May 13, 1988

To: K. Kellermann
From: F. J. Lockman
Subject: The NLSRT: a proposal for a BFD

NLSRT memo No. 1, while ostensibly a neutral "call for discussion", veered off in an unfortunate direction with its reference to the "NRAO tradition" of building telescopes that "do everything for everyone", referring, no doubt, to the 140-foot, the VLA and the VLBA. In this memo I want to invoke the other great NRAO tradition: that of making a quick, decisive move to acquire a new instrument when it would advance our facilities without costing a bundle (by current standards) or requiring a large and potentially devastating operating expense. This tradition has produced the 300-foot telescope, the upgrade of the 36-foot to the 12-meter and, in the same spirit, the HEMPT development effort and the purchase of the first CONVEX computer. I do not have to broaden the category too much to have it also include the development of the Green Bank interferometer and the construction of the 36-foot. These facilities were fairly quick and cheap, and thus could be built along with, *not* in lieu of, other projects. They been wonderfully successful – it is hard to imagine what radio astronomy would be like without them. The extension of the VLA to low frequencies may well be added to this list in the future.

In this spirit I propose that we build a large ($\sim$ 100-meter), offset parabolic reflector with full sky coverage and horizon-to-horizon tracking that would operate only at $\lambda \gtrsim 6$ cm. Let's call this instrument the Big Floppy Dish (**BFD**) to emphasize that it is not an Efflesberg-type telescope, and also because this acronym is certain not to stick. Rick Fisher discusses some technical aspects of a BFD design (including its $\sim$ \$10M cost), and a lot of other important things, in his memo of 7-Dec-1987 which is essential reading and which should be considered the NLSRT Memo No. 0.

There are several "administrative" advantages to a BFD design. First, since it operates at low frequencies, where interference is a problem but the atmosphere is not, the ideal site for the telescope is somewhere in the National Radio Quiet Zone, i.e. at Green Bank. Second, the BFD will do most everything that the 300-foot telescope can do, so there will be no point in maintaining the 300-foot telescope as a general-purpose user instrument. We could continue to operate it for special programs (ones that could be run without an operator, and that did not require frequent equipment changes) but at a very reduced cost. The savings would fund much of the operating expenses of the BFD. At the absolute worst, i.e. if we did not reduce operations of the 300-foot, the new enterprise might cost an additional $\sim$ \$0.5M a year: the cost of telescope operations and maintenance for the 140-foot. This is not a large burden.

To first order, the BFD will be a 300-foot with vastly increased sky coverage and tracking, and with much better sensitivity. This ought to be scientific justification enough. But for the querulous, here are some points to consider:

Sky Coverage. The horizon at GB is at $\delta \sim -50°$; the 140-foot telescope can follow a source for about two hours a day at declination $-47°$. The BFD will thus be able to observe 87% of the **entire** sky! It will be able to study a similar percentage of all galaxies, HII regions, pulsars, globular clusters and OH/IR stars. The galactic center will be above 10° elevation for $> 6^h$ a day. In contrast, the 300-foot covers only 2/3 of the sky, and that with limited tracking. It does not reach the galactic center.

VLBI. The BFD will be a superb addition to the VLBA at cm-wavelengths, and will be essential for observations of weak objects, like pulsars to detect their annual parallax, extragalactic supernovae to follow their expansion, and weak OH masers, to measure their proper motion. The VLBA will need the additional sensitivity of a BFD for these and other problems. The BFD will be able to do VLBI with Arecibo, something that the 300-foot does not often do because of the semi-transit nature of each telescope.

Frequency Coverage. The combination of the Radio Quiet Zone and the low sidelobes of an offset design make the BFD unique for work at frequencies outside of protected bands. This is especially important for redshifted HI, but past experience also indicates that every frequency is likely to be in demand sometime, for something not previously anticipated. Who knows, maybe the BFD will be so good that it will be possible to observe the 1612 MHz OH line again. The BFD will certainly be as interference-resistent as a large filled aperture can be.

Sensitivity. The BFD will have about the same sensitivity to point sources as the VLA.

What great science would this telescope do? Basically, everything that the 300-foot now does, only over more of the sky, and with more sensitivity. Examples include:

HI in Galaxies. It will be the great redshift machine. Even now the 300-foot, with its very limited tracking and only adequate sky coverage, is very much in demand for this work. Observations of extragalactic HI, OH and H_2CO alone justify the BFD.

Galactic HI. As an offset reflector, the BFD would be a unique instrument for galactic HI work. It would have good angular resolution, and not suffer from the stray radiation that contaminates HI spectra from all other large telescopes. This capability will be especially important in the next decade when high quality HI spectra will be needed for the analysis of data from satellites like ROSAT, COBE and AXAF.

Pulsars. The use of pulsars as reference standards, for everything from calibrating clocks, to measuring the gravitational potential in globular clusters, to searching for gravity waves, is great and growing. The BFD will be able to observe > 80% of all galactic pulsars, including those in globular clusters, which are concentrated toward low declinations. With its all-sky coverage, large area, frequency agility, interference resistance and sensitive receivers, the BFD will be the premier telescope worldwide for general pulsar observations.

Zero Spacing Data. The BFD will have an exceptionally clean main beam. It should be useful in supplying zero-spacing data for aperture synthesis telescopes.

How the BFD Fits Into the NLSRT Program. Most of the items in the Scientific Justification section of NLSRT Memo No. 1 have been already discussed. The optimum design of a BFD is treated below. This makes many items in section 3 of Memo 1, *Novel Design Features*, redundant. Very low sidelobe levels follow from off-axis designs. Permanent installation of most frequently used receivers is a fact for the VLA, VLBA, and the 140-foot (for the maser-upconverter systems) and should have little impact on telescope design. The same for focal plane arrays. And our experience both at Green Bank and Soccoro suggests that the issue of remote observing, like the placement of paths on a college campus, will be decided by the users before very long.

The design of the BFD, as noted above, settles the issue of its location, and funding is a problem for administrators, not scientists. Note that the BFD, given its very modest construction and almost negligible operations costs, does not compete with the VLBA or the mm-Array. It hardly competes with the cost of operating the VLBA for a year. Finally, while the BFD may in some sense "replace the aging 300-foot" it is not because of the 300-foot's age. The 300-foot is a lot younger than I am, and is a child compared to the 200-in! The 300-foot will be replaced, or more likely reassigned, because the BFD is a **better**, not just a **younger** instrument.

Final Notes, Design Considerations, etc.. (Much of this will seem obscure if you are not familiar with Rick Fisher's memo.) A telescope with the frequency coverage of a good 25m (0 to 100 GHz) and the effective area of a 100m is a very, very useful instrument. It would certainly help my current research. But I want to argue strenuously against drifting toward a design of that type. (Of course, if some group like NASA or the Soviet Union wants to *give* us an Efflesberg clone we should be ready to receive.) It is probable that the requirement of high surface accuracy and large diameter immediately leads to a > $50M pricetag, with all the problems and delay that implies. It may be too much to ask that a telescope combine a very good surface with a very large surface. At Efflesberg, only the inner portion of the dish is used at the highest frequencies, but they still have to drag the outer, unused portion around, with its contribution to wind loading and cost. Conversely, at low frequencies they don't need the very accurate pointing and surface that must be built in to accommodate high frequency work.

A great increase in cost must come when some large fraction of a surface is required to be solid rather than composed of Sears' best chicken wire. Wind and snow loading become much larger, which requires a stiffer backup structure, stronger bearings, more torque in the motors, and there we are, marching down the path to the 100m. Thus, a good BFD will have a mesh surface and that keeps operations below about 5 GHz.

On the question of offset vs. on-axis parabaloids, however, I come down firmly on the high-tech, off-axis side. Why build a big aperture only to block it? Why construct a telescope with built in far sidelobes when the sky and ground are increasingly filled with transmitters? Why not put the effective area where we want it to be – pointed at the narrowest part of the sky? Main beam efficiencies of order 98% should be achievable and, besides making the telescope a gem for galactic HI, this will make a 10K total system temperature (at L band) really possible. Right now > 25% of the L-band system temperature (on the 140-foot) comes from the ground via scattering and spillover. Rick Fisher discusses how a large, floppy telescope could be made from flat surface panels, and how that reduces the problem that asymmetric designs have a high surface panel cost. The curvature of an off-axis dish is smaller than that of an equivalent size on-axis dish, so flat panels are an even more suitable approximation to the desired shape.

I disagree with Rick on just one point. It is OK to restrict slew rates, coverage close to zenith, and operation in the occasional high wind. But I think that it is not at all satisfactory to have a *lower* limit on the allowed elevation angle. The telescope should be able to observe to negative elevation (i.e. in the dirt) at least to the South. We should not give up sky coverage unless it seriously compromises the design or seriously increases the cost.

How to get it done. I would like to see some size vs. rms surface accuracy graphs for designs of a *fixed cost*! What exactly are the compromises necessary to reach 1 cm, or 6 cm for that matter. How much smaller does a telescope have to be if the same bucks are spent for an offset or on-axis design? What is the cost for the ability to track within 10° of the zenith? How about 20°? These are questions that a curious engineer could answer. If we can get a little money to such a person then we could begin. The important thing is to move quickly, not let it get out of hand, and not make a BFD out of the BFD.