The Future of Radio Astronomy

(from a single dish perspective)

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NRAO

Single Dish Telescopes Today

- Green Bank Telescope (100m diameter):
  - Frequency range: 0.1-116 GHz
  - Sky coverage: $-50^\circ < \delta < 90^\circ$
  - Resolution: $40' - 0.1'$
  - Approx. ≤5,200 hours/year under "open skies" agreement

- Arecibo Telescope (305m diameter):
  - Frequency range: 0.4-10 GHz
  - Sky coverage: $-05^\circ < \delta < 38^\circ$
  - Resolution: $15' - 0.4'$
  - Approx. 4750 hours/year under "open skies" agreement

Single Dish Telescopes Today

Telescope	Diameter	Frequencies	Location	Astronomy Time
Arecibo	300m	0.4-10 GHz	Puerto Rico, USA	~80% open skies
GBT	100m	0.1-116 GHz	West Virginia, USA	≤85% open skies
Efflesburg	100m	0.4-90 GHz	Germany	40% open skies
Lovell	76m	0.2-26 GHz	Jodrell, UK	UK/EU only
Nançay	200x40 m	1-4 GHz	Nançay, France	EU only
Parkes	64m	0.4-23 GHz	Parkes, Australia	100% open skies
Sardinia	64m	0.3-26.5GHz	Sardinia, Italy	Limited availability
LMT	32m	75-350 GHz	Pico Veleta, Mexico	UMass, INAOE
IRAM	30m	80-280 GHz	Pico Veleta, Spain	100% open skies
SHAO	64m	1.4-43 GHz	Shanghai, China	Primarily VLBI

Single Dish Telescopes – the Future

New Telescopes

China – QTT (2018):

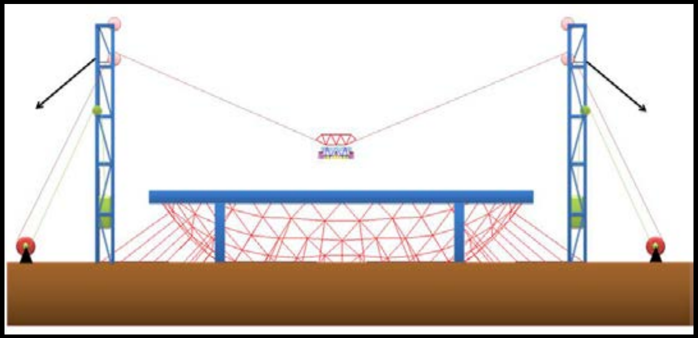
- 110m, fully steerable antenna
- Five+ year project
- Construction to begin in 2016 (?)
- 0.2-117 GHz frequency range

Single Dish Telescopes – the Future

New Telescopes

China – FAST (2017?):

- 500m aperture, 300m radius antenna
- Suspended feed cabin
- Active reflector (cable mesh + actuators, real time control)
- 70 MHz – 3 GHz frequency range
- Tracking range 4-6 hours (za ≤ 40°)
- 19 pixel L-band feed



Single Dish Telescopes – the Future

Telescope	Diameter	Frequencies	Location	Astronomy Time
Arecibo	300m	0.4-10 GHz	Puerto Rico, USA	~80% open skies
GBT	100m	0.1-116 GHz	West Virginia, USA	95% open skies
Efflesburg	100m	0.4-90 GHz	Germany	40% open skies
Lovell	76m	0.2-26 GHz	Jodrell, UK	UK/EU only
Nançay	200x40 m	1-4 GHz	Nançay, France	EU only
Parkes	64m	0.4-23 GHz	Parkes, Australia	100% open skies
Sardinia	64m	0.3-8 GHz*	Sardinia, Italy	
LMT	32m**	75-350 GHz	Pico Veleta, Mexico	TBD
IRAM	30m	80-280 GHz	Pico Veleta, Spain	100% open skies
Shanghai	65m	1-43 GHz	Shanghai	Primarily VLBI
QTT	110m	0.2-117 GHz	Xinjaing, China	TBD
FAST	500m	.07-3 GHz	Gixhou, China	TBD

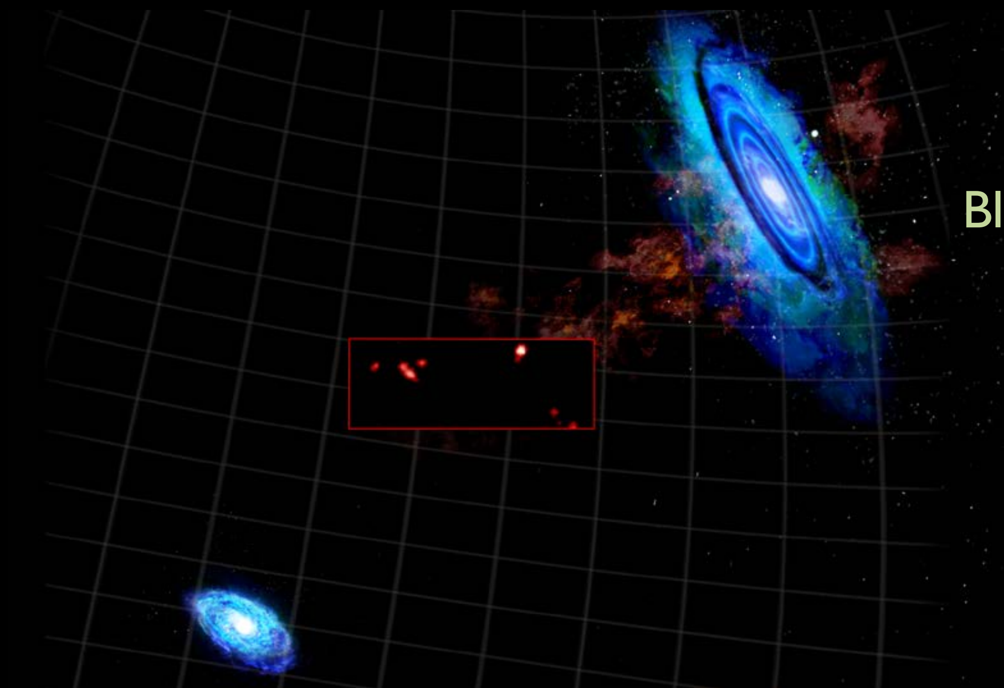
* To be upgraded to 100 GHz; ** To be upgraded to 50m

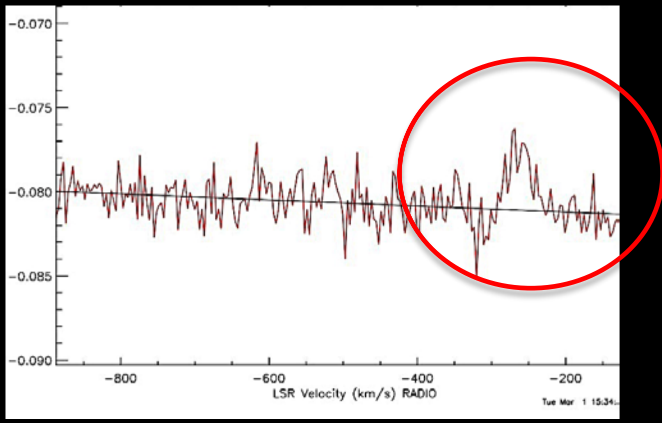
Single Dish Telescopes

Its all about sensitivity…

The GBT is the only telescope in the world which can reliably map gas to extremely low densities (10^{17} cm^{-2})

Blocked aperture of other large single dish telescopes prevents deep, detailed maps

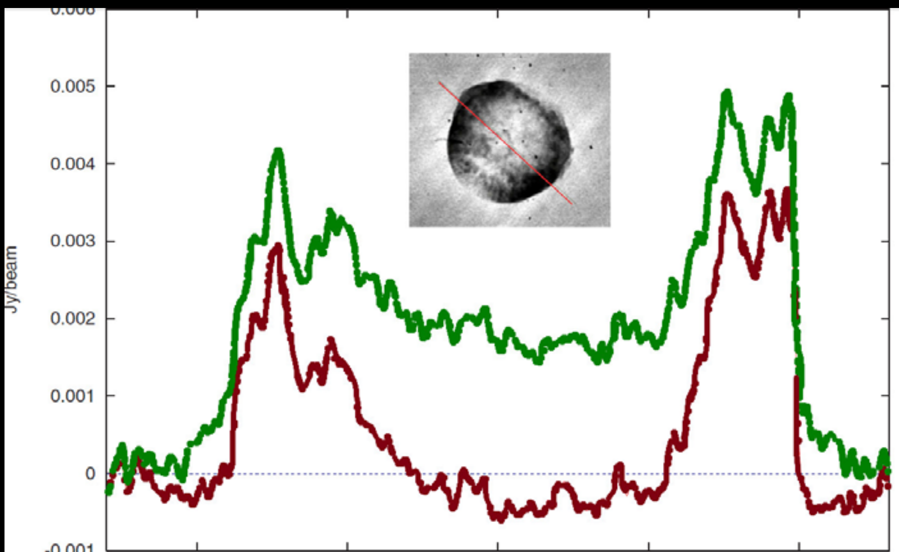




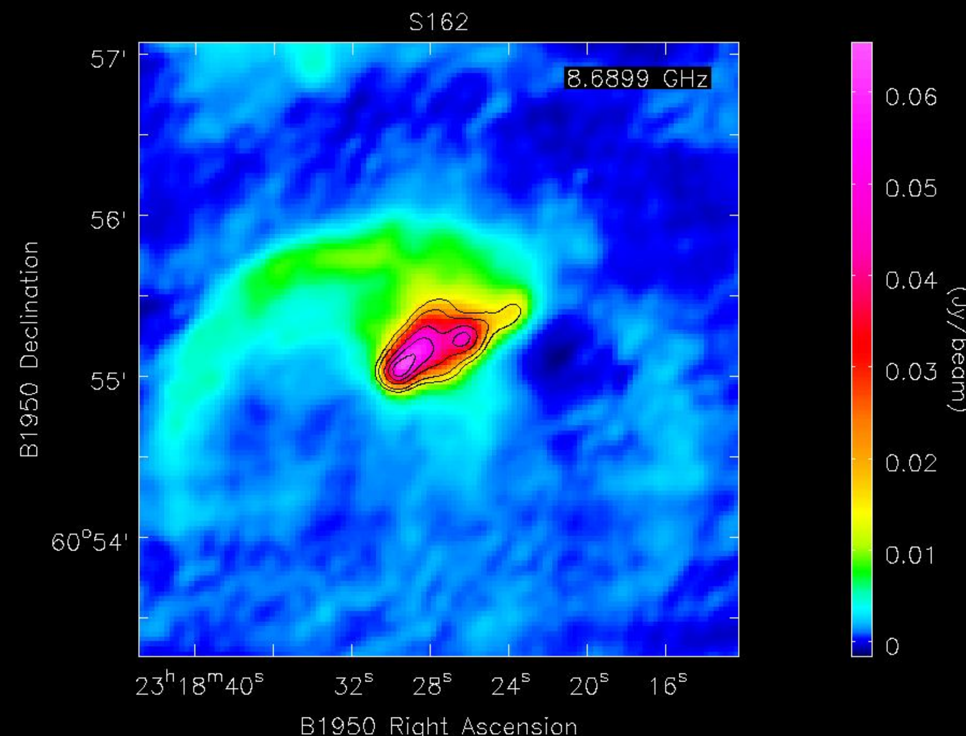
Large single dish telescopes are necessary for diffuse gas detections.

Single Dish Telescopes

… spatial frequency …



SN1006. VLA only flux in red;
GBT+VLA flux in green. (Dyer, et al. 2009 AJ)

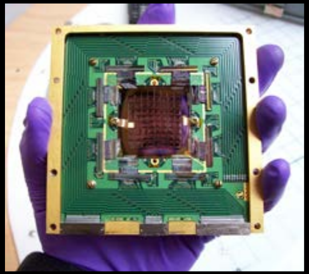


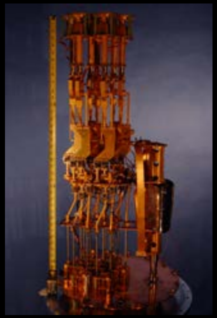
HII region in S152.
Contours are VLA only; Image is VLA+100m (D. Balser)

Only large dishes provide information on low spatial frequencies

Single Dish Telescopes

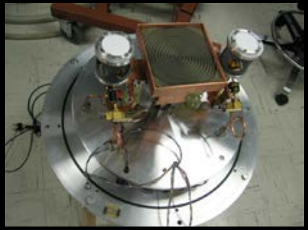
…and ease of use.





Pushing the limits of digital signal processing

Designing new Radio Cameras



High load, precision engineering

Optimized, cooled receivers

Simple and sensitive, large single dish telescopes are ideal test beds for new instrumentation and ideas,

Single Dish Telescopes - Now

Primary limitations:

- Instantaneous field of view
  - Limited to a single beam/few beams on the sky
- Interference
  - More difficult to remove with single beam than array
- Clean beam
  - Not true for all telescopes, but often a problem
- Angular resolution
  - Confusion limit is readily reached due to resolution

Single Dish Telescopes - Now

Primary limitations:

- Instantaneous field of view
  - Limited to a single beam/few beams on the sky
    - ➢Solution: Radio Cameras
- Interference
  - More difficult to remove with single beam than array
    - ➢Solutions: Mitigation, Excision, Cameras (PAF)
- Clean beam
  - Not true for all telescopes, but often a problem
    - ➢Solution: Off-axis design (e.g. GBT)
- Angular resolution
  - Confusion limit is readily reached due to resolution
    - ➢Solution: None – need interferometric array

Single Dish Telescopes – The Future

Improved Sensitivity

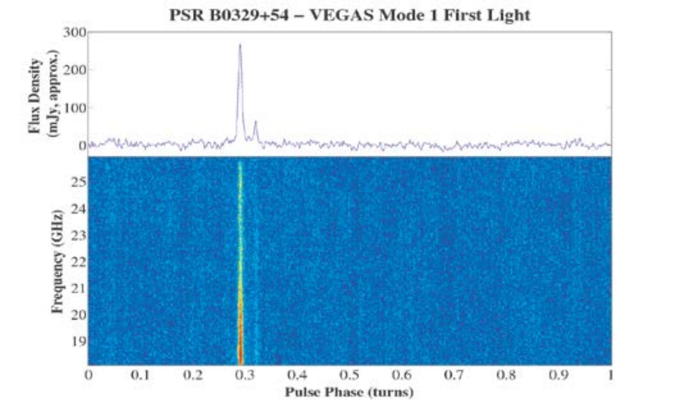
- Lower noise amplifiers
  - Possible in some cases; will always improve sensitivity
- Wide bandwidth
  - Aids for continuum, pulsar work
  - Also useful when interested in multiple lines
- Optimized systems
  - Continued improvements in hardware/matched parts for receivers and data transmission
  - Telescope improvements at high freq. (pointing, surface)

Single Dish Telescopes – The Future

Digital Signal processing

FPGA/GPU backends

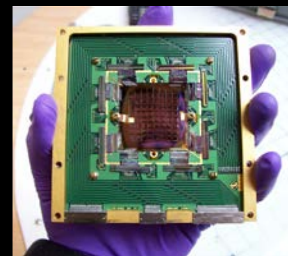
- Greatly increased dynamic range
- Increased spectral and time resolution
- Readily increased bandwidth
- Highly configurable
- Excellent tool for RFI excision



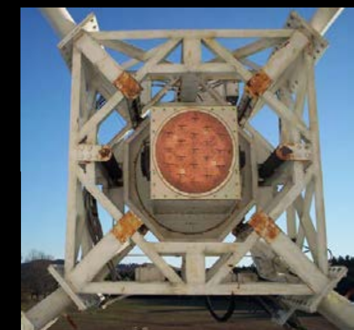
Arecibo
- PUPPI: FPGA-based pulsar backend

GBT
- GUPPI: FPGA-based pulsar backend
- VEGAS: FPGA+GPU backend

Single Dish Telescopes – The Future

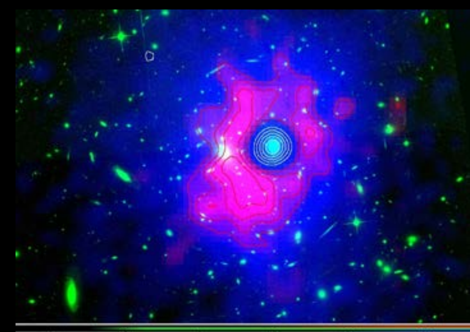


Radio Cameras:



Three primary types:

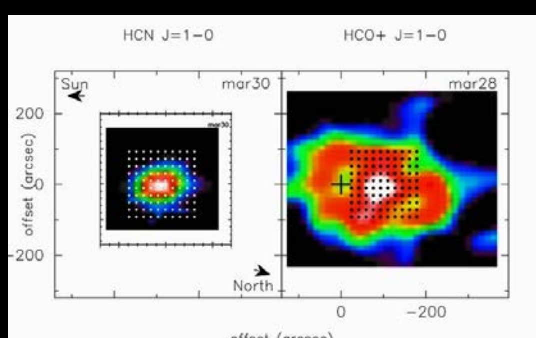
- Traditional feed horn arrays
- Phased array feeds
- Bolometer arrays



Provide greatly increased instantaneous field of view

Improved sampling

Potential for RFI excision



Single Dish Telescopes – The Future

Radio Cameras:

GBT:

- 7-pixel 18-26 GHz traditional feed array (on telescope)
- 64+ pixel 80-100 GHz bolometer array (on telescope)
- 16 pixel 93-116 GHz traditional feed array (2015)

- 16+ element 90-100 GHz phased array feed (2016?)
- 8 element 0.7-0.9 GHz traditional array (2016?)
- 19+ element 1-2 GHz phased array feed (2016?)

Arecibo:

- 7 element 1-2 GHz traditional feed array (on telescope)

Single Dish Telescopes – The Future

Two new, large telescopes coming online in the next 5+ years

Radio cameras are becoming a reality;

→ Vast leap forward for single dish telescopes

New hardware provide sensitivity increases

→ Existing telescopes can upgrade, improve

FPGA/GPU technology providing vast improvements in signal reduction

→ Specialty backends, wide bandwidth, excellent baselines, high resolution

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So what about the rest of radio astronomy?

Radio Astronomy – Telescopes Arrays

Telescope Arrays provide details otherwise unattainable

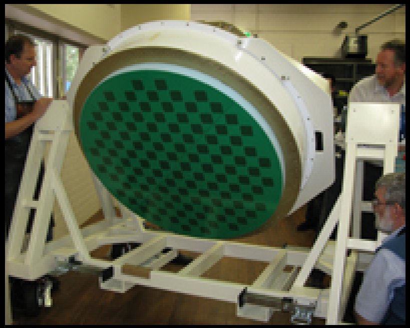
- Do not suffer as readily from confusion
- Far less affected by RFI
- Lack single dish sensitivity, low spatial frequencies, simplicity

Major Radio Telescope Arrays Today				
Telescope	**# Dishes**	**Diameter**	**Frequencies**	**Comments**
ALMA	66	7m-12m	84-720 GHz	Operational (more next week!)
VLA	27	25m	1-50 GHz	New Mexico; Recently upgraded
VLBA	10	25m	1-96 GHz	Array across North America
GMRT	30	45m	0.1-1.4 GHz	Pune, India
Westerbork	14	25m	0.3-9 GHz	Westerbork, Netherlands
ATCA	6	22m	1-106 GHz	NSW, Australia
Plateu de Bure	6	15m	80-280 GHz	Plateu de Bure, France
Nobeyama	6	10m	80-230 GHz	Nobeyama, Japan

Telescopes Arrays – The Future

MeerKAT (South Africa – 2017)

- Sixty-four 13.5m telescopes
- 0.6-15 GHz (approximately)
- Traditional feed horn technology
- Seven prototype antennas open for science



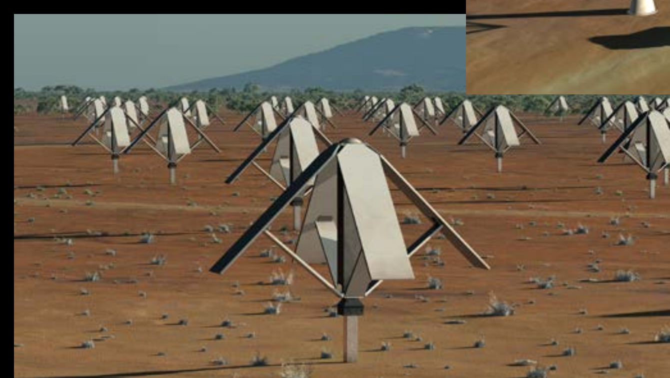
ASKAP (Australia –2014??)

- Thirty-six 12m telescopes
- 0.7-1.8 GHz
- 188 element (30 beam) PAFs
- First 6 antennas in early science

Telescopes Arrays – The Future

Square Kilometre Array

- Southern Africa and Australia
- 5,000 m^2/K (area/system temperature)
- 0.07 – 10 GHz frequency range
- FoV: 200 sq degrees (< 0.3 GHz); 1 sq degree (> 1 GHz)
- Timeline:
  - 2020: 10% complete (phase I)
  - 2030: 100% complete (phase II)



The Future of Radio Astronomy

New research and instrumentation:

- Vastly improved field of view;
- Increased sensitivity & dynamic range;
- Improved opportunities for RFI excision (R&D needed)

New telescopes coming soon:

- Significant improvements to existing telescopes
- New large single dish telescopes (China)
- New powerful arrays in Australia, South Africa

The Future of Radio Astronomy

Critical studies cannot be done outside radio wavelengths

- Most phenomenon require sensitivity and resolution
- The future requires sensitive single dish telescopes and arrays

New instrumentation and development is providing major leap forward in scientific research in radio astronomy

New international large telescopes and arrays are coming online

The future of radio astronomy looks very bright!

The Future of Radio Astronomy

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The Future of Radio Astronomy

The future of radio astronomy looks very bright ❓

Funding for U.S. single dish telescopes is in jeopardy

GBT (VLBA) recommended for divestment; Arecibo funding decreasing.

International funding has decreased in the past few years;

Costs estimates for SKA continue to increase

The Future of Radio Astronomy

The future of radio astronomy looks very bright ?

Funding for U.S. single dish telescopes is in jeopardy

GBT (VLBA) recommended for di… …ibo funding decreasing.

Now what?

International fun… …ecreased in the past few years;

Costs estimates for SKA continue to increase

The Future of Radio Astronomy

The landscape for astronomy is changing:

- International instruments are coming online (ALMA, FAST, etc)
- Open skies access is declining rapidly (disappearing?)
- Funding is increasingly difficult even as construction costs grow

But…

Fantastic opportunities exist now, and the future can be even better

The astronomy community in the U.S. and internationally needs to decide what the future should be and than act. Now.