Accelerators, Ground Motion and Space-Time Diffusion

Vladimir Shiltsev
Fermilab

Accelerator Physics and Technology Seminar

Acknowledgements

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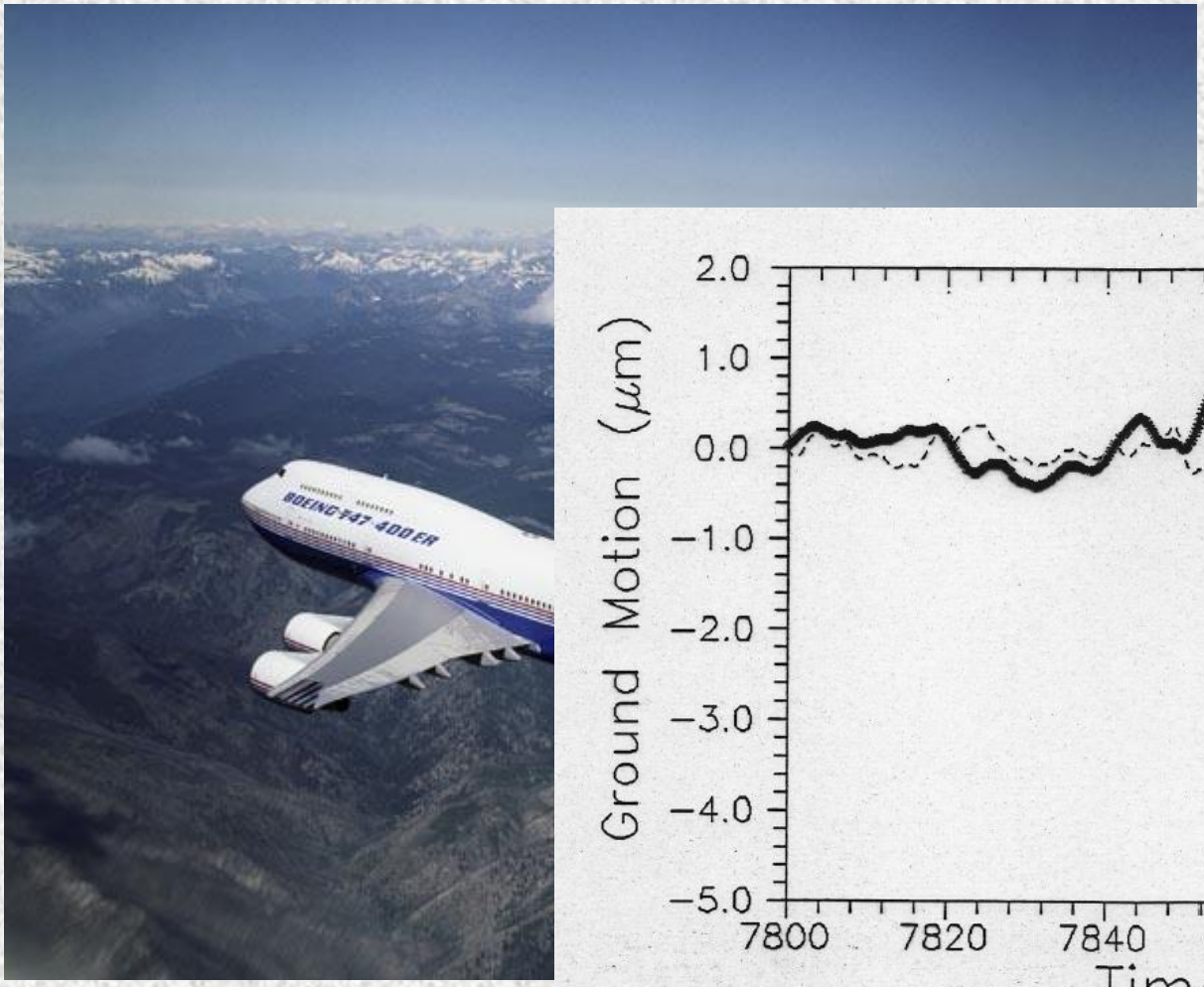
Three things we are all "experts" in:

- Baseball (in Europe - soccer)
- Foreign Affairs
- Ground Motion
  - We all know what vibrations are
  - We all've seen these disastrous Earthquakes on TV
    - Some of us even felt them … even in Illinois
  - We all know that continents drift and that mountains grow
  - Some of us aware of Earth tides
    - Up and down 1 foot twice a day

…how about smth not many of you know…

Ground Bends Under Airplanes



Shiltsev et al,
DESY HERA 95-06
(1995)

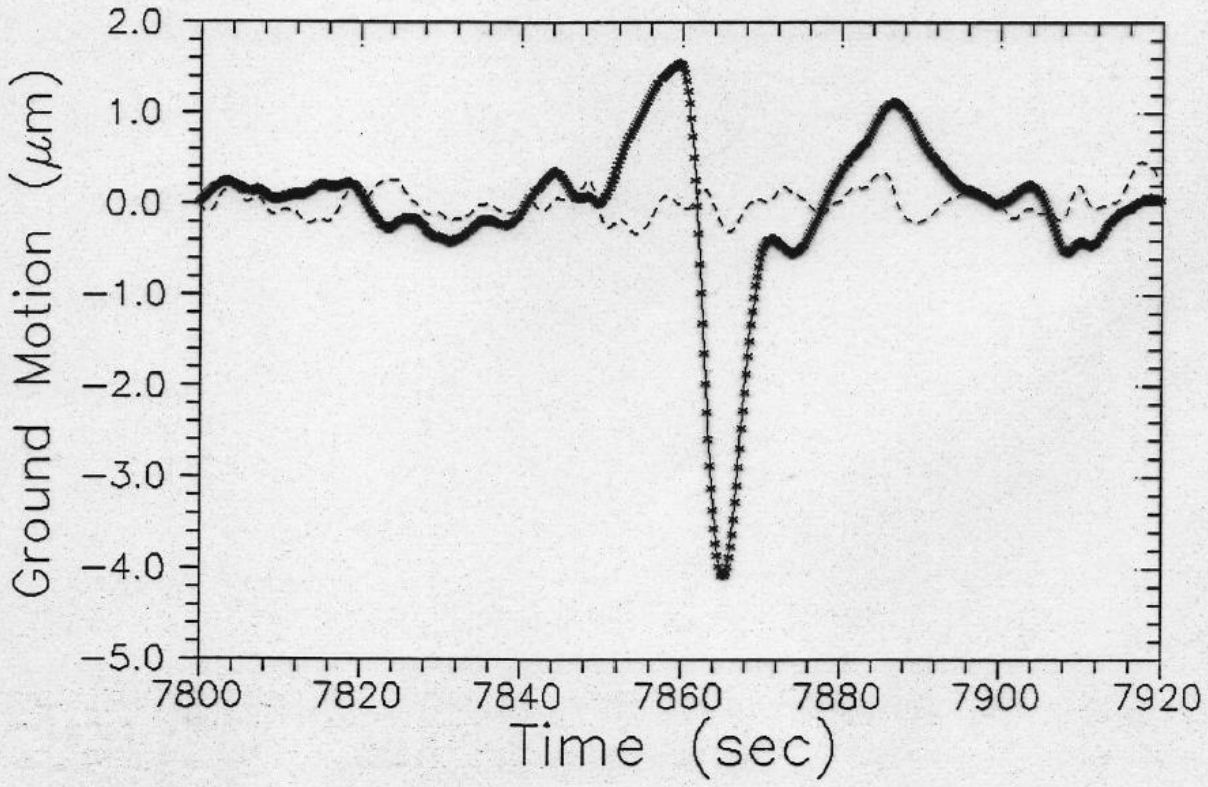
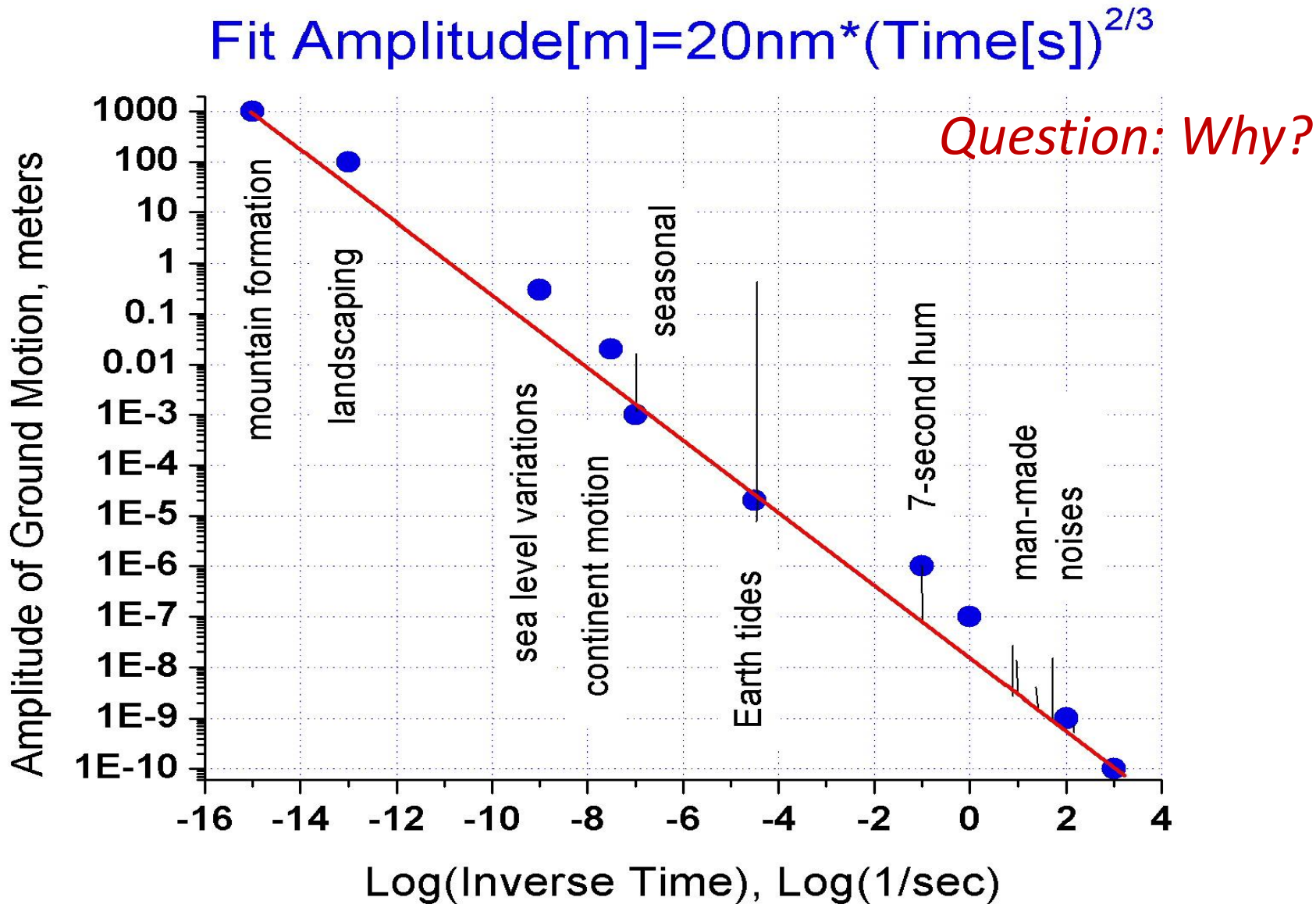
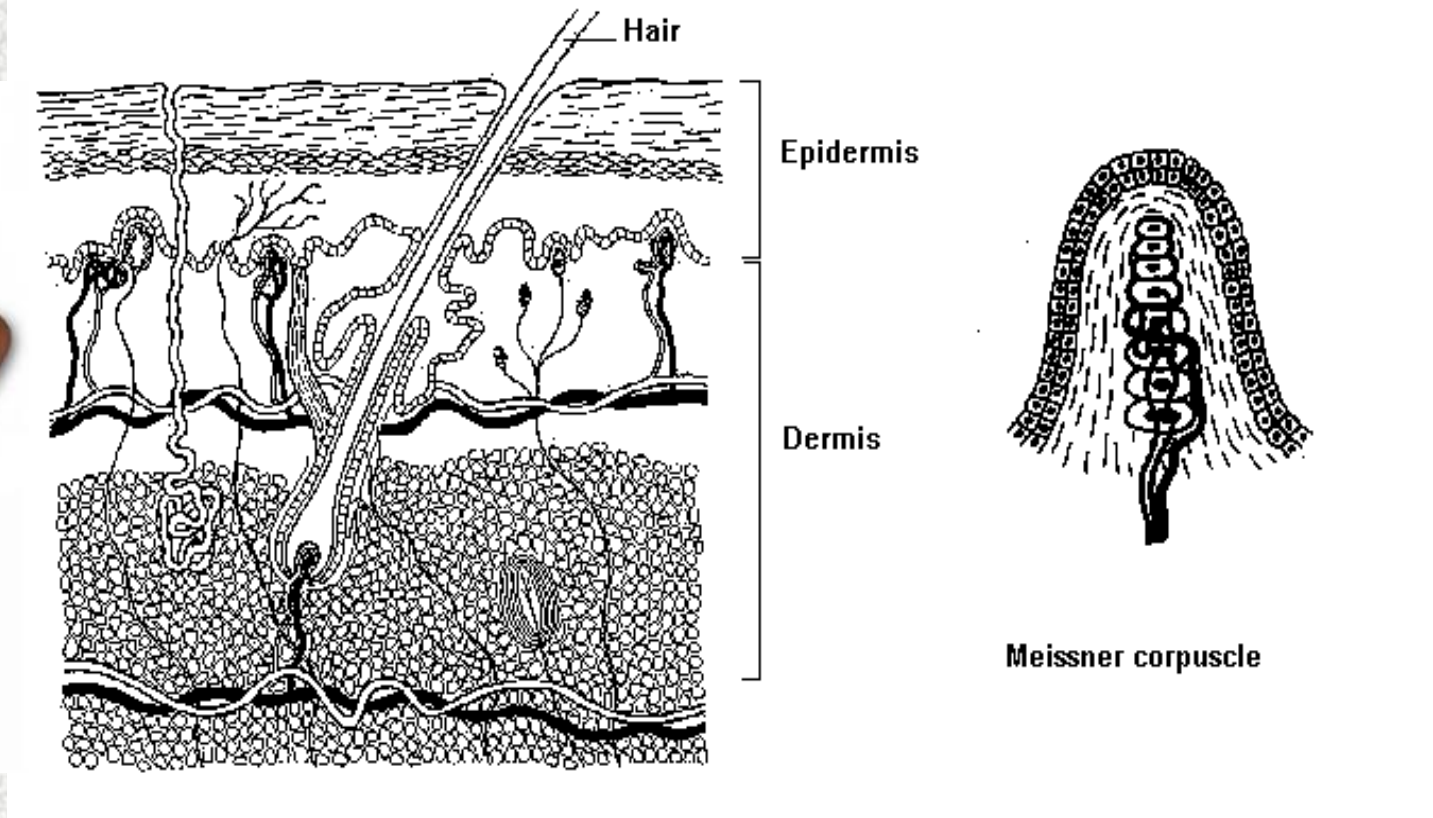


Fig.5 up Ground surface motion and log-book of planes.
dn Ground bending beneath flying airbus, $h \approx 1$ km.

Introduction: Ground Motion

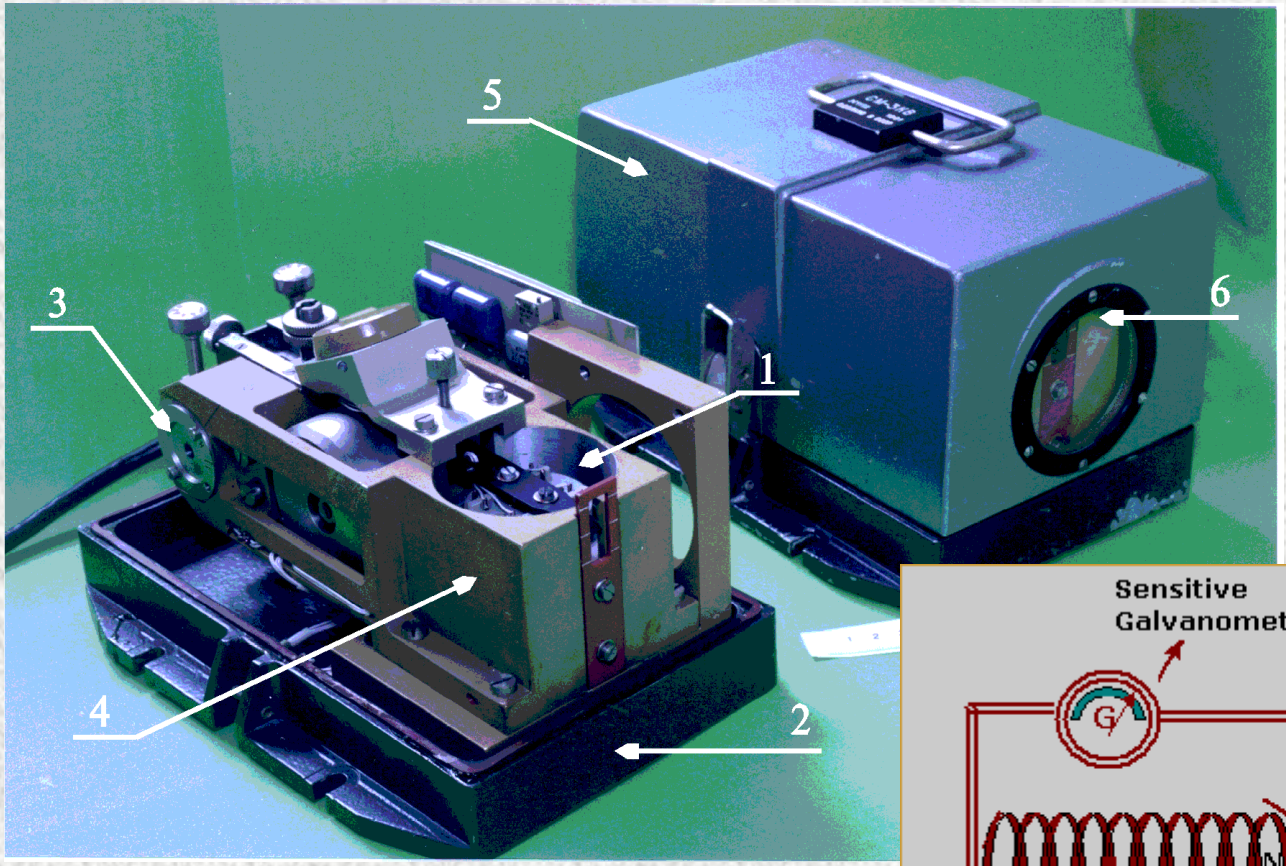


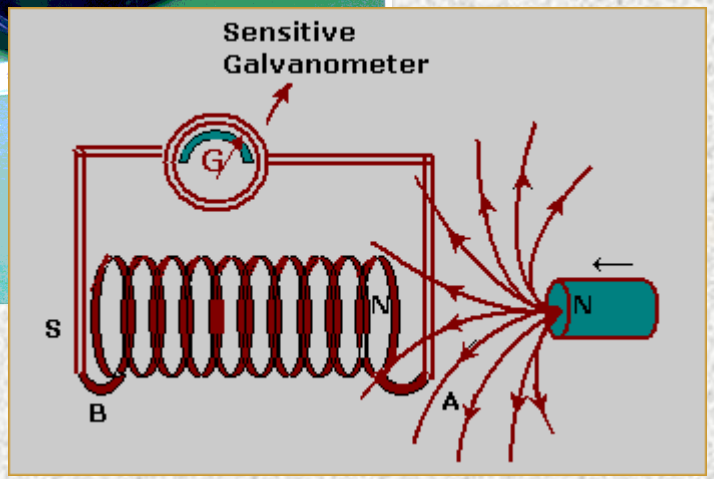
Detectors: Meissner Corpuscles



- Sensitive to Pressure=$F/A \propto$ *Acceleration*= $\omega^2 x$
  - hand is accelerometer, 20-40 Hz, 0.4%*g*
  - Cost= free

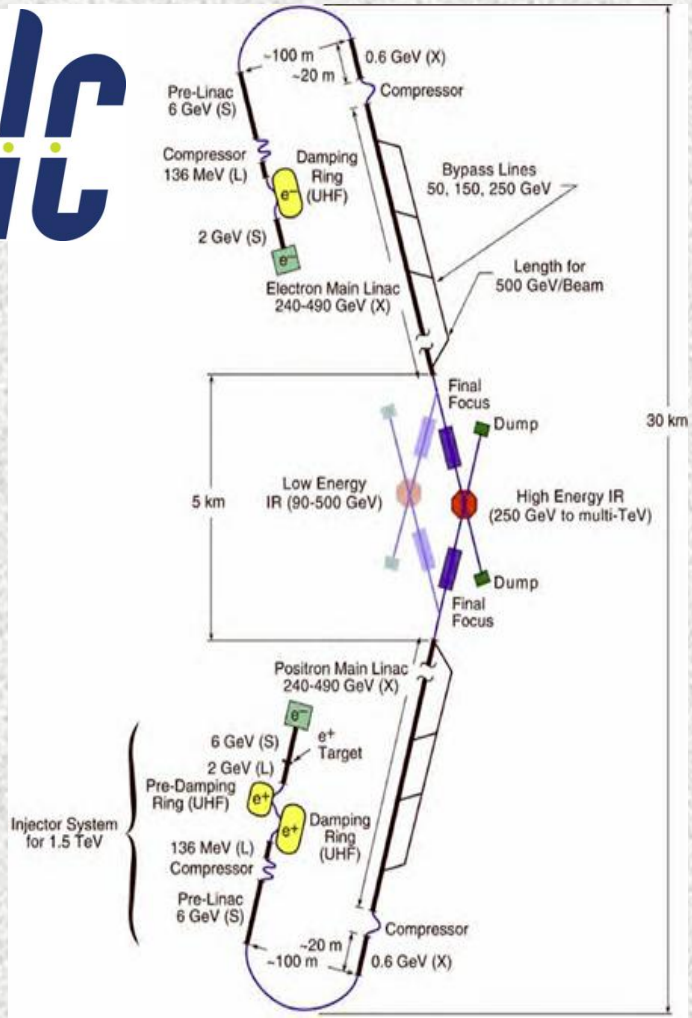
Detectors: Geophones





- Sensitive to *dB/dt* $\propto$ *Velocity* = ωx
  - Some employ FB, noise ~1A=0.1nm at 100 Hz
  - Cost ~3-5k$

Detectors: Accelerators



- Sensitive to *displacement* = *x*
  - need several FB's, tolerance ~1A (IPs), 10 nm in Linac
  - Cost ~10-15B$

What Kind of GM is Most Dangerous?

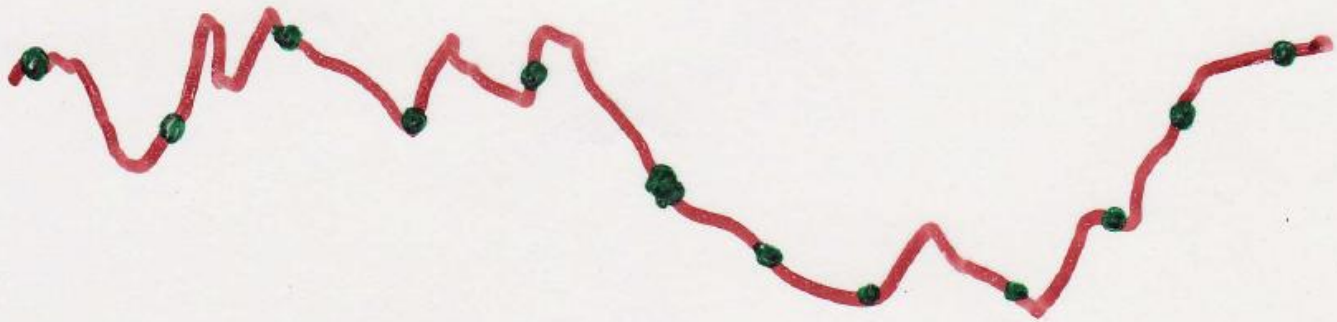
Parallel displacement - OK

Tilt (as a whole) - OK

microseismic wave

Short wavelength - danger!

Uncorrelated fractures - danger!



Natural ground motion

Shiltsev EPAC'96

Tolerances

Table 1: Stability of Factories

Parameter	APS	PEP-II
Energy/beam E, GeV	7	9/3.1
Circumference C, km	1.1	2.2
Emittance ϵ_V/ϵ_H, nm	1/10	~2/50
5%-jitter σ_V/σ_H, μm	0.1/0.3	0.3/1.5
Measured jitter, μm	0.06	0.05
Alignm. goal, μm	~100	~150

Shiltsev EPAC'96

Tolerances

Table 2: Stability of Linear Colliders

Parameter	TESLA	NLC	2-TEV
Energy/beam, TeV	0.25	0.25	1
f_{RF}, GHz	1.3	11.4	11-30
Tot. Length L, km	32	21	22
Rep. rate f_0, Hz	10	180	300
Linac jitter σ_q, nm	100	9	4
FFS jitter, nm	50	4	1
FD jitter, nm	10	1	0.3
Measured jitter, nm	5-80	1-3	0.2-4
Alignment of quads, cav., μm	500	100	$\sim$50
BPM align., μm	100	100	10
BPM resol., μm	10	2	0.2
FF BPM resol.,μm	1	1	0.3

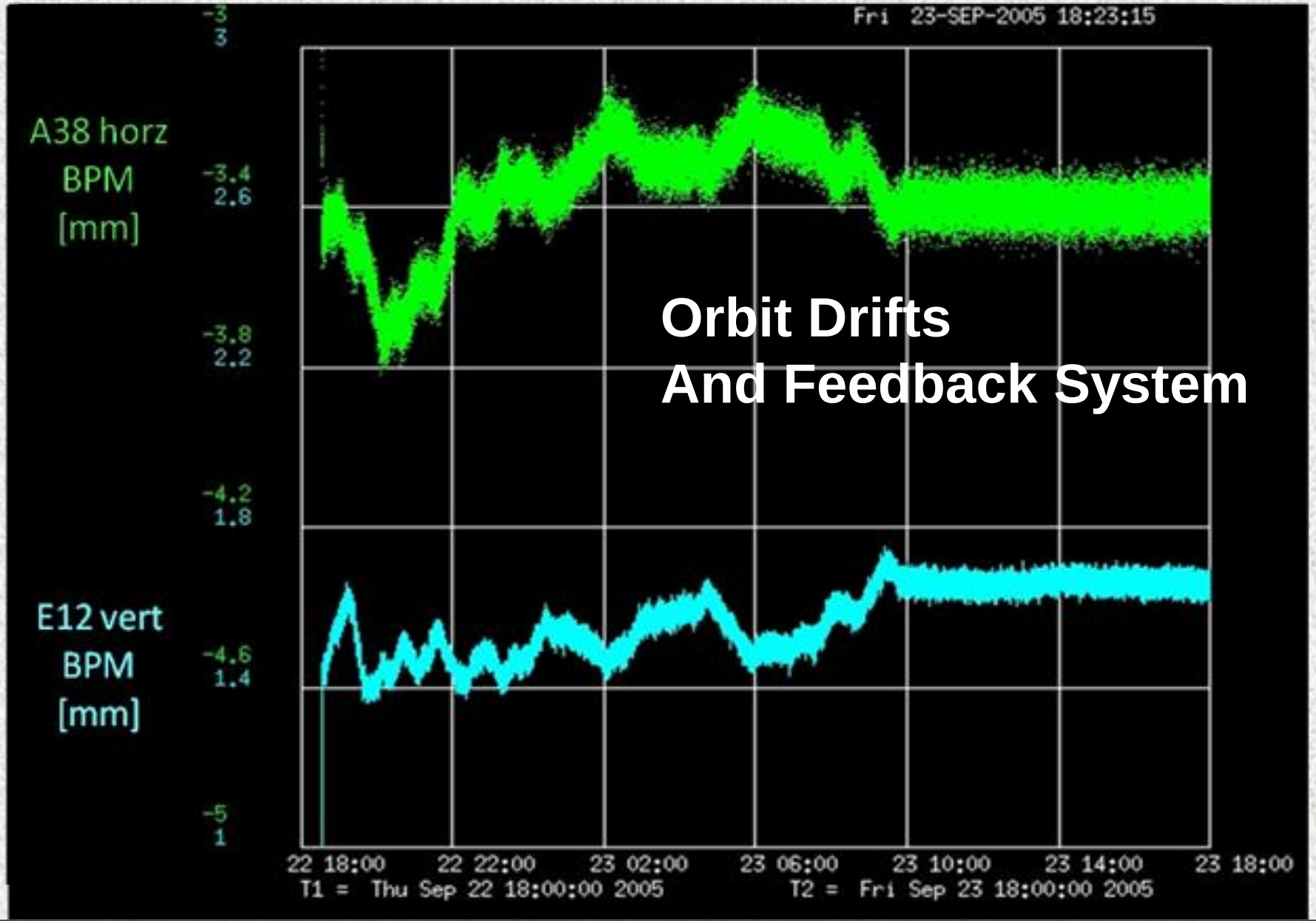
Shiltsev EPAC'96

Tolerances

Table 3: Stability of Hadron Colliders

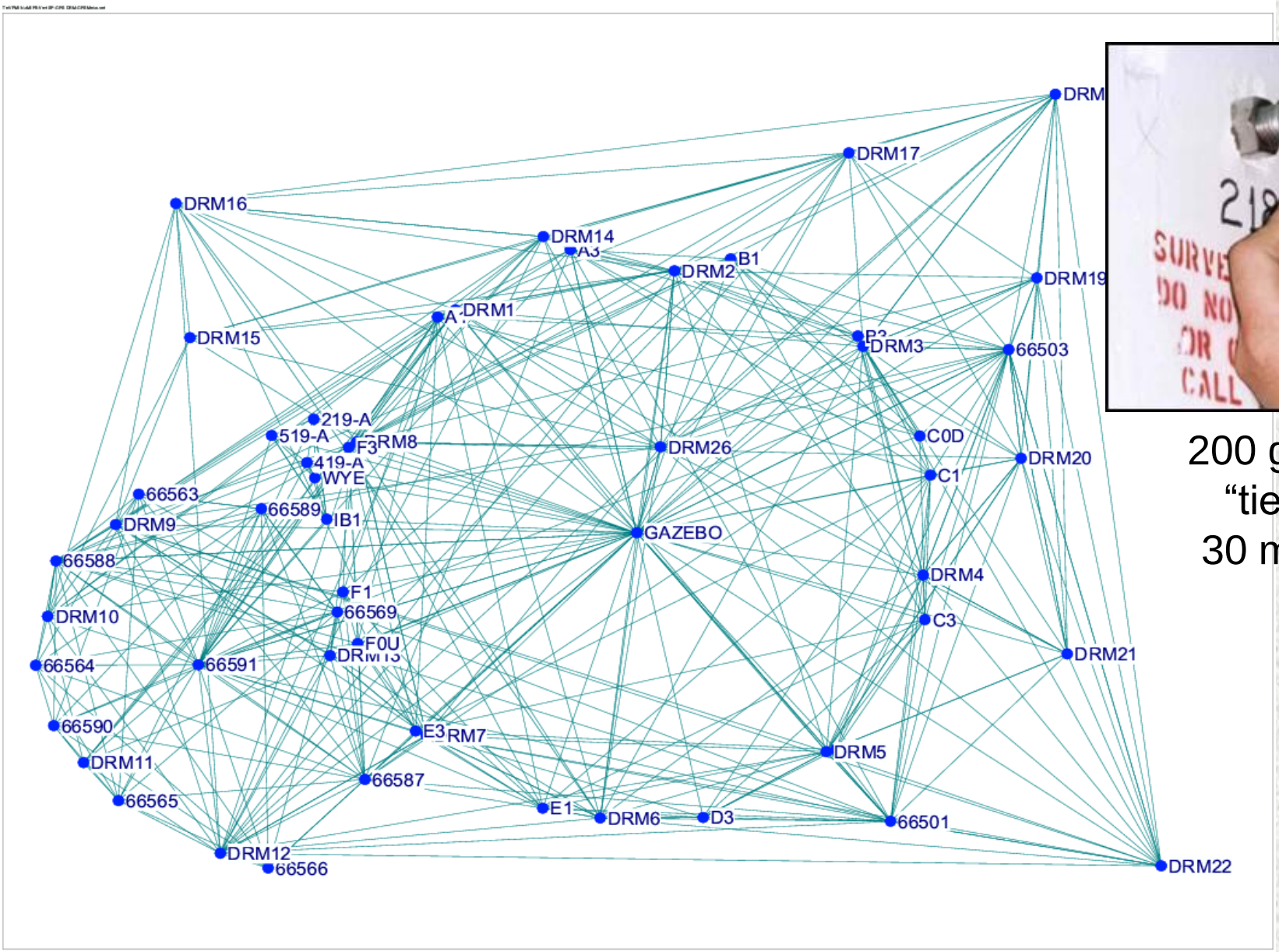
Parameter	LHC	SSC	Mega
Energy E, TeV	7	20	100
Circumference C km	26.7	87.1	1000
Emittance ϵ_N, μm	4	1	1
L-lifetime τ, hrs	10	20	5
$\Delta\nu f_0$, Hz	3100	760	66
Quads jitter σ_q, nm	0.15	0.1	0.2
Measured jitter, nm	0.01-0.1	0.2	0.1-50
$\Delta B/B$, 10^{-9}	~ 1	~ 1	~ 0.1
5mm COD align., μm	100	60	30
Realign. time, days	$\sim$200	$\sim$45	$\sim$5

Realities of the Tevatron



Tev Alignment: What it really means…

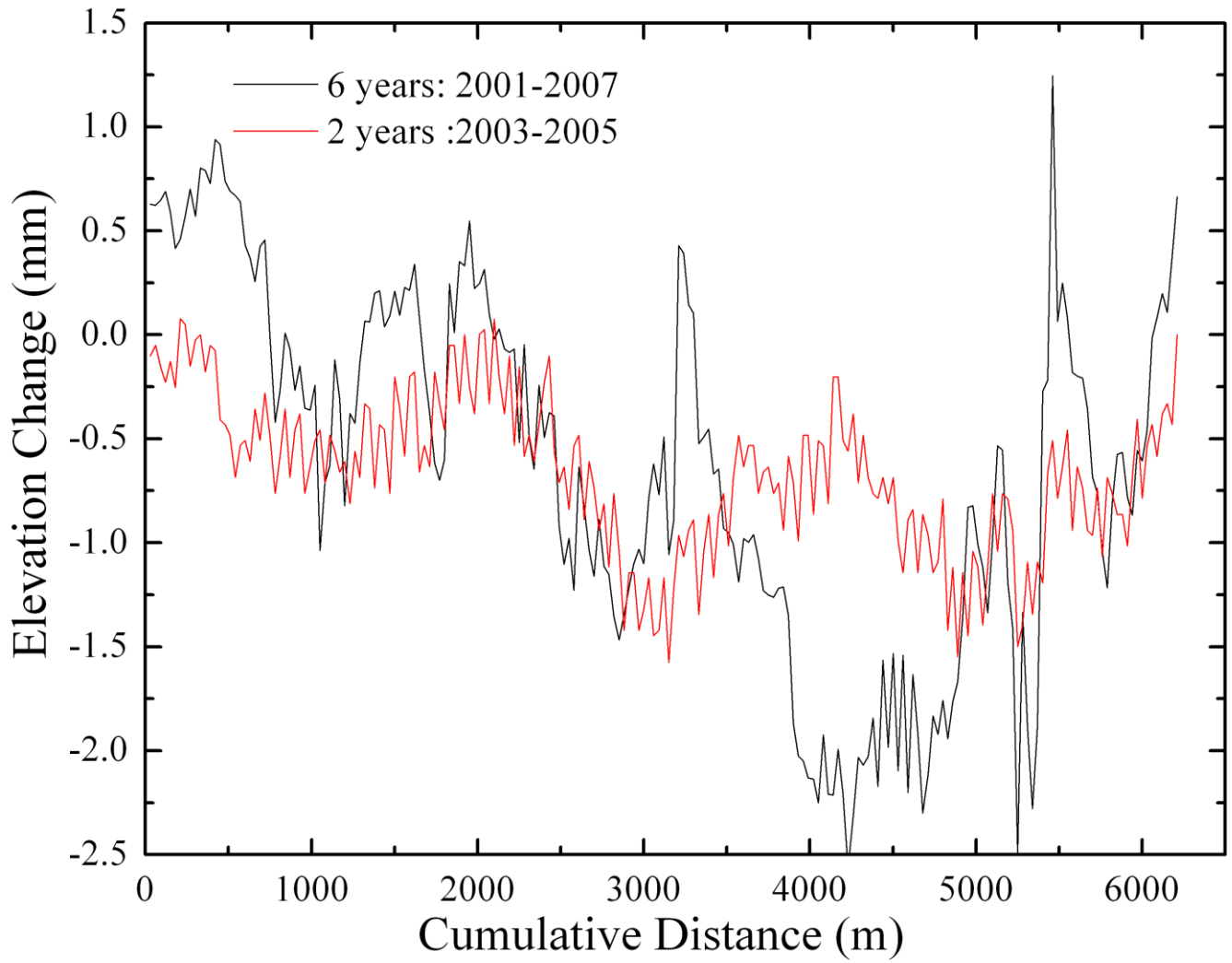
TevNet and "TieRods"



200 geodetic
"tie rods"
30 m apart.

Tevatron Tie Rods Position Data

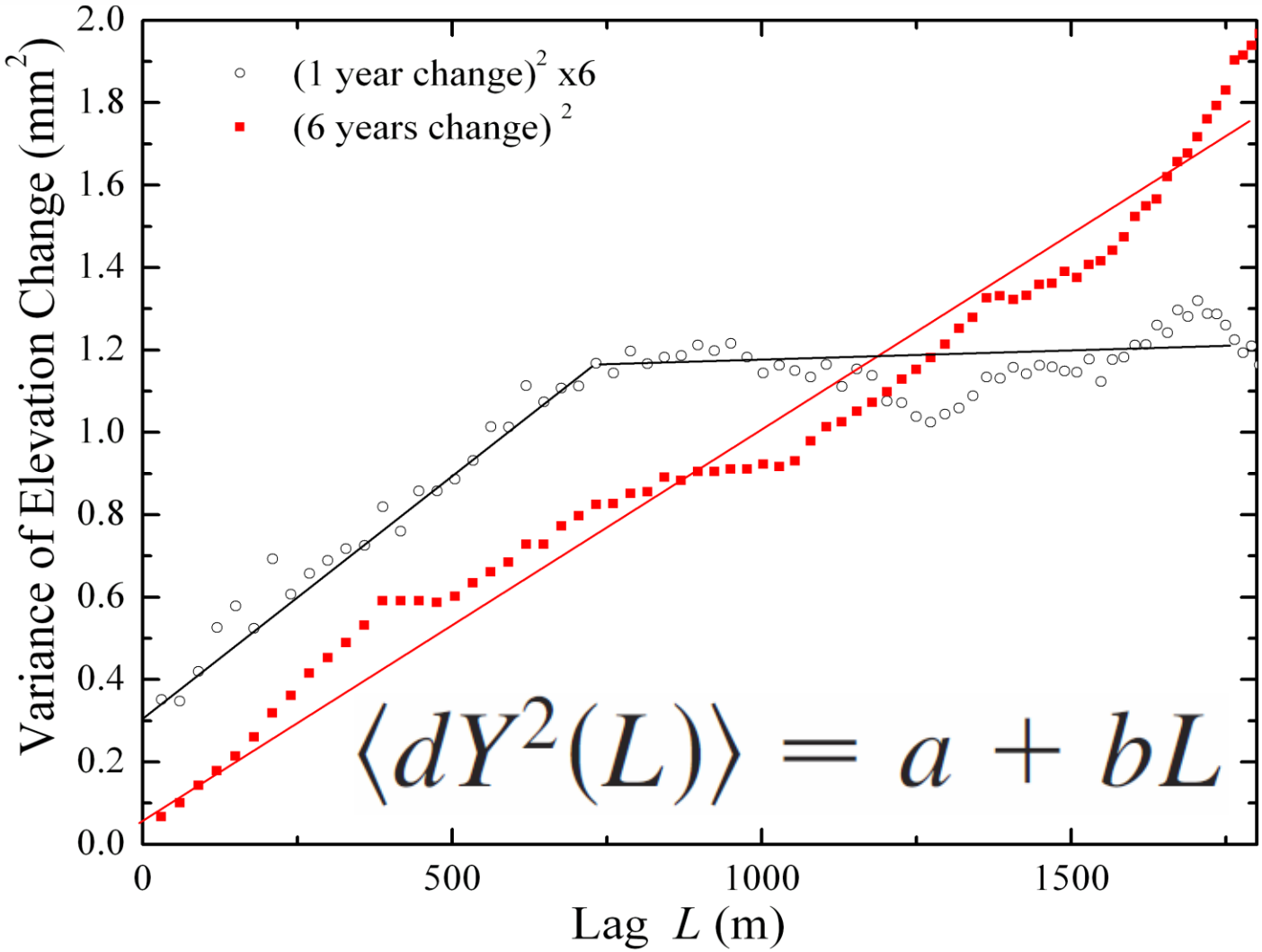
Tie rods elevations data are available for the years of 2001,2003,2005,2006 and 2007.



Shiltsev PRL 104, 238501 (2010)

Analysis: The Variogram

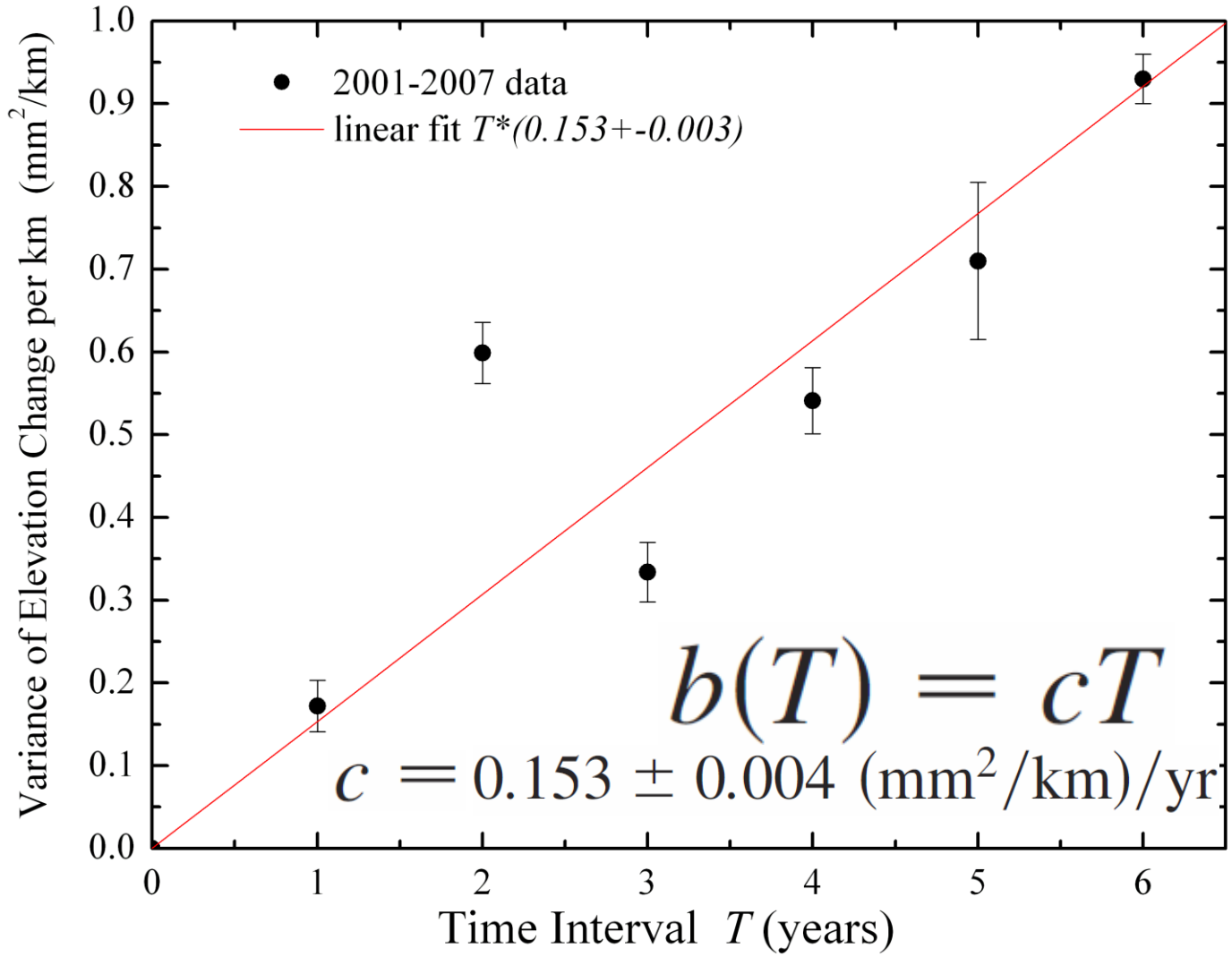
$$\langle dY^2(L)\rangle = \langle (dY(z) - dY(z+L))^2\rangle$$



Shiltsev PRL 104, 238501 (2010)

Analysis of Slopes $b=\langle dY^2\rangle/L$

$$\langle dY^2(L)\rangle = \langle (dY(z) - dY(z+L))^2\rangle \quad \langle dY^2(L)\rangle = a + bL$$



Shiltsev PRL 104, 238501 (2010)

In Summary:

we observe that the variance scales linearly with distance/lag *L* and with time interval *T*:

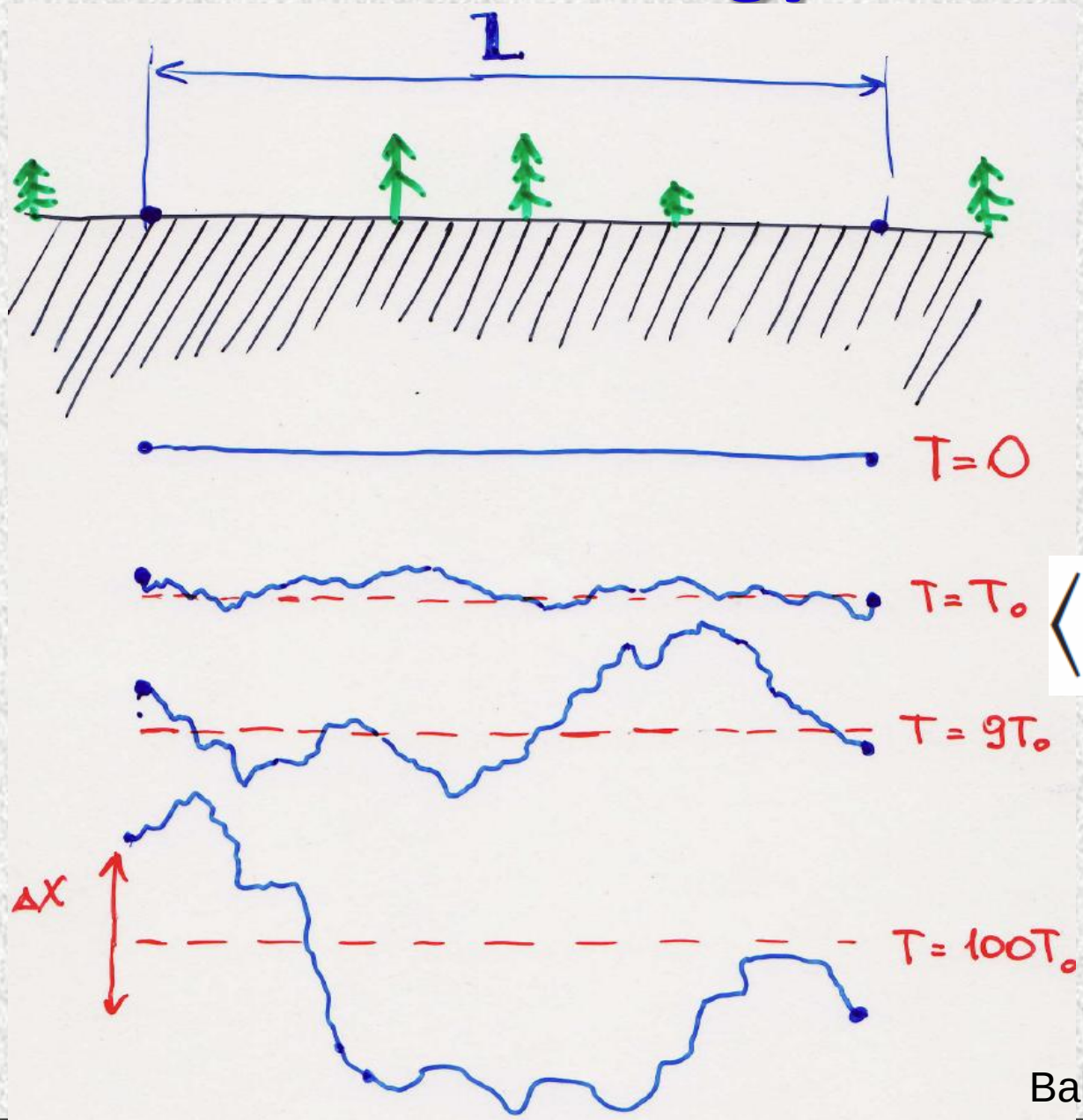
$$\langle dY^2 \rangle = ATL$$

$$A_{\mathrm{Tev}} = (4.9 \pm 0.13) \times 10^{-6}\ (\mu\mathrm{m}^2/\mathrm{s})/\mathrm{m}$$

THIS IS "*ATL* LAW"

Shiltsev PRL 104, 238501 (2010)

Phenomenology of the "ATL Law"



- statistical averaging of squared relative displacements in space (all points distanced by *L*) and time (all time moments different by *T*)
- about the same in vertical and horizontal

$$\langle dY^2 \rangle = ATL$$

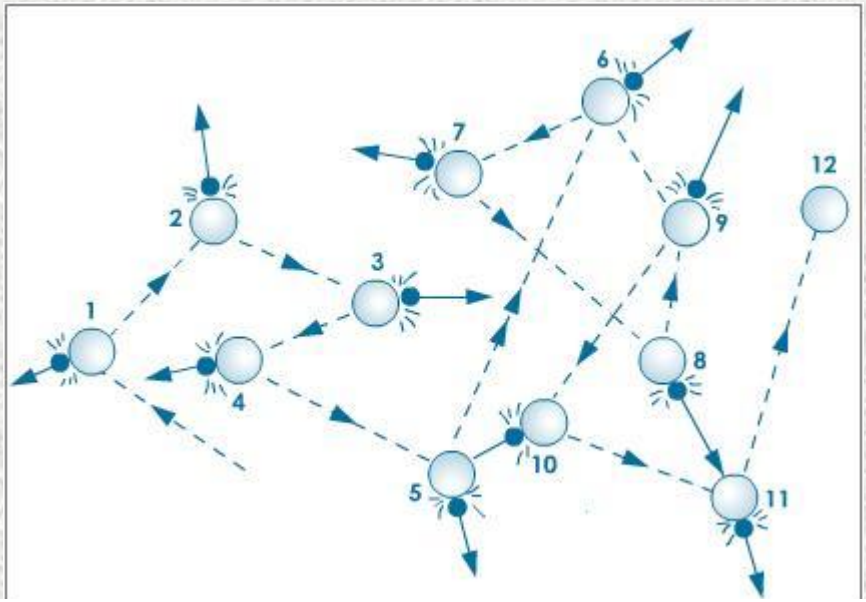
Often background to other processes:

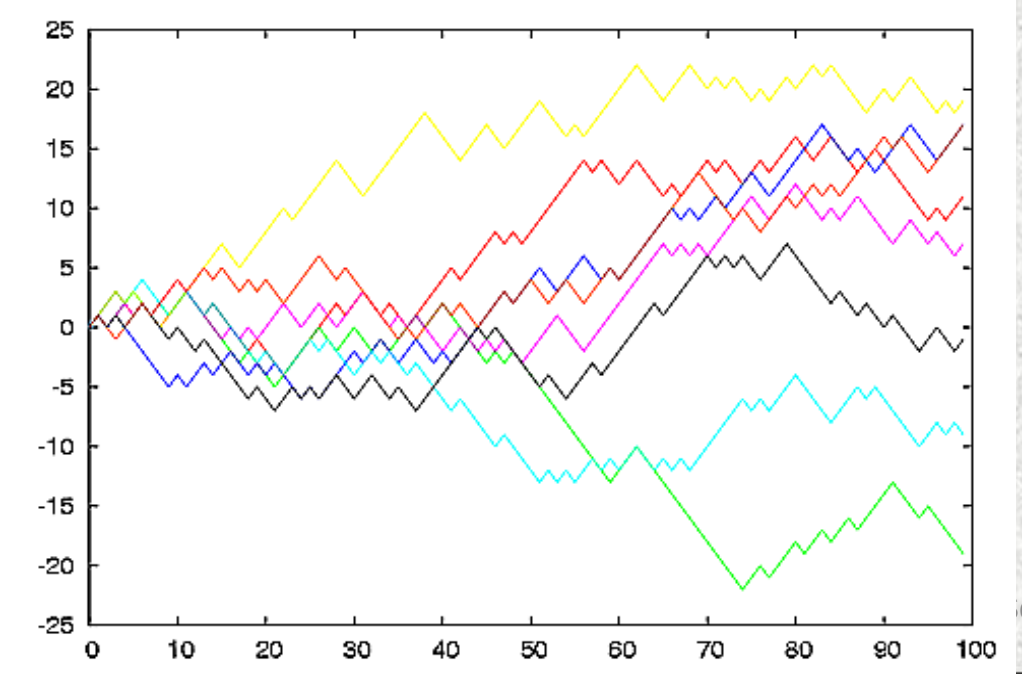
- tides
- precipitation
- t- variations
- winds, ground water, etc

Baklakov, et al, *Proc. PAC* 1991

(give assignments)

“ATL Law” is a Diffusion





…like Brownian motion in time

$$< dR^2(T) > = 2DT$$

…like random walk in space

$$< dY^2(L) > \propto L$$

..but - SIMULTANEOUSLY !

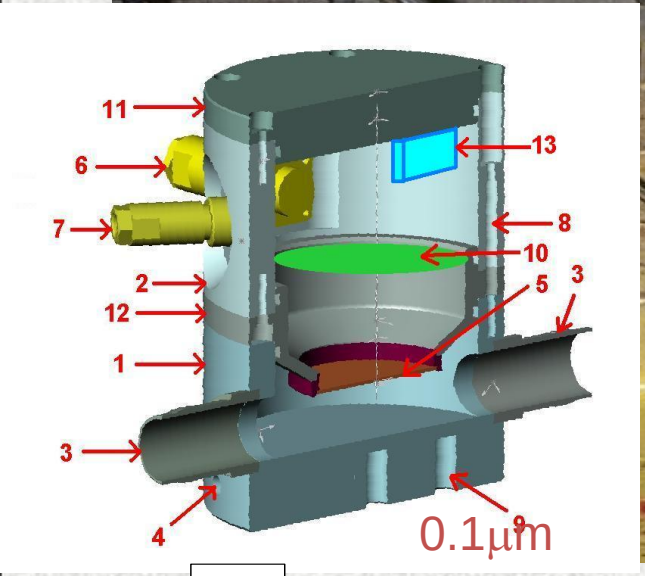
Geophysicists knew about that, but:

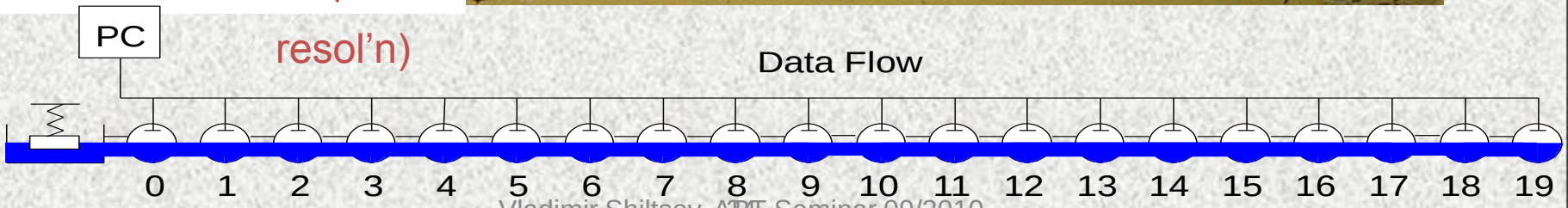
- separetely *T* (two points), *L* (one time topography)
- large arrays of detectors needed

Tev On-Line Survey System

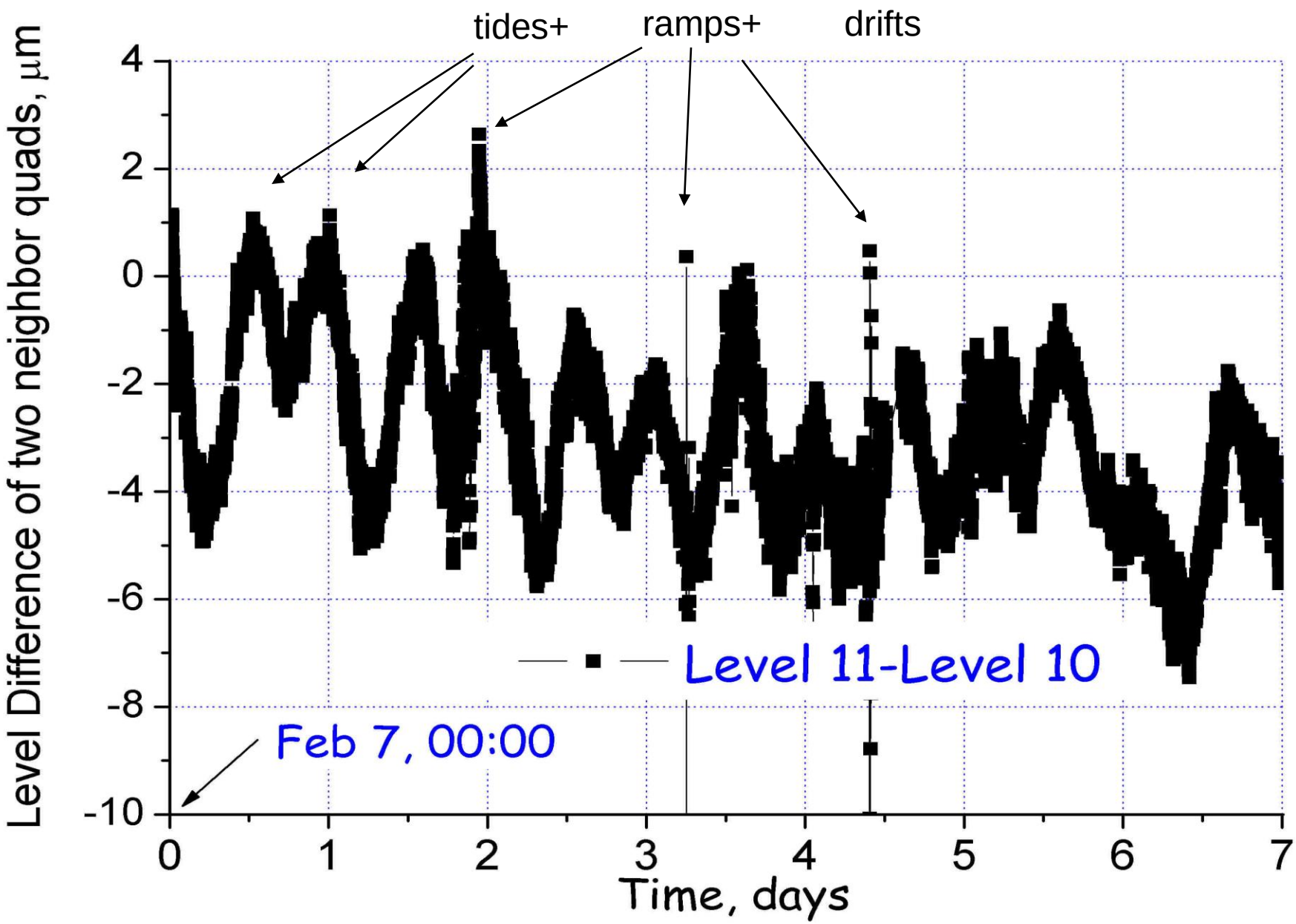
24 water level sensors every 30m in B-sector

J.Volk, V.Shiltsev, BINP(Novosibirsk),

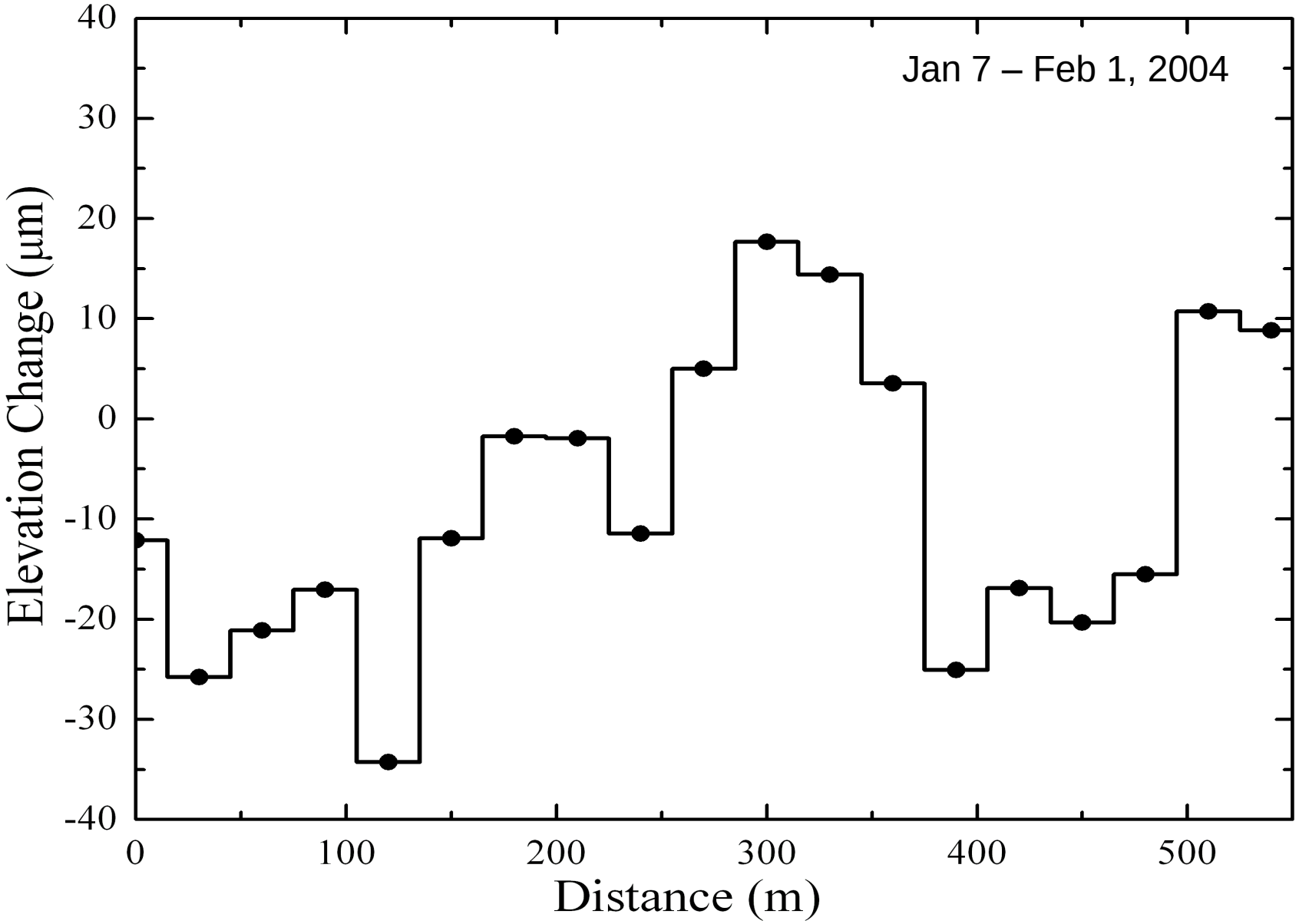




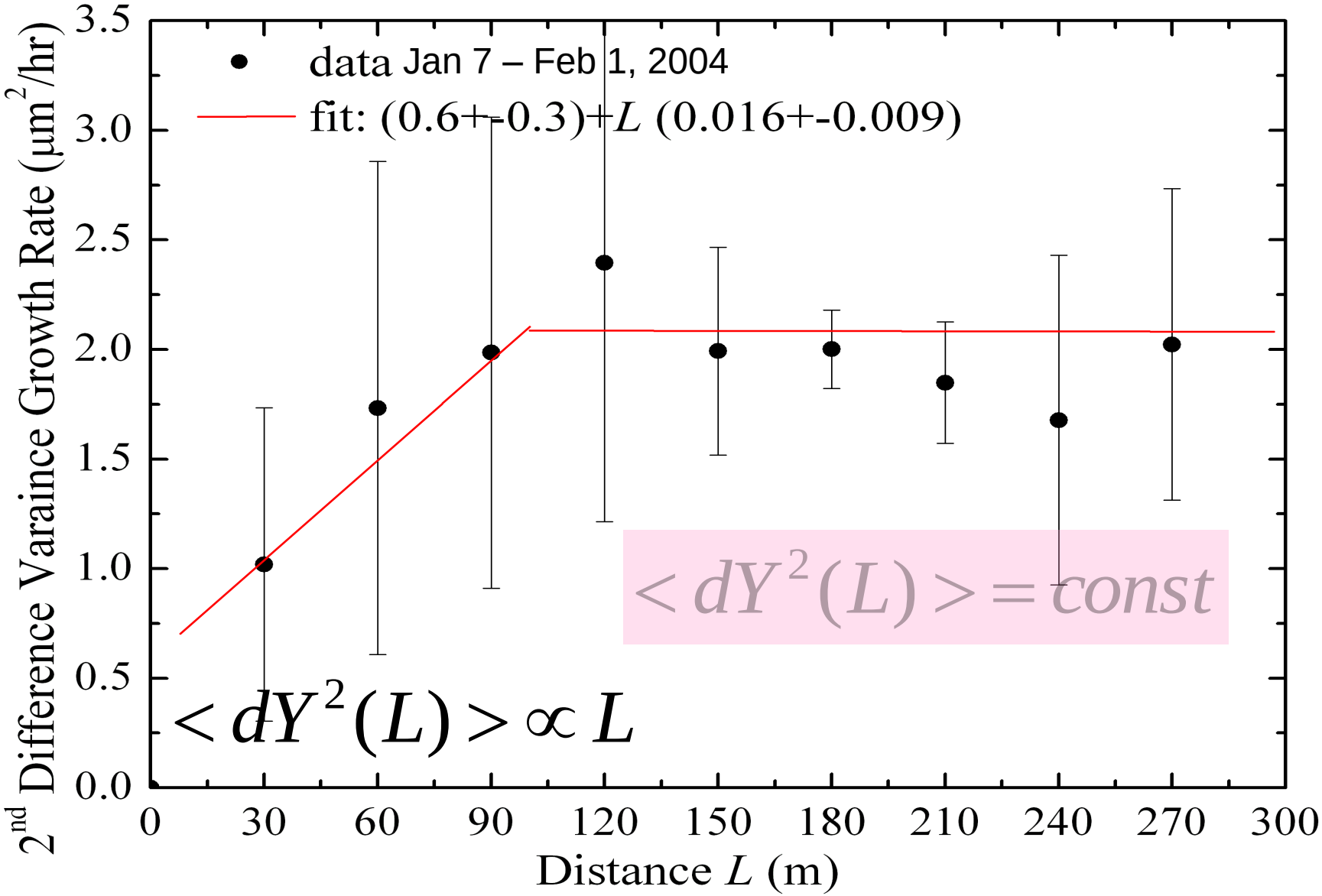
(Relative) Magnet Movement: 1 week



Change of Magnet Positions : 23 days



Phenomenology of the "ATL Law"



What does that transition mean?

If movements of all the points are random in time and totally uncorrelated , then

$$< (Y_1(t) - Y_2(t))^2 > = const(L) \propto T$$

That's what one should expect for GM at small time intervals and large distances btw points

ATL is different: $$< dY^2(T, L) > = ATL$$

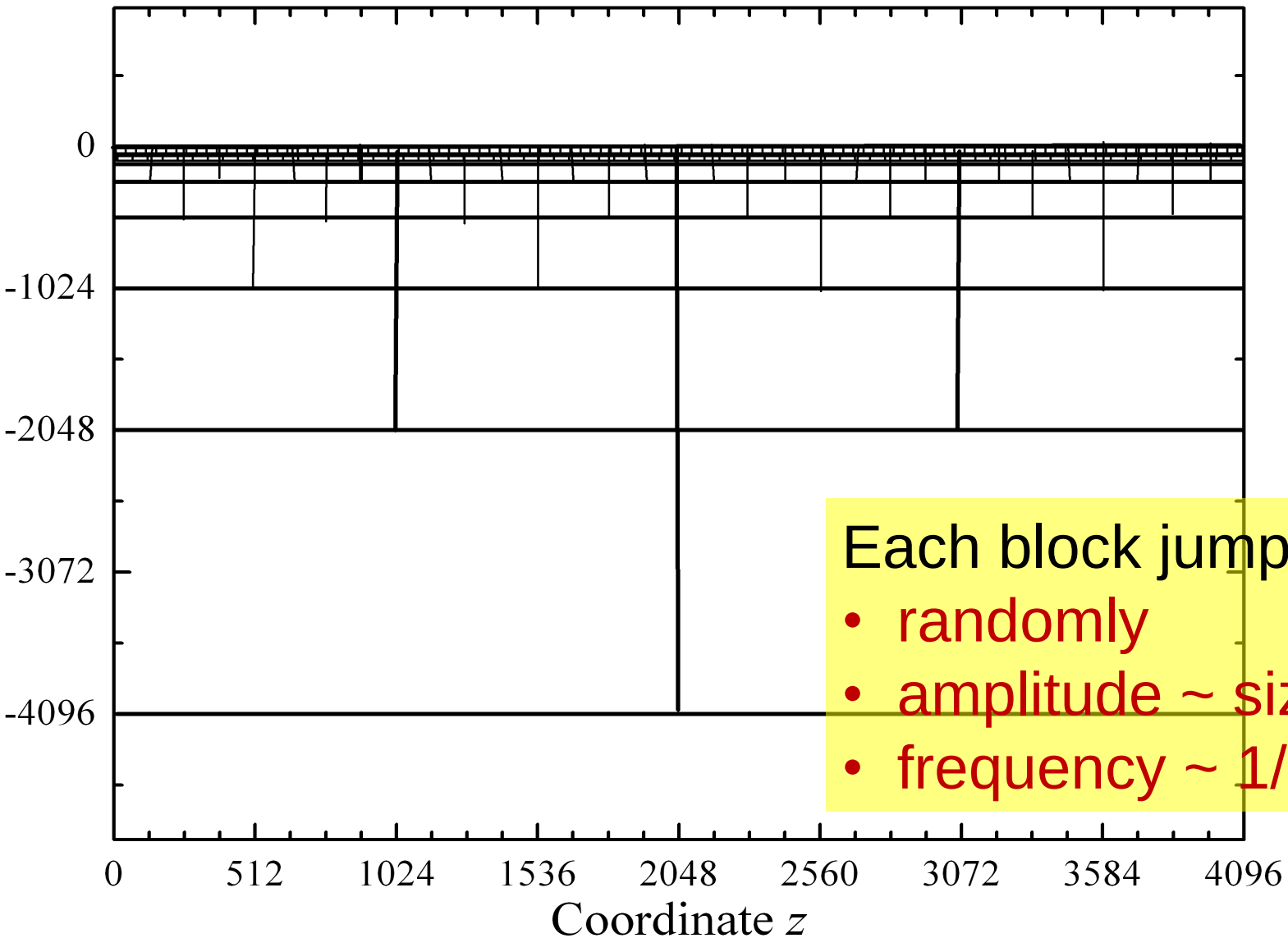
Where is the boundary?

B0 data	*T=1 week*	*L_m ~110 m*
Tevatron alignment data	*T=52 weeks*	*L_m ~750 m*

$$L_m \propto \sqrt{T}$$

6 10 2008

Fractal Model

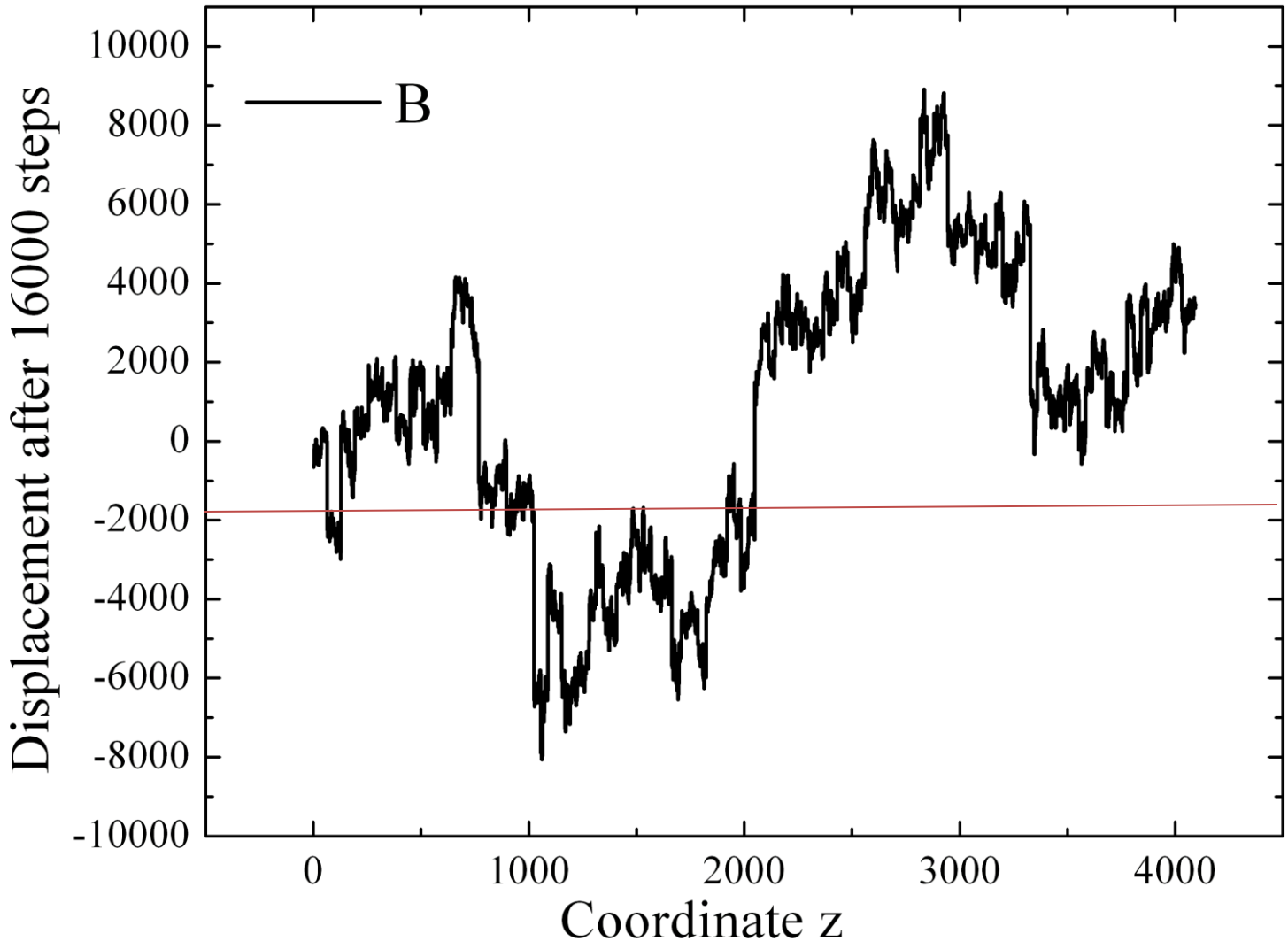


Each block jumps

- randomly
- amplitude ~ size^a
- frequency ~ 1/size^b

Shiltsev PRSTAB 13, 094801 (2010)

E.g. after 16000 steps

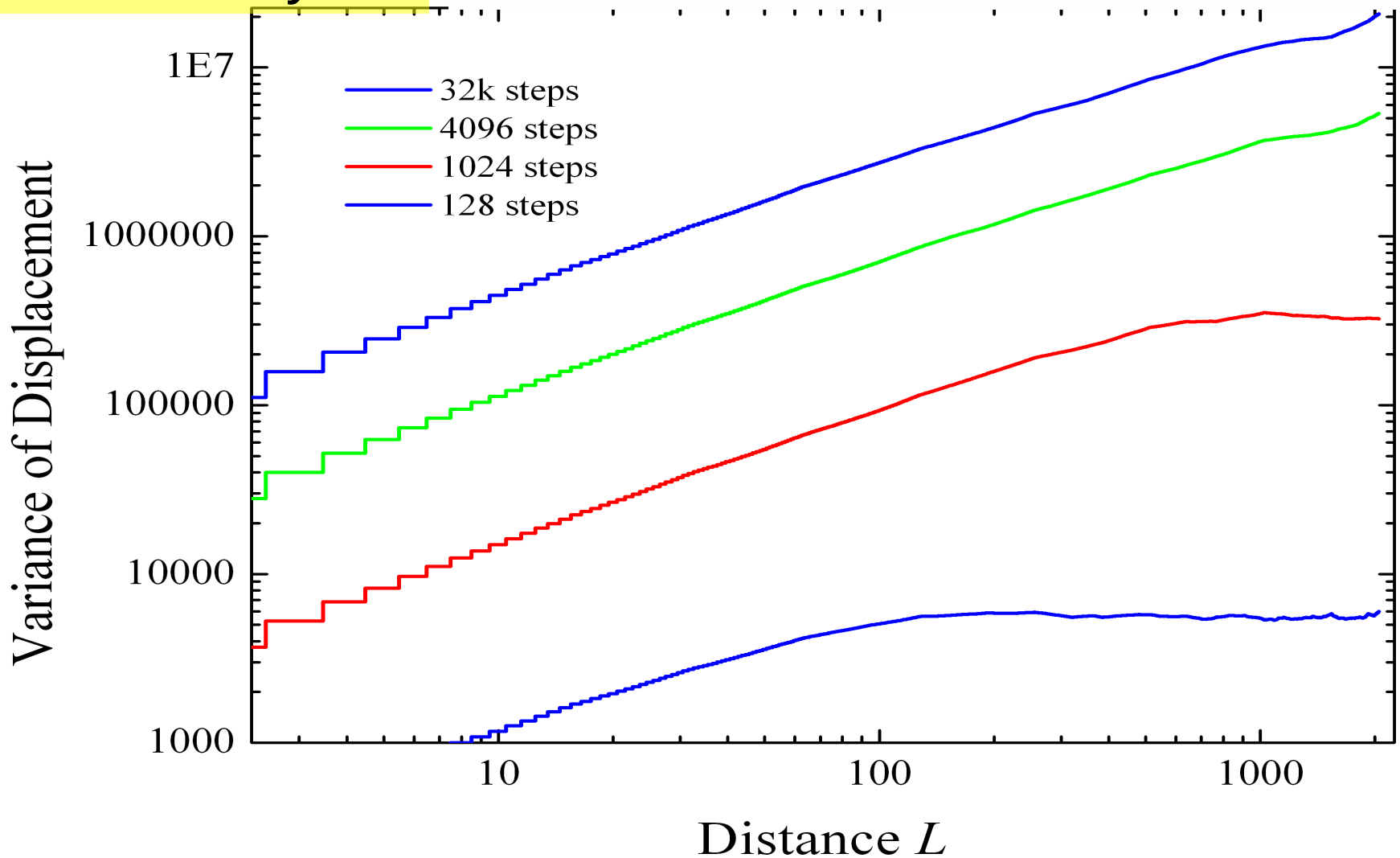


Shiltsev PRSTAB 13, 094801 (2010)

Variance of the Displacements

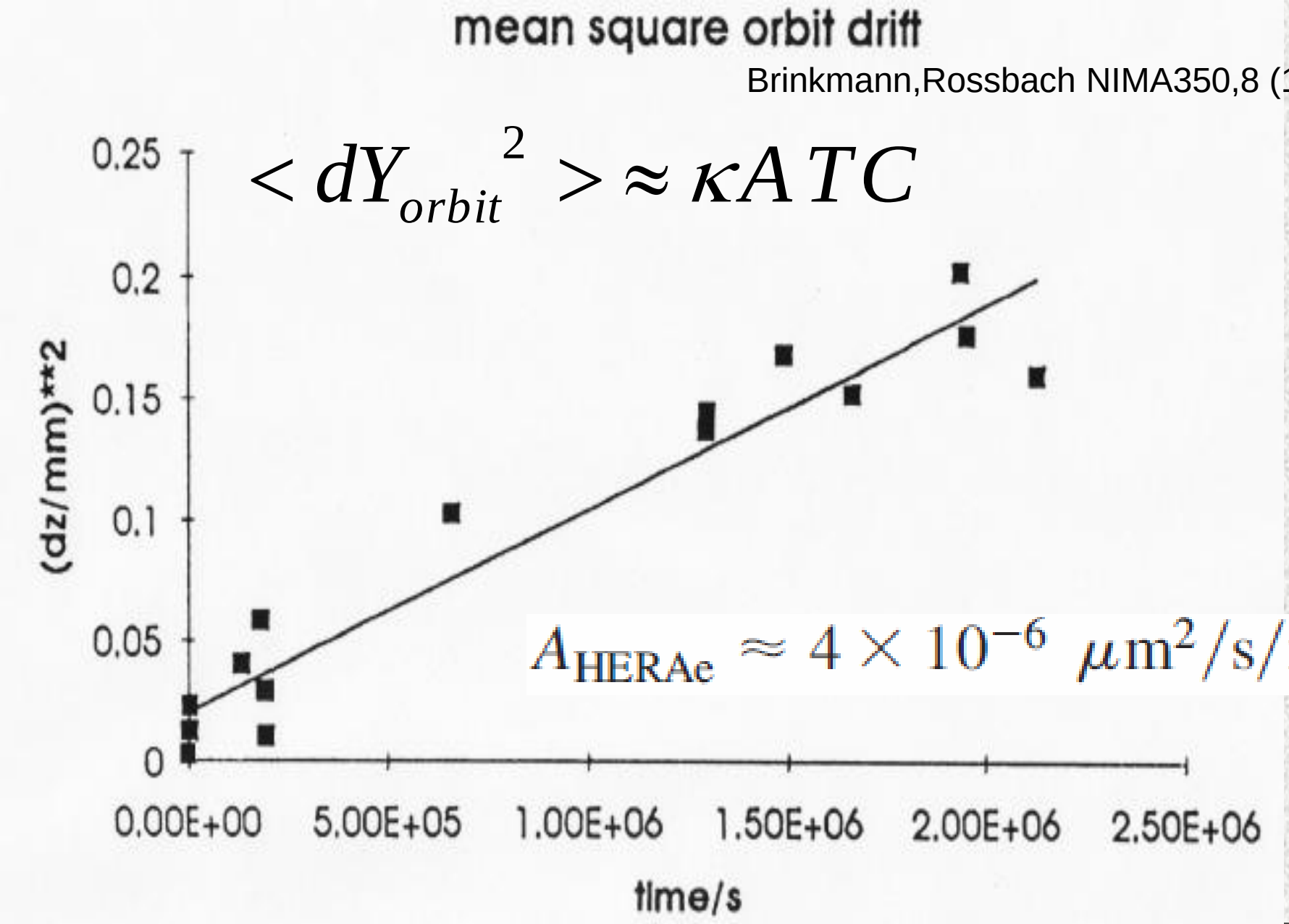
ATL-like analysis

$$\langle dY^2(L)\rangle = \langle (dY(z) - dY(z+L))^2\rangle$$

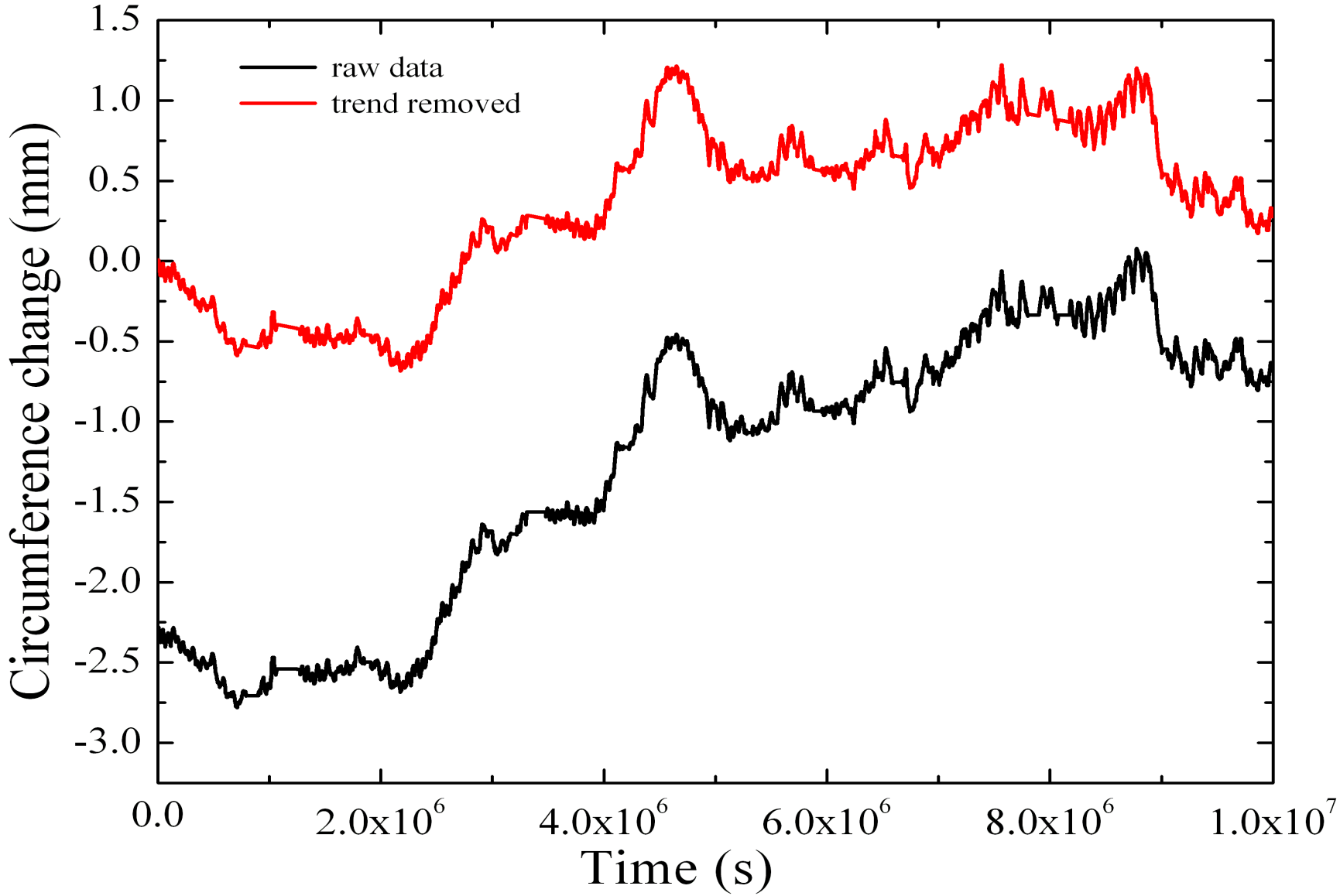


Shiltsev PRSTAB 13, 094801 (2010)

Back to Observations: HERA-p/e orbits



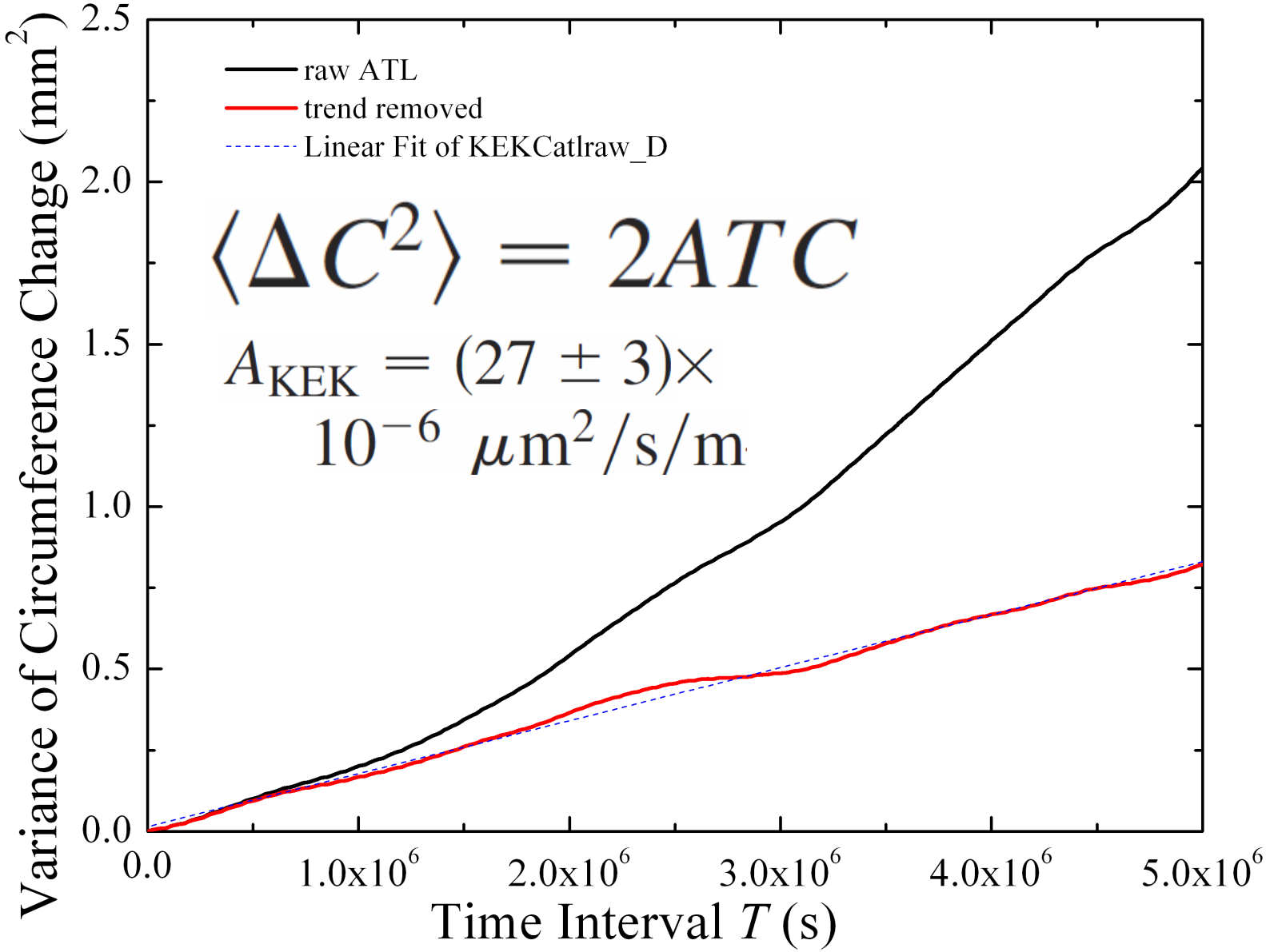
KEK-B Circumference Drifts



Masuzawa et al, IWAA'2002

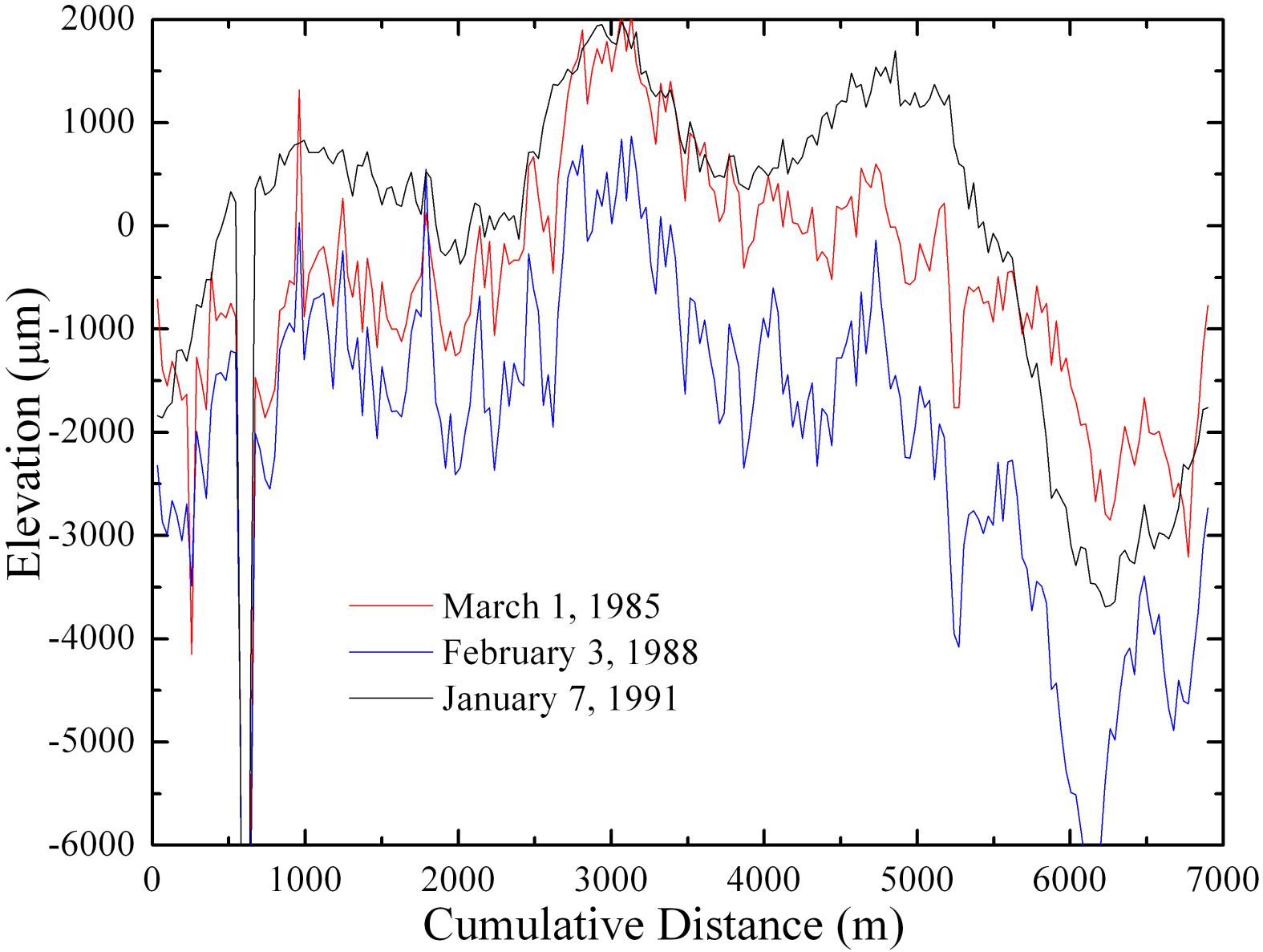
Data courtesy K.Oide (KEK)

KEK-B Orbit Drifts Analysis



Shiltsev PRSTAB 13, 094801 (2010)

SPS Alignment Data Analysis

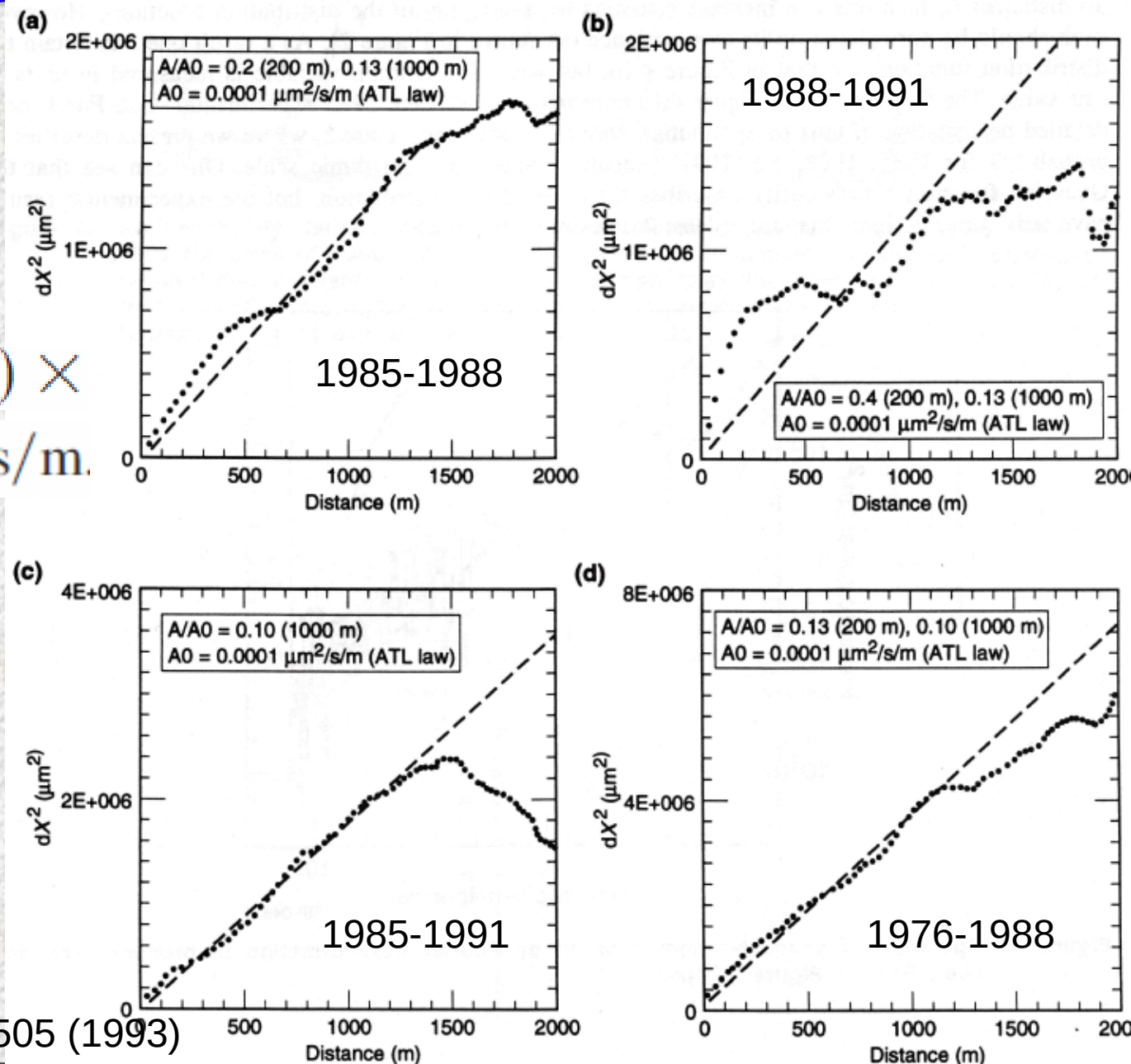


Shiltsev,Stiening, SSCL-505 (1993)

Data courtesy J.P.Quesnel (CERN)

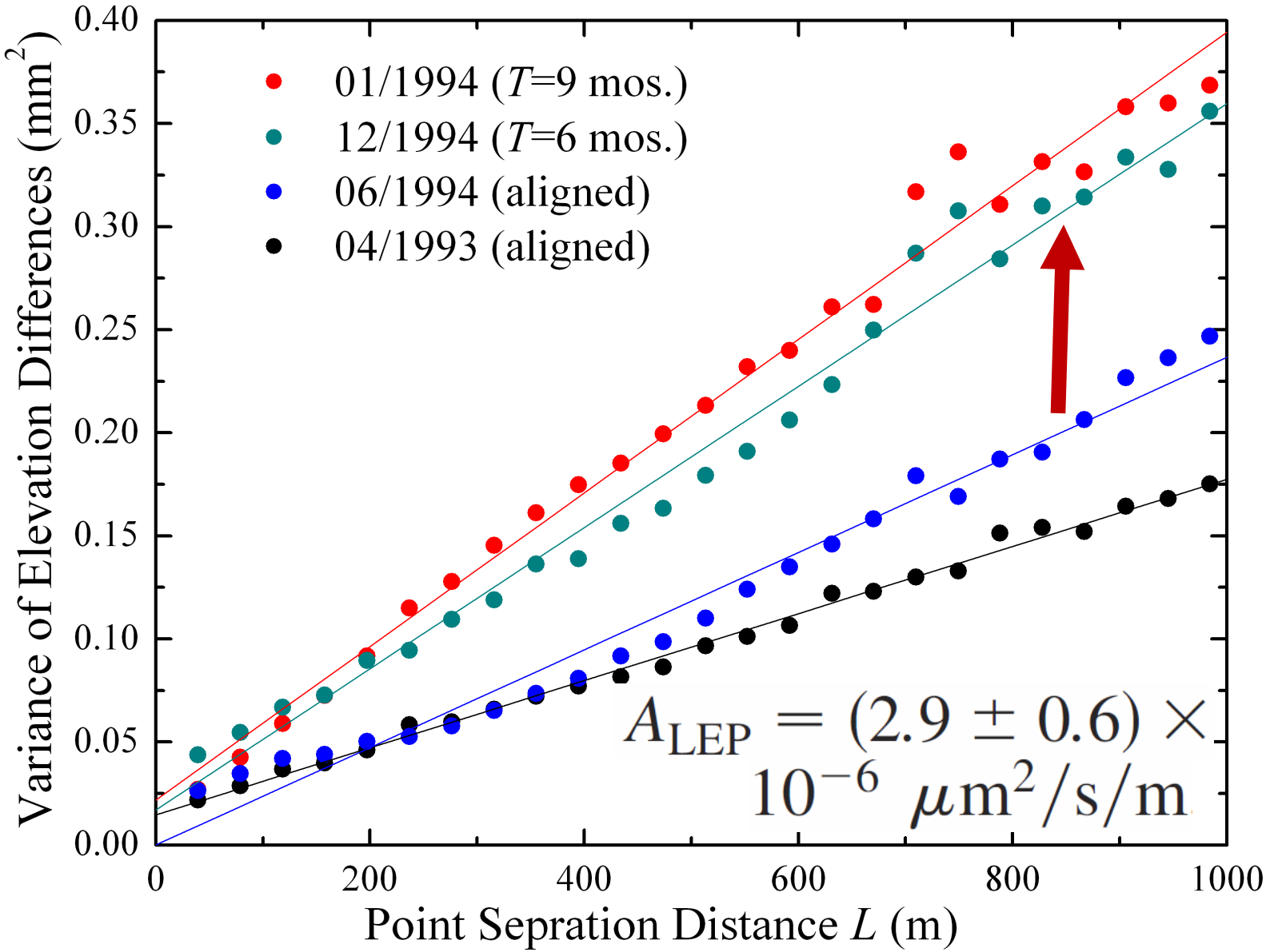
SPS Alignment Data Analysis

$$A_{SPS} = (14 \pm 5) \times 10^{-6}\ \mu m^2/s/m.$$



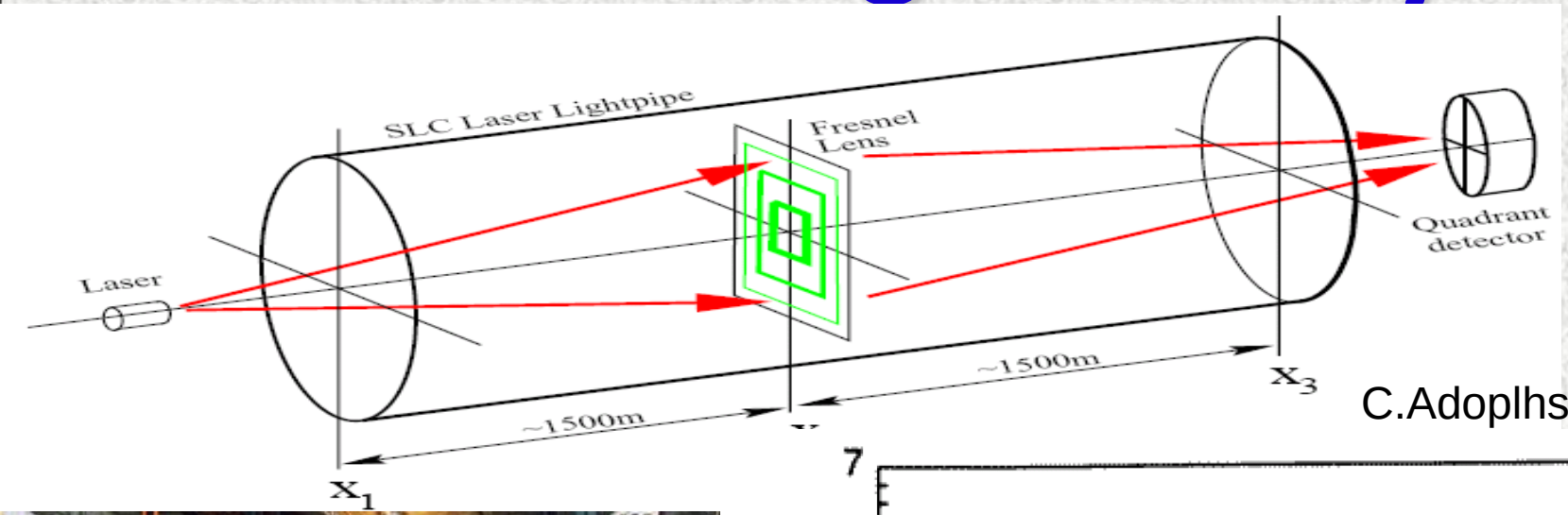
Shiltsev,Stiening, SSCL-505 (1993)

LEP Alignment Data Analysis

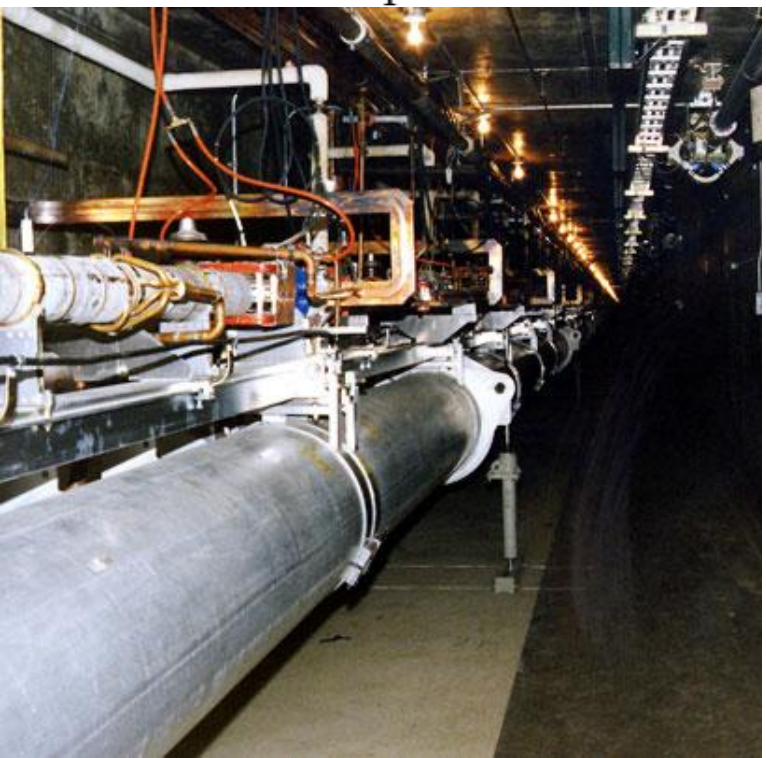


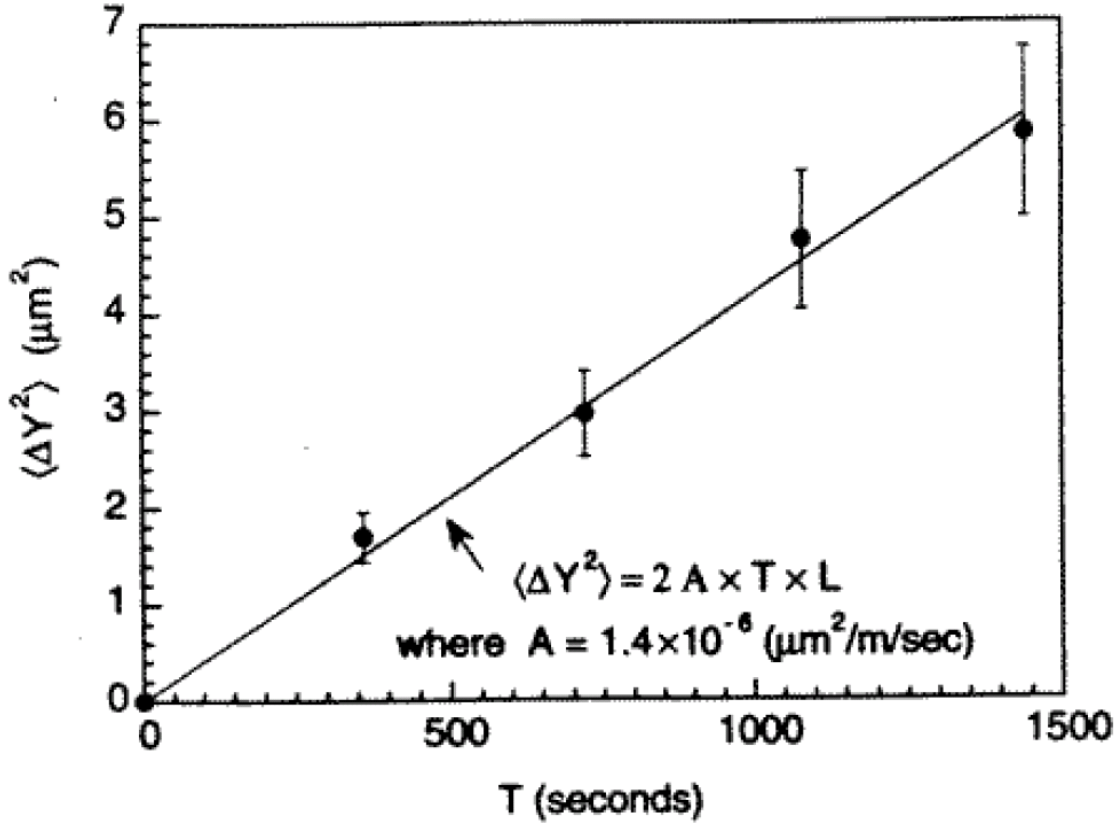
Shiltsev, IWAA'1995

SLAC Linac Alignment System



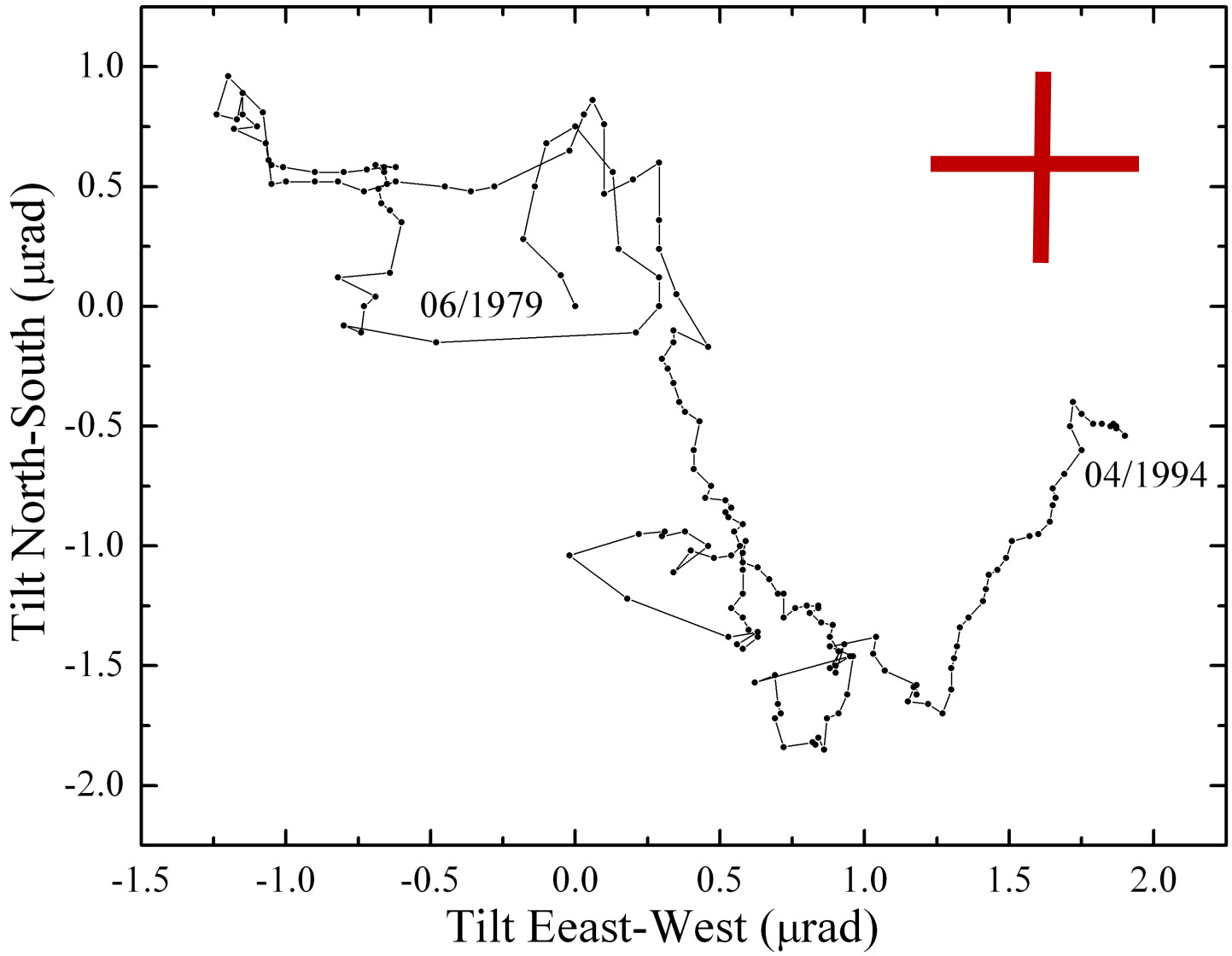
C.Adoplhsen, LC997





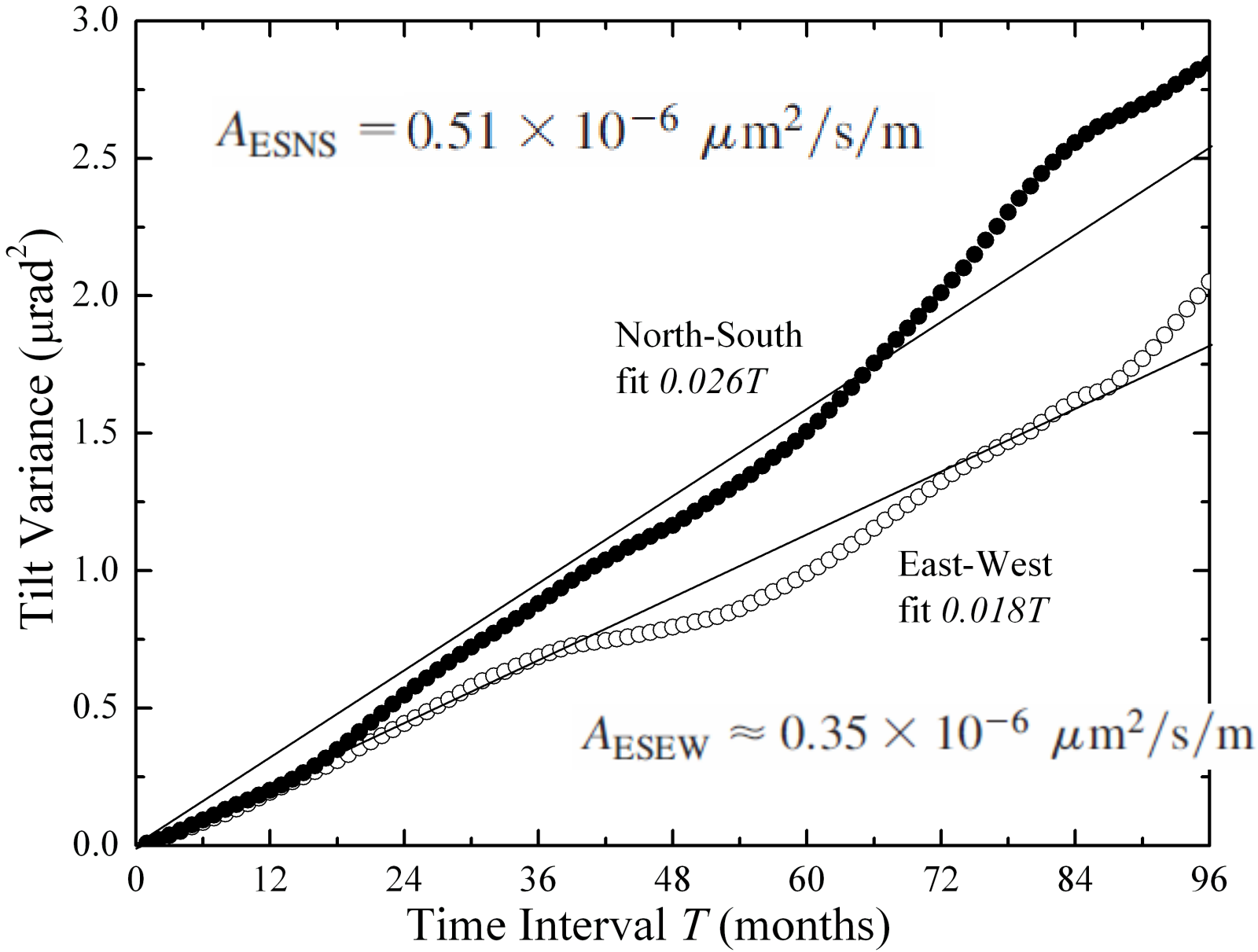
Geophysics Lab (Esashi, Japan)

60 m underground, two tHLS iltmeters N-S and E-W 50 m long each, 15 yss=1979-94



Data courtesy S.Takeda (KEK)

ATL in the Esashi data

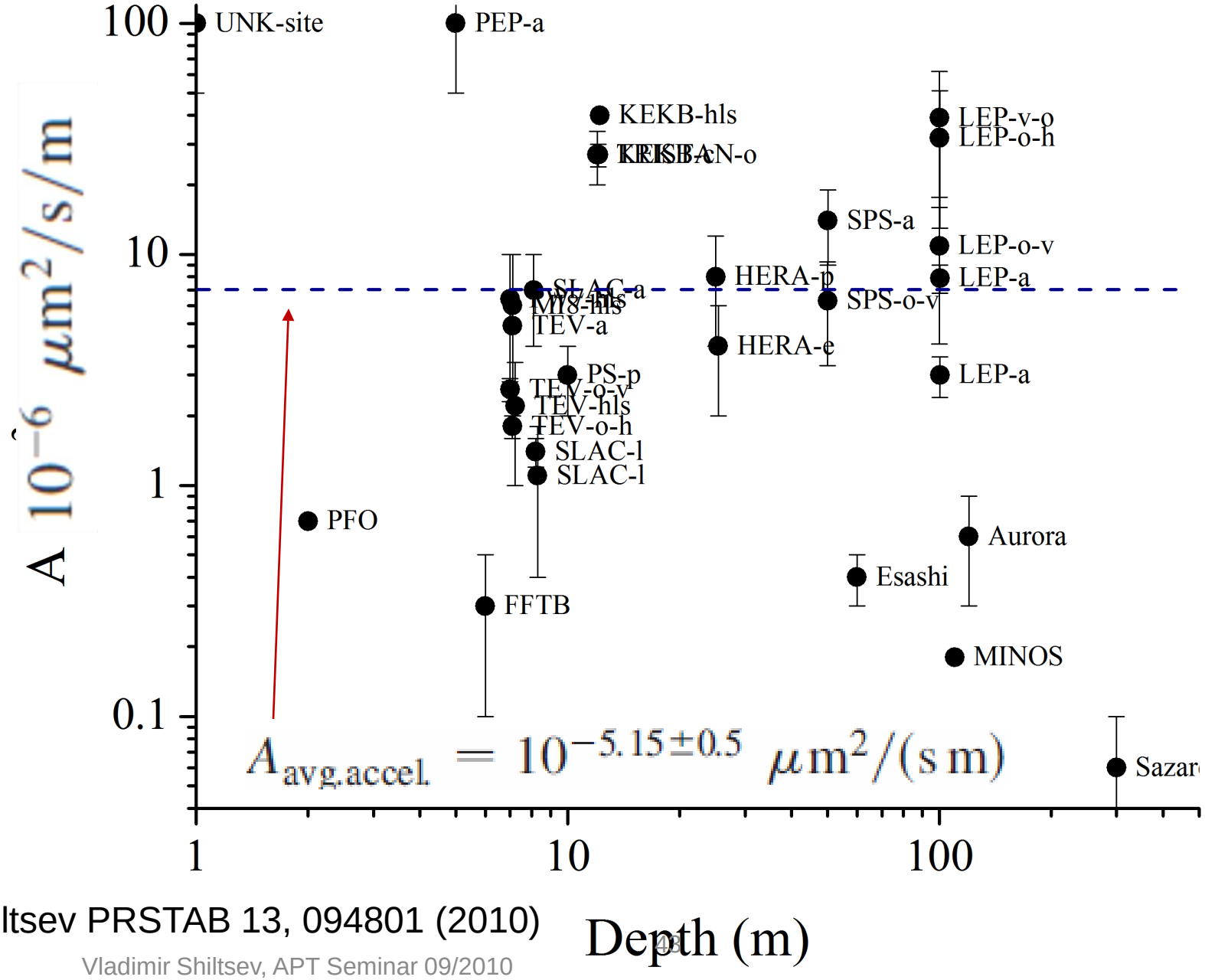


Shiltsev, IWAA'1995

Review of Diffusive GM: Shiltsev PRSTAB (2010)

		A, 10^{-6} $\mu m^2/s/m$	Time	Scale	Reference	Comments
			Beam orbit drifts in accelerators			
HERA-e vertical	T	4 ± 2	25 days	6.3 km	[18]	25 m deep, $\Delta L = 23$ m
HERA-p vertical	T	8 ± 4	5 days	6.3 km	[17,18]	25 m deep, $\Delta L = 47$ m
TRISTAN vertical	T	27 ± 7	2 days	3.0 km	[17,19]	12 m deep, $\Delta L = 47$ m
Circumference KEK-B	T	27 ± 3	4 months	3.0 km	[20]	$\beta \approx 2.2$
Tevatron vertical	T	2.6 ± 0.3	15 hrs	6.3 km	[21]	~7 m deep, $\Delta L = 30$ m
Horizontal	T	1.8 ± 0.2	15 hrs	6.3 km		
LEP vertical	T	10.9 ± 6.8	18 hrs	26.7 km	[22,24]	~100 m deep, $\Delta L = 39$ m
LEP vertical	T	39 ± 23	3.3 hrs	26.7 km	[23]	Tides not excluded
Horizontal	T	32 ± 19	3.3 hrs	26.7 km	[23]	Tides not excluded
SPS vertical	T	6.3 ± 3.0	2 hr	6.9 km	[23]	50 m deep, $\Delta L = 32$ m
			Accelerator Alignment Data Analysis			
CERN LEP vertical	L, T	6.8–9.0	6, 9 mos	26.7 km	[17,26]	45–170 m deep
		3 ± 0.6	6 years	26.7 km	[27]	$\Delta L = 39$ m
CERN SPS vertical	L, T	14 ± 5	3–12 yr	6.9 km	[28]	50 m deep, $\Delta L = 32$ m
Tevatron vertical	L, T	4.9 ± 0.1	1–6 yr	6.3 km	[29,30]	~7 m deep, $\Delta L = 30$ m
SLAC PEP vertical	L	100 ± 50	20 mos	2 km	[28]	Cut-and-cover tunnel
SLAC linac vertical	L	200 ± 100	17 yr	3 km	[15,28]	Cut-and-cover tunnel
	L	<10	17 yr	3 km	[31]	Linear trends removed
UNK site vertical	L	100 ± 50	2 yr	500 m	[15,28]	Surface monuments
			Geophysics Instruments Data			
PFO (CA, USA)	T	0.7	5 yr	732 m	[32]	Laser interferometer
SLAC linac vertical	T	1.4 ± 0.2	0.5 hr	3 km	[34]	$\Delta L = 1500$ m
	T	0.2–2	1 hr	3 km	[35]	From PSD fit
CERN PS pillar	T	3 ± 1	2.5 yr	10 m	[36,37]	10 m depth
SLAC FFTB	T	0.1–0.5	15 hrs	~30 m	[38]	Wire, in the lab
Esashi (Japan)	T	0.3–0.5	15 years	50 m	[17,39]	60 m deep, NS-EW
Sazare (Japan)	T	0.01–0.12	6 weeks	48 m	[40]	300 m deep
Kamaishi (Japan)	T	0.06–0.14			[43]	Granite
SPring8 (Japan)	T	0.8			[43]	Granite
Miyazaki (Japan)	T	15			[43]	Diorite
Rokkoh (Japan)	T	~36			[43]	Granite
KEK-B tunnel	T	40	4 days	42 m	[41]	12 m deep, joints
FNAL PW7	T	6.4 ± 3.6	3 months	180 m	[45]	$\Delta L = 30$ m, $t°$-effects
FNAL MI8 line	T, L	1–10	1 month	285 m	[46]	$\Delta L = 15$ m, m.b. $\gamma < 1$
FNAL Tevatron	T, L	2.2 ± 1.2	1 week	600 m	[30]	$\Delta L = 30$ m, $\gamma = 0$ $L > 120$ m
FNAL MINOS hall	T, L	0.18	1 month	90 m	[30]	$\Delta L = 30$ m, ~100 m deep
Aurora mine (IL)	T, L	0.6 ± 0.3	2 weeks	210 m	[46,47]	$\Delta L = 30$ m, ~100 m deep

Summary Plot from Shiltsev PRSTAB (2010)



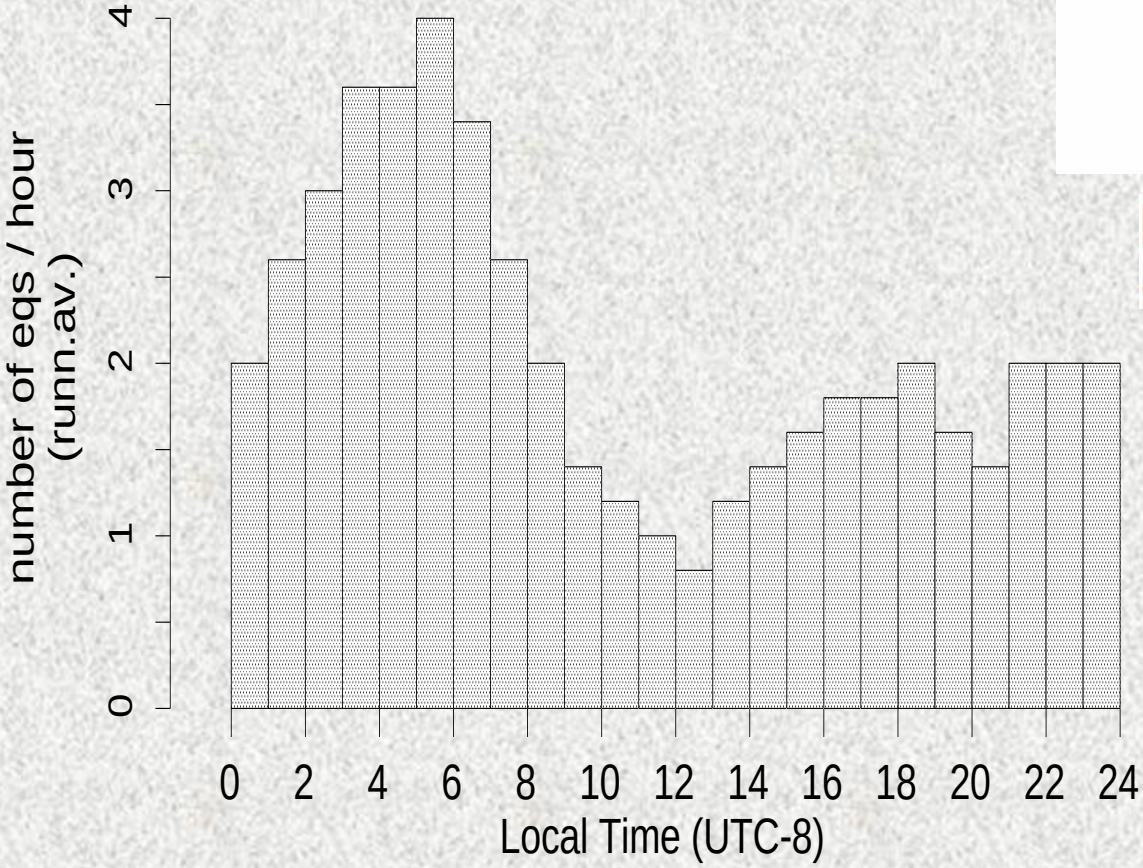
Shiltsev PRSTAB 13, 094801 (2010)

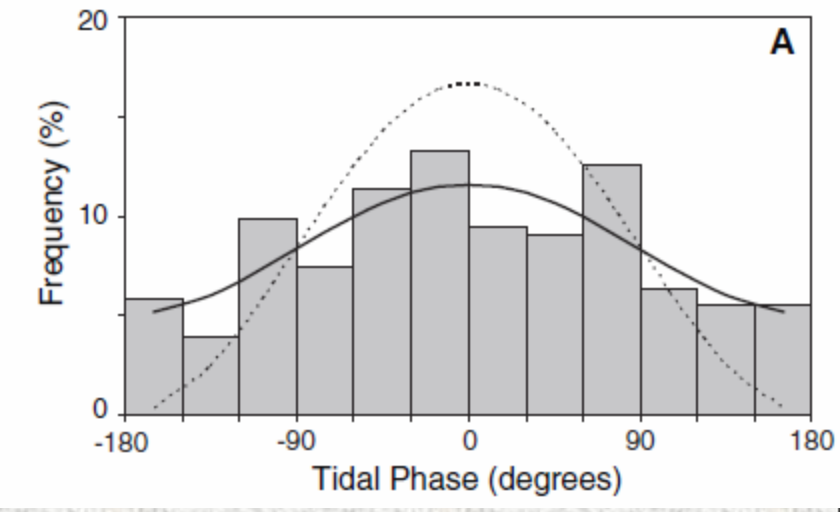
(get estimates)

Next Step #1: *A* vs Local Time

Histogram of fifty M>6.0 earthquakes in Southern California (1880-2005) vs. local time.

Duma, Ruzhin (2003)





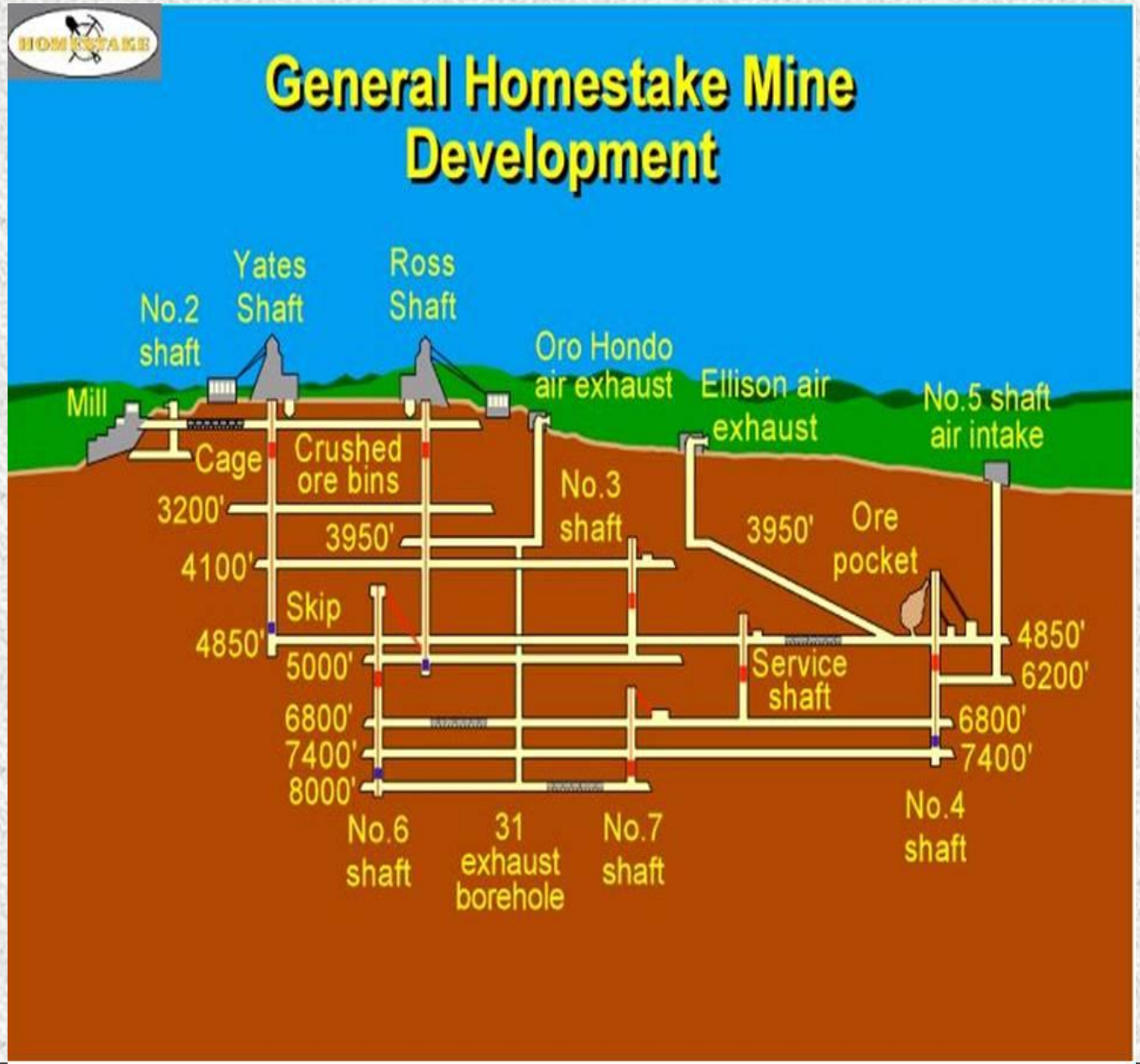
Elizabeth S. Cochran, *et al.* *Science* **306**, 1164 (2004);

Measure diffusion rate *A* every hour, seek possible correlations with :

- tidal phase
- ionosphere
- magnetosphere
- solar activities/flares

More on Tides

Distribution of strong earthquakes ($M = 7.9 - 8.7$) *during synodic month from 1903-1956 occurring near perigee* (± 2.5 *days*) *(after Tamrazyan,* 1968*b*).

Magnitude (M)	Number of earthquakes			
	New Moon	First quarter	Full Moon	Last quarter
8.7			1	
8.6			1	
8.4	3	1	2	
8.3	2	1	3	
8.1		1	2	2
7.9	5	1	3	1
Total	10	4	12	3

Next Step #2: *A* vs Depth