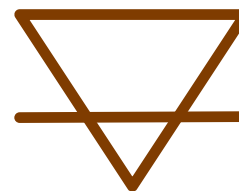
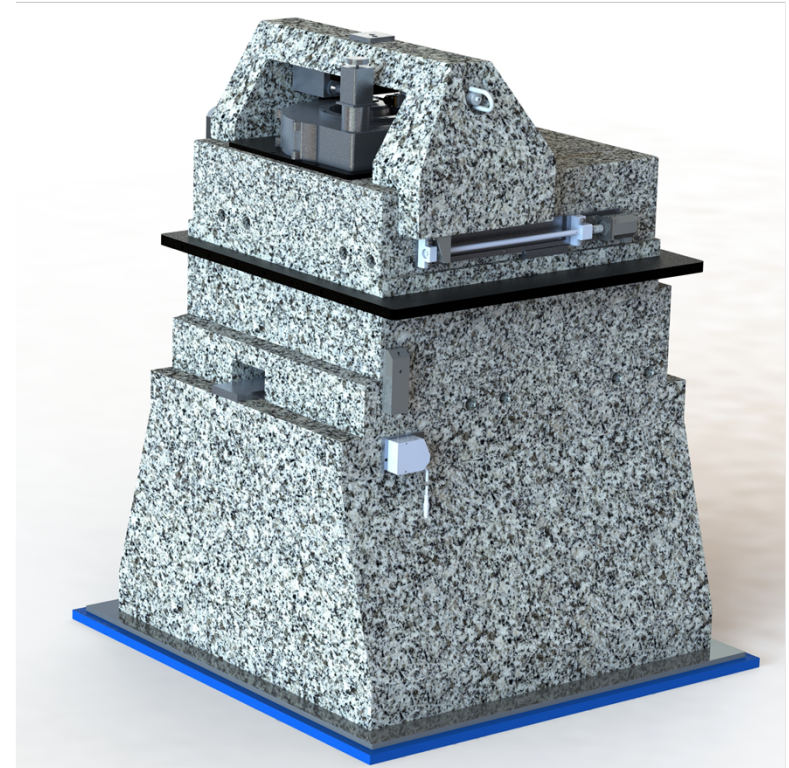


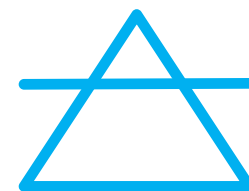
EARTH, WIND, & FIRE: THE NEW FAST- SCANNING VELOCIPROBE

CURT PREISSNER

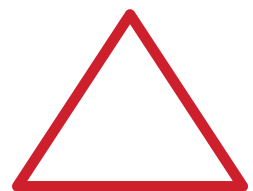
Principal Mechanical Engineer
Advanced Photon Source



EARTH



WIND



FIRE

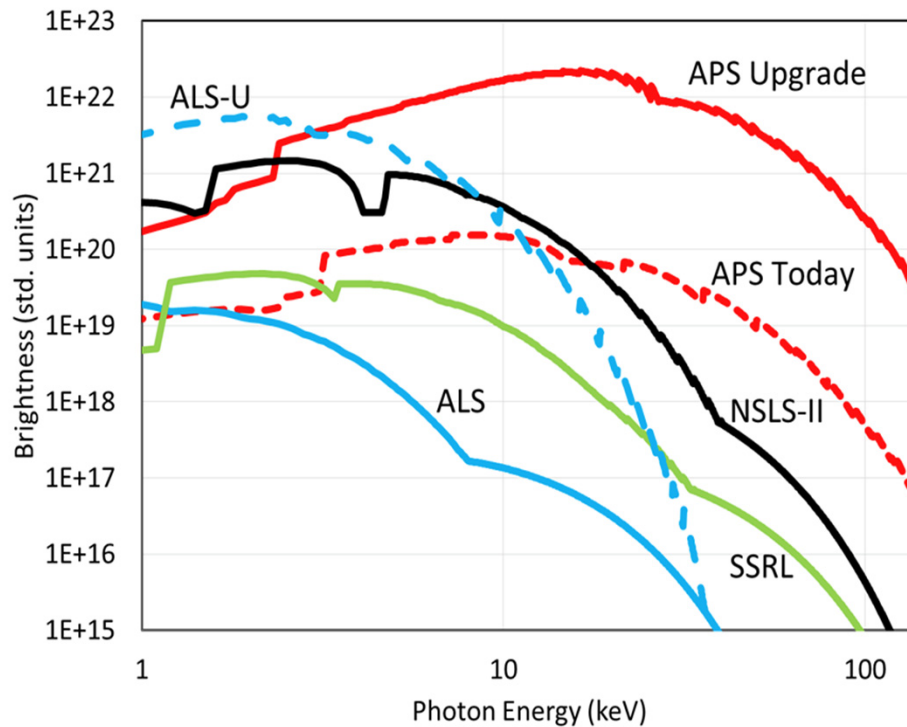
ACKNOWLEDGEMENTS

- Shane Sullivan
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APS-U

An opportunity to revolutionize scanning probe microscopies...



- 100X+ increase in brightness
- Micro/nanoprobes are brightness driven
- Possible to get 100% of APS flux into a 300 X 250 nm spot!!!
- Can use increase in flux to:
 - Reduce scanning time
 - Increase resolution
 - Some combination



VELOCIPROBE OVERVIEW

Instrument goals and concept

- Goals
 - Build prototype high-speed, high-resolution X-ray nanoprobe
 - Scan a $1\mu\text{m} \times 1\mu\text{m}$ area in 10 seconds or less at 10 nm spatial resolution
 - Extended objects and high spatial resolution through ptychography
 - Fluorescence mapping at better than 50 nm
 - Tomography

- Concept
 - Design vibrationally and thermally stable instrument
 - Employ control strategy to reject disturbances and maximize bandwidth
 - Explore nontraditional scanning and image acquisition modes

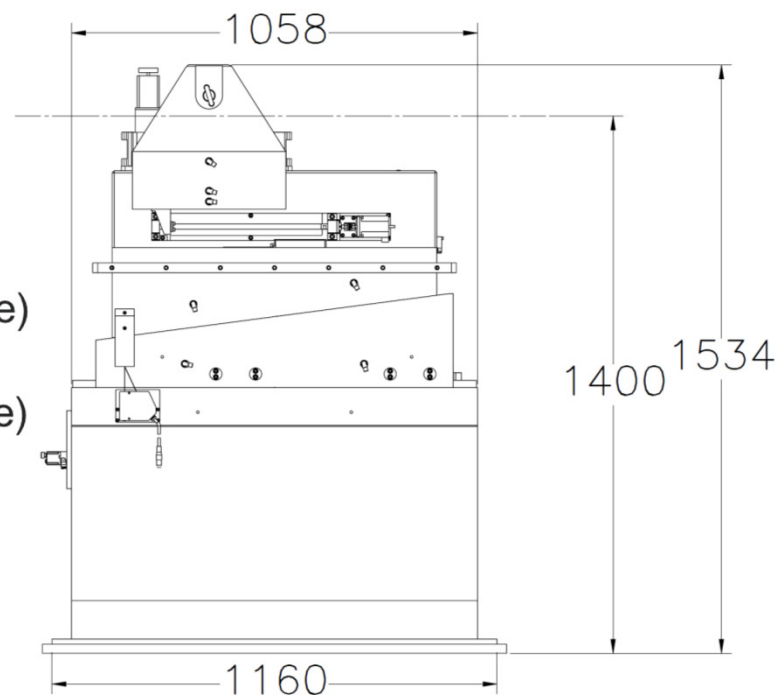
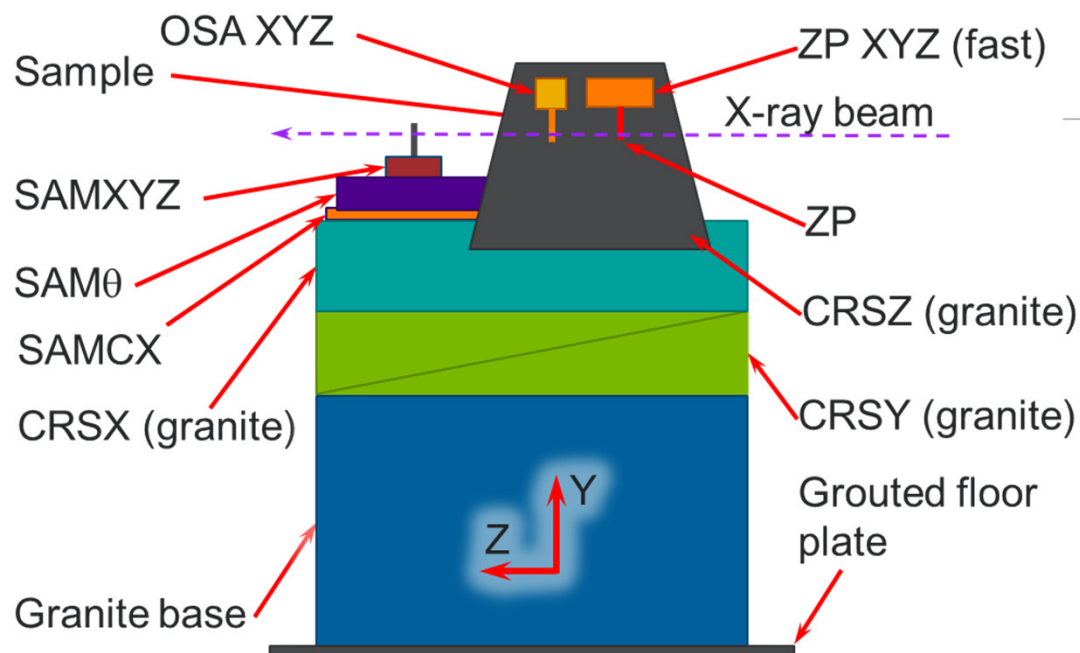
VELOCIPROBE OVERVIEW

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ptychography + fluorescence + APS-U flux = need for speed

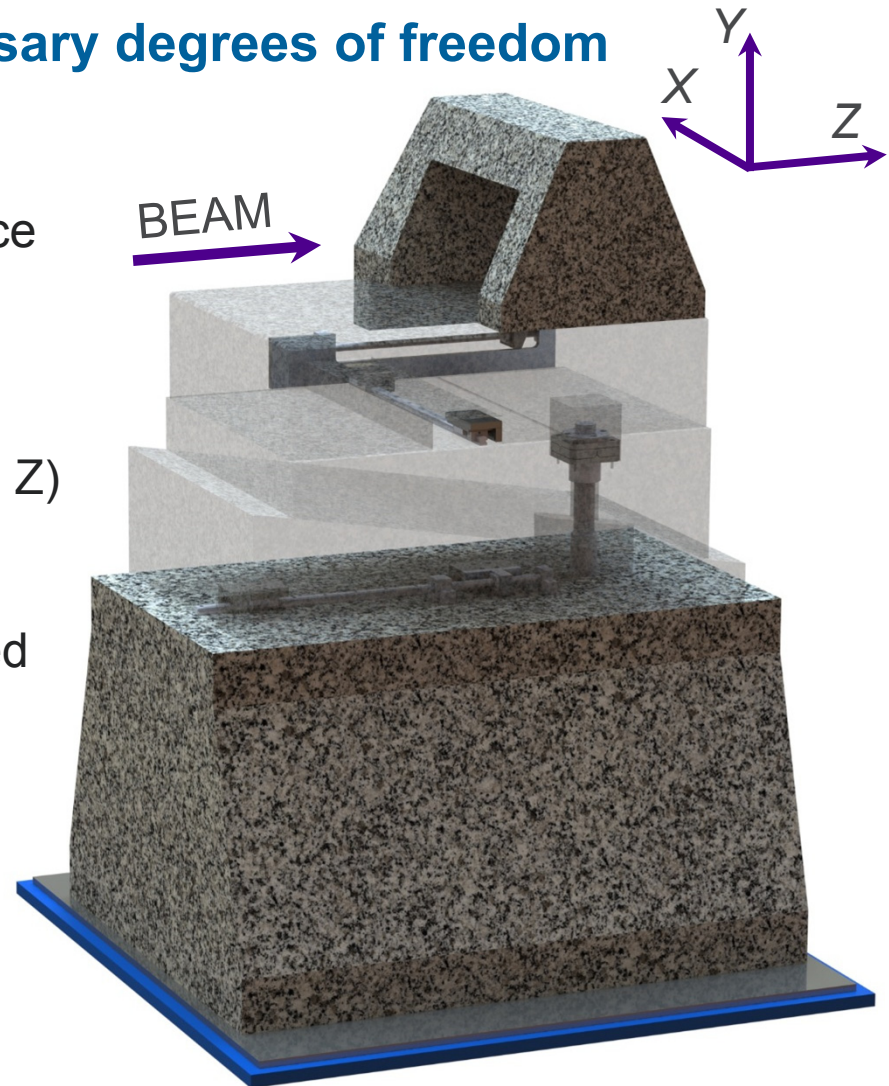
VELOCIPROBE MECHANICS



COARSE MOTION CONCEPT

Maximum stability, minimum necessary degrees of freedom

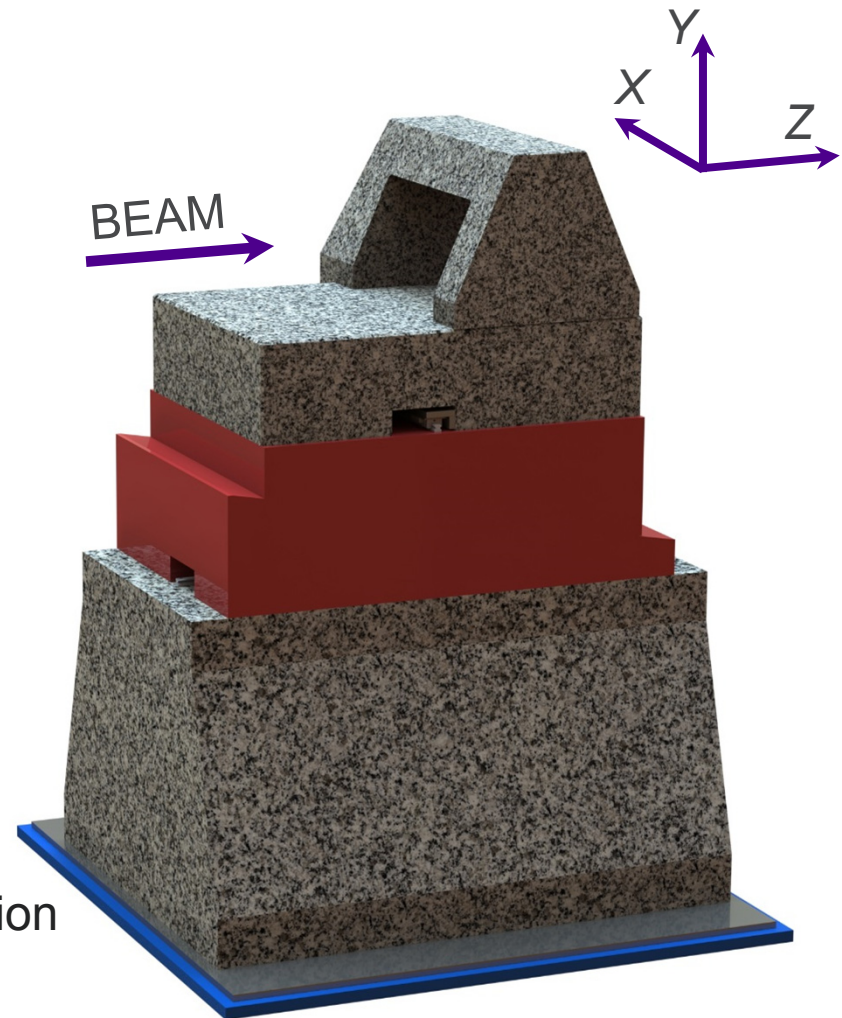
- Coarse axes used only for alignment
- Why compromise stability with compliance from rolling-element bearings?
- Novel concept:
 - Granite stages
 - Travel 25 mm, 10 mm, 400 mm (X, Y, Z)
 - Integrated air bearings guide all axes
 - *Fly-move-land* operation
 - As stable as solid granite when landed
- Designed to be inherently stable
- Mass: ≈ 3612 kg (7946 lb)
- Air bearing lift: $\approx <5$ μm
- Vendor: Starrett Tru-Stone
- US patent in progress: 15/253,092



Y AXIS STAGE (VERTICAL)

Air-lifted, stepper driven wedge-style

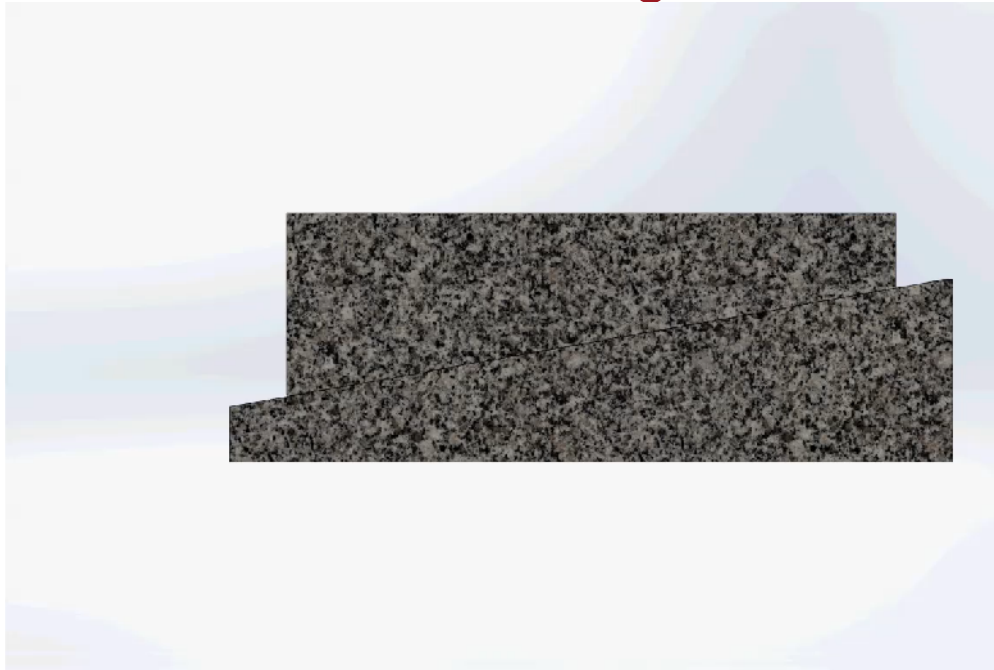
- Motor
 - Oriental motor PKP268MD14BA-L
 - .9 deg./step, bipolar, 4-lead, 2.23 N*m
- Drive
 - THK MDK 1402-3 Ball Screw
 - 2 mm pitch, 145 mm travel
- Guiding
 - THK HSR 15A Linear Guide
 - THK SLF 40 Ball Spline
- Theoretical minimum full step
 - 5 μm for driving wedge (horizontal)
 - .7 μm for driven wedge (vertical)
- Encoder: Keyence LK-G80, <.1 μm resolution
- Moving mass ≈ 850 kg
- Friction-stable 7.5 degree wedge



Y AXIS STAGE

Principle of operation

Driven wedge

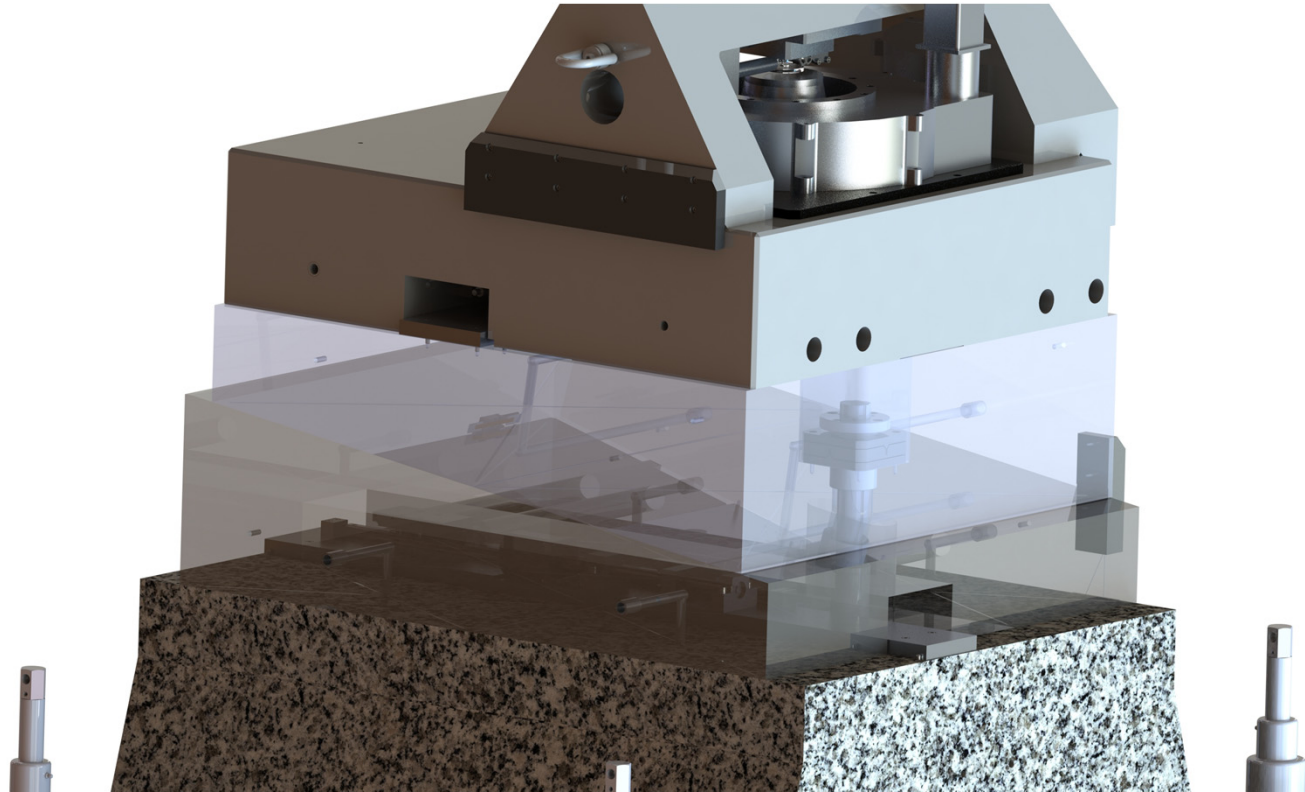
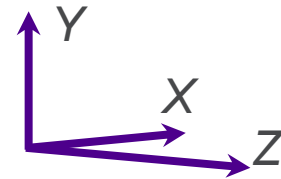


Driving wedge

Proper constraints are applied to ensure correct motion

Y AXIS STAGE

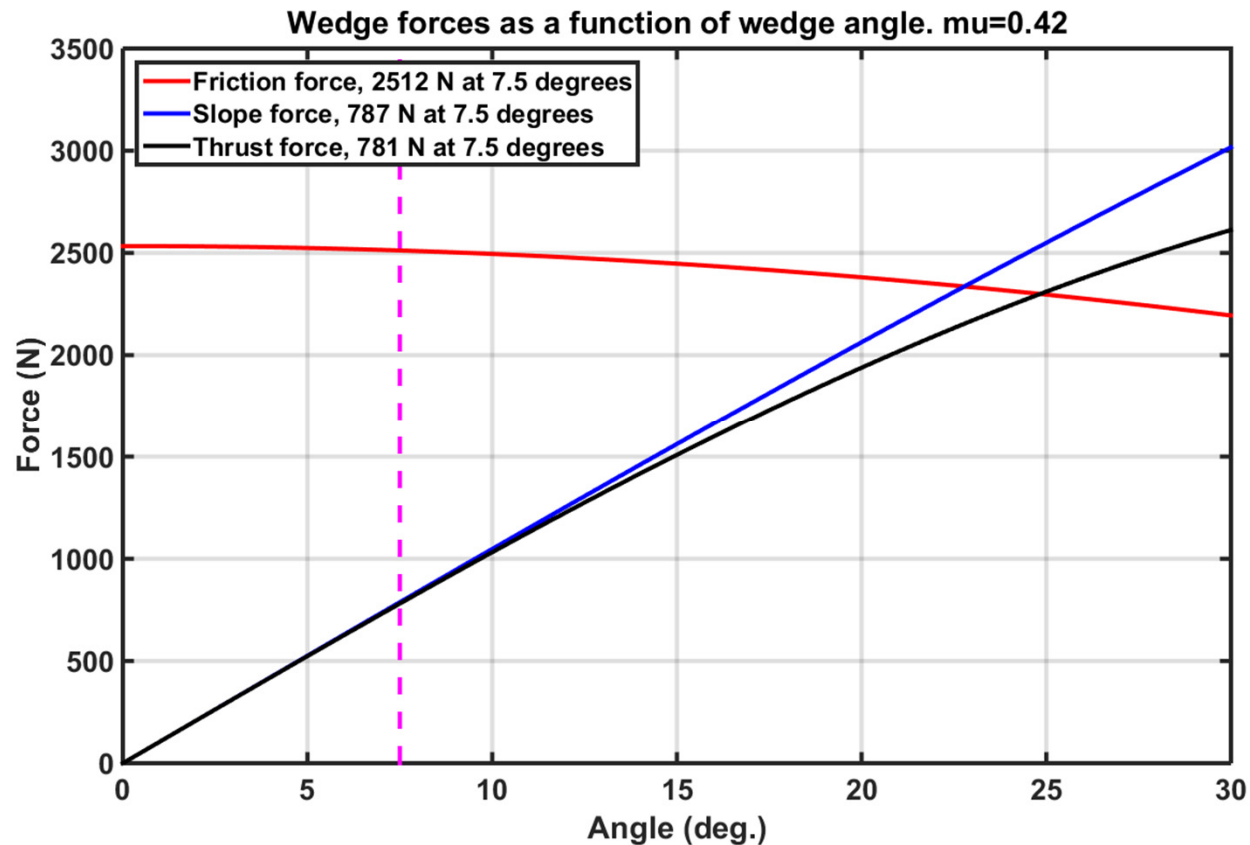
Kinematics of wedges



- One axis of motion needed on each wedge $\Rightarrow$ five constraints are needed
- Driving wedge has THK rail, driven wedge has THK ball spline
- Flexures allow for movement when the air bearing is lifted

Y AXIS STAGE

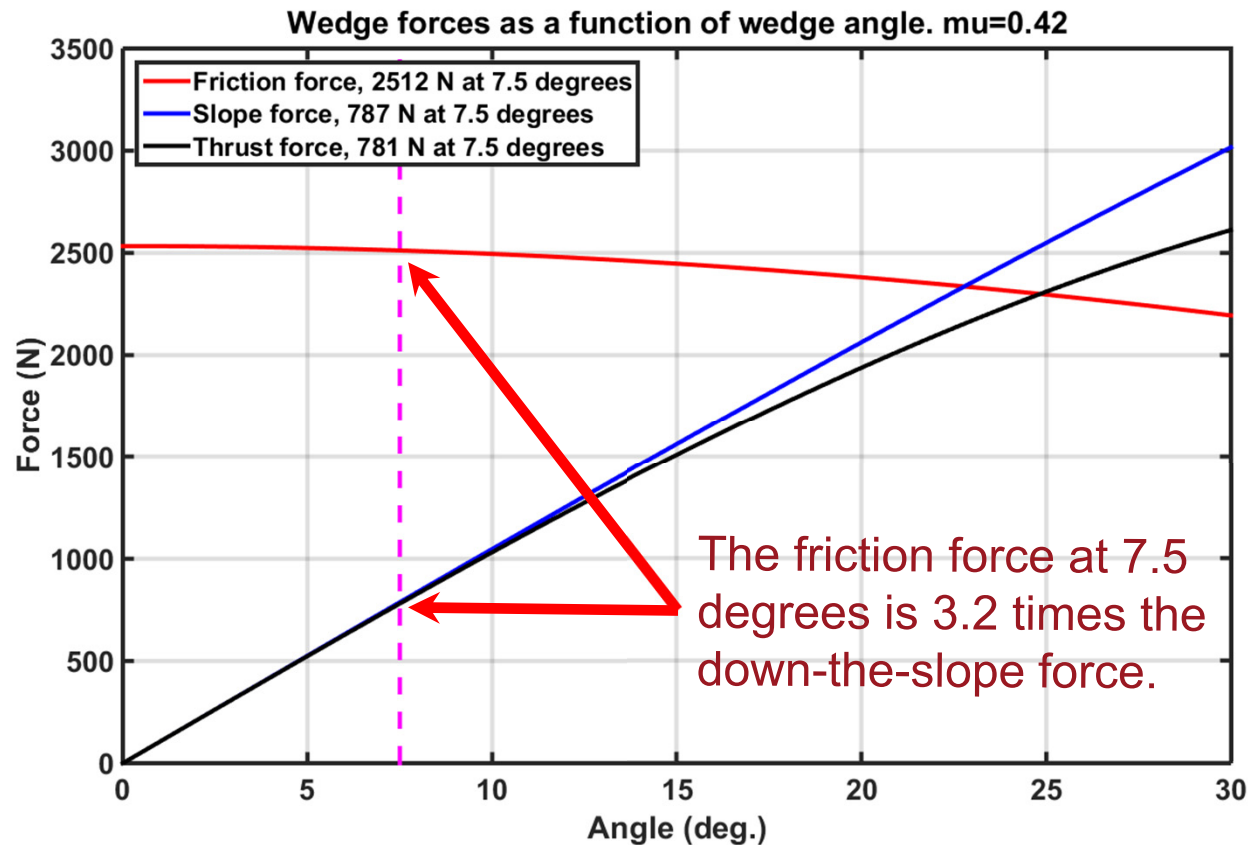
Wedge forces



- Friction has been measured for the particular granite and surface finish

Y AXIS STAGE

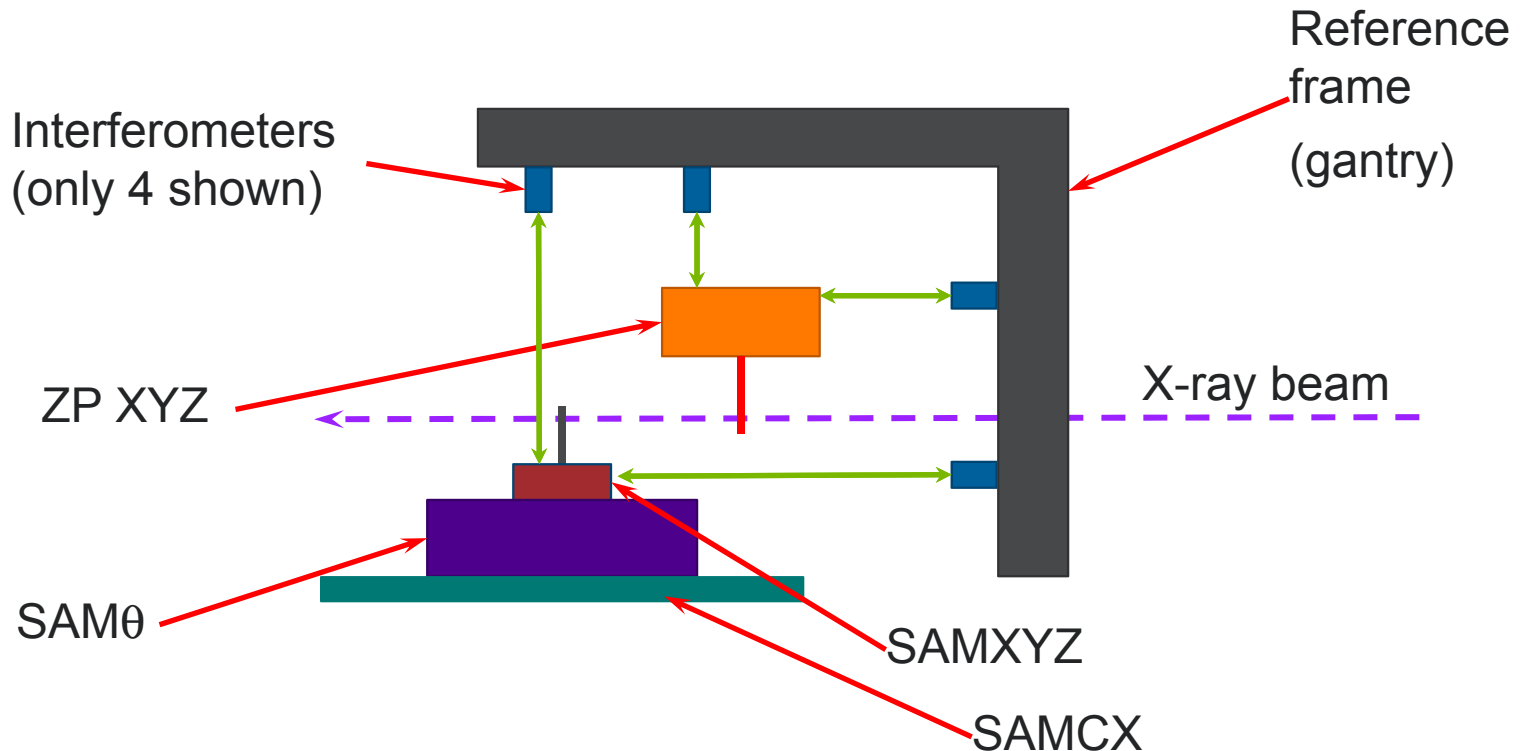
Wedge forces



- Friction has been measured for the particular granite and surface finish
- Stage is rigid when air lift is vented

METROLOGY USING INTERFEROMETERS

Single reference frame with 6 interferometers (only Y and Z axes shown)



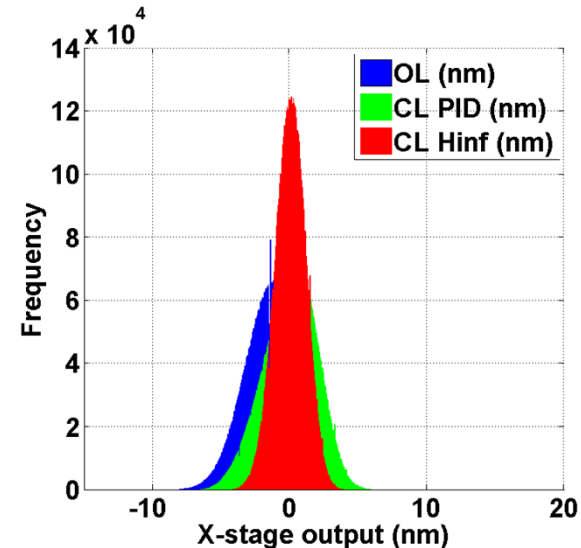
- Using Attocube IDS sensors
- Need to accommodate the rotation of sample (cylindrical/faceted reference surface)

INSTRUMENT CONTROL

Optimized negative feedback approach

- H_∞ Mixed-Sensitivity Minimization:
 - Increase tracking bandwidth
 - Increase position resolution
 - Better disturbance rejection
 - Adequate noise rejection
 - Robustness to unmodeled system dynamics
 - Can exploit axes coupling
- Techniques proven in SPM field and for X-ray microscope
- Implemented on fast FPGA hardware
 - NI-9039 cRIO hardware
 - Can implement almost any algorithm

Comparison using an existing instrument

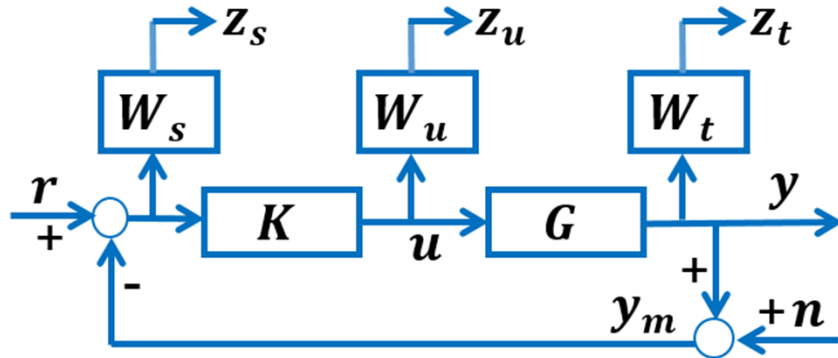


- Resolution:
 - Hinf 3.33 nm vs PID 6.08 nm
 - **45% better than PID**
- 3 dB Bandwidth:
 - Hinf 31.2 Hz vs PID 5.6 Hz
 - **>5 times better than PID**

Mashrafi ST, Preissner C, Salapaka SM, Zhao H. ASPE 28th Annual Meeting. 2013.
Mashrafi, Salapaka, and Preissner (in preparation)

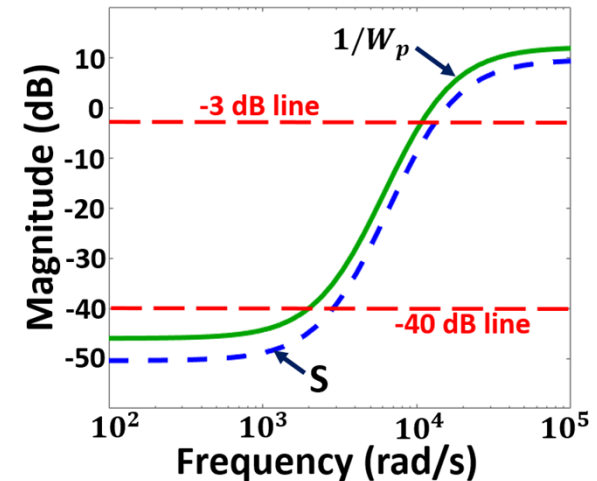
INSTRUMENT CONTROL

Design process

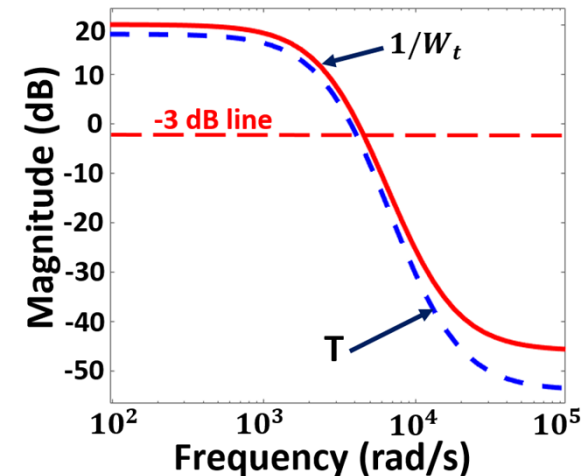


- Exogenous Inputs, $w = [r \quad n]$
- Regulated Outputs, $z = [z_s \quad z_t \quad z_u]$
- $T_{wz} = [W_s S \quad W_t T \quad W_u K S]^T$, t.f. $w \rightarrow z$
- Performance objectives are achieved by minimizing the H_∞ -norm of the closed-loop transfer function matrix T_{wz} for all stabilizing controllers K .

$$\inf_K \|T_{wz}\|_\infty$$



Weight W_p is chosen such that resulting S has high-pass filter shape

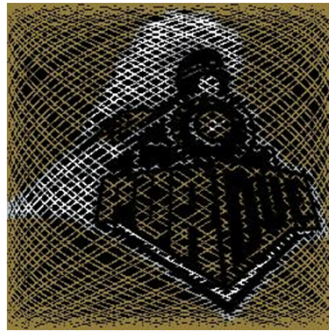
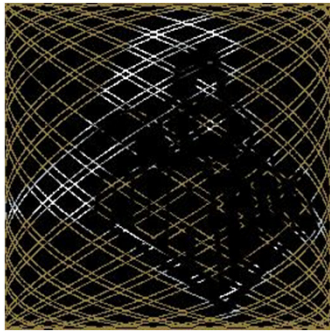


Weight W_T is chosen such that resulting T has low-pass filter shape

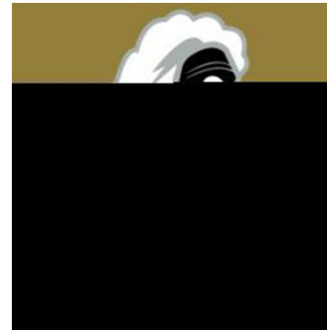
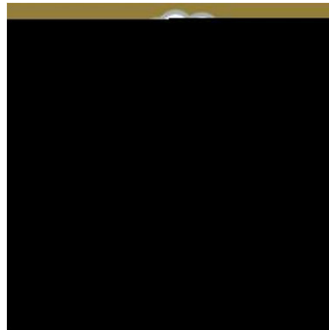
INSTRUMENT CONTROL

Better dynamics can translate to more efficient scan trajectories...

Lissajous trajectory scanning



Raster scanning



1 ms

2 ms

10 ms

20 ms

Work by Shane Sullivan: Optics Express, Vol. 22, Issue 20, pp. 24224-24234 (2014)

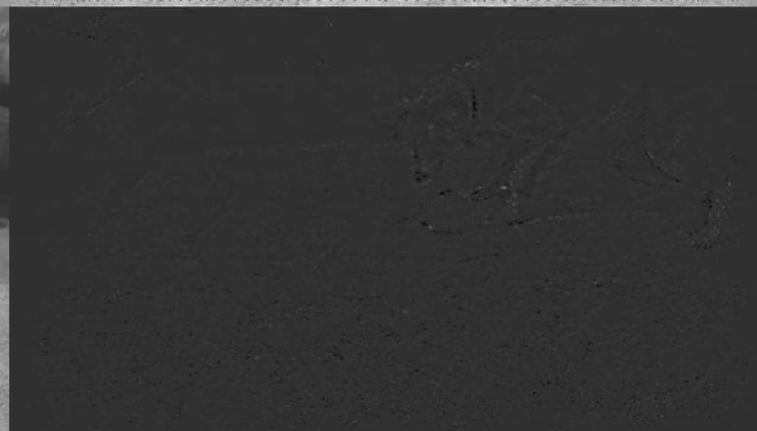
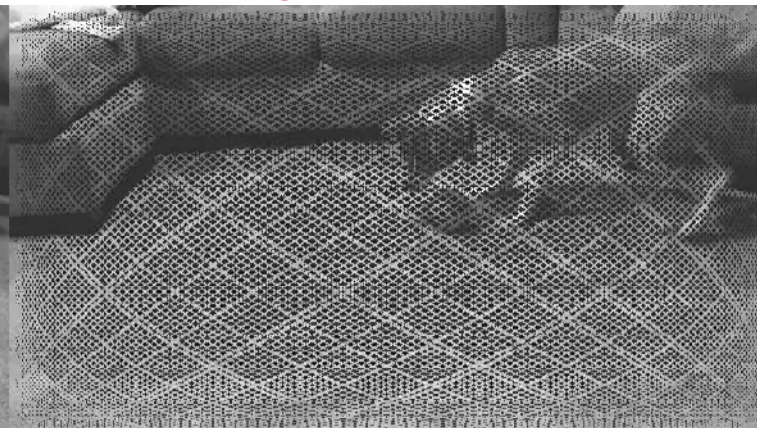
INSTRUMENT CONTROL

More efficient scanning can yield more efficient imaging...

Original movie



Sparsely sampled movie



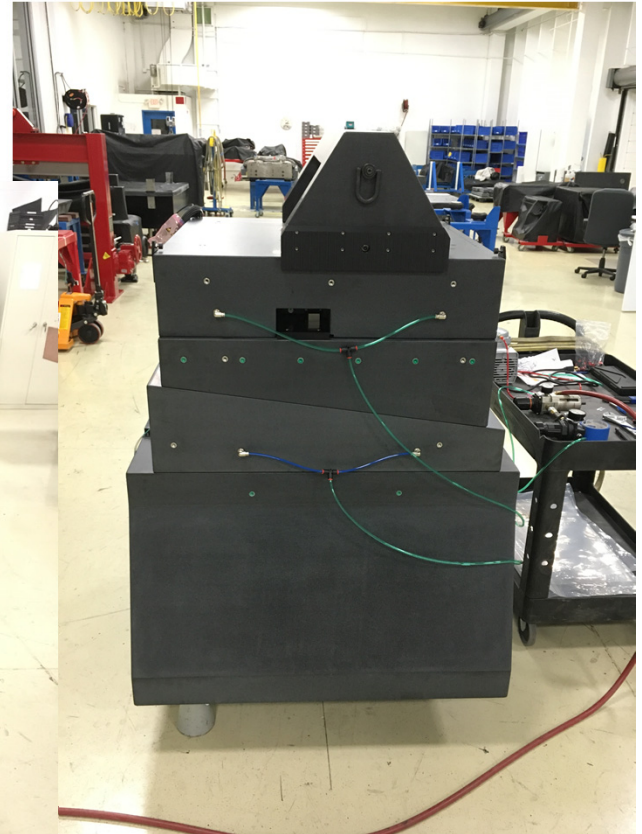
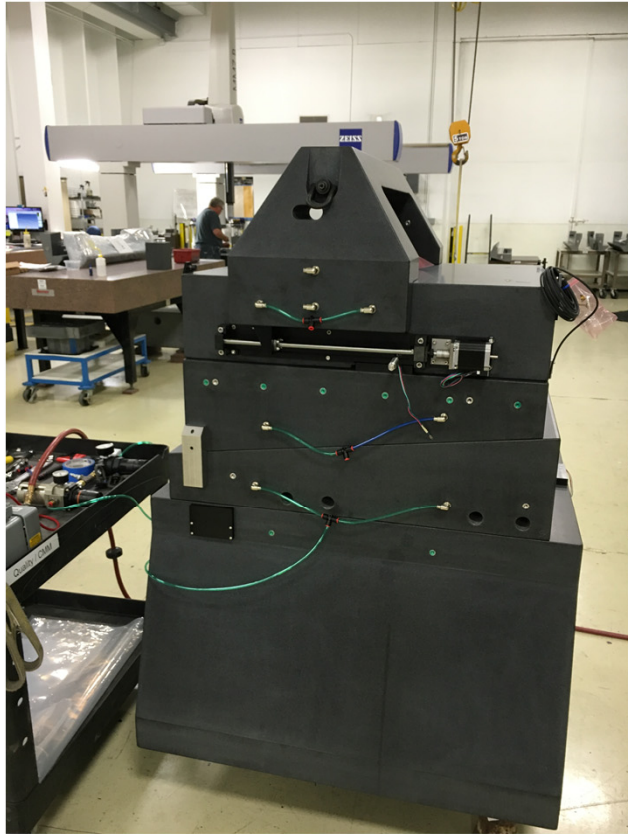
In-painted reconstruction

Error

Work by Shane Sullivan: Optics Express, Vol. 22, Issue 20, pp. 24224-24234 (2014)

STATUS...

Granite stage assembly will arrive at APS next Tuesday!





MOLTES GRÀCIES!