# The ATCA 7-mm line survey of Sgr B2
## as a guide to some ALMA Band 1 science

**Paul Jones**
Maria Cunningham
(University of New South Wales, Australia)

Thanks to collaborators, in particular Joanna Corby

# Why an interferometric line survey at 7-mm ?

- See Maria Cunningham's talk
- Would like multiple molecules to characterise chemistry (line survey). Resolve chemically distinct / different excitation regions (interferometry)
- 7-mm = band 1 - gives complementary information to other bands for determining molecule excitation and depending on molecule (larger ?) and conditions (cooler ?) may be optimal band to use

  e.g. McGuire et al 2016, Science, "Discovery of the Interstellar Chiral Molecule Propylene Oxide ($CH_3CHCH_2O$)" with GBT (PRIMOS) and Parkes, at 2-cm band (12.1, 12.8 and 14.0 GHz) – we tried and failed at 3-mm band as that was not the optimal choice !

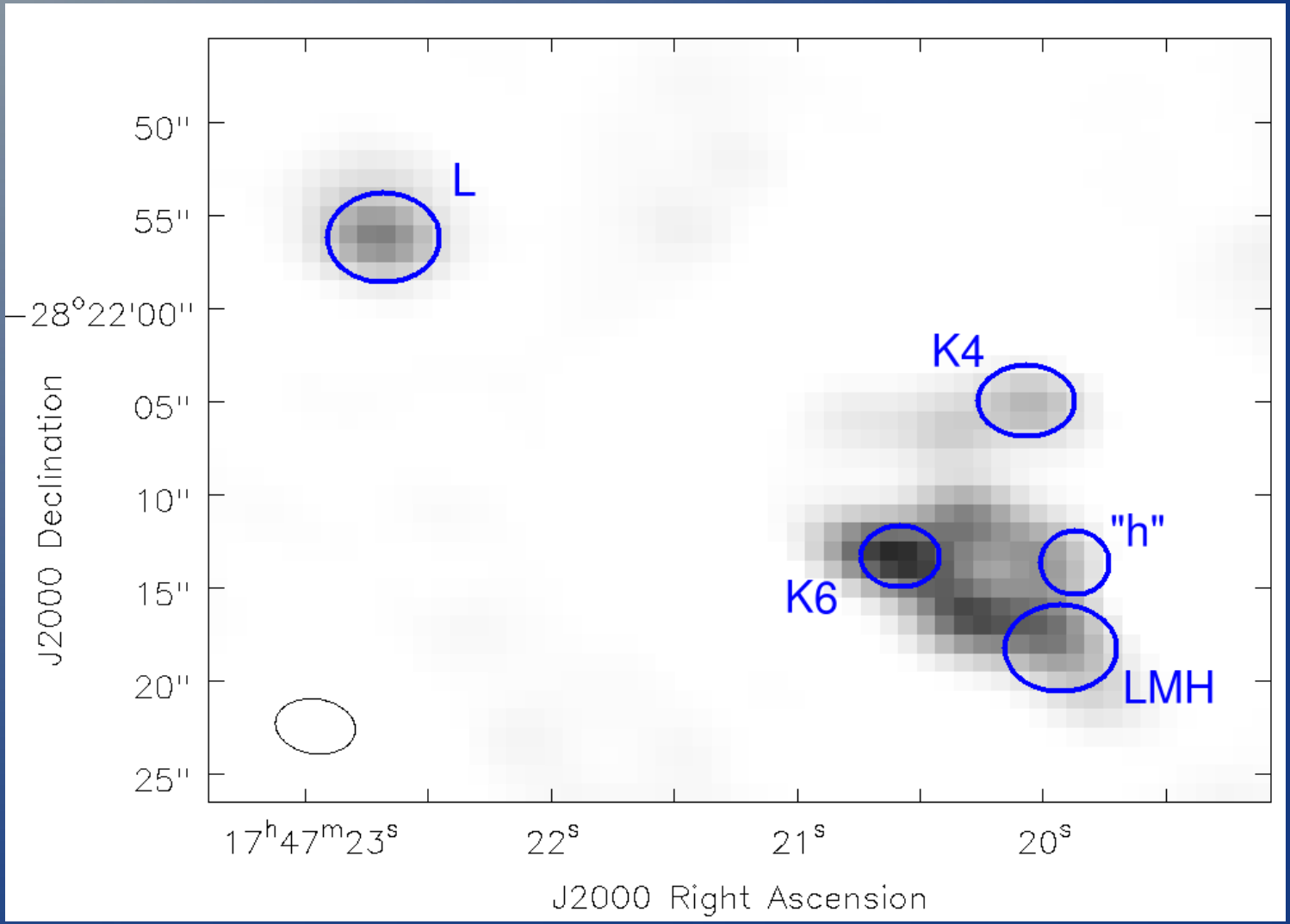
# Why Sagittarius B2 N ?

- Very chemically-rich hot molecular core, LMH = Large Molecule Heimat
- Single-dish Green Bank Telescope PRIMOS survey 300 MHz to 46 GHz - A. Remijan et al.
- Australia Telescope Compact Array (ATCA) Broadband Backend (CABB) 2 x 2 GHz BW makes feasible (7-mm sweet spot)
- Note - before JVLA upgrade to wide band correlator, and Sgr B2 overhead for ATCA, rather than at low elevation for VLA
- Complements single-dish Mopra 22-m 7-mm Sgr B2 mapping (over few arcmin area)

# ATCA observing parameters/limitations

- 5 x 22 m dishes used in array = **10 spacings**
- CABB broadband mode covers 2 GHz BUT with 2048 x 1 MHz channels, so **6 to 10 km/s** channels – marginal even given wide linewidths in Sgr B2
- 11 tunings of 2 GHz needed to cover 30 to 50 GHz (with a bit of overlap)
- 3 x 8 hour tracks, with 2 simultaneous IFs and time-shared so 4 tunings per track
- 1 in H75 array (shorter than requested from TAC, used for high frequency end) 2 in H214 giving resolution **3.4 to 13 arcsec**
- Low elevation site

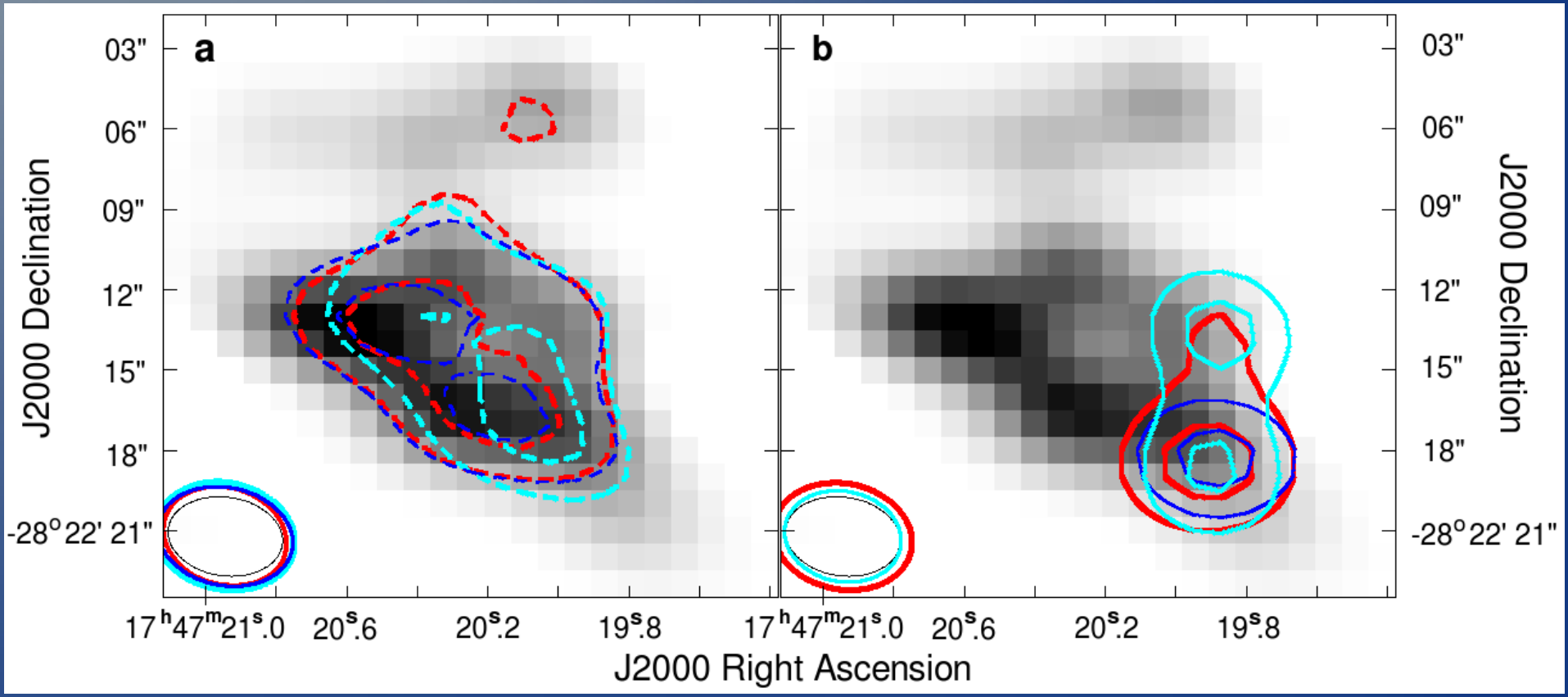
# results - see Corby et al. 2015, MNRAS, 452, 3969
# Sgr B2 N – hot molecular core, H II regions
# greyscale = continuum (mostly free-free), ellipses = regions used



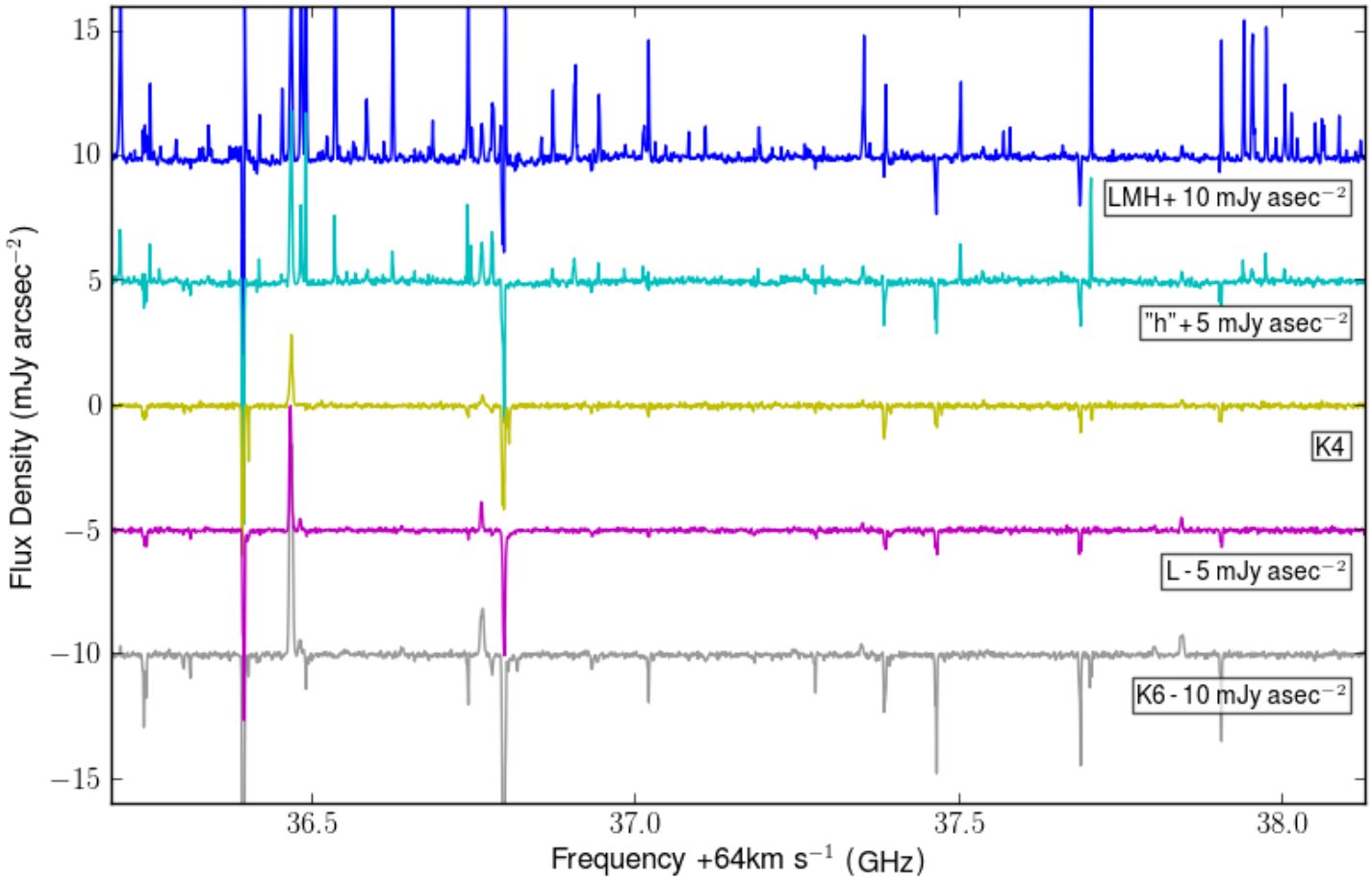
# Resolving chemically distinct regions

## a) $CH_2CN$, $CH_3CHO$, Z-$CH_3CHNH$ in absorption at K6, K5

## b) $CH_3CH_2CN$, $NH_2D$ and $SO_2$ in LMH and h



# LMH (Large Molecule Heimat) and h chemically very rich – not fully identified/characterised (Corby et al 2015 concentrated on K4, L and K6)

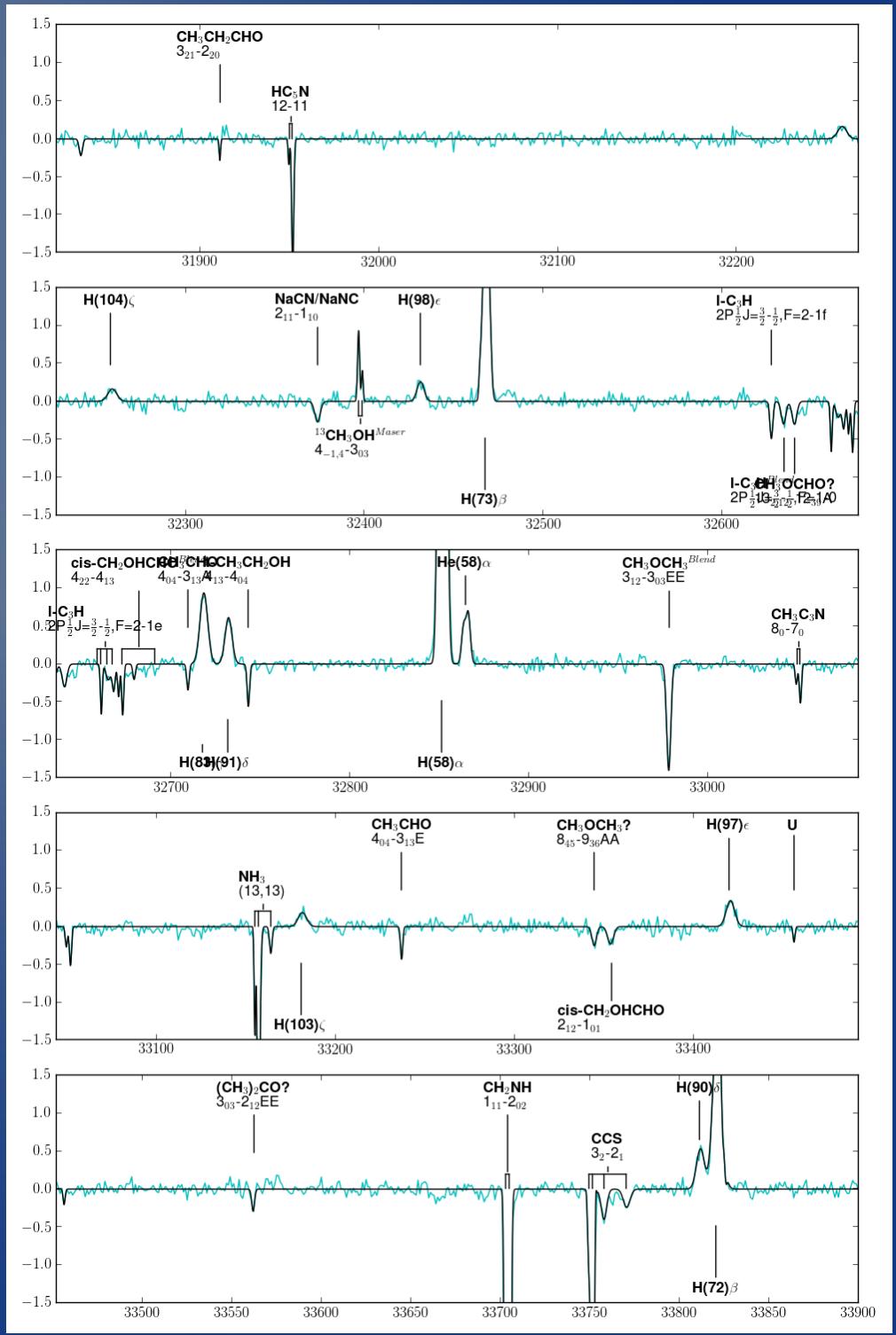


K6 identifications (over 2 GHz section ie 0.1 x band)

Fitting to ~3.5 sigma level have:

| | |
|---|---|
| LMH | 1089 |
| h | 490 |
| K6 | 618 |
| K4 | 222 |
| L | 308 |

components



# Molecules detected

- **CS Family:** CS, $C^{34}S$, $C^{33}S$, $^{13}CS$, $^{13}C^{34}S$, $HCS^+$ , $H_2CS$, CCS, $CC^{34}S$, OCS, CCCS
- **Silicon Species:** SiO, $^{29}SiO$, $^{30}SiO$, $Si^{18}O$, SiN, SiS, $SiC_2$
- **Other Inorganic Molecules:** SO, PN, $Na^{37}Cl$ (?)
- **Hydrocarbon Chains:** l-$C_3H$, l-$C_3H^+$ , $C_4H$
- **Ring Species:** c-$C_3H_2$ , c-$H^{13}CCCH$, c-$HCC^{13}CH$, c-$H_2C_3O$, c-$H_2COCH_2$
- **Amines:** $NH_3$ , $NH_2D$, $CH_3NH_2$ (?), $NH_2CN$, $CH_3CONH_2$ , $H_2NCO^+$ (?)
- **Isonitriles:** $CH_3NC$, HCCNC
- **Nitriles:** CCCN, HSCN, NaCN/NaNC, $CH_2CN$, $CH_3CN$, $CH_3{}^{13}CN$, $^{13}CH_3CN$, $CH_2CHCN$, $CH_3CH_2CN$, $HC_3N$, $HCC^{13}CN$, $HC^{13}CCN$, $H^{13}CCCN$, $HC_5N$, $CH_3C_3N$
- **Imines:** $CH_2NH$, E-$CH_3CHNH$, Z-$CH_3CHNH$, HNCHCN
- **Aldehydes:** $H_2CO$, $H_2COH^+$ , $CH_3CHO$, $NH_2CHO$, $NH_2{}^{13}CHO$, $CH_3OCHO$, cis-$CH_2OHCHO$, t-$CH_2CHCHO$, $CH_3CH_2CHO$
- **Alcohols:** $CH_3OH$, $^{13}CH_3OH$, t-$CH_3CH_2OH$, g'Ga-$(CH_2OH)_2$
- **Other Oxynated Species:** HNCO, t-HCOOH, $H_2CCO$, $CH_3OCH_3$, $(CH_3)_2CO$
- **Other Organic Species:** $CH_3SH$

# FITS cubes, spectra and python scripts are public (thanks again to Joanna Corby)

- Final FITS cubes (after ATCA reduction with miriad, extra baseline fitting) public via CDS ftp://cdsarc.u-strasbg.fr/pub/cats/J/MNRAS/452/3969/fits/
- Spectra and some line-fitting and line-identification python scripts public via github https://github.com/jfc2113/MicrowaveLineFitter
- Policy is that data are shared in a useful form for others to do more science (e.g. maybe identify new molecules) particularly given value of combining line data from different bands

# ALMA band 1 – do even better

- N x 12-m antennas (N ~ 15 to N > 40)
- Also 7-m ACA and 12-m TP for short spacings
- Longer baselines to get ~ 1 arcsec resolution
- Excellent site at 7-mm for gain calibration (phase and amplitude)
- Flexible correlator (tradeoffs of frequency coverage, spectral resolution and polarisation) with spectral scan mode observing
- We know what ALMA can do here - compare existing Sgr B2 line surveys in bands 3 and 5 (3-mm and 1.5-mm)

# ALMA (band 3) 3-mm Sgr B2 N

- Project : Expanding the frontiers of chemical complexity with ALMA, P.I.:  A. Belloche.
- 84.1 to 114.4 GHz in 5 setups each with 4 windows of 1.875 GHz, 1.3 to 1.7 km/s (after smoothing from 0.24 MHz), ~ 2 arcsec resolution
- Belloche et al., 2016, A&A, 587, 91 – deuterated complex molecules
- Muller et al., 2016, A&A, 587, 92 – alkanethiols and alkanols

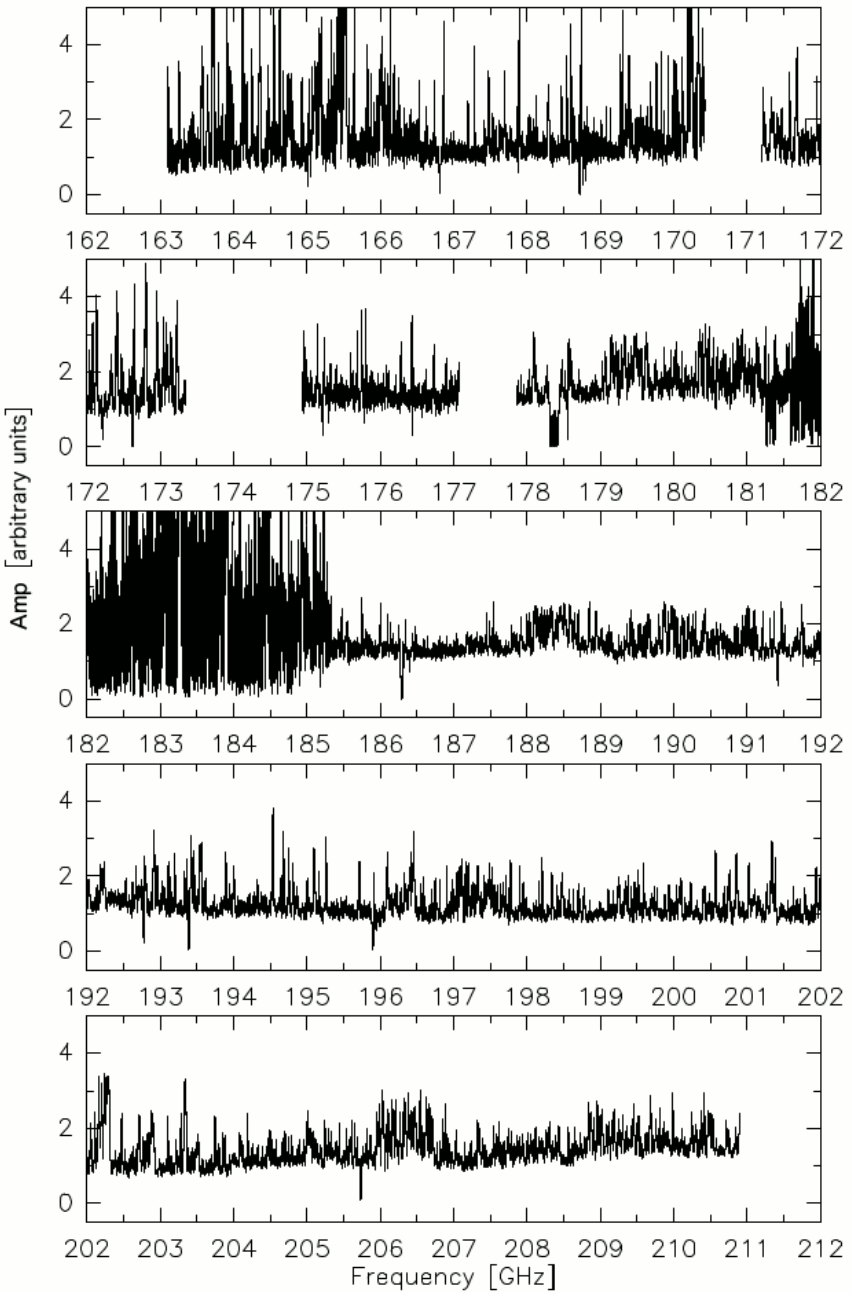
# Last paragraph of Muller et al. 2016

"In addition, more sensitive observations of Sgr B2(N), Orion KL, or other sources with **ALMA** or other interferometers are required to establish whether and possibly in what quantities ethanethiol, normal-propanol, and iso-propanol are present in the ISM. Such observations may be **more promising at wavelengths longer than 3 mm** for the first two molecules."

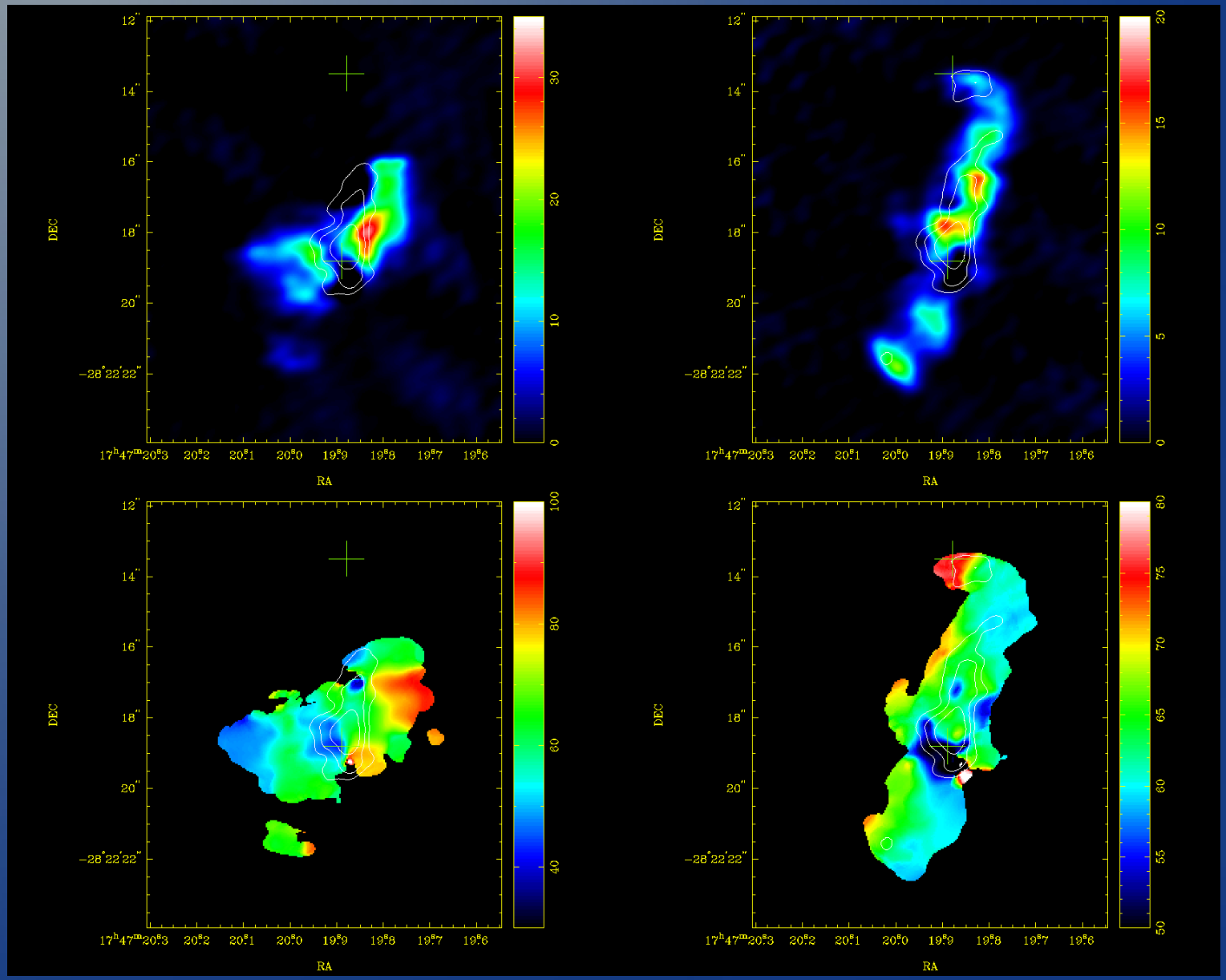
# ALMA band 5 (~1.5-mm) Sgr B2 N

- Recently released science verification data
- 13 tunings, from 163 to 211 GHz in steps of 4 GHz, each with 4 windows, 0.488 MHz resolution
- Note that as verification data, taken with a range of antenna configurations (may be missing extended flux) and as very crowded spectra, are NOT continuum subtracted

# Sgr B2 ALMA band 5 spectrum (short spacings)



# ALMA Band 5 data (~ 165 GHz) – integrated emission (top) and velocity (bottom), $HC_3N$ (left) and $CH_3OH$ (right)



# Conclusions

- Lots of potential for line surveys with ALMA band 1
- Consider added value of combining data from multiple bands
- Not just Sgr B2 N, of course, this just used as example here of a SFR
- e.g. nearby starburst galaxies – to compare with Central Molecular Zone of our Galaxy (Mopra 22-m 7-mm and 3-mm etc) and more distant starbursts at high redshift