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Highlights from the observatories

Compiled by D.J. Saikia

Forbush decrease events and CME fronts

Forbush decreases are short-term reductions in the cosmic ray flux reaching the Earth due to coronal mass ejections (CMEs) from the Sun and also the co-rotating interaction regions originating from the Sun. Prasad Subramanian from IISER and his collaborators from TIFR, Osaka City University and Nagoya Women's University (GRAPES-3, Gamma Ray Astronomy at PeV EnergieS 3rd establishment) have examined the cosmic ray data from the GRAPES-3 tracking muon telescope at Ooty for three observed Forbush decrease events between 2001 and 2003. The tracking muon telescope, operating as part of the GRAPES-3 experiment (Gupta et al. 2005; Hayashi et al. 2005), is a unique instrument to search for high-energy protons emitted during the active phase of a solar flare or CME. Each of these Forbush events is associated with front-side halo CMEs and near-Earth magnetic clouds. From their study, they estimate the ratio of energy density in the turbulent magnetic fields to that of the mean magnetic fields near the CME fronts to be ~2 and 6 per cent for the 2001 April 11 and 2003 November 20 Forbush decrease events, but ~249 per cent for the much more energetic event of 2003 October 29 (Subramanian et al. 2009).

New pulsars discovered with the GMRT

Three new pulsars have been discovered from an on-going blind survey of the north Galactic pole by Bhal Chandra Joshi and Nikhil Pawar from NCRA and their collaborators, Maura McLaughlin, Andrew Lyne, D. Ludovici, Andrew Faulkner, Duncan Lorimer, Michael Kramer and M. L. Davies from the West Virginia University, Jodrell Bank Centre for Astrophysics, University of Cambridge and the Max-Planck Institut für Radioastronomie, using the Giant Metrewave Radio Telescope (GMRT) at 610 MHz (Joshi et al. 2009). Although most recent surveys have been done at frequencies larger than about a GHz to minimize the effects of interstellar scattering (e.g. Manchester et al. 2001), they chose a frequency of 610 MHz taking into consideration the increased flux density of pulsars at low frequencies, effects of interstellar scattering and dispersion, and the beamwidth for the 45-m GMRT antennas. The survey covered 106 square degrees with a sensitivity of approximately 1 mJy to long-period pulsars, defined to be those with a period longer than 1s. The three new pulsars which have been discovered, J0026+6320, J2208+5500 and J2217+5733 (Fig. 1), have periods of 318, 933, and

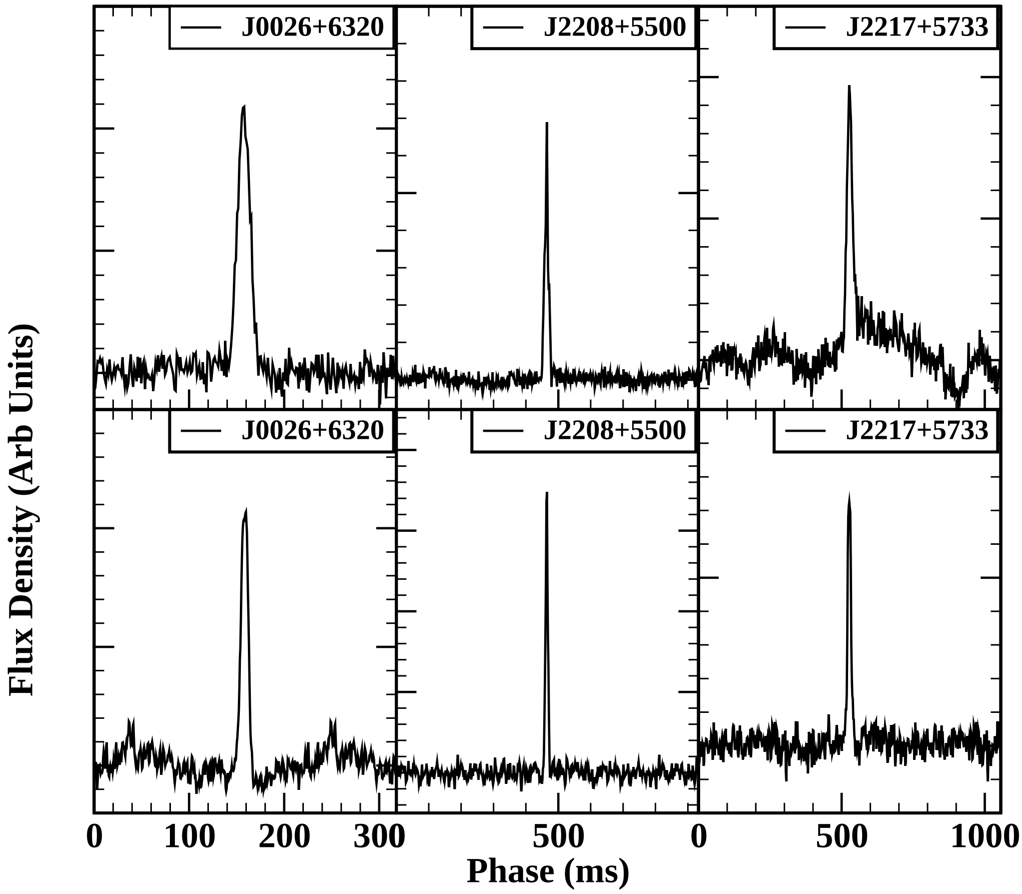

Figure 1. Average pulse profiles for PSRs J0026+6320, J2208+5500 and J2217+5733 at 626 MHz using the GMRT (top panel) and at 1400 MHz using the Lovell telescope (lower panel). The features in the baseline of average profiles for PSRs J2217+5733 (626 MHz) and J0026+6320 (1400 MHz) are probably due to RFI (Joshi et al. 2009)

1057 ms respectively. Their timing parameters and flux densities have also been obtained from follow up observations with the Lovell Telescope at Jodrell Bank and the GMRT. Their characteristic ages have been estimated to be 33.6, 4.2 and 51.5 Myr respectively, consistent with the normal pulsar population. There is no obvious association of the newly discovered pulsars with either globular clusters, supernova remnants or any known high-energy sources. Follow up observations of PSR J2208+5500 with 13 antennas of GMRT in a phased array mode (145-m equivalent single dish) at 626 MHz indicate a nulling behaviour similar to other nulling pulsars (Joshi et al. 2009).

Pulsar emission mechanism

A single radio pulse is observed as the pulsar emission beam sweeps past the observer. A single pulse may consist of one to several subpulses, and a stable mean or average profile is obtained by adding a large number of single pulses. These average pulses may contain one to several components depending on how the observer's line of sight intersects the pulsar beam axis. For small angles, it usually consists of a central or core component flanked by one or more pairs of conal components. The position angle (PA) of linear polarisation across the average profile has a characteristic S-shape, caused by the intersection of the line of sight with the open magnetic field lines, which is described by the rotating vector model (Radhakrishnan & Cooke 1969). Although it has been well known that single pulses are highly linearly polarized, recent high-quality, single-pulse polarization observations of 10 pulsars with the GMRT by Dipanjan Mitra from NCRA along with Janusz Gil and George Melikidze from the University of Zielona Gora have helped clarify the pulsar emission process. They find that the PA of linear polarization in subpulses follow closely the mean PA curve at the corresponding profile components, implying that the observed emission is due to waves excited by the coherent curvature radiation rather than maser radiation (Mitra, Gil & Melikidze 2009).

The locations of the pulsar radio emission in the magnetosphere are usually not well determined. The effects of aberration and retardation can shift and/or delay the photons depending on the height of emission in the magnetosphere. To examine these effects, multifrequency observations have been made with the GMRT and Arecibo Observatory and archival European Pulsar Network data analyzed by K. Krzeszowski, J. Kijak and J. Gil from the University of Zielona Gora, and their collaborators Dipanjan Mitra and Yashwant Gupta from NCRA, and A. Acharyya from the University of Southampton. They find that in cases where the effect can be established the core emission originates below the conal emission region (Krzeszowski et al. 2009).

Bhaswati Bhattacharyya and Yashwant Gupta from NCRA, and Janusz Gil from the University of Zielona Gora, have presented a detailed study with the GMRT of the wide-profile PSR B0818−41, which show multiple drift regions with well-defined phase relationship. They find that the drift pattern from two 'rings' are phase locked in this pulsar and estimate a carousel rotation period of $\sim$10 s, which makes it the fastest known carousel (Bhattacharyya, Gupta & Gil 2009).

Young stellar objects and variable stars

The initial results from a long-term observing programme which began in 2004 to monitor young stellar objects in the Orion Nebula Cluster (ONC) have been reported by Padmakar Parihar and N.S. Shantikumar from the IIA, Sergio Messina and Elisa Distefano from the INAF-Catania Astrophysical Observatory and Biman Medhi from ARIES. Photometric observations of the ONC were obtained using the 2m Himalayan Chandra Telescope (HCT) and the 2.3m Vainu Bappu Telescope (VBT). This project aims to i) explore various manifestations of stellar magnetic activity in very young low-mass stars; ii) search for new pre-main sequence eclipsing binaries; and

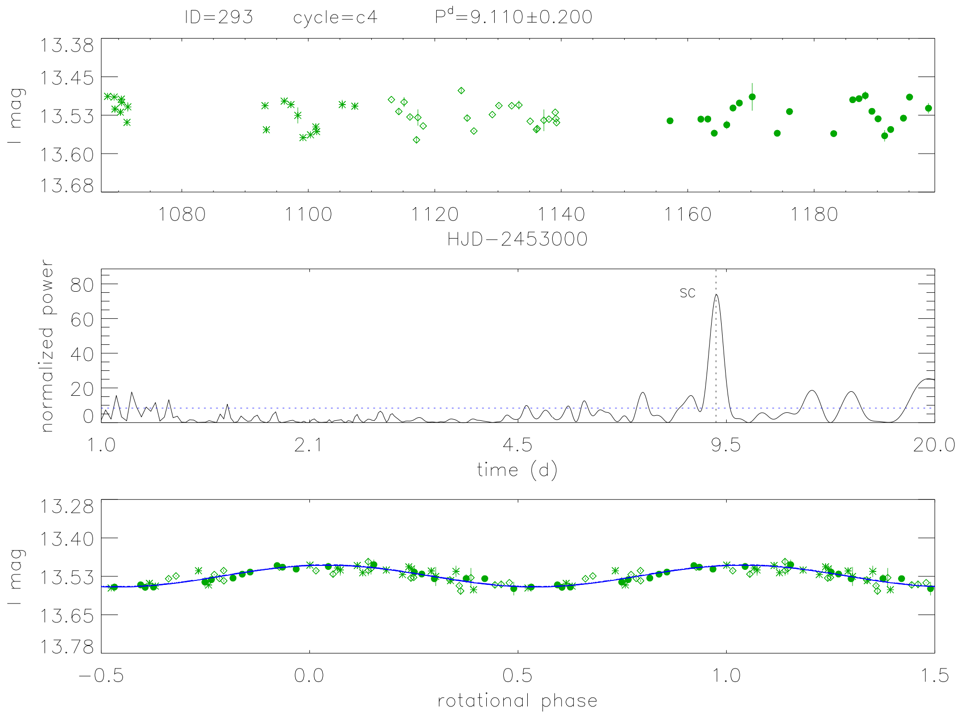

Figure 2. Results for the newly discovered periodic variable ID=293. The figure shows the I-band time series (top panel), power spectra from Scargle analysis (middle panel) and the phased light curve using the detected period (bottom panel). The figures are from Parihar et al. (2009b).

iii) look for any EXor and FUor like transient activities associated with young stellar objects (YSOs). They present a large number of new periodic variables detected from the first five years of time-series photometric data. As an example, their results on the newly-discovered variable ID=293 are shown in Fig. 2. They find that about 72 per cent of classical T-Tauri stars (CTTS) are periodic, compared with only 32 per cent for the weak-lined T-Tauri stars (WTTS), indicating a more stable behaviour for the classical T-Tauri stars (Parihar et al. 2009b).

Padmakar Parihar, P. Bama and C. Velu from IIA, along with their collaborators S. Messina from the INAF-Osservatorio Astrofisico di Catania, B.J. Medhi from ARIES and A. Ahmad from Armagh Observatory, have also reported the results of a spectroscopic survey to identify new chromospherically active components and low-mass pre-main sequence (PMS) stars in the All Sky Automated Survey (ASAS) eclipsing binaries. The strength of the Hα emission was used to characterize the level of chromospheric activity in a sample of 180 candidate eclipsing binary stars from the ASAS-I and II releases. Their survey reveals that out of 180 stars about 36 binary systems show excess Hα emission. One of the objects, ASAS 081700−4243.8, displays strong

Hα emission, and is likely to be a classical Be-type system with K0III companion (Parihar et al. 2009a).

Observations with the HCT and the Sampoornanand Telescope, as well as archival data in the infrared from the Two Micron All Sky Survey and the Spitzer telescope were used to examine the 'small-scale sequential star formation' hypothesis in and around bright-rimmed clouds (BRCs). The BRCs are small molecular clouds at the edges of evolved HII regions and are good laboratories for studying radiatively driven implosion of the cloud, leading to star formation. Neelam Chauhan and A.K. Pandey from ARIES, K. Ogura from Kokugakuin University, D.K. Ojha and S.K. Ghosh from TIFR, B.C. Bhatt from the IIA and P.S. Rawat from Kumaon University have found age gradients in almost all the BRCs they studied and evidence in favour of a radiatively driven implosion scenario. They also find that in general WTTSs are somewhat older than CTTSs, with the fraction of CTTSs among the T-Tauri stars (TTSs) associated with the BRCs decreasing with age, consistent with the possibility of CTTS evolving into WTTS (Chauhan et al. 2009).

Novae and supernovae

A white dwarf star accreting material from its companion undergoes thermonuclear runaway in the hydrogen burning shell at the bottom of the accreted material when sufficient matter has been accumulated, and becomes a classical nova. The characteristics of the nova depend on the mass and core temperature of the white dwarf, and the rate of mass accretion from the binary companion. Sachindra Naik, D.P.K. Banerjee and N.M. Ashok from PRL have presented near-infrared JHK spectroscopic observations with the Mt. Abu 1.2m telescope, of novae V2491 Cygni and V597 Puppis in the early declining phases of their 2007 and 2008 outbursts respectively, and classify both objects as He/N novae. Both novae have also been detected in the post-outburst supersoft X-ray phase, and these white dwarfs could be close to the Chandrasekhar limit (Naik, Banerjee & Ashok 2009). D.P.K. Banerjee, R.K. Das, and N.M. Ashok, from PRL, have continued their work on the recurrent nova RS Ophiuchi, and have presented near-infrared photo-spectroscopy in the H and K bands of the 2006 outburst and cover the period between 1 and 94d after eruption. The hydrogen line profiles shows broad wings on both flanks of a strong central component, suggesting a bipolar outflow consistent with high-resolution images. They propose that the FeII lines originate from a site of high particle density, which could be a region between the shocked ejecta and the red giant wind (Banerjee, Das & Ashok 2009).

S.P.S. Eyres from the University of Central Lancashire and his collaborators have reported Multi-Element Radio-Linked Interferometer Network (MERLIN), Very Large Array (VLA), One-Centimetre Radio Array, Very Long Baseline Array (VLBA), Effelsberg and GMRT observations beginning 4.5 days after the discovery of RS Ophiuchi undergoing its 2006 recurrent nova outburst. They suggest a two-component model consisting of a decelerating shell with mixed thermal and non-thermal emission along with faster bipolar ejecta emitting non-thermal emission. They estimate an ejecta mass of $4{\pm}2{\times}10^{-7}$ $M_\odot$, consistent with a white dwarf mass of $1.4M_\odot$ (Eyres et al. 2009).

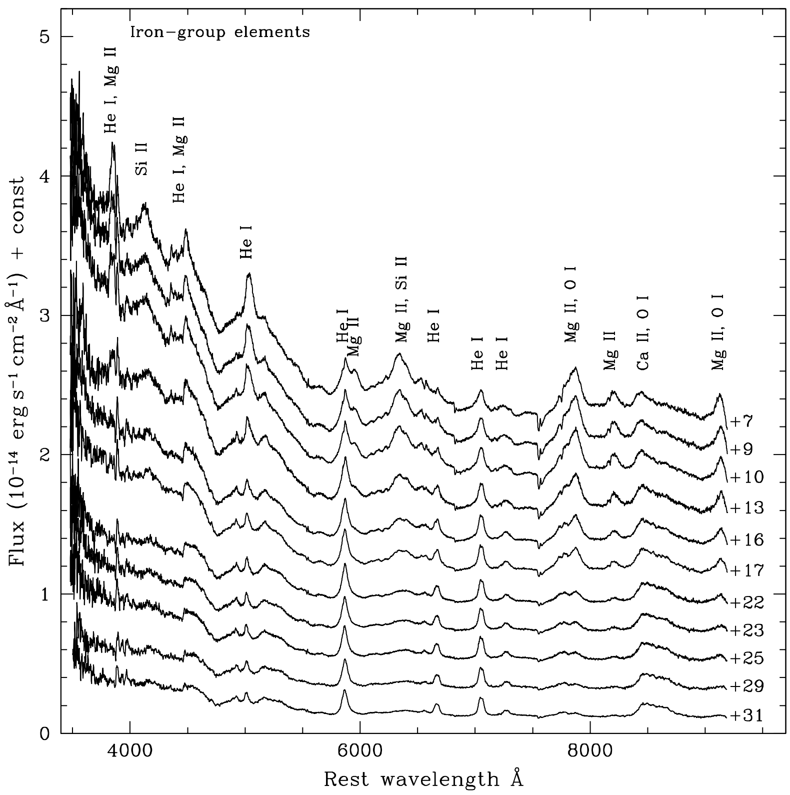

Figure 3. Spectroscopic evolution of SN 2006jc during +7 to +31 days since the maximum on JD 2454016 (Anupama et al. 2009).

Studies of core-collapse supernovae by an Indo-Japanese collaboration using extensive data from the HCT have brought out the diversity amongst these types of supernovae based on progenitor mass and evolution prior to explosion. D.K. Sahu, G.C. Anupama and Uday Gurugubelli, from IIA, and Masomi Tanaka and Ken'ichi Nomoto from the University of Tokyo, have presented photometric and spectral evolution of the Type Ic supernova SN 2007ru until around 210 days after maximum. The spectra show broad spectral features due to a high expansion velocity, the photospheric velocity being higher than other typical Type Ic supernovae. They suggest that SN 2007ru may be an aspherical explosion viewed from the polar direction (Sahu et al. 2009). G.C. Anupama, D.K. Sahu, Uday Gurugubelli and T.P. Prabhu from IIA, and their collaborators N. Tominaga from the National Astronomical Observatory, and M. Tanaka and K. Nomoto, from the University of Tokyo, have presented optical UBVRI photometric and spectroscopic data of the Type Ibn supernova SN 2006jc, until the onset of the dust-forming phase. The observed helium line fluxes indicate that the circumstellar shell is dense, with a density of $\sim 10^9 - 10^{10}$ cm^{-3}. The

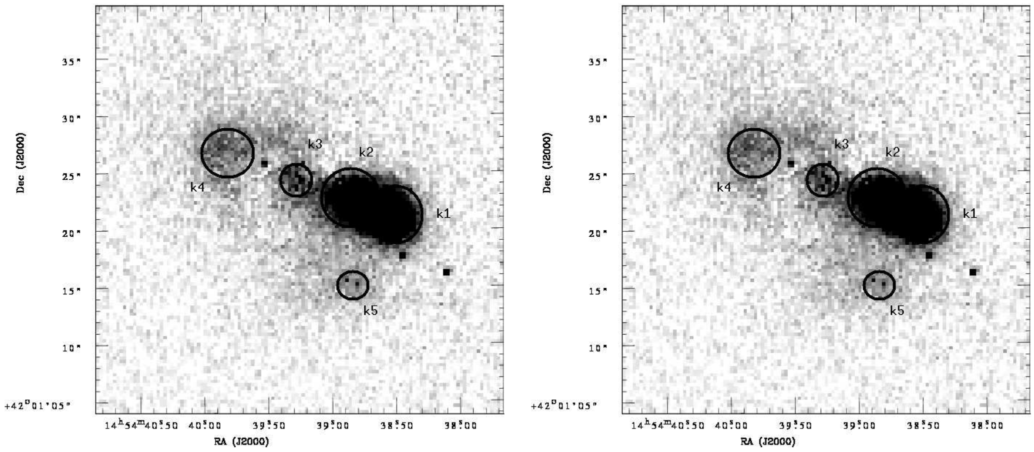

Figure 4. The images of I Zw 97 in B band (left panel) and continuum−subtracted Hα (right panel). North is up and east is to the left and the field of view is 1 arcmin on each side (Ramya, Sahu & Prabhu 2009).

optical light curve shows clear signature of dust formation, and its evolution is similar to those of typical Ib/c supernovae (Fig. 3; Anupama et al. 2009).

Blue compact dwarf galaxies

Blue compact dwarf galaxies (BCDs) are usually dwarf irregulars currently undergoing a burst of star formation and whose colour is dominated by emission from hot, young stars. Their spectra consist of nebular emission lines superposed on the continuum emission from hot, young stars. BCDs are also known to consist of an older underlying stellar population in addition to the more recently formed hot young stars. They appear to be deficient in CO and there have been suggestions that CO and H_2 may have been destroyed in the compact, intense environments of BCDs.

S. Ramya, D.K. Sahu and T.P. Prabhu from IIA have studied two BCDs, Mkn 104 and I Zw 97 (Fig. 4) both photometrically and spectroscopically using the HCT. Mkn 104 has been found to have three distinct bright star forming regions, while I Zw 97, a cometary BCD, has two bright and three faint star-forming regions. Both these galaxies show evidence of episodic star formation and are similar in their stellar content, with an old population of ~4 Gyr, an intermediate population of ~500 Myr and the current burst of star formation with an age of ~5−13 Myr (Ramya, Sahu & Prabhu 2009).

A GMRT radio continuum and HI study of the BCDs Mrk 1039 and Mrk 0104 have been reported by S. Ramya and T.P. Prabhu from the IIA, and Nimisha Kantharia from NCRA. The continuum emission from Mrk 1039 appears to steepen away from the star-forming region suggesting that this may be due to an older (few 100 Myr) burst. Mrk 0104 shows an extended HI

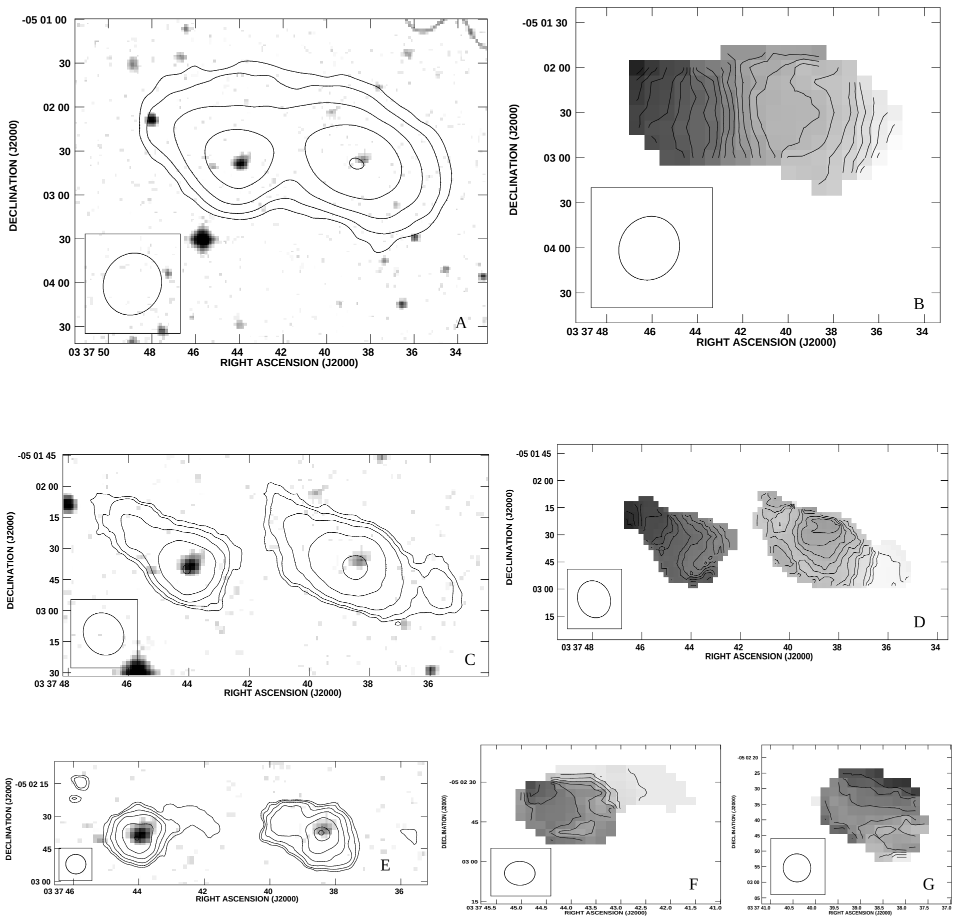

Figure 5. **(A)** Integrated HI emission map of SBS 0335–052 system, in contours, at a resolution of ∼40 arcsec, overlaid on the *B*-band Digitized Sky Survey-II (DSS-II) image, and **(B)** The HI intensity-weighted velocity field (contours and grey-scales) at a resolution of ∼40 arcsec. The velocity contours are from 3997 to 4074 km s^{-1}, in steps of of 3.3 km s^{-1}. **(C and D)** Same as A and B, but with an angular resolution of ∼20 arcsec. **(E)** Same as A, excepting that angular resolution is ∼9 arcsec. **(F,G.)** Same as B, except that the velocity field is at an angular resolution of ∼9 arcsec. In F, the velocity contours range from 4037 to 4060 km s^{-1} (SBS 0335–052E), and in G, from 4013 to 4036 km s^{-1} (SBS 0334–052W), in steps of 3.3 km s^{-1} (Ekta, Pustilnik & Chengalur 2009).

distribution, ∼1.3 times the optical size, with a mass of ∼9×10^{8} M$_\odot$, and an HI cloud ∼4.5 kpc north of the galaxy, which may have triggered the burst of star formation (Ramya, Kantharia & Prabhu 2009).

Metal deficient dwarf galaxies

Low-mass, star-forming galaxies with metallicities of $Z_{\odot}/10$ (eXtremely Metal-Deficient or XMD galaxies) are rare in the local Universe, comprising perhaps less than ~2 per cent of known emission-line galaxies. Studies of such systems might provide valuable insights into star formation in primeval galaxies which are also perhaps characterized by low metallicity, large gas fraction and small gravitational potential. Ekta and Jayaram Chengalur from NCRA, and Simon Pustilnik from SAO of RAS, have presented GMRT HI observations of the SBS 0335−052 system (Fig. 5), which contains the lowest known metallicity XMD galaxies, and consists of a galaxy pair with a separation of ~22 kpc. These galaxies also exhibit blue colours in their outer parts, suggesting small ages. The HI observations show that SBS 0335−052 is a strongly interacting system, probably representing a major merger of extremely gas-rich galaxies. An ionized superbubble identified by Thuan, Izotov & Lipovetsky (1997) from HST observations of SBS 0335−052E is extended along one of the diffuse tidal features. Ekta et al. have suggested that propagating star formation is driven by the superbubble expanding into a medium with a tidally produced density gradient (Ekta, Pustilnik & Chengalur 2009).

Ekta and Jayaram Chengalur have studied two XMD galaxies, SDSSJ011914.27-093546.4 and UM133, with no known nearby companions. From their observations with the GMRT, they find both the galaxies to have highly disturbed HI morphologies and velocity fields, which could be due to interactions with more distant companions, merger with gas-rich dwarf companions, or perhaps cold gas accretion from the intergalactic medium, which could also be responsible for the observed low emission-line metallicities of XMD galaxies (Ekta & Chengalur 2010).

Galaxy interactions, groups and clusters

Galaxy interactions and mergers are well known to affect star formation and the evolutionary history of galaxies. HI observations of interacting systems provide an essential ingredient towards understanding these interactions and their effects on star formation. In order to study the HI gas properties and their correlation with star-forming regions, Chandreyee Sengupta and D.J. Saikia from NCRA, and K.S. Dwarakanath from RRI, have started a programme to observe a sample of interacting systems with the GMRT and have reported the results on the archetypal pair, Arp 86 (Fig. 6). In addition to HI emission from the two dominant galaxies, NGC7752 and NGC7753, these observations show a complex distribution of HI tails and bridges due to tidal interactions. The regions of highest column density appear related to the recent sites of intense star formation. They find a tidal dwarf galaxy, and a non-thermal radio continuum bridge between NGC7752 and NGC7753 (Sengupta, Dwarakanath & Saikia 2009).

Tailed radio galaxies, such as the wide-angle (WAT) and narrow-angle tailed sources, are those whose jets appear to bend in a common direction and occur in clusters of galaxies. The bent nature of WATs, which are usually associated with the dominant cluster galaxies, are often attributed to strong intracluster winds caused by dynamical interactions, while the narrow-angled ones could be due to motion of the parent galaxy through the intracluster medium. The detection

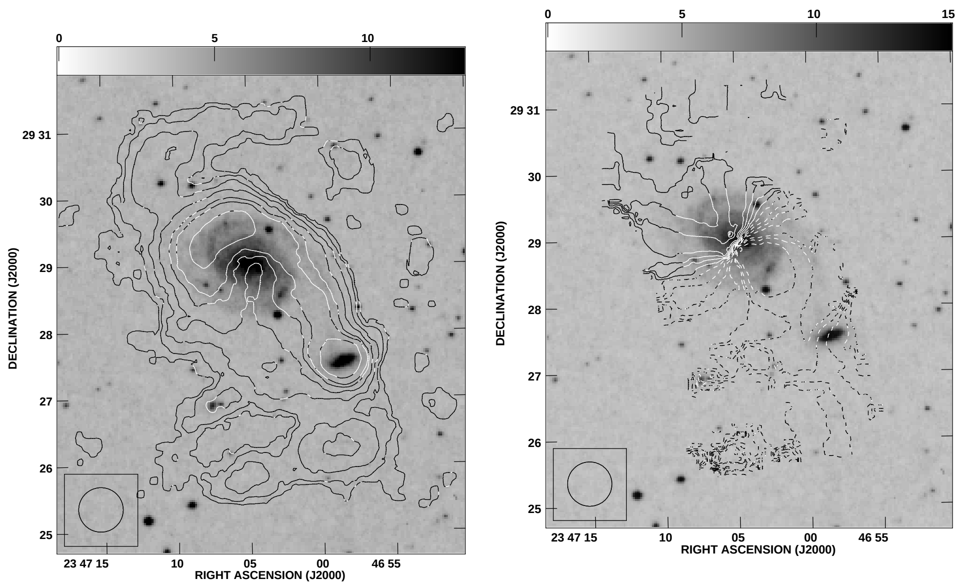

Figure 6. Hɪ column density and velocity field map of Arp 86 with an angular resolution of 45 arcsec (Sengupta, Dwarakanath & Saikia 2009).

of such sources in radio surveys could be used to identify clusters of galaxies at moderate and high redshifts. Simona Giacintucci from CfA and Tiziana Venturi from INAF, Istituto di Radioastronomia have reported the serendipitous discovery of a few tailed radio galaxies with the GMRT (Giacintucci & Venturi 2009) while Nimisha Kantharia and Gopal-Krishna from NCRA, and Mousumi Das from RRI have reported the finding of a WAT source with the GMRT (Kantharia, Das & Gopal-Krishna 2009).

In addition to tailed or double-lobed radio sources, radio haloes, relics and core haloes or mini haloes may also be associated with clusters of galaxies. While core haloes are usually associated with a dominant galaxy in a cooling core cluster and are less than ~500 kpc in size, haloes and relics are often larger and not associated with any particular galaxy. While models for haloes include reacceleration of particles by turbulence to production of relativistic electrons by hadronic collisions, relics possibly arise due to cluster mergers accompanied by shocks. D. Dallacasa from the Universitá di Bologna and his collaborators, G. Brunetti, R. Cassano, T. Venturi, G. Macario and G. Setti from INAF Istituto di Radioastronomia, S. Giacintucci from CfA, and N.E. Kassim and W. Lane from NRL, have reported the discovery of a radio halo with a very steep spectrum in the merging galaxy cluster A521 through observations with the GMRT. They suggest that the steep spectrum of the halo supports a turbulent acceleration scenario (Dallacasa et al. 2009). Venturi et al. (2009) have summarized their results on the GMRT Radio Halo Survey, carried out at 610 MHz to investigate the statistical properties of cluster radio halos in a complete cluster sample selected in the redshift range 0.2−0.4, while Ruta Kale and K.S. Dwarakanath from RRI have reported their results on a low-frequency study of the diffuse radio emission in the galaxy cluster A754. They present a new 150-MHz image of the galaxy cluster, suggest that one of the diffuse features is a cocoon lurking for $\sim 9 \times 10^7$ yr, and also explore the possibilities of shocks and turbulent reacceleration being responsible for the other diffuse features in A754 (Kale & Dwarakanath 2009).

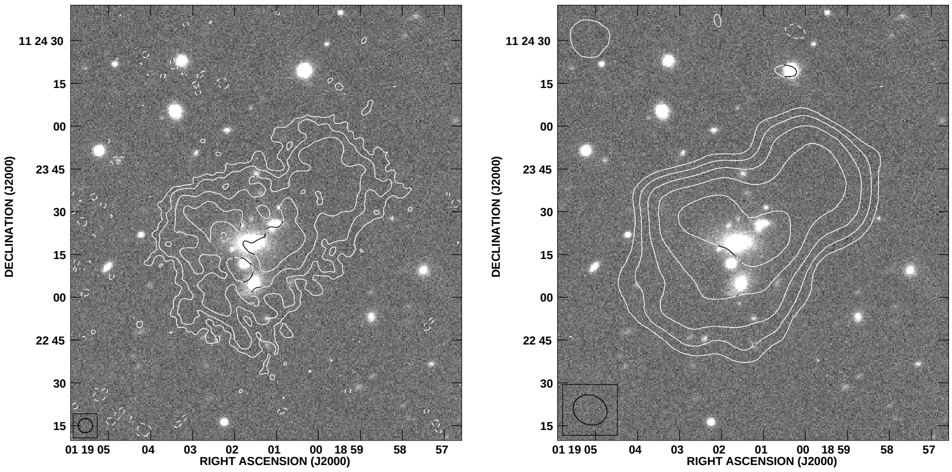

Figure 7. The GMRT radio images at 1.28 GHz (left panel) and 240 MHz (right panel) superimposed on the IGO R-band image of the cluster of galaxies (Bagchi et al. 2009).

Joydeep Bagchi from IUCAA, Joe Jacob from Newman College, India, Gopal-Krishna from NCRA, Norbett Werner from Stanford University, Nitin Wadnerkar and A.C. Kumbharkhane from SRTM University, India, and Jaydeep Belapure from Pune University, India have presented GMRT and IUCAA Girawali Observatory (IGO) observations of MRC0116+111 (Fig. 7), revealing a luminous, miniradio halo of ~240-kpc diameter located at the centre of a cluster of galaxies at redshift z = 0.131. The radio source does not show any signs of an active AGN either in the form of a radio core or jets. The bubbles of radio-emitting plasma were possibly created in an earlier cycle of activity and are rising buoyantly into the putative hot intracluster medium (Bagchi et al. 2009).

AGN heating in clusters

Feedback by the AGN is a promising possibility which has been proposed to solve the 'cooling flow problem' in clusters of galaxies, i.e. the lack of evidence of gas cooling to low temperatures as predicted by the models (Peterson & Fabian 2006). This was highlighted in early studies by Pedlar et al. (1990) who estimated that the energy input is comparable to the X-ray luminosity, and they noted that "its effects should be considered in models of cooling inflows in the central parts of the Perseus cluster." A striking manifestation of this is that the lobes of radio emitting plasma could push aside the X-ray emitting gas in the cluster leaving apparent cavities in the X-ray images (e.g. Bîrzan et al. 2009 and references therein). Images from the Chandra observatory have shown that many clusters have X-ray cavities in their atmospheres, and a combination of deep X-ray and low-frequency radio imaging are likely to provide the most promising diagnostics for determining the ages, energetics and duty cycles of AGN in these clusters.

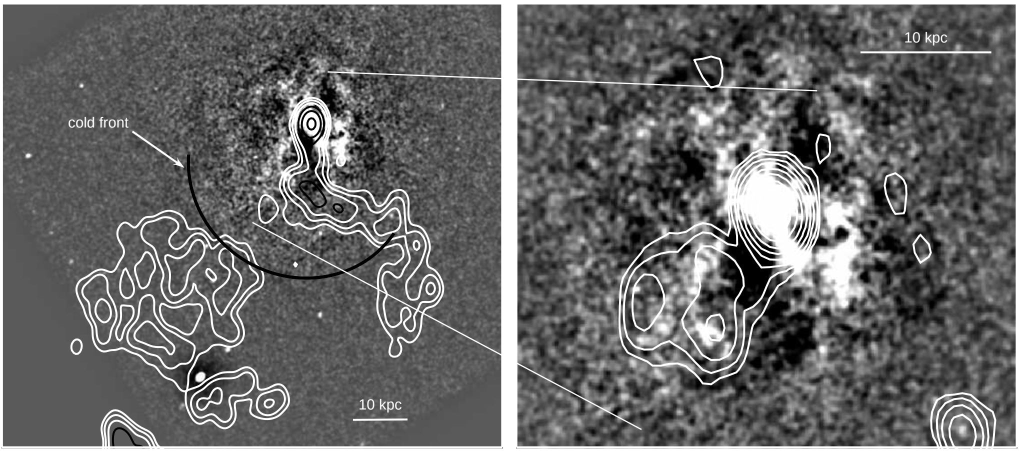

Figure 8. GMRT 235-MHz (left panel) and 610-MHz (right panel) contours overlaid on the Chandra unsharp masked image of the X-ray bright group NGC5044 in the 0.3−2 keV band (David et al. 2009). This figure has been reproduced from Giacintucci et al. (2009).

The importance of combining deep X-ray and low-frequency radio imaging is seen in the results of NGC5044, presented by Laurence David, Christine Jones, Simona Giacintucci, William Forman, Paul Nulsen, Jan Vrtilek and Ewan O'Sullivan from CfA and Somak Raychaudhury from the University of Birmingham, which hosts many small radio quiet cavities, filaments and a semi-circular cold front (David et al. 2009; Giacintucci et al. 2009). The GMRT 610-MHz image (Fig. 8, right panel) shows a core and a lobe which extends along a cold filament, while the 235-MHz image (Fig. 8, left panel) shows not only more extended emission in the central region, but a detached radio lobe. The western edge of this detached lobe is close to the cold front, and has possibly been produced in an earlier cycle of activity. This feature is not seen in the 610-MHz image, suggesting that it has a steep spectrum as expected for an old lobe (Giacintucci et al. 2009). The GMRT observations reveal at least two cycles of AGN activity, the youngest is seen close to the core and visible in the 610-MHz image and the oldest is identified with the detached radio lobe.

Another interesting source which has been studied in detail using data from the GMRT, VLA and Chandra is Abell 262, by T.E. Clarke and Namir Kassim from NRL, E.L. Blanton, L.D. Anderson and E.M. Douglass from Boston University, C.L. Sarazin from the University of Virginia and Gopal-Krishna from NCRA. The X-ray observations provide evidence of an X-ray tunnel, while the radio images show that the central source is about three times larger than previously known. The south-western extension in the central S-shaped source B2 0149+35 is co-spatial with the X-ray tunnel, while the eastern extension shows clumps of emission coincident with either a faint X-ray cavity or depressions in the X-ray emission. The newly estimated total AGN energy output could be capable of offsetting radiative cooling over several outburst episodes (Clarke et al. 2009).

Myriam Gitti, Ewan O'Sullivan, Simona Giacintucci, Laurence P. David, Jan Vrtilek and Paul Nulsen from CfA and Somak Raychaudhury, from the University of Birmingham have reported the results of an analysis of Chandra, XMM-Newton and new GMRT data of the X-ray bright compact group of galaxies HCG 62, as part of an ongoing X-ray/low-frequency radio study to examine AGN and hot gas interactions. While minimal if any radio emission was detected at higher frequencies, the GMRT observations at 235 and 610 MHz clearly detect extended low-frequency emission from radio lobes corresponding to the cavities. They find evidence of a shock front near the southern lobe which may have heated the gas in the southern region (Gitti et al. 2009).

Rejuvenated and large radio galaxies

A very striking example of episodic jet activity is when a new pair of radio lobes is seen closer to the nucleus before the 'old' and more distant radio lobes have faded (see Blundell 2008; Saikia & Jamrozy 2009 for a review). Such sources are known as double-double radio galaxies (DDRGs). From radio and X-ray observations of radio galaxies, there are about two dozen good examples of sources which exhibit evidence of recurrent AGN activity. Studies of such sources are important for understanding episodic jet activity, constraining their time scales, studying the propagation of jets in different media and also understanding their effects on galaxy formation and evolution. Marek Jamrozy from the University of Krakow, D.J. Saikia from NCRA and Chiranjib Konar from IIA have reported GMRT observations of the first double-double radio quasar (Fig. 9), and find the outer lobes to be highly asymmetric in both location and brightness compared to the DDRGs (cf. Saikia, Konar & Kulkarni 2006). This could be due to a combination of relativistic motion as well as intrinsic asymmetries (Jamrozy, Saikia & Konar 2009).

From a detailed multifrequency study of the DDRG J1548−3216 (Safouris et al. 2008; Saripalli, Subrahmanyan & Udaya Shankar 2003), using both the GMRT and the VLA, Jerzy Machalski, Marek Jamrozy from the University of Krakow and Chiranjib Konar from IIA estimate the dynamical ages of the outer and the inner doubles to be 132±28 Myr and 9±4 Myr, respectively. They find the radiative age of the oldest plasma in the outer lobes is ∼65−75 Myr towards the centre of the old cocoon, and ∼5−15 Myr for the inner double (Machalski, Jamrozy & Konar 2010). As seen in the earlier GMRT and VLA studies of the DDRGs J1453+3308 (Konar et al. 2006) and 4C29.30 (Jamrozy et al. 2007), they find the injection spectral indices of the outer and inner lobes to be similar, suggesting that the electron energy spectrum may be set close to the central engine.

Yogesh Chandola and D.J. Saikia from NCRA and Neeraj Gupta from ATNF have reported the detection of HI absorption with the GMRT towards the core of the rejuvenated radio galaxy 4C29.30, consistent with the trend for HI gas to be often seen towards the central regions of rejuvenated radio sources (Chandola, Saikia & Gupta 2009).

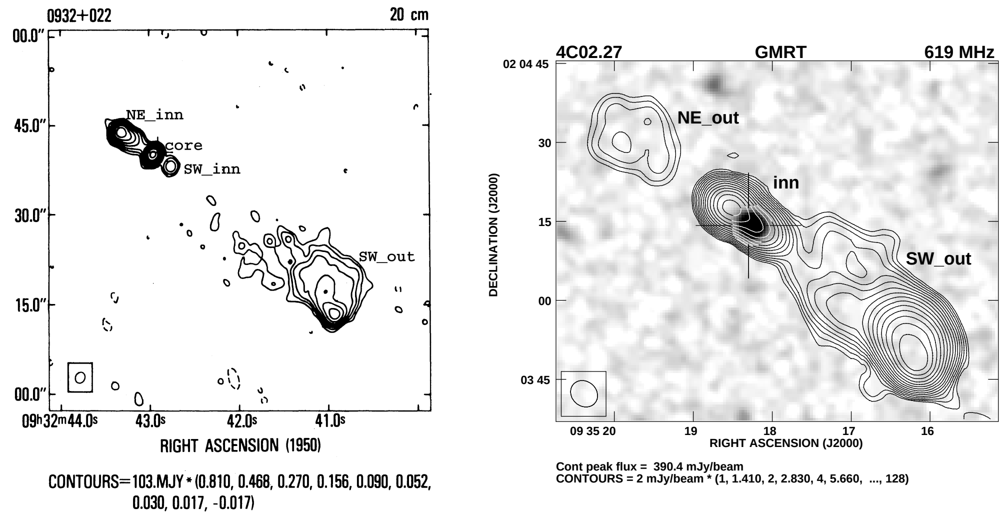

Figure 9. VLA image of the DDRQ 4C 02.27 at 1413 MHz (left panel) with an angular resolution of ∼1.7 arcsec reproduced from Hintzen et al. (1983), with the components NE_{inn}, SW_{inn} and SW_{out} marked. The GMRT image of 4C 02.27 at 619 MHz with an angular resolution of ∼5 arcsec showing the outer north-eastern component, NE_{out}. The cross marks the position of the quasar (Jamrozy, Saikia & Konar 2009).

A deep multi-frequency survey at 153, 244, 610 and 1260 MHz towards a field containing clusters of galaxies was used to examine the structure and spectra of 374 sources for evidence of recurrent or episodic AGN activity by Sirothia, Saikia, Ishwara-Chandra and Kantharia from NCRA. No unambiguous case was found, suggesting that such activity is not commonly seen even at low radio frequencies. However, most of the sources observed by Sirothia et al. (2009a) are small, with a median angular size less than about 10 arcsec, which corresponds to a linear size of only ∼60 and 80 kpc at redshifts of 0.5 and 1 respectively, suggesting that they are rarely seen in small sources. Radio sources with clear signs of recurrent activity are usually of larger dimensions.

Chiranjib Konar from IUCAA along with Martin Hardcastle and Judith Croston from the University of Hertfordshire and D.J. Saikia from NCRA have presented a detailed study of the large radio galaxy 3C457 using the GMRT, VLA and XMM-Newton. They determine the radio spectrum over a large frequency range and attribute the X-ray emission from the lobes to the inverse Compton scattering of cosmic microwave background photons. The magnetic field strength of the lobes is very close to the equipartition value (Konar et al. 2009).

Optical variability of AGN

Variability of the total and/or polarized flux density has been observed in a wide variety of Active Galactic Nuclei (AGN) over a large range of time scales, and has been one of the defining characteristics of an AGN. The most dramatic cases of variability are usually found in blazars, which consist of both BL Lac type objects and highly polarized quasars. The observed variability is usually associated with shocks as the Doppler boosted relativistic jets, emitting synchrotron radiation, interact with inhomogeneities along their paths. There could also be changes in the orientation of the jet, leading to changes in the observed flux density. In order to understand the variability of quasars and blazars, samples of these objects have been monitored over the years using the 104-cm Sampurnanand telescope of ARIES, the 201-cm HCT and the 200-cm IGO.

Arti Goyal, S. Joshi and Ram Sagar from ARIES, Gopal-Krishna from NCRA, Paul Wiita from Georgia State University, and G.C. Anupama and D.K. Sahu from IIA have presented the results of optical monitoring of a sample of radio-intermediate quasars (RIQs). These objects span the range of radio loudness between the radio-loud and radio-quiet quasars, and there have been suggestions that these might be the tail of the radio-loud distribution rather than being a separate population. Studies of RIQs could help understand the relationships between the radio-loud and radio-quiet quasars. They find that the RIQs are much less extreme than blazars in their variability. They estimate the duty cycle of intra-night optical variability to be between 9 and 14 per cent for RIQs, compared with 60 per cent for BL Lac objects and $\sim$15 per cent for both radio-loud and radio-quiet quasars for similar durations of observations (Goyal et al. 2010).

From a long-term monitoring programme which involved observations on 17 nights spanning 11 years (1998−2008) Arti Goyal and Ram Sagar from ARIES, Gopal-Krishna from NCRA, G.C. Anupama and D.K. Sahu from IIA, S. Britzen and M. Karouzos from MPIfR, and M.F. Aller and H.D. Aller from the University of Michingan, have established an interesting long-period INOV quiescence in the radio-selected BL Lac object PKS 0735+178 (Goyal et al. 2009). Using other unpublished optical data they extend this period of quiescence to 1989, when a large radio outburst was observed. Although reasons for this long period of quiescence is unclear, perhaps Very Long Baseline Interferometric observations of the inner jet, may help clarify the situation.

A recoiling black hole or merging galaxies?

Spectra of thousands of quasars in the Sloan Digital Sky Survey have revealed a small number of sources with two sets of emission lines powered by an AGN-like continuum source (Komossa, Zhou & Lu 2008; Boroson & Lauer 2009; Shields, Bonning & Salviander 2009; Shields et al. 2009). These objects open up the possibility of studying recoiling black holes and/or binary super-massive black holes.

M. Vivek and K.C. Kuriakose from Cochin University of Science and Technology, and R. Srianand, P. Noterdaeme and Vijay Mohan from IUCAA, report long-slit spectroscopic observations with the IGO of SDSSJ092712+294344, which has three sets of emission lines at 0.6972,

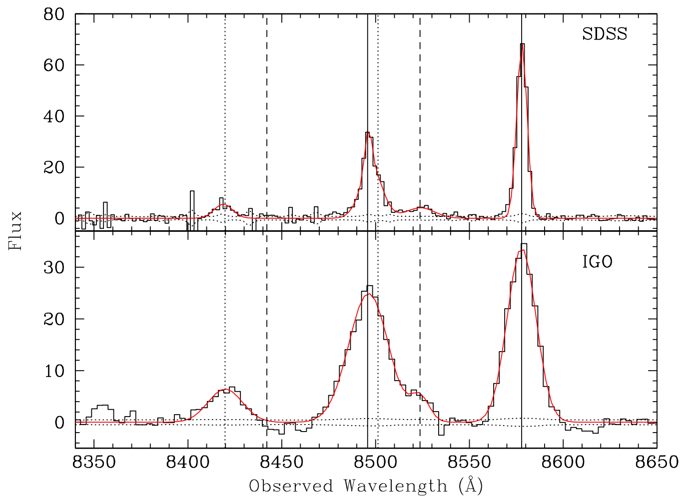

Figure 10. Comparison of the spectra of SDSS J0927+2943 obtained with IGO and SDSS. Best fit Gaussians are over-plotted. The solid, dotted and dashed vertical lines mark the locations of the different [OIII] lines from the red, blue and the third system at z_{em}=0.7020 (Vivek et al. 2009).

0.7020 and 0.7128. Comparing their spectra with the SDSS, obtained 4 years earlier, they put a 3-σ limit on the relative acceleration to be less than 32 km s^{-1} yr^{-1} between different emitting regions (Fig. 10). They estimate the linear extent of the the [OIII]λ5008 emitting region in the z=0.7128 system to be ~8 kpc in extent. From their observations they find the binary black hole model to be unlikely, and suggest that the sizes are consistent with both black hole recoil and merging scenarios (Vivek et al. 2009).

21-cm absorbers at intermediate redshifts

Neeraj Gupta from ATNF, R. Srianand and P. Noterdaeme from IUCAA, Patrick Petitjean from IAP and D.J. Saikia from NCRA have presented the results of a systematic GMRT survey of 21-cm absorption in a representative and unbiased sample of 35 strong MgII systems in the redshift range z_{abs} ~1.10−1.45. The survey using ~400h of telescope time has resulted in nine new 21-cm detections (Fig. 11) and stringent 21−cm optical depth upper limits for the remaining 26 systems. This is by far the largest number of 21−cm detections from any single survey of intervening absorbers. Prior to this survey, no intervening 21-cm system was known in the above redshift range, and only one system was known in the redshift range 0.7≤z≤1.5. They explore the relation between the detectability of 21−cm absorption and various properties of UV absorption lines, and suggest that the number of 21−cm absorbers per unit redshift decreases with increasing redshift, possibly due to the evolution of the cold neutral medium filling factor in MgII systems (Gupta et al. 2009).

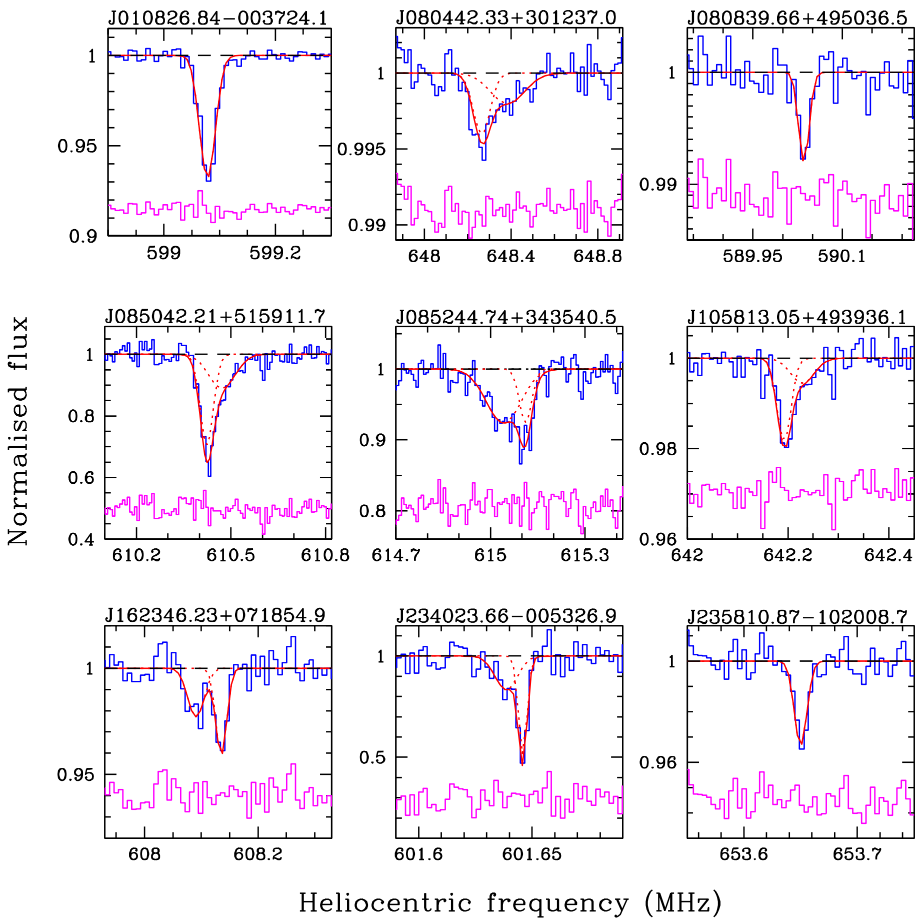

Figure 11. GMRT spectra of detected 21-cm absorption lines. Individual Gaussian components and resultant fits to the absorption profiles are overplotted as dotted and continuous lines respectively. Residuals, on an offset arbitrarily shifted for clarity, are also shown (Gupta et al. 2009).

Nissim Kanekar from NRAO and now at NCRA, J.H. Prochaska from UCO/Lick Observatory, S.L. Ellison from the University of Victoria and Jayaram Chengalur from NCRA, have reported the results of a deep search for redshifted Hɪ 21-cm absorption in 55 strong Mgɪɪλ2796 absorbers in the redshift range $z_{abs} \sim 0.58-1.70$ with the Green Bank Telescope and GMRT. Nine detections of Hɪ 21-cm absorption were obtained, all at $z_{abs}=1.17-1.68$, including three reported earlier by Gupta et al. (2007, 2009). Absorption was not detected in 32 other Mgɪɪ absorbers, while data for 13 systems were affected by radio frequency interference. They use the observed detection rate to infer the cosmological mass density of neutral gas in DLAs, and find it to be consistent with earlier estimates (Kanekar et al. 2009a).

In another study, Nissim Kanekar and Jayaram Chengalur from NCRA, Alain Smette from ESO and Frank Briggs from ANU, report evidence for an anti-correlation between spin temperature and metallicity [Z/H], in a sample of 26 damped Lyα absorbers in the redshift range 0.09−3.45. The high spin temperature possibly reflects the underlying gas temperature distribution. The reported anti-correlation is consistent with the presence of a mass−metallicity relation in DLAs (Kanekar et al. 2009b).

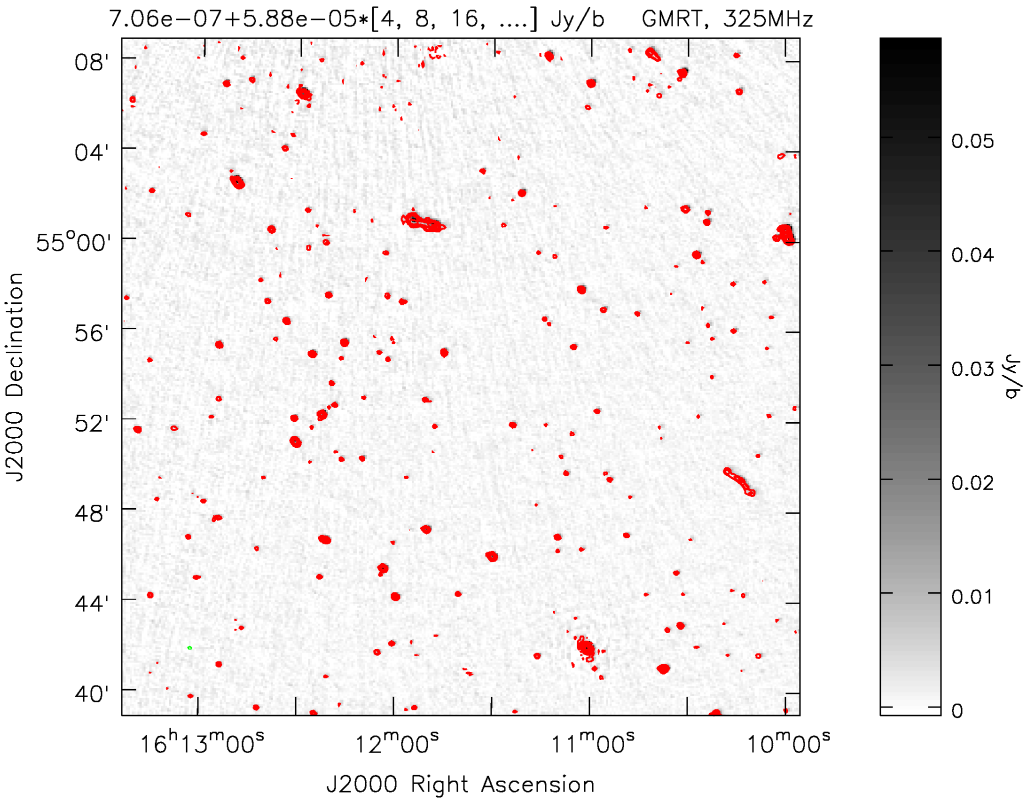

Figure 12. GMRT image of an area of 30×30 arcmin^2 from GMRT observations at 325 MHz (Sirothia et al. 2009b).

Deep continuum surveys

To explore issues related to galaxy formation and evolution with cosmic epoch and possible relationships between AGN and starburst activity, a number of different fields are being studied at different wavebands. A well-known one, selected at infrared wavelengths is the European Large Area ISO (Infrared Space Observatory) Survey (ELAIS), the northern one being termed ELAIS-N1. The ELAIS-N1 field is in a region of the sky with low-IR foreground emission, to allow detection of fainter and possibly more distant galaxies. S. Sirothia and D.J. Saikia from NCRA, Michel Dennefeld, Francoise Ricquebourg and Jacque Roland from IAP and Herve Dole from Institut d'Astrophysique Spatiale have reported deep 325-MHz observations of the ELAIS-N1 field using the GMRT, with the ultimate objective of identifying AGN and starburst galaxies and examining their evolution with cosmic epoch. They have achieved a median rms noise of $\approx 40\mu$Jy beam^{-1}, which is the lowest that has been achieved at this frequency. They identify very steep spectrum sources which are likely to be either relic sources or high-redshift objects as well as inverted-spectra objects which could be Giga-Hertz Peaked Spectrum objects. They report evidence of a flattening in the normalized differential counts at low flux densities which has so far been reported at higher radio frequencies (Sirothia et al. 2009b).

Edo Ibar and R.J. Ivison, from the Royal Observatory, Edinburgh, P. N. Best and J. S. Dunlop from the University of Edinburgh, K. Coppin and Ian Smail from Durham University and A. Pope from NOAO, have imaged the Lockman Hole at 610 and 1400 MHz using the GMRT and the VLA respectively and have reached rms noise levels of $\sim$15 and 6 μJy beam^{-1} respectively. They detected about half of the sub-mm galaxies (SMGs) in the field, and find a mean spectral index of 0.75$\pm$0.06, similar to those of local star-forming galaxies, showing that their emission is dominated by optically thin synchrotron emission. They find that SMGs identified from Spitzer mid infrared colours tend to have steeper radio spectral indices, suggesting that their injection spectral indices may be different or that they may reside in denser environments (Ibar et al. 2010). From their observations Edo Ibar, R.J. Ivison and A.D. Biggs from the Royal Observatory, Edinburgh, D.V. Lal from ASIAA, P.N. Best from the University of Edinburgh, and D.A. Green from the University of Cambridge, do not find any clear evidence of evolution of spectral index with flux density, and that the bulk of the sources are optically thin synchrotron sources, ruling out a dominant flat-spectrum or ultra-steep spectrum population (Ibar et al. 2009).

The relationship between star formation rate (SFR) and radio synchrotron luminosity in galaxies over the redshift range 0 to 2 have been examined by Timothy Garn from the ROE, who passed away recently in a tragic accident, and David Green, Julia Riley and Paul Alexander from the University of Cambridge, who have presented new GMRT observations of the ELAIS-N2 field and have used earlier results on ELAIS-N1 and the Lockman Hole for this study. They find that for almost all galaxies, the local calibration between radio luminosity and star formation can be applied to radio-selected, high-redshift, high-SFR galaxies (Garn et al. 2009).

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