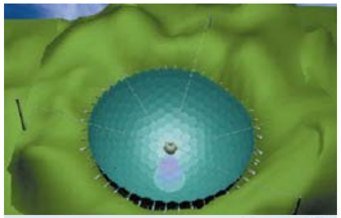
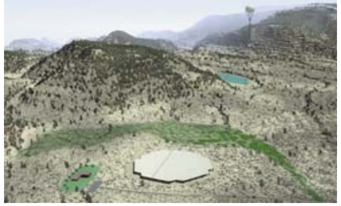
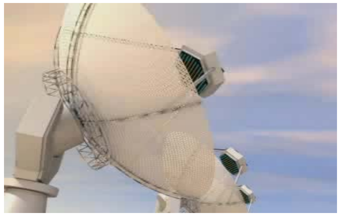
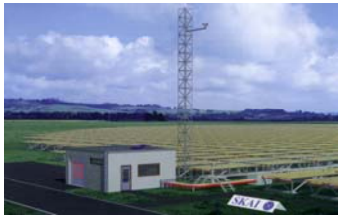



Focal Plane Arrays & SKA

Peter Hall

SKA International Project Engineer

www.skatelescope.org

Dwingeloo, June 20 2005

Outline

- **Today:**
  - SKA and antennas
  - Phased arrays and SKA
  - Hybrid SKA possibilities
    - A hybrid based on AA + SD/FPA
  - FPAs, AAs and SKA
- **Tomorrow:**
  - Politics and collaboration
  - Re-useable deliverables in SKA demonstrators

SKA Challenges

- Technology

Performance + Cost

- Wideband, efficient antennas
- Fast, long-distance, data transport
- High performance DSP & computing hardware
- New data processing and visualization techniques

- Project Management

- Evolving science goals
- High levels of technical risk
- International politics
  - Possible funding phase slips
- Ambitious delivery timescale
- Industry liaison
  - Pre-competitive alliances +

Main Technology Drivers

- Frequency range
- Field-of-view
- Number of independent fields-of-view
- Balance between survey and targetted instrument

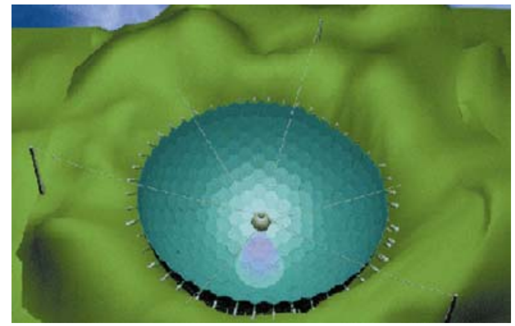
- See EWG whitepaper reviews + demonstrator evaluations

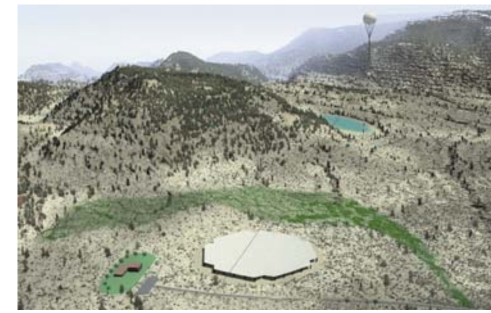
SKA Antennas

- **Range of possible solutions**
  - Aperture phased arrays
  - Flux concentrators (dishes)

- **Need at least two antenna types to meet current spec**
  - Cost effective high-frequency solutions don't provide enough area at low frequencies
  - Want good efficiency at high frequency AND multi-fielding (or at least wide field-of-view) at low frequency
  - The "hybrid" approach

- **SKA concepts have different antennas BUT much post antenna**





Phased Arrays & SKA

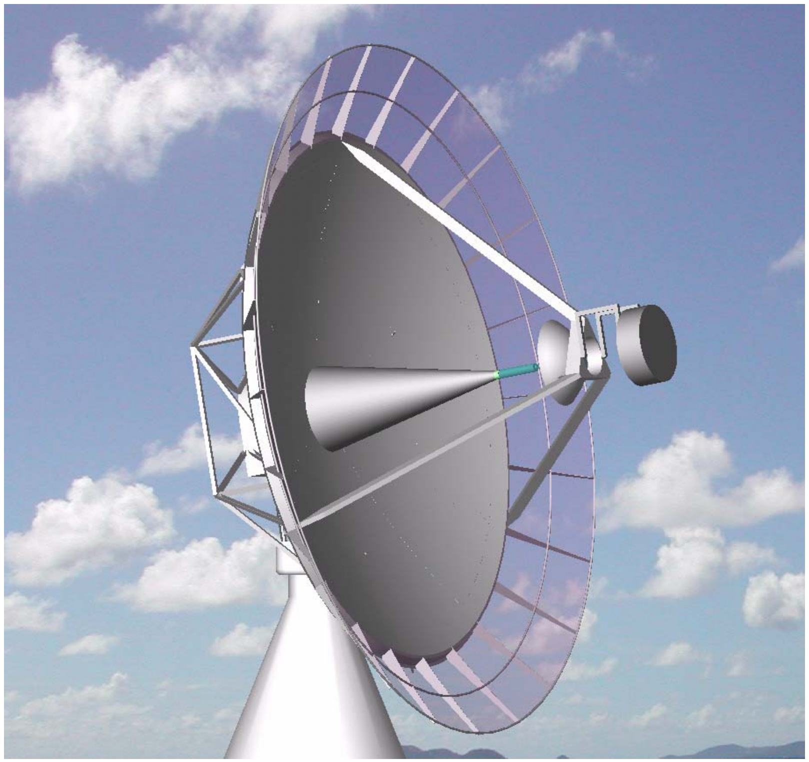
- **Originally:**
  - Phased FPAs for very large concentrators (dish, cylinder) to get ‘reasonable’ FOV (~1 deg^2 at 1.4 GHz)
    - Small N concepts
  - Aperture arrays with very small RF-phased elements (‘patches’)
    - Large N concept
- **Now:**
  - All of the above
  - Wide-field cylinder (> tens of deg^2)
  - Small dish (~12m) + FPA to get wide FOV below ~2 GHz
    - (tens of deg^2)
  - Digital AA concept feasible?

- ***Phased arrays are (almost) ubiquitous in the SKA***
  - *Central to (almost) all wide-field concepts*

Story So Far

- **Concept whitepapers and EWG/SWG reviews**
  - Rounds 1 and 2
- **Demonstrator EWG reviews and ranking**
  - Including initial risk (performance + economic) assessment
- **Combining versatile wide-field concentrator with FPA may be attractive**
  - Concentrator = small dish?
  - Captures some (cost?) benefits of dishes with some wide FOV advantages of phased arrays
  - No whitepaper at this point
    - » But interesting to think what overall SKA performance and budget might be achievable
  - Low filling factors (~0.1) but versatile mosaic modes conceivable
- **Recognize compelling case for aperture array sub-300 MHz**

A Hybrid SKA?

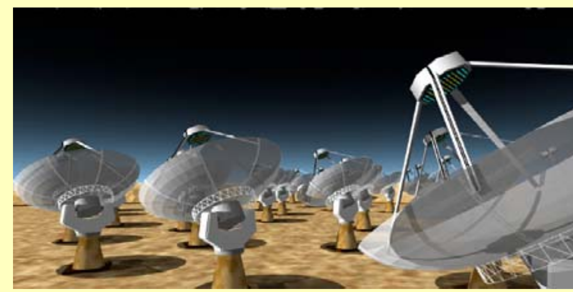


Courtesy S. Weinreb, Caltech

> 2 GHz

Courtesy ASKACC

Via SD/FPA?

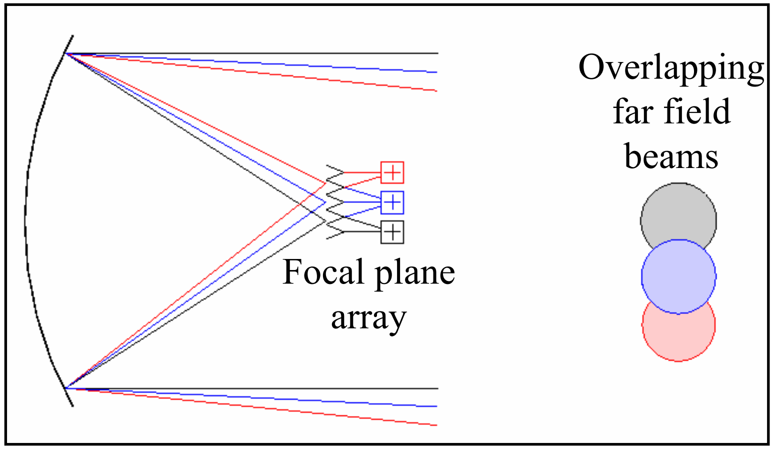


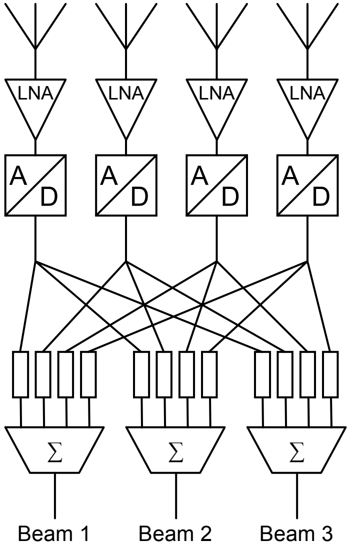
< 2 GHz

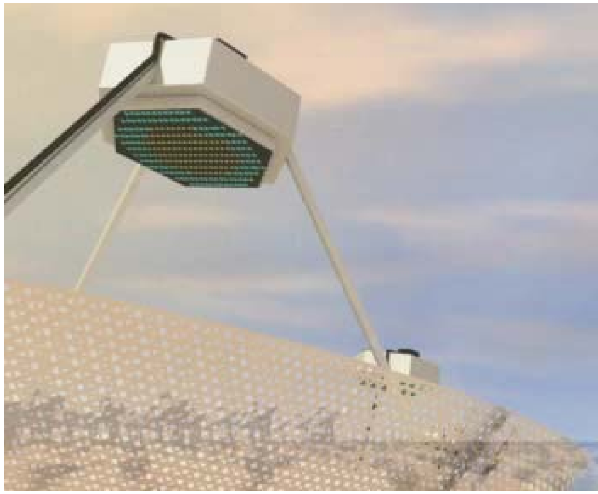
Courtesy ASTRON

Phased Focal Plane Arrays

- **Distinguished from "multi-feed" systems by:**
  - Elements combined in a beamformer
  - Element spacing chosen to fully-sample the focal field information
- **For radio astronomy:**
  - Bandwidth: >2:1
  - Low noise





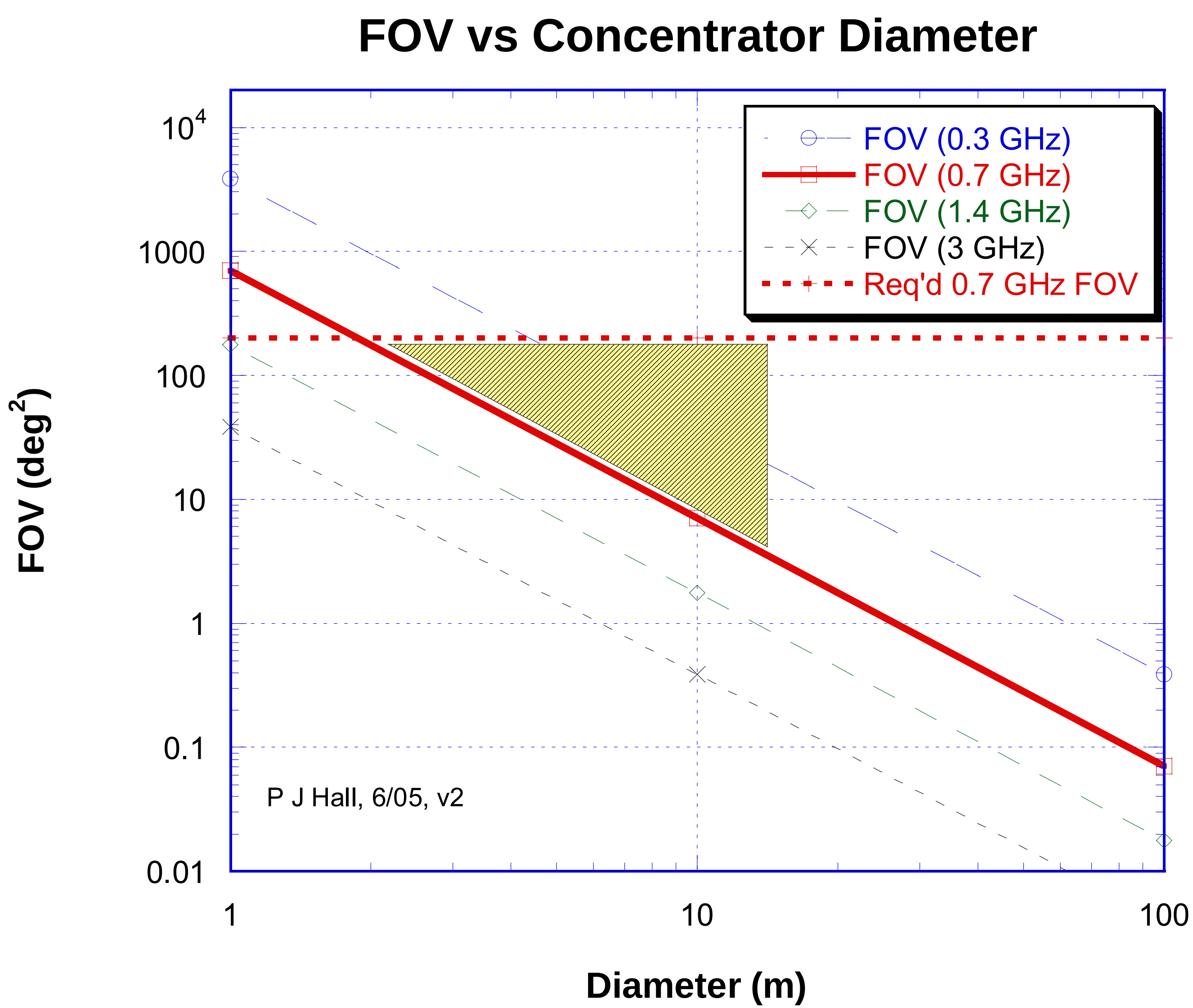


Courtesy Scitech

Amplitude and phase weighting

Conceptual beamformer architecture

Plain Person's View of FOV Expansion



FPAs and SKA

- **Much commonality between AA and FPA development work**
- **But different optimizations**
  - Physical (mechanical/weight/…, operating temperature, …)
  - Electrical (e.m. properties, beam-forming arrangements, …)
- **Expect play-off between AA and SD/FPA for < 2 GHz SKA**
  - Can putative cost benefits of SD/FPA be realized?
  - Does the SD/FPA win over just having more (smaller) dishes?
    - » Depends partly on level of DSP/correlation needed for SD/FPA to meet demanding SKA cal and imaging specs
    - » 6 m dish → ~300 MHz lower limit
  - Can maturity of AA be suffciently demonstrated?
  - What are the science trade-offs for each approach?

Example SKA Hybrid

- **Assume:**
  - Frequency range ~0.1 to ~ 3 GHz
  - Budget remains at ~ 1B $/€
  - Need to design a survey instrument from Day-1
    - Biases some resource allocation in design
- **Acknowledge the insight of Jaap Bregman**
  - See forthcoming EXPA papers

Thumbnail of Instrument

- **A sky-noise limited aperture array covering 0.1 – 0.3 GHz**
  - 33 tiles, each, 1.8 m square per aperture (12 m dish equiv.)
  - Each tile: 2 x 2 bow-tie elements spaced at 0.9 m
  - 2900/cos(θ) deg^2 FOV at 0.17 GHz; scales with λ^2
    - » 33 beams per FOV; multiple FOVs possible
  - Const A_{eff} to ~ 0.2 GHz (dense array)
    - » Above 0.2 GHz A_{eff} scales with λ^2 (sparse array)
- **A small dish/FPA array covering 0.3 – 3+ (?) GHz**
  - 4000 x 12 m dishes; F/d ~ 0.5
  - 8 x 8 FPAs (Vivaldi notch elements)
    - » 3 bands: 0.3-0.7 GHz, 0.7-1.6 GHz, 1.6-3.6 GHz
  - A_{eff}/T_{sys} per beam ~ 9000
    - » A_{phys} = 452 000 m^2; A_{eff} = 272 000 m^2; T_{sys} ~ 30 K
  - Acknowledged issues of FPA co-location or switching (translation)

Thumbnail (2)

0.3 – 3 GHz

0.1 – 0.3 GHz

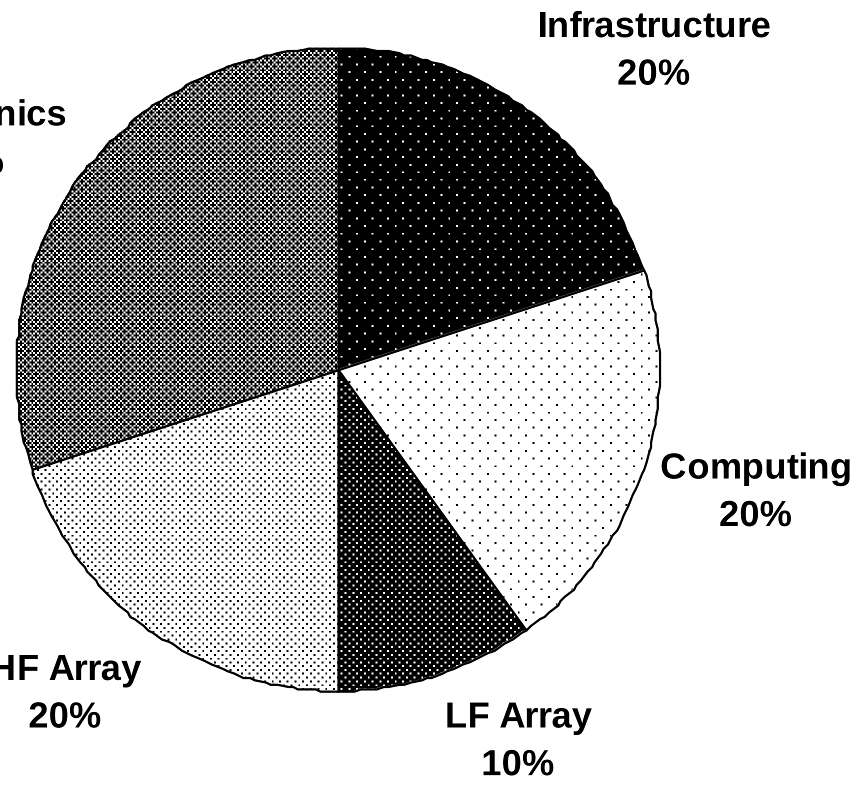
A SD/FPA Fly-Over

Visualization by Scitech

Performance Snapshot

- **For 0.1 – 0.3 GHz array**
  - A_{eff} ~ 1 km^2 at < 0.17 GHz
  - 7 sr sky survey in 1.5 days with 5 hr integration per field (reaches thermal noise sensitivity, assumes full u,v coverage in 5 hrs)
- **For 0.3 – 3 GHz array**
  - A_{eff}/T_{sys} per beam ~ 9000 (cf 20 000 current SKA target
  - 25 % fractional bandwidth target met or exceeded
  - 0.7 GHz survey: 2 x 10^{18} units (cf 1.5 x 10^{19} target)
  - 1.5 GHz survey: 8 x 10^{17} units (cf 3 x 10^{17} target)
    - » Survey LF sensitivity reduced because of FOV and A/T shortfall
    - » Maybe gain factor of ~2 with less conservative BW assumptions
  - FOV approx frequency independent within each band
    - » 130 deg^2 at 0.7 GHz
    - » 25 deg^2 at 1.5 GHz
    - » 5 deg^2 at 3 GHz

Ball-Park Costing



Aperture Arrays v. SD/FPA

- **AA upper freq limit looks firm at ~1.6 GHz**
  - Primarily economics
- **Sky coverage, field agility and TRUE MULTI-FIELDING are real AA advantages**
- **AA is innovative, high risk, technology**
  - But *no less* demonstration in SKA context than cheap dishes + FPAs
    - By no means certain that one can make a 12m dish, mounts, drives, plus 3 FPAs for $100k per antenna
    - However, AA is *very* sensitive to per-unit component and manufacturing costs
- **Analog (RF) beamforming stages limit current AA concepts (e.g. in number of FOVs)**
  - Digital tiles (e.g. 2-PAD) are ultimate technology which overcome RF B/F limits
  - Might they be viable on a 2015 timescale?
- **Digital tiles are also key to SD/FPA approach**
  - Economic viability on ~2015 timescale is critical
- **Substantial calibration and related issues to be resolved for *both* AAs and SD/FPA**

Closing Thoughts

- **SKA technology selection based on demonstration**
  - FPA-based demonstrators will play a key part
- **Technology shortlisting 2007; selection 2009**
- **SKA international funding proposals (2009) rest on credible technology proposals**
  - Delayed or impaired technology demonstration will sink the SKA as a next-decade project
- **Collaboration is a way of maximizing the likelihood of quality demonstrators**
- **A favourable industry reaction to SKA will be central to funding success in Eu, Aust, SA ….**
  - Virtue in early industry links at regional and international level