HI (SKA) science with MeerKAT

Claude Carignan
South African SKA Research Chair
in Extragalactic Multi-Wavelength Astronomy
Department of Astronomy, University of Cape Town

MeerKAT Science Programme

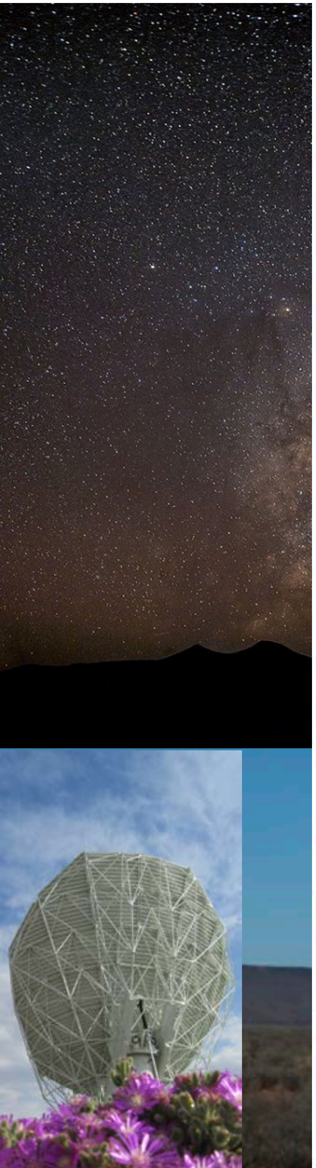
- 2010: Open invitation by SKA SA to propose MeerKAT "Key Science Projects" resulted in 10 approved "Large Survey Projects" (LSPs; each > 1000 hours of telescope time over 5 years)

- 2016: Relevant scientific context has evolved; also, particularly at L-band (~1.4 GHz), MeerKAT will be far more sensitive than planned

- *Makes sense to revisit LSPs*: eight revised LSPs submitted in mid 2016, and presented in May at MeerKAT Science Workshop (MSW)

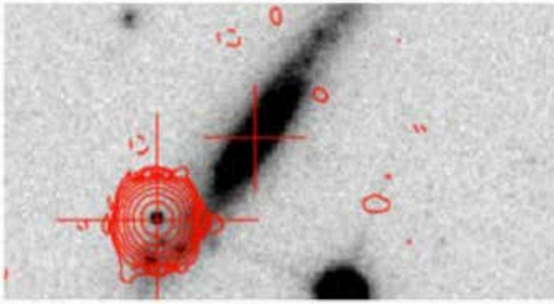
- SKA SA aim to schedule ~70% of telescope time for LSPs, ~30% for "Open Time" projects

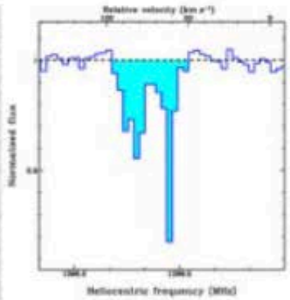
- Some ideas for Open Time and "Early/Shared-risk Science" were also presented at MSW



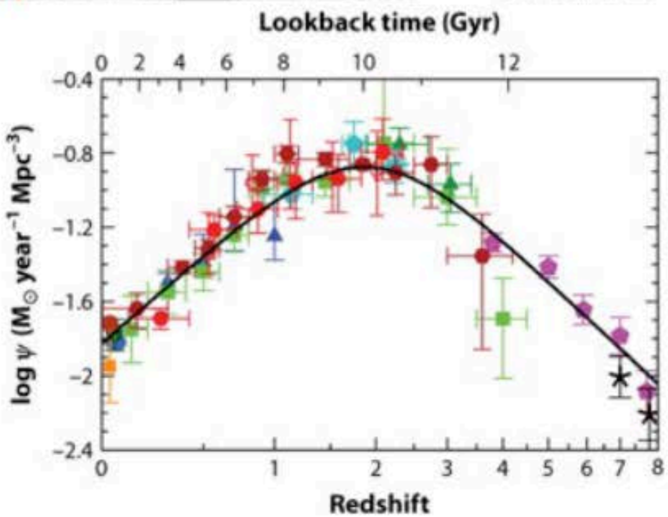
MeerKAT science projects	Research leaders
Priority Group 1	
Radio Pulsar Timing: Testing Einstein's theory of gravity and gravitational radiation - Investigating the physics of enigmatic neutron stars through observations of pulsars.	Professor Matthew Bailes, Swinburne Centre for Astrophysics and Supercomputing, Australia
LADUMA (Looking at the Distant Universe with the MeerKAT Array) - An ultra-deep survey of neutral hydrogen gas in the early universe.	Dr Sarah Blyth, University of Cape Town in South Africa; Dr Benne Holwerda, European Space Agency, The Netherlands; Dr Andrew Baker, Rutgers University, United States
Priority Group 2	
MESMER (MeerKAT Search for Molecules in the Epoch of Re-ionisation) - Searching for CO at high red-shift (z>7) to investigate the role of molecular hydrogen in the early universe.	Dr Ian Heywood, CSIRO/ATNF, Australia
MeerKAT Absorption Line Survey for atomic hydrogen and OH lines in absorption against distant continuum sources (OH line ratios may give clues about changes in the fundamental constants in the early universe).	Dr Neeraj Gupta, Inter-University Centre for Astronomy and Astrophysics, India; Dr Raghunathan Srianand, Inter-University Centre for Astronomy and Astrophysics, India
MHONGOOSE (MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters) - Investigations of different types of galaxies; dark matter and the cosmic web.	Professor Erwin de Blok, ASTRON, The Netherlands
TRAPUM (Transients and Pulsars with MeerKAT) - Searching for, and investigating new and exotic pulsars.	Dr Benjamin Stappers, Joddrell Bank Centre for Astrophysics, UK; Professor Michael Kramer, Max Planck Institute for Radio Astronomy, Germany
A MeerKAT HI Survey of the Fornax Cluster (Galaxy formation and evolution in the cluster environment).	Dr Paolo Serra, CSIRO/ATNF, Australia
MeerGAL (MeerKAT High Frequency Galactic Plane Survey) - Galactic structure and dynamics, distribution of ionised gas, recombination lines, interstellar molecular gas and masers.	Dr Mark Thompson, University of Hertfordshire, UK; Dr Sharmila Goedhart, South African SKA Project
MIGHTEE (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey) - Deep continuum observations of the earliest radio galaxies	Dr Kurt van der Heyden, University of Cape Town, South Africa; Professor Matt Jarvis, University of the Western Cape, South Africa and the University of Hertfordshire, UK
ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT) - eg gamma ray bursts, novae and supernovae, plus new types of transient radio sources.	Professor Patrick Woudt, University of Cape Town, South Africa; Professor Rob Fender, University of Southampton, UK

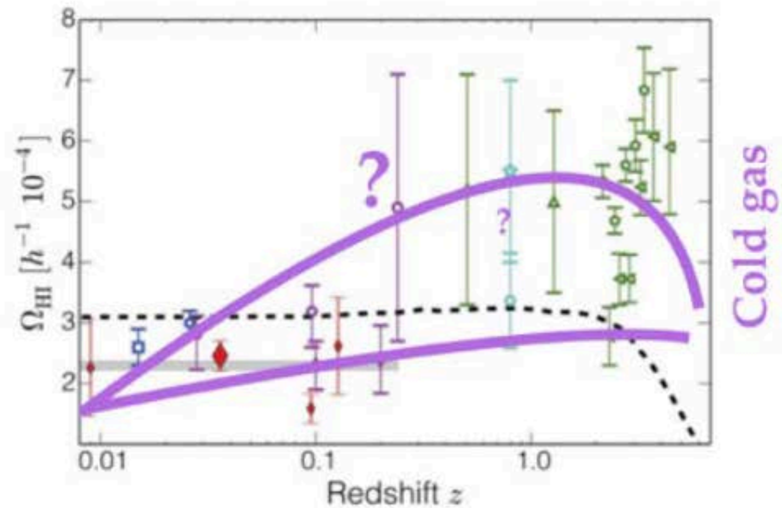
MALS The MeerKAT Absorption Line Survey





4000 hrs for the most sensitive search of HI 21-cm and OH 18-cm absorption lines to map the evolution of cold atomic and molecular gas in galaxies at 0<z<2: the redshift range where most of the evolution in the star-formation rate density takes place.





MeerKAT: only telescope to cover the entire redshift range with good sensitivity.

MALS: probe of cold gas in galaxies over the entire z-range in a luminosity- and dust-unbiased way.

MALS: an order of magnitude increase in the number of HI 21-cm and OH 18-cm absorbers

(only ~50 intervening 21-cm and 3 intervening OH absorbers known)

PIs: N. Gupta and R. Srianand (IUCAA)

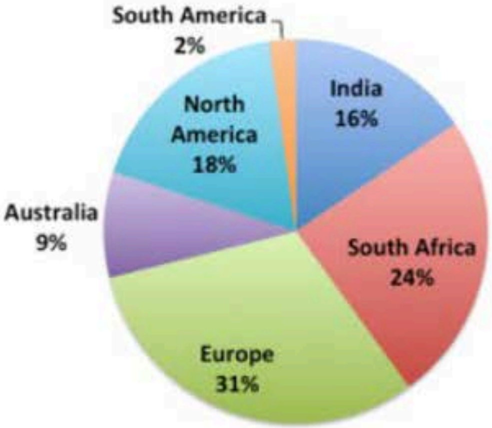
http://mals.iucaa.in/

MALS The MeerKAT Absorption Line Survey

Main science themes:

- Evolution of cold gas in galaxies and its relationship with SFR density,
- Fuelling of AGN, AGN feedback and determining fraction of dust-obscured AGNs,
- Variation of fundamental constants of physics: most stringent constraints (comparable to terrestrial atomic clocks), and
- Physical modelling of ISM, astrochemistry and cosmology.

Strong synergies with multi-wavelength facilities such as ALMA, GMRT, SALT, VLA, VLT and Keck: a large survey with SALT to identify targets for MALS is in progress.



MALS team composition

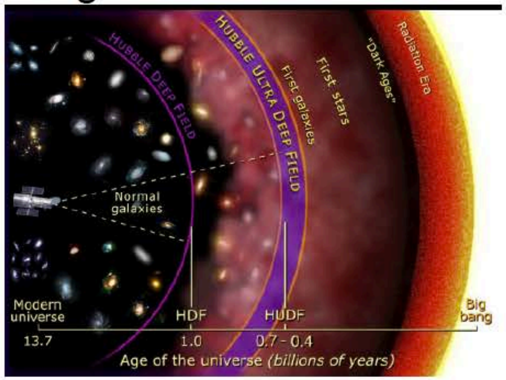
- MALS will also be a highly competitive HI emission, Radio continuum and polarisation survey.
- Strong collaboration and participation of South African researchers in all the aspects of the survey, e.g. Ayanda Zungu (UKZN): M.Sc., Ph.D. on MALS.

PIs: N. Gupta and R. Srianand (IUCAA) http://mals.iucaa.in/

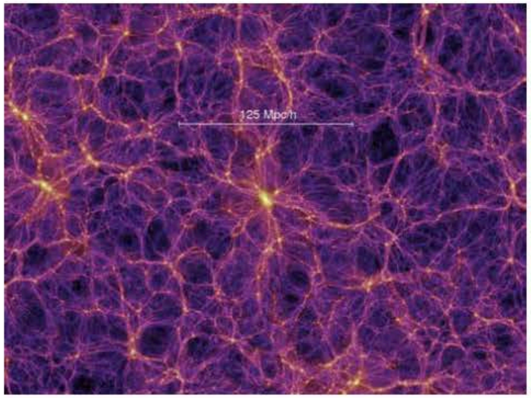
MIGHTEE: Galaxy Formation, Cosmology and Cosmic Magnetism

M. Jarvis (Oxford) & R. Taylor (UCT/UWC)

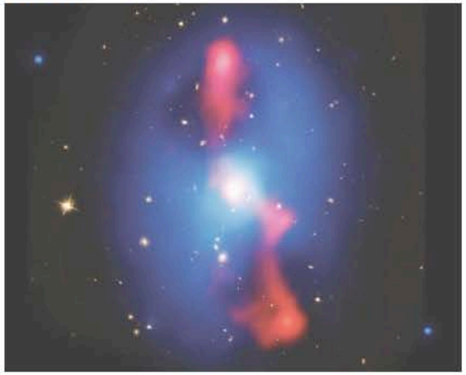
How and when were the first galaxies formed?

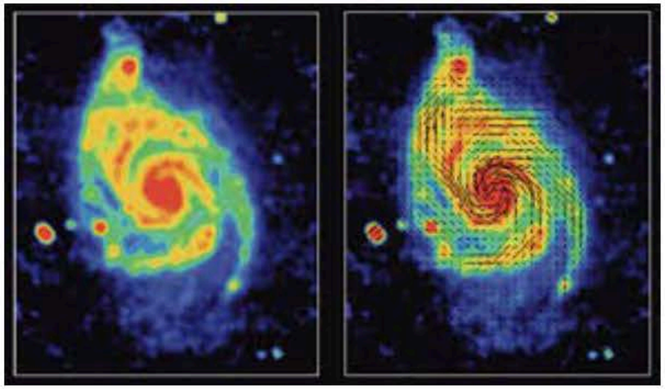


How do Baryons trace and affect the Dark Matter distribution?

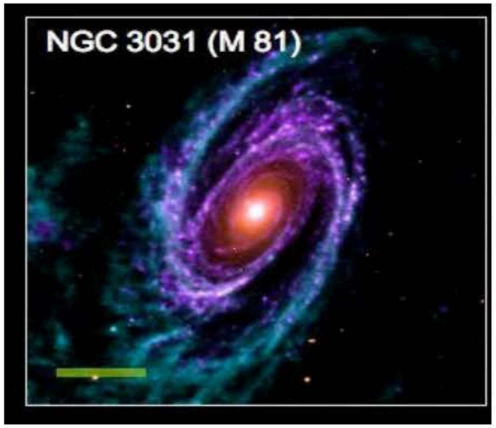


How are BHs fueled and how does BH accretion affect the evolution of galaxies?





What is the origin of cosmic magnetism, and how do magnetic fields influence global galaxy evolution?



How do we go from gas to stars in galaxies?

What is the environmental influence?

Multi-wavelength data critical to MIGHTEE Science

- MIGHTEE consortium members involved in multi-wavelength surveys over MIGHTEE fields
- key involvement in VISTA, *Herschel*, *Spitzer*, *XMM* surveys
- In the future, team members are playing leading roles in ESO-MOONs and ESO-4MOST multi-object spectroscopic surveys that will target the MIGHTEE fields.
- The MIGHTEE fields are also the LSST Deep Drilling Fields – key fields for SA researchers

The MeerKAT International GHz Tuned Extragalactic Exploration (MIGHTEE) Survey

Matt Jarvis & Russ Taylor
on behalf of the MIGHTEE Consortium

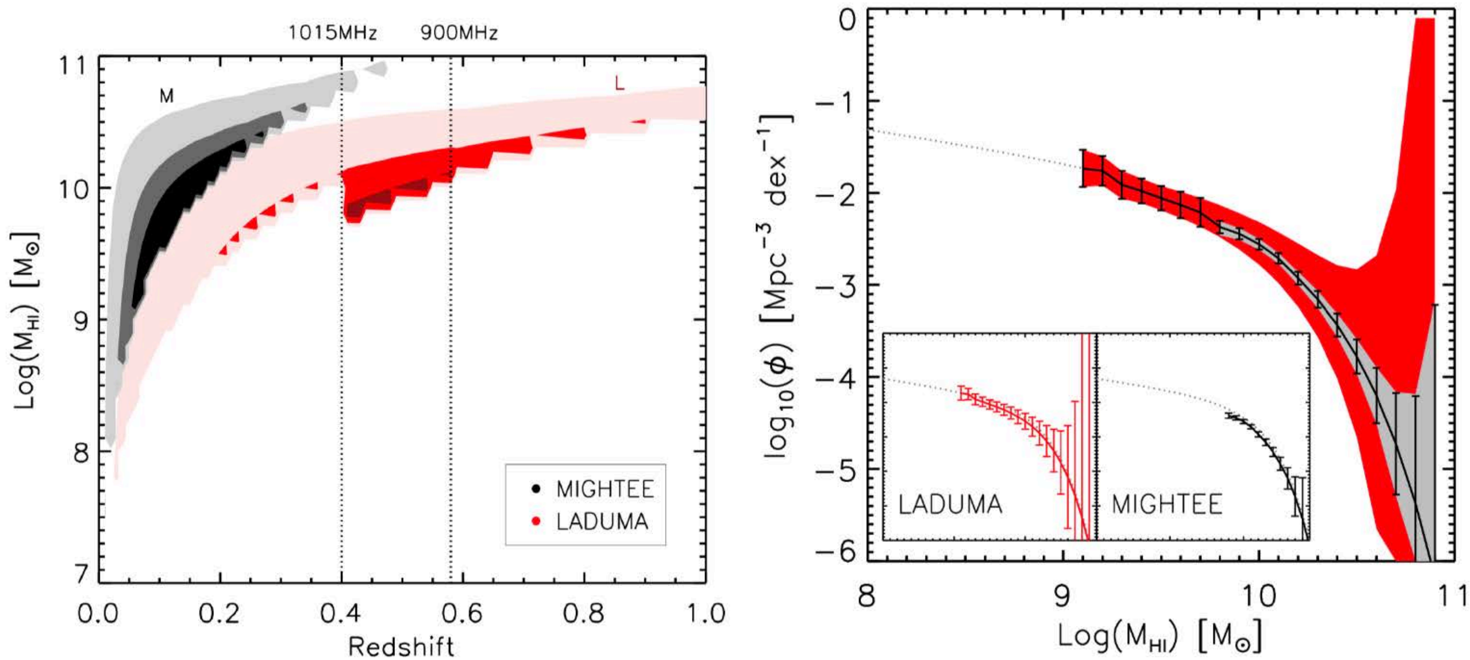
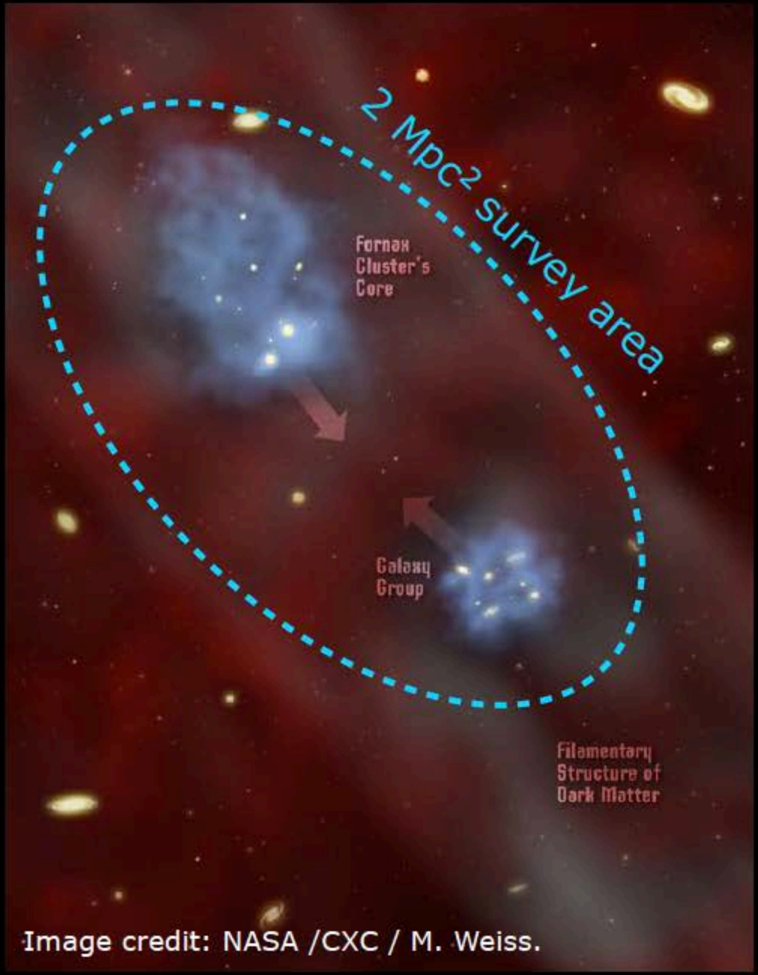
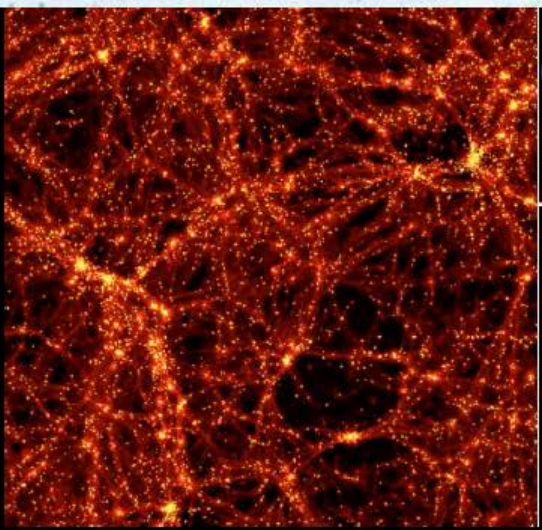
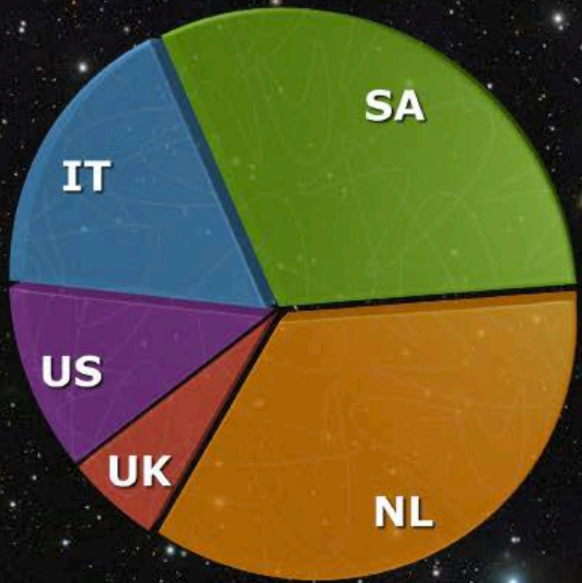


Figure 2: (*left*) The expected coverage of the HI mass versus redshift plane by combining the LADUMA and MIGHTEE surveys. The grey shaded regions show the MIGHTEE coverage and the red shaded regions show the LADUMA coverage. (*right*) The expected constraints on the HI mass function. It is clear that MIGHTEE is required to measure the high-mass end whereas LADUMA pins down the low-mass end at $z < 0.5$. Taken from Maddox et al. (2016).

MeerKAT Fornax Survey (Serra et al.)







Combining MeerKAT data with
ESO VST and MUSE (optical imaging, IFU)
Herschel (dust)
ALMA (molecular gas)
Chandra (X-rays)
... and many more!

Image credit: ESO

MHONGOOSE

MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters

PI: W.J.G. de Blok (ASTRON/UCT/Kapteyn)

- Galaxies do not have enough has to keep forming stars - this gas has to come from outside galaxies
- Simulations predict the gas must fall in from the surroundings of these galaxies, but is extremely faint
- MeerKAT is the first and (until SKA) only telescope worldwide with the sensitivity to detect this gas *and* to make detailed maps
- MHONGOOSE will survey this gas and map it around 30 nearby galaxies over a large range of total mass

Tentative detection of infalling gas (red blob) around galaxy NGC 2403 (blue) observed with the GBT single dish telescope. The resolution of the GBT is low (about the size of the blob) so it cannot resolve the structure of the gas. MeerKAT will increase the resolution by a factor of 10 or more.

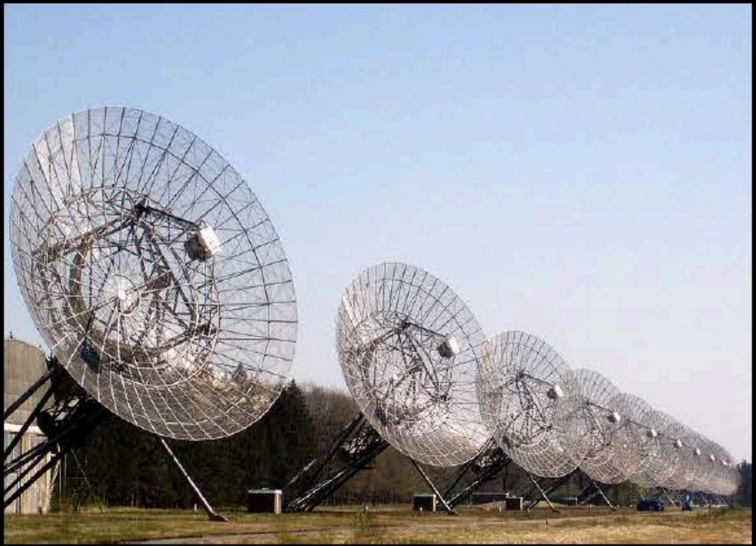
Faint HI in the Local Group

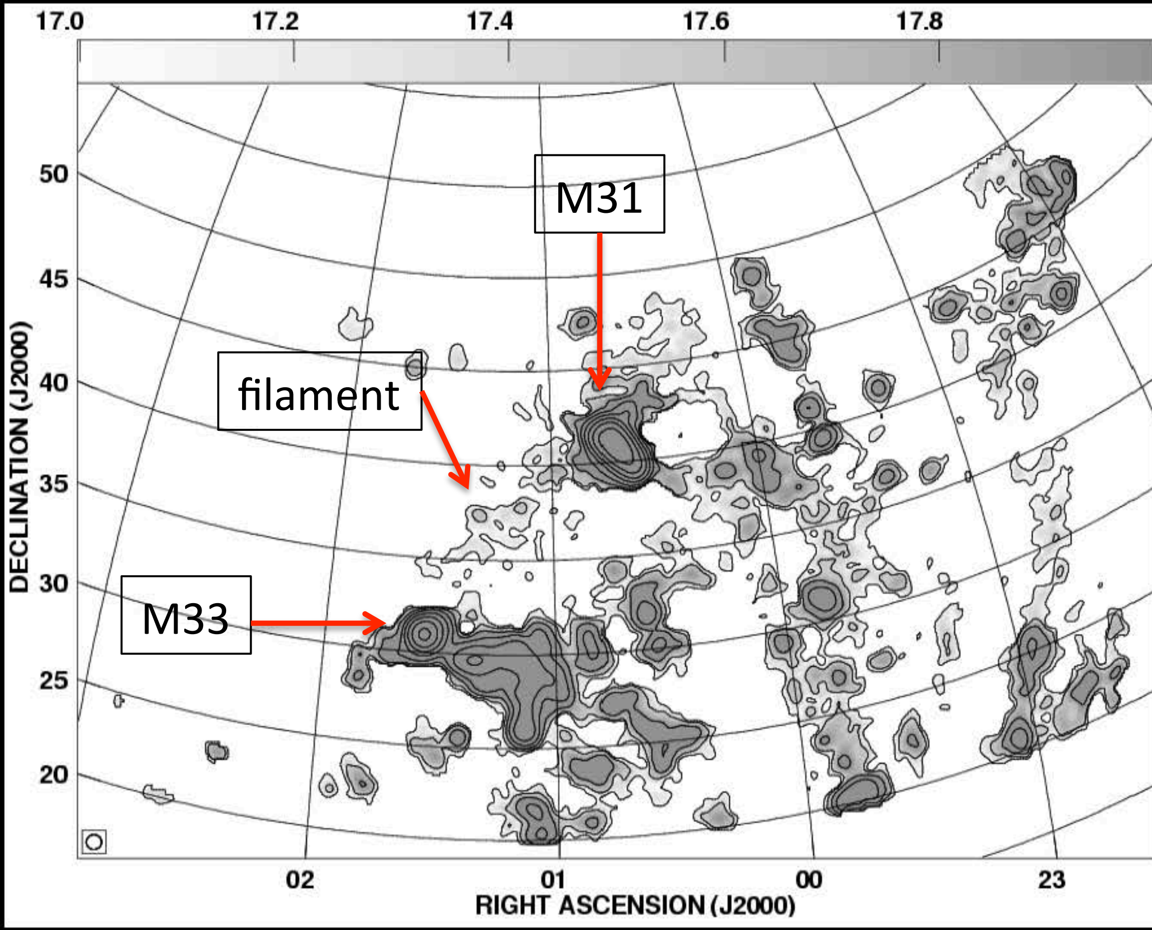
Braun & Thilker (2004, BT04)

Westerbork Synthesis Radio Telescope – each dish as a separate antenna

Survey of HI in the Local Group

$\log(N_{HI}) = 17.0\ cm^{-2}$ (2-3σ)

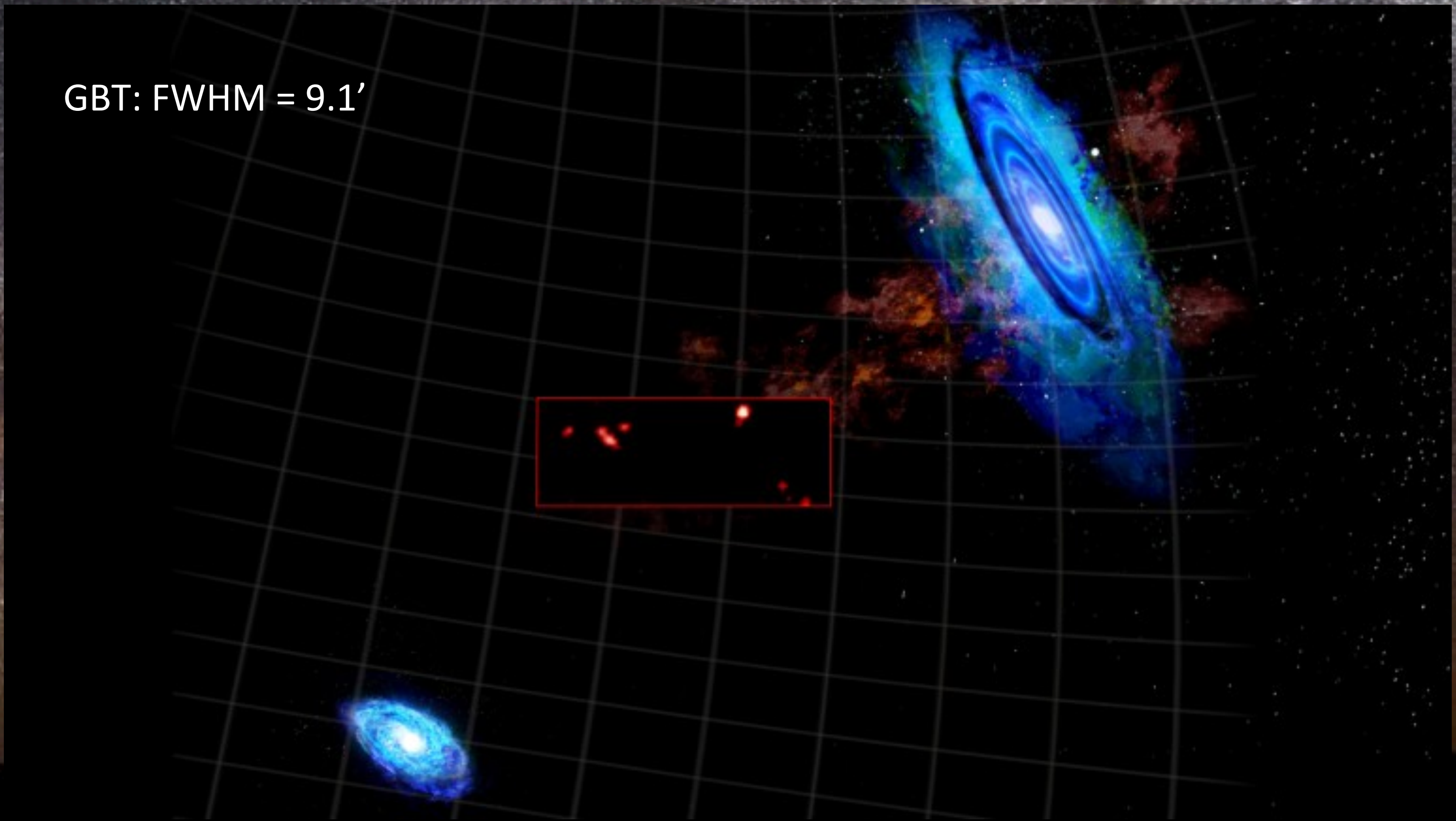




Braun & Thilker (2004), A&A, 417, 421-435

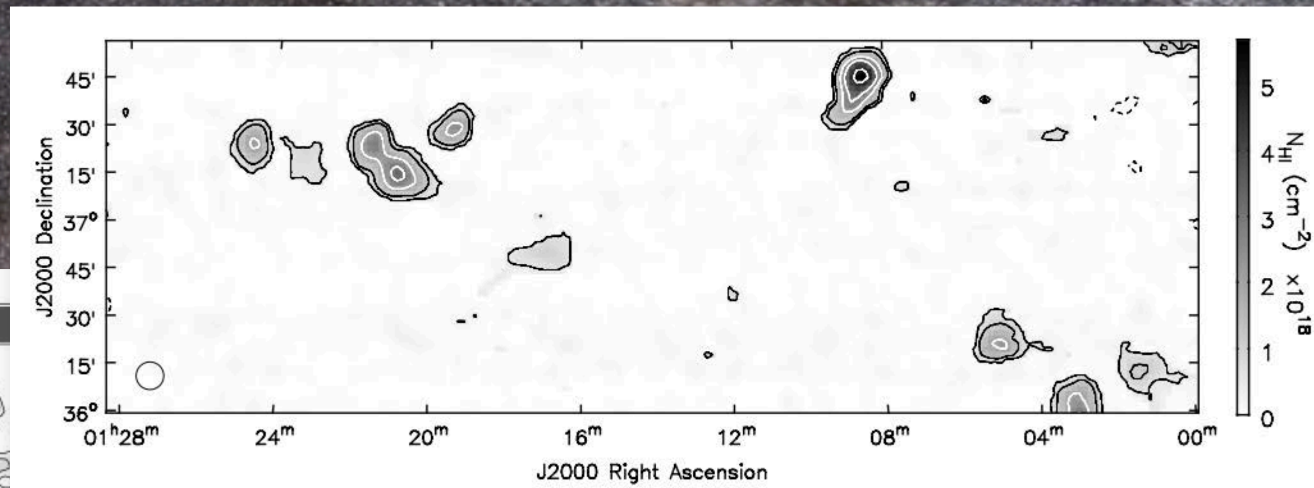
Resolution = single dish ~ 49’

Faint HI in the Local Group

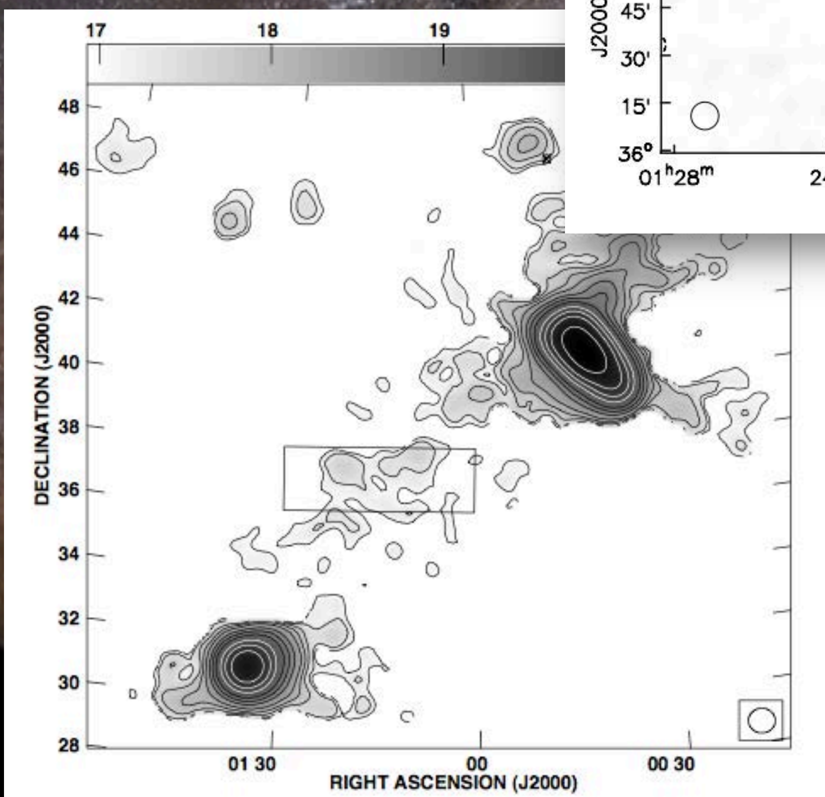


Wolfe et al. 2013, Nature, 497, 224

Faint HI in the Local Group

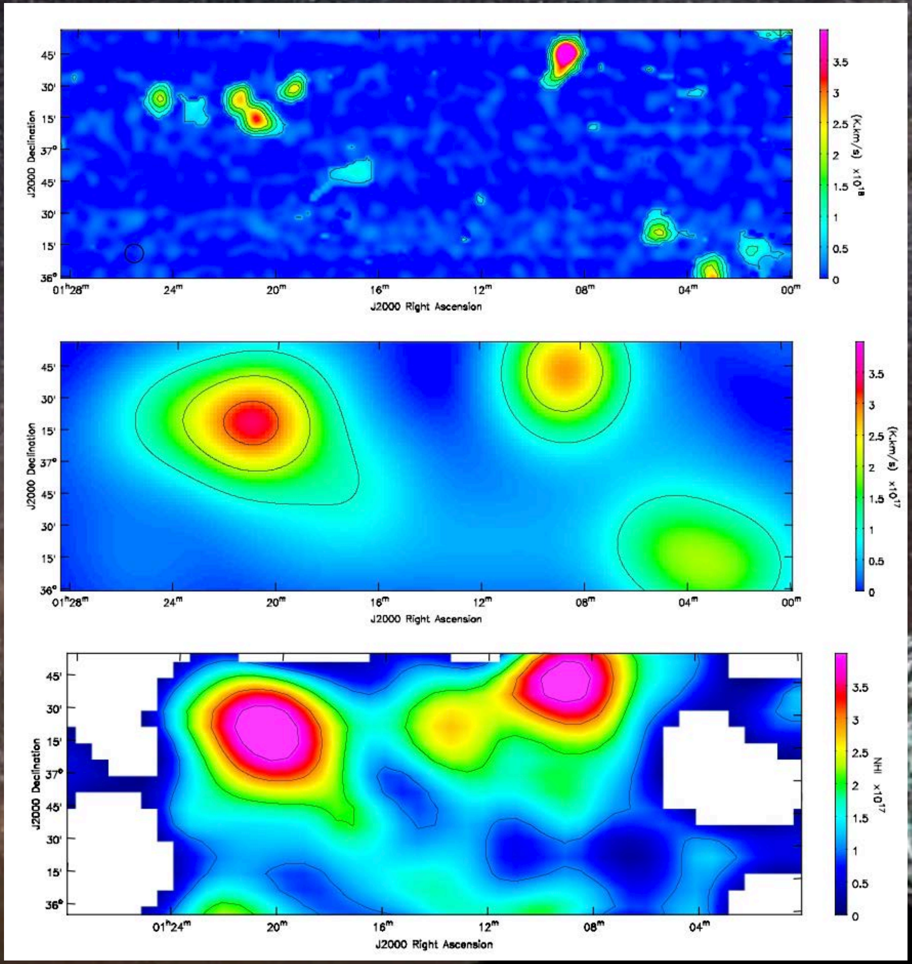


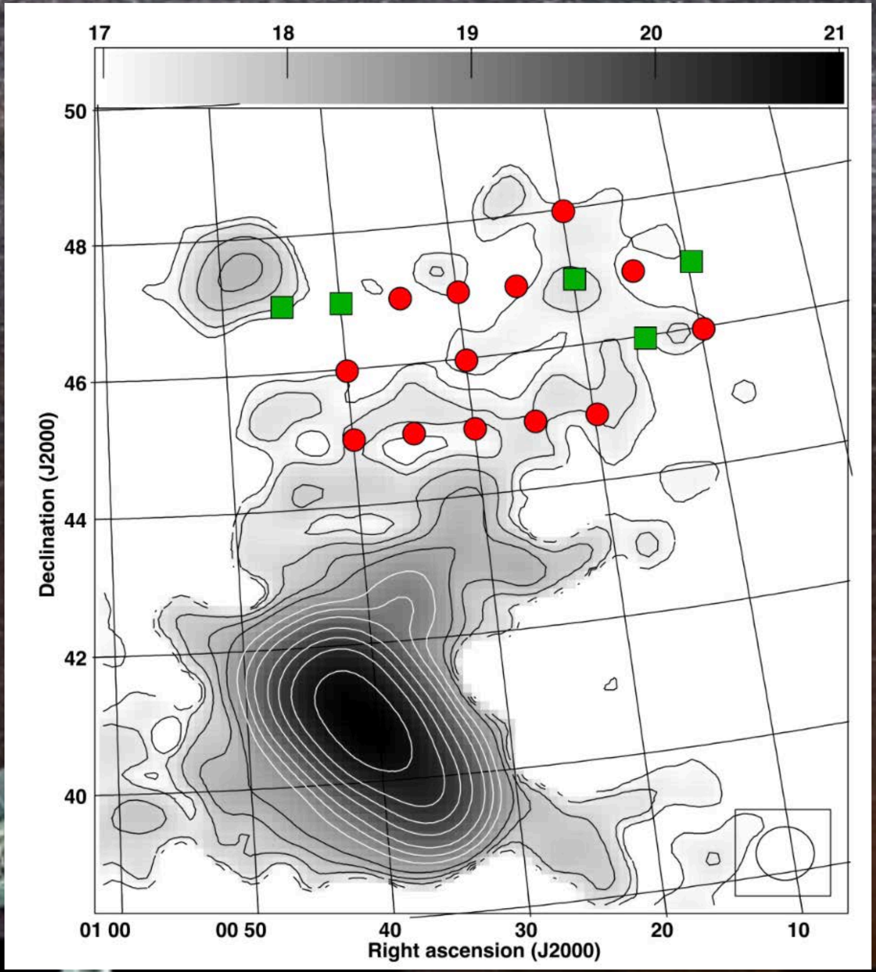
Wolfe et al. 2016 / res ~ 9'



Braun & Thilker 2004 / res ~ 49'

Faint HI in the Local Group





Wolfe et al. 2016

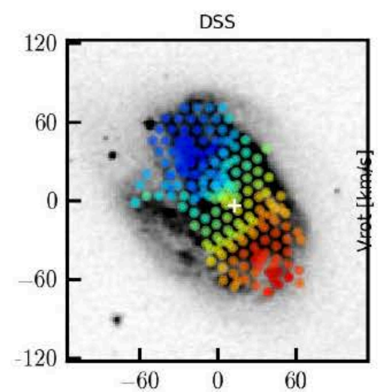
MHONGOOSE

MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters

PI: W.J.G. de Blok (ASTRON/UCT/Kapteyn)

- MHONGOOSE will also investigate how gas in galaxies turns into stars: for our 30 galaxies we are collecting data in many parts of the spectrum to map all phases of star formation
- We also measure kinematics of the gas from which stars form using optical telescopes (PhD Thesis Moses Mogotsi, UCT)
- Moses is one of ~10 South African PhD and Masters students that have so far worked within MHONGOOSE, in addition to ~5 postdocs
- MHONGOOSE's largest nationality is South African (26%) and South African MHONGOOSE team members played a large role in the commissioning of KAT-7

Picture of H alpha emission of star forming regions in one of the sample galaxies. This is an example of one of the many multi wavelength images already available.



Example optical velocity field of one of the MHONGOOSE galaxies from the thesis of Moses Mogotsi (UCT)

Understanding the Galactic gas cycle with MHONGOOSE

MHONGOOSE:

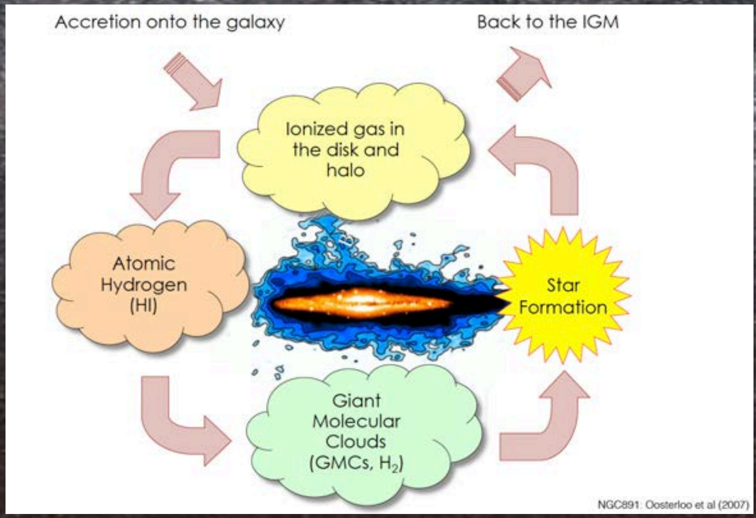
- Deep observations of 30 nearby galaxies
- 200 hours per galaxy; 6000 hours total
- 25 times longer than THINGS
- twice as deep as HALOGAS

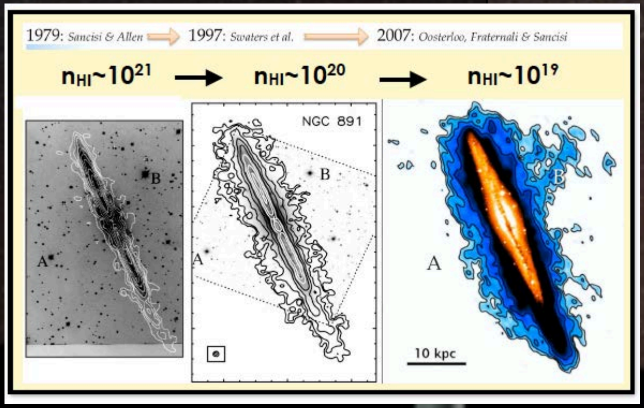
High resolution:

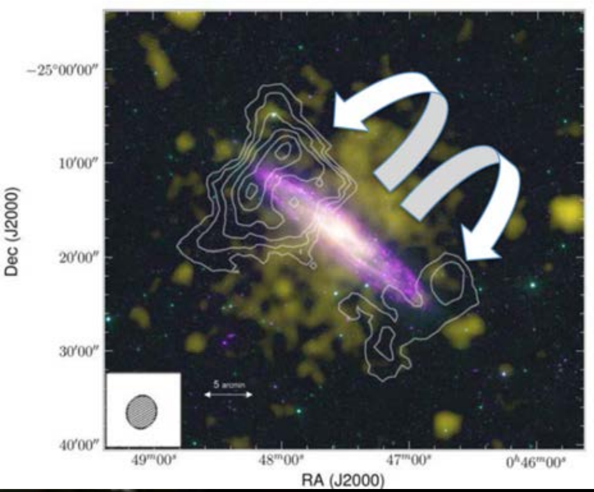
- star formation
- dynamics
- structure of the ISM

High sensitivity:

- cosmic web
- accretion







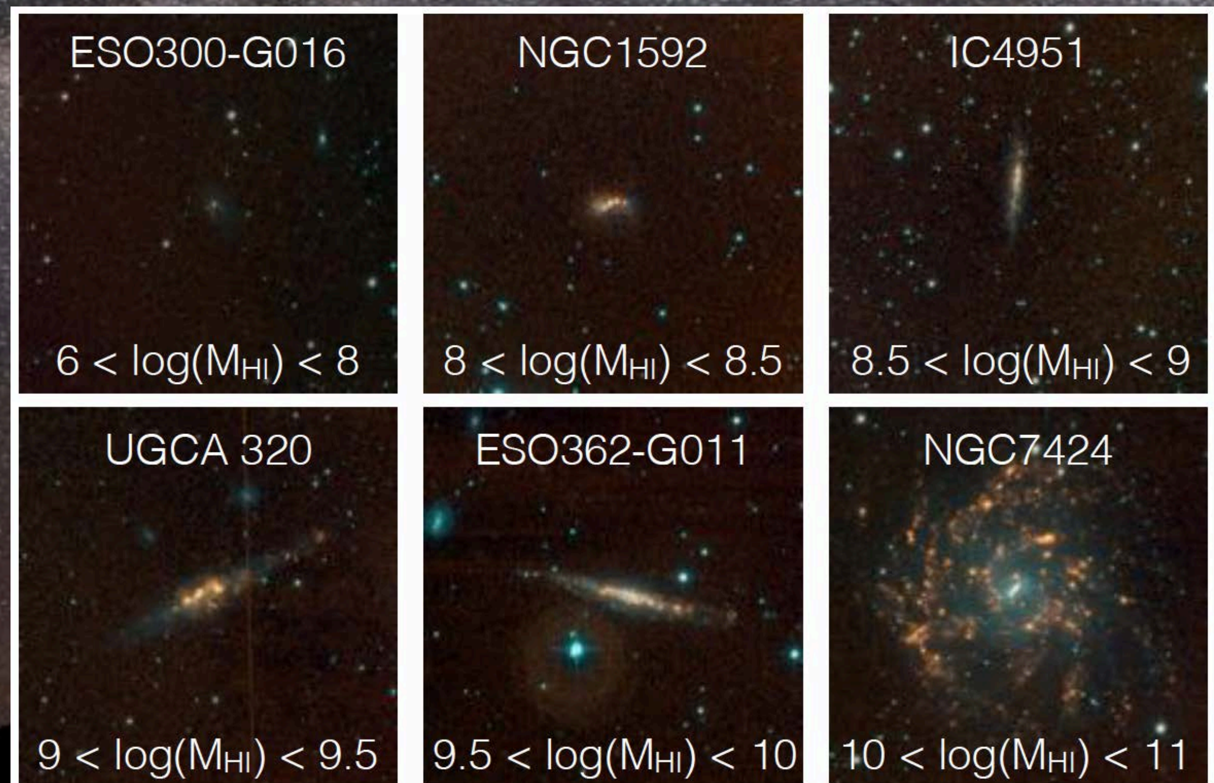
KAT7 - NGC 253: Lucero et al. 2015

MHONGOOSE sample

- representative number of galaxies as uniformly as possible over $\log(M_{HI})$

$6 < \log M_{HI} < 8$	5
$8 < \log M_{HI} < 8.5$	16
$8.5 < \log M_{HI} < 9$	18
$9 < \log M_{HI} < 9.5$	26
$9.5 < \log M_{HI} < 10$	15
$10 < \log M_{HI} < 11$	7
	30 gal.s

- 5 galaxies per bin
- All i from face-on to edge-on



MHONGOOSE

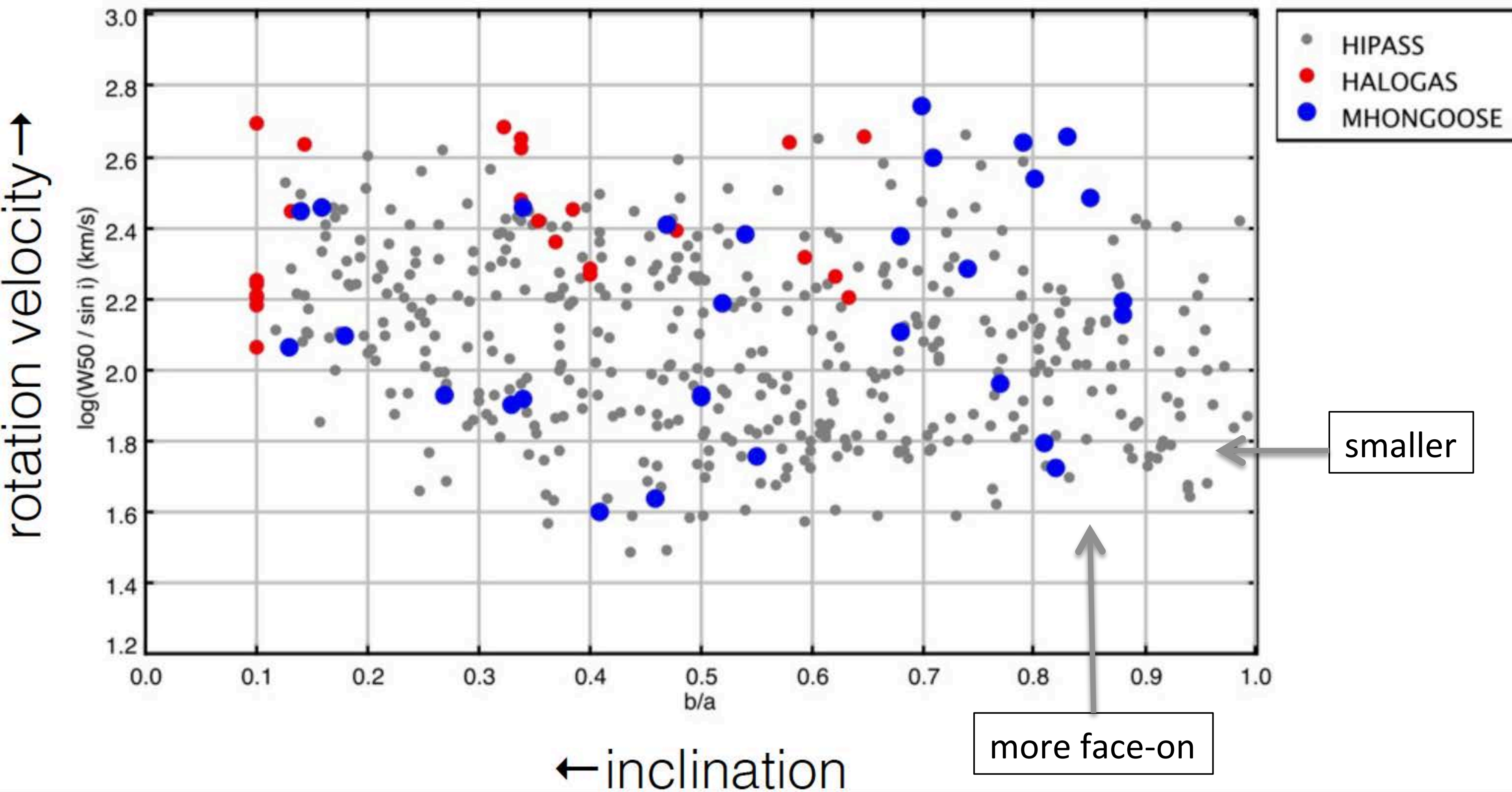
Selection of the sample

Criteria for the MHONGOOSE final sample

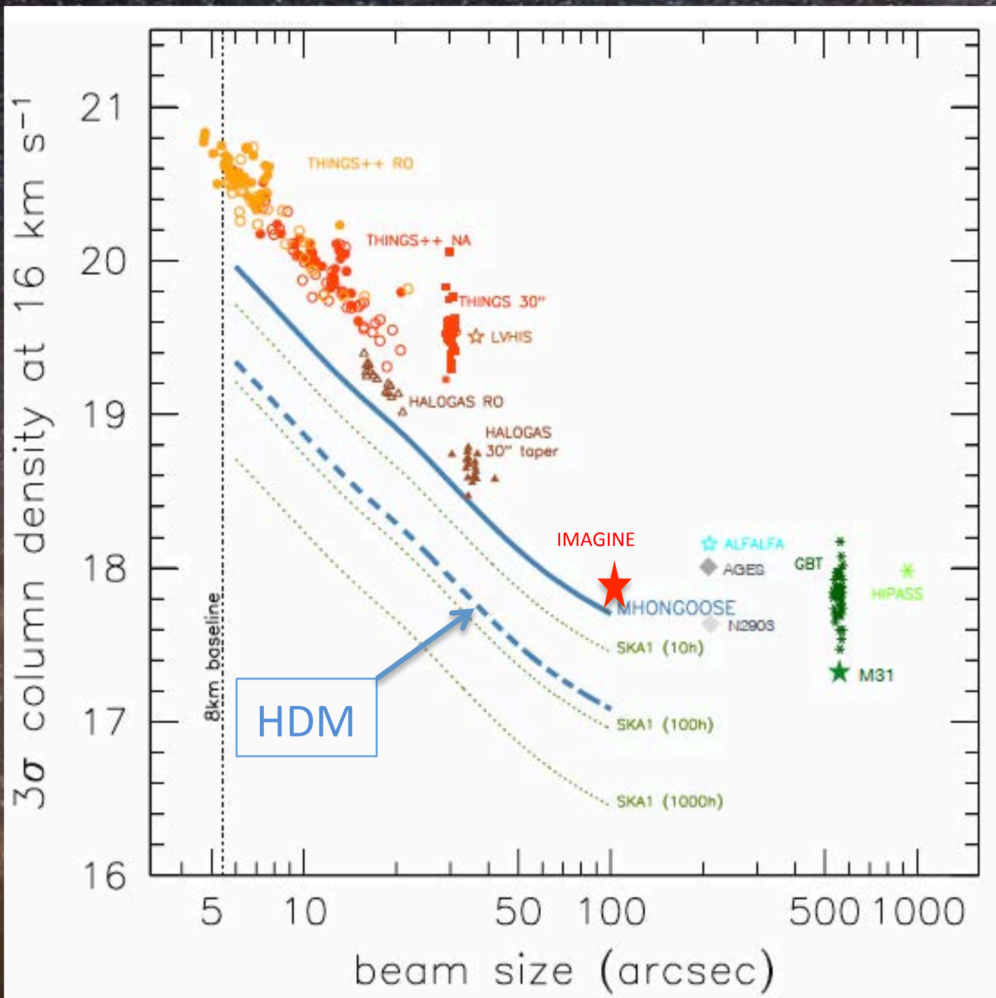
- Exclude galaxies with obvious quality issues
- Exclude interacting galaxies
- Must fit in one MeerKAT field (no mosaic)
- Best edge-on (extra-planar), face-on (dispersion) and ~60 deg inclination (kinematics)
- With these, large range in surface brightness and SFR

MHONGOOSE

Selection of the sample



MHONGOOSE



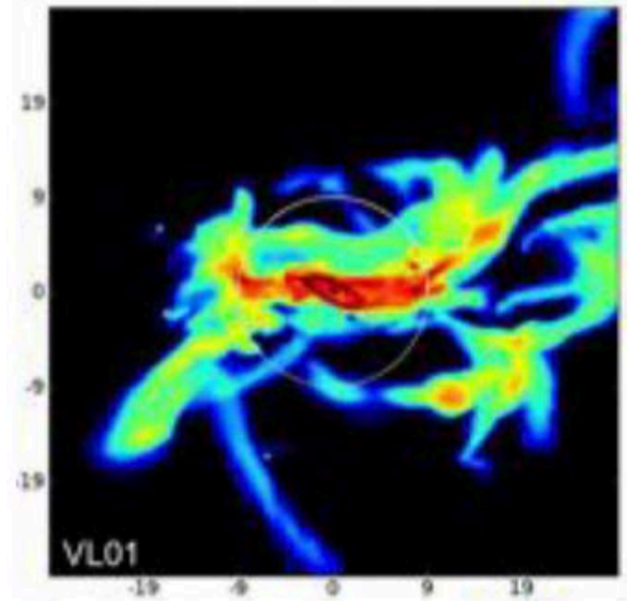


Figure 1: Visual impression of the morphology of simulated cold accretion features. The small dark brown ring in the center represents the main galaxy disk. The figure measures ~ 30 kpc on the side, the circle has a diameter of ~ 10 kpc. This area would fit within one MeerKAT primary beam for distances $D > 2$ Mpc. Figure taken from Danovich et al. (2015).

Revised MHONGOOSE

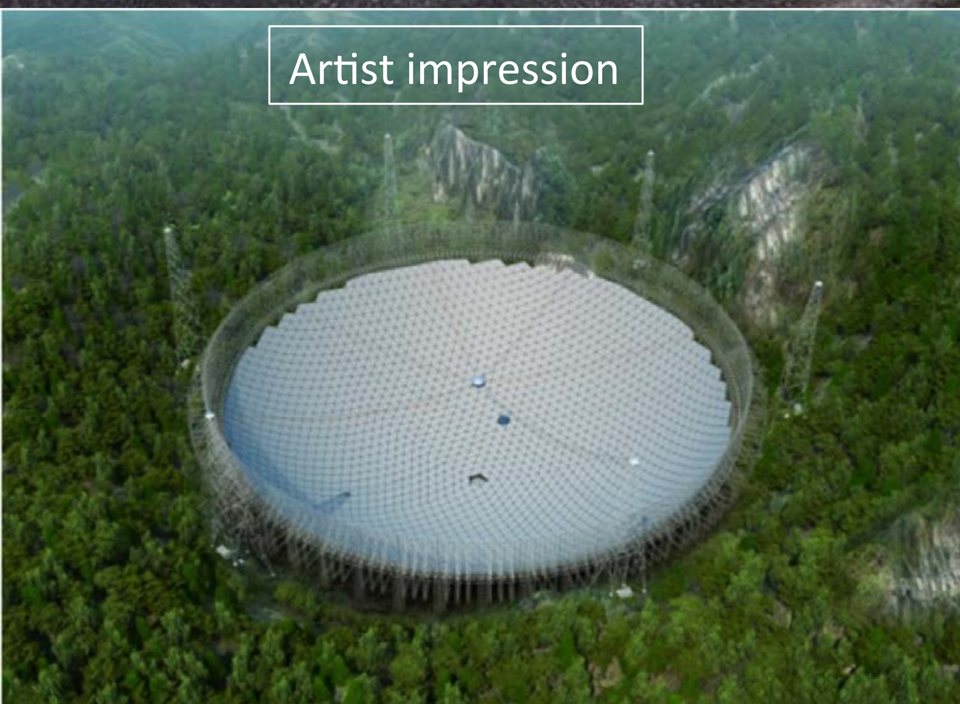
- The desired column density limit as specified in the **2010** proposal was $7.5 \cdot 10^{18}$ cm^{-2} at 3σ over 16 km s^{-1} at 30” resolution. For the 2010 MeerKAT parameters, this corresponded to a noise of 0.075 mJy beam^{-1} per 5 km s^{-1} channel assuming natural weighting. This would be reached after 200h of observing time per galaxy (including calibration overhead). For the complete sample of 30 galaxies, the total allocated observing time is therefore 6000h.

- With the new MeerKAT parameters, this noise level is reached after 48h on-source. Assuming 15% overhead this becomes 30 X 55h = 1650 hours.

Revised MHONGOOSE

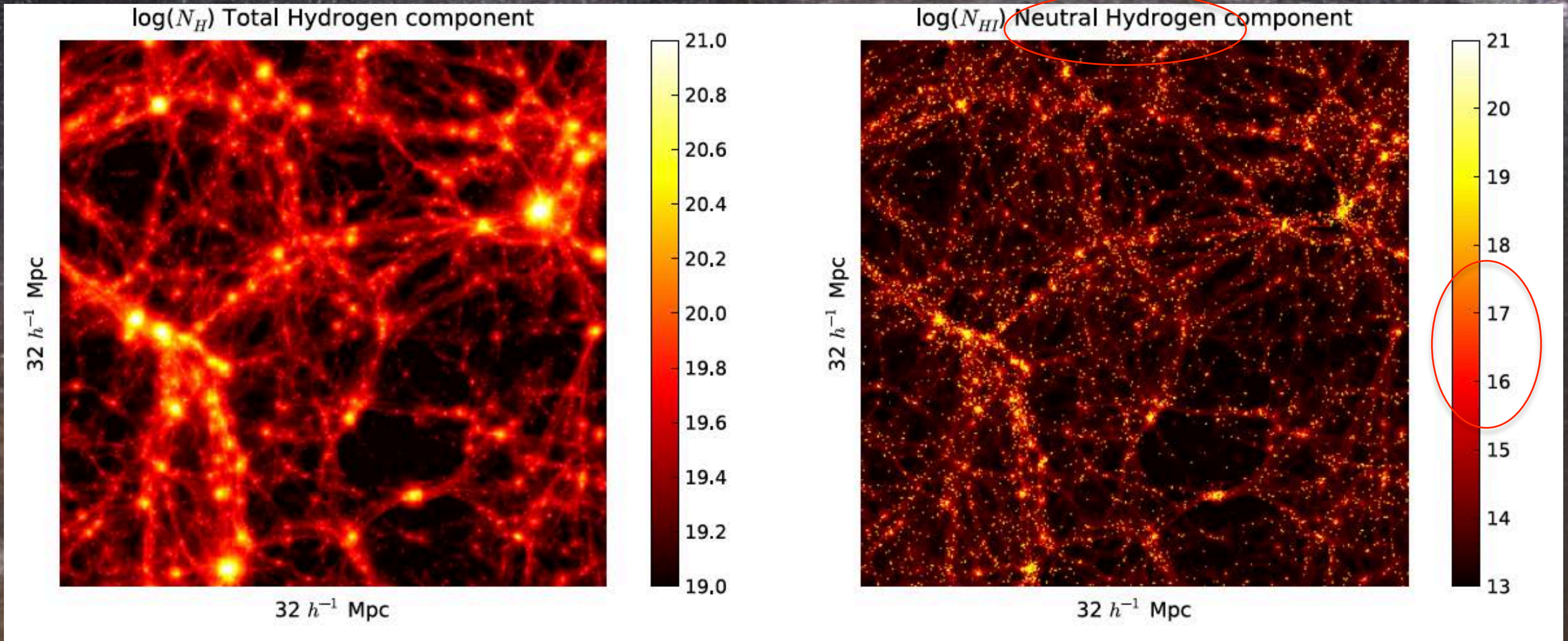
- The increased sensitivity of MeerKAT offers an unprecedented opportunity to go beyond the original MHONGOOSE and aim for SKA science, even in the current pre-SKA1 era. Last May we proposed additional ultra-deep observations of three MHONGOOSE galaxies with the aim to make full use of the increased sensitivity, and push the column density sensitivities down to ~ $1 \cdot 10^{17}$ cm^{-2} at 90” resolution.
- We proposed then to choose three galaxies from the MHONGOOSE sample consisting of an edge-on, face-on, and intermediate inclination galaxy. 1000 hours would reach the desired sensitivity, so 3 X 1000h = 3000 h + 1650 h = 4650 h for the whole survey, still 20% below the allocated 6000h.

Reaching the Cosmic Web
with MeerKAT + FAST



FAST: “Five-hundred-meter Aperture Spherical Telescope”
In China’s Guizhou province

Galaxy – IGM Connection



Popping et al, 2015, PoS, AASKA14, 132

See also sim.s by Powers & Davé)

To reach the Cosmic web, need to go down to $10^{16} – 10^{17}$ cm^{-2}

Sensitivities prospects in the SKA era

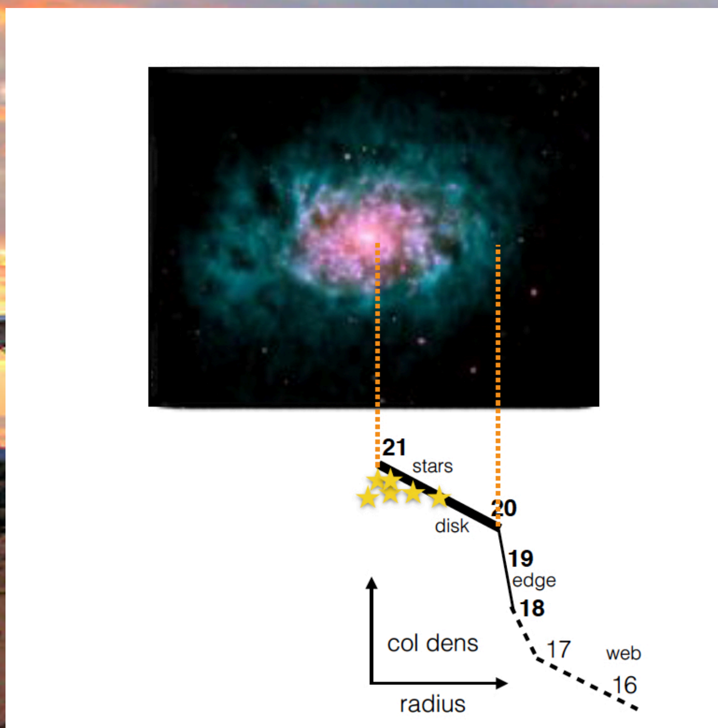
Table 1. Expected sensitivities of different telescopes at 5σ.

Telescope Array(s)	Integration hours	resolution km s^{-1}	beam arcsecs	sensitivity cm^{-2}	Expected date
VLA (THINGS)	10	5	30	5.0×10^{19}	
KAT-7	100	5	210	5.0×10^{18}	
WSRT (HALOGAS)	120	5	30	5.0×10^{18}	
KAT-7 + WSRT	100	16	210	1.0×10^{18}	
MeerKAT	200	16	90	5.0×10^{17}	2017
SKA_1-MID	100	5	30	7.5×10^{17}	2023
SKA_2	10	5	30	2.5×10^{17}	2030
SKA_2	100	5	30	7.5×10^{16}	2030

Carignan 2016

~2018: MeerKAT + FAST @30” < $5.0x10^{17}$ **cm^{-2}**

Reaching the Cosmic Web with MeerKAT + FAST



$3.1\cdot10^{17}\ SdV/\theta^2$ atoms/cm²

where θ is beam size (arcmin)
dV km/s
S mJy/beam

- THINGS (VLA): 10h 5σ over 5 km/s @30”: 5×10^{19} cm^{-2}
- KAT-7 : 100h 5σ over 5 km/s @3’: 5×10^{18} cm^{-2}
- HALOGAS (WSRT): 120h 5σ over 5 km/s @30”: 5×10^{18} cm^{-2}
- KAT-7 + WSRT 100h 5σ over 16 km/s @3’: 1×10^{18} cm^{-2}
- MeerKAT: 200h 5σ over 16 km/s @90”: 5.0×10^{17} cm^{-2}

- **MeerKAT + FAST s @30” <** 5.0×10^{17} **cm^{-2}**

2018-19

- SKA_1-mid: 100h 5σ over 5 km/s @30”: 7.5×10^{17} cm^{-2} **2023**
- SKA_2: 10h 5σ over 5 km/s @30”: 2.5×10^{17} cm^{-2} **2030**
- SKA_2: 100h 5σ over 5 km/s @30”: 9.0×10^{16} cm^{-22} **2030**

MeerKAT + FAST

- In the near future (2018-19), the best combination to study low column density HI with a good spatial resolution will be to combine the sensitivity of FAST with the spatial resolution of MeerKAT.

- The combination of the data from those two telescopes will allow, 5 years before SKA1-MID, to do "cosmic web" research to levels < 5 X 10^{17} cm^{-2}, close to 10^{16} cm^{-2}, densities that would normally only be accessible to the full SKA around 2030.

- It is at those densities that we expect the galaxies to connect with the surrounding cosmic web.

Towards a Full Census of the Obscure(d) Vela Supercluster

A MeerKAT M32 Early Science survey to map the fully obscured part of the Vela SCL

Background: *Recent spectroscopic observations of ~4500 galaxies (SALT, AAOmega, +)*

- revealed a potential massive supercluster at 18000 km/s (possibly Shapley-like)
- straddling the Milk Way in Vela ($l \sim 275^o \pm 20^o$, $|b| \sim 5^o$-10^o)
- close to where cosmic flow fields suggest significant mass excess
- due to foreground contamination ($|b| < 5^o$) ***major part of supercluster can not be charted at any wavelength,*** **except through the 21cm line of HI**

MeerKAT survey: *map all galaxies with $\log M_{HI} > 9.5\ M_\odot$ within 16-24000km/s across ZOA over minimal suspected supercluster extent ($l \times b \sim 20^o \times 12^o = 240^o$)*

- MeerKAT sensitivity, survey speed, and resolution ideal for mapping supercluster
- Simulations show: primary goals can be achieved on reasonable time scales
- Nyquist sampling: 960 pointings → **240 hrs for M32 (possibly 1-2 fields with M16)**

Why M32?

- Testing & preparation of data pipelines for MeerKAT HI-LSP's (Fornax, Laduma)
- While aiming for potential high-impact early-science results

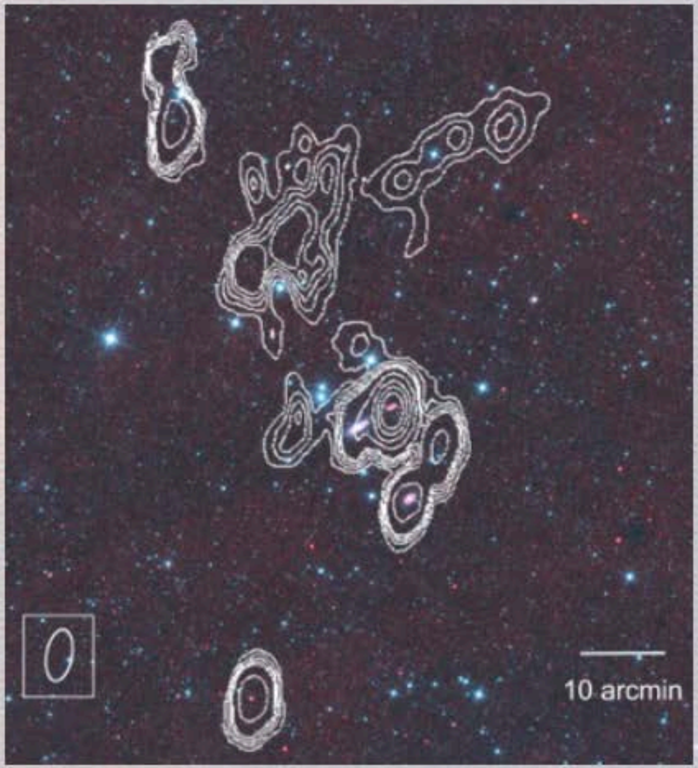
Collaboration:

Renée Kraan-Korteweg (PI), Sarah Blyth (co-PI Laduma), Claude Carignan, Ed Elson, Brad Frank, Tom Jarrett @UCT; Michelle Cluver @UWC; Gyula Jozsa @SKA;Paolo Serra (PI Fornax) @INAF

The MeerKAT study of Intragroup HI

Michelle Cluver (UWC), Lourdes Verdes-Montenegro (IAA-CSIC)

Where is the "missing" atomic gas and what is it doing?



KAT-7 looks at HCG 44

Why use GAMA Groups?

state-of-the-art Group Catalogue (high spectroscopic completeness + 21 band photometry

Why use Hickson Compact Groups?

wealth of multiwavelength observations, evolutionary sequence evident

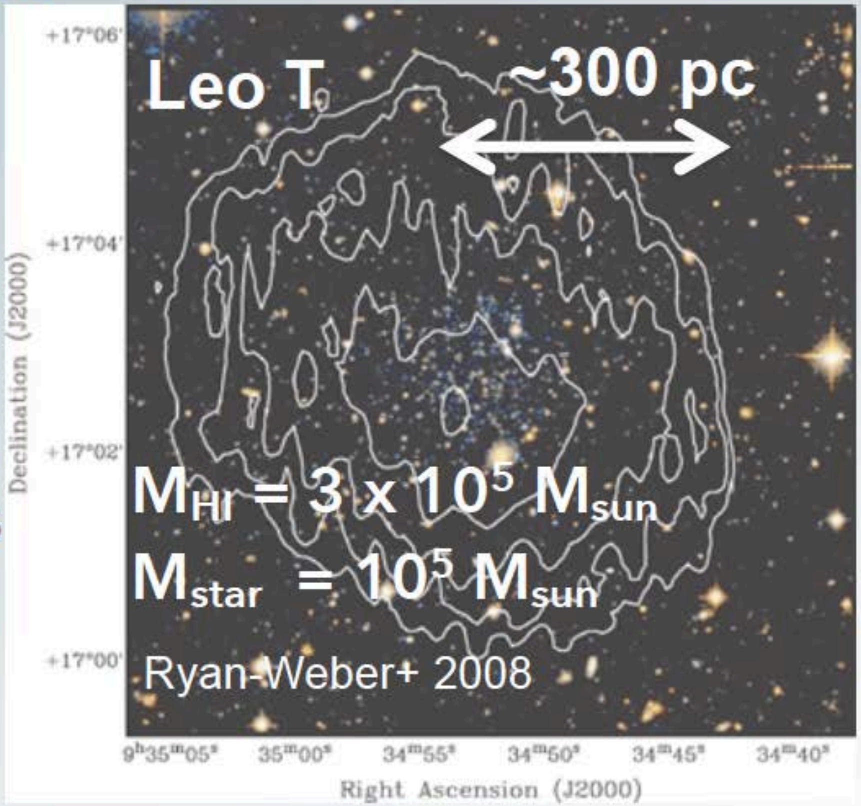
Why MeerKAT?

column density sensitivity + large field of view, best UV coverage at short baselines (to recover diffuse emission)

(B. Adams)

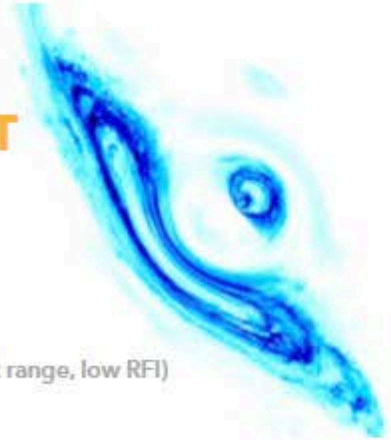
MeerKAT and low-mass galaxies

- Important for testing cosmological models on small scales and understanding galaxy formation
- Detect a hundred galaxies below 10 million solar masses with planned surveys
- A survey of the nearby Centaurus region answers the question: How common are marginal galaxies like Leo T?



A dedicated HI strong lensing survey with MeerKAT

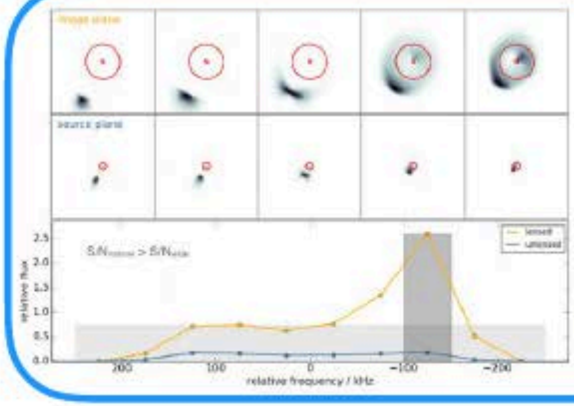
Roger Deane (Rhodes University)



- **MeerKAT will (emphatically) be the best facility to detect lensed HI pre-SKA**
  (due to: sensitivity, frequency coverage, well-matched angular resolution, wide bandwidth and FoV, high dynamic range, low RFI)
- **will provide the deepest view of HI emission in galaxies**
- **only way to directly detect Milky Way-like HI galaxies towards peak epoch of AGN/star formation**
- **high-impact, rapid-turnaround science during commissioning**
- **important cross-checks with stacking/statistical methods**
- **significantly lower risk on calibration for high-z HI**
- **high legacy value well into SKA era**
- **strong synergy with SALT**

Roger Deane
Danail Obreschkow
Ian Heywood
Sandeep Sirothia
Sphesihle Makhathini
Oleg Smirnov

lensing simulations



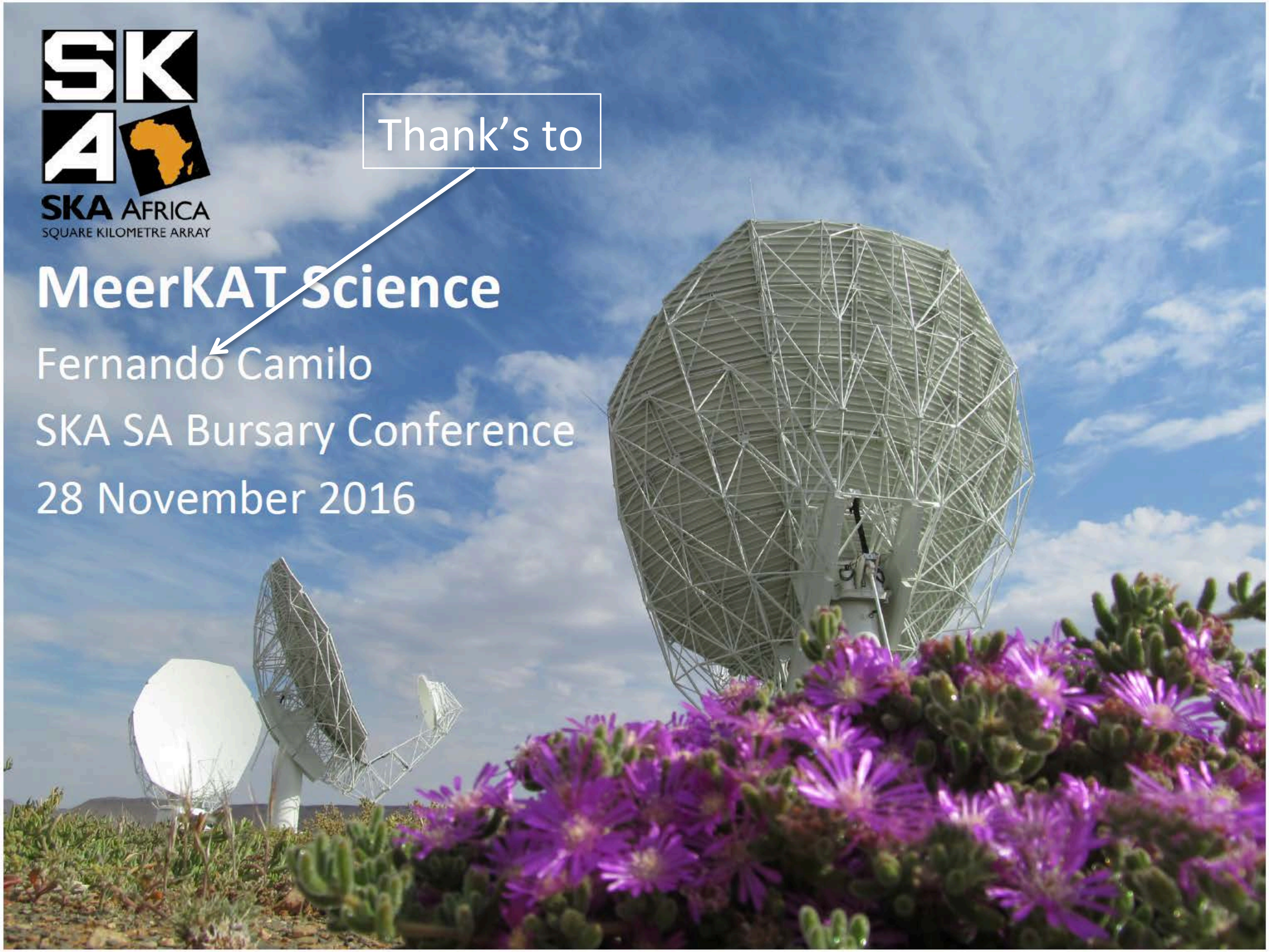
Deane et al. 2015:

channelised ray-tracing of 150 deg² HI light cone

predictions for HI surveys

optimisation of observing strategies

MeerKAT shown to be best placed to lead pre-SKA


SKA AFRICA
SQUARE KILOMETRE ARRAY
Thank's to
MeerKAT Science
Fernando Camilo
SKA SA Bursary Conference
28 November 2016

LADUMA PIs:Blyth (UCT), Holwerda (Leiden), Baker (Rutgers)

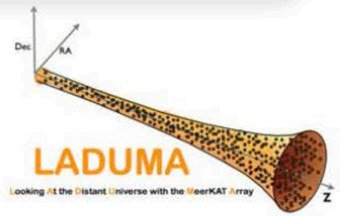
LADUMA: Looking At the Distant Universe with the MeerKAT Array

MeerKAT's high sensitivity combined with its low-frequency capability will enable the deepest, highest redshift measurements of HI in emission prior to SKA1

Headline science goals are to investigate:

- the HI mass function in different environments out to $z \lesssim 0.6$
- for the first time, the evolution of Ω_{HI} using HI emission out to $z \lesssim 1.45$
- how galaxies' HI masses depend on stellar/halo mass vs. z
- evolution of the baryonic Tully-Fisher relation with z

- the cosmic merger rate with OH megamasers
- HI properties of optically selected absorption line systems



LADUMA

Observing plan:

- single pointing encompassing ECDF-S field (δ = -27°)
- proposed 333h with L-band (z<0.58), 3091h with UHF band (0.42 < z < 1.4)

The LADUMA science case benefits from the wealth of multi-λ data available in the field:

Imaging	optical, multiband (*HST*, VST ~26 AB)	central region + larger region
	near+mid IR (VISTA + *Spitzer*)	full region
	UV (*GALEX*)	central region
	X-ray	central
Photometric redshifts	COMBO-17, SWIRE, MUSYC	various coverage
Spectroscopic redshifts	~4000 publicly available ~3000 LADUMA	more to come as surveys complete

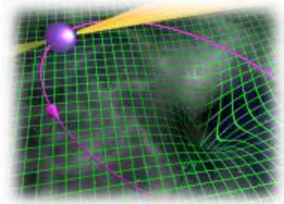
SA participation:

- 1/3 PIs (Blyth)
- 1/3 working group leads
- ~1/3 of CoIs (22.5/69)

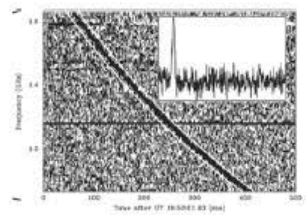
TRAPUM - TRansients And PUlsars with MeerKAT

Use MeerKAT to reveal numerous new pulsars and fast radio transients to improve our understanding of physics in extreme environments.

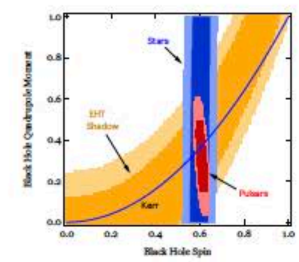
- Discover exotic pulsar systems for tests of general relativity, detection of gravitational waves and measuring neutron star masses.



- Discover pulsars in the Galactic centre and use them to probe the central super-massive black hole, dark matter and central stars



- Search the Universe with the best sensitivity, search volume; time resolution; search for fast radio transients to study the highest energy density events in the Universe and use them for cosmology



- Study the properties, dynamics, and evolution of globular clusters

- Investigate the dependence of the pulsar and fast transient populations on properties such as metallicity and star formation history, by searching for them in external galaxies

- Combine with multi-wavelength studies – MeerLICHT, SALT, *Fermi*, HESS, CTA, Chandra, XMM, ….. --- detailed understanding of the nature of the transients and pulsar companions

TRAPUM

Why MeerKAT?

Exceptional sensitivity – *lots of new sources*
Wide field of view --- *fast surveys, rare transients*
Resolution – *essential accurate localisation of fast transients*
Wide range of frequencies --- *Optimally search different regions of Galaxy*
Location -- *views of Galactic plane, Magellanic Clouds*
Flexibility & commensality --- *sophisticated observing modes.*

TRAPUM Team?

Led by Ben Stappers and Michael Kramer we are a team of 37 scientists
Currently including 7 from South Africa from 5 institutions.
We are very keen to include more South African expertise.

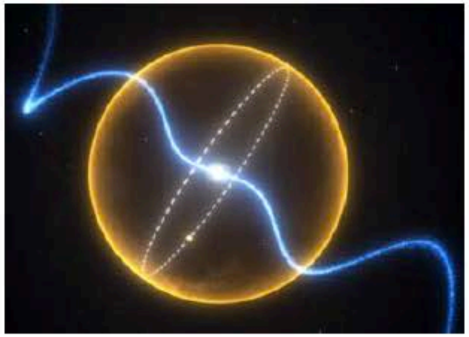
Instrumentation Inputs

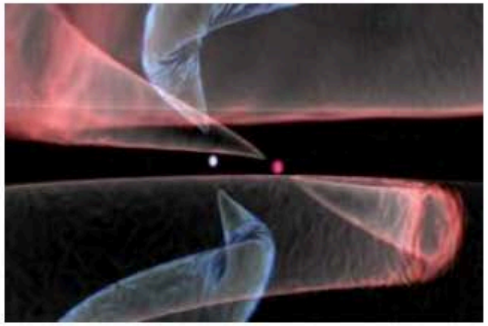
Grants from MPIfR and the Max-Planck Society are funding the supply of S-band (2-3.5 GHz) receivers and a 200 beam beamformer and computing
An ERC Advanced Grant to the MeerTRAP project is funding a further 200 beams and funding to undertake real time searches for pulsars/transients

MeerKAT LSP on Pulsar Timing (MeerTime) *(M. Bailes, Swinburne U)*

Science Goals:

- Was Einstein Right?
- What is the structure of nuclear matter?
- Can we detect gravitational waves using pulsars?
- How do massives stars live and die?





The Power of MeerKAT

- Most sensitive telescope south of the border!
  - 50 x faster to science than the existing facilities
- SA participation:
  - UKZN, UCT, SKA-SA
- Pulsar phase reference for satellite missions
  - Fermi, etc
- Instrumentation provided by Swinburne:
  - Collaborating on a computer to process 1100 TB/ day

ThunderKAT 2016

Synopsis

ThunderKAT PIs: Patrick Woudt (UCT) & Rob Fender (Oxford)
ThunderKAT membership (open): 60 co-investigators from 10 countries (32% ZA)

ThunderKAT is the image-plane transients programme for MeerKAT. The goal is to find, identify and understand high-energy astrophysical processes via their radio emission (often in concert with observations at other wavelengths).

> *"Through a comprehensive and complementary programme of surveying and monitoring Galactic synchrotron transients (across a range of compact accretors and a range of other explosive phenomena) and exploring distinct populations of extragalactic synchrotron transients (microquasars, supernovae (SNe) and possibly yet unknown transient phenomena) – both from direct surveys and commensal observations – we will revolutionise our understanding of the dynamic and explosive transient radio sky." (ThunderKAT 2010 Science Case)*

As well as proposing for targeted programmes of their own, ThunderKAT has made agreements with the other LSPs to search their data for transients. This **commensal** use of the other surveys, which remains one of the key ThunderKAT programme goals in 2016, means that the combined MeerKAT LSPs will produce by far the largest GHz-frequency radio transient programme to date. ThunderKAT will focus on Target-of-Opportunity (ToO) and monitoring programmes of a set of well-defined transients.

ThunderKAT 2016

Science Themes

Relativistic Accretion

- Black holes and neutron stars in X-ray binaries, Tidal Disruption Events, Ultra-luminous X-ray sources

White Dwarf Accretion

- Outflows from accretion-power outbursts of white dwarfs, outflows from thermonuclear eruptions on white dwarfs

Cosmic Explosions

- Gamma-ray bursts; Core-collapse supernovae; Type Ia supernovae

Fast and Coherent Transients

- Fast radio bursts (imaging)

Gravitational Wave Sources

- Gravitational wave events and electro-magnetic counterparts

ThunderKAT 2016

Innovations: MeerLICHT

MeerLICHT PIs: Patrick Woudt (UCT), Paul Groot (Radboud) & Rob Fender (Oxford)
MeerLICHT membership (institutional, closed): UCT, Radboud, Oxford, SAAO, Manchester

Whatever MeerKAT observes, MeerLICHT observes [at the same time]

ThunderKAT 2016

Innovations: MeerLICHT

MeerLICHT PIs: Patrick Woudt (UCT), Paul Groot (Radboud) & Rob Fender (Oxford)
MeerLICHT membership (institutional, closed): UCT, Radboud, Oxford, SAAO, Manchester

The MeerLICHT project is currently in its final phase of construction, and soon moves into the 'installation and commissioning' phase. The telescope is expected to arrive at the Sutherland station of the South African Astronomical Observatory in 2017 March for installation and engineering/science commissioning.

Pre-construction: 2012 – 2015
Construction: 2016 – 2017 (Jan-February)
Installation and commissioning: 2017 (March-June)
Early science: 2017 (July-December)
Science operations: 2018 – 2022Time Lines

Whatever MeerKAT observes, MeerLICHT observes [at the same time]