

Square Kilometre Array eInfrastructure: Requirements, Planning, Future Directions

Duncan Hall SPDO Software and Computing ESFRI @ EGEE 2009



### <u>Outline</u>

SKA – in a nutshell How do radio telescope arrays work? What are the SKA's prime characteristics? Real-time data: pushing the HPC envelope How much data do we need to store? Where are we at? What is the future direction? Summary



# A global project: 75+ institutes in 19 countries

### Similarities to CERN?



## Science drivers

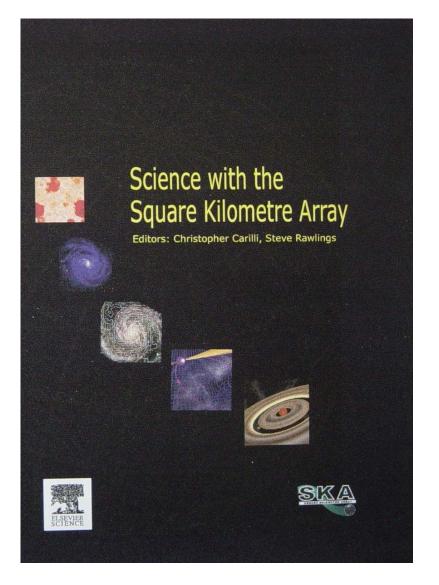
#### Origins

- Cosmology and galaxy evolution
- Galaxies, dark matter and dark energy
- Probing the "Dark Ages"
- Formation of the first stars
- Cradle of life
- Search for signs of life

#### Fundamental Forces

- Strong-field tests of general relativity
- Was Einstein correct?
- Origin and evolution of cosmic magnetism
- Where does magnetism come from?

#### Exploration of the Unknown

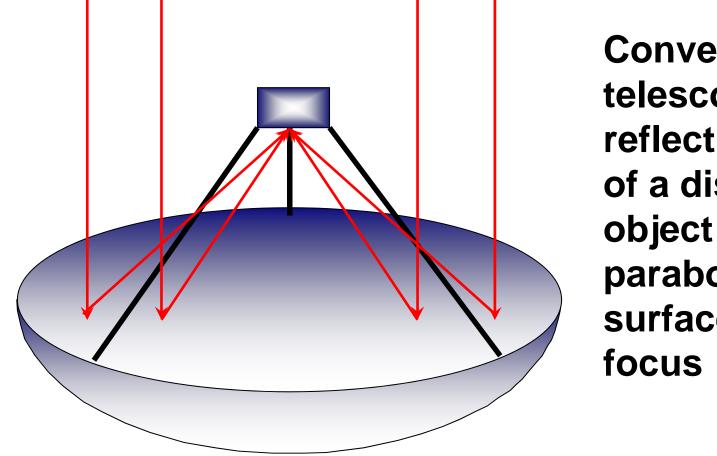




### How do radio telescope arrays work?



### How telescopes work



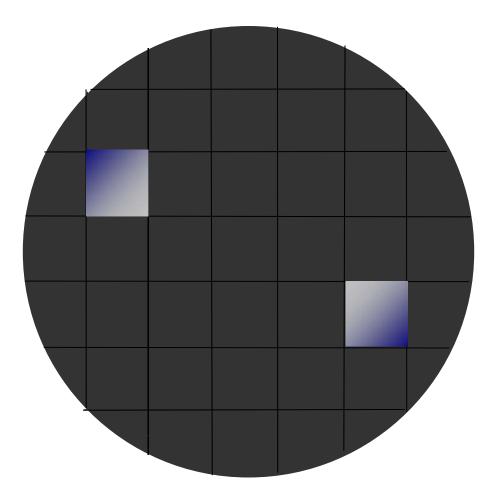
Conventional telescopes reflect the light of a distant object from a parabolic surface to a focus



## <u>76 m: 3,000+ tonnes</u>



# A partially filled aperture ...

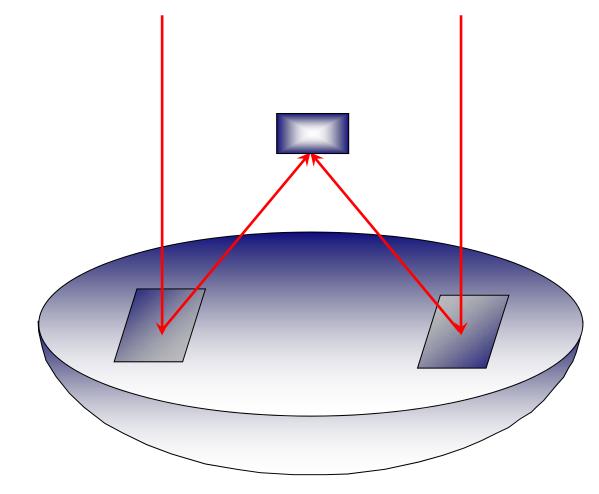


But the reflecting surfaces do not need to be part of the same surface

Suppose we cover up most of the surface of the mirror



### <u>... can produce images</u>

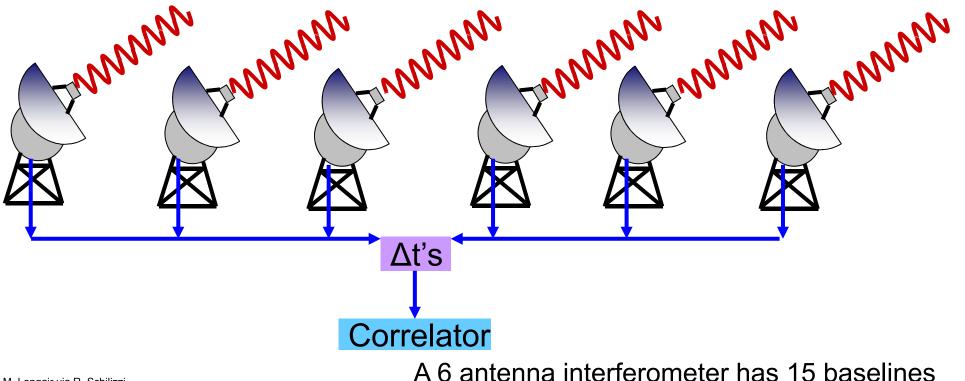


We can still combine the radiation from the uncovered sections to create an image of the distant object, if we arrange the path lengths to the focus to be the same.



### Radio interferometry

- Each pair of antennas is called a baseline
- More different baselines  $\rightarrow$  more detailed the image
- Short baselines antennas are close to each other provide coarse structure
- Long baselines provide the fine detail: the longer  $\rightarrow$  the finer the detail

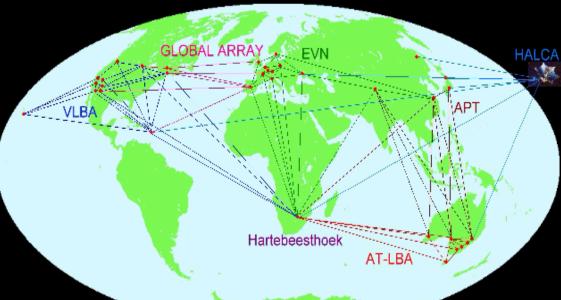






### Array Telescopes







### What are the SKA's prime characteristics?

### SKA: prime characteristics

- 1. More collecting area: ~1km<sup>2</sup>
  - Detect and image hydrogen in the early universe
  - Sensitivity ~ 50 x EVLA, LOFAR
- 2. Bigger field of view
  - Fast surveying capability over the whole sky
  - Survey speed ~ 1,000,000 x EVLA

#### 3. Wide ranges of frequencies

- Low : 70-300 MHz
- > Mid: 300 MHz-10 GHz
- > High: 10-25+ GHz

#### 4. Large physical extent : ~3,000+ km

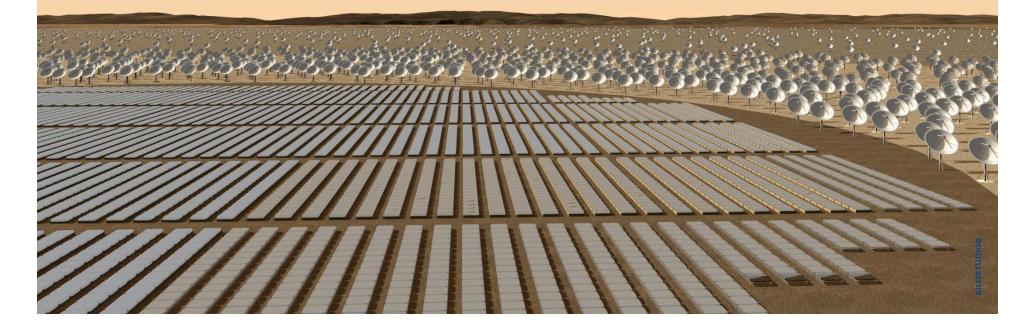
- Detailed imaging of compact objects
- Astrometry with ~0.001 arc second angular resolution



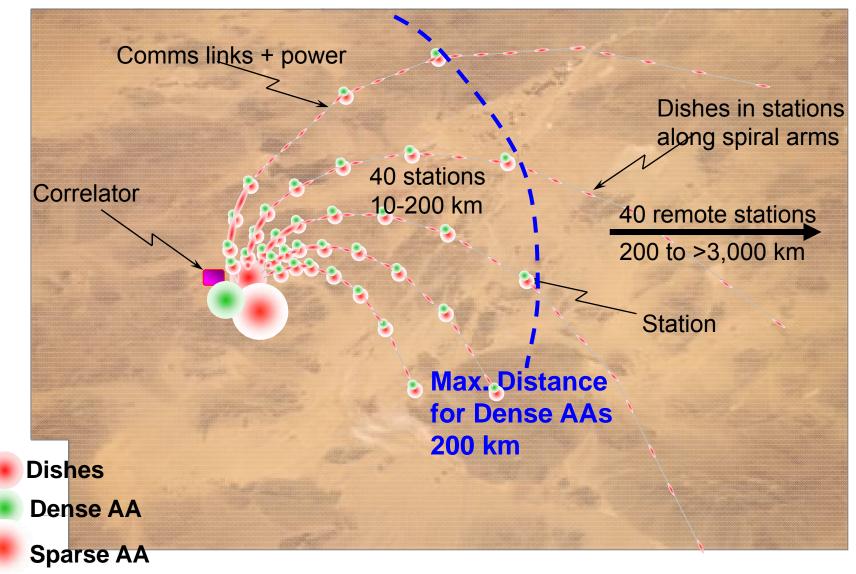


### Artist's impression

- 1,500 dishes (~15m diameter) in a 5 km core
- Additional 1,500 dishes from 5 km to ~3,000+ km
- Aperture arrays (AA) in a core
- Signal processing: (1) beam forming
- Optical fibre connection to (2) correlator
- Optical fibre to remote (3) High Performance Computer

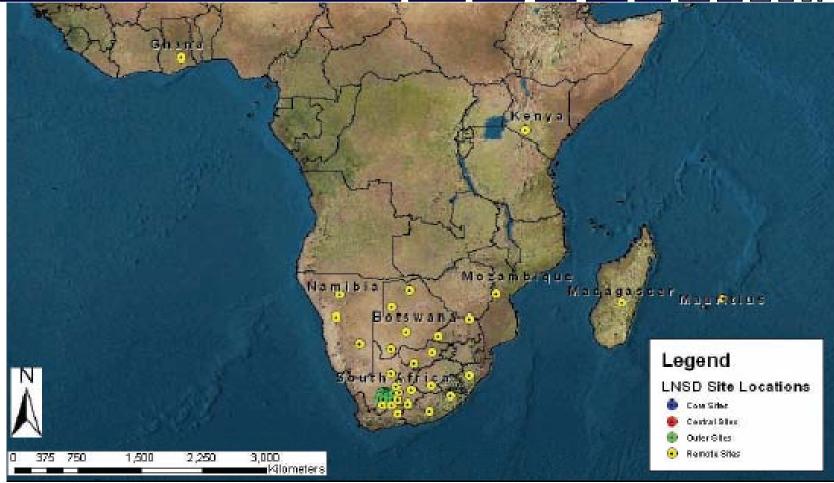






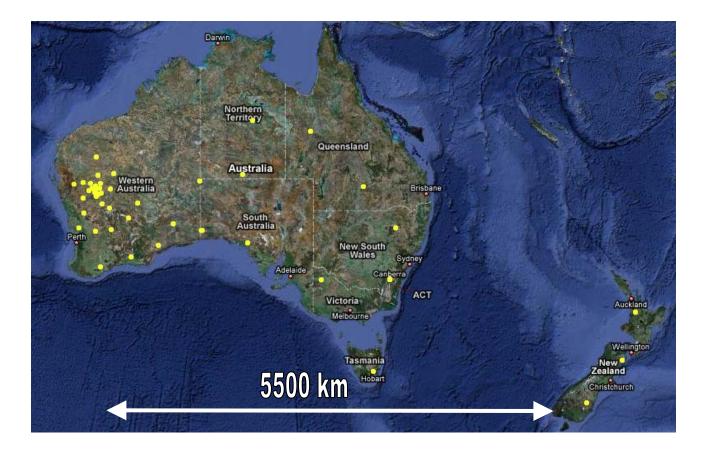


## South Africa + 7 countries





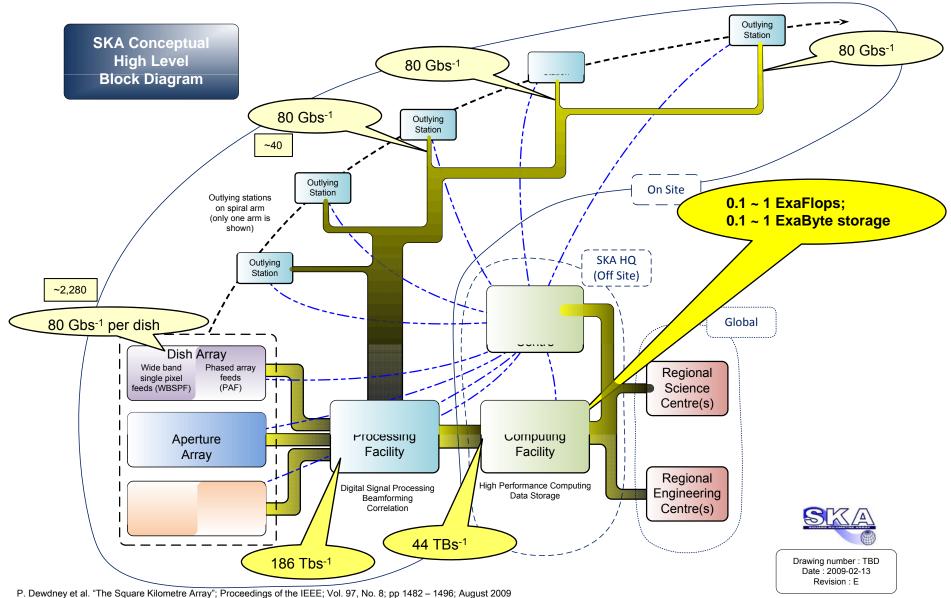
## Australia + New Zealand





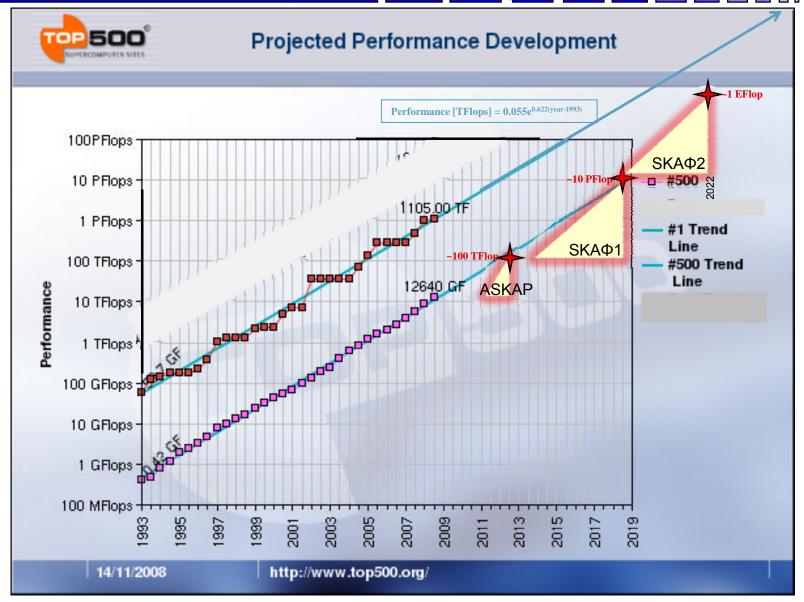
# Real-time data: pushing the HPC envelope ...

### Φ2 real-time data from dishes



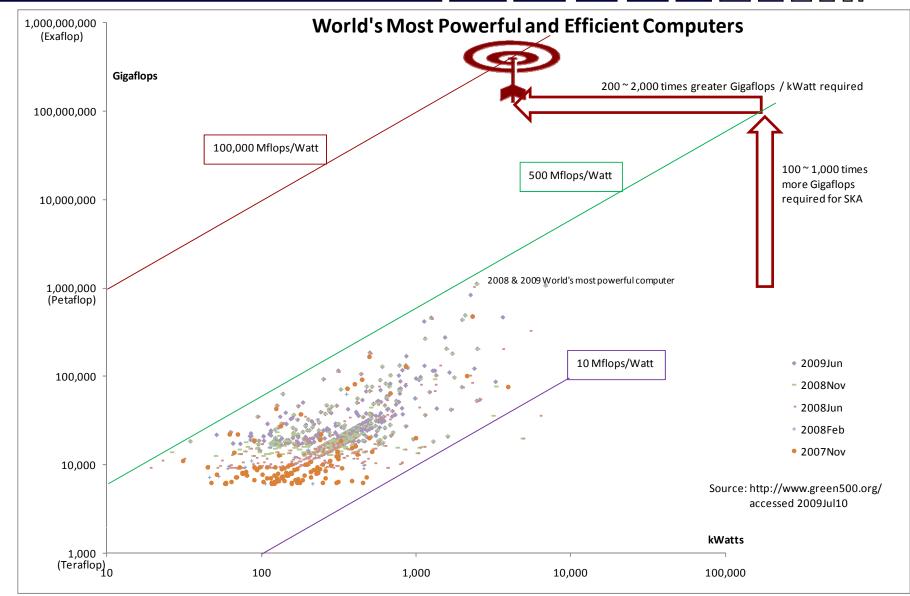
J. Cordes "The Square Kilometre Array – Astro2010 RFI #2 Ground Response" 27 July 2009; Table 1, pp 9 - 10

### Pushing the Flops envelope



Cornwell and van Diepen "Scaling Mount Exaflop: from the pathfinders to the Square Kilometre Array" http://www.atnf.csiro.au/people/Tim.Cornwell/MountExaflop.pdf

# Power efficiency challenges:

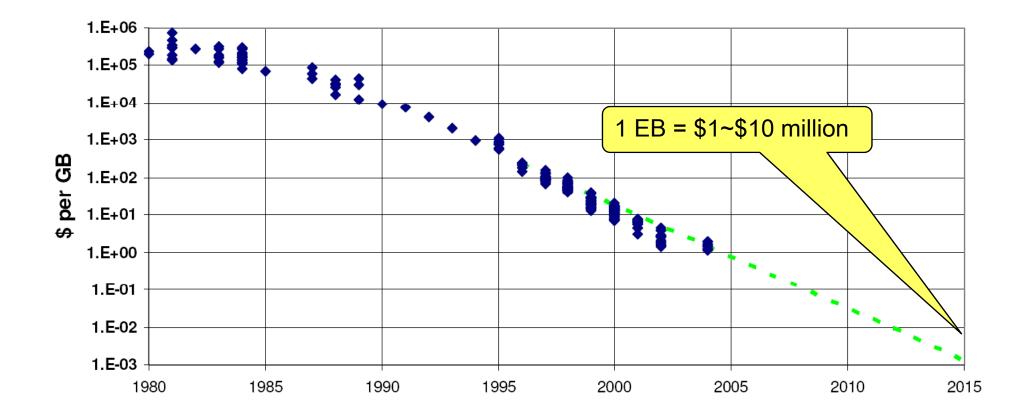




#### How much data do we need to store?



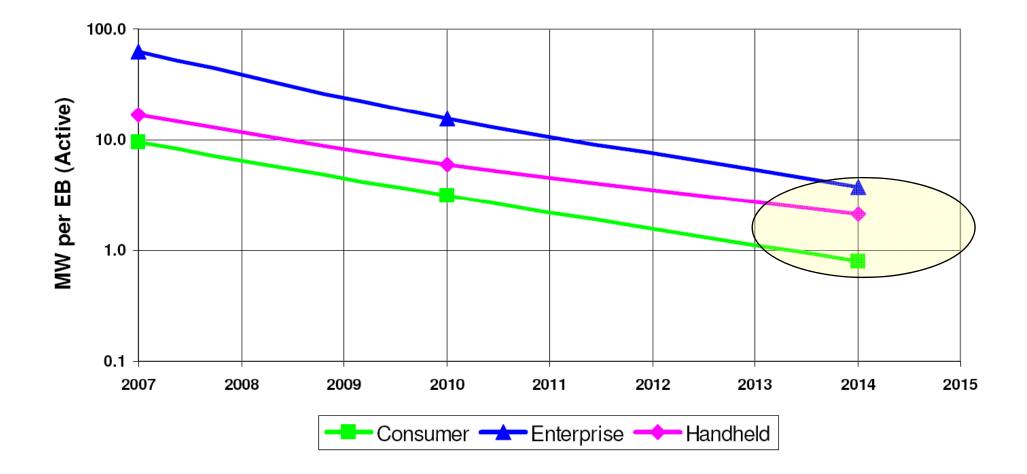
#### Disk storage: annual 50% cost reduction



P. Kogge et alia "ExaScale Computing Study: Technology Challenges in Achieving Exascale Systems"; TR-2008-13, DARPA ExaScale Computing Study, 2008 Sep 28, page 125 Note: neither RAID, controllers, nor interconnect cables are included in these estimates



#### Power for EB-size disk looks reasonable



P. Kogge et alia "ExaScale Computing Study: Technology Challenges in Achieving Exascale Systems"; TR-2008-13, DARPA ExaScale Computing Study, 2008 Sep 28, page 124 Note: power numbers here are for the drives only; any electronics associated with drive controllers [e.g. ECC, RAID] needs to be counted separately



#### 10 PetaByte tape robot at CERN



http://www.flickr.com/photos/doctorow/2711081044/sizes/o/in/set-72157606675048531/ C. Doctorow "Welcome to the Petacentre"; Nature, Vol. 455, \$ September 2008, pp. 17-21 500-GB tapes switched to 1-TB models – an upgrade that took a year of continuous load/read/load/write/discard operations, running in the interstices between the data centre's higher-priority tasks



#### Where are we at?



### Current development

PrepSKA 2008-2011

The Preparatory Phase for the SKA is being funded by the European Commission's 7<sup>th</sup> Framework Program

 €5.5M EC funding for 3 years + €17M contributed funding from partners (still growing)
€150M SKA-related R&D around the world

Coordinated by the Science and Technology Facilities Council (UK)



# WP2: Design + Cost

Coordinated by the SKA Program Development Office in Manchester

- System Definition
- Dishes, feeds, receivers
- Aperture arrays
- Signal transport
- Signal processing
- Software
- High performance computers
- Data storage
- Power requirements



### What is the future direction?



### Schedule to 2018

	2009 2010 <u>SKAP</u>		2011 Preparatory Phase		2012		2013 Detailed Desi & Top		2014 gn, Prod. Eng oling		2015 <u>Phase 1</u>		2016 uction, Comn legration & Fin	2017 issioning, Acceptance st Science		2018	
System	CoDR	¥		SRR↓		PC		CDR	•				Į		ems integration		TRR SAT↓
Engineering			De	inition and Design				System r		refinement, change management		t				ation and Commi	•
				CoDR 🚽 PDR		, CE	R					l		Continued System Engineering for Phase 2			>
Project management	PrepSKA Plan WBS, resource allocat				8		Deployment P fing & develop	ployment Plan & development				Proje	ct execution,	xecution monitor and control			
F	REV↓	REV 🗸					1			REV	ł						
Science	DRM Dev	RM Development			nce Case	Science / Enginee	ring tradeoffs	i tradeoffs		Ead		y Science Proposals		Phase 2 Scie	Shared Risk Science Operations		
		CoDR			SRR		R	CDR	I ↓	PR		RE	-	REV	4		
Antennas		Definition	Dish Sub- Definitio AA Sub-6	an Bys. /	Fabrication	Prototype Dish Testin Prototype AA Testing		Antenna Detailed Design		Tooling and Early Fabrication				tegration and Te	A	Phase 2 Cor	ntinuation >
		CoDR	Definitio	on	Fabrication			CDR		PR				, integration a			
Signal transport & Networks				b-System Definition		Preliminary Design	De	Detailed Design		Purchase or Fabrication				egration and Testing Phase 2 Contin ly, Integration and Testing Phase 2 Co			
& Networks			₀DR↓					PDR		CDR				, megradori and	l I		
Signal Processing	Front End and Channeliser Beamformer and Correlator			Sub-System Defi		Ť	I Preliminary	Preliminary Design		Detailed Design		PR Hardware Correlator Early Fabrication Temporary Software Cor		ssembly, Integration Site Assembly	nd Testing , Integration and Testing Phase 2 Correlator Design		n >
	Pulsar and	Transient Proc				SRR					Iem		e Correlator		l I		2
Software & Computing	CoDI Imaging Concept Monitoring & Control Data Storage			Software Require Preliminary high		ments Definition		Refine high level archite Preliminary Design		ecture Detailed Detai		sign, Coding, th platforms and		e Testing	Phase 1 Refinement and Roll-out		
oonpaning		Data Storag	•			PD		DR↓		te	sting						10002
Site Engineering	RFI Monitoring RQZ Site characteristics Atmospheric studies		Lo Cont Mo	inued RFI mitoring	Remote Station Land Acquisition & Environmer Studies	Infrastruc	Infrastructure Detailed		Central Data Processing F Science Computing Fac Ops and Maintenance Fa		ility Site		nce tests includi	ng RFI qualification Phase 2 Continuation			
	C	onfiguration stud	lies			,	+							,	↓ ↓		
Milestones	Final Design Reference Mission			Non bind Impleme Agreeme & Phase		entation syste nt on Site desi	m Funding	1 and	Start of Const		Phase 1 ruction			Fun	se 2 dding cation		
les "The Square Kilo	2009	<b>201</b>			11	<b>2012</b>	-	0 <b>13</b>		2014		2015		2016	2017		2018

J. Cordes "The Square Kilometre Array – Astro2010 RFI #2 Ground Response" 27 July 2009; Table 1, page 51



# Phased construction

#### Phase 1:

- 2013 2018 construction
- 10-20% of the collecting area

#### Phase 2:

- 2018 2022 construction
- Full array at low and mid frequencies

#### Phase 3:

- 2023+ construction
- High frequencies



### <u>Summary</u>

#### Required elnfrastructure in host region

- Distributed 100's Gb fibre optic signal transport and networks
- Distributed 10's MW power for collecting dishes and stations
- Central Digital Signal Processing Facility: specialised hardware
- Fibre to Science Processing Facility

#### Other elnfrastructure: could be anywhere

- Science Processing Facility ExaFlop "production" environment
- Tiered hierarchy (1-3 ?) of ExaByte storage, archive and distribution
- Software applications development and maintenance environments
- Power for computing and (-H)VAC: 10's MW

#### Current state of planning

• Preparatory costing and high level design / architecture development