Stereoscopic Magnetography with SHAZAM

(Solar High-speed Zeeman Magnetograph)

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Summary of talk

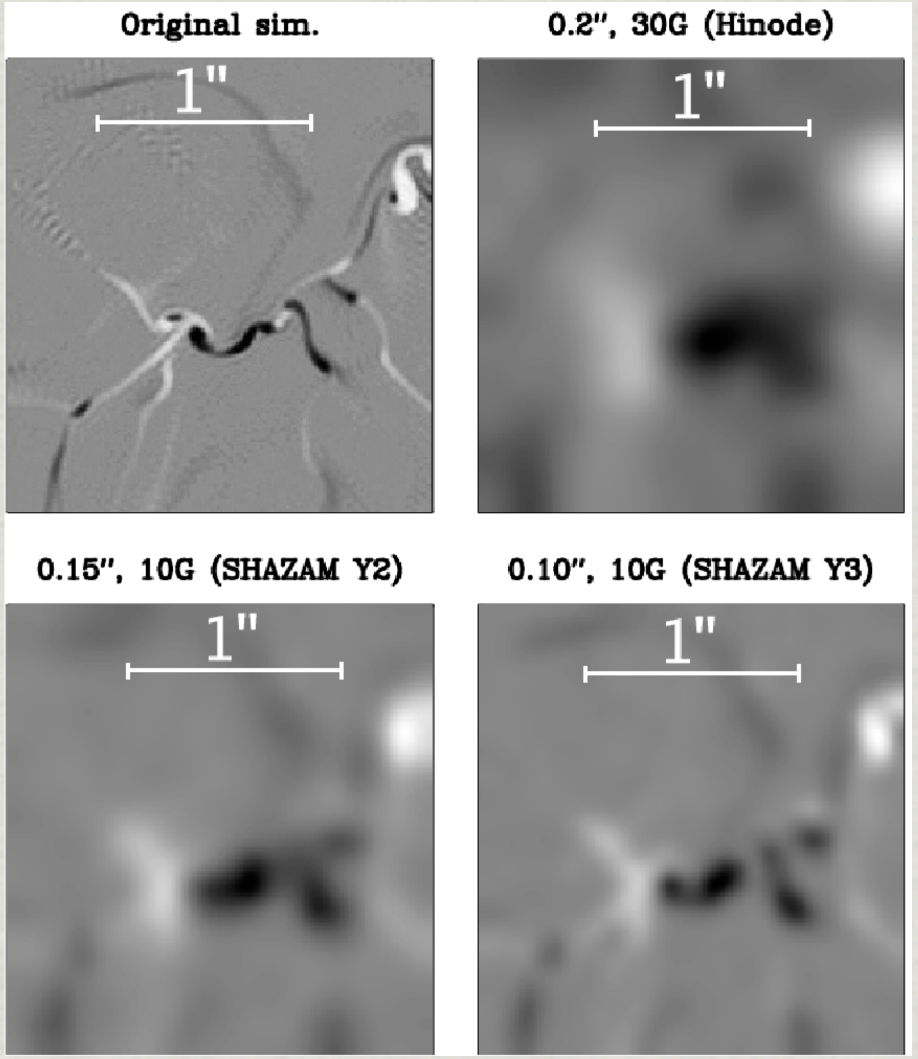
- What and why is SHAZAM?
- How does a stereoscopic magnetograph work?
- Current status of SHAZAM
- Some sample data from a prototype run
- Conclusions

SHAZAM: a Stereoscopic Magnetograph

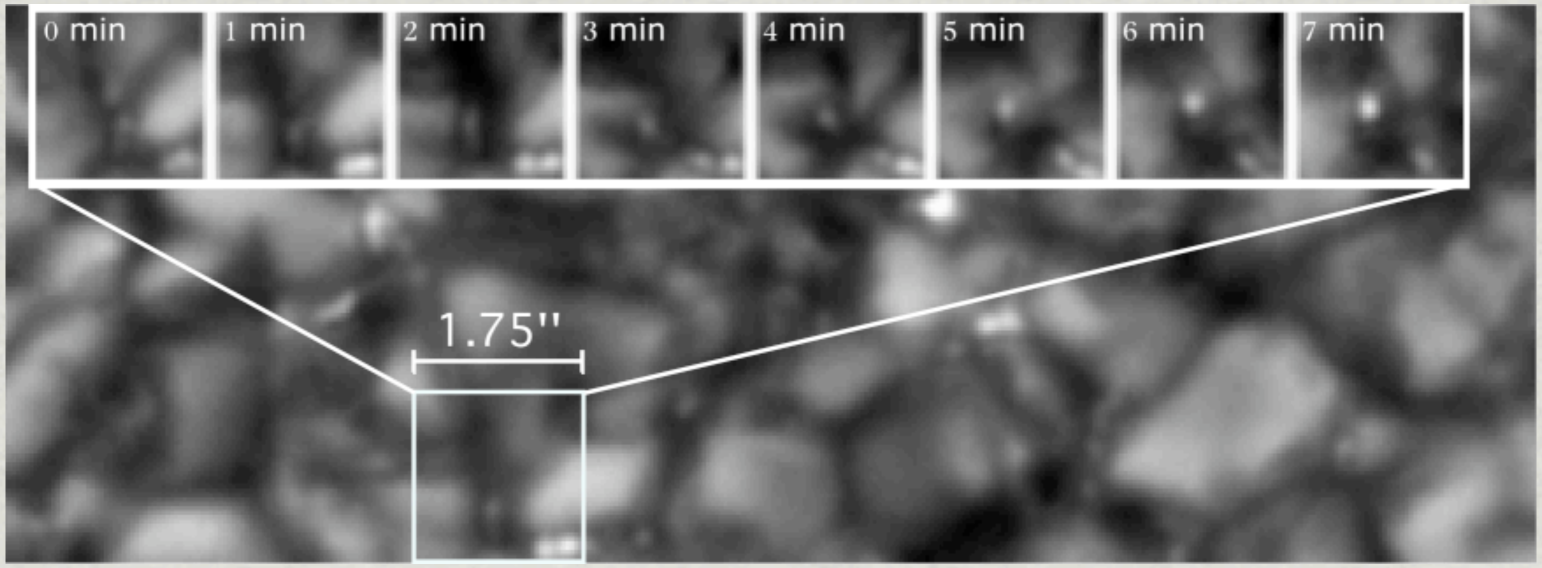
- Instrument concept for highest resolution applications: DST, SVST, (ultimately) ATST
- Goals: <10 Gauss photon noise level, <1 sec cadence
- Single exposure acquisition (to motion & seeing crosstalk)
- Being developed under the NASA/SHP-SR&T program

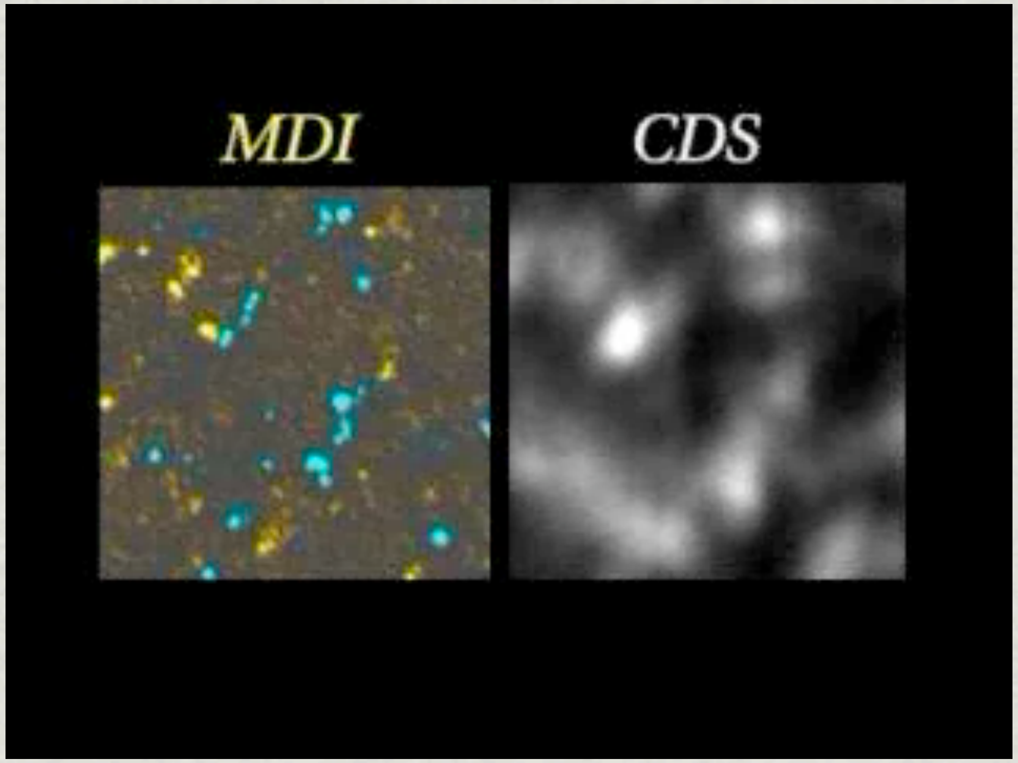
SHAZAM Science Goals

- How does magnetic flux behave on the smallest observable scales?
- What is the fundamental length scale of the small scale solar dynamo?
- Can network heating events and bright points be explained by previously unresolved photospheric motion?



(sim: Cattaneo et al. 2004)





The Spectral Imaging Problem: photon starvation

- Pixel size (arcsec^2) at the diffraction limit is proportional to aperture (m^2).
- At the diffraction limit in red, the solar photon flux is just 5×10^8 ph. sec^{-1} pix^{-1} in each 0.5Å band.
- Exposure time depends on detector efficiency and desired sensitivity, *not* on final resolution.
- *BUT*: Exposure time requirements are set by resolution(!)

BOTTOM LINE:
PHOTON STARVATION GETS WORSE WITH BETTER RESOLUTION.

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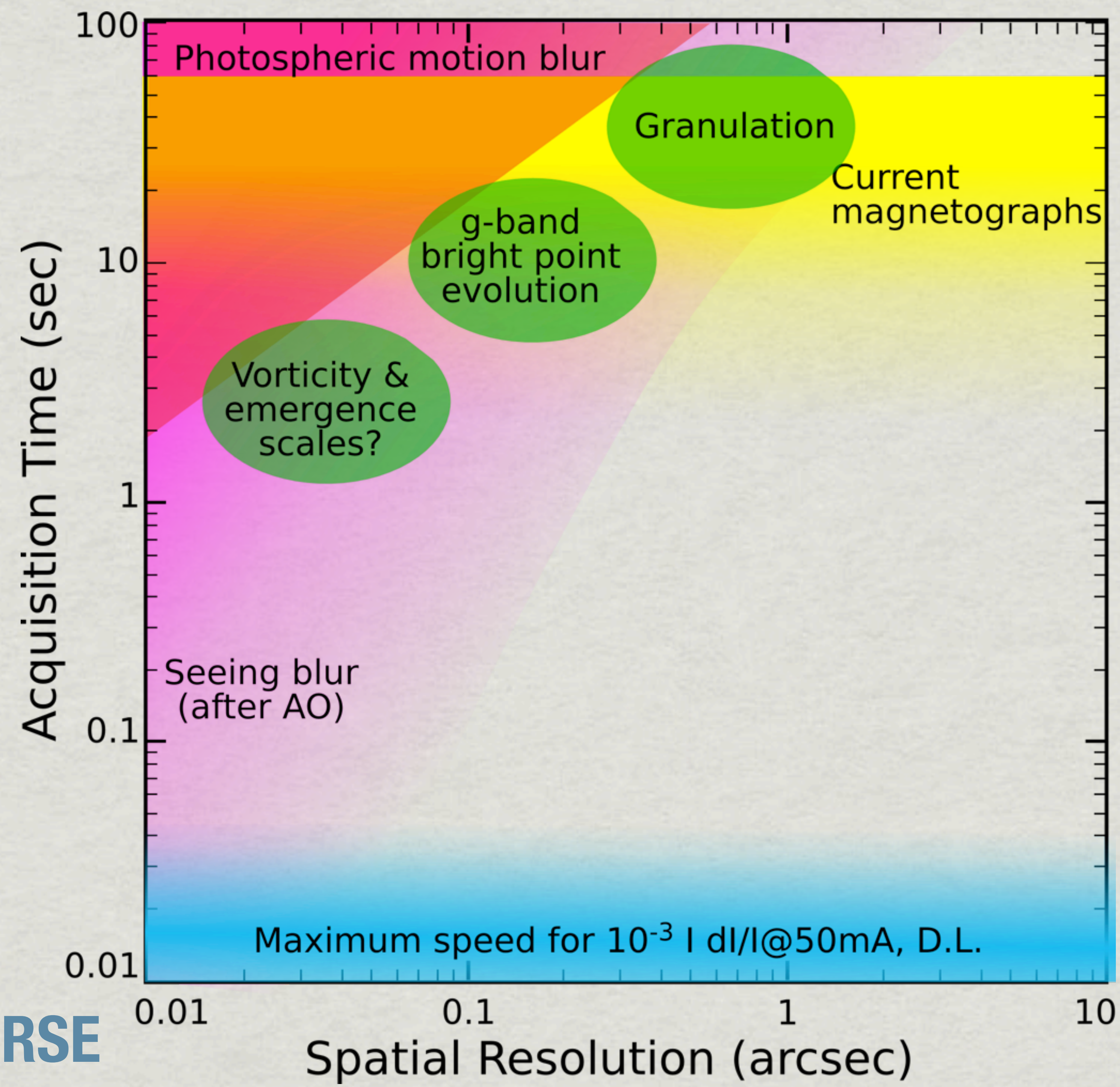

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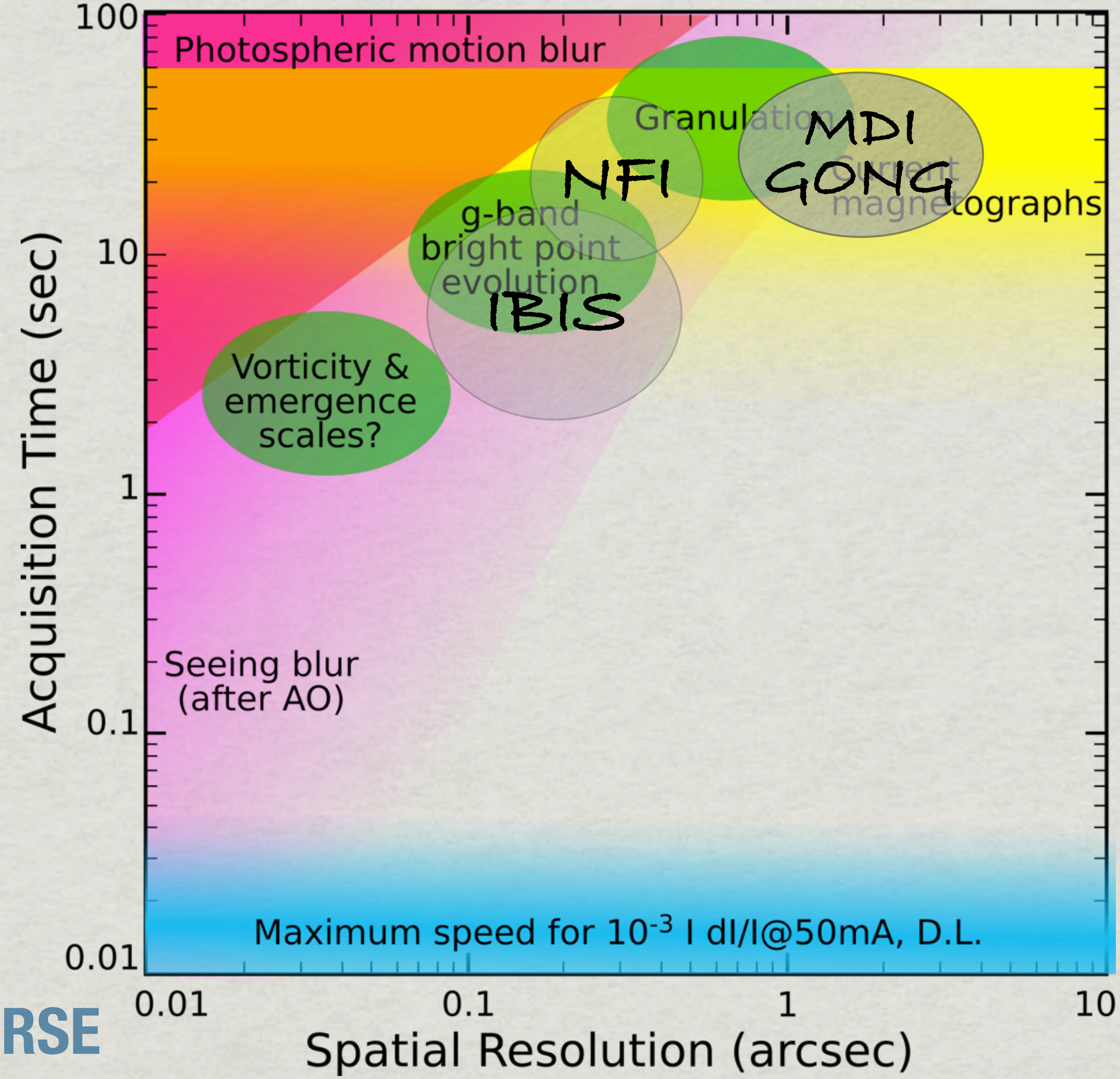

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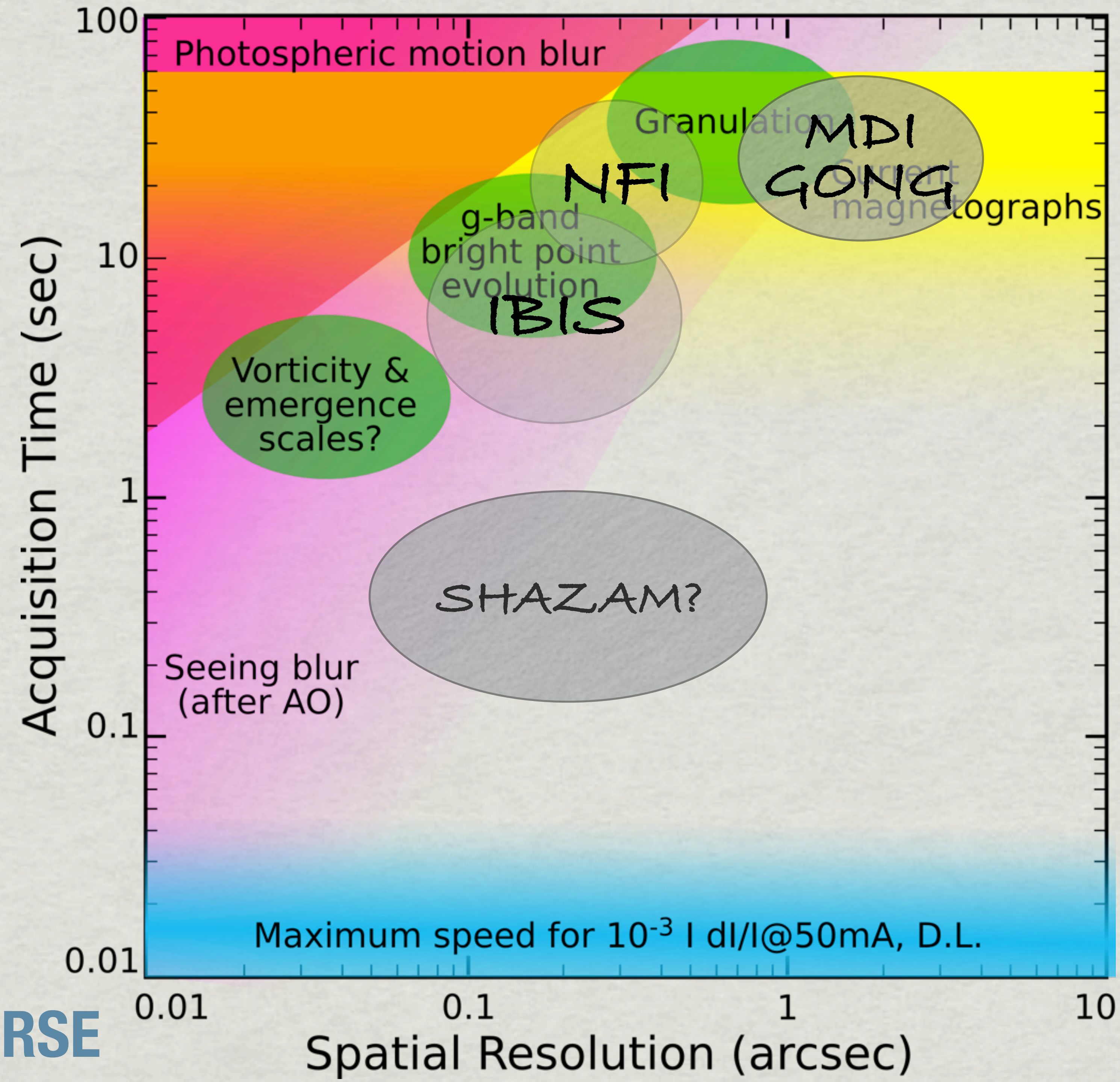

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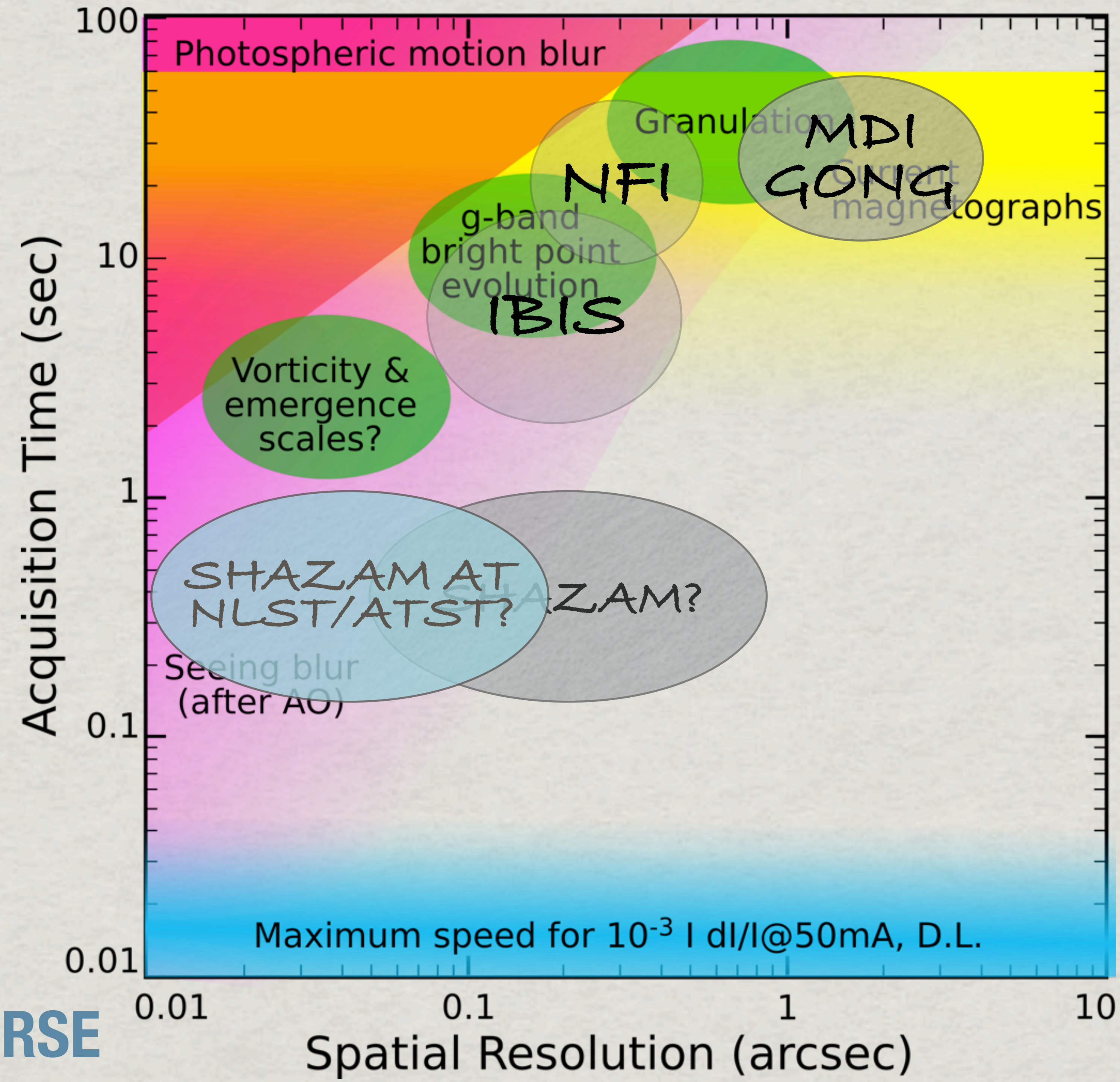

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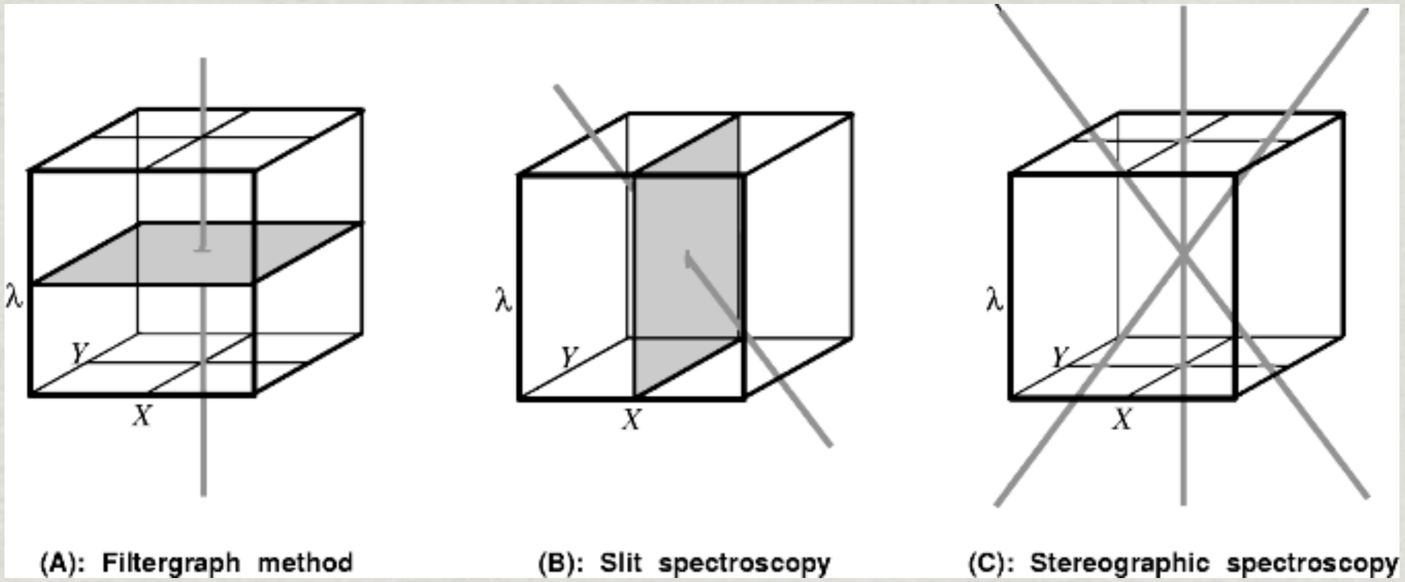
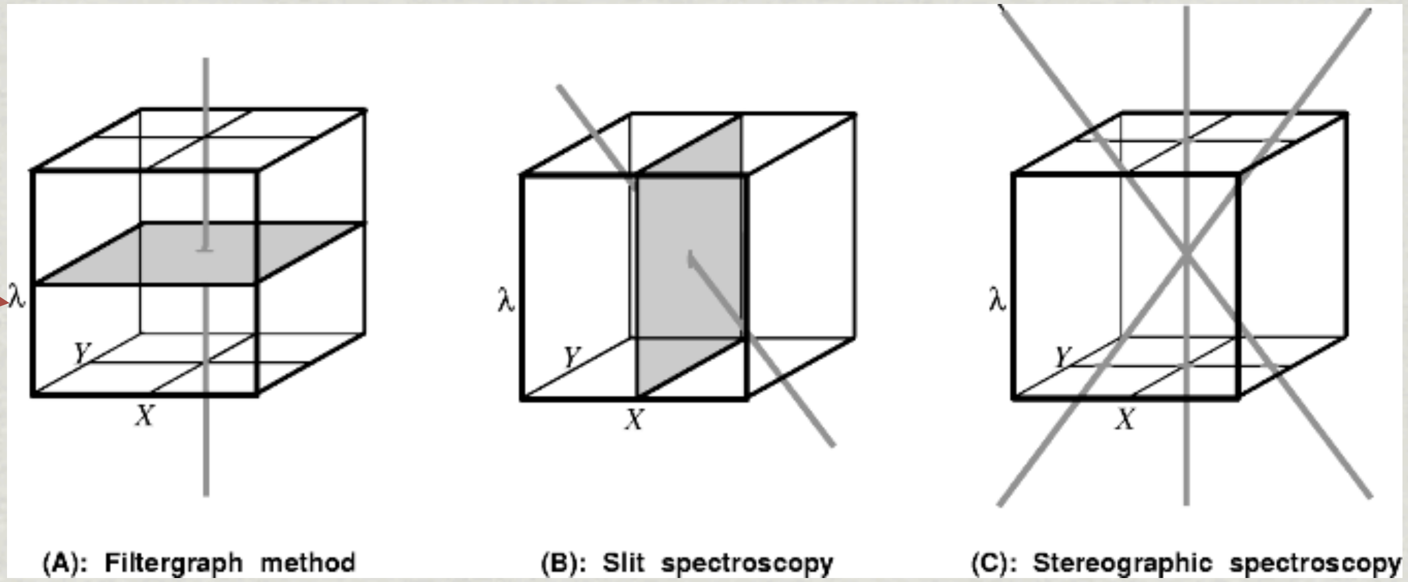
The Spectral Imaging Problem: Projection



- Spectral imagers (including magnetographs) have three independent variables: x, y, λ.
- Detectors have two: x,y.
- Most current technologies use scanning in y, in λ, or in some function of λ to build up an image of the 3-D space.
- Spectral stereographs collect multiple spectral orders, and treat the spectral problem as a stereoscopic one.

The Spectral Imaging Problem: Projection

SOHO/MDI
HINODE/NFI
IBIS



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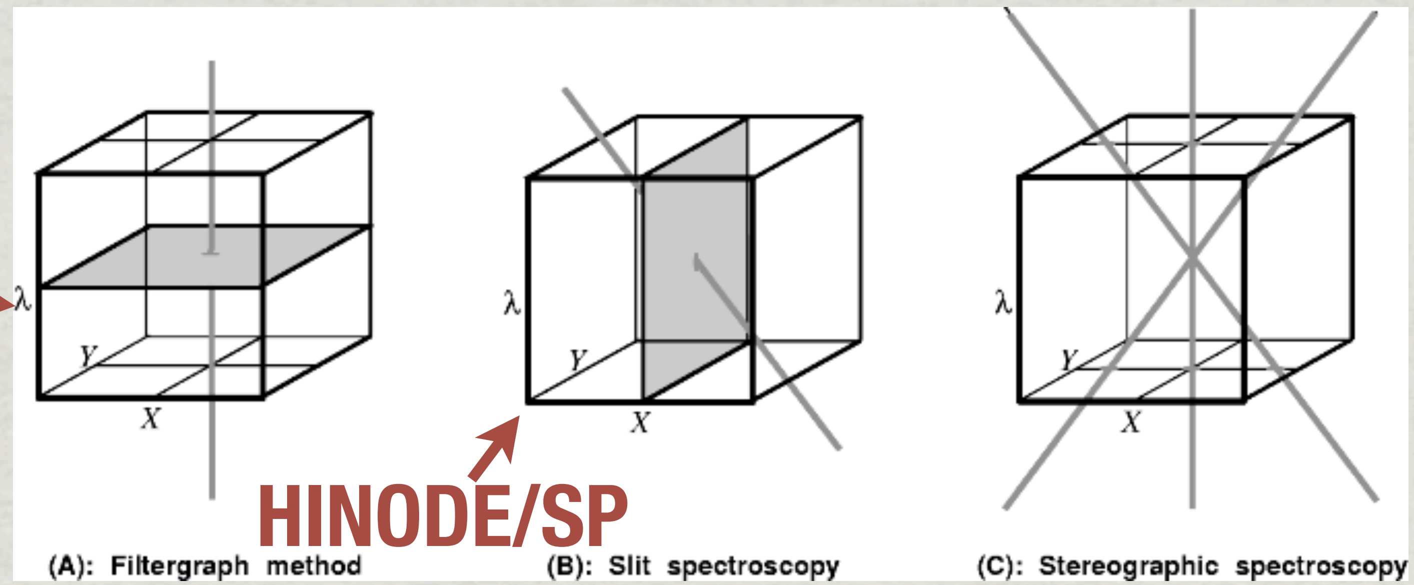

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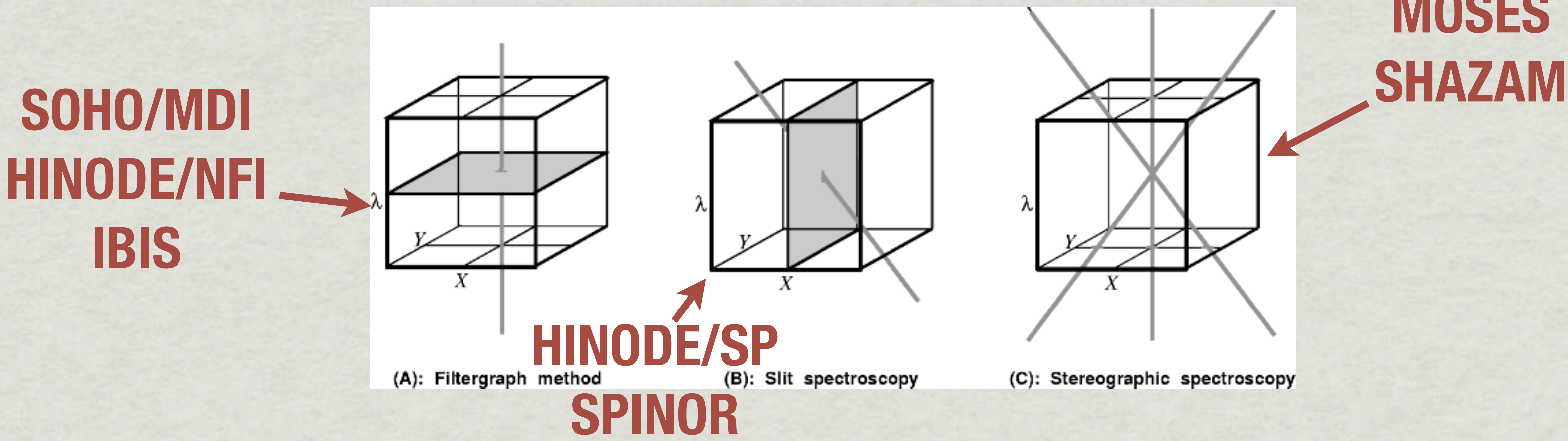

(A): Filtergraph method (B): Slit spectroscopy (C): Stereographic spectroscopy

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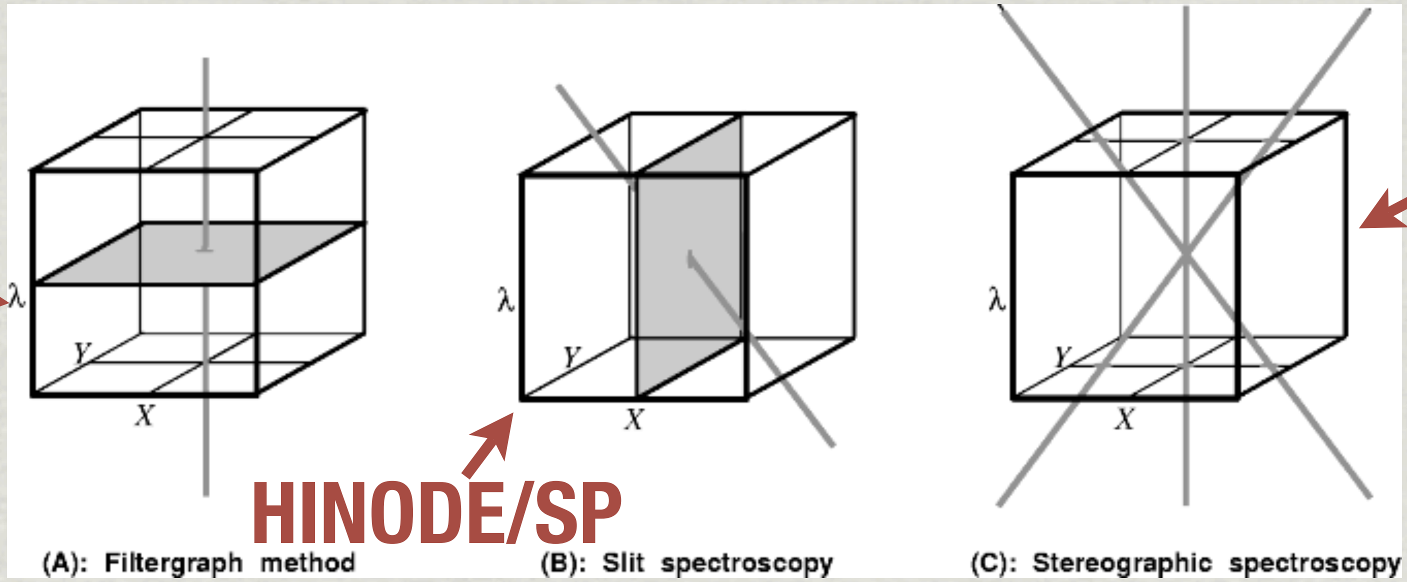

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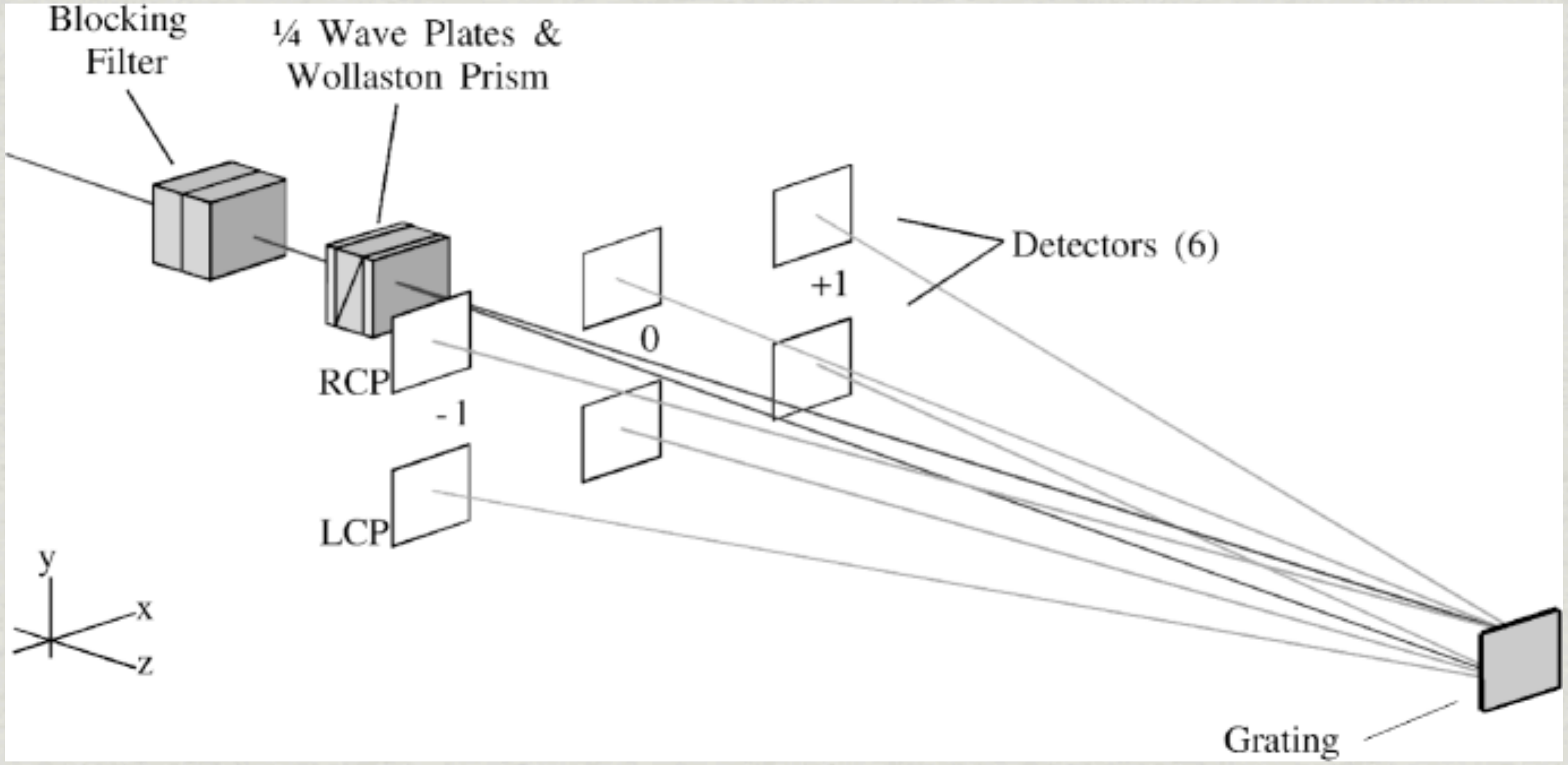
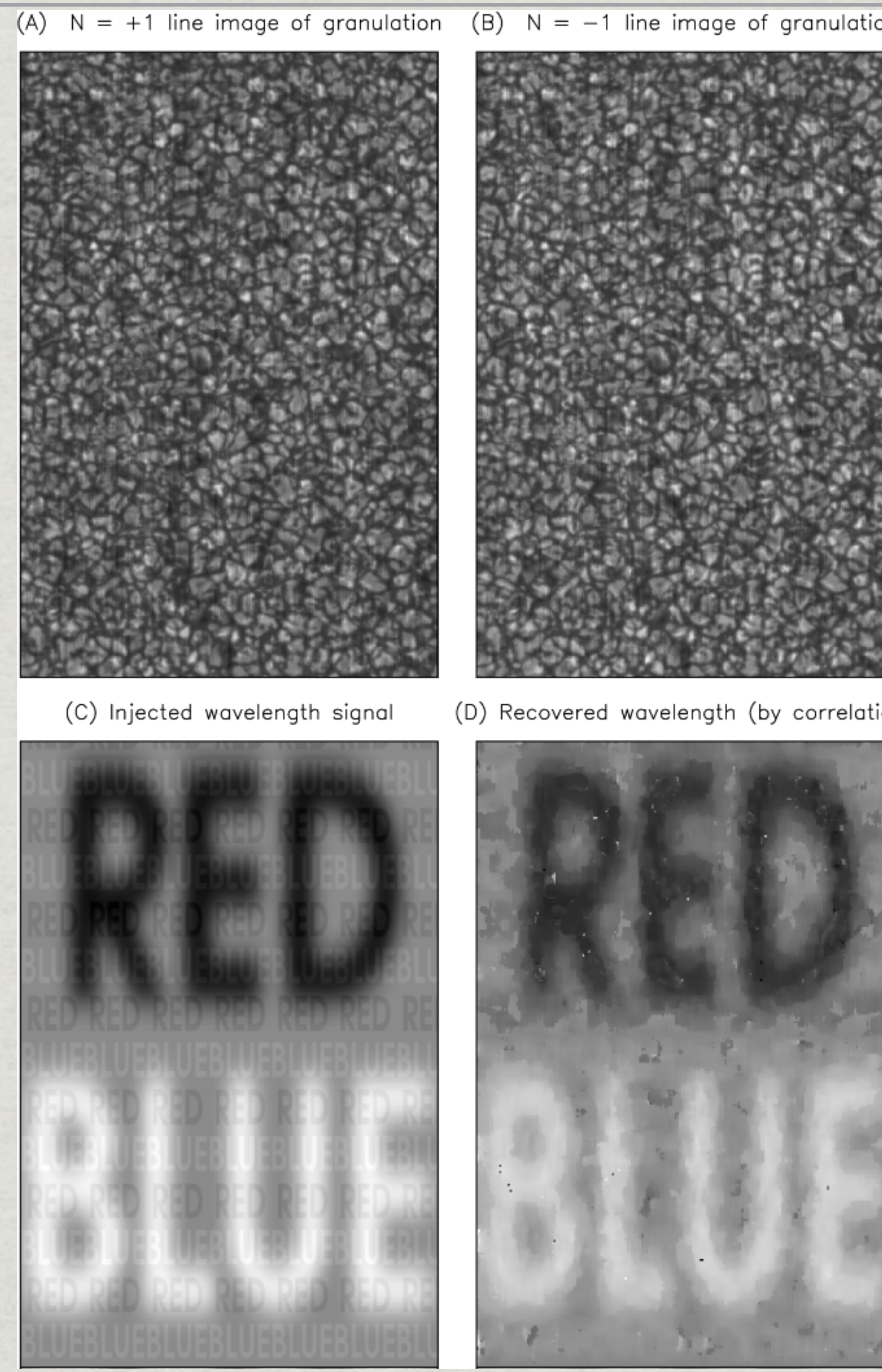
Stereoscopic instrument concept



- Ultimately: six focal planes collect images with different polarization and dispersion characterisics. (We used four, for this experiment).
- Post facto, the images are combined stereoscopically.
- The data give the first two line moments in each circular polarization.

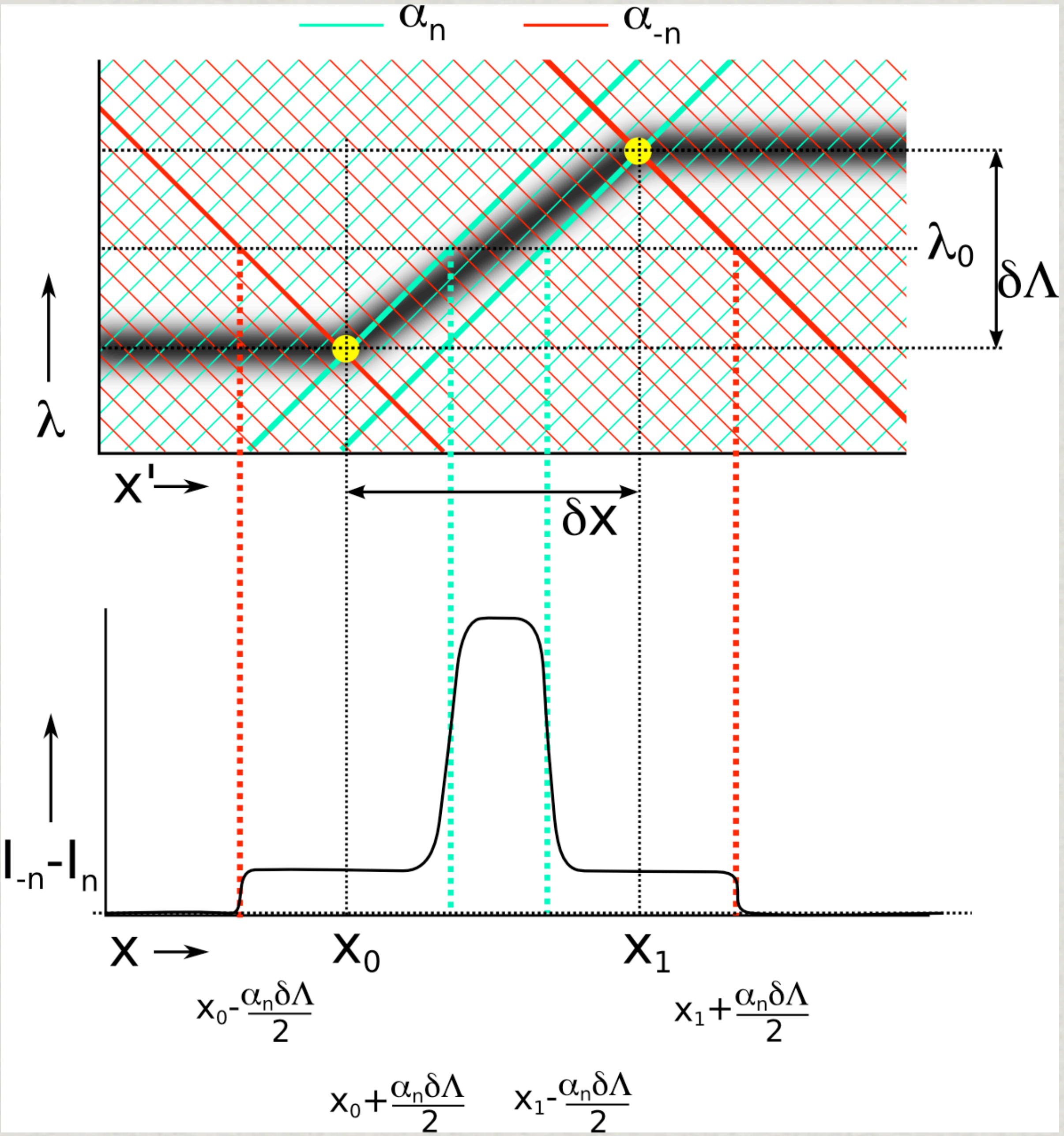
Spectral stereoscopy

- Dispersion converts wavelength shifts into spatial shift.
- The shift differs between spectral orders.
- Conventional correlation stereoscopy recovers the low spatial frequencies.



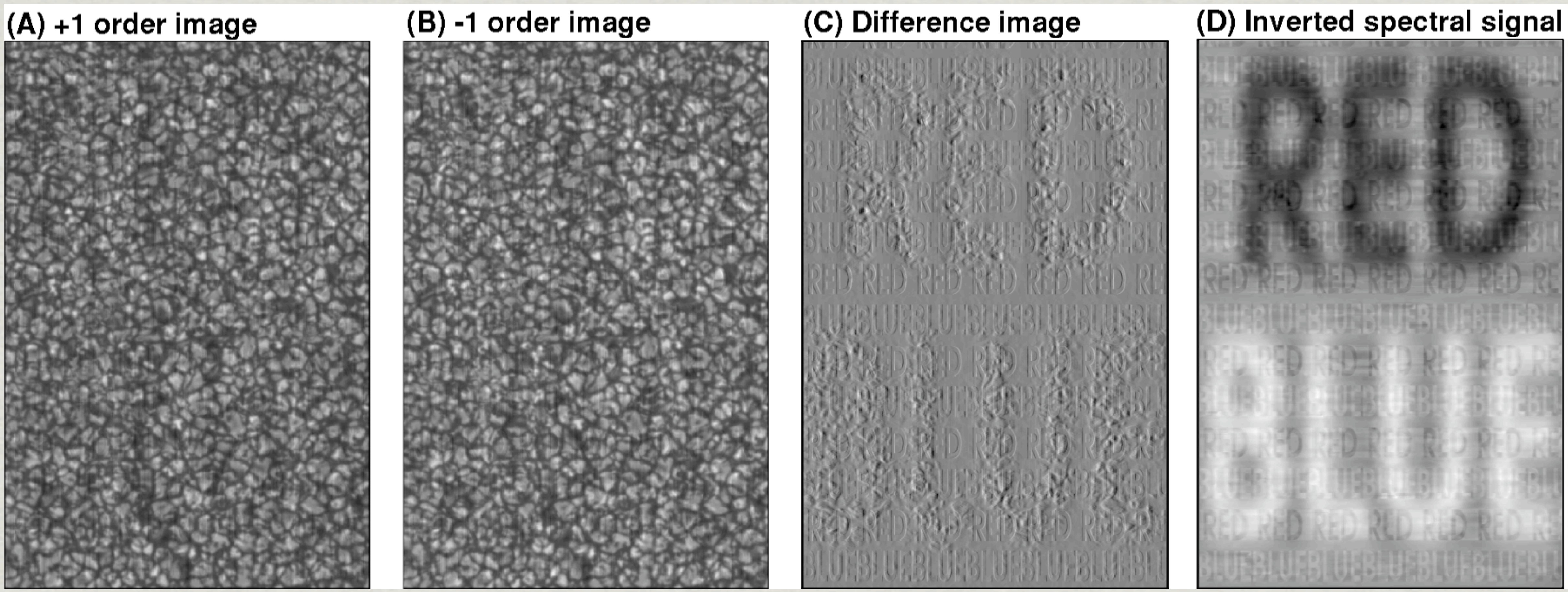
Differential stereoscopy

- Converts line offsets into intensity signal in combined images.
- Subtract line images taken from opposite orders.
- The dispersion of the lines yields brightness terms proportional to dΛ/dx; “leaky” integration gets the high spatial frequencies.
- Dispersion is chosen to minimize spatial smearing effects.
- Conventional stereoscopy (using correlation) is used to retrieve low spatial frequencies.



How well does hybrid stereoscopy work?

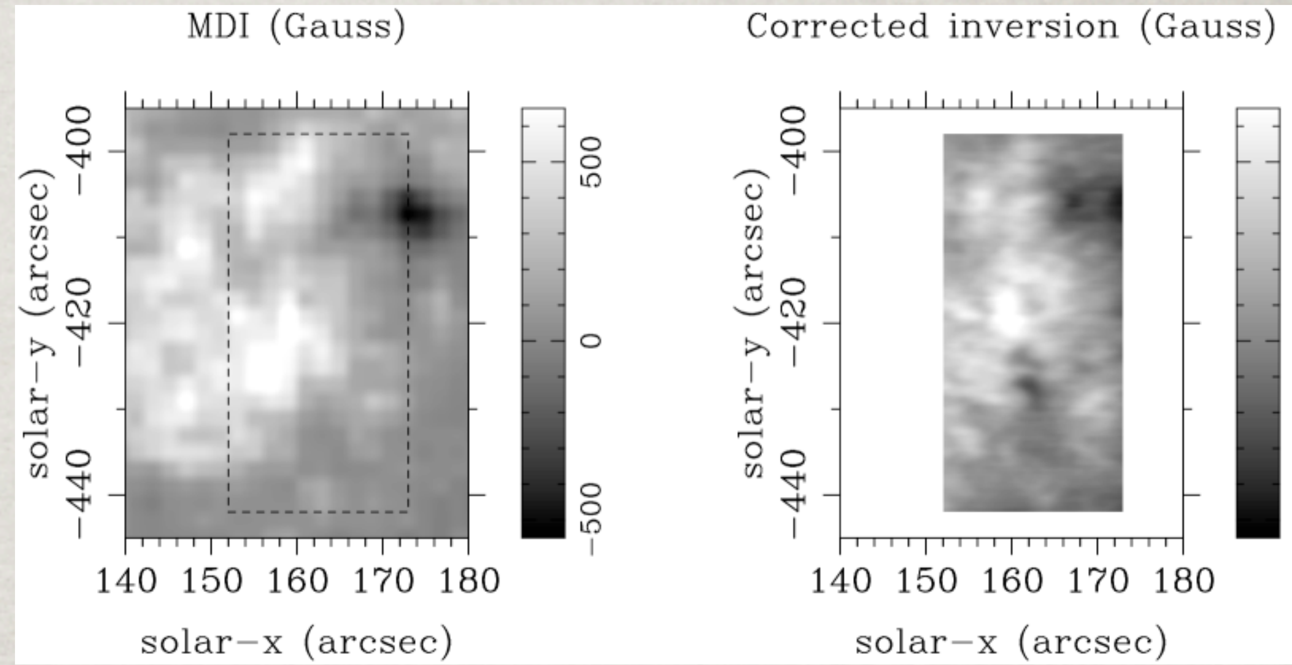
SwRI Space Studies est. 1994

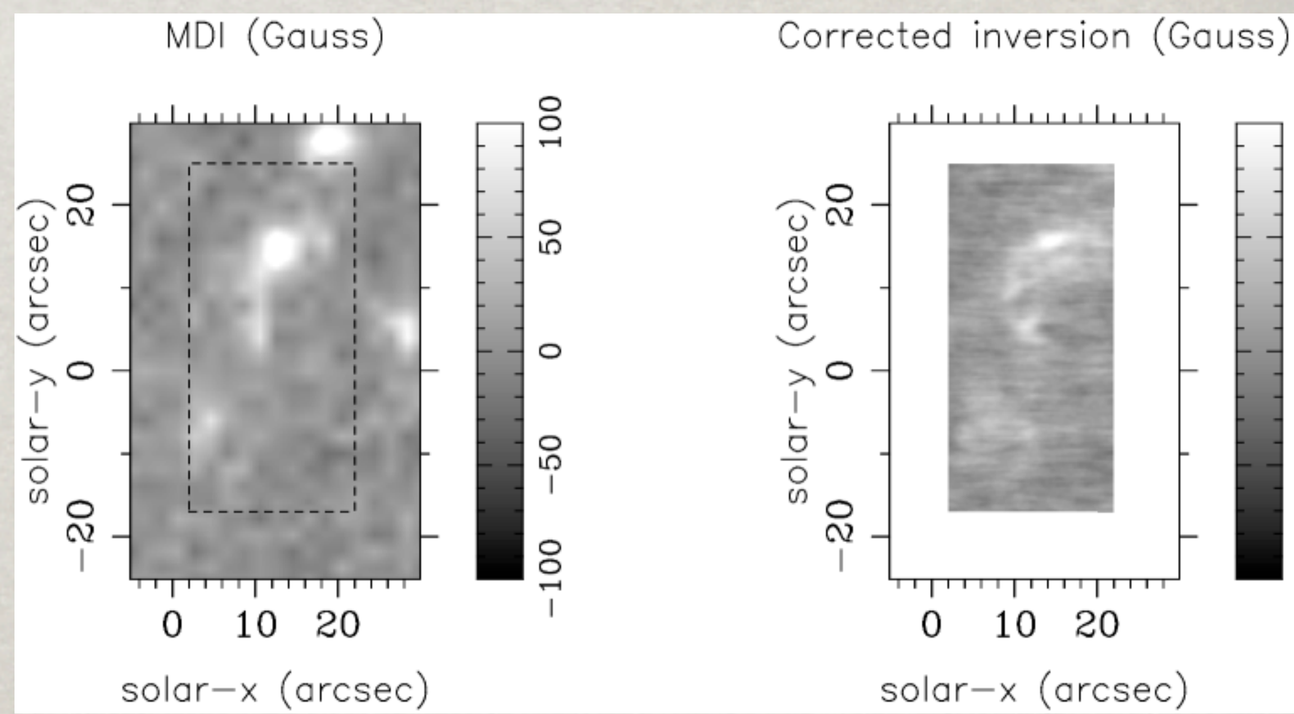


- Answer: pretty well.

Proof-of-concept observations

- Stereoscopic test observations: shown to work using DST/ASP (Nov 2003: moderate seeing, low-order AO)
- SHAZAM: prototype instrument (currently proposed) for DST & SST
- Estimated capabilities: ~10 G RMS magnetograms in <100 ms at the DST (or ATST)



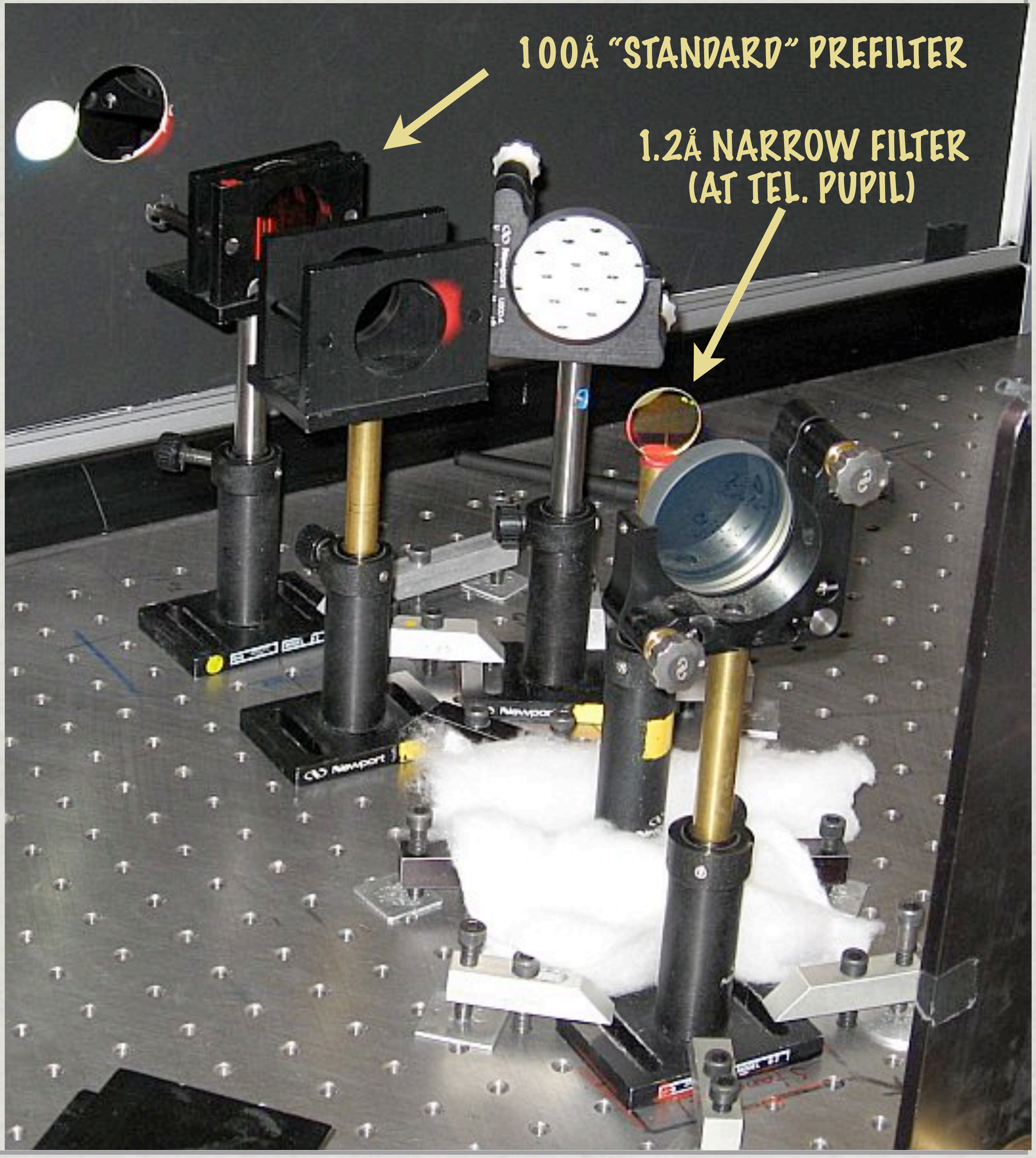


SHAZAM status:

- Proof-of-concept and prototype runs completed (DeForest et al. 2004; DeForest et al. 2009)
- All required components procured
- DST interface software (“Virtual Camera”) under development
- First 3-camera DST run planned for Spring 2009

SHAZAM components

- Prefiltering is quite narrow, to limit smearing by the dispersed continuum.



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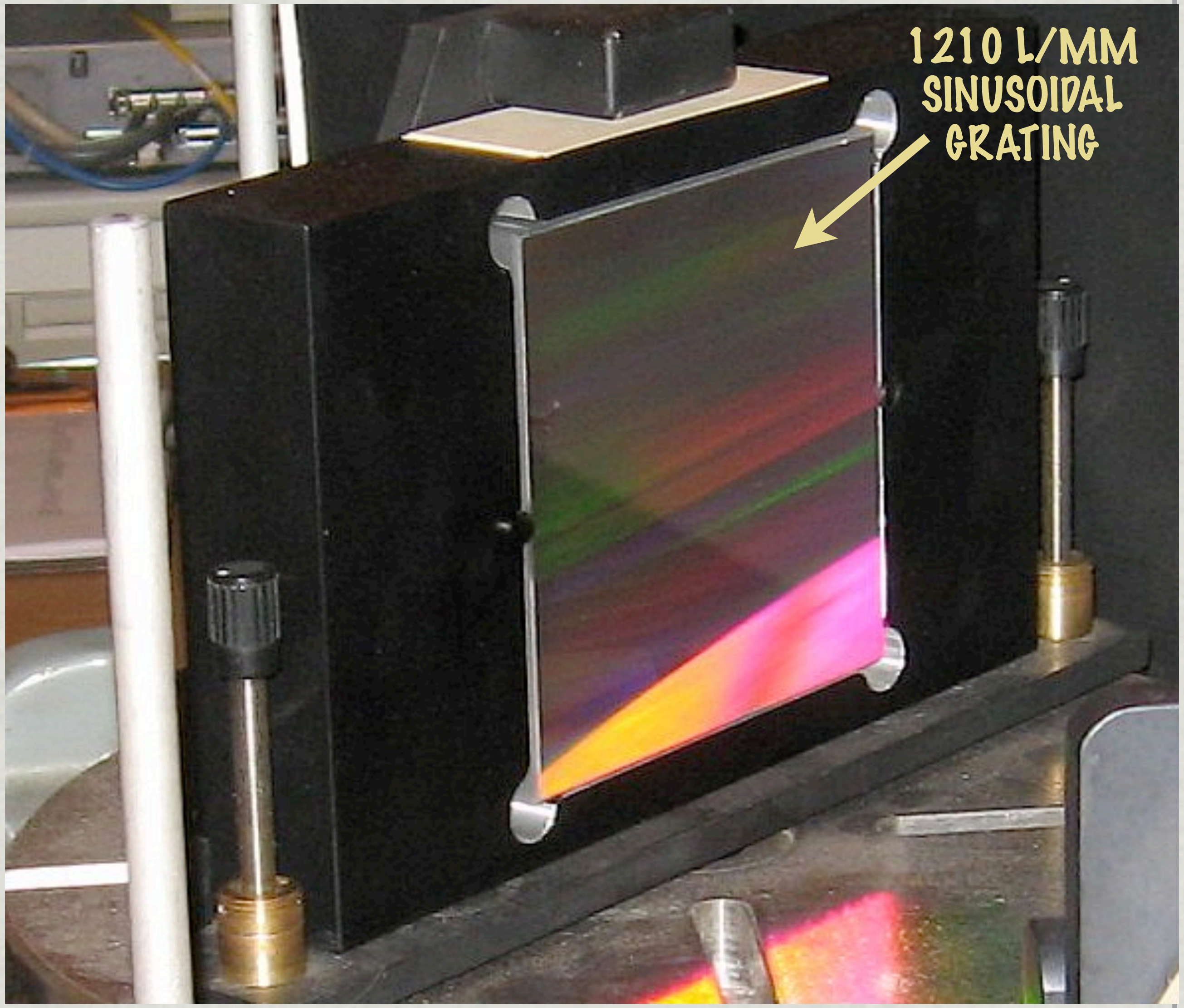
- Grating is sinusoidal for equal distribution to different orders, rejects orders higher than +/- 1.



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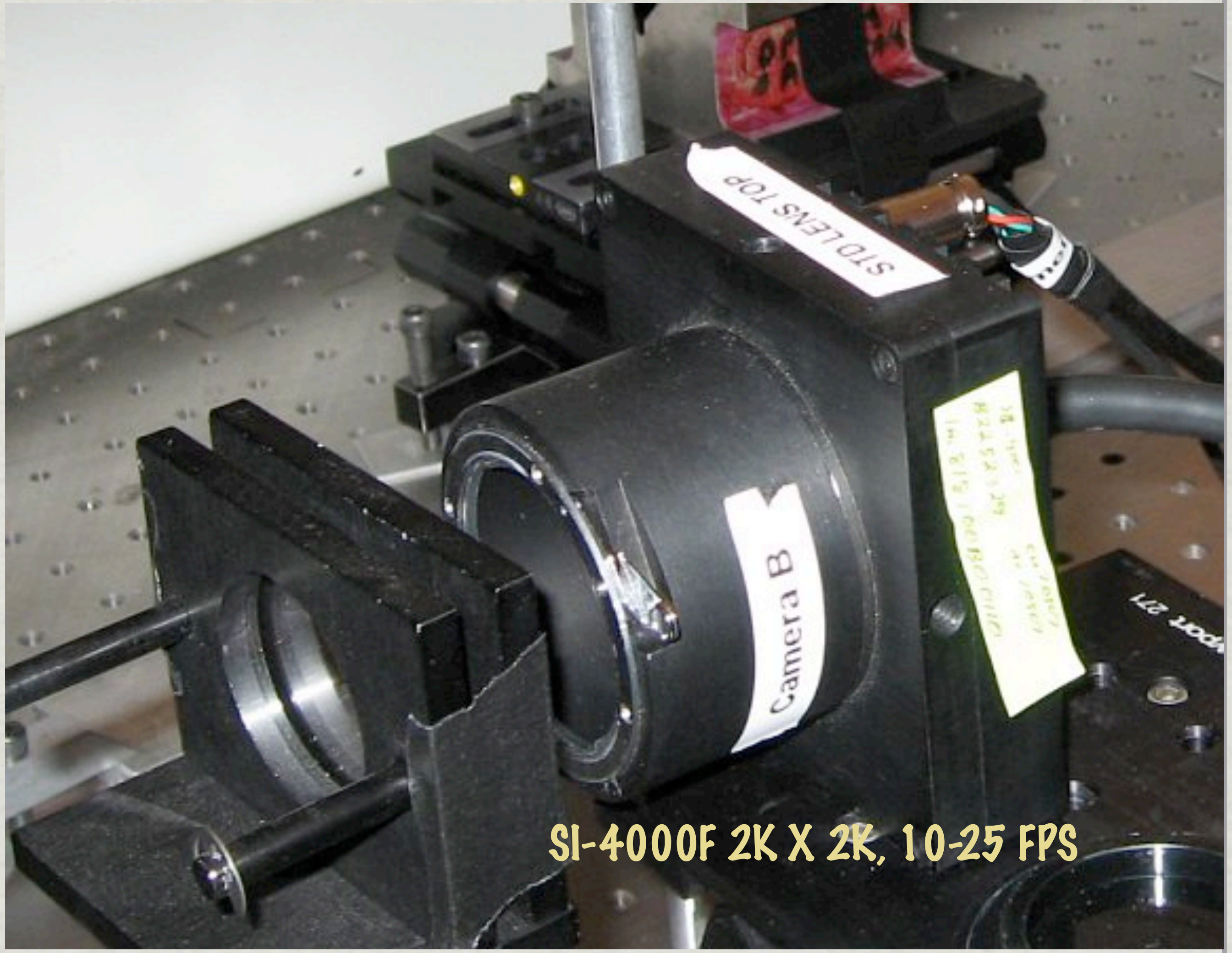
- Cameras are high speed, high resolution (2k x 2k 12µm pixels, 10 fps)



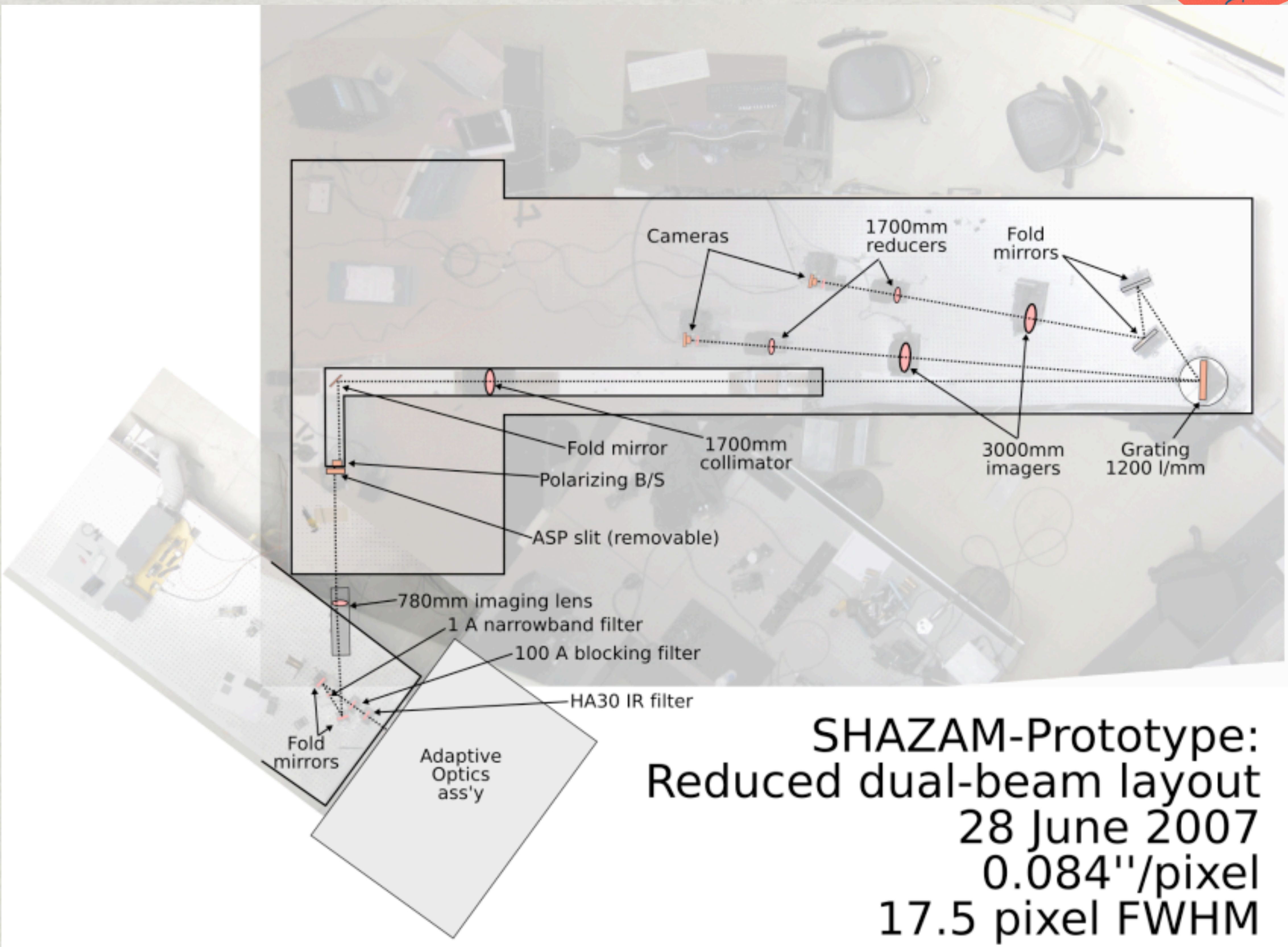
SHAZAM components

- Acquisition computers: 3 PCI-Express quad-core Xeon machines, with total storage >25 TB.
- Computers acquire data on the observing deck, then reduce and frame-select overnight.

SHAZAM-P: a Prototype Magnetograph (test run with only 2 spectral orders)

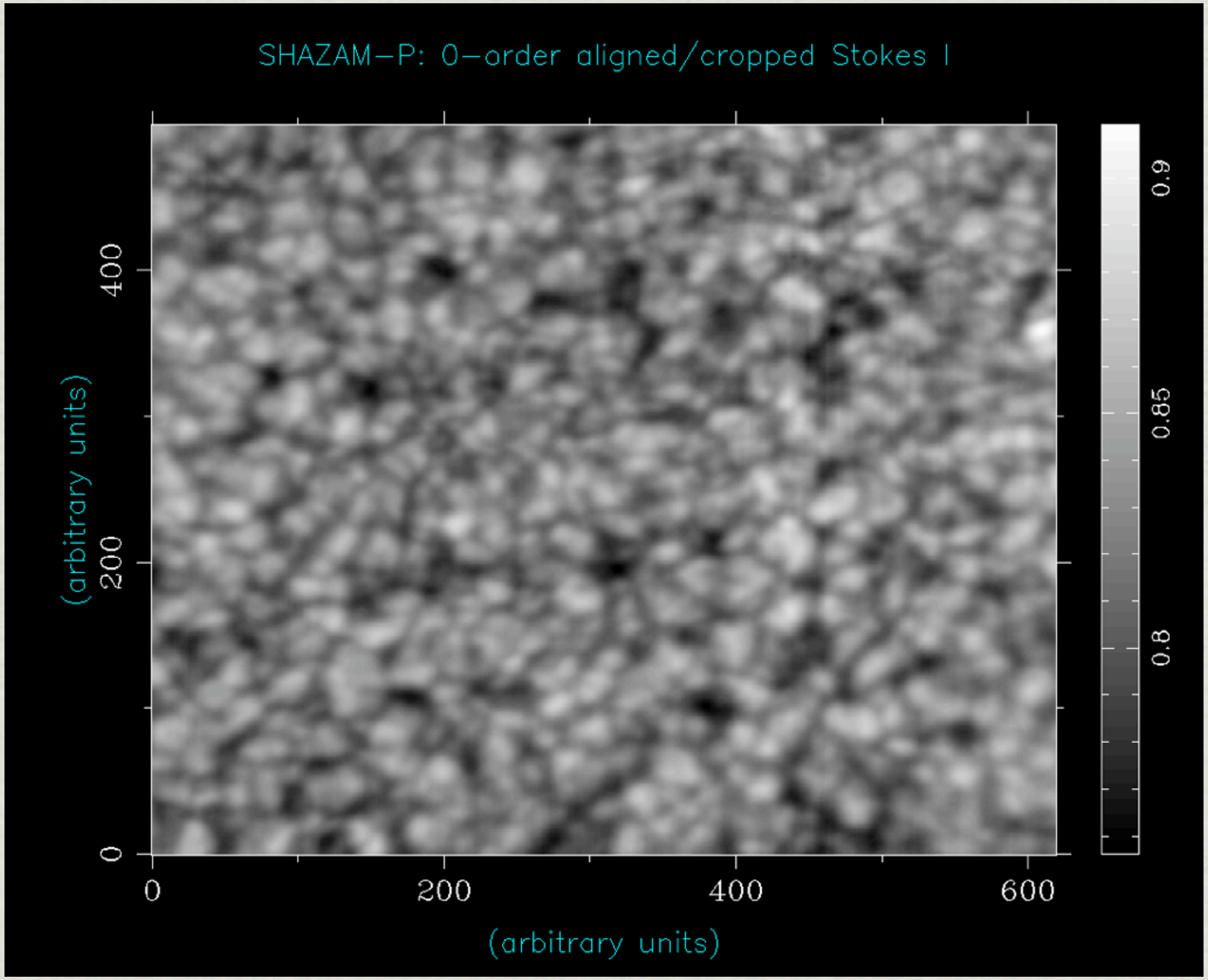
- Minimal prototype experiment “on the cheap”
  - Optics & DST obs. run Summer 2007: <$30k
- Only 1 dispersed order (RCP/LCP to get parallax)
- 3.2 second acquisition
- Used existing ASP polarizer and beamsplitter
- Single hard drive pipeline
- Rapid development camera software/firmware:
  - written in Perl in 3 weeks from scratch

SHAZAM-P at the DST (1 of 5 configurations)



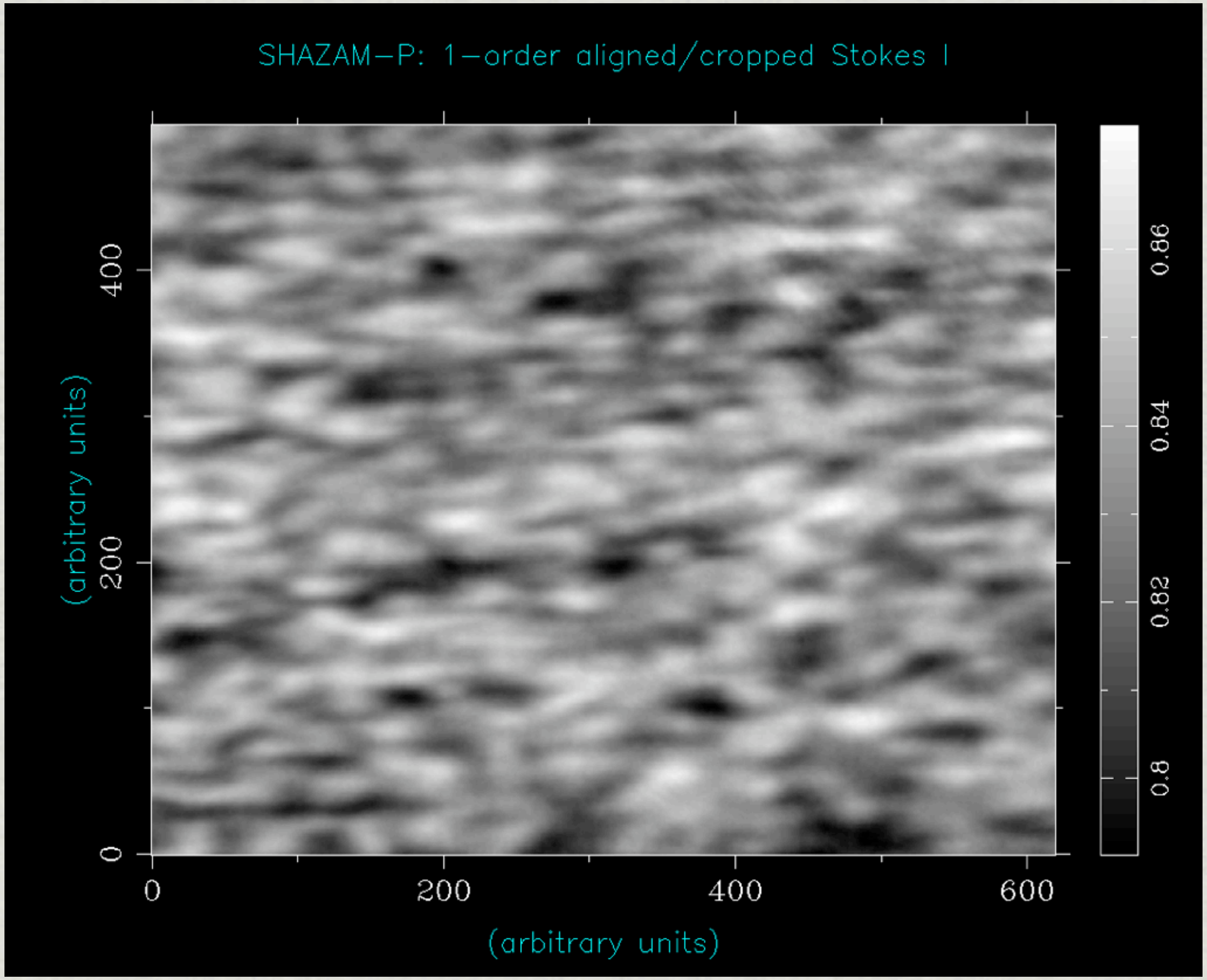
SHAZAM-P initial test (2 cams only)

RAW 0-ORDER IMAGE



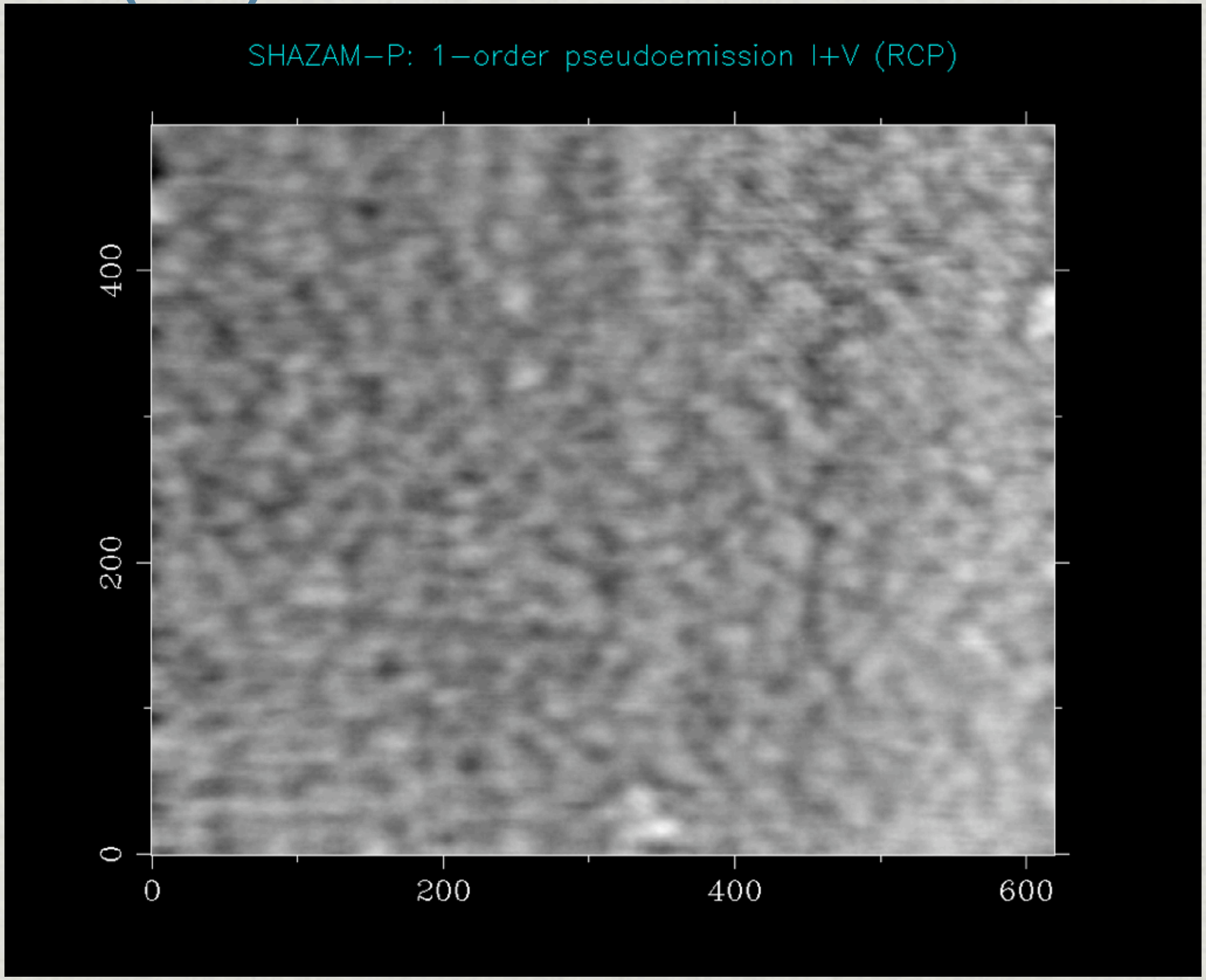
SHAZAM-P initial test (2 cams only)

RAW 1ST-ORDER IMAGE



SHAZAM-P initial test (2 cams only)

I+V (RCP) 1ST ORDER LINE CORE IMAGE



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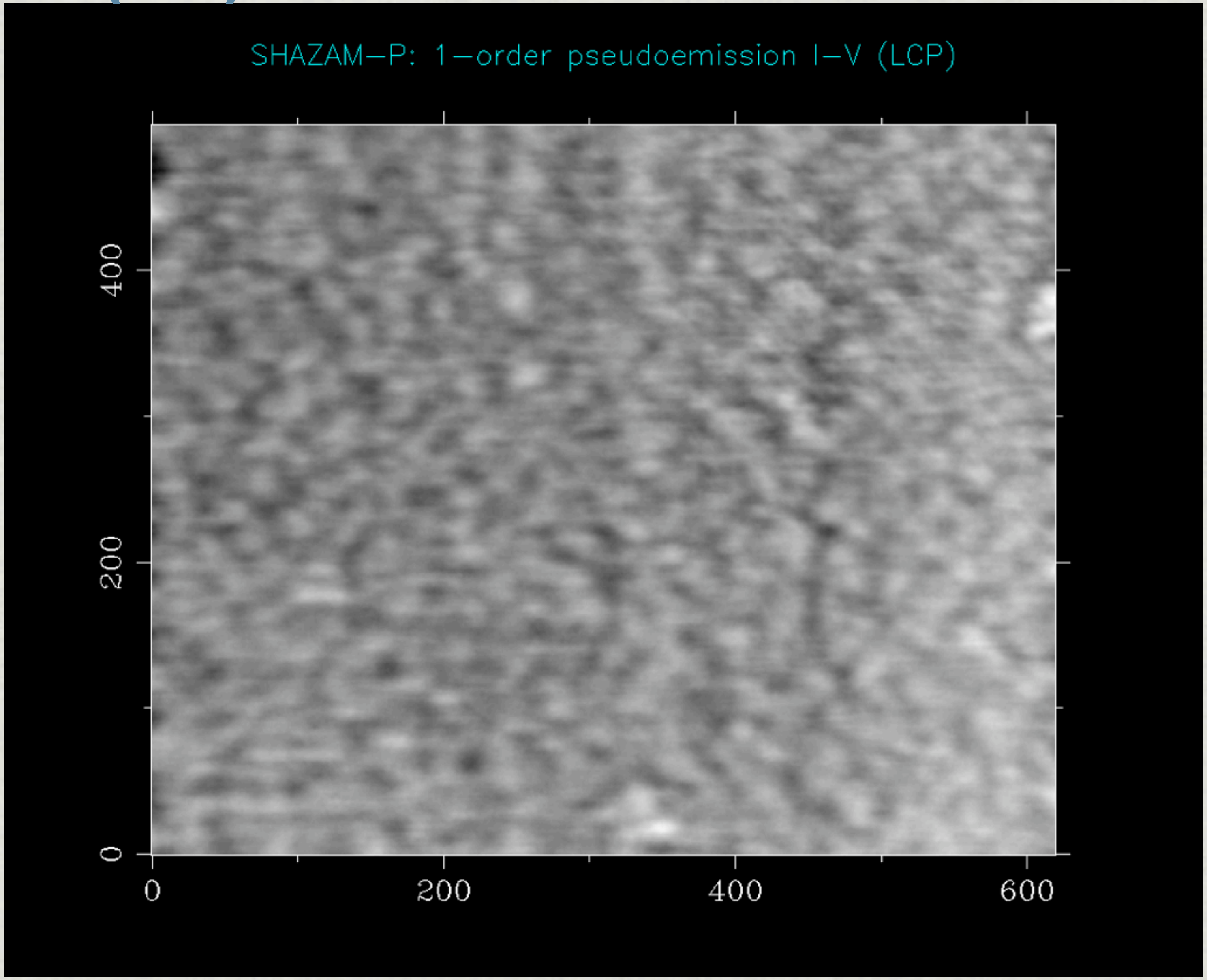
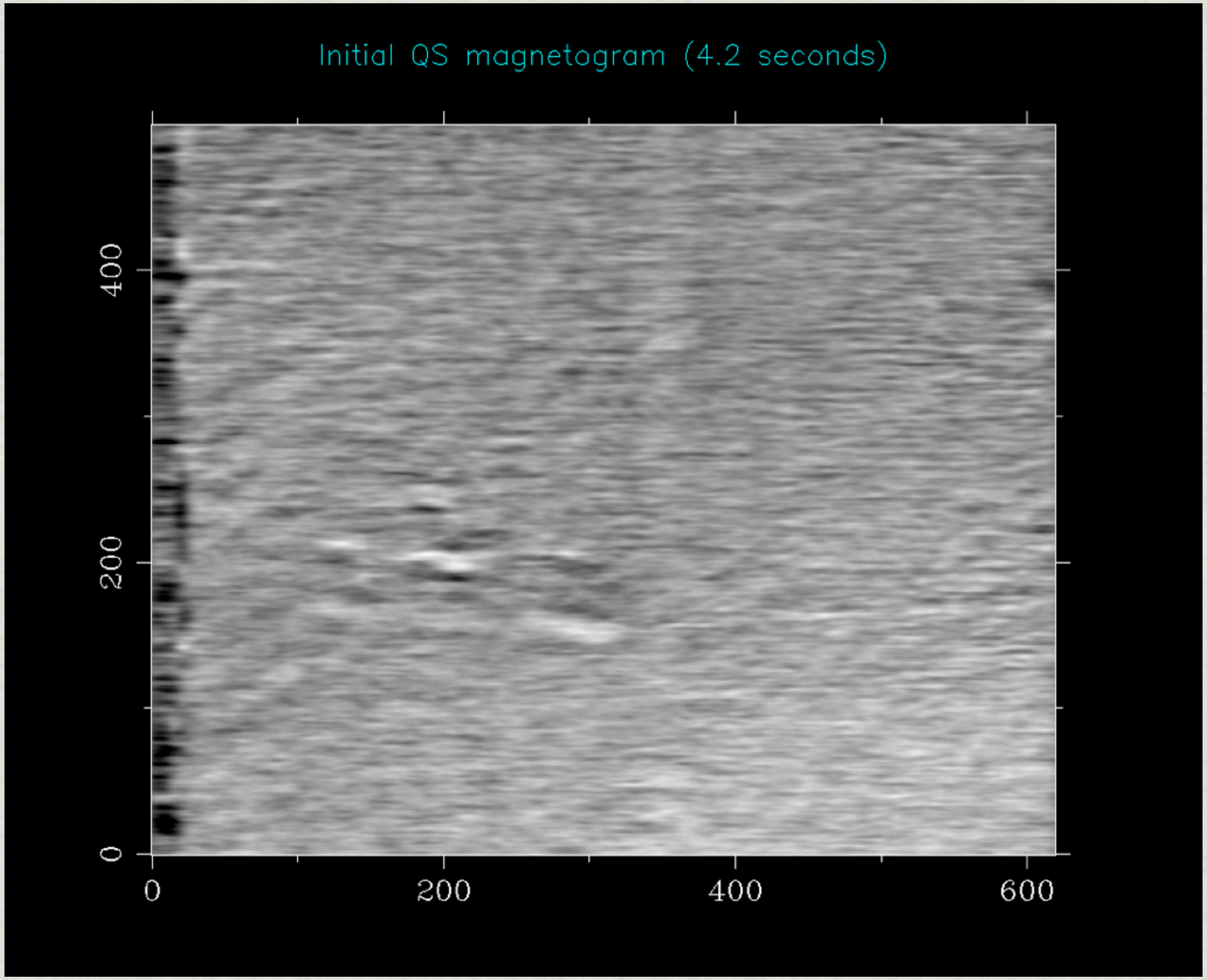
I-V (LCP) 1ST ORDER LINE CORE IMAGE



SHAZAM-P initial test (2 cams only)

INITIAL QUIET-SUN MAGNETOGRAM



Conclusions

- Concept appears viable
- All components procured; S/W prep in progress
- NSO/DST tabletop-observing model enabled prototype observations “on a shoestring”.
- 3-camera rig is important: simultaneous exposures are absolutely required to avoid seeing crosstalk.
- Initial full-instrument run planned for Spring 2009.