The influence of star formation and nuclear activity on the molecular gas in nearby active galaxies

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Figure 1: Composite Hα/I/V/B image of the nearby starburst galaxy M82 (NASA, ESA, The Hubble Heritage Team)

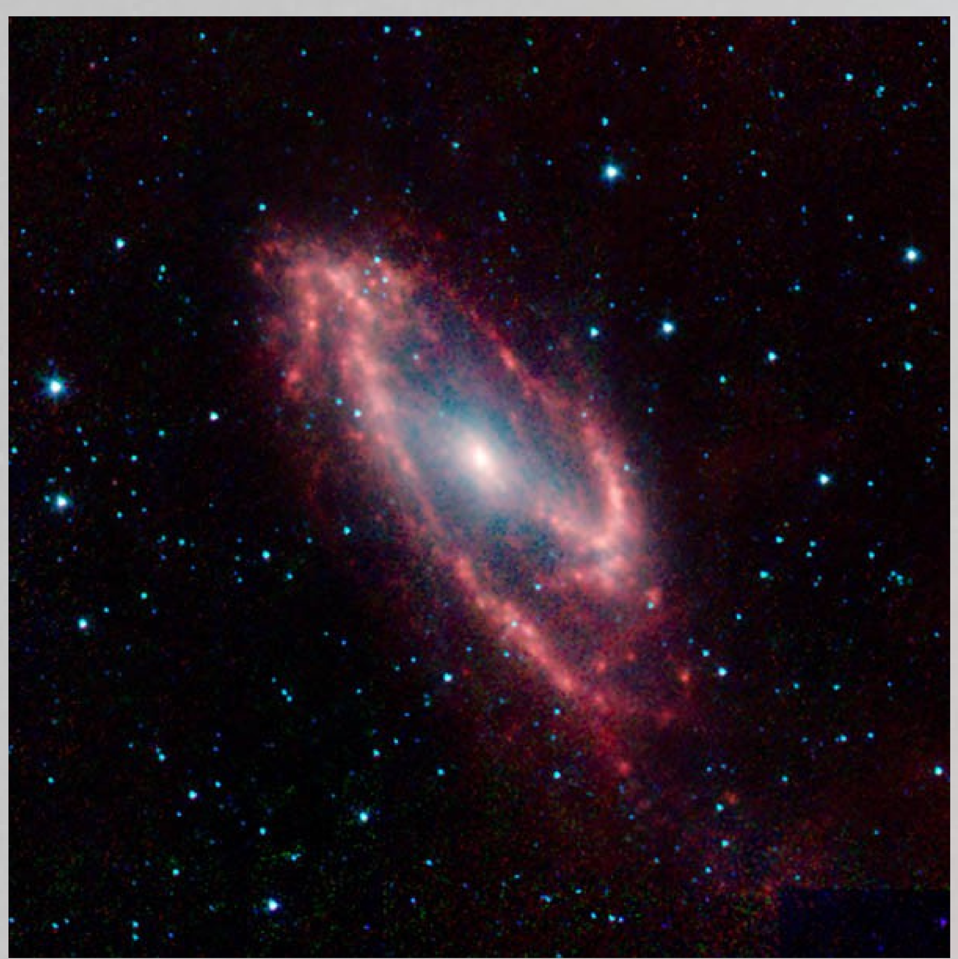


Figure 2: Composite IR image (3.6-8.0 μm, IRAC) of the nearby starburst galaxy Maffei2 (NASA/JPL-Caltech/J. Turner (UCLA))

Star formation, molecular gas and the IMF

Whether or not the initial mass function (IMF) is universal, i.e. the same in all kinds of environments, is still subject to intense debate [1]. A number of recent observations in a variety of targets have been interpreted as evidence for a top-heavy IMF, from the centre of our Galaxy to ultra-compact dwarf galaxies [e.g. 2]. Hydrodynamic simulations can reproduce such a top-heavy IMF if the raw material of star formation, the dense molecular gas, is assumed to have a kinetic temperature of ~100 K or more [5]. Such a molecular gas phase is not observed in the dense cores in the Milky Way disk, but may be present in active environments like the nuclei of starburst galaxies or near AGN [e.g. 7,11]. Possible heating mechanisms of the dense molecular gas include X-rays, cosmic rays, both of which penetrate even the densest molecular cores, and mechanical heating [10,3]. Unfortunately, the kinetic temperature of the molecular gas in external galaxies is usually not well constrained yet.

An extragalactic thermometer – and more

Formaldehyde (H_2CO) is a slightly asymmetric top molecule with a rich mm and submm spectrum [e.g. 6]. It is one of the few good tracers of the temperature of extragalactic molecular gas, because its fractional abundance varies only little in a variety of Galactic environments [4] and transitions of different K_a ladders can be observed (Fig. 3). Based on our non-LTE radiative transfer code and also taking observational aspects into account, we identified a set of lines that is particularly well-suited for the determination of the kinetic temperature *and* the density of extragalactic molecular gas: The line ratio $H_2CO(3_{03}-2_{02})/H_2CO(3_{21}-2_{20})$ is very sensitive to the kinetic temperature of the molecular gas, while the ratio $H_2CO(2_{02}-1_{01})/H_2CO(3_{03}-2_{02})$ traces the density (Fig. 4).

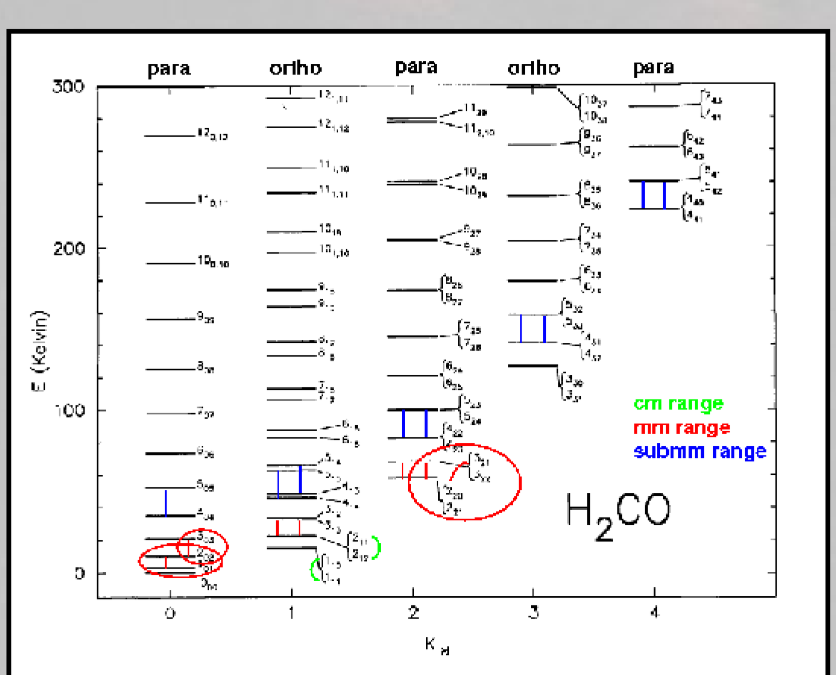


Figure 3: Energy level diagram of formaldehyde (H_2CO) adapted from [6] with a selection of observable transitions marked by colored lines. The H_2CO transitions used for our line ratio analysis are highlighted by ellipses. The $H_2CO(3_{03}-2_{02})$ and $H_2CO(3_{21}-2_{20})$ transitions are at a rest frequency of 218.22 GHz and 218.76 GHz, respectively, and the $H_2CO(2_{02}-1_{01})$ transition at 145.60 GHz.

Figure 4: Line intensity ratios derived from our LVG code shown as cuts through the parameter space (T_{kin} in K, n_{H2} in cm^{-3}, $N_{pH2CO}/\Delta v$ in $cm^{-2}\,km^{-1}\,s$) along a plane of constant p-H_2CO column density per velocity interval (left) and of constant kinetic temperature (right). The line ratio $H_2CO(3_{03}-2_{02})/H_2CO(3_{21}-2_{20})$ (red) is very sensitive to the kinetic temperature of the molecular gas, while the ratio $H_2CO(2_{02}-1_{01})/H_2CO(3_{03}-2_{02})$ (green) traces the density.

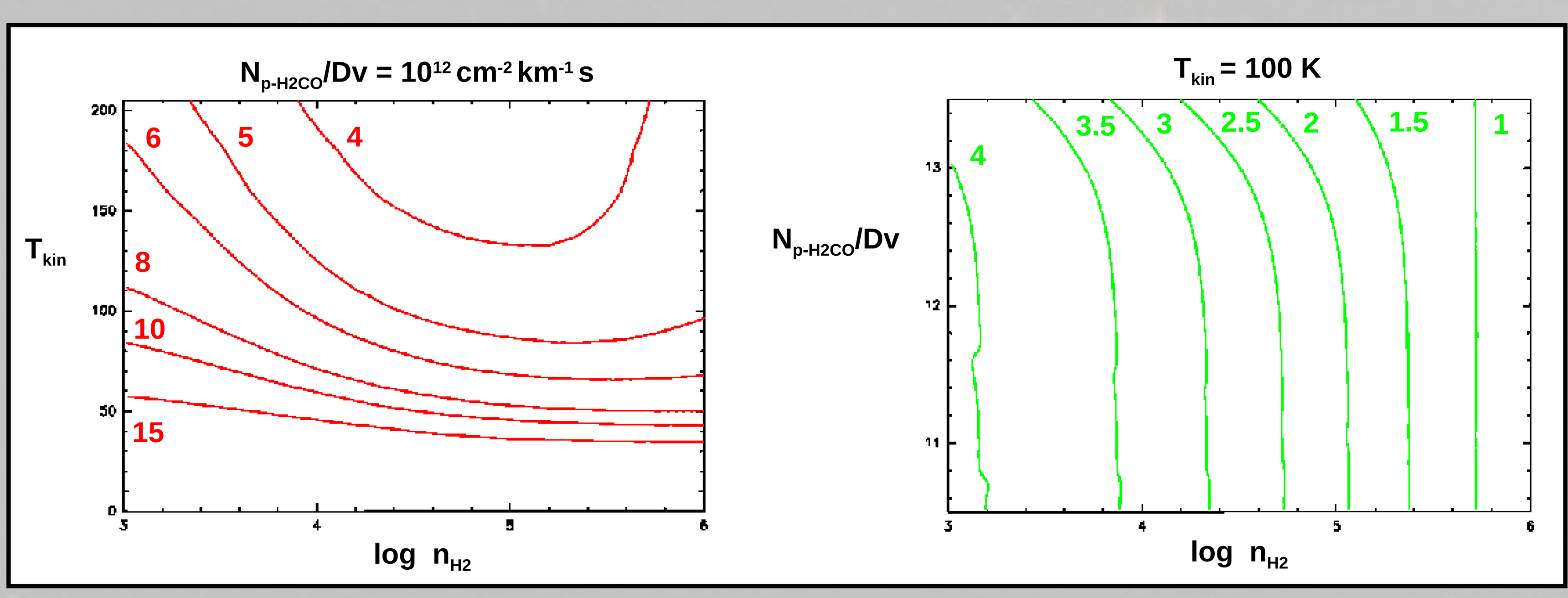
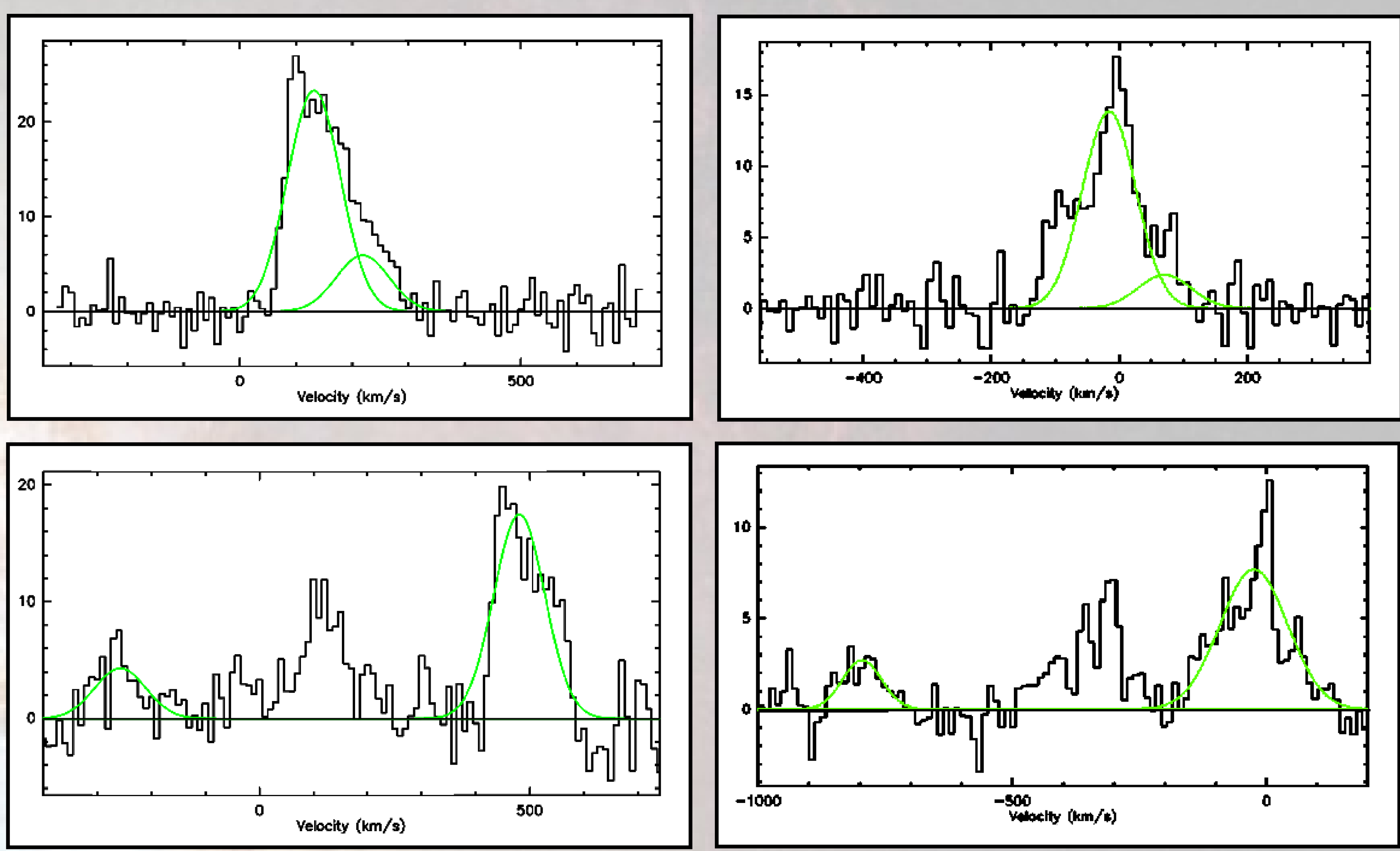


Figure 5: The detected H_2CO lines in the spectra of the southwestern lobe of M82 (left column) and in the nucleus of Maffei2 (right column) at 145.60 GHz (top panel) and 218.48 GHz (bottom panel) as well as the Gaussian fits used to derive the line intensities. The main-beam temperature is in mK. Note that although the $H_2CO(2_{02}-1_{01})$ line at 146 GHz is usually partially blended with the $HC_3N(16-15)$ transition, marked here by a Gaussian fit as well, its intensity can be determined with high confidence thanks to the constraints provided by the other H_2CO lines.



The temperature in nearby active galaxies

We have started to observe the diagnostic H_2CO lines with the IRAM 30-m telescope towards the nuclei of nearby galaxies showing starburst and/or AGN activity (Fig. 5). Using our LVG code, we calculated the expected line ratios for a large range of physical conditions: T_{kin} = 5 - 300 K, log(n) = 3.0 - 6.0 (in cm^{-3}), $\log(N_{pH2CO}/\Delta v)$ = 10.5 - 14.5 (in $cm^{-2}\,km^{-1}\,s$). For M82, we derive similar physical conditions in the two lobes of the molecular circumnuclear ring, in particular a high kinetic temperature of T_{kin} ~ 200 K and a moderate gas density of n_{H2} ~ $7.4 \times 10^3\,cm^{-3}$. The preliminary results of our observations towards other galaxies of our sample support the idea of a molecular gas phase at a kinetic temperature of T_{kin} > 100 K in the nuclei of other starburst galaxies as well and also suggest significant variations in the properties of the dense molecular gas throughout the nuclear region. Please see [8,9,12] for more details.

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