Detection of [CI] 1-0 and CO 4-3 in NGC4945 and Circinus
with the new NANTEN2 submillimeter telescope

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Abstract

We studied the central regions of the starburst galaxies Circinus and NGC4945. With the new NANTEN2 submm observatory in Pampa la Bola, Chile, we observed CO 4-3 and [CI] 1-0 for the first time. Both galaxies are very [CI] 1-0 bright objects with luminosities of 67 and 91 $Kkms^{-1}kpc^2$.

Including previous CO and ^{13}CO observations we study the density, column density and kinetic temperatures in both sources using escape probability models.
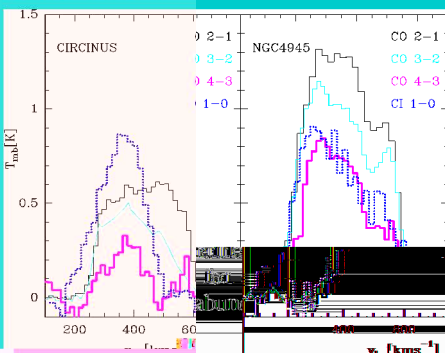
Observations

Fig.4 ^{13}CO 4-3 and [CI] 1-0 in Circinus and NGC4945 were observed with the NANTEN2 telescope. All other spectra are shown on 38" resolution apart from CO 3-2 in Circinus at 15".

Circinus: [CI] 1-0 peak temperature is at 900mK a factor of 3 brighter than CO 4-3.
NGC4945: [CI] 1-0 peak temperature is at 900mK while CO 4-3 peaks at 850mK.

Circinus

Fig. 1 2MASS image of Circinus showing a 8.7'*8.7' area.

Circinus is a nearby starburst spiral at 4.0 Mpc distance. Former studies (i.e. Johnson et al. 1991) detected large amounts of molecular gas.

NGC4945

Fig. 2 2MASS image of NGC4945 showing a 19.5'*19.5' area.

NGC4945 is a nearby (3.7 Mpc distance) galaxy with a very bright FIR luminosity in the center region. Former studies (i.e. Whiteoak et al. 1990, Mauersberger et al. 1996) suggest a substantial amount of molecular gas in the nucleus.
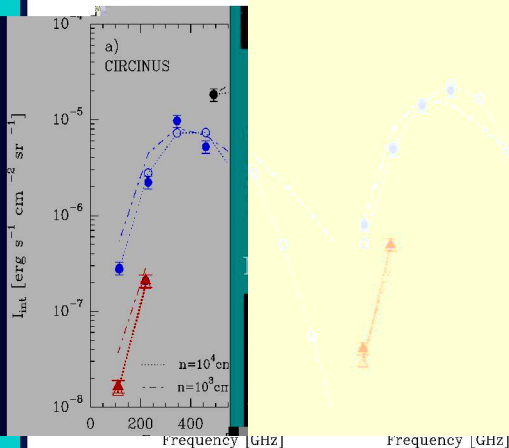
Radiative Transfer
CO and ^{13}CO

Fig.3 The dashed curves show two well fitting modelling results, a low temperature solution, and a high temperature solution.

Approach

The radiative transfer model assumes a homogenous clump of uniform density, temperature and column density as fitting parameters.

The ratios of the observed integrated intensities are computed for a fixed velocity width and a $^{12}CO/^{13}CO$ ratio and the best fit is determined.

To convert to integrated intensities we account for beam dilution of the signle clump in the beam and velocity filling from the modeled to the observed velocity width.

Results for Circinus and NGC4945

CO:
In Fig.4 two solutions are presented to show the degeneracy in density and temperature for a approx. constant pressure $n*T \sim 10^5 Kcm^{-3}$. The results agree well with results of previous studies in Circinus (Curran2001, Curran 1998, Wang 2004) and NGC4945 (Curran2001, Wang 2004, Mauersberger1996).

[CI]:
Assuming the isotope conditions, beam dilution and velocity filling in carbon as for CO we derive the CO/C abundance and the C/CO cooling intensity.

Summary of the modelling results

	Circinus		NGC4945	
χ^2	35	64	5	1
n_{kin} [cm^{-3}]	10^4	10^3	$3 \cdot 10^4$	10^3
T_{kin} [K]	20	100	20	100
N_{CO} [10^6 cm^{-2}]	35	50	76	63
N_{H_2} [10^{20} cm^{-2}]	37	46.5	89	74
M [$10^8 M_\odot$]	630	792	1385	1114
Δv_{model} [kms^{-1}]	5	5	10	10
N_{cl}	50	38	35	40
ϕ_A	2.0	6.3	1.5	1.0
CO/C abundance	0.15	1.67	0.23	0.64
[CI] cooling intensity	4.1	7.88	7.2	11.8
CO cooling intensity	2.1	2.8	6.6	5.7
[CI] /CO cooling intensity ratio				

The N_{CO}, N_{H_2} and M denote the total column density of CO, H2 and the total mass. N_{cl} is the number of clumps in the beam, Δv is the modeled velocity width and ϕ_A is the total filling factor. Cooling intensities are in 10^{-5} ergs^{-1}cm^{2}sr^1.

Discussion

[CI] luminosities :
The centers of Circinus and NGC4945 show very bright [CI] 1-0 emission and lie at the top end of the previously observed ~ 30 galactic nuclei (i.e. Israel&Baas 2002).

[CI]/CO 4-3 line ratio:
Israel et al. (2005) studied 13 galactic nuclei and find that [CI] is generally weaker than CO but not by much. Ratios vary from 0.1 to 1.2. In Circinus we find 3.1 and in NGC4945 1.2.

Total CO and [CI] cooling:
Bayet et al. (2006) find in all studied sources but NGC 6946 a higher CO cooling intensity with [CI]/CO cooling ratios varying from 0.3 - 2 predicted from PDR modelling. In Circinus and NGC 4945 [CI] to CO cooling intensity ratios are 2-3 and 1-2 respectivly.

Pressure of the molecular gas:
Previous studies (e.g. Bayet et al. 2006, Israel&Baas 2002) find a large range of kinetic temperatures (25-150K) and densities ($5 \cdot 10^2 - 7 \cdot 10^5$ cm^{-3}). The density/temperature degeneracy also cannot be resolved in our observed sources. In Circinus and NGC4945 we find a density range $\sim 10^3-10^4$ cm^{-3} depending on the temperature. The temperature range is less well constrained with values of 20-100K depending on the density.

Summary

Circinus and NGC4945 are very [CI] 1-0 bright objects with luminosities of 67 and 91 $Kkms^{-1}kpc^2$ at the top end of previously found values (Israel 2005) and show high [CI]1-0/CO 4-3 ratios of 3.1 and 1.2 (Hitschfeld et al. 2007).

Escape probability results show a range of densities and temperatures for a presure of around ~10^6 cm^{-3}K. The predicted CI cooling intensities are stronger than the CO intensities in both souces by up to a factor of ~2-3. The CO/C abundance is estmated to be 0.15-1.67 in Circinus and 0.23-0.64 in NGC4945.

References

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