Very Large Array Sky Survey

8th International Fermi Symposium
October 19, 2018
Ashley Zauderer

Acknowledgements

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Survey Implementation Working Group: Casey Law (Berkeley), Kunal Mooley (Oxford)

Data Products and Archiving Working Group: Eric Murphy (NRAO), Erik Rosolowsky (Alberta)

Expert Community Members at Large:

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Credit: Alex Savello

https://science.nrao.edu/science/surveys/vlass

Acknowledgements

VLASS team (NRAO):

Claire Chandler (VLASS Director)
Steve Meyers (Technical Lead)
Mark Lacy (Project Scientist)

Amy Kimball

Credit: Alex Savello

https://science.nrao.edu/science/surveys/vlass

Talk Overview

I. New VLASS science result
II. Radio Observations
III. Fermi-radio synergies
IV. VLA Sky Survey

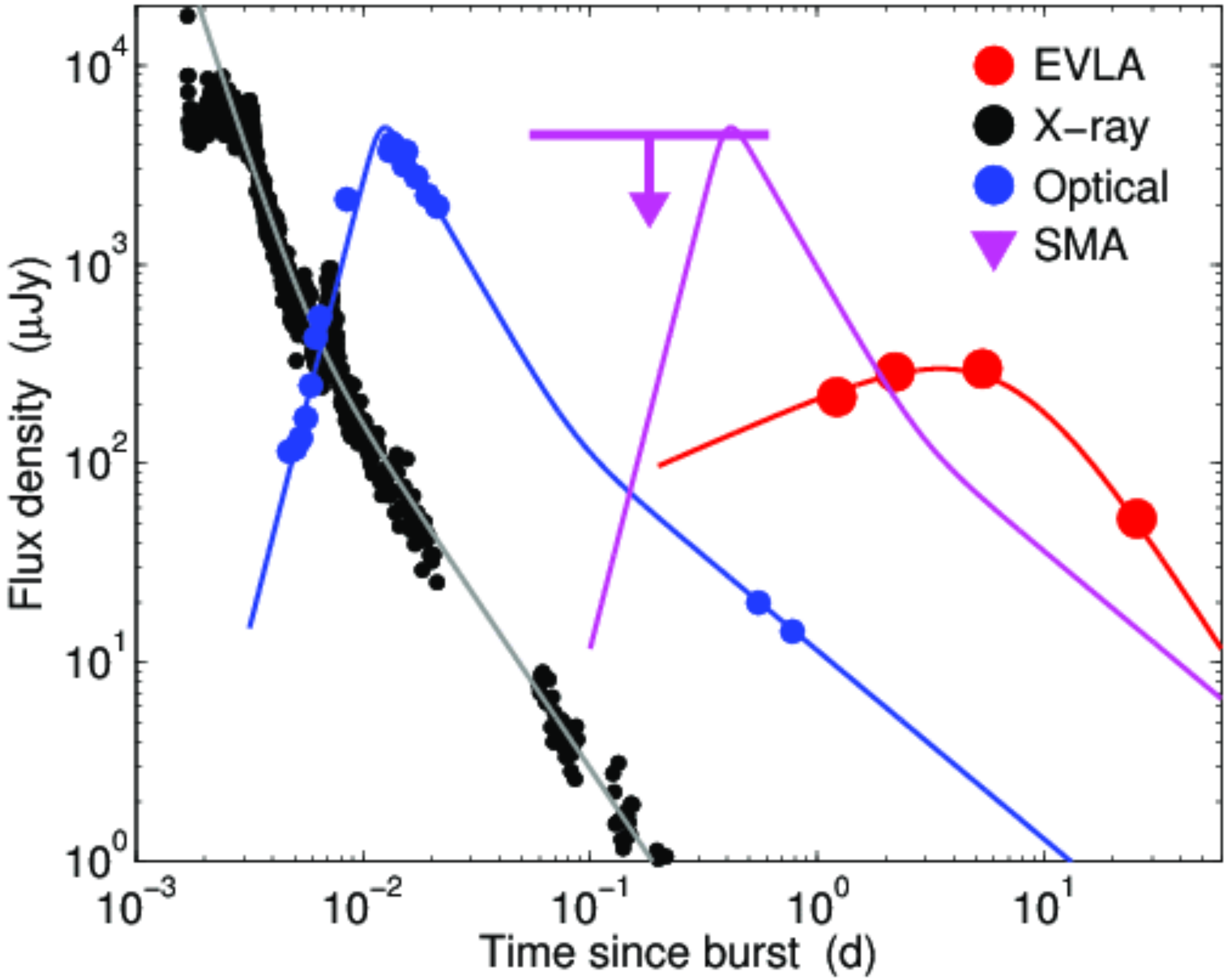
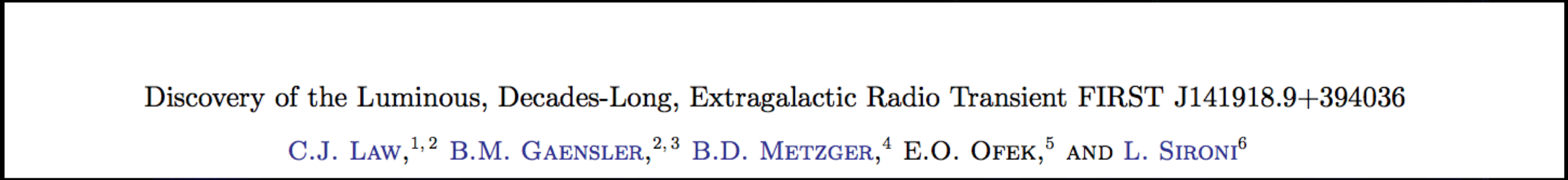
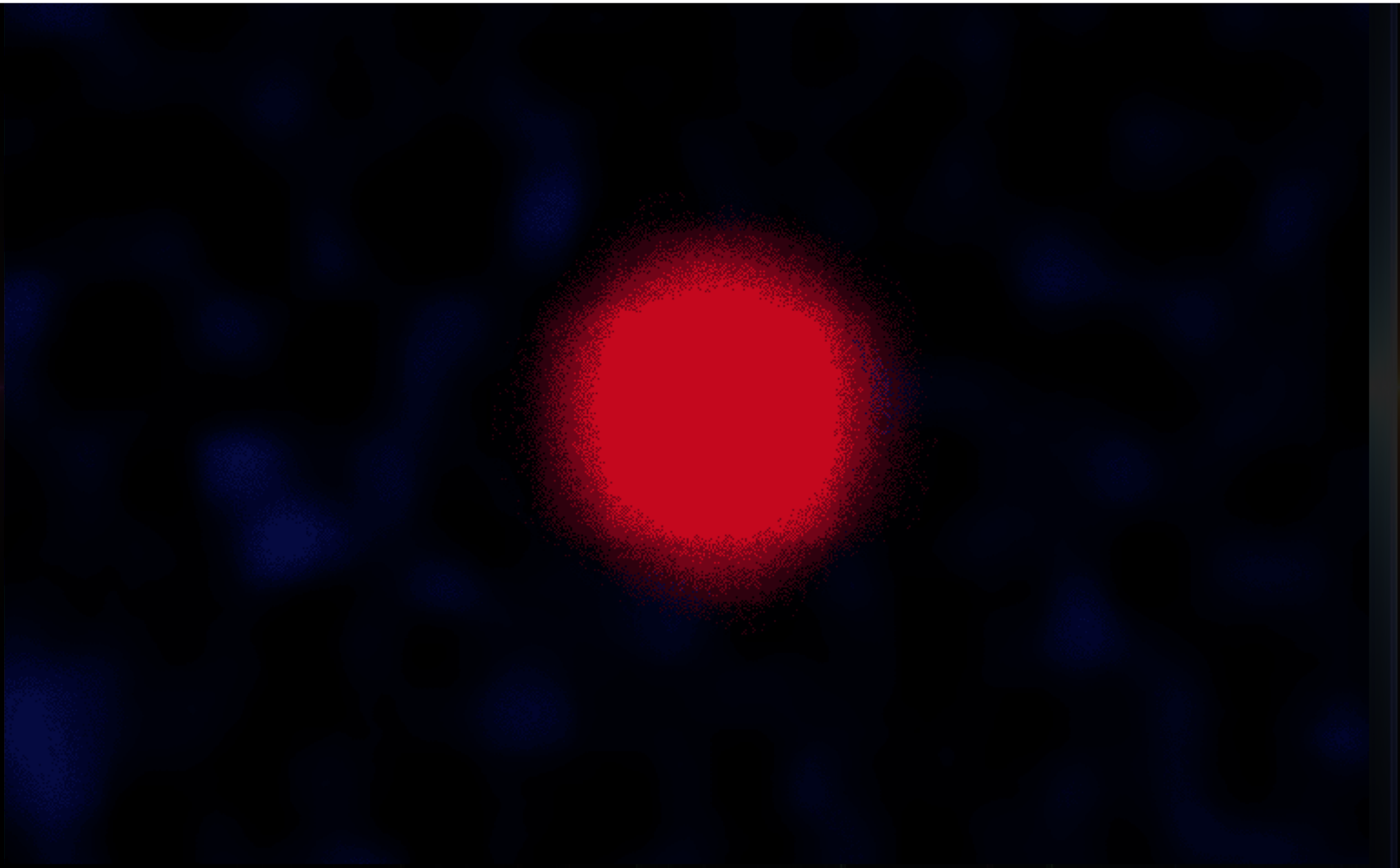


Figure: Tanmoy Laskar

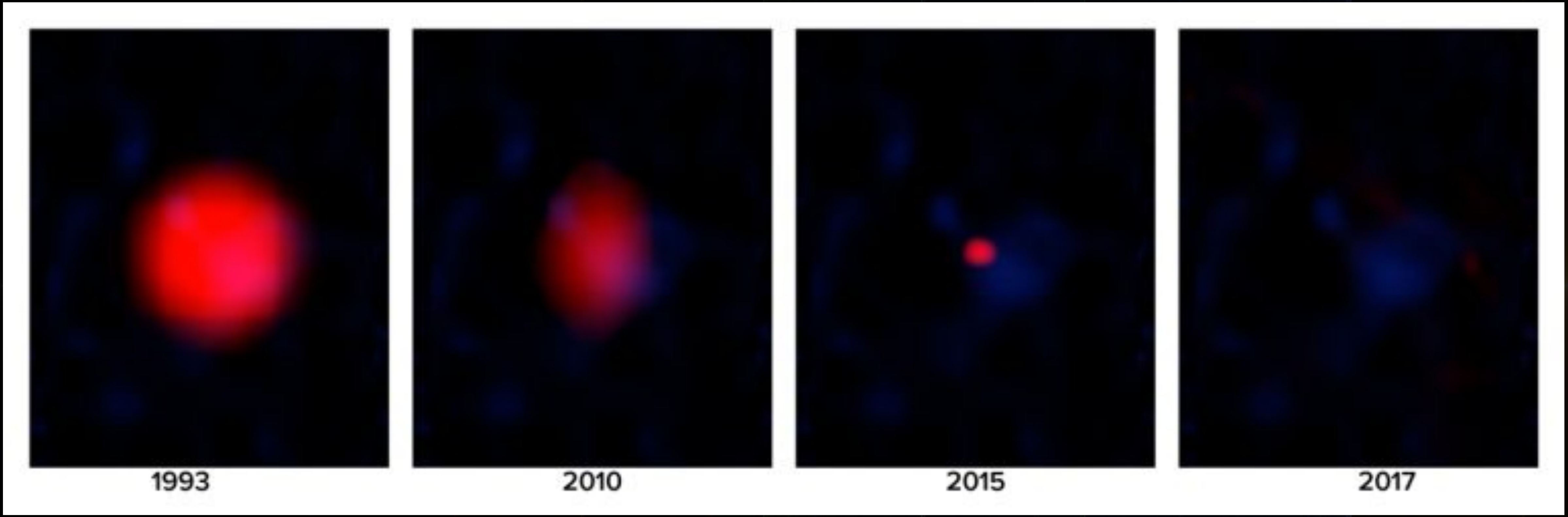


Discovery of the Luminous, Decades-Long, Extragalactic Radio Transient FIRST J141918.9+394036

C.J. Law,[1,2] B.M. Gaensler,[2,3] B.D. Metzger,[4] E.O. Ofek,[5] and L. Sironi[6]



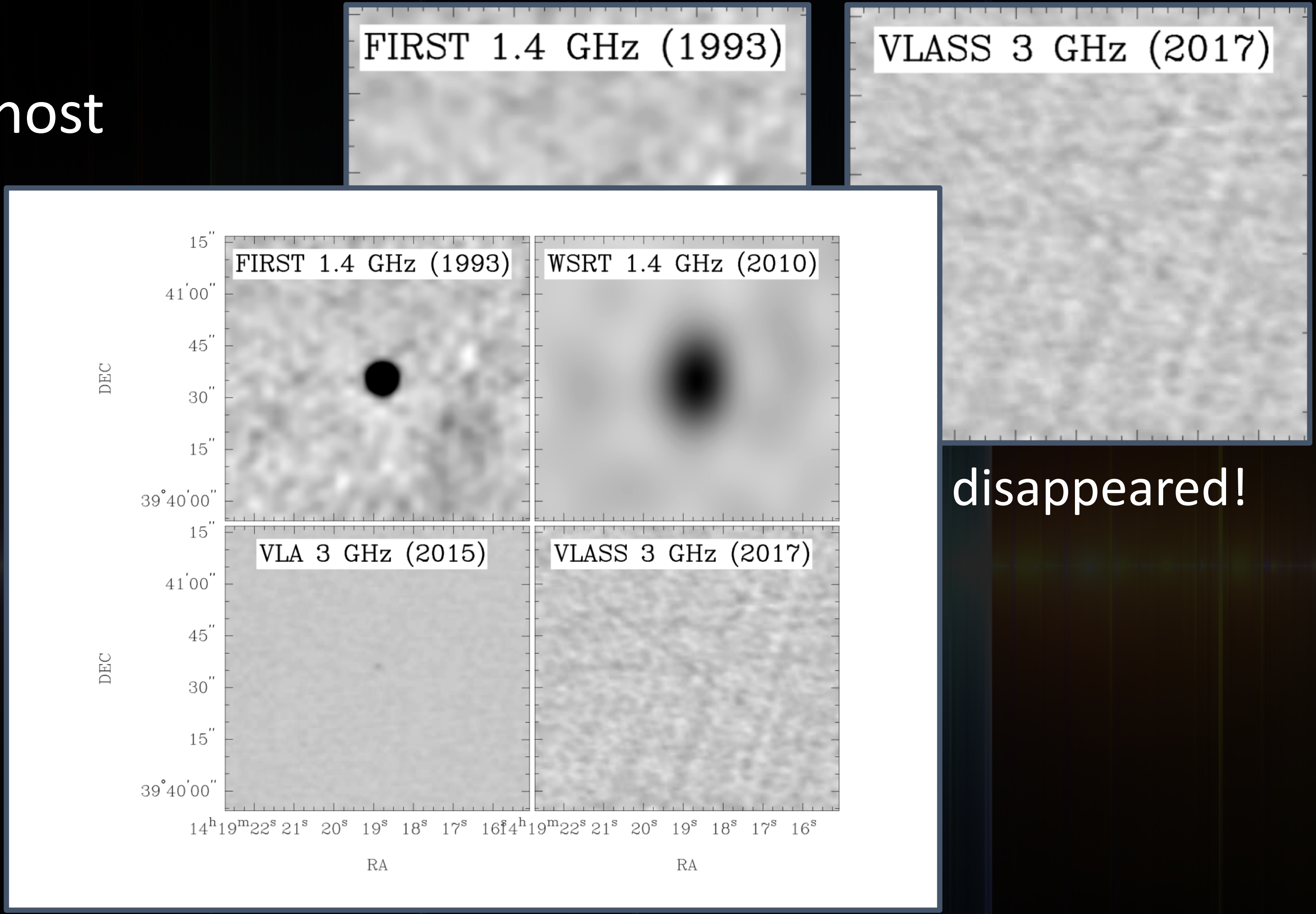
Visualization of FIRST J141918.9+394036 (credit: NRAO)



FIRST J1419+3940

Credit: Law et al., Bill Saxton, NRAO/AUI/NSF

- FIRST J141918.9+394036 in host galaxy at 87 Mpc



disappeared!

Four views of FIRST J141918.9+394036

What Is It?

Casey Law (UC Berkeley)

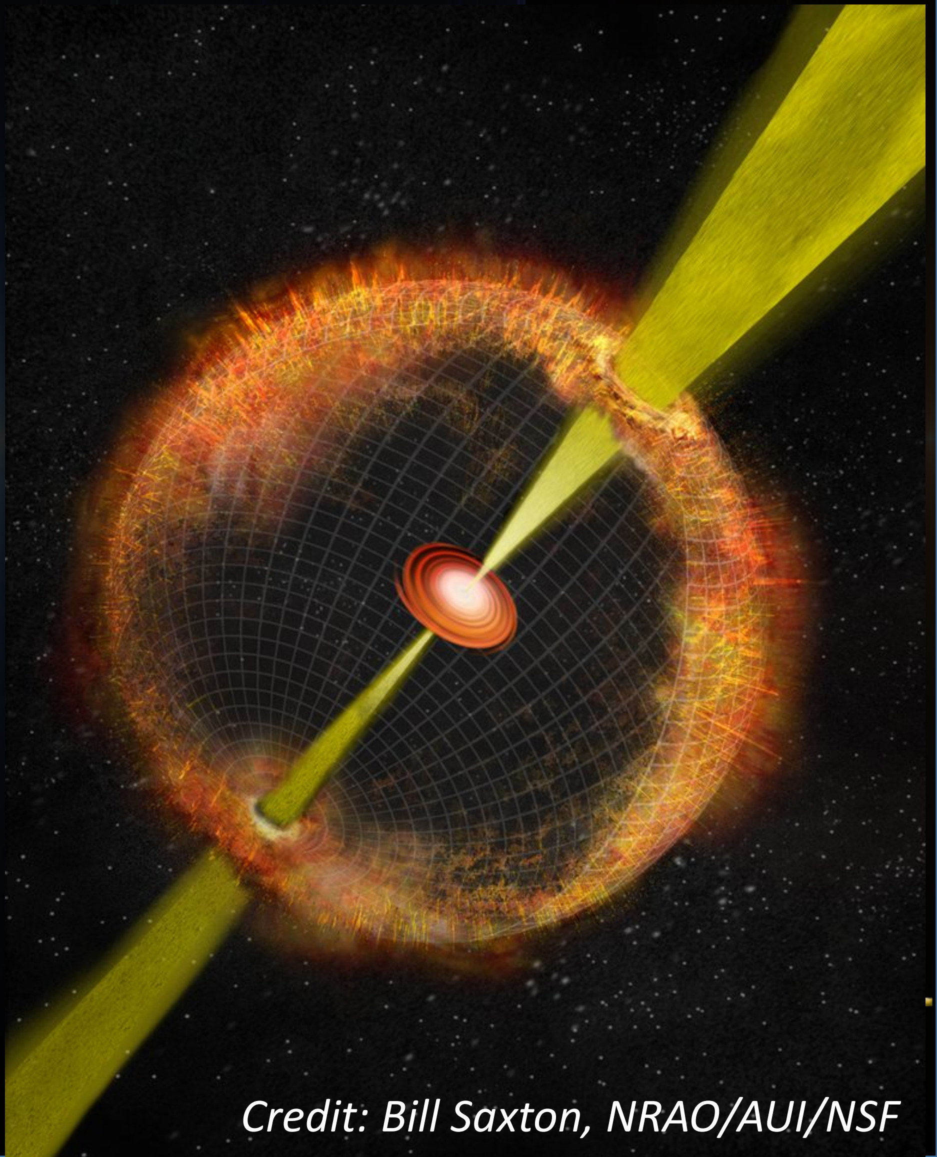
with Bryan Gaensler (Dunlap/Toronto), Brian Metzger (Columbia),
Eran Ofek (Weizmann), Lorenzo Sironi (Columbia)

- Orphan GRB
  - Luminosity and timescale
  - Spectral index change
  - High-energy limits
  - Host galaxy type and star-formation
  - Volumetric rate
- Magnetar powered supernova
  - Volumetric rate is a bit high for GRB
  - Host and star forming region similar to FRB 121102 and SLSN hosts
  - Explosion would be ~decades earlier than first detection (Margalit & Metzger 2018)

Unification via Magnetar Birth

Casey Law (UC Berkeley)
with Bryan Gaensler (Dunlap/Toronto), Brian Metzger (Columbia),
Eran Ofek (Weizmann), Lorenzo Sironi (Columbia)

- J1419 may be a rosetta stone for unification of multiple classes of astrophysical transient
- SLSN, GRBs, FRBs as signatures of magnetar birth
- Were we lucky or are there more slow, luminous transients out there?



Credit: Bill Saxton, NRAO/AUI/NSF

Talk Overview

I. New VLASS science result
II. **Radio Observations**
III. Fermi-radio synergies
IV. VLA Sky Survey

Sources of radio emission:

Expanding H II regions

Thermal

Non-thermal coherent

Synchrotron

- Novae
- Symbiotic Stars

Slide courtesy
Laura Chomiuk, MSU

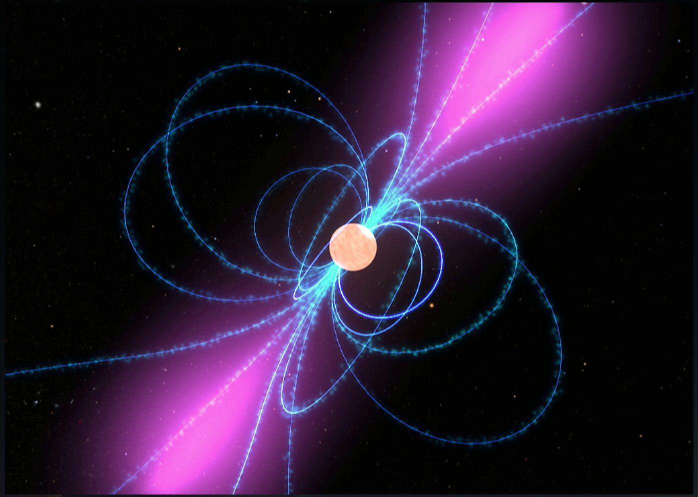
Sources of radio emission:

‘Fast’ radio transients (<~ 1 sec duration)

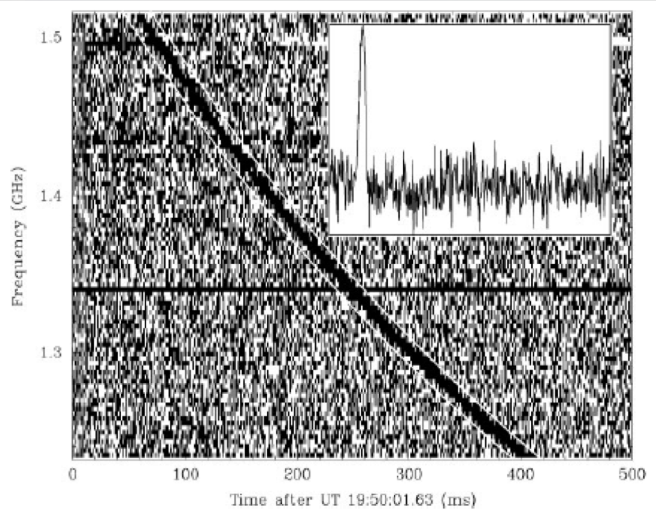
Thermal

Non-thermal coherent

Synchrotron



- Pulsars
- Flare Stars



Different strategies used to study these---but can be complementary with searches for ‘slow’ transients (>1 sec)

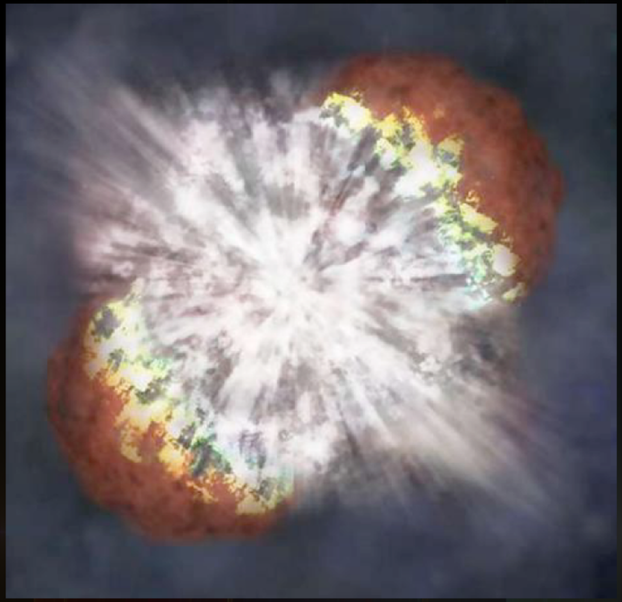
Slide courtesy
Laura Chomiuk, MSU

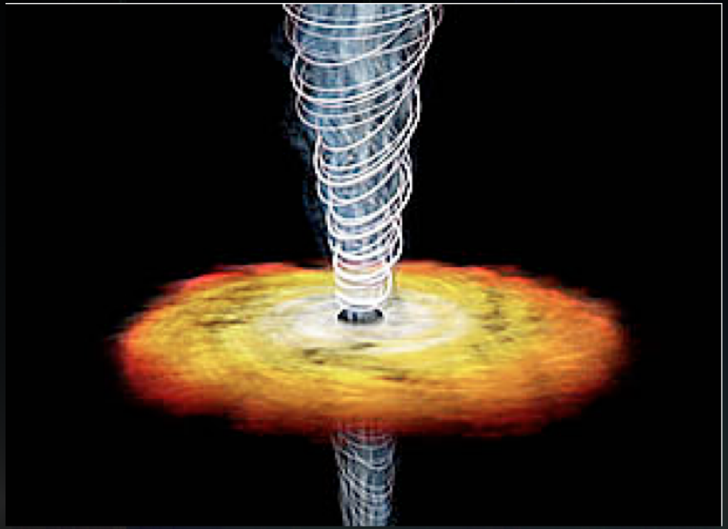
Sources of radio emission:

Thermal

Non-thermal coherent

Synchrotron

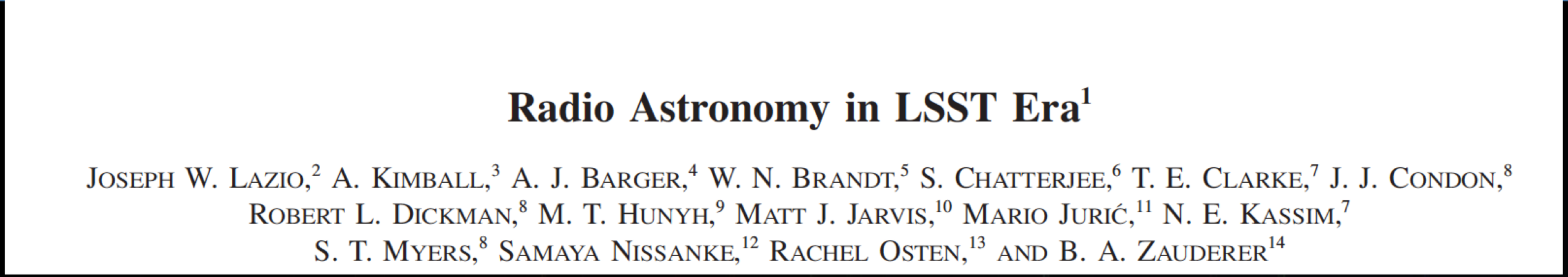




- Gamma-ray bursts
- Supernovae
- X-ray binaries
- (Jetted) Tidal disruption events

(the majority of 'slow' radio transients)

Slide courtesy
Laura Chomiuk, MSU



Radio Astronomy in LSST Era[1]

Joseph W. Lazio,[2] A. Kimball,[3] A. J. Barger,[4] W. N. Brandt,[5] S. Chatterjee,[6] T. E. Clarke,[7] J. J. Condon,[8]
Robert L. Dickman,[8] M. T. Hunyh,[9] Matt J. Jarvis,[10] Mario Jurić,[11] N. E. Kassim,[7]
S. T. Myers,[8] Samaya Nissanke,[12] Rachel Osten,[13] and B. A. Zauderer[14]

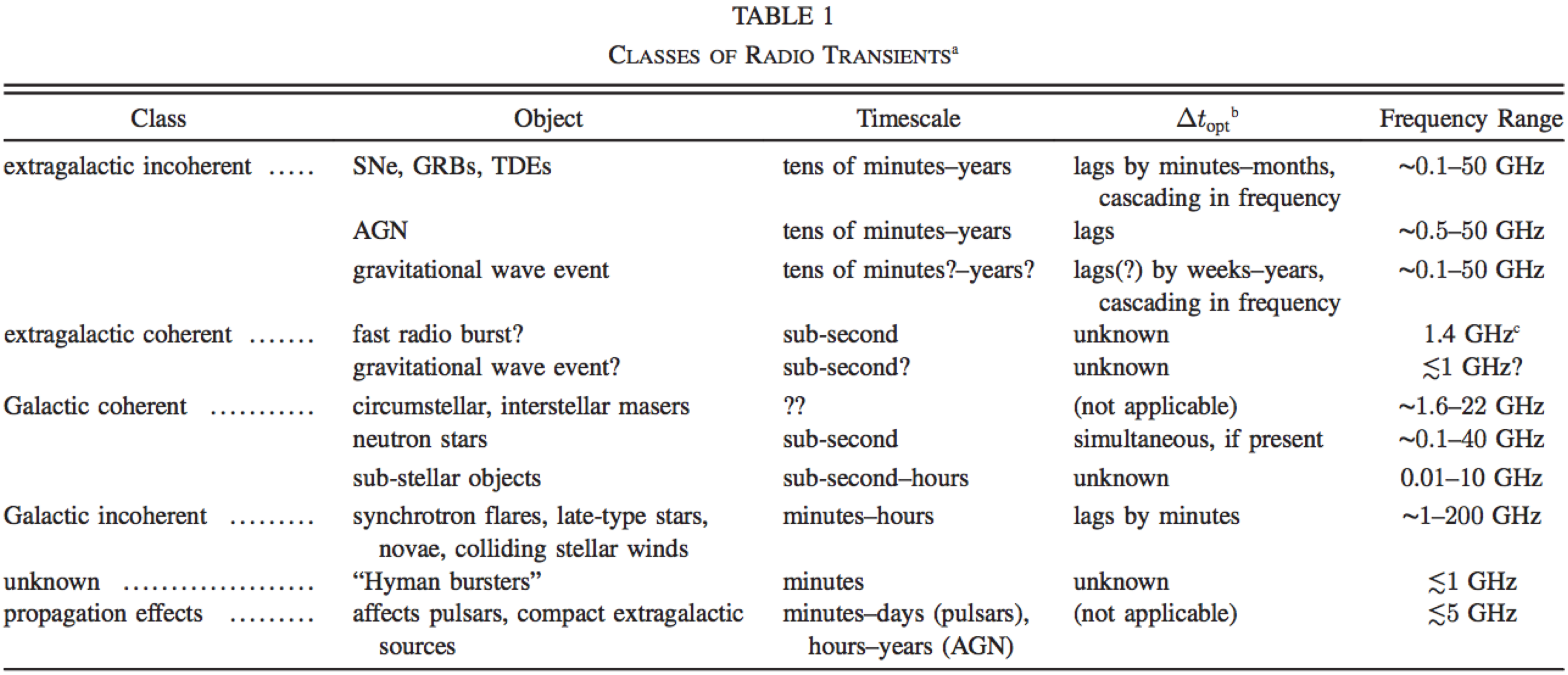
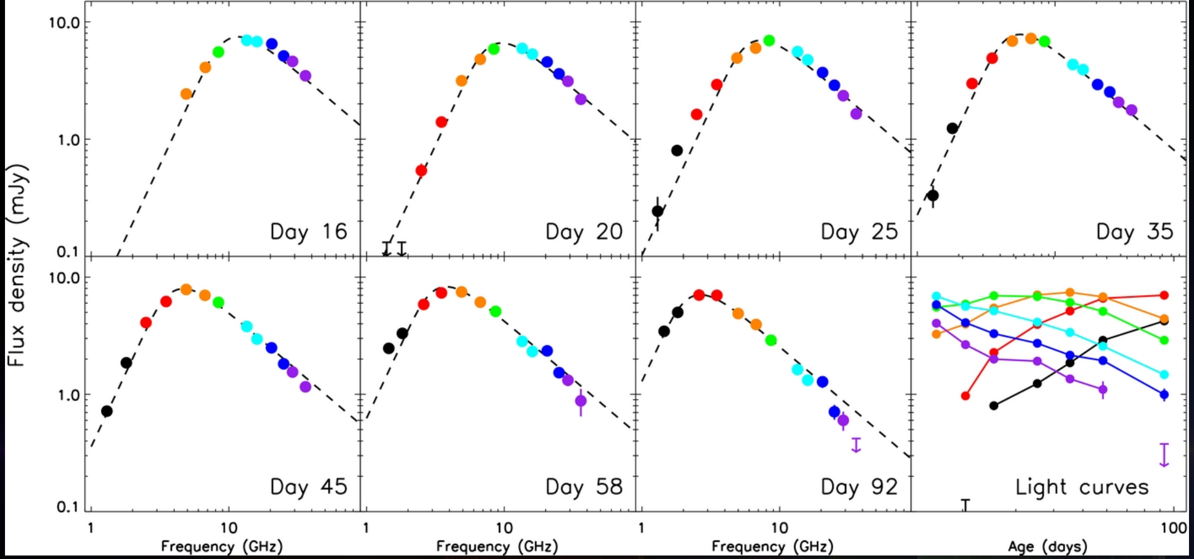


TABLE 1

Classes of Radio Transients[a]

Class	Object	Timescale	$\Delta t_{\rm opt}$[b]	Frequency Range
extragalactic incoherent	SNe, GRBs, TDEs	tens of minutes–years	lags by minutes–months, cascading in frequency	~0.1–50 GHz
	AGN	tens of minutes–years	lags	~0.5–50 GHz
	gravitational wave event	tens of minutes?–years?	lags(?) by weeks–years, cascading in frequency	~0.1–50 GHz
extragalactic coherent	fast radio burst?	sub-second	unknown	1.4 GHz[c]
	gravitational wave event?	sub-second?	unknown	$\lesssim$1 GHz?
Galactic coherent	circumstellar, interstellar masers	??	(not applicable)	~1.6–22 GHz
	neutron stars	sub-second	simultaneous, if present	~0.1–40 GHz
	sub-stellar objects	sub-second–hours	unknown	0.01–10 GHz
Galactic incoherent	synchrotron flares, late-type stars, novae, colliding stellar winds	minutes–hours	lags by minutes	~1–200 GHz
unknown	"Hyman bursters"	minutes	unknown	$\lesssim$1 GHz
propagation effects	affects pulsars, compact extragalactic sources	minutes–days (pulsars), hours–years (AGN)	(not applicable)	$\lesssim$5 GHz

Synchrotron Emission



SN 2011dh – Type IIb

Krauss et al. ApJL, 750, 250 (2012)

See also Horesh et al. (2012)
Soderberg et al. ApJ, 752, 78 (2012)

Timing of observations important

Chevalier, ApJ, 499, 810 (1998)
“Synchrotron Self-Absorption in Radio Supernovae"

Granot & Sari, ApJ, 568, 820 (2002)
“The Shape of Spectral Breaks in Gamma-Ray Burst Afterglows”

Duran, Nakar & Piran, arXiv:1301:6759 (2013)
“Radius constraints and minimal equipartition energy of relativistically moving synchrotron sources”

See also NYU Afterglow library
Hydrodynamic simulations (UCSC)

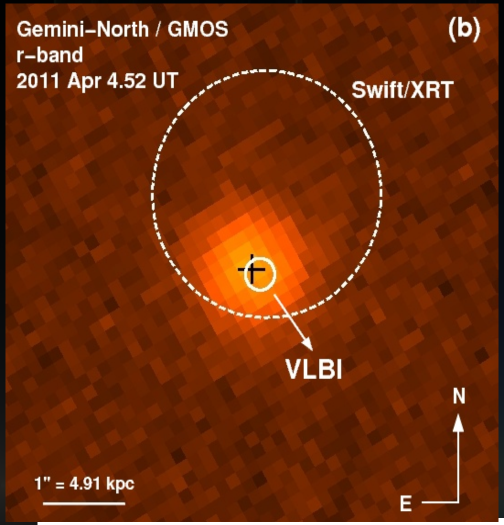
Information from Radio Synchrotron

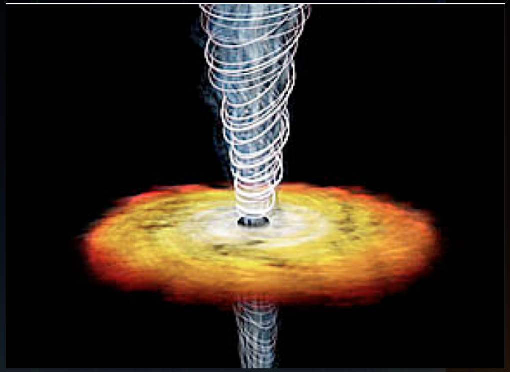
Localization

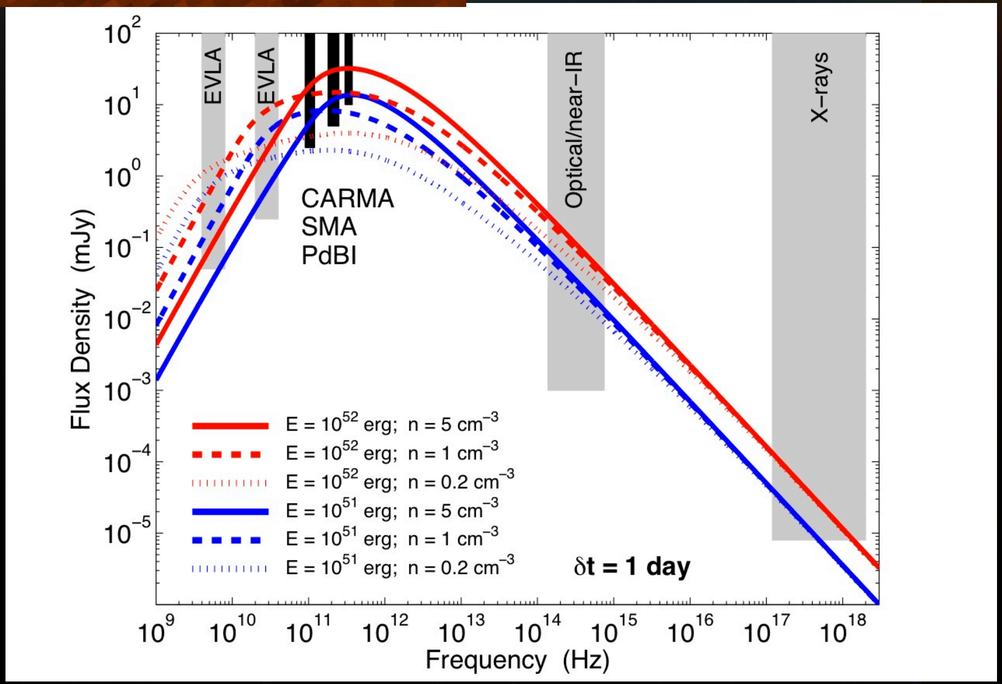
Circumburst density

Velocity / energy scale
- -Beaming
- -radius constraints and size evolution

Magnetic field strength/ outflow line-of-sight orientation (via polarization)

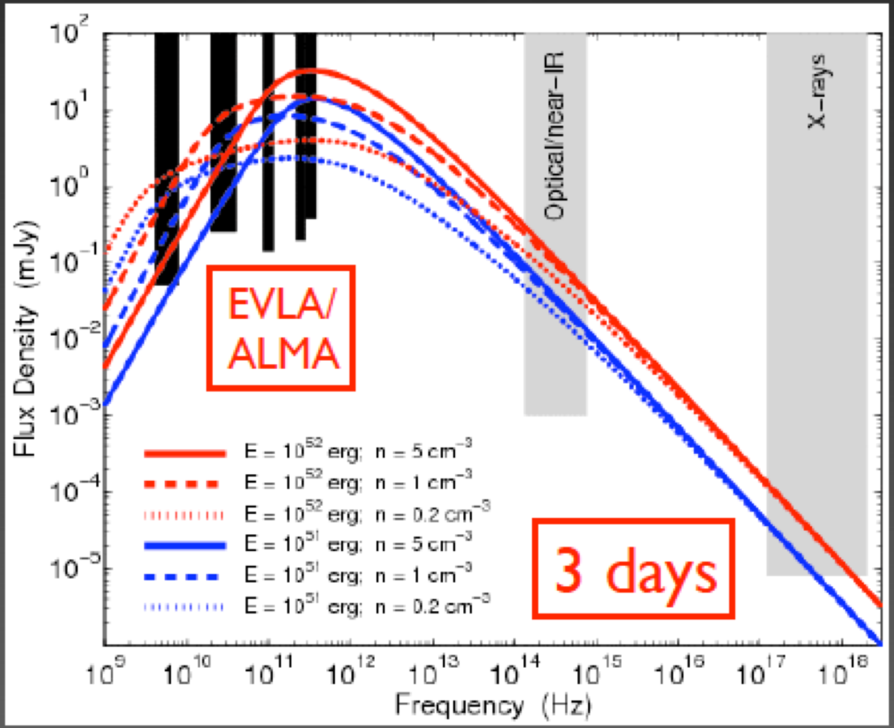


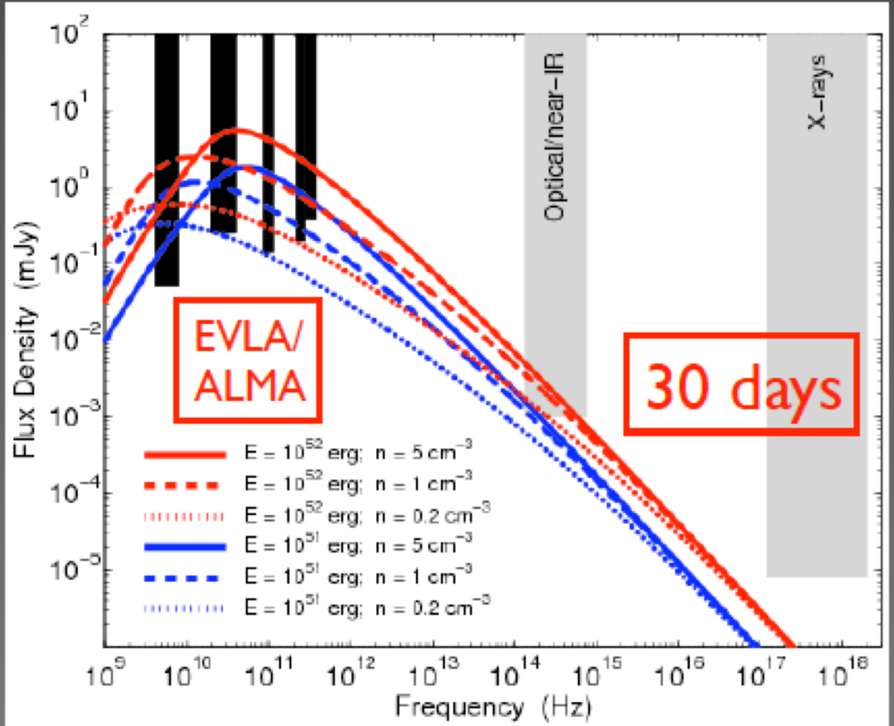




Environment: Circumstellar Environment

cm/mm observations (EVLA/ALMA) uniquely determine the density profile (optical/X-ray degenerate)





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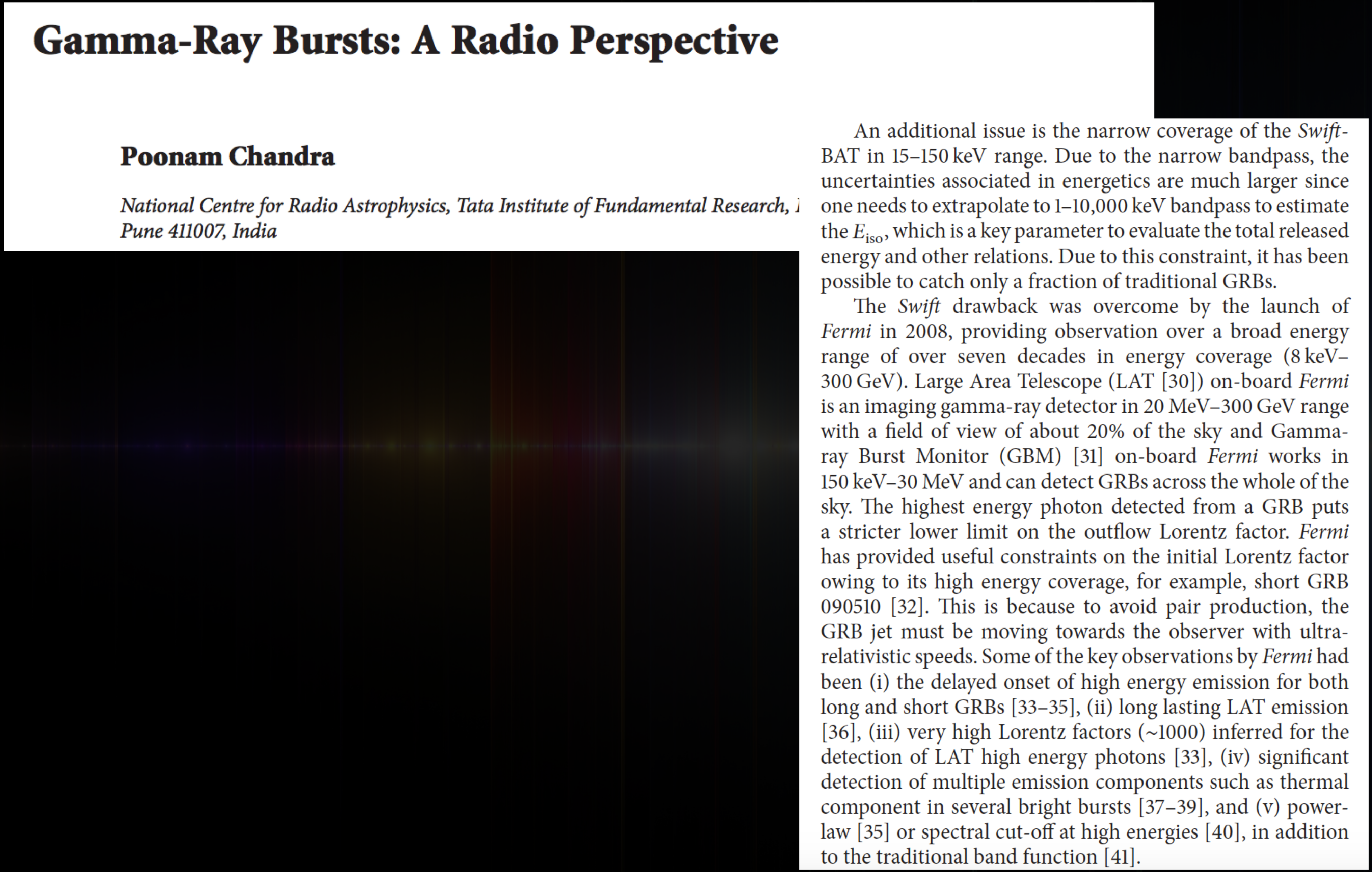
III. Fermi-radio synergies

IV. VLA Sky Survey

- Blazars
- Pulsars
- Gamma-ray bursts
- Tidal Disruption Events (Relativistic/jetted)
- Fast Radio Bursts
- GW counterparts



Gamma-Ray Bursts: A Radio Perspective

Poonam Chandra

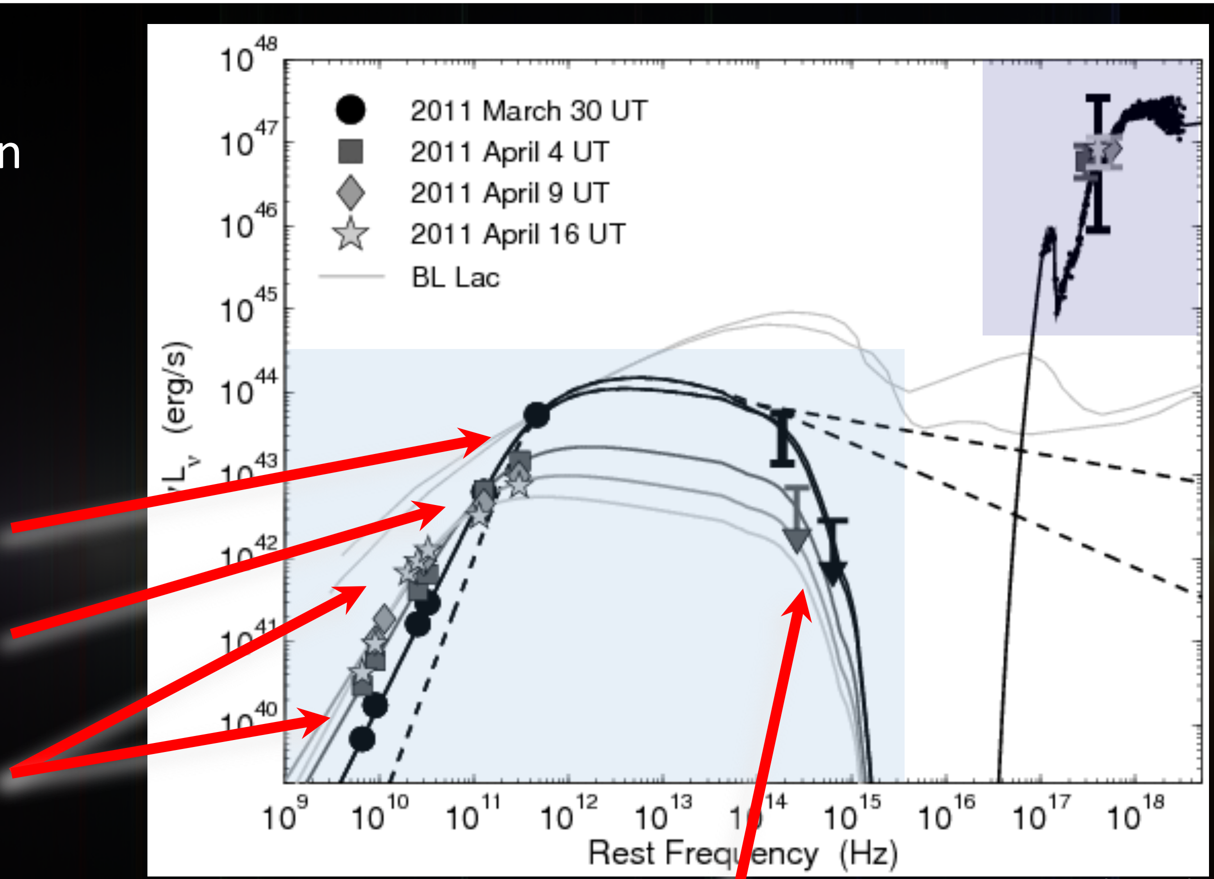
National Centre for Radio Astrophysics, Tata Institute of Fundamental Research,
Pune 411007, India

An additional issue is the narrow coverage of the *Swift*-BAT in 15–150 keV range. Due to the narrow bandpass, the uncertainties associated in energetics are much larger since one needs to extrapolate to 1–10,000 keV bandpass to estimate the E_{iso}, which is a key parameter to evaluate the total released energy and other relations. Due to this constraint, it has been possible to catch only a fraction of traditional GRBs.

The *Swift* drawback was overcome by the launch of *Fermi* in 2008, providing observation over a broad energy range of over seven decades in energy coverage (8 keV–300 GeV). Large Area Telescope (LAT [30]) on-board *Fermi* is an imaging gamma-ray detector in 20 MeV–300 GeV range with a field of view of about 20% of the sky and Gamma-ray Burst Monitor (GBM) [31] on-board *Fermi* works in 150 keV–30 MeV and can detect GRBs across the whole of the sky. The highest energy photon detected from a GRB puts a stricter lower limit on the outflow Lorentz factor. *Fermi* has provided useful constraints on the initial Lorentz factor owing to its high energy coverage, for example, short GRB 090510 [32]. This is because to avoid pair production, the GRB jet must be moving towards the observer with ultra-relativistic speeds. Some of the key observations by *Fermi* had been (i) the delayed onset of high energy emission for both long and short GRBs [33–35], (ii) long lasting LAT emission [36], (iii) very high Lorentz factors (~1000) inferred for the detection of LAT high energy photons [33], (iv) significant detection of multiple emission components such as thermal component in several bright bursts [37–39], and (v) power-law [35] or spectral cut-off at high energies [40], in addition to the traditional band function [41].

Sw1644+57: SED

- Radio spectrum ⇒ synchrotron
- No optical ⇒ $A_V > 3$ mag
- L_X exceeds L_{syn} by ~10^3



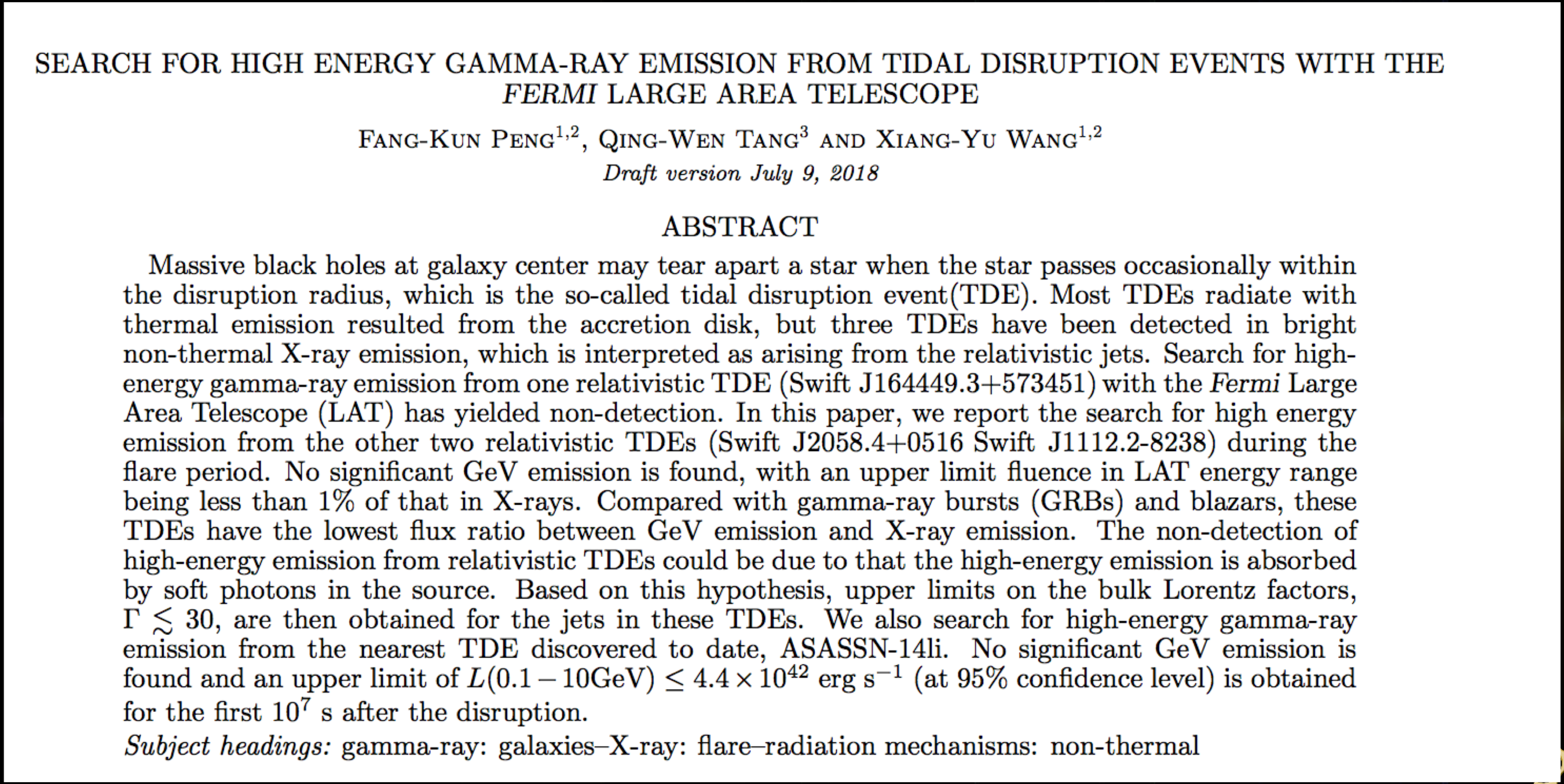
SMA

CARMA

EVLA, Ryle,
OVRO 40-m

Zauderer et al. Nature (2011)

no optical / weak NIR



SEARCH FOR HIGH ENERGY GAMMA-RAY EMISSION FROM TIDAL DISRUPTION EVENTS WITH THE *FERMI* LARGE AREA TELESCOPE

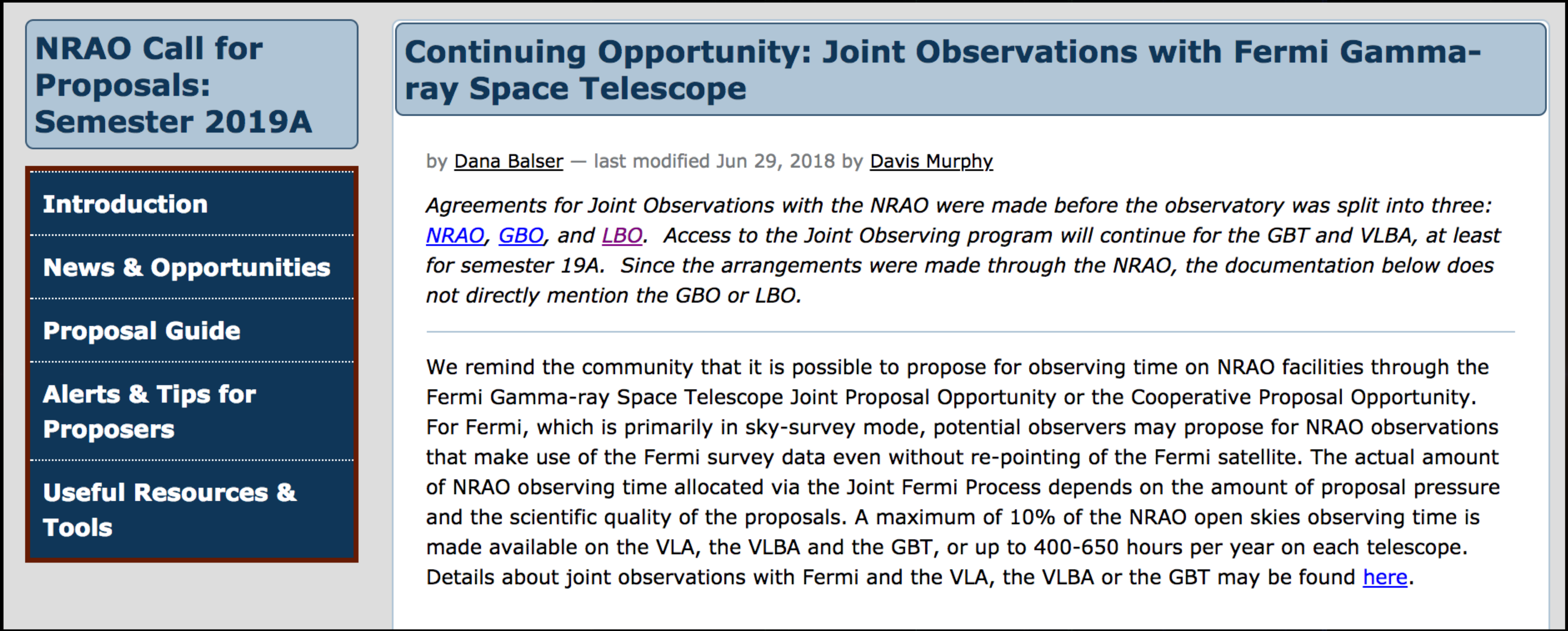
Fang-Kun Peng[1,2], Qing-Wen Tang[3] and Xiang-Yu Wang[1,2]

Draft version July 9, 2018

ABSTRACT

Massive black holes at galaxy center may tear apart a star when the star passes occasionally within the disruption radius, which is the so-called tidal disruption event(TDE). Most TDEs radiate with thermal emission resulted from the accretion disk, but three TDEs have been detected in bright non-thermal X-ray emission, which is interpreted as arising from the relativistic jets. Search for high-energy gamma-ray emission from one relativistic TDE (Swift J164449.3+573451) with the *Fermi* Large Area Telescope (LAT) has yielded non-detection. In this paper, we report the search for high energy emission from the other two relativistic TDEs (Swift J2058.4+0516 Swift J1112.2-8238) during the flare period. No significant GeV emission is found, with an upper limit fluence in LAT energy range being less than 1% of that in X-rays. Compared with gamma-ray bursts (GRBs) and blazars, these TDEs have the lowest flux ratio between GeV emission and X-ray emission. The non-detection of high-energy emission from relativistic TDEs could be due to that the high-energy emission is absorbed by soft photons in the source. Based on this hypothesis, upper limits on the bulk Lorentz factors, $\Gamma \lesssim 30$, are then obtained for the jets in these TDEs. We also search for high-energy gamma-ray emission from the nearest TDE discovered to date, ASASSN-14li. No significant GeV emission is found and an upper limit of $L(0.1-10\mathrm{GeV}) \leq 4.4\times10^{42}$ erg s^{-1} (at 95% confidence level) is obtained for the first 10^7 s after the disruption.

Subject headings: gamma-ray: galaxies–X-ray: flare–radiation mechanisms: non-thermal



NRAO Call for Proposals: Semester 2019A

Continuing Opportunity: Joint Observations with Fermi Gamma-ray Space Telescope

by Dana Balser — last modified Jun 29, 2018 by Davis Murphy

Agreements for Joint Observations with the NRAO were made before the observatory was split into three: NRAO, GBO, and LBO. Access to the Joint Observing program will continue for the GBT and VLBA, at least for semester 19A. Since the arrangements were made through the NRAO, the documentation below does not directly mention the GBO or LBO.

We remind the community that it is possible to propose for observing time on NRAO facilities through the Fermi Gamma-ray Space Telescope Joint Proposal Opportunity or the Cooperative Proposal Opportunity. For Fermi, which is primarily in sky-survey mode, potential observers may propose for NRAO observations that make use of the Fermi survey data even without re-pointing of the Fermi satellite. The actual amount of NRAO observing time allocated via the Joint Fermi Process depends on the amount of proposal pressure and the scientific quality of the proposals. A maximum of 10% of the NRAO open skies observing time is made available on the VLA, the VLBA and the GBT, or up to 400-650 hours per year on each telescope. Details about joint observations with Fermi and the VLA, the VLBA or the GBT may be found here.

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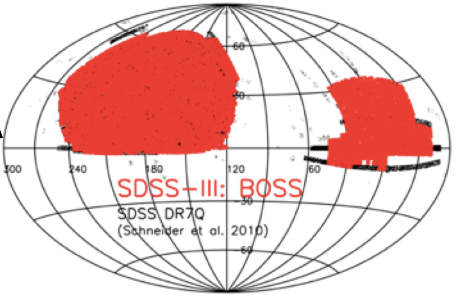
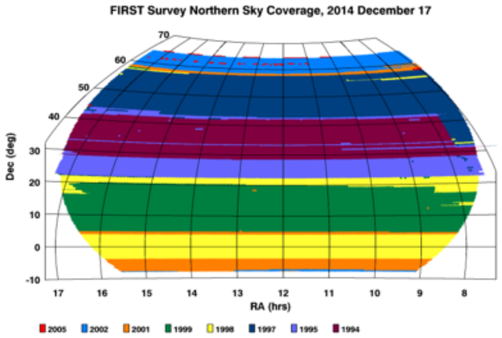
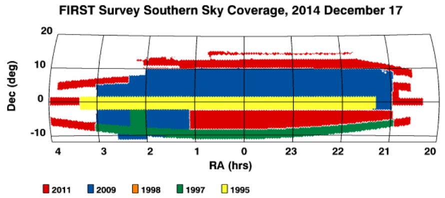
Very Large Array Sky Survey

Why a VLA Sky Survey and why now?

- Science based on surveys comprise a steadily increasing fraction of VLA publications
- 20 years since VLA surveys NVSS and FIRST; 5+ years before SKA-1







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

Slide: A. Kimball

In Context…

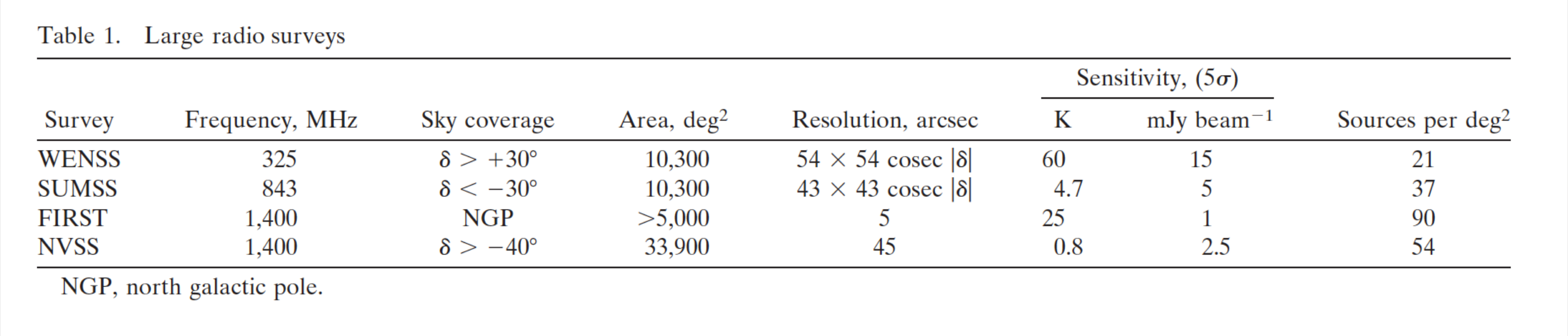
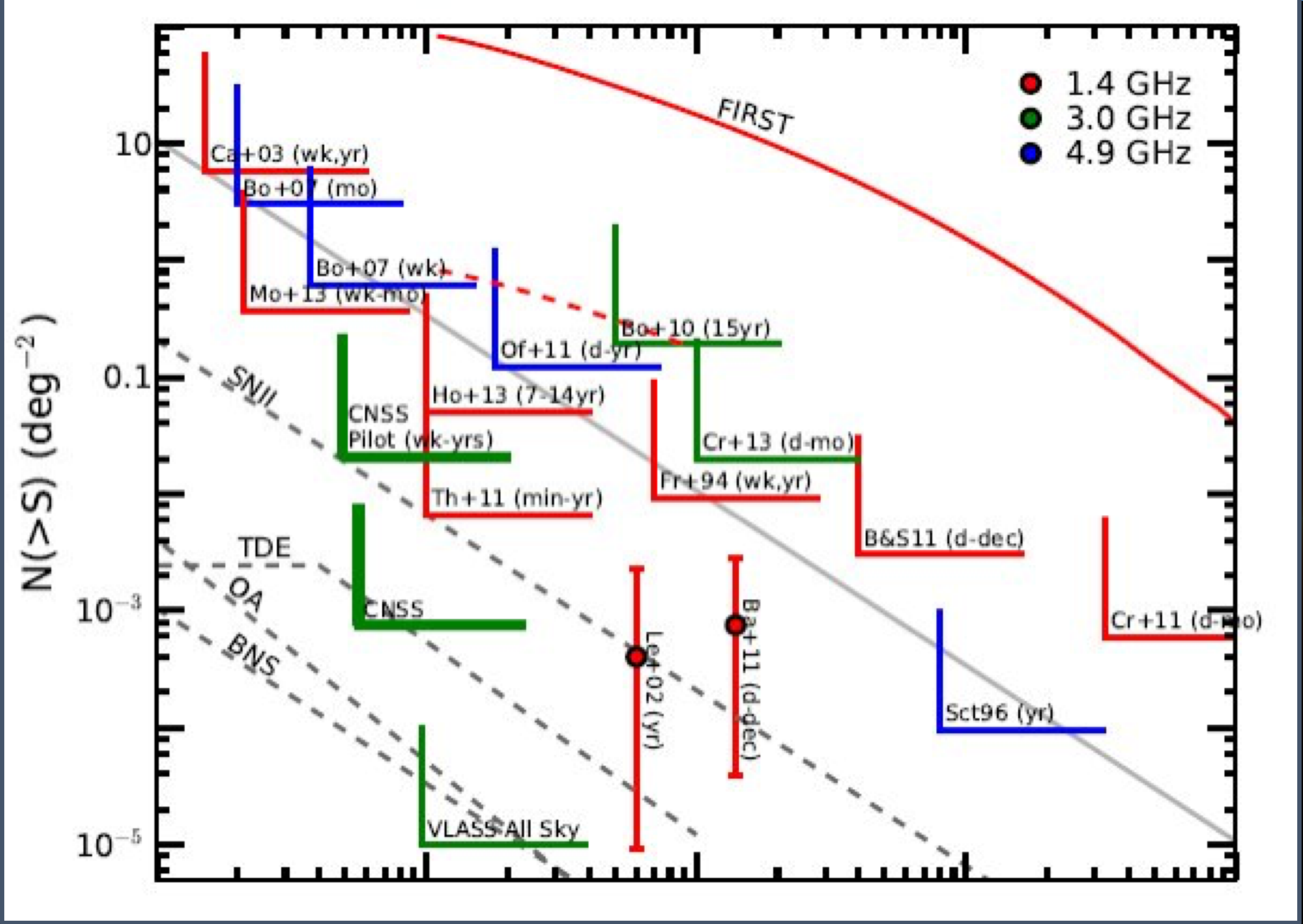


Table 1. Large radio surveys

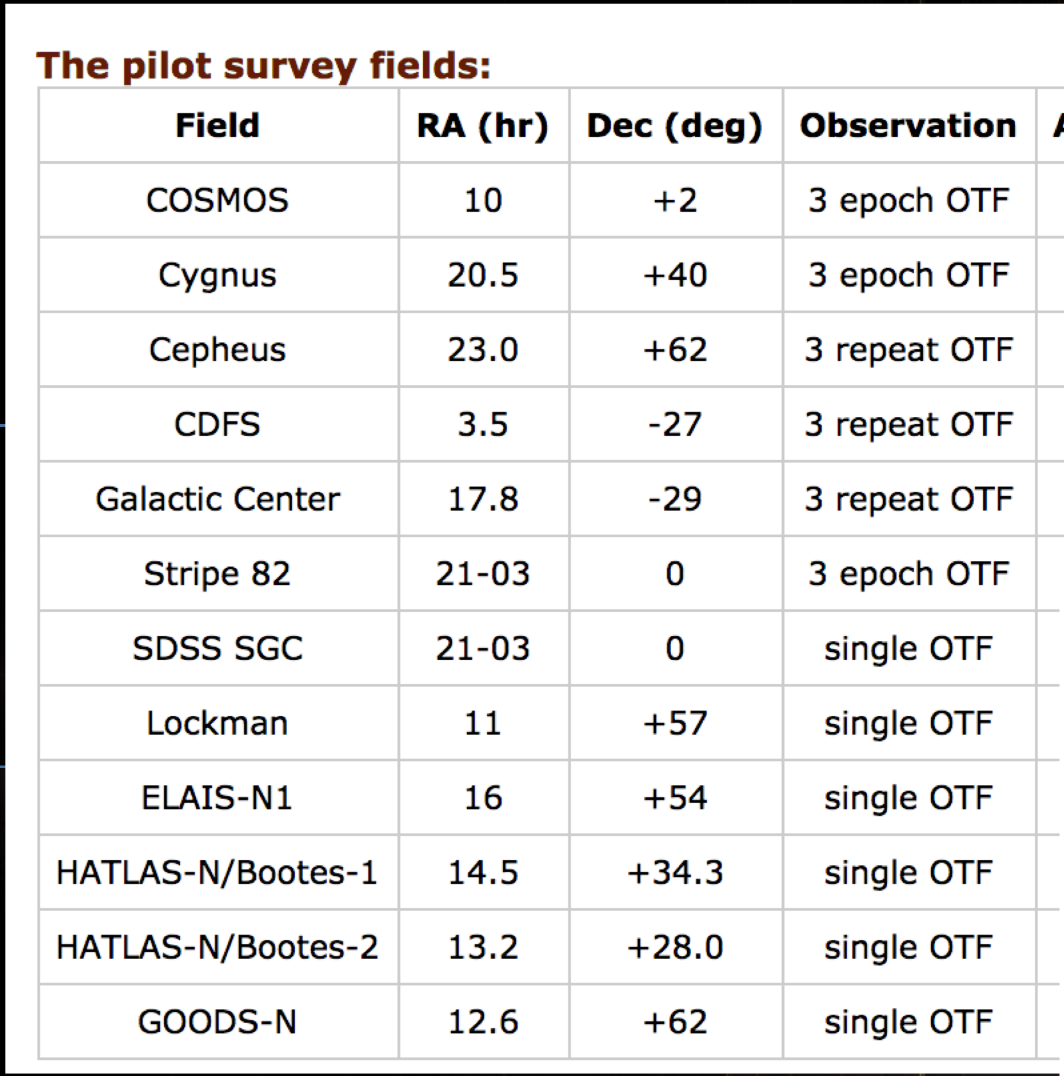
					Sensitivity, (5σ)		
Survey	Frequency, MHz	Sky coverage	Area, deg^2	Resolution, arcsec	K	mJy beam^{-1}	Sources per deg^2
WENSS	325	$\delta > +30°$	10,300	54×54 cosec $\lvert\delta\rvert$	60	15	21
SUMSS	843	$\delta < -30°$	10,300	43×43 cosec $\lvert\delta\rvert$	4.7	5	37
FIRST	1,400	NGP	>5,000	5	25	1	90
NVSS	1,400	$\delta > -40°$	33,900	45	0.8	2.5	54

NGP, north galactic pole.

Era of large surveys (optical/radio/gamma) forthcoming with more discovery potential to obtain observations to answer some of the open questions



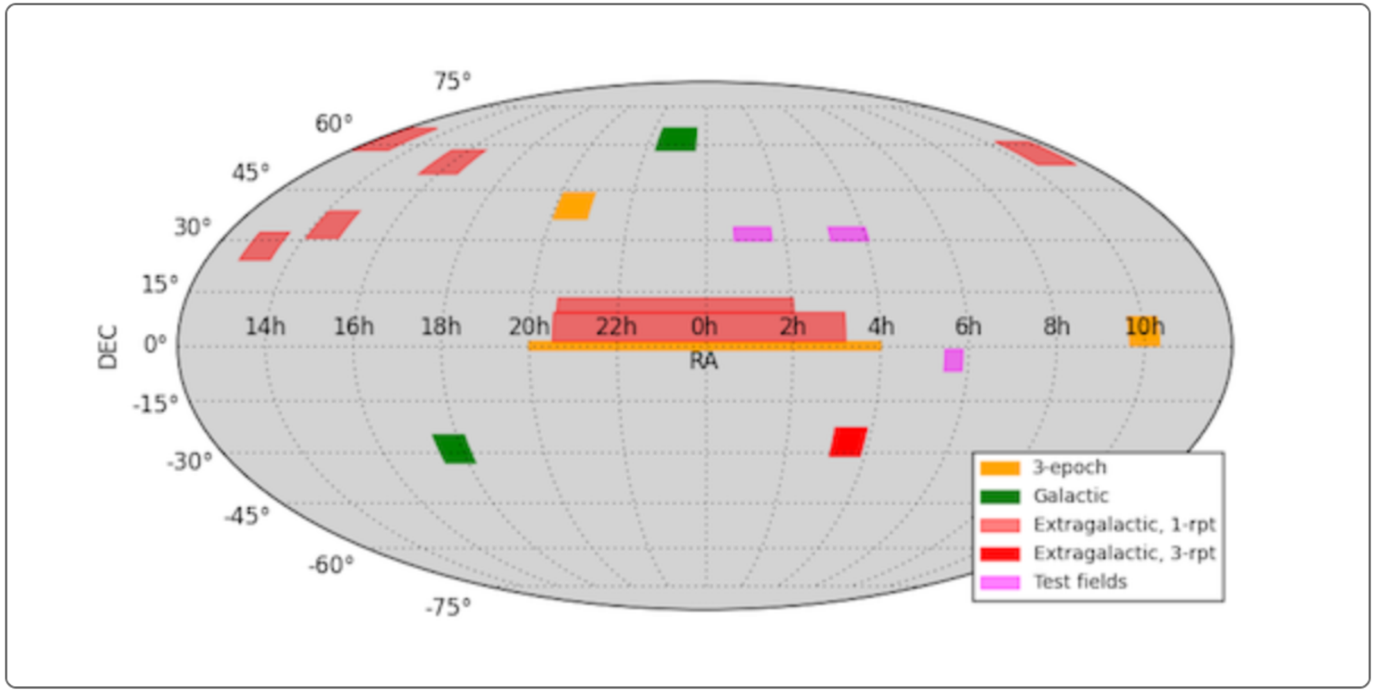
Slow radio transient rates (Mooley et al 2016)



The pilot survey fields:

Field	RA (hr)	Dec (deg)	Observation	Area (sq deg)	# hrs
COSMOS	10	+2	3 epoch OTF	80	12
Cygnus	20.5	+40	3 epoch OTF	80	12
Cepheus	23.0	+62	3 repeat OTF	80	12
CDFS	3.5	-27	3 repeat OTF	80	12
Galactic Center	17.8	-29	3 repeat OTF	80	12
Stripe 82	21-03	0	3 epoch OTF		
SDSS SGC	21-03	0	single OTF		
Lockman	11	+57	single OTF		
ELAIS-N1	16	+54	single OTF		
HATLAS-N/Bootes-1	14.5	+34.3	single OTF		
HATLAS-N/Bootes-2	13.2	+28.0	single OTF		
GOODS-N	12.6	+62	single OTF		

VLASS Pilot Sky Coverage:

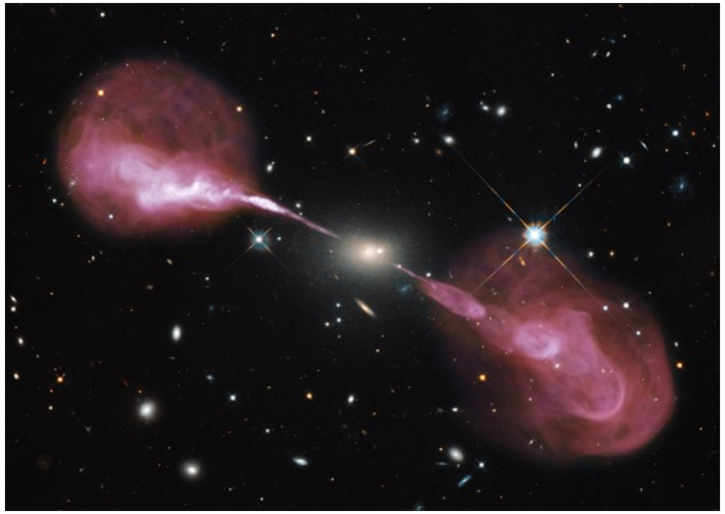


Scientific capabilities of the upgraded VLA relevant for a sky survey

- Wide bandwidths:
  - Continuum sensitivity
  - Spectral index information
  - Rotation measure studies
  - Survey speed for wide-field mosaics

- Correlator flexibility:
  - Very fast dump times
  - High resolution, flexible tuning

- New "On-the-Fly" mosaicking mode:
  - Decreased overheads for large, relatively shallow surveys

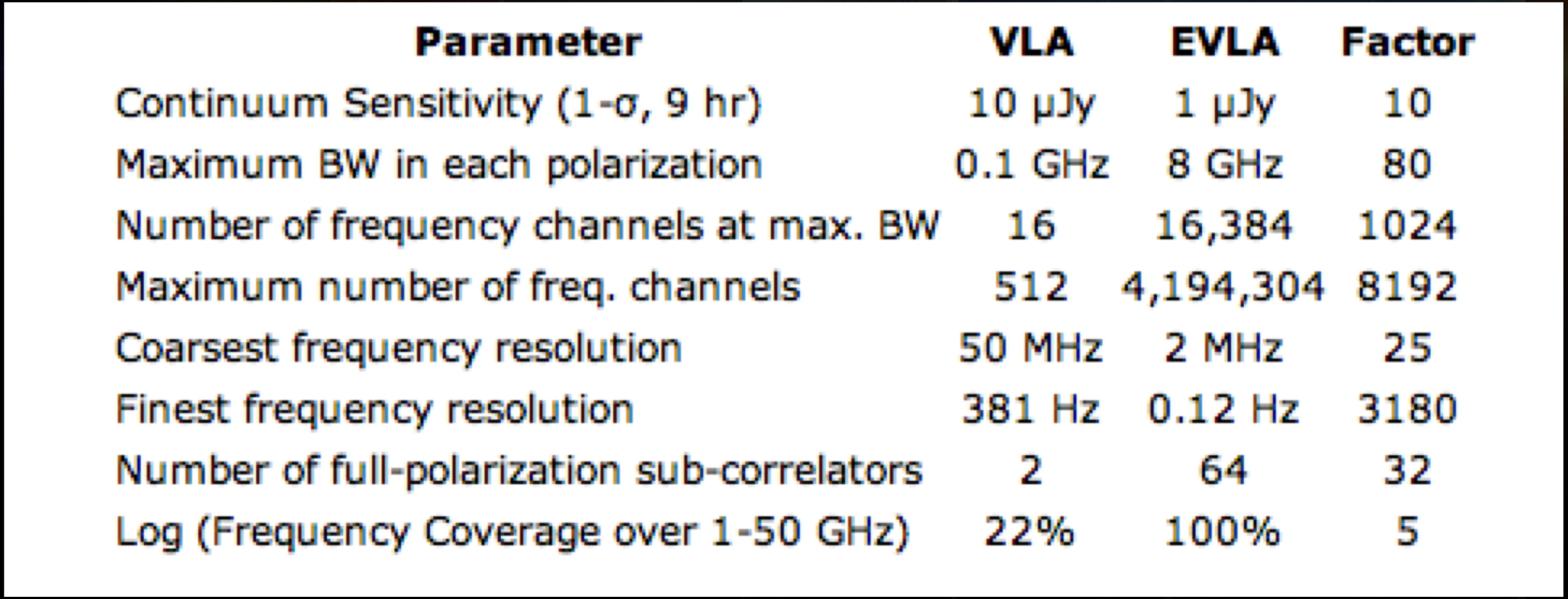


Hercules A image credit: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

Slide: A. Kimball

Karl G. Jansky VLA upgrade

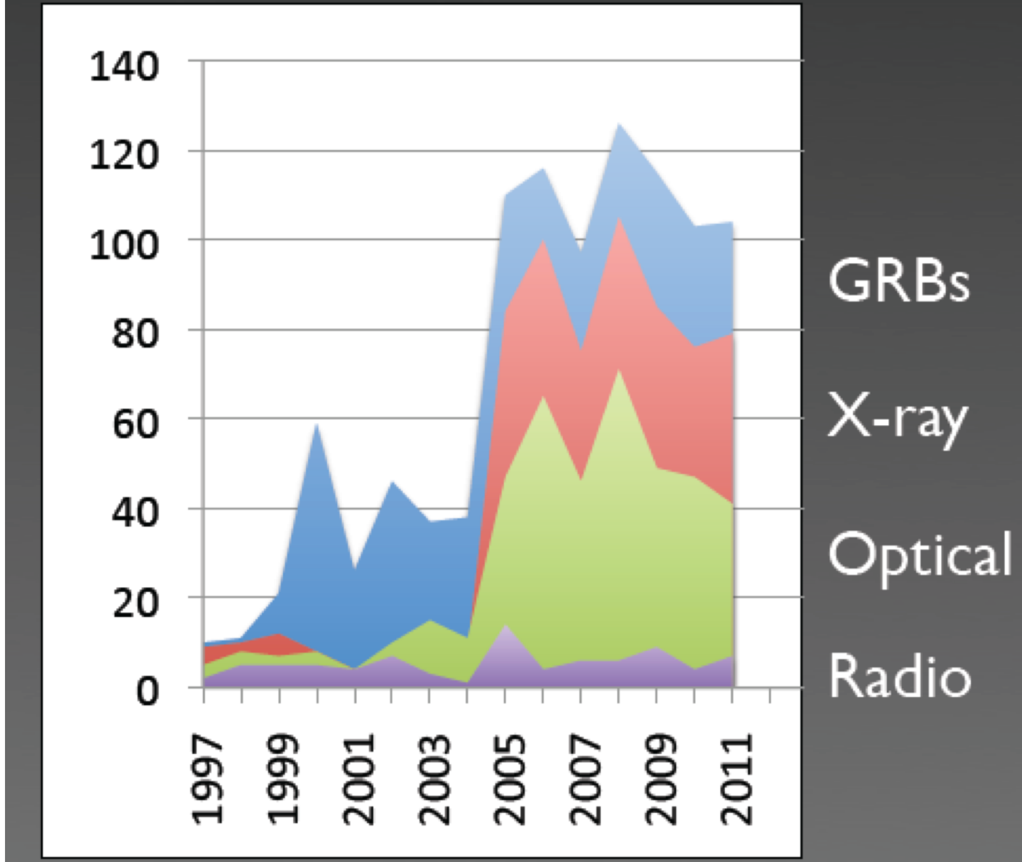
$$\Delta I_m = \frac{SEFD}{\eta_c\sqrt{n_{\mathrm{pol}}N(N-1)t_{\mathrm{int}}\Delta\nu}}$$

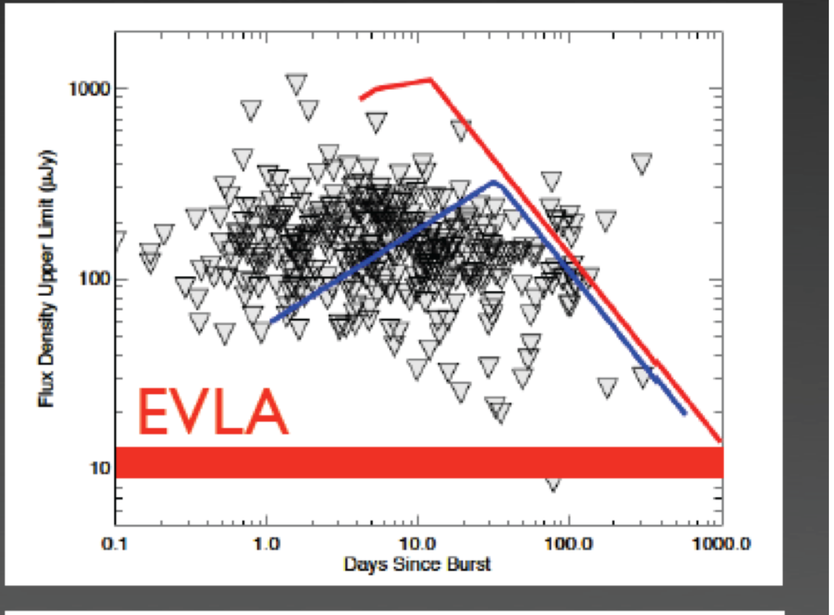


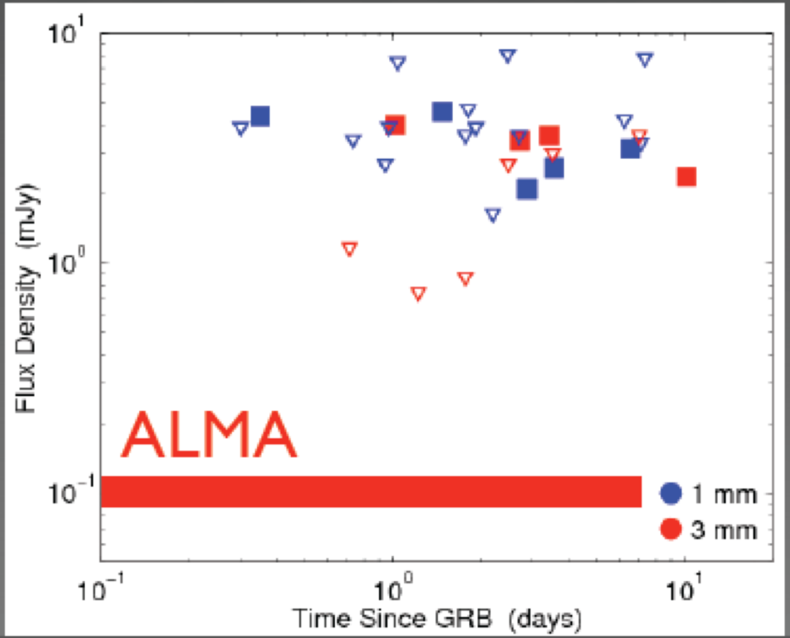
Parameter	VLA	EVLA	Factor
Continuum Sensitivity (1-σ, 9 hr)	10 μJy	1 μJy	10
Maximum BW in each polarization	0.1 GHz	8 GHz	80
Number of frequency channels at max. BW	16	16,384	1024
Maximum number of freq. channels	512	4,194,304	8192
Coarsest frequency resolution	50 MHz	2 MHz	25
Finest frequency resolution	381 Hz	0.12 Hz	3180
Number of full-polarization sub-correlators	2	64	32
Log (Frequency Coverage over 1-50 GHz)	22%	100%	5

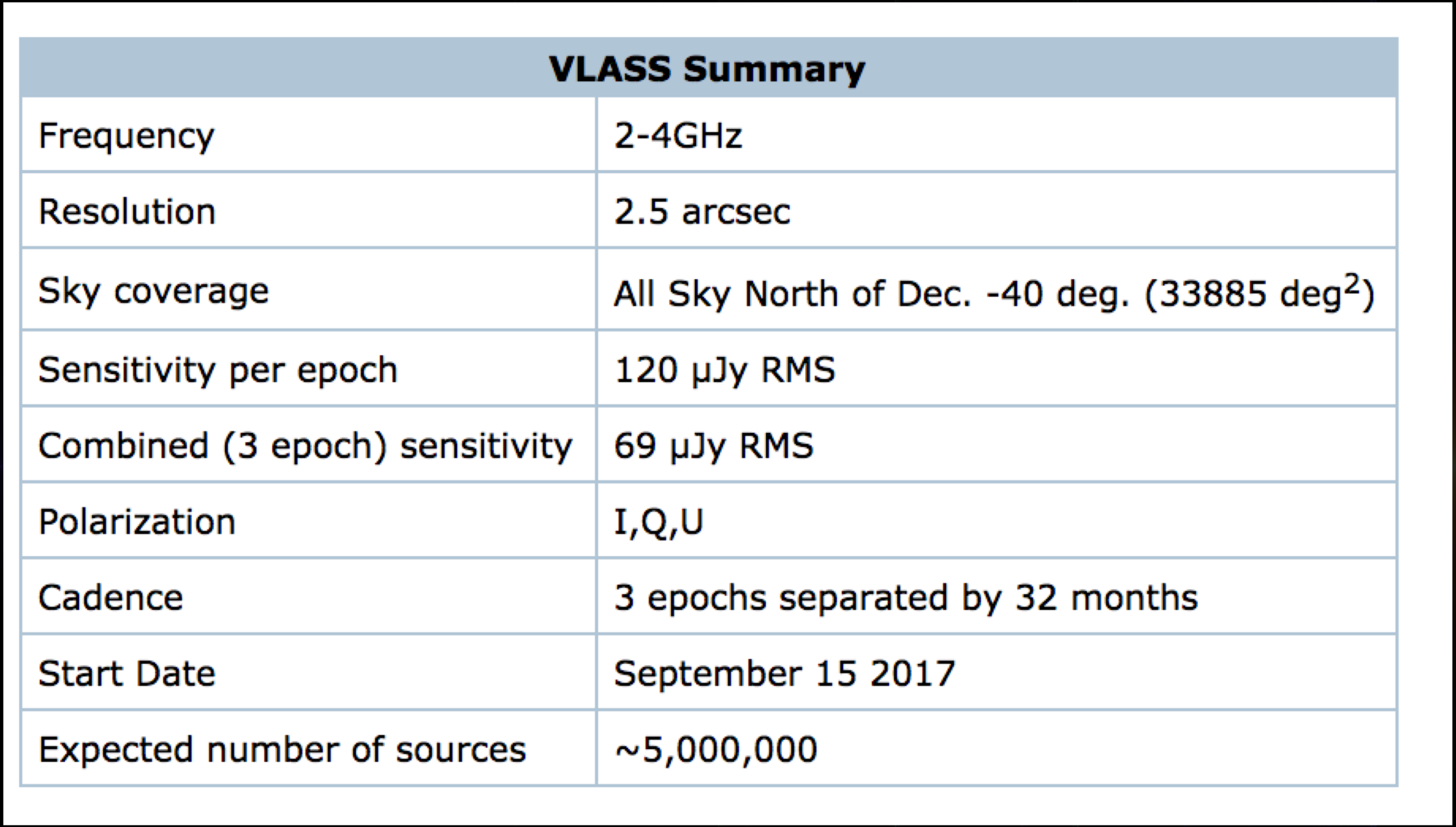
Future Directions

Pre-EVLA/ALMA, radio afterglow detection rate is only ~10%









VLASS Summary

Frequency	2-4GHz
Resolution	2.5 arcsec
Sky coverage	All Sky North of Dec. -40 deg. (33885 deg^2)
Sensitivity per epoch	120 μJy RMS
Combined (3 epoch) sensitivity	69 μJy RMS
Polarization	I,Q,U
Cadence	3 epochs separated by 32 months
Start Date	September 15 2017
Expected number of sources	~5,000,000

VLASS Survey Definition

- Highest spatial resolution, all-sky radio survey to date
  - All-sky (33,885 deg^2 above declination –40°)
  - Frequency: 3 GHz (2-4 GHz, less RFI affected regions) "S-band"
  - 64x2 MHz channels per spectral window, 16 spectral windows
  - High angular resolution: 2.5" (VLA B-configuration)
  - 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 ($\delta > -40°$)	2.5"	120 \ 69	~150	5,000,000

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

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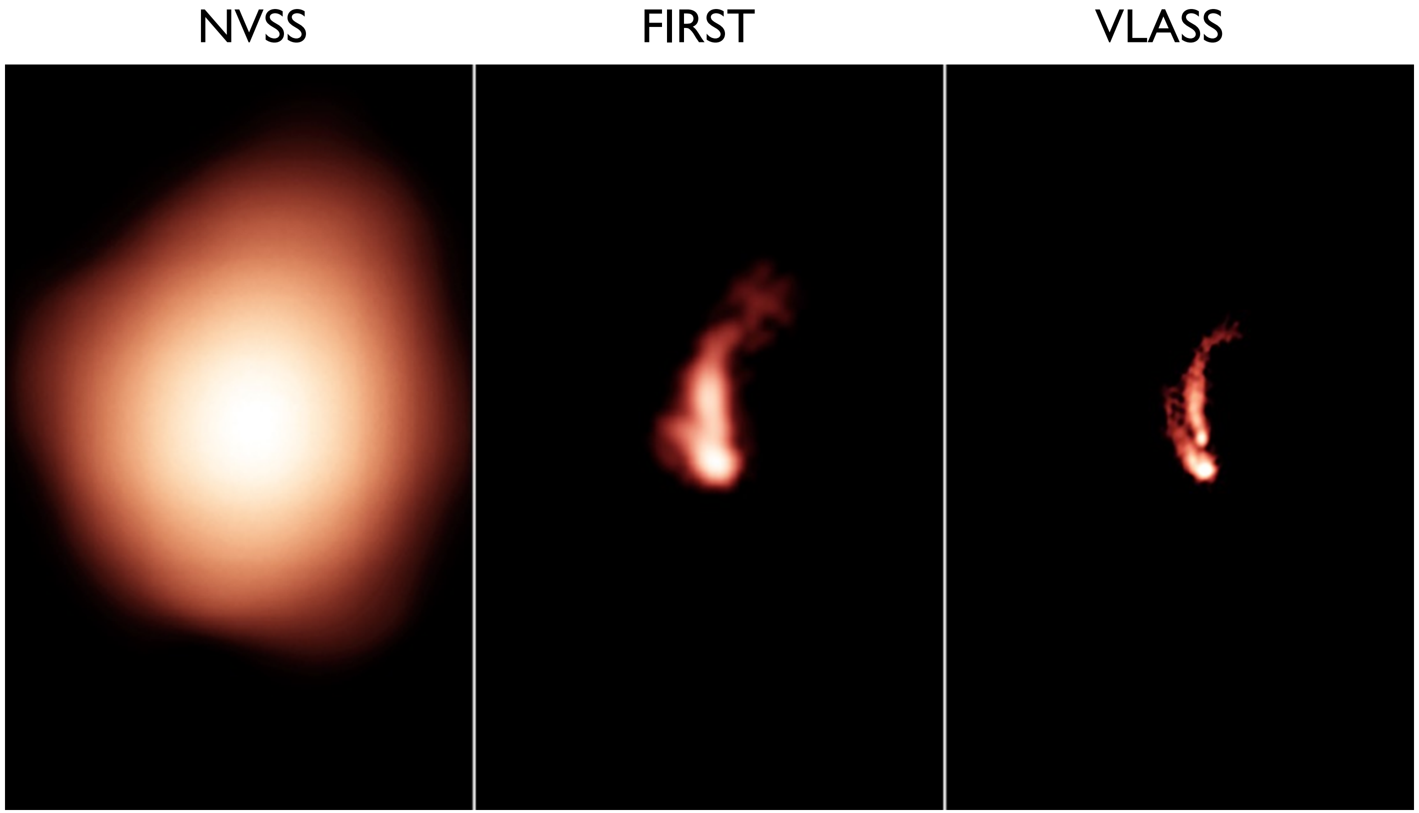
Improvement in resolution from NVSS and FIRST



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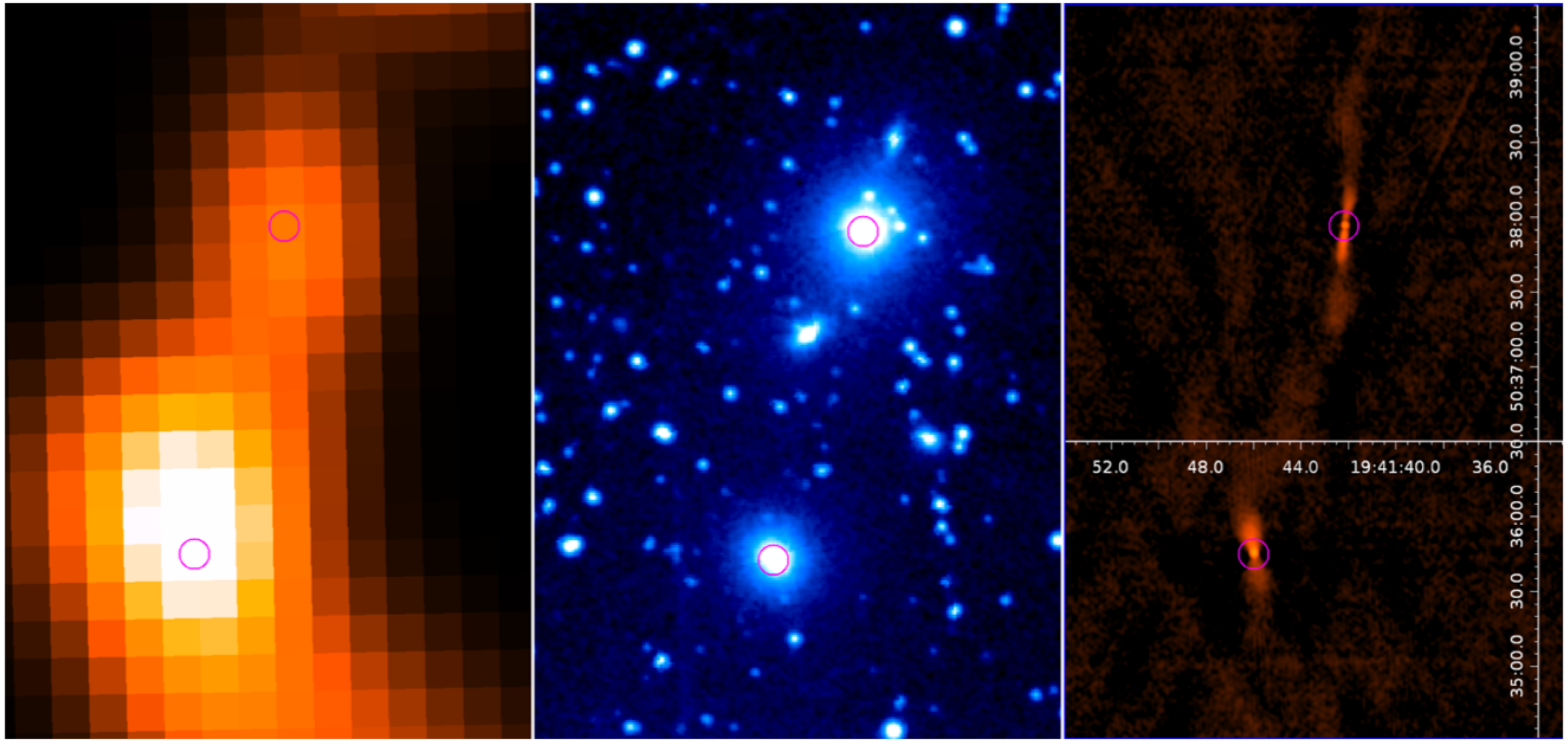
VLASS resolution advantage

Radio “galaxy” 3C 402



NVSS **DSS** **VLASS**

M. Lacy et al. (in prep)

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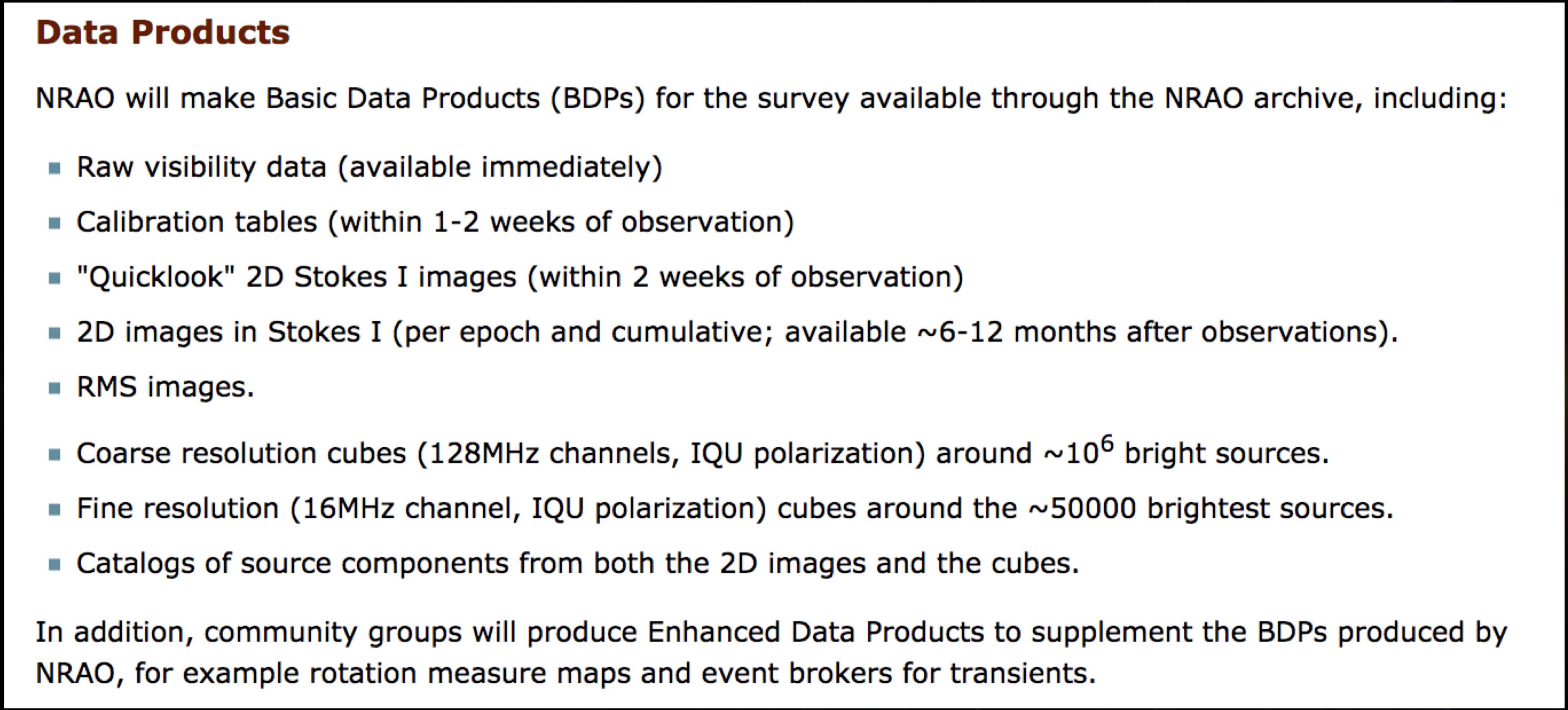


Data Products

NRAO will make Basic Data Products (BDPs) for the survey available through the NRAO archive, including:

- Raw visibility data (available immediately)
- Calibration tables (within 1-2 weeks of observation)
- "Quicklook" 2D Stokes I images (within 2 weeks of observation)
- 2D images in Stokes I (per epoch and cumulative; available ~6-12 months after observations).
- RMS images.
- Coarse resolution cubes (128MHz channels, IQU polarization) around ~10^6 bright sources.
- Fine resolution (16MHz channel, IQU polarization) cubes around the ~50000 brightest sources.
- Catalogs of source components from both the 2D images and the cubes.

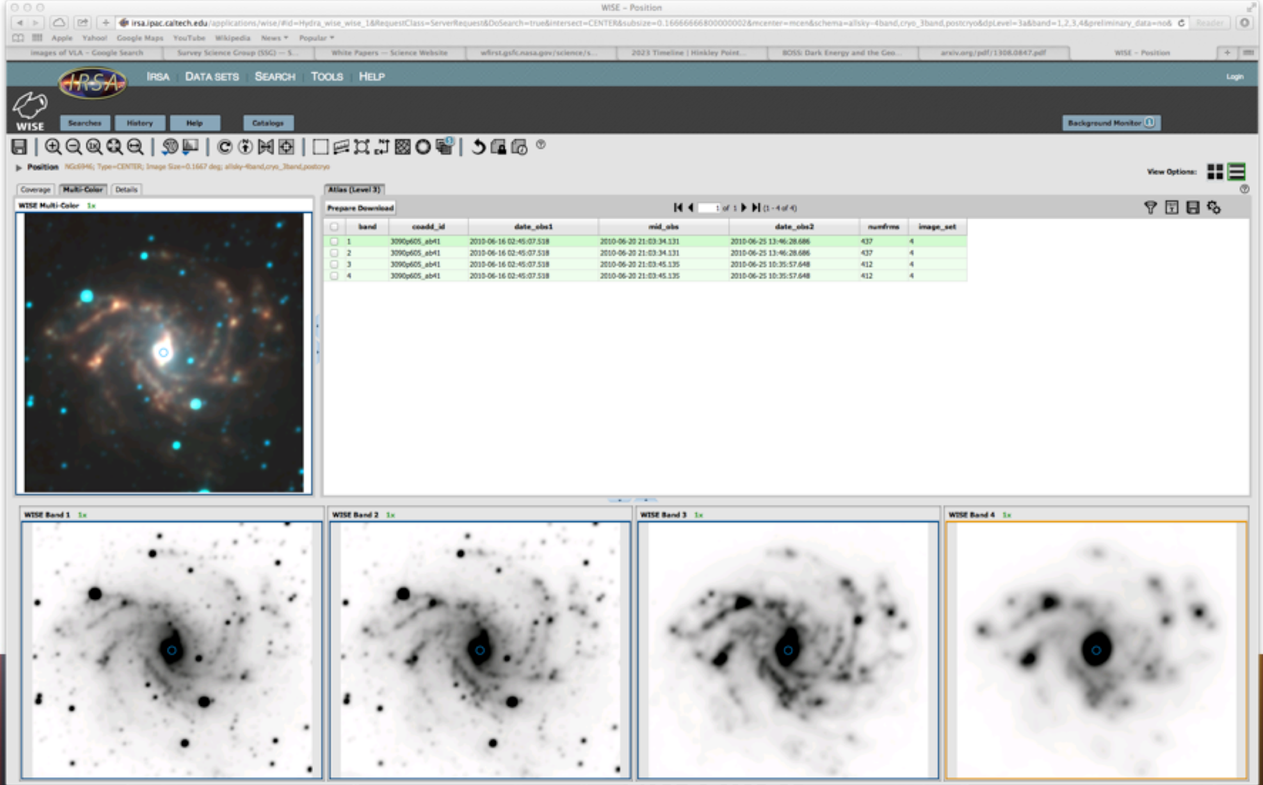
In addition, community groups will produce Enhanced Data Products to supplement the BDPs produced by NRAO, for example rotation measure maps and event brokers for transients.

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…**



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☐	2	3090p605_ab41	2010-06-16 02:45:07.518	2010-06-20 21:03:34.131	2010-06-25 13:46:28.686	437	4
☐	3	3090p605_ab41	2010-06-16 02:45:07.518	2010-06-20 21:03:45.135	2010-06-25 10:35:57.648	412	4
☐	4	3090p605_ab41	2010-06-16 02:45:07.518	2010-06-20 21:03:45.135	2010-06-25 10:35:57.648	412	4

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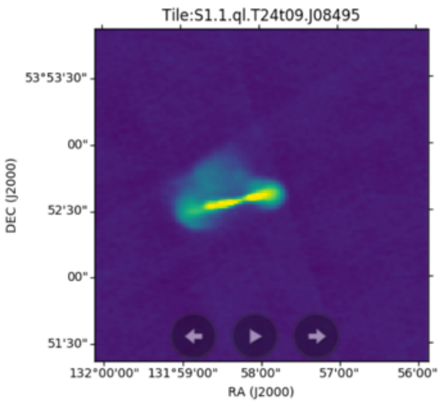
Community Effort:

- 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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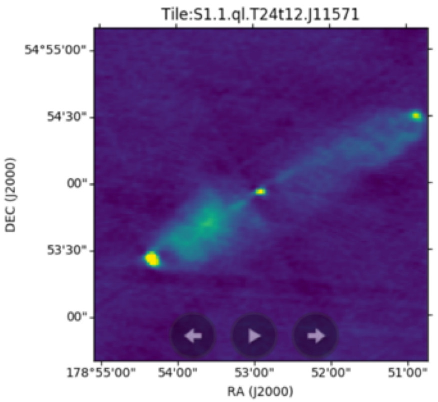
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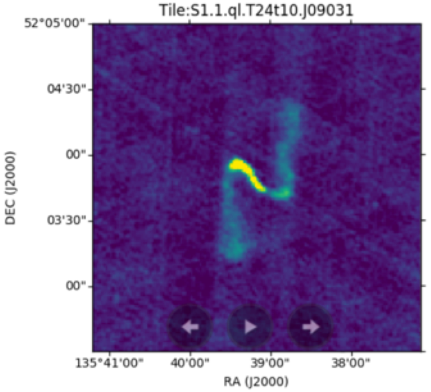
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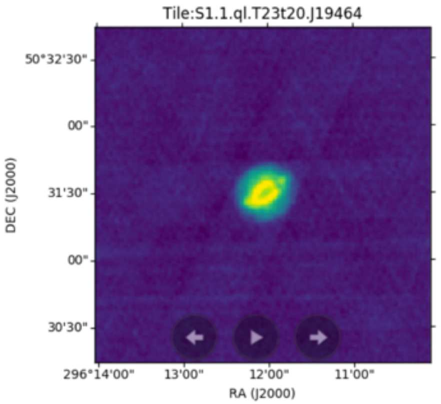
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Slide: A. Kimball

CIRADA:

Canadian Initiative for Radio Astronomy Data Analysis

- Led by Prof Bryan Gaensler (Director, *Dunlap Institute*)
- Canadian Foundation for Innovation (CFI) award
  - $3.5 million (CFI) + $6 million partner funds (w/ NRAO in-kind)

With VLASS: produce rotation measure images and catalogs

CIRADA

CANADIAN INITIATIVE FOR RADIO ASTRONOMY DATA ANALYSIS

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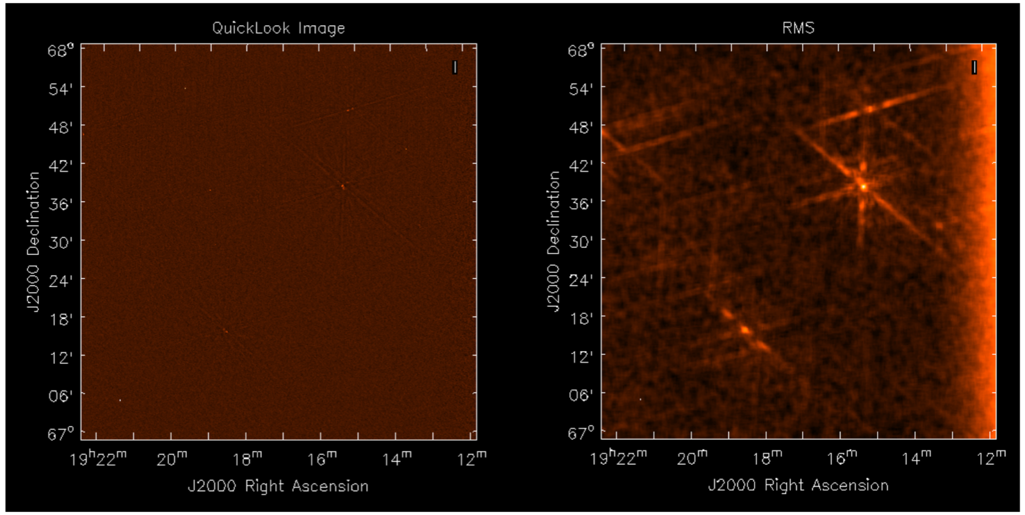
Current VLASS status

- Observations of VLASS 1.1 completed!
  - 12,921 deg^2 in B config: 130 data sets
  - 3910 deg^2 in BnA config: 35 data sets
  - Total of 916.5 hours ~ 16,831 deg^2



- All data sets available to public:
  - [old] NRAO archive, Project code “VLASS1.1”:
  - https://archive.nrao.edu/archive/advquery.jsp
  - **> 94,000 GB of *raw* data**
  - >14,000 deg^2 of “QuickLook” images published

Slide: A. Kimball

Thank you

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