A NIR Pin-Hole Projection System: Status and Plans

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SNAP Site Visit

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Requirements

SNAP SuperNova Acceleration Probe at the University of Michigan

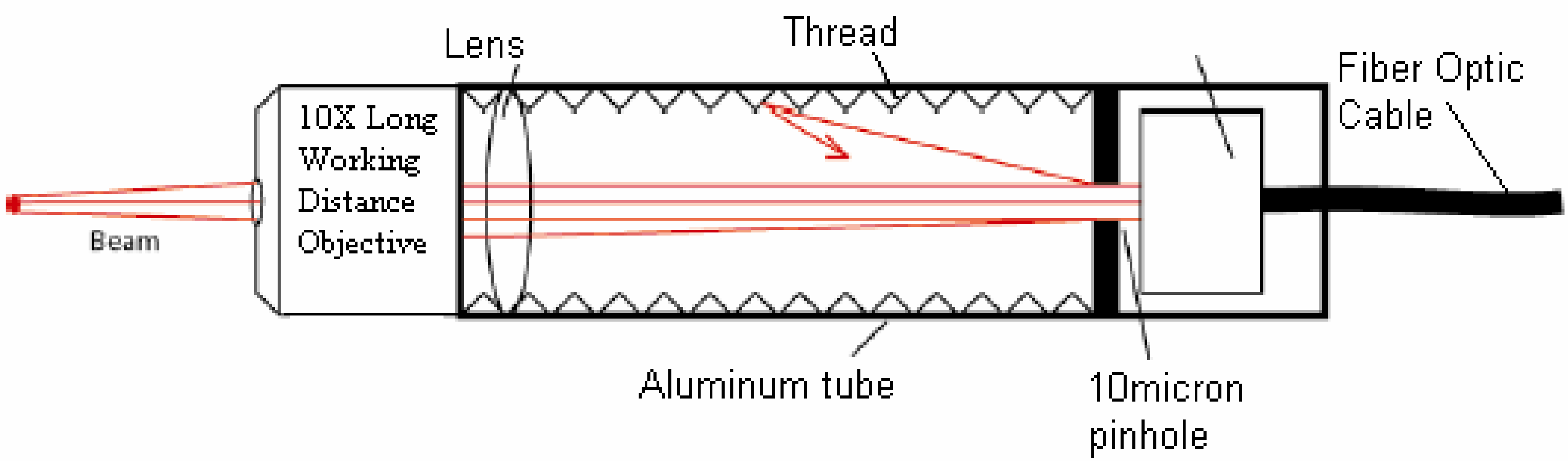
- Project μm-size NIR spots through dewar window onto detectors
  - be able to move spot around VERY precisely
  - achieve sub-pixel size reproducibility
  - maintain sub-percent intensity stability
  - be able to vary spot size
- Measure intra-pixel sensitivity variation
  - evaluate dithering schemes
  - test predictions in laboratory
    - ⇒ demonstrate required photometric accuracy
- Measure lateral charge diffusion

Brief History

SNAP SuperNova Acceleration Probe
at the University of Michigan

Start in April 2003

- base initial design on LBL pinhole projector (visible)
- adapt for NIR and improve design

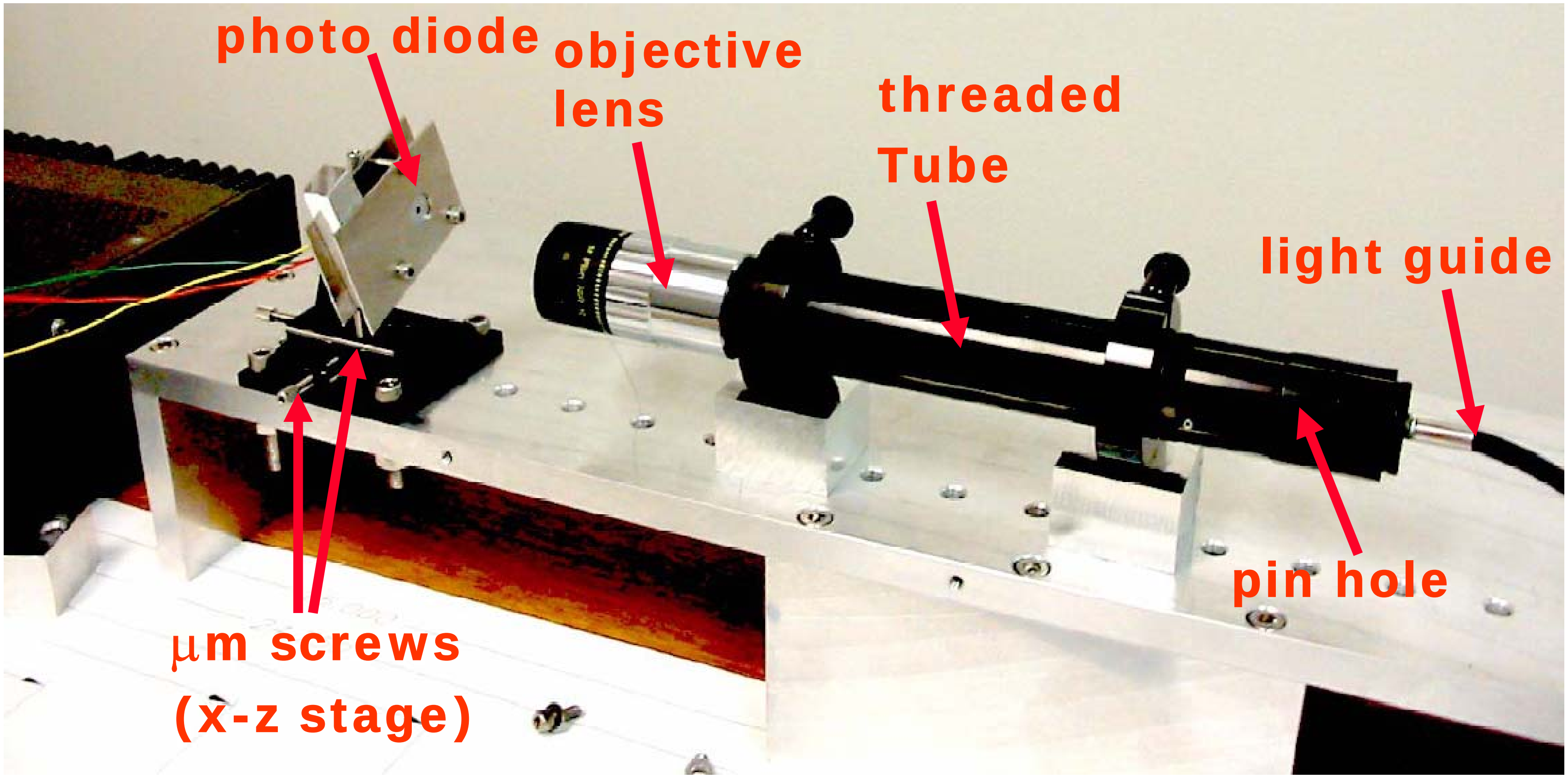


Courtesy of W. Kolbe, LBL 2002

REU Project: Summer 2003

SNAP SuperNova Acceleration Probe at the University of Michigan

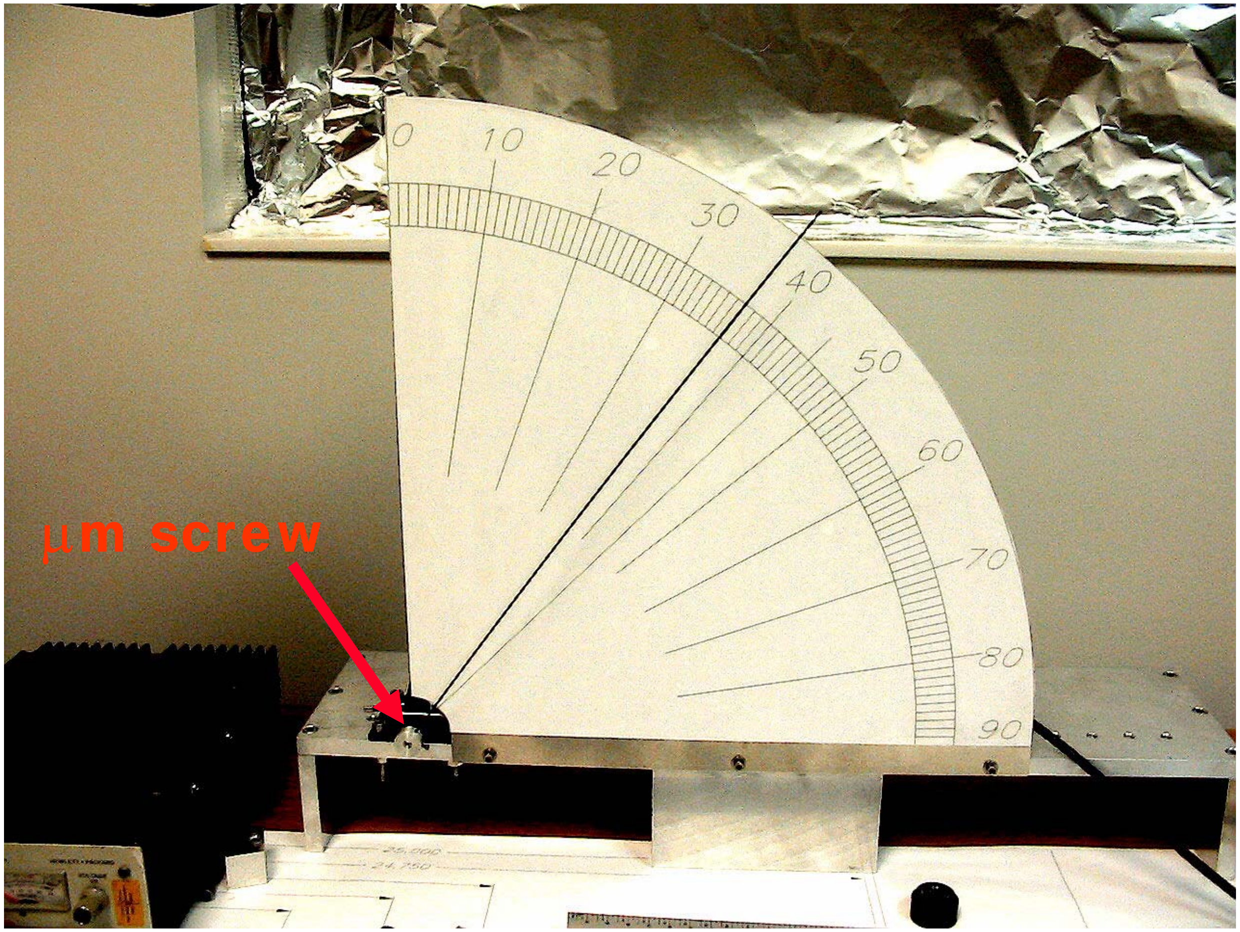
Trying to find a focus



REU Project: Summer 2003

SNAP SuperNova Acceleration Probe
at the University of Michigan

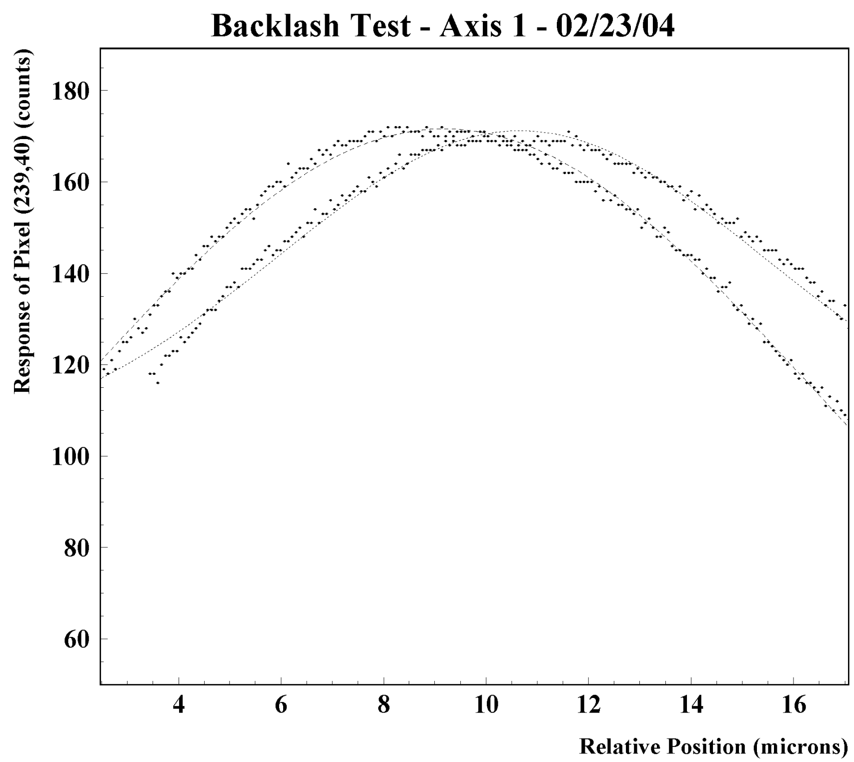
Trying to move in small steps (μm)



Senior Thesis Project: Winter 04 semester

SNAP SuperNova Acceleration Probe at the University of Michigan

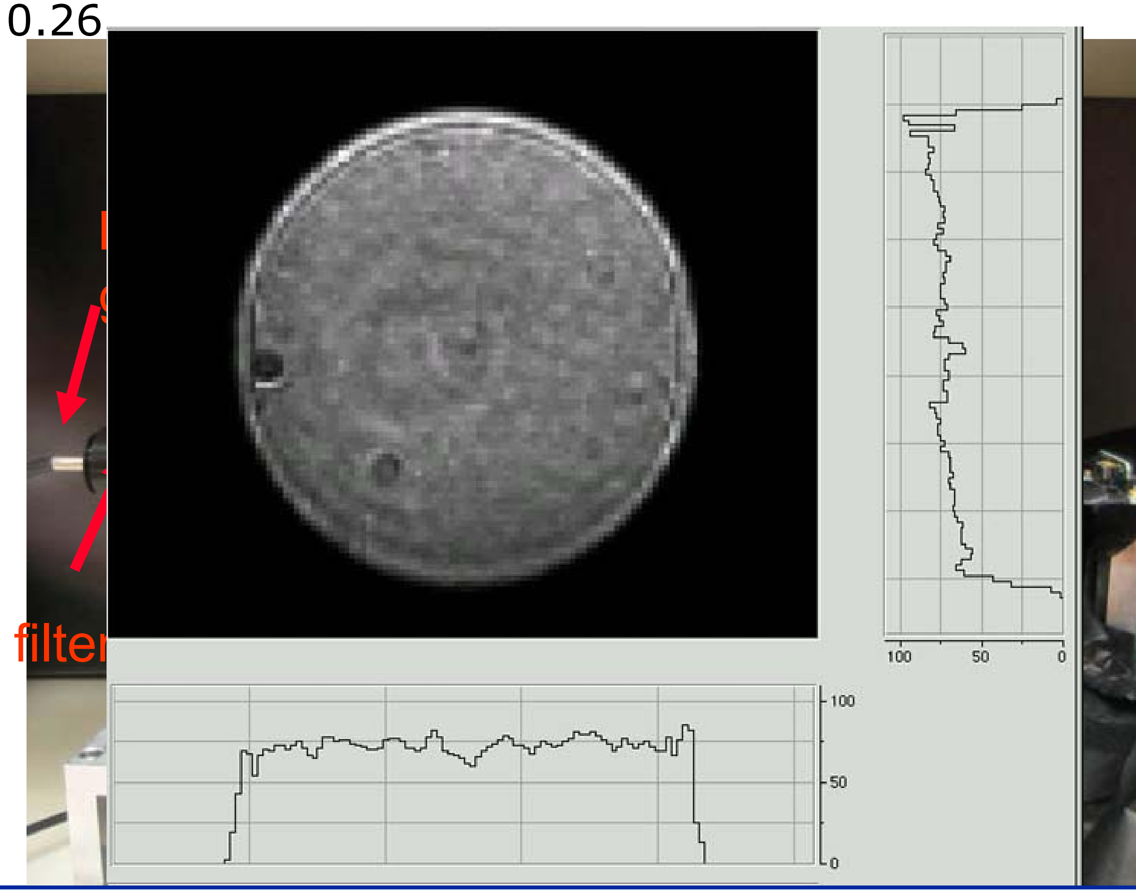
- Installation of automated x-y-z stage
  - step size: 0.075 μm (±1 mm per inch of travel)
- Characterization
  - backlash: 1.0 – 1.5 μm (different for + or – direction)
    - correct in software
  - drift: 0.3 μm (similar for all 3 axes)
  - repeatability: 0.3 μm (similar for all 3 axes)



Senior Thesis Project: Winter 04 semester

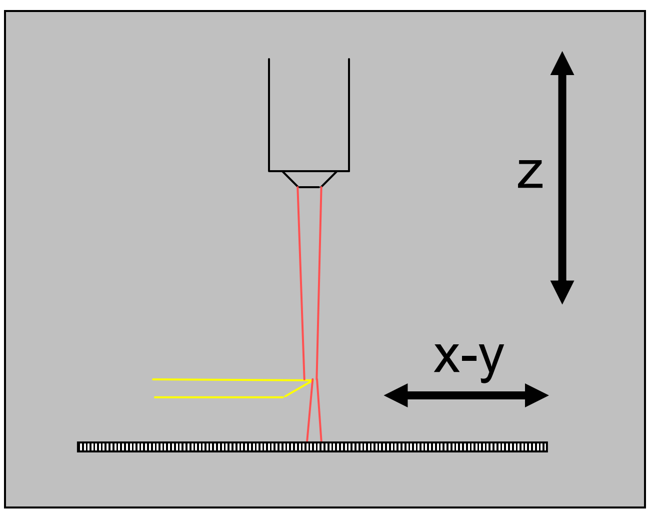
SNAP SuperNova Acceleration Probe
at the University of Michigan

- Installation of optics
  - M Plan NIR series (Mitutoyo Long Working distance objective)
  - magnification (microscope configuration): 10x
  - range (chromatically corrected): 480-1800 nm
  - numerical aperture (NA): 0.26
    - ⇒ minimal spot size [=f(λ)]:
      0.96 – 3.6 μm (σ)
      2.25 – 8.44 μm (FWHM)
- Characterization
  - understanding the optics using visible light on CCD
    - fighting bright spots
    - imaging pin holes
  - knife edge scans
    - determining spot sizes

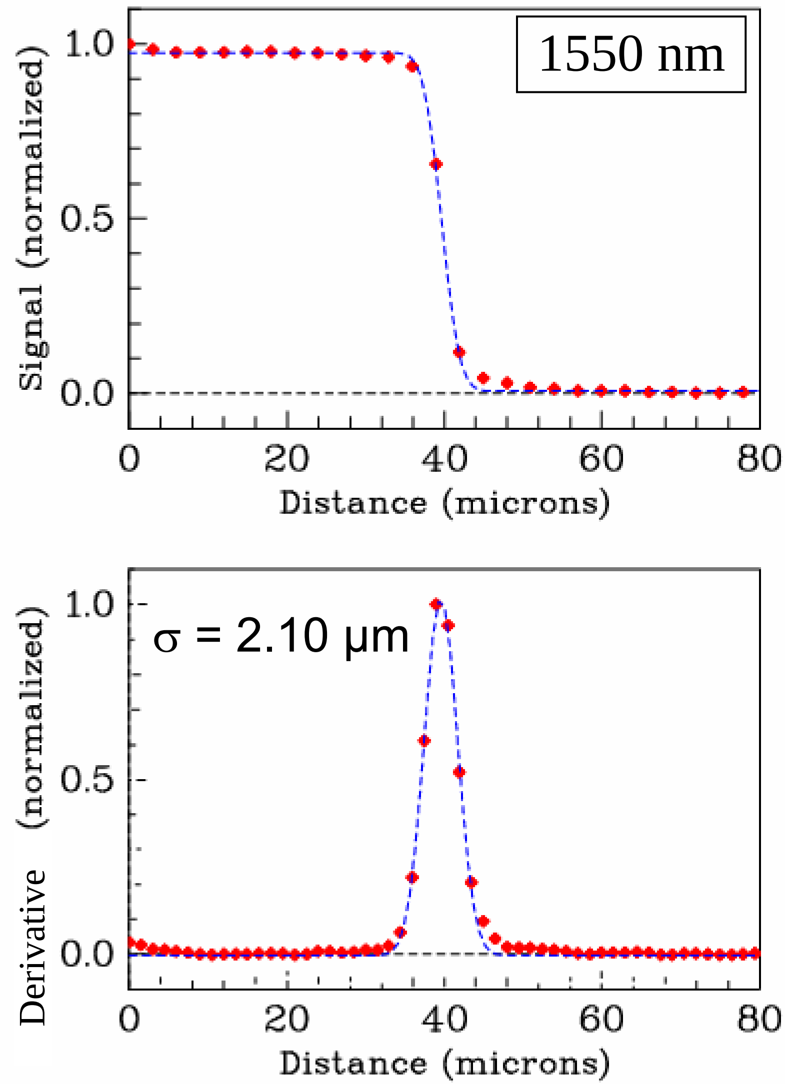


Knife Edge Scan

- A knife edge is placed ~6 mm above the detector surface
- Spot-O-Matic is scanned across knife edge in x-y while focusing in z to minimize the spot size and determine the point spread function (PSF)

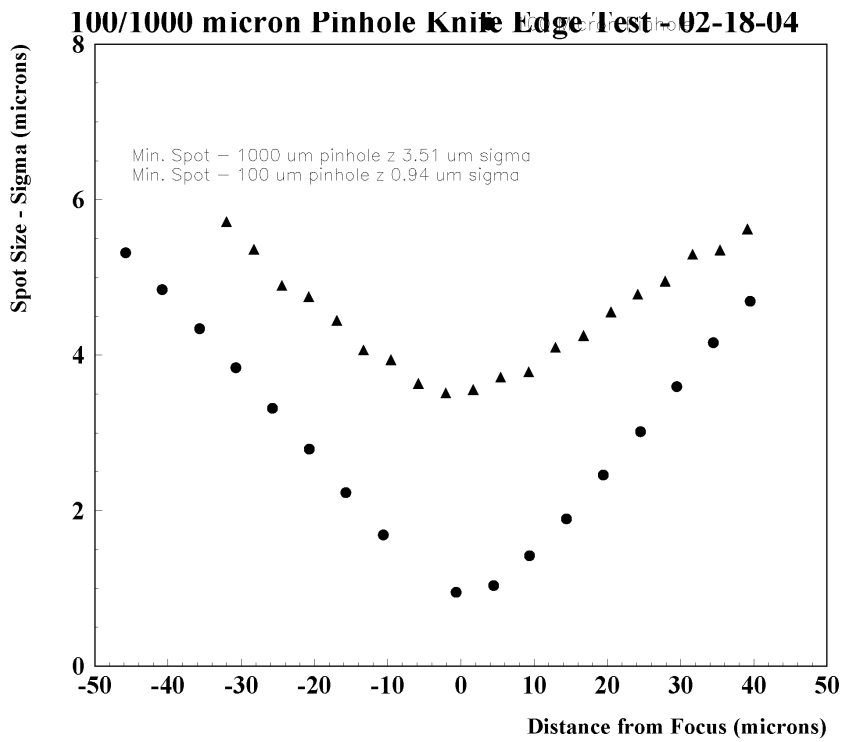


Best Focus

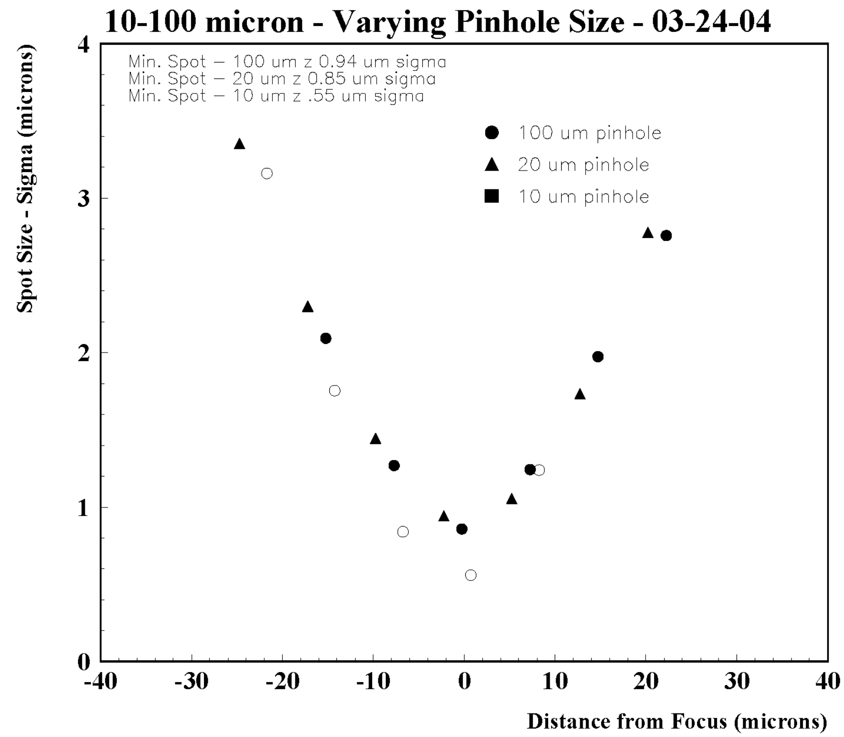


Varying Pinhole Size

SNAP SuperNova Acceleration Probe at the University of Michigan



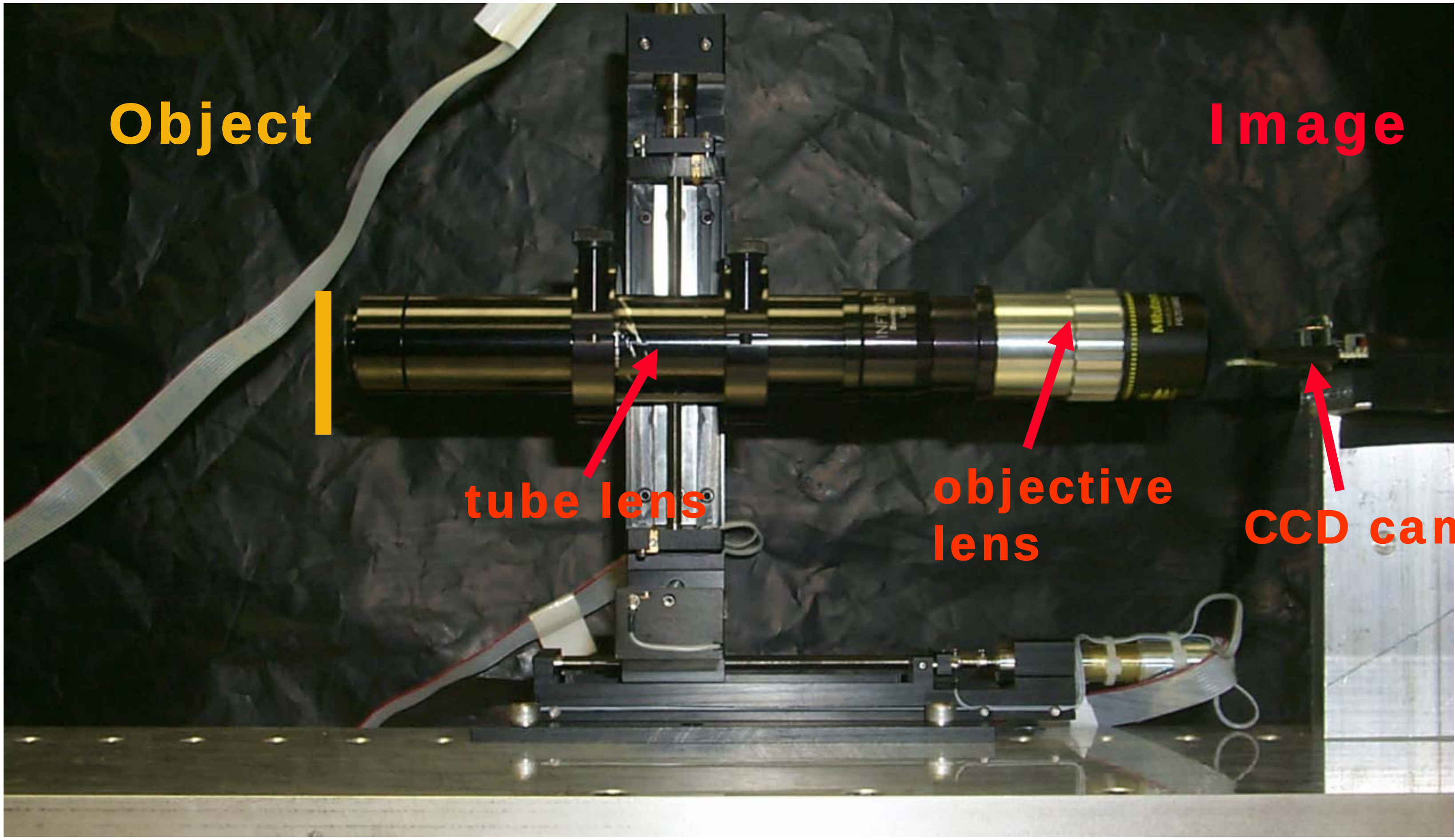
Expected behaviour



Unexpected behaviour

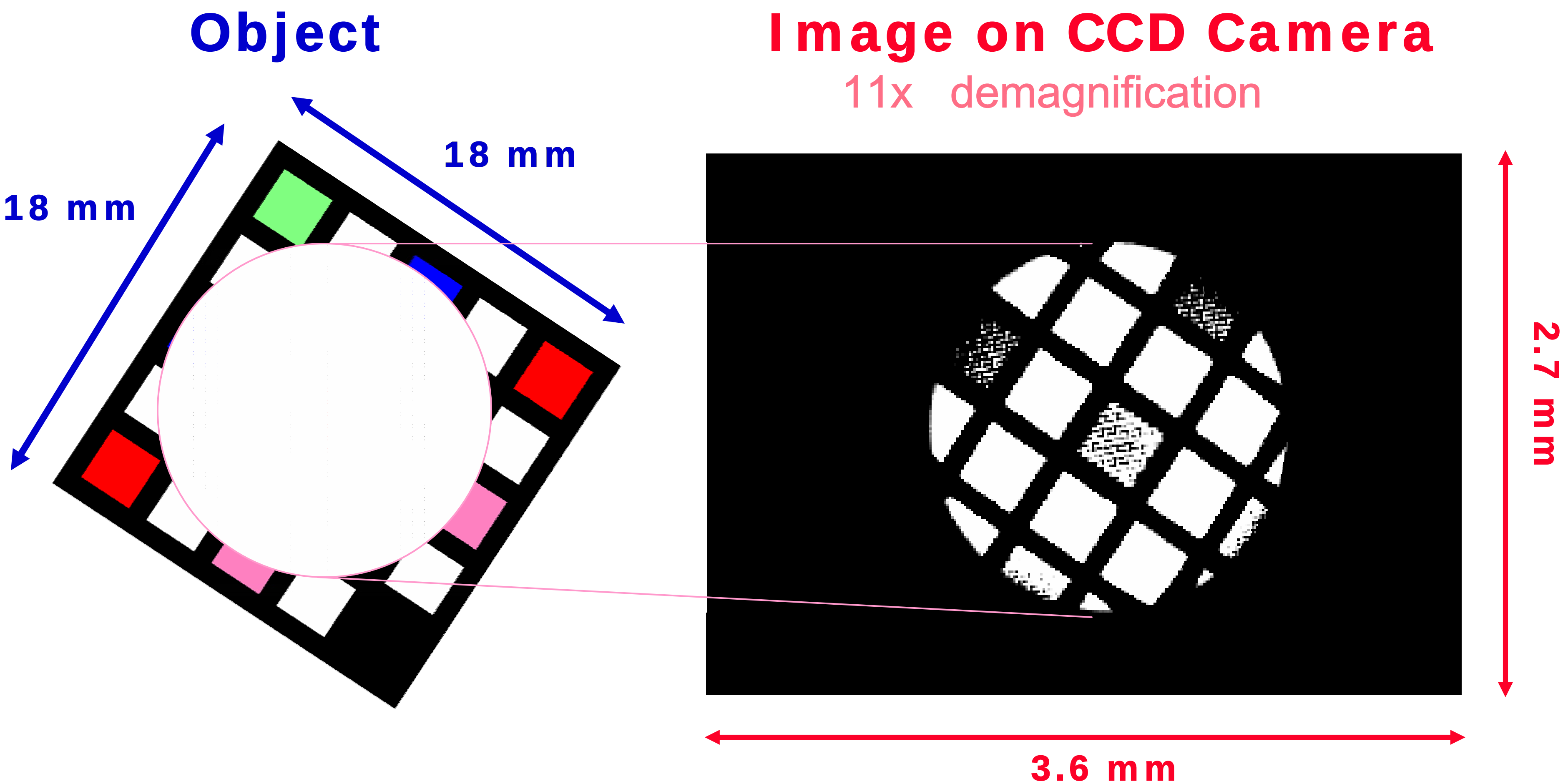
Testing General Properties

SNAP SuperNova Acceleration Probe
at the University of Michigan

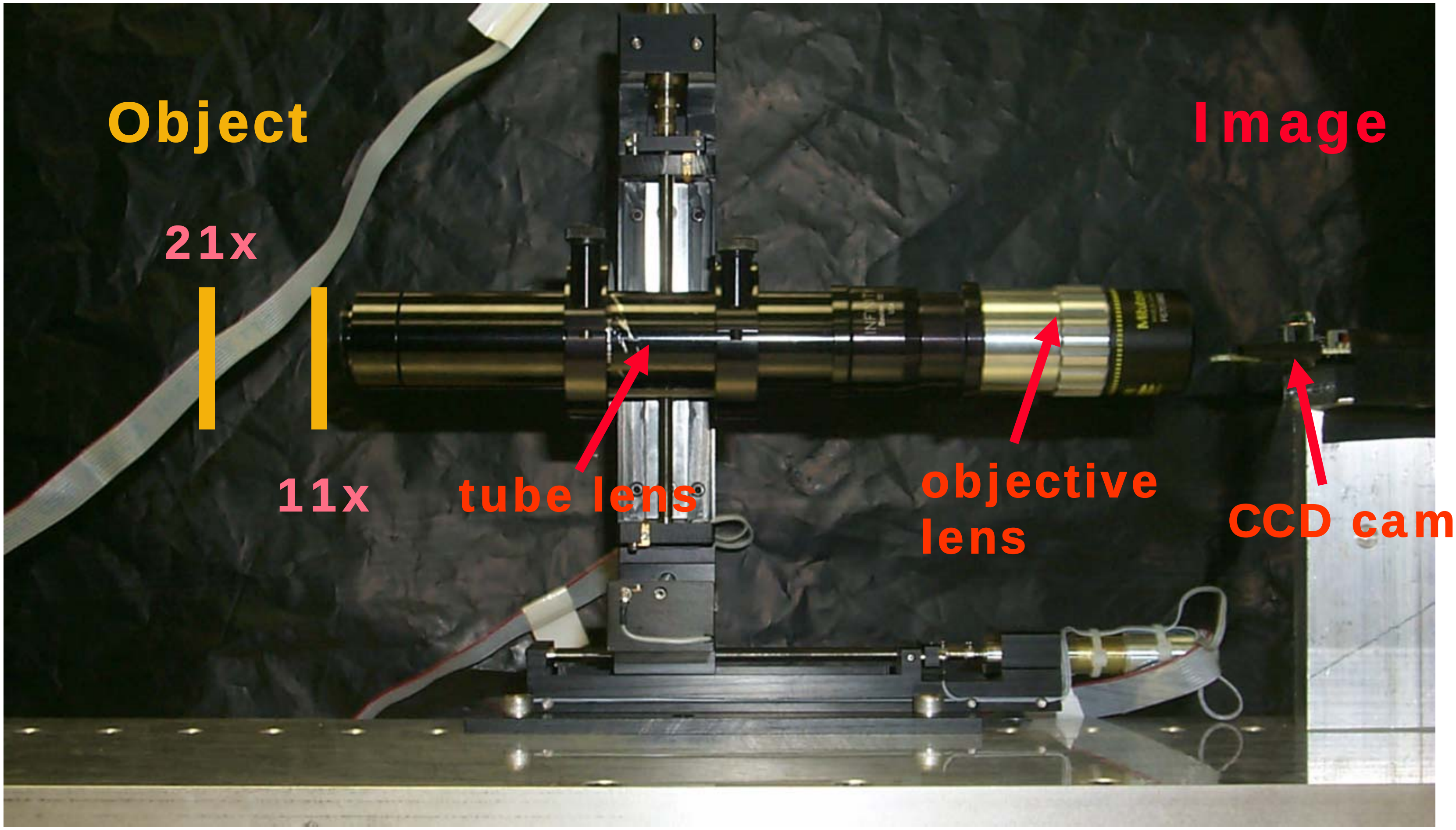


Testing General Properties

SNAP SuperNova Acceleration Probe
at the University of Michigan

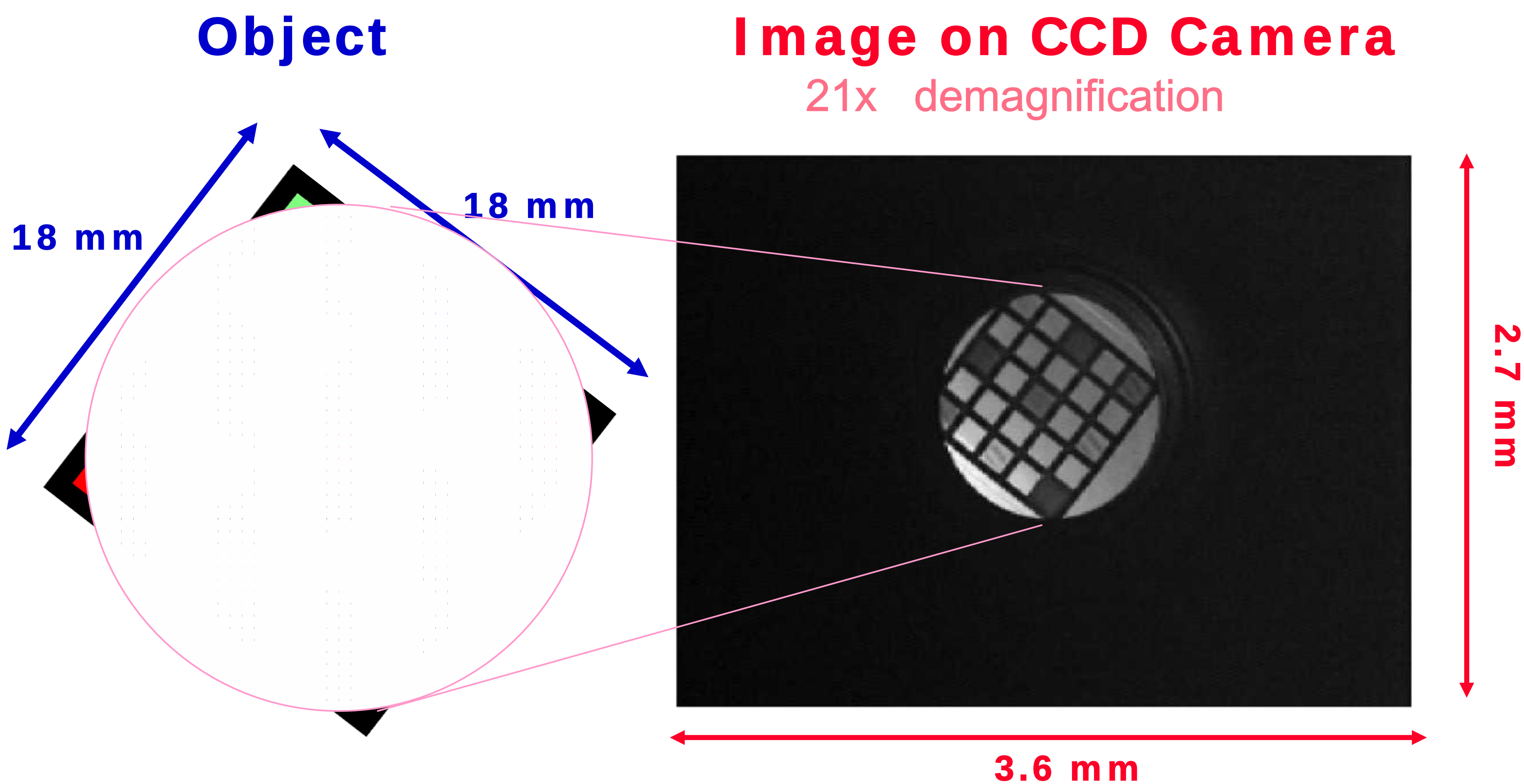


Testing General Properties

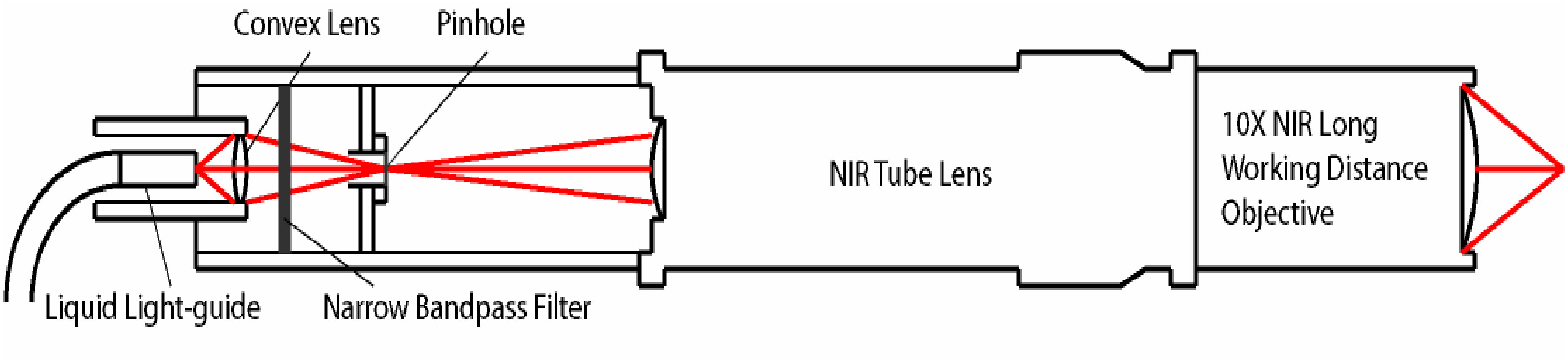


Testing General Properties

SNAP SuperNova Acceleration Probe
at the University of Michigan



How it Works


Convex Lens
Pinhole
NIR Tube Lens
10X NIR Long
Working Distance
Objective
Liquid Light-guide
Narrow Bandpass Filter

Results

SNAP SuperNova Acceleration Probe at the University of Michigan

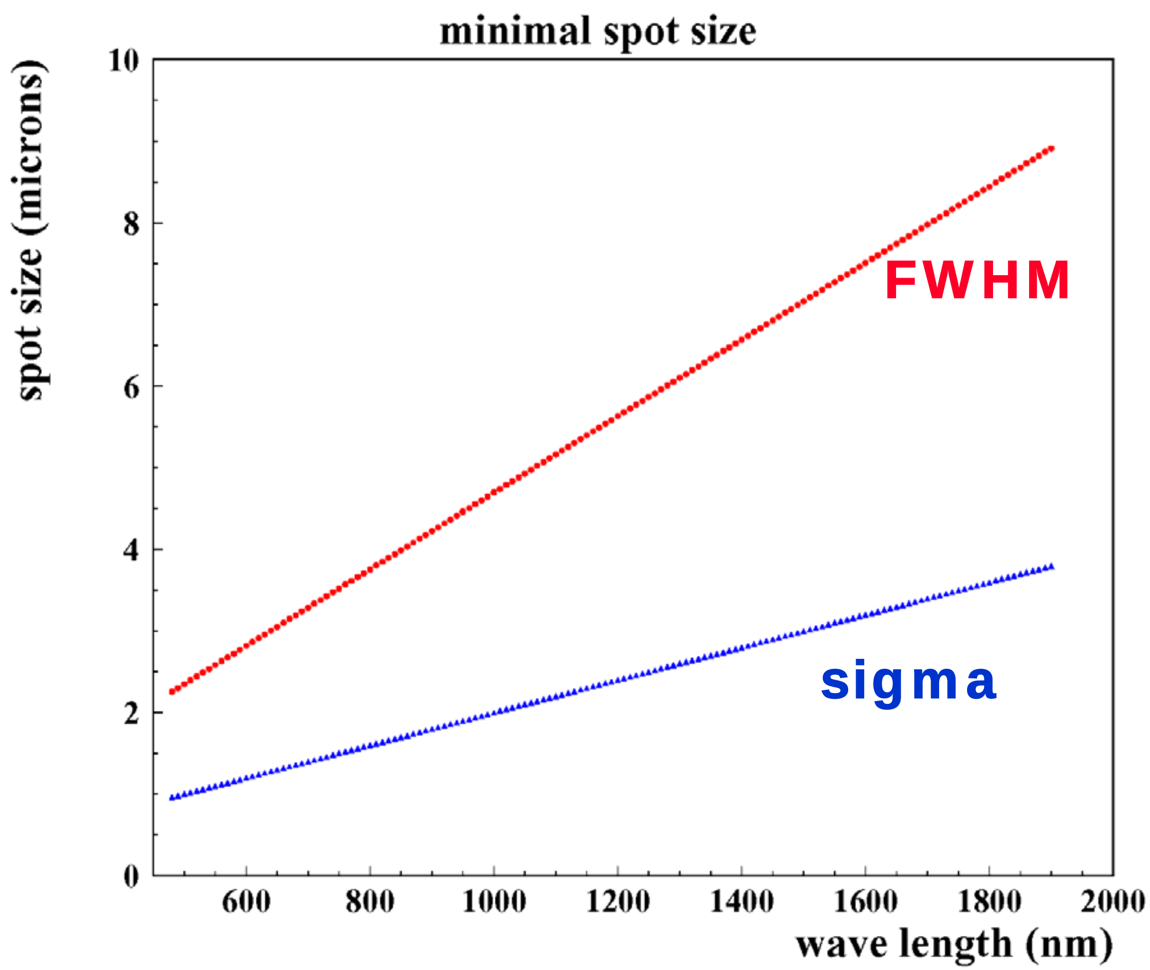
Summary (visible light)

Pinhole Size	Smallest spot measured on CCD	Expected spot size (no diffraction)	Expected spot size (incl. diffraction)
100 μm	5.9 μm	4.8 μm	5.4 μm
10 μm	2.5 μm	0.48 μm	2.5 μm

Demagnification: 21x

Resolving Power = $0.61\lambda / N.A. \approx 1.2\ \mu$m.

Spot Size vs Wavelength

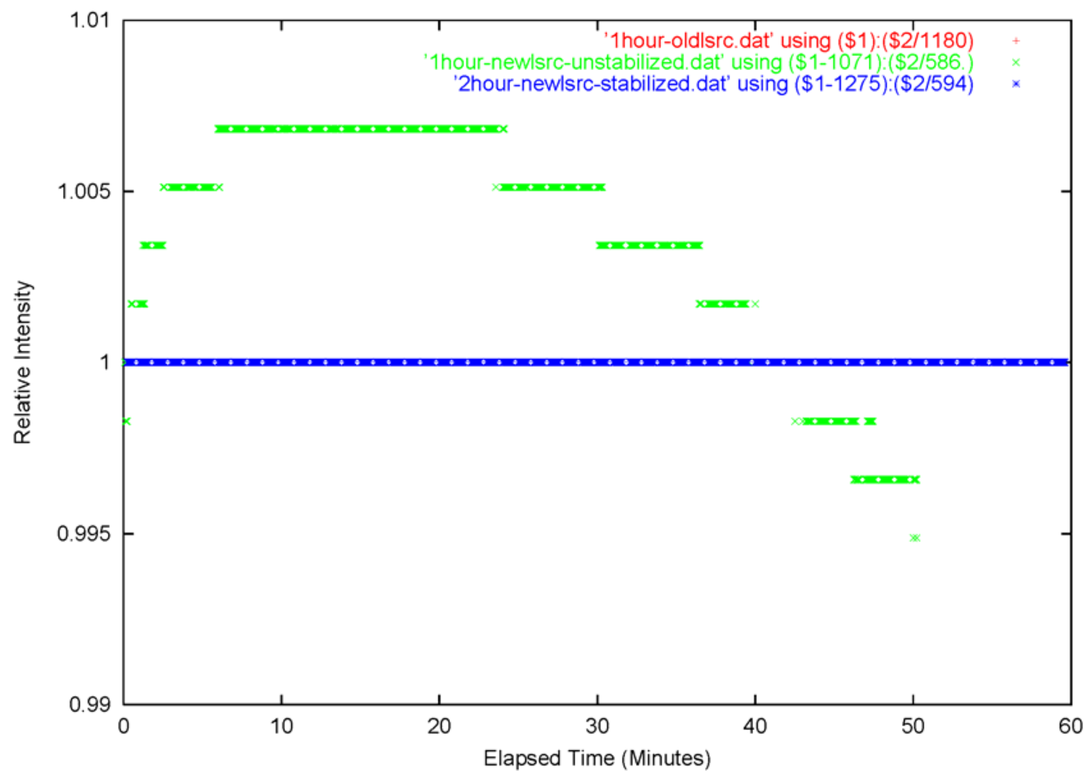


Diffraction limited spot size

Improvements

SNAP SuperNova Acceleration Probe
at the University of Michigan

Light (In)Stability



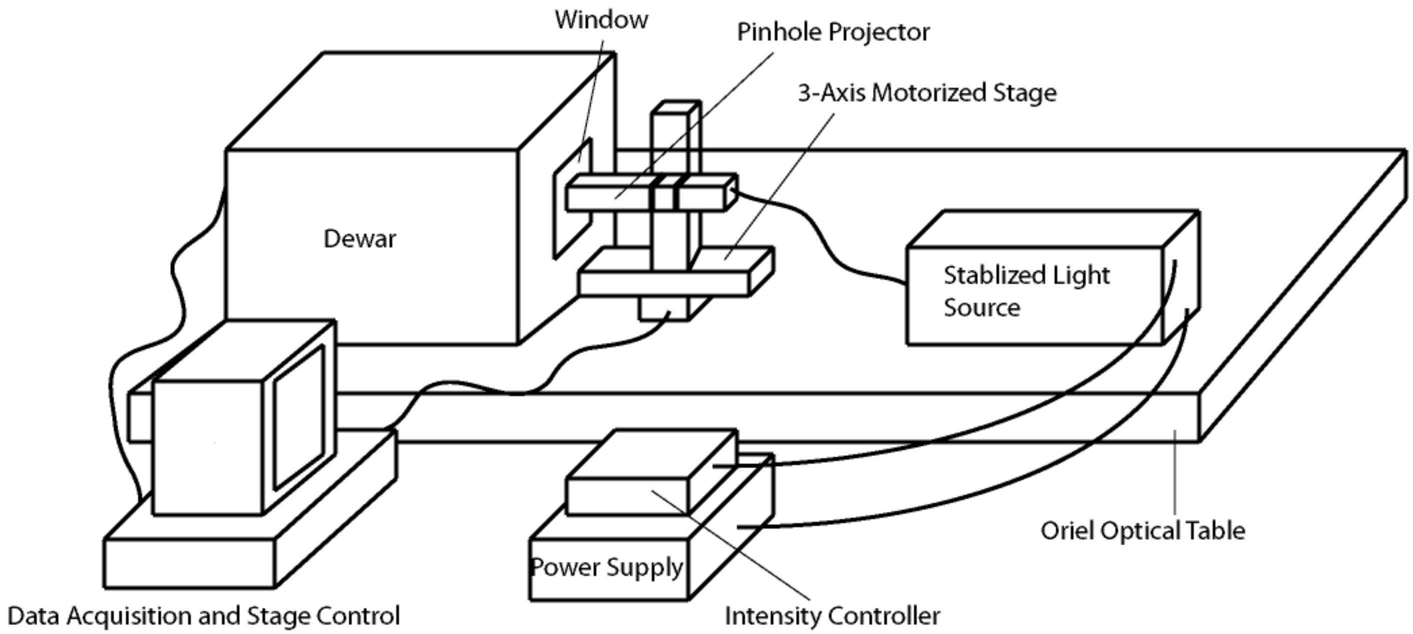
Need stable light source

(<1% variation) for:

- knife-edge scans
- PSF evaluation
- inter-pixel variation
- intra-pixel variation

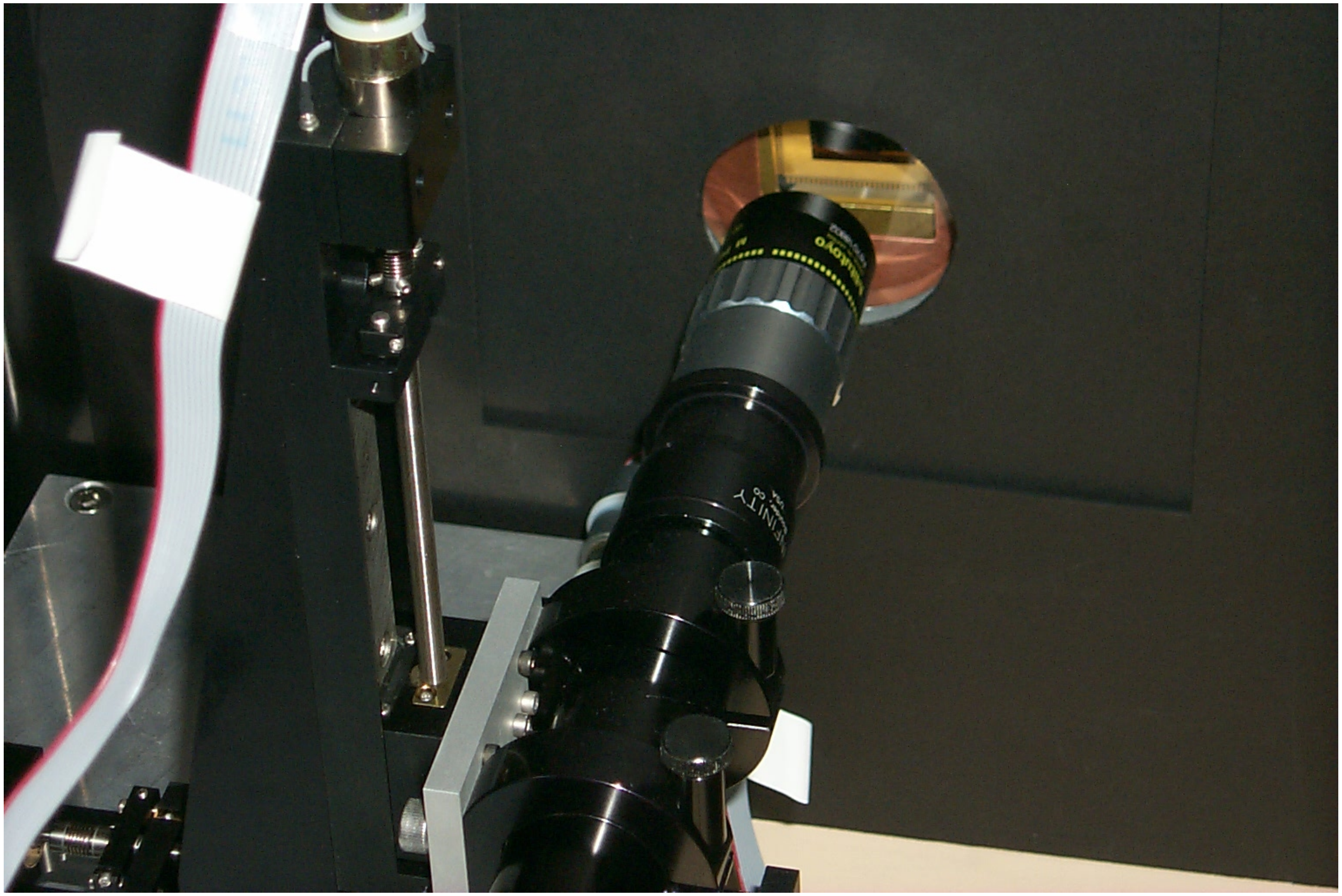
Further Improvements

- Installed linear encoder on z-axis
  - improve speed, accuracy and repeatability of pixel scans
- Installed optical table
  - improve precision and repeatability of measurements
- many improvements to motion control and analysis software

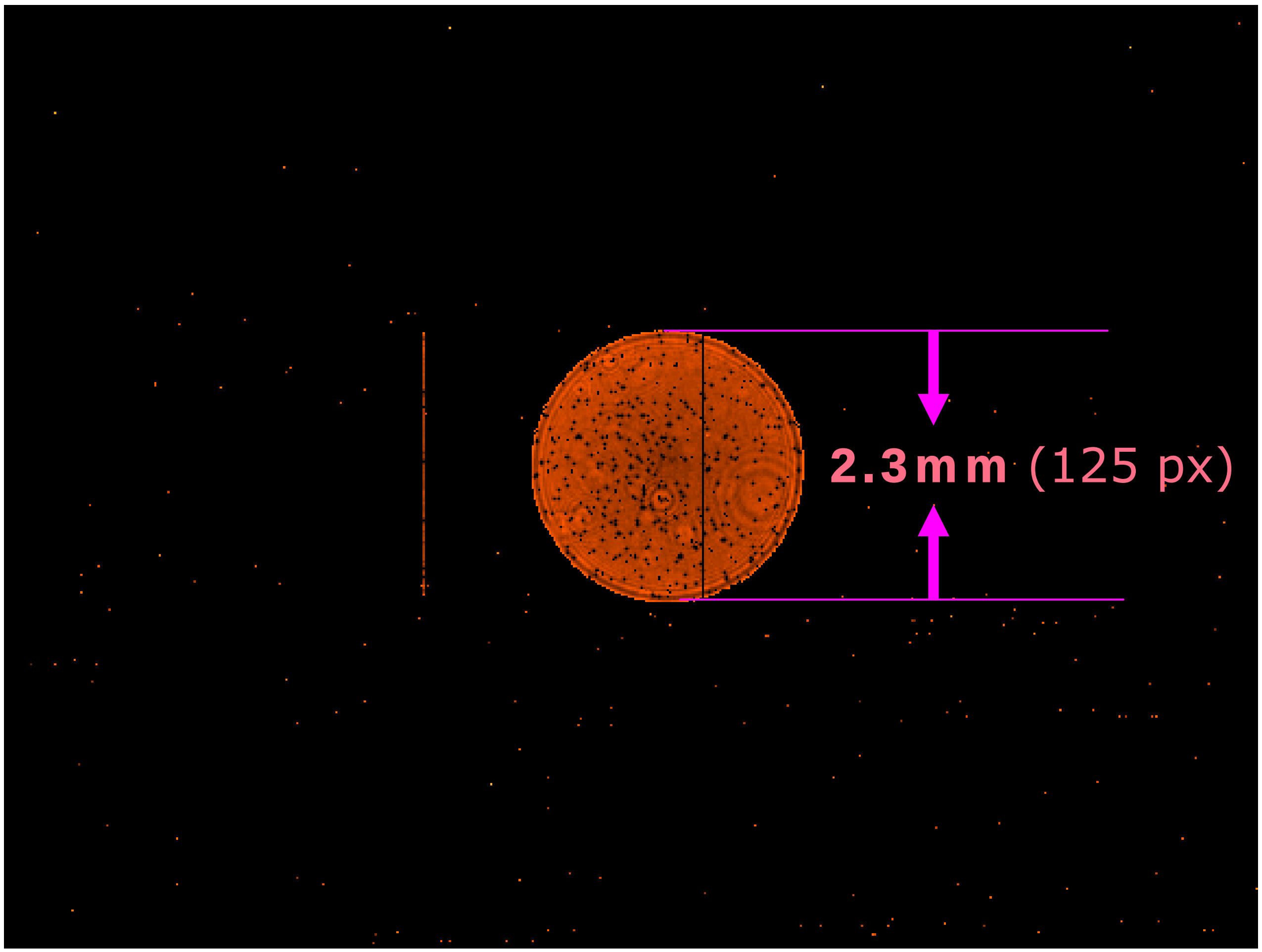


SNAP SuperNova Acceleration Probe at the University of Michigan

Putting a Spot on the InGaAs Detector



Putting a Spot on the InGaAs Detector(II)



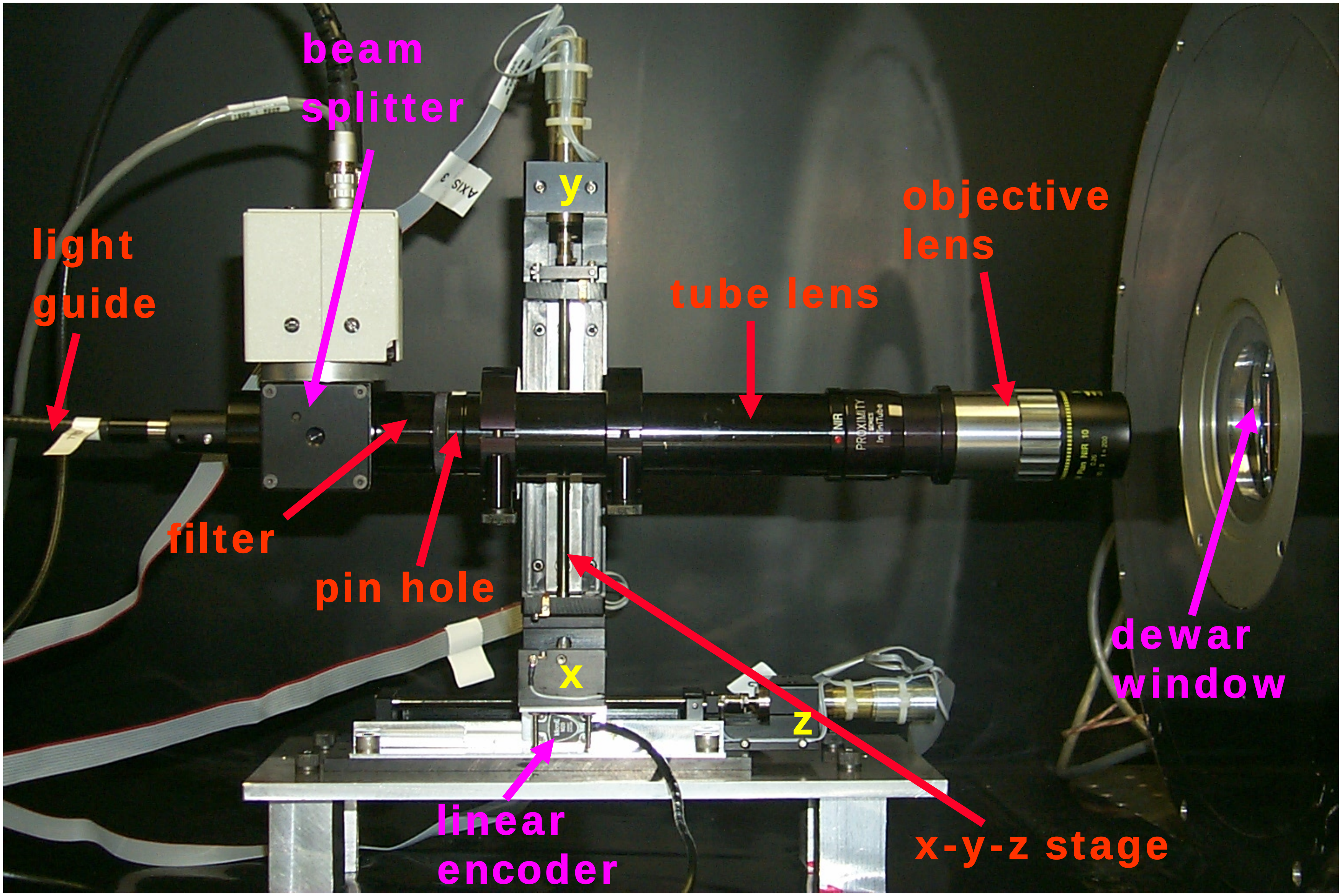
filter:

1400 ± 50 nm

4.2 mm from focus

Summer 2004

SNAP SuperNova Acceleration Probe
at the University of Michigan



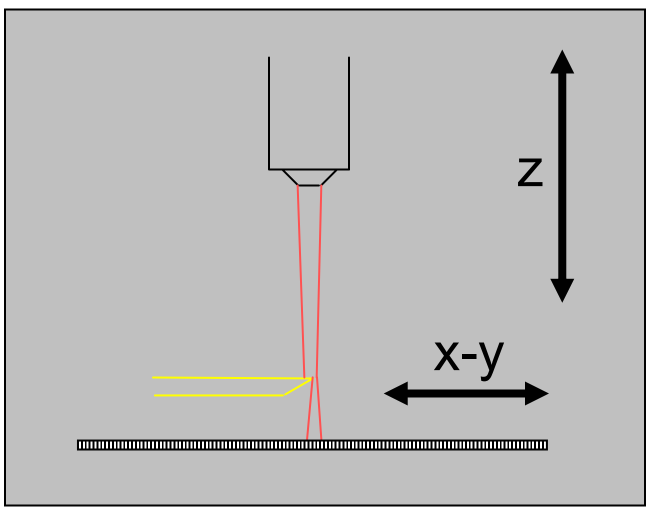
Knife-Edge Scan

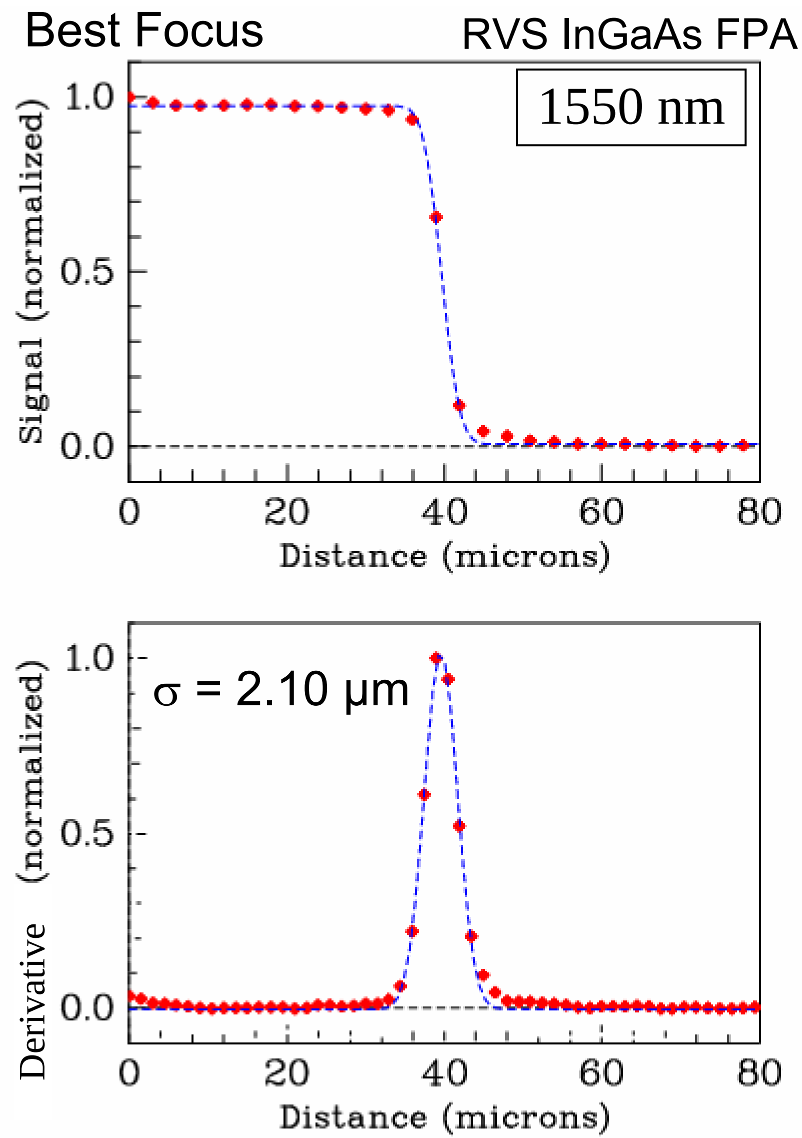
SNAP SuperNova Acceleration Probe at the University of Michigan

Characterize a beam spot

• A knife edge is placed ~6 mm above the detector surface

• Spot-O-Matic is scanned across knife edge in x-y while focusing in z to minimize the spot size and determine the point spread function (PSF)





Virtual Knife-Edge Scan

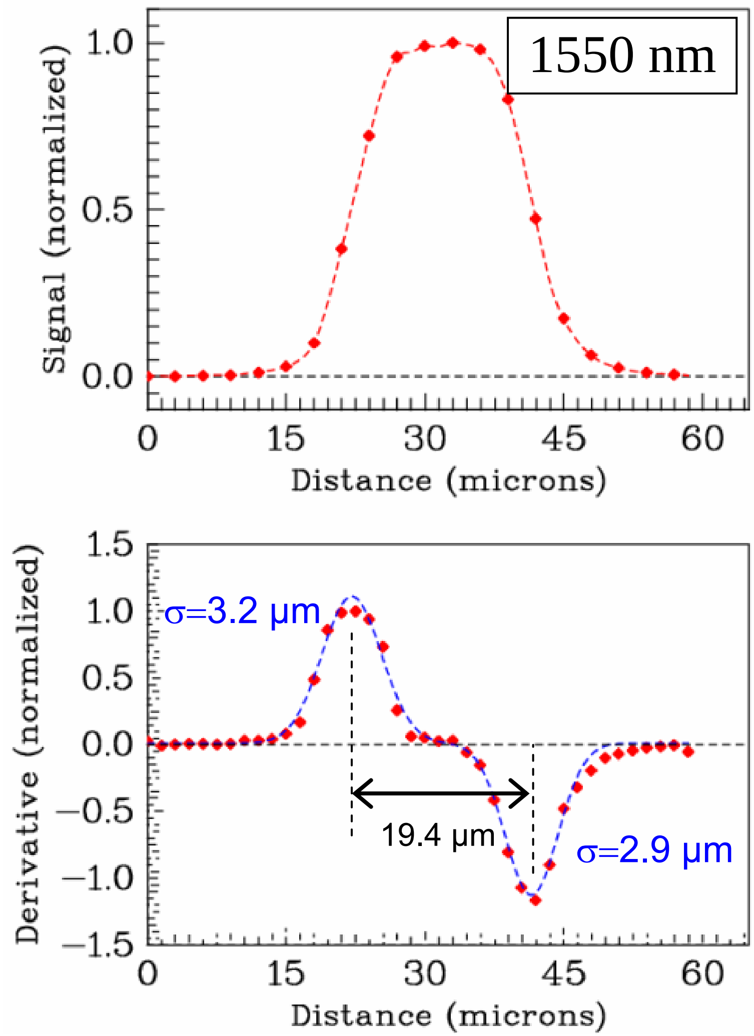
Characterize a pixel

- Virtual knife edge scans (pixel boundary) used to focus Spot-o-Matic onto detector surface

- Intensity profile is a 1-dim convolution of Spot-o-Matic PSF with pixel response function

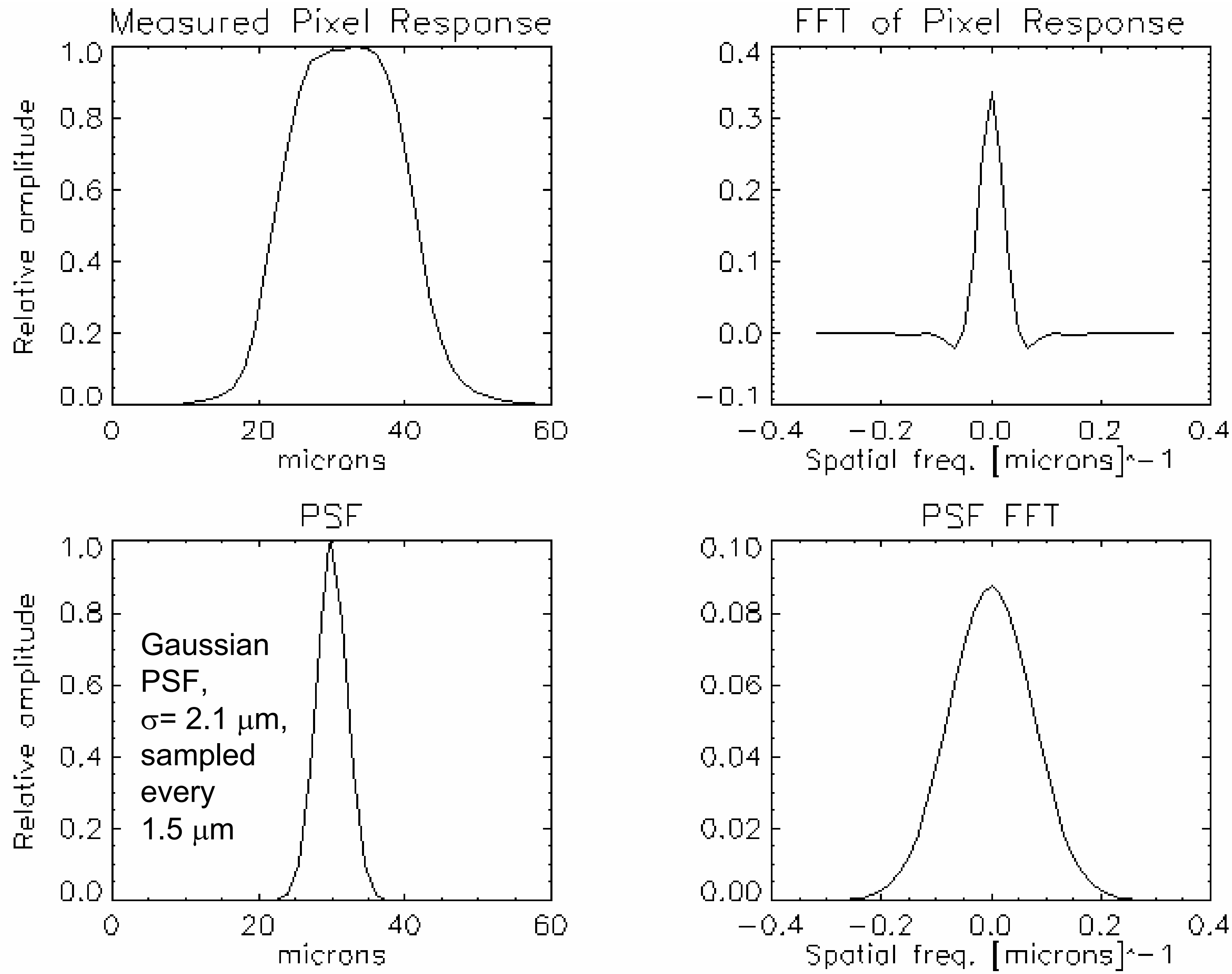
- Note that edge transition is σ = 2.9 – 3.2 µm, increased from the σ = 2.1 µm spot size obtained from the knife-edge scan, indicating intra-pixel sensitivity variation

- Pixel pitch (19.4 µm instead of 20.0 µm) is most likely an artifact of the 1.5 µm discrete step size



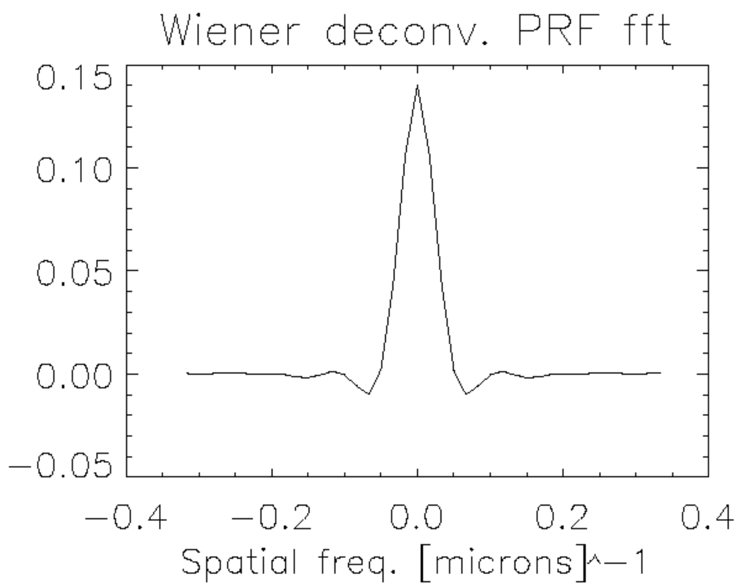
Input Data for Deconvolution

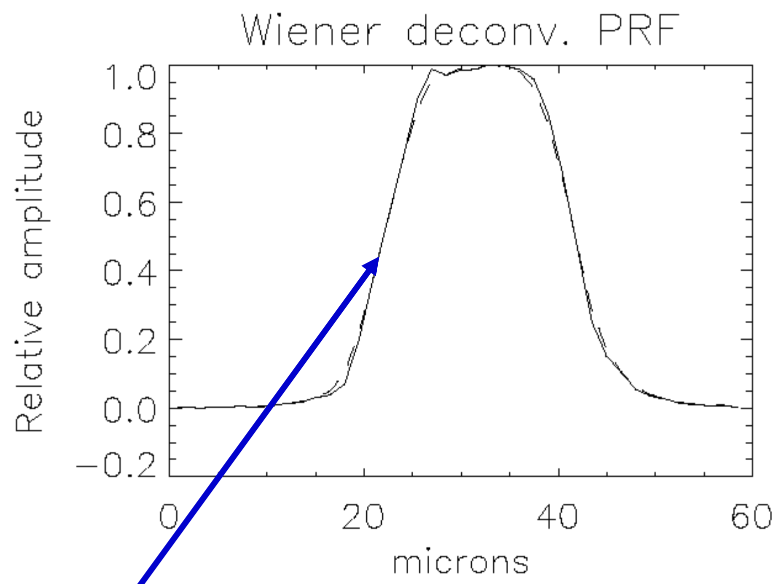
SNAP SuperNova Acceleration Probe
at the University of Michigan



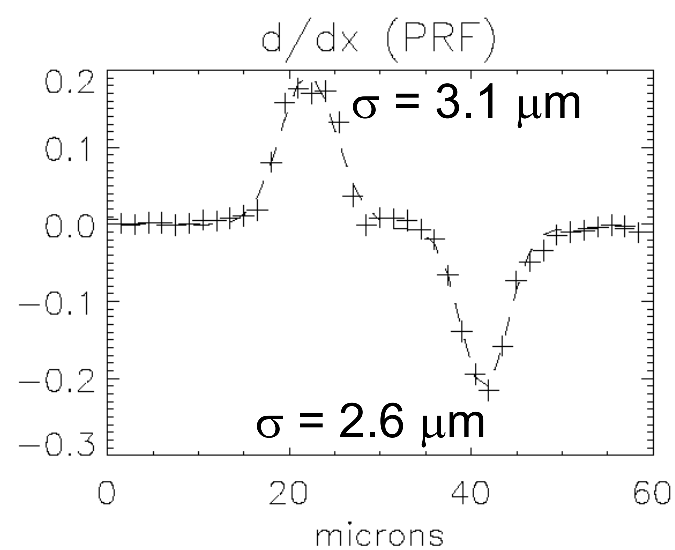
Wiener Deconvolution

SNAP SuperNova Acceleration Probe
at the University of Michigan





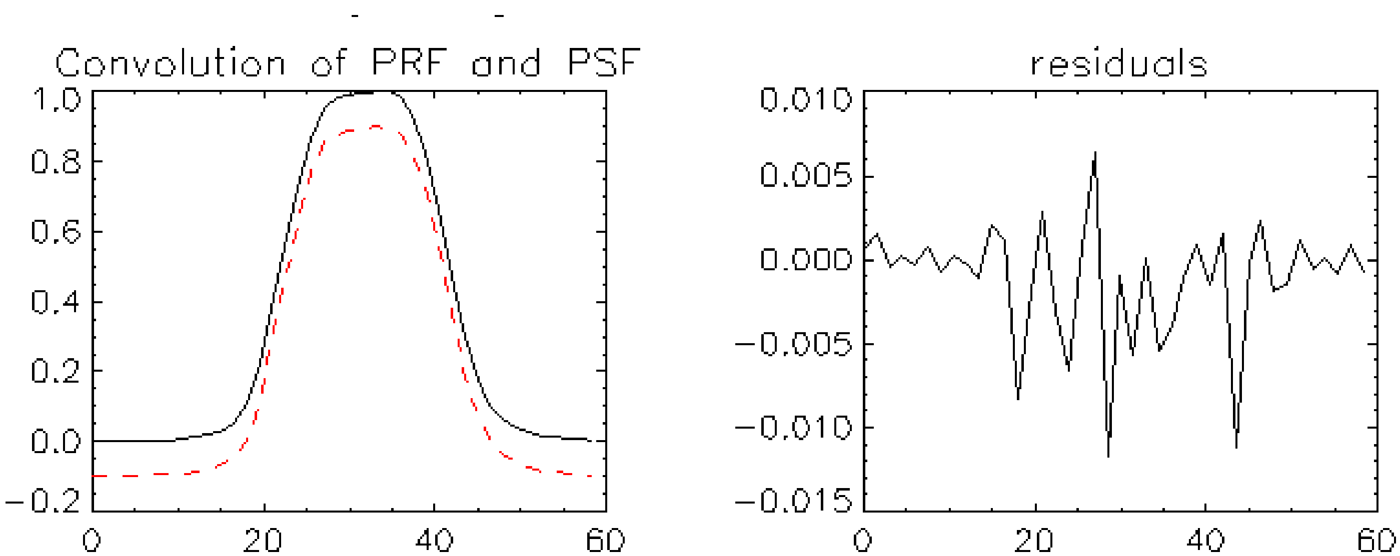
- PSF(k) = FFT[psf(x)]
- MEASPRF(k) = FFT[measprf(x)]
- PRF(k) = FFT[prf(x)]
- PRF(k) = MEASPRF(k)*PSF(k) / [(PSF(k)^2 + 10^{-4})]
- Simple deconvolution is too noisy.
  Wiener deconvolution filters high frequency noise.



- Note deconvolved PRF (solid curve) is "steeper" than measured PRF (dashed curve). "Dip" is artifact of reset persistence.

Re-convolution as a Sanity Check

SNAP SuperNova Acceleration Probe at the University of Michigan

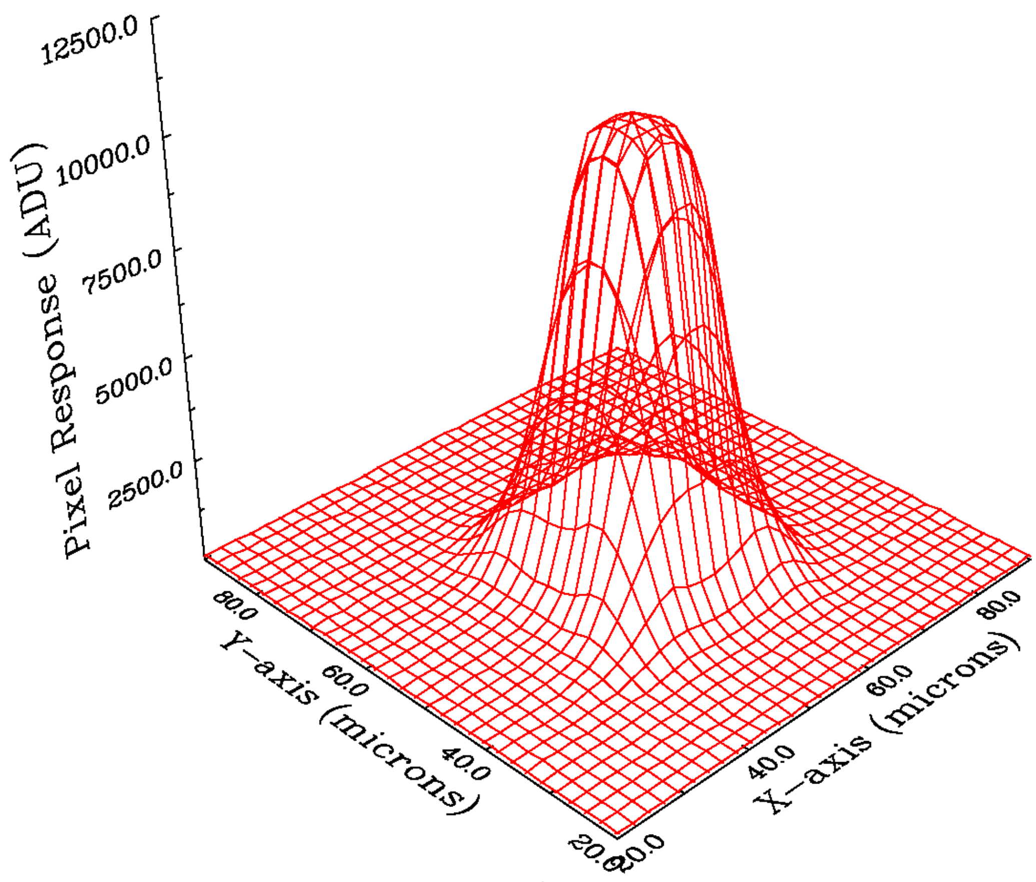


- “Re-convolution” (solid black curve) compares to measured PRF(x) (red dashed curve offset for clarity) with residuals at the ~1% level or below

Pixel Response Profile

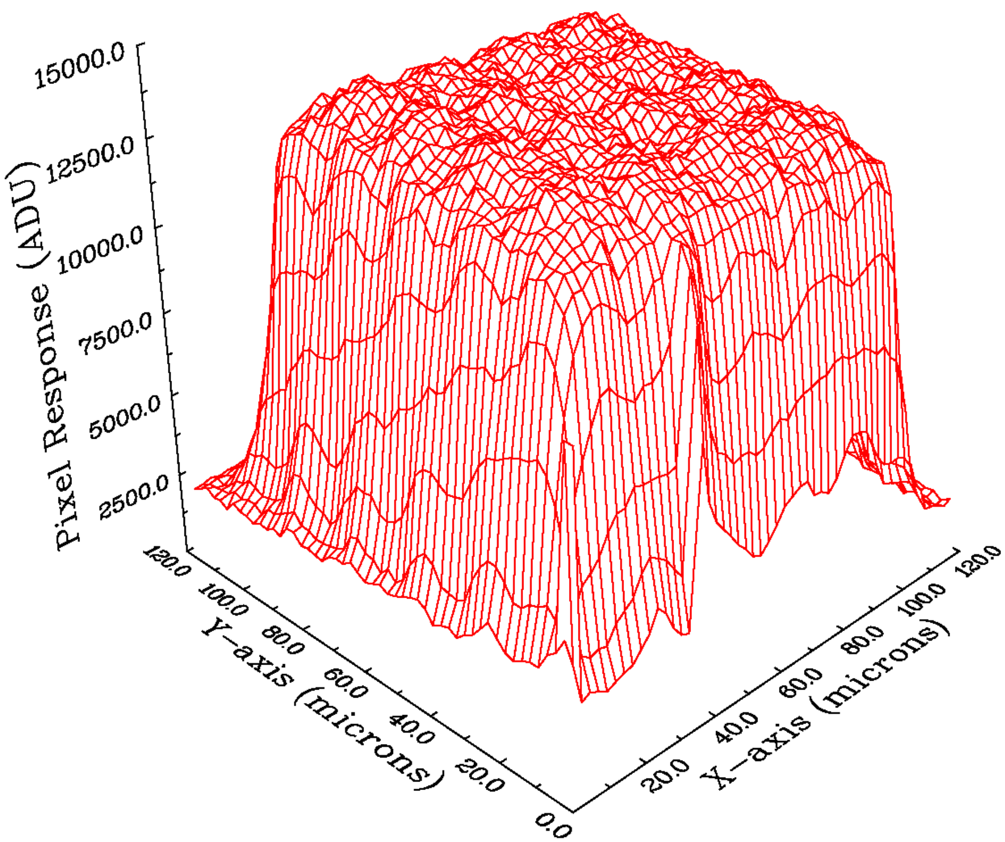
SNAP SuperNova Acceleration Probe
at the University of Michigan

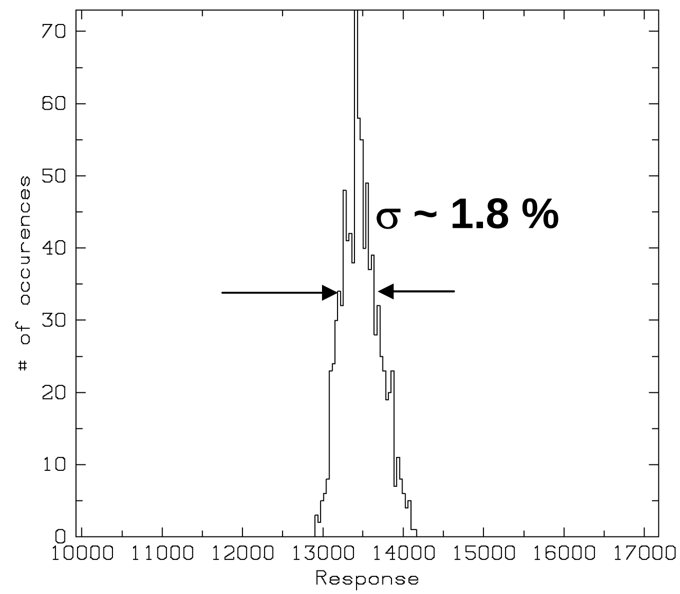
Pixel scan at focus determines two-dimensional pixel response profile (convolution of 2D spot PSF with 2D pixel response function).



Diffusion vs. Inefficient Charge Collection

Summation of adjacent pixels shows negligible deviation at pixel boundaries, suggesting diffusion rather than inefficient charge collection as the dominate source of intra-pixel variation in this InGaAs device.





Diffusion vs. Inefficient Charge Collection

SNAP SuperNova Acceleration Probe
at the University of Michigan

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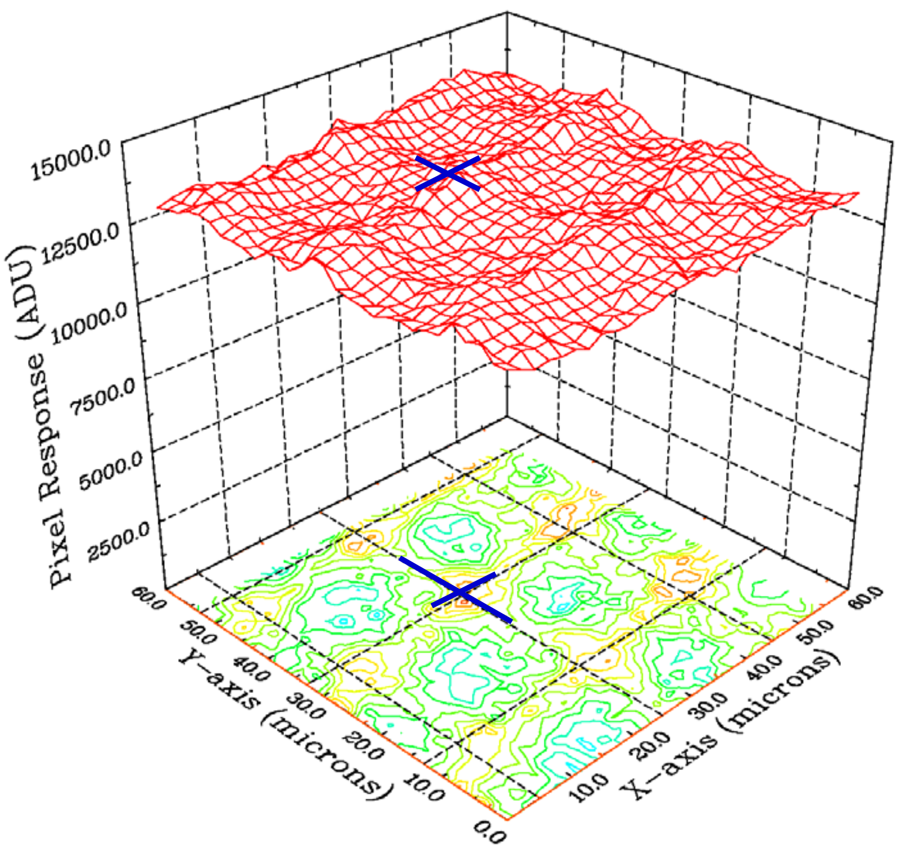
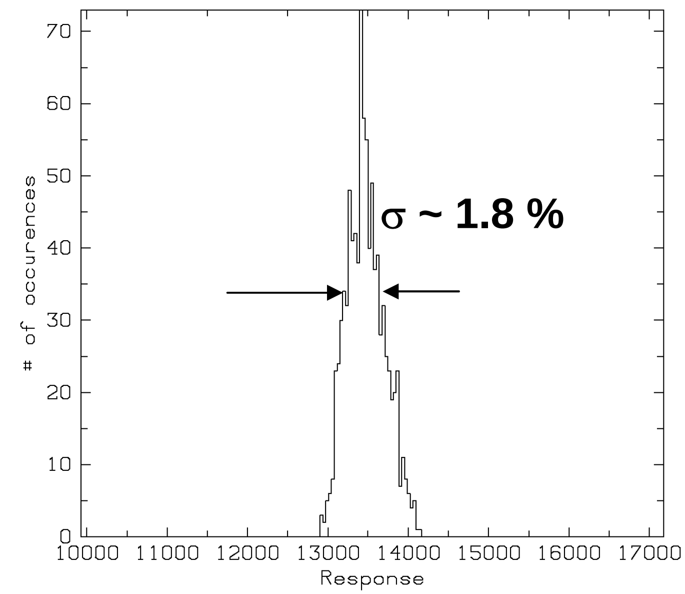




Why 2-3 μm?
and why Diffusion only?

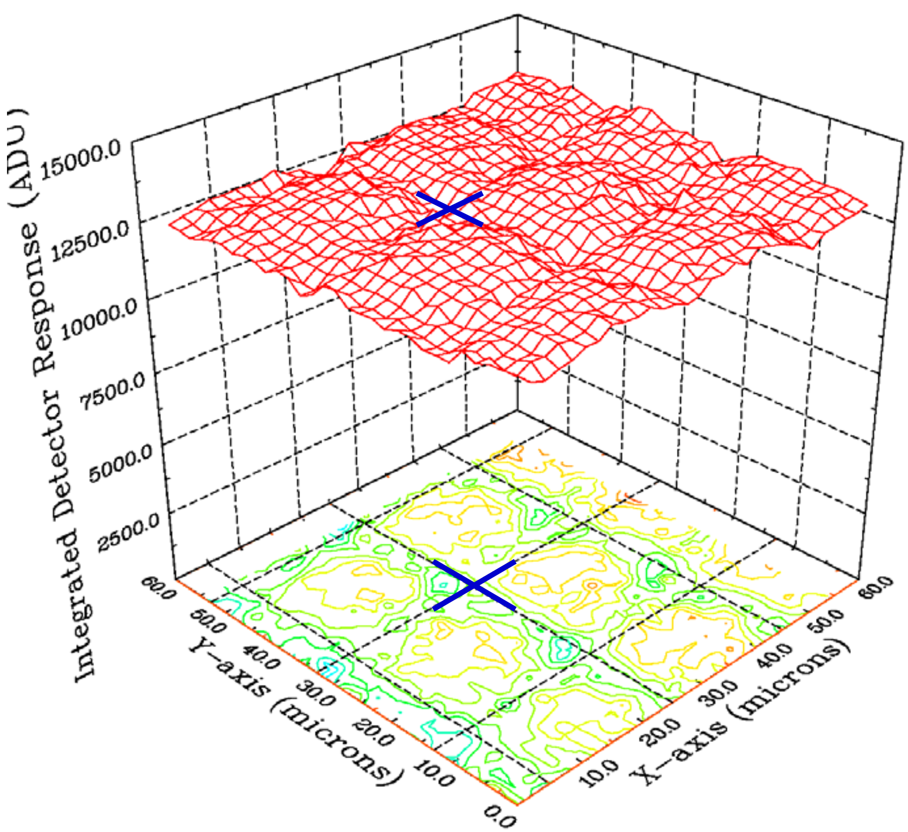
SNAP SuperNova Acceleration Probe
at the University of Michigan

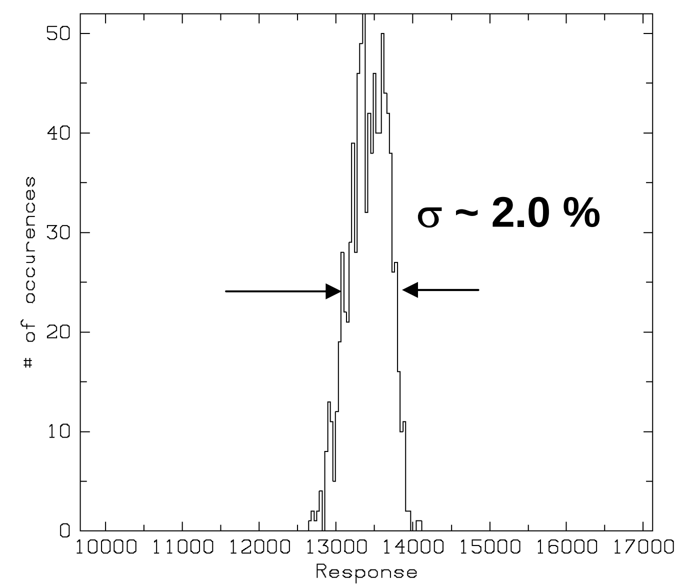
- Simplest explanation:
  - photons get absorbed in a pixel
  - generating photoelectrons which diffuse across pixel boundaries near edges and are collected with unit efficiency
- The 2 μm is significant:
  - because edge effects should be important when light is absorbed within ~1/2 pixel thickness of the edge
- Martin Ettenberg of Sensors Unlimited confirms
  - InGaAs pixel thickness is 3.5 μm
- Fact that pixel sum is ~flat across pixel boundaries confirms
  - there is a ~100% chance of the electron being collected in some pixel.
  - consistent with large junction size (12 μm square) in these detectors.

Saturation Effects?

SNAP SuperNova Acceleration Probe at the University of Michigan

- Remove pixel response non-linearity:
  - saturation will produce ridges at pixel boundaries:
  - e.g, at boundary, signal is split between two pixels
  - sum of these two signals will be greater than saturated signal at center of pixel (~1% effects!!)



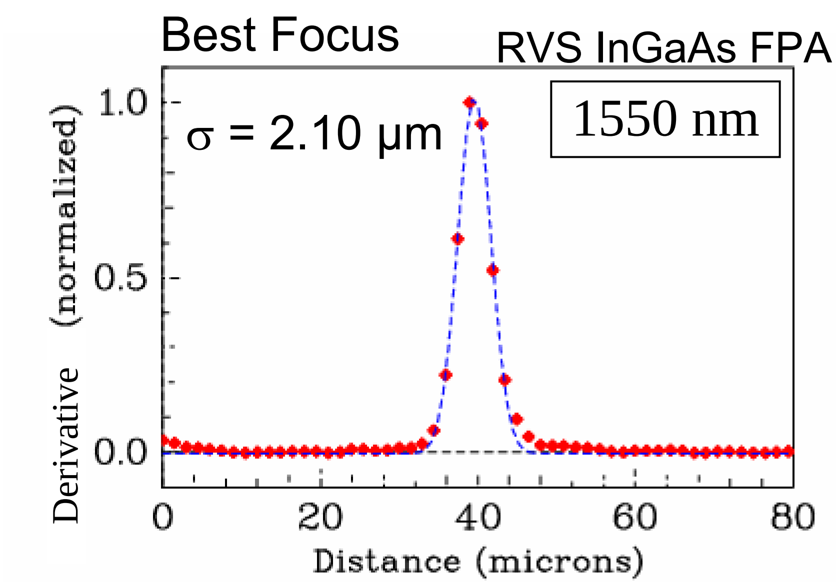


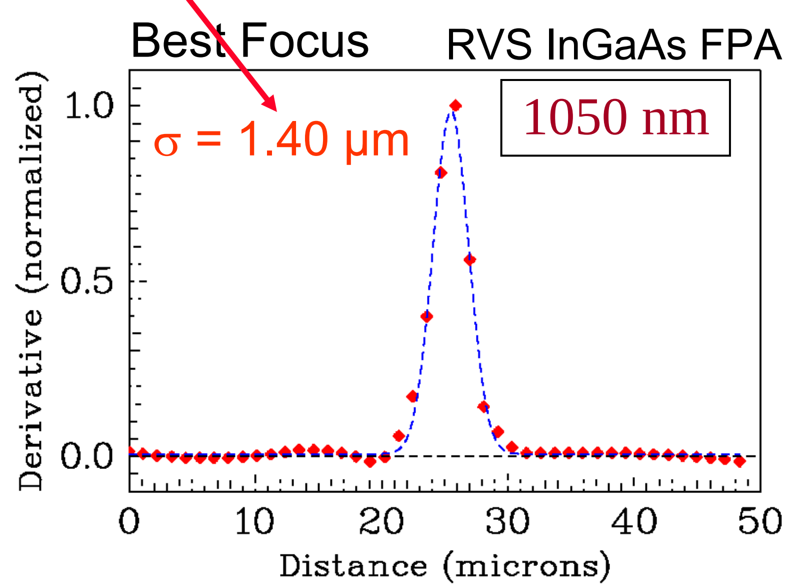
- dips after correction due to loss of charge? (minor effect)
- can measure these small effects

Knife-Edge Scan at 1050 nm

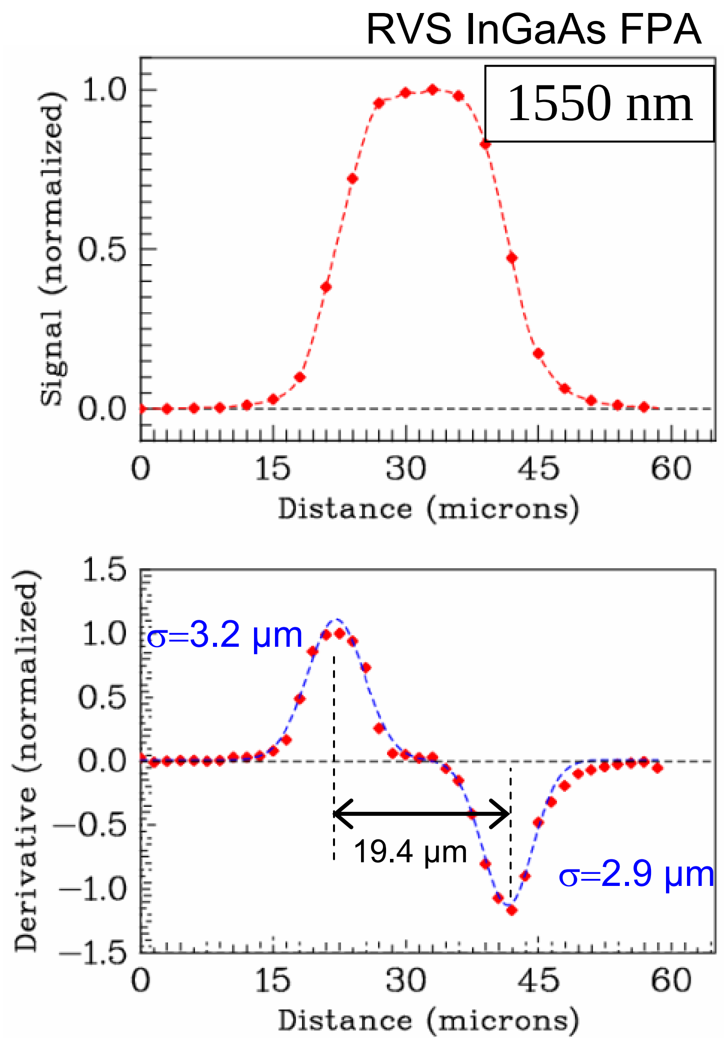
SNAP SuperNova Acceleration Probe
at the University of Michigan

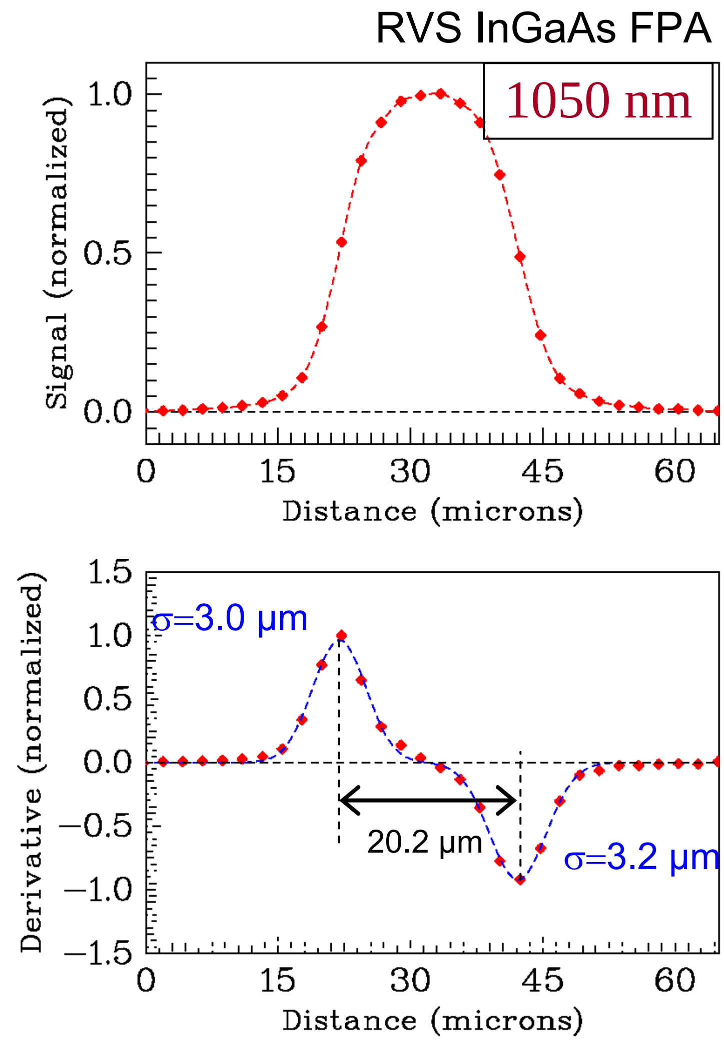
- Diffraction limited spot size: $\sigma_{min} = 1.22\lambda / N.A.$
- Expect: $\dfrac{1050\text{ nm}}{1550\text{ nm}} \cdot 2.10\mu m = 1.42\mu m$
- Excellent agreement





Virtual Knife-Edge Scan at 1050 nm





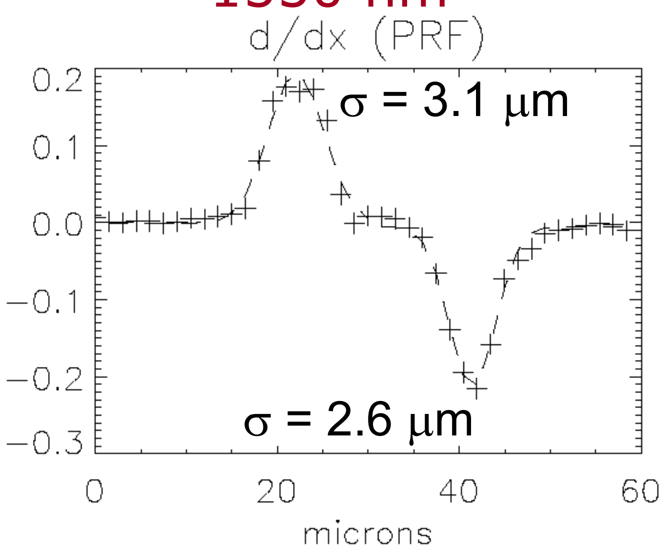
- Need to do de-convolution

Diffusion at 1050 nm

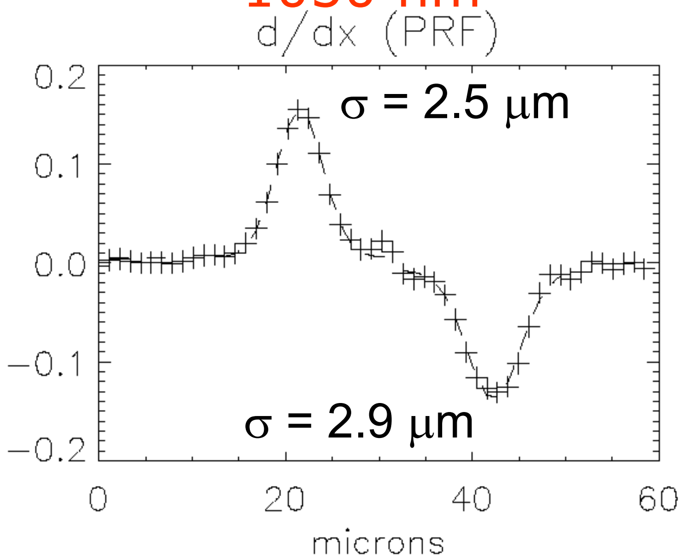
SNAP SuperNova Acceleration Probe
at the University of Michigan

- Edge effects should be important when light is absorbed within ~1/2 pixel thickness of the edge
- Light at 1050 nm penetrates pixel less before being absorbed
  – edge effects are larger
- Expect: more diffusion at 1050 nm than at 1550 nm
- Limitation of finite sampling (1.5 μm → 0.5 μm)

1550 nm



1050 nm



Plans

SNAP SuperNova Acceleration Probe at the University of Michigan

- Study pixel response for contiguous groups of pixels
  - study short and long range scale trends
  - repeat at various wavelengths, bias voltages, other parameters
  - compare different devices and different vendors
- Extract true 2-dim PSF
  - introduce knife-edges with a variety of orientations
  - is PRF symmetric?
- Use PRF as input to simulations
  - evaluate dithering schemes
    - random and *nxn*, for integer and non-integer fractions of pixel sizes
- Test predictions in laboratory
  - defocussed spot to simulate SNAP PSF

    ⇒ demonstrate required photometric accuracy with different dithering schemes
- Provide feedback to vendors as they modify manufacturing parameters
  - improve intra-pixel performance
  - alert them when required photometric accuracy is achieved

Additional Equipment Needed

SNAP SuperNova Acceleration Probe at the University of Michigan

- Encoder system for x and y
  - get rid of backlash
  - reproducibly get to desired point in x-y-z
  - remove great source of occasional confusion interpreting data
- Receive most advanced Spot Projection Facility available to date for additional $2,000!
  - Represents a unique facility for SNAP

Conclusions

SNAP SuperNova Acceleration Probe
at the University of Michigan

- The Spot-o-Matic is up and running
- The Raytheon InGaAs device shows a very flat pixel response with ~2-3 μm edge effects dominated by diffusion
- A simple addition of adjacent pixels restores photometry to better than ~2%
- Higher resolution sampling will come next (0.5 μm step size)
- Imperfect spot PSF determination, non-linearities in pixel response and persistence after reset all contribute to artifacts in the measurements. All of these can be refined and corrected with further measurements
- Will turn our attention to the RVS H2RG part 40
  - smaller junction size → how is charge collection affected?
  - expect new results soon
  - detailed comparison among two vendors soon