NBS

Technical Note 169

PROFILES OF ELECTRON DENSITY OVER THE MAGNETIC EQUATOR OBTAINED USING THE INCOHERENT SCATTER TECHNIQUE

K. L. BOWLES et al.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

Technical Note 169

ISSUED MARCH 16, 1963

PROFILES OF ELECTRON DENSITY OVER THE MAGNETIC EQUATOR OBTAINED USING THE INCOHERENT SCATTER TECHNIQUE

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Instituto Geofisico del Peru
Lima, Peru

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Profiles of Electron Density Over the Magnetic Equator Obtained Using the Incoherent Scatter Technique

K. L. Bowles

and

Staff of Jicamarca Radar Observatory, Lima, Perú

A joint venture of the National Bureau of Standards, Boulder, Colorado, and the Instituto Geofísico del Perú, Lima, Perú

The technique of electron density measurement by incoherent scatter, using a high powered radar, has now been thoroughly explored in the literature. A representative bibliography on the subject, as well as a summary of experimental aspects, current early in 1962, has been given by Bowles, Ochs, and Green [1962]. The object of this note is to present a number of profiles obtained using incoherent scatter near Lima, Perú.

It appears that the theory of the "incoherent scatter" phenomenon, as applied to the ionosphere and exosphere, is now well established. The scattering cross section per free electron, σ, is related to the classical Thomson cross section σ_{th} by the approximate formula

$$\sigma = \sigma_{th} \left[\frac{1}{1 + T_e/T_i} \right] \qquad (1)$$

as long as

$$\lambda << 4\pi\lambda_D \qquad (2)$$

where T_e and T_i are the electron and ion kinetic temperatures, respectively, λ is the radio wavelength and λ_D is the Debye shielding distance. For all of the experiments to be disucssed in this note, the inequality (2) is correct.

At first there appeared to be some question as to the validity of (1), raised by some of the experimental results. The paper of Bowles et al. [1962] showed that the scattering cross section measured experimentally is within about 20 percent experimental error of agreeing with the theory, at least under conditions of thermal equilibrium. Recently Renau [1962] has questioned the earlier theories, all of which led to (1), and suggests that $\sigma \rightarrow \sigma_{th}$ as T_e/T_i increases. Unfortunately Renau's theory leads to the inconsistent result that the electron and ion fluctuations behave quite differently as T_e/T_i changes, a result which is known to be impossible from the theorem of charge neutrality. Quite recently Evans, in work which will be published shortly [J. V. Evans, private communication, 1962], has obtained accurate spectra of incoherent scattered echoes observed in Massachusetts These spectra agree precisely with the earlier theoretical spectra, which correspond with (1), and apparently do not agree with Renau's spectra. Thus we assume, for the present purpose, that (1) is correct.

Now the ratio T_e/T_i can be measured from the incoherent scatter echoes by observing the spectrum of the scattered energy. Unofrtunately we were not prepared to make such measurements when the profiles given herein were obtained. We estimated [Bowles et al., 1962] that at Lima, and at the F2 layer maximum, T_e/T_i approximates unity during the majority of the daylight hours, and approximates 2 just at sunrise in the F region. We had very little data for the nighttime hours. On the other hand, [Evans, private communication, 1962] finds that in Massachusetts T_e/T_i approximates unity during the hours of darkness and rises to about 1.6 at midday at heights from 300 to 600 km. Other reports also seem to indicate that thermal equilibrium is by no means necessary and that values of T_e/T_i approximating 2 or more are quite common.

The profiles given in this note are therefore subject to whatever errors might be introduced by variations in T_e/T_i with height at any given time. Obviously if T_e/T_i does not vary with height, σ is the same at all heights and the profiles are plotted correctly.

Only one point on the profiles is directly related to the correct electron density. This is the point of maximum electron density, the value of which is obtained from the ordinary-trace penetration frequency of a conventional swept-frequency ionogram. All other points are relative measurements normalized to the maximum value. The error flags shown on the profiles give only the relative accuracy for scaling the incoherent scatter echo power which is proportional to the electron density at each height. No errors due to variations of T_e/T_i are shown.

It may be seen that most of the profiles were obtained in three distinct sections. Error flags appearing in the vicinity of 700 km height pertain to the section of the profile which also includes the F layer maximum. The incoherent scatter technique uses direct measurements of echo power. The sensitivity of the radar decreases with height h as $1/h^2$. Therefore the measurement involves observations over a dynamic range of more than 50 decibels of received power. This requires operating the radar at three different sensitivities in succession in order to obtain the entire profile. At the higher sensitivities measurements cannot be made at the F layer maximum due to saturation of the radar receiver. Therefore the complete profile is a composite obtained by fitting sections of profile obtained at three different sensitivities. The accuracy of the higher sections obviously depends upon the accuracy of curve fitting. Readers may judge for themselves whether the fitting has been done properly, since data points pertaining to each section of the profile have been plotted using distinct symbols. In some of the profiles, all of the available data points have been plotted individually. In others only a few have been plotted as a means of identifying the three sections of profile.

At times coherent irregularities are present at certain heights giving rise to radar echoes stronger than the background of incoherent scatter. The most obvious of these are associated with the appearance of spread-F echoes on the conventional swept frequency ionograms. When the spread-F is intense it has proven impossible to obtain reliable electron density profiles. At times of weak spread F we have excluded the range of heights corresponding to the spread-F echoes from the electron density analysis. Now it may logically be asked whether our observations are not always contaminated to some extent with scattered power due to coherent irregularities. Having been unable as yet to make adequate spectrum observations we have not yet been able to exclude the coherent echoes from the electron density observations with absolute certainty. However several factors lead us to believe that the coherent irregularities are normally of trivial importance. First, the coherent irregularities in the E region and above are always observed to be quite aspect sensitive and aligned with the lines of force of the earth's magnetic field. Therefore the echoes due to these irregularities must maximize in an angular region within about 1 degree of perpendicular to the lines of force, according to our spread-F observations. Except when spread F is also observed with the ionosonde, there is no evidence of significant echo power from coherent irregularities even when the radar antenna is directed perpendicular to the magnetic field line in the F region. All of the profiles of electron density reported herein were obtained with the antenna directed 3 degrees away from perpendicularity. Under this arrangement the coherent echo power should be reduced perhaps three to four orders of magnitude relative to the perpendicular direction. Therefore we feel justified in ignoring the coherent irregularities for analysis of most of the profiles presented herein. Exceptions are noted directly on the graphs.

At heights below about 200 km there is some evidence that the indicated electron densities are up to a factor of 2 too high. This is suggested by comparisons made using the so-called true height method of analysis of conventional ionograms. Below 200 km the mean free path of the gas becomes short enough that coherent irregularities due to turbulence and other hydrodynamic sources may become of some concern. Also the role of collisions in the incoherent scatter process is not yet well understood. We are making efforts to understand the scatter from this height region better. For the present it must be assumed that the profiles given in this note are reliable only above 200 km, and that the electron densities indicated below that height are overestimated.

Most of the details of our technique in making incoherent scatter profile measurements have been given in the paper by Bowles et al. [1962]. In the profiles given herein, the transmitter peak power P_t and antenna cross section A were as follows:

January 1962	$P_t = 10^6$ watts	$A = 2.1 \times 10^4 m^2$
February 1962	$P_t = 2 \times 10^6$ watts	$A = 4.2 \times 10^4$
April 1962 et seq.	$P_t = 4.5 \times 10^6$	$A = 8.4 \times 10^4 m^2$.

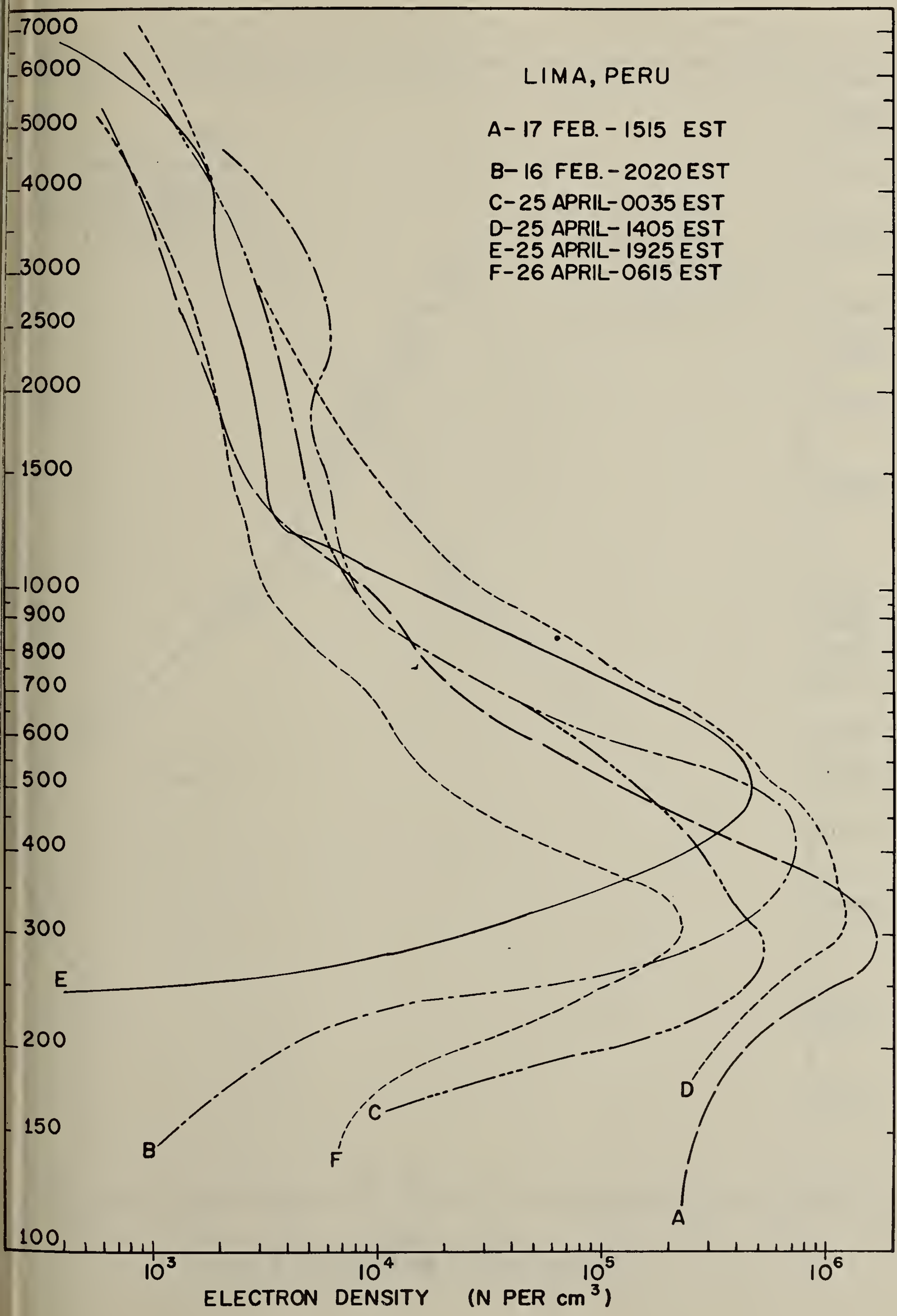
In February and following, the top section of the profile was extended through the use of longer pulses (up to 3 milliseconds) and improved in integration of the receiver output.

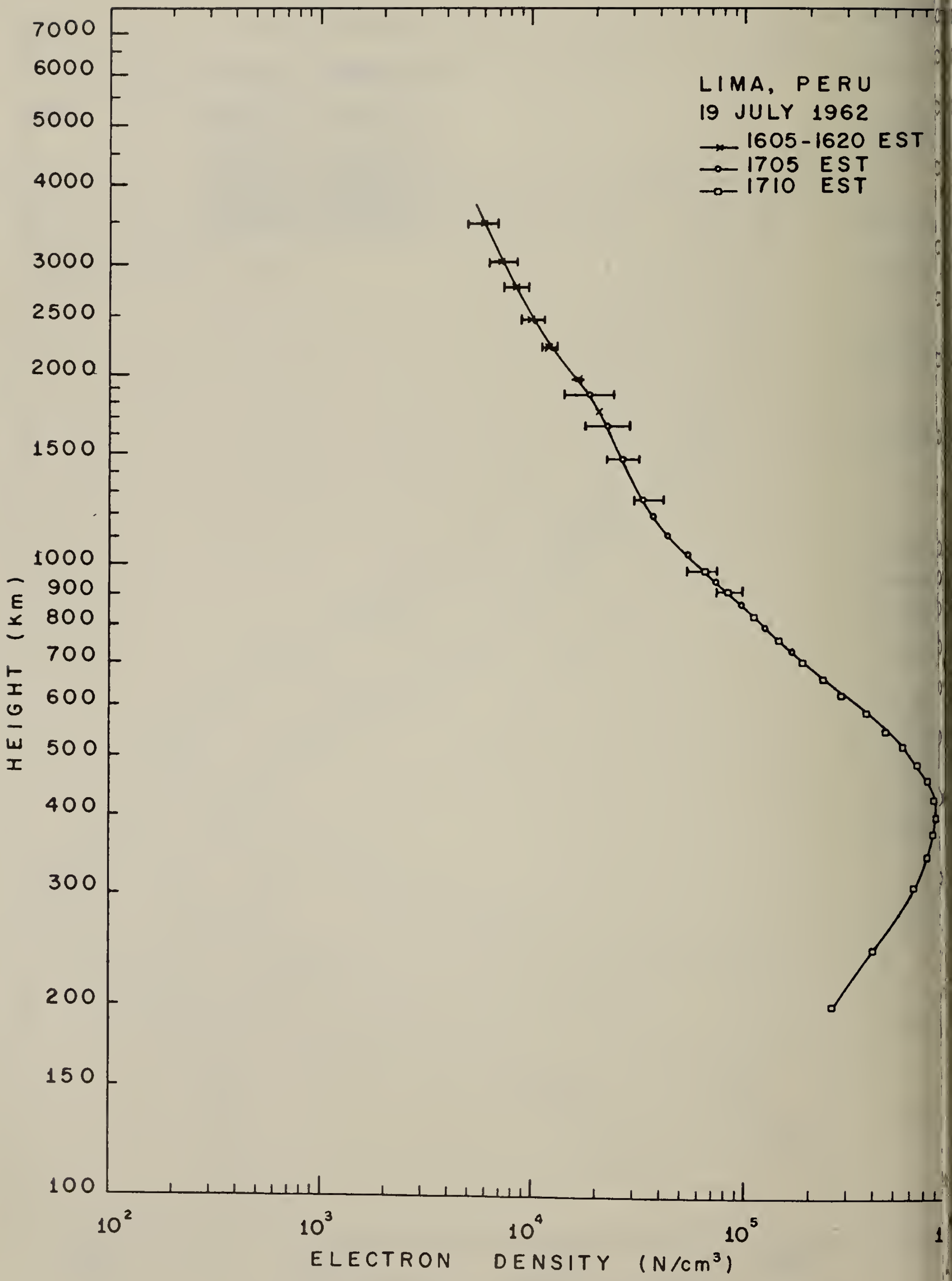
Our experimental program includes the measurement of the incoherent scatter spectrum in order to determine T_e/T_i. Equipment to permit this is now essentially complete. Every effort will be made to produce profiles in greater quantities and for longer periods of continuous operation.

Bibliography

Bowles, K. L., G. R. Ochs, and J. L. Green, On the absolute intensity of incoherent scatter echoes from the ionosphere, J. Res. NBS 66D (Radio Prop.), 395-407 (1962).

Renau, J., The cross section for scattering of electromagnetic waves from an ionized gas in thermal nonequilibrium, J. Geophys. Res. 67, 3624-3526 (Aug. 1962).


LIMA, PERU
A- 17 FEB. - 1515 EST
B- 16 FEB. - 2020 EST
C-25 APRIL-0035 EST
D-25 APRIL- 1405 EST
E-25 APRIL- 1925 EST
F-26 APRIL-0615 EST
7000
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
A
B
C
D
E
F
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N PER cm^3)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19 JULY 1962
1605-1620 EST
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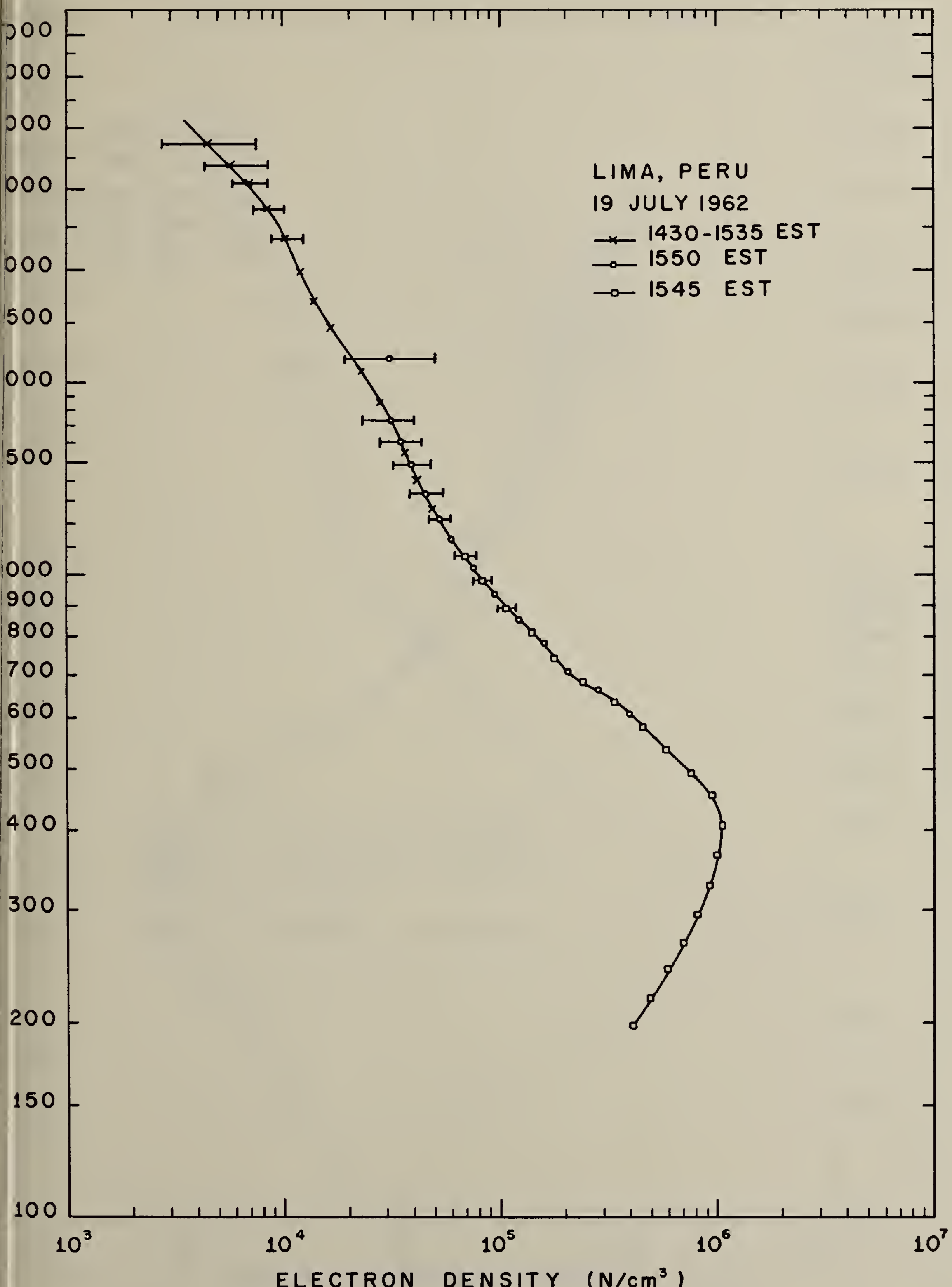
1710 EST
7000
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
HEIGHT (km)
10^2
10^3
10^4
10^5
ELECTRON DENSITY (N/cm³)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19 JULY 1962
1430-1535 EST
1550 EST
1545 EST
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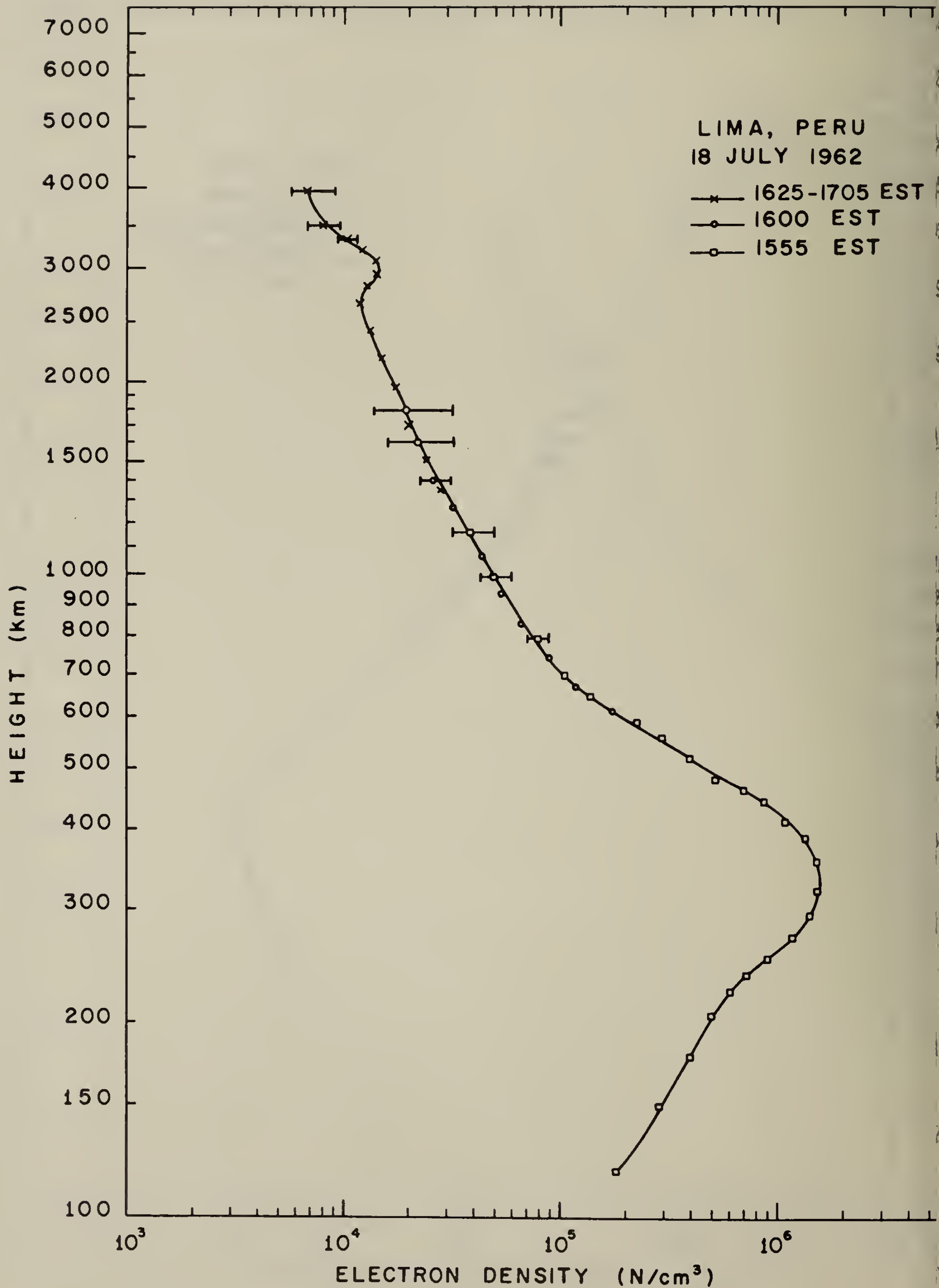
150
200
300
400
500
600
700
800
900
000
500
000
500
000
000
000
000
000
10^3
10^4
10^5
10^6
10^7



LIMA, PERU
18 JULY 1962
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1600 EST
1555 EST
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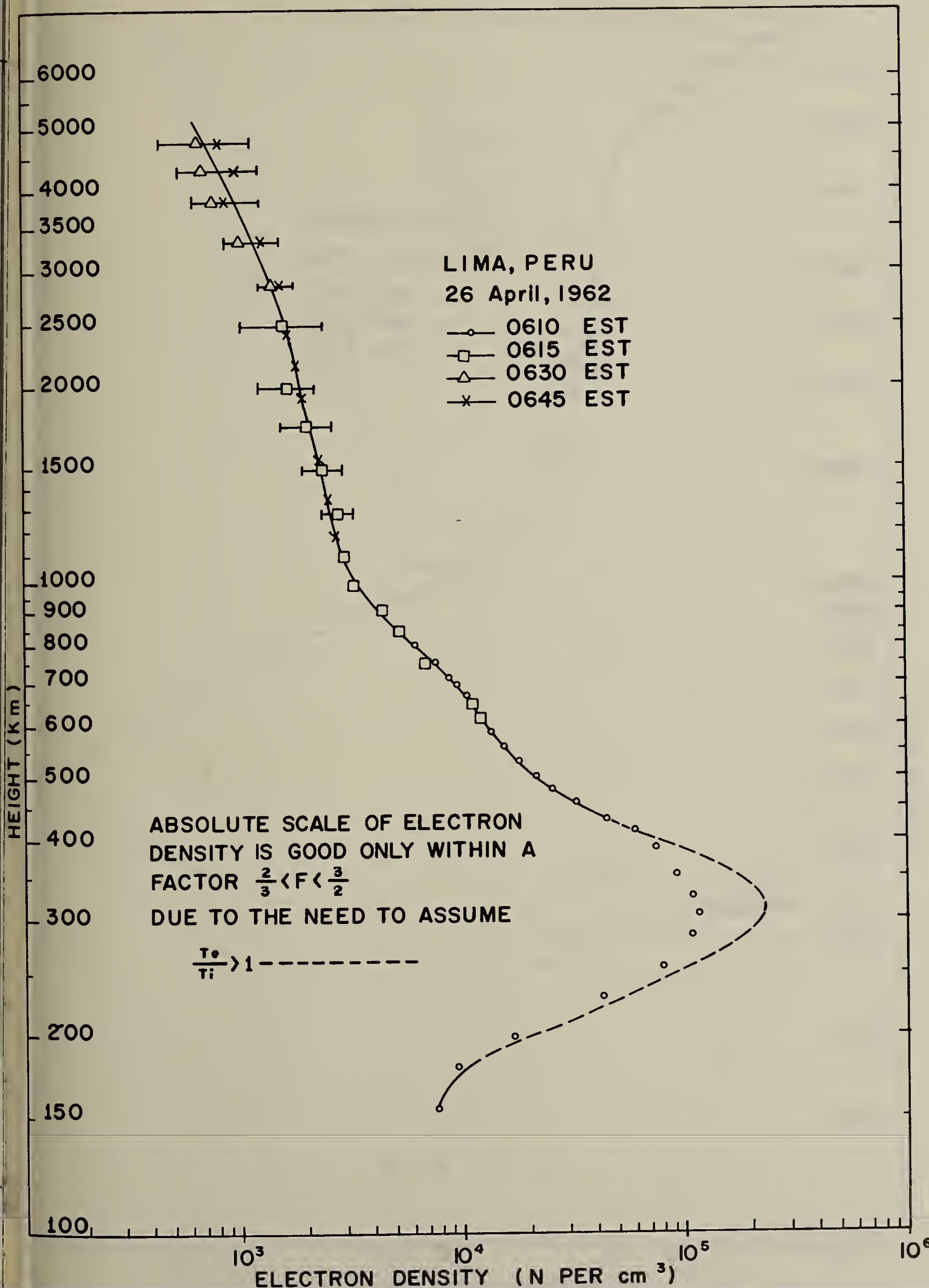
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm^3)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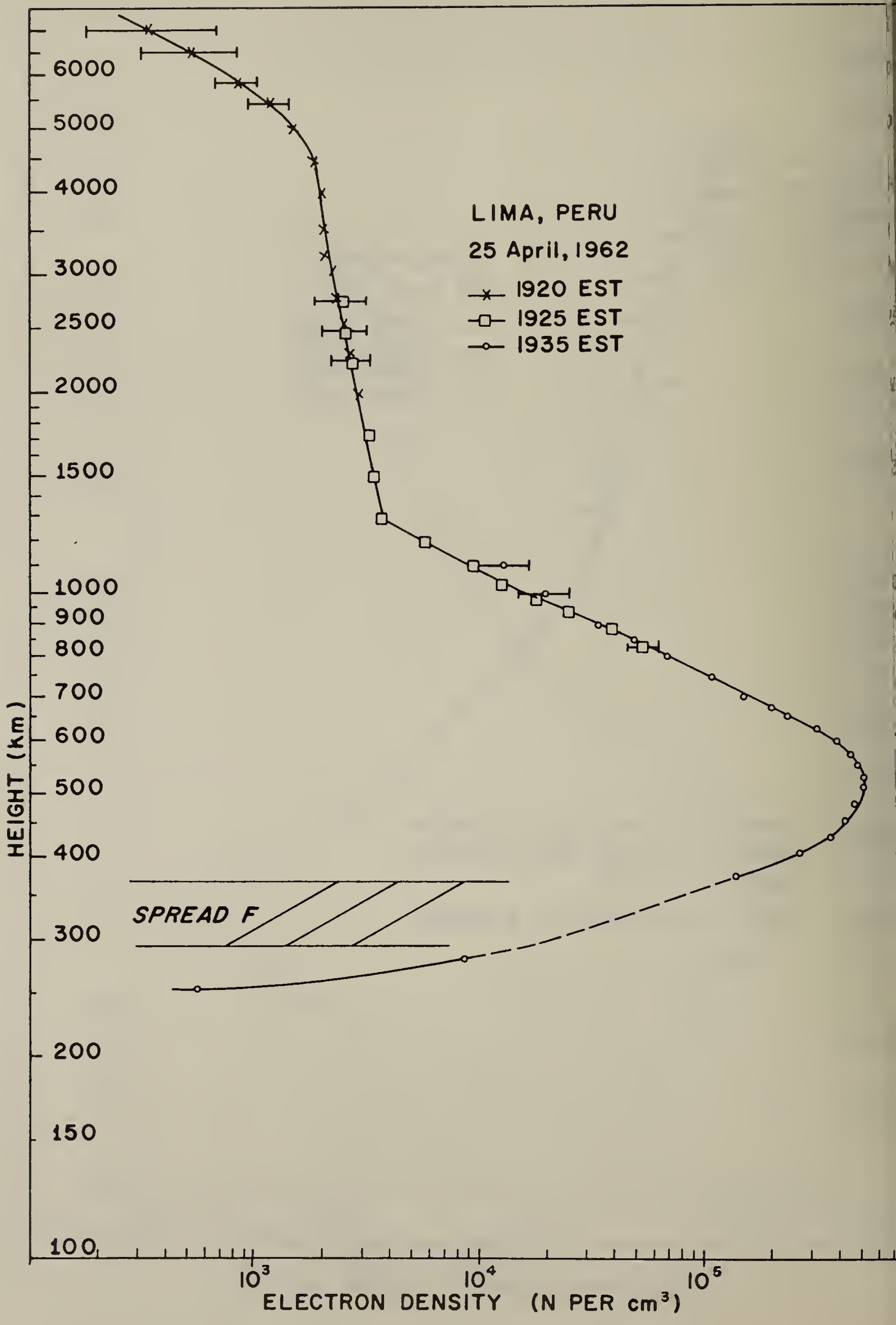
26 April, 1962
0610 EST
0615 EST
0630 EST
0645 EST
ABSOLUTE SCALE OF ELECTRON DENSITY IS GOOD ONLY WITHIN A FACTOR 2/3 < F < 3/2
DUE TO THE NEED TO ASSUME
Te/Ti > 1
HEIGHT (Km)
6000
5000
4000
3500
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
10³
10⁴
10⁵
10⁶
ELECTRON DENSITY (N PER cm ³)


LIMA, PERU
25 April, 1962
1920 EST
1925 EST
1935 EST
SPREAD F
HEIGHT (km)
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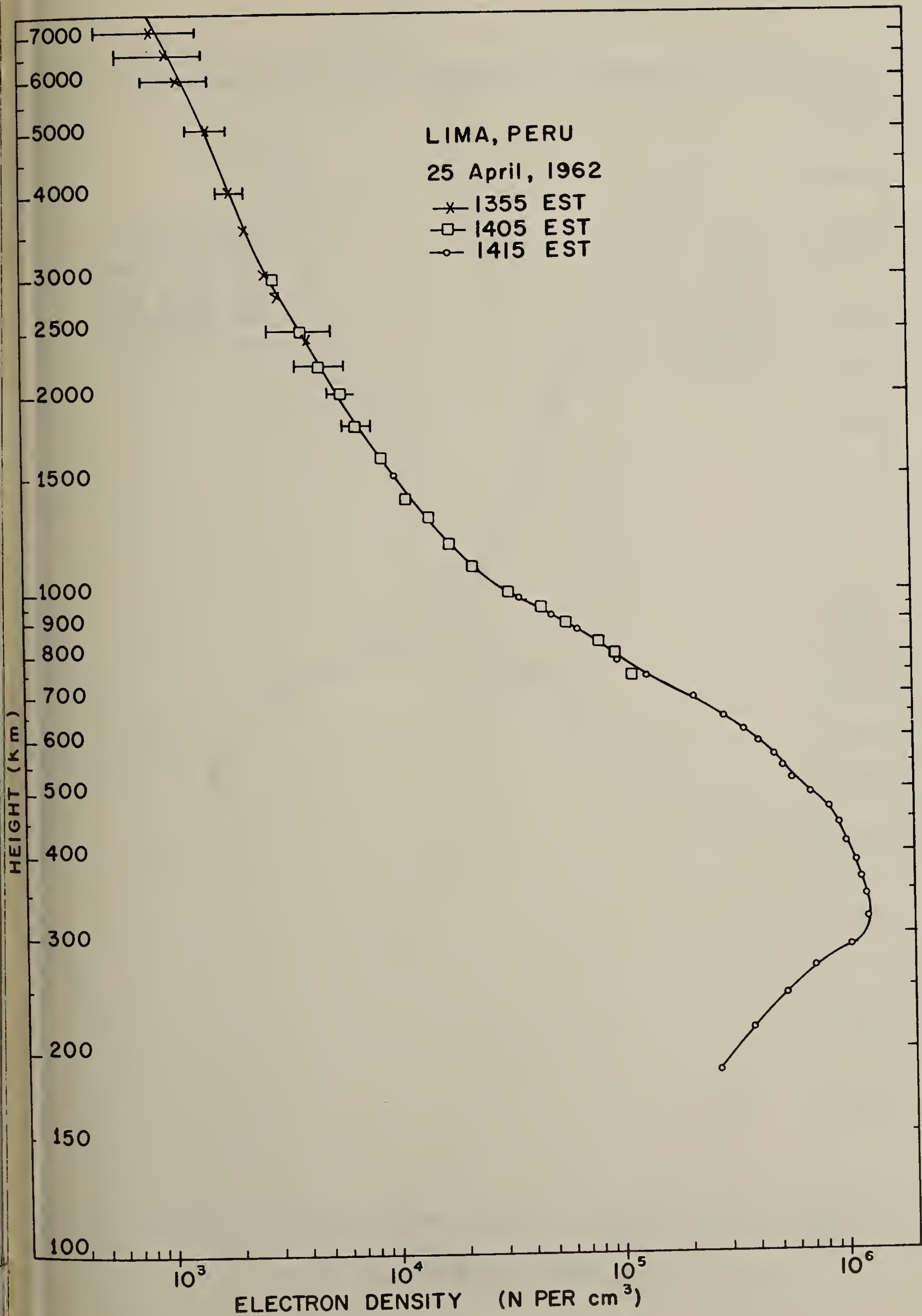
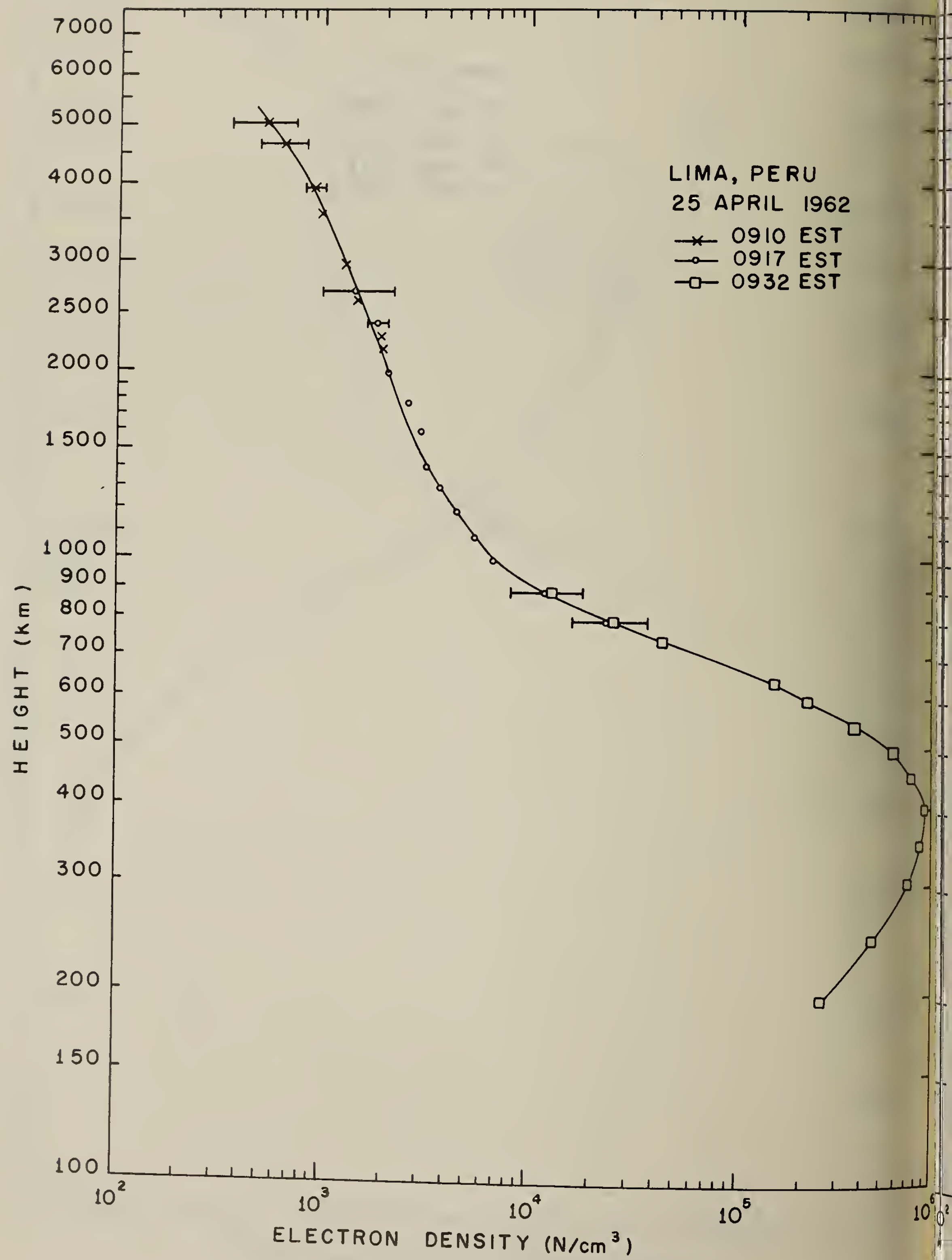
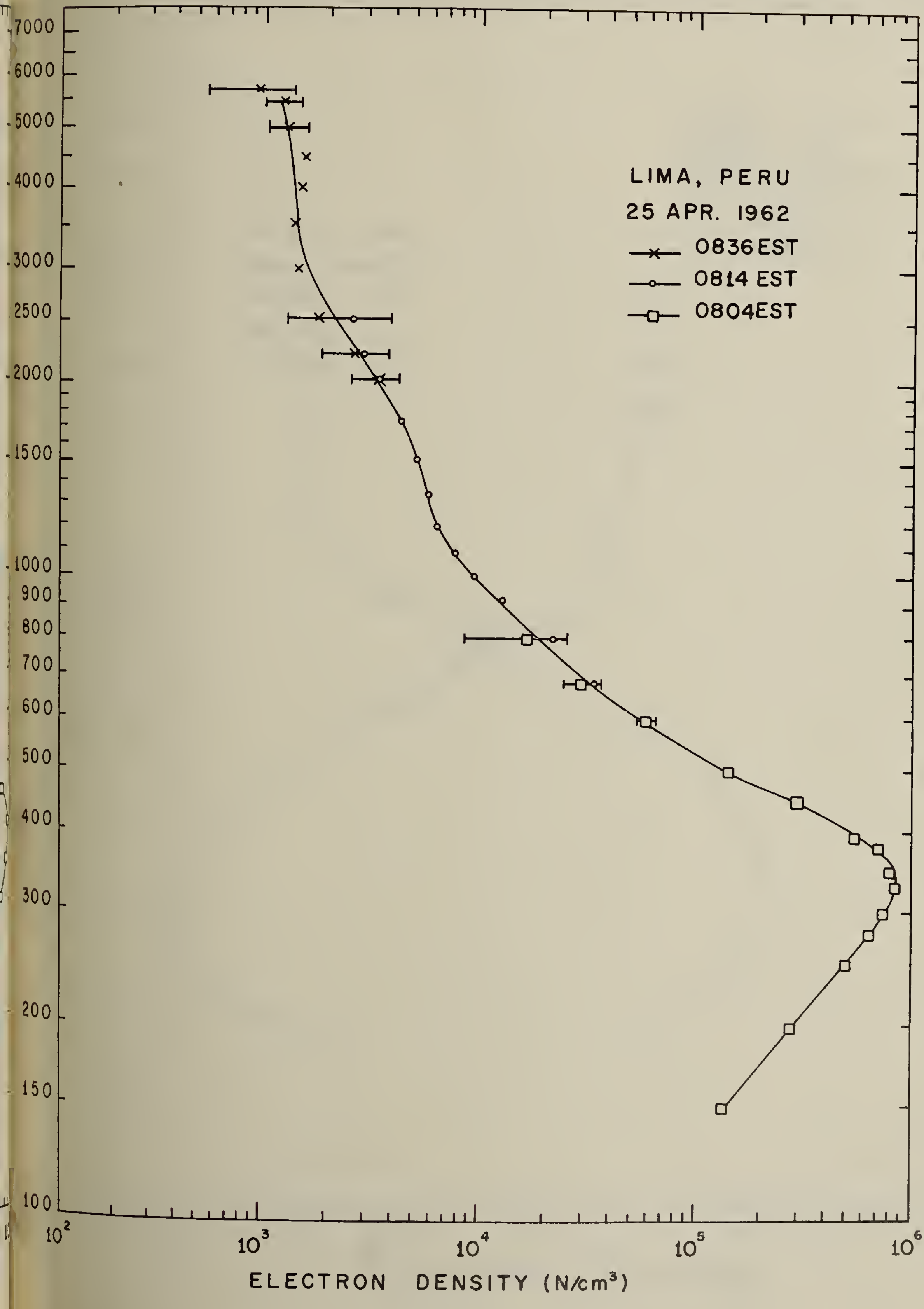
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
ELECTRON DENSITY (N PER cm³)
10³
10⁴
10⁵


LIMA, PERU
25 April, 1962
1355 EST
1405 EST
1415 EST
HEIGHT (km)
7000
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N PER cm^3)



LIMA, PERU
25 APRIL 1962
0910 EST
0917 EST
0932 EST
HEIGHT (km)
ELECTRON DENSITY (N/cm³)



LIMA, PERU
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0814 EST
0804 EST
7000
6000
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4000
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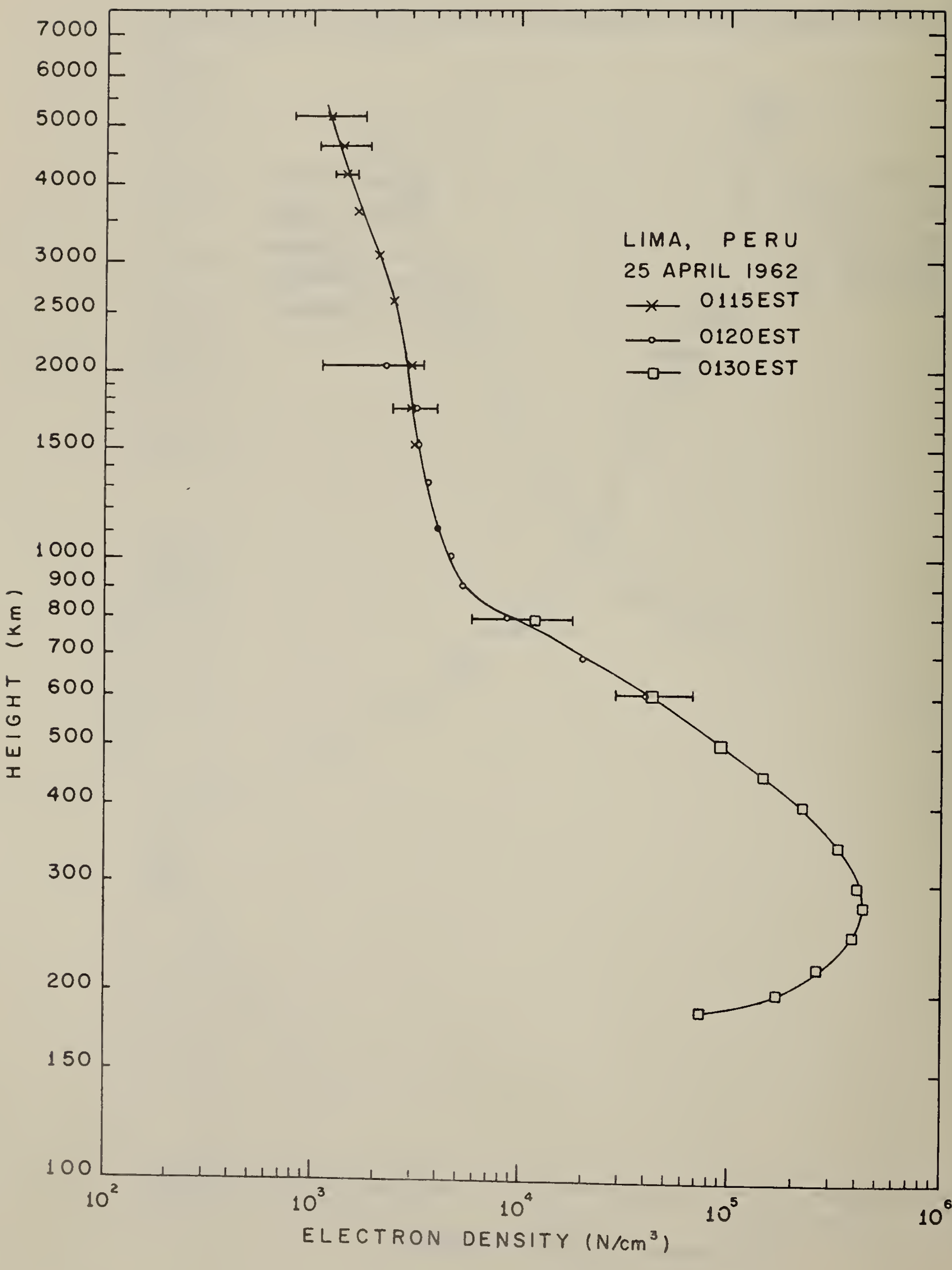
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
10^2
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm^3)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25 APRIL 1962
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0120 EST
0130 EST
HEIGHT (km)
7000
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
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500
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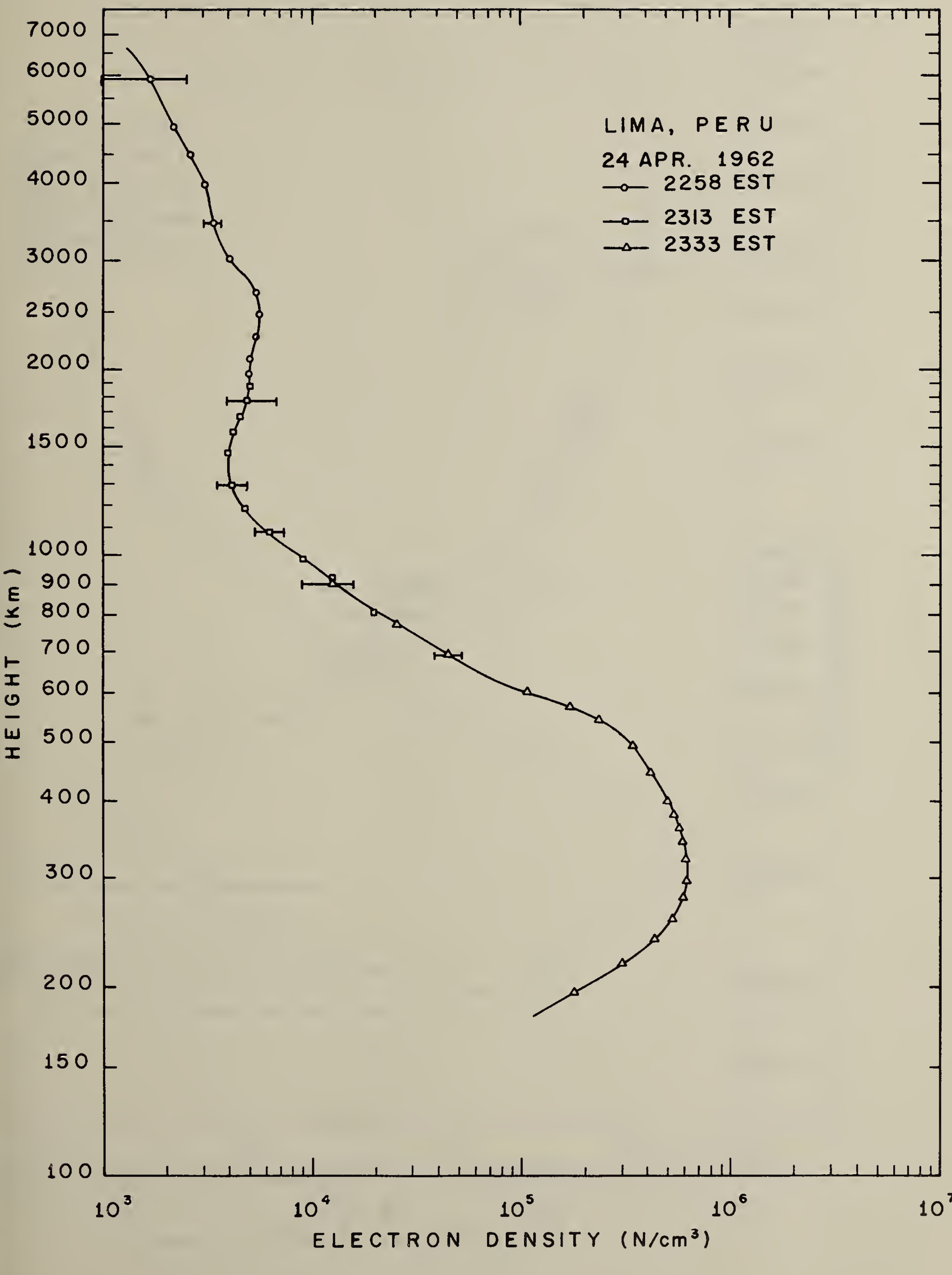
10^2
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm³)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24 APR. 1962
2258 EST
2313 EST
2333 EST
HEIGHT (km)
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1500
1000
900
800
700
600
500
400
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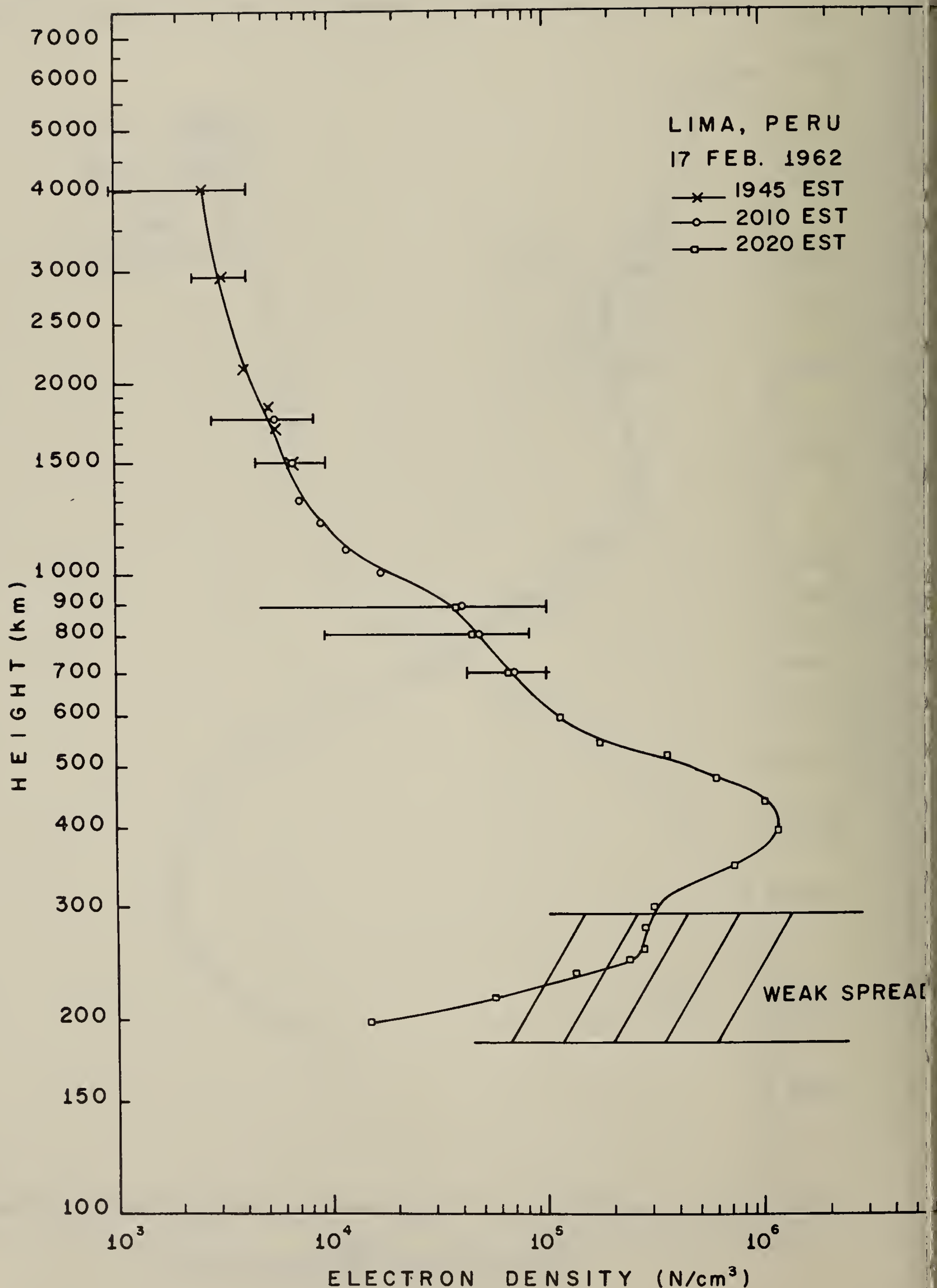
200
150
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (N/cm³)



LIMA, PERU
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1945 EST
2010 EST
2020 EST
WEAK SPREAD
HEIGHT (km)
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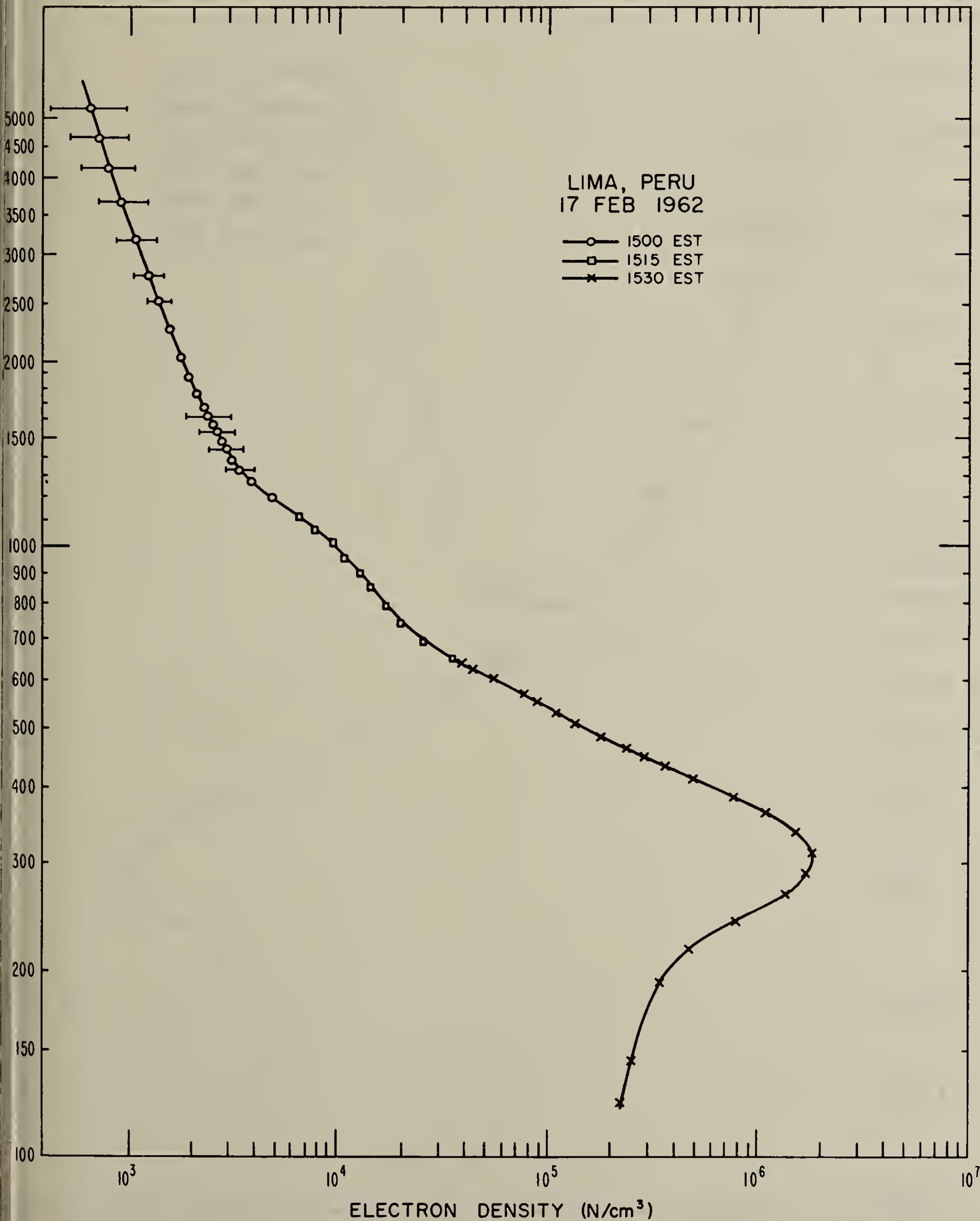
6000
5000
4000
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200
150
100
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm^3)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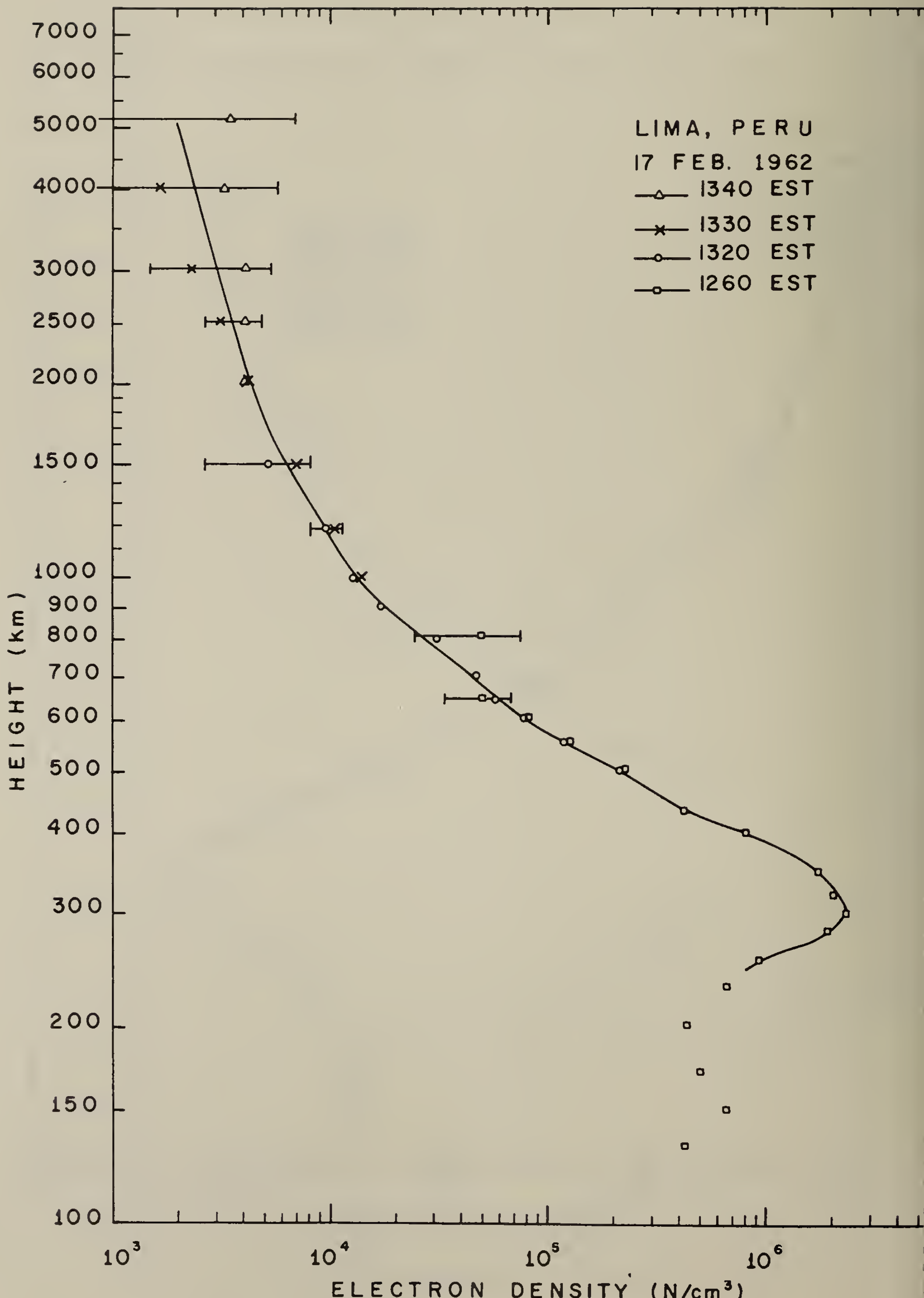
800
700
600
500
400
300
200
150
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (N/cm³)



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1260 EST
HEIGHT (km)
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5000
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3000
2500
2000
1500
1000
900
800
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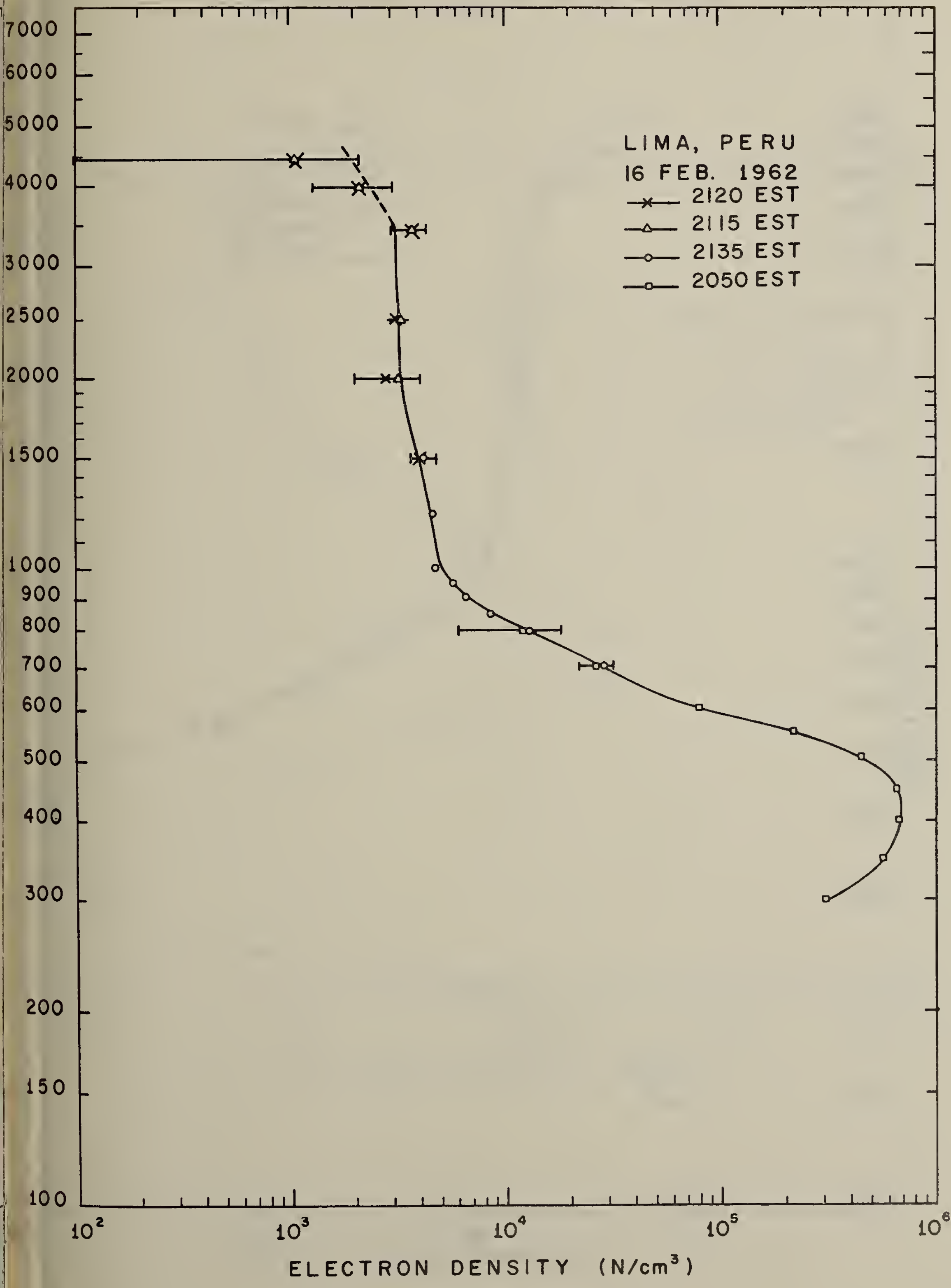
200
150
100
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm³)



7000
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5000
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3000
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2000
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1000
900
800
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600
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300
200
150
100
LIMA, PERU
16 FEB. 1962
2120 EST
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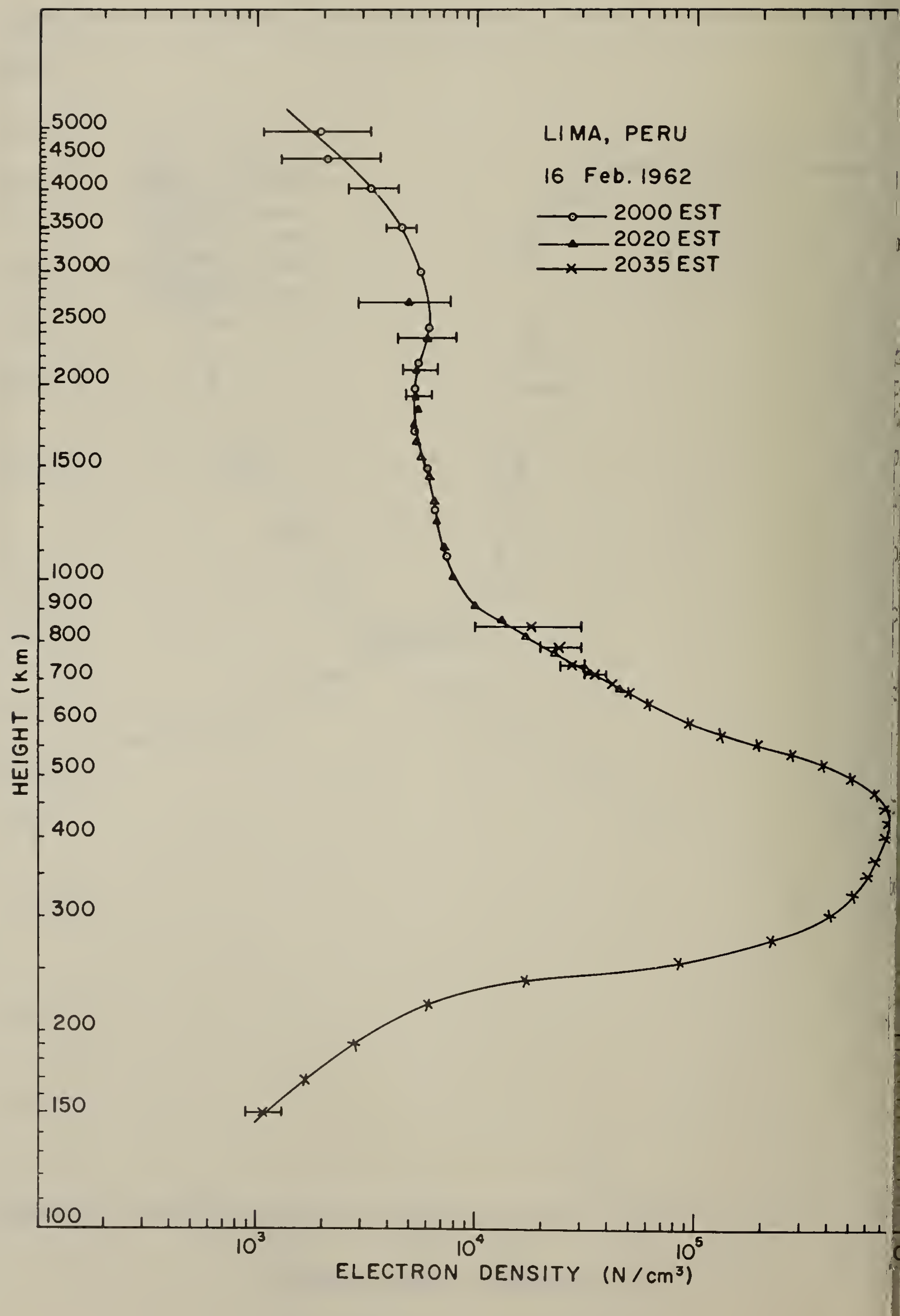
2135 EST
2050 EST
10^2
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm³)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16 Feb. 1962
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2020 EST
2035 EST
HEIGHT (km)
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3000
2500
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900
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700
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500
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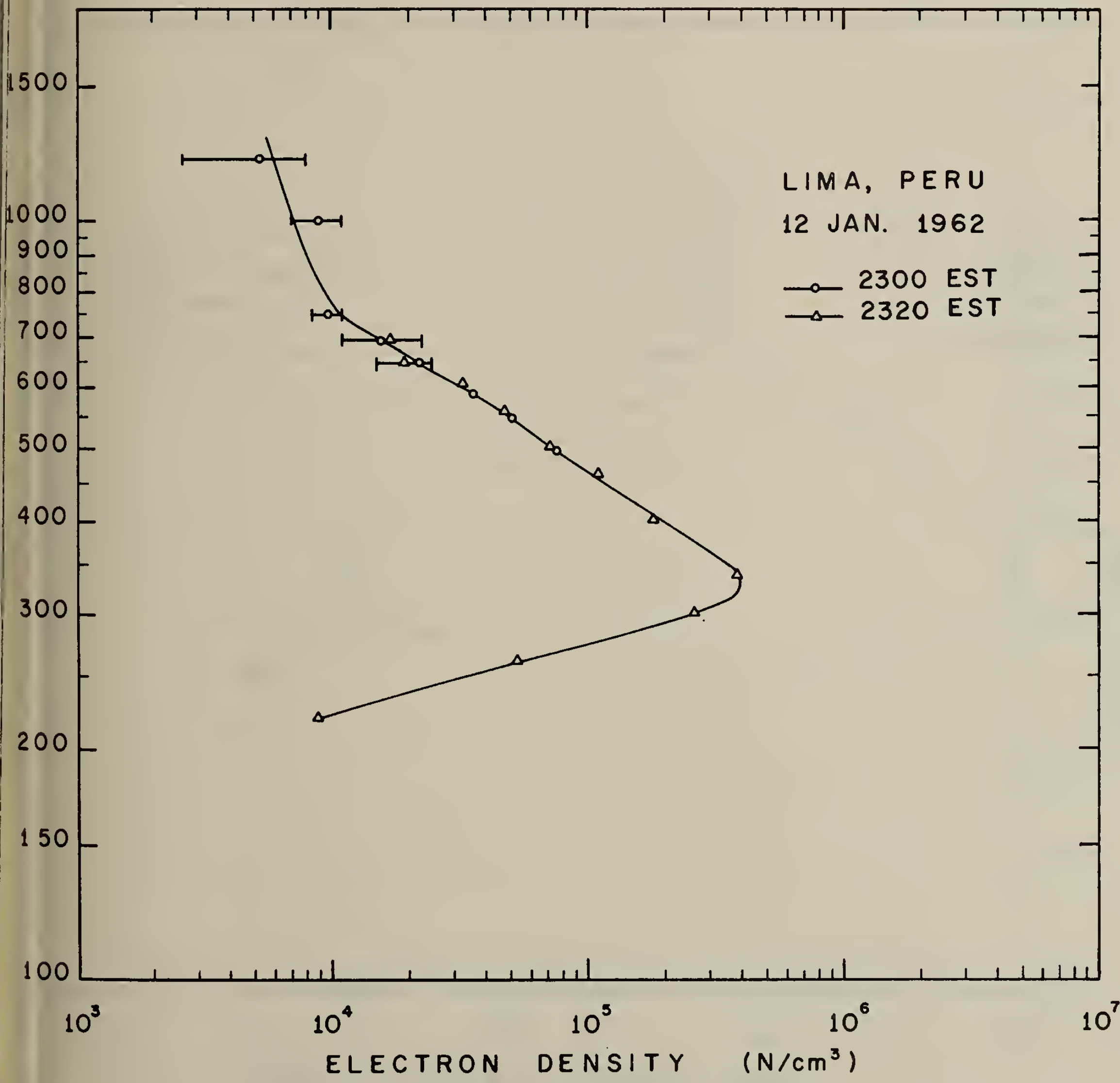
300
200
150
100
10^3
10^4
10^5
ELECTRON DENSITY (N/cm³)


LIMA, PERU
12 JAN. 1962
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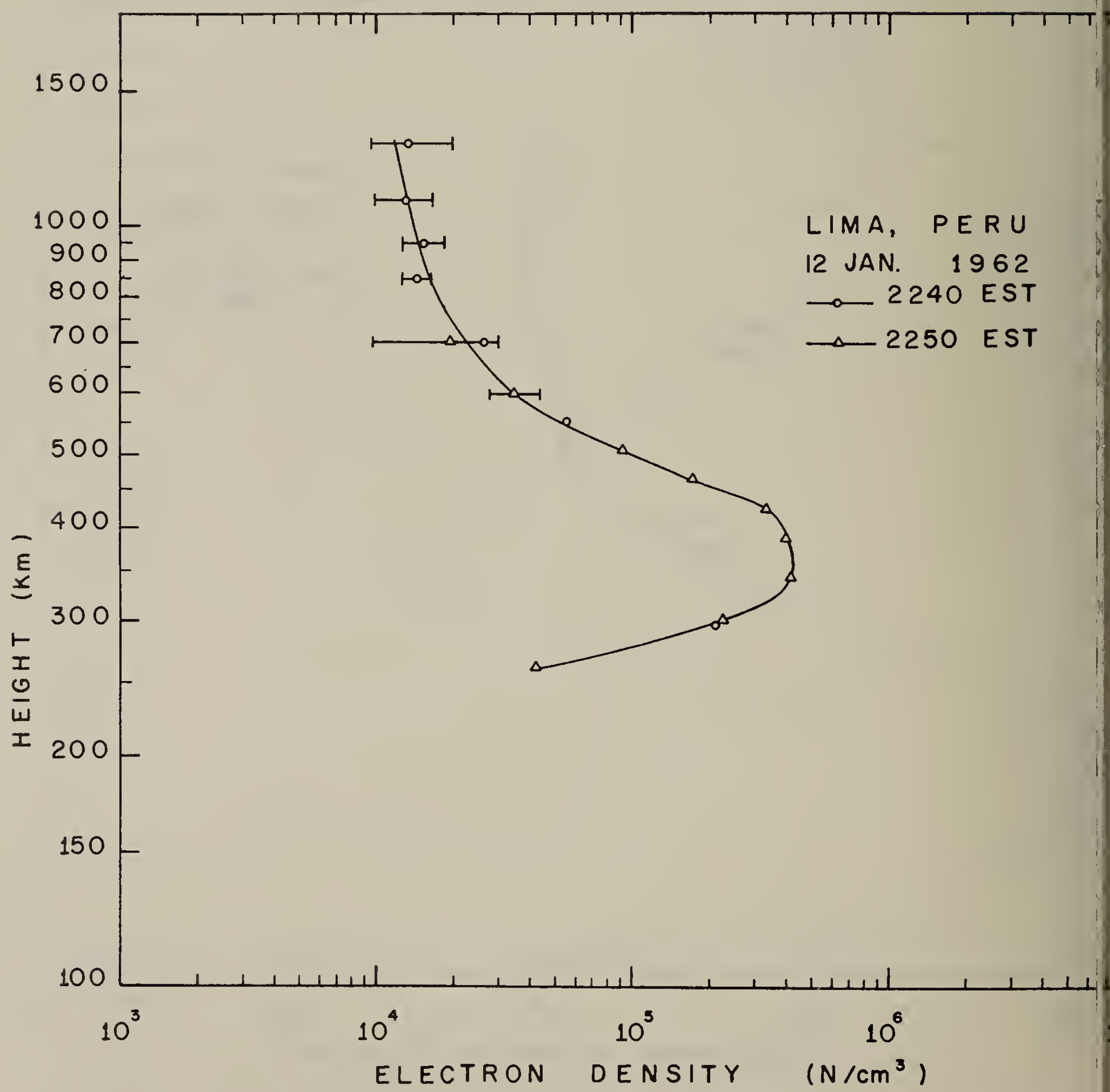
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (N/cm³)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1000
900
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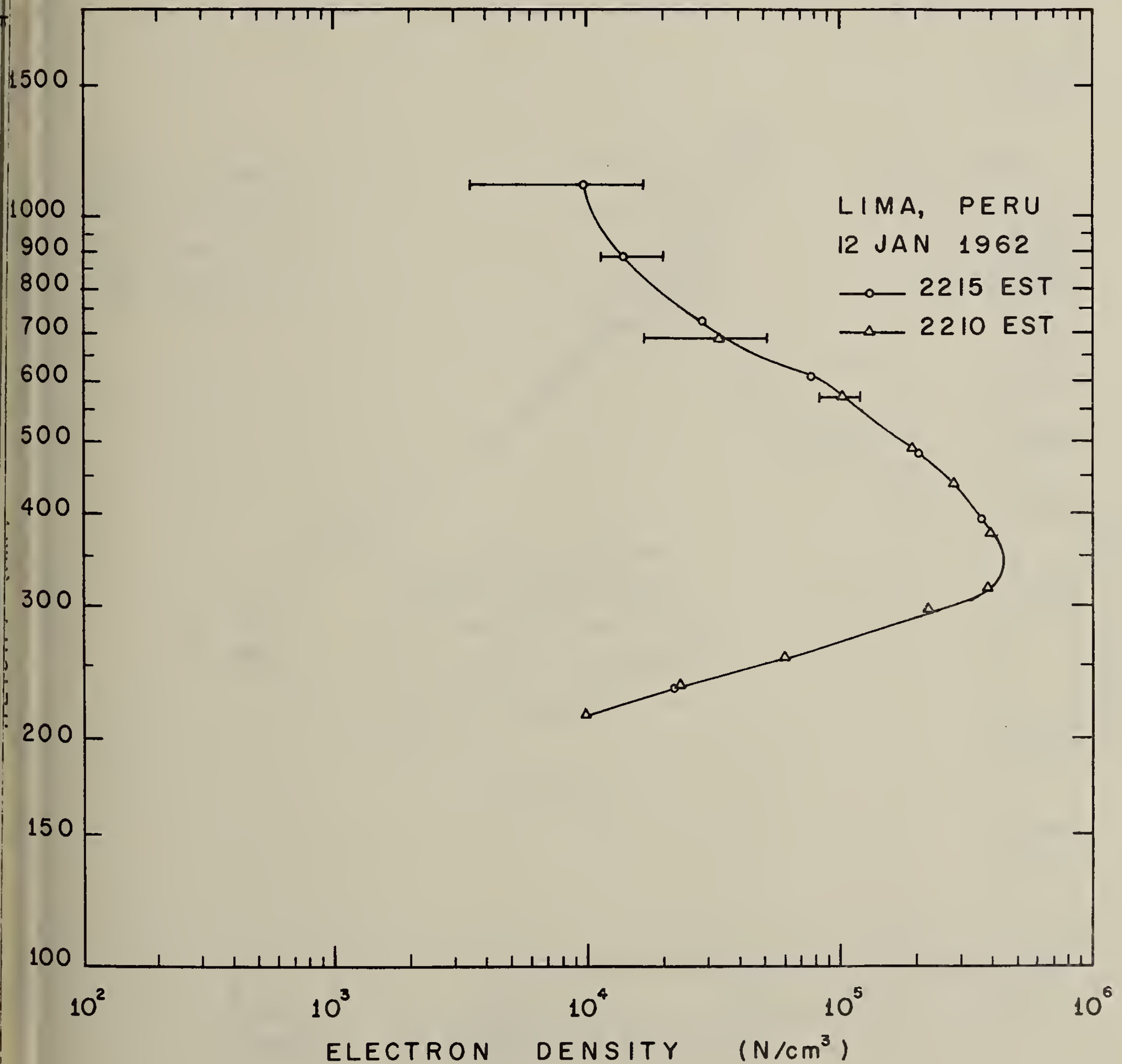
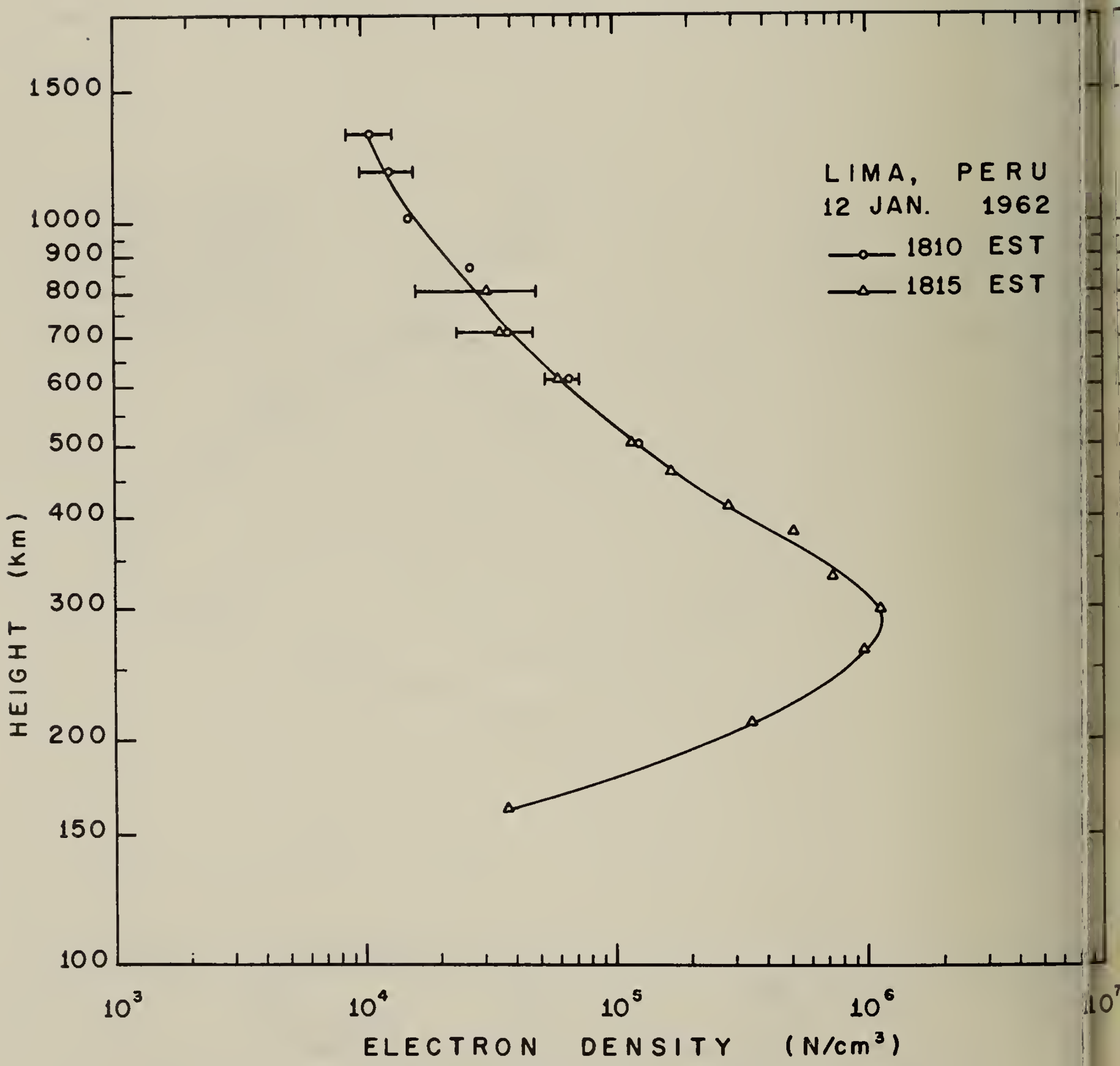
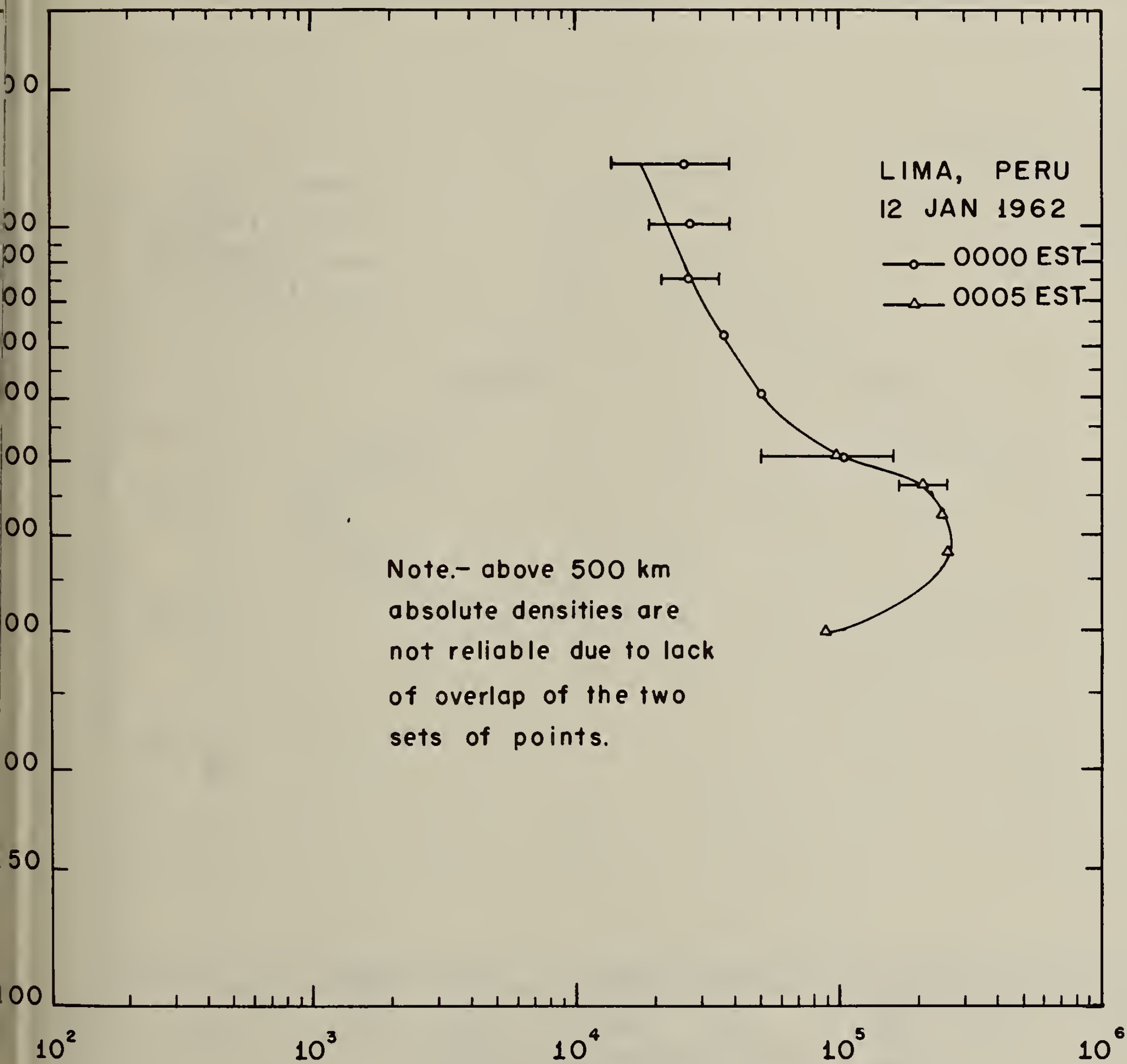
500
400
300
200
150
100
HEIGHT (Km)
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm³)
LIMA, PERU
12 JAN. 1962
2240 EST
2250 EST



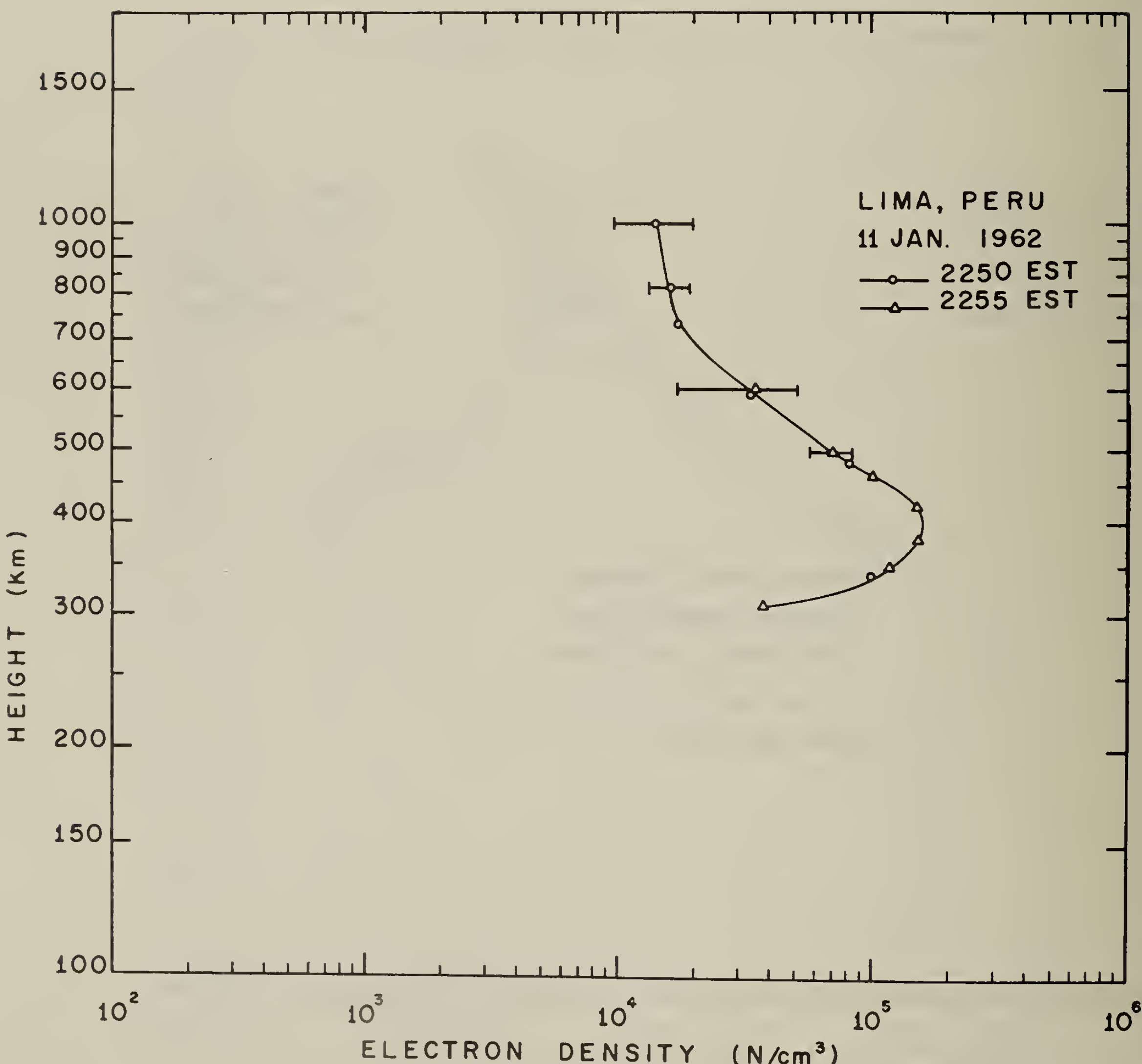
1500
1000
900
800
700
600
500
400
300
200
150
100
LIMA, PERU
12 JAN 1962
2215 EST
2210 EST
10^2
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm^3)



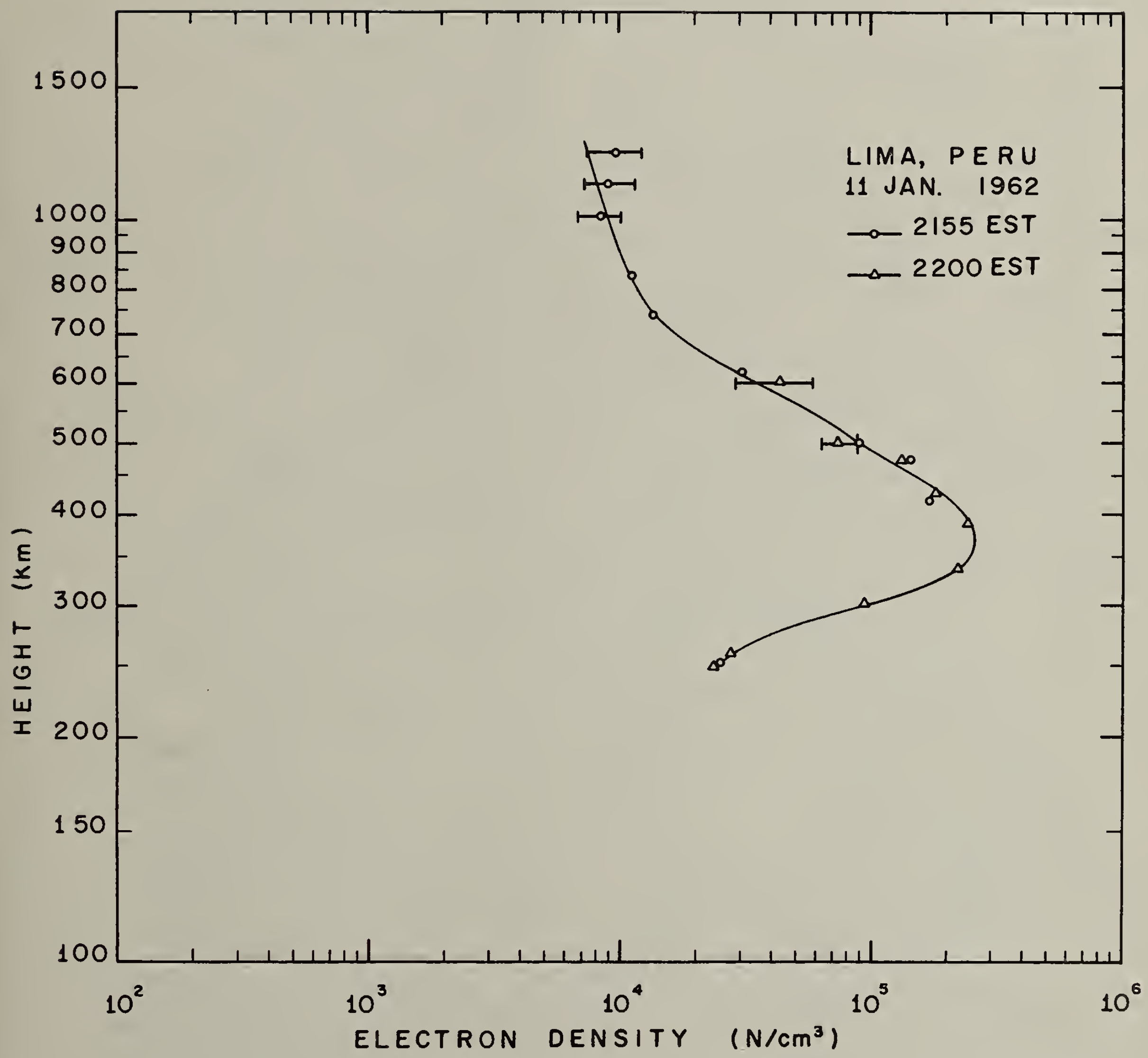
LIMA, PERU
12 JAN. 1962
1810 EST
1815 EST
1500
1000
900
800
700
600
500
400
300
200
150
100
HEIGHT (Km)
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (N/cm³)



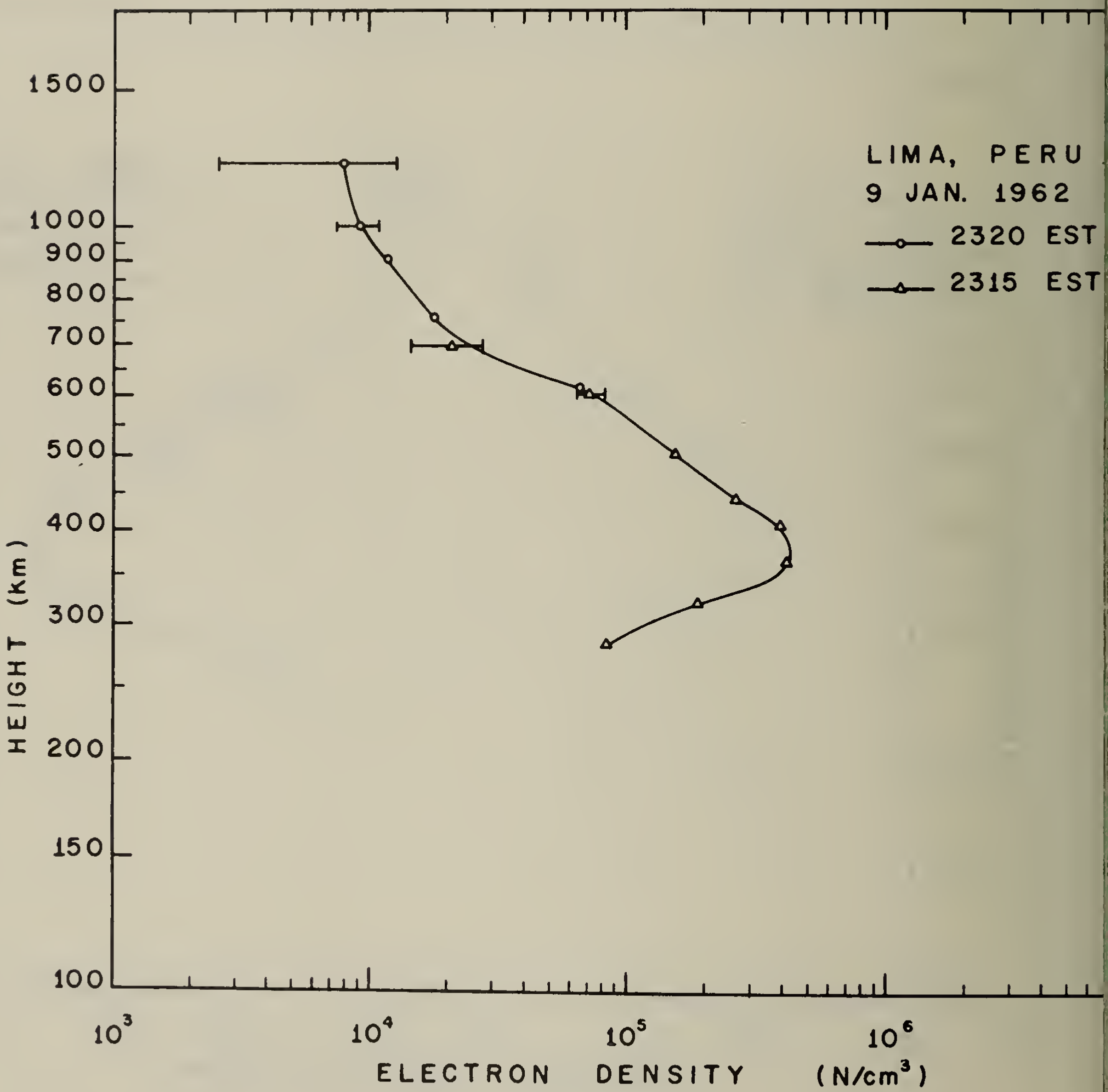
LIMA, PERU
12 JAN 1962
0000 EST
0005 EST
Note.– above 500 km absolute densities are not reliable due to lack of overlap of the two sets of points.
10²
10³
10⁴
10⁵
10⁶



LIMA, PERU
11 JAN. 1962
2250 EST
2255 EST
HEIGHT (km)
1500
1000
900
800
700
600
500
400
300
200
150
100
10²
10³
10⁴
10⁵
10⁶
ELECTRON DENSITY (N/cm³)



LIMA, PERU
11 JAN. 1962
2155 EST
2200 EST
1500
1000
900
800
700
600
500
400
300
200
150
100
HEIGHT (Km)
10^2
10^3
10^4
10^5
10^6
ELECTRON DENSITY (N/cm³)



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Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

NBS