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ON ROTATION OF AN ISOLATED GLOBULE

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During CO observations of new Southern objects with the15-m SEST mm telescope (Cerro La Silla, Chile) we have found that the globule connected with the object CLN127-128 rotates with an angular velocity $4.3 \cdot 10^{-14} s^{-1}$, which corresponds to the velocity of extremely fast rotating globules. The object CLN127-128 is a chain of 3 stars, two of them are connected with bright nebulae, and the third is a suspected Herbig Ae-Be star. All three stars are bright in near IR, which is specific for the existence of circumstellar shells (or disks) around them. The specific angular momentum of the globule confirms that it is in virial equilibrium. Besides the finding of a rotating globule, CO observations suggest the presence of a blue-shifted outflow from CLN127-128 with a velocity of -1.1 km/s (in the system connected with the globule).

Key words: *(stars:) globules: rotation*

1. *Introduction.* Dark globules have a rather important role in evolution of stars with low and/or middle masses. Many globules are connected with such stars, mainly pre-main-sequence young stars (T Tauri type, Herbig Ae/Be type, etc.). In this paper we investigate an isolated globule connected with a chain of three stars, one of which is Herbig Ae/Be type and the other two are connected with bright nebulae. We present the results of the CO observations of molecular gas associated to this globule. There is a velocity gradient in the CO emission that can be explained by the presence of a rotating globule. The rotation is rather fast as compared with known so far rotating globules. Arquilla and Goldsmith [1] investigated several rotating globules and they concluded that the rotation of globules is a rather rare phenomenon. Investigation of rotation of globules is important for understanding the evolution of stars: as a rule, the specific angular momentum is much larger for globules than for binary and single stars (see e.g. Kane and Clemens, [2]).

2. *The object CLN127-128 as a chain of three young stars.* This paper is devoted to the results of CO observations of an isolated small dark globule. In the central part of this globule an interesting object is found: a system of three stars, almost on one straight line, the two extreme stars are connected with nebulae while the central one is not. Fig.1 shows the DSS2 R image of CLN127-128. Gyulbudaghian et al. [3] interpreted this object as two stars with cone-like nebulae; in the list of cometary nebulae they have

being named as CLN127-128 (Gyulbudaghian, [4]), with the central star just in the middle of them. Bruck & Godwin [5] interpreted this object as a central star with two lobes, but with *I* and *R* filters the three stars have almost the same images, so it is difficult to argue against their star origin. The central

Fig.1. DSS2 R image of CLN127-128. N is to the top, E to the left. The sizes of image are 18' x 18'. The arrow shows three stars, composing CLN127-128.

star has a B8 type spectrum with $H\alpha, H\beta$ in emission (Bruck & Godwin, [5]). The spectra of the nebulae have $H\alpha, H\beta$ etc. in absorption and the spectrum of the southern object (star) resembles the spectrum of an A0 type star (Bruck & Godwin, [5]); as the colours of southern and northern stars are rather similar, we can conclude that the spectrum of the northern star is also near A0.

The spectrum of the central star is extremely puzzling. The strength of the sodium D lines is compatible with a star of type K2-K5, but none of the other features of late-type star, namely the Mg I triplet at $\lambda 5781$Å and G band, the *H* and *K* lines of Ca II or the TiO bands are present [5]. The star *UBV* colours, however, are consistent with a B8 star reddened by $1^m.5$ in $B-V$. Therefore we can conclude that the spectrum of the central star corresponds to a B8e + K2 type.

An IRAS point source, IRAS 13542-6335, is connected with CLN127-128 [6]. In [7] the ranges of IR colour indexes are calculated, which are valid for different kinds of objects. For $R(1,2) = \log((F(100) \times 12)/(F(12) \times 25))$, $R(2,3) = \log((F(60) \times 25)/(F25) \times 60))$, $R(3,4) = \log((F(100) \times 60)/(F(60) \times 100))$ the following ranges, for three different kinds of young objects, are obtained. 1. Objects connected with water masers. For them $R(1,2) = (0.2 - 0.8)$; $R(2,3) = (0 - 1.3)$, $R(3,4) = (-0.3 - 0.3)$. 2. T Tauri type stars. For them

$R(1,2) = (-0.25 - 0.15)$; $R(2,3) = (-0.5 - 0.1)$; $R(3,4) = (-0.25 - 0.2)$. 3. Cold sources embedded in dark clouds. For them $R(3,4) > 0.3$. For the source IRAS 13542-6335 we have $R(1,2) = -0.15$; $R(2,3) = 0.6$, $F(100)$ is given in [6] with large error, so we did not calculate $R(3,4)$. We can see that $R(1,2)$ corresponds to a T Tauri type star, and $R(2,3)$ to an object connected with water maser, therefore we can conclude that IRAS 13542-6335 can be a T Tauri type star, but with a rather thick envelope. The IR source can coincide with the central star of CLN127-128, because the Ae/Be Herbig stars mainly have IR colours typical for T Tauri type stars (see e.g. [8]), and the difference of coordinates between the central star and the IRAS source is about 10" (the error of coordinates in [6] is about 0'.5).

It is interesting to consider also the 2MASS data on these three stars. For the southern star we have: $R - J = 1.155$, $J - H = 0.245$, $H - K = 0.19$ (all data in this paper on R, J, H, K bands are taken from Internet, Vizier). For the northern star: $R - J = 0.897$, $J - H = 0.454$, $H - K = 0.308$. The spectra of these stars are close to A0. In Table 1 the 2MASS and R data for several occasional A0 type stars are given. We can see from Table 1 that almost all colours are about zero, as we could anticipate for A0 type stars. The data for southern and northern stars are rather different from zero, hence we can conclude that there are thick dust shells around these stars.

Table 1

R AND 2MASS DATA ON A0 TYPE STARS

Name	Spectra	$R - J$	$J - H$	$H - K$
HD 4902	A0 V	0.06	-0.01	-0.03
HD 4881	A0 V	0.2	0.0	0.02
CLN127-128 s.s.	A0	1.155	0.245	0.19
CLN127-128 n.s.	A0	0.897	0.454	0.308

For the central star we have: $R - J = 3.157$, $J - H = 0.755$, $H - K = 0.547$. In Table 2 there are data on R and 2MASS colours on several Herbig Ae/Be stars (see [9]). The large value of $R - J$ for the central star we can explain as an existence of a double star, one Ae/Be type, and the second K2 type, or an Ae/Be type star with a thick dust shell.

In Table 3 there are data on several occasional B8 and K2 type stars (these stars were taken from [10]).

We can see from Table 3 that the central star has much larger values of $R - J$, $J - H$ and $H - K$ than the occasional B8 type stars, moreover, larger than for occasional K2 type stars. These values for the central star are comparable with those for Herbig Ae/Be stars with shell or nebula (V380 Ori, PV Cep, HK Ori, MWC 1080, see Table 2), therefore we can

Table 2

2MASS AND *R* DATA ON SEVERAL HERBIG Ae/Be STARS

Name	Spectra	*R - J*	*J - H*	*H - K*
V380 Ori	A+neb	2.71	1.14	1.02
V586 Ori	A2Vea	1.05	0.54	0.72
NX Pup	A0/F2IIIc	1.42	1.29	1.21
HD203024	Ae	0.52	0.17	0.09
MWC 863	A0/4Ve	1.95	0.74	0.73
T Ori	B8-A3eap	1.68	1.03	1.02
PV Cep	A5e+shell	4.45	2.85	2.2
HKOri	B7-A4ep	3.0	1.1	1.0
TY CrA	B9Vea	2.0	1.52	0.3
HD53367	B1/2ne	0.77	0.11	0.1
MWC 300	B1Iae	1.19	1.15	1.95
AS 442	B8e	1.95	0.95	1.08
MWC 361	B2Ve	1.39	0.64	0.82
MWC 1080	B0e+shell	3.54	1.48	1.15
CLN127-128 c.s.	B8e+K2	3.16	0.76	0.55

Table 3

R AND 2MASS DATA ON SEVERAL B8 AND K2 TYPE STARS

Name	Spectra	*R - J*	*J - H*	*H - K*
HD 8053	B8 V	0.01	-0.11	0.02
HD 8346	B8 V	0.07	-0.07	0.03
HD 9234	B8 V	0.32	-0.01	0.02
HD 3765	K2 V	1.71	0.42	0.11
HD 4256	K2 V	1.8	0.43	0.13
HD 4628	K2 V	1.43	0.65	0.04
HD 4635	dK2	1.68	0.44	0.08

conclude that the central star is rather a Herbig Ae/Be star with a shell than a double star.

The axis of the object lies at position angle 34°.0 W of N. The three stars are collinear within 0°.2. The major axis of the globule is oriented 18° from that of three stars system.

The northern star is variable, the brightness of central star at least in *B* appears unchanged (Bruck & Godwin, [5]).

We can suppose that here we have a group of three young stars just emerged from the globule. Such groups of young stars just emerged from dark nebulae have been found also in other places (see e.g. Gyulbudaghian et al., [11]). The existence of such groups is in favor of the idea that many low mass stars are born in groups. Such groups of low mass stars are very unstable because the gravitational attraction is rather low (in the case of systems consisting of high mass stars the instability of systems is not so definite).

3. *Rotation of globule connected with CLN127-128.* The globule was observed with the 15-m SEST (Swedish-ESO Submillimetre Telescope) telescope (Cerro La Silla, Chile).

The telescope beam size at 115 GHz is 45" and the beam efficiency is 0.70. The positions toward CLN127-128 were observed with a spacing of 40" in frequency-switched mode, with a frequency throw of 10 MHz. The telescope was equipped with a SIS detector and a high-resolution acousto-optical spectrometer with 1000 channels and a velocity resolution of 0.112 km/s.

Fig.2 shows the ^{12}CO (1-0) spectra observed toward CLN127-128, arranged in a map-like distribution. In Table 4 the distribution of CO velocity, obtained from Fig.2, is given. The rows correspond to right ascension (1950), increasing from top to bottom, the columns correspond to declination (1950), increasing from right to left. The width of each column is 40", the width of each row is also 40". The place of three stars is marked by asterisk. The coordinates of the system of three stars are: R.A.(1950) = $13^h54^m18^s.0$, DECL.(1950) = -63°36'00". A velocity gradient is evident in the W - E direction, from -22.5 km/s to -18.2 km/s. As established by Ho & Therebey [12], a rotating molecular cloud has the following characteristics: a clearly defined velocity gradient and a flattened cloud morphology, where the elongation is parallel to the velocity gradient as to be expected in rotation. These characteristics of rotation take place in the case of the globule investigated in this paper. The globule is flattened with a length to width ratio of 1.7.

There is an interesting phenomenon associated to these data (see Fig.2). From row 1 to row 7 the velocity of the globule material at the edges is more negative than the velocity of the main body of the globule. While from row 7 to row 17 the velocity of the globule material at the edges is less negative than the velocity of main body of the globule. We can interpret it as follows. There is a rotation of the globule as a whole around the axis, passing approximately through row 7. The material near the edges is less dense and during the rotation is falling behind the main body of the globule. In the system connected with the globule we will have velocity 0 km/s near the axis of rotation of globule, that is the velocity of globule in the LSR is -21.4 km/s. Fig.2 shows the distribution of velocity in the system connected with the globule.

The distance to the globule is 1 kpc (Bruck & Godwin, [5]). We can calculate the momentum of inertia, angular velocity of rotation, specific angular momentum and energy of rotation of the globule.

The angular velocity of rotation of the globule $\omega = \Delta V / \Delta R$, that means it is equal to the gradient of the radial velocity, and hence $\omega = 4.3\,\mathrm{km/s}/3.2\,\mathrm{pc} = 4.3 \cdot 10^{-14}\,\mathrm{s}^{-1}$. From the data the diameter of the globule was measured to be about 640", while the velocity difference for this size gives 4.3 km/s (from

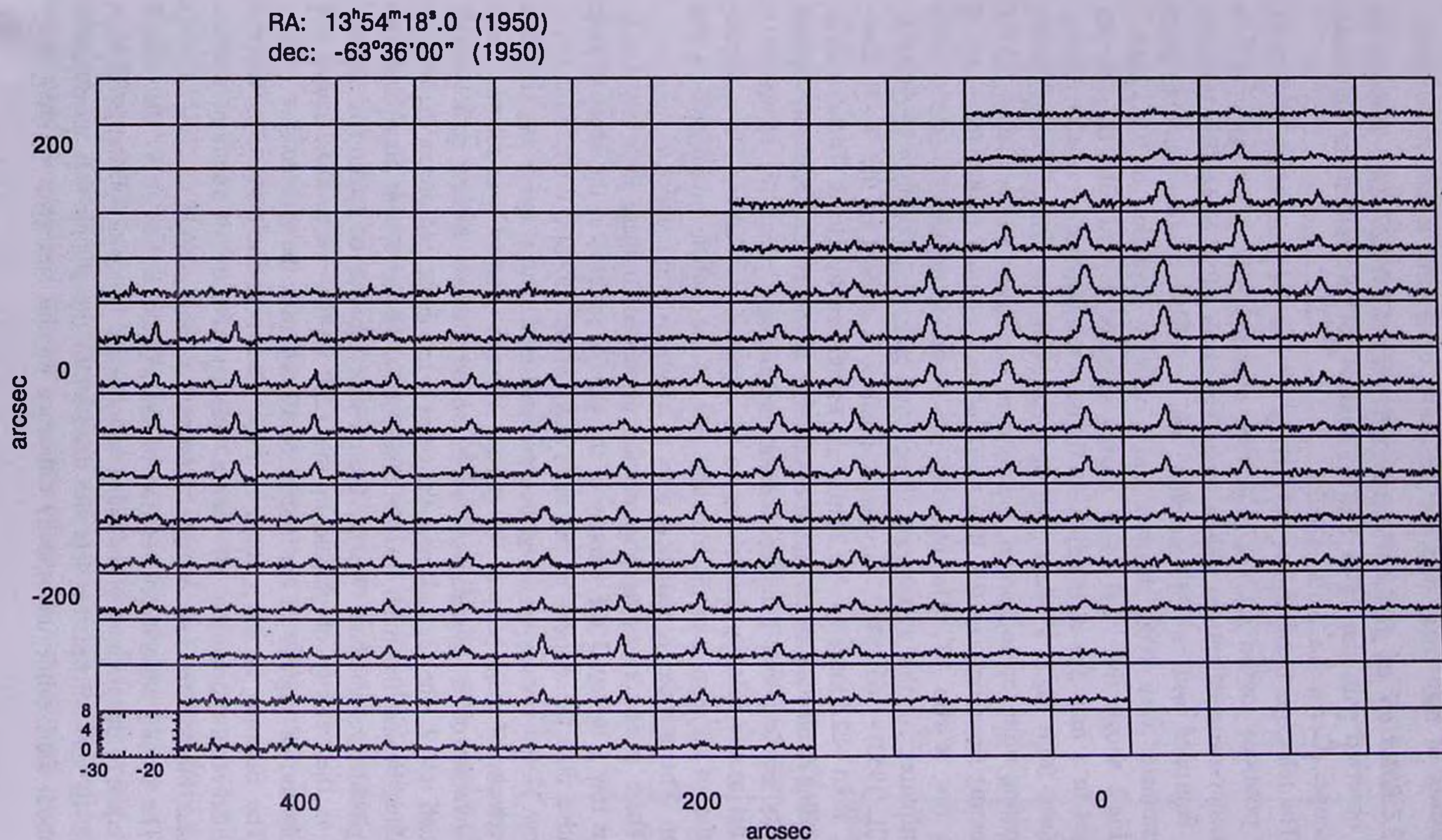

Fig.2. ^{12}CO spectra toward CLN127-128, arranged in a map-like distribution.

-1.1 km/s to 3.2 km/s). Taking the distance of the globule to be 1 kpc, 640" corresponds to 3.2 pc. The period of rotation will be $T = 2\pi/\omega = 4.7 \cdot 10^6$ year. The momentum of inertia $I = (1/2)Mr^2$ (for the disk, as we supposed that the globule has a flattened disk-like structure), where M - the mass of the globule, r - radius of disk. The mass of the globule was estimated in [5] as being about 50 solar masses. We will have $I = 2.1 \cdot 10^{59}\,\mathrm{g^2\,cm^2\,s^{-2}}$. The energy of rotation $W = 1/2\, I\, \omega^2 = (1/4)Mr^2\omega^2$, $W = 4.6 \cdot 10^{45}$ erg. The angular momentum $J = I\,\omega$, $J = 2.2 \cdot 10^{22}\,\mathrm{g\,pc^2\,s^{-1}}$. The specific angular momentum $J/M = 2.2 \cdot 10^{-13}\,\mathrm{pc^2\,s^{-1}}$.

In [2] the rotation of globules without embedded stars is investigated. The specific angular momentum J/M of the starless globules ranges from $4 \cdot 10^{-17}$ to $2 \cdot 10^{-15}\,\mathrm{pc^2\,s^{-1}}$ and is similar to the values found for dense NH_3 cores in molecular clouds [13]. Simon et al. [14] made a near IR lunar occultation and direct imaging survey of T Tau binary systems in Ophiuchus and Taurus star-formation regions. The binaries observed ranged in separation from 3AU to almost 1400AU and on average contained 50 times less specific angular momentum than the Goodman et al. dense cores [13] or the Yun & Clemens [10] embedded protostellar binaries ($10^{-15}\,\mathrm{pc^2\,s^{-1}}$) or the starless globules [2].

Table 4

DISTRIBUTION OF RADIAL VELOCITY ALONG THE GLOBULE

200"					0					-200"		
			-22.0	-22.0								
	-22.5	-22.5	-22.5	-22.5	-22.0	-22.0						
-22.5	-22.5	-22.5	-22.5	-22.5	-22.5	-22.0	-22.0	-22.0	-22.0			
-21.4 -22.5	-21.4 -22.5	-21.4 -22.5	-22.0	-22.0	-22.0	-22.0	-22.0	-22.0	-22.0			
	-21.4 -22.5	-21.4 -22.5	-21.4 -22.5	-21.4 -22.5	-22.0 *	-22.0	-22.0	-21.4				
	-21.4	-21.4 -22.5	-21.4 -22.5	-21.4 -22.5	-21.4 -22.5	-21.4	-21.4	-20.9				
	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4	-21.4		
		-21.4	-20.9	-20.9	-20.9	-20.9	-20.9	-20.9	-20.9	-21.4	-21.4	-22.0
			-20.4	-20.4	-20.4	-20.4	-20.4	-20.9	-20.9	-21.4	-21.4	-21.4
			-20.9	-20.9	-20.4	-20.4	-20.4	-20.4	-20.9	-20.9	-20.9	-20.9
					-20.4	-20.4	-20.4	-20.4	-20.4	-21.4	-21.4	-21.4
					-19.3	-19.3	-19.8	-19.8	-20.4	-21.4	-21.4	-21.4
					-19.3	-19.3	-19.8	-19.8	-19.8	-20.4	-20.4	
			-19.8	-19.8	-19.3	-19.3	-19.3	-19.3	-19.8	-20.4	-20.4	
			-19.3	-18.8	-18.8	-18.8	-18.8	-18.8	-19.3	-19.8		
				-18.8	-18.8	-18.8	-18.8	-18.2	-18.8	-19.3		
				-18.8	-18.8	-18.8	-18.2	-18.8	-19.3			

In our case the specific angular momentum of the globule ($2.2 \cdot 10^{-13}\ pc^2 s^{-1}$) is much larger than in all cases described above. We can suspect that large amounts of angular momentum are being lost due to processes occurring after cloud core formation and fragmentation.

The CO observations suggest that, besides the rotation of the globule, a blue-shifted outflow from CLN127-128 in the NE direction exists (see Fig.2, where the double values of velocity are present). The velocity of outflow is -22.5 km/s, or in the system connected with the globule, -1.1 km/s, see Table 5.

Table 5

DISTRIBUTION OF RADIAL VELOCITY (IN THE SYSTEM, CONNECTED WITH GLOBULE) ALONG THE GLOBULE

200"					0					-200"		
			-0.54	-0.54								
	-1.1	-1.1	-1.1	-1.1	-0.54	-0.54						
-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-0.54	-0.54	-0.54	-0.54			
0; -1.1	0; -1.1	0; -1.1	-0.54	-0.54	0.54	0.54	0.54	0.54	0.54			
	0.0; -1.1	0.0; -1.1	0.0; -1.1	0.0; -1.1	-0.54 *	-0.54	-0.54	0.0				
	0.0	0.0; -1.1	0.0; -1.1	0.0; -1.1	0.0; -1.1	0.0	0.0	0.54				
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
		0.0	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.0	0.0	-0.54
			1.1	1.1	1.1	1.1	1.1	0.54	0.54	0.0	0.0	0.0
			0.54	0.54	1.1	1.1	1.1	1.1	0.54	0.54	0.54	0.54
					1.1	1.1	1.1	1.1	1.1	0.0	0.0	0.0
					2.1	2.1	1.6	1.6	1.1	0.0	0.0	0.0
					2.1	2.1	1.6	1.6	1.6	1.1	1.1	
			1.6	1.6	2.1	2.1	2.1	2.1	1.6	1.1	1.1	
			2.1	2.7	2.7	2.7	2.7	2.7	2.1	1.6	1.1	
				2.7	2.7	2.7	2.7	3.2	2.7	2.1		
				2.7	2.7	2.7	3.2	2.7	2.1			

4. *Summary*. The CO observations of an interesting globule were carried out. The existence of a velocity gradient along the globule (in W-E direction) implies the presence of rotation of the globule as a whole, with an angular velocity of rotation $\omega = 4.3 \cdot 10^{-14}\ s^{-1}$ and an energy of rotation $W = 4.6 \cdot 10^{45}$ erg (if the distance is 1 kpc). We could establish the place of the axis of rotation analysing the complex structure of the rotation: at the edges of the globule the material is falling behind the main body of the globule (in the part approaching

us the velocity of that material is larger than the velocity of main body of the globule while in the part moving away from us the velocity is smaller). These observations also suggest the existence of a blue-shifted outflow in the NE direction from CLN127-128, the connected object with the globule (a chain of three stars), with outflow velocity -1.1 km/s (in the system connected with the globule).

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О ВРАЩЕНИИ ОДНОЙ ИЗОЛИРОВАННОЙ ГЛОБУЛЫ

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В результате CO наблюдений новых южных объектов на 15-м телескопе SEST (Ла Силлья, Чили) выяснилось, что глобула, связанная с объектом CLN127-128, вращается с угловой скоростью $4.3 \cdot 10^{-14}$ с$^{-1}$, которая соответствует скорости наиболее быстро вращающихся глобул. Объект CLN127-128 является цепочкой из трех звезд, две из них связаны с яркими туманностями, третья (центральная) является кандидатом в Ae/Be звезды Хербига. Все три звезды яркие в ближнем ИК, что свидетельствует о наличии околозвездных оболочек (иди дисков) вокруг них. Удельный момент вращения глобулы подтверждает, что глобула находится в вириальном равновесии. Кроме вращения глобулы, CO наблюдения показывают наличие молекулярного истечения из CLN127-128 (к нам), со скоростью -1.1 км/с (в системе, связанной с глобулой).

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