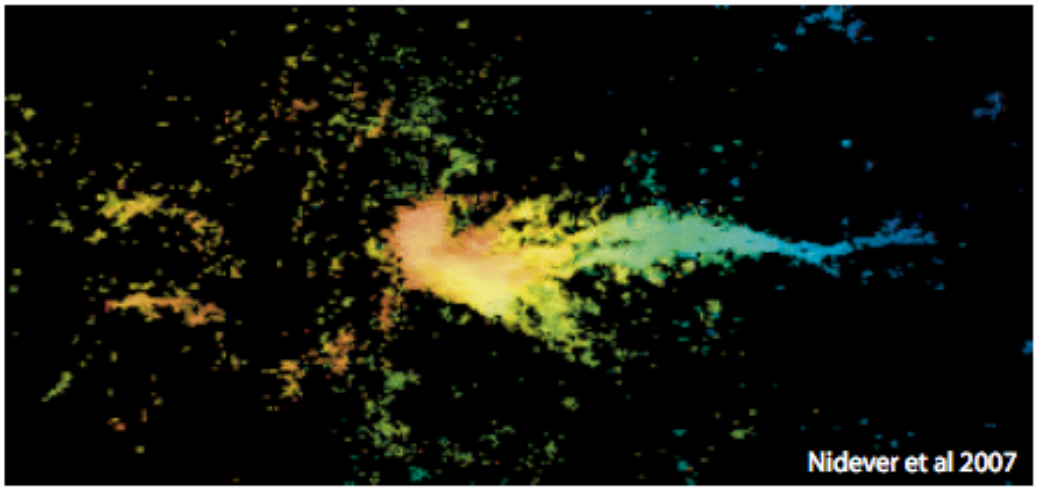
Ionized Gas in the Magellanic Stream



Greg Madsen

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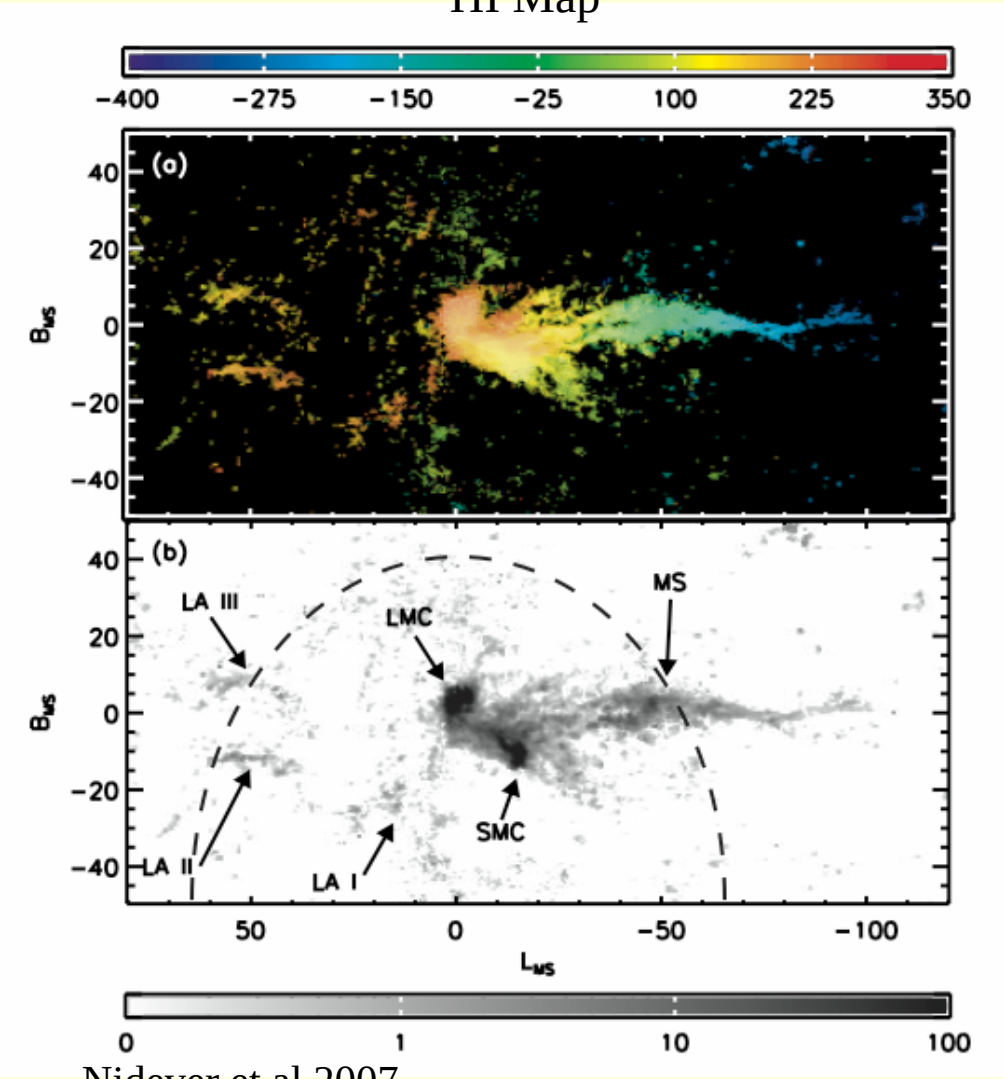
L.M. Haffner, S. Stanimirovic, R.J. Reynolds (Wisc.)

The Magellanic Stream

HI Map



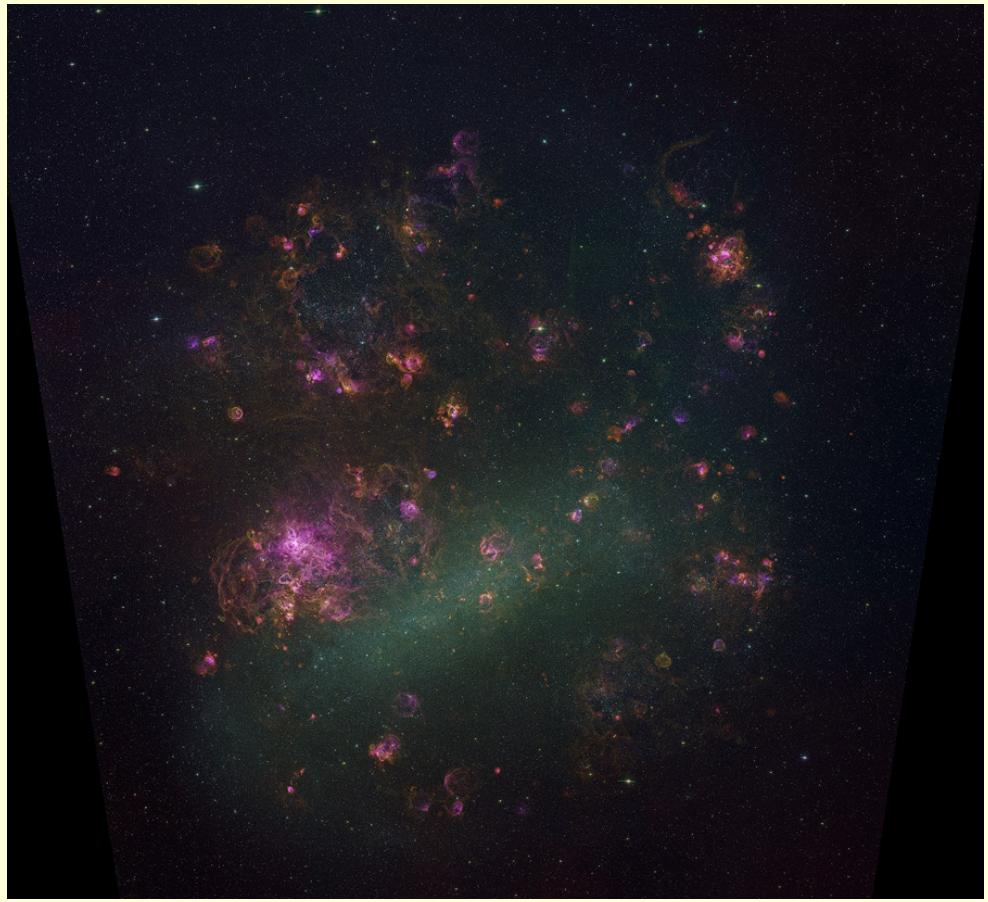
Nidever et al 2007

- HI filament extends 100º ‘behind’ the LMC/SMC, no stars
- ~ 500 km/s velocity gradient
- Provides detailed view of present-day galaxy formation/evolution
- Probe of low-density Galactic halo
- Origin remains debated:
  - tidal? (Gardinier & Noguchi 96, Connors et al, 06, Bekki)
  - ram-pressure? (Weiner & Williams 96, Mastropietro)
  - LMC blowout? (Nidever et al 07)
- How large is it?
- What is the total gas content?

Ionized Gas

- Traced by diagnostic emission lines (e.g., Hα, [NII]λ6584, [SII]λ6716, [OI]λ6300, [OIII]λ5007)
- Probe of temperature, density, excitation mechanism, metallicity, ionization fraction
- Line widths of different ions used to quantify non-thermal motions
- Hα emission toward ~ 10 sightlines in the Stream (Weiner & Williams 1996, Putman et al 2003)
    - brighter than other HVCs, not photoionized?
    - shocks?
- New WHAM data on northern tip, ~ 20 sightlines

LMC in Hα, [SII], [OIII]



MCELS, C. Smith et al 2006 / NOAO

Wisconsin H-Alpha Mapper

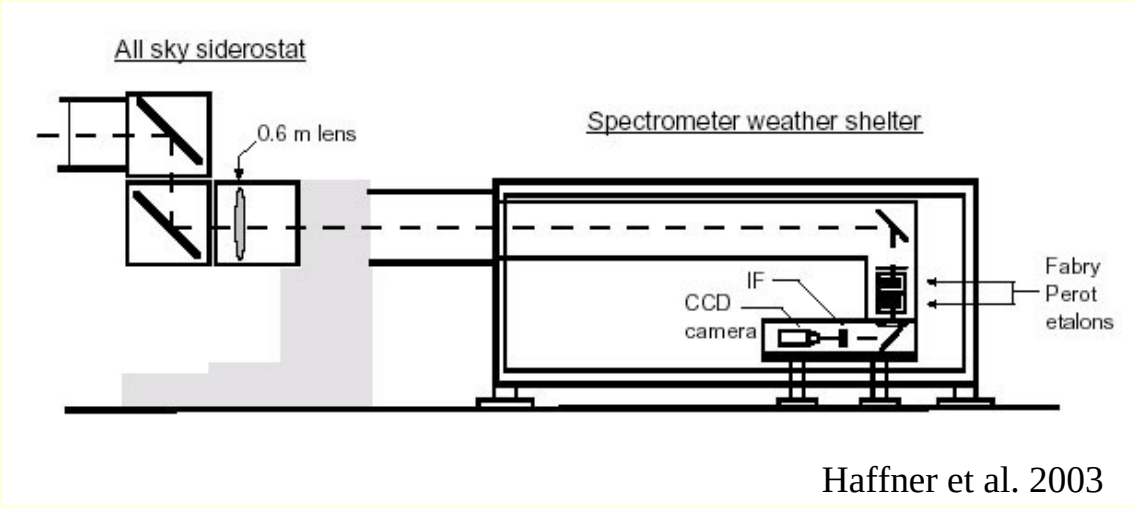
•15 cm, dual etalon Fabry-Perot on a dedicated 60 cm telescope located at Kitt Peak and remotely operated
• designed to study ionized gas in Galactic interstellar medium

• 1.º0 diameter beam on sky
• 12 km s^{-1} velocity resolution (R ~ 25,000)
• 200 km s^{-1} spectral window can be centered between 4800Å and 7300Å

• High sensitivity (EM~0.1 in 30 s)
• Provides high throughput and high spectral resolution

• Moving to southern hemisphere (late 2008)

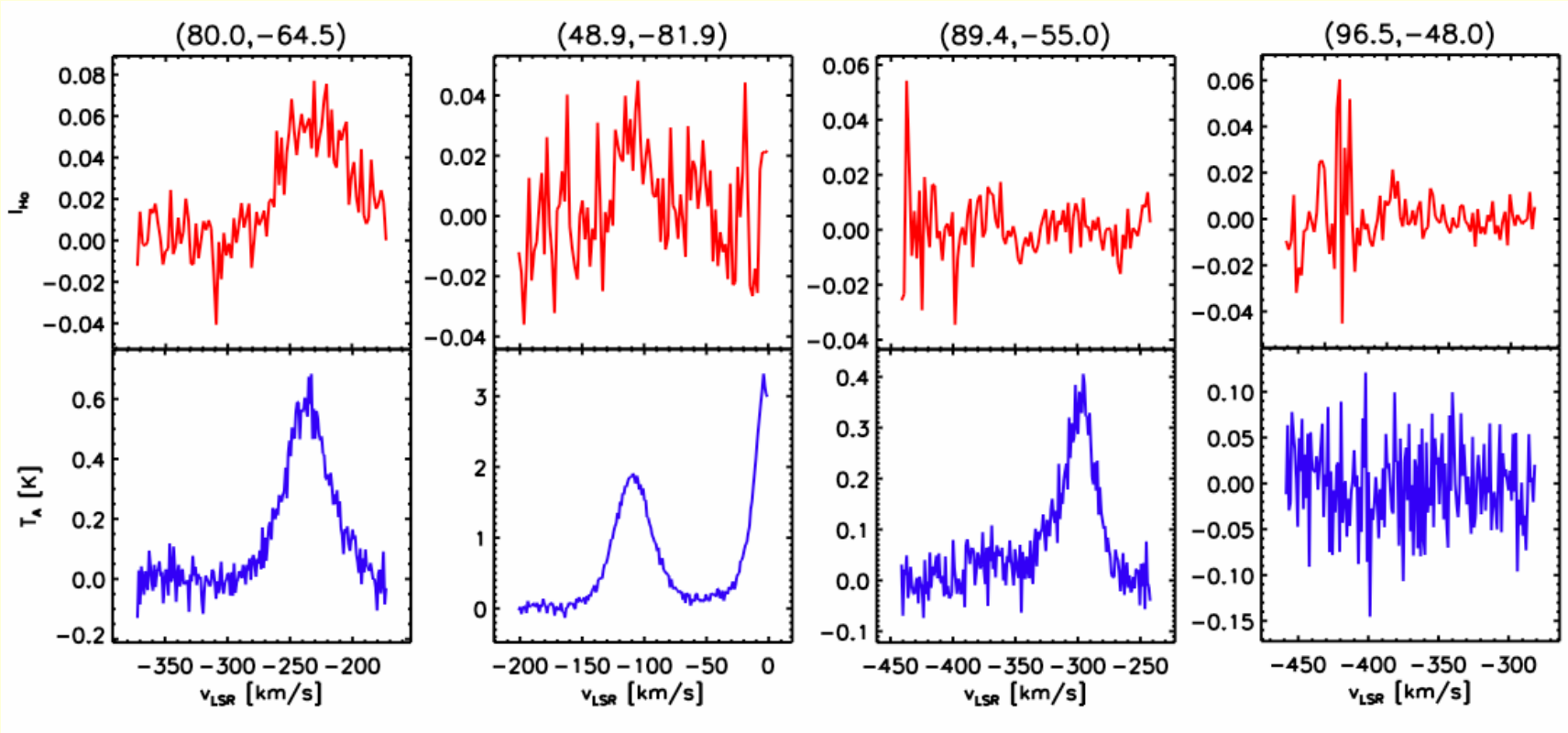
http://www.astro.wisc.edu/wham/



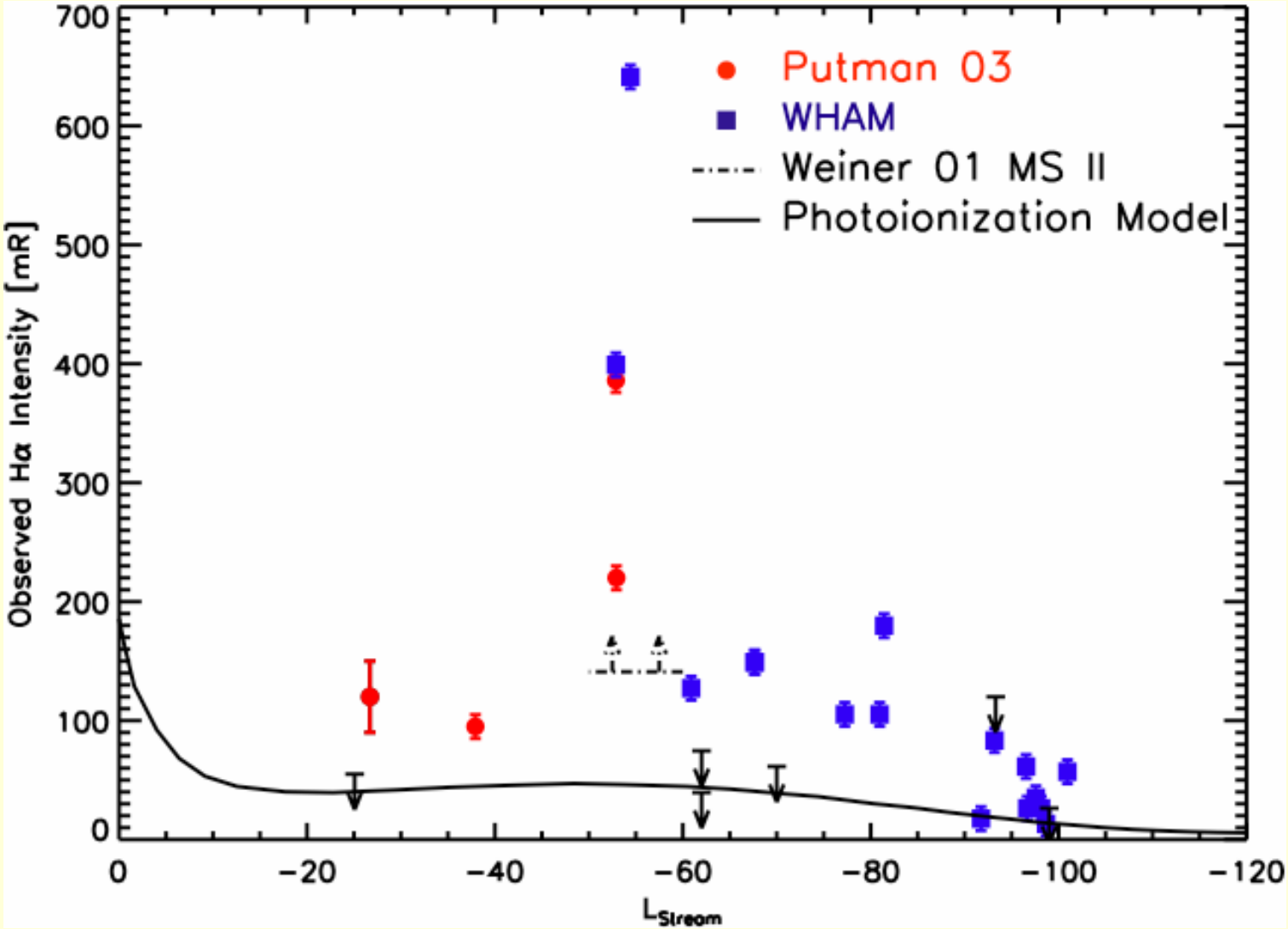
Haffner et al. 2003

Hα Observations

- 22 sightlines in/around northern tip using 'ON-OFF' technique
- Surface brightness $I_{H\alpha}$ = 0.03 - 0.6 Rayleigh (EM ~ 0.01 - 0.2 cm^{-6} pc)
- Strong correlation in Hα–HI velocity centroids, line widths ~ 40 km/s
- No correlation between $I_{H\alpha}$ and N_{HI}

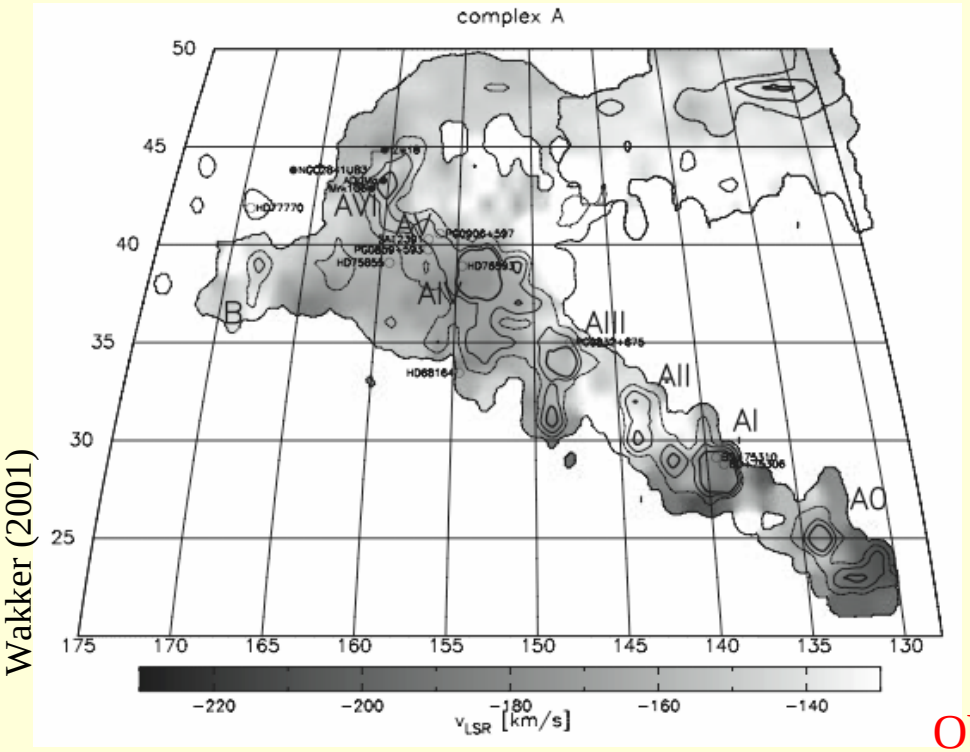


Hα toward the Magellanic Stream



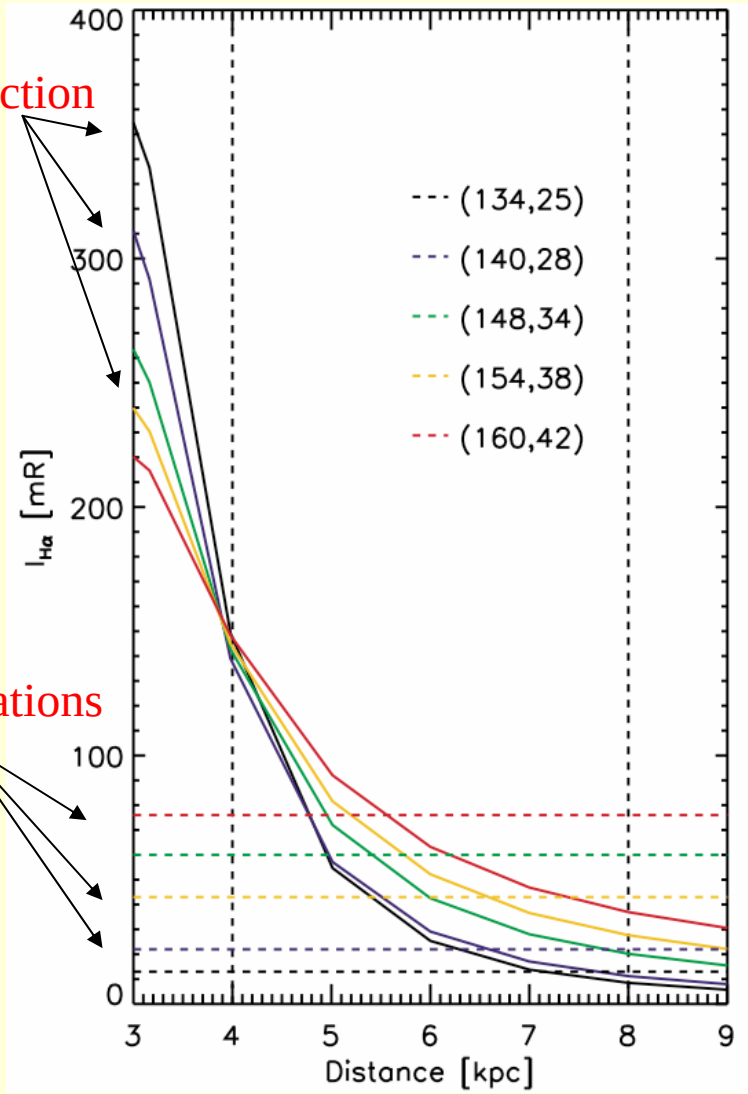
HVC Complex A: Testing Photoionization Model

HI Velocity Map



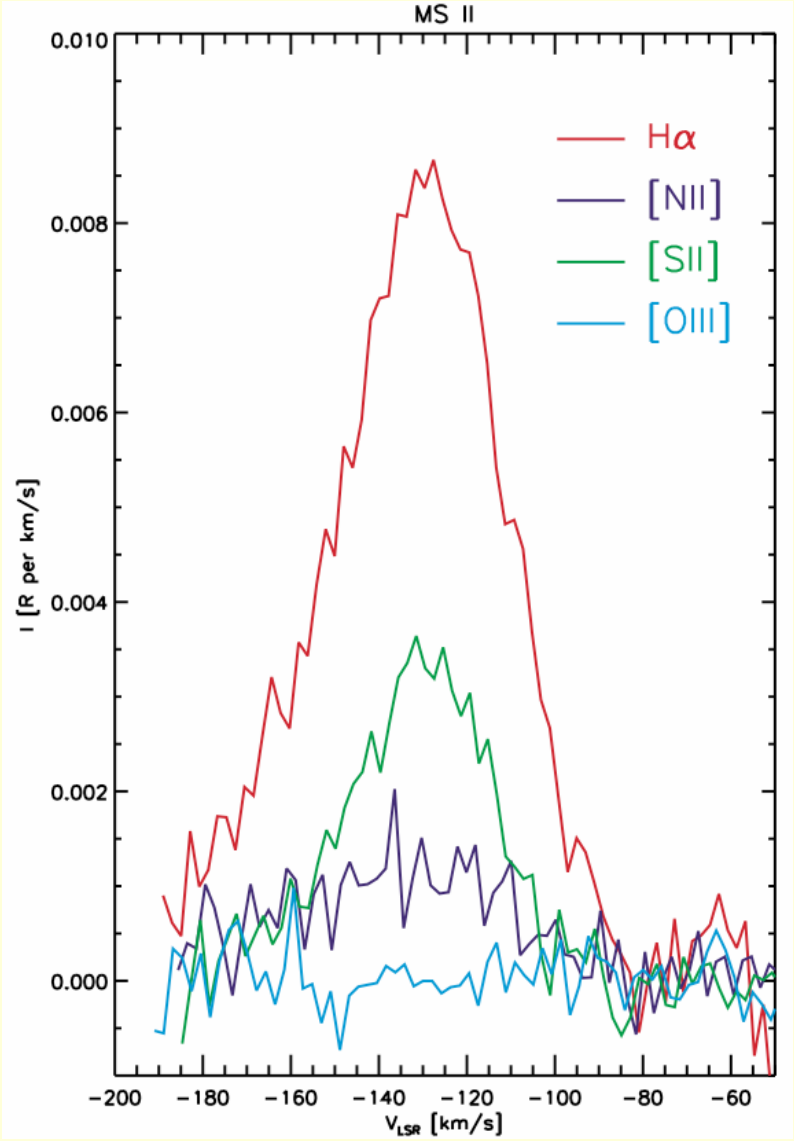
Prediction

Observations



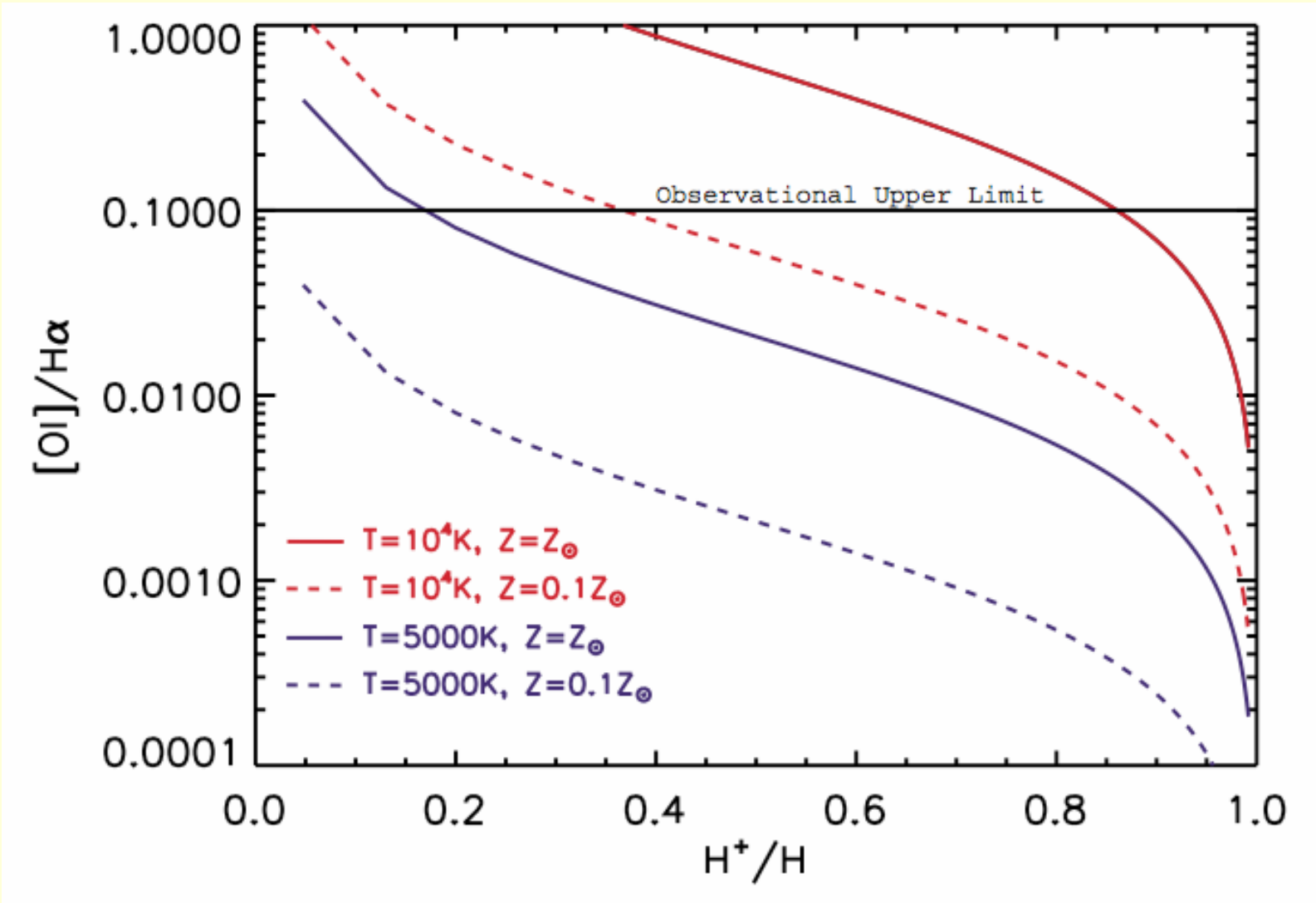
- 4 < D < 8 kpc (Wakker 2001)
- Several HI bright ‘cores’
- Hα emission is faint, increases with increasing latitude -> consistent with model
- Need to consider cloud geometry!

[NII], [SII], and [OIII] in the Stream

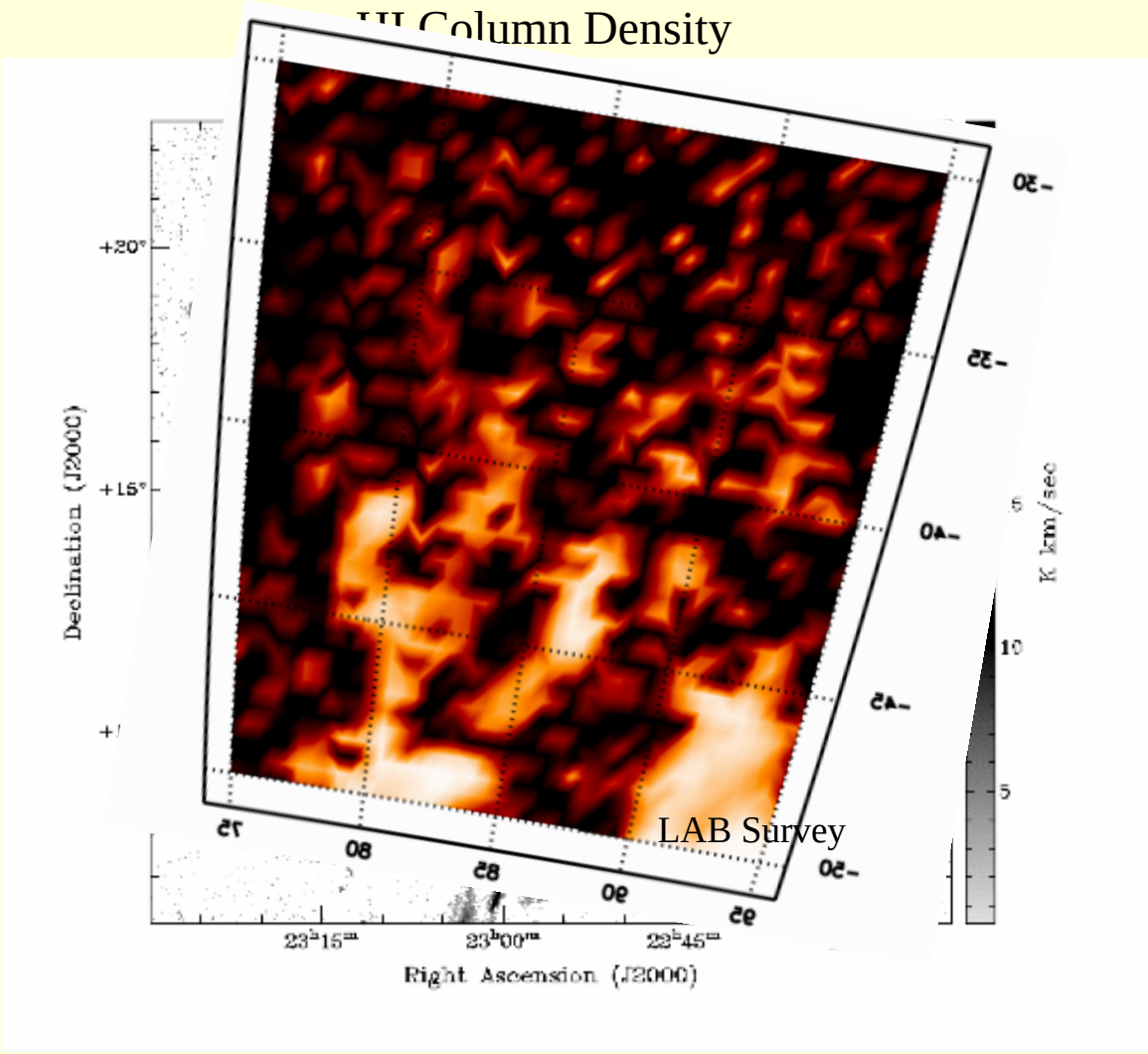


- 'MS II' brightest sightline in Hα
  - Weiner: 1.3 R (7' FOV)
  - WHAM: 0.65 R (60' FOV)
- [NII]/Hα traces temperature
- [SII]/[NII] traces ionization state
- [NII]/Hα = 0.20, [SII]/Hα = 0.34
- If $Z = Z_{Sun}$:
  - T = 6,000 K, $S^+/S = 1$
- If $Z = 0.1\ Z_{Sun}$
  - T = 30,000 K, $S^+/S = 0.2$
- [OIII]/Hα < 0.06

[OI] toward MS II: Ionization Fraction



High Resolution HI with Arecibo

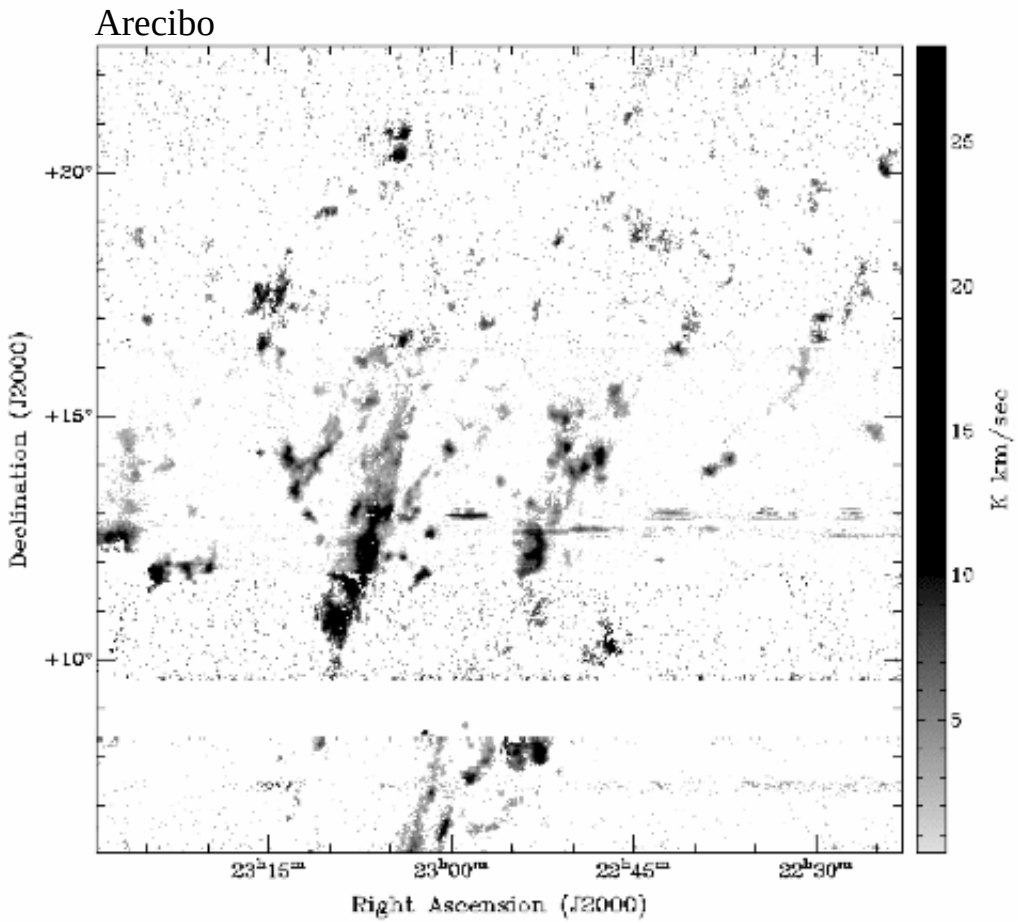


Stanimirovic et al 2007, in prep

- GALFA: Galactic Science with ALFA
- Northern tip observed with 3.5’ resolution
- Very compact clouds (6’) at -360 km/s
- Continuous velocity gradient
- HI spectra show multi-phase structure
  - narrow core, broad wings (7 km/s, 25 km/s)
- Some compact clouds have cold core/warm envelope structure

High Resolution HI with Arecibo

HI Column Density



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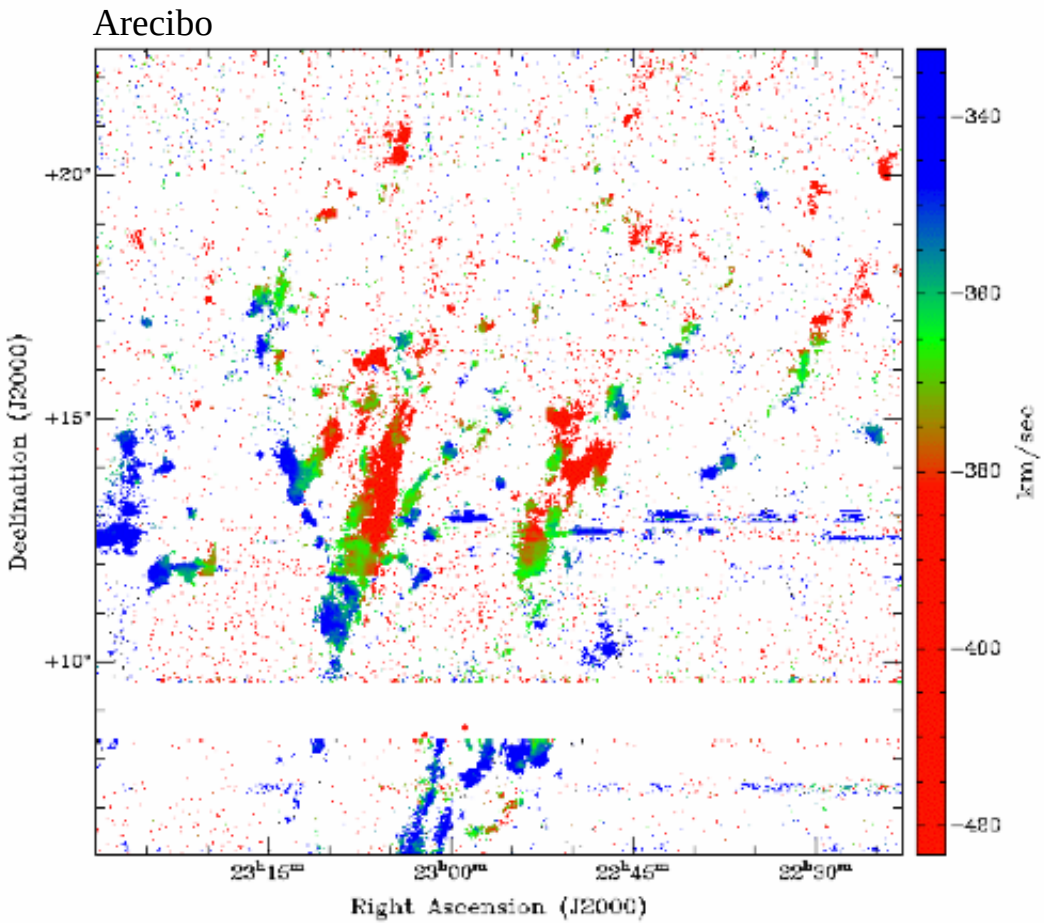
HI Velocity Field



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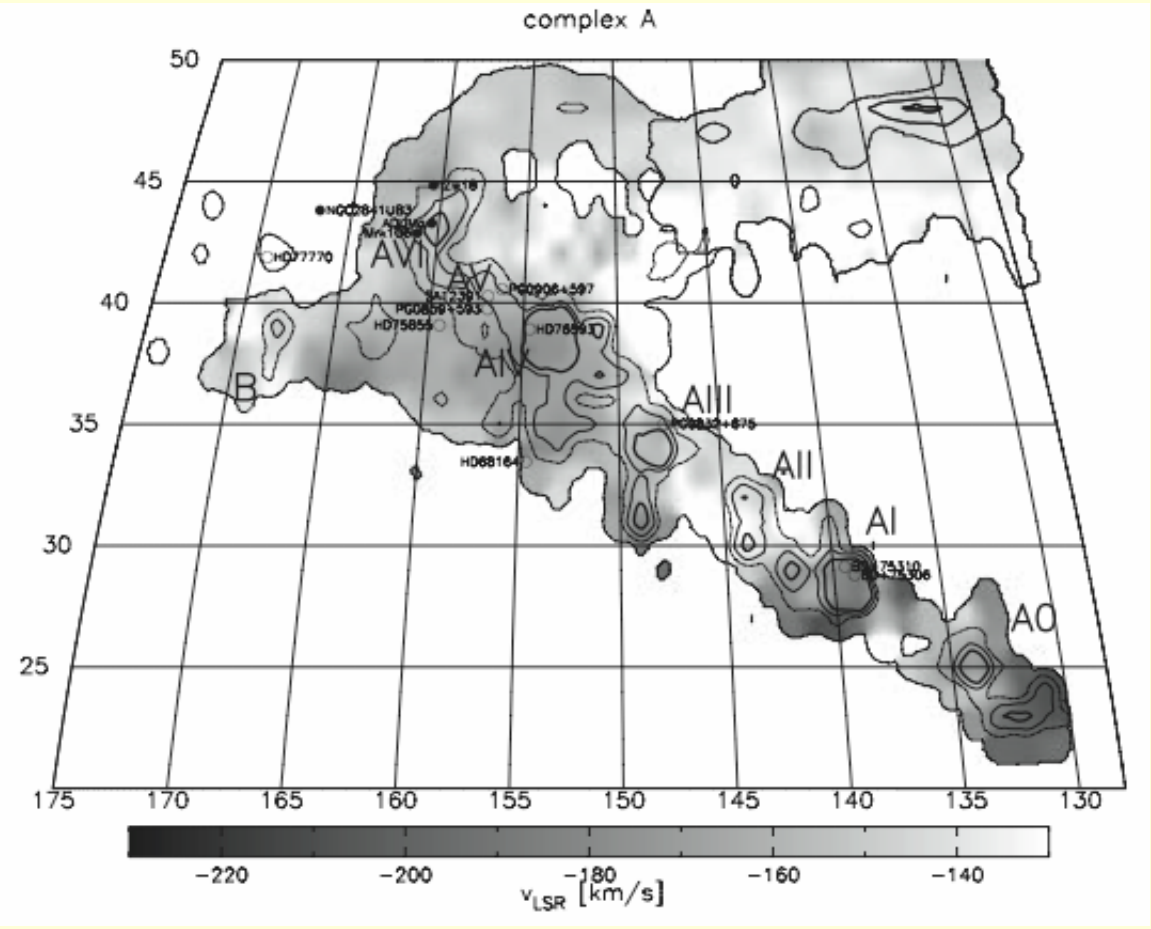
Summary

- Emission lines from ionized gas in the Stream provide important constraints on physical conditions
- Hα is bright, has significant structure on ~arcmin scales
    - Line widths ~ 40 km/s, weak evidence for velocity offset from HI
- [SII]/[NII] is unusually bright, no [OIII] -> low ionization state?
- H^+/H is > 50%
- Small-scale, multi-phase structure (pressure confinement?)

- Look for He I/Hα; traces shape of ionizing spectrum
- Need models that account for ionized gas, predict line strengths/ratios
- What is full extent of the Stream? Signatures detected outside $N_{HI} \sim 10^{18}$ contours
  HI: Lockman et al (2002), Braun & Thilker (2005)
  Mg I: Gibson et al (2000)
  OVI: Sembach et al (2003)

Complex A

HI Velocity Map



Wakker (2001)

- 4 < D < 8 kpc (Wakker 2001)
- Extends ~ 4 kpc above plane
- Metallicity uncertain
  - < 0.4 solar (Wakker 2001)
- Several HI bright ‘cores’
- ~ 80 km/s velocity gradient
- 21 sightlines observed with WHAM, 17 Hα detections
- Hα emission is faint, increases with increasing latitude
  -> consistent with models