# CO study of the cometary globule CG 1

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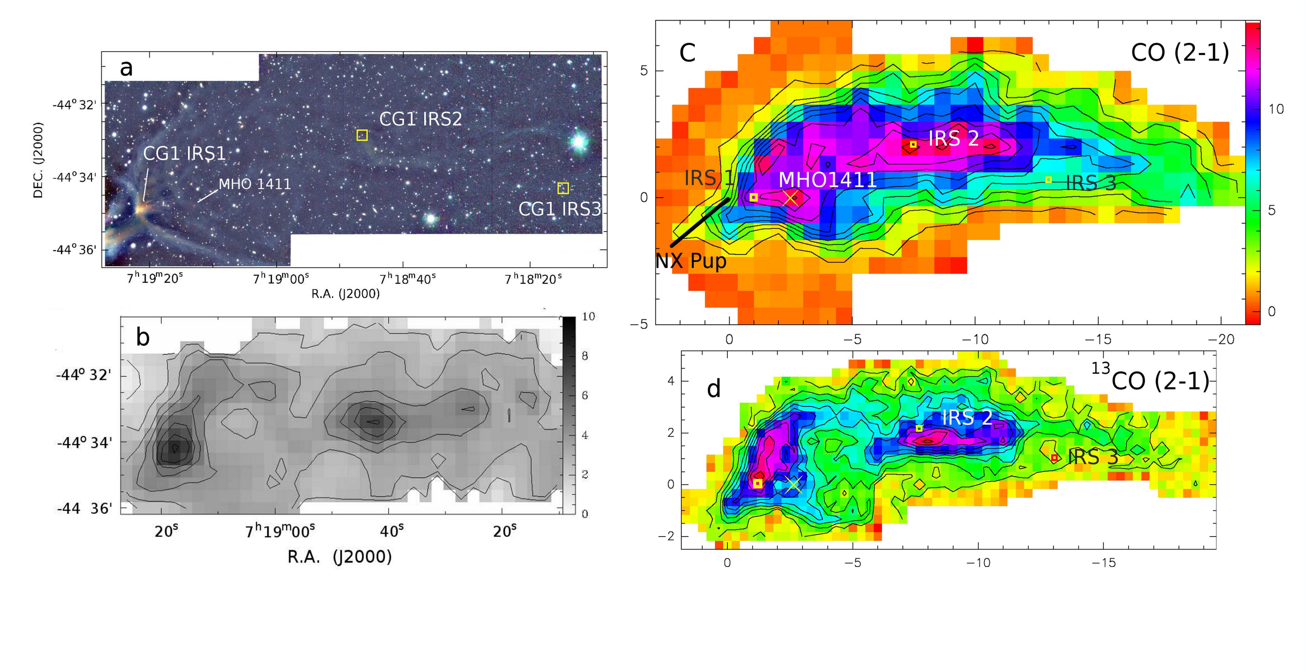
## Introduction:

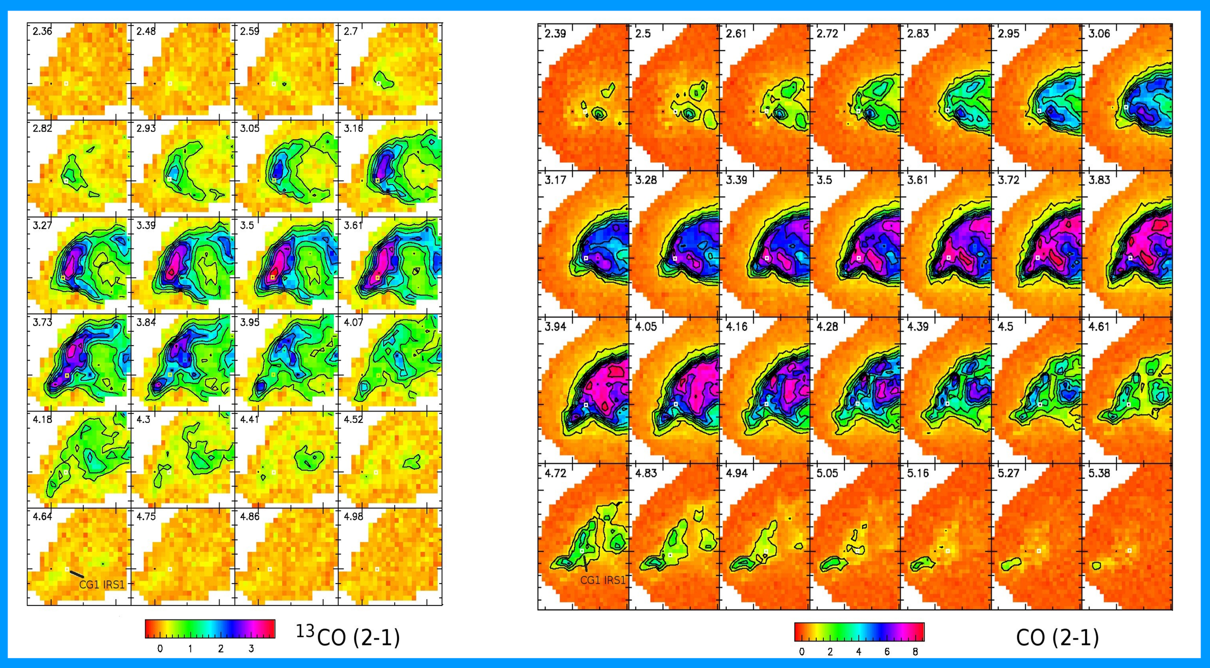
Cometary globule CG 1 is a ´´classic´´ cometary globule in the Gum nebula. We study the structure and mass distribution of CG1 and star formation in it using NTT SOFI NIR photometry and SEST molecular line observations. We aim to find clues to the cometary globule formation mechanism: radiation driven implosion (RDI) or a supernova blast. In RDI models major part of the CG mass is concentrated in the globule head whereas in the supernova blast models large part of the mass can lie in the tail. Gum nebula is a HII region and a possible supernova remnant and either RDI or supernova blast or both mechanisms are possible.

## Observations:

CG1 was mapped in CO, $^{13}$CO and C$^{18}$O(1-0) and (2-1) at SEST. NTT SOFI and IRSF SIRIUS NIR *J, H and Ks* imaging was reported in Haikala, Mäkelä and Väisänen (2010, HMV 2010) and Mäkelä and Haikala, (2013, MH 2013). Both optical extinction and CO emission trace the globule gas and dust column density. CG1 has been previously mapped at SEST in CO by Harju et al (1990). The new SEST CO observations are better sampled, more sensitive and the S/N, especially in the (2-1) transitions, is significantly better.

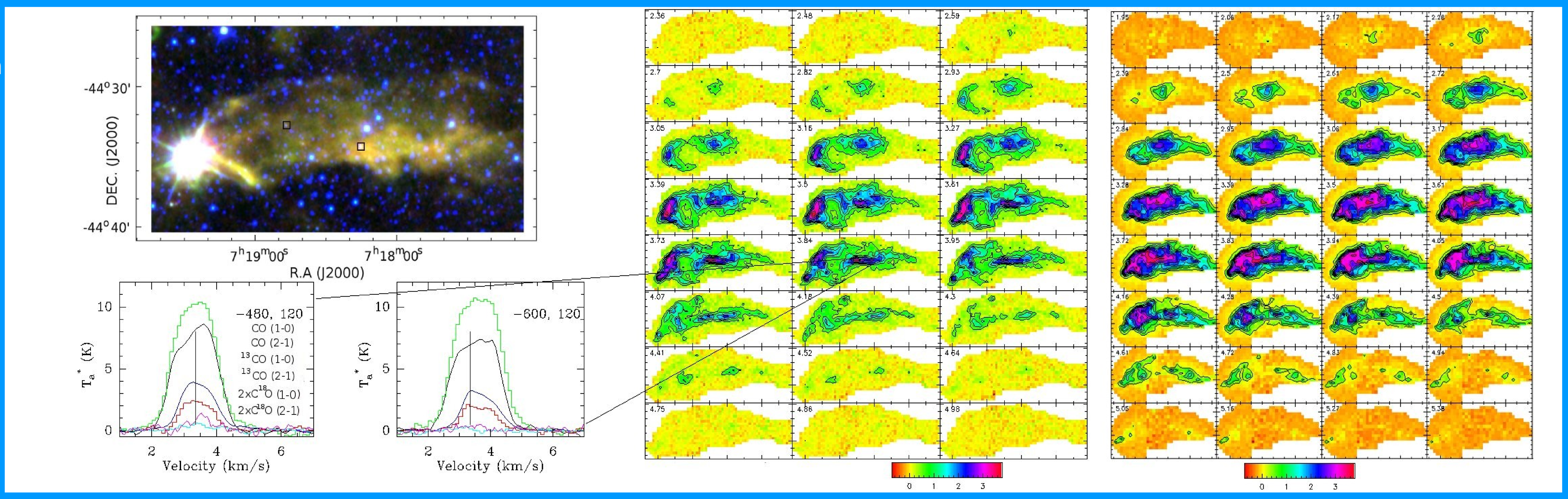



On the left: Fig. a: CG1 false colour *J, H, Ks* image (NTT SOFI, MH2013). Three NIR excess stars, CG1 IRS1, 2 and 3, were detected. NX Pup, which lies outside the globule head on the left, was also formed in CG1. A molecular hydrogen object MHO 1411 lies West from CG1 IRS1. Optical extinction from *JHKs* measurements (MH2013) is shown in Fig. b. Two maxima of which the western maximum is fragmented into two are seen. $^{13}$CO (2-1) and CO (2-1) line integrals in CG1 are shown in Figs. c and d. $^{13}$CO emission follows closely to the extinction in the cloud and the bulk of the emission is in the direction of the extinction maxima.




On the right $^{13}$CO (2-1) (left) and CO (2-1) (right) channel maps of CG1 Head. CG1 IRS1 is indicated with a box in the panels. The globule ´´nose´´ in SE is separate in velocity as already seen in C$^{18}$O (HMV 2010).

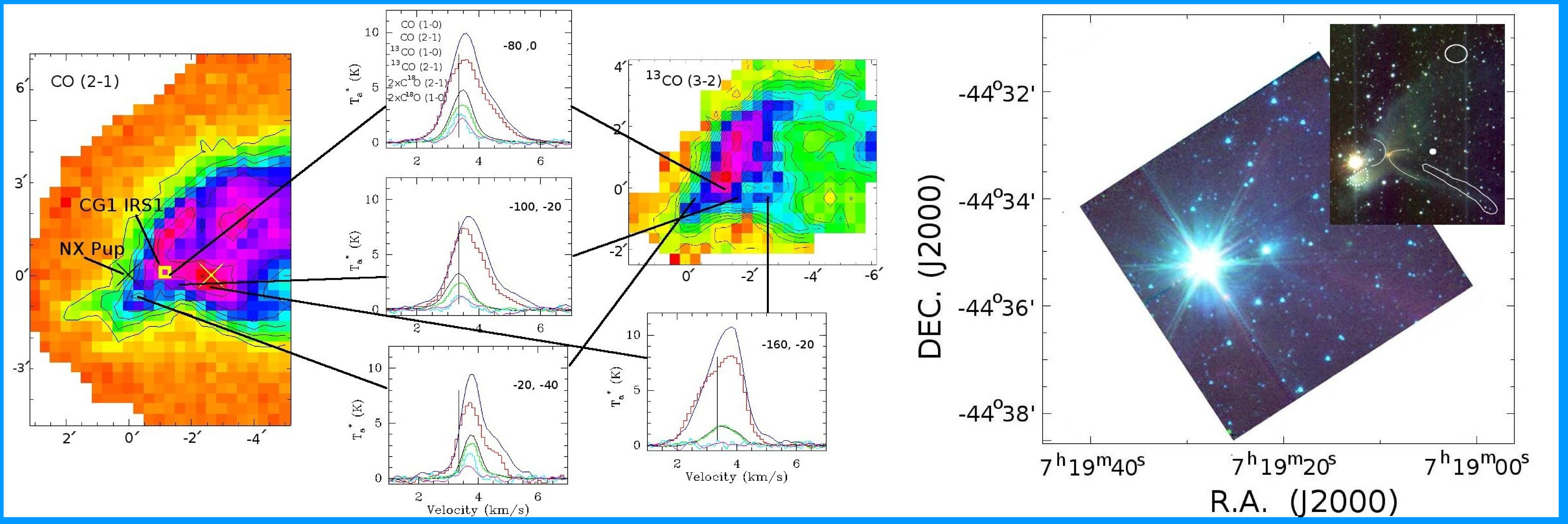
On the left WISE false colour 4.6 (blue), 12 (green) and 22 µm (red) image. CG1 IRS2 and IRS3 are marked with boxes. Bright surface emission at 12 and 22 µm is seen in a localized spot NW and in a streamer SW of NX Pup. Extended bright surface emission is seen to the West of IRS3. The latter is called Tail-South (MH 2013). The excess emission is interpreted to arise from PAHs or very small grains heated up by UV radiation from the bright OB stars in the Gum nebula.




$^{13}$CO and CO (2-1) channel maps of CG1 are shown in the middle and right. The CG1 ``spine`` , which breaks into individual clumps, is seen in $^{13}$CO. No trace of Tail-South is seen in $^{13}$CO which indicates that it can not be a separate cometary globule seen in the direction of CG1 tail. $^{12}$CO traces more diffuse gas than $^{13}$CO but only marginal emission at Tail-South is detected. Whereas CG1 IRS1 and 2 are located near a localized CO maximum no associated CO emission is seen near IRS3. C$^{18}$O emission is detected in the globule head (HMV 2010) and in the clump near IRS2. These locations coincide with the CG1 extinction maxima. Sample CO and isotopologue spectra in the tail maximum are shown below the WISE image. C$^{18}$O emission is detected but it is less intense than in the head (see below).

CO (2-1) (left) and $^{13}$CO (2-1) (middle) in the CG1 head. Sample CO and isotopologue spectra are shown. The tick line is at 3.4 kms$^{-1}$. Even though the CO lines are rather narrow (<2kms$^{-1}$) the velocity structure is complicated. Red outflow CO wing emission is seen in the spectra near CG1 IRS1. At position -160",-20", near MHO1411, CO line peak intensity is high but $^{13}$CO, C$^{18}$O and wing emission is low. Possible CO self absorption complicates the interpretation of the spectra.

On the right Spitzer IRAC 3.6, 4.5 and 8.0 µm false colour image (MH2013). The bright star is NX Pup. In the insert (SIRIUS *JHKs* image, HMV 2010) the arcs mark the probable edges of outflow cavities seen in the IRAC image. The dashed line shows reflected light from the nose. The ellipse and the elongated feature lower right shows positions of enhanced WISE 12 and 22 µm emission.




## Cloud structure, mass and star formation:

According to NIR photometry the globule total mass is 49 Mʘ of which 16.8 Mʘ is in the head (MH2013). The complicated optical depth/velocity/excitation structure in the cloud prevents a straightforward mass estimation from the CO emission without sophisticated modelling. However, as a first step LTE approximation can be used to obtain an indication of the head/tail mass distribution in CG1. On the average the C$^{18}$O emission in the head is more intense by a factor of two compared to the tail. The observed maximum integrated intensity in the head and the tail is however approximately the same corresponding to a N($H_2$) LTE column density of 9x10$^{21}$cm$^{-2}$. The C$^{18}$O LTE masses are 5 and 3 Mʘ (only the emission maxima are covered) in the head and tail, respectively. The corresponding $^{13}$CO masses are 10 and 13 Mʘ. The total head/tail $^{13}$CO masses are 13 and 23 Mʘ and the maximum column density is 1x10$^{22}$cm$^{-2}$. These are similar to those obtained from the NIR photometry and in agreement with the Harju et al (1990) values. The bright pre-main sequence binary Herbig AeBe star NX Pup was formed in the globule head and according to its SED CG1 IRS1 is a low mass Class I proto-star. The SED fits of the two other NIR excess objects show that they also are young low mass stars (MH2013). The presence of a MHO, CO line wing emission and the structures seen in the NIR imaging (SOFI, Spitzer, WISE) show that IRS1 is likely to drive an extended molecular out-flow. Low mass star formation and the associated molecular outflows modify strongly the structure of their parent cloud. In CG1 the star formation (NX Pup, CG1 IRS 1,2,3) and the outflow probably associated with IRS1 have modified the globule and the original head/tail mass ratio and no firm conclusion on the CG formation mechanism can be drawn from the present CG1 observations.

## References:

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