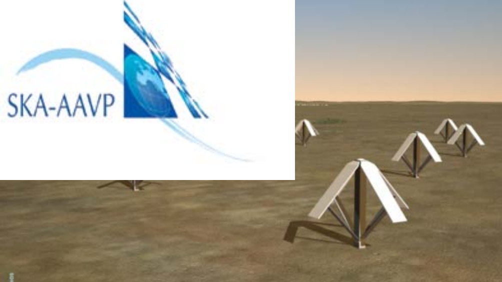


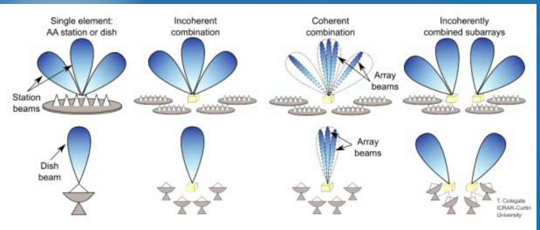
Aperture Arrays for the SKA

Arnold van Ardenne

AAVP-Coordinator

ardenne@astron.nl

Courtesy: Lofar & SKADS/AAVP teams



Courtesy: JPMacquart

Paradigm shifts:

- Huge flexibility by electronic control
- Multi- vs. Single sky pixel processing

SKA$_2$ Key Science Drivers

ORIGINS

- **Neutral hydrogen in the universe from the Epoch of Re-ionisation to now**

  When did the first stars and galaxies form?
  How did galaxies evolve?
  Dark Energy, Dark Matter

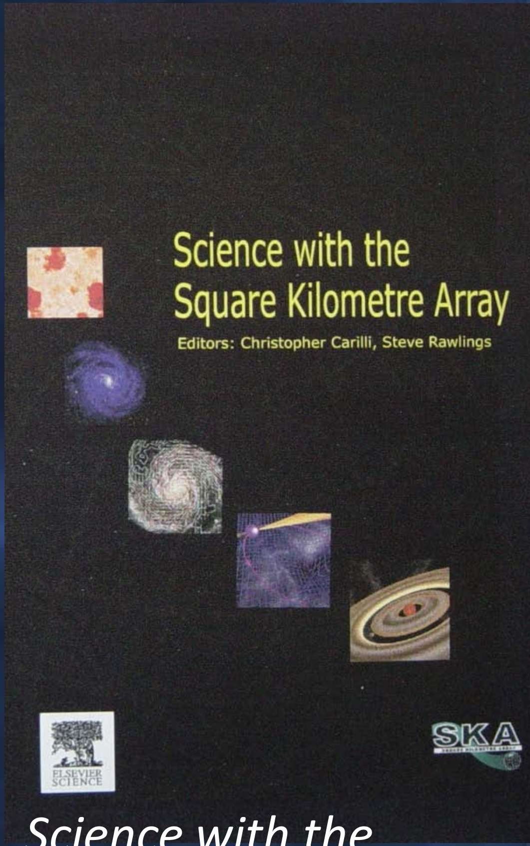
- **Astro-biology**

FUNDAMENTAL FORCES

- **Pulsars, General Relativity & gravitational waves**

- **Origin & evolution of cosmic magnetism**

TRANSIENTS (NEW PHENOMENA)



Science with the Square Kilometre Array

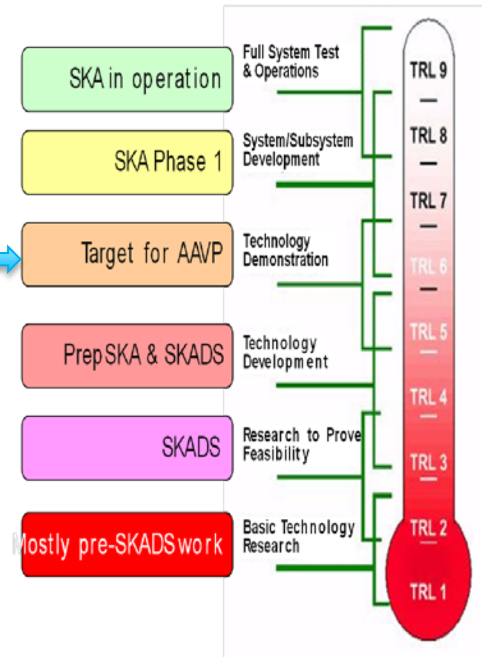
(2004, eds. C. Carilli & S. Rawlings, *New Astron. Rev.*, **48**)

SKA AA System Design 2005-2012

- **(Early R&D 1995- 2004)**

- **SKADS - EC funded SKA design Study 2005-2009**
  - EC FP6 funding 2005-2009 (€ 10.4M) plus additional for Marie Curie
  - All material incl. White Paper available through website www.skads-eu.com

- **AAVP 2010- 2012**
  - nationally funded (Eur/Aus) supplemented by PrepSKA
  - Context provided by SKA/SPDO
  - Activities based on (continued)System design approach



- **AA-Relevant Pathfinders & Demonstrators**
  - LOFAR-ILT, MWA, LWA, EMBRACE , APERTIF
  - Others for e.g. SP/network purposes e.g. JIVE/UniBoard

- **From 2012 SKA-AA moving from Preparation into Detailed design and Pre-Construction: PEP**

AA's in SKA phased planning

SKA_1

Freq. Range	Collector	Sensitivity	Number / size	Distribution
70 MHz to 450 MHz	**AA-low** Sparse AA	1,000 m^2/K at 100 MHz	50 array stations, Diameter 180 m	70% within 5 km dia., 30 % along 3 spiral arms out to 100 km radius
300 MHz to 3 GHz	Dishes with single pixel feed	1,000 m^2/K at 1.4 GHz	250 dishes Diameter 15 m	

SKA_2

Freq. Range	Collector	Sensitivity	Number / size	Distribution
70 MHz to 450 MHz	**AA-low** Sparse AA	4,000 m^2/K at 100 MHz	250 array stations, Diameter 180 m	66% within 5 km dia., 34% along 5 spiral arms out to 180 km radius
400 MHz to 1.45 GHz	**AA-mid** Dense AA	10,000 m^2/K at 800 MHz	250 array stations, Diameter 56 m	
300/1000 MHz to 10 GHz	Dishes with single pixel feed + PAF	10,000 m^2/K at 1.4 GHz	2000 – 3000 dishes Diameter 15 m	50% within 5 km dia, 30% 5km - 180 km 20% 180 km-3,000 km.

Principal AAVP Deliverables in time

UNIBOARD processor ASTRON, JIVE

- 4TMAC's/ 400W
- 7304 components /25798 connections

AA-low

Technol. demonstrator & Costed sub-system design	AAVS1/2013
SKA_1 full pre-production prototype array	AAVS2/2015
SKA_1 manufacturing data package	2015

Courtesy: Gijs Schoonderbeek

AA-mid

single array performance demonstrator	AAVS1	2013
multi-array interferometer performance demonstrator	AAVS2	2015
SKA_1 capable costed design, Station level size (~2000sqm)		>2016

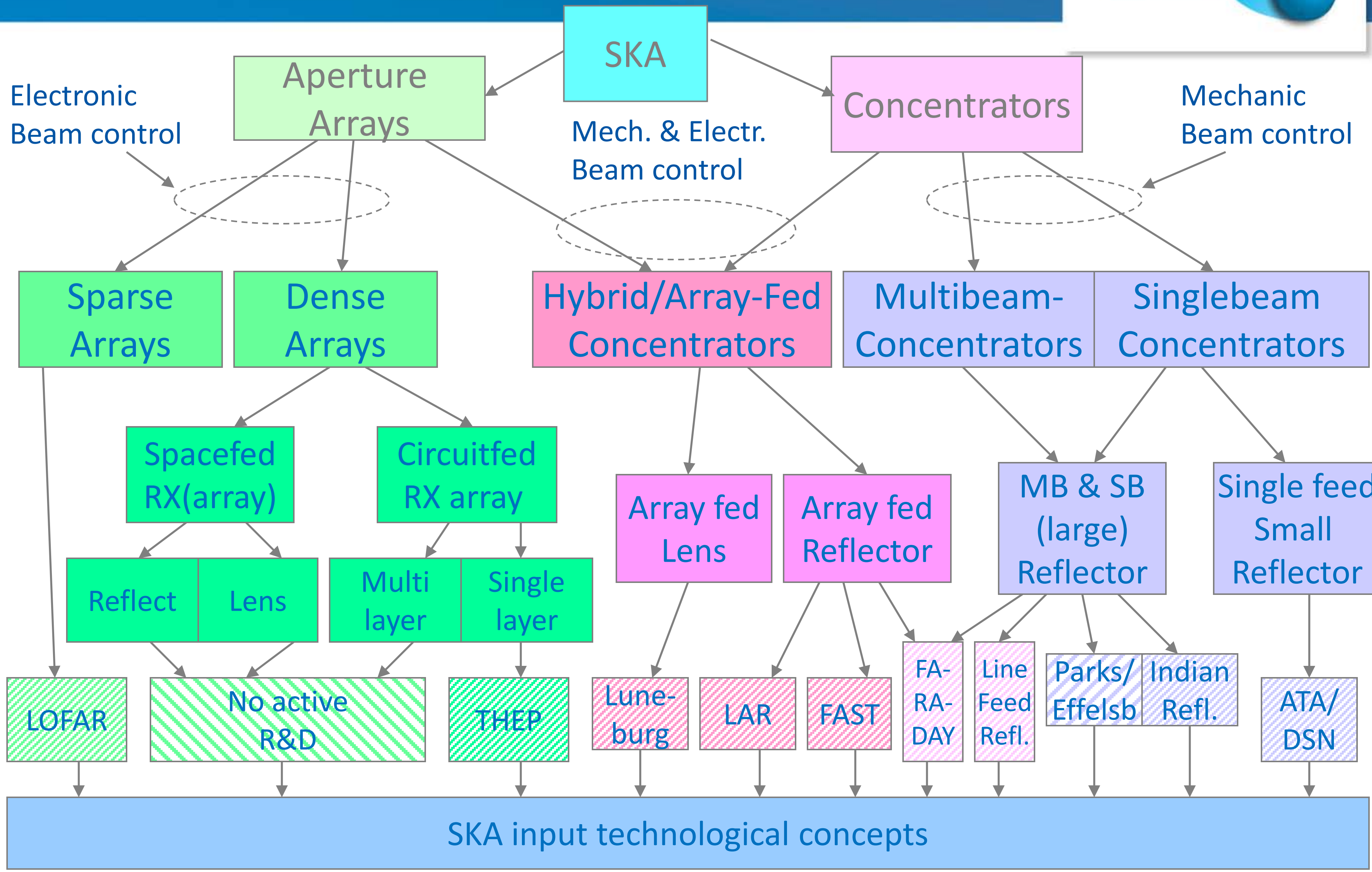
AA system

AA-lo and AA-mid CoDR	2011
SKA_2 technology roadmap & costed system design	2014

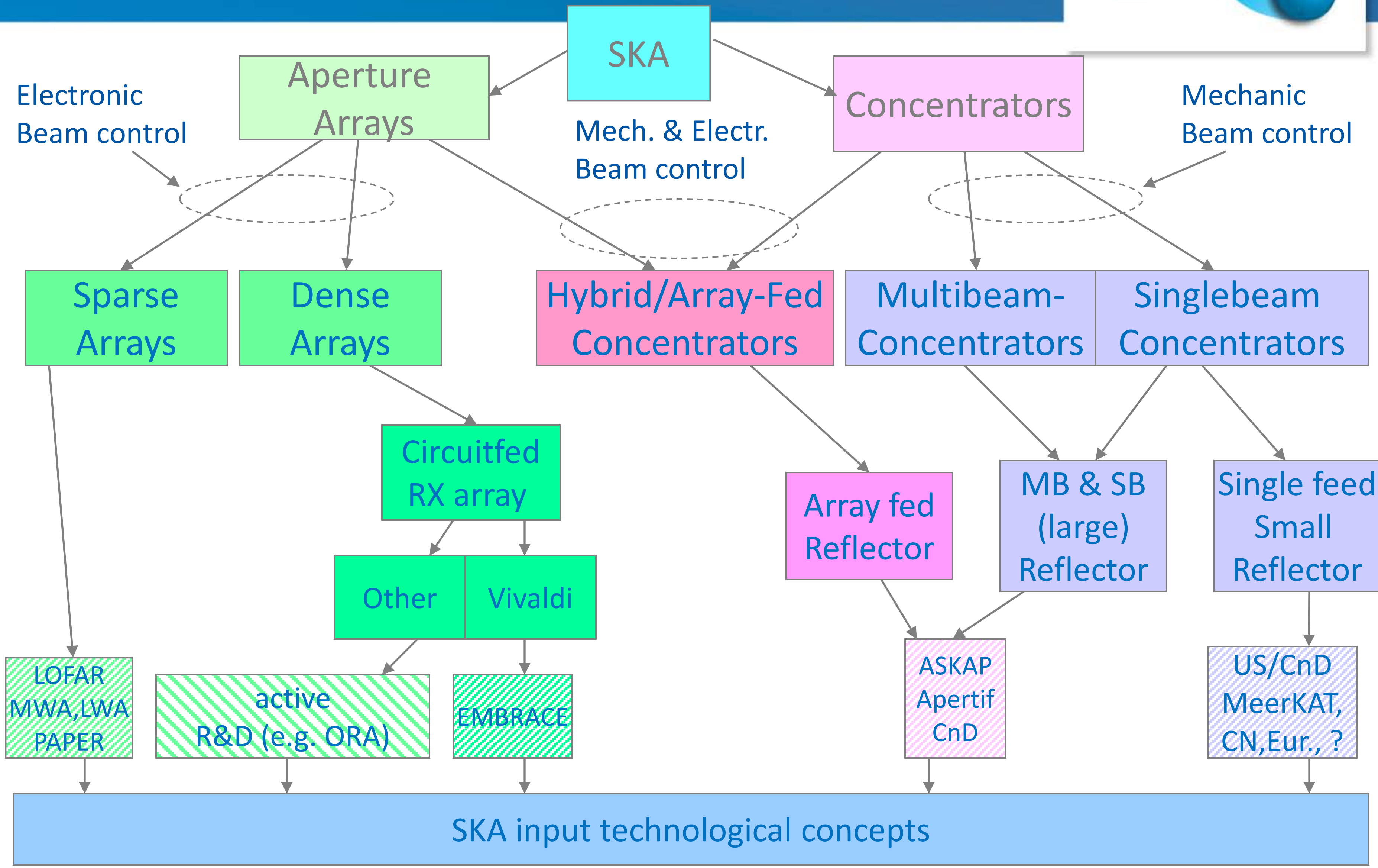
AAVP Programmatics 2011

- Appointed Project Manager, Verification Scientist
  - *Derek McKay-Bukowski (PM)& Ilse van Bemmel (VSc)*
  - *Funded through PrepSKA-SPDO*
- SPDO AADomain specialist
  - *Andre Gunst (50%)*
- Passed AA-CoDR 19-20 April/23-24 November
- Endorsed: Workshop ICT in R.A. workshop in Aveiro(Pt) 24-25 May
- AA-Low workshop Perth 6-9th September @ ICRAR
  - Main purpose: Preparing for Preliminary Design AA-Low Req. Review in March ’12
- Now: AA-workshop Dwingeloo 12-16th December
  - From AAVP toward Preconstruction Phase
- Collaboration toward PEP phase

Systematics: Concept tree widefield Radiotelescopes for the SKA 2003

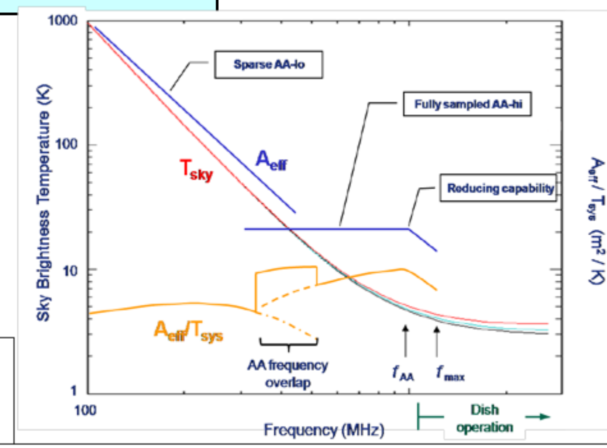


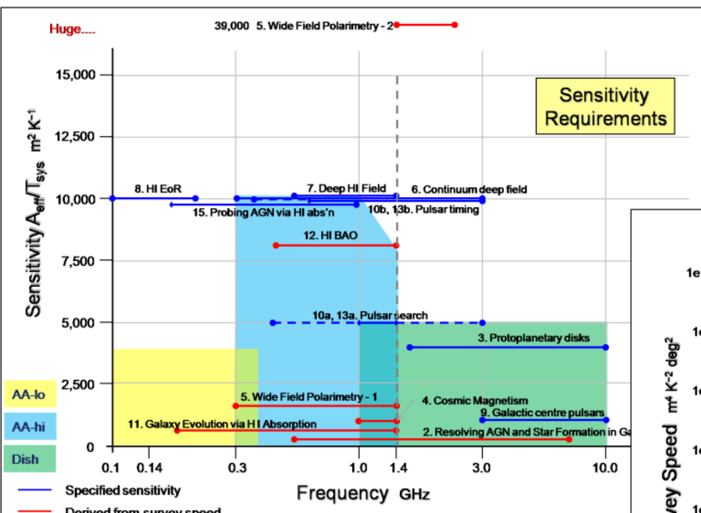
Selection: Concept tree widefield Radiotelescopes for the SKA 2010



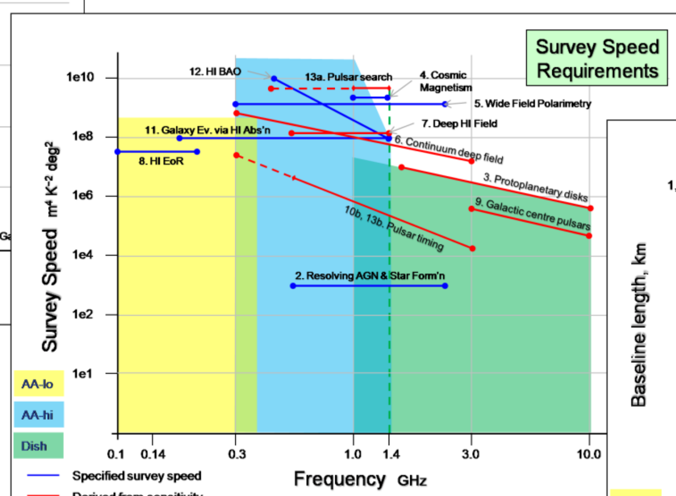
AA's in SKA Widefield System scenario

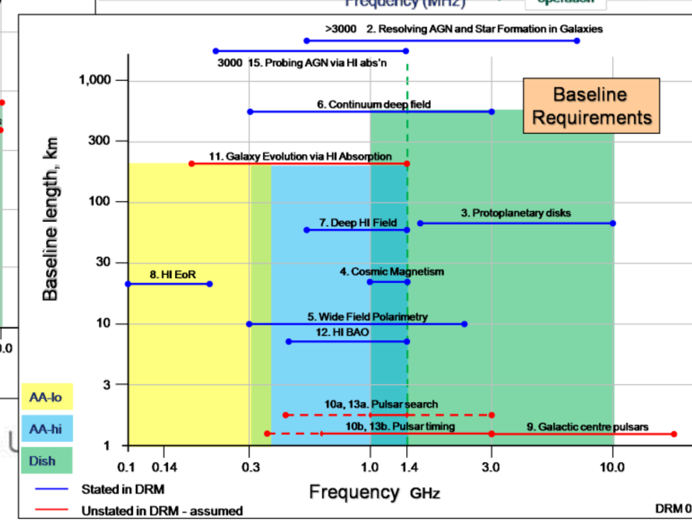
System concept	Sparse Aperture array (AA-lo) *250 stations , 180m*	Dense Aperture array (AA-hi) *250 stations , 56m*	Dishes with single pixel feed *1200 dishes, 15m*
Freq. Range	70 MHz to 450 MHz	400 MHz to 1.4 GHz	1.2 GHz to 10 GHz





See e.g.SKADS White Paper,
SKA memo 122 or
www.SKADS-eu.org

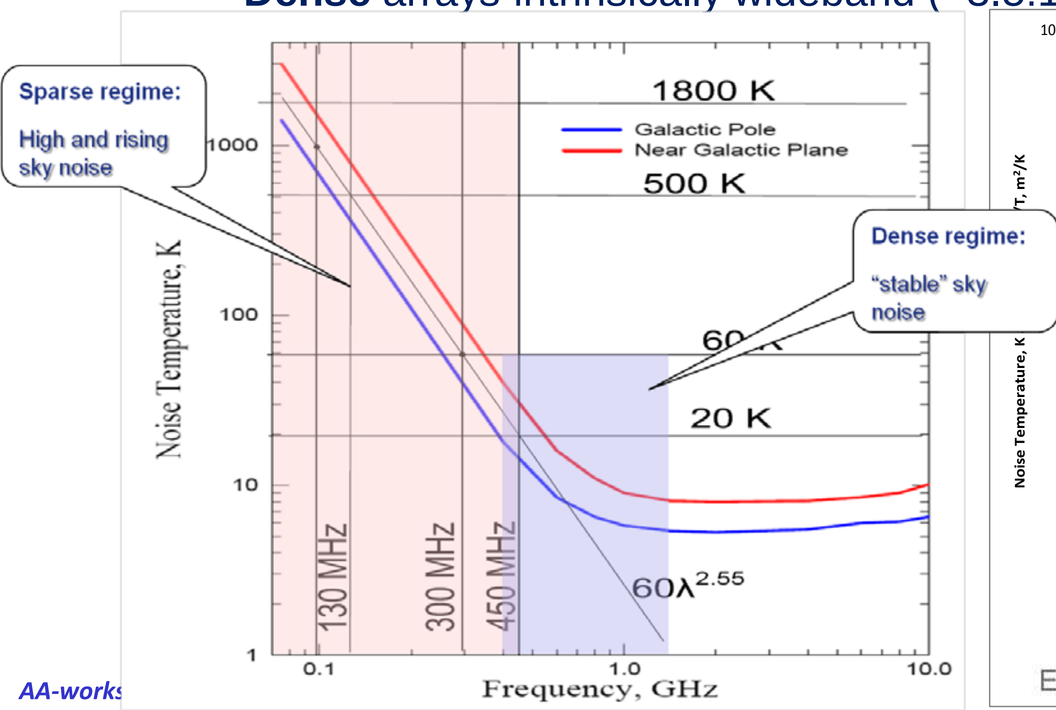


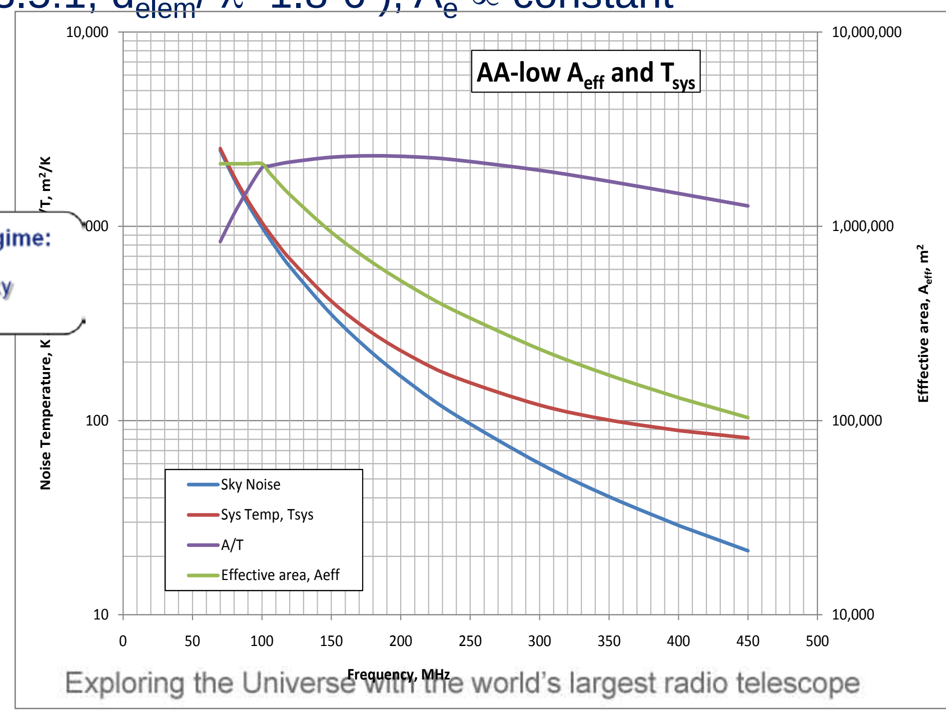


Exploring the U

Array choice vs. Sky noise

- Below ~300 MHz
  - $T_{sky} \propto \lambda^{2.6}$ hence **sparse** arrays are needed ($A_e \propto \lambda^2$); A_{eff}/T_{sys} not much varying
  - Receiver temperature is not very critical
  - Frequency bandwidth determined by individual element
- Above ~300 MHz
  - T_{sky} ~ constant, receiver temperature is critical
  - **Dense** arrays intrinsically wideband (~3.5:1, d_{elem}/λ~1.8-6), $A_e \propto$ constant



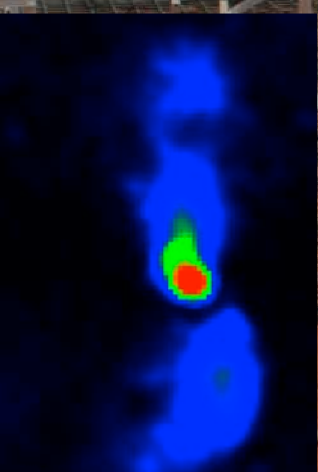


AA input from ongoing work e.g. Int. Murchison Widefield Array (& LWA)

Key players

- AUS/ICRAR, CSIRO, Swinb. e.o.
- US/MIT-Hayst,, e.o.
- India/RRI

- **80-320MHz, Bl ~1.5km/32T**
- **Extension planned toward 128 tiles**



Centaurus A

Courtesy: Peter Hall, Steve Tingay, Frank Briggs

Possibly also from PAPER (S.A.)

- Solely focused on EOR (120-180MHz)
- 2010: 32 stations in Karoo, SA
- Established working array from scratch in < 1 yr, with invaluable help from SA (MeerKAT project, Durbin Univ.)
- Berkeley, NRAO, Penn, South Africa

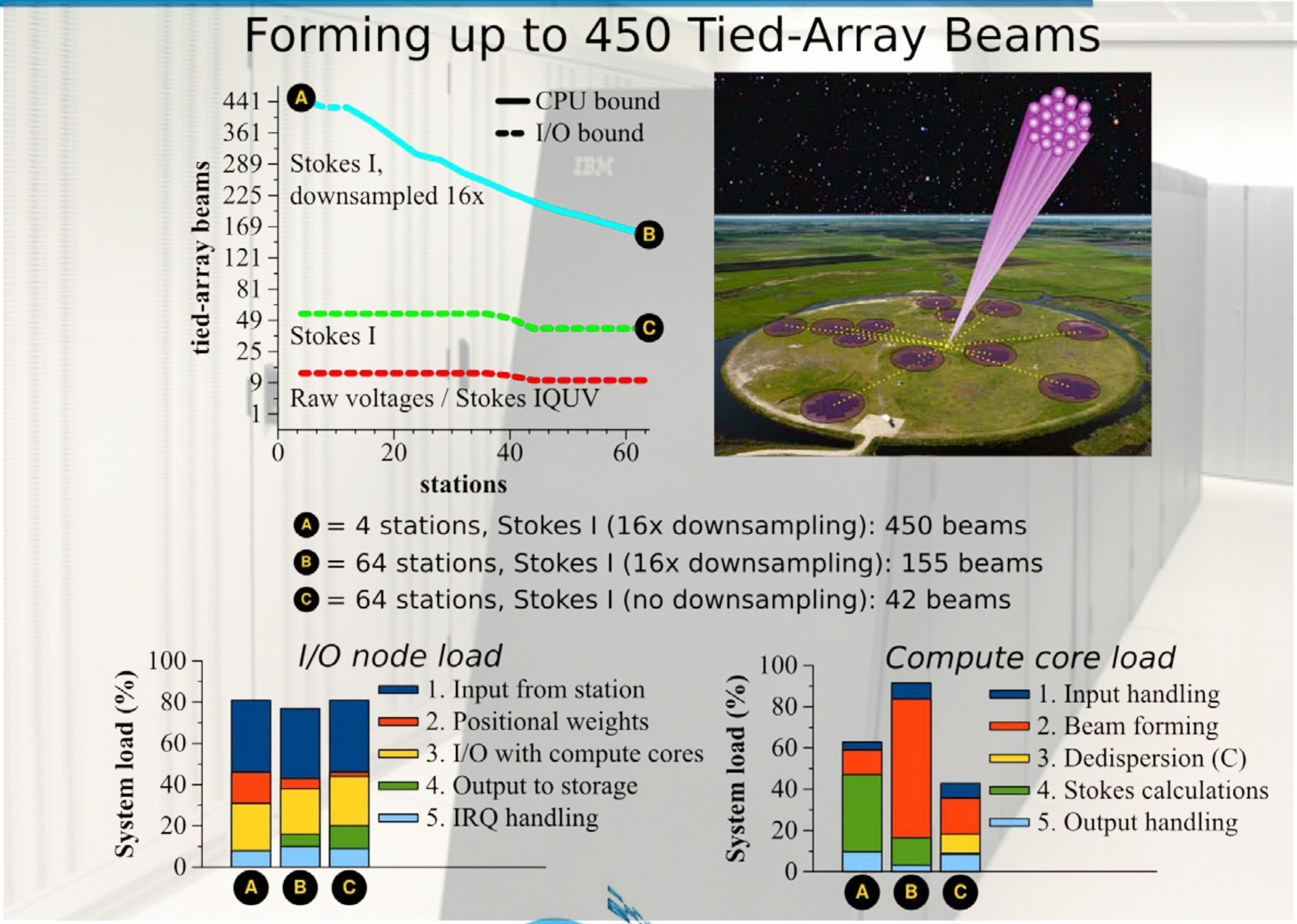
Courtesy: Chris Carilli

Durbin University of Technology

LOFAR Stations Across Europe; 70% naar Nl industrie

Courtesy: Jason Hessels et .al.

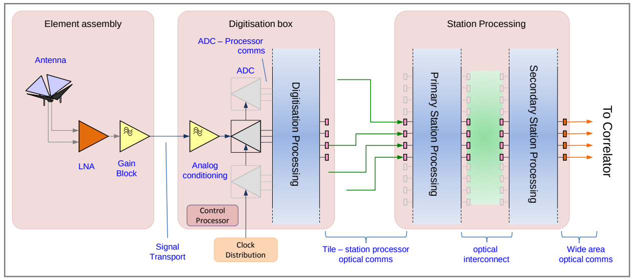
Flexibility, beams and computations

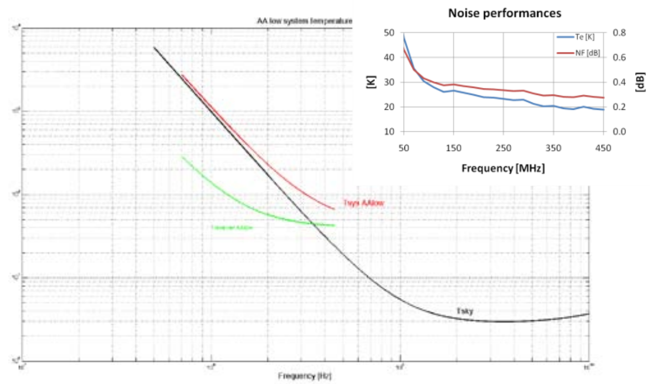


Courtesy: Jan David Mol, Jason Hessels, John Romein

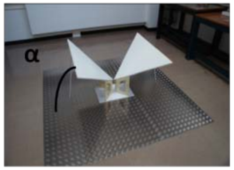
AA- low design issues

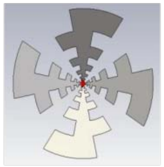
- Dealing with strong frequency dependent skynoise vs receiver noise





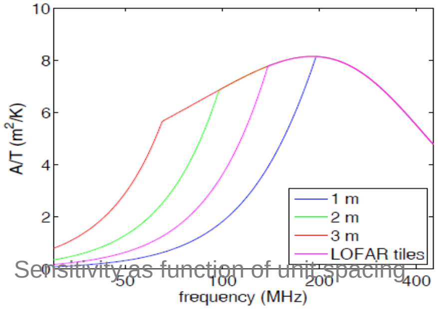
- Antenna design e.g dual vs single band



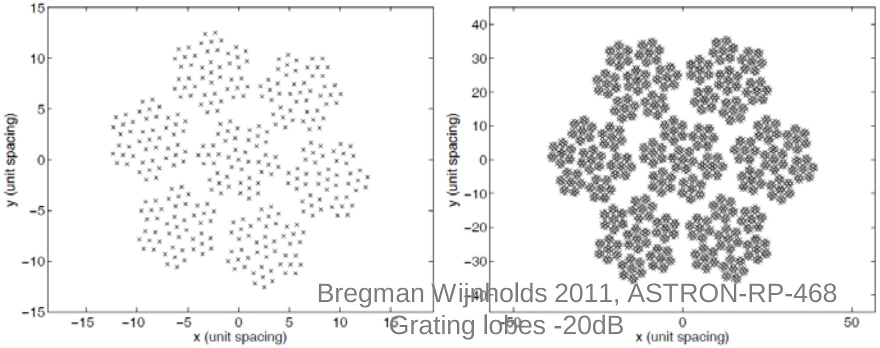


Courtesy: AAVP teams, Jan Geralt bij de Vaate

- Optimal frequency dependent Configuration (e.g. “snowflake”)



Sensitivity as function of unit spacing



Bregman Wijnholds 2011, ASTRON-RP-468

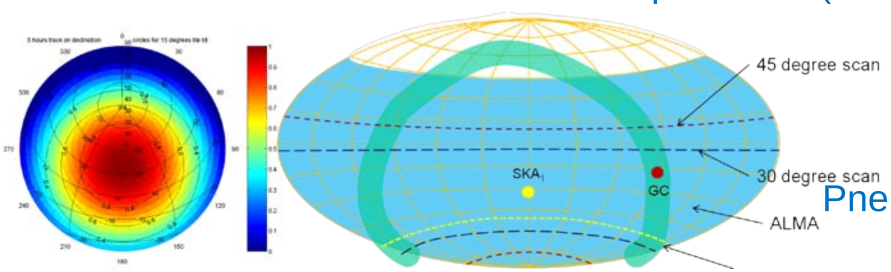
Grating lobes -20dB

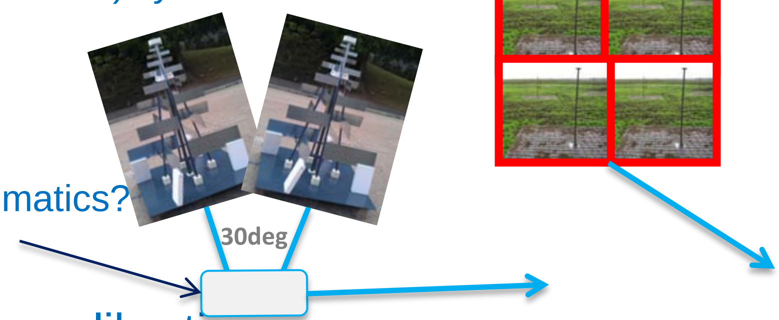
- Dense vs sparse vs science requirements
  - Connected to configuration, filling factor, calibratibility, e.m. design, etc. See above.

AA- low design issues (2)

- Antenna design e.g dual vs single band

- Higher gain antennas means higher Aeff at expense of sky coverage
  - Widest sky-coverage (+/- 80deg) with dipole (gain ~<3dB), LPDA ~7dB (+/-30deg), 0dB(+/-45deg)
  - Alternative 1: 4 dipoles becoming sparse at lowest freq. with single infra trench
  - Alternative 2: LPDA with 2 positional (mechanical) system





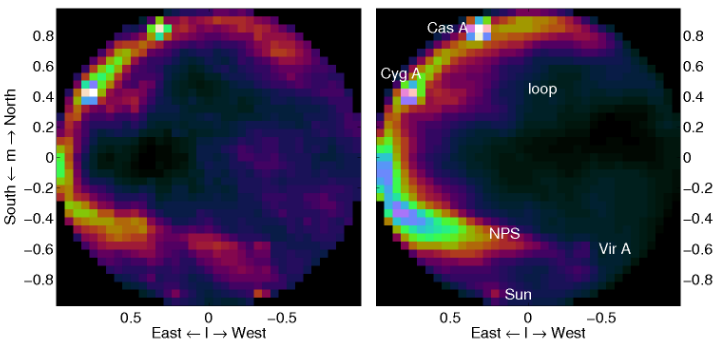
- Filling factor @station level, coverage, calibration

- Assume: Antenna elements are self powered i.e. Only optics to central station

Calibration and Imaging

- Strong Calibration , Imaging and Commissioning team
  - Strong infusion from LOFAR
  - Task lead by Keith Grainge (UCam). Core: Keith, Stefan Wijnholds (SP, algorithms, station calib), Oleg Smirnov (ME, HDR imaging), Ronald Nijboer (algorithms, math.), Tobia Carozzi (widefield polarimetric Imaging), Fred Dullich(beam sim.)
  - Associated: Jan Noordam, Parisa Noorishad, Paul Alexander, Rosie Bolton
- Complex multi-issue task;
  - Configuration, computational efficiencies e.g. modelbased station calibration (N cubed vs NxNlogN) vs other approaches
  - Multiple sources (changing over frequency), propagation effects, computing resources (large data rates (Tbts, Ebps), real-time calibration)
- Interacts with SKA-Calim and co-workers
  - US, Aus, Europe
- Strategy; hierarchy:
  - Instrument characterization
  - System health monitoring / system diagnosis
  - Station- & Array Calibration

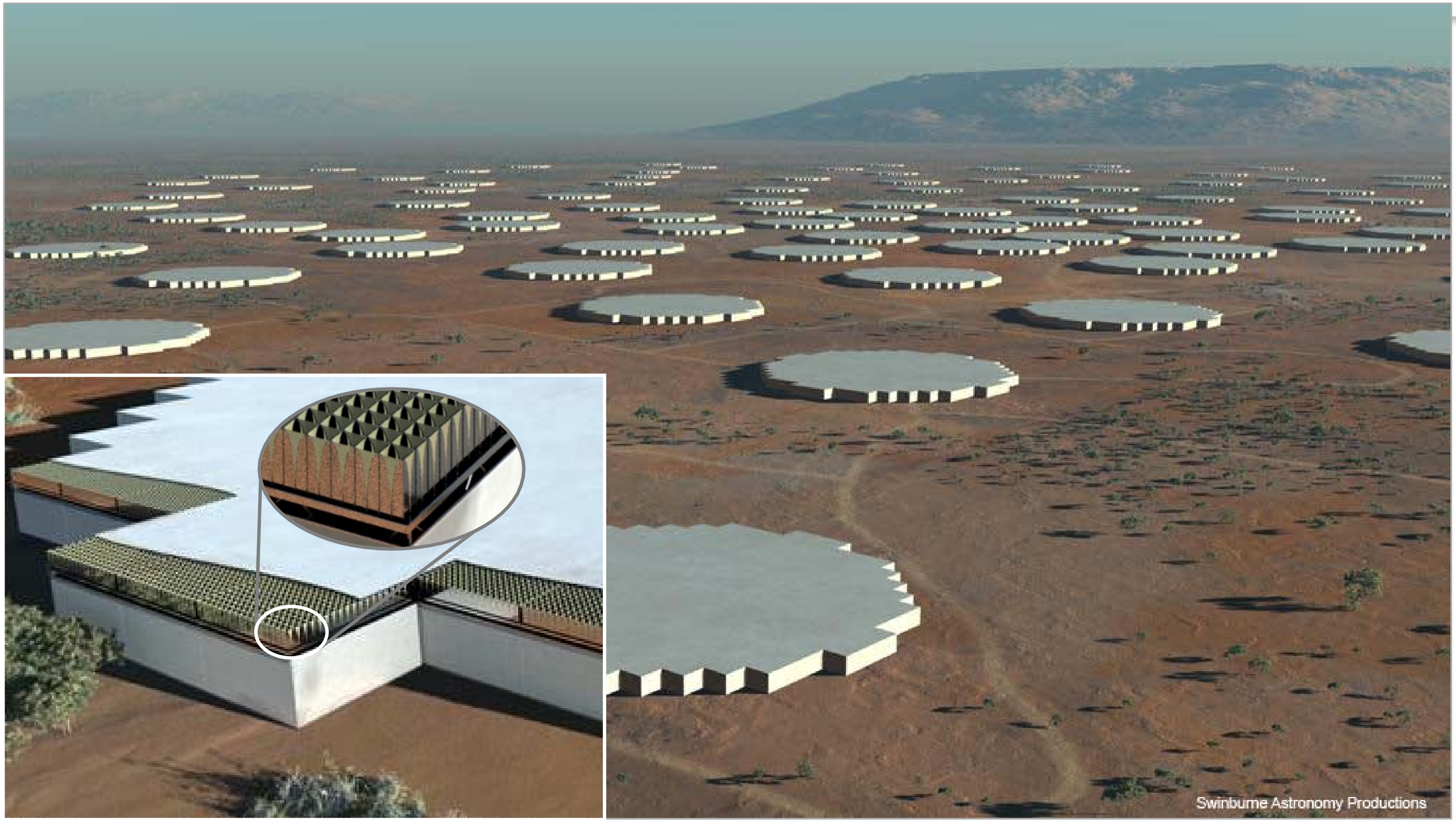
DFT vs. LS imaging (1)
S.J. Wijnholds, URSI Benelux Forum, Jun. 2009
S.J. Wijnholds, Ph.D. thesis, Mar. 2010



Exploring

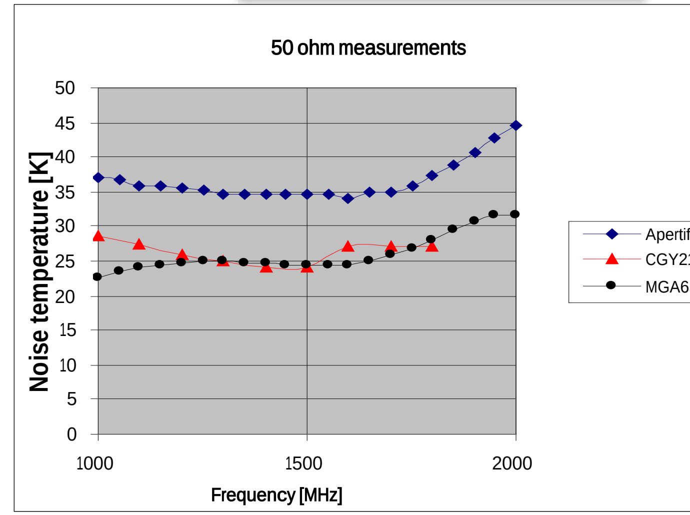
__Several Presentations__

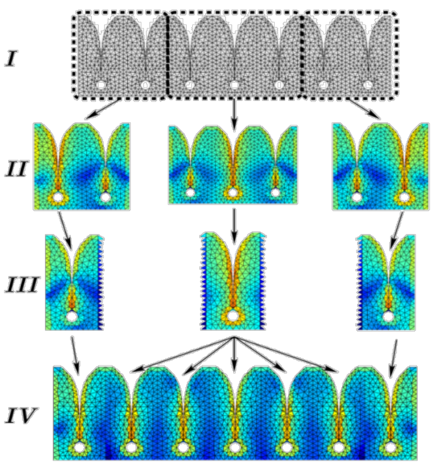
AA-mid Array

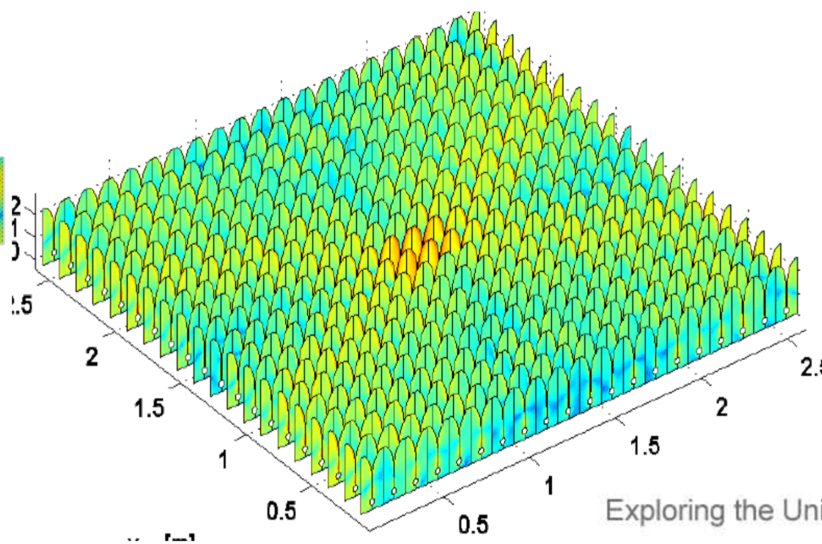


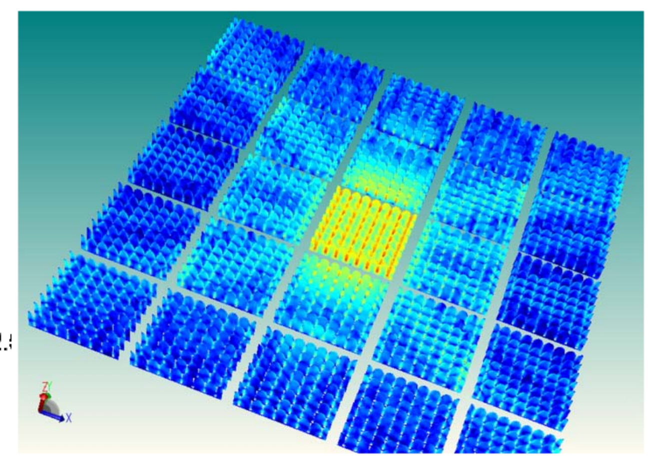
AA-mid (SKADS) resolved issues

- E.M. modelling large arrays
- Math. Phys. Modelling of antenna-circuitry
  - vs scan-angle and system noise
- LNA noise achievable
- Bandwidth >3.5:1 e.g. 400-1,4GHz
- Principles demonstrated to work for R.A.
- Prototype Substation (Embrace)Constructed





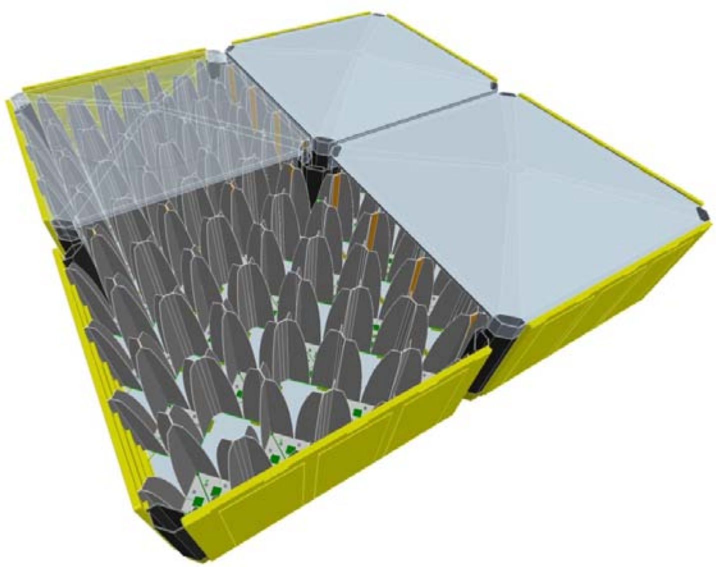


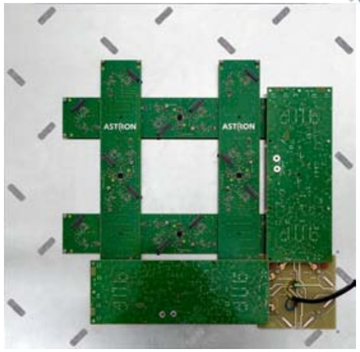


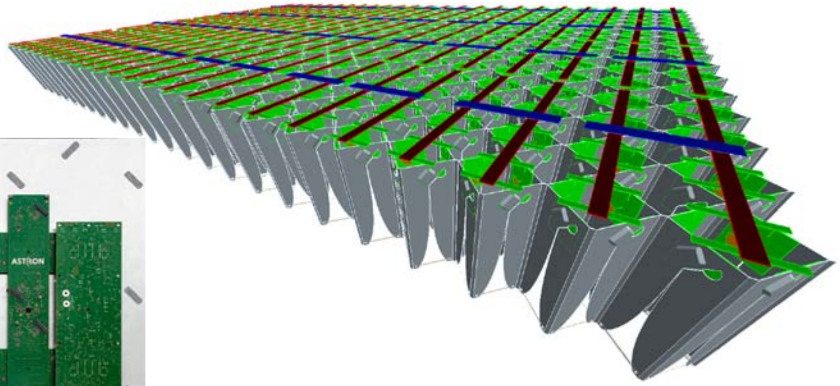
Courtesy: SKADS teams, Rob Maaskant

Next: AA-Mid development to

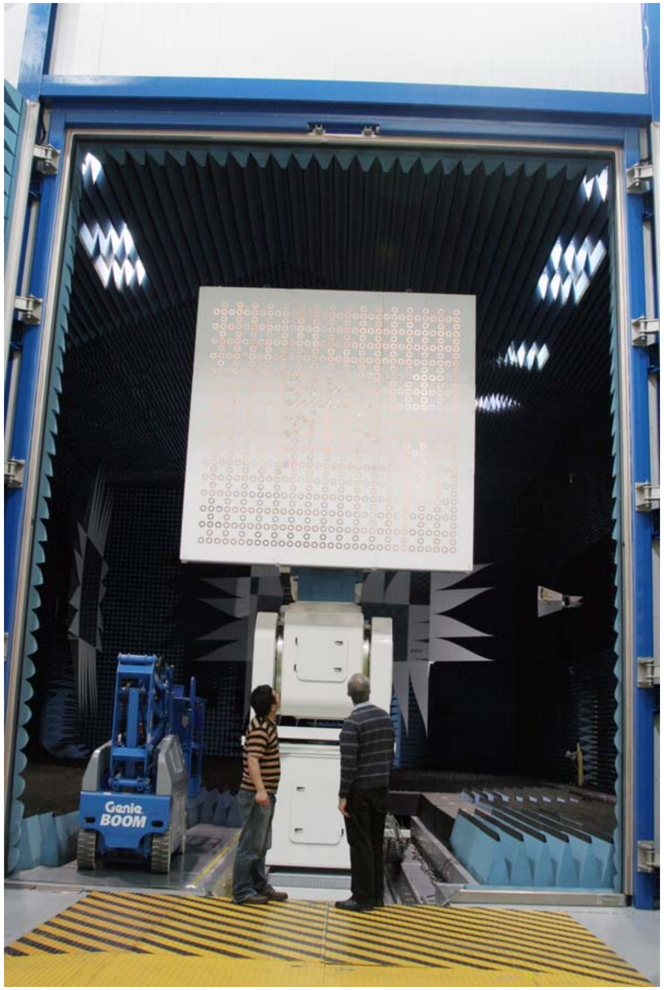
- EMBRACE as teststations
- Full Dual polarisation
- Focus on frontend: RF electronics, Antennas & Mechanics
- Low cost: Improved manufacturability with high level of integration
- Low power: ~2.5x lower i.e. <40W/sqm collecting area
- Production proto expected 2013
- Build station on SKA site in 2013-2014







ORA; a Planar structure approach



16×16 Finite Array Measured

- The rings are attached to the surface of the expanded polystyrene foam (EPS) with a defined separation between two layers and the groundplane

Electrical Power Consumption

- AA-mid
  - Presented in Analogy-report is 113 W/m^2 for a single channel
  - Reference document AA-mid power: a single channel 39 W/m^2.
- There is a clear difference in the values, can be explained by
  1. EMBRACE frontend is designed for a high RFI environment, LNAs are driven by relative high currents.
  2. Difference of integration of the station processing
  3. Changes in sub-systems design

  4. Industry actually focus to power reduction of electronics.
  5. Based on 2007-2009 technology.
- Projecting towards low RFI environment and 2019 timeframe: significant reduction of the presented power values by 5 previous mentioned topics.

- *As with AA-low; self (i.e. solar) powered stations possible?*

After PrepSKA - AAVP

- Toward next major SKA milestone: SRR to be done in 1st PEP Phase
- Stream: SKA system design, Architectural Design, Costed
  - SPO task, in preparation
- Stream: prepare SOW
  - Inventory of outstanding issues to be resolved for SRR
  - Roadmapping, purpose increase maturity (sub)systems
  - **Technologies** into **components** into **systems** form (e.g. AA)**concept**
  - **IP-policy** required (soon)
  - Document control system to be installed asap (i..e cannot continu to work from SKA memos)

- Need: Keep dynamics in this “intermediate” phase (1 yr?)
- Work to be done through focussed Aperture Array Collaboration Group (“AACG”) or AA Design Consortium (“AADC”)
  - In line with present activities: Coordinated through ASTRON

Summary

- Science potential: Wide field technologies (AA's and PAF's) for the SKA planned
- AA techniques are also widefrequency band
- Lessons from demonstrators and pathfinders incorporated toward next phase
- AA activities part of PEP Phase i.e. preparing for next major SKA milestone