logue. Group 4 includes 6 galaxies close in projection (in particular 4 of them), Group 5 is a triplet very close in projection, and Group 6 is located at the bottom of the potential well, around the cD galaxy.

Luminosity Function in the V Band

The luminosity function in the V band shown in Figure 4 has been derived:

– directly, for the brightest galaxies ($V < 18$) with velocities belonging to the cluster;

– for fainter galaxies, for all the objects of our CCD photometric catalogue, to which we have subtracted the background counts in the V band taken from the ESO-Sculptor survey (Bellanger et al., 1995, Arnouts et al., 1996, see preprint by Lobo et al., 1996 for details on this subtraction).

The best fit is obtained for a power law of index $\alpha = -1.5 \pm 0.1$, similar to that obtained in central regions of clusters, such as e.g. in Coma, which we have re-analysed in detail recently (Biviano et al., 1996, Lobo et al., 1996 and references therein).

Conclusions

The combined data obtained with the MAMA measuring machine, CCD imaging and spectroscopy with MEFOS have led to one of the richest velocity catalogues for a single cluster. This will allow a detailed analysis of the physical properties of Abell 85, which will be compared to those derived from X-rays (Pislar et al., 1996).

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Fishing for Absorption Lines with SEST

THE REDSHIFT OF THE GRAVITATIONAL LENS TO PKS 1830–211

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Background

Molecular gas is the cold and dense part of the interstellar medium (ISM) which is directly involved in the formation of stars. The possibility of studying this ISM component at high redshifts would give us an insight in the conditions for stellar formation when these may have been quite different from what is seen in present-day galaxies. It was therefore with great interest that astronomers greeted the news in 1991 that emission from the rotational J=3–2 line of carbon monoxide (CO) had been detected in the galaxy F10214+4724 at a redshift of $z = 2.29$ (Brown & Vanden Bout, 1991). A standard conversion factor between the integrated CO emission and the column density of H_2 implied a molecular gas mass of 2×10^{11} $M_\odot$, which meant that the molecular gas constituted a major part of the total mass of the galaxy. Three years later CO emission was detected in the Cloverleaf quasar at $z = 2.56$ (Barvainis et al., 1994). In this case it was known that the CO emission was magnified by gravitational lensing, making it impossible to derive the intrinsic H_2 mass. It is now clear that also F10214+4724 is a gravitationally lensed system (Matthews et al., 1994) and that the molecular gas mass is overestimated by a factor of 10 or more (Radford, 1996). Yet another gravitationally lensed galaxy has been detected by Casoli et al. (1996). They observed CO emission from a gravitational arc at $z \approx 0.7$. With a magnification factor of ~ 50, this is intrinsically a relatively inconspicuous galaxy.

Apart from these gravitationally lensed objects, there have been searches for CO emission in nonlensed systems at high redshifts, which have all been negative. In fact, there are no confirmed observations of CO emission in nongravitationally lensed objects at redshifts higher than $z \approx 0.3$. Hence, high-z galaxies, including those with detected CO emission, appear not to contain extremely high molecular gas masses. At most, they are similar to nearby examples of merger systems, such as Arp 220. Nevertheless, the lensed systems have shown that molecular gas which has undergone a substantial stellar processing does exist at high redshifts.

Gravitationally magnified CO emission is, however, not our only means to study molecular gas at high redshifts. Just as in the optical wavelength band, it is easier to detect molecular absorption lines than the corresponding emission lines and, with an appropriate alignment of an intervening galaxy and a background radio continuum source, it is possible to probe the molecular ISM at very large distances. This has been demonstrated by the detection of more than 40 different molecular transitions at redshifts ranging from $z = 0.25$ to $z = 0.89$ (Wiklind & Combes, 1994, 1995a, 1995b; Combes & Wiklind, 1995). Due to the greater sensitivity of absorption lines, it is possible to observe molecules other than CO. Paradoxically, this is easier to do for gas at large distances, since Galactic absorption almost always gets confused with emission.

Molecular Absorption Lines at Intermediate Redshifts

The first molecular absorption at a cosmologically significant distance was detected with the SEST telescope in December 1993, towards the BL Lac object PKS1413+135 (Wiklind & Combes, 1994). The CO($J = 1 \leftarrow 0$) transition was seen at a redshift of $z = 0.247$. The continuum radio source is completely obscured at optical wavelengths and coincides with an edge-on galaxy with the same redshift as the absorption. The redshift of the BL Lac itself is not known, but since the impact parameter between the radio core and the nucleus of the galaxy is < 0.1″ and since there are no indications of gravitational lensing effects, it is likely that the absorbing gas resides in the host of the BL Lac object.

A second molecular absorption line system, this time at a redshift $z = 0.685$, was detected towards the radio source B0218+357 (Wiklind & Combes, 1995). B0218+357 has been identified as a gravitational lens on the basis of its radio morphology (cf. Patnaik et al., 1993). It consists of two compact flat-spectrum cores, separated by 0.34″ and a steep-spectrum ring. The absorption takes place in the lensing galaxy, where we have detected 15 different molecular transitions of molecules such as HCO^+, HCN, HNC, CN, H_2CO and CS (Wiklind & Combes, 1995; Combes & Wiklind, 1996). Surprisingly, we have been able to observe the isotopomers ^{13}CO and $C^{18}O$, while $C^{17}O$ remains below our detection limit. Together with a nondetection of molecular oxygen O_2, the molecular line data has allowed a stringent limit on the O_2/CO ratio, with implications for chemical models (Combes & Wiklind, 1995).

A third molecular absorption-line system was detected in June 1995 towards the background source B3 1504+377, at a redshift of $z = 0.673$. Similarly to PKS1413+135, a small impact parameter and the absence of gravitationally lensed images of the radio source implies that the absorption takes place in the host galaxy to B3 1504+377 (Wiklind & Combes, 1996b).

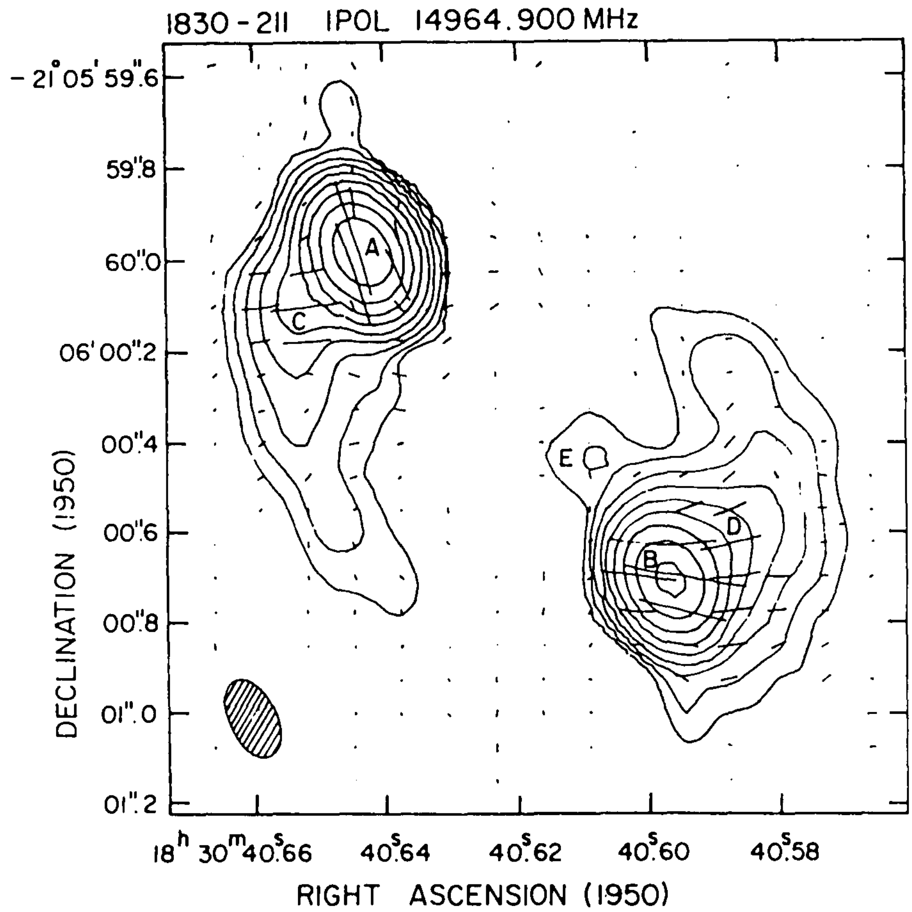

Figure 1: VLA image of PKS1830–211 at 15 GHz (from Subrahmanyan et al. 1990), showing contours of the flux and the electric field polarisation vectors.

Searching for More Molecular Absorption Line Systems . . .

We have also searched for molecular absorption lines associated with MgII and CIV absorption-line systems, as well as in the host galaxies of optically visible AGNs, without detecting any. The metal absorption-line systems are characterised by impact parameters (projected distance between the line of sight to the background AGN and the centre of an intervening galaxy) of tens of kpc and, due to the centrally concentrated molecular gas distribution found in nearby galaxies, it is not surprising that we find no molecular gas. The nondetections of molecular absorption at the redshifts of optically visible AGNs is readily understood as a selection effect; a molecular cloud in the line of sight is likely to cause several magnitudes of extinction, making the AGN virtually invisible at optical wavelengths. The three detected molecular absorption-line systems are characterised by a small impact parameter between a radio source and the centre of a galaxy which, albeit distant and faint, has been optically identified. The AGN associated with the radio source is not seen at optical wavelengths. The redshifts obtained from optical spectroscopy has been that of the intervening or associated galaxy.

While optical spectroscopy has a large instantaneous bandwidth, but limited spectral resolution, the contrary applies for millimetre wave spectroscopy. Measured in velocity, the bandwidth of a typical mm-wave receiving system is ~ 3000 km s^{-1}, while the resolution is ~1 km s^{-1}. This means that one needs to know the redshift of an absorbing galaxy to a relatively high accuracy in order to correctly tune the receivers. An alternative is to search for molecular absorption in a source with unknown redshift by sequential tuning of the receivers. From our experience with the known molecular absorption line systems, we know that it is not only CO which is likely to show strong absorption, but also HCO^+, HCN and HNC. Hence, by searching over the 3-mm band (80–115 GHz) we can cover the redshift intervals $z =$ 0–0.44 and $z = 0.55–3.32$. The 'hole' at $z = 0.44–0.55$ can be filled by observing the 149–160 GHz band at λ2-mm (Table 1). The SEST telescope is ideal for such a search since it is equipped with new low-noise SIS receivers covering the 3- and 2-mm bands and has an instantaneous bandwidth of 1 GHz. Furthermore, the receivers can be tuned from the control room, making it possible to rapidly change the frequency. With a strong continuum source, i.e. 1–2 Jy, the whole 3-mm band can be searched in less than 12–20 hours. The additional search in the 2-mm band increases this time only slightly, as SEST supports a dual observing mode where the 3- and 2-mm receivers can be used simultaneously.

. . . and Finding One with Unknown Redshift

A small impact parameter and the absence of an optically visible AGN seems to be a prerequisite for detecting molecular absorption lines, making radio identified gravitational lenses with small image separation good candidates. One such object is the gravitational lens can-

TABLE 1: Redshift coverage of saturated molecular absorption lines.

Molecular transition	3-mm band (80–115 GHz)	2-mm band (149–160 GHz)
CO(1–0)	0.00–0.44	
HCO^+(2–1)	0.55–1.23	0.12–0.20
CO(2–1)	1.00–1.88	0.44–0.55
HCO^+(3–2)	1.31–2.34	0.67–0.80
CO(3–2)	2.00–3.32	1.16–1.32

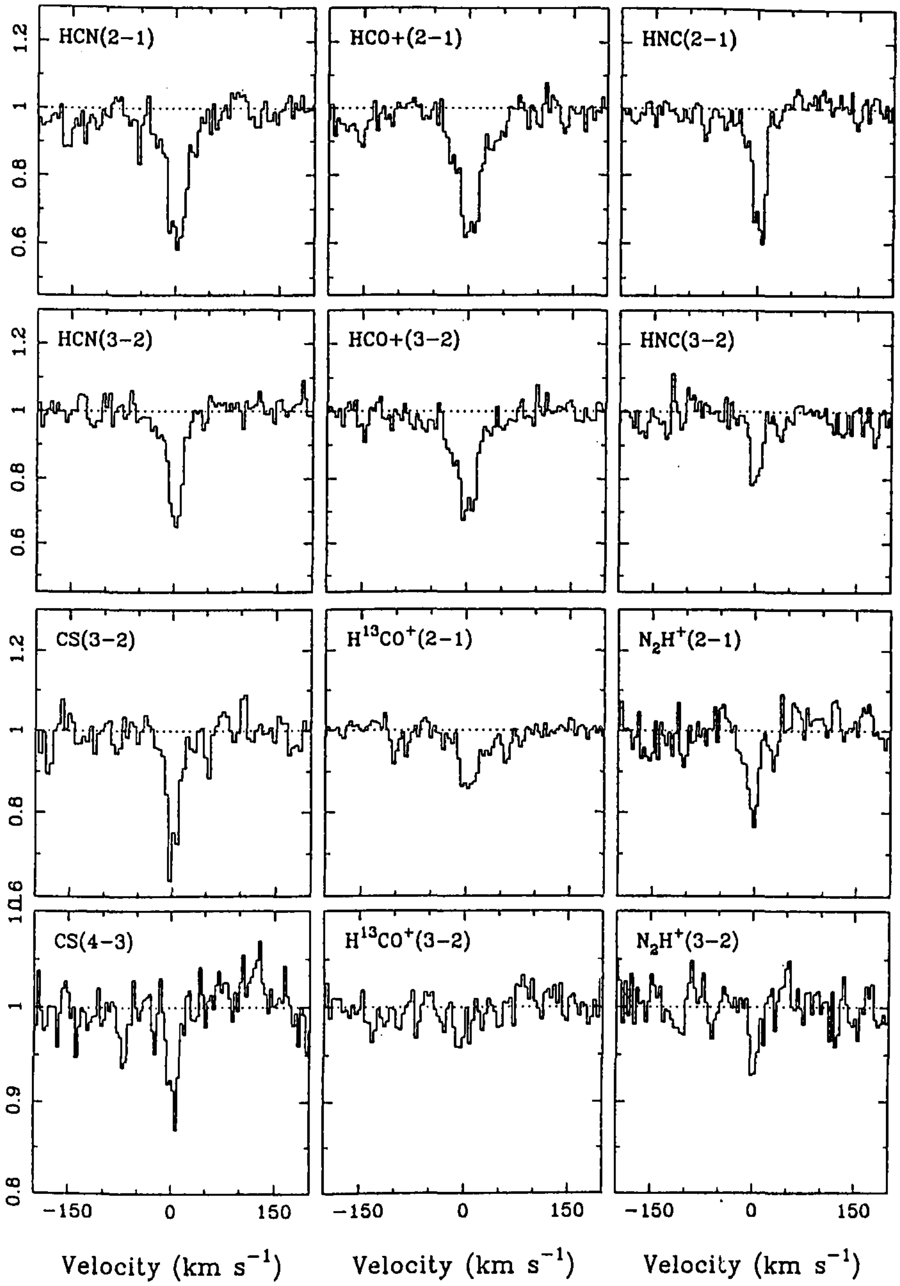

Figure 2: Absorption spectra from the lens to PKS1830–211 at z = 0.88582 observed with the SEST. The flux level has been normalised to unity and represents the flux from both images of the background radio source (which remains unresolved by the SEST telescope beam).

didate PKS1830–211. It is a strong radio source, with a radio morphology consisting of two compact components, separated by ~ 1″ and connected by an elliptical ring (Fig.1). The two components are parity-reversed images of a background quasar consisting of a core and a jet (Kochanek & Narayan, 1992; Nair et al., 1993). The extended feature of the lensed image makes PKS1830-211 ideally suited for modelling of the potential of the lensing galaxy and for deriving cosmographic parameters. One major drawback has been the unknown redshift of both the lens and the source. PKS1830–211 is located close to the Galactic Centre, at l = 12.2°, b = –5.7°, but the galactic extinction is moderate, with $A_V \approx 2.7^m$ (Subrahmanyan et al., 1990). Nevertheless, deep imaging in the BVRIK bands (Subrahmanyan et al., 1990; Djorgovski et al., 1992) has failed to detect an optical counterpart of neither the lens nor the background QSO. A recent attempt with the Keck telescope also failed (Djorgovski, private communication). Since PKS1830–211 is a strong source even at mm-wavelengths, with a flux ≥ 2Jy at λ3 mm, we decided to search for molecular absorption lines towards it, despite the unknown redshift.

We started our search in June 1995 and found the first absorption line after only a few hours of observation, at a frequency of 96.2 GHz. After confirming the detection, we observed at selected frequencies in the 3- and 2-mm band in order to establish the identity of the line. The candidate absorption line did not reach the zero level, but had a depth of ~ 35% of the continuum level. Our first interpretation was that the absorption was unsaturated. However, since the background source consisted of two components, separated by 1″, we could not exclude the possibility that the absorption was caused by molecular gas covering only one of them. It finally turned out that the absorption was caused by the HNC(2←1) line at a redshift of z = 0.88582 ± 0.00001. This was established by detecting the J = 2←1 lines of HCN and HCO^+ as well as the J = 3←2 lines of HCN, HCO^+ and HNC. Subsequently we also observed absorption lines of CS(3←2), N_2H^+(2←1), N_2H^+(3← 2) and $H_2CO(2_{11} \leftarrow 1_{10})$. The detection of the N_2H^+ molecule suggested that the absorption of the more abundant molecules like HCN, HCO^+ and HNC were saturated, despite not reaching the zero level. We therefore tuned to the isotopic $H^{13}CO^+$(2 ← 1). After some integration this transition was also detected, clearly showing that the HCO^+(2←1) line was heavily saturated. Some of the observed absorption profiles are shown in Figure 2.

The flux ratio between the two lensed images of the compact core represents different point-image magnifications. VLBI observations at λ2 cm gives a flux ratio of the NE and SW cores of 1.78 ± 0.10. If the molecular gas only covers one of the compact cores, the point-image magnification ratio is directly given by $R = (T_c/T_{abs}) - 1$, where T_c and T_{abs} are the total continuum flux and the depth of a saturated absorption line measured from the continuum level, respectively. Our molecular absorption-line data imply a point-image magnification ratio of 1.75 ± 0.15. From this we conclude that the SW core is obscured by molecular gas, while the NE component is not.

Utility of the Absorption Lines Towards PKS1830–211

The individual continuum fluxes coming from the NE and SW cores can be derived directly from a single spectrum of the saturated J=2←1 lines of HCN, HCO^+ or HNC. Since PKS1830–211 is known to have changed its millimetre continuum flux with a factor of two on a time scale of ~ 8 months (Steppe et al., 1993), these lines can be used as a sensitive probe of the time delay between the lensed images of the core. The lensed image of PKS1830–211 shows considerable structure at low radio frequencies (but not at millimetre wavelengths), making it possible to construct a detailed model of the gravitational potential of the lens. A measurement of the time delay therefore has the potential of giving an accurate value for the angular-size distance and, hence, a value for the Hubble constant. This may prove to be the most valuable result from the detection of molecular absorption lines towards this source.

An interesting application of redshifted molecular absorption lines in general comes from the fact that the excitation of the molecules might be dominated by the cosmic microwave background radiation. For dense gas this requires relatively high redshifts, but for diffuse gas, where collisions between molecules are infrequent, this can occur at intermediate redshifts. This latter situation seems to apply to the absorbing gas towards PKS1830–211. For the HCN, HCO^+ and HNC molecules we have derived an excitation temperature of 6–8 K. This is significantly higher than the expected temperature of the cosmic microwave background radiation, T_{CMB}, which at a redshift of $z = 0.89$ should be 5.16 K[1], but since these lines are heavily saturated they only give an upper limit to T_x. The unsaturated lines of CS, N_2H^+ and $H^{13}CO^+$, which directly give T_x, have an excitation temperature of only ~ 4 K. This is less than the expected temperature of the cosmic background radiation, but given the 3σ errors, the excitation temperatures are still consistent with a T_{CMB} at $z = 0.89$ of 5.16 K. The very low values of T_x show that the excitation of the molecular lines is dominated by the cosmic microwave background radiation and, given our observational uncertainties, we can derive a conservative upper limit to T_{CMB} of 6.0 K. Detection of more molecular absorption-line systems at similarly high, or higher, redshifts offers the possibility of observing the evolution of T_{CMB} as a function of redshift.

Although the excitation temperature of the molecular lines is low, the actual kinetic temperature of the gas may be considerably higher. The abundance ratio of the isomeric molecules HCN/HNC acts as a thermometer of the kinetic temperature; when this ratio is ~ 1, the gas has a T_k of approximately 15–20 K, whereas if the ratio is well in excess of 1, the temperature is 50–100 K. This effect stems from the way molecules are formed through gas-phase reactions. For our absorption lines towards PKS1830–211, we estimate the kinetic temperature to be around 16 K.

[1]In the big-bang theory, the temperature of the microwave background radiation scales as $T_{CMB} = T_{bg}(1+z)$, where T_{bg} is the temperature at $z = 0$.

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The Break-Up of Periodic Comet Schwassmann-Wachmann 3: Image Documents from La Silla Telescopes

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1. Science with an Ordinary Comet

Until recently comet 73P/Schwassmann-Wachmann 3 (hereafter SW3) was considered a rather ordinary comet and as not being worthwhile a dedicated observing programme. Therefore, not much more than orbital elements and brightness estimates were available when the European Space Agency ESA became interested in this object as a potential target for the next cometary mission ROSETTA. SW3 belongs to the family of Jupiter comets a group of comets with orbits substantially and repeatedly affected by Jupiter's gravitation. Indeed, it was Jupiter that brought SW3 into its present orbit: two encounters in 1965 and 1978 changed the perihelion distance and inclination of the comet's orbit from 1.02 to 0.94 AU and from 17.3 to 11.4°, respectively (Belyaev et al., 1986).

But what is the scientific interest in observing SW3 nowadays? The driver was ESA's selection of the comet as a back-up target for the ROSETTA mission. The design of the scientific experiments onboard ROSETTA and the planning of the mission operations require the knowledge of basic physical properties of the comet, such as the nuclear size, rotation, activity profile, chemistry, the production rates of gas and dust, etc. Addressing these mission-related parameters on the basis of observations, one simultaneously contributes to the characterisation of SW3 as a member of the Jupiter family comets. It is important to learn about the similarities and diversities among comets and comet families and to establish a classification scheme for these solar-system objects which are believed to represent the most pristine and unaltered remnants of the solar system nebula. In that way it may be possible to constrain the formation history and conditions of our planetary system and furthermore the development of comets since their formation in the interplanetary and interstellar environment around the Sun.

2. The Prelude Observations

As a potential ROSETTA target, comet SW3 was monitored more thoroughly than usual. Almost monthly, broadband filter imaging of SW3 was performed by