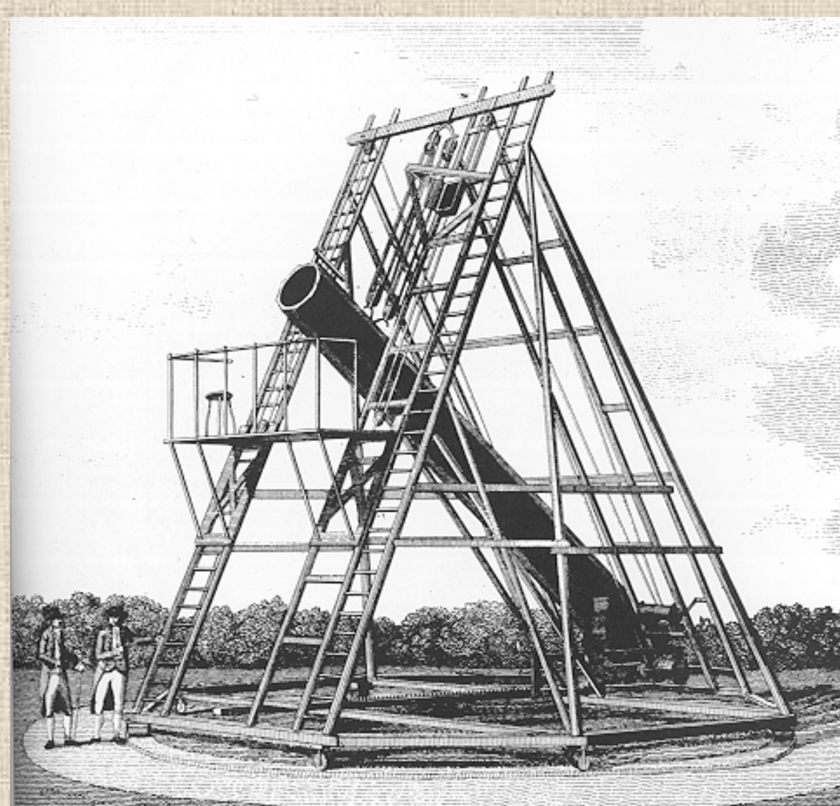
Before Phil Myers, dense cores were without form and void,
And darkness was upon the face of the deep.....

Vacancies in the Heavens:

The Discovery of Dark Nebulae

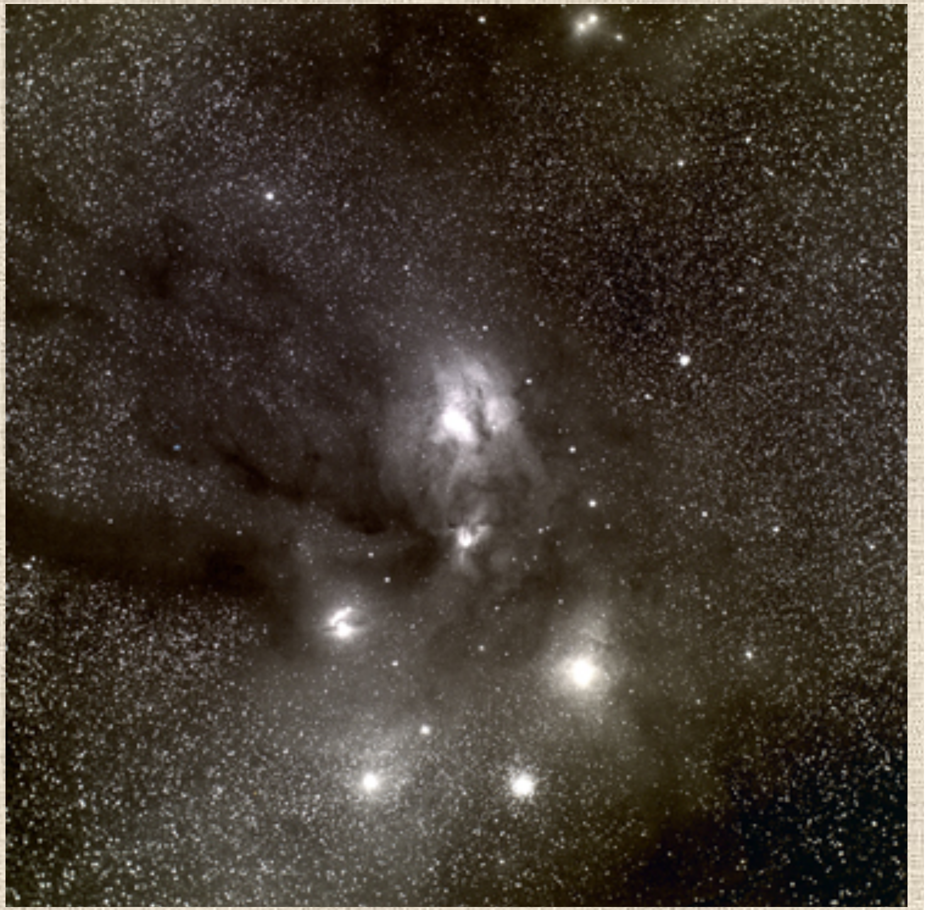
William Herschel
1738-1822



Caroline Herschel
1750-1848

An Opening in the heavens

"...for instance, in the body of the Scorpion is an opening, or hole, ...I found it while I was gauging in parallel from 112 to 114 degrees north of polar distance…As I approached the Milky Way the gauges were gradually running up …when all of a sudden, they fell to nothing!

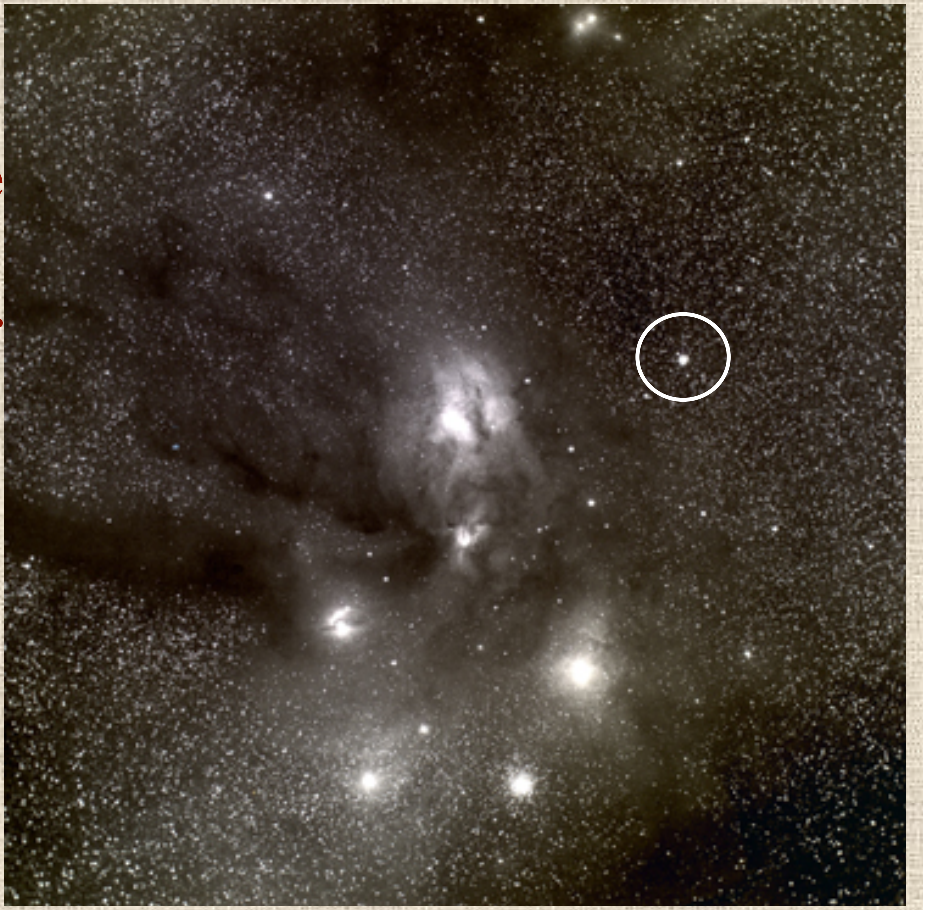


http://www.library.gatech.edu/barnard

William Herschel
1785, Phil. Trans. LXXV, pp. 213-266

An Opening in the heavens

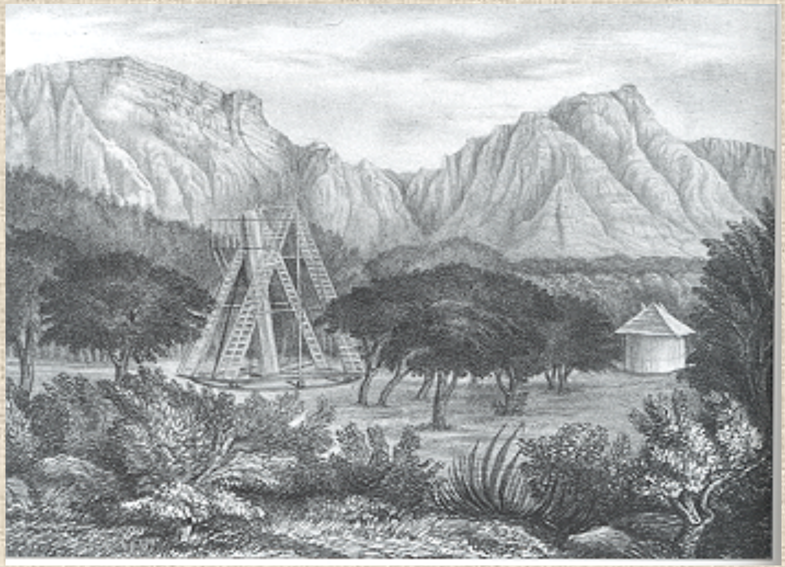
"...It is remarkable, that one of the richest and most compressed clusters of small stars I remember to have seen, is situated on the western border of it, and would almost authorise a suspicion that the stars, of which it is composed, were collected from that place and had left the vacancy."



William Herschel
1785, Phil. Trans. LXXV, pp. 213-266

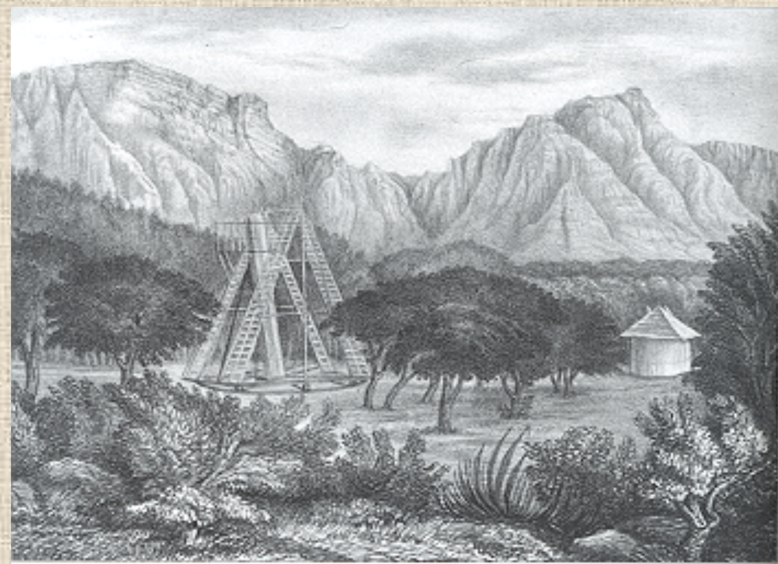
John Herschel
1792-1871

Feldhausen, South Africa:1834



"…for I remember your father returned several nights and years to the same spot but could not satisfy himself about the uncommon appearance of the heavens. It was something more than a total absence of stars."

Feldhausen, South Africa:1834



And "… remembering having once heard your father... exclaim, **'Hier ist wahrhaftig ein Loch im Himmel!'"**

First Catalog of Dark Nebula

1912 *The Scientific Papers of Sir William Herschel*, (London: The Royal Society & Royal Astronomical Society), Vol II, pg 712.

VACANT PLACES

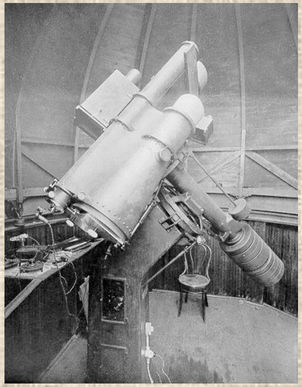
[*Extracted from the Sweeps. Places for the Year of Observation.*]

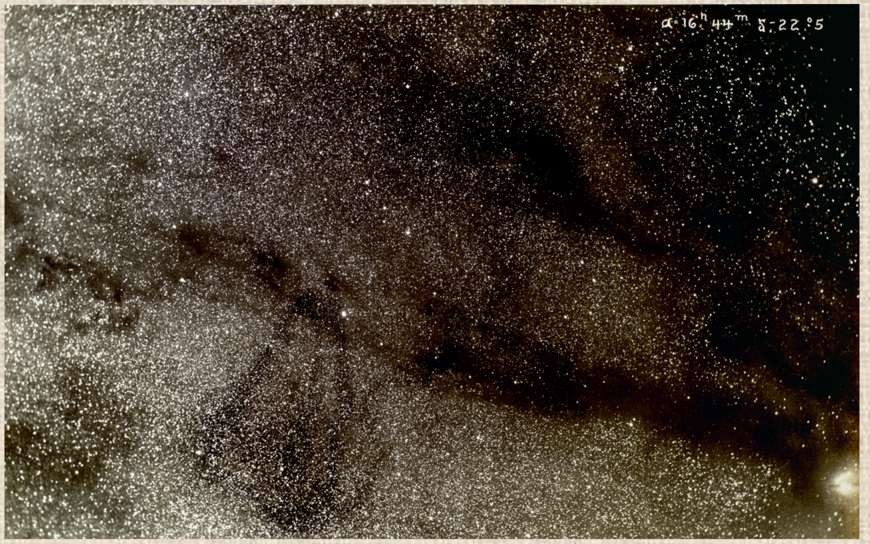
Sweep.	R.A.	P.D.	Stars.	
383 Mar. 10 1785	16 5 22	109 25	0	
	16 6 22	109 20	0	
	16 6 32	109 31	0	
	16 7 22	109 49	0	
	16 7 42	109 12	0	
	16 11 52	110 17	0	
	16 12 22	109 11	0	
	16 12 40	110 25	0	
	16 13 0	111 29	2	
485 Dec. 7 1785	4 17 37	65 29		Upper border of a vacancy, but it is a very irregular one.
	4 18 30	65 27		Do.
	4 19 17	65 29		Do.
	4 21 35	64 31	0	
	4 22 26	64 22	0	
	4 23 53	64 4	0	and many such in the neighbourhood.
	4 25 17	..		There is a vacancy between the bright row of stars in the direction of Orion's belt and the Bull's head, Perseus' body and the Milky Way, and I am now in that vacancy.
	4 27 26	65 4	0	
	4 28 6	64 10	0	
	4 28 42	65 11	0	Intermixed with places that have many stars.
	4 29 24	65 15	0	
	4 30 54	65 16	0	
	4 37 51	65 16	0	
	4 39 16	..		The straggling stars of the Milky Way seem now to come on gradually, most small.
	4 43 20	..		They begin now to be intermixed with some larger ones.
516 Jan. 30 1786	5 32 16	98 30	0	
	5 32 42	100 21	0	Vacant spaces picked out, between stars sparingly and irregularly scattered.
	5 33 5	99 33	0	
	5 34 40	100 39	0	
566 May 26 1786	16 8 52	113 18		Vacant between these two places.*
	16 9 12	112 25		
	16 11 56	112 53		From this place to the bottom of sweep [113° 20′] vacant.
	16 16 8	112 36		From these places downwards vacant, the night very fine.
	16 17 6	112 37		
	16 18 25	112 27		
	16 20 32	112 54		

* [Compare Vol. I. p. 253.—Ed.]

“...my own photographs convinced me...that many of these markings were not simply due to an actual want of stars, but were really obscuring bodies nearer to us than the stars.”

E. E. Barnard
1857-1923





“In a considerable number of cases no other explanation seems possible, but (that) some of them are doubtless only vacancies.”

1919 *Astrophysical Journal* **49,** 1.

Max Wolf

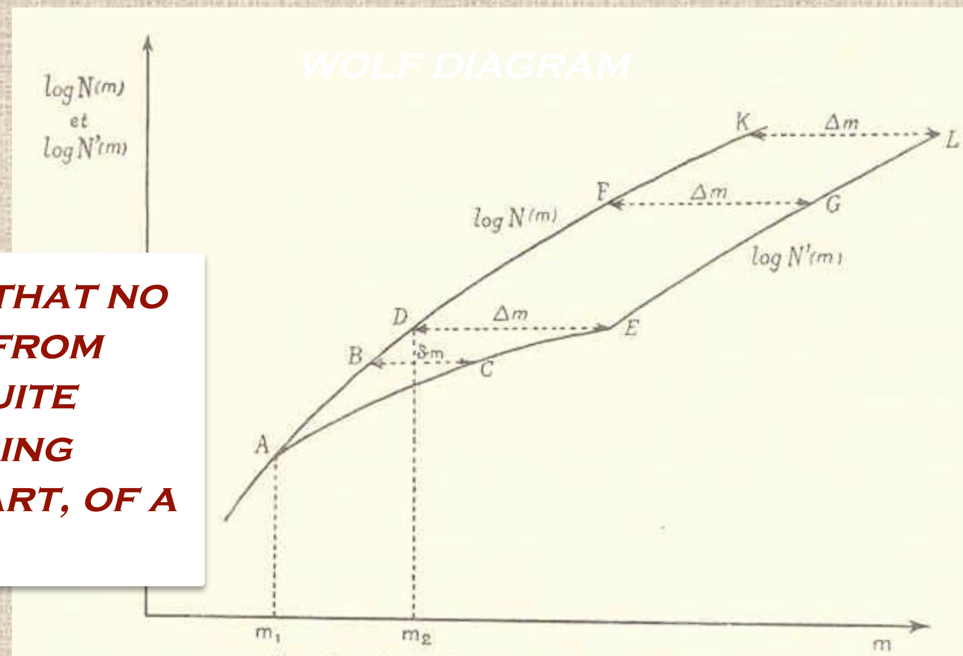


Fig. 16.—Illustration of Max Wolf's Method.

"We must therefore conclude that no reddening of the stars arises from the dark cloud…and it seems quite probable that the light-capturing cloud consists, for the most part, of a dust mass."

1923 Astr. Nachr., 219, 109.

On The Nature of Dark Clouds

H.N. Russell

"The chief difficulty here is …how such (clouds) should have possessed so little angular momentum as the stars have at present."

"…dark nebulae…may alone be permanent just because of their chaotic nature. As far back in time as our reasoning carries us, they may even then have been substantially the same as now —'without form and void'."

Russell, Dugan and Stewart 1927

Bok Ties Star Formation to Dark Clouds!

Bart J. Bok
1906-1983

SMALL DARK NEBULAE

BART J. BOK AND EDITH F. REILLY
Harvard College Observatory
Received January 10, 1947

ABSTRACT

Attention is drawn to the small, round, dense dark nebulae with diameters varying between 5′ and 10′. We propose that these be named "globules." The region of Messier 8 abounds in globules. Published photographs show at least sixteen of them projected against the bright background of the diffuse nebula. At the derived distance of 1260 parsecs for Messier 8, the diameters of twelve of the sixteen observed globules are between 10,000 and 35,000 A.U. It is noteworthy that there is no evidence for globules in the region of the Orion nebula.

At least twenty of the dark objects in Barnard's lists are true globules. A preference is shown for the regions of Sagittarius and Ophiuchus and for the Scutum Cloud, but some isolated examples of large globules (with diameters of the order of 100,000 A.U.) are found in the anticenter region.

The estimated *minimum* absorptions for the small globules are 2-5 mag. The larger globules are more transparent (1 mag.).

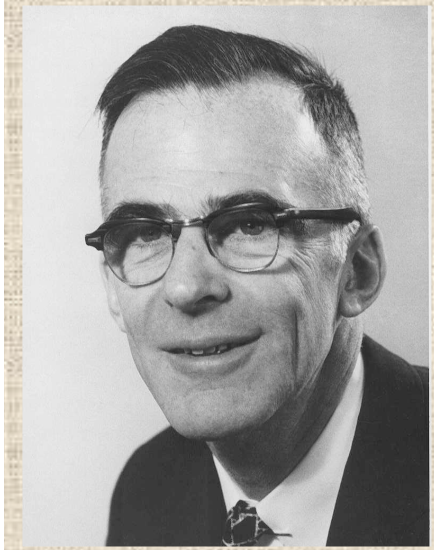
In recent years several authors have drawn attention to the possibility of the formation of stars from condensations in the interstellar medium.[1] It is therefore necessary to survey the evidence for the presence in our galaxy of relatively small dark nebulae, since these probably represent the evolutionary stage just preceding the formation of a star.

In the early days of astronomical photography, Barnard drew attention to the preva-

"…in some cosmic clouds we are now witnessing the operation of the process of star formation."
Bok 1948

1946: Harvard Observatory Centennial Symposium

The Concept of a Protostar

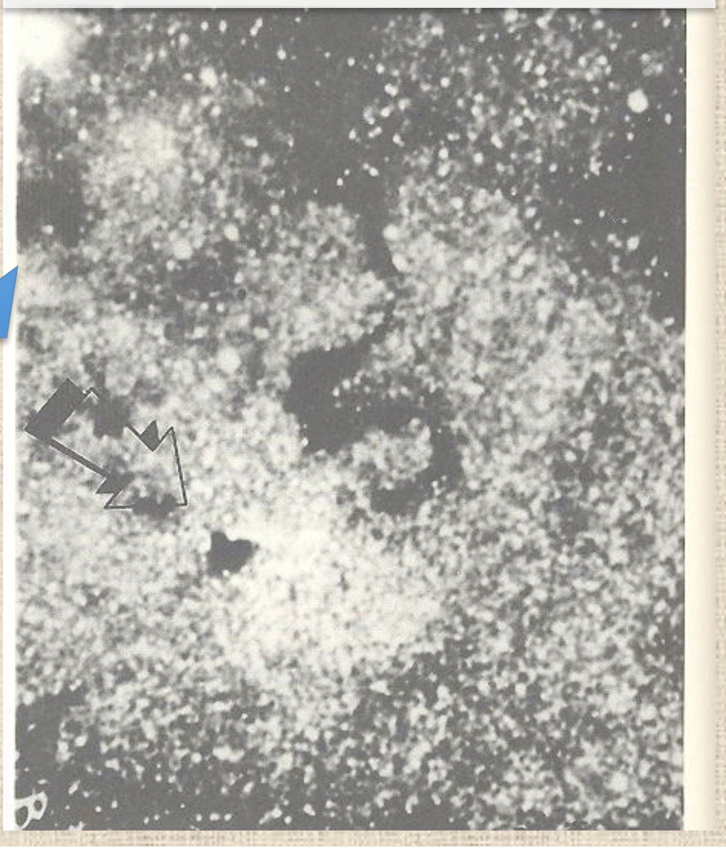


Lyman Spitzer Jr. (1914-1997)

During this stage of gravitational contraction an aggregation of dust and atoms will be stable against most disruptive influences' it should no longer Be regarded as a cloud, and will here be called a "*Protostar*".

Spitzer 1948

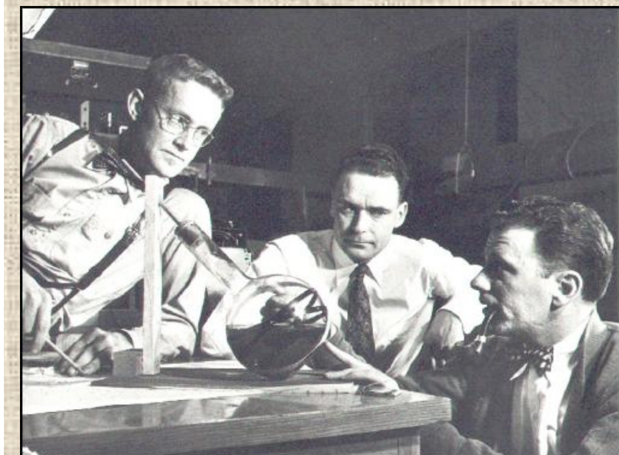
Physics Today, 1948 1, 6

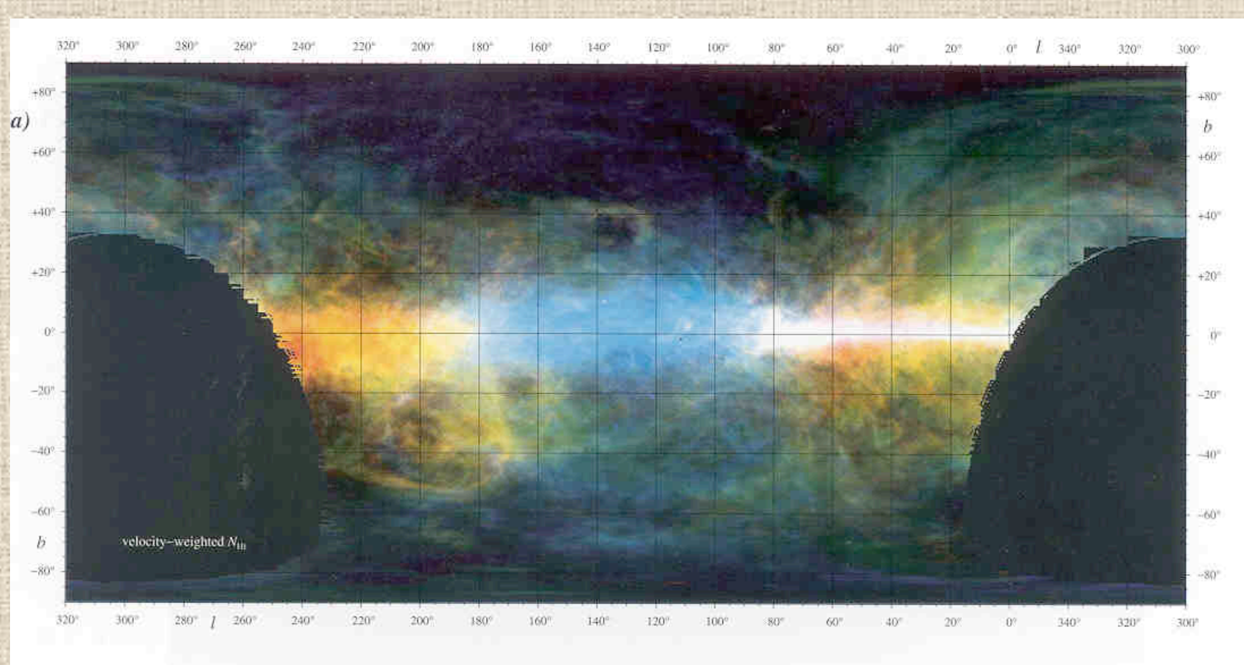


"...(although) the results presented here are therefore favorable to the hypothesis that stars…have originated recently from interstellar matter, this hypothesis remains extremely tentative at the present time." ***Spitzer 1948***

1946: Harvard Observatory Centennial Symposium

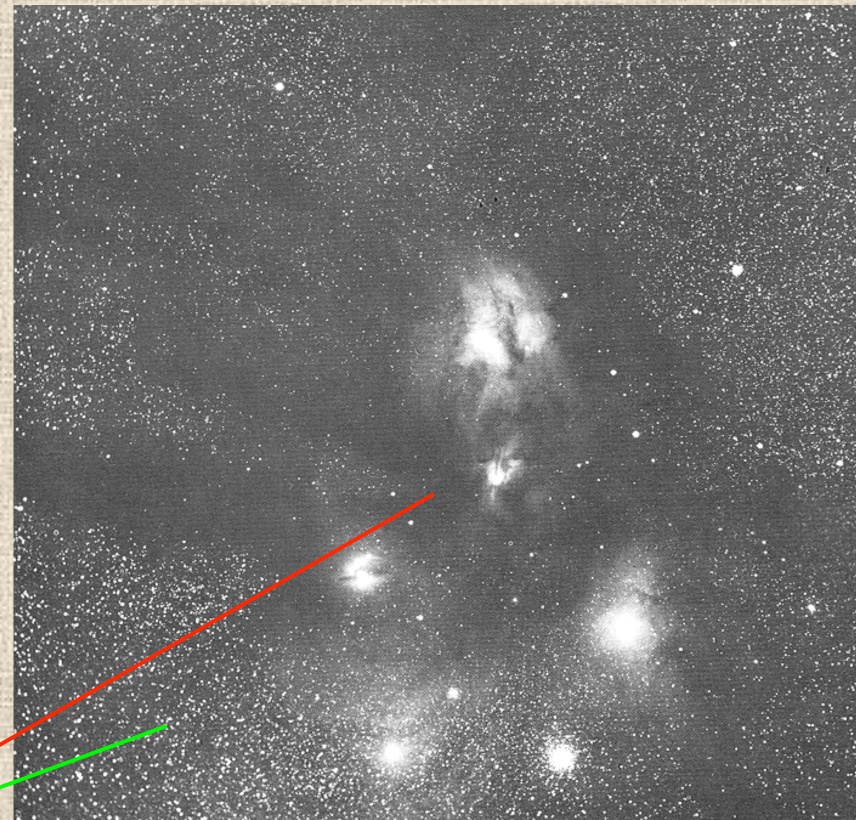
A Hydrogen-rich Interstellar Medium

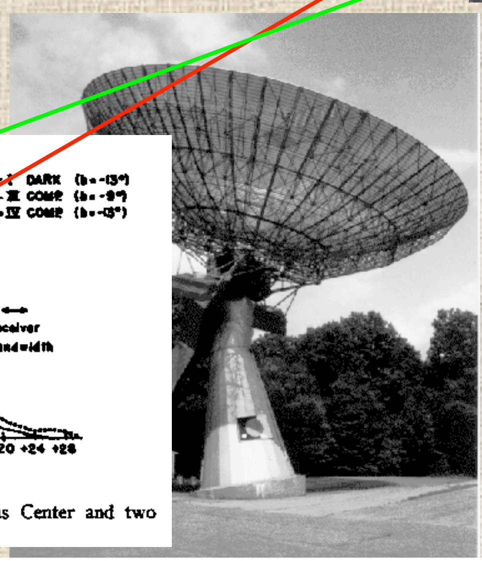




The discovery of pervasive HI emission in the galaxy by Ewen and Purcell in 1951 convincingly demonstrated that the raw material for building stars existed in substantial concentrations between the stars.

Bart J. Bok
1906-1983





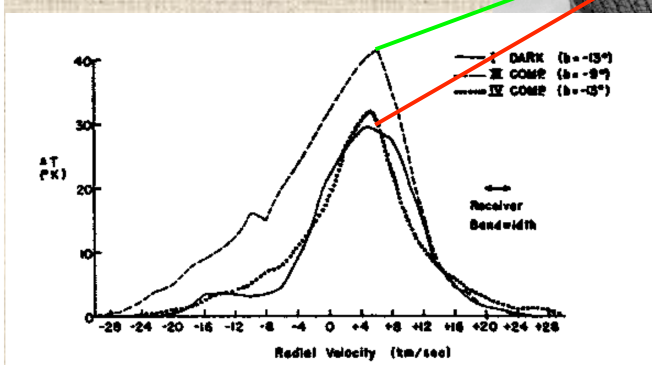


FIG. 4.—Reduced 21-cm profiles for the Ophiuchus Center and two comparison fields.

"There remains the possibility that the neutral hydrogen in the dark clouds is mostly in ***molecular*** form....."

1956, *PASP* **67**, 108.

The Astrophysical Journal, Vol. 148, April 1967

ON THE "GENERAL" CORRELATION OF DUST AND ATOMIC HYDROGEN

One of the avowed purposes of the comprehensive intermediate-latitude survey of van Woerden, Takakubo, and Braes (1962; hereafter referred to as "WTB") was the comparison of number of neutral hydrogen atoms per square centimeter in the line of sight, N_H, with the optical extinction τ as determined by the galaxy counts of Hubble (1934), since both surveys sampled similarly sized areas centered on the same points of the sky. In view of the recent results of Garzoli and Varsavsky (1966; hereafter referred to as "GV"), which are in direct disagreement with the only previously given quantitative results on the subject (Lilley 1955), it seemed appropriate to actually perform the comparison suggested by WTB.

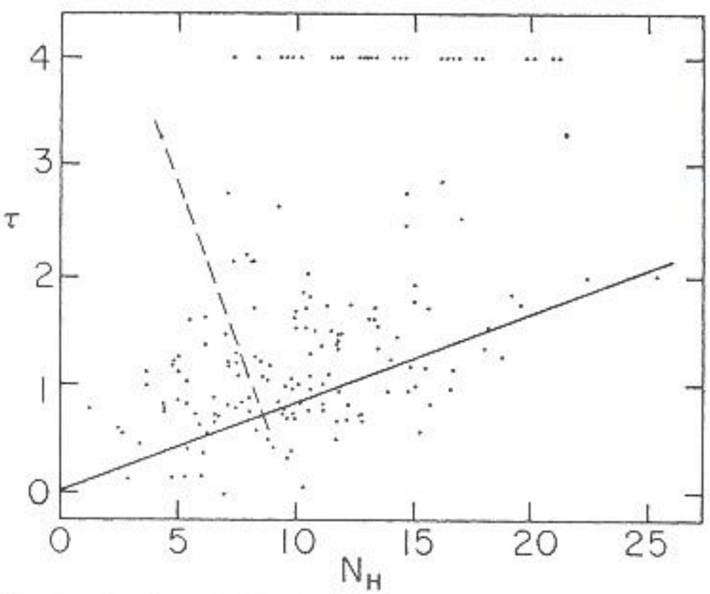
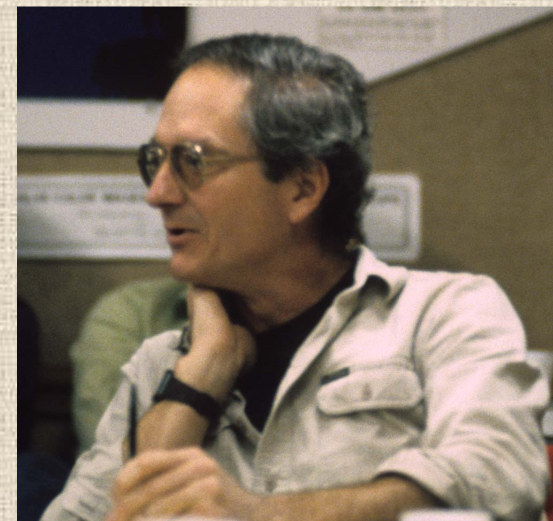


Fig. 1.—The plotted points form the bivariate distribution of N_H and τ as found from the data of WTB and Hubble. N_H is in units of 10^{20} neutral hydrogen atoms/cm². The solid line is the relation found by Lilley; the dashed line is that found by GV.



"...thus the reasonable conclusion to be drawn is that...the abundance of molecular hydrogen is several times that of atomic hydrogen"

Discovery of the Molecular Universe

1963: OH in absorption

1965: OH in emission

1968: NH_3 in emission

1969: H_2O in emission

1969 : H_2CO in absorption

NORMAL OH EMISSION AND INTERSTELLAR DUST CLOUDS

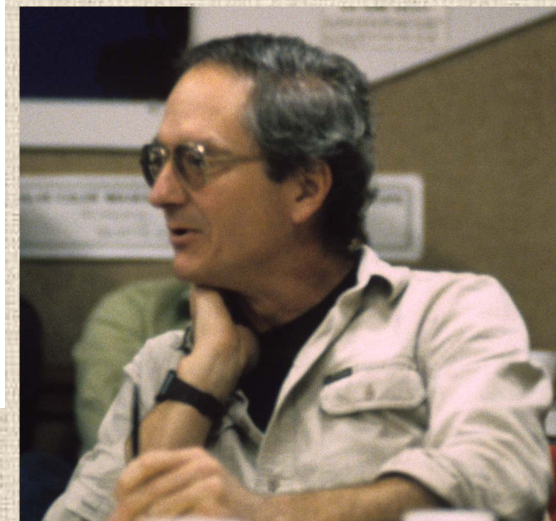
CARL E. HEILES
Berkeley Astronomy Department, University of California
Received August 23, 1967; revised September 21, 1967; and in proofs

ABSTRACT

Normal emission from OH in interstellar dust clouds has been detected. The clouds have normal cosmic abundances; the hydrogen, which is not observed to emit 21-cm line radiation, is probably all H_2. The amounts of OH and H_2 are consistent with statistical equilibrium with known reactions. The clouds are sufficiently opaque to exclude nearly all of the galactic radiation field so that photodissociation does not occur; also, the resulting radiation pressure differential helps hold the clouds together.

I. INTRODUCTION

Normal OH radio line emission from spatially extended regions has heretofore never been detected. This paper reports the detection of such emission from very dark dust clouds and analyzes the properties and physical processes characterizing these objects. Previously known OH emission is abnormal: the line ratios are abnormal, the emis-



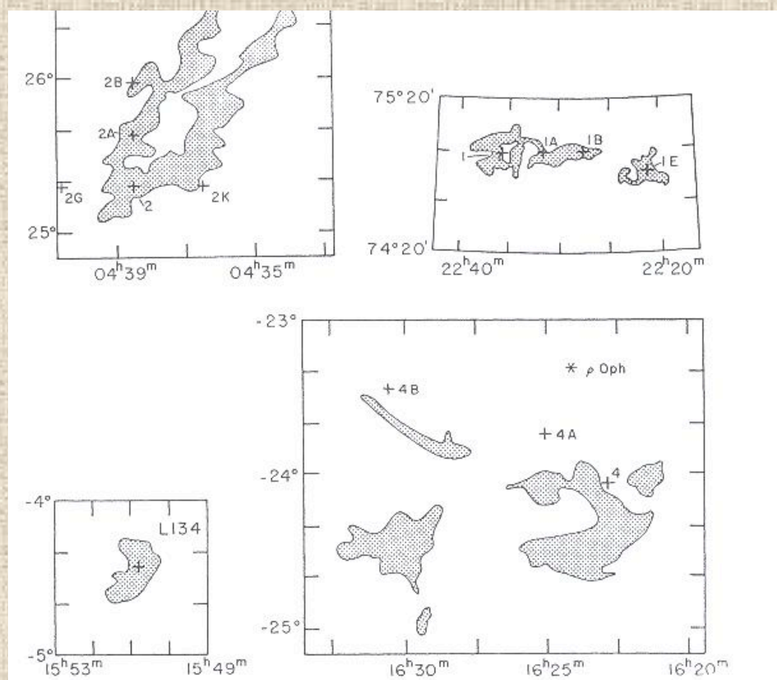


FIG. 1.—Sketches showing boundaries of the dust clouds studied. The crosses mark some of the position observed; OH emission was not detected from all of these positions (see Tables 2–4).

THE ASTROPHYSICAL JOURNAL, Vol. 156, June 1969

FORMALDEHYDE ABSORPTION IN DARK NEBULAE

PATRICK PALMER
University of Chicago

B. ZUCKERMAN
University of Maryland

AND

DAVID BUHL AND LEWIS E. SNYDER
National Radio Astronomy Observatory*
Received May 19, 1969

ABSTRACT

The $1_{11} \rightarrow 1_{10}$ rotational transition of formaldehyde (H_2CO) has been observed in absorption in the direction of four dark nebulae. The radiation that is being absorbed appears to be the isotropic microwave background; this would imply that the excitation temperature of these two levels in these clouds is less than 1.8° K.

Recently we reported the detection of H_2CO in the interstellar medium (Snyder *et al.* 1969; Buhl *et al.* 1969). The H_2CO transition studied falls at 4830 MHz. In late March 1969 we searched for H_2CO in the direction of four dark nebulae from which "normal" OH emission had been detected (Heiles 1968). There are no known discrete sources of 6-cm continuum radiation in these directions. Formaldehyde was found in all four clouds, but, surprisingly, the lines were in absorption in all cases.

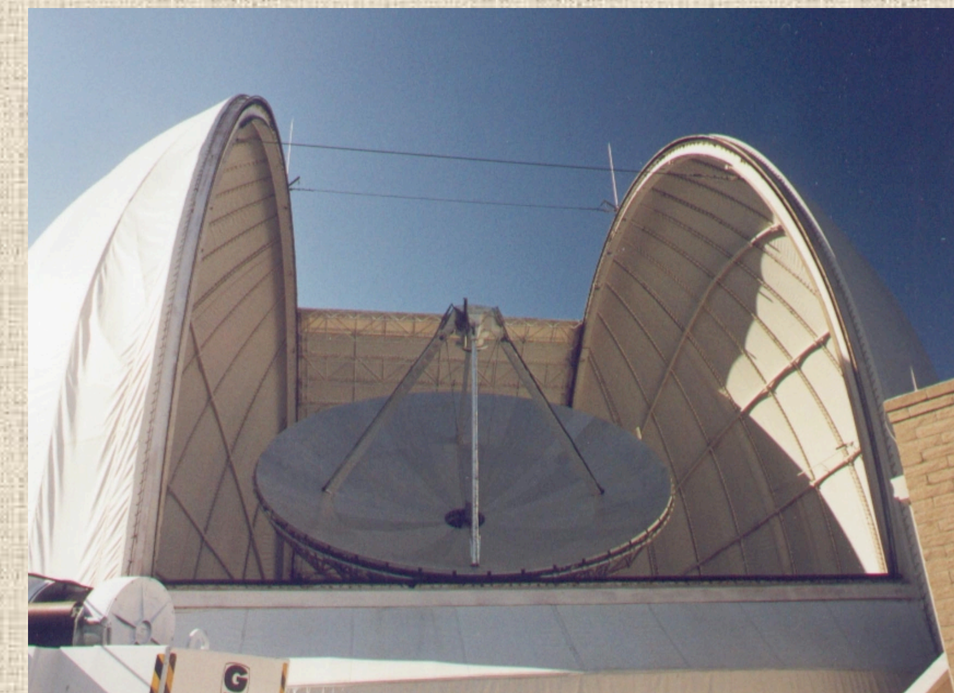
CARBON MONOXIDE IN THE ORION NEBULA

R. W. Wilson, K. B. Jefferts, and A. A. Penzias
Bell Telephone Laboratories, Inc., Holmdel, New Jersey, and
Crawford Hill Laboratory, Murray Hill, New Jersey
Received 1970 June 5

ABSTRACT

We have found intense 2.6-mm line radiation from nine galactic sources which we attribute to carbon monoxide.

R. Wilson



A. Penzias

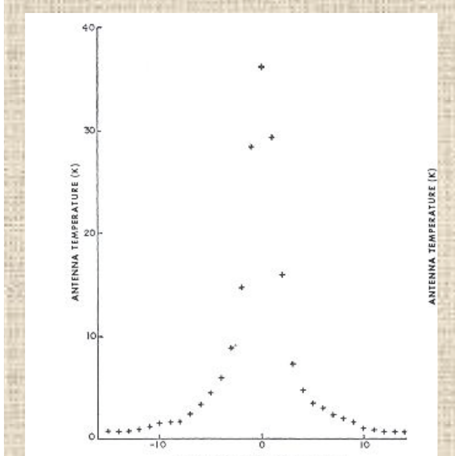


Fig. 1

Detection of CO in 1970

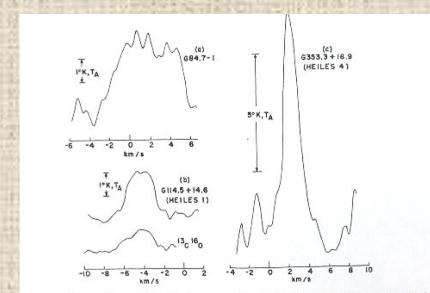


Fig. 1.—Observed line profiles of carbon monoxide emission in three dark interstellar clouds

THE ASTROPHYSICAL JOURNAL, 186:L13–L17, 1973 November 15

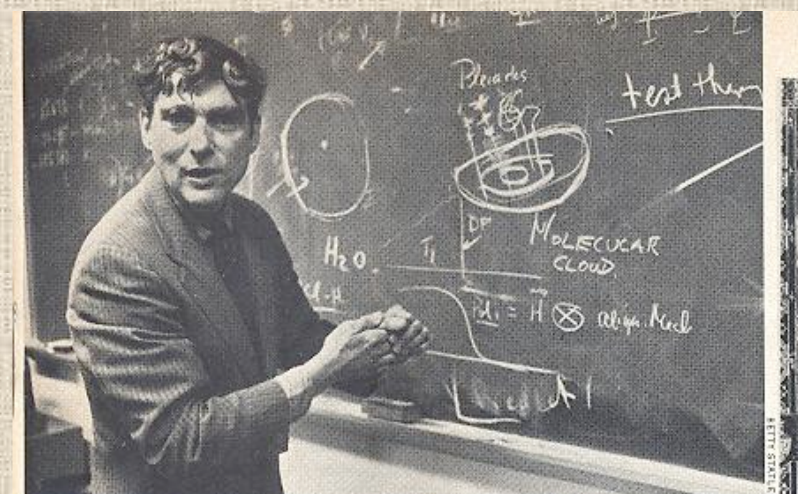
A LARGE CARBON MONOXIDE CLOUD IN ORION

K. D. TUCKER, M. L. KUTNER, AND P. THADDEUS
Goddard Institute for Space Studies, New York City
Received 1973 August 22

ABSTRACT

Carbon monoxide line emission at $\lambda = 2.6$ mm has been observed over an area of $\sim 1\frac{1}{2}° \times 4°$ in L1630, a diffuse dark nebula bridging NGC 2024 and the reflection nebula NGC 2068. The absence of a 21-cm counterpart to this region of high visual extinction suggests that L1630 is mainly molecular hydrogen. The H_2 mass is estimated from the carbon monoxide observations to be $2.5 \times 10^4 \lesssim M \lesssim 1 \times 10^5 M_{\odot}$, a significant fraction of the total mass of stars and gas within the boundaries of the I Ori association.

Subject headings: molecules, interstellar — nebulae



NASA ASTROPHYSICIST PATRICK THADDEUS AT BLACKBOARD
Searching for molecules of interstellar compost.

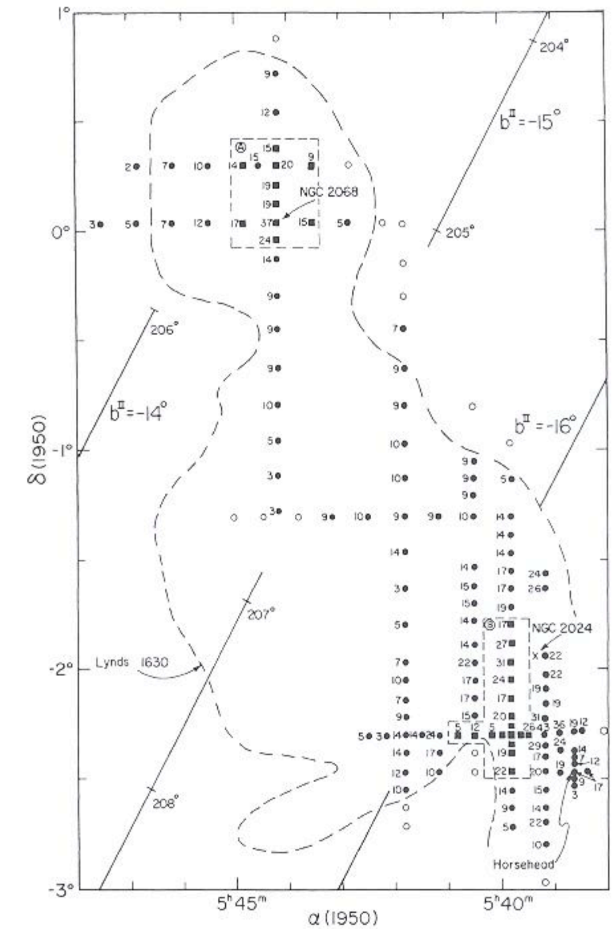


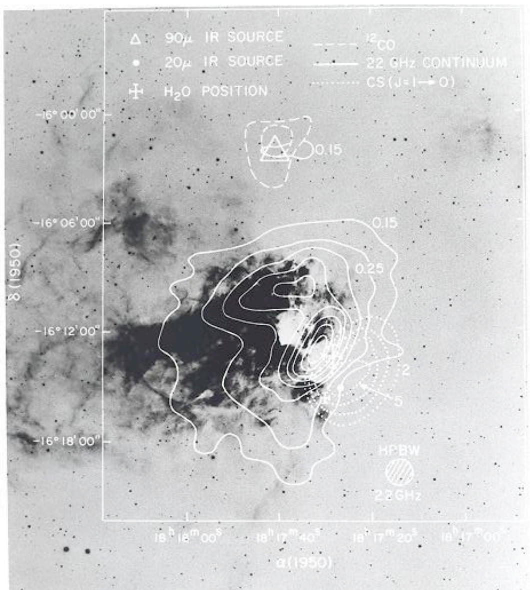
FIG. 1.—CO observations in L1630. Filled circles or squares are the size of the antenna bean

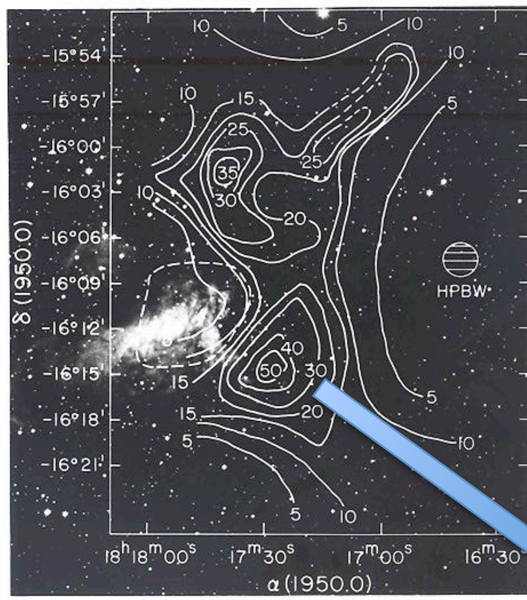
DISCOVERY AND CO OBSERVATIONS OF A NEW MOLECULAR SOURCE NEAR M17

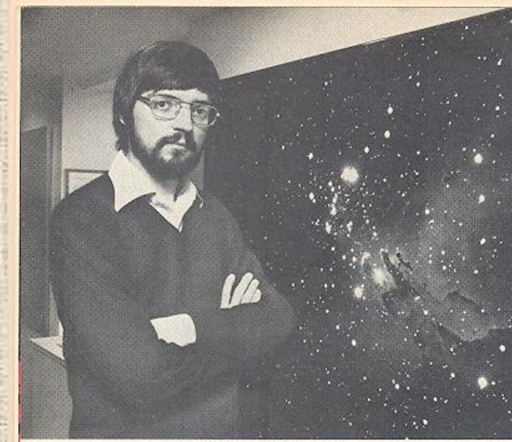
CHARLES LADA, DALE F. DICKINSON, AND HAYS PENFIELD
Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138
Received 1974 January 15

ABSTRACT

A rich new source of molecular line radiation has been found near M17. Its position is in the immediate vicinity of the new infrared source recently discovered by Kleinmann and Wright and very near the position of a strong time-varying H_2O maser. Extended emission from HCN, SO, and millimeter H_2CO has been detected. Emission lines of ^{12}CO and $^{13}C^{16}O$ have been mapped throughout this region, and $^{12}C^{18}O$ has been detected in two locations. Results of the CO observations set a lower limit on the mass of this source of $M > 6000\ M_{\odot}$ and indicate that the cloud may be undergoing collapse.






HARVARD UNIVERSITY ASTRONOMER CHARLES LADA

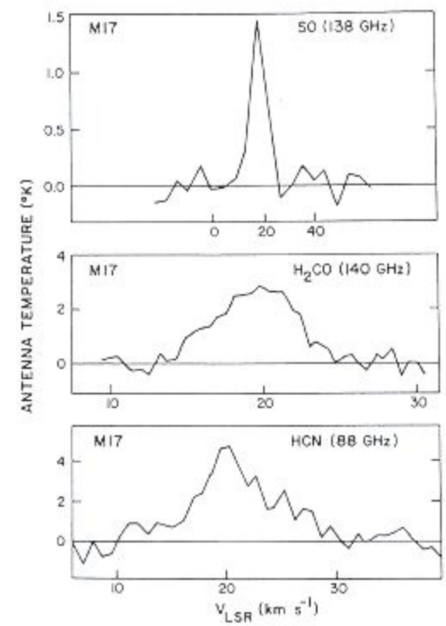


FIG. 4.—Observed spectra of the $J_K = 4_3 \rightarrow 3_2$ transition of SO, the $J_{K-1K+1} = 2_{12} \rightarrow 2_{11}$ transition of H_2CO, and the $J = 1 \rightarrow 0$ rotational transition of HCN in M17 SW. The spectral resolutions are 4.34, 0.53, and 0.84 km s^{-1} for the SO, H_2CO, and HCN profiles, respectively.

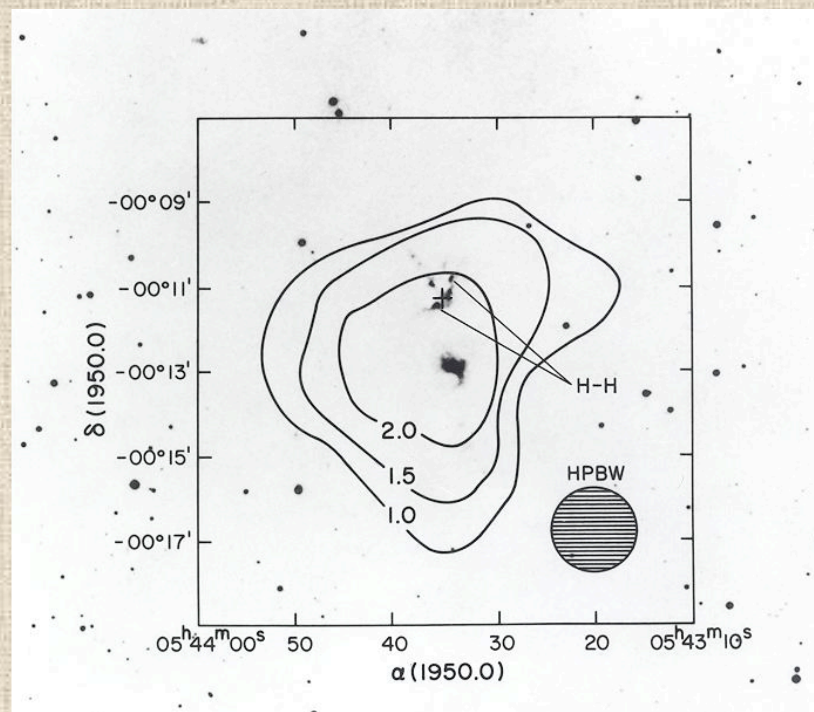
MOLECULAR STUDIES OF TWO DARK NEBULAE ASSOCIATED WITH HERBIG-HARO OBJECTS

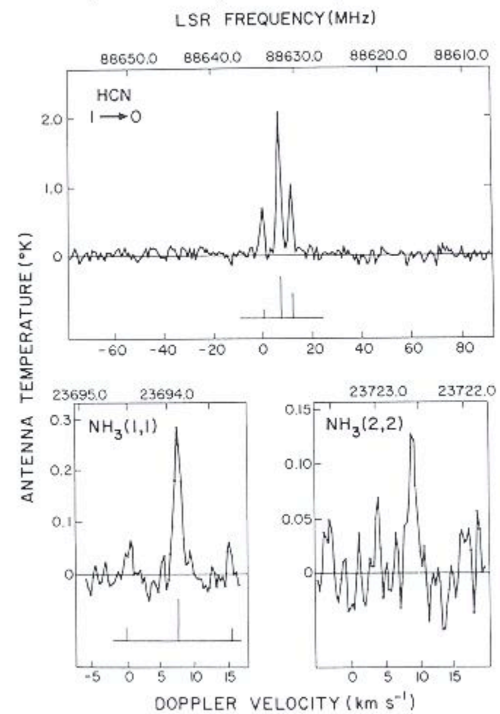
C. J. LADA, C. A. GOTTLIEB, M. M. LITVAK, AND A. E. LILLEY
Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory
Received 1974 June 4

ABSTRACT

Narrow ($\lesssim 2$ km s^{-1} wide) emission lines from millimeter- and centimeter-wave transitions of a number of molecules have been detected toward several dark nebulae known to contain H-H objects and infrared stars that are thought to be very young. Large dense clouds have been mapped in 2-mm H_2CO emission toward NGC 1333 and M78. Determinations of nearly constant kinetic temperature through ^{12}CO and NH_3 observations in NGC 1333 indicate that the slight peaking of the emission from H_2CO, CS, and HCN is probably due to increased gas density near the H-H object/infrared-star associations. The observations and radiative-transfer models yield a probable lower limit of $\gtrsim 2 \times 10^4$ cm^{-3} to the hydrogen density in NGC 1333. Gravitational-collapse velocities implied by the mass of $\sim 10^3\ M_\odot$, assuming this density is uniform over a spherical cloud, are much larger than those allowed by the observed narrow molecular line widths.

Subject headings: molecules, interstellar — nebulae — pre-main-sequence stars





HCN, NH_3 (1, 1), and NH_3 (2, 2) taken toward the IR star near H-H 12. The antenna te
Earth's atmosphere, and the velocity scale is referred to the LSR and to a line rest freque
48 MHz for NH_3 (1, 1), and 23,722.71 MHz for NH_3 (2, 2). The vertical bars below the H
sitions of the hyperfine components in their optically thin ratios. The instrumental resolu
for NH_3 (1, 1), and 0.63 km s^{-1} for NH_3 (2, 2). Linear baselines have been removed.

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 36: 1–51, 1978 January

MICROWAVE SPECTRAL LINES IN GALACTIC DUST GLOBULES

ROBERT N. MARTIN AND ALAN H. BARRETT
Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology
Received 1977 April 18; accepted 1977 July 7

" In conclusion, the results are consistent with the notion that globules are small, collapsing, and/or rotating dark nebulae which could be locations for future star formation."

SELF-SIMILAR COLLAPSE OF ISOTHERMAL SPHERES AND STAR FORMATION

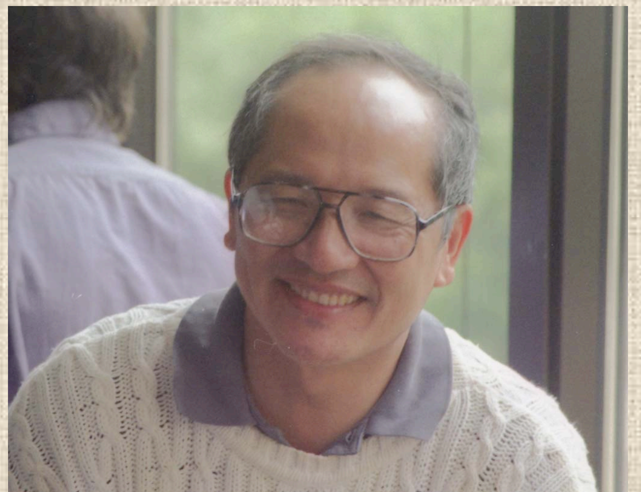
FRANK H. SHU
Astronomy Department, University of California, Berkeley
Received 1976 June 10; revised 1976 September 27

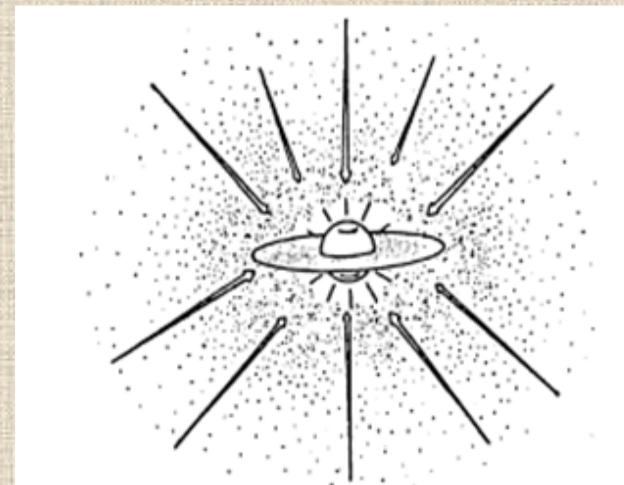
ABSTRACT

We consider the problem of the gravitational collapse of isothermal spheres by applying the similarity method to the gas-dynamic flow. We argue that a previous solution obtained by Larson and Penston to describe the stages *prior* to core formation is physically artificial; however, we find that the flow *following* core formation does exhibit self-similar properties.

The latter similarity solution shows that the inflow in the dense central regions proceeds virtually at free-fall before the material is arrested by a strong radiating shock upon impact with the surface of the core. Two types of similarity solutions are obtained: one is the prototype for starting states which correspond to unstable hydrostatic equilibrium; the other, for states where the mass of the cloud slightly exceeds the maximum limit allowable for hydrostatic equilibrium. In both cases, an r^{-2} law holds for the density distribution in the static or nearly static outer envelope, and an $r^{-3/2}$ law holds for the freely falling inner envelope. Rapid infall is initiated at the head of the expansion wave associated with the dropping of the central regions from beneath the envelope. A numerical example is presented which is shown to be in good agreement with the envelope dynamics obtained in previous studies of star formation using hydrodynamic codes.

Subject headings: hydrodynamics — stars: formation





SELF-SIMILAR COLLAPSE OF ISOTHERMAL SPHERES AND STAR FORMATION

FRANK H. SHU
Astronomy Department, University of California, Berkeley
Received 1976 June 10; revised 1976 September 27

ABSTRACT

We consider the problem of the gravitational collapse of isothermal spheres by applying the similarity method to the gas-dynamic flow. We argue that a previous solution obtained by Larson and Penston to describe the stages *prior* to core formation is physically artificial; however, we find that the flow *following* core formation does exhibit self-similar properties.

The latter similarity solution shows that the inflow in the dense central regions proceeds virtually at free-fall before the material is arrested by a strong radiating shock upon impact with the surface of the core. Two types of similarity solutions are obtained: one is the prototype for starting states which correspond to unstable hydrostatic equilibrium; the other, for states where the mass of the cloud slightly exceeds the maximum limit allowable for hydrostatic equilibrium. In both cases, an r^{-2} law holds for the density distribution in the static or nearly static outer envelope, and an $r^{-3/2}$ law holds for the freely falling inner envelope. Rapid infall is initiated at the head of the expansion wave associated with the dropping of the central regions from beneath the envelope. A numerical example is presented which is shown to be in good agreement with the envelope dynamics obtained in previous studies of star formation using hydrodynamic codes.

Subject headings: hydrodynamics — stars: formation

And then there was Phil & Priscilla

And all was light!!!

DENSE CORES IN DARK CLOUDS. II. NH_3 OBSERVATIONS AND STAR FORMATION

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ABSTRACT

We present partial results of a survey of ~100 visually opaque regions in nearby dark clouds in the 1.3 cm $(J, K) = (1, 1)$ line of NH_3, with mapping of all strong sources ("dense cores") and (2, 2) line observations in selected positions. For 27 dense cores with distance estimates, mean properties are: FWHM diameter, 0.1 pc; density, 3×10^4 cm^{-3}; mass, 4 $M_\odot$; kinetic temperature, 11 K; and FWHM velocity width, 0.3 km s^{-1}. We compare line shapes with cloud motion models, and source density, size, and temperature with equilibrium and stability requirements. These indicate that most dense cores are in the early stages of collapse or in near-critical equilibrium; if in equilibrium, they are probably supported by a combination of thermal and subsonic turbulent motions. In Taurus-Auriga, positions of the 10 known dense cores are well correlated with positions of emission-line star groups. In the next dense core free-fall time, 2×10^5 yr, the Taurus-Auriga complex is expected to form 25–50 emission-line stars. This is consistent with the estimated number of dense cores, 25. Taken together, these results suggest that most of the dense cores described here will form low-mass stars in the next ~10^6 yr.

Subject headings: interstellar molecules — nebulae: general — stars: formation

I. INTRODUCTION

elsewhere, in the $(J, K) = (1, 1)$ and (2, 2) lines of NH_3

THE END!