1. Introduction

Over the past decade our understanding of the structural and physical properties of discs around young stars has increased from basic theoretical modeling of the SEDs lacking any spatial information to the full three-dimensional disc structure modelling based on not only the SED, but also spatially resolved dust observations, like scattered light images and interferometry (Pinte et al. 2008; Panić et al. 2008; Tannirkulam et al. 2008). With the first submillimetre interferometers two decades ago, the molecular gas emission was spatially resolved and this has allowed major progress in understanding of disc kinematics, structure and chemistry (see Beckwith & Sargent 1987; Koerner et al. 1993; Dutrey et al. 1994, and later work by the authors). Recently, disc modelling including constraints of both dust and molecular gas observations has stressed the importance of studying both gas and dust, and comparing their amounts and spatial extent (Wilner et al. 2003; Panić et al. 2009). (Sub)millimetre gas and dust emission is the ideal probe of the global disc properties, like size, mass and radial distribution of disc material, because the bulk of the disc mass is located beyond 100 AU from the star and at temperatures of only 10-50 K that dominate this part of the spectrum.

Until the recent years, observations of rotational transitions of molecules in the submillimetre regime were focused primarily towards low-J emission from $^{12}$CO, up to the J=3–2 line (Greaves et al. 2000; Thi et al. 2001; Qi et al. 2004; Thi et al. 2004; Dent et al. 2005). In two of the brightest and most studied sources, TW Hya and LkCa 15, the observations of higher-J transitions of $^{12}$CO were compared to the low-J lines, providing indications of the gas temperature in the intermediate-height molecular layer (van Zadelhoff et al. 2001). In LkCa 15 this temperature was estimated to be 20-40 K, and in TW Hya higher than 40 K, using simplistic disc models to fit the single-dish line spectra. Qi et al. (2006) analysed submillimetric interferometer observations of TW Hya in the context of disc structure based on the accretion disc model (Calvet et al. 2002) and showed that X-ray heating of gas is efficient in this source, in addition to the stellar radiation field.

The emerging millimetre facilities in the Southern hemisphere like the Australia Telescope Compact Array (ATCA), Atacama Pathfinder EXperiment (APEX), and in future the Atacama Large Millimetre Array (ALMA), begin to open the window towards the star-forming regions of the Southern sky and are well suited to study the circumstellar discs in these regions. We use APEX receivers APEX-2a and CHAMP to observe the $^{12}$CO $J=7–6$, $J=6–5$, $J=3–2$, $^{13}$CO $J=3–2$ and [C I] $J=2–1$ line emission towards the disc around the young intermediate-mass star HD 100546. A wealth of observations of dust in this bright disc has motivated us to probe its molecular gas content for the first time. The chosen transitions are particularly sensitive to the gas in the warm upper layers and kinematics of the outer disc. The numerous observational constraints and the dust content of this disc are an excellent basis for the interpretation of our observations, especially the known outer radius and inclination.

HD 100546 is a young B9V type, 2.5 M$_\odot$, star, classified as a Herbig Be star due to its isolation, infrared excess and silicate emission (The et al. 1994; Waelkens et al. 1996; Malfait et al. 1998). With the distance of 103±6 pc, measured by Hipparcos,
this is one of the nearest Herbig Ae/Be stars. Van den Ancker et al. (1998) estimate the age of the star to be larger than 10 Myr, making the presence of circumstellar material intriguing, considering that the disc is expected to dissipate within 10 Myr in most young stars (Hernández et al. 2007, e.g.). The infrared spectrum of HD 100546 shows crystalline silicates similar to those seen in cometary dust (Malfait et al. 1998). Henning et al. (1998) report a substantial amount of mass around the star based on spatially unresolved millimetre flux measurements. This material has been imaged in scattered light and reveals an interesting structure of the disc extending up to 4″ from the star viewed at an inclination of 50° (Pantin et al. 2000; Augereau et al. 2001; Grady et al. 2001). Structure resembling spiral arms at opposing sides of the disc have been interpreted as due to disc perturbation by a companion (Quillen et al. 2005) or by a warped disc structure (Quillen 2006). Coronographic imaging by Augereau et al. (2001) find steep surface brightness profiles in the environment of HD 100546 indicative of optically thin emission in the near-infrared, deriving surface densities as low as 10⁻¹⁵ g cm⁻². Their images trace the emission of small dust (≪ 5 μm), extending out to 800 AU from the star. The authors suggest the presence of an optically thick disc and an optically thin flattened halo or envelope. Direct evidence of cold disc material is provided by Australia Telescope Compact Array observations of Wilner et al. (2003) at 89 GHz (3.4 mm) and 2″ resolution, with the flux of 36±3 mJy. They do not detect HCO⁺ J=1–0 line emission and speculate that photodissociation of CO in the upper disc layers or an overall gas depletion may be the reason for this. In the recent spectroastrometric observations of rovibrational 12CO transitions, van der Plas et al. (2009) suggest that 12CO is depleted from the inner disc regions (up to 30 AU from the star).

In Sect. 2 we present our observations of 12CO and 13CO rotational lines. All three lines are detected, and we model them in Sect. 3 deriving disc gas temperature.

2. Observations and Results

The observations of 12CO J=6–5 at 691.472 GHz and [C I] J=2–1 at 809.344 GHz towards HD 100546 at 11°33′25.4″ and Decl. =70°11′41″ (J2000) were obtained simultaneously with the CHAMP⋆ heterogeneous array receiver on APEX on 2008 November 10 (Güsten et al. 2008). The 7 pixels in each wavelength band are arranged in a hexagon of 6 pixels around one central pixel pointed towards the source, with beam sizes of 9″ at 690 GHz and 7.7″ at 810 GHz. The data were obtained in a staring mode with a chop of 120″. The background consists of Fast Fourier Transform Spectrometer units was used on all pixels, providing a spectral resolution of 0.12 MHz or 0.05 km s⁻¹ at these frequencies. Main beam efficiencies are 0.56 at 690 GHz and 0.43 at 810 GHz. Calibration is uncertain by ≲ 30% at both frequencies. Pointing was performed directly near-infrared, deriving surface densities as low as 10⁻¹⁵ g cm⁻². Emission from the inner disc regions (up to 30 AU from the star) is negligible. It is well known that an extended low-temperature and low-velocity component is present in the central pixel of our CHAMP⋆ data probes the 12CO J=6–5 line emission from the region of 9″ centered on the position of the star (450 AU radius), while the surrounding pixels probe the more distant regions (roughly 1000-2000 AU). Similarly, at the frequency of the 12CO J=7–6 line a smaller region around the star of 7.7″ is probed with the central pixel (390 AU radius), and regions roughly 1000-2000 AU with the surrounding pixels. Table 2 provides an overview of the pixel positions and the corresponding fluxes integrated from 0 to 10 km s⁻¹ velocity range, in which the 12CO lines are firmly detected in the central pixel. Compared to the on-source fluxes, these measurements clearly show that the surrounding material does not emit nearly as strongly as the region of 400 AU around the star. The 12CO J=3–2 line was observed with a single pointing and the beam of 14″, large enough to include any emission from regions beyond 400 AU. However, the strong resemblance in the line profile suggests that both low-J and high-J lines arise from the disc and that any contribution to the line emission by an extended low-temperature and low-velocity component is negligible. It is well known that an extended component described as an optically thin flattened envelope is present around HD 100546, at distances up to 800 AU. However, considering the low dust density in the envelope, the photodissociation of the molecular gas is expected to be efficient, resulting in largely atomic gas that does not contribute significantly to the 12CO line flux. Considering this, it is puzzling that the [C I] line emission is not detected in any of the CHAMP⋆ beams. However in IM Lup we have an extended component like this, but we do observe the CO 2–1!

The 12CO J=3–2 observations were presented in (7). Our data clearly show presence of warm molecular gas in the region extending up to several hundred AU from the star (390 AU for the 6–5 line and 700 AU for the 3–2 line). We obtain the following integrated intensity ratios, corrected for beam dilution: 12CO lines (6–5)/(3–2)=1.0±0.2 and (12CO 3–2)/(12CO 3–2)=2.8±0.5.

<table>
<thead>
<tr>
<th>Line</th>
<th>J</th>
<th>I  (K km s⁻¹)</th>
<th>FWHM (km s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12CO J=6–5</td>
<td>12±2.19</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>12CO J=6–5</td>
<td>10.5±0.9</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>12CO J=3–2</td>
<td>4.0±0.6</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>12CO J=3–2</td>
<td>1.3±0.6</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>CI J=2–1</td>
<td>0.7±0.2</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Observed 12CO J =6–5 and J =3–2 line integrated line intensities, \( I = \int T_{\text{mb}} \, dv \), and line widths FWHM. [C I] line integrated over 7–8 km s⁻¹ range where emission is suspected.
Table 2. Observed $^{12}$CO $J=6–5$ and $J=7–6$ intensities integrated over the velocity range 0-10 km s$^{-1}$, for each pixel of the CHAMP+ heterodyne array.

<table>
<thead>
<tr>
<th></th>
<th>$^{12}$CO $J=6–5$</th>
<th>$^{12}$CO $J=7–6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA offset</td>
<td>Dec offset</td>
<td>$I_{CO(6-5)}$</td>
</tr>
<tr>
<td>(”)</td>
<td>(”)</td>
<td>(K km s$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-9.8</td>
<td>-17.0</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>+8.8</td>
<td>-18.0</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>-18.9</td>
<td>-0.2</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>+19.4</td>
<td>-1.2</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>-9.3</td>
<td>+16.6</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>+10.0</td>
<td>+16.6</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>

There is a clear asymmetry in the profile of the $^{12}$CO lines, observed at a high signal-to-noise ratio. This asymmetry is often seen in the literature toward sources where disc emission is combined with a more extended cloud emission or where there is a large scale asymmetry in the disc structure. In the following section we investigate the possible causes of the observed line asymmetry.

3. Discussion

3.1. CO line emission

The $^{12}$CO $J=3–2$ and $J=6–5$ line emission from circumstellar discs is generally optically thick and arises from warm upper disc layers. These lines are particularly sensitive to the temperature of these layers, and therefore to the stellar and external illumination of the disc surface. The ratio of the $^{12}$CO lines ($6–5)/(3–2)=1.0±0.2$, is somewhat higher than the ratios $≈0.5$ found for discs around T Tauri stars LkCa 15 and TW Hya, in van Zadelhoff et al. (2001) and Qi et al. (2006). This may be due to the higher temperature in the disc heated by the A type star HD 100546. The line ratio ($^{12}$CO $3–2)/(^{13}$CO $3–2)=2.8±0.5$ indicates that the $^{12}$CO line emission is optically thick and thus substantial amounts of gas are present in the disc around HD 100546. The low $^{13}$CO line flux may be in part due to freeze-out and/or selective photodissociation. Detailed modelling and spatially resolved submillimetre line observations of $^{12}$CO and isotopologues would allow to constrain the disc structure better, and evaluate the effect of these processes (Panić et al. 2008).

The line emission of $^{13}$CO $J=3–2$ is less optically thick than $^{12}$CO, tracing deeper into the disc colder layers. A deeper integration of this line resulting in a higher signal-to-noise ratio would provide a better defined spectral profile. The comparison to $^{12}$CO line profile would allow us to draw conclusions on the relative spatial extent of the emission region of the two molecules and enable a more detailed modelling, including a disc vertical temperature structure and simple processes like freeze-out in the cold outer regions below disc surface layers.

The submillimetre $^{12}$CO line emission is analysed using two different modelling approaches in the literature. Disc physical models, like the irradiated accretion disc models of D’Alessio et al. (2005), e.g., are especially well suited when the emission is spatially resolved and disc three-dimensional structure can be investigated, for example when transitions of different optical depths are observed (refsXX). For spatially unresolved observations, like those presented here, simplistic models with a limited number of free parameters are more appropriate to derive some basic constraints on disc properties based on the line spectrum (refsXX).
3.2. Disc parametric model and best-fit parameters

In (??) we show that simple power-law disc models, with $M = 0.01 \, M_\odot$, $\Sigma \propto R^{-1}$ and $T = 60 \, \text{K} (R/100 \, \text{AU})^{-0.5}$, are a useful tool to analyse low-$J$ $^{12}$CO transitions from discs around gas-rich Herbig Ae stars. We use these models to fit the $^{12}$CO spectra. We fix the outer radius and inclination to the observationally constrained values 400 AU and 50° (Augereau et al. 2001). The size estimate is based on the scattered light observations and is a reliable guidance for molecular line modeling. Without sufficient amounts of gas the dust settles to the midplane, and the disc becomes self-shadowed. As the scattered light only probes the illuminated disc surface at some height above the midplane, it provides a lower limit to the actual size of the disc. The inner radius is assumed to be 0.6 AU, close to the dust sublimation radius. Although an inner hole of 13 AU is found in HD 100546, its presence would not affect our results as the molecular lines observed are dominated by the outer disc regions, far beyond inner tens of AU. The surface density is given by a powerlaw $\Sigma \propto R^{-1}$, and the temperature $T = T_{100} (R/100 \, \text{AU})^{0.5}$, where $T_{100}$ is a free parameter. The disc models are vertically isothermal, and the vertical density structure is calculated assuming hydrostatic equilibrium. $^{12}$CO abundance with respect to H$_2$ is assumed to be $10^{-4}$, constant throughout the disc. Because the observed $^{12}$CO lines trace warm molecular material and are insensitive to the colder regions deeper in the disc, it is reasonable to neglect freeze-out in these calculations.

For the estimated disc mass and observed $^{12}$CO/$^{13}$CO line ratio, the observed $^{12}$CO lines are optically thick, with H$_2$ surface density of $10^{22}$ cm$^{-2}$. Therefore the evident line asymmetry mentioned in Sect.XX can not be fit by assuming different density at the two sides of the disc, because this would lead to unphysically large tangential density gradient. Any such gradient would be smoothed out over several orbital periods. A pointing offset could not cause the observed asymmetry if the emission arises entirely from the disc, because the line peaks from a disc in Keplerian rotation are not dominated by the outermost disc regions, like in the case in extragalactic sources, where the velocity increases with the radius. However, a pointing offset in direction of a hypothetical clump of material emitting at 4 km s$^{-1}$ velocity is a plausible, although highly unlikely.

For the optically thick $^{12}$CO lines, the temperature and the outer radius determine the line intensity, and any asymmetry in either temperature or the outer radius affects the emerging line profile. We consider these two possibilities separately.

3.2.1. $^{12}$CO $J=6$–$5$ and $J=3$–$2$ line fit

Temperature asymmetry. In this scenario we consider that the observed line asymmetry is caused by temperature asymmetry in the disc, i.e., one side of the disc being colder than the other. We use different $T_{100}$ parameters for the two sides of the discs, with respect to the minor axis. These two sides of the discs contribute almost entirely to the two respective sides of the spectral line (with respect to the line centre at 5.6 km s$^{-1}$). The radial density structure as given by the disc mass, outer radius and surface density power-law is axially symmetric. Some difference in the disc vertical thickness may be present as a result of different temperatures at the two sides, but this difference is negligible and the resulting spectra are insensitive to it.

We use the molecular excitation and radiative transfer code RATRAN (Hogerheijde & van der Tak 2000) to calculate the line emission from the model. In these calculations, Keplerian rotation of the disc around a 2.5 $M_\odot$ star and disc inclination of 50° (0° corresponding to face-on) are assumed. Dust continuum emission is included in the calculation, although negligible for the molecular line transfer, and subtracted from the final image cubes. The calculated emission is convolved with the corresponding beam size and spectra toward the image centre extracted.

We obtain the best fit to the $^{12}$CO $J=6$–$5$ spectrum by assuming $T_{100}$ of 40 and 60 K for the two disc sides, respectively. The $^{12}$CO $J=3$–$2$ spectrum is fitted assuming 40 and 50 K. The corresponding synthetic spectra are compared to the observations in Fig. 3. The temperatures of 40-60 K compare well to the theoretical predictions of where these lines saturate in discs (see Fig. 6 in van Zadelhoff et al. 2001). This difference in temperature between the two sides of the disc may be explained by a warped inner disc, as illustrated in Fig. 3.1, with the elevated side of the inner disc intercepting a fraction of stellar light that would otherwise reach the outer disc, while the opposite side is sightly more illuminated, with the inner part shifted downwards. The possibility of an inner warp is suggested in (Quillen 2006) for HD 100546, with an inner component extending up to 200 AU inclined by $\approx 15°$ with respect to the outer component extending beyond that radius. The temperature asymmetry is possible also if the disc has different thickness at the two sides. This may happen in a disc with dust settling underway, if a planet or another body embedded in the disc stirs the dust back up. In this case the ‘stirred’ part of the disc intercepts more stellar light and becomes somewhat warmer. A companion body in HD 100546 is suggested in the literature, to explain the observed spiral arms (Quillen et al. 2005).

Asymmetry in the disc spatial distribution. If one side of the disc extends slightly further out than the other (e.g., on the SE side), the increase in disc surface at that side will contribute to the line flux at the corresponding frequency range (low velocities) and cause line asymmetry. This may be a plausible explanation for the 3-2 line, but not the 6-5 line with 9° beam size,
unless the asymmetry is within 450 AU. Such asymmetry would likely have an effect on the scattered light images of HD 100546, with the disc extending further to the SW than to the NE of the star. However this is not seen in the observations of Augereau et al. (2001).

Disc density asymmetry. A different density on the two sides of the disc, with one side significantly denser than the other, may cause asymmetry in the molecular line emission. This scenario only applies if the observed line emission is at least marginally optically thin and thus sensitive to the disc midplane density. If we decrease the disc mass so to allow the $^{12}$CO line emission in our models to be sensitive to the density variations in the midplane, we would be obliged to assume the disc midplane temperature in the calculations, that can be as low as 10-20 K in the outer disc. In this case, to fit the observed line intensities we would require a disc mass much higher than 0.01 M$_\odot$ (see results of the temperature asymmetry scenario), thus making this scenario impossible.

**Pointing offset** A systematic pointing offset towards SE of $\delta$RA=1°.1 and $\delta$Dec=-1°.6, well within the measured pointing accuracy of 3"., may cause line asymmetry as observed in the $^{12}$CO $J$=3–2 and $J$=6–5 lines. Figure 3 shows the comparison between the observed spectra of the two lines and the spectra extracted from axially symmetric models using the abovementioned offset. The $T_{100}$ parameter in these models is 50 K for the $^{12}$CO $J$=3–2 and 60 K for the $J$=6–5 line. Interferometric observations of this source in future would provide an answer whether the apparent asymmetry is real or due to a pointing offset.

### 3.2.2. $^{13}$CO $J$=3–2 and $^{12}$CO $J$=7–6 line fit

The $^{13}$CO $J$=3–2 spectrum appears asymmetric, but the difference between the line intensity at the expected location of the two peaks is within the noise level. This line arises from denser and colder disc layers, distinct to those traced by the high-$J$ transitions. A temperature asymmetry in the upper layers is unlikely to have a detectable effect on the temperature deeper in the disc, and it is likely that any future, high-sensitivity observations of CO isotopologue emission, will reveal symmetric line profiles.

As in the calculations of the Sect. 3.2.1, we use RATRAN code, including Keplerian rotation and disc inclination values as above. No freeze-out is included. We adopt a constant $^{13}$CO abundance, assuming an isotopic ratio $[^{13}\text{C}] / [^{12}\text{C}]=77$ (2). We fit the $^{13}$CO $J$=3–2 spectrum assuming an axiymmetric temperature structure, with $T_{100}=25$ K. The comparison of the synthetic spectrum from our best-fit model to the observed is shown in Fig. 3.

The $^{12}$CO $J$=7–6 is fit with $T_{100}=50$ K, close to the temperatures used to fit the $J$=6–5 lines. These two transitions are energetically close and our data is consistent with the expectation that they should trace the same disc layers. The $^{12}$CO $J$=7–6 line profile is therefore likely asymmetric, but hidden in the noise of our observations.

### 3.3. CI $J$=2–1 line observations

Figure 1 includes the high-quality spectrum around the [C I] $J$=2–1 line at 809.344 GHz. No significant feature is detected down to 0.2 K rms in a 0.27 km s$^{-1}$ velocity bin, implying a limit on the integrated intensity of $\approx 1$ K km s$^{-1}$ assuming a similar line profile as $^{12}$CO 3–2. Model B2 of (Jonkheid et al. 2007) predicts integrated [C I] intensities, scaled to the distance of HD 100546, around 15-20 K km s$^{-1}$ whereas the model intensities are even larger in disks with significant grain growth and settling (models BL2–BL4). Thus, while the CO data appear entirely consistent with their sophisticated UV-heated disk atmosphere models, the [C I] data are clearly discrepant by an order of magnitude.

One possible solution could be that the radiation field contains more carbon ionizing photons than assumed here, shifting the chemical balance from neutral to ionized atomic carbon. Indeed, the predicted [C II] line intensities for the model disks of Jonkheid et al. (2007) are very low, $< 0.1$ K km s$^{-1}$ whereas they are more than an order of magnitude higher for disks around T Tauri stars with excess UV emission (Jonkheid et al. 2004). Such excess of UV emission could come from the disk-star accretion boundary layer. Indeed, HD 100546 is observed to undergo significant accretion, in spite of the known (dust) gap in the inner disk (Veier et al. 1999). Searches for the [C II] line with HIFI instrument on the Herschel Space Observatory can test this scenario. In this case, the [C I] line intensity or the [C II]/[C I] line ratio could be a diagnostic of the presence of excess UV emission over that of the stellar photosphere.

### 3.4. Implications for dust continuum emission

Our assumed gas mass of 0.01 M$_\odot$ corresponds to $10^{-4}$ M$_\odot$ of dust adopting a gas-to-dust mass ratio of 100. To calculate the continuum fluxes, we assume that the dust emission is optically thin and arises at temperatures close to 25 K, the 100 AU temperature found to fit the $^{13}$CO line emission well. With these parameters, the dust continuum flux at 3.4 mm of 36 mJy reported in the observations of (Wilner et al. 2003) at 2" resolution and the flux at 1.3 mm of 690 mJy reported in Henning et al. (1998) at 23" resolution can both be fitted with a dust emissivity $\alpha_{\text{Dust}} = 0.1 \times (1.3 \text{ mm}/4 \text{ mm})^{0.9}$, representative of grain growth to 100 cm sizes in discs (Draine 2006). The shal-
We summarise our conclusions as follows:

4. Conclusions
We summarise our conclusions as follows:

- We present evidence for warm molecular gas associated with the disc around HD 100546, in the regions within 400 AU from the star, successfully separated from more extended material in our CHAMP$^*$ observations;
- Gas kinematics are consistent with Keplerian rotation around an 2.5 M$_\odot$ star of the disc with 400 AU radius, viewed at an inclination of 50$^\circ$ from face-on;
- The $^{12}$CO (6–5)/(3–2) line ratio of 1.0±0.2 is twice higher than measured towards discs around T Tauri stars.
- Line asymmetry seen in $^{12}$CO $J$=6–5 and $J$=3–2 lines can be explained by a temperature asymmetry, with one side of the disc slightly colder than the other, possibly due to a partial obscuration of one side by a warped inner disc or a high disc rim, but a systematic pointing offset of the telescope is also possible;
- Our data are consistent with a disc of total mass 0.01 M$_\odot$. We exclude the possibility of a low-density disc and optically thin $^{12}$CO emission, as disc midplane temperature is insufficient to reproduce the observed line intensities. Furthermore, efficient freeze out would limit the emission to a much smaller radius, altering the line profile.
- The puzzling non detection of [C I] $J$=2–1 line may indicate efficient photoionisation.

Future observations with ALMA will be crucial to characterise the disc around HD 100546, spatially resolve its kinematics and structure. In particular, these observations will allow a detailed comparison between the spatial distribution of the gas traced by the rotational transitions of $^{12}$CO and its isotopologues, and the dust traced with the millimetre continuum emission.

Acknowledgements. The research of O. P. and M. R. H. is supported through a VIDI grant from the Netherlands Organisation for Scientific Research. We thank L. Kristensen for advice on the reduction of APEX data. We thank C. M. Wright for sharing the information on their ATCA data.

References


low emissivity slope $\beta \approx 1.0$ is also suggested by (Wilner et al. 2003).