



Galactic Magnetic Fields

... as traced by Zeeman splitting

Jimi Green | Sydney Magnetic Field Workshop 2012

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Overview

Zeeman splitting of hydroxyl masers & the star formation environment

- Physics
- Scales
- Environment

Brief history

- Previous maser work in the context of Galactic magnetic fields

The MAGMO project

- Aims
- Observations
- First results

Section 1:

Zeeman splitting & the star formation environment

Zeeman splitting of hydroxyl masers

General Theory

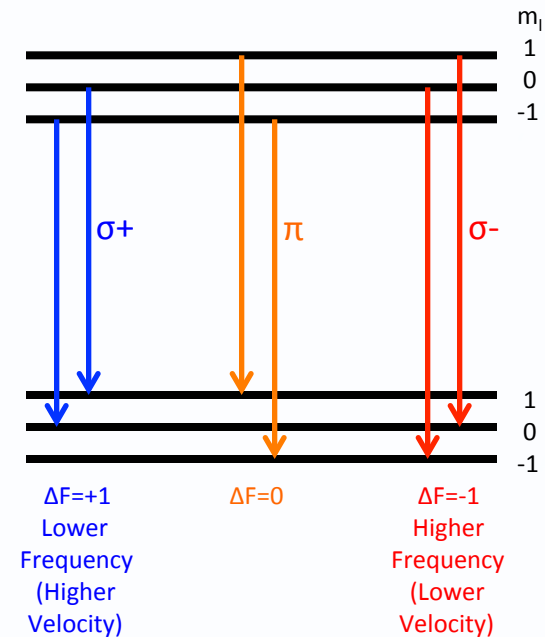
- Hydroxyl is a paramagnetic molecule – high levels of polarisation observed, particularly circular polarisation (up to 100%)
 - Large Zeeman splitting factors for hydroxyl masers (e.g. Heiles et al. 1993):
 - 1665 MHz: $0.590 \text{ kms}^{-1} \text{ mG}^{-1}$, 1667 MHz: $0.354 \text{ kms}^{-1} \text{ mG}^{-1}$
 - Typical field strengths are of the level of a few mG.
 - Typical linewidths of individual features $<1 \text{ kms}^{-1}$
- Clearly separated Zeeman pairs
- Zeeman splitting enables us to determine the (total) strength and line-of-sight orientation of the in situ magnetic fields.

Zeeman splitting

Conventions & definitions

- Splitting of otherwise degenerate energy levels in presence of magnetic field.
- Maser emission seen from transitions between levels.
- Three components: $\sigma+$, $\sigma-$, π .

*In presence of
a magnetic
field*



IAU definition of Stokes V:

*Associates Right
Hand Circular
Polarisation (RHCP)
with this*

*Associates Left
Hand Circular
Polarisation (LHCP)
with this*

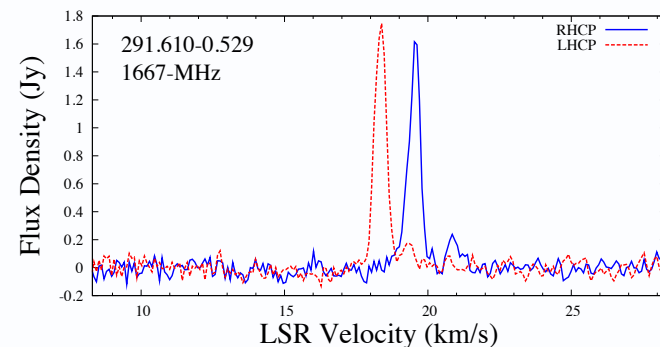
*IEEE definition of
Polarisation handedness:*

*Counterclockwise
rotation of the
electric field vector as
it travels from source
to observer*

*Clockwise
rotation of the
electric field vector
as it travels from
source to observer*

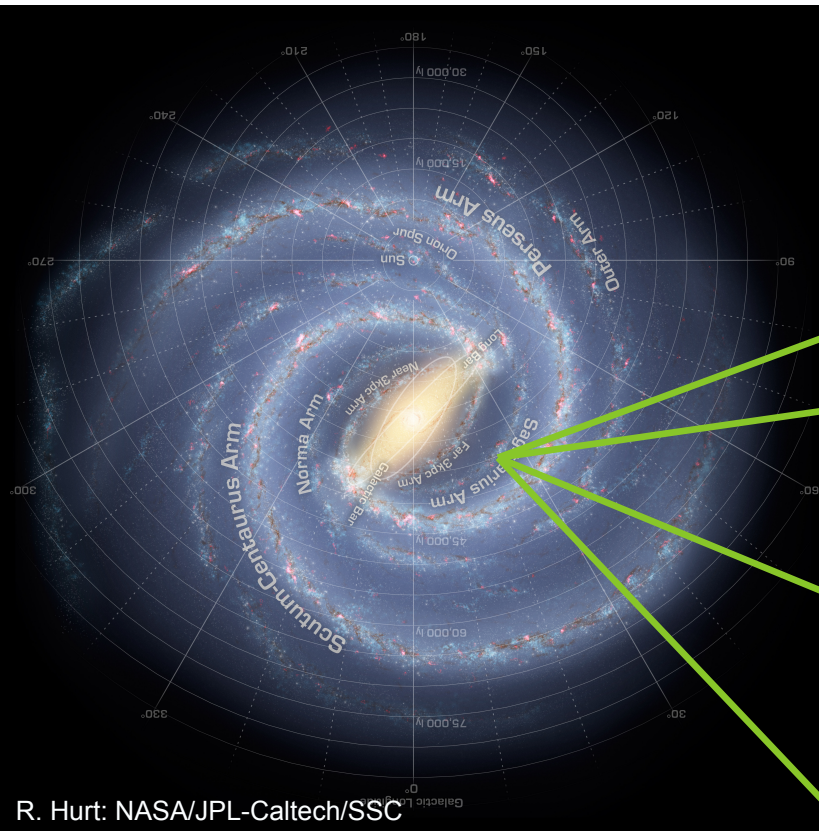
By convention:

This represents a field away from us

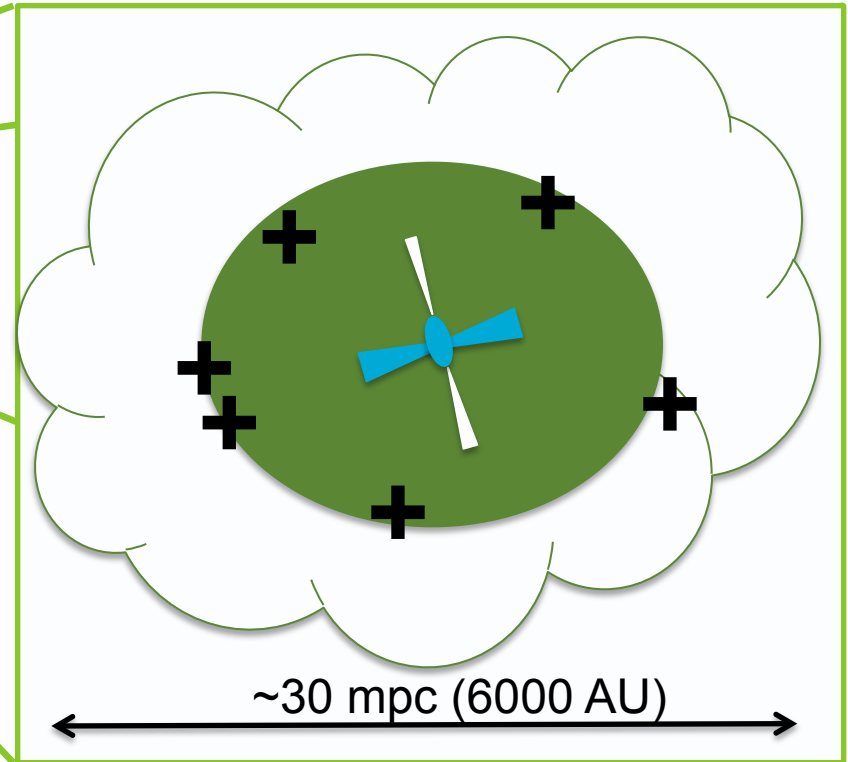


Star formation environment

Scales & maser location



Temperatures: 30 K to >150 K
H₂ densities: 10^6 to 10^7
OH abundances: 10s – 100s cm⁻³



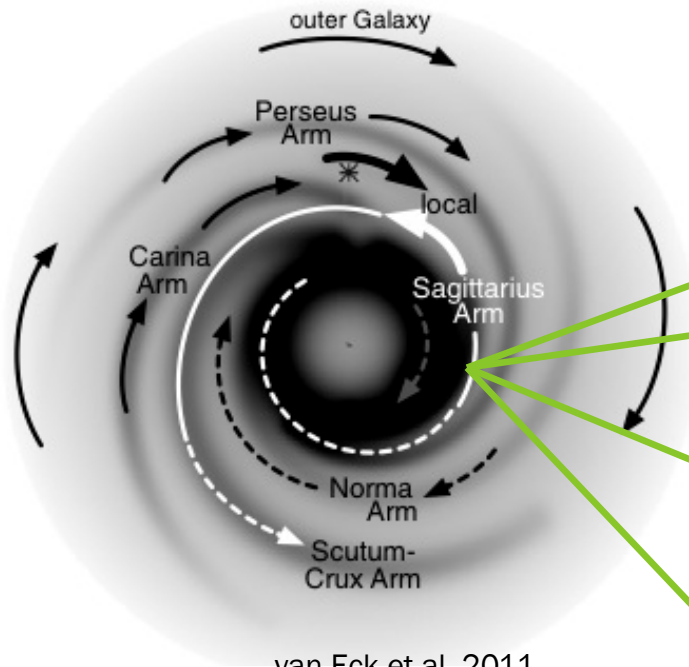
Star formation environment

Scales & maser location

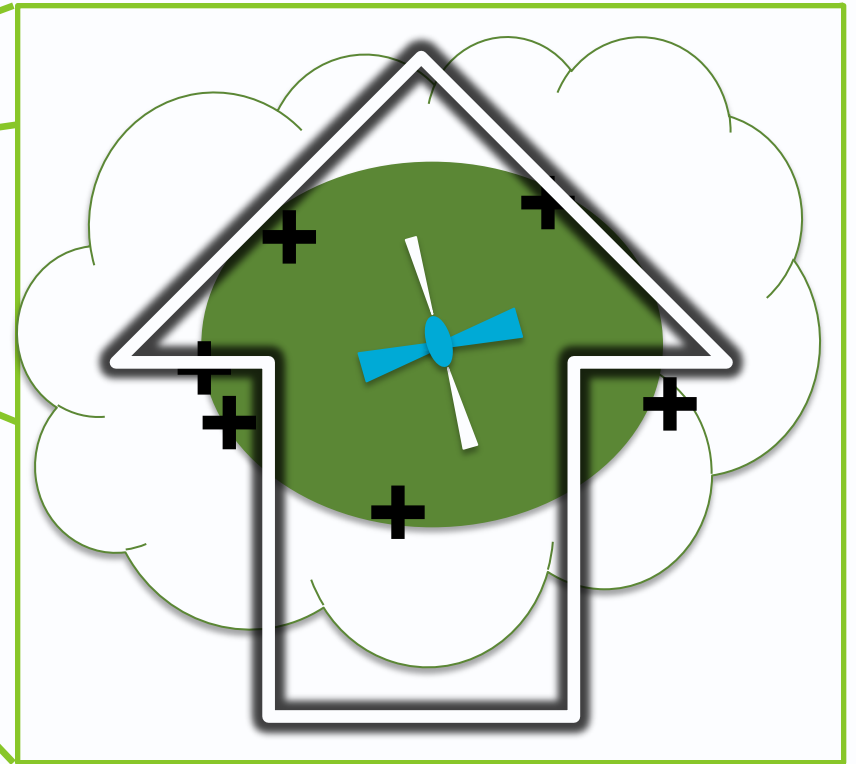
- Hydroxyl masers:
 - Radiatively pumped by infrared emission – combination of radiative excitation and collisional de-excitation (e.g. Gray et al. 1992, Gray 2007).
 - Emission spectrum susceptible to effects of in situ magnetic field.
 - Believed to lie on edge of Ultra-Compact HII region containing the high-mass star(s).
- Large scale magnetic field known from rotation measure observations (e.g. Brown et al. 2007 and van Eck et al. 2011)
- Ultra-Compact HII regions known to exhibit orientation of Galactic magnetic field (e.g. Harvey-Smith et al. 2011)
- Hydroxyl masers tracing Galactic magnetic field?

Star formation environment

Scales & maser location



van Eck et al. 2011

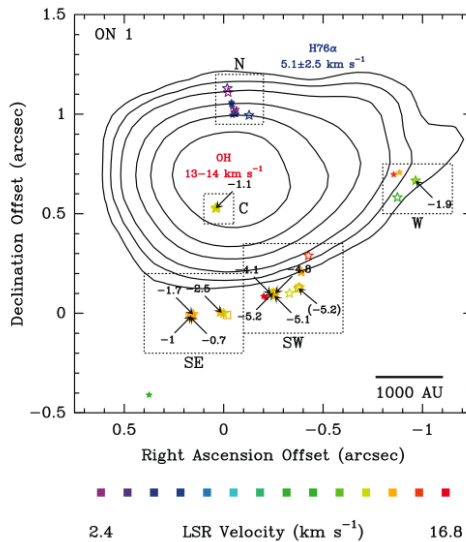


Section 2: Brief History

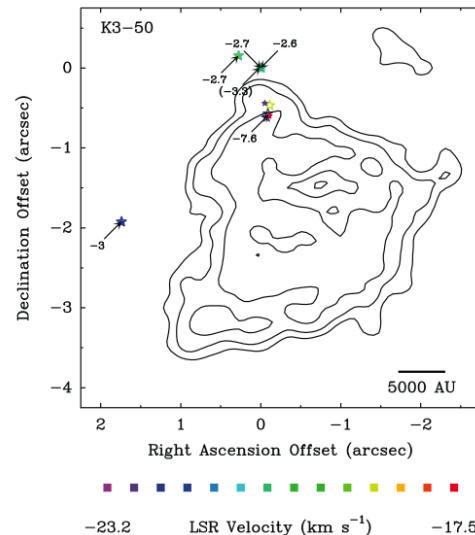
Brief history

Magnetic fields within individual star forming regions

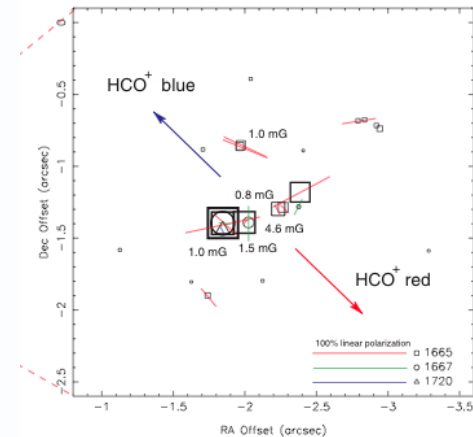
- masers typically exhibit consistent line-of-sight field orientations with comparable field strengths
- e.g. Fish & Reid 2007, Nammahachak et al. 2006, Caswell et al. 2010, Vlemmings et al. 2010



Fish & Reid 2007



Fish & Reid 2007

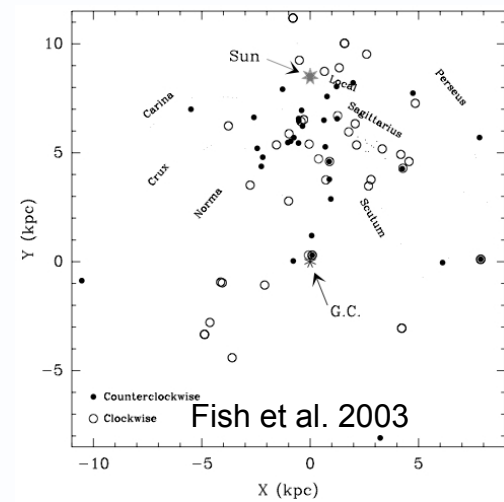
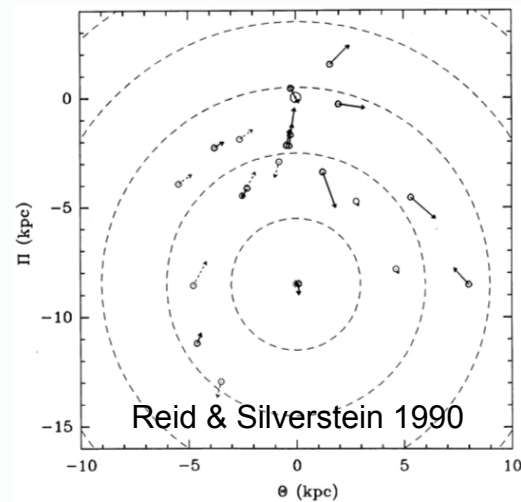
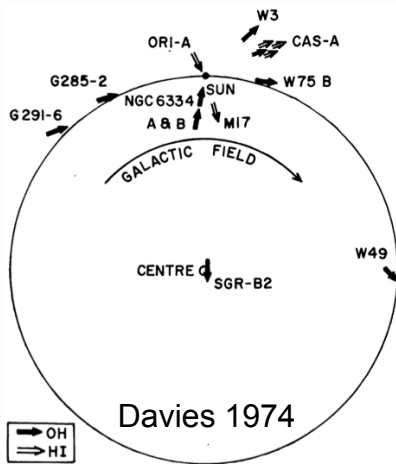


Nammahachak et al. 2006

Brief history

Magnetic fields across the Galaxy

- limited studies have found coherence across multiple sites of star formation, over scales of a few kpc.
- Evidence for coherence in 2nd & 3rd quadrants, and locally in 1st and 4th.
- e.g. Davies 1974 , Reid & Silverstein 1990, Fish et al. 2003, Han & Zhang 2007 compilation



Section 3:

The MAGMO project

The MAGMO project



Description

- Project to examine large scale magnetic fields pervading regions of high-mass star formation.
- Measuring Zeeman splitting of hydroxyl maser emission to determine the strength and orientation of the in situ magnetic field.
- Aims to test whether or not the orientations of weak large-scale magnetic fields can be maintained in the contraction (and field amplification) to the high densities of high-mass star formation.
- Correlating homogeneous observations of 100s of sites of high-mass star formation spread throughout the spiral arms of the Galaxy, increasing previous magnetic field studies of this type by an order of magnitude.

The MAGMO project

Collaborators

Naomi McClure-Griffiths

James Caswell

Tim Robishaw

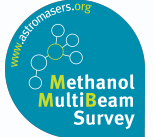
Lisa Harvey-Smith

+ MMB Collaboration



The MAGMO project

Observations



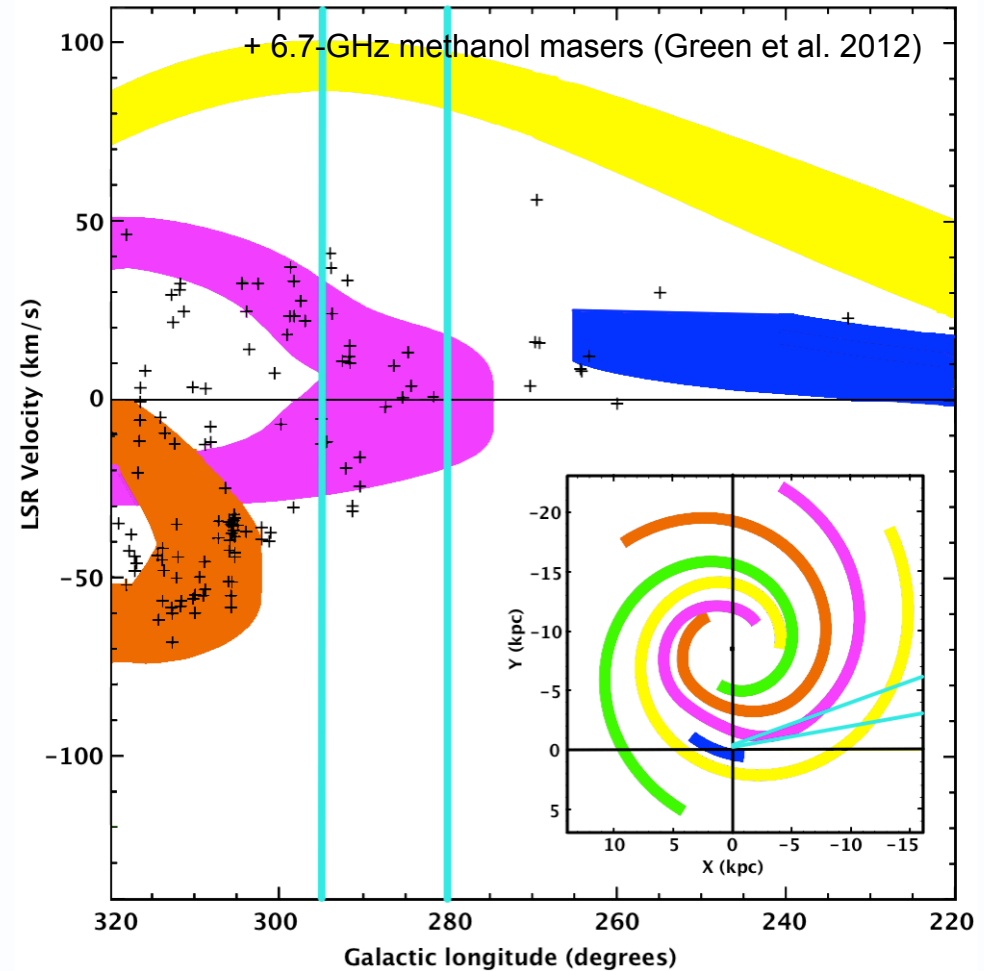
- Targeted observations of sites of 6.7-GHz methanol masers (from the Methanol Multibeam survey).
- Observe all four ground-state hydroxyl transitions (1612, 1665, 1667 and 1720 MHz), and HI, using the new broadband backend on the Australia Telescope Compact Array
- 16 tunable ‘zoom’ bands of 1 MHz width with 2048 channels (velocity channel spacing of $\sim 0.09 \text{ km s}^{-1}$) at 2 IFs.
- simultaneously observe HI absorption at 1420-MHz, indicative of the cold neutral medium.
- ~ 30 arcmin primary beam, 6 km array configuration $\Rightarrow \sim 7$ arcsec synthesized beam.
- ‘snapshot’ mode with 4/5 cuts across 12 hr period
- typically 30mins on source $\Rightarrow 50 \text{ mJy rms channel noise}$



The MAGMO project

First Results

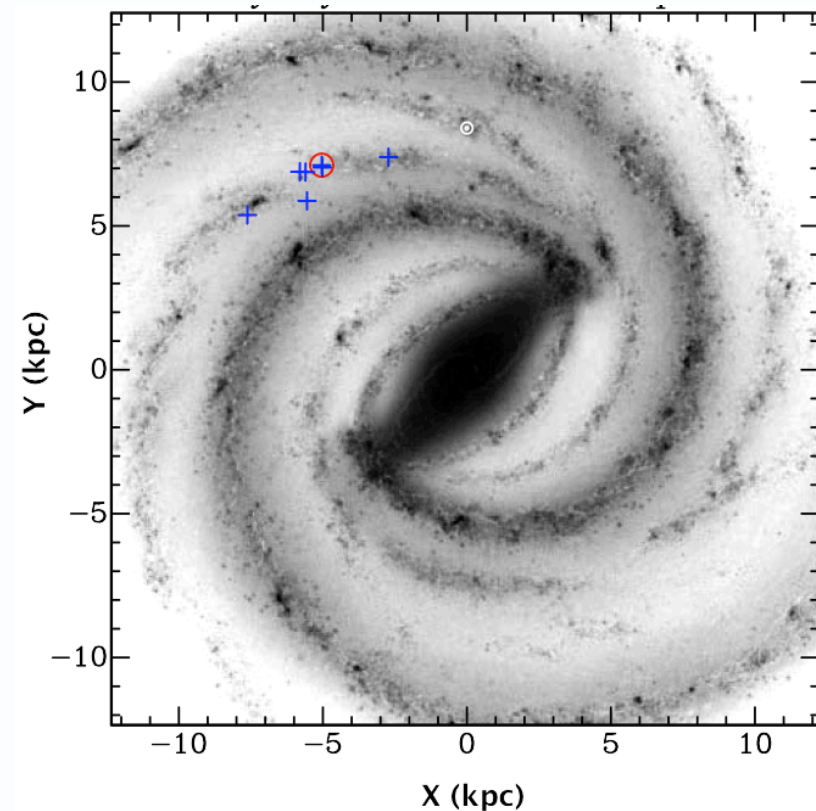
- 23 sites of high-mass star formation observed towards Carina-Sagittarius spiral arm tangent.
- Detected 17 sites of hydroxyl masers (9 new discoveries)
- Fractional linear polarisation 22 to 95%
- Fractional circular polarisation 6 to 100%
- 11 Zeeman pairs, plus 3 from literature (RHCP + LHCP coincident to within $0.4''$)
- Field strengths -1.5 to +8.9 mG



The MAGMO project

First Results

- Of all the field measurements:
 - 3 negative B-Field measurements (circles)
 - 11 positive B-Field measurements (pluses)
- Considering only measurements above 5σ : all positive.
- Opposite orientation to that indicated by rotation measures (crosses & squares)

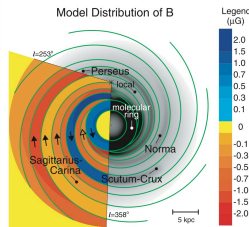


The MAGMO project

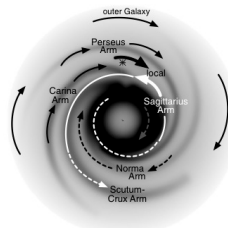
Future



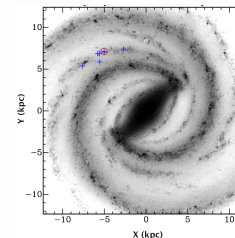
- Observations made towards all sites of high-mass star formation traced by 6.7-GHz methanol masers between longitudes 186° and 20° .
- Detection rate so far implies ~ 500 hydroxyl masers will be detected, with ~ 300 Zeeman pair measurements across the Galaxy.
- First result for Carina-Sagittarius arm tangent implies coherent field orientation over ~ 5 kpc of the arm with a field directed away from us (*possible need for field convention reversal?*)



Brown et al. 2007



van Eck et al. 2011



MAGMO ?

- MAGMO (targeted survey of star formation hydroxyl with I,Q,U,V)
 - GASKAP (blind survey of all hydroxyl with I,V)
 - POSSUM (MAGMO and GASKAP Zeeman measurements complement)

Thank you

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