"Other ideas for gamma ray instruments"

Stephan LeBohec

1) Preserving the highest energies

2) Other utilizations of low energy ACT arrays

Toward the future of very-high energy gamma ray astronomy
KIPAC November 8th 2007

New "Hot" Topics that came up since the 1st Palaiseau Workshop 1992 [?]

* AGN -> low energy ?
* EBL -> low energy ?
* Galaxy cluster shocks and haloes
* Super-symmetric dark matter -> low energy ?
* Predominant role of IC

New "Hot" Topics that came up with the present generation ACT observatory (~2003)

* All we wished for: SNRs, PWNs, Binaries, AGNs & fast variability, non blazar galaxies, dark accelerators,...

  1) Not the product of a threshold reduction.

  2) Will E<100GeV provide info on these objects that is not available at few 100GeV?

* Correlation UHECR % nearby AGN (tomorrow in Science)

* Ice cube coming on line, km3net starting up

So, what about staying at a **few 100GeV** (300-500GeV)?

& improve **sensitivity**

& improve **highest energies coverage**

Benefits associated with extending our coverage at higher E

* Required Mechanics/optics on smaller scales (experience, easier, cheaper)

* E>10TeV astronomy now is a viable discipline-> Science output guarantied

* More electron synchrotron cooling
    -> Compact object variability recovered at high energy
    -> Morphology%Energy relation as in HESS J1825-137

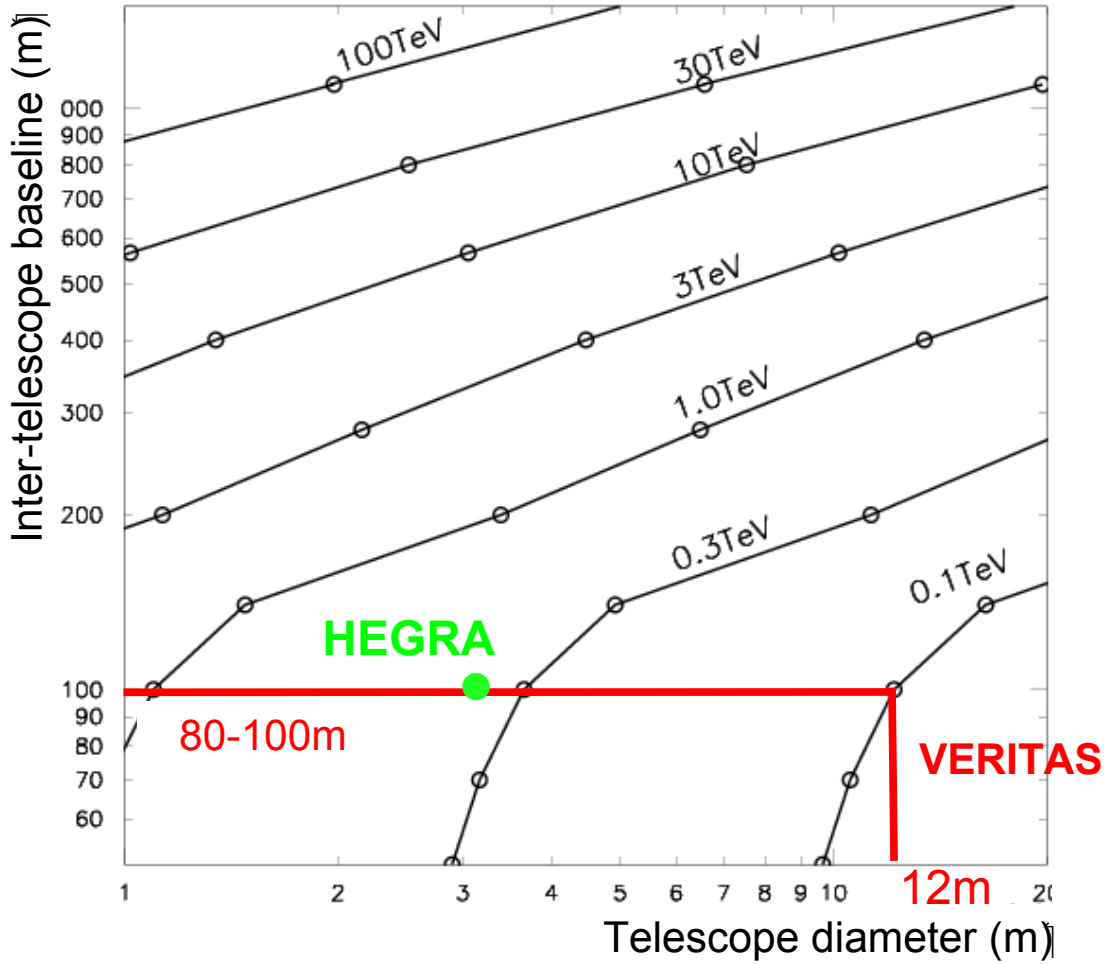
* Increased Hadron Larmor radius
    ->Morphology%Energy inverted compared to electron

* More Klein Nishina suppression
    -> Hadron/Electron discrimination from spectral profiles

* 100TeV gamma from knee energy CR
    -> Chance to address the origin of the knee (CR acceleration and propagat.)

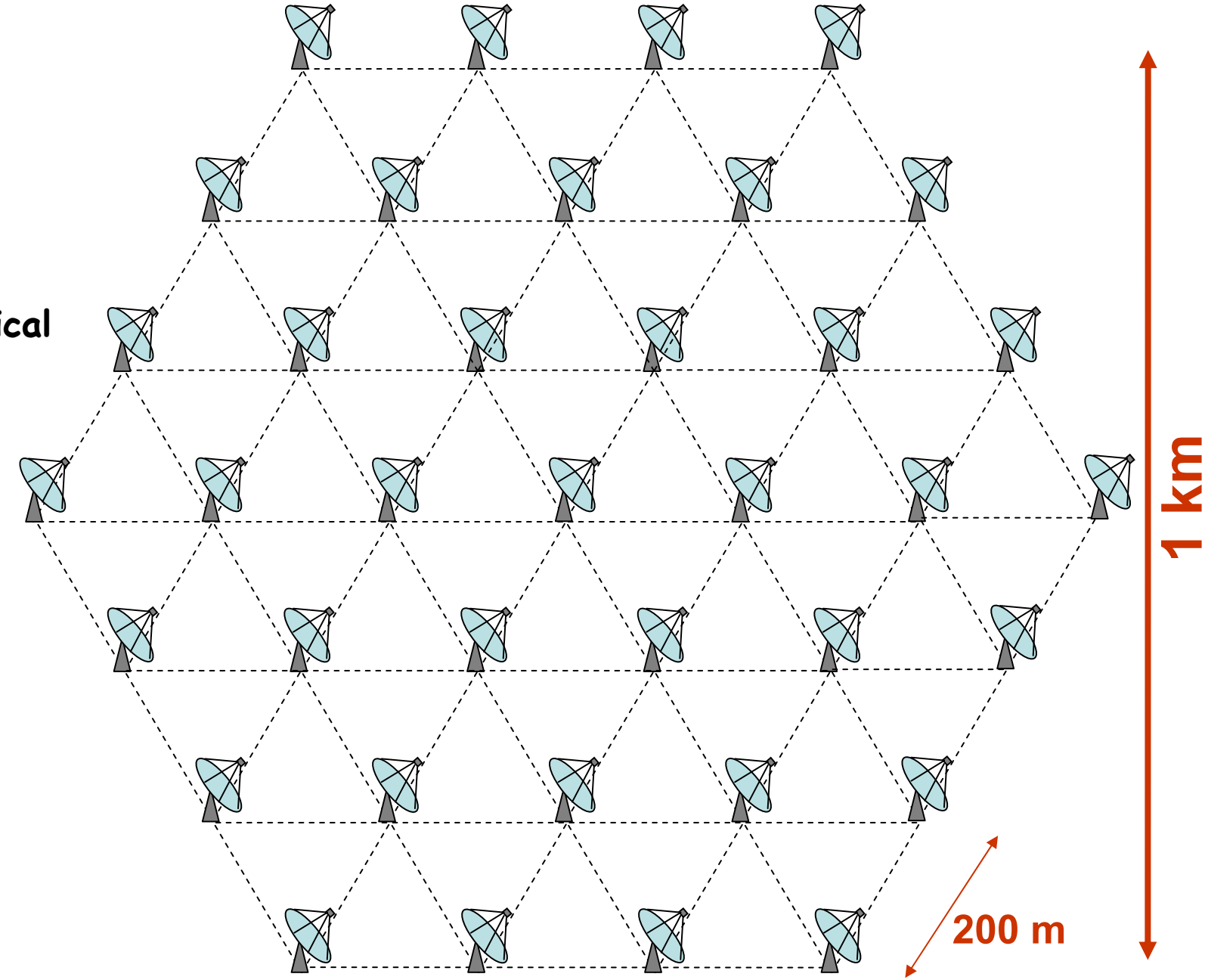
* >10TeV gamma ray astronomy = higher angular resolution

What is required for what threshold?



<u>Note</u>: Can not save money by spacing telescope much more than ~150m while preserving a given threshold.

Gamma
Ray
Astrophysical
Telescope
Imaging
System

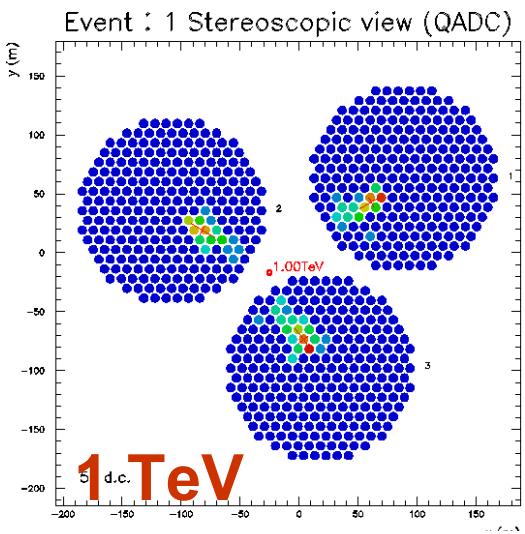


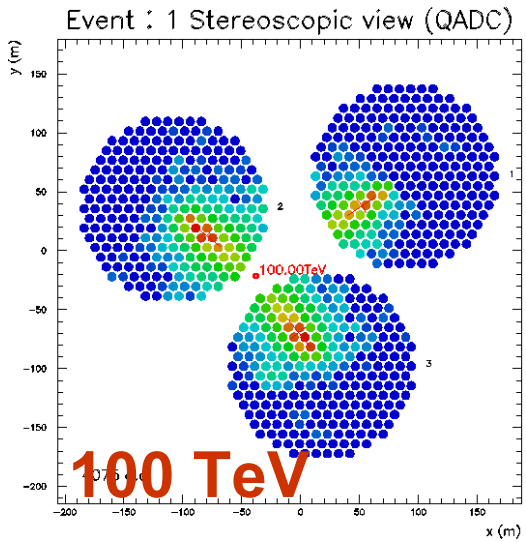
37 Telescopes → 54 Triangles → ~1km^2

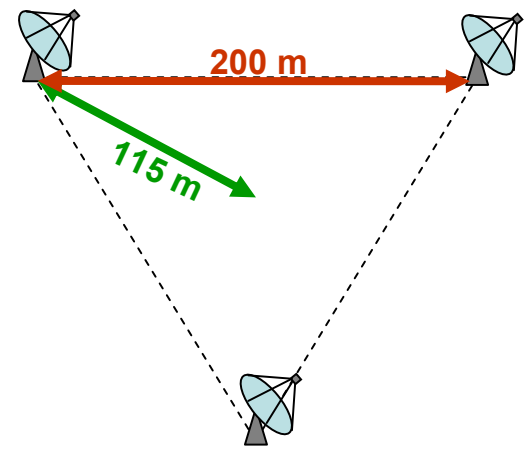
Mirror: Ø5.4 m
60 facets of Ø60 cm
Focal: 6 m

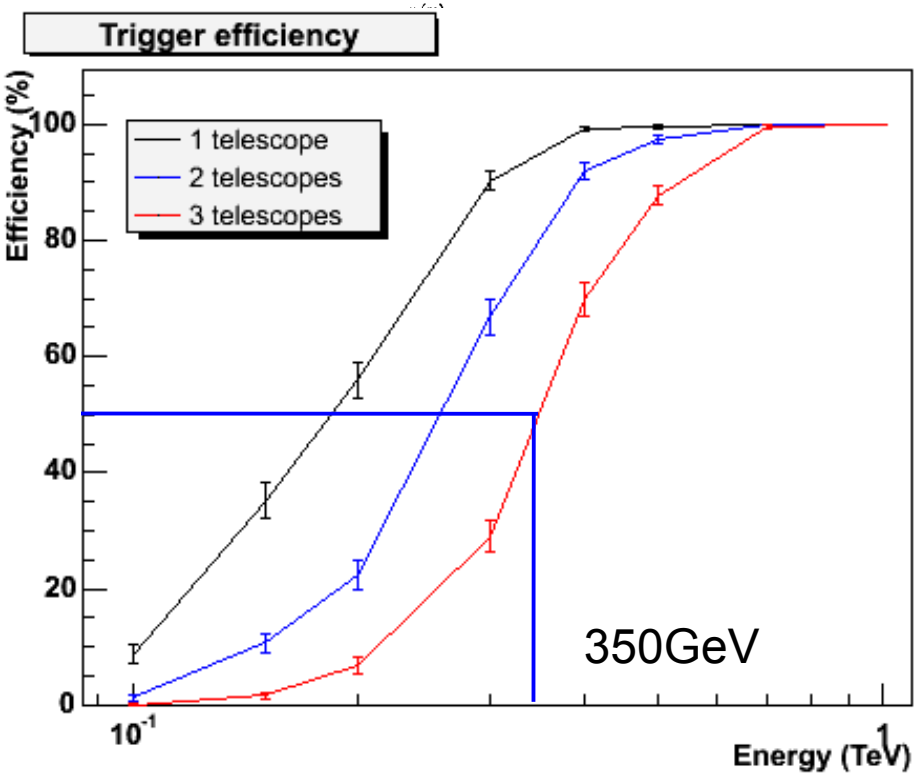
Camera: FOV = 4°
253 pixels of 0.25°

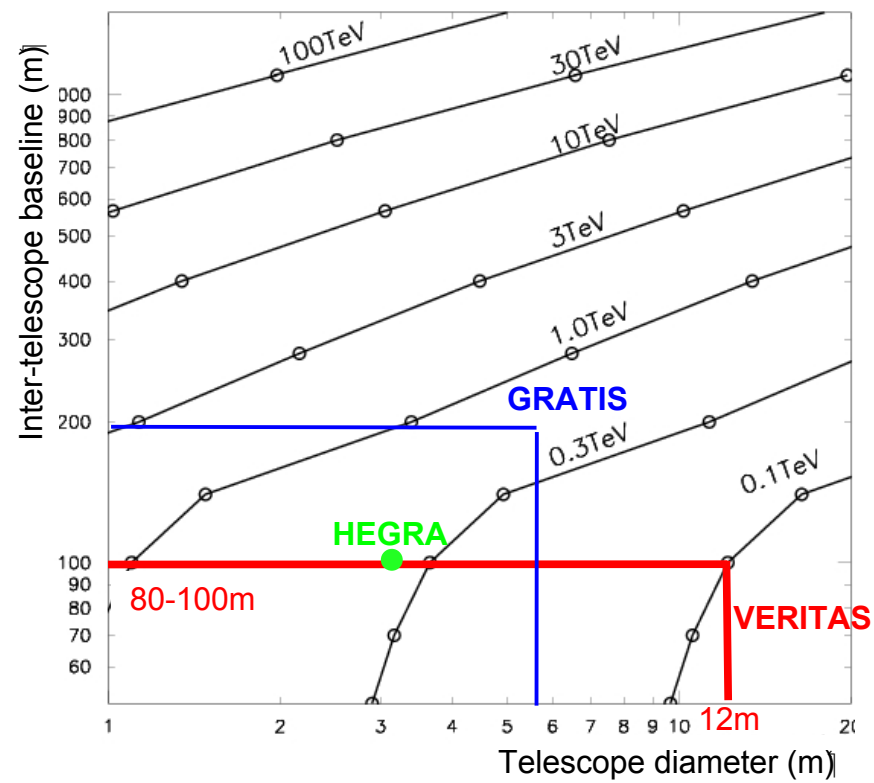
Electronics:
Whipple 10m telescope,
thresholds at same S/N





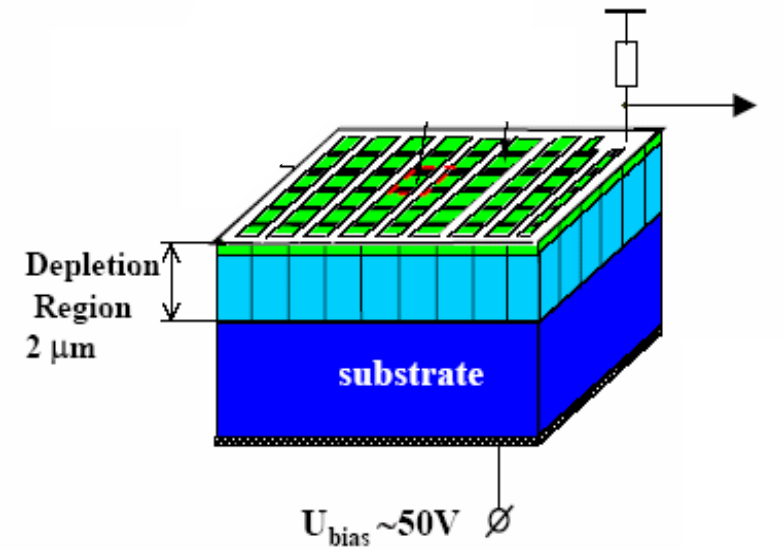


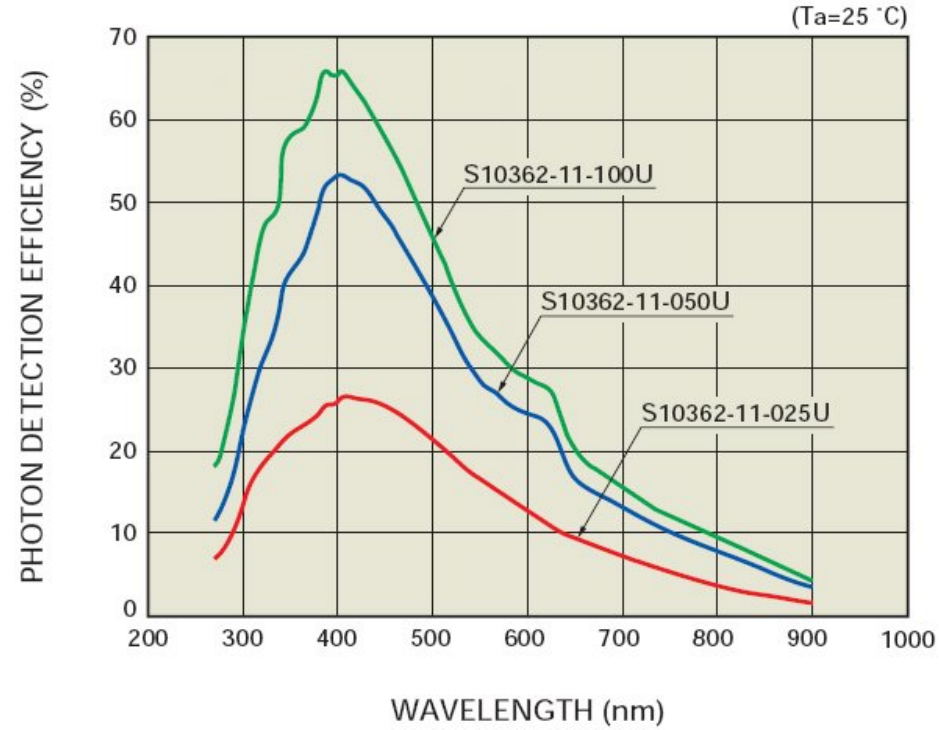




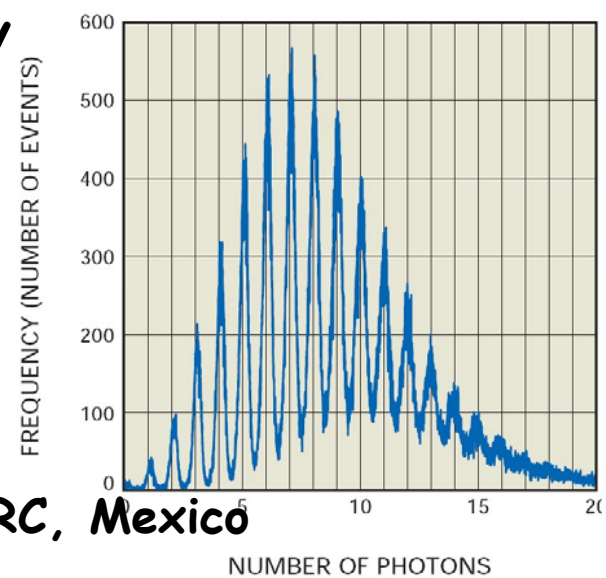
	Item	One Off	Per Item	Required	Per Scope	Explanation
	Software + Licences	£10,000				
	Peripherals	$10,000				Mirror Alignment System
	Mirror Setup	$82,000				Upgrading existing mirror coating system
	Mirrors		$765	60	$45,900	VERITAS Costs
	Mirror Mounts		$140	60	$8,400	
	Positioner		$30,000	1	$30,000	Allan Telescope Array Costs
	OSS		$10,000	1	$10,000	Guess
PMT	PMTs + Bases		$300	253	$75,900	VERITAS Costs
PMT	HV Crate		$10,000	1	$10,000	VERITAS Costs
PMT	HV 48 Channel Module		$4,000	6	$24,000	VERITAS Costs
Focal Plane	Focus Box Mechanical		$10,000	1	$10,000	VERITAS Costs / 4
Focal Plane	Components and Connectors		$18,000	1	$18,000	VERITAS Costs
Focal Plane	Light Cones		$50	253	$12,650	VERITAS Costs
Focal Plane	Current Monitor Electronics		$690	8	$5,520	VERITAS Costs
Focal Plane	PreAmps		$50	253	$12,650	VERITAS Costs
Focal Plane	PreAmp Power Supply and Comms		$2,700	1	$2,700	
Front End	ADCs		$125	253	$31,625	CAEN V792AA (32 ch ECL/LVDS)
Trigger	Discriminators		$100	253	$25,300	CAEN Guess
	Delay/Signal Splitting Cable		$50	253	$12,650	Guess
Trigger	Coincidence Module		$5,000	1	$5,000	Homemade ? Guess
Front End/Trigger	Crate		$7,000	1	$7,000	VERITAS Costs
Front End/Trigger	Controller		$4,000	1	$4,000	VERITAS Costs
Trigger	GPS		$4,000	1	$4,000	VERITAS Costs
	Cables and Connectors		$15,000	1	$15,000	Scaled Estimate from VERITAS
Callibration	Fast LED Pulser		$50	1	$50	Sheffield ANTARES pulser, Guess
Computing	Array Control PCs	$20,000				
		£122,000			**$370,345**	
Nbr of Scopes					37	
					$13,824,765	
Facilities	Fac + Project Office (VERITAS)	$3,500,000				VERITAS costs only.
TOTAL					**$17,324,765**	

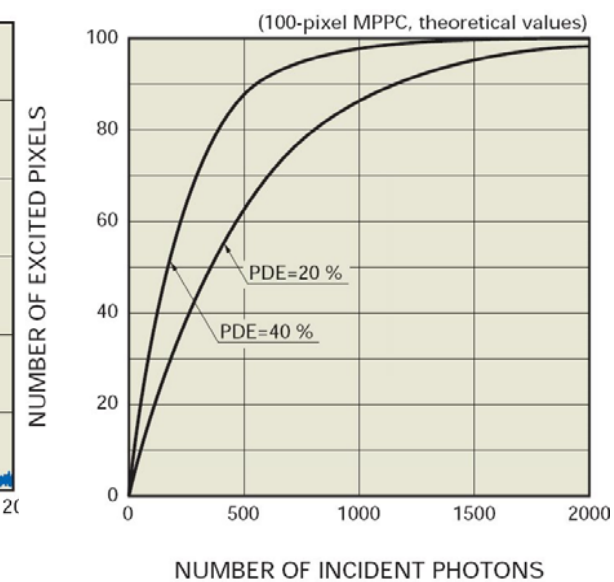
Multi-Pixel Photon Counter (MPPC)
Geiger Avalanche Photo-Diode (G-APD)





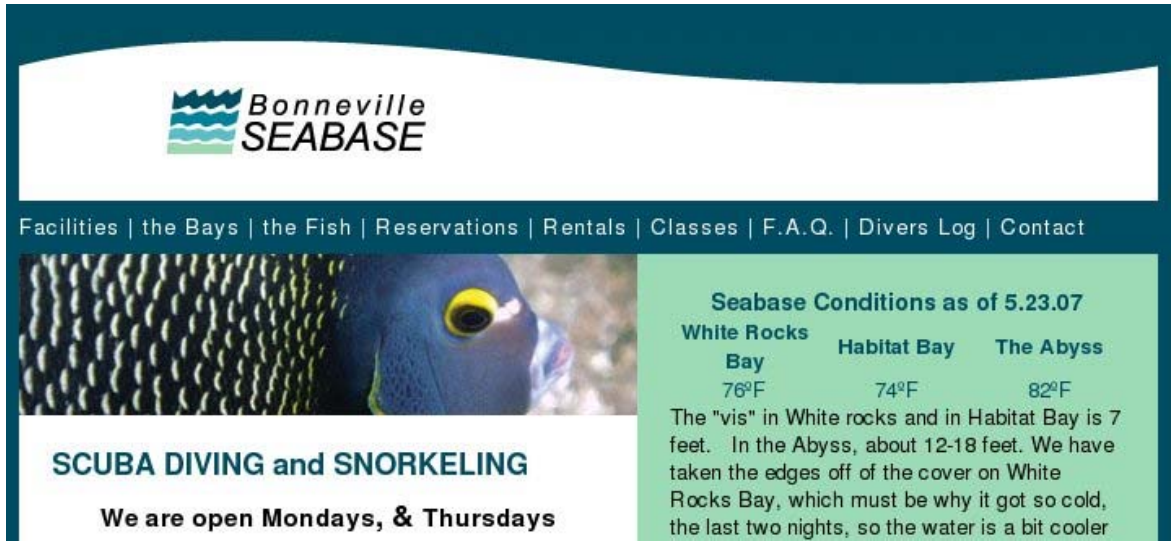
- Small size (<5mm)
- Temperature sensitivity (2.5%/degree)
+ 60%Photo-detection efficiency
+ High internal gain (10^5-10^6)
+ Small excess noise

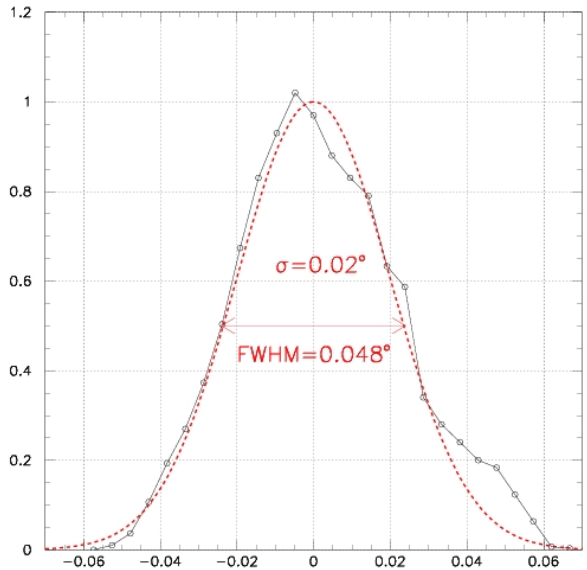


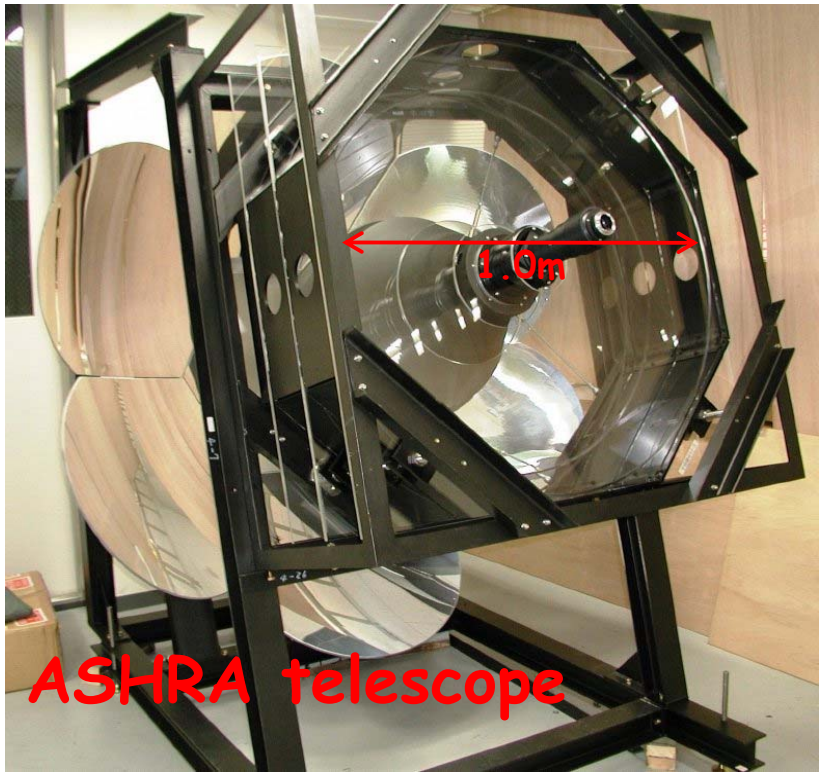


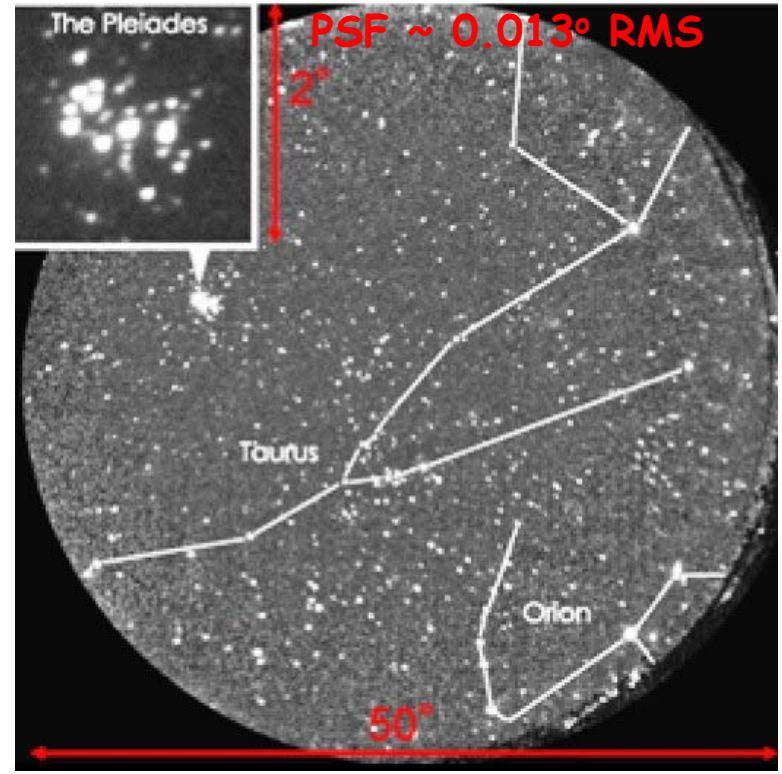
A. Nepomuke Otte, 2007, 30th ICRC, Mexico

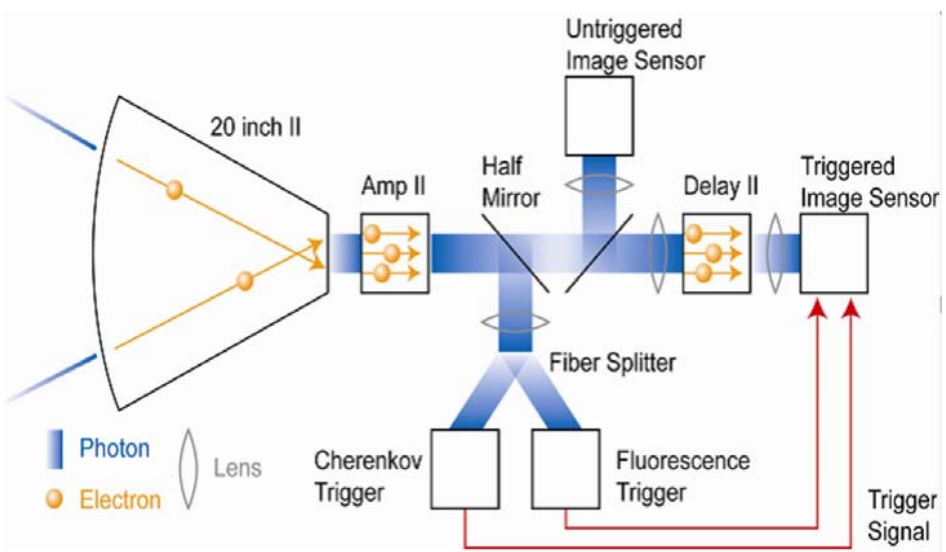
So it might be possible to use even smaller telescopes and still be at ~300GeV

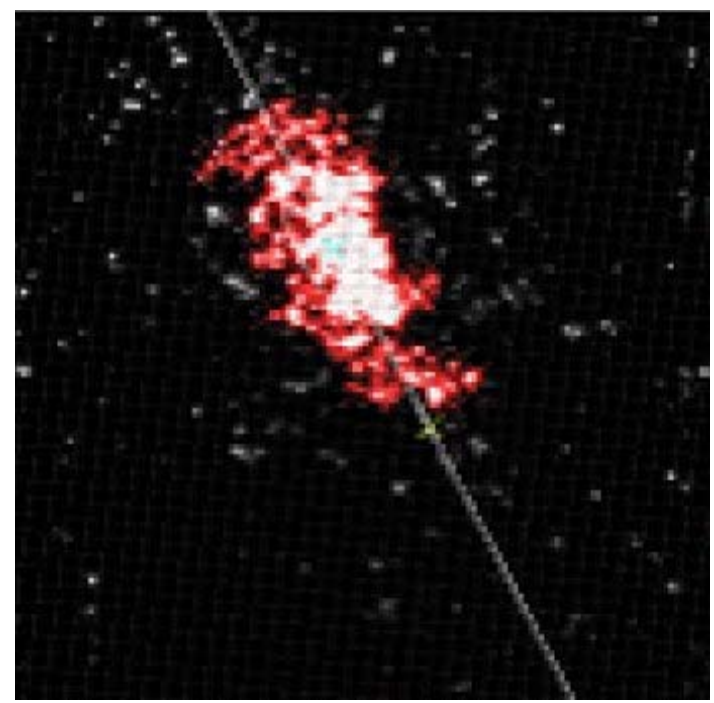




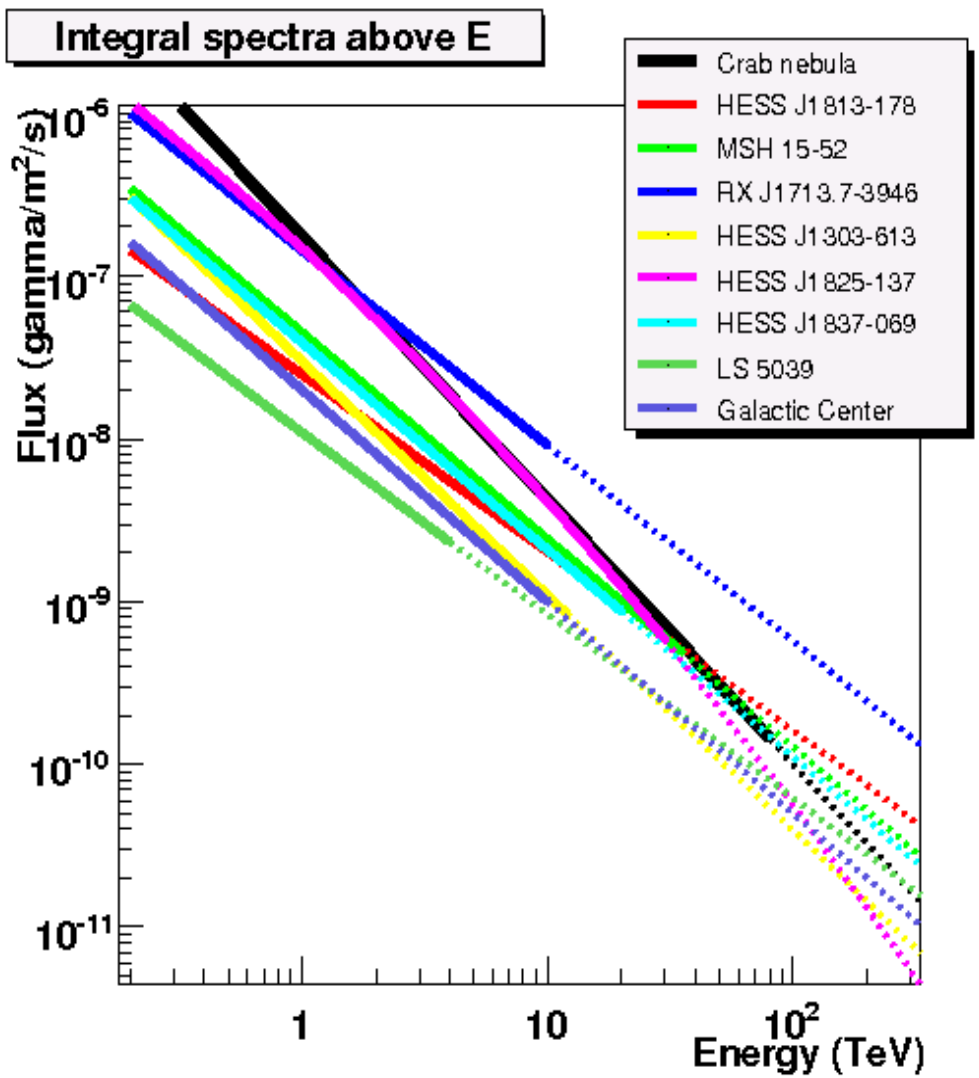

1.0m
ASHRA telescope

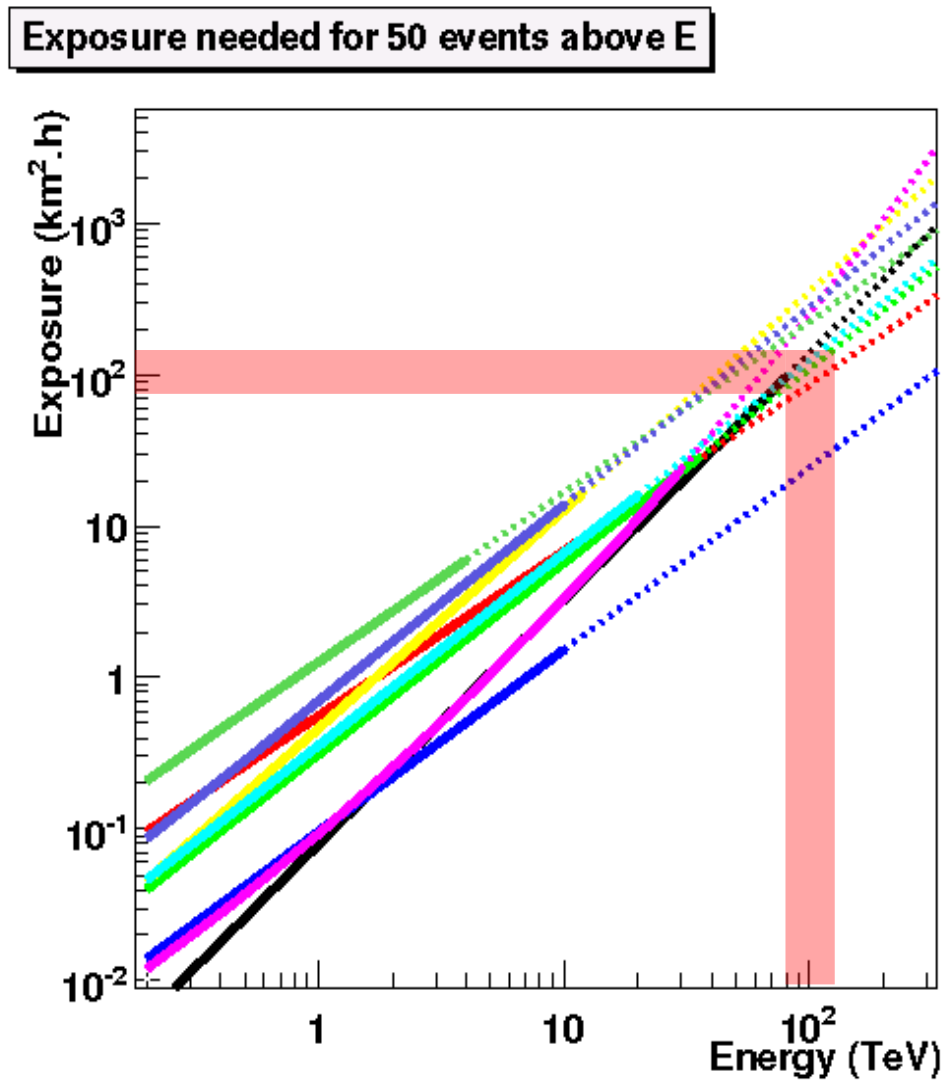

The Pleiades
PSF ~ 0.013° RMS
2°
Taurus
Orion
50°


Untriggered
Image Sensor
20 inch II
Amp II
Half
Mirror
Delay II
Triggered
Image Sensor
Fiber Splitter
Photon
Electron
Lens
Cherenkov
Trigger
Fluorescence
Trigger
Trigger
Signal



Necessary exposure for a 100TeV astronomy:

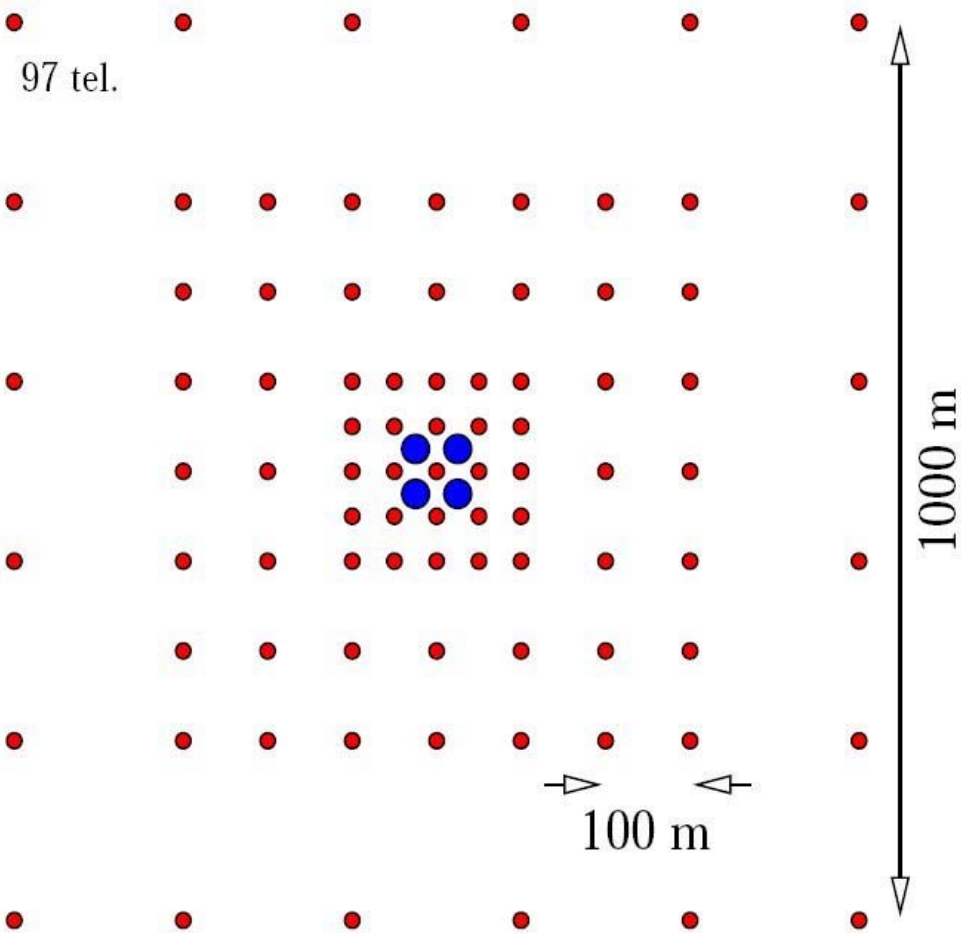




100 km²h ~ 10km² x 10h -> 100$M

Other things we could do with
a large array ($1km^2$)
of large telescopes ($100m^2$):

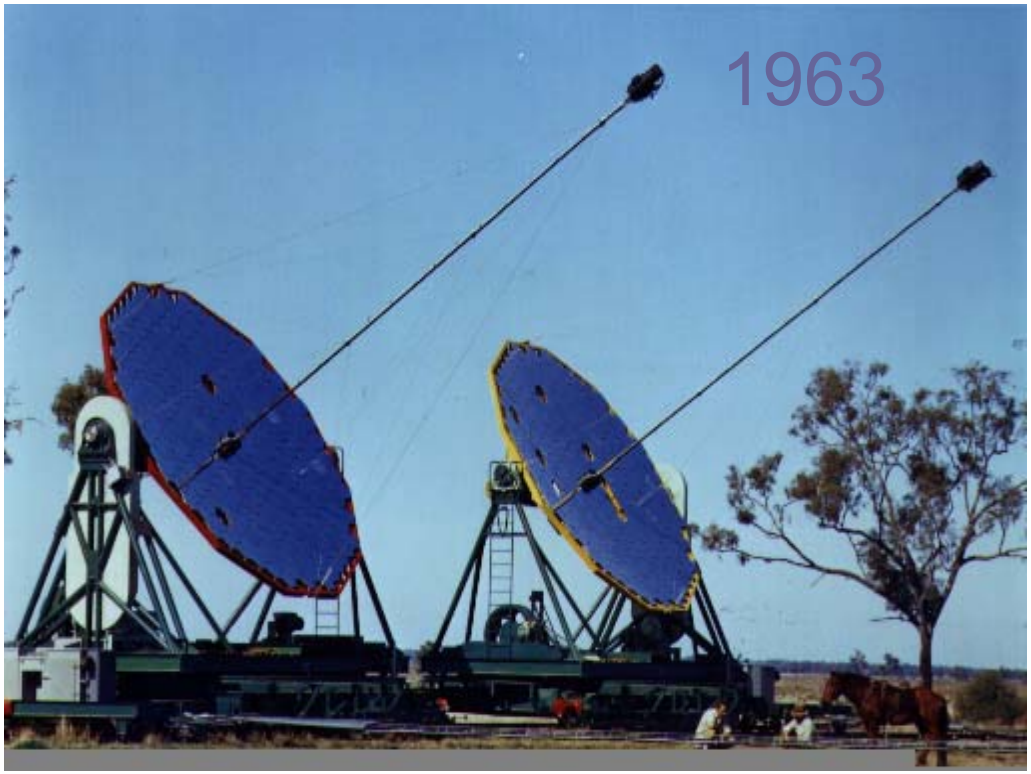
Possible implementation of CTA:



97 x 100m^2 telescopes
equivalent to a
single 111m telescope!
PSF ~ 0.05°
-> magnitude 10

* in a 1m^2 telescope:
->2x10^{6}s^{-1} photons
* in CTA:
->2x10^{10}s^{-1} photons

Intensity Interferometry with Air Cherenkov Telscope Arrays



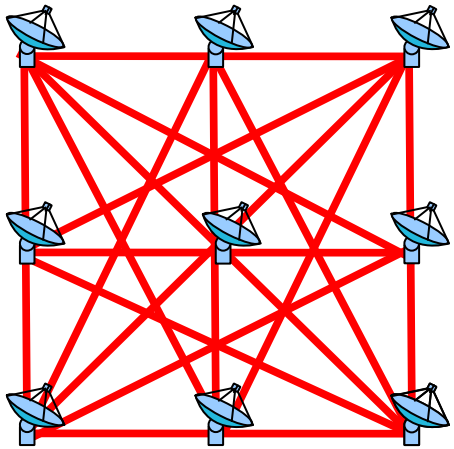
and modern signal processing technology!

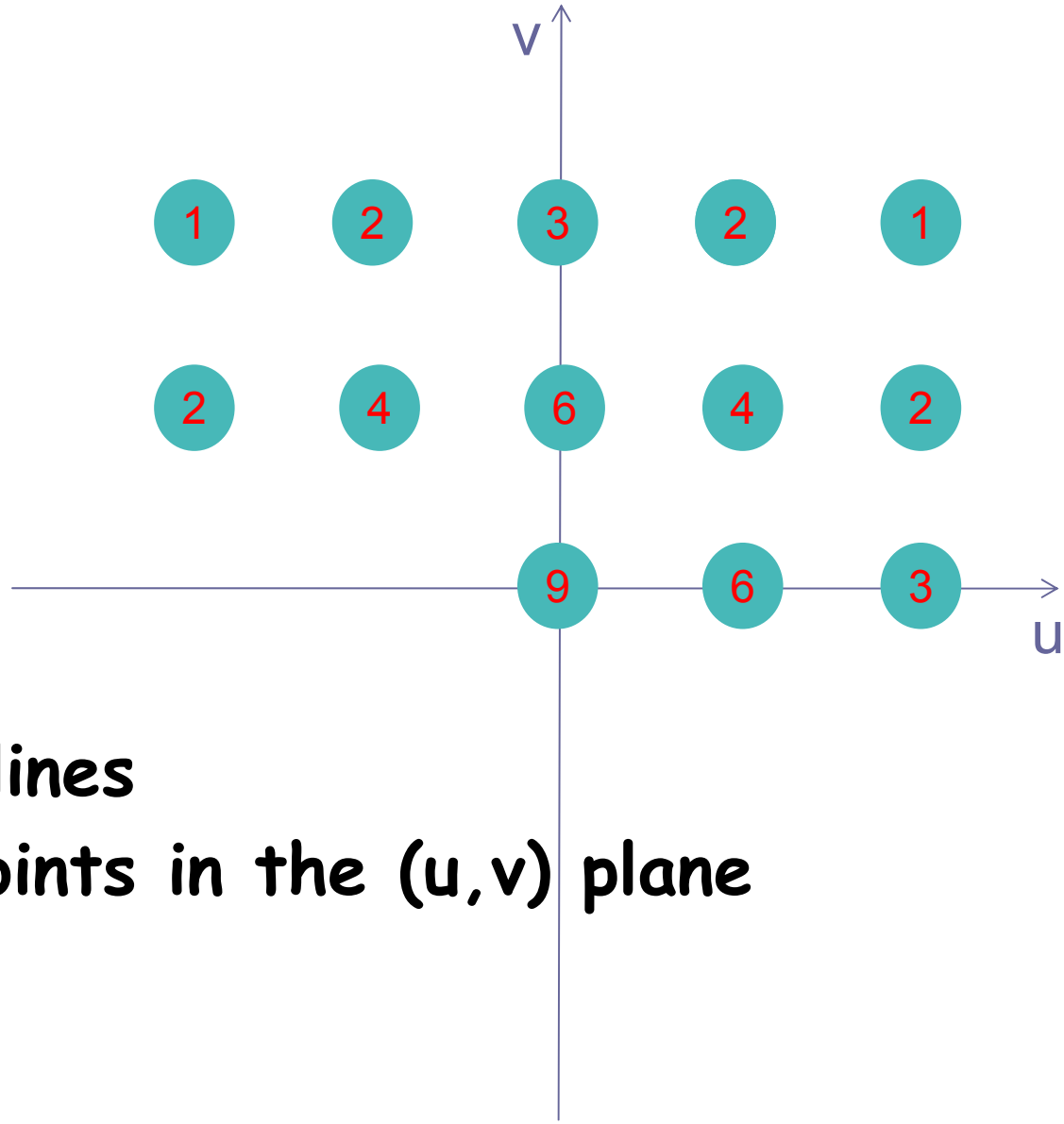
Inter-telescope intensity fluctuation correlation

->Squared magnitude of the Fourier transform

of the source luminosity distribution

The interferometric (u,v) plane



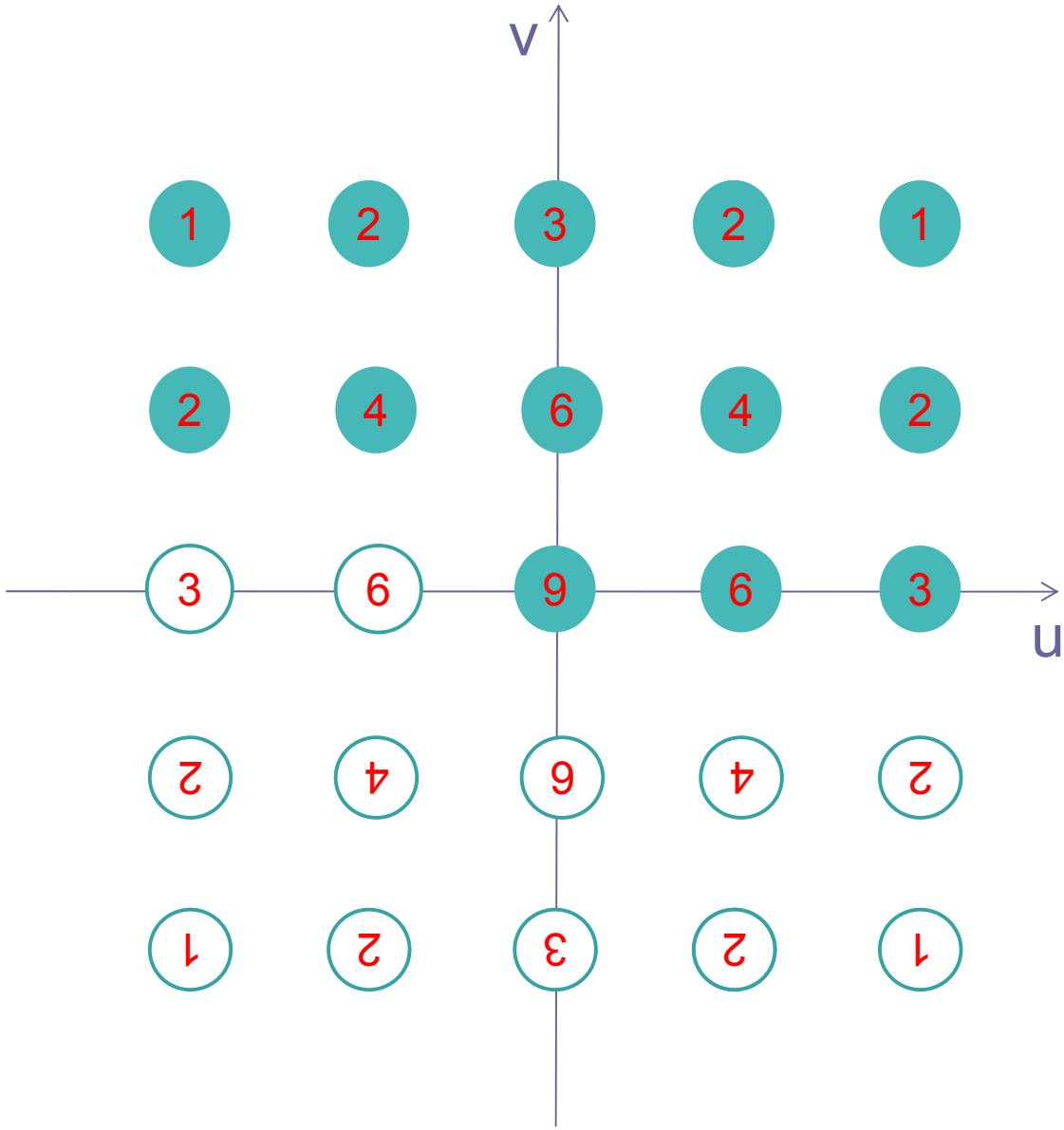


From 9x8/2=36 baselines

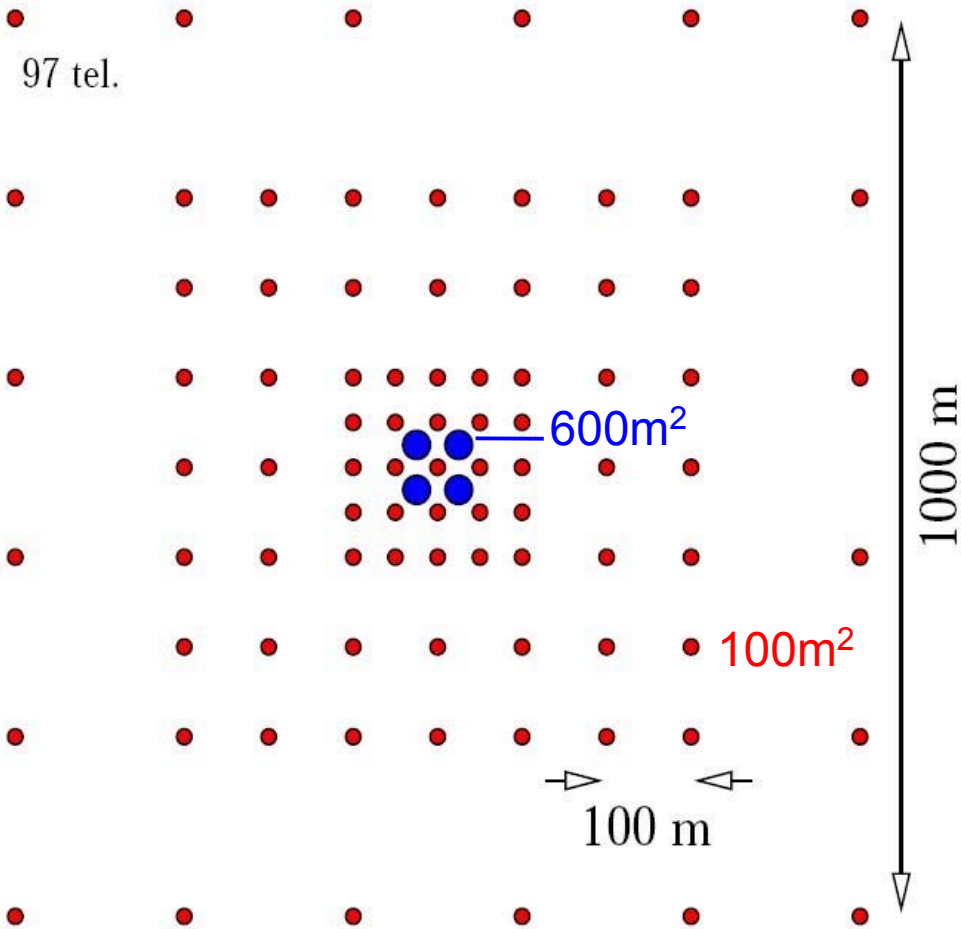
we are down to 13 points in the (u,v) plane

The interferometric (u,v) plane

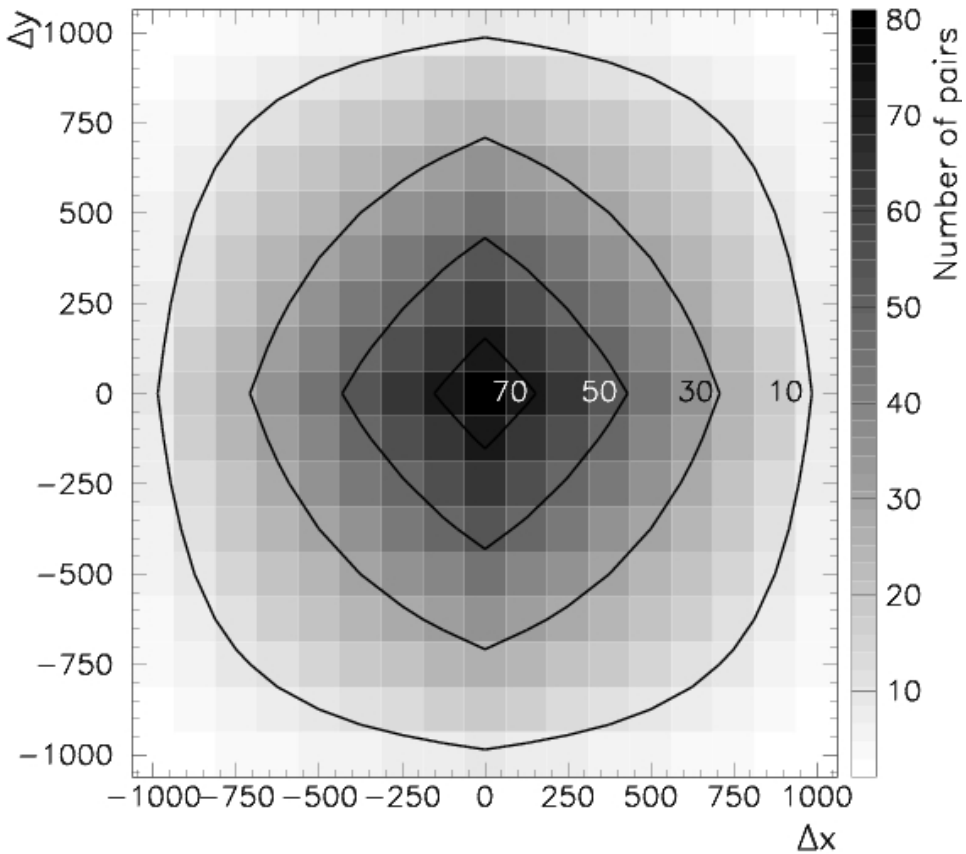
Magnitude of the Fourier transform of a real image is center symmetric

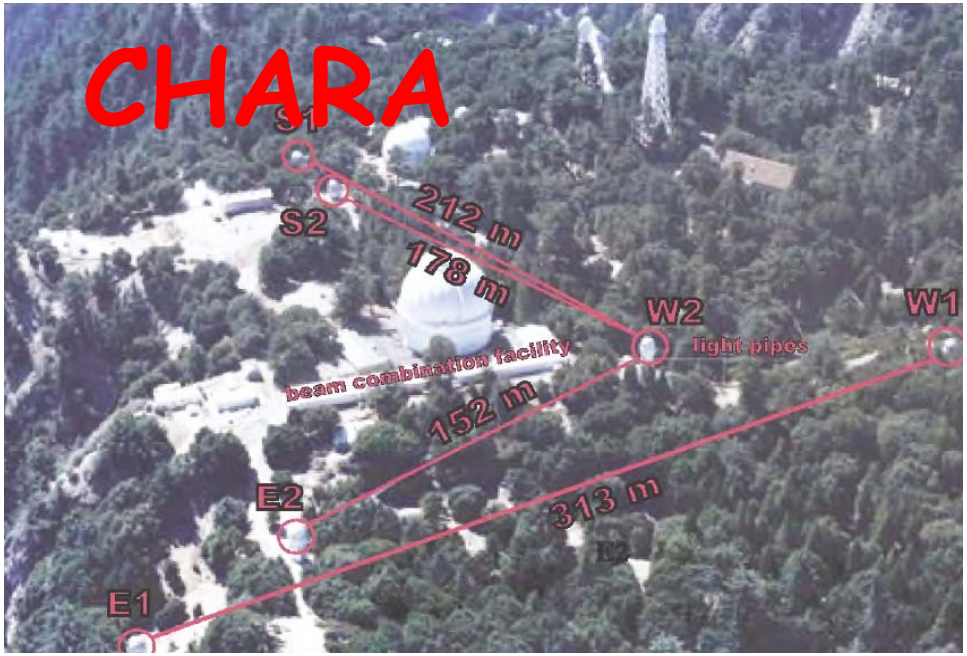


CTA configuration



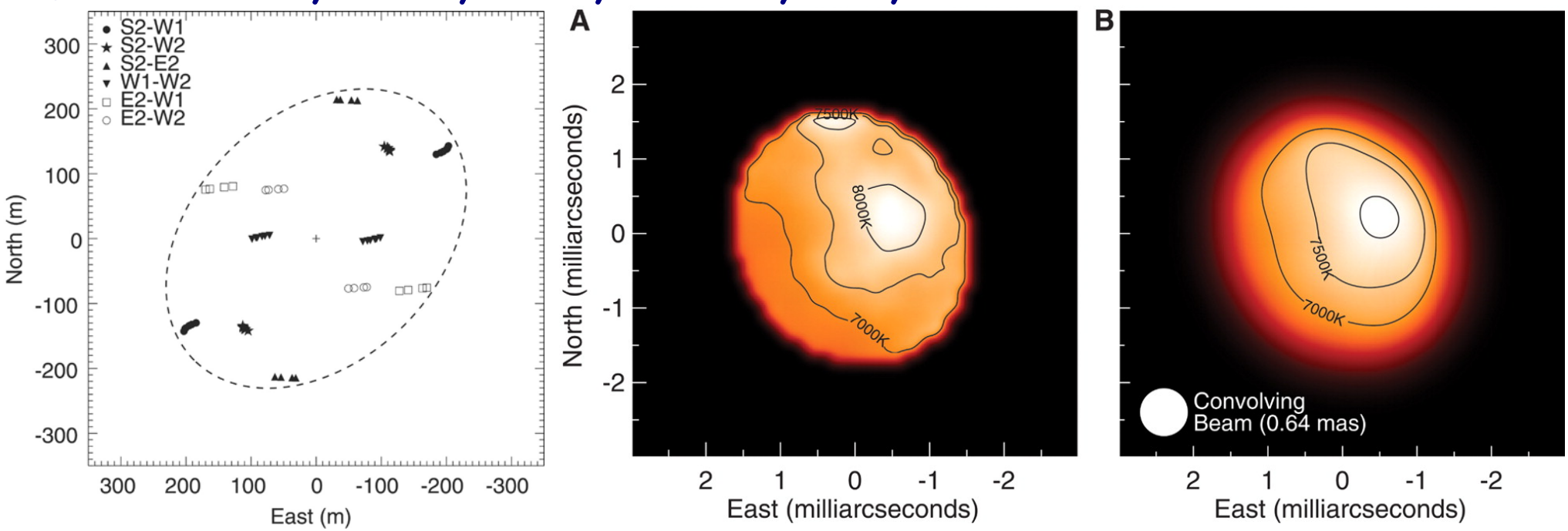
4656 baselines !



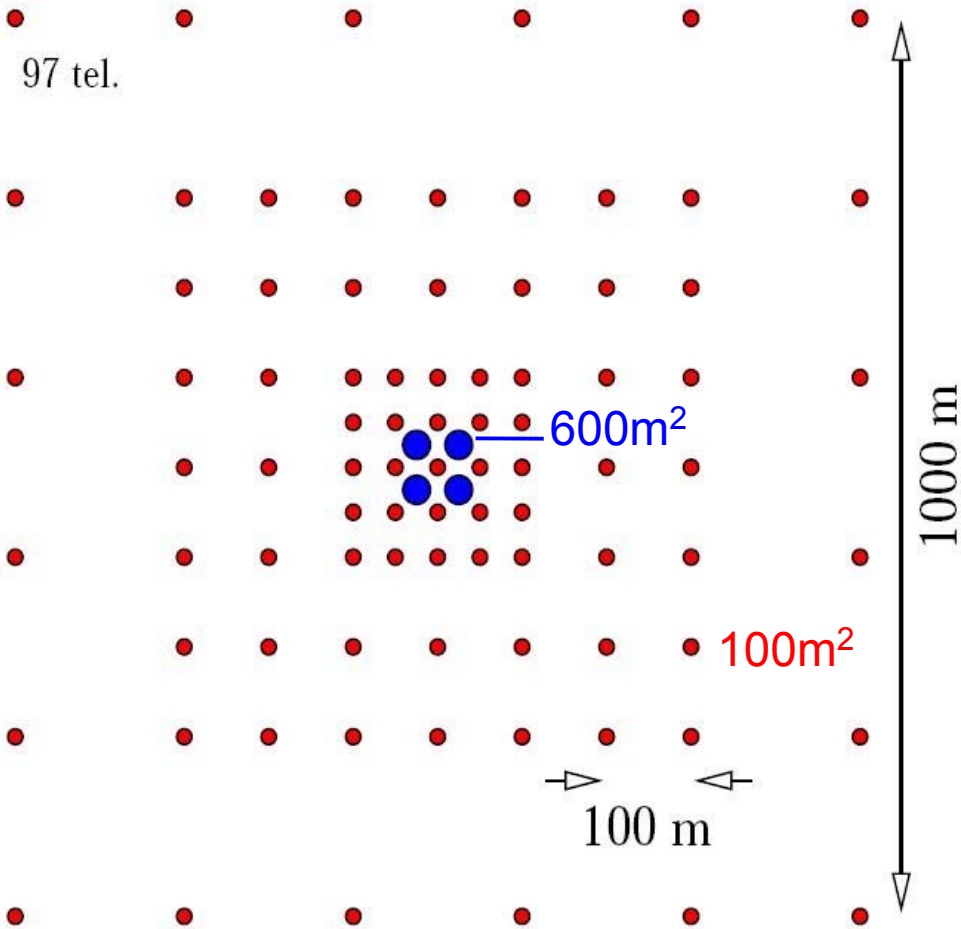


"Imaging the surface of Altair"

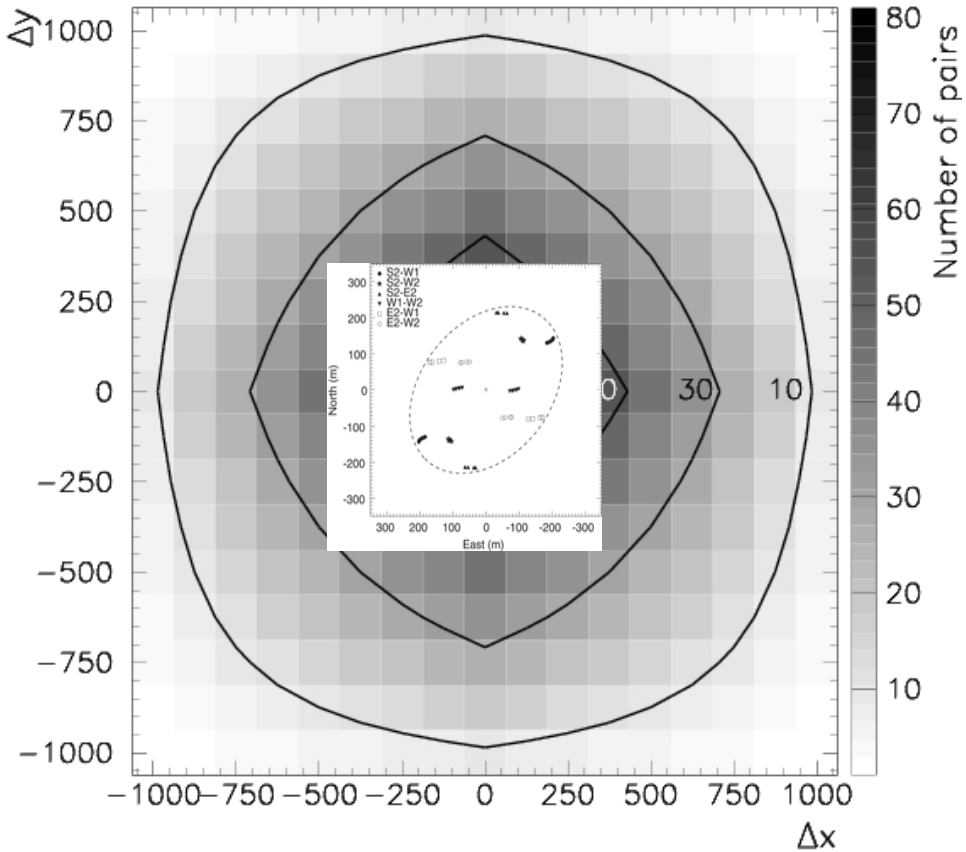
J.D. Monnier, et al., 2007, Science, 317, 342.



CTA configuration

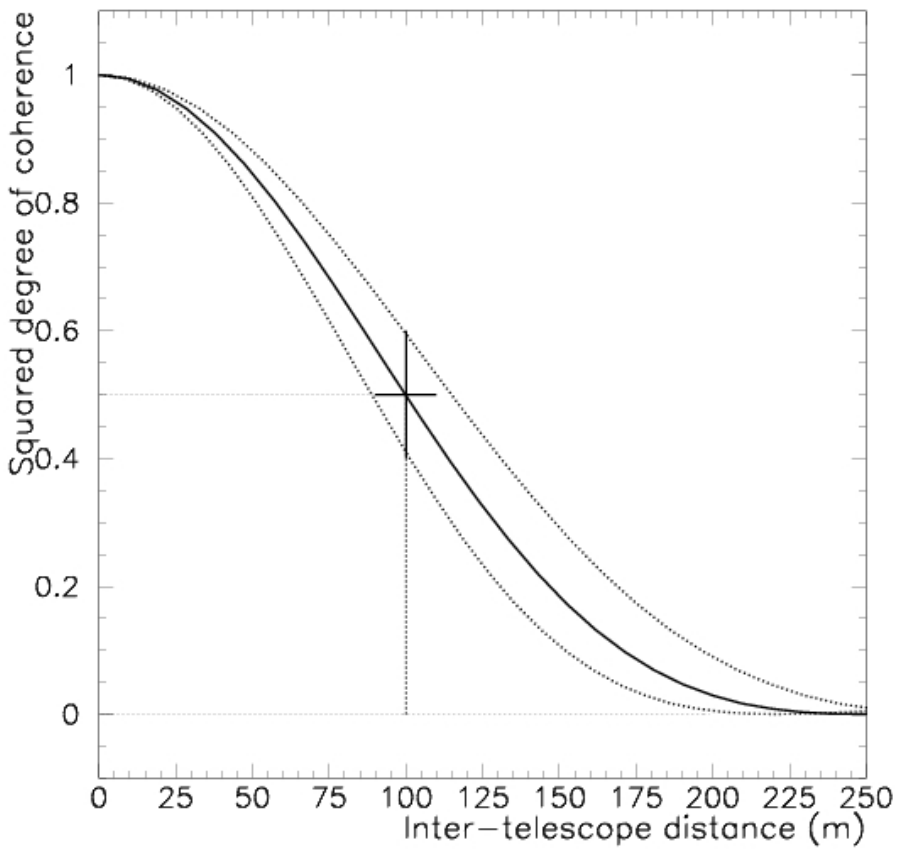


4656 baselines



Sensitivity and telescope design

$$(S/N)_{RMS} = A \cdot \alpha \cdot n \cdot |\gamma|^2 \sqrt{\Delta f \cdot T/2}$$



A=100m^2

α=30%

Δf=1GHz not with Davis-Cotton optics

T=5 hours

S/N=5

⇩

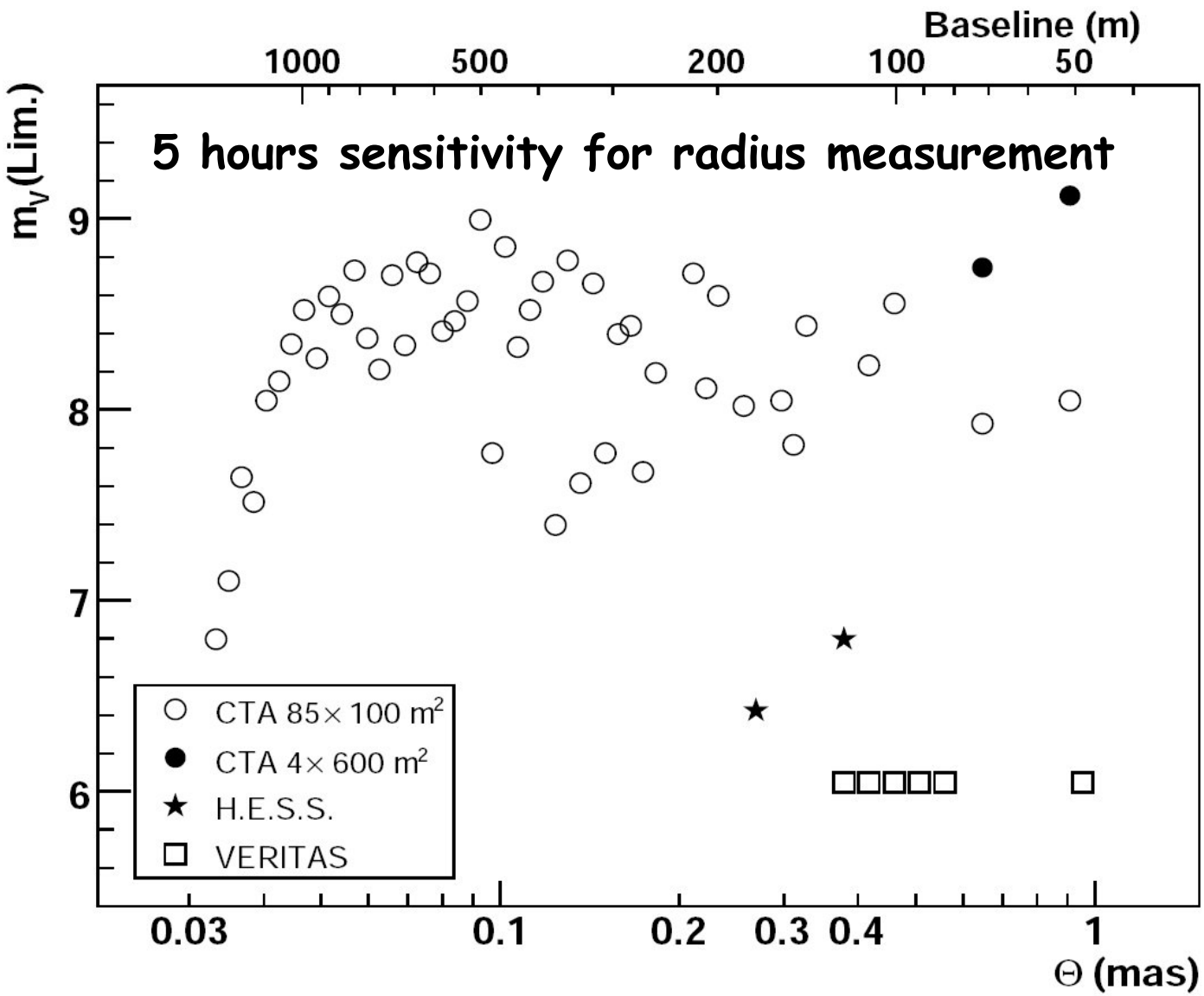
n ~ 6.7m$_V$ &

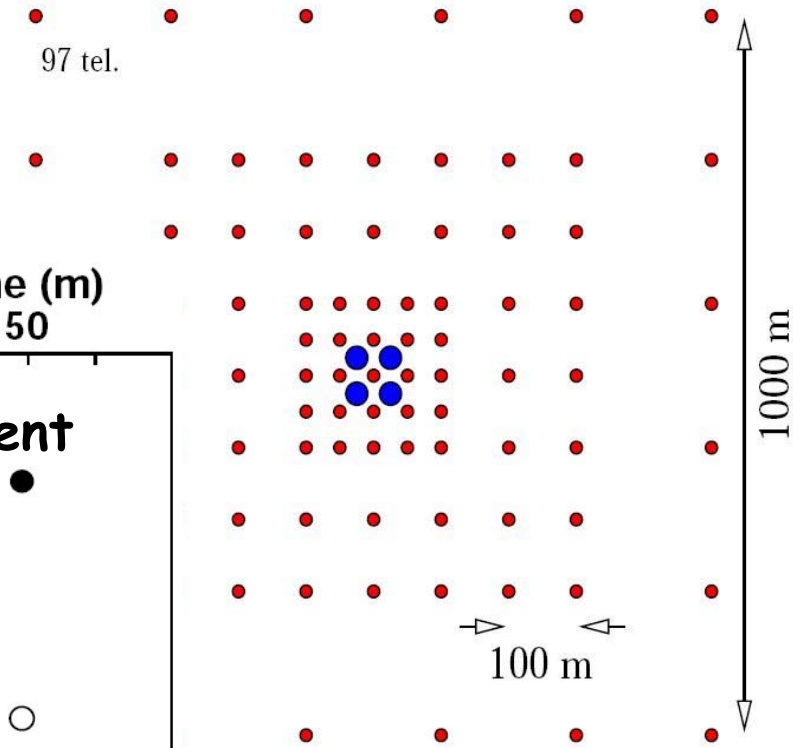
Δr=14%

@ 5m$_V$, Δr=3%

This is with just one baseline!!!

With many baselines...



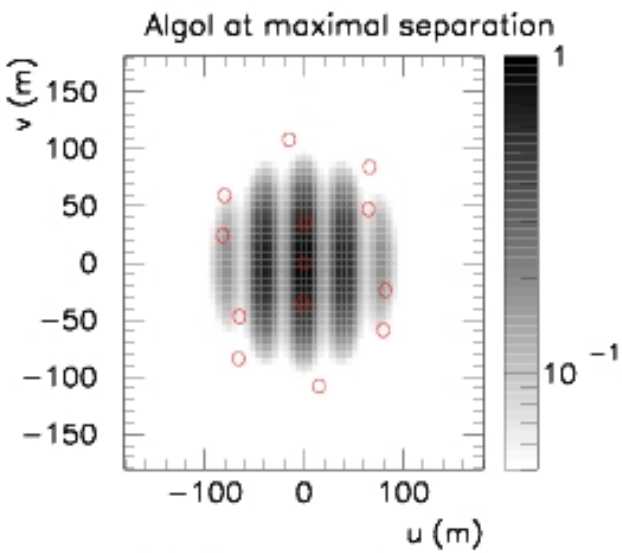


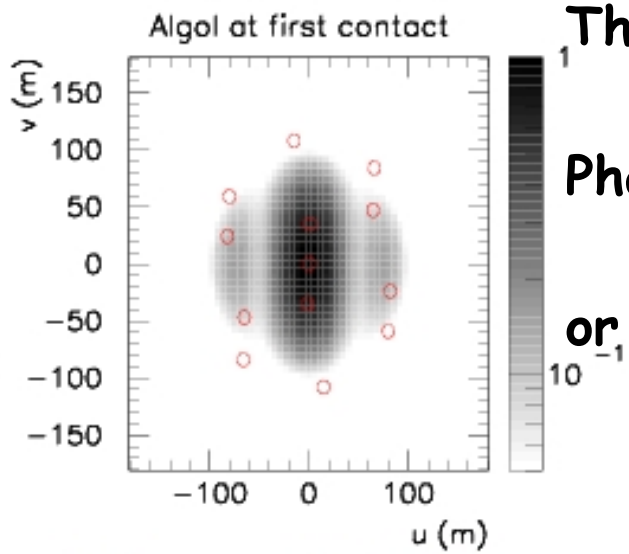
PSF limitation:

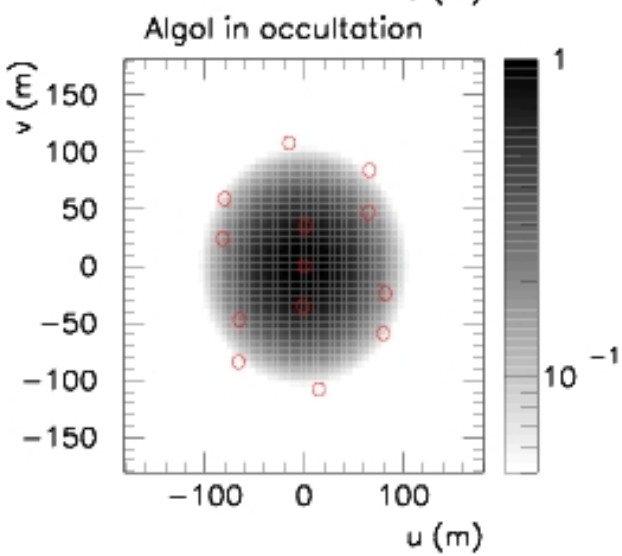
0.05° -> 9.6m_V

0.01° -> 13.0m_V

Why do we need to minimize redundancy?







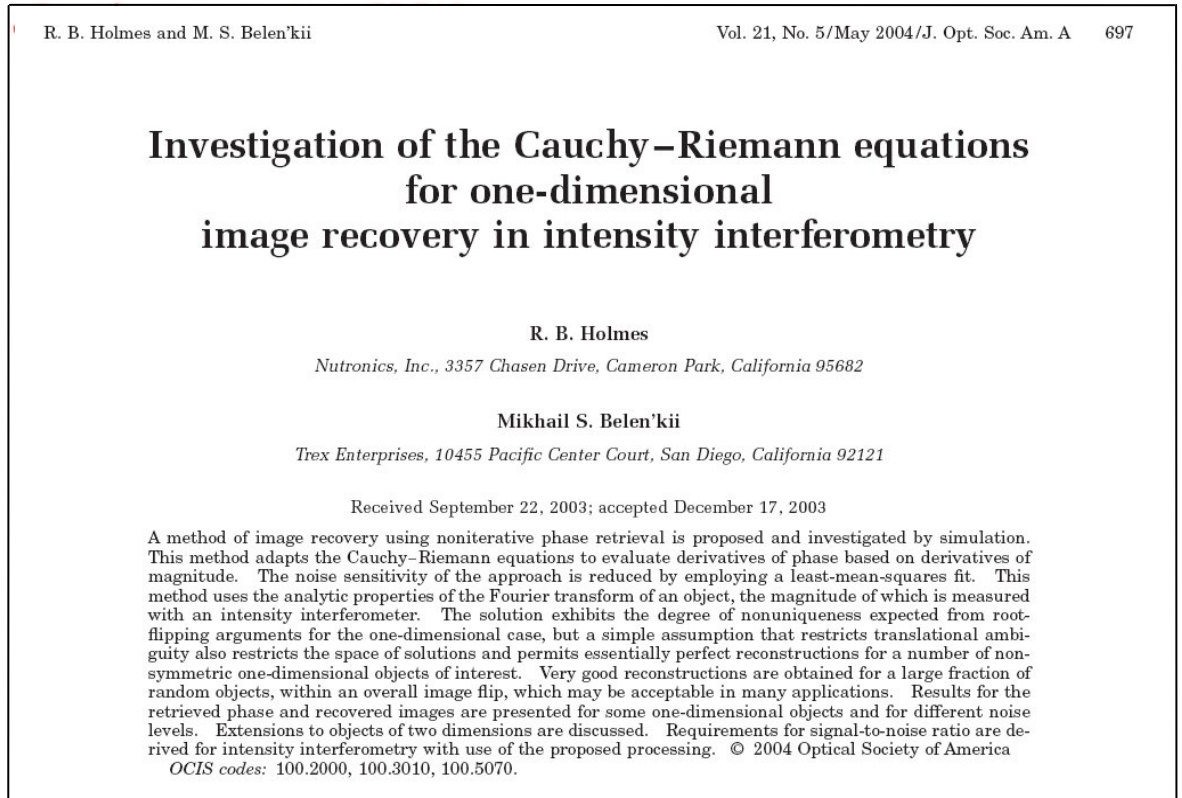
The phase is missing!

Phase recovery based on:

-three point correlation

or

-dF/du & dF/dv & Cauchy-Riemann



Investigation of the Cauchy–Riemann equations for one-dimensional image recovery in intensity interferometry

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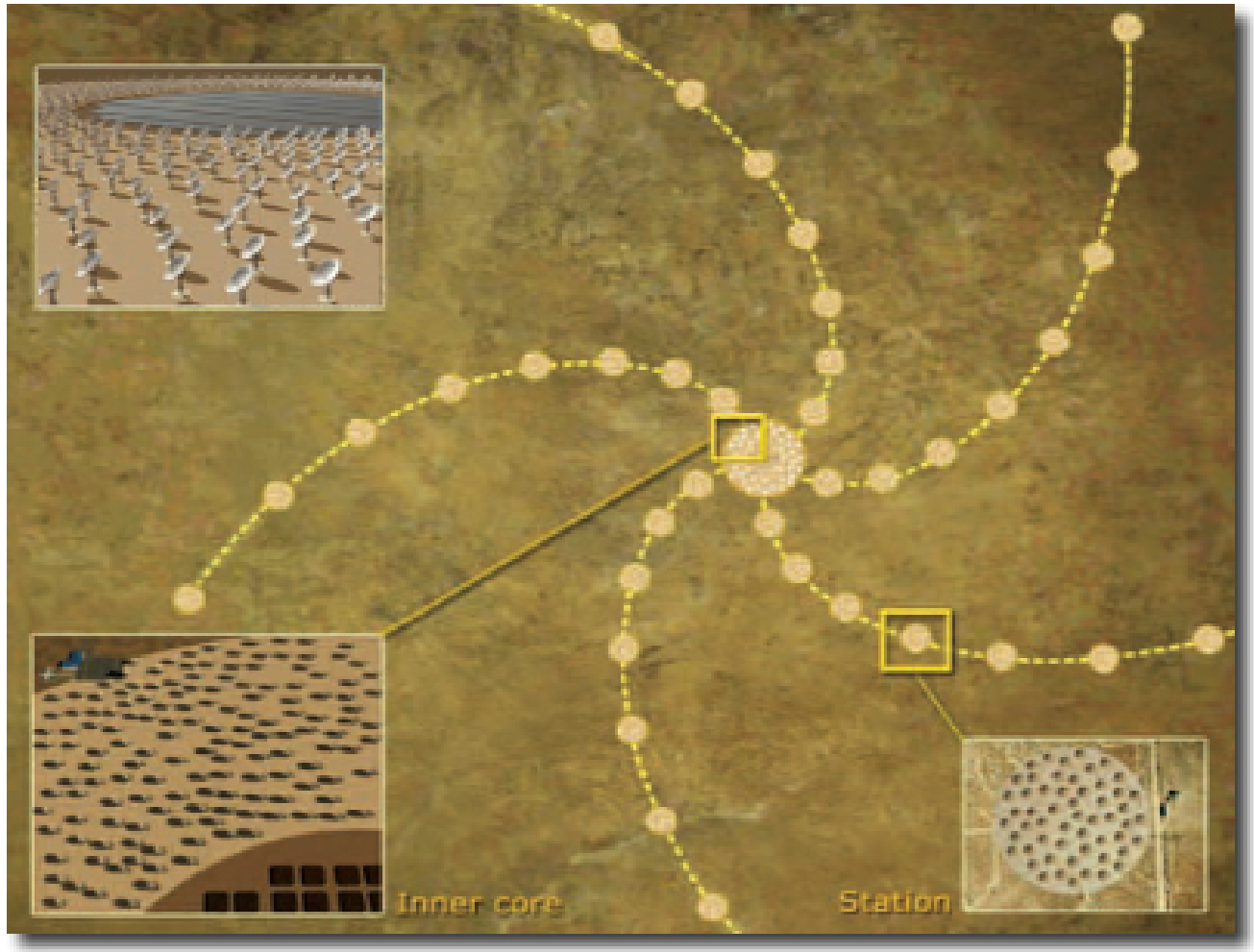
Received September 22, 2003; accepted December 17, 2003

A method of image recovery using noniterative phase retrieval is proposed and investigated by simulation. This method adapts the Cauchy–Riemann equations to evaluate derivatives of phase based on derivatives of magnitude. The noise sensitivity of the approach is reduced by employing a least-mean-squares fit. This method uses the analytic properties of the Fourier transform of an object, the magnitude of which is measured with an intensity interferometer. The solution exhibits the degree of nonuniqueness expected from root-flipping arguments for the one-dimensional case, but a simple assumption that restricts translational ambiguity also restricts the space of solutions and permits essentially perfect reconstructions for a number of nonsymmetric one-dimensional objects of interest. Very good reconstructions are obtained for a large fraction of random objects, within an overall image flip, which may be acceptable in many applications. Results for the retrieved phase and recovered images are presented for some one-dimensional objects and for different noise levels. Extensions to objects of two dimensions are discussed. Requirements for signal-to-noise ratio are derived for intensity interferometry with use of the proposed processing.

OCIS codes: 100.2000, 100.3010, 100.5070.

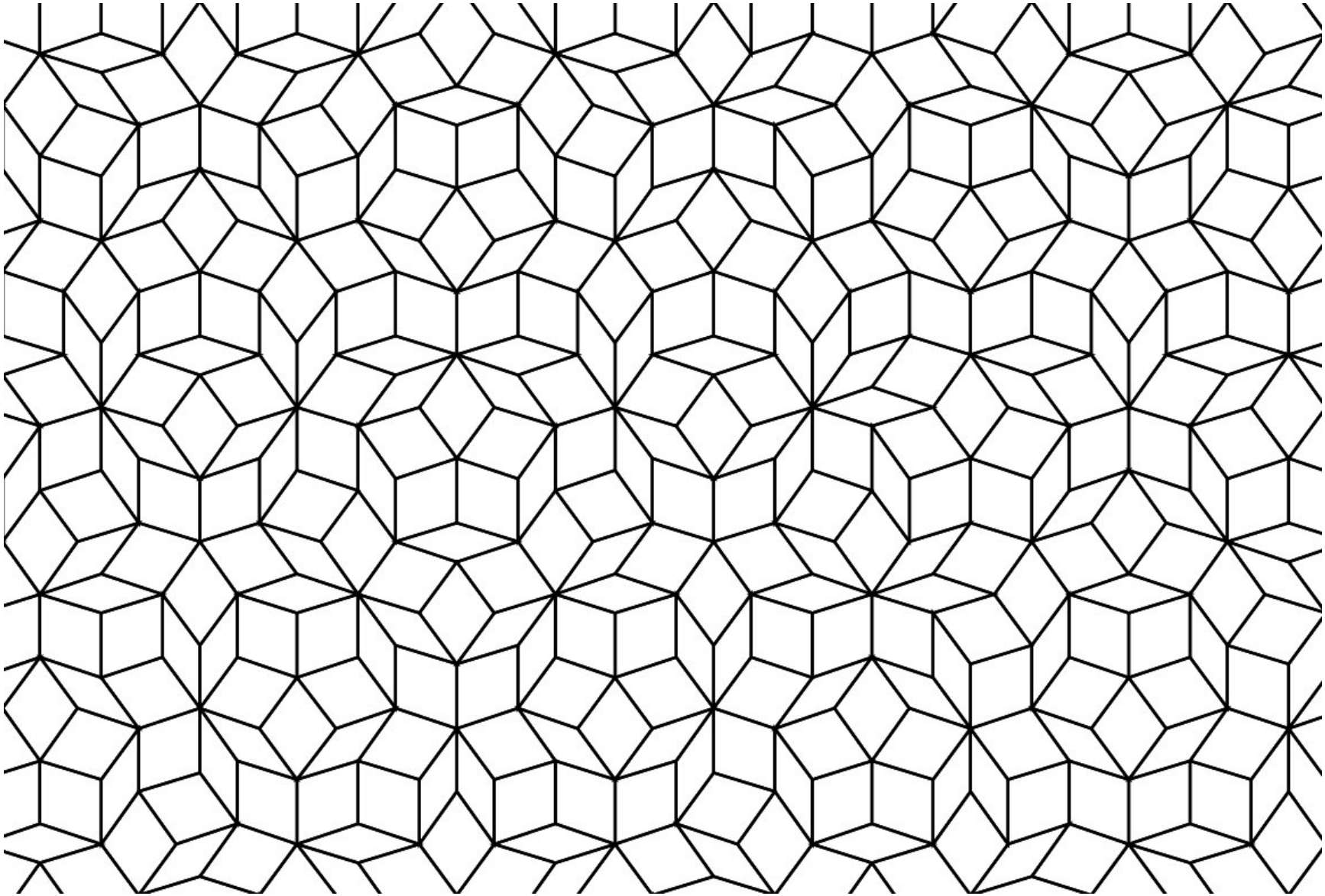
Logarithmic spiral design for minimizing baseline redundancy
(or maximizing (u,v) plane coverage) in interferometric arrays

Example SKA (Square Kilometer Array)

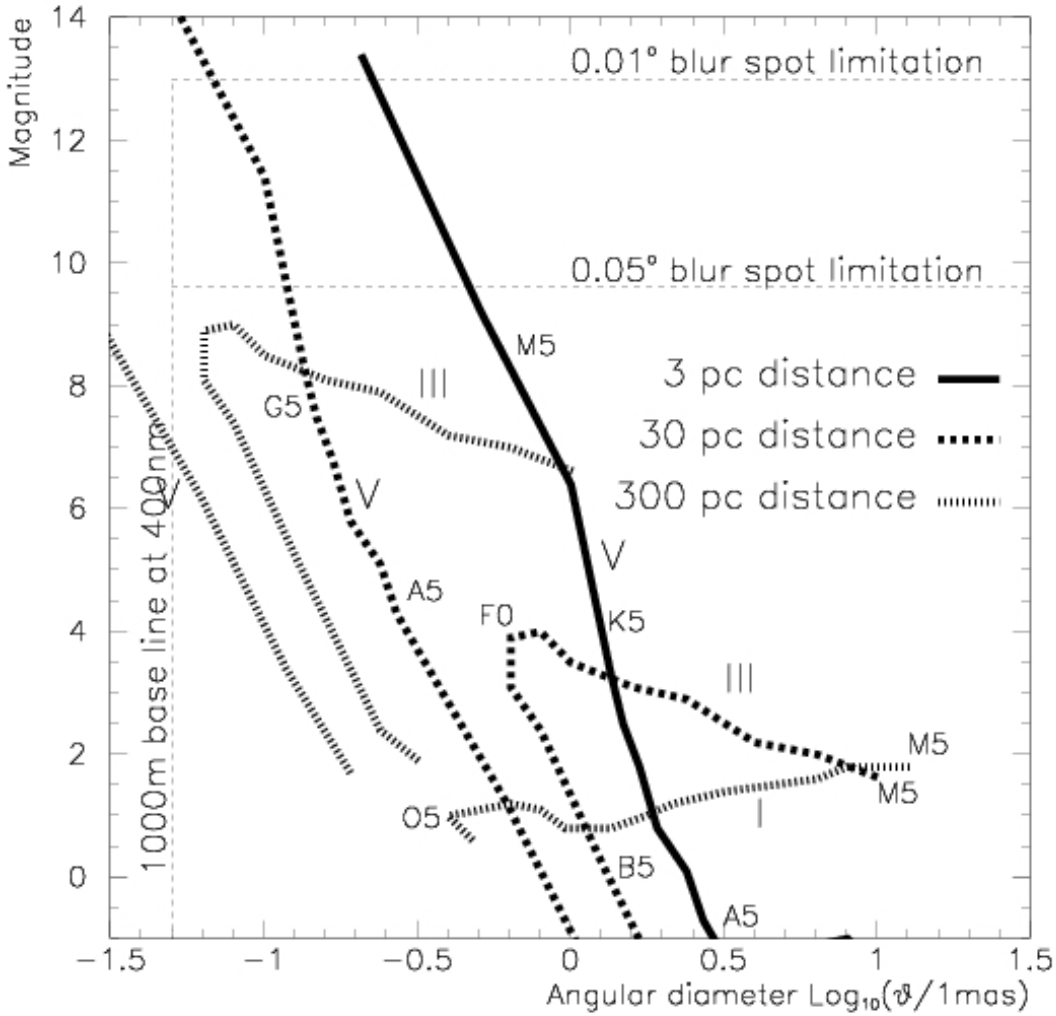


Penrose tiles arrays,

- **reduce redundancy**
- **finite number of cell geometries**



What science could we do?

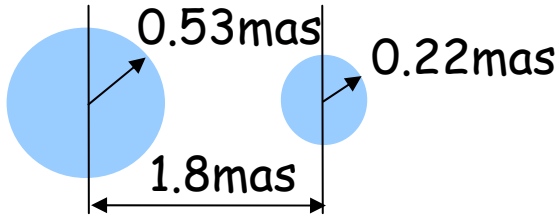


More or less the same science as regular Michelson interferometers with:

*** shorter wavelength**
*** longer baselines**
*** many (many!) baselines**

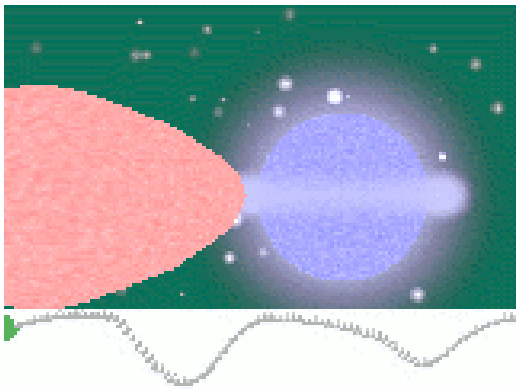
* Distances to Cepheid stars (60 Cepheids with m_v<8)
* Fast rotator Be stars (300 stars with m_v<8)
* Circum stellar material

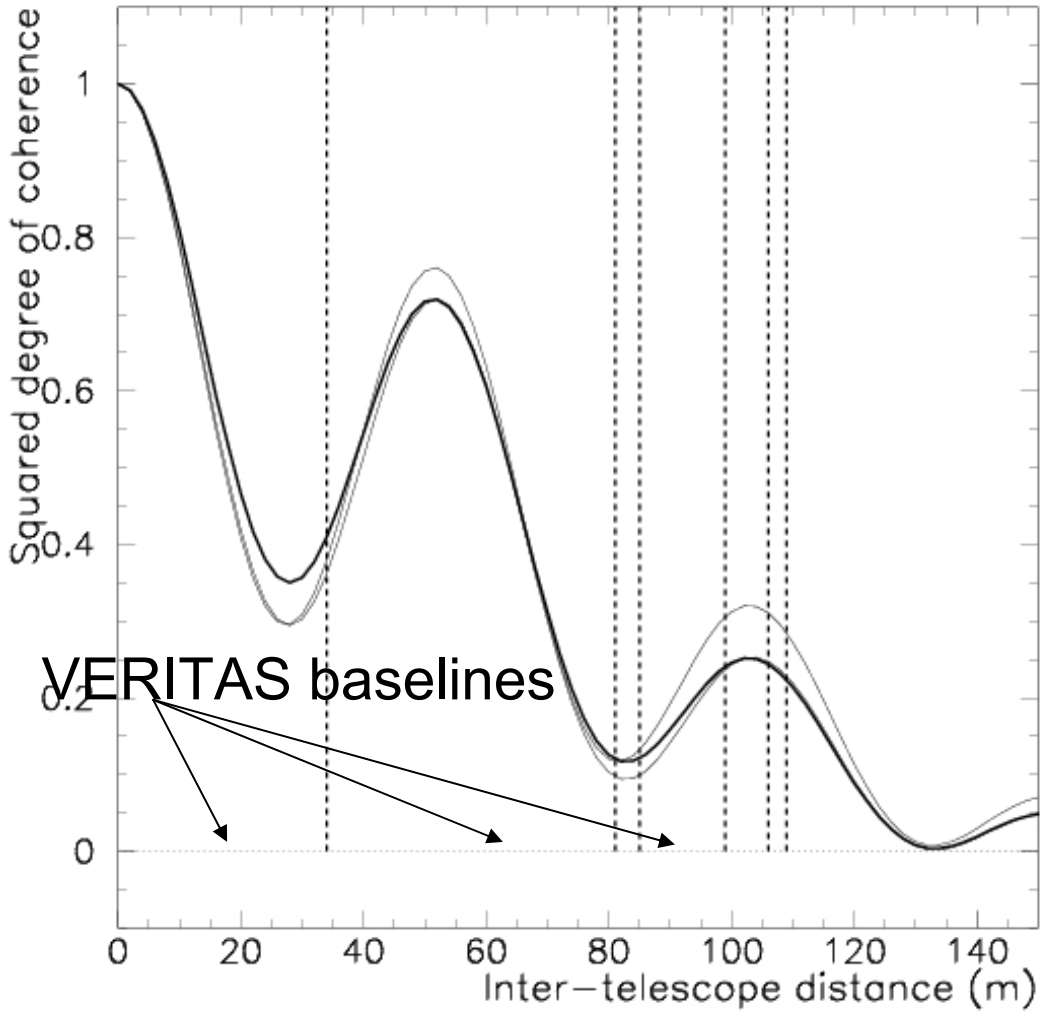
Close Binary star example: Spica



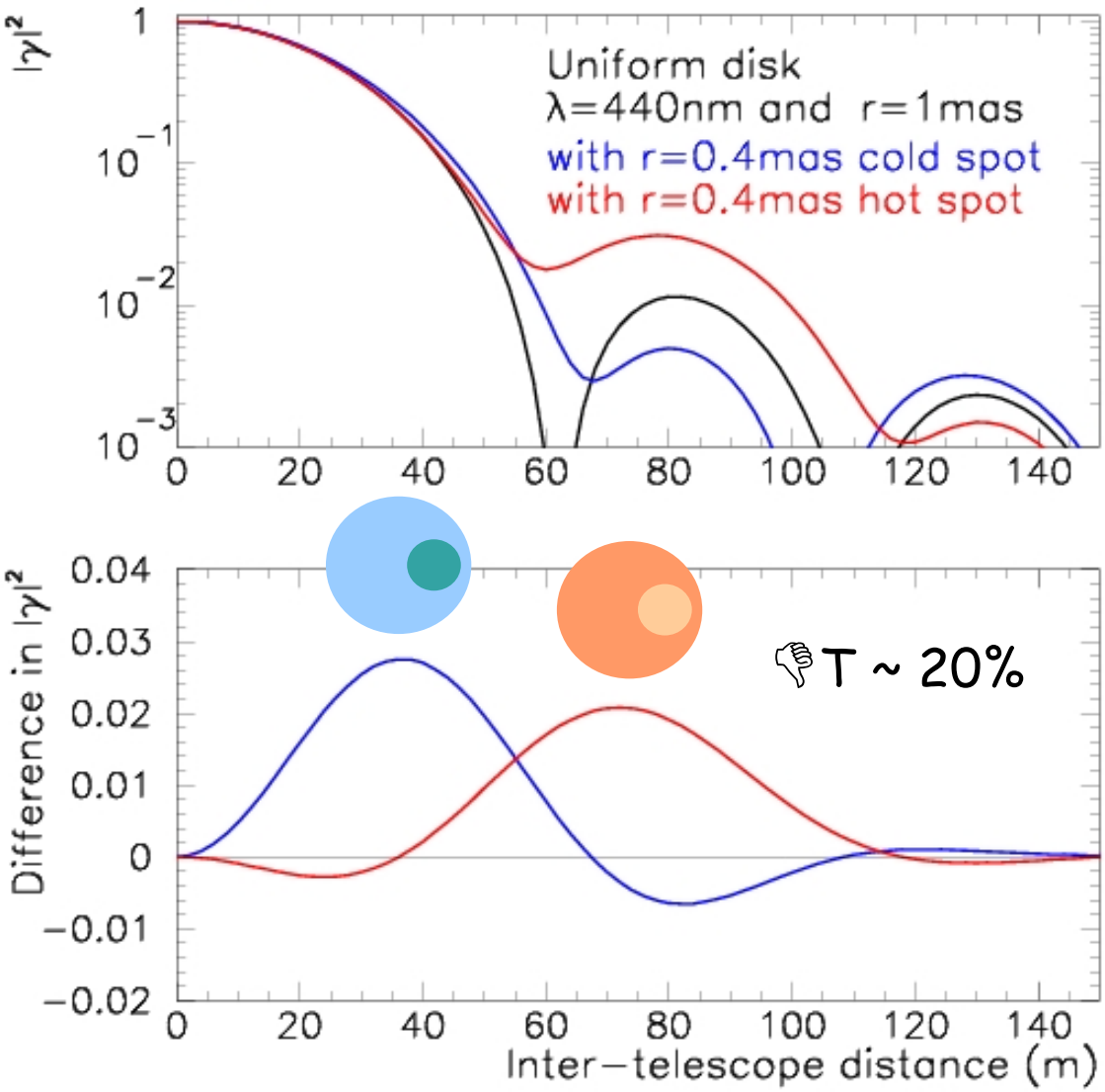
Limb and gravity darkening,
mutual irradiation
tidal distortion
non radial oscillation
...

β Lyrae





50 pre-main sequence stars (PMS) with m_V<8 & less than 50pc away



With CTA

m_v=8, $|\gamma|^2$=0.5

-> S/N=5 in 5 hours

so $\Delta|\gamma|^2 \sim 0.1$

m_v=5.5 -> $\Delta|\gamma|^2 \sim 0.01$

Conclusions:

* larger arrays of smaller telescopes to cover the 0.3TeV- 100TeV and do the science we have been talking about for 15 years.

* With low energy arrays, in the design take into account other possible uses & get optical people involved.