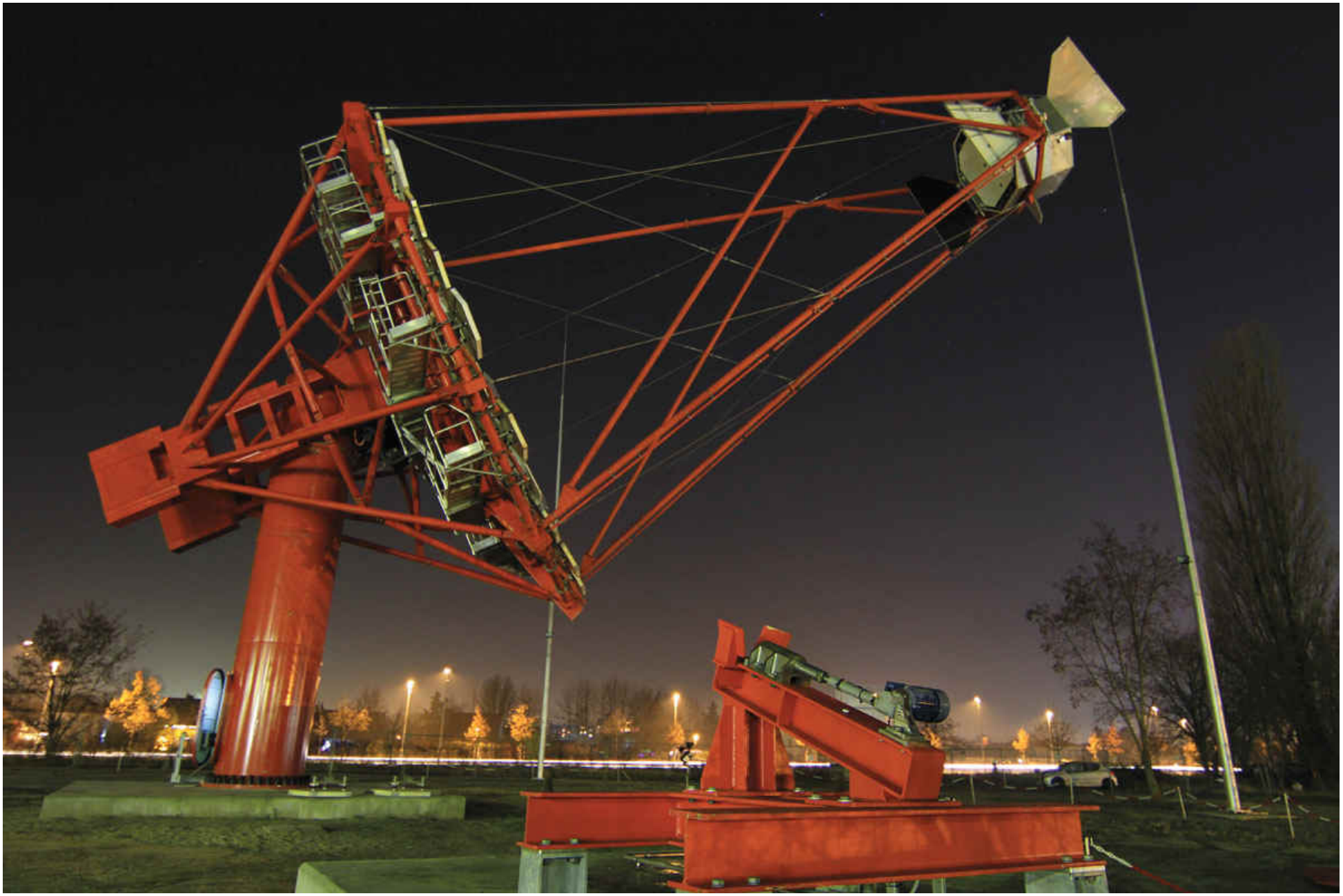
Northern site:
Observatorio del Roque de los Muchachos (ORM/IAC), La Palma (Spain)
Southern site:
European Southern Observatory (ESO), Paranal (Chile)

Large Size Telescopes (LST)

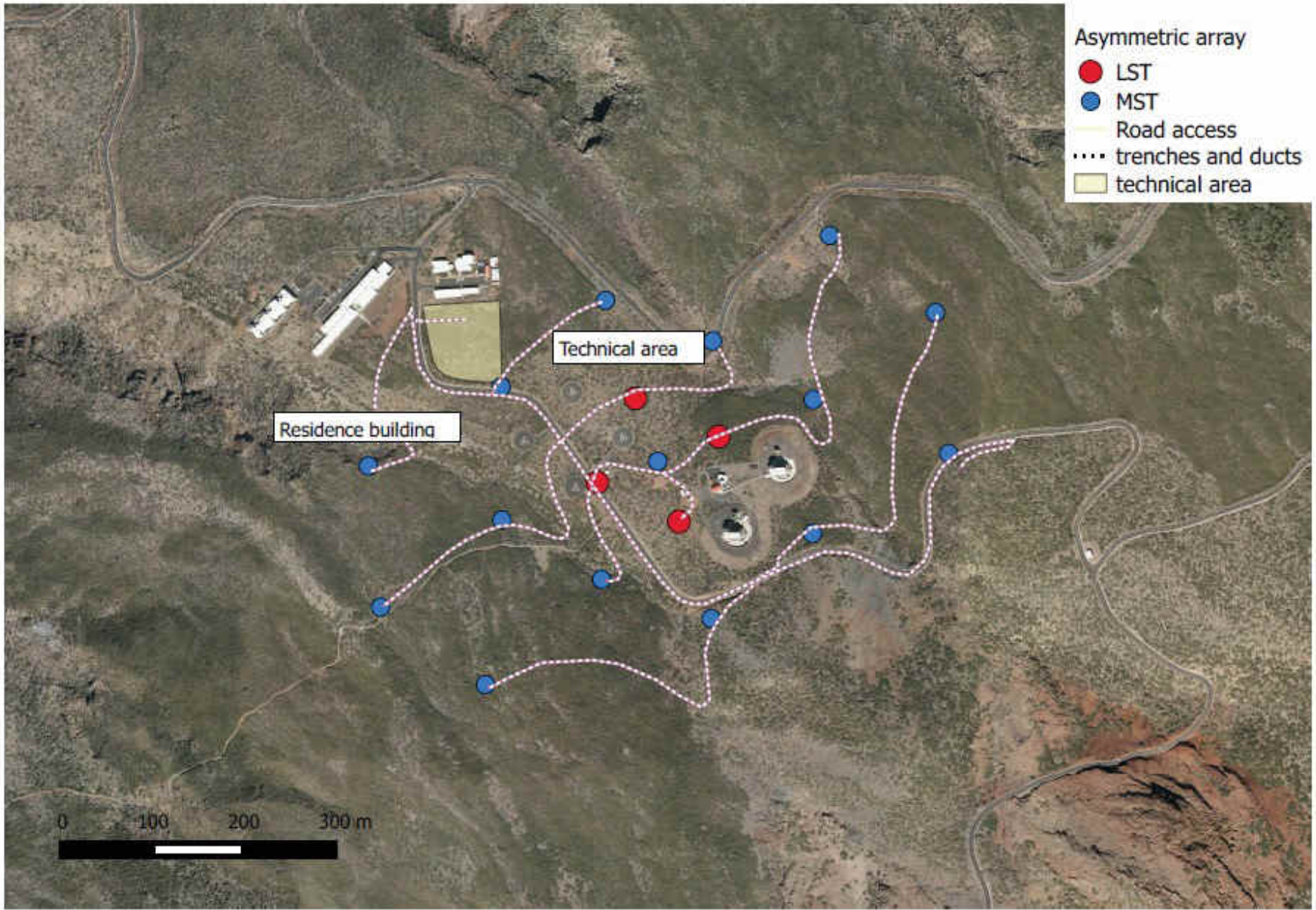
Carbon fibre structure (fast-repointing)
1.5 m glass-on-aluminum honeycomb mirror facets
Active mirror alignment using cameras on each facet
Pointing in 20 s to any sky position

Lowest energies (< 200 GeV)
Transient phenomena: Active Galatic Nuclei, Gamma-Ray Bursts, pulsars, Dark Matter,,,

Prototipo de los telescopios de 12 m

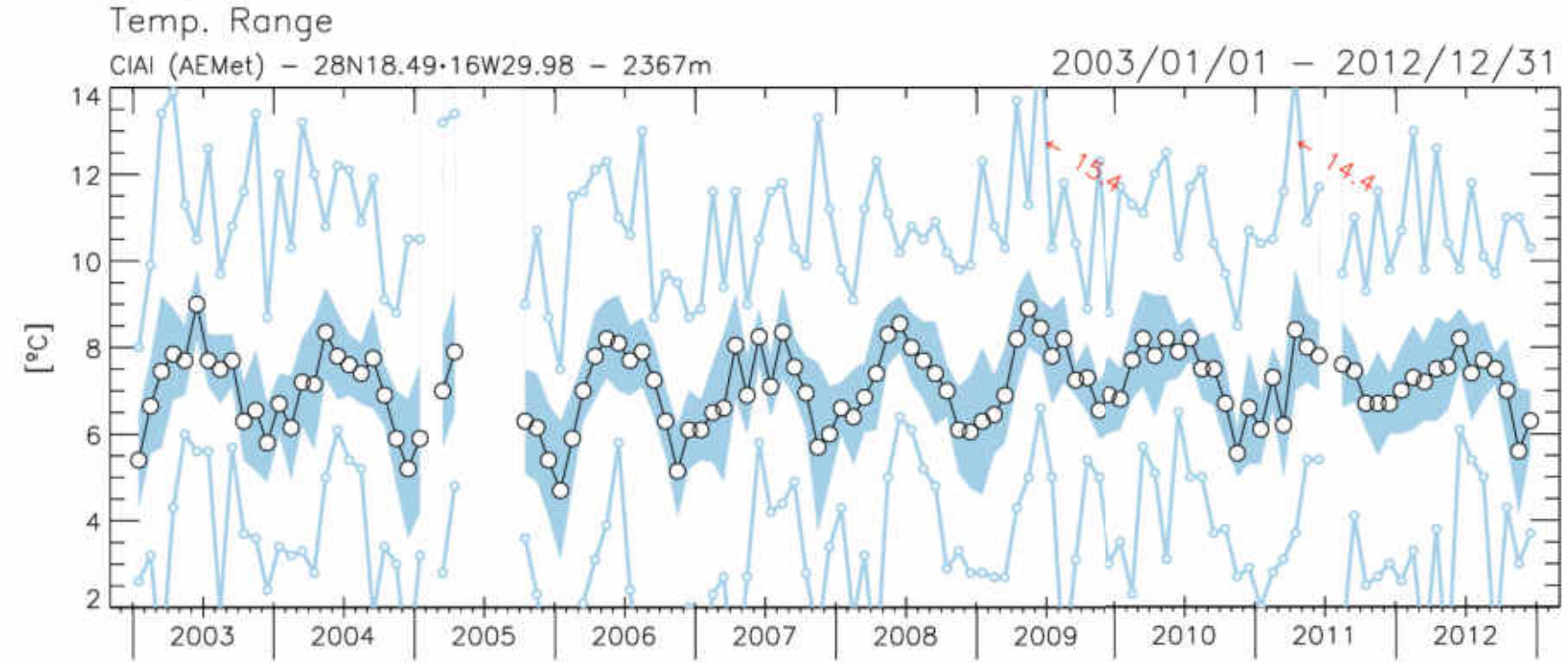


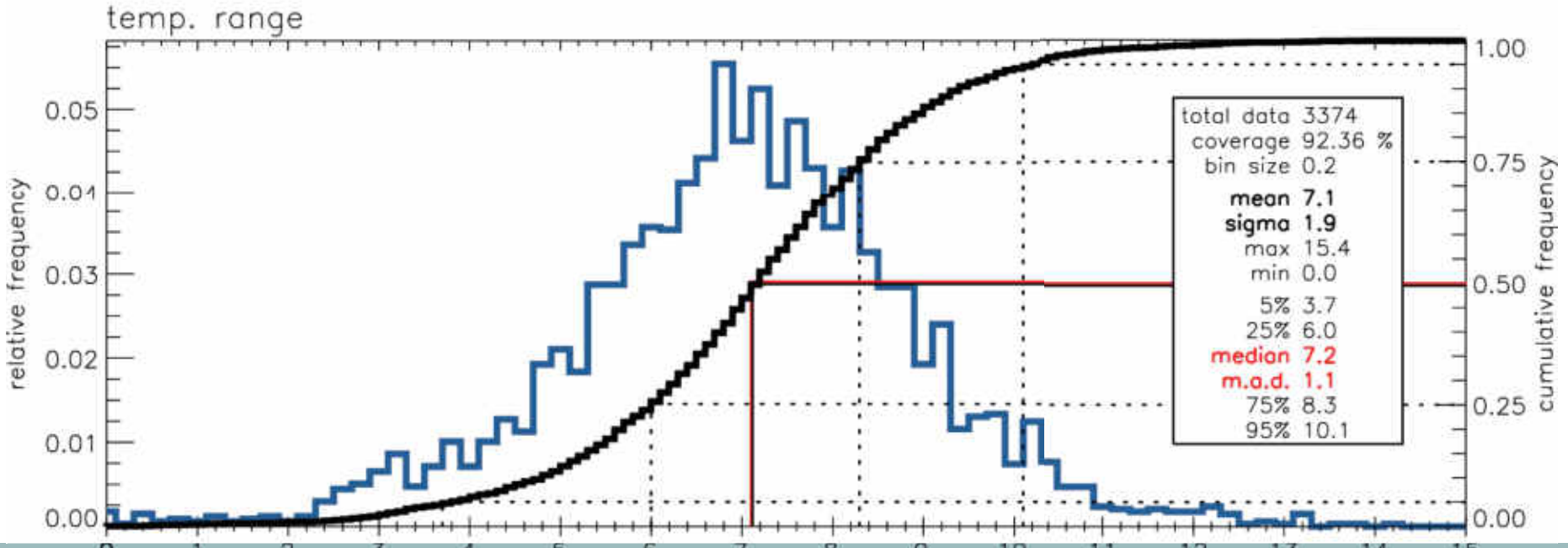
Distribución de los telescopios ORM- La Palma



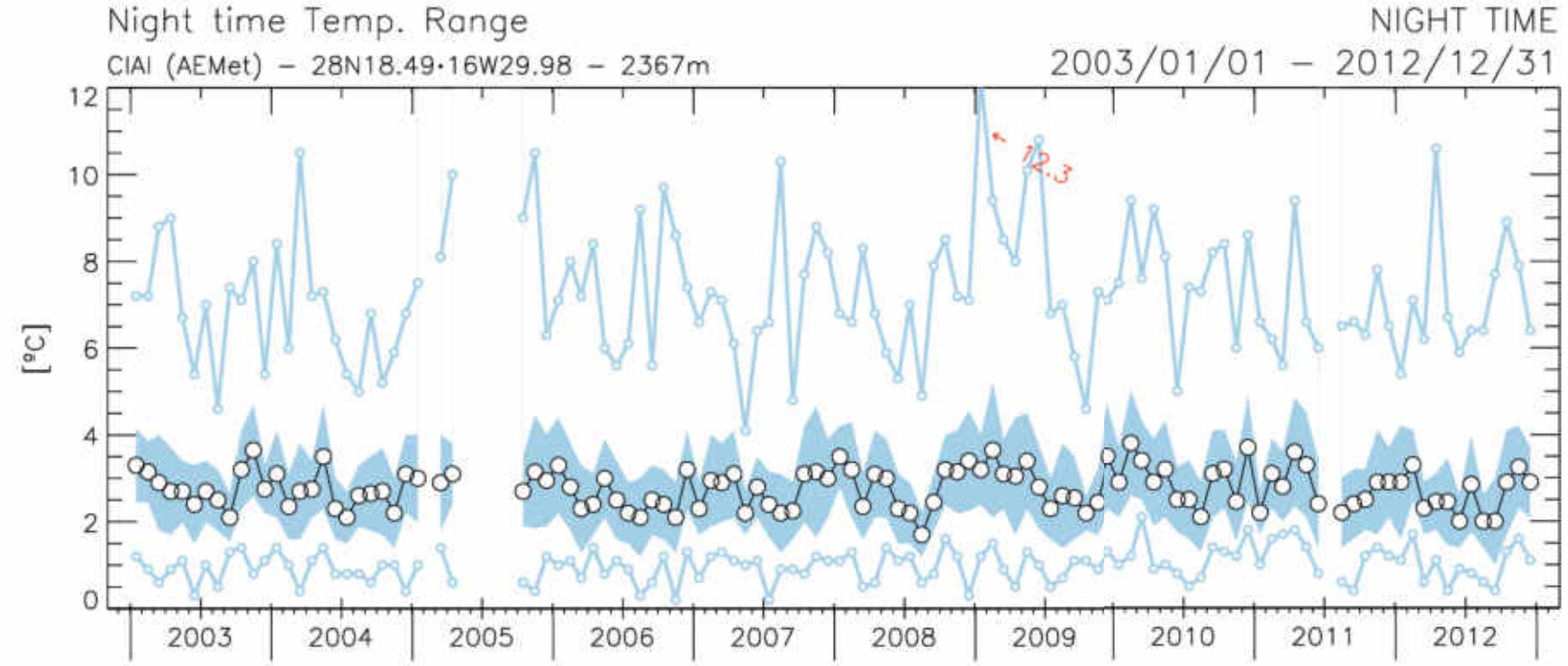
METEO data

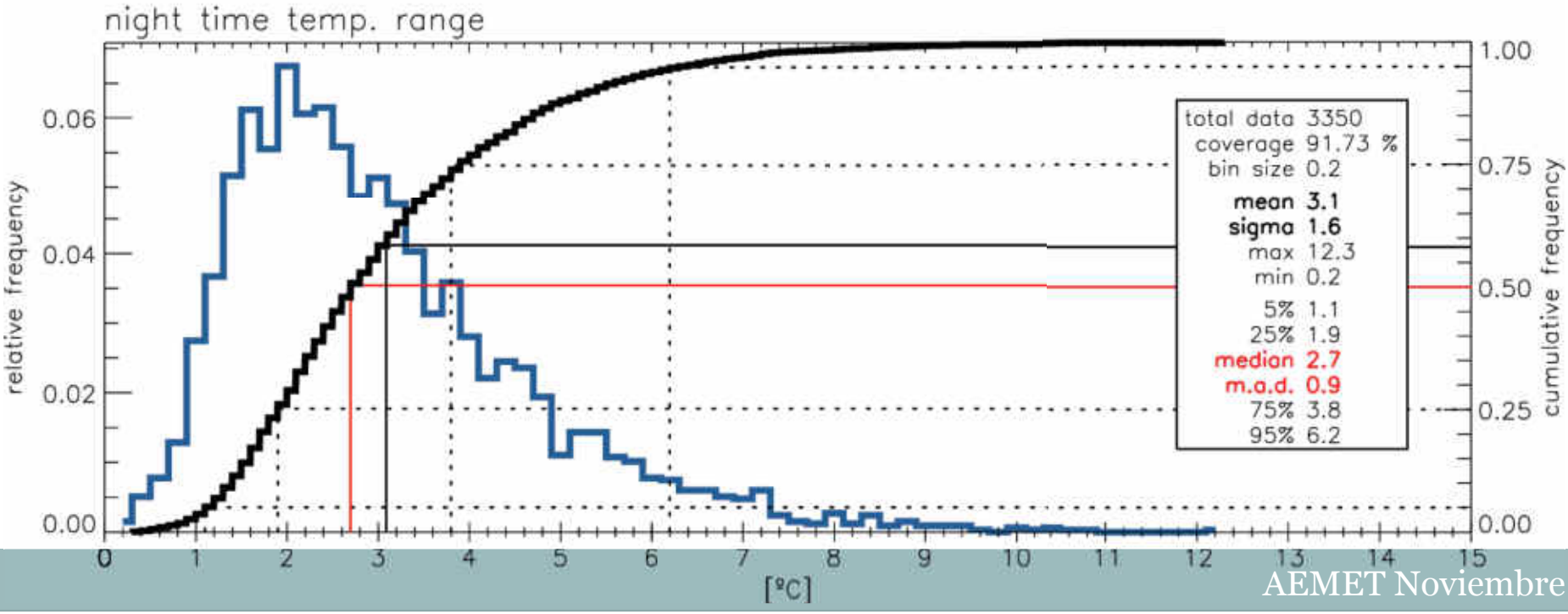
IZAÑA


Temp. Range
CIAI (AEMet) – 28N18.49·16W29.98 – 2367m
2003/01/01 – 2012/12/31
[ºC]
15.4
14.4
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012


temp. range
relative frequency
cumulative frequency
[ºC]
total data 3374
coverage 92.36 %
bin size 0.2
mean 7.1
sigma 1.9
max 15.4
min 0.0
5% 3.7
25% 6.0
median 7.2
m.a.d. 1.1
75% 8.3
95% 10.1

IZAÑA


Night time Temp. Range
NIGHT TIME
CIAI (AEMet) – 28N18.49·16W29.98 – 2367m
2003/01/01 – 2012/12/31
[ºC]
12.3
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012


night time temp. range
relative frequency
cumulative frequency
[ºC]
total data 3350
coverage 91.73 %
bin size 0.2
mean 3.1
sigma 1.6
max 12.3
min 0.2
5% 1.1
25% 1.9
median 2.7
m.a.d. 0.9
75% 3.8
95% 6.2

2002-2012 Izaña Meteo Report

Julio A. Castro-Almazán and Casiana Muñoz-Tuñón
Instituto de Astrofísica de Canarias (IAC)

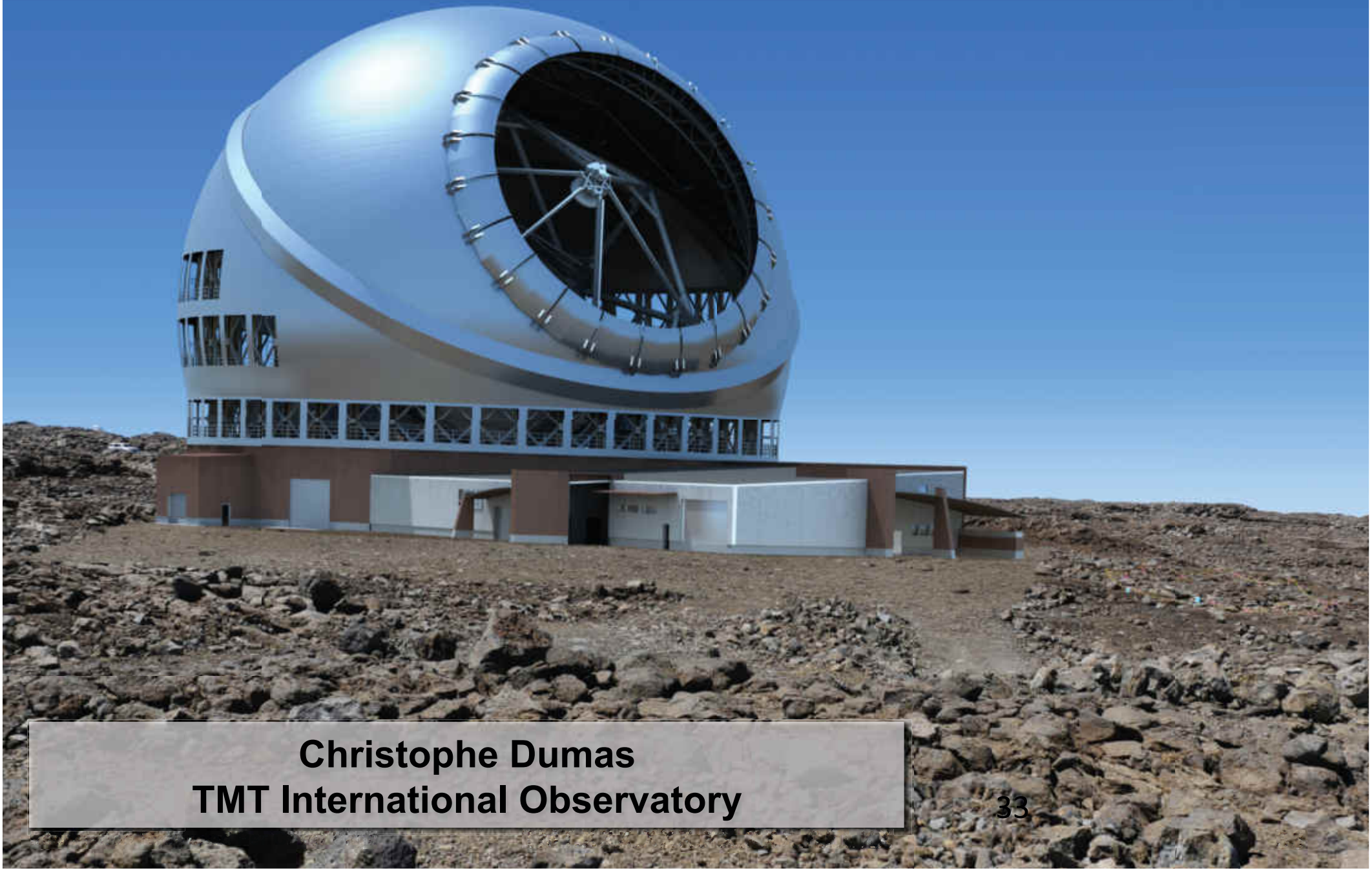
October 24, 2014

ACKNOWLEDGMENTS

This report made use of 10 years data recorded by the spanish Agencia Estatal de Meteorología (AEMet) at the Izana Atmospheric Research Center (CIAI) and by the Global Oscillation Network Group (GONG) at Teide Observatory (OT). Additionally, some wind data from the Cherenkov Telescope Array (CTA) *atmoscope* station at Tenerife was also used for comparison.

We are grateful to all of them for the kindly distribution of their data. We particulary thank Ricardo Sanz from the AEMet Delegation in Santa Cruz de Tenerife, Pere Lluís Pallé from GONG, Diego Sierra from the IAC Network department and Irene Puerto and Ramón García López from the CTA team at IAC.

The Thirty-Meter-Telescope

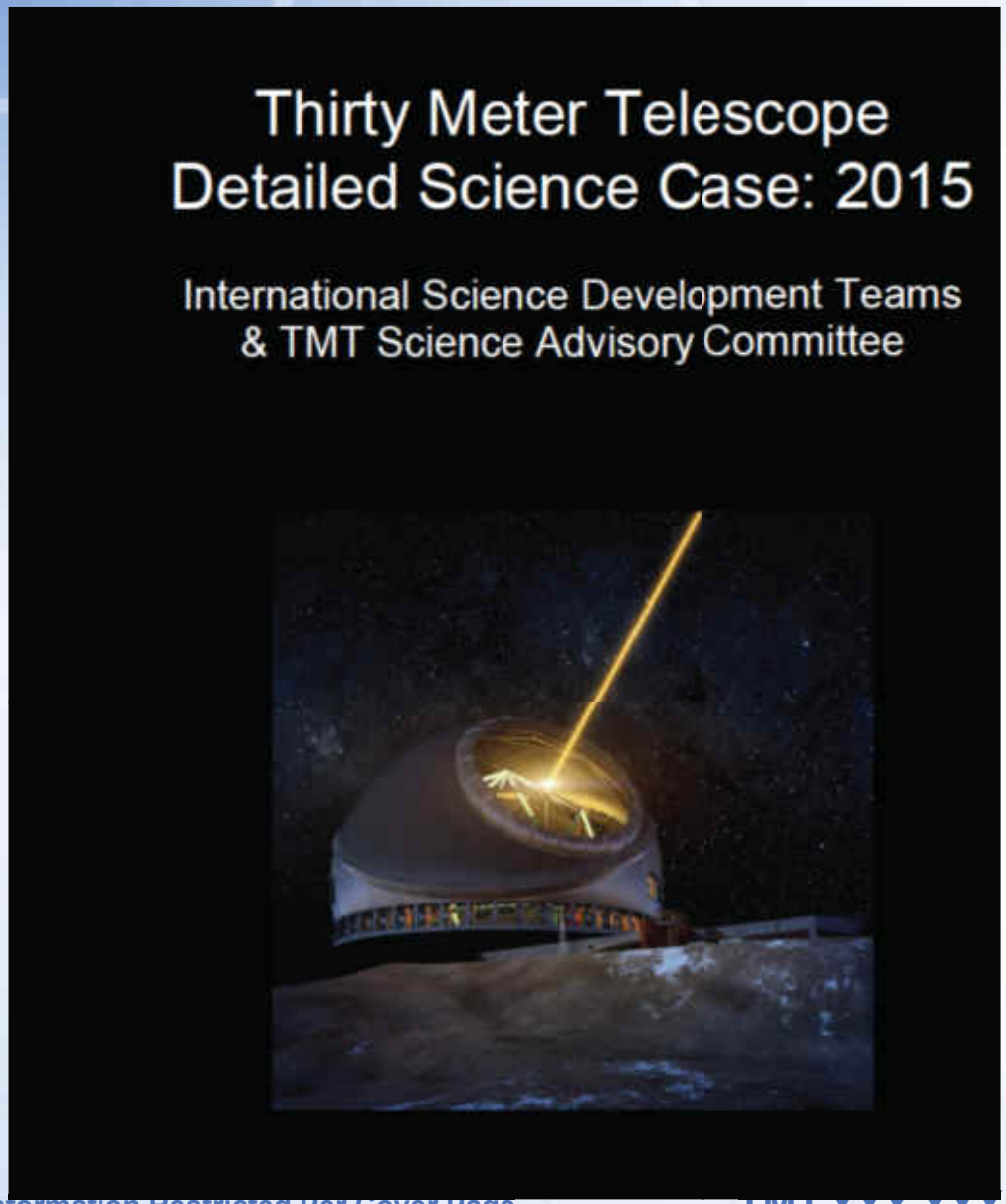


Christophe Dumas
TMT International Observatory

TMT in a nutshell

- Wide-field, Alt-Az Ritchey-Chretien telescope
- 30 meter diameter primary mirror (**492 hexagonal segments**, 1.44m across corners)
- Active secondary mirror (not adaptive)
- Flat tertiary mirror beam light to Nasmyth focus
- **Up to 8 instruments**, over 2 Nasmyth platforms, to cover visible to infrared wavelengths
- **First-light AO system** (NFIRAOS):
  - Laser Guide Star Facility (LGSF) Multi-Conjugate-AO (MCAO)
  - Diffraction-limit at J, H, and K bands, can feed 3 instruments.

TMT Science



- Fundamental physics & cosmology
- Early Universe & galaxy formation
- Super massive black-holes
- Nearby-galaxies & Milky-way
- Star formation & exoplanets
- Time-domain science
- Solar-system

Mauna Kea & TMT

- July 2009 : TMT Board of Directors select Mauna Kea as the preferred site for the Thirty-Meter Telescope
  - Mauna Kea is a superb astronomy site
  - Northern hemisphere / Center of 'Pacific rim'
  - Synergy with existing partner observatories

- May 2015: Start the TMT construction phase
  - Sill, while offsite construction/development activities are proceeding well, according to plan …
  - … the onsite construction was interrupted by demonstrations and Hawaii Supreme Court mandating rehearing of construction permit (Dec. 2015)

TMT site (re-)selection timeline

- **TMT is planning to resume construction early 2018**
- This means:
  - Selection of an alternate site (announcement expected October 30th)
  - Selection of final site before September 2017
  - Start of construction on selected site in April 2018
- Construction will take ~8 years and start of operations soon after
- **No descope *wrt* original project design (i.e. full primary mirror and AO/LGS at first-light)**

Current timeline

- April 2018: Start of Construction
- End 2019: Start erection of enclosure base
- 2020-2022: Enclosure shell
  - End 2023: End construction of summit buildings
- 2022-2024: Telescope structure integration
- 2024-2026: AIV

- **“First-light”: End 2026/early 2017**
  - **Commissioning and start of operations soon after**

Summary of the site testing results at the Roque de los Muchachos Observatory

Sky Quality Team*
www.iac.es/site-testing
Instituto de Astrofísica de Canarias, E-38200, La Laguna, Spain
Send correspondence to skyteam@iac.es
March-2016

Abstract

The characterization of the atmosphere for astronomical observations is a key project for the IAC. From nearly 30 years of systematic work including routine and intensive campaigns, a wide set of parameters characterizing the Canarian sites have been gathered. In this document we make a summary of them with a particular emphasis to those relevant for the Adaptive Optics at the ORM. The main result are: the seeing, isoplanatic angle, coherence time median values are $0.65'' \pm 0.5$, $2.74'' \pm 1.2$ and > 5 ms, respectively. The vertical distribution of the turbulence shows an important concentration of $\approx 65\%$ in the Boundary Layer. The results are supported by different techniques and measurements, including the more than 190,000 vertical profiles obtained at the ORM using a SCIDAR at the Jacobus Kapteyn Telescope. The ORM is an excellent site not only because of its atmospheric quality but also by the actions that have been adopted to protect and continuously characterize it.

Contents

SKY parameters for AO

$$r_0 = 0.185\lambda^{6/5}\left(\int_0^\infty C_N^2(h)dh\right)^{-3/5}. \qquad (1)$$

$$\varepsilon_{\text{fwhm}} = 0.98\frac{\lambda}{r_0} = 5.25\lambda^{-1/5}\left(\int_0^\infty C_N^2(h)dh\right)^{3/5}. \qquad (2)$$

$$\theta_0 = 0.058\lambda^{6/5}\left(\int_0^\infty h^{5/3}C_N^2(h)dh\right)^{-3/5}. \qquad (3)$$

$$\tau_0 = 0.058\lambda^{6/5}\left(\int_0^\infty |\mathbf{V}(h)|^{5/3}C_N^2(h)dh\right)^{-3/5}, \qquad (4)$$

Seeing (ϵ) and coherence radius (r_0)

Site		← ORM →						**Armaz.**	**MKEA**
Instrument		**radiosonde**	**DIMM**	**DIMM**	**DIMM**	**G-SCIDAR**	**DIMM***	← **DIMM*** →	
Period		1990	1994-1995	1995-1999	1995 -2009	2004-2009	2008-2009	← 2004-2008 →	
Notes		6 balloons	TNG site	GTC site	routine runs	routine runs	E-ELT campaign	← TMT campaign →	
Refs.		a	b	c	own data	d	e	← f →	
ϵ ($''$)	med	0.70	0.64	0.65	0.69	0.63	0.72	0.64	0.75
	σ	0.49	0.47	0.40	0.53	0.34	0.55	—	—
r_0 (cm)	med	15.9	17.3	17.1	16.1	17.6	15.4	17.3	14.8

The **seeing** values at the ORM ranges from **0.63**$''$ to **0.72**$''$ (25th perc. = **0.53**$''$). These values, well below 1$''$, assure the optimal conditions for High Resolution and AO in particular.

The results, obtained with different techniques and periods, are all in very good agreement with differences below one tenth.

The ϵ distribution corresponding to **summer** (Jun–Sep) gives **better mean and median values and smaller** σ. The minimum values are also recorded in summer (the best seeing measured is **0.17**$''$) and $\epsilon < \mathbf{0.3}''$ the **7%** of the time.

Boundary Layer (BL) and Free Atmosphere (FA) seeing

Site		← ORM →			**Armaz.**	**MKEA**
Instrument		**radiosonde**	**MASS-DIMM**	**G-SCIDAR**	← **MASS-DIMM** →	
Period		1990	2008-2009	2004-2009	← 2004-2008 →	
Notes		6 balloons	E-ELT campaign	routine runs	← TMT campaign →	
Refs.		*a*	*b*	*c*	← *d* →	
ϵ ($''$)	*med*	0.70	0.72	0.63	0.64	0.75
ϵ_{FA} ($''$)	*med*	0.41	0.31	0.35	0.43	0.33
	σ	0.16	0.38	0.22	—	—
ϵ_{BL} ($''$)	*med*	0.56	0.58	0.41	0.35	0.54
	σ	0.43	0.38	0.35	—	—
BL contribution to ϵ	%	69.0	70.0	63.6	36.6	57.8

The contribution of the **BL** to the total seeing at ORM is **64% – 70%**. This ratio (higher than measured at other very good sites) improves the potential for compensation with Multiconjugated AO (MCAO).

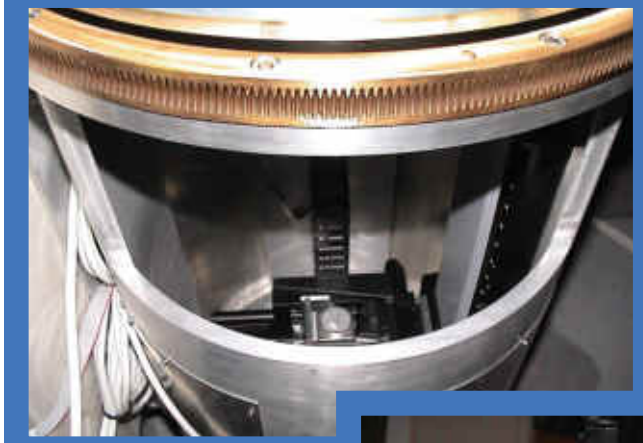
Coherence time (τ_0) and isoplanatic angle (θ_0)

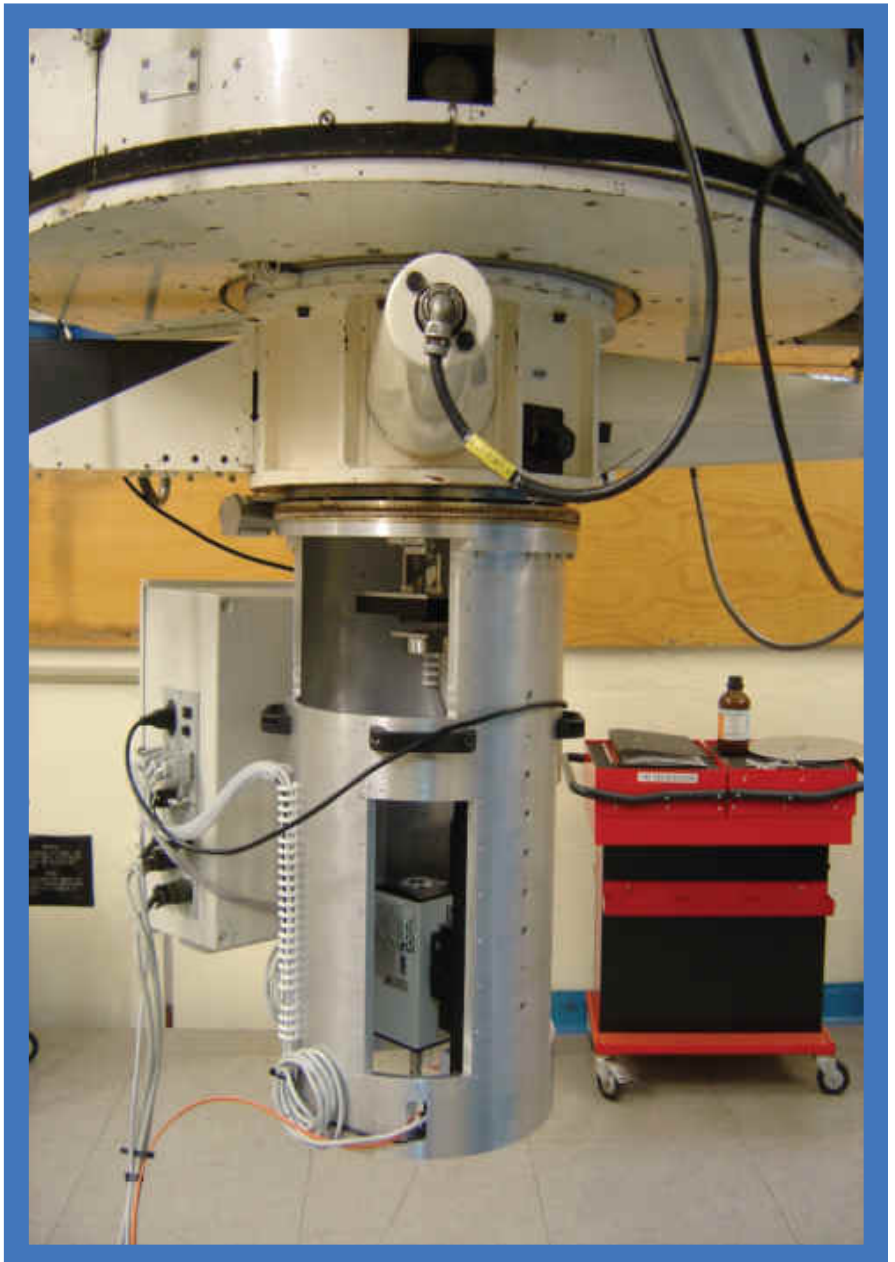
Site		← ORM →			**Armaz.**	**MKEA**
Instrument		**radiosondes**	**MASS-DIMM**	**G-SCIDAR**	← **MASS-DIMM** →	
Period		1990	2008-2009	**2004-2009**	← 2004-2008 →	
Notes		6 balloons	E-ELT campaign	**routine runs**	← TMT campaign →	
Refs.		a	b	c	← d, e →	
θ_0 ($''$)	*median*	1.42	1.93	**2.74**	2.04	2.69
	σ	0.32	0.77	**1.19**	—	—
τ_0 (ms)	*median*	6.28	5.58	**5.37**	4.62	5.14
	σ	2.14	4.14	**2.23**	—	—

The isoplanatic angle (θ_0) obtained at ORM after 6 years of routine operations of G-SCIDAR is **2.74$''$ ± 1.2**.

The results obtained for τ_0 at ORM show median values always over **5 ms** for the different campaigns. This large τ_0 reduces the band width requirements for the AO closed loop control and increases the sensibility of the WFS microlenses that allows for using less bright guide stars.

It is based on the original **Generalized-SCIDAR**, to be used systematically- Designed fo the EELT-FP6 EECC grant (2000-2005). UNIV NIZA+IAC





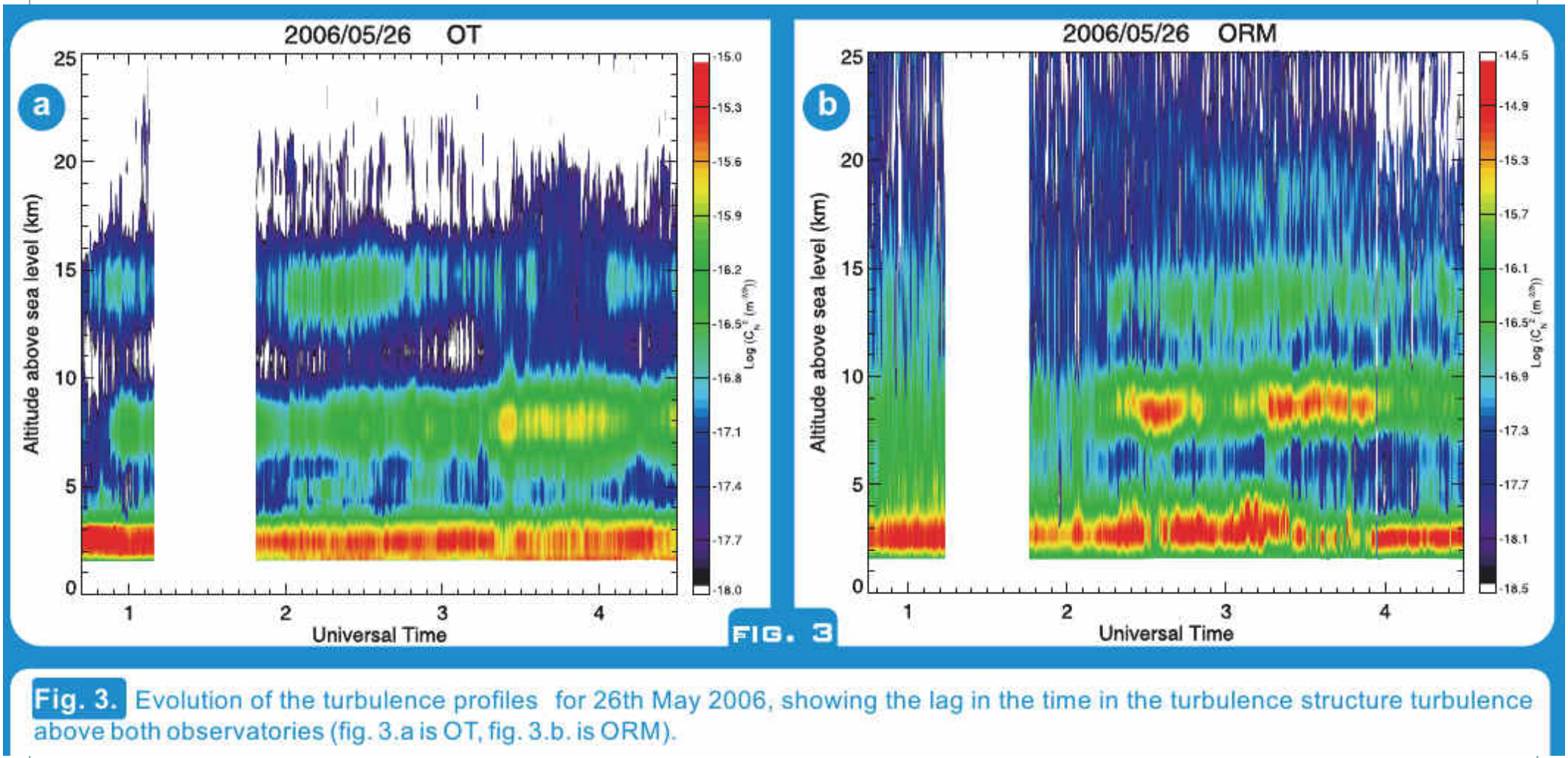
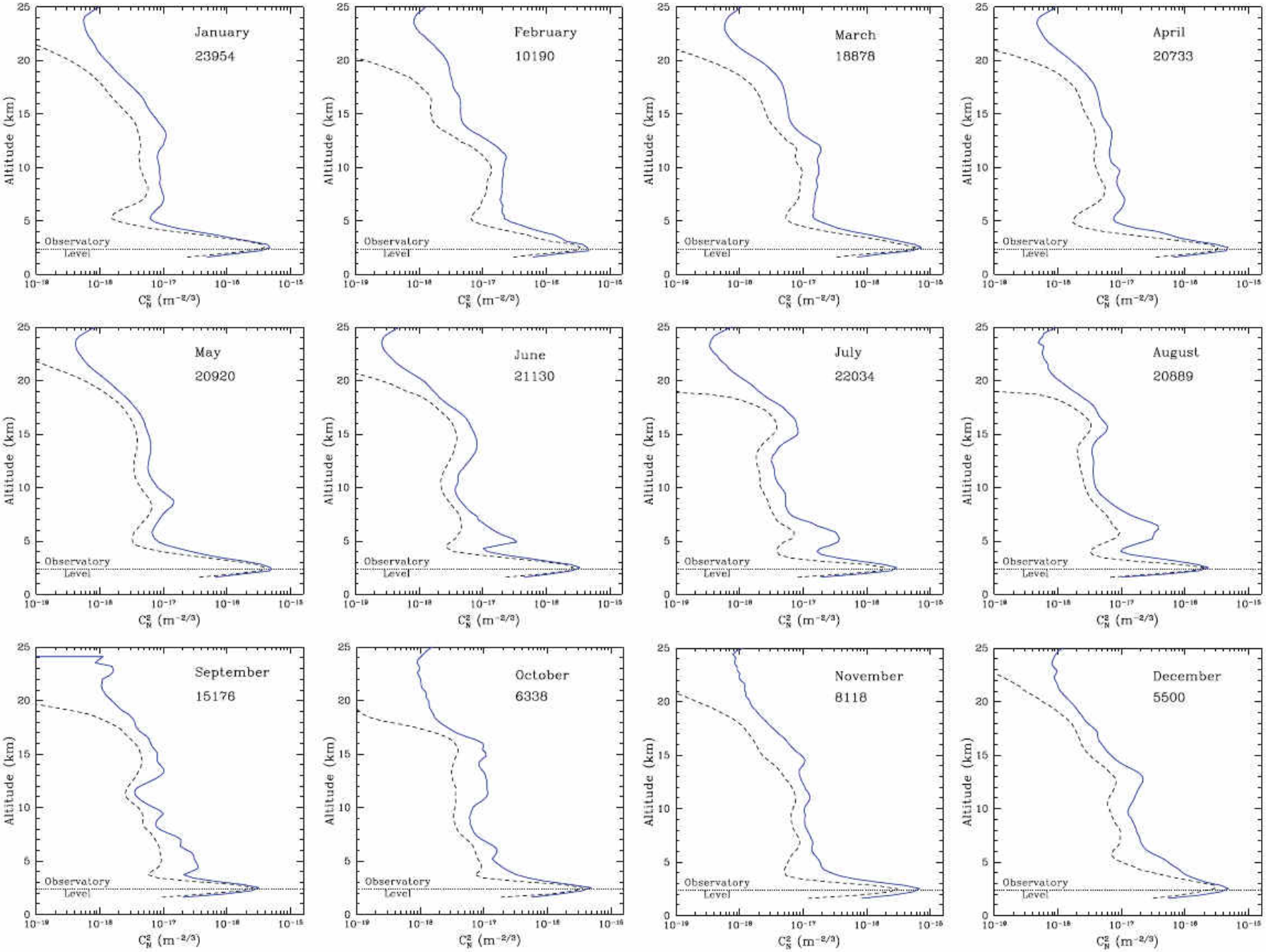
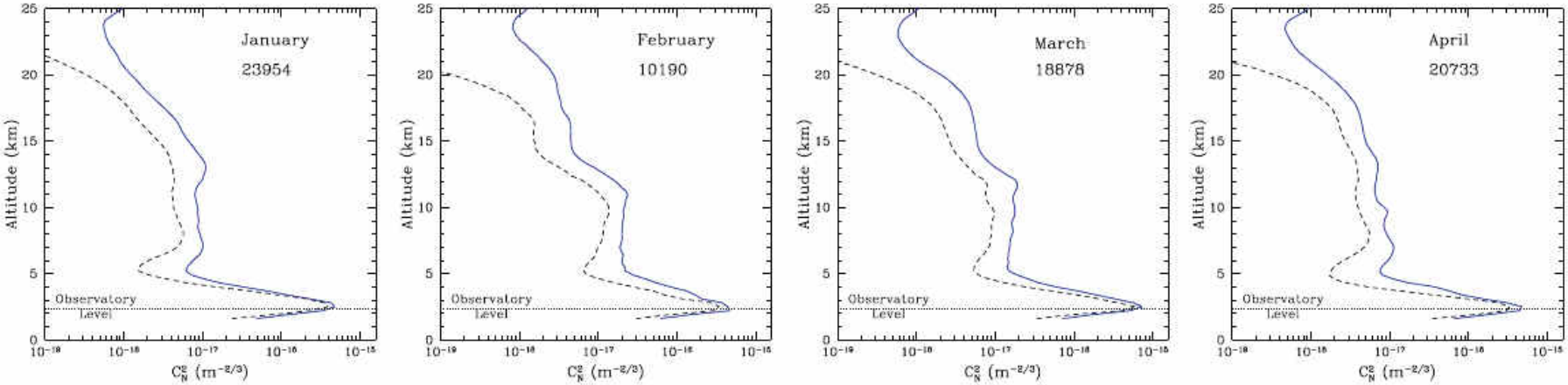


Fig. 3. Evolution of the turbulence profiles for 26th May 2006, showing the lag in the time in the turbulence structure turbulence above both observatories (fig. 3.a is OT, fig. 3.b. is ORM).

C_N^2 turbulence vertical distribution

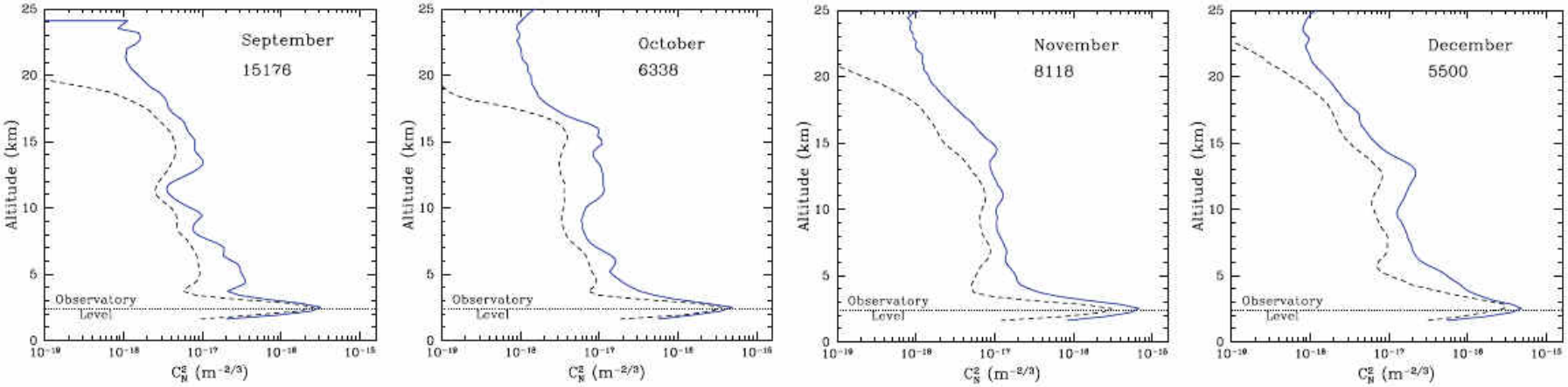


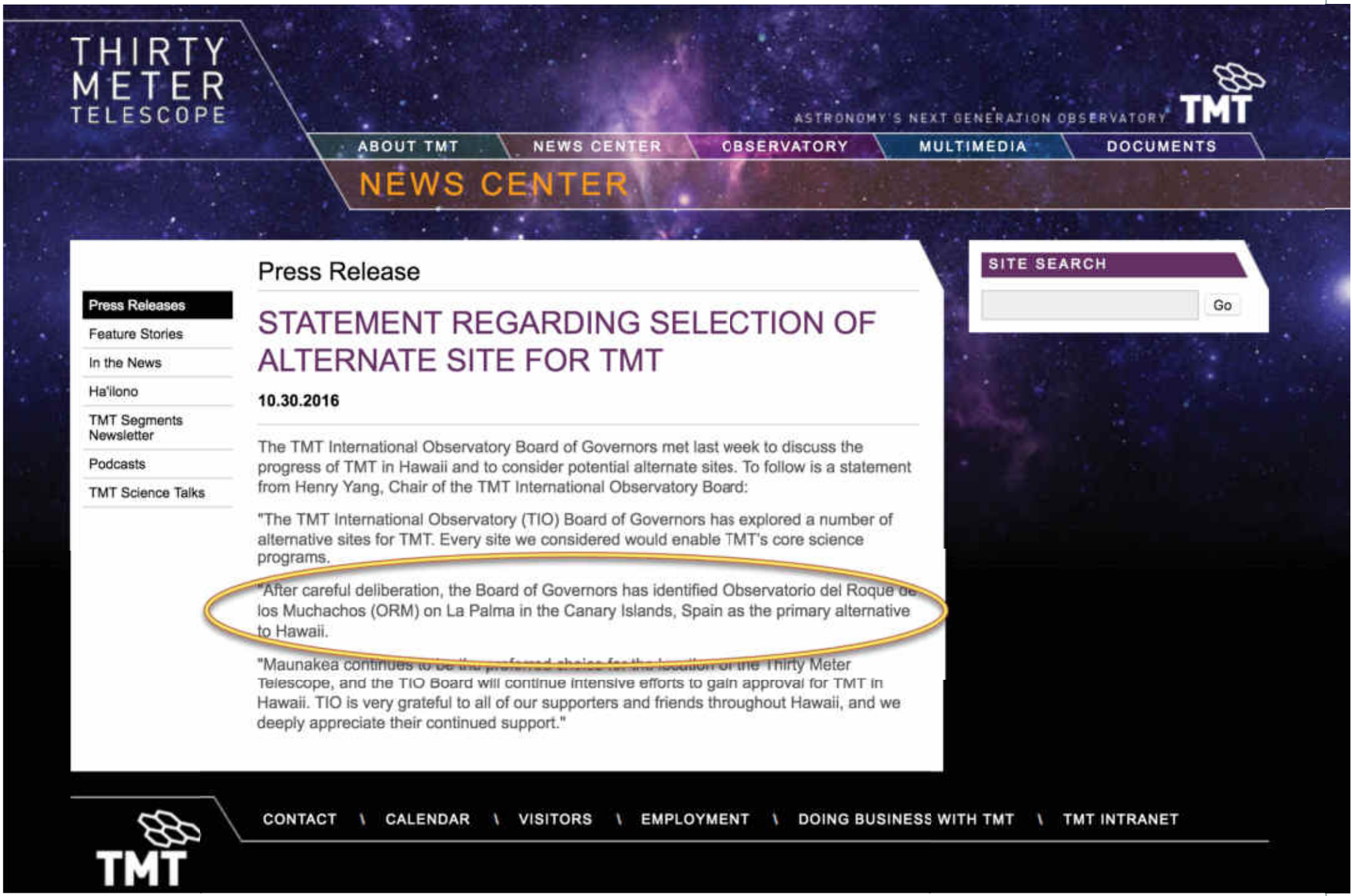
C_N^2 turbulence vertical distribution



The monthly turbulence distribution shows the **predominance of the BL (GL in Fig. 8)**. Other layer in importance is at 5 km.

A complete database of **197,035** $C_N^2(h)$ and $|V(h)|$ **profiles** from **211 nights (2004–2009)** is available for AO simulations at **ORM**. At OT, there are 93,662 profiles from 153 nights (2002–2009).

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STATEMENT REGARDING SELECTION OF ALTERNATE SITE FOR TMT
10.30.2016
The TMT International Observatory Board of Governors met last week to discuss the progress of TMT in Hawaii and to consider potential alternate sites. To follow is a statement from Henry Yang, Chair of the TMT International Observatory Board:
"The TMT International Observatory (TIO) Board of Governors has explored a number of alternative sites for TMT. Every site we considered would enable TMT's core science programs.
"After careful deliberation, the Board of Governors has identified Observatorio del Roque de los Muchachos (ORM) on La Palma in the Canary Islands, Spain as the primary alternative to Hawaii.
"Maunakea continues to be the preferred choice for the location of the Thirty Meter Telescope, and the TIO Board will continue intensive efforts to gain approval for TMT in Hawaii. TIO is very grateful to all of our supporters and friends throughout Hawaii, and we deeply appreciate their continued support."
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