Radio Wavelength Evidence for High Energy Particles in the Nearby Universe

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Ginzburg Conference on Physics
Lebedev Institute, Moscow, 28 May - 2 June 2012

Vitaly Ginzburg 1916 - 2009

- 1950 – Non-thermal radio emission due to synchrotron emission
  - Beginning of Cosmic Ray Astrophysics
- 1977
  - Ekers and Sancisi detect a radio halo in NGC4631
- 1982 IAU General Assembly, Patras, Greece
  - Optimum strategy for a scientist is to know something about everything and everything about something
- 1990
  - NGC4631 image on cover of "*Astrophysics of Cosmic Rays*"
    - » Ed V.L.Ginzburg
- 1995
  - ICRC Adelaide

Summary

- Vitaly Ginzburg (1916 - 2009)
- Cosmic Ray Astrophysics
  - Synchrotron radio emission
- The Cosmic Ray halo model
- The detection of a radio halo in NGC4631
- Other normal galaxies
- Radio Galaxies
  - Centaurus A
- UHE cosmic rays and neutrinos
- SKA and the future

Cosmic Ray Astrophysics comments by Ginzburg

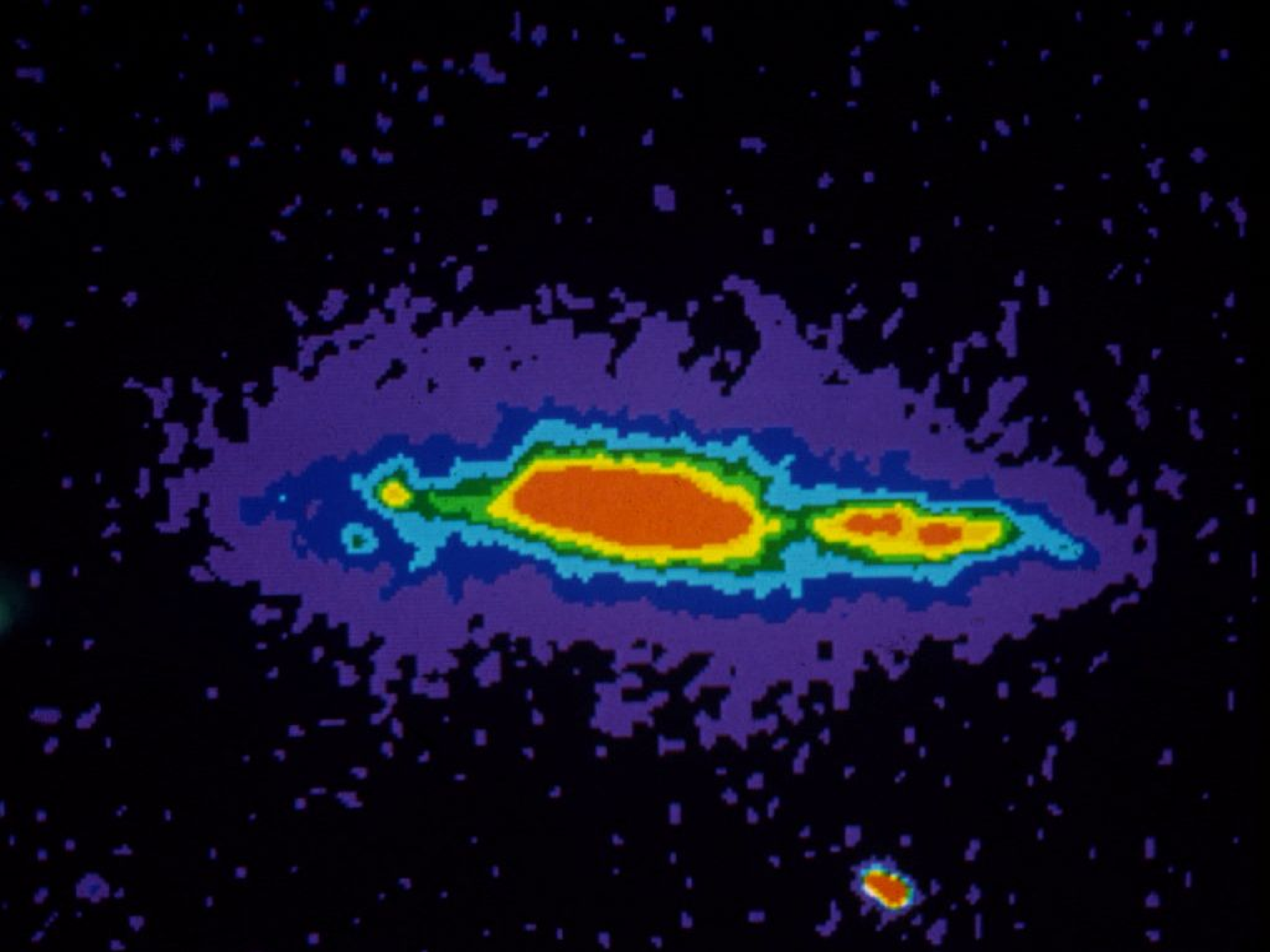
- Cosmic ray astrophysics was born in the early 1950s when it became possible to observe cosmic rays far from the Earth.
  - Non-thermal continuum radio emission is from the synchrotron process
  - Crab nebula, and the first radio galaxies identified
  - Because radio waves propagate rectilinearly, the reception of cosmic radio emission provides a tool to obtain information about the electron component of cosmic rays at a distance from the Earth, in our Galaxy, other galaxies, and quasars.
  - From Ginzburg 1996, Cosmic ray astrophysics
    - *Physics Uspekhi, Volume 39, pp. 155-168 (1996)*
- CR now traced at all wavelengths, and directly in gamma rays and UHE cosmic rays.

Cosmic Ray Halo
Ginzburg & Ptuskin

- Need a halo to get consistency between the observed CR abundances, the lifetimes and the radio luminosity
  - Be isotopes and the mean path length for observed cosmic rays
- CR ages are 10^8 years rather than 10^6 years in the disk models
  - *Rev Mod Phys 48, 161 (1976)*
- Ginzburg & Ptuskin
  - *"the assertion of the validity of the galactic disk model, often heard of late, and the use, in accordance with this, of the age 3.10^6 years may be characterized as adopted by repetition"*
  - *Usp. Fiz. Nauk , 117, 585 (1975)*

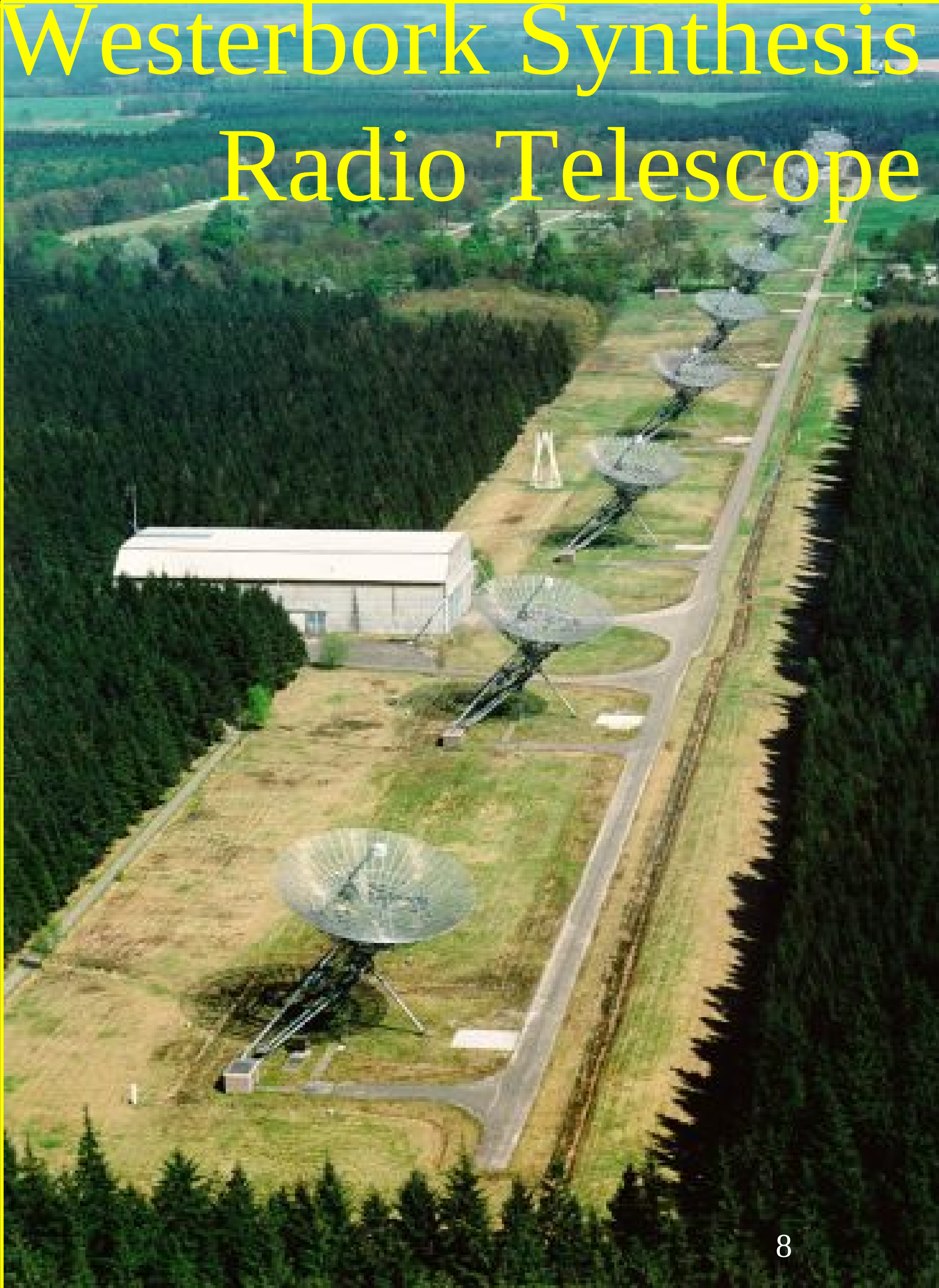
Ginzburg’s galaxy NGC4631

- Ginzburg visited Cambridge in late 60’s
  - exhorted them to look for radio halos in edge-on galaxies
  - NGC463 was already known to have relatively strong radio emission
- Pooley (1969) imaged disk but insufficient sensitivity to see the halo
- NGC4631 became known as Ginzsburg’s Galaxy



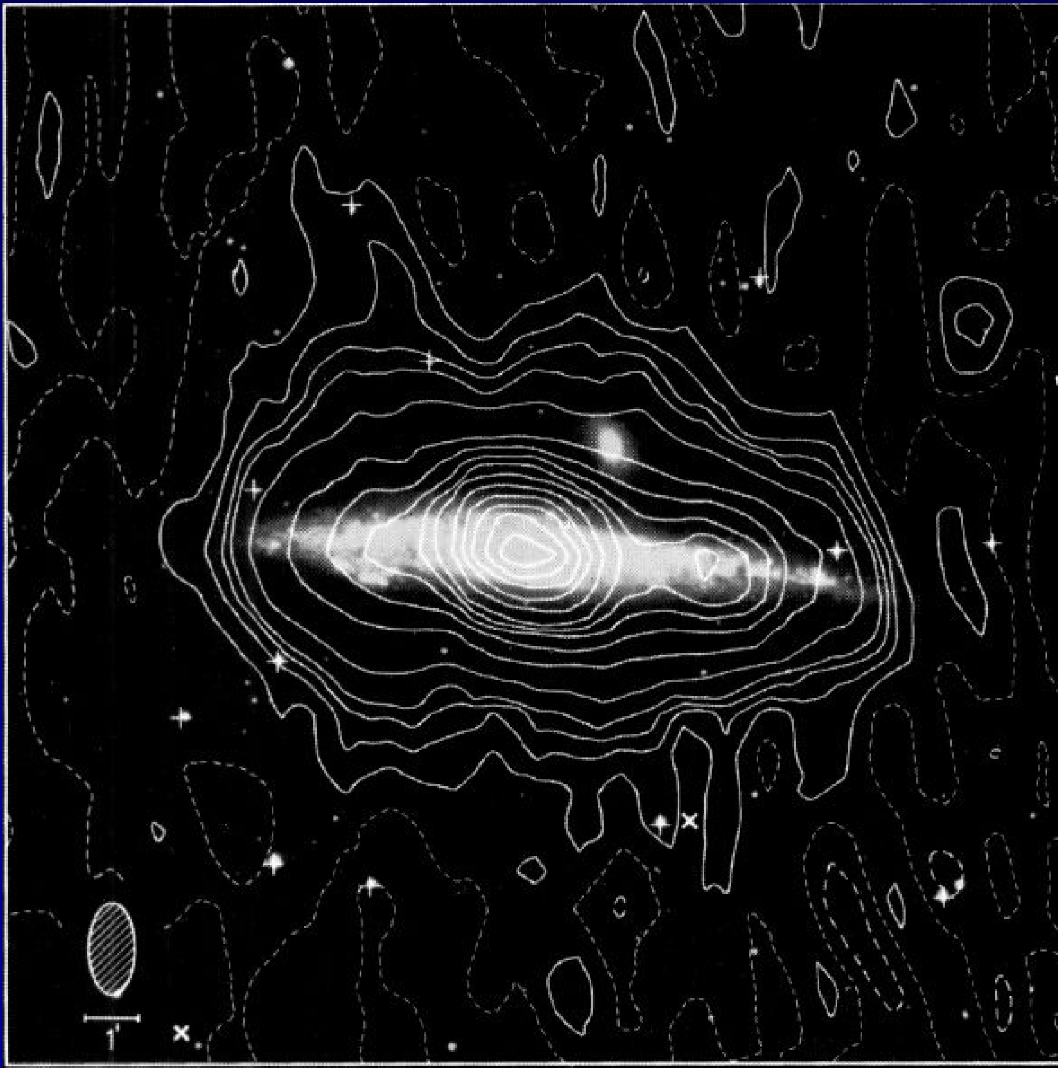
Westerbork Synthesis Radio Telescope

- 12 (14) x 25m dishes
- Sufficient sensitivity to image synchrotron radio emission from normal galaxies

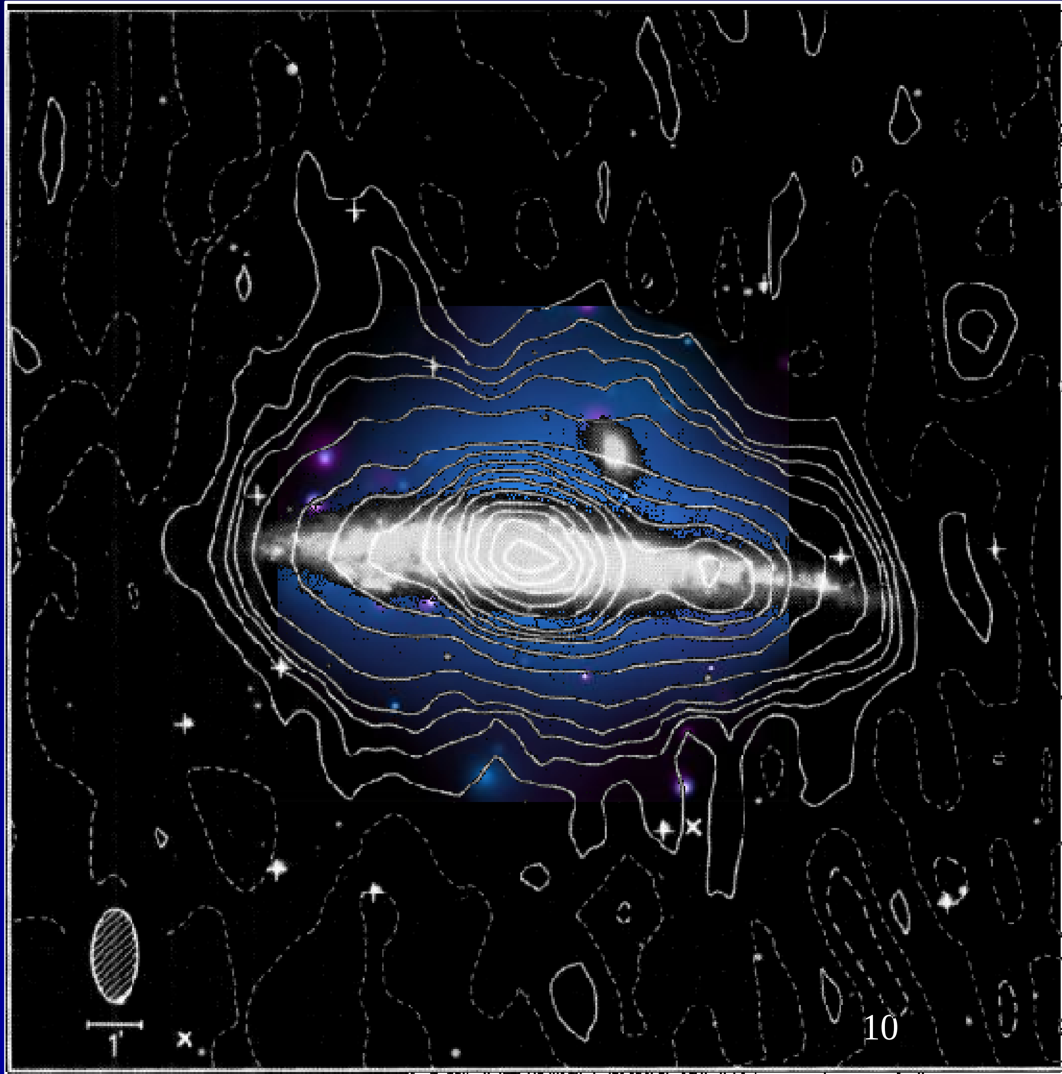


NGC4631 Radio Halo

- Ekers &Sancisi
  - A&A 54, 973 (1977)
- Westerbork 1973-7
- 610 MHz
  - Size 23 x15 kpc
  - Emissivity 0.3K kpc^{-1}



NGC4631 Radio & X-ray Halo

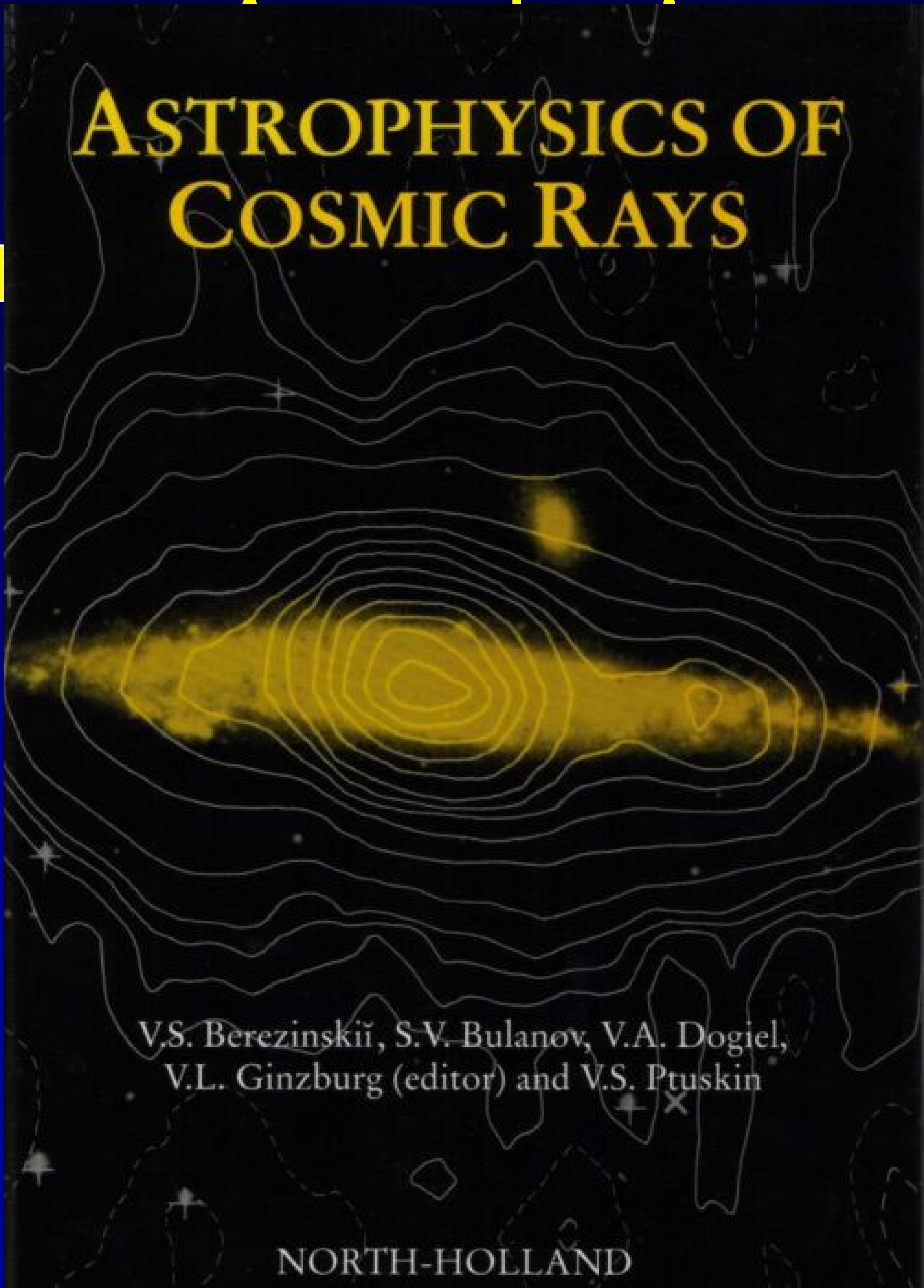


X-ray emission from NGC4631

- Wang et al
  - ApJ 555, L99 (2001)
- Chandra X-ray
  - 0.3 to 7 keV
- 2-7 x 106K
- Extends to 8kpc
- Close connection between hot gas, cosmic rays and magnetic fields

NGC4631 magnetic field distribution

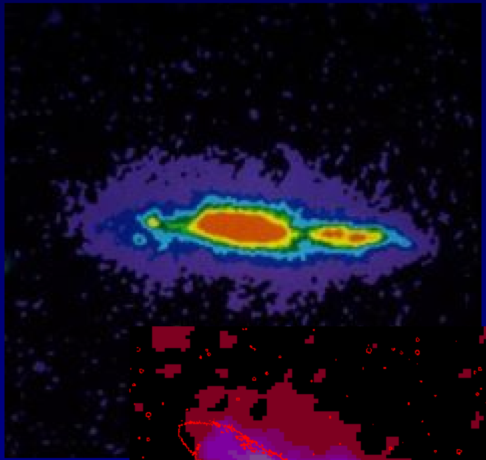
- Editor: V.L.Ginzburg
- Published 1990

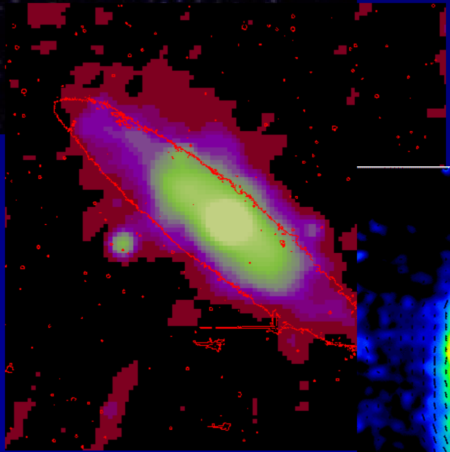


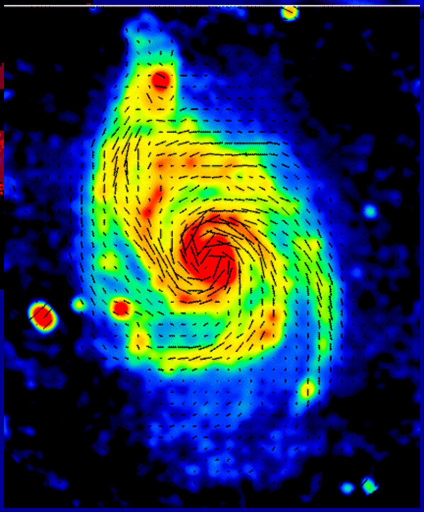
Other normal galaxies

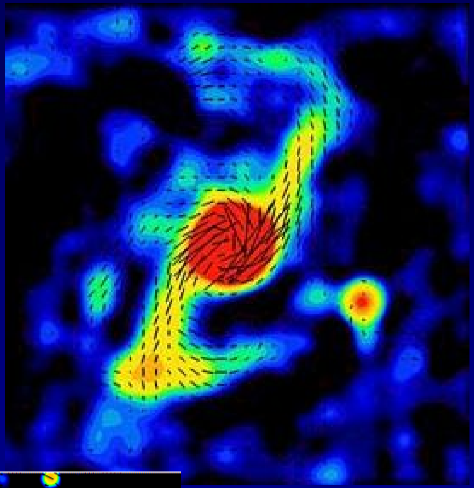
- Halos seen in a few (10s of edge-on galaxies observed)
  - NGC4631 is the extreme example
  - Starformation rate is very high throughout the entire disk.
  - Plentiful Crsources
  - Evidence for gas and fields pushed out of the plane.
- can now measure spectral change with z
  - steeping seen in all cases
  - best fit by a dynamic flow not a pure containment halo
- polarization
- statistics
- current focus is on the strabursts rather than cosmic rays in normal galaxies

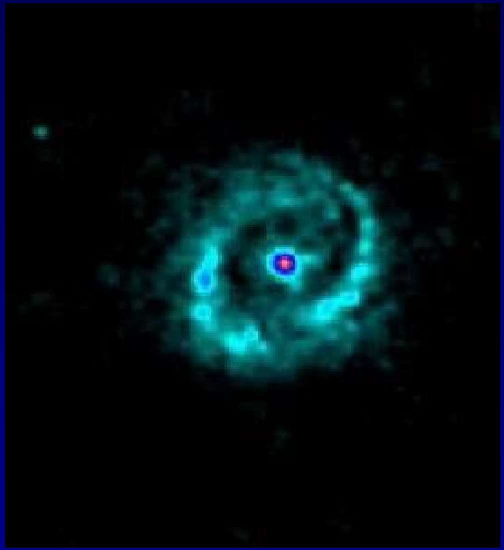
Normal Disk Galaxies VLA, WSRT ATCA

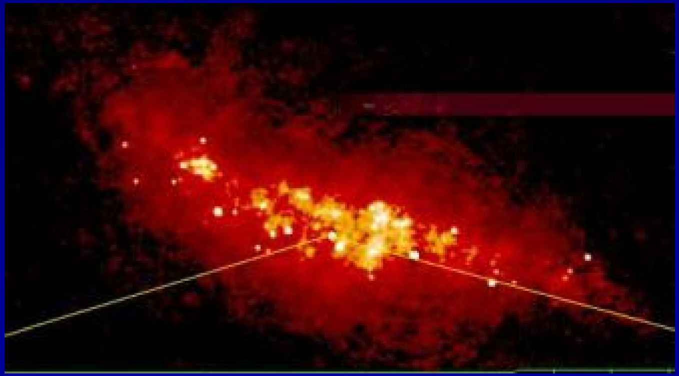




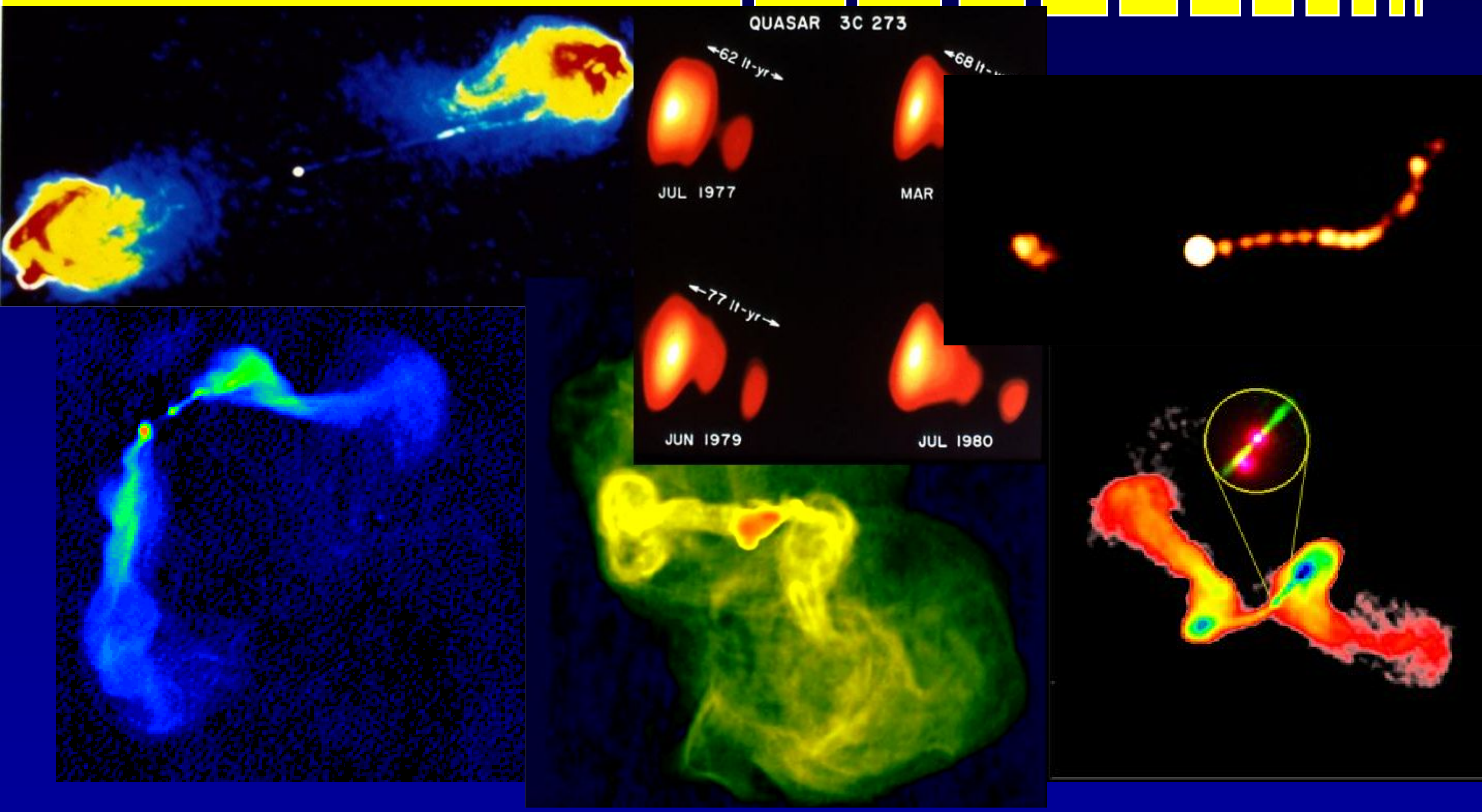




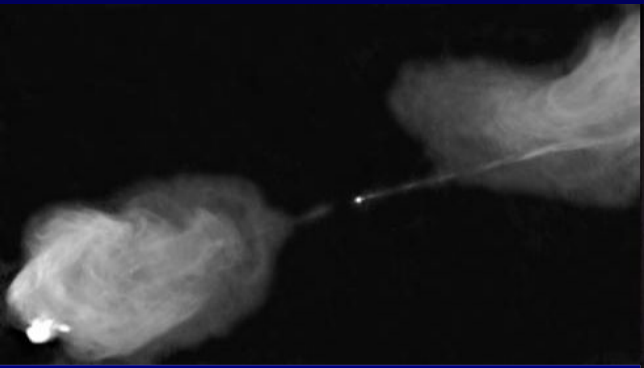


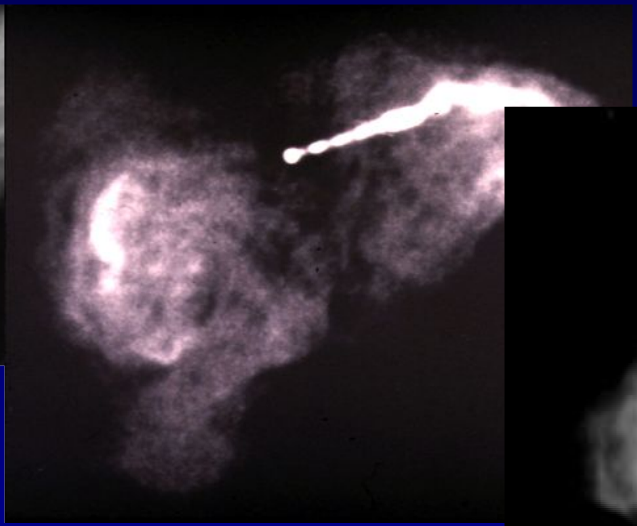


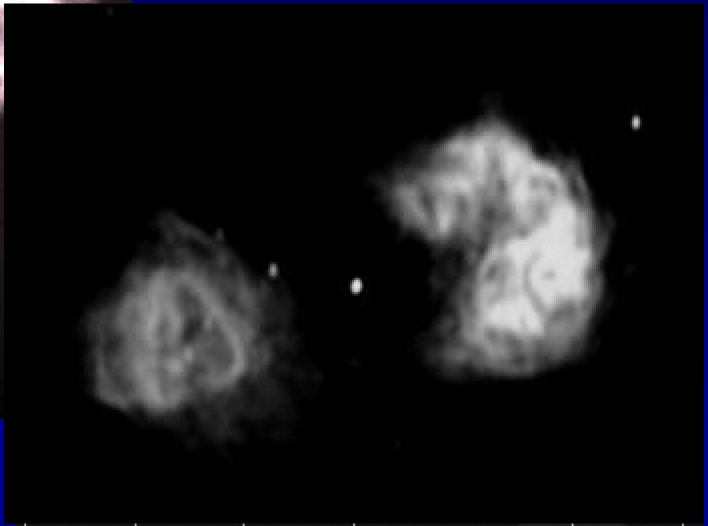
Radio Galaxies and QSOs

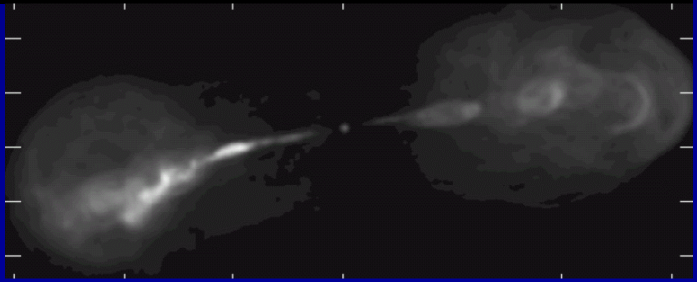


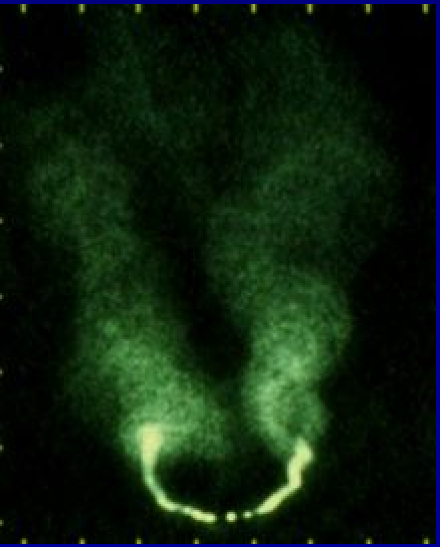
Radio Galaxies

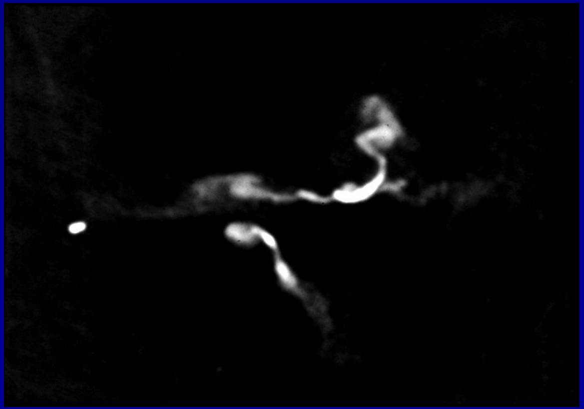






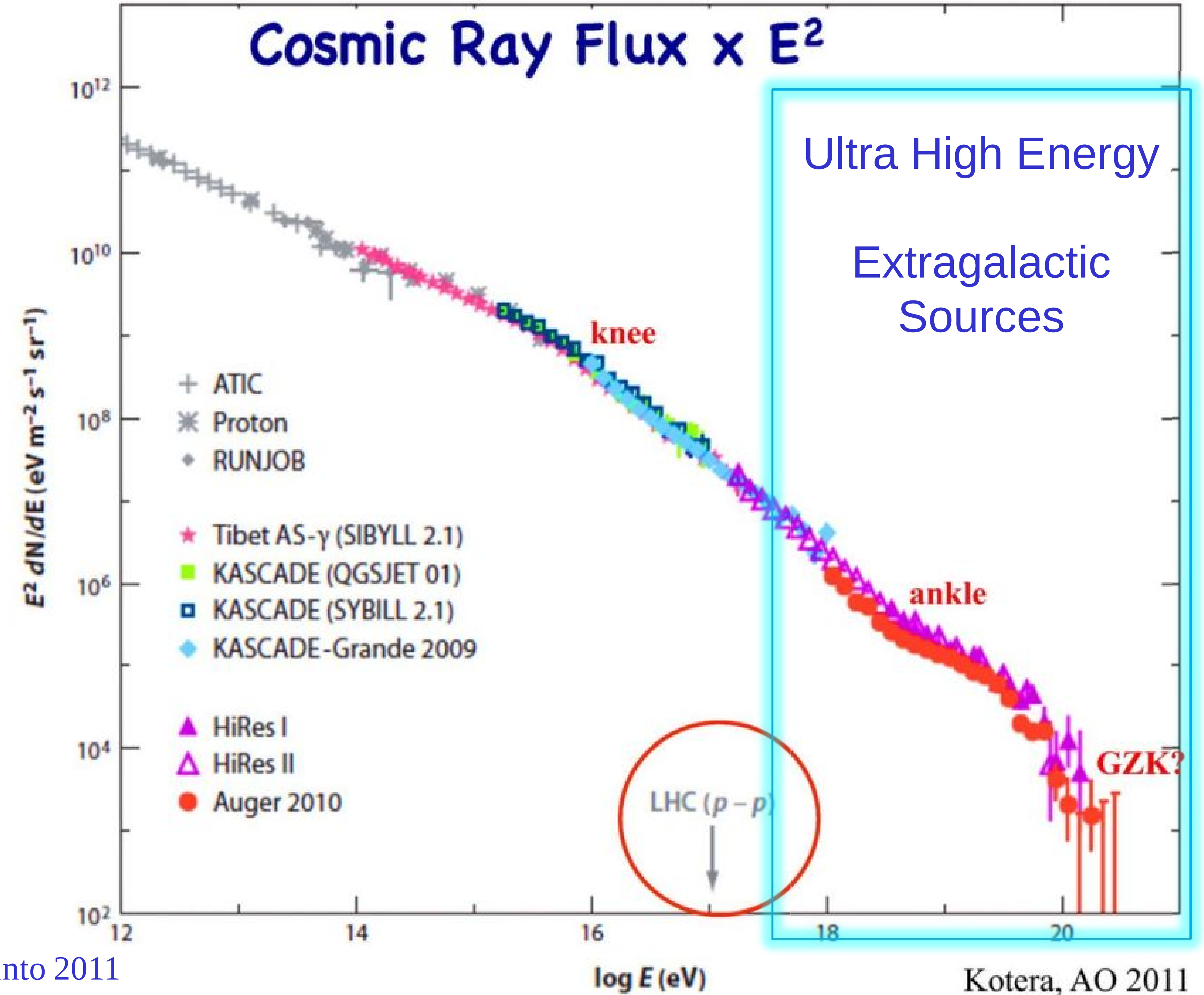






High Energy Cosmic Rays

- “great outstanding mysteries of astrophysics”
  - From Quarks to the Cosmos
- Highest energy cosmic rays > 10^{20} eV
  - High cross section for pair production on CMB photons
  - GZK cutoff limits volume to 10Mpc
- AGN candidate sites for acceleration can be traced by UHE neutrinos
  - No cutoff so can explore a large volume
  - No deflection so they point to the source
  - No loss of spectral information

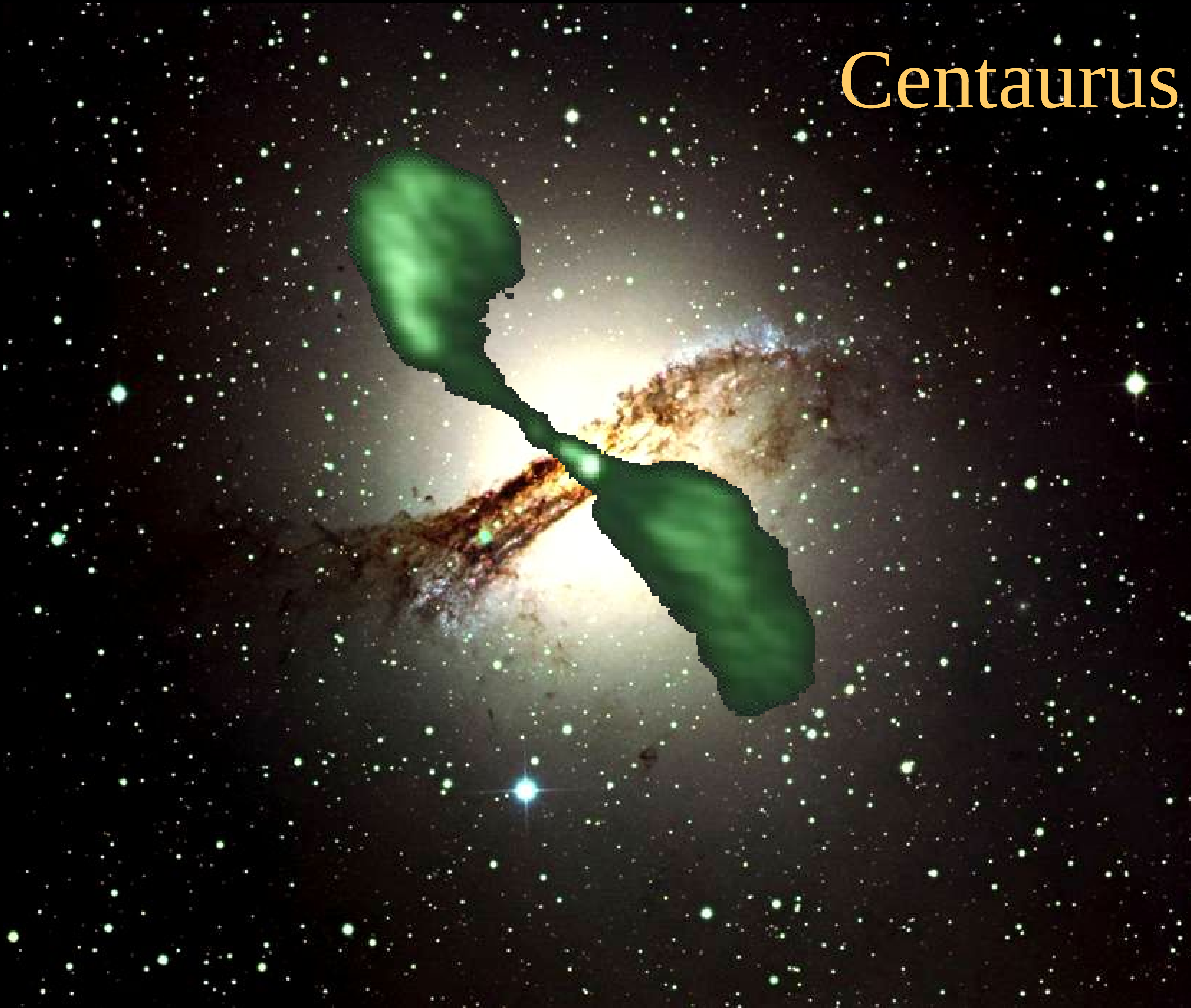


From Olinto 2011

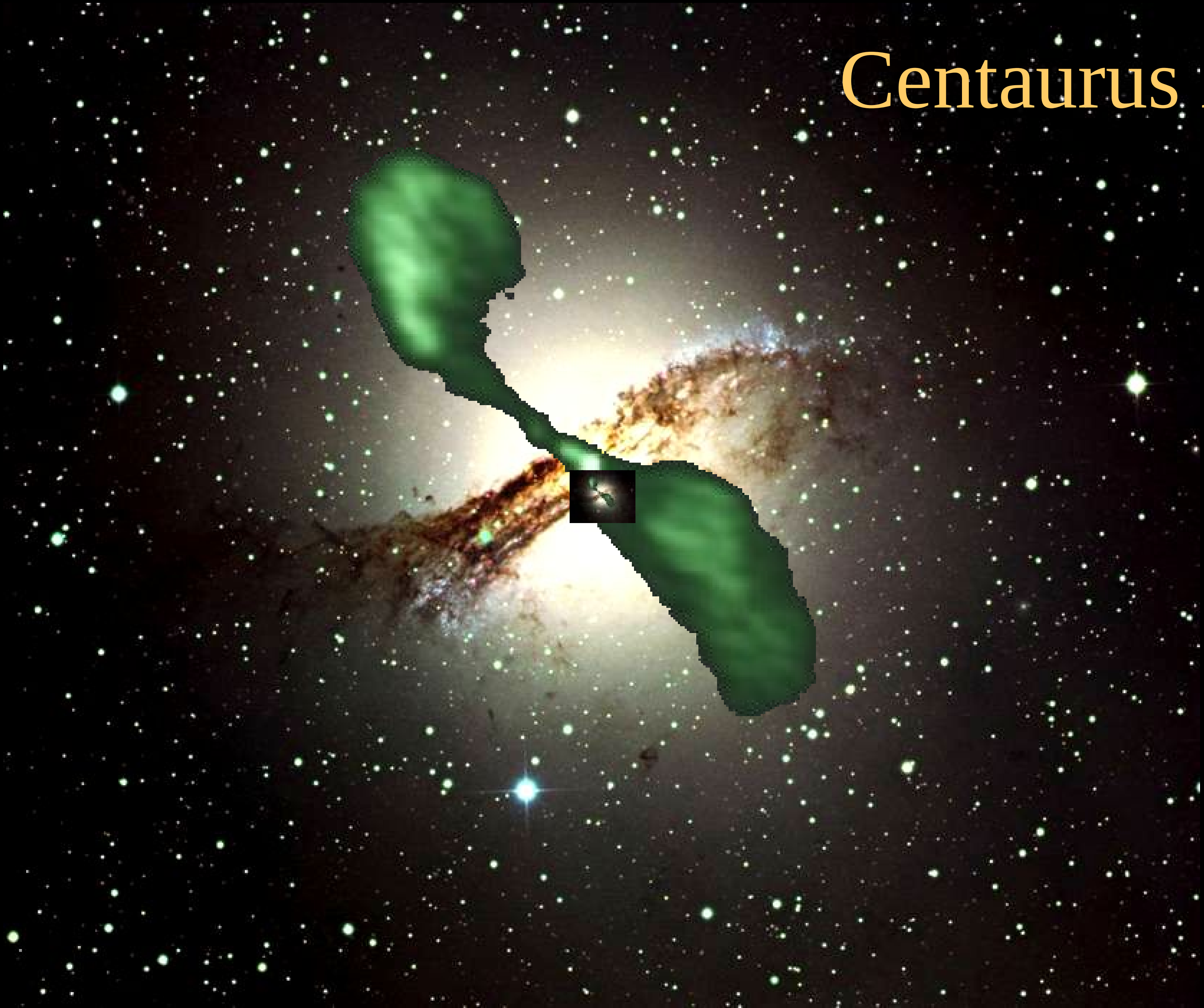
Extragalactic Cosmic Rays

- Ginzburg & Syrovatskii (1963)
  - Predicted that the radio galaxies
    - Centaurus A (= NGC5128),
    - Virgo A (= NGC4486 = M87), and
    - For nax A (= NGC1316)
  - should be good candidates to provide most of the extragalactic cosmic rays.
- and more recently
  - Caramete1 and Biermann, *arXiv: 1106.5109*
  - show that Cen A produces a predicted UHECR flux which is about ten times higher than from M87, and about 15 times higher than For A.

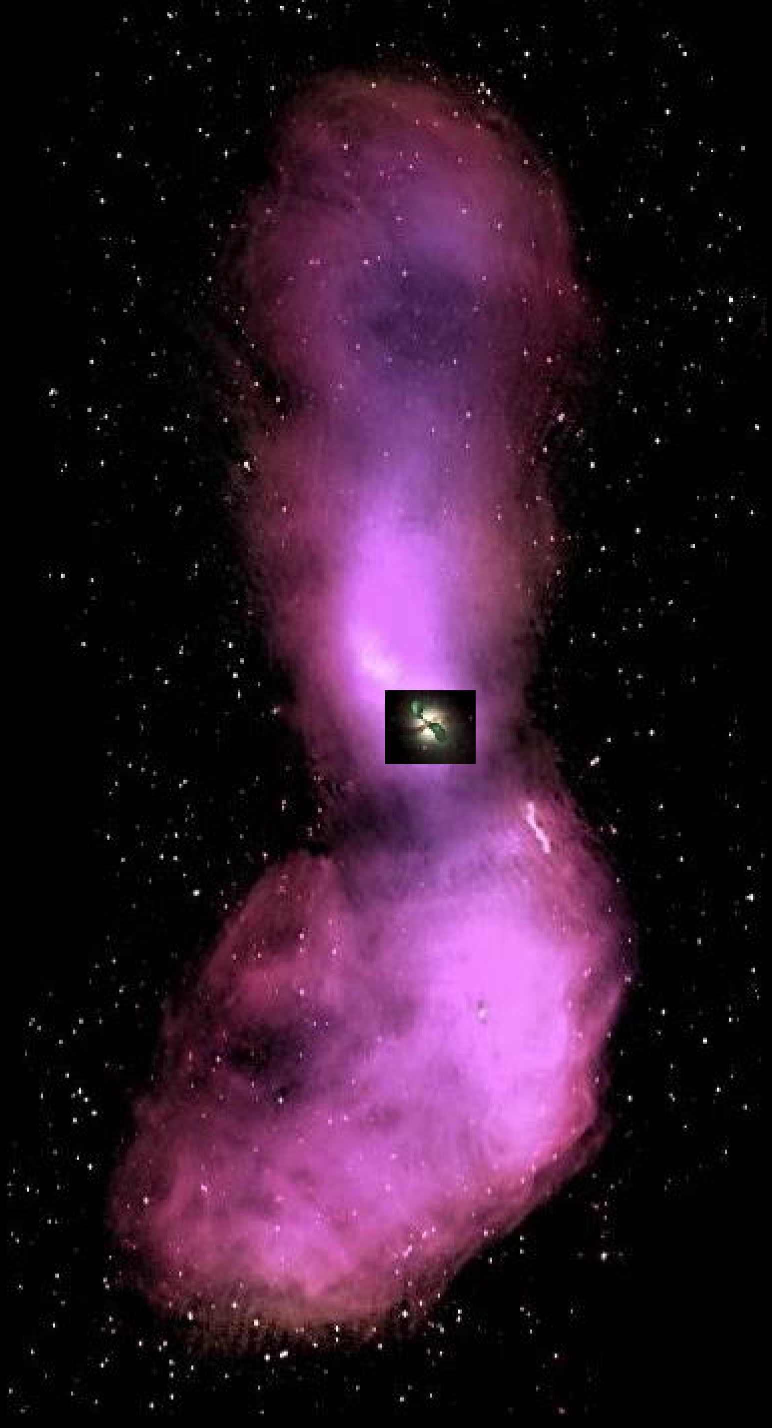
Centaurus A



Centaurus A

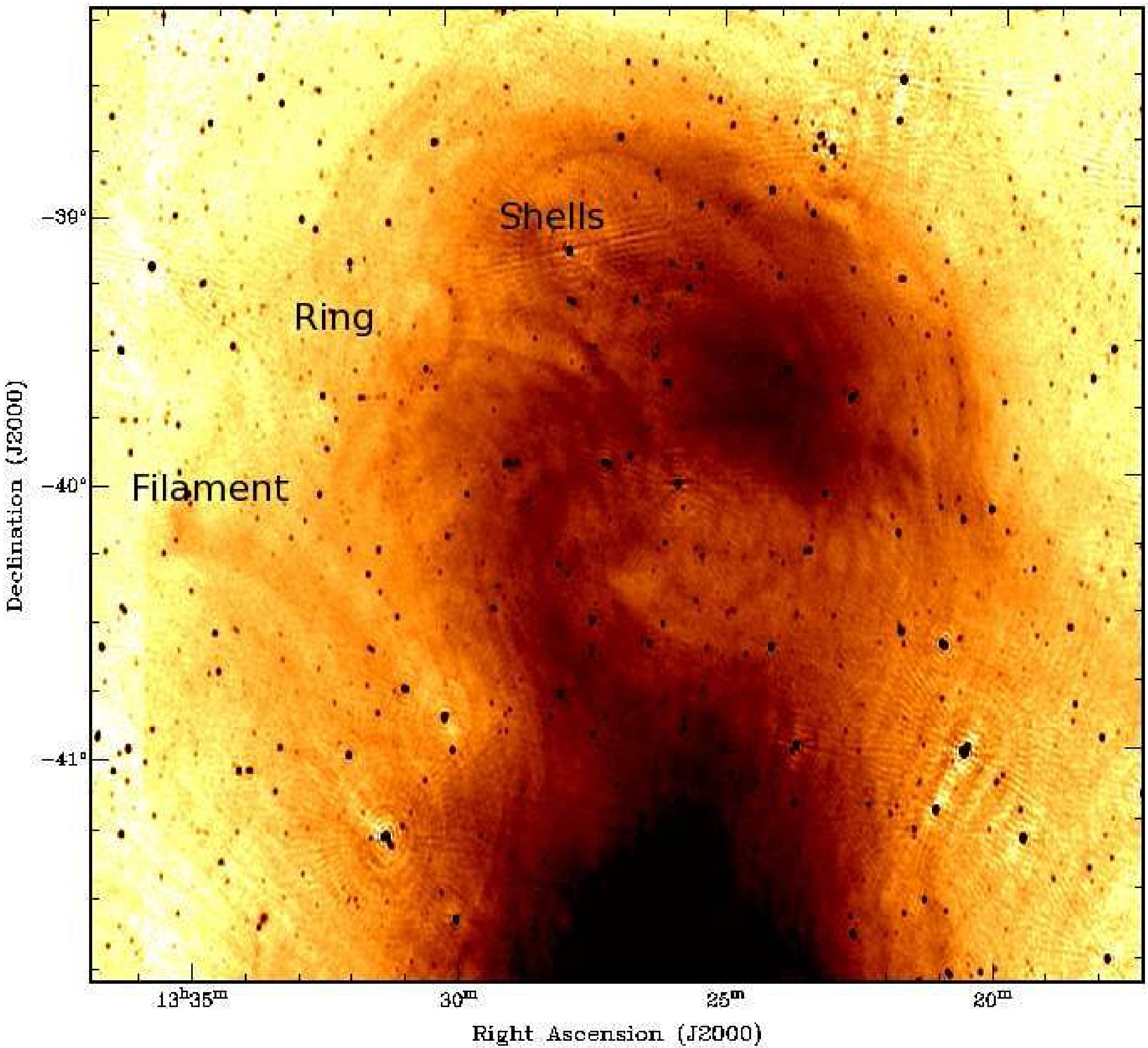


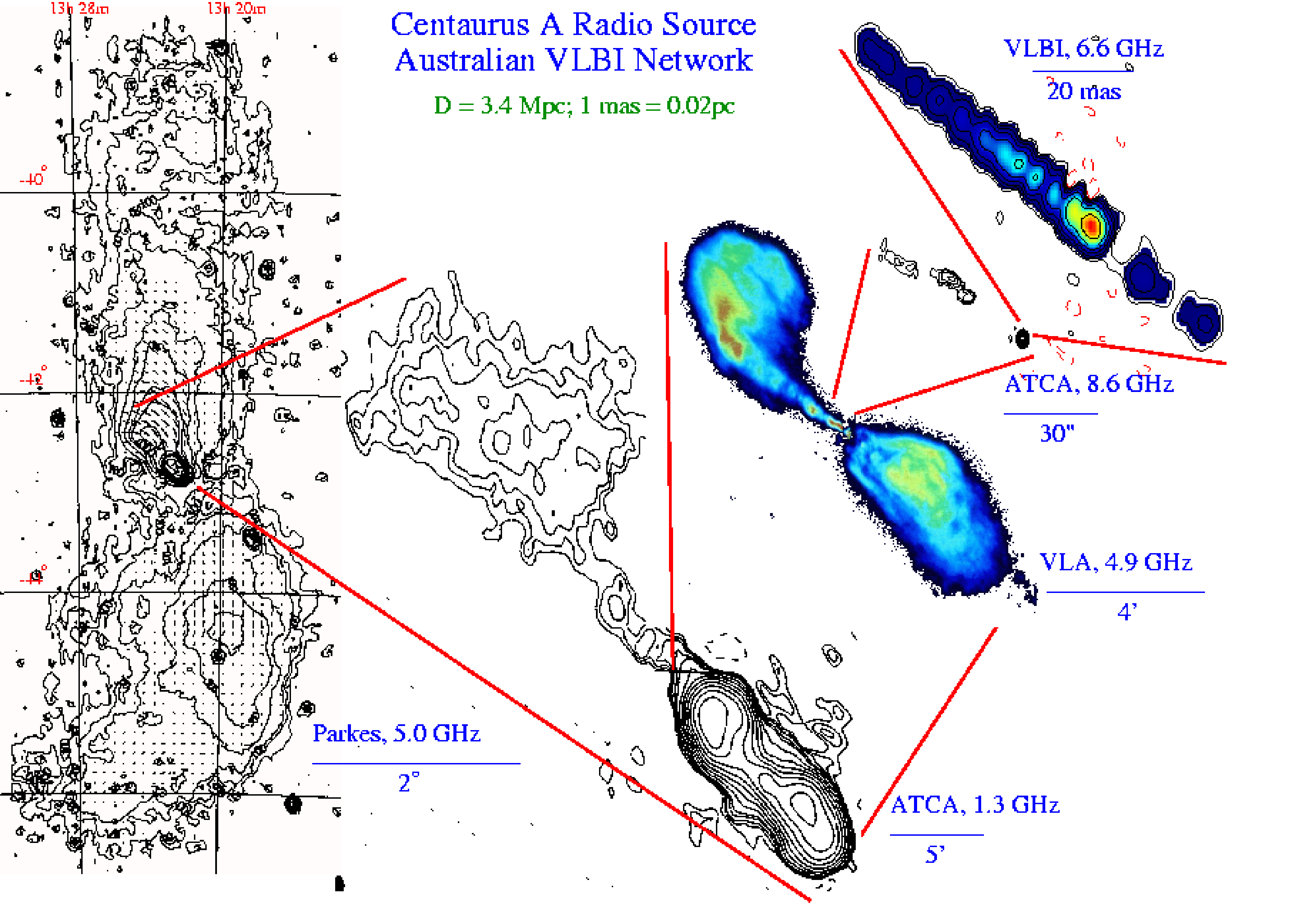
Centaurus A
ATCA Mosaic



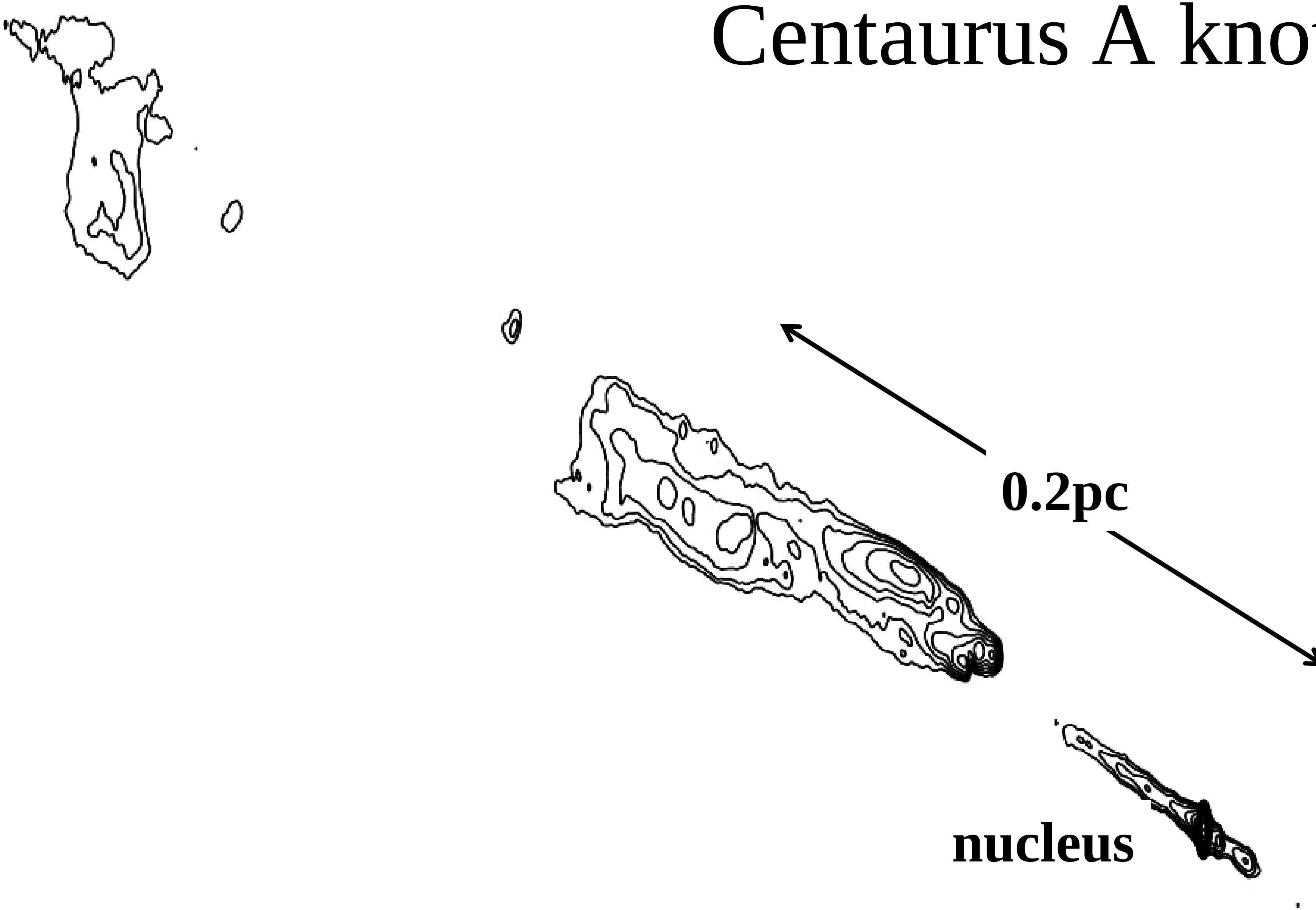
Centaurus A
the closest AGN

- Distance 3.4 Mpc
- Next closest comparable AGN M87 at 17 Mpc !
- Luminosity = 10^{42} ergs/sec
- Total Energy = 10^{60} ergs (relativistic particles)
- Giant radio galaxy 0.5 Mpc in size
- Subtends a large angular size (8^{o})

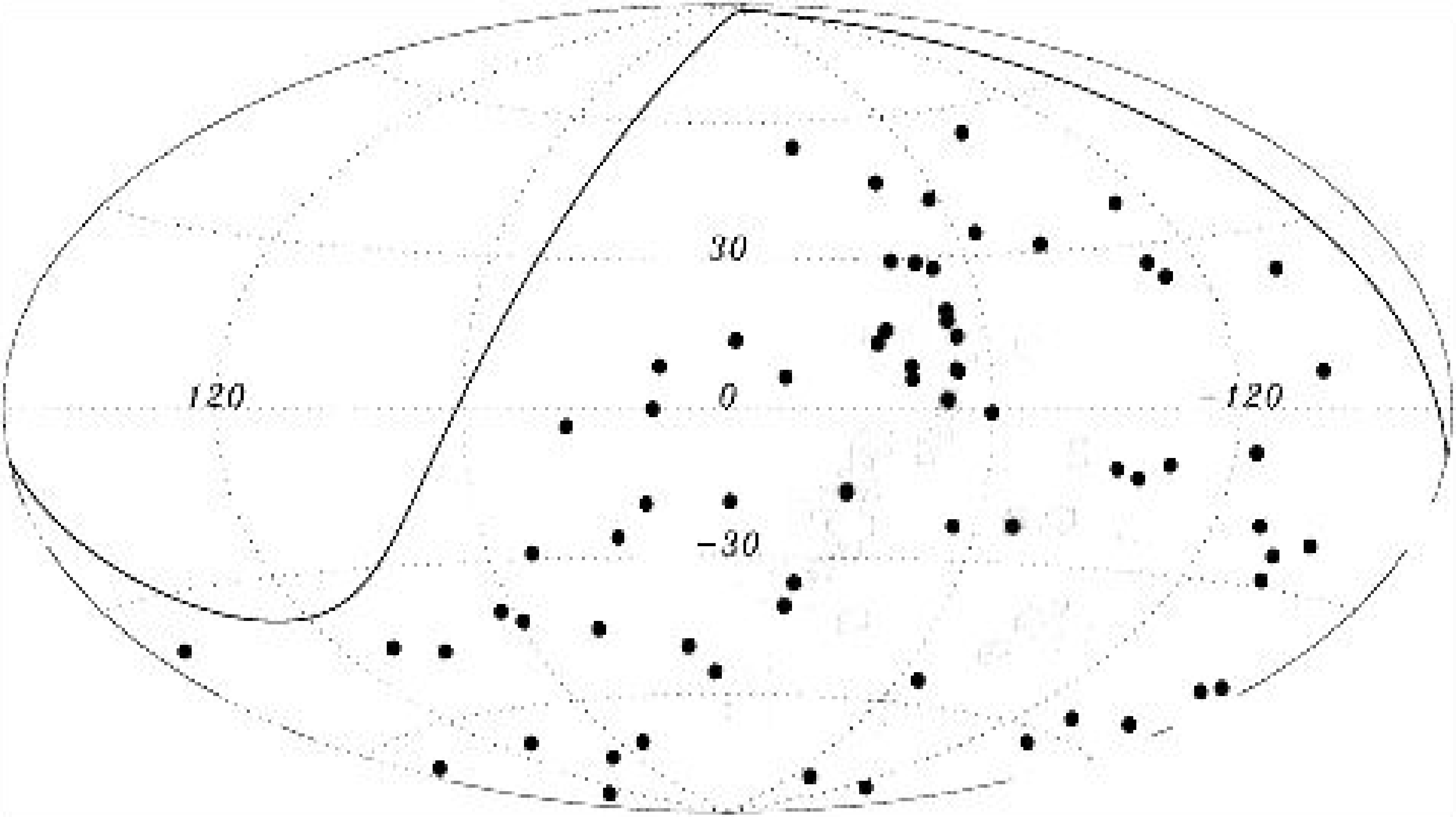

Shells
Ring
Filament
-39°
-40°
-41°
Declination (J2000)
13h35m
30m
25m
20m
Right Ascension (J2000)


Centaurus A Radio Source
Australian VLBI Network
D = 3.4 Mpc; 1 mas = 0.02pc
13h 28m
13h 20m
-40°
-42°
-44°
Parkes, 5.0 GHz
2°
ATCA, 1.3 GHz
5'
VLA, 4.9 GHz
4'
ATCA, 8.6 GHz
30"
VLBI, 6.6 GHz
20 mas

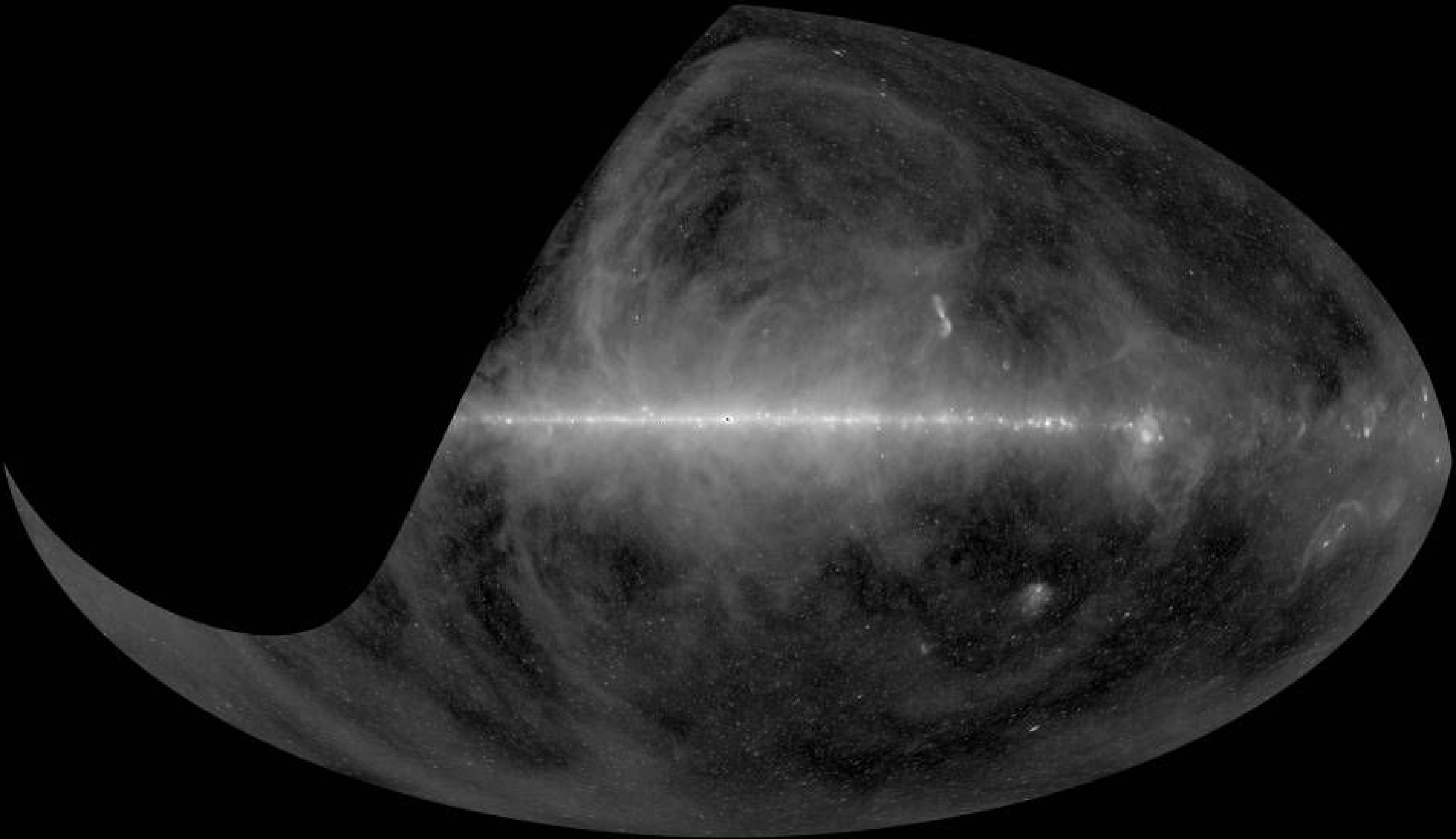
Centaurus A knots



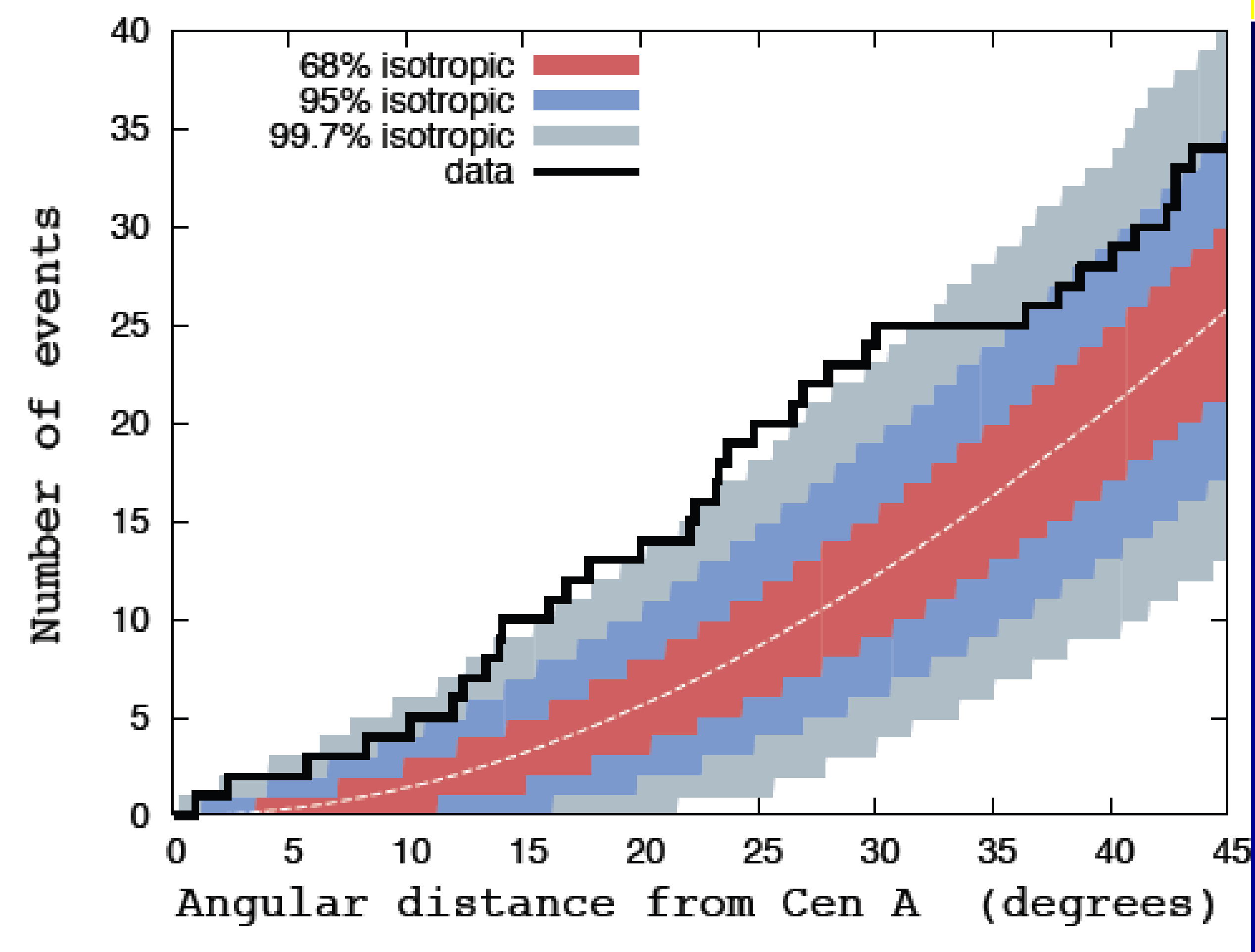
Auger Cosmic Rays



Radio continuum



Auger UHE Cosmic Rays from Centaurus A



- 19/84 events within 24^{o}
- 7.6 expected
- But not predicted so cant calculate probability!
- BUT!
  - Ginzburg & Syrovatskii (1963)

Detecting High Energy Neutrino's

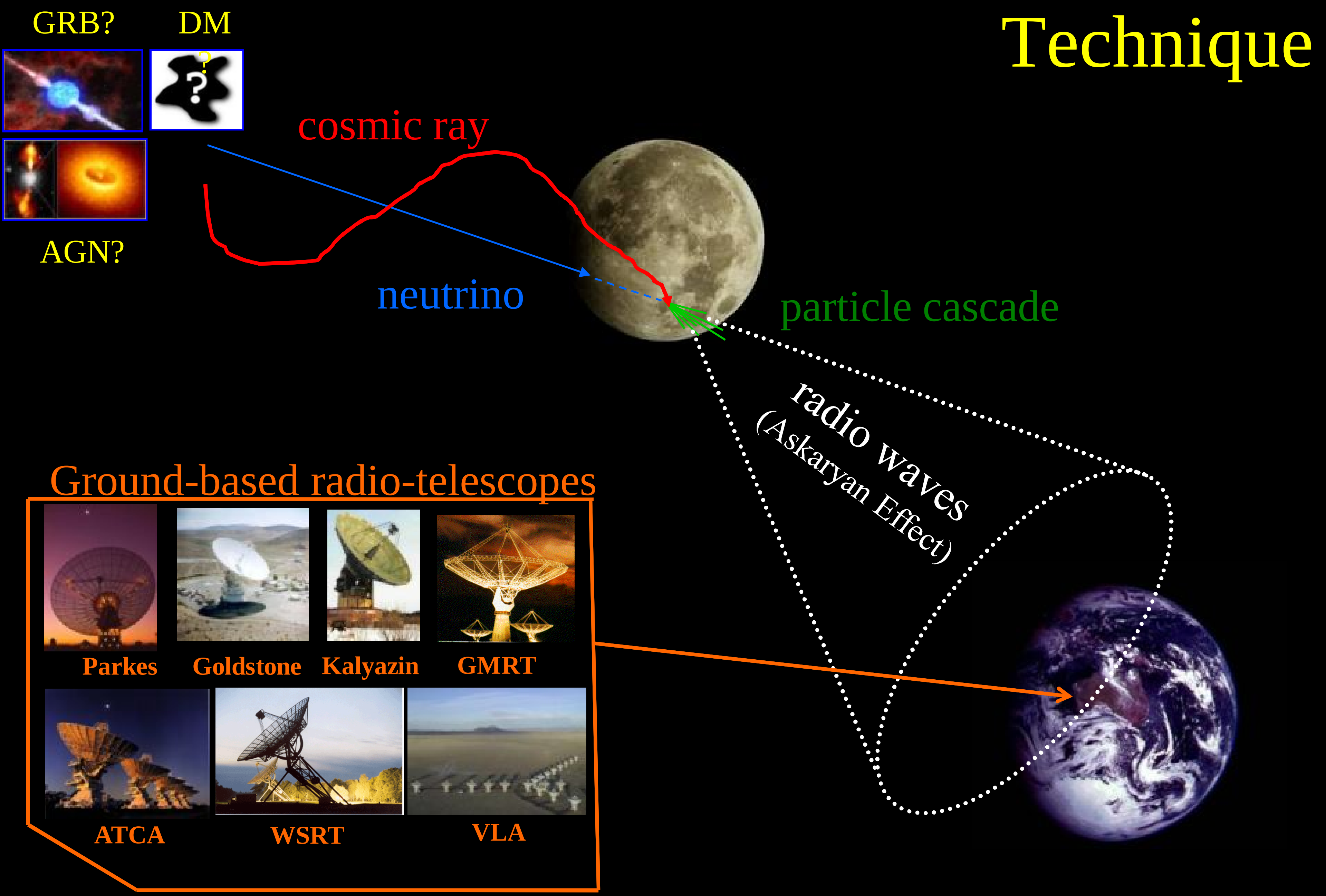
- Detection of UHE neutrinos is difficult
  - low flux - 2 per km^2 per day per steradian for the standard GZK model
  - low interaction probability (0.2% per km of water).
- A detector on the order 1000 $km^3 sr$ is required to get reasonable rates
  - far larger than any current neutrino detector

Lehtinen N.G. et al., Phys. Rev. D., 69, id 013008 (2004).

G. Askaryan, early 60's

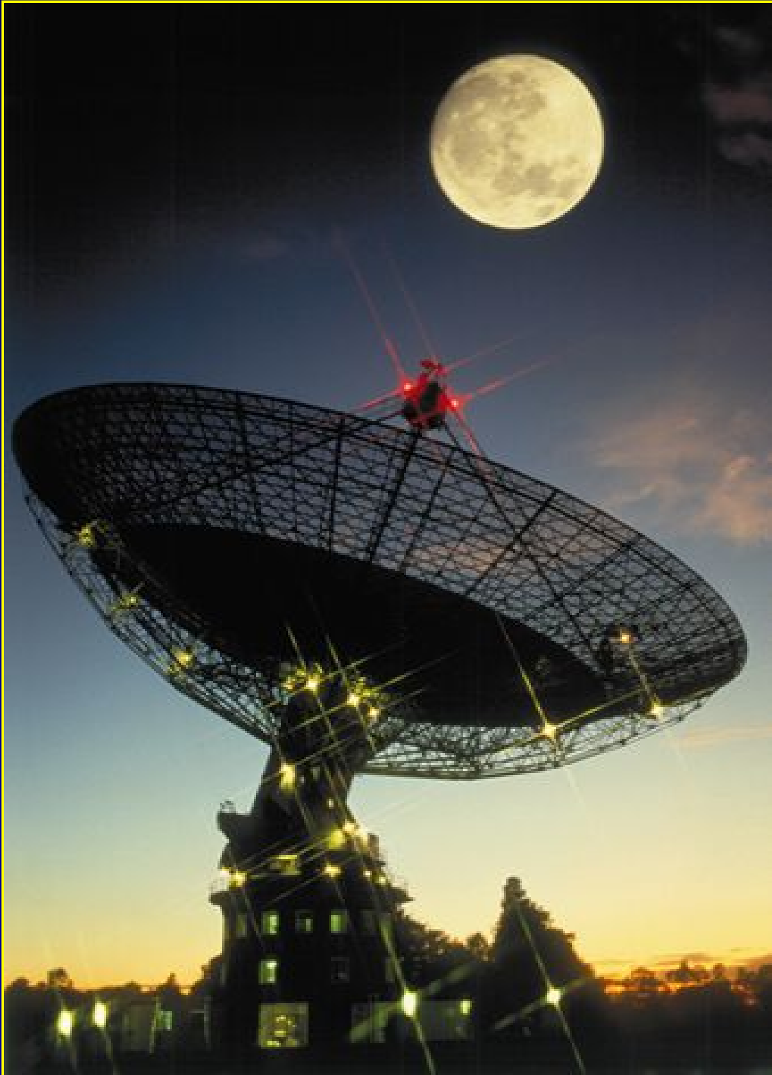
- High energy particle cascades produce ~20-30% more electrons than positrons
  - ⇨ showers in the dielectric,
  - – each particle emits Cherenkov radiation
  - – coherent microwave emission if $\lambda >$ shower diam
- One should look for low-loss microwave dielectrics abundant in nature
  - – Ice, many rocks
  - – Lunar regolith

The Lunar Cerenkof Technique



First radio experiment Parkes 64m radio telescope

- Jan 1995
  - Triggered by Adelaide ICRC meeting
  - Ginzburg
  - Berezinnskii
- Receiver:
  - 1.2 – 1.9 GHz. (SETI receiver)
- Beamwidth:
  - 13 arc min.
  - Moon ~ 30 arc min, hence reduced sensitivity at Moon’s limb !
- *Hankins, Ekers & O’Sullivan MNRAS* ***283****, 1996*

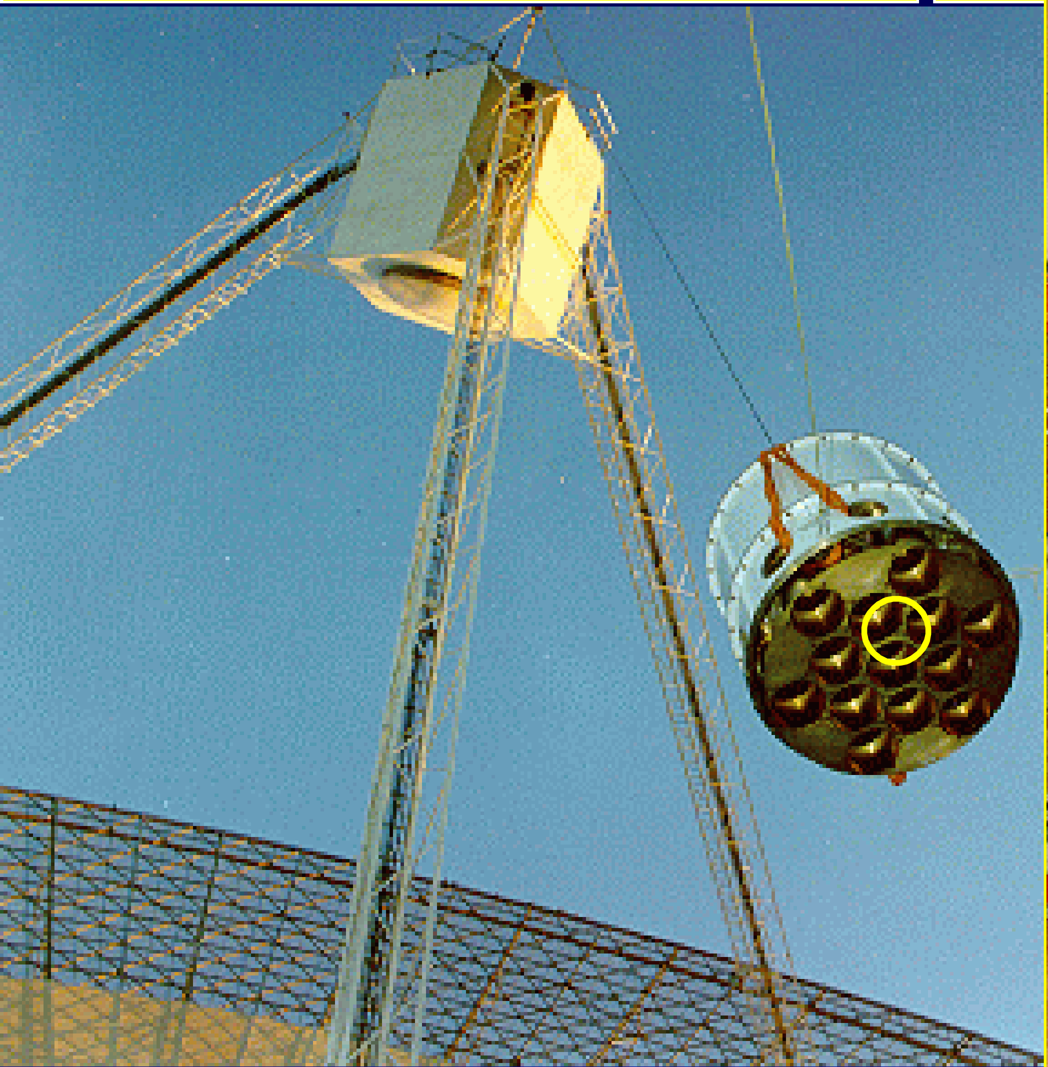


UHE neutrinos from Centaurus A?

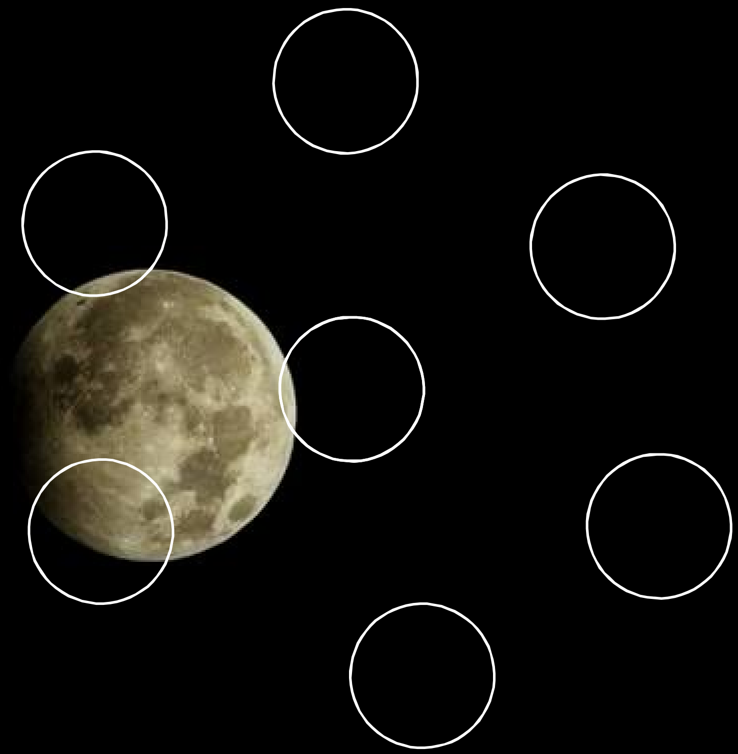
- Change strategy to search for neutrinos from Centaurus A instead of isotropic
  - ANITA has 10x better sensitivity for isotropic and has not seen any UHE neutrinos.
- Centaurus A can't be seen by ANITA
- No penalty for a smaller beam from a larger telescope

CSIRO

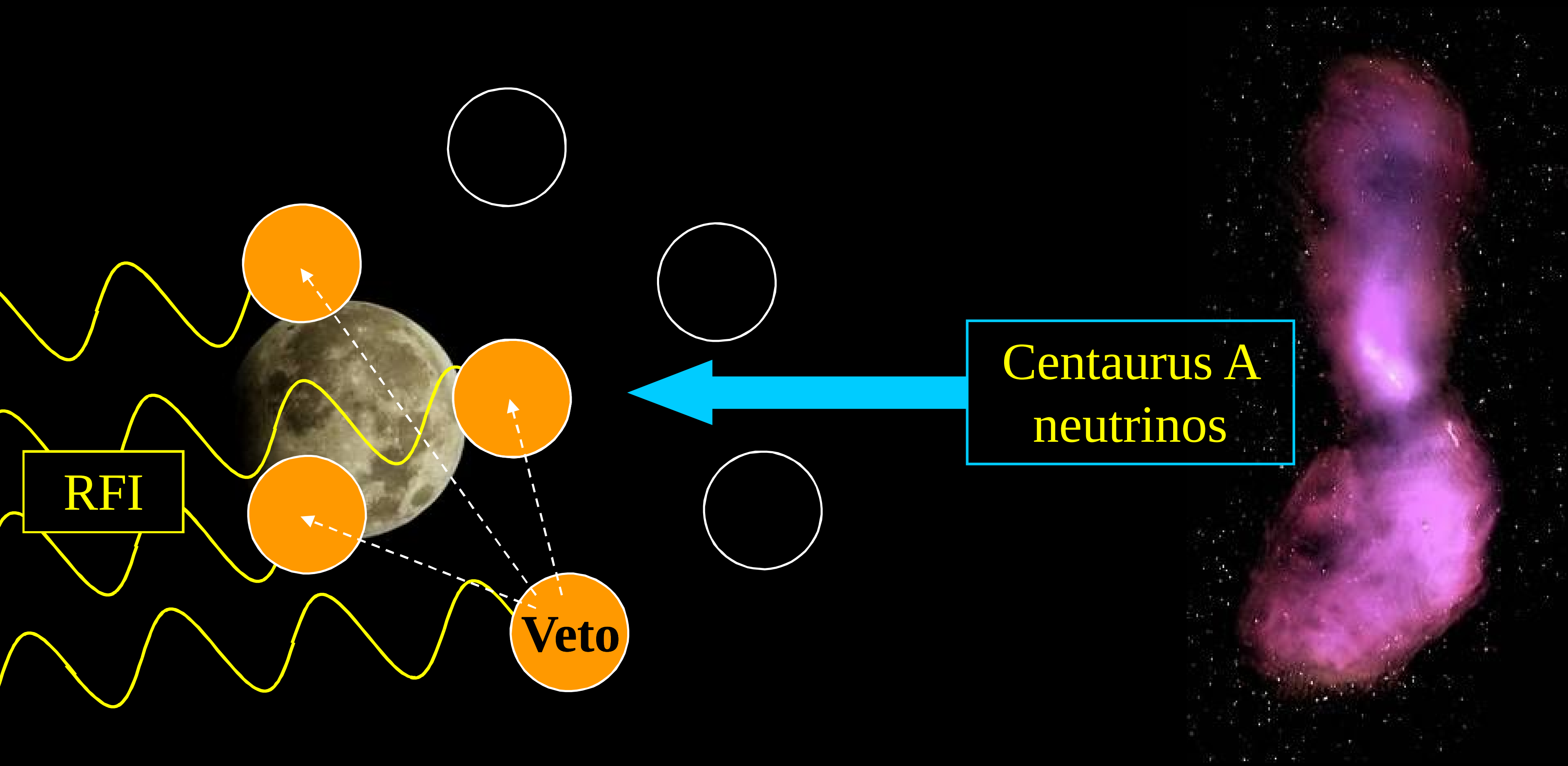
Installing th
Multi



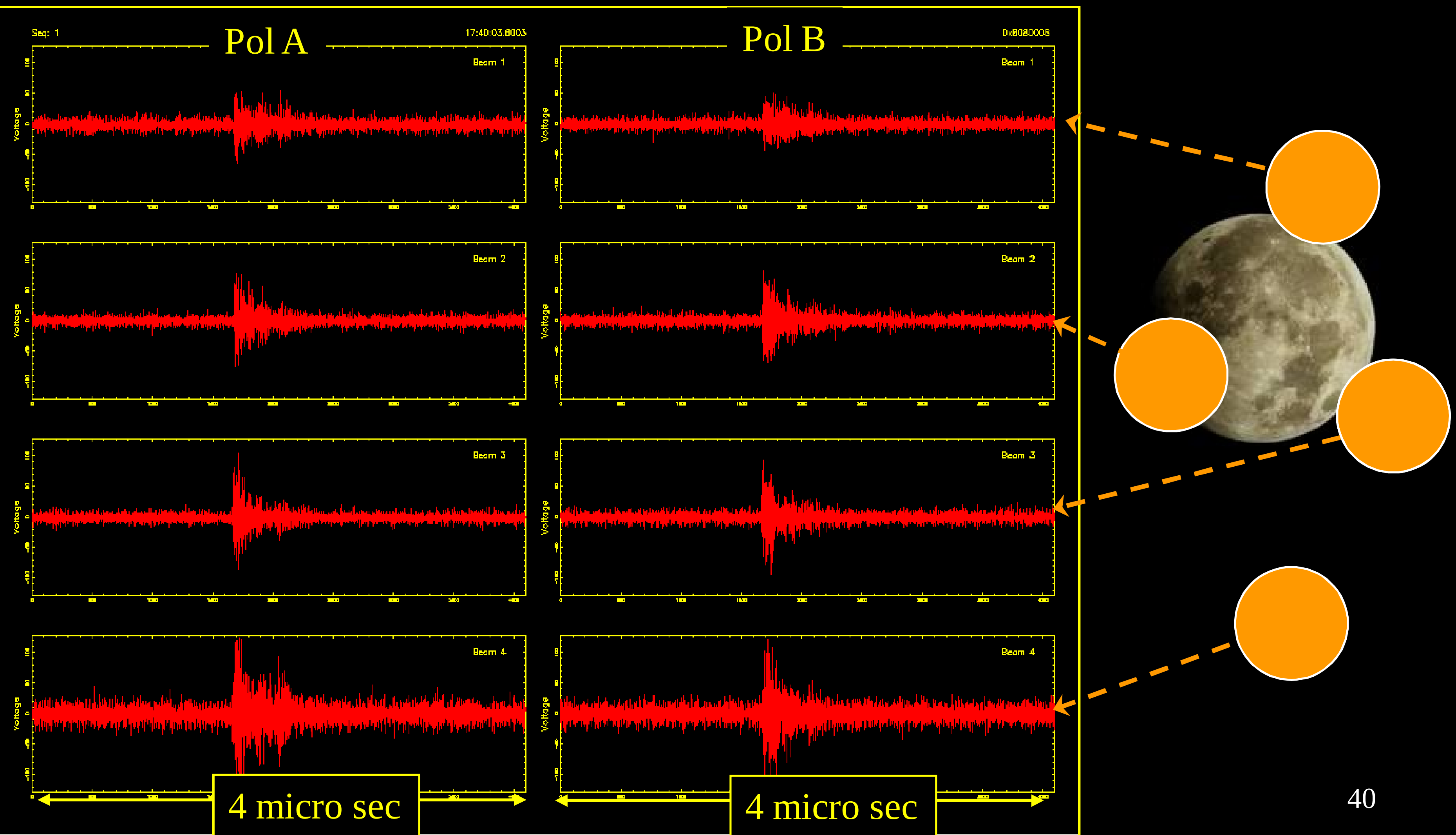
Parkes 21cm Multibeam Experiment



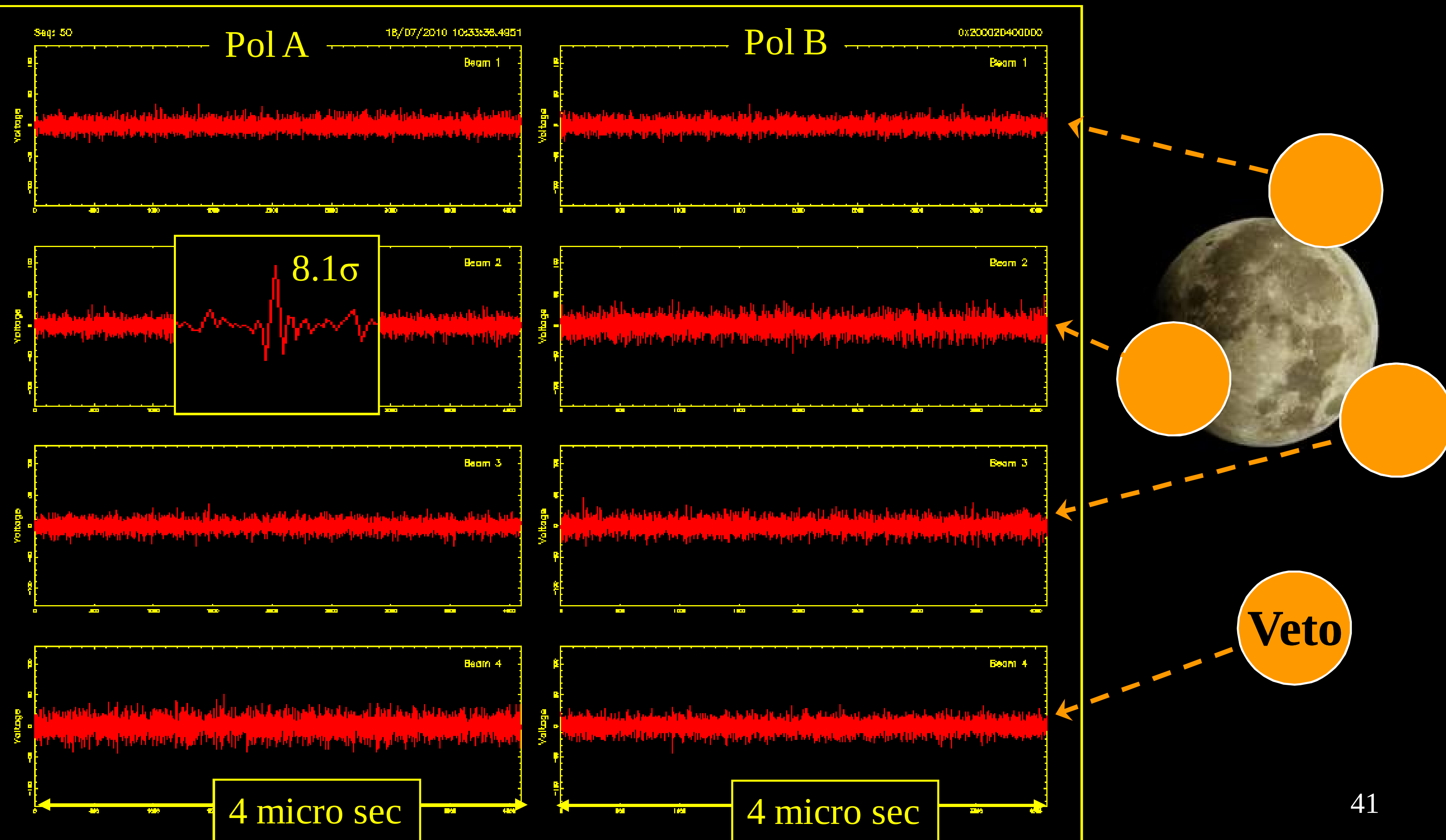
Parkes 21cm Multibeam Experiment



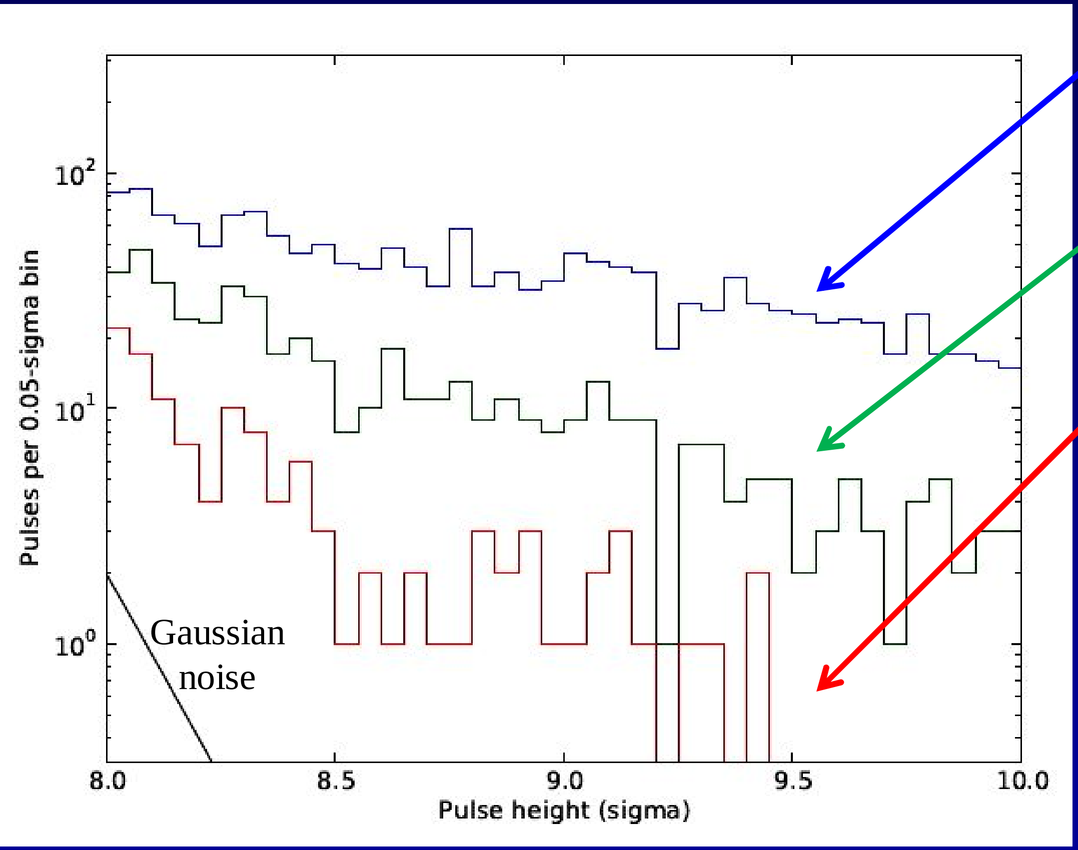
Parkes: RFI pulse



Parkes: Possible Event

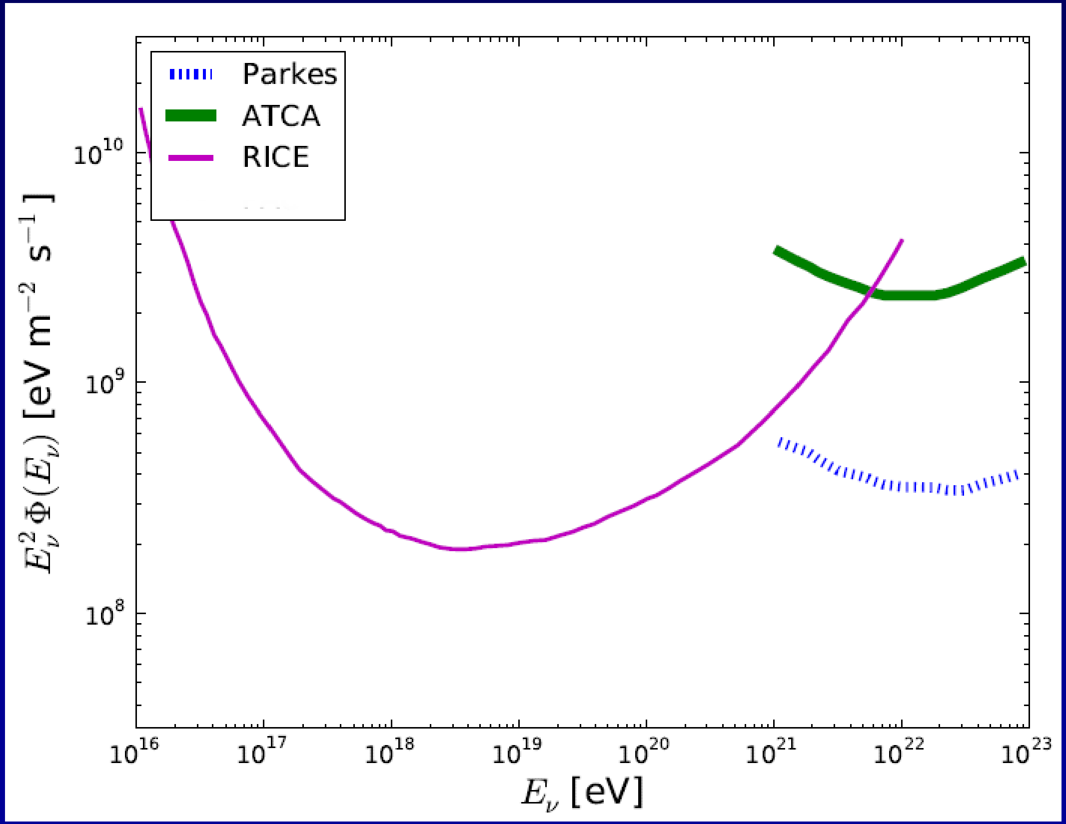


Parkes results
160 hours observing



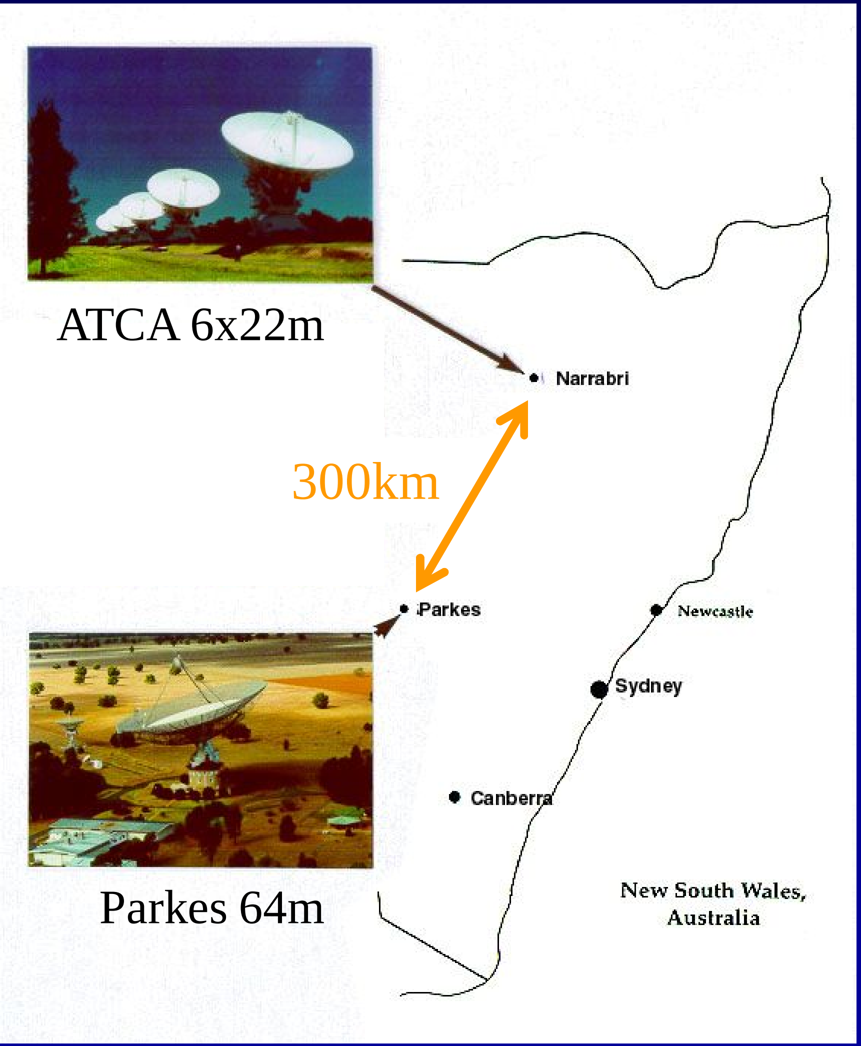
- Real time rfi screening
- Extended and multiple pulse rfi screening
- Multibeam rfi screening
- What are the remaining events???
  - No limb brightening
  - No radial polarisation
  - 27 events > 8.5sigma
    - ≈6hr per event

Parkes results Centaurus A

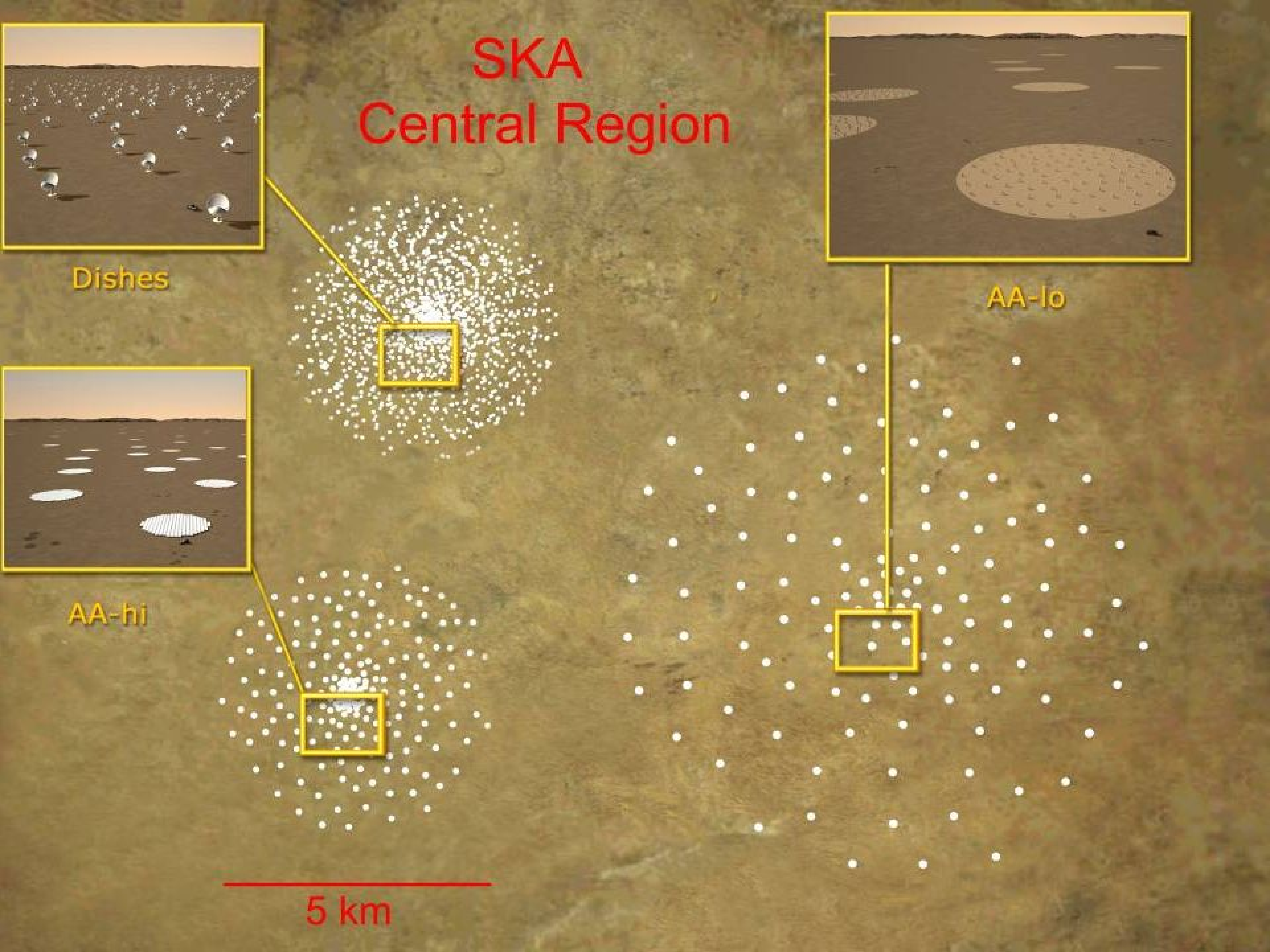


- Current detection limit
  - 160 hours observing
- Bray et al,
  - ARENA 2010
  - arXiv:1010.5942
- But still following up the excess at 8.5 sigma

The Parkes –ATCA coincidence experiment



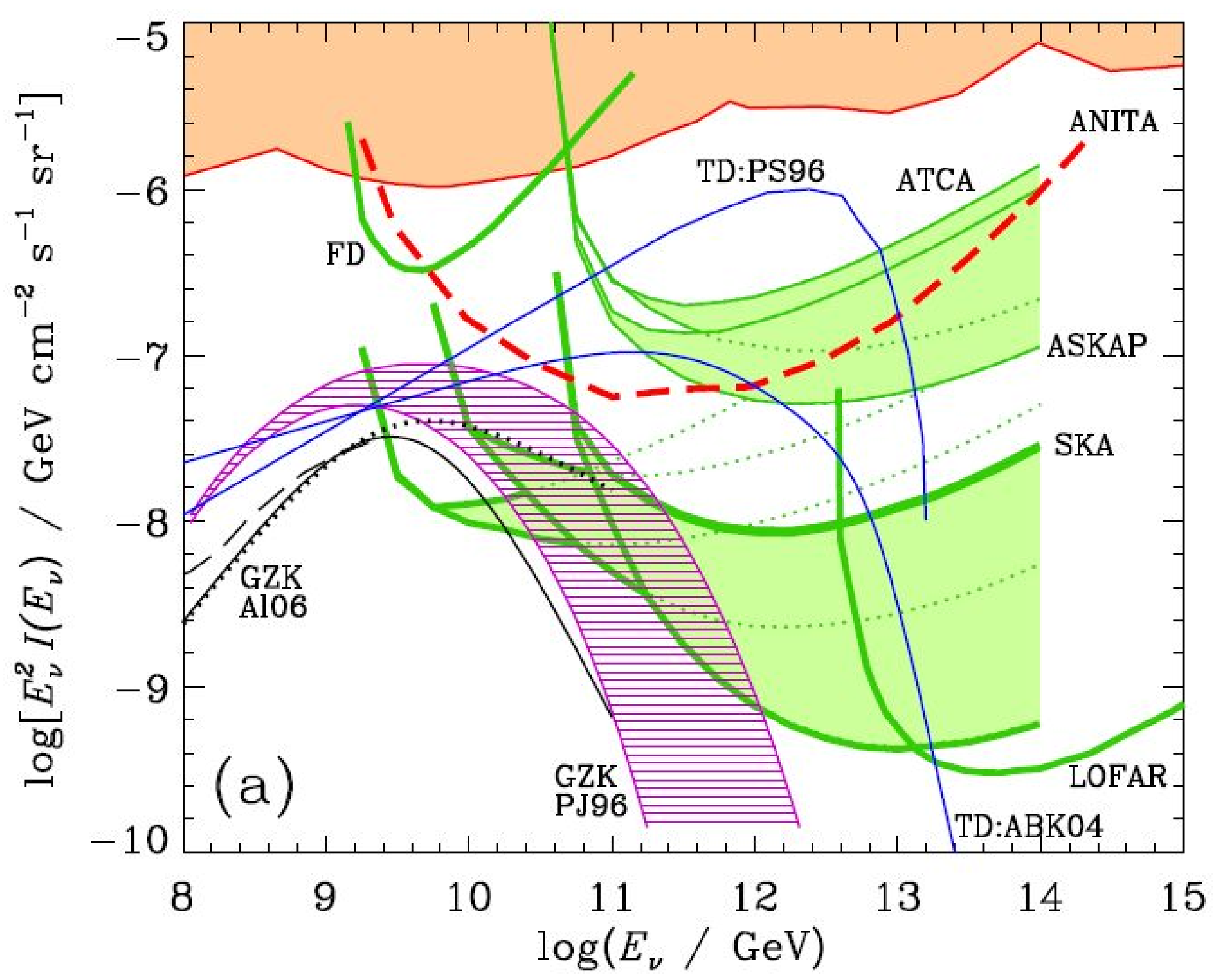
- Parkes to ATCA - 300km
  - Fibre communication network
  - 1msec total delay
  - 10 μsec range for lunar position
- Observations 4-7 August 2011
  - Parkes generates trigger (7sigma)
  - Time tagged and sent to ATCA
  - ATCA dumps correct 10 μsec of data from buffer
  - Need measurement of Δt in real time!
    - » 1 μsec achieved – good enough


SKA
Central Region
Dishes
AA-lo
AA-hi
5 km

UHE neutrino models and future experimental limits

- ATCA
- ASKAP
- SKA
  - High
  - Mid
  - Low
- Two regolith depth assumptions

James and Protheroe arXiv:0802.3562v2



Why are there no UHE neutrinos?

- The UHE neutrino cross section?
- Are UHE Cosmic Rays heavy nuclei ?
  - Decreased neutrino production
  - Increased deflection of cosmic rays

Quotes from Cosmic Ray Astrophysics

- Ginzburg 1996: Cosmic ray astrophysics
  - *Physics Uspekhi, Volume 39, pp. 155-168 (1996).*
- About forty years ago the use of radio-astronomical data allowed the following inferences to be drawn
  - Cosmic rays are a universal phenomenon and play an important role in the Universe.
  - The bulk of cosmic rays observed near the Earth are of galactic origin and fill up the galactic halo.
  - The basic cosmic ray sources in the Galaxy are super-novae.
  - Some elements of this picture had long remained hypothetical but were all fully confirmed later.
    - » The long- standing controversy concerning the existence of radio halo was practically settled in 1977.
    - » The metagalactic models were finally invalidated after the discovery of relic radiation (1965).