FINDING GIANT RADIO GALAXIES in IMAGING RADIO SURVEYS

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Poster presented at ESO Workshop "Science from the Next Generation Imaging and Spectroscopic Surveys", 15-18 October 2012

ABSTRACT

We did the first visual inspection of all ~3500 images of the NVSS, SUMSS and WENSS radio surveys to search for candidate Giant Radio Galaxies (GRGs). We define GRGs here as having a largest linear (projected) size of LLS > 1 h_{75}^{-1} Mpc, of which ~100 were known before our work. We cover the entire sky and do not limit our search by flux density or Galactic latitude. Apart from recovering most GRGs reported in the literature, we

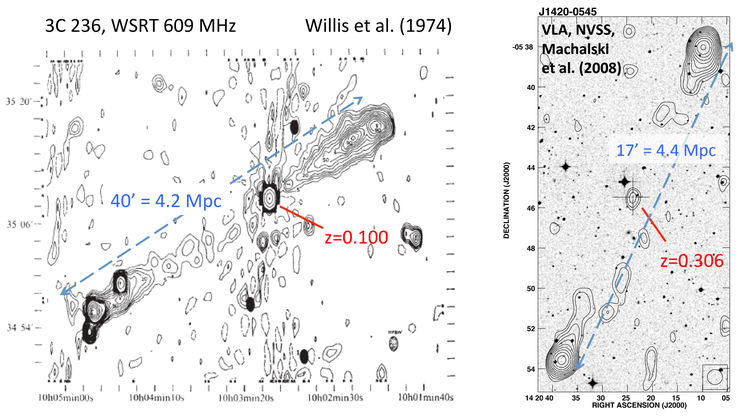
- ❑ find one GRG of **5.8 Mpc** (see § 5), 30% larger than the largest previously known GRG (of 4.4 Mpc)
- ❑ **duplicate** the number of known GRGs to over 200 (confirmed by the redshift of their host galaxies (not including photometric redshifts).
- ❑ **quadruple** the number of GRGs with LLS > 3 Mpc.
- ❑ add 4 GRGs (3 QSOs) to the 8 known ones at z>1.
- ❑ find the 5th, and largest so far, radio galaxy (RG) of LLS = 1.5 Mpc identified with an **optical spiral**
- ❑ find several hundred promising candidates for radio/optical follow-up: to measure redshifts, confirm the radio structure, or find the optical host.

We demonstrate that visual inspection even of large data sets, as done by generations of astronomers in the past, is still feasible and competitive. Our results can be used to provide further criteria to find GRGs based on automated algorithms. We estimate that for a radio survey like EMU (covering 75% of the sky at 10" resolution, with 70 million sources) a visual inspection for GRGs would take five (wo)man-years.

Some GRG candidates have very faint optical IDs, only allowing lower limits to be put on their LLS. A few of these are likely larger than ~5 Mpc. The potentially largest GRGs are those with host galaxies below the detection limits of current optical imaging surveys.

1. The largest known GRGs as yet

Willis et al. (1974) found the first GRG: 3C 236 with LLS = 5.7 h_{50}^{-1} Mpc = 4.2 h_{75}^{-1} Mpc, a "record" that stood for 34 years, until Machalski et al. (2008) found J1420−0545 (LLS = 4.4 Mpc).



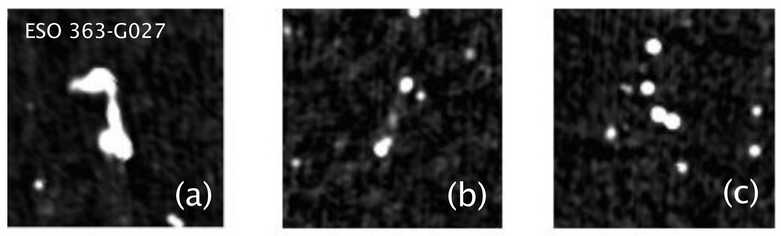
Various authors have used H_0 = 50, 75 or 100 km/s/Mpc to define GRGs as having LLS > 1 Mpc; we adopt H_0=75, with which currently ~100 GRGs are known, all of which with LLS < 3 Mpc, except the above two with LLS > 4 Mpc. We set out for a complete census of GRGs based on the deepest radio surveys sensitive to very extended structure: NVSS (Condon+1998, 1.4 GHz, δ >−40°) and SUMSS (Bock+ 1997, 843 MHz, δ<−30°), both with 45" angular resolution and together covering the whole sky.

2. Observational Material

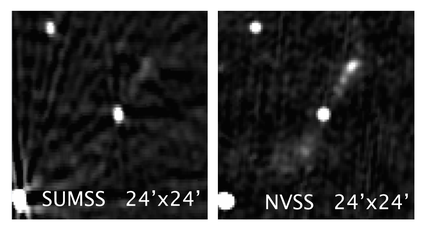
We inspected all 2326 NVSS and 723 SUMSS images (4° x 4° each) covering the whole sky. We started with the sky strip (−40° < δ < −30°) where NVSS and SUMSS overlap, and we "trained" ourselves with known GRGs from the literature. Moreover we perused the 25% of sky at δ≥30° covered by 491images of the Westerbork Northern Sky Survey (WENSS, HPBW = 54" x 54"csc δ)

3. Method of candidate selection

Using XFITSview (W. Cotton, NRAO) we logged the positions of all GRG-like sources with LAS >~4' and classified them into 3 classes: (a) obvious, (b) likely and (c) possible RG's. Here some examples of NVSS images (24'x 24' each):



For category (a) we searched NED for optical counterparts at suitable positions and for those with known z we calculated their LLS from their LAS as measured on the radio images.



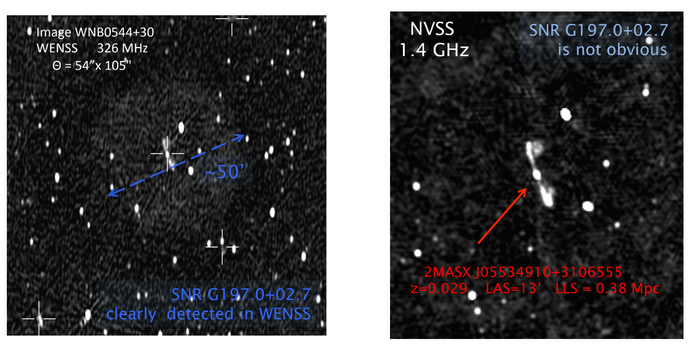
Comparison of SUMSS and NVSS images: SUMSS is not that sensitive to faint extended structures; shown here: 2MASX J22561507-3617589, z=0.090 LAS=13' → LLS =1.3 Mpc

This is a HYMOR = hybrid morphology (FR II for the N lobe, FR I for the S lobe) Note also the "spoke" features emanating from strong SUMSS sources.

Our new GRGs with large & very diffuse emission are mostly undetected on low-res. images (GB6/PMN @5GHz, Θ = 3.5'). For some GRGs we checked the diffuse lobe nature, and inner jet PA's on FIRST survey images (Θ=5"; Becker+1995). The NVSS, despite its exposure time of **only 23 seconds**, proves to be the best current survey to find large numbers of real and candidate GRGs. Both VLSS (74 MHz, Cohen et al. 2007) and TGSS (150 MHz, tgss.ncra.tifr.res.in) surveys are less apt for this purpose, due to either a low sensitivity (VLSS), or too high angular resolution (24"x15"@30°, TGSS).

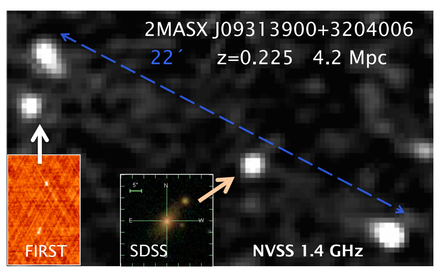
4. Some Surprises from WENSS

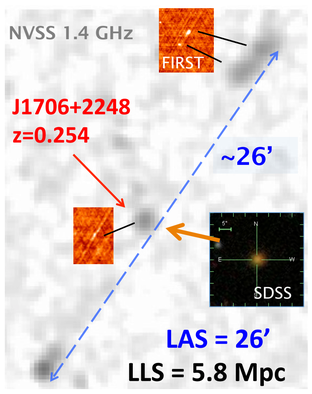
While WENSS is generally less sensitive to GRGs than NVSS, it is superior for structures >40': we rediscovered a RG near the center of SNR G179.0+02.7 (Fürst et al. 1989). A γ-ray source 2FGL J0553.9+3104 is within ~6' of the RG ! So, which then is the γ-ray source : the SNR or the RG ?



5. Three new GRGs > 4 Mpc (one of 5.8 Mpc !)

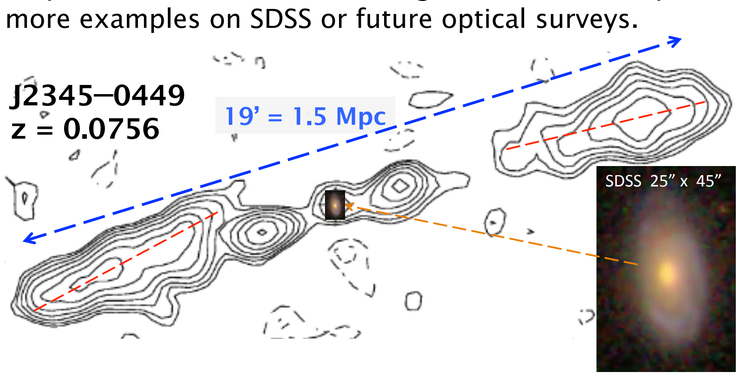
All 3 are triple with very aligned outer hotspots, lacking jets that would connect to the core. Lobes are a bit misaligned to major axis.





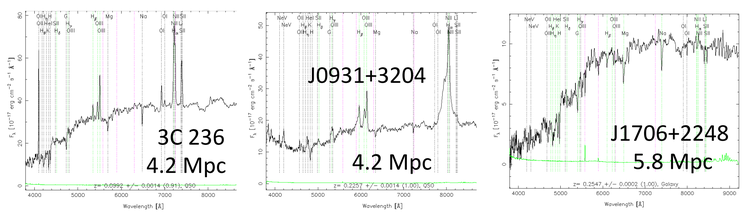
6. The first optical spiral found to be a GRG

Until now at most four spirals were found to have double-lobed RG morphology, all of them smaller than ~500 kpc. Double-double lobed RGs (DDRG) are also very rare. We report one DDRG with LLS=1.5 Mpc. Its spiral arms are only seen on SDSS (not DSS) images, thus there may be more examples on SDSS or future optical surveys.



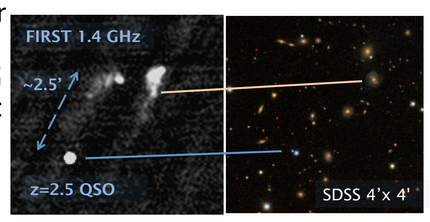
7. Optical Spectra

We found SDSS spectra only for 3 of the 4 largest sources. All show emission lines typical of AGNs or LLAGNs. The spectrum published for J1420-0545 is consistent with this.

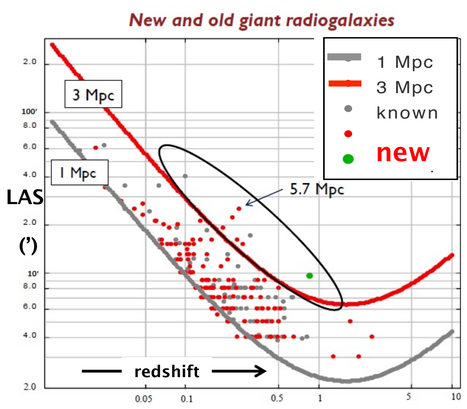


8. The size – redshift distribution of GRGs

For H_0=75, Ω_m=0.3, Ω_Λ=0.7 a GRG has LAS > 2' at any z. For 1<LLS< 3Mpc we **duplicate** the number of known GRGs, while for >3 Mpc we **quadruple** it (2→8). For z > 1 we duplicate (2→4) the number of GRGs of >2 Mpc; also we find the first candidate GRG at z > 2.05 (current record): γ-ray blazar B3 0727+409 (OI+446, Brundage+1971) at z=2.5 → LLS=1.2 Mpc ?

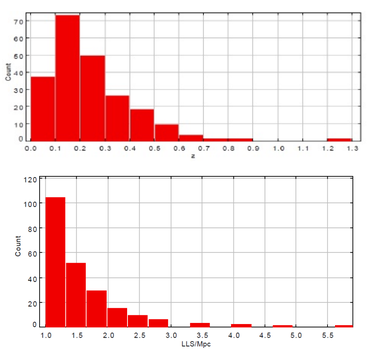


Surprisingly we find ~12% of all GRG cores to be CRATES (flat-spectrum) sources (Healey+2007), for most of which the extended structure had never been reported.



In this LAS−z diagram the grey and red lines indicate the LAS of "standard rulers" of 1 and 3 Mpc. For z>1 our 4 newly found GRG (3 QSOs) are shown, but another 8 GRQs from Kuzmicz et al. 2012 are not yet shown.

This diagram will be completed with missing literature data and corrected for some LAS slightly overestimated by us.

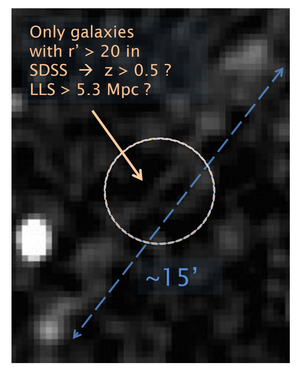


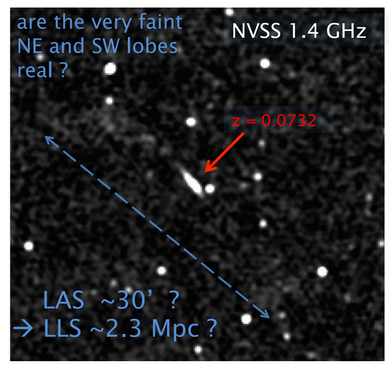
Distribution of GRGs (known and new) in redshift: median z~0.2. With most recent data the distribution is sparse, but continuous from z~1 to z~2.

Distribution of largest linear size (LLS): we managed to fill the gap between 3 and 4 Mpc and extend beyond 5 Mpc.

9. Conclusions and Outlook

- ❑ It is very difficult to find large (>20') lobe-dominated GRGs with radio-quiet cores. Some lobes may appear only on two neighboring atlas images. We find most GRGS are of FR II type (Subrahmanyan+96), which may be a selection effect: they are much easier to detect by eye.
- ❑ We found no single GRG at |b| < 9° that has a redshift, showing that imaging and spectroscopy avoid this zone. We found several potential GRG host galaxies within b~5°.
- ❑ Visual inspection of 3500 NVSS, SUMSS and WENSS images, has led to a vast improvement of our knowledge of GRGs. This was done in ~200 hr for the 2.2x10^9 pixels of NVSS, or ~100 hr per 10^6 sources. For the ASKAP-EMU survey (Norris+2011) we estimate 5 man-years, or ~ one person permanently during the ~5 yrs of EMU observing.
- ❑ We found a few hundred candidates, many of them with very faint host galaxies, some of which are potentially larger than 5 Mpc. Here are two speculative examples:





- ❑ GRGS are **very rare**: In the nearby Universe (z<0.2) GRGs have a space density ~5 x lower than rich superclusters. They constitute less than 1% of all radio galaxies !
- ❑ In NVSS alone there are of order 10^5 pairs and over 10^4 triplets of sources with 4' < LAS < 2', which, if identified with galaxies or QSOs near z ~ 1, will be GRGs.

10. References

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Acknowledgements: H.A. thanks ESO for partical financial support. EFJA & RFMS are grateful to Académia Mexicana de Ciencias (AMC) for a summer research grant. This project made use of the NASA/IPAC Extragalactic Database (JPL; ned.ipac.caltech.edu).