The Geodetic Interferometers at Gran Sasso

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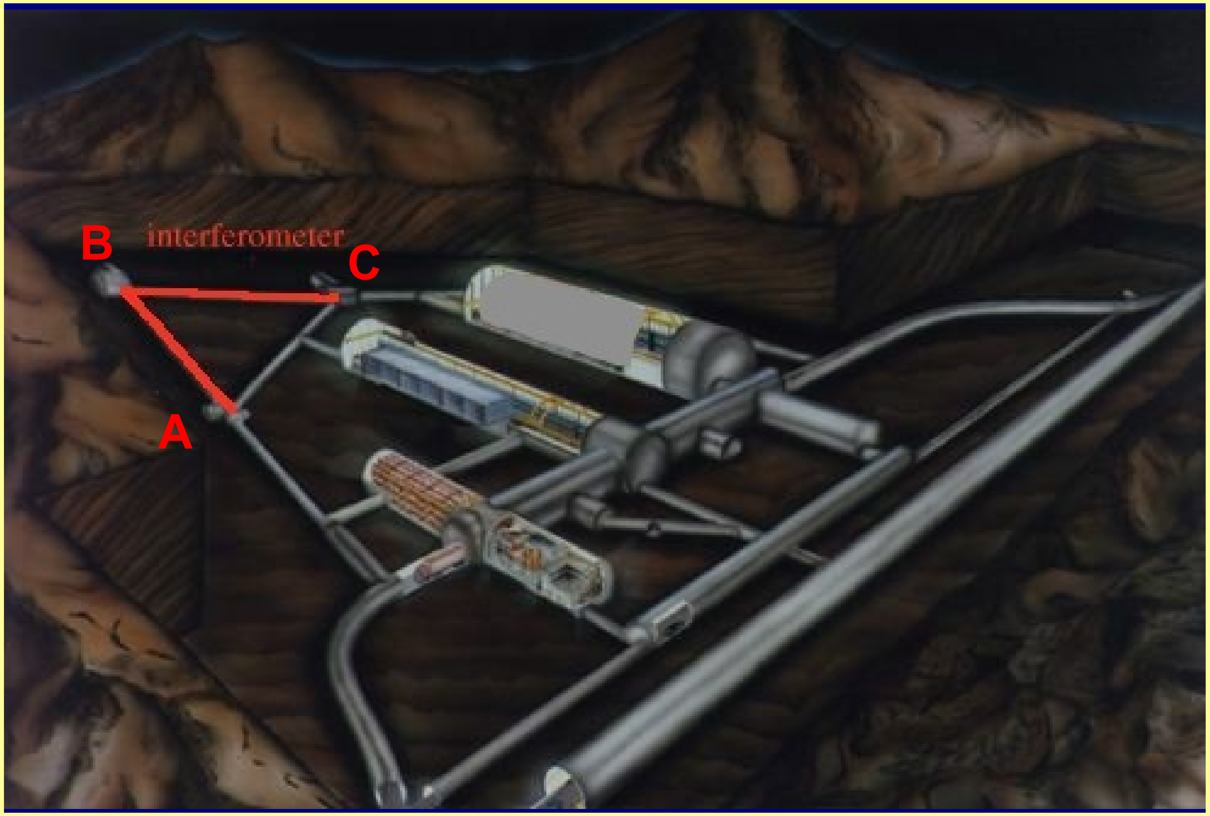
Outline

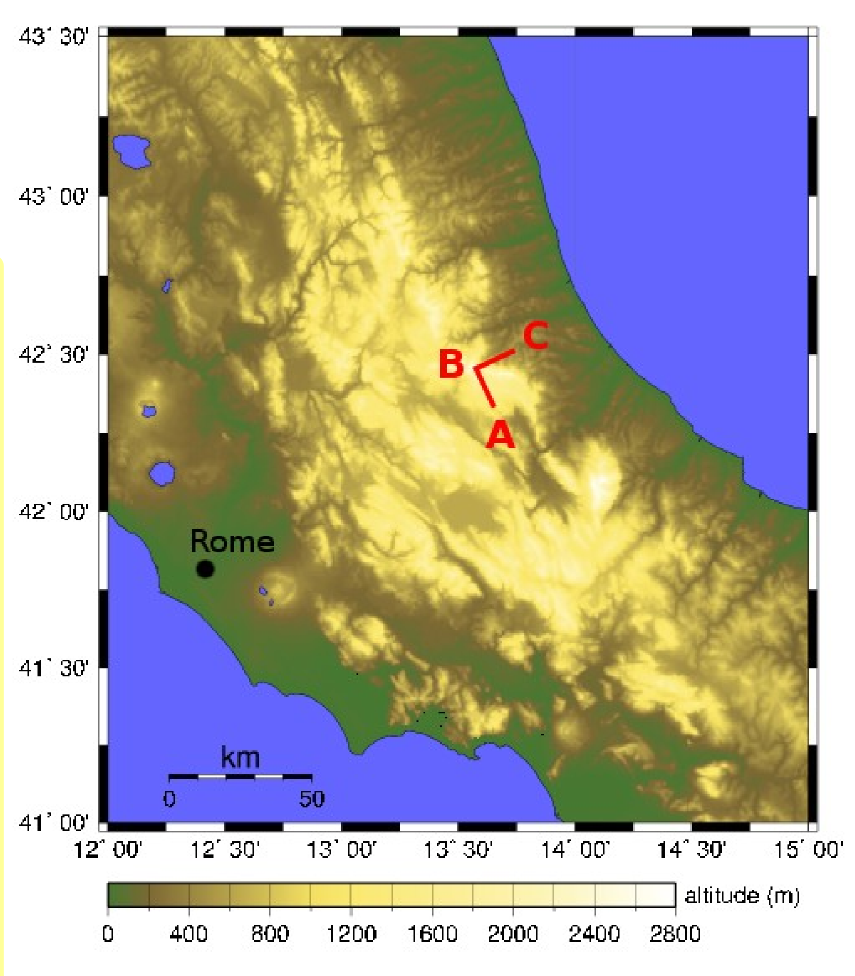
- *What do we measure?*
- *What is the experimental set-up?*
- *Why are we using laser interferometers?*
- *What do we aim to study?*
- *What about our main results?*
- *What about current activities?*

Q: What do we measure?

A: A-B and B-C distance changes with time

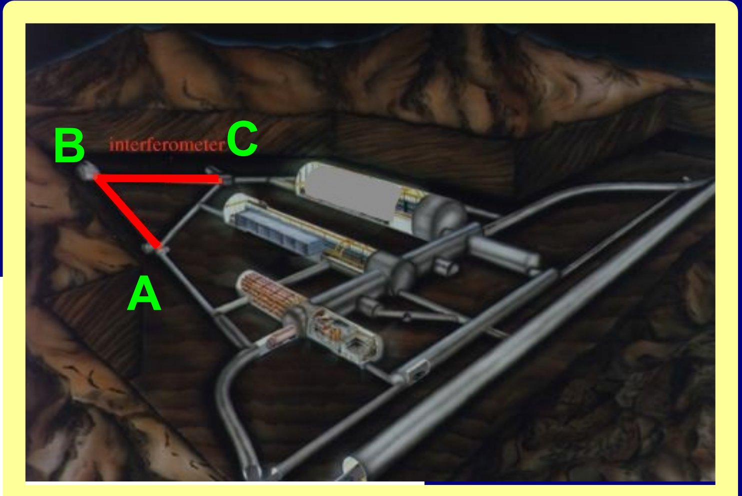
- two independent components of the strain tensor;
- close to the free surface only three components are independent

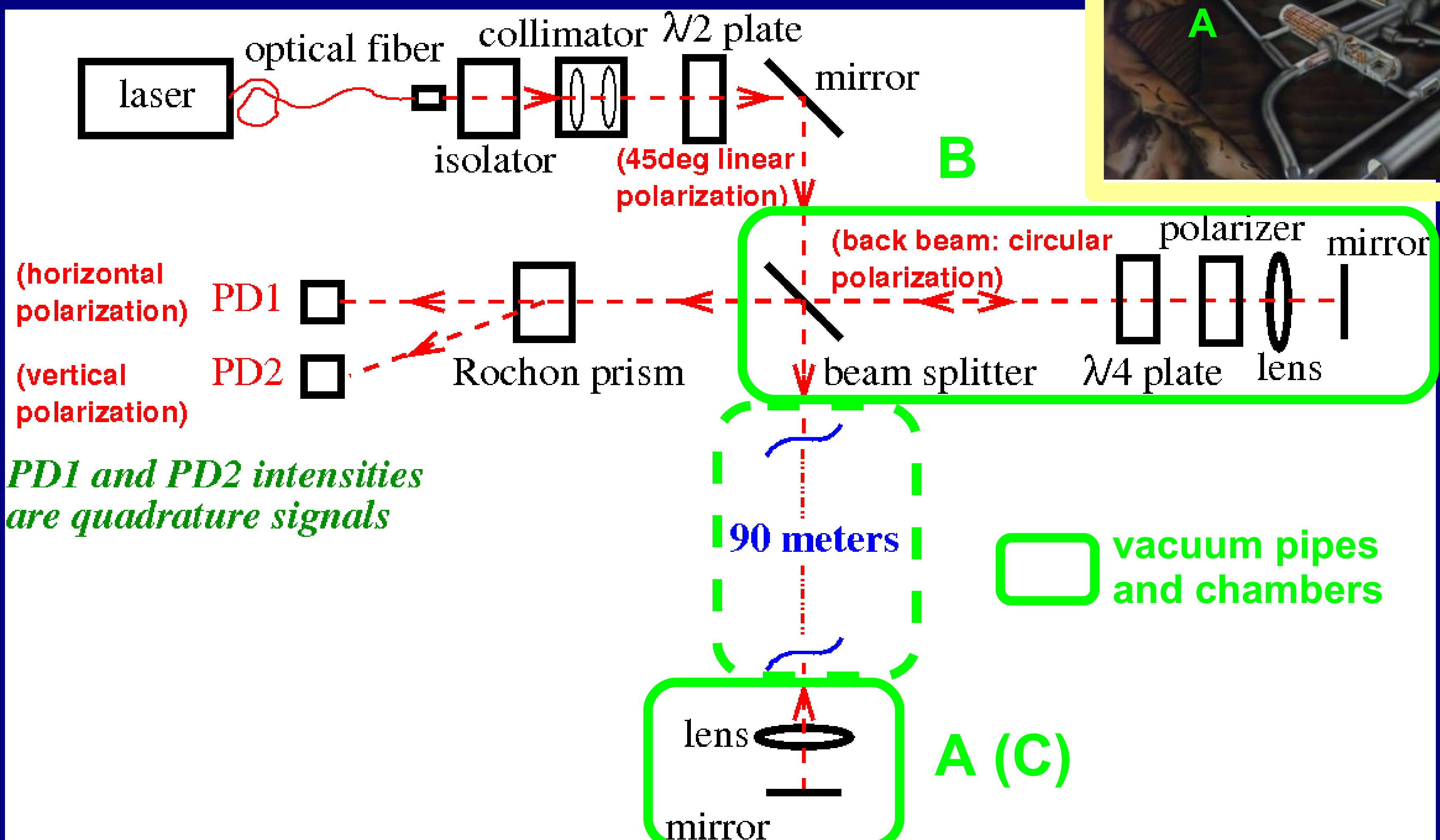




Q: What is the experimental set-up?

A: Unequal-arm Michelson interferometers





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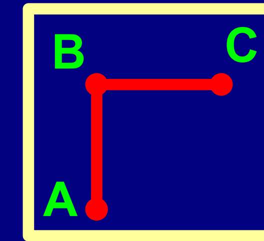

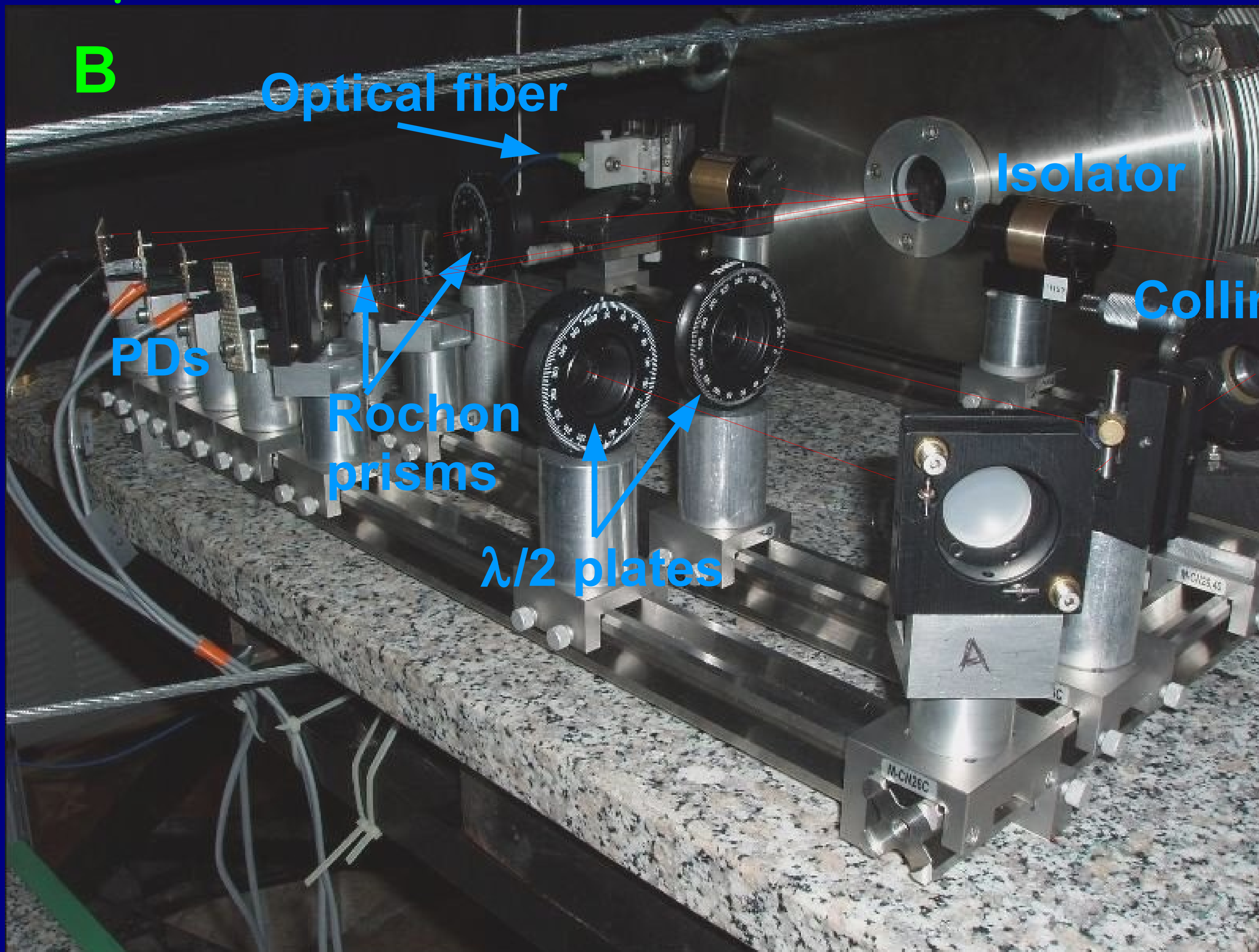

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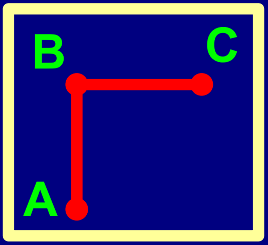

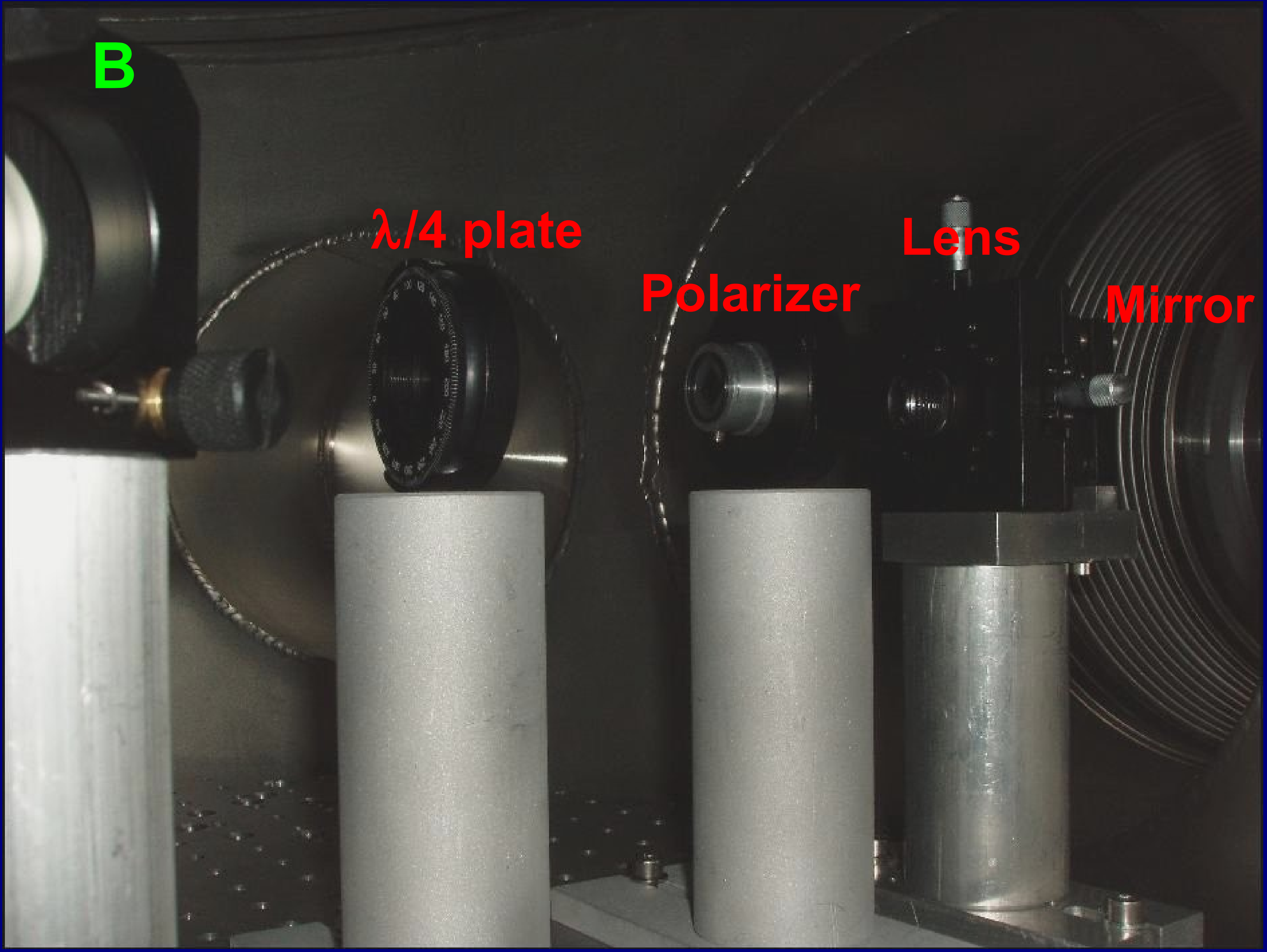

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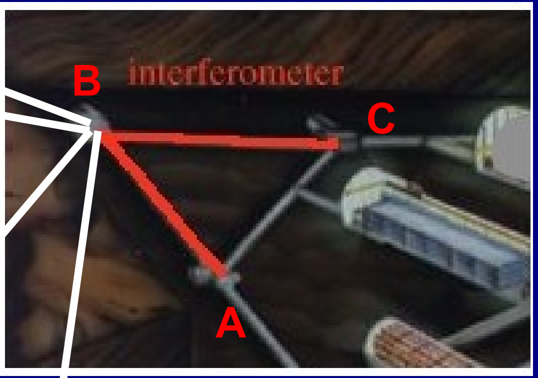

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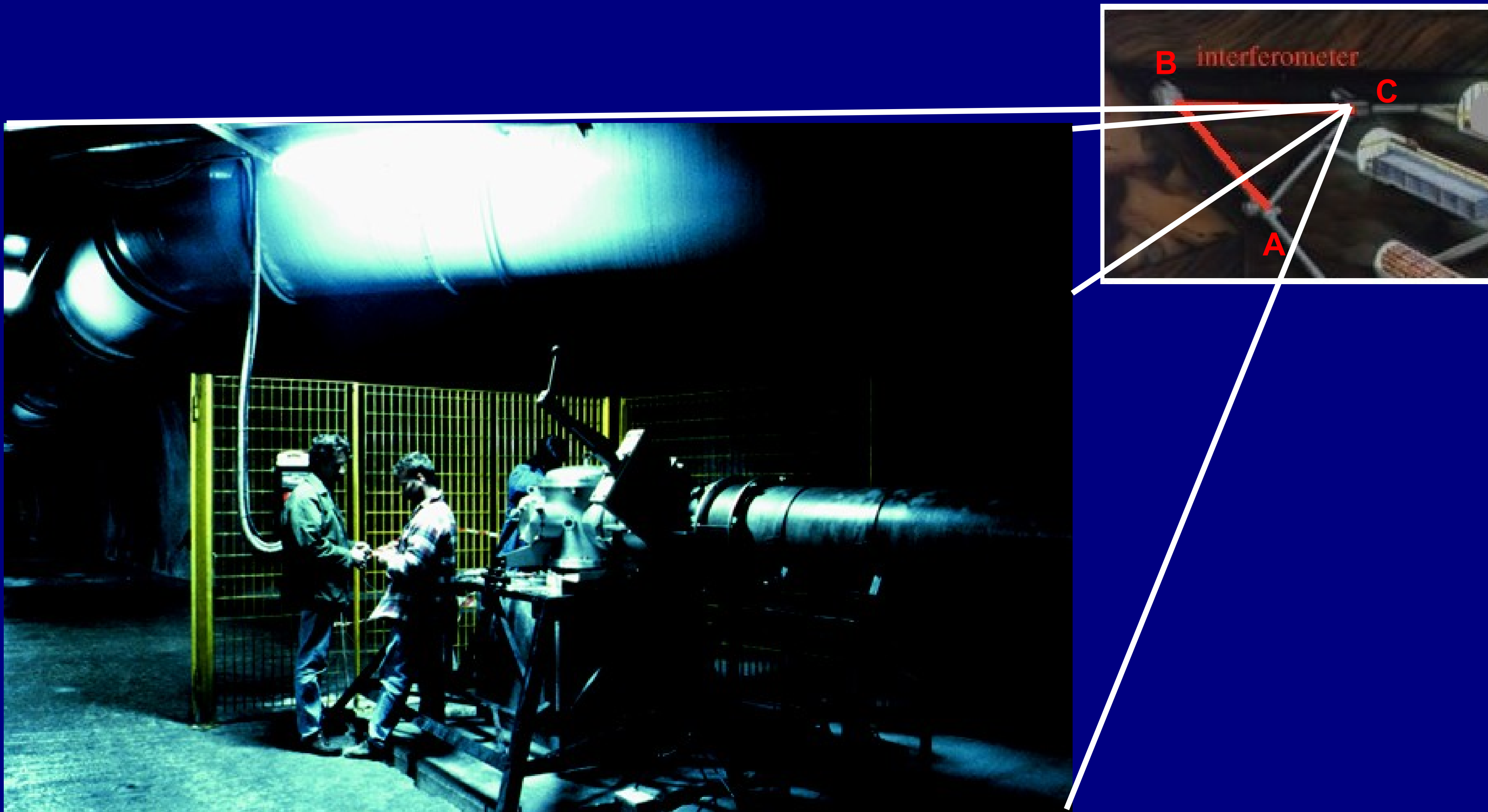

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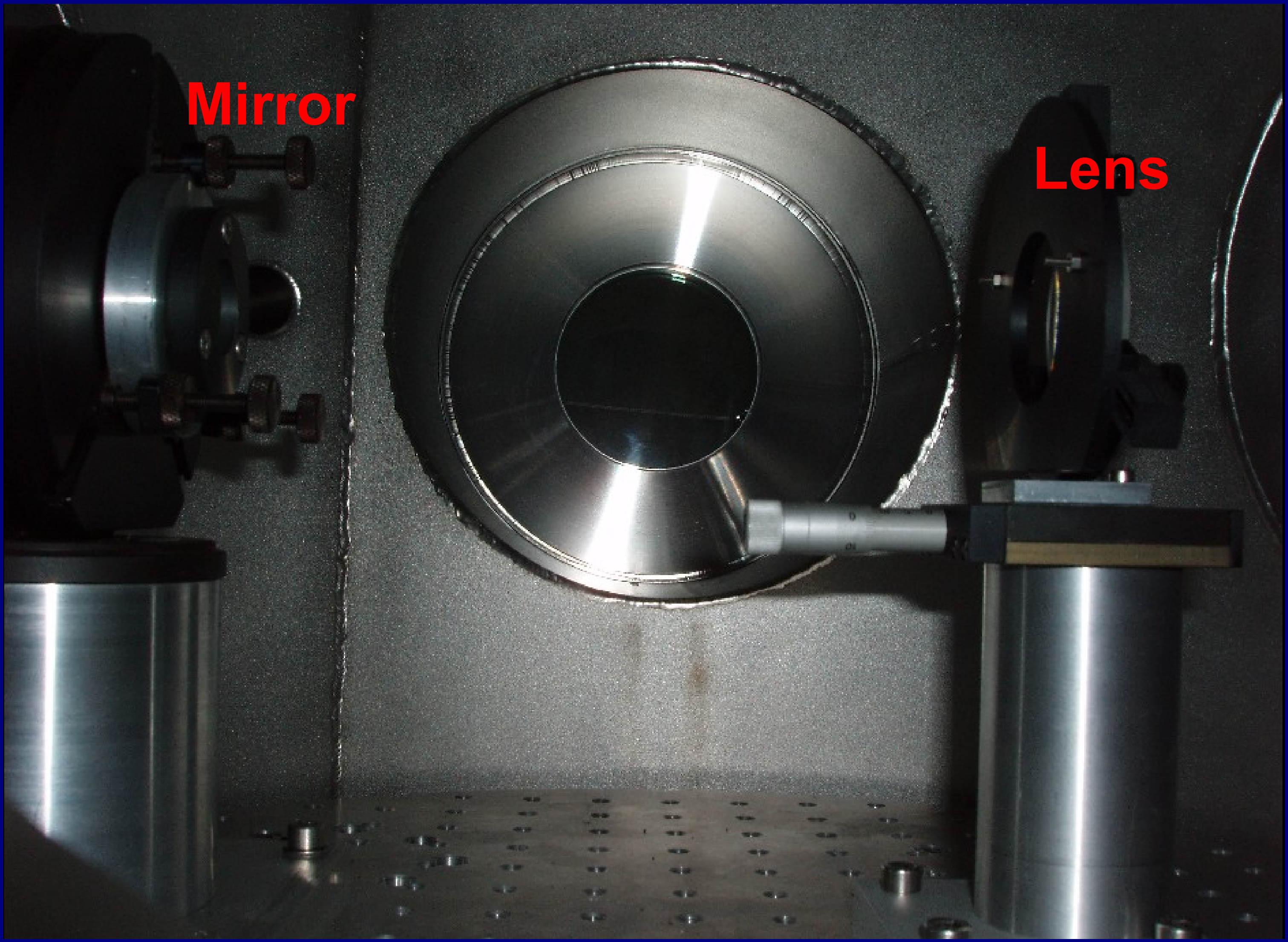

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IF

VP and HP were in-phase and quadrature components,

& IF

both channels were perfectly balanced (zero-mean, same amplitude)

THEN

VP=sin(ϕ); HP=cos(ϕ)

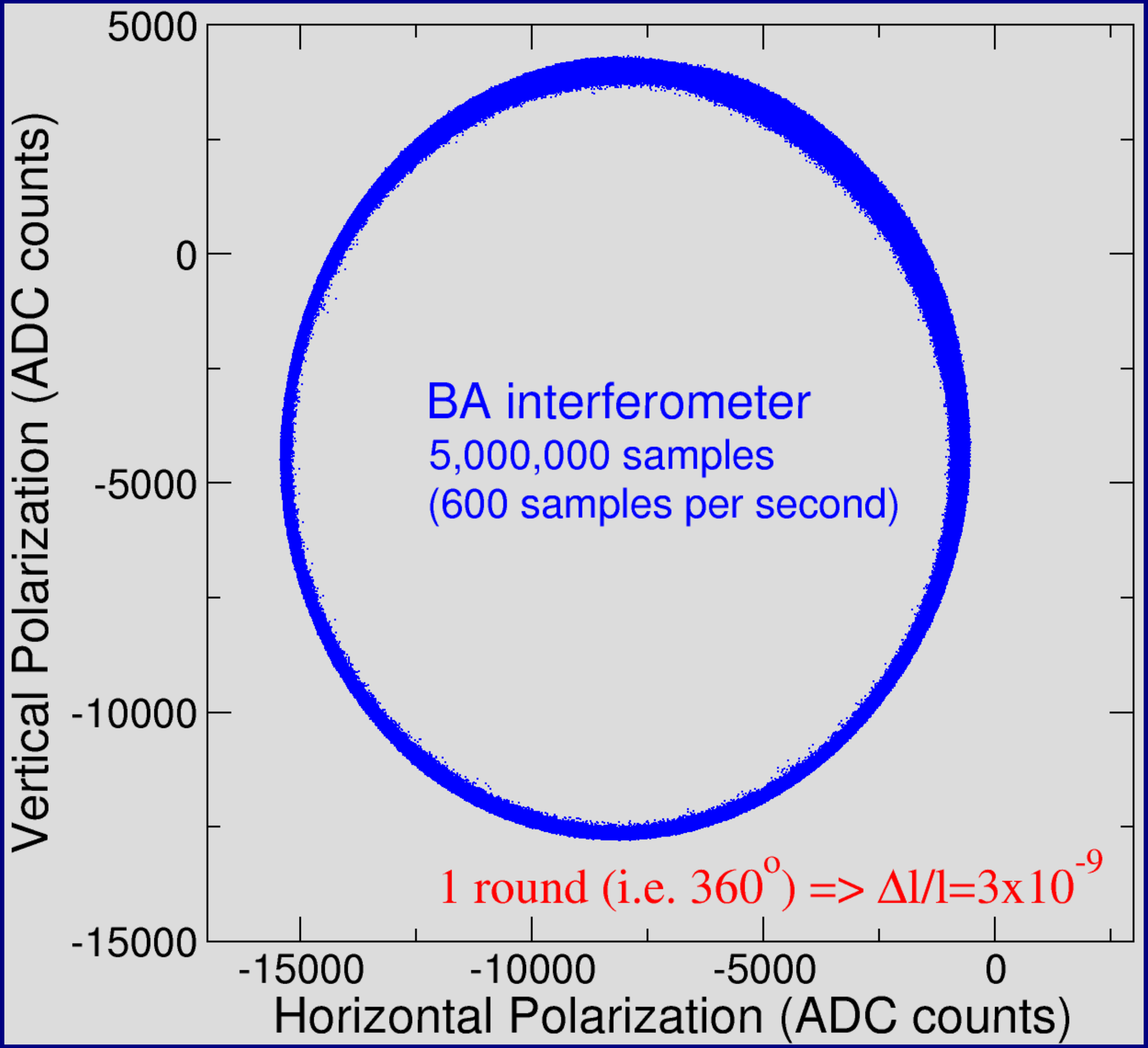
BUT

it is not so

THUS

two-step procedure:

1) Nonlinear fit of an ellipse to ~1hr samples
2) Phase retrieval for each sample, using the best-fit ellipse parameters



What do we aim to study?

Nominal resolution is $\Delta l/l \approx 10^{-12}$

Maximum $\Delta l/l$ is nominally unlimited

Nominal bandwidth is ≈ 200 Hz to 0 Hz

THUS

it is (at least in principle) possible to observe the entire geodynamical spectrum:

- short- and long-period seismic waves
- free oscillations of the Earth
- slow earthquakes
- Earth tides
- seasonal phenomena (e. g. charging and discharging of the aquifer)
- tectonic deformation

Question:

Is a so huge apparatus (pipes, holders, etc.) necessary?

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Absolutely NO!

Extra size was chosen to allow for several different solutions (e.g. multi-pass configuration).

Now we are confident on the adopted set-up and everything can be make much smaller for future installations.

Why are we using laser interferometers?

Because long-baseline laser interferometers:

- **have long-term stability (much longer than mechanical instruments)**
- **average over small-scale heterogeneities**
- **measure strain even in porous fluid-satured rock (it is not so for borehole strainmeters)**

What about our main results?

- *Slow earthquakes (hundreds of seconds)*
- *Free oscillations (thousands of seconds)*

What about our main results?

Slow earthquakes

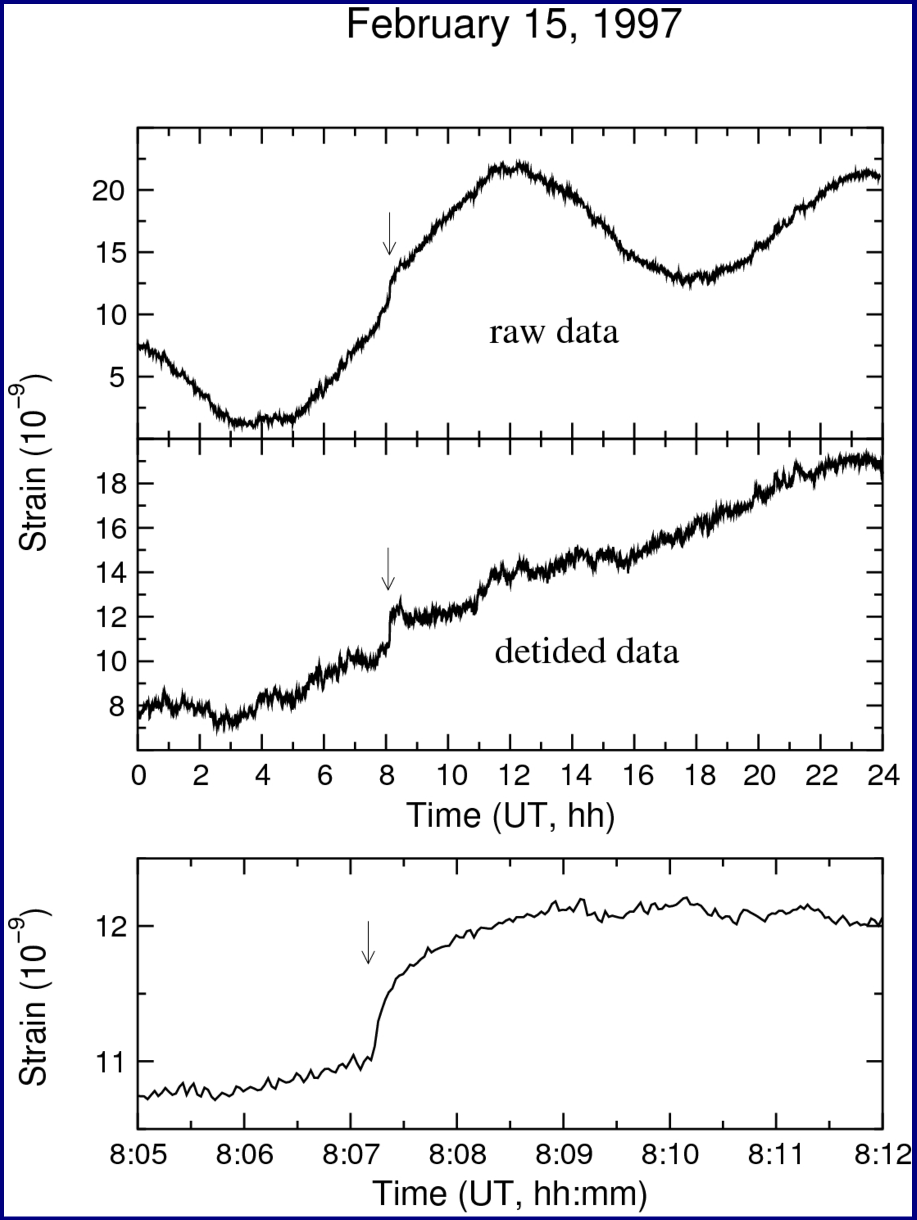
A slow earthquake is a discontinuous, earthquake-like event that releases energy over a period much longer than usual earthquakes.

Slow earthquakes might play an important role in the stress redistribution process.

L. Crescentini, A. Amoruso, and R. Scarpa, Constraints on Slow Earthquake Dynamics from a Swarm in Central Italy, *Science*, **286**, 2132, 1999.

A. Amoruso, L. Crescentini, A. Morelli, and R. Scarpa, Slow rupture of an aseismic fault in a seismogenic region of Central Italy, *Geophys. Res. Lett.*, **29**(24), 2219, 2002.

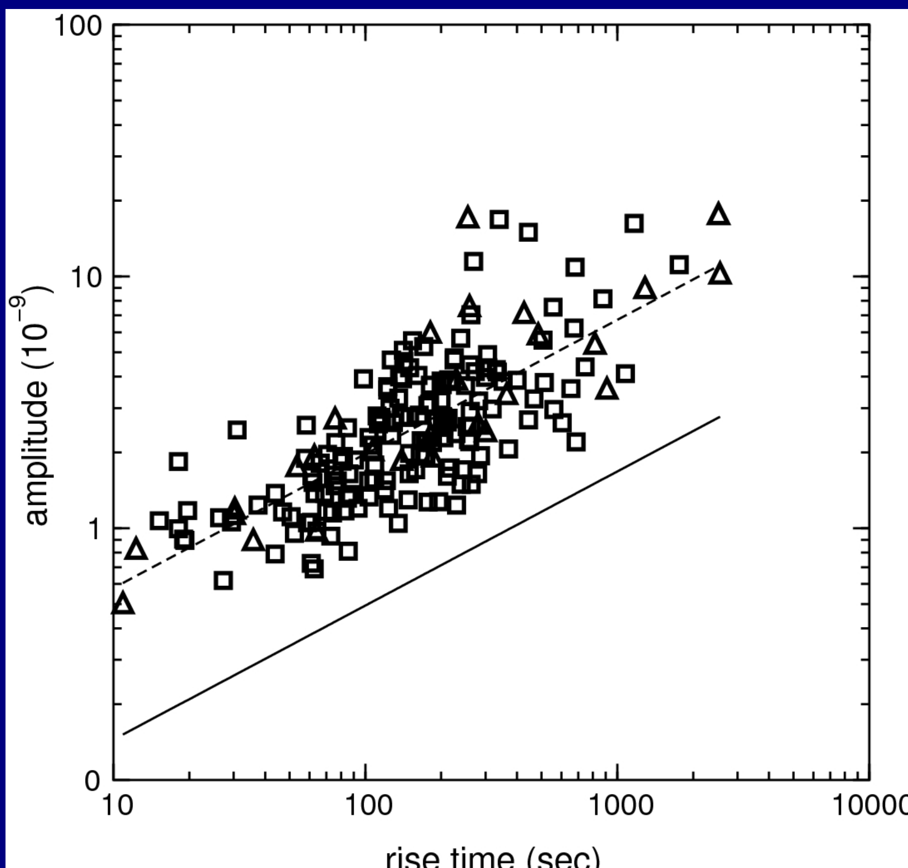
A. Amoruso, L. Crescentini, M. Dragoni and A. Piombo, Fault slip controlled by gouge rheology: a model for slow earthquakes, *Geophys. J. Int.*, **159**, 347, 2004.

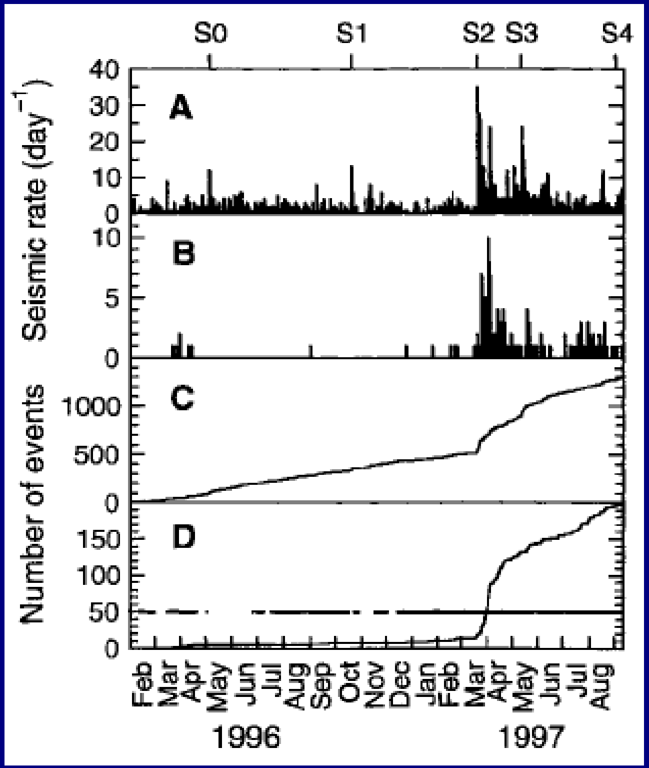


What about our main results?

Slow earthquakes

Novel scaling law between the strength of the events (seismic moment) and the duration of the rupture, different from that for usual eartquakes.





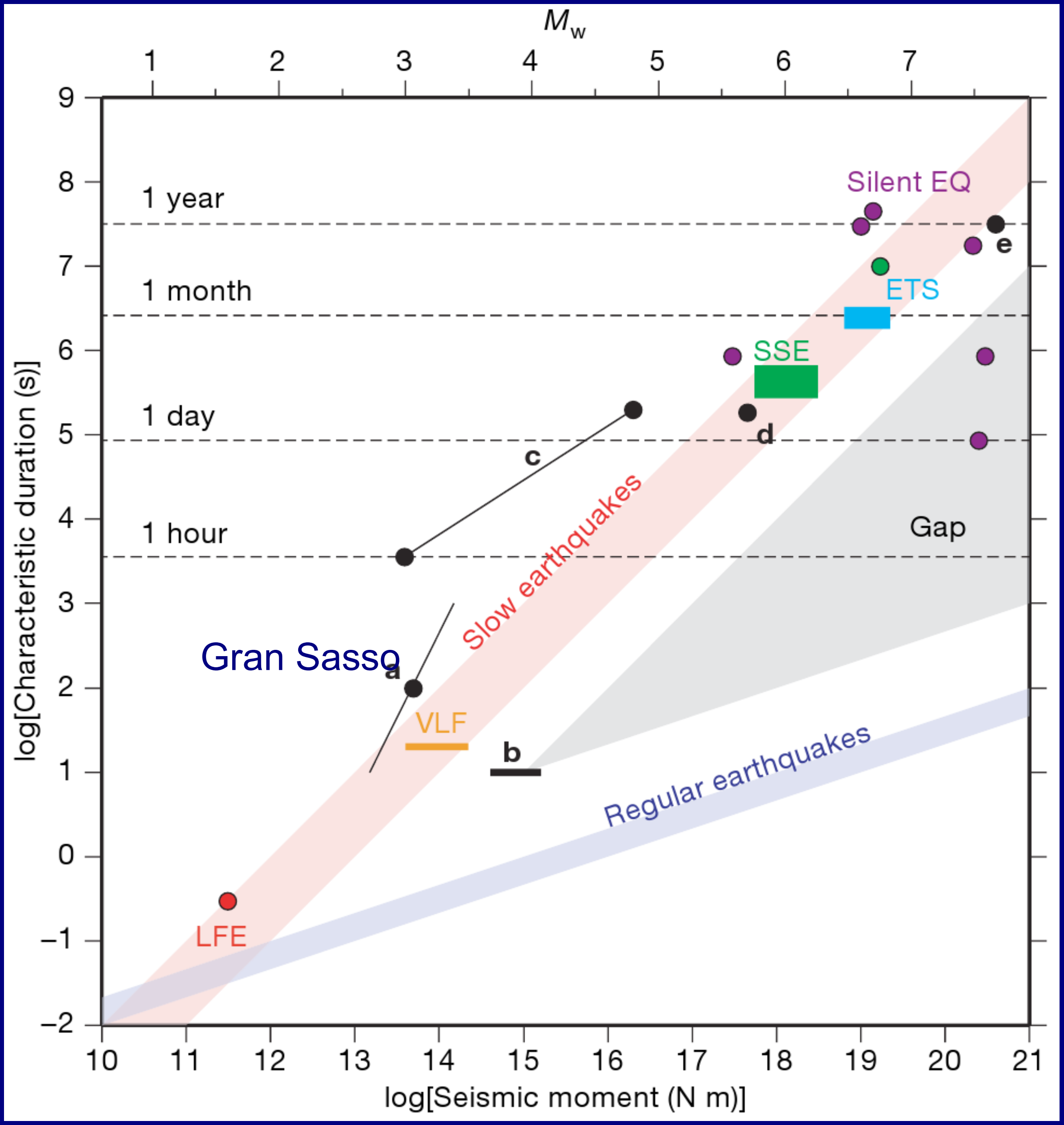
Slow-earthquake seismicity and 1997 regular earthquakes as a the consequence of a single stress redistribution phenomenon affecting a large area of the Apennines.

What about our main results?

Slow earthquakes

The existence of a peculiar scaling law for slow earthquakes has been recently confirmed using more than 10-year data from all the word.

S. Ide, G. C. Beroza, D. R. Shelly, and T. Uchide, A scaling law for slow earthquakes, *Nature*, **447**, 76, 2007.

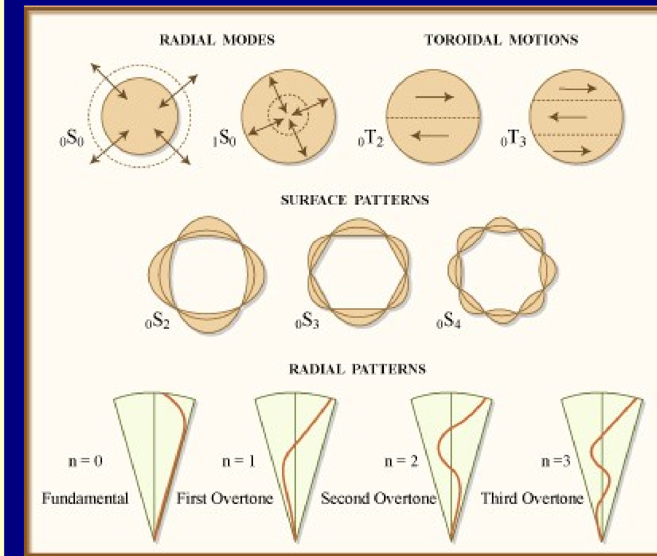


What about our main results?

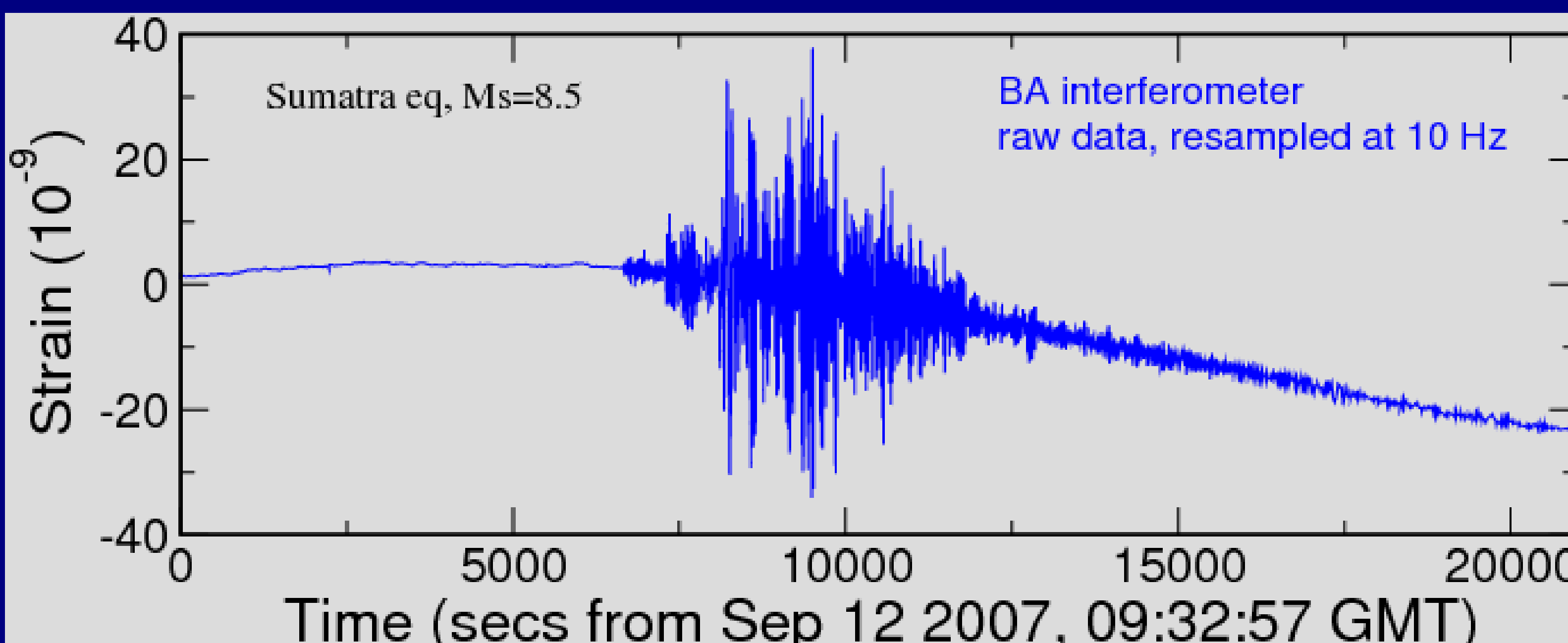
Free oscillations of the Earth

J. Park, A. Amoruso, L. Crescentini, and E. Boschi, Long-period toroidal earth free oscillations from the great Sumatra–Andaman earthquake observed by paired laser extensometers in Gran Sasso, Italy, *Geophys. J. Int.*, **173**, 887, 2008.

Earth's free oscillations can be triggered by large earthquakes.



Surface and nodal patterns of free oscillations. (Image by MIT OCW.)

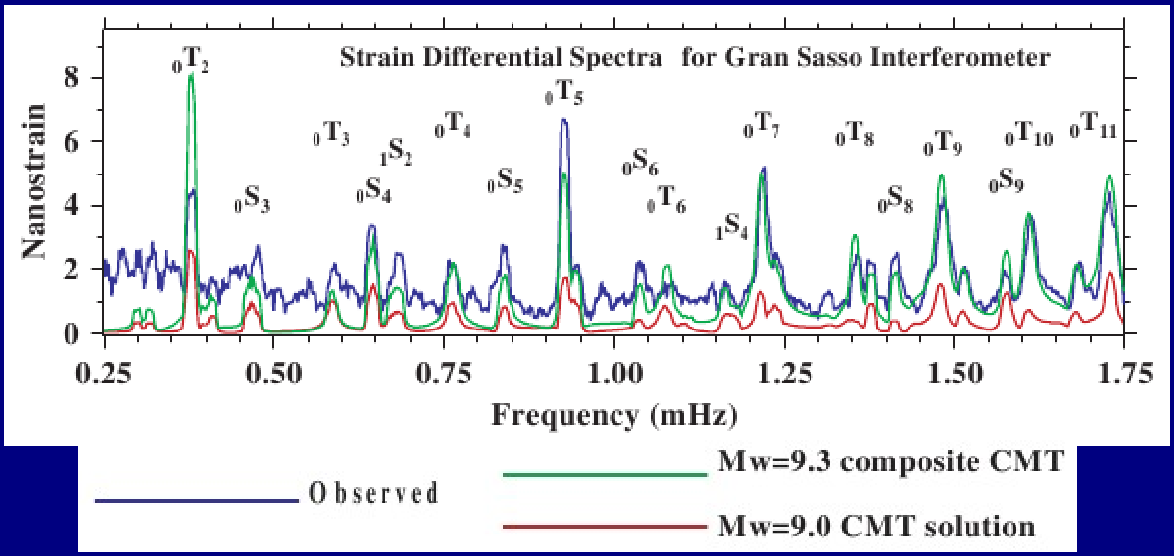


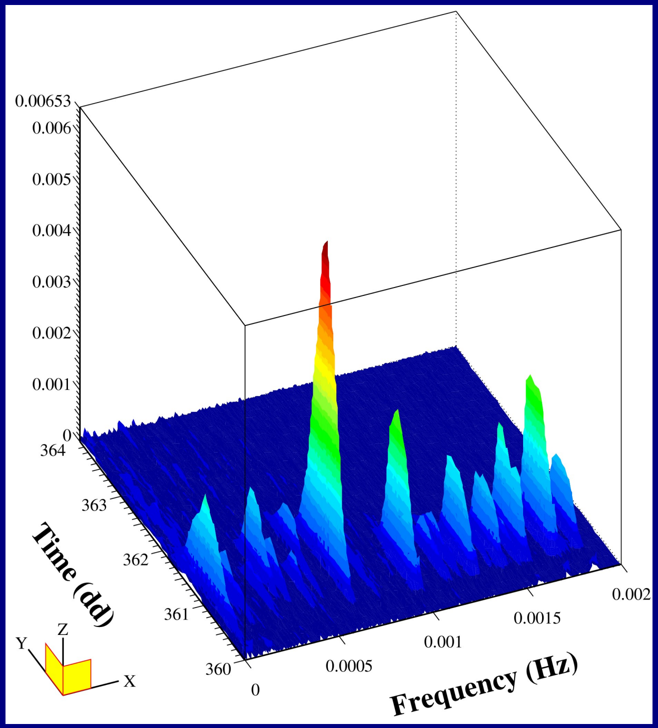
What about our main results?

Free oscillations of the Earth

Envelopes for free oscillations with period T<1000 s are approximated adequately by a M_w=9.3 composite CMT source. Envelopes for several toroidal free oscillations with T>1000 s are predicted less well. The amplitude of ${}_0T_2$ is overpredicted at Gran Sasso by a factor of two, and other modes are underpredicted. The amplitude discrepancy for ${}_0T_2$ is confirmed at selected exceptionally low-noise seismic stations.

The most plausible explanations are a slow-slip component of the seismic moment release and feedback from the Sumatra–Andaman tsunami on Indian Ocean coastlines.



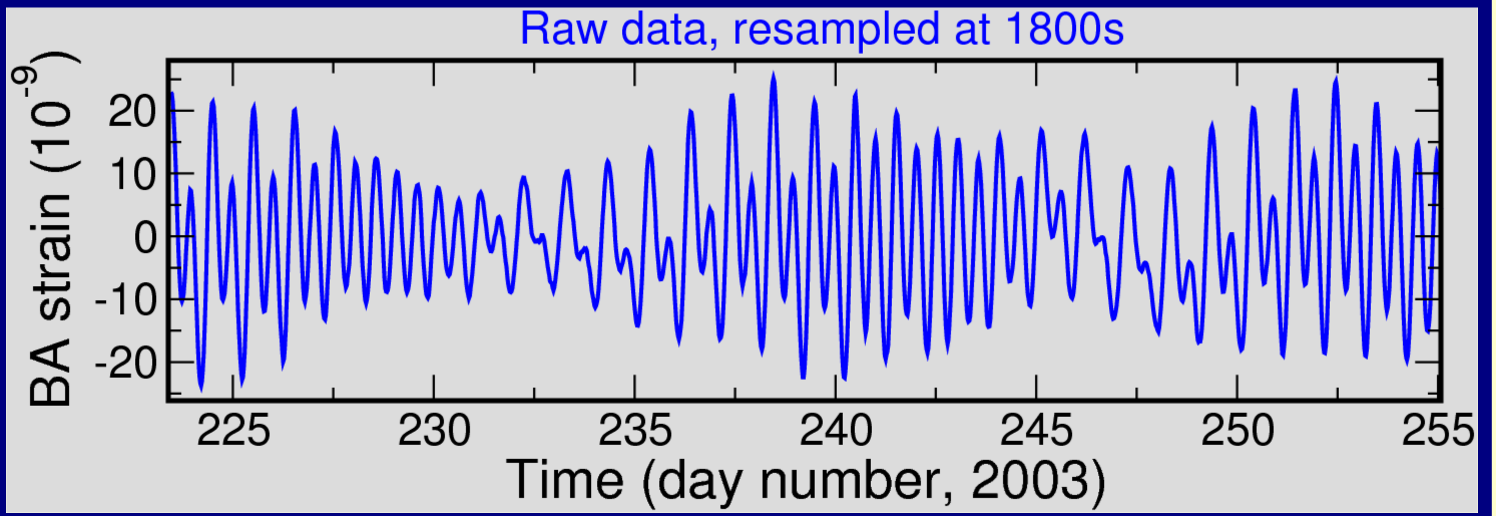


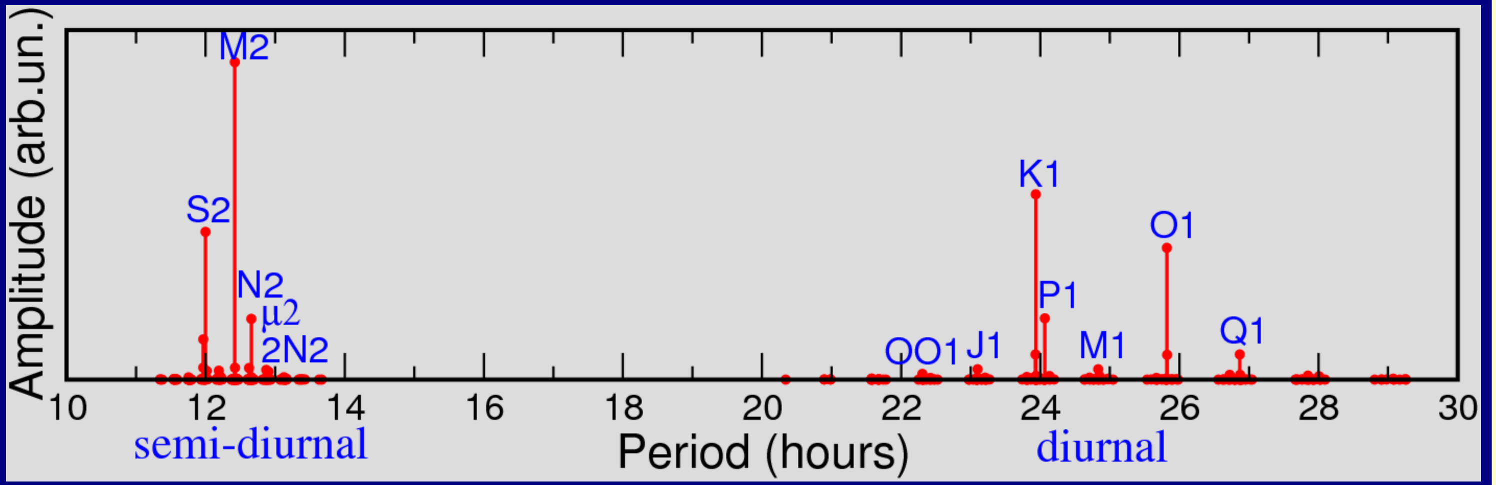
What about current activities?

- *Earth tides (Free Core Nutation) (several hours)*
- *Charging and discharging of the regional aquifer (months)*

What about current activities?

Earth tides (Free Core Resonance)





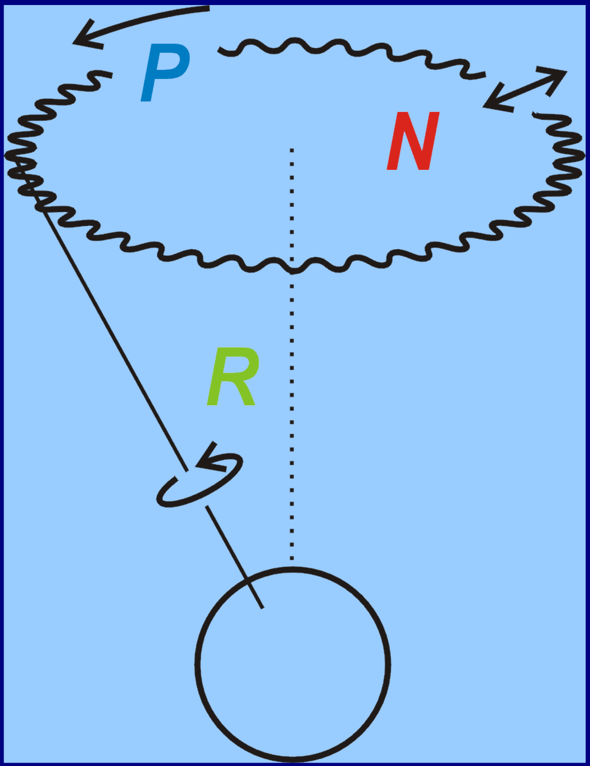
By earth tides, we understand all phenomena related to the variation of the Earth's gravity field and to the deformation of the Earth's body induced by the tide generating forces, i.e. the forces acting on the Earth due to differential gravitation of the celestial bodies as the Moon, the Sun and the nearby planets.

What about current activities?

Earth tides (Free Core Resonance)

The Free Core Nutation (FCN) is a rotational eigenmode which appears in addition to the well-known Chandler period (≈ 435 days). This mode is due to the pressure coupling between the liquid core and the solid mantle which acts as a restoring force.

The FCN causes a resonance on the Earth response to tidal forcing whose period T_{FCR} (situated in the diurnal tidal band) and quality factor Q depend on the core-mantle boundary (CMB) ellipticity, the Earth's inelasticity, and the viscomagnetic coupling of the CMB.

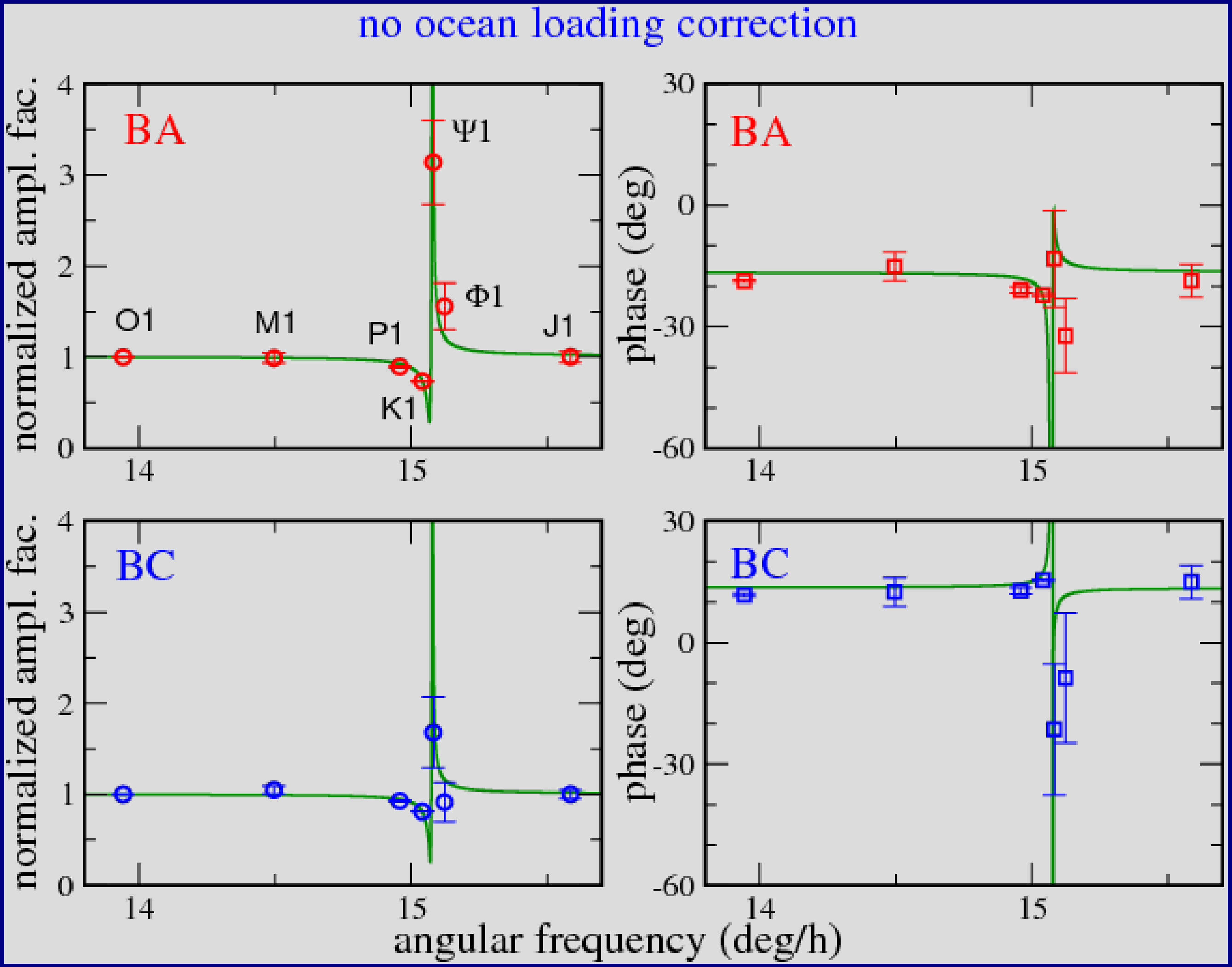


What about current activities?

Earth tides (Free Core Resonance)

The FCN is usually studied using satellite techniques and gravimeters.

Our preliminary results from strain tides give a very reasonable value for Earth inelasticity, much better than that obtained from gravity tides.



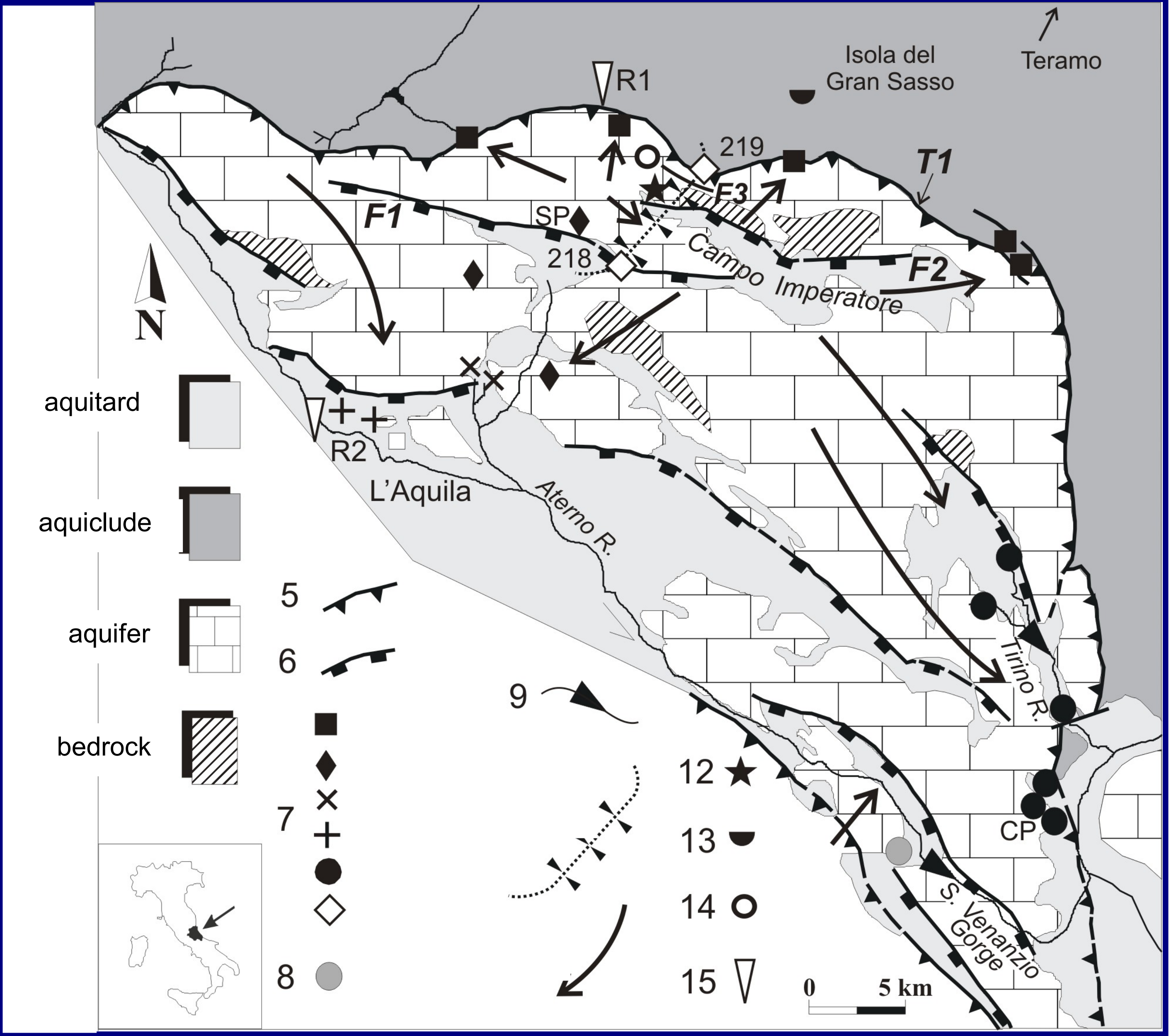
What about current activities?

Charging and discharging of the regional aquifer

in cooperation with
- M. Petitta (Univ. of Rome “La Sapienza”)
- M. Tallini (Univ. of L'Aquila)

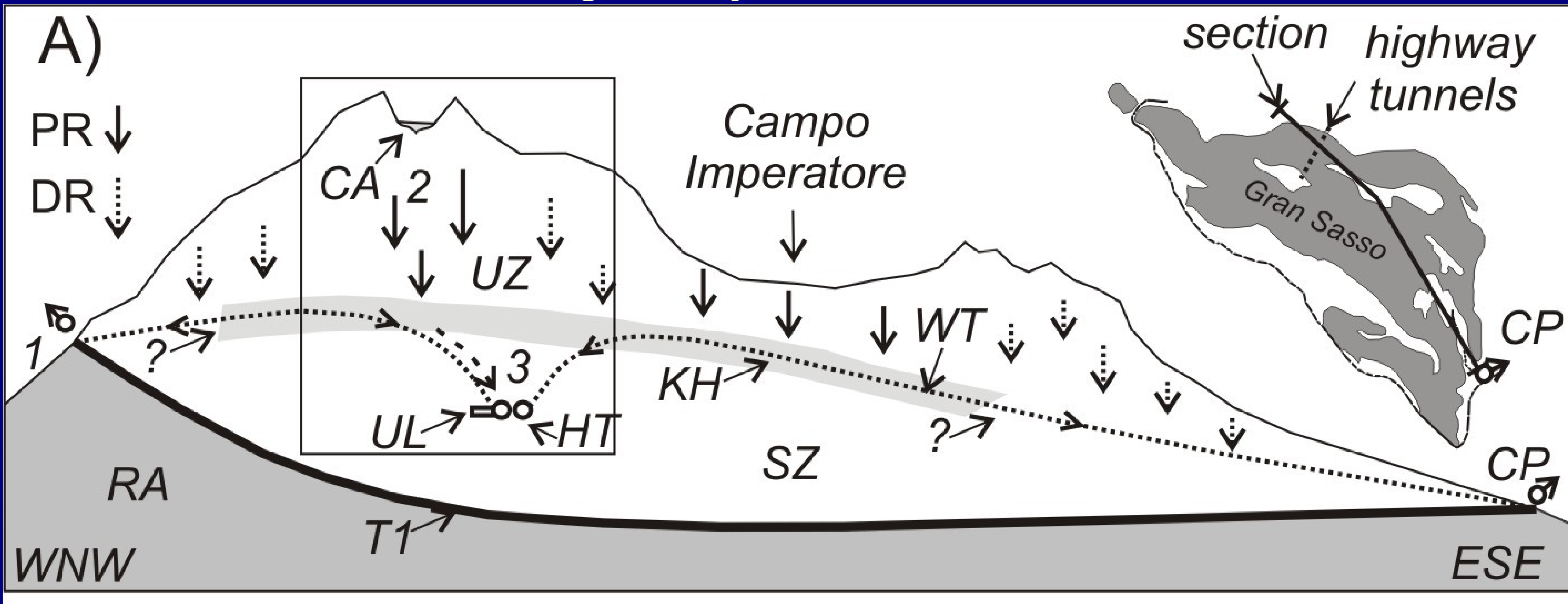
Hydrogeological setting

- Total spring discharge: 25 m^3/s
- Main faults represent groundwater divides, separating main flowpaths
- Recharge is 700-800 mm/anno and tecnono-karst depressions (Campo Imperatore) contribute to the infiltration process
- Springs do not show typical karst features and discharge regimen is steady (small changes during the year)
- Northern side springs have minor discharge, due to the elevation
- Higher discharge for southern springs
- Recent chemical and isotope studies have supported and refined this conceptual model



Adinolfi Falcone, R. et al., *J. Hydrol.* (2008), doi:10.1016/j.jhydrol.2008.05.016

Hydrogeological changes due to INFN Lab and Highway tunnels



- Drainage of the regional aquifer by the INFN Lab and tunnels ('70-'80) has caused depletion of the water table
- Around 1.5-2 m^3/s are nowadays intercepted by the underground cavities (max: 1.8 m^3/s tunnel; 0.2 m^3/s INFN Lab)
- Springs at the aquifer boundary have lower discharge
- New steady-state condition for the aquifer has been reached after tunnel drainage: further discharge lowering are due to decrease of recharge for climatic changes
- Detailed hydrogeological and hydrogeochemical studies have detailed INFN Lab hdyrogeological features
- INFN Lab corresponds to the transition from the unsaturated to saturated aquifer (water table), with a complex geology
- Groundwater flow in the INFN Lab can be referred to a dual-flow velocity model: a fast flow through main fractures and fault and a slow flow through minor fracture network.
- Recharge area of the INFN Lab is represented by high-altitude ridge, including Calderone glacier

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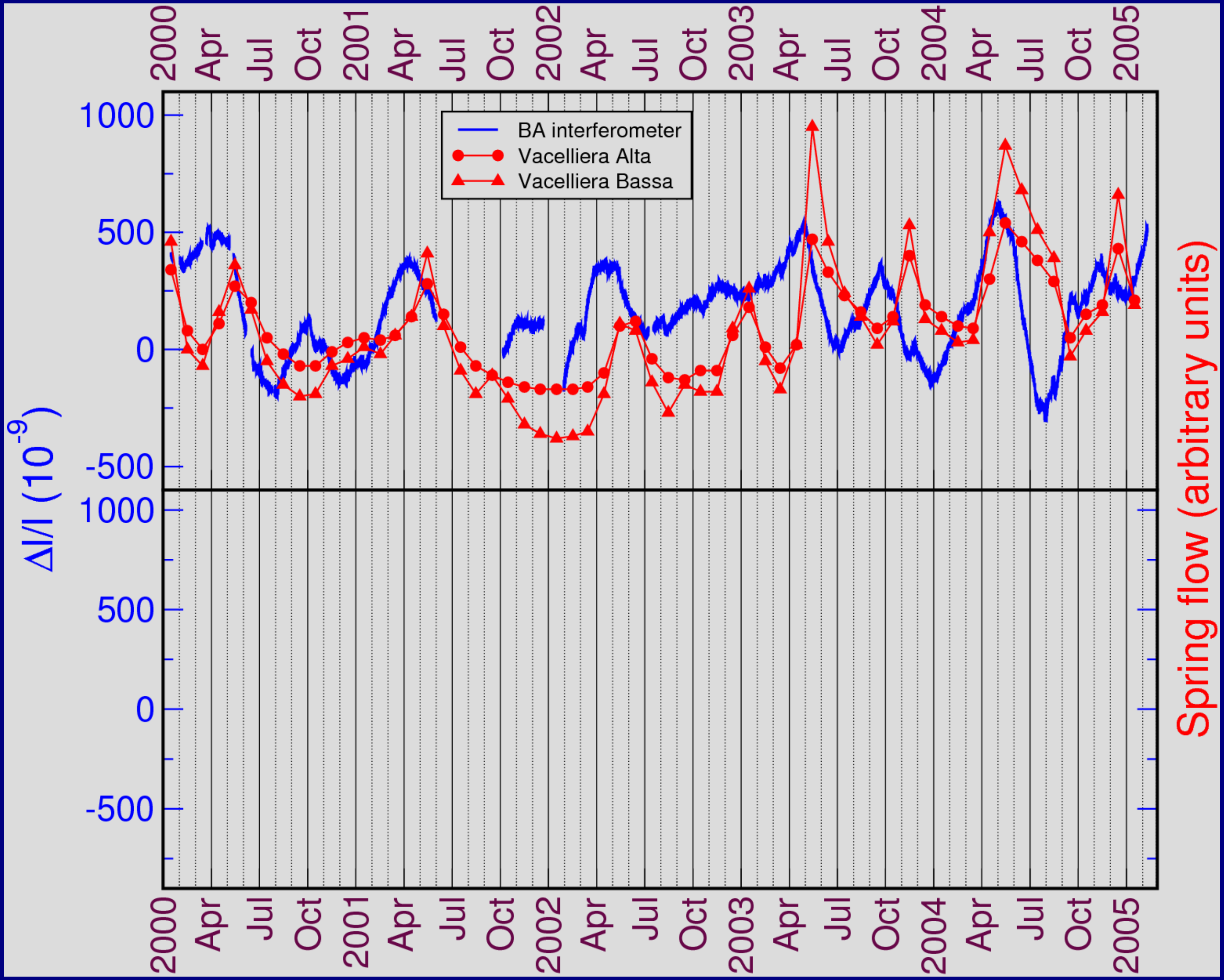

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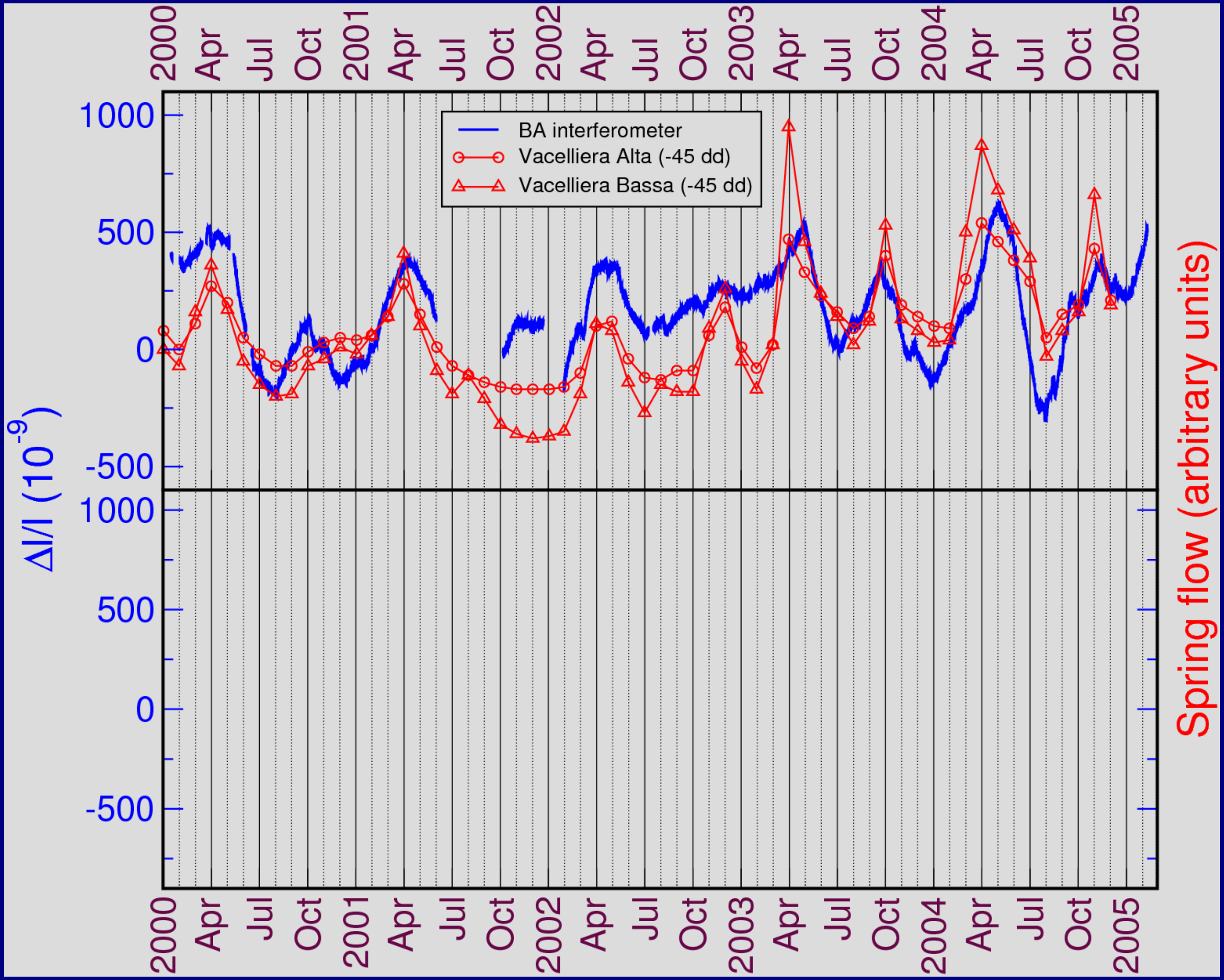

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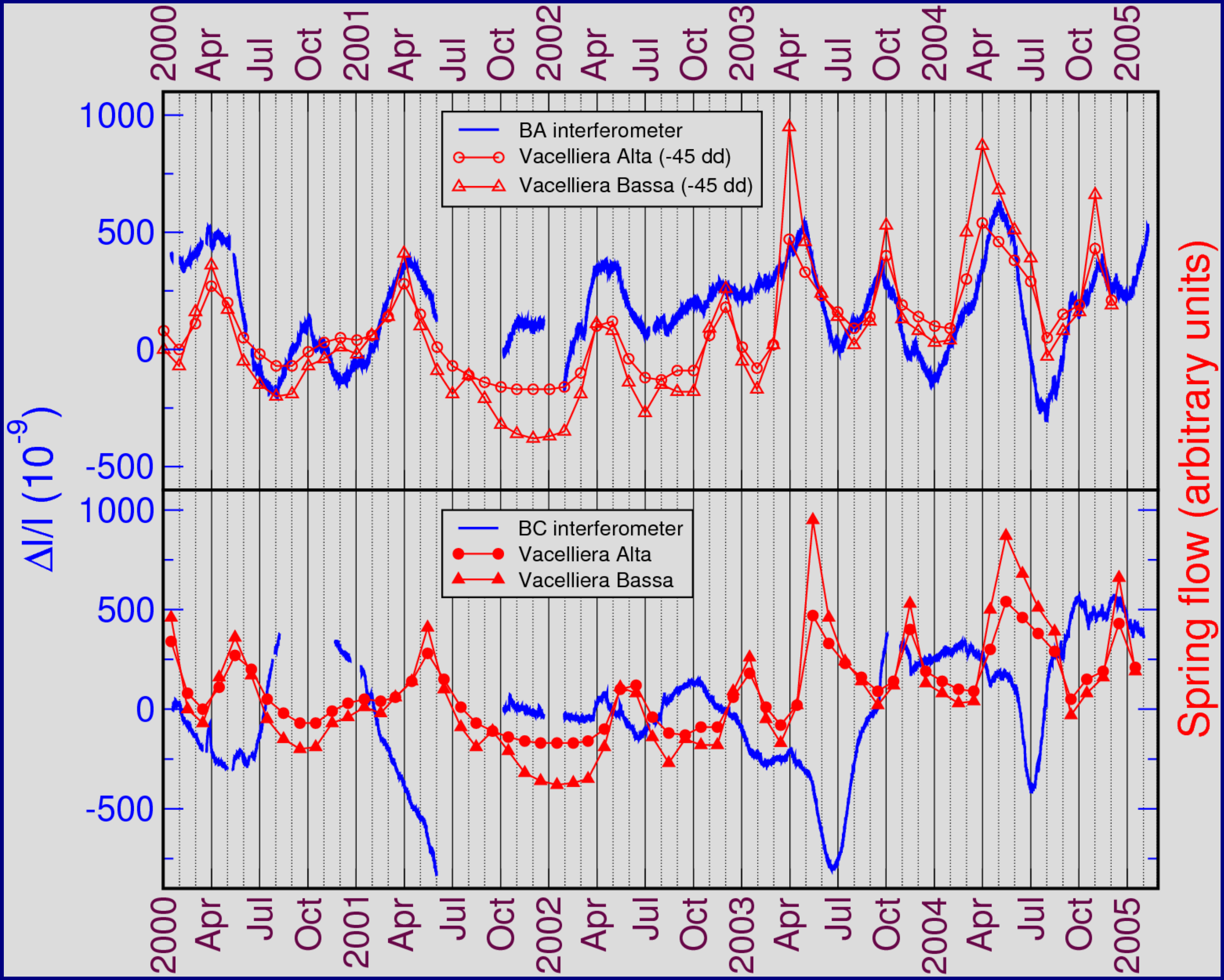

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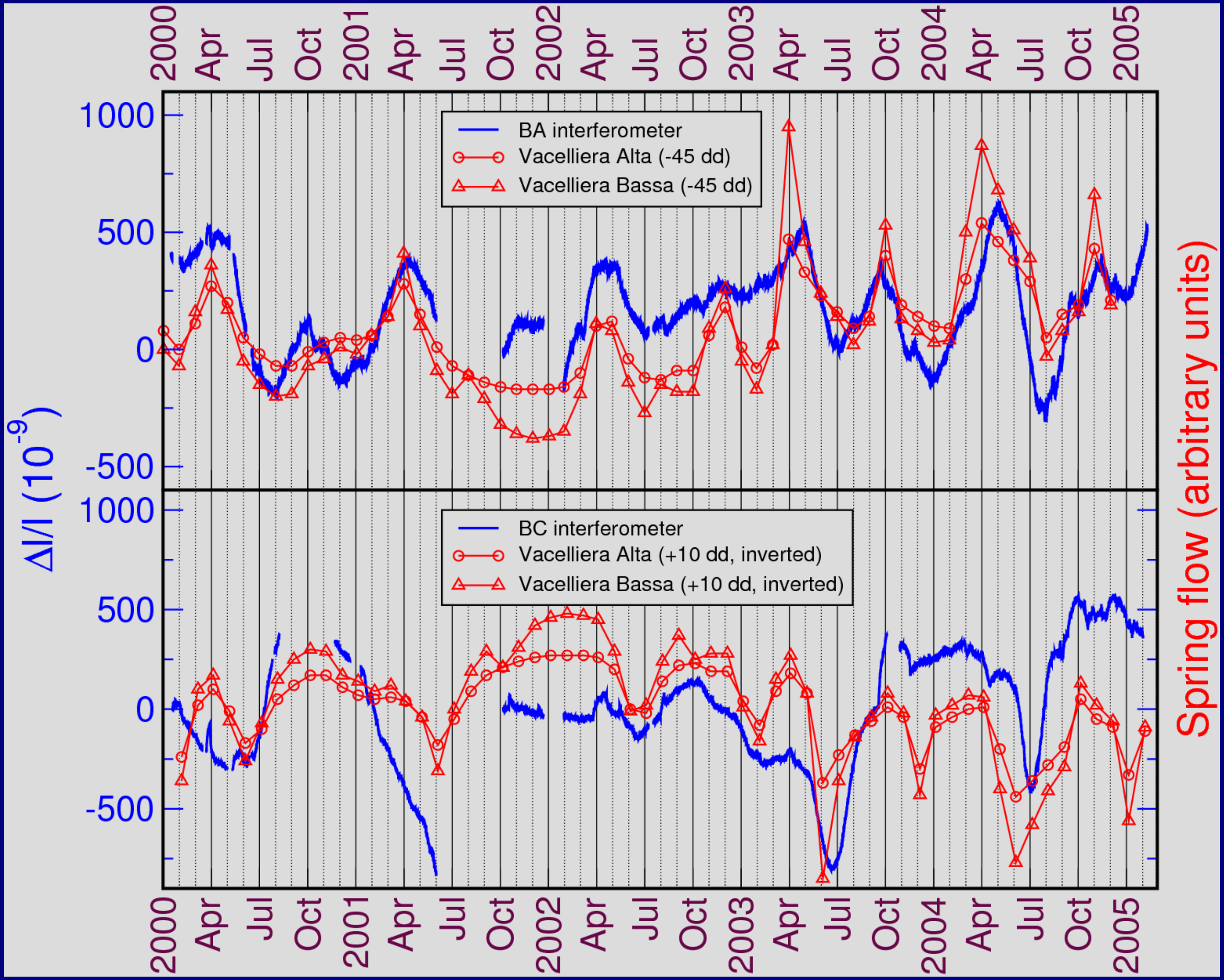

Thanks