The VLA Sky Survey

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NRAO NSF Associated Universities, Inc.

What is the VLA Sky Survey?

- With the completion of the Expanded VLA construction project the astronomy community proposed a new radio survey taking advantage of the improved capabilities:
  - Full frequency coverage, 1–50 GHz
  - *Up to 8 GHz/pol instantaneous BW*
  - Up to 4.2e6 channels in up to 64 independent sub-bands
  - *5 to 10 times better continuum sensitivity*
  - Few millisecond time resolution
  - *New observing mode: On-The-Fly Mosaicing*
- Reviewed by an independent panel and approved by the Director last year

Survey Parameters

- All-sky (33,885 deg^2 above declination –40°)
- Frequency: 3 GHz (2-4 GHz, less RFI affected regions)
- Angular resolution: 2.5" (robust weighted): VLA B-configuration
- Time resolution: 0.45 sec (equiv. TOS per field ~5s)
- Scan rate and survey speed: 3.3'/s and 24 deg^2/hr
- Cadence: 3 epochs separated by 32 months
- Continuum image RMS per epoch: 120 μJy
- Co-added continuum image RMS: 69 μJy
- Observing time requested 920 hrs per configuration cycle (<15% science time), 5520 hrs over ~7 years
- Data products:
  - Stokes I,Q,U polarization (intensity & linear pol)
  - Spectral cubes: 128 MHz & 10 MHz resolution

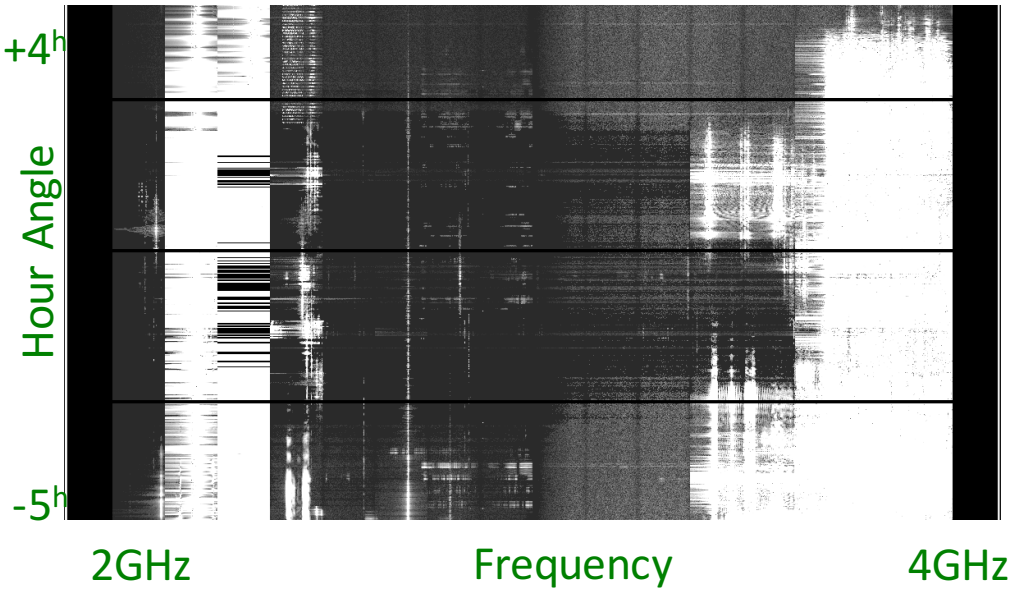
Science Goals

- Goal:
  - An all-sky reference atlas that will be unsurpassed in resolution and sensitivity for decades – a launch pad for transformational astrophysics

- Headline science:
  - Hidden explosions – the transient sky
  - Faraday tomography – the magnetic sky
  - AGN and galaxy evolution – building blocks of structure
  - Peering through the dusty Milky Way – stellar evolution
  - "Missing physics" – astrophysics from radio to Υ-rays

The VLASS Pilot

- Currently in design phase
- Many technical challenges
  - Tracking of antenna pointing (new ACUs being installed)
  - Radio Frequency Interference at S-band (Clarke Belt the worst):



  - Data volumes
  - Data processing and imaging algorithms

$\Longrightarrow$ 200 hr pilot undertaken summer 2016 at low-pressure LSTs

Pilot Survey and Test Fields

- Cover significant area for transients with good overlap with FIRST
- Overlap SDSS & representative extragalactic Deep Fields
  - COSMOS, GOODS-N, CDFS, Elais-N1, Lockman Hole, Lonsdale SWIRE, HAtlas-Bootes, and SDSS Stripe-82
- Cover some galactic regions (including Galactic Center)
- ~2400 deg^2 covered
- Some areas repeated 3x to demonstrate sensitivity of full survey

Field	RA	Dec	Observation type	Area (sq. deg.)	# hrs
COSMOS	10.0h	+2°	3 epoch OTF (3x4hr)	80	12
Cygnus	20.5h	+40°	3 epoch OTF (3x4hr)	80	12
Cepheus	23.0h	+62°	3 repeat OTF (3x4hr)	80	12
CDFS	3.5h	–27°	3 repeat OTF (3x4hr)	80	12
Galactic Center	17.8h	–29°	3 repeat OTF (3x4hr)	80	12
Stripe 82	21h–03h	0°	3 epoch OTF (12x4hr)	320	48
SDSS SGC	21h–03h	0° to 15°	1 repeat OTF (17x4hr)	1360	68
SDSS NGC	10h–17h	50° to 60°	1 repeat OTF (5x4hr)	400	20

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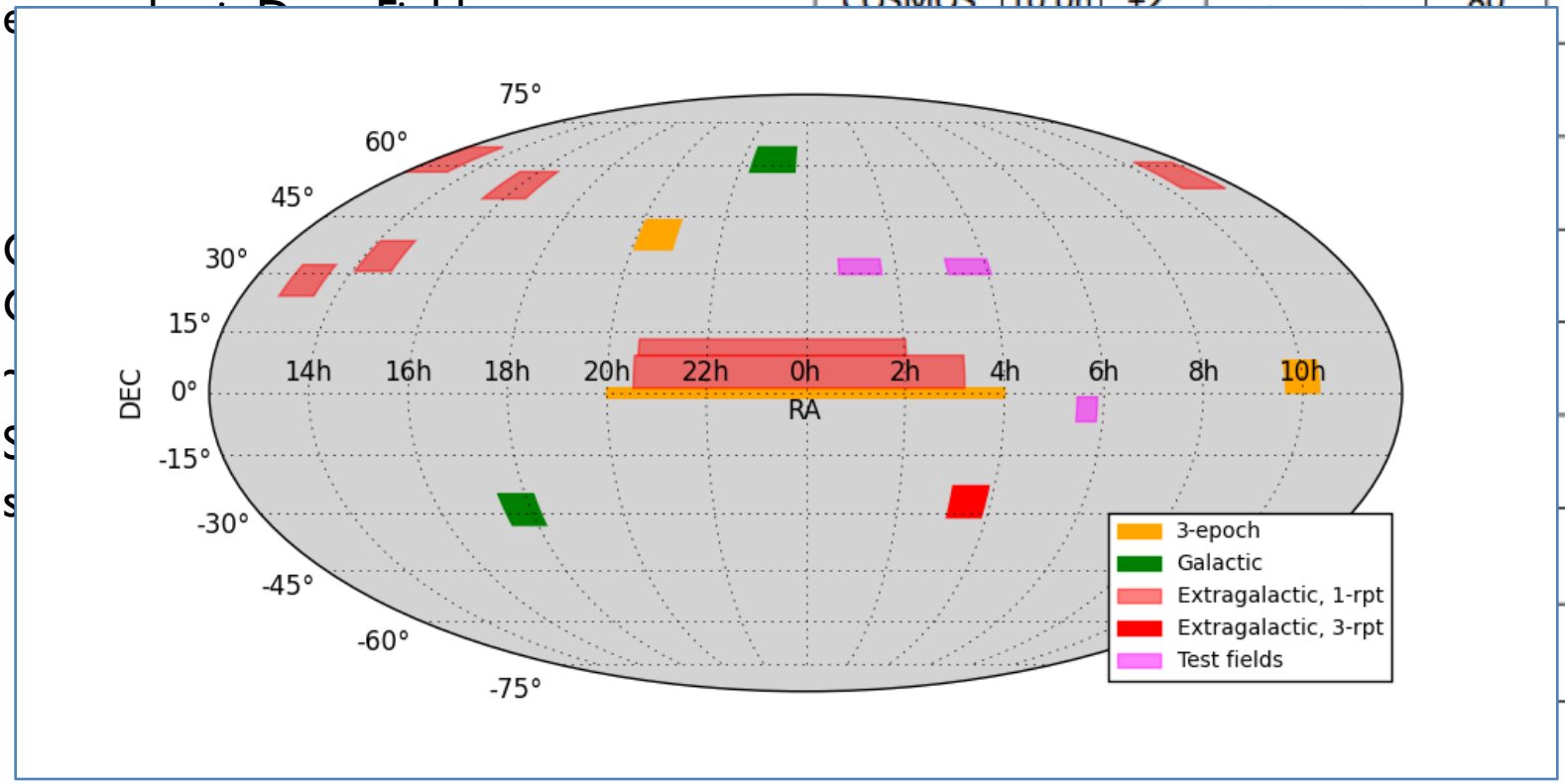
					12
					48
					68
					20



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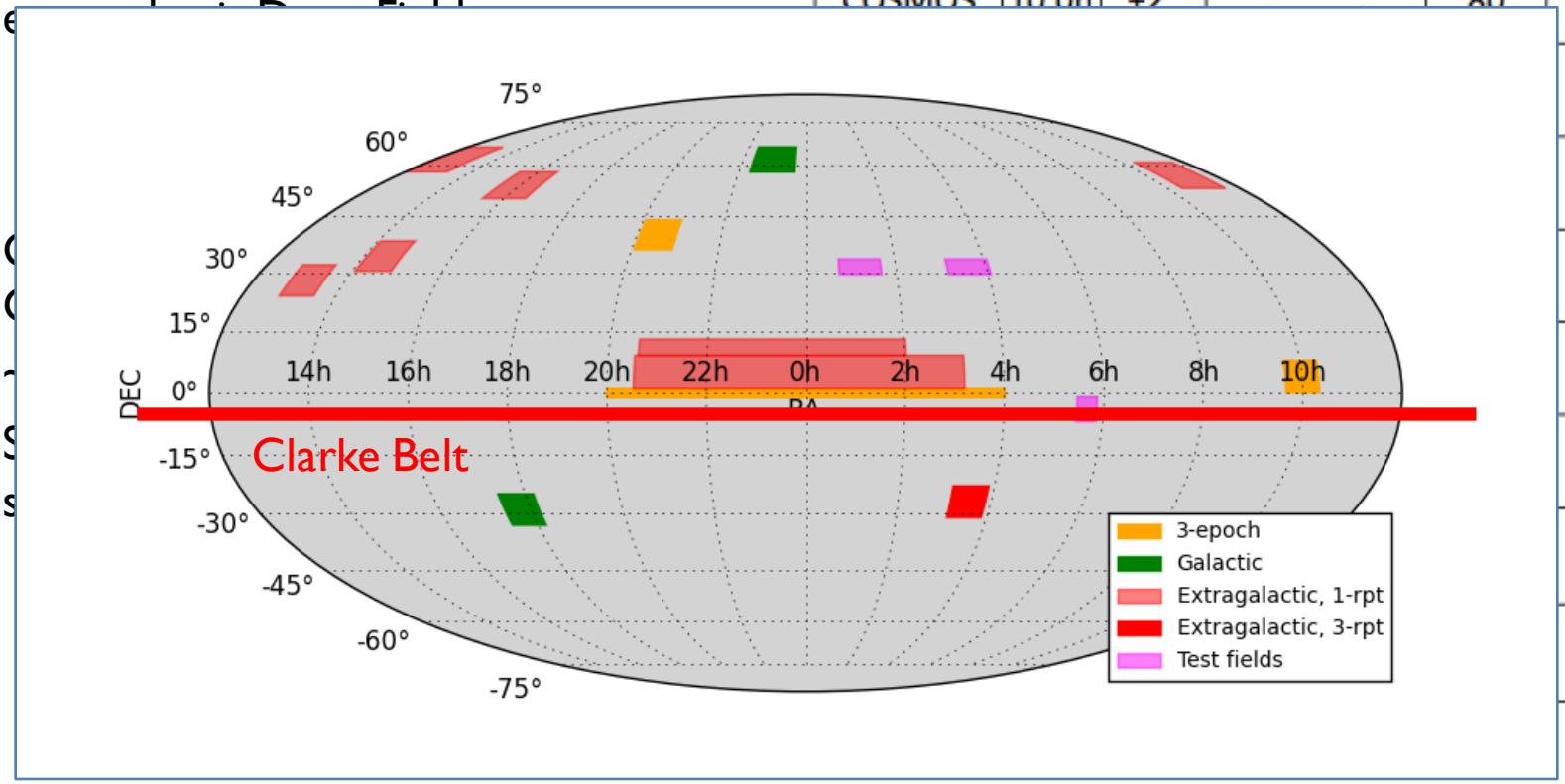
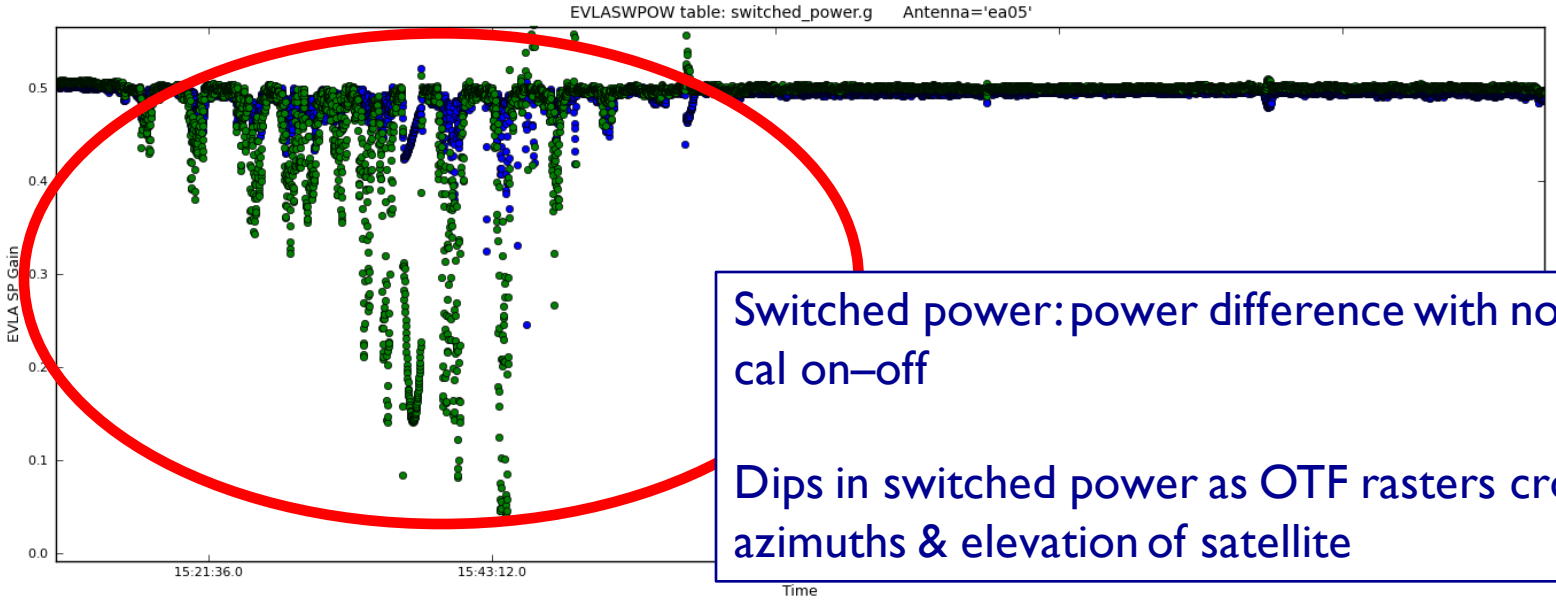


Impact of RFI: Orion test observations

- Clarke Belt is at $\delta \sim -5°$ from the VLA; test observation of Orion shows compression when encountering a geostationary satellite
  - Switched power data shows compression
  - Below: antenna #5 R and L polarizations



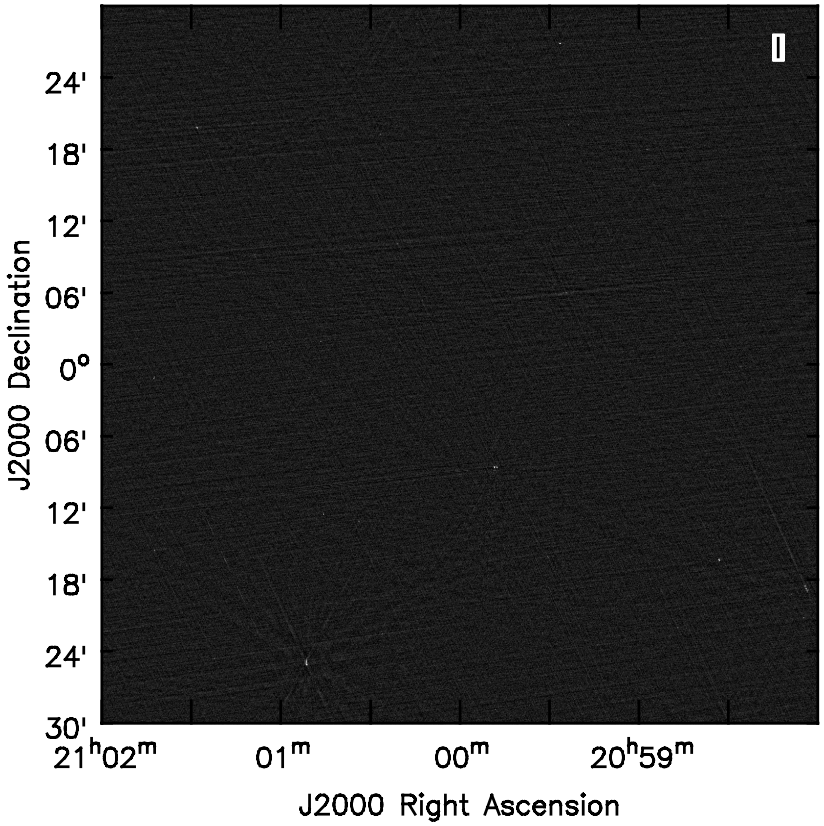
Switched power: power difference with noise cal on–off

Dips in switched power as OTF rasters cross azimuths & elevation of satellite

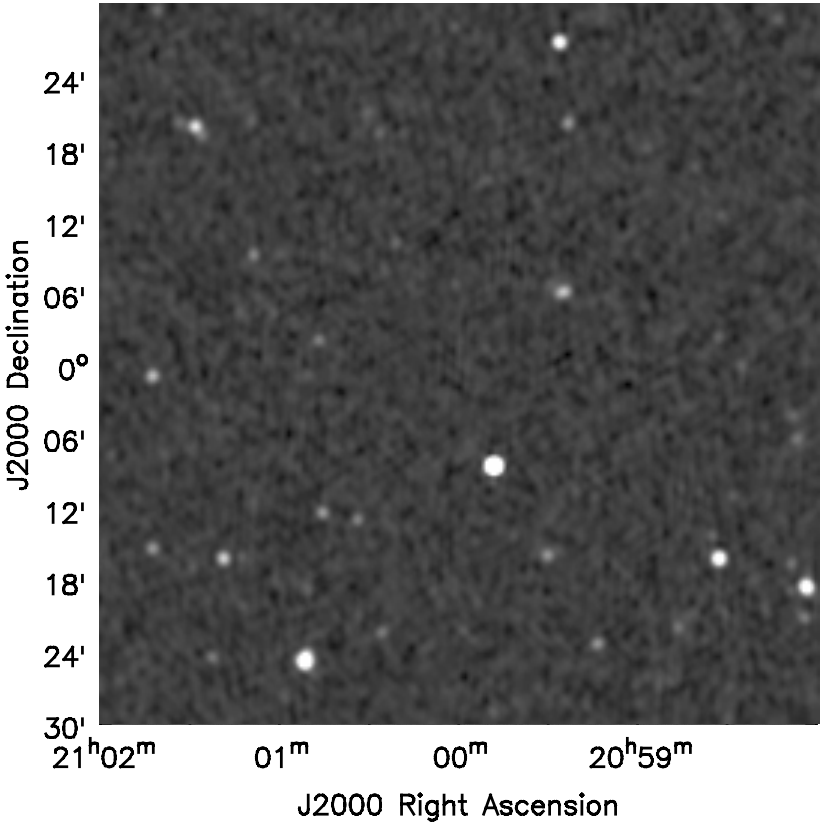
Stripe 82 at 2100+0000

- Example 1°x1° sub-mosaic

VLASS Pilot



NVSS



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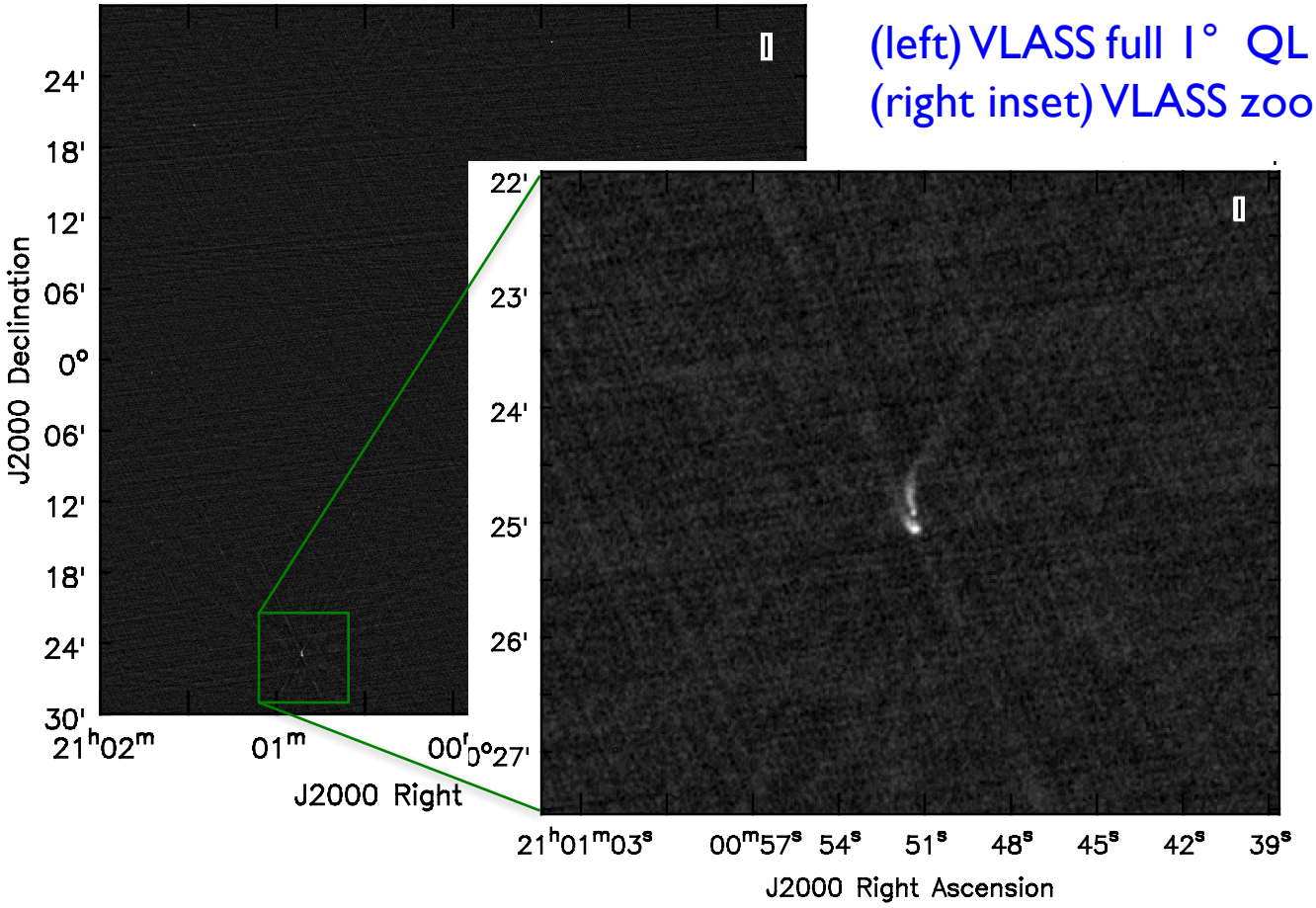
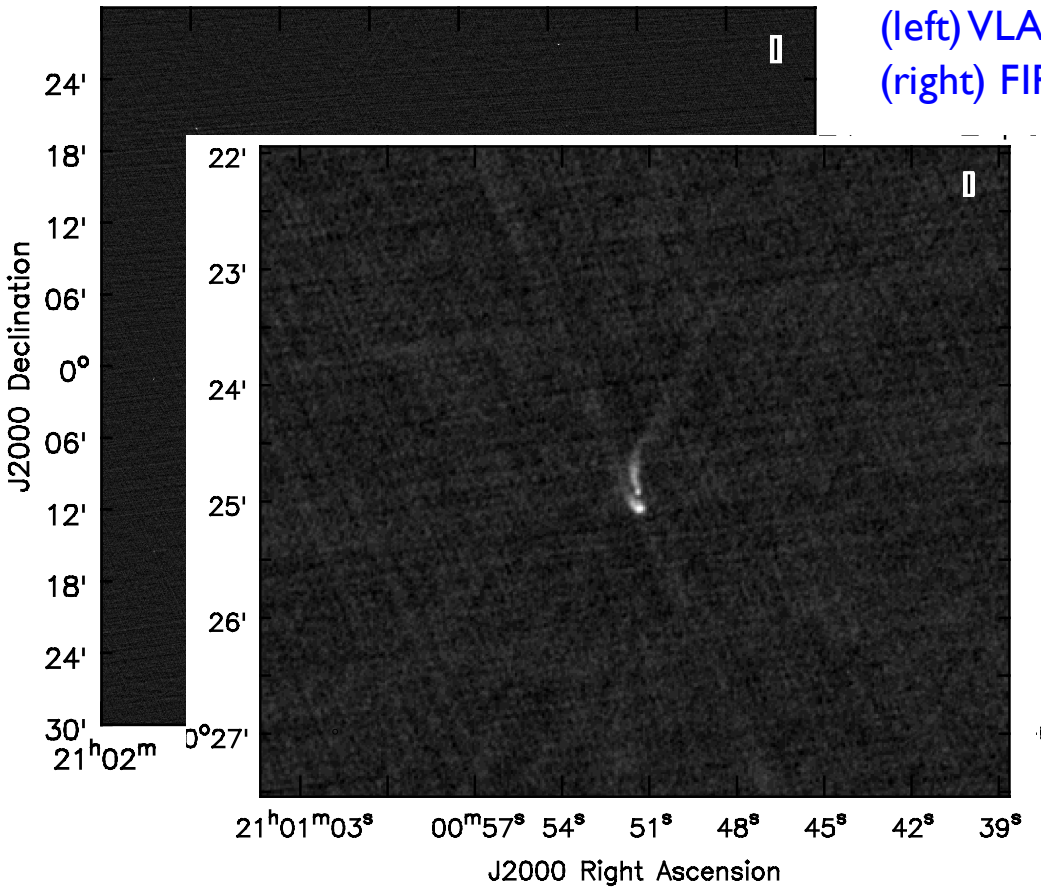


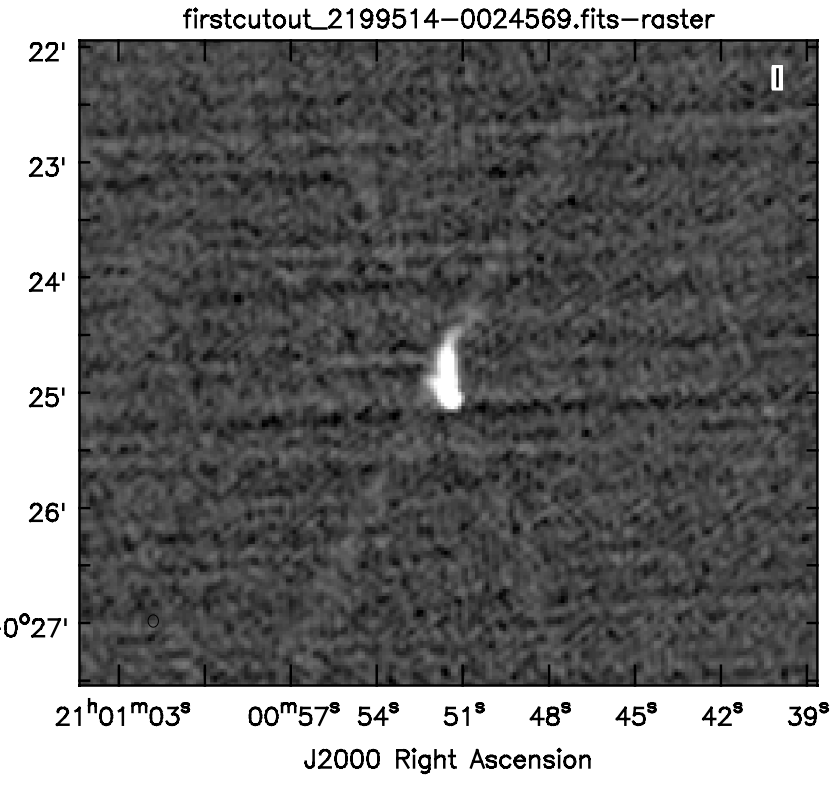
(left) VLASS full 1° QL image;
(right inset) VLASS zoom-in on extended source

Stripe 82 at 2100+0000

- Example 1°x1° sub-mosaic

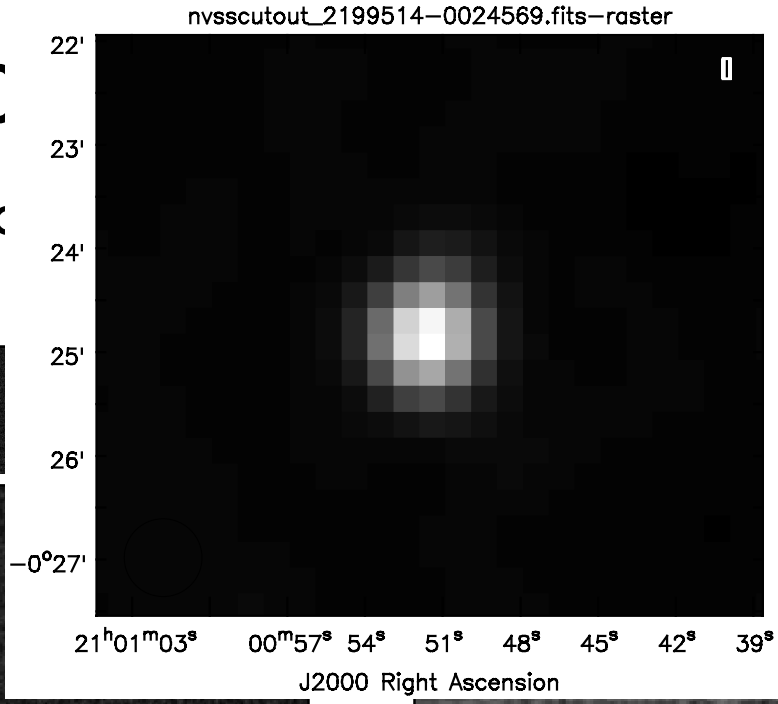


(left) VLASS full 1° QL image & zoom-in, 2.5";
(right) FIRST cutout image, 5" resolution



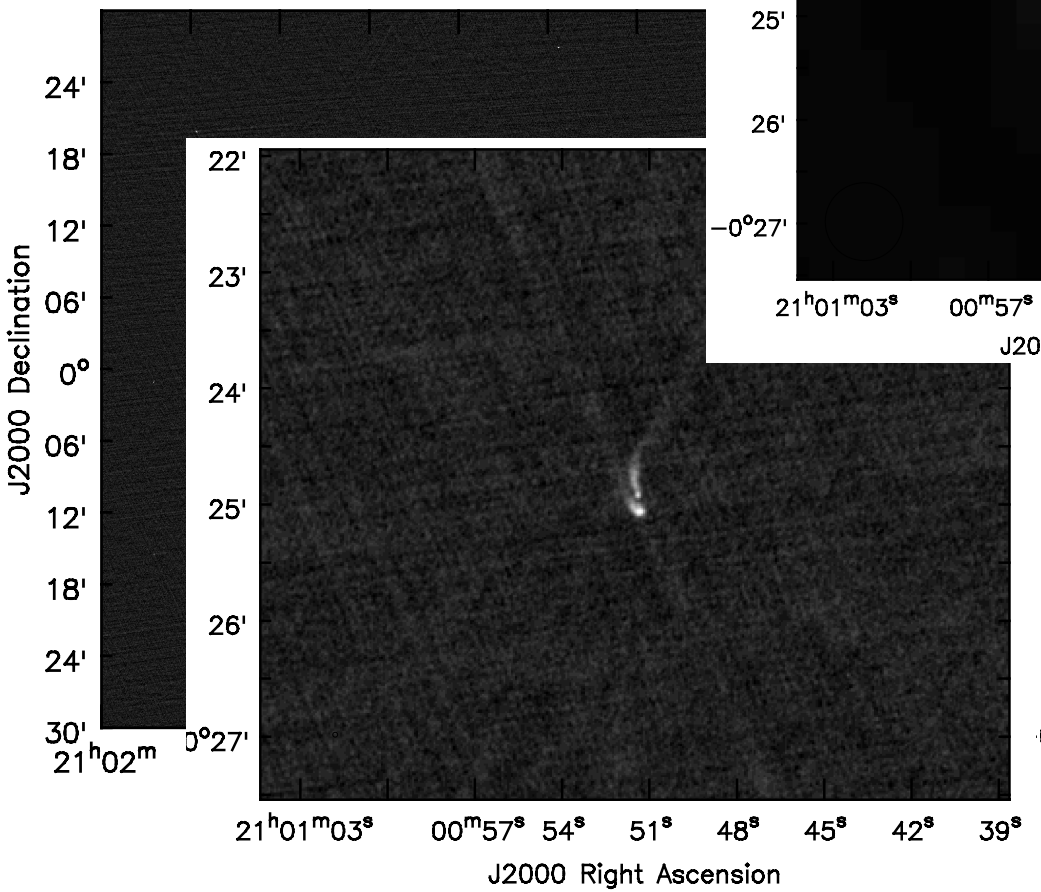
Stripe 82 at 2100+0

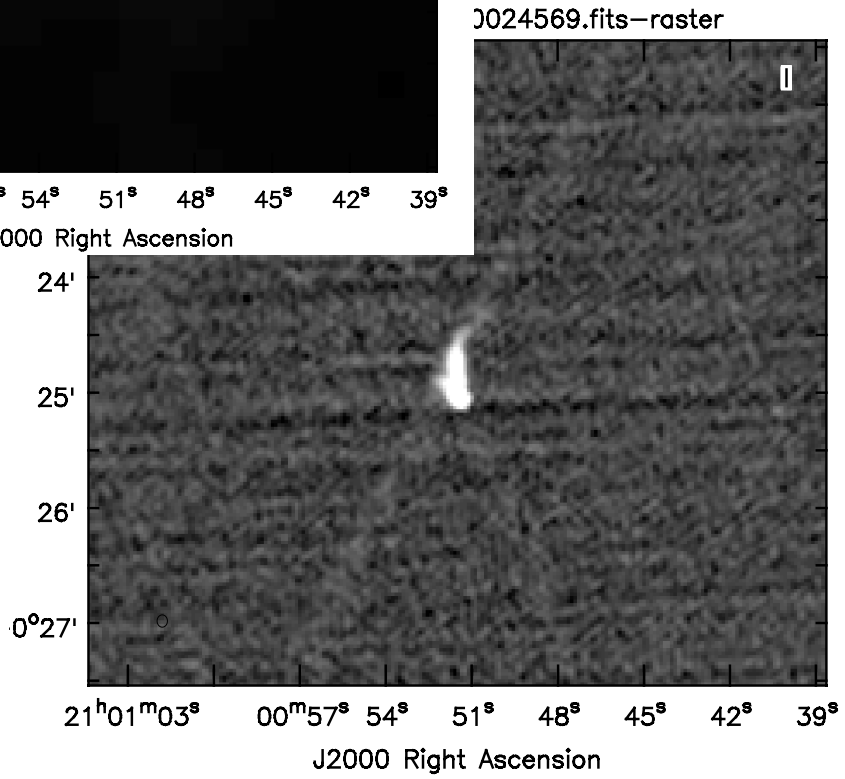
- Example 1°x1° sub-mo



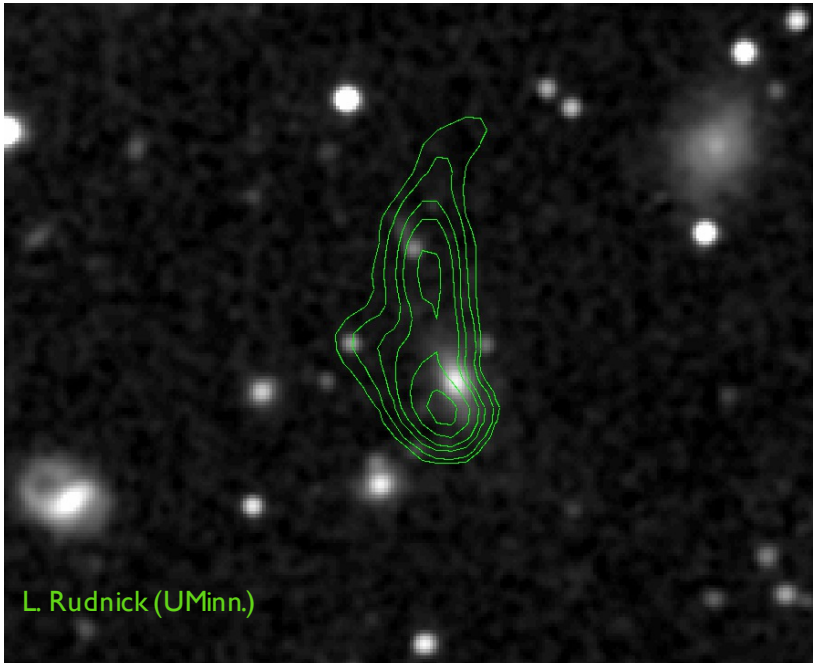
NVSS 45"

n-in, 2.5";
ution

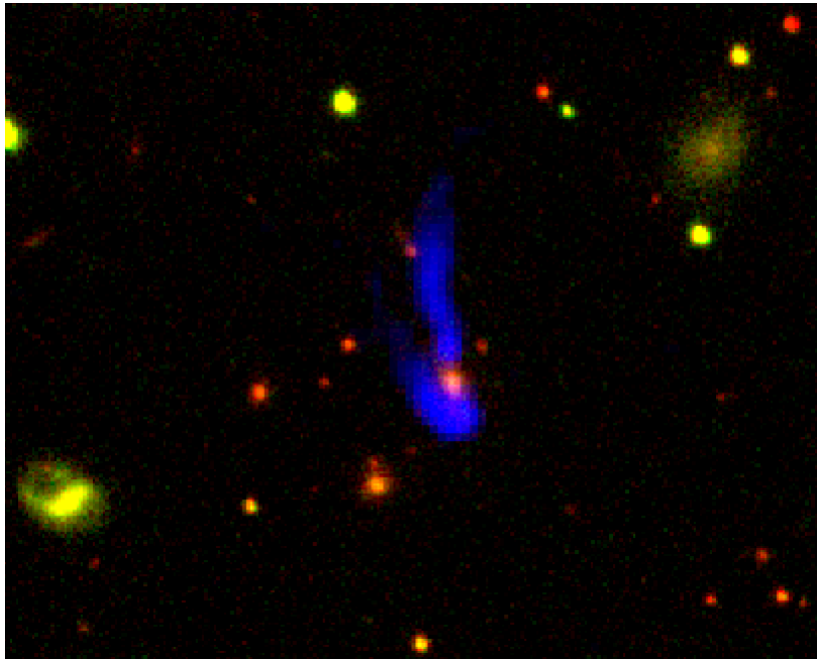




Resolution of VLASS enables association with optical galaxy



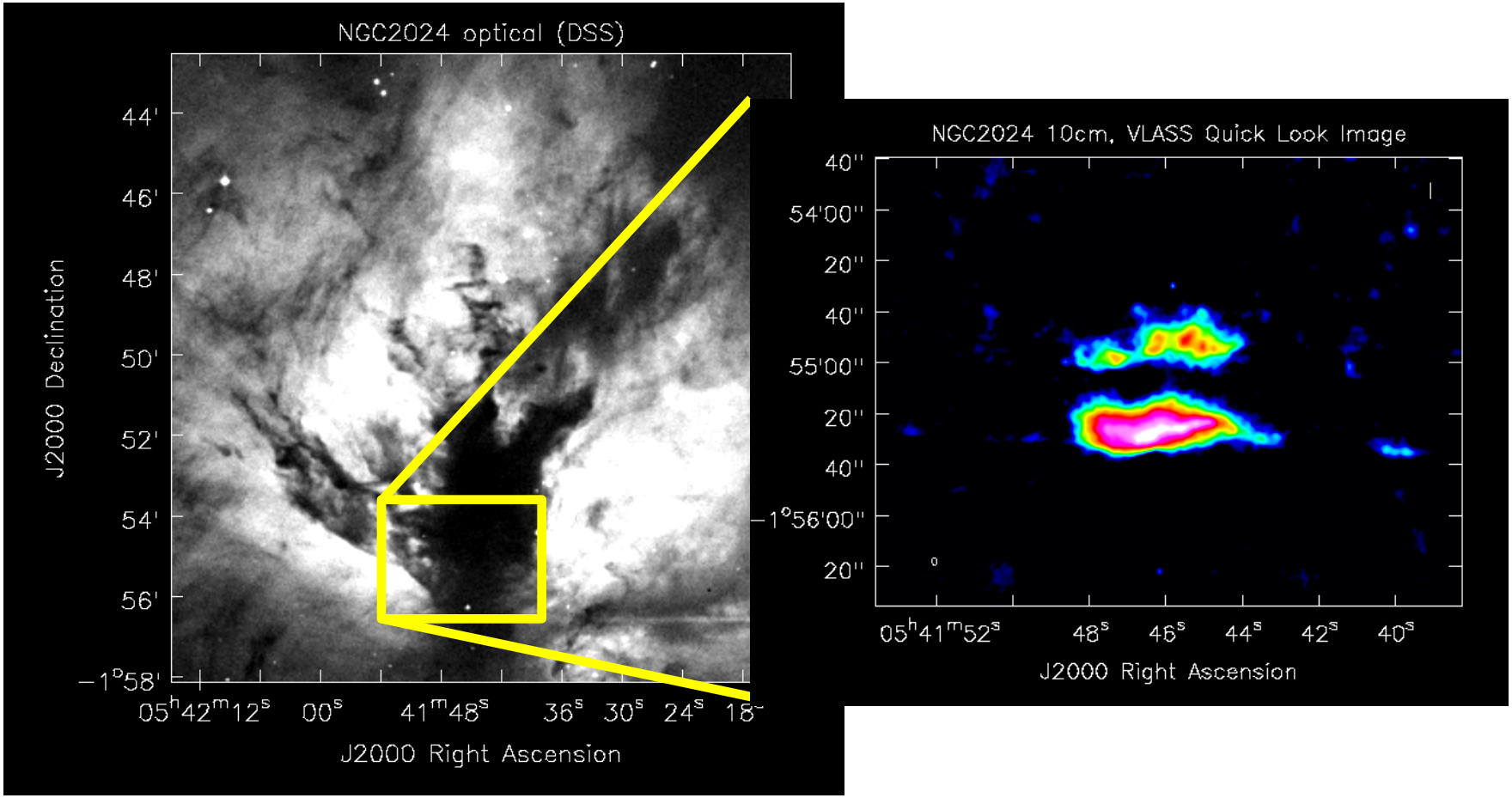
FIRST contours on SDSS



SDSS (red/green) image overlay on VLASS (blue). Improved VLASS resolution allows us to classify the radio source as a galaxy at z=0.25, possibly in a cluster.

Survey has sensitivity to scales from 2.5” to 20”

- NGC2024 (Flame Nebula), Orion B



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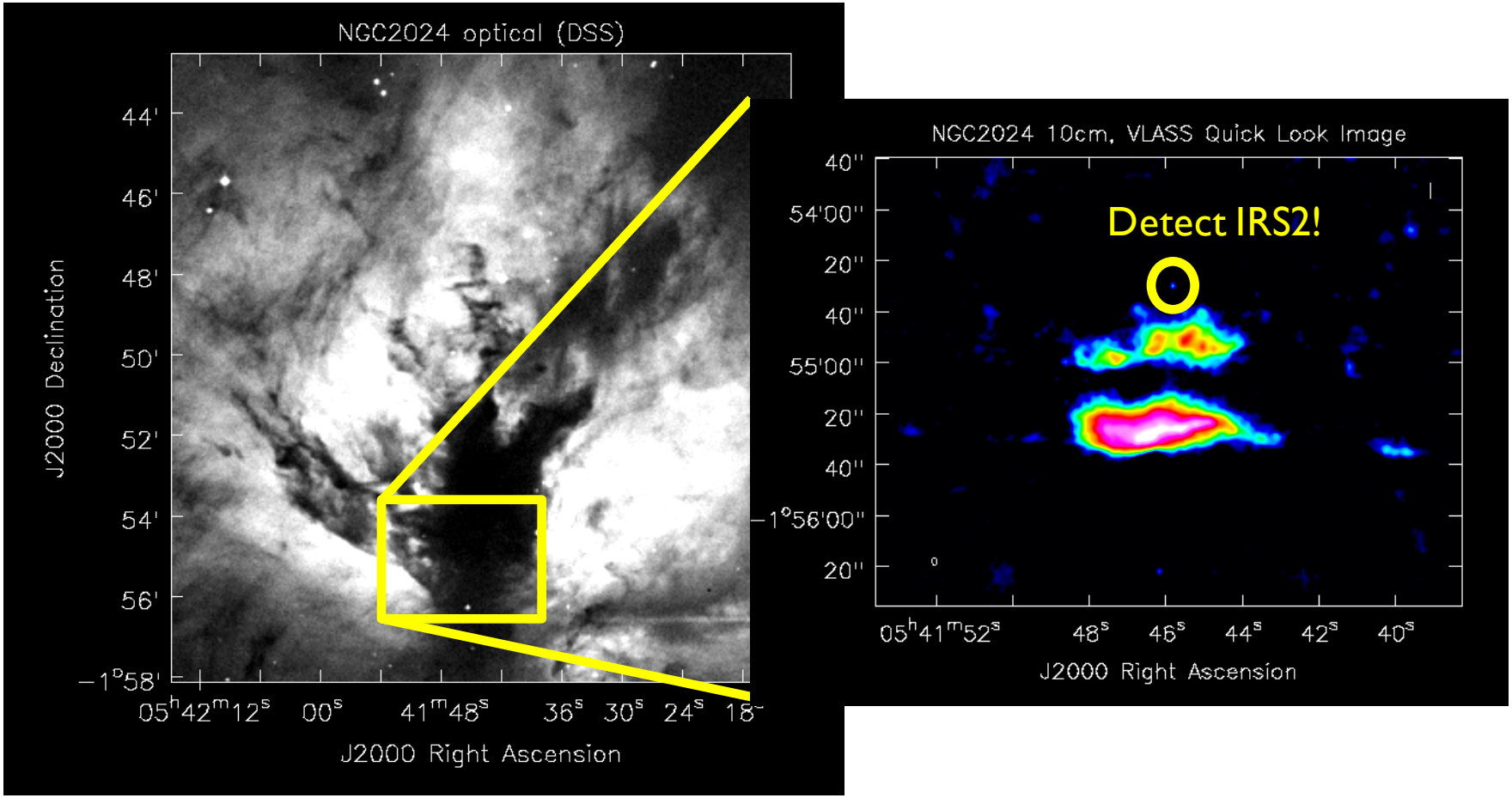
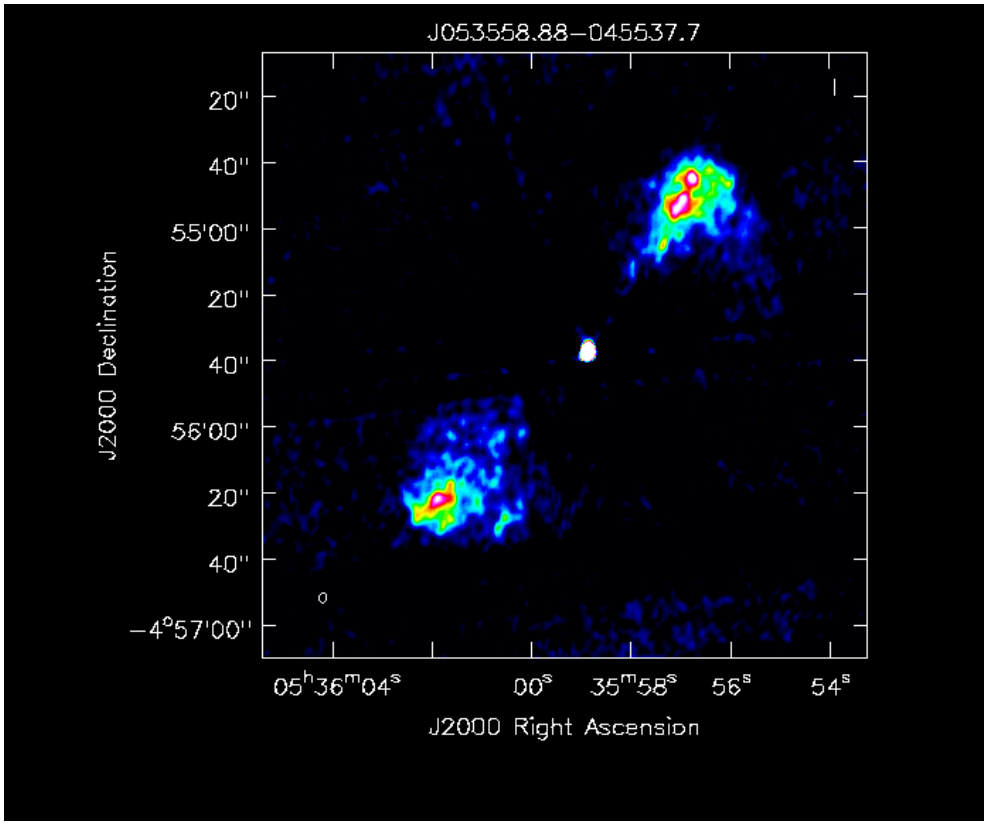


J053558.88–045537.7

- Identified as candidate Young Stellar Object in the literature, based on previous 6cm observations
  - Kounkel et al. 2014
- VLASS pilot/test data show it is an FRII radio galaxy



Summary

- The new VLA Sky Survey will be the highest spatial resolution, all-sky radio survey ever undertaken
  - Resolution critical for cross-identification with other wavelengths
  - Multi-epoch for identifying transients obscured at other wavelengths
  - Polarimetry to reveal the magnetic universe

- Next steps
  - Processing pilot data
  - Finalizing design
  - Preparing for design and operational readiness reviews
  - Start observing in the next B-configuration, September 2017!

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All-Sky comparisons (past)

Parameter	VLASS All Sky	VLA – NVSS	VLA – FIRST
Frequency (MHz)	2000 – 4000	1365, 1435	1365, 1435
Bandwidth (MHz)	2000	84 (2x42)	42 (2x21)
Area (sr)	3.3π	3.3π	π
RMS (μJy bm^{-1} / K) ✚	69 / 1.5	260 / 0.018	88 / 0.41
Resolution (")	2.5	45	5.4
Source Density (deg^{-2})	~280	~60	~100
Total Sources (10^6)	~10	~2	~1
Start Date	Sep 2017	Complete	Complete

✚ RMS values scaled to 3GHz assuming $S_\nu \sim \nu^\alpha$ where $\alpha = -0.7$

All-Sky comparisons (future)

Parameter	VLASS All-Sky	ASKAP/EMU	Apertif/ WODAN	LOFAR "Tier 1"
Frequency (MHz)	2000 – 4000	1130 – 1430	1130 – 1430	120 – 180
Bandwidth (MHz)	2000	300	300	50
Area (sr)	3.3π	3π	π	2π
RMS (μJy bm^{-1} / K)✚	69 / 1.5	20 / 0.016*	12 / 0.008	12 / 0.039
Resolution (")	2.5	10	14	6.5
Source Density (deg^{-2})	~280	~1460	~1480	~1360
Total Sources (10^6)	~10	~45	~15	~28
Start Date	Sep 2017	2017?	July 2016	Ongoing

Also note: Multiple epochs; full polarization at high resolution

✚ RMS values scaled to 3GHz assuming $S_\nu \sim \nu^\alpha$ where $\alpha = -0.7$

* Given current PAF performance and number of antennas expected, we assume 20 μJy bm^{-1} is more realistic than the goal 10 μJy bm^{-1}