N85-26549

ASTEROID AMPHITRITE: SURFACE COMPOSITION AND PROSPECTS FOR THE POSSIBLE GALILEO FLYBY.

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The asteroids are of fundamental importance to understanding the origin and evolution of the solar system for several reasons: 1) They probably represent remnants of the population of small bodies which accumulated to form the planets, and preserve an otherwise lost intermediate stage in the formation of planetary systems, between dust and planets; 2) Some of them have escaped the melting processes which have destroyed evidence of the original geochemistry in planetary rocks; 3) Study of meteorites has provided a vast body of geochemical, mineralogical, and isotopic data which probably refers to some asteroids; 4) The asteroid belt is located between the rocky inner planets and the the icy outer solar system and should preserve the compositional transition between these radically different classes of bodies. While much has been learned about the size, shape, and composition of asteroids from telescopic observations, no spacecraft has visited an asteroid. However, studies of the trajectory of the Galileo mission to Jupiter recently revealed that the spacecraft can pass close to one of the largest asteroids (#29 Amphitrite). NASA has therefore altered the mission plan of the Galileo spacecraft to include a possible close flyby of Amphitrite in early December 1986, if the condition of the spacecraft allows. If this option is actually implemented, Amphitrite will become the only asteroid for which any high-spatial resolution images and reflection spectra will be available. To evaluate the value of this data and place Amphitrite in the context of the more than 600 asteroids for which some compositional information exists, we have reexamined existing data, obtained new telescopic spectra of Amphitrite, and constructed simulated Galileo data sets.

Previous studies of Amphitrite have provided good information on its size and shape. Observations of infrared thermal emission indicate that Amphitrite has an average diameter of about 200 kilometers, and that its surface reflects about 15% of the sunlight falling on it. The amount of reflected light varies with a period of 5.39 hours in a highly irregular fashion, which indicates a jagged "pyramidal" shape with projections possibly as much as 30 kilometers above the mean radius. Attempts to deduce the orientation of the rotation pole from the light variations have produced solutions which differ radically; this parameter must be considered essentially unknown. Measurements of the polarization of reflected light indicate that the surface is covered with a layer of pulverized material, presumably created by small impacts.

Studies of the spectral distribution ("color") of reflected light provides the best means of determining asteroidal surface compositions. Data obtained in the visible spectral region (0.3 to 1.1 microns wavelength) indicate that Amphitrite belongs to the common spectral class S. These objects are characterized by strongly reddened spectral curves with shallow absorption bands diagnostic of the silicate minerals olivine and pyroxene. Among the 14 asteroid spectral classes identified in the most recent taxonomic analysis (by David J. Tholen, based on the University of Arizona 8-color asteroid survey), the S-types are the only abundant class with such complex spectra. Unfortunatly, this class is also the most controversial, with two opposing schools of thought supporting contradictory interpretations of the spectral data. The conventional method of interpreting asteroid spectra is to pulverize meteorite samples to approximately the texture of asteroid regoliths (as indicated by the polarization data), obtain spectra in the laboratory, and compare them with asteroid spectra. This is an imperfect technique, because some meteorite classes are very rare and museum curators dislike having them destroyed, and because many common types contain large masses or networks of nickel-rich iron alloy (with mechanical properties similar to man-made stainless steel) which makes them difficult to pulverize. In fact, none of the meteorite spectra obtained to date match the S-type asteroid spectra closely. This fact is explained in two ways: A.) The most common meteorites (ordinary chondrites) also contain shallow olivine and pyroxene absorption bands, but lack the steep red slope also present in S asteroids. Since the red slope appears in pure iron meteorites, slope should be correlated with metal abundance. Increasing the metal abundance in an S-type regolith would tend to increase the spectral slope. Therefore, the S-type asteroids are undifferentiated ordinary chondrites covered with a regolith whose apparent metal abundance is enhanced by the regolith-forming process. The simulated regoliths prepared from ordinary chondrites found on Earth do not spectrally resemble the natural regoliths on asteroids because their pulverization is an inadequate simulation of the real regolith-altering processes. B.) The spectral differences between S-type asteroids and ordinary-chondrite meteorites represent a real compositional difference. The lack of spectral matches for S-asteroids in the meteorite spectra collection is an artifact of the incomplete nature of that data set. S-asteroids are composed of differentiated stony-iron material similar to the pallasite and lodranite meteorites, for which no lab spectra have been obtained.

These two opposing interpretations have radically different implications in many areas. If interpretation A is correct, 1) the most common meteorites correspond to the most common asteroids; 2) asteroid spectra are highly nonrepresentative of the bedrock beneath; 3) S-type asteroids were only slightly heated and metamorphosed. If interpretation B is correct, 1) the most common meteorites have no known parent body in the asteroid belt, and the most common asteroid type is the source of some of the rarest meteorite types; 2) asteroid regoliths are merely pulverized bedrock and asteroid spectra are easily interpretable; 3) S-type asteroids were strongly heated and melted, but the segregation of silicate and metal components was still incomplete when the heat source decayed and the melt solidified. The controversy thus cuts to the very heart of asteroid and meteorite research.

Several lines of research over the past several years have converged to suggest that interpretation B is the correct one (see also paper by M. J. Gaffey at this conference). D. J. Tholen has defined a new spectral class "Q" of which asteroid #1862 Apollo is the prototype. Spectra of this object are nearly identical with that of some pulverized ordinary chondrites. About 10-20% of the asteroids of Earth-crossing orbits appear to belong to this class, which is totally absent in the main belt. The abundance of ordinary chondrites in meteorite collections may therefore be a artifact of current orbital relationships between their parent bodies and Earth. Gaffey has produced simulated ordinary chondrite regoliths in which the metal abundance is enhanced by magnetic separation. Surprisingly, even very metal-rich simulations show no increase in the red slope thought to be characteristic of nickel-iron metal. Apparently the spectral signature of metal in undifferentiated meteorites differs from that in differentiated meteorites. Gaffey also has made observations of asteroid #8 Flora (which has been nominated by promoters of interpretation A as the best match for ordinary chondrites) to search for mineralogic variations across its surface. Such variarions were found and exhibit trends not found in chondritic meteorites. J. F. Bell and B. R. Hawke have conducted the first comprehensive asteroid spectral survey in the near-infrared spectral region, which indicates that Gaffey's conclusions for Flora extend to S-type asteroids in general. Finally, a newly defined spectral class "A" has been shown by Bell to correspond closely to spectra of simulated stony-iron regoliths created by dispersing olivine grains on a metal substrate. This method avoids the problems of pulverizing metal-rich meteorites; with the addition of pyroxene it should be possible to simulate S-type regoliths as well. Recent observations by Bell and D. P. Cruikshank suggest that the S and A types are not distinct as indicated by earlier low-spectral-resolution data, and that both belong to a large and highly varied group of asteroids which is the source of most types of stony-iron meteorites. Despite these developments, several prominent and vocal supporters of interpretation A remain active; discussions between the two factions continue to enliven coffee breaks at scientific meetings.

As part of the infrared spectral survey mentioned above, J. F. Bell and B. R. Hawke obtained a spectrum of Amphitrite at the NASA Infrared Telescope Facility on 28 December 1983 which covers the 0.8-2.5 microm wavelength range. This is about half the wavelength coverage of the Near Infrared Mapping Spectrometer aboard the Galileo spacecraft (0.7-5.2 microns). In the attached figure this spectrum is combined with shorter wavelength data obtained by C. R. Chapman in 1971. From this it is apparent that Amphitrite has the typical S-type infrared spectrum. The absorption band near 0.95 microns is due to a combination of olivine and pyroxene bands, while the band near 2 microns is due to pyroxene alone. Comparison of the relative strengths of these bands with a calibration derived from lab spectra indicates that the silicates in Amphitrite are about 40% olivine / 60% pyroxene. Wavelengths of the pyroxene absorptions indicate a low-calcium, medium-iron pyroxene. The olivine abundance and pyroxene mineralogy are inconsistent with any type of chondritic meteorite. Together with the curved red continuum, this indicates a differentiated stony-iron assemblage according to the principles of interpretation C above. The only meteorites which could be derived from Amphitrite are a few rare "anomalous stony-irons" or "primitive achondrites", most likely the lodranites which are meteorites composed of olivine and pyroxene crystals enclosed in a metal matrix. The very small number of such meteorites relative to the large number of S-type asteroids makes it very unlikely that we have a fragment of Amphitrite available for analysis on Earth.

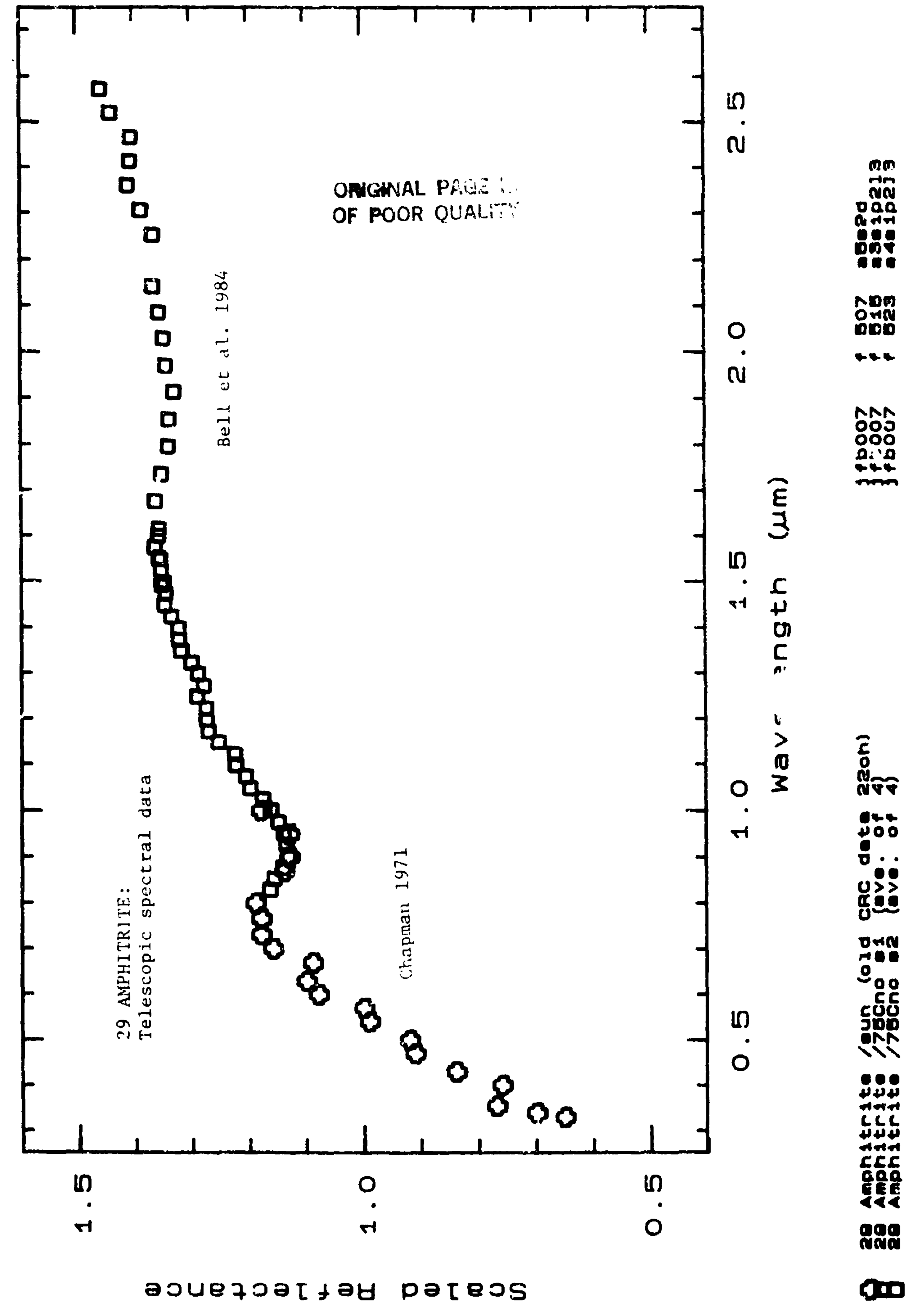
As an aid to Galileo mission planning, we have used our telescopic spectra to construct simulated mapping spectrometer data sets. These indicate that the instrument, although intended for compositional mapping of the satellites of Jupiter, is ideally suited for the Amphitrite encounter. Even in the lowest resolution modes useful compositional data can be obtained.

Since we already posess a spectrum of Amphitrite essentially identical to those to be returned by Galileo, how will the possible flyby data help us resolve the dispute outlined above? The spatial resolution possible with the

Galileo mapping spectrometer will allow the mapping of spectral units on the surface. Under interpretation A, Amphitrite should be essentially homogenous (except for small differences due to metamophism). However, if it has melted and differentiated to some extent, different depths should have different mineralogies. The highly irregular surface of Amphitrite was presumably created by impact erosion of a larger parent body, and higher "mountains" should correspond to shallower layers. Provided that the regolith gardening on the surface has not completely obscured the differences in the bedrock, the Galileo spectral maps should resolve radial differences in mineralogy. There is some evidence for spectral units on a hemispheric scale from telescopic data. Unpublished 0.3-1.0 micron, spectra obtained by Gaffey in August 1978 indicate variations in the spectrum on the order of 2% correlated with rotation. If these are real they suggest that we can expect a fair amount of structure in the spectral maps from Galileo. The authors plan to look for these variations with improved instrumentation during the May 1985 opposition of Amphitrite. In any case the Galileo imaging experiment will provide the first detailed information on the shape, crater density, and surface structure of an asteroid. At present these parameters are inferred from unconvincing theoretical models or analogies with the moons of Mars (which have a totally different composition and bombardment environment.) The irregular shape inferred for Amphitrite suggests that the images should prove highly interesting.

In summary, the Amphitrite encounter is the right mission with the right instruments to the right asteroid at the right time to fill major gaps in our knowledge of asteroids. It will provide a firm foundation for planning future dedicated asteroid belt missions and Earth-based observational programs.

FIGURE 1


J. F. Bell 2 Nov. 1984
29 AMPHITRITE:
Telescopic spectral data
Bell et al. 1984
Chapman 1971
Scaled Reflectance
1.5
1.0
0.5
Wave ngth (µm)
0.5
1.0
1.5
2.0
2.5
29 Amphitrite /sun (old CRC data 22oh) }fb007 ↑ 507 *5e2d
29 Amphitrite /78Cno #1 (ave. of 4) }f:007 ↑ 515 *3e1p213
29 Amphitrite /78Cno #2 (ave. of 4) }fb007 ↑ 523 *4e1p213