Variable-delay Polarization Modulators (VPMs) for Far-infrared through Millimeter Astronomy

David T. Chuss
NASA Goddard Space Flight Center

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Science Goals

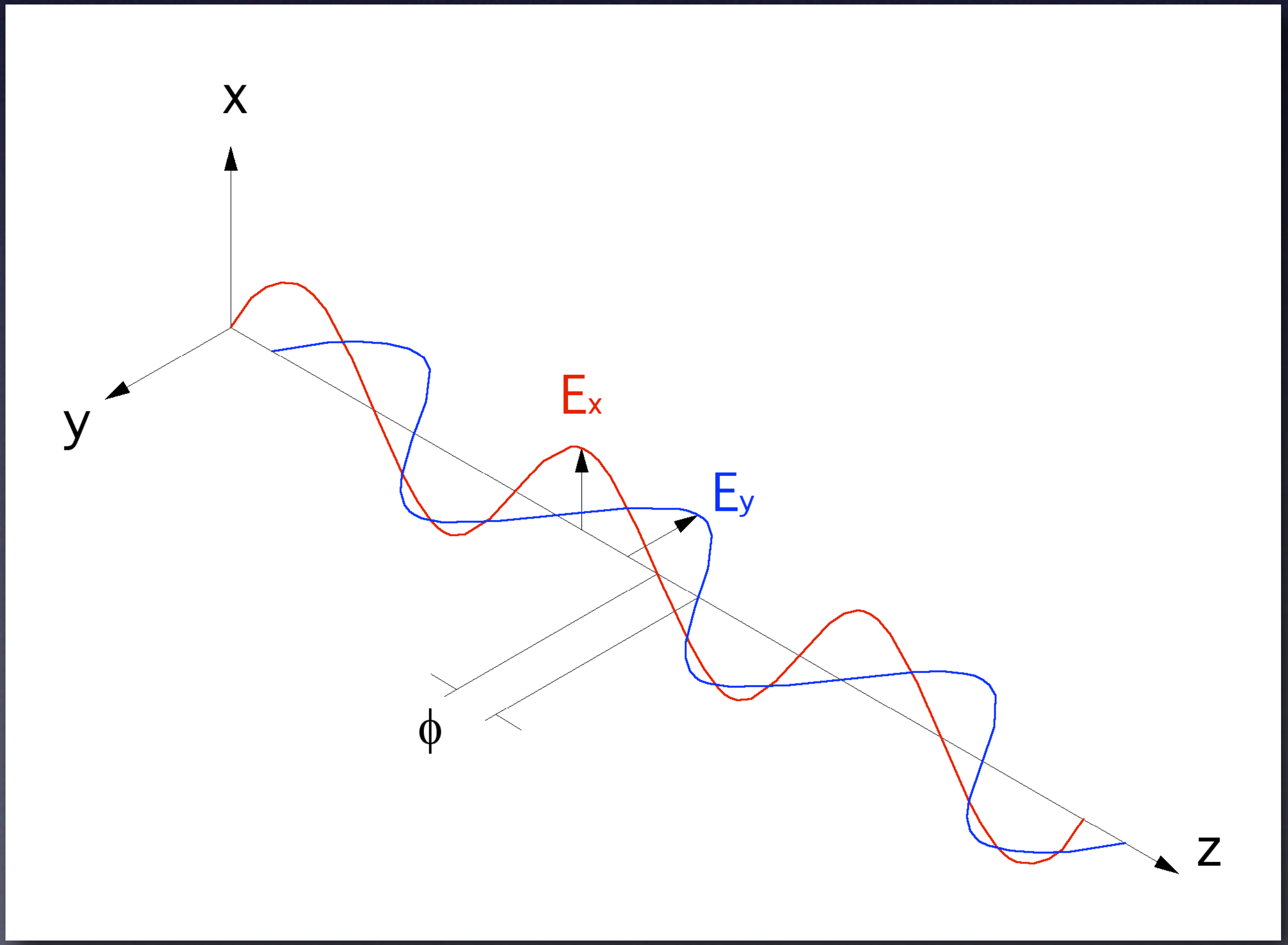
- Polarized emission from partially-aligned dust provides a probe of the role of magnetic fields in star formation.

- The polarization of the CMB will test theories of the very early universe and provide a probe of fundamental physics

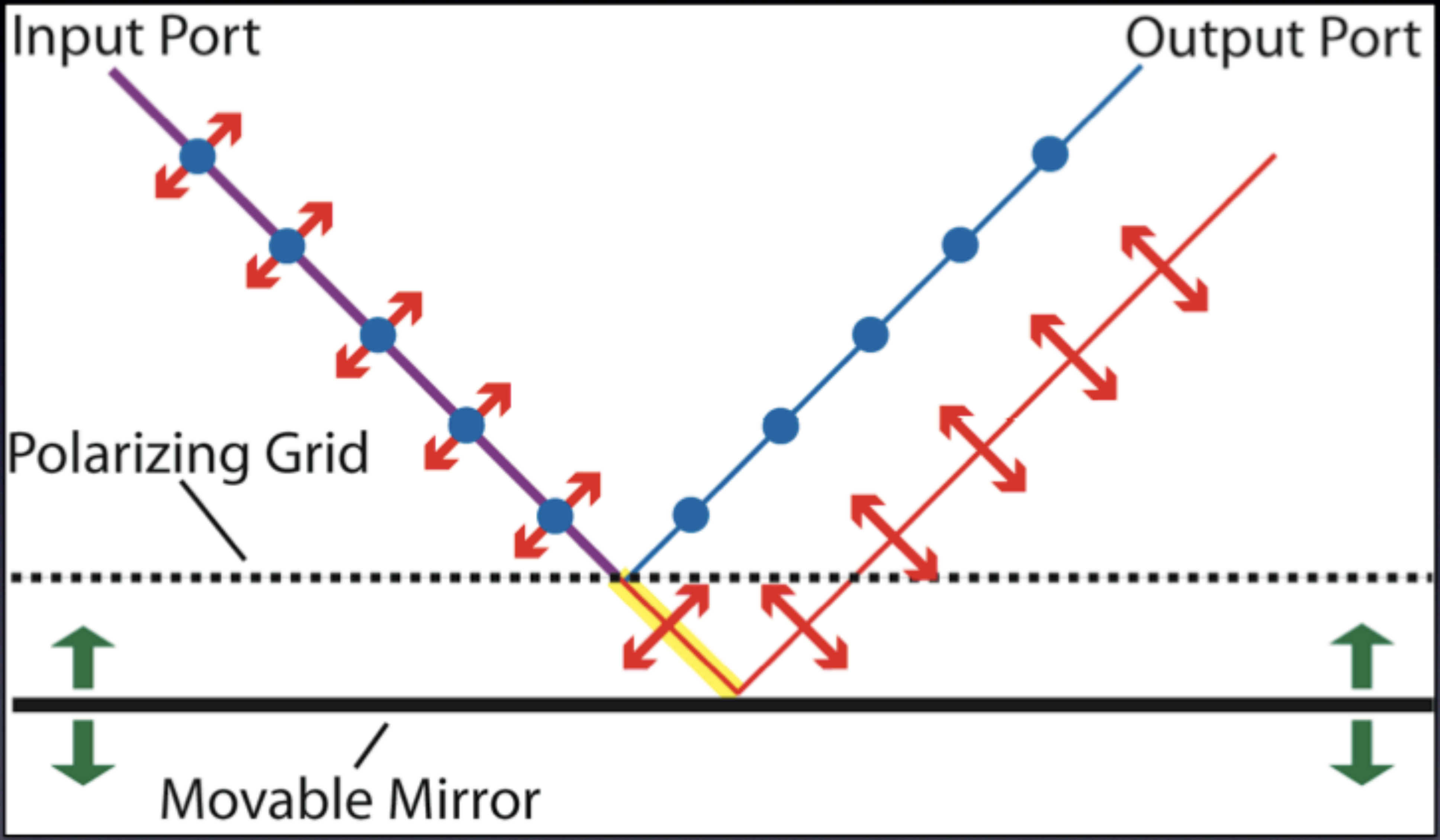
Polarization Modulation- systematic variation of the polarization state of the incoming signal for subsequent demodulation and detection.

2 free parameters:

1. Orientation of the basis (eg. HWP)
2. Magnitude of phase shift (eg. Faraday Rotator)



Variable-delay Polarization Modulators (VPMs)



$$U_{detector} = U\cos\phi + V\sin\phi$$

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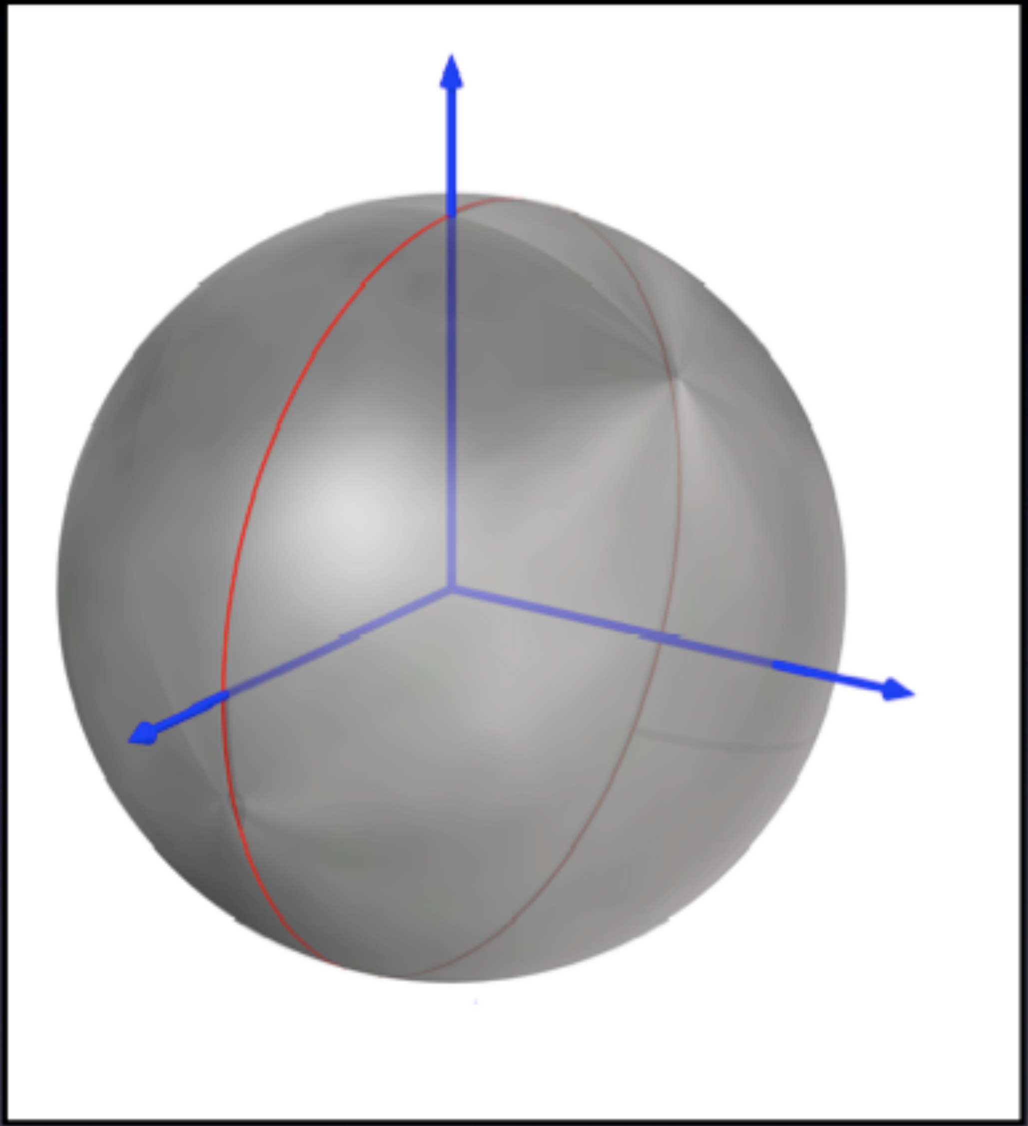

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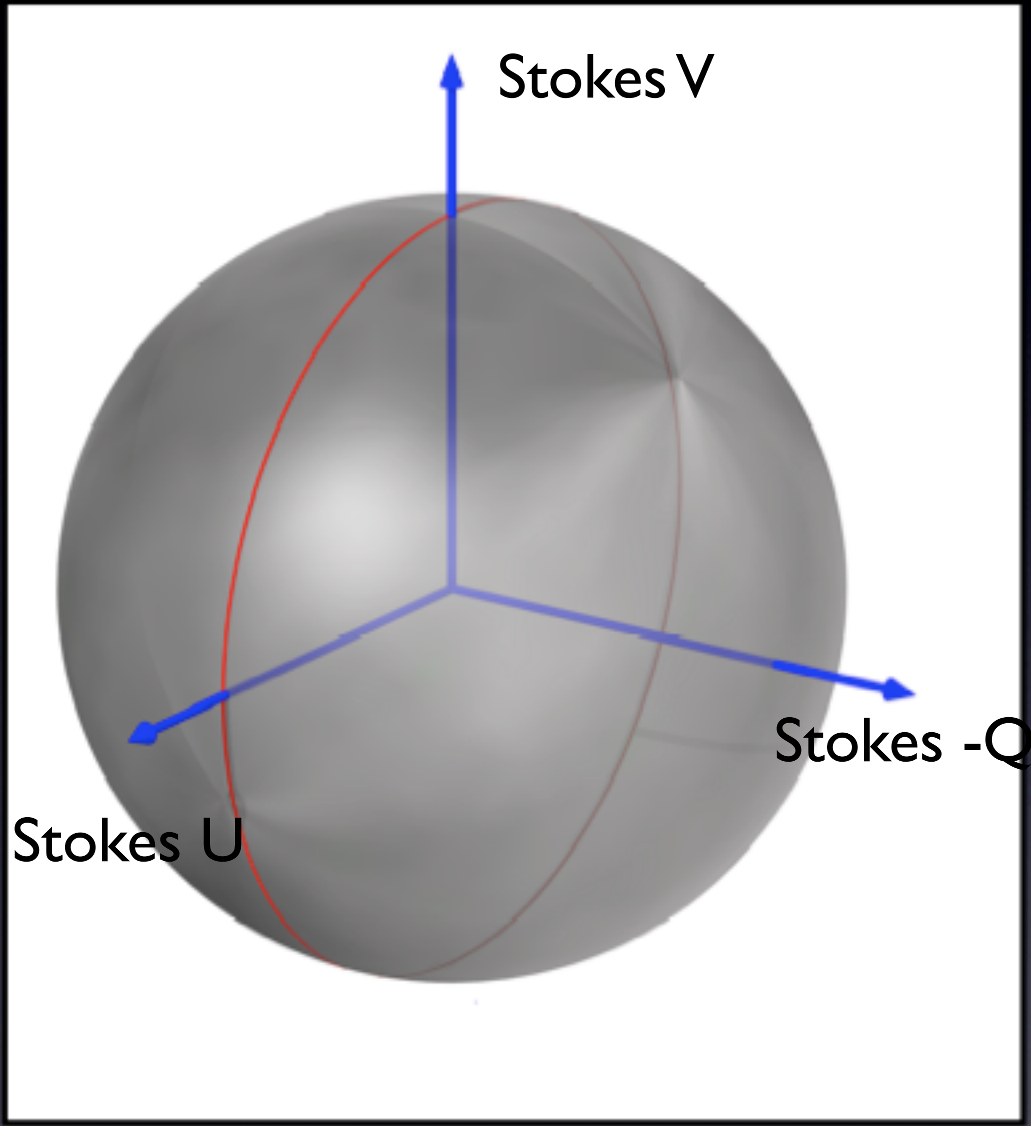
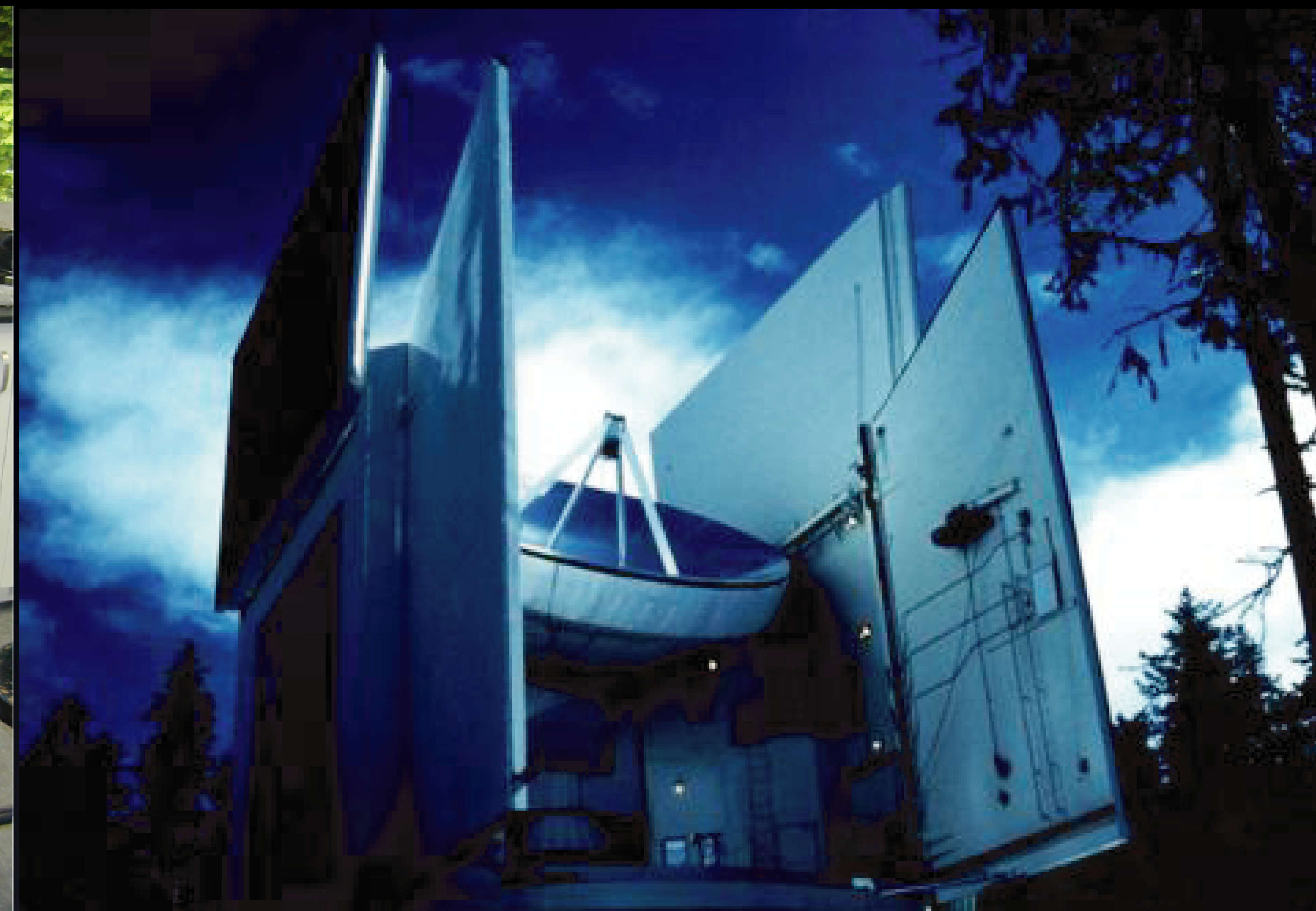


$$U_{detector} = U \cos \phi + V \sin \phi$$

Advantages of VPMs

- Can be made intrinsically broadband
- Can measure circular polarization
- Used in reflection- no dielectrics to introduce differential loss
- Employs small linear motions rather than large circular ones- a reliability advantage for space missions

Hertz/SMTO



Using a pair of VPMs, we have integrated the 350 micron, 32 pixel polarimeter Hertz onto the SMTO in Arizona

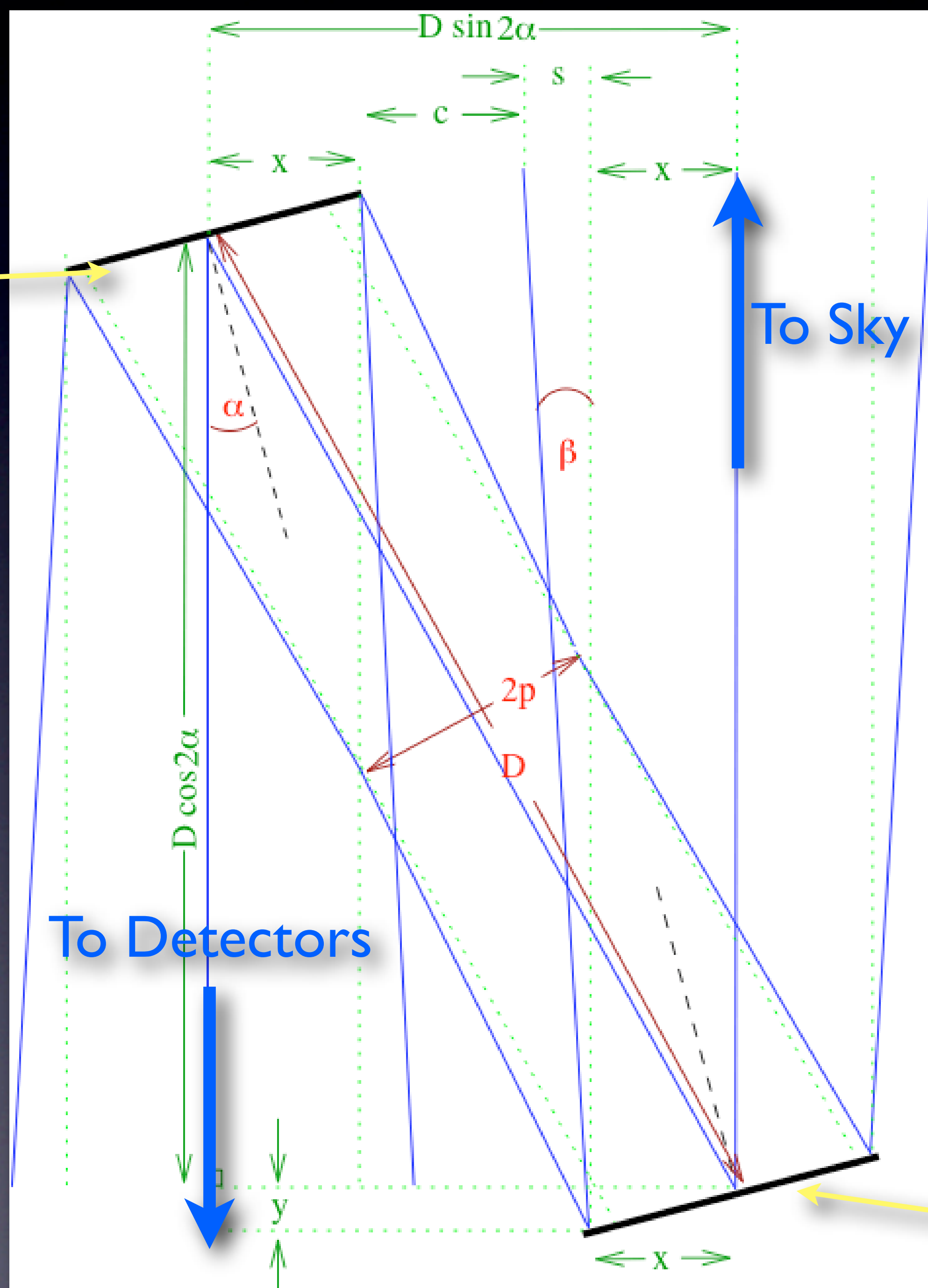
Collaborators: G. Novak, M. Krejny (NU), C. Walker, C. Kulesa, C.Y. drouet D'Aubigny, D. Golish (Arizona), G. Voellmer, E. Wollack, H. Moseley (GSFC), R. Loewenstein (Chicago)

Instrument Specifications

Angular Resolution	20”/pixel
Number of Detectors	32 in each polarization
Passband	350 μm $\Delta\nu/\nu=0.10$
Telescope Primary	10 m

Dual-VPM system

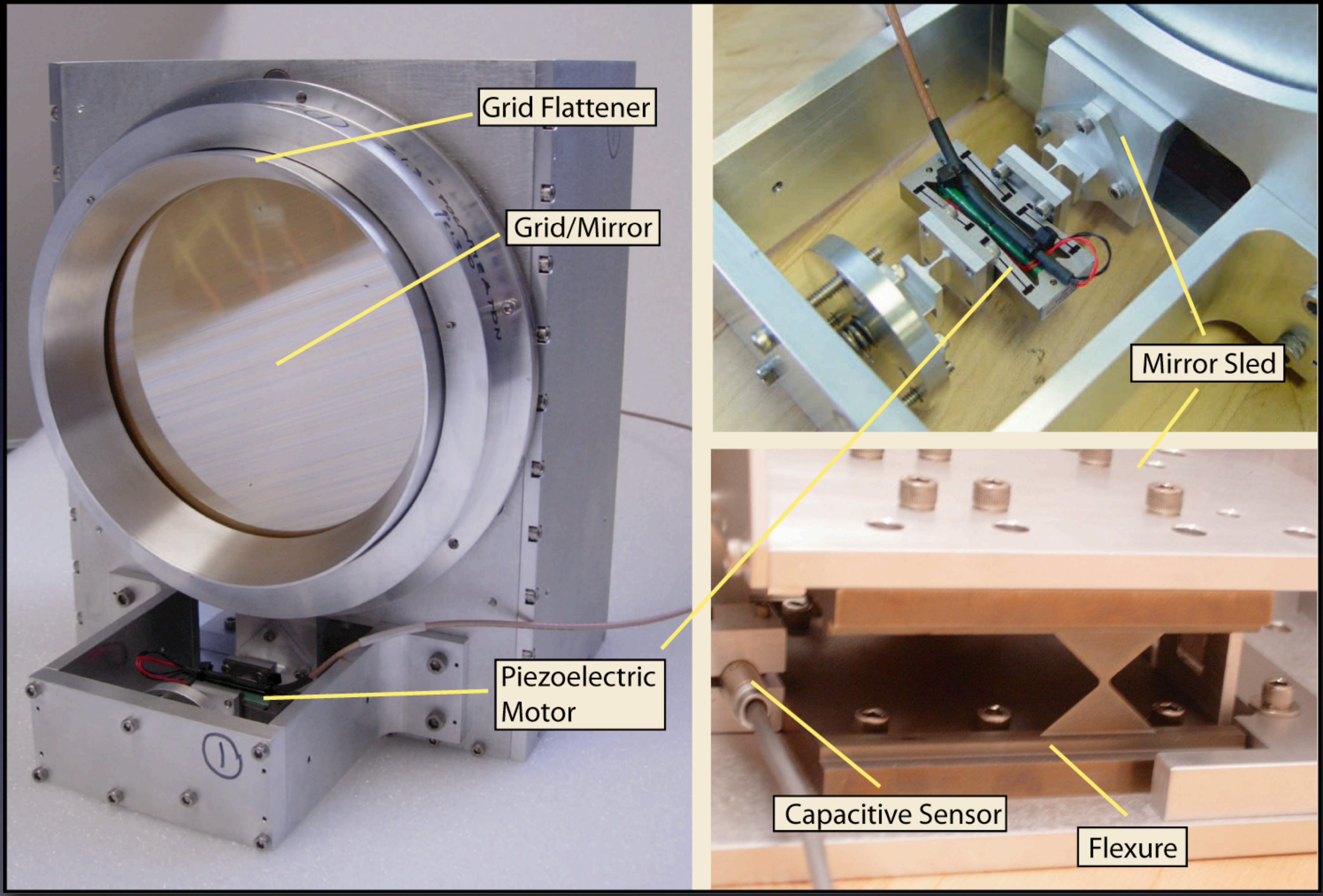
VPM 2: Toggles Roles of detectors (Q->-Q) (Grid wires at 45 degrees)



VPM 1: Selects Between Q & U (Grid wires at 22.5 degrees)

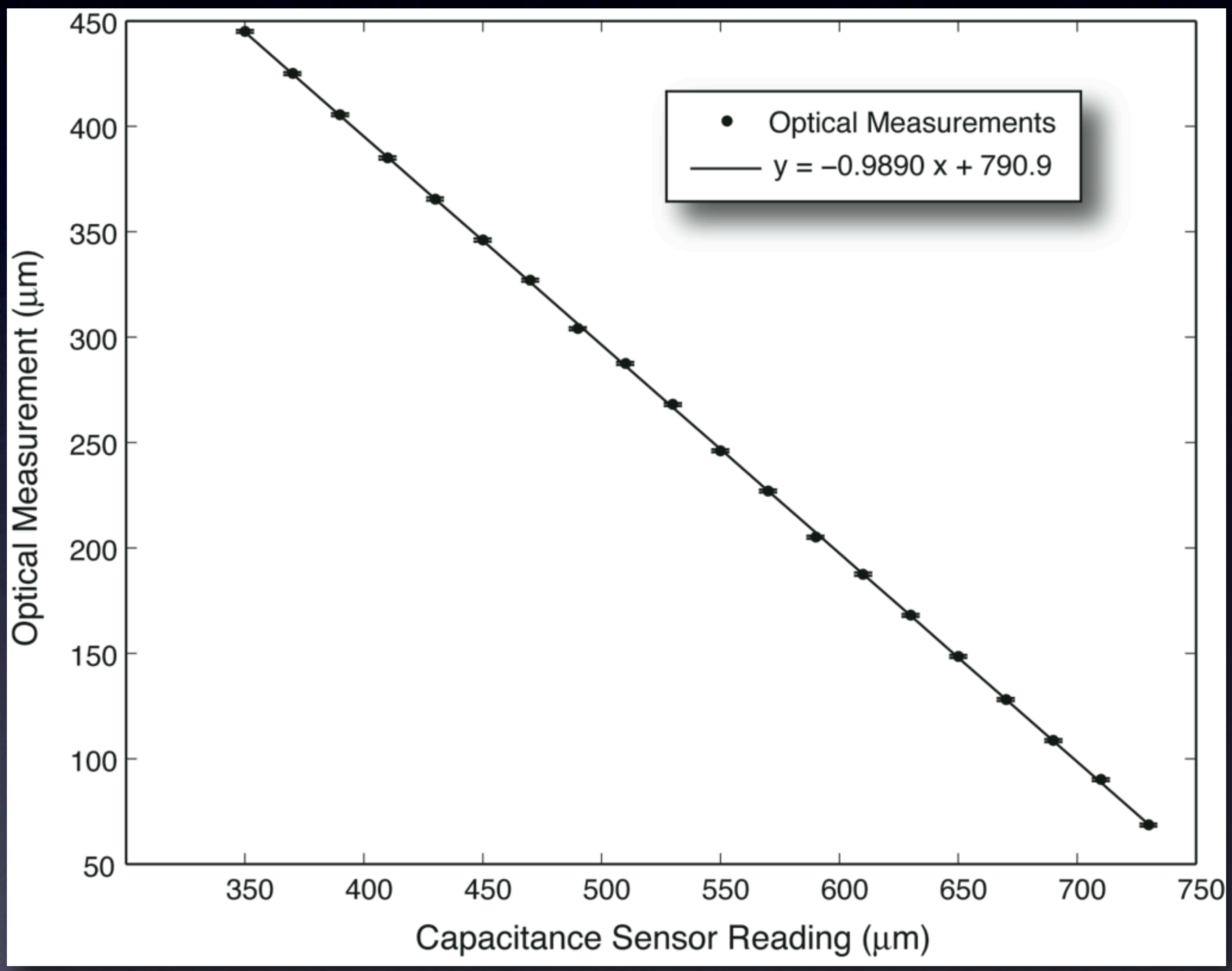
Δ_1	Δ_2	Q_{det}
0	0	Q_{sky}
0	π	$-Q_{sky}$
π	0	U_{sky}
π	π	$-U_{sky}$
0	$\pi/2$	$-V_{sky}$
$\pi/2$	0	$\frac{1}{2}(Q_{sky}+U_{sky})+\frac{1}{\sqrt{2}}V_{sky}$
$\pi/2$	π	$-\frac{1}{2}(Q_{sky}+U_{sky})-\frac{1}{\sqrt{2}}V_{sky}$
π	$\pi/2$	V_{sky}
$\pi/2$	$\pi/2$	$\frac{1}{\sqrt{2}}(Q_{sky}+U_{sky})$

Submillimeter VPMs



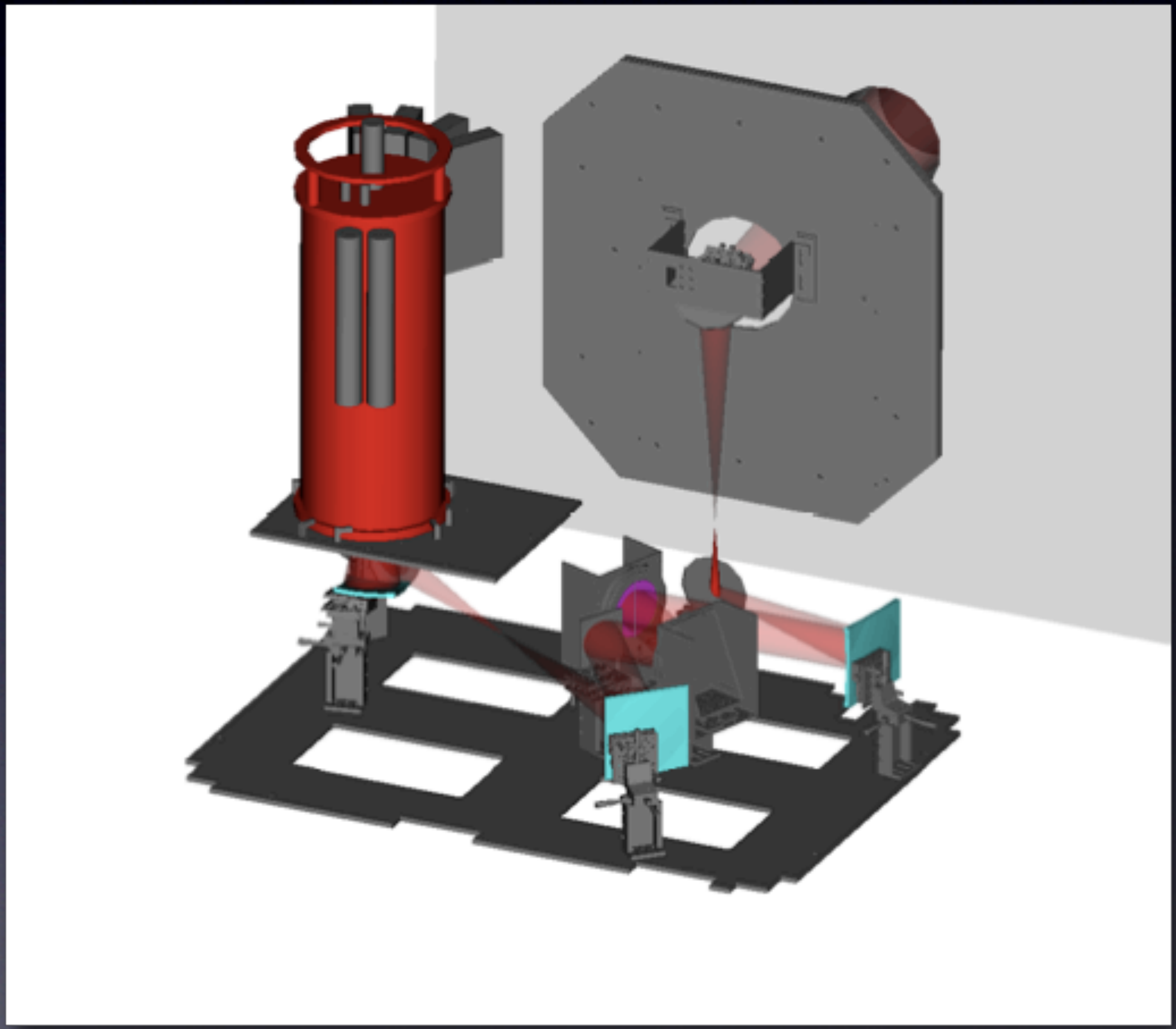
Voellmer et al. (2006)

VPM Systematics

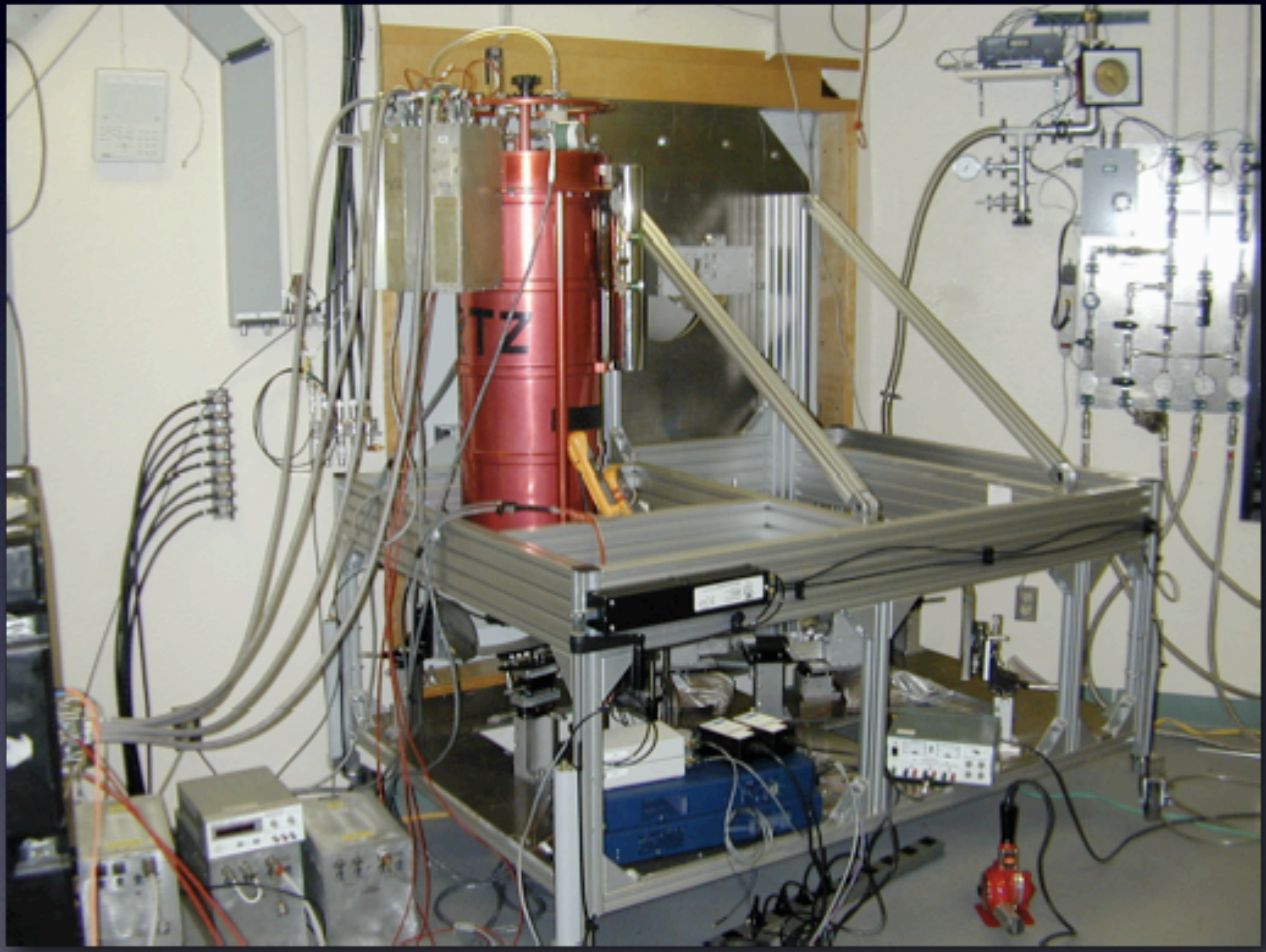


- VPM travel parallel to +/- 2 microns
- Grid surface is flat to ~2 microns

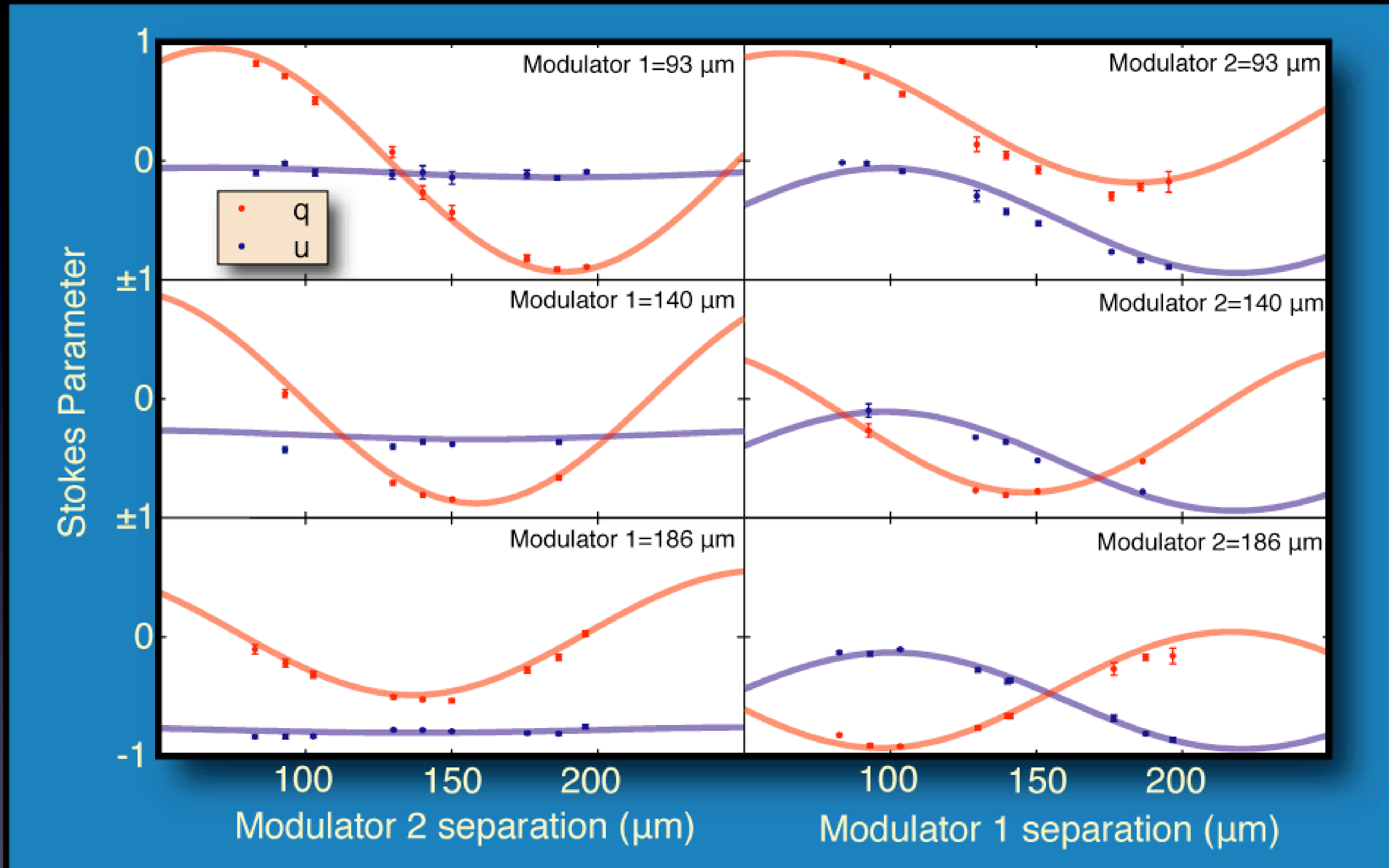
Hertz/SMTO



Hertz/SMTO



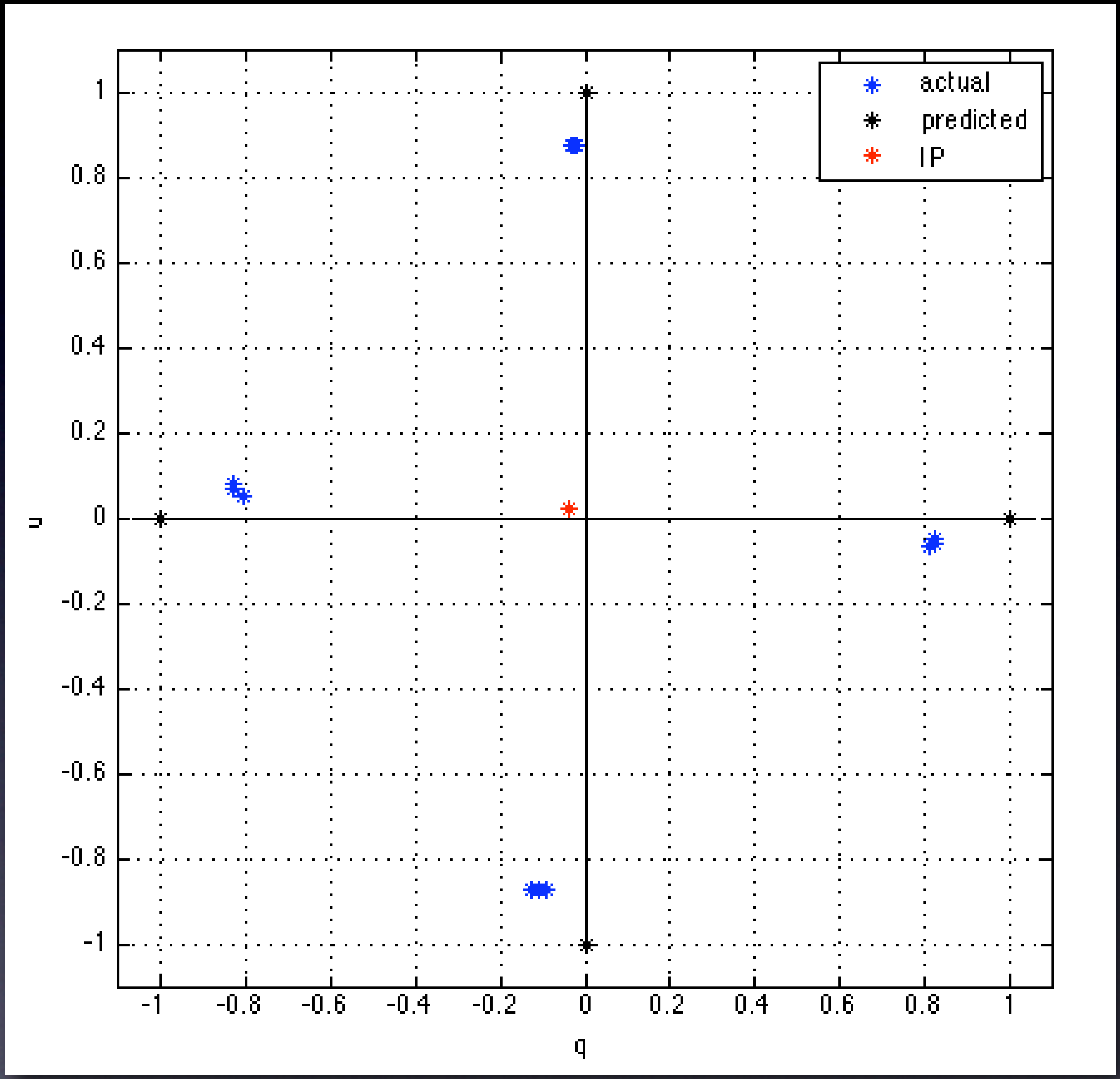
Polarization Transfer Function



Dual VPM model from Chuss et al. 2006

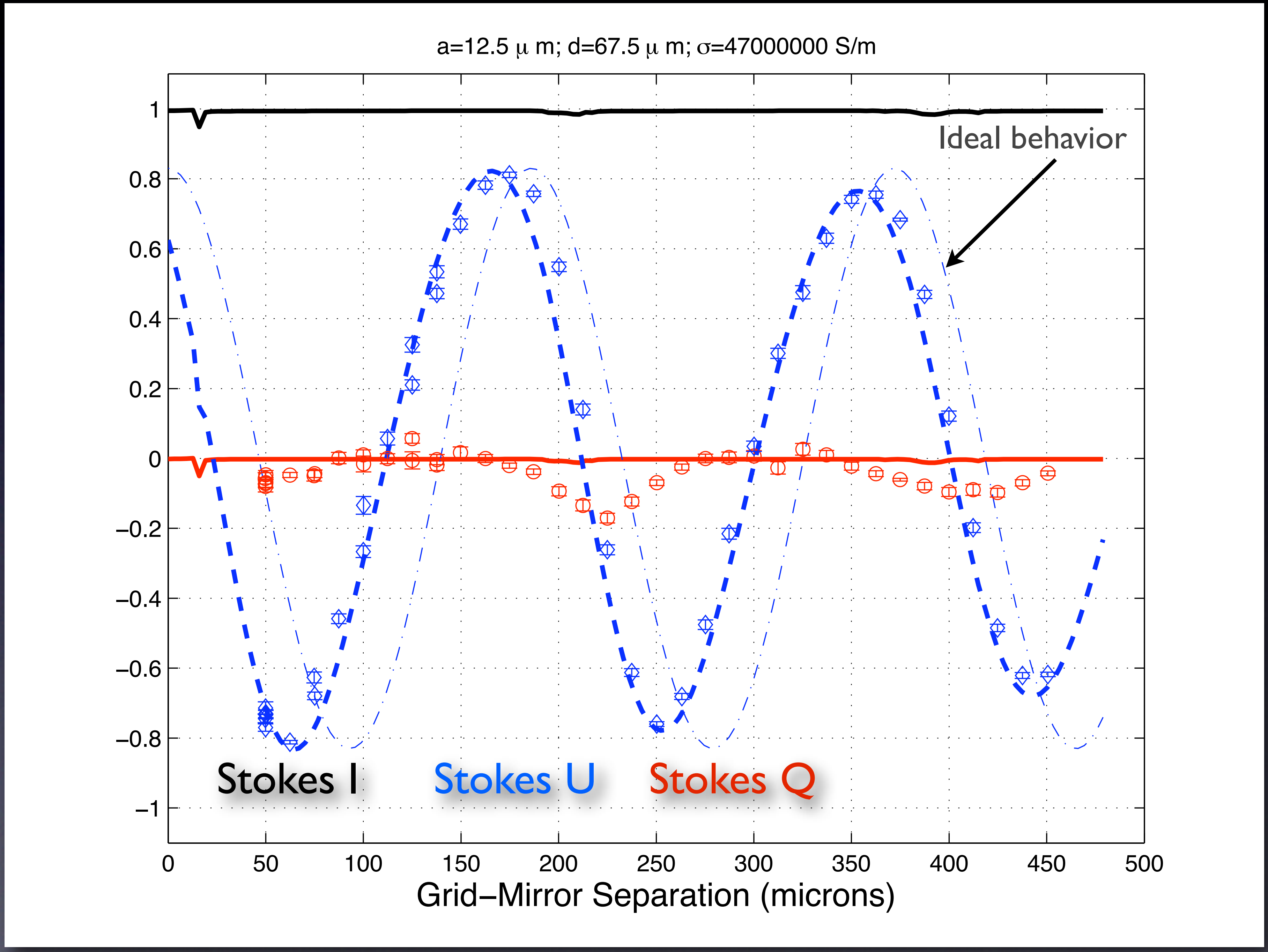
Instrumental polarization: 0.53 ± 0.2% (Krejny et al. arXiv: 0803.3759v1)

Laboratory Tests- 350 microns



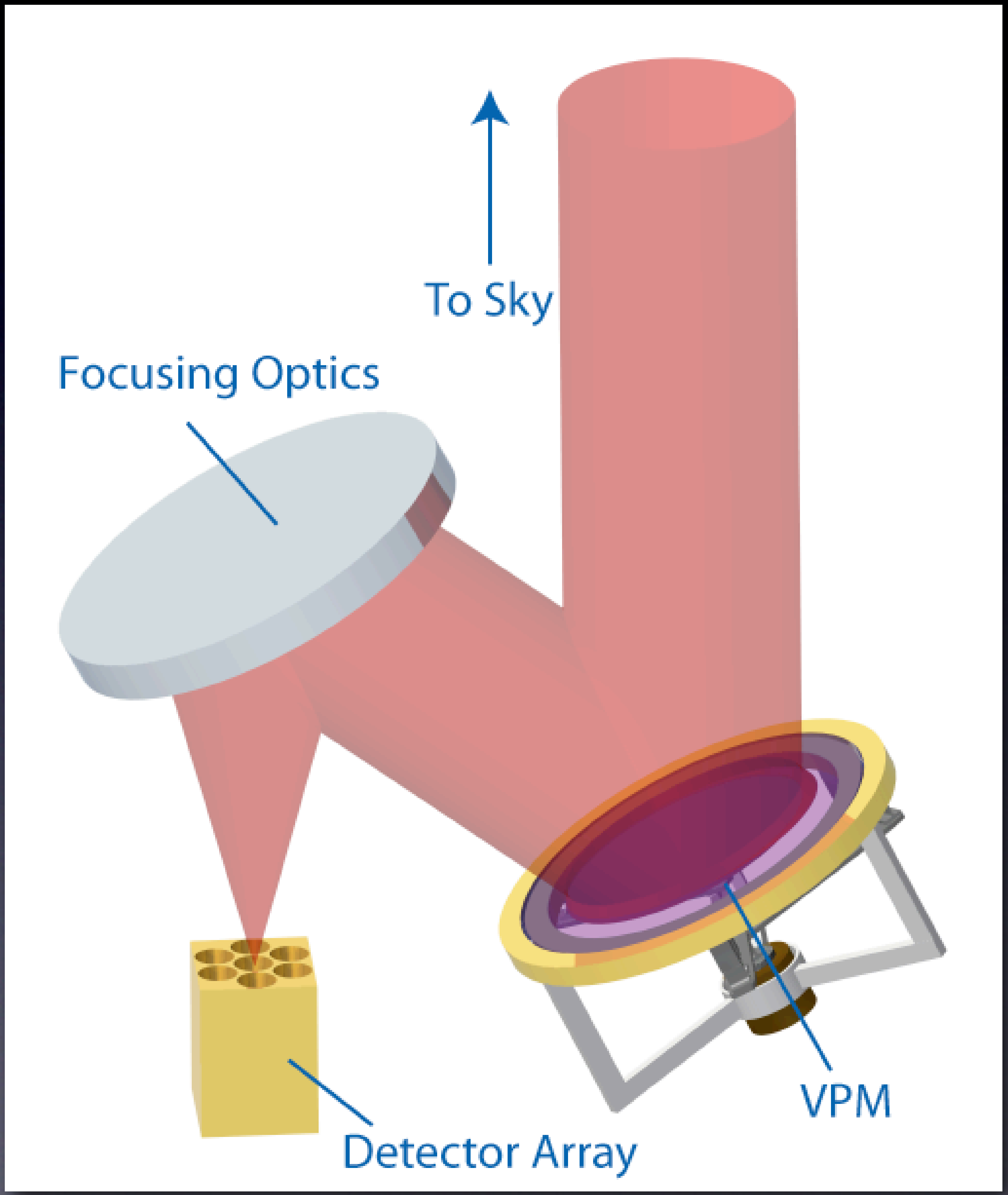
Krejny et al. arXiv: 0803.3759v1

NU Laboratory Tests- 350 micron

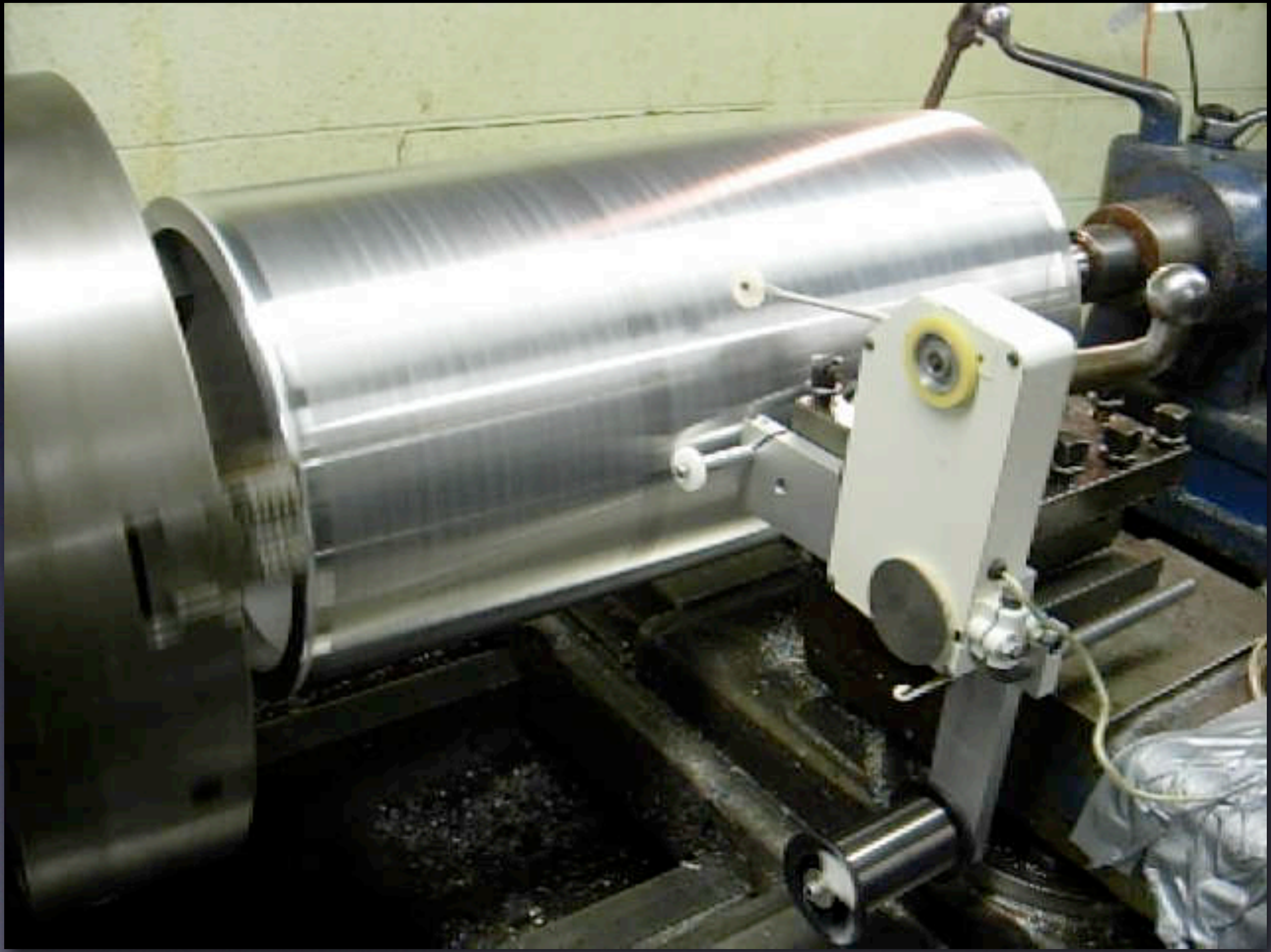


VPMs for CMB Polarimetry

Collaborators: C. Bennett, J. Eimer, L. Zeng (JHU), H. Hui (OSU), G. Novak (NU), G. Voellmer, E. Wollack, H. Moseley, G. Hinshaw (GSFC)



Large-Aperture VPM



Technique derived from Novak, Pernic, & Sundwall (1989)

VPMs for CMB Polarimetry

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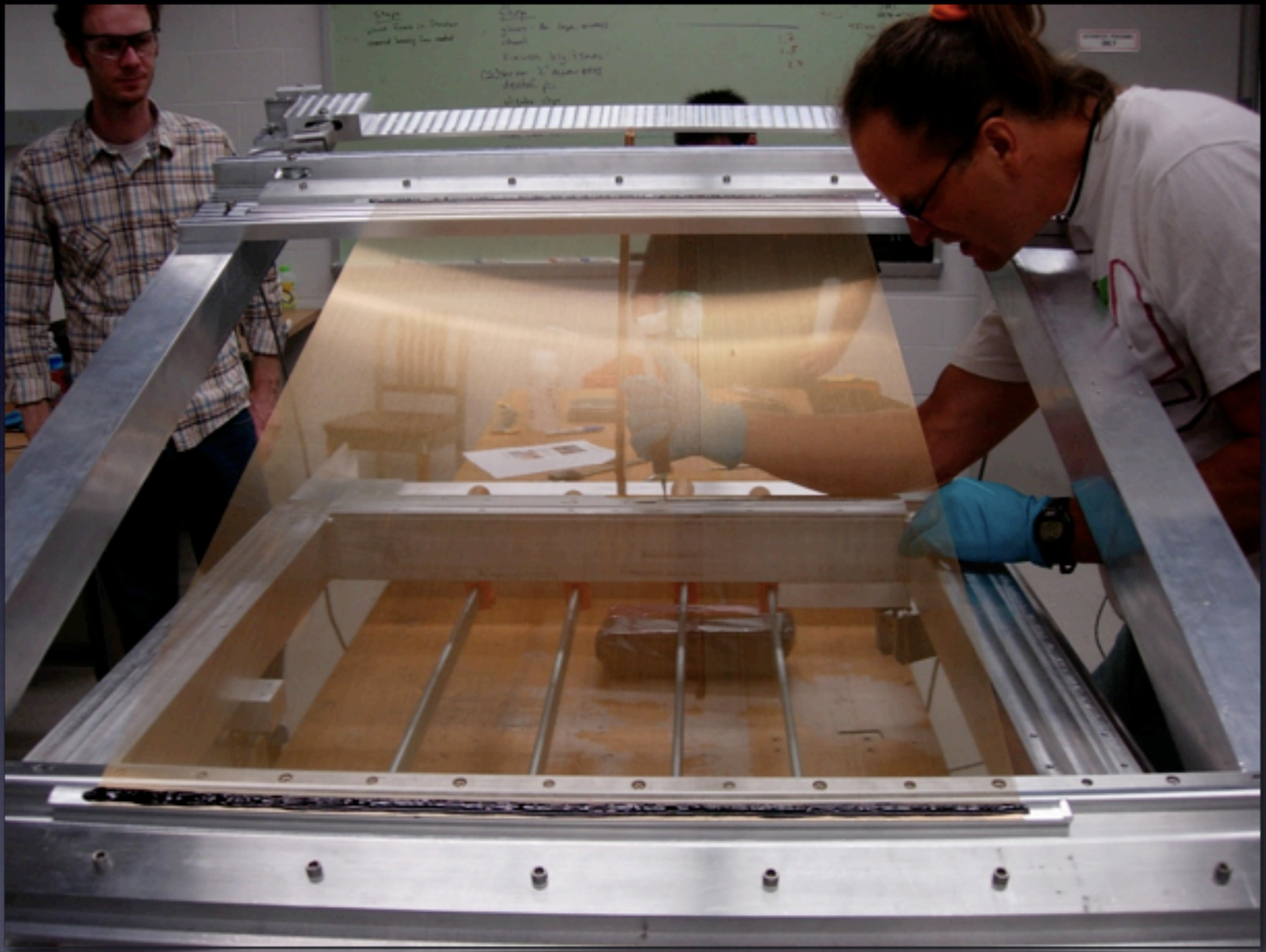

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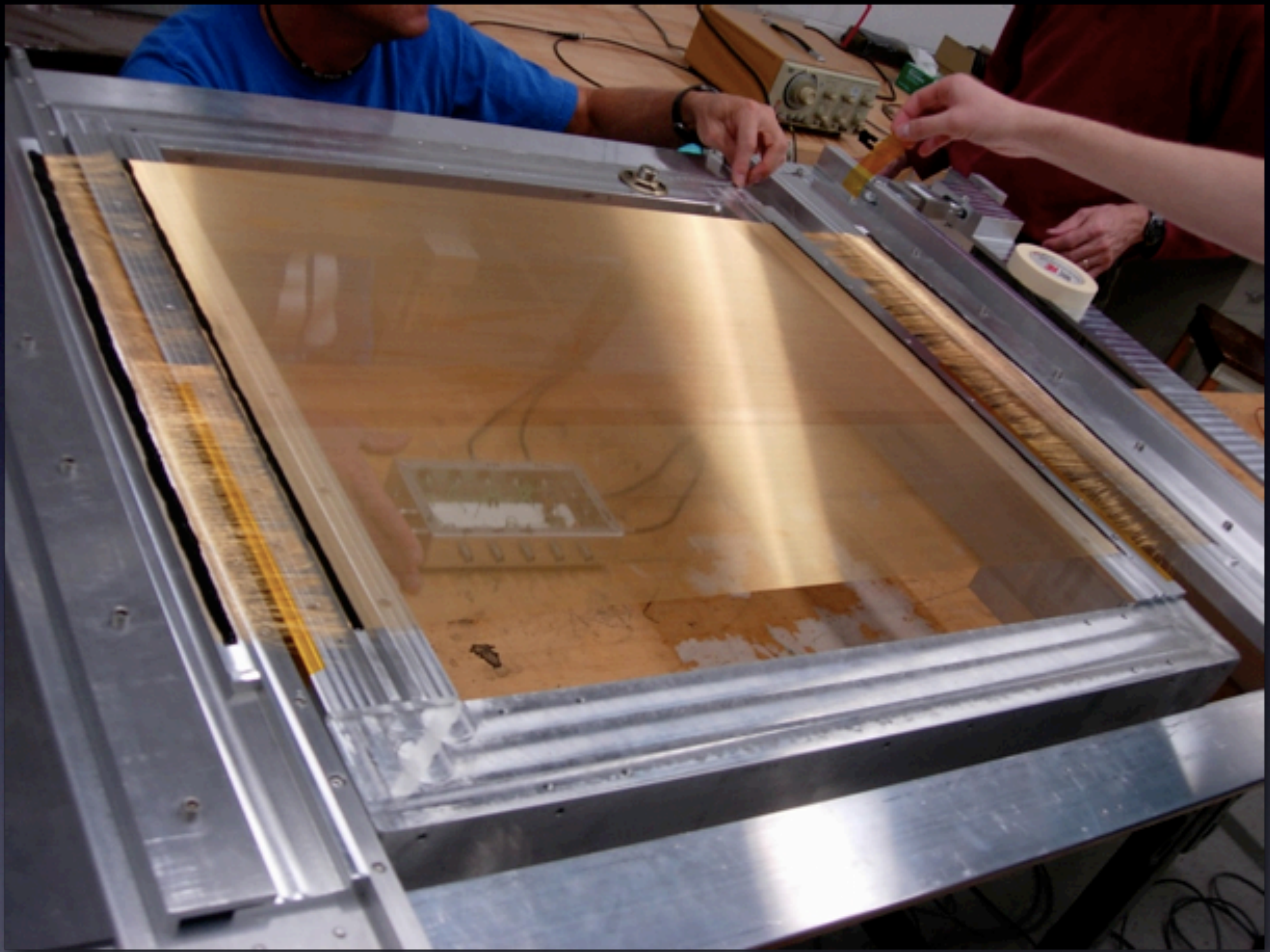
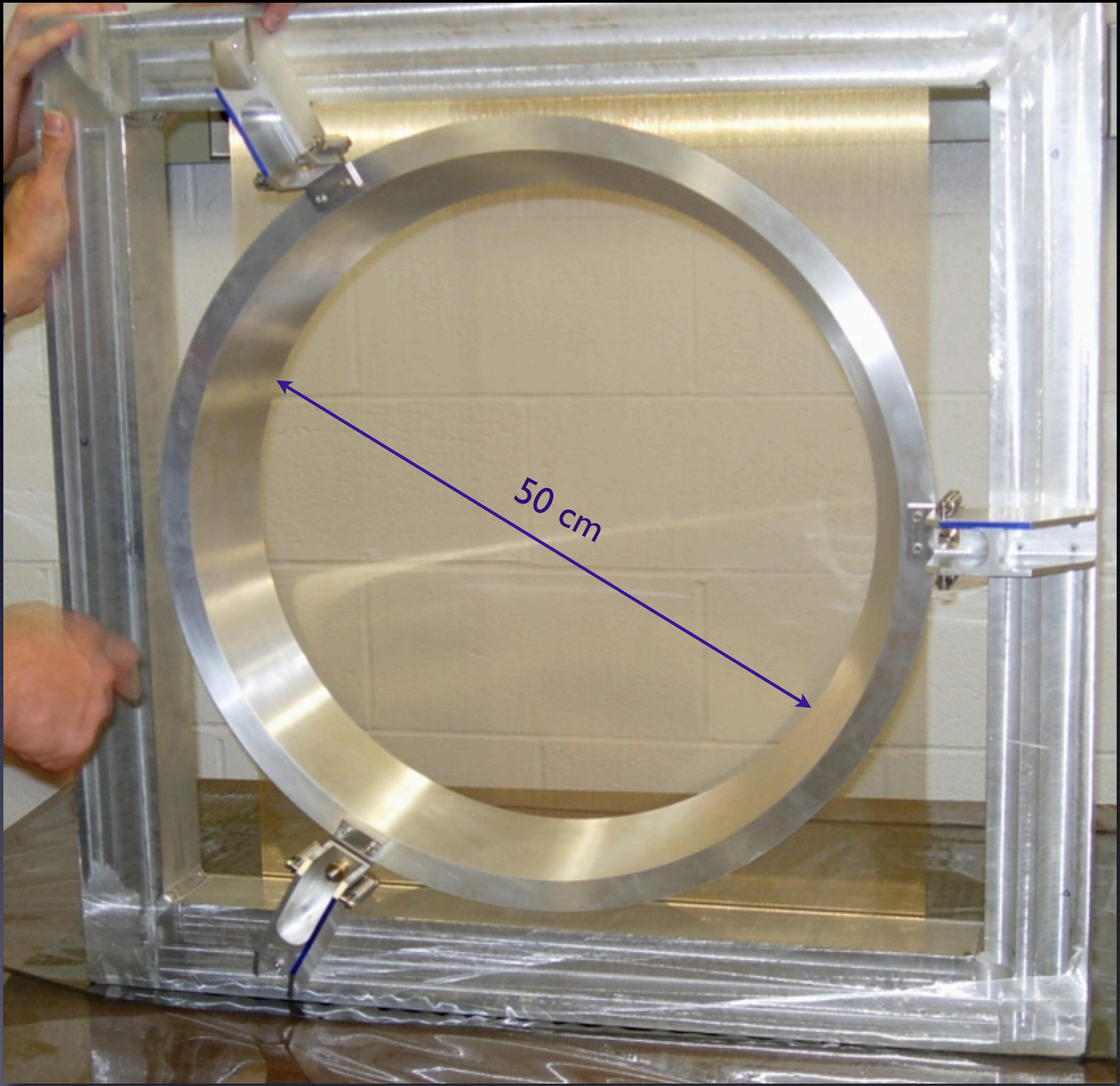


- Wire diameter = 67 μm
- Wire spacing = 200 μm
- Grid diameter = 50 mm
- Flatness < 50 μm
- Wire resonant frequency > 128 Hz
- 2 miles of wire
- 2 Tons of force on the frame



Voellmer et al. (2008)

Summary

- The Hertz dual VPM architecture looks promising for low I.P. and good efficiency

- VPMs are a candidate technology for CMBpol. Large VPMs are under development for this purpose.

3 mm Laboratory Tests