

Applications of Statistical Optics

- Radio Astronomy
- Michelson Stellar Interferometry
- Rotational Shear Interferometer (RSI)
- Optical Coherence Tomography (OCT)

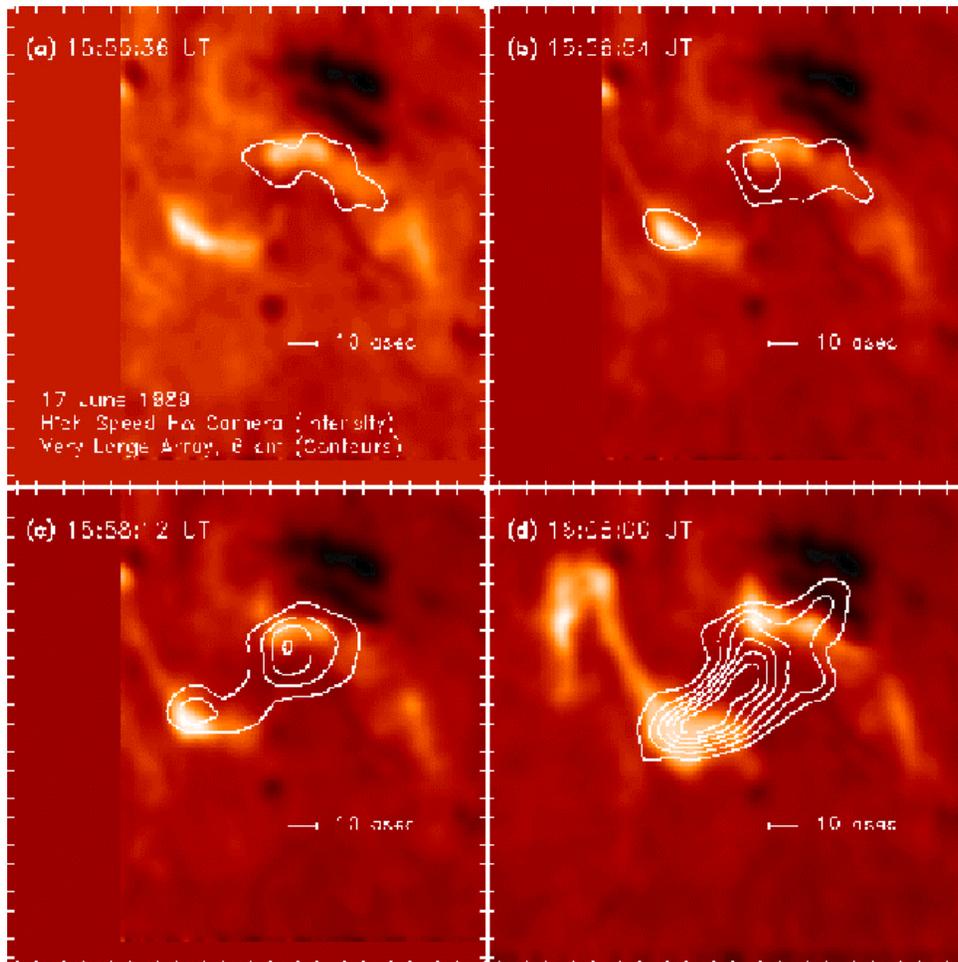
Radio Telescope (Very Large Array, VLA)



www.nrao.edu

- 27 Antennae (parabolic dishes, diameter 25m, weight 230t each)
- “Y” radius ranges between 1km and 36km
- wavelengths 90cm – 7mm
- resolution 200-1.5arcsec in smallest configuration; 6 to 0.05 arcsec in largest configuration
- signals are multiplied and correlated at central station to obtain $\mu(\Delta x, \Delta y)$.
- van Cittert-Zernicke theorem is used to invert the observations and obtain the “source” $I(\xi, \eta)$, e.g. a constellation of galaxies

VLA images

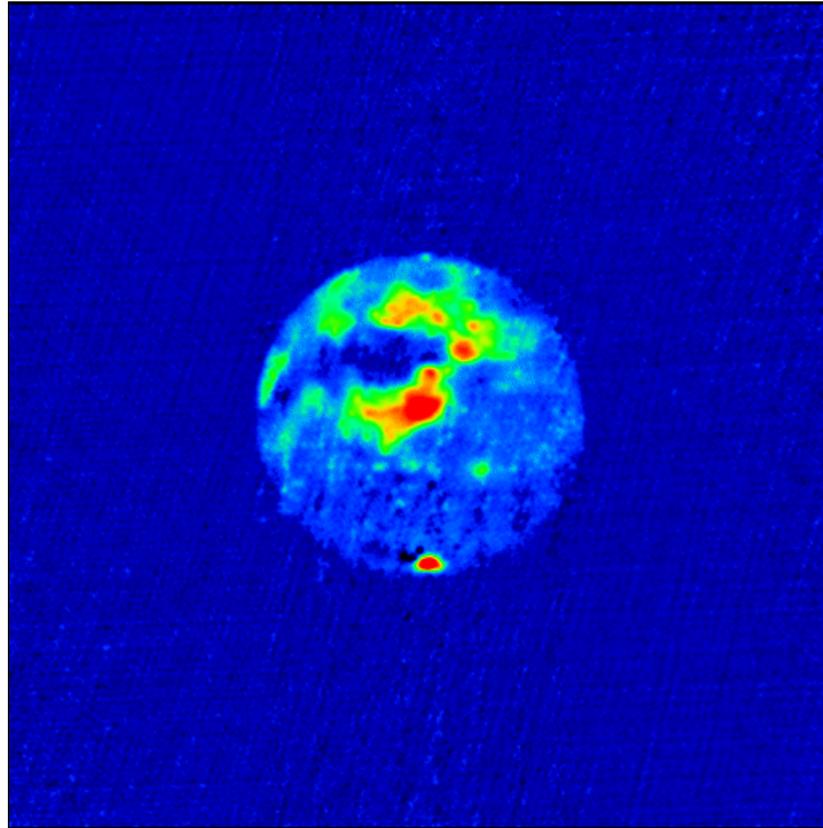


from www.aoc.nrao.edu

These four images are combined radio-optical images of a large solar flare that occurred on 17 June 1989. The red-orange background images are optical images (H-Alpha) and the superimposed contours show radio emission as seen with the VLA at a wavelength of 4.9 GHz. The four images are from four different times during the event, showing the progression toward maximum radio emission (bottom right). This soft X-ray flare was accompanied by a coronal mass ejection.

The two H alpha ribbons correspond to the "footpoints" of an arcade of magnetic loops which arch NE/SW. The magnetic field is strongest toward the NW, where prominent sunspots appear dark in H alpha. Early in the event, the magnetically stronger footpoint emits radio waves first (a), followed by magnetically conjugate footpoints to the SW (b). The entire magnetic arch connecting the two footpoints then emits (c,d).

VLA images



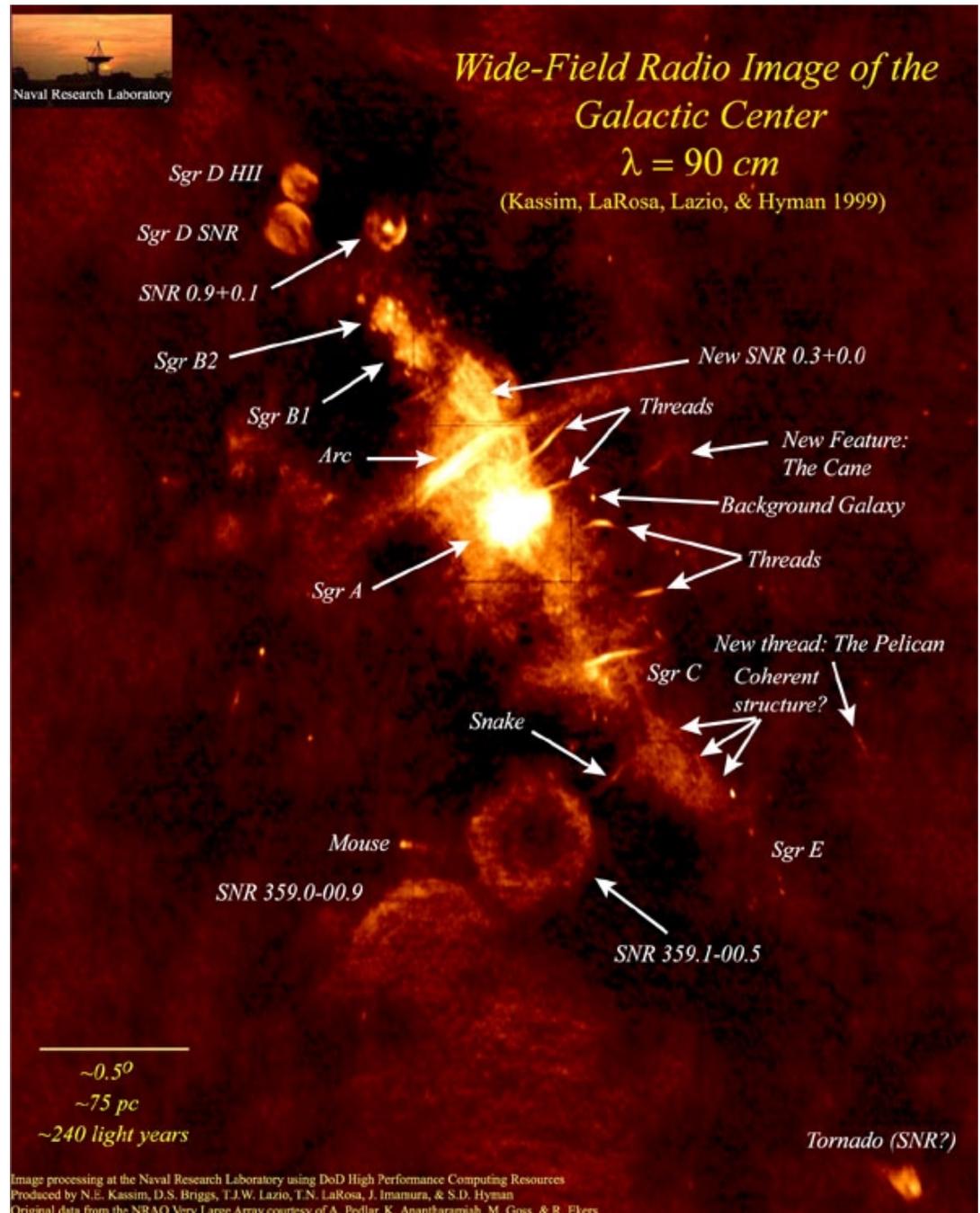
from www.aoc.nrao.edu

This is a radar image of Mars, made with the Goldstone-VLA radar system in 1988. Red areas are areas of high radar reflectivity. The south polar ice cap, at the bottom of the image, is the area of highest reflectivity. The other areas of high reflectivity are associated with the giant shield volcanoes of the Tharsis ridge. The dark area to the West of the Tharsis ridge showed no detectable radar echoes, and thus was dubbed the "Stealth" region.

VLA images

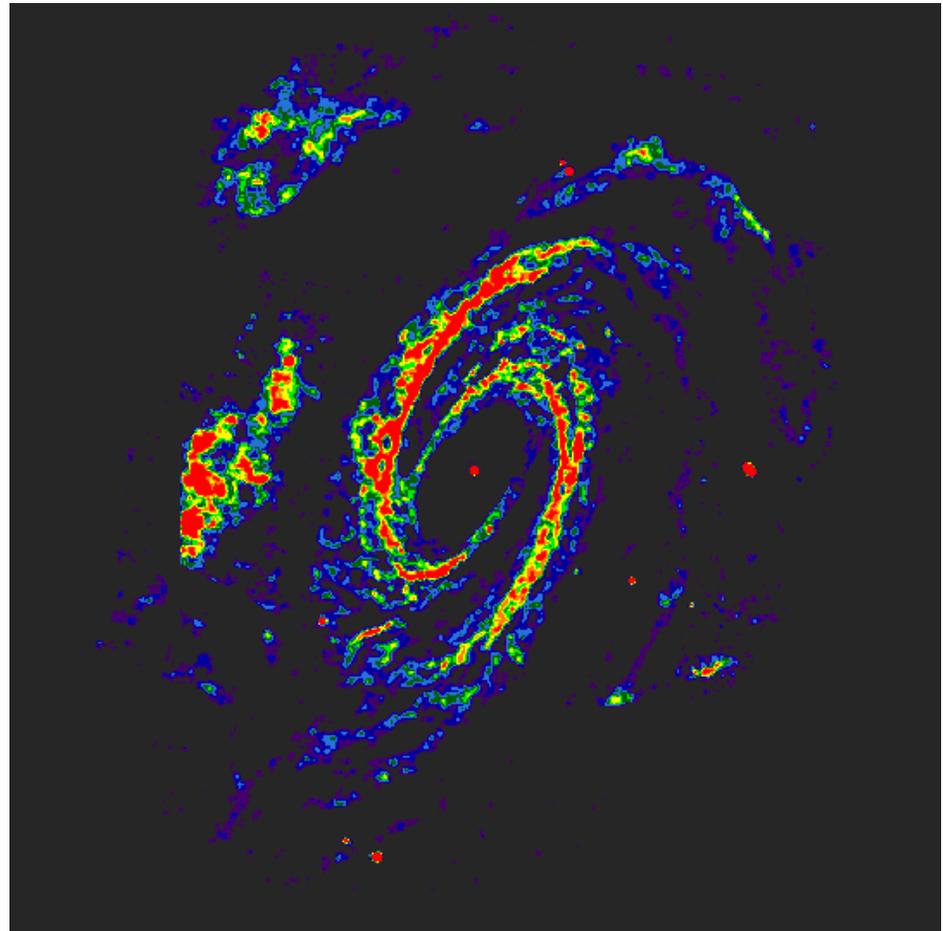
The center of the Milky Way

from www.aoc.nrao.edu



VLA images

from www.aoc.nrao.edu

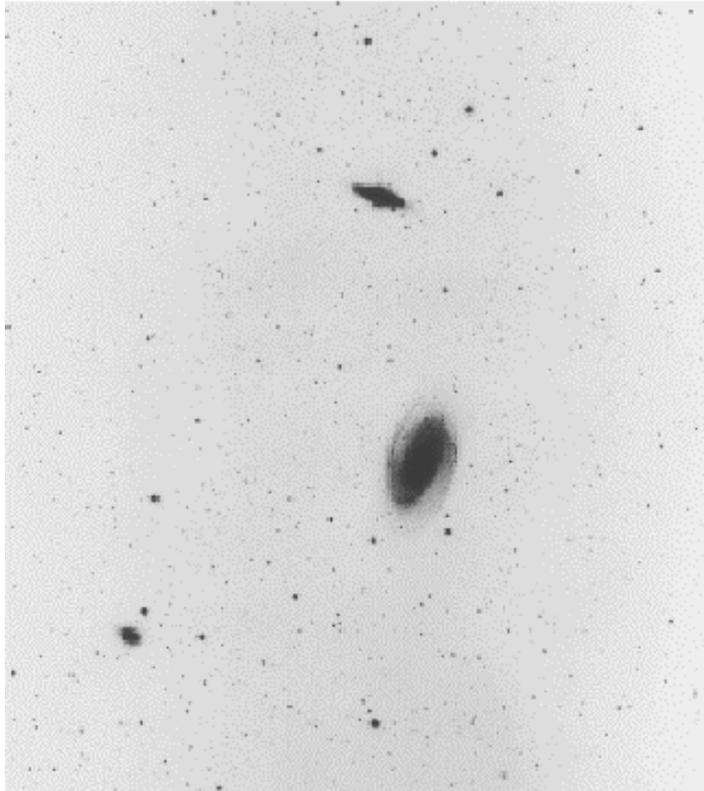


The galaxy M81 is a spiral galaxy about 11 million light-years from Earth. It is about 50,000 light-years across. This VLA image was made using data taken during three of the VLA's four standard configurations for a total of more than 60 hours of observing time. The spiral structure is clearly shown in this image, which shows the relative intensity of emission from neutral atomic hydrogen gas. In this pseudocolor image, red indicates strong radio emission and blue weaker emission.

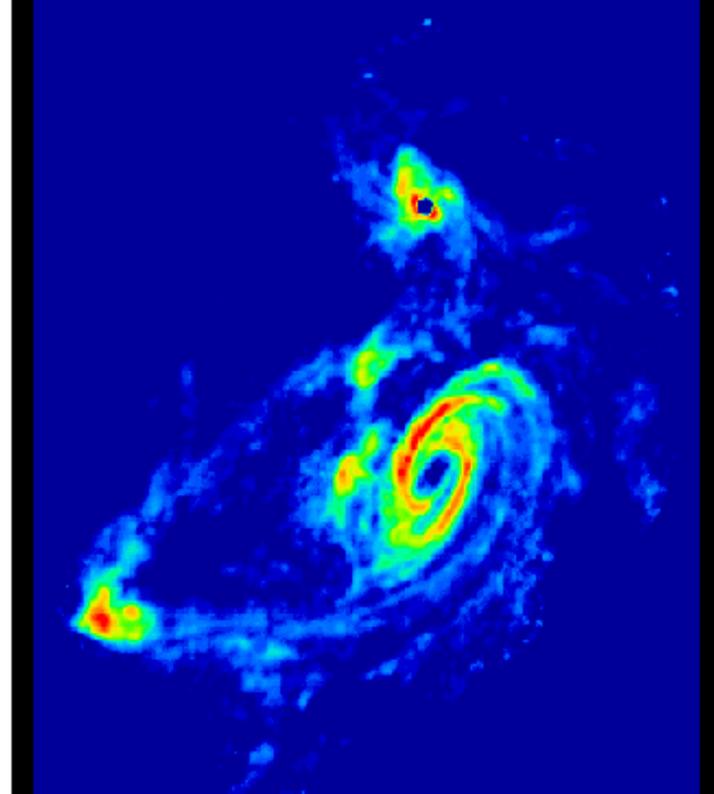
from www.a

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution



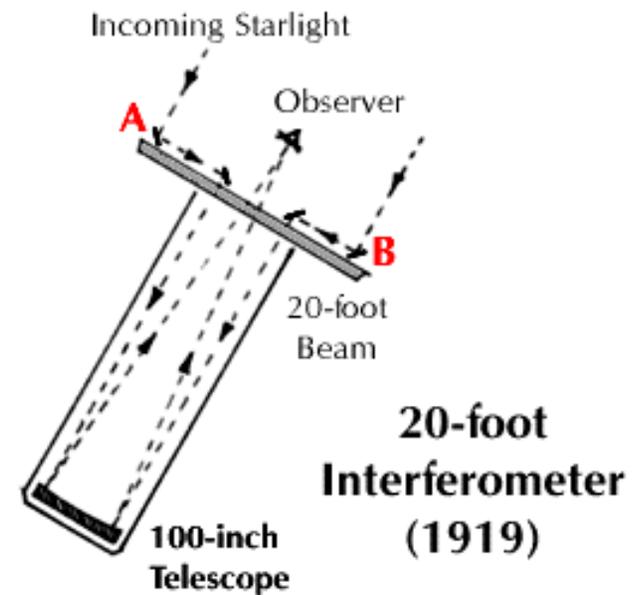
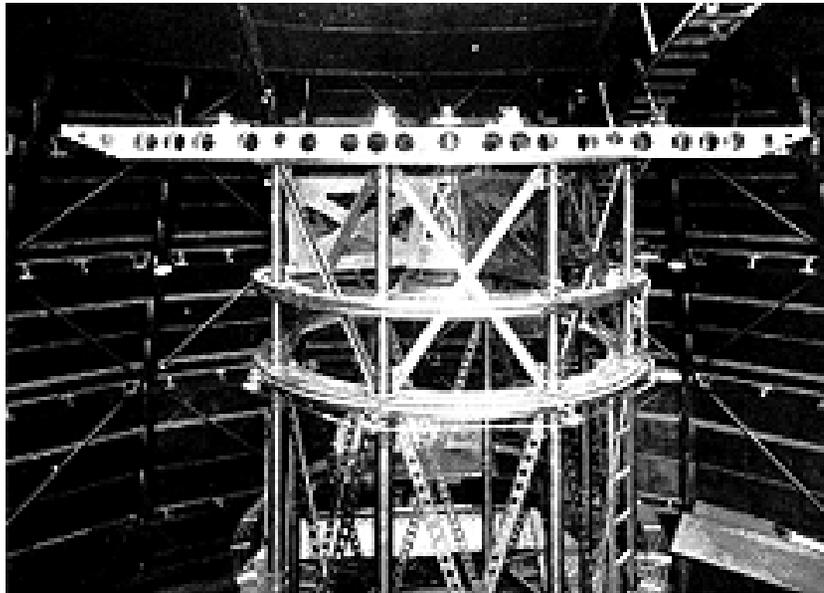
21cm HI Distribution



This pair of images illustrates the need to study celestial objects at different wavelengths in order to get "the whole picture" of what is happening with those objects. At left, you see a visible-light image of the M81 Group of galaxies.

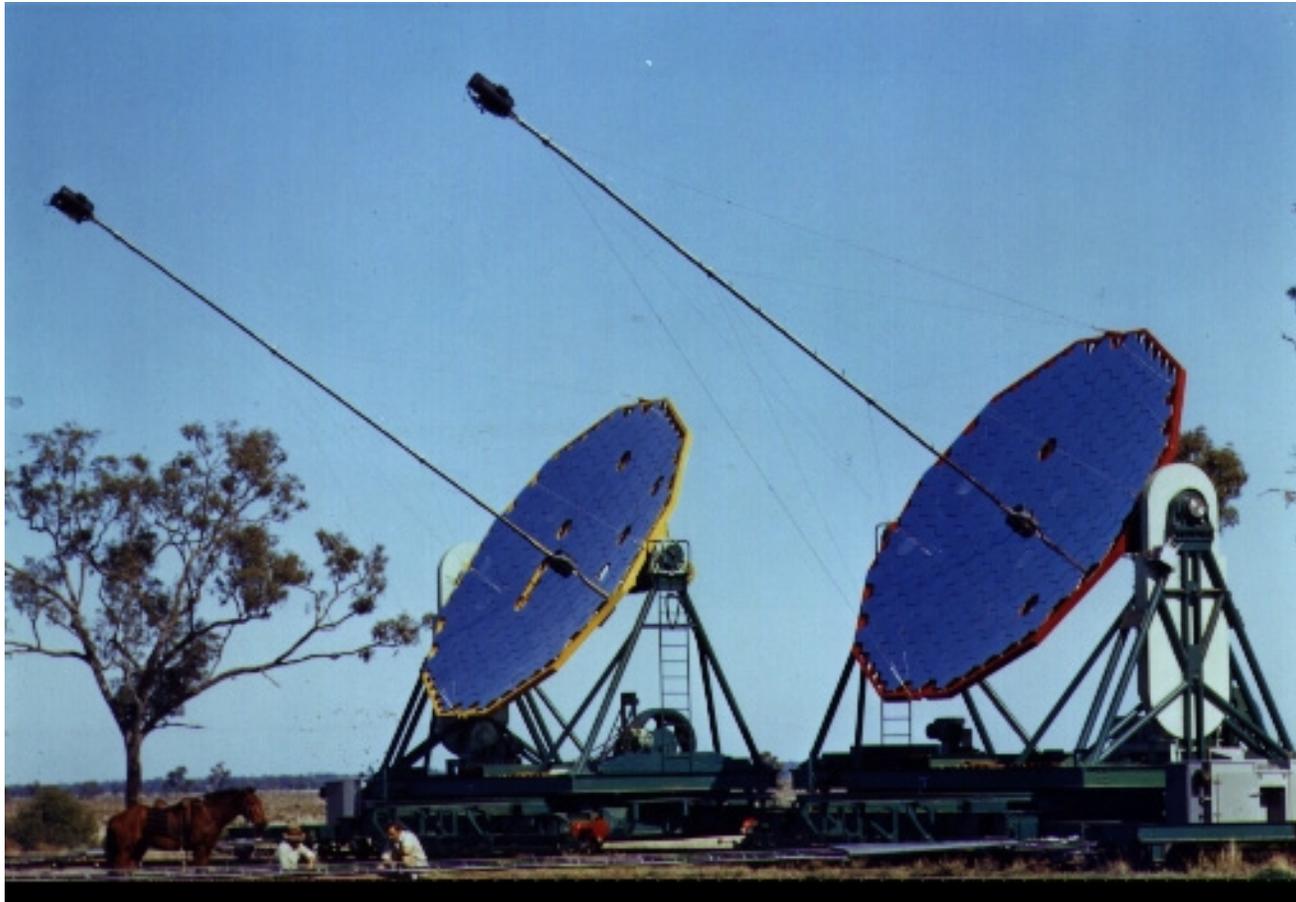
This image largely shows light coming from stars in the galaxies. At right, a radio image, made with the VLA, shows the hydrogen gas, including streamers of gas connecting the galaxies. From the radio image, it becomes apparent that this is an interacting group of galaxies, not isolated objects.

Michelson Stellar Interferometer



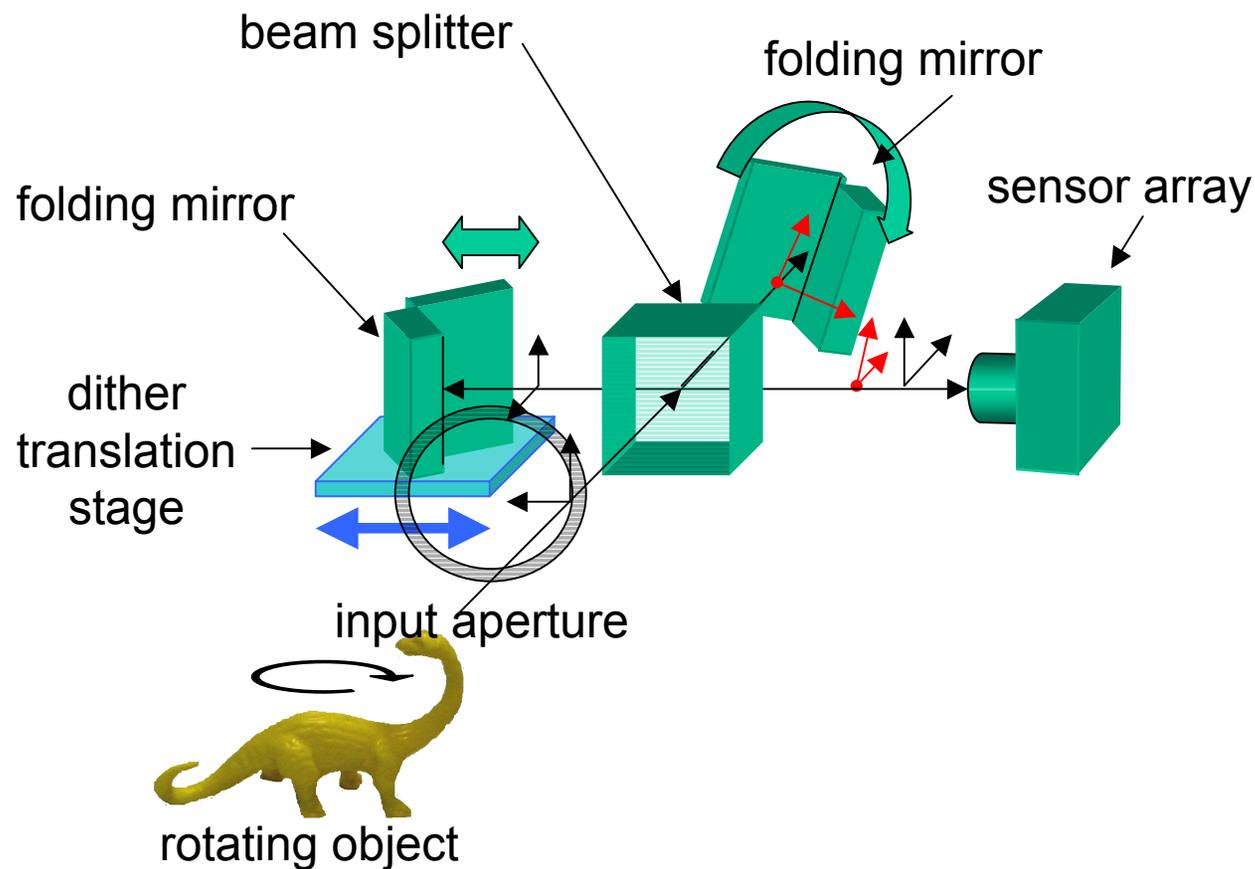
- Optical version of the van Cittert-Zernicke theorem
- Since multiplication cannot be performed directly, it is done through interference (Young's interferometer)
- Extreme requirements on mechanical and thermal stability (better than $\lambda/100$ between the two arms)
- Alternative: intensity interferometer (or "Hanbury Brown – Twiss" interferometer)

Hanbury Brown – Twiss interferometer

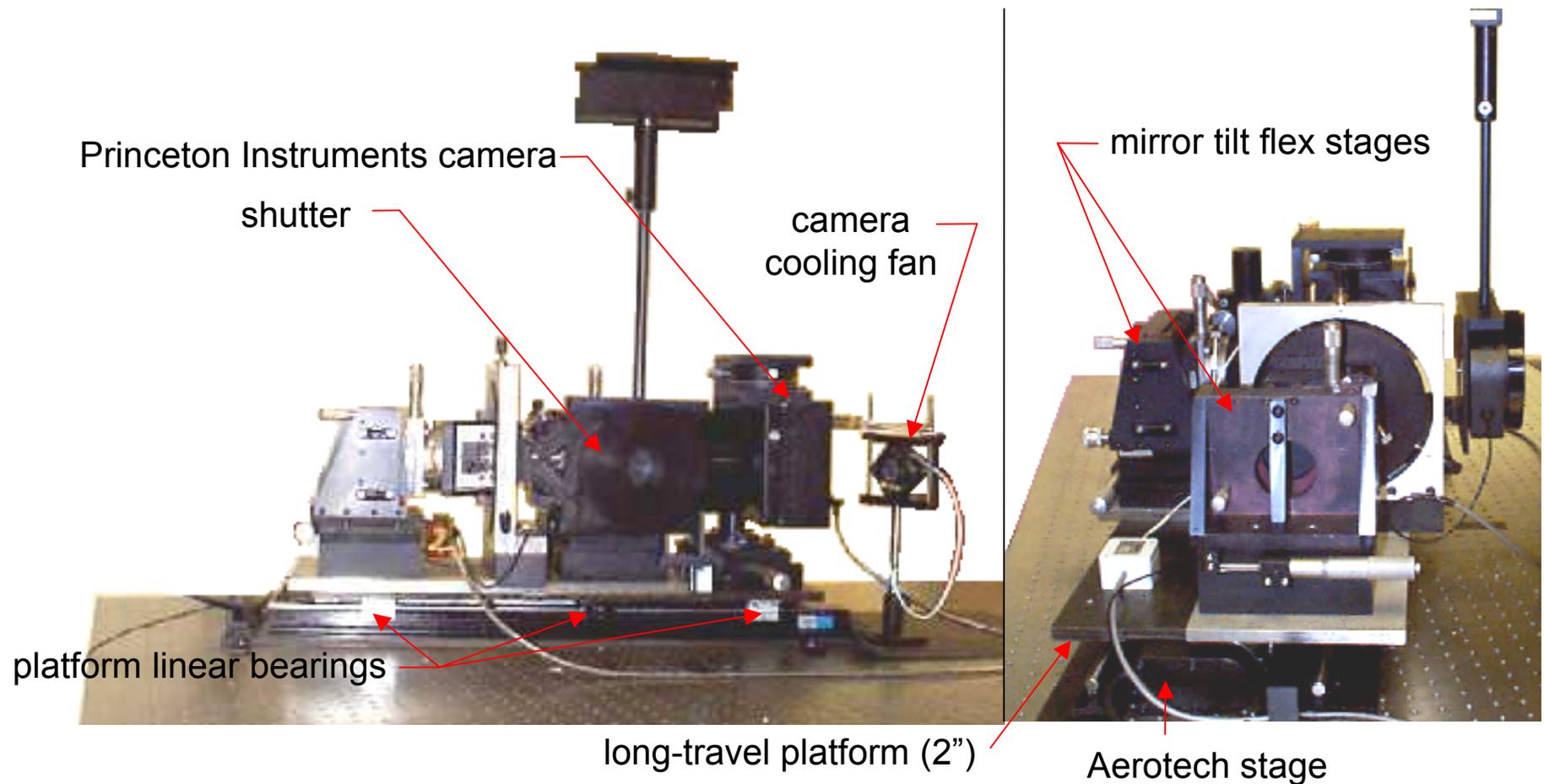


from www.physics.usyd.edu.au/astron/susi

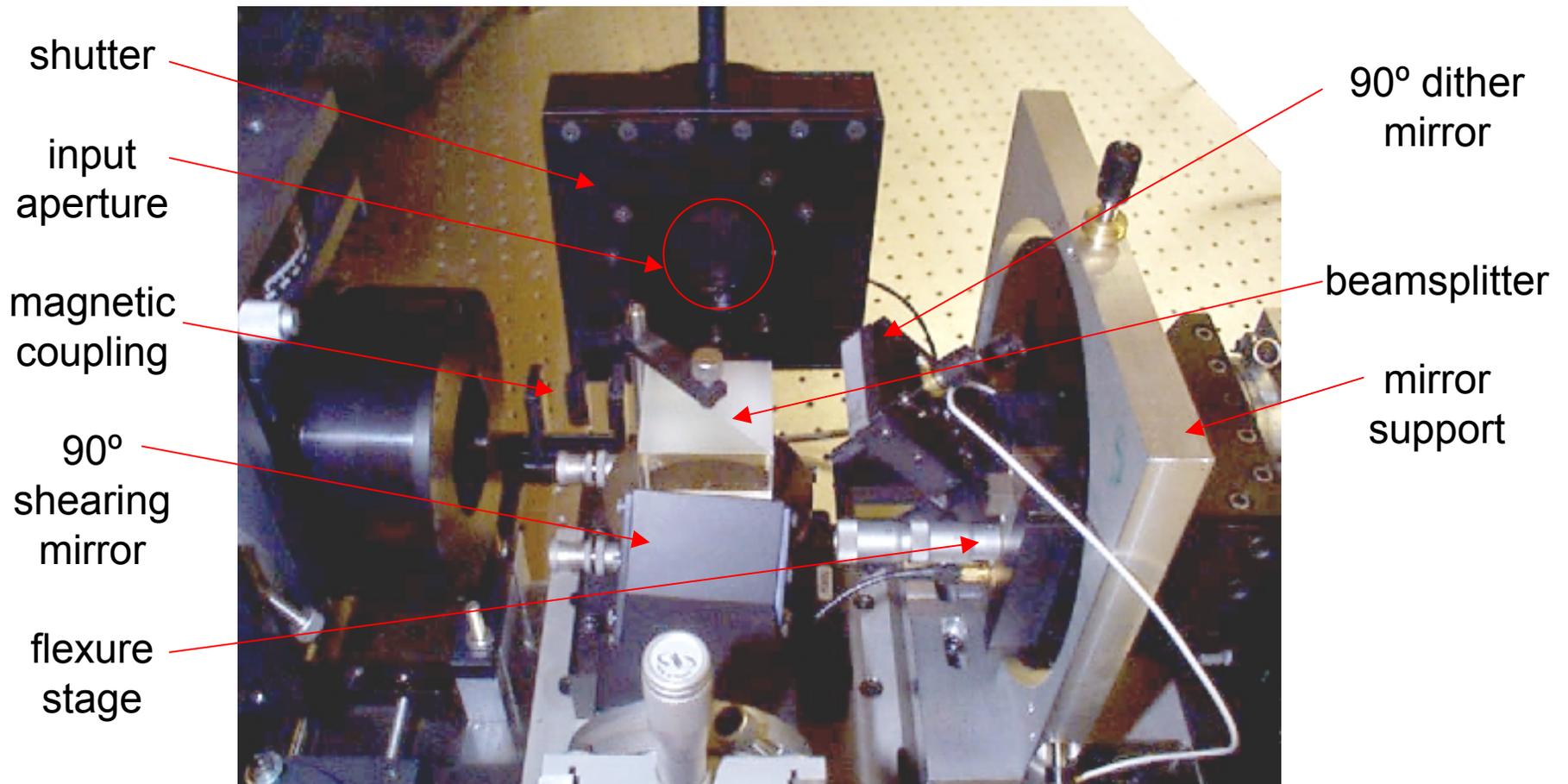
The Rotational Shear Interferometer



Experimental RSI implementation (University of Illinois)



Close-up view of the Interferometer Section of the RSI



Mobile RSI

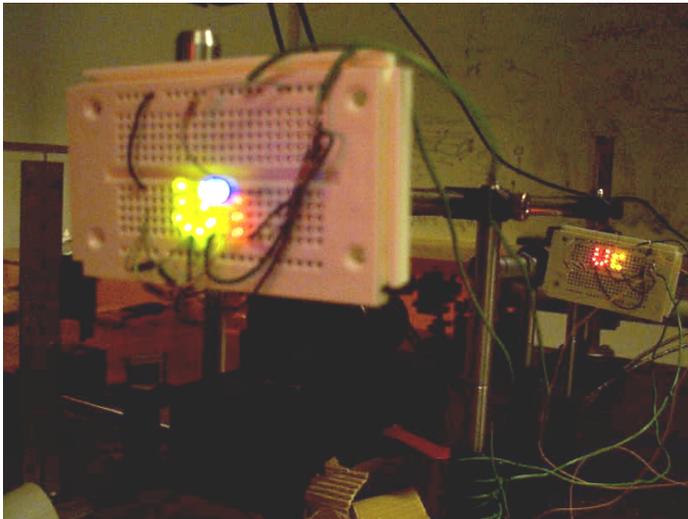
(University of Illinois and
Distant Focus Corporation)



EXPERIMENTAL RESULTS: 3-D

2-D spatial / 1-D spectral RSI reconstruction

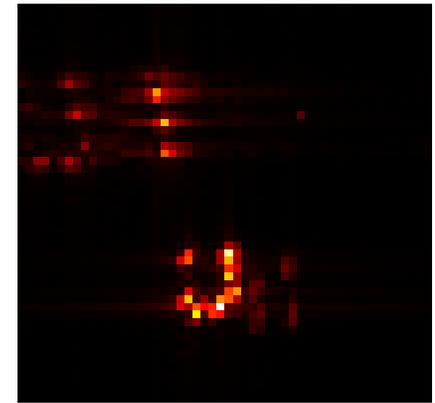
Experimental Setup



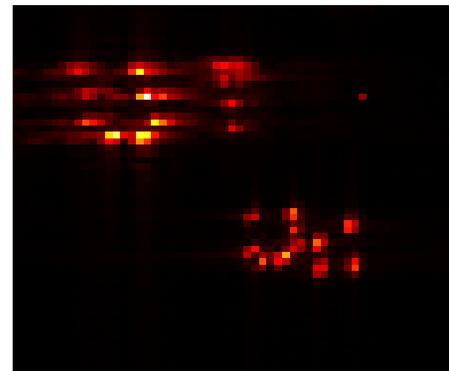
by David J. Brady, Duke University
www.fitzpatrick.duke.edu/disp/



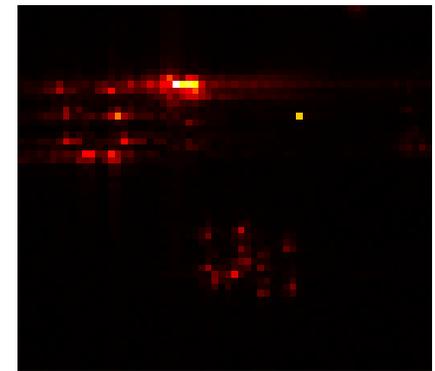
Color Composite Image



Red (590-650 nm)

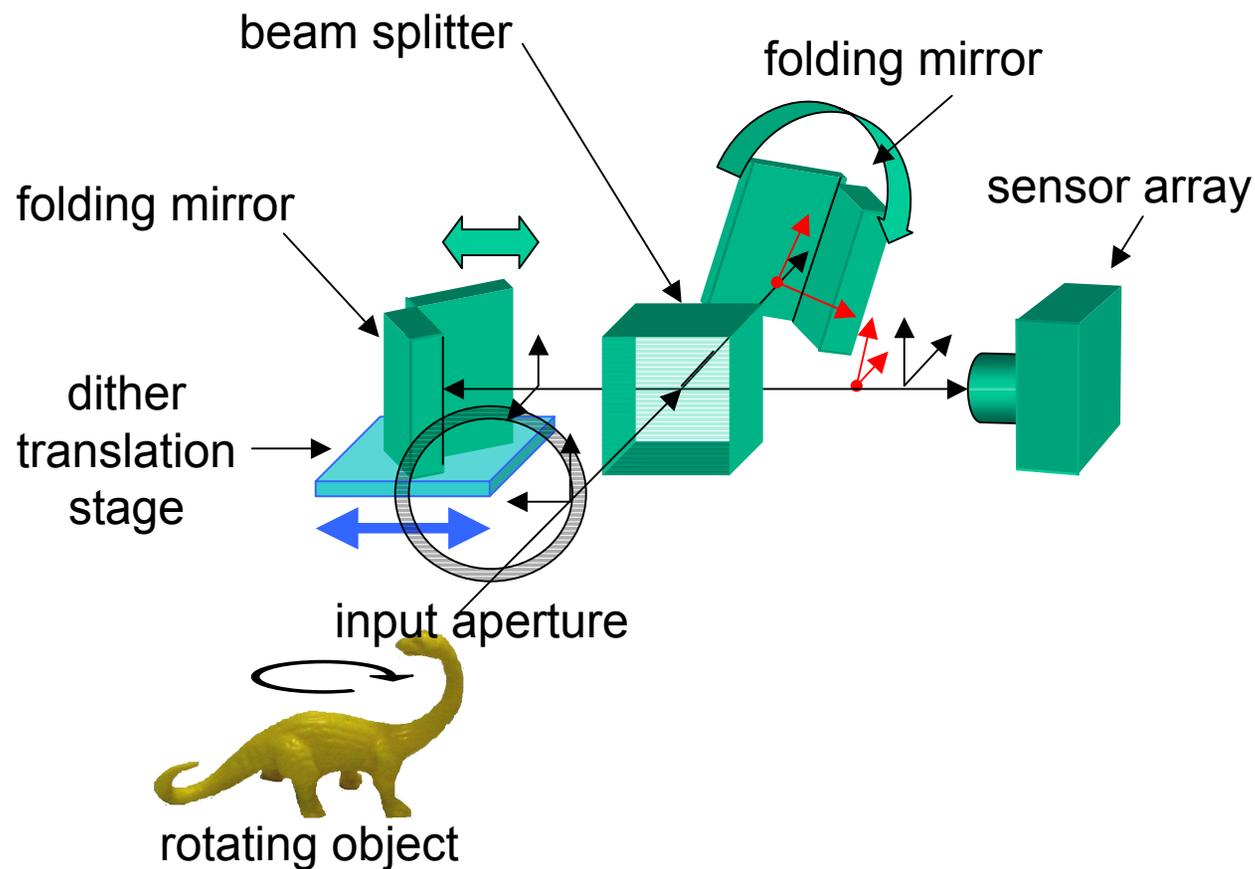


Green (520-570 nm)

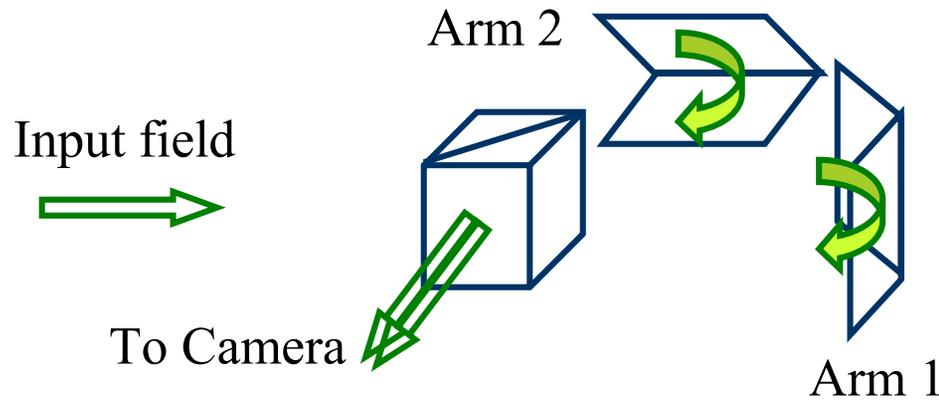


Blue (430-500 nm)

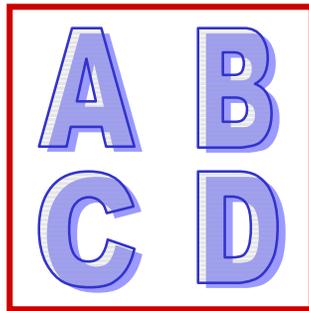
The Rotational Shear Interferometer



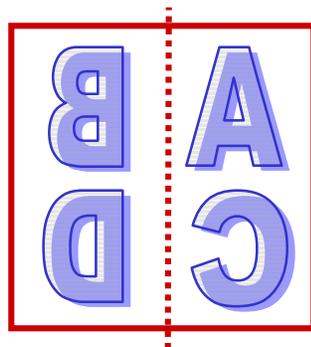
What does the RSI measure?



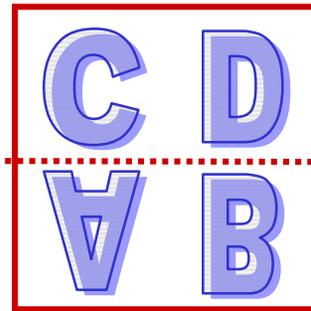
Special case:
 $\theta=90^\circ$



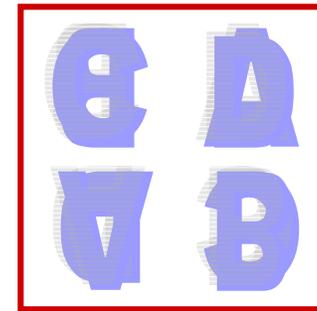
Input field



Folding prism
at Arm 1



Folding prism
at Arm 2 ($\theta=90^\circ$)

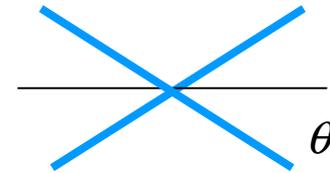


Arms 1 & 2
combined
at camera plane

Intensity on the RSI Sensor Plane

The field on arm 1 is:

$$E_1(x, y) = E_o (x \cos 2\theta + y \sin 2\theta, -x \sin 2\theta - y \cos 2\theta)$$



The field on arm 2 is:

$$E_2(x, y) = E_o (x \cos 2\theta - y \sin 2\theta, x \sin 2\theta - y \cos 2\theta)$$

$$I_s(x, y) = \langle |E_1 + E_2|^2 \rangle$$

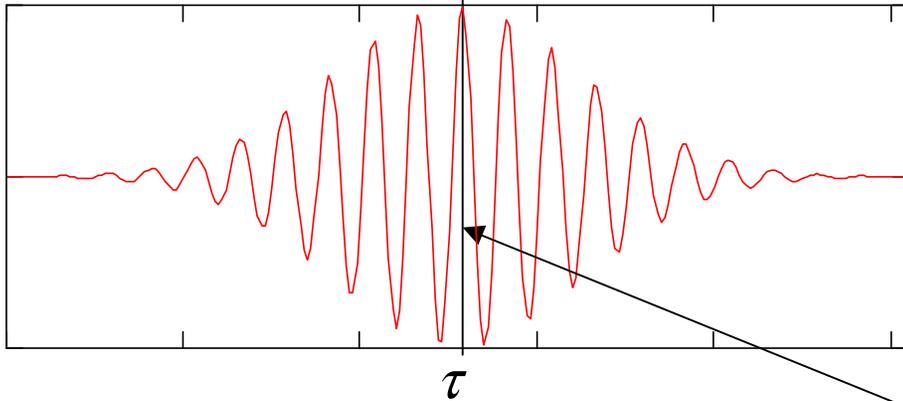
$$= \langle |E_1|^2 + |E_2|^2 + E_1^* E_2 + E_1 E_2^* \rangle$$

$$= I_1 + I_2 +$$

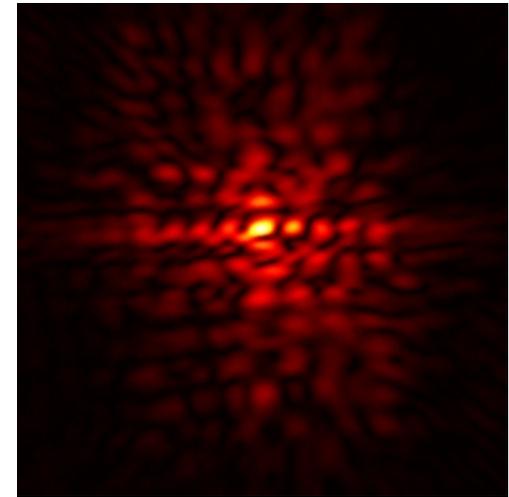
$$\Gamma(\Delta x = 2y \sin 2\theta, \Delta y = -2x \sin 2\theta, \hat{x} = 2x \cos 2\theta + x_o, \hat{y} = y_o - 2x \cos 2\theta, \tau = 2\delta / c) \\ + \Gamma^*$$

Coherence imaging using the RSI

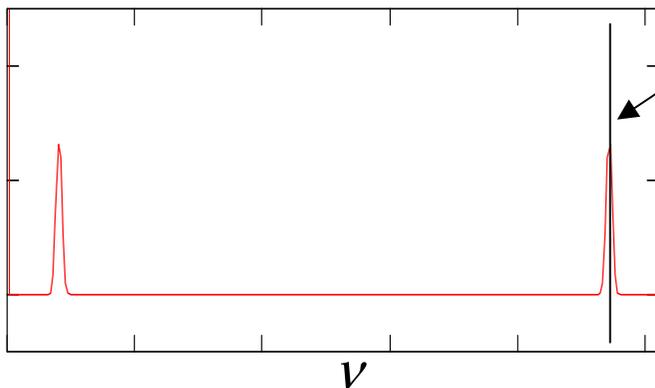
$$\text{Re}[\Gamma(\Delta x_k, \Delta y_l, \hat{x}_i, \hat{y}_j, \tau)] + dc$$



Interference on CCD



$$|S(\Delta x_k, \Delta y_l, \hat{x}_i, \hat{y}_j, \nu)|$$



$$J(\Delta x_k, \Delta y_l, \hat{x}_i, \hat{y}_j) \Big|_{\nu=\nu_0}$$

$$\text{Re}[\Gamma(\Delta x, \Delta y, \hat{x}_i, \hat{y}_j, \tau_0)] + dc$$

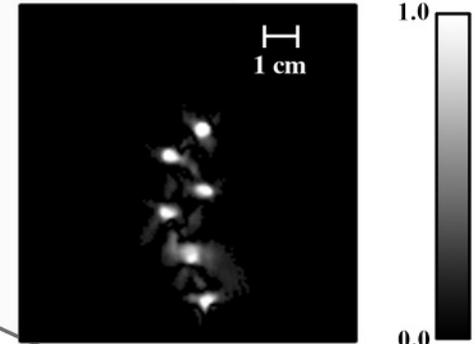
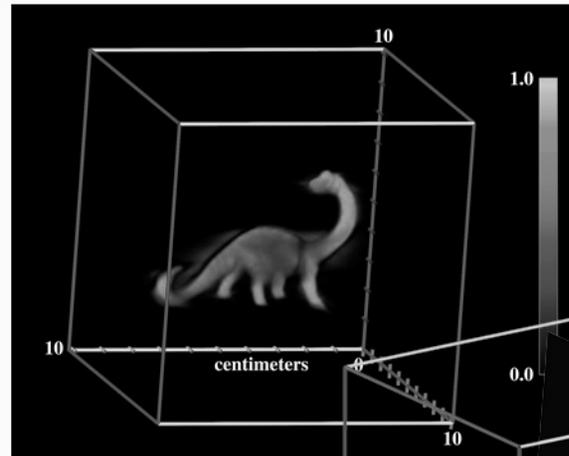
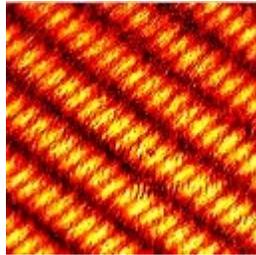
4-D Fourier transform relationship

$$\Gamma(\Delta x, \Delta y, q, \tau) \Leftrightarrow S[x', y', z', \nu]$$

Example RSI Images



2 point sources



Experimental

