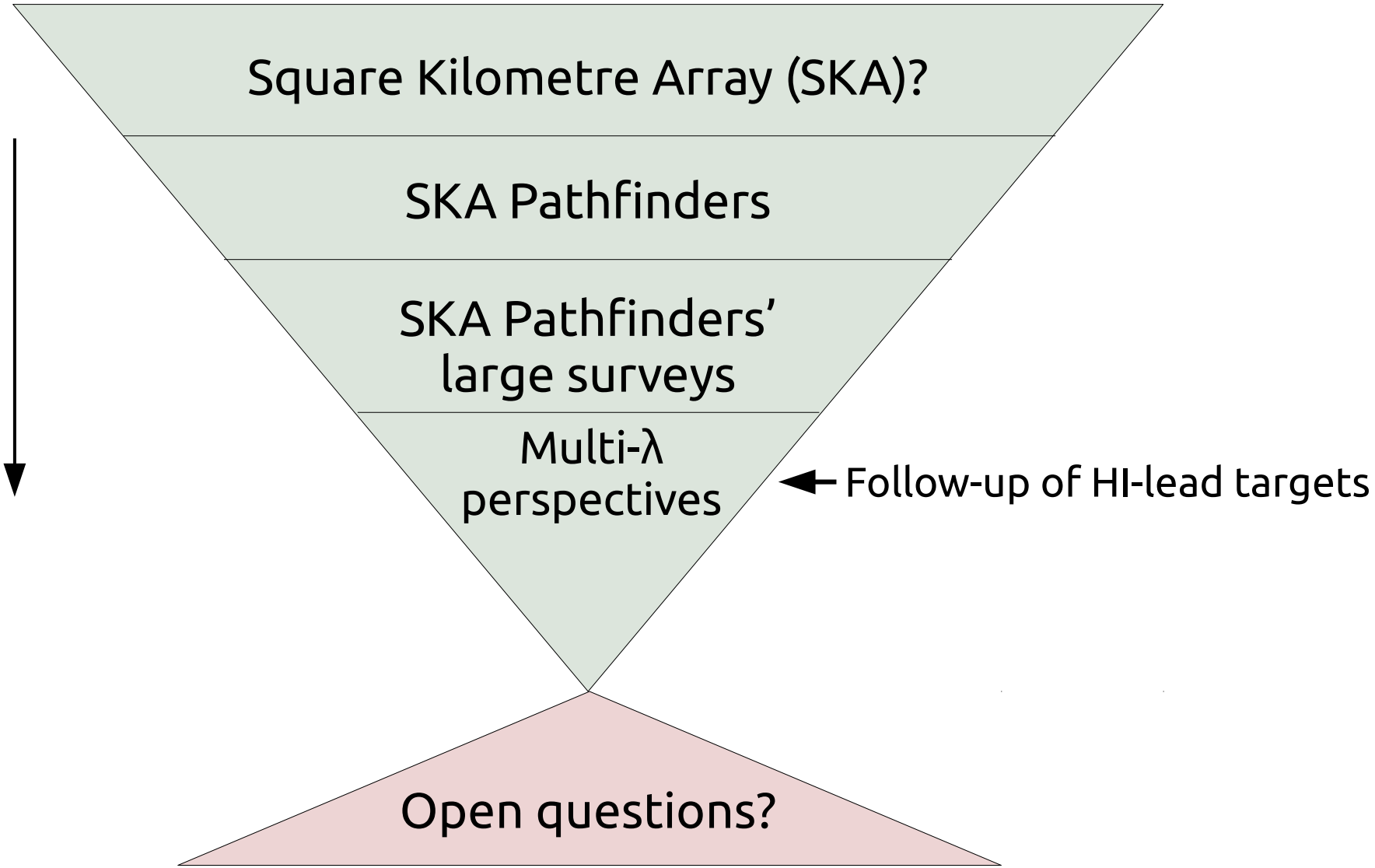
SKA pathfinders' large galaxy surveys

Se-Heon Oh

(KASI ALMA Group)

Note some images in the slides taken from internet, belonging to respective owners...

A new golden age for HI science



Square Kilometre Array (SKA)

: South Korean Array (by Ho-Gyu Lee)

- The largest radio telescope array in the 21st, with the total collecting area over 1,000,000 square metres
- Initiated by the Large Telescope Working Group at the international Union of Radio Science (URSI) in 1993
- Aimed at observing EM waves (50 MHz ~ 15 GHz) in the Universe since the cosmic re-ionization, covering a wide range of science:

  - chronological distribution of HI in the Universe

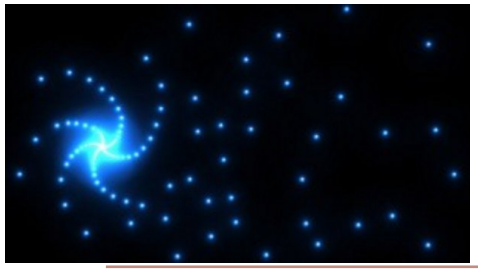
  - large scale structure (~10^{10} pc)

  - origin of life (~10^{-10} pc)

  - ...

SKA Key Science

- Cosmic dark age & recombination era
- Galaxy formation/evolution, cosmology & dark energy
- Origin of comic magnetism & its evolution
- Strong-field tests of gravity using pulsars & black holes
- Origin of life



SKA key specifications needed

SKA phase I design reference

Table 8-2. SKA Phase 1 Technical Requirements Summary

Chapter	Title	Frequency Range (MHz)	Survey Speed (m^4 K^-2 deg^2)	Ae/Tsys (m^2 K-1)	Frequency Resolution (kHz)	Temporal resolution (s)	polarisation purity	Imaging dynamic range (dB)	Spectral Dynamic Range (dB)	Observation type	Key Science Case Ref	Notes
2	Probing the Neutral Intergalactic Medium during the Epoch of Reionization	70-240	N/A	1000	100	SL	full	N/A	N/A	Line	Probing the Dark Ages	
3	Tracking Galaxy Evolution over Cosmic Time via HI absorption	200-1400	1.0E+07	N/A	5	SL	N/A	35	43	Line	Galaxy Evolution, Large-Scale Structure, & Dark Energy	possible technology change
4	Probing the Epoch of Reionization with the 21-cm Forest	70-240	N/A	N/A	0.2	SL	N/A	N/A	61	Line	Probing the Dark Ages	
5	Pulsar Surveys with the SKA1	400-3000	N/A	1000	10	5.00E-05	N/A	N/C	N/C	Time Domain	Strong Field Tests of Gravity Using Pulsars and Black Holes	non-imaging data required
6	Pulsar Timing with the SKA1	800-3000	N/A	10000			40 dB	N/C	N/C	Time Domain	Strong Field Tests of Gravity Using Pulsars and Black Holes	high frequency agility required, no imaging data required, polarization purity likely needs to be achieved only on-axis, post-calibration
7	Additional Telescope Considerations	70-10,000					full-field capability	74 dB capable			multiple	"forward capatibility"

→ 50 MHz ~ 15 GHz

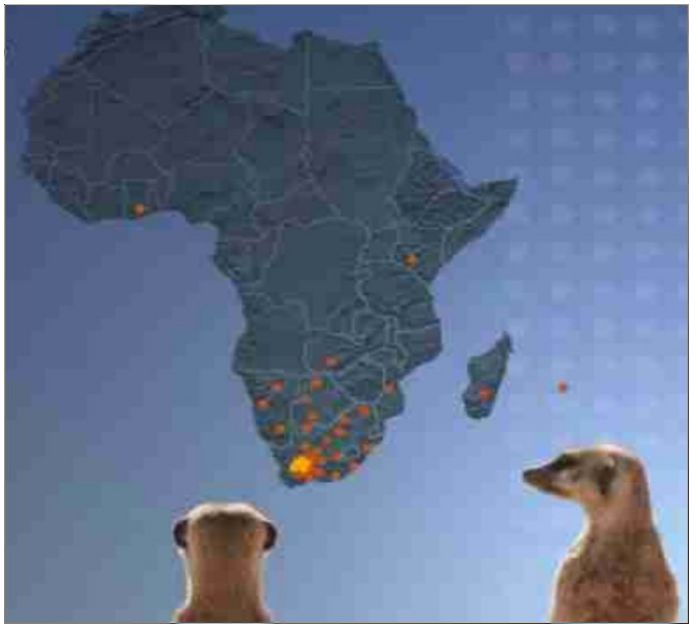
→ ~ 15m x 2,000 dishes + ~1,000,000 dipoles in a spiral layout design

SKA hosting to be split: South Africa + Australia
(decision made in 2012)

Australia + New Zealand

+

South Africa + 8 African countries



SKA1 LOW (2018 – 2023)

- 50 MHz – 350 MHz
- ~130,000 aperture arrays (dipoles)
- maximum baseline : 65 km
+ ASKAP (12m x 34)

→ *SKA2 LOW (> 2023)*

SKA1 MID (2018 – 2023)

- 350 MHz – 14 GHz
- 15x200 dishs
- maximum baseline: 150 km
+ MeerKAT (13.5m x 64)

→ *SKA2 MID (> 2023)*

SKA timeline & cost

SKA 1 (2018 – 2023)

- 10% of the full SKA
- Low-mid frequencies focused
- AUS: ~500 stations with 250 dipoles each
- SA: ~15m x 200 dishes

SKA 2 (2023 – 2033)

- 100% of the full SKA
- High-frequency antennas
- AUS: ~1,000,000 dipoles
- SA: ~2000 dishes

SKA 3 (> 2033)

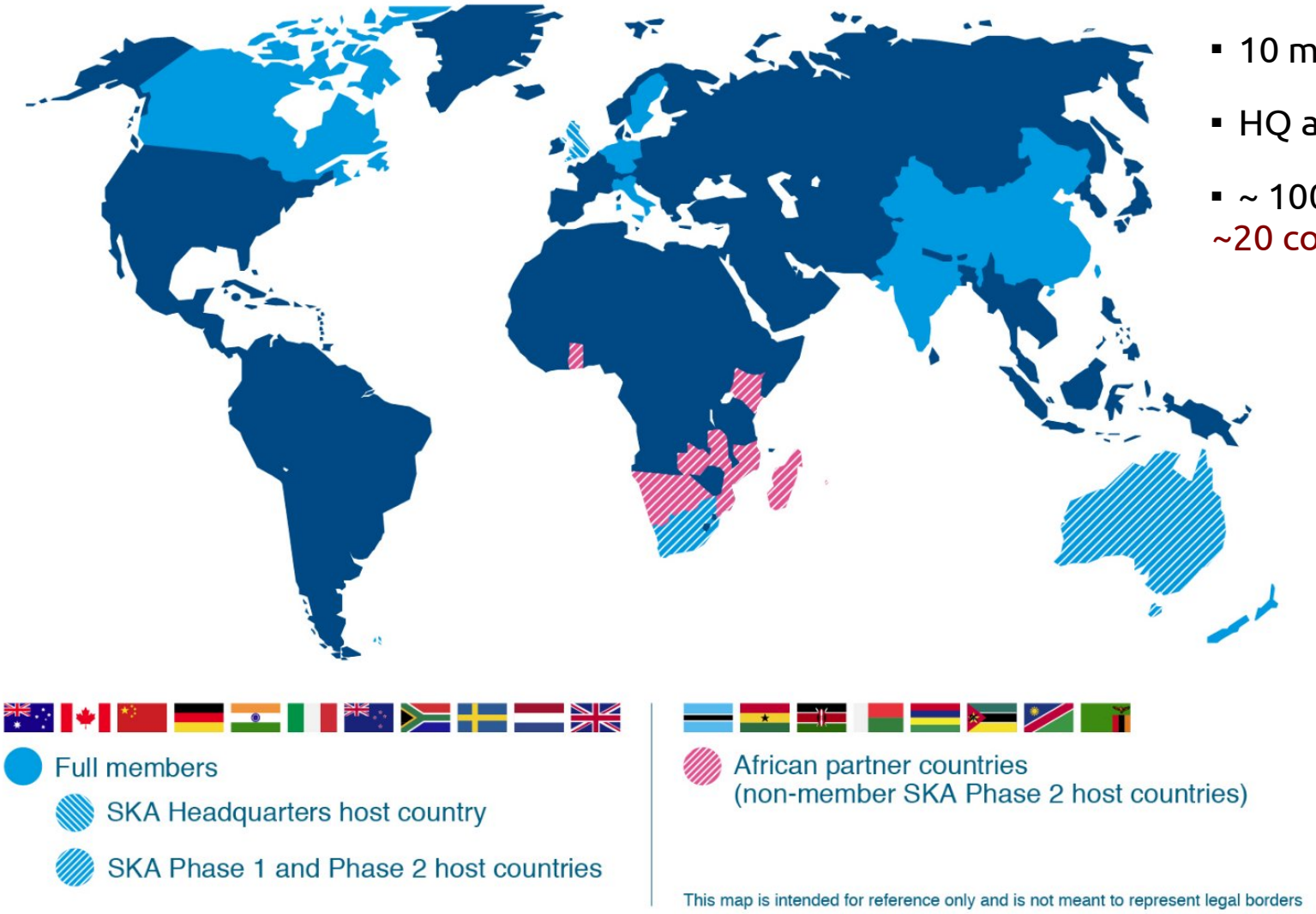
- Extended to higher frequencies
- Will be in operation over 50 years

- Pre-construction ~€150M
- SKA 1 ~ € 650M

- ~€ 1.5B +

- ?

SKA members



- 10 member countries
- HQ at Jodrell Bank Obs.
- ~ 100 organisations across ~20 countries*

(* all member countries + Brazil, France, Japan, Malta, South Korea, Poland, Portugal, Russia, Spain, the USA)

Korean SKA activities over the last 7 yrs

- Participating in the SKA committee as an observer
- Some (five) Korean researchers involved as co-Is of the SKA white book (updated in 2015)
- ~10 actively involved-in, ~30 relevant, and ~50 – 100 showing interest including the gravitational wave community
- Expression of interests by Korean industries (e.g., antenna maintenance, smart grid etc.) and KISTI (e.g., SKA regional centre)

Korean SKA science

- Cosmic magnetism (*Ryu, Dong-Su et al.*)
- Study of cosmic dawn and cosmic reionization (*Ahn, Kyungjin et al.*)
- HI gas as the probe of environmentally driven galaxy evolution (*Chung, Aeree et al.*)
- Cosmic large-scale structure with SKA (*Song, Young-Sun et al.*)
- Large field-of-view SKA-VLBI AGN survey (*Sohn, Bong-Won et al.*)

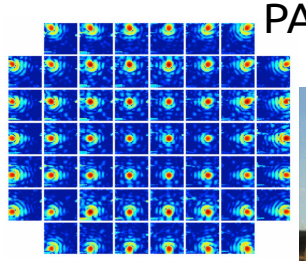
Finding & paving the way to the SKA1 : SKA pathfinders

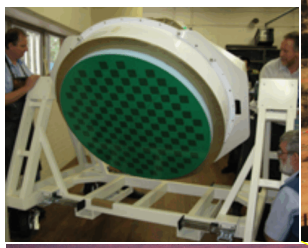
- Australian SKA Pathfinder (ASKAP) : 12m x 36
- Karro Array Telescope (MeerKAT) : 13.5m x 64
- Westerbork Synthesis Radio Telescope (WSRT) Apertif : 25m x 14
- Five hundred meter Aperture Spherical Telescope (FAST) : 500m
- Murchison Widefield Array (MWA) + PAPER : 256 tiles of dipoles

→ will open a new golden age for HI science for the next decade...

ASKAP large survey proposals

PAF (radio camera)





- 12m x 36 dishes, 10–30" beam (up to 6 km baseline)
- 700 MHz – 1.8 GHz (32,768 channels over 300 MHz BW)
- 188 phase array elements → 30 deg^2 FOV
- Continuum & spectral lines
- 12 Phased Array Feeds (PAFs) are installed → *ASKAP-12 early science observation will start from early 2017*

10 ASKAP Large Survey Projects

- Evolutionary Map of the Universe (EMU)
- **Widefield ASKAP L-Band Legacy All-Sky Blind Survey (WALLABY)**
- The First Large Absorption Survey in HI (FLASH)
- An ASKAP Survey for Variables and Slow Transients (VAST)
- The Galactic ASKAP Spectral Line Survey (GASKAP)
- Polarization Sky Survey of the Universe's Magnetism (POSSUM)
- The Commensal Real-time ASKAP Fast Transients survey (CRAFT)
- **Deep Investigations of Neutral Gas Origins (DINGO)**
- The High Resolution Components of ASKAP: Meeting the Long Baseline Specifications for the SKA (VLBI)
- Compact Objects with ASKAP: Surveys and Timing (COAST)

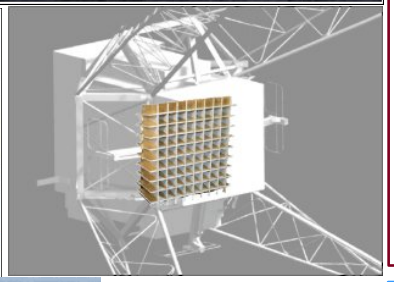
MeerKAT large survey proposals

- 13.5m x 64 dishes, 8" beam over 1.8 deg^2 FOV
- Antenna layout: a dense inner component (70%) + an outer component (30%) over 30m to 8 km
- 580 MHz – 14.5 GHz (32,768 channels over 300 MHz BW)
- Continuum & spectral lines
- *MeerKAT AR1 (16 dishes) will start its early science observation from early 2017*

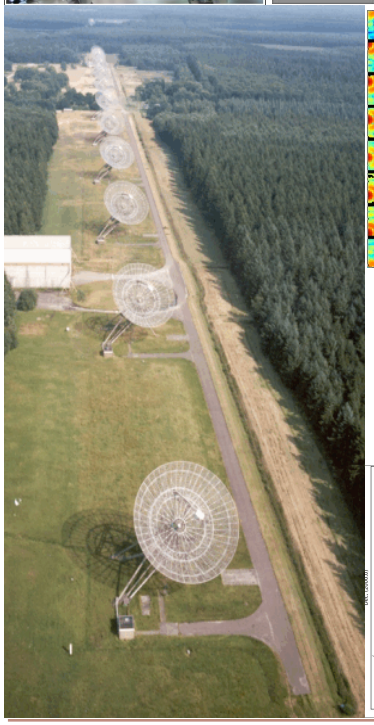
10 MeerKAT Large Survey Projects

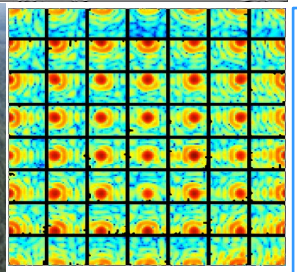
- Radio Pulsar Timing: Testing Einstein's theory of gravity and gravitational radiation
- **LADUMA (Looking at the Distant Universe with the MeerKAT Array)**
- MESMER (MeerKAT Search for Molecules in the Epoch of Re-ionisation)
- MeerKAT Absorption Line Survey for atomic hydrogen and OH lines in absorption against distant continuum sources
- **MHONGOOSE (MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters)**
- TRAPUM (Transients and Pulsars with MeerKAT)
- A MeerKAT HI Survey of the Fornax Cluster (Galaxy formation and evolution in the cluster environment)
- MeerGAL (MeerKAT High Frequency Galactic Plane Survey)
- MIGHTEE (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey)
- ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT)

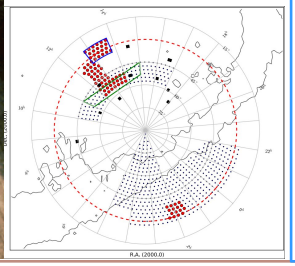
WSRT Apertif large survey proposals



- 25m x 14 dishes with Apertif : being upgraded to an HI survey telescope with FOV of ~8 deg2; ~15” beam
- 1.0 – 1.7 GHz (16,384 channels over 300 MHz)
- *Early science observations will start from 2017*





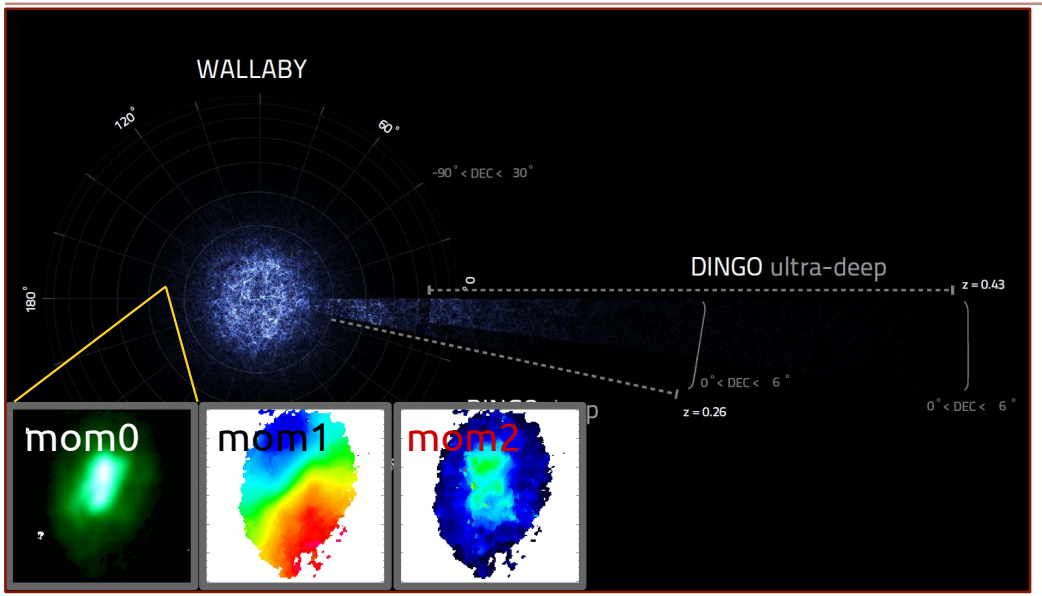


Apertif large surveys

- An HI survey telescope in northern sky comparable to ASKAP
- A large area, shallow imaging survey of HI and polarised radio continuum emission covering ~3500 deg^2
- A medium-deep imaging survey of HI and polarsised radio continuum emission covering ~450 deg^2
- A time domain survey for pulsars and fast transients over 15,000 deg^2
- Follow-up of some LOFAR fields

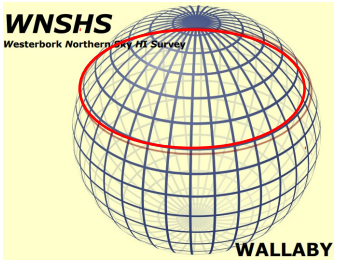
ASKAP all-sky HI survey (WALLABY)

: Baerbel Koribalski (CASS/CSIRO) & Lister Staveley-Smith (ICRAR/UWA)



- ASKAP 3∏ HI galaxy survey
- ~5,000 hours of ASKAP time
- ~500,000 galaxies out to z~0.26 (~1 million if combined with Apertif WNSHS)
- ~10,000 galaxies within 200 Mpc are spatially resolved → Resolved galaxy kinematics

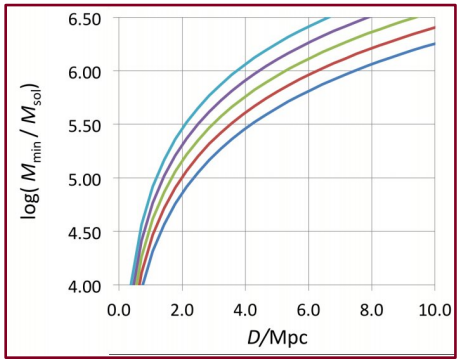
→ Galaxies in local Universe / Galaxy environments / Intergalactic HI / HI mass function / Large-scale structure / Galaxy clusters / High-velocity clouds / Multi-frequency synergies etc.

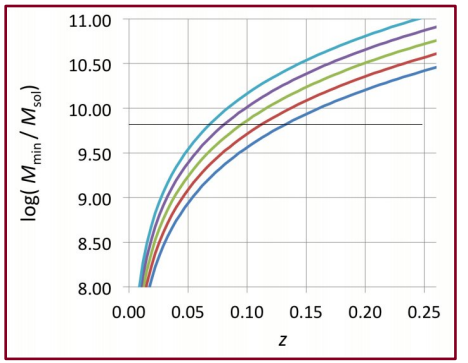


WALLABY + WSRT Northern Sky HI Survey (WNSHS)

- 4∏ all-sky HI survey (ASKAP 3∏ + WNSHS 1∏)
- ~1 year of ASKAP + ~2 years of Apertif integration time
- Angular resolution : 15 – 30”
- Velocity resolution : ~ 4 km/s
- Correlations : full stokes
- Redshift range : 0 – 0.26 **(~ 1 million galaxies)**
- Frequency range : 700 MHz – 1800 MHz
- RMS sensitivity (0.1 MHz) : 0.55 – 0.7 mJy/beam
- 12 hours integrations per pointing

  : 5σ sensitivity limit (ΔV ~ 24 km/s) → < $(1+z)^4$ 0.7 x 10^{20} atoms cm^{-2} @ 30”





→ HI content / (dark) mass distribution in galaxies / galaxy dynamics / environment of galaxies (with multi-wavelength data)

→ HI mass function / total mass function (in tandem with near/mid IR data)

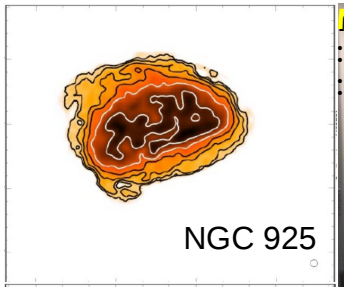
→ Cosmic flows via galaxy peculiar motions etc.

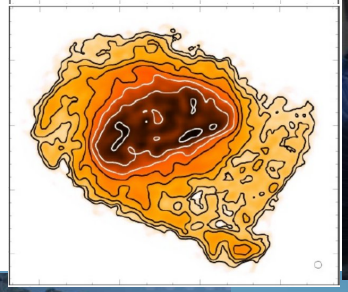
MHONGOOSE

: MeerKAT ultra-deep HI survey for nearby galaxies (< 20 Mpc)

THINGS

MHONGOOSE





- **MHONGOOSE** : **M**eerKAT **H**I **O**bservations of **N**earby **G**alactic **O**bjects: **O**bserving **S**outhern **E**mitters
- **MeerKAT ultra-deep HI observations** of **30 galaxies** for 200 hours each (**6,000 hours**; **Super THINGS**)

- How do galaxies get their gas?
- How is star formation regulated?
- How are outer disks and cosmic web linked?

→ Ultimate observational data for investigating the central DM distribution in galaxies

Some open questions

- 현재 국내 천문학계의 외부은하 중성수소 관측 / 이론 연구에 대한 동향과 SWOT 분석은 어떠한가 ?

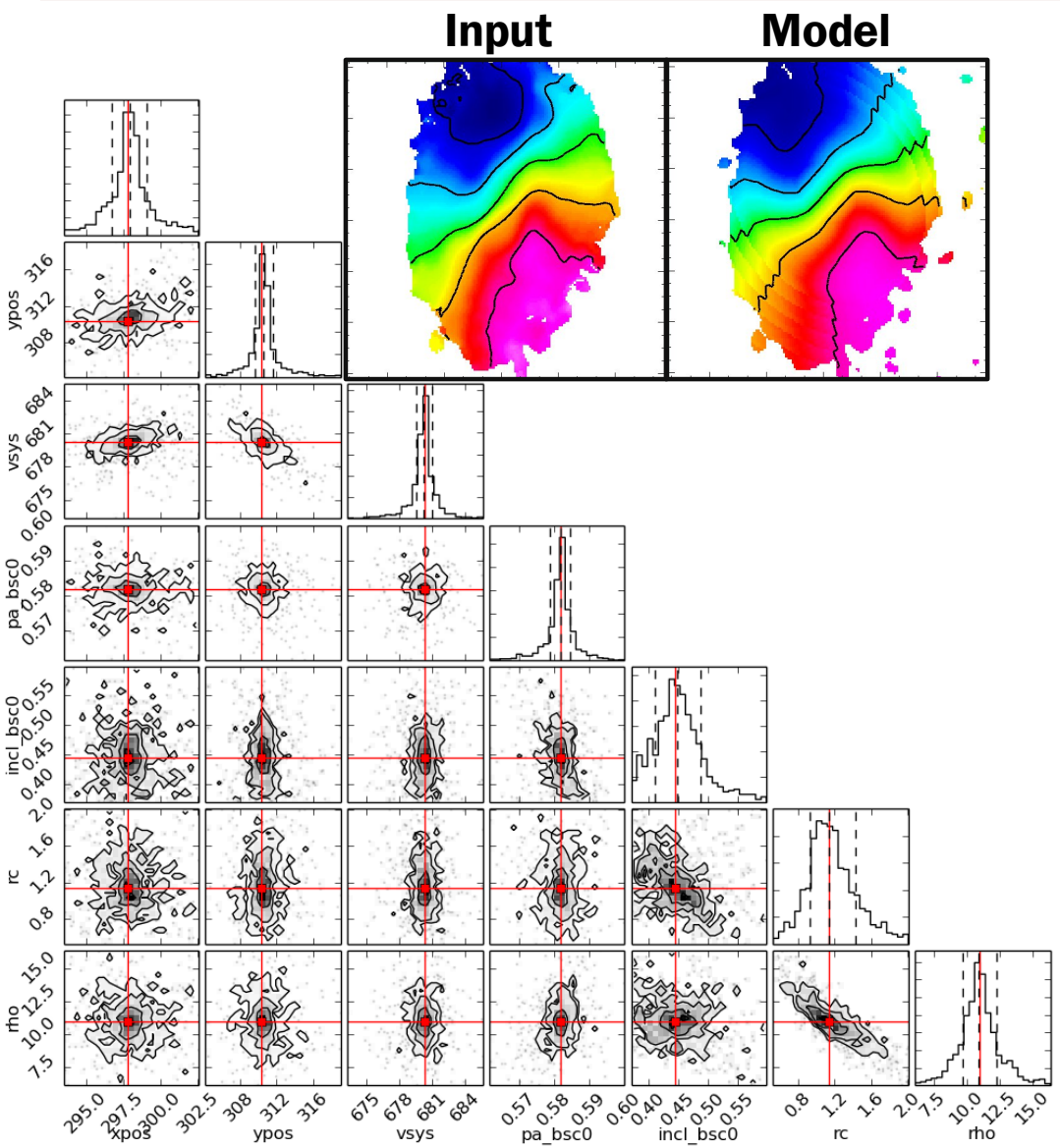
- 현재 진행중인 국내 천문학계의 대형 프로젝트들과의 중복성을 최소화하고 동시에 이들과의 시너지를 극대화 할 수 있는 연구주제 발굴을 위한 전략적인 방안은 무엇인가 ?

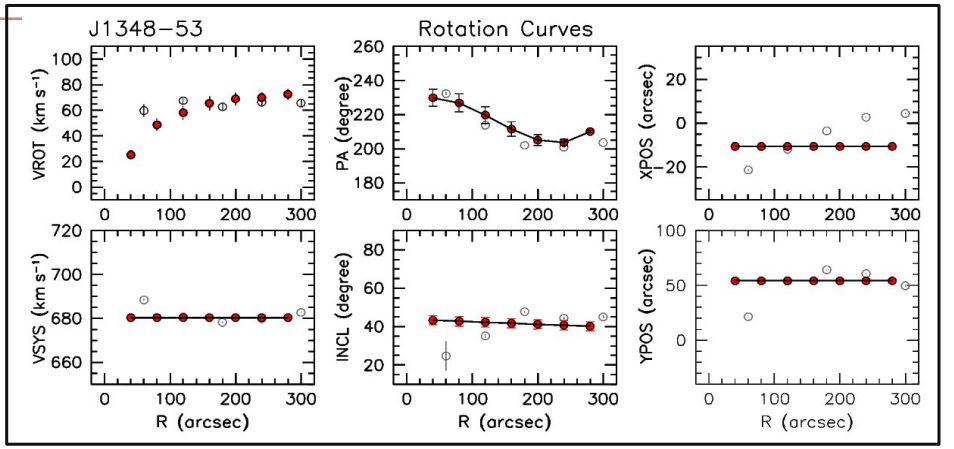
- SKA pathfinders' large surveys 와 시너지를 만들어낼 수 있는 (SSG-lead) 외부은하 - 관련 과학연구 주제들은 ?

- 궁극적으로 경쟁력 있는 SKA 과학 / 기술 연구주제들을 선도할 차세대 연구 인력풀을 만들 수 있는 전략적인 방향은 ?

2D Bayesian Automated Tilted-ring fitter (2DBAT)

(Oh et al.)





- A new 2D tilted-ring fitting algorithm based on Bayesian MCMC technique developed (a standalone C program)
  - **fully automated**: only broadly defined ranges of priors are required for a given 2D velocity field
  - **MPI supported**: written in standard MPI for parallel implementation
- Successfully tested using WALLABY-like 26 LVHIS galaxies (Oh et al. in prep.)
- Blind experiment using WALLABY-like ~10,000 cubelets with resolved detections under work