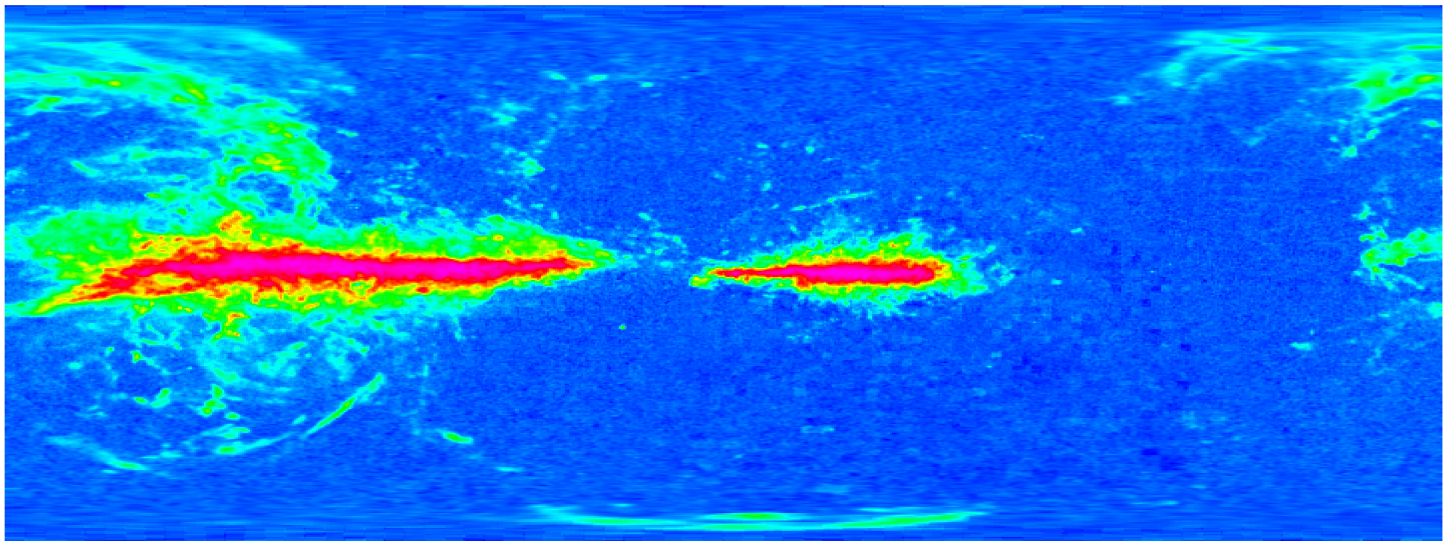
# HI clumps outside the solar radius

Leonidas Dedes



v~ -68km·s$^{-1}$

Argelander-
Institut
für
Astronomie

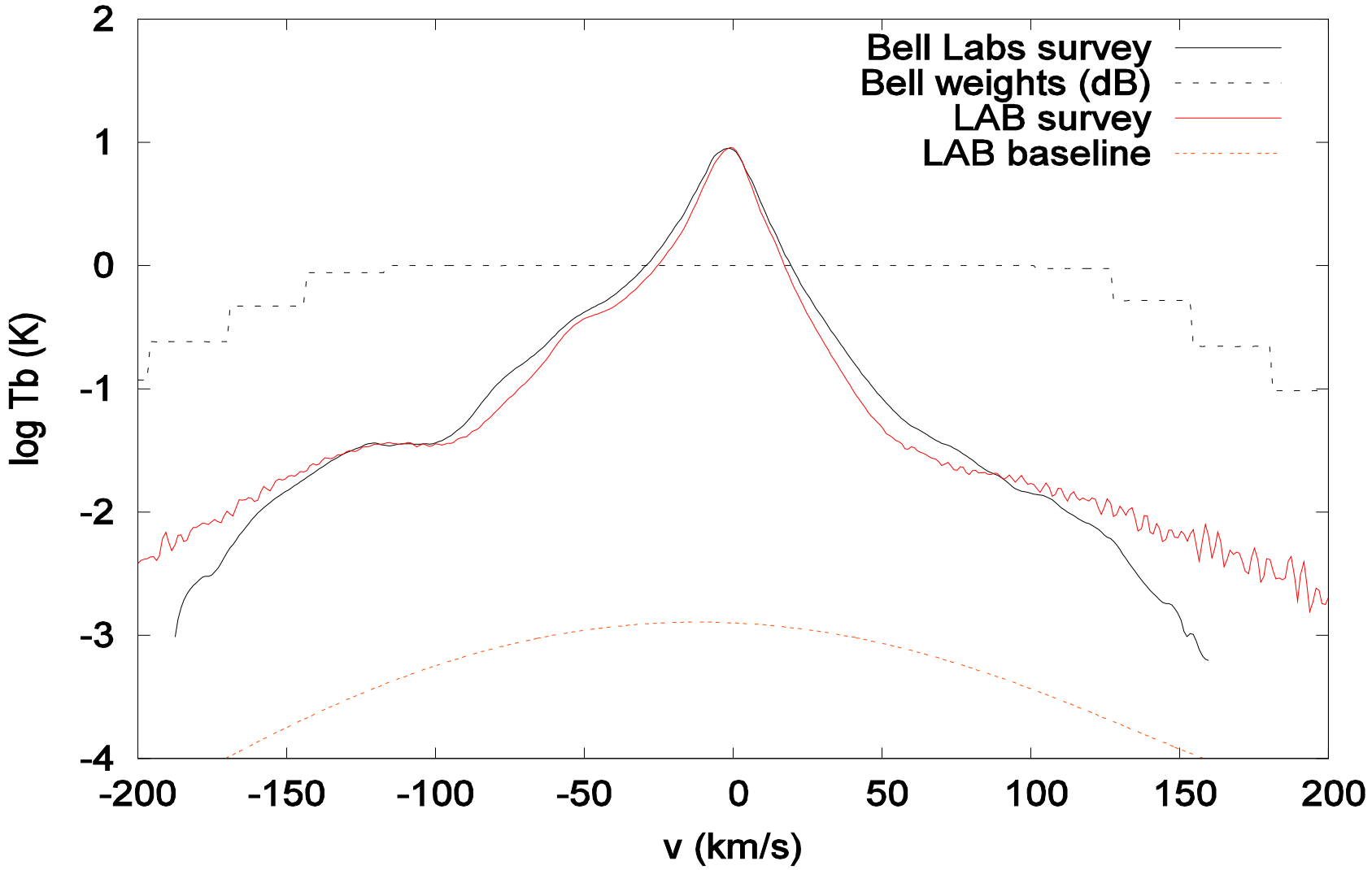
Argelander-Institut für Astronomie

Bonn
29 May 2007

# Introduction

- Neutral Gas Halo surrounding Milky Way disk←Averaging over large areas

i.Bell Labs 21cm survey→scale height ~1.5kpc, σ~35km/s ( Lockman & Gehman 1991)
ii. LDS HI survey→ scale height ~4kpc, σ~60km/s ( Kalberla et al 1998 )




Bell Labs survey – LAB survey, b > 20°

- Isothermal hot plasma ( T~$10^6$K )  Halo with scale height~4kpc

- diffuse soft X-ray background← Rosat & LDS data ( Pietz et al 1998)

- Two component gaseous Halo( Kalberla & Kerp 1998 )

50% in HI, two phases in pressure equilibrium→clumpy neutral medium

Recently:

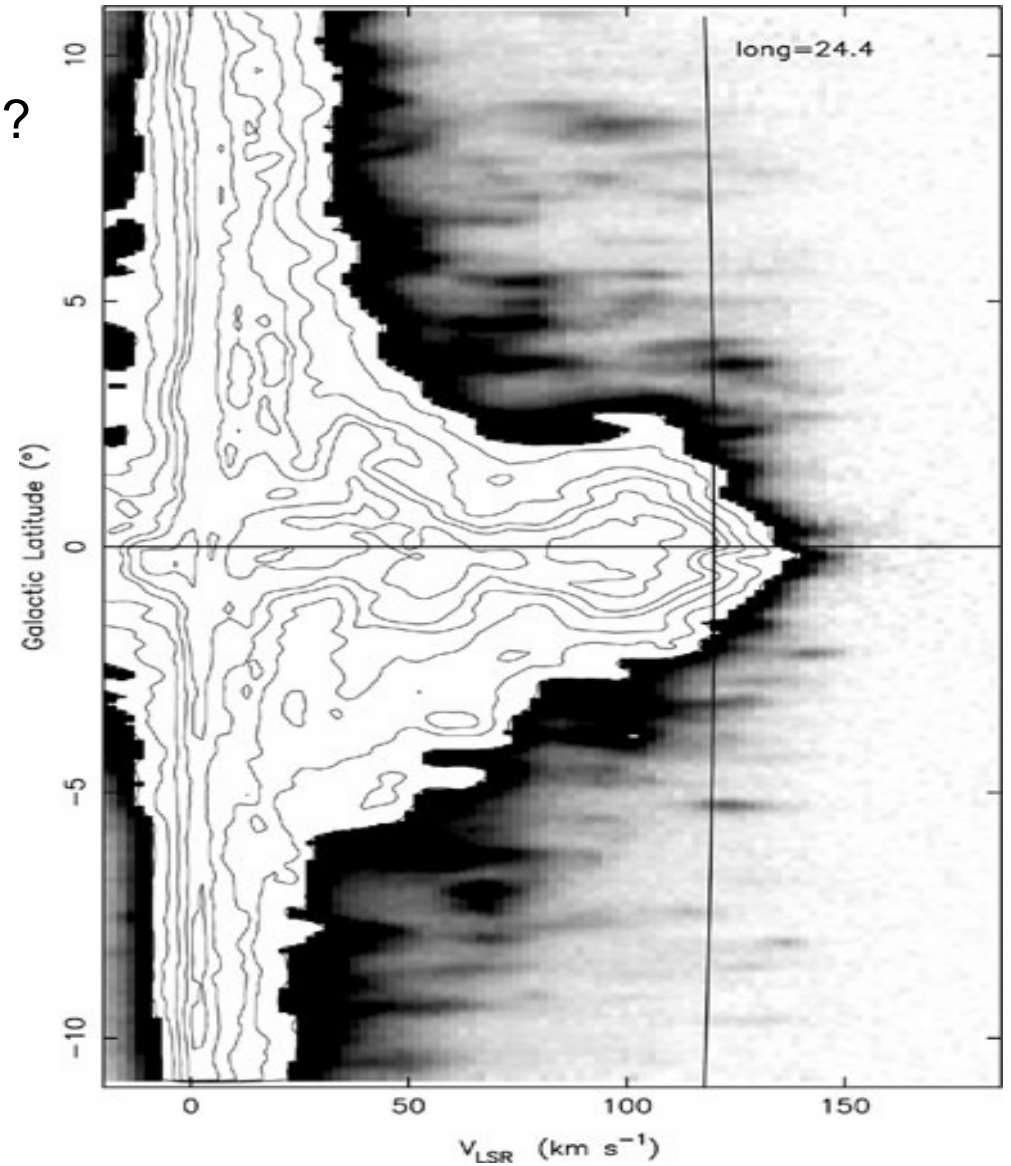
- Extra-planar gas layer detected in external galaxies: NGC-891,NGC2403

Deep interferometry observations→ extended layer surrounding the disk, slightly slower rotation,inflows( Fraternalli et al 2001 & 2004, Fraternalli & Binney 2006 )

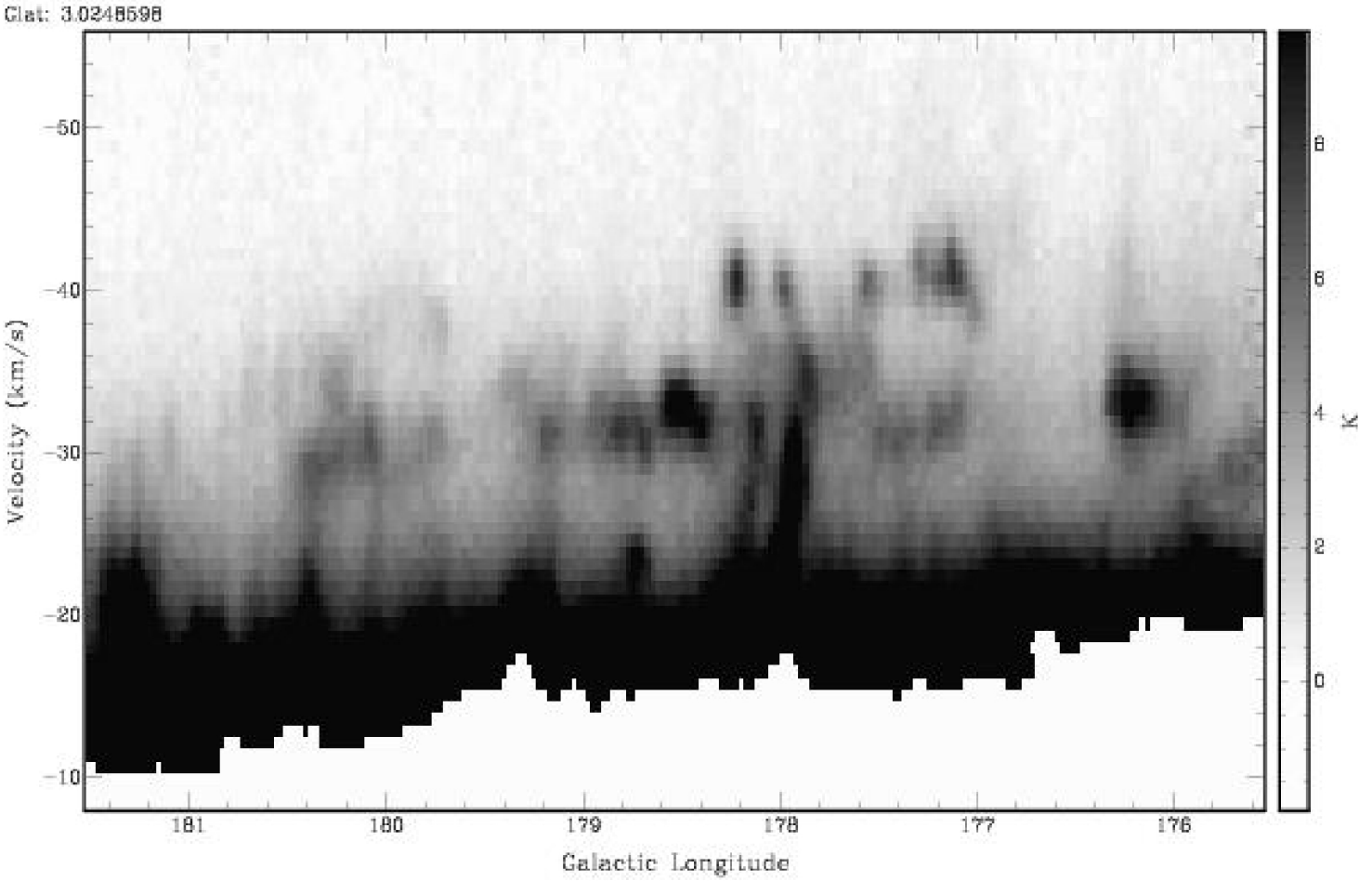
- First direct detection of the HI clumps in the Halo ( Lockman 2002 )
  - Observation at tangent points ⇒ Determine the distance
  - Envelope-core structure
  - Galactic fountain(Shapiro & Field 1976) ?

Properties of Halo Clouds

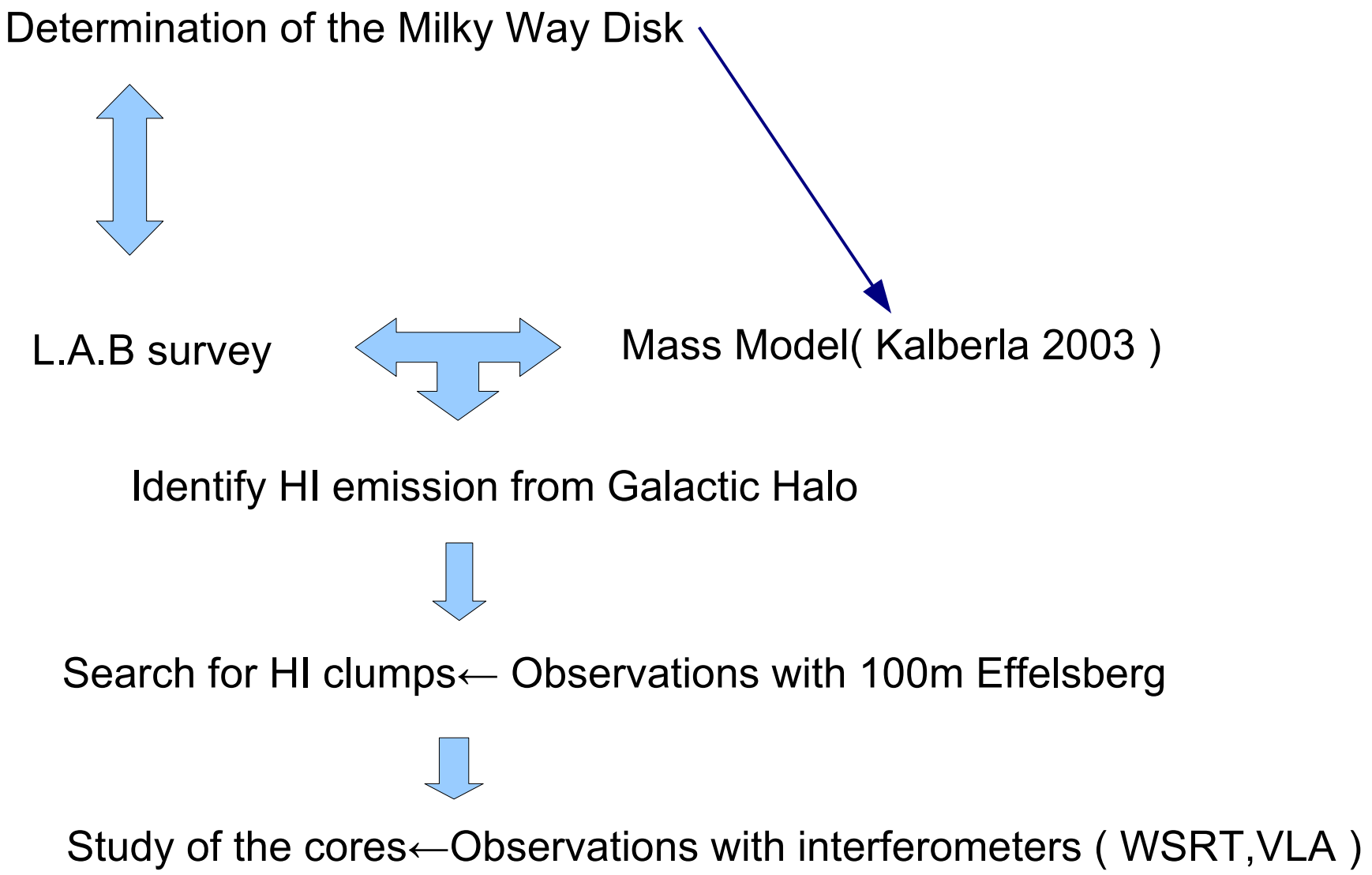
| | Median | 90% Range |
|---|---|---|
| z(pc) | -940 | -640 → -1210 |
| $T_L$(K) | 1.0 | 0.4 → 2.7 |
| $\Delta v$(kms$^{-1}$) | 12.2 | 5.4 → 26.3 |
| $N_{HI}$(x10$^{19}$cm$^{-2}$) | 2 | 0.7 → 6.3 |
| Diameter(pc) | 24 | 19 → 35 |
| <n>(cm$^{-3}$) | 0.25 | 0.1→ 0.9 |
| $M_{HI}$($M_o$) | 50 | 12 → 290 |



- Detection of similar neutral hydrogen clumps using Arecibo (Stanimirovic et al. 2006 )
- Anti-center region
- Distance 0.2-3 kpc



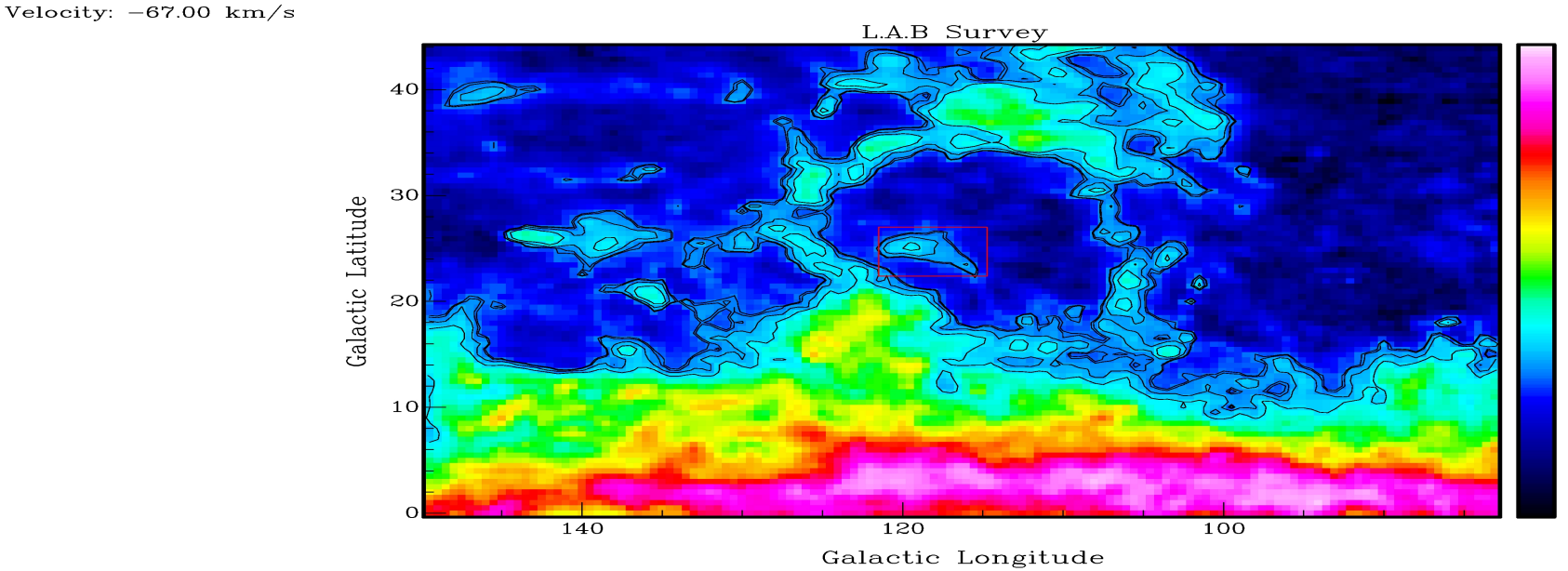
# Search for halo cores



# Search for the HI clumps in the Milky Way

Criteria for selection of observed regions:

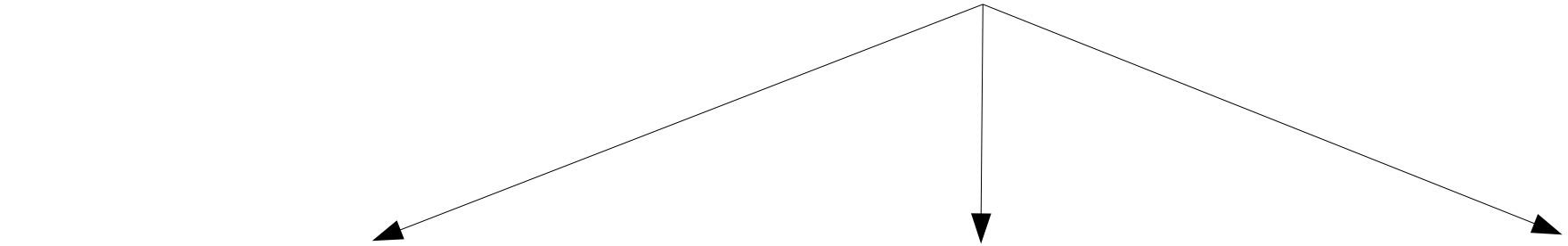
1. Regions with faint emission in the L.A.B survey.
2. Reside in the Outer galaxy
3. Avoid regions towards anti-center→ Distance determination uncertain



# Effelsberg Observations

- 100m dish
- at 21cm – ~9' resolution

Approximately 20 fields observed.



i.) ~20 HI clumps
- FWHM <10km/sec
- Angular diameter < 18'
- -95km/sec > $u_{LSR}$ > -40km/sec

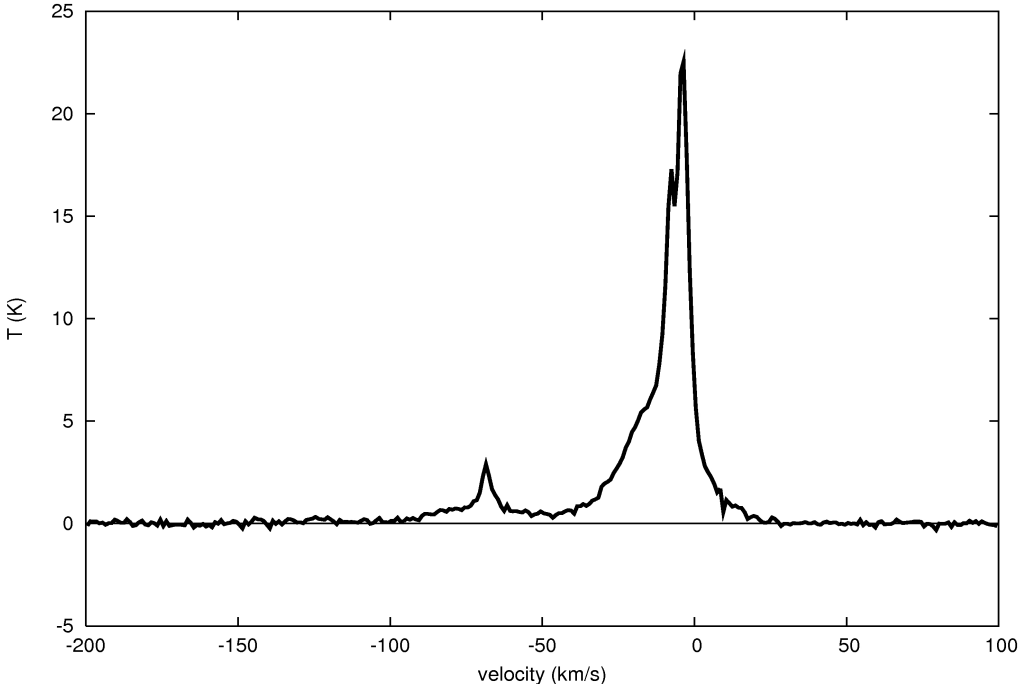
ii.) ~10 HI clumps
- FWHM >10km/sec
- Angular diameter < 18'

iii.) IVC's
- Extended emission
- Intermediate velocities

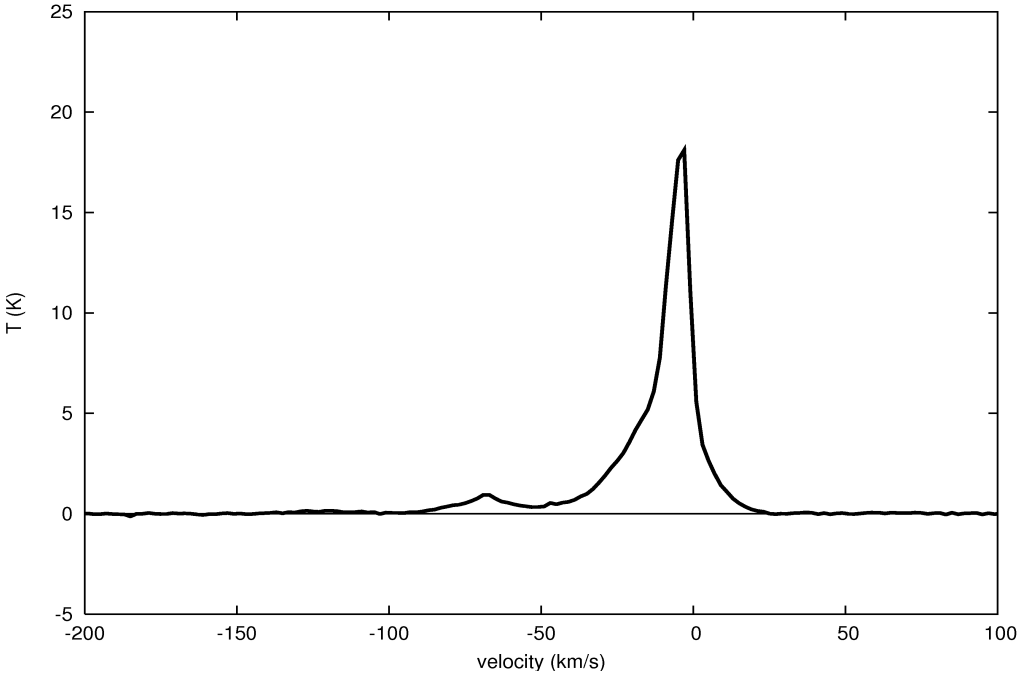
- In most regions with b>40° no detections

- Upper limit for the presence of HI clumps?
  Only very faint diffuse phase

# Effesberg




# LAB survey



# Data Analysis Effelsberg Observations

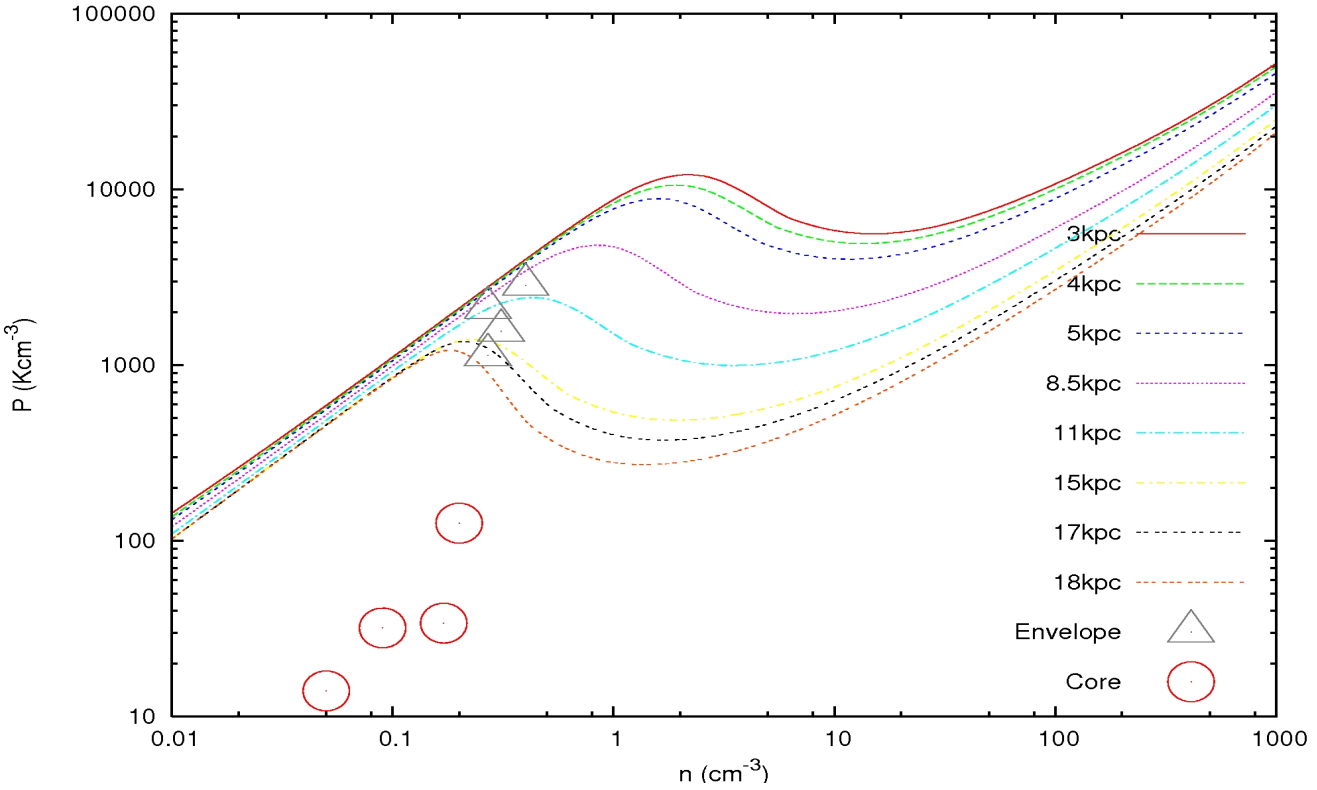
- Gaussian decomposition:core-envelope structure
- Distance← $v_{LSR}$ to R & z from Milky Way model
- Clumps unresolved→diameter 1-2 Effelsberg beams

| | FWHM | $T_{Kin}$ | $N_{HI}$ | diam |
|---|---|---|---|---|
| | $km \cdot s^{-1}$ | K | $cm^{-2}$ | pc |
| Envelope | 13 - 20 | 3000-7700 | 1.7 - 2.4 | 19-30 |
| Core | 3 – 5.1 | 200-580 | 0.7-2.4 | 19-30 |

•Wolfire, 2003→ Thermal equilibrium of Neutral Atomic Phases

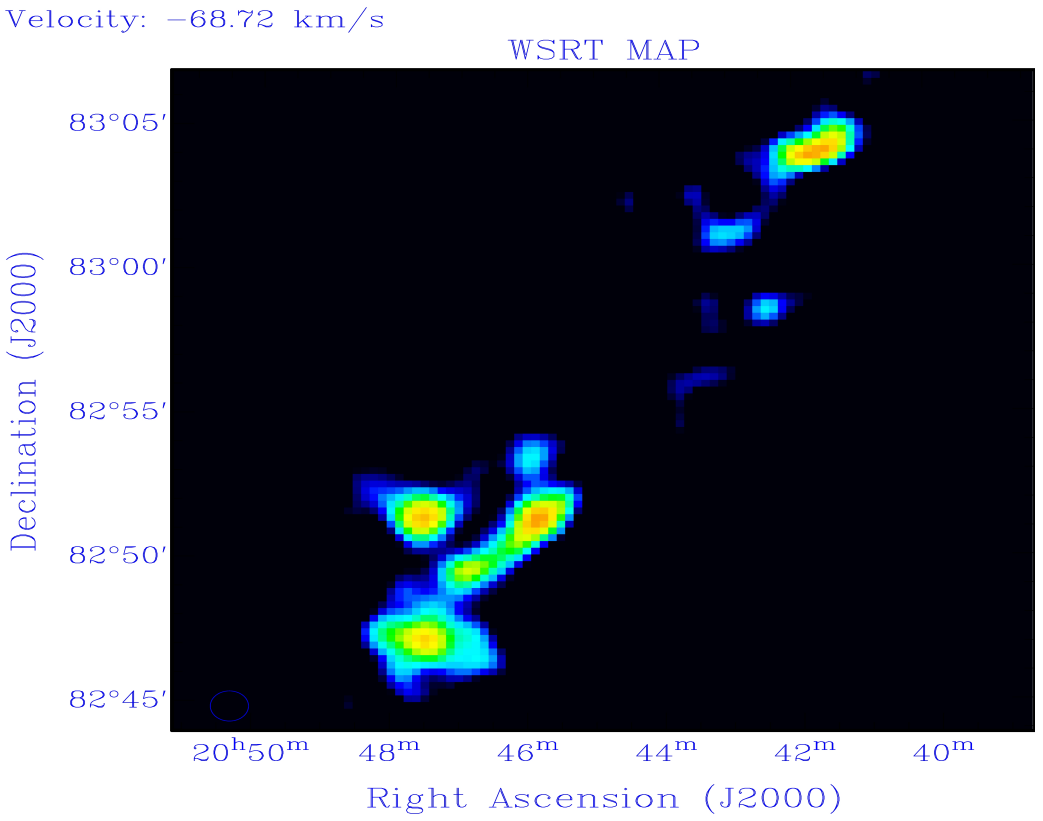
- Photoelectric Heating(PAH)
- Cooling from fine structure CI
- Depends on FUV fields, dust & metal distribution

Calculate range of P, <n> where two phases can coexist.

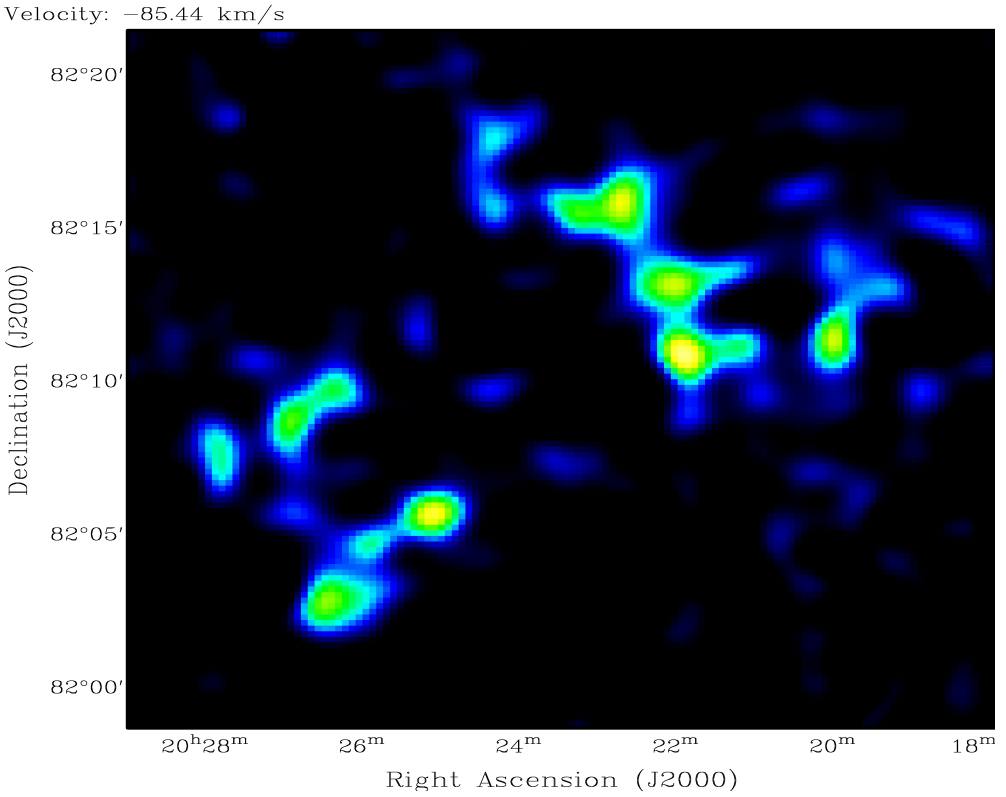


# Interferometry Observations

## WSRT Observation




## VLA Observation



# Physical Parameters of the Cores

## Parameters of the Clumps from WSRT data

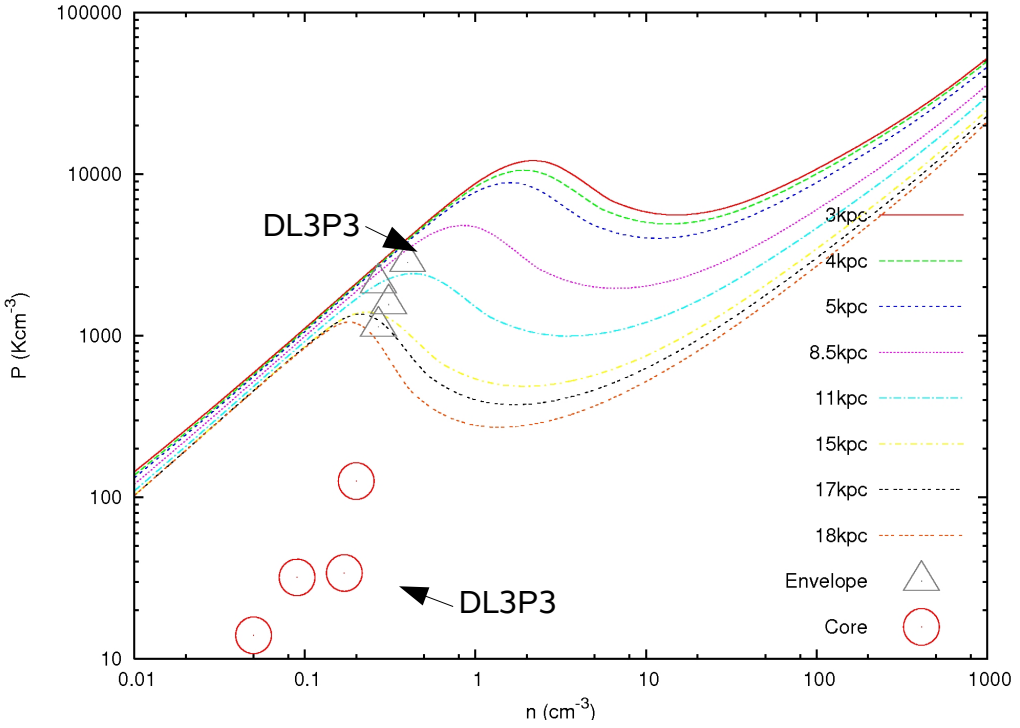
| | Ang. Diam | $N_{HI}$ | FWHM | $T_{Kin}$ |
|---|---|---|---|---|
| | arcmin | $10^{19}$ $cm^{-2}$ | $km \cdot s^{-1}$ | K |
| C_1 | 1 – 1.24 | 4 – 5 | 4 – 7 | 350 – 1000 |
| C_2 | 0.6 – 2 | 1.5 - 3.1 | 2.4 – 4 | 130 - 340 |

## Parameters of the Clumps from VLA data

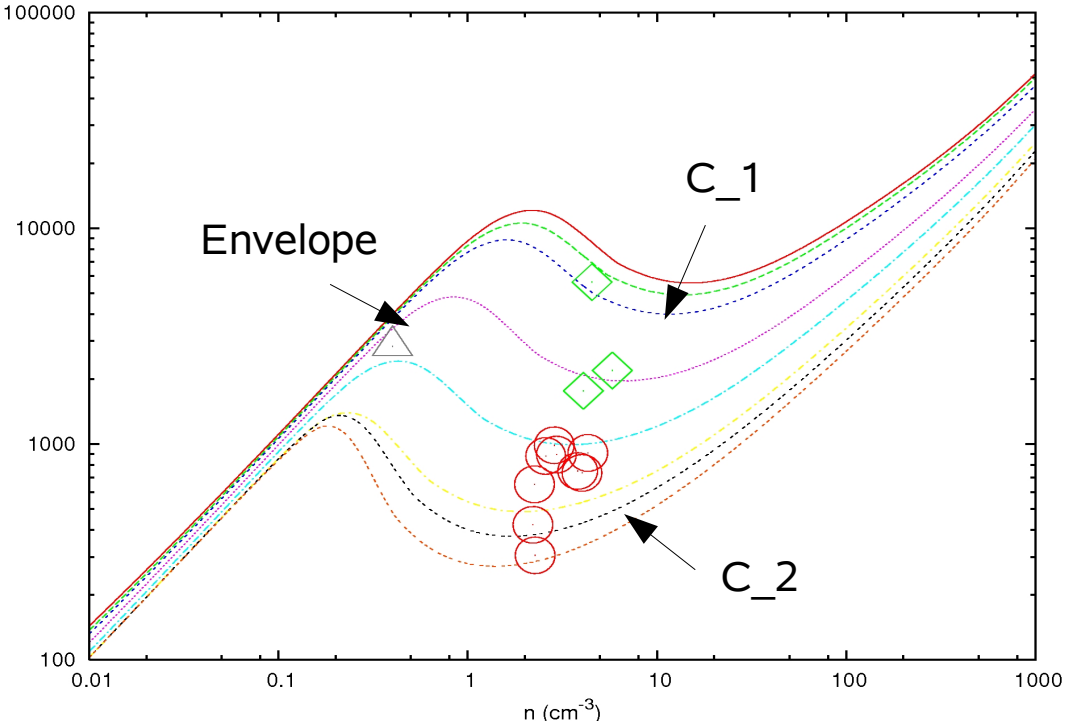
| | Ang. Diam | $N_{HI}$ | FWHM | $T_{Kin}$ |
|---|---|---|---|---|
| | arcmin | $10^{19}$ $cm^{-2}$ | $km \cdot s^{-1}$ | K |
| C_1 | 0.96 – 2.7 | 0.9- 3 | 3.4 – 5 | 260 - 560 |

# Phase diagrams vs observational parameters from WSRT

Effeslberg data




WSRT data



# Comparison of the HI clumps parameter between different telescopes

| | $N_H$ ($10^{19}$ cm$^2$) | d (pc) | Mass ($M_\odot$) | $T_{Kin}$ (K) |
|---|---|---|---|---|
| GBT (Lockman 2002) | 1 – 6 | <19 – 35 | 12 – 290 | <2000 |
| Effel. 100m | 1 - 4 | 15 - 50 | 16 – 800 | 200 - 1200 |
| Arecibo (Stanimirovic et al. ) | 2 | 0.5 – 8 | 0.03 - 7 | 350 |
| WSRT & VLA | 1 – 5 | 1.3 – 4 | 0.2 - 14 | 400 |

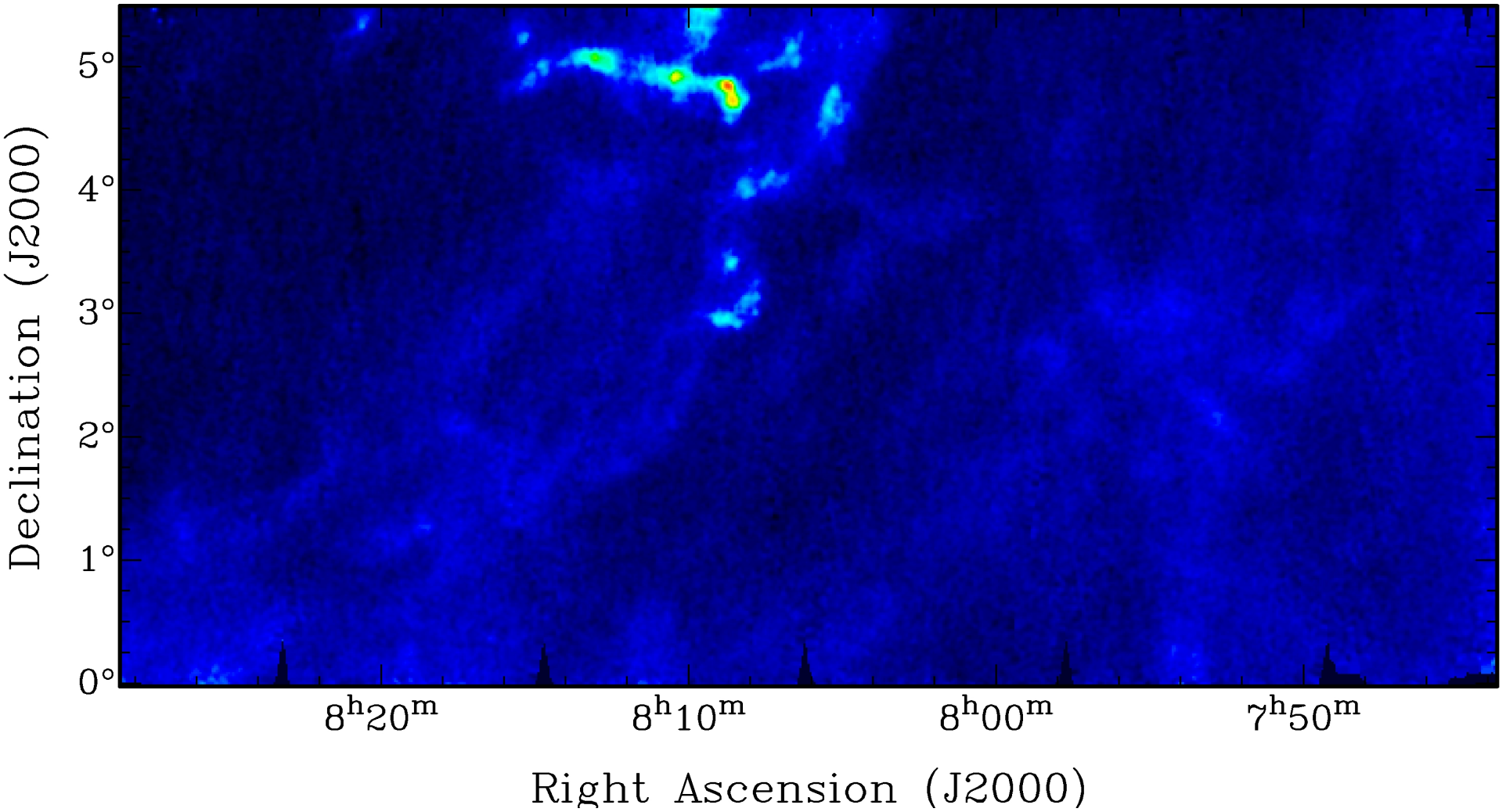
# Arecibo Observations

- Map a region 15° x 4°
- Detect HI clumps with d~4'
- At D=4kpc → size ~ 4pc
- $T_{kin}$ 280 K

- 300m dish
- ~3' resolution
- 7-pixel receiver

Courtesy of NAIC- Arecibo Observatory, a facility of the NSF

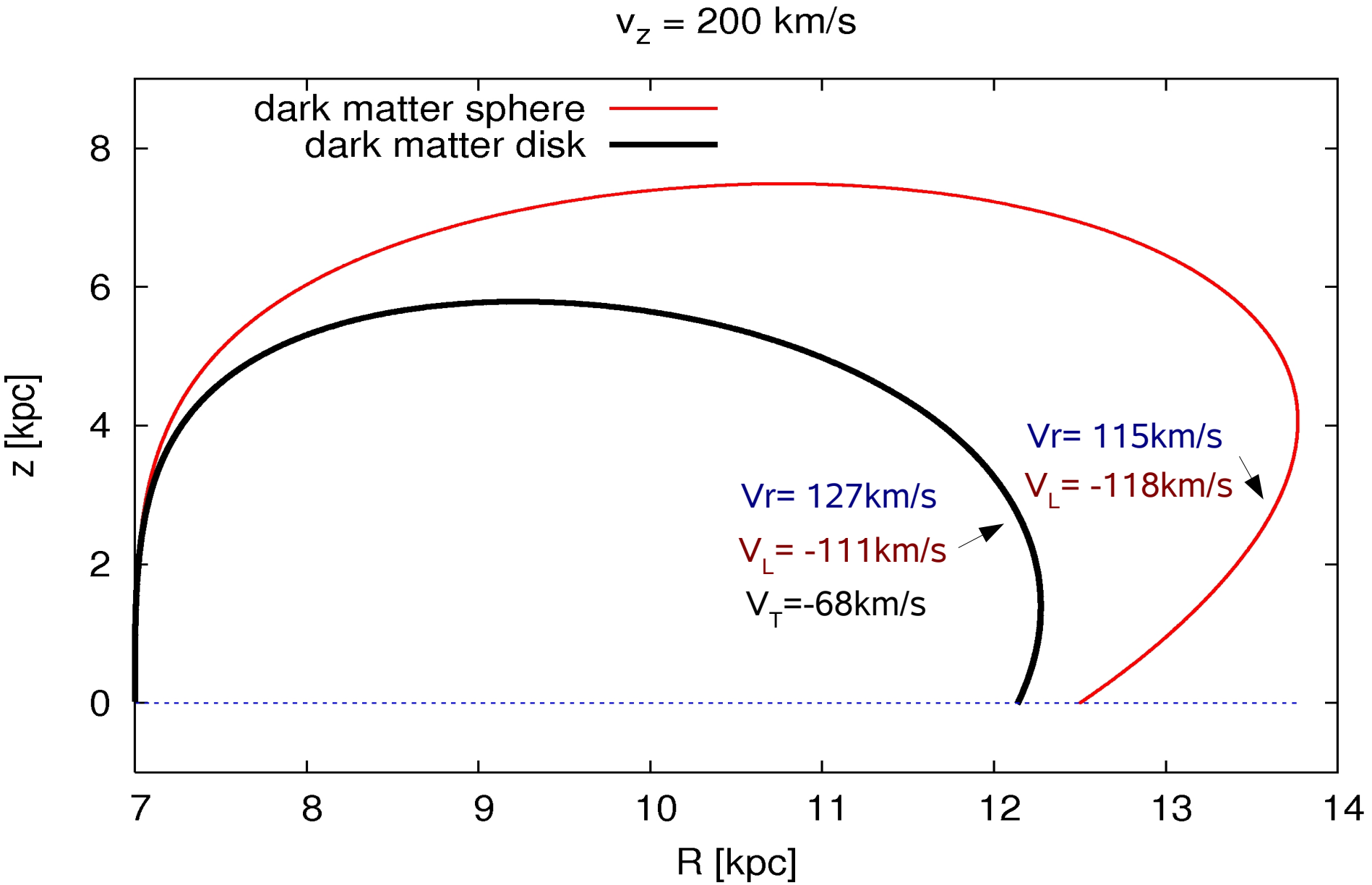
Velocity: 37 km/s



Galactic Fountain?

- Hot gas rises through the Halo

- Ballistic orbits



# Summary

- Extra-planar HI gas exists as filaments. HI clumps observed as parts of filaments reaching heights of few kpc.
- Effelsberg parameters agree quite well with GBT parameters
- Further interferometry observation resolve clump into a number of small cores
- Two component structure
- Possible existence of equilibrium between envelope & core
- HI clumps are observed as parts of larger filaments
  - at R = 5 kpc (Lockman, GBT) up to z = 1.5 kpc
  - at R = 13 kpc at z = 3 kpc (Dedes, Effelsberg, WSRT, VLA)
  - at distance d=0.2-3 kpc in the anti-center (Stanimirovic, Arecibo)