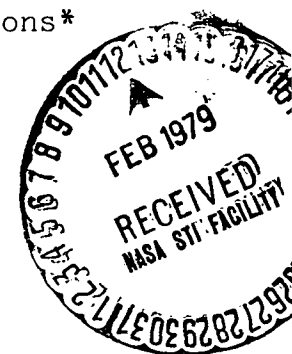# The Brightness Distribution of IRC +10216 at 11 Microns*

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ABSTRACT

The brightness distribution of IRC +10216 at a wavelength of 11 microns has been measured in detail using a spatial interferometer. This brightness distribution appears to have azimuthal symmetry; an upper limit of 1.1 may be set to the ellipticity at 11 microns if the object has a major axis oriented either along or perpendicular to the major axis of the optical image. The radial distribution shows both compact and extended emission. The extended component, which is due to thermal emission from circumstellar dust, contributes 91% of the total flux and has a 1/e diameter of $0.90''$. The tapered shape of this component is consistent with a $1/r^2$ dust density dependence. The compact component is unresolved (less than $0.2''$ in diameter) and represents emission from the central star seen through the circumstellar envelope.

I. Introduction

The bright infrared source IRC +10216 has an extensive circumstellar envelope of gas and dust. The dust component of this envelope is important in determining the overall spectral distribution of the radiation. The spectrum of IRC +10216 peaks in the infrared near 5 microns and is similar to that of a 650 K blackbody (Becklin et al. 1969). Dust which is optically thick at visible wavelengths presumably absorbs virtually all of the radiation from the central star and reradiates the energy in the infrared. Since the central object in IRC +10216 is thought to be a carbon star, the dust grains are likely to be composed of graphite and SiC. The presence of SiC grains in this object is inferred from the observation of an emission feature of these grains at 11.5 microns (Treffers and Cohen, 1974; Merrill and Stein, 1976).

Some studies of the size and shape of this object at infrared wavelengths have been carried out in order to determine the spatial distribution of the dust. The first size measurements were made by Toombs et al. (1972) who observed lunar occultations of IRC +10216 at four different infrared wavelengths. The results at 2.2, 3.5, and 4.8 microns were all fit by uniform circular disks approximately 0.4" in diameter. At 10 microns the source was spatially more extended and a more elaborate model was required. The authors chose to describe it in terms of two uniform circular components which were 0.4" and 2" in diameter and

which contributed equally to the 10 micron flux. Since then these two components have often been interpreted as discrete shells of material ejected from the central star, although the data were not sufficient to justify such a distinct division between the two components. Recently Selby and Wade (1979) have measured the size of IRC +10216 at 2.2 microns using a technique involving spatial-frequency filtering. They report a diameter of 0.35" as the equivalent width of a Gaussian model fit to their data, in agreement with the size reported by Toombs et al. at this wavelength. McCarthy (1979) has made size measurements at a number of infrared wavelengths which are also in qualitative agreement with Toombs et al. Information on the azimuthal shape of IRC +10216 has come primarily from less direct evidence. Shawl and Zellner (1970) found that the 1 micron radiation from this object was highly polarized along a position angle of 120°. In addition, the visual photograph published by Becklin et al. (1969) showed a diffuse image elongated along a position angle of 30°, which is perpendicular to the direction of polarization in this source. The ellipticity of the image (the ratio of lengths of major and minor axes) was approximately 2. Both of these pieces of evidence suggest that the short wavelength radiation is primarily light scattered by an asymmetric circumstellar envelope. At longer wavelengths the radiation comes from thermal dust emission instead of scattering. McCarthy (1979) has measured the shape of IRC +10216 at a wavelength of 5 microns and reports

it to be extended north-south. This direction, however,
bears no obvious relationship to the axis determined from
the scattered light. Thus a number of questions remain about
the brightness distribution of this source. Among these are
whether the 10 micron radiation comes from discrete shells or
rather a continuous distribution of material and whether the
azimuthal distribution of the infrared radiation has the same
symmetry as is observed in the visible. The interferometric
measurements reported here provide answers to these questions.

II. Observations

Observations of IRC +10216 were made at Kitt Peak National
Observatory[1] using the two 81 cm McMath auxiliary telescopes.
These telescopes are used as part of a heterodyne spatial
interferometer as previously described by Sutton et al.
(1977, 1978). The wavelength band of the observations, centered
at 11.106 microns and 0.1 cm^{-1} in width, was contained within
the 11.5 micron SiC emission feature commonly seen in carbon
stars.

The two telescopes of the interferometer were separated
by 5.5 meters in an east-west direction. Determination of a

[1]Operated by the Association of Universities for Research in
Astronomy, Inc., under contract with the National Science
Foundation

source's brightness distribution requires that the source be measured with a variety of interferometer baselines. Where it is not otherwise possible to change the baseline, the earth's rotation may be used to provide variation both in the length and orientation of the baseline as projected into the plane of the sky. For a source on the meridian the projected baseline always appears in an east-west direction in the sky and is the full 5.5 meters in length. Off of the meridian the baseline appears both foreshortened and rotated. These effects are the same in the eastern and western halves of the sky except that the sense of the baseline rotation is reversed. Thus by comparing observations at equal distances to the east and west of the meridian, an object can be viewed with identical resolutions but at different orientations. The range of baseline lengths which are practical for sources at the declination of IRC +10216 extends as short as approximately 2 meters, and the range in baseline position angles is roughly from 45° to 135°.

Fringe visibility measurements of IRC +10216 are presented in Figure 1. The data are divided into two parts corresponding to observations west and east of the meridian. The observations west of the meridian are from February and April, 1978 and are plotted in Figure 1a. Those east of the meridian are from November and December, 1978 and are plotted in Figure 1b.

III. Results

a) Azimuthal symmetry

The degree of azimuthal symmetry of the 11 micron thermal emission from IRC +10216 may be determined by comparing the two parts of Figure 1. The data measured to the east of the meridian, although of somewhat poorer quality, reproduce the visibility curve of the data from west of the meridian. Thus there is no evidence for asymmetry in this source at 11 microns. The most sensitive indication of angular shape comes from a comparison of the data taken at the extremes of baseline position angle, which are approximately 45° and 135°. From this, various upper limits may be set to the ellipticity at 11 microns depending on the assumed orientation of the major axis. If the position angle of the major axis is in the range from 30° to 60° or from 120° to 150°, the ellip- ticity must be less than 1.1. This range includes the direc- tion of linear polarization at 1 micron and its perpendicular, the major axis of the optical image, which are the two most likely axes for elongation. A less stringent limit on the ellipticity may be set if the major axis is assumed to lie outside of this range, although the limit remains less than 1.5 except for orientations within 5° of exact east-west or north-south. A north-south elongation such as that suggested by McCarthy (1979) at 5 microns can not be ruled out, and its presence would complicate the analysis which follows.

b) Radial brightness distribution

The radial dependence of the 11 micron brightness distribution may be determined from the data in Figure 1a. A good empirical fit is obtained with a simple two component model. In this model one component, which contributes the majority of the flux, has a Gaussian distribution with a full-width to 1/e intensity of $0.90''$. The other component has a diameter less than or equal to the resolution limit of $0.20''$. The fractional contribution of the smaller component to the 11 micron flux is somewhat dependent on its size. If it is as large as possible ($0.20''$ in diameter) it contributes 14% of the flux; if it is significantly smaller ($0.10''$ or less in diameter) its contribution drops to 9% of the flux. The remaining flux (in the latter case, 91% of the flux) is associated with the $0.90''$ component. In comparison with this, the model of Toombs et al. (1972) is distinctly different and does not fit the present visibility data as is illustrated in Figure 1. Nevertheless, their model is qualitatively correct in that their characteristic size for the object, as determined by an average of their $0.4''$ and $2''$ components, is comparable to the $0.90''$ diameter determined from this work. Also their use of two uniform circular components provides a rough approximation to the tapered shape of the Gaussian distribution used in this model. An alternative method for interpreting visibility data which avoids the artificial assumptions about component shapes inherent to model fitting

is given by a procedure similar to that used for "cleaning"
radio interferometry maps (Högbom, 1974). The results of
this procedure are shown in Figure 2. This picture of the
brightness distribution is virtually the same as that obtained
when the model described above is convolved with the synthe-
sized beam used in making this map.

In the outer parts of the distribution there is no
evidence for a concentration of dust at any unique radius.
Instead, the surface brightness drops off smoothly indicating
a continuous distribution of material. This implies a steady
rate of mass loss instead of a series of discrete events in
which shells of material were ejected from the central star.
If the rate of mass loss and the outflow velocity are both
constant, a $1/r^2$ density dependence is expected in the cir-
cumstellar envelope. Crabtree and Martin (1979) have shown
that a model based on such a density dependence is consistent
with the previous lunar occultation and interferometry data.
Such a model may also be used to provide a reasonable fit
to the surface brightness observed here.

The brightness distribution of the circumstellar envelope
may be calculated on the basis of a dust temperature depen-
dence similar to that given by Jones and Merrill (1976) and
a $1/r^2$ density dependence outside of some inner radius r_0
at which the grains are formed. No reasonable models have
been found which fit the data and have dust extending in
very close to the star. The data are best fit with an inner
radius of about $0.2''$ ($5 R_*$ for a stellar radius of $0.04''$). At

this radius the equilibrium temperature of graphite grains would be about 1000 K, which is lower than the ~1800 K condensation temperature for such grains. In this model, the optical depth of the circumstellar envelope at 11 microns must be approximately 0.5 in order to account for the total 11 micron flux observed from this object.

The central part of the brightness distribution contains an unresolved peak which in the two component model was described as being less than or equal to $0.2''$ in diameter and contributing from 9% to 14% of the total flux from IRC +10216. Additional evidence for a compact central component at 11 microns has been provided by the spectroscopic work of Betz, McLaren, and Spears (1979) who observed infrared lines of NH_3 in absorption against a central continuum source contributing approximately this fraction of the total 11 micron flux. This unresolved component is distinctly smaller than the region of dust emission and represents photospheric emission from the central star. In order for the central star to be seen, the dust can not be too optically thick at 11 microns, consistent with the optical depth of 0.5 determined above. This does not conflict with the view that the circumstellar envelope is optically thick at visible wavelengths due to the rapid drop in opacity expected with increasing wavelength. A carbon star with a temperature of 1800 K and a radius of $0.04''$ (1.2×10^{14} cm at a distance of 200 pc) could account for the flux observed in the unresolved component. These parameters

were chosen so that the luminosity of the star agreed with the observed luminosity of IRC +10216.

IV. Summary

The distribution of dust around IRC +10216 has been studied through measurements of the spatial distribution of the 11 micron radiation from this source. The circumstellar envelope probably has a high degree of spherical symmetry. In particular, the ellipticity of the object at 11 microns must be less than 1.1 if it has a major axis either parallel or perpendicular to the major axis of the optical image. The radial distribution does not consist of a few discrete shells of material, but instead may be characterized by a $1/r^2$ density dependence. This $1/r^2$ distribution starts at an inner radius of about 5 R_*. The optical depth of the dust is approximately 0.5 at 11 microns, and the central star may be seen through the circumstellar shell at this wavelength.

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Figure Captions

Figure 1. Fringe visibility data on IRC +10216. The solid
curves plotted with the data in parts a) and b)
are identical and are derived from a two component
model of the brightness distribution fit to just
the data in part a). The dashed curves represent
the fringe visibility calculated for the model of
Toombs et al. (1972). In these graphs the value
of the abscissa is proportional to the length of
the projected baseline at the time of each observa-
tion. The angular orientation of the baseline may
be read off of the graphs directly below the data.

Figure 2. Radial dependence of the surface brightness of
IRC +10216 at 11 microns. The source intensity is
normalized to 10^{-13}W cm^{-2}μm^{-1}. This map represents
the actual surface brightness distribution convolved
with the synthesized interferometer beam, whose
half-width-half-maximum is shown. Since the width
of the central peak in this map is comparable to
the resolution, the actual brightness distribution
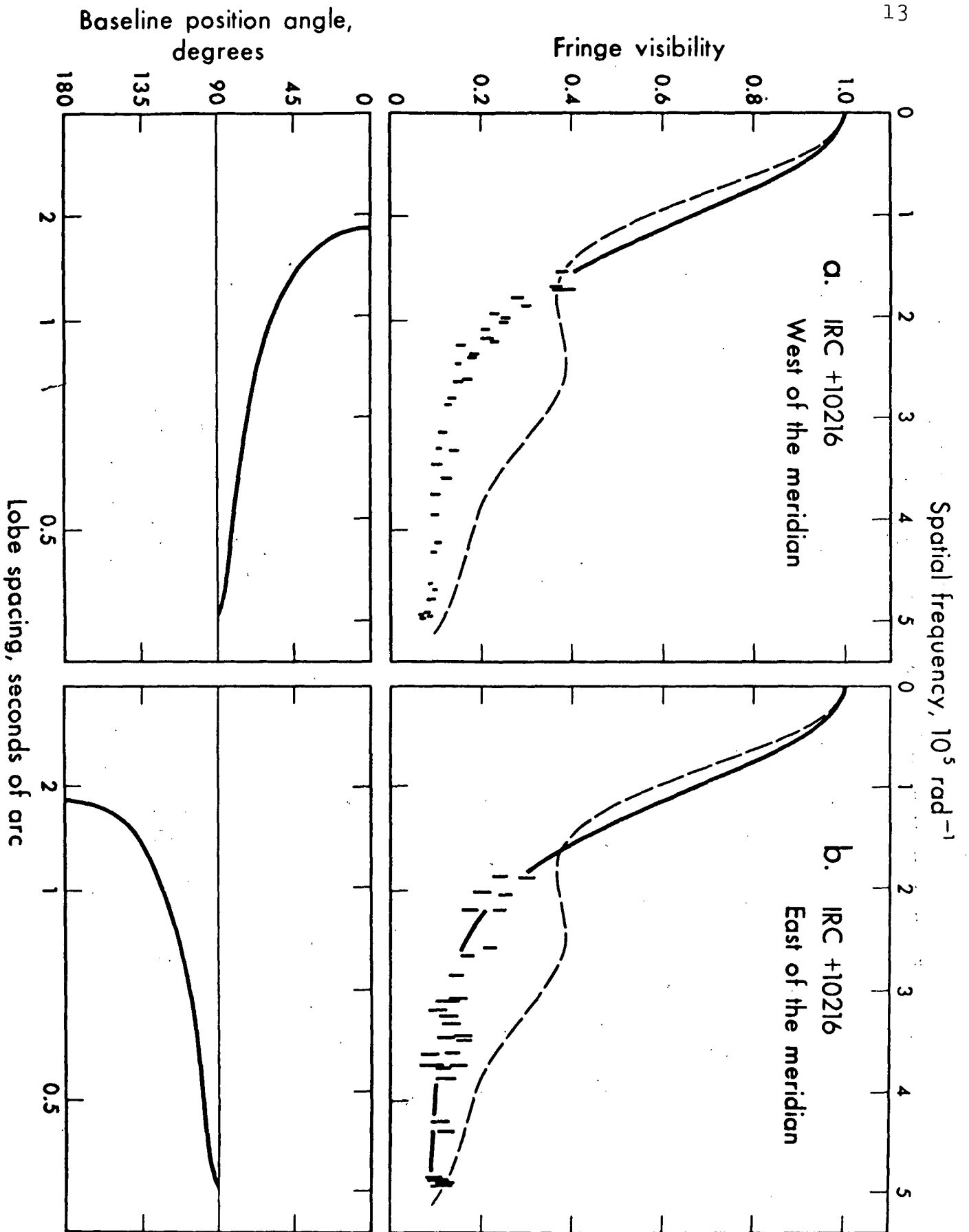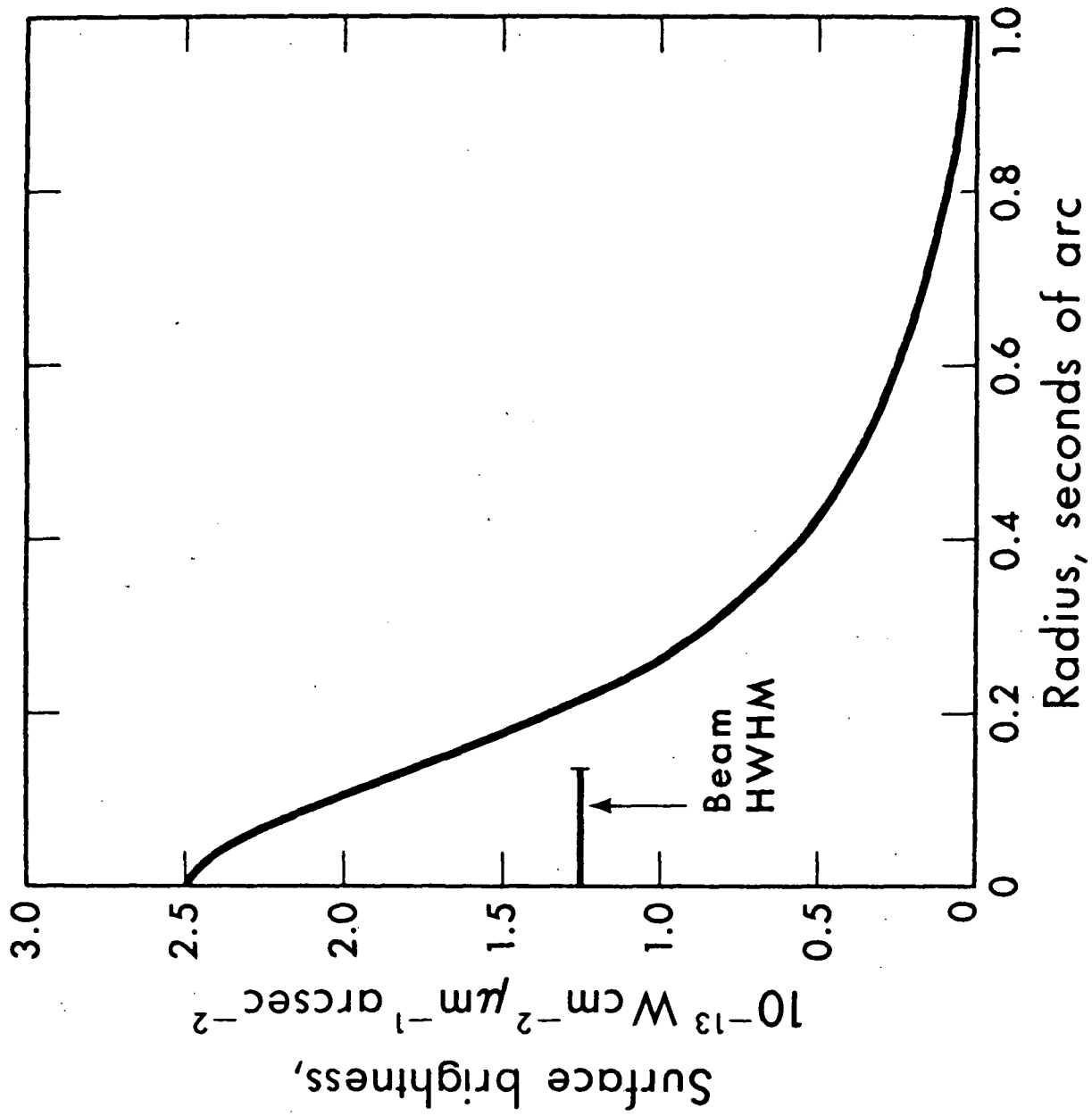contains a bright and compact central source.

Figure 1

Figure 2

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