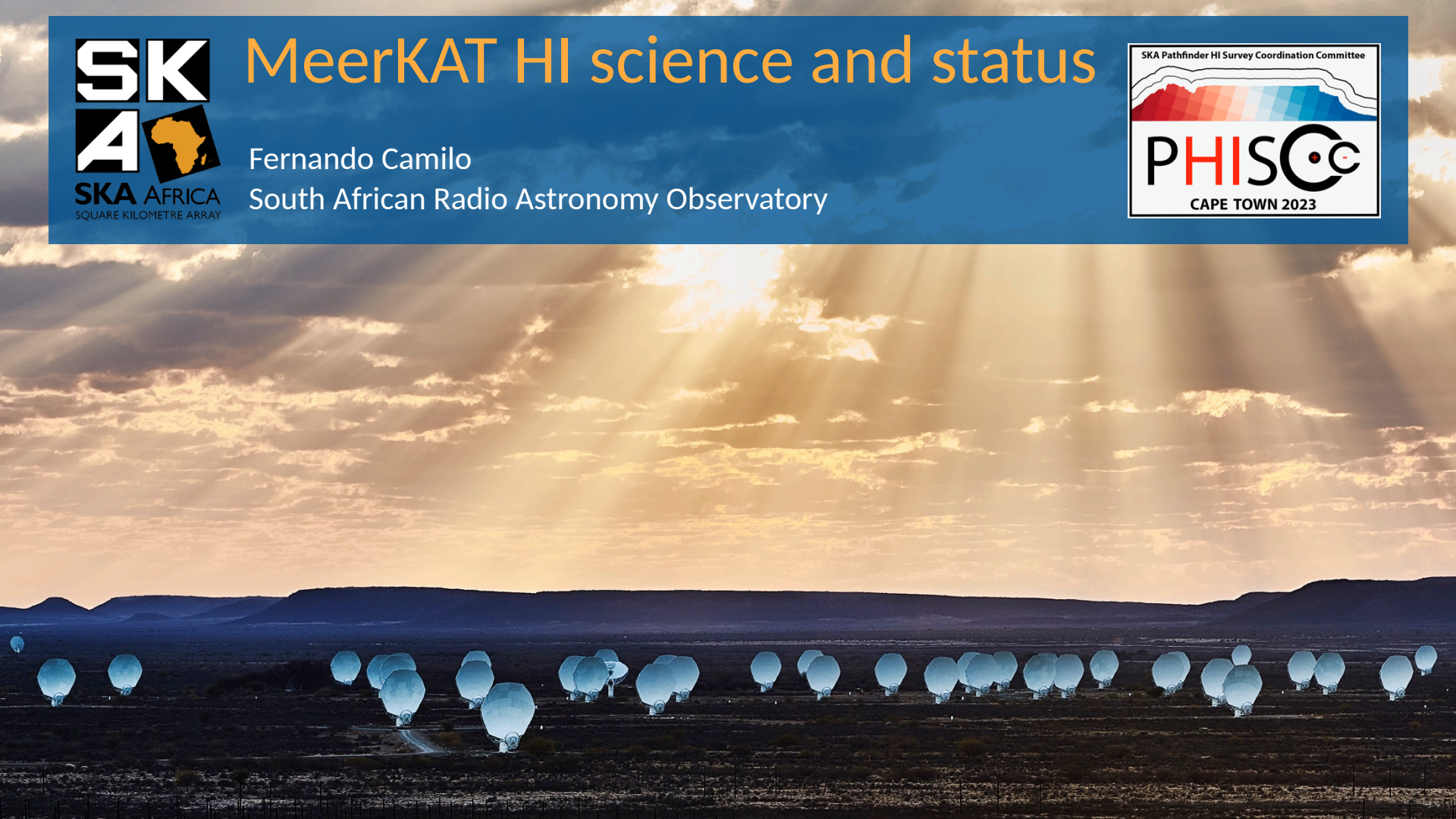
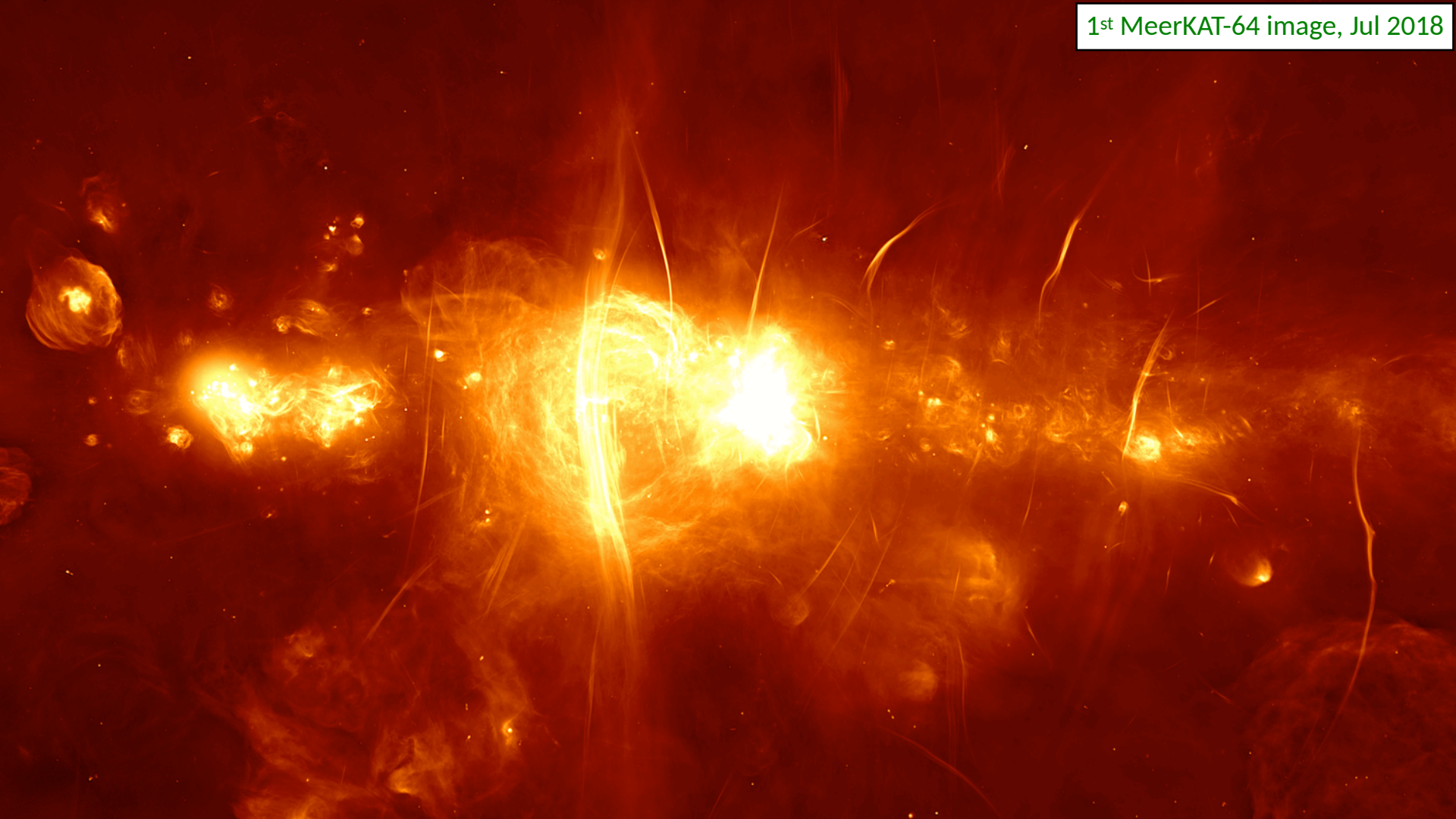
MeerKAT HI science and status

Fernando Camilo
South African Radio Astronomy Observatory

SKA Pathfinder HI Survey Coordination Committee
PHISCC
CAPE TOWN 2023




1st MeerKAT-64 image, Jul 2018

LETTER (1st MeerKAT-64 paper, Sep 2019)
https://doi.org/10.1038/s41586-019-1532-5

Inflation of 430–parsec bipolar radio bubbles in the Galactic Centre by an energetic event

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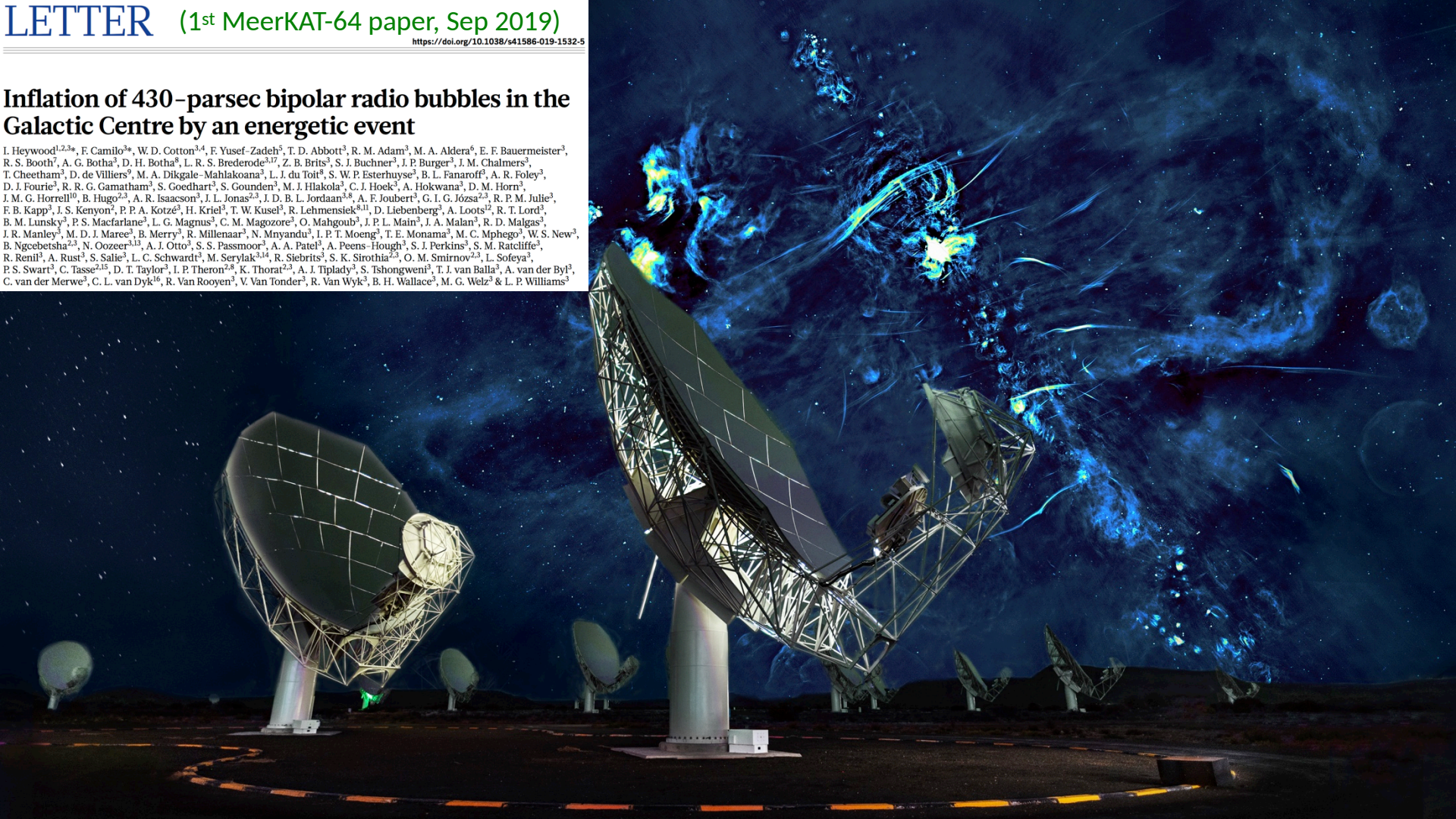
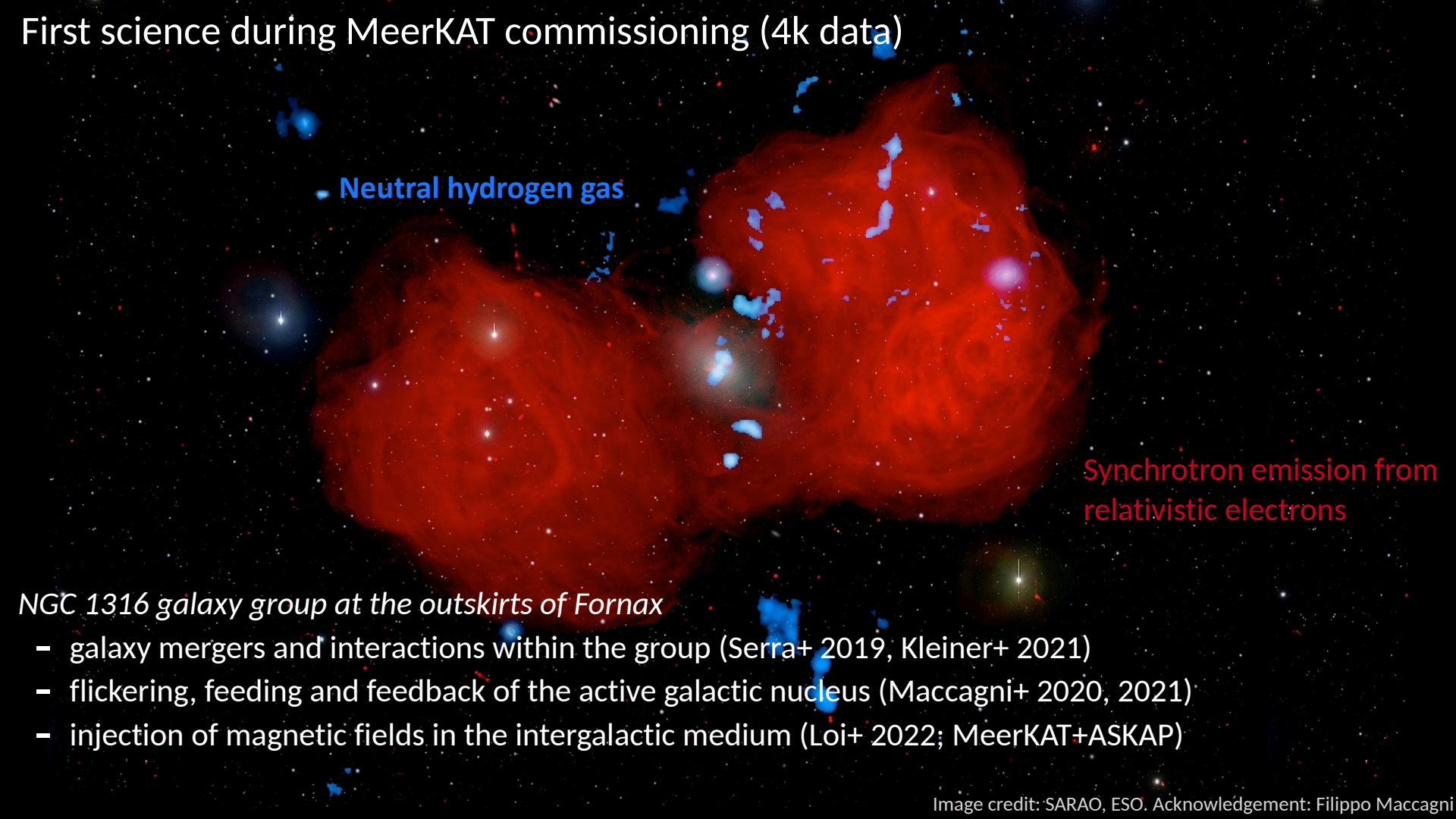


MeerKAT capabilities over time

- 2016: First Light (16 antennas); L-band (856-1712 MHz); ROACH2 correlator
- 2018: 64 antennas; SKARAB correlator (4k imaging mode; 209 kHz; 44 km/s @ z=0)
- 2019: Beamformed pulsar timing mode (PTUSE); 32k-wide mode (26 kHz; 5.5 km/s @ z=0)
- 2020: UHF band (544-1088 MHz; 16 kHz resolution with 32k-wide); pulsar/transient search mode (FBFUSE/APSUSE/TUSE); 32k-narrow (NE107) mode (3.3 kHz @ L-band)
- 2021: NE54 32k-narrow mode (1.6 kHz @ L-band); 4 steerable beams
- 2022: S-band; BLUSE (SETI) commensal mode
- Future: MeerKAT Extension (MK+)

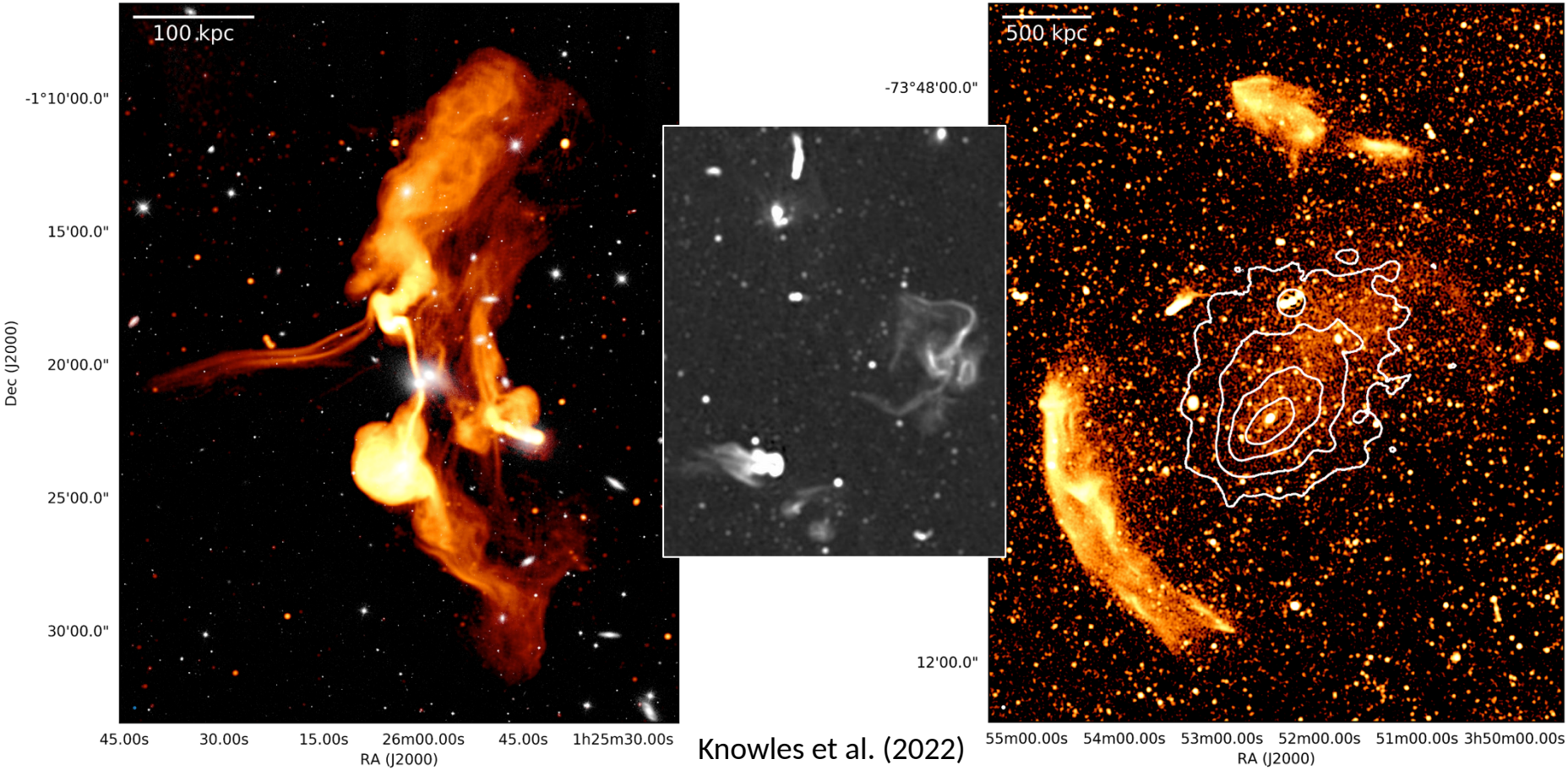
First science during MeerKAT commissioning (4k data)



NGC 1316 galaxy group at the outskirts of Fornax

- galaxy mergers and interactions within the group (Serra+ 2019, Kleiner+ 2021)
- flickering, feeding and feedback of the active galactic nucleus (Maccagni+ 2020, 2021)
- injection of magnetic fields in the intergalactic medium (Loi+ 2022; MeerKAT+ASKAP)

Image credit: SARAO, ESO. Acknowledgement: Filippo Maccagni



Knowles et al. (2022)

Probing distant HI in and behind HFF clusters

- Hubble Frontier Field clusters: Abell 2744, Abell S1063, Abell 370 at $0.3 < z < 0.4$
- MeerKAT Galaxy Cluster Legacy Survey (MGCLS, Knowles+ 2022; 4k data)
  - HI cubes: 60 km/s resolution, rms~0.12 mJy/(15” beam) per channel
- Source finding with SoFiA (Serra+ 2015) - no direct detections
- HI spectral stacking in clusters, based on spectroscopic redshifts (Shipley+ 2018)
- HI mass upper limits:

	n stacked sources	**Average HI mass**
Abell 2744	30	$M_{HI} < 2.06 \times 10^{10}\ M_\odot$
Abell S1063	98	$M_{HI} < 1.94 \times 10^{10}\ M_\odot$
Abell 370	49	$M_{HI} < 2.31 \times 10^{10}\ M_\odot$

NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

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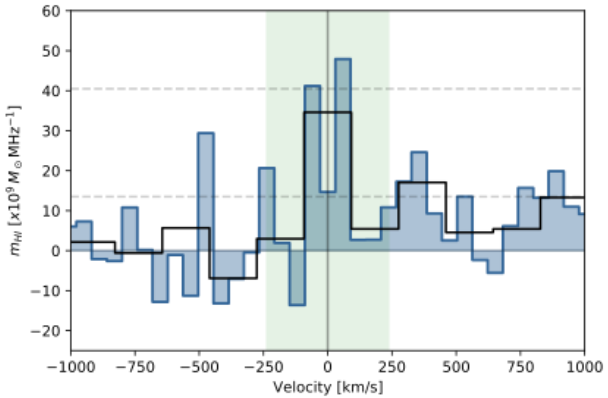
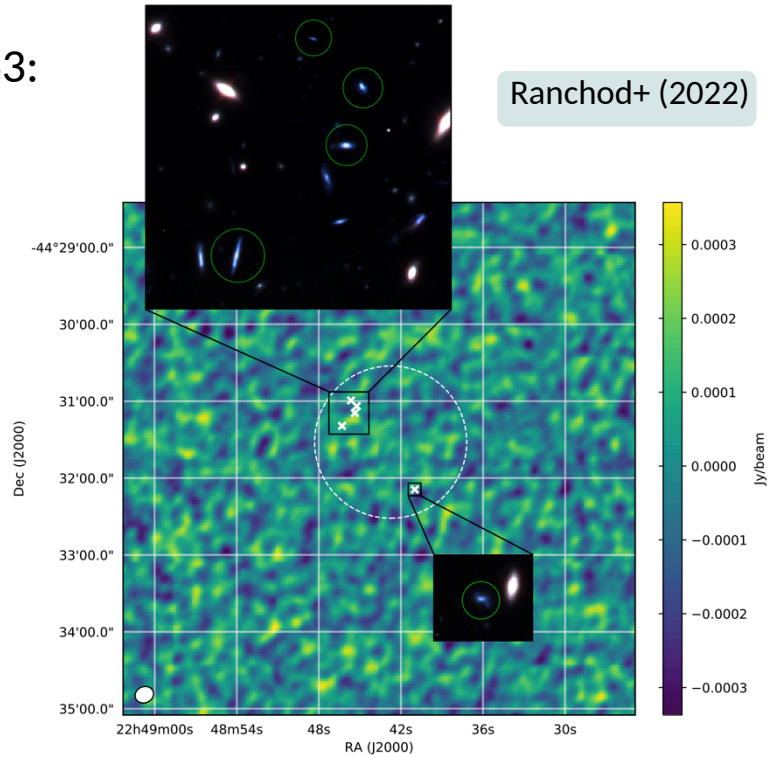
Ranchod+ 2022
(MNRAS, 509, 5155)

- 3σ stacked detection for blue galaxies in Abell S1063:
  - Average $M_{HI} = 1.22 \pm 0.38 \times 10^{10}\ M_{\odot}$



- Candidates are heavily clustered (< 140 kpc) near virial radius – recently in-fallen group?



Ranchod+ (2022)

Lensed HI

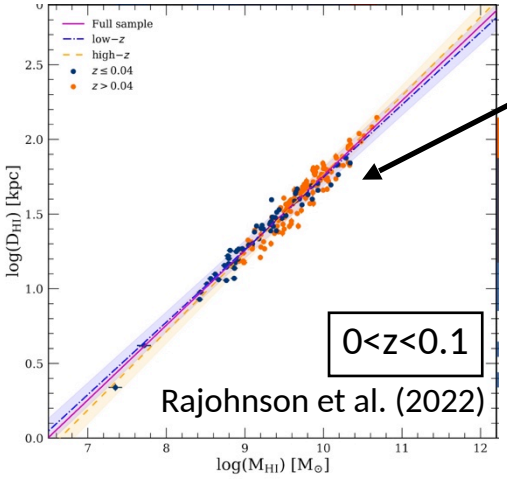
- Targeted search for known lensed sources at z < 0.58
- No direct detections
- Future work: UHF-band observations of Abell 370, 0.6 < z < 1.4

(For more on MGCLS HI, see also today's talk by Dawson and Wednesday's by Lawrie)

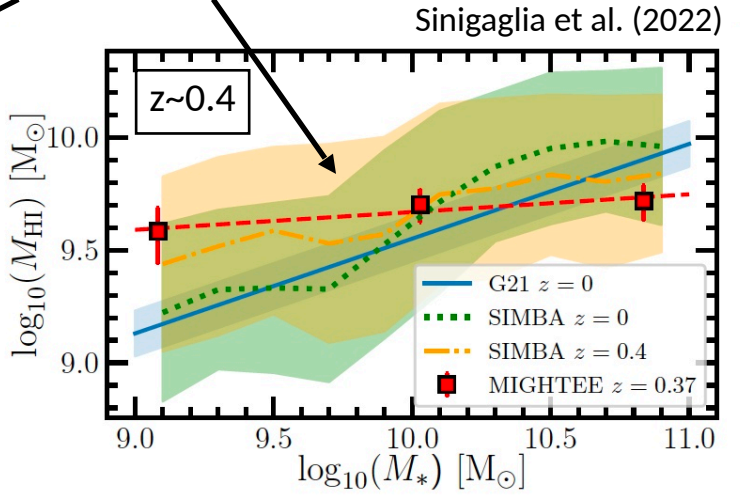
MIGHTEE-HI results so far...

- Natasha Maddox et al. 2021: MIGHTEE-HI survey description
- Shilpa Ranchod et al. 2021: HI galaxy group discovery (MSc U Pretoria)
- Anastasia Ponomareva et al. 2021: Blind Tully-Fisher relation (Oxford)
- Wanga Mulaudzi 2021: Blind HI velocity width function (MSc UCT)
- Sambatriniaina Rajohnson et al. 2022: Blind M_{HI}-D_{HI} relation (PhD UCT)
- Madalina Tudorache et al. 2022: HI vs the cosmic web (PhD Oxford)
- Francesco Sinigaglia et al. 2022: HI stacked scaling relations (PhD Padova)
- Brenda Namumba et al. 2023: NGC 895 case study (Wits U)

Scaling relations from z=0 to z=0.4



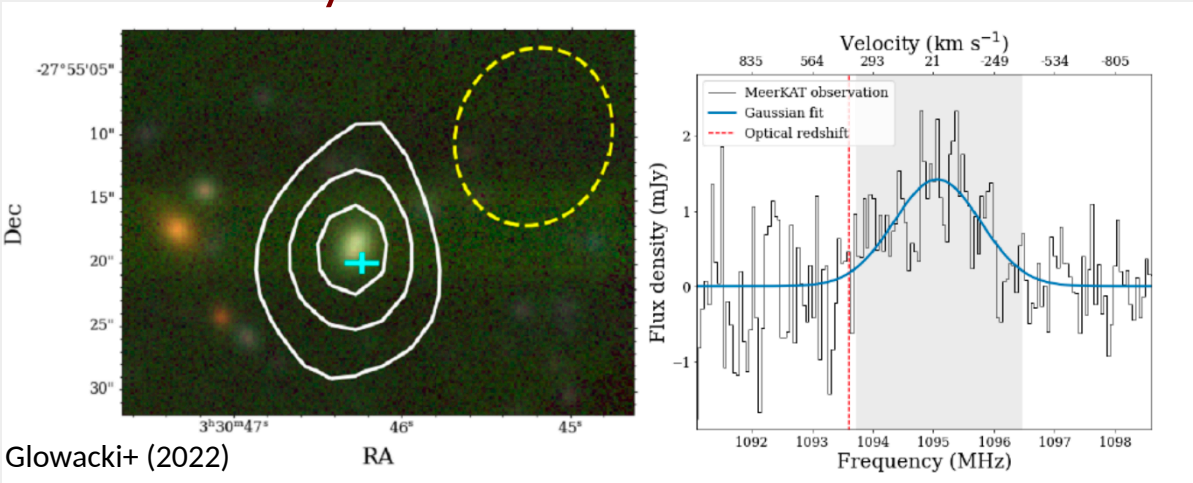
Sinigaglia et al. (2022)



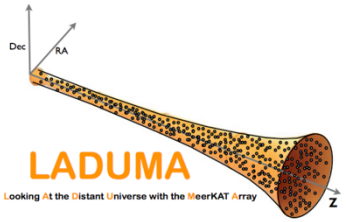
LADUMA: Looking At the Distant Universe with the MeerKAT Array

First publication (Glowacki et al. 2022, ApJ, 931, L7) based on early L-band data:

- Discovery of most distant main-line OH megamaser ("Nkalakatha") at z = 0.52
- Likely gas-rich galaxy merger
- Multi-wavelength follow-up underway



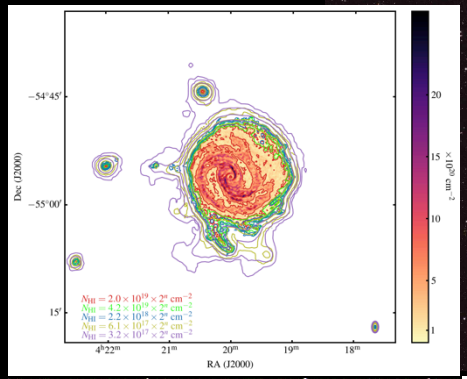
Glowacki+ (2022)

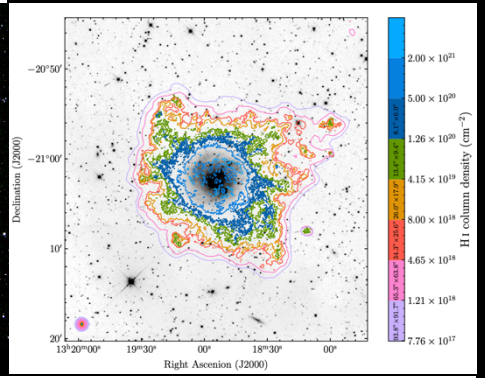


Several LADUMA-related talks & posters coming up at PHISCC:

- Sarah Blyth – LADUMA overview (Monday)
- Jacinta Delhaize – HI & OH source-finding (Tuesday)
- Leyya Stockenstroom – Source-finding in the LADUMA field (Tuesday)
- Amir Kazemi-Moridani – HI mass function in the LADUMA field (Tuesday)
- Tilman Oelgeschläger – Filaments in the LADUMA field (poster)

MHONGOOSE





- First analyses of full-depth data underway
- Many signs of minor interactions
- Discovery of low-mass dwarfs
- Diffuse extended HI components
- *All of these will be shown in talks this week*
- Survey sensitivity up to spec!

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university of groningen
faculty of science and engineering
kapteyn astronomical institute

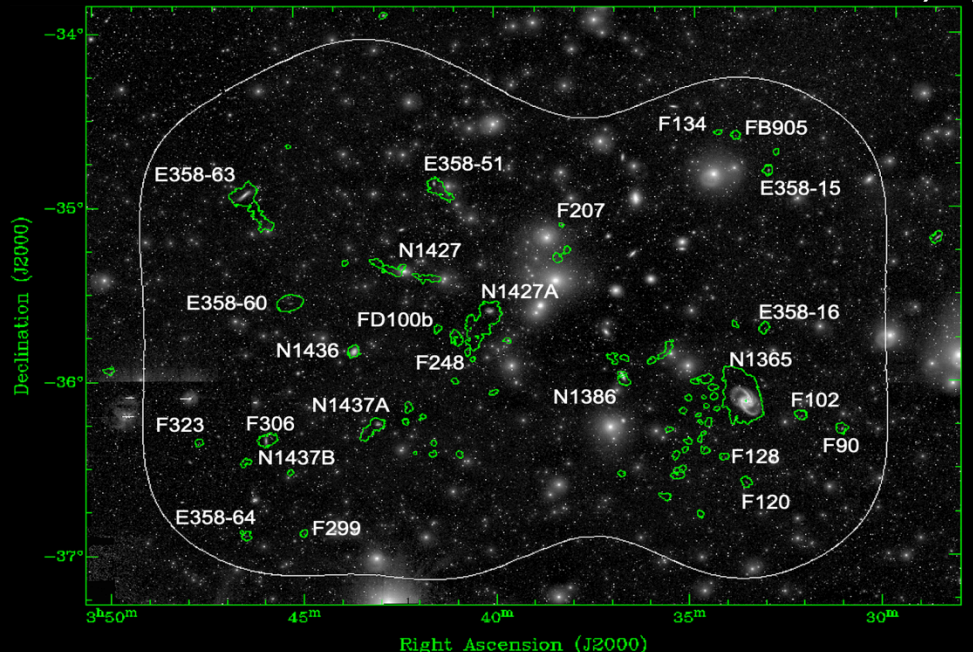
MeerKAT Fornax Survey

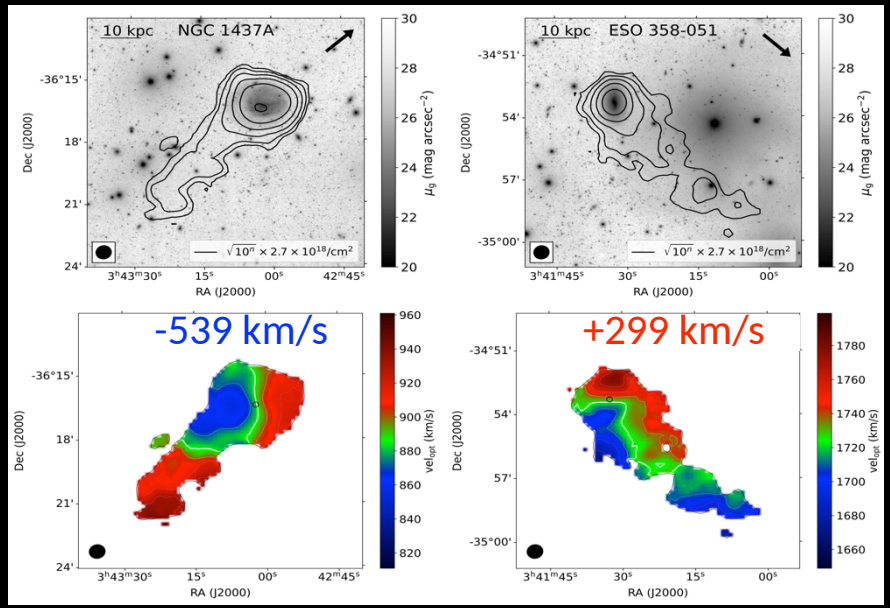
HI imaging out to 2 R_{vir} and down to 5×10^{19} – 8×10^{17} cm^{-2} at resolution 1 – 10 kpc

Observations 70% complete, all data processed, first papers coming out

- Ram pressure shaping the distribution of HI after tidal interactions (Serra+ 2023, A&A, in press)
- Fast depletion of HI in dwarfs (Kleiner+, A&A, submitted)
- Gas depletion and quenching in a lenticular galaxy in Fornax (Loni+, MNRAS, submitted)

See Alessandro Loni's survey update talk on Wednesday!





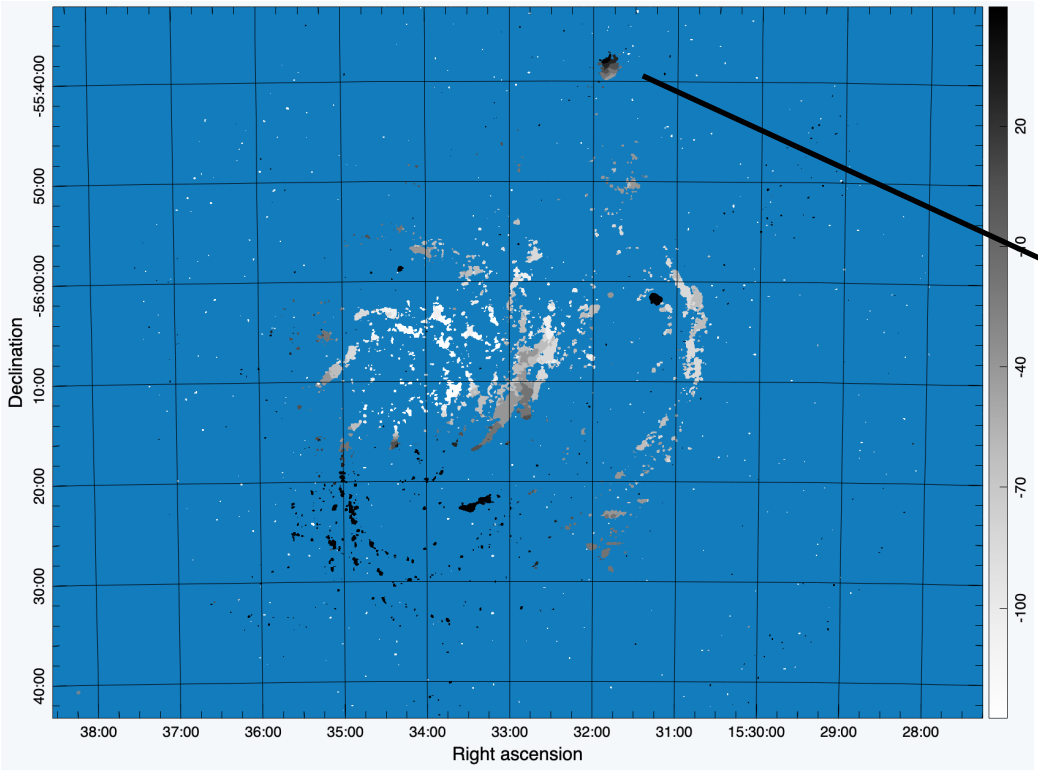
SARAO SDP data products

(Courtesy ~1 PFLOP GPU cluster in the Karoo + hardware-optimized pipelines)

- Visibility data
  - Via the archive: Raw data by default
  - Using mvf2ms:
  - Raw (L0):
    - `--flags=cam,data_lost,ingest_rfi`
  - Cross Cal (L1):
    - `--flags=cam,data_lost,ingest_rfi,cal_rfi,static --applycal=l1`
  - Phase Selfcal (“L1.5”):
    - `--flags=cam,data_lost,ingest_rfi,cal_rfi,static,postproc --applycal=default`
  - Phase+Amp Selfcal (“L2”):
    - `--flags=cam,data_lost,ingest_rfi,cal_rfi,static,postproc --applycal=all`
- *Multiple pushes (combinations of the above) and subset selections can be transferred to IDIA by request*: **support@ilifu.ac.za**

Example: Giant galaxy imaged from Phase Selfcal SDP data

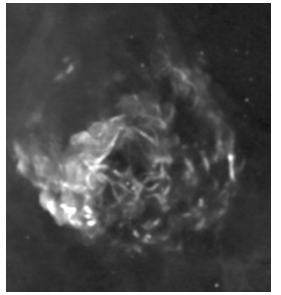
Velocity field



Follow-up observation; work in progress (B Frank et al.)

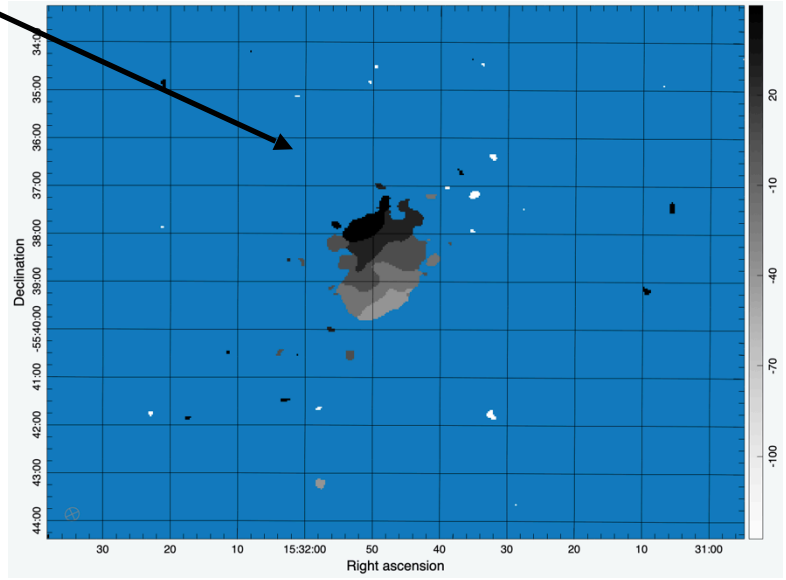
Right through the ZOA!
(SARAO Galactic Plane Legacy Survey; 4k data)

(See Wednesday talks by Kurapati, Rajohnson, on more ZOA HI results)



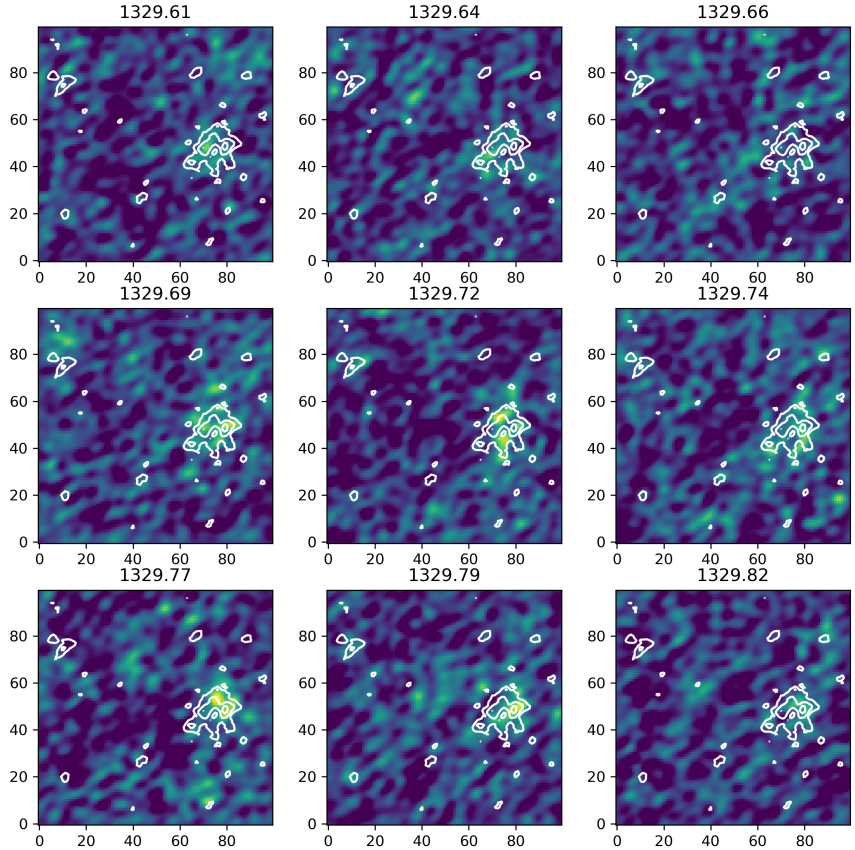
E.g., SNR (continuum)

Neighbouring galaxy!



SDP data products: II

- Images
- Continuum & Spectral Line (PB corrected)
- Individual per-channel images can be downloaded and stitched together
- Example: MOM0 contours + channel map for *one detection* in GAMA23 field (32k public data): 70 pointings, ~1 hr each with good uv coverage, rms~0.5 mJy/beam per 26 kHz channel



Work in progress (B Frank et al.)

The MeerKAT Extension (MK+) project

- Started in 2019 as a joint SARAO/MPIfR project
- INAF joined in 2020
- Goal: to develop exciting novel capabilities for MeerKAT, in the context of contributions to SKA1-Mid
- Enormous project, drawing on resources from: systems engineering, infrastructure, dish structures, receivers, vacuum/cryogenics, fiber optic networks, digitizers, correlator, time & frequency reference, science processor, control and monitoring, commissioning

MK+ capability summary & use model

- 13-16 new antennas, of 'SKA design' (each ~1.35x more sensitive than MeerKAT's)
  - Maximum baselines ~17 km (~twice as much as MeerKAT)
  - Populated with L- and S-band receivers (not UHF)
    'L' are SKA Band-2 receivers (0.95–1.76 GHz, compared to 0.9–1.67 GHz for MeerKAT L)
- Backend to process all 80 antennas simultaneously
  - New independent GPU-based correlator for all 80
  - Initial wideband correlator mode: 8k channels
  - Upgraded SDP to ingest and store visibilities of this mode
  - Current SKARAB-based (any) 64-antenna correlator will remain fully functional

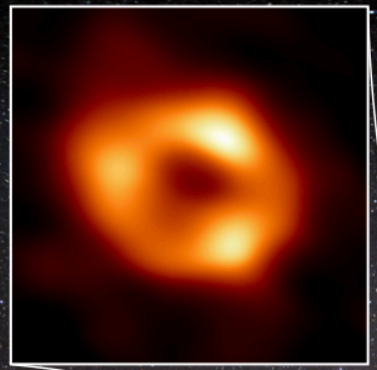
- When new capabilities become available (from 2025?), and until SKA1-Mid integration
  - ~10% of available science time to be used for Legacy Survey(s) by project partners
  - ~90% to be allocated through SARAO Open Time Calls/DDT

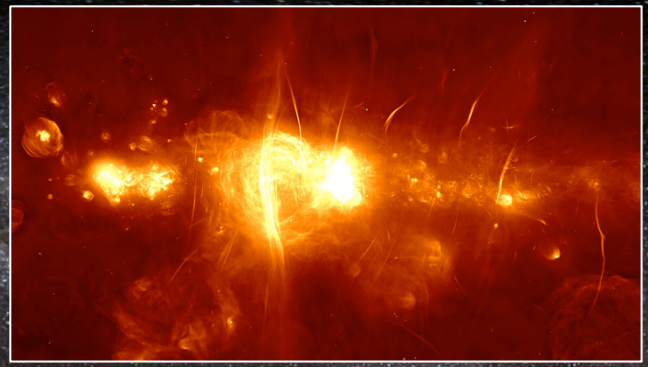
MeerKAT status

- All 8 LSPs ongoing (started 2018-20) – using 2/3 of telescope time over 5 years
- Robust Open Time and DDT program
- ~50% of the time used for science (mostly at L-band; also UHF; S-band starting)
- (Lots still to learn about a hugely complex instrument!)

- 190 refereed publications with MeerKAT data (tinyurl.com/meerkat-ads)
- Many datasets no longer proprietary; visibilities + some SDP images available through the archive interface: https://apps.sarao.ac.za/katpaws/archive-search

- 4th Open Time Call for Proposals: issued March 15, 2023, closing on May 3
  - Regular: < 125 hr within 12 months
  - Multi-year: up to 4 years
  - Large: > 125 hr
  - N.B.: Large proposals must be exceptionally well justified (including the Data Management Plan), and must have retired risk through pilot projects





Thank you

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