IRAM Observing School 2007

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Lecture 3: Observing techniques

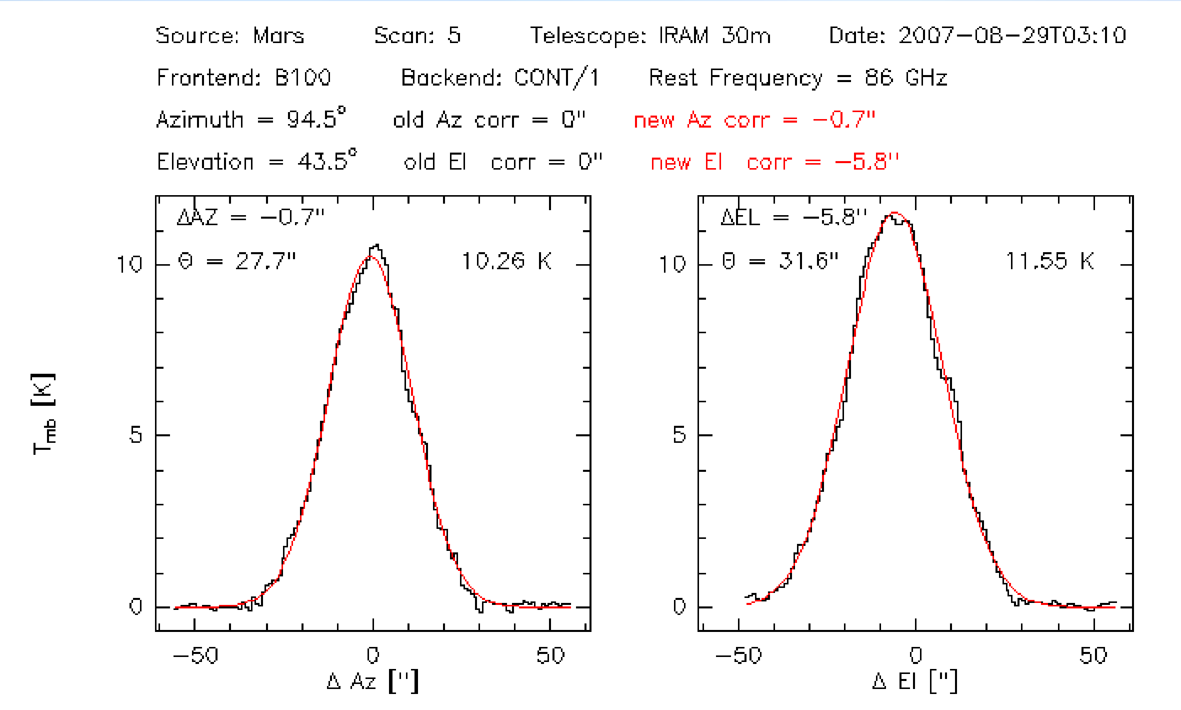
- pointing, focus
- anomalous refraction
- calculation of observing time
- combining receivers, backends

pointing - 1

$AZ^{actual} = AZ^{com} +$ 👎 AZ

$EL^{actual} = EL^{com} +$ 👎 EL

observer input



commanded values = astronomical input + homology + pointing model + refraction

- average of 2 encoders on each axis, resolution < 0.1” (36” devided in 12 bit)
- conversion of astronomical input (♋,♎) to Az,El is assumed free of errors (clock)☑
- homology: function of elevation
- pointing model: 9 parameters, functions of azimuth or elevation or both
- refraction: function of elevation and weather parameters (read from meteo station)

pointing – 2: the homological principle

the antenna surface maintains its parabolic shape and its focal length under the changing influence of gravity. The orientation of the parabola axis moves however.

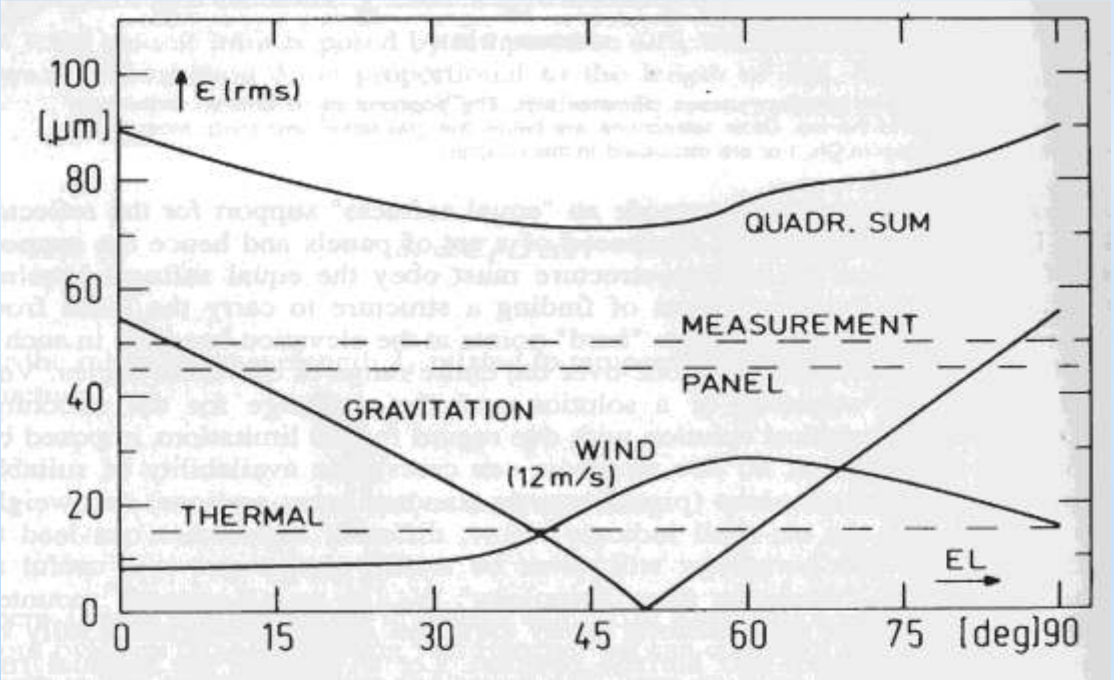
S. von Hoerner (1967)

consequences at 30m:

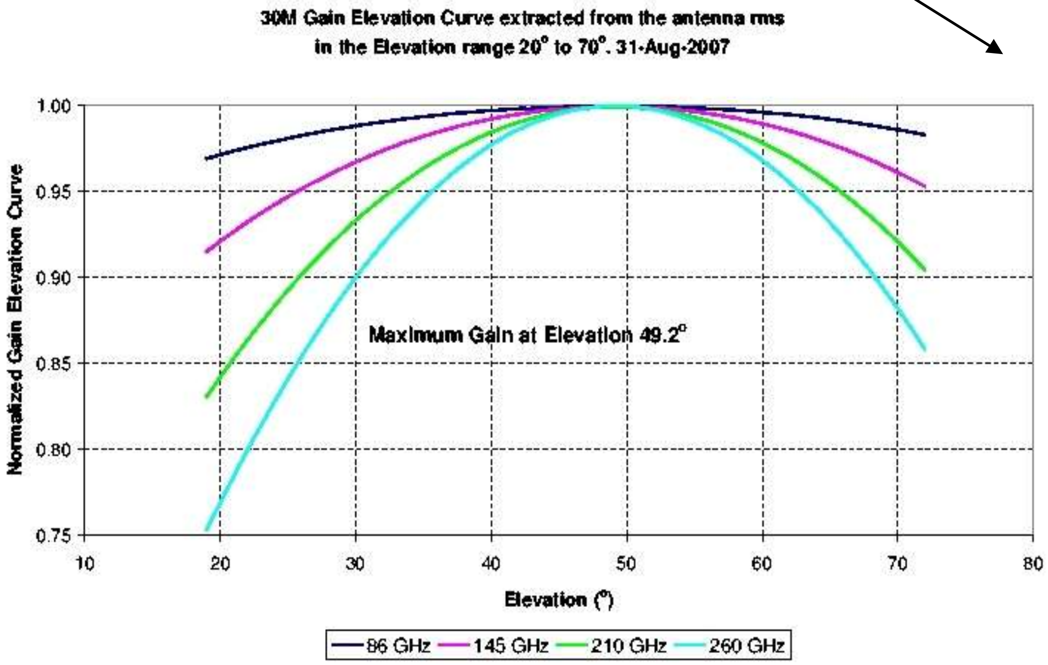
- ✮ subreflector tracks sag of focal point (3cm motion)
- ✮ a tilt is introduced to maintain the subreflector perpendicular to parabola axis (0.1°)
- ✮ surface imperfections are a function of elevation

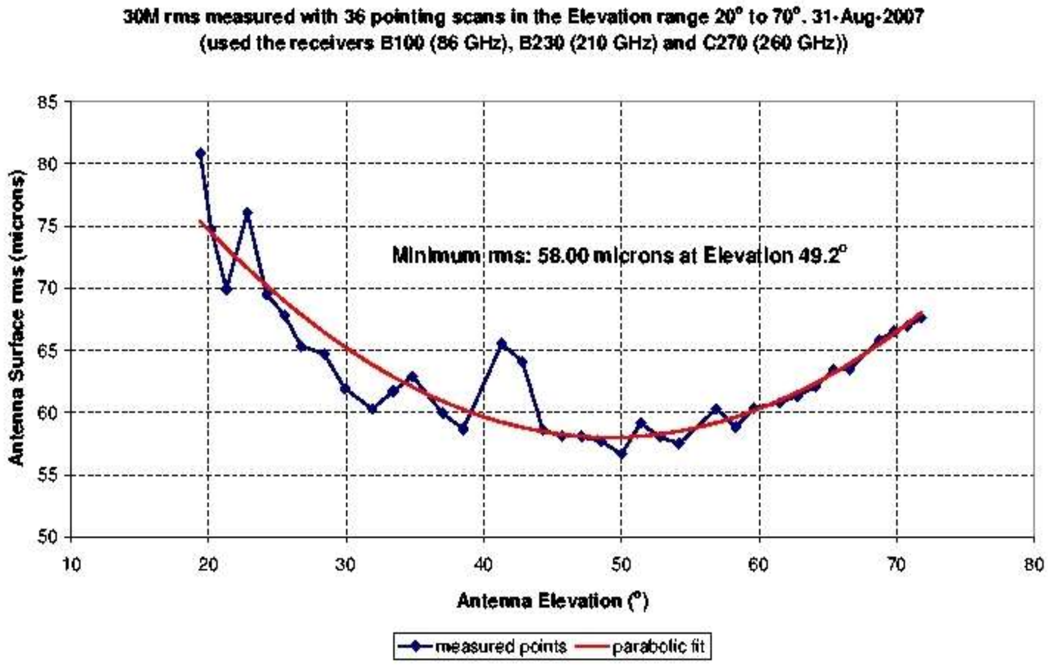
measurement of the gain/elevation effect

design study of 30m telescope
(J.W.M. Baars et al. 1979)



measurements by J. Peñalver
(August 2007)


30M Gain Elevation Curve extracted from the antenna rms
in the Elevation range 20° to 70°. 31-Aug-2007


30M rms measured with 36 pointing scans in the Elevation range 20° to 70°. 31-Aug-2007
(used the receivers B100 (86 GHz), B230 (210 GHz) and C270 (260 GHz))

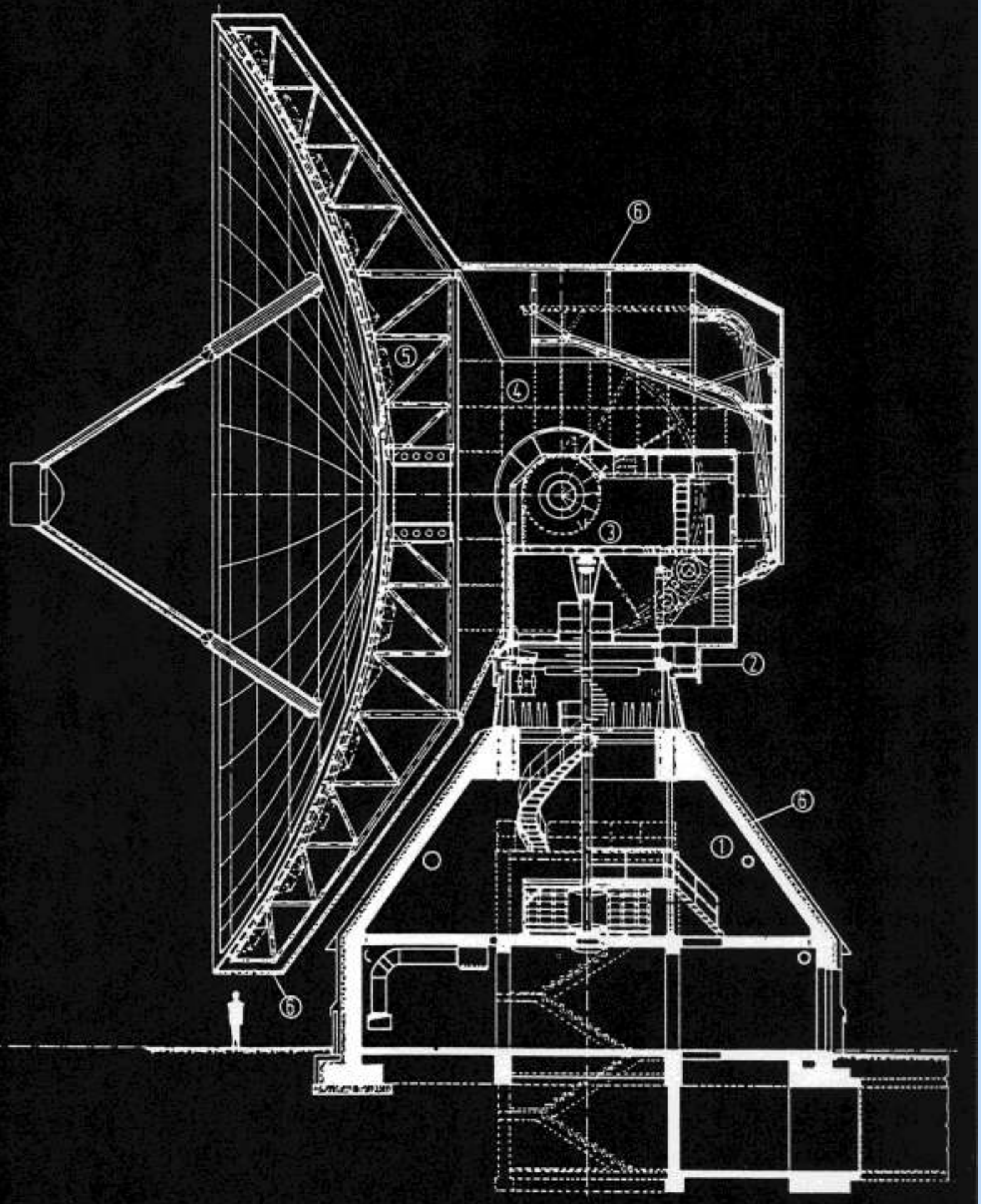


Schéma du télescope de 30-m : 1) Piédestal 2) Roulement en azimuth 3) Cabine de récepteurs 4) [illegible] 5) [illegible]

30m telescope: principal components

- pedestal
- azimuth bearing
- elevation axis
- Nasmyth cabin

housing receivers, optics

- backup structure

steel space frame

temperature controlled (1 K, 0.1mm)

- surface

420 aluminum honeycomb panels

thermal insulation, de-icing

- subreflector

first large carbon fiber structure

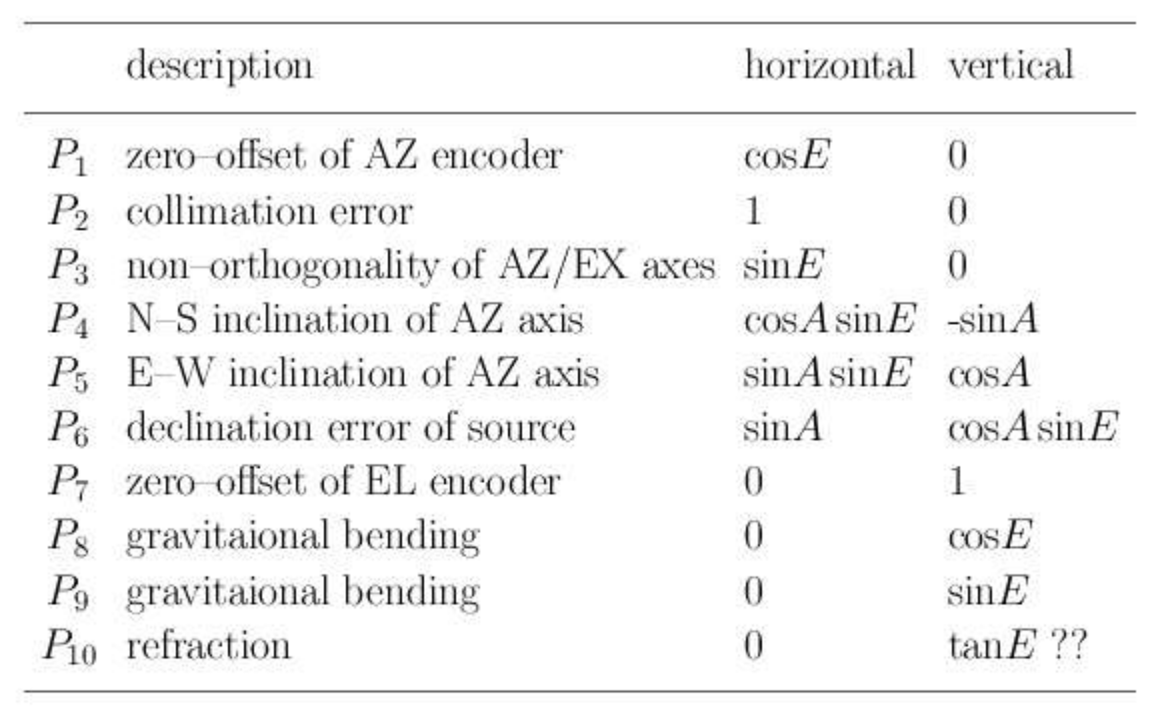
supported by quadripod

- wobbler

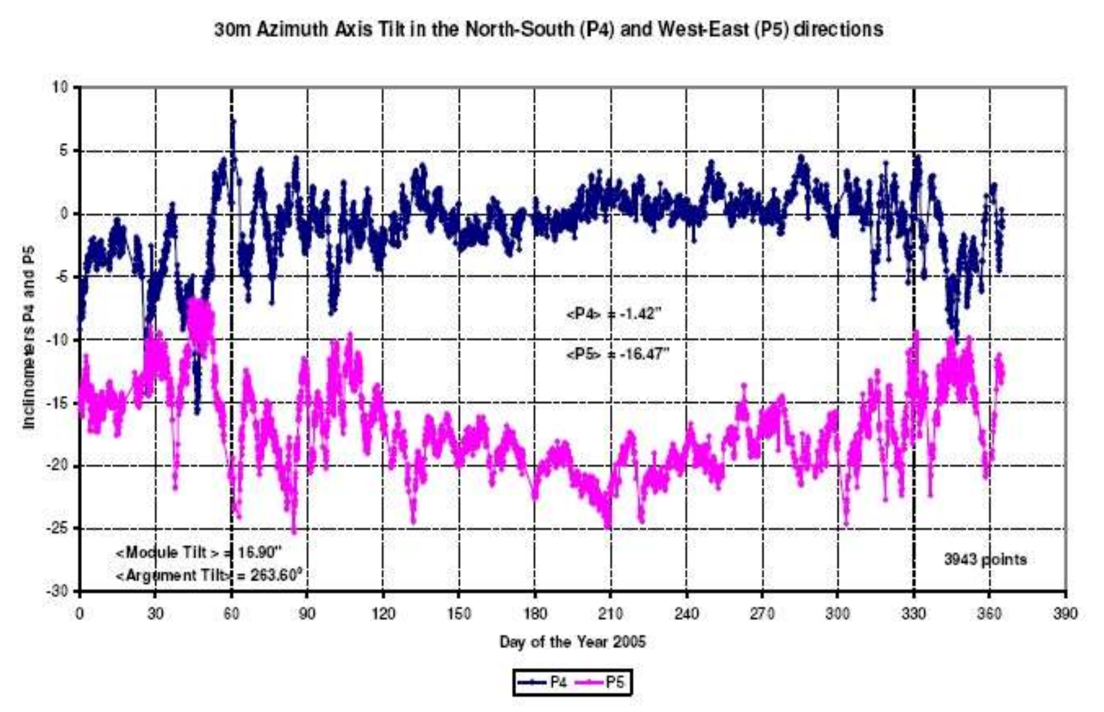
pointing – 3: the model

pointing model parameters:

- some should be constant in time (P8)
- some vary due to temperature changes
- some vary by mistake
- strongly numerically correlated



	description	horizontal	vertical
P_1	zero–offset of AZ encoder	$\cos E$	0
P_2	collimation error	1	0
P_3	non–orthogonality of AZ/EX axes	$\sin E$	0
P_4	N–S inclination of AZ axis	$\cos A \sin E$	$-\sin A$
P_5	E–W inclination of AZ axis	$\sin A \sin E$	$\cos A$
P_6	declination error of source	$\sin A$	$\cos A \sin E$
P_7	zero–offset of EL encoder	0	1
P_8	gravitaional bending	0	$\cos E$
P_9	gravitaional bending	0	$\sin E$
P_{10}	refraction	0	$\tan E$??



P4, P5 are measured by inclinometers
rest of pointing parameters more stable
variation of P4, P5 stronger in winter

work in progress:
inclination above azimuth bearing

important:
receiver assumed to be on pointing axis

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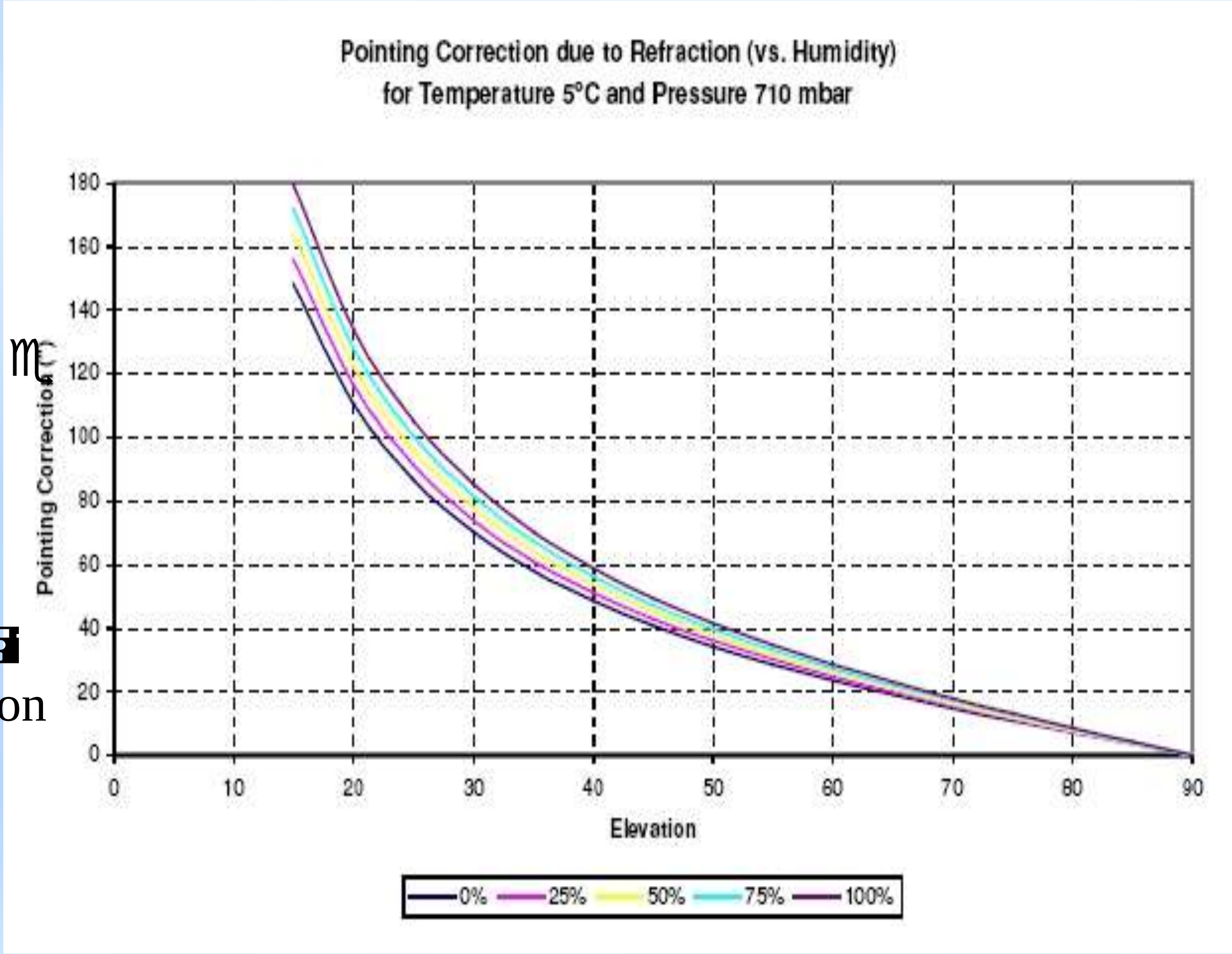
pointing – 4: refraction

refractive index:
n = f(p,T,H)

pointing correction:
P10 = n cot ♏ (1- 0.002 cot^3 ♏
☽☑
45" at 45° elevation

dependence on humidity
- strong effect below elevation ♏ ▣ 30º
- can be a very local phenomenon
- can be very time variable



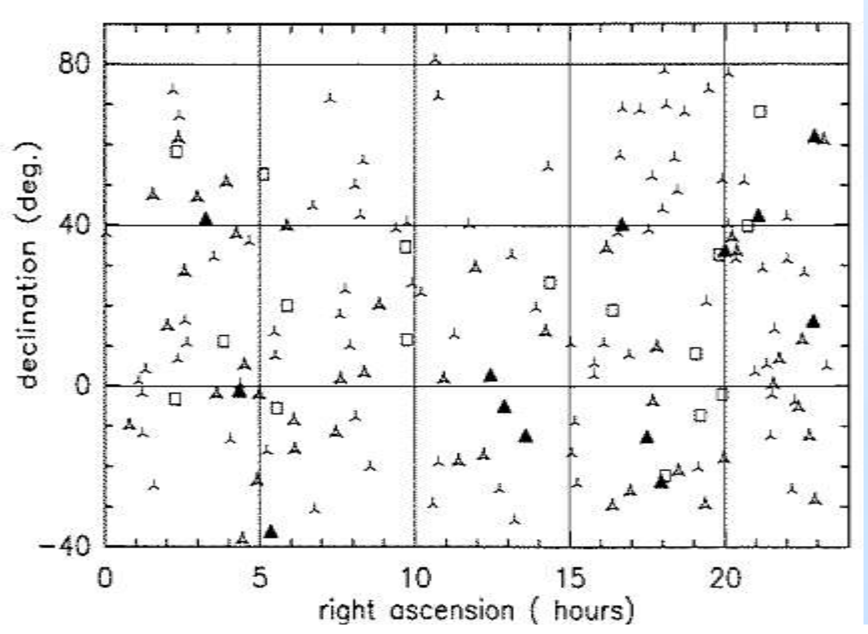
(from J. Peñalver)

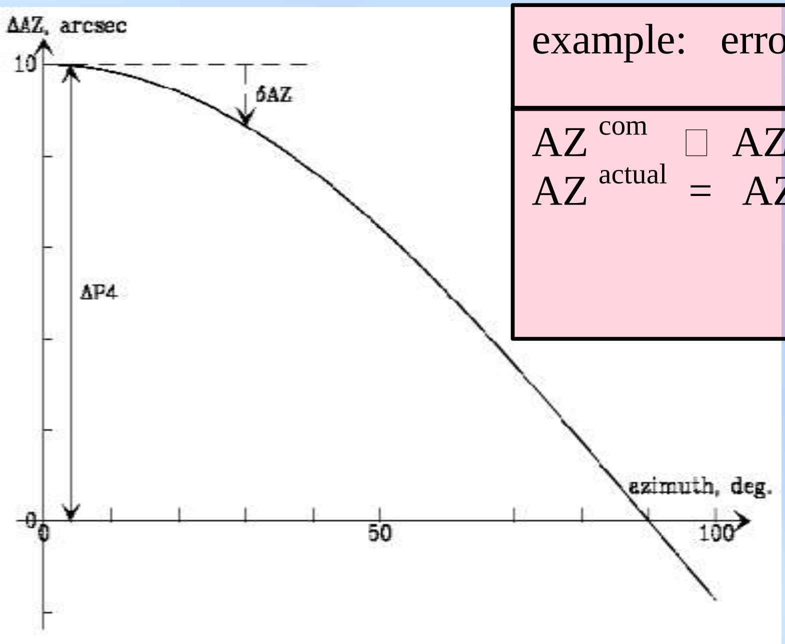
pointing – 5 : getting practical

pointing catalog

- contains ca. 140 sources
- well distributed over the visible sky
- detectable at 3mm with sufficient S/N
- average separation 10⌖📪 ✇🖱 🔔

within 20⌖

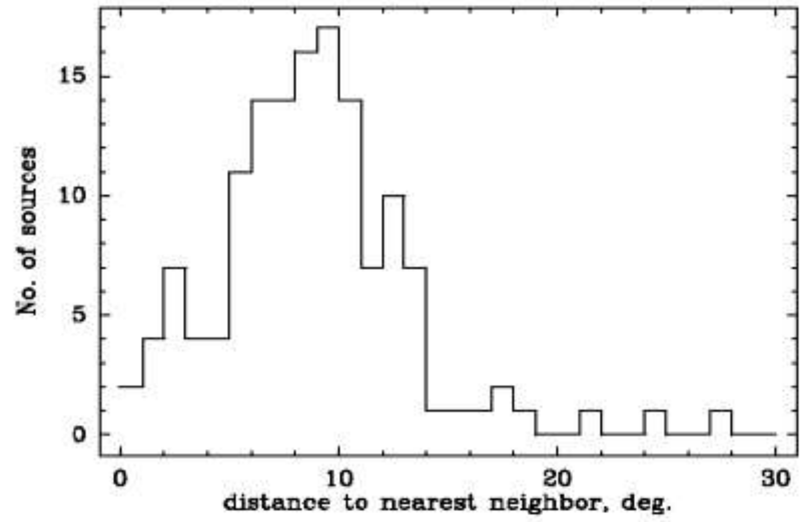




example: error in P4

$\mathrm{AZ}^{\mathrm{com}}$ □ $\mathrm{AZ}^{\mathrm{com}} + \mathrm{P4}\cos A \sin E$

$\mathrm{AZ}^{\mathrm{actual}} = \mathrm{AZ}^{\mathrm{com}} +$ 👎 AZ

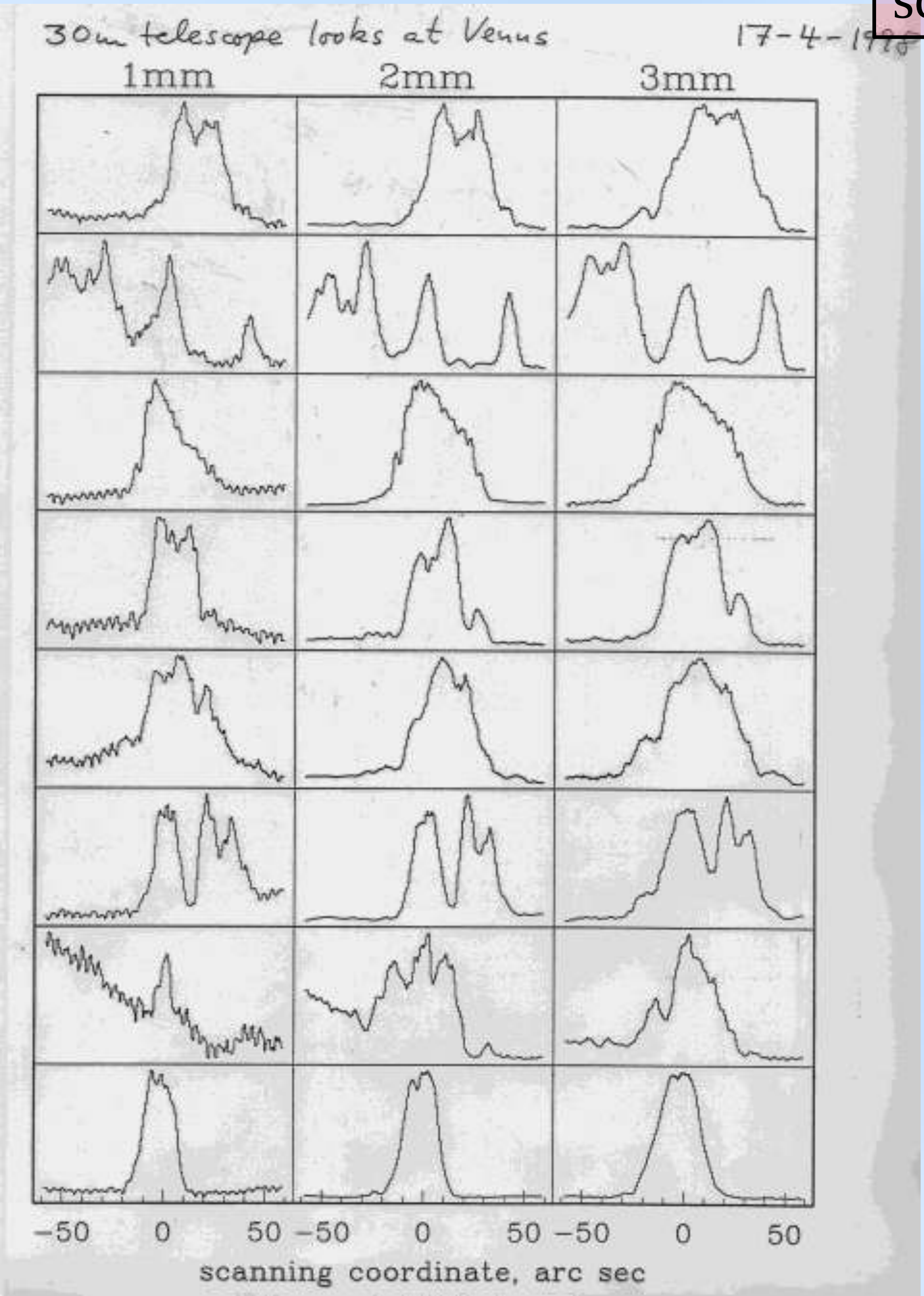


conclusions:

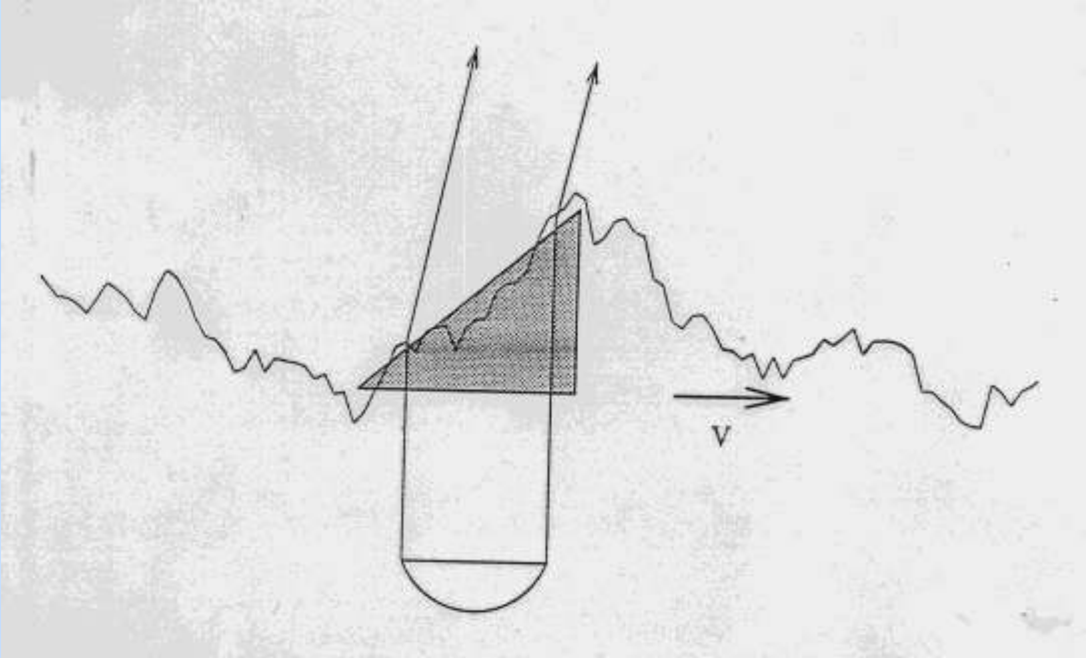
- pointing good enough (error ≤ beam/10) most of the time
- recommended time between pointings: 2 hours at ●1.3 mm

pointing - 6: anomalous refraction

also known as radio seeing or angular scintillation



screen of humid air moves across the aperture
scale size > aperture



recommendation:
make fast pointing scans

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pointing – 7: anomalous refraction

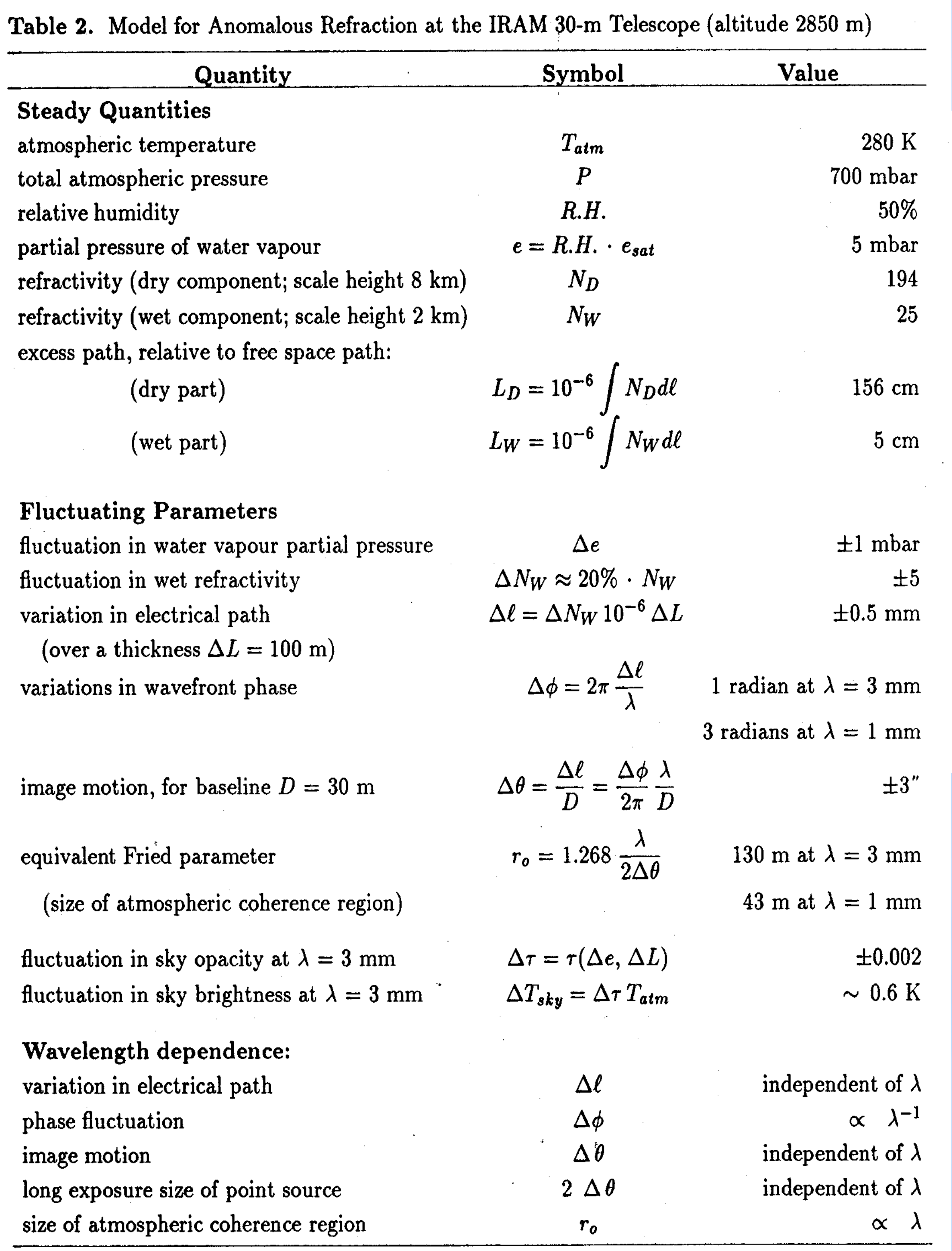
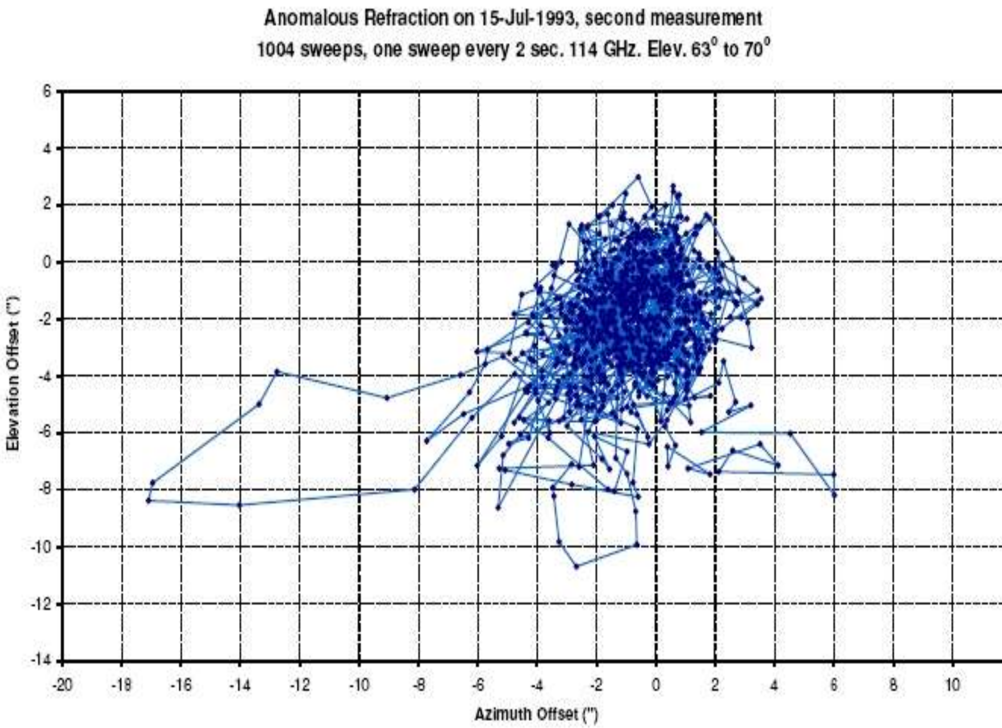


Table 2. Model for Anomalous Refraction at the IRAM 30-m Telescope (altitude 2850 m)

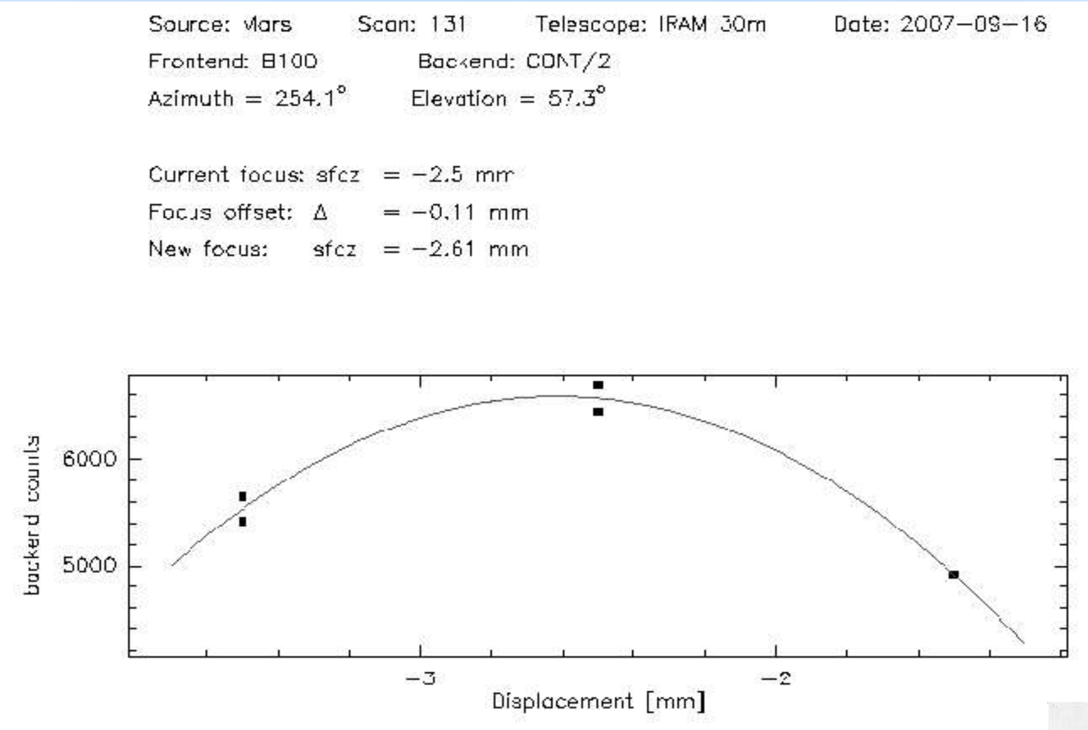
Quantity	Symbol	Value
Steady Quantities		
atmospheric temperature	T_{atm}	280 K
total atmospheric pressure	P	700 mbar
relative humidity	$R.H.$	50%
partial pressure of water vapour	$e = R.H. \cdot e_{sat}$	5 mbar
refractivity (dry component; scale height 8 km)	N_D	194
refractivity (wet component; scale height 2 km)	N_W	25
excess path, relative to free space path:		
(dry part)	$L_D = 10^{-6} \int N_D d\ell$	156 cm
(wet part)	$L_W = 10^{-6} \int N_W d\ell$	5 cm
Fluctuating Parameters		
fluctuation in water vapour partial pressure	Δe	±1 mbar
fluctuation in wet refractivity	$\Delta N_W \approx 20\% \cdot N_W$	±5
variation in electrical path	$\Delta \ell = \Delta N_W 10^{-6} \Delta L$	±0.5 mm
(over a thickness $\Delta L = 100$ m)		
variations in wavefront phase	$\Delta \phi = 2\pi \frac{\Delta \ell}{\lambda}$	1 radian at $\lambda = 3$ mm
		3 radians at $\lambda = 1$ mm
image motion, for baseline $D = 30$ m	$\Delta \theta = \frac{\Delta \ell}{D} = \frac{\Delta \phi}{2\pi} \frac{\lambda}{D}$	±3″
equivalent Fried parameter	$r_o = 1.268 \frac{\lambda}{2\Delta\theta}$	130 m at $\lambda = 3$ mm
(size of atmospheric coherence region)		43 m at $\lambda = 1$ mm
fluctuation in sky opacity at $\lambda = 3$ mm	$\Delta \tau = \tau(\Delta e, \Delta L)$	±0.002
fluctuation in sky brightness at $\lambda = 3$ mm	$\Delta T_{sky} = \Delta \tau \, T_{atm}$	~ 0.6 K
Wavelength dependence:		
variation in electrical path	$\Delta \ell$	independent of λ
phase fluctuation	$\Delta \phi$	$\propto \lambda^{-1}$
image motion	$\Delta \theta$	independent of λ
long exposure size of point source	$2 \ \Delta \theta$	independent of λ
size of atmospheric coherence region	r_o	$\propto \lambda$

(figure from Peñalver & Altenhoff)



(from Downes & Altenhoff 1989)

focus measurement



Source: Mars Scan: 131 Telescope: IRAM 30m Date: 2007–09–16
Frontend: B100 Backend: CONT/2
Azimuth = 254.1° Elevation = 57.3°

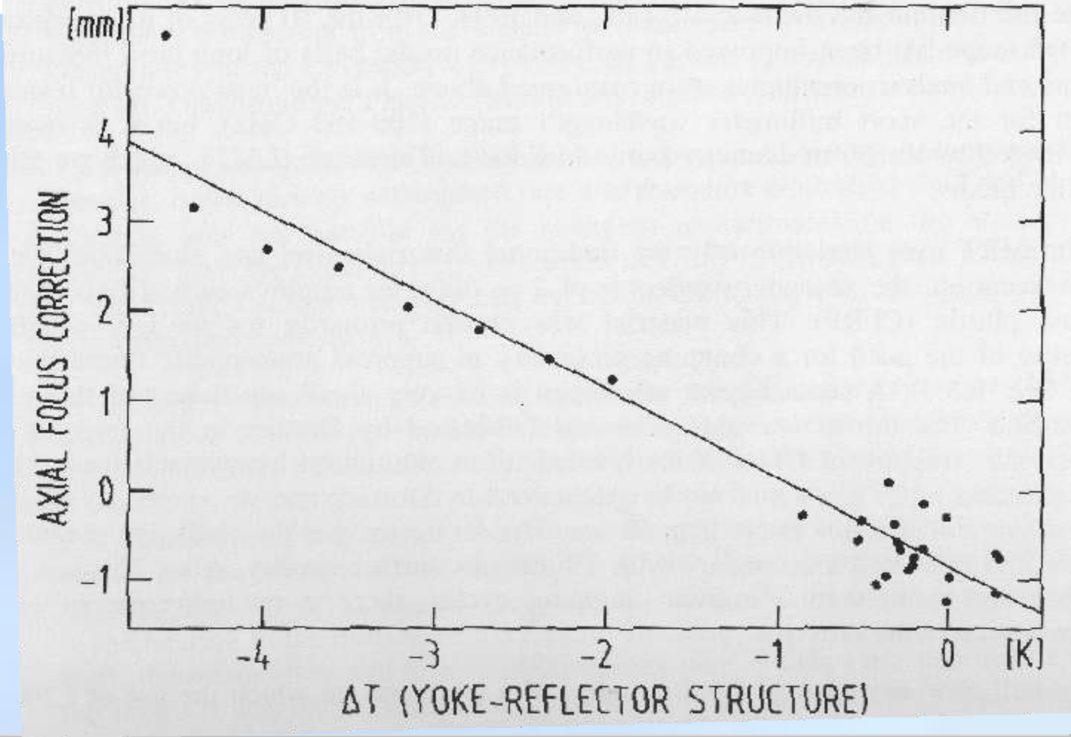
Current focus: sfcz = −2.5 mm
Focus offset: Δ = −0.11 mm
New focus: sfcz = −2.61 mm

- subreflector is stepped in axial direction
- receivers may have small focus differences
- small drifts may occur near sun rise or set

(from J. Baars 1985)☑

axial focus varies with temperature imbalance

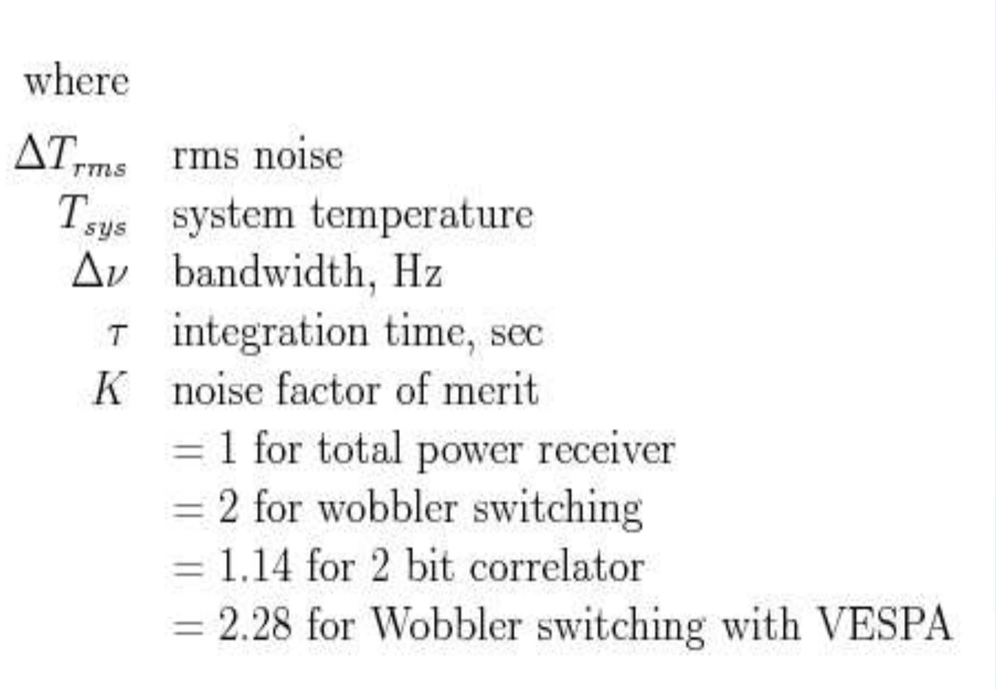
- panels heated or cooled excessively
- energy is transferred into backup structure
- temperature difference between yoke and backup sturcture leads to deformation of surface and change of focal length
- transparent to observer



estimation of integration time

$$\Delta T_{rms} = \frac{K\,T_{sys}}{\sqrt{\Delta\nu\,\tau}}$$

(radiometer formula)



where

ΔT_{rms}	rms noise
T_{sys}	system temperature
$\Delta\nu$	bandwidth, Hz
τ	integration time, sec
K	noise factor of merit $= 1$ for total power receiver $= 2$ for wobbler switching $= 1.14$ for 2 bit correlator $= 2.28$ for Wobbler switching with VESPA

remarks:

✸ ⮰ is the noise equivalent bandwidth

not the spectral resolution

not the channel spacing

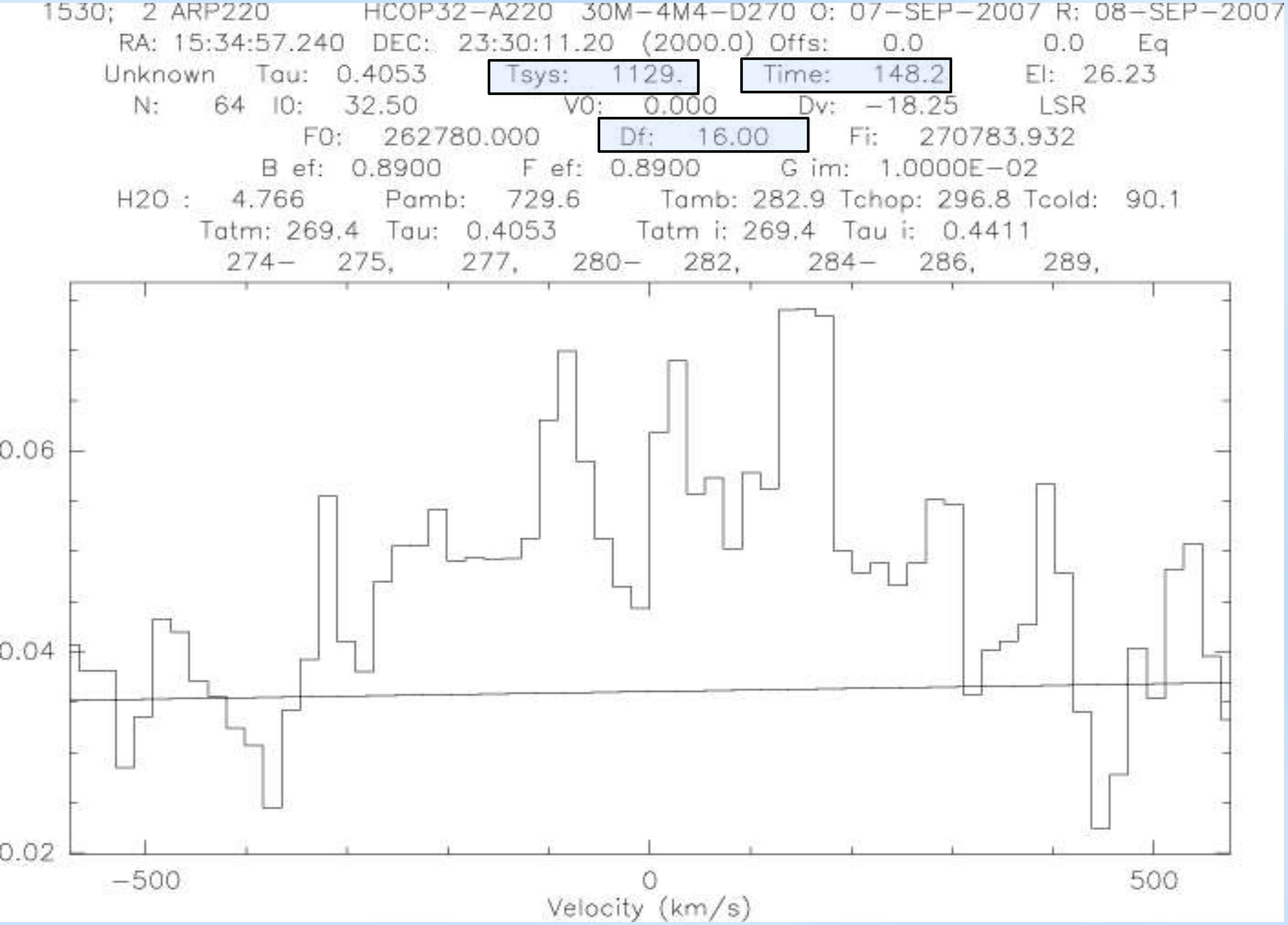
integration time ≠ telescope time

- transition times between phases (dead times)
- time between subscans (backend synchroniztion, telescope motion)
- time to drive to the source, time for calibrations (temperature, pointing, focus, etc.)
- receiver tuning
- receivers can be combined
- time for thinking .....

❿ use the official Time Estimator

(cautiously)

time estimator: a simple example



```
1530;  2 ARP220        HCOP32-A220  30M-4M4-D270 O: 07-SEP-2007 R: 08-SEP-2007
    RA: 15:34:57.240  DEC:  23:30:11.20  (2000.0) Offs:    0.0          0.0    Eq
   Unknown   Tau:  0.4053      Tsys:    1129.      Time:    148.2       El:  26.23
    N:     64  I0:    32.50              V0:   0.000       Dv:  -18.25        LSR
              F0:   262780.000       Df:    16.00       Fi:    270783.932
            B ef:   0.8900        F ef:  0.8900       G im:   1.0000E-02
   H2O :    4.766        Pamb:    729.6       Tamb: 282.9 Tchop: 296.8 Tcold:  90.1
        Tatm: 269.4  Tau:   0.4053       Tatm i: 269.4  Tau i:  0.4411
          274-    275,      277,    280-    282,     284-    286,      289,
```

radiometer formula:

rms = 5.4 mK
(wobbler switching)

observed:

pp-noise 👍 28 mK

¤ rms ≃ 6.2 mK

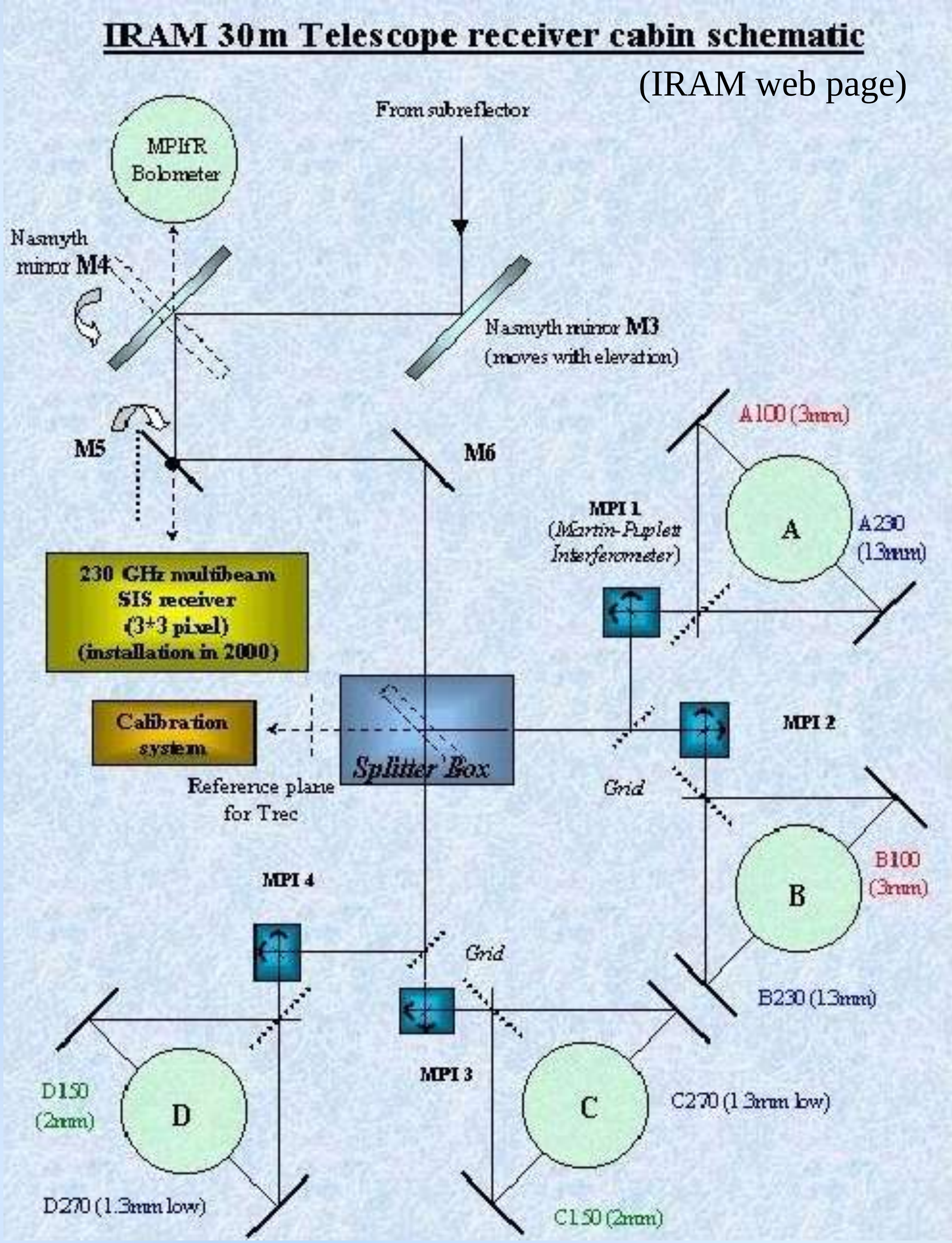
receiver combinations

4 configurations are possible:

AB   CD   AD BC

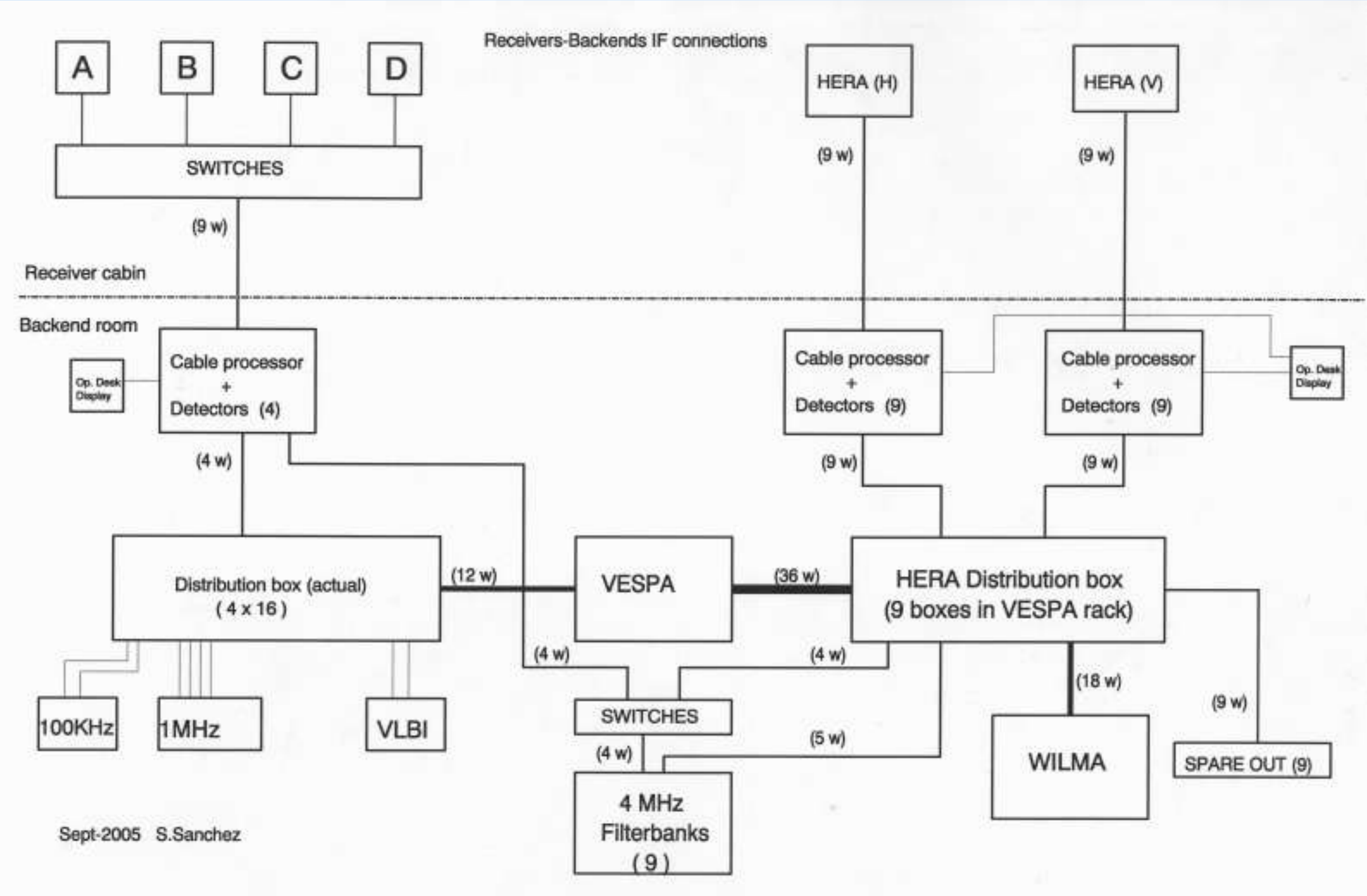
optical design is guided by
- dewars A and B are identical
- dewars C and D are identical
- MPI rotates the polarization plane
- grids split beams according to polarization

limitations:
- MPIs have some losses
- these losses increase with bandwidth
- alignment between receivers
- receiver beams are slightly different



(IRAM web page)

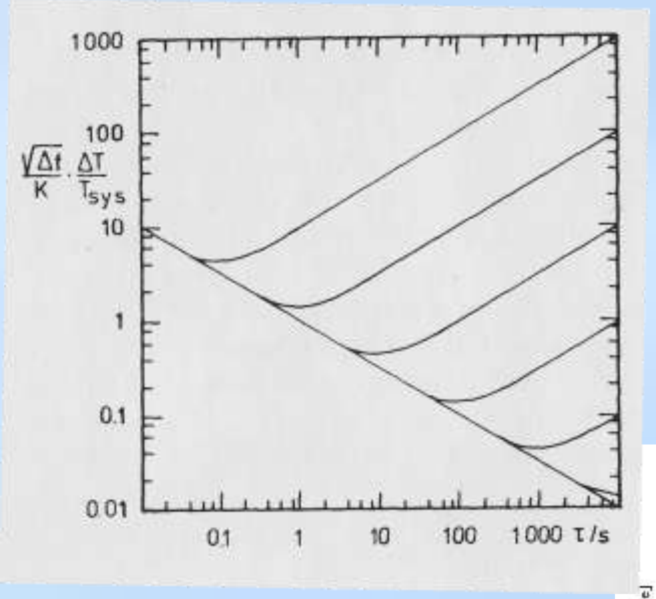
receiver – backend connections



remarks:

- not all backends can be connected to all receivers
- not all observations are adequately supported by backends: limitations in bandpass
- the Time Estimator keeps track of illegal connections

stability of the detection chain

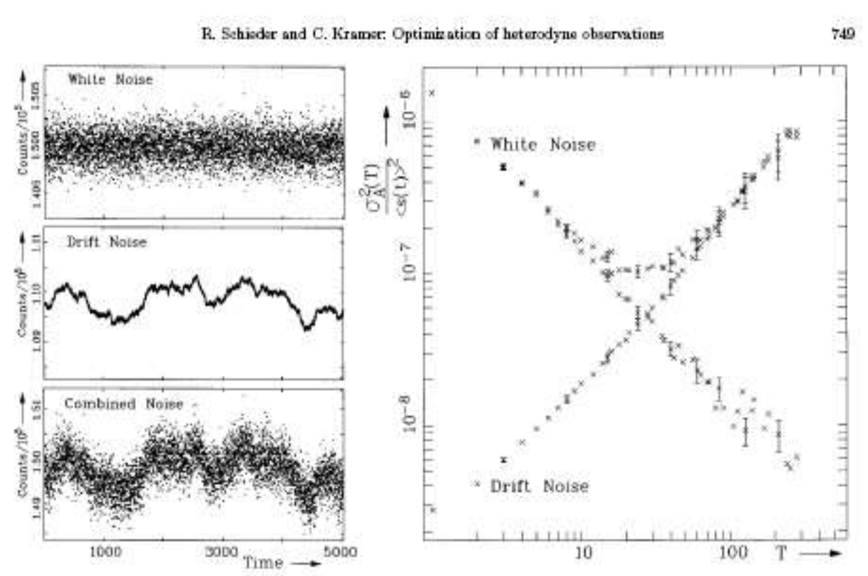


the textbook

(Rohlfs & Wilson)

the simulation

(Schieder & Kramer)


R. Schieder and C. Kramer: Optimization of heterodyne observations 749

Allan variance:

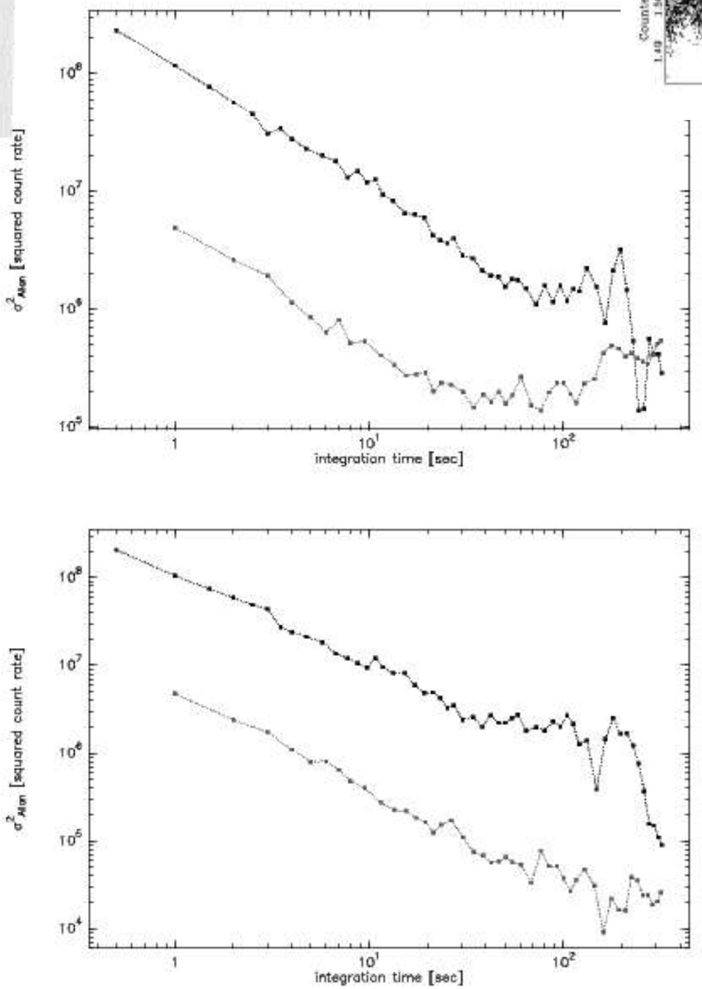
$$\Delta T_{rms} = \frac{K\,T_{sys}}{\sqrt{\Delta\nu\,\tau + \left(\frac{\Delta G}{G}\right)^2}}$$

$$\left(\frac{\Delta G}{G}\right)^2 = \gamma_0 + \gamma_1 \tau$$

$$\sigma(N) = \frac{1}{N}\sqrt{Q_N - S_N^2}$$

$$\text{where} \quad S_N = \textstyle\sum_{i=1}^{N} x_i$$

$$Q_N = \textstyle\sum_{i=1}^{N} x_i^2$$



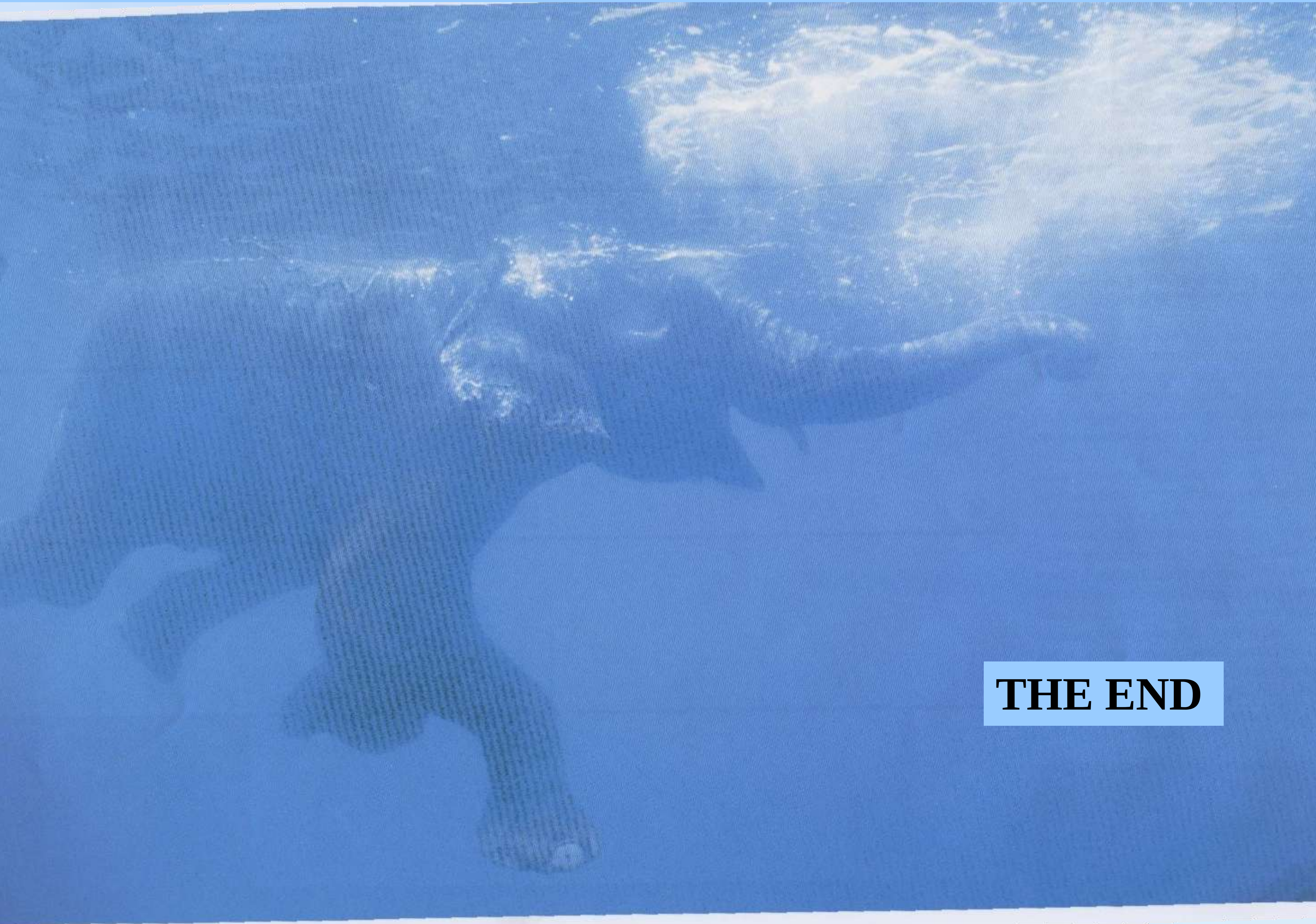
the real data

(Wiesemeyer et al. 2007)

Test of a Fourier Transform spectrometer
(B. Klein et al, MPIfR)

result:
very good stability
limited by receiver
sufficient for o-t-f

focus: change!



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