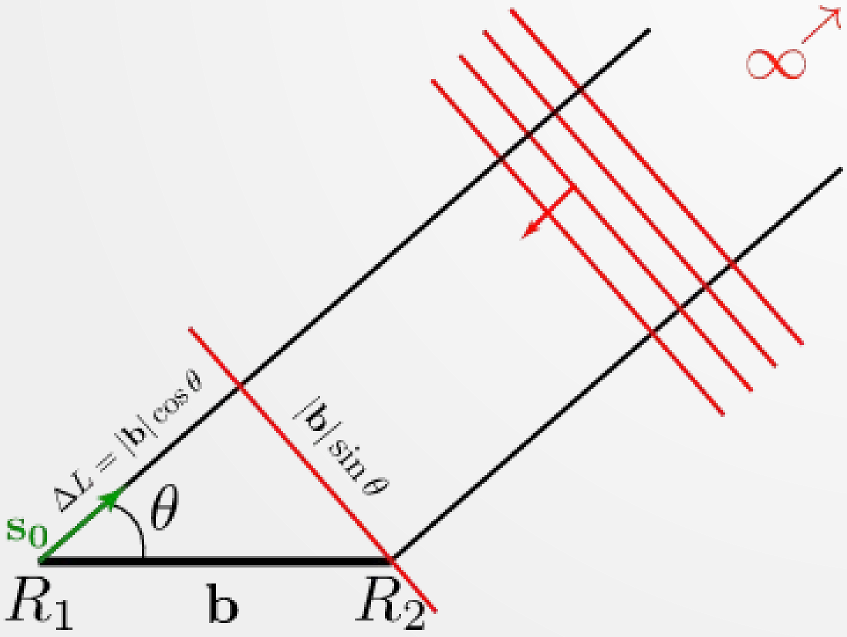
Deep Space Exploration Society
Science Meeting

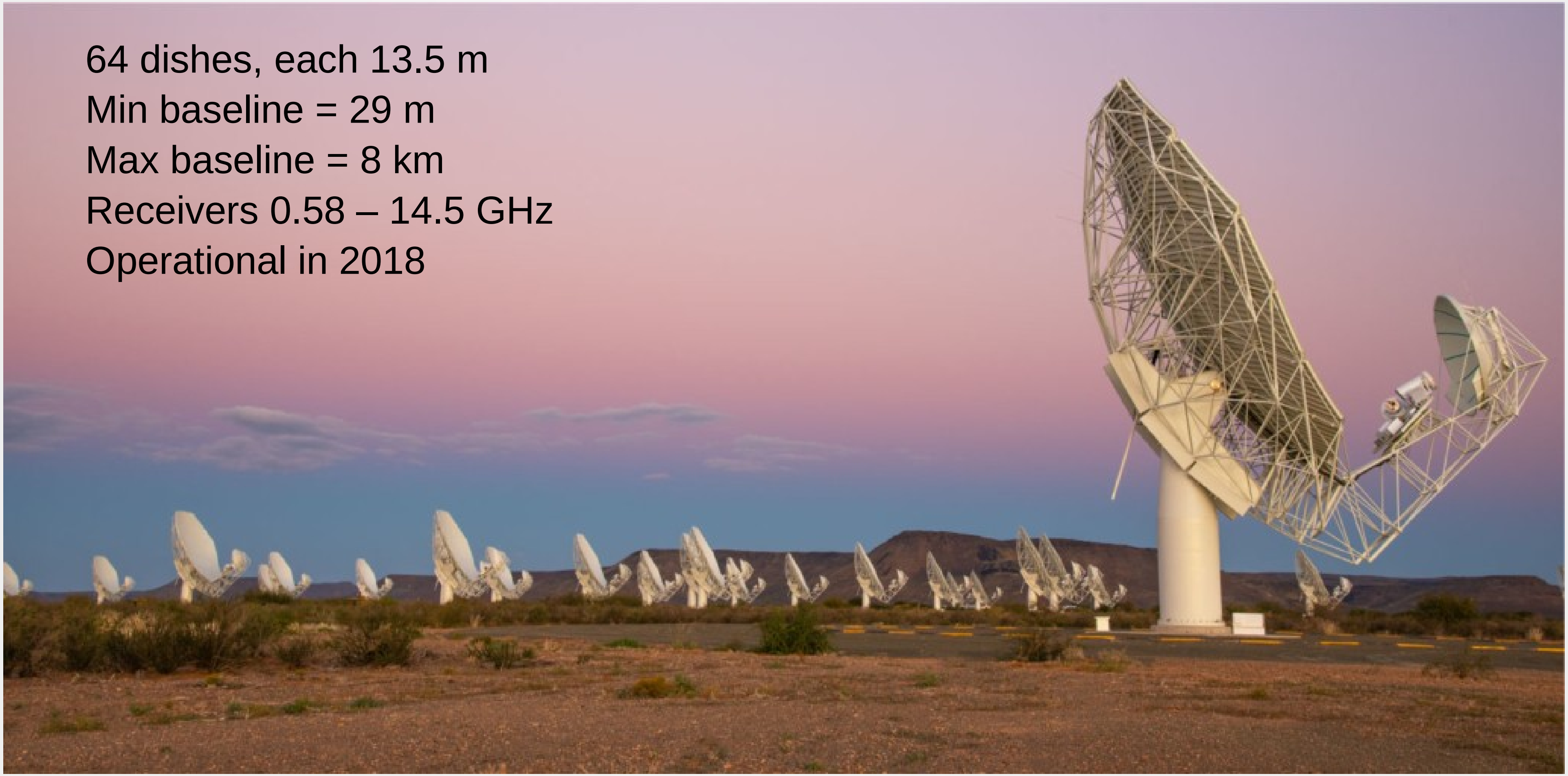


October 25, 2021

Dan Layne

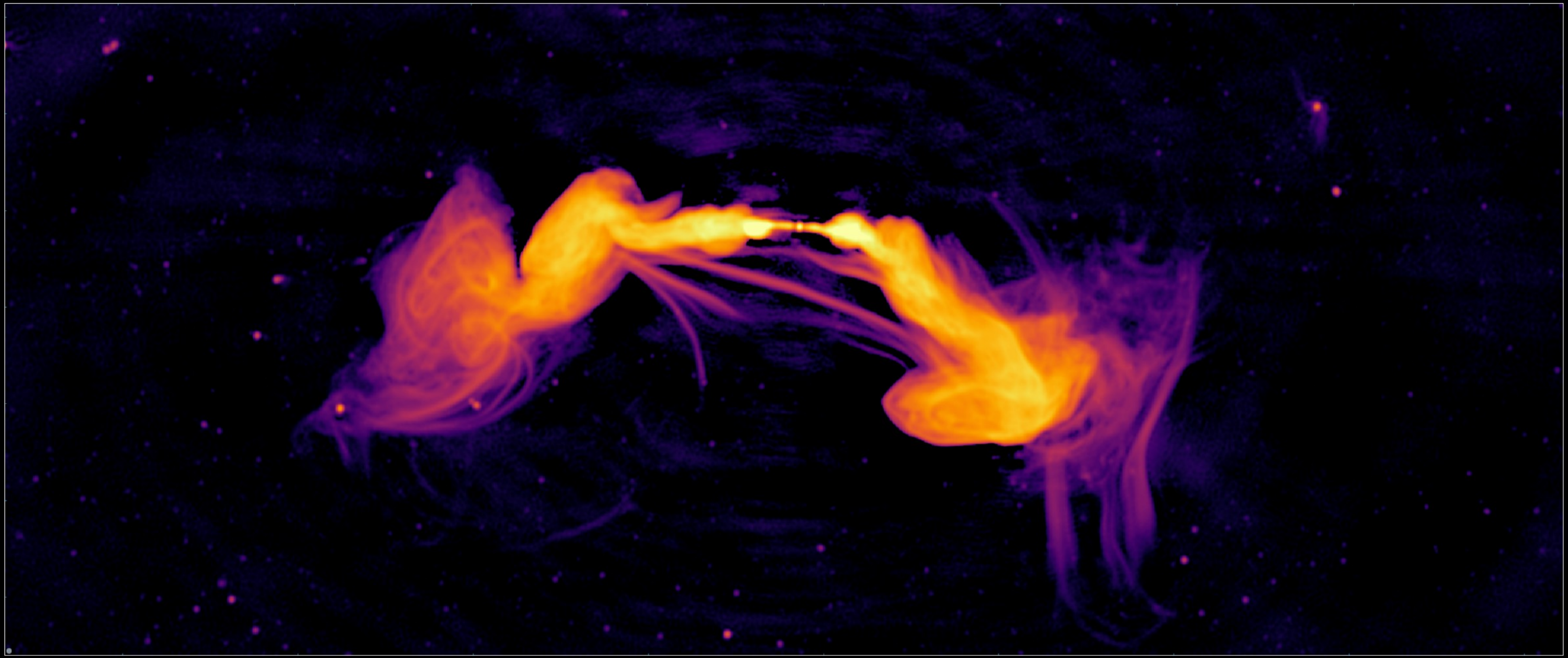
DSES.science

MeerKAT, S. Africa, Precursor to SKA



64 dishes, each 13.5 m
Min baseline = 29 m
Max baseline = 8 km
Receivers 0.58 – 14.5 GHz
Operational in 2018

The radio galaxy ESO 137-006



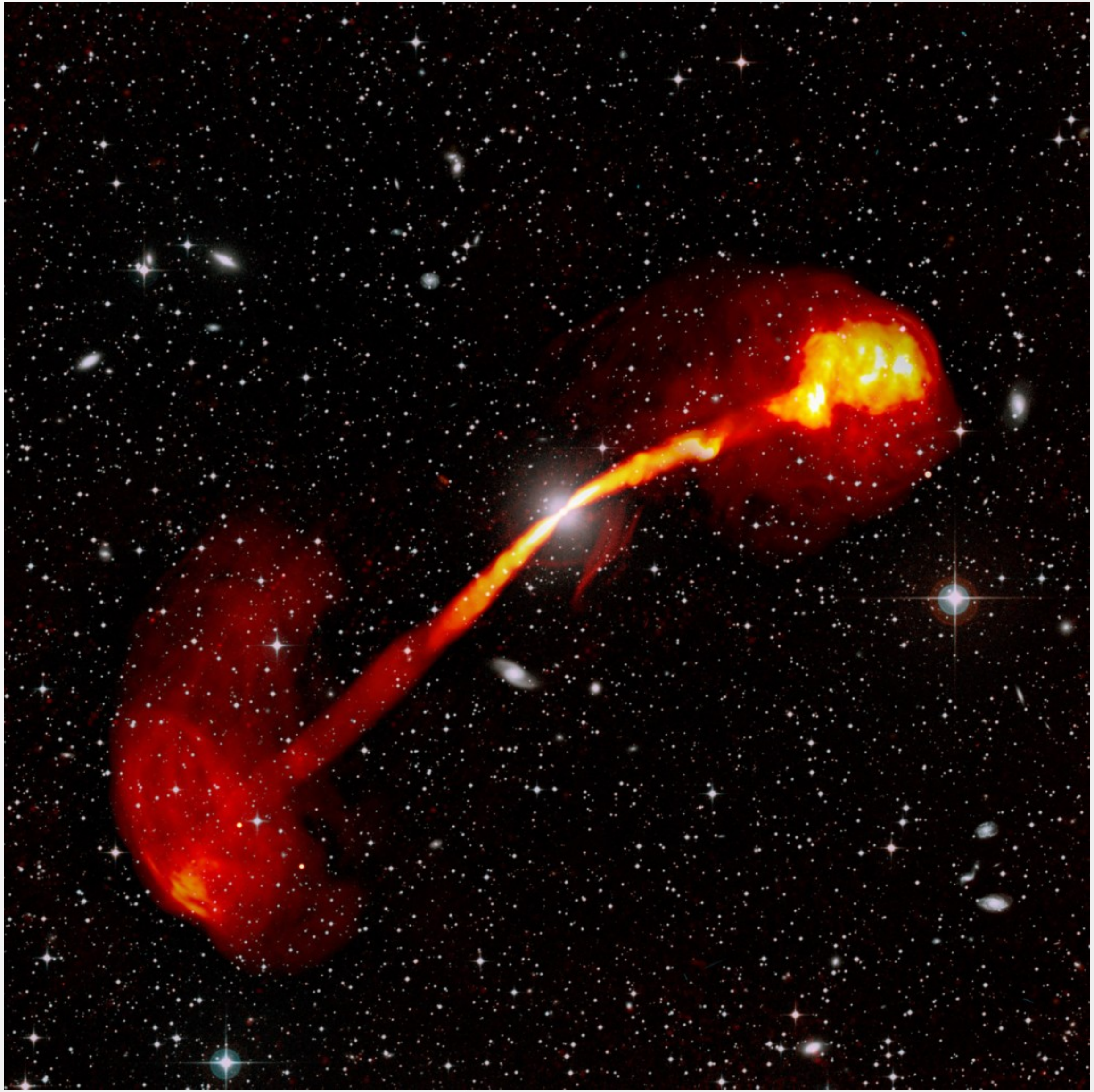
"Collimated synchrotron threads linking the radio lobes of ESO 137-006", M. Ramatsoku et al. 2020, A&A
MeerKAT Radio Telescope image at 1000 MHz
Image credits: Rhodes University / INAF / SARAO

Jets from supermassive black hole at center of radio galaxy shoot into interstellar gas. Magnetic filaments or threads connect the jets. Threads are 260,000 light years long. Galaxy is 220 million light years away. Imaged at 1.0 and 1.4 GHz

Composite image of giant elliptical galaxy IC 4296 (distance of 160 million light years). Visible light image from SuperCOSMOS Sky Survey. MeerKAT data in red/orange.

Massive rotating black hole at center sends two radio jets of magnetic fields and relativistic electrons. Escaping electrons form faint threads and ribbons. Smoke rings in left lobe are about 1 million light years from central galaxy.

MeerKAT’s high sensitivity, angular resolution and dynamic range allowed discovery of these threads and ribbons in June, 2021.



DSES Information (1/2)

- SARA Drake's Lounge 12 noon 3rd Sunday of every month
- Updated DSES Radio Astronomy Observation Guide available
- EdX "Radio Sky II: Observational Radio Astronomy" 9/30 – 11/18
- Pointing and tracking updates – see Mount Cal presentation 9/13/21
- 9 ft dish – Spectacyber running. Conducting cal runs on S7 for T_{sys}
- SuperSID – working and porting data to Stanford Solar Center
- Radio Jupiter – SDR and antenna ready
  - Need laptop (or desktop) for software and TeamViewer

DSES Information (2/2)

- HamSCI Dec. 2021 Antarctic solar eclipse: Record WWV Dec. 1-10
  - https://hamsci.org/december-2021-eclipse-festival-frequency-measurement
- Citizen science (AI pattern recognition algorithms need human help):
  - Identify FRB's from CHIME https://www.zooniverse.org/projects/mikewalmsley/bursts-from-space
  - Identify radio galaxies from LOFAR https://www.zooniverse.org/projects/chrismrp/radio-galaxy-zoo-lofar
  - Identify gravity waves from LIGO https://www.zooniverse.org/projects/zooniverse/gravity-spy
- 15 pulsars detected so far at Haswell
  - 13 in 2020 (408 MHz): B0329+54, B0531+21 (Crab), B0740-28, B0833-45 (Vela), B0950+08, B1133+16, B1508+55, B1642-03, B1749-28, B1929+10, B1933+16, B1946+35, B2016+28
  - 2 in 2021 (1420 MHz): B1641-45, B2021+51
  - 2021 (1296 MHz):

Observation / Feed Schedule

- Oct. – Dec. 2021: 1296 MHz feed installed for EME and pulsars
  - ARRL 1296 EME contest dates: Nov. 20-21, and Dec. 18-19
- January 2022 – ? 1420 MHz feed for pulsar and HI observations?
  - Raster scans
  - Calibration studies
    - Use 21 cm absorber to determine T_{sys}
    - Determine T_{sys} via Wolfgang's April 2020 SARA Journal article
  - HI zenith drift scan via Airspy SDR and Raspberry Pi
  - Pulsars: Periodically observe the same pulsar
    - Measure spin-down rate
    - Monitor pulse profiles for shape changes

HI Drift Scan with 1420 MHz Feed

- Use 60’ dish in stow position (near zenith) or 3.8 m dish for meridian scan
- Airspy SDR at 10 MHz bandwidth
- Raspberry Pi 4B for data collection and processing
  - Ubuntu 21.04 mate, GnuRadio 3.8, Python 3.9.5
  - Remote access via TigerVNC (SSH). Need to forward a port on DSL modem
    - Neither TeamViewer nor RealVNC will install on R-Pi Ubuntu 21.04 (re-try with 21.10)
  - Two HI software applications: Astro-virgo spectrometer and WVURAIL DSPIRA (+ cal)
    - Some dropouts (overflow) at 10 MHz, none at 2.5 MHz. Not critical for HI
- Deploy to Haswell for 24x7 unattended drift scan
- Sample continuously during Milky Way transit. Periodically the rest of each day
  - Store data on 64 GB flash drive if DSL upload too slow (2 Mbps ~ 1 GB/hour)

Miscellaneous Observing Notes

- B210 has frequency ripples ~6 MHz; used to be 12 MHz
  - Now able to reproduce ripples at home on max RF gain
    - Not visible on spectrum analyzer. Clearly visible on integrated spectrum
    - AGC is off. Switching channels reduced ripples
    - Some broadband noise at 1296, not at 1420
    - Need to find optimal gain to avoid saturation/overload
- New DSL modem is working
  - During observations turn Wi-Fi off; use wired internet connection
- 10 MHz (GPS) source ready (BNC) on distribution panel

Interferometry Discussion

Deep Space Exploration Society

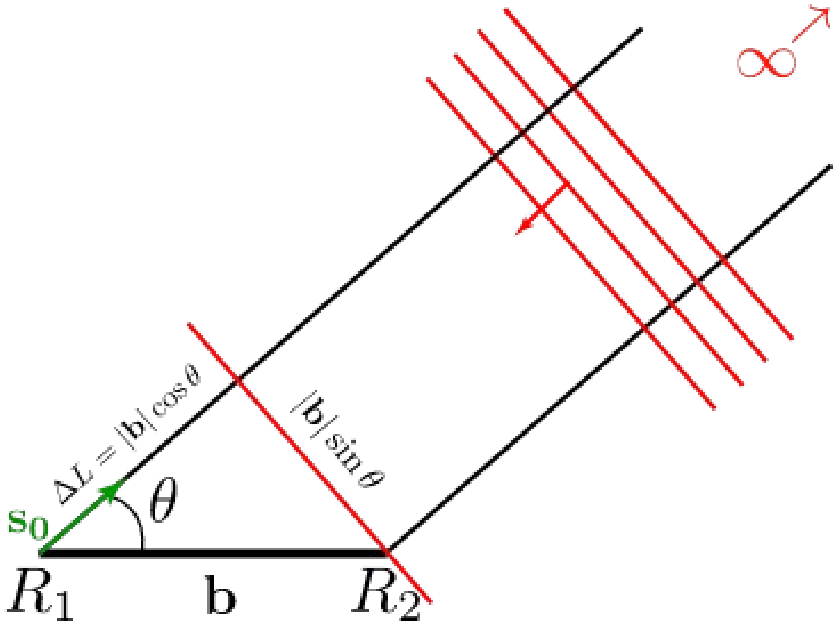
Some C-Band (4-8 GHz) Science Goals

- Spectral line emission (rest freq in GHz)
  - H_2CO ortho-formaldehyde (4.829660)
  - CH_3OH methanol (6.668518), including masers
- Continuum emissions. Use fringe to separate point source from background
  - Thermal
    - 7.5 cm (4 GHz) nebula scan (Orion A)
    - Sun, moon
  - Non-thermal (synchrotron)
    - Map emissions from extended radio galaxies: 3C 405 (Cyg A), 3C 273, M87 (Virgo A)
    - Supernova remnants (Cas A, Crab, Vela)
    - Massive black hole at center of Milky Way (Sag A)
    - Jovian magnetosphere

Haswell Two-Dish Interferometer

- 1st dish installed 9/18/2021 (3.8 m)
  - Need to install and characterize C-band (3.7 – 4.2 GHz) feed horn, LNA, down-converter and coax
- Interferometer design
  - 2nd 3.8 m dish to be located due East
  - Use dual channel coherent SDR (*e.g*., N210, B210, Lime)
  - Use time delays to correct phase due to geometry and cabling
  - S/W: Try CCERA Spectro Radiometer, or WVURAIL DSPIRA

Two Antenna Radio Interferometer



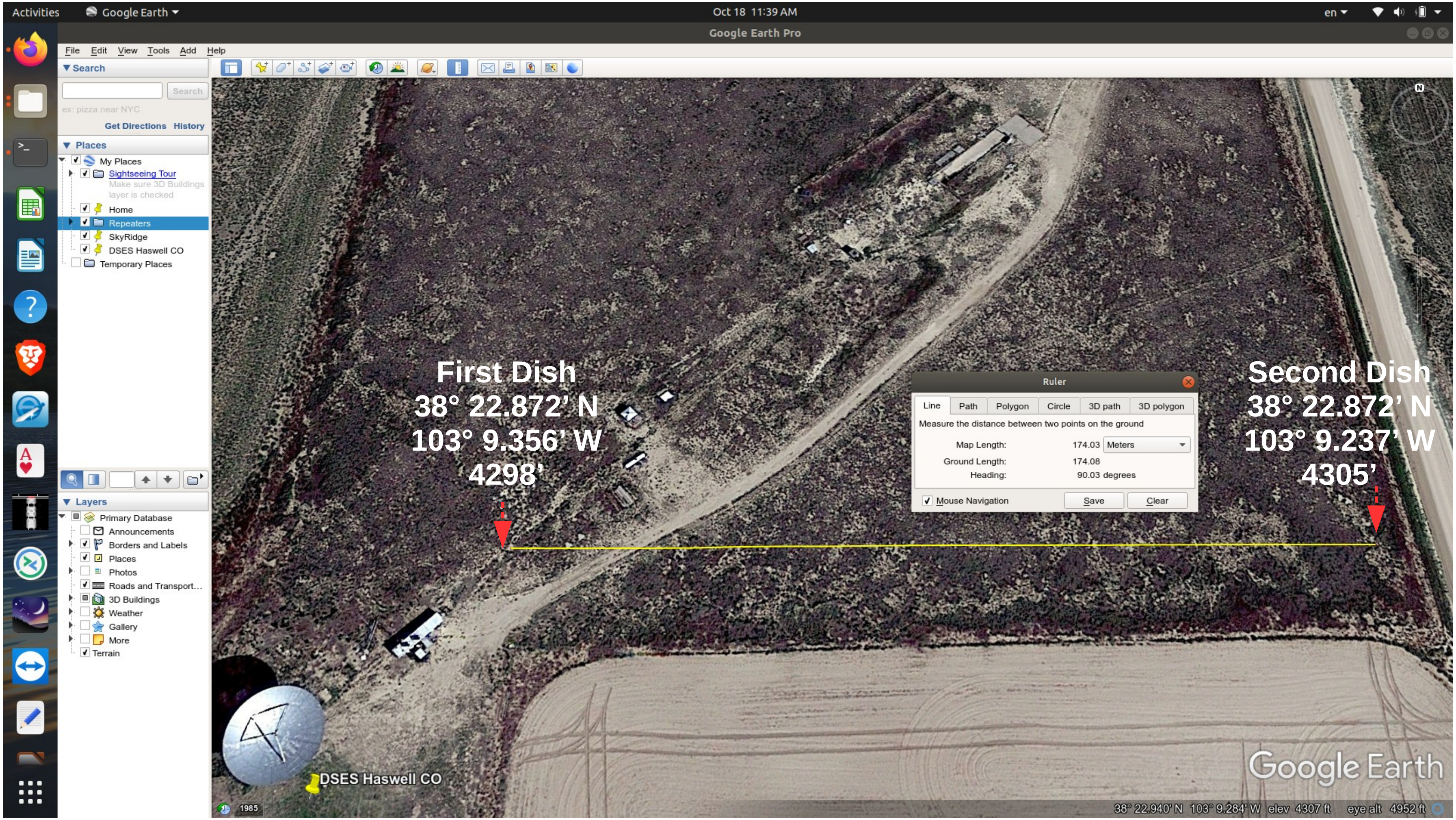
- Antennas R1, R2 separated by baseline distance b
- Wave first reaches R2, then R1
- A geometric time delay corrects for the extra path length to R1
- Another time delay corrects for difference in cable length from R1, R2 to SDR

$|\boldsymbol{b}| \cos\theta = extra\ path\ length\ for\ wave\ travel$

$|\boldsymbol{b}| \sin\theta = projected\ baseline$

$Near\ zenith\ \theta \rightarrow 90\text{, } so\ projected\ distance = ground\ separation$

2nd Dish Location ~174 m (571') East

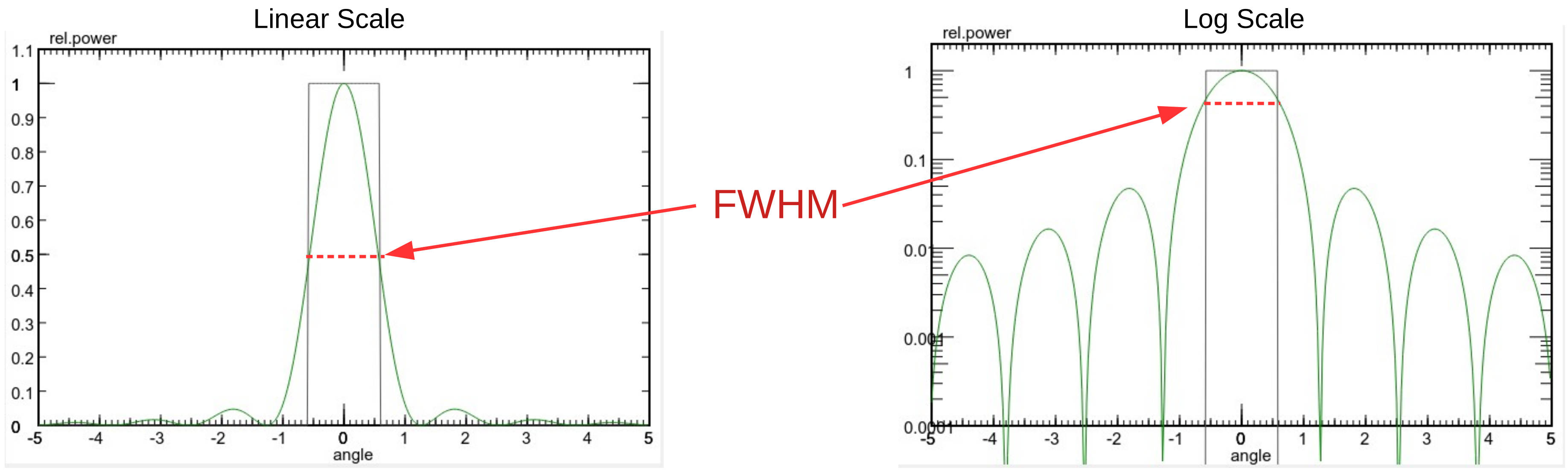


Single Dish Angular Resolution (Beamwidth)

- Resolving power = Full Width at Half Max (FWHM = -3 dB peak)
- Based on Airy disk separation, FWHM (or HPBW) defined as

$$\Theta_{rad} = 1.02\,\lambda / D\,,\ alternatively\ \Theta_{deg} = 70\,\lambda / D\,,\ Wavelength\ \lambda\,,\ meters\,;\ Dish\ diameter\ D\,,\ meters$$

  – Beam pattern for 3.8 m dish at 4.0 MHz (7.5 cm); FWHM = 1.4 degrees



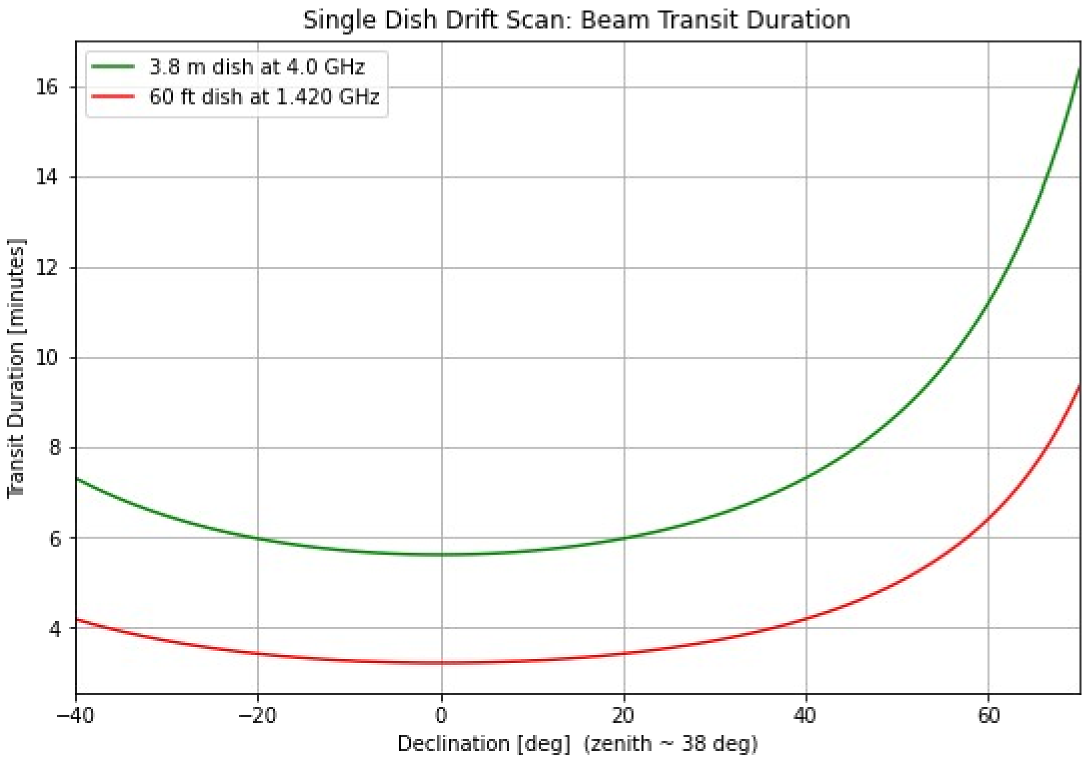
Single Dish Drift Scan Beam Transit Duration

Single Dish Resolution

Dish Diam. [m]	Wavelength [cm]	Frequency [GHz]	FWHM [degrees]
3.8	7.5	4.0	1.4
18.3	21	1.420	0.8

$$FWHM = 70\,\lambda / D$$

The operational curves help define sampling periods during drift scans.



$$Transit\ Duration(hours) = FWHM / (15 * \cos(dec))$$

Two Dish Angular Resolution Example

Two 3.8 m dishes at 571'
(b = 174 m)

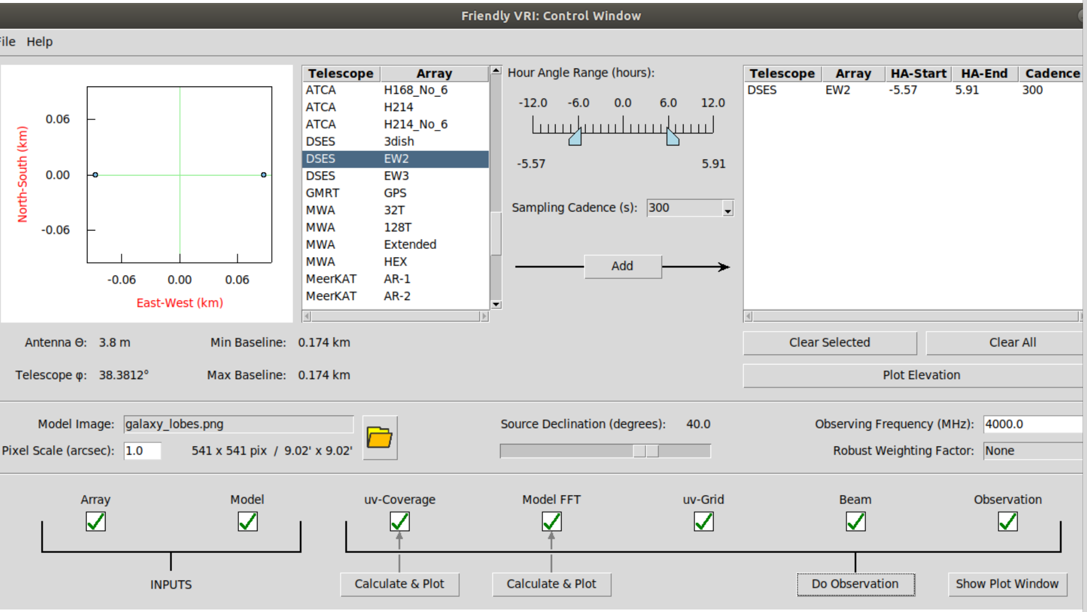
Wavelength [cm]	Resolution [arcsec]	Resolution [degrees]
21	304	0.08
7.5	108	0.03

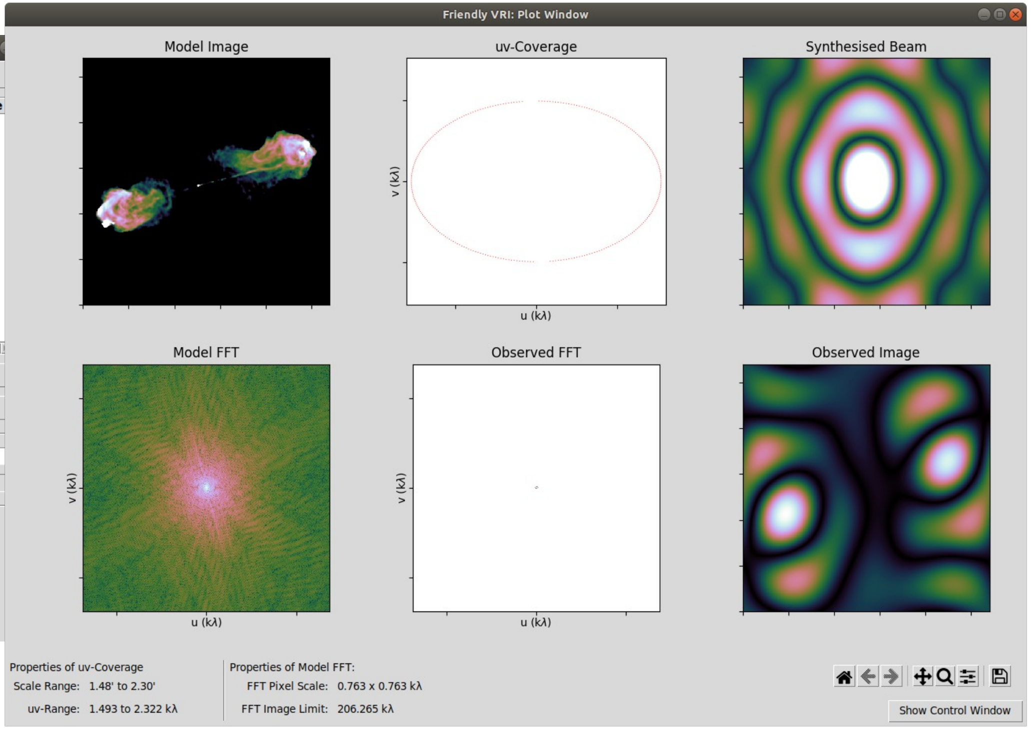
Using a Two Antenna Radio Interferometer

- Angular resolution could improve by factor of 10 over 60’ dish
- Sensitivity depends on T_{sys} (LNA, receiver temperature, etc.)
  - Use SEFD and Radiometer eqn to plan observation for desired sensitivity
  - But use calibration sources to actually fit the flux
- Pointing errors: Compare predicted and observed transit times
- What about fringe patterns from a meridian scan?
  - We sample visibilities in Fourier domain (u,v) using rotating earth
  - Visibility = Fourier transform of source’s brightness distribution
  - Then use inverse Fourier Transform to recover image
  - Simulations in progress. Stationary antennas observe as object transits
    - Observe for many days (adjust elevation), or add tracking capability, or 3rd dish

Virtual Radio Interferometer (VRI)

Simulation controls on left, results on right
Two 3.8 m dishes, with baseline = 174 m

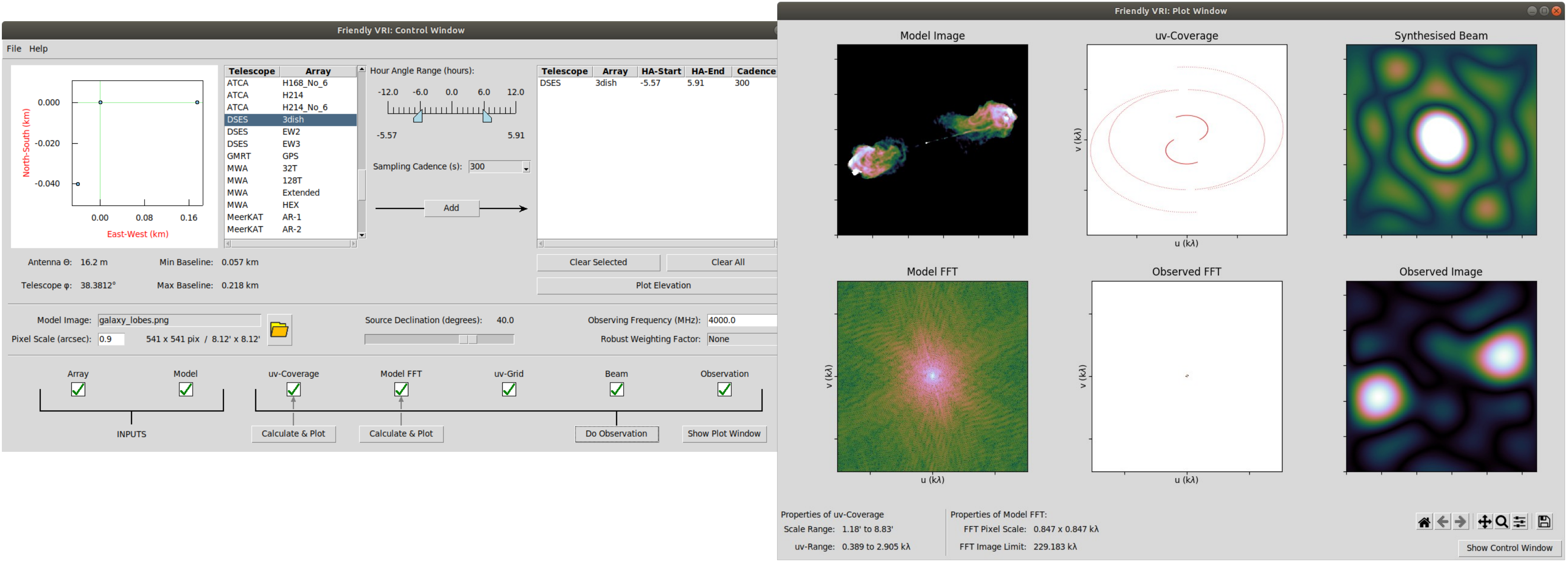




https://github.com/crpurcell/friendlyVRI

Virtual Radio Interferometer (VRI)

Simulation controls on left, results on right
Three 16.2 m dishes, triangle with 3 baselines



Questions?

Future Topics?