HI in External Galaxies

In a very productive visit to Arecibo, Chris Impey & Valorie Burkholder (Steward Observatory) measured the $\lambda 21$-cm HI emission of low surface brightness (LSB) galaxies taken from an optical sample selected on UKSTU plates. During the course of a ten-day run, they observed more than 100 galaxies with a detection rate of over 50%. The average HI mass detected was $10^8 M_\odot$, though they did make several $10^9 M_\odot$ detections for nearby galaxies. These observers were able to reduce the data on site and left Arecibo with a list of over 50 new detections and measures of HI mass. They have learned that low surface brightness is most likely the result of low surface mass density, which inhibits star formation. Therefore, galaxies with higher surface brightness should have lower gas mass fractions (indicating more efficient star formation) and lower HI mass to blue luminosity. Fig. 4 shows the new detections, combined with results on the same sample from an earlier Arecibo run; this is among the largest HI surveys of LSB galaxies ever carried out. There is a strong trend towards higher gas content for a lower surface mass density of stars. Unfortunately, the simple interpretation of this trend – LSB galaxies are young and therefore unevolved – ignores the red optical colors and high metallicities of many of these galaxies. This enigmatic population is still not understood.

In May 1999, Chris Impey & Cathy Petry (Steward Observatory) obtained deep $\lambda 21$-cm HI observations toward the quasar, Q1214+1804. The goal was to look for gas-rich galaxies at small impact parameters to this line of sight, and to subsequently relate the galaxies to 20 Ly-\alpha absorbers in the quasar spectrum. The redshift range $0 < Z < 0.2$ was covered in two correlator settings. In addition to looking for galaxy counterparts to the diffuse hydrogen absorbers, the experiment provides an independent test of the blind HI surveys that define the HI mass function, work also done at Arecibo. Working over this broad redshift range exposed them to the full problems of interference and other artifacts. Fig. 5 shows the $1 \sigma$ HI mass detection limit as a function of $Z$ for about 2 hours integration for tow of the configurations: low $Z$ (top) and high $Z$ (bottom). This represents about half of the low-$Z$ data and a fifth of the high-$Z$ data obtained. The increasingly challenging astronomical environment at lower frequencies is clearly seen. The final pencil beam will reach a $5 \sigma$ limit at $Z = 0.08$ of about $3 \times 10^7 M_\odot$, and will cover sufficient volume to detect 5-6 galaxies by their HI emission, in addition to any quasar absorbers that correspond to gas-rich galaxies.

Galactic High Velocity Clouds (HVCs) have recently gained attention as being massive gas clouds distributed throughout the Local Group. The HVCs could be primordial objects raining on the Galaxy, either as remnants from the formation of the Local Group or as representatives from an intergalactic population of dark matter-dominated mini halos in which hydrogen has collected and remained stable on cosmological time scales (Blitz et al. 1999, Ap. J., 514, 818, and Braun & Burton 1999, A&A, 341, 437). These mini halos are generally predicted by semi-analytical simulations of galaxy and group formation in much larger numbers than can be accounted for by the known dwarf galaxy population. Assuming that the HVCs are dark matter dominated, with the fraction of hydrogen to total mass approximately equal to 0.1, it can be shown that they are gravitationally stable at typical distances of 1 Mpc from the Local Group’s barycenter. Placed at those distances, the HVC HI masses are $\sim 5 \times 10^7 M_\odot$, and typical diameters are $30$ kpc. If this extragalactic interpretation of HVCs is true, similar clouds are expected in other galaxy groups. Martin Zwaan & Frank Briggs (Groningen) performed a targeted survey for these clouds in 5 nearby galaxy groups at distances between 25 and 40 Mpc, for which the Arecibo beam matches the typical cloud size, and most clouds should be detectable within a few minutes. A total of 300 pointings were observed on square grids centered on the group’s barycenters. The pointings extended to radii of 2 Mpc and thus cover different environments within each group. The selected groups cover a range of compactness, group richness and total HI mass centered around the properties of the Local Group. The survey was sensitive to HI masses of $5 \times 10^6 M_\odot$ at the 5-$\sigma$ level. After a first round
of observations in April, all 4.5-σ peaks in the spectra were selected and re-observed in June with double the integration time. None of the peaks could be confirmed as being real HI detections. This null result places interesting upper limits on the space density of primordial gas clouds in galaxy groups.

Phil Choi & Anthony Gonzalez (UC Santa Cruz) have observed 12 galaxy clusters in the redshift range of 0.12 < Z < 0.26 (1130-1270 MHz) using a drift-scan observing mode. Mean integration times of 4 hr per cluster were achieved with the purpose of obtaining total cluster HI masses. All of the clusters in the sample are already well observed at both X-ray and optical wavelengths, so by combining that data with HI masses these observers will investigate the role that the hot intracluster medium (X-ray) and the cold galactic HI reservoir (radio) have on the star-formation history (optical) of the cluster. Despite working in a relatively unexplored region of the radio spectrum, clean observations with stable baselines were successfully obtained. In addition, a useful byproduct of these observations is that RFI in the frequency range of 1120-1280 MHz was mapped out over the course of the week-long observing run.

**Molecular-Line Studies**

Jeremy Darling & Riccardo Giovanelli (Cornell) report the discovery of 11 OH megamasers (OHMs) and one OH absorber, along with upper limits on the OH luminosity of 54 other luminous infrared galaxies at Z > 0.1. The new megamasers show a wide range of spectral properties, but are consistent with the extant set of 55 objects, 8 of which

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![Graph](graph.png)

**Fig. 5:** The 1-σ HI mass detection limit as a function of Z for about 2 hours On-Off data at low Z (top) and high Z (bottom). (Courtesy Chris Impey)

**RFI Notes From T.Ghosh:** The degradation of detection limit at several z-ranges in this unprotected band is due to a number of military radars including a recently installed frequency-hopping system (‘-’ marked). There are also resonance modes at several frequencies in this range in the ‘L-wide’ receiver. For more information, see http://
The new OH detections are the preliminary results of an in-progress Arecibo survey for OHMs which is expected to produce several dozen detections. The ultimate goal of the survey is to calibrate the luminosity function of OHMs to the low-Z galaxy merger rate (0.1 < Z < 0.2), and to use this measure to estimate the merger rate at higher Z using pointed and blind surveys. The survey will also provide an enhanced sample of OHMs for the study of their environments, engines, lifetimes, and structure. The selection criteria for candidate OHMs require IRAS detection at 60 µm, and Z > 0.1. The redshift limit is imposed by the RFI environment, while IRAS detection guarantees that candidates are luminous infrared galaxies, which are galaxy mergers (Clements et al. 1999, MNRAS, 302, 391). OHMs require a high density of molecular gas, an energetic population-inversion mechanism (such as shocks, AGN or starbursts), and a radio-continuum source to stimulate emission. Mergers are quite efficient at shocking the ISM, funneling gas into the centers of the merging galaxies, fueling AGN, and producing bursts of star formation, so we expect mergers to be ideal environments for the production of OHMs. The detection rate is 1 in 6 to date, and a typical OHM detection is shown in Fig. 6.

Murray Lewis (NAIC) has undertaken reobservation of OH/IR stars within the Arecibo sky in a program that has been both a learning experience in spectral-line use of the 305-m telescope, and a happy blend of science with student education. Its purpose is to obtain simultaneous 1612, 1665, and 1667 MHz quality spectra for about 400 OH/IR stars identified in earlier surveys of color-selected IRAS sources. Those observed by summer students in 1998 & 1999 provided instant visual gratification, as they are obvious, have a recognized classic norm, yet have diversity of morphology, intensity, and velocity range. These data are also well suited to learning reduction processes, with good feedback on both the software utilized and the observation’s quality. Spectra are taken with an 0.39-MHz total bandwidth, giving a 0.14-kms⁻¹ resolution at the OH lines. Moreover, the digital filters defining the narrower correlator bandwidths provide very smooth bandpasses. Our experience shows that observations of strong (>50 mJy) features need no comparison OFF-source spectra, nor is observation confined to nighttime by
baseline ripples; good observations can be secured at midday. About 25% of Arecibo OH/IR stars have been reob-
served to date, including all high-latitude stars.

An extra stimulus is lent to this project though, by the new transient shell scenario. This expects the duration of the superwind supplying the dense shells hosting 1612-MHz masers to be rather brief, often < 1000 yr, while the duration of masers is even briefer. Thus, over 10 yr a few stars may exhibit intensity changes well beyond the factor of ~3 associated with the regular pulsation cycle. The program has already scored several successes in this regard. Thus, Ben Oppenheimer (REU student in 1998) found the peak intensity in 18455+0448 had dropped from 2000 to 200 mJy over 10 yr, while Lewis found that it then dropped to < 10 mJy in the following six months. Likewise, the OH masers in VY Her have decreased by a factor of >10 and disappeared. However, the most spectacular changes are those exhibited by 19566+3423, (see Fig. 7). Ten years ago this had a rather unusual 1612-MHz spectrum, prompting its early reobservation. While the factor of three increase in 1612-MHz intensity is dwarfed by the factor of 30 increase in 1665-MHz intensity, unprecedented changes in the velocity range of its emission have been observed. This has expanded from 16 to 42 kms^{-1} in the 1612-MHz line, and at 1667 MHz from 28 to 80 kms^{-1}. It is presumably a supergiant or hypergiant star with a rapidly evolving circumstellar shell that may well have been lost in a sudden mass ejection event, rather than in a wind. Its spectra are distantly reminiscent of IRC+10420, which has, however, always exhibited the same velocity range throughout the 24 yr since its discovery.

The IRAS satellite provided positions for many thick dust shells. At Arecibo, about 400 of these were confirmed as OH/IR stars by detecting their 1612-MHz masers, though up to 75% of candidates remained undetected. These OH/IR star color “mimics” need explanation. Lewis has found that mimics are a mandatory feature of the transient-shell paradigm, in which a superwind only endures for ~500 yr after a He-shell flash, while the extra “flash” luminosity causes the star to expand, thereby increasing its period and mass-loss rate. The gas density in the circumstellar shell then rises past the threshold that allows dust to couple photon momentum to it, with an immediate increase in its expansion velocity. Since a newly accelerated shell quickly moves beyond its dust-shroud, its molecules are rapidly degraded by interstellar UV. Hence the mimics. The subsequent acquisition of masers by a mimic shows that its superwind has long climaxed, and that a protective dust-shroud from the current expansion is again extending the longevity of molecules. 19586+3637, (alias V1511 Cyg = IRC+40371), is a mimic from Arecibo searches of 1988 and 1991 (and an earlier search at Nançay). On 29 May 1999, Lewis found this star to exhibit a 300-mJy 1612-MHz maser (see Fig. 8); a mimic that has recently become an OH/IR star.

**Fig. 8:** The 1612-MHz, OH-maser emission spectrum of 19586+3637, on 29 May 1999. (Courtesy Murray Lewis)

**Pulsars**

Alex Wolszczan, Ian Hoffman & Maciej Konacki (Penn State) and Kiriaki Xilouris (NAIC/NRAO) have conducted multi-frequency timing observations of the planet pulsar, PSR B1257+12. Measurements were made on a daily basis between May 5 and June 6, 1999, at 430, 611.5, 1130 and 1410 MHz, using the Penn State Pulsar Machine (PSPM). The purpose of this project was to investigate the claim published in 1997 by K. Scherer et al. (Science, 278, 1919) that a 25.3-day periodicity seen in the timing residuals of the pulsar is caused by a propagation effect in the interplanetary plasma induced by solar rotation, rather than being due to orbital motion of a Moon-sized planet (planet A), orbiting the pulsar with the same periodicity. The highest quality data, obtained at 430 and 1130 MHz, are shown in Fig. 9 in the form of the best-fit residuals for a two-planet timing model including planets B and C and ignoring the inner planet A and its 25.3-day orbit. Clearly, both the 430- and 1130-MHz data (shown as open and filled circles, respectively) exhibit a 25-day periodicity with approximately the same ~3.5 µs amplitude. The best-fit model for planet A, based on the entire 8-year data set, is shown as a solid curve. Since the amplitude of a propagation-induced periodicity would have to scale as λ², it should be entirely invisible at 1130 MHz given a ~4 µs timing precision at that frequency. Consequently, this result adds to the evidence in favor of a Moon-mass, 25.3-day orbit companion to PSR B1257+12 and proves that this periodicity cannot be induced by a propagation effect as postulated by Scherer et al.
Don Backer & Andrea Somer (UC Berkeley) have begun to investigate “orthogonal mode emission” from pulsars — a phenomenon known for many years, where it appears that two modes of orthogonally or quasi-orthogonally polarized emission are competing in pulsar magnetospheres. The net result is a randomization of the integrated polarization position angle. In order to study the implications of this phenomenon on the emission mechanism, Backer and Somer aim to measure the extent to which the two competing modes each follow the “rotating vector model” proposed by Radhakrishnan & Cooke some 30 yr ago. They are developing an operation mode of the 168-MHz bandwidth Berkeley-Arecibo-Caltech Swift Pulsar Instrument (BACSPIN) that can deliver dedispersed time series of power in orthogonally polarized channels (single or subbands) and will soon have full Stokes parameter capability. Any observers interested in using BACSPIN are encouraged to contact Don Backer.

Duncan Lorimer, Fernando Camilo (Jodrell Bank/Colombia) & Kiriaki Xilouris have begun a timing campaign on 17 pulsars discovered over 25 years ago by Hulse & Taylor during their survey of the Galactic plane. The Hulse-Taylor survey is most remembered for its discovery of the binary pulsar, B1913+16, which Joe Taylor and collaborators have used as a Gravitational Laboratory for the last 20 yr. Probably as a result of this, very little is known about the remaining pulsars. It is hoped that the new series of measurements will yield some surprises about the remaining pulsars from this survey.

Andy Fruchter (STScI), Kiriaki Xilouris, Duncan Lorimer, Jo Ann Eder & Angel Vázquez (NAIC) have confirmed six more pulsars from the STScI/NAIC drift-scan search. PSRs J0137+16, J1549+21, J1822+11, J1838+16, J1849+06 and J2040+16 are all slow, low-luminosity pulsars with periods ranging between 0.4 and 2.2 sec, bringing the total number of pulsars resulting from the STScI/NAIC drift-scan search to nine.

Kiriaki Xilouris & Duncan Lorimer have been regularly monitoring the polarization properties of millisecond pulsars in globular clusters, aiming at contrasting their properties with those of field millisecond pulsars. Preliminary polarimetric profiles resulting from long integrations with the Arecibo Berkeley Pulsar Processor (ABPP) seem to indicate that the brightest pulsars in M15 exhibit very little polarization, unlike normal pulsars, but similar to field millisecond pulsars.

The Princeton pulsar search collaboration (Walter Brisken, David Nice, Kiriaki Xilouris, Steve Thorsett, & Fernando Camilo) made follow-up observations based on pulsar search data taken with the PSPM during the upgrade. Three new pulsars (J1829+14, J2055+21, and J2227+30) were confirmed, each with period slightly under one second. These pulsars were discovered in data covering roughly 600 square degrees of sky. Twenty known pulsars (including three recycled pulsars) were also redetected blindly in this data.

Bill Sisk, Jeff Hagen & Andy Dowd (NAIC) have made excellent progress on implementing WAPP – the Wideband Arecibo Pulsar Processor. This instrument uses an existing board that was developed for the AO spectral-line correlator. To manage the processing load, a Linux-PC performs post-processing and data storage. This combination gives wideband performance (100-MHz bandwidths), with good time and frequency resolution (64 lags every 64 µs). Larger numbers of lags may be possible for appropriately longer sampling times (e.g. 128 lags every 128 µs, etc.) Since much of the processing is handled in the Linux-PC, it is quite flexible. It can support a large number of modes including full polarization measurements. The difficult job of rapidly reading the correlation functions has been done and, during a test run in late August, the first pulses from B1541+09 were successfully recorded by WAPP (see Fig. 10). Presently, work is in progress to implement and test the required modes and converting the development unit into a working system. The current plan is that WAPP will be available for use as a 100-MHz search/polarimetry machine by the pulsar community by February 2000 and, as such, observing proposals to use the system were actively encour-
aged for the October 1999 deadline. Future enhancements to WAPP presently envisaged include wider band modes (adding more 100-MHz units) and narrower band modes suitable for low-frequency work.

**VLBI**

The terrestrial, 18-cm wavelength, VLBI test experiment, INTAS98.5, organized by Molotov, Likhachev & Chuprikov (Astro Space Center) and observed on 2 Dec. 1998, has now been correlated at the S2 correlator at Penticton, Canada. Between Arecibo and the Green Bank 140-ft telescope, signal-to-noise ratios of about 37:1 were measured on both of the pulsars, PSRs 0950+08 and 1133+16, with SNRs of 211:1 being registered for the quasar, B1156+295.

Arecibo has participated in twenty four 5-GHz observations in support of the Japanese-led VSOP Space-VLBI mission. So far in 1999, the targets have all been quasars. In an experiment proposed by Garrett (JIVE) & Patnaik (MPIfR, Bonn), fringes were detected on the small separation, gravitational-lens candidate, J0226+343, between Arecibo and both the HALCA orbiting antenna and the Noto 32-m dish. Of the other experiments, 19 were observed for the Deep Interferometric VSOP-Arecibo Survey (DIVAS) of weak AGNs by Hirabayashi (ISAS, Japan), Ulvestad (NRAO) and collaborators, and 4 for the VSOP 5-GHz flat-spectrum, bright AGN survey program. Fringes have been detected in all cases but three, which await correlation.

![Fig. 10: The first pulses successfully recorded by the Wide-band Arecibo Pulsar Processor (WAPP). The pulsar being observed was PSR B1541+09. (Courtesy Duncan Lorimer)](image-url)