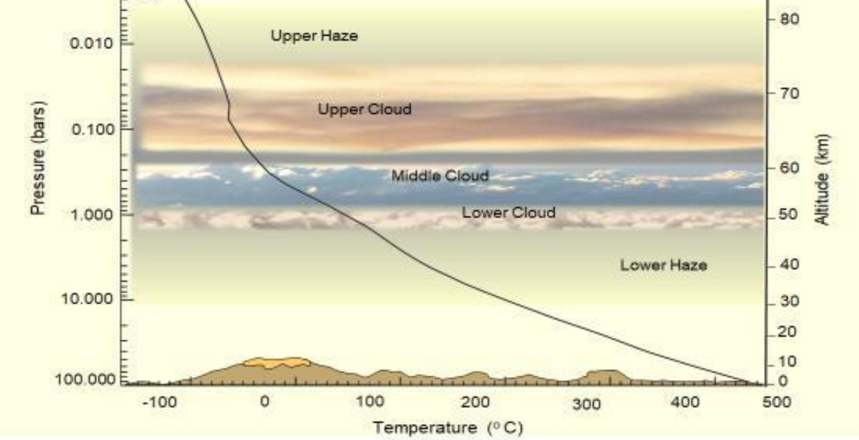

WHY SEARCH FOR BIO-SIGNATURES IN THE CLOUDS OF VENUS

Sanjay Limaye, Kandi Jessup a nd Mark Bullock

Venera-D Workshop on Habitability of the Cloud Layer on Venus

Space Research Institute, Moscow, Russia

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Two parallel themes for the search:

- Where there is water, there is life (as found on Earth)
  "Venus may have been the first habitable planet" – Way et al. (2016)

- Identity of substances responsible for absortion of solar radiation incident on Venus still unknown (besides SO2).

The unknown absorbers of sunlight in the atmosphere could be microorganisms considering that many terrestrial specimen have absorption properties that mimic the spectral absorption on Venus

Suggestive clues

- *Chemical disequilibrium in the atmosphere*
- *A puzzling detection of methane that cannot be explained as instrumental error (Donahue and Hodges, "Venus methane and water." Geophysical Research Letters 20(7): 591-594.)*

Finally, we cannot resist pointing out that many examples of anaerobic, terrestrial microorganisms are known in which the reduction or oxidation of various forms of sulfur are important sources of energy in their metabolisms. Such bacteria were very likely present on the Soviet Venera spacecraft and will be difficult to eliminate from the Pioneer-Venus entry probes. If these microorganisms do not find conditions in the clouds totally inimical, their effect on the energy balance of the planet may not be negligible.

Hapke and Nelson, Evidence for an elemental sulfur component of the clouds from Venus spectroscopy, JAS, 32, 1212-1218, 1975,

WHEREVER THERE IS WATER, THERE IS LIFE

https://mars.jpl.nasa.gov/programmissions/overview/

There are many other bodies with water in liquid or vapor form in the solar system: Venus, Earth, Mars, Europa, Enceladus and other icy moons of Jupiter and Saturn and even Pluto

Yet the focus has been on Mars for the last three decades with NASA and ESA missions

The Mars Science Laboratory mission and its Curiosity rover mark a transition between the themes of "Follow the Water" and "Seek Signs of Life." In addition to landing in a place with past evidence of water, Curiosity is seeking evidence of organics, the chemical building blocks of life. Places with water and the chemistry needed for life potentially provide habitable conditions.

The Defining Question for Mars Exploration: Life on Mars? *Why not Venus?*

Among our discoveries about Mars, one stands out above all others: the possible presence of liquid water on Mars, either in its ancient past or preserved in the subsurface today. Water is key because almost everywhere we find water on Earth, we find life. If Mars once had liquid water, or still does today, it's compelling to ask whether any microscopic life forms could have developed on its surface. Is there any evidence of life in the planet's past? If so, could any of these tiny living creatures still exist today? Imagine how exciting it would be to answer, "Yes!!"

- Presence of liquid water on the surface of Venus in the past inferred from elevated D/H ratio below the clouds compared to sea water on Earth
- The D/H ratio above the clouds found to be even higher above the clouds from Venus Express
- OH radicals escaping from Venus also detected by Venus Express
- Water vapor in the atmosphere has been measured by multiple experiments
- Clouds are made of droplets of dilute sulfuric acid solution (75-85%) with water
- Sulfuric acid has no absorption from UV to NIR
- Liquid water could have existed on Venus for up to 2 billion years (Way et al., 2016)

- If life evolved independently on Venus or was seeded by comets, asteroids, it could have survived in surface water.

- As the liquid water was lost from the surface life could have migrated to the habitable niche in the clouds where it could be extant today (Limaye et al., 2018)

- Terrestrial experience indicates that life survives and can exist the the clouds and in extreme environments and even under high acidity conditions

- ***Why shouldn't we look for signs in the habitable zone on Venus?***

The Case for Life at Venus

Viability of Venus to Host Extant Life Linked to Climate History

- **Inferred Water and Climate History**
- **Known Bulk and Trace Gas Species include:**

  CO_2, N_2, H_2SO_4, H_2O, SO_2, COS, CO, SO, HF, HCl, Fe, etc.

➢ **Many organic building blocks/biomarkers detected including phosphorus, COS, maybe CH_4!**

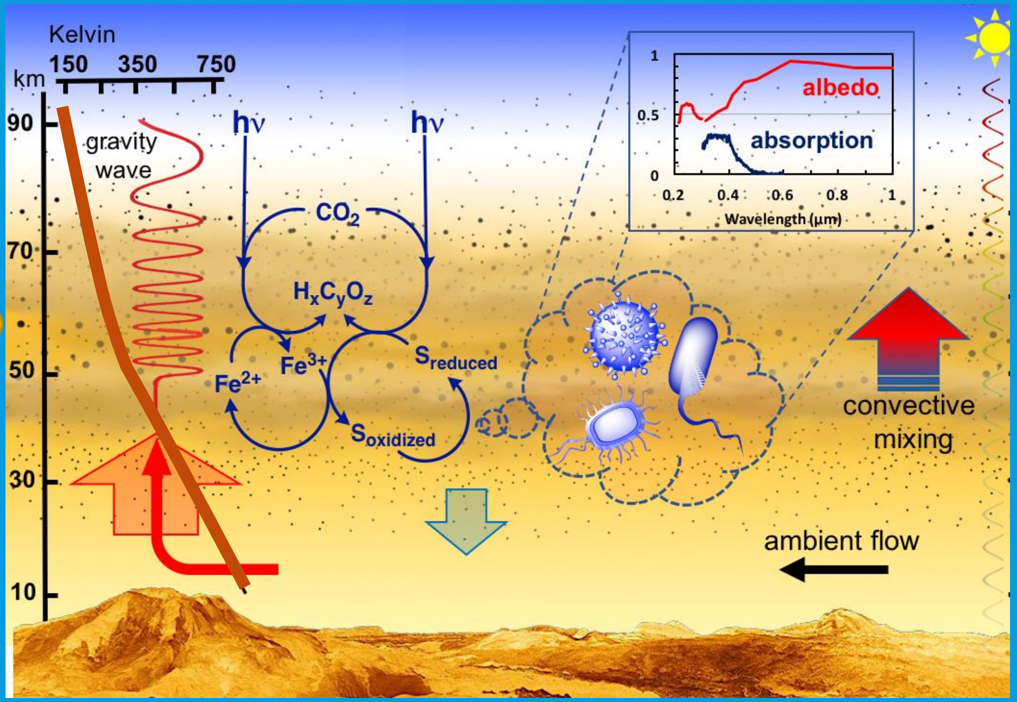
- **Observed environment:**

✓ H_2SO_4 + H_2O clouds represent persistent and ubiquitous habitable zone with nutrients, energy

P~ 0.04 to 0.54 bar

T ~ 230-347 K -43 to 70C

*

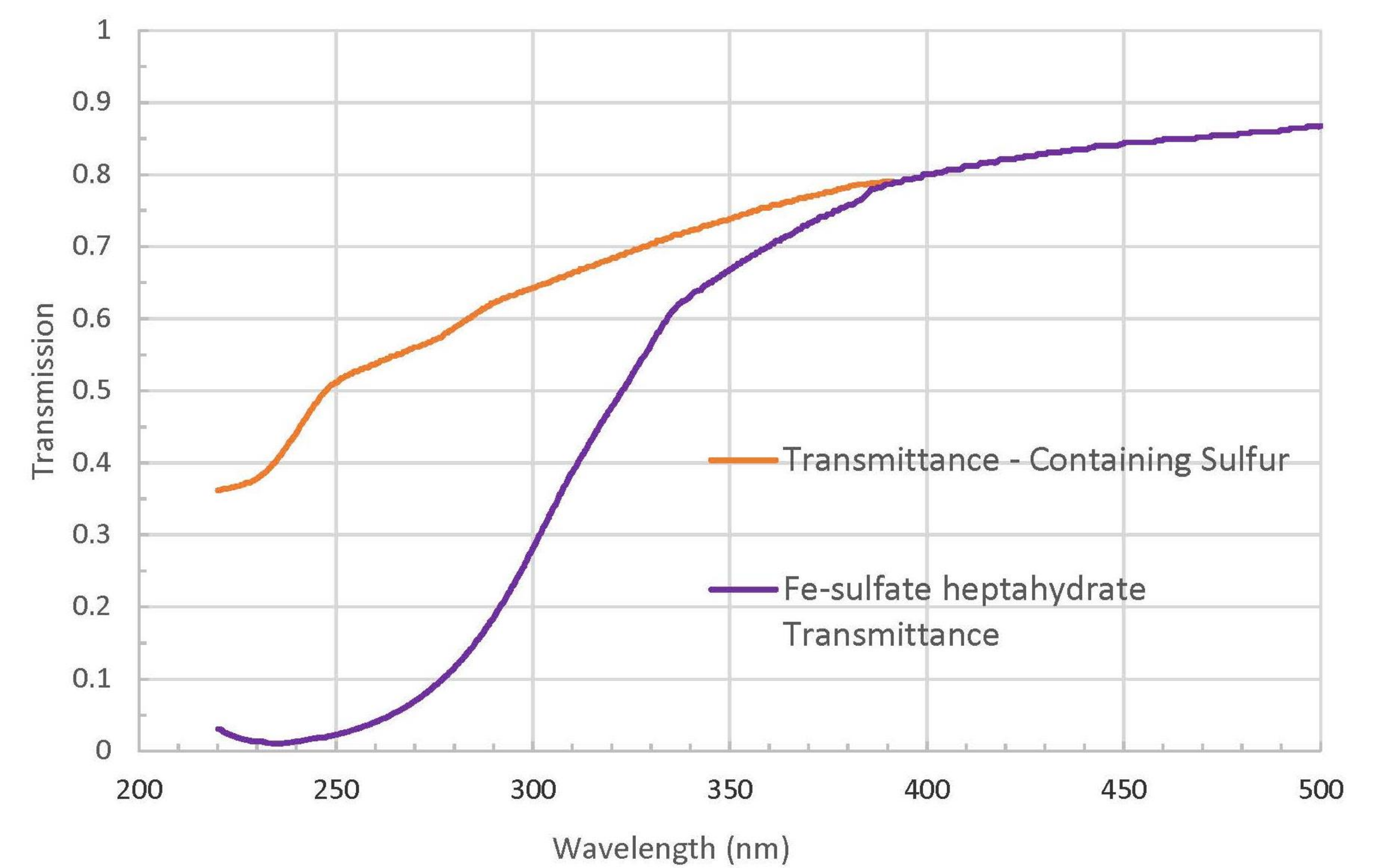


Limaye et al. Why Search for Bio-signatures in Clouds of Venus

Number	Absorber	Reference	Absorption Range (nm)	Remarks
1	SO2	Barker (1975)	240 - 330	
2	SO		UV	
3	COS	Krasnopolsky, 1986	240	
4	CS_2	Barker (1978), Young (1978)		
4	Disulfur Oxide and disulfur dioxide (OSSO)	Frandsen et al. 2017, Perez-Hoyos et al., 2018, Wu et al. 2018	320 - 400	Wu et al. (2018)
5	S_2O	Hapke and Graham (1985, 1989)	310-470, 650 - 740	
6	S_8	Hapke and Nelson (1975), Young (1977)	320-500	10 µm size grains of morphous sulfur
7	Amorphous sulfur (S3, S4)	Toon et al., 1982	UV	
8	SCl_2	Krasnopolsky, 1986	270 - 450	
9	Ammonium pyrosulfite. $(NH4)_2S_2O_5$	Titov 1983	320 - 500	
10	Nitrosylsulfuric acid $NOHSO_4$	Watson et al. 1979	250 - 500	
11	Carbon suboxide polymer	Sinton (1953), Shimizu, 1977	215	
12	Cl_2	Pollack et al. 1980	190 - 500	
13	Croconic acid - $C_5H_5O_2$	Hartley et al. 1989	220 - 420	
14	NO	Shaya and Caldwell 1975	215, 226.5	222.5 nm band never observed
15	N_2O	Shaya and Caldwell 1975	170 - 220	Abundance should reach 10^{-4} of CO_2 to explain absorption at 200 nm (Shimizu, 1977)
16	H_2S	Shaya and Caldwell 1975	180 - 230	
17	HNO_3	Shaya and Caldwell 1975	2000, 300	If mixed with H_2SO_4, absorption shifts to 260 nm (Shimizu 1977)
18	$FeCl_3$	Zasova et al. 1987	300-450	
19	$FeCl_2$	Kuiper, 1969	UV	
20	Perchloric acid ($HClO_4$)	Zahn et al. (1983)	UV	
21	Anhydrous silicate	Pollack et al. (1975)	2700 - 4000	
	Photosynthetic microorganisms	Grinspoon (1997)		
	Hypothetical Chemolithotrophic Microorganisms	Limaye et al. (2018)	Broad spectrum	Many terrestrial biotic materials and proteins have absorption features comparable to Venus spectrum

Absorbers proposed for UV absorption in the Venus atmosphere/clouds

UV spectrum of iron-sulfur proteins obtained after growth of T. ferrooxidans on medium containing iron sulfate heptahydrate (purple), sulfur (orange)



Więckowski, A.B., G.P. Słowik, J.A. Gąsiorek, P. Gąsiorek, F. Domka, and A. Perkowska, EPR study and structural aspects of ferredoxins obtained from Thiobacillus ferrooxidans, *Applied Microbiology Biotechnology (1999) 52, 96-98*

To resolve this issue, we must consider the following properties that the absorbers must meet either singly or together:

1. If particulate in nature, size parameters must match the observations.
2. If gaseous in nature, it must be inhomogeneous and compatible with the atmospheric composition, photolysis and ambient chemistry observed within the clouds.
3. Life times, local changes over time and space consistent with spatial and local time variations of the absorption properties observed within the clouds
4. Vertical distribution of absorption within the wavelengths where the mystery species is known to dominate Venus' radiance spectrum.
5. Spatial distribution at altitudes within the clouds from the candidate species consistent with that observed within the clouds, relative to the (Jessup et al., 2017b) temperature variations observed within the clouds with local solar time.
6. Plausible sources and sinks within the atmosphere or on the surface for the absorbers.
7. Optical properties must be consistent with night side near infrared opacity.

Questions/needs to be addressed:

Are the required abundances of nutrients and liquid water consistent?
Are the microorganisms able to reproduce within the atmosphere?

What studies/measurements are needed?
Capable aerial platforms to sample cloud layer for extended periods

Society of Venereal Biologists

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IN THE EARLY DAYS of NASA, much of the planning for space biology came before a group I belonged to, The Planetary Biology Subcommittee. Before Sputnik, the idea of experimental space biology had been an abstraction so that the "experts" were scientists from several domains who had an interest in the subject or were recruited for their expertise as biological generalists. Many of the early discussions, which took place in Washington DC, Cape Canaveral, Florida, Mountain View, California, and Houston, Texas, focused on which astral body was the most likely choice to search for extraterrestrial life. No one believed that the Moon was a possibility. The discussion tended to focus on the two most accessible planets, Mars and Venus, Mars being the heavy choice. One evening, after a day of discussion, four of the committee members thought that Venus might have been passed over too quickly, so we arranged to meet for dinner at the hotel. As the only survivor of that group, I feel that the time has come to reveal the results of that meeting.

The foursome consisted of Wolf Vishniac, then of the University of Rochester; Carl Sagan, then of Harvard; Kimball Atwood, then of the University of Illinois; and myself, then of Yale. The topic during the first cocktail was whether living forms were able to float in the dense atmosphere in a zone where the temperature might permit the stability of the covalent bonds and other structures we all felt were necessary for life. Very little was known about the extremely hot surface of our neighboring planet, including the amount and status of water in the atmosphere.

As the second cocktail appeared, someone began to worry that except for the four of us the biology of Venus might disappear as a subject of interest. (Through the haze of time I can't exactly recall who said what, so all attributions must be collective.) We decided to forestall any lessening of interest by forming a society dedicated to the study of life on Venus. The first suggestion was that it be called "The Society of Venutian Biologists." This seemed like an awkward name, lacking a certain rhetorical power.

We considered "The Society of Cytherean Biologists." This title was rejected as being too snobbish. We paused to order dinner, decided on another round of cocktails, and returned to the naming problem. I wish I could recall who offered "Society of Venereal Biologists." The name immediately won unanimous approval. Elections were held, and each companion was awarded high office by acclaim. I have never put it on my résumé, fearing that promotion and tenure committees would not understand, and now that my fellow officers are no longer with us I would deem it improper to claim honor for myself. It was truly a collective enterprise.

Although the society never met again, Carl Sagan and I continued to examine the Venus issue, and in September 1967 we published a brief analysis of the subject as a letter to the journal *Nature* (an abstract is shown next page). Although I have not followed this subject in any detail, I do notice an occasional article in the astrobiology literature in which the possible biology of the planet is reexamined. I don't think that we can rule out the possibility of Venusian life.

A few years later, Wolf Vishniac was in Antarctica searching for extremophilic microbial life in a Mars-like environment. While exploring in the dark he fell 500 feet from a cliff and died. In an obituary, Carl Sagan noted, "He is thus the first person since Bruno to lose his life in the pursuit of extraterrestrial life." Space biology lost one of its earliest and most brilliant devotees. Kimball Atwood moved from Illinois to Columbia, where he continued his distinguished career in several domains of biology. He passed away in October 1992. Carl Sagan, the leader of space biology and chief representative of that discipline to both the community of scientists and the broader public, died in 1996. His name is virtually synonymous with the search for life in the Cosmos.

And now, as last surviving officer of the Society of Venereal Biologists, I feel that the time has come to tell this story and to honor my fellow society members. They were pioneers of astrobiology and a wonderful group to have dinner with.

Address correspondence to:
Harold Morowitz
The Krasnow Institute for Advanced Study
George Mason University
Fairfax, VA 22030
United States

E-mail: morowitz@gmu.edu

Founding members:
H. Morowitz
Carl Sagan
Wolf Vishniac
Kimball Atwood

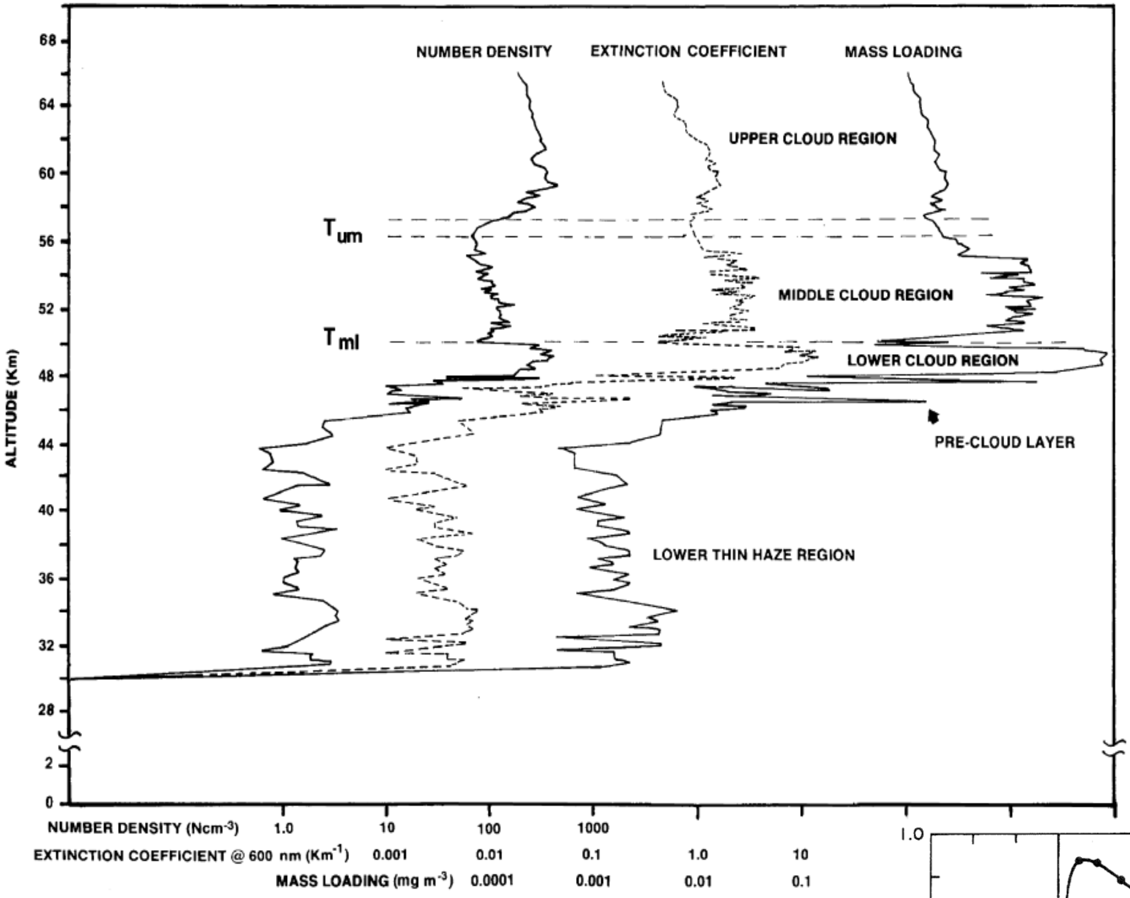

Figure 2. Cloud property vertical profiles. T_{ml} is the middle-lower cloud transition. T_{um} i
transition. [From *Knollenberg et al.*, 1980]

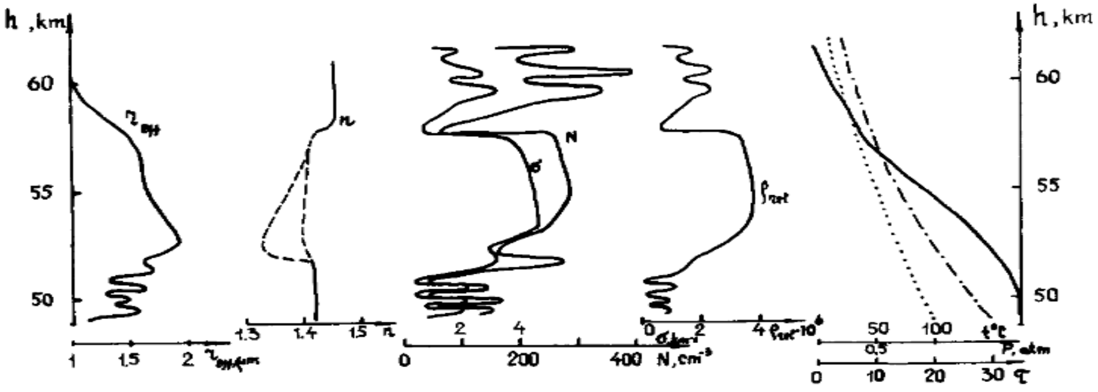

FIG. 28. Optical and structural characteristics of cloud aerosol versus *h*.

Marov et al. ICARUS 44, 608--639 (1980)

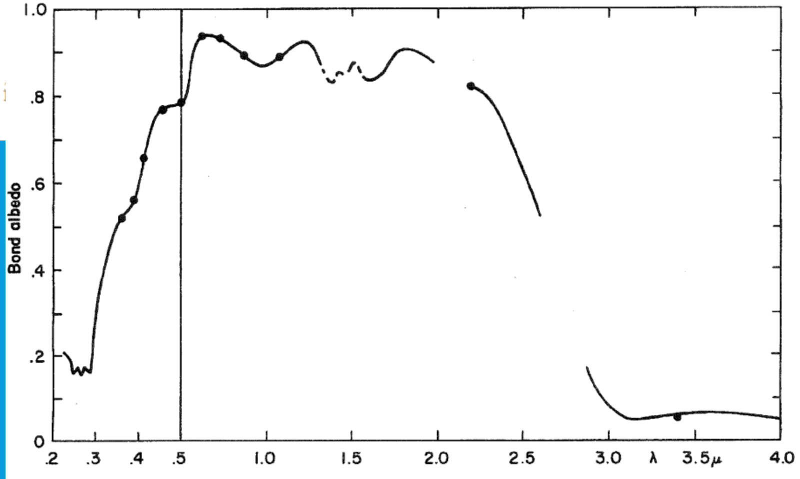

Fig. 2 Bond albedo vs. wavelength 0.2–4.0 μ. Sources described in text. Details near 1.5 μ somewhat uncertain.