Imaging science – the journey from seeing to believing

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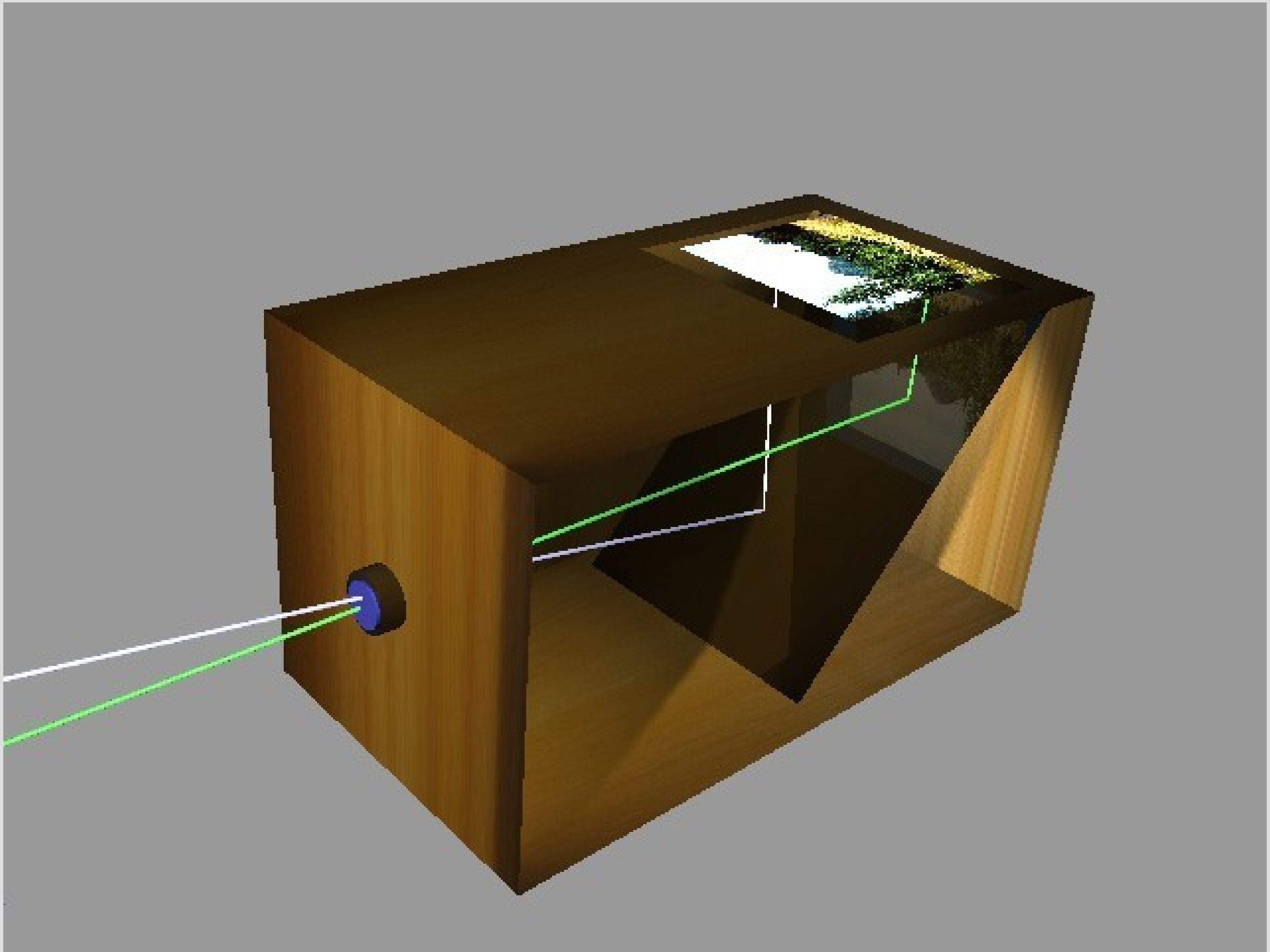
It all began in a dark room....the camera obscura

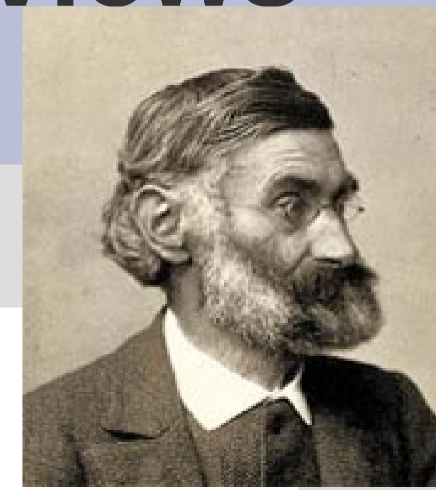


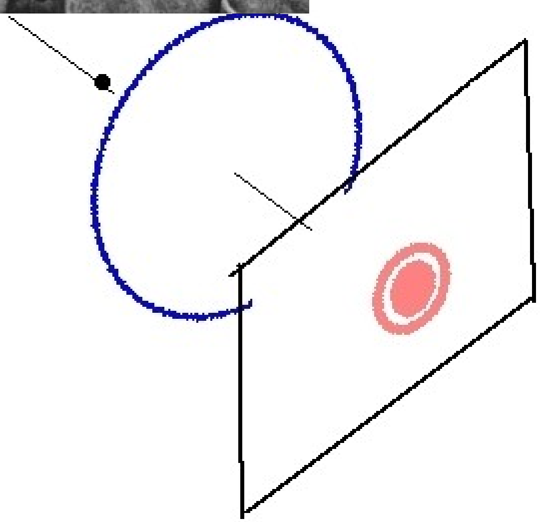
Improve-ments to the pinhole camera included a mirror to set things right and a lens to collect more light – it predated and gave rise to photography

The problems of lenses

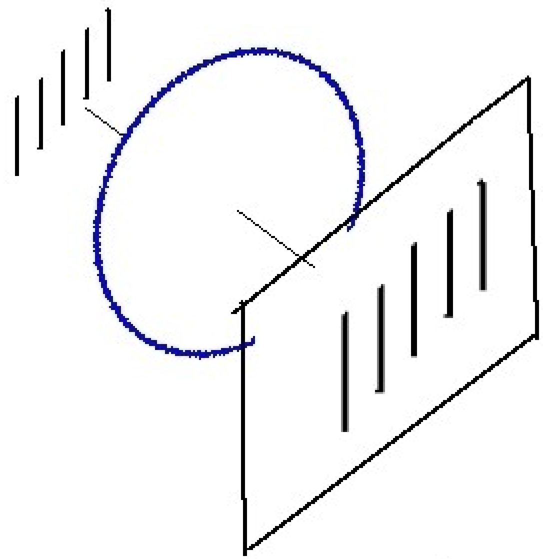
- Gathering enough light and focusing it – wide angle and no aberrations
- Objects at different distances are not in focus at the same plane (the price of mapping three dimensions to two)
- Even at the same distance, (as in astronomy) objects off axis are not in focus
- And even on the axis, the wavelength of light sets a lower limit to the size of the focal spot

Two nineteenth- century views of imaging



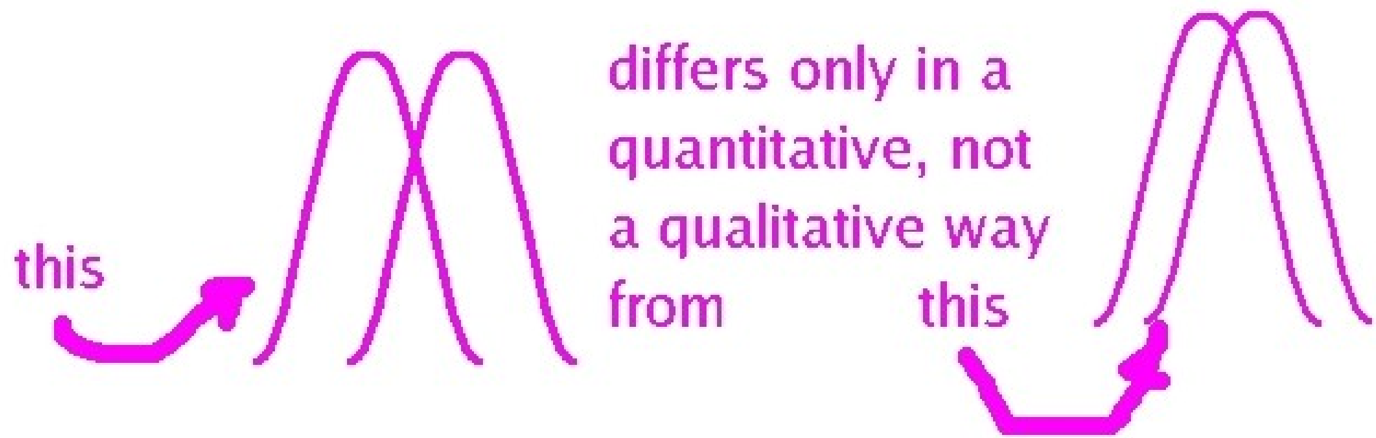


Rayleigh: Point spread function



Abbe' : Modulation transfer function

A closer look at the Rayleigh criterion

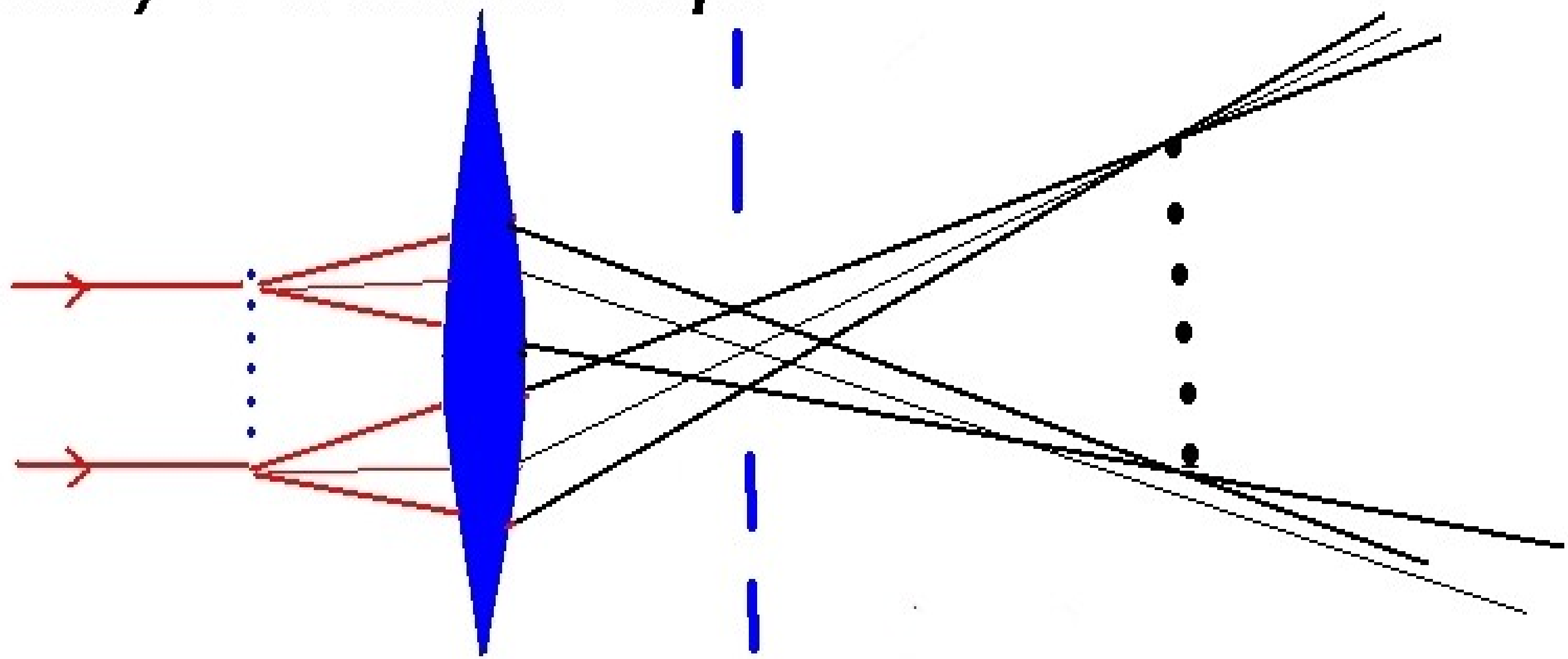


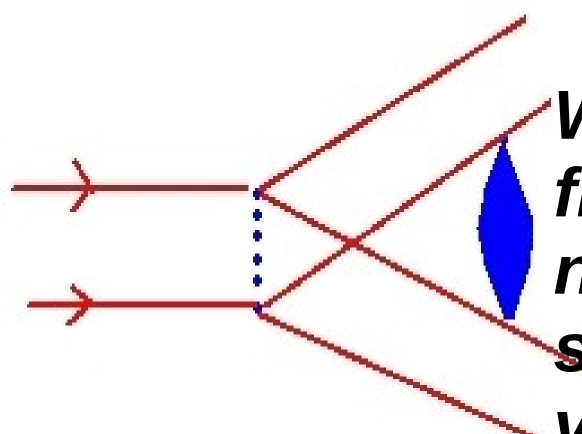
How can one say that the first is resolved and the second is unresolved??

In fact, one can argue from analyticity that the smallest piece of the image can give full information on the object!

The fly in the ointment: signal to noise ratio...optics should be viewed in the frame of information theory (D.Gabor, 1954)

The limits to resolution in an MTF approach : Abbe theory of the microscope

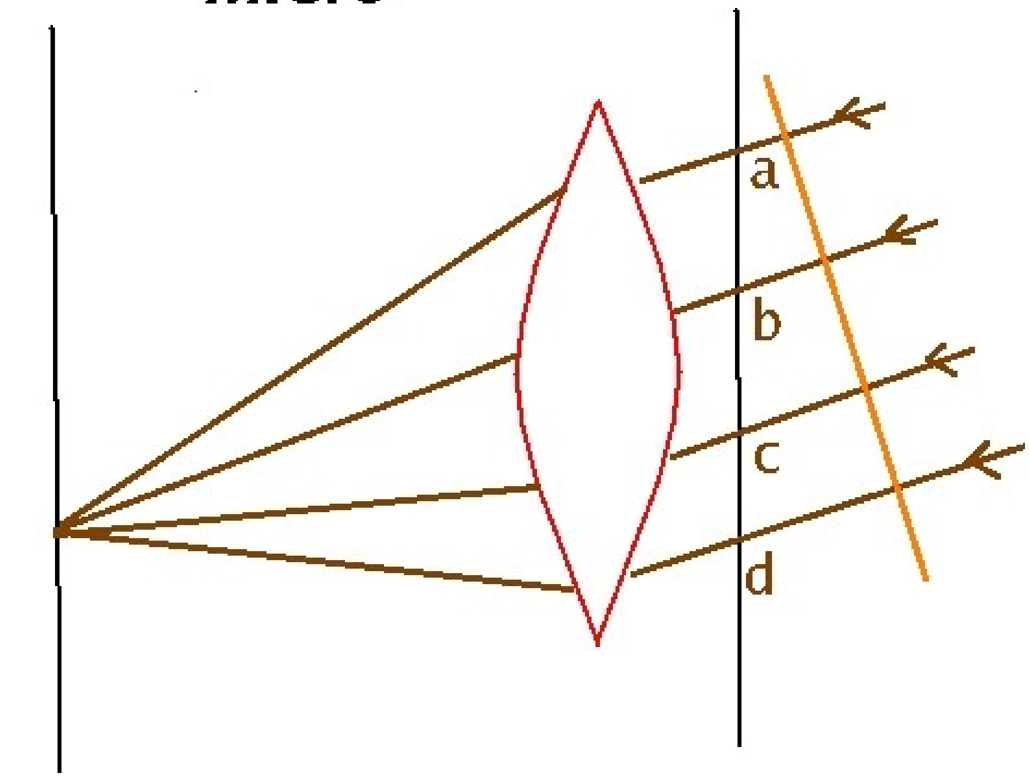




When the grating is too fine, the modulation is not transferred! The angle subtended by the lens is the vital parameter

Images are made of correlations: Abbe, Zernike, Michelson....

All ***tele/micro scopes are interferometers***



$$E = a + b\,e^{-i\phi} + c\,e^{-2i\phi} + d\,e^{-3i\phi}$$

= *Fourier transform of input field*

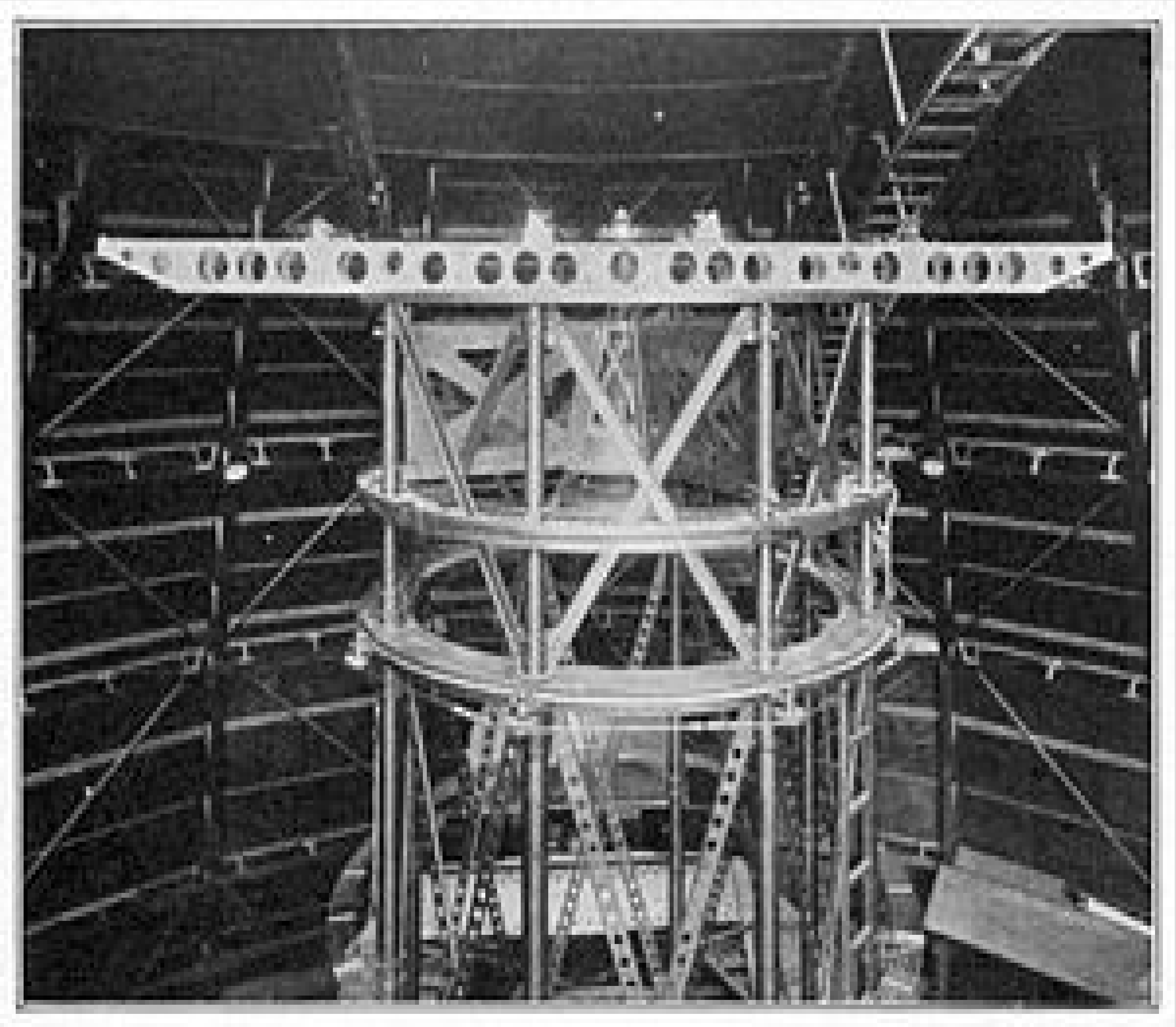
$$I = |E|^2 = a\,a^* + b\,b^* + \ldots\ldots\ldots$$

$$+\, a\,b^*\,e^{i\phi} + a\,c^*\,e^{2i\phi} + \ldots\ldots\ldots$$

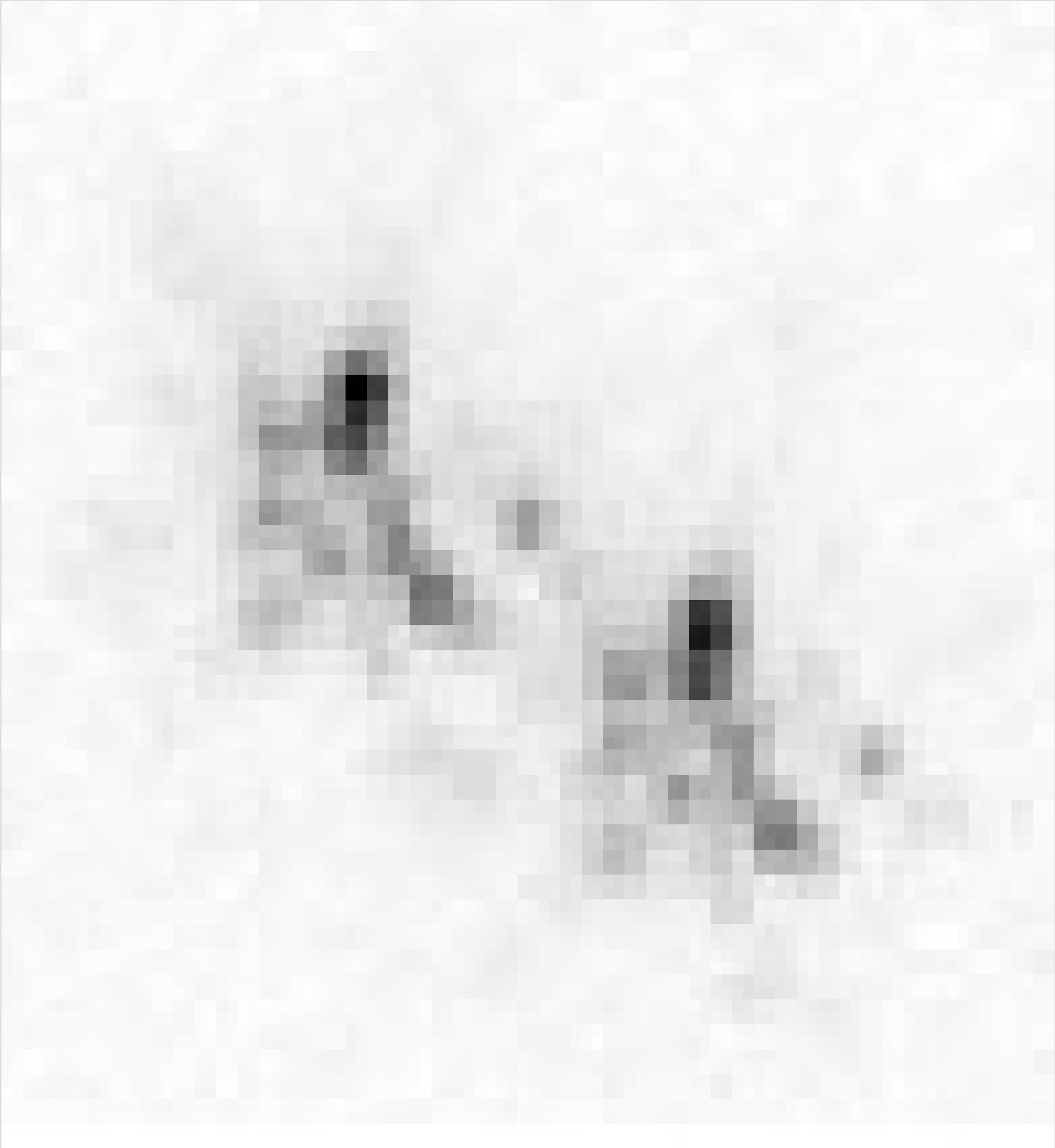
$$+\, b\,d^*\,e^{2i\phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

Fourier transform of input correlations

Michelson and his stellar interferomenter



Short exposure of Zeta Bootis: the PSF of the atmosphere!



In this short exposure, all the Fourier components are present but their phases have been scrambled.

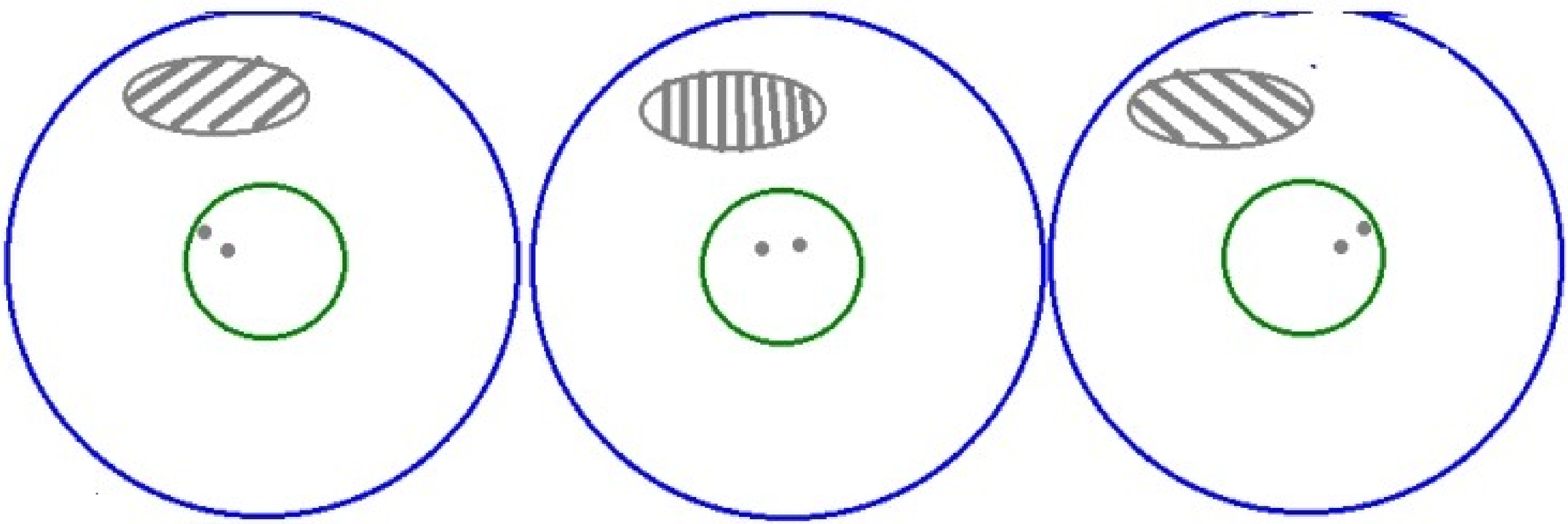
Some information about the amplitudes is present (and some phase informatiion) and this was the basis of speckle imaging
How much better to correct the errors befoe they can do so much damage

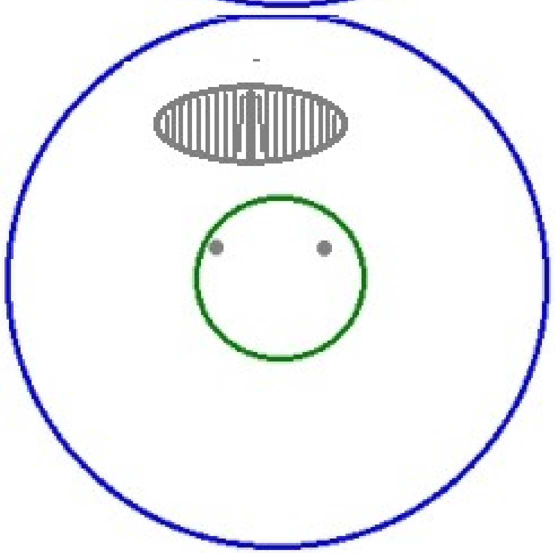
The breakthrough for radio astronomy

M.Ryle, Cambridge, 1950's onwards proposed and implemented "Earth Rotation Aperture synthesis" which b basis of radio frequency imaging ever since

Correlations can be measured at leisure

The geometry of Earth rotation aperture synthesis.....





.....and the algebra

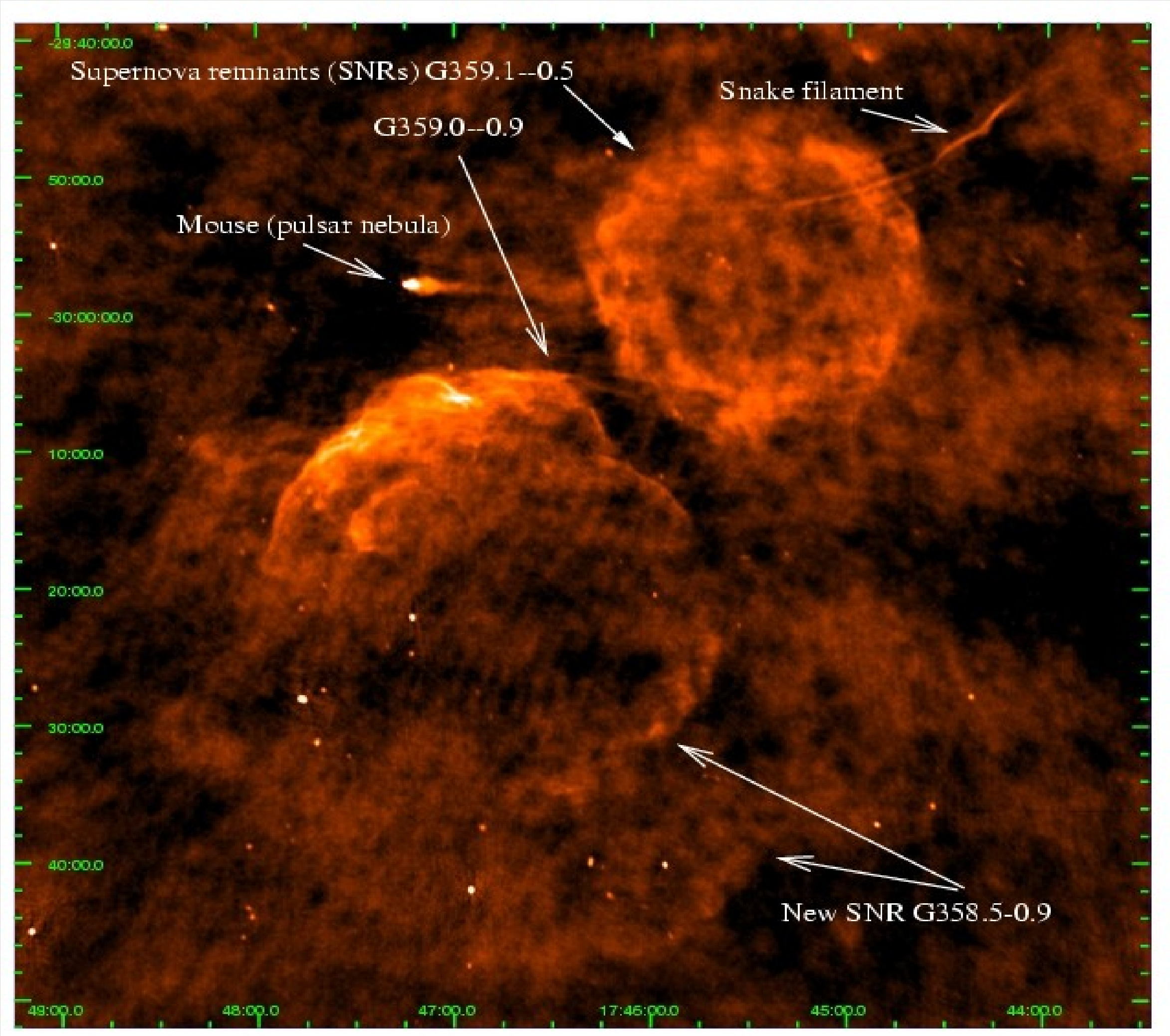
$$E(x,y) = \sum \tilde{E}(k_x,\ k_y)\ \exp\ (\ i\ (k_x x +\ k_y y)\ )$$

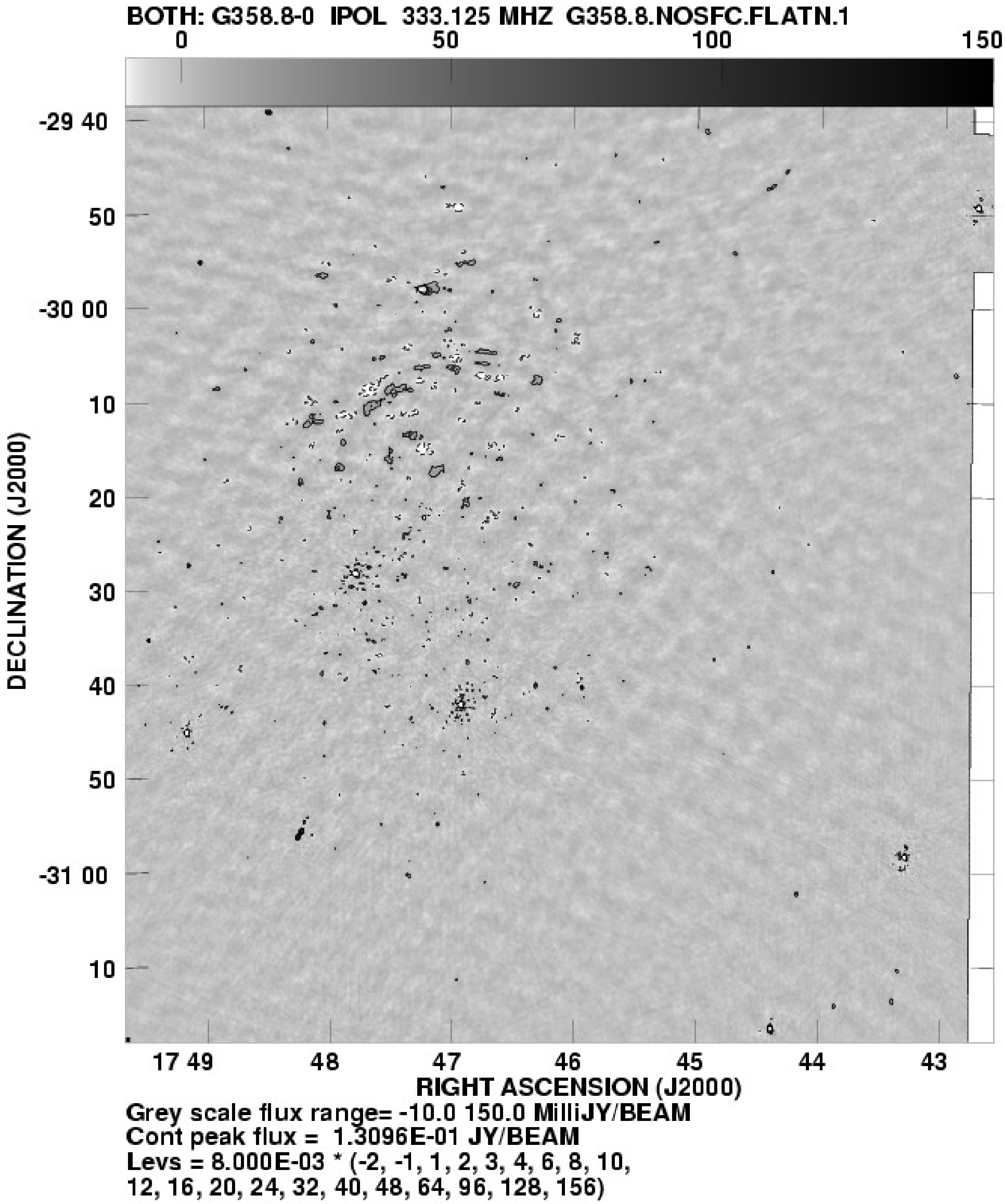
$$\left|\tilde{E}(k_x,\ k_y)\right|^2 = \quad \text{I.F.T of} \left\langle E^*(x+u,y+v)\ E(x,y)\right\rangle$$

Synthesis imaging in radio astronomy-sixties to eighties

- In the original version, telescopes were moved along a railway track to fill in the entire 'lens' by earth rotation.
- Full coverage was abandoned so the set of Fourier rcomponents has holes and the PSF looks bad but is known accurately
- The known “aberrations” corrected by 'CLEANing'
- The unknown aberrations are corrected by '*self-calibration*' – in which parameters of the effective lens are varied iteratively to get an image. This takes care of instrumental and ionospheric effects

GMRT looks near the Galactic centre:S.Roy(NCRA), S.Bhatnagar (NRAO)

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DECLINATION (J2000)
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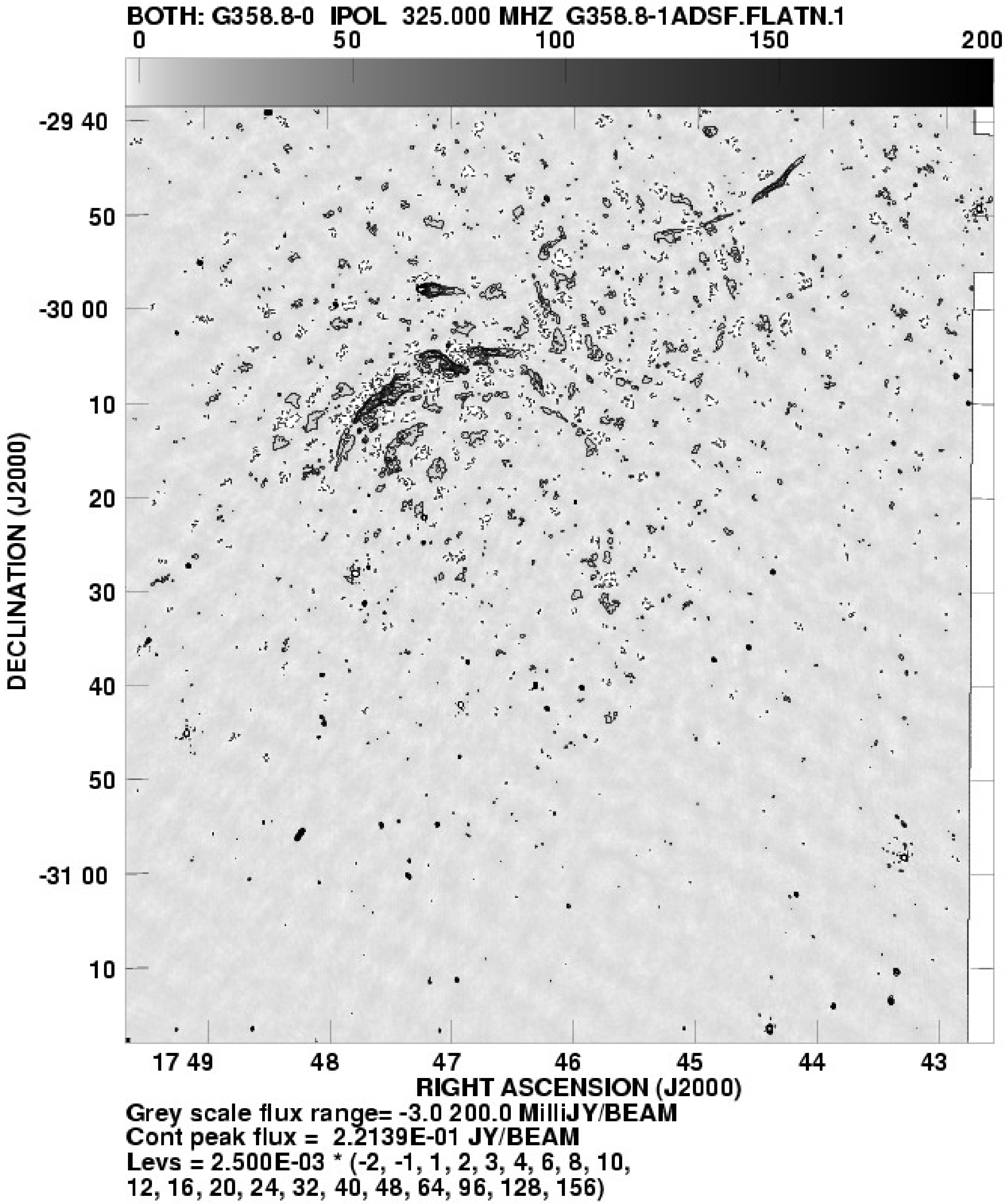
RIGHT ASCENSION (J2000)
Grey scale flux range= -10.0 150.0 MilliJY/BEAM
Cont peak flux = 1.3096E-01 JY/BEAM
Levs = 8.000E-03 * (-2, -1, 1, 2, 3, 4, 6, 8, 10,
12, 16, 20, 24, 32, 40, 48, 64, 96, 128, 156)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DECLINATION (J2000)
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RIGHT ASCENSION (J2000)
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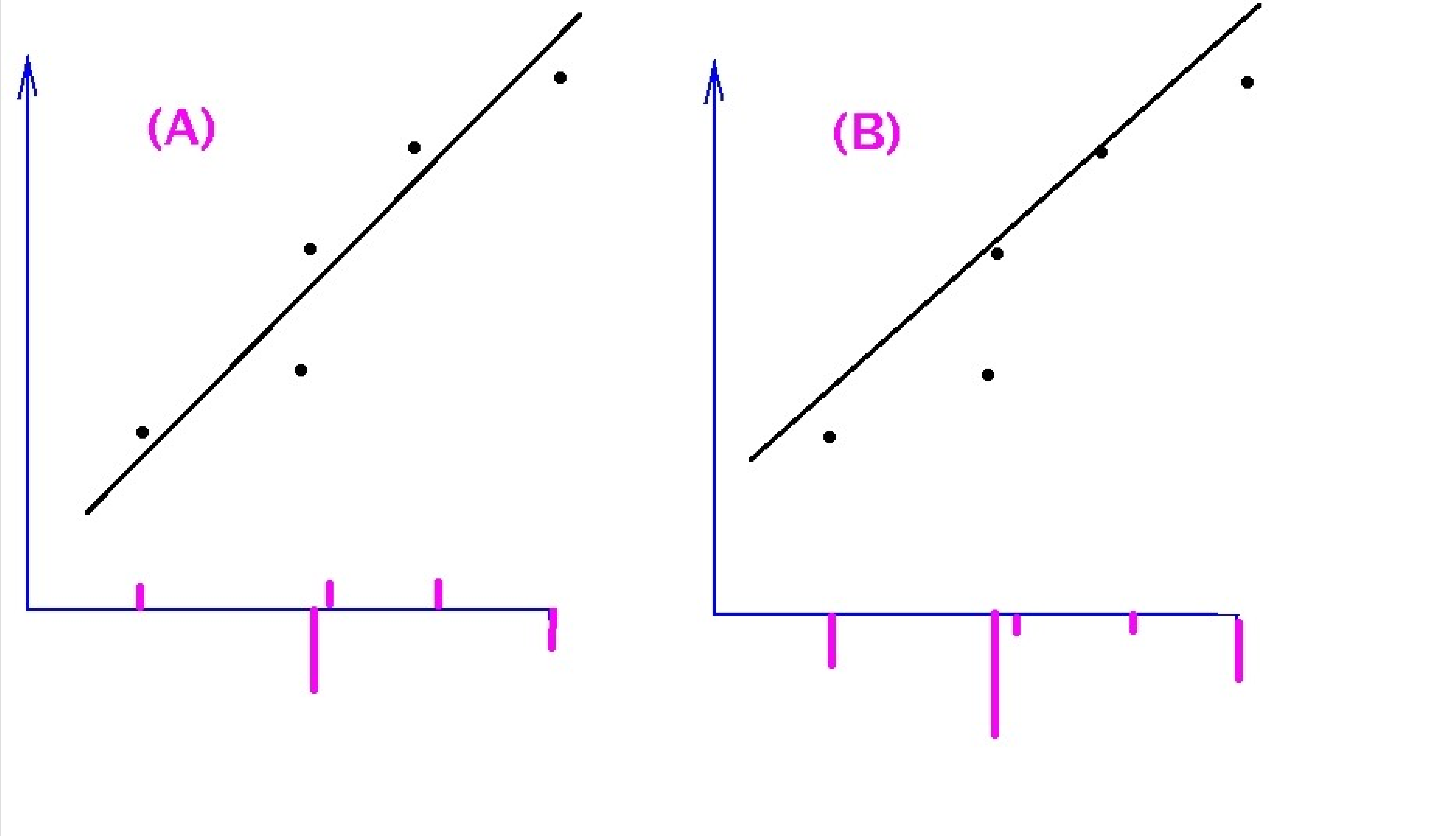
Levs = 2.500E-03 * (-2, -1, 1, 2, 3, 4, 6, 8, 10,
12, 16, 20, 24, 32, 40, 48, 64, 96, 128, 156)

Back to basics: Gauss and least squares



imaging is really inference about the object from data!

- When data is incomplete and noisy, or when one wants to squeeze the maximum out of it, we should view it in terms of a model or hypothesis being matched to the data.

- In modern imaging, a significant role is played by extra constraints (e.g chemical information in X-ray crystallography, confinement for CAT scans), and/or a model, and by statistical considerations

Real time correction in optics

- Old fashioned telescope guiding was a way of correcting the overall slope of the wavefront
- Autofocus exists in the human eye and in cameras – using   'sharpness'
- In plain vanilla AO, the model is a thin phase changing screen, whose parameters have to be solved for every few milliseconds
- But other flavours, with multiple screens, and / or multiple patches are coming on the market

Multiconjugate optics in your hands? Lytro camera

- Principle proposed and demonstrated by Ren Ng in his Stanford PhD work - started a company

- An array of lenses in front of the detector hence like an array of small telescopes
- Records inintensity as a function of position and direction – i.e data in phase space!
- Can reconstruct image in any desired plane. ***Shoot first, focus later!***

Refocusing geometric optics by recording in phase space