Recent southern maser surveys

- *James Caswell*

A review of recent maser surveys allows us to see the context of the new methanol multibeam survey that we are currently conducting – described in the next session by James Green. I will confine this discussion to essentially the surveys of masers in Star Formation Regions.

Why surveys? From yesterday's session, there was the reminder:

masers of OH, methanol and water play three special roles in studying birth of massive stars

- *They are one of the earliest and most prominent indicators of the birth of a massive star, and a principal means of discovering such sites*
- *Each maser site is powered by a single embryonic star, but comprises many high brightness maser spots of small diameter and narrow velocity width, making them excellent kinematic probes*
- *Conditions necessary for maser excitation yield information on the chemical and physical conditions pertaining to the site at an early stage before the fully developed star has blown it all away*

Three main threads:

- *Brief summary of the more extensive surveys of the recent past*
- *Some interesting outcomes from comparing the surveys*
- *Discussion of some very recent surveys that we have conducted but which are not yet published.*

Starting with methanol:

Compilation by Michele Pestalozzi; very useful, but use with caution since the source material is of highly variable quality

Targeted surveys, and 'Blind' surveys.

This begs the question of what we mean by survey…..

Methanol surveys, (targeted)

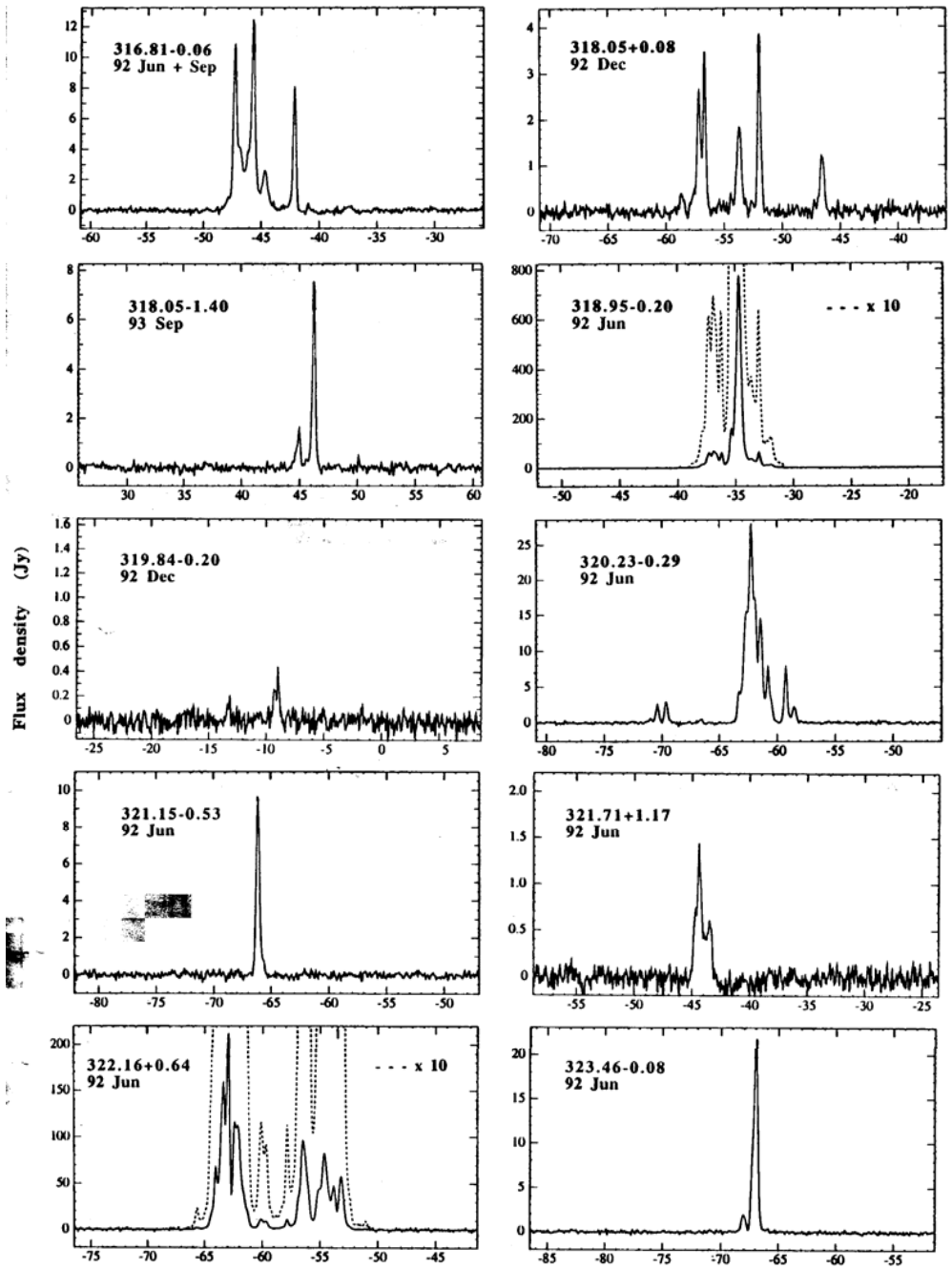
Menten (1991) chose a variety of targets loosely associated with Star formation regions.

The Hartebeesthoek surveys – chose IRAS targets in the southern sky – a valuable discoverer of sources off the galactic plane – regions that might have remained unsearched by blind surveys.
- and especially valuable in recognising the rather limited value of IRAS as a maser site predictor,

Torun – similar search of IRAS sources in the northern sky.

Parkes (1995) – A search of several hundred OH maser targets, with high success rate, and the first extensive atlas of spectra with high sensitivity (see next slide).

Typical methanol spectra from Parkes survey



Methanol surveys, (blind)

Hobart, with 25m dish; published longitude 325-335 (1996), detected 50 masers, about half of them new.

Torun with 32m dish; similar work in the northern sky, with large numbers of new masers as well as re-detection of those found during the IRAS searches.

Arecibo survey: recent survey which will be described at this meeting. Large dish, good sensitivity, quite good positions, but inherently limited sky coverage.

Methanol surveys (continued)
- additional to single dish surveys we have:

ATCA exploratory pilot survey to achieve simultaneous search AND precise positions. Small latitude coverage in longitude range 325-340. Approximately 50 sources. Successful but will not be pursued further until current poor sensitivity at this frequency is remedied by new broadband receivers ca. 2008

Not really surveys, but revealing additional serendipitous detections:

ATCA follow up of targeted surveys. Walsh following up single dish detections towards IRAS sources.

ATCA follow up of targeted surveys. Caswell following up the single dish detections towards OH masers.

Moving on to OH surveys:

In the southern sky – a series of surveys with Parkes, and followed by the ATCA.

Blind Parkes surveys at 1665 and 1667 MHz.

Blind ATCA surveys at 1665 and 1667 MHz

Combined catalogue, with precise positions Caswell (1998)

6035 and 6030 MHz complete follow up of the 1665-MHz extensive catalogue of targets (Caswell 2001; 2003).

1720 MHz similar complete follow up of the above targets.

1612-MHz survey (Sevenster et al.1997): although optimised for late type stars, it is a valuable resource for recognising the relative scarcity of 1612 MHz towards SFRs.

Water maser surveys.

Large numbers of water masers known.

They arise from a very mixed bag of targets, over more than 30 years.

A valuable compilation plus monitoring database, from Medicina (Arcetri) - next session

Unbiased surveys – very little work since a small pilot survey by Matthews et al. in 1985 – (a long time ago!)

Outcomes of the surveys.

1. The galactic distribution obtained from OH. Effectively, other species mimic OH, which is the only extensive blind survey so far (i.e. distributions of the derivative surveys of methanol maser and water maser compilations chiefly reflect the target distribution).

2. Luminosity functions are useful for estimating expectations from future more extensive surveys.

3. From the OH 1720, 6035 and 6030 MHz, (and even 13 GHz) derivative surveys – these have proved to be some of the best targets for revealing magnetic field distributions via the observed Zeeman splitting.

Outcomes of the surveys (continued).

4. Variability – with fascinating outcomes shown by Sharmila Goedhart yesterday.

5. The typical velocity spread; follow-up with high positional precision often reveals that sources with extreme velocity spreads are really close juxtaposition of sources with much smaller intrinsic widths.

Finally, a reminder again that targeted surveys with large beams can constitute a useful degree of blind surveying, as becomes clear when the discoveries prove on examination of precise positions to be significantly offset from the targets.

Outcomes of the surveys (concluded).

Intriguingly, the class II 6668-MHz methanol masers have proved to be the most profitable targets for discovering class I methanol masers – despite their mutual exclusivity. See the poster by Maxim Voronkov which describes the southern campaign to study class I methanol masers. The conundrum of relationships between class I and class II is one that Simon Ellingsen will address in his talk later today.

Part 2 – some unusual discoveries - from the follow up of surveys, and inter-comparing surveys.

After excluding the spuriously large apparent velocity spreads, there remain some OH and some methanol masers where the spread is large. What then is the systemic velocity?

Among the methanol masers, there are relatively few with large widths, and most of these arise in strong sources, where strongest emission is near the median velocity, and the wings extending from this are very weak. The systemic velocity then seems most likely to be at the median velocity. Overall, methanol appears to be an excellent indicator of systemic velocity.

In contrast to the methanol, there are some striking examples of OH masers with wide velocity spreads where the emission is concentrated at the velocity extremes.

Where, in these cases, is the systemic velocity?

Is it in the middle, where there is little or no emission? (as in the late type stars where the front and back of an expanding shell dominate the observed maser emission).

Or is it at one extreme or the other; and if so, which extreme? And why?

To understand these OH masers we compare them with their coincident methanol counterparts – with interesting results.

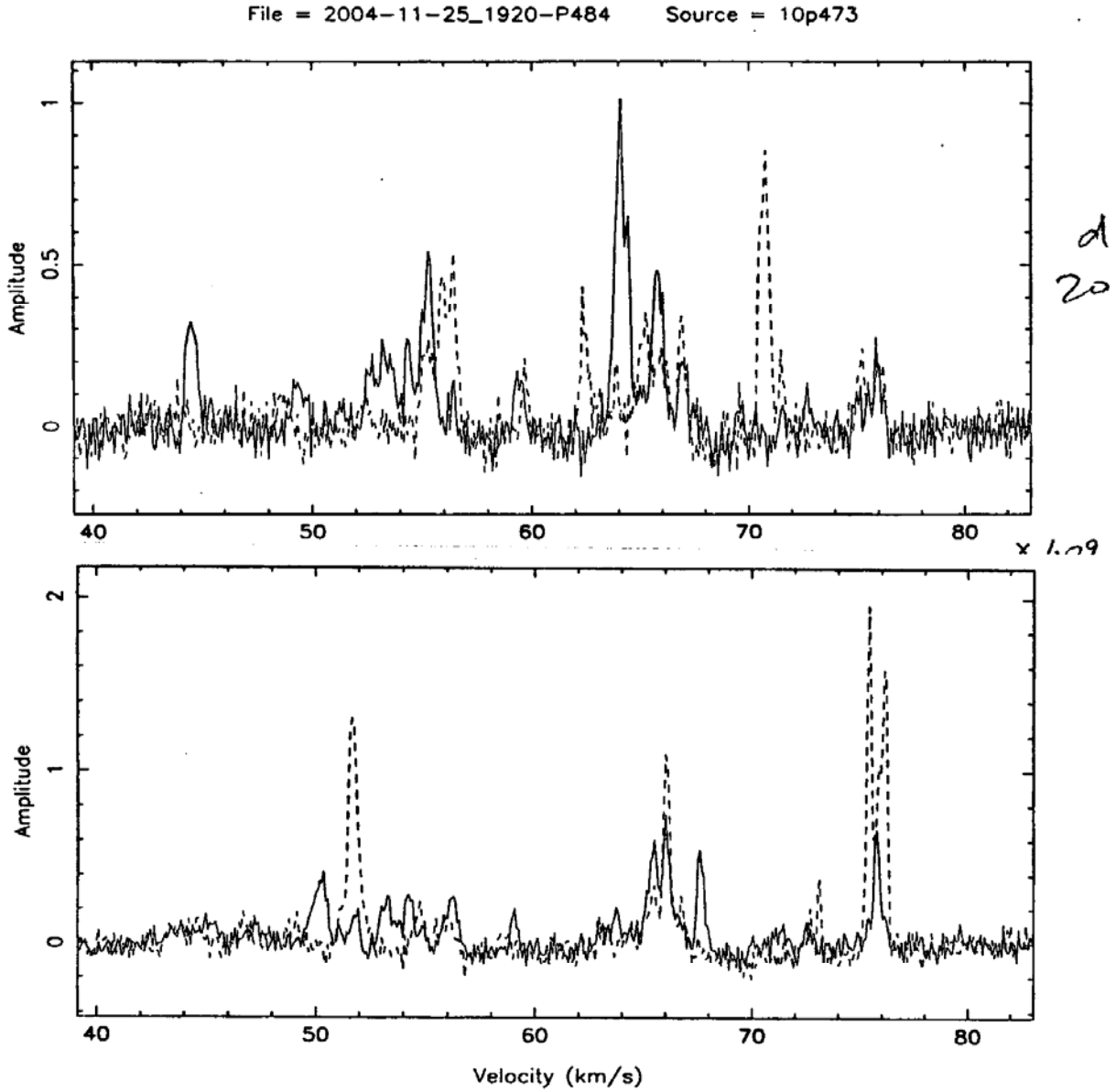
Assuming that the methanol defines the systemic velocity, we find several examples of OH showing outflows, in some cases blue-shifted, and in some cases red-shifted.

I will show a few examples of a general trend for several OH masers studied so far.

10.473

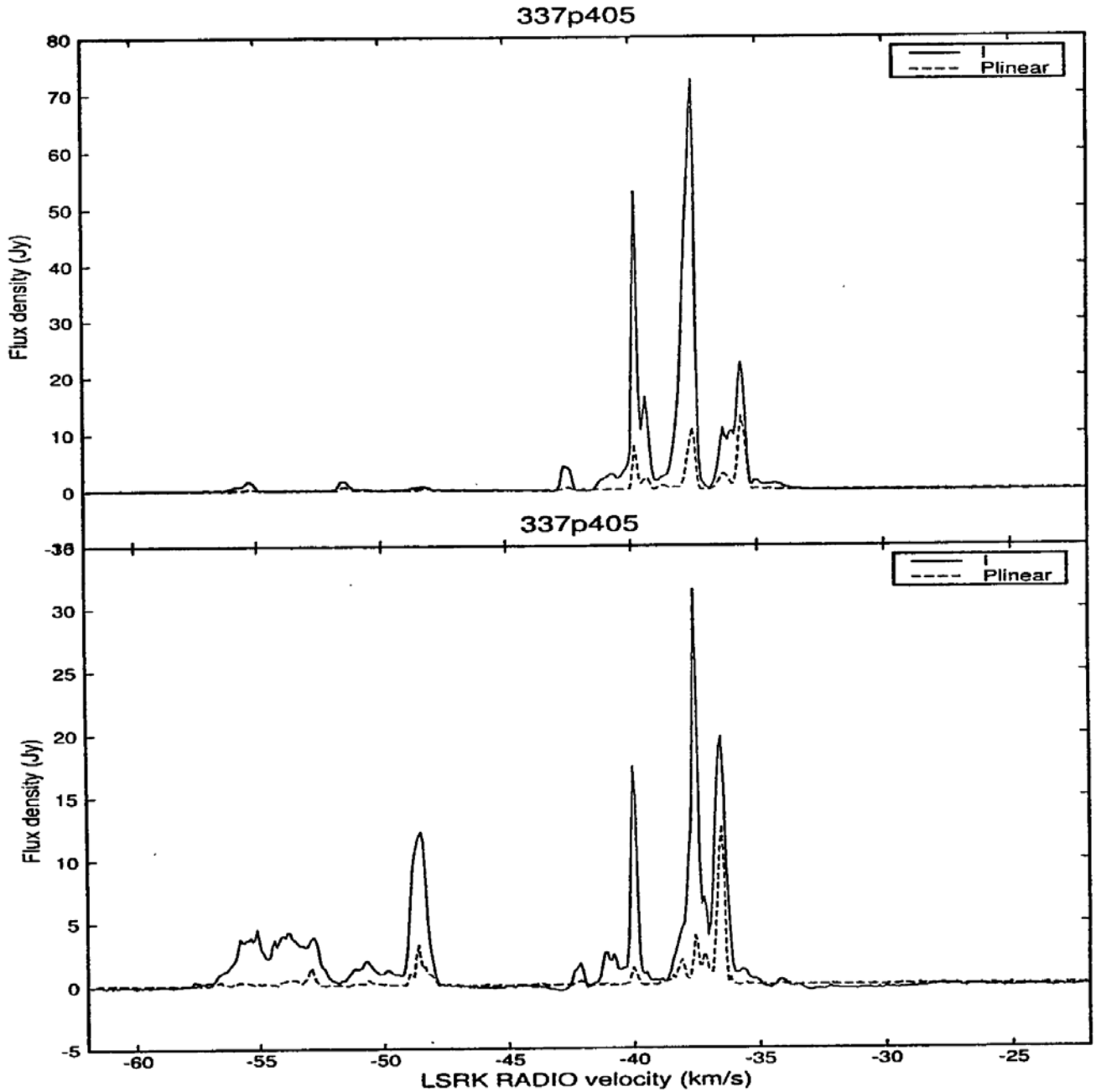
methanol spectrum is a somewhat confused, because there are several nearby sources, but it generally indicates a systemic velocity near +75 km/s, with strongest OH here as well.

The additional OH emission is blue-shifted.


File = 2004-11-25_1920-P484 Source = 10p473
Amplitude
0
0.5
1
40
50
60
70
80
Amplitude
0
1
2
40
50
60
70
80
Velocity (km/s)
Channels plotted = 1900 to 2400 Quadrants = 1 to 1
Seq Typ Position GHz Date
264 S 18:08:38.25 -19:51:49.40 1.6660 2004/11/26
264 S 18:08:38.25 -19:51:49.40 1.6660 2004/11/26
1667 MHz - RR/LL

337.405

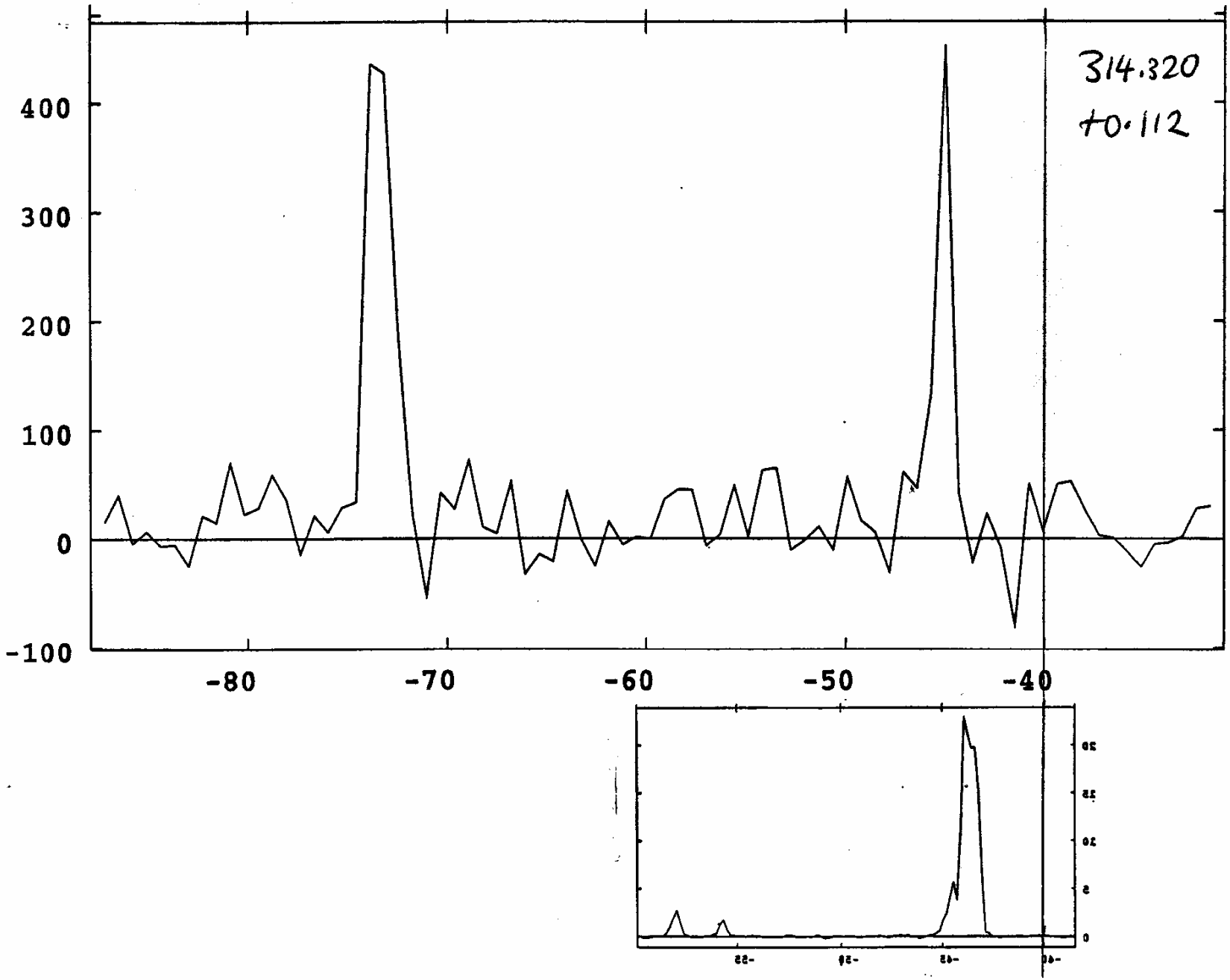
methanol indicates a systemic velocity near -38 km/s, with strongest OH here as well. And the additional OH emission is blue-shifted, although quite weak.


337p405
I
Plinear
Flux density (Jy)
80
70
60
50
40
30
20
10
0
337p405
I
Plinear
Flux density (Jy)
30
25
20
15
10
5
0
-5
-60
-55
-50
-45
-40
-35
-30
-25
LSRK RADIO velocity (km/s)

314.320

methanol indicates a systemic velocity near -45 km/s, with strongest OH here as well.

We find the additional OH emission is blue-shifted and has shown considerable variability, but at some times having intensity comparable to that at the systemic velocity.
Intriguingly, we find that methanol also shows blue-shifted emission, but very weak, and with smaller offset from systemic than OH.


314.320
+0.112
400
300
200
100
0
-100
-80
-70
-60
-50
-40

In summary, the OH masers with wide velocity spreads are found to comprise emission at the systemic velocity, with a preponderance of blue-shifted 'ejecta'

There is some indication that the ejecta show enhanced variability, and unusually large linear polarization.

This is an ongoing investigation.

Moving on to Part 3 – yet more surveys (unpublished) I.

With Chris Phillips – water maser search at the locations of all the southern SFR OH masers. Performed with ATCA so as to yield precise positions simultaneous with the discovery (and avoid the frustration of variability preventing follow-up positioning).

Preliminary results:

Precise (positionally coincident) water counterparts for 170 of the 200 OH masers searched.

Many additional water masers in the field of view investigated.

Analysis continuing, including a second epoch search.

Part 3 – yet more (unpublished) surveys II.

A blind water maser search with the ATCA over two small (each 0.5 square degrees) regions of sky, chosen to have only a few known masers.

Preliminary results:

Discovery of more than 20 masers, most of them new. Note that these are not necessarily SFR type masers. However, SFR masers are likely to dominate in a flux-limited sample.

Future plans:

To extend the survey to a much greater area as soon as the new CABB is installed on the ATCA.

Part 3 – more surveys III.

Extensive water maser surveys - the last frontier.

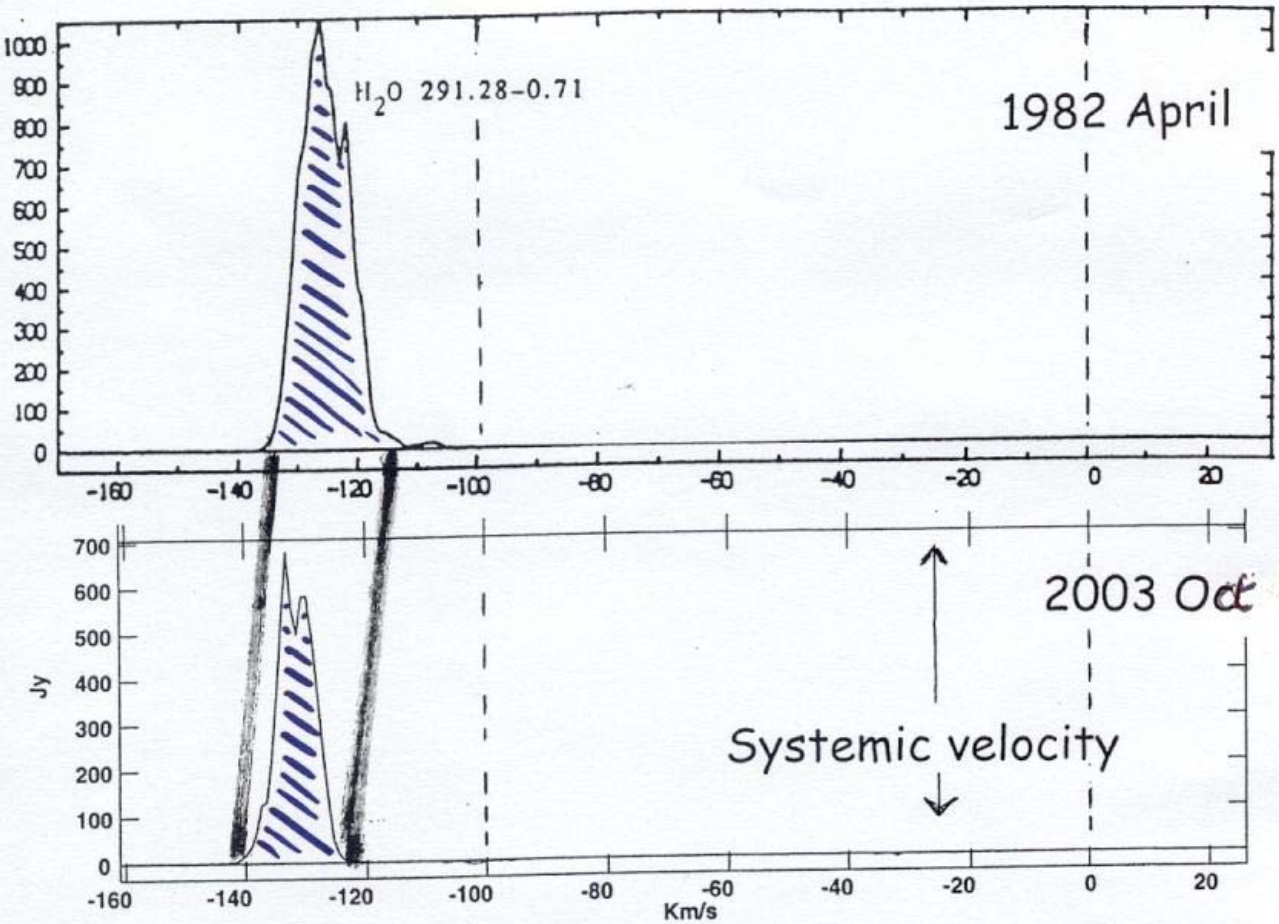
Saving the best to last?
Simply a matter of practicality?

Both.

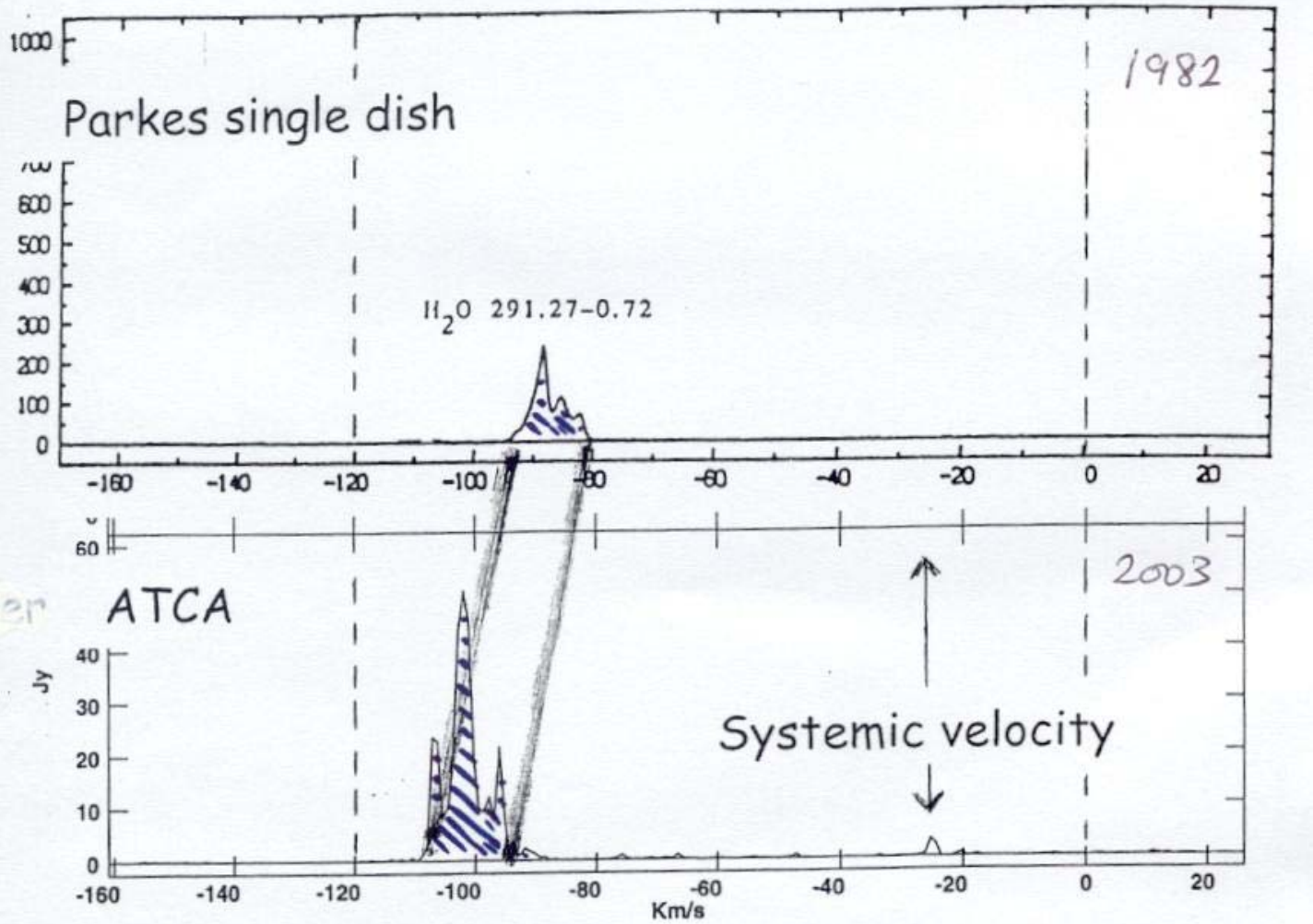
Interesting discoveries from the new water maser surveys so far.

Several sources which are DOMINATED by emission from a blue-shifted outflow – similar perhaps to the discovery described earlier for the OH masers.

It will be interesting to track these in time to see whether they include any of the exotic variety showing acceleration of the outflow, shown on the next two slides.



291.284-0.716 is the most dramatic example, and potentially the archetype of the class. We show spectra from 1982 and 2004, displaying the broad high velocity feature with intensity of several hundred Jy. We believe the systemic velocity to be near -20 km/s and the distance to be 3 kpc (see Caswell 2004 MNRAS 351, 279). From these measurements spaced 20 years (supplemented by slightly earlier data and some from intermediate epochs), we find that the velocity of emission has become more negative, with an average acceleration of 1 km/s every 2.5 years.



291.270-0.719 lies in the same SFR, at 3 kpc. Its spectra (shown likewise for 1982 and 2004) differ from 291.284-0.716 in that there is weak emission at the systemic velocity, with position coincident to the arcsec accuracy of the positions. Furthermore, there is methanol maser emission spatially coincident to similar high accuracy. The high velocity emission is again broad and strong, and appears to have accelerated at a rate of 1 km/s every 1.5 years.

Part 3 – more (unpublished) surveys IV.

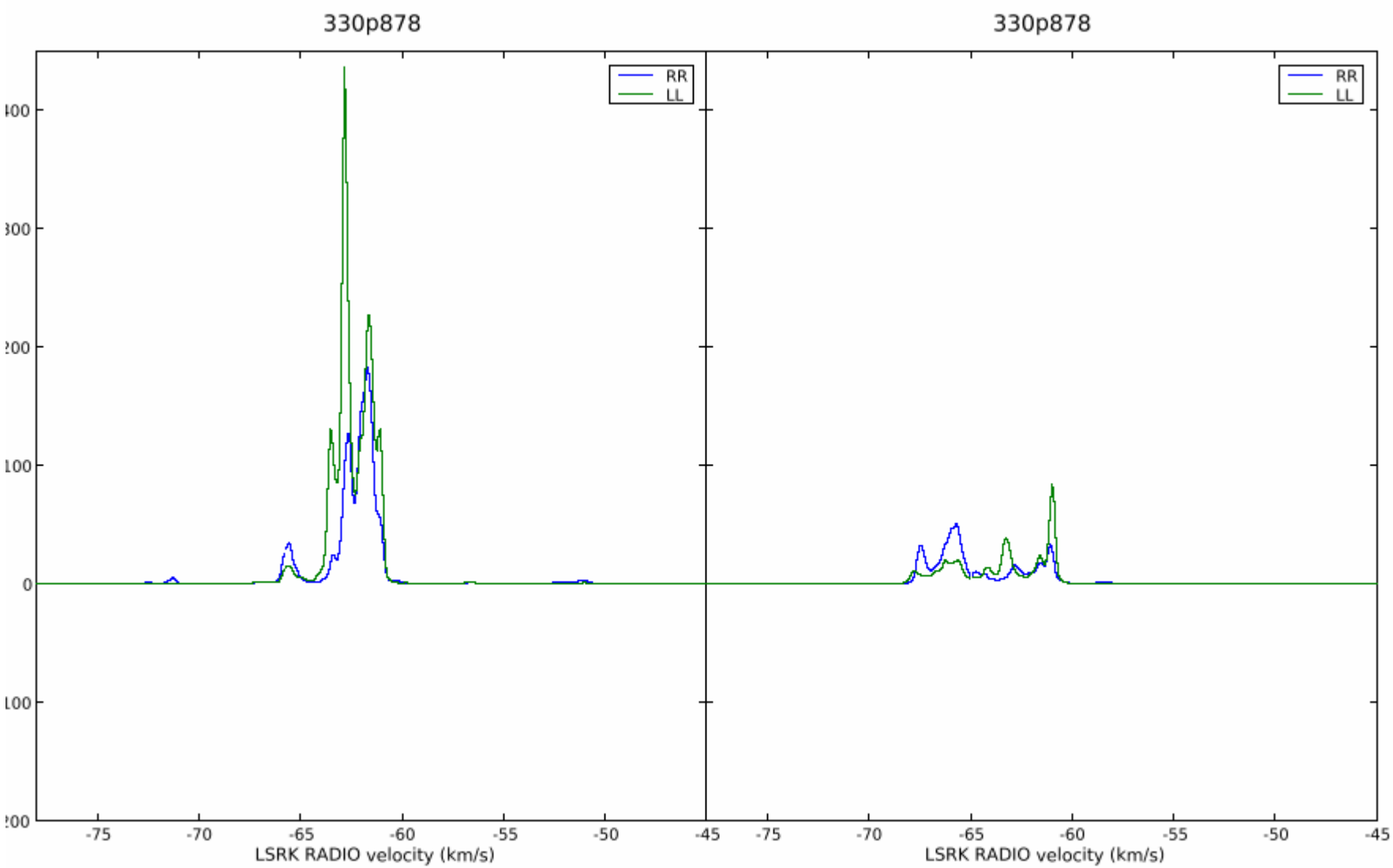
Again with Chris Phillips –
not really a survey, but a spectropolarimetric investigation of all the known southern OH 1665/1667MHz masers in SFRs (more than 200).

An example is shown on a poster by Chris, which also demonstrates the capabilities of the ATNF new single dish spectral line reduction package, ASAP.

The spectra complement the positional measurements with the AT compact array.

Preliminary results: Especially interesting is recognition of sources that have features with marked linear polarization. There is some indication that `outflow' features are especially likely to be linearly polarized.

In the following spectra, the 1665-MHz transition is shown at the left, and 1667-MHz transition on the right.


330p878
RR
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400
300
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0
100
200
-75
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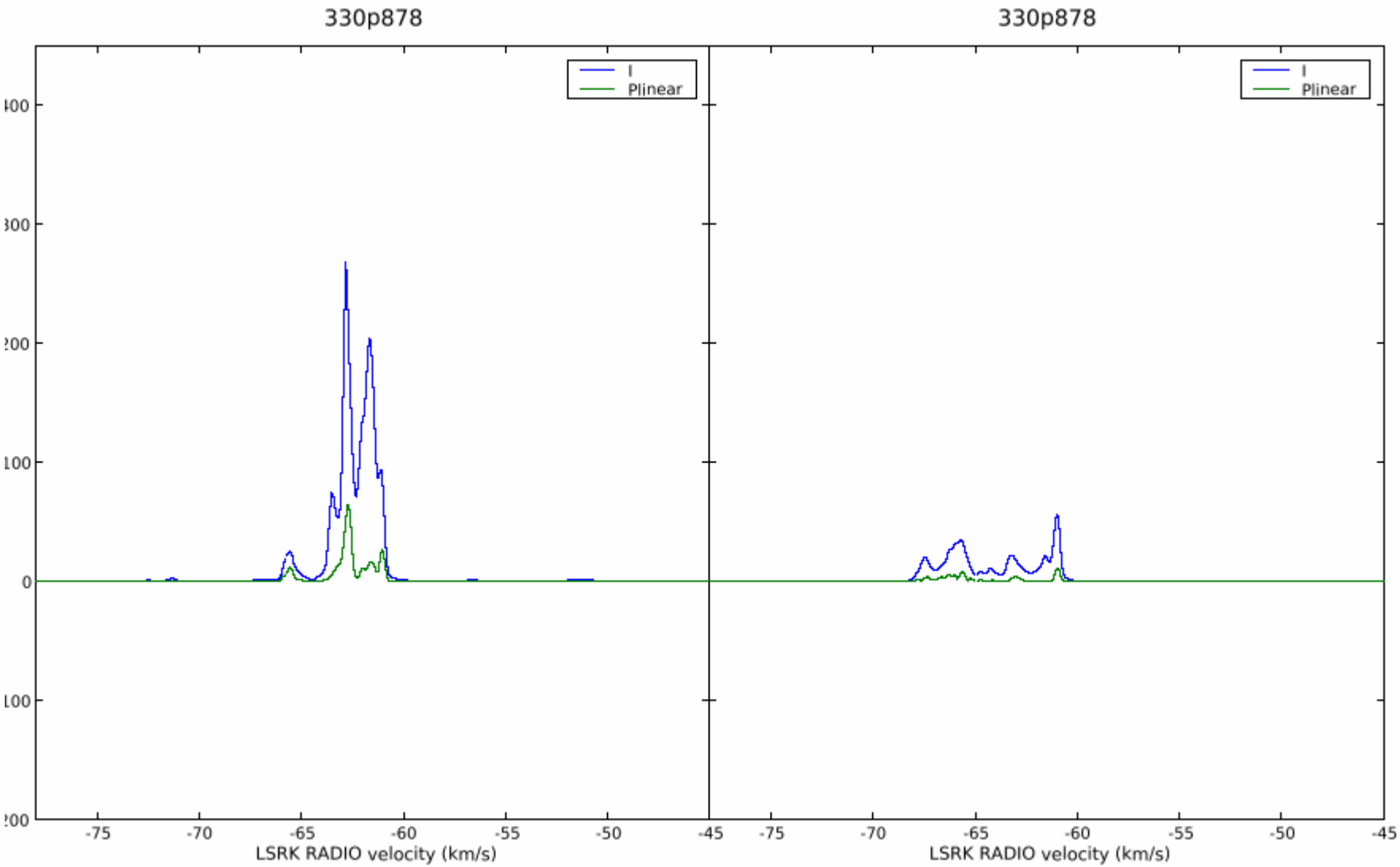
-65
-60
-55
-50
-45
LSRK RADIO velocity (km/s)
330p878
RR
LL
-75
-70
-65
-60
-55
-50
-45
LSRK RADIO velocity (km/s)


330p878
I
Plinear
LSRK RADIO velocity (km/s)
330p878
I
Plinear
LSRK RADIO velocity (km/s)

Part 3 – more surveys V.

At present, the spectral capability at Parkes is far superior to that of the ATCA. Despite blending at low spatial resolution, single dish polarimetry reveals high degrees of both circular and linear polarization.

These spectra allow us to select the best targets for Long Baseline studies. Examples of these studies are given in the posters – have a look at the one from Indra Bains, a study of 340.054-0.244, and from Busaba Kramer, a study of 330.953-0.182

Northern hemisphere work of this type is being conducted by Vincent Fish with the VLBA.

In several years, with CABB on the ATCA, we will simultaneously achieve high spatial resolution AND high velocity resolution spectropolarimetry.

Ultimately:

- *complete surveys of Galactic plane for all tracers of massive stars*

- *O and B stars*
- *Ultracompact HII regions*
- *OH masers at several transitions*
- *Methanol masers at several transitions*
- *Water masers at 22 GHz*