Mapping the Gaseous Local Universe

Mary Putman

U. Michigan

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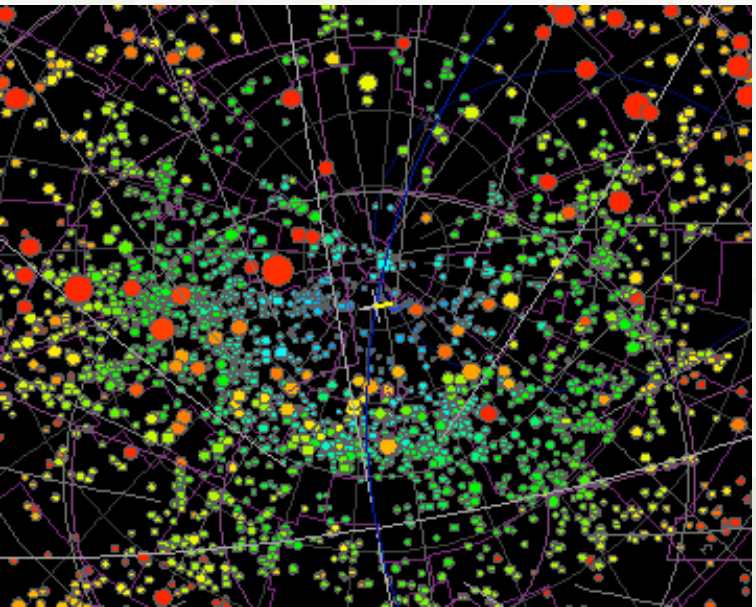

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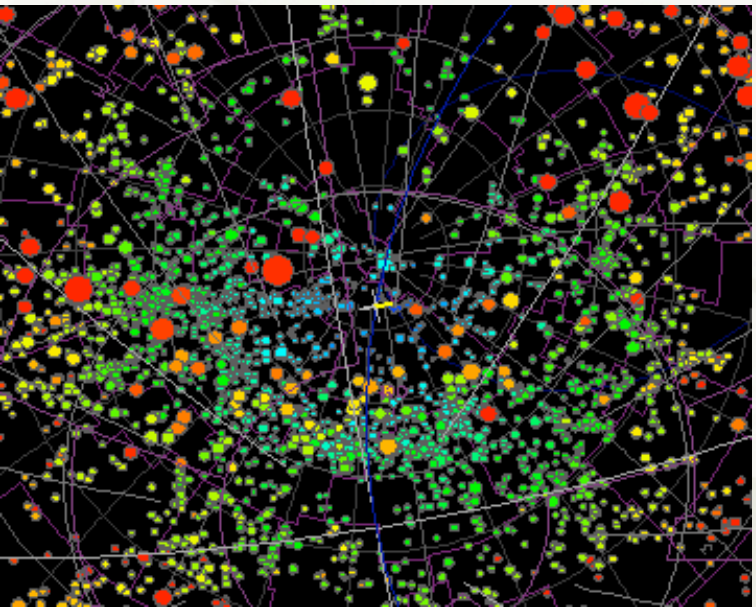

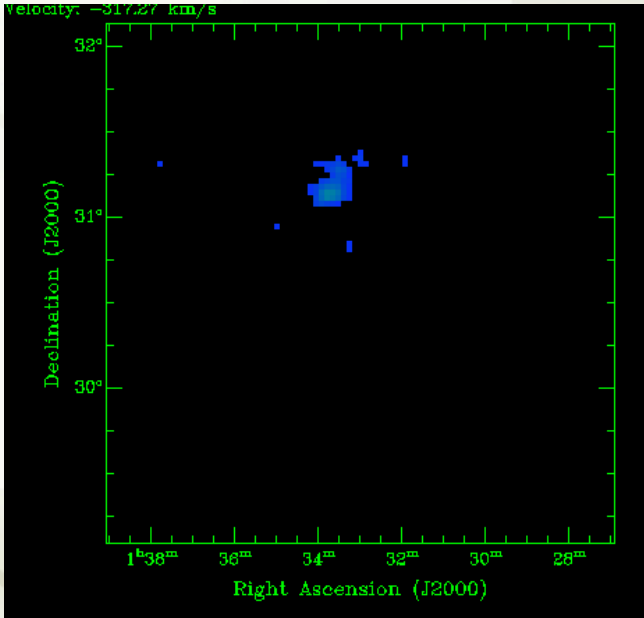

A Biased Presentation: Mapping the Gaseous Local Universe in Neutral Hydrogen (HI)

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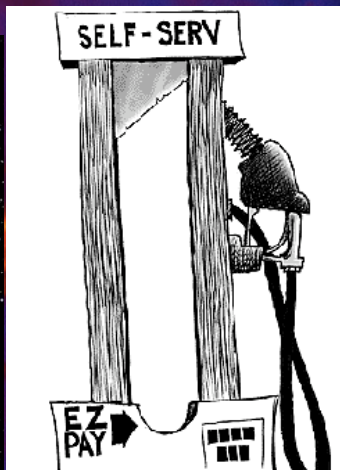
- 21-cm Spectral Line = 3D Maps

A Biased Presentation: Mapping the Gaseous Local Universe in Neutral Hydrogen (HI)

- 21-cm Spectral Line = 3D Maps
- All-sky (or very large area) Surveys
  - Low resolution (3.4'-36') - single dish
- Pointed Surveys of Galaxies
  - High resolution (6"+) - synthesis telescopes

Galaxy Fuel



Background Image: Galactic HI emission from the Galactic Arecibo L-Band Feed Array (GALFA; Peek et al.)

Galaxy Fuel

Images from Gnedin and Westmeier galleries

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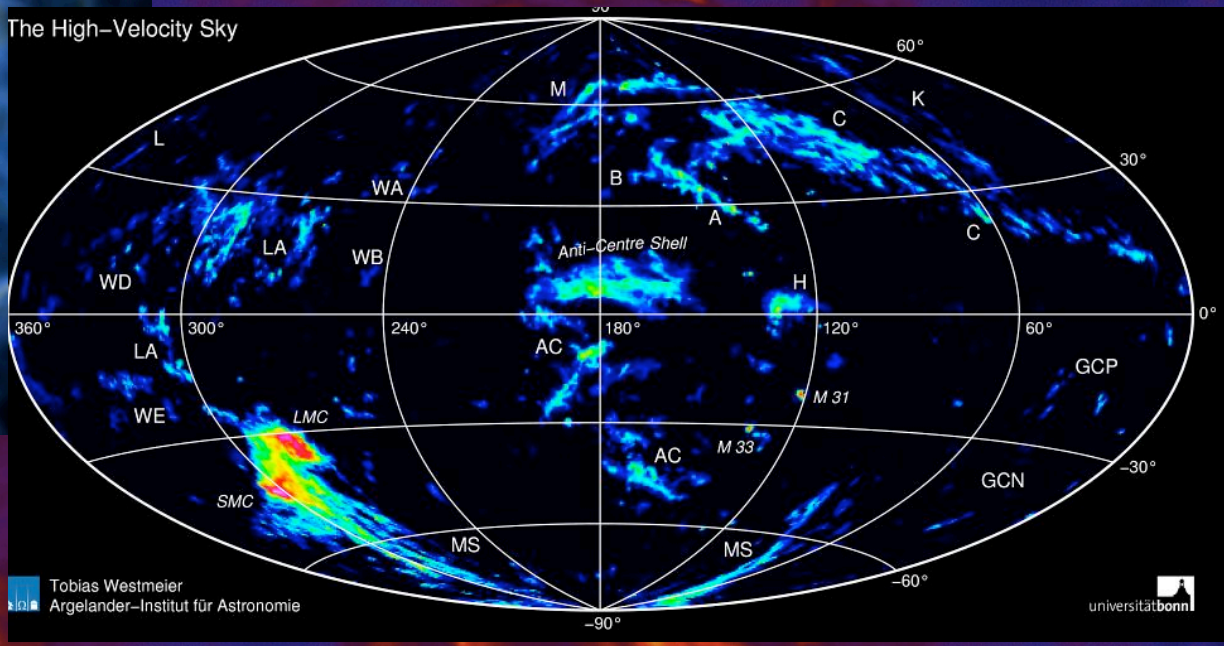

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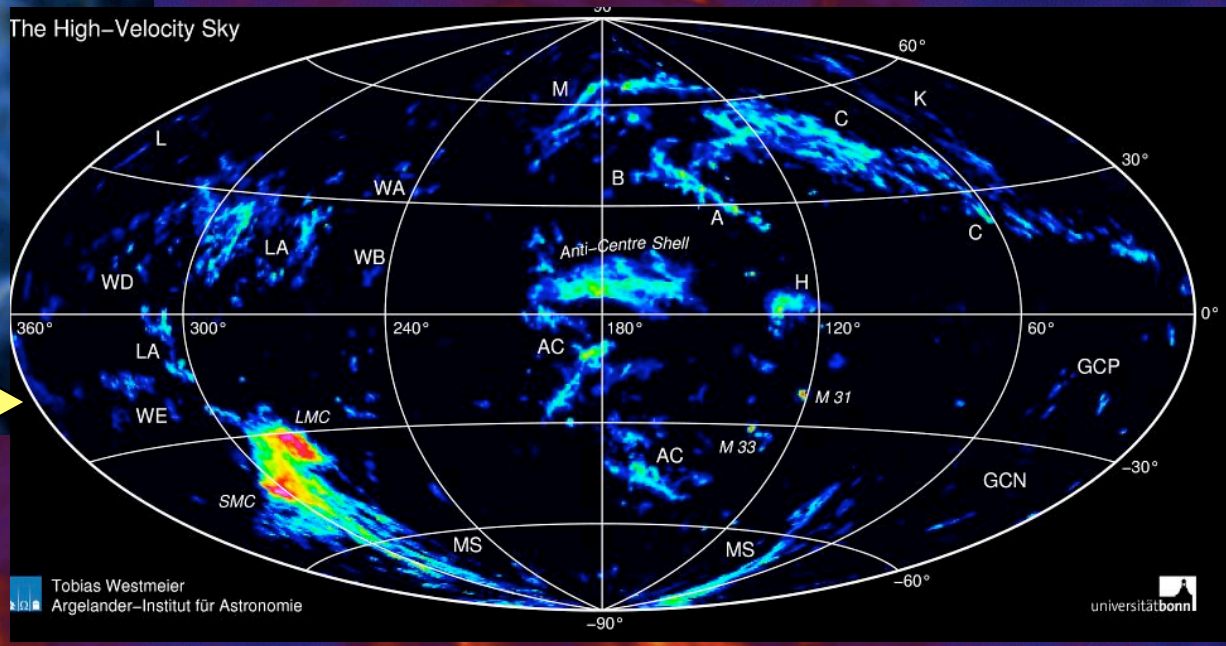

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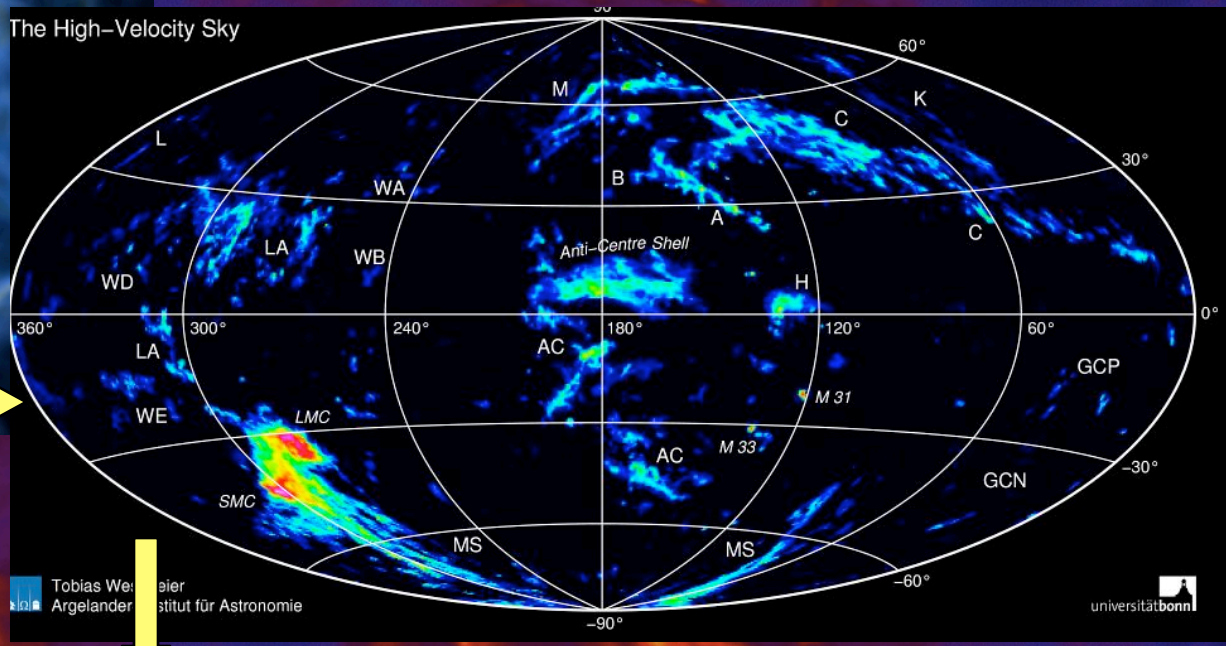
Galaxy Fuel



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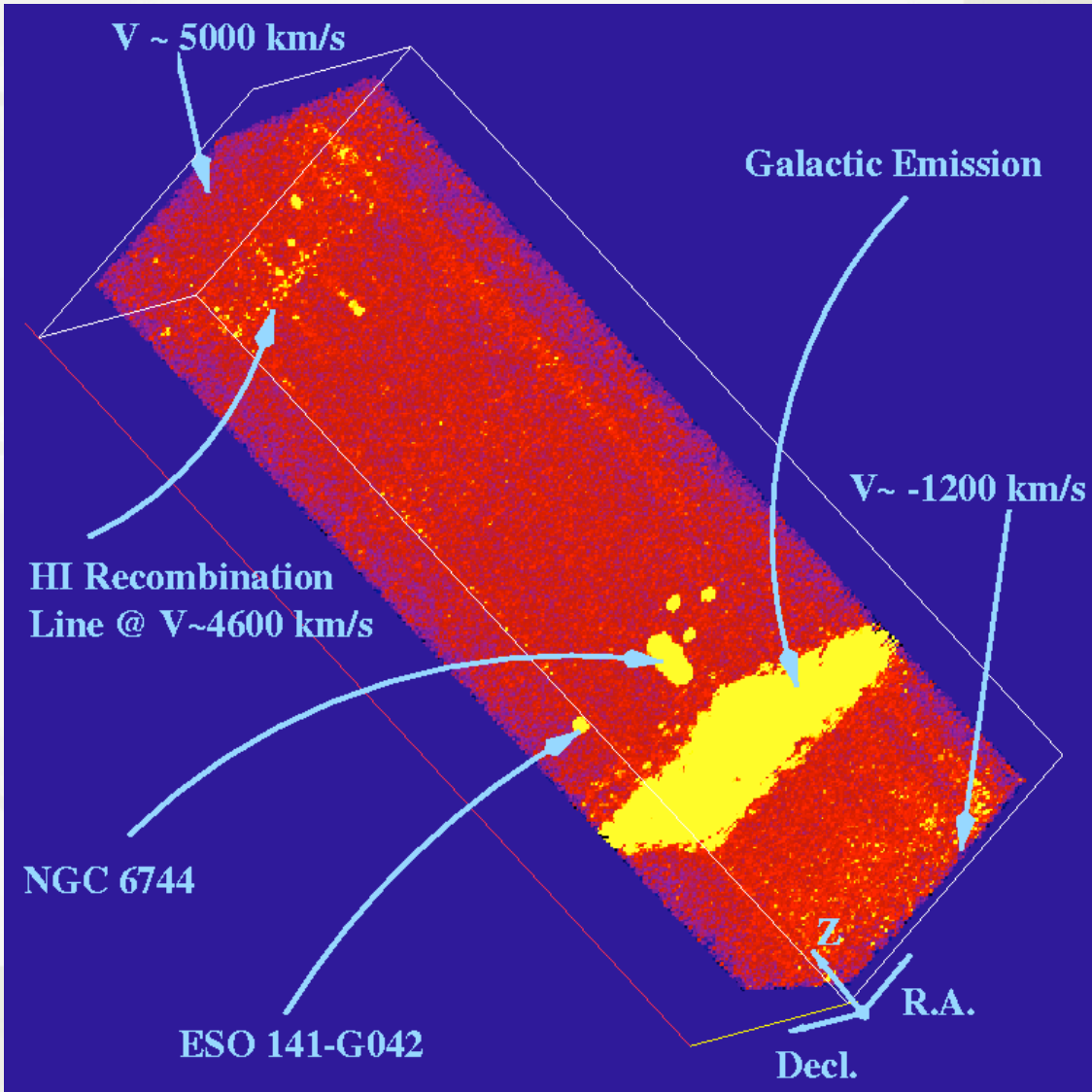
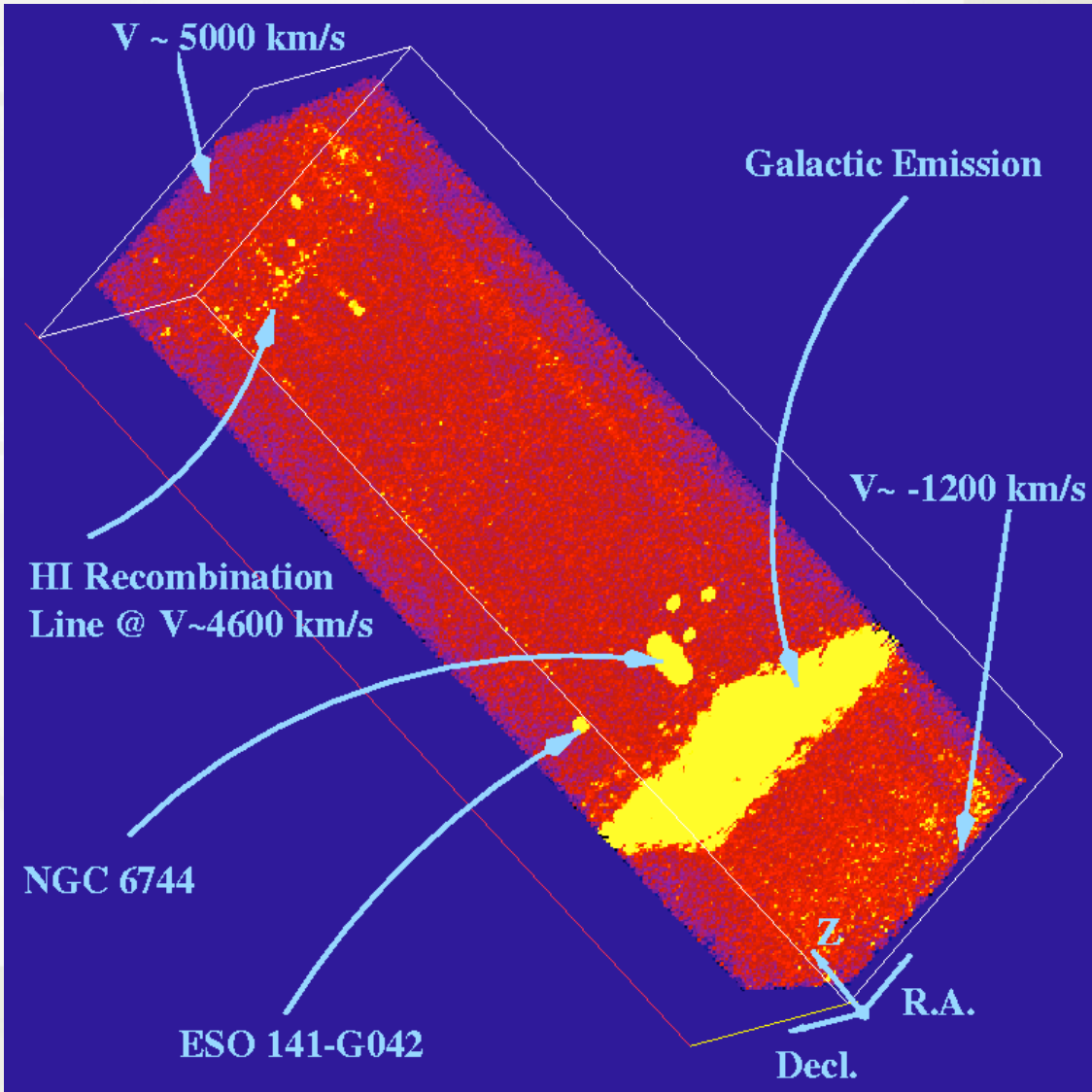
Cubes of Data



Cubes of Data

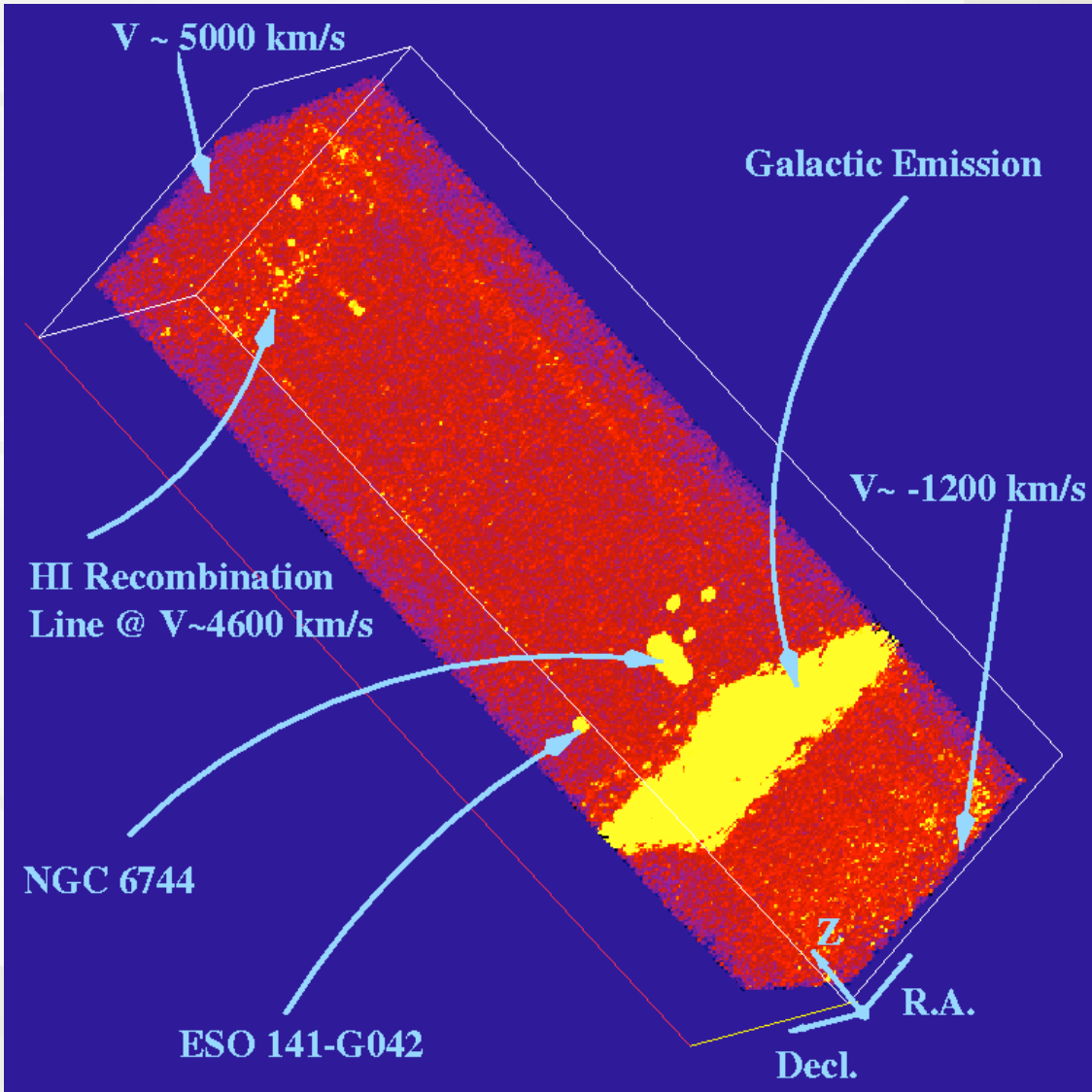
Data Presentation:



Cubes of Data

Data Presentation:

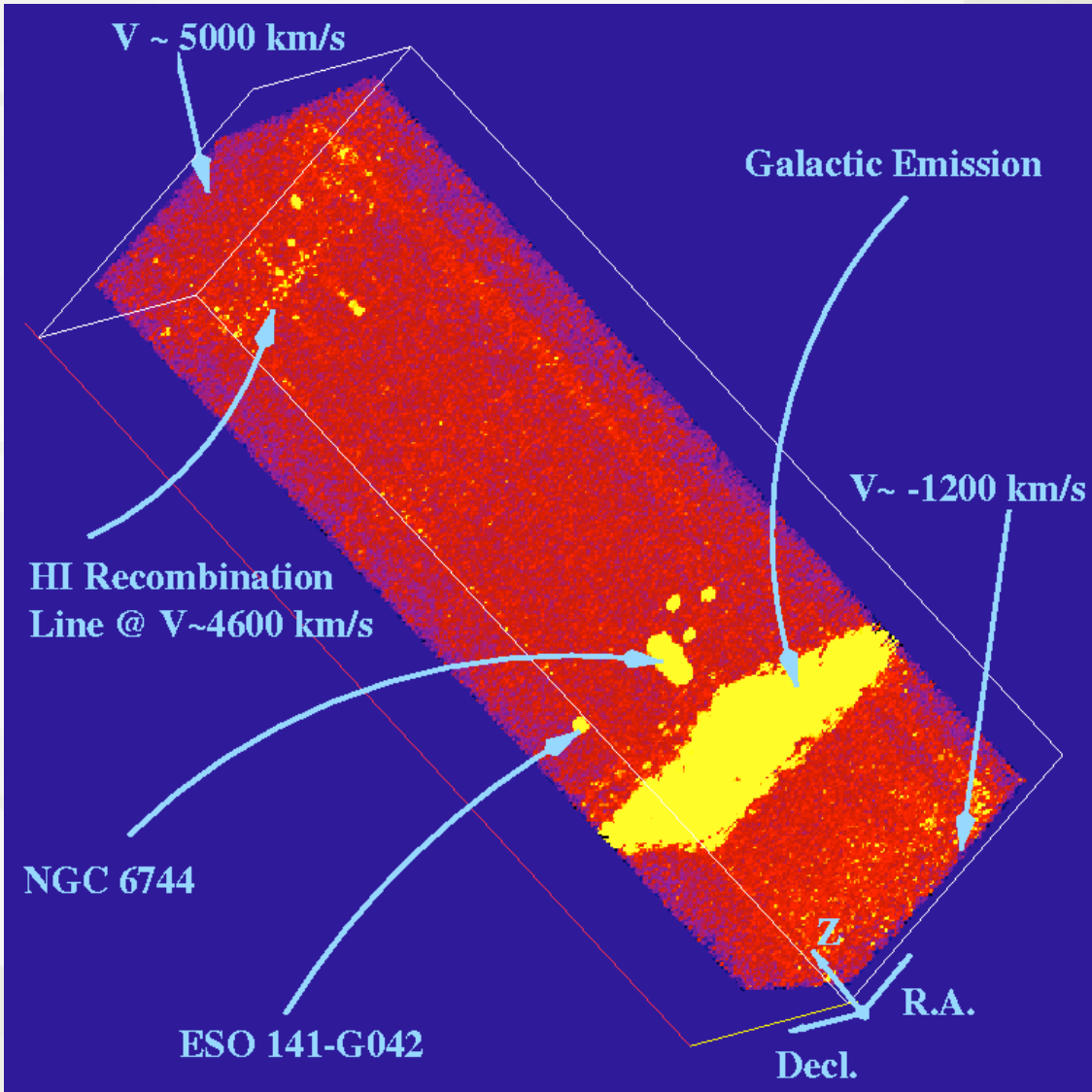
- Movies or channel/ velocity maps



Cubes of Data

Data Presentation:

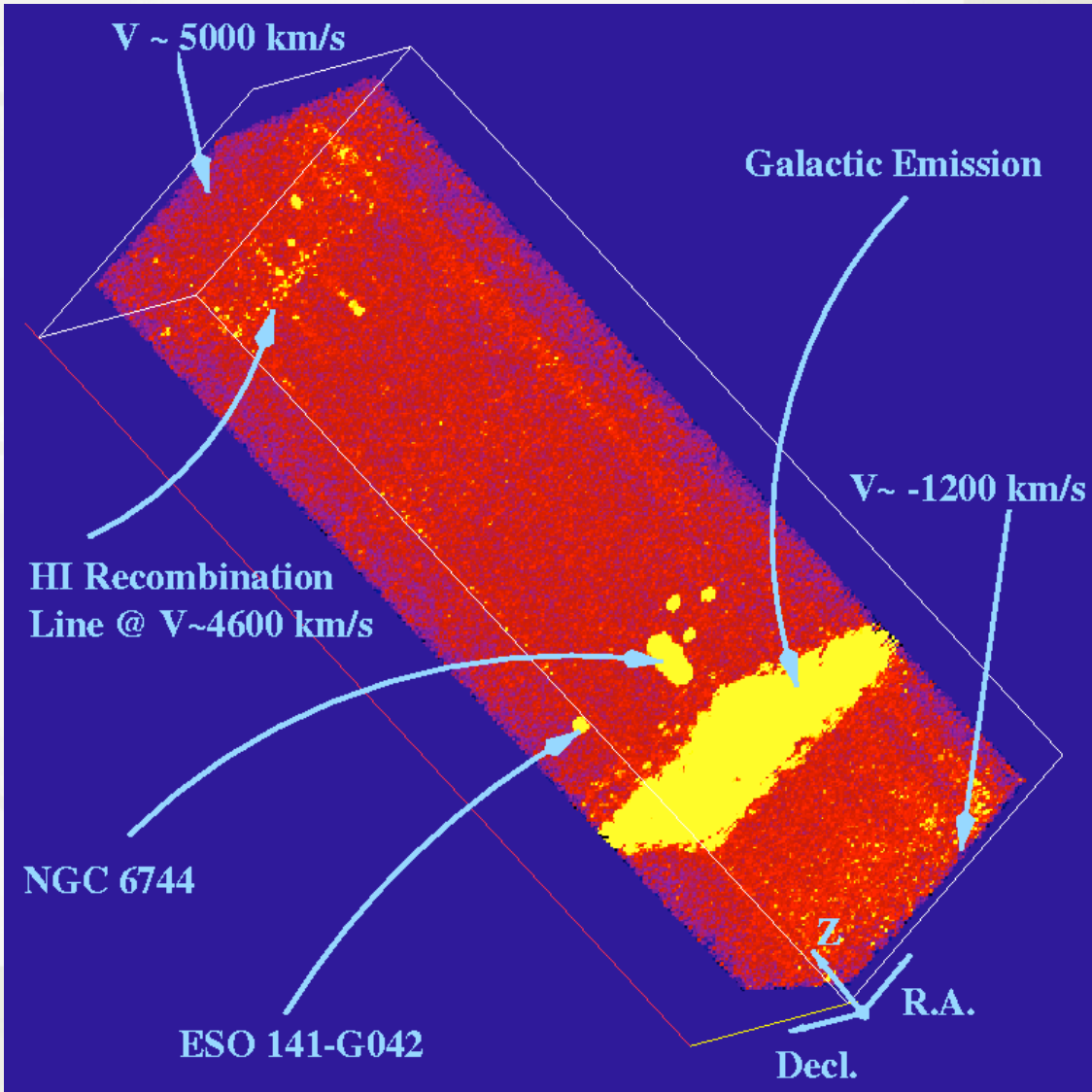
- Movies or channel/ velocity maps
- Squash the velocity axis = avg. velocity or total intensity maps



Cubes of Data

Data Presentation:

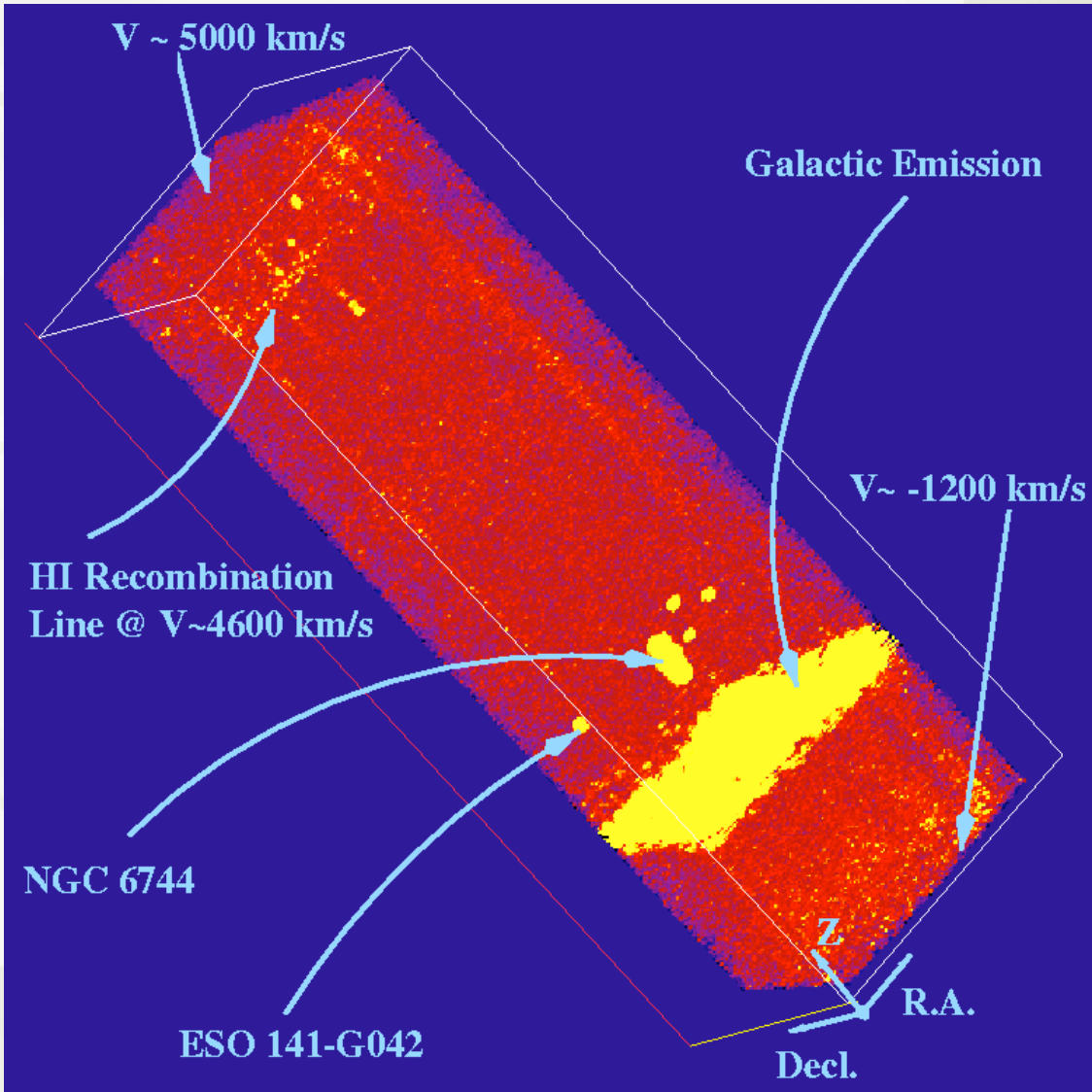
- Movies or channel/ velocity maps
- Squash the velocity axis = avg. velocity or total intensity maps
- Squash one of the position axes = position-velocity maps



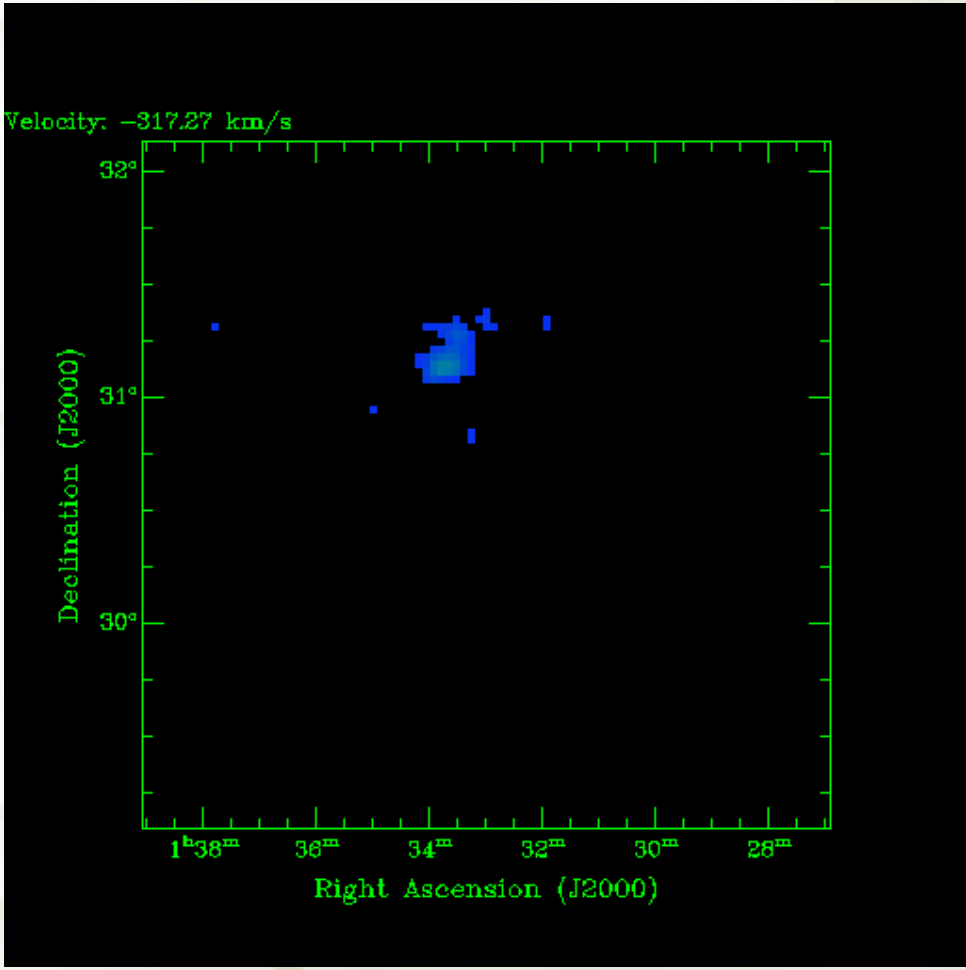
Cubes of Data

Data Presentation:

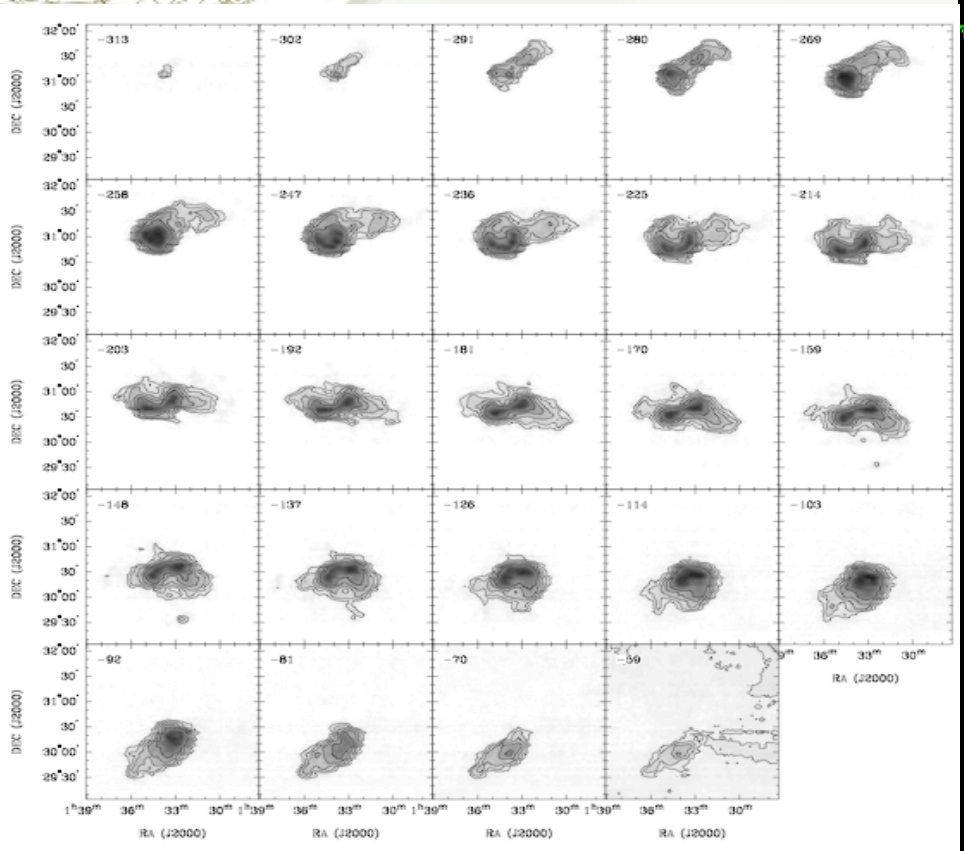
- Movies or channel/ velocity maps
- Squash the velocity axis = avg. velocity or total intensity maps
- Squash one of the position axes = position-velocity maps
- Single line through cube = spectrum

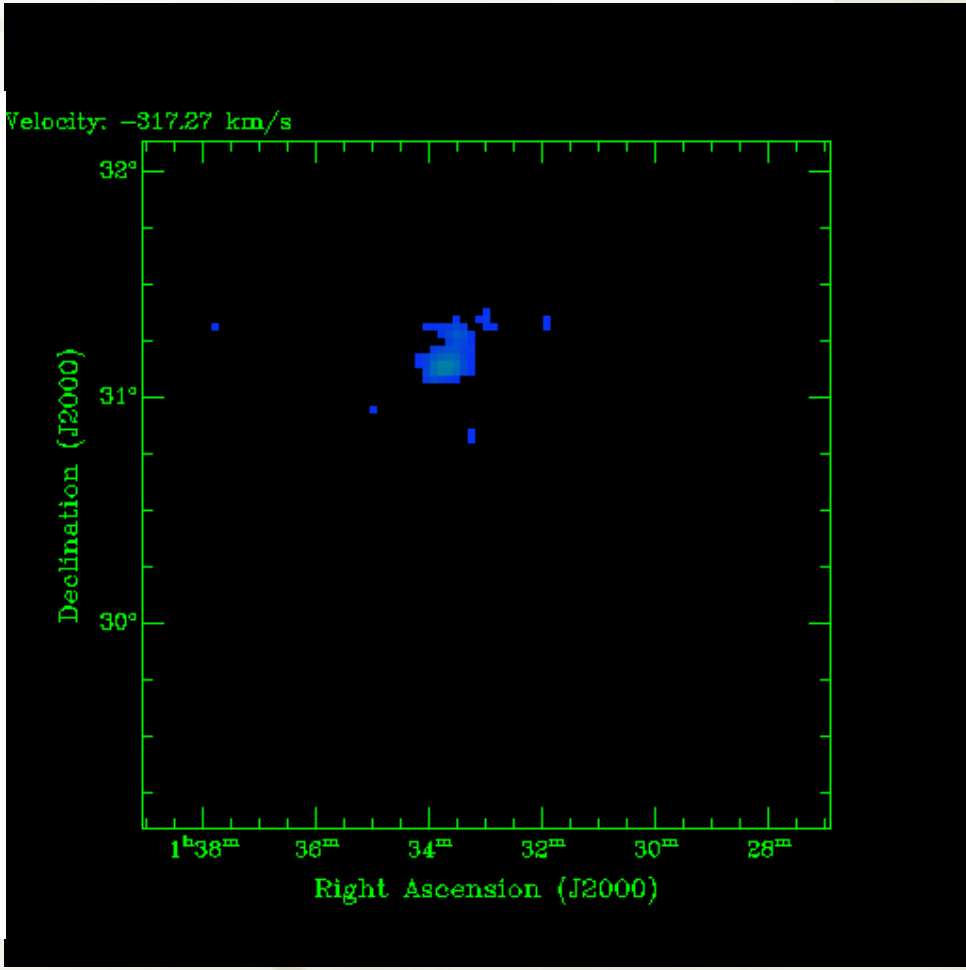


Movies/Channel Maps



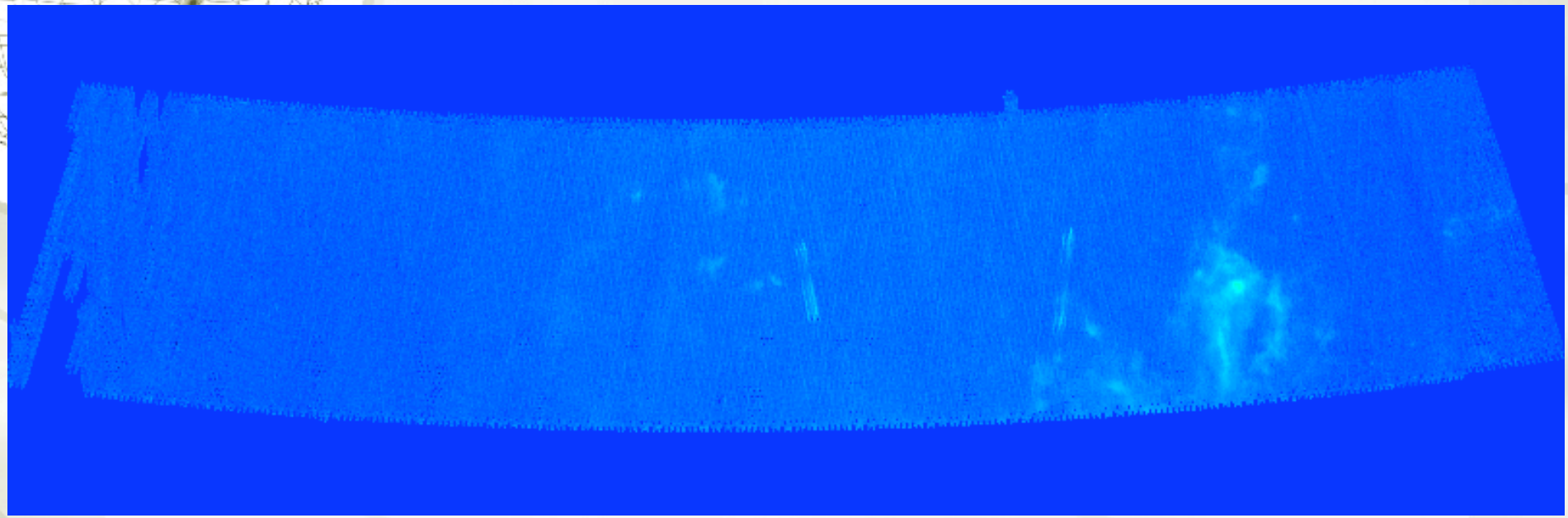
Movies/Channel Maps





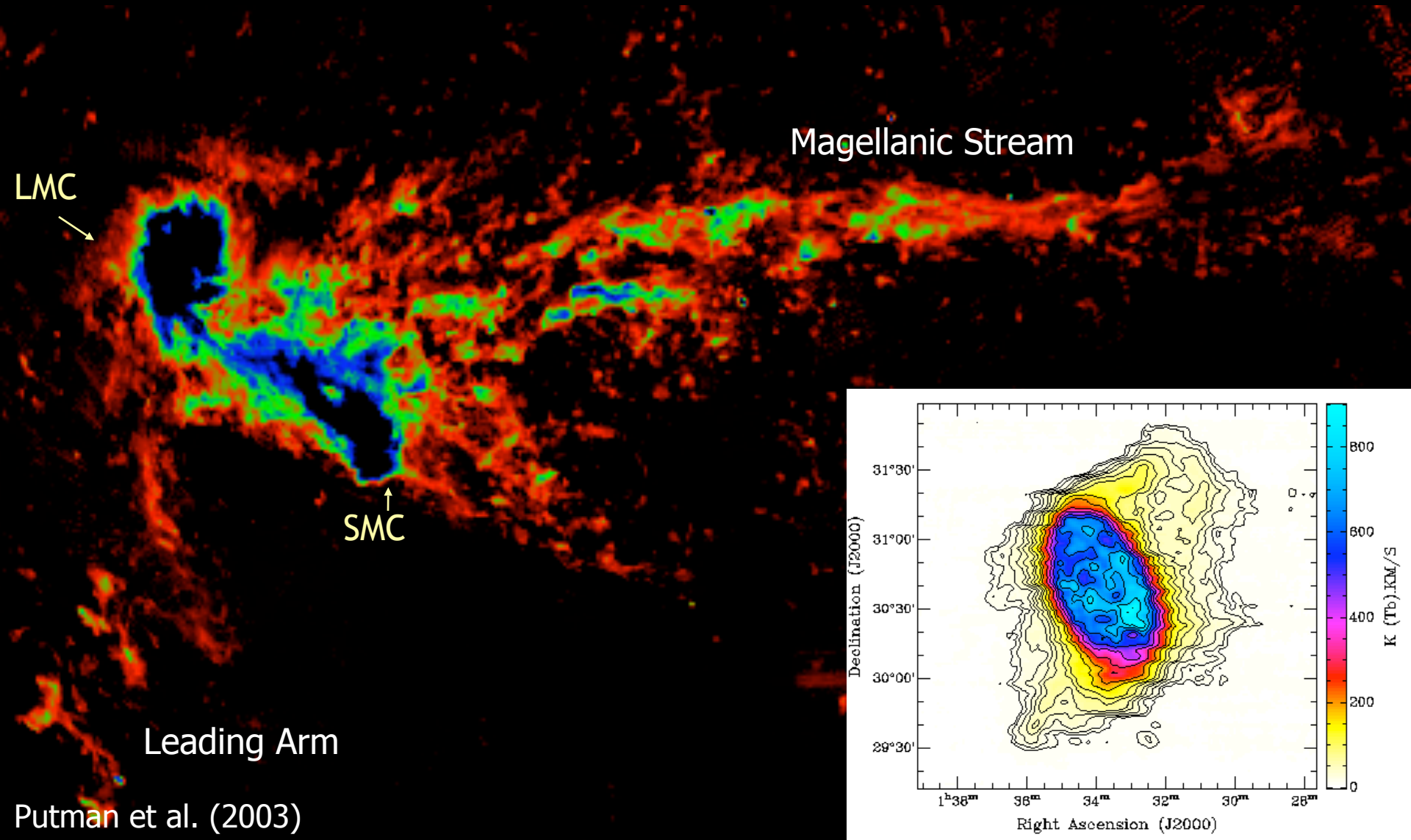
Galactic Emission: The Anti-center Region

Stepping in velocity from 31 to -116 km/sec



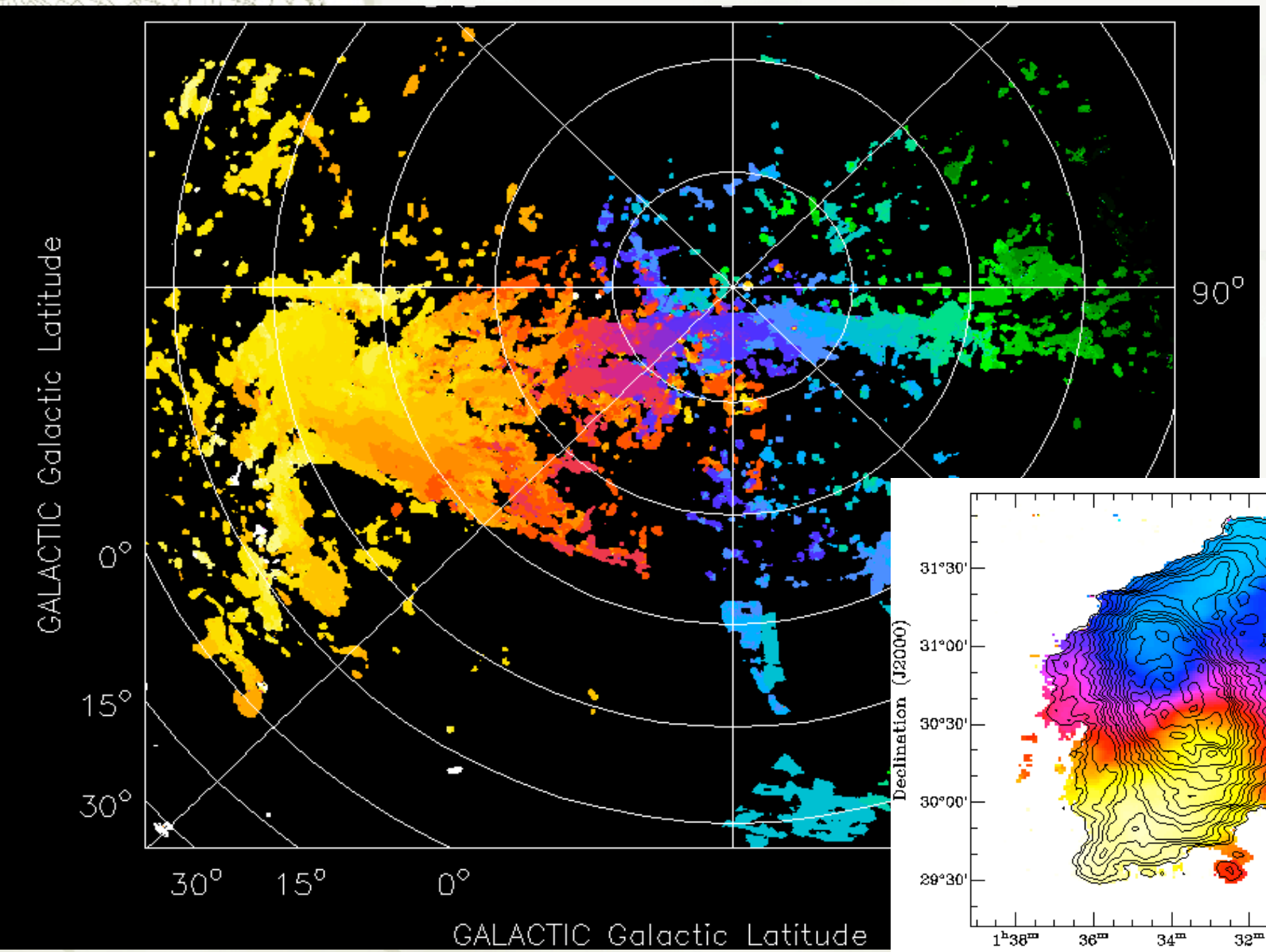
Stanimirovic, Putman, Peek et al. (2006)

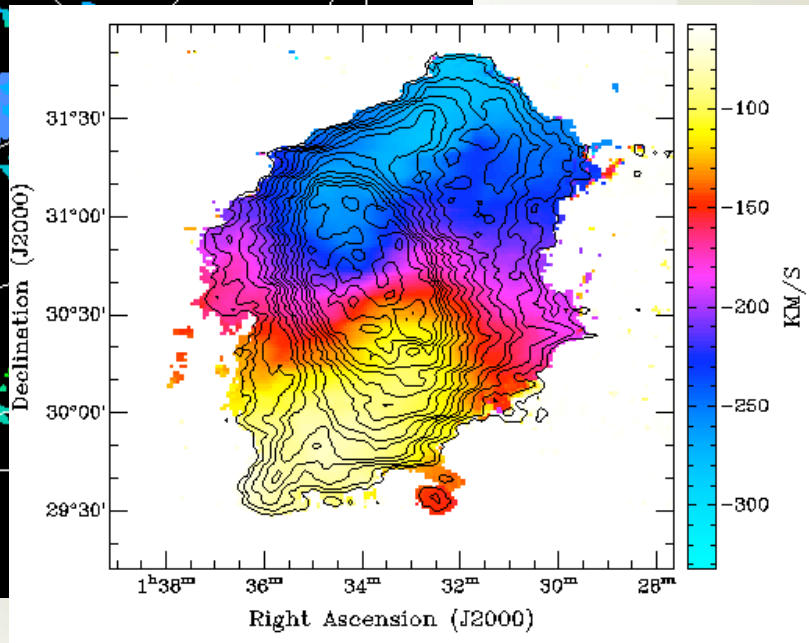
Total Intensity Maps



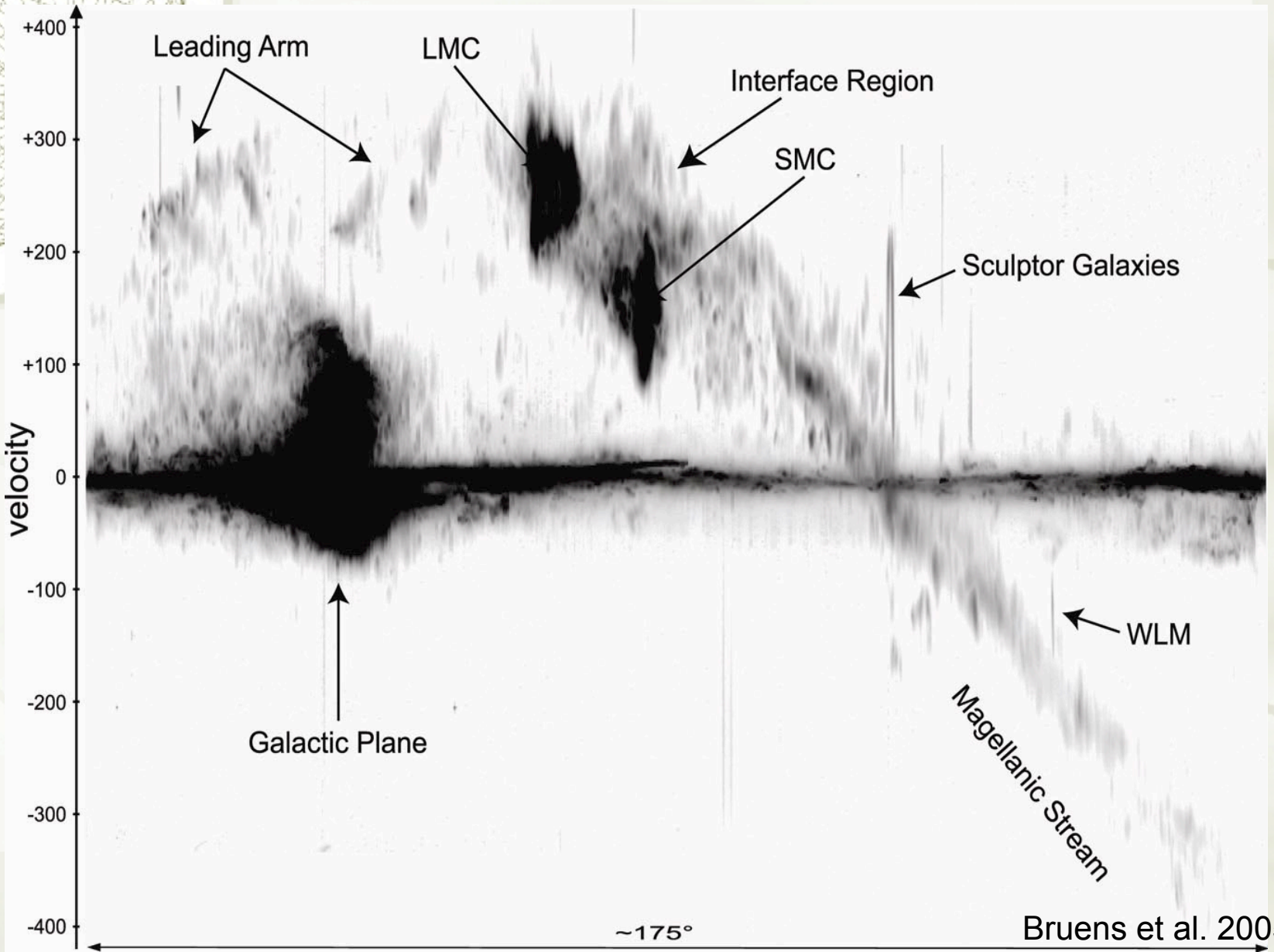
Putman et al. (2003)

Velocity Maps



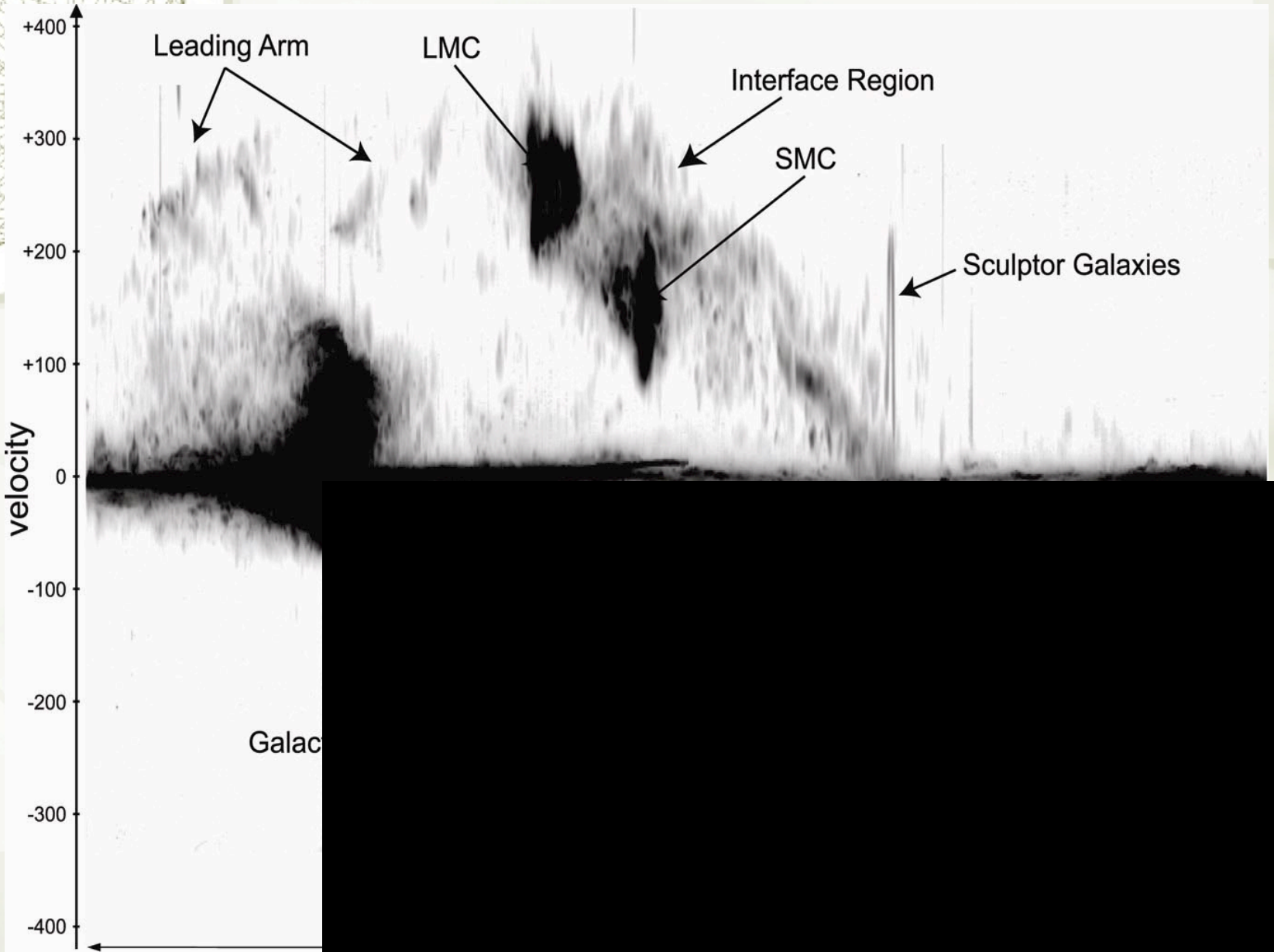


Position-Velocity Maps



Bruens et al. 2005

Position-Velocity Maps

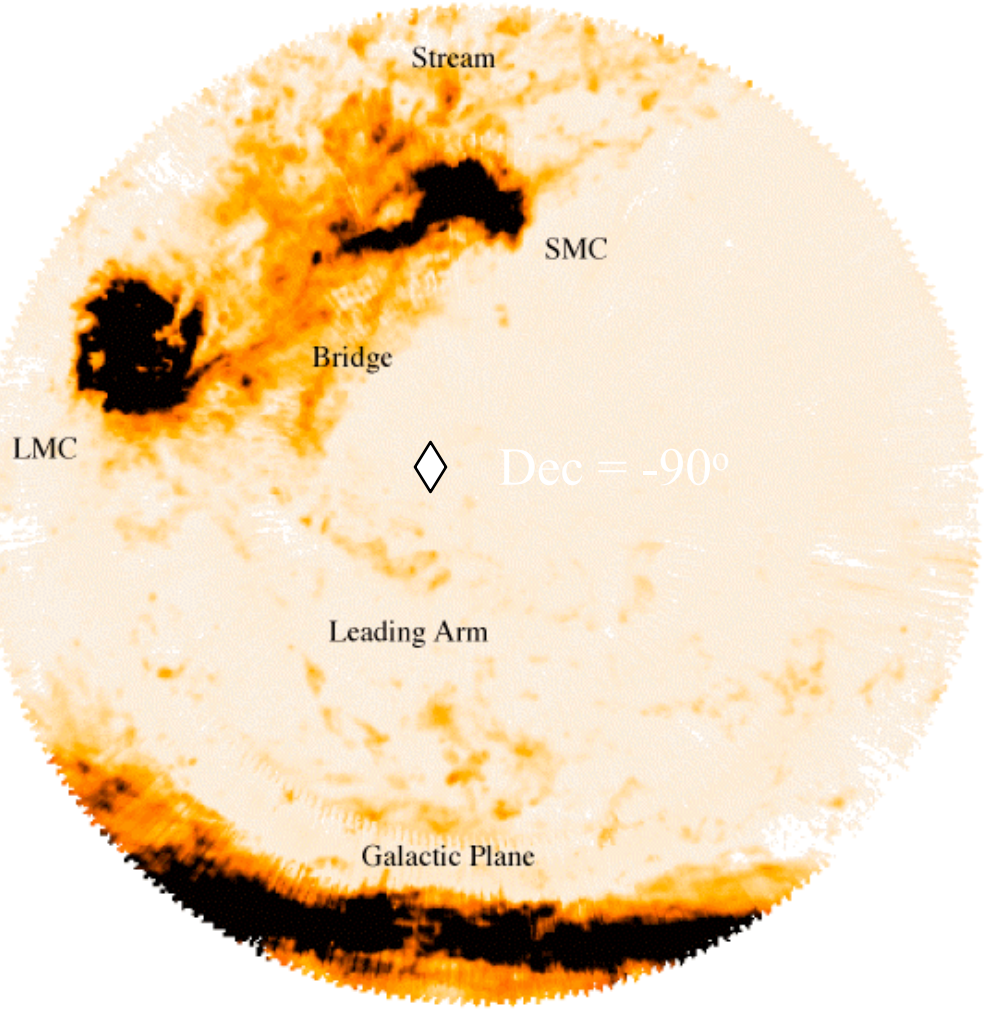


All-sky/Large Area Surveys

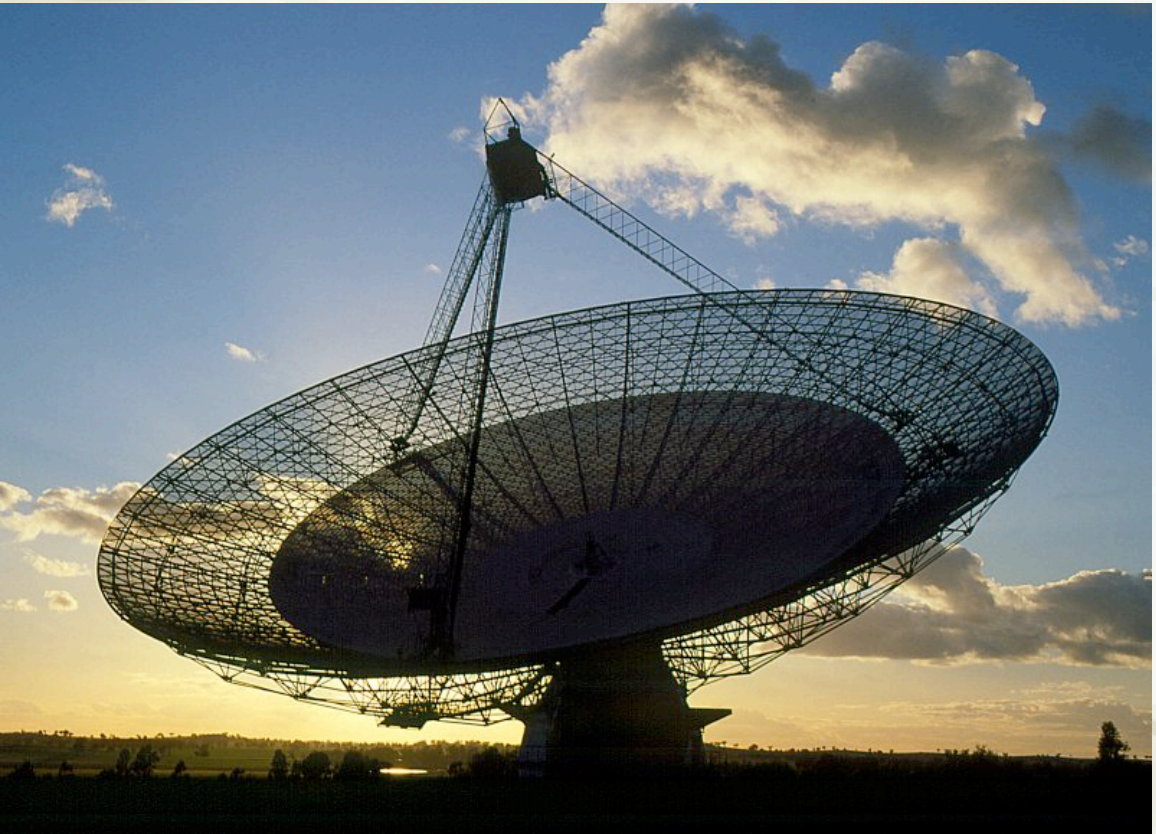
- Gaseous galaxy distribution up to z~0.06
- Gas in the Galaxy, Galactic Halo and Local Group

- Made possible with famous telescopes and the installation of multibeam receivers
  - e.g., A 2500 deg^2 area can be mapped to the same sensitivity in 2 months instead of 1.5 years

2500 deg^2



HI Parkes All-Sky Survey (HIPASS)



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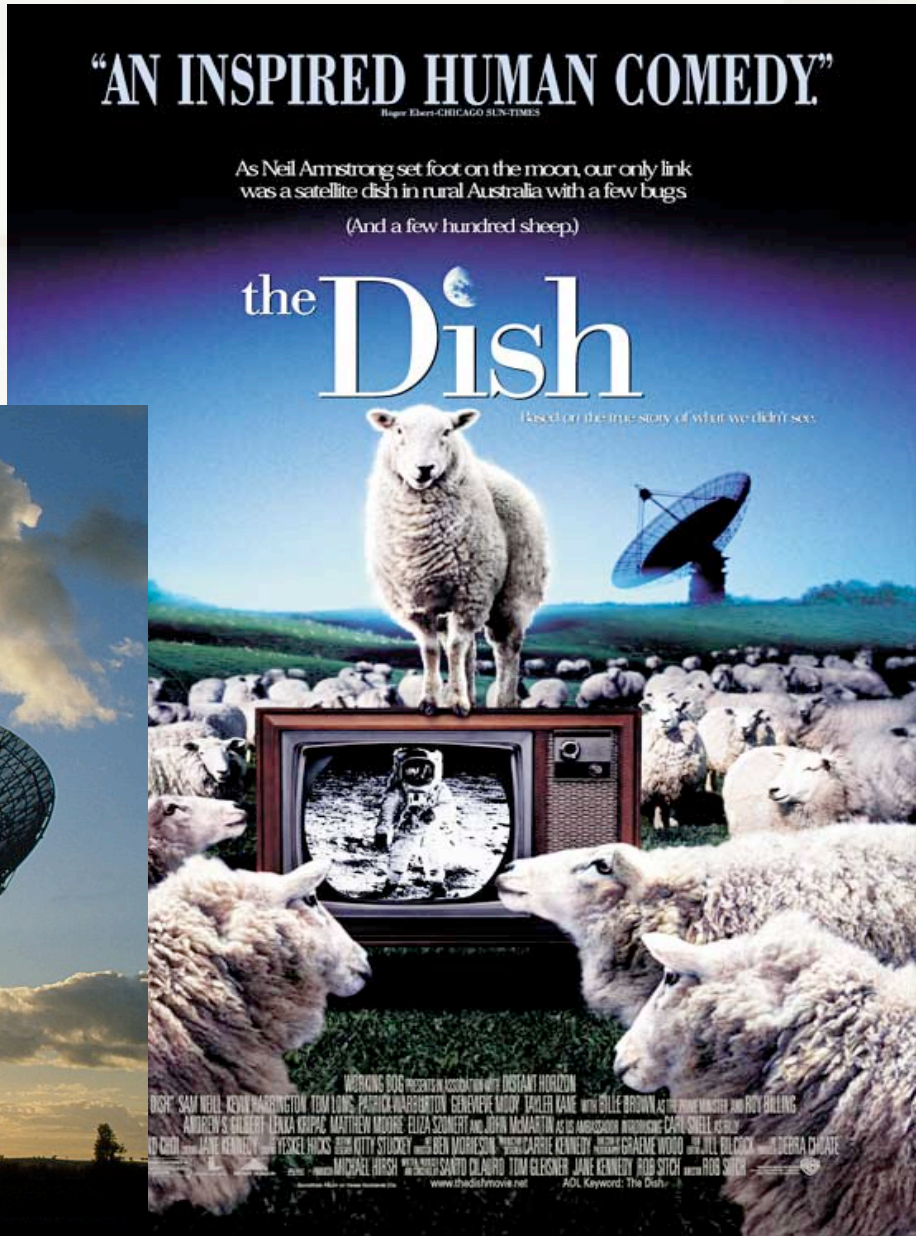
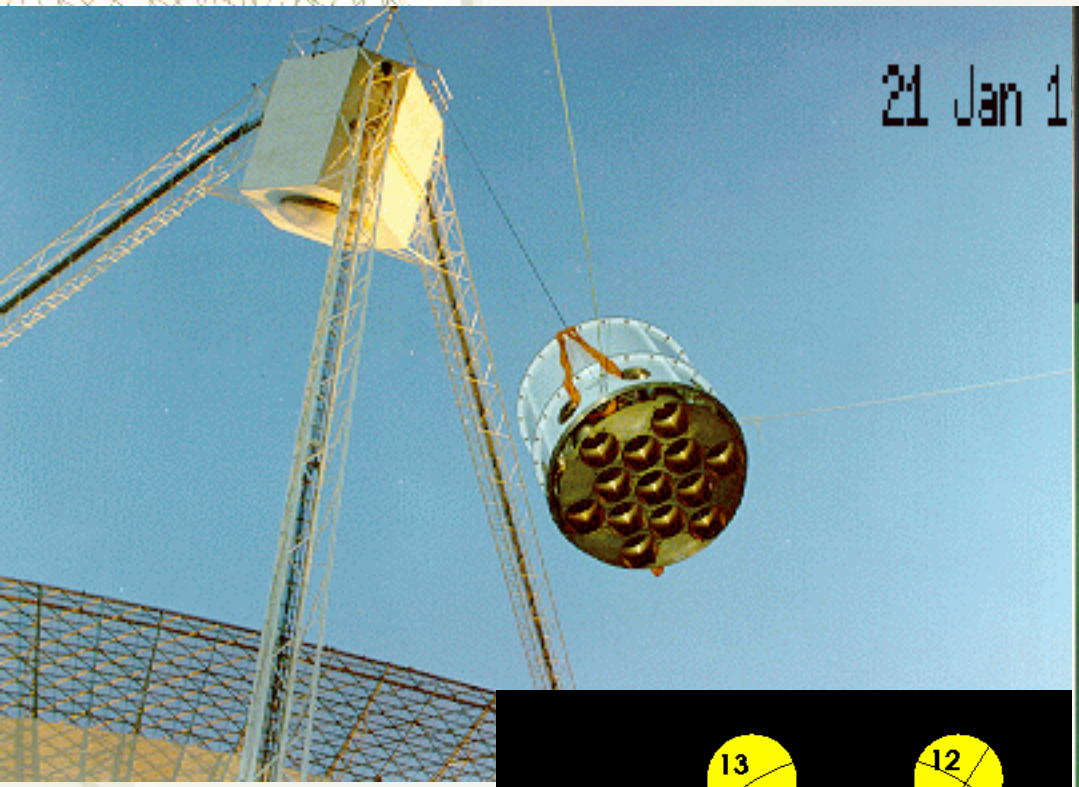
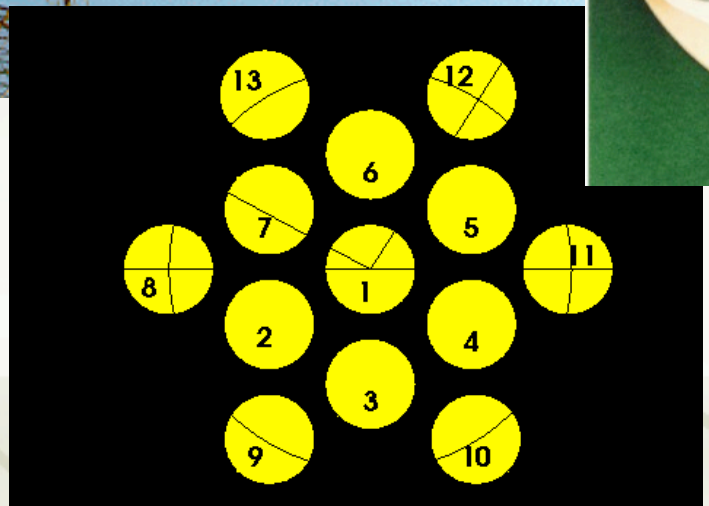


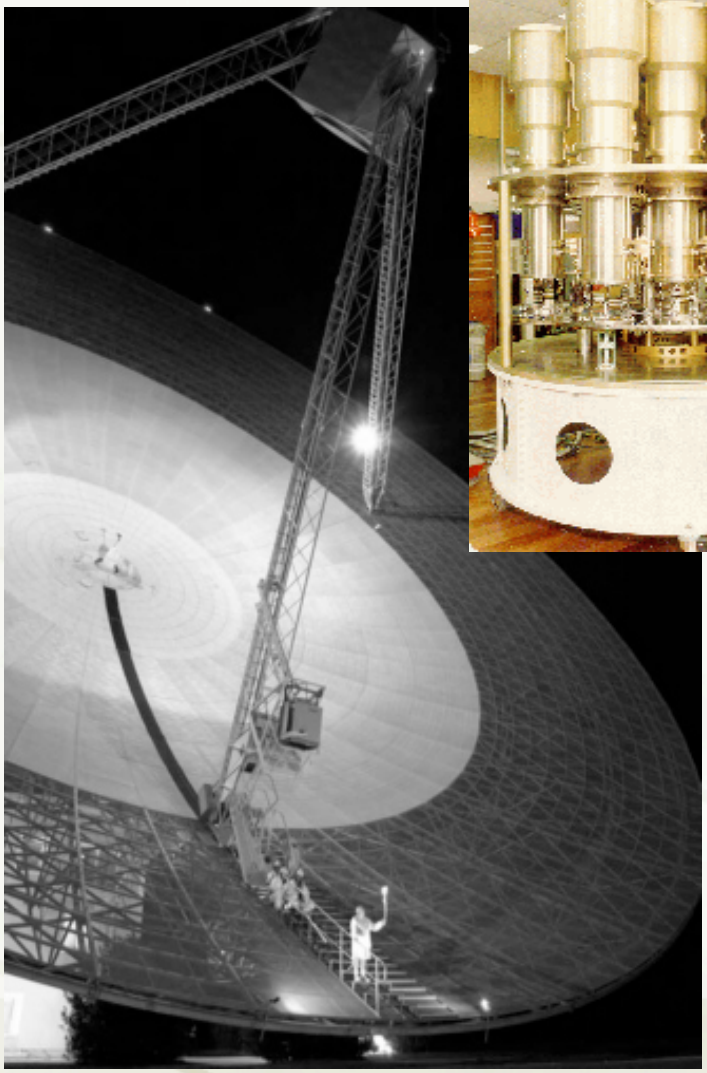
13-beam Focal Plane Array





HIPASS (HI Parkes All-Sky Survey)

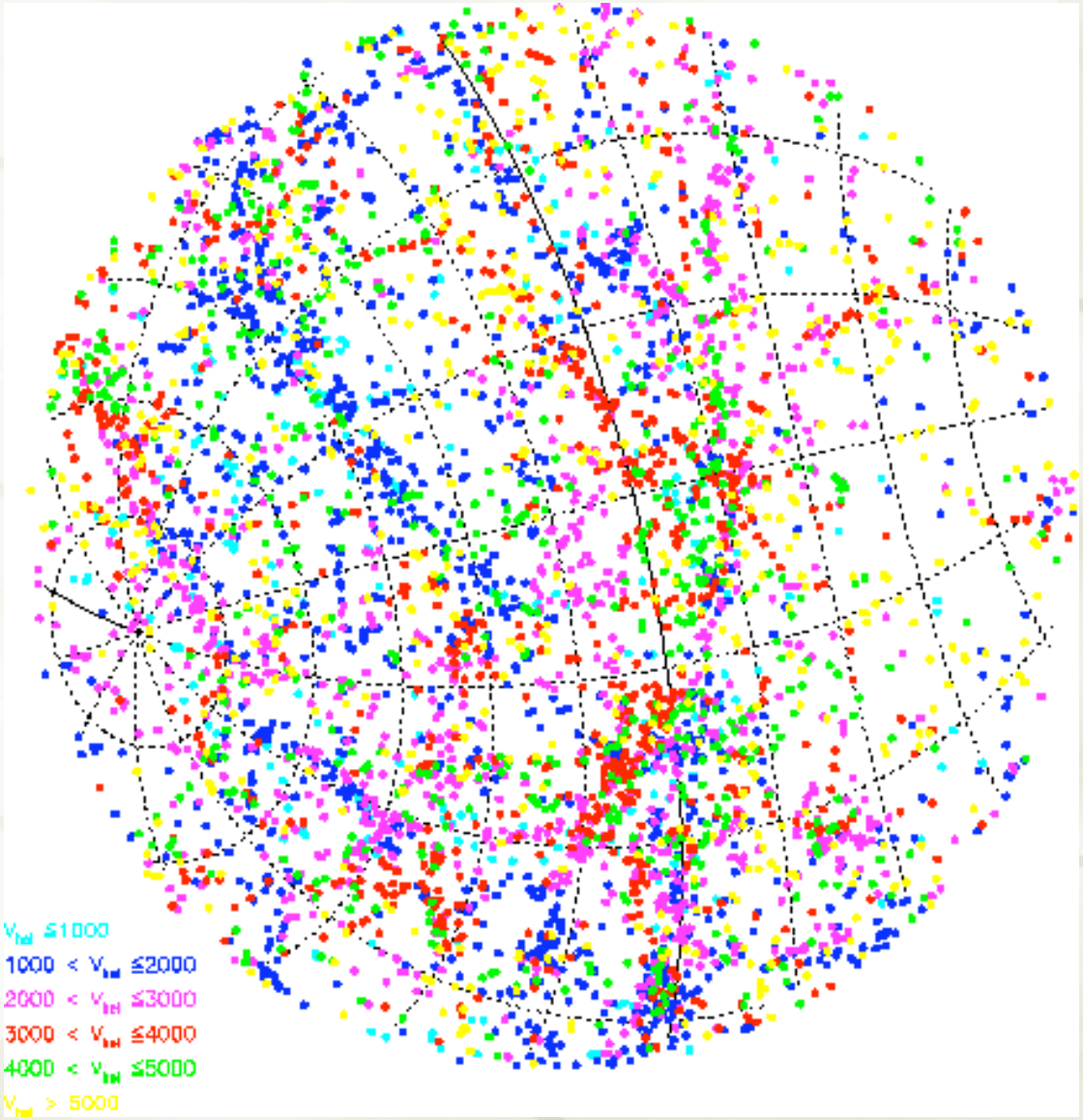
- Decl. Range = –90 to +25
- Vel. Range = -1200 to 12700 km/s
- Resolution = 15.5’ and 18 km/s
- N_{HI} (5σ) = 2.2 x 10^{18} cm^{-2}
- M_{HI} (5σ) = 10^3 M_0 (50 kpc),
  10^6 M_0 (1 Mpc)
- 5 years of observations
  (see Barnes et al. (2001) for obs. and data reduction paper)
- Public data http://www.atnf.csiro.au/research/multibeam/release/



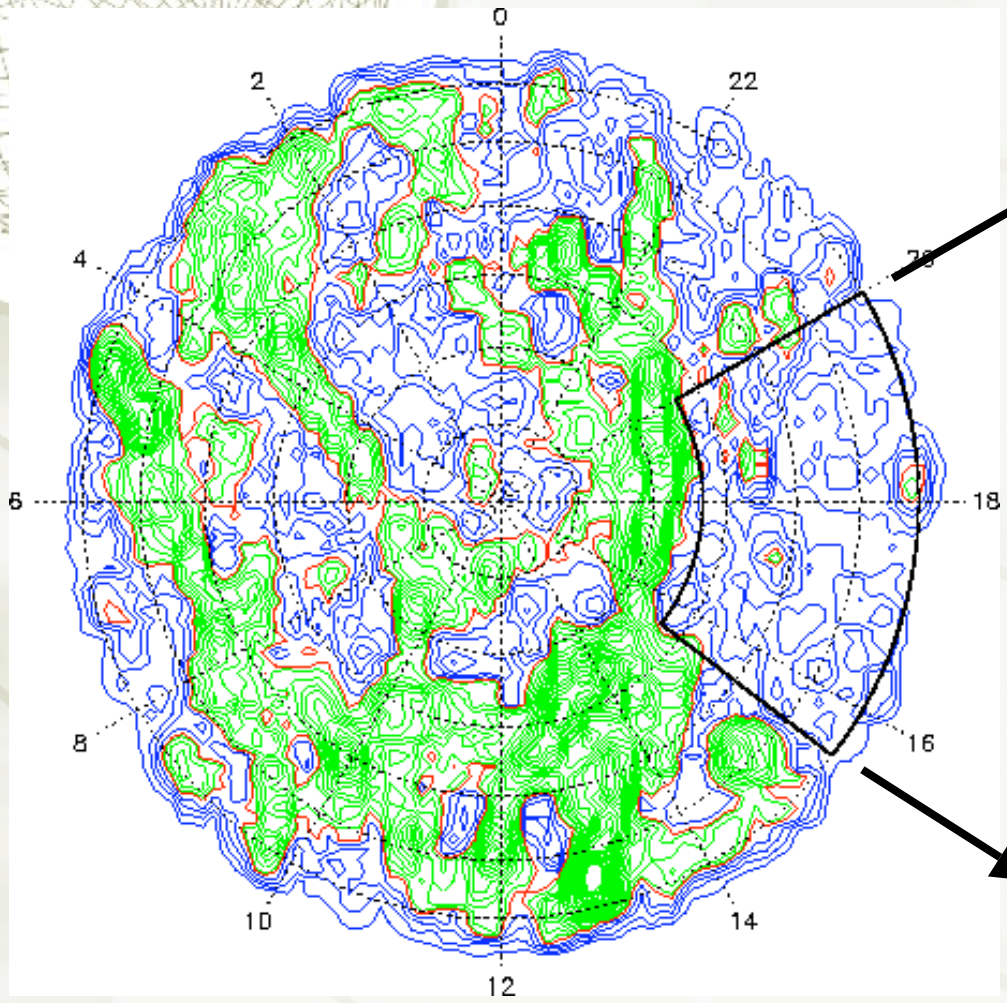
Galaxy Catalog

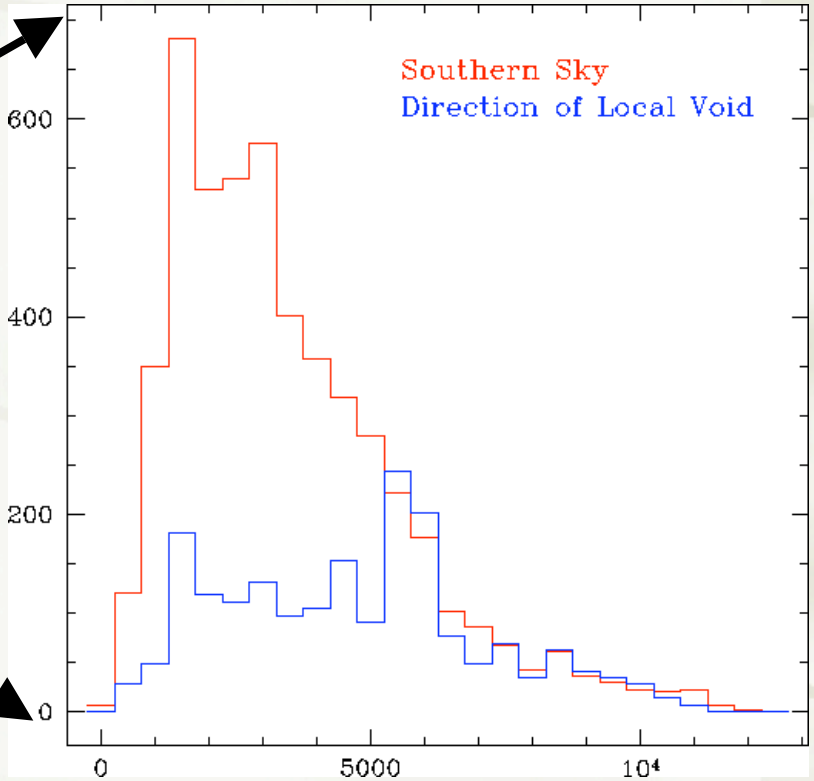
~7000 galaxies
(Meyer et al. 2004; Wong et al. 2006; Koribalski et al. 2004)

$V_{hel} \leq 1000$
$1000 \leq V_{hel} < 2000$
$2000 \leq V_{hel} < 3000$
$3000 \leq V_{hel} < 4000$
$4000 \leq V_{hel} < 5000$
$V_{hel} > 5000$



Large-Scale Structure: the Local/Sagittarius Void



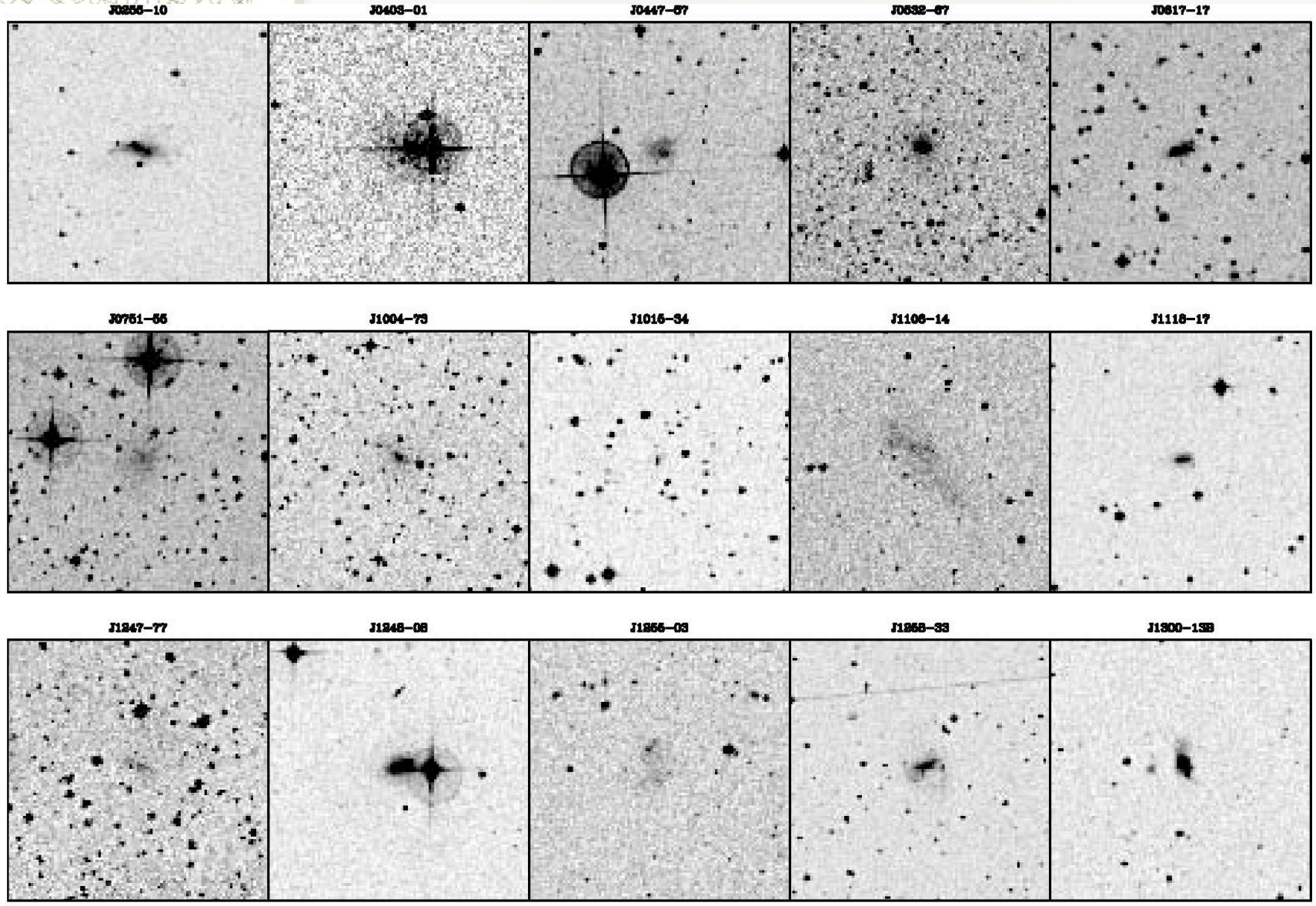


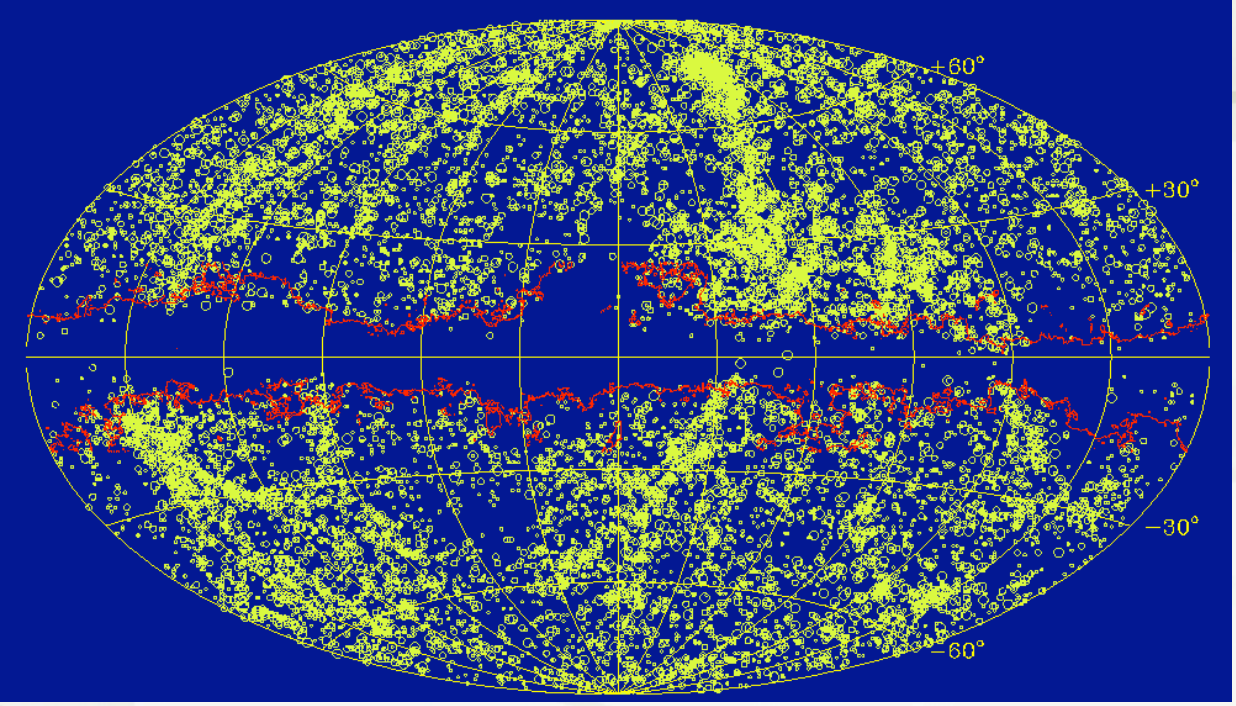
Breaks the Optical/IR selection bias

(Meyer et al. 2004; see also Saintonge et al. 2008)

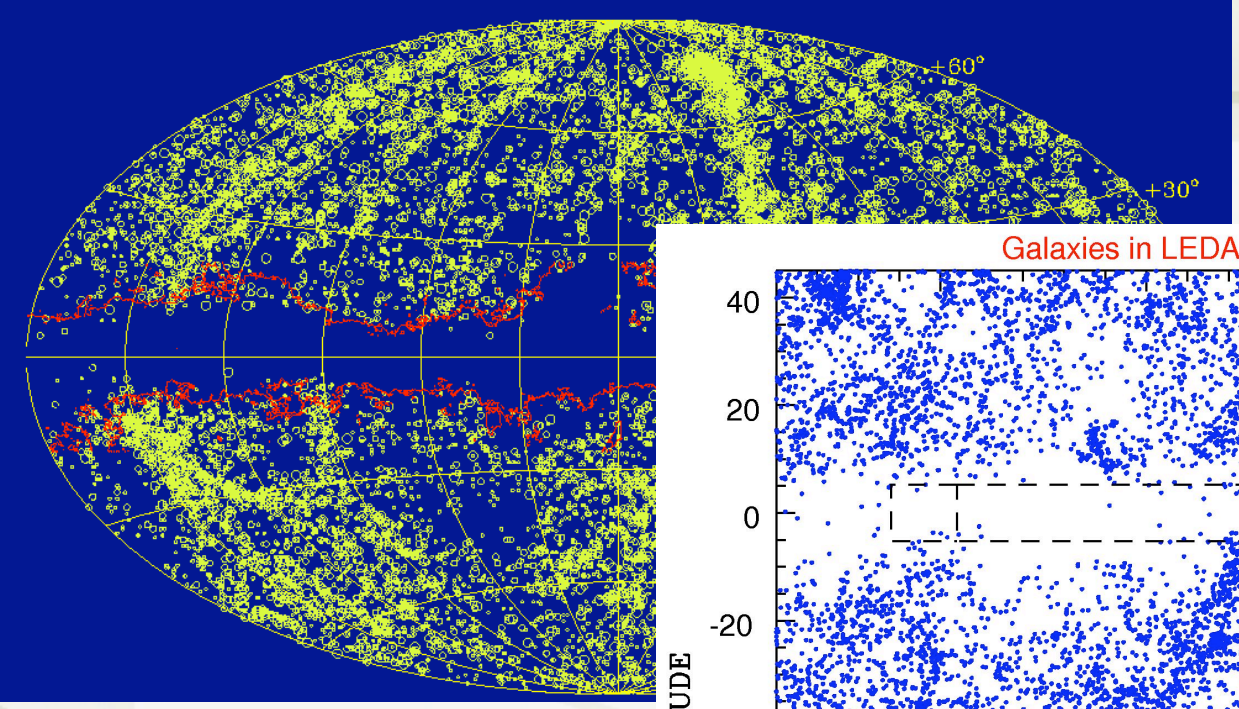
New HIPASS bright galaxies

Ryan-Weber et al. (2002)





Filling in the Zone of Avoidance (Henning, Kraan-Korteweg, Staveley-Smith et al.)



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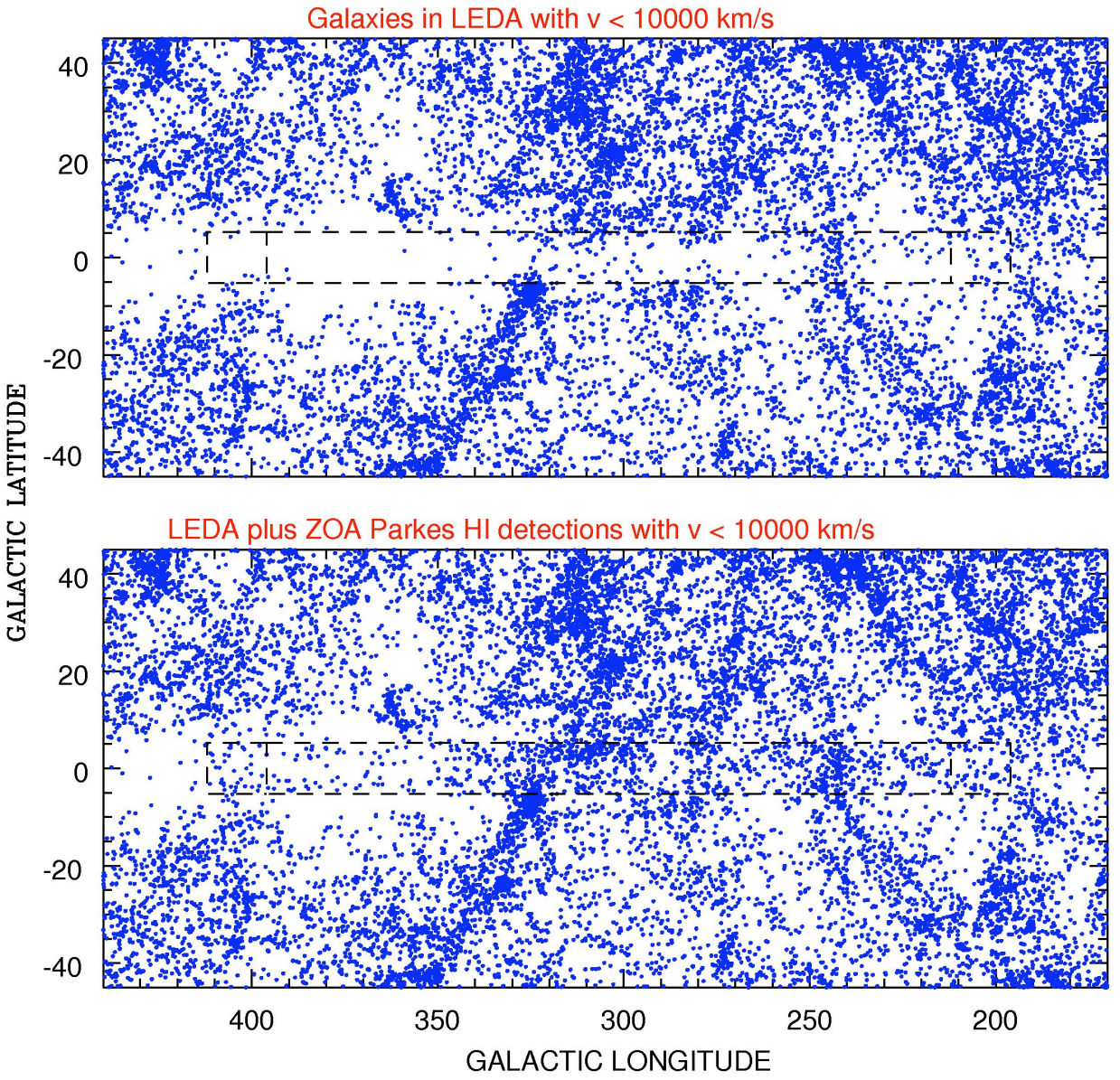
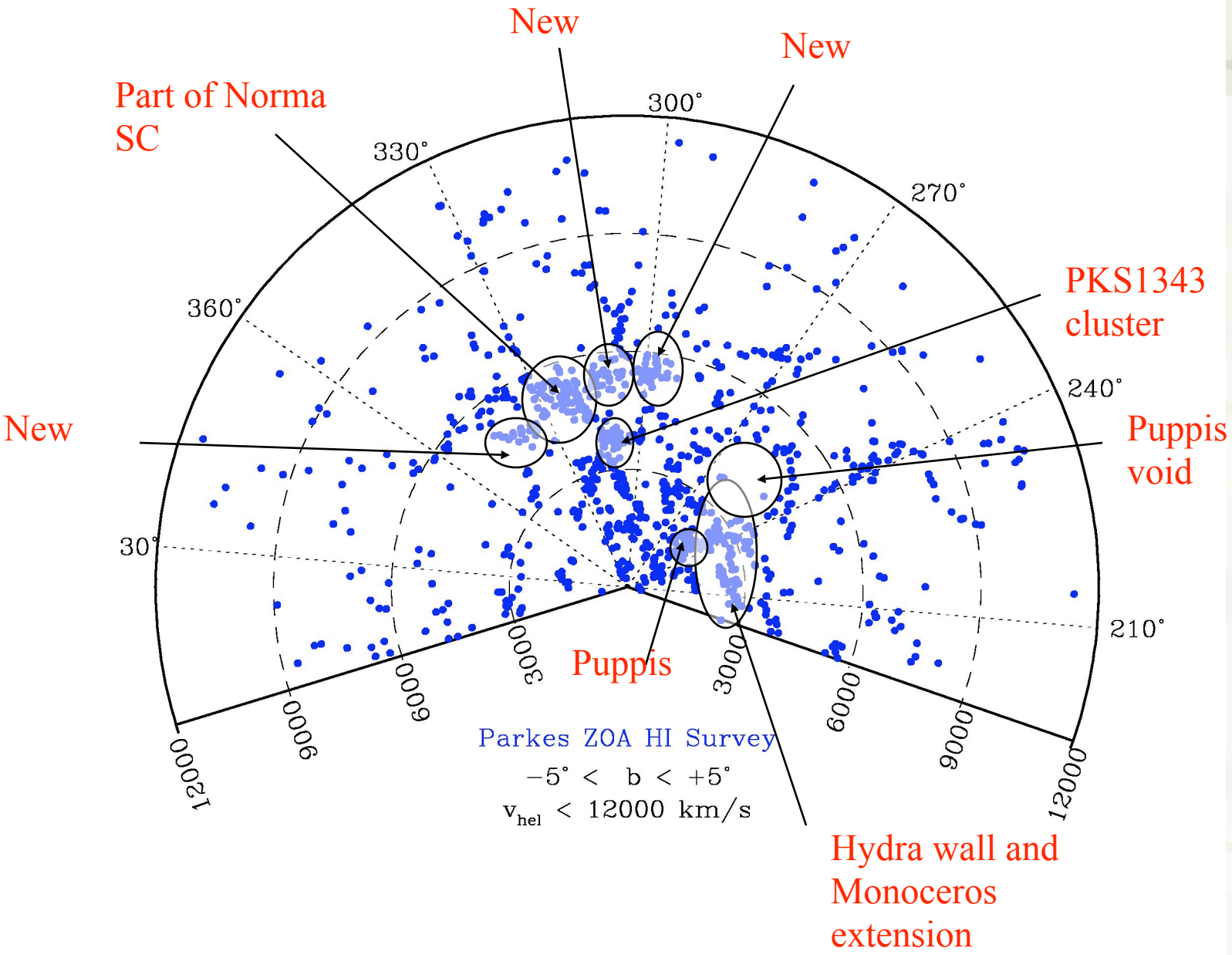
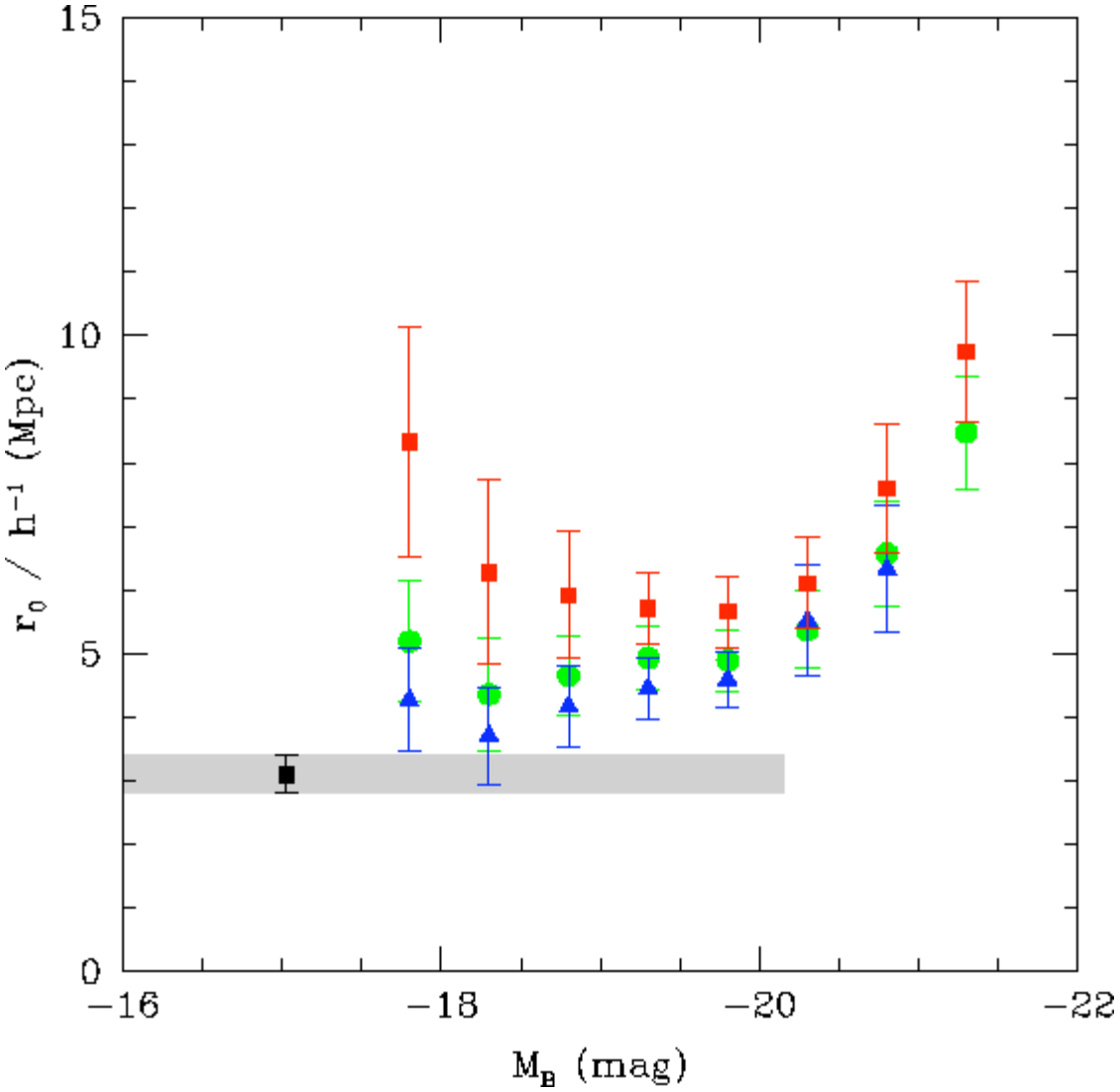



New
New
Part of Norma SC
300°
330°
270°
PKS1343 cluster
360°
240°
New
Puppis void
30°
210°
3000
6000
9000
12000
Puppis
Parkes ZOA HI Survey
−5° < b < +5°
v_hel < 12000 km/s
Hydra wall and Monoceros extension

Correlation Function Comparison

(Staveley-Smith et al.)



HIPASS

2dF – all spectral types

2dF – early type

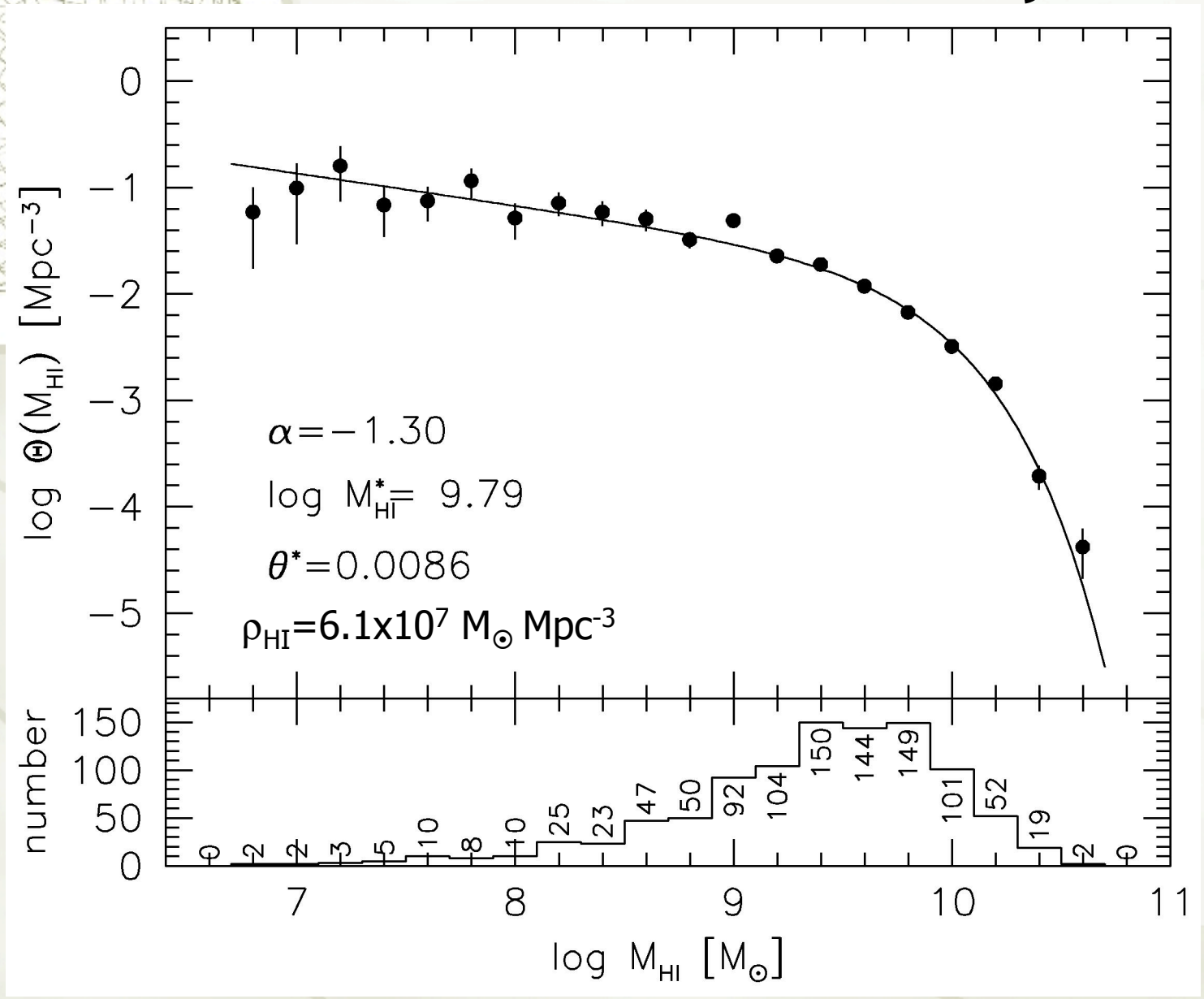
2dF – late type

(Norberg et. al. 2002)

Results from the Correlation Functions

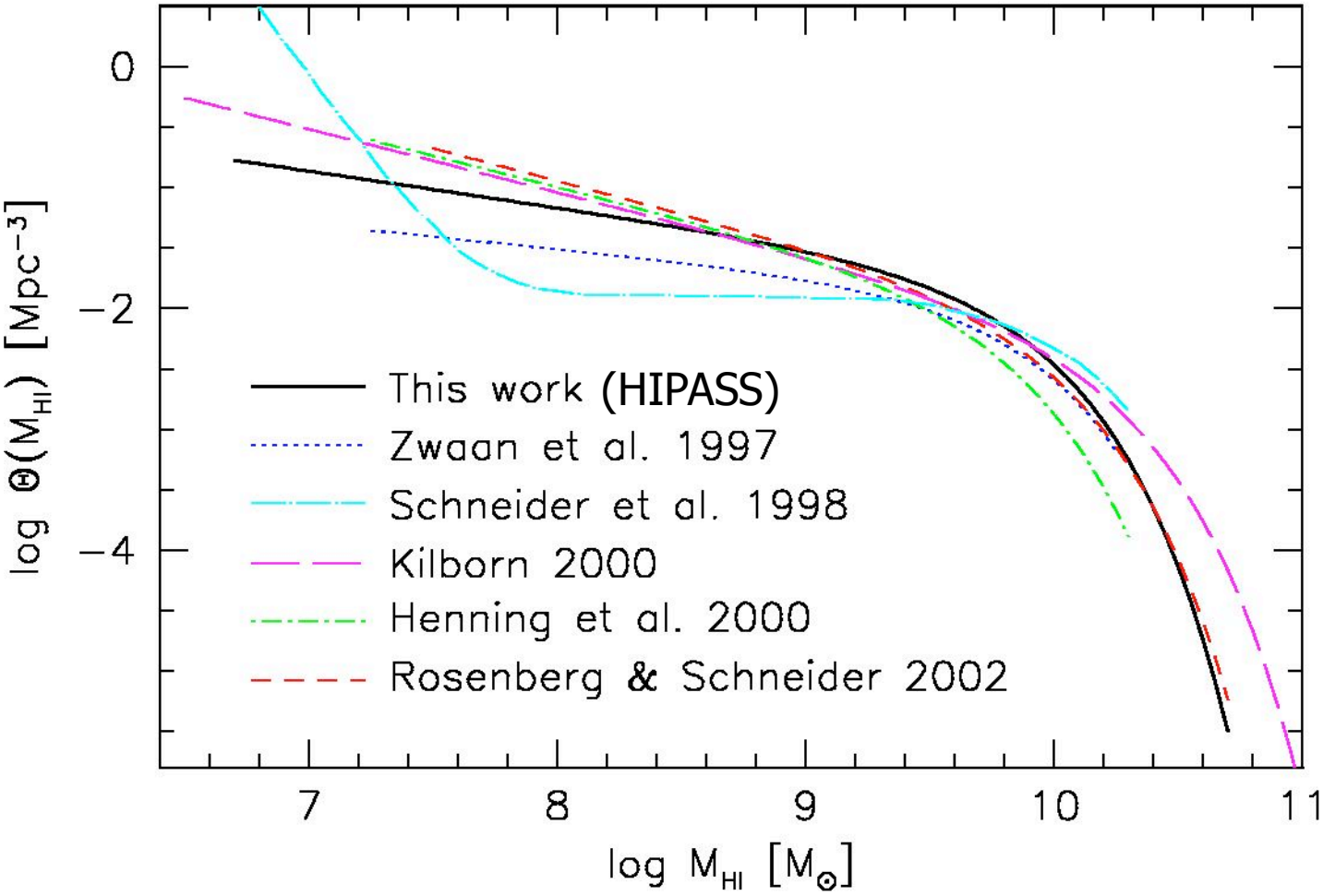
- HI-rich galaxies **less clustered** than 2dF galaxies
  - but within the errors of the late-type galaxies.
- HIPASS galaxies probably anti-biased – i.e. less clustered than underlying dark matter.
- HI-rich galaxies avoid the densest regions.
  - possibly HI-rich galaxies collapse late in low-medium density peaks in the initial density field.
  - possibly environmental effects deplete HI.

HIPASS HI mass function

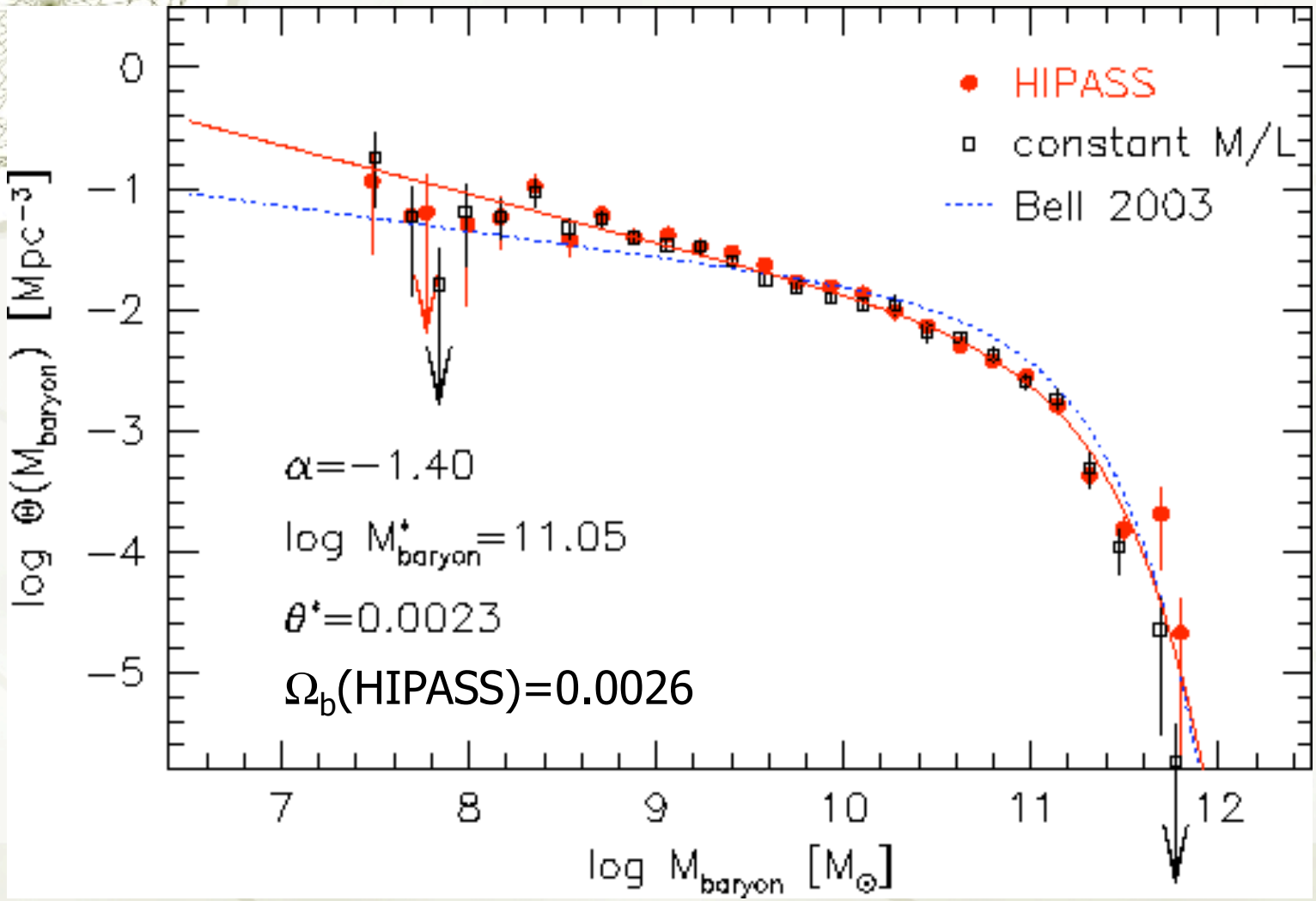


Zwaan et al.

Comparison with previous work



HIPASS baryonic mass function gives combined stellar+gas density

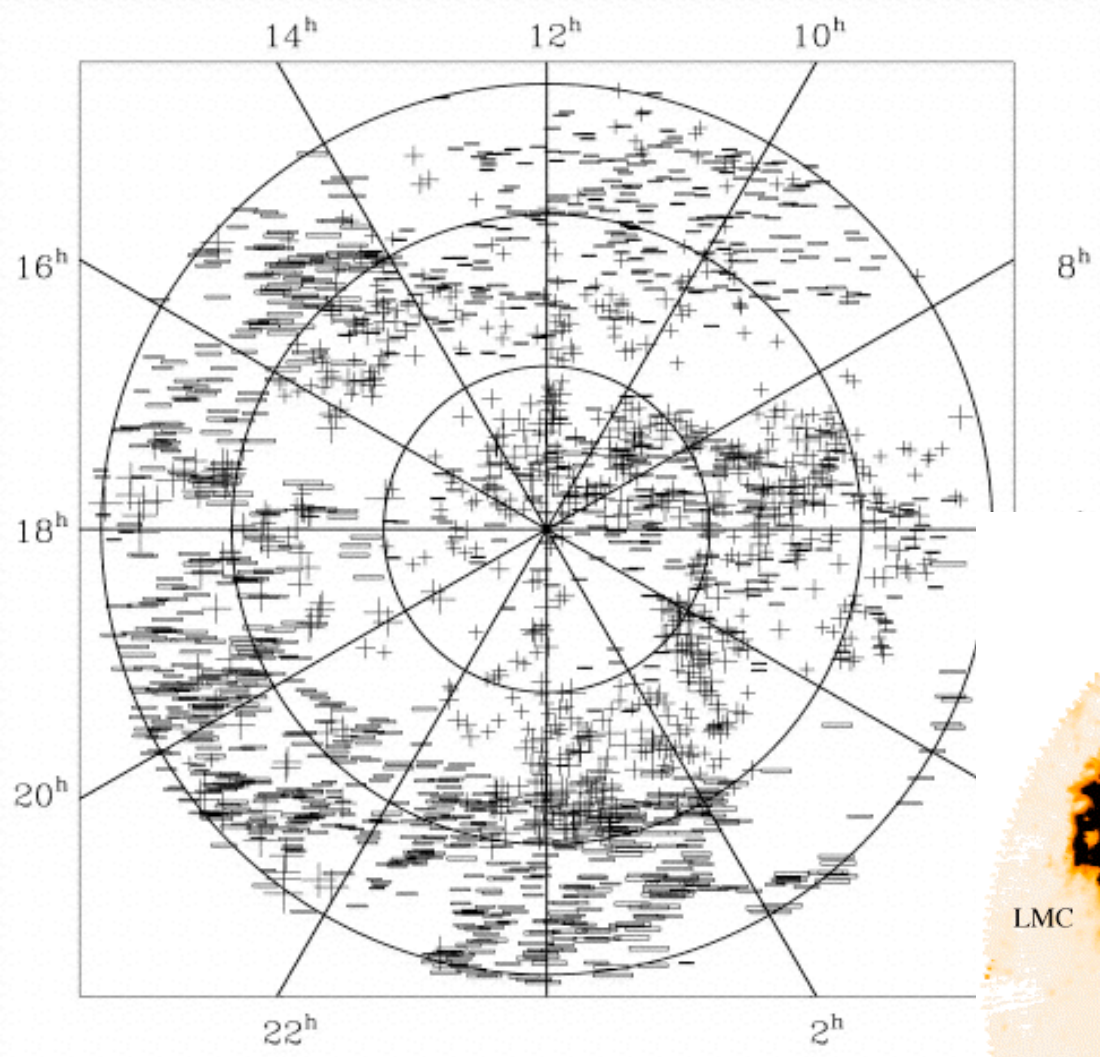


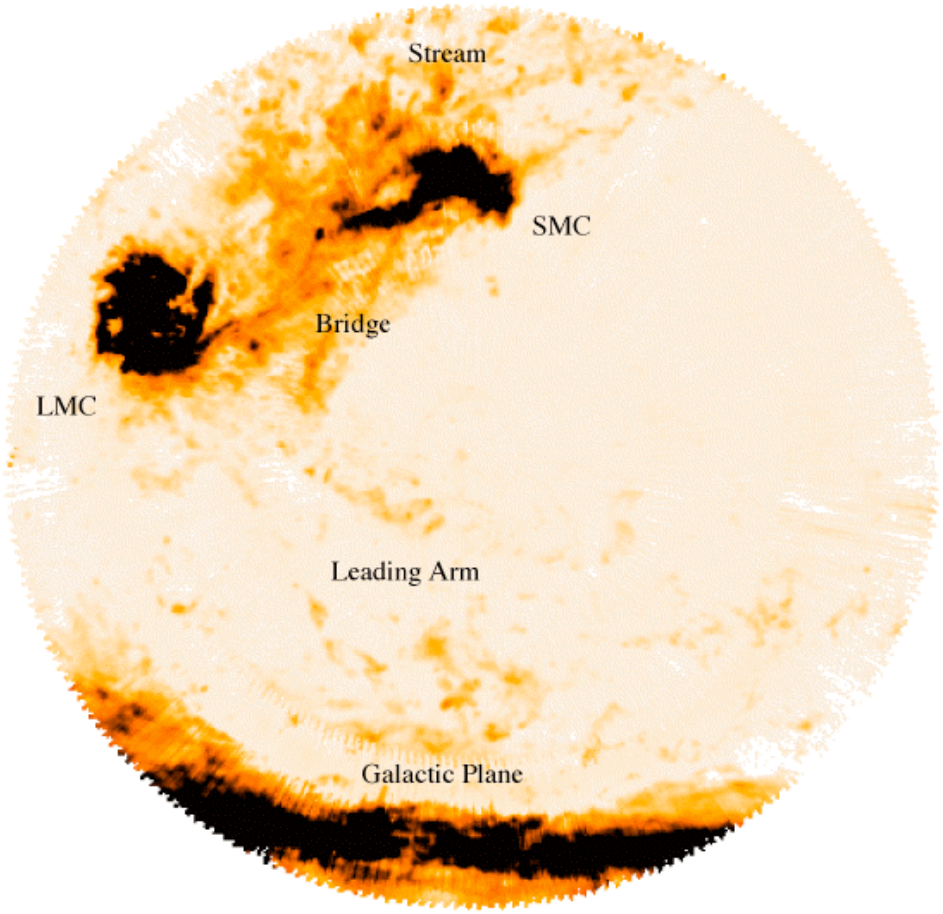
Results from the HI mass function

- z=0 HI density pinned down
  - $\Omega_{HI}=(3.8\pm0.6)\times10^{-4}$
- No vast HI reservoir in LSB galaxies.
- Ω_{HI} dominated by M* galaxies.
- Damped Ly-α absorbers dominated by sub-M* galaxies.
- No significant source of baryons not traced by HI surveys (even ellipticals)

HIPASS Halo Cloud Catalogs and Images

- Over 2000 Halo Clouds (Putman et al. 2002)





- Interaction of Magellanic Clouds (Putman et al. 2003; 1998)

Reveals Interaction With the Halo medium for a Large number of Clouds

Sims by F. Heitsch

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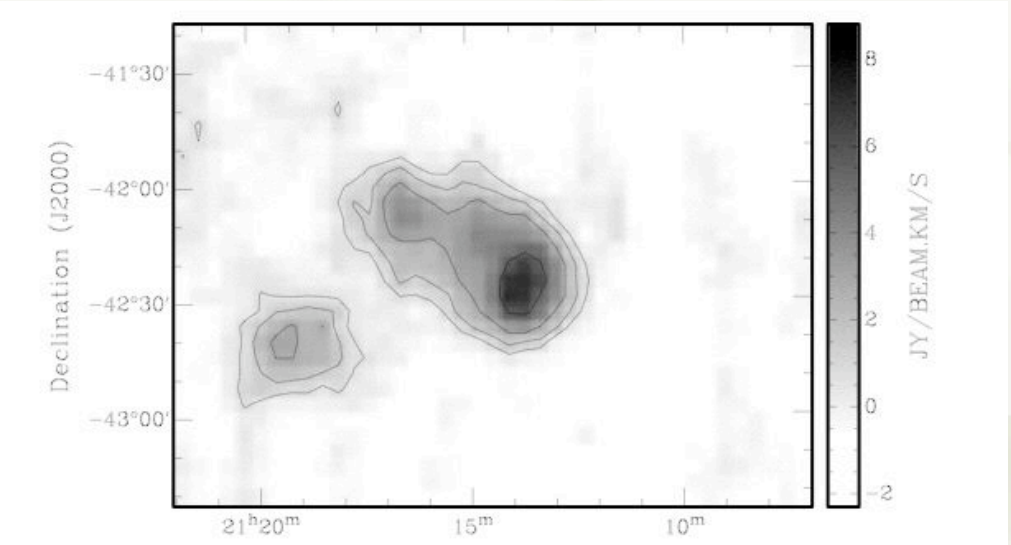

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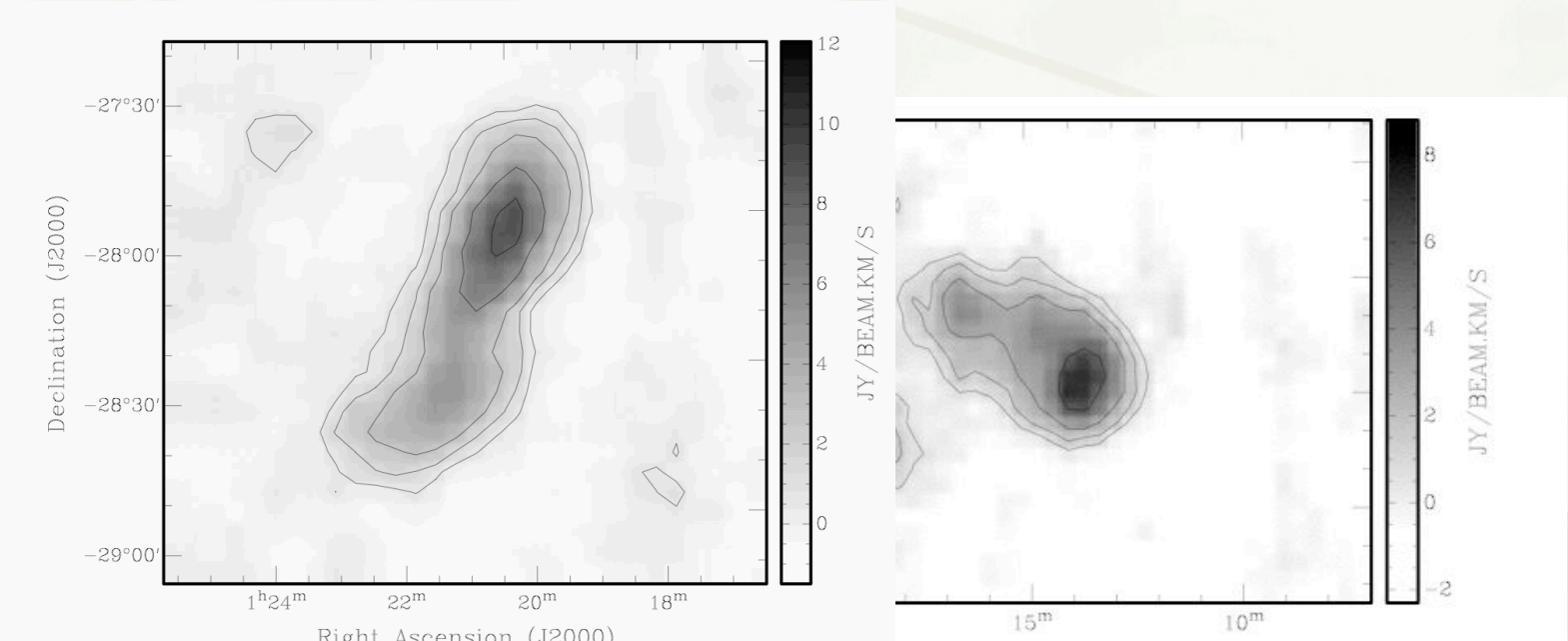

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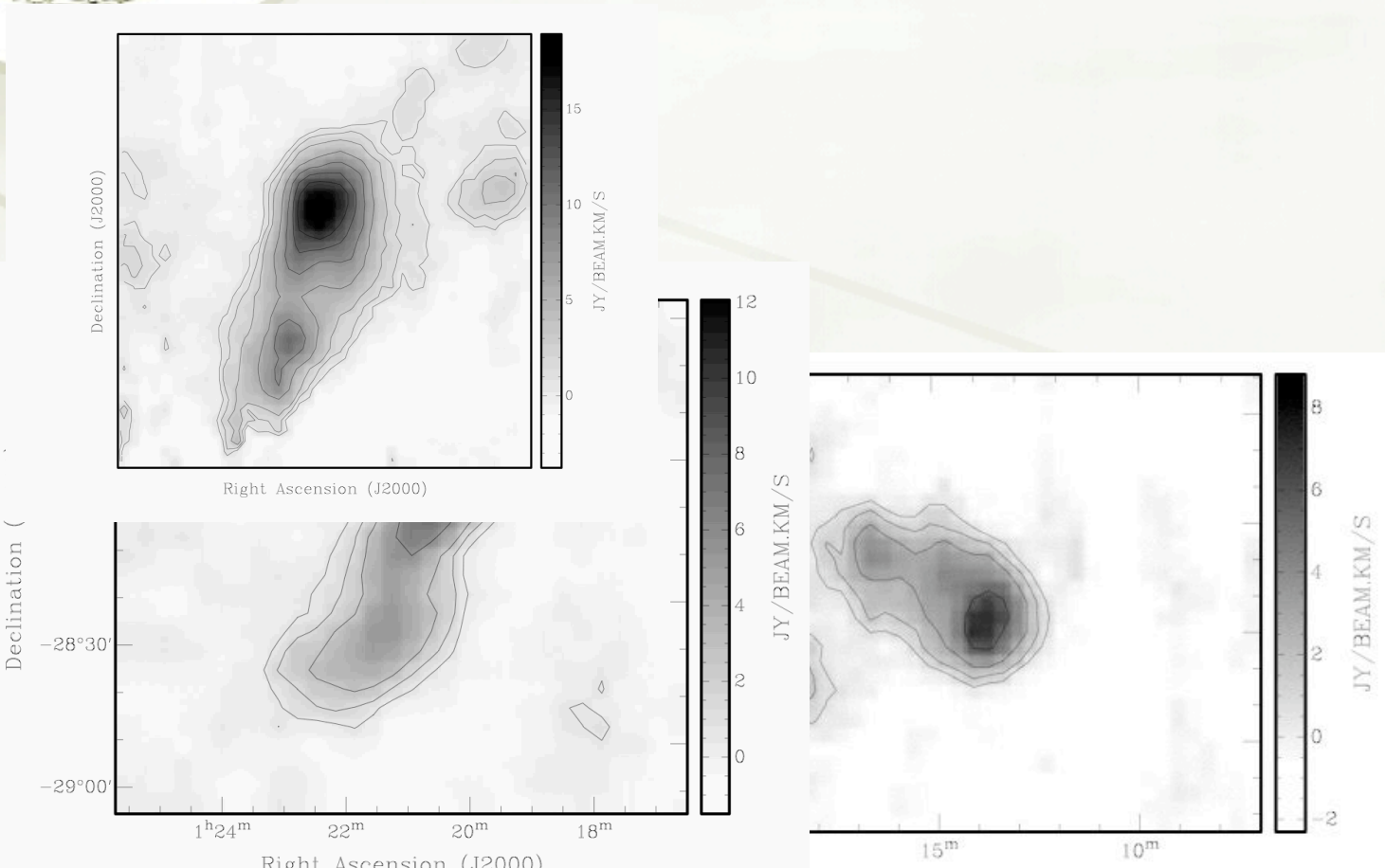

Reveals Interaction With the Halo medium for a Large number of Clouds

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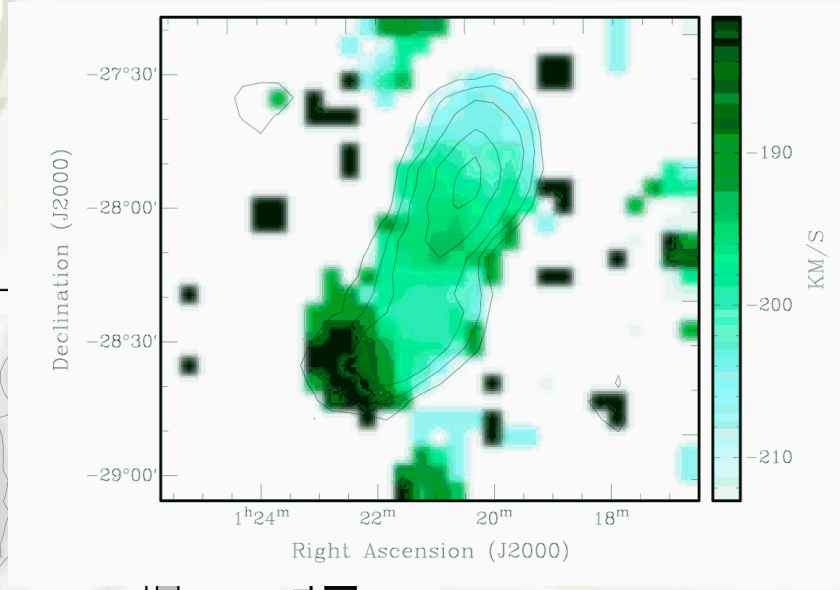

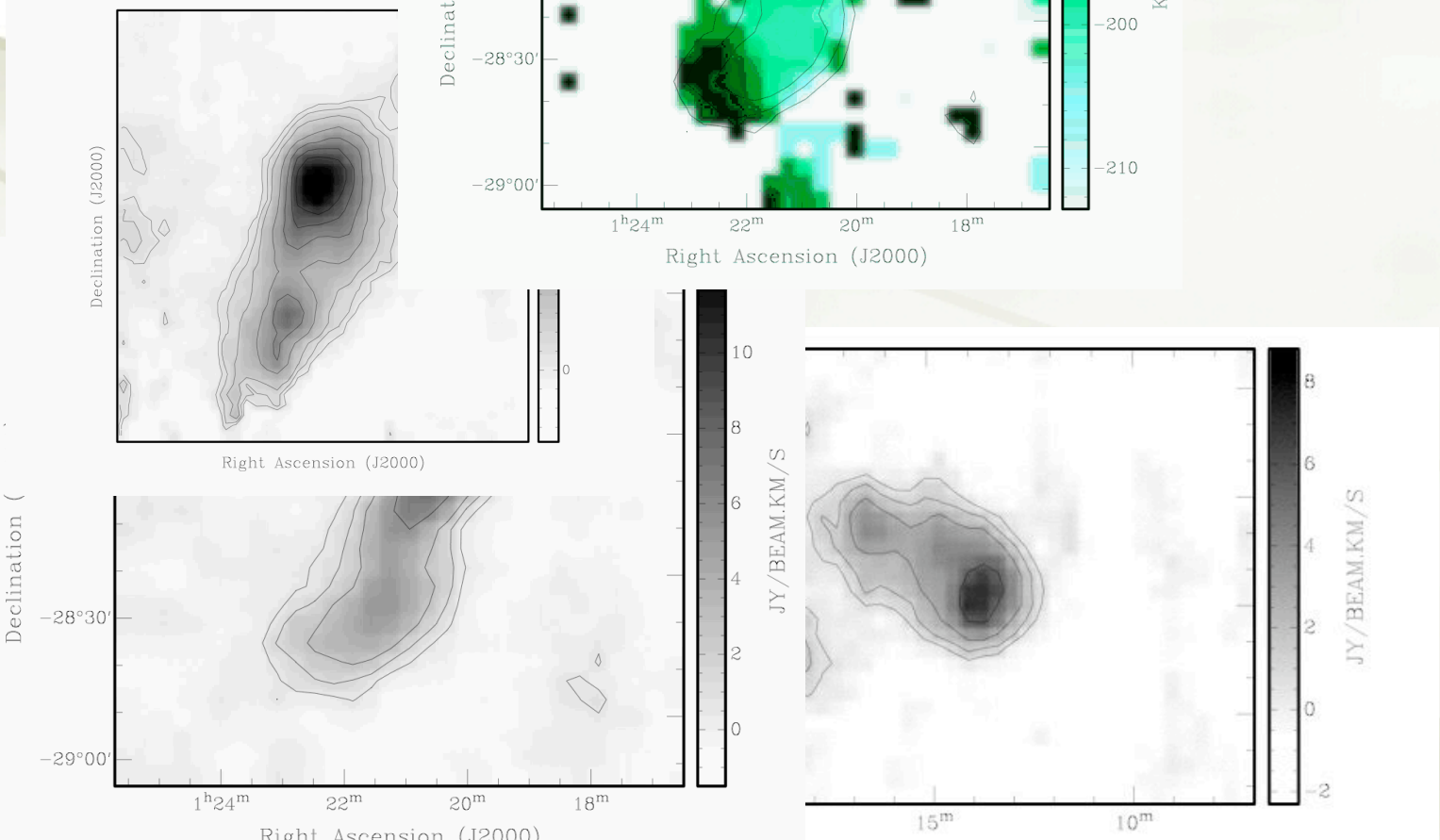

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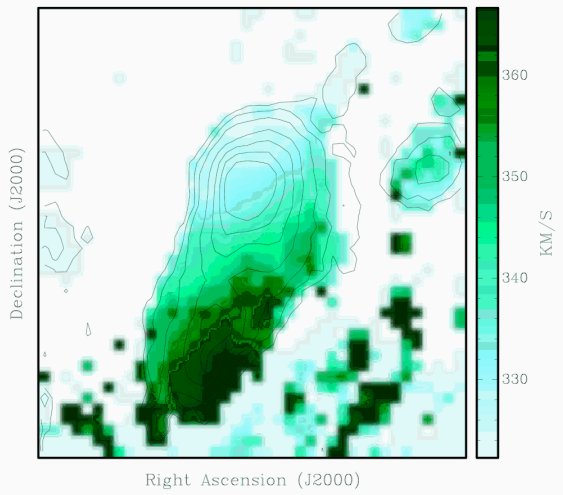

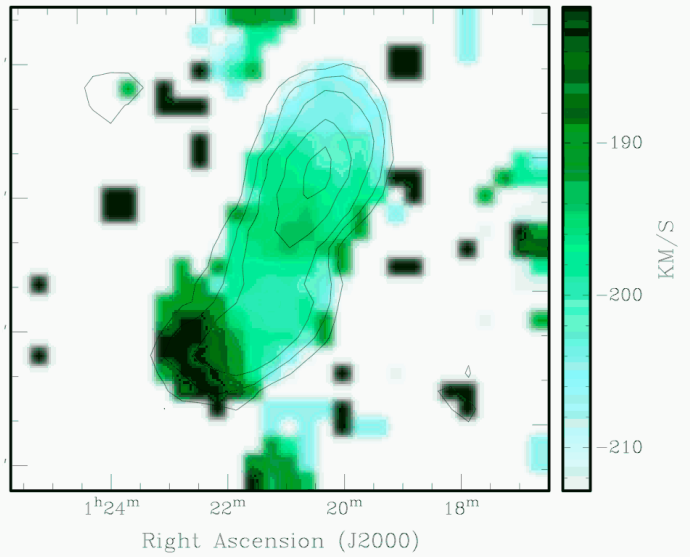

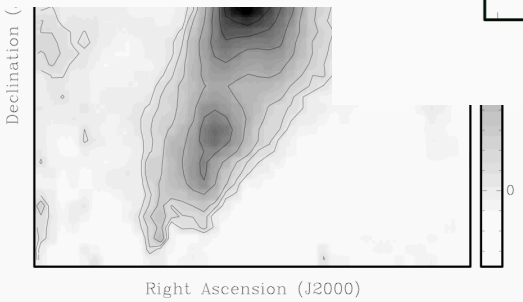

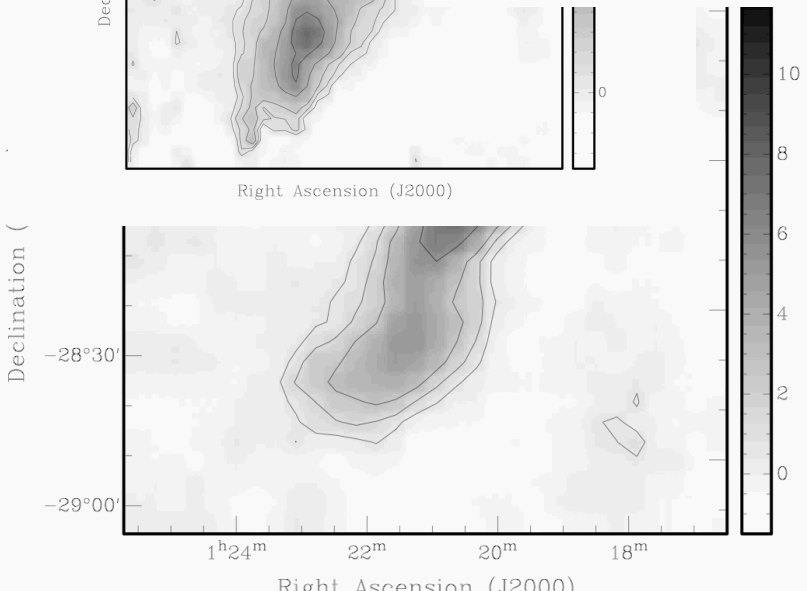

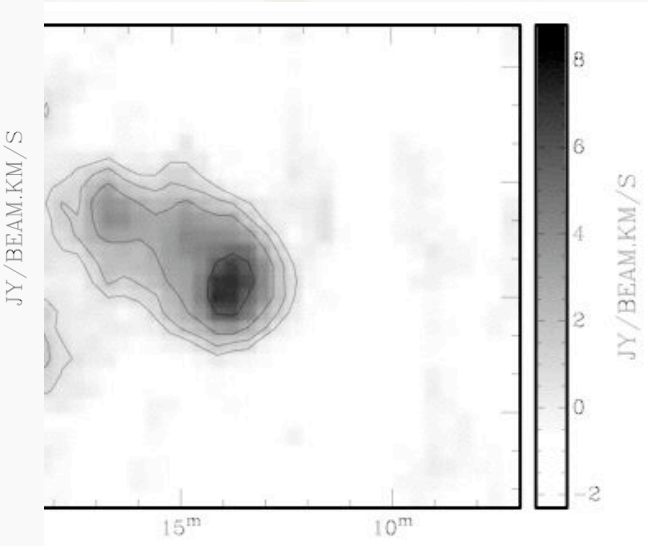

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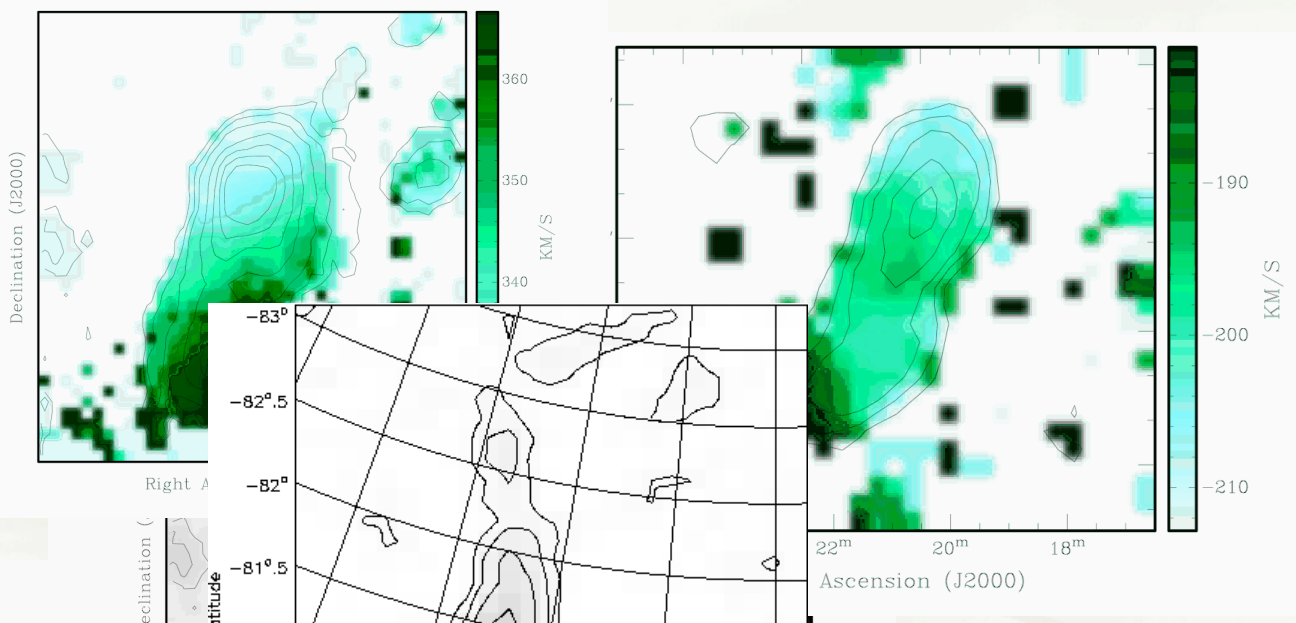

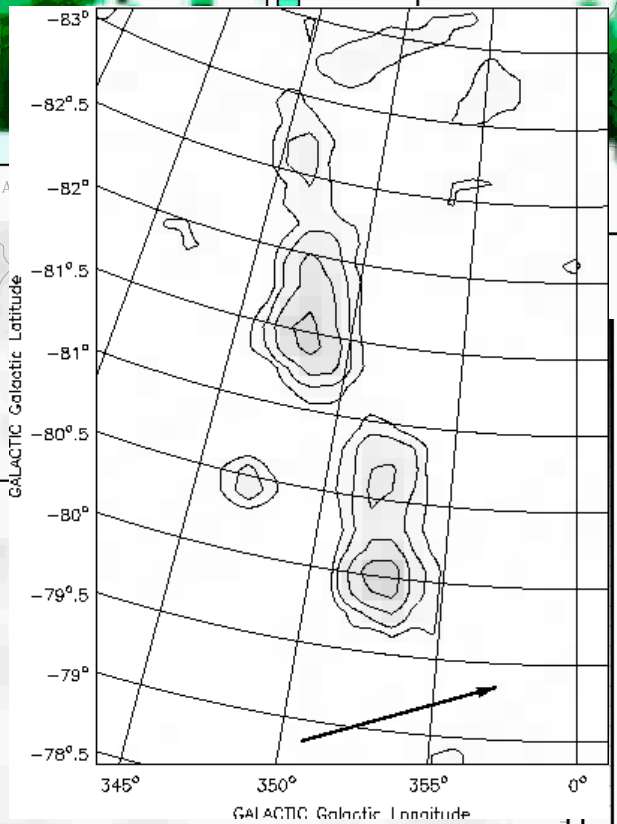

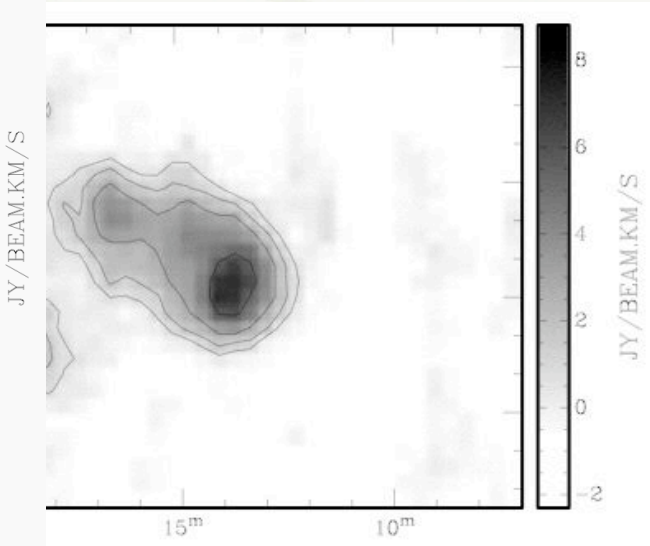

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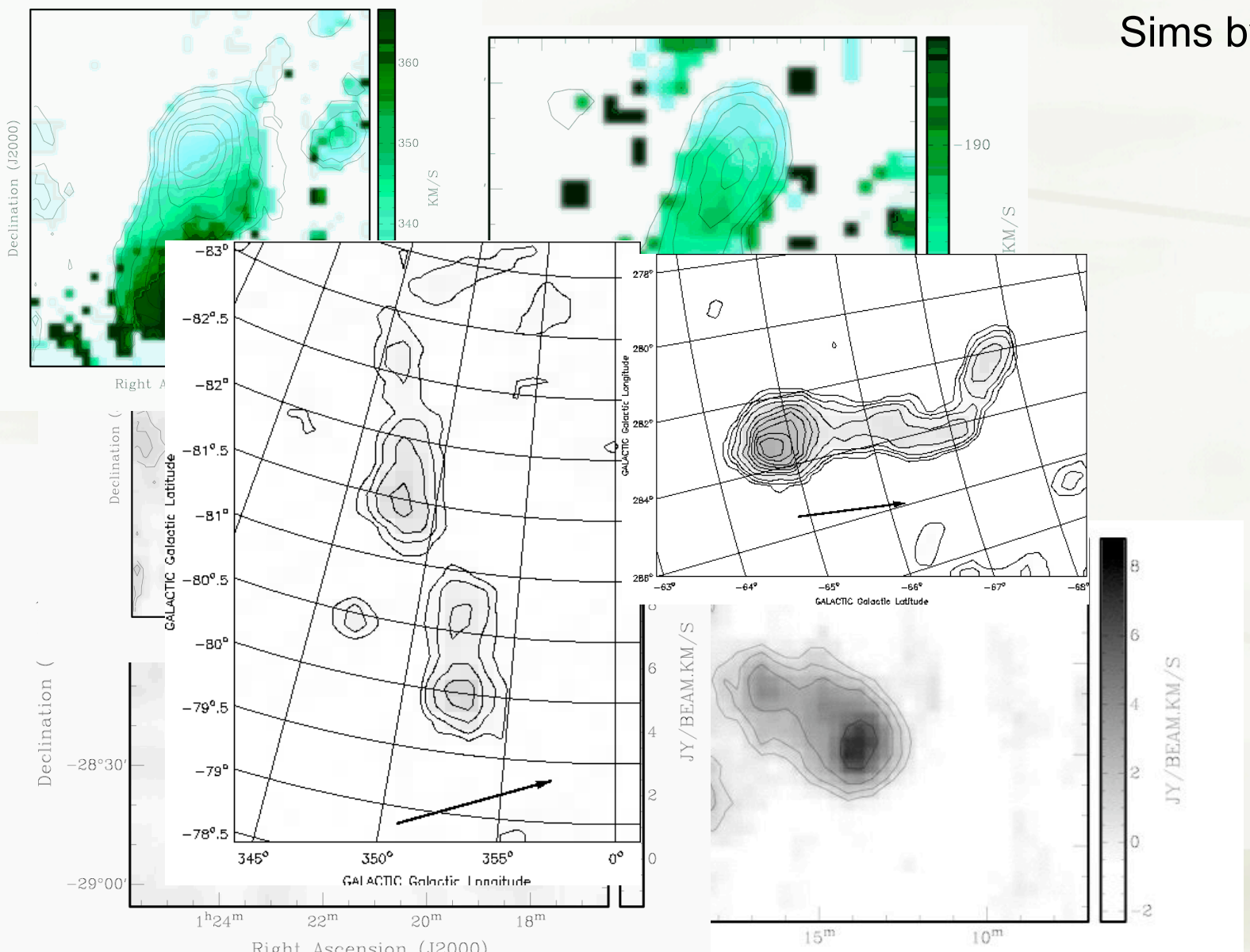

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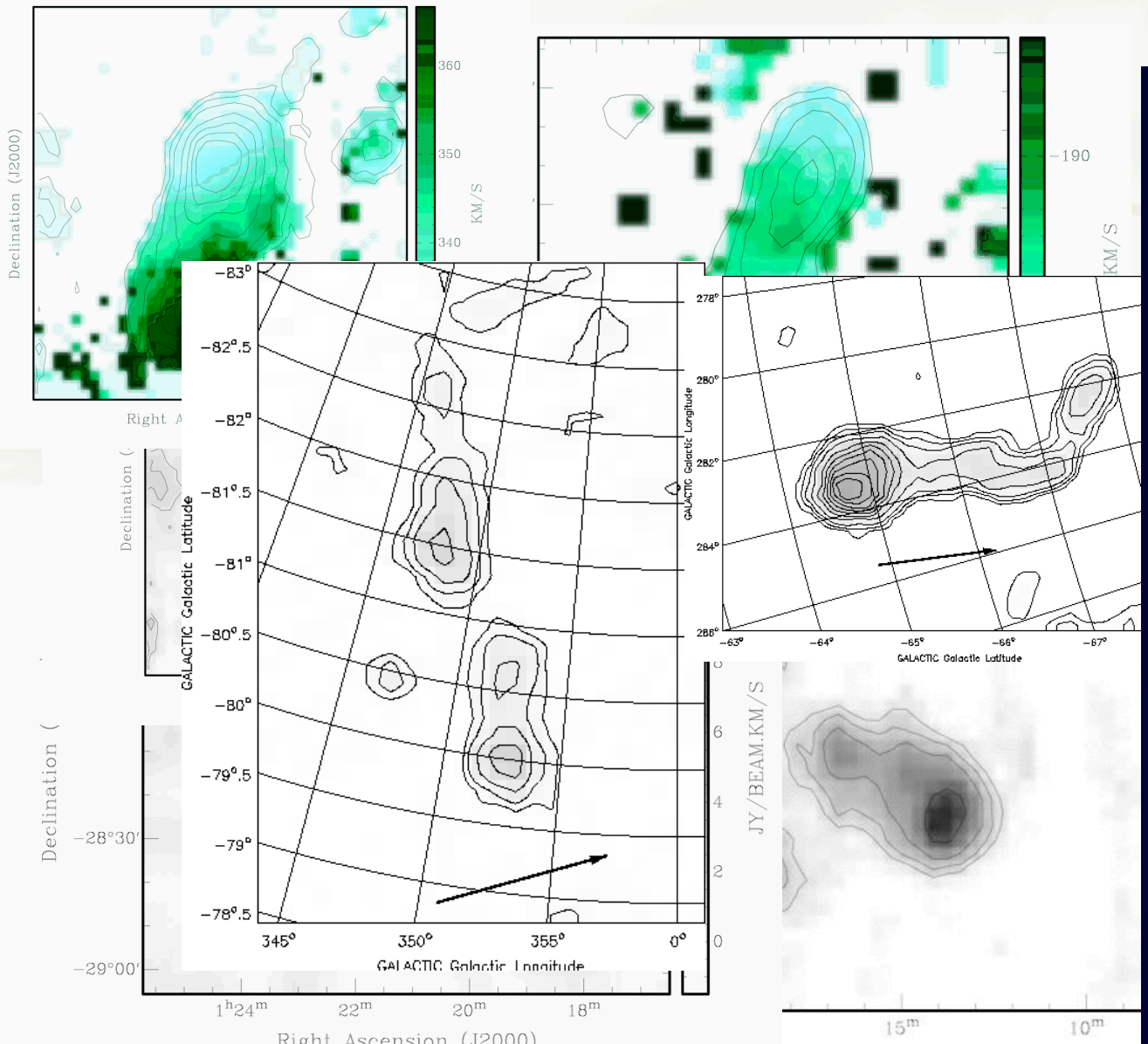
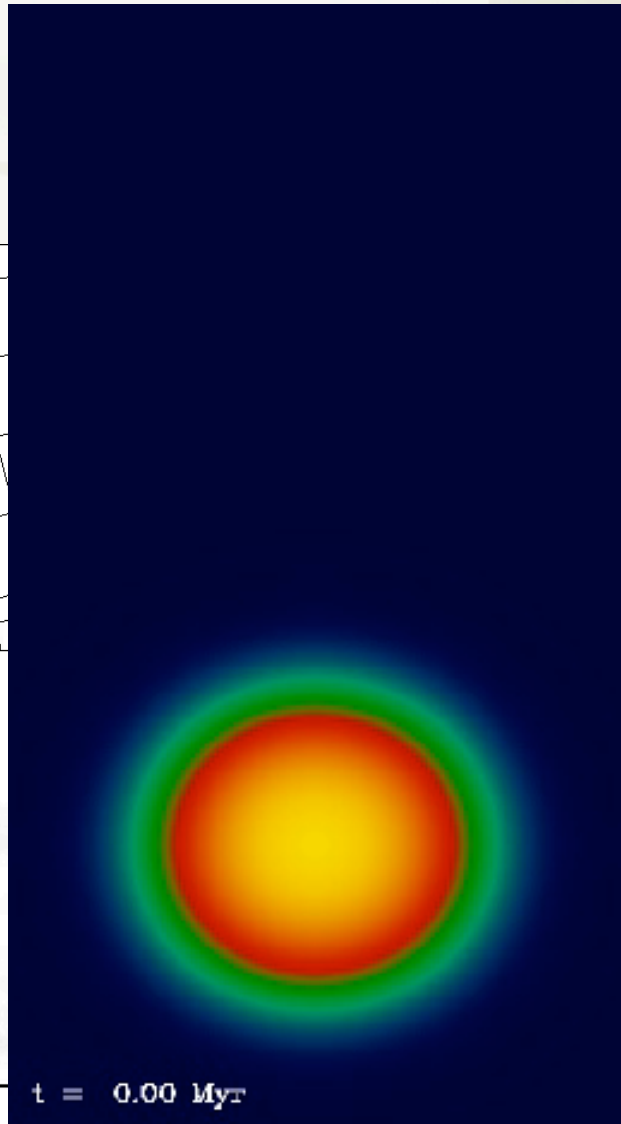
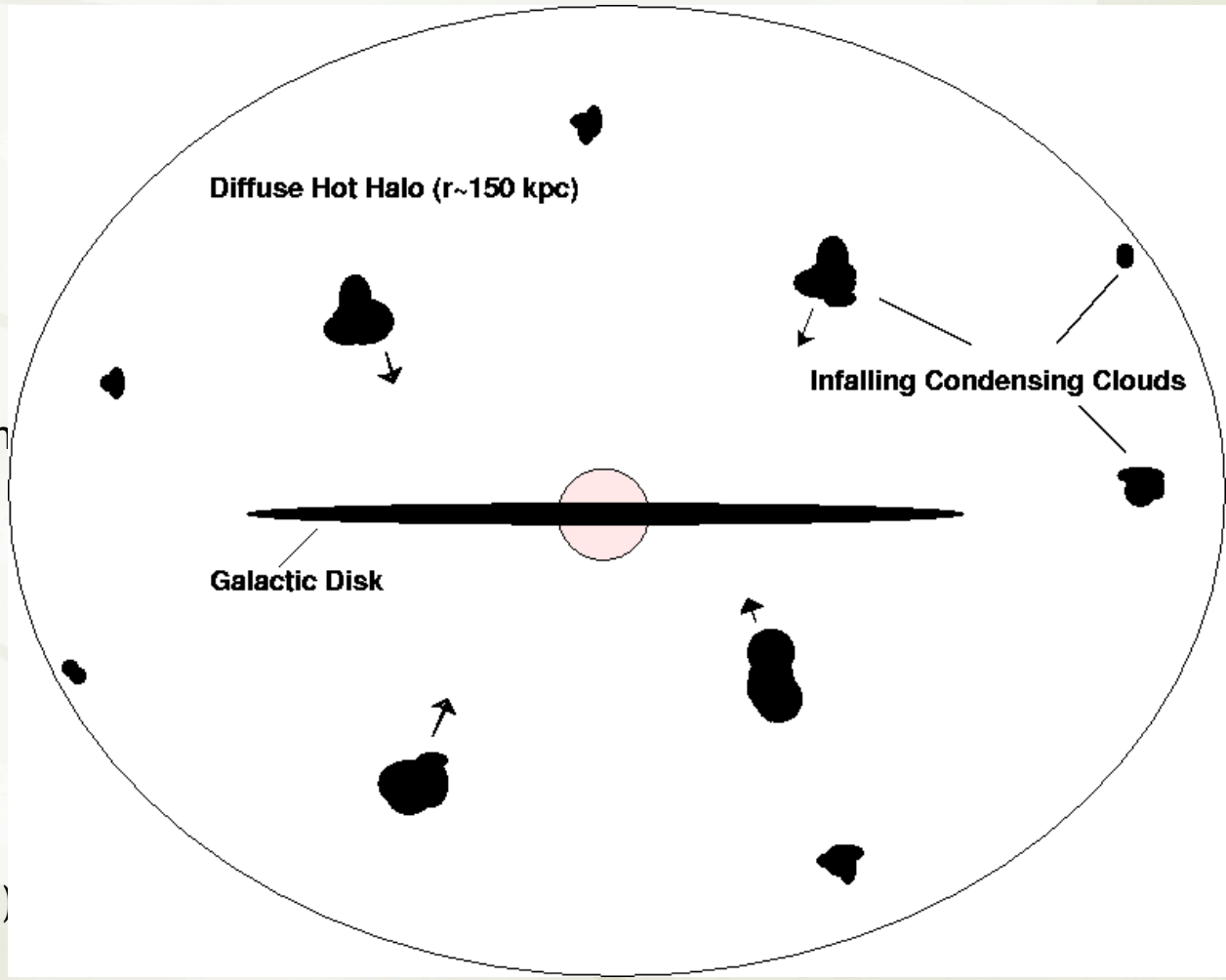
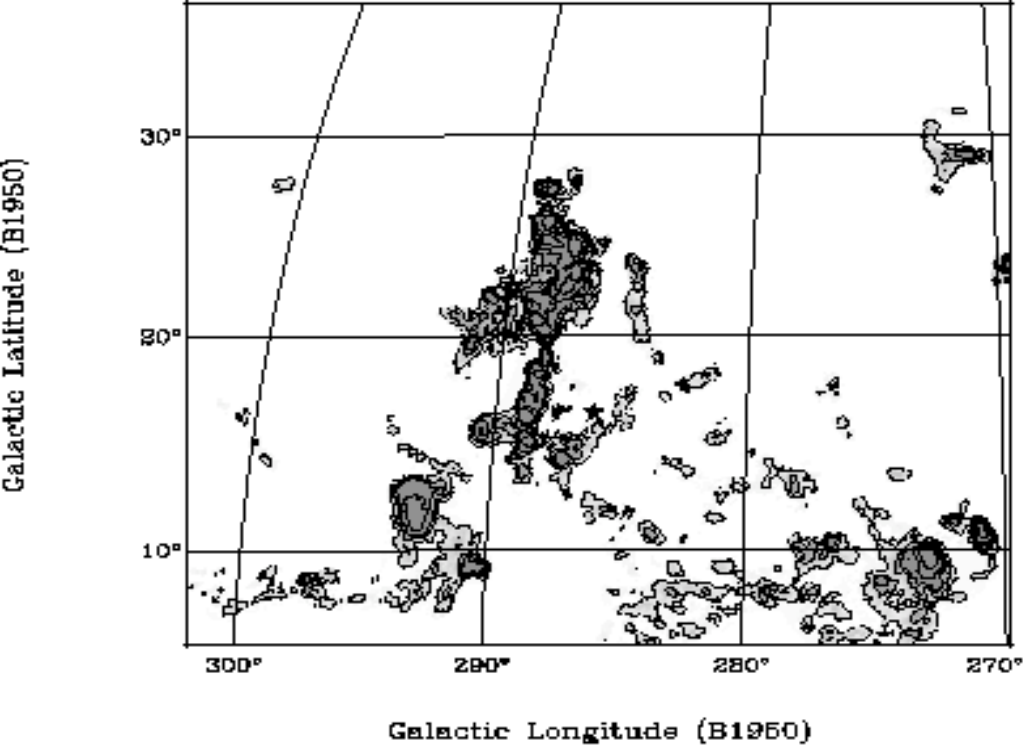




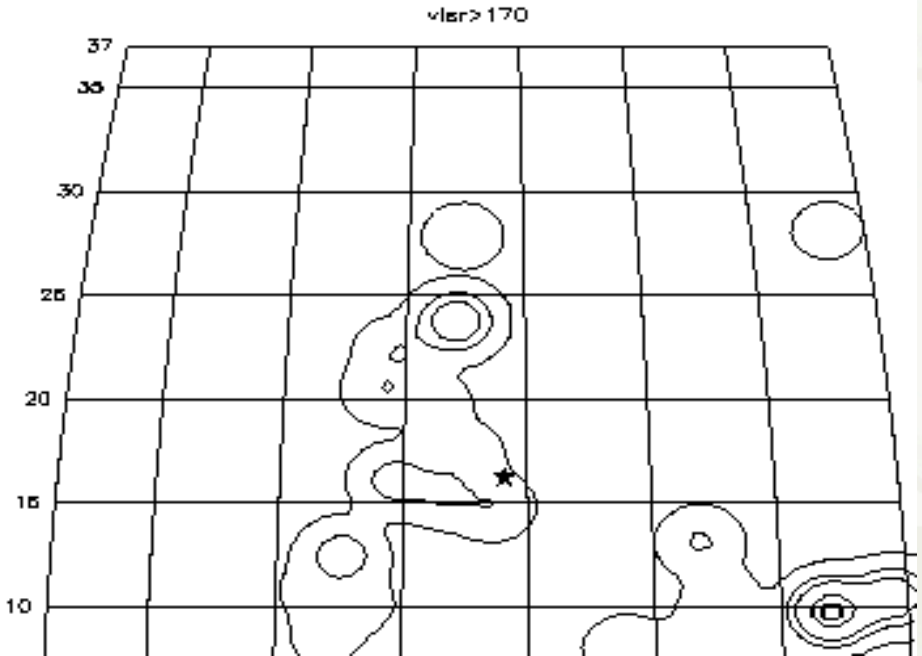
Halo Clouds in a Diffuse Medium

- Thermal instabilities in the massive hot halo form cool halo clouds (e.g., Murray & Lin 1990; Burkert & Lin 2000; Maller & Bullock 2004; Sommer-Larsen 2006; Kaufmann et al. 2005; Fukugita & Peebles 2006; Connors et al. 2006)
- Prevents over-cooling and a great place to hide baryons
- Peek, Putman & Sommer-Larsen (2007); Putman (2006)

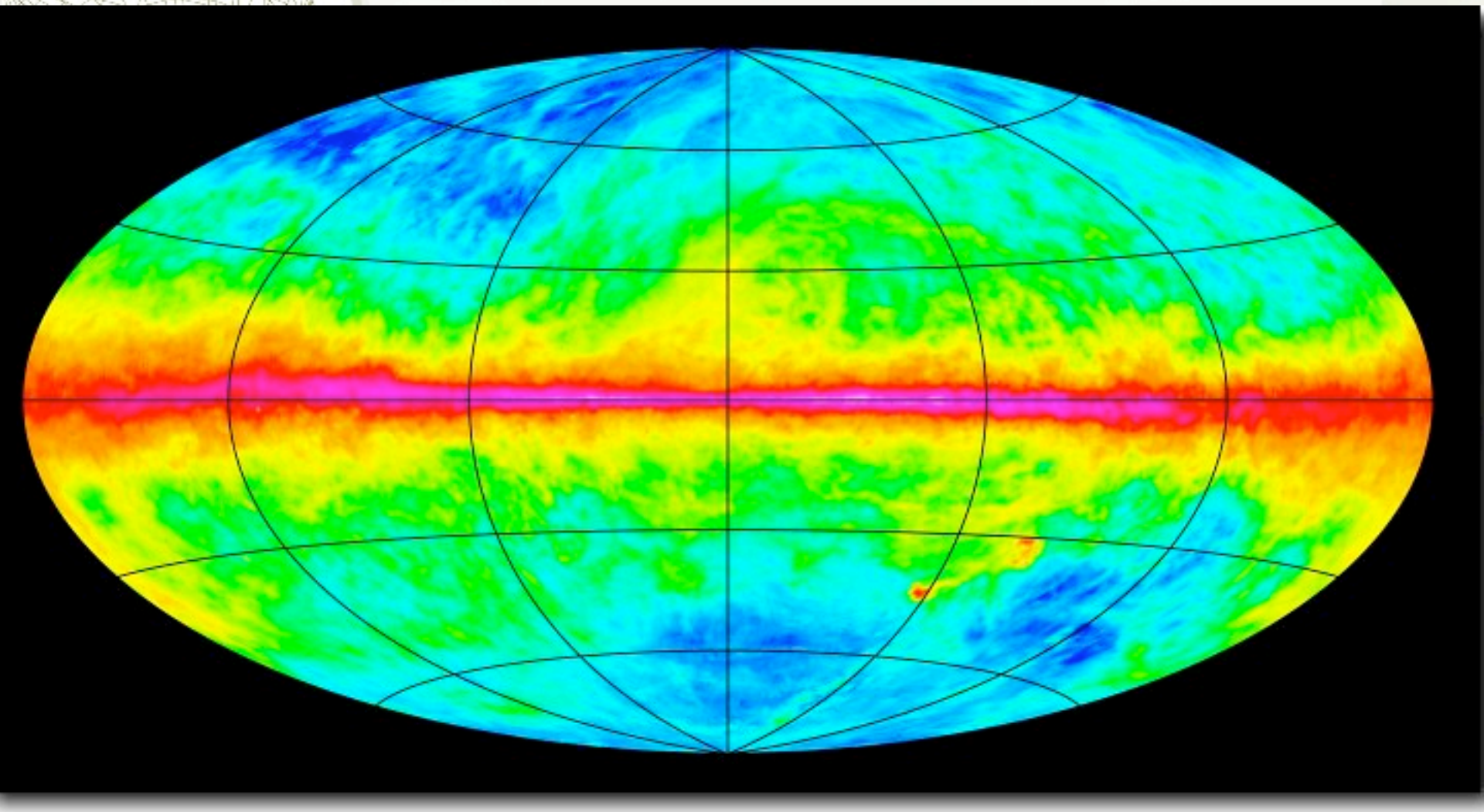




HIPASS
(15.5′)



Previous Southern HVC Survey (2° x 2° grid)



LAB: Kalberla et al. (2005)

Arecibo L-band Feed Array (ALFA) Surveys

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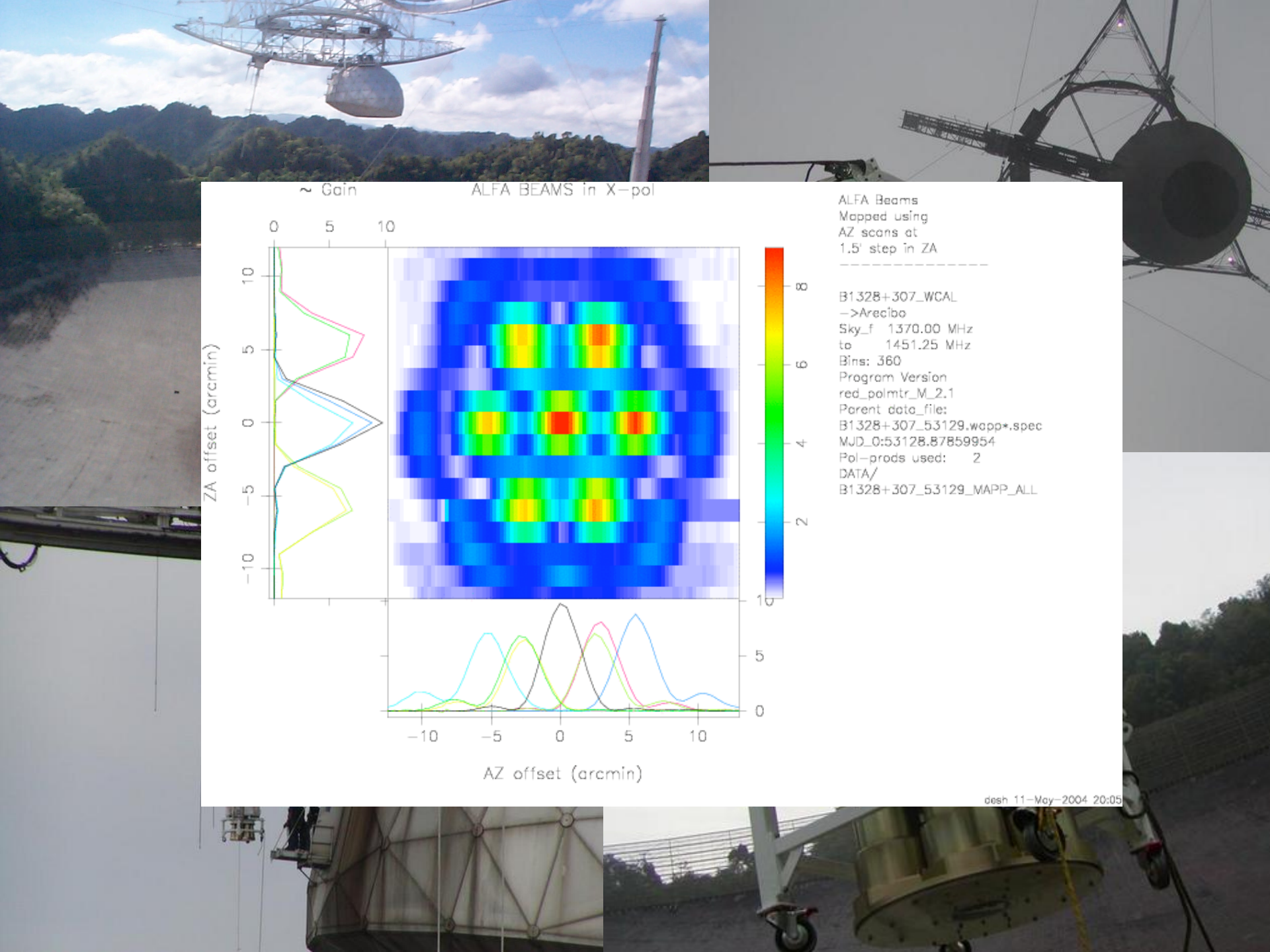
~ Gain
ALFA BEAMS in X-pol
ZA offset (arcmin)
AZ offset (arcmin)
ALFA Beams
Mapped using
AZ scans at
1.5' step in ZA
B1328+307_WCAL
->Arecibo
Sky_f 1370.00 MHz
to 1451.25 MHz
Bins: 360
Program Version
red_polmtr_M_2.1
Parent data_file:
B1328+307_53129.wapp*.spec
MJD_0:53128.87859954
Pol-prods used: 2
DATA/
B1328+307_53129_MAPP_ALL
dash 11-May-2004 20:05

Arecibo ALFA HI Surveys *(3.4')*

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- **GALFA** - HI in the Galaxy, Galactic Halo and Local Group, +/- 700 km/s, 0.2 km/s channels, 13000 deg^2 (TOGS)

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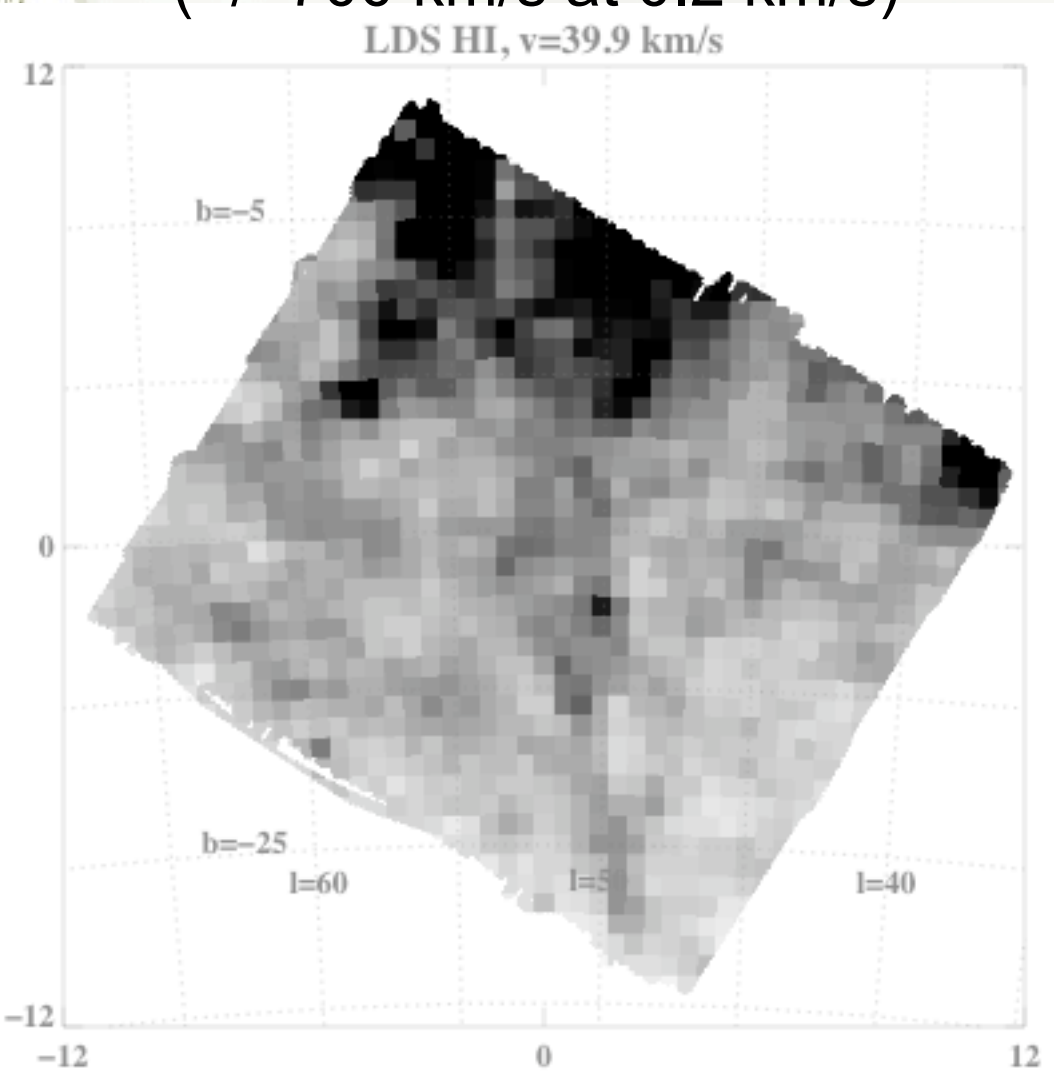
GALFA/TOGS Arecibo Data

(+/- 700 km/s at 0.2 km/s)



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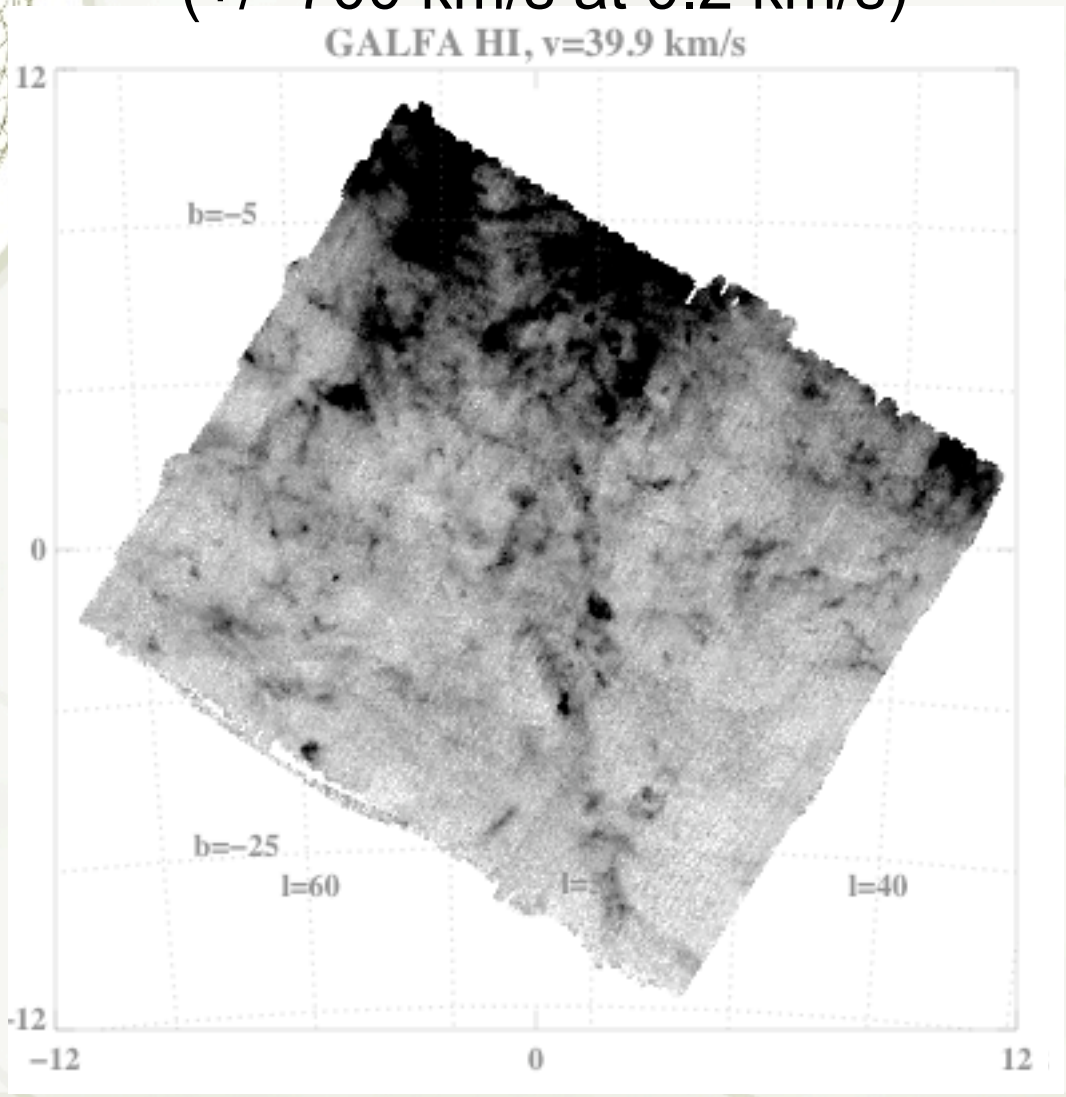
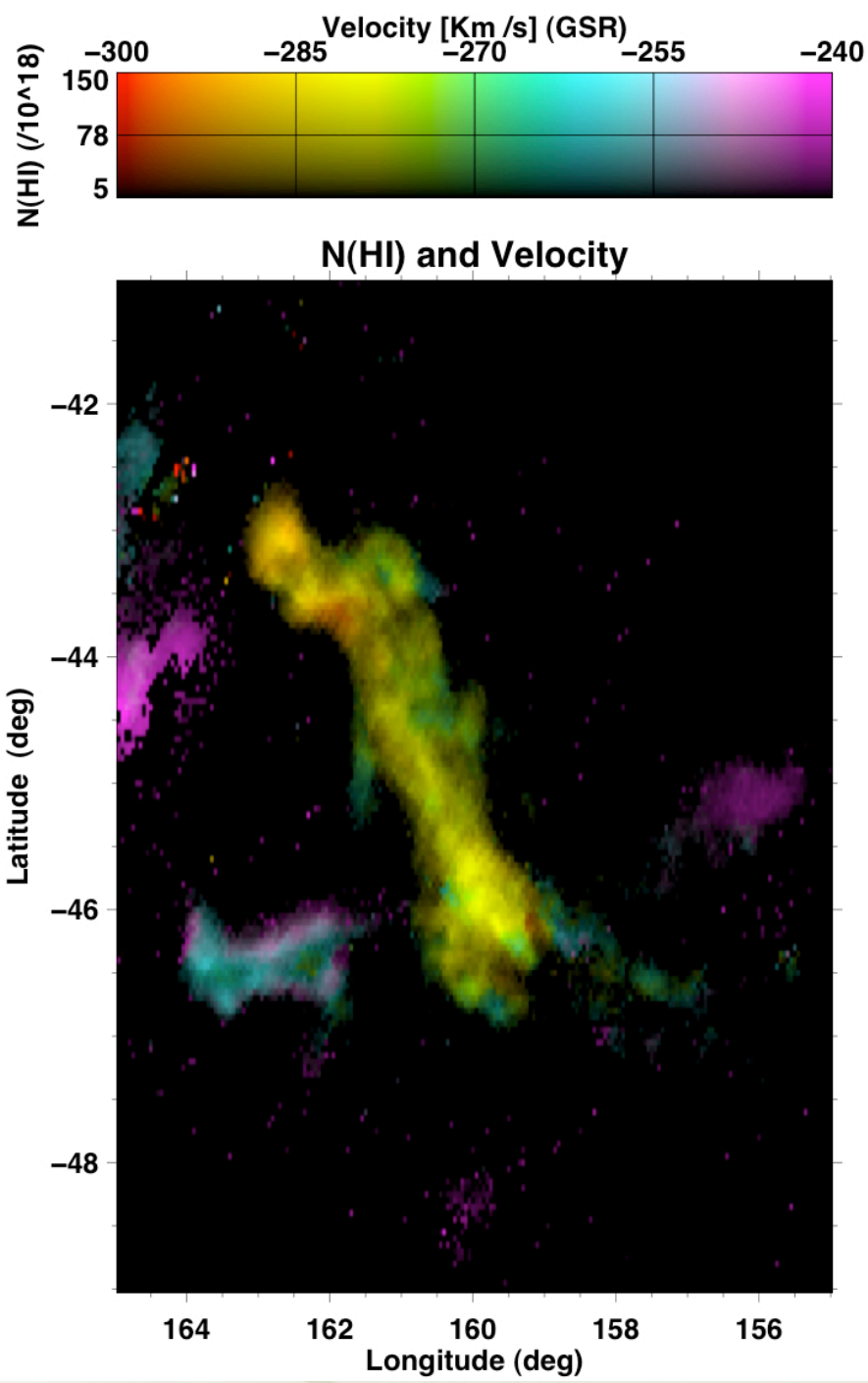


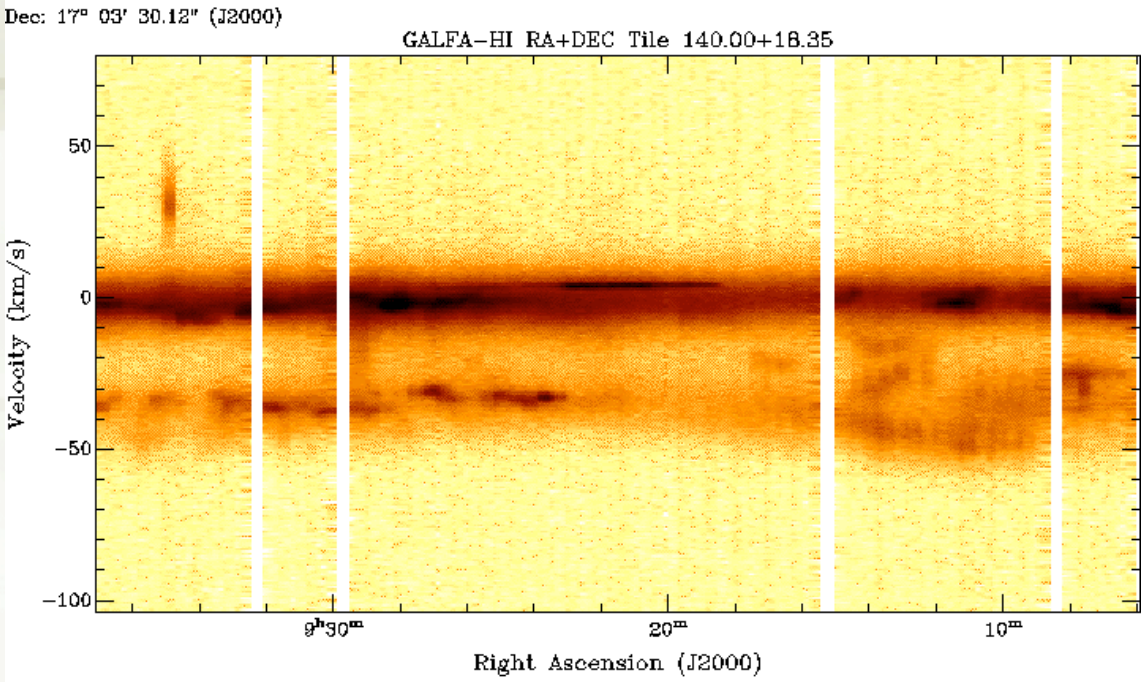
Simulated cloud moving at 300 km/s through the halo

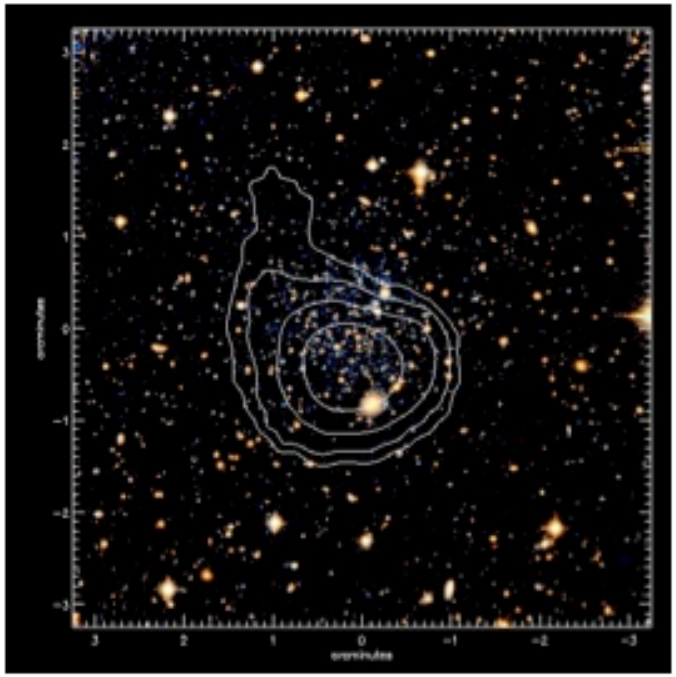


Differential shear on a cloud; physical separation of features dependent on velocity and column density of cloud and halo (~2 x 10^{-4} cm^{-3} at ~15 kpc; Peek, Putman, McKee, Heiles & Stanimirovic 2006)

Leo T: Newly discovered gaseous morsels

- Lowest luminosity galaxy discovered which has gas (Irwin et al. 2007
- Optical Vel. = 38.1 km/s
- HI Vel. = 35 km/s

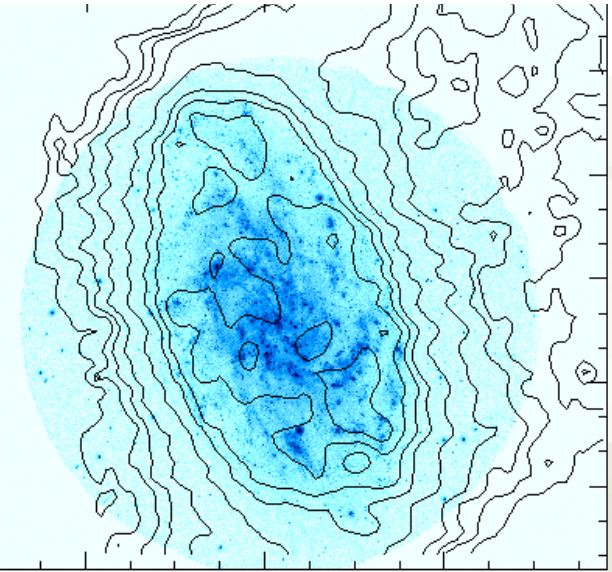




(Ryan-Weber et al. 2007)

Halo Gas around other

- M33
  - The little sister of the Local Group
  - Disruption by M31 or accretion of a satellite?



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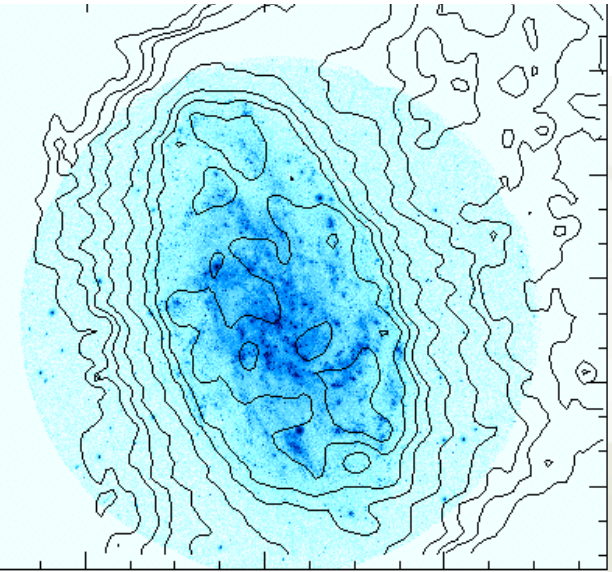
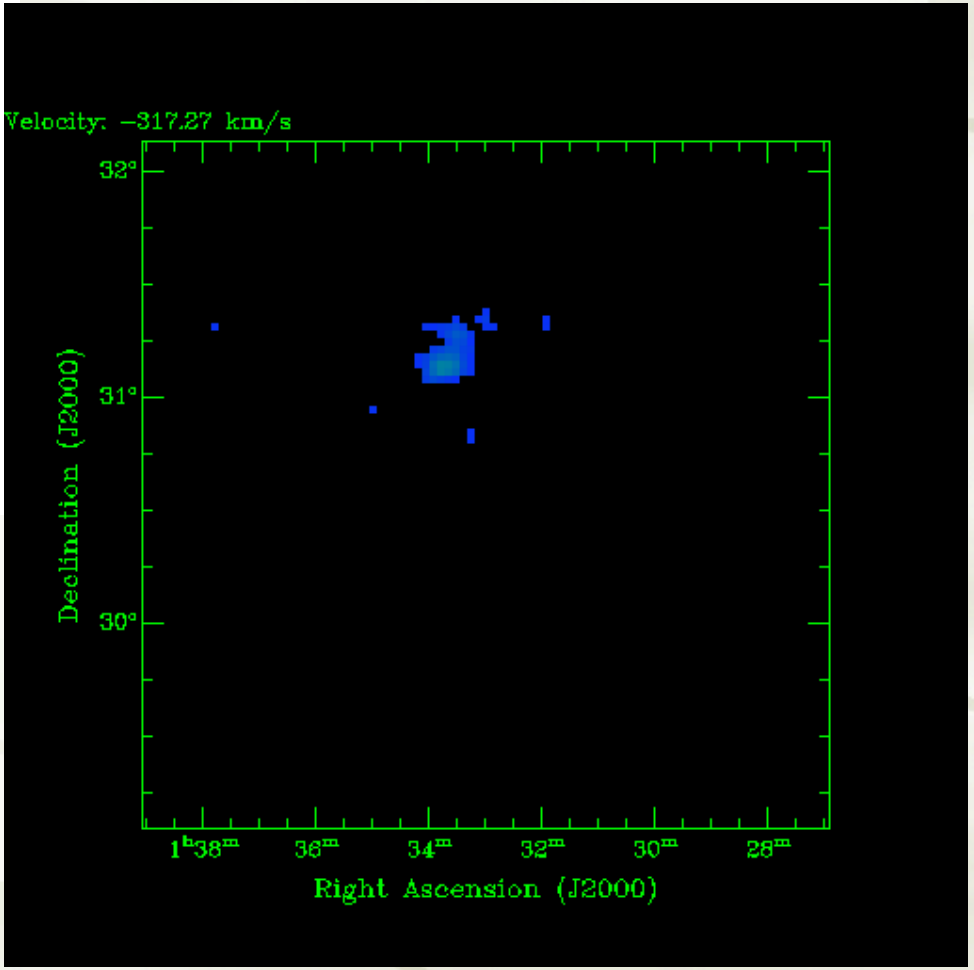
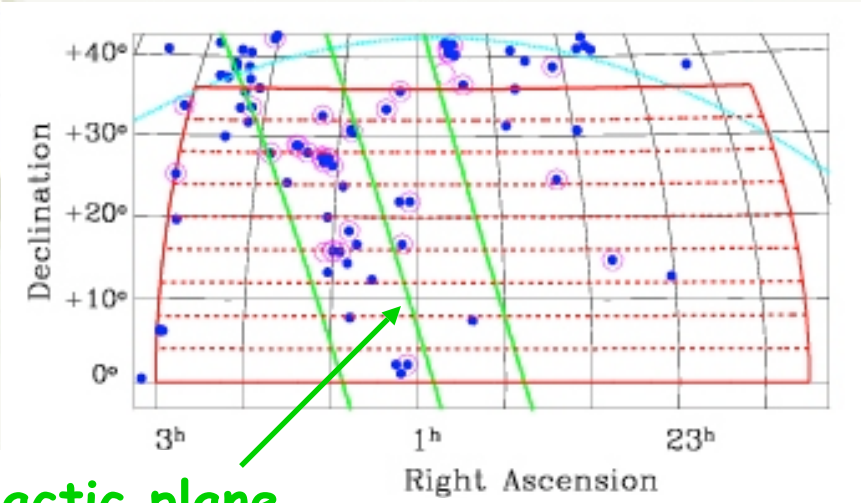
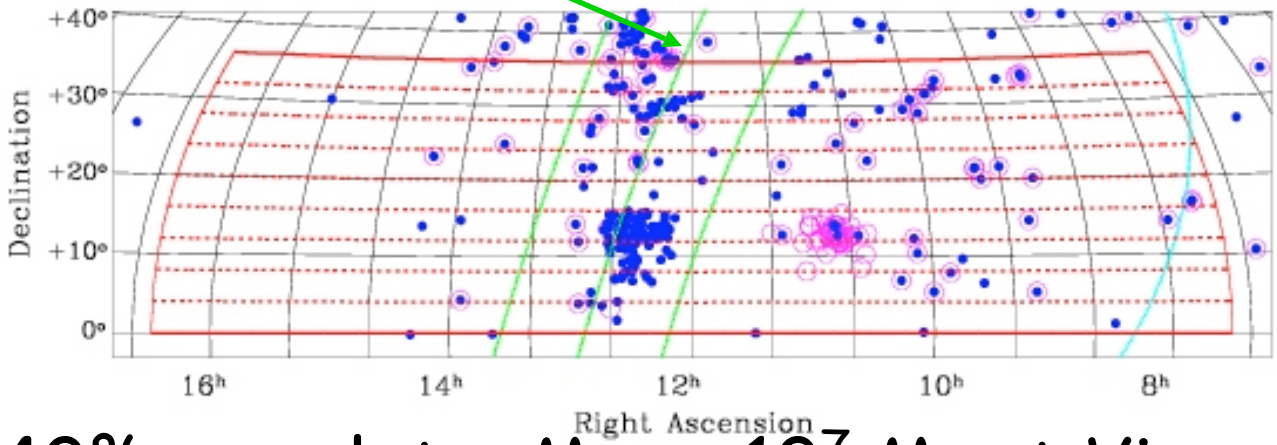




ALFALFA Survey Coverage



Supergalactic plane



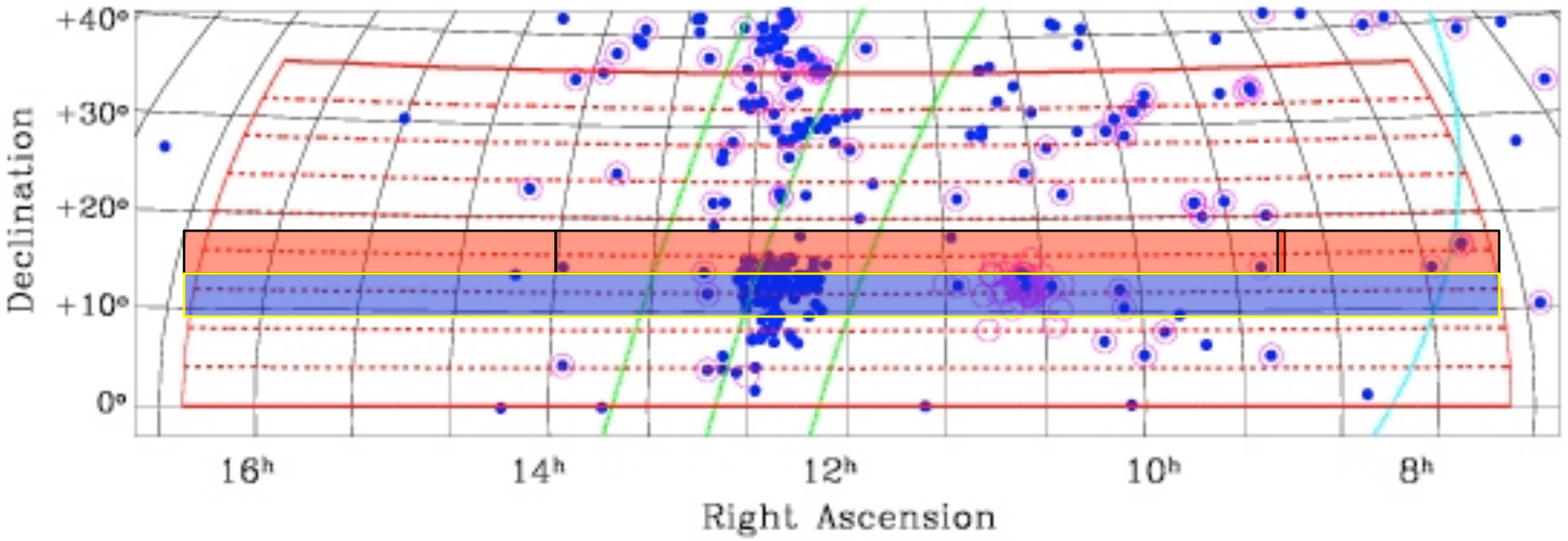
40% complete, $M_{HI} = 10^7 M_o$ at Virgo Cluster

(10 x more sensitive than HIPASS) http://egg.astro.cornell.edu/alfalfa

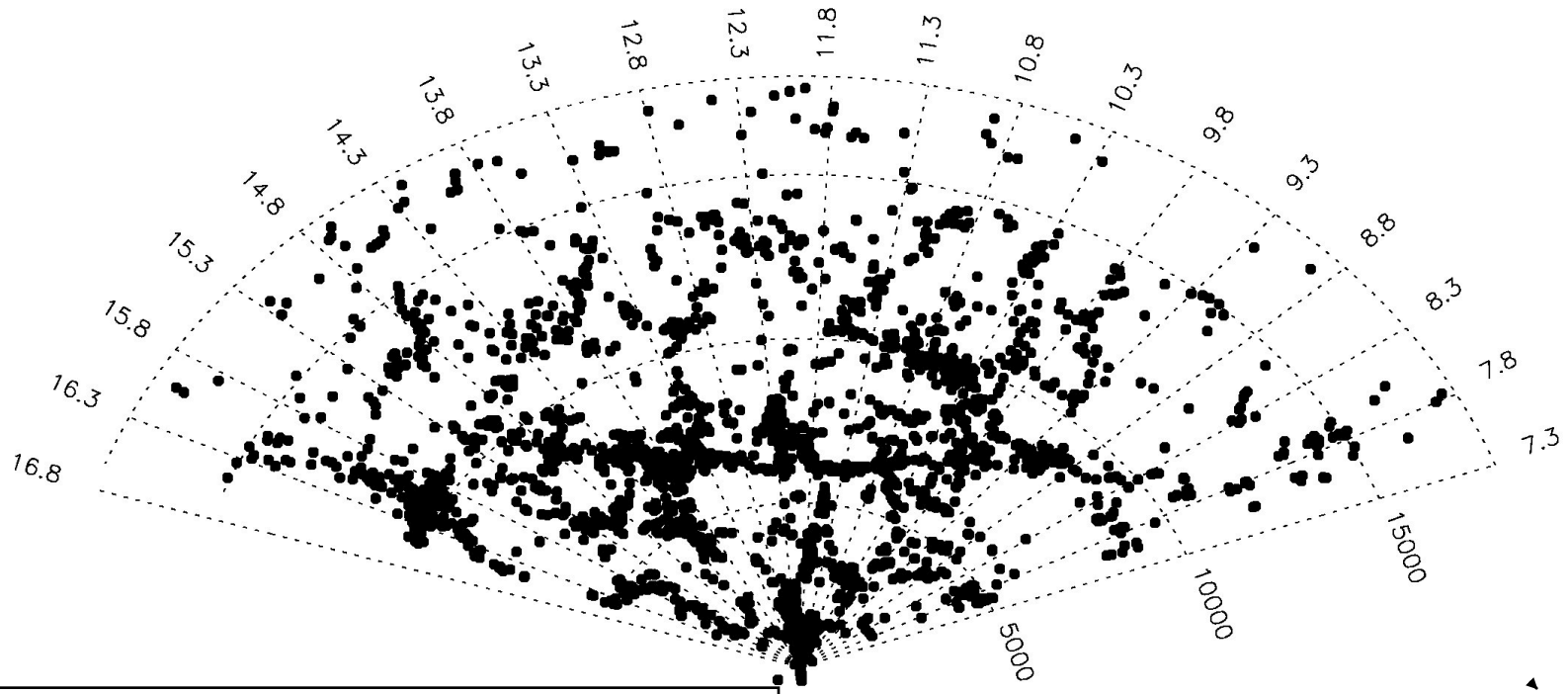
ALFALFA: Preliminary Results from 2 strips through Virgo

RA: 07:40h - 16:30h
Dec: 8 - 16 deg
1028 sq deg (15% of survey)

Giovanelli et al. 2007



Wedge Plots of two 4deg wide ALFALFA Strips



Over the ~1000 sq. deg. including the northern part of Virgo :

➔ ***ALFALFA detects 5200 sources, HIPASS 178***

➔ *Intensively studied area, yet* ***69% of detections are new***

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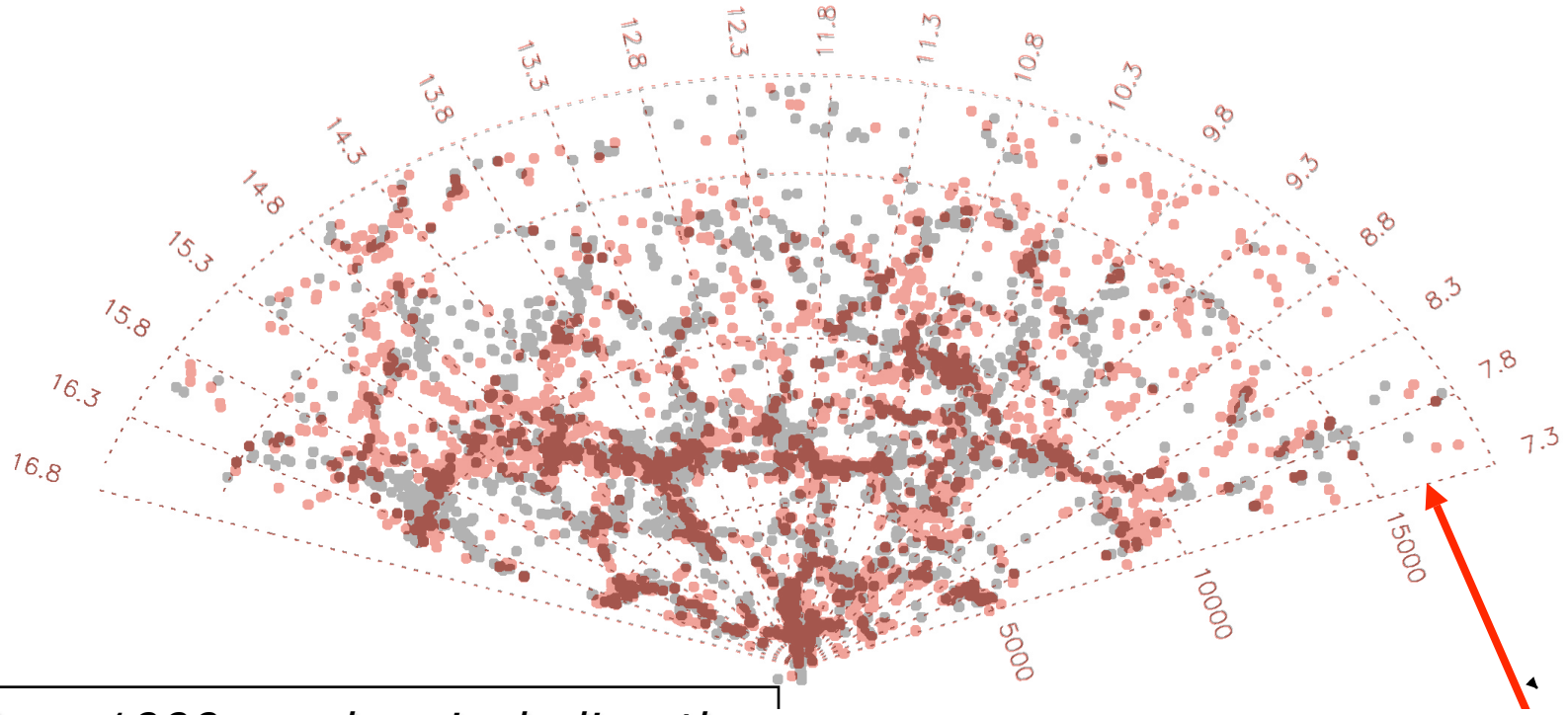

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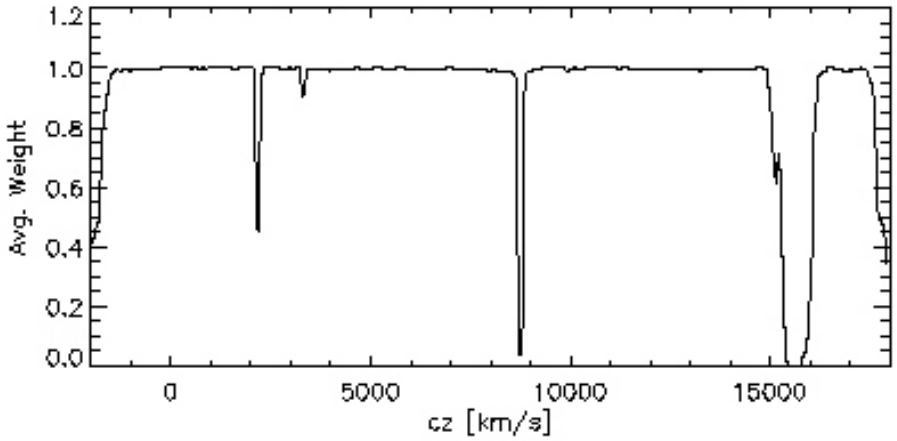

Pointed High Resolution HI Surveys

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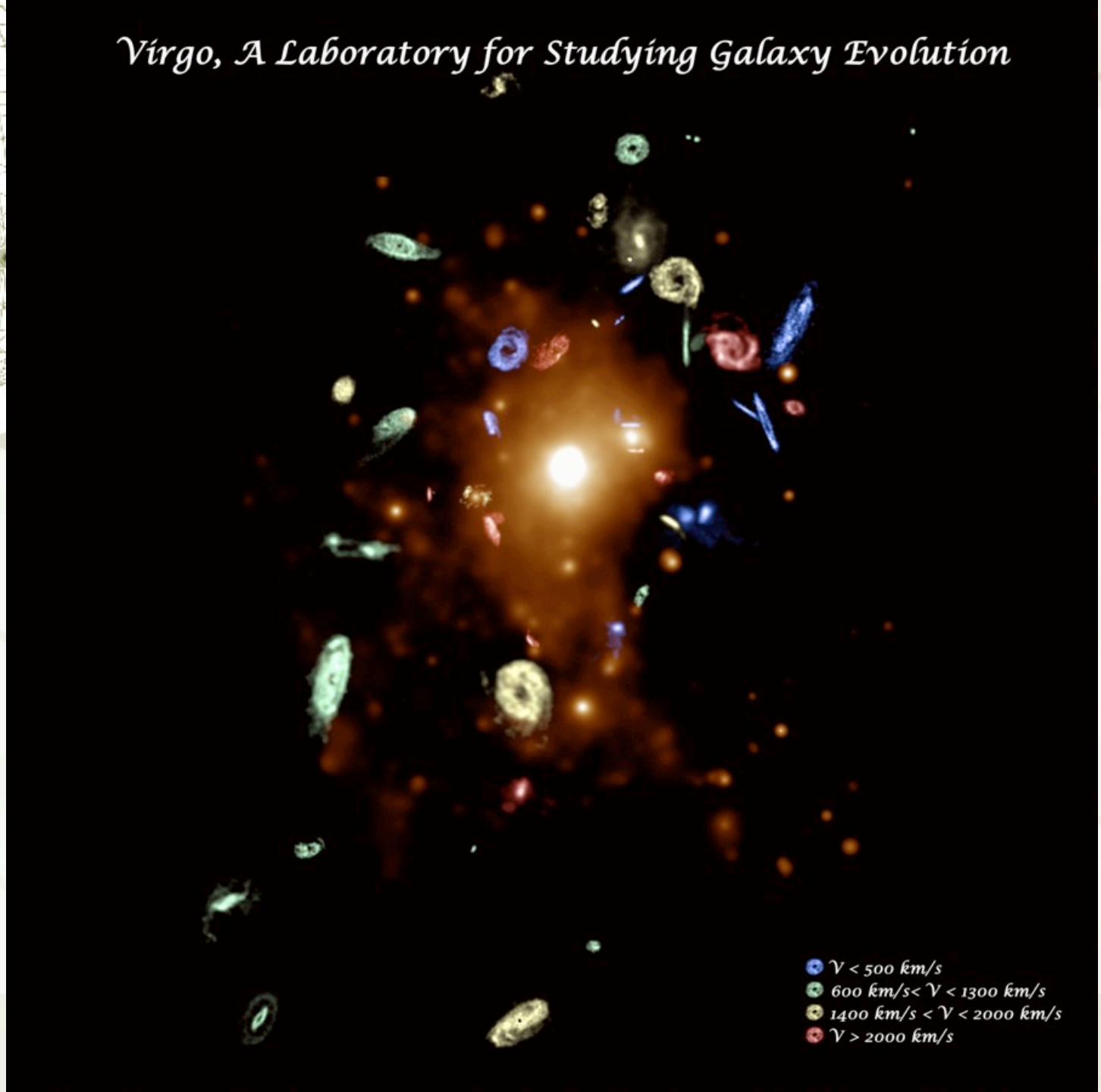
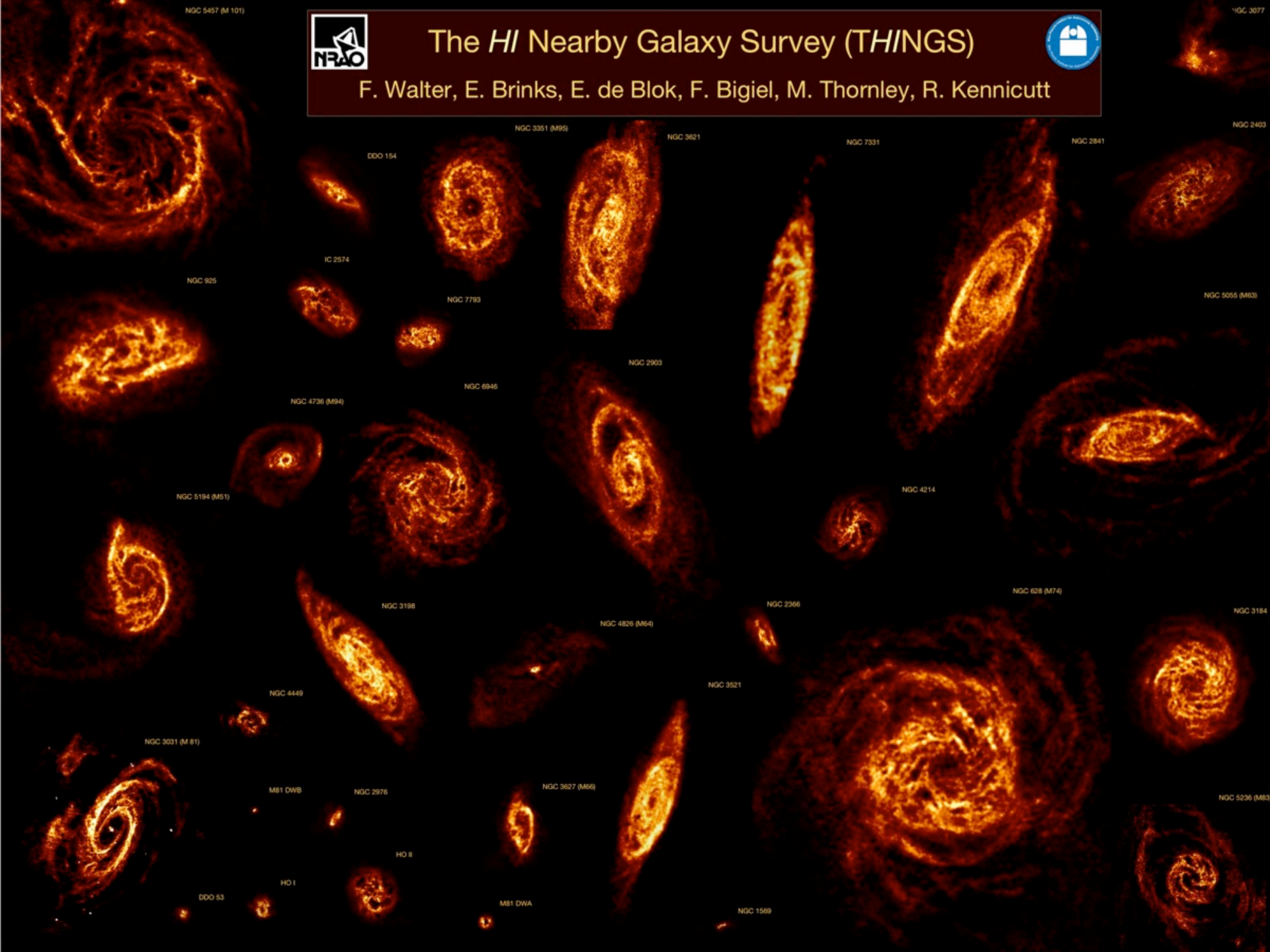
- VLA Large Proposals
  - Virgo Cluster and other clusters (Chung, van Gorkom, Kenney et al.)
  - THINGS (34 galaxies; 7", 5 km/s; Walter et al.)
  - Little THINGS Survey (Hunter et al.)
  - VLA ANGST (36 galaxies; 6"; Ott, Skillman, Dalcanton et al.)

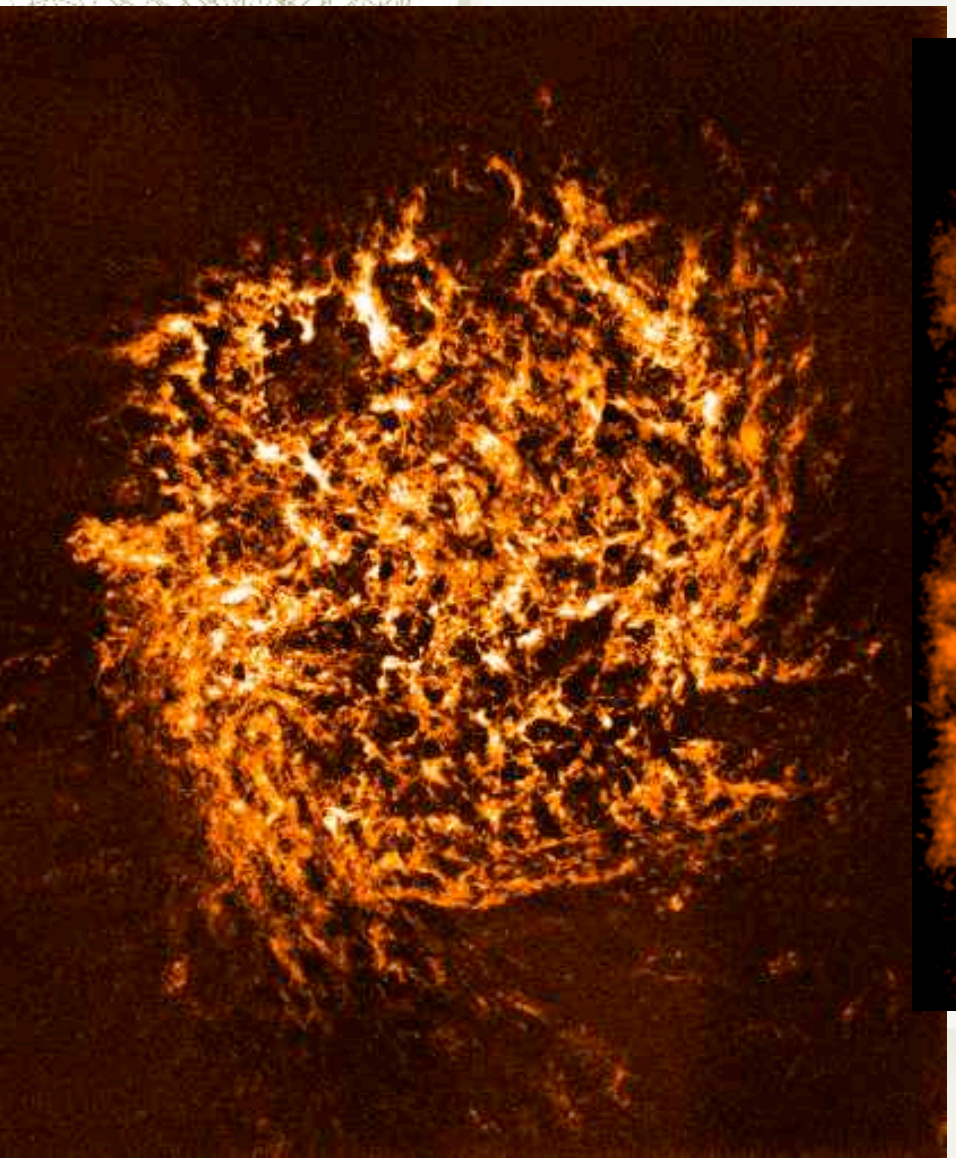

Virgo, A Laboratory for Studying Galaxy Evolution
V < 500 km/s
600 km/s< V < 1300 km/s
1400 km/s < V < 2000 km/s
V > 2000 km/s

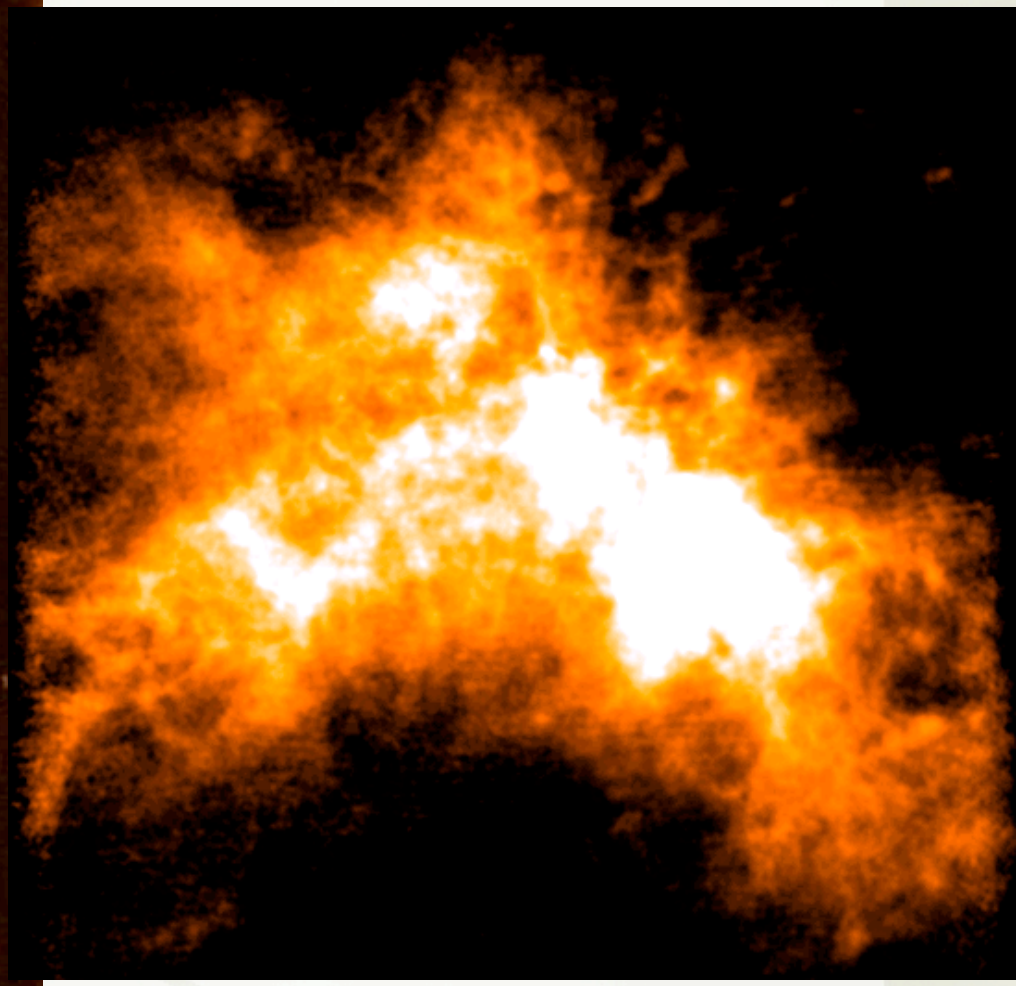
A. Chung


The HI Nearby Galaxy Survey (THINGS)
F. Walter, E. Brinks, E. de Blok, F. Bigiel, M. Thornley, R. Kennicutt
NRAO
NGC 5457 (M 101)
NGC 3077
NGC 3351 (M95)
NGC 3621
DDO 154
NGC 7331
NGC 2841
NGC 2403
IC 2574
NGC 925
NGC 7793
NGC 5055 (M63)
NGC 2903
NGC 6946
NGC 4736 (M94)
NGC 5194 (M51)
NGC 4214
NGC 628 (M74)
NGC 3198
NGC 2366
NGC 3184
NGC 4826 (M64)
NGC 4449
NGC 3521
NGC 3031 (M 81)
M81 DWB
NGC 2976
NGC 3627 (M66)
NGC 5236 (M83)
HO II
HO I
DDO 53
M81 DWA
NGC 1569

Magellanic Clouds

(Stanimirovic et al. 1999; Kim, Staveley-Smith et al. 2003)





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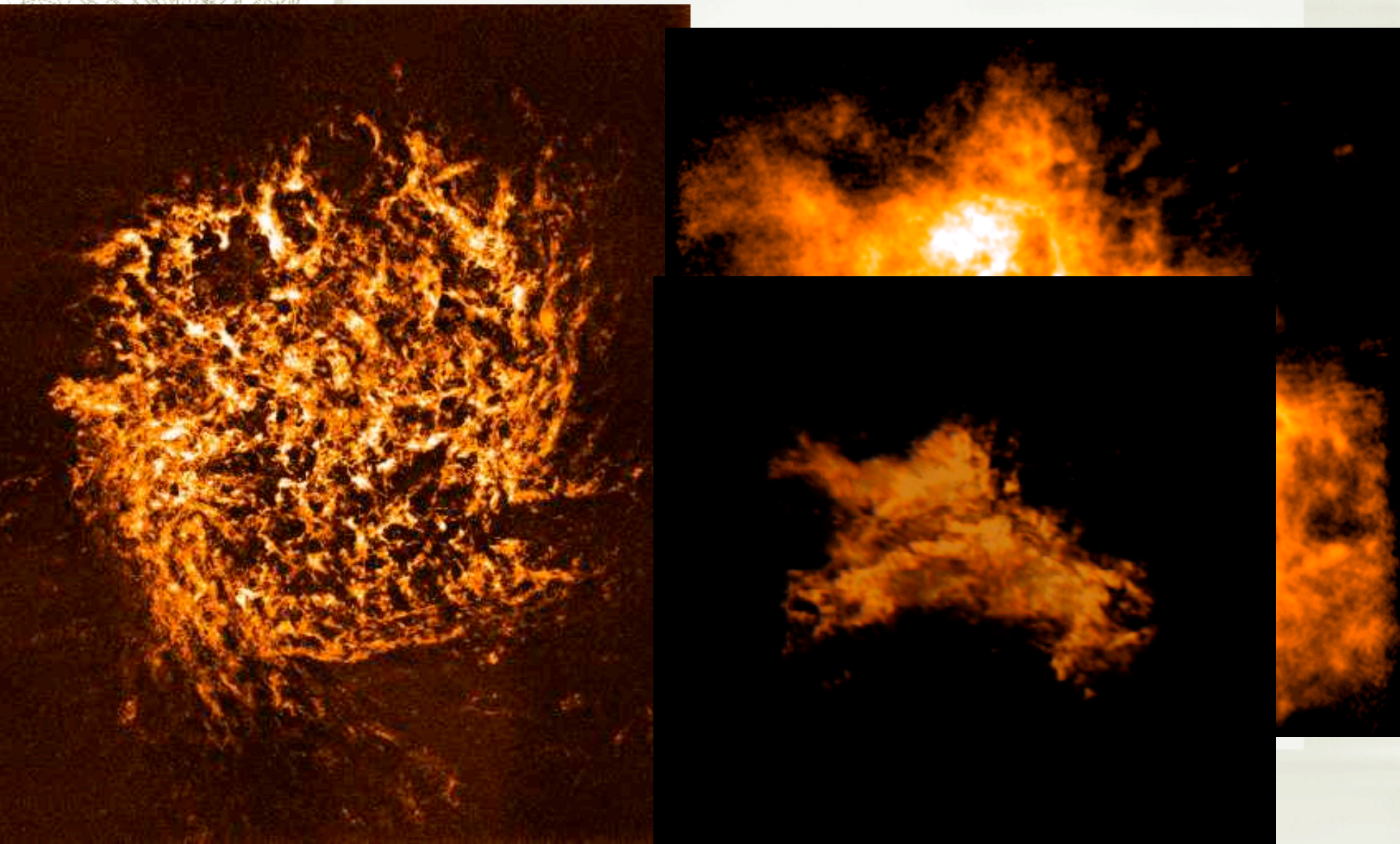
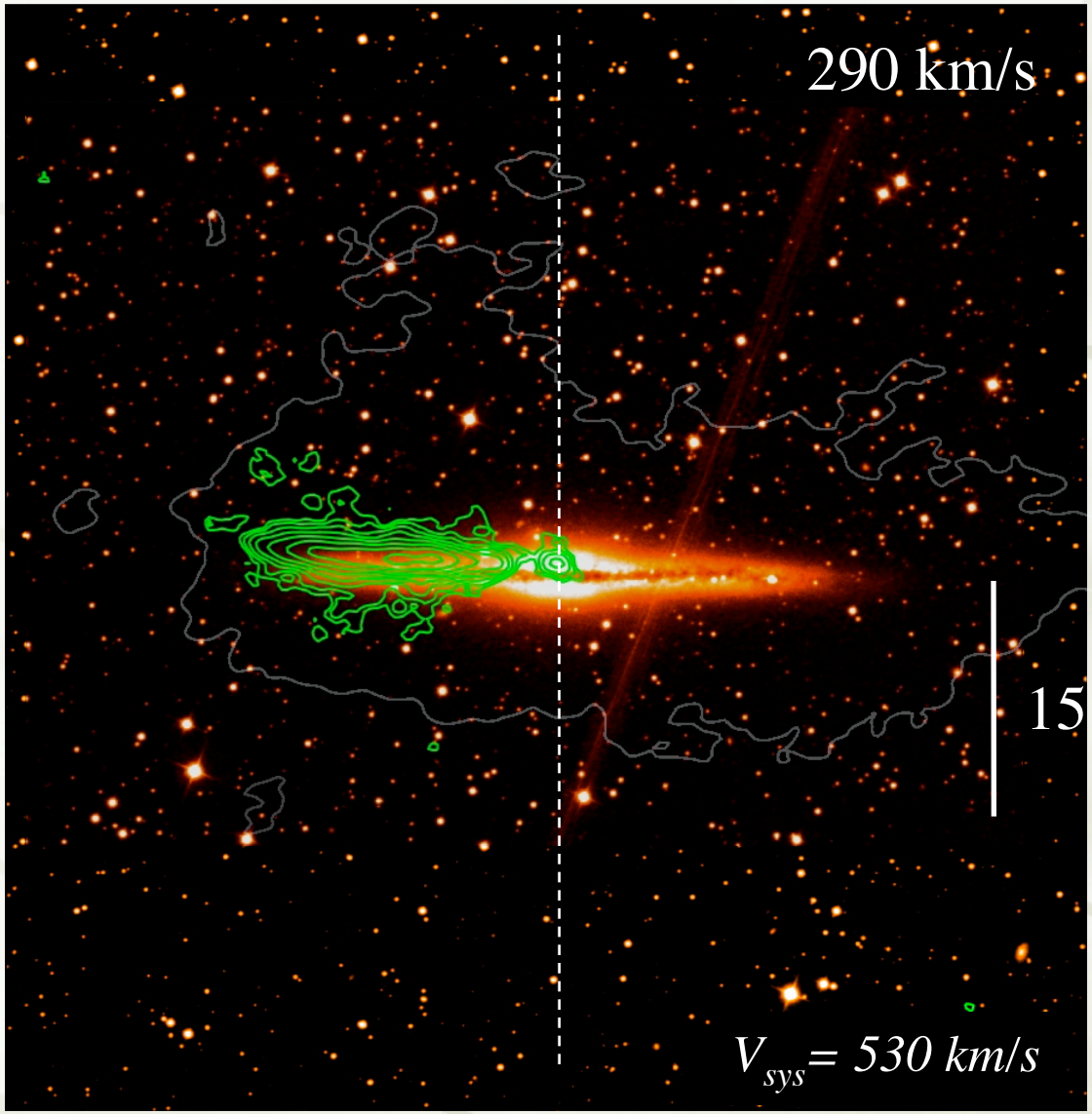


NGC 891:
HI channel maps overlaid on DSS
Complements Fraternali et al.



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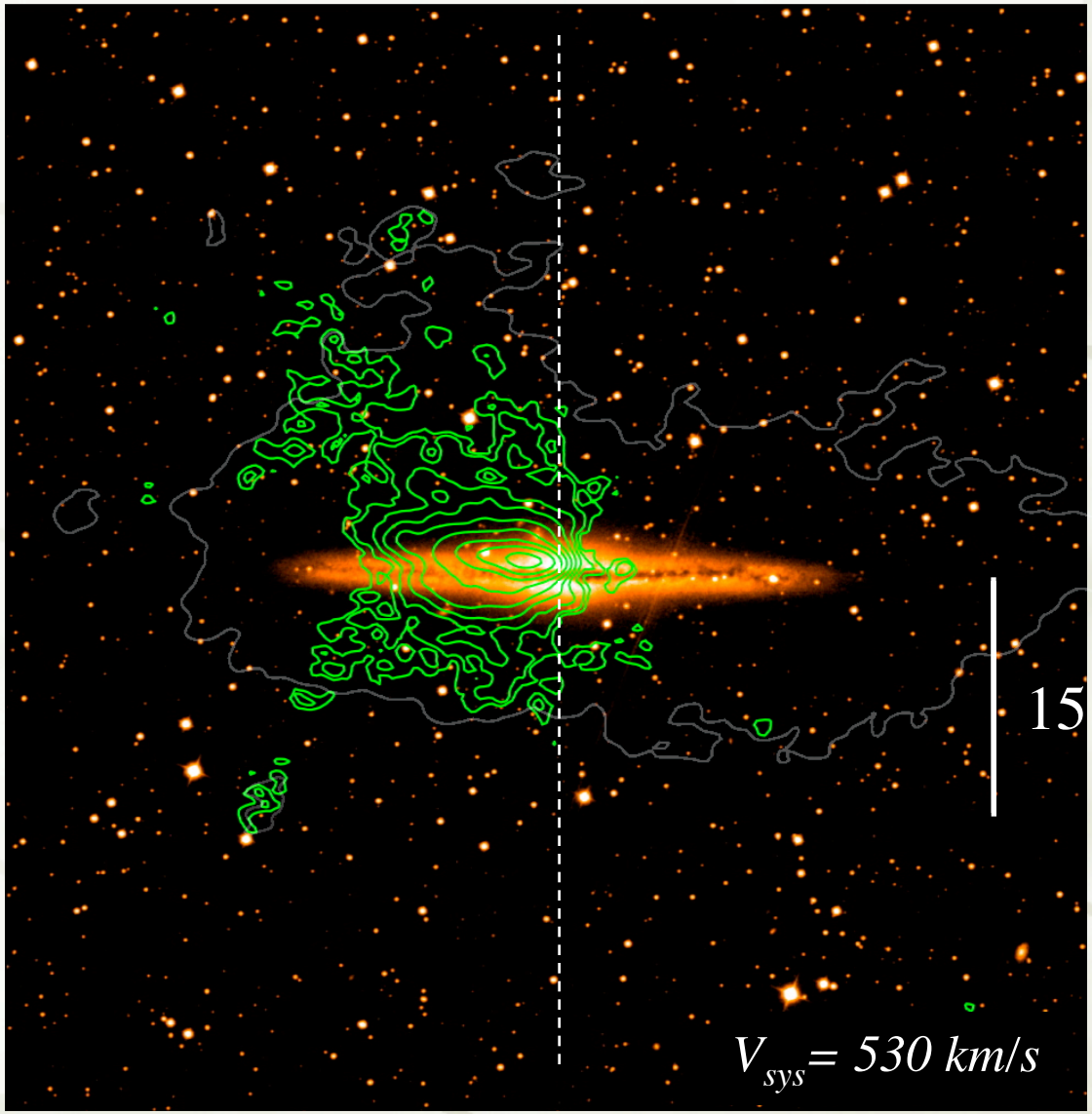

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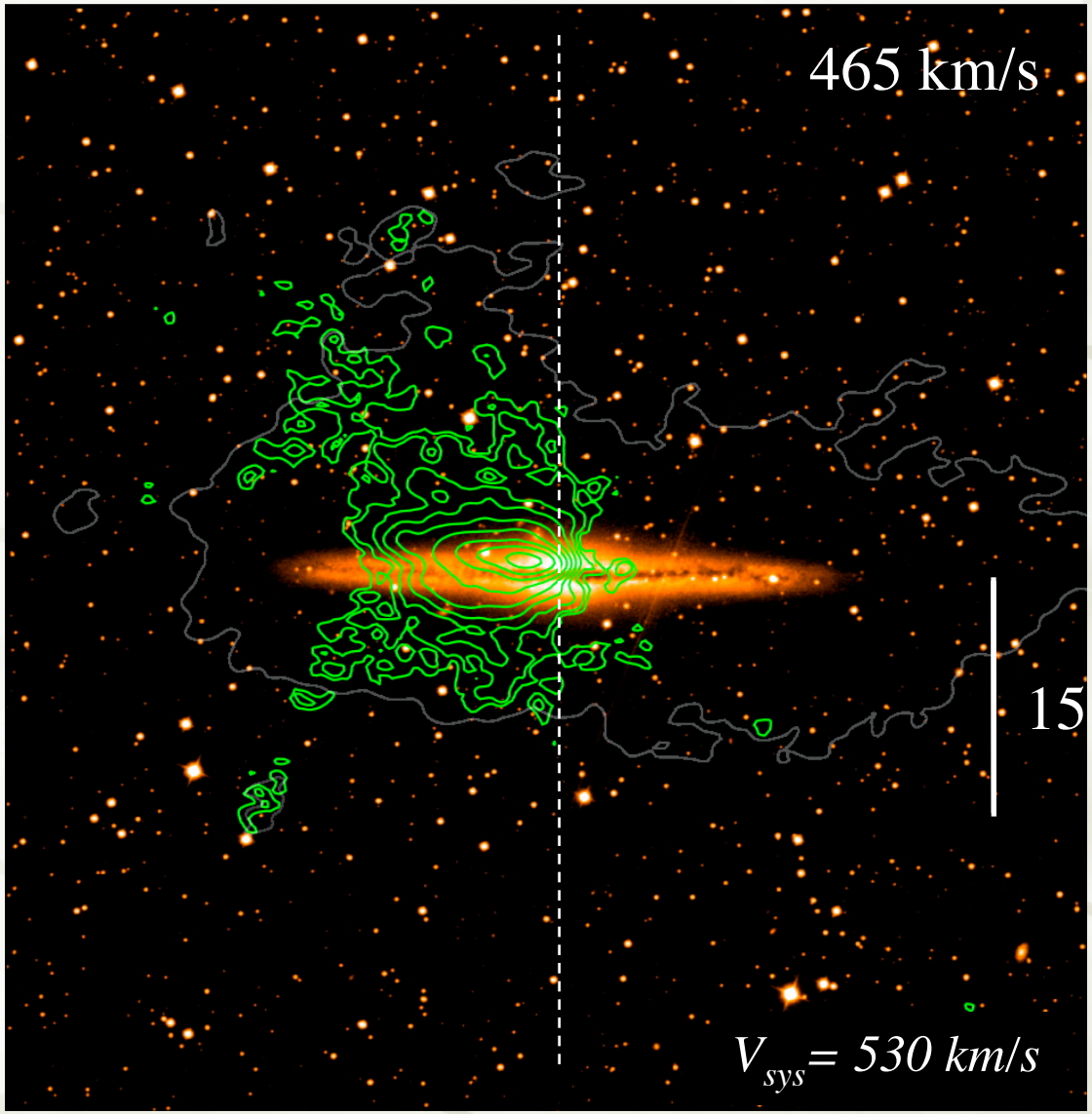

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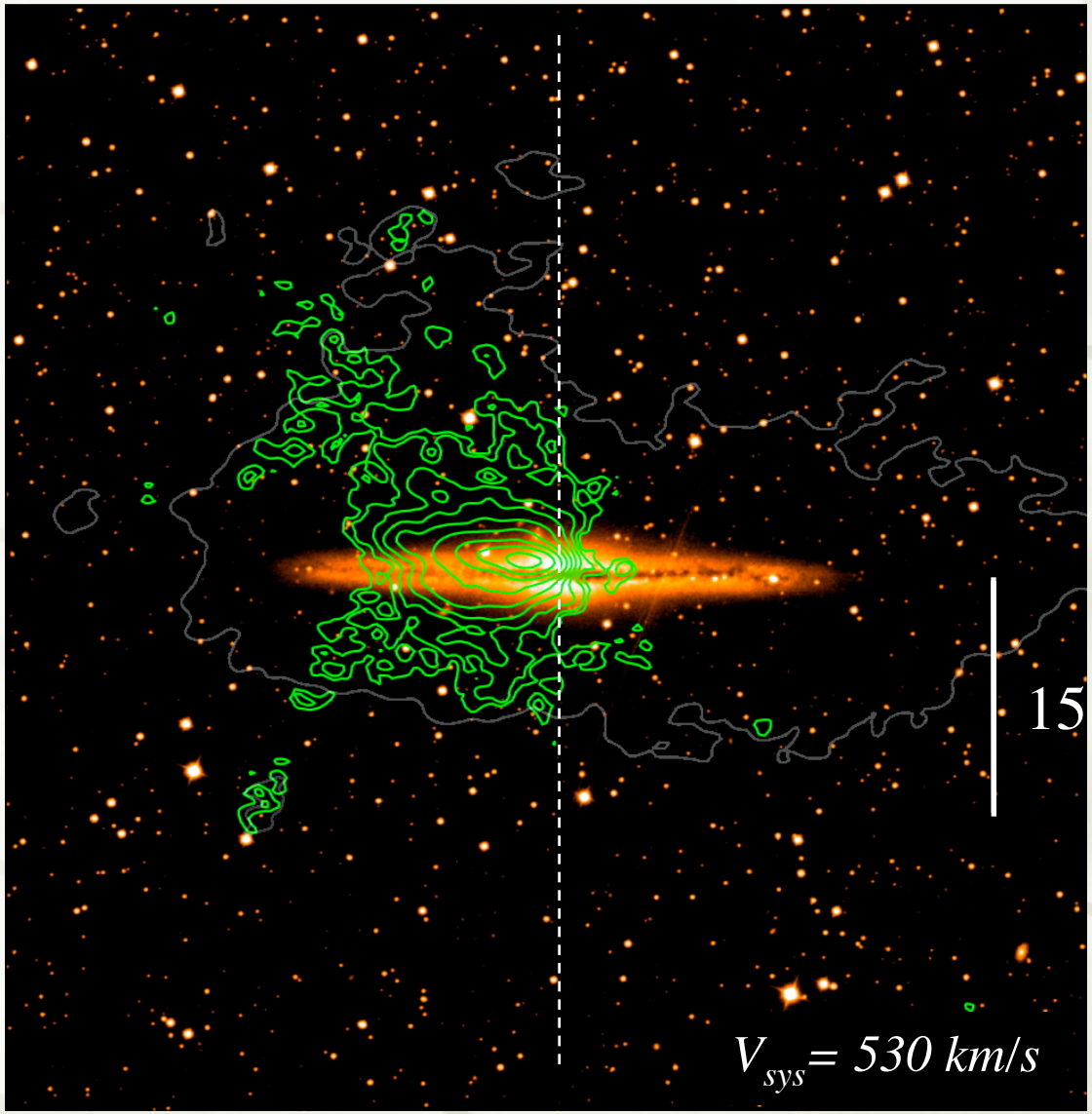

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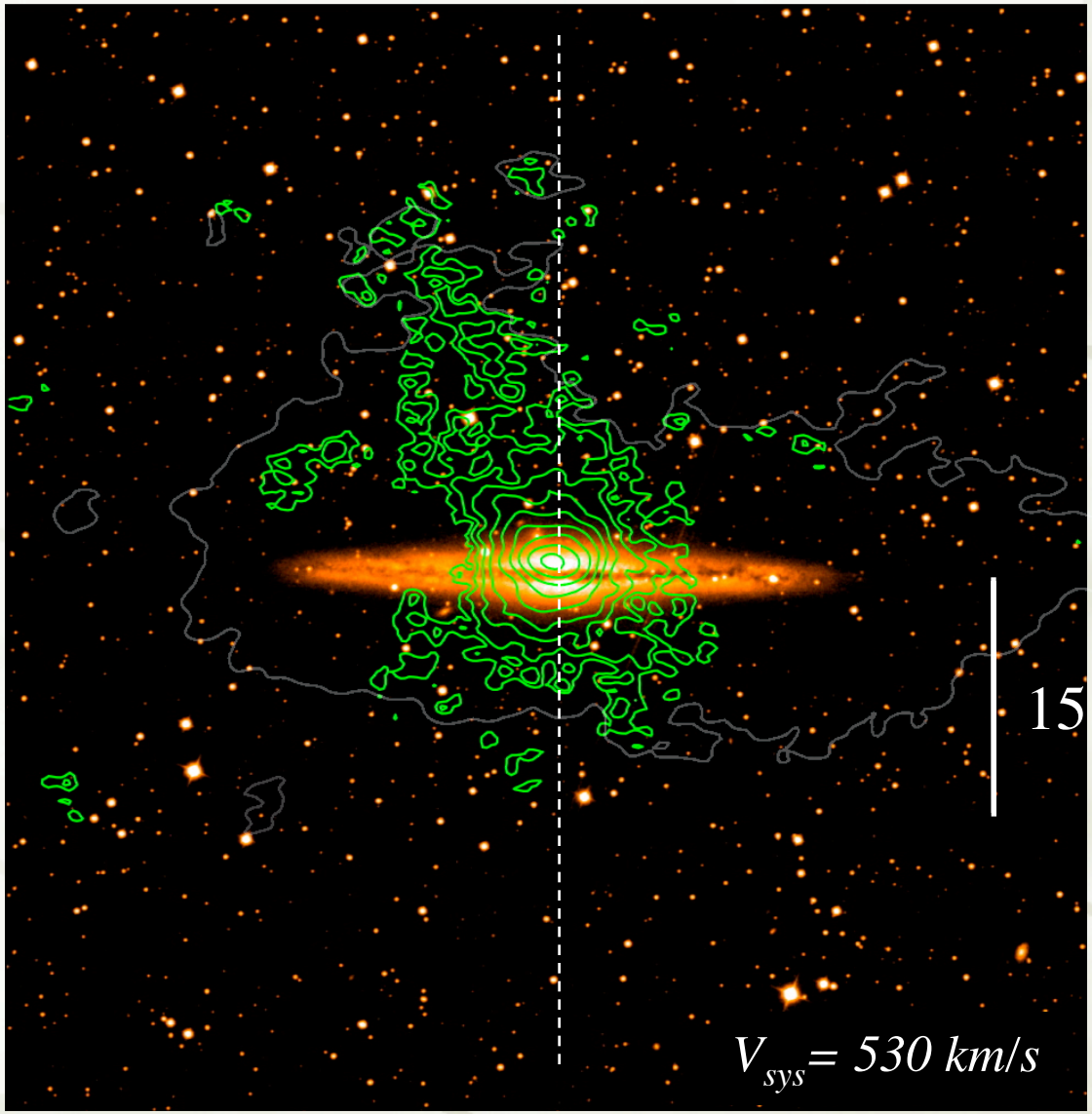

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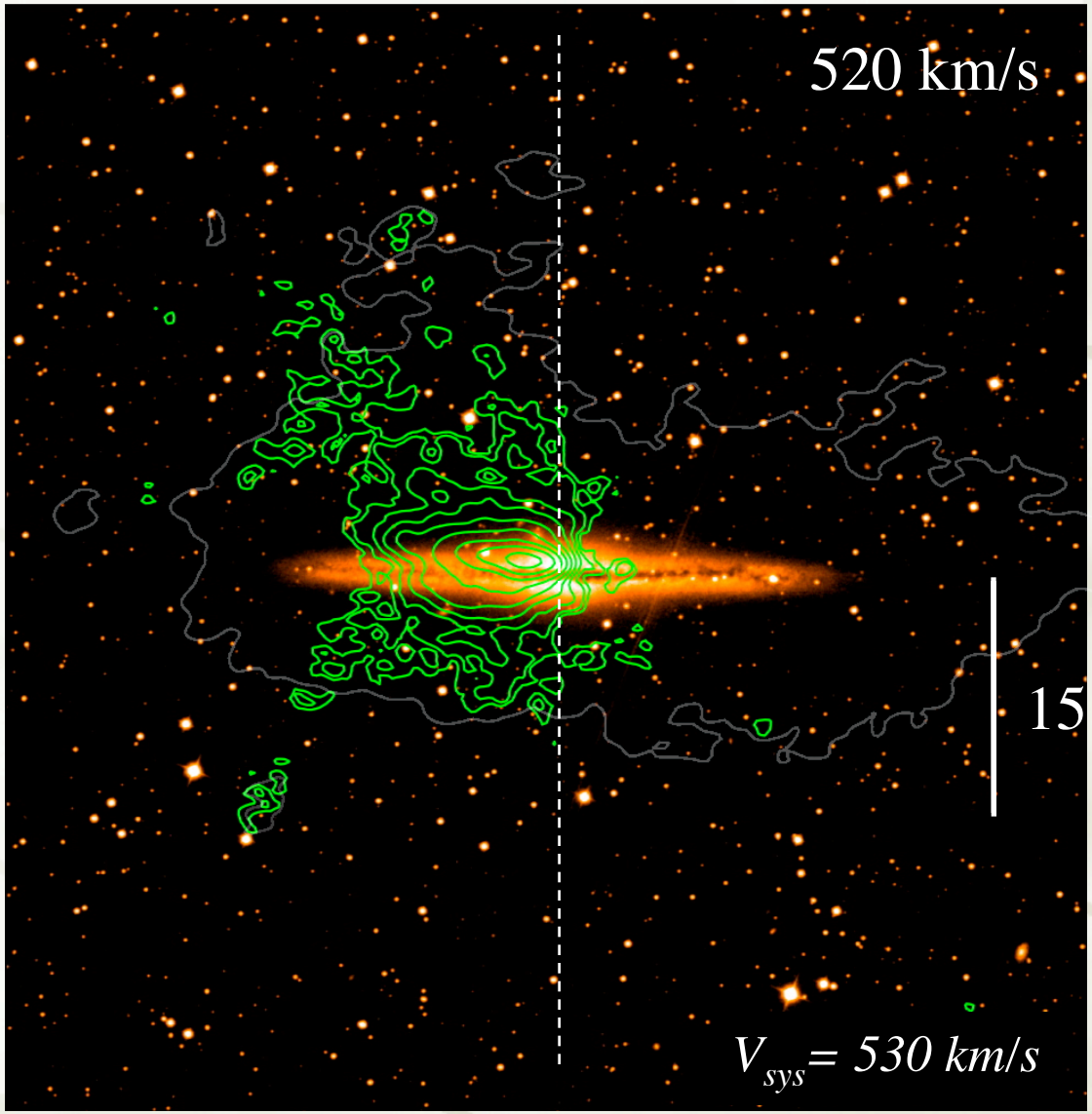

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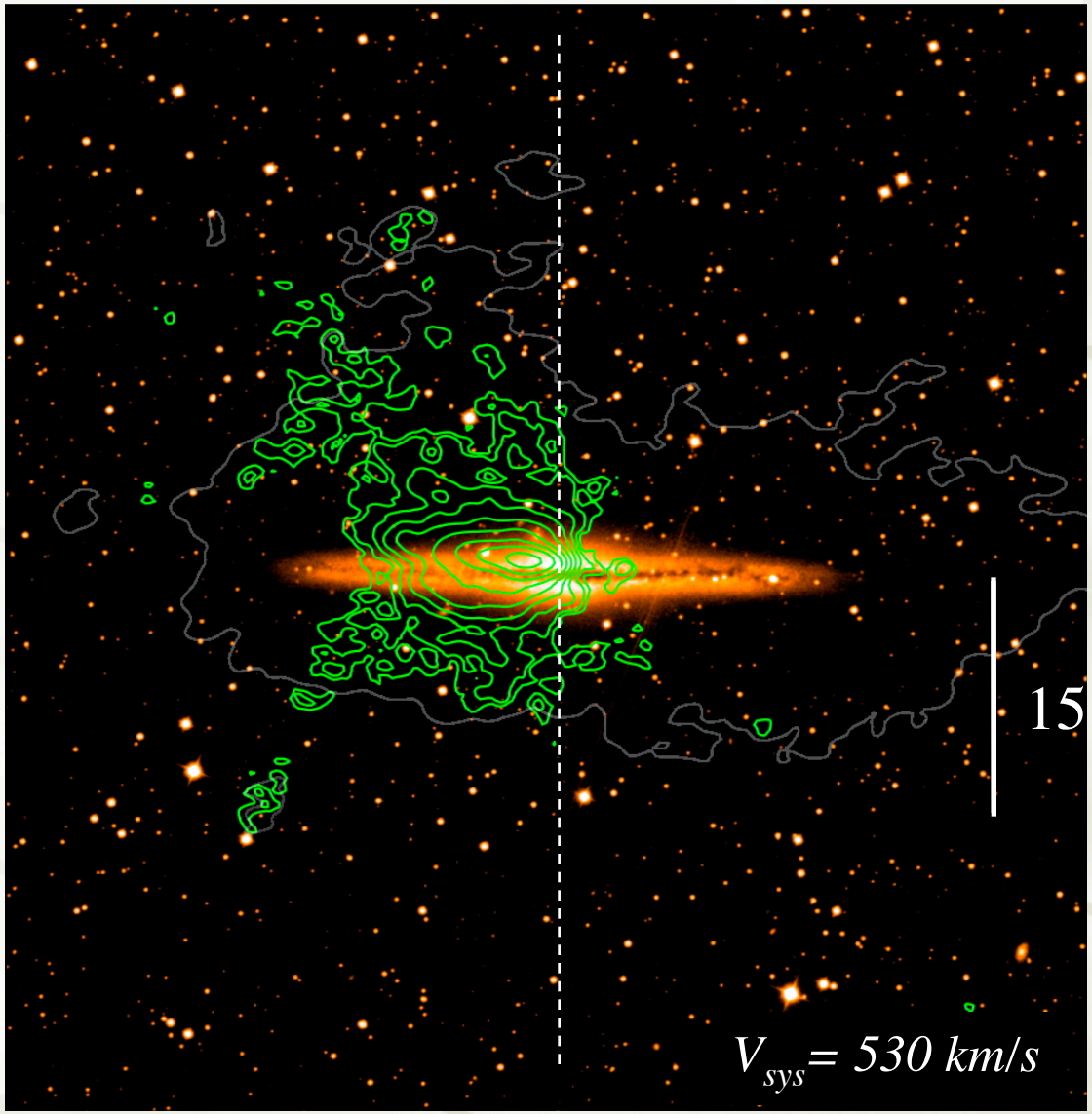

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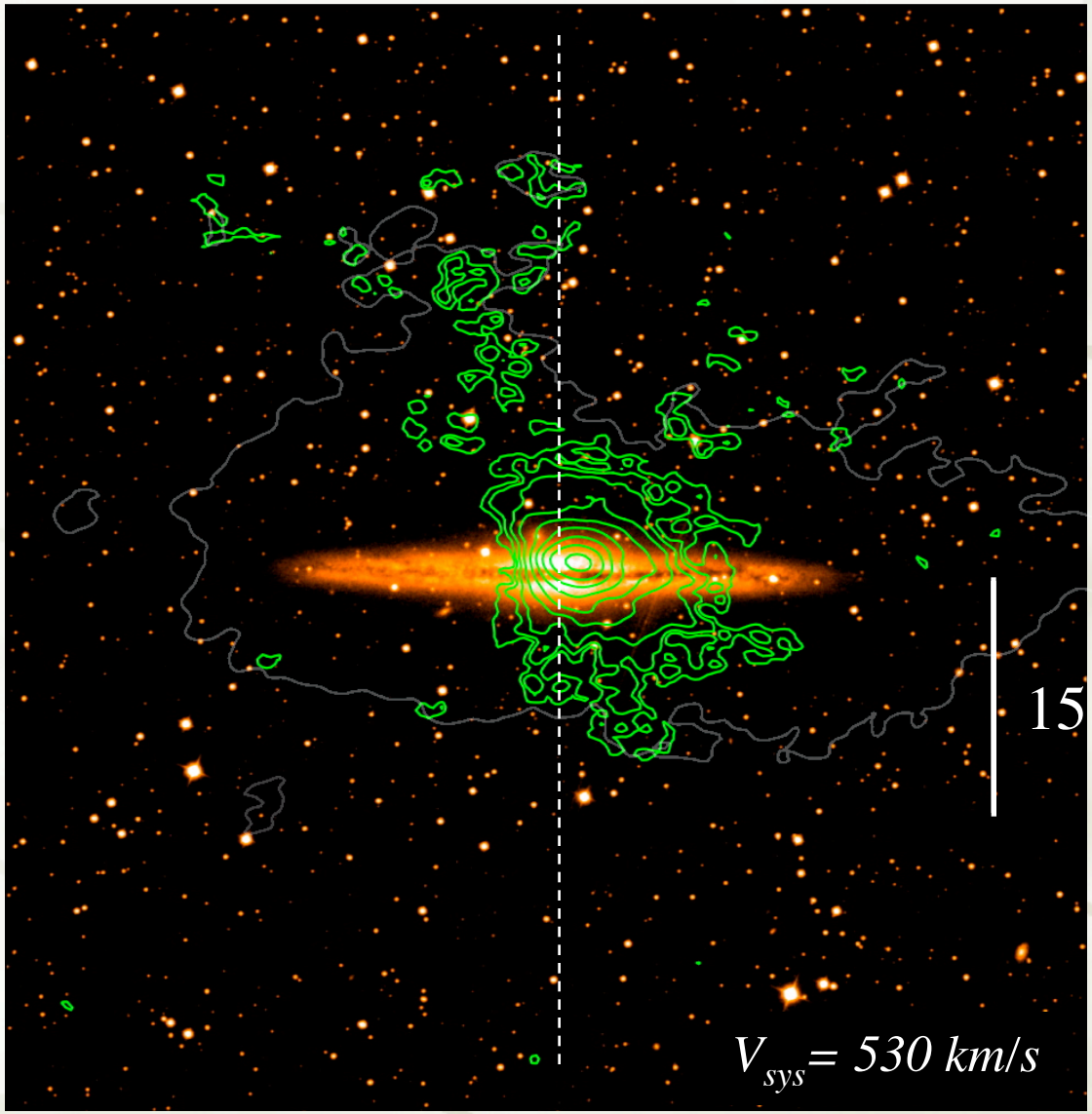

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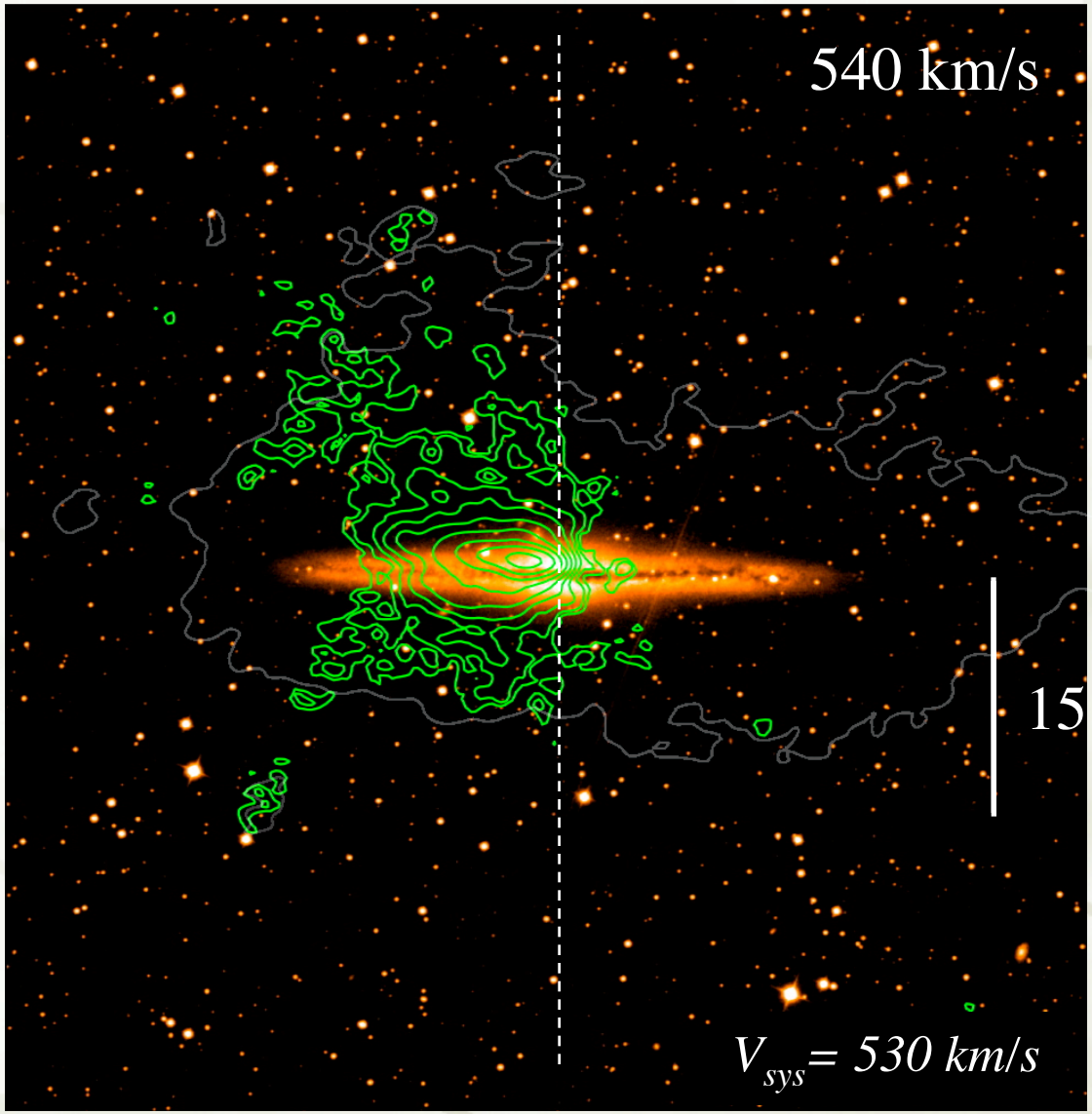

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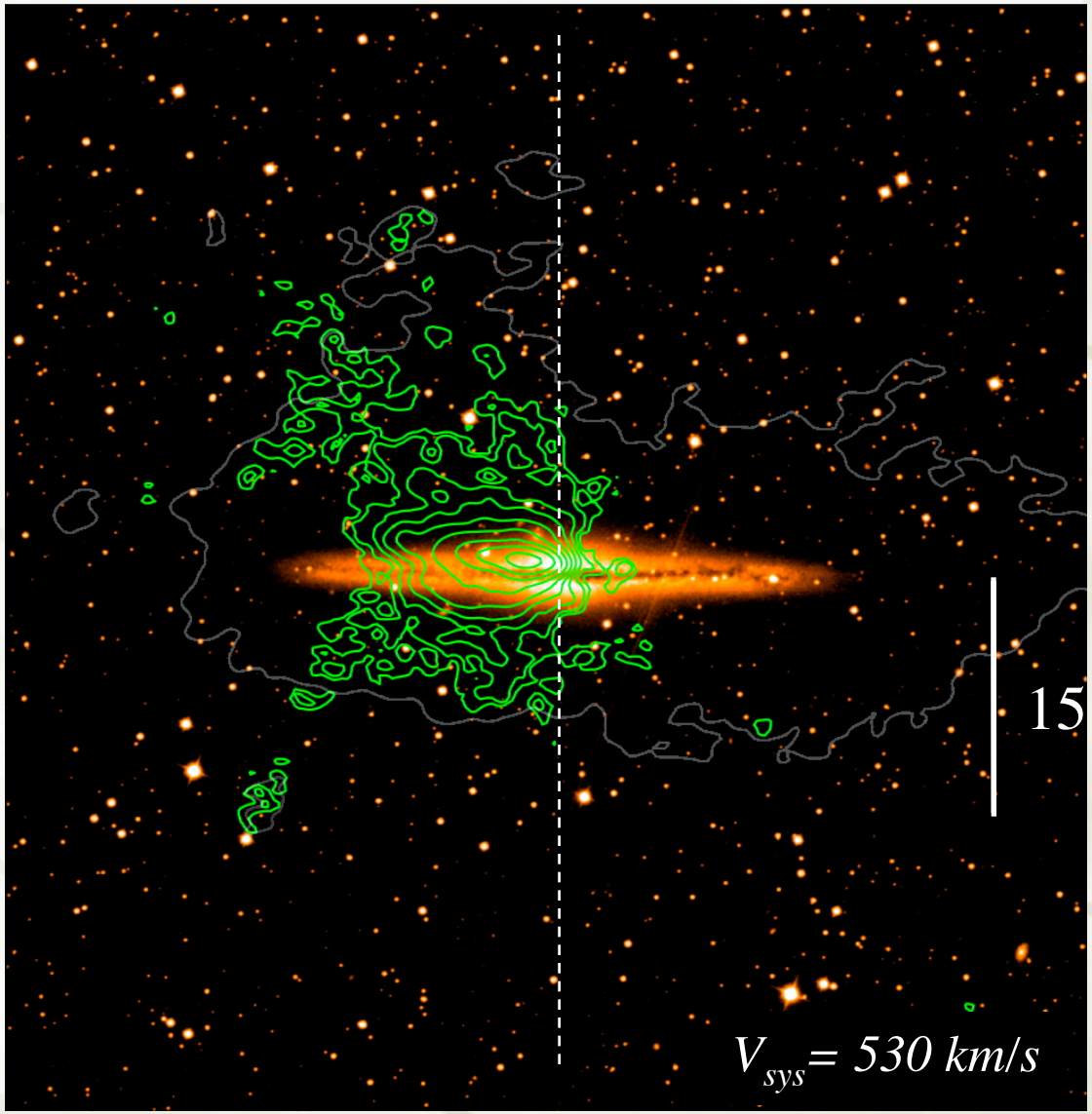

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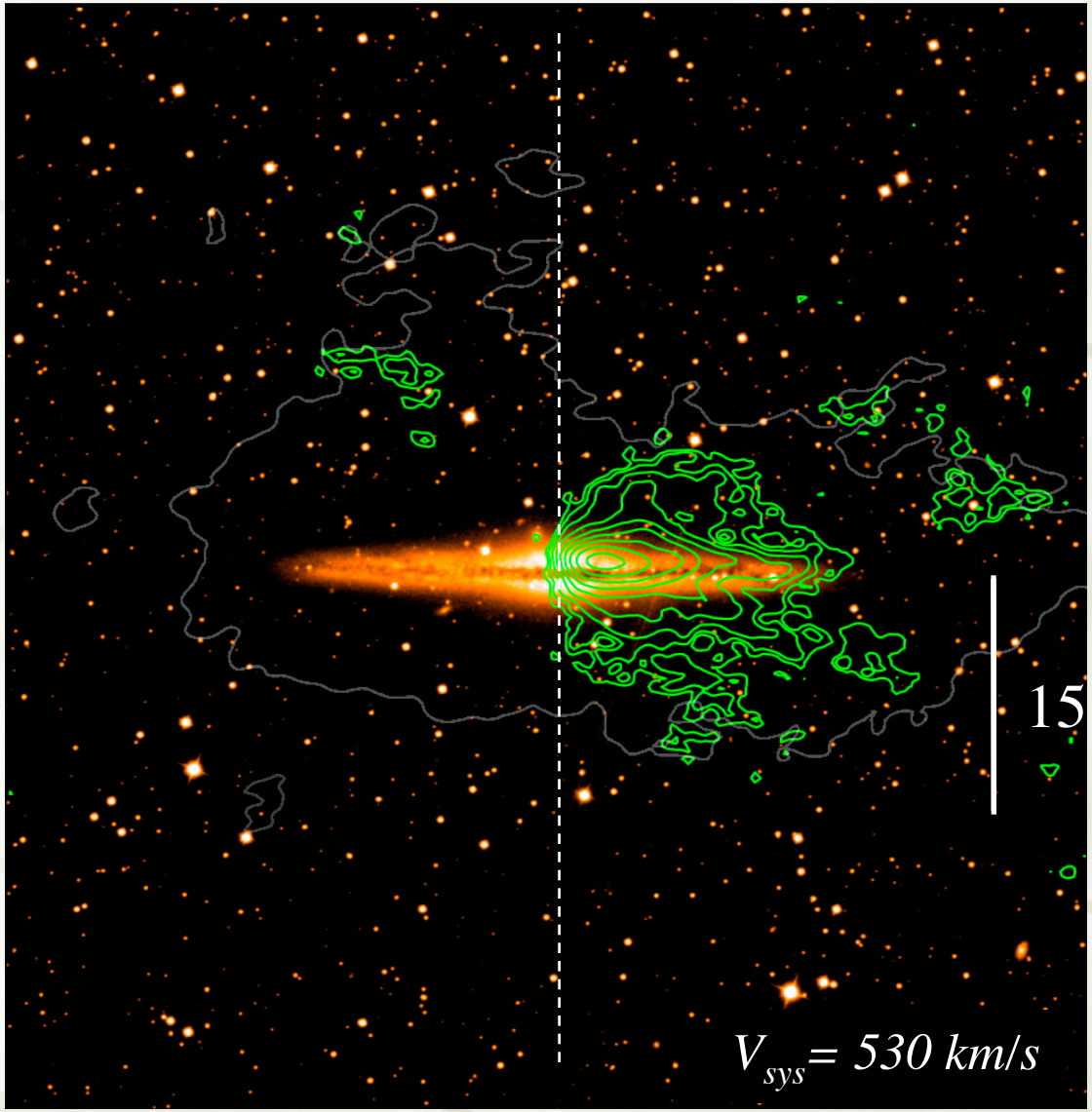

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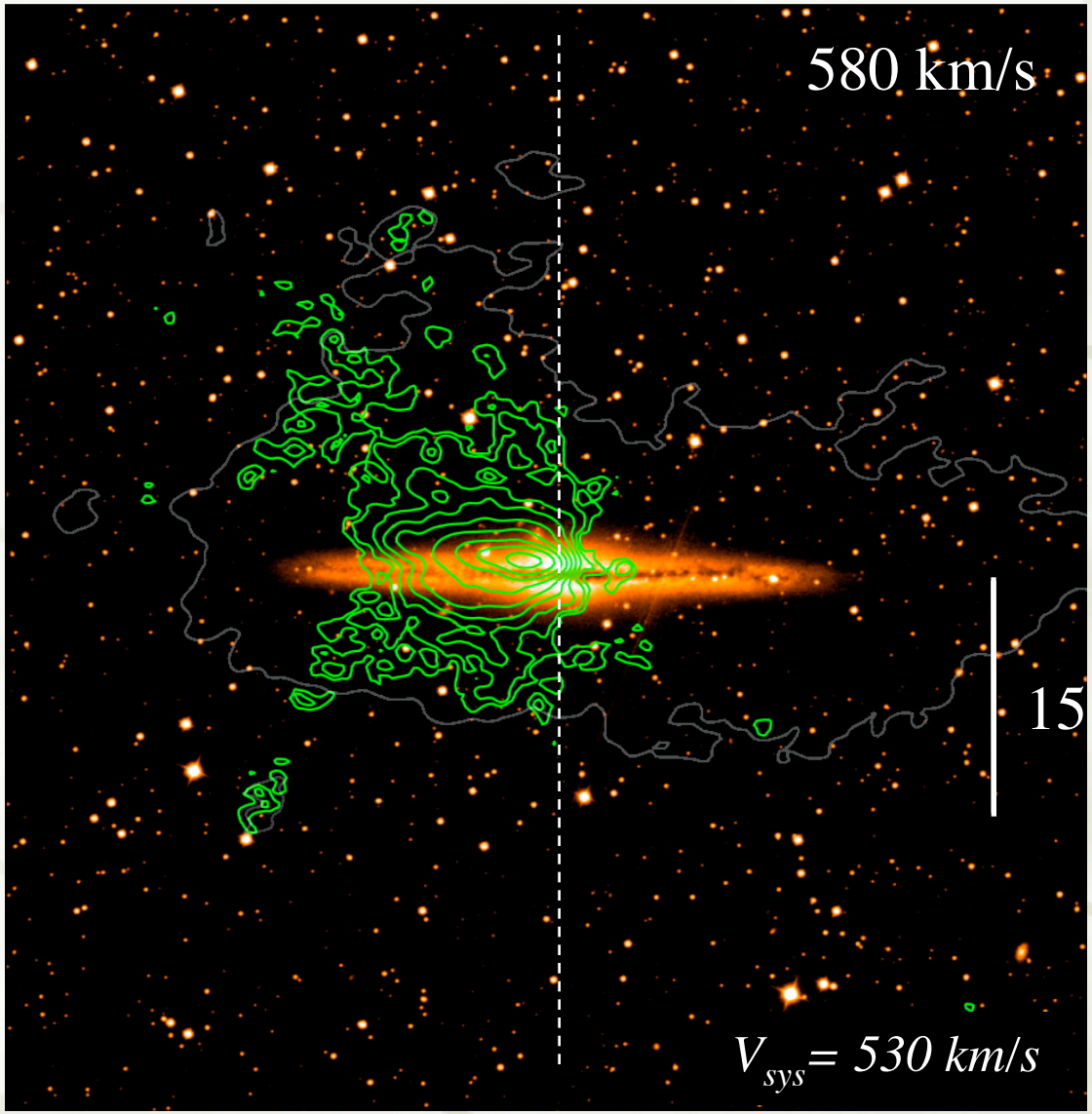

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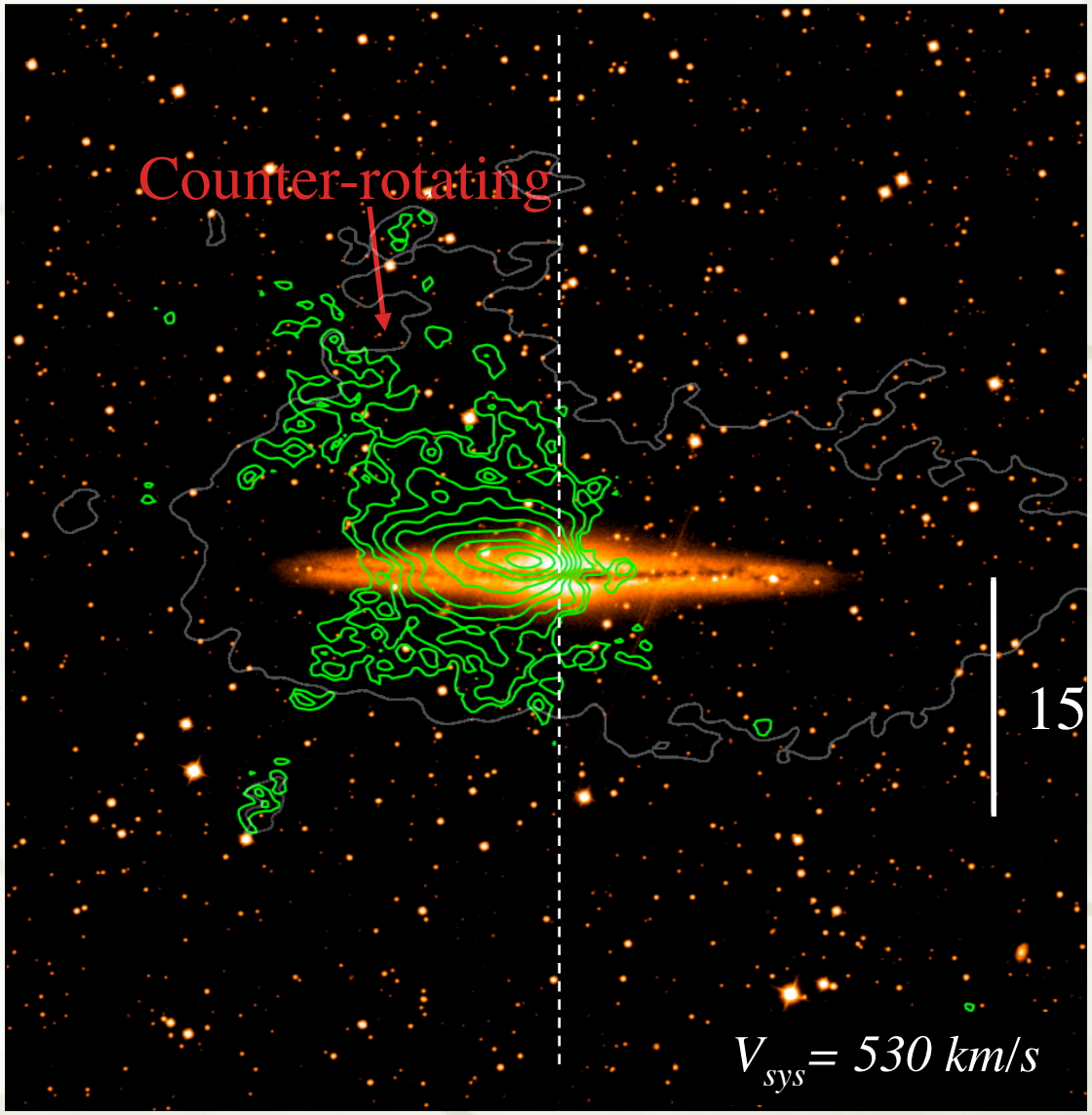

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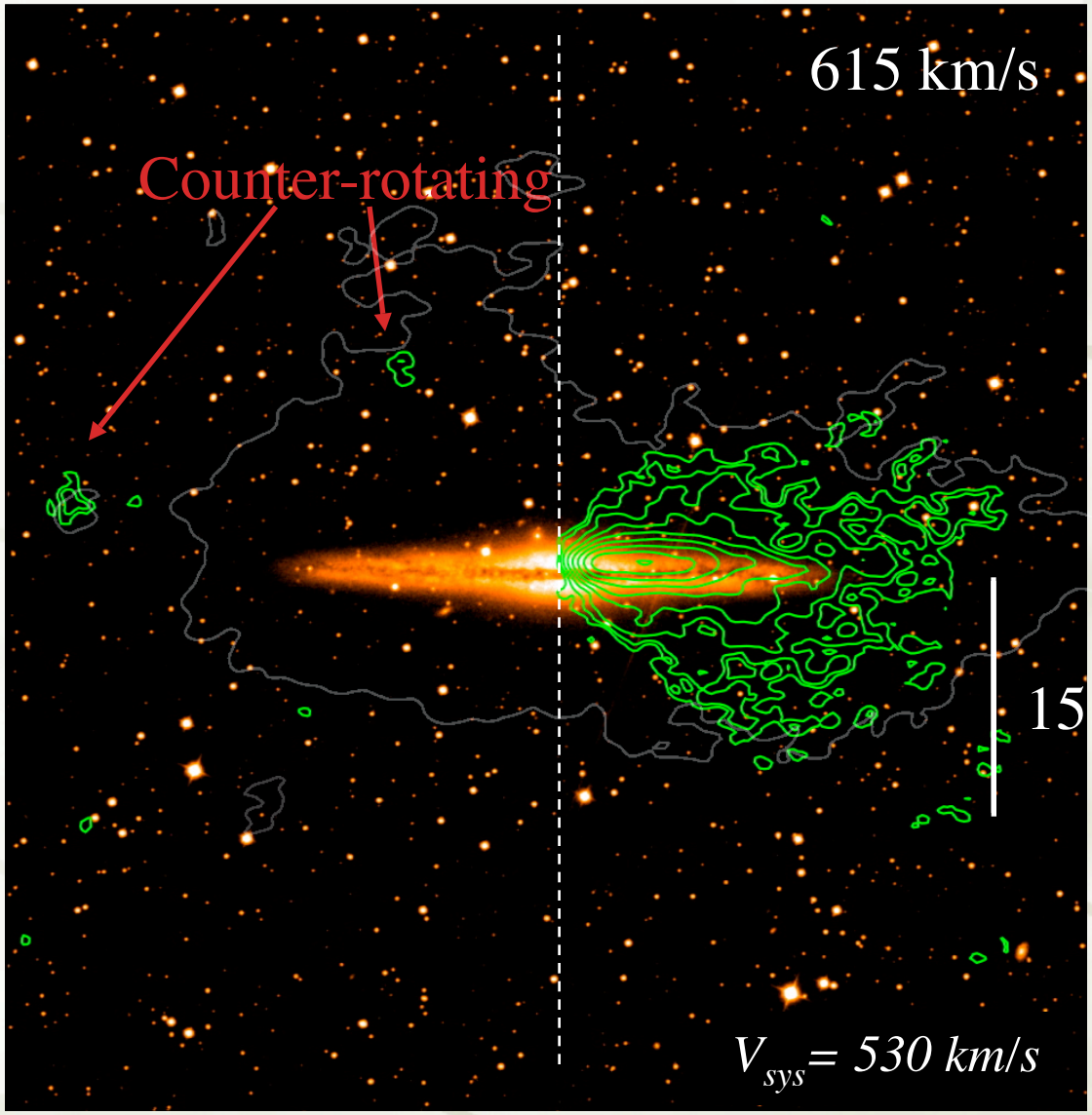
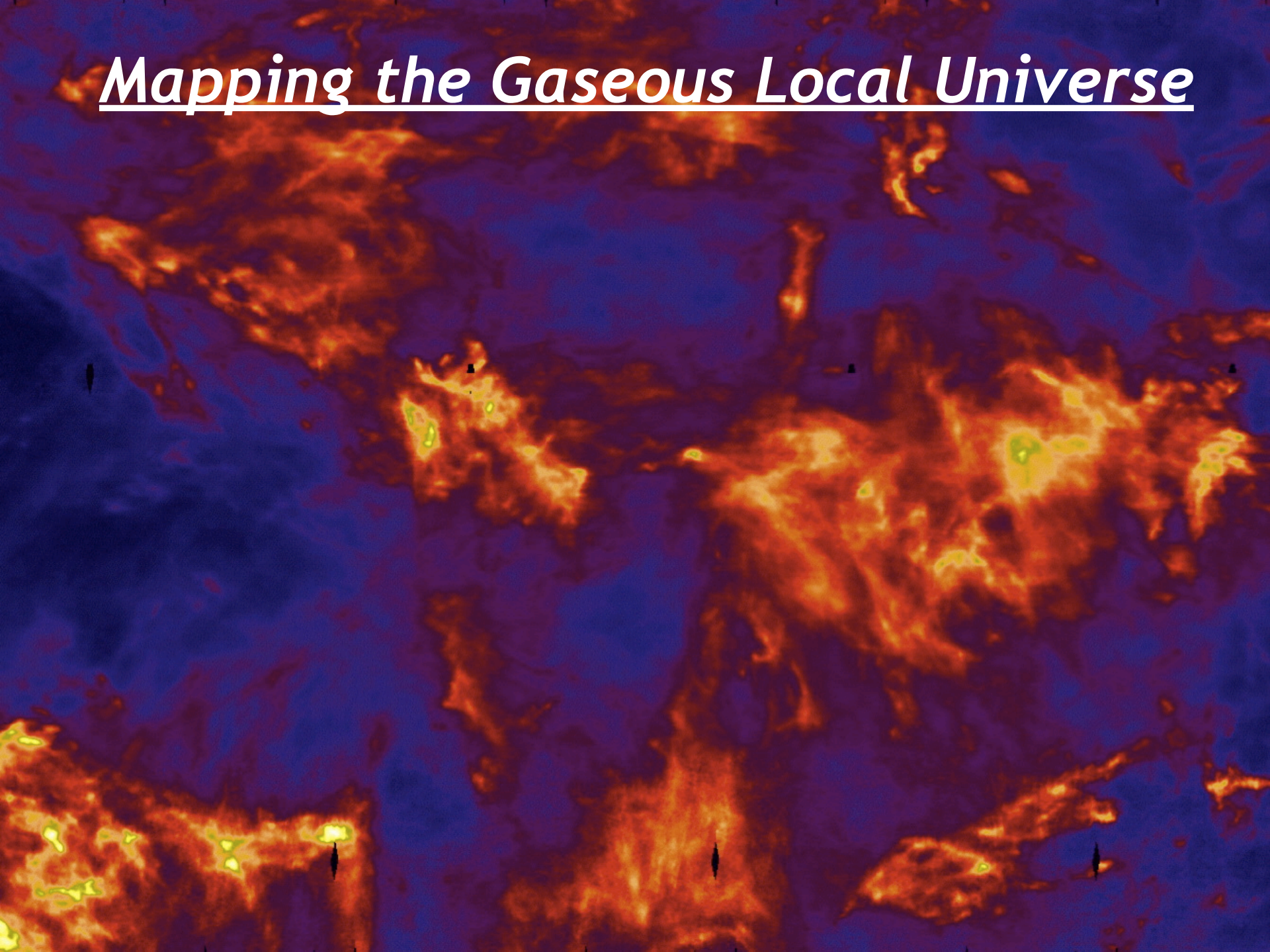


Mapping the Gaseous Local Universe



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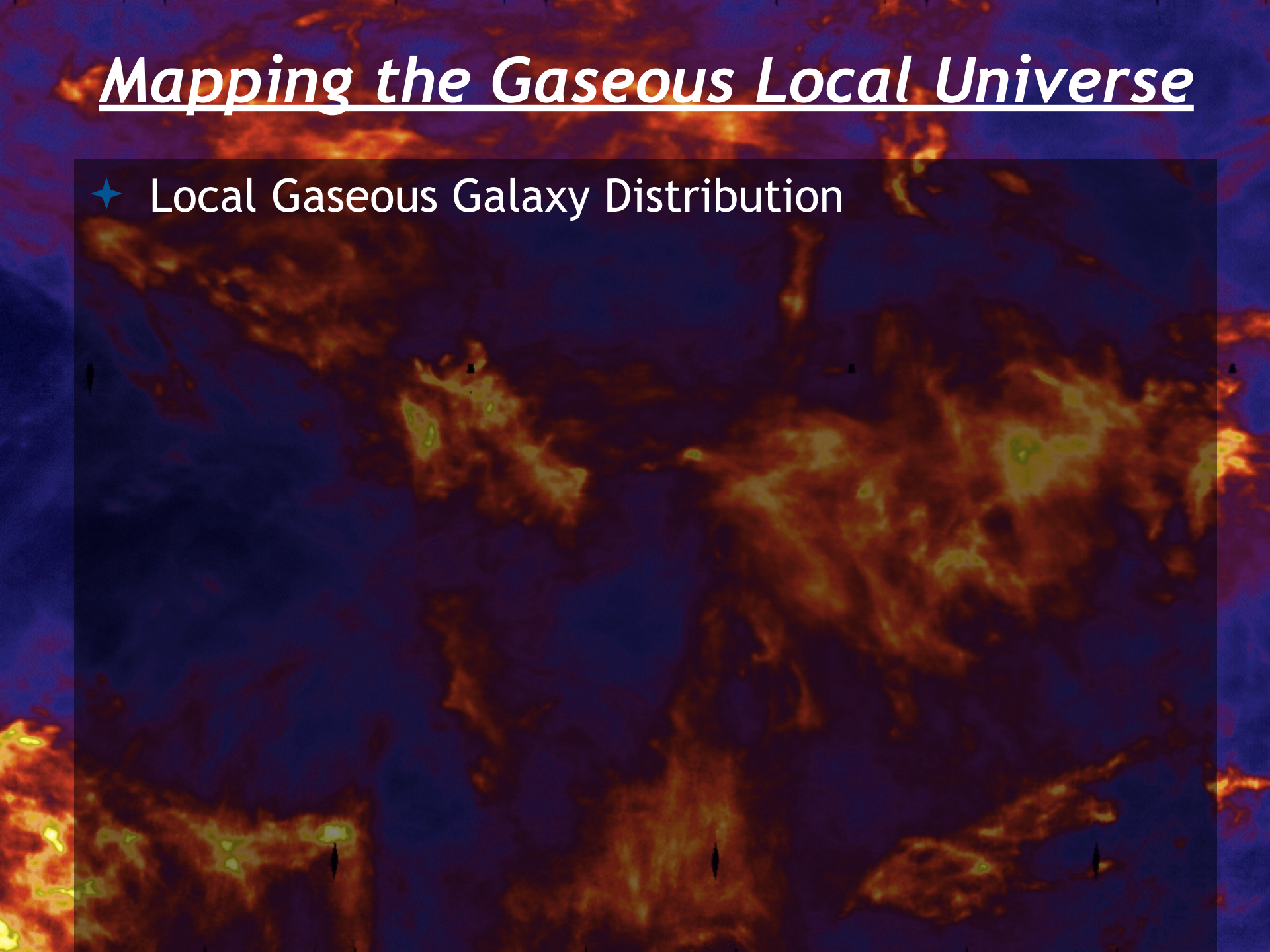

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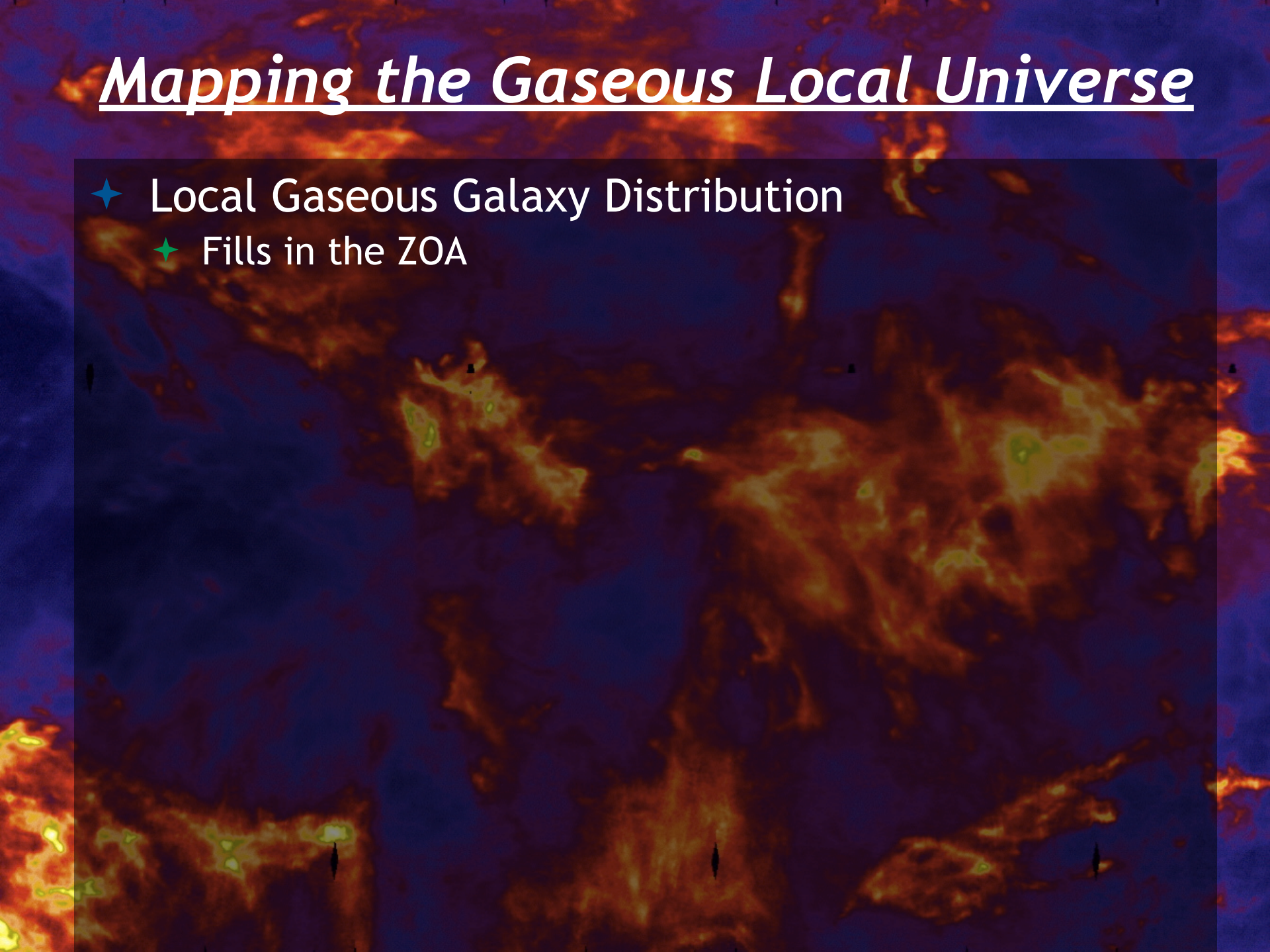
  - Fills in the ZOA



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- Future - HI evolution with redshift, Link to the IGM, etc.