NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

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25 Meter Millimeter Wave Telescope
Memo #75

MEMORANDUM

To: D. S. Heeschen

From: R. L. Brown

Subj: The 25-Meter Telescope Site: A Potpourri of Scientific Considerations

The NRAO's proposal to build a new millimeter-wave telescope appears to be such an obvious project that we have in a most perfunctory way contented ourselves that adequate scientific justification for such a project exists and have gone on to design an instrument that represents an improvement in sensitivity, angular resolution and frequency coverage over the 36-foot millimeter-wave telescope. To the present, scientific considerations need not and certainly have not impacted in any noticeable way on the project. However, when we consider the telescope site we can no longer deal with weighted generalities; we must necessarily consider the specific scientific demands that will be placed on the telescope. To this end Burton and Liszt have addressed the questions of the site latitude and the atmosphere transmission in a manner appropriate for a discussion of the 25-meter telescope as an astronomical instrument. I would like to extend this discussion by briefly summarizing several outstanding scientific problems that uniquely exploit the capabilities of the 25-meter telescope; in so doing I will stress the constraints such observations place on the telescope site.

THE BOUNDARY CONDITIONS

(1) Even at the earliest expected completion date there will be at least four new millimeter telescopes in the northern hemisphere, most (all?) of which likely will have been operational for several years. Although the 25-meter telescope offers advantages in angular resolution and sensitivity over three of these instruments, it is nevertheless decidedly inferior to the

German 40-meter telescope in these same respects at frequencies below ∿160 GHz. (2) In view of this we can expect (and indeed deserve) community support for the 25-meter telescope only to the extent that it is superior to the other contemporary instruments. (3) The single salient characteristic of the 25-meter telescope that sets it apart from all the other millimeter telescopes under construction or planned is its capacity for efficient observations at frequencies of ∿200 GHz and above. (4) As it is this property that makes the telescope unique, it is precisely this property that constitutes its raison d'etre--provided that there exists an adequate scientific justification.

CONTINUUM OBSERVATIONS AT FREQUENCIES $\gtrsim$200 GHz

In this section, I intend to dwell solely on the scientific need for continuum observations at frequencies above 200 GHz; the line observations are emphasized by B. E. Turner in a separate memo. I shall briefly touch on three topics: HII regions, embedded early-type stars in dust clouds and compact extragalactic objects.

HII Regions:

The bright HII regions oft-studied by radio astronomers are nearly always associated with massive molecular clouds, the remnants presumably, of the material from which the O star(s) which excite the nebulae were formed. As is well known, the radiation spectrum seen toward HII regions is a synthesis of bremsstrahlung emission from the hot gas and a sub-millimeter thermal spectrum from heated dust in the adjacent molecular cloud. A typical spectrum--that seen toward Orion A--is shown in Figure 1: the lower panel is an expanded view of the spectral region of interest to the discussion of the 25-meter telescope.

At frequencies of 150 GHz and below the only contribution to the radio emission is the bremsstrahlung radiation from the HII region that has been well studied by observations at longer wavelengths. However, at $\nu \gtrsim 200$ GHz we expect the radiation to be a mixture of bremsstrahlung and thermal dust emission, while at still higher frequencies ∿345 GHz the dust component is entirely dominate and intense, ∿700 Jy! Hence by mapping at several frequencies from 150 - 345 GHz one can easily observe the transition from hot to cold material in the nebula. Moreover, such observations at all frequencies can be made with essentially the same angular resolution (15") which is an enormous improvement over that presently available at sub-millimeter wavelengths (∿1!3 on the 200-inch telescope).

These observations are possible in a large number of Galactic HII regions, the Galactic center and the nuclei of nearby (< 5 Mpc) external galaxies. They absolutely require that one work at 200 - 345 GHz at a site with outstanding atmospheric transmission and long-term (hours) stability.

Embedded Early-Type Stars:

In the same manner that one can observe the sub-millimeter thermal spectrum of heated dust near HII regions, one can also observe the dust emission from isolated B stars that are newly formed and still embedded in dust clouds. Such stars are detectable in the near infrared as highly reddened point-sources, but they have not been directly observable heretofore at radio frequencies. However a study of these objects will be quite straightforward with the 25-meter telescope operating at the highest frequencies.

In the upper panel of Figure 2, I have provided a (smoothed) illustration of the expected flux density from embedded stars of spectral types 07-AO at three frequencies. The solid lines refer to stars at 170 pc distance, the distance of such objects as the Scorpio-Centaurus association, the Austrina clouds and the Ophiuchus clouds, while the dashed lines refer to stars at the distance of the Orion clouds, 500 pc. Here again one can see the advantages that accrue from observations at the highest frequencies: (1) the flux density for stars of a given spectral type is greater the higher the frequency, and (2) for a given limiting flux density one can study more stars at the higher frequencies. To amplify this latter point, assume that we can achieve a detection limit of 5 Jy at all frequencies and that at this limit we can detect the sub-millimeter thermal emission from one star at 100 GHz. How many stars can we detect at higher frequencies? The result is illustrated in the bottom panel of Figure 2--at 250 GHz we can detect 16 stars and at 345 GHz we can see 36 stars in an embedded association at 170 pc.

Compact Extragalactic Sources:

The physics of these objects is one of the most outstanding puzzles in radio astronomy and will likely remain so largely because of the difficulties present in obtaining any meaningful data on sources that are unresolved to all instruments except the intercontinental baseline interferometers. The 25-meter proposal correctly notes that if we observe at higher frequencies we expect these objects to show marked time variability, the study of which may provide some modicum of understanding. The argument is actually somewhat stronger than this and of a somewhat different character.

Of a sample of 30 compact sources stronger than 1 Jy at 90 GHz studied recently by Owen and Porcas, approximately one-fourth had a flat or increasing spectrum. These sources were identified with optical objects of 16th to 20th magnitude--that is, their flux density at 6×10^{14} Hz is $10^{-3} - 10^{-5}$ Jy. Hence the source spectrum must fall extremely rapidly between 90 GHz and 6×10^{14} Hz. Precisely how fast can a synchrotron radiation spectrum decrease in this frequency interval? Let us consider the most restrictive case and assume that the emission at 90 GHz is produced by the absolutely highest energy electrons present in the source; in this case the synchrotron spectrum above 90 GHz falls approximately as $\nu \exp(-\nu^{2/3})$: a synchrotron spectrum can decrease no faster than this at high frequencies. This behavior is illustrated by the solid line drawn for two representative sources in Figure 3. Notice that the high-frequency extension of the radio spectrum does not conflict with the optical flux of these objects. Now consider the possibility that the low-frequency spectrum continues unchanged to 345 GHz. In this case if we again assume that the emission at 345 GHz is produced by the highest energy electrons in the source then the minimum expected synchrotron fluxes at optical frequencies (dashed line in Figure 3) are 1 to 5 magnitudes brighter than the observed optical objects. As this cannot be the case, we surmize that the shape of the radiation spectrum in the interval 100 - 345 GHz will be a decisive probe of the physics of these objects.

Arguments such as these which hinge neither on cosmological distance scales nor on source geometry demonstrate in a straightforward way the overwhelming advantages that accrue to observations obtained at and particularly somewhat beyond the design ($\lambda/16$) limit of the telescope that are simply not obtainable at lower frequencies.

SUMMARY

The most urgent scientific justification for the 25-meter telescope as a continuum instrument lies in its capacity to work efficiently at the highest frequencies, viz. 200 - 345 GHz. For both Galactic and extragalactic objects, the science that one can do with observations at >200 GHz is qualitatively different from that which one can do at the lower frequencies: the most easily appreciated example of this is afforded by the Galactic HII regions in which observations at <200 GHz allow one to see only bremsstrahlung emission from the 10^4 K gas whereas observations at 200 - 345 GHz allow one to sample fully the transition from hot gas to cold dust emission. Moreover, this high frequency capability can be uniquely exploited by the 25-meter telescope--provided that it is located in an outstanding site. Since Wade's site survey concludes that Mauna Kea is the only viable site for observations at these frequencies, I believe that the specific scientific demands imposed on the telescope compel us to locate the instrument on Mauna Kea.

I recognize that the decision to go to Mauna Kea means that we will have to answer a myriad of questions; e.g., How do we staff the site? How do we operate at 13000 feet? and on and on. We avoid all these questions by locating instead on Kitt Peak, but we do so by essentially sacrificing all the continuum (and of course line) science obtainable at $\nu \gtrsim 230$ GHz. We are left then with an instrument having a sky coverage, frequency range, sensitivity and angular resolution not unlike that of four other new millimeter-wave telescopes that will have been in operation for several years by the time the 25-meter telescope is completed. In no sense do we have a unique astronomical instrument if it is on Kitt Peak. Given this choice (Kitt Peak), we are left to account for only a single question--What is it that is so appealing about the German experience with the Effelsberg telescope at centimeter wavelengths that causes us to be eager to repeat that experience at millimeter wavelengths?

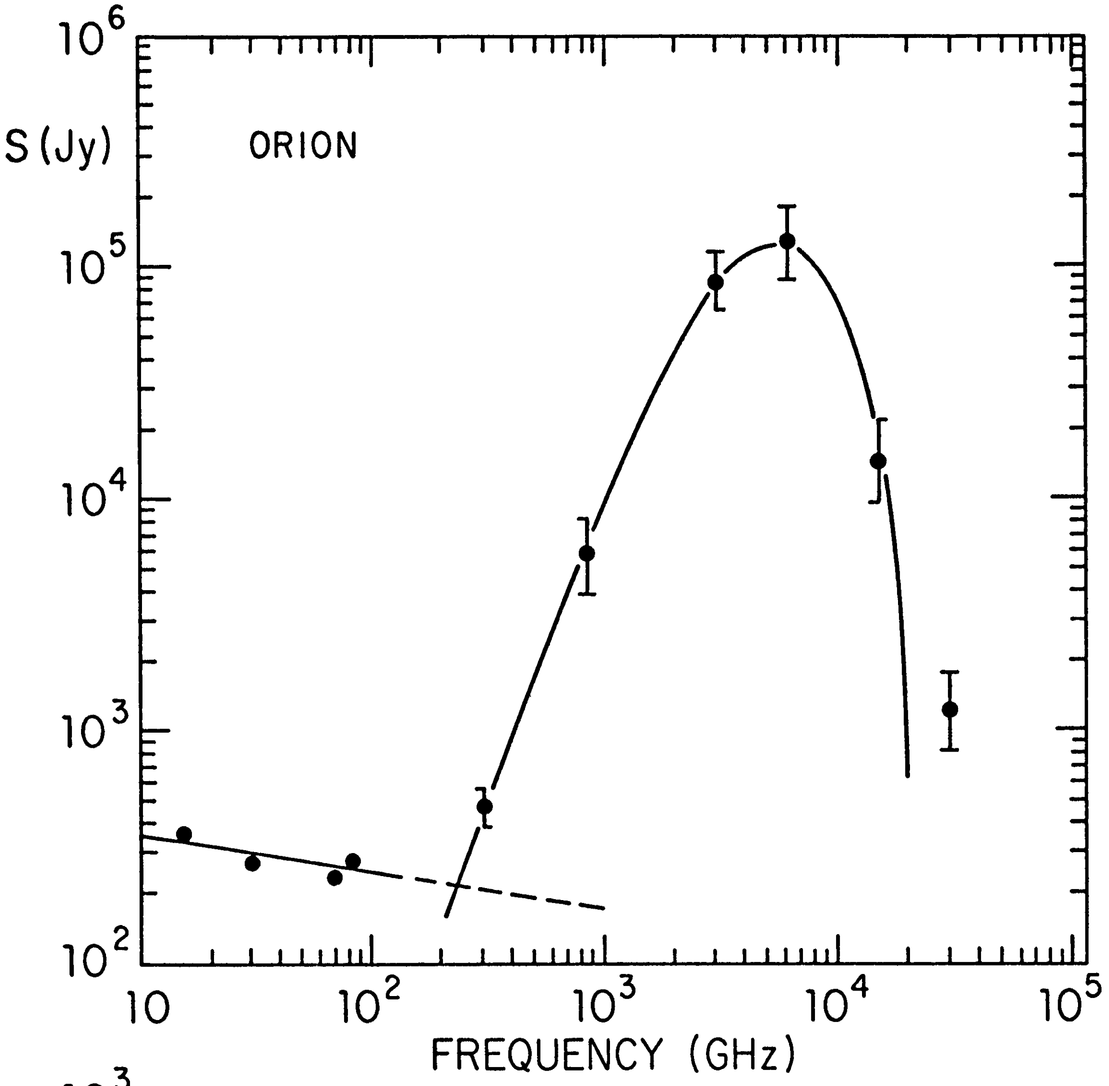
RLB/pj

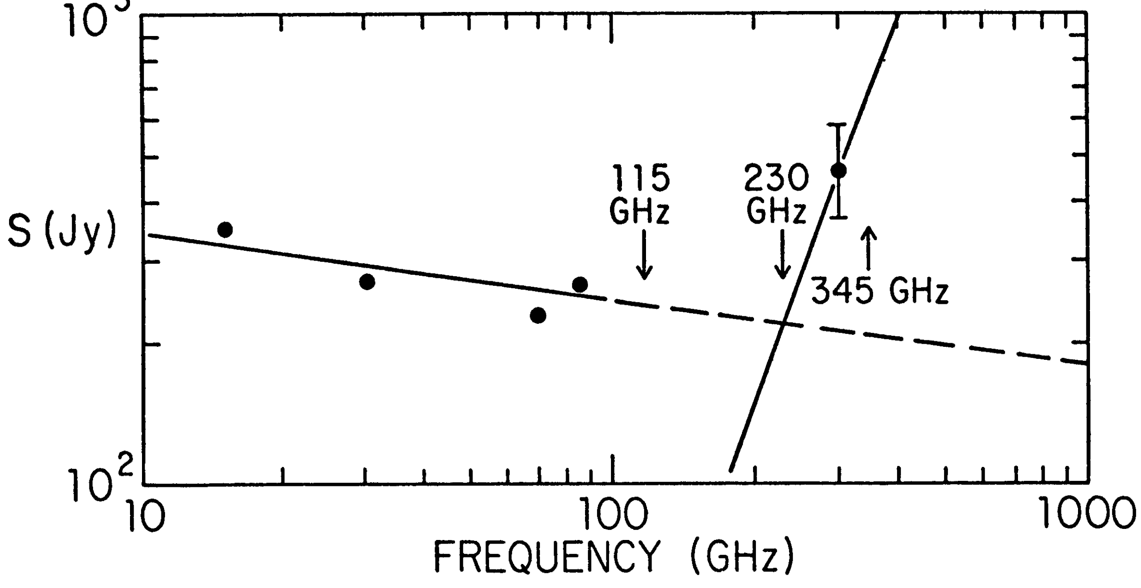
FIGURES

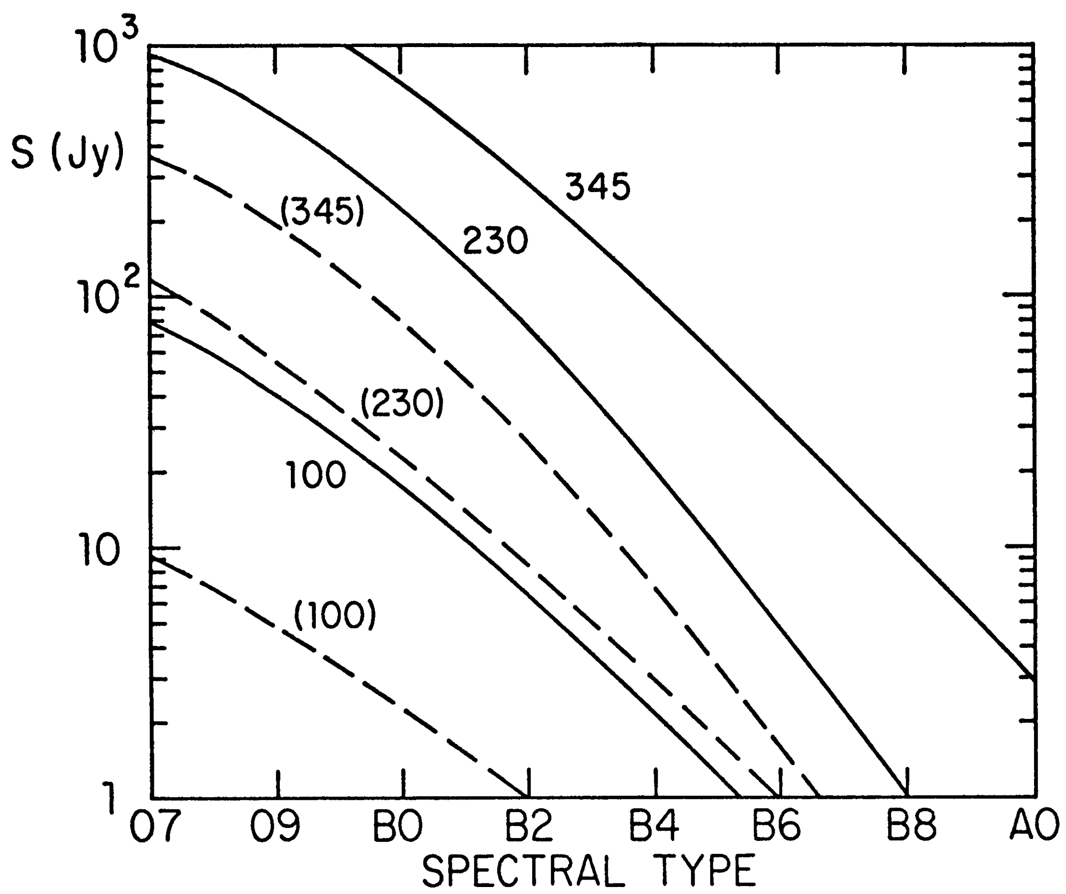
Figure 1. The radio and infrared spectrum seen toward Orion A. (lower panel) An expanded view of the frequency range accessible to the 25-meter telescope.

Figure 2. (upper panel) The expected flux density from heated dust surrounding stars of various spectral types that are embedded in dust clouds. The curves are labeled by the observing frequency in GHz. Solid lines refer to stars at 170 pc; dashed lines refer to stars at 500 pc. (lower panel) The relative number of stars detectable as a function of observing frequency.

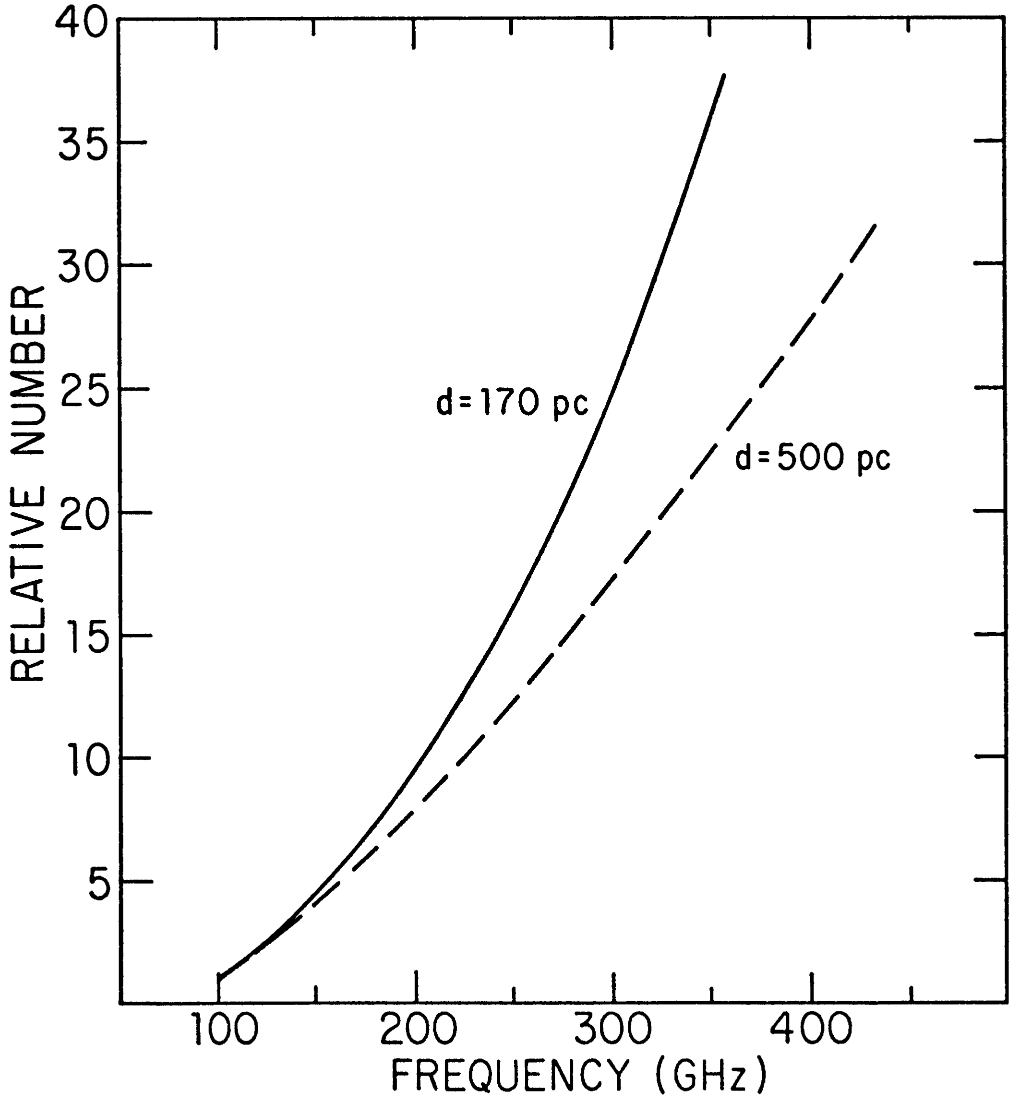
Figure 3. The radiation spectrum of two compact extragalactic objects from radio frequencies to optical frequencies. The solid line represents the minimum high frequency synchrotron flux from these sources assuming that the critical frequency of the highest energy electrons in the source is 90 GHz. The dashed line represents the minimum high frequency synchrotron flux assuming that the critical frequency of the highest energy electrons in the source is 345 GHz.


10^6
10^5
10^4
10^3
10^2
S (Jy)
ORION
10
10^2
10^3
10^4
10^5
FREQUENCY (GHz)


10^3
S (Jy)
115 GHz
230 GHz
345 GHz
10^2
10
100
1000
FREQUENCY (GHz)



10^3
S (Jy)
10^2
10
1
345
230
(345)
(230)
100
(100)
07
09
B0
B2
B4
B6
B8
A0
SPECTRAL TYPE



40
35
30
25
20
15
10
5
RELATIVE NUMBER
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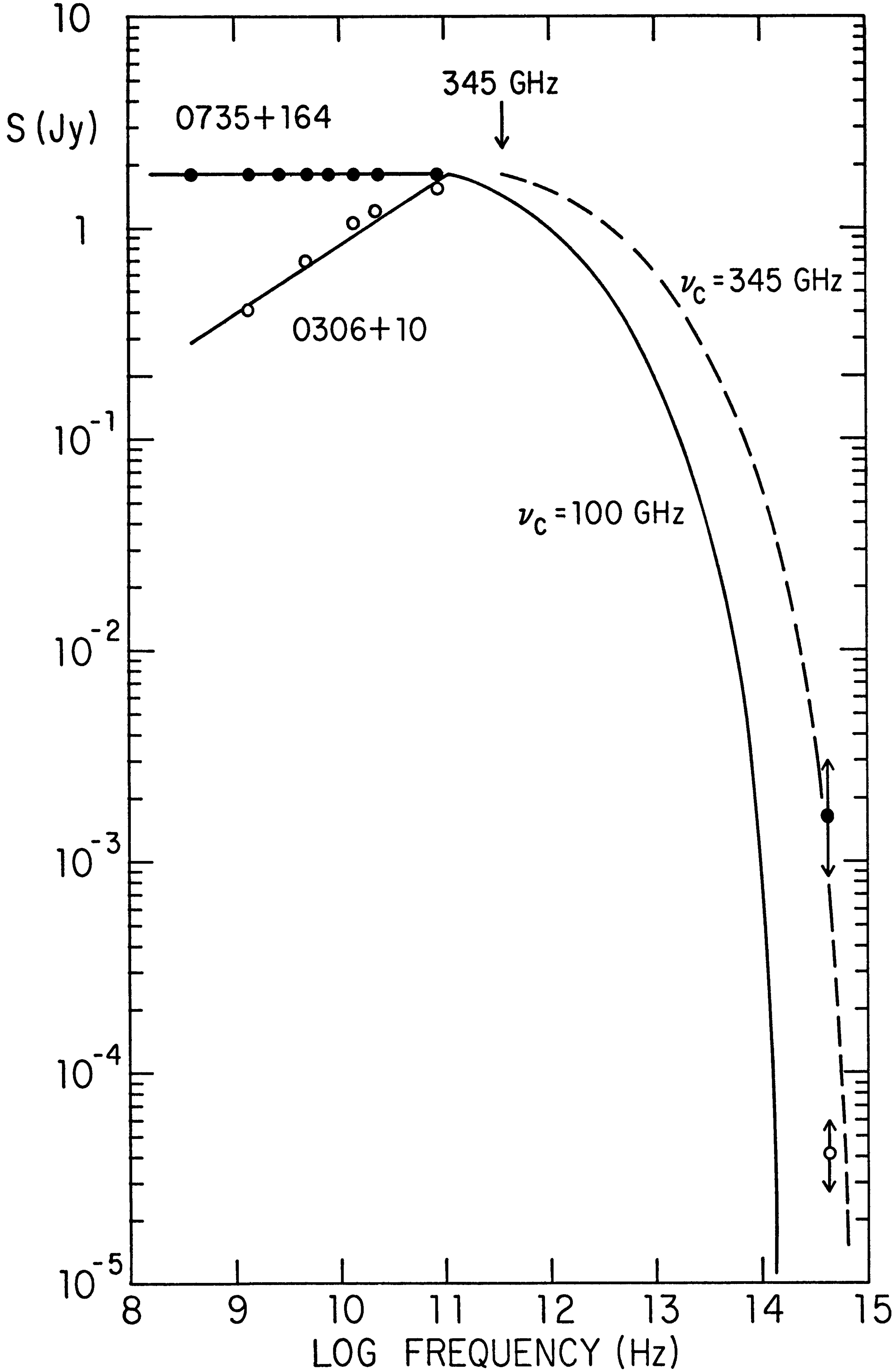
d=500 pc
100
200
300
400
FREQUENCY (GHz)



10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
S (Jy)
0735+164
345 GHz
0306+10
ν_c = 345 GHz
ν_c = 100 GHz
8
9
10
11
12
13
14
15
LOG FREQUENCY (Hz)