“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)

* $E>10\text{TeV}$ astronomy now is a viable discipline $\rightarrow$ Science output guarantied

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

* Increased Hadron Larmor radius
  $\rightarrow$ Morphology$\%$Energy inverted compared to electron

* More Klein Nishina suppression
  $\rightarrow$ Hadron/Electron discrimination from spectral profiles

* 100$\text{TeV}$ gamma from knee energy CR
  $\rightarrow$ Chance to address the origin of the knee (CR acceleration and propagat.)

* $>10\text{TeV}$ gamma ray astronomy $=$ higher angular resolution
What is required for what threshold?

Note: Can not save money by spacing telescope much more than ~150m while preserving a given threshold.
Gamma Ray Astrophysical Telescope Imaging System

37 Telescopes \rightarrow 54 Triangles \rightarrow \sim 1\text{km}^2
**Mirror:** Ø5.4 m
60 facets of Ø60 cm

**Focal:** 6 m

**Camera:** FOV = 4°
253 pixels of 0.25°

**Trigger efficiency**

- 1 telescope
- 2 telescopes
- 3 telescopes

- **Energy (TeV):**
  - 350 GeV
  - 1 TeV
  - 100 TeV

**Electronics:**
Whipple 10m telescope, thresholds at same S/N
<table>
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<th>Per Item</th>
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<th>Per Scope</th>
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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.
Necessary exposure for a 100TeV astronomy:

$100 \text{ km}^2\text{h} \sim 10\text{km}^2 \times 10\text{h} \rightarrow 100\$M$
Other things we could do with a large array (1km\(^2\)) of large telescopes (100m\(^2\)):
Possible implementation of CTA:

97 x 100m² telescopes equivalent to a single 111m telescope!
PSF ~ 0.05°

* in a 1m² telescope:
  -> 2x10⁶ s⁻¹ photons

* in CTA:
  -> 2x10¹⁰ s⁻¹ photons
Intensity Interferometry with Air Cherenkov Telescope 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 \(9 \times 8 / 2 = 36\) 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

97 tel.

600m²

100m²

100 m

4656 baselines!
"Imaging the surface of Altair"
Sensitivity and telescope design

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

\[A=100m^2 \quad \alpha=30\% \quad \Delta f=1GHz\]

\[T=5 \text{ hours} \quad S/N=5\]

\[n \sim 6.7mV \quad \Delta r=14\%\]

@ 5mV, \(\Delta r=3\%\)

This is with just one baseline!!!

not with Davis-Cotton optics
With many baselines...

PSF limitation:

- $0.05^\circ$ -> $9.6\, m_V$
- $0.01^\circ$ -> $13.0\, m_V$

5 hours sensitivity for radius measurement
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

R. B. Holmes

Nadirtec, Inc., 3357 Chasen Drive, Camarillo Park, California 95682

Mikhail S. Belen’kii

Tez Enterprises, 16455 Pacific Center Court, San Diego, California 92121

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A method of image recovery using noniterative phase retrieval is proposed and investigated by simulation. This method adopts 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 non-symmetric 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. © 2004 Optical Society of America 10.1364/JOSAA.21.000697.
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

VERITAS baselines

Squared degree of coherence

Inter-telescope distance (m)
50 pre-main sequence stars (PMS) with $m_V < 8$ & less than 50pc away

With CTA
$m_V = 8$, $|\gamma|^2 = 0.5$
$\rightarrow \text{S/N}=5$ in 5 hours
so $\Delta|\gamma|^2 \sim 0.1$
$m_V = 5.5 \rightarrow \Delta|\gamma|^2 \sim 0.01$

$T \sim 20\%$
Conclusions:

* larger arrays of smaller telescopes to cover the 0.3 TeV- 100 TeV 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.