# Kelvin Probe Measurements of the Patch Effect

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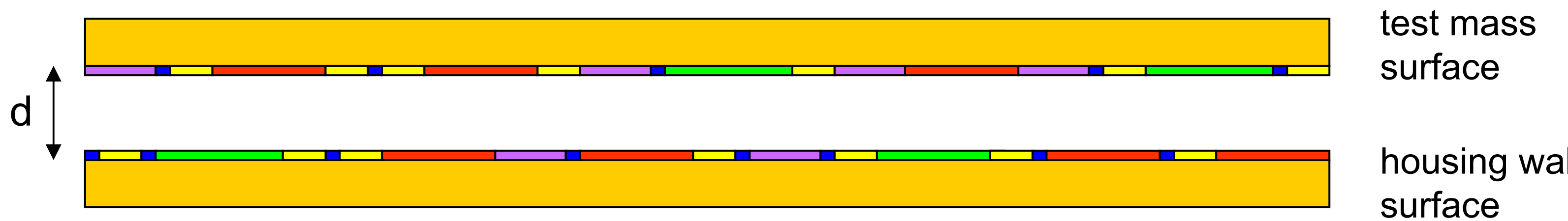
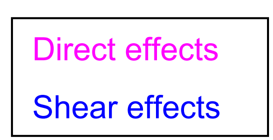
*Work done while at Stanford University, in collaboration with S. Buchman, R. L. Byer, D. Gill, J. Hanson, S. Williams, P. Zhou (Stanford University) and J. R. Blackwood, J. Camp (GSFC).

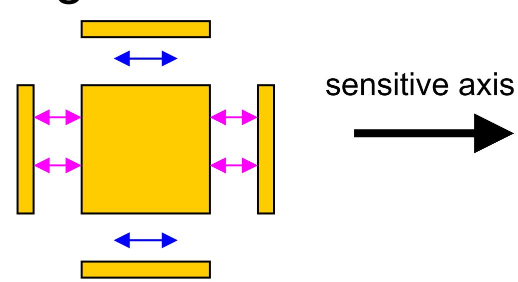
# The Patch Effect in ST-7 and LISA

- The patch effect refers to spatial variations in surface potential
- Sources include:
  - Polycrystalline structure of metal - potential varies with crystal orientation
  - Contamination
- Patch fields are present on test mass and housing wall surfaces




- Effects of patch fields may include time-varying forces and force gradients (stiffness), both of which lead to acceleration noise
- The effects can act to give force or stiffness directly along the sensitive axis *and* in the sensitive axis through shear force/stiffness from patches on transverse axes



# The Patch Effect continued

Spatial effects

- Interactions between patch fields cause forces that change with position (stiffness)
- Combination of stiffness and residual relative motion of test mass and spacecraft produces an acceleration noise term
- Stiffness is of the form[1]

$$\frac{K\varepsilon_0 A v^2}{d^3}$$

where *A* is the area of cube face, *v* is the standard deviation of the potential fluctuations (on appropriate spatial scale), *d* is the gap, and *K* is of order 1.

Temporal effects

- *temporal* variations in surface potential may produce a significant acceleration noise term in conjunction with
  - an ambient DC voltage, or
  - net free charge on the test mass[2]
- magnitude of temporal noise terms are proportional to $1/d^2$



[1]Speake C C 1996 *Class. Quantum Grav.* **13** A291-A297, [2]S Vitale

# Noise Estimates and Requirements

- Spatial effect
  - Requirement for ST-7: $v$ < 100 mV on appropriate spatial scale
  - $v$ ~100 mV also used by Schumaker[2] as working assumption in her noise budget analysis for LISA
- Temporal effect
  - Schumaker uses $10^{-5}$ V/√ Hz at $10^{-4}$ Hz in noise budget analysis for LISA
  - She comments that a value ten times larger, in combination with DC offset of 30 mV or net free charge of $10^{-13}$ C would dominate the total acceleration noise budget

Note: Numbers quoted assume gap size of 2 mm and other parameters as given in Schumaker's paper. Both effects are strong functions of gap size:

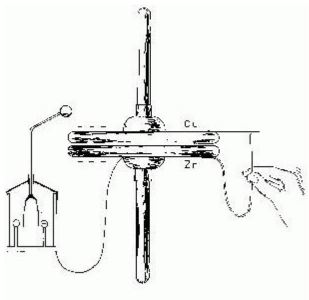
spatial effect $\propto 1/d^3$, temporal effect $\propto 1/d^2$



[2]Schumaker B L 2003 *Class. Quantum Grav* **20** S239-S253

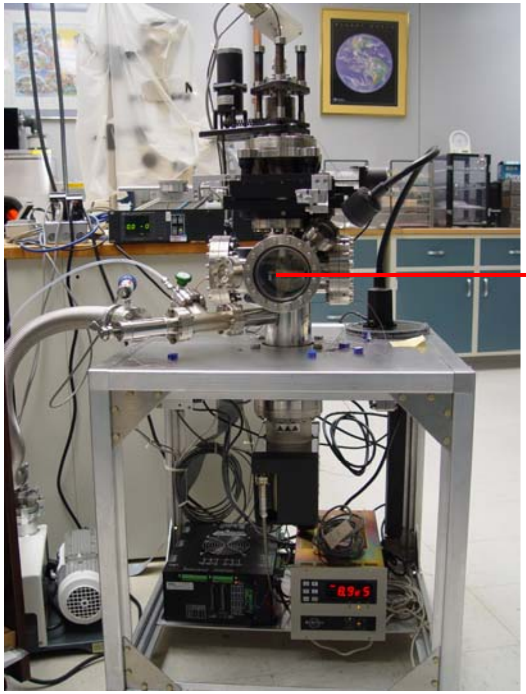
# Kelvin Probe

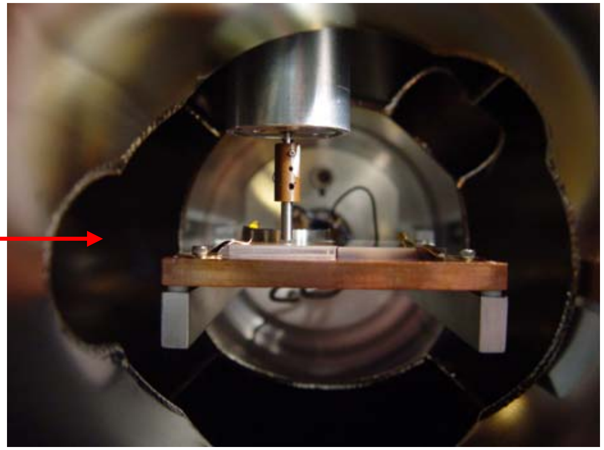
- The Kelvin probe measures contact potential difference (Vc) between a conducting specimen and a vibrating probe tip
- It is a non-contact, non-destructive vibrating capacitor device
- A backing potential Vb electrically connects specimen and probe tip
- When Vb = -Vc, circuit is balanced
- Null condition can be detected accurately



Kelvin's original apparatus

- The Goddard probe is a custom-built UHV system with scanning capability



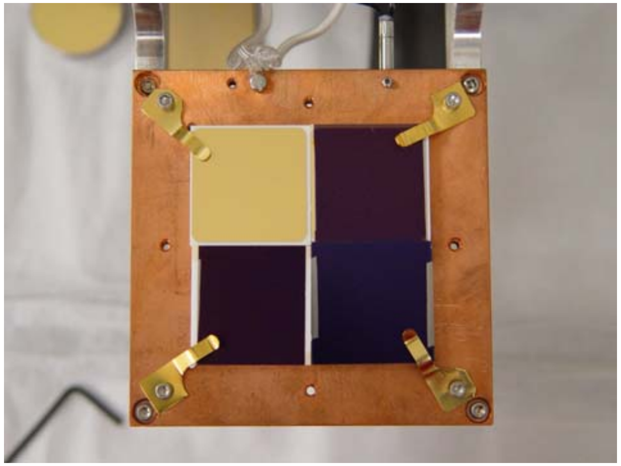


View of probe (diameter 3mm) sitting above samples

# Materials Studied

- Test mass:
  - Au/Pt with gold coating
- Housing walls:
  - substrate: beryllia, alumina or titanium (for inserts)
  - coatings: gold, diamond-like carbon (DLC), indium tin oxide, titanium carbide

+ various underlying layers chosen for adhesion, conductivity and smoothness



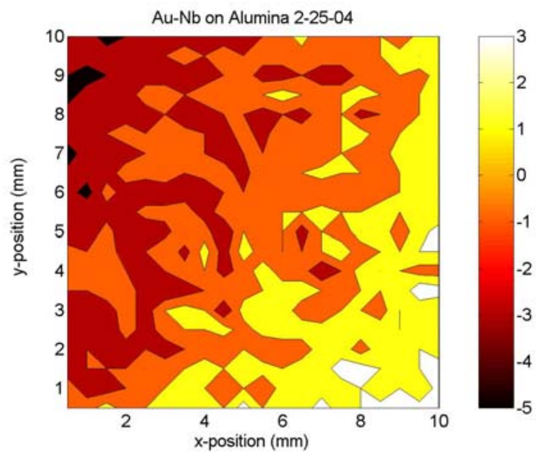
Example of samples ready for measurement in the Kelvin probe

Clockwise from top left: AuNb on alumina, DLC/Ti/Au/Nb on beryllia, DLC/Ti/Au/Ti on titanium, DLC/Ti/Au/Ti on alumina

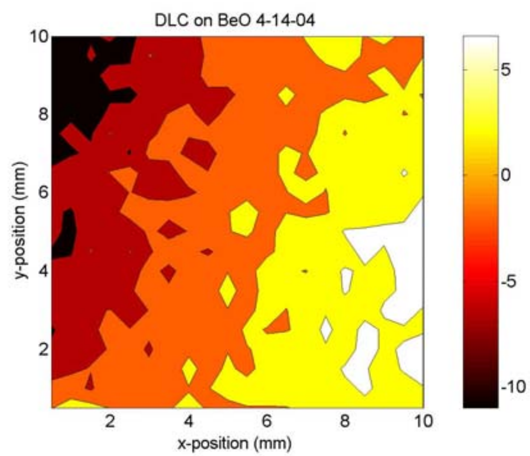
Note: many of the samples were precision coated in-house at Stanford

# Examples of Spatial Scans

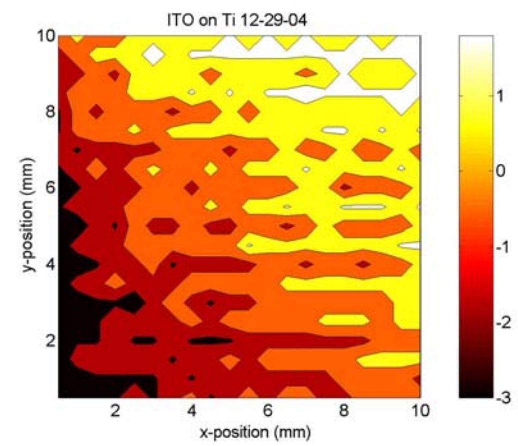
Gold-niobium on alumina (p-to-p 10 mV)



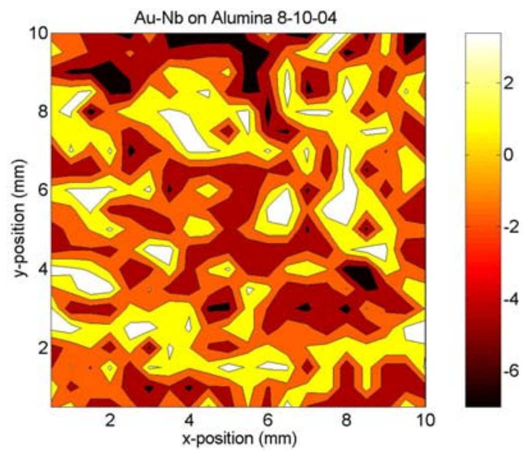

DLC on beryllia (p-to-p 22 mV)



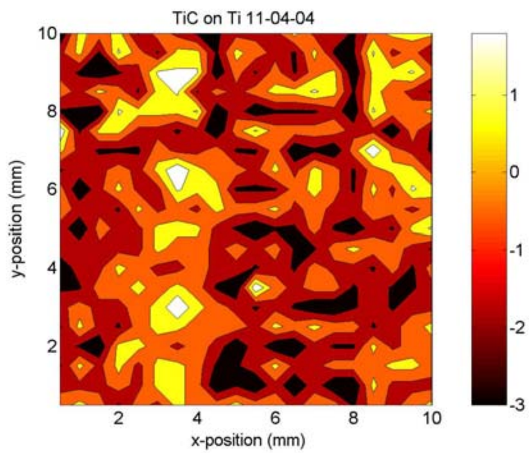

Indium tin oxide on titanium (p-to-p 6 mV)



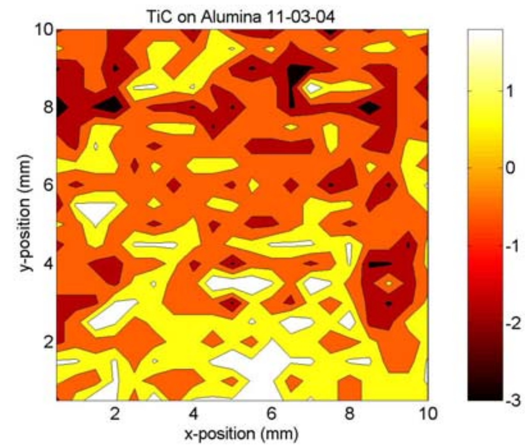

Gold-niobium on alumina (p-to-p 13 mV)




Titanium carbide on titanium (p-to-p 6 mV)

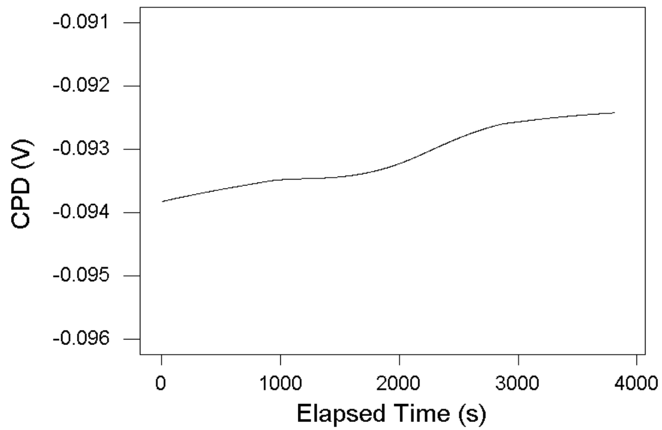


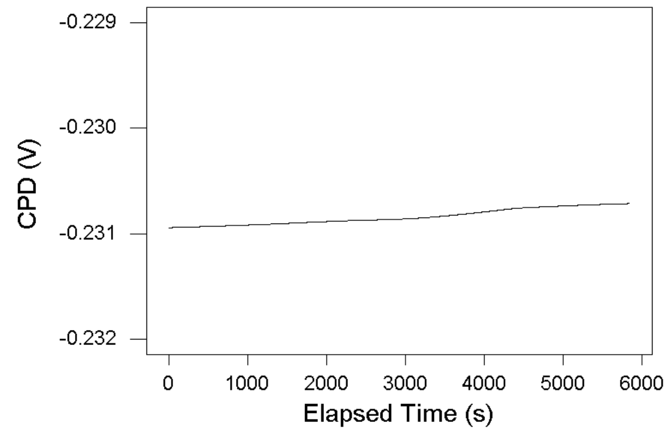

Titanium carbide on alumina (p-to-p 6 mv)

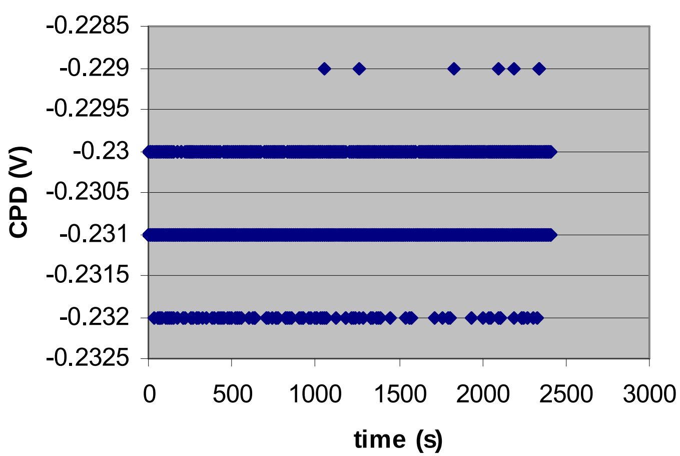


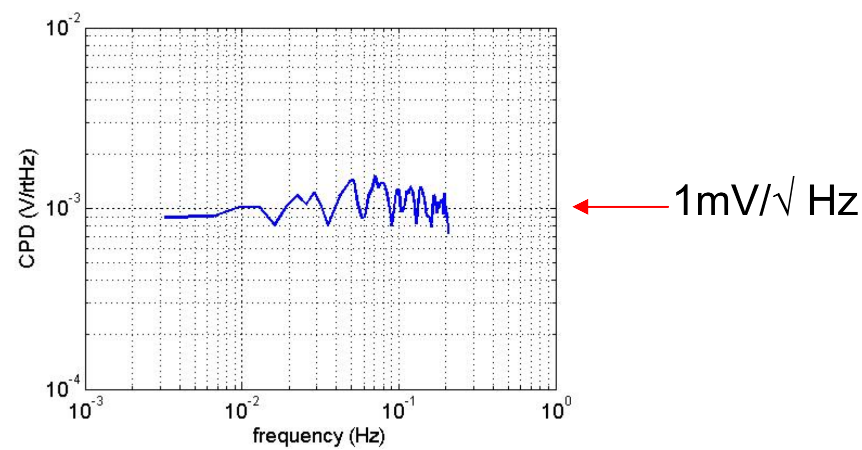

Contact potential difference in volts over 10 mm by 10 mm area (400 data points) with offset removed.

# Examples of Temporal Investigations




Time variations of contact potential differences.

Top left: Au on Au/Pt, pressure 10^-7 mbar, Top right: Au/ITO on Alumina, pressure 10^-9 mbar, Bottom left: Raw data for the first 2400 seconds of graph top right. Bottom right: amplitude spectral density of the data shown at bottom left.

# Conclusions to date

## Spatial Variations:

- Peak to peak ~6 to ~50 mV, standard deviation (sd) ~1 to ~10 mV
- Extrapolate sd to relevant spatial scale (recall data taken with 3 mm probe) - multiply by factor of ~3 to ~7.5 (model dependent*). We conclude results appear to meet 100 mV requirement assuming extrapolation valid
- The data also revealed evidence of behavioral trends with pressure and probable contamination effects which could affect the interpretation of the results

## Temporal Variations:

- In general lower pressure decreased variation
- Current accuracy of instrument (~1mV) is limiting measurements at level above that needed to compare to likely LISA requirements

* e.g. flat spectral distribution of patch size, or fixed size of patches.



Further details in N A Robertson et al, 2006 *Class. Quantum Grav* **23** 2665 - 2680

# Proposed Future Program

- The Goddard Kelvin probe has now been moved to Stanford
- The Stanford group in collaboration with Goddard proposes to start a new campaign including measurements using the probe and using a complementary technique of UV photoemission.
- Experimental areas to investigate with the probe are
  - the use of a smaller probe tip to give information on smaller spatial scales
  - investigation of the non-random features observed in some spatial scans
  - investigation of the variation of the patch effect with pressure and temperature
  - investigation of the effect of contaminants
  - further studies of temporal variations of the patch effect (with instrument upgrade)

# General Conclusions

The patch effect is a noise source which is not as yet well characterised. An integrated effort is required to:

- achieve reliable reproducible coatings with acceptable properties
- understand the properties of the patch effect under flight-like environmental conditions (pressure, temperature, presence of contaminants..)
- establish magnitude of spatial and temporal effects, relate these to noise requirements, update noise tree analysis and reassess parameters/requirements as needed

**Such reassessment could include advocating use of a larger gap size to attenuate these effects.**