THE ATACAMA ARRAY:
A POSSIBLE LMSA-MMA COLLABORATION IN CHILE

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December 1995

Overview

The similarities between the scientific goals and the array concepts of the LMSA and the MMA suggest that it may be to the mutual benefit of both projects to explore ways that the two instruments can benefit by the existence of the other. Presently the NRAO and the NRO are cooperating on array configuration issues and site testing data for the MMA and LMSA, respectively, under the framework of a Memorandum of Agreement. Here I propose to extend this cooperation in a manner such that it will be possible to combine the LMSA and the MMA together periodically (one or two months per year?) to form a joint array of 90 antennas, the "Atacama Array," that will have an angular resolution approximately five times greater than that of either the LMSA or the MMA alone. The Atacama Array will be used to study extremely small sources, such as protostars, protoplanetary disks, normal stars, and active galactic nuclei. Land area for the Atacama Array is available in Chile but not on Mauna Kea.

Array Sites/Configuration

Creation of a joint Atacama Array requires that both the MMA and the LMSA are located on a common Chilean site within 10 km or so of each other. This provides an opportunity for sharing of site and infrastructure costs between the two instruments. Either of the sites presently under study, Rio Frio or San Pedro, are suitable for the Atacama Array. Just to be definite, I will consider the San Pedro site because I am more familiar with it.

The San Pedro site at 5000 m elevation, shown in Figure 1, is large enough to accommodate a $\geq$ 10 km array. There are several places on the site to locate arrays of the size of the MMA or LMSA, and on Figure 1, I show an example of two such locations. The area where I show the MMA to be

located is exposed to the prevailing westerly winds and is a windy place. I have put the LMSA in a place called Pampa el Vallecito, which is sheltered from the westerly winds by Cerro Toco and Cerro Chajnantor, both of which are 5800 m high and would make excellent sites for future optical telescopes. The wind on the antennas should be much lower on Pampa el Vallecito than at the MMA location. The site is flat, firm, and with a gradual slope downward toward the northeast; it is very close to the international road (Paso de Jama).

With the MMA and LMSA located approximately 10 km apart, as shown in Figure 1, we form the Atacama Array by building antenna stations for "outrigger" antennas in a triangular pattern extending first between the LMSA and the MMA, and then southeast from the MMA, around Cerro el Chascon and back to the LMSA. With antennas spaced randomly around such a triangular configuration, we can expect good uv-coverage. There are several ways of forming the Atacama Array from outrigger antennas on a triangular configuration. Figure 2 shows the case where a few antennas are used on outrigger stations. Figure 2 has six MMA antennas and six LMSA antennas used this way. Figure 3 shows the instantaneous uv-coverage for this case. (Note that the wavelength scale for this plot and Figure 5 was done, for computational convenience, for a wavelength of 1 meter.)

In Figure 4, I show the situation in which the large Atacama Array configuration is populated by all 40 MMA antennas and all 50 LMSA antennas. Figure 5 is the instantaneous uv-coverage for the array. This is a truly excellent imaging array; the angular resolution is given below.

Angular Resolution of the Atacama Array

For a 12 km Atacama Array such as that given in Figure 1 which operates at all the MMA and LMSA frequencies, the angular resolution varies over the range from 60 to 6 milli-arcseconds. The table below illustrates this and includes the corresponding linear resolution at the distance of some important astronomical sources.

Table 1. Atacama Array Resolution

Frequency	Angular Resolution	Linear Resolution At:				
		Ophiuchus	Sgr A	Magellanic Clouds	Cen A	QSO z ~ 1
90 GHz	60 mas	10 AU	520 AU	0.06 pc	1.5 pc	1.5 kpc
230	20	3.4	170	0.02	0.5	0.5
345	15	2.6	130	0.015	0.4	0.4
650	8	1.4	70	0.008	0.2	0.2
850	6	1	50	0.006	0.15	0.15

With a resolution of a few milli-arcseconds to a few tens of milli-arcseconds, the Atacama Array provides an imaging capability comparable with that of centimeter-wave VLBI instruments, but it does so as a connected phase-stable interferometer and it operates at wavelengths where thermal sources are bright. For thermal sources, the only instruments of comparable angular resolution are the optical interferometers, but these instruments give only primitive visibility functions, not high-fidelity images.

LMSA-MMA Collaboration Specifics

In order to use the Atacama Array as a mechanism to build collaboration between the MMA and the LMSA, and to create a joint scientific capability that extends capabilities already present in the LMSA and MMA designs, we need to discuss the following issues:

- SITE: The LMSA and MMA will need to share a common site that is much bigger, > 10 km, than either the LMSA or MMA.
- CONFIGURATION: Both the MMA and the LMSA will need to add "outrigger" antenna stations to their array configuration design. The location of all the outrigger stations will need to be jointly agreed upon, and it will also have to be agreed which of the stations are built by which array.

- OPERATIONS: The LMSA and the MMA are independent telescopes. The LMSA is operated by NAO/NRO and the MMA is operated by the NRAO. Occasionally, perhaps one or two months a year, all the LMSA antennas and all the MMA antennas are moved onto the outrigger stations forming the Atacama Array. Half of this 1-2 month period, the Atacama Array, all 90 antennas, is operated from the LMSA control building for the benefit of the LMSA community and half the time it is operated from the MMA control building for the benefit of the MMA user community. In each case the data from all 90 antennas can be correlated in the existing LMSA or MMA correlators by trading full polarization capability (4 Stokes parameters) with 40-50 antennas for dual polarization total intensity only (2 Stokes parameters) with 90 antennas.
- HARDWARE AND SOFTWARE COMPATIBILITY: Creating the Atacama Array from the LMSA and MMA will mean that the two arrays have common observing frequencies, a common LO and IF design, a common phase calibration technique, and, if possible, the same or very similar monitor and control systems. All these need to be discussed. It will also be necessary, of course, to have LO, IF, and communications ports at both the MMA and LMSA control buildings which are connected to the entire signal transmission system of the Atacama Array antenna stations.

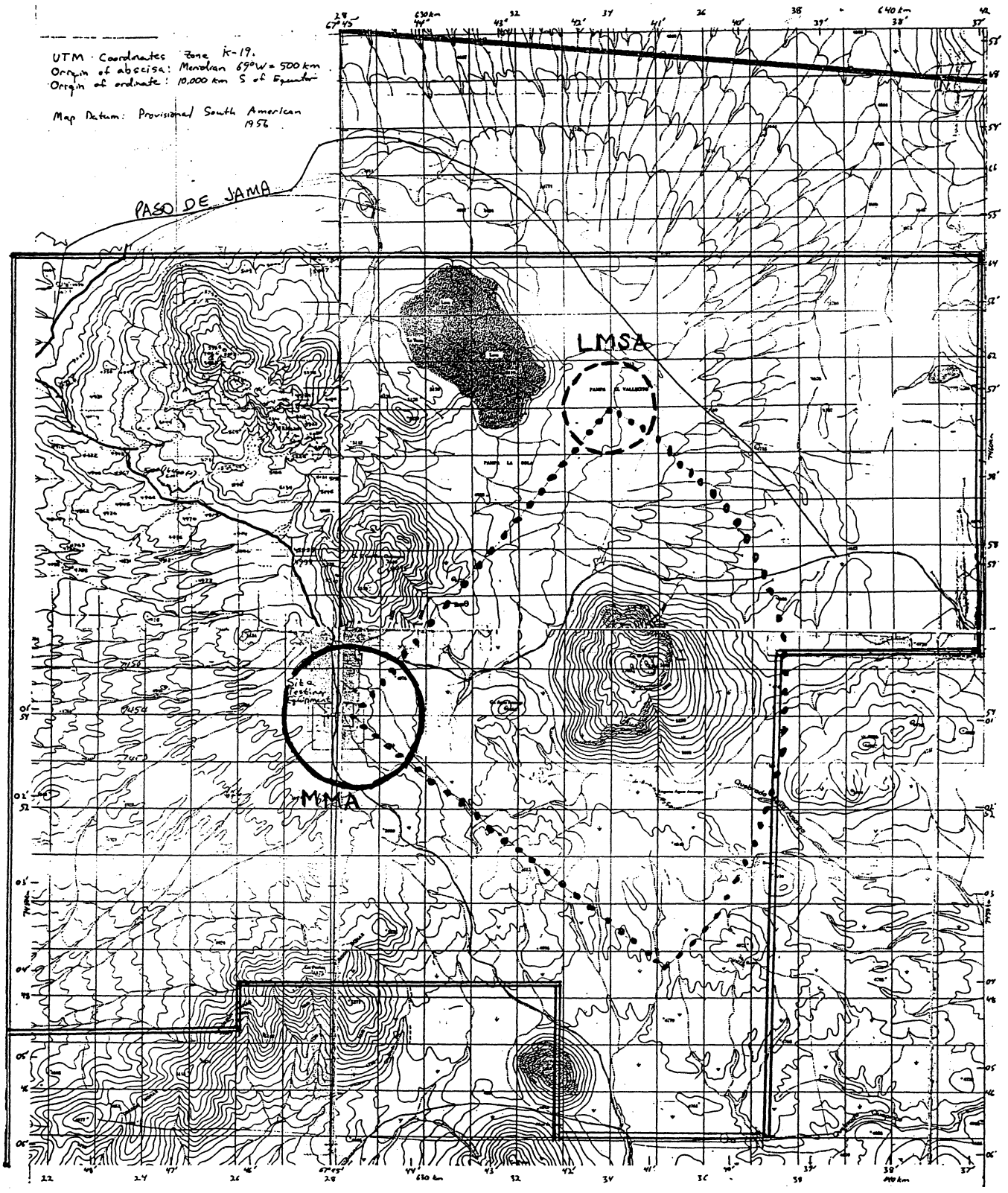
The First Steps Toward LMSA-MMA Collaboration on the Atacama Array

Very soon it would be good if the following could happen:

1. NRO and NRAO people work together (in Nobeyama?, Mitaka?, Tucson?) on the Atacama Array configuration.
2. Site tests are begun for a possible LMSA location on the San Pedro site. The Pampa el Vallecito looks very favorable, but the location at the southeast extreme of the Atacama Array drawn on Figure 1 should also be looked at. It would be good if one of the

NRO weather stations could be put at Pampa el Vallecito to measure the wind. It would also be good to measure the phase stability with a satellite interferometer at this location.

3. A joint NRAO-NRO technical group should be formed to look into all issues associated with hardware and software compatibilities of the two arrays.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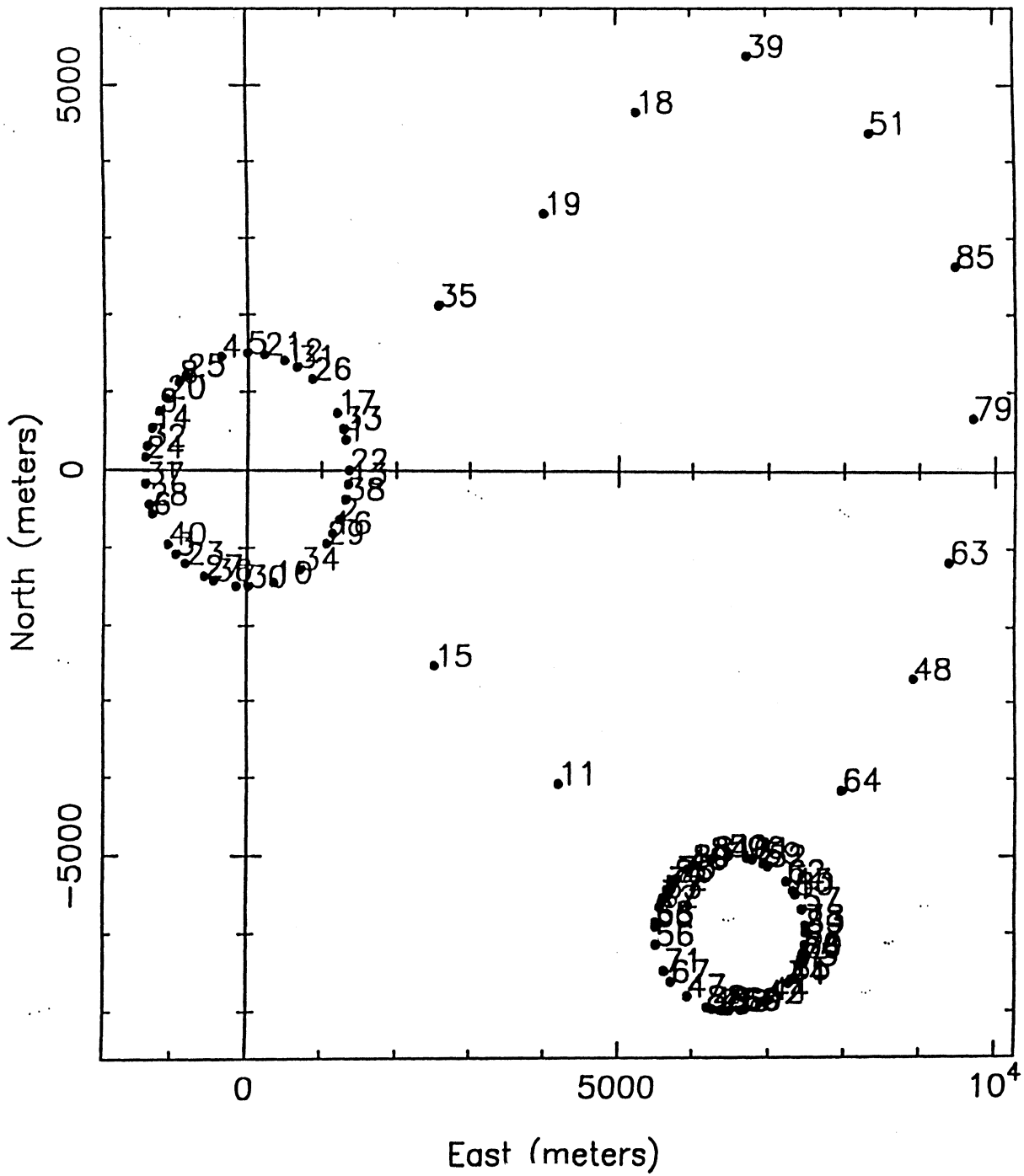
PASO DE JAMA
LMSA
MMA
SCIENCE RESERVE
LOCUS OF JOINT "ATACAMA ARRAY"

Fig. 1



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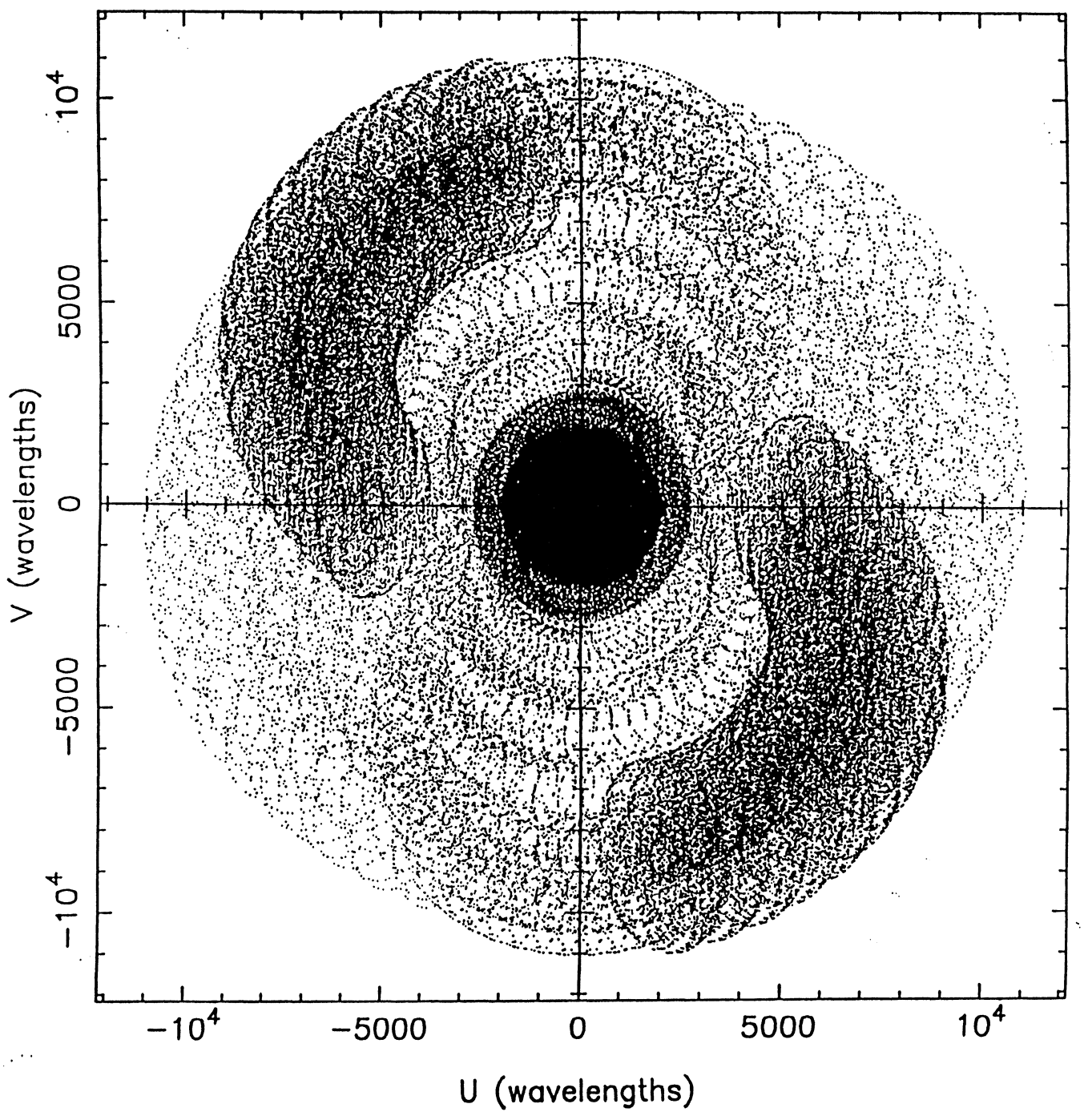
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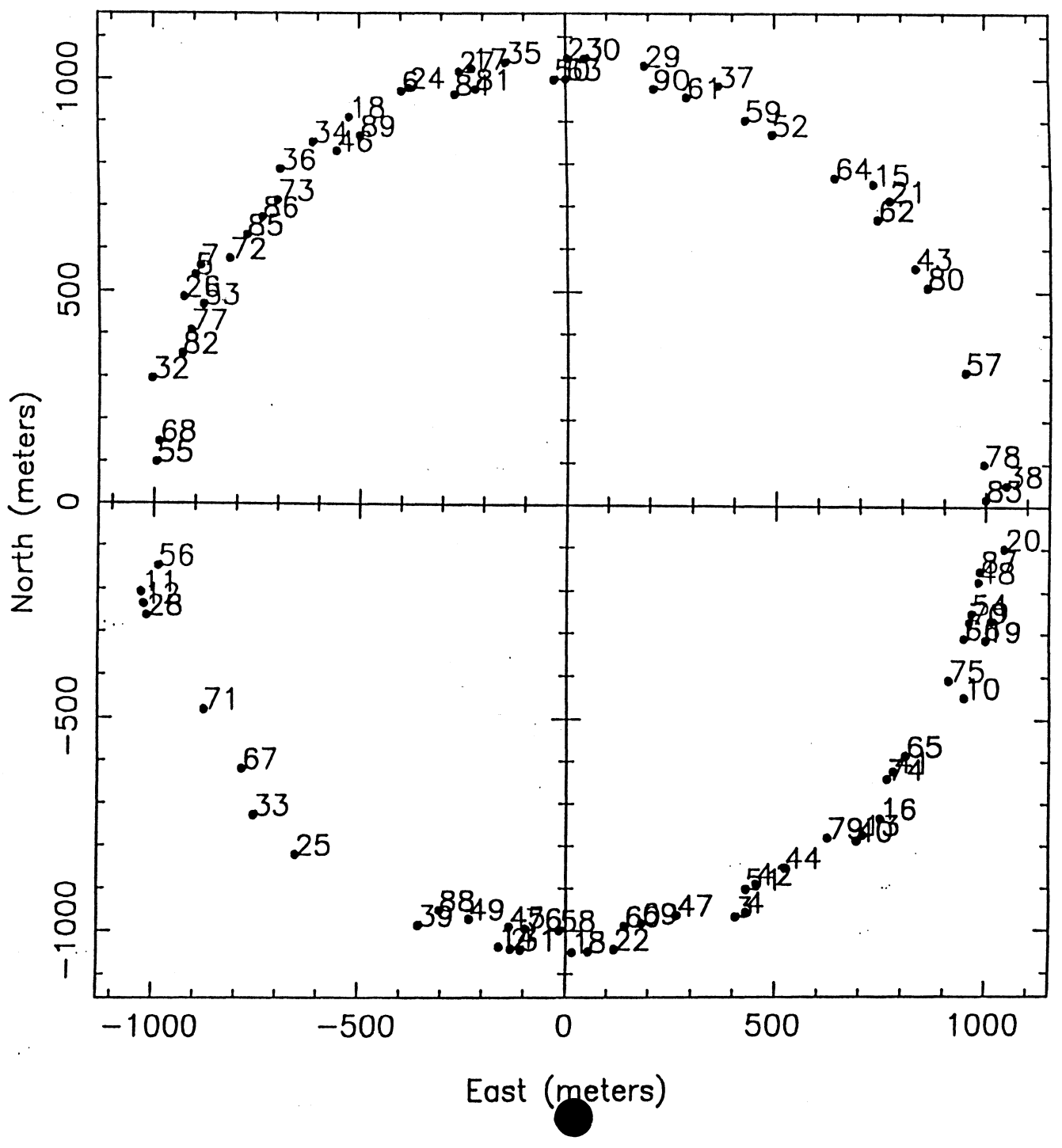

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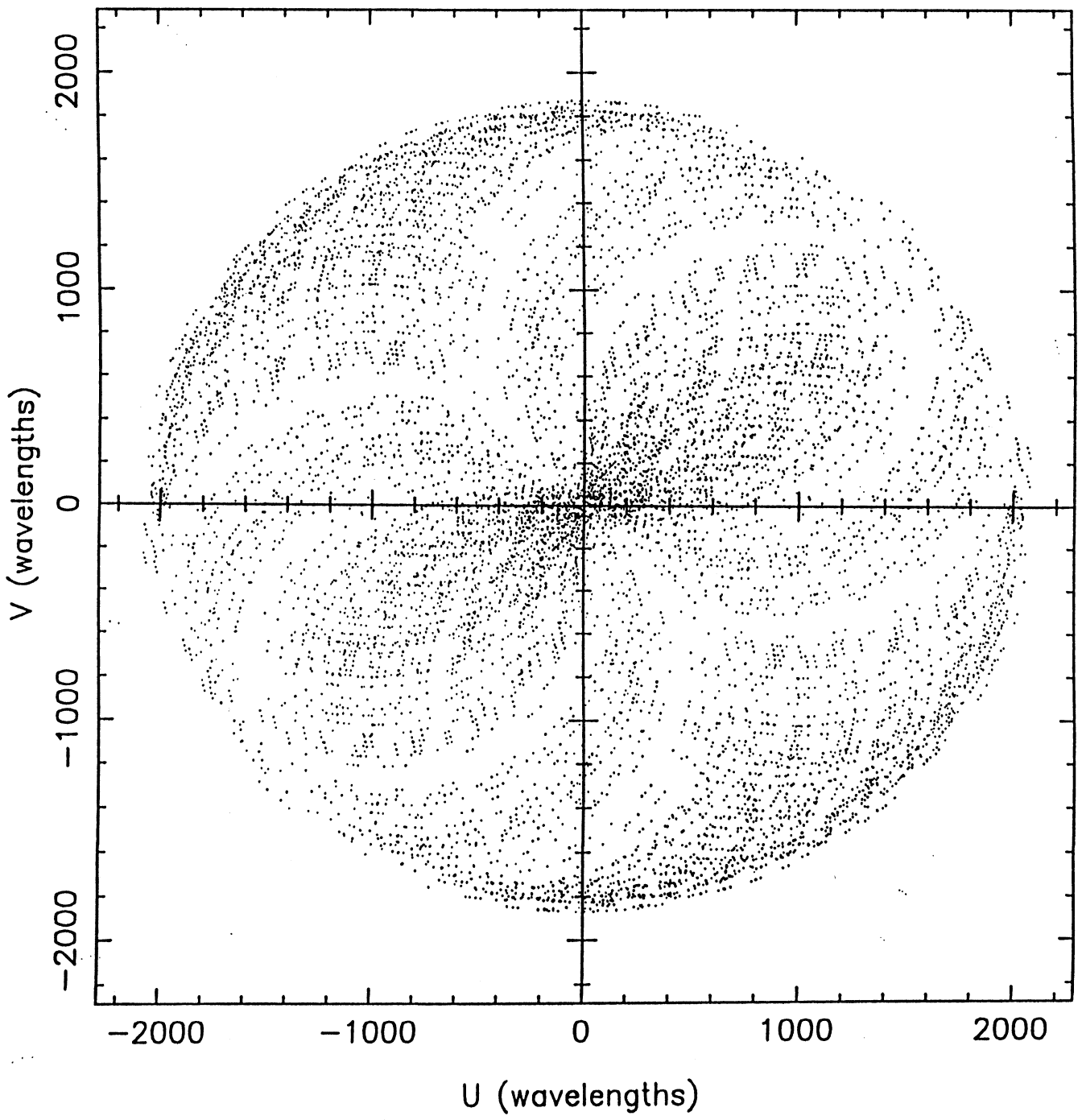
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