C. Project Description

The Pushchino Radio Astronomy Observatory in Russia is the only remaining facility in the world making regular, high quality observations of pulsars in the decameter portion of the radio-frequency spectrum. Pulsars are known primarily by their extremely broadband, radio-frequency (RF) radiation, whose physical origin is still inadequately understood. While pulsar observations over the entire band of their emission are important, low frequency observations—those at some 100 MHz and below—are particularly valuable because they are so difficult. Most of the world's major observatories have abandoned this part of the radio band, in part because it is so difficult to control or compensate for intense man-made radio interference. Pushchino has pioneered in such low frequency techniques, and their observations now regularly cover the band between 25 and 120 MHz.

Radio signals from the city-sized stars known as pulsars have a different character in each wave band, probably because their high frequency emission comes from relatively close to the star and *vice versa*. Their average emission characteristics provide information on their magnetic field configuration in the emission region, whereas their pulse sequences exhibit a rich variety of phenomena which reflect plasma processes under extreme electrodynamic conditions. Great efforts have been made to understand pulsar emission physically and to develop appropriate physical models, but none as yet provides direct quantitative predictions. Pulsar emission thus remains one of the most challenging and potentially insightful unsolved problems in astrophysics, and observations at low radio frequencies remain essential to many key approaches to the problem.

Furthermore, pulsars have proven to be invaluable tools in studying the nature and dynamics of the interstellar medium (ISM). Pulsar observations remain the primary source of knowledge about its ionized component and a major source about magnetic fields within it. Scattering phenomena on widely different length scales within the ISM produce a variety of scintillation effects with different time scales, which have been one of the most rewarding areas of investigation in recent years. Scintillation carries fundamental information about dynamical processes of the ISM and has implications for other areas of astronomy. Its effects often scale steeply with frequency (*i.e.*, scattering broadening as $f^{-4.4}$), so that observations at the lowest possible frequencies are desirable.

The Pushchino Radio Astronomy Observatory is located about 100 km SE of Moscow and is one of the facilities of the Astro-Space Center of the Lebedev Physical Institute of the Russian Academy of Sciences. Its two main pulsar instruments are the BSA, a 275x275-meter, 111-MHz array and the DKR-1000, a 30–120-MHz steerable cross with 40-m by 1-km elements, both of which have been in operation since the early 1970s. Further information about the Pushchino Observatory and its instruments can be found at www.prao.psn.ru. These are the most significant instruments in the world for pulsar research at low frequencies, and their combination at one facility offers coverage over the entire band and the possibility of simultaneous observations. Several other facilities have limited capability at decameter wavelengths, but nothing approaching that of Pushchino. Even the newly constructed Giant Metrewave Radio Telescope in India will have receivers at 50- and 150-MHz and nothing in between. Other existing decameter instruments, such as those at Kharkov, in Ukraine, Gauribidinur or Ahmedabad, in India, or Mauritius, are single band.

This proposal is then a multi-project, multiple co-PI proposal for collaborative research in the broad area of pulsar science between US-based scientists and our colleagues at Pushchino and the Astro-Space Center. Our first objective is to carry out a series of excellent research projects at Pushchino and to conduct followup research with our Pushchino colleagues both there and in the US. Beyond this, our purpose is to see that Pushchino's capabilities and accomplishments are better known to US radio astronomers and that this collaboration and exchange is useful to Pushchino scientists in their ongoing process of further upgrading their facilities, so as to achieve even better observations and new types of observations in future throughout the decameter band.

The number of co-PIs on the US and Russian sides (8 each) exceeds the space available, so only one PI is listed. She (also Tim Hankins) has collaborated with Pushchino pulsarists for some 15 years and now wishes to pursue several new lines of research with them. Her new programs at Pushchino would be greatly facilitated by equipment proposed below which would also make other excellent projects by US radio astronomers at Pushchino possible. All projects are described below.

C.1 Proposal by Prof. Joanna Rankin, UVM

“Investigation of the Pulsar Emission Problem Through Subbeam-Circulation Mapping of Pulsar B0943+10 and Other Pulsars”

The subbeam-circulation mapping technique for studying the emission beam configuration of pulsars with “drifting” subpulses stems directly from Pushchino research over a 30-year period. The pulsar to which this mapping method was first applied, B0943+10, was discovered at Pushchino (Vitkevich et al. 1969) and most subsequent studies of the pulsar have also been carried out there (*i. e.*, Suleymanova, S. A. & Izvekova, V. A. 1984). It was collaborative work between Arecibo and Pushchino observers of this pulsar (Suleymanova et al. 1996, 1998) which first alerted us to the remarkable stability of this star’s pulse sequences, which then led to intensive studies and the development of new analytical methods (Deshpande 1999; Deshpande & Rankin 1998, 1999a,b, 2000; Rankin & Deshpande 1998, 1999)—that is, methods for resolving aliasing, the “cartographic” mapping method as applied both to still and “moving” images, and several new polarimetric methods extending earlier work (Rankin & Rathnasree 1995, 1996a,b, 1997, 2000).

Since this first rush of exciting work to successfully map 0943+10's emission-beam structure, three different directions of research have developed: first, efforts to determine unique solutions for other pulsars; second, efforts to answer the many questions raised by 0943+10's emission-beam system in the context of its profile and polarization modes, etc; and finally, efforts to clarify the physical implications of these results and their compatibility with emission theories such as that of Ruderman & Sutherland (1975). These results are exciting in the context of the longstanding problem of accounting for pulsar radio emission, because the subbeam circulation time (37 stellar rotations or 41 seconds for pulsar 0943+10) is apparently the result of **E**×**B** drift in the 100-meter scale polar cap, and thus gives a physical measure of the extreme conditions in this region. Overall, this work won NSF support last year under Grant AST 99-86754; so here we stress the importance of Pushchino’s work and capability in this area.

Pertinent here are the circumstances that a) all those pulsars with prominent “drifting” subpulses are best observed below 300 MHz, and most are still bright at frequencies below 100 MHz. We do not understand *why* this is true, but observationally the pattern is very clear. b) Of the half-dozen most promising such stars, only 0943+10 lies in that part of the sky accessible to the Arecibo in-

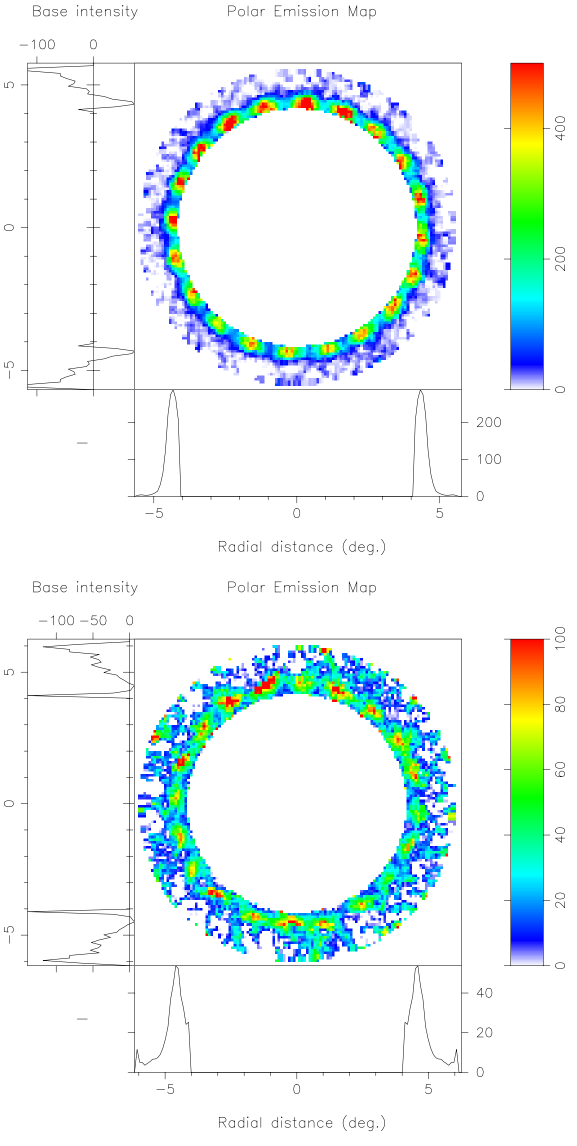

Figure C.1, 1—Images of Pulsar 0943+10’s sybbeam structure computed from 1992 Pushchino observations at 103 and 40 MHz, respectively (Suleymanova 2000). Note the system of 20 emission centers which rotate around the star’s magnetic axis in about 41 seconds or 37 pulse periods. The subbeam pattern, emitted at heights of perhaps 100 km above the stellar surface, is mapped down along the dipolar field line to the polar cap. Here, the pattern has a radius of some 150m and the emission cells a radius of some 10m and a spacing of some 25 m strument, and c) many factors, observational, analytical and physical, point to the desirability of simultaneous observations at two or more bands—for instance, to compare the beam structure at what are probably two different height in the pulsar's polar emission zone. Emission-beam maps from such a pair of simultaneous observations at Pushchino are shown in Fig. C.1.1, which have been compensated for the dispersion delay between 103 and 40 MHz, so the two figures display the pattern in the same orientation. In this case, the patterns are quite similar, but in others they are not.

Recent work in progress (Suleymanova et al. 2000) demonstrates that the Pushchino instruments are exceedingly important to this overall effort to observe circulating subpulse beams and to understand them physically. Pulse-sequence observations of pulsars 0320+39, 0809+74, 0950+10 as well as dual-band one of 0943+10 at different epochs have already proven Pushchino's value.

We thus propose to intensify collaboration with Dr. S.A. Suleymanova and her colleagues, to make further and better such observations on those pulsars with highly periodic subpulse modulation: B0031-07, 0320+39, 0818-13, 0820+02, 0809+74, 0834+06, 0943+10, 1612+07, etc. If all Pushchino ever did was to make long-duration observations and dual frequency observations on 0943+10, it would be well worth the effort, but we believe that it will very likely be Pushchino observations which provide the clues essential to discerning the physically important subbeam-circulation time for other pulsars. To these ends, the proposed equipment would provide more sensitive and reliable decameter observations by something like a factor of 5-10—more usable bandwidth, a greatly improved ability to reject interference, and more accurate dedispersion—as well as a much better facility for measuring the linear polarization, which is also of great importance to this work. The other planned enhancements to the Pushchino instruments would also facilitate our effort—the multi-beam system on the BSA giving longer tracking, and the receiver amplifier improvements on the DKR-1000, which would make it both more sensitive and less prone to interference.

"Spectra of Mean Pulse-Profile Components"

A principal characteristic of pulsar radiation is its spectral dependence. Pushchino has specialized in the determination of pulsar spectra since shortly after the pulsar discovery in 1968, both making and compiling (high frequency) observations from other instruments and carrying out the difficult decameter ones at home. Reliable flux-density estimates over a wide frequency range are thus now available for 336 pulsars (Malofeev & Malov 1980; Malofeev et al. 1994; Malofeev 1999). All of these spectra, however, apply to the overall pulsar profiles, and there are several reasons to believe that the spectra of individual pulse components are more physically significant. The form of a pulsar's spectrum must be related to the emission mechanism, since the emissivity depends on physical conditions in the magnetosphere—namely on the magnetic field strength and the density and γs of relativistic particles. Thus, understanding the formation of the RF spectrum is closely related to understanding the emission physics. Many emission theories (Benford & Buschauer 1977; Melrose 1978; Michel 1978 as well as Ruderman & Sutherland 1975) address the emission spectra directly, and none can presently be reconciled with the observed correlation between the form of a pulsar's spectrum and its rotation period. Some of the more elaborate models are based on coherent curvature radiation (Ochelkov & Usov, 1984; Malov, 1979). Beskin et al. (1988), for example predicted three different types of spectra. Kazbegi et al. (1992), suggested of plasma-theory mechanism to explain the complex profiles of pulsars. Pulsar mean profiles usually have from one to five components. We know that polarization, intensity fluctuations, mode changing, and drifting correlate with the component structure of a pulsar's profile. The PI (Rankin (1983 a,b; 86; 90a,b; 93) developed an empirical classification of pulsars and identified two distinct mechanisms of emission (core and cone) as well as several different types of cones ("inner" and "outer"). Unsuccessful attempts to explain all pulsar spectra with one mechanism (*e.g.*, Malofeev et al., 1994) provide strong impetus to study the spectra of individual components. The several components, with their different spectra do largely explain a profile's frequency evolution, so the overall spectrum must only be a weighed average. Core and conal components in a given profile usually have markedly different spectra; however, Lyne & Manchester (1988) suggested that the observations are best described by gradual changes in emission characteristics from the near the magnetic axis to the periphery of the cone. In order to clarify all of these possibilities, we must investigate the individual component spectra for a significant sample of pulsars. Only a few such studies have ever been carried out, those on PSRs 1133+16 (Bartel et al., 1978), 1237+25 (Bartel et al. 1982), 1822-09 (Gil et al., 1993), and 1451–68 (Wu et al. 1998).

I therefore propose to collaborate with Dr. Valerij Malofeev and his colleagues at Pushchino in such a study. Most of the spectral data on pulsars in the world is in Malofeev's possession; he and his colleagues have measured flux densities for many pulsars themselves, using the Bonn and Jodrell telescopes at higher frequencies and Pushchino around and below 100 MHz, and he has collected a great many such observations from others as well. Clearly, further such lower frequency measurements can be carried out by his group to complement those at higher frequencies. Together, we have carried out a pilot project on pulsar 1451–68 (Wu et al. 1998) in which the this pulsar's five components were fitted by Gaussians and their spectra separately computed from the overall spectrum. Since this time, the techniques of Gaussian fitting have advanced considerably through the work of Kramer (1994) and Kramer et al. (1994), and we would now have the benefit both of Kramer's advice and computer codes.

We propose to make new observations of about 100 pulsars at 111 MHz at Pushchino and a few dozen pulsars in Arecibo at 2700 MHz and higher frequencies in order to obtain a more reliable sample of spectra. Observations of a few pulsars would continue at 111 MHz in order to resolve the size of the pulsar magnetosphere using interstellar scintillation (Smirnova et al. 1995), so that these sizes could be compared with the components of the mean profiles. Overall, we would collect all published mean pulse profiles, and then use this catalog together with the catalogue of mean spectral data to construct the individual component spectra of as many pulsars as possible. On this basis, we would carry out a thorough analysis of the results in order to see what spectral dependencies are characteristic of the five known classes of pulsars. Much of the work has already been carried out for this project; many spectra and profiles have already been catalogued. What remains to do is a) a systematic collation of these data and a modest program of new observations to enhance it, b) computation of individual component spectra for a large sample of some 50–70 pulsars, c) a thorough statistical analysis of the resulting component spectra, and d) physical interpretation of the results. The observational part of this project at Pushchino could be carried out with the existing equipment, but would be greatly facilitated and improved both by the new data acquisition system and by the planned improvements to both the BSA and DKR-100 instruments.

"'Radius-to-frequency Mapping' and the Spectral Behavior of Pulsars with 'Classic' Conal Double Profiles"

Pulsars with "classic" double profiles—B0525+21 and 1133+16, for instance, which also grow in width at lower frequencies—have suggested by their beauty and symmetry that pulsar emission is associated with a magnetic dipolar-field structure and that lower frequencies are emitted at greater heights in their magnetospheres. Closely associated with this idea is that field-line curvature provides the basic charge acceleration responsible for their emission. Various efforts have been made to assess these assumptions. In an influential paper, Thorsett (1991) found that the frequency separation of conal component pairs could not be fitted with two power laws, but required continuous curve. Strangely, little effort has been made to follow the full consequences of these assumptions and then assess the results. It is not quite possible to work out the emission geometry of most such pulsars with reasonable confidence (Rankin 1993a) and, on this basis, begin to inquire whether the type and amount of so-called "radius-to-frequency" mapping with compatible with model predictions. The PI has begun working on such an assessment with her colleague Dr. Dipanjan Mitra. However, any such analysis and interpretation depends crucially on the quality of the lowest frequency observations which are available (or possibly available) for a given pulsar under study.

Therefore, Pushchino again comes prominently into the picture. A recent study by Dr. S.A. Suleymanova (2000) on B0329+54 demonstrates how much difficult 85-MHz observations contribute when 103/111-MHz ones were widely available!. We therefore propose to collaborate with Dr. S.A Suleymanova and her colleagues in this work in any effort to achieve detections on a selected group of particular conal double pulsars at the lowest possible frequencies, so that the frequency evolution of their emission height and conal width can be assessed as sensitively as possible.

C.2 Proposal by Prof. Donald C. Backer, UC Berkeley

“Interstellar Plasma Weather”

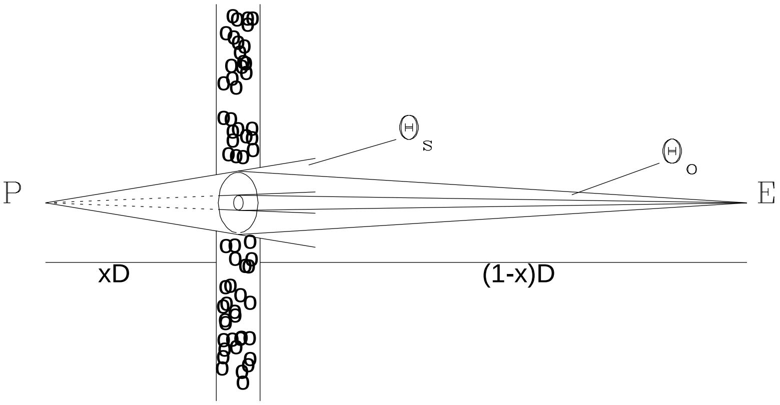

Figure C.2 1—Geometry of interstellar scattering with the pulsar at P and the observer at E. The inner cone corresponds to scattering at a high radio frequency and the outer to scattering at low frequency

Turbulence, or turbulent-like structures, in the interstellar medium when combined with motions of the medium and the pulsar-Earth line of sight lead to observable changes in pulse arrival time owing to both dispersion measure changes and multipath propagation (pulse broadening). The amount of multipath propagation itself also changes. In objects within supernova remnants such as the Vela (B0833-45; Backer 1997b, and Crab (B0531+21; see Backer 2000a) pulsars, the column density variations are dominated by structures within the high density material associated with the surrounding supernova remnants and pre-stellar matter. In other pulsars the effects are much smaller and are associated with structures on length scales of $10^{14\text{-}15}$ cm in the general intervening interstellar medium (Backer 1993, and references therein). At frequencies below 100 MHz dispersion variations can be detected in nearby pulsars by routine monitoring at several frequencies (Phillips 1991, 1992b). This provides a unique probe of the local interstellar medium which is the focus of many parallel studies (Phillips 1992a, Bhat 1998, Toscano 1999b). In the presence of scattering the effective dispersion measure at a given frequency is averaged over the volume of plasma set by multipath propagation (Backer 1997b). The effective dispersion measure then varies with radio frequency owing to the frequency dependence of scattering. Multi-frequency monitoring thus allows one a crude level of “imaging'” of the column density variations.

We illustrate this for one example—PSR B1937+21. Consider a slab of turbulent plasma along the line of sight as shown in Figure C.2.1. A plane wave incident upon this slab will be scattered by the phase fluctuations into a cone of dimension $\Theta_s = \lambda/l_o$. This scattering angle is a property of the slab independent of its location. The apparent size of a point source seen through the slab is $\Theta_o = x\Theta_s \propto \nu^2$. The observable image broadening effect of scattering by the slab Θ_o decreases as the slab is moved toward the emitter. The angular scattering results in multipath propagation and therefore a broadening of sharp impulses sent through the slab. The broadening time is $\tau_s = x(1-x)D\Theta_s{}^2/2c \propto \nu^4$. A further effect of that scattering is that the region of the slab through which radiation is received has a transverse scale of $l_d = x(1-x)\Theta_s D$. ⊥

One cannot measure *the* dispersion measure along a single sight line as a function of time *DM* (*T*). What one measures is a *smoothed*, or effective, dispersion measure, $<DM\ (T)>_\nu$, where the ν-dependence arises via the ν-dependence of Θ_s. In the case illustrated in Figure C.2.1, the smoothing time scale is $l_d/(1-x)v_\perp = x\backslash\Theta_s/v_\perp$, where $v_\perp$ is the perpendicular motion of the sight line with respect to the plasma screen.

At NRAO Green Bank, Backer & Wong (1997) conducted a precision timing program with PSR B1937+21 at four radio frequencies: 327, 610, 800 & 1395 MHz. Figure C.2.2 displays the timing residuals from a model fit to the 1395-MHz data. The figure also displays the 610-MHz residuals from the same timing model. These residuals are larger as expected from the radio frequency dependence of the dispersion. The dotted lines in Figure C.2.2 follow the 800-MHz data with scaling by the ratio of $(1/610^2\text{-}1/1395^2)/(1/800^2\text{-}1/1395^2)$ to show what the effects of dispersion would be, assuming that the 800-MHz residuals are dispersive. There is good agreement through about MJD 50120 (1996 February 7). After this date there appear to be several swings of the 610-MHz residuals above and below the dispersive extrapolation. Inspection of other data from this telescope show no evidence for equipment problems. In particular, the residuals for PSR J0437-4715 in the interval since MJD 50228 are smaller than that shown in Figure C.2.2. Moreover, there is evidence in the 327-MHz data (not shown) for events with different temporal behavior associated with the abrupt changes in the 610-MHz residuals shown in Figure C.2.2. Cognard et al. report sudden changes in the propagation effects of B1937+21 which they conclude are the result of crossing a caustic; see also Lestrade (98).

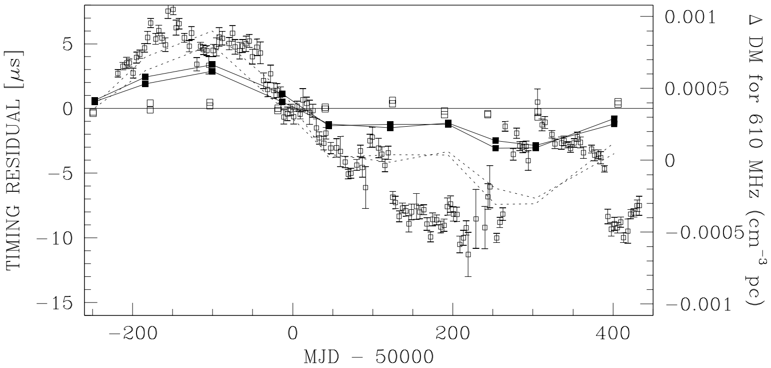

Figure C.2.2—Dispersion measure variations for PSR B1937+21 from the Green-Bank Pulsar-Monitoring Telescope and the 140-ft Telescope. Open squares are 1395-MHz data; solid squares are 800-MHz data and densely sampled open squares with error bars are 610-MHz data. A model is fit to the 1395-MHz points to produce near zero residuals. The deviations of the 800-MHz data from zero are interpreted as dispersive and dashed lines represent how this dispersive delay would scale to 610 MHz. There is an arbitrary zero for the three sets of residuals, and some uncertainty surrounds the continuity of the 610-MHz residuals at MJD 50228, owing to equipment changes.

The effects of angular scattering are the most likely explanation for the lack of agreement of the four frequency data with a simple model of variable, inverse square-law plasma dispersion. The disagreement between frequencies will be most evident on the refractive time scale, the time scale for the averaging volume to displace itself. At 610 MHz we estimate that the refractive time scale is some 40 days, consistent with what we have observed.

Scintillation of pulsar signals is the result of interference in multi-path propagation. The characteristic length scale sample is, as defined in previous paragraphs, l_o, $10^{10\text{-}12}$ cm. Models of the cascade of MHD turbulence suggest that the spatial structure of these density perturbations is highly anisotropic: the scale length perpendicular to the magnetic field is much smaller than that parallel to the field (Goldreich 1997). One may be able to detect the signature of this anisotropy by monitoring the diffractive time scale of pulsars throughout the year (Backer 2000b, Chandran 2000). In favorable cases of low pulsar motion, the time scale depends on the ratio of the diffraction pattern scale, l_o, to the transverse motion of observer. The diffraction pattern will be anisotropic, $l_x \neq l_y$ and the motion of the Earth around the Sun can allow us to sample this anisotropy. Low frequency observations are excellent, owing to the short time scale of scintillation that allows a statistically significant measurements with a modest amount of observations.

We propose to collaborate with our Pushchino colleagues in carrying our observations designed to detect this anisotropy in the diffraction pattern. Presently, scintillation observations are best carried out using the DKR-1000 instrument, but the planned multibeam tracking system for the BSA will make useful scintillation observations possible on the BSA as well. In both cases, the proposed data-acquisition equipment would improve existing facilities for sampling a relatively wide band and culling interference in both the time and frequency planes. We would expect to collaborate particularly with Drs. Shishov and Smirnova as well as some of their other colleagues.

Pulsar timing observations, likes the ones shown in Fig. C.2.2 provide another useful approach to these questions, and Pushchino’s long experience in carrying out timing observations at low frequency is of relevance here. Methods have been developed in the last several years even for detecting and timing the lower DM millisecond pulsars (Kuz’min 1999; Shabanova 1999), and the possibility of simultaneous observations at multiple low frequencies using Pushchino instruments —as well as simultaneous observations between the Pushchino telescopes and higher frequency instruments elsewhere—makes such measurements over a very wide range of spectrum possible. In this work we would expect to collaborate with Dr. Shabanova and her colleagues, and all of the requested equipment as well as the instrumental enhancements to the Pushchino instruments would facilitate our program of timing observations to answer the questions we have discussed above.

C.3 Proposal by Dr. Ramesh Bhat, Arecibo Observatory

“Low Frequency Pulse Broadening Measurements: Investigation of Interstellar Electron Density and Structure of the Local Interstellar Medium”

Pulsars show a variety of observable effects due to Interstellar Scattering (ISS), such as temporal broadening of pulse profile, angular broadening and scintillation of pulse intensity in time and frequency. Measurements of these effects provide important inputs for developing the models for the distribution of free electrons in the Galaxy. Such models are essential for understanding the physics of the Interstellar Medium (ISM) as well as several aspects of pulsars (population studies, for example). The current model by Taylor & Cordes (1993), while sophisticated compared to its predecessors, needs substantial refinements, particularly towards the inner Galaxy and outside of the Galactic plane.

While moderately scattered and bright pulsars allow ISS studies via dynamic spectra, fainter and heavily scattered ones are best studied by quantifying the lengthening and distortion of their pulse profiles which results from multi-path scattering. Measurements of the pulse-broadening times exist for only about 170 of the ~1250 known pulsars. This deficiency motivated us to undertake a project at Arecibo Observatory, whereby many distant, presumably heavily scattered pulsars visible in the Arecibo sky, including the new discoveries from the ongoing Parkes multibeam survey, are studied for their pulse broadening effects at frequencies in the range 430–1400 MHz. Here we propose extensive pulse broadening measurements of a large number of low dispersion measure (DM < 100) pulsars using the Pushchino 102-MHz BSA telescope, which in conjunction with dynamic spectral studies, will provide an excellent data set complementary to that now being obtained at Arecibo. This will facilitate a better modeling of the distribution of the Galactic electron density in general, and that in the Local Interstellar Medium (LISM) in particular.

Much progress has been made in recent years in understanding the structure of the LISM; a large body of X-ray and UV data reveal the existence of several large-scale features in the LISM. In particular, prominent features such as the Local Bubble, the low-density, X-ray-emitting cavity surrounding the Solar system, and the Loop I Bubble (also known as the North Polar Spur) have been of considerable interest to many observers and theorists (c.f., Breitschwerdt et al. 1998). Investigations based on new pulsar scintillation measurements from the Ooty Radio Telescope (ORT) and the Parkes 64-m telescope have led to interesting results pertaining to the distribution of scattering plasma in and around these local features. Specifically, observations show anomalous scattering towards many nearby pulsars, which can be understood if large concentrations of turbulent plasma are present near the edges of these features. The low frequency pulse broadening data from Pushchino will be very promising for further detailed study of LISM's structure, specifically, we intend to probe the interaction zones of the Local Bubble with other nearby bubbles.

The proposed study, in conjunction with similar studies at shorter wavelengths using the Arecibo instrument and other large telescopes (the GBT, for example), will enable us to revisit the scaling of pulse broadening times with radio frequency. Evidence for a much weaker scaling has been seen in recent low frequency studies from Pushchino Observatory (Kuz’min 2000). In their recent work, Cordes & Lazio (2000) address the influence of anomalous scattering by filamentary structures on the shape of the scattered pulse and discuss possible departures of the pulse broadening time from the expected $\lambda^{4.4}$ scaling. Further, Pushchino observations, along with data from ongoing projects at Arecibo, will significantly improve upon the available pulse broadening data, and this will let us examine the relevance of a large inner scale for the plasma turbulence process in the ISM.

These observations, initially on the BSA would benefit from the longer integrations times possible with the planned multibeam tracing system. Their signal-to-noise ratio and reliability (in regard to interference corruption) would be enhanced by the proposed new data-acquisition system for use with the BSA.

C.4 Proposal by Prof. Carl Gwinn, UC Santa Barbara—

“Paradoxical Scintillation: Large Deviations from Expected Scaling at Low Frequencies”

Low-frequency observations will help to understand spectral variations of radio emission from pulsars. In such studies, differentiating between intrinsic spectral properties, arising from the emission mechanism, and extrinsic spectral variations, imposed by interstellar propagation, is essential. Observations at low frequencies are essential to discriminating between these effects, because intrinsic spectral properties are expected to be most pronounced and easily observable at meter and longer wavelengths, and because scintillation has a known spectral signature that a sufficiently wide range of frequencies can trace. In particular, we expect the decorrelation bandwidth of scintillations, $\Delta\nu$, to scale with observing frequency ν as $\Delta\nu \approx \nu^{4 \text{ to } 4.4}$.

Pulsars radiate at meter wavelengths by coherent radiation from groups of particles, moving in phase. (In order to radiate with observed brightness temperatures incoherently, energies of the electrons would have to exceed 10^{26} eV, much greater than that produced by any known mechanism.) Their radio emission is broadband, with average spectra that change significantly only with changes of order unity in observing frequency. This broadband, coherent emission stands in contrast to laboratory plasmas, where most coherent emission processes result in radiation with relatively narrow bandwidths (see, for example, Kruer 1988). Theories of pulsar emission can produce the observed wide-bandwidth emission by superposing many narrow-band emitters (see, for example, Lyutikov 2000), by lifetimes of only a few oscillation periods for the coherently-radiating clumps of electrons (Weatherall 98) or by amplifying an externally-imposed noiselike broadband spectrum.

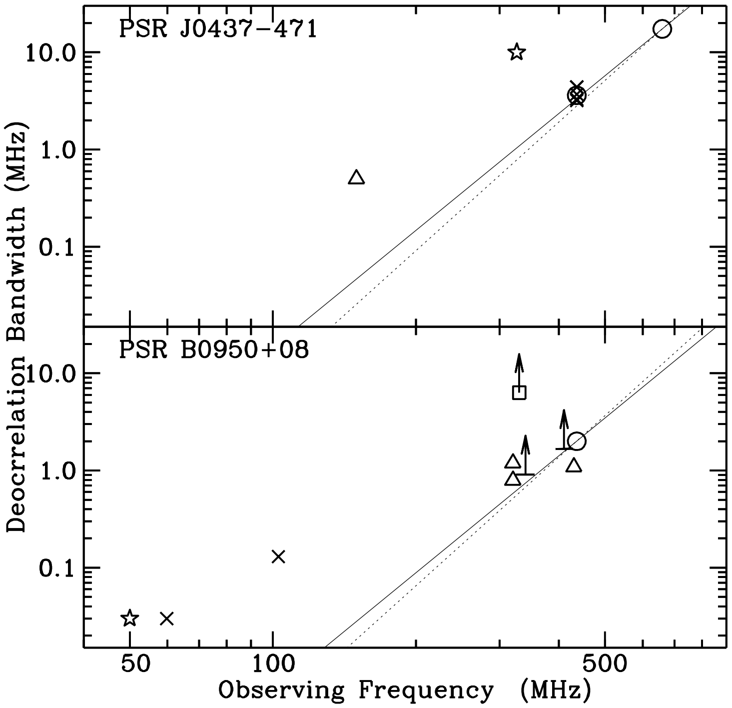

Figure C.4, 1—Measurements of decorrelation bandwidth *vs.* observing frequency, for 2 strong nearby pulsars. Upper panel: PSR J0437–471. Circles: Nicastro & Johnston 1995, crosses: Johnston et al. 1998, star: Hirano & Gwinn 2000, triangle: Deshpande 2000. Solid line shows the expected scaling of decorrelation bandwidth $\Delta\nu \approx \nu^{4.4}$, where ν is observing frequency; dotted line shows $\Delta\nu \approx \nu^{4}$. Lower panel: 0950+08. Bars: lower limits from Armstrong & Rickett (1981), box: lower limit of Roberts & Ables (1982), triangles: Cordes, et al. (1985), crosses: Smirnova & Shabanova (1992), star: Phillips & Clegg (1992).

Observationally, pulsar emission is usually regarded as indistinguishable from amplitude-modulated white noise (Rickett 1975). Some interesting and important exceptions stand out. Notably, the low-dispersion measure pulsar B0950+08 has been reported to show quite complicated spectral structure at frequencies near 300 MHz (Roberts & Ables 1982). They concluded that this structure was not caused by scintillation because of its large variability over short times and its unusual frequency structure. Several other groups have reported bandwidths of 1 or 2 MHz, or similar lower limits, near 300 MHz. Phillips & Clegg (1992) found that the pulsar has a scintillation bandwidth of 30 kHz at an observing frequency of 50 MHz, so that it should be in weak scintillation at 300 MHz. Smirnova & Shabanova (1992) report simultaneous observations of this pulsar at 60 and 103 MHz. They find narrow-bandwidth fluctuations similar to scintillations. However, they noted that the spectra were different for different pulse components, and found a scaling of decorrelation bandwidth with frequency of $\Delta\nu \approx \nu^{2.7}$. These are inconsistent with interstellar scintillation.

Pulsar J0437–471 also shows paradoxical scintillation properties. Nicastro & Johnston (1995) and Johnston et al. (1998) report a scintillation bandwidth of 3.6 MHz at an observing frequency of 430 MHz, and expected scaling to 660 MHz, at 15 epochs over 4 years. More recently, C. Hirano & C. Gwinn have observed pulsar J0437–471 at 330 MHz at 2 epochs, and found that its decorrelation bandwidth is about 10 MHz, inconsistent with the expected scaling. Deshpande (2000) found a decorrelation bandwidth of 0.5 MHz for this using the Mauritius Radio Telescope at a frequency of 150 MHz. Figure 1 summarizes the measurements of $\Delta\nu$ for these 2 pulsars. These measurements cannot be reconciled with the theoretically-expected $\Delta\nu \approx \nu^{4 \text{ to } 4.4}$ scaling.

Although the apparent discrepancies among the measurements might be caused by orders-of-magnitude variations of the strength of scintillation over months or years, this would require the existence of quite strong and extremely localized (<100 AU) regions of scattering. Alternatively, some of the spectral variations might be arise from intrinsic spectral variations of pulsar emission, perhaps reflecting the bandwidth of maser amplification in the pulsar magnetosphere (Lyutikov et al. 2000). Scattering of radiation within the magnetosphere is expected to produce the scaling $\Delta\nu \approx \nu^0$ (Lyutikov & Parikh 2000); a combination of magnetospheric and interstellar scattering could easily match the observations. All of these possibilities are exciting, and suggest that the surprising scaling represents a completely new phenomenon.

Contemporaneous observations at low, multiple frequencies are required to determine the source of the paradoxical scintillation. These observations would be most valuable if repeated at regular intervals. Comparisons among spectra from different phases of the pulsar pulse would be most important, because it offers the possibility of distinguishing between intrinsic spectral variations (which might change synchronously with pulse phase) and extrinsic effects (which cannot). The Pushchino Radio Telescope offers all these capabilities. We propose observations of strong, nearby pulsars at low frequencies with the Pushchino Radio Astronomy Observatory to study the spectra of pulsar emission. It has the capability of observations at multiple, low frequencies; it can record scintillation spectra; and it is capable of comparing scintillation spectra at different pulse phases. Among the pulsars we wish to study are B0950+08, B0834+06, B1133+16, B1237+25, and B1919+21. We anticipate that T. Smirnova will play an essential role in these observations, because of her experience with similar observations in the past. Indeed, Smirnova et al. (1996) report variations in dynamic spectra between pulse phases, which they interpret as changes in the position of the pulsar's emission region between pulse phases. An alternative explanation, which we propose to investigate, would be that the pulsars have intrinsic spectral variations, which vary between pulse phases.

The primary goal of the proposed observation is to determine how interstellar scintillation and intrinsic effects contribute to the observed frequency variations. The signatures of interstellar scintillation are its characteristic $\Delta\nu \approx \nu^{4 \text{ to } 4.4}$ scaling with frequency, its consistency with pulse phase, and its exponential probability distribution (Gwinn et al. 1998). Intrinsic spectral variations are expected to show other scalings or distribution functions, and may vary with pulse phase. To obtain the broadest measure of decorrelation bandwidth, we will propose contemporaneous observations at higher frequencies at other observatories.

These proposed observations entail use of both the BSA array and the DKR-100 telescope, often simultaneously. They would benefit greatly from the planned enhancement of tracking time of the BSA and better receivers for the latter instrument. They would also benefit greatly from the proposed enhancements in the data-acquisition facilities of both instruments and require enhanced disk and tape storage systems. Optimum sensitivity and more effective means of RFI abatement will contribute significantly to the scientific utility of this project. The Budget provides funding for one exchange in either direction as well as subsistence for Russian colleagues while in the US.

C.5 Proposal by Prof. Timothy Hankins, NM Tech & VLA

“Multifrequency Studies of Micropulses in Pulsar Radio Emission as Probes of Neutron Star Magnetospheres”

During each rotation of a pulsar, a narrow beam of radio radiation is emitted, which we can detect as a period string of pulses. The radio pulses appear instantaneously so “bright” that the emission mechanism must involve the organized, coherent motion of the radiating plasma particles. A number of physical mechanisms have been proposed to produce the radiation, and the refinement of these theories is an active area of current plasma physics research in the FSU, USA, France, Japan, and Australia. In general the mechanisms may be classified into three groups: emission by charge “bunches”, plasma instabilities, and maser emission, as summarized and compared by Melrose (1992). There are also several theoretical predictions for the generation of ultra short time scale intensity fluctuations; the theories are based on nonlinear temporal models describing the interaction of a high energy beam of particles and plasma wave packets in the pulsar magnetosphere (Asseo et al. 1990; Weatherall 1998). Key tests of these mechanisms are the instantaneous time duration and bandwidth of the basic emitting entities.

Propagation through the interstellar medium of pulsar radio signals distorts the signals due to the dispersion of the radio signals by the tenuous plasma of interstellar electrons. “Coherent dispersion removal” pioneered by Hankins (1971) and developed in the FSU by Popov & his group in the 1970s, involves direct recording of the received signal *voltage* and subsequent off-line processing by computer software to remove dispersion distortion. Although the method is computationally intensive, it can achieve time resolution limited only by the maximum bandwidth that it is practical to sample, and in principle, allows perfect compen sation for all deterministic propagation, instrumental, and systematic effects. We will use this approach in our new studies.

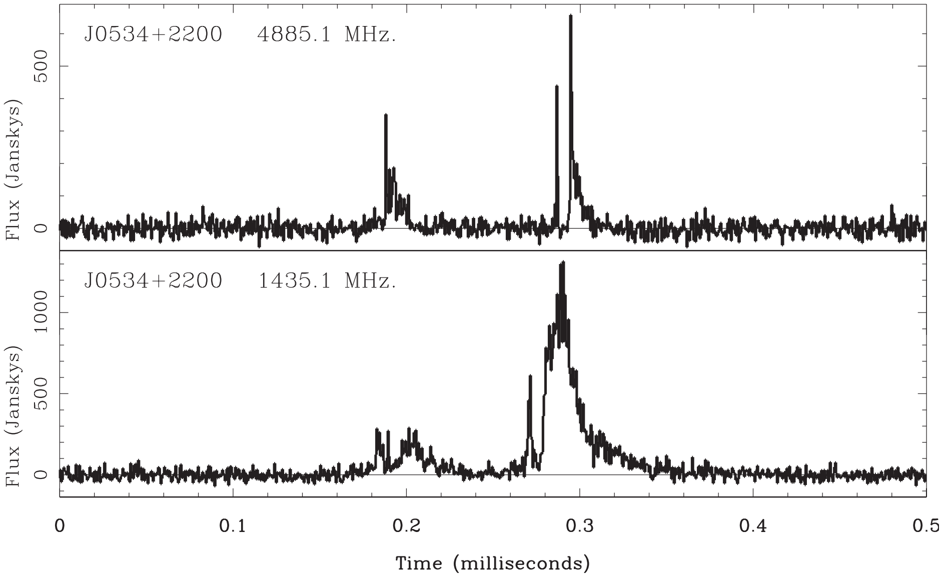

Figure C.5.1—A single “Giant” pulse from the Crab Nebula pulsar, observed simultaneously at two frequencies using the VLA. The time resolution is about 20 nanosecs.

The general properties of microstructure were determined by microsecond time resolution observations in the 1970s. However, the early microstructure studies did not distinguish between “core” and “conal” regions of the pulses. We may expect to see different time signatures at high resolution for core and conal emission regions of pulse phase.

The “giant” pulses from the Crab Nebula pulsar are intrinsically very short; Moffett & Hankins (1996) recently found pulse structure as short as 10 nanoseconds and peak fluxes over 10000 Jy using the coherent dedispersion technique. If we interpret the pulse duration in terms of the maximum possible size of an emitting region, 10 ns corresponds to an emitting body of only 3 m in size, by *far the smallest entity ever detected outside our solar system.* The giant pulses are so strong that they are easy to identify over a broad range of frequency. Their bandwidth can be a strong test of the current emission theories. Several studies (Sallmen et al. 1999;Hankins & Weatherall 1998) have shown that the giant pulses have a bandwidth of at least 3:1 in frequency; we propose to make this test even more strenuous by extending the bandwidth measurements over a much greater frequency range.

We propose two observing programs: We will conduct simultaneously in the USA and Russia multifrequency measurements of micropulses for several bright pulsars with submicrosecond time resolution. Since no radio observatory is equipped to observe simultaneously at more than a single frequency, we must use two or more observatories to obtain the data required for our hypothesis testing. We will observe several bright pulsars with low dispersion measure to reduce influence of the scattering of radio waves on the inhomogenities of interstellar plasma. The pulsars B0809+74, B0950+08, B1133+16, B1237+25, and B1929+10 meet these criteria. Furthermore, they are representative of conal emission (all five are thought to have conal components; B1237+25 and B1929+10 also have core emission.). By measuring micropulse intensities, polarization and accurate arrival times simultaneously at several frequencies we will accomplish the following: a) We will be able to formulate strong constraints on the localization of the emitting regions in the magnetosphere of a neutron star (through retardation and abberation effects; see Cordes 1978 and Kardashev et al. 1982), b) We will be able to evaluate important local physical conditions by looking for magnetospheric propagation effects (*e.g.,* cyclotron resonance, refraction by the intrinsic plasma, depolarization). c) We will be able to distinguish between the ``antenna'' and ``maser'' mechanisms of coherent radio emission by measuring the instantaneous radio spectrum of individual micropulses and by comparing statistical properties of micropulses with the amplitude modulated noise model (Rickett 1975; Cordes 1976a,b; Moffett & Hankins 1996). d) We will test for statistical differences in the high time resolution intensity fluctuations in the core and conal regions of these pulsars. 2. We will extend the test of the emission bandwidth the Crab pulsar “giant” pulses to a ratio of 40:1.

We will achieve this objective in two steps: a) We will coordinate a multinational simultaneous set of observations of the Crab giant pulses which will include the Very Large Array and Arecibo Observatories (USA), the Kalyazin telescope (Russia), the Westerbork Radio Synthesis Telescope (Netherlands), the Effelsberg 100-m telescope (Germany), and the radio telescope at Jodrell Bank (UK). In addition to shedding light on the emission bandwidth, they will allow precision measurements of the dispersion and scattering in the ISM. b) We will use the unique low-frequency (111 MHz) capability of the BSA in Pushchino, Russia, simultaneously with 5 GHz at the Green Bank 100-meter radio telescope, (when it becomes available) to extend the low-frequency range of the bandwidth tests.

We will have acquired and analyzed simultaneous high-time resolution data with which we should be able to constrain the range of emission mechanisms. Our simultaneous multifrequency measurements should allow us to put strong limits on the bandwidth of the emission mechanism and possible frequency-dependent changes in rotational phase of micropulses. The multinational effort on the Crab pulsar will comprise the best ever data set for analysis of the “giant” pulse phenomenon. We will have determined whether the “core” and “conal” components of pulsar emission require separate theoretical or environmental explanations. A byproduct of our observations will be precision pulse-intensity and polarization profiles. These data, combined with the individual pulse sequences, offer the best diagnostics for mapping the polar cap magnetic field and thus limiting the possible range of physical parameters related to the coherent emission process environment.

A large volume of digital data must be recorded and transferred between Pushchino, Kalyazin, the ASC, and NMIMT to make possible the comparison of micropulses observed by Russian and USA scientists. We will exchange preliminary data directly *via* the Internet, but for production data analysis we will use CDs and Exabyte tapes for exchange. Again the requested Exabyte Ultra 160 tape systems will provide the needed recording, storage and transport facility. We anticipate acquiring at least two of these systems for use at the VLA and at NMIMT (with the costs defrayed by another research grant), so that a convenient overall compatibility will be achieved.

This project requires face-to-face planning and coordination to proceed smoothly. Hankins would thus go to Moscow at least once and Popov to the VLA. If other international telescopes can be scheduled for the observations, detailed planning must be carried to ensure that the various observations, even if successful, are conveniently compatible for analysis.

C.6 Proposal by Dr. Mark McKinnon, NRAO Green Bank

“The Polarization and Bifurcation of Conal Single Pulsars”

The pulse profiles of conal single, or type **S**$_d$, pulsars typically have a broad, single component at high radio frequency which bifurcates into two components at low frequency (Rankin 1983, 1990). The profile bifurcation typically occurs at low radio frequency (about 100 MHz). The broadening and subsequent bifurcation of these pulse profiles have generally been attributed to a radius-to-frequency mapping (RFM). The frequency of the radio emission is supposedly related to the local plasma frequency at a given height in the magnetospheric emission region above the stellar surface. Since the particle density, and thus the plasma frequency, decreases with increasing altitude the radio emission at high frequency originates near the stellar surface and the low frequency emission originates much higher. The radio emission at a given height is thought to originate on preferentially-curved dipolar magnetic field lines above the pulsar polar cap. Therefore, the pulse profile broadens or bifurcates with increasing emission height (decreasing frequency). The profile bifurcation that is a characteristic signature of type **S**$_d$ pulsars is attributed to a specific viewing geometry where our line of site intersects the edge of the pulsar’s radio beam.

However, Barnard & Arons (1986) have cited observational evidence that suggests RFM may not be operative in pulsar radio emission. The RFM hypothesis predicts time delays between pulses of different radio frequency due to retardation and aberration, but these delays have yet to be observed (Cordes 1978, Cordes & Stinebring 1984, Phillips & Wolszczan 1992). Furthermore, the constant widths of average profiles at high frequency are inconsistent with the proposition that pulsar radio emission is narrow-band over a small range of emission heights (Cordes 1981).

An alternative explanation for the bifurcation of the pulse profiles of type **S**$_d$ pulsars is the bi-refringence of the plasma in the pulsar magnetosphere. The wave propagation modes in a bi-refringent plasma are orthogonally polarized and can be spatially-separated due to their different indices of refraction. A pulsar’s magnetospheric plasma may be bi-refringent because polarization observations of the individual pulses from pulsars show orthogonal transitions in the position angle of the emission’s linear polarization. Theories of radio wave propagation within the dense, relativistic plasma of a pulsar magnetosphere predict that one mode propagates along straight ray paths parallel to the pulsar’s magnetic axis, and that the other mode is spread or “ducted” along the magnetic field lines. If the magnetic field lines are dipolar in shape within the emission region, the bi-refringence of a pulsar’s magnetospheric plasma can cause both a frequency-dependent broadening of the pulse profile due to mode ducting along the magnetic field lines and a depolarization of the emission near the center of the pulse profile due to the overlap of the orthogonally-polarized radiation of the two modes. As with RFM, the bifurcation of profiles that is prevalent in type **S**$_d$ pulsars may be a consequence of the edge-on viewing geometry of the pulsar radio beam. The observations of PSR B0950+08, a prototypical type **S**$_d$ star, at 150 MHz by Schwartz & Morris (1971) are consistent with this interpretation. Furthermore, the observation that type **S**$_d$ pulsars appear to depolarize rapidly at frequencies above that of profile bifurcation (McKinnon 1997) also support this interpretation.

Polarization observations of individual pulses from type **S**$_d$ pulsars at low radio frequency may provide evidence for the pulse broadening mechanism. If differential refraction in the pulsar magnetosphere leads to pulse broadening, one would expect the polarization of a particular mode to dominate the emission on the outer edges of the profile. There would also be significant competition between the modes towards the center of the profile. Single pulse polarization observations at 111 MHz and below with the BSA LPI instrument and the DKR-1000 wide-band cross Radio telescope are ideally suited for such a study. On both instruments it would be necessary to measure the linear polarization using the Faraday-rotation method. This method has been extensively used at Pushchino, and the proposed Pentium processor with the DSP card would provide digital data on which this technique could be carried out more accurately and reliably. The planned increased of tracking time on the BSA and front-end receiver enhancements on the DKR-1000 would also be very useful for this project.

C.7 Proposal by Prof. Barnaby J. Rickett, UC San Diego

“Probe for an Inner Scale in Interstellar Turbulence”

Studies of interstellar scattering and scintillation have revealed a “Kolmogorov” power-law spectrum for the plasma density over at least six and perhaps as many as twelve orders of magnitude in wavenumber (Armstrong et al. 1995). Though the evidence for a truly turbulent process (velocity or magnetic field spectra) does not exist, the density spectrum suggests that the interstellar plasma is turbulent. Attempts to understand the underlying physics are still tentative, but there is a clear need to establish the lower limit to this spectrum—that is, the shortest scale present which defines the inner scale. In turbulence this is the scale at which the turbulent energy is dissipated; a determination of this scale is a major clue in determining the underlying physics. The scale is expected to be in the range 10^5–10^8 m. Weak scintillations at cm-wavelengths can probe scales of 10^7–10^8 m on a few nearby pulsars. The frequency correlation of diffractive scintillation and pulse-broadening are also useful techniques for these small scales; measurements at DM-wavelengths have probed the range 10^6–10^7 m, but meter-wavelengths have the potential to probe scales down to 10^5 m, and this is what is proposed here. Spangler & Gwinn (1990) suggested that the ion inertial length is $\propto$ (plasma density)$^{-0.5}$ as the inner scale. A density of 0.05 cm^{-3} in the warm ionized medium makes this scale 10^6 m. On very heavily scattered paths they were able to use angular broadening to find evidence for inner scales as small as 10^5 m, suggesting larger densities, and more evidence is needed on this interesting physical question. The goal of the proposed project is to estimate this inner scale for several paths in the interstellar plasma, including some with only moderate scattering.

The proposal is to use the large Pushchino BSA array at 102 MHz to record the pulse broadening function caused as signals are scattered by the irregularities in the interstellar plasma. This is a well-known phenomenon, but the form of the broadening function at large delays has never been studied in detail. The theoretical work by Lambert & Rickett (1999) shows that such “scattering tails” are a valuable diagnostic of the high wavenumber region of the density spectrum. The basic idea is that a large time delay comes from waves arriving at large angles, which in turn are caused by high wave numbers in the density spectrum [$\kappa \approx (2\pi/\lambda)(2ct/L)^{1/2}$ for delay t at distance L). The method depends only weakly on the *spatial* distribution of scattering. The goal will be a specific test for

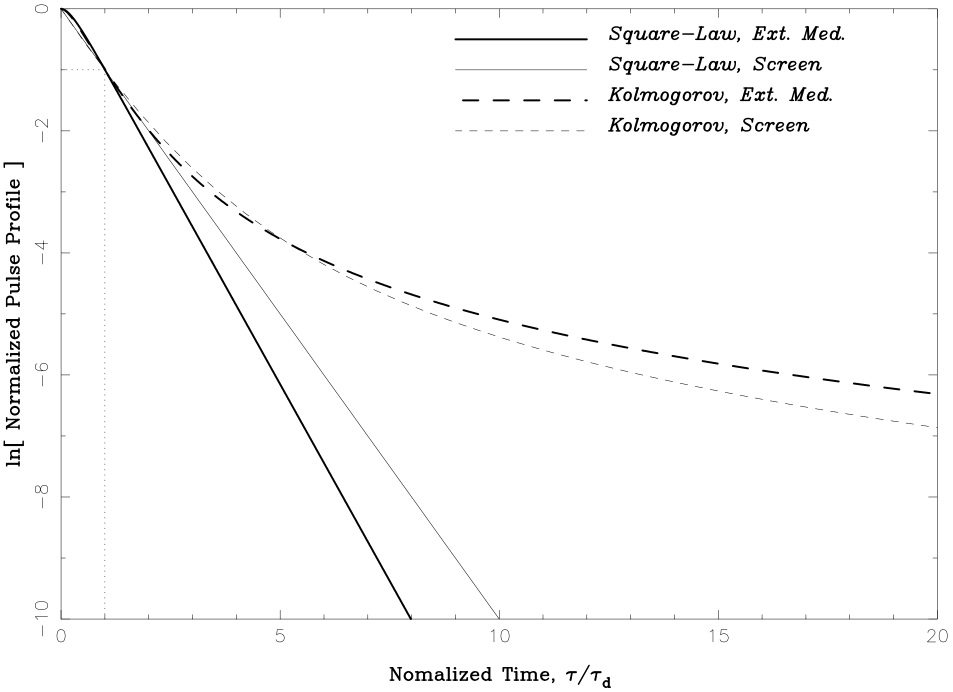

Figure C.6, 1—Normalized pulse shapes for spherical waves propagating in an extended plasma and spherical or plane waves incident on a thin plasma phase screen located between the source and the observer plotted on a ln–linear scale. For the screen geometry, the time variable is such that the shape of the profiles does not depend on its position. The dashed lines are for the simple Kolmogorov spectral model, and the solid lines for the square-law structure function model, which is the extreme of a large inner scale. The thick and thin lines correspond to the screen and extended medium geometries respectively. The dotted line shows the 1/e time, which is scaled to be equal in all four cases.

the inner scales as small as 3×10^5 m.

The method requires average pulse shapes, with peak signal to noise ratios greater than about 400:1 and large enough scattering delays above the intrinsic width. Even though the BSA is very sensitive there are only a few pulsars with a suitable combination of strong flux and sufficient scattering. A calculation of the necessary broadening time, signal to noise, time resolution and bandwidth from the pulsar catalog shows that the following pulsars are the prime candidates: B0136+57, B0355+54, B0540+23, B0611+22, B2111+46, B2154+40, B2217+47.

In looking far out in the scattering tails of highly scattered pulsars, we will need to distinguish the intrinsic profile from the effects of scattering. The key point here is that multi-frequency observations are needed to distinguish scattering from intrinsic beam shape which varies quite slowly with frequency. There are several observers with archives of useful profiles (particularly Tim Hankins), but where needed we will plan new observations at higher frequencies, using Arecibo or the new Green Bank Telescope.

There several are other objects which will be so heavily scattered that the pulse will not decay sufficiently in one period. These will also be of interest to explore the shape near the rising edge of the broadening function. The rising edge depends strongly on the spatial distribution of the scattering plasma and can be used to constrain the spatial distribution (*e.g.*, Rankin & Isaacman 1977). Here the best candidates are pulsars: B0531+21, B0740-28, B1804-08, B1818-04, B1844-04, B1907+10, B1911-04, B1920+21, B1933+16, B2148+64, and B2255+58.

The focus of this project will be collaboration with Drs. V. I. Shishov and T. V. Smirnova. Dr. Shishov’s expertise in the theory of radio scintillation will be critical as will the experimental expertise of Dr. Smirnova, who has already used the BSA to obtain pulsar profiles of the needed high signal-to-noise ratio. Observations will be made of all of the listed pulsars with the twin goals of studying the rising edge to explore the line-of-sight distribution of the scattering plasma and the scattering tail to characterize any high-wavenumber cut-off in the density spectrum. Typically ten days of observations on each pulsar (each transit time of about 3.5 minutes) will be needed to optimize the sensitivity, given the beamwidth, the linear polarization of the antenna and the strong contribution of the background noise at low Galactic latitudes.

The planned multi-beam tracking system for the BSA would be very useful to this project as would be the PC-based Pentium data-acquisition system equipped with the digital-signal-processing card. Even without the new tracking system, the greater bandwidth and interference rejection capabilities of the proposed data-acquisition system would facilitate observations of significantly improved sensitivity and quality. If these observations are successful, then a followup series of observations could be conducted using the DKR-1000 at frequencies below 100 MHz. The planned improvements to its receiver system and a similar PC-based data-acquisition system (again with larger available bandwidth and interference rejection capabilities) would make possible high signal-to-noise ratio observations throughout the decameter band. Two visits for this project over the three-year project duration are included in the Budget as well as per diem and other expenses for Dr. Shishov or Smirnova while in the US.

C.8 Proposal by Dr. Chris Salter, Arecibo Observatory

"Investigation of the Shell of Enhanced Turbulence Surrounding the North Polar Spur"

The North Polar Spur (NPS) is an immense arc of radio continuum emission rising from the Galactic plane near l = 30 deg, and passing close to the north Galactic pole. In addition, it also possesses extensive emission arcs in the 21-cm wavelength line of neutral hydrogen (HI) and in soft X-rays. While all three arcs are concentric, the HI arc lies outside the radio continuum, with the X-ray emission lying interior to both. The favored explanation for the nature of the feature is that it represents a very nearby, very old supernova remnant.

It has long been demonstrated that there is a region with a statistically significant lack of compact radio sources showing interplanetary scintillation (IPS) at 81 MHz forming in a band some 20 deg outside the NPS (Rickard & Cronyn 1979). To investigate the cause of this effect, follow up IPS observations have been made of a complete sample of radio sources down to 1.5 Jy at 408 MHz using the Ooty Radio Telescope (ORT) at 327 MHz. This sample included sources covering the NPS continuum ridge as well as the region of scintillator deficiency found by Rickard & Cronyn, plus a corresponding control sample for regions reflected about the celestial equator and differing from those in the NPS region by -12 hr of right ascension. Initial analysis shows the NPS source samples contain objects that are no less compact at 327 MHz than the control sample, in contrast to the 81-MHz results. The simplest explanation of this effect is that at the lower frequency the sources in the band outside the NPS are scatter broadened by a shell of turbulence lying outside the continuum arc. For any source, such broadening by turbulence is expected to to have a wavelength dependence of $\Delta\theta \propto \lambda^{2.2}$.

In order to extend investigating of this effect via deeper IPS measurements at wavelengths of a few meters, we propose dedicated 102-MHz observations of the full Ooty sample from Pushchino. This would extend the measurements to a much larger sample at this frequency, giving also detailed comparison with the 327-MHz results. We would anticipate analyzing the data via the method of Manoharan & Ananthakrishnan (1990), which yields accurate source sizes on the subarcsecond scale.

In addition, we intend to make observations of the interstellar scintillation properties of pulsars projected against the region defined by the lack of 81-MHz scintillators. A detailed comparison of the scintillation properties of these pulsars with the same properties for pulsars of similar dispersion measures lying outside the region can be expected to yield an accurate distance to the feature that gives rise to the enhanced scintillation. This is especially so given the accuracy now possible in converting pulsar dispersion measures into distance estimates (Taylor & Cordes 1993). Specifically, we plan to make measurements of dynamic spectra and pulse-profile scattering tails at 102 MHz from Pushchino, as well as at shorter wavelengths from Arecibo (see accompanying proposal by Dr. Ramesh Bhat).