Radio Astronomy: Science Highlights

Chris Salter
(with thanks to Robert Minchin)

Arecibo Observatory

Time-Domain Science

- In the time-domain, there is no substitute for raw collecting area.
- Time-domain science at Arecibo includes:
  - Pulsars
  - Fast Radio Bursts
  - Periodically flaring brown dwarfs
  - Maser & mega-maser monitoring
  - AGN monitoring
  - Planetary Radar

Pulsars

- NANOGrav
- PALFA
- AO327
- Fermi sources

NANOGrav

- Observations of an ‘array’ of millisecond pulsars with Arecibo and the GBT.
- New limit on Gravitational Waves from individual BH binaries published (Arzoumanian et al. 2014);
  - Most constraining limit of its type.
- 9-year result on stochastic background in preparation – uses new PUPPI data;
  - Constraining BH merger history of the Universe.

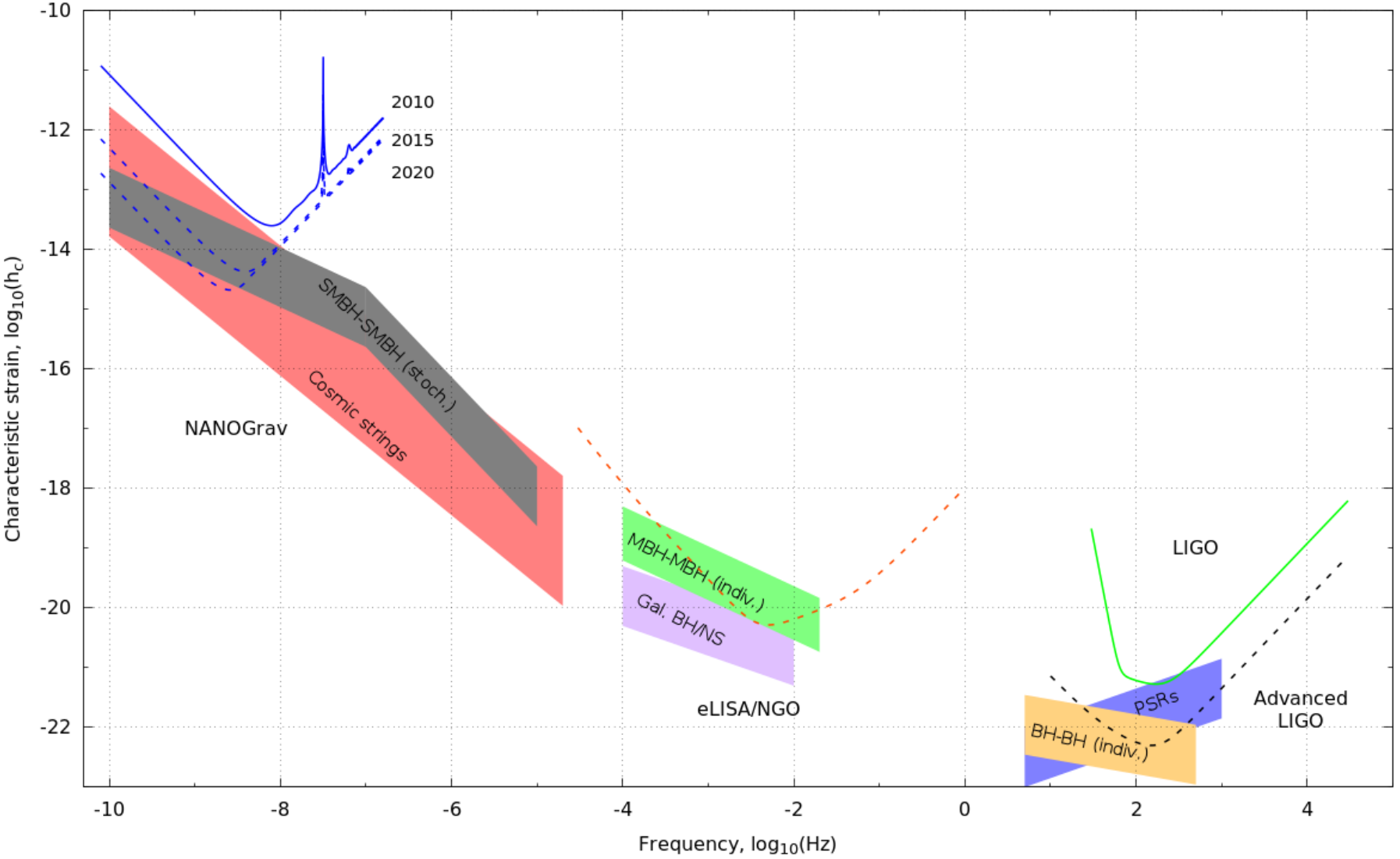
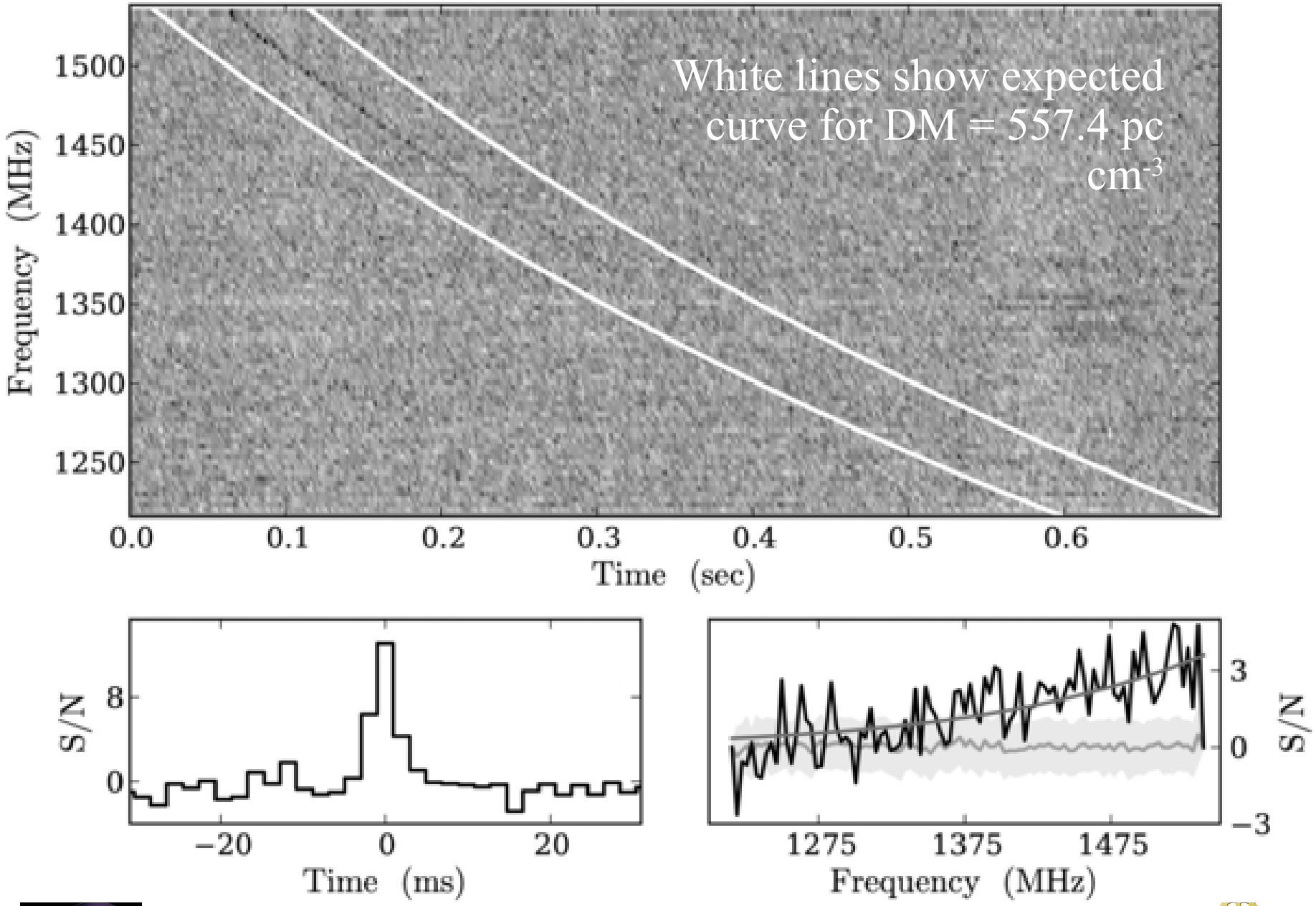


Image credit: NANOGrav Consortium

PALFA

- PALFA has now discovered 149 pulsars;
  - 29 via **Einstein@Home** (Citizen Science).
- 23 discoveries (so far) in 2014-15 include 2 MSPs ($P < 10$ msec) and 2 RRATs.
- Also the discovery of the first Fast Radio Burst (FRB) discovered outside of Parkes.
- This FRB was found in *commensal* observations with the (primary) ALFA ZOA HI survey.



From Spitler et al. (2014)

Low-Frequency PSR Surveys

- AO327 is a high-*b* PSR drift survey at 327 MHz;
  - Has found 62 pulsars to date, 30 in 2014-15.
  - Includes 12 RRATs, 6 (possible) nullers, 7 binaries and 4 MSPs ($P < 10$ msec).

A grand total of 211 PSRs found to date in PALFA+AO327

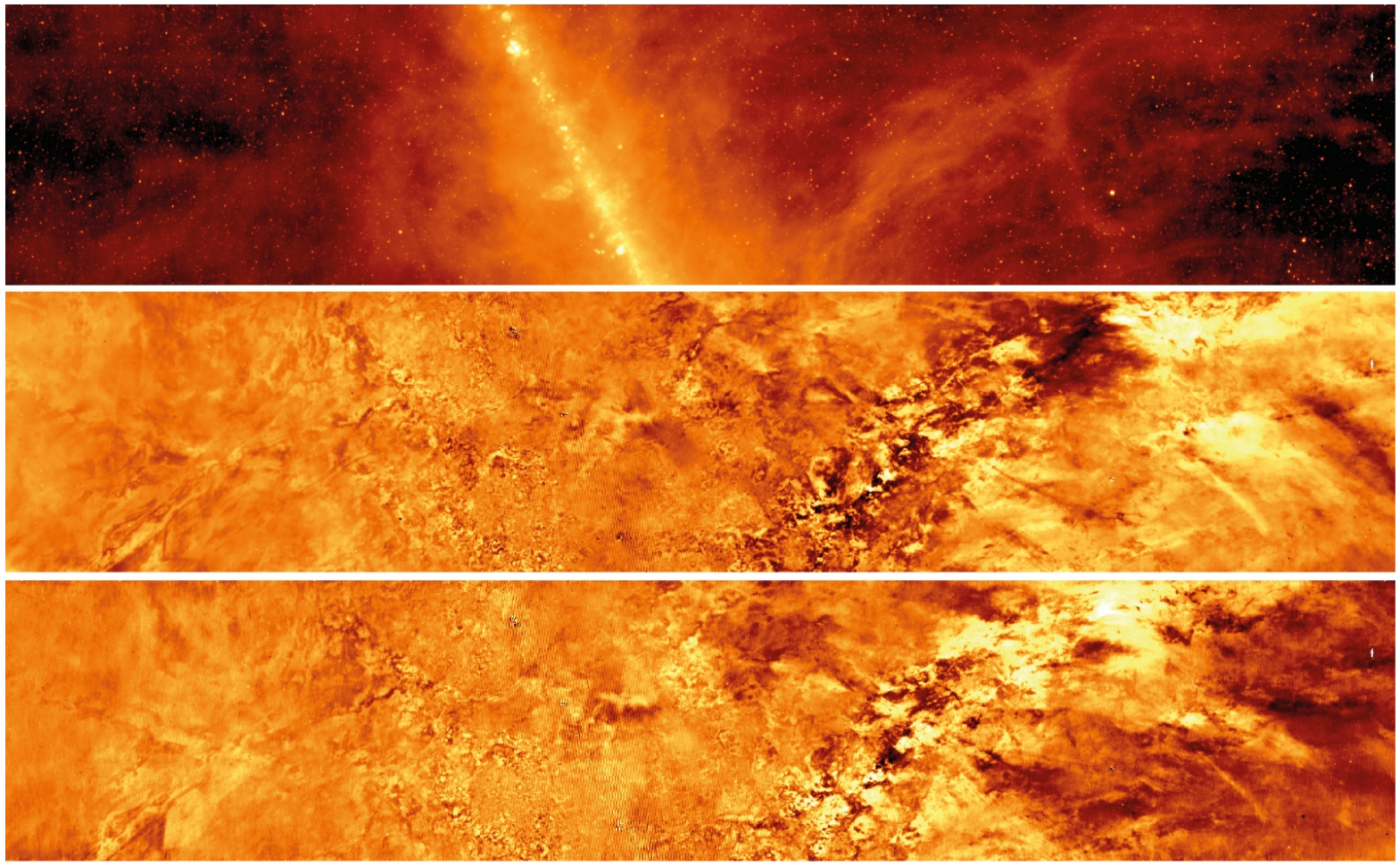
- The 327-MHz receiver is also being used for follow-up of unidentified Fermi sources;
  - Beam size matches with Fermi positional uncertainties.
  - 7 MSPs found so far.

Galactic Astronomy

- GALFACTS
- GALFA-HI
- Flares from Ultracool Dwarfs

GALFACTS
(GALFA Continuum Transit Survey)

- Full-Stokes continuum survey of the whole Arecibo sky.
- NODing on meridian for N & S fields, WAGing for zenith fields.
- Use Faraday tomography, and RMs of extragalactic sources, to study Galactic magnetic fields.
- Will also look for transients (e.g. FRBs).
- Tidying up of gaps about half done;
  - Expect completion in the next few months.

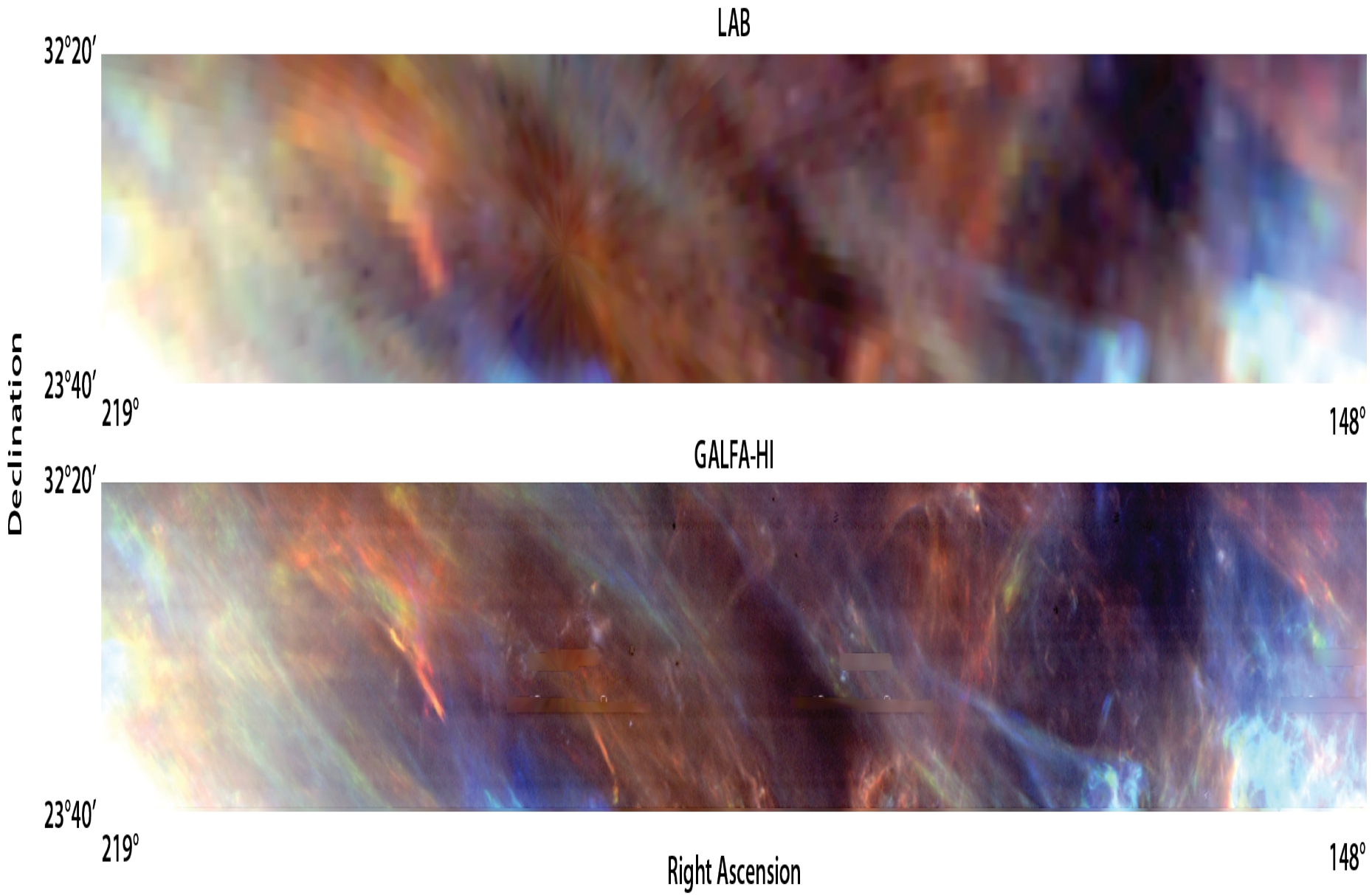


Stokes I, Q, U of the field showing the base of the North Polar Spur

(Image courtesy: Russ Taylor)

GALFA-HI

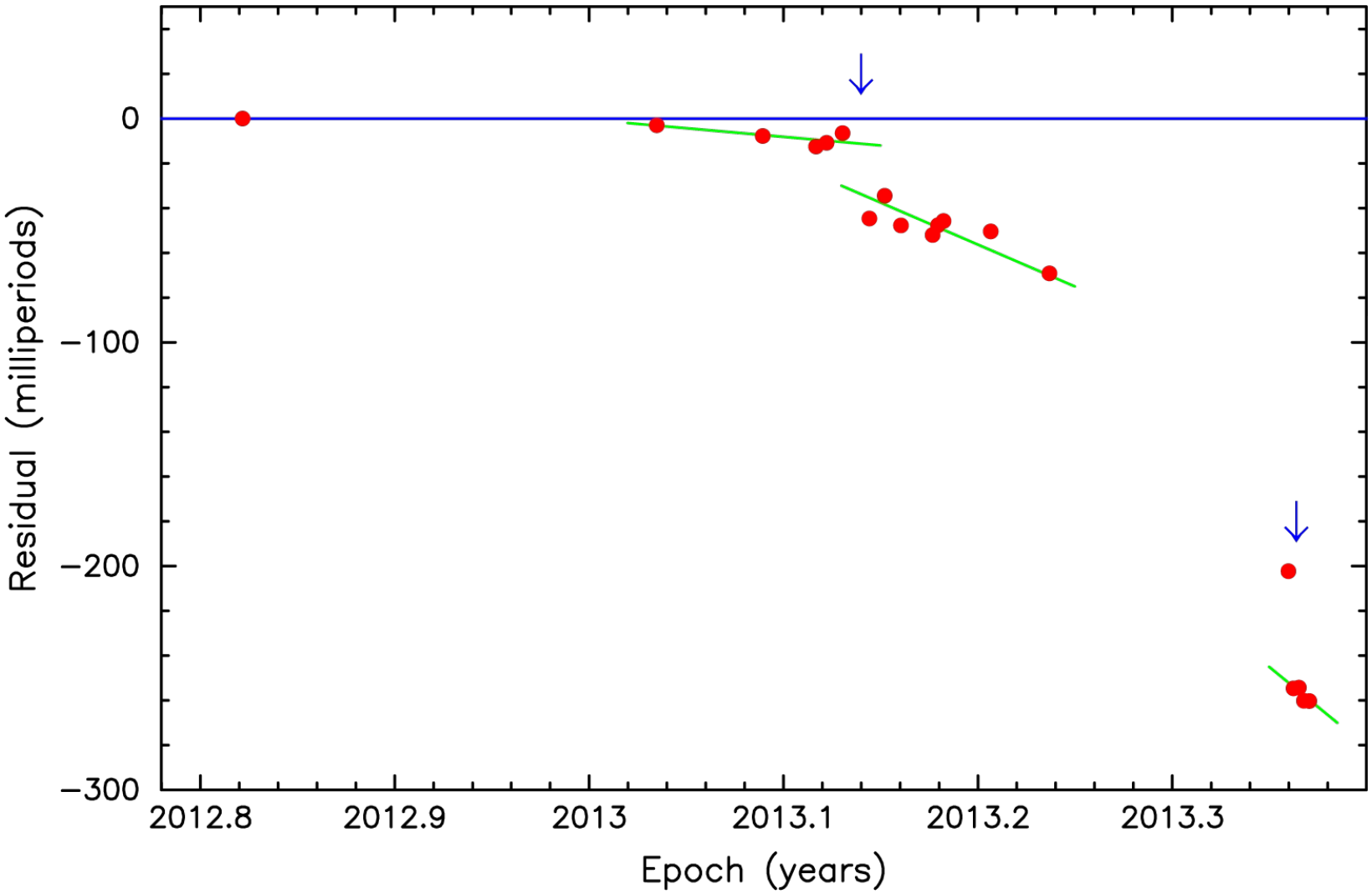
- Slender, linear, clustered ‘fibers’ seen in diffuse, cold HI gas at high Galactic latitudes.
- Very well aligned with the interstellar magnetic field (from starlight polarization).
- Not scale-free: see higher correlation with higher resolution observations.
- Conclude that “Magnetic fields may play a crucial role in determining the structure of the diffuse ISM.”



Filaments in GALFA-HI

Flares from Ultracool Dwarfs

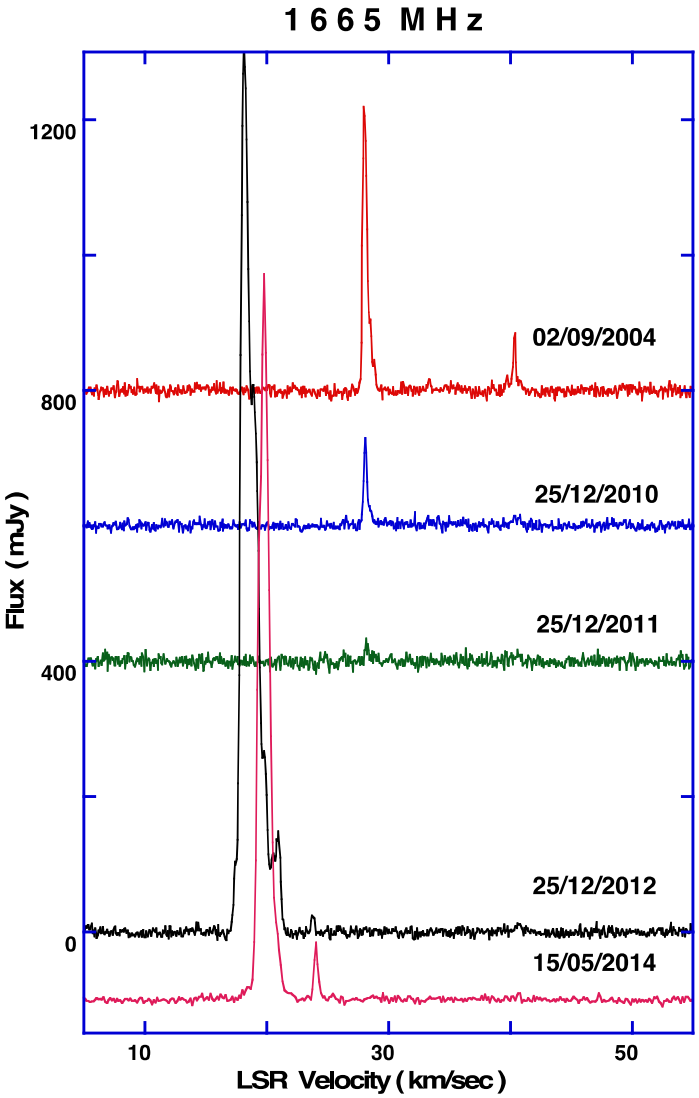
- Periodic radio flares thought to be caused by electron-cyclotron maser mechanism.
- Theorized that 10 M_{Jup}, 1000 K planets could produce similar flares;
  - Flares observed in T6.5 dwarf at 900 K.
- Change observed in the period of M9 dwarf TVLM 513–46546;
  - Could be due to differential rotation.
  - Similar to Sun-spots.



(Wolsczcan & Route, 2014)

OH Masers

- Time-domain science.
- IRAS18455+0448 – proto-planetary nebula;
  - Post-upgrade did not see pulsations characteristic of AGB stars.
  - Hoped a jet would become evident (seen in optically-resolved PPNs).
- Probable jet appeared in 2011 (1667 MHz only, 1665 MHz in 2012).
- Changing velocity of jet a surprise;
  - In binary system: first maser binary discovered.



Courtesy: Murray Lewis

E-ALFA Surveys: Summary

Survey	σ (mJy)	Completeness	Area	Papers	Data Availability
AGES	0.7	75%	200	11	30%
ALFALFA	2.2	100% (2012)	7000	65 (4)	40%
ALFA ZOA	5.4	Shallow: 100% (2009)	1000	2 (1)	14%
	1	Deep: 32%	280		0% (5%)
AUDS	0.08	100% (2012)	1.35	1 (1)	0% (50%)

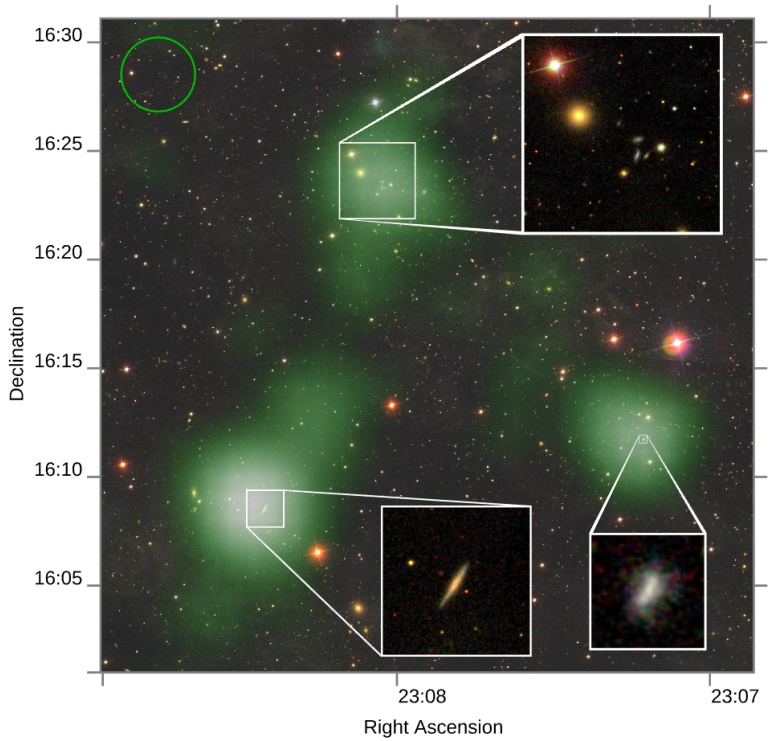
Numbers in brackets indicate submitted papers/data

AGES & ALFA ZOA

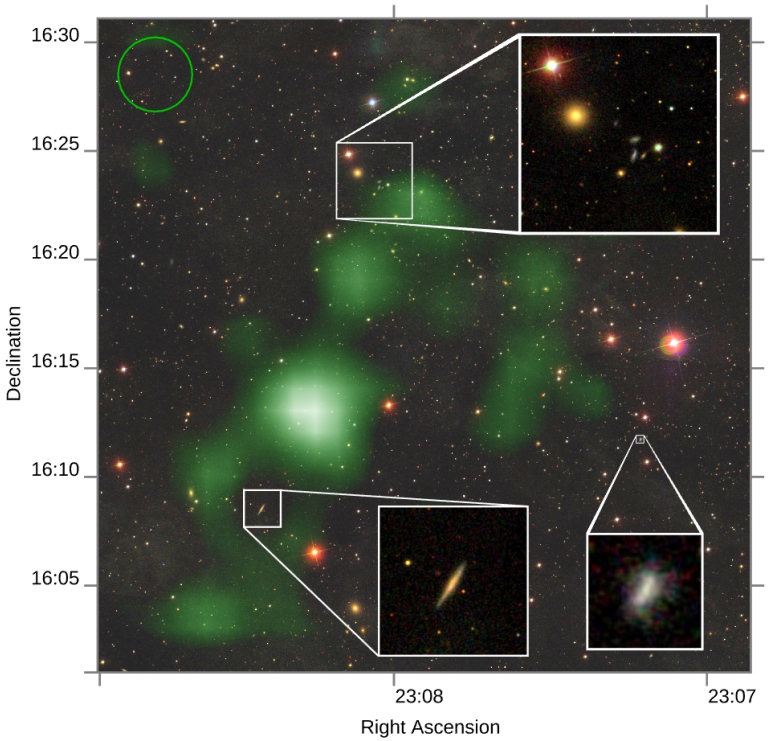
- Survey observations are ongoing;
  - AGES moving toward completion in 2015.
  - ALFA ZOA commensal with PALFA.
- 2 Puerto Rican undergrads who worked on AGES started PhDs this summer.
- The first ALFA ZOA PhD was obtained earlier this year.
- AGES papers this year include a nearby isolated dwarf and an 800-kpc stream in the field

AGES & ALFA ZOA

HI total intensity map



HI map with point sources subtracted



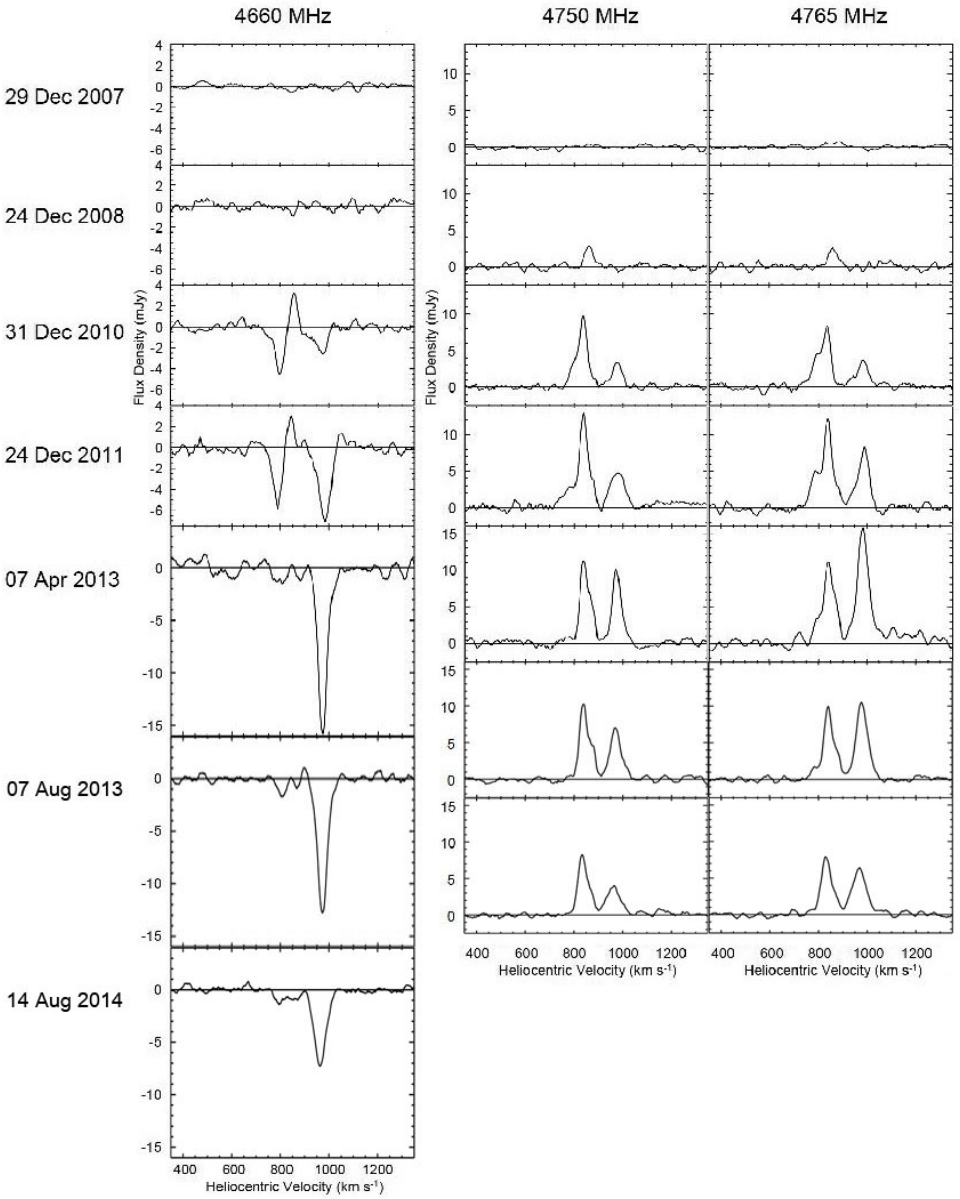
800 kpc HI stream: Taylor et al. (2014)

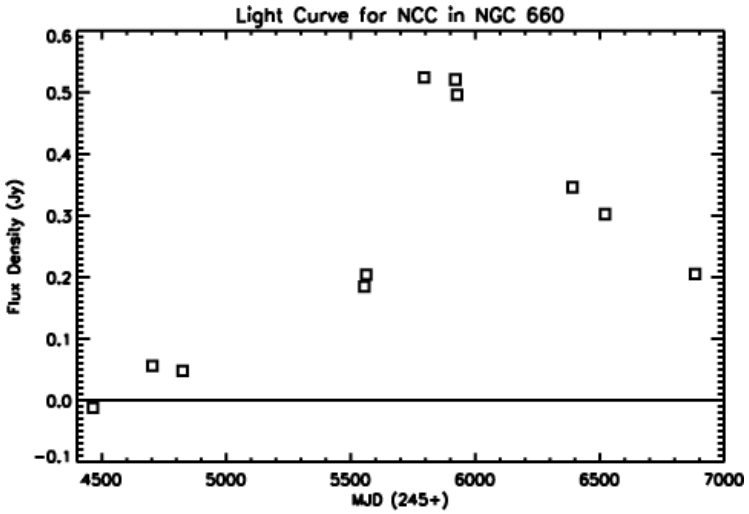
HIGHz

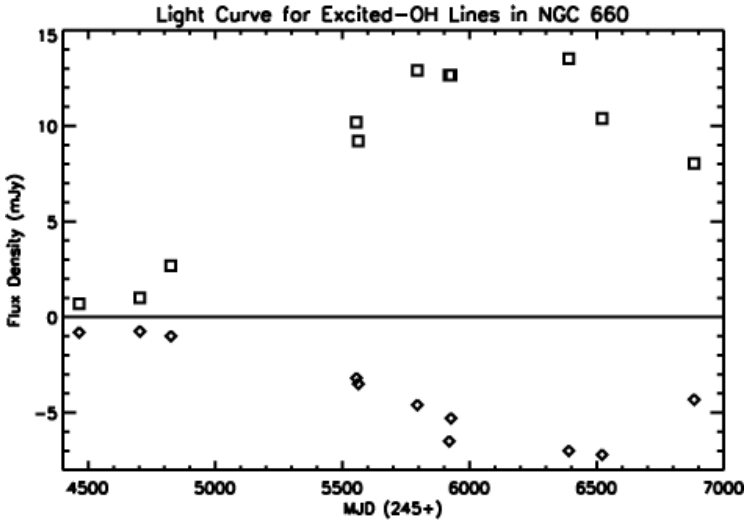
- 39 galaxies at $z = 0.17 – 0.25$ from SDSS.
- Stellar and HI masses $> 10^{10}$ $M_{\odot}$.
- HI reservoirs consistent with optical & UV.
- Lie on baryonic Tully-Fisher relation.
- Longest Arecibo integrations on galaxies;
  - Up to 4.3 hr on individual galaxies.
  - RMS noise continues to fall as $\sqrt{t}$.
- Similar to ALFALFA ‘High Mass’ galaxies

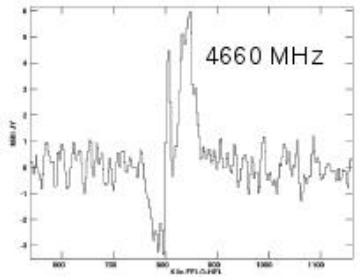
NGC 660

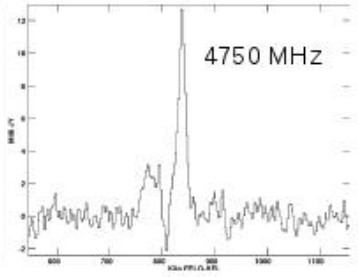
- Time-domain science.
- AGN ‘outburst’ caught starting via OH-line switch-on during molecular line observations in 2008.
- Also identified new continuum component.
- Monitoring has continued for 7 yr;
- Flux of both lines and continuum now declining.

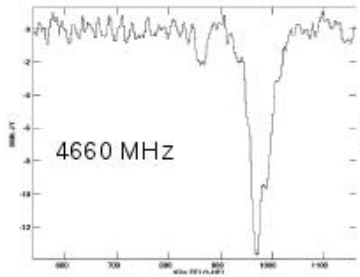

4660 MHz
4750 MHz
4765 MHz
29 Dec 2007
24 Dec 2008
31 Dec 2010
24 Dec 2011
07 Apr 2013
07 Aug 2013
14 Aug 2014
Flux Density (mJy)
Heliocentric Velocity (km s-1)

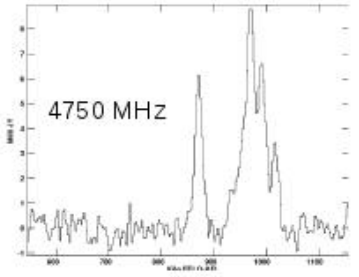

Light Curve for NCC in NGC 660
Flux Density (Jy)
MJD (245+)

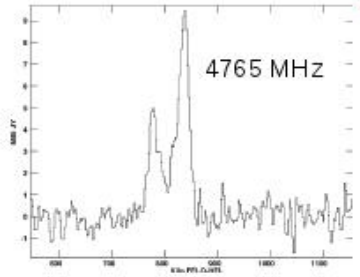

Light Curve for Excited-OH Lines in NGC 660
Flux Density (mJy)
MJD (245+)

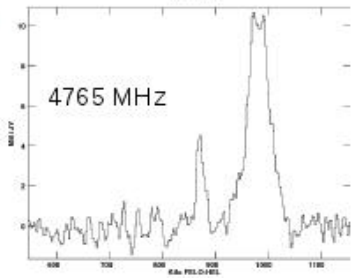

4660 MHz

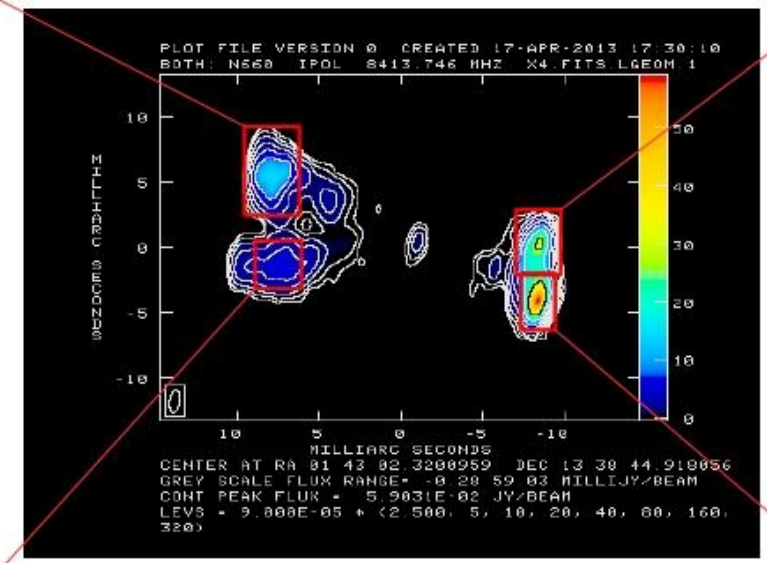

4750 MHz


4660 MHz


4750 MHz


4765 MHz


4765 MHz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MILLIARC SECONDS
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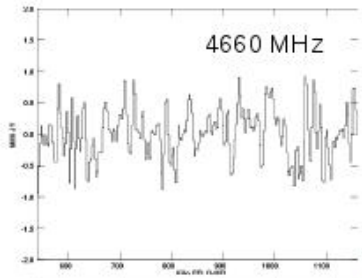
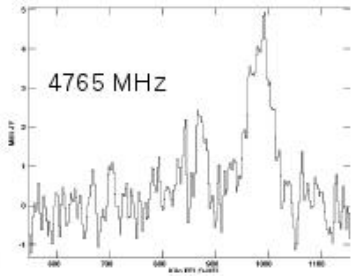
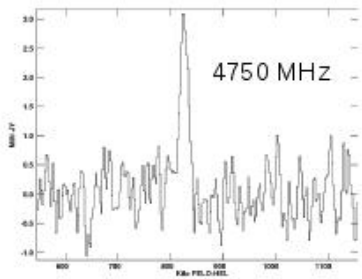
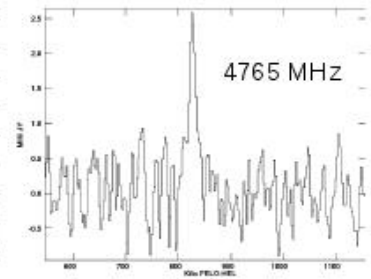
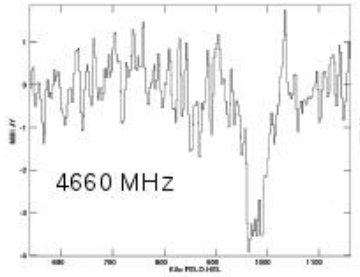
MILLIARC SECONDS
CENTER AT RA 01 43 02.3200959 DEC -13 30 44.910056
GREY SCALE FLUX RANGE= -0.28 59.03 MILLIJY/BEAM
CONT PEAK FLUX = 5.903IE-02 JY/BEAM
LEVS = 9.000E-05 * (2.500, 5, 10, 20, 40, 80, 160, 320)

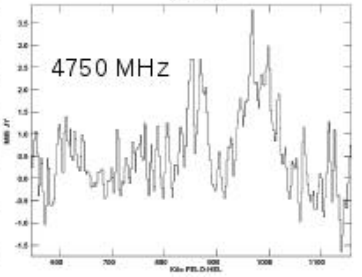

4660 MHz


4765 MHz


4750 MHz


4765 MHz


4660 MHz

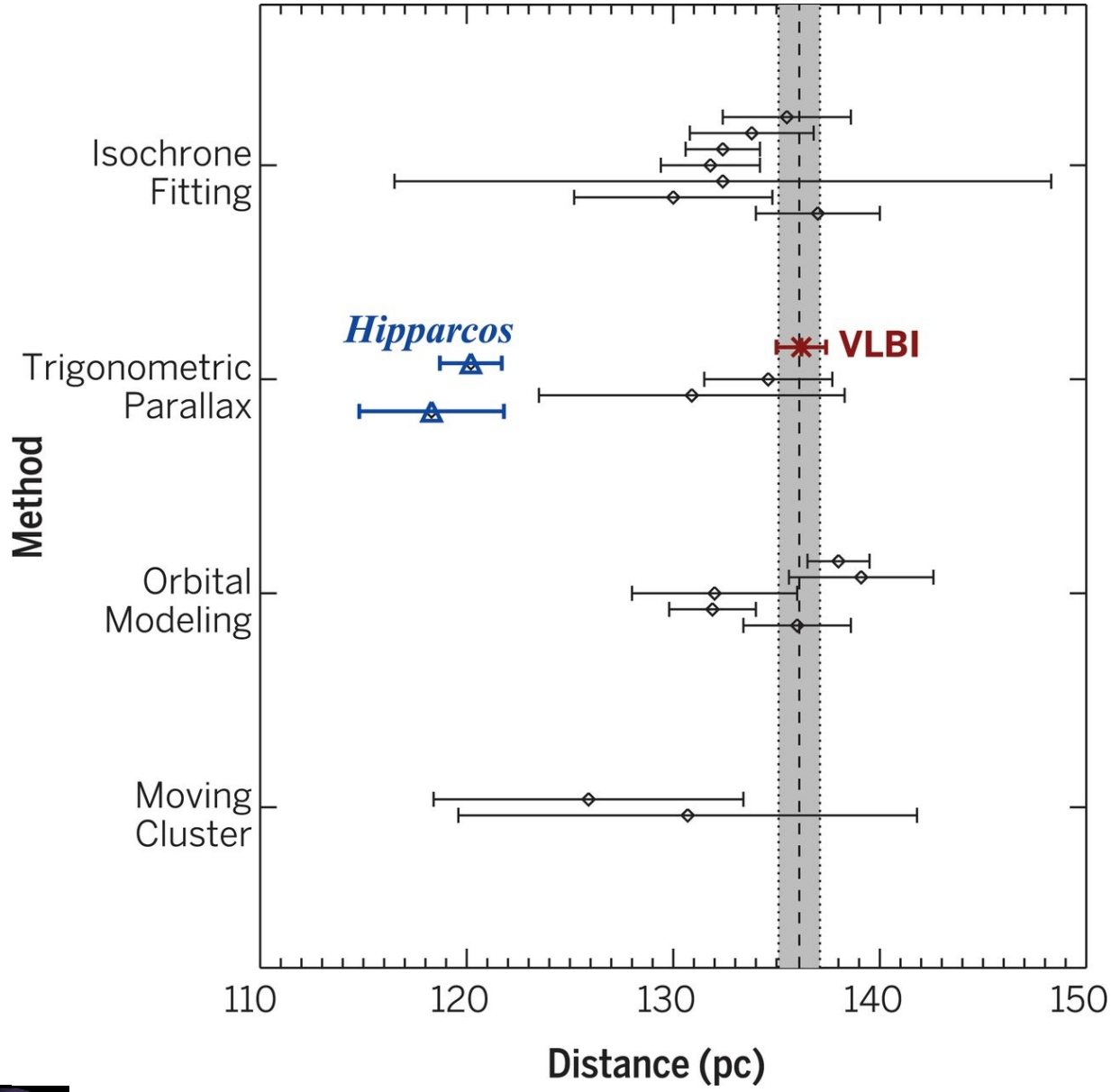

4750 MHz

Arecibo in VLBI

- High Sensitivity Array (VLBA, Arecibo,phased-VLA, GBT, Effelsberg);
  - 20 runs in 2014-15.
- European VLBI Network;
  - 7 runs in 2014-15.
- Global VLBI;
  - 7 runs in 2014-15.
- RadioAstron (Space VLBI);
  - 106 runs in 2014-15 (AGNs +PSRs).

Pleiades Distance Controversy

- The Pleiades is one of the primary calibrators for the ‘Zero Age Main Sequence’ and hence a cornerstone of the distance scale..
- Pre-Hipparcos terrestrial measurements gave a distance to the Pleiades of ~133 pc.
- Hipparcos measured 120.2 ± 1.5 pc.
- HSA measurements of 7 double/triple Pleiades stars (65 μJy < S < 1 mJy) gives 136.2 ± 1.2 pc



(Melis et al. 2014)

Planetary Radar: Planets, Moons & Asteroids

- Monitor Venus both to study its rotation state (which includes a very slow rotation of order a Venusian year) and look for active volcanism or tectonics

- Monitor the Galilean satellites of Jupiter to accurately determine their positions as a function of time. This will provide insight into the tidal properties of Jupiter itself.

- Study ~80 near-Earth asteroids per year, providing orbit improvement and physical characterization. Saving the Earth from "Space Invaders"!

Asteroid 2006 SX217

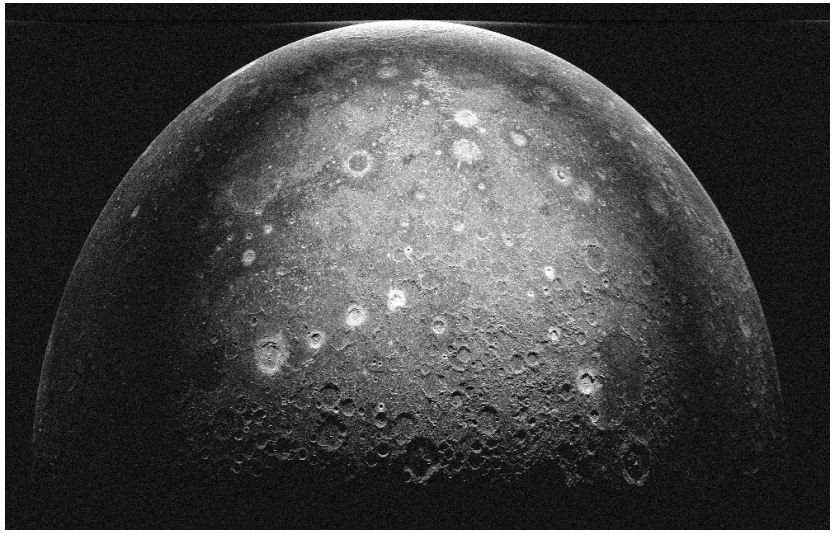
Diameter = 1 km

Resolution = 15 m/pixel

Arecibo + GBT

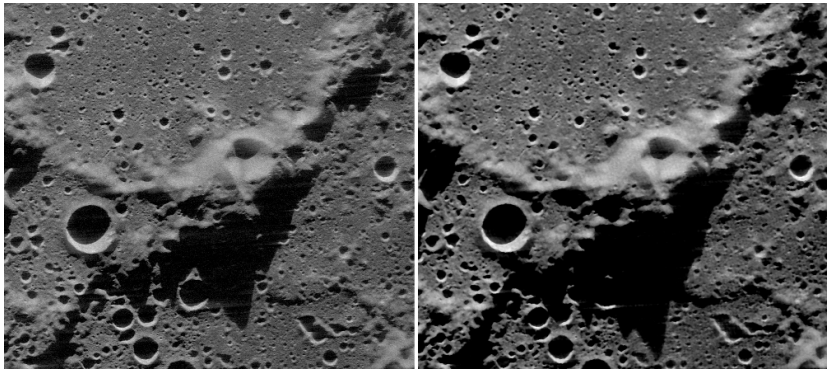
Planetary Radar: Our Moon

- The observations were made by Arecibo + the GBT.
- Frequency = 430 MHz
- Spatial resolution = 300 m.
- Imaging a depth of some 10 meters.
- Shadows are “radar shadows”, not “solar” shadows.



Lunar N. Pole is at bottom center.

The dark ring is the 1st null of the beam.



A region near the lunar N. Pole imaged on different days. The movement of the shadows between the images is due to the Moon's libration or “wobble”


Muchas
Gracias