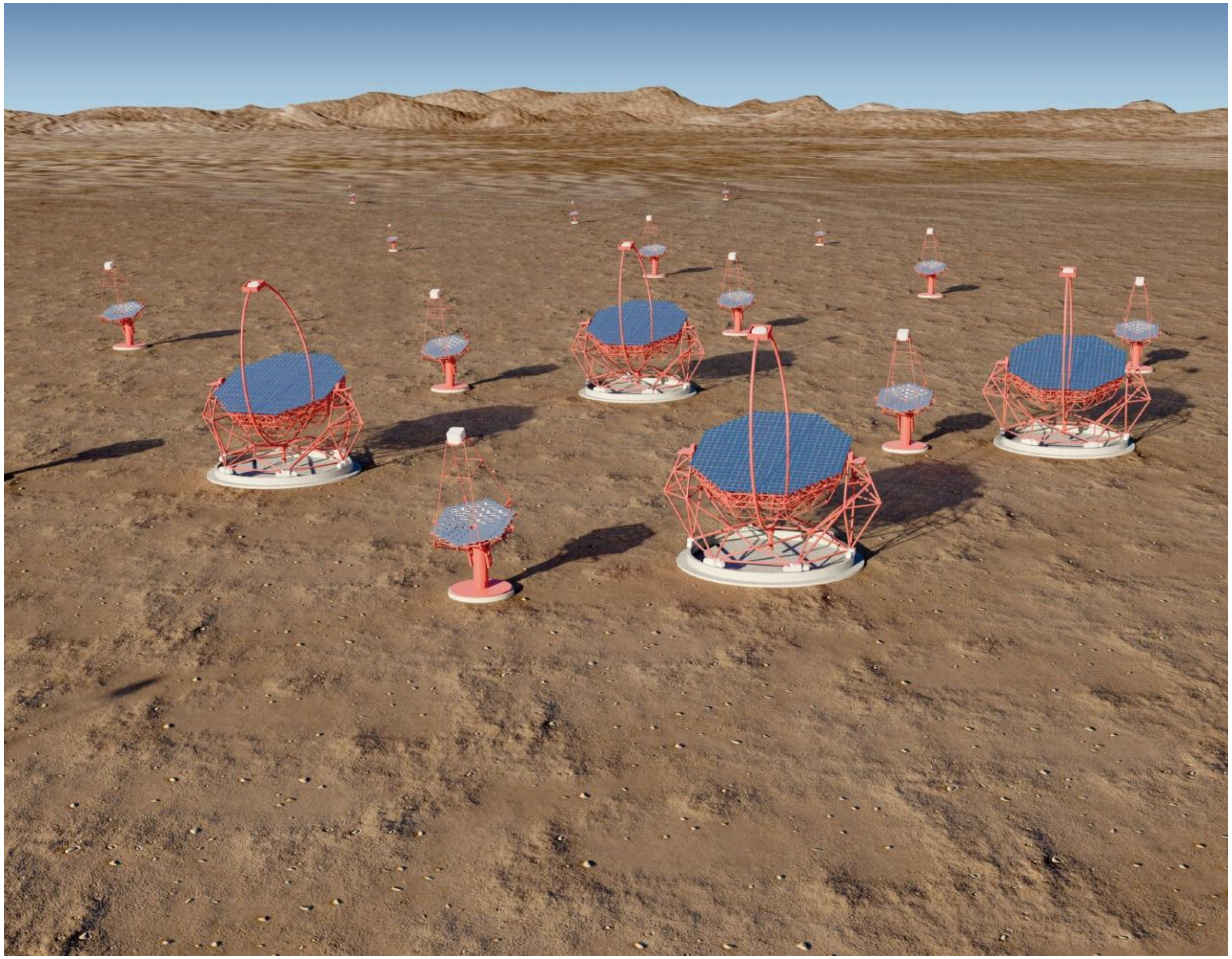
The Cherenkov Telescope Array Project

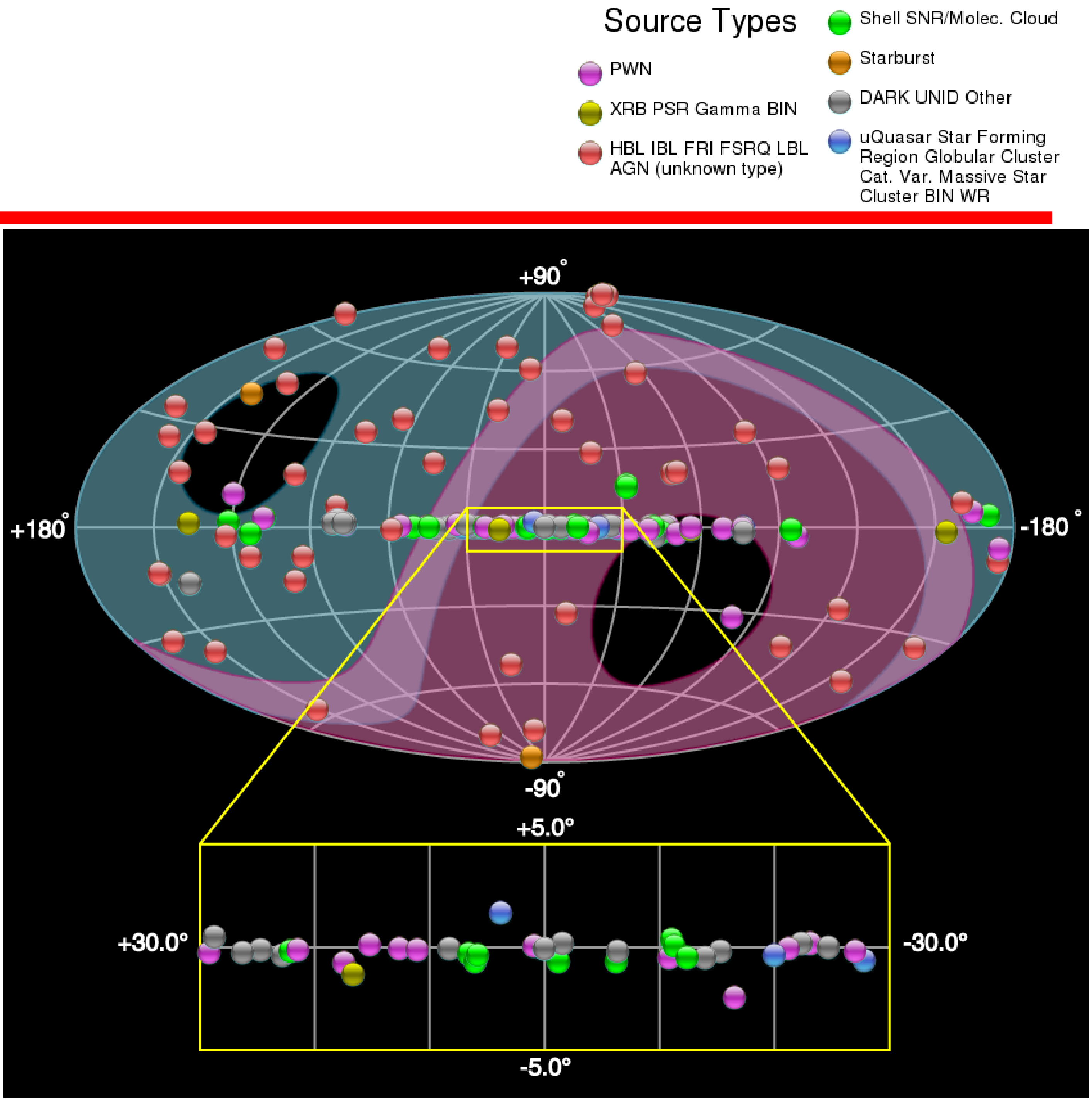
Tim Greenshaw, Liverpool University, for CTA-UK

- CTA goals
- Detecting Cherenkov light from air showers
- Performance of telescope arrays
- The CTA concept
  - Large telescopes
  - Medium telescopes
  - Small telescopes
- SC SST:
  - Mirrors
  - Camera
- CTA site
- Summary



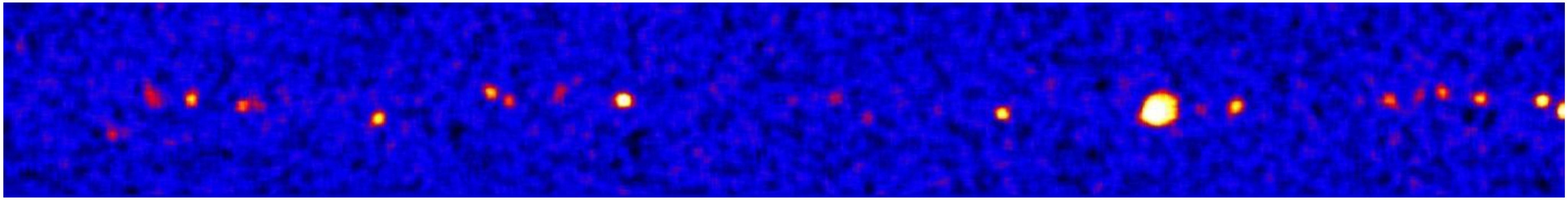
CTA goals

- 1st April 2012.
- 136 γ-ray sources.
    - ~ 85 galactic.
    - ~ 50 extra-galactic.
    - ~ 110 found with IACTs.
- Further progress requires:
    - Improved sensitivity.
    - Better energy and...
    - ...angular resolution.

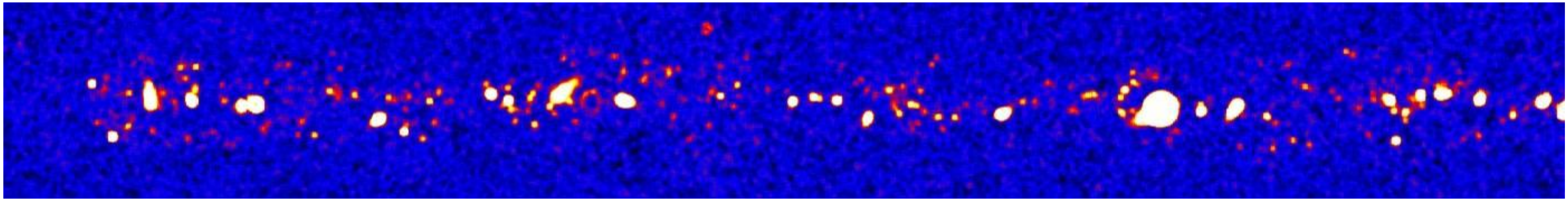


CTA performance goals

- Aim for factor of 10 improvement in sensitivity.
- Compare HESS ~ 500 hour image of galactic plane...



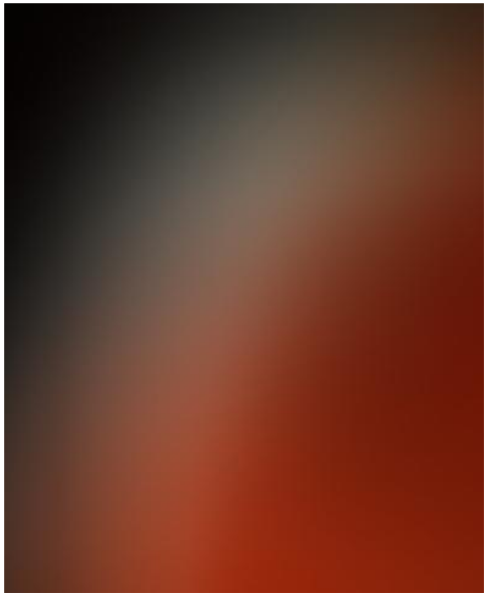
- ...with expectation with increased sensitivity, same exposure.



- Expect to observe around 1000 sources (galactic and extra-galactic).

CTA performance goals

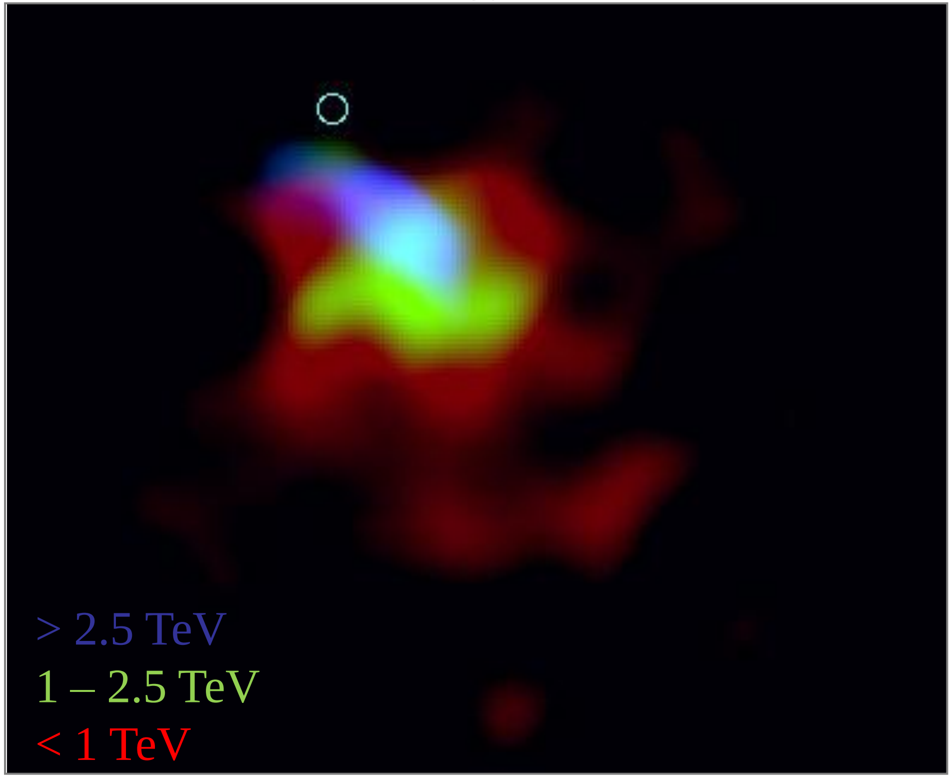
- Improve angular resolution by factor ~ 5.
- Substructure of SNR shock fronts can then be resolved:



Resolution 0.1°.

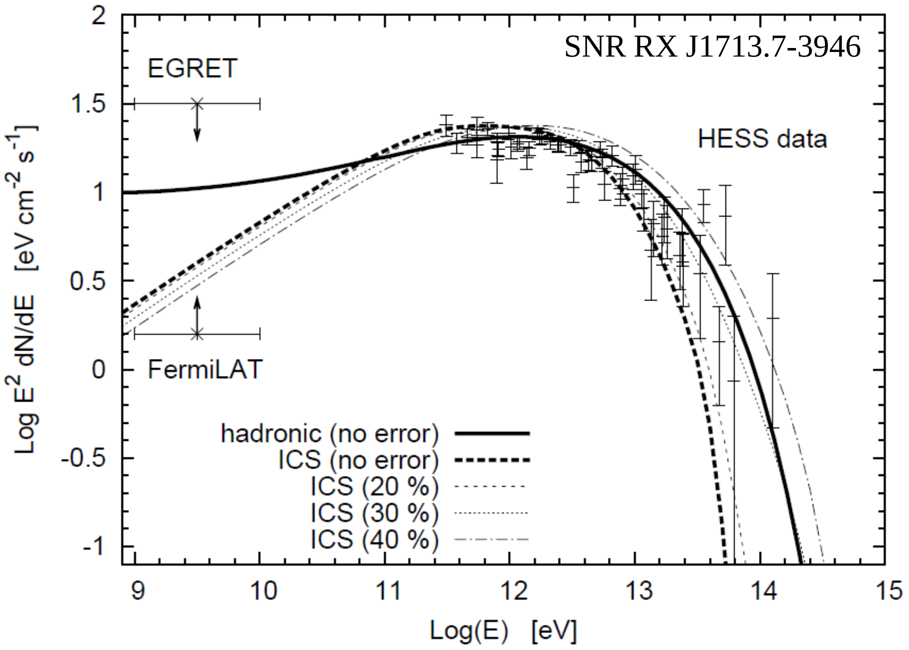
Resolution 0.02 °.

- Better understand energy dependent morphology of pulsar wind nebulae.
- HESS J 1825-137, PWN size decreases with energy:



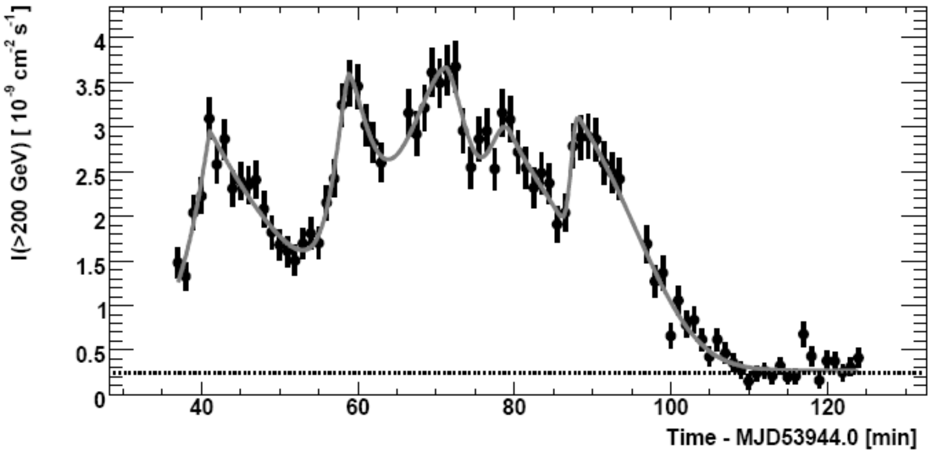
CTA performance goals

- Extend energy coverage to higher and lower energies:



- Understand processes in sources: hadronic showers or inverse Compton scattering?

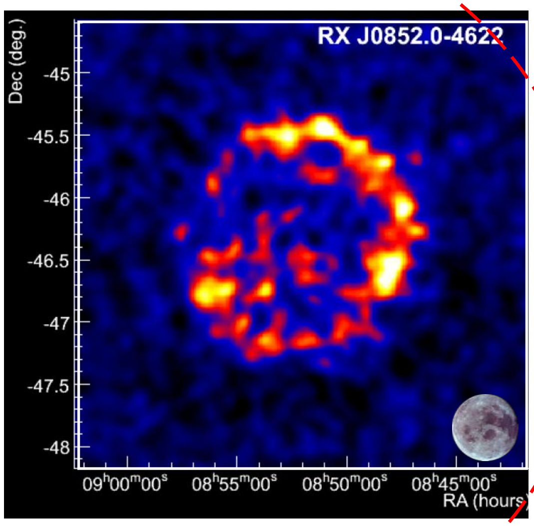
- Increase detection rate, map activity on sub-minute timescales.
- E.g. blazar PKS 2155-304 (HESS):



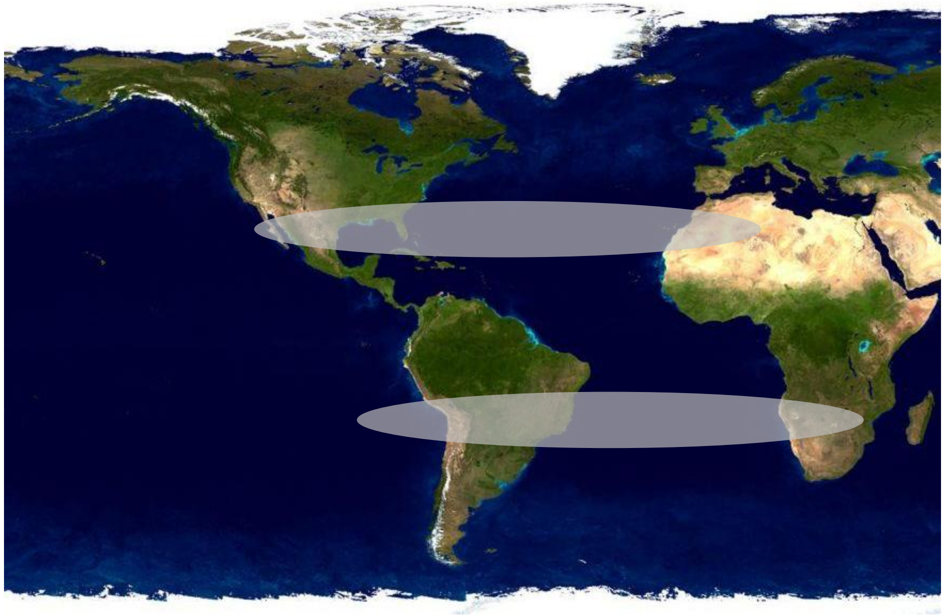
- Determine size of emission regions around active galactic nuclei.
- Study quantum gravity.
- Fast slewing, large FoV (fastest burst notification from Fermi γ-ray burst monitor precision ~ 10°).

CTA performance goals

- Increase field of view w.r.t. current instruments by factor ~ 2 to 6...8°.

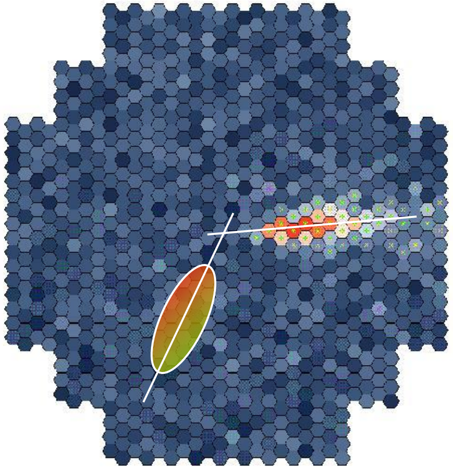


- Detect and map extended sources.
- Improve survey capability: galactic plane at ~ 0.001 Crab in 250 hours, full sky at ~ 0.01 Crab in 1 year.

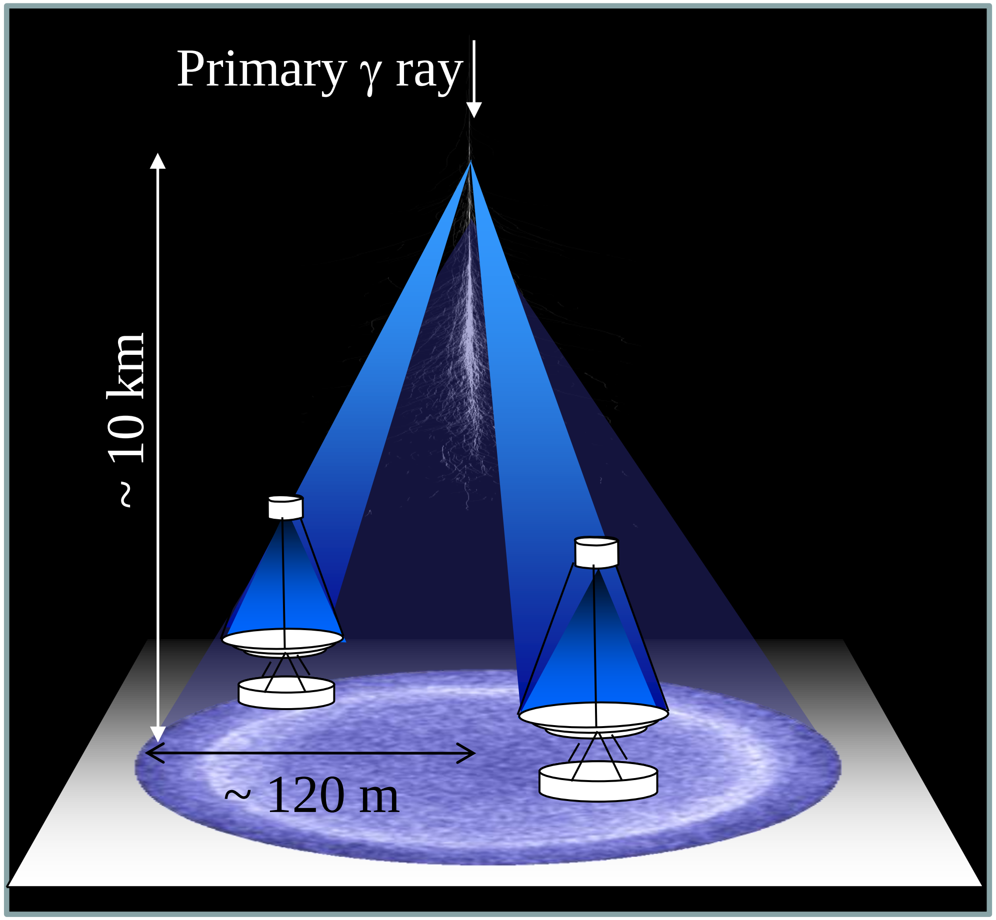


- Southern array:
  - Galactic and extragalactic sources.
  - 10 GeV...100 TeV.
  - Angular resolution 0.02...0.2°.
- Northern array:
  - Mainly extragalactic sources.
  - 10 GeV...1 TeV.

Detecting Cherenkov radiation from air showers

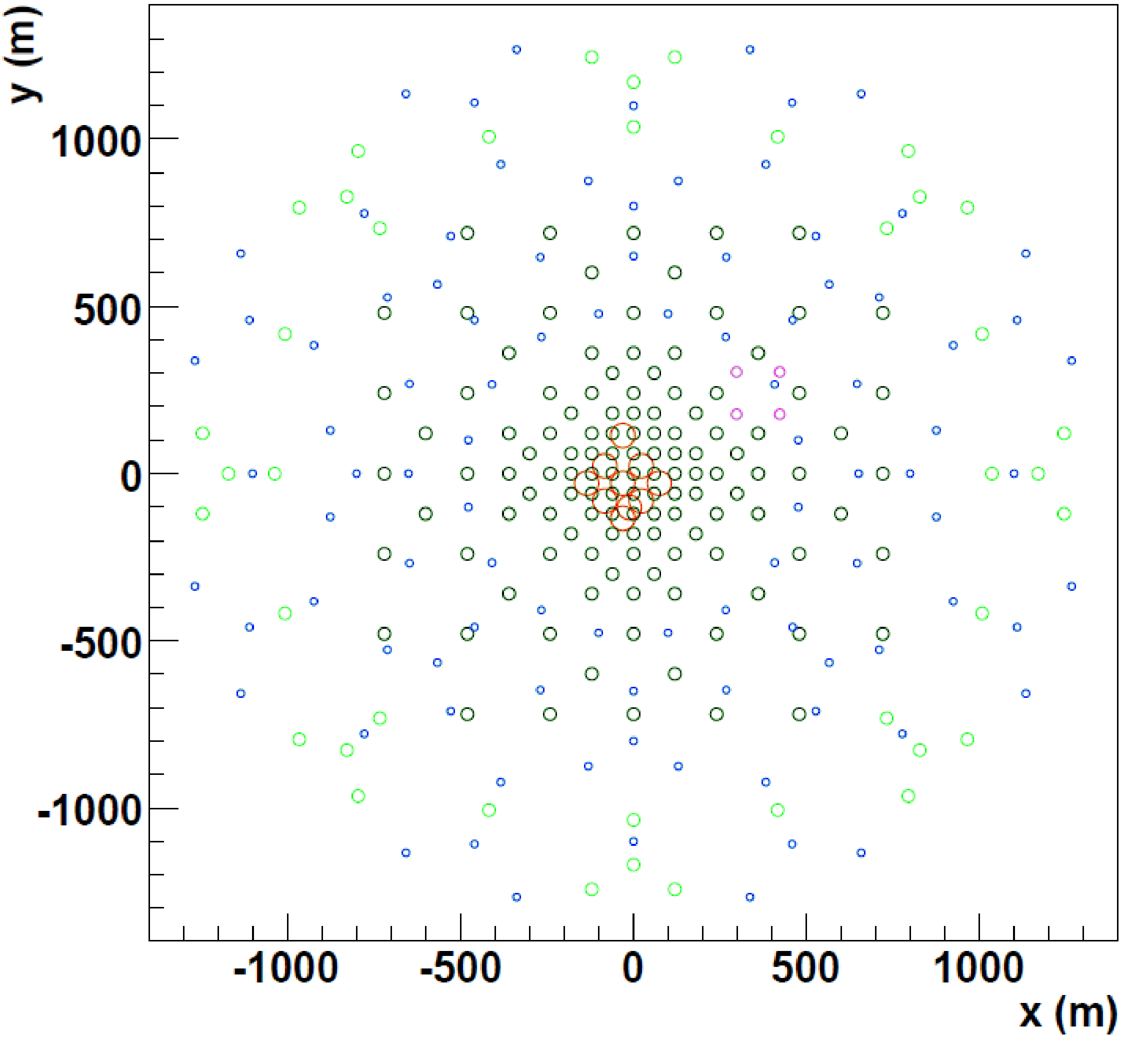


- VHE γ causes electromagnetic shower with max. at height ~ 10 km.
- Cherenkov angle ~ 1°: get light pool on ground with radius ~ 120 m.
- Cherenkov emission, attenuation in air, QE of PM lead to:
  - About 1 p.e./m^2 in few ns for (frequent) 100 GeV γ-ray.
  - About 10^3 p.e./m^2 in few 10 to 100 ns for (infreq.) 10 TeV γ-ray.
- Limitations:
  - E < 100 GeV, NSB.
  - E ~ 0.1...5 TeV, CR BG (γ/h sep).
  - E > 5 TeV, rate.
- Need array of different telescopes.



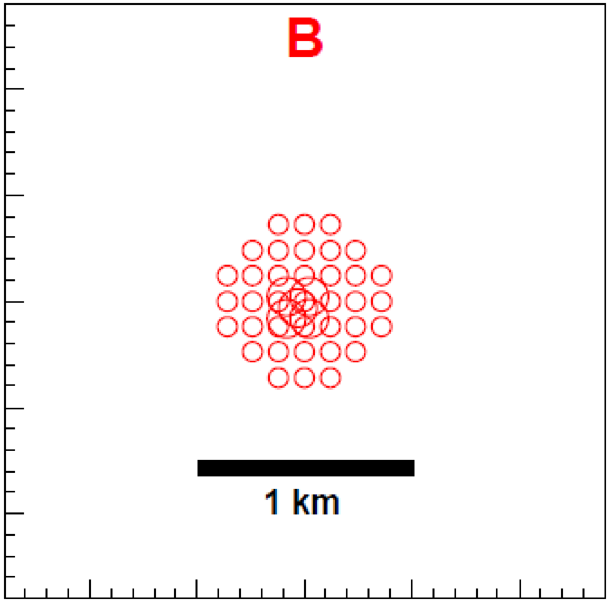
Performance of multi-telescope arrays

- Concentrate here on instrumentation for CTA southern site.
- Simulate large array with 275 telescopes of 5 different sizes.
- Select sub-sets of this array.
- Obey constraint: construction cost ~ 80 M€.
- Study performance of these sub-arrays.

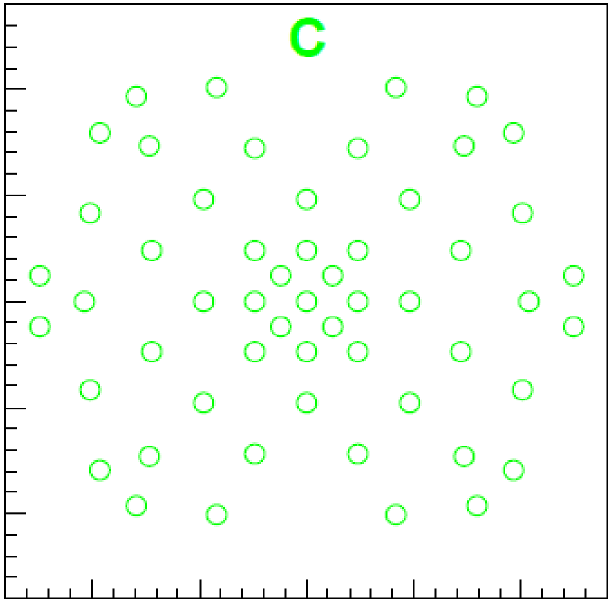


Performance of multi-telescope arrays

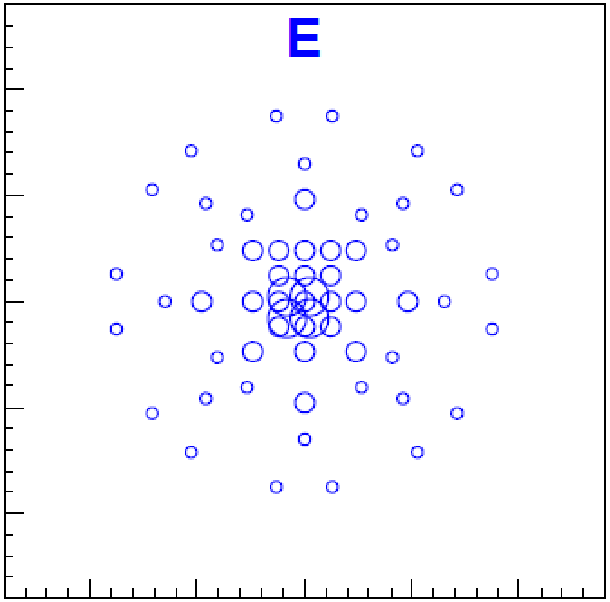
- Examples of sub-arrays:



- Dense array of 12 and 24 m telescopes.
- Good low E, but poor high E performance?



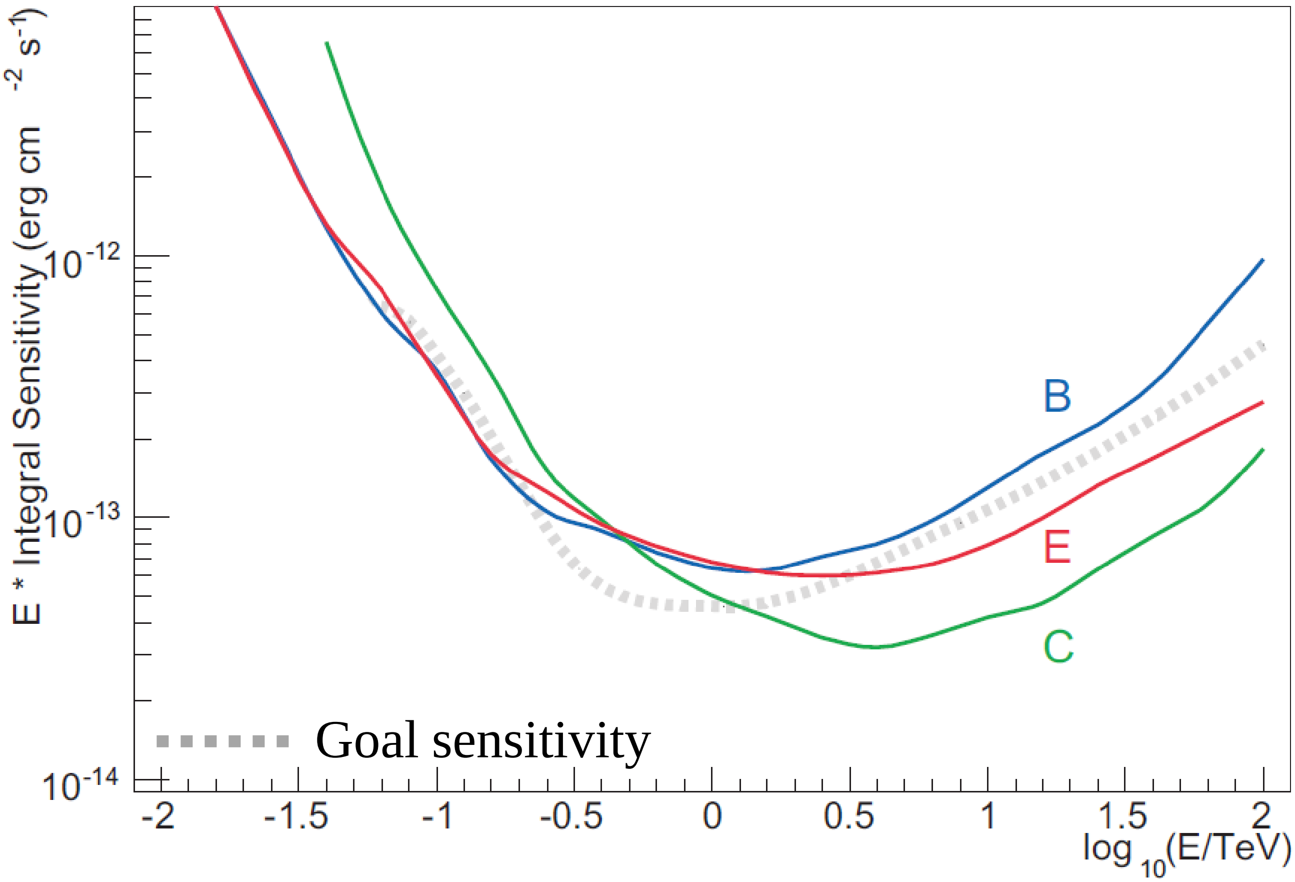
- Low density array of 12 m telescopes.
- Good high/medium E, but poor low E performance?

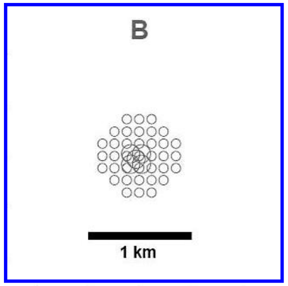


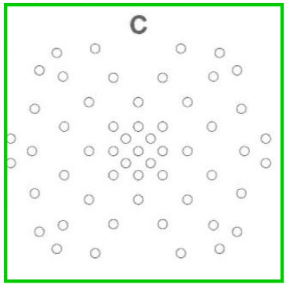
- Array of 7, 12 and 24 m telescopes.
- Provides sensitivity across complete energy range?

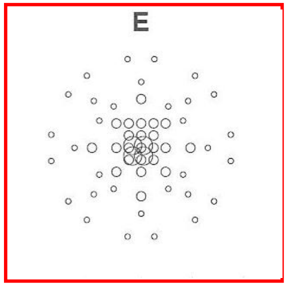
Performance of multi-telescope arrays

- Performance measure: integral sensitivity for point sources, 50 hour exposure.



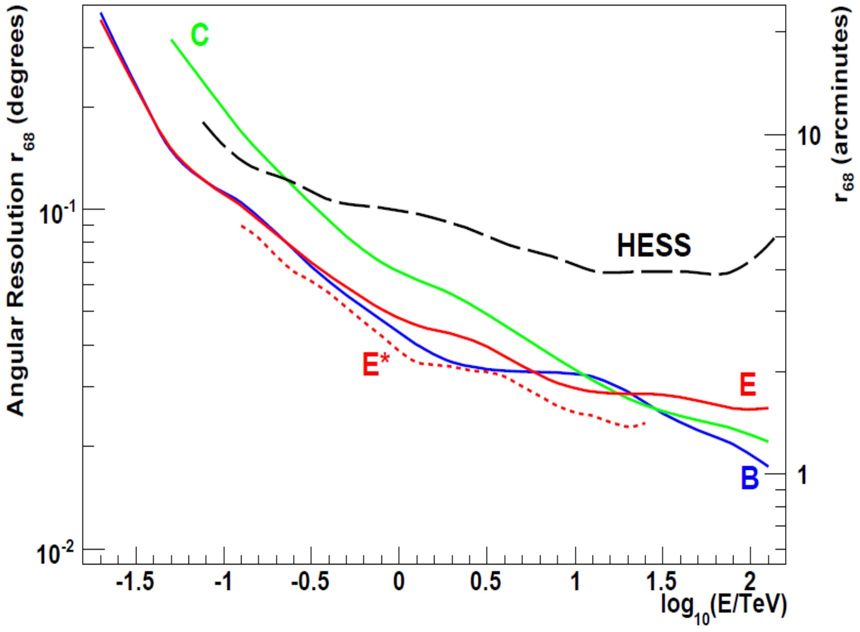




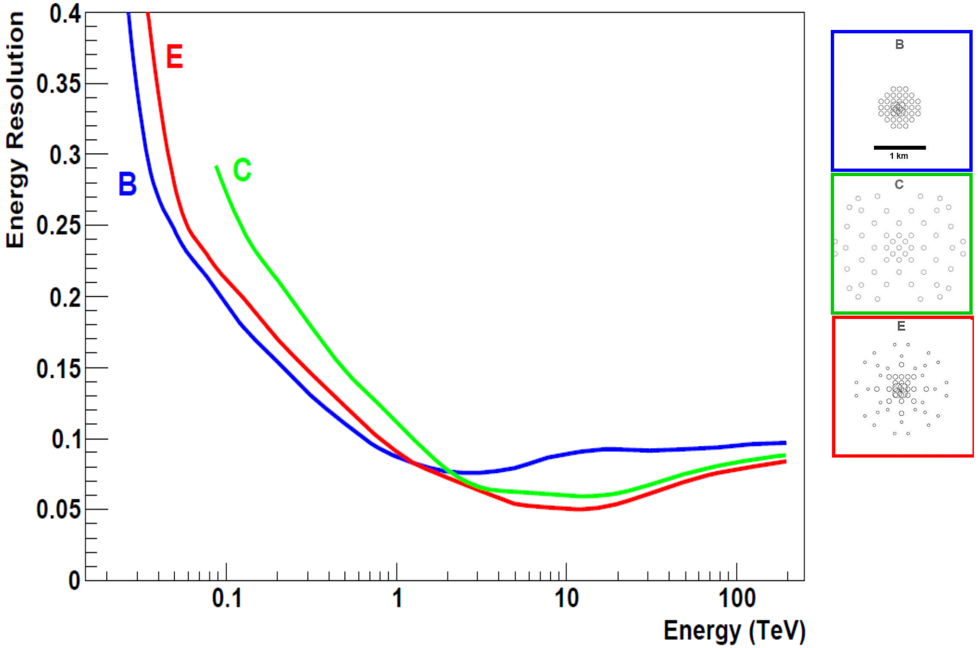


Performance of multi-telescope arrays

- Performance measure: angular res.



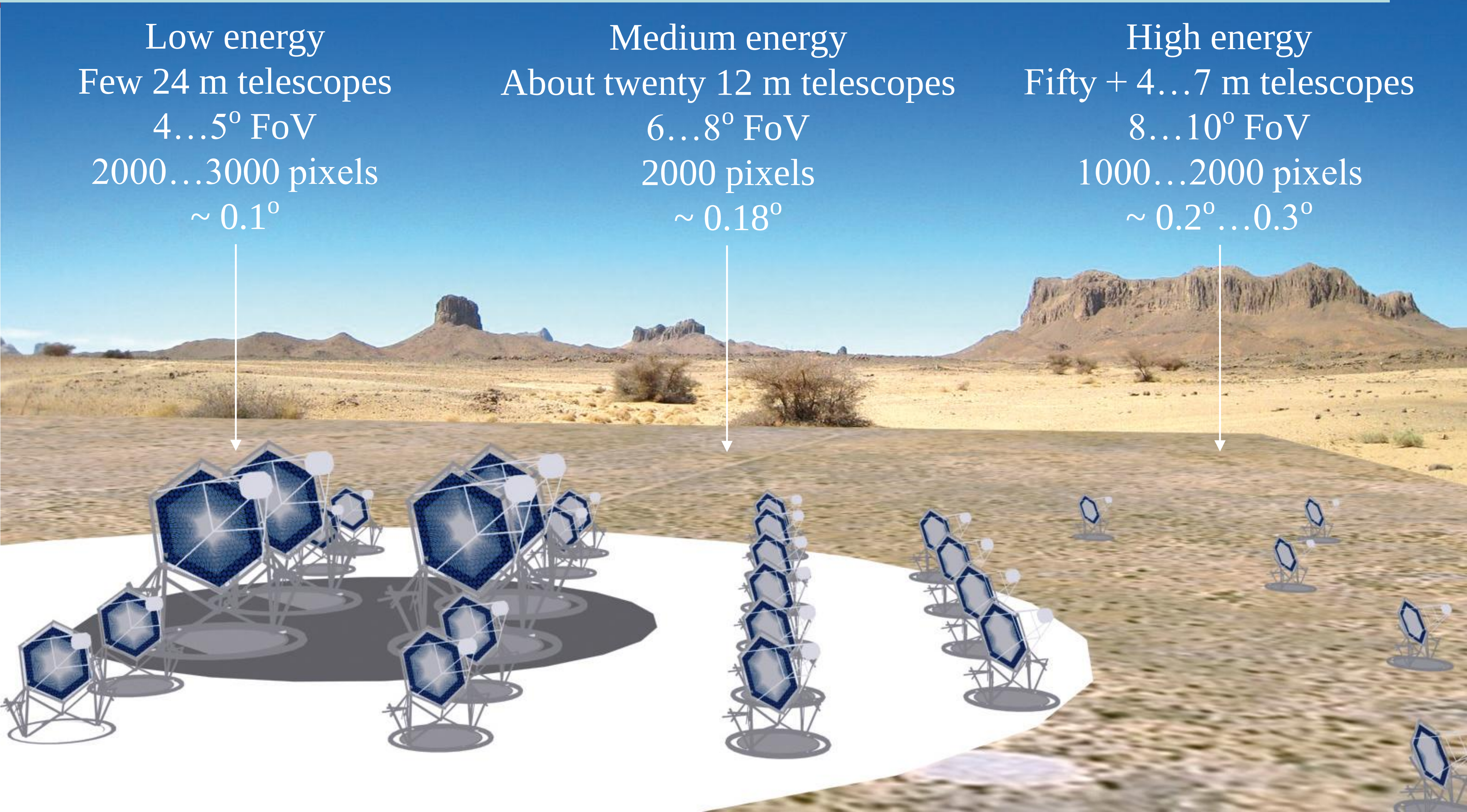
- Performance measure: energy res.



- 1...2 arcmin. (3 × 10^{-4} rad.) angular resolution achieved for E > 1 TeV.

- Energy resolution 5...10% in TeV energy range.

The Cherenkov Telescope Array concept



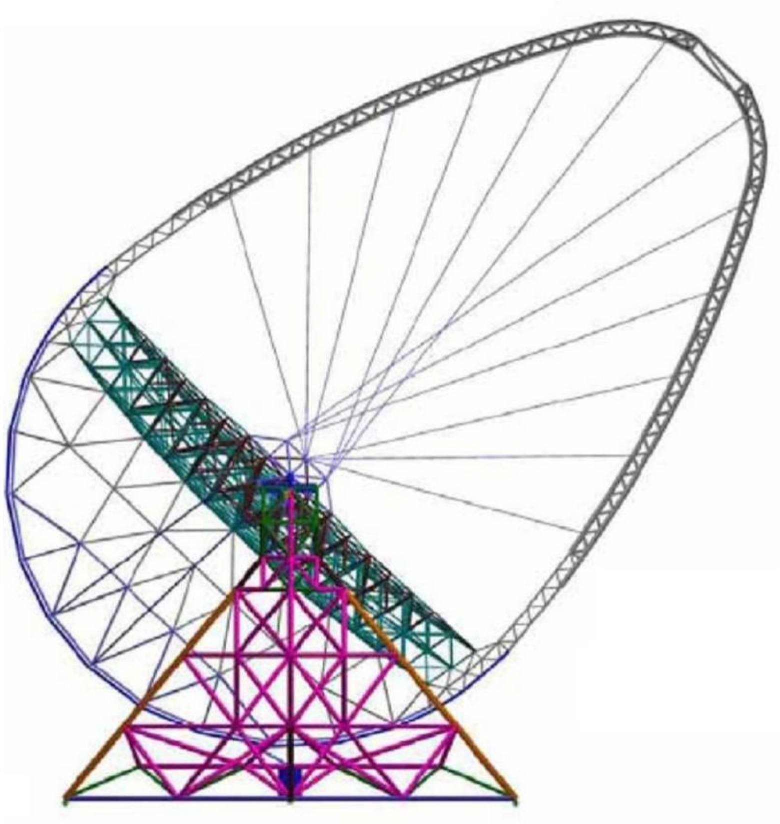
Low energy
Few 24 m telescopes
4…5° FoV
2000…3000 pixels
~ 0.1°

Medium energy
About twenty 12 m telescopes
6…8° FoV
2000 pixels
~ 0.18°

High energy
Fifty + 4…7 m telescopes
8…10° FoV
1000…2000 pixels
~ 0.2°…0.3°

Large size telescope design

- Diameter 23 m, focal length 28 m.
- (Modified) Davies-Cotton optics.
- Support structure carbon fibre.

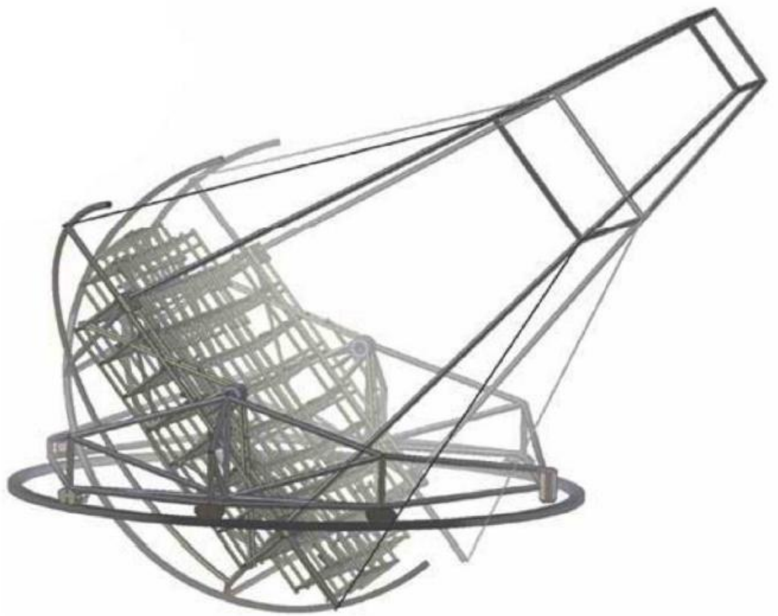


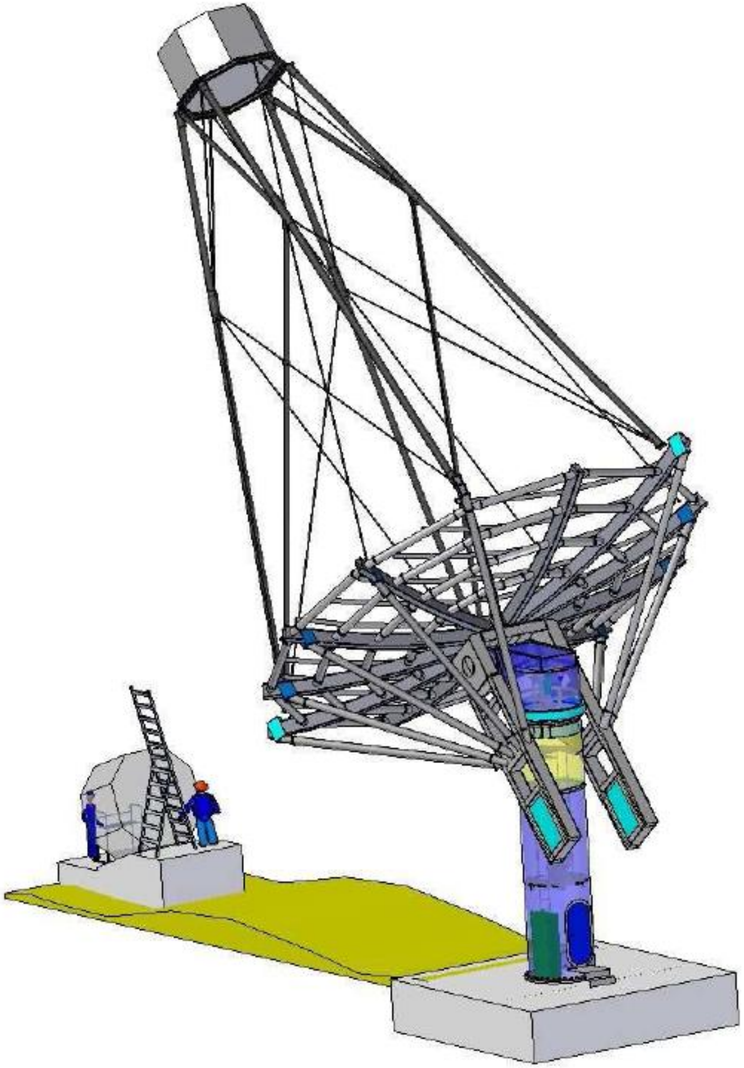
- Camera uses conventional (super-bialkali) photomultipliers.
- Similar to that for HESS II:

- Camera diameter ~ 2.5 m, mass ~ 2 t.

Medium size telescope design – take one

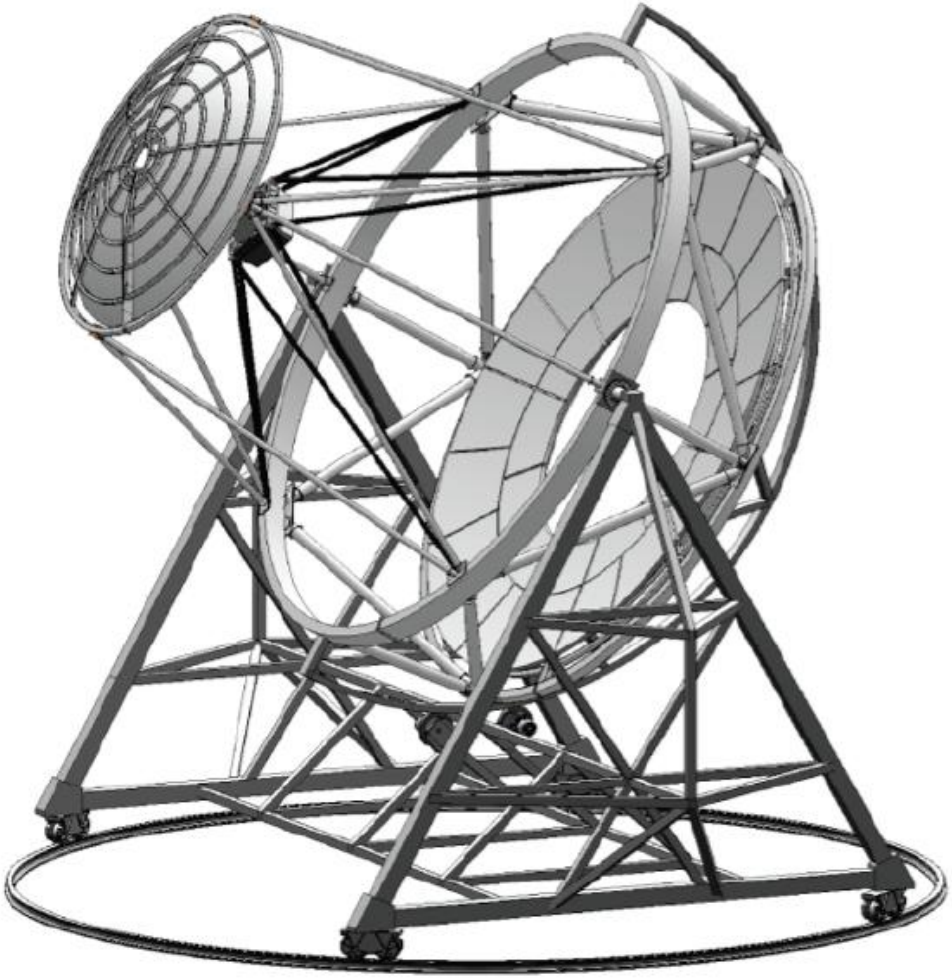
- Diameter 12 m, focal length 17 m.
- (Modified) Davies-Cotton optics.
- Camera support carbon fibre, dish steel/aluminium.
- Camera diameter ~ 2.2 m, mass ~ 2.5 t.





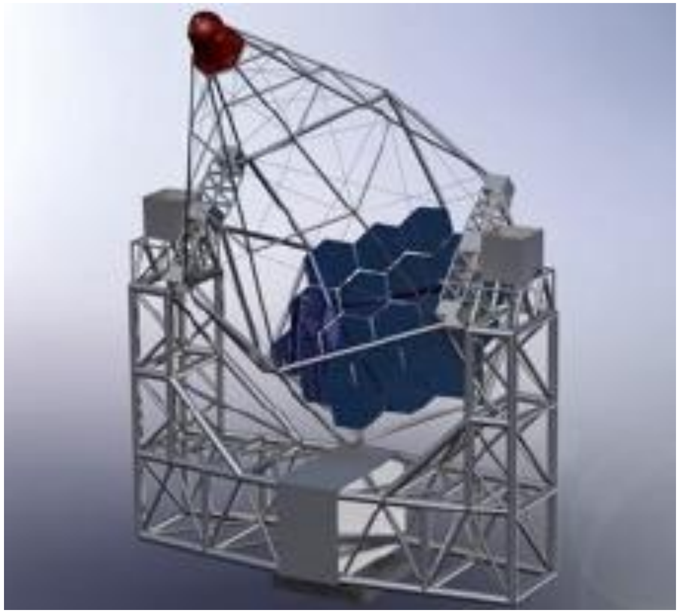
Medium size telescope design – take two

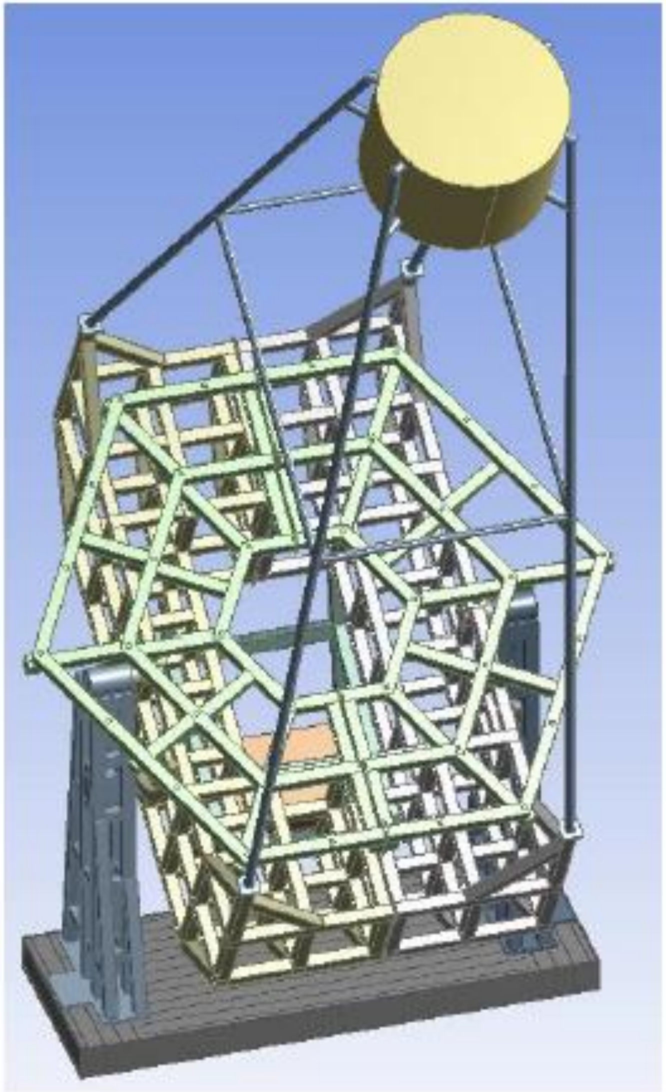
- Dual mirror system allows better correction of aberrations at large field angles.
- Schwarzschild-Couder optics.
- Primary 11.5 m, secondary 6.6 m diameter.
- Effective focal length ~ 5 m.
- Allows use of small pixels, e.g. multi-anode photomultipliers, silicon photomultipliers.
- Proposed ~15 kpixel camera provides coverage to large field angles and ~ 0.06° angular pixel size.



Small size telescope design – take one

- Diameter ~7 m, focal length ~ 11 m.
- DC optics, support structure steel.
- Camera diameter ~ 2 m, mass ~ 2 t.
- Several designs investigated – common feature: camera cost dominates.

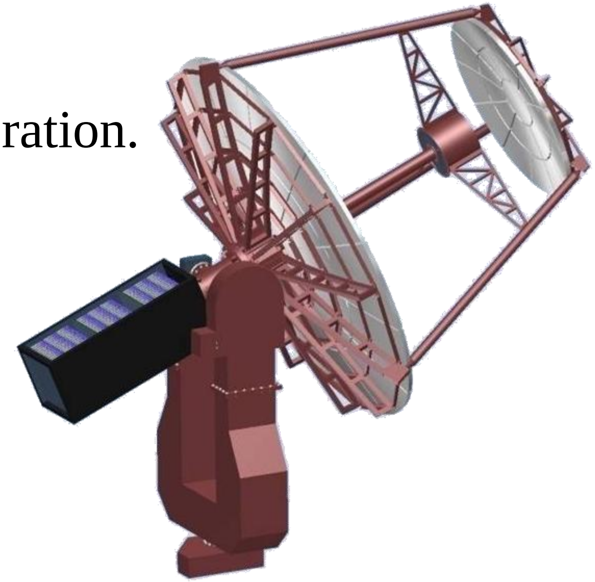




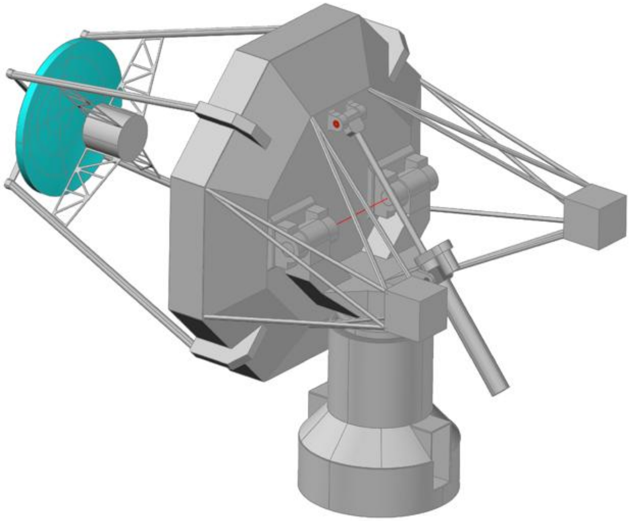
Small size telescope – SC design

- Idea is to utilize MAPMs or SiPMs so can reduce camera costs.
- Commercially available devices give pixel sizes ~ 6 × 6 mm^2.
- In order to get angular pixel size of about 0.2° need focal length F ~ 2 m.
- Maintain reasonable area, D ~ 4 m, so trigger at ~ 1 TeV.
- Implies F/D ~ 0.5, cannot use Davies-Cotton optics as aberrations at large field angles too big.
- Dual mirror (Schwarzschild-Couder) solution promising...
- ...but mirrors aspherical, small radius of curvature, focal plane curved.

- Two designs under consideration.
- UK/France.



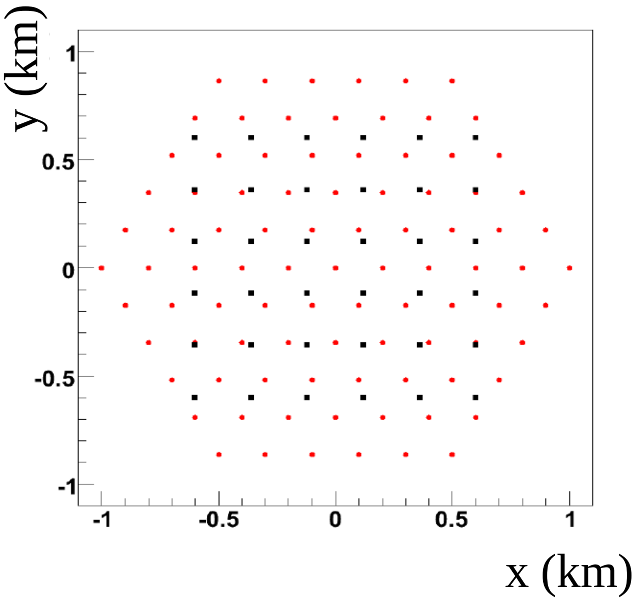
- Italy.

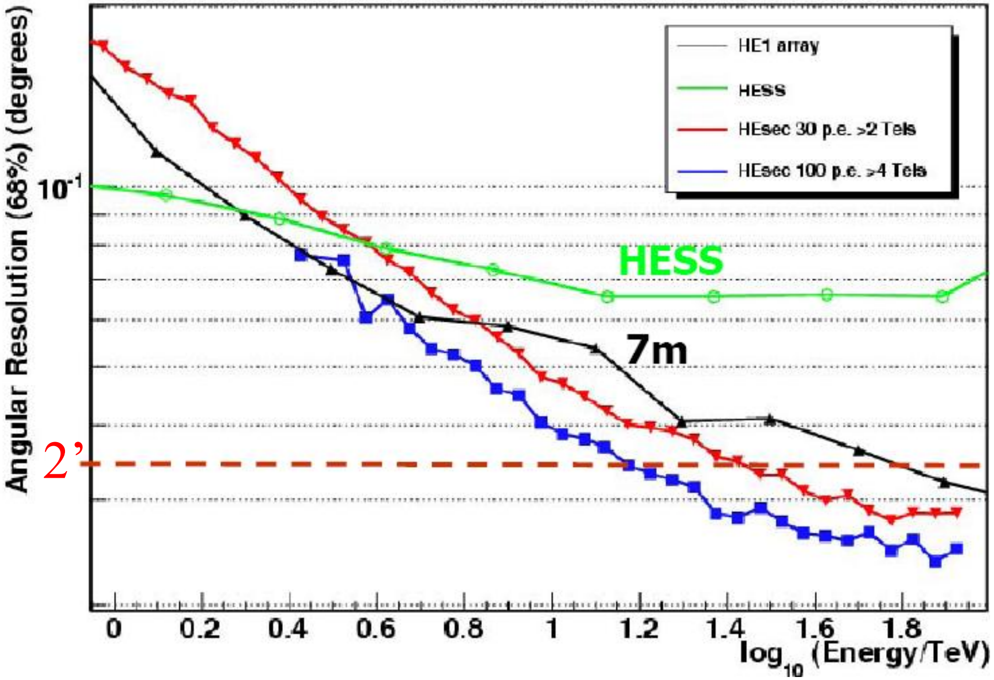


Small size telescope – SC performance

- If challenges presented by these designs can be solved, offer potential to provide better performance per Euro.
- Simulate DC and SC arrays of similar cost.

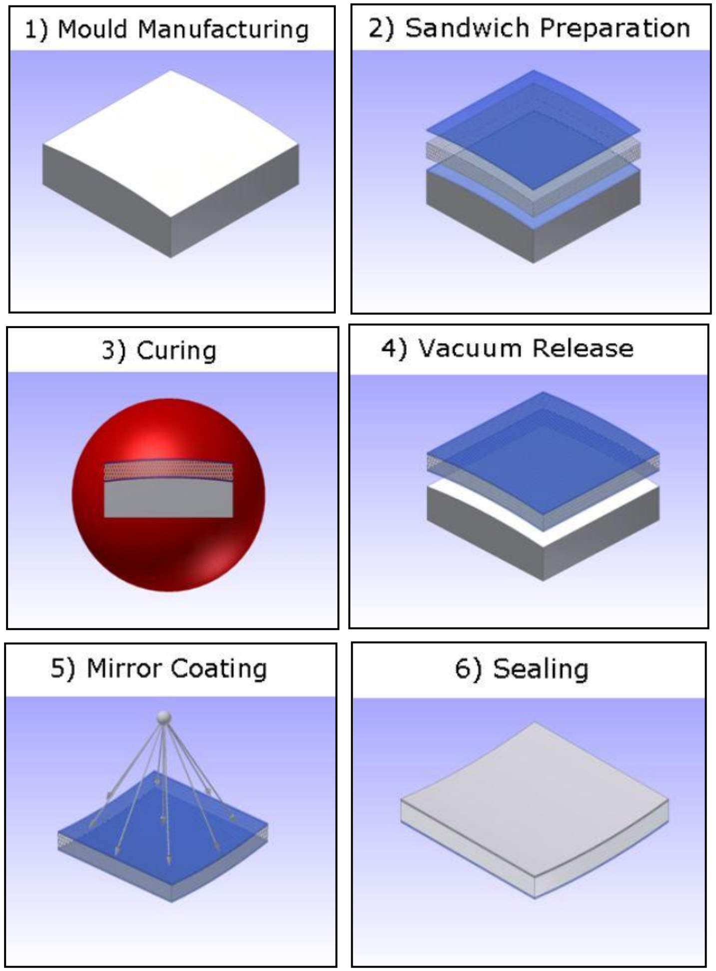
- Look at angular resolution for DC (“7 m”) and SC arrays.
- Higher multiplicity in latter case leads to better angular resolution.



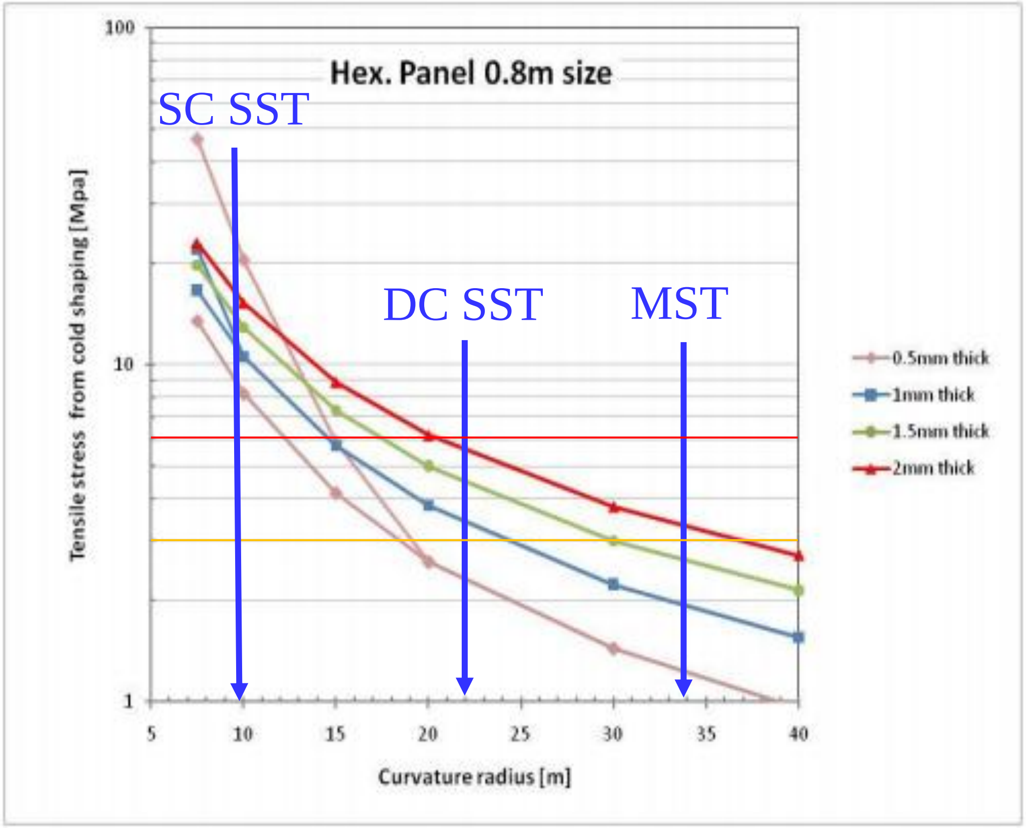


Mirrors for the SST

- MST and LST, use cold slumping:



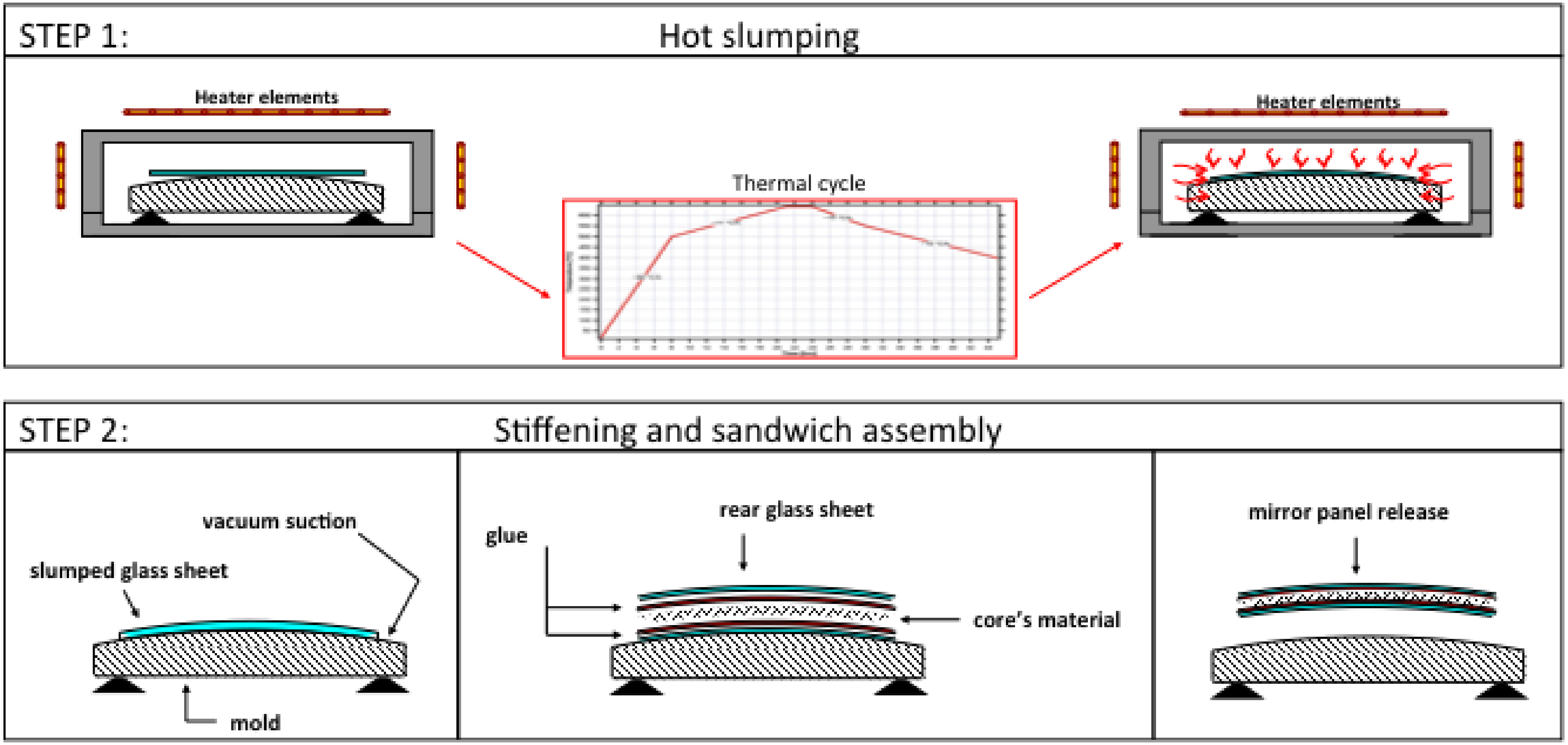
- Not possible for SST, problem is small radius of curvature.



- SC design also aspherical shape.

Mirrors for the SST

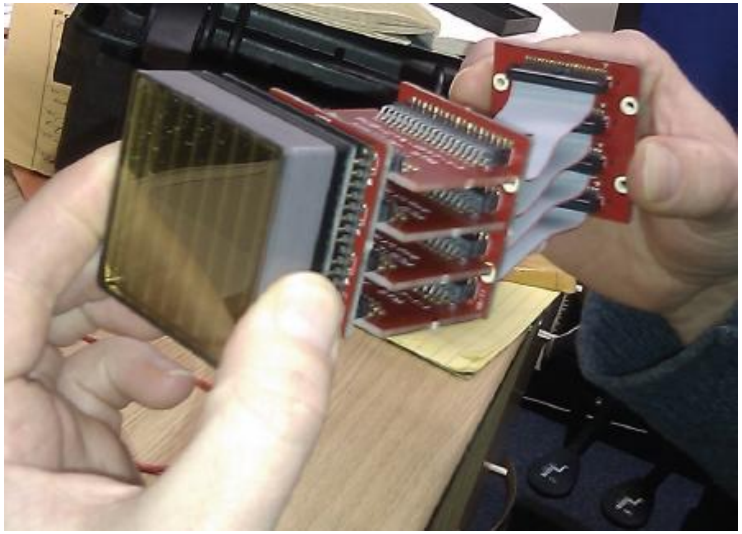
- Solution...

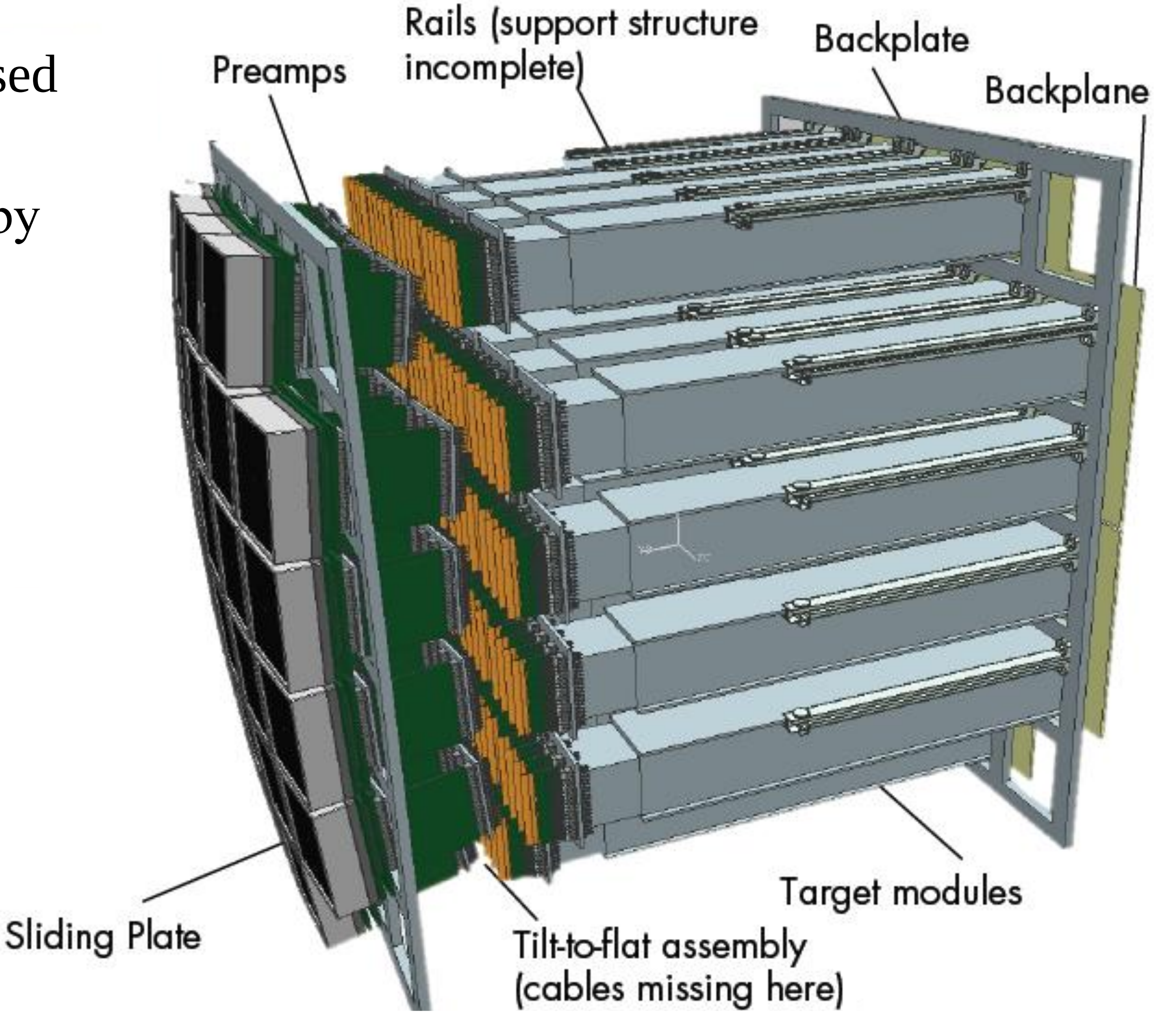


- Required radii of curvature achieved with excellent surface quality.

Camera for the SC SST

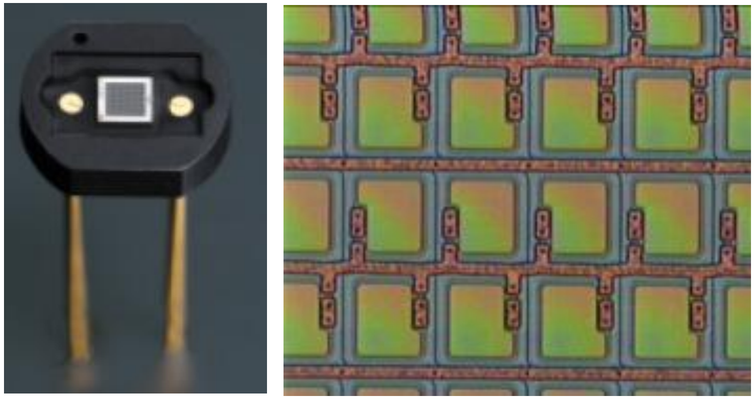
- Durham, Leeds, Leicester and Liverpool designing MAPM-based camera.
- "Target" electronics developed by Japanese/US collaborators and provided by SLAC.
- Sensor Hamamatsu H10966:



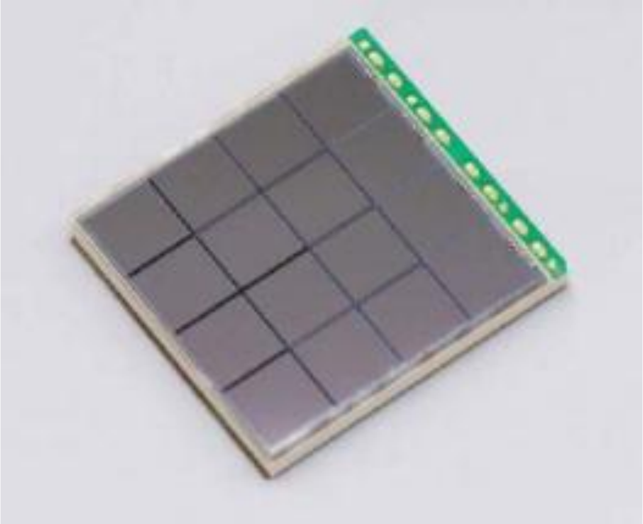


Alternative sensors – Si PMs

- Silicon photomultipliers, reverse biased p-n junction.
- Photon liberates initial e-h pair.
- High bias voltage leads to "shower" of electrons and holes and significant current pulse.
- "Quench" by restricting bias voltage.
- Each pixel many cells:



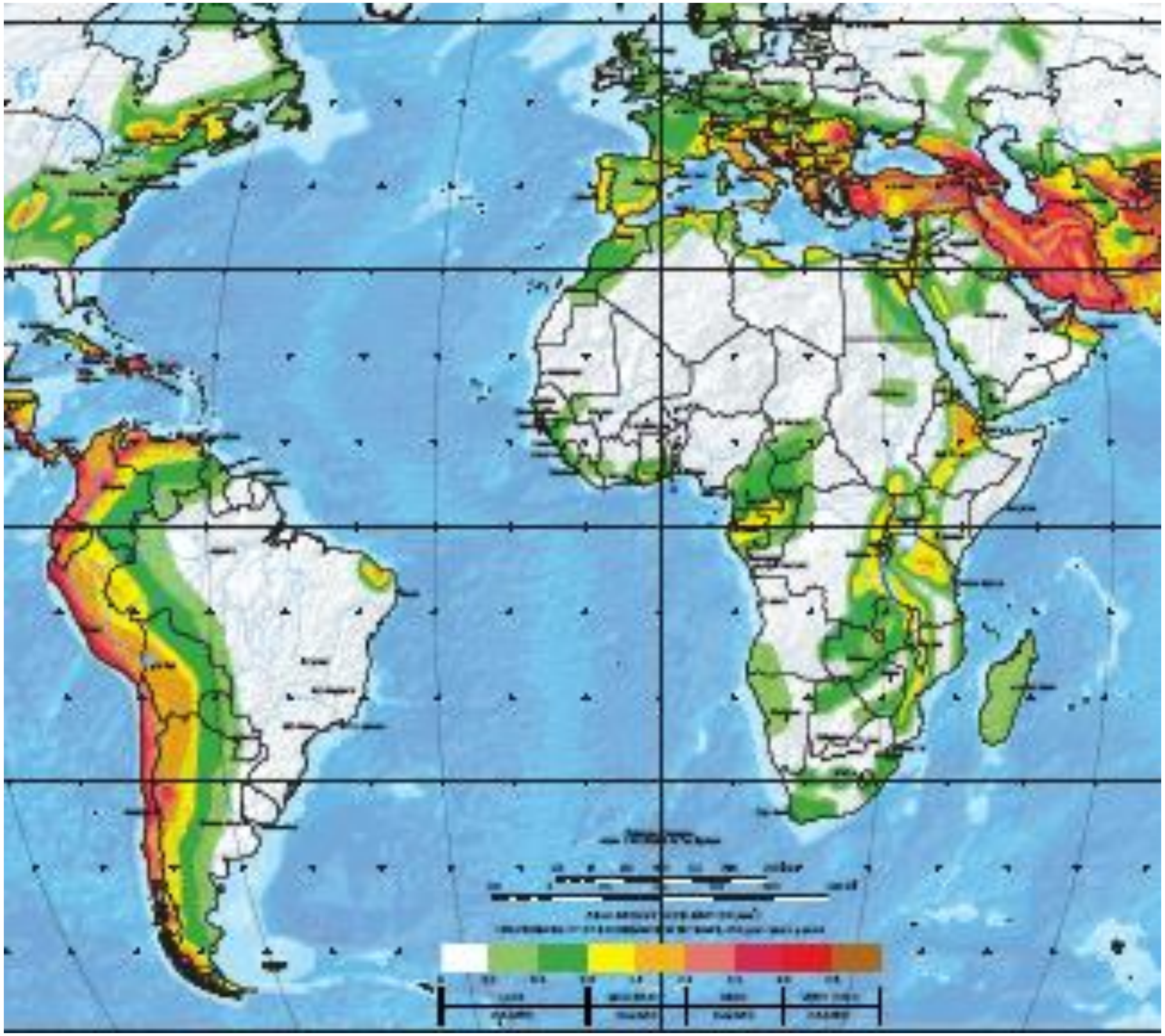
- Recently available are arrays of Hamamatsu Si PMs, 4 × 4 pixels, each of size 3 × 3 mm^2:



- Design camera so can exchange MAPM sensor plane and pre-amp for Si PMs with matched pre-amp.

CTA site choice

- Sites under consideration in Argentina and Namibia.
- Considerations include altitude, cloud cover, seismic loads (see right)...
- Max Likely Earthquake horizontal accelerations:
  - Namibia, 0.08 g.
  - Argentina, 0.34 g.
- Vertical accelerations approx. $^{2}/_{3}$ of above.
- Effects depend strongly on local conditions, e.g. soil type.



Advantages and disadvantages of Namibia!

Summary

- Next steps in γ-ray astronomy/astrophysics need new instruments – CTA.
- CTA could be built now, using existing technologies, but there are areas where better performance per pound can be achieved.
- UK groups are leading much of this innovative effort.
- Aim to have CTA operational by end of the decade...
- ...and UK scientists in a position to profit fully from the data it will deliver.