Optical Turbulence applied to ground-based astronomy and AO

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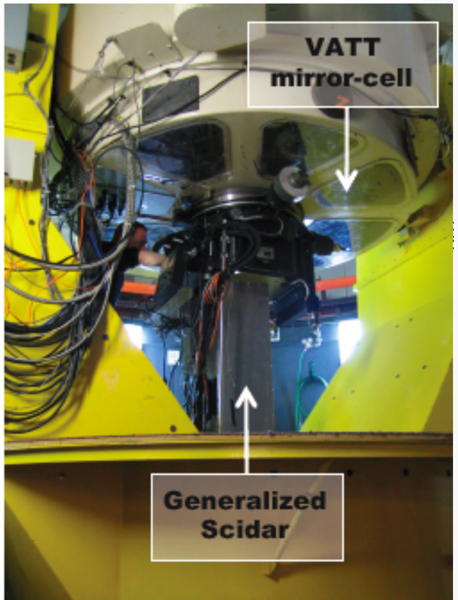
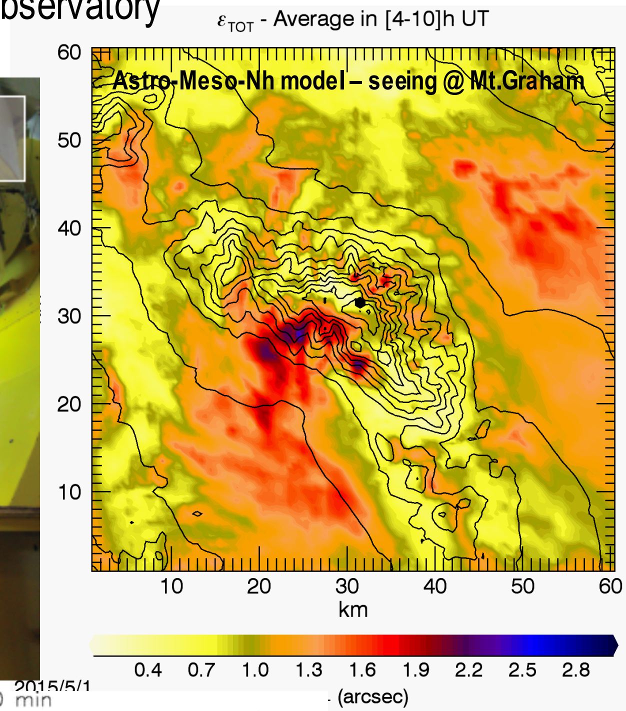
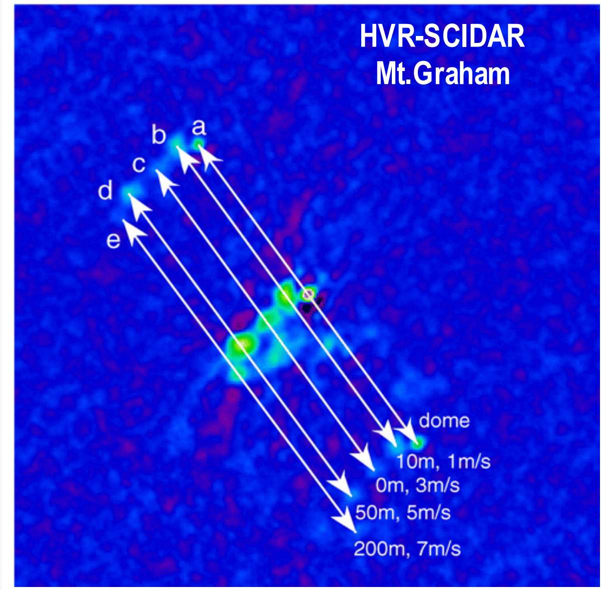
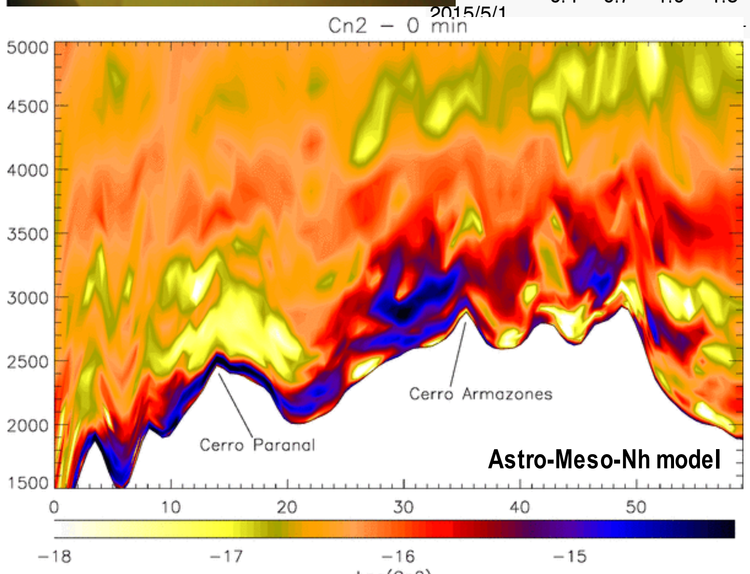
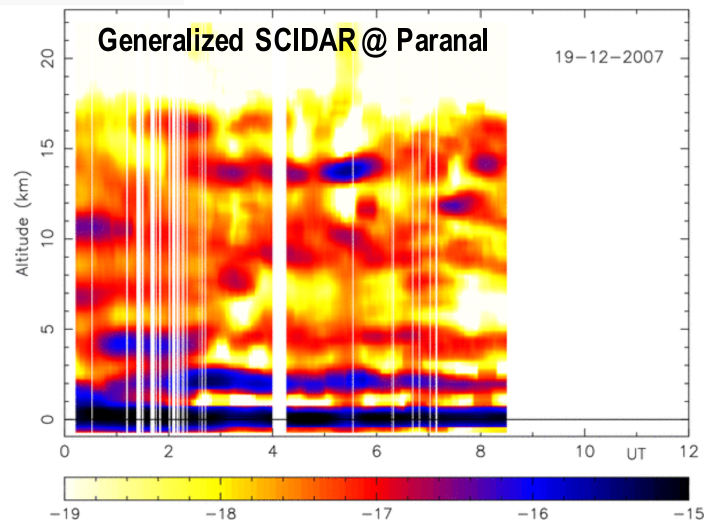










OUTLINE

- Main **research activities/projects** that the OT group in Arcetri si carrying on

- ***Synergies*** with Adaptive Optics and ***benefits*** in terms of astronomical observations

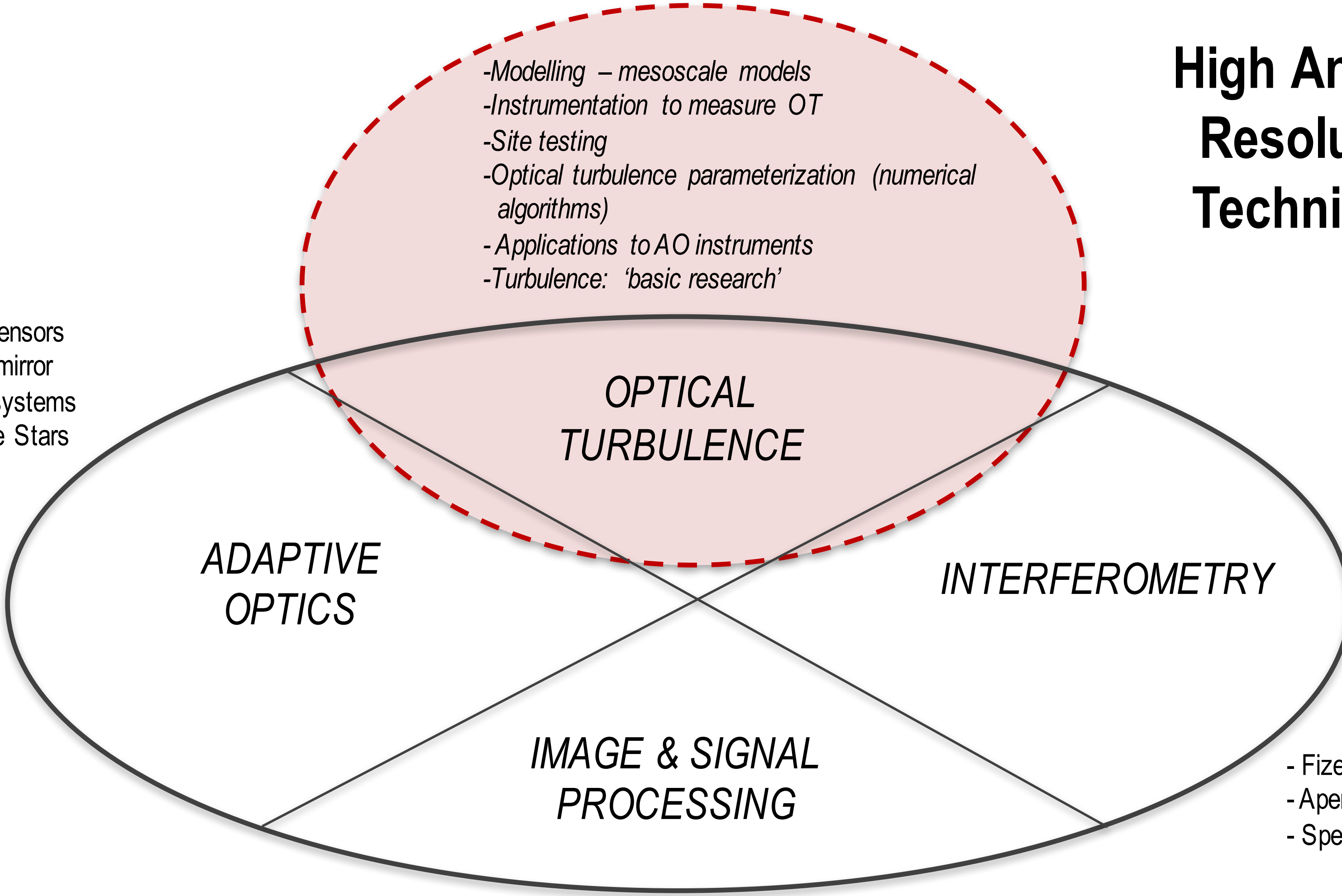
- Perspectives keeping in mind:

1. Potentialities of results already achieved

2. The most ambitious challenges in the field of the OT research applied to the ground-based astronomy

3. General development plan of research activities in the HAR techniques at national level

High Angular Resolution Techniques



- -Wave front sensors
- -Deformable mirror
- -AO Control systems
- -Lasers Guide Stars
- -Extreme AO
- -WFAO

- - Fizeau-Interferometry
- - Aperture synthesis
- - Speckle interferometry

- - High contrast imaging processing (SDI, ADI…)
- - Coronography
- - Scintillaton effects on direct imaging
- - PSF reconstruction

From 2006 @ INAF- Arcetri

ForOT

Marie Curie Excellence Grant

■ **Site testing**

- Characterization of the Mt.Graham

43 nights measured with a Generalized SCIDAR (the most complete characterization ever done of Mt.Graham)

Masciadri et al., 2010, MNRAS

■ **Development of instrumentation and <u>new techniques</u> for the OT measurements**

- HVR-Generalized SCIDAR – High vertical resolution in the first 600 m with Δh ~20-30m
- Microthermal sensors for C_N^2 estimations (UNSW Sydney, INAF-Arcetri; ENEA Rome, Italian Air Force Rome)

Egner & Masciadri, 2007, PASP
Masciadri et al., 2010, MNRAS

■ **Optical Turbulence forecast with atmospheric non-hydrostatical models**

- Optical turbulence forecast for Service Mode
- Development of OT algorithms in strong stable regimes

Hagelin et al., 2010, MNRAS
Lascaux et al., 2009, MNRAS
Lascaux et al., 2010, MNRAS
Hagelin et al., 2011, MNRAS
Lascaux et al., 2011, MNRAS
Masciadri et al., 2013, MNRAS

■ **Direct applications to AO**

- Identification of the grey-zones for ARGOS
- Composite profiles for the estimate of ARGOS performances
- GLAO performances at Dome C
- Implementation of Meso-Nh outputs directly in AO systems

Ex: GeMS (collaboration with LAM, France and Univ. Pontificia, Chile)

Masciadri et al., 2010, MNRAS
Stoestz et al., 2008, SPIE.
Neichel et al., 2014, SPIE
Masciadri et al., 2016, MNRAS, in prep.

OPTICAL TURBULENCE FORECAST: SCIENTIFIC DRIVERS

1) Traditional queue system : *High scientific challenge of the program* **PARADOX** → *Low probability that the program is executed*

2) Service Mode is a must to optimize the exploitation of an ELT

3) Adaptive Optics techniques are strongly dependent from the OT conditions

4) Cost of a night of observation at a top-class telescope is of a few hundreds of K$!!!

5) The advantages of the Service Mode can be fully achieved **ONLY** if most of the available observing time is scheduled in this mode

↓

The Service Mode has been established to be the baseline observing mode at the E-ELT (E-ESO-SPE-066-0283)

Permanent instruments at different focal stations. Typical time required to move the beam from an instrument to another one: $\mathbf{\Delta T_{min} \sim 10\text{-}20\ min}$. (E-ESO-SPE-066-0283)

OPTICAL TURBULENCE FORECAST: SCIENTIFIC DRIVERS

1) Traditional queue system : *High scientific challenge of the program* **PARADOX** → *Low probability that the program is executed*

2) S

3) A

4) C

5) T
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★ The *optical turbulence forecast* is fundamental for the ***success*** of the ELTs

★ *Measurements* ***can not*** provide this information

★ *Non-hydrostatical mesoscale models* are ***the unique tool*** that can attain such a scientific goal

the E-ELT (E-ESO-SPE-066-0283)

Permanent instruments at different focal stations. Typical time required to move the beam from an instrument to another one: **ΔT_{min} ~ 10-20 min**. (E-ESO-SPE-066-0283)

BENEFITS in TERMS OF ASTRONOMICAL OBSERVATIONS

Lascaux et al., MNRAS, 2015

★**Surface temperature**: fundamental to eliminate the thermal gradient air/mirror and eliminate the *'mirror seeing'* contribution.

129 nights: **$BIAS_m \leq 0.5^{\circ}C$; $RMSE_m \leq 0.9^{\circ}C$, $\sigma_m \leq 0.54^{\circ}C$**

★**Surface wind speed**: it is the main source of vibrations of critical structures: adaptive secondary, primary mirror.

129 nights: **$BIAS_m \leq 0.85\ ms^{-1}$; $RMSE_m \leq 2.3ms^{-1}$; $\sigma_m \leq 1.45\ ms^{-1}$**

★**Surface wind direction**: the atmospheric parameter more easily correlated to the seeing conditions.

129 nights: **$BIAS_m \leq 4^{\circ}$; $RMSE_{REL,m} \leq 16\%$; $\sigma_{REL,m} \leq 9\%$**

★**Vertical stratification atm. parameters on [0,20km]**:

- Particularly **wind speed**, main *'ingredient'* for the wavefront coherence time (τ_0).
- There are not *monitors* that can routinely measure the wind speed stratification in an Observatory.

Masciadri et al., 2013, MNRAS
50 radiosoundings

★**Optical Turbulence**: mesoscale models represents the **unique** method that is able to provide 3D maps of the C_N^2 from which we can retrieve all the astroclimatic parameters integrated along whatever line of sight.

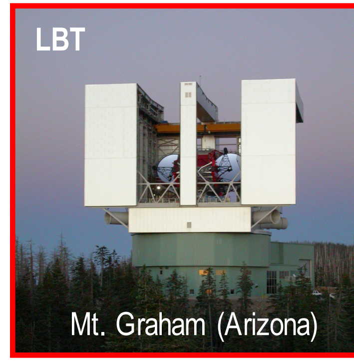
Practical examples of optimization of the AO observations that we can obtain:

1) Identification of temporal windows in which AO can not work at all (ε > 1.5" or $\tau_0 < \tau_{0,threshold}$)
2) Identification of temporal windows in which the total seeing is particularly weak ($\varepsilon < \varepsilon_{0,threshold}$) *for high-contrast imaging (extra-solar planets)*
3) Identification of temporal windows in which the turbulence in the free atmosphere is weak → *GLAO, MCAO and WFAO*

Just one tool for a huge number of benefits in different contexts !

ALTA Center: Advanced LBT Turbulence and Atmosphere Center

Operational system for the forecast of OT and atmospherical parameters relevant for ground-based astronomy @ Mt.Graham (LBT) ***funded by LBT Consortium***



First contract (signed on October 2014): 5 years [1/1/2015 – 31/12/2020]

Milestones:

- **December 2015**: automation completed
- **June 2016**: atmospherical parameters (online) - *commissioning*
- **December 2016**: astroclimatic parameters (online) - *commissioning*

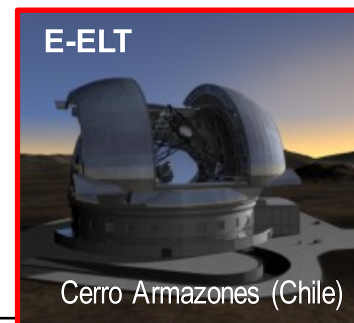
Feasibility study *funded by ESO*

Phase A: *[4/2011 – 4/2013] – two years*

Phase B: *[6/2014 – 6/2015] – one year*

On 17 March 2016 we concluded negotiation with ESO for a '*DEMONSTRATOR*':

- Starting date: December 2016
- Budget defined
- Duration: 2 years

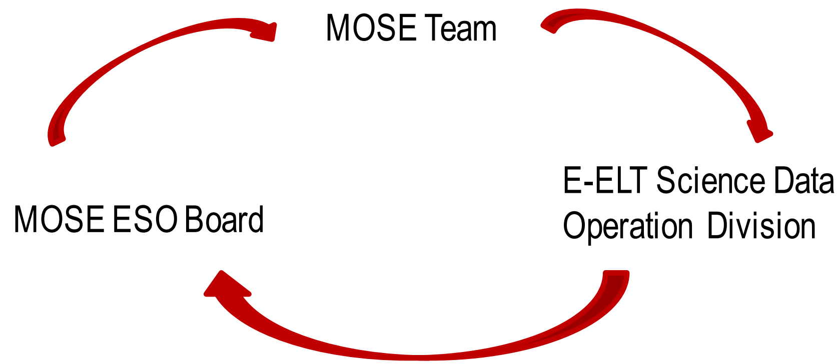


Goal: *managing OT forecasts above different astronomical sites*

A few facilities with D ≥ 6.5 m around the world

pictures with red frames: facilities with our operational system

On 17 March 2016



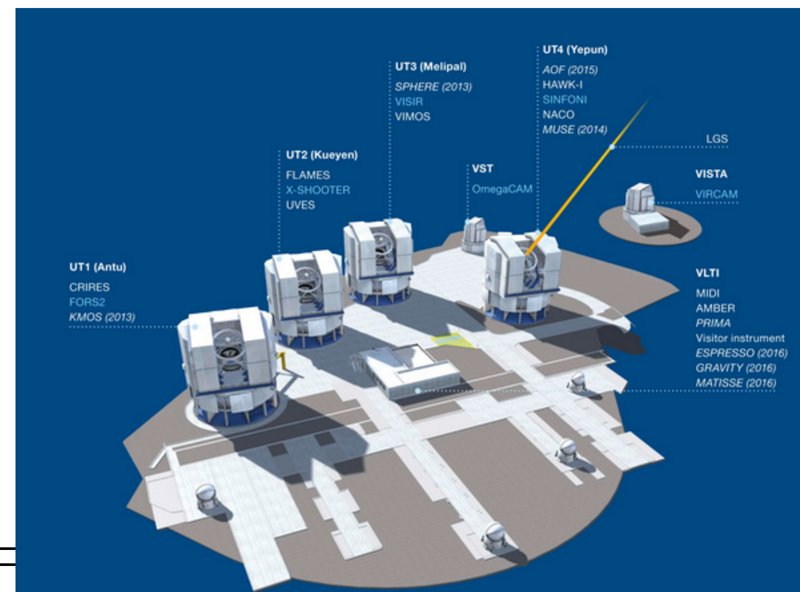
PRIORITY for ESO:
AOF - GRAAL & GALACSI

MAORY (PI: Italy-Bologna)

HARMONI (PI: UK-Oxford)

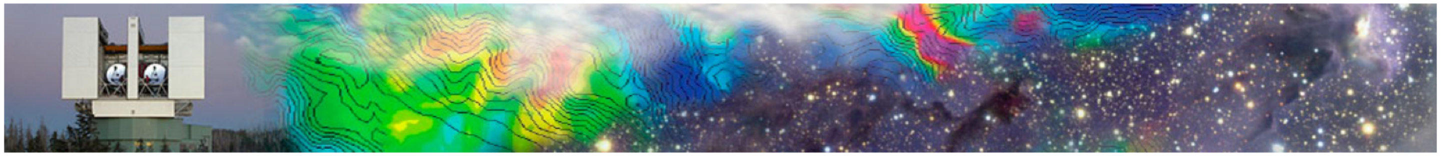
HIRES (PI: Italy-Arcetri)

MOSAIC (PI: France-Observatoire de Paris)



ALTA Center

Advanced LBT Turbulence and Atmosphere



Home

Optical Turbulence Tutoring

Forecasts Legend

- Forecasts
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  - Yesterday
- Trends

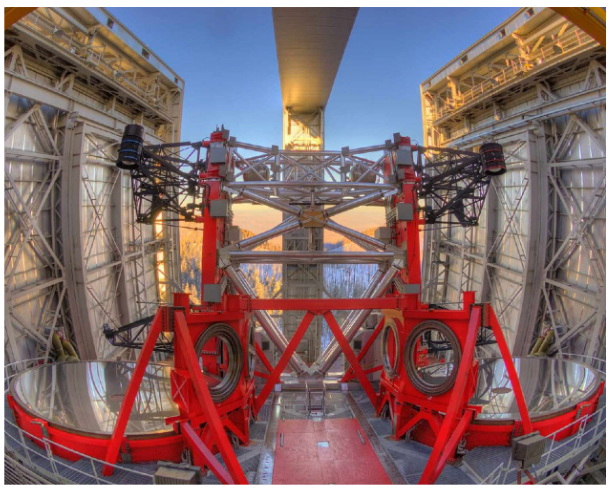
Team

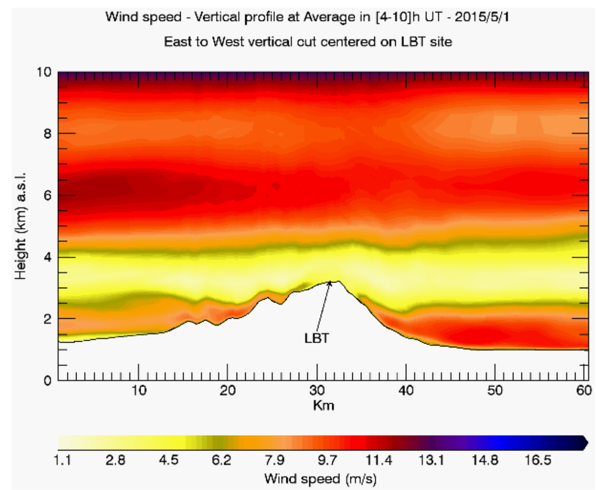
Bibliography

Contact

The ALTA Center is a project aiming at forecasting automatically and nightly the optical turbulence and other integrated astroclimatic parameters as well as atmospheric parameters relevant for ground-based astronomical observations, mainly supported by Adaptive Optics systems. The project has been conceived for the Large Binocular Telescope (LBT) located at Mt.Graham, Arizona, Us.

The project is lead by INAF - Arcetri Astrophysical Observatory.

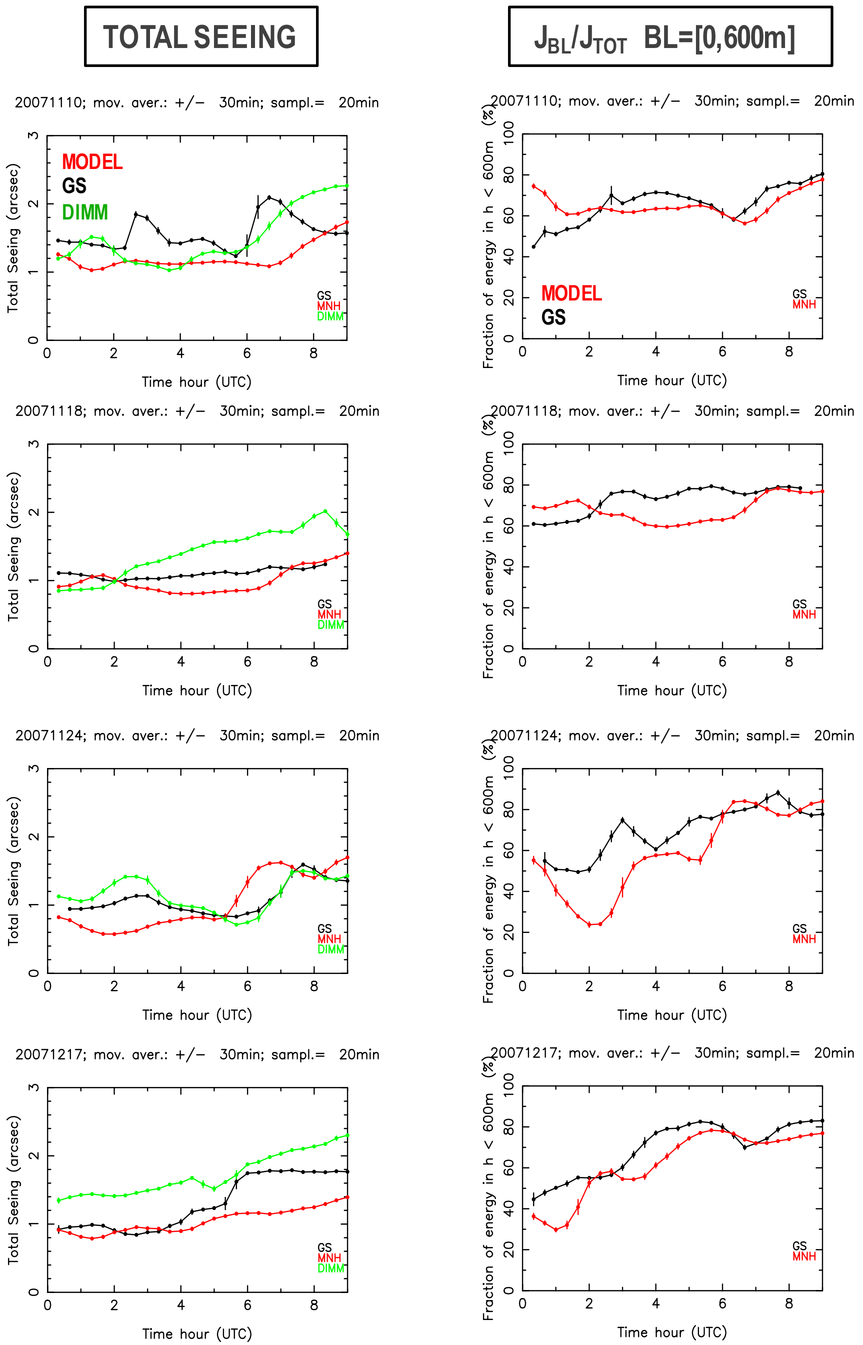


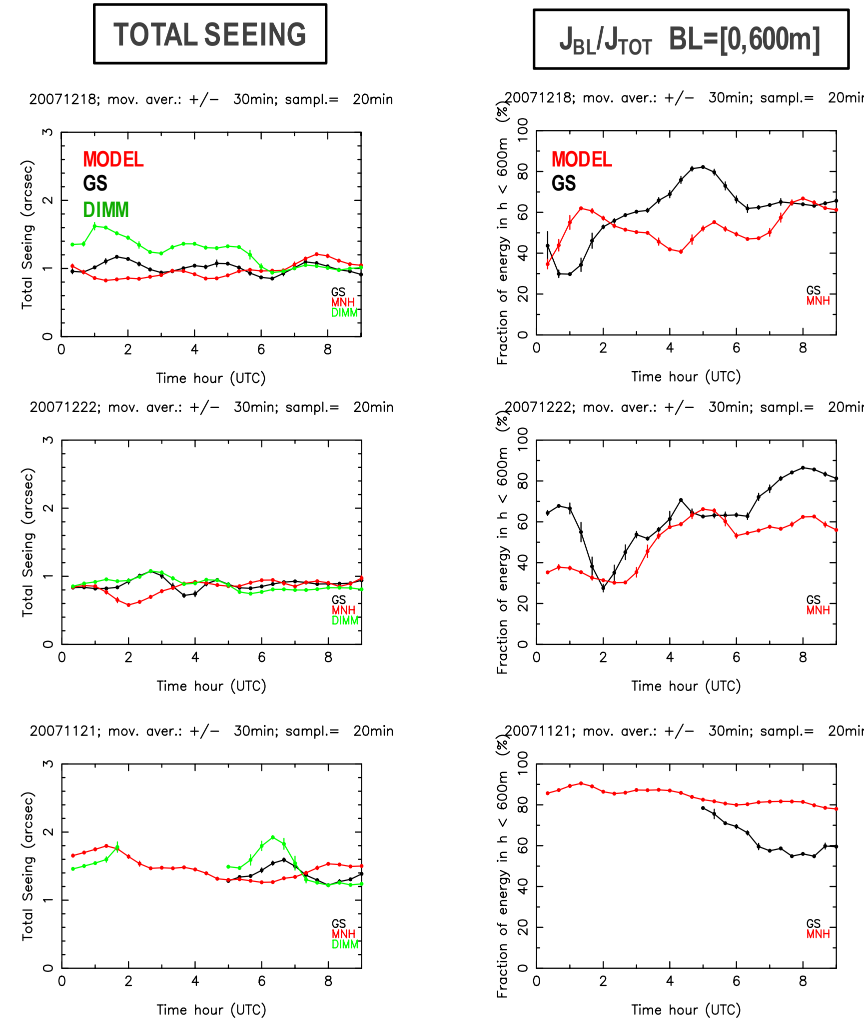


June 2016: *commissioning of automatic operation of atmospheric parameters forecasts*

December 2016: *commissioning of automatic operation of OT forecasts*

Site Testing Campaign Paranal 2007 (PAR2007)



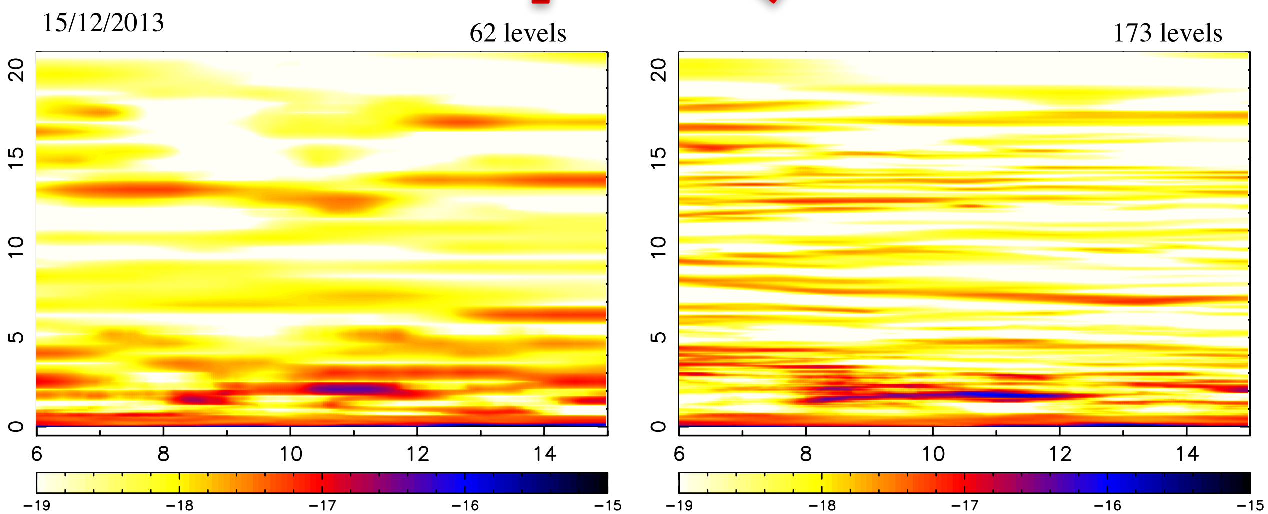


Fraction of turbulent energy close to the ground

J_{BL}/J_{TOT} : very useful figure of merit for the WFAO

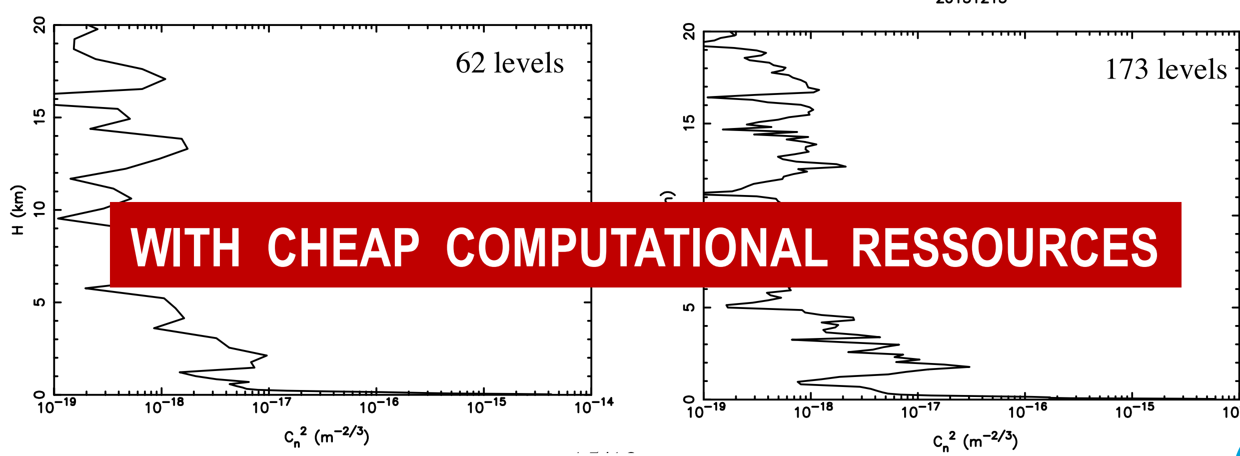
HIGH VERTICAL RESOLUTION C_N^2 PROFILES

Thanks to a new C_N^2 algorithm we proposed



up to Δh~150m

Crucial for WFAO (MCAO, MOAO)!



WITH CHEAP COMPUTATIONAL RESSOURCES

Optical Turbulence and AO - Challenges

Third AO4ELT Conference - Adaptive Optics for Extremely Large Telescopes
Florence, Italy. May 2013
ISBN: 978-88-908876-0-4
DOI: 10.12839/AO4ELT3.13542

A roadmap for a new era turbulence studies program applied to the ground-based astronomy supported by AO.

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PRIORITIES for Arcetri's OT group

- ★ Algorithms development for turbulence in stable regimes
- ★ Application to solar telescopes (to validate the model on daytime conditions)

} OT forecasts

- ★ Development of '*light*' instrumentation for "automatic monitoring of the OT"
- ★ '*Absolute measurements*' of the OT
- ★ Outer scale (L_0) (*SPIE paper: Arcidiacono, Masciadri, Agapito*)

[6] GEPI, Observatoire de Paris, CNRS, Univ. Paris-Diderot, 5 place Jules Janssen, 92195 Meudon cedex, Paris, France
[7] Instituto de Astrofisica de Canarias, C/Via Lactea S/N, 38305 La Laguna, Tenerife, Spain
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CONCLUSIONS

■ We proved that we are able to forecast the atmospherical parameters and the OT with a score of success that **is already sufficiently high** to definitely guarantee a benefic impact on the service mode of top-class telescopes and the ELT.

■ We proved that a relatively cheap equipment is sufficient to implement automatic operational forecast systems.

- Three among the most relevant observatories in the world expressed interest for such a system
- Space for development in this field – possible SPIN-OFF …????
- Applications to: global climate change, sustainable energy, pollutant transportation, …

■ We proved that we are able to forecast *C_N^2 profiles with a vertical resolution as high as 150 m*
This implies exciting perspectives for the WFAO (MCAO, MOAO,…)

■ We can develop "*dedicated service tools*" for basically all the AO systems of LBT, VLT and E-ELT

■ The **Optical Turbulence** is strictly correlated to the **Adaptive Optics** however….

Lack of a national coordination that can enhance the leadership of the different disciplines of the HAR techniques in INAF to optimize the scientific impact on the international panorama

END

THANKS for the ATTENTION