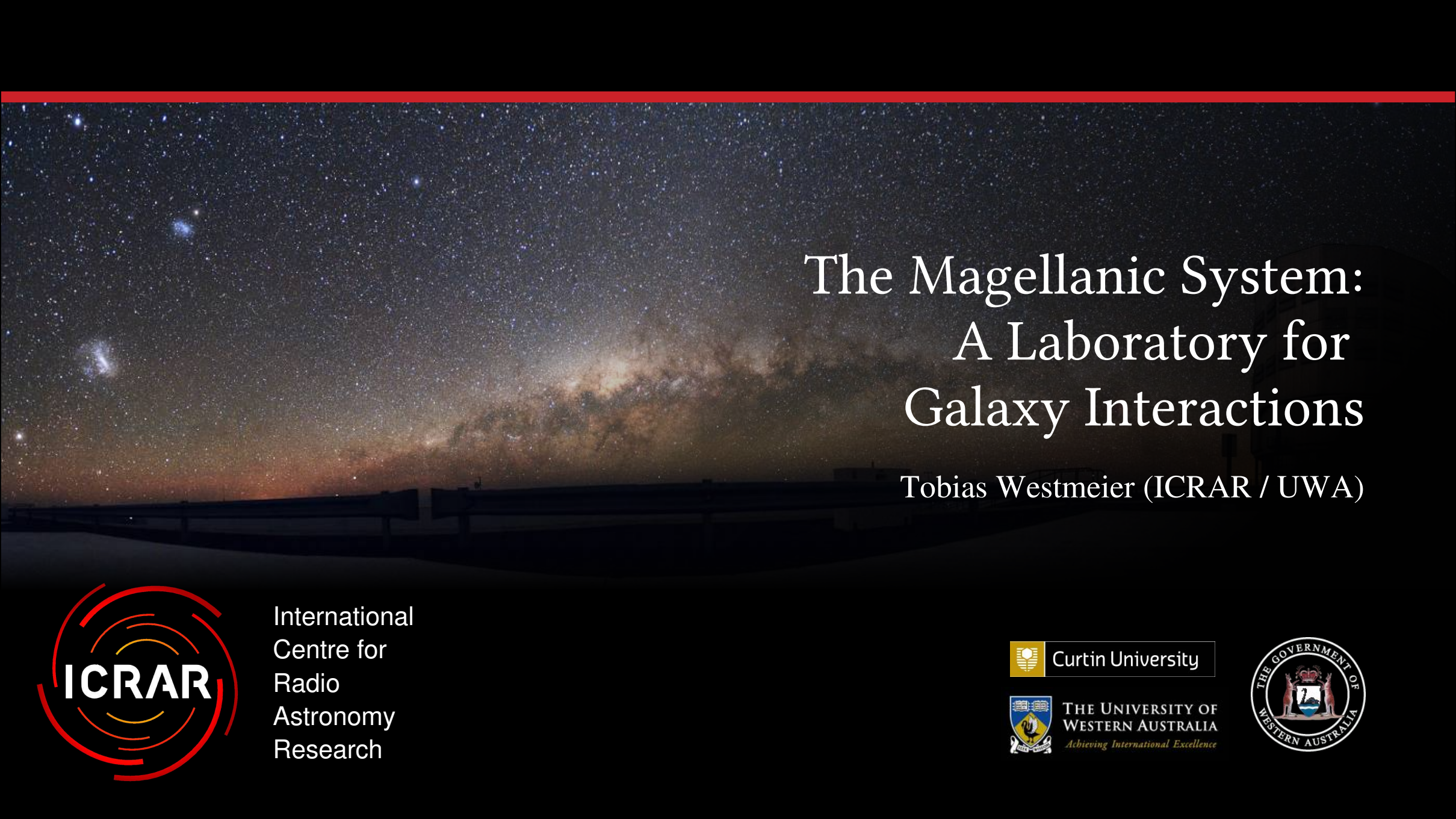


The Magellanic System: A Laboratory for Galaxy Interactions

Tobias Westmeier (ICRAR / UWA)

International Centre for Radio Astronomy Research

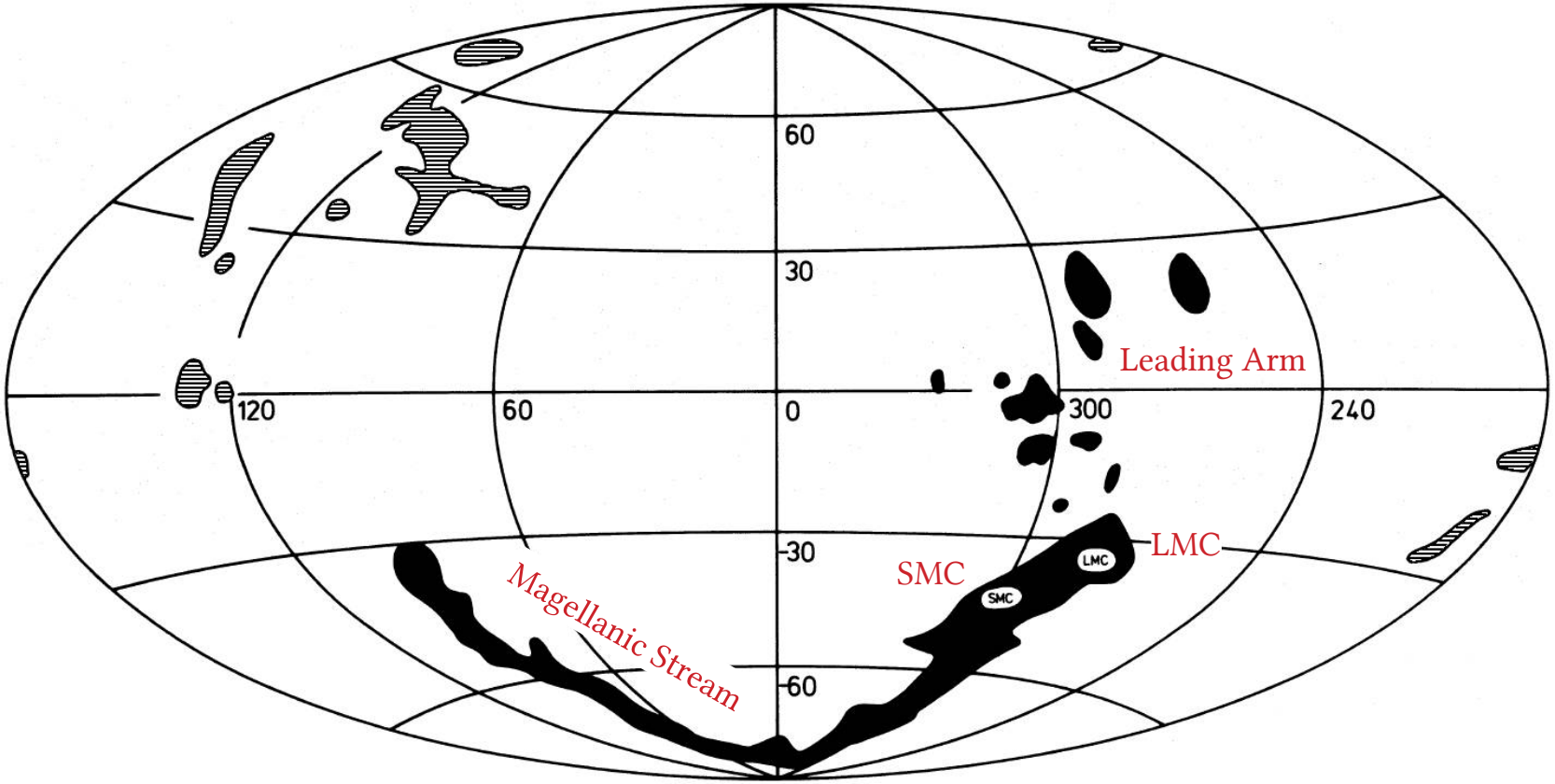
Curtin University

The University of Western Australia
Achieving International Excellence

Introduction

Introduction

★ Magellanic Stream discovered in 1960s and early 70s.



Mathewson, Cleary & Murray (1974)

Introduction

- Why do we care?

Introduction

- ★ Why do we care?
  - ▸ The Magellanic system is the nearest example of an interacting system of galaxies with pronounced gaseous tidal tails.
    - Hierarchical (Λ)CDM structure formation happening on our doorstep ($d \approx 50$ kpc).
    - System can be studied in great detail on a large range of spatial scales.
    - Impact of interaction on star formation history of LMC / SMC.
    - Impact of interaction with / accretion of Magellanic Clouds on evolution of Milky Way.

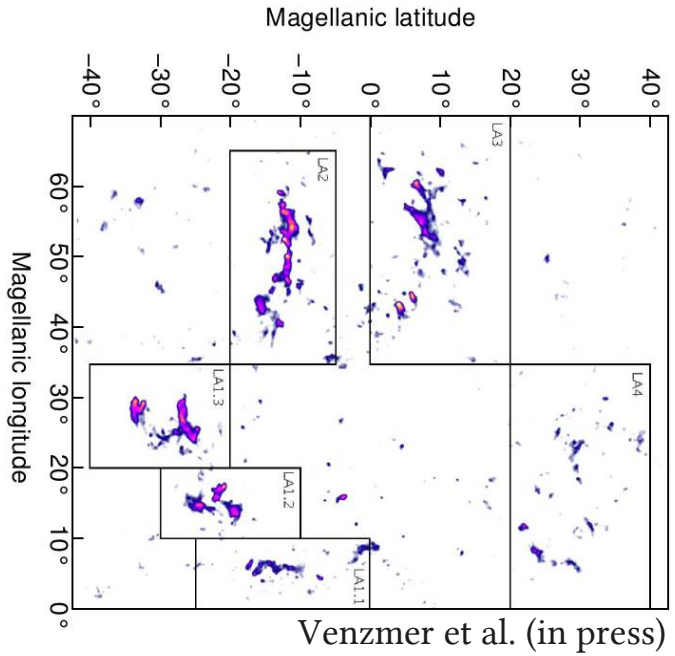
Introduction

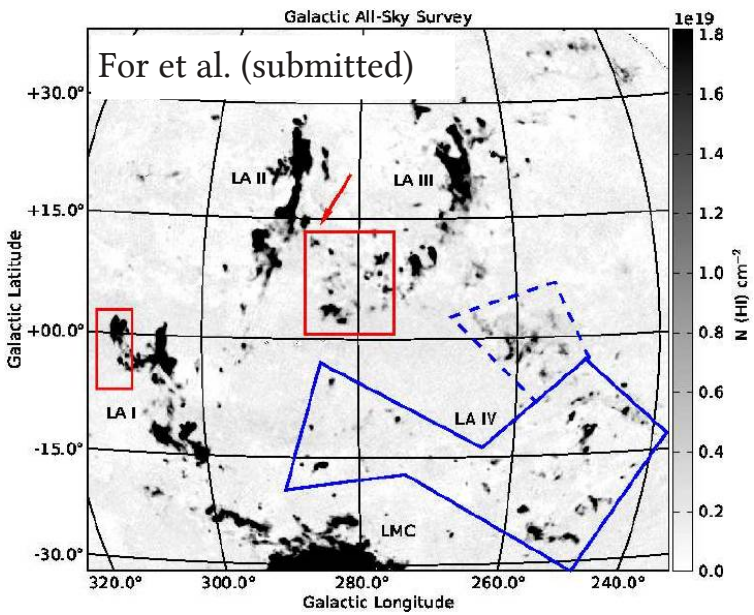
- ★ Why do we care?
  - The Magellanic system is the nearest example of an interacting system of galaxies with pronounced gaseous tidal tails.
    - Hierarchical (Λ)CDM structure formation happening on our doorstep ($d \approx 50$ kpc).
    - System can be studied in great detail on a large range of spatial scales.
    - Impact of interaction on star formation history of LMC / SMC.
    - Impact of interaction with / accretion of Magellanic Clouds on evolution of Milky Way.
  - Putman et al. (2003):
    - "*Uncovering the Magellanic Stream and its surroundings is crucial to the understanding of the formation and evolution of not only the Milky Way, but the entire Local Group* [...]"
  - Nidever et al. (2008):
    - "[...] *the MW–LMC–SMC system is regarded as an important laboratory with which to study the formation, evolution, and interaction of galaxies and their stellar populations.*"

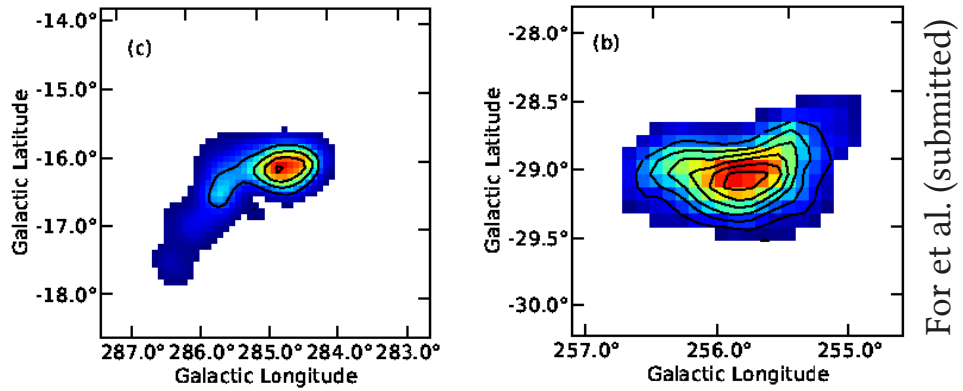
The Magellanic Stream and Leading Arm

Magellanic Stream / Leading Arm

- ★ Leading Arm found to be more extended than previously thought:
  - ▸ For et al. (submitted)
  - ▸ Venzmer et al. (in press)
- ★ Head–tail structures common, suggesting importance of ram-pressure stripping.
- ★ Morphological difference between LA and MS possibly due to varying environmental conditions.

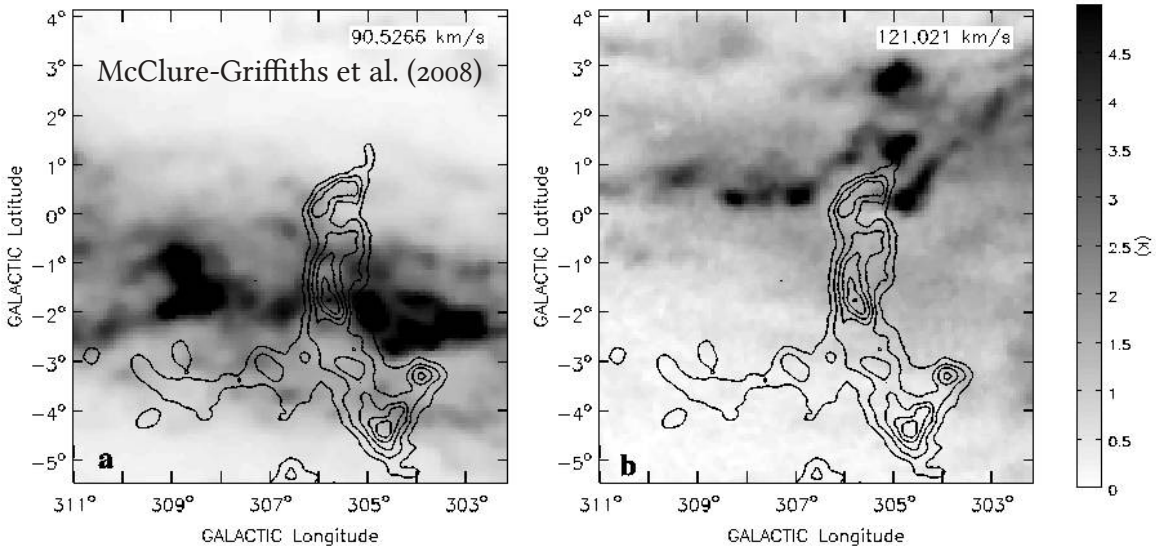


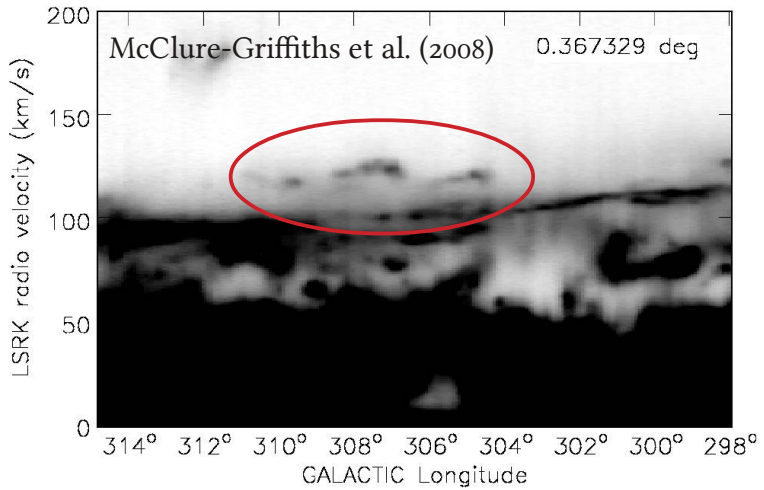




Magellanic Stream / Leading Arm

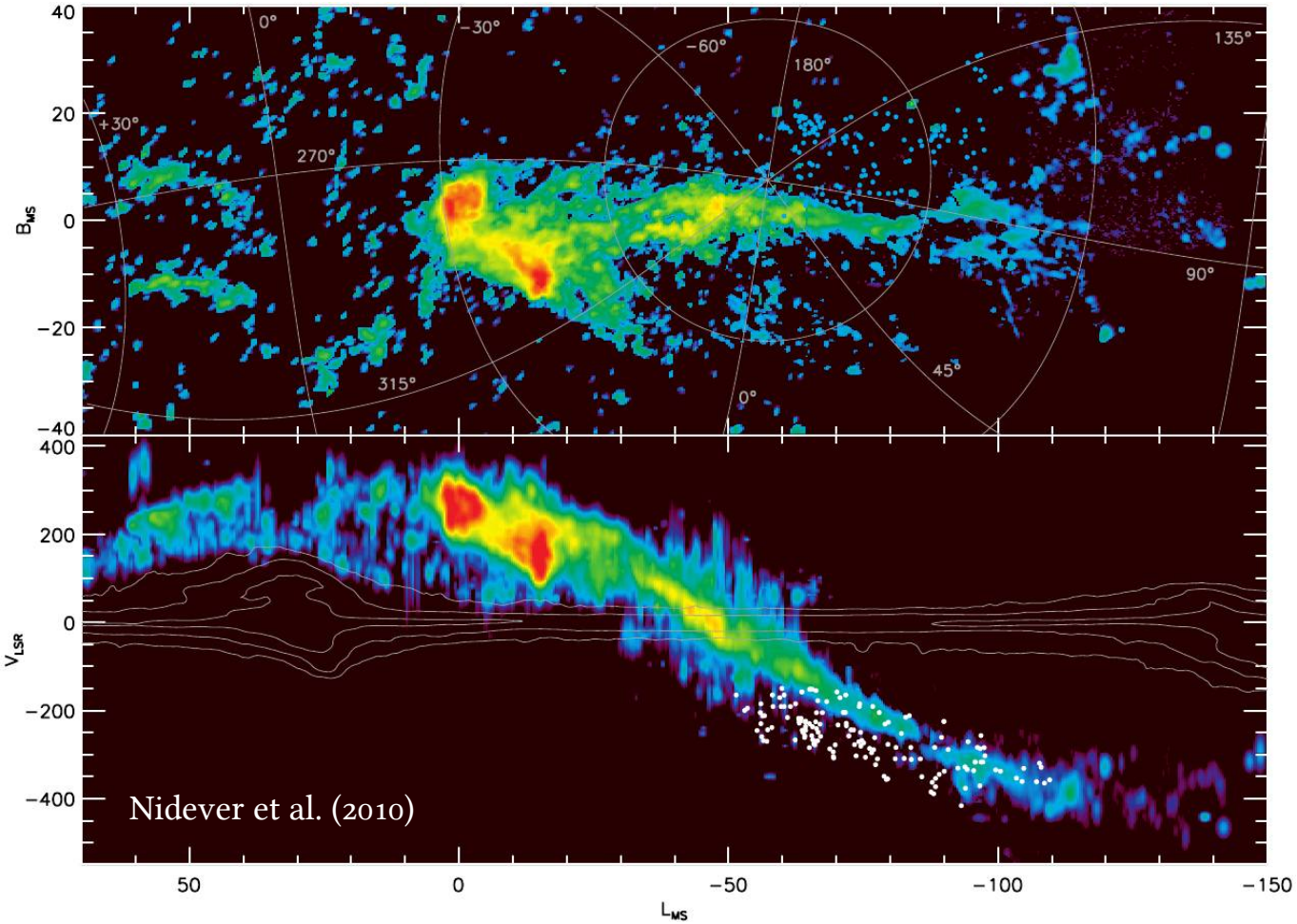
- ★ Evidence of Leading Arm colliding with the Galactic disc.
  - ▸ McClure-Griffiths et al. (2008)
- ★ Relevance:
  - ▸ Distance / galactocentric radius: r = 17 kpc ± 20%
  - ▸ Constraint for numerical simulations of Magellanic system.
  - ▸ Test of LMC / SMC proper motion measurements.
  - ▸ Test case for hydrodynamical simulations of HVC interaction.





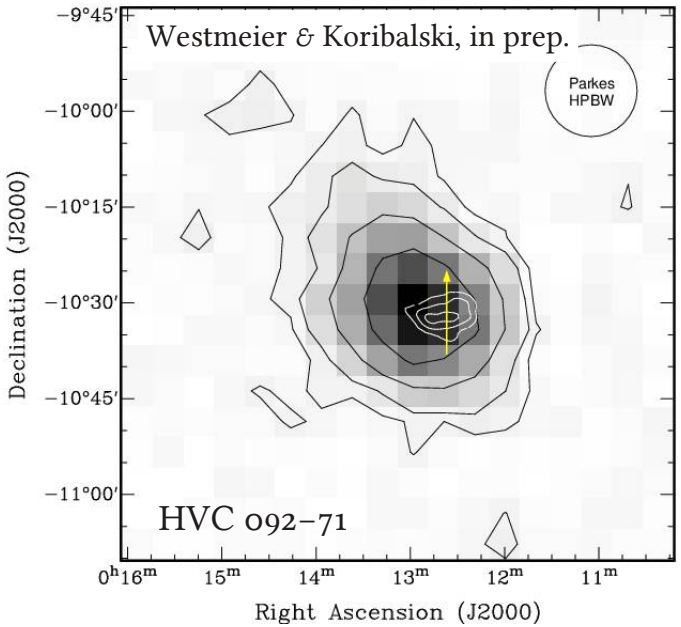
Magellanic Stream / Leading Arm

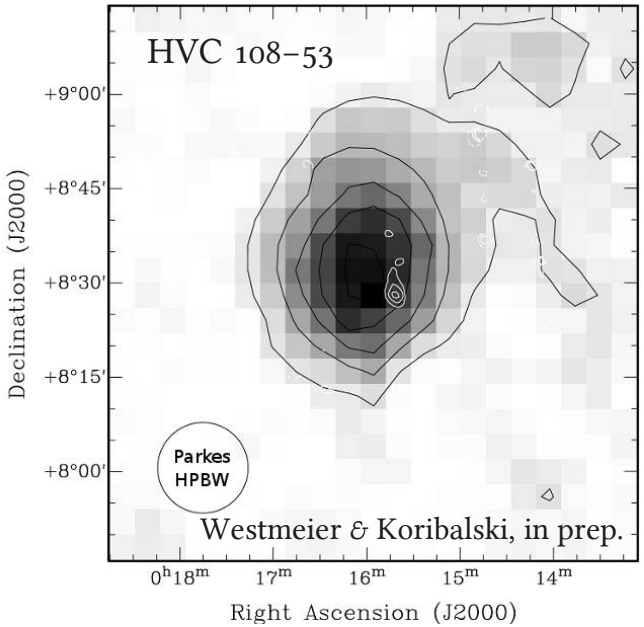
- ★ Recent discoveries of extended filaments of the Magellanic Stream:
  - ▸ Braun & Thilker (2004)
  - ▸ Westmeier & Koribalski (2008)
  - ▸ Stanimirović et al. (2008)
  - ▸ Nidever et al. (2010)
- ★ Magellanic Stream is at least
  - ▸ 160° – 165° long (Nidever et al., in prep.)
  - ▸ and tens of degrees wide (Westmeier & Koribalski 2008)

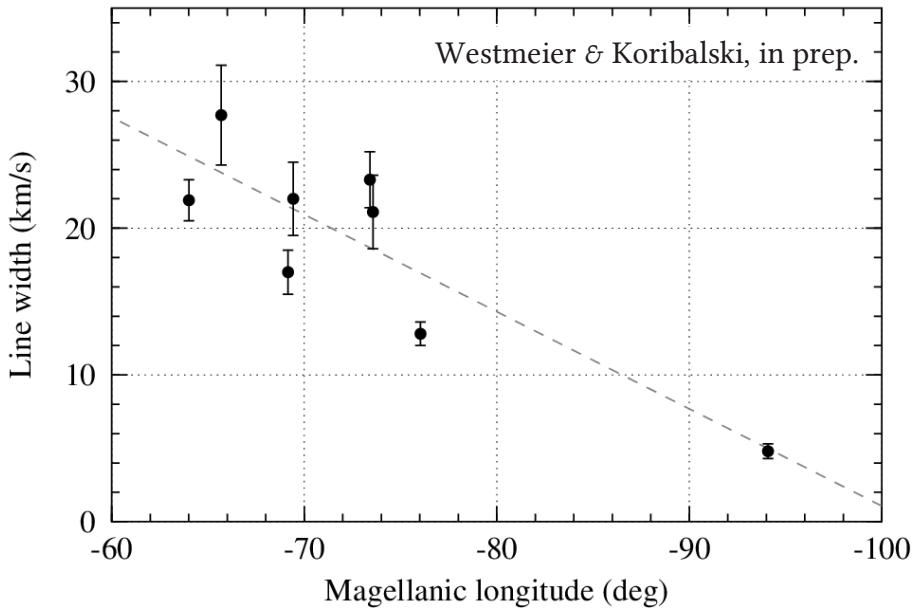


Magellanic Stream / Leading Arm

- ★ Study of interaction between Magellanic Stream and Galactic halo
  - ▸ Variation of line width with Magellanic longitude implies temperature gradient along the stream and change of physical conditions in ambient medium for different galactocentric radii.
  - ▸ Head–tail structure common in stream clouds, indicating ram-pressure stripping.

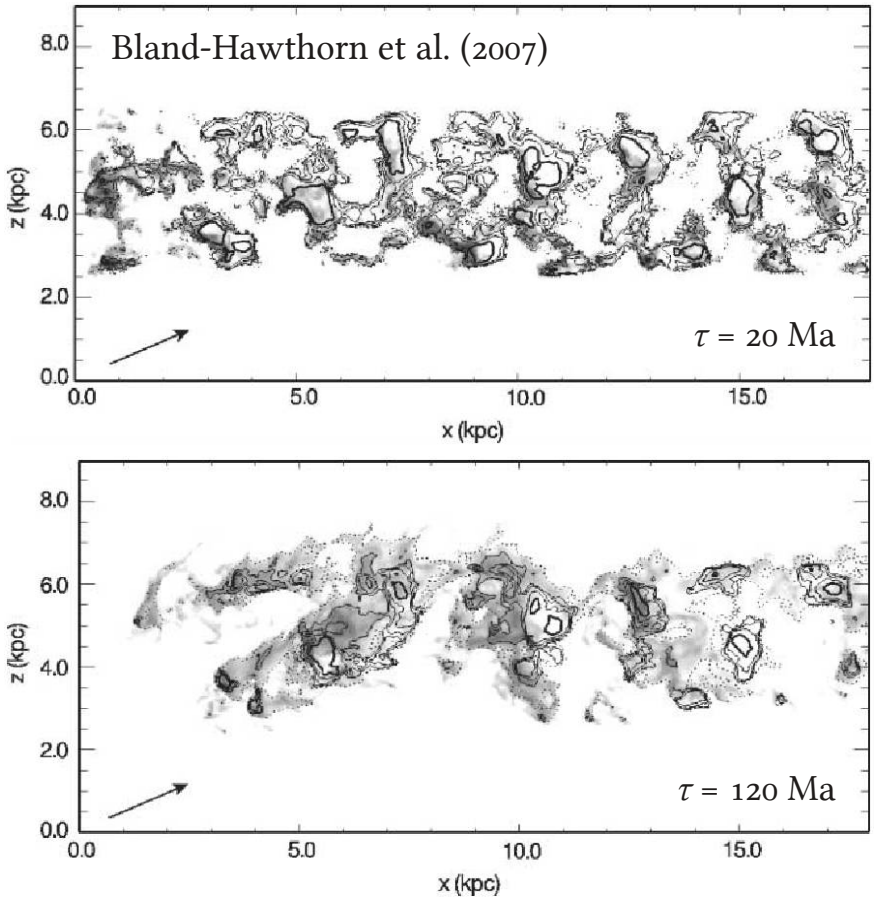






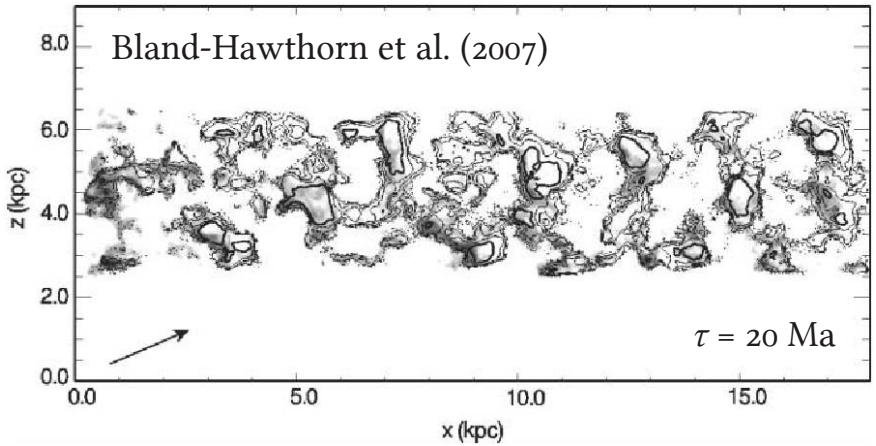
Magellanic Stream / Leading Arm

- ★ Lifetime of clouds:
  - ▸ Hydrodynamical simulations by Bland-Hawthorn et al. (2007) suggest lifetime of $\tau \approx 10$ Ma.
  - ▸ Clouds would get destroyed within a fraction of the orbital time scale.

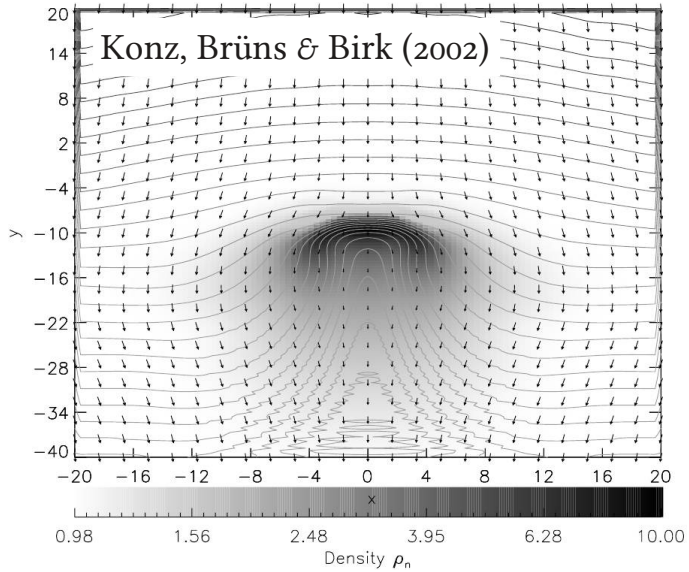


Magellanic Stream / Leading Arm

- ★ Lifetime of clouds:
  - ▸ Hydrodynamical simulations by Bland-Hawthorn et al. (2007) suggest lifetime of $\tau \approx 10$ Ma.
  - ▸ Clouds would get destroyed within a fraction of the orbital time scale.

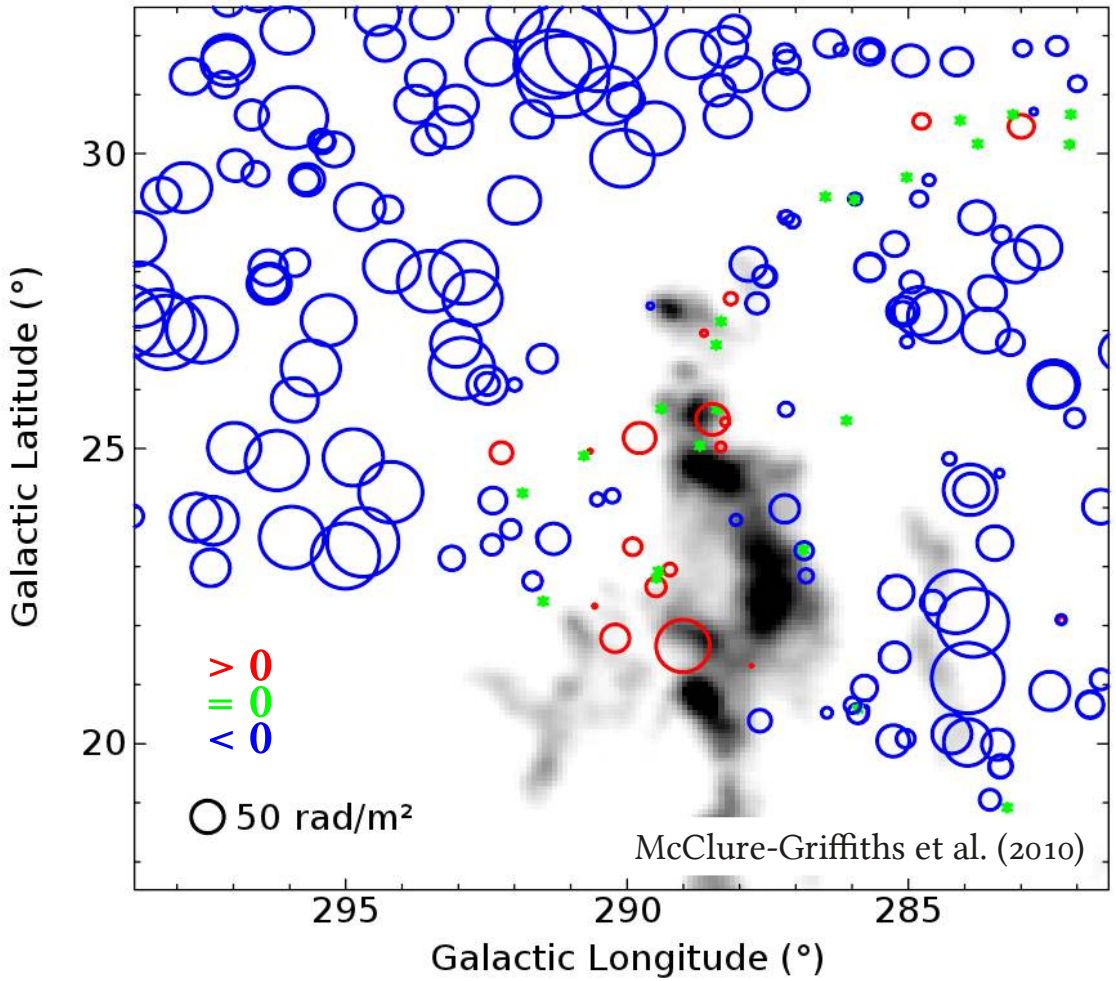


- ★ Magnetic stabilisation:
  - ▸ Magneto-hydrodynamical simulations of neutral gas cloud moving through hot, magnetised plasma (Konz, Brüns & Birk 2002).
  - ▸ Stabilising effects by magnetic field of $B > 1.5 \times 10^{-12}$ T:
    - Plasma deflected by magnetic field barrier near front of cloud.
    - Reduced thermal conduction between cold gas and surrounding plasma.
  - ▸ Life times in excess of 140 Ma.

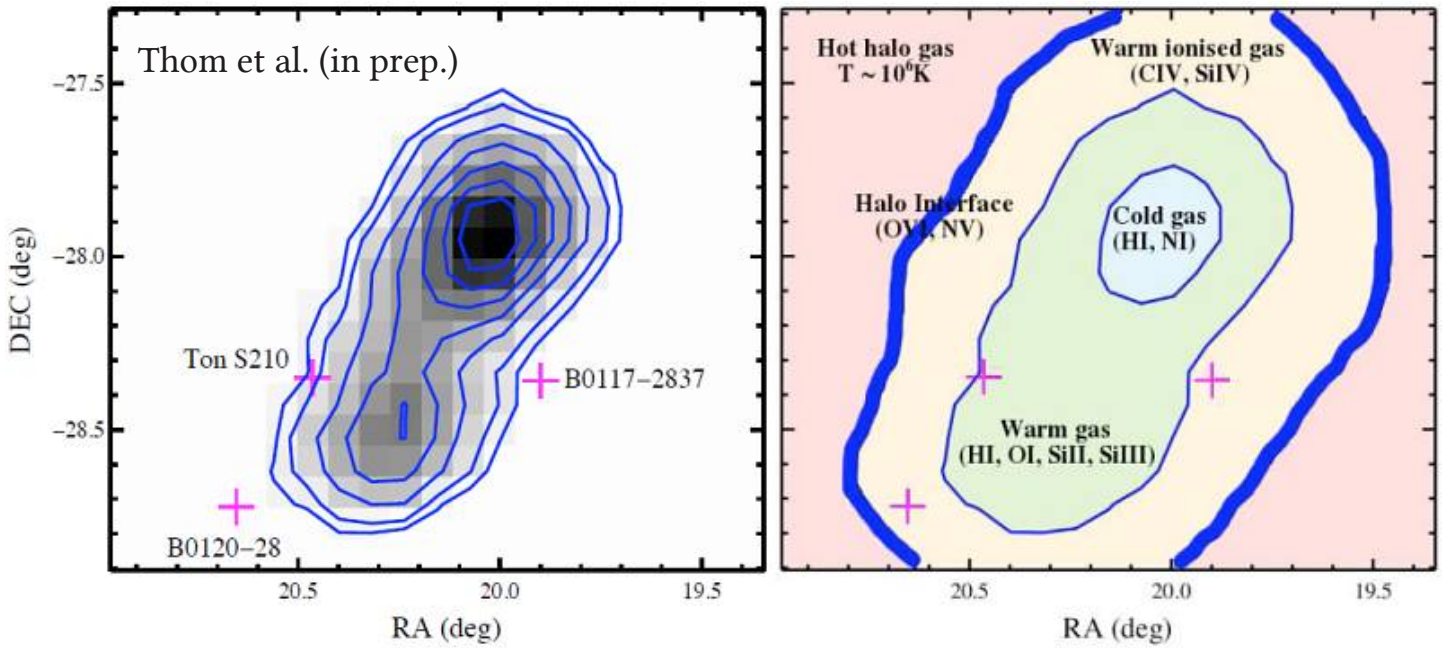


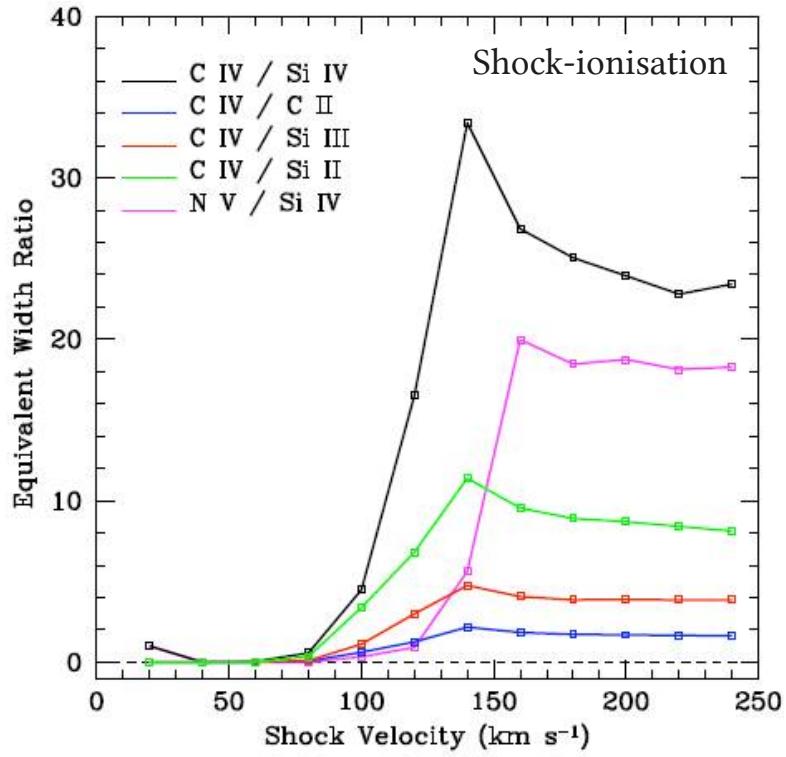
Magellanic Stream / Leading Arm

- ★ Detection of magnetic field in the Leading Arm (McClure-Griffiths et al. 2010).
  - ▸ $\Delta\theta = RM \times \lambda^2$
  - ▸ $RM \propto \int n_e(r)\, B_\parallel \, \mathrm{d}r$
- ★ Coherent magnetic flux density:
  - ▸ $\langle B_\parallel \rangle \gtrsim 0.6$ nT (= 6 μG)
- ★ Sufficient to dynamically and thermally stabilise the gas.



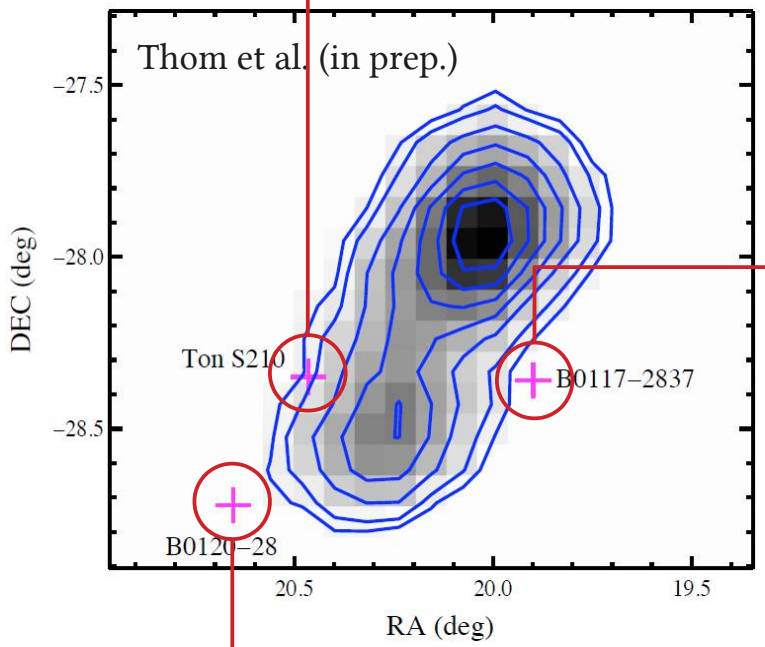
- ★ Measurement of chemical abundances
  - ▸ Follow-up observations with the Hubble Space Telescope (PI: *C. Thom*)
  - ▸ Detection of different transitions (C I, C II, C IV, Si II, Si III, Si IV, etc.)
    - Constrain ionisation mechanism, temperature, density, abundances.

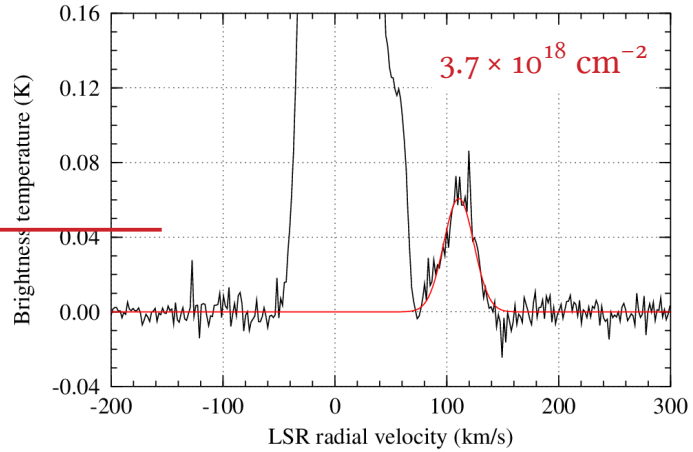


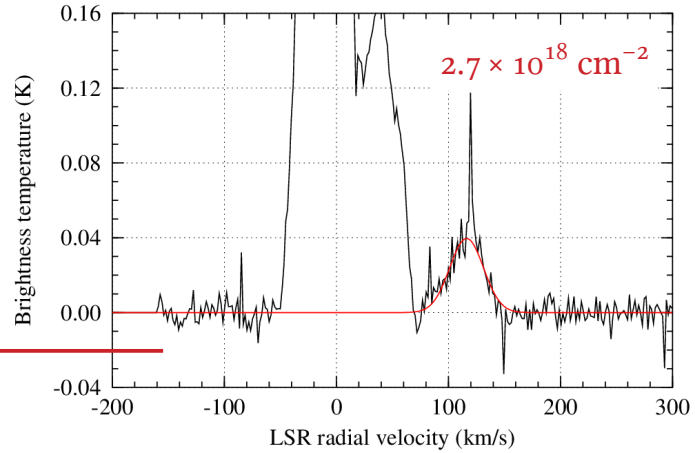


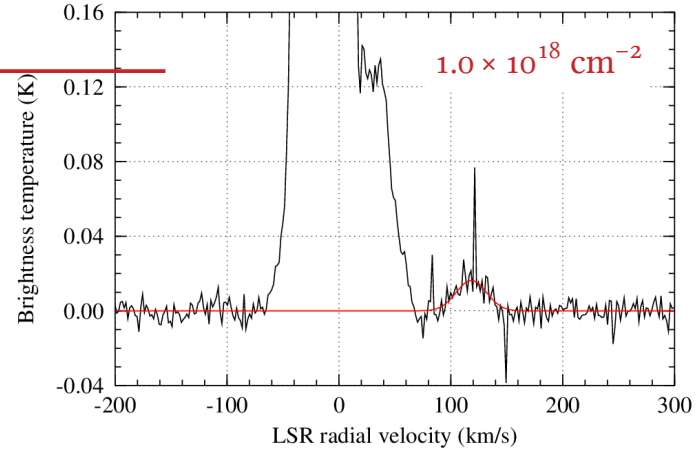
Magellanic Stream / Leading Arm

- ★ Measurement of chemical abundances
  - ▸ H I observations with Parkes to get N_{HI}.



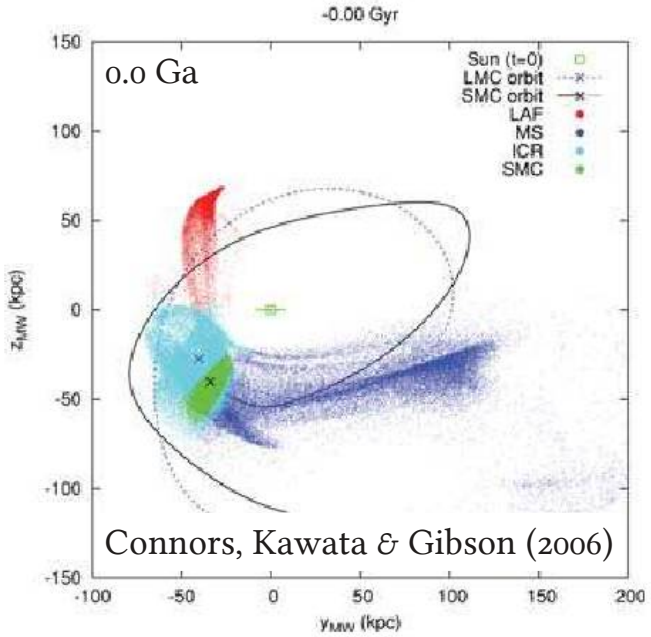




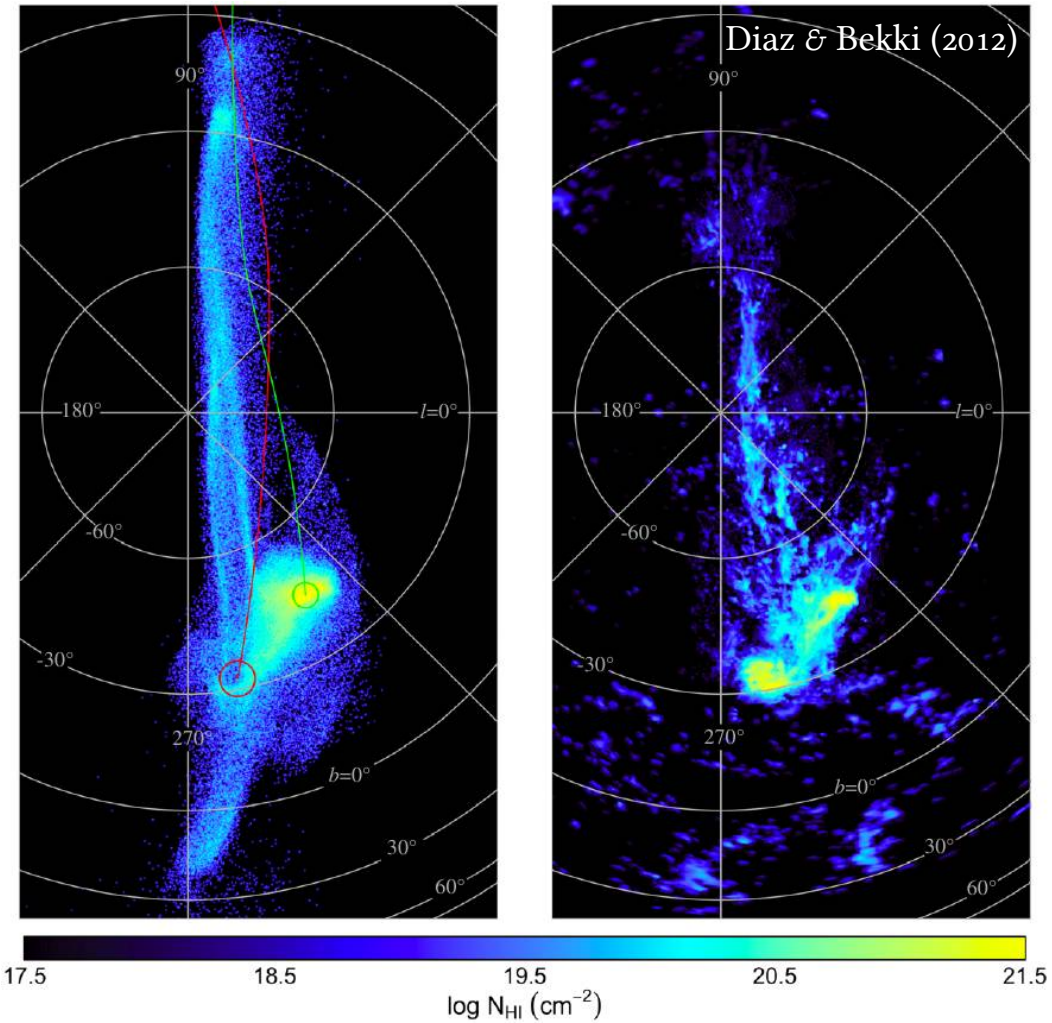


Magellanic Stream / Leading Arm

- ★ Comparison with simulations:
  - ▸ Different formation scenarios:
    - tidal forces
    - ram pressure
    - outflows
  - ▸ Details of models:
    - Orientation and distance of stream
    - Origin of different filaments



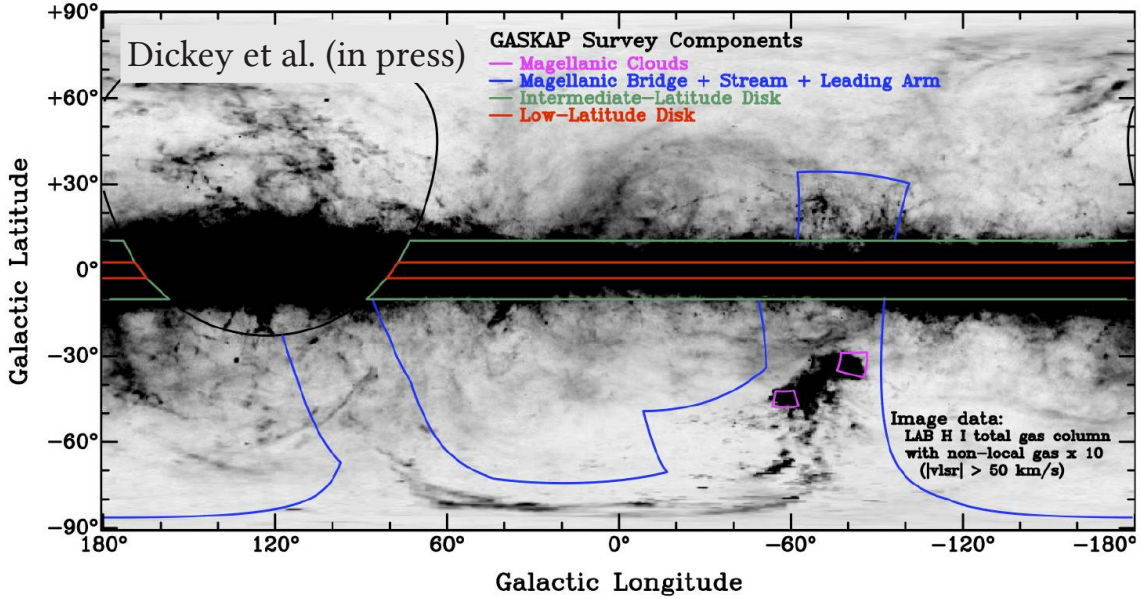
Connors, Kawata & Gibson (2006)



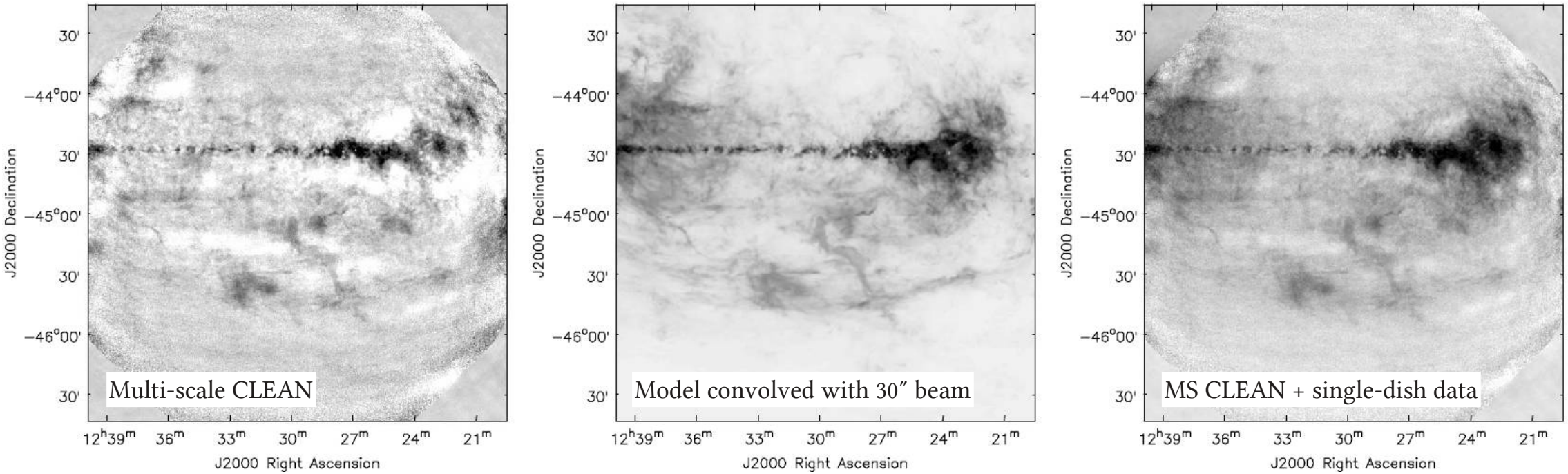
The Future: GASKAP

GASKAP

- ★ GASKAP:
  - Galactic ASKAP Survey
  - PIs: *N. McClure-Griffiths, J. Dickey*
- ★ Improvements over existing surveys:
  - HI / OH simultaneously
  - Large area covered
  - Velocity resolution: $0.2\ \mathrm{km\,s^{-1}}$
  - Surface brightness: $1.9\ \mathrm{K}$ (MS at 30″, $1\ \mathrm{km\,s^{-1}}$)
    $0.5\ \mathrm{K}$ (MCs at 30″, $1\ \mathrm{km\,s^{-1}}$)
  - HI column density: $2 \times 10^{19}\ \mathrm{cm^{-2}}$ (MS, 5σ, 30″, $1\ \mathrm{km\,s^{-1}}$)
    $4 \times 10^{18}\ \mathrm{cm^{-2}}$ (MCs, 5σ, 30″, $1\ \mathrm{km\,s^{-1}}$)



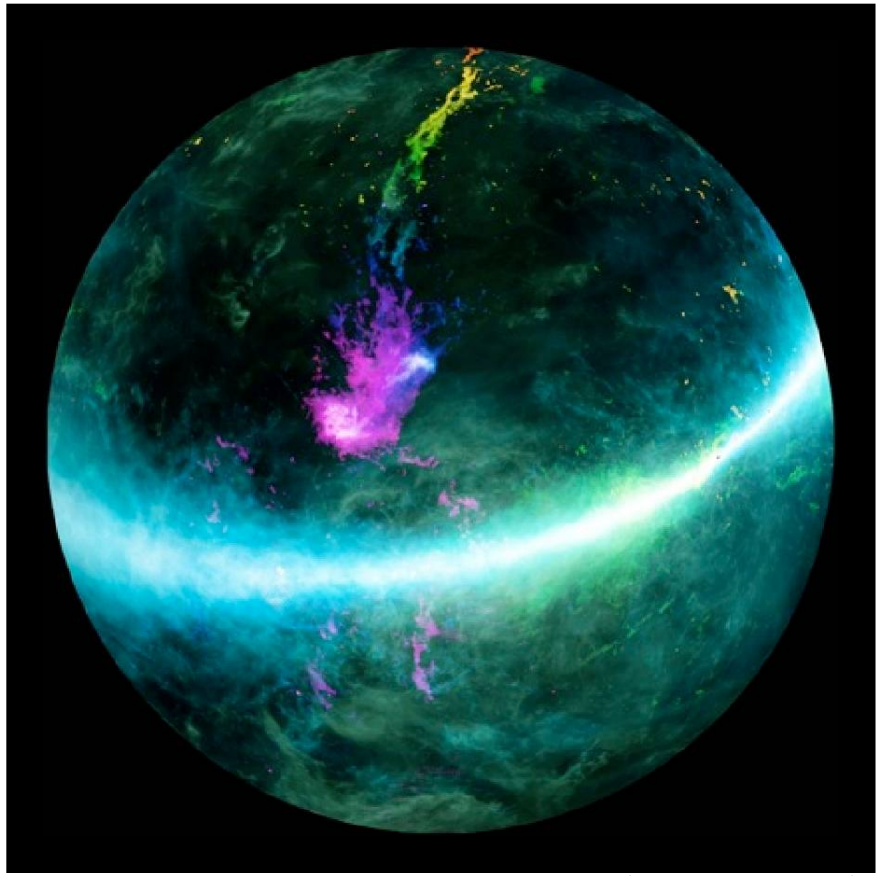
- ★ Combination of ATCA / ASKAP data with single-dish data essential for recovery of flux of extended sources.
  - ▸ Both HI and diffuse OH line emission.
  - ▸ Important aspect of the GASKAP project.



Summary & Conclusions

Summary & Conclusions

- ★ Deep H I mapping:
  - ▸ Tracing low-$N_{\mathrm{H\,I}}$ environment of MS / MW
  - ▸ Zero-spacings data for ASKAP:
    - H I line (1420 MHz)
    - OH lines (1612 – 1667 MHz)
  - ▸ MB / FPA receiver at 1.4 – 1.8 GHz
- ★ Deep, pointed H I observations:
  - ▸ Complement absorption line studies
  - ▸ Crucial for metal abundances in the MS
- ★ Parkes is the only telescope of its kind in the southern hemisphere and hence essential for future studies of the Magellanic system.



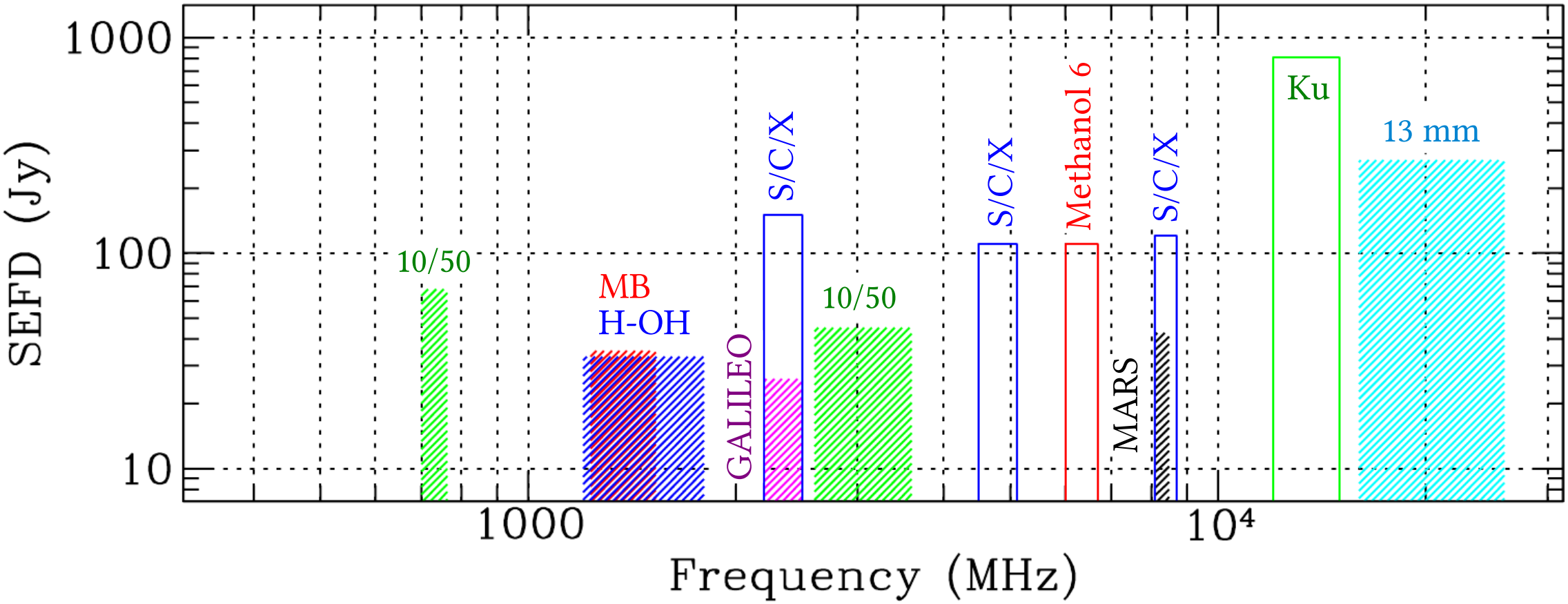
GASS; Credit: S. Janowiecki

Thank you!

Additional Material

Parkes Receiver Fleet

★ Current Parkes receivers:

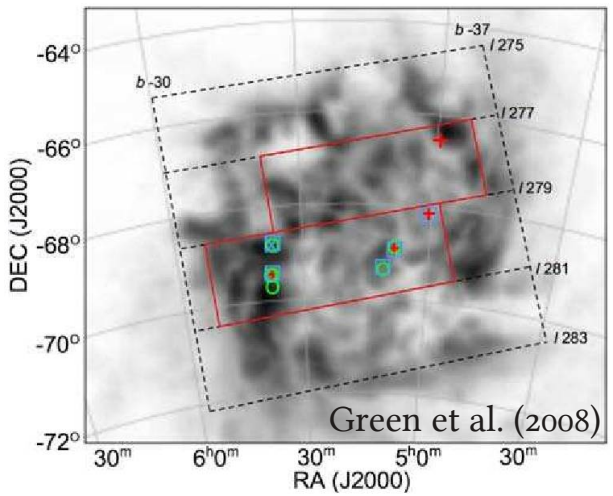


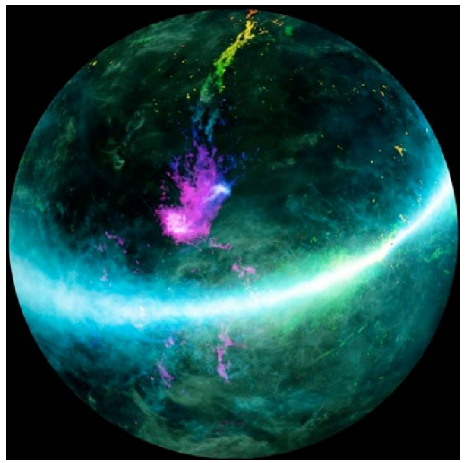
Parkes-based Publications of Magellanic Science

★ Publications from 2008 – 2012:

- Papers by topic:
  - HI / HVCs in Magellanic Stream 5 / 17
  - CO / dust in Magellanic Clouds 4 / 17
  - OH / CH_3OH masers 3 / 17
  - Others (magn. fields, PNæ, pulsars, etc.) 5 / 17
- Papers by citations:
  - Methanol Multibeam Survey 46 / 202
  - Galactic All-Sky Survey 45 / 202
  - Others 111 / 202
- Papers by receivers:
  - MB–20 11 / 17
  - MMB 6–7 GHz 3 / 17
  - S / C / X 2 / 17
  - H–OH 1 / 17

- Details:
  - Search for "Magellanic Parkes" in ADS abstracts on 18 / 10 / 2012.
  - 17 peer-reviewed papers in total, 3 of which are submitted / in press.
  - 9 / 17 papers are using archival data.
  - 6 / 17 papers related to MMB / GASS surveys.



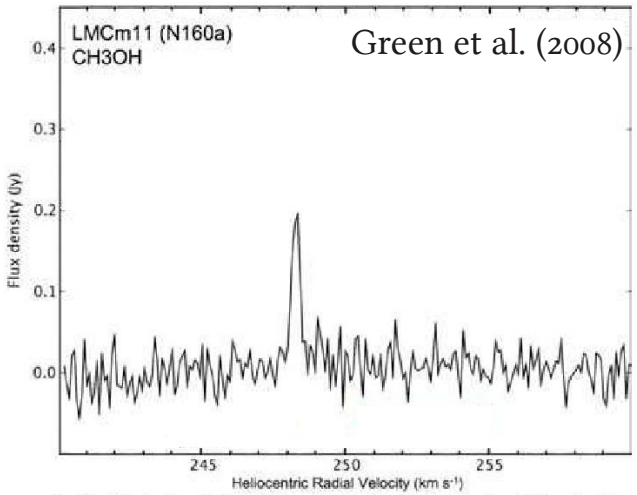


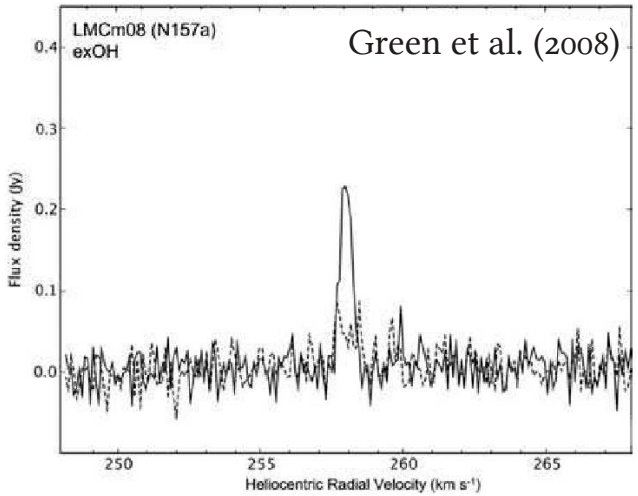
McClure-Griffiths et al. (2009)

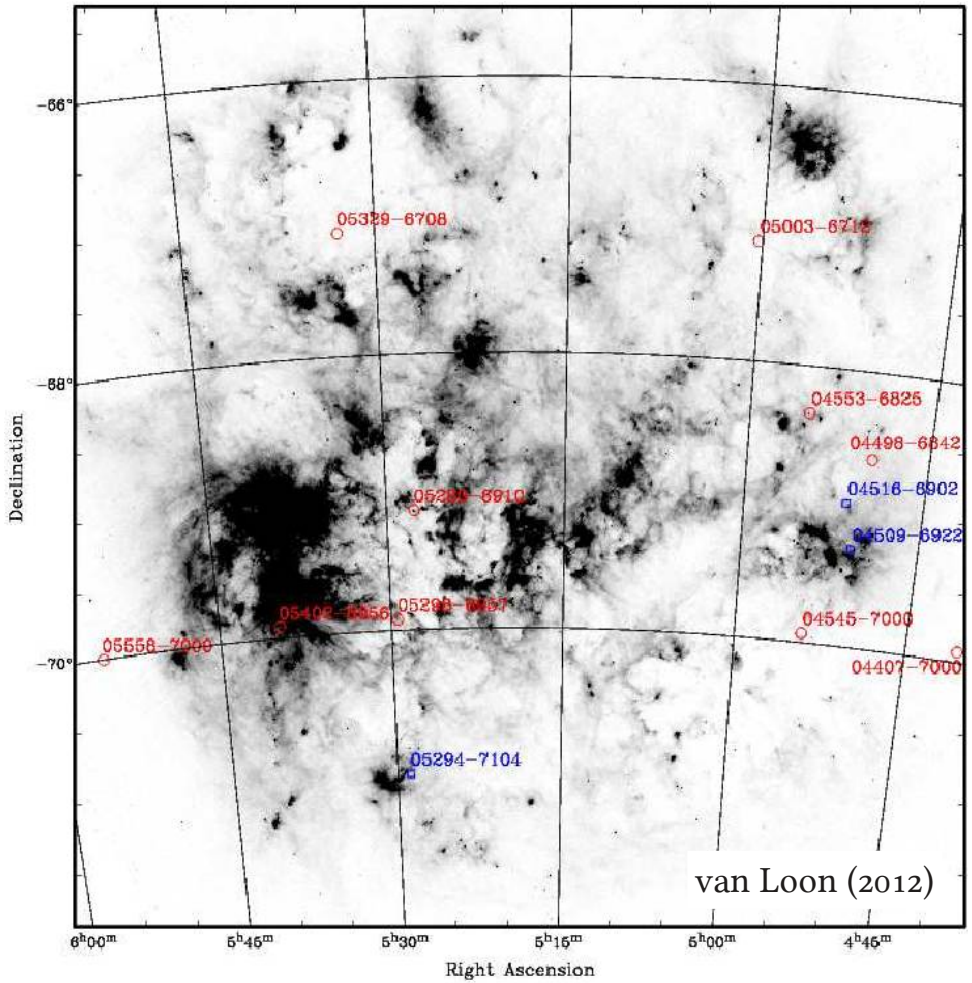
Beyond HI

Maser Emission

- Surveys of masers in LMC and SMC:
  - OH (e.g. Green et al. 2008, 2009)
  - CH_3OH (e.g. Ellingsen 2010, Green et al. 2008, 2009)
  - H_2O (e.g. Oliveira et al. 2006)

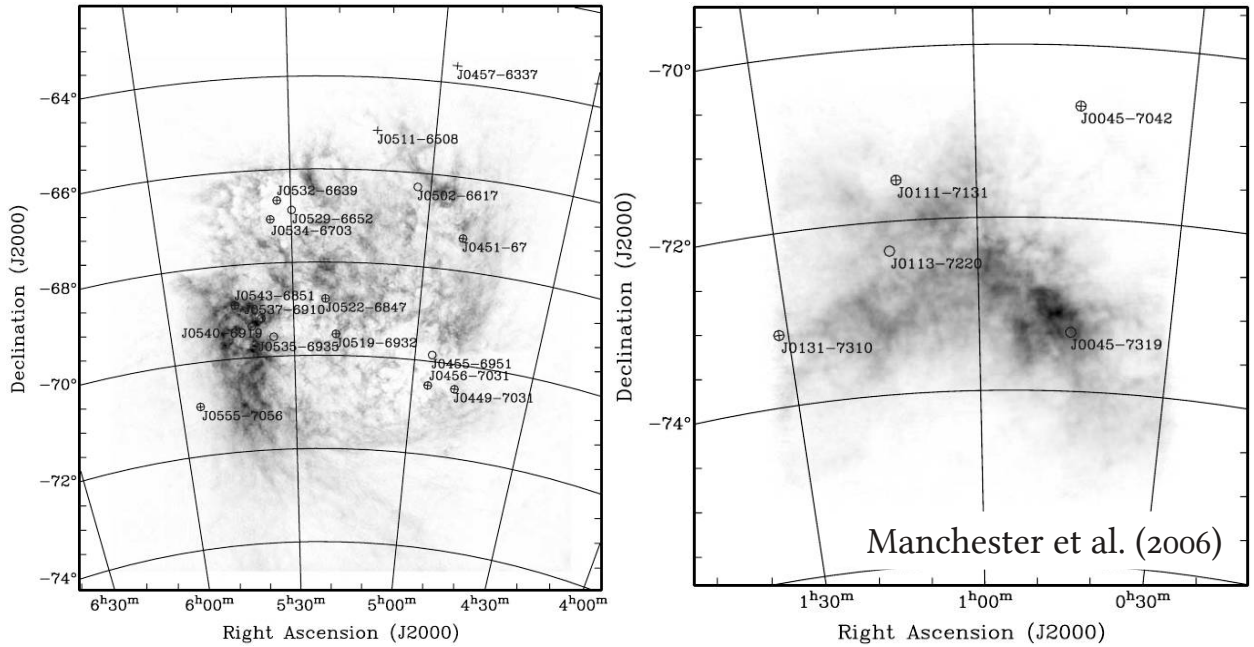






Pulsars / Magnetic Fields

- Pulsars:
  - Magellanic Clouds are the only external galaxies where pulsars can be detected and studied.



Pulsars / Magnetic Fields

- ★ Pulsars:
  - ▸ Magellanic Clouds are the only external galaxies where pulsars can be detected and studied.
- ★ Radio continuum observations:
  - ▸ Polarisation
  - ▸ Magnetic fields