The VLA Sky Survey (VLASS):

A New Generation Radio Sky Survey with the VLA

Amy Kimball (NRAO)

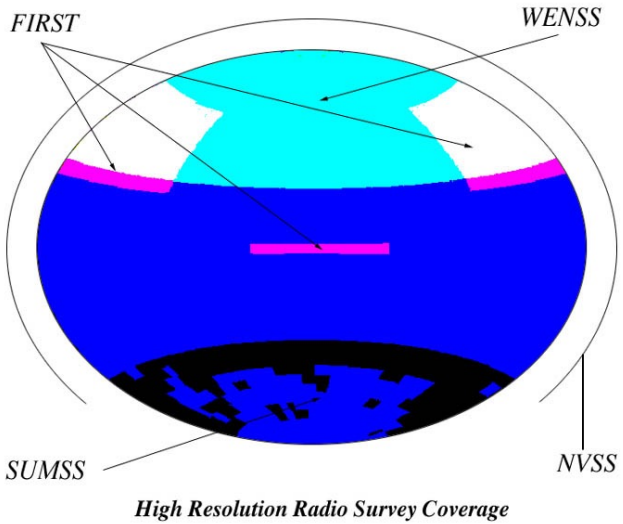
for the VLA Sky Survey team

Karl G. Jansky Very Large Array

- High desert plain of New Mexico, USA
- 27 antennas (25-m)
- 1-50 GHz + low-bands (P,W)
- 1-km to 30-km (four configs)

Why a VLA Sky Survey and why now?

- Survey science is an increasing fraction of VLA publications
- 20 years since VLA surveys **FIRST** and **NVSS**; 5+ years before SKA-1



High Resolution Radio Survey Coverage

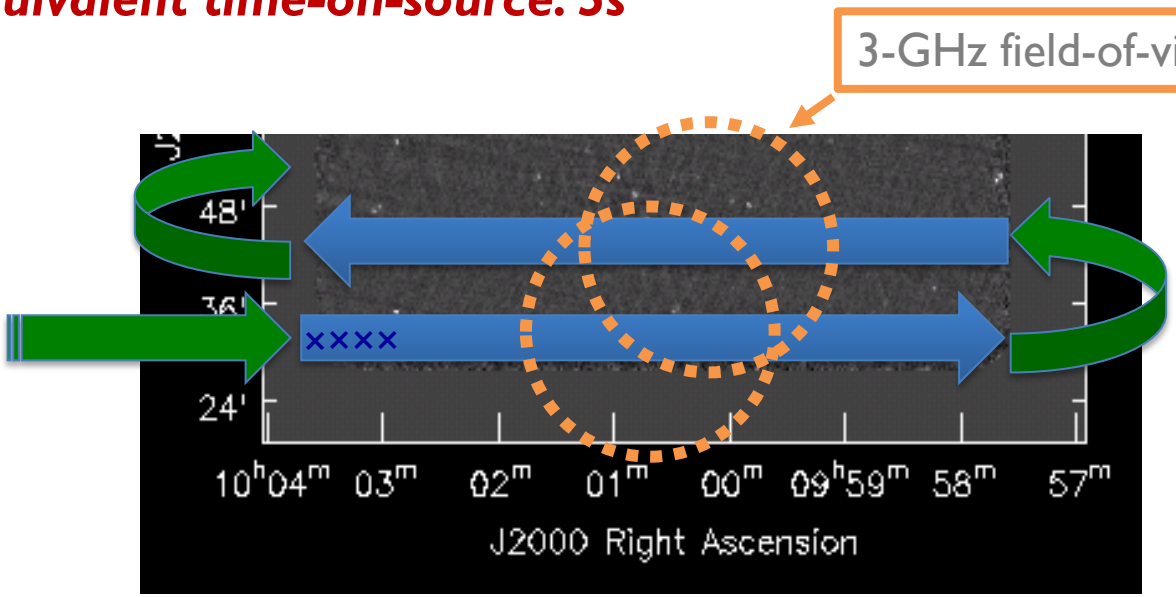
- ***New scientific opportunities***
  - build time series for time domain studies
  - multi-messenger surveys need radio counterpart *with comparable or better resolution*
- ***Community driven survey***
  - Astronomy community proposed new survey taking advantage of VLA's upgraded capabilities
  - Reviewed by independent panel, approved by NRAO Director in 2015

Upgraded VLA capabilities relevant for sky survey

- Wide bandwidths:
  - Continuum sensitivity
  - Spectral index information
  - Rotation measure studies
- Correlator flexibility:
  - Very fast dump times (> 5-ms)
  - High spectral resolution, extremely flexible tuning
- New "On-the-Fly" mosaicking mode:
  - Decreased overheads for large, relatively shallow surveys

On-The-Fly-Mosaicking observations

- Antennas scan while taking array data
  - VLASS net survey speed ~20 deg^2/hr
  - Scan rate 3.31'/s
  - Correlator dump 0.45s (1.5'/integration)
  - ***Equivalent time-on-source: 5s***



VLASS Survey Definition

- **Highest spatial resolution, all-sky radio survey to date**
  - Frequency: 3 GHz (2-4 GHz, less RFI affected regions) "S-band"
  - 1024 x 2-MHz channels
  - Synoptic: 3 epochs separated by 32 months
  - Observing time: 920 hours per configuration cycle X 6 cycles

Area (deg^2)	Resolution (robust)	Rms (μJy/bm)	Density (deg^{-2})	Total Detections
33,885 (δ > -40°)	2.5"	120 \ 69	~150	5,000,000

- Full survey, 7 years observing: September 2017 --- October 2024

VLASS Basic Data Products (Public!)

~1 PB
Raw data 523 TB
Images 440 TB

Product	Production timescale: Goal *(requirement)*	Notes
Raw visibility data	Immediate	In standard archive
Calibrated data	1 week *(1 month)*	From standard archive
Quick Look Images	2 days *(1 week)*	Stokes I wide-band continuum only
Single Epoch Images	6 months *(12 months)*	Stokes I wide-band continuum
Single Epoch Images	12 months *(16 months)*	Polarization and cubes
Single Epoch Catalogs	w/Single Epoch Images	By product
Cumulative Images	12 months *(16 months)*	Stokes I wide-band continuum
Cumulative Images	12 months *(16 months)*	Polarization and cubes
Cumulative Catalogs	w/Cumulative Images	By product

- CASA ALMA/VLA data calibration pipeline (VLASS "recipe")
- New imaging pipeline
- NRAO → Science-Ready Data Products

VLA Sky Survey Team at NRAO

- *Project director*: Claire Chandler
- *Project Scientist*: Mark Lacy (Project Scientist)
- *Technical Lead*: Steve Myers
- *Operations coordinator*: Amy Kimball
- *Scientific research, development, coordination team*: Joshua Marvil, Frank Schinzel, Anna Kapinska, Joan Wrobel, Lorant Sjouwerman
- *Computing team*: James Robnett, Stephan Witz, Daniel Lyons, Felipe Madsen
- *Pipeline developers*: Brian Kent, Joseph Masters
- *Data Analyst team (operations, quality assurance)*: Drew Medlin (DA Lead), Karlee Radford, Angelica Vargas, Alex Sobotka

Current VLASS status

- "Pilot" survey: May – Sep 2016
  - ~200 hours observing, ~2400 deg^2 (Galactic centre and representative extra-galactic observing fields; overlap with FIRST/SDSS)
  - some areas observed 3x to demonstrate full survey sensitivity

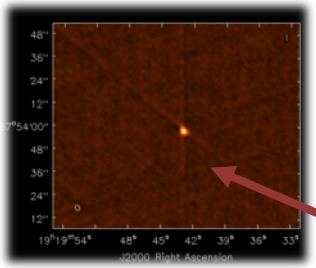
- "VLASS 1.1": 1st half of 1st epoch Sep 2017 – Feb 2018
  - 920 hours observing, ~16,831 deg^2
  - **> 94,000 GB of *raw* data** + calibrations available in NRAO data archive
  - nearly 17,000 deg^2 of "QuickLook" images available in NRAO data archive
  - development for "Single Epoch" data products ongoing

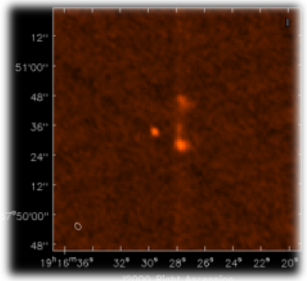
- "VLASS 1.2": 2nd half of 1st epoch Feb – Jul 2019 *(current)*

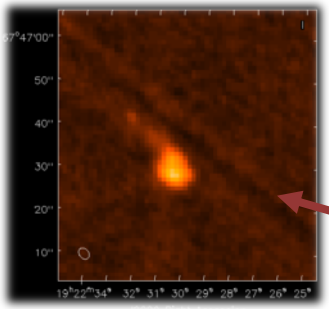
Individual QuickLook images: 1x1 deg^2

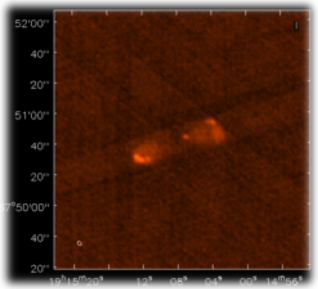
https://archive-new.nrao.edu/vlass/quicklook/VLASS1.1/

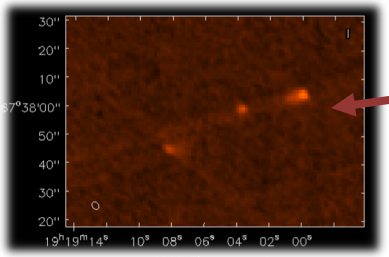
Very first QL image (centered at 1917+6730)

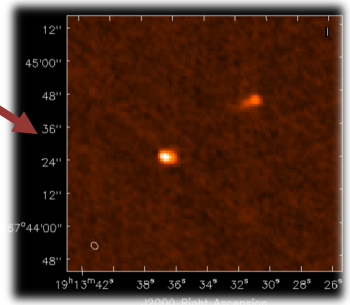


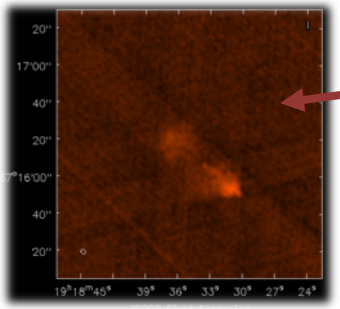


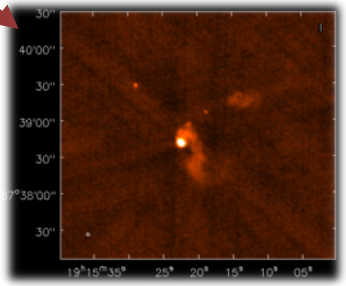


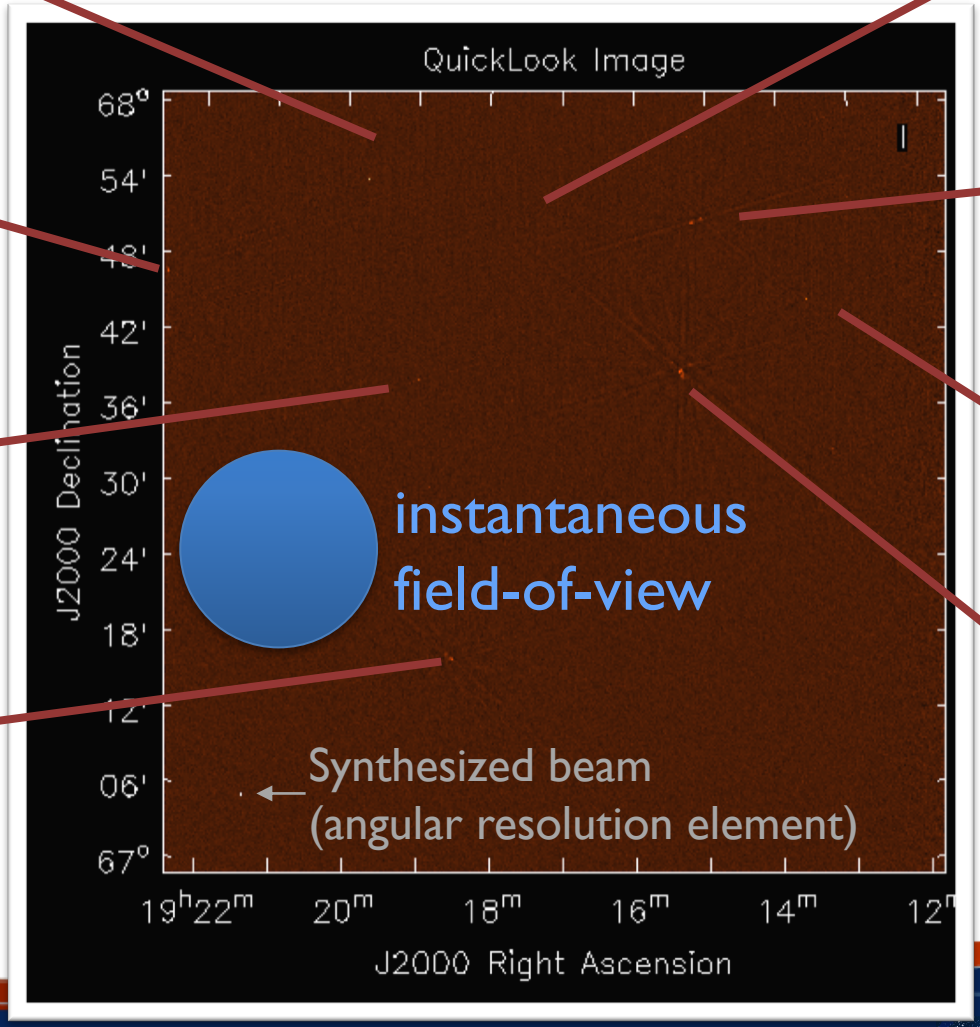




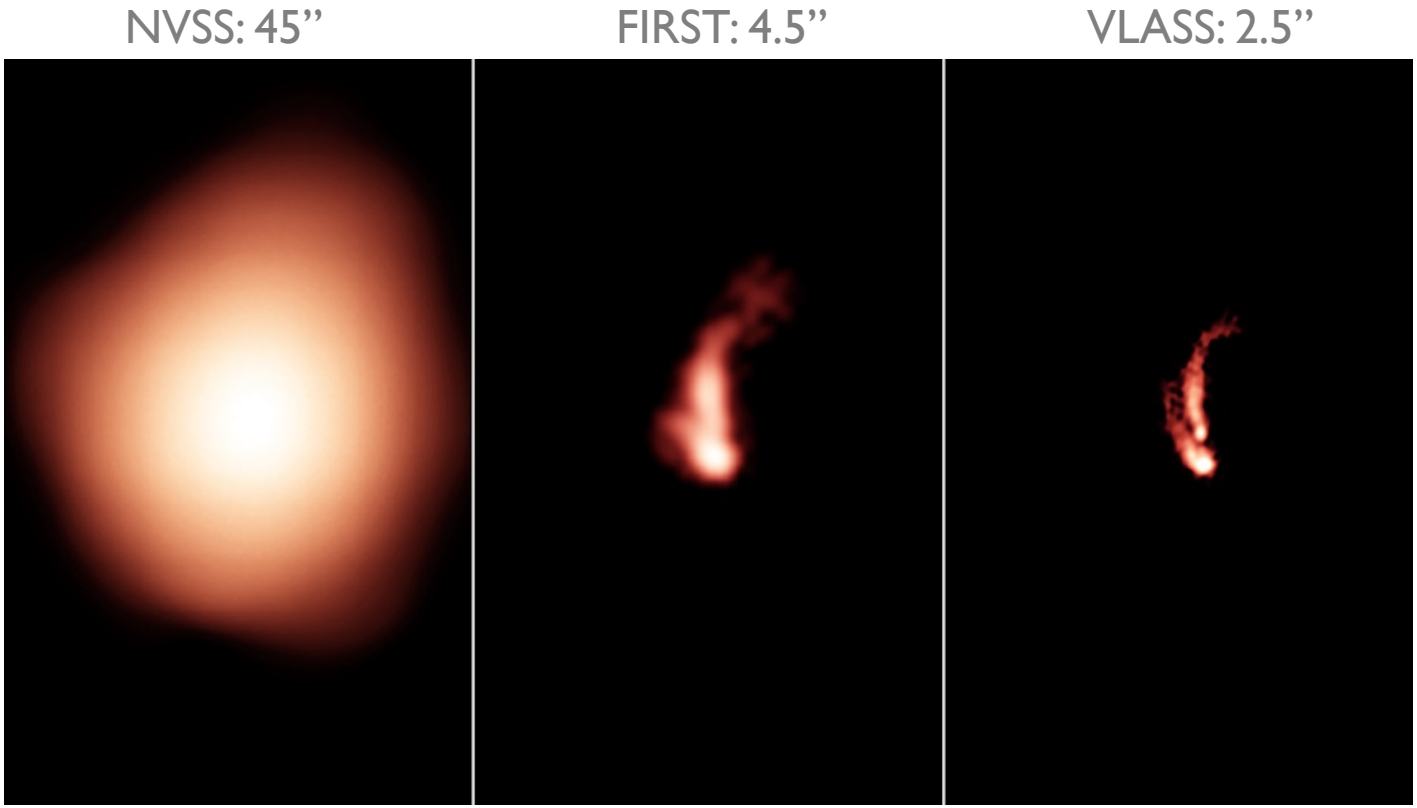




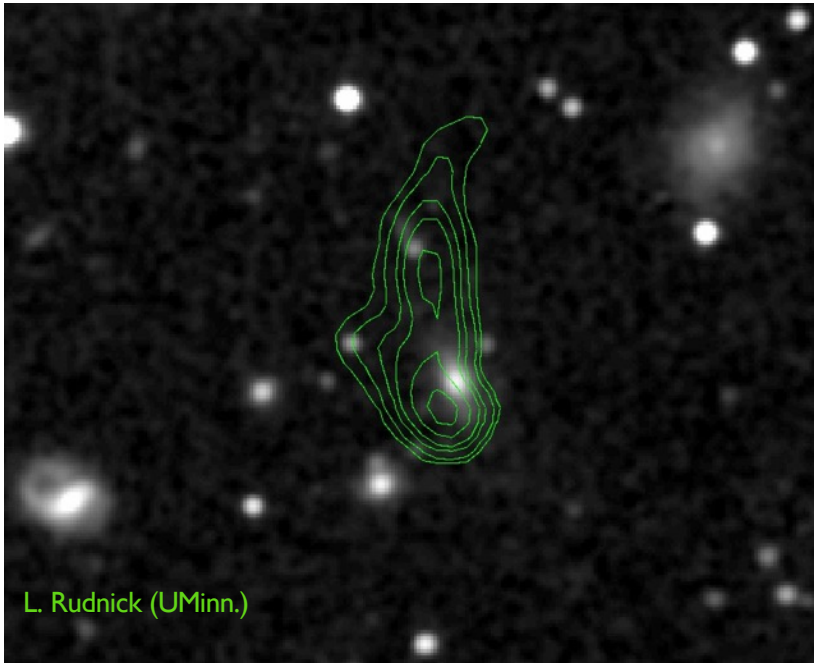




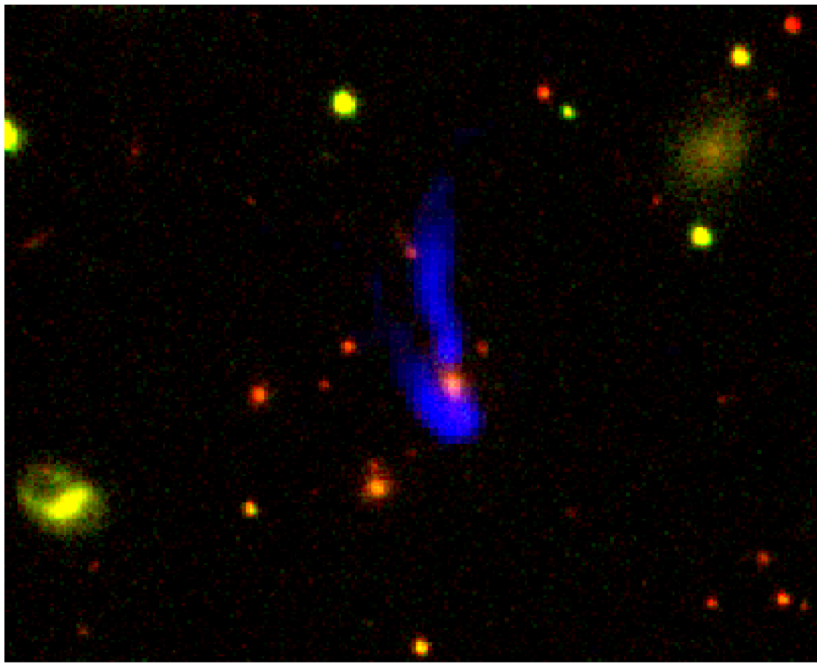
VLASS resolution is key!



Resolution enabling association with optical galaxy



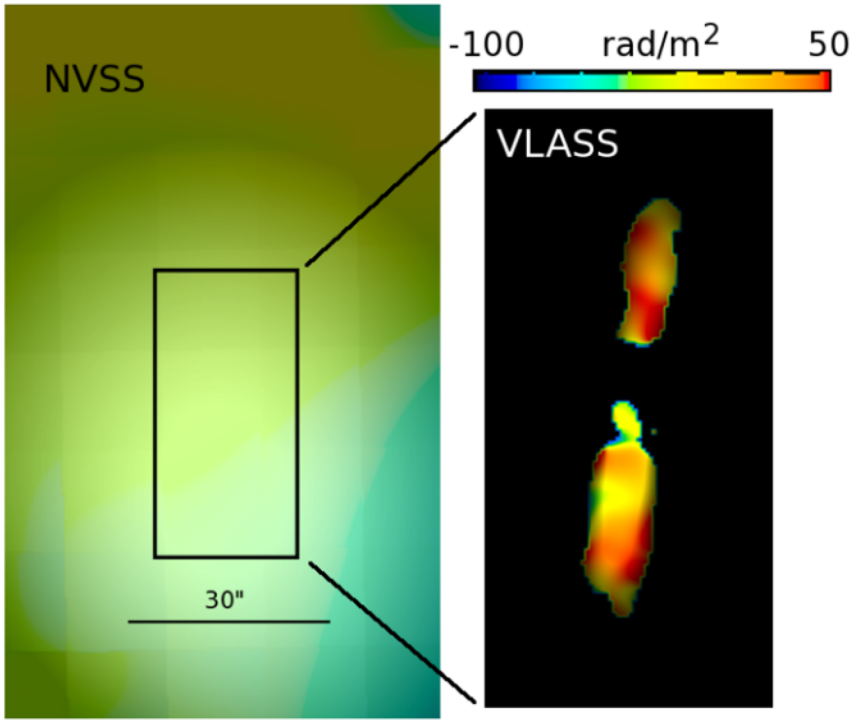
FIRST contours on SDSS



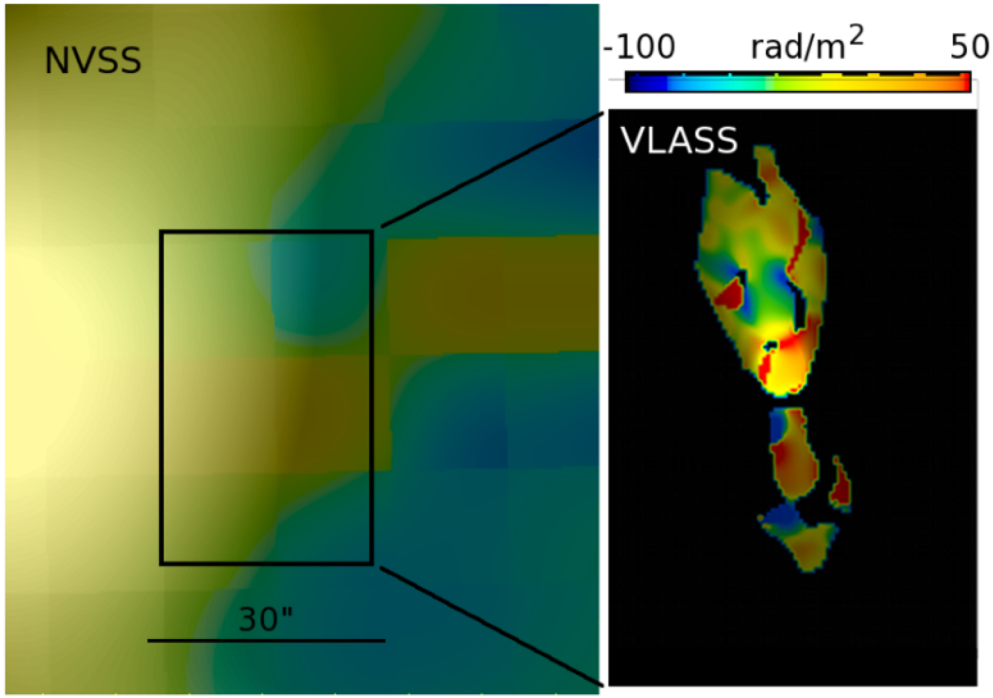
SDSS (red/green) image overlay on VLASS (blue).

Initial results: polarization mapping

3C 402 North



3C 402 South



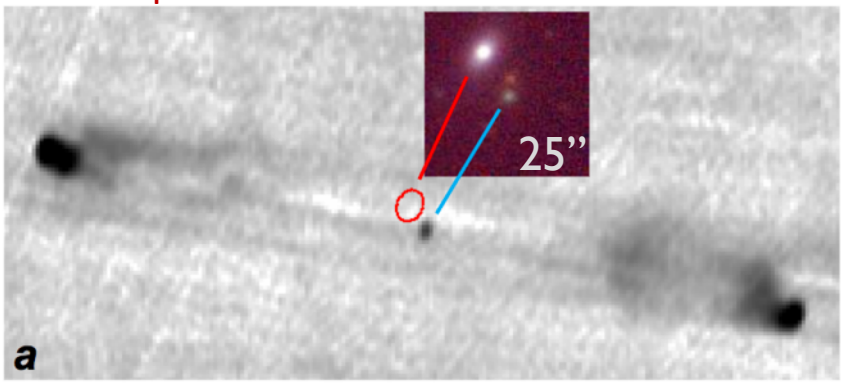
M. Lacy et al. (in prep)

Initial science results: Giant Radio Galaxies

- Villarreal Hernández & Andernach (*astro-ph 1808.07178*)
  - Identified 9 new Giant Radio Galaxies from 4300 deg^2 of QL images

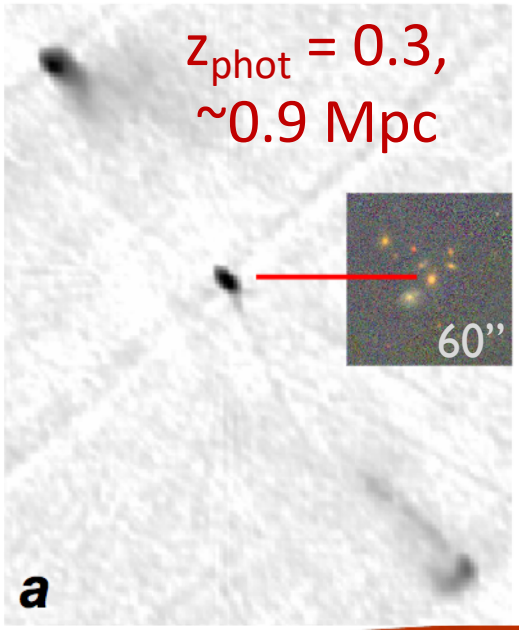
J1452−1311

z_{phot} = 2.2; size ~1.7 Mpc



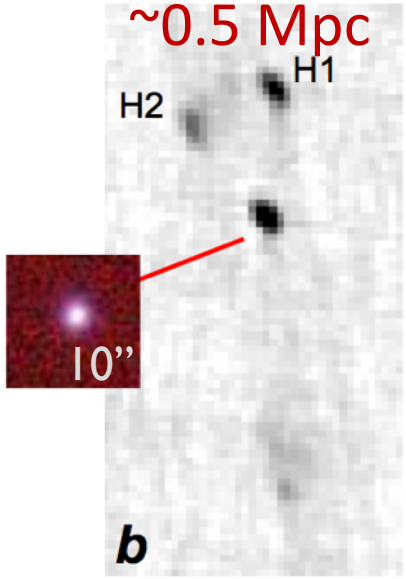
J0342−0435

z_{phot} = 0.3, ~0.9 Mpc

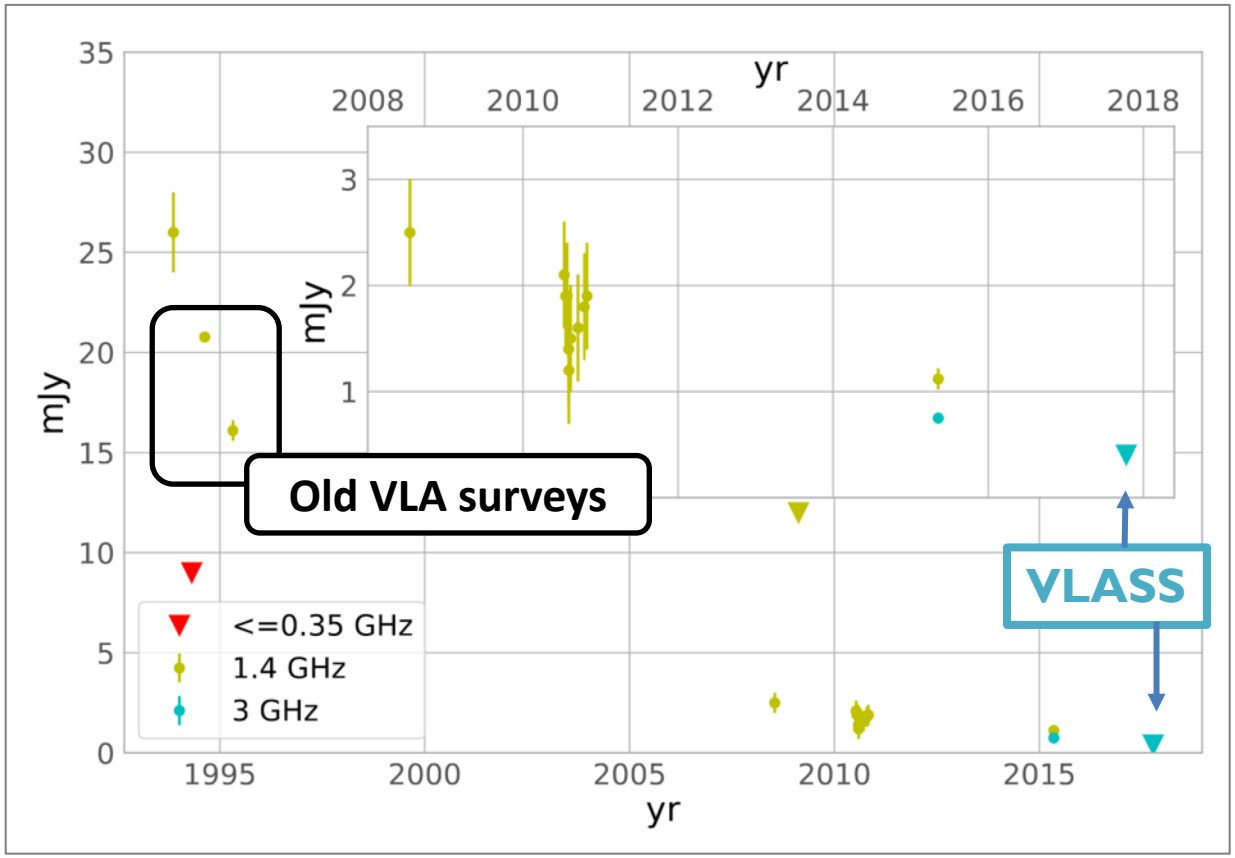


J0105−2146

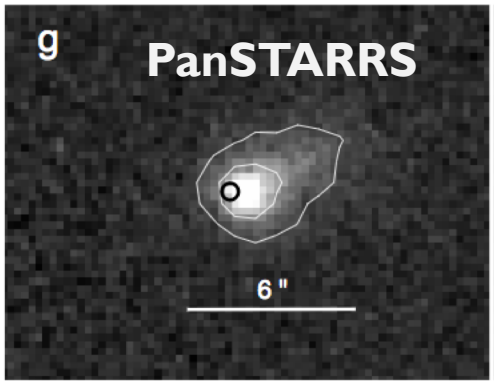
z_{phot} = 1.5, ~0.5 Mpc



Initial science results: Luminous decades-long transient



Chatterjee et al. 2017
Ofek et al. 2017
Law et al. 2018

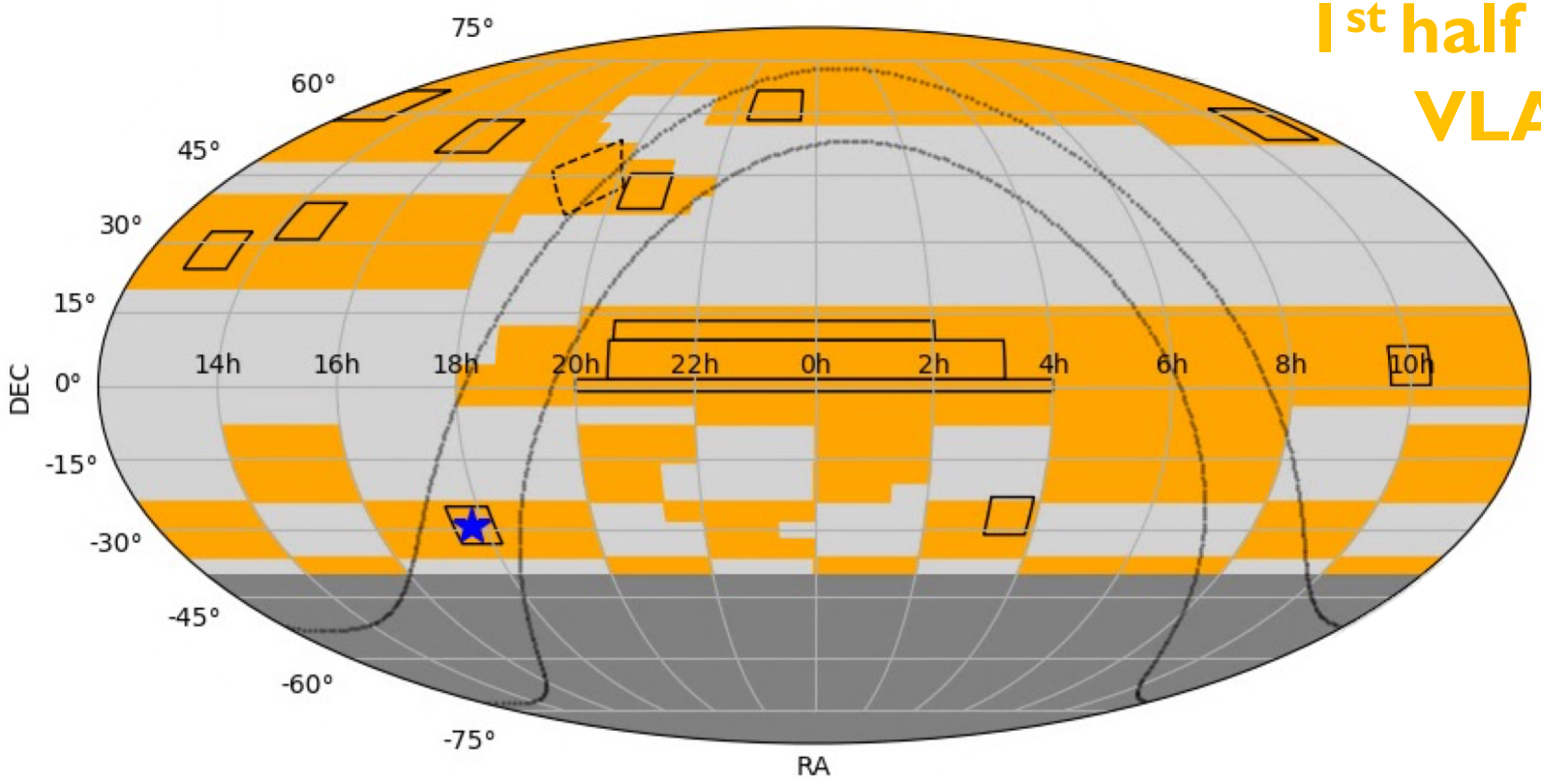


GRB afterglow?
Magnetar wind nebula?

Sky survey challenges

VLASS Challenges: Sky coverage / tiling

- Goal: constant RA observing pressure in each observing epoch

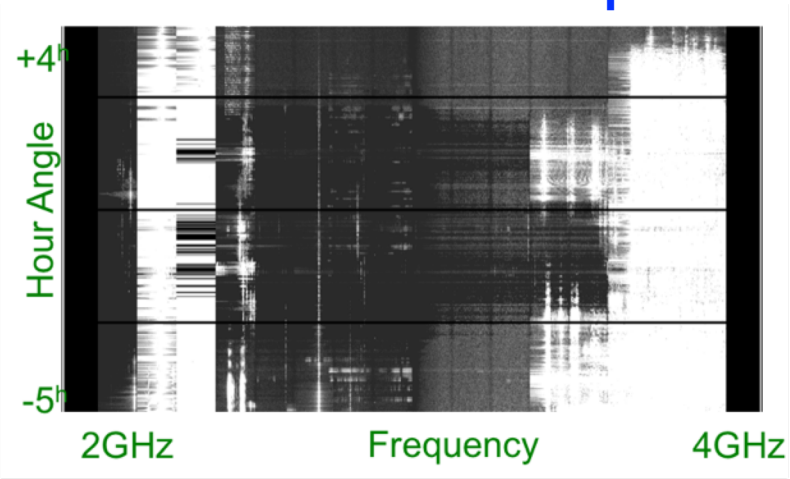


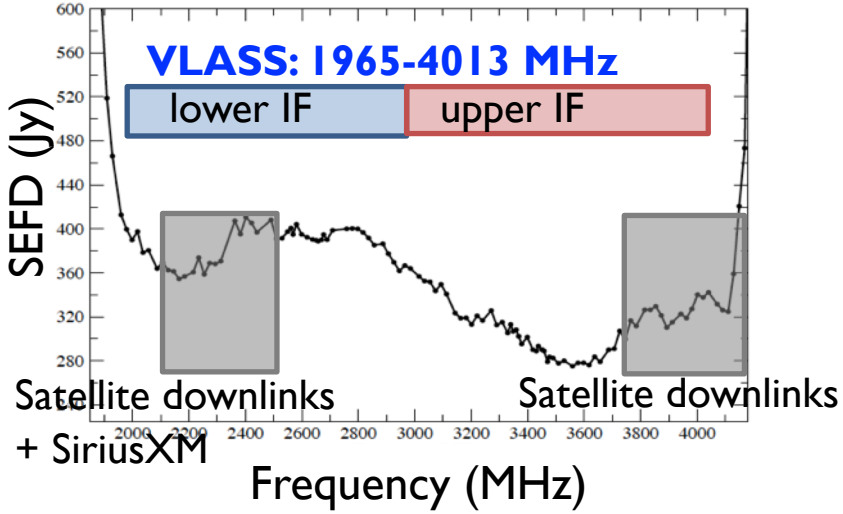
1st half of sky: VLASS1.1

Pilot fields

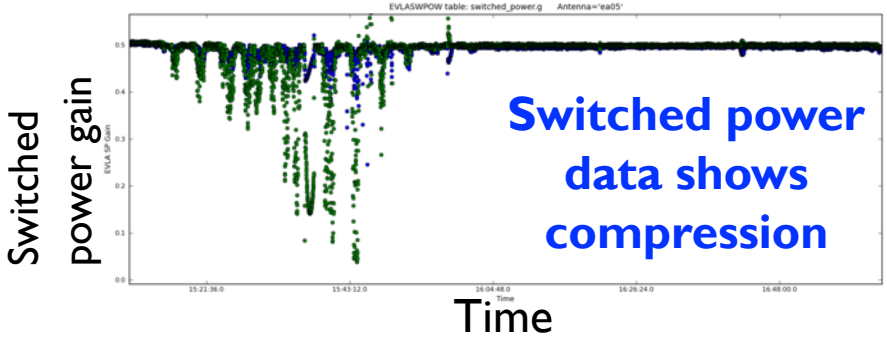
Observing challenges: RFI / satellite avoidance

Results of RFI sweep





Strong RFI leads to gain compression



Areas of sky (az/el) to avoid worst of compression

2-4 Ghz satellites seen from VLA

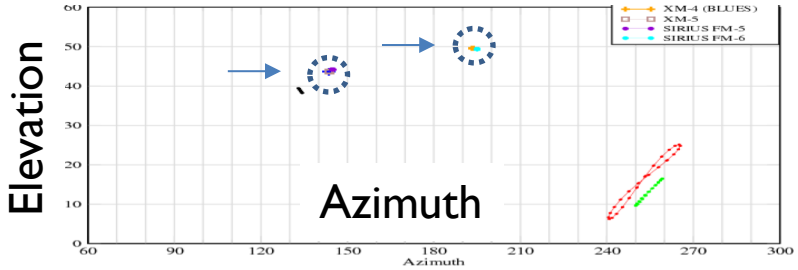
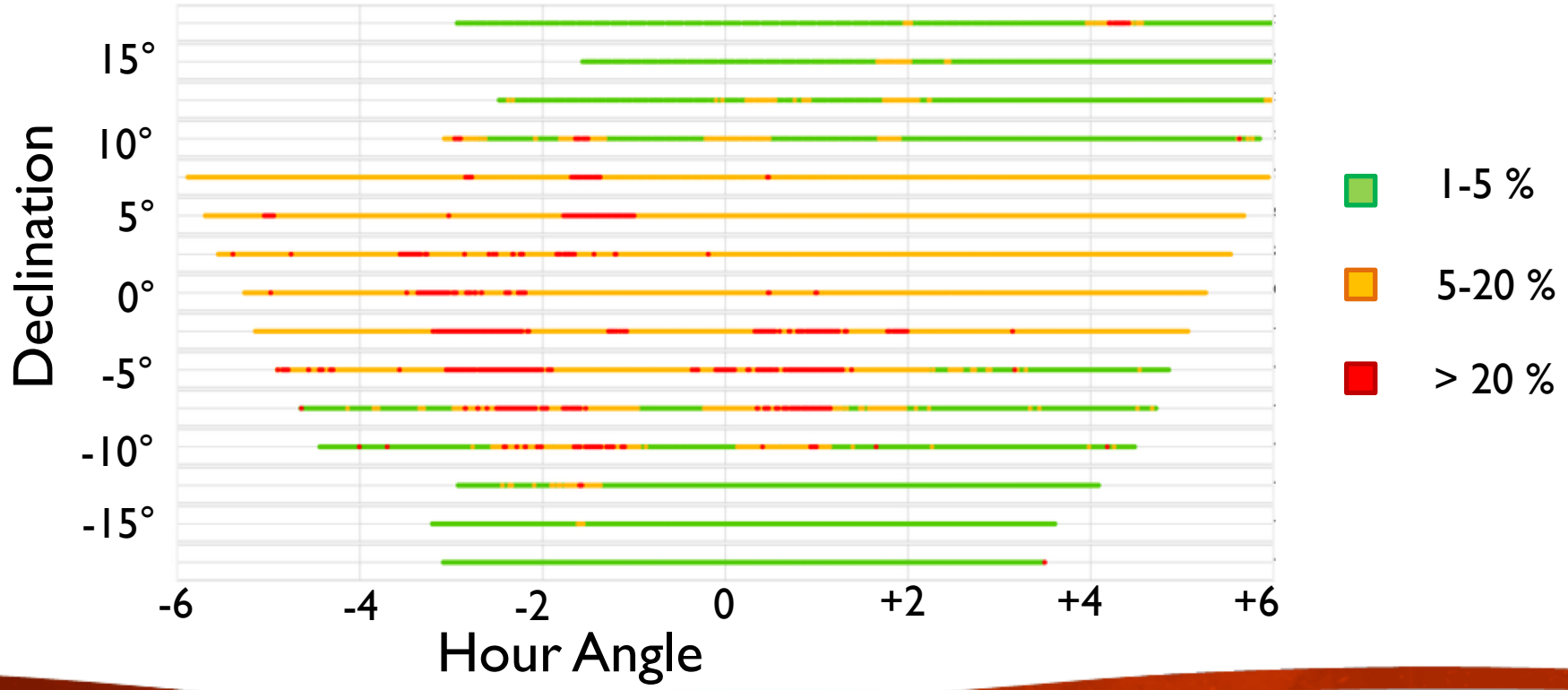


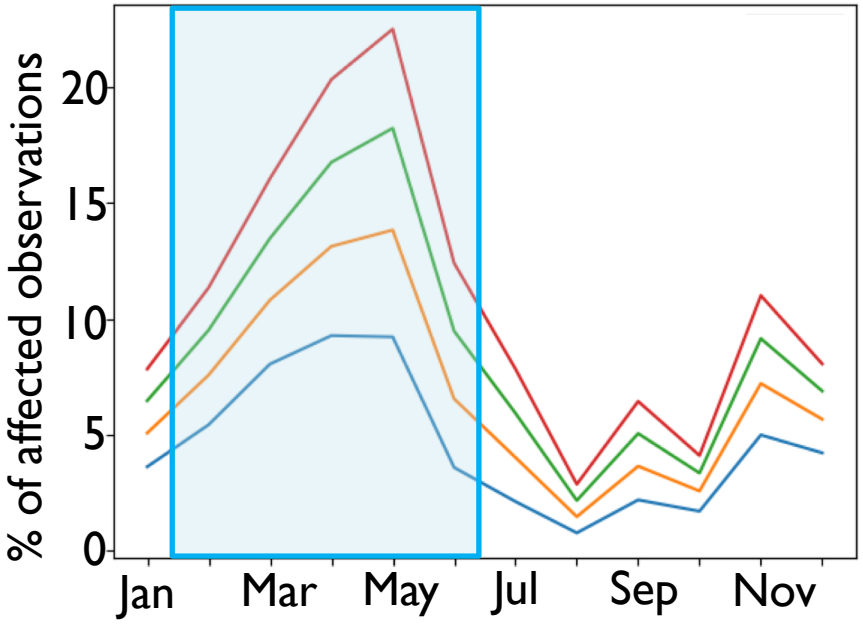
Figure below by
Frank Schinzel



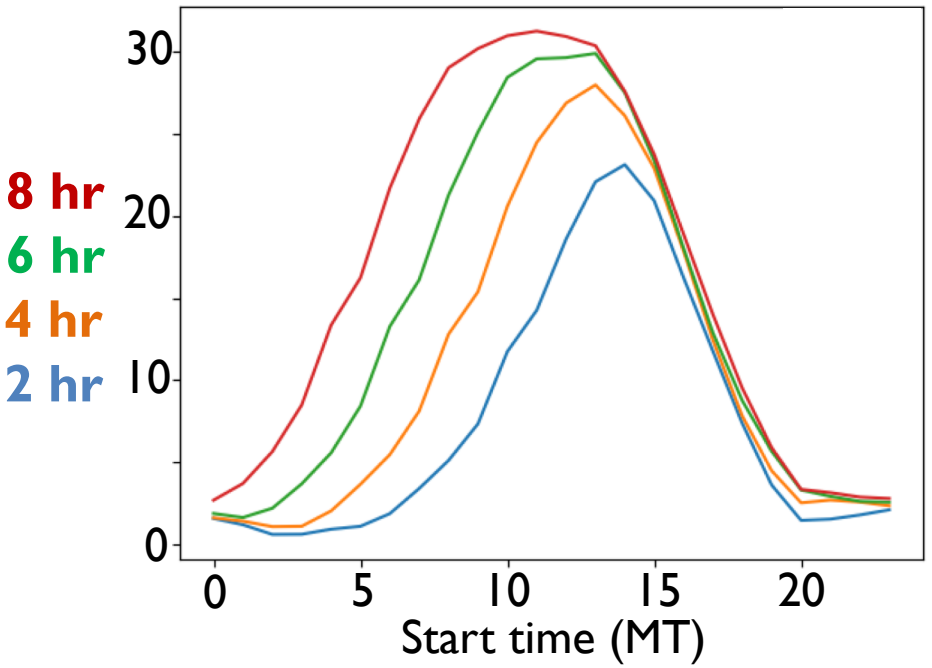
WIND: phase errors, antennas stow

Short observing blocks → High Overhead

Estimated wind stows vs month
(threshold = 40 mph)

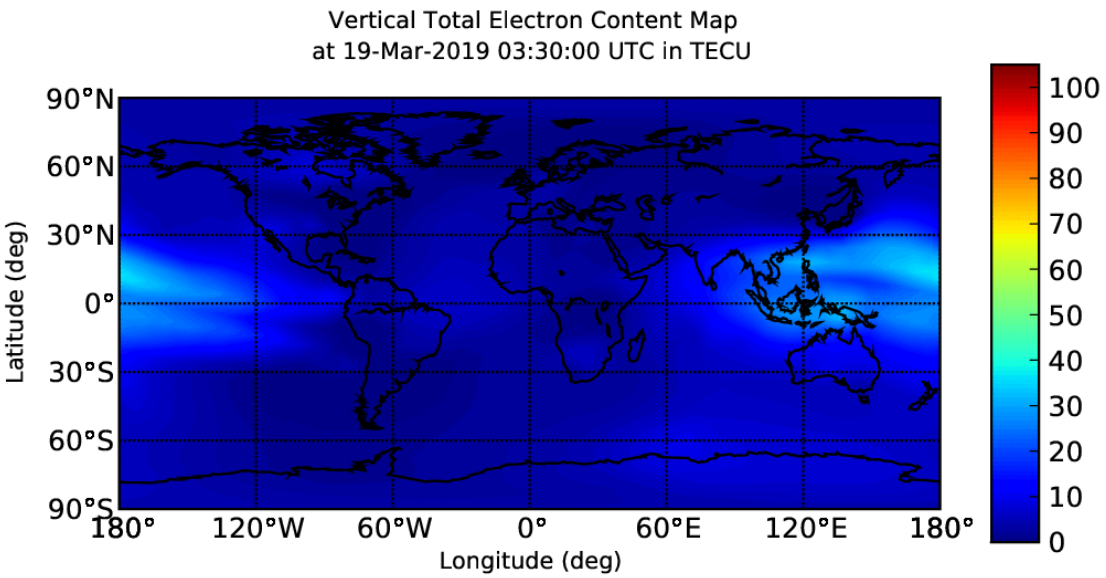


Estimated wind stows for VLASS 1.2B
(threshold = 40 mph)



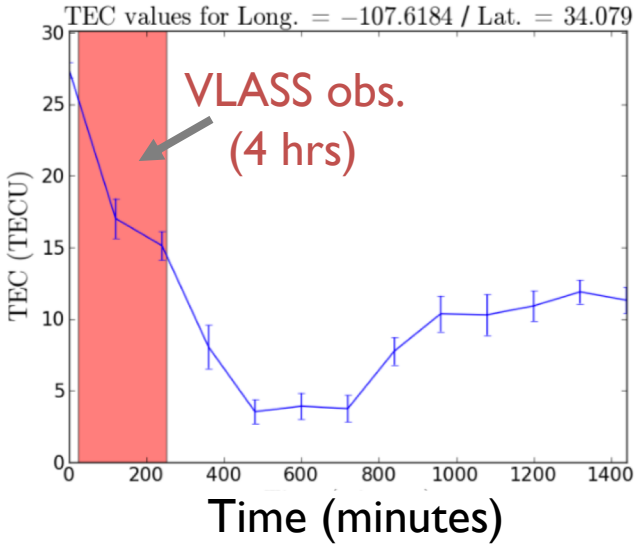
Challenges: ionosphere (TEC: total electron count)

TEC vs position



iono.jpl.nasa.gov/latest_rti_global.html

TEC vs time



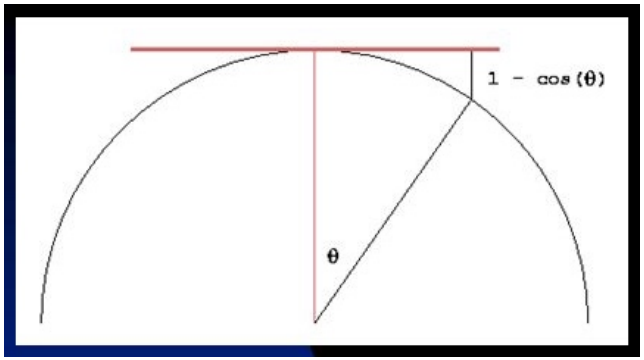
F. Schinzel, VLASS memo series #11

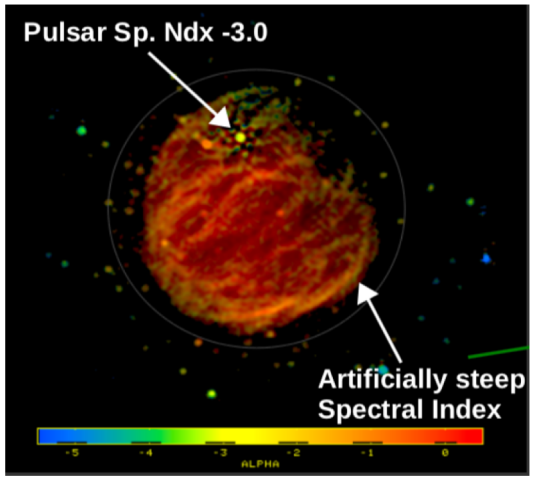
Conclusion: due to coarse sampling of TEC models, little effect on data. Will not use. (Can investigate higher-res models.)

VLASS imaging challenges

- Algorithm for Single-Epoch products (Sanjay and Preshanth talks yesterday)
  - Wide-field effects and beam rotation:
    AW-projection
  - Polarization: full-Mueller?
  - Spectral indices / wide-band effects
    - x2 change in primary beam size
  - Pointing offset corrections
    - Add reference pointing to observations?

All problems solvable with time/computing = $$$





S. Bhatnagar's talk

Community Effort:

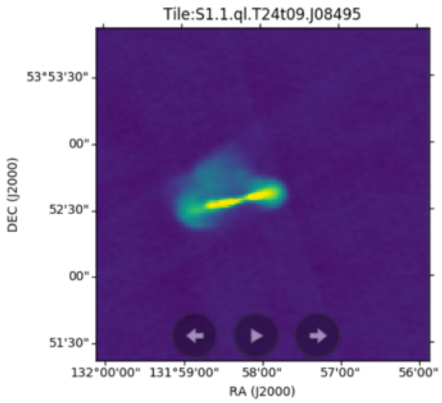
- Led by Shea Brown (*U. Iowa*)

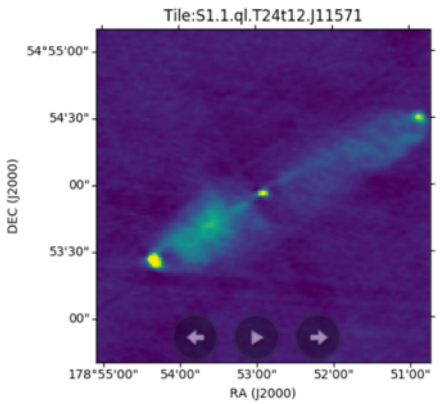
  https://bablai.com/vlass

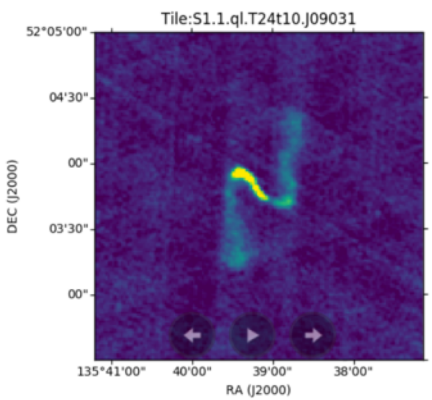
  – Machine Learning for source classification

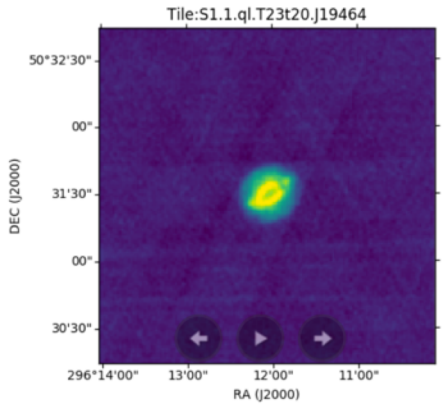
  – Training on VLASS QuickLook images (prep for cubes)

  – Basic catalogs and postage-stamp images







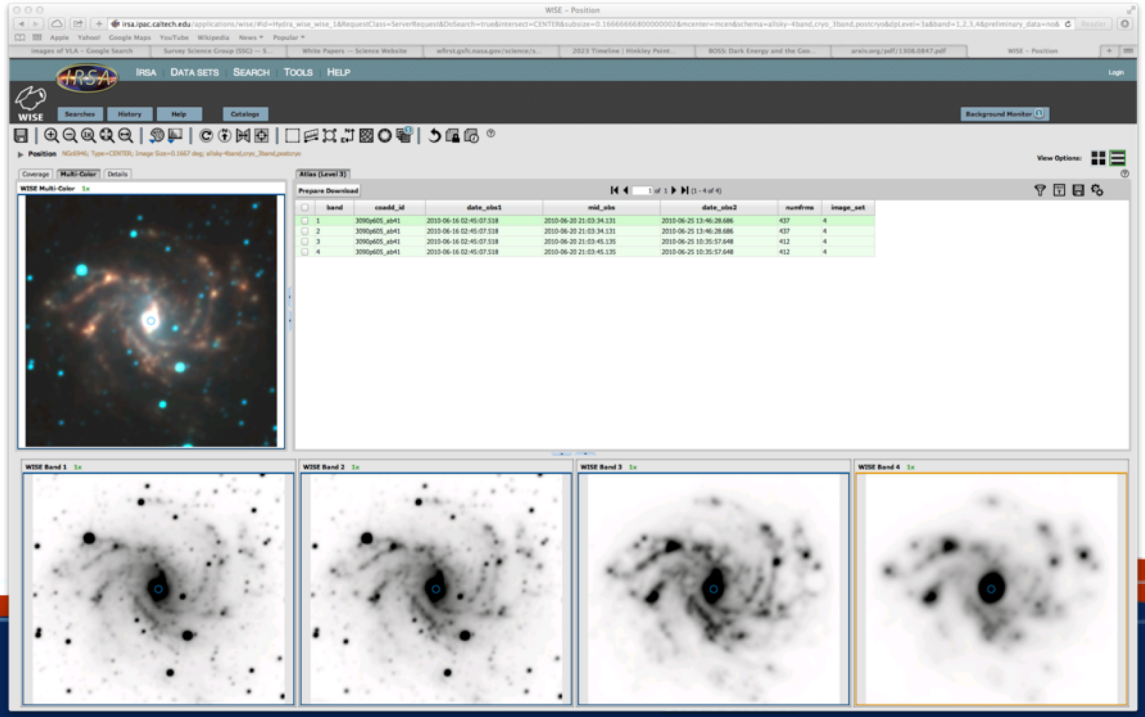


Enhanced Data Products & Services

Community led effort

- Transient Object Catalogs & Alerts
- Multi-Wavelength Catalogs for VLASS sources
- Rotation Measure Images and Catalogs
- Light Curves (IQU)
- A hosted VLASS Archive with Image and Catalog Service

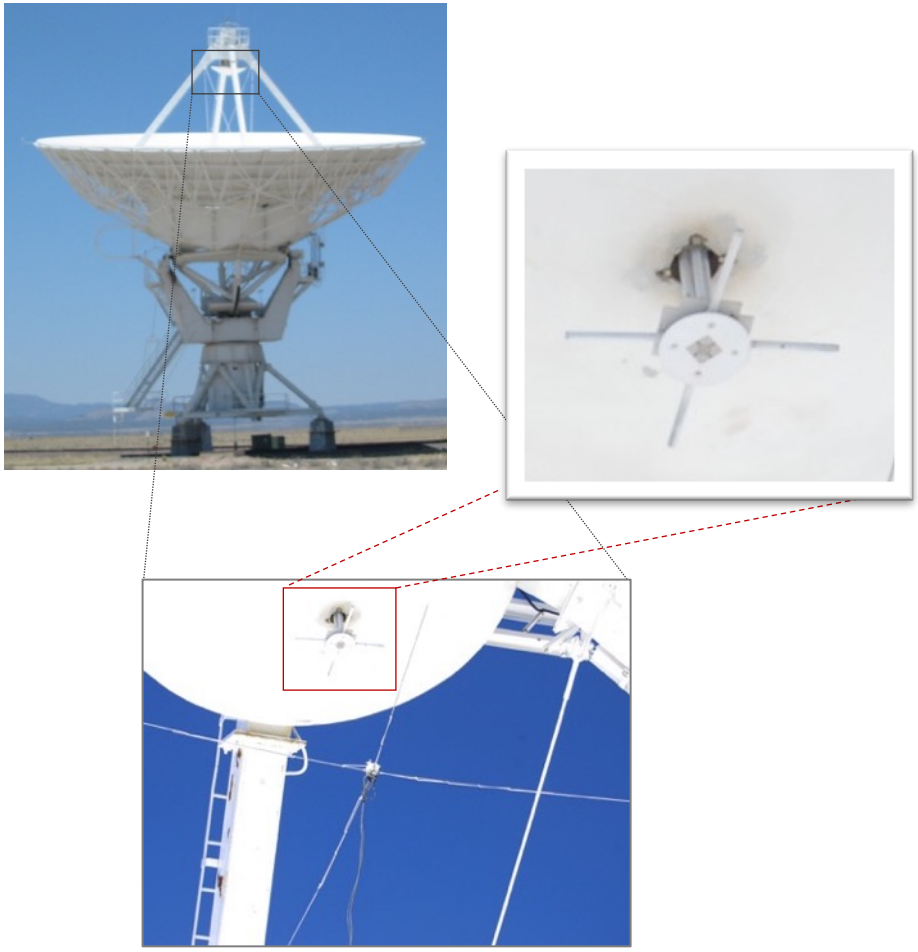
✧ **e.g., as currently available by IPAC/IRSA allowing for VLASS to be integrated with Spitzer/Planck /WISE/Euclid/etc…**



VLITE:
A commensal VLA(SS) survey

(with thanks to Tracy Clarke, NRL)

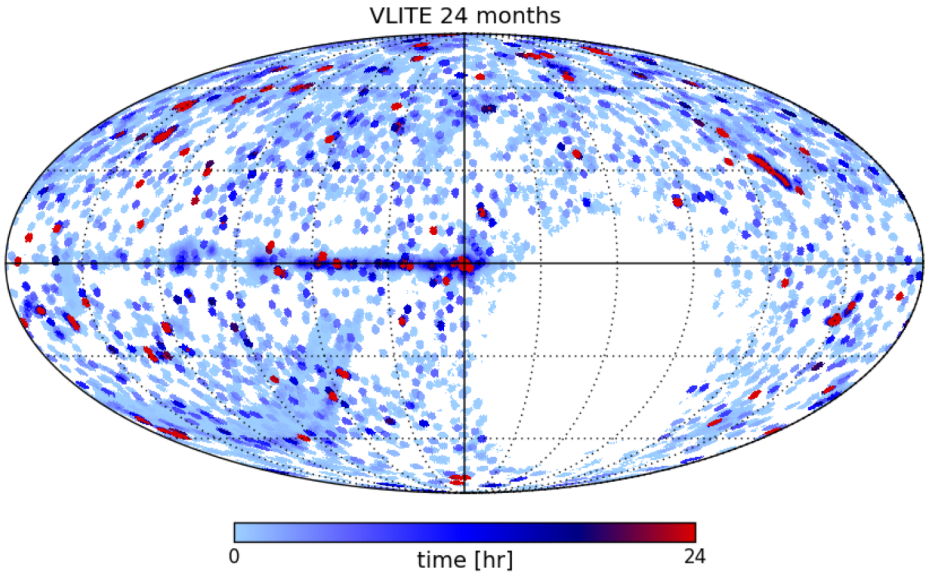
VLA Low Band Ionosphere and Transient Experiment (VLITE) Clarke et al. (2016)

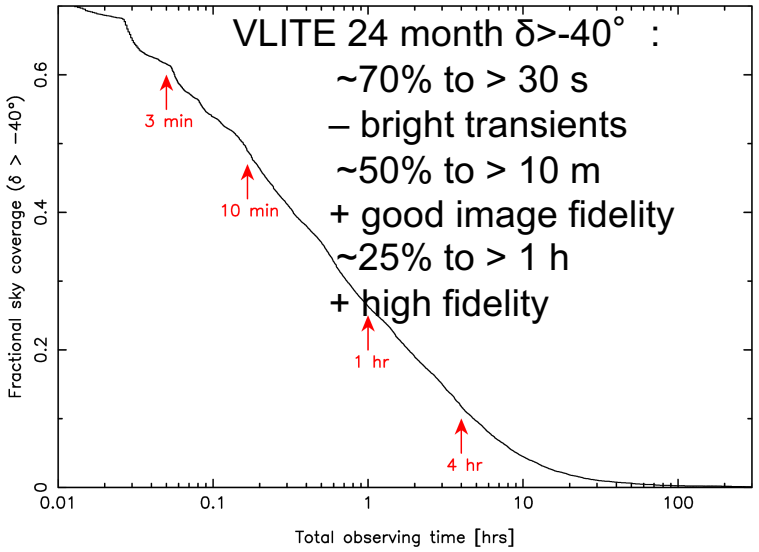


- VLA "P-band" dipoles installed at prime focus
- Independent optical stream and independent correlator

- 15 antennas, 330 MHz band
  - 320 – 384 MHz, $\Delta\nu$ = 100 kHz
  - 2s integrations
  - Full polarization (linear)
  - Field of view: > 5 deg^2
  - 5" – 3' resolution, up to 1° largest angular scale

The Power of a Low Frequency Commensal System: Sky Coverage



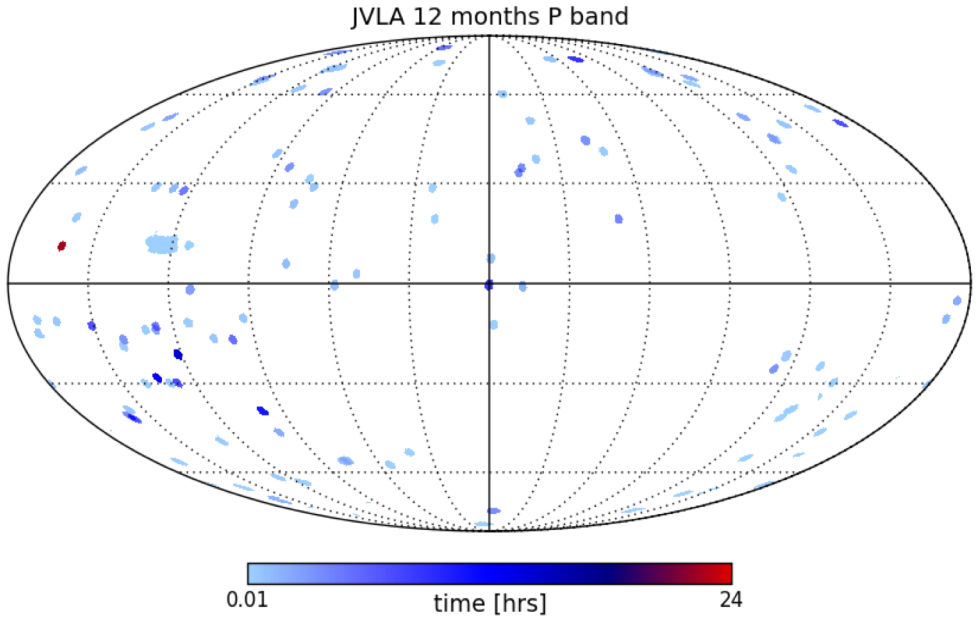


WIDAR 12 months:

- Deepest P band field is 22h

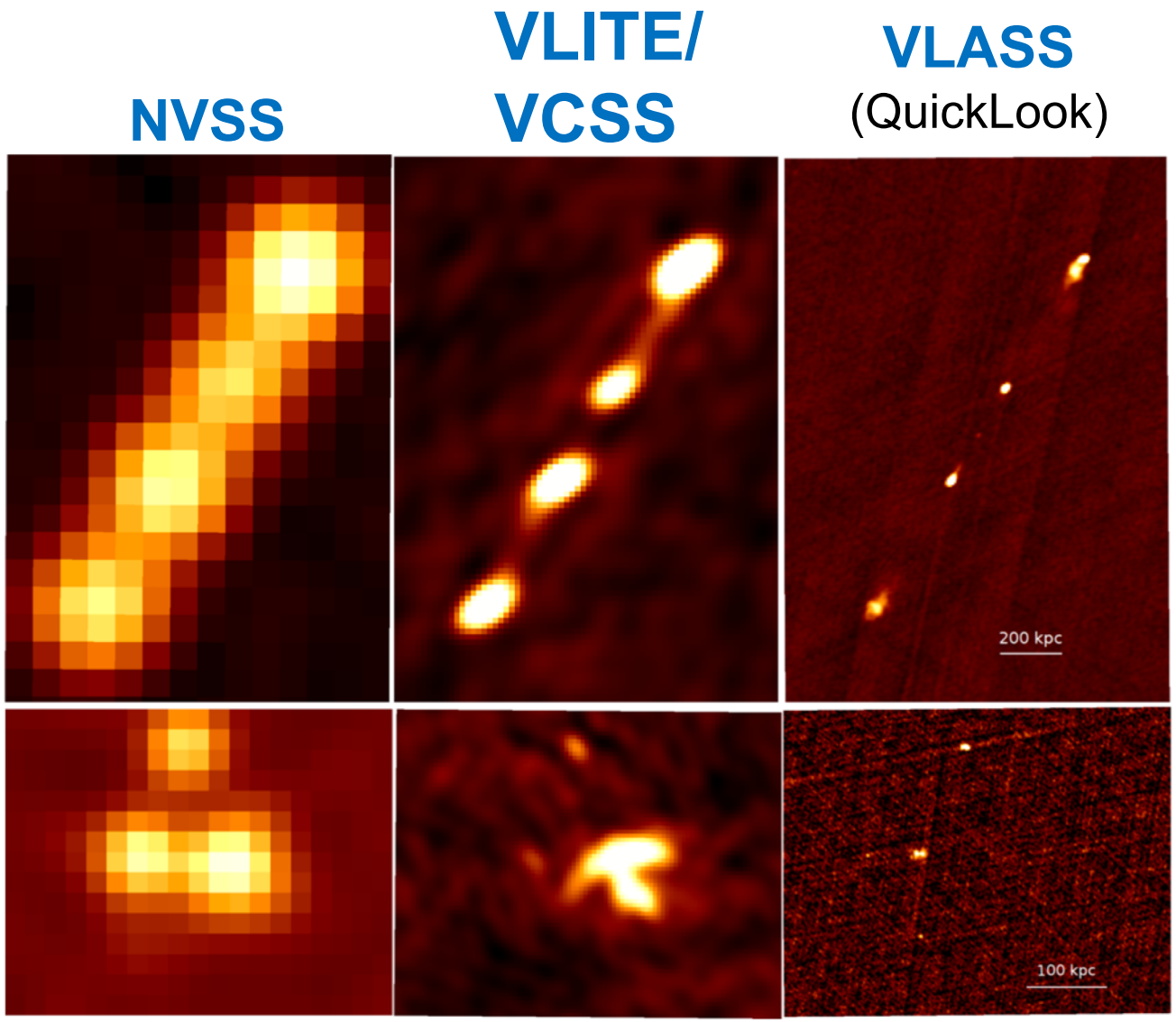
VLITE 24 month:

- VLITE recorded ~12,540h or 71% wall time
- Deepest P band field is > 520h (COSMOS) over 669 days



U.S. NAVAL RESEARCH LABORATORY

VCSS: VLASS Commensal Sky Survey



VLA Sky Survey summary

- Highest spatial resolution all-sky radio survey ever undertaken
  - Resolution critical for cross-identification with other wavelengths
  - Multi-epoch for transient identification
  - Polarimetry to reveal the magnetic universe

- On 2nd observing cycle (observing remainder of sky, 1st pass)
  - Raw data, calibrations, "QuickLook" images available

- Overcoming obstacles
  - Scheduling/observing for RFI
  - Algorithm research/development for Single-Epoch images

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