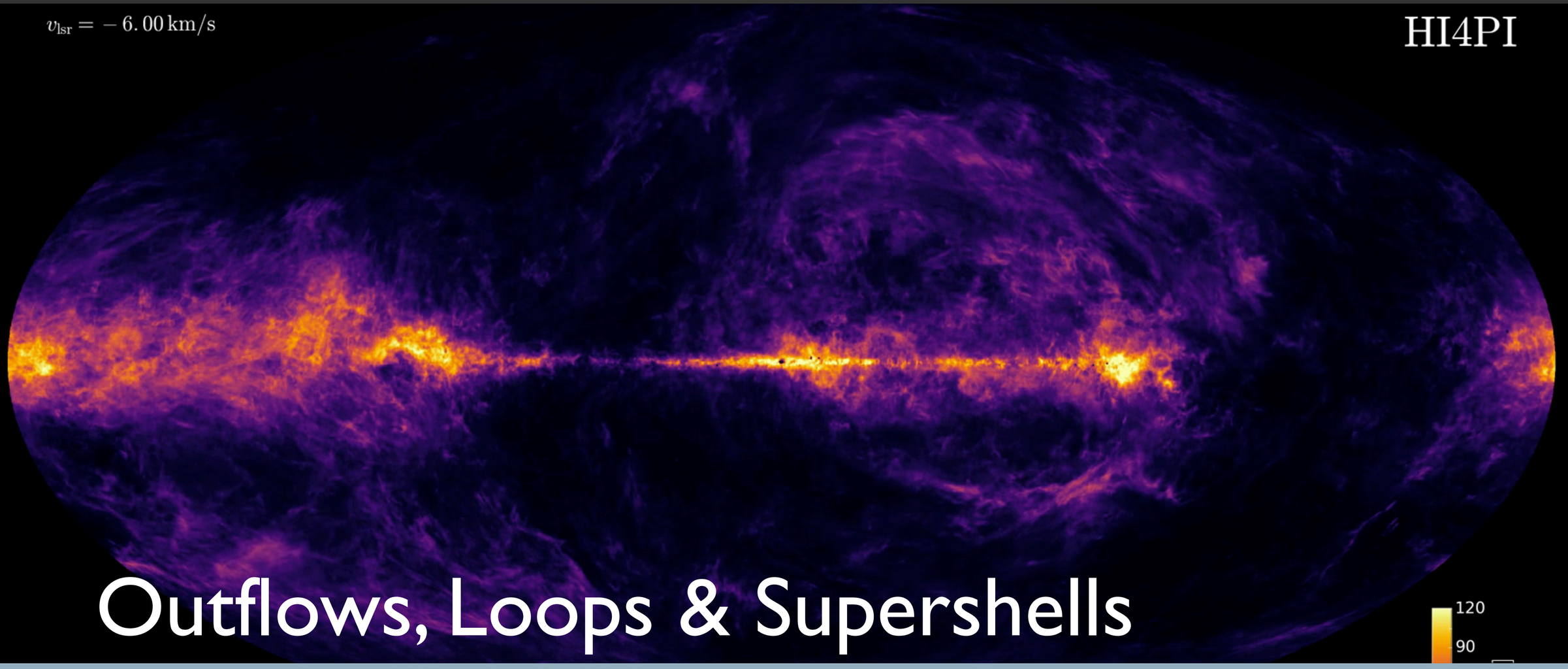
Australian National University



Outflows, Loops & Supershells

NAOMI McCLURE-GRIFFITHS
Australian National University

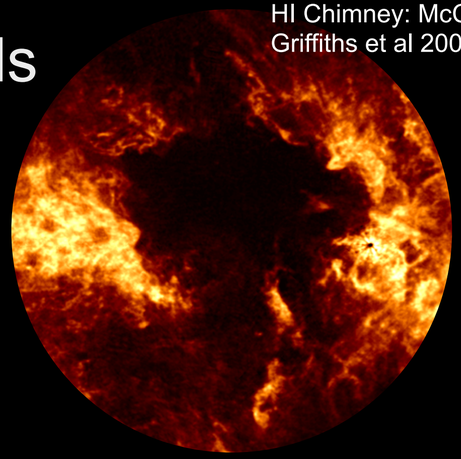
@naomimcgriff

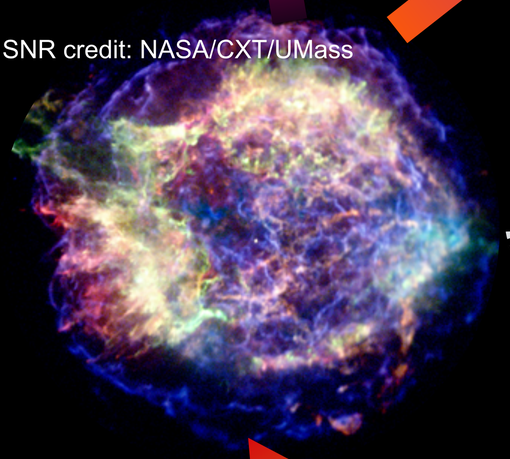
Thinkshop September 2018

Galactic winds

HI Chimney: McClure-Griffiths et al 2003

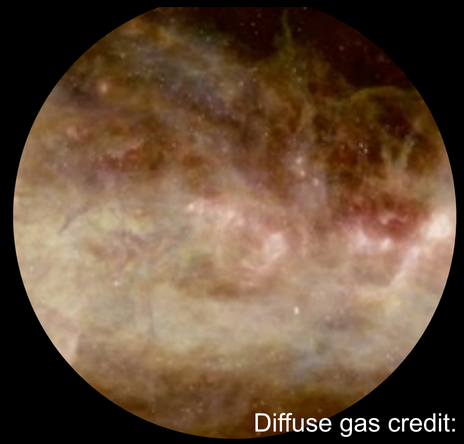
Galactic inflow





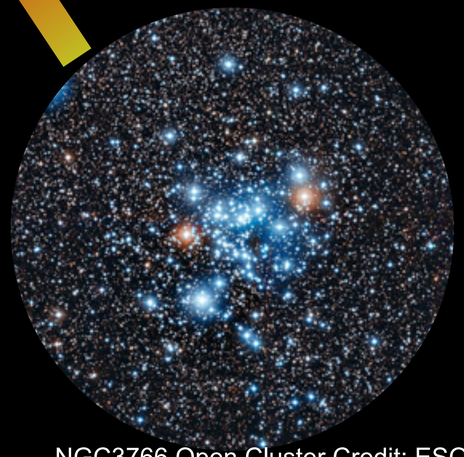
Cas A SNR credit: NASA/CXT/UMass

white dwarfs/black holes



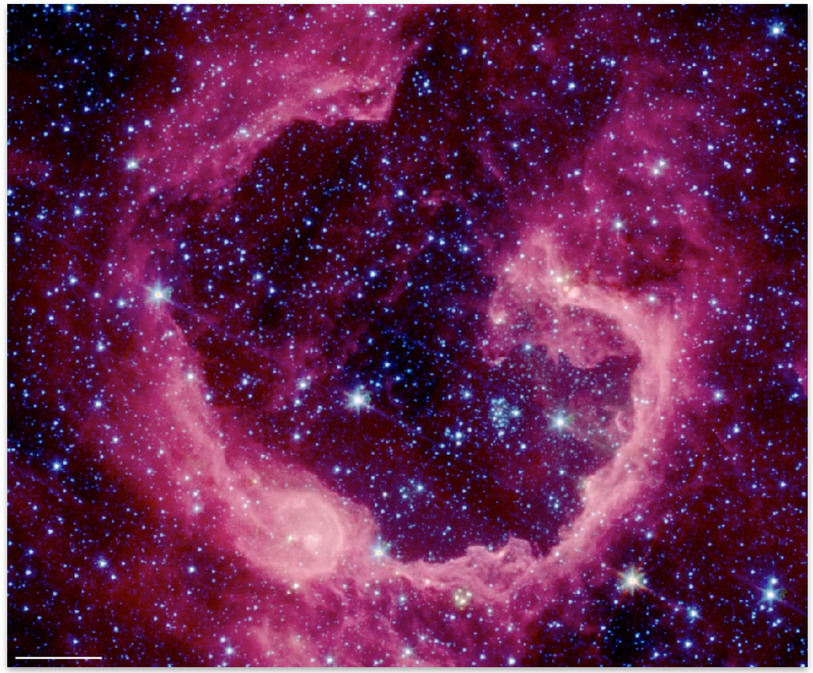
Diffuse gas credit: CGPS

Molecular clouds Credit: NASA/HST



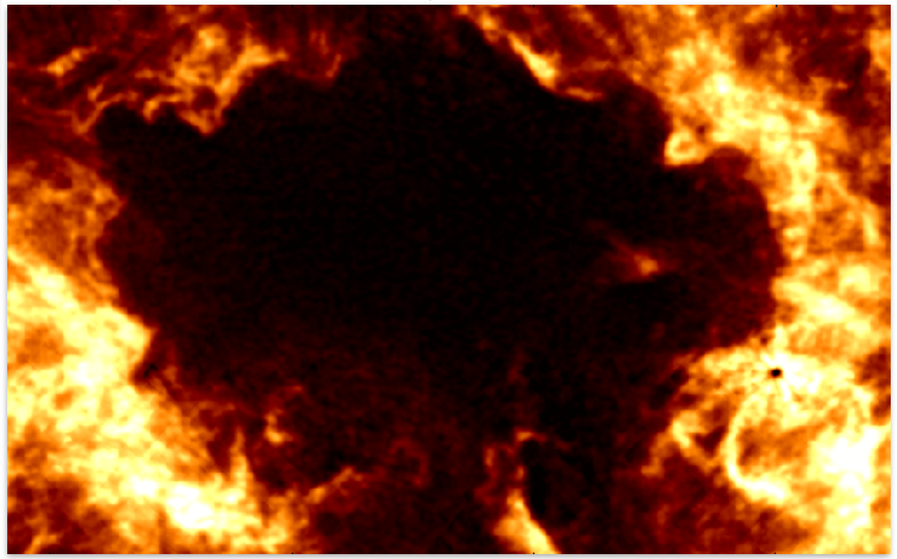
NGC3766 Open Cluster Credit: ESO

Bubbles, Shells & Supershells



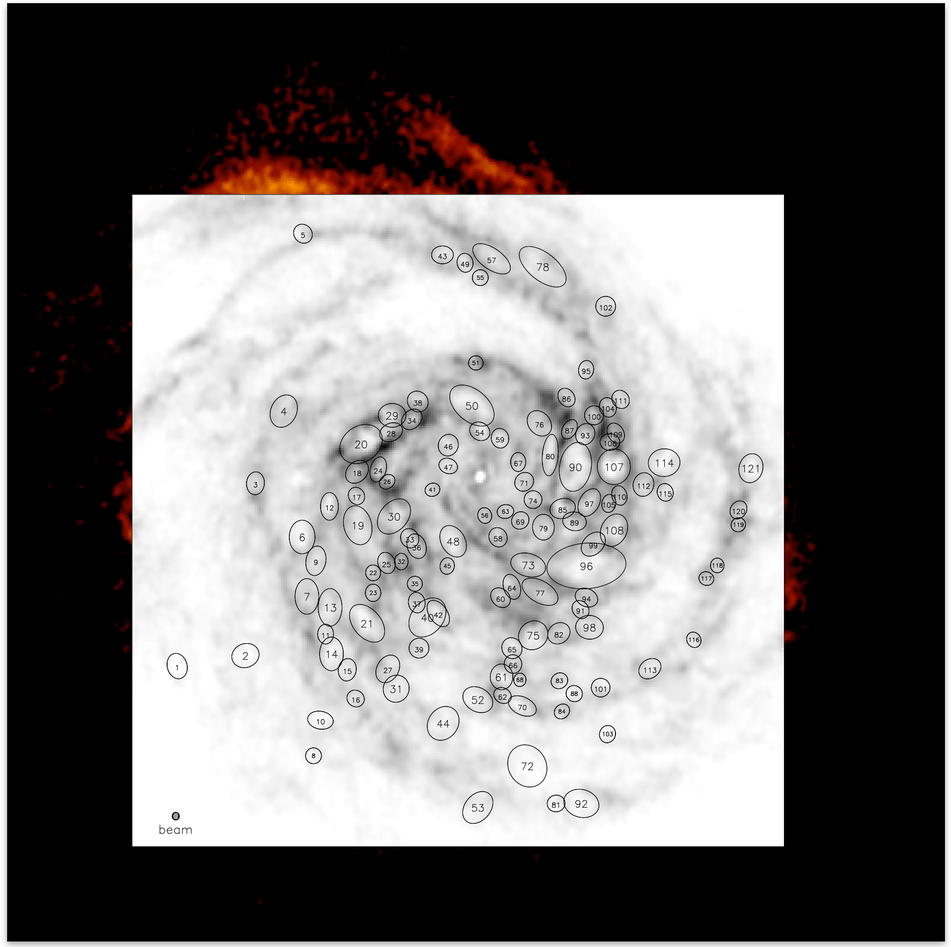
GLIMPSE RCW 79, ~15 pc, E~10^{51} ergs (Churchwell et al. 2006)

GSH 277+00+36, ~300 pc, E~10^{53} ergs (McC-G et al. 2003)



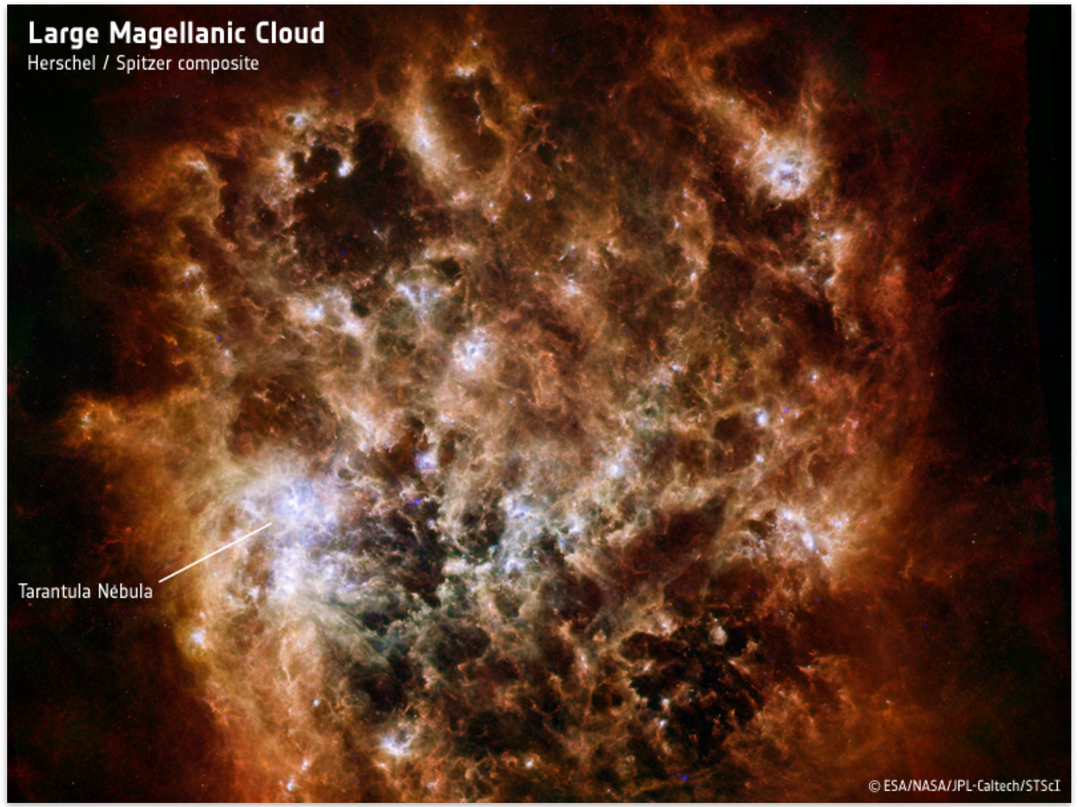
LMC N44 (Gemini/AURA) ~70 pc, E~10^{52} ergs

Galactic Impact of Supershells



NGC 6946, Boomsma et al. (2008)

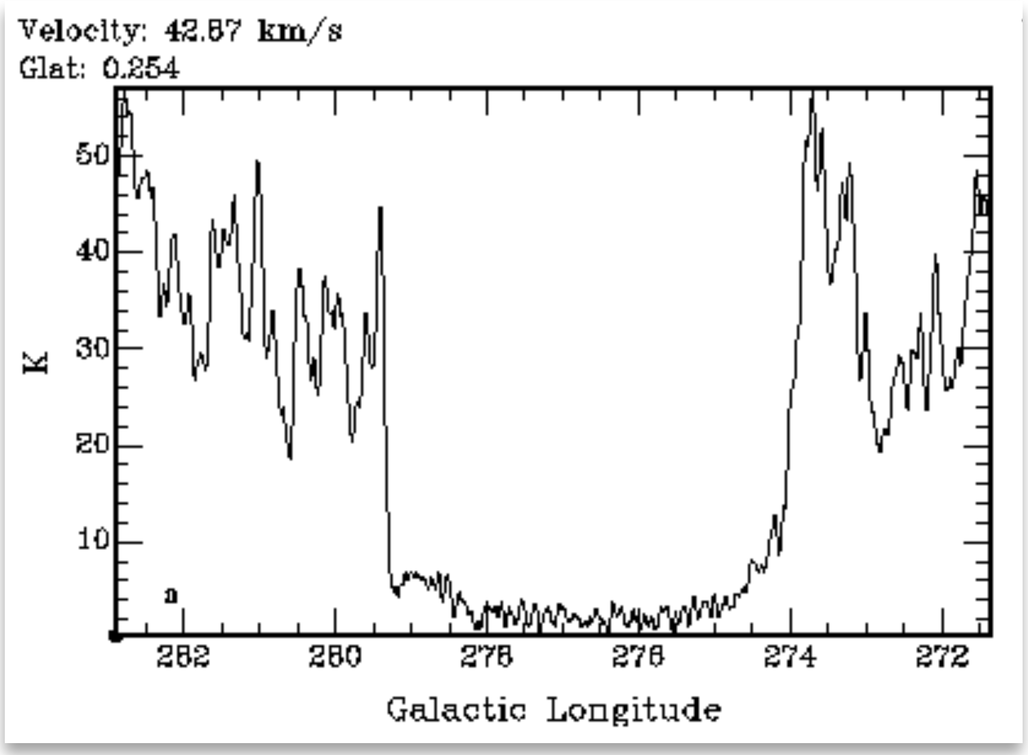
Size distribution: ~10 pc to >1 kpc (e.g. Kim et al. 1999, McG et al 2002, Boosma et al. 2008)



MW space density of shells at $R_{\odot}$ ~4 kpc^{-2} (Ehlerova & Palous 2005)

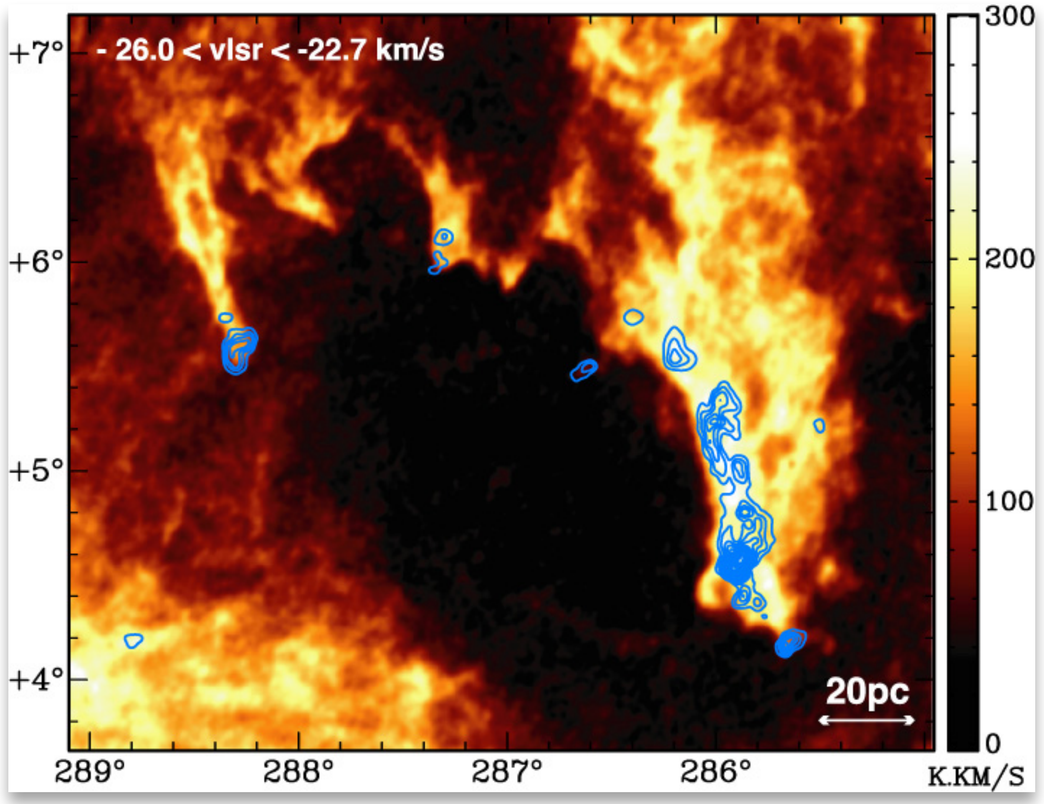
Supershells and Gas Cooling

Density contrasts >10x



McClure-Griffiths et al. (2003)

HI in wall features T~ 40 - 150 K

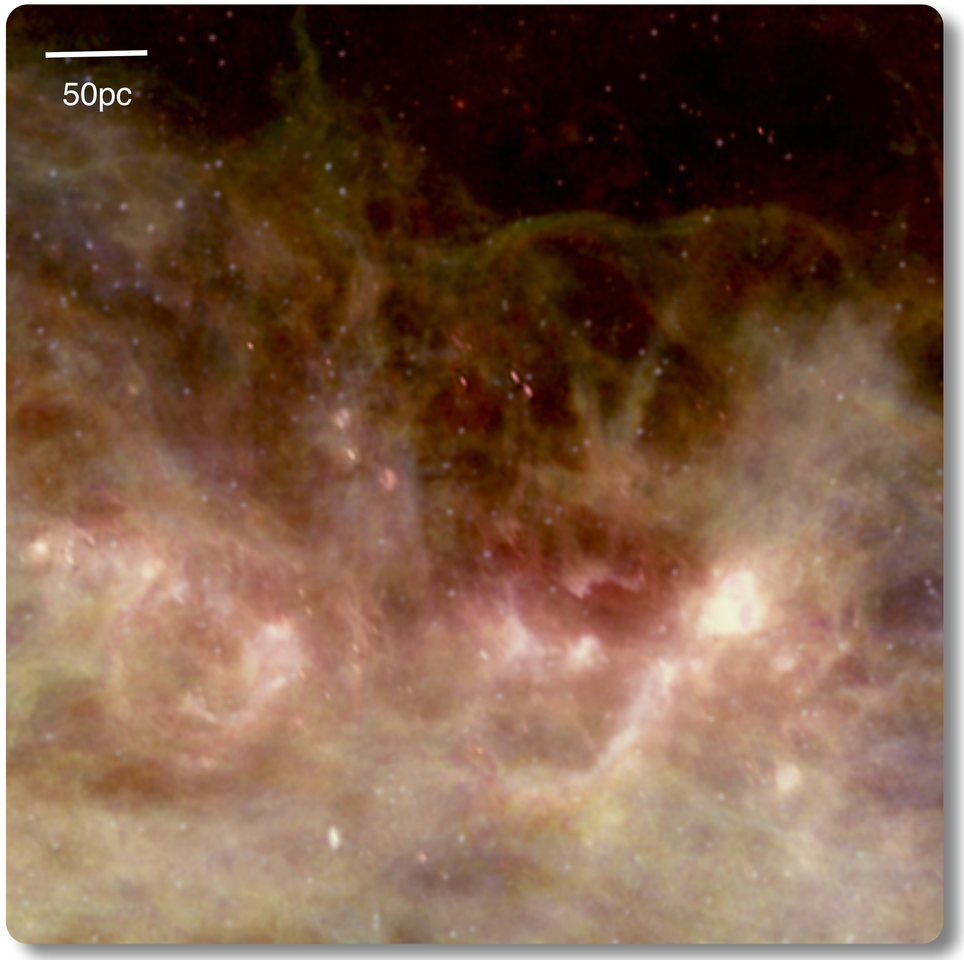


Dawson et al. (2011)

Molecular cloud formation - in situ or by collection?

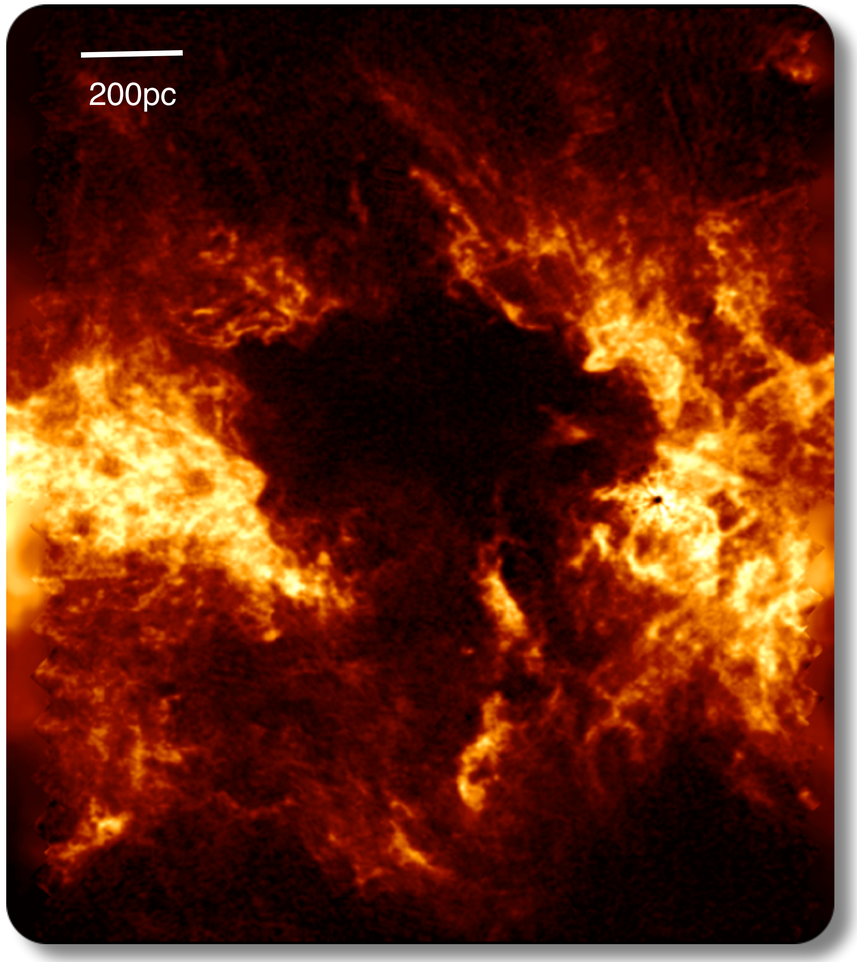
Powering Outflows

Fountain model (e.g. Bregman et al 1984)



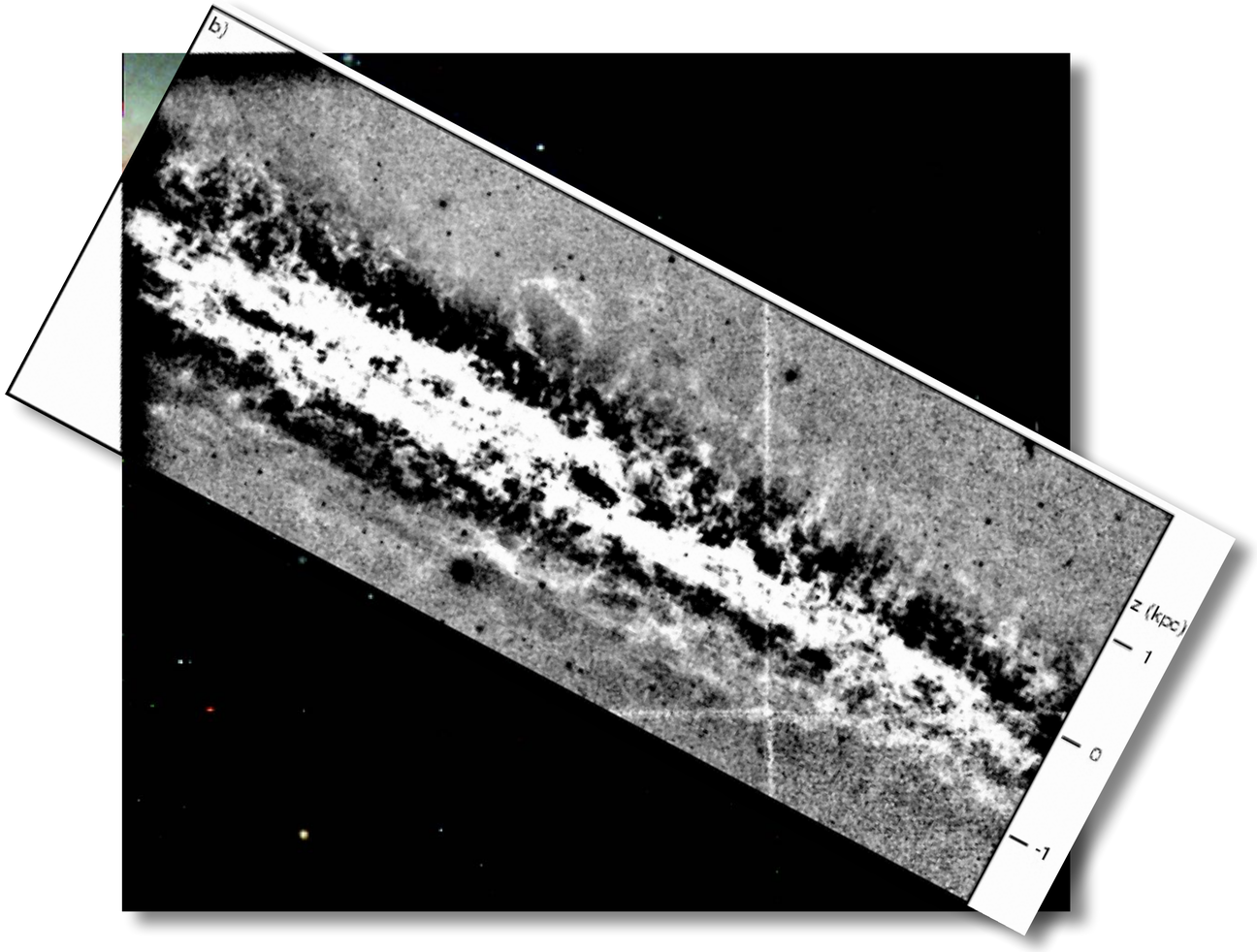
W4. credit: J. English/ M. Normandeau

“Popping” chimneys (e.g. Norman & Ikeuchi 1989)

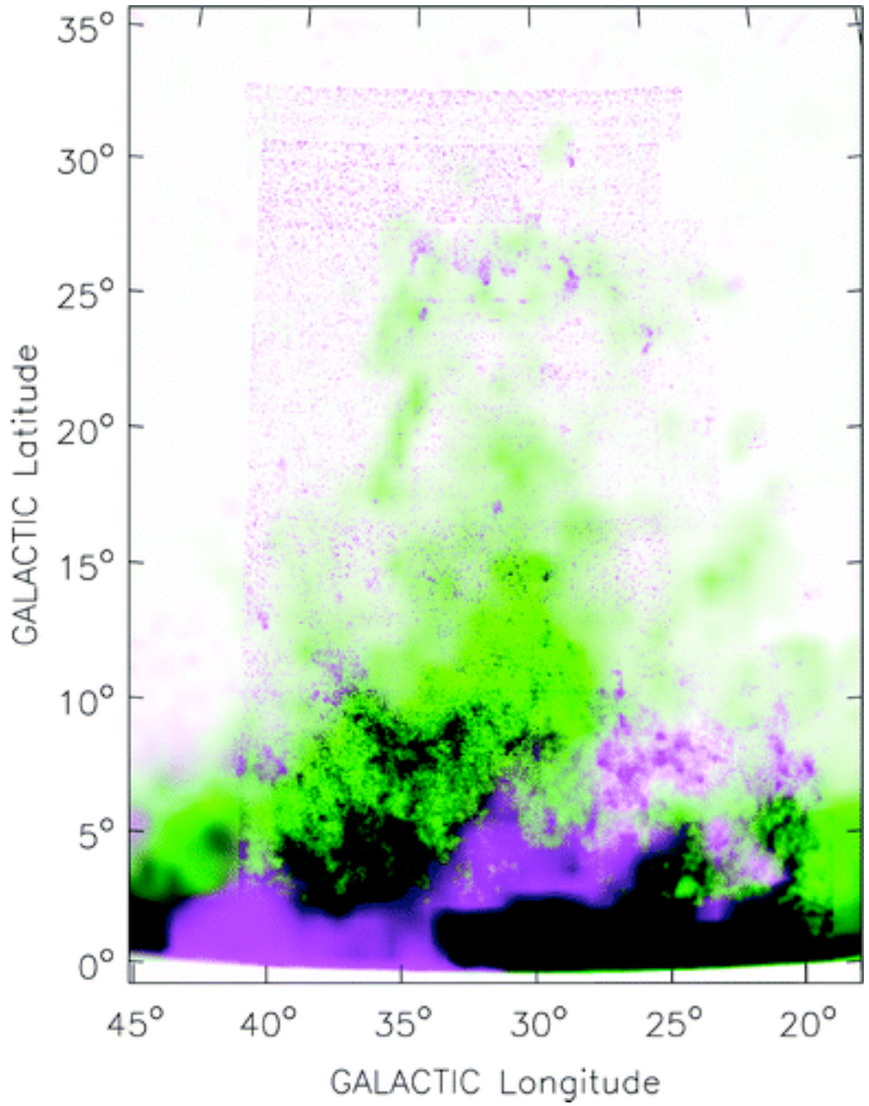


GSH 277+00+36 (McClure-Griffiths et al. 2003)

Cool Gas in Galaxy Halos



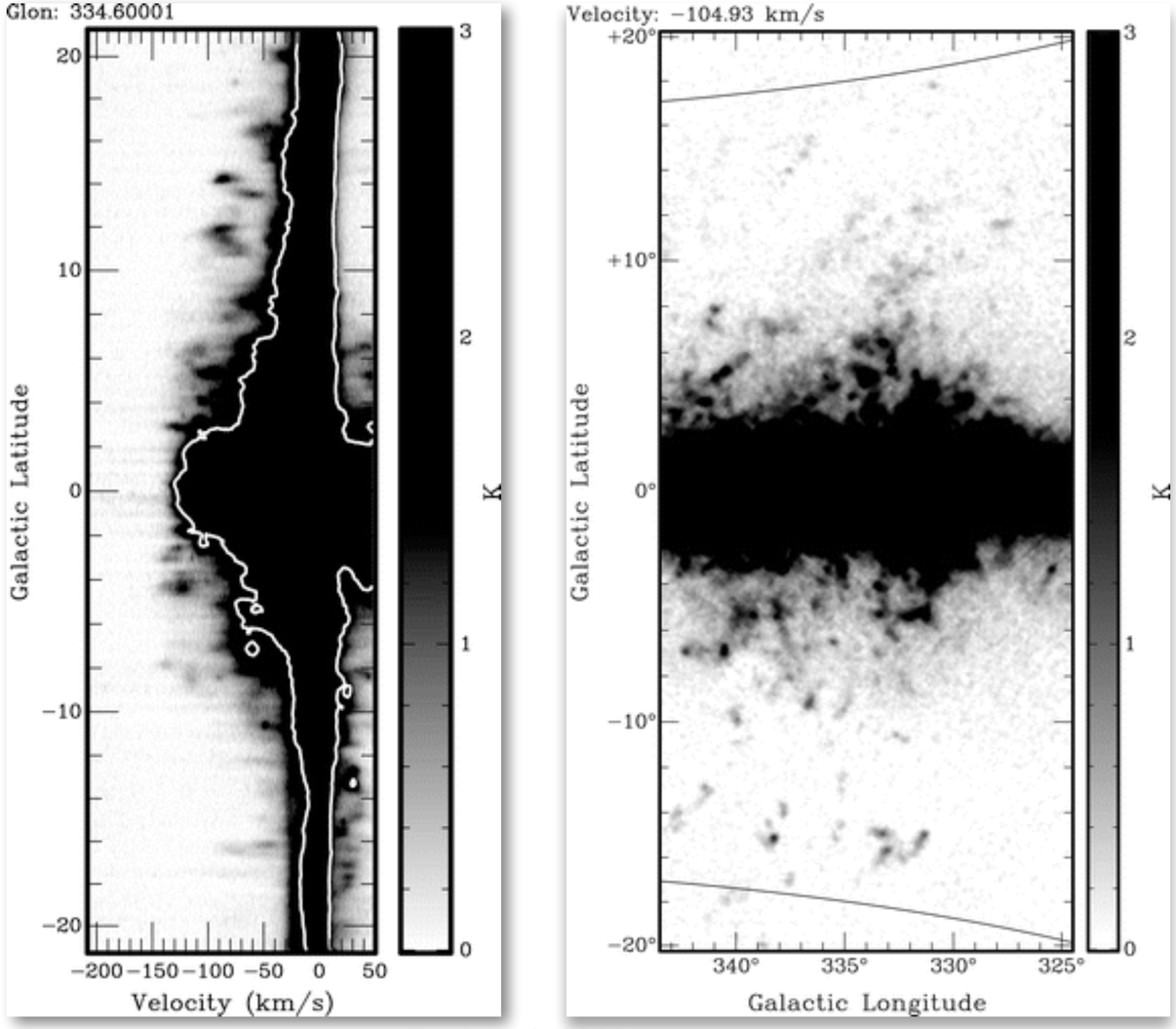
NGC 4217 (Thompson, Howk & Savage 2004)



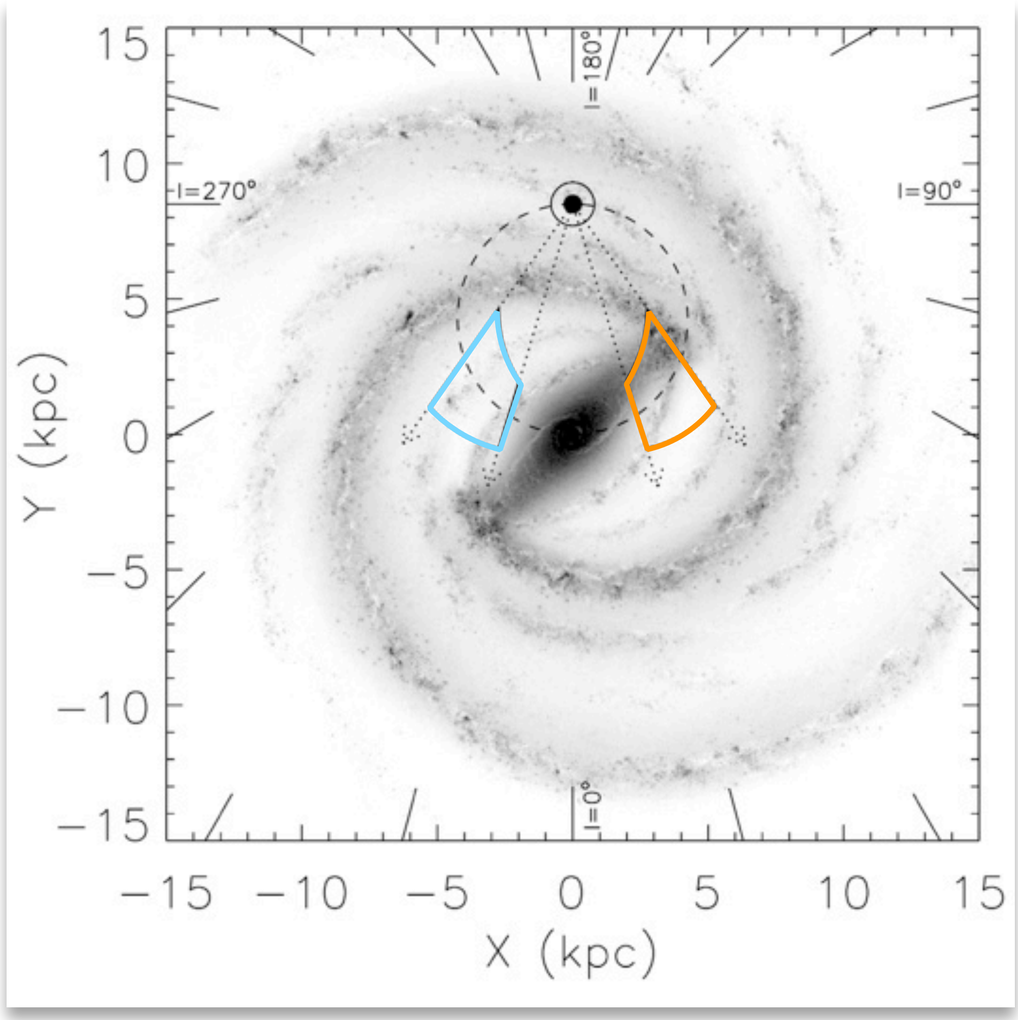
Ophiucus superbubble (Pidopryhora et al. 2007)
HI (purple), Hα (green)

Halo structure tied to the disk SFR

4x # of clouds
~2x SFR



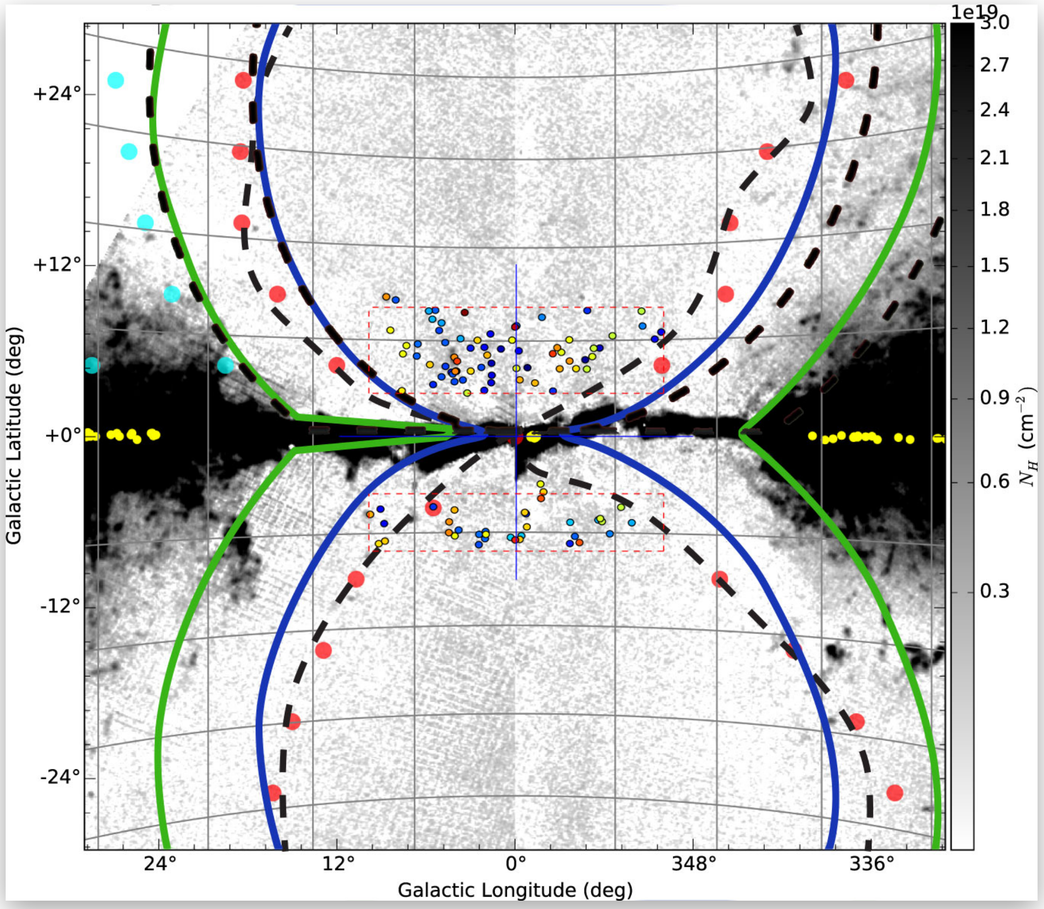
Ford et al (2008)



Ford, Lockman & McClure-Griffiths (2010)

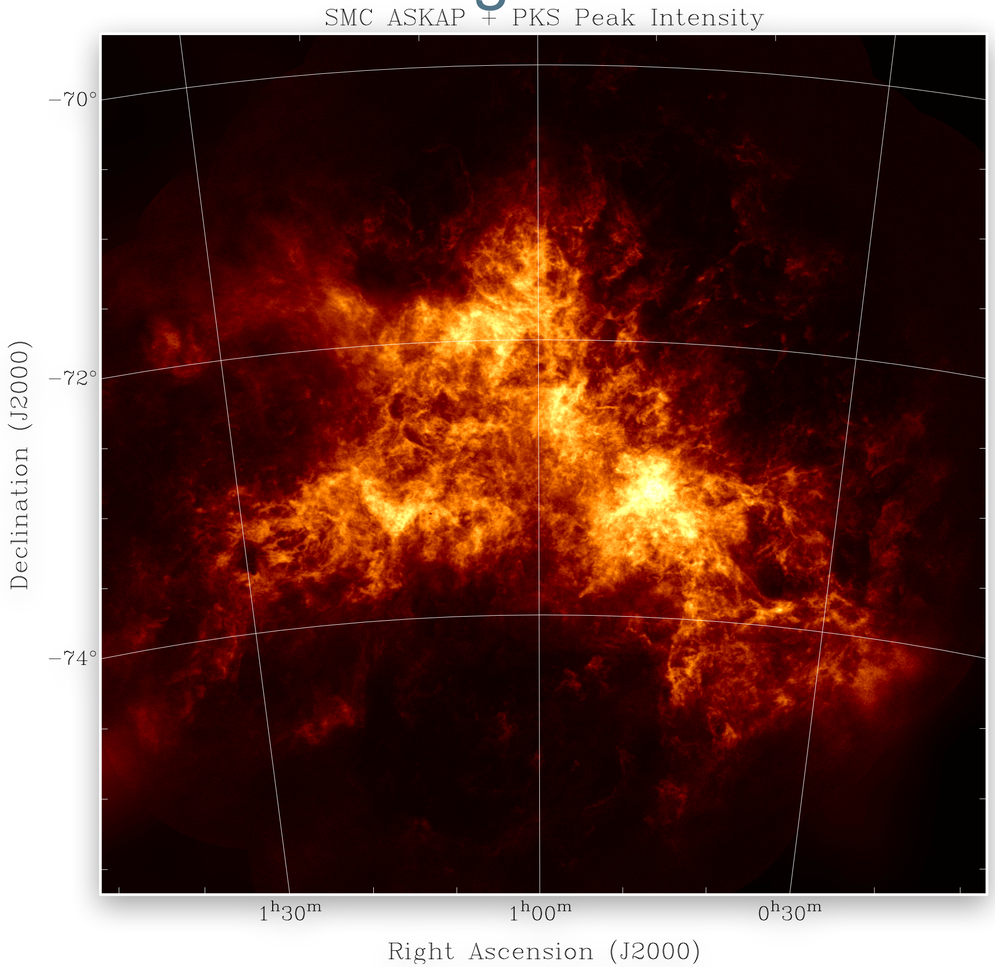
Some Illustrative Examples

Galactic Centre



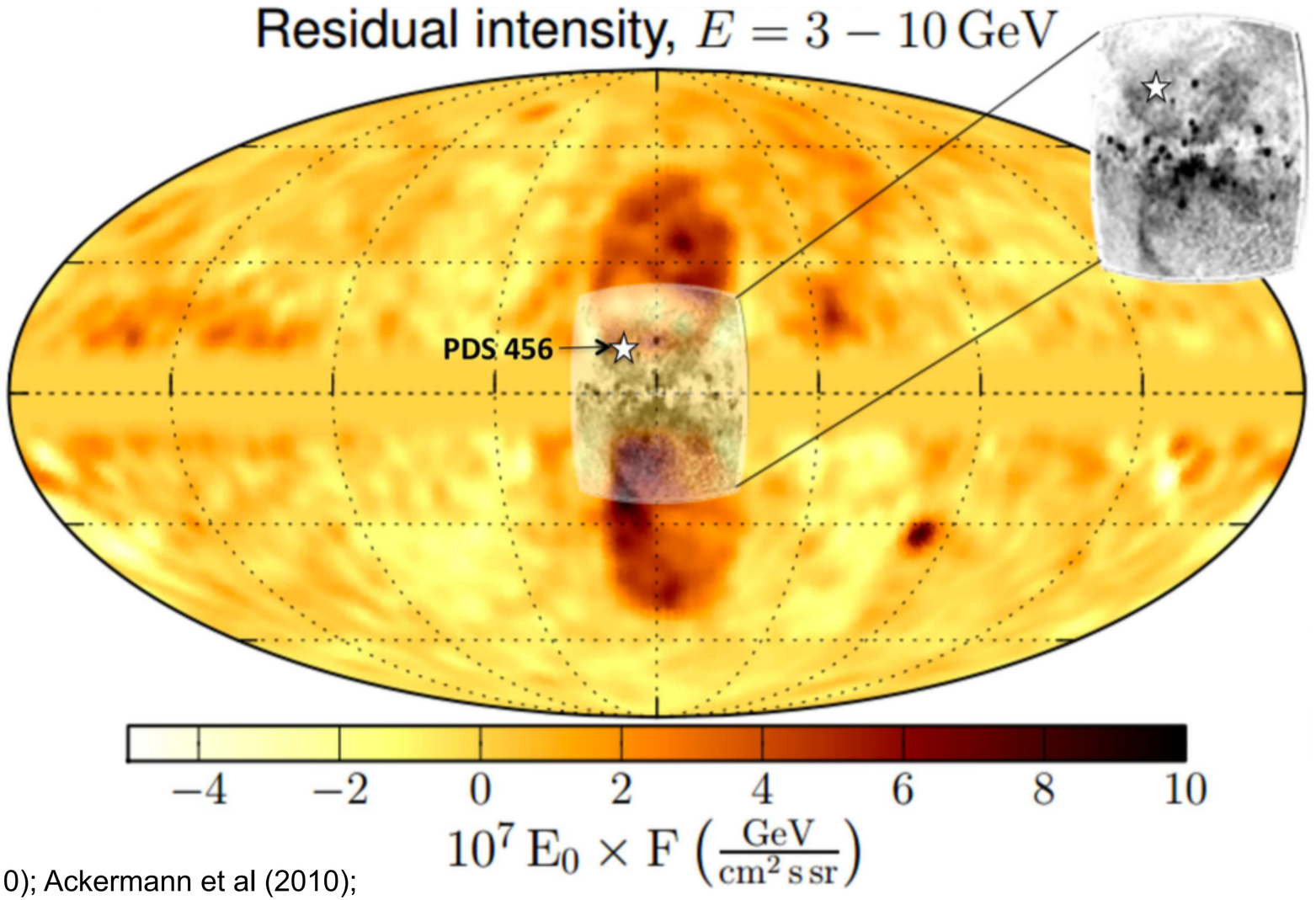
resolution of 5-30 pc over 7 kpc

Small Magellanic Cloud



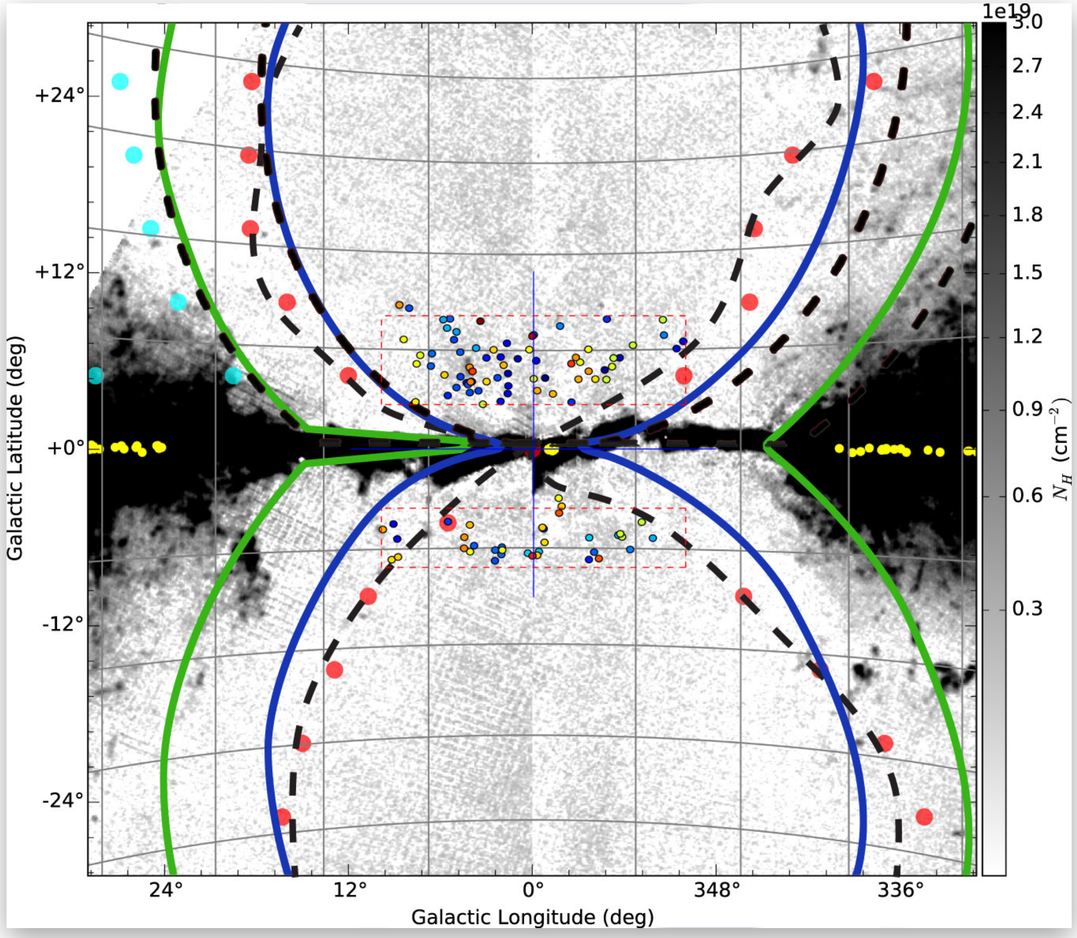
resolution of 10 pc over 6.2 kpc

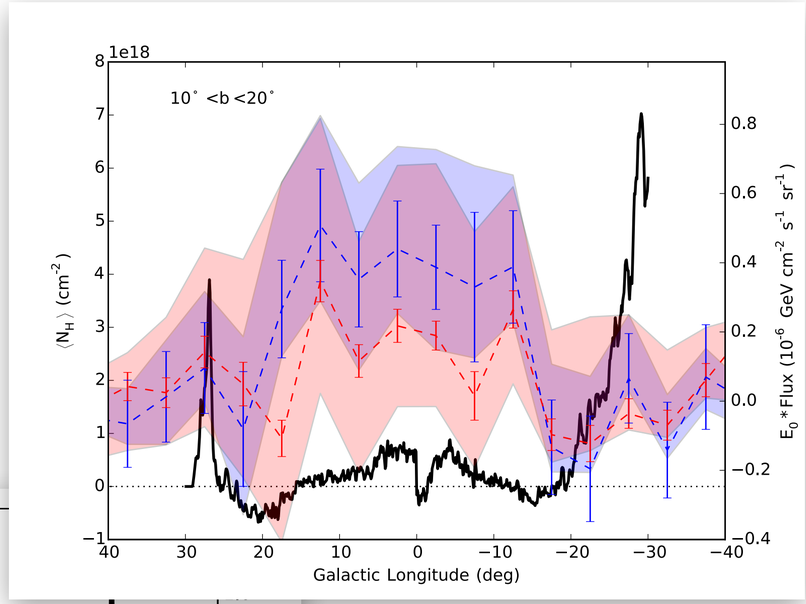
The Milky Way Wind: Fermi Bubbles

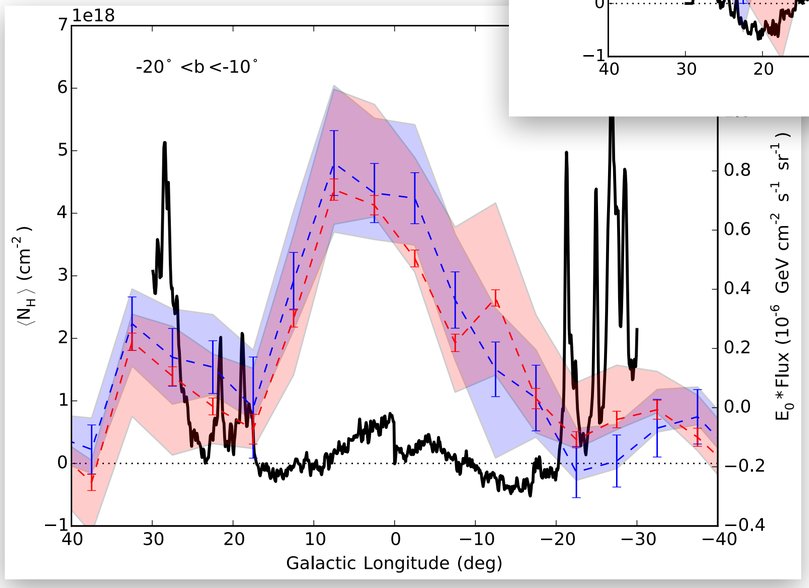


Fox et al (2014); Su et al (2010); Ackermann et al (2010); Bland-Hawthorn & Cohen (2003)

Evacuated inner Milky Way



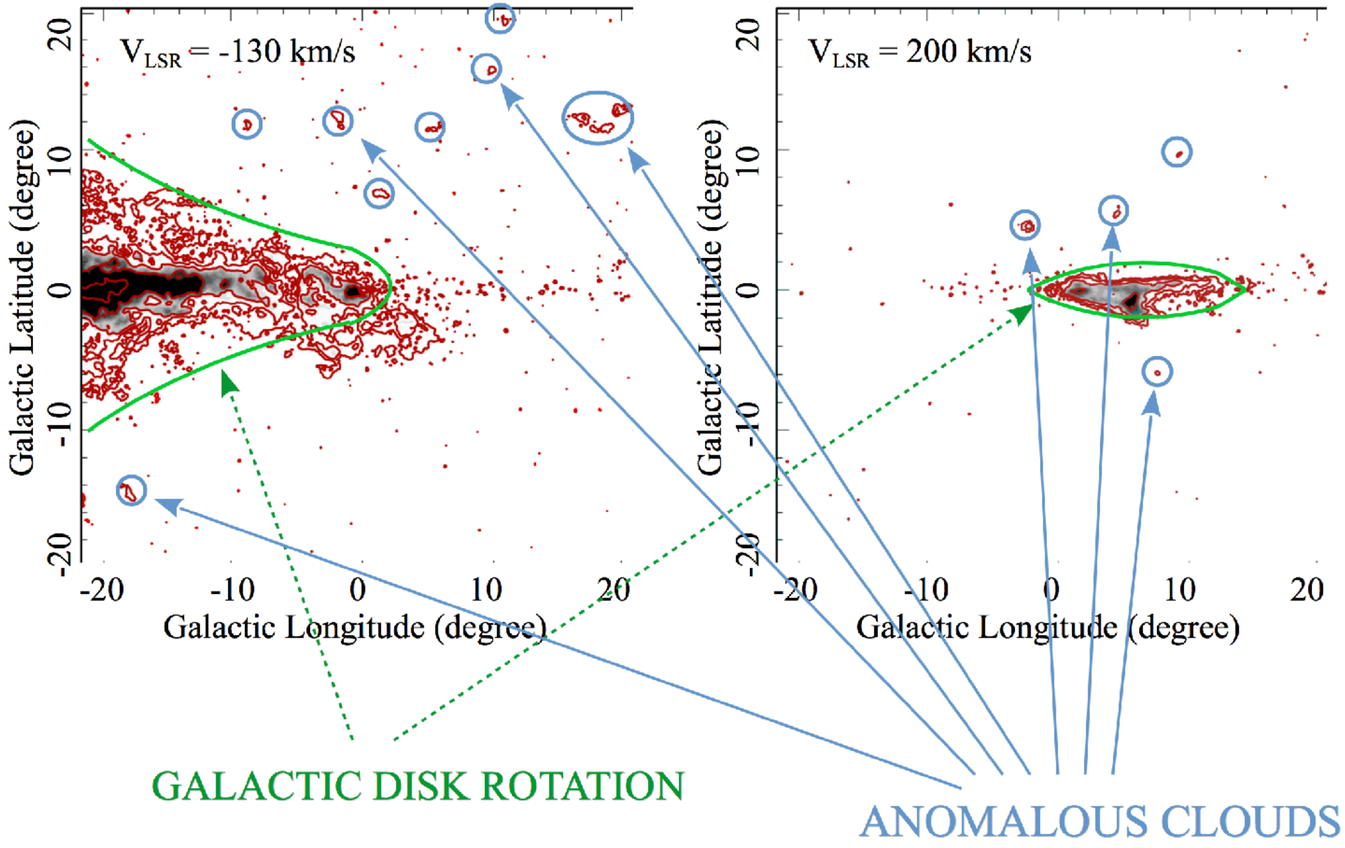




modified from Lockman & McC-G (2016)

lines: Miller & Bregman (2016)
clouds: McC-G et al (2013), Di Teodoro et al (2017)

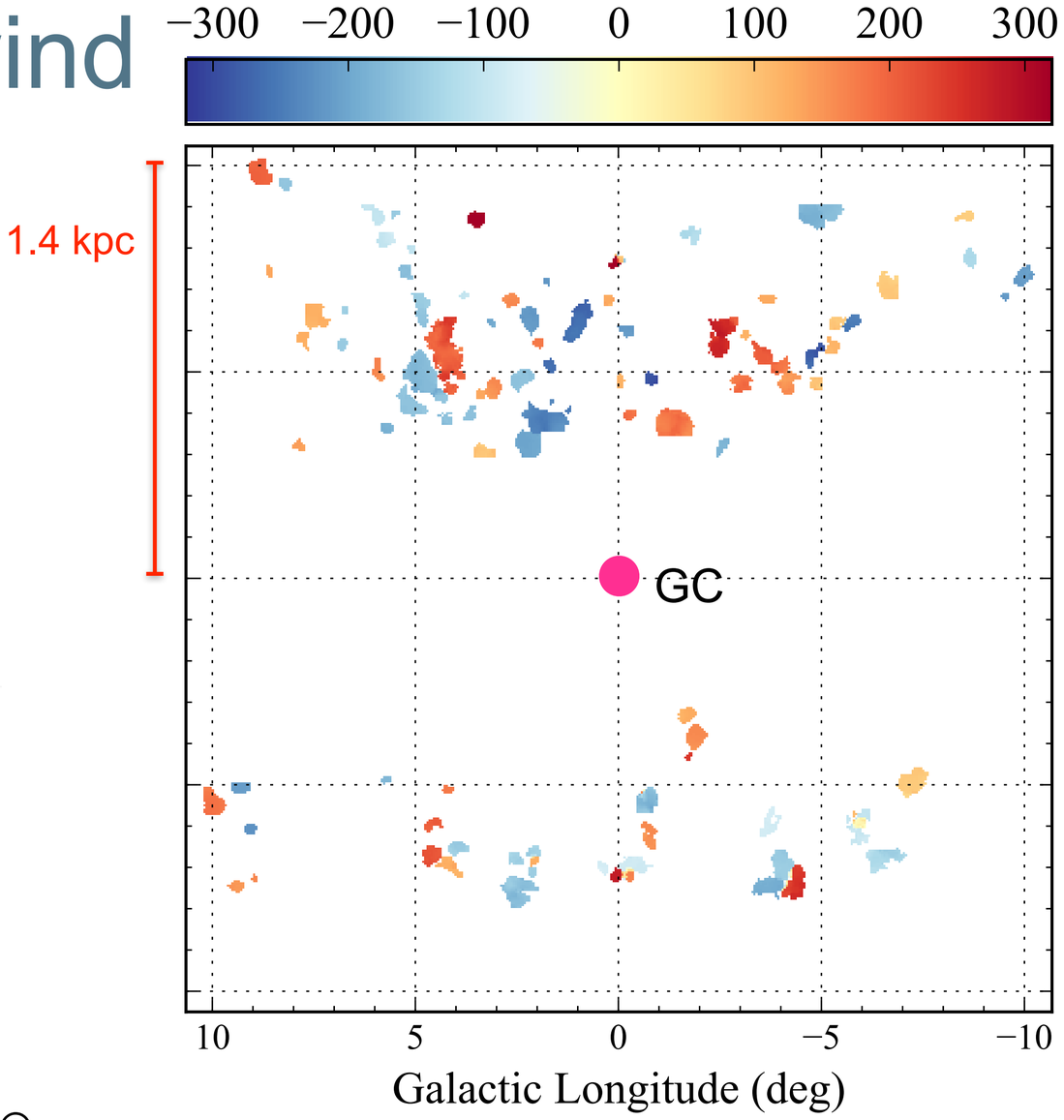
Cold clouds in a Milky Way wind



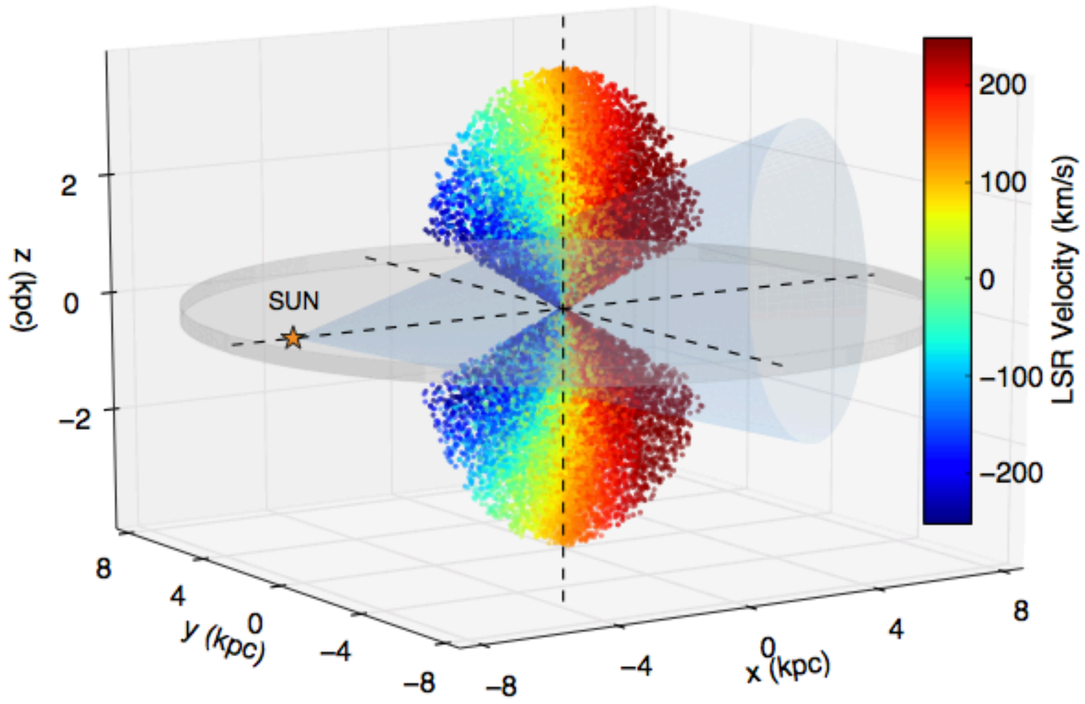
Di Teodoro et al (2017)

size: 10-50 pc

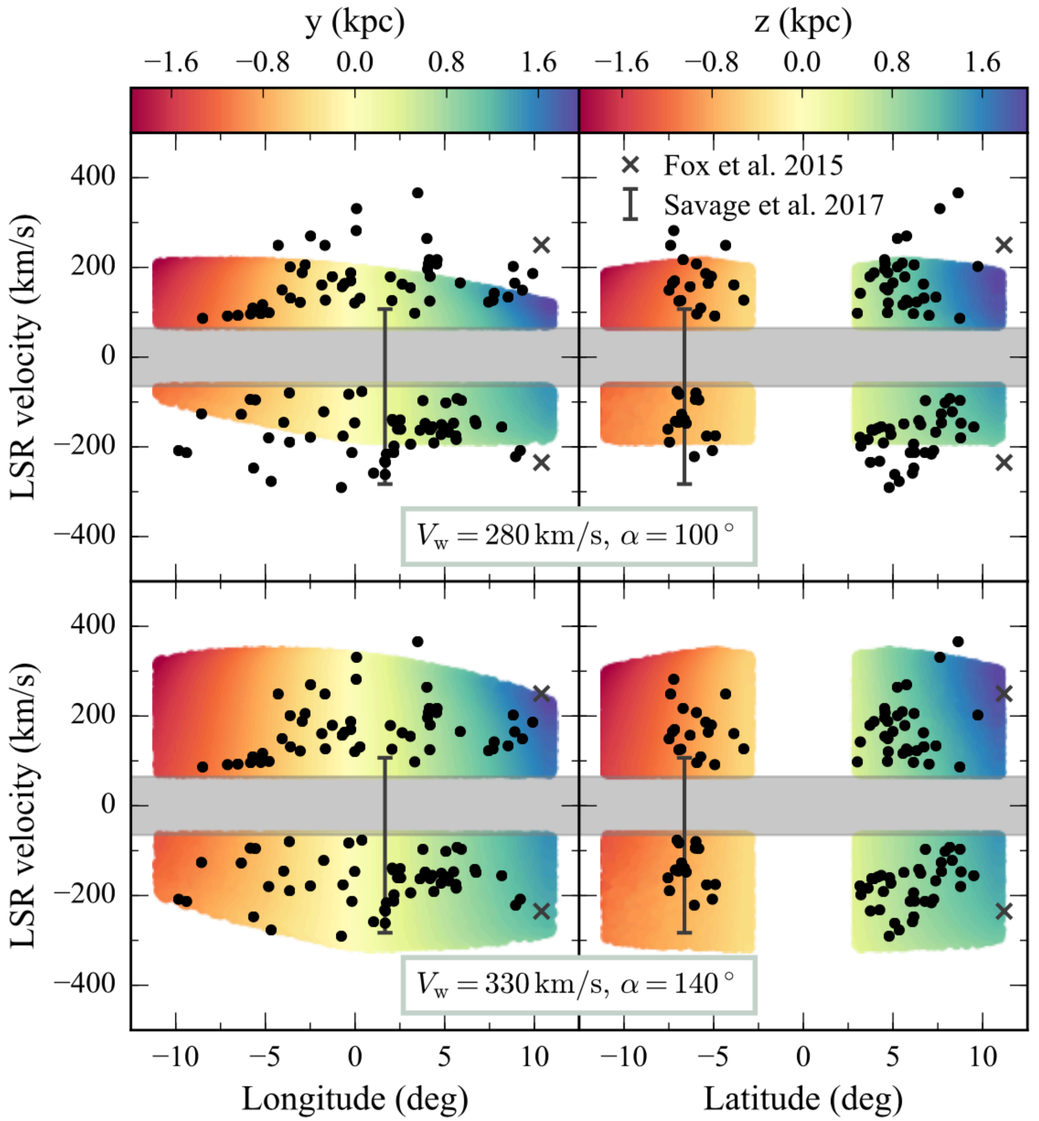
mass: 10 - 10^5 $M_\odot$



wind luminosity: $L_w \simeq 3 \times 10^{40}$ erg/s
cold gas mass flux: 0.1 $M_\odot$ yr^{-1}



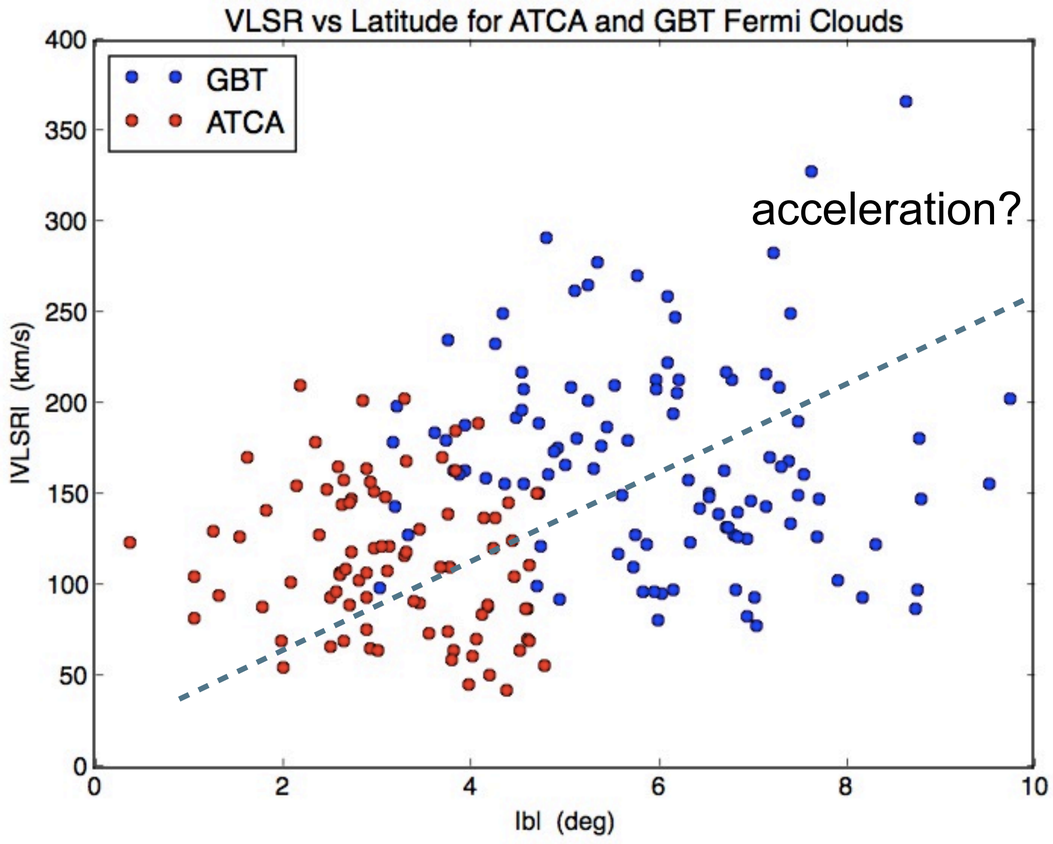
V_w = 300-400 km/s
α > 140 deg



Di Teodoro et al. (2017)

Milky Way HI outflow parameters

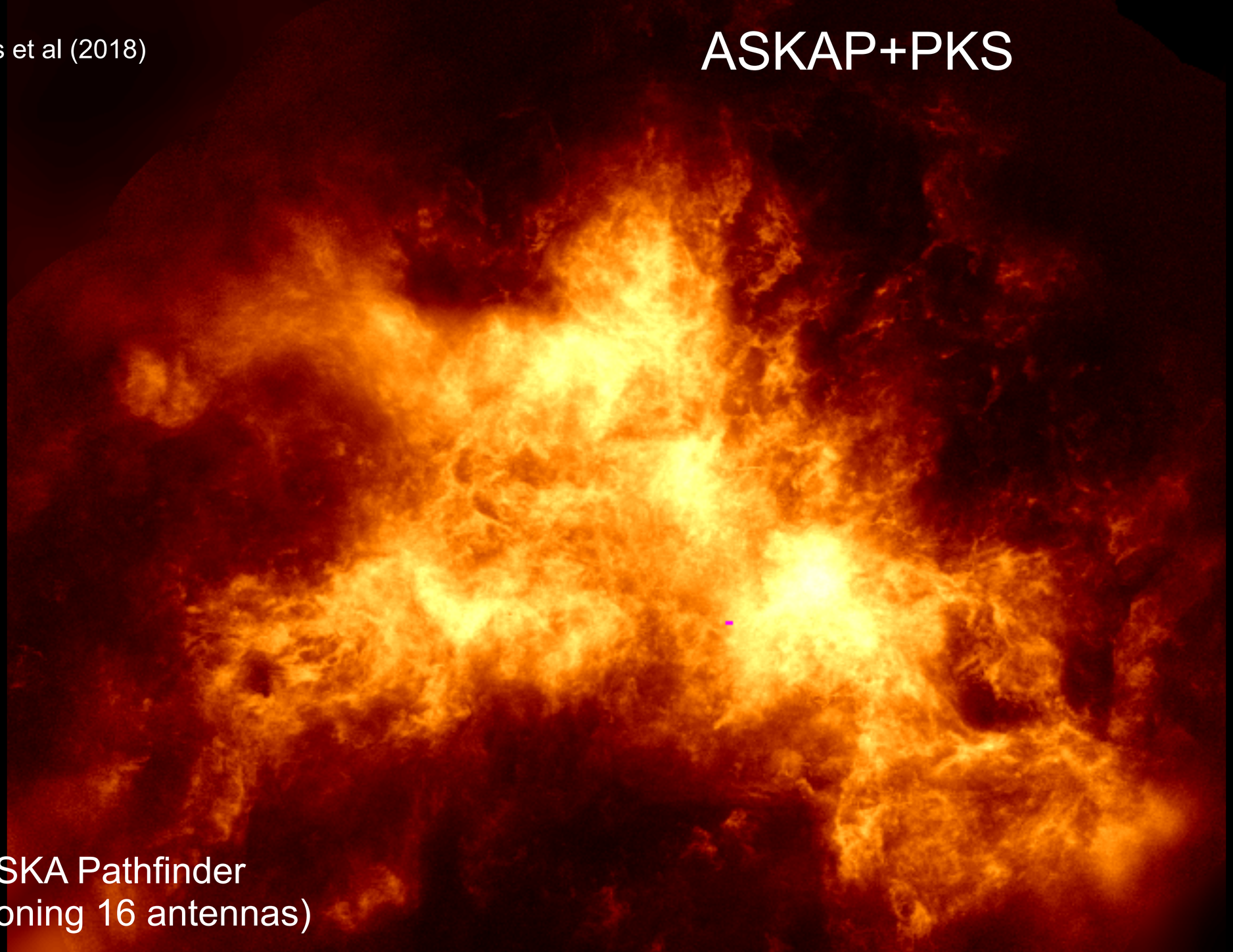
- Total HI mass in clouds: 10^6 $M_\odot$
- Kinetic power of the clouds: 5 x 10^{39} erg/s
- Mass loading rate ~0.1 $M_\odot$/yr
- Velocities consistent with UV absorption line measurements (Fox et al 2014, Bordoloi et al 2017)



Lockman, McG, & Di Teodoro 2018, in prep

McClure-Griffiths et al (2018)

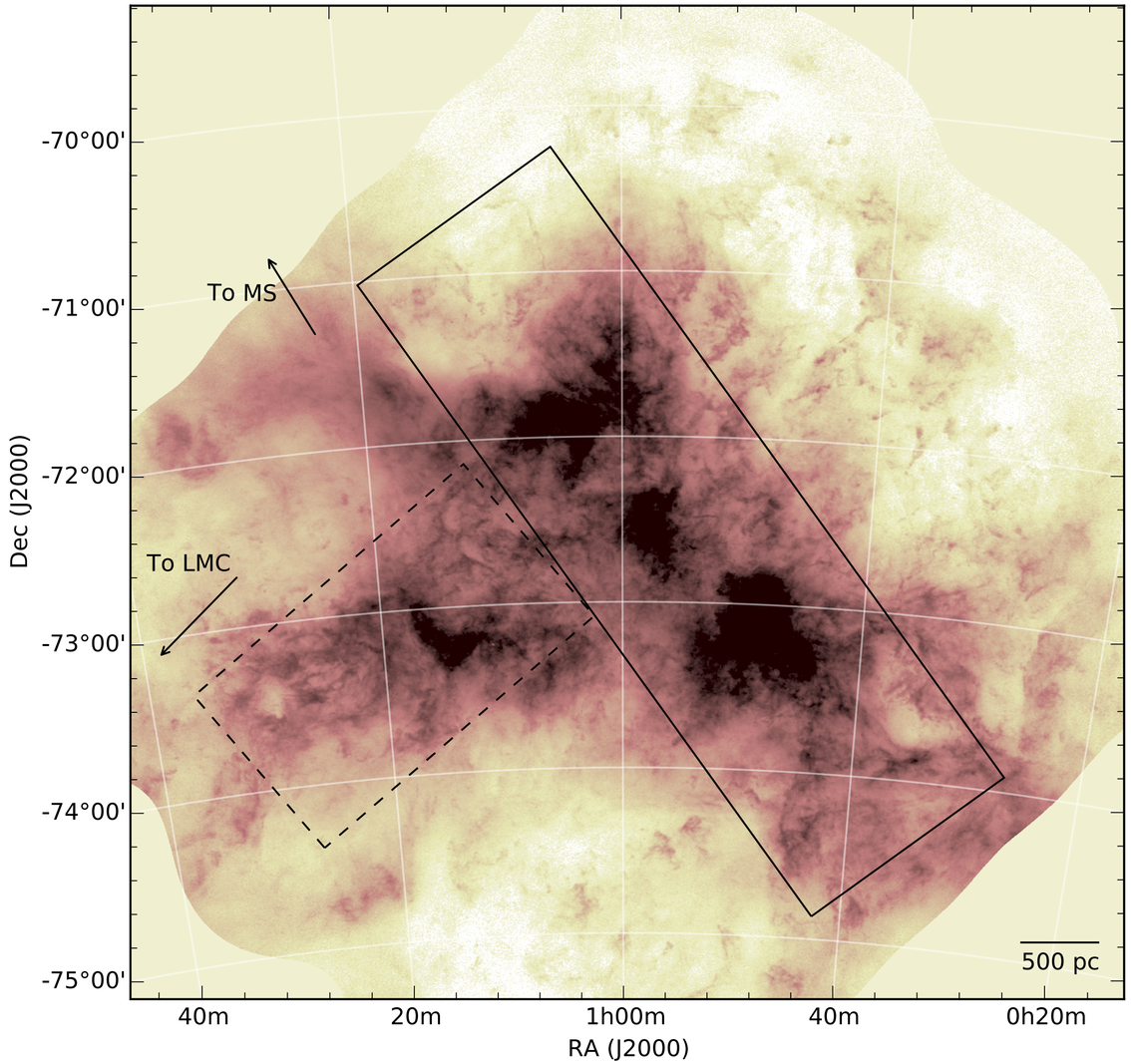
ASKAP+PKS



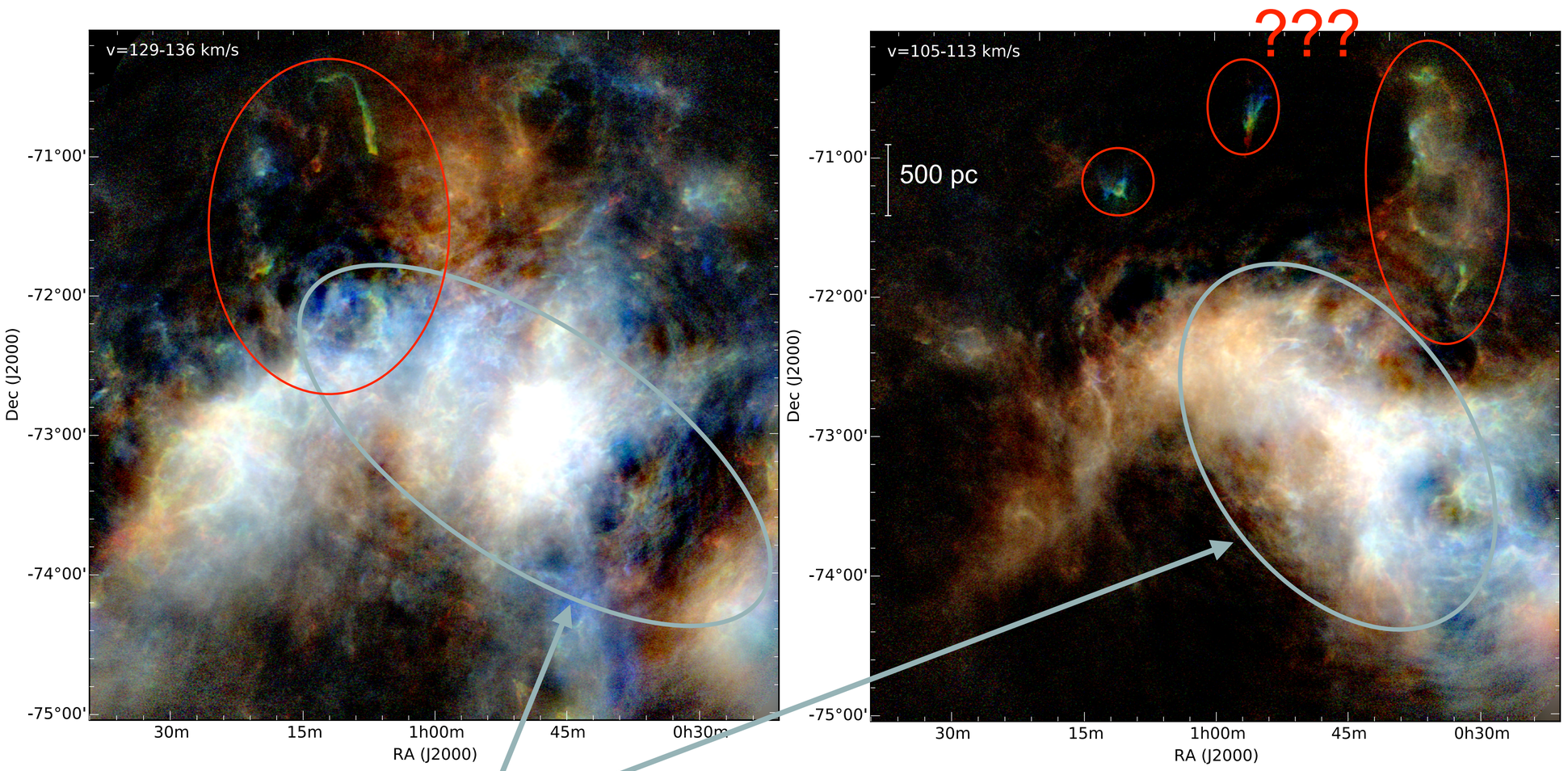
Australian SKA Pathfinder
(Commissioning 16 antennas)

The Small Magellanic Cloud

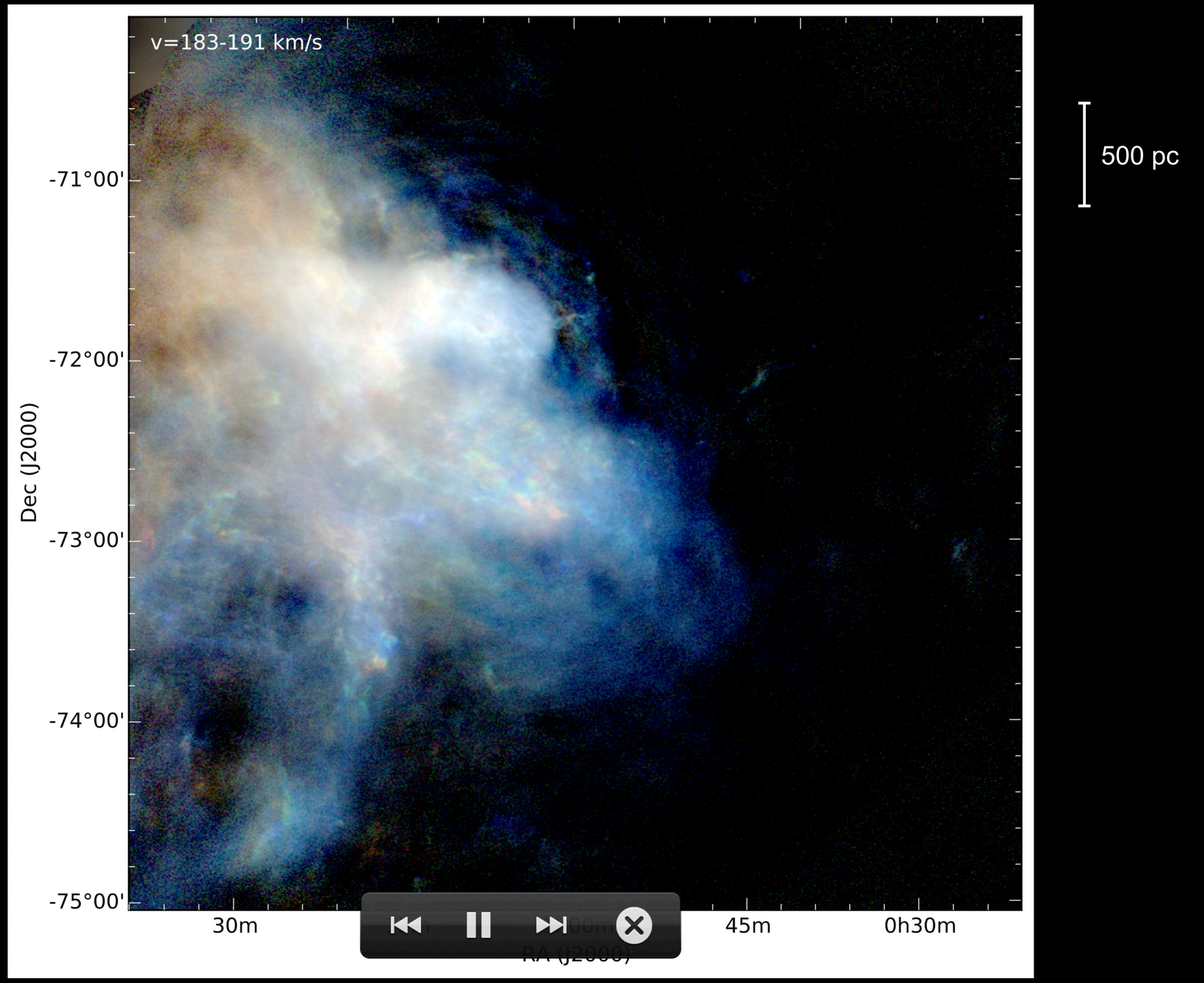
- Distance 60 kpc
- Interacting with MW and LMC (20 kpc away)
- Mass:
  - HI: ~ 4×10^8 $M_\odot$ (Brüns et al 2000)
  - total: ~ 2.4×10^9 $M_\odot$ (Stanimirović et al 2004)
- Complex structure:
  - extended along line-of-sight, “bar” and “wing”
  - inclination ~40+/-20 deg (Stanimirović et al 2004)



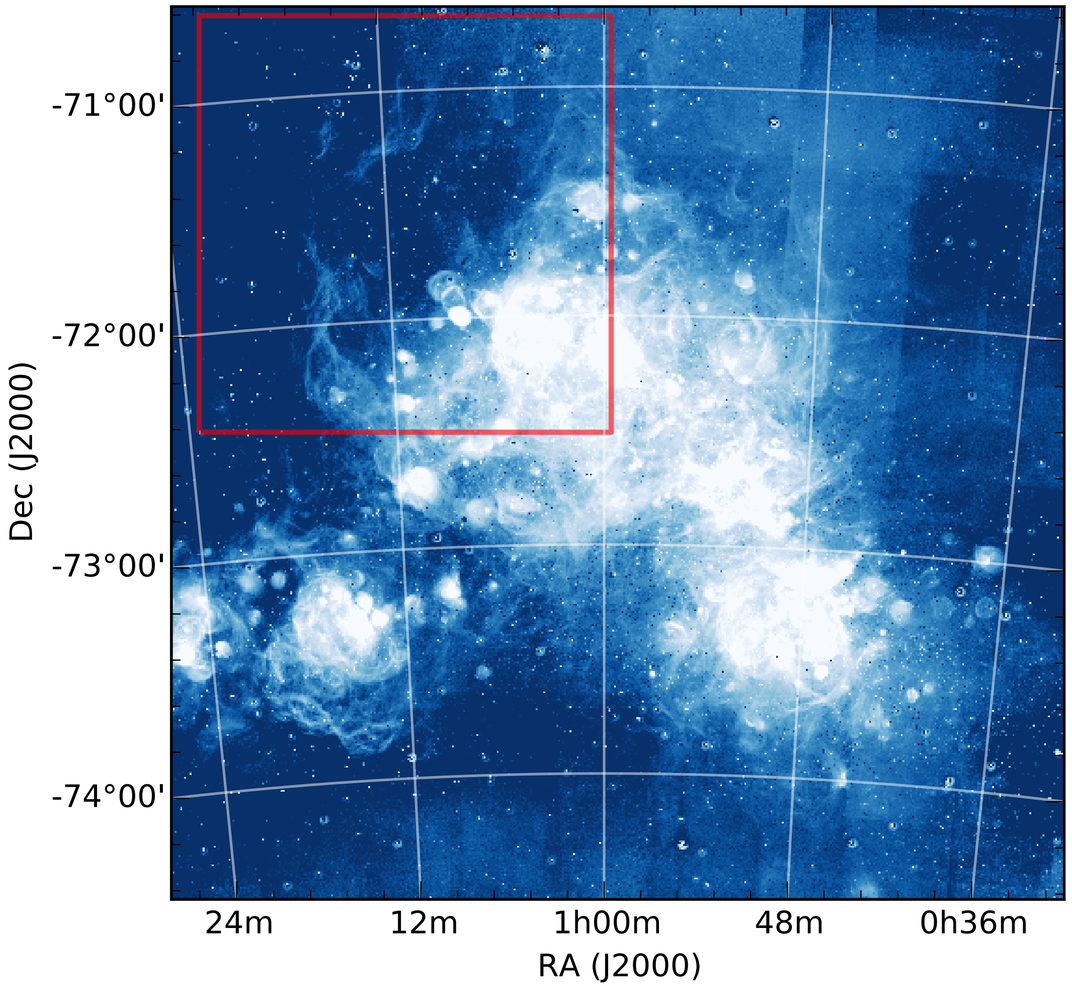
Anomalous external gas

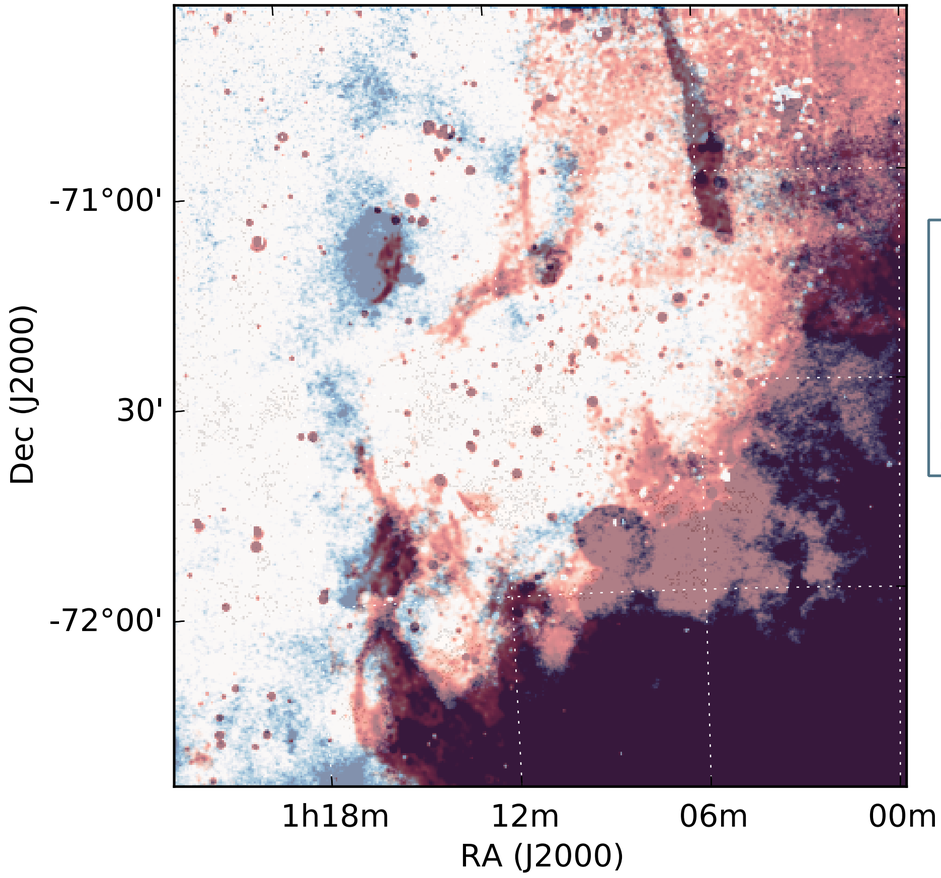


Total mass of anomalous gas: $1.3 \times 10^7 M_\odot$


v=183-191 km/s
-71°00'
-72°00'
-73°00'
-74°00'
-75°00'
Dec (J2000)
30m
45m
0h30m
RA (J2000)
500 pc

HI + Hα indicating outflow





SF rate 35 - 60 Myr ago:
~0.1 $M_\odot$/yr

expansion velocities 35 - 65 km/s

McC-G et al (2018)

Fountain or Escape?

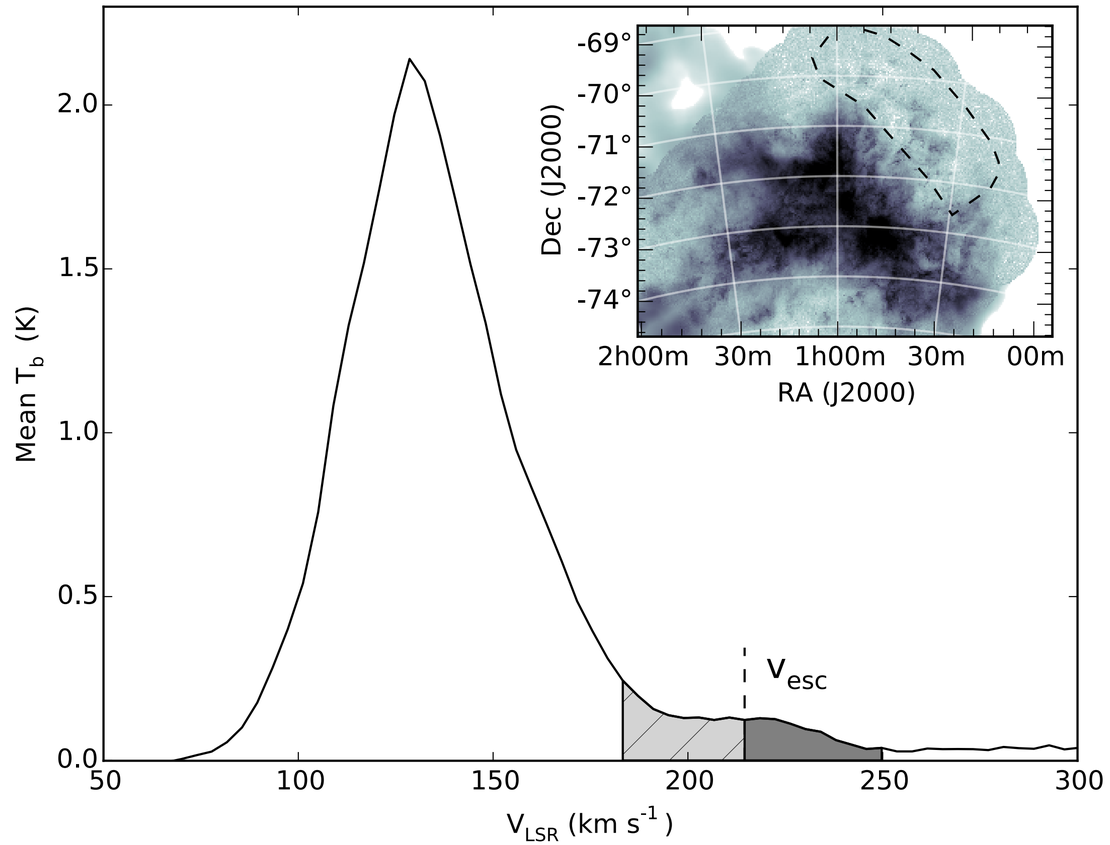
HI mass loss rate:
0.2 - 1 $M_\odot$/yr
2 - 10 x SFR

High velocity line-wing

- Is any of this gas beyond the escape velocity?

$$v_{esc} \sim 65 - 85 \text{ km s}^{-1}$$

- Mass beyond v_{esc}:
  - 2.5 - 5 x 10^6 $M_\odot$



Some gas should escape

Conclusions

- Shells, bubbles and outflows have a dramatic impact on local ISM
  - gas cooling, molecular gas formation
  - reshape spiral arms, determine structure of galaxy
  - Lift gas out of the disk to ~1 - 2 kpc
- Some key examples of parsec scale resolution over kiloparsecs:
  - Galactic Centre:
    - Cleared out Galactic centre, anti-correlated with Fermi Bubbles (Lockman & McG 2016)
    - Outflowing cold pc-scale clouds, total mass 10^6 $M_\odot$ (Di Teodoro et al 2017)
    - Cold wind velocity ~330 km/s
  - SMC:
    - HI outflow of 10^7 $M_\odot$ (McClure-Griffiths et al 2018)
    - Helping to form the Magellanic stream (e.g. Bustard et al 2018)?