Think Global, Act Local: HI in (and around) the Milky Way

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Circum-Galactic Medium

Figure from J. Peek
Circum-Galactic Medium

How do galaxies work?
Circum-Galactic Medium

HIM
WIM
WNM
CNM
MCs
UNM

Figure by Josh Peek
How does MW interact with the circumgalactic medium?
Multi-phase gas-loss from galaxies

M82. Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

MW HI GSH277+00+36: McClure-Griffiths et al. (2003)
Cool HI halo structure

GALFA examples:
Stanimirovic et al. (2006)
Begum et al (2010)
Saul et al (2012)

Galactic Wind: Fermi Bubbles

(Lack-of) HI in the Galactic Centre

Lockman & McClure-Griffiths (2015, in prep)
HI in the Galactic Centre

HI anti-correlated with $\gamma$-ray at $|b|>10$ deg

HI halo missing - typical of spirals?
HI entrained in a Galactic wind

Typical clouds:
- ~15 pc
- ~270 $M_{\text{Sun}}$

Acceptable wind velocities: 150 km/s to 270 km/s
Models of nuclear outflows

M82 wind simulations: Cooper et al (2008)
• Improve estimates of:
  – opening angle and velocity
  – cloud lifetime
  – entrained mass

Where do they go and what are their properties?

Lockman, Harrington, McG, Ford et al
Gas circulation? Infall?

Figure courtesy Josh Peek
A deceptive view of the HI sky?

3.2 x10^8 M⊙ HI halo (Marasco & Fraternali 2010)

reservoir of <10^{18} \text{ cm}^{-2} HI gas?
significant optically thick HI?

Putman, Peek, & Joung (2012 ARA&A); Westmeier (2007); LAB data
HI Halo: Wide vs Deep

- Deep HI obs (Lockman et al 2002) compared with wide (Moss et al 2013)

- Ratio of dense to diffuse gas is: 0.2 - 0.8, consistent with lots of “undetected” HI (Moss et al, 2015)

Moss (2014 PhD)

FWHM ~20 km/s

FWHM ~30 km/s
Multi-phase high-velocity gas

• HVCs as barometers
  – “Cold” cores: FWHM \( \sim 7 \) km/s, “Warm” envelopes: FWHM \( \sim 20 \) km/s

• 20 - 24 % of HVC sight-lines have multi-phase structure (Moss et al 2013, Kalberla & Haud 2006)
And …

Multiphase Magellanic Steam clouds shouldn’t

- **What is the kpc** (Stanimirovic et al. 2009)
- **What other forces play a role?**
- **magnetic fields?**
Accretion in action?

- MS travelling at \(~380\) km/s (Kallivayelli et al. 06), \(P_{\text{ram}} > 10^{2.5}\) K cm\(^{-3}\)

- Survival time \(~150\) Myr, travel 16 kpc (Putman et al. 11)
B-fields and HVCs

- HVC in Leading Arm of Magellanic System
  - Head-tail morphology
Rotation Measures & HVC HI Emission

\[
\langle B_{\parallel} \rangle = 3.8 \times 10^{18} \langle RM_{HVC} \rangle / N_{\text{HII}}
\]

- Average electron density from H\(\alpha\) WHAM-South upper limit and Si II and Si II abs lines (Shull et al 09)
- Given \(N_{\text{HII}} < 4 \times 10^{19}\) cm\(^{-2}\) and \(\langle RM_{HVC} \rangle \sim 55\) rad m\(^{-2}\)
  \(\Rightarrow B_{\parallel} > 6\) \(\mu\)G (towards us)

\(RM > 0\)
\(RM < 0\)

Magnetic field in the Smith Cloud?

HI $v_{GSR} = +247$ km/s
($v_{LSR} = +100$ km/s at head)

$RM > 0$
$RM < 0$

$\langle RM \rangle = +108 \pm 3$ rad m$^{-2}$
$\langle EM \rangle = 1.22 \pm 0.04$ pc cm$^{-6}$
$B_{||} \geq +8$ μG (towards observer)

Hill et al (2013)
Summary

• Taking full multi-phase ISM into the halo:
  – Gaseous outflows in the Milky Way are multiphase
  – Galactic centre outflow evacuated HI cavity inside $R_g < 2.5$ kpc
    • However, HI clouds of ~20-30 pc entrained in wind
  – The high velocity HI halo is devious
    • undetected diffuse HI
    • “multi-phase” clouds often shouldn’t exist
    • magnetic fields

• How to make progress:
  – Better measurements of temperature (HI absorption?)
  – More metallicities
  – Census of role of magnetic fields
Next steps...
Galactic ASKAP Survey (GASKAP)

Aim: To study the evolution of the Milky Way and Magellanic Clouds through their interstellar gas and star formation

Surveys of the Galactic plane and Magellanic System:

- HI $\lambda$21-cm emission and absorption
- OH $\lambda$18-cm diffuse emission and absorption
- OH $\lambda$18-cm masers

More than order of magnitude more sensitive

GASKAP + POSSUM

Taylor, Stil & Sunstrum
2009

Nidever+10