AGNs and Starbursts in the HDF-N and HFF: Deep, global VLBI Observations

Seungyoup Chi [1, 2, 3], Michael A. Garrett [2, 4, 5], Peter D. Barthel [1]

[1] Kapteyn Institute, Rijksuniversiteit Groningen, The Netherlands; [2] Netherlands Foundation for Research in Astronomy (ASTRON), The Netherlands
[3] Joint Institute for VLBI in Europe (JIVE), The Netherlands; [4] Swinburne University of Technology, Australia; [5] Universiteit Leiden, The Netherlands

Introduction

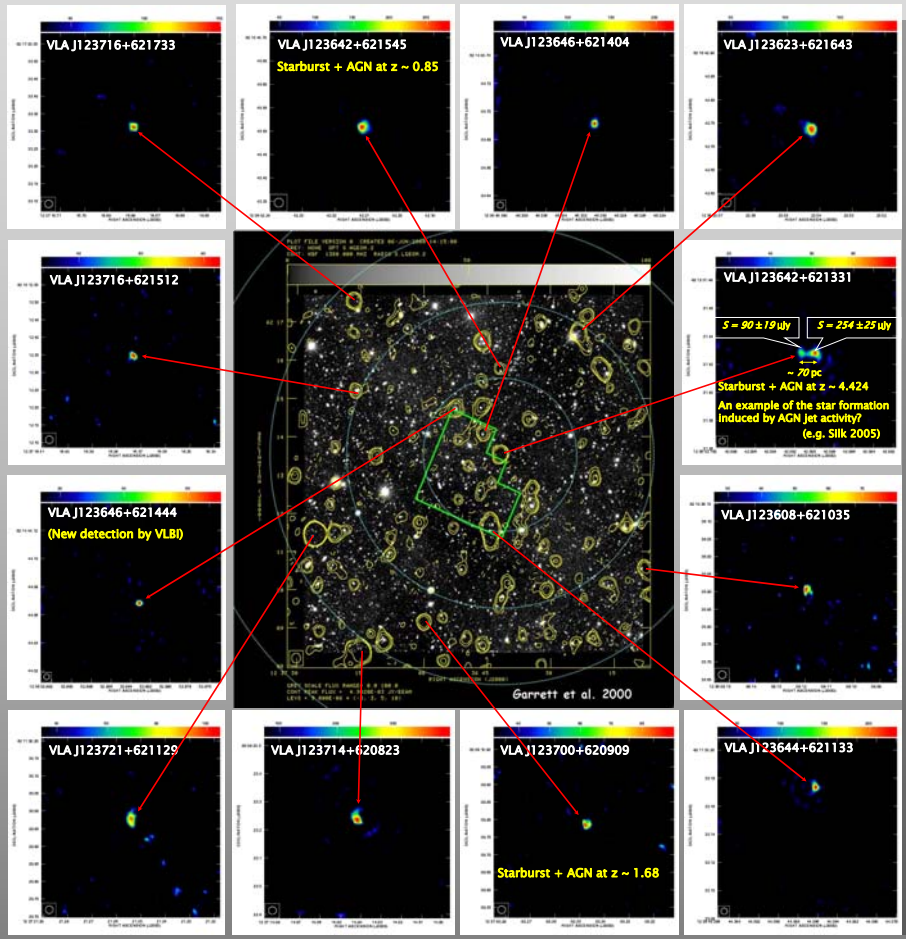
High sensitivity radio observations of Hubble Deep Field North (HDF-N) and surrounding Flanking Field (HFF) have revealed a population of faint sub-mJy and microJy radio sources, which appear to be associated with high-redshift star-forming galaxies (Richards et al. 1998, 1999, 2000; Garrett et al. 2001; Muxlow et al. 2005). One of the most remarkable results of the radio-optical study of these fields was the discovery of a number of optically-faint radio sources, some of which are undetected in the deepest optical images. These optically faint systems are thought to be distant, dust-obscured galaxies. Recent Spitzer imaging of sub-mm galaxy sample suggest that IR luminosities are dominated by star-formation rather than nuclear activities (Pope et al. 2006).

Some of the sources have the properties of a starburst galaxy with an embedded AGN. Such systems are only detectable in the radio and/or sub-mm, and deep, high angular resolution radio observations are currently the best way to detect those embedded AGNs.

In this poster, we present the results of deep, wide-field global VLBI 1.4 GHz observations of the HDF-N and HFF. These high sensitivity (σ ~ 7.3 μJy/beam) and high angular resolution (~ 4 mas) radio data can discriminate between starburst and AGN activity in dust obscured systems. In addition, we also discuss possible correlations between the mid-IR, X-ray, and radio luminosities.

Global VLBI observation

- 20 ~ 22 Feb. 2004 (3 × 12 hrs.)
- 2x8 MHz (RR, LL), 2-bit samples [128 Mbps recording rate]
- 16 telescope array including 100-m Greenbank and Effelsberg plus 76-m Lovell
- Frequency : 1.4 GHz
  → Max. Angular resolution : ~ 4 mas (in the HDF-N) increasing in HFF (tapered)
- Data Correlated at JIVE:
  - Each (1 x 8 MHz) polarisation channel correlated in a separate pass
  → maximise spectral resolution (minimise bandwidth smearing)
- Wide-field techniques used to image out entire HDF-N and HFF
- Total data size : ~ 800 Gbytes (3 epochs, 6 Ifs, 256 sp ch/IF; 0.25 sec. int. time)
- 1σ r.m.s. noise level: ~ 7.3 μJy/beam in the HDF-N (lower sensitivity in HFF)
- Survey fields : 201 arcmin²
- Detections : 12 radio sources

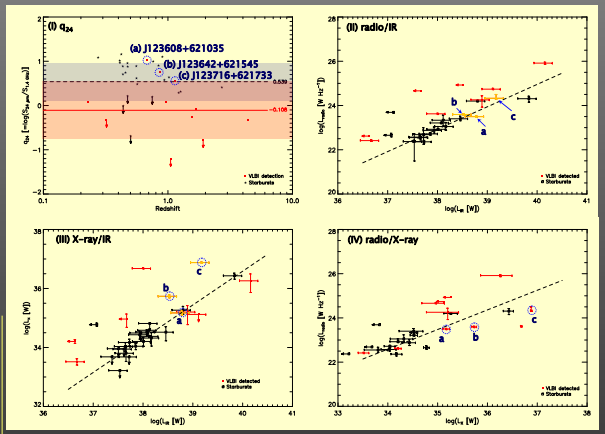


Global VLBI Detections in the HDF-N and HFF

The center image is WSRT 1.4 GHz contour map superposed on CFHT I-band image (Garrett et al. 2000). The HDF-N region is represented by solid green line and four annular fields (2', 4', 6', and 8' radius from the correlation phase center) are indicated with dotted blue circles. Each of the fields has different sensitivity (7~37 μJy/beam) and angular resolution (4~27 mas) due to image tapering. Surrounding it are 12 stamp images of radio sources detected in the HDF-N and HFF, whose color scales are from 3σ to the peak intensity level of each source.

We imaged out all of 92 targets of MERLIN+VLA survey (Muxlow et al. 2005). 12 faint radio sources clearly detected with 5σ detection level among about 48 detectable targets, limited by the sensitivities of the each fields. These compact radio components strongly suggest that these sources habour AGN. Especially, we resolved a jet-like extension emanating from the AGN core of a distant (z~4.424), dust-obscured starburst galaxy (VLA J123642+621331). There are two more hybrid system candidates, which are likely starbursts with embedded AGNs detected in HFF.

Correlations between mid-IR, X-ray, and radio luminosities



We also calculated $q_{24\mu m}$ value and tested possible correlations between mid-IR, X-ray, and radio luminosities. We selected 55 sources detected in all of three catalogs, *Spitzer* MIPS 24μm (DR1+, Feb. 2005), *Chandra* 2Ms catalog (Alexander et al. 2003), and VLA 1.4 GHz (Richards et al. 1998). In order to compare AGNs with starbursts, we classified each source as a starburst or an AGN. Since source classification is still unclear depending on wavelengths, we take only 18 starbursts into count, which are classified as starbursts in both radio and X-ray domain, and 12 sources, detected by our VLBI observations, represent AGNs. We used SED model fitting (Chary & Elbaz 2001) for IR luminosities.

- (I) The $q_{24\mu m}$ plot show radio-excess properties (the smaller value of $q_{24\mu m}$) of AGN sample. The mean value, $<q_{24\mu m}>$, for starbursts is 0.539, which is well consistent with previous results of 0.52 (Beswick et al. 2007) and 0.69 (Norris et al. 2006). There are three AGN samples (a, b, and c), which are not lying with AGNs, but with starbursts.
- (II) In radio/IR luminosity plot shows the typical tight correlation of starburst galaxies, and radio-excess of AGNs. As we expect from $q_{24\mu m}$ plot, (a), (b), and (c) lie on the correlation for starbursts, while the other AGNs are out of the line.
- (III) There is also tight correlation in X-ray/IR. Unlike (b) and (c), (a) is still following the correlation in plot (III) and (IV).
- (IV) There is likely another possible correlation in radio/X-ray. And, there seems to be the separation between radio-quiet and radio-loud AGN populations.

Conclusions

- Deep, high-resolution observations:
  ~ 7.3 μJy/beam r.m.s. noise level in the HDF-N
  ~ 4 mas angular resolution in the inner field
- 12 detections of radio sources above 5σ detection level in the HDF-N and HFF (~ 48 detectable among total 92 targets)
- 3 hybrid (SB+AGN) system
  (VLA J123642+621331, VLA J123642+621545, VLA J123700+620909)
- Global VLBI observations successfully revealed AGNs
  → demonstrate the power of deep, high-resolution VLBI imaging in discriminating and looking into relations AGNs and starbursts in distant, dust-obscured system
- Radio/IR and X-ray/IR show tight correlations, and also there is a possible correlation between radio and X-ray
- In the radio/X-ray correlation, there might be the separation between radio-quiet (or X-ray loud) and radio-loud (or X-ray quiet) source populations
- Tbyte new global VLBI observation of the HFF
  → expect to present resolved structures of additional high-z radio sources and reveal embedded AGNs in dust-obscured starbursts

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Contact:
chi@astro.rug.nl