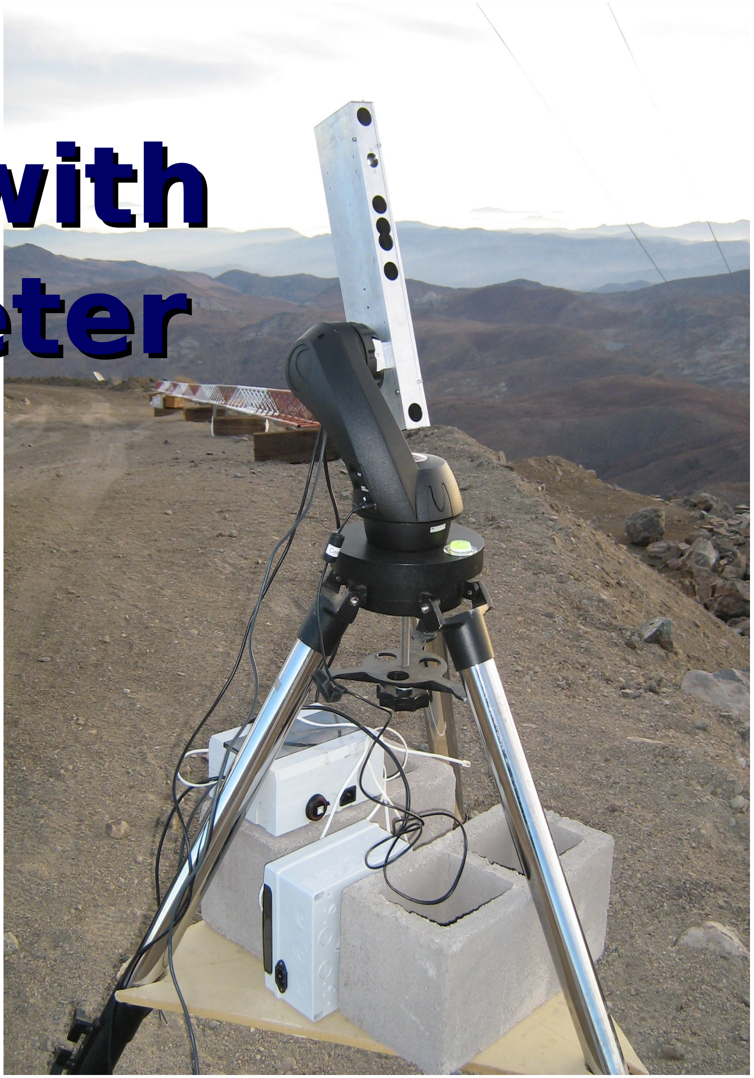
Surface-layer turbulence measurements with lunar scintillometer



- Idea of the method
- Hardware & software
- Campaigns & results
- New horizons

Andrei Tokovinin
NOAO/CTIO

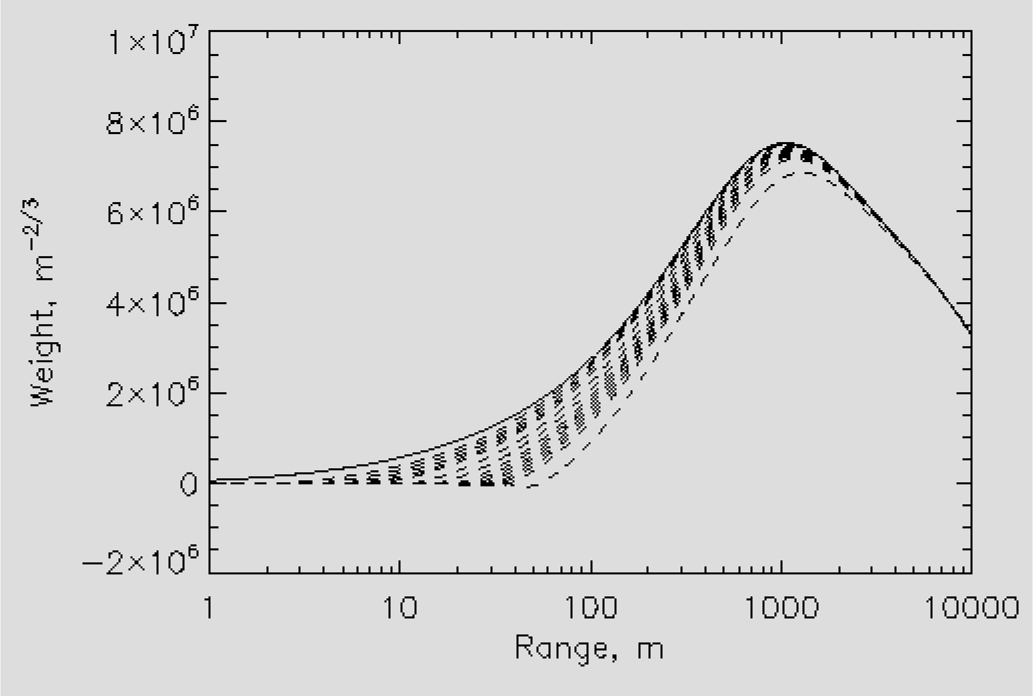
Turbulence measurement from scintillation of extended sources

- Moon’s angular diameter

  θ=0.5 deg
- Correlated scintillation

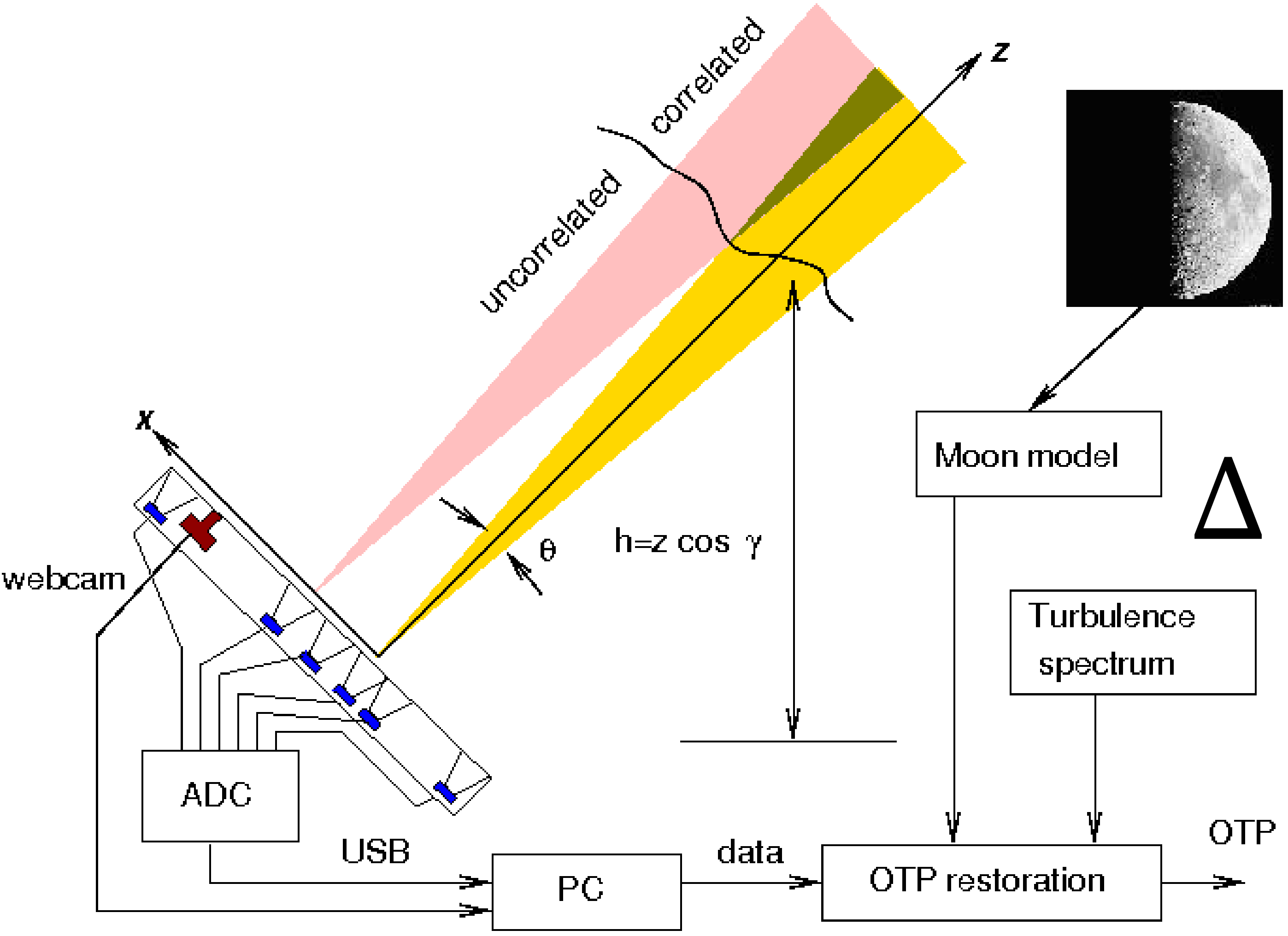
  for b > θ z
  - z=10m → b=0.1m
  - z=100m → b=1m
  - z=10km → b=100m

$$\boxed{B_I(b) = \int W(b,z)\, C_n^2(z) dz}$$



Weighting functions zW(z) for b=0…0.4m and d=1cm

The principle



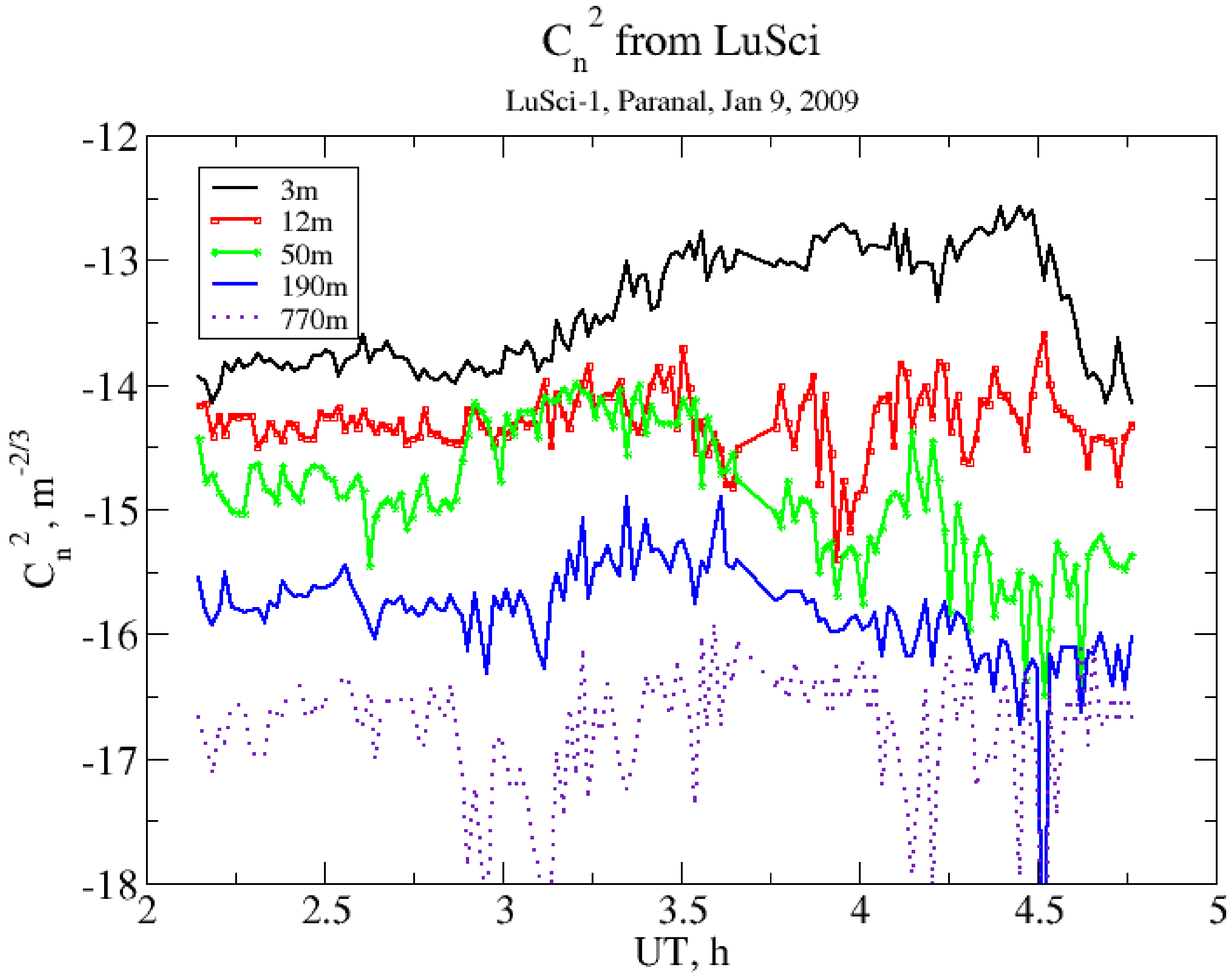
$\Delta\, I/\langle I\rangle \sim 10^{-4}$

2010 MNRAS, 404, 1186

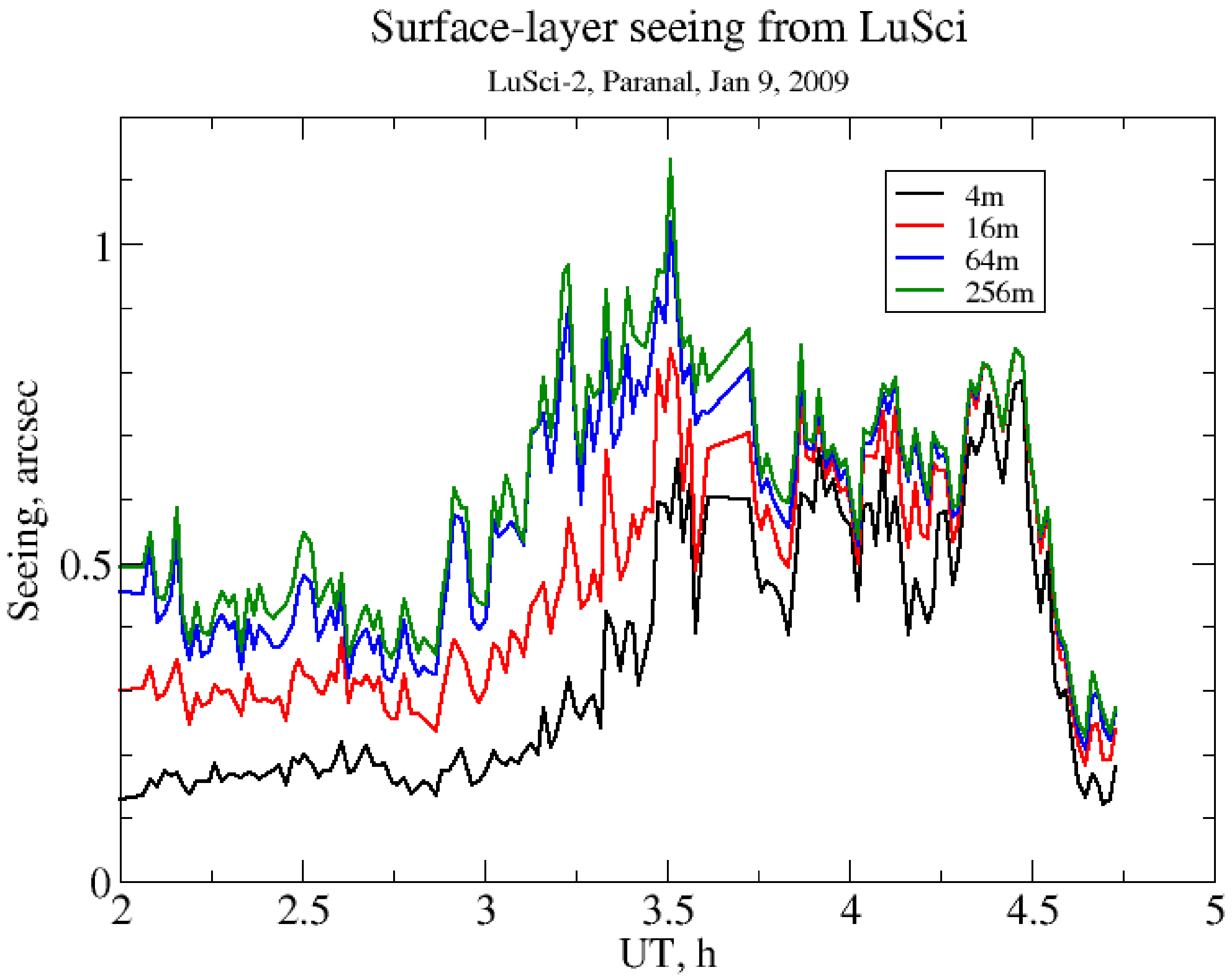
Restoration of turbulence profile

- C_n^2 is non-local by definition. No “thin layers”!
- Fit covariance $B_l(b)$ to a smooth function $C_n^2(z)$ using $W(b,z)$
- Use 5 “pivot points”, power-law segments
- Calculate seeing etc. from the model
- Old method: linear combination of data → turbulence integrals in “layers”

Example (1)


C_n^2 from LuSci
LuSci-1, Paranal, Jan 9, 2009
3m
12m
50m
190m
770m
C_n^2, $m^{-2/3}$
-12
-13
-14
-15
-16
-17
-18
2
2.5
3
3.5
4
4.5
5
UT, h

Example (2)


Surface-layer seeing from LuSci
LuSci-2, Paranal, Jan 9, 2009
Seeing, arcsec
0
0.5
1
UT, h
2
2.5
3
3.5
4
4.5
5
4m
16m
64m
256m

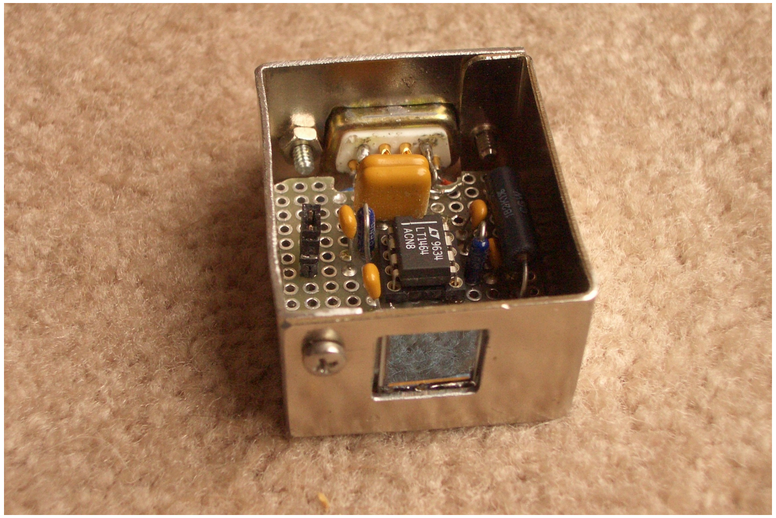
Pros and cons

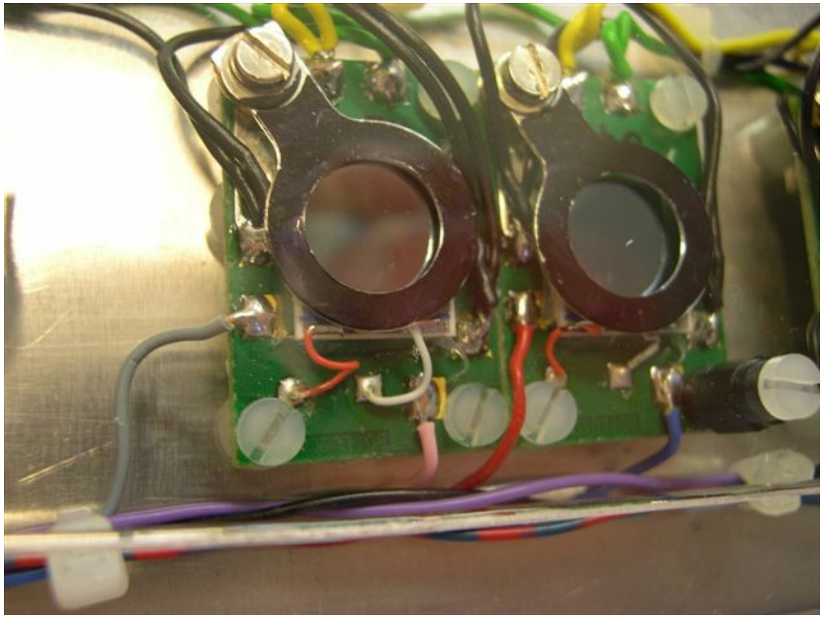
- Simple instrument
- Absolute calibration
- Solid theory (no saturation, achromatic)

- Does not measure high turbulence
- Sensitive to outer scale
- Wind bias
- Non-Kolmogorov?

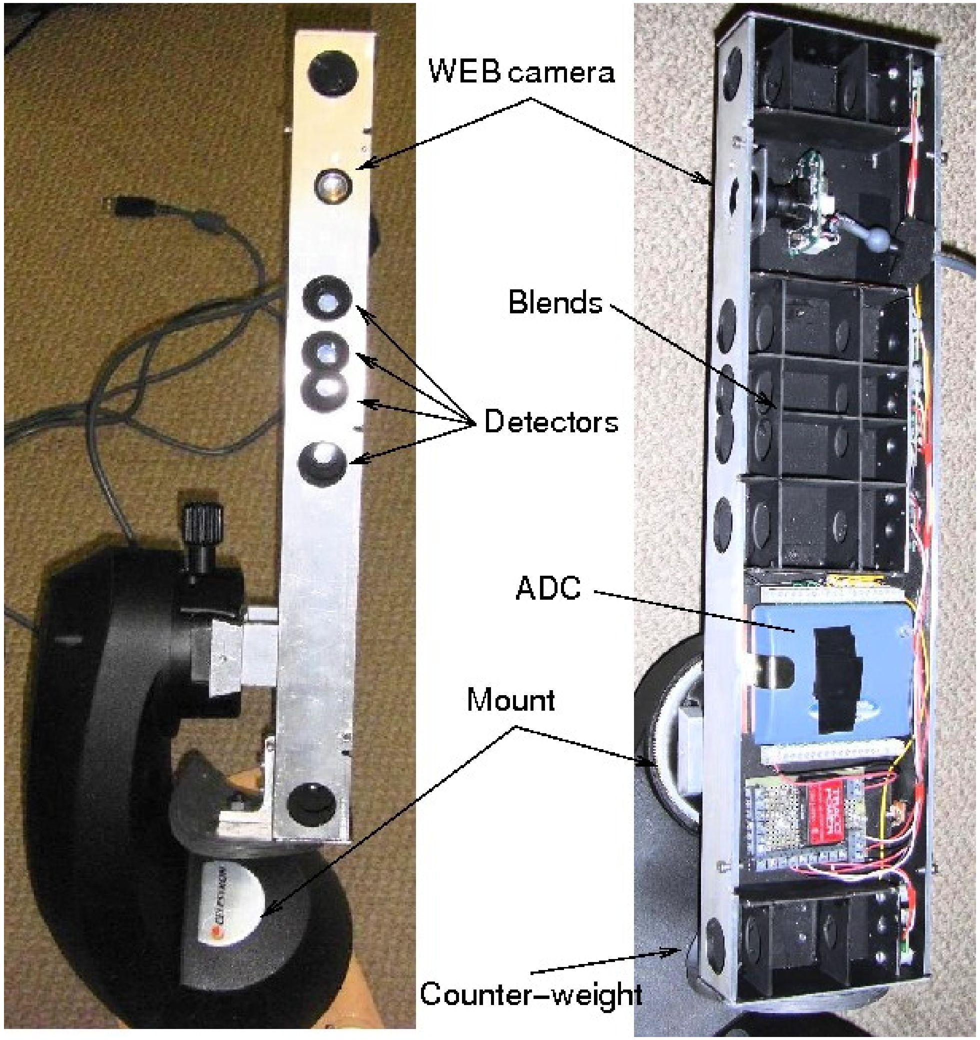
Various implementations

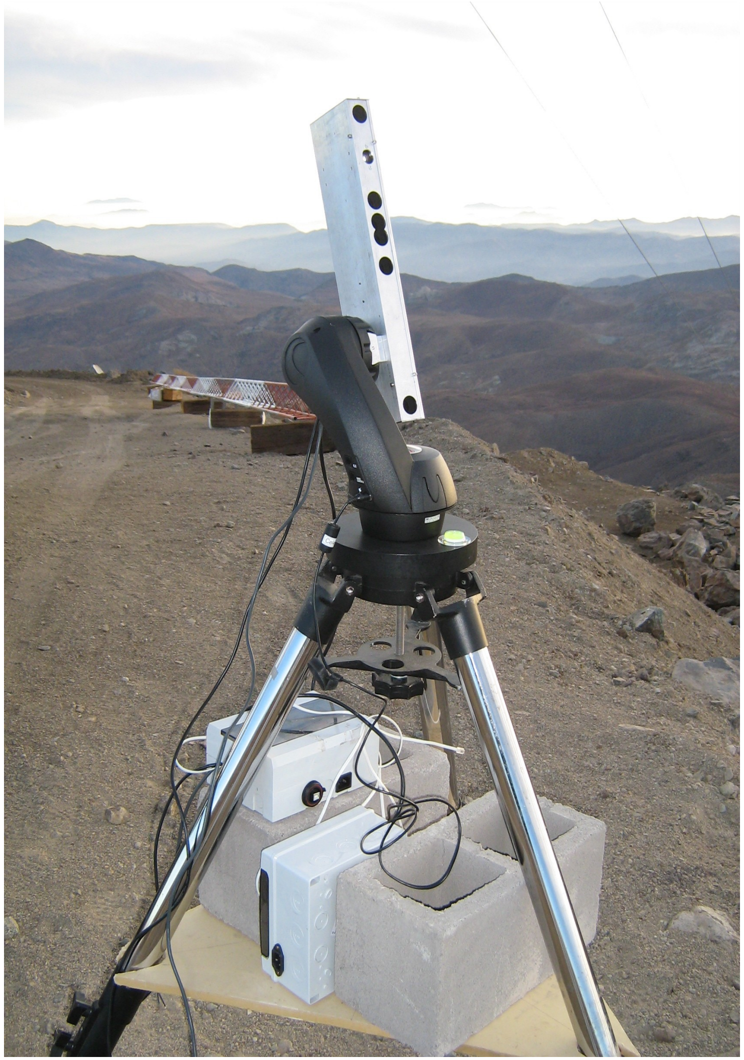
- J.Beckers: SHABAR (ATST site campaign)
- P.Hickson: lunar SHABAR (CTIO, Arctic & Mauna Kea)
- CTIO: lunar scintillometer, LuSci (several prototypes)
- ESO: several LuSci instruments
- Las Campanas: MooSci



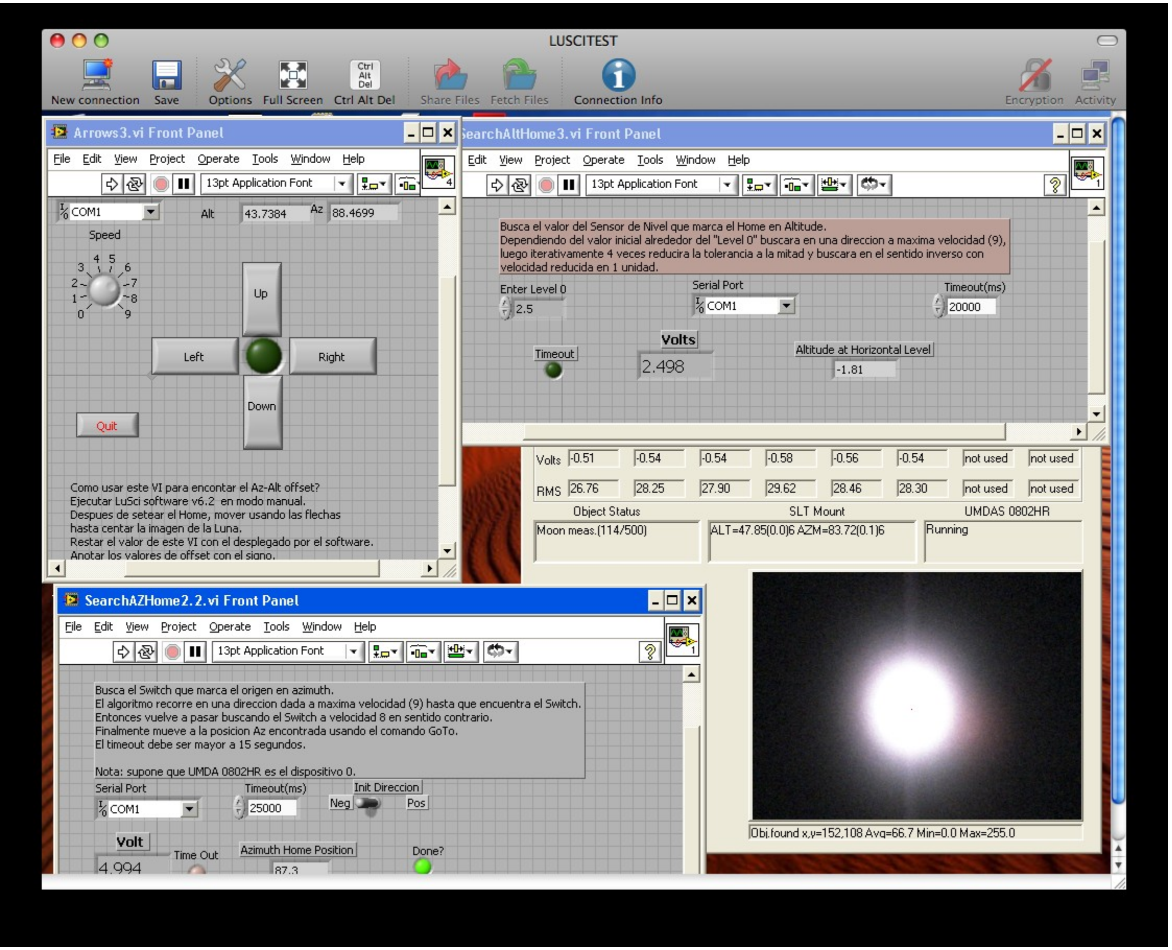


The CTIO instrument





Instrument control software



COM1 Alt 43.7384 Az 88.4699

Como usar este VI para encontar el Az-Alt offset?
Ejecutar LuSci software v6.2 en modo manual.
Despues de setear el Home, mover usando las flechas
hasta centar la imagen de la Luna.
Restar el valor de este VI con el desplegado por el software.
Anotar los valores de offset con el signo.

Busca el valor del Sensor de Nivel que marca el Home en Altitude.
Dependiendo del valor inicial alrededor del "Level 0" buscara en una direccion a maxima velocidad (9), luego iterativamente 4 veces reducira la tolerancia a la mitad y buscara en el sentido inverso con velocidad reducida en 1 unidad.

Enter Level 0: 2.5
Serial Port: COM1
Timeout(ms): 20000
Timeout
Volts: 2.498
Altitude at Horizontal Level: -1.81

Volts	-0.51	-0.54	-0.54	-0.58	-0.56	-0.54	not used	not used
RMS	26.76	28.25	27.90	29.62	28.46	28.30	not used	not used

Object Status	SLT Mount	UMDAS 0802HR
Moon meas.(114/500)	ALT=47.85(0.0)6 AZM=83.72(0.1)6	Running

Obj.found x,y=152,108 Avg=66.7 Min=0.0 Max=255.0

Busca el Switch que marca el origen en azimuth.
El algoritmo recorre en una direccion dada a maxima velocidad (9) hasta que encuentra el Switch.
Entonces vuelve a pasar buscando el Switch a velocidad 8 en sentido contrario.
Finalmente mueve a la posicion Az encontrada usando el comando GoTo.
El timeout debe ser mayor a 15 segundos.

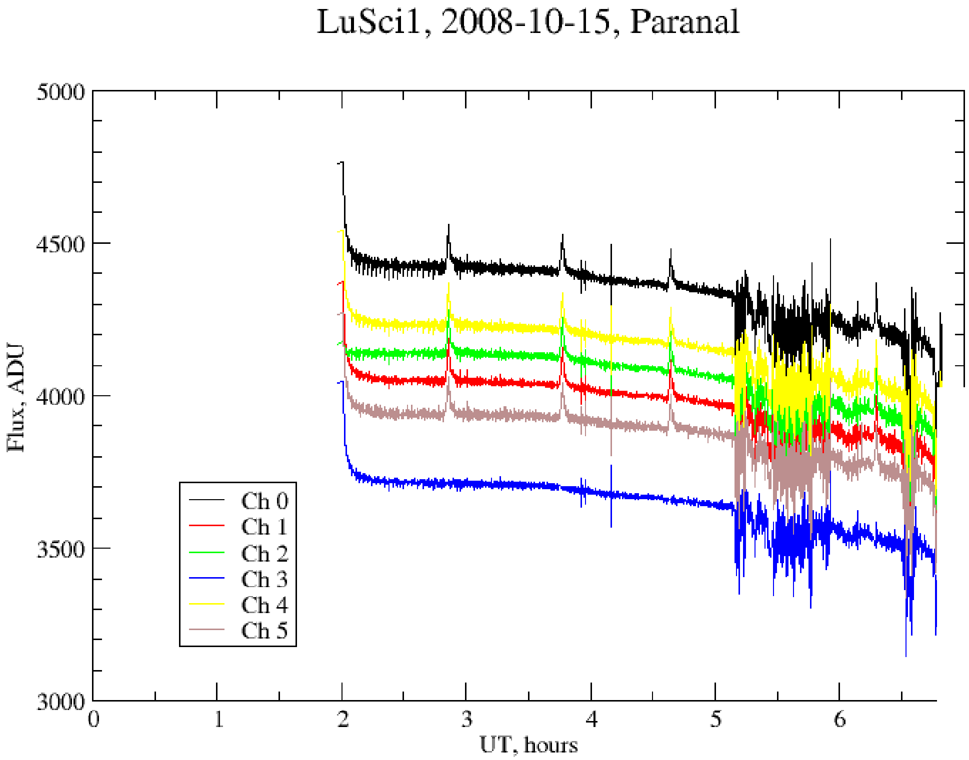
Nota: supone que UMDA 0802HR es el dispositivo 0.

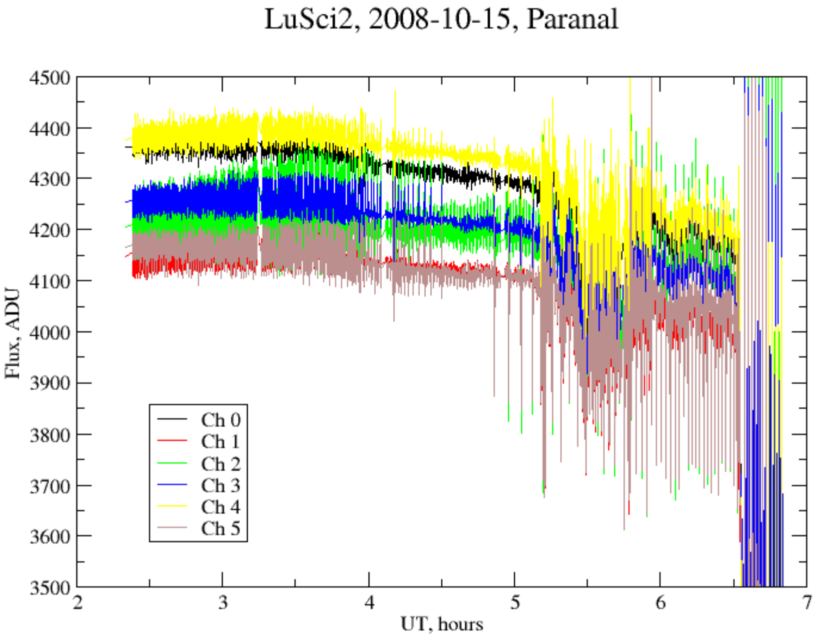
Serial Port: COM1
Timeout(ms): 25000
Init Direccion: Neg Pos
Volt: 4.994
Time Out
Azimuth Home Position: 87.3
Done?

- Remote observing
- “Cold start” possible
- Correct pointing by webcam
- Automatic acquisition
- Periodic sky meas.

Software written by E.Bustos, for Windows

What can go wrong? Pointing!


LuSci1, 2008-10-15, Paranal


LuSci2, 2008-10-15, Paranal

Flux vs. time plots

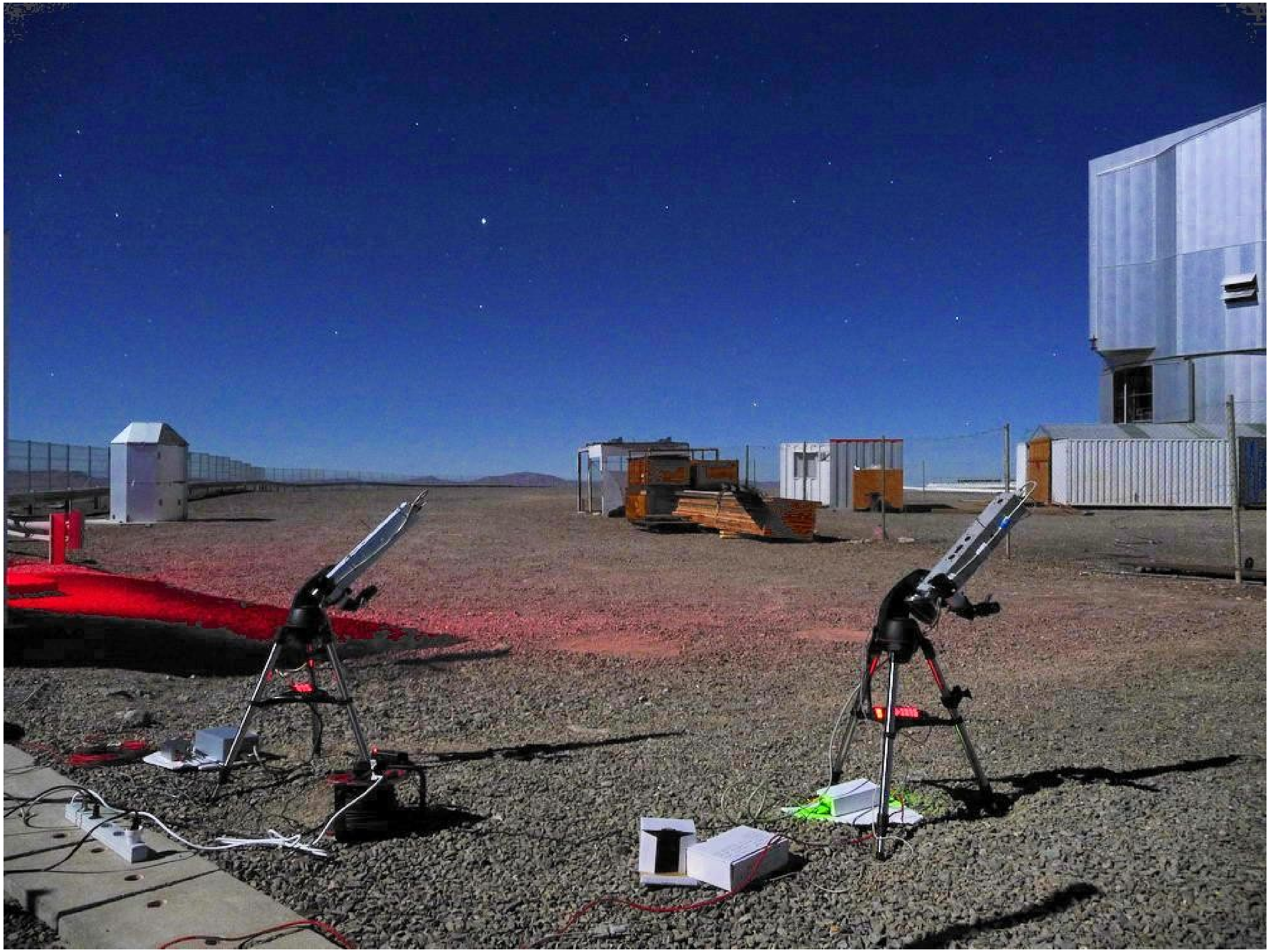
Data processing (IDL)

- Filter the data for each night
- Calculate covariances → .cov file
- Calculate W(b,z) and fit OTP → .tp file
- Use the OTP to compute SL seeing etc.

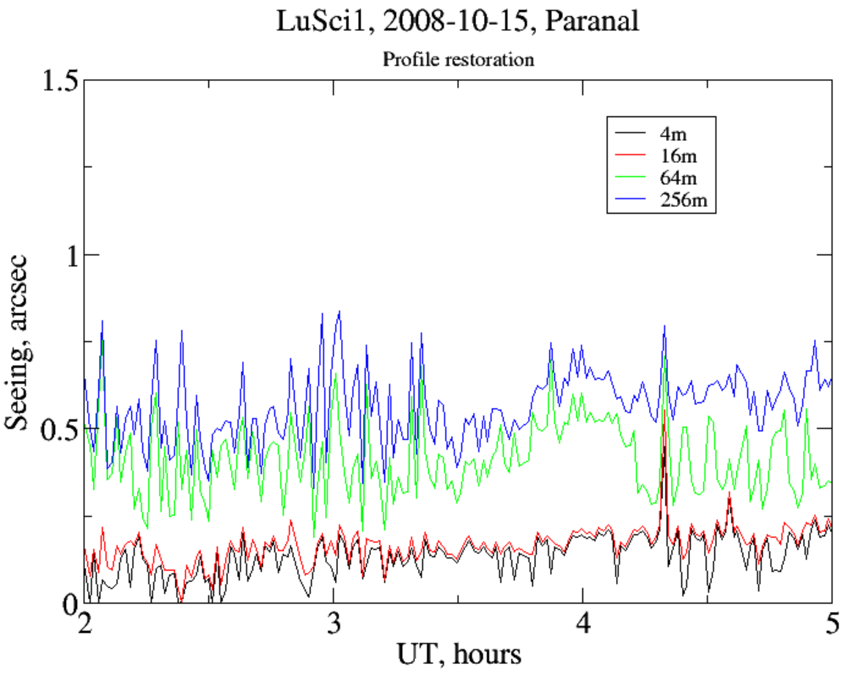
The code is available at

http://www.ctio.noao.edu/~atokovin/profiler/code2.tar.gz

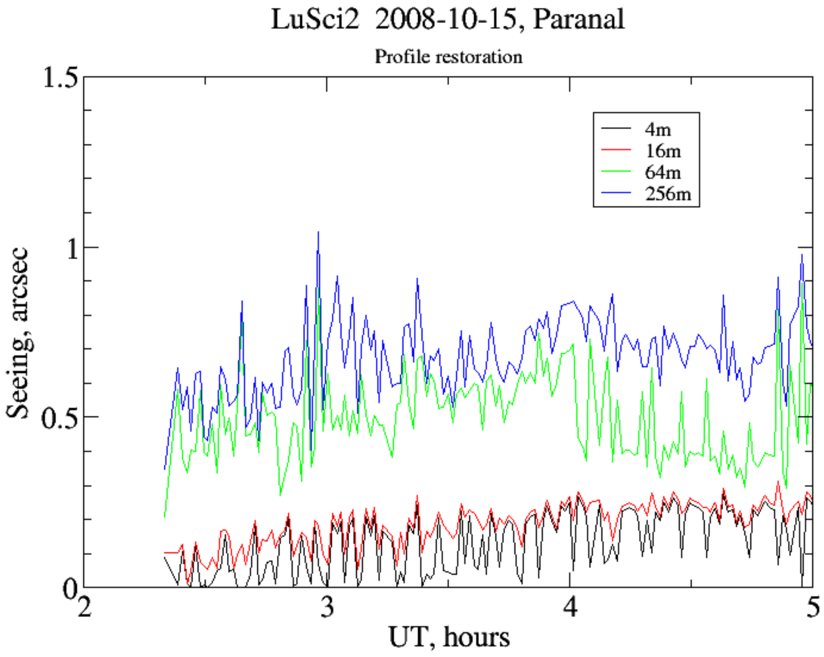
Paranal: October 14, 2008



Instrument comparison (ESO)



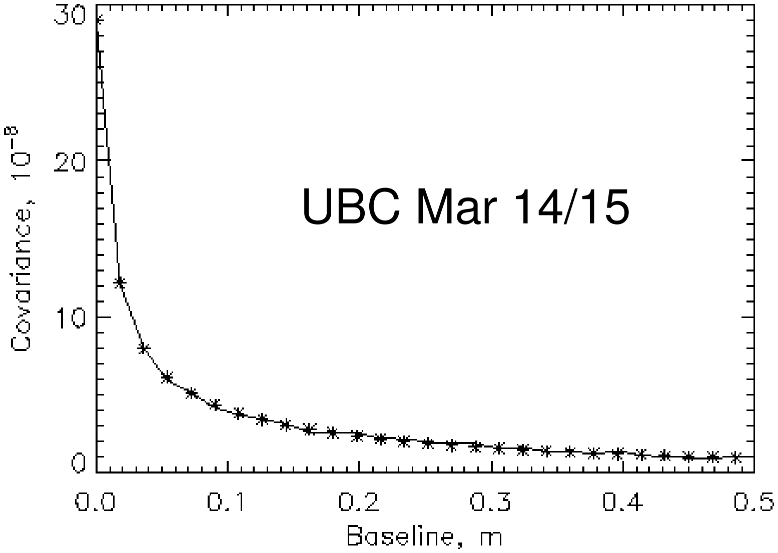
LuSci-1

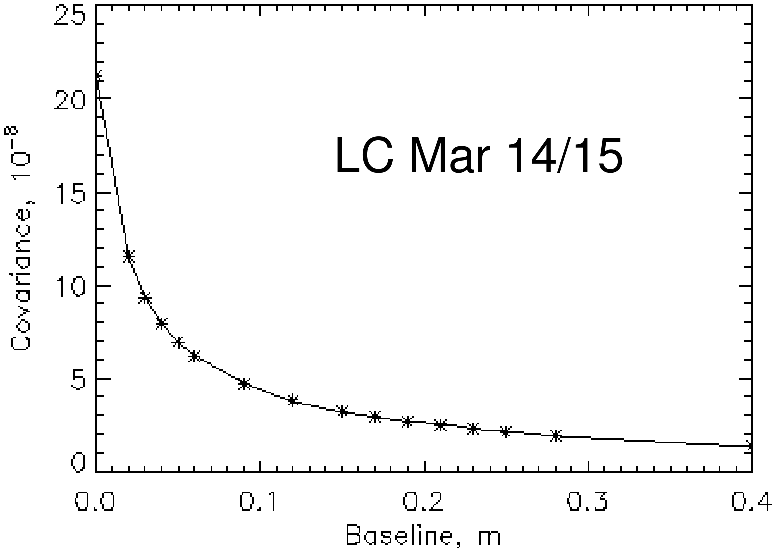


LuSci-2

Cerro Tololo, March 2009

- Hickson's 12-channel scintillometer (UBC)
- CTIO LuSci (LC)
- ESO LuSci-3 (L3)
- MASS-DIMM site monitor

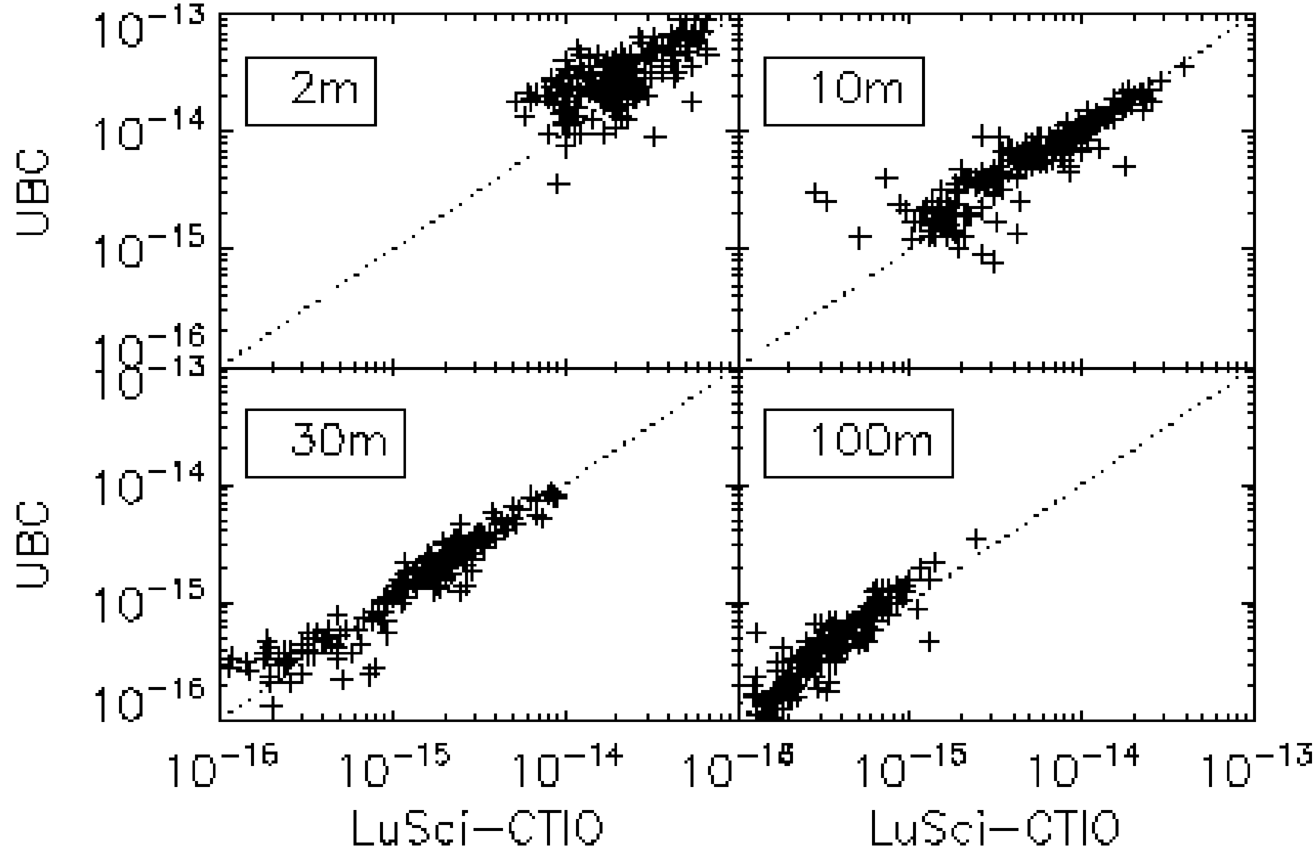




Scintillometer comparison

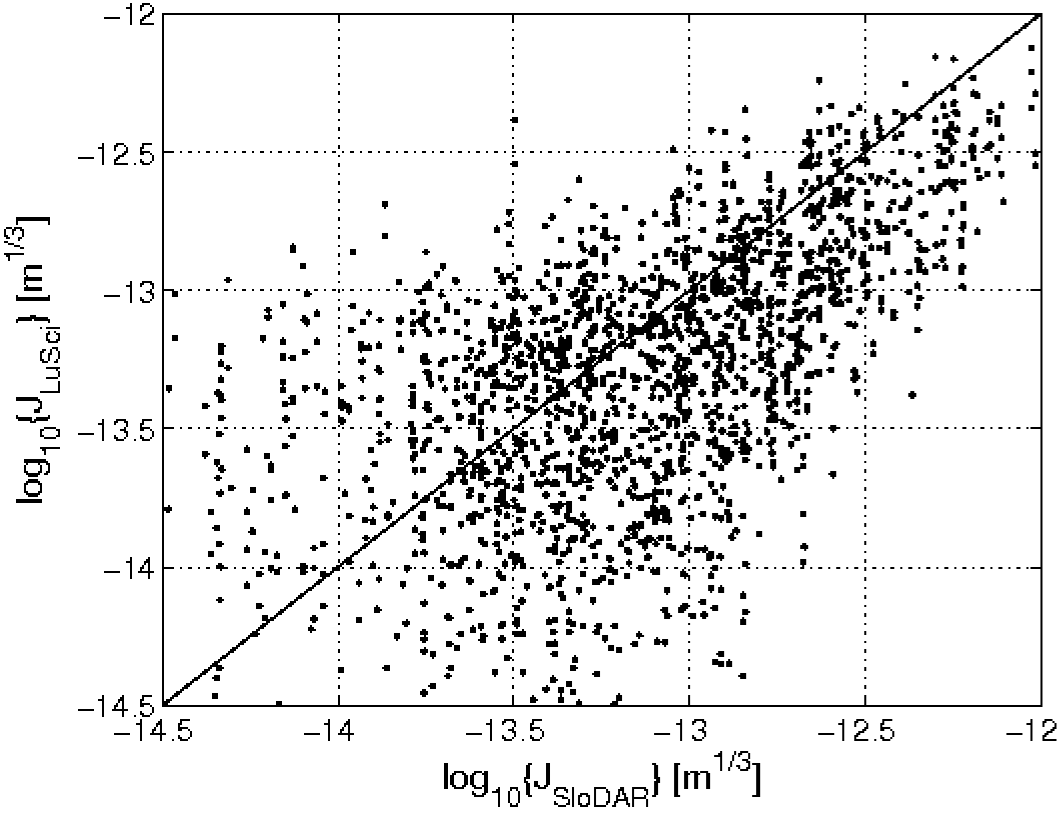
Δ log(Cn2):

- av. <0.12
- rms 0.2
- +-30% C_n^2



Can SLODAR measure 10^{-15} $m^{-2/3}$??

Comparison with SL-SLODAR



Turbulence integral

$J_{SL} = \int C_n^2(h)\, dh$,

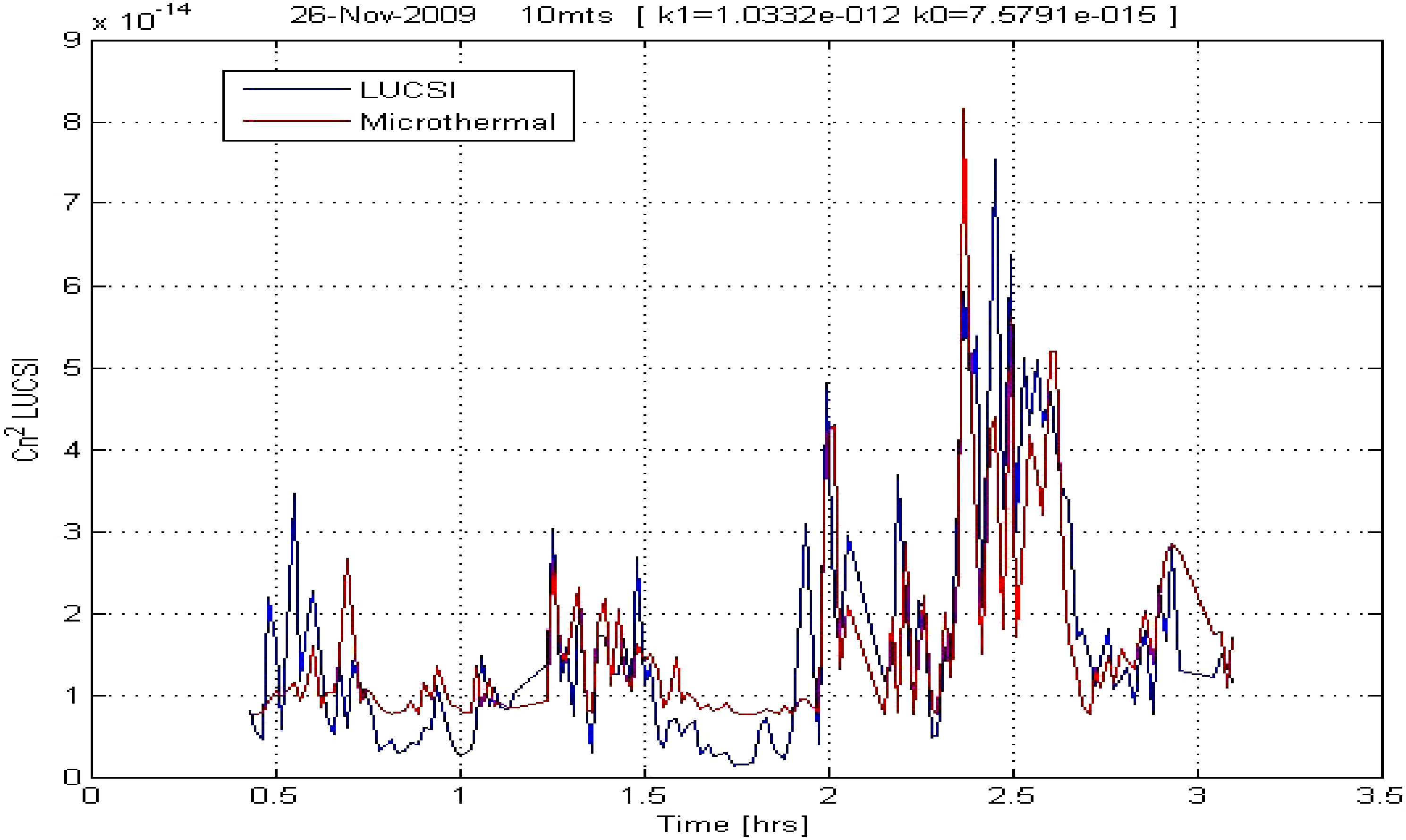
in 10^{-13} $m^{1/3}$

limits (h_{min}, h_{max})

Paranal, 2009 (J. Osborn, A. Berdja)

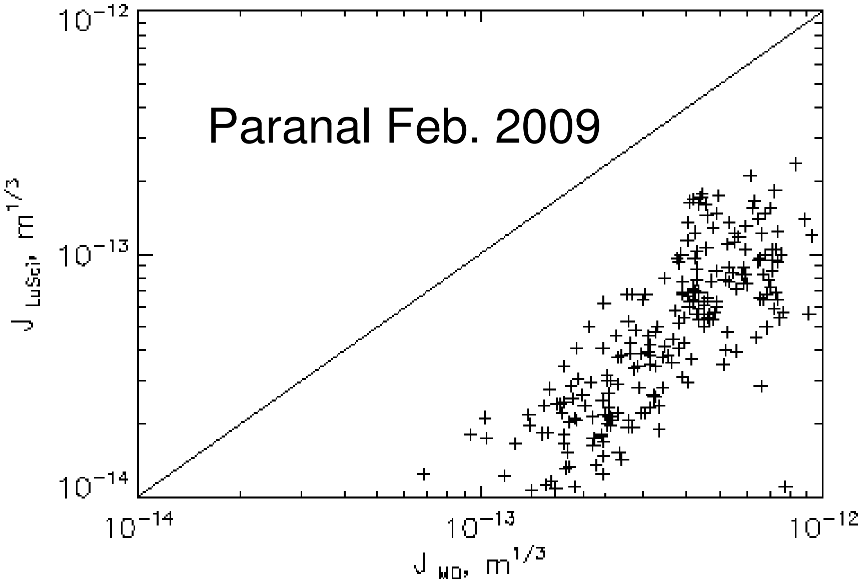
Osborn et al. 2010, MNRAS

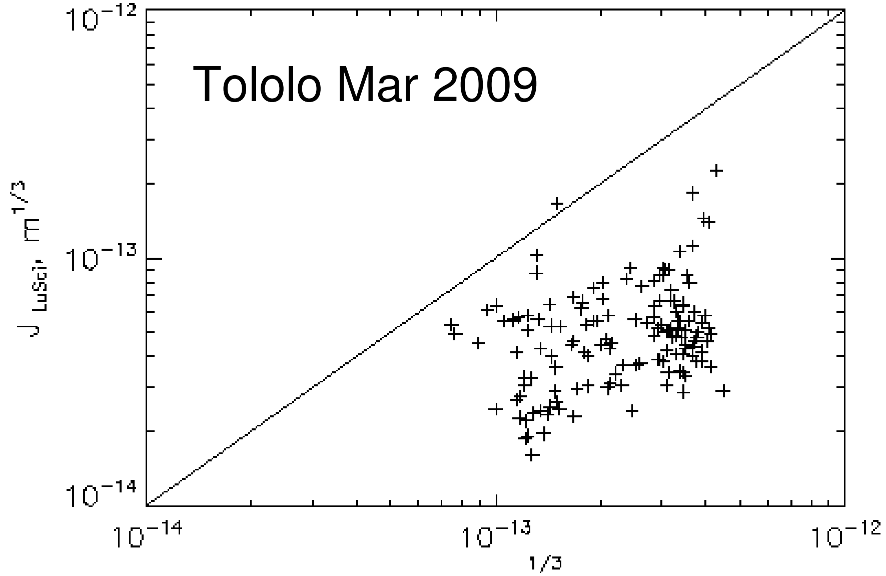
Comparison with micro-thermals

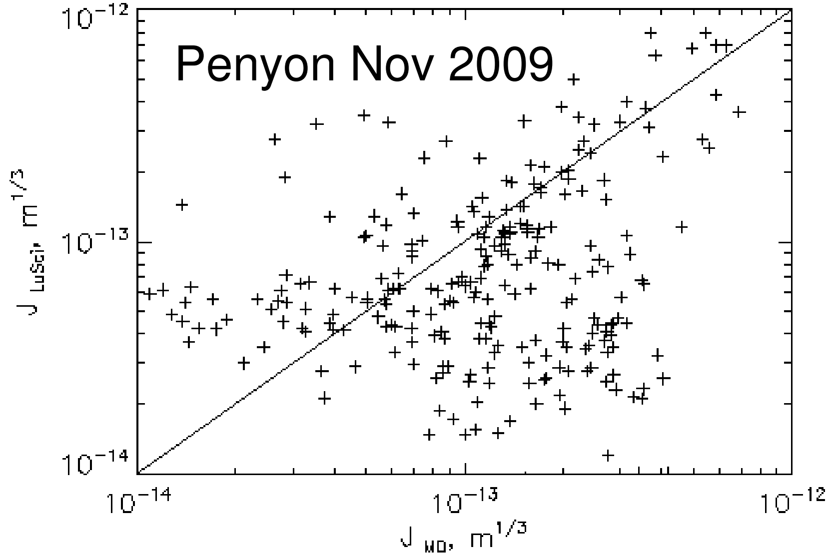


Penyon, Nov. 26, 2009, h=10m (J. Sebag)

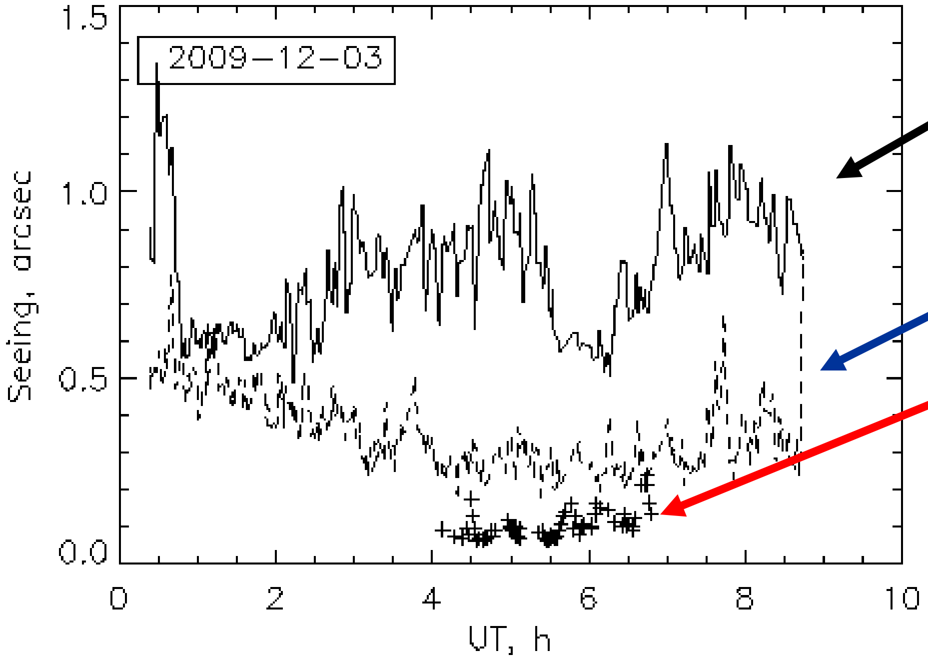
Comparison with DIMM-MASS


Paranal Feb. 2009


Tololo Mar 2009


Penyon Nov 2009

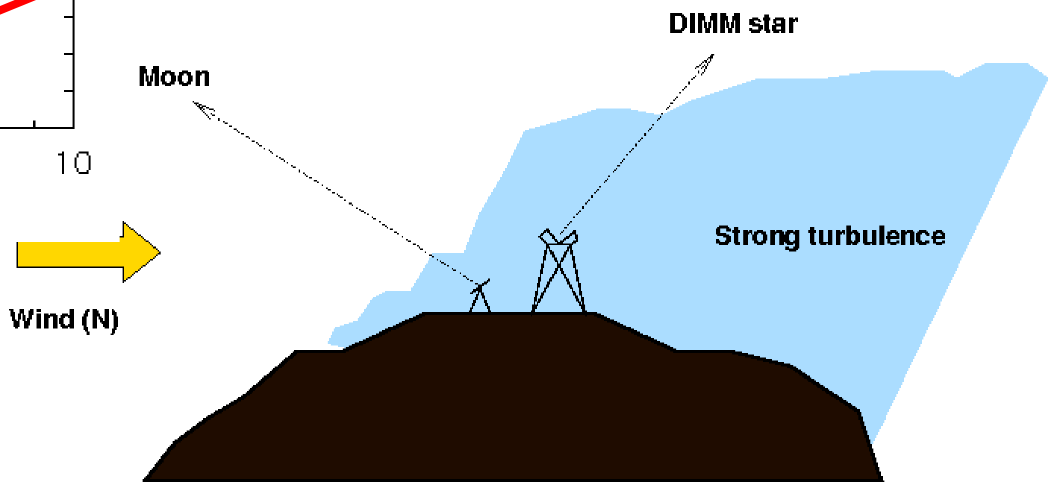
Where is the surface-layer turbulence?



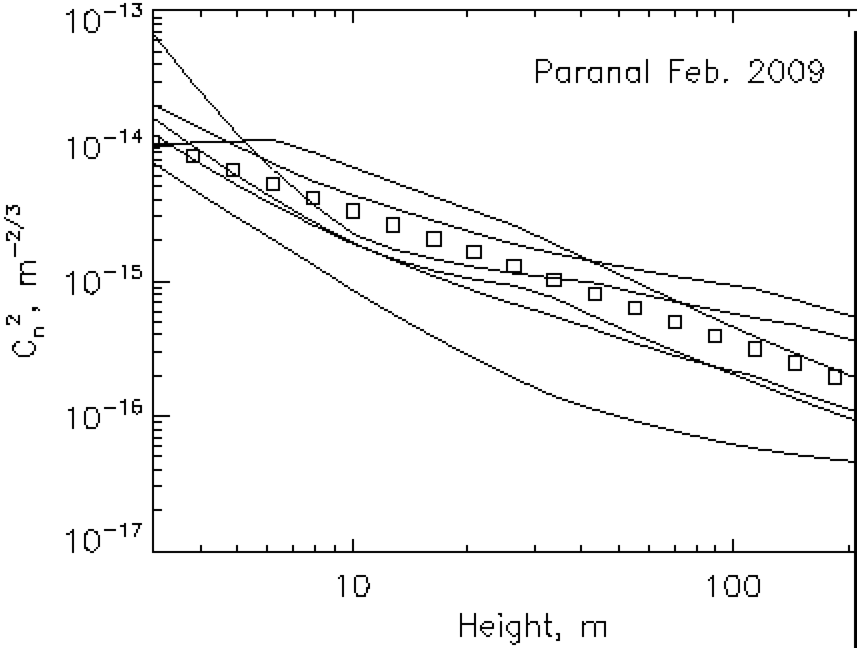
Total seeing (DIMM)

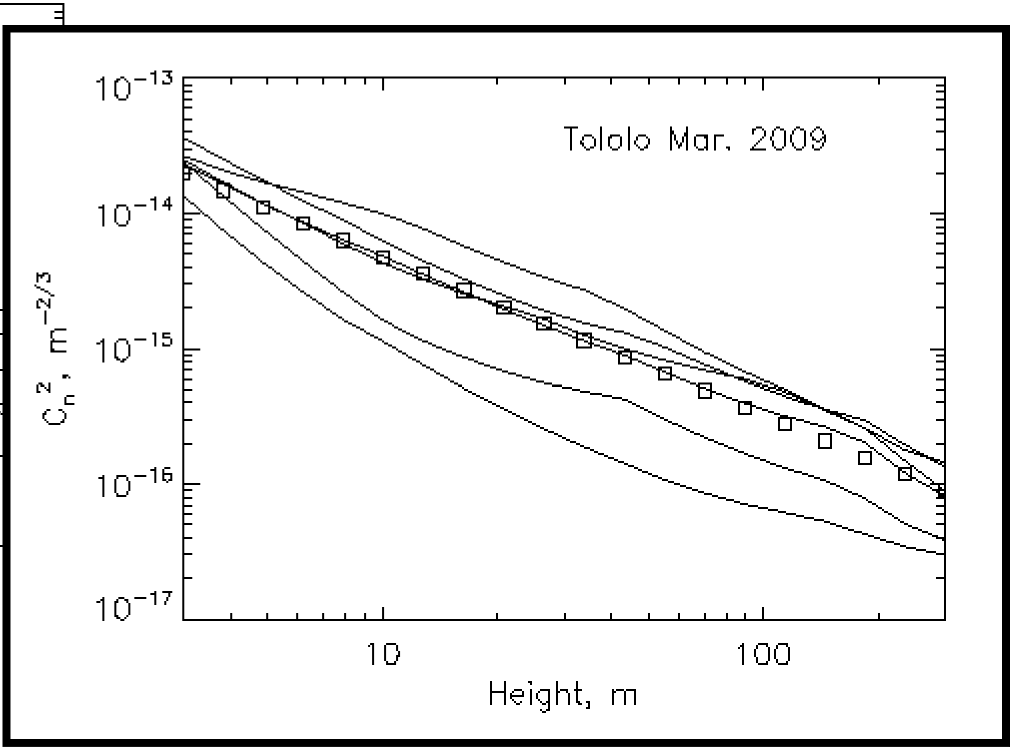
Free atm. (MASS)

Surface layer (LuSci)



Average profiles in the SL





$$\boxed{C_n^2(h) \cong 10^{-15} (h/30m)^{-1}}$$

J(6,500) = 1.3 (0.37”)

SL thickness and strength are meaningless without (h_{min},h_{max})

SL integral is dominated by h_{min}

Is the SL turbulence *really* weak?

- Paranal, 1998: J(3,21)=0.4 (micro-thermal), no difference between GSM (2m) and DIMM (6m)
- Paranal, SL-SLODAR: J(6,65)=0.6
- Racine (2005): J(6,100)=0.5
- Lunar scintillometers at Paranal, Tololo, Penyon, Mauna Kea: J(6,200) ~ 0.5

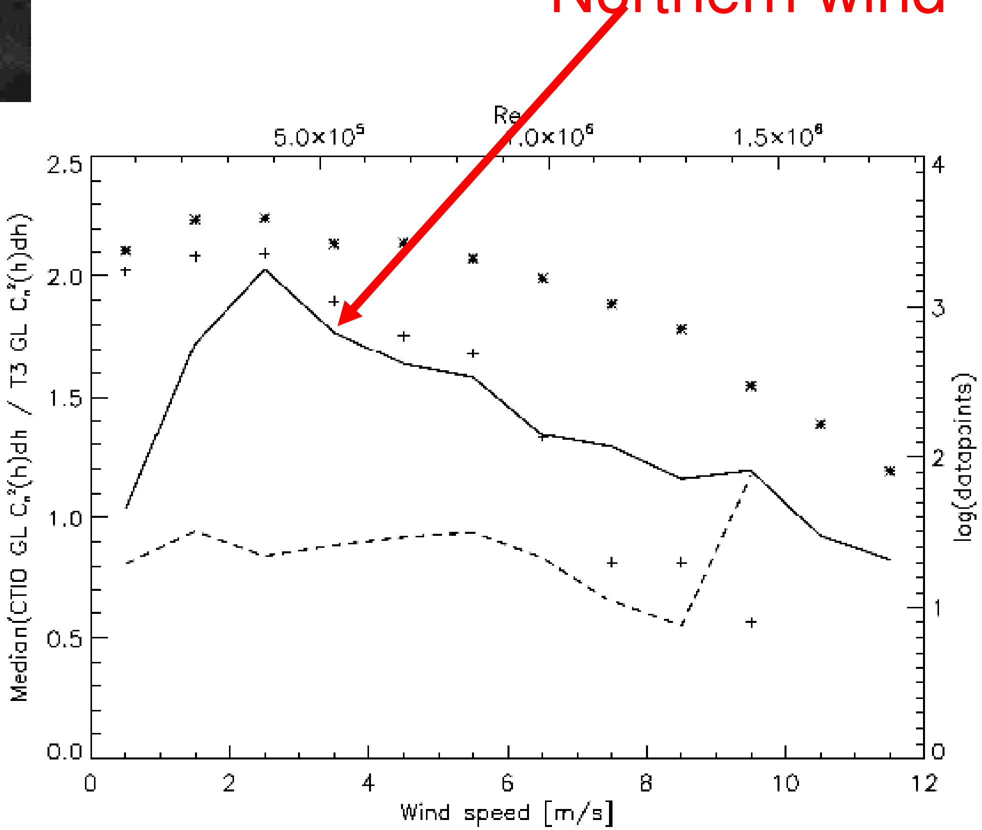
Turbulence integral $J_{SL}(h_{min},h_{max})$ in 10^{-13} $m^{1/3}$

DIMM-MASS: J_{SL} = 2…3 typically

Can a DIMM be wrong?...

Els et al. 2009, PASP, 121, 922

… yes, sometimes!



Northern wind

J_{GL}(CTIO DIMM)/J_{GL}(TMT DIMM)

The "SL discrepancy"

- The assumption that all site monitors have zero local turbulence is questionable.
- We do not know how strong J_{loc} is.
- DIMMs give an upper limit on seeing, it can in fact be better!
- Local turbulence is detected in all telescopes by SCIDARs, SLODARs, etc.
- It matters under good seeing only

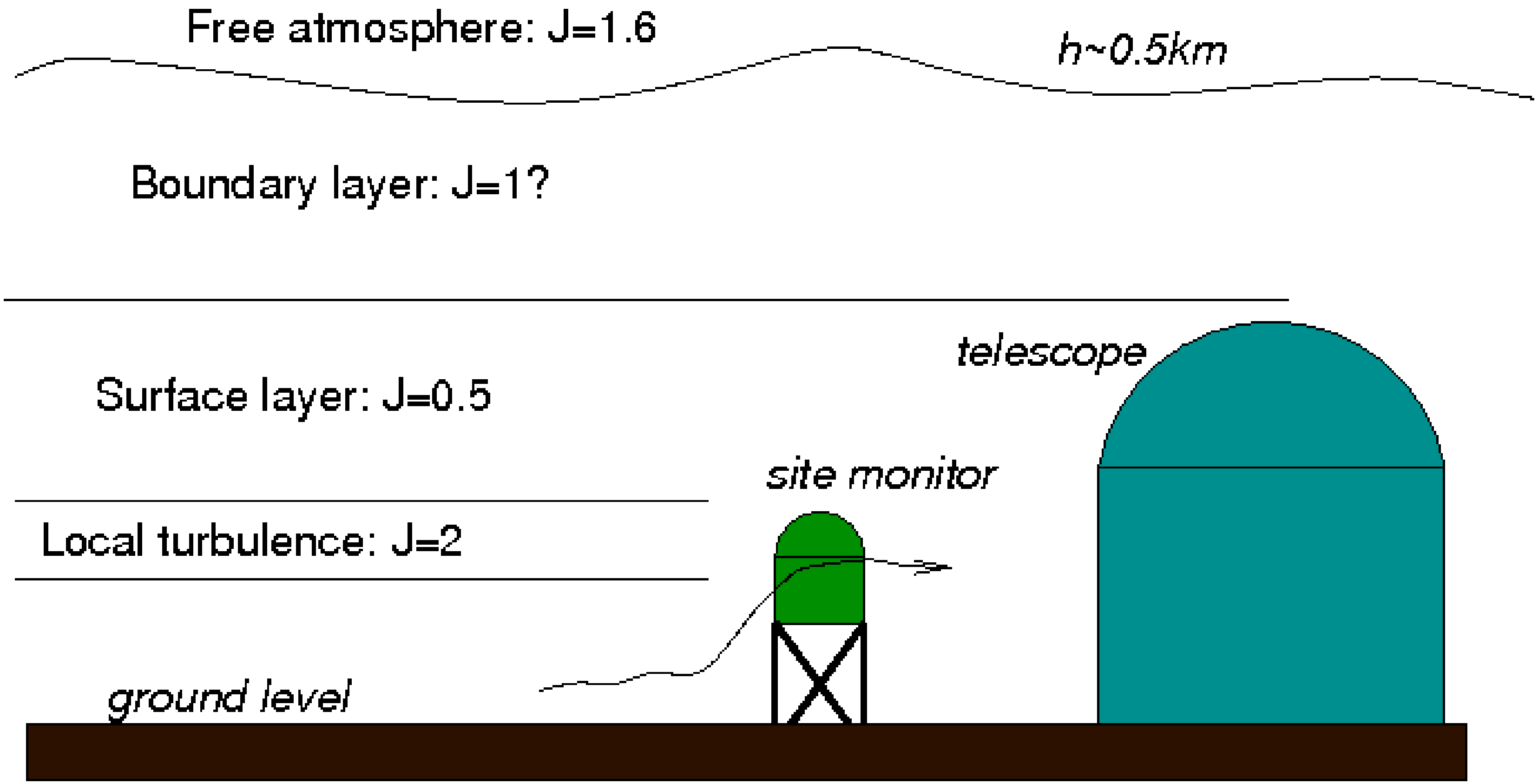
Elusiveness of “site seeing”

- Site seeing depends on the elevation of the site monitor (cf. R. Racine)
- Systematic bias by local turbulence
- A model-dependent concept (real distortions are not stationary, the Kolmogorov model is approximate; gravity waves?)
- Telescopes have internal seeing, too

  (1990s: ~2” → now: 0.5” or 0”?)

Maidanak, 1975

A typical situation?



Seeing 0.84”/0.62” with/without J_{loc}

A new exciting challenge

- If J_{SL}=0.5 (0.2" seeing), can telescopes get images that good?
- A new round of dome/mirror environment study and optimization?
- Active optics → wide-field GLAO?

IMAKA (Chun et al. 2010): CFHT, 1° FoV, NGS

Site-testing and telescope optimization is not over yet!

Acknowledgement

This presentation makes use of data obtained by many people at many sites. Thanks for sharing the data and for the collaboration!

CTIO – E. Bustos, A. Berdja
ESO – M. Sarazin, G. Lombardi
UBC – P. Hickson
U. Durham – R. Wilson, J. Osborn
LSST – J. Sebaq
LCO – J. Thomas-Osip

http://www.ctio.noao.edu/~atokovin/papers/sl.pdf