The Magellanic System: A Laboratory for Galaxy Interactions

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

Mathewson, Cleary & Murray (1974)
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- 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.
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- 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
★ 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.
★ Evidence of Leading Arm colliding with the Galactic disc.
  ◄ McClure-Griffiths et al. (2008)
★ Relevance:
  ◄ Distance / galactocentric radius:
    \[ r = 17 \text{ kpc} \pm 20\% \]
  ◄ Constraint for numerical simulations of Magellanic system.
  ◄ Test of LMC / SMC proper motion measurements.
  ◄ Test case for hydrodynamical simulations of HVC interaction.
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

- $160^\circ - 165^\circ$ long (Nidever et al., in prep.)
- and tens of degrees wide (Westmeier & Koribalski 2008)
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.
★ 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.
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★ 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.
Detection of magnetic field in the Leading Arm (McClure-Griffiths et al. 2010).

- $\Delta \theta = RM \times \lambda^2$
- $RM \propto \int n_e(r) B_\parallel dr$

Coherent magnetic flux density:
- $\langle B_\parallel \rangle \gtrsim 0.6 \text{ nT} \quad (= 6 \mu\text{G})$

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\textsc{i}, C\textsc{ii}, C\textsc{iv}, Si\textsc{ii}, Si\textsc{iii}, Si\textsc{iv}, etc.)
  - Constrain ionisation mechanism, temperature, density, abundances.

Thom et al. (in prep.)

[Diagram showing various gas regions and transitions with Shock-ionisation graph on the right.]
Measurement of chemical abundances
- HI observations with Parkes to get $N_{\text{HI}}$.

- Thom et al. (in prep.)
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
The Future: GASKAP
**GASKAP:**
- Galactic ASKAP Survey
- PIs: N. McClure-Griffiths, J. Dickey

**Improvements over existing surveys:**
- $\text{H}_1$/OH simultaneously
- Large area covered
- Velocity resolution: $0.2 \; \text{km s}^{-1}$
- Surface brightness:
  - 1.9 K (MS at 30", 1 km s$^{-1}$)
  - 0.5 K (MCs at 30", 1 km s$^{-1}$)
- H I column density:
  - $2 \times 10^{19} \; \text{cm}^{-2}$ (MS, 5$\sigma$, 30", 1 km s$^{-1}$)
  - $4 \times 10^{18} \; \text{cm}^{-2}$ (MCs, 5$\sigma$, 30", 1 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
Deep H I mapping:
- Tracing low-\(N_{\text{H I}}\) 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.
Thank you!
Additional Material
Current Parkes receivers:

- MB
- H-OH
- GALILEO
- S/C/X
- 10/50
- S/C/X
- Methanol 6
- S/C/X
- MARS
- 13 mm
- 10/50
- S/C/X
- Ku

Frequency (MHz)

SEFD (Jy)
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$_3$OH 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.

Green et al. (2008)
McClure-Griffiths et al. (2009)
Beyond H I
Maser Emission

★ Surveys of masers in LMC and SMC:

- **OH**  (e.g. Green et al. 2008, 2009)
- **CH$_3$OH**  (e.g. Ellingsen 2010, Green et al. 2008, 2009)
- **H$_2$O**  (e.g. Oliveira et al. 2006)

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van Loon (2012)
Pulsars:

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

Manchester et al. (2006)
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★ Radio continuum observations:
- Polarisation
- Magnetic fields