Large-Scale Radio Surveys: Finding Giants by just looking at images

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Jasper Wall @ 75, UBC Vancouver, Dec 05, 2018

“**At the beginning** “ (~1988) . . .
there was **no image atlas of the radio sky** ….

30 years ago (NED/Simbad in its infancy) I noted their lack of radio data
➔motivation for me to collect/recover source catalogs in e-form
* original intention: alert the data centers to do their job in this area
* never became reality → I turned into a . . . **One-Man's Data Center**

* 1989: I started collecting; NED/Simbad: little interest
* 1994: ~60 catalogs (>500,000 sources) searchable via
  “EINLINE” (CfA, Xray) → abandoned (lack of resources)
* 1997 creation of CATS (cats.sao.ru): catalog browser
  (today: ~410 radio catalogs with ~7 million entries)
* after ~2000: the VizieR catalog browser gradually becomes the
  most complete system to search in astronomical catalogs
* 2018: I collected ~2400 radio source catalogs (over 900 of these
  I recovered via Optical Character Recognition, OCR), including
  all **PKS** 408-MHz (1964–1969) and **2.7-GHz** installments (1971–1979)
  ➔ project with Jasper: prepare the real **PKSCAT_2.7**

BUT: only about one third of my catalog collection is searchable in public databases

(maintained at http://www.astro.ugto.mx/~heinz/cats.sum)

Electronic **radio** source catalogues in H. Andernach's collection

Service	Ncats	%-cats	Nsrcs/1e6	%-recs
CDS archive/VizieR:	938	**36.8**	8.24	**79.3**
CATS database:	419	16.5	7.19	69.2
in HA collection ONLY:	1482	58.2	1.78	17.1
Full collection HA+CDS:	**2620**	100.0	**10.38**	100.0

Electronic **non-radio** source catalogues in H. Andernach's collection

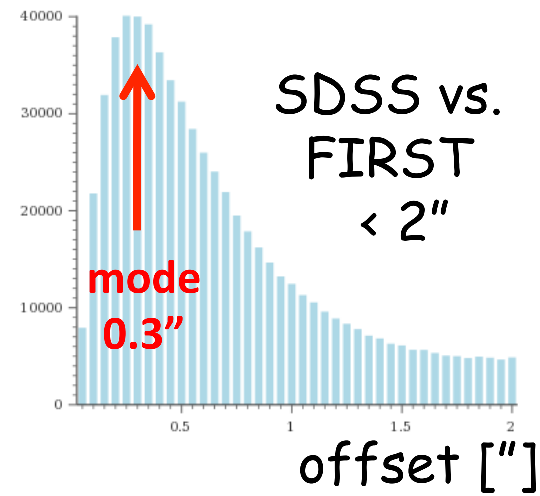
Service	Ncats	%-cats	Nsrcs/1e6	%-recs
CDS archive/VizieR:	948	38.2	9.87	5.4
CATS database:	39	1.6	5.04	0.3
in HA collection ONLY:	1512	60.9	1716.8	94.4
Full collection HA+CDS:	2483	100.0	1818.6	100.0

The above applies for the mere catalogs, but the situation with image atlases (or individual images) is not better (usually not archived at data centers)

Radio Astronomy: Fishing in the Dark?
The optical identification problem

Example: what fraction of the ~950,000 FIRST sources have an opt/IR ID in the largest opt/IR catalogs ? → Xmatch @ CDS within 2"

Catalog	$N_{obj}/10^6$	%FIRST	mode
USNO B1.0	1050	20%	0.5"
SuperCOSMOS	241	10%	0.3"
2MASS	471	8%	0.35"
2MASX	1.65	3.8%	0.6"
SDSS DR12	769	28%	0.3"
PanSTARRS	1909	31%	0.25"
AllWISE	747	42%	0.4"



How many FIRST sources we expect to have opt/IR IDs ?

→ take off all the lobes & hotspots...

e.g. 2015MNRAS.446.2985VanVelzen+ → ~60,000 candidate FRII's < 1'

→ 120,000 lobes/hotspots,

excluding false doubles, including all the ones > 1' are missing ... (which ?)

→ perhaps ~200,000 FIRST sources are hotspots or lobes ?

Ann. Rev. Astron. Astrophys. 1980. 18 : 165–218

Back to imaging surveys and extended radio galaxies …

THE STRUCTURE OF EXTENDED EXTRAGALACTIC RADIO SOURCES

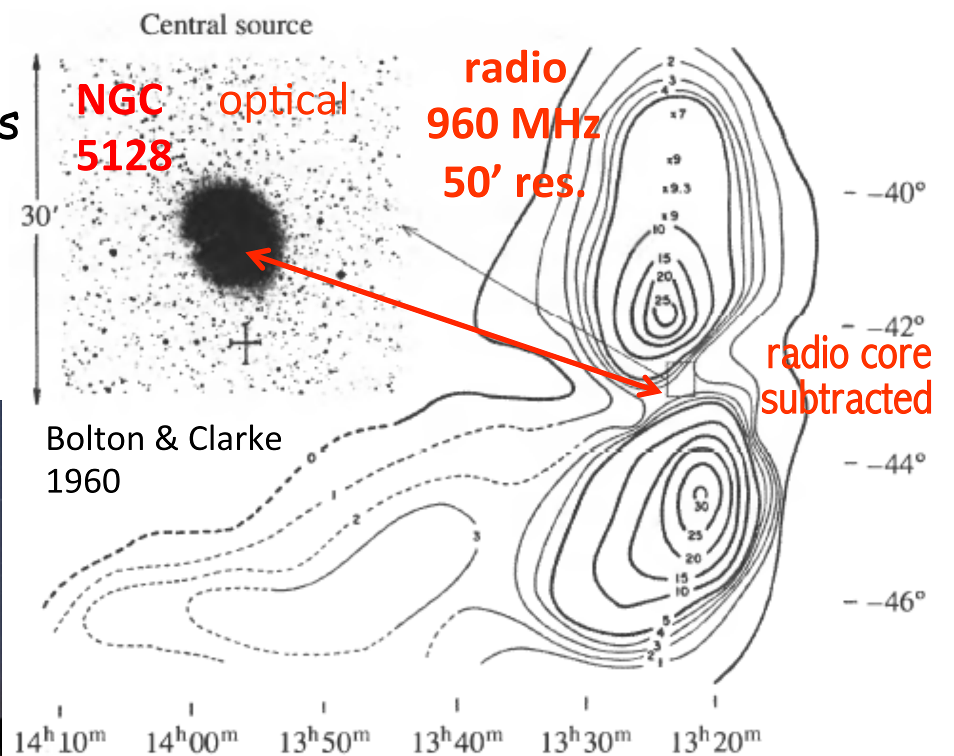
George Miley
Sterrewacht Leiden, P.O. Box 9513, 2300 RA Leiden, The Netherlands

George Miley starts his 1980 review by saying:
… to some of us the ***most fascinating objects*** *known in the Universe …*
…they are also objects of ***considerable beauty****.*

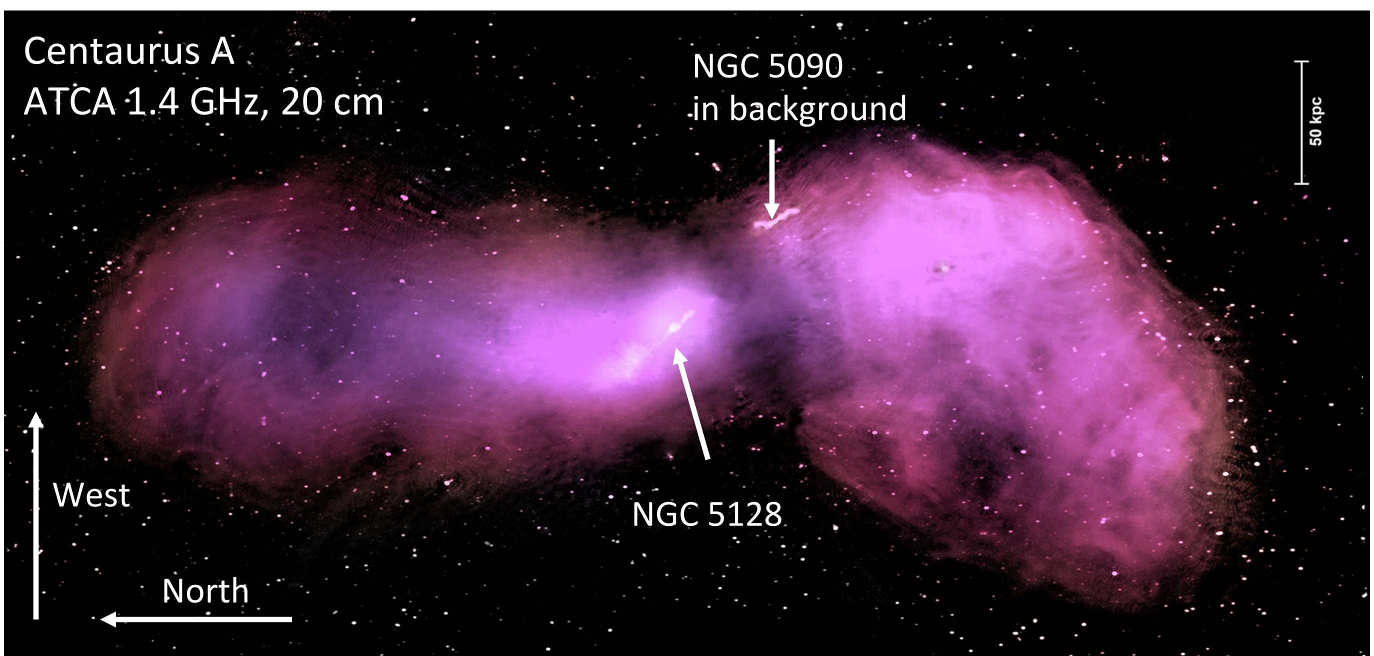
Set aside their morphology (from beautiful to pathologic)
how large can a radio galaxies grow ?
In **angular size,** Centaurus A is still by far the largest: ~10°
(no other radio galaxy yet known larger than one degree!

Radio galaxy with largest **angular** size is **still** Cen A, ~10° = 600 kpc). Core coincides with NGC 5128 (LLS ~ 60 * opt. size).

Using the Hubble law $D = H_0/v_{rad}$ =
→ LLS = 1.4 Mpc, but its
z-independent D = 3.8 Mpc
→ **LLS=0.6 Mpc**



Modern ATCA+PKS 1.4 GHz image: ang. resolutión ~45". Moon's size gives the scale (Feain et al. 2009)



Based on 1200 h of integration with ATCA → 406-pointg. mosaic using older Parkes data (Junkes+1993) to recover missing short spacings

Historical note on the physically largest radio source 50 years ago

Jasper Wall's first paper as a first author:
Publ. Astron. Soc. Austral. **1**, p. 98 on PKS 1233-24

a QSO at z = 0.355 was found to have a radio size (LAS = largest angular size) of 1.95' → the then "accepted" cosmolog. models would give a "largest linear size" (LLS) of 270 – 450 kpc; today with H_0=70 km/s/Mpc, Ω_m=0.3, Ω_Λ=0.7 it would have LLS = **580 kpc**

A Summary of Recent Observations with the Parkes Interferometer

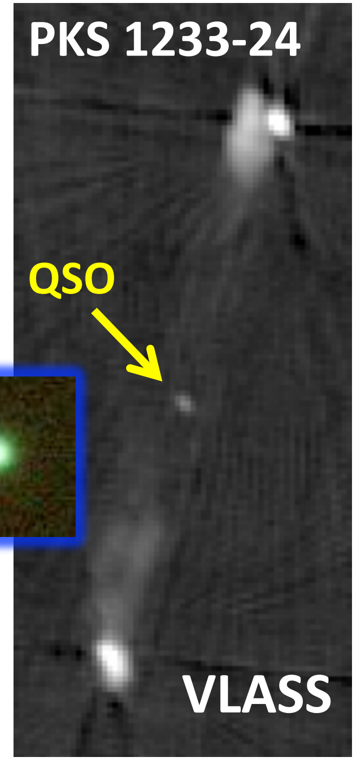
J. V. Wall
Mount Stromlo Observatory, Australian National University, Canberra

D. J. Cole and D. K. Milne
Division of Radiophysics, CSIRO, Sydney

The source 1233-24, resolved in the present series of observations, is of interest. It has been identified with a quasi-stellar object[5] for which *UBV* observations indicate $V = 17^{m}.19$, $B - V = +0^{m}.36$, and $U - B = -0^{m}.58$.[6] The preliminary interferometer observations show that the radio source is a double with components of equal intensity separated by about $1'.95$ arc along position angle $\sim 355°$. A red shift of 0.355 has been obtained with the Cassegrain image tube spectrograph of the Mount Stromlo 74-inch reflector.[7] With a cosmological interpretation of this red shift, the range of model universes considered by McVittie[8] yields a linear separation of the radio components of 275 to 450 kpc, the largest found to date for a quasi-stellar object.

1 Cole, D. J., *Proc. ASA*, **1**, 30 (1967).
2 Ekers, R. D., Ph.D. thesis, Australian National University, 1967.
3 Shimmins, A. J., Clarke, Margaret E., and Ekers, R. D., *Aust. J. Phys.*, **19**, 649 (1966).
4 Fomalont, E. B., Ph.D. thesis, California Institute of Technology, 1967.
5 Bolton, J. G., and Kinman, T. D. *Astrophys. J.*, **145**, 951 (1966).
6 Westerlund, B. E., private communication.
7 Ford, W. K., private communication.
8 McVittie, G. C., *Astrophys. J.*, **142**, 1637 (1965).

Its LAS = 1.95′ was later confirmed from several high-resol. images (e.g. NED), incl. the most recent **public** "all-sky survey" image (VLASS at S-band = 2–4 GHz) confirms the LAS, only that in 2018 its rank in LLS is ~3600 among all radio galaxies ~ 600 among radio quasars



PanSTARRS
grizy 15"x15"

The **sad fact** is that our "modern" databases (NED, Simbad) do not (yet ?) credit the original authors for their discovery (published in a "non-core" or "obscure" journal . . .)

The oldest of 75 NED references on PKS 1233–24 :

69.	1973AJ.....78....1D	Douglas, J., Ba...	First results from the Texas interf
70.	1973A&A....25..303S	Strom, R.	Faraday Depolarization of Radio C
71.	1972ApJ...178..583B	Burbidge, G. R....	The Distribution of Redshifts of Qu
72.	1972ApJ...178...25S	Lynds, R. (quot...	The Redshift-Distance Relation. II
73.	1971PASP...83..611D	de Veny, James ...	A Catalogue of Quasars
74.	1966AuJPh..19...27B	Bolton, J. G., ...	The Zone of Hydrogen Emission in
75.	1966ApJ...145..951B	Bolton, J., Kin...	Radio and Optical Data on Twelve

Wall et al. 1968

The oldest of 74 Simbad references on PKS 1233–24 aka 6dFGS gJ123537.8-251217

1972MNRAS.156..275K [0]
Mon. Not. R. Astron. Soc., 156, 275-282 (1972)
The polarization of radio sources with appreciable redshift.
KRONBERG P.P., CONWAY R.G. and GILBERT J.A.
Simbad objects: 62

1971PASP...83..611D [0]
Publ. Astron. Soc. Pac., 83, 611-625 (1971)
A catalogue of quasars.
DE VENY J.B., OSBORN W.H. and JANES K.
Simbad objects: 202

1968AJ.....73..953P [0]
Astron. J., 73, 953-969 (1968)
Measurements of the flux density and spectra of discrete sources at centim wavelengths. II. The observations at 5 GHz (6cm).
PAULINY-TOTH I.I.K. and KELLERMANN K.I.
Simbad objects: 506

1968ApJS...15..203F [0]
Astrophys. J., Suppl. Ser., 15, 203-274 (1968)
The east-west structure of radio sources at 1425 MHz.
FOMALONT E.B.
Simbad objects: 534

Wall et al. 1968

1966ApJ...145..951B [0]
Astrophys. J., 145, 951-953 (1966)
Radio and optical data on twelve quasi-stellar objects.
BOLTON J.G. and KINMAN T.D.
Simbad objects: 12

1966AuJPh..19..275B [0]
Australian J. Phys., 19, 275-277 (1966)
Identification of radio sources between declinations -20 and -30 degres.
BOLTON J.G. and EKERS J.
Simbad objects: 14

1966AuJPh..19..649S [0]
Australian J. Phys., 19, 649-685 (1966)
Accurate positions of 644 radio sources.
SHIMMINS A.J., CLARKE M.E. and EKERS R.D.
Simbad objects: 642

1964AuJPh..17..340B [0]
Australian J. Phys., 17, 340-372 (1964)
The Parkes catalogue of radio sources declination zone -20 to -60 degres.
BOLTON J.G., GARDNER F.F. and MacKEY M.B.
Simbad objects: 303

How many "Giant Radio Galaxies" (GRG) are known ?

Many partial lists of GRGs exist:

1996MNRAS.279..257Subrahmanyan
1999MNRAS.309..100Ishwara-Chandra
2001A&A...370..409Lara+
2001A&A...374..861Schoenmakers+
2005AJ....130..896Saripalli+
2009AcA....59..431Kuligowska
2009ARep...53.1086Komberg+
2012ApJS..199...27Saripalli+
2015AstBu..70...45Amirkhanyan+
2017MNRAS.466..921Coziol R.+
2017MNRAS.469.2886Dabhade+
+ many other smaller samples
2018ApJS..238....9Kuzmicz+
213 with LLS > 1 Mpc

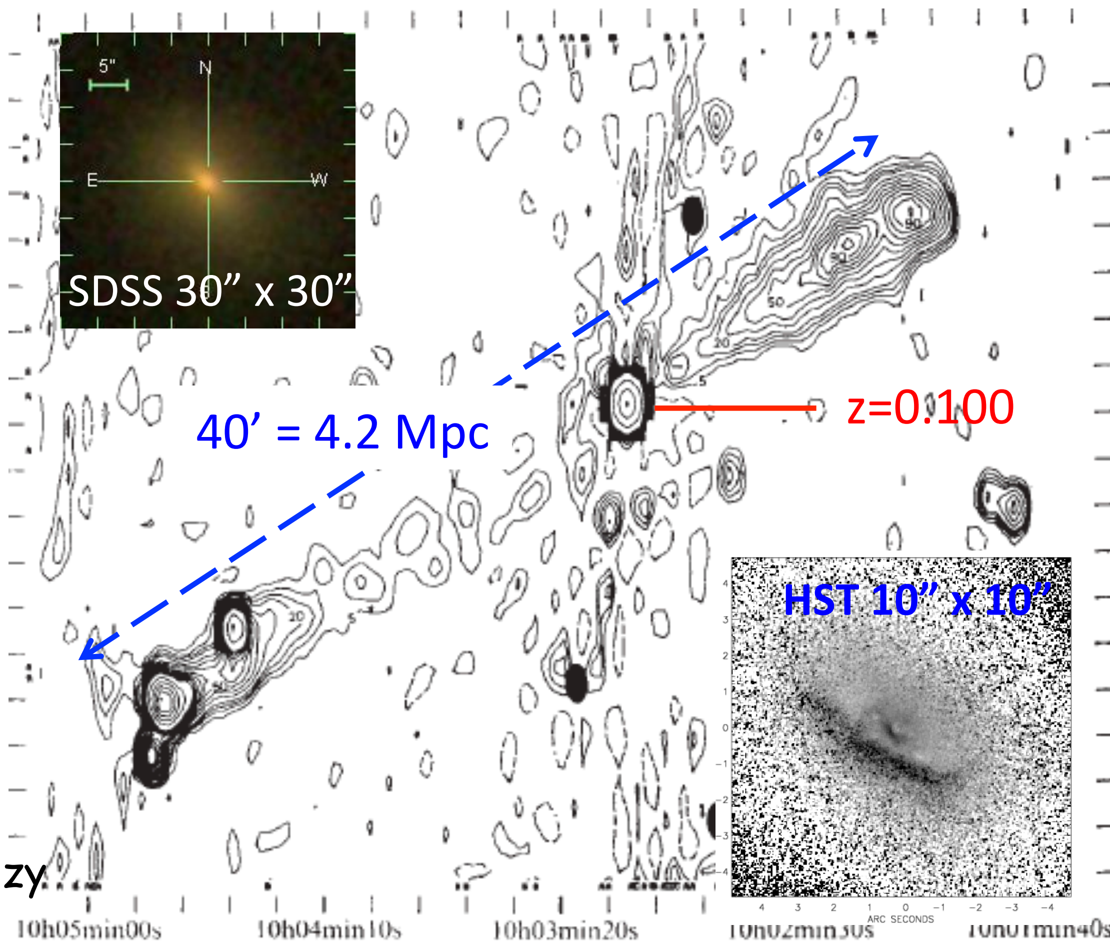
~85% are galaxies, but
~15% are quasars (**GRQs**) :

2004MNRAS.347L..79Singal
2010A&A...523A...9Hocuk & Barthel
2011AcA....61...71Kuzmicz+
2012MNRAS.426..851Kuzmicz & Jamrozy

3C 236 = first GRG found: claimed to have LLS = 5 Mpc with H_0=50, now 4.3 Mpc/h_{70}

The record holder for 34 years:

3C 236, WSRT 609 MHz Willis et al. (1974)



Of all radio galaxies, GRGs are NOT the most radio luminous sources, but

* they have the lowest minimum energy densities (down to ~ 10^{-15} J m^{-3}) in particles and magnetic field (U_{min}), and, due to their huge volume,
* they have the highest energy content (a bit forgotten today, as only energy densities are quoted)
* "put the greatest strain on radio source models" (1974MmSAI..45..535Strom+)

So, how are GRGs found ?

- sometimes accidentally: looking for an optical ID of an "extended" radio source → if at high z and LAS >~ 2 arcmin ➔ LLS > 1 Mpc

- once we "know" their radio morphology we can do a systematic search in radio surveys covering large parts of the sky (GRGs are rare!)

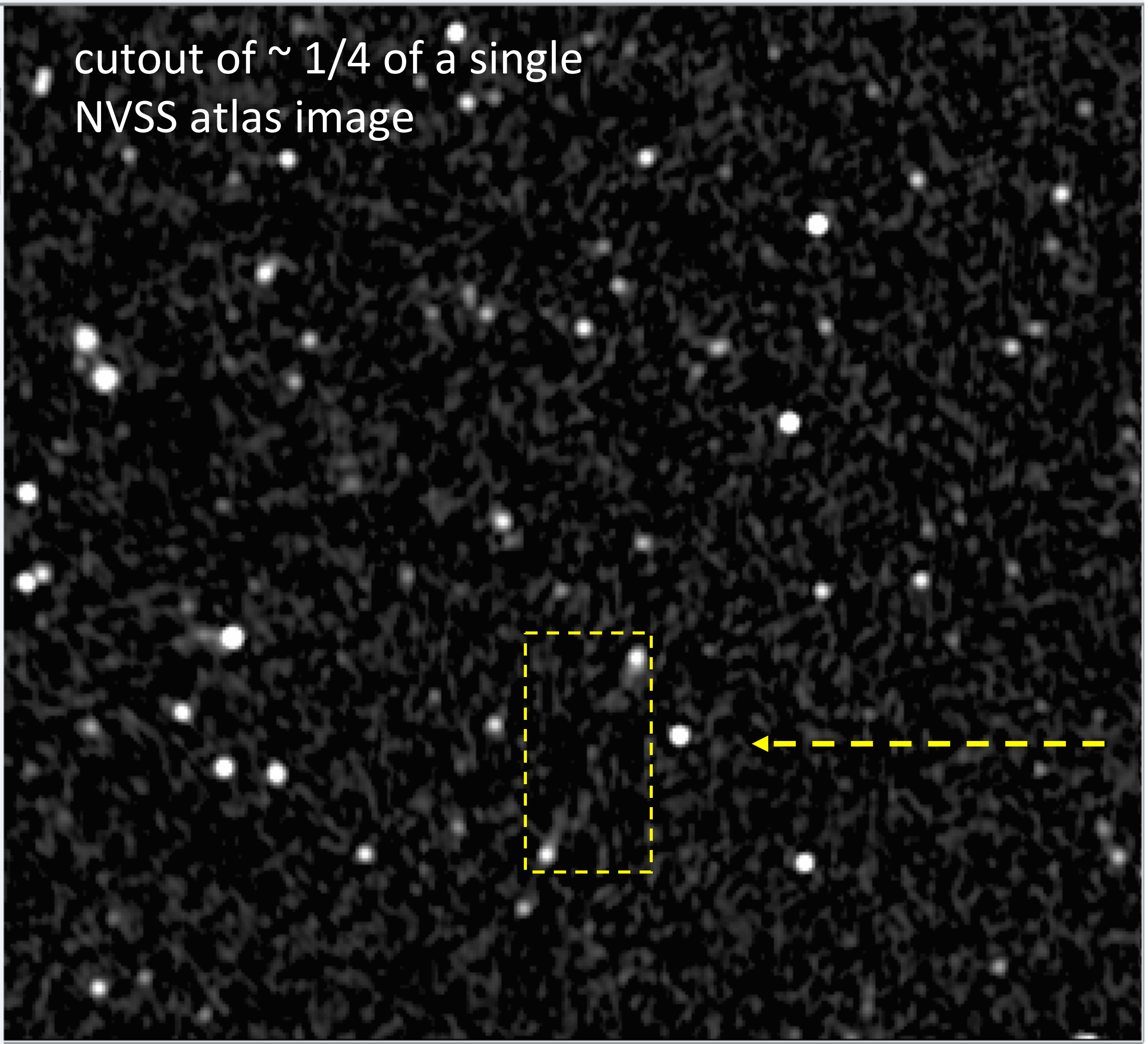
Example:

2001A&A...374..861Schoenmakers+ inspected the 325-MHz WENSS
→ found 105 candidate GRGs (now: 57 confirmed)

advantages of WENSS (and more recently TGSS-ADR1)

* sensitive to spatial components up to ~1°
* radio lobes dominate at lower frequencies
* radio cores (host galaxies) dominate at higher frequencies

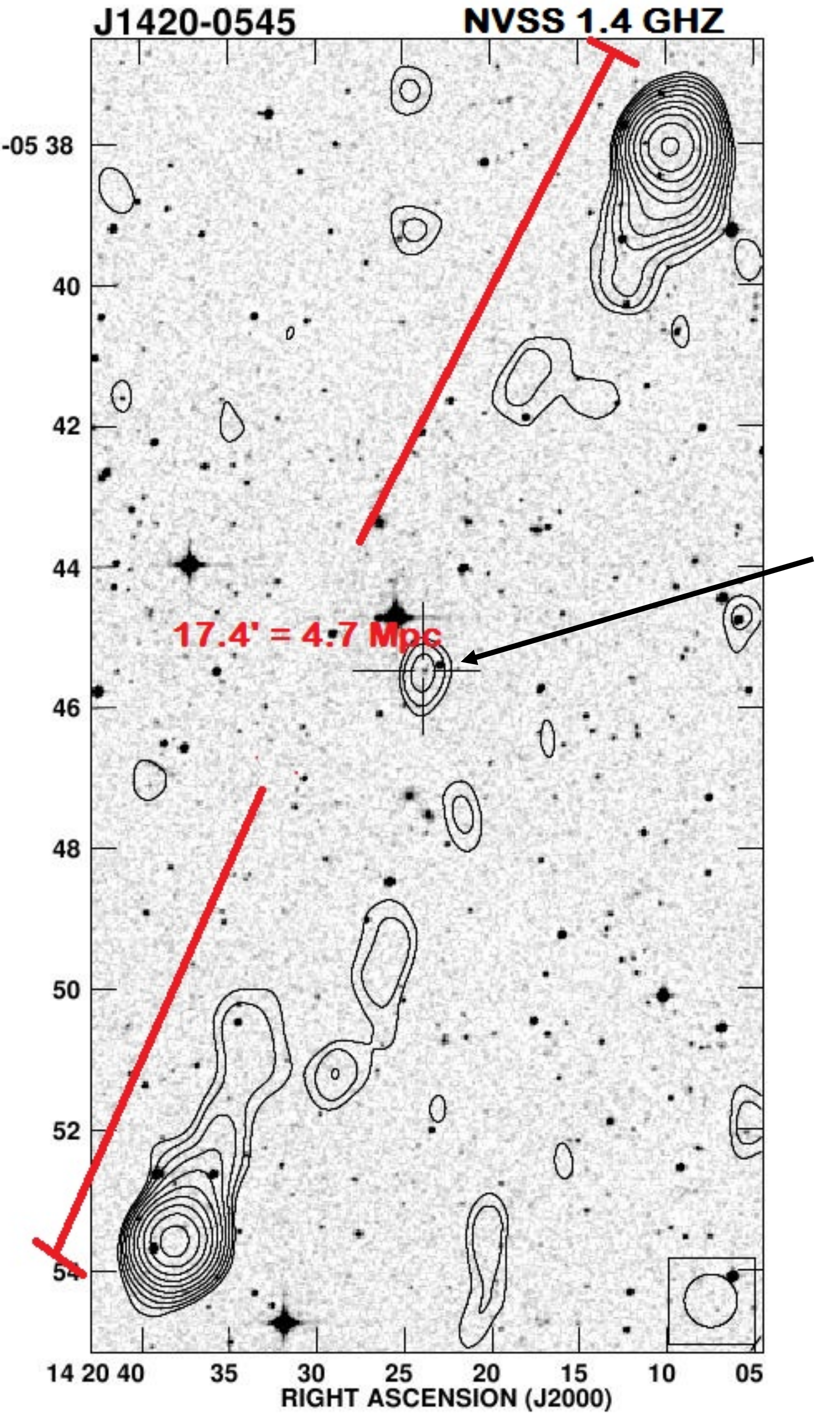
Since 1998 (20 yrs ago): a more complete and sensitive survey:
NVSS (NRAO VLA Sky Survey, Condon et al. 1998)
-covers 82 % of the sky (Dec > -40°) at 1.4 GHz (λ= 21 cm)



- angular resolution 45"
- minimum flux ~2 mJy
- catalogue of 1,800,000 sources
- atlas of 2300 images of 4° x 4°

The currently largest GRG, is J1420-0545 (cf. Machalski et al. 2008ApJ...679..149M)

discovered on NVSS atlas image by eye inspection



How does one know it is a GRG?

* The nucleus must coincide with a galaxy or QSO, which may be very faint
* the supposed lobes must NOT coincide with a galaxy (except for projection)
* the radio structure should show certain symmetry (by experience from other GRGs)

host galaxy (R=19.7, z=0.31)

total angular size = LAS ~ 17.4',
→ LLS = 4.84 Mpc /h_{70}
(2008ApJ...679..149Machalski et al.)

This is only the **projected size** :
with an inclination with respect to the plane of the sky it may well be larger !

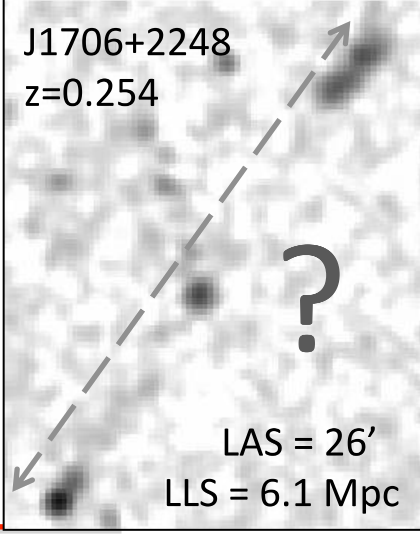
In 2012: only ~100 GRGs were known, and NOBODY HAD INSPECTED the full image atlas of the NVSS . . . (already available for 14 yrs since 1998 !)

Finding Giant Radio Galaxies (GRGs) in Imaging Radio Surveys

Heinz Andernach & three summer students
Universidad de Guanajuato, Mexico 2012

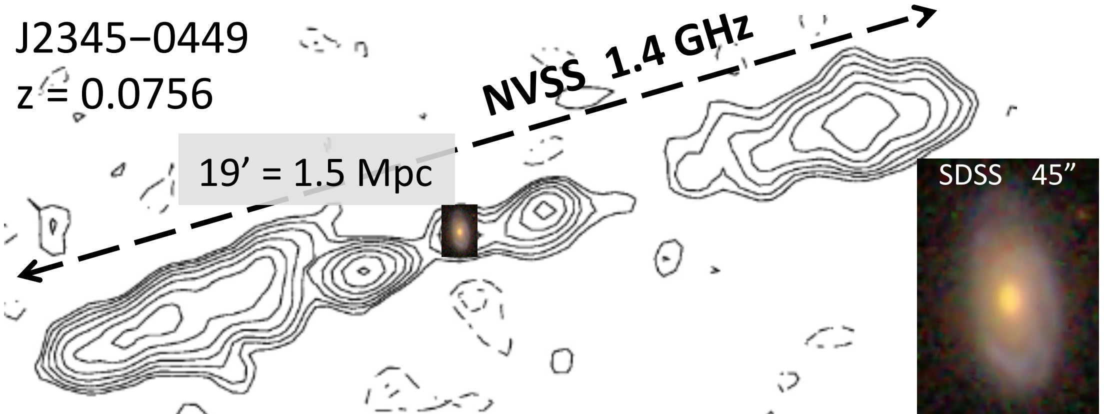
poster at adsabs.harvard.edu/abs/2012sngi.confE..33A

Known in 2012: ~100 GRGs with LLS > 1 Mpc /h_{70}
all have LLS <3 Mpc; except 2 with 4.2 and **4.4 Mpc**
(only small fraction from visual inspection of survey images)



Method: inspect **all 3050 images** (4° x 4°) of NVSS and SUMSS covering **all sky** at ~45" resolution
look for : extended or triple sources with LAS >~ 4' (after "training" with known GRGs in NVSS)
* check NED for optical ID with known z, near radio core or symmetry center → derive LLS (Mpc)
* classify the optical ID: (a) already known as GRG, (b) known RG, (c) yet unknown as radio source

Results Aug. 2012: we find the largest GRG **candidate**: LAS = 26', z = 0.254 → LLS = **6.1 Mpc/h_{70} (?)**
* we **duplicate** the number of GRGs to ~200, and **quadruple** N_{GRG} with LLS > 3 Mpc (from 2 to 8)
* we add 4 new GRQs at z > 1, and find the first GRG identified with an **optical spiral**



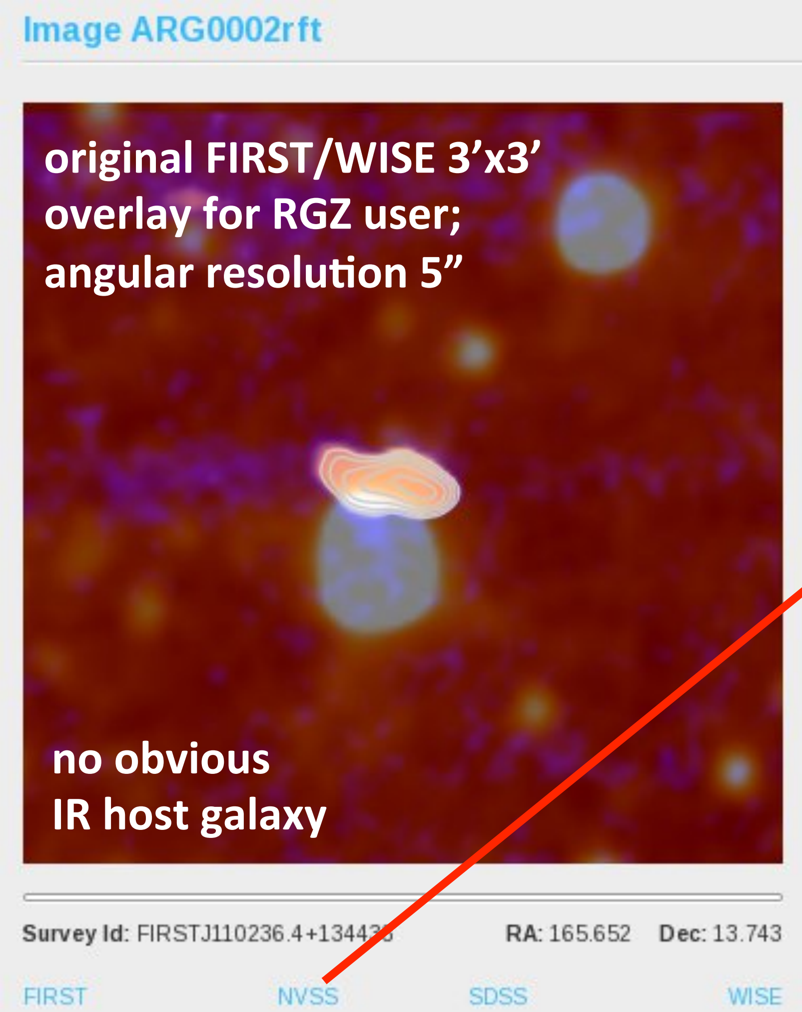
- ❑ Summer 2012: 3 students logged the positions of **~17,000 potential GRGs** in NVSS, WENSS & SUMSS
- ❑ Most promising ones followed up by H. A. since 2012
- ❑ Additional sources of GRG candidates: e.g.

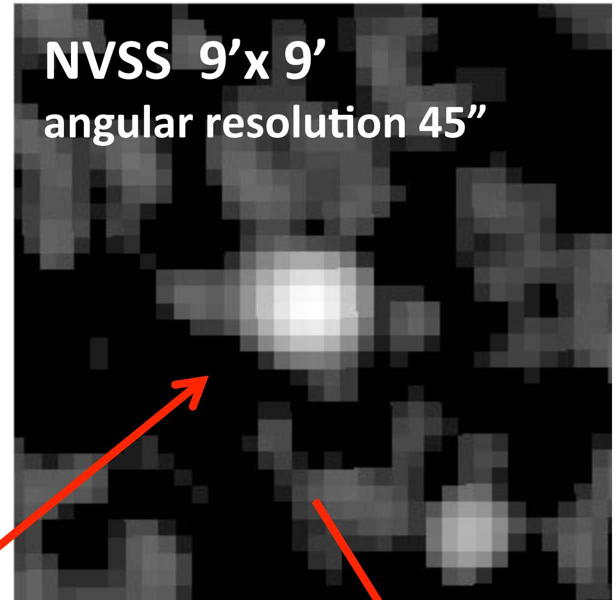
➢ 2016ApJS..224...18**Proctor** D.D.: Selection of Giant Radio Sources from NVSS (no optical IDs, ~1/3 of her 1620 candidates were already in my compilation; LAS up to ~20', already 20 new GRGs found, perhaps another 20 expected)

➔ altogether ~500 references with promising samples of objects (. . .) were checked (mainly by myself) in NVSS contour maps
→ easy + fast from command line: central cross is **extremely useful**

- ❑ I learnt "Messier's lesson": keep track also of smaller sources… not to stumble over them again and again …
- ❑ During 2012–2018: my GRG compilaton increased by ~1 GRG every 2.5 days, and by ~4 extended radio sources every day

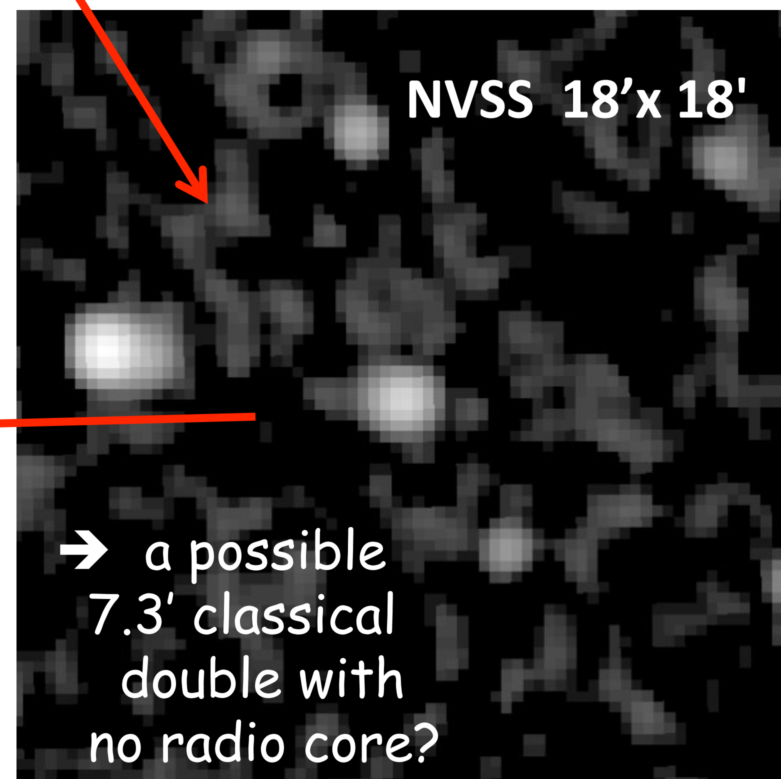
❑ **Also,** some independent "outsourcing" came to unexpected help . . . in Dec. 2013: **Radio Galaxy Zoo** was launched





nothing suspicious...

➔ open up to double the image size



use FIRST to find the radio core

SDSS J110252.76+134516.2, r =20.95 mag; z_{spec} = 0.671 measured by us with the 10.4-m GTC on Canary Islands,

➔ **LLS = 3.1 Mpc**

Will Giant Radio Galaxies (GRG) be found in RGZ ?

FIRST: angular resolution 5.4", largest component detectable ~2'

➔ unlikely to reveal new GRGs (needs LAS$\gtrsim$2 arcmin at $z \sim 1.0$–1.5)

From Dec 2013 through Nov 2018:

RGZ users found / refound / pointed me at

- 400 giant RGs (> 1 Mpc/h_{70}); 250 of them newly found in RGZ;

of these 250, **143** have no doubt about LAS, optical ID or GRG nature;

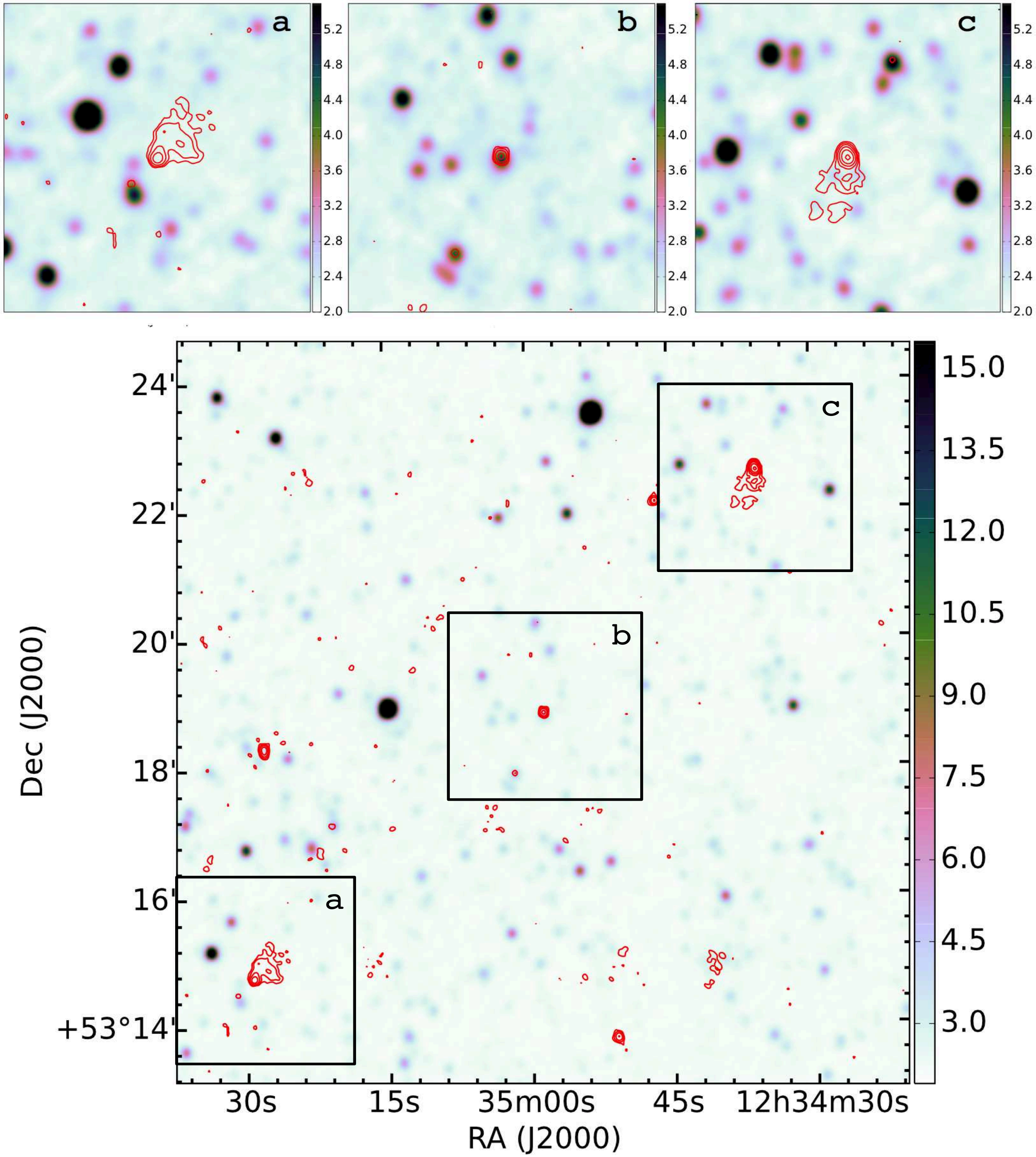
>70% of these were found by 2 specific "super"volunteers

(the two are already coauthors of non-GRG papers based on RGZ)

Comparison of published GRGs and those newly found in RGZ

	260 published	250 new from RGZ
median z	**0.24**	**0.57** ←
fraction of QSOs	16 %	18 %
median r'mag	18.2	20.8
median LAS (')	6.2	3.3
median LLS (Mpc)	1.38	1.25
N (LLS > 2 Mpc)	47	10

this table includes all likely candidates



J1234+5318 was rediscovered in Radio Galaxy Zoo 6 days after its start!

Looking at only one lobe (with no opt. ID) 2 volunteers noted its huge size of 11.2′

z_{phot} = 0.6 → **4.24 Mpc/h_{70}**

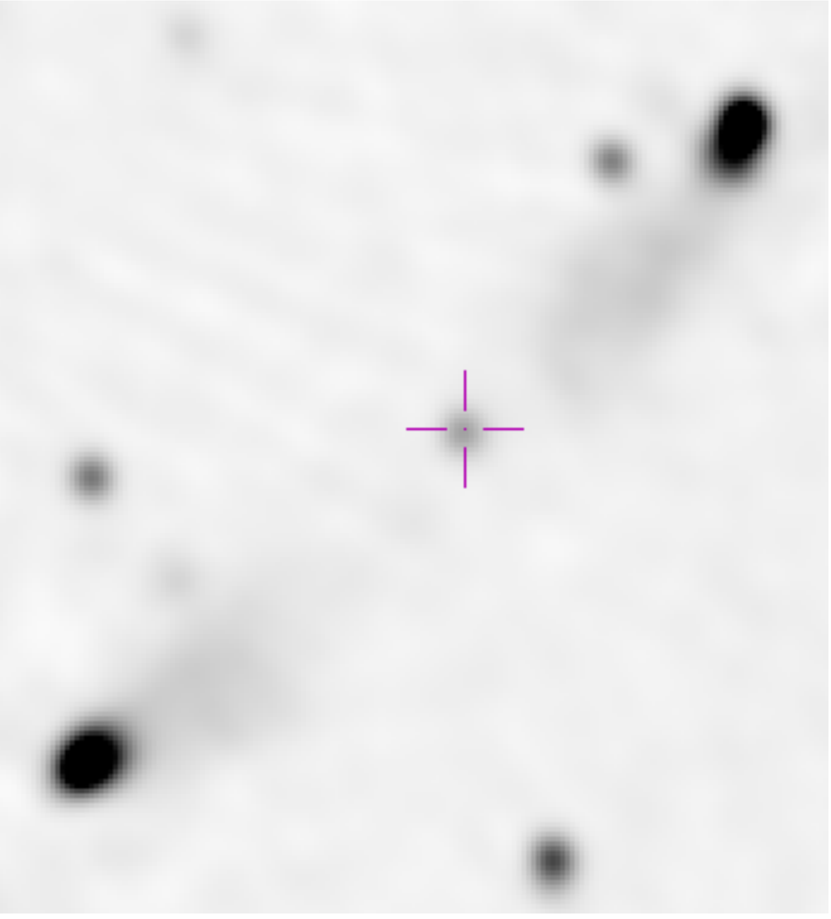
Image from the RGZ "definition paper" 2015MNRAS.453.2326B

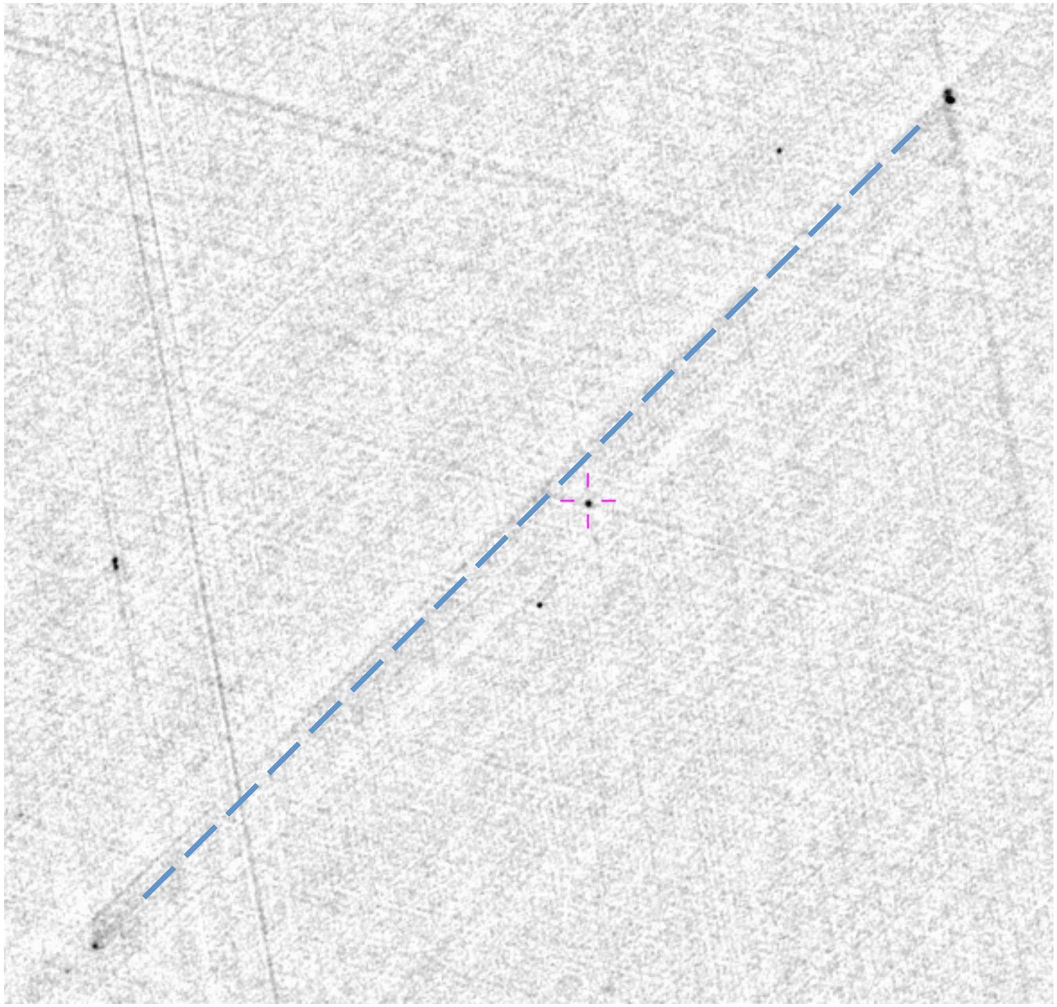
→ our optical spectroscopy confirmed z_{phot} to within ~4%,

we also confirmed z_{phot} for two QSOs at z=1.3 and 1.8 to within 5% of z_{phot}

Apparently "confirmed" in LoTSS and VLASS

2017A&A...598A.104Shimwell T.W. et al.: The LOFAR Two-metre Sky Survey I.
300 deg ^{2} with 25" resolution at 150 MHz





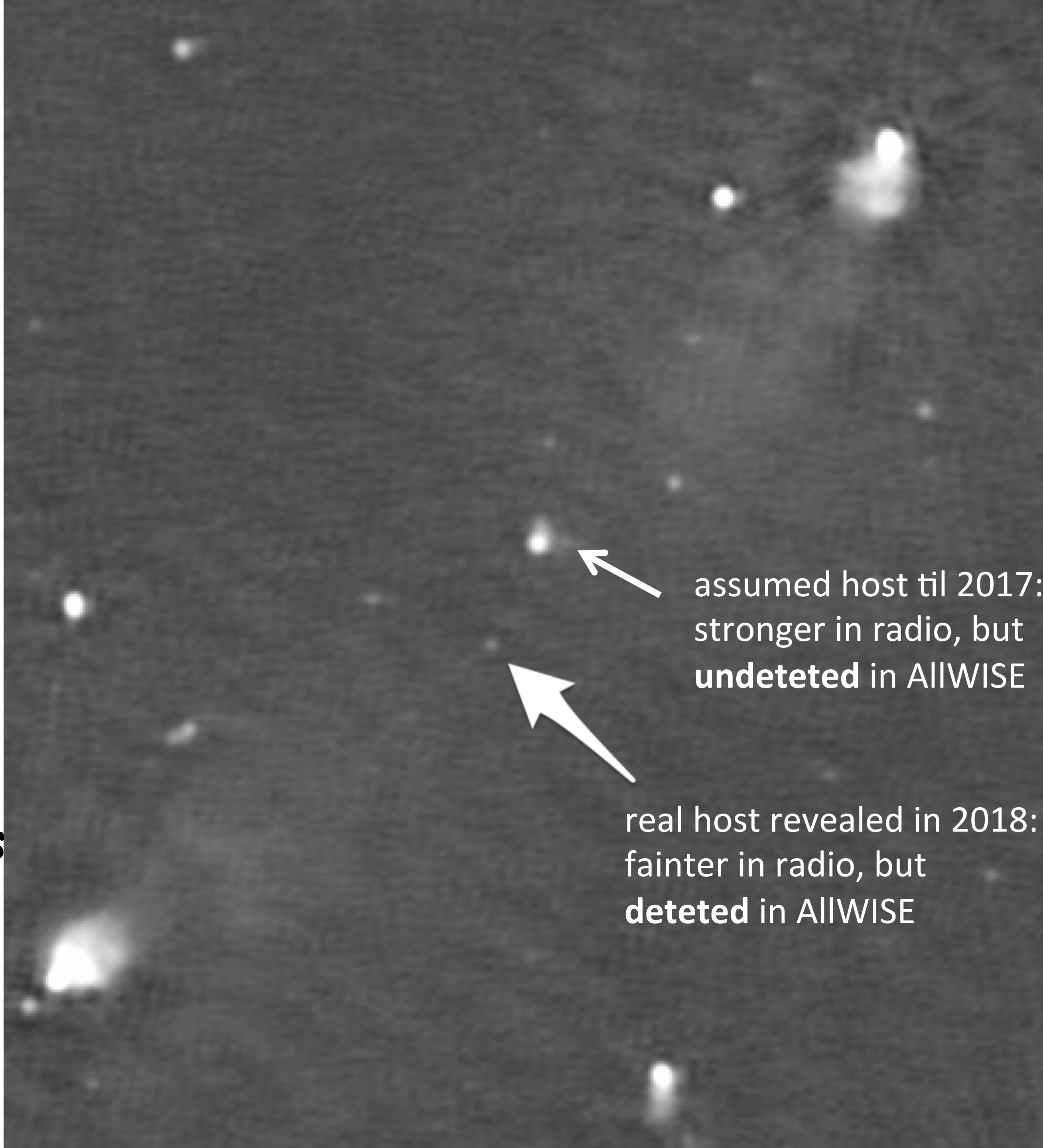
Very Large Array Sky Survey (VLASS)
2017–2024, 2–4 GHz, B-configuration
angular resolution 2.5"

A big surprise from LoTSS high-resolution image (6", 150 MHz, arXiv:1811.07934)

➔real host is further off-axis, and at lower z=0.34,
➔LLS =3.25 Mpc
LoTSS shows the **longest continuous radio jet ever seen** (~1.5 Mpc)

Feb 2019: **LoTSS-LDR1**
424 deg² of 6" images

By ~2025: LoTSS covers DEC > 0°
➔ ~25 TB of images
~ 17 million sources



Results of Summer Internships in 2017: inspection of 2 recent surveys:

a) Heywood+2016: JVLA Stripe82 1.4 GHz (resol. 16″ x 10″)

b) Shimwell+2017: LoFAR 2-m Sky Survey at 150 MHz (resol. 25″)

arXiv.org > astro-ph > arXiv:1710.10731

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Astrophysics > Astrophysics of Galaxies

New Giant Radio Galaxies in the SDSS-JVLA Stripe82 and LoTSS-PDR Survey

Jonatan Rentería Macario, Heinz Andernach

(Submitted on 30 Oct 2017 (v1), last revised 12 Nov 2017 (this version, v2))

Extragalactic radio sources with projected linear size larger than one Megaparsec 1 Mpc = 3.09e22 m = 3.3e6 light years) are called Giant Radio Galaxies (GRGs) or quasars (GRQs). Over the past few years our search for such objects by visual inspection of large-scale radio surveys like the NRAO VLA Sky Survey (NVSS) and Faint Images of the Radio Sky at Twenty Centimeters (FIRST) has allowed us to quadruple the number of GRGs published in literature. Here we report the discovery of 7 new GRGs in two recent surveys, the JVLA 1-2 GHz Snapshot Survey of SDSS Stripe82 and the 150-MHz LOFAR Two-metre Sky Survey Preliminary Data Release

arXiv.org > astro-ph > arXiv:1710.11490

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Astrophysics > Astrophysics of Galaxies

A search for giant radio galaxies in recent deep radio surveys

Brissa Gómez Miller, Heinz Andernach

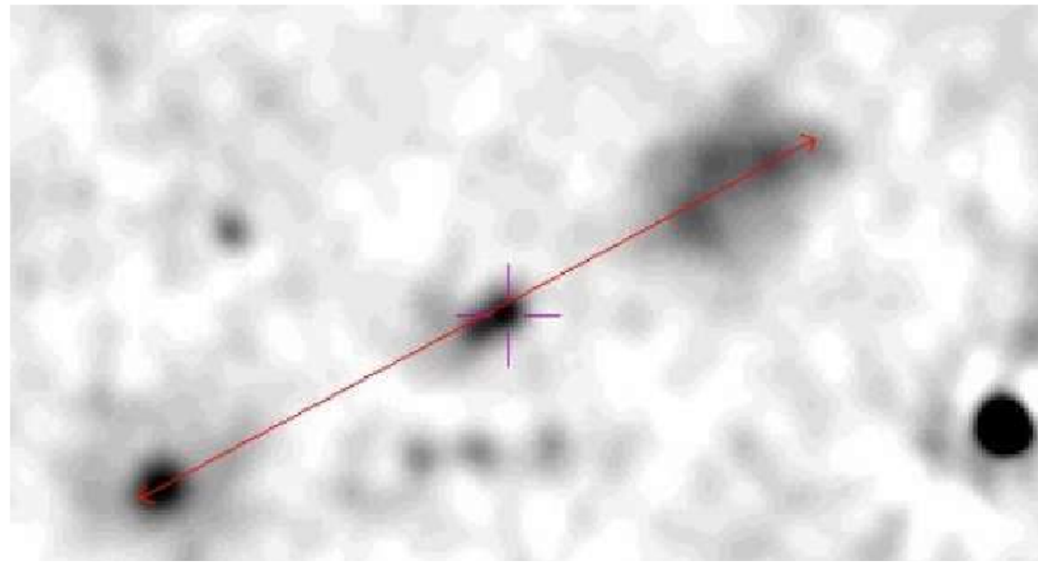
(Submitted on 30 Oct 2017)

Giant Radio Galaxies (GRG) are those whose linear size projected on the sky exceeds one Megaparsec (1 Mpc = 3.09e22 m = 3.3 million light years). Since only about 300 of these have been reported in literature, we used two recent deep radio surveys to search for further examples of these rare objects. Here we describe the discovery of several new GRGs in these surveys.

https://phys.org/print429256872.html

Seven new giant radio galaxies discovered

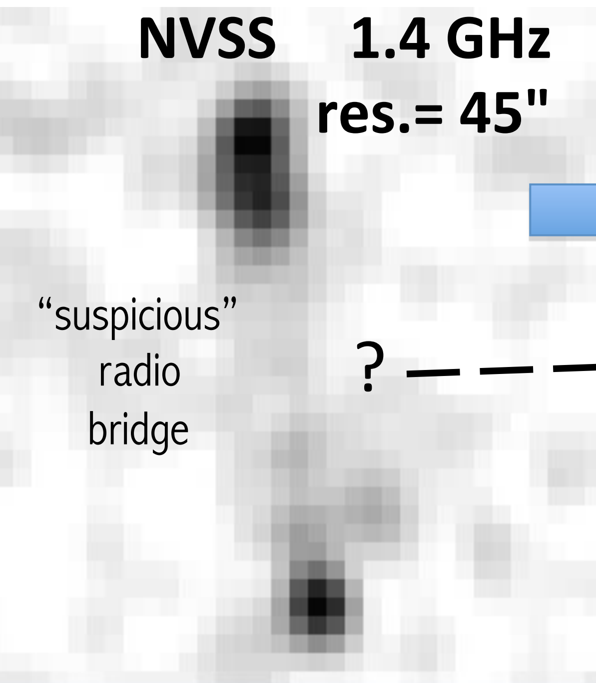
November 7, 2017 by Tomasz Nowakowski in Astronomy

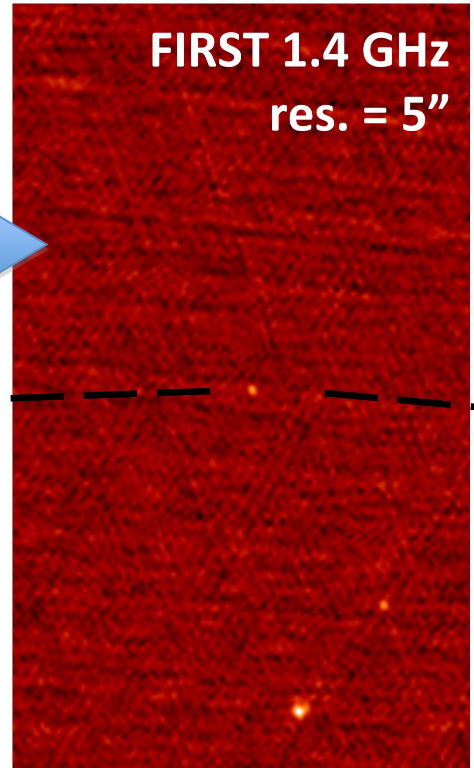


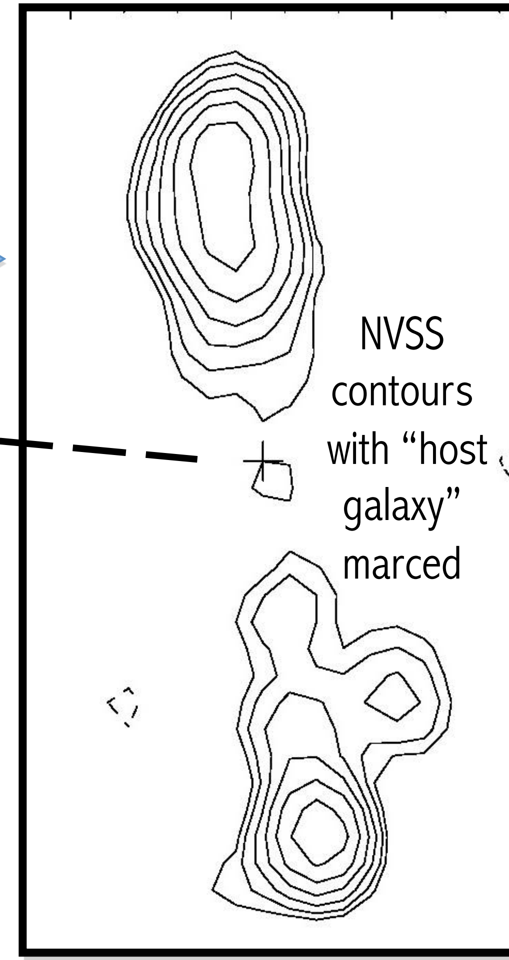
(Phys.org)—Mexican astronomers report the discovery of seven new large extragalactic radio sources called giant radio galaxies (GRG). The GRGs were found by visual inspection of radio images provided by two astronomical radio surveys. The findings were presented October 31 in a paper published on arXiv.org.

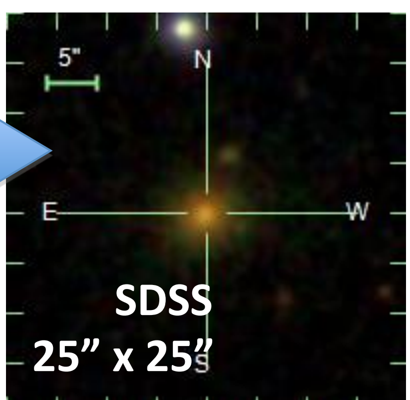
Optical identification: much easier in areas covered BOTH by

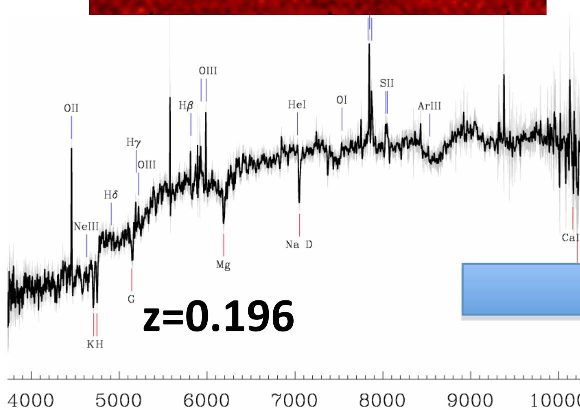
- Sloan Digital Sky Survey (SDSS) → optical images "in color" (5 filters)
- FIRST survey (angular resol. ~5") → often reveals the nucleus/host











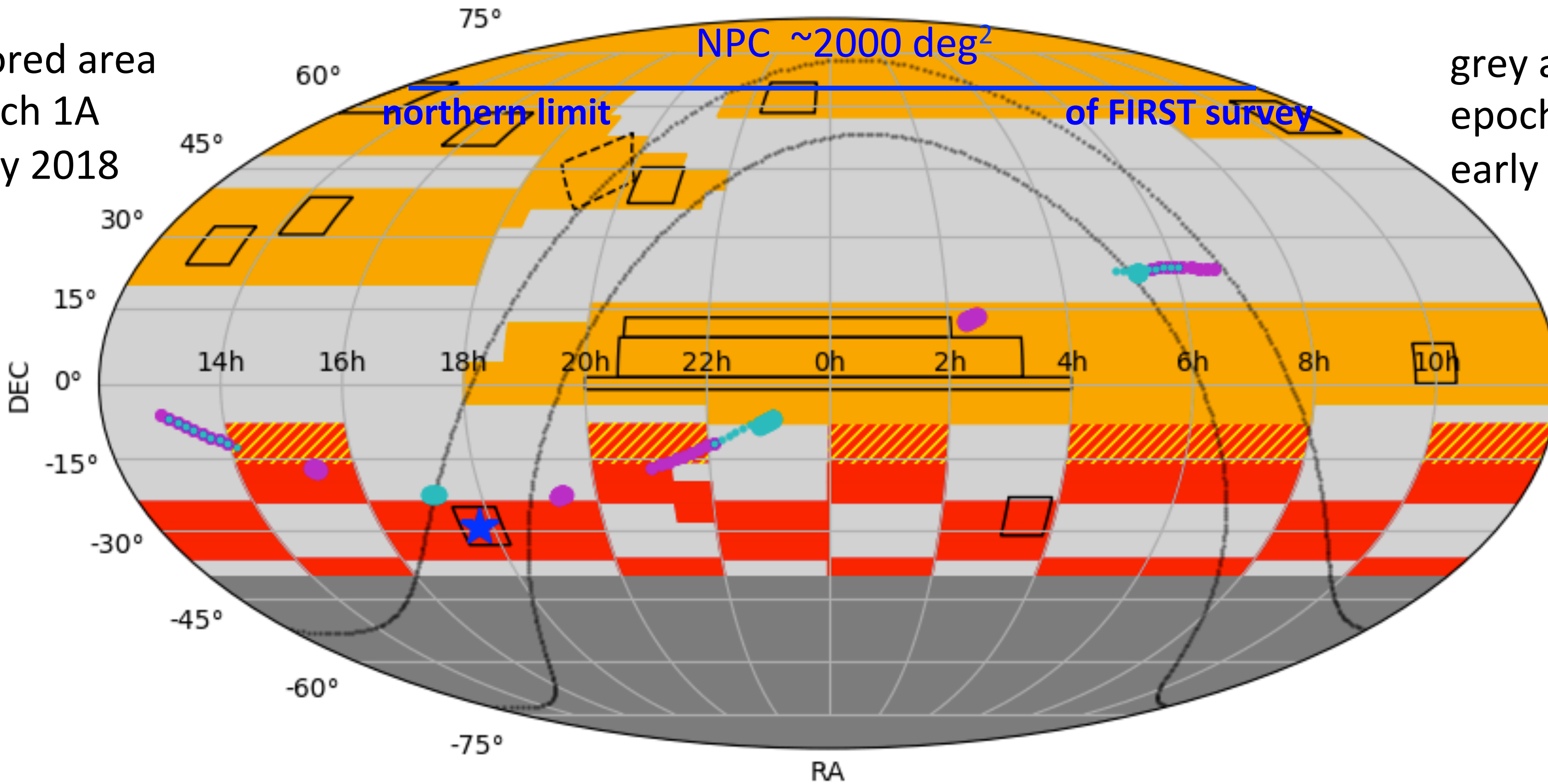
J0107+0246 LAS = 7.6'

z = 0.196 LLS = 1.4 Mpc

Could VLASS + PanSTARRS be useful to find more Giants ?

Survey of entire sky with DEC > −40° ➔ 82% of sky (~34,000 deg^2)
using the VLA at S-band (2–4 GHz) in its B configuration,
first time VLA is used with new technique: "on-the-fly" (OTF)
six observing epochs 1A, 1B 2A, 2B, 3A, 3B (2017–2024)
angular resolution 2.5" ; σ per epoch ~0.12 mJy/b, σ_{final} ~ 0.07 mJy/b
release Quicklook (QL) images (1 deg^2) within weeks of observations

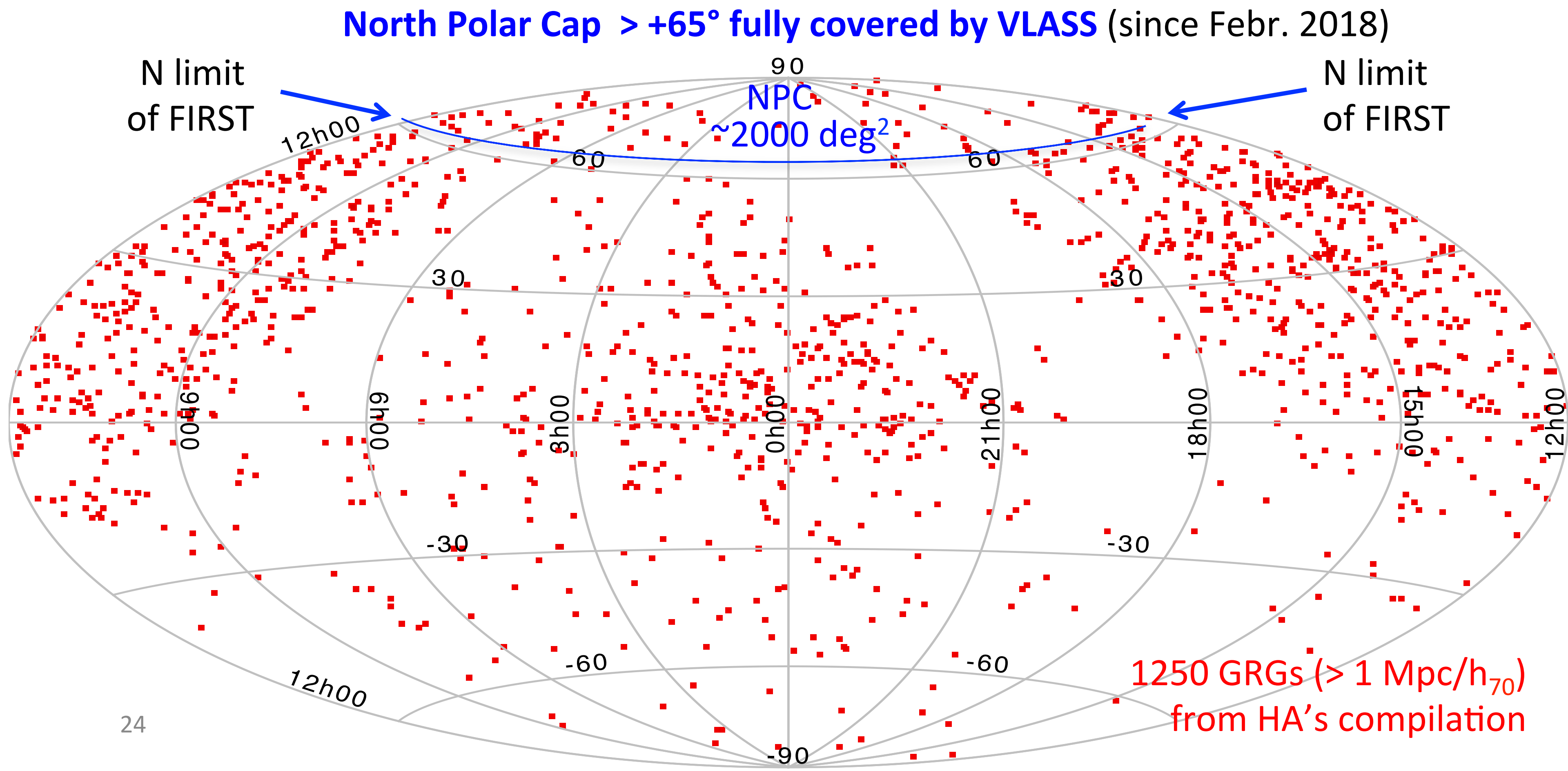
colored area
epoch 1A
early 2018



grey area
epoch 1B
early 2019

Sky distribution of all ~1250 GRGs/GRQs compiled until March 2018

- all-sky average of ~1 GRG every 35 deg^2
- only 187 for DEC < −10° → 1 GRG every 120 deg^2
- highest surface density ~0.1 deg^{-2} in the area covered by NVSS, FIRST and SDSS



Progress and current status of VLASS:

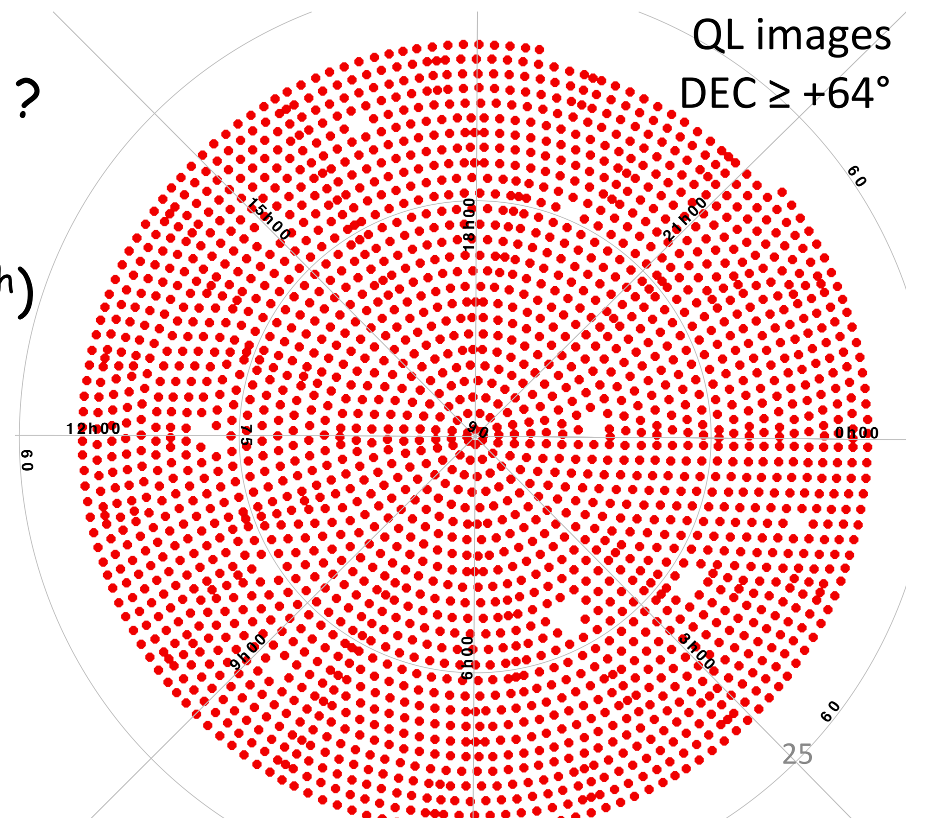
- started on Sept. 07, 2017
- June 2018: 17,500 QL images are public (~96% of epoch 1A, 40% sky)
- but according to the VLASS team :

  QL images are available to identify potential transients
  but are **not recommended to be used for science.** Later "SingleEpoch" images will use more sophisticated techniques (timescale >> months) ...

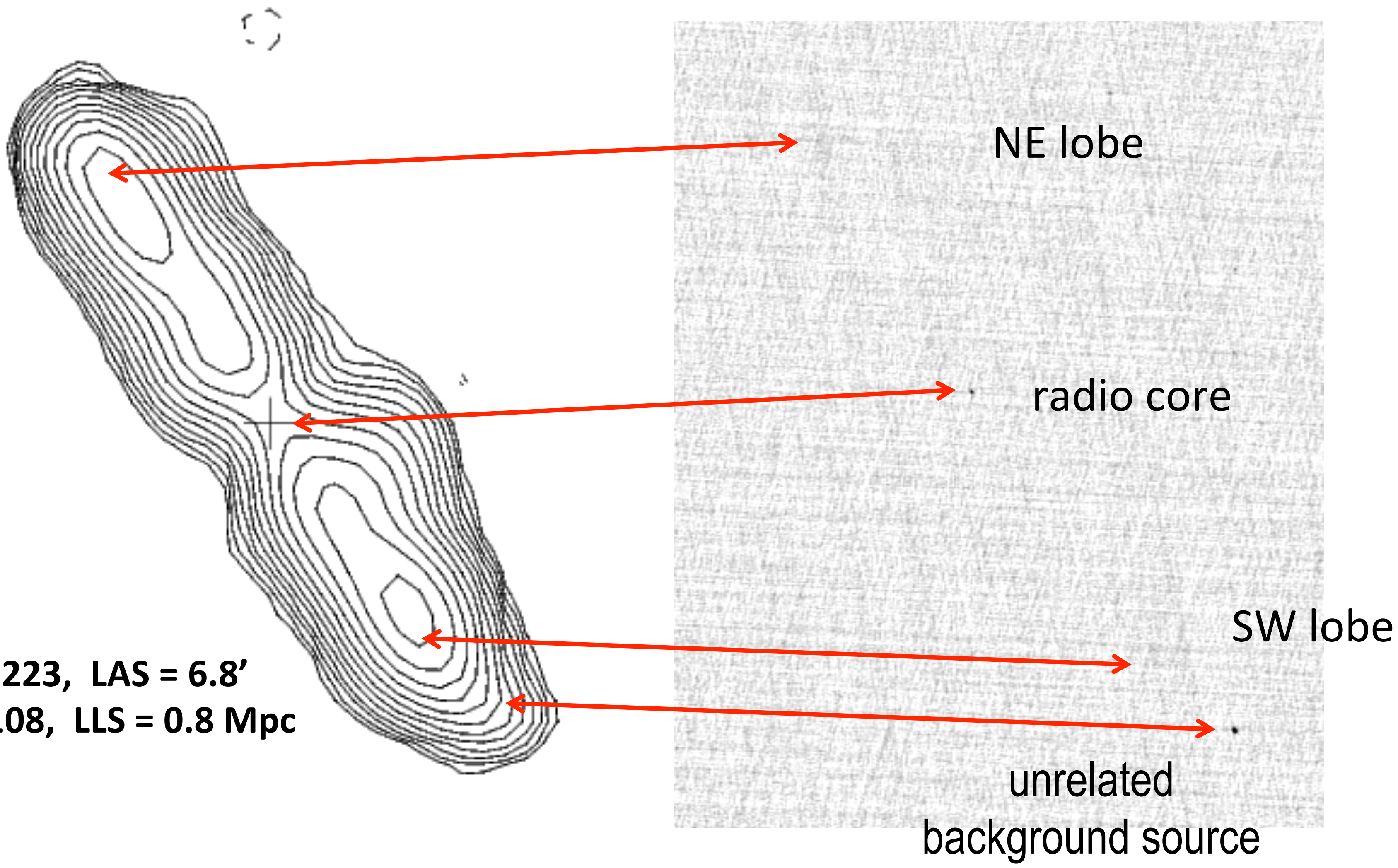
My **curiosity**: can I find new GRGs or confirm/reject candidates in the NPC ?
NVSS covers the NPC, but FIRST (revealing the radio cores) only reaches to DEC = +64° (07^h ... 17^h)
VLASS covers ALL except
~16 rejected QL images

Previously known GRGs:
23 for DEC > +70° (1 in 55 deg^2)

2229 VLASS
QL images
DEC ≥ +64°



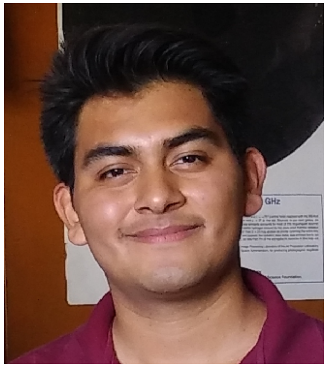
What most people would expect from VLASS :
yes, there are examples of giants unrecognizable in VLASS



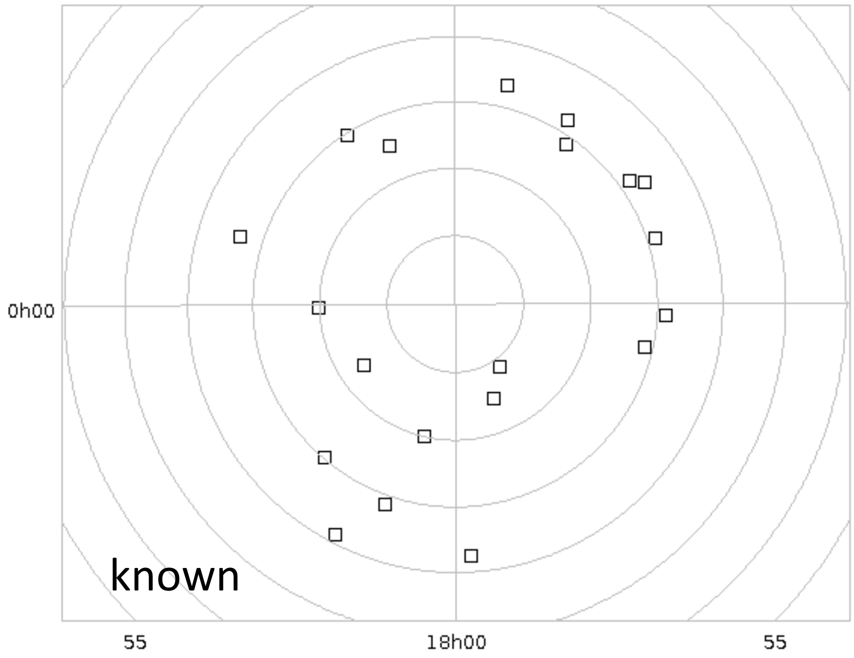
J0017-2223, LAS = 6.8'
z_{sp} = 0.108, LLS = 0.8 Mpc

About 3000 extended sources were recorded by H.A. and followed up by summer student **J. Guerrero Glz.**

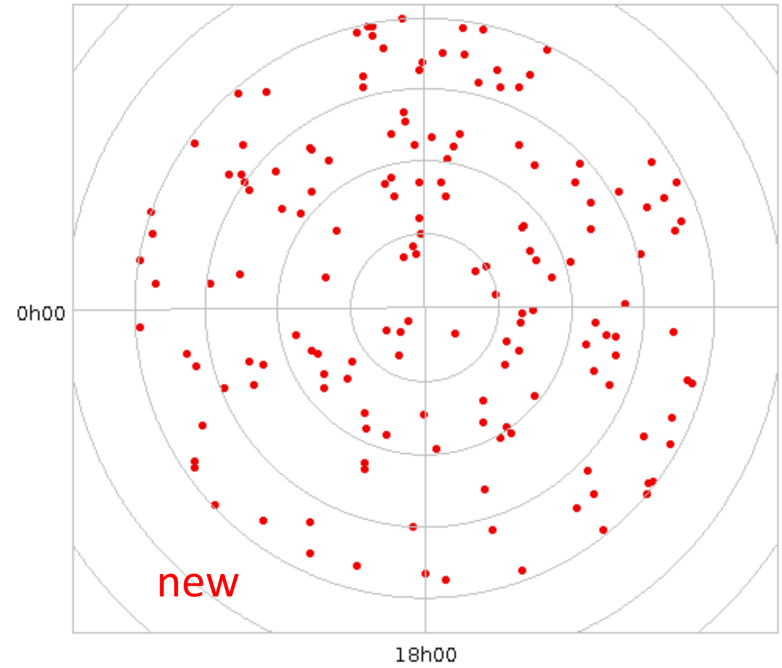
* those with radio core were X-matched with opt/IR catalogs, verified in NVSS + TGSS
* those without radio core : likely host searched



known RGs with LLS ≥ 0.7 Mpc from 2018ApJS..238....9Kuzmicz et al.



newly found RGs with LLS ≥ 0.7 Mpc by H. Andernach & J. Gonzalez



Current result of inspection: for DEC > 70°:

increased number of GRGs > 1 Mpc by factor **five**

increased number of GRGs > 0.7 Mpc by factor of **nine**


How to keep the summer students motivated . . .
Dept. of Astronomy
Univ. Guanajuato

Summer student A. Villarreal inspected 4300 deg^2 of VLASS
not covered by FIRST

Agueda Villarreal Hdz.

arXiv.org > astro-ph > arXiv:1808.07178

Search or Art

(Help | Advanced sea

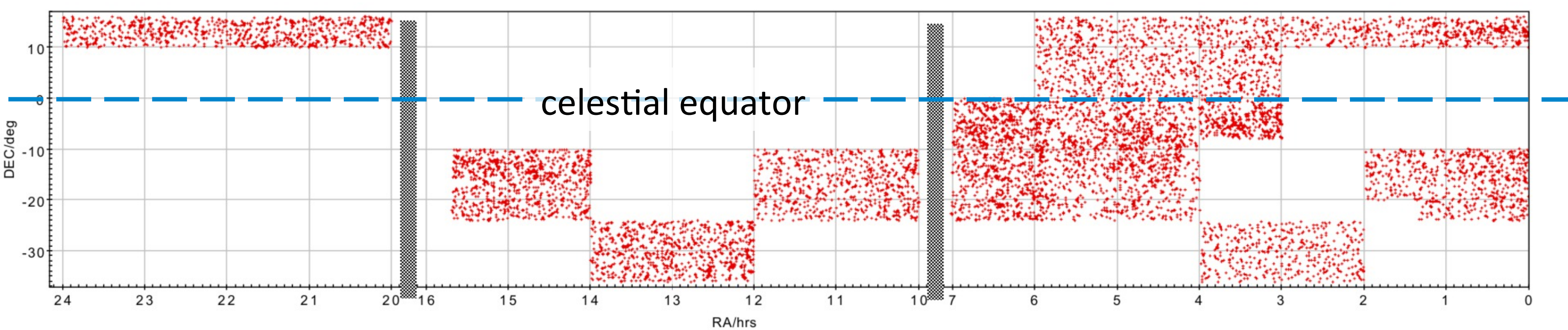
Astrophysics > Astrophysics of Galaxies

A Search for Extended Radio Sources in 1.3 sr of the VLA Sky Survey (VLASS)

Agueda C. Villarreal Hernández, Heinz Andernach

(Submitted on 22 Aug 2018)

We report preliminary results of a visual inspection of ~4300 deg^2 covered by 4414 images of the 3-GHz VLA Sky Survey (VLASS, epoch 1.1) in search of extended radio structures. Over 7600 positions were registered, and for a subset of 270 of the most promising candidates their host objects were searched in optical and



Sky distribution of 7600 candidate ext. RGs : to be followed up . . .

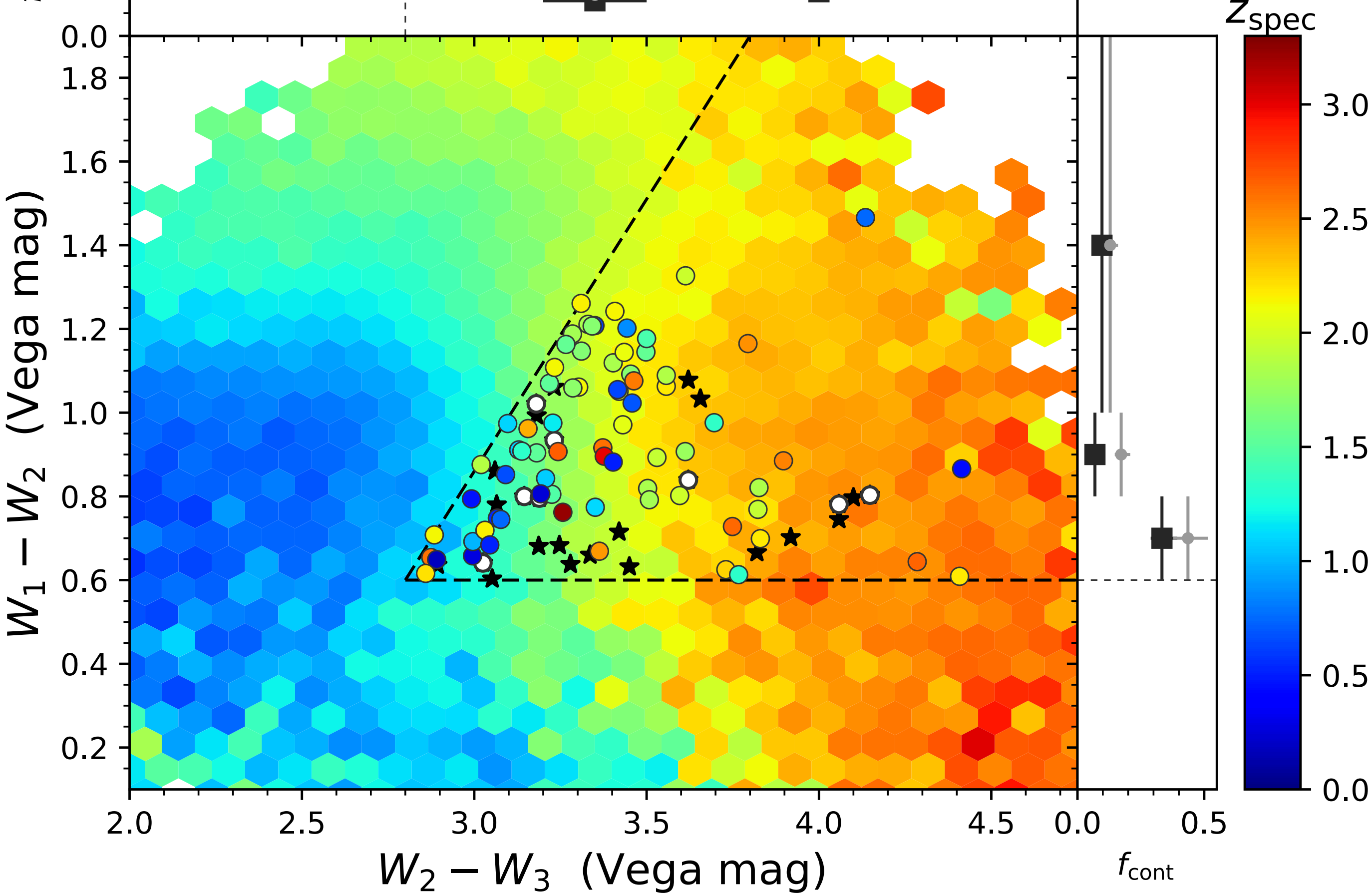
Very essential for this work: catalogs of photometric redshifts

2004ApJS..155..257Richards+	SDSS DR1 QSOs	100,563
2004MNRAS.351.1290Rowan-Rob.	ELAIS field	3,523
2005ApJS..158..161Hsieh+	RedClusterSequence	1,464,939
2007MNRAS.380.1608Lopes P.A.A.	LRGs in SDSS-DR5	1,459,536
2007MNRAS.375...68Collister+	SDSS DR4 LRGs	1,214,117
2009ApJS..180...67Richards+	SDSS DR6 QSOs	1,015,082
2010ApJ...714.1305Strazzuolo+	Deep SWIRE AGNs	1,580
2011MNRAS.416..857Smith+	Herschel-ATLAS	6,876
2011ApJ...729..141Bovy J.+	SDSS DR8	4,009,058
2011AJ....141..105Peth M.A.+	SDSSDR6/UKIDSS QSOs	172,186
2011ApJ...736...21Szabo+	SDSS clusters	69,173
2012ApJ...757...83Desai+	Blanco Cosm. Survey	1,955,400
2009ApJ...690.1236Ilbert+	COSMOS fld (2 deg^2)	385,065
cesam.lam.fr/cfhtls-zphots	SDSS stripe82	13,621,717
2013MNRAS.428..226Polsterer+	SDSS DR6 high-z QSOs	121,109
2013MNRAS.428.1958Rowan-Rob.	SWIRE, Lockman	1,009,607
2014ApJS..210....9Bilicki+	2MASS 2MPZ	928,352
2014A&A...568A.126Brescia+	SDSS-DR9	143,500,000
2014MNRAS.437..968Cavuoti+	SDSS DR4 AGNs	3,201,824
2015ApJS..219...12Alam+	SDSS DR12	208,474,076
2015PASA...32...10Flesch	Half Million Quasars	510,764
2015MNRAS.452.3124DiPompeo+	SDSS QSO candidates	5,537,436 ←
2015ApJS..219...39Richards+	SDSS-III/BOSS	2,490,080
2015ApJS..221...12Secrest+	WISE survey	1,354,775
2016ApJS..225....5Bilicki +	SCOSxWISE	78,000,000
2018MNRAS.475.3613Soo J.Y.H.+	CFHT-Stripe82	5,577,379
2016MNRAS.460.1371Beck R.+	SDSS DR12	208,474,076
2016ApJS..224...24Laigle C.+	COSMOS2015 catalog	1,182,108
2017A&A...608A..39Muntrichas G.+	X-ATLAS field	1,031
2017arXiv170302991deJong+	KiDS-ESO-DR3	48,736,590
2017AJ....154..269Yang Q.+	SDSSstripe82 QSOs	45.505
2018ApJ...862...12Gao J.+	SCUSS-u survey	23,067,608
2018A&A...618A..52Ruiz A.+	XMMPZCAT	100,178
2018A&A...616A..69Bilicki M.+	KIDS-DR3	39,166,070

some very large catalogs with z-photo data are NOT available via VizieR @ CDS

Total :
770,045,500 records

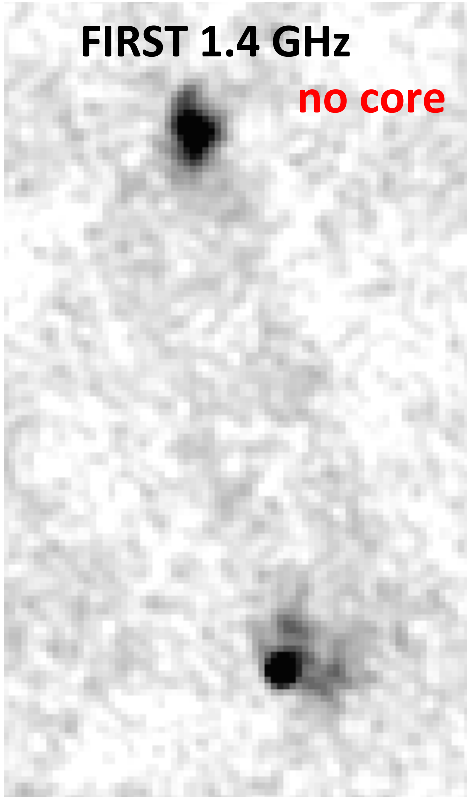
Why has nobody attempted z_{phot} for PanSTARRS ?

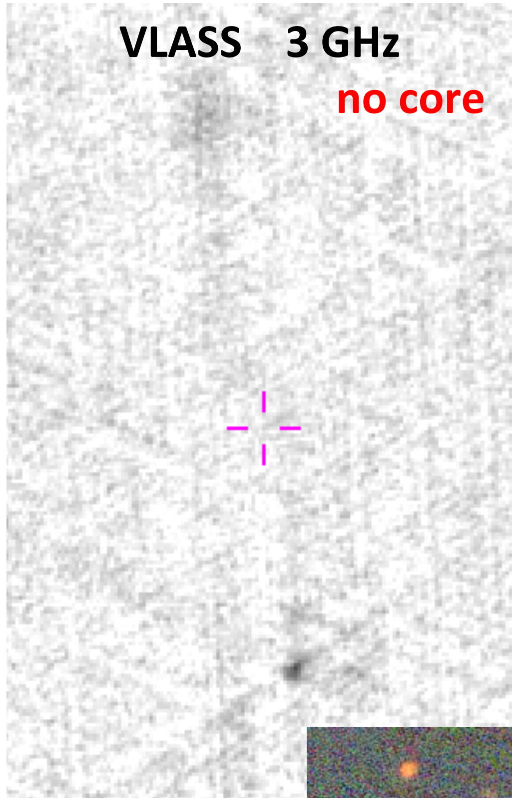


2018ApJS..235...10Krogager J.-K.+ present the median z_{spec} for 300,000 QSOs as function of WISE color → serves as a very crude z estimate for optically starlike objects with QSO-like colors in mid-IR

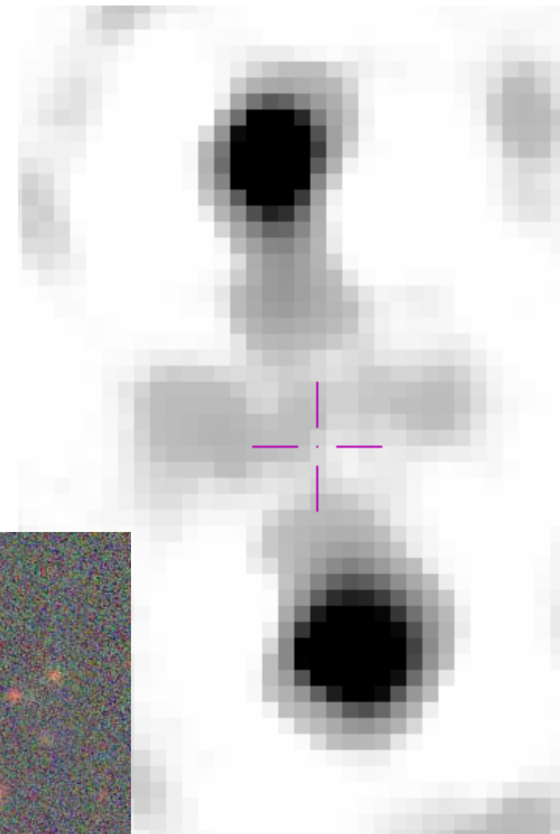
Figure 2. *WISE* color-color plot for quasars. The underlying distribution shows spectroscopically observed quasars from the Sloan Digital Sky Survey (Pâris et al. 2017). The color coding corresponds to the mean redshift of quasars in a given bin. The MALS quasars are shown as large, colored dots (following the same color coding). Black stars indicates contaminating stars or galaxies and white dots mark the candidates for which no classification was possible. The dashed lines show the region of color-space that we used to select high-redshift candidates. The two panels at the top and right edges indicate the contaminating fraction, f_{cont}, of stars and galaxies in dark gray, and the contamination including the unidentified sources is shown in light gray.

Another surprise in VLASS: over half of the large RGs have no radio core
J1344+4845: found in RGZ, later refound in LoTSS

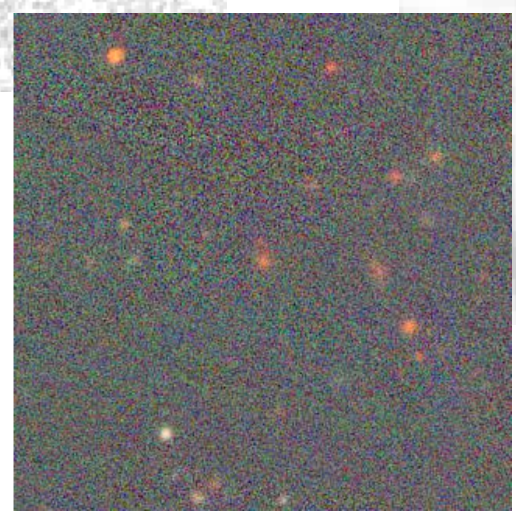




LoTSS 150 MHz: previously unknown **"wings" show up**



SDSS J134415.64+484549.2, r'=21.68,
z_{ph} ~ 0.663, LAS=2.9' → LLS ~ 1.13 Mpc
PanSTARRS gri 80" (560 x 560 kpc)
→ **host is in a cluster** !



So what is it that GRGs allow to grow that large ?

2009ARep...53.1086Komberg & Pashchenko discuss standard "paradigms" . . .

- GRGs can occur only in low-density environments ?
  - ➔ NO! They are found both in the "field" and in rich clusters

  Our own analysis (R. Ortega-Minakata using SDSS DR7):

  GRG size shows no correlation with number of neighboring galaxies

- GRGs lie mostly in the plane of the sky ...?

  NO! Fraction of broad-line spectra among GRGs is not much lower than for other RGs ➔ discordance with "unified scheme"

- Our work: a few very large GRGs show 1-sided jets ➔ Doppler-boosted
  - ➔ are they much larger in 3-D ? (3C 326: Schilizzi+2001)

- GRGs have higher-power jets ... ? ➔ NOT confirmed by observation

  ➔ 2009ARep...53.1086Komberg & Pashchenko suggests that it is the lifetime of the central engine is ~10 x longer for GRGs

- GRGs and GRQs do not differ in their asymmetry parameters
  - ➔ if unified scheme works, asymmetry due to external environment

The GRG compilation as of 01-Dec-2018

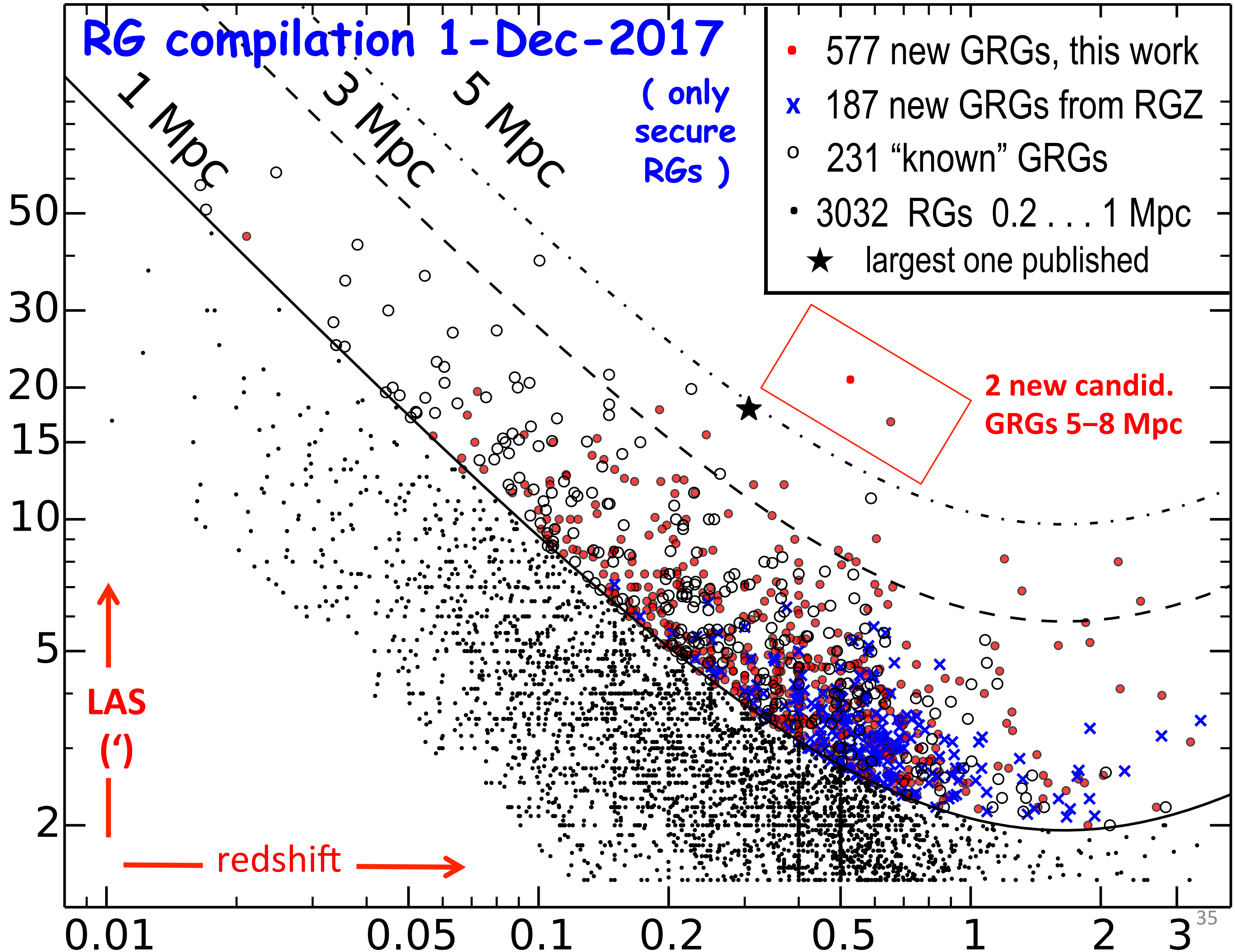
* Total of **1310 GRGs** > 1 Mpc/h_{70} (~400 have minor doubts)
  only ~250+ were reported as GRGs in literature
* vast majority of **FR II** morphologies, but often one or both
  lobes are resolved out (very diffuse) in FIRST
* **~50% have z_{spec}**; ~40% have good z_{phot}, ~10% are "best guesses"
* 83% galaxies, 16% quasars, ~1.5% unknown (e.g. WISE-only)

  median z is ~0.4: 0.36 for galaxies and 0.83 for QSOs

  ~75 GRQs lie at z > 1, and a few **up to z~3** !

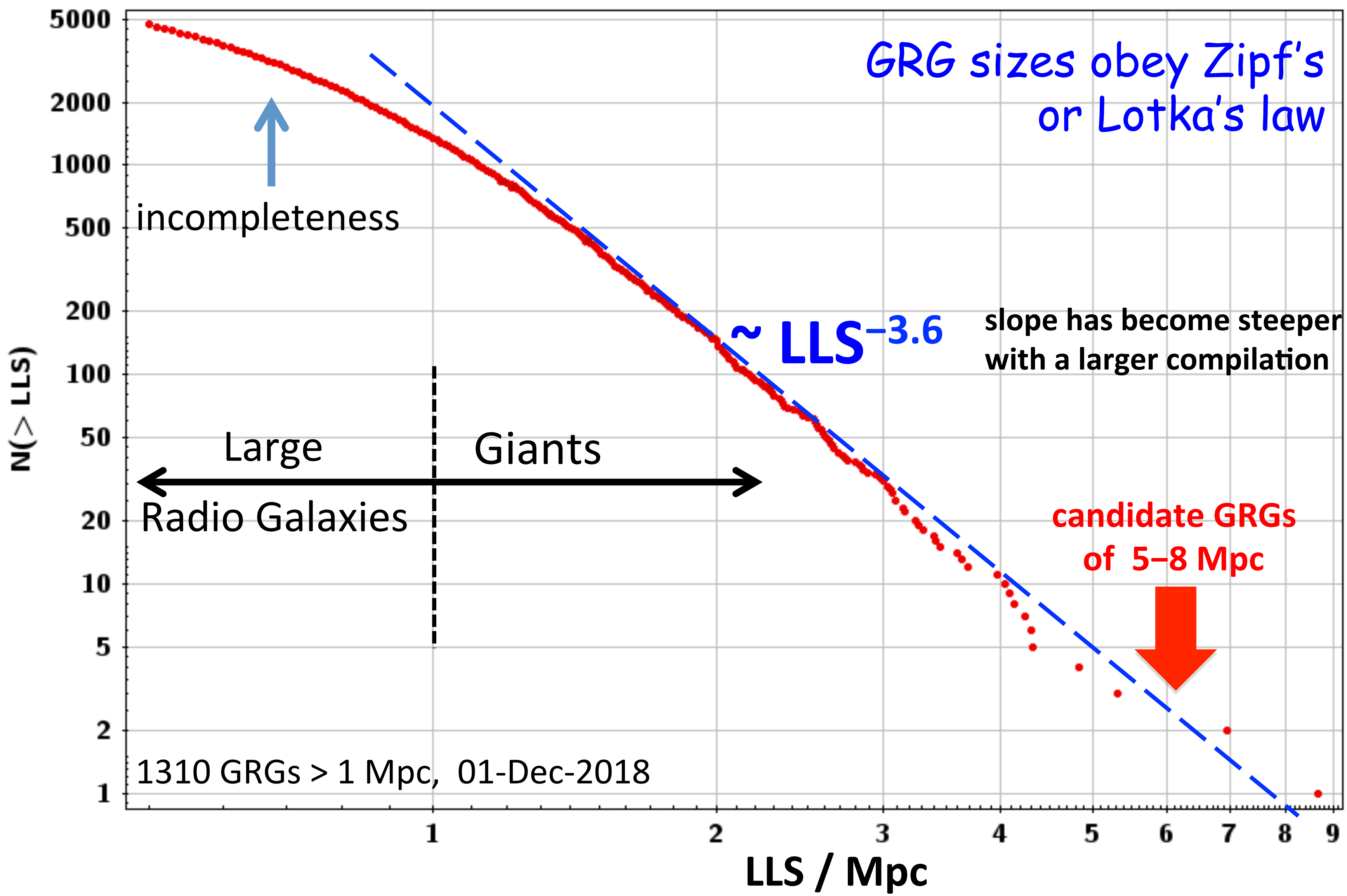
  Additional objects collected "in passing" ...

- 4500+ sources of LLS = 200 kpc ... 1 Mpc (INCOMPLETE)
- of these, ~1600 are larger than 750 kpc (called GRGs by some)
- this is the largest-ever compilation of linear source sizes
  and becoming the largest for optical IDs of extended sources


RG compilation 1-Dec-2017
(only secure RGs)
1 Mpc
3 Mpc
5 Mpc
577 new GRGs, this work
187 new GRGs from RGZ
231 "known" GRGs
3032 RGs 0.2 . . . 1 Mpc
largest one published
2 new candid. GRGs 5–8 Mpc
LAS (')
redshift
50
30
20
15
10
5
2
0.01
0.05
0.1
0.2
0.5
1
2
3

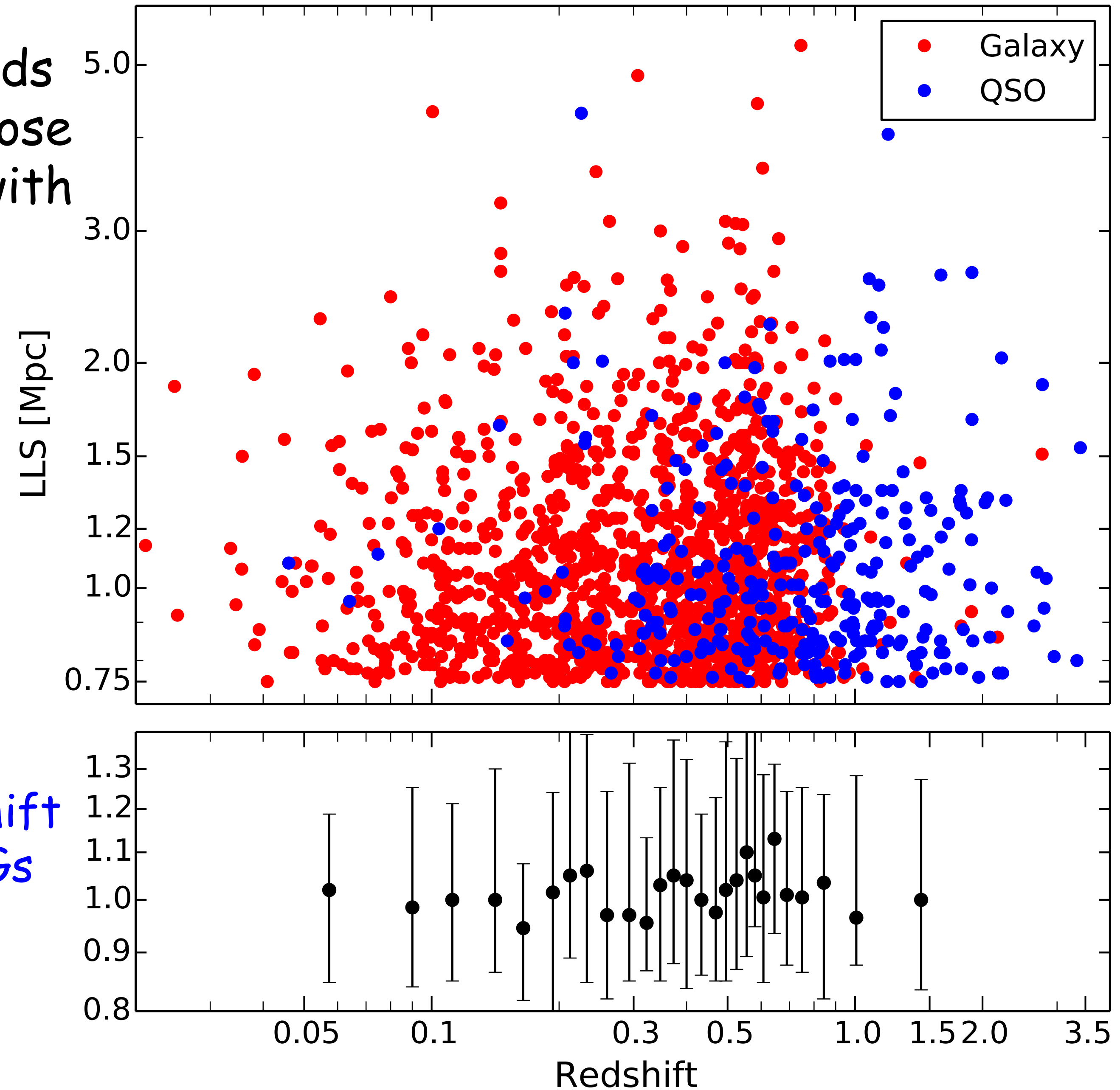
How fast does the number of GRGs decrease with linear size ?

The Log(N) – log(Size) distribution of GRGs



Any trend for the LLS to decrease with redshift ? NO . . .

To avoid bias towards very large sizes, I chose 1640 **safe** GRGs with LLS > 750 kpc/h_{70}



median LLS vs. redshift
each bin has **60** GRGs

Some challenging trends . . .

- **mean density of Universe** grows as ~ $(1+z)^3$

  So, how can GRGs grow to these sizes even at z > 1 ?

- **CMB photon density** grows as $\sim(1+z)^4$

  ➔ synchrotron-emitting electrons suffer severe "inverse Compton" losses

  ➔ diffuse sources at high redshift should "disappear" more rapidly than nearby ones (at z ~ 0)

- Cosmology predicts a **surface brightness dimming** $\sim(1+z)^4$

  ➔ diffuse sources should become undetectable at high z

  ➔ interesting project : simulate how well-known "local" GRGs would look like at much higher redshift (D. Scott) :

  - change angular dimensions with angular diameter distance,
  - change brightnesss according to luminosity distance,
  - include surf. brightness dimming, k-correction (radio spectral index)
  - include effects of uv coverage (sensitivity to source components of different angular sizes)

Thank you !

and

Happy Birthday, Jasper !