ASTRON

Netherlands Institute for Radio Astronomy

Magnetized disk-halo interface in spiral galaxies

George Heald

MKSP Meeting, Bologna

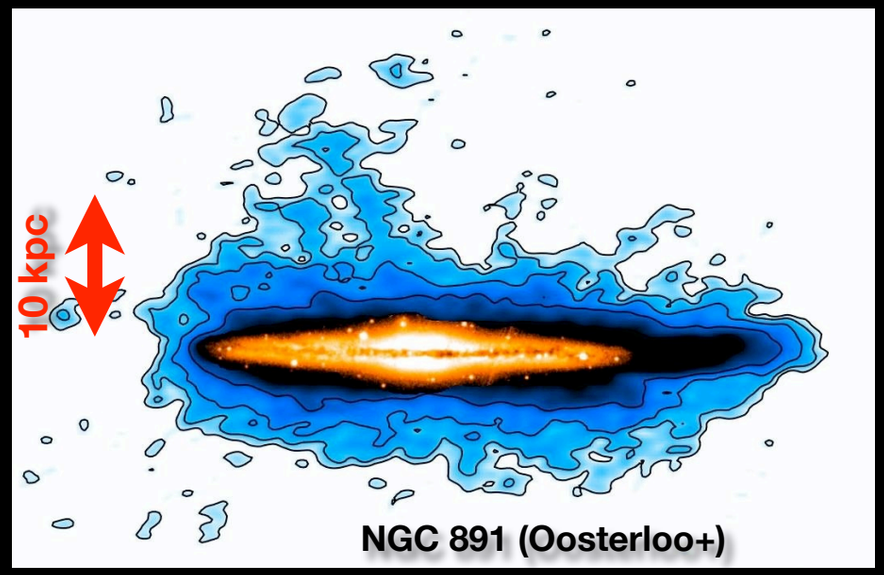
25 November 2011

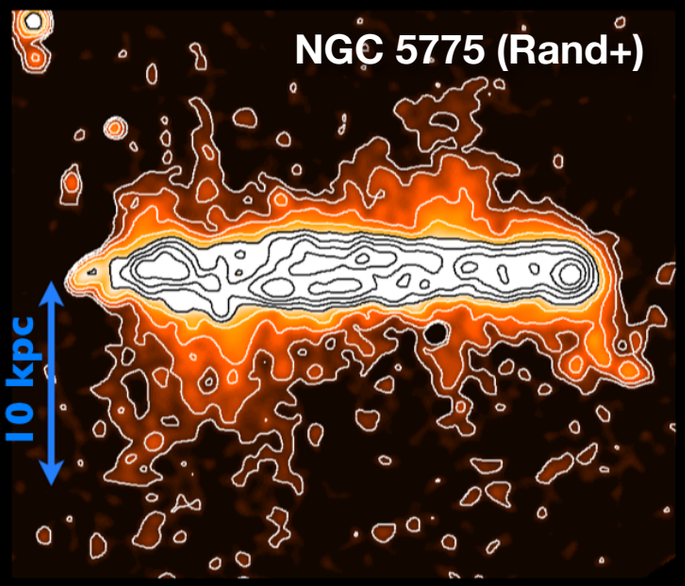
Outline

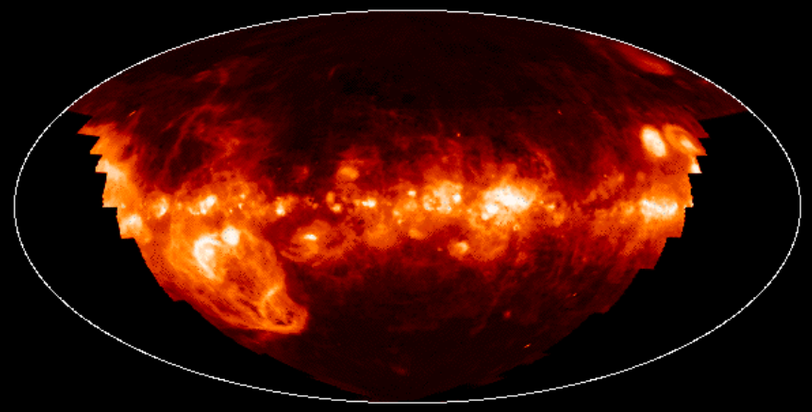
- Disk-halo interactions: motivation
- Why are magnetic fields relevant?
- First attempts to trace disk-halo interactions in RM:
  - NGC 6946: using WSRT-SINGS data
  - M101: using WSRT data to observe SN 2011fe
- How can LOFAR contribute?

Multiphase extraplanar regions

- Deep observations of (edge-on) spirals show thick, vertically extended, multi-phase layers of gas, dust, and magnetic fields

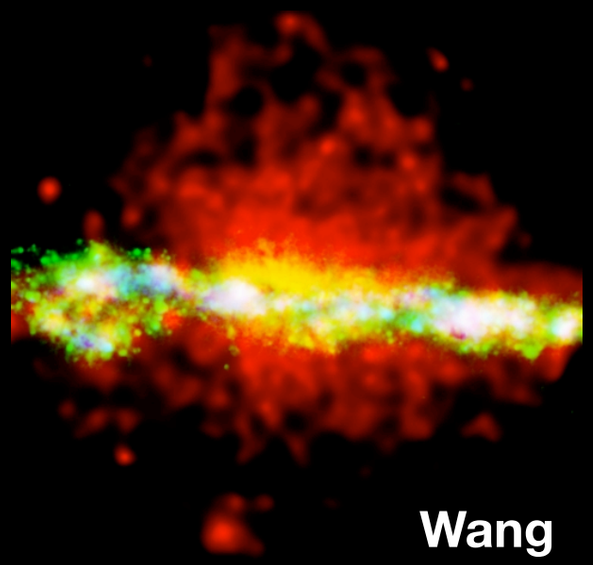




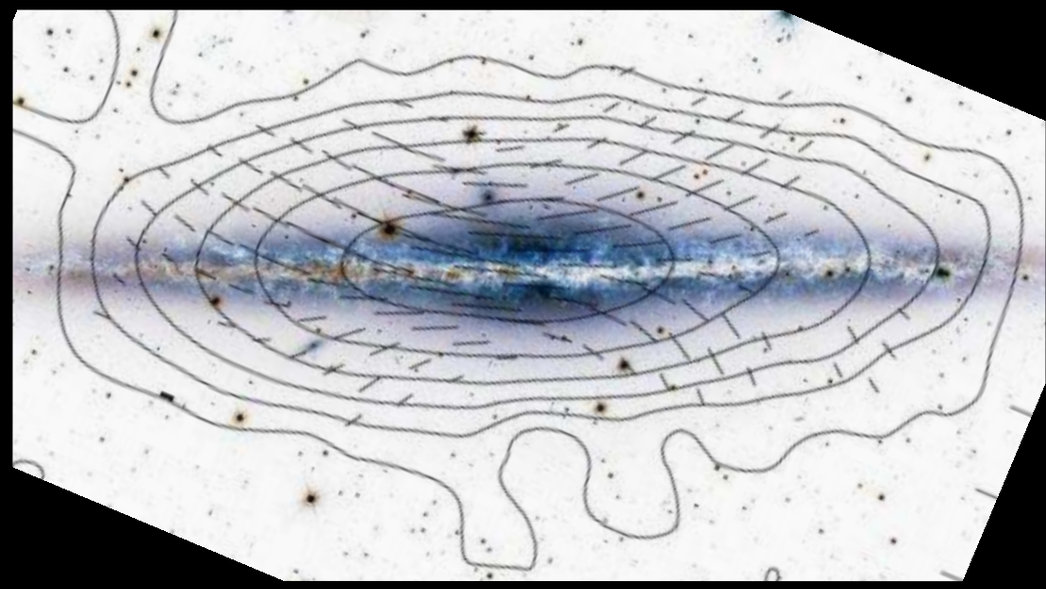


WHAM

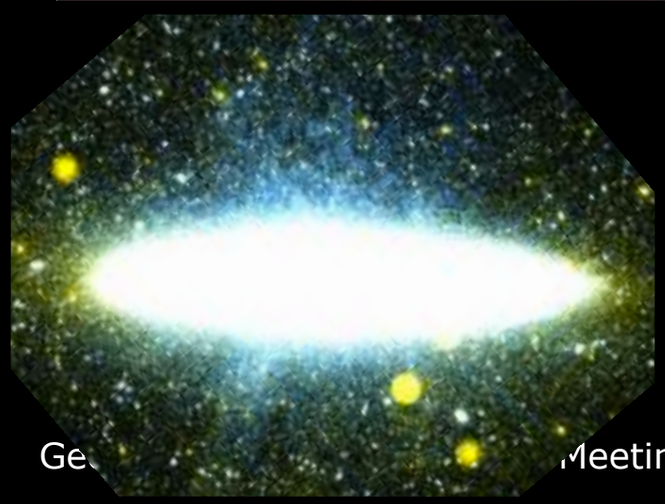
Howk



Wang



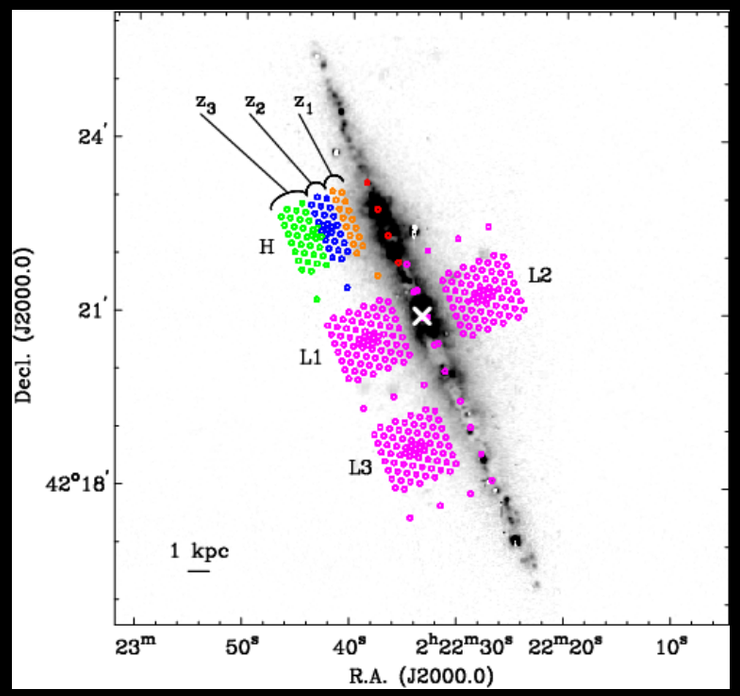
Krause



Hoopes

Extraplanar kinematics

- Extraplanar kinematics "lag" the disk rotation curve
  - This is seen as "beard" emission in inclined galaxies



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Ionized gas kinematics match HI kinematics from Fraternali et al. (2005)

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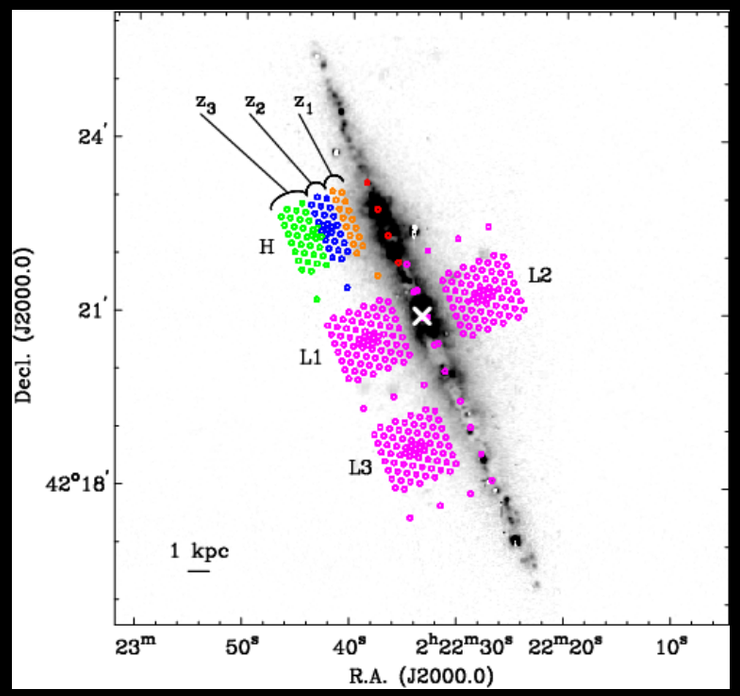

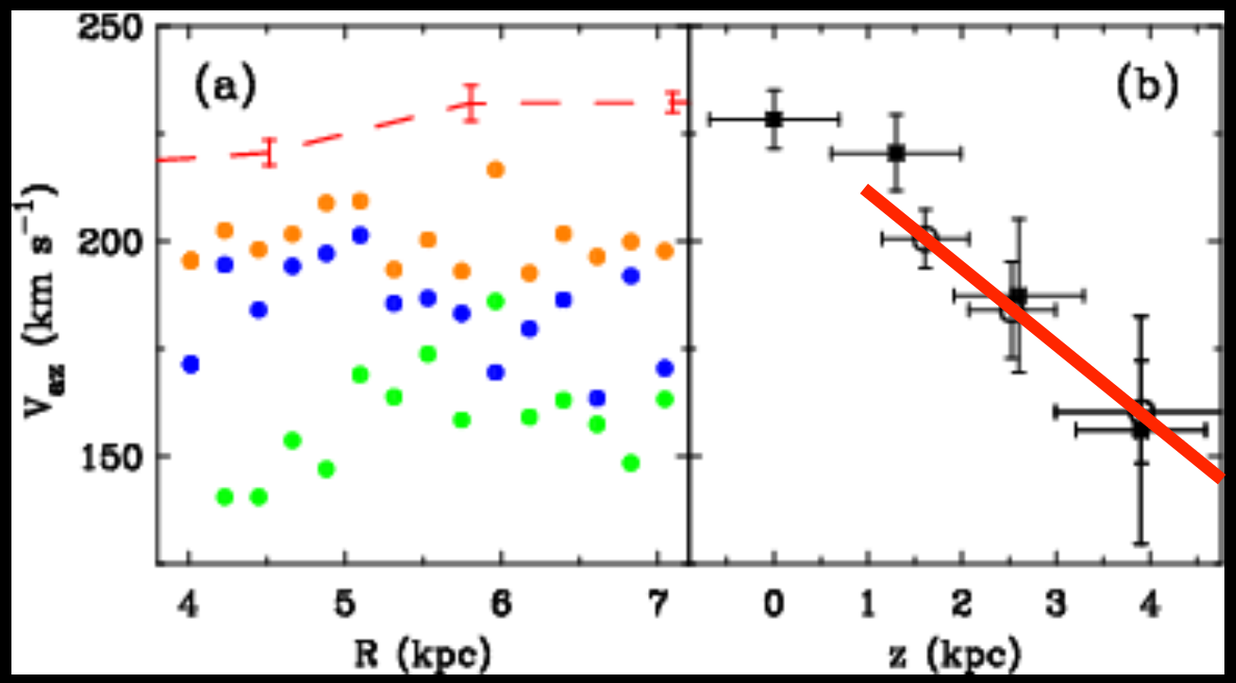

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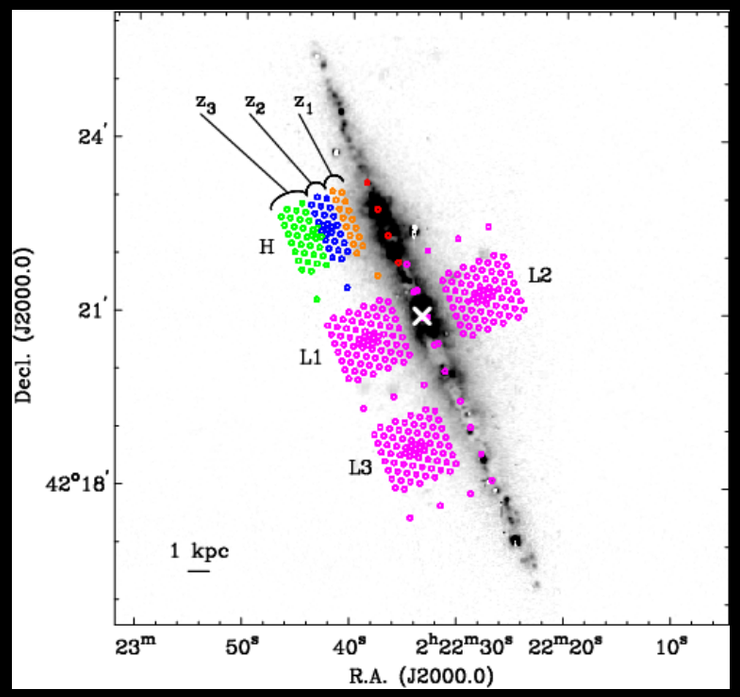

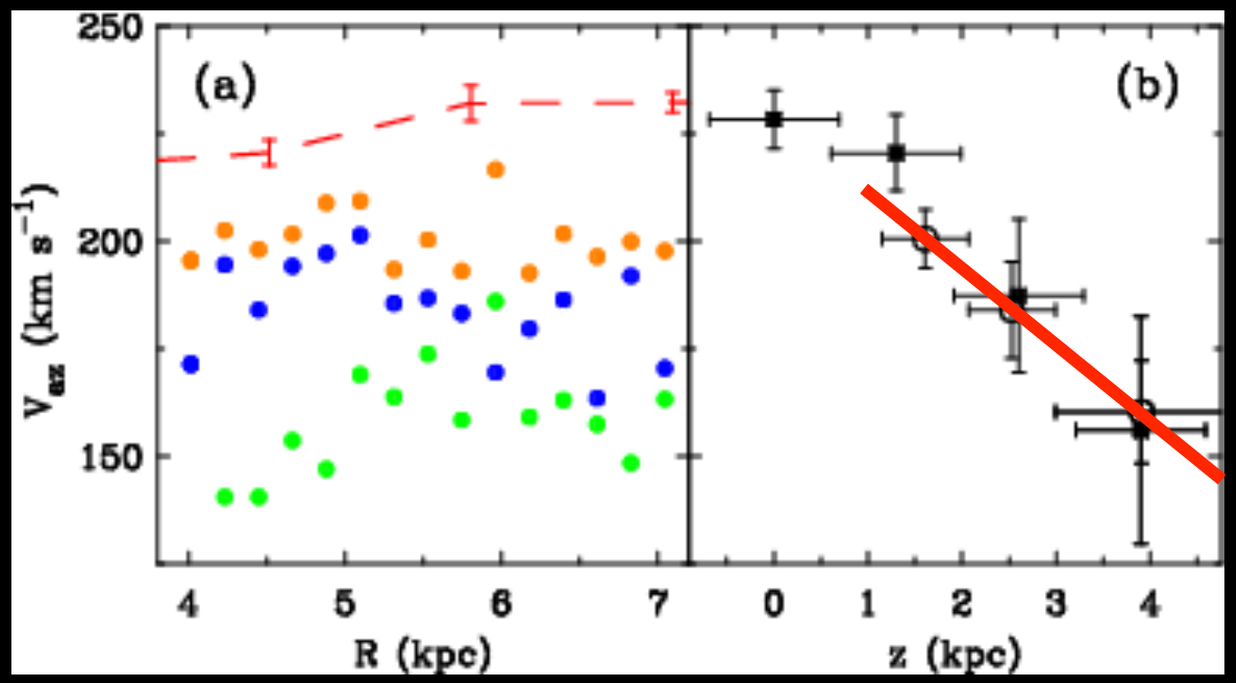

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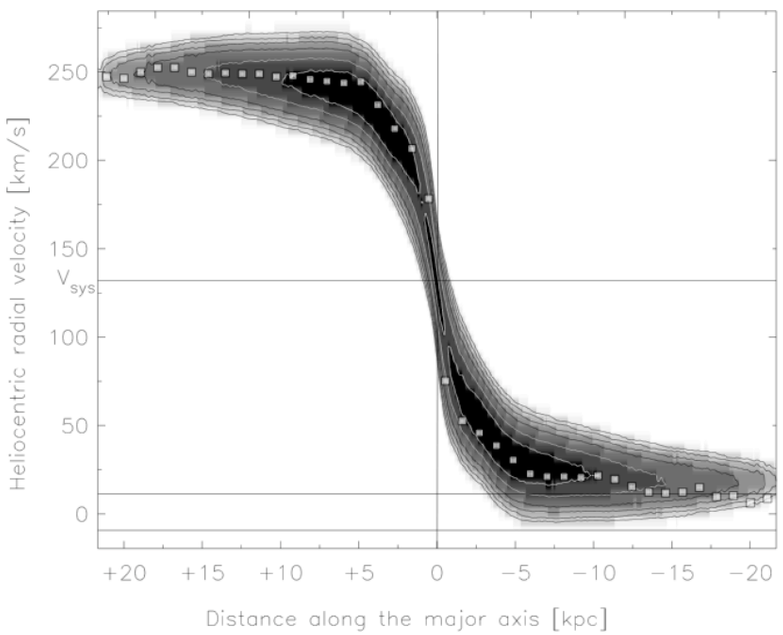

NGC 2403 (Fraternali et al. 2001)

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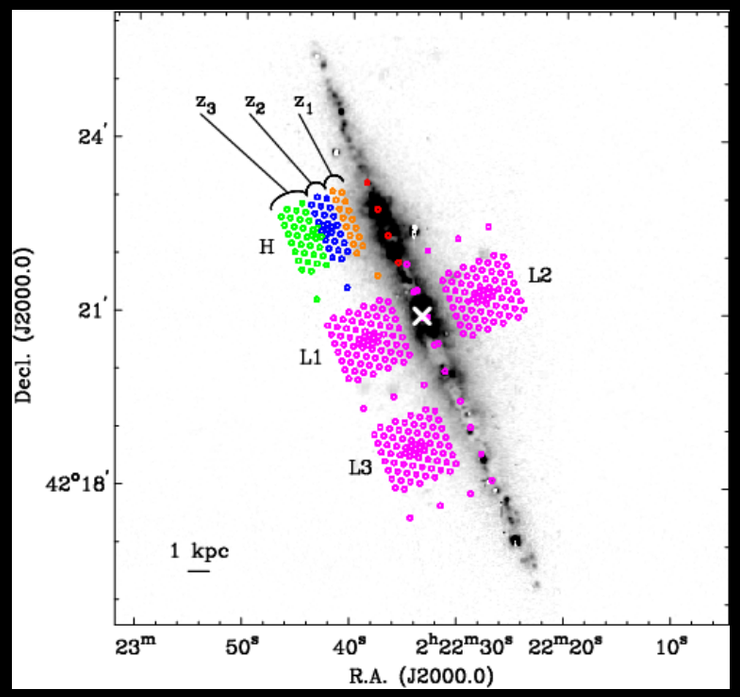

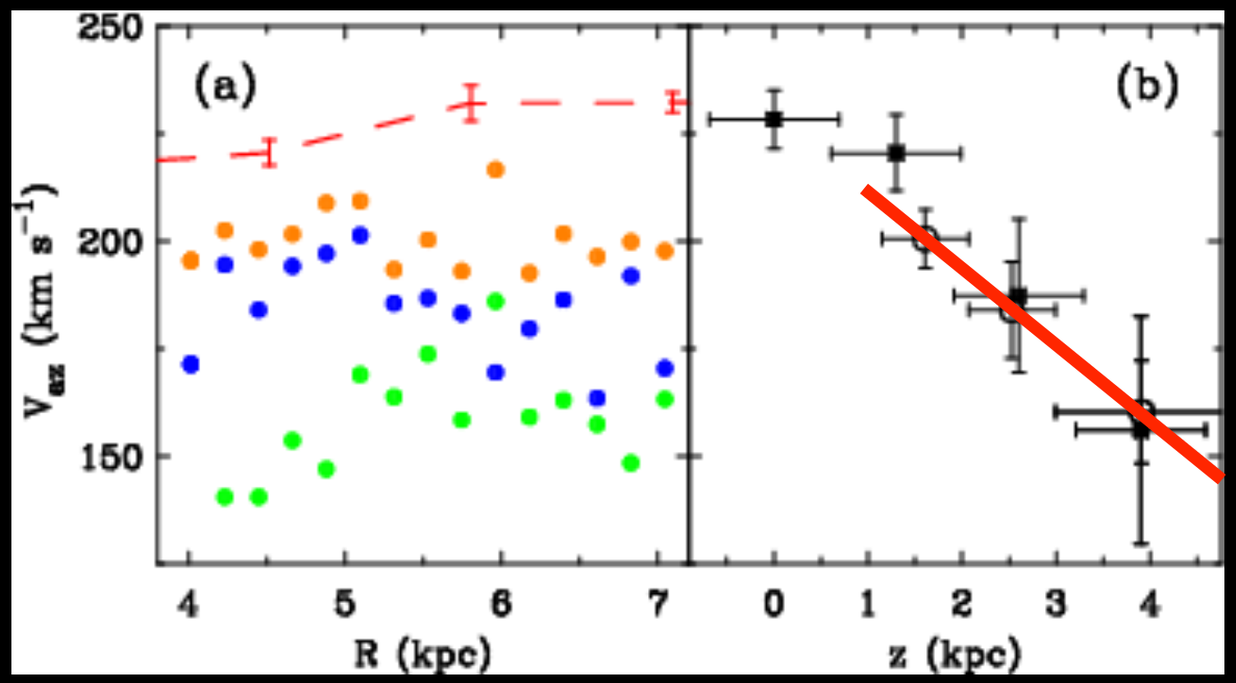

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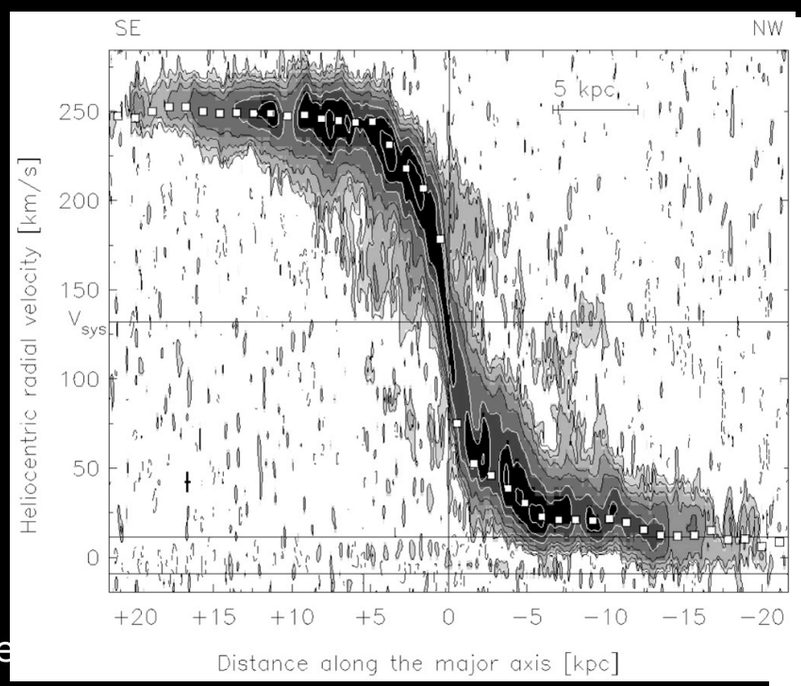

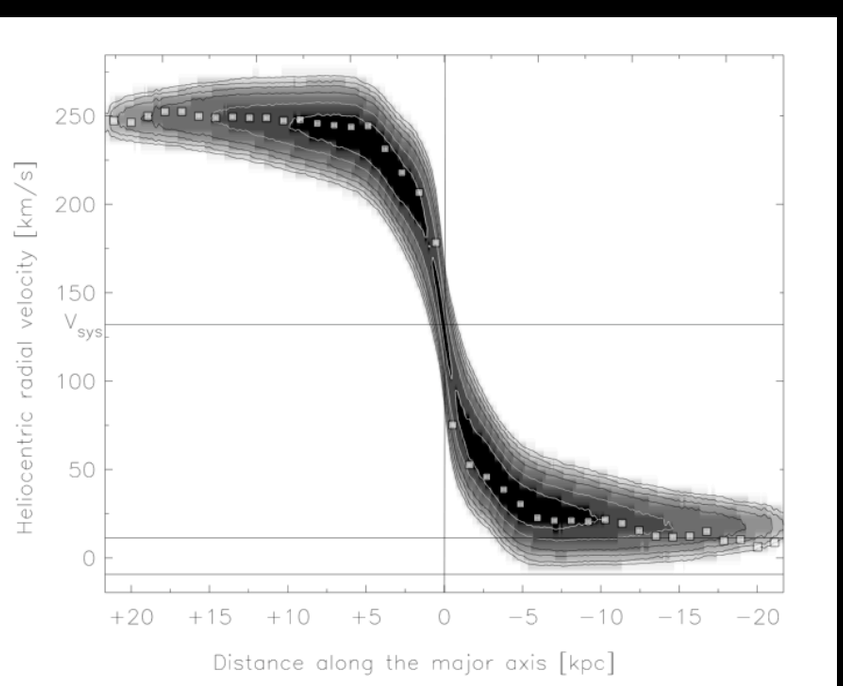

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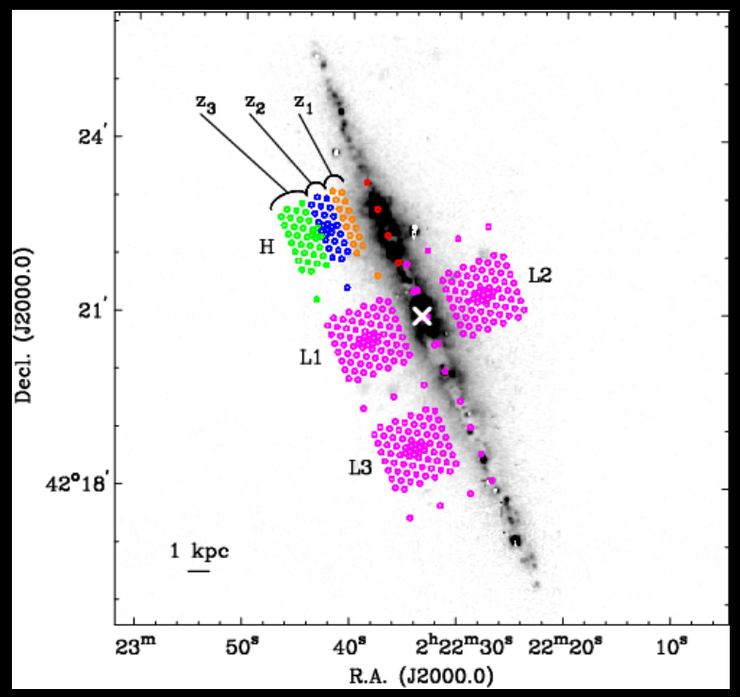

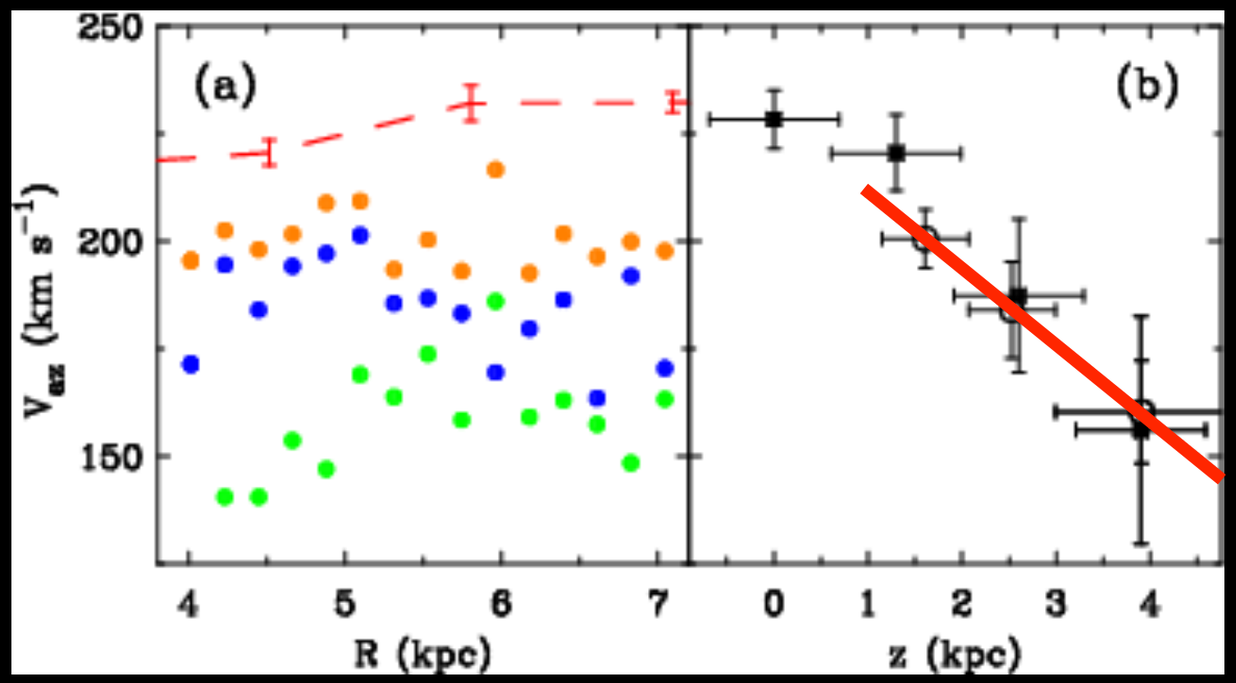

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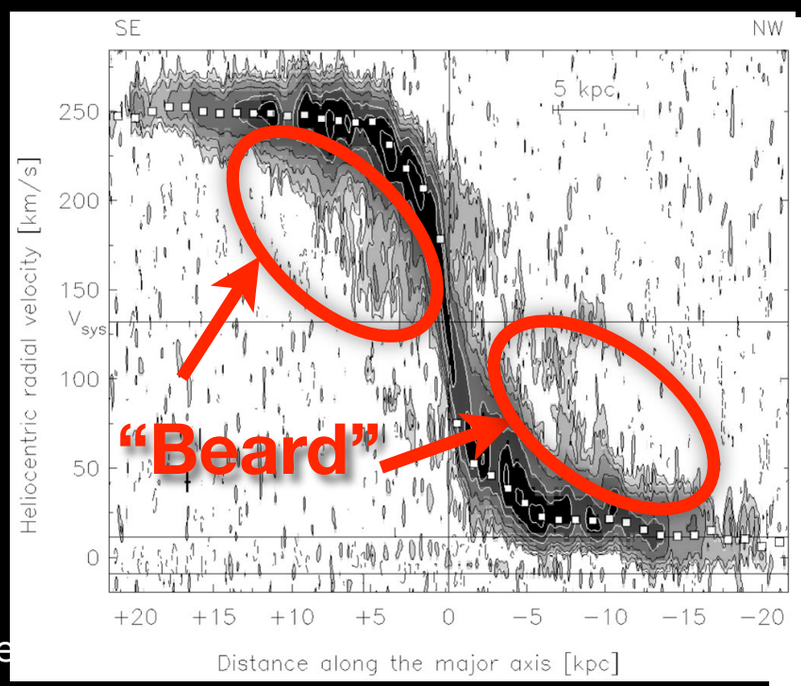

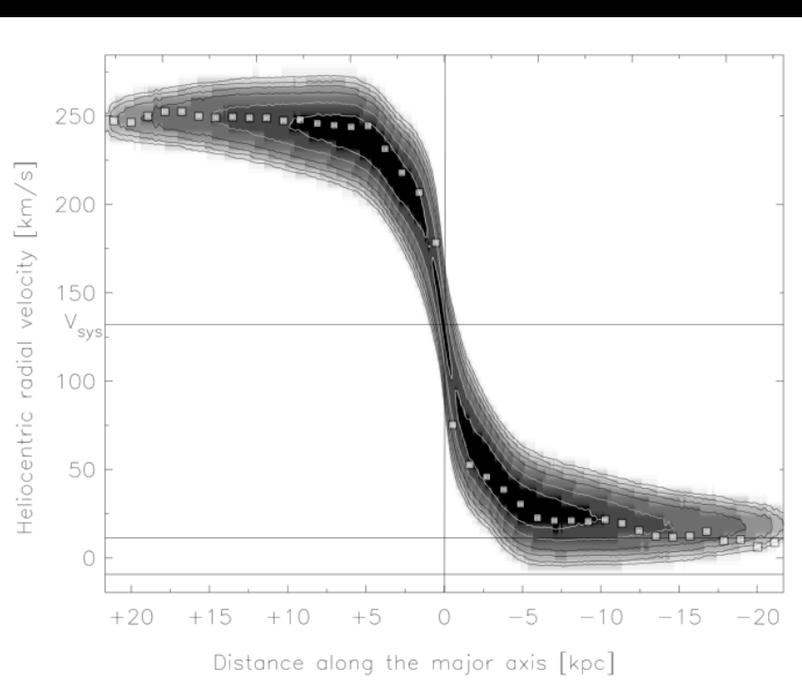

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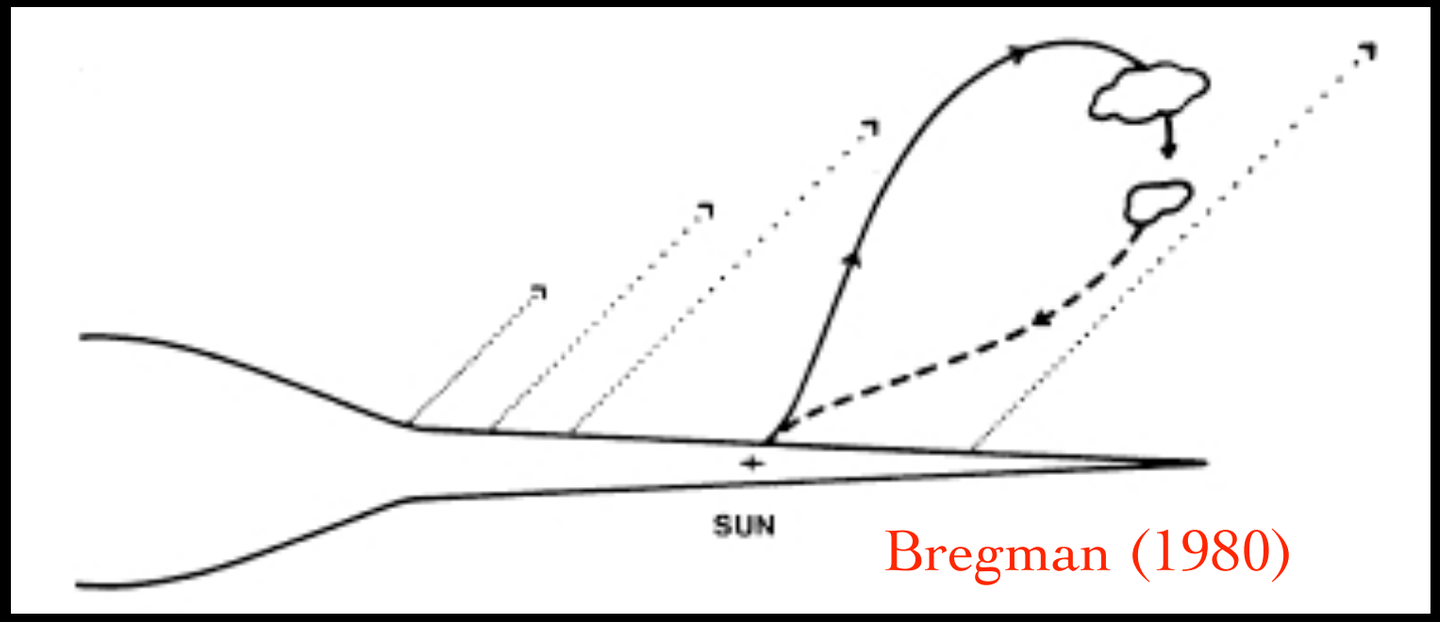
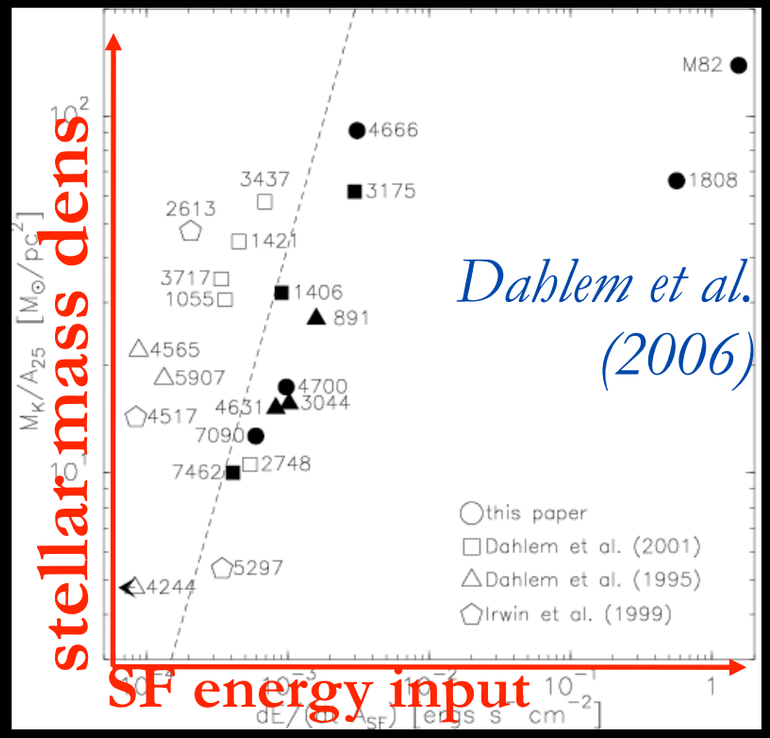
Understanding extraplanar gas

- Origin thought to be dominated by galactic fountain material



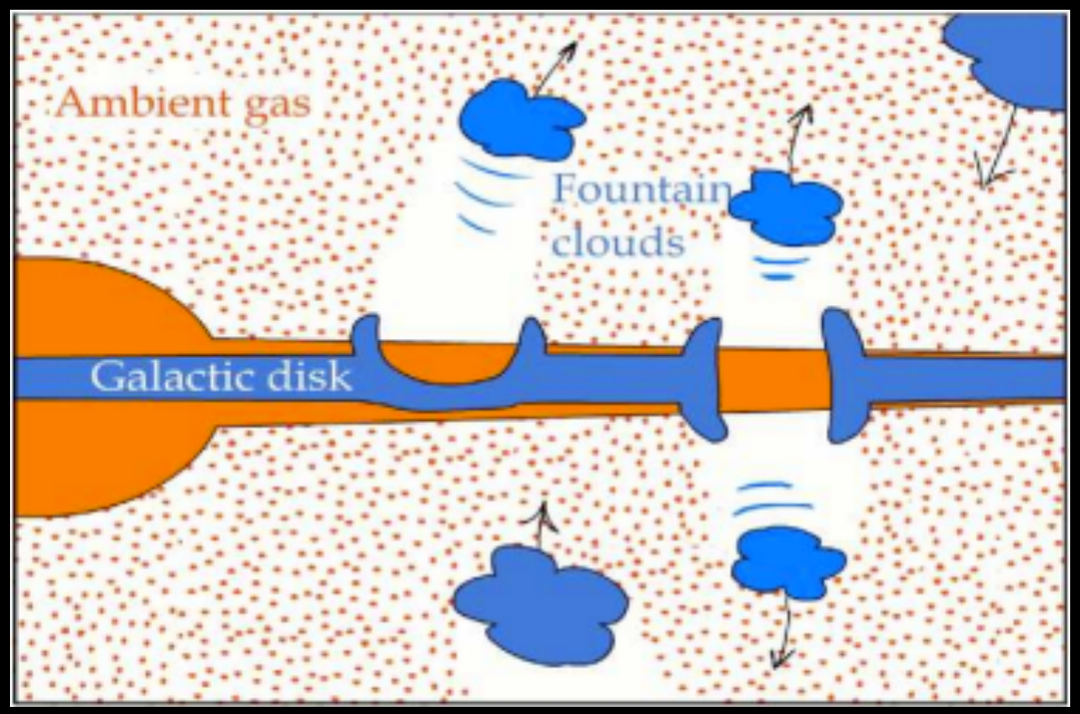
Bregman (1980)



Dahlem et al. (2006)

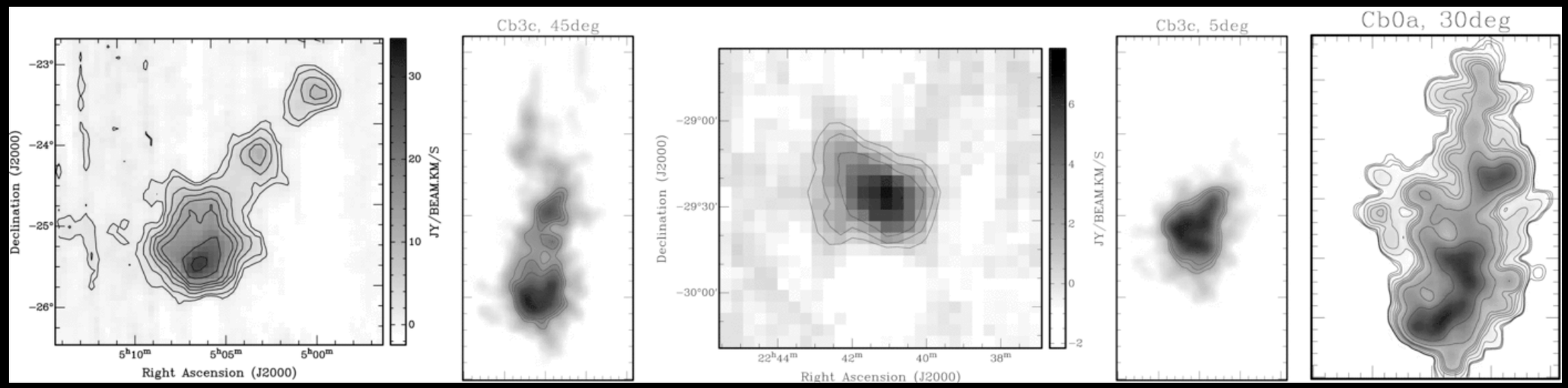
with some accreting material (e.g. Fraternali & Binney 2008)

This combination can explain the kinematics, and appears to imply a reasonable accretion rate for the galaxies they considered



HVC survival

- If HVCs are accreting onto galaxies, how do they remain intact?
- Hydro simulations (Heitsch & Putman 2009) reproduce morphology of observed head-tail HVCs:



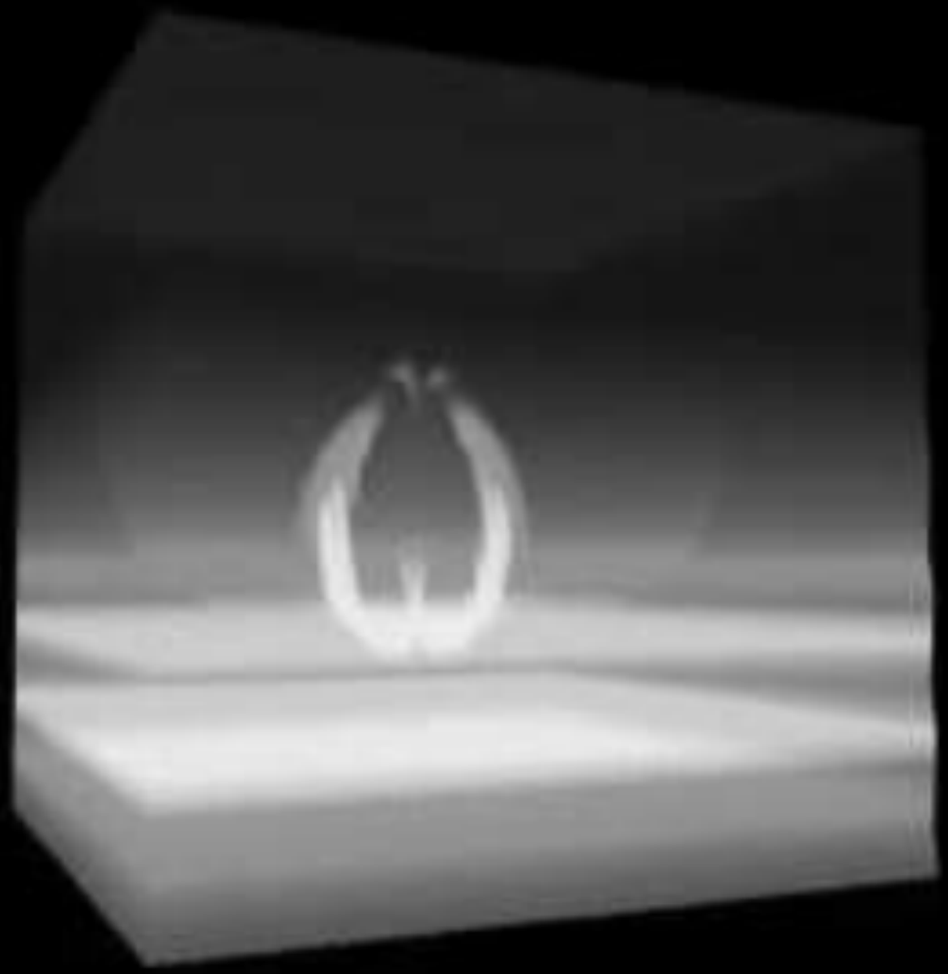
and suggest that clouds < $10^{4.5}$ $M_\odot$ disrupt over path < 10 kpc (or, equivalently, a travel time of 10^8 yr).

- These are upper limits due to the model assumptions...
- Factors that would tend to *increase* lifetime / travel distance include magnetic fields, which tend to suppress dynamic instabilities

HVC survival

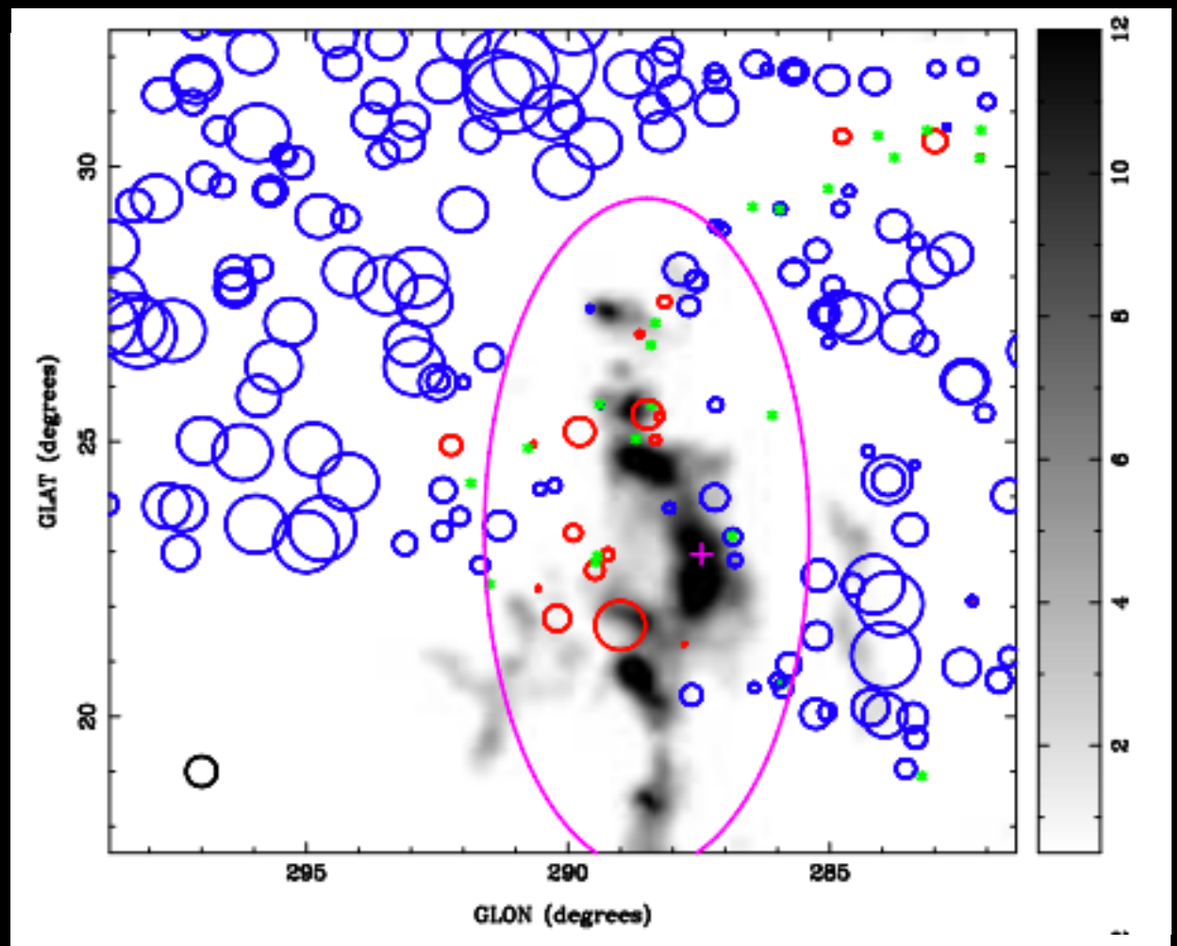
- Santillan et al. (2004) present MHD simulations of HVCs falling into a galaxy with a field geometery parallel to the plane

- The fields tend to form a head-tail structure, and to shape into a “magnetic barrier” that gathers the cloud material and keeps it from fragmenting
- However the simulations are very limited, and travel distances are short ... more simulations of this kind are needed ... !



Magnetic fields in HVCs

- Magnetic field (>~6μG) detected via NVSS RM map (McClure-Griffiths et al. 2010)
- Based on simple calculation, destruction timescale without magnetic field is <25 Myr, but travel time is >500-1000 Myr (Connors et al. 2006)
- Surface tension required to balance ram pressure is estimated at ~4μG - so the observed field is sufficient
- Are there magnetic fields in more HVCs, and what about the extraplanar regions of galaxies?
- Zeeman splitting measurements (e.g. Kazès et al. 1991) ...



Red = positive RM
Blue = negative RM
Green = zero RM

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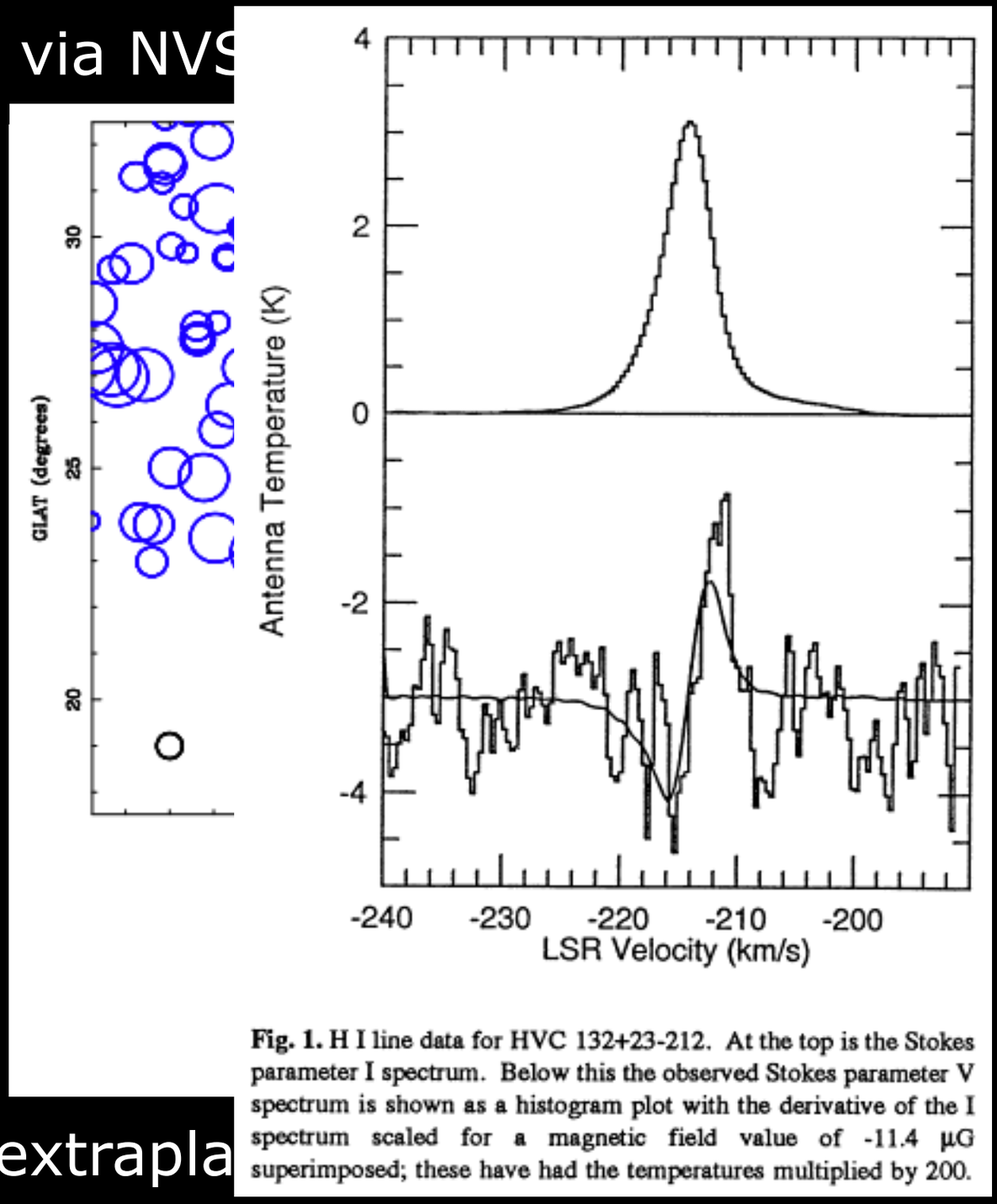

Fig. 1. H I line data for HVC 132+23-212. At the top is the Stokes parameter I spectrum. Below this the observed Stokes parameter V spectrum is shown as a histogram plot with the derivative of the I spectrum scaled for a magnetic field value of -11.4 μG superimposed; these have had the temperatures multiplied by 200.

Chimney model

- In the chimney model, RM gradients across HI "hole" features would be expected if magnetic field is pushed up along with gas

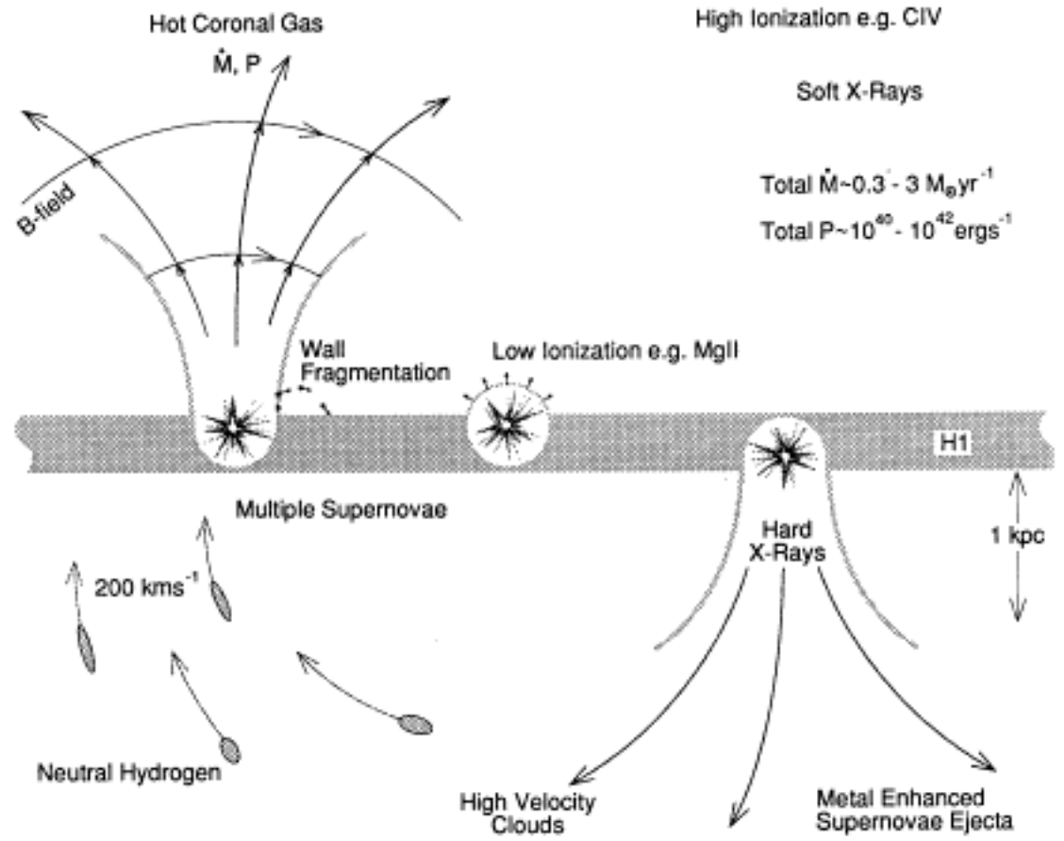

FIG. 5.—A sketch of some of the obvious qualitative aspects of the halo structure in the chimney model. The observational characteristics and effects on galaxy evolution of these disk-halo connections are discussed in §§ IV and V.

Norman & Ikeuchi (1989)

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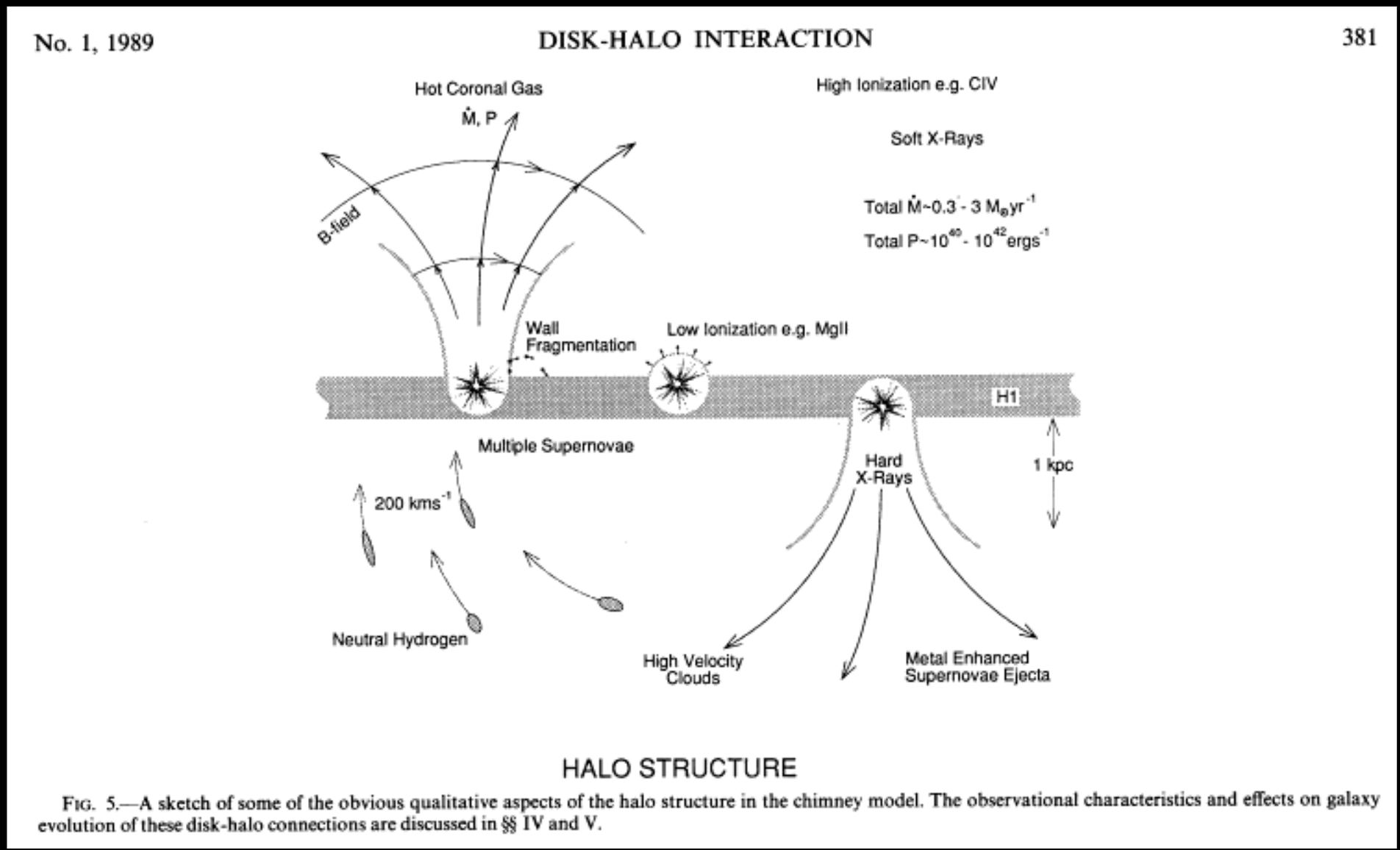

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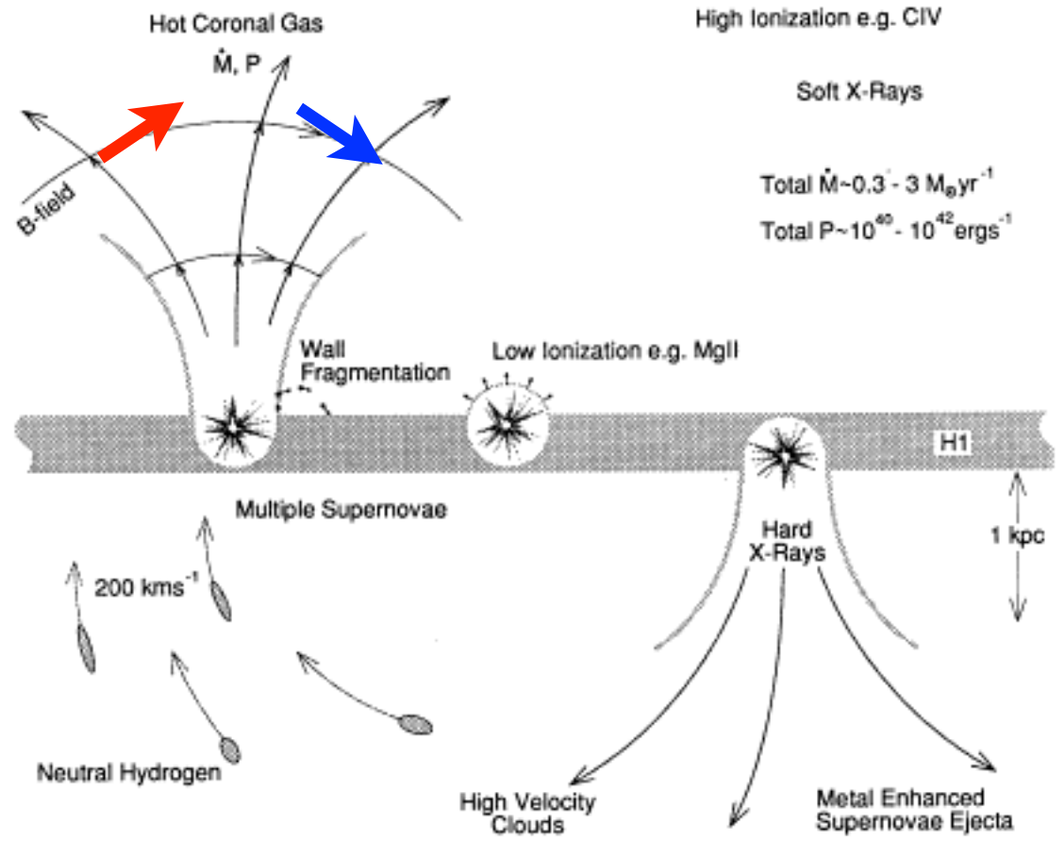

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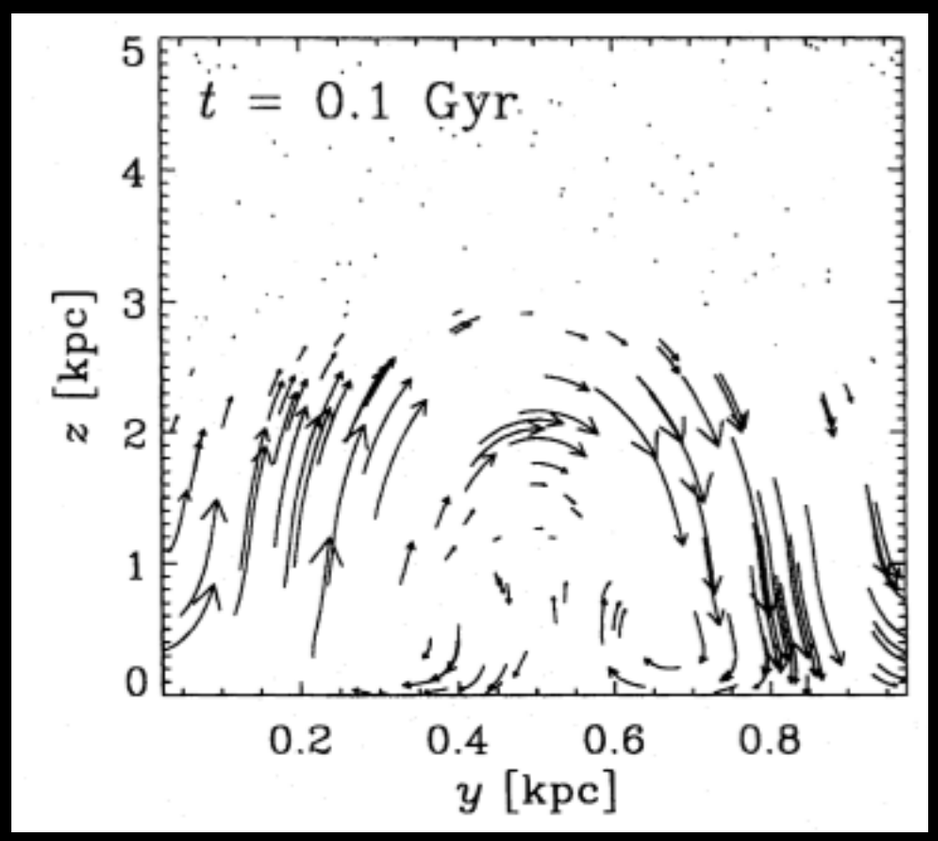
Norman & Ikeuchi (1989)

Consequences for mean-field dynamo

- Galactic fountains have been invoked in the context of mean-field dynamo theory, e.g.
  - Transport of small-scale fields away from the dynamo region, to solve the quenching problem (Shukurov et al. 2006)
  - Inducing significant (large-scale) magnetic field strengths several kpc above the midplane (Brandenburg et al. 1995)

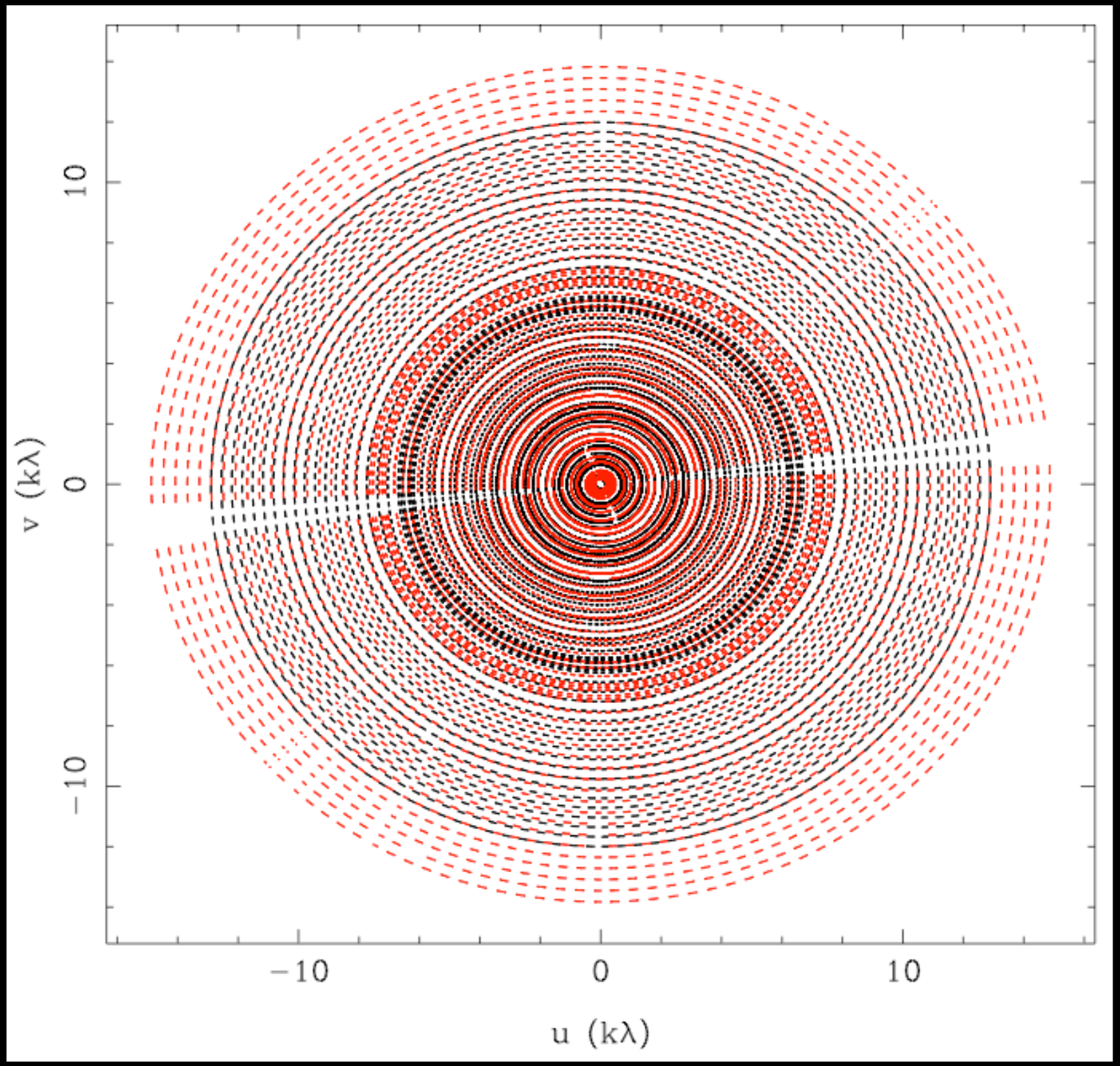


Chimney diameter = 1 kpc
Kick velocity = 100 km/s
Vertical scale height = 1 kpc
B-field fully vertical at z=5 kpc

Model not more than illustrative, but indicates that characteristic timescales make this process relevant to enhancing the dynamo

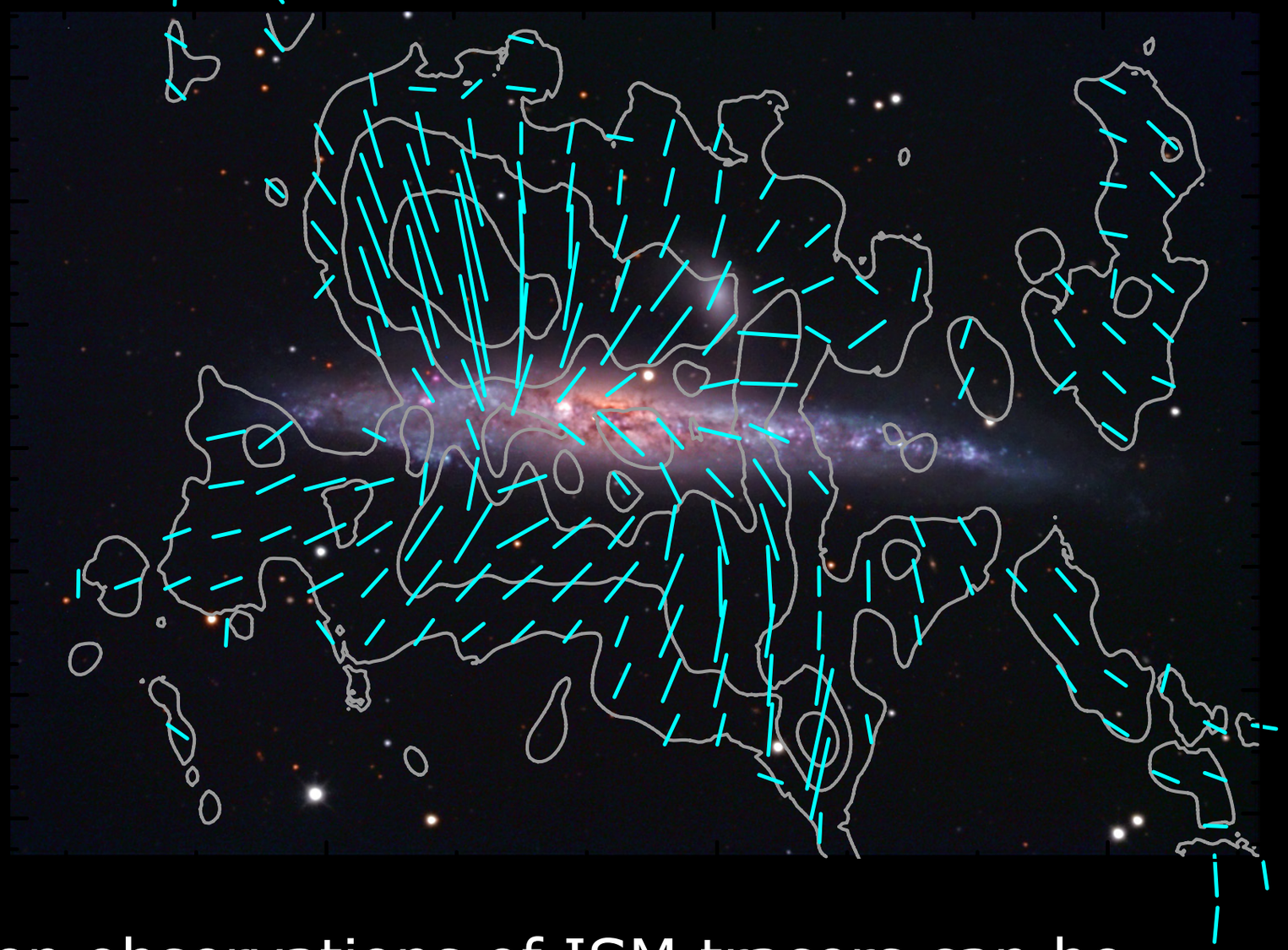
WSRT-SINGS

- 2 broad (160 MHz) bands at 18cm and 22cm (high Faraday depth regime)
- Typical noise levels
  ~10 μJy/beam rms
  (6h/galaxy/band)



WSRT-SINGS results

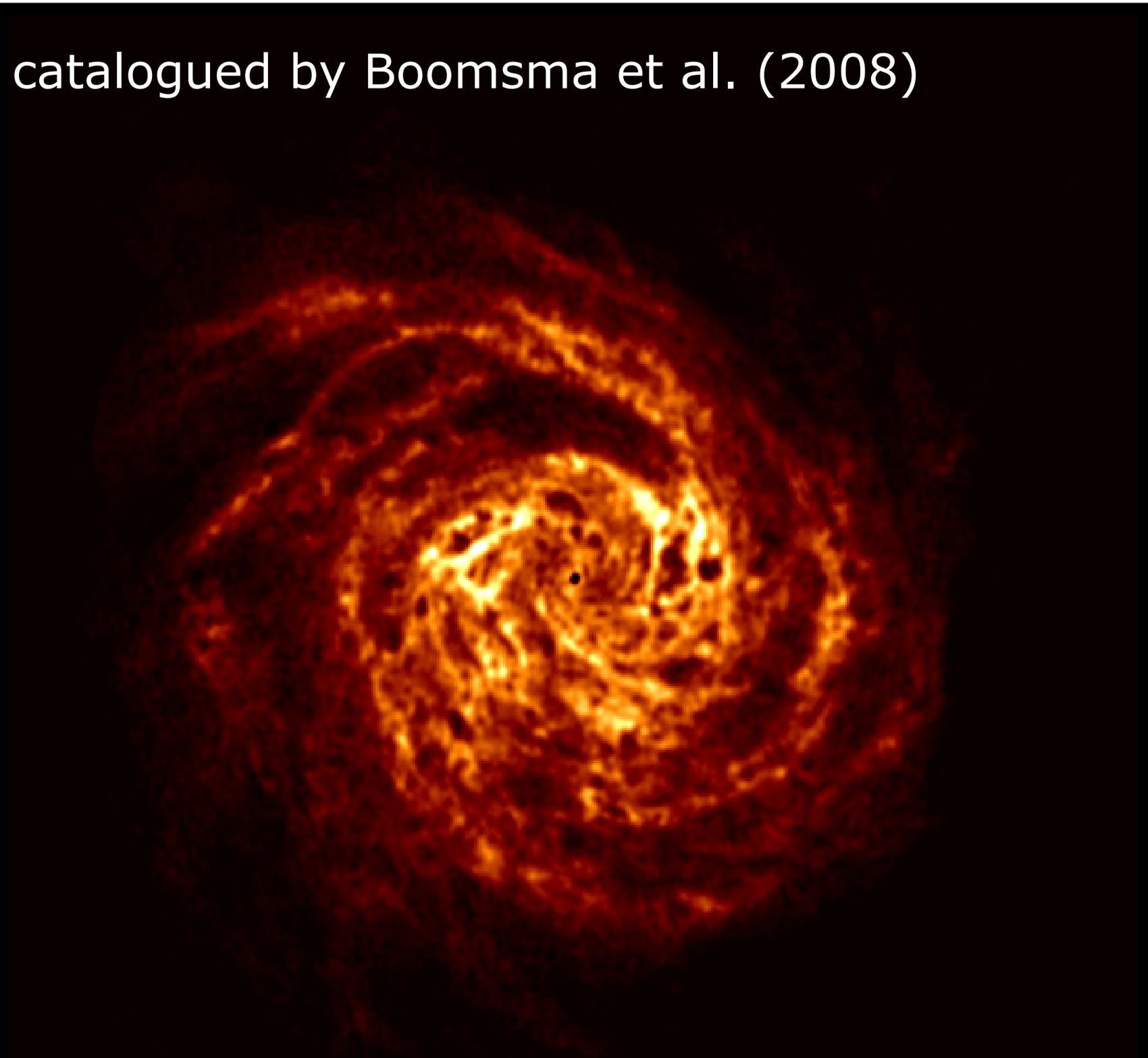
- 28 galaxies studied in polarization, following RM Synthesis
  - Polarization in 0/4 Magellanic/elliptical, 21/24 spirals
- Used to model the global magnetic field in spirals: Braun+ (2010)
- Reanalysis now underway at low resolution / better sensitivity to extended emission



- Combination with deep observations of ISM tracers can be very powerful! (e.g. HALOGAS, Heald+ 2011)

Bfield-HI connections: NGC 6946

- HI holes catalogued by Boomsma et al. (2008)



HI image courtesy R. Boomsma

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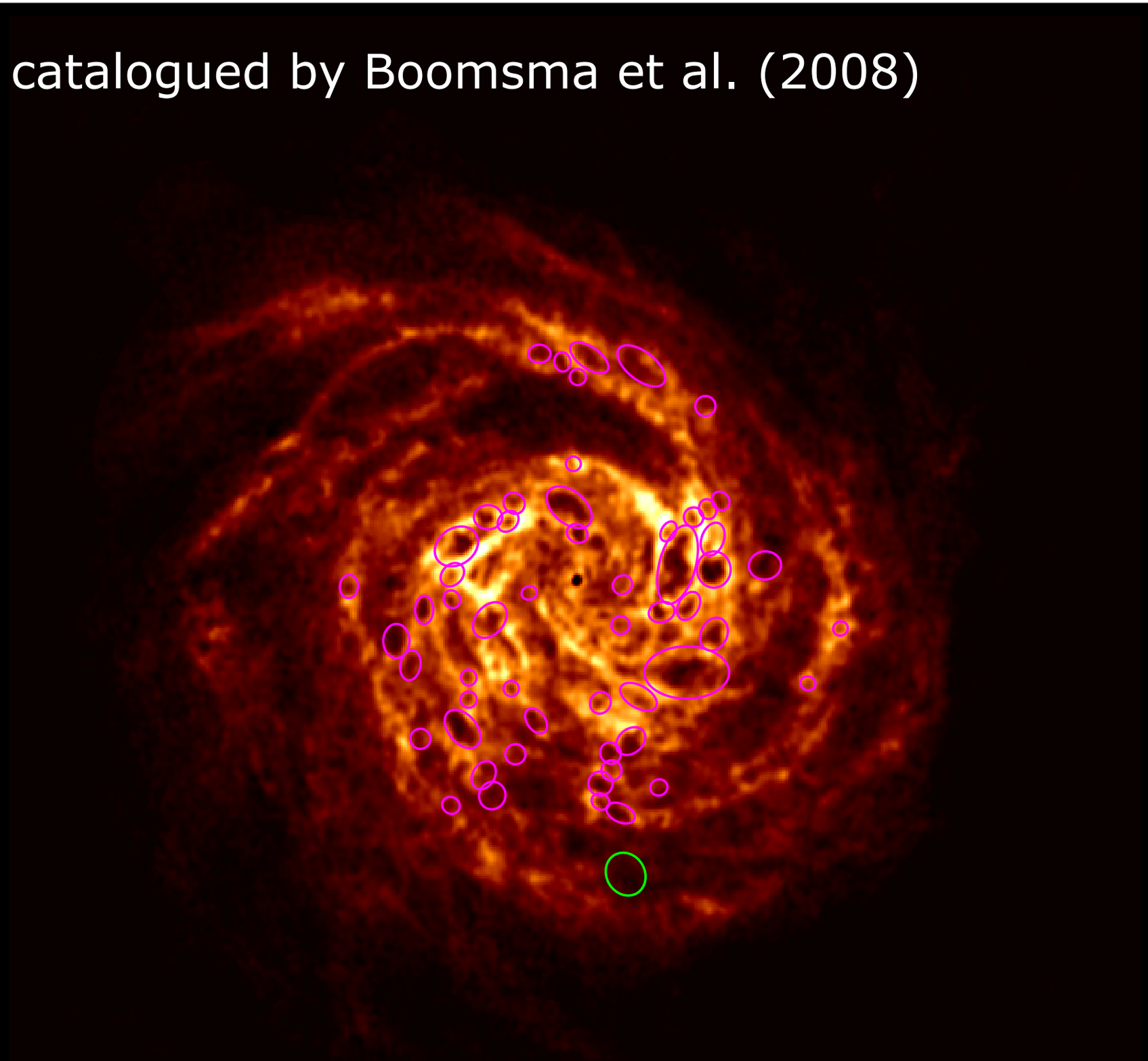

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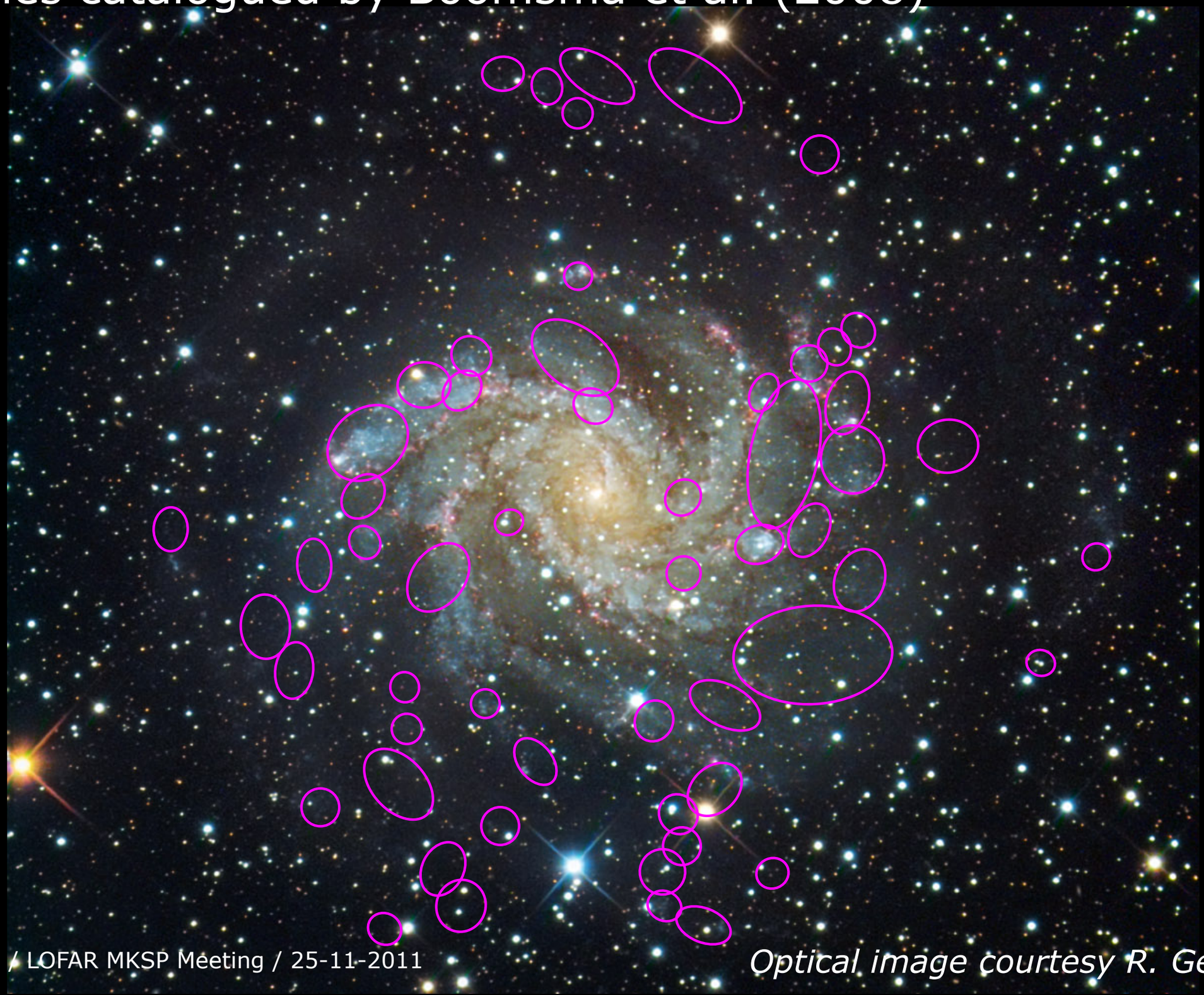

Optical image courtesy R. Gendler

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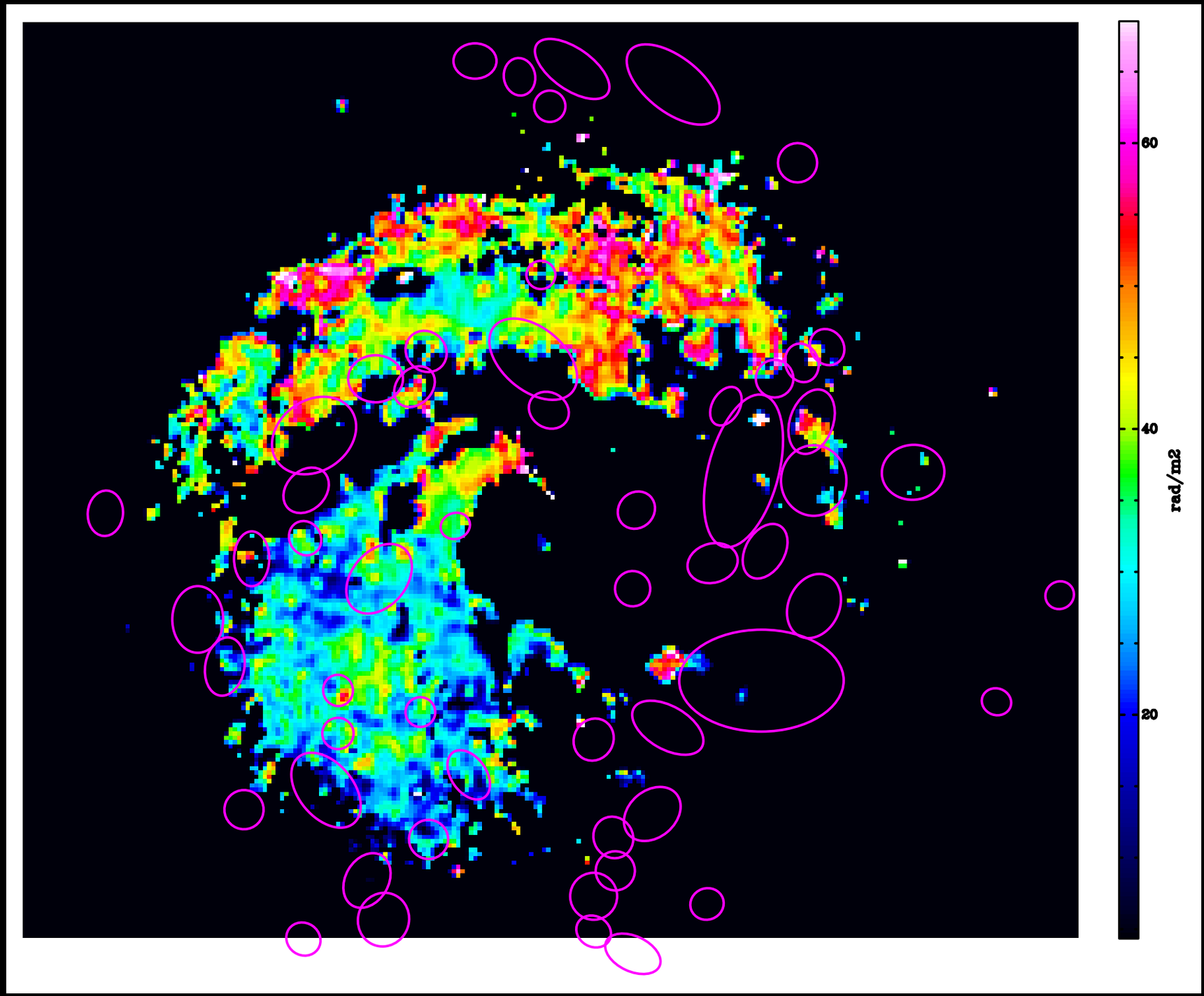

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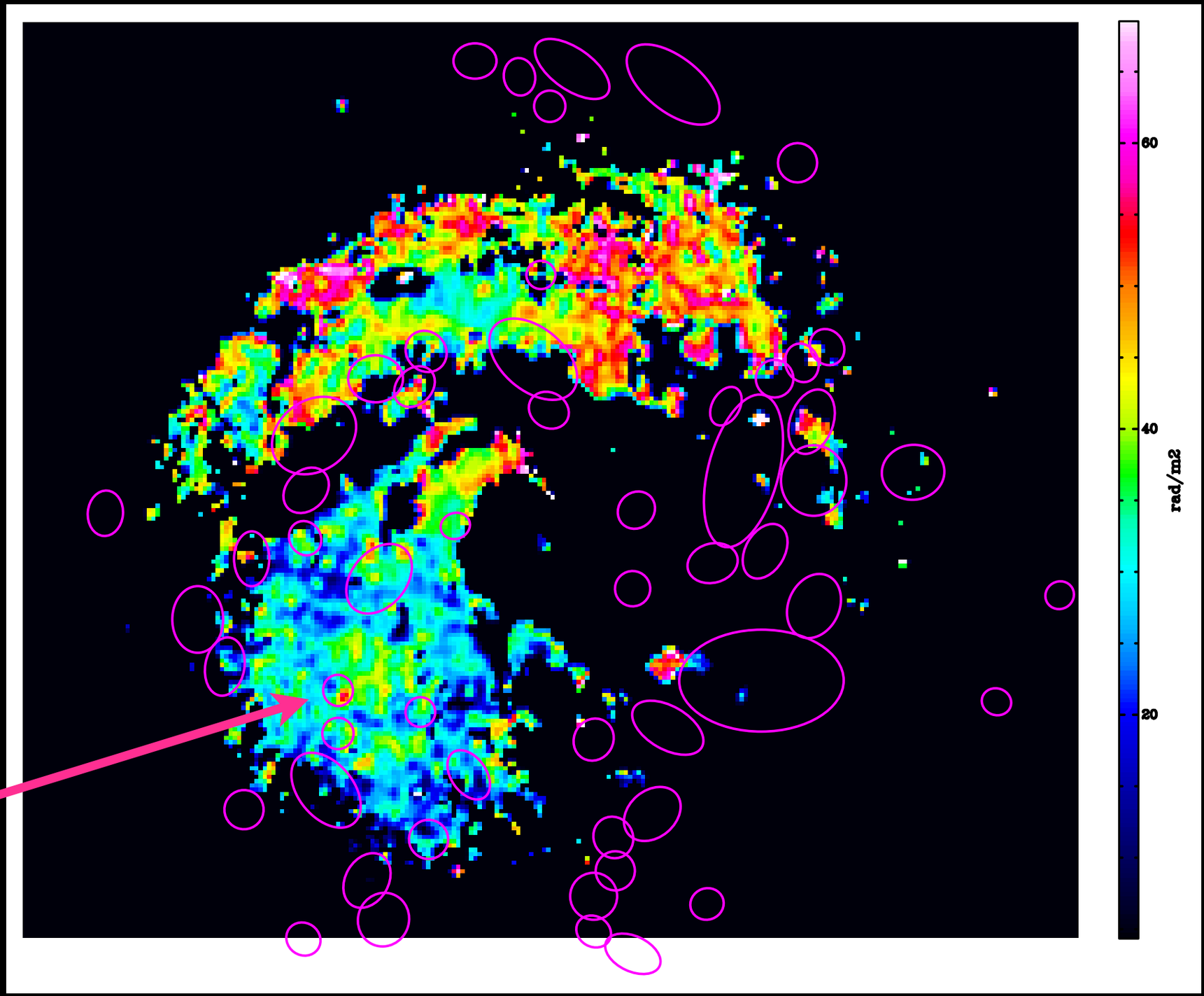

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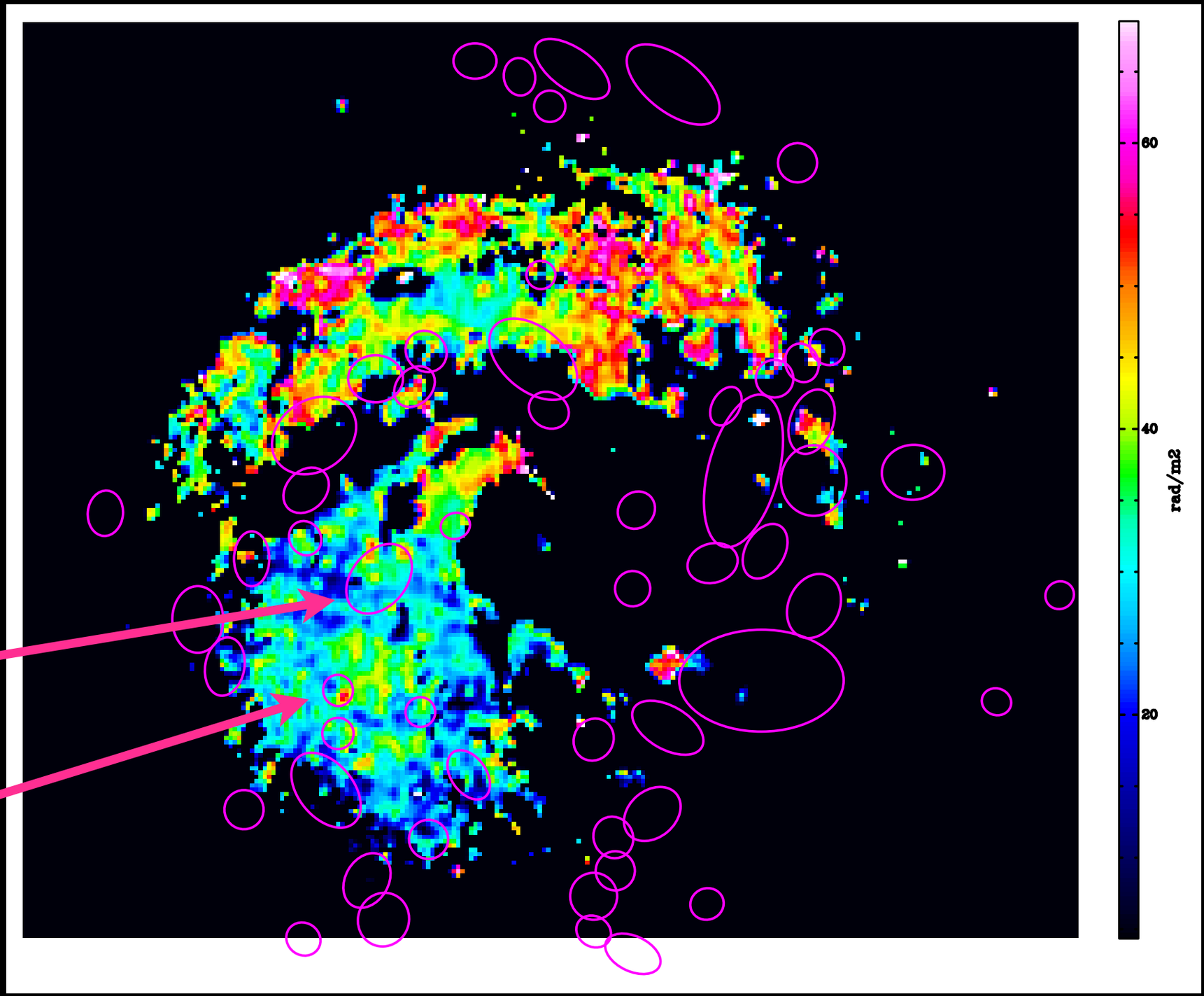
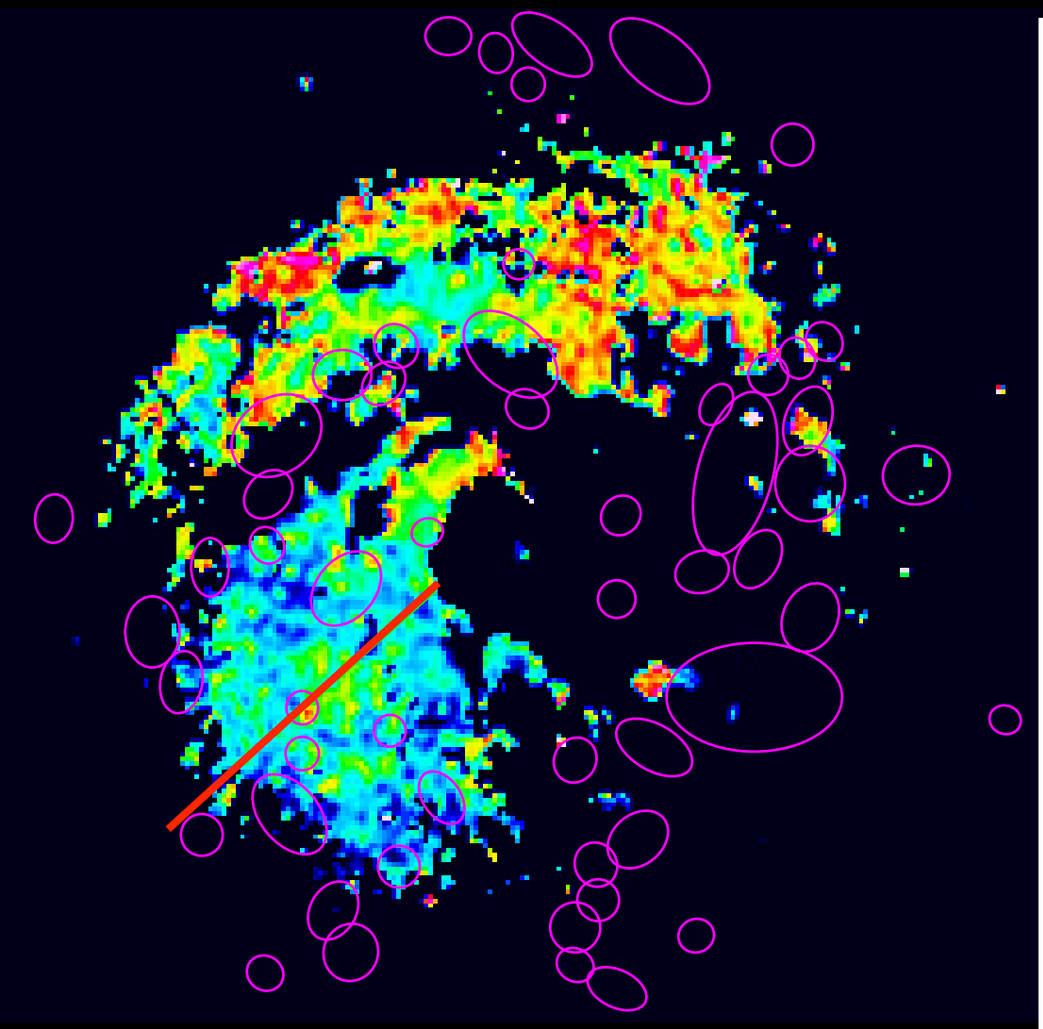
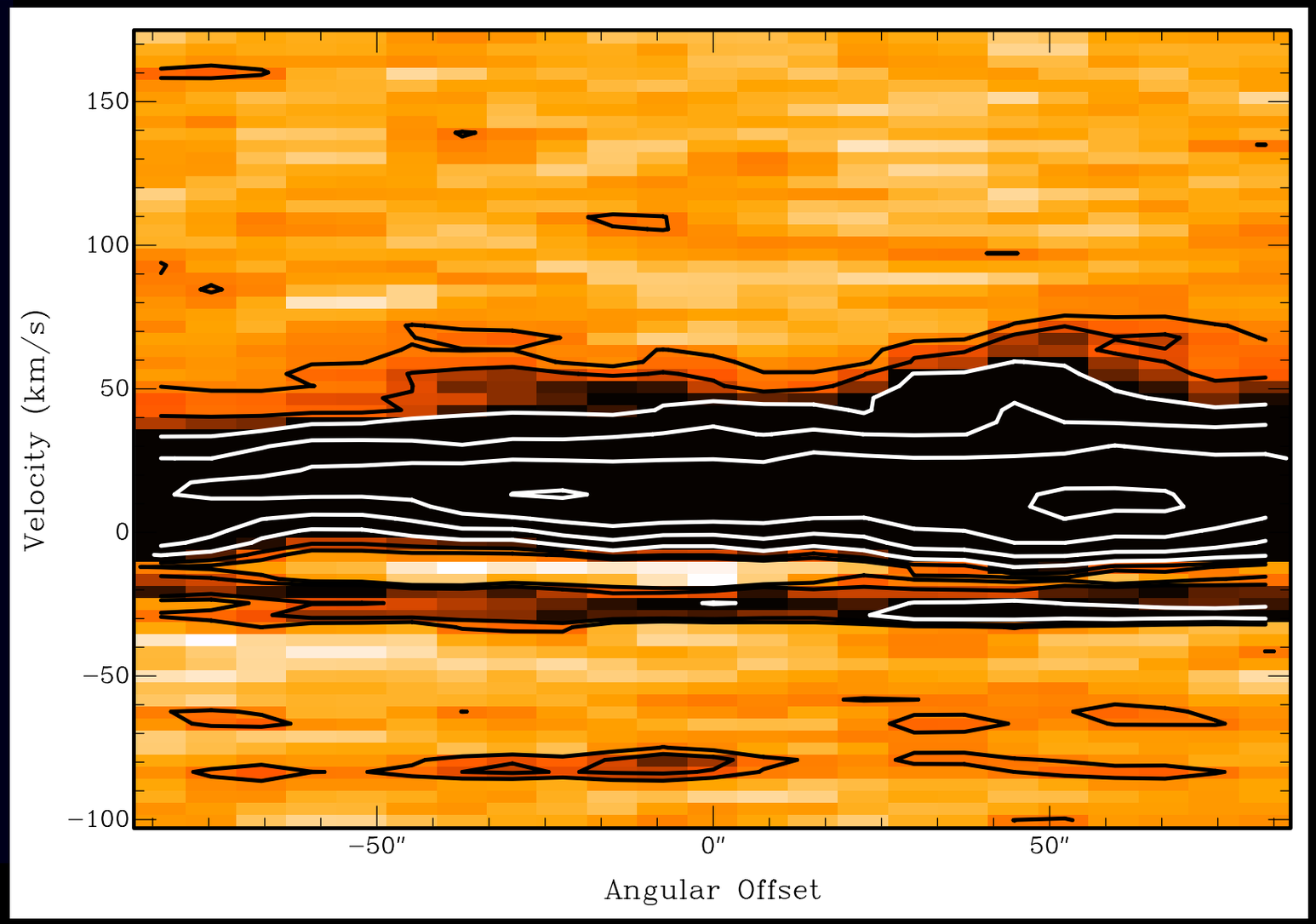


Hole 22

- Slight evidence of kinematic anomaly in edges of HI hole





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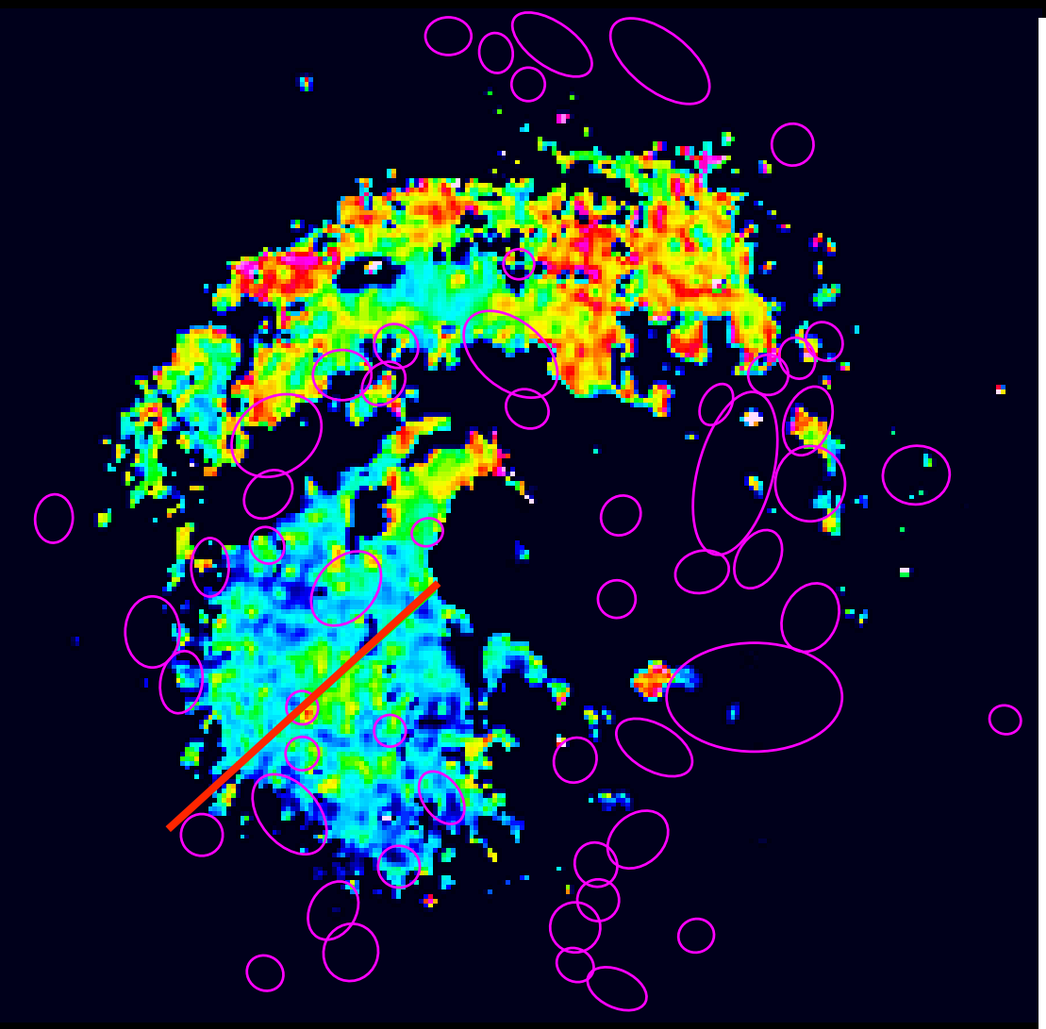

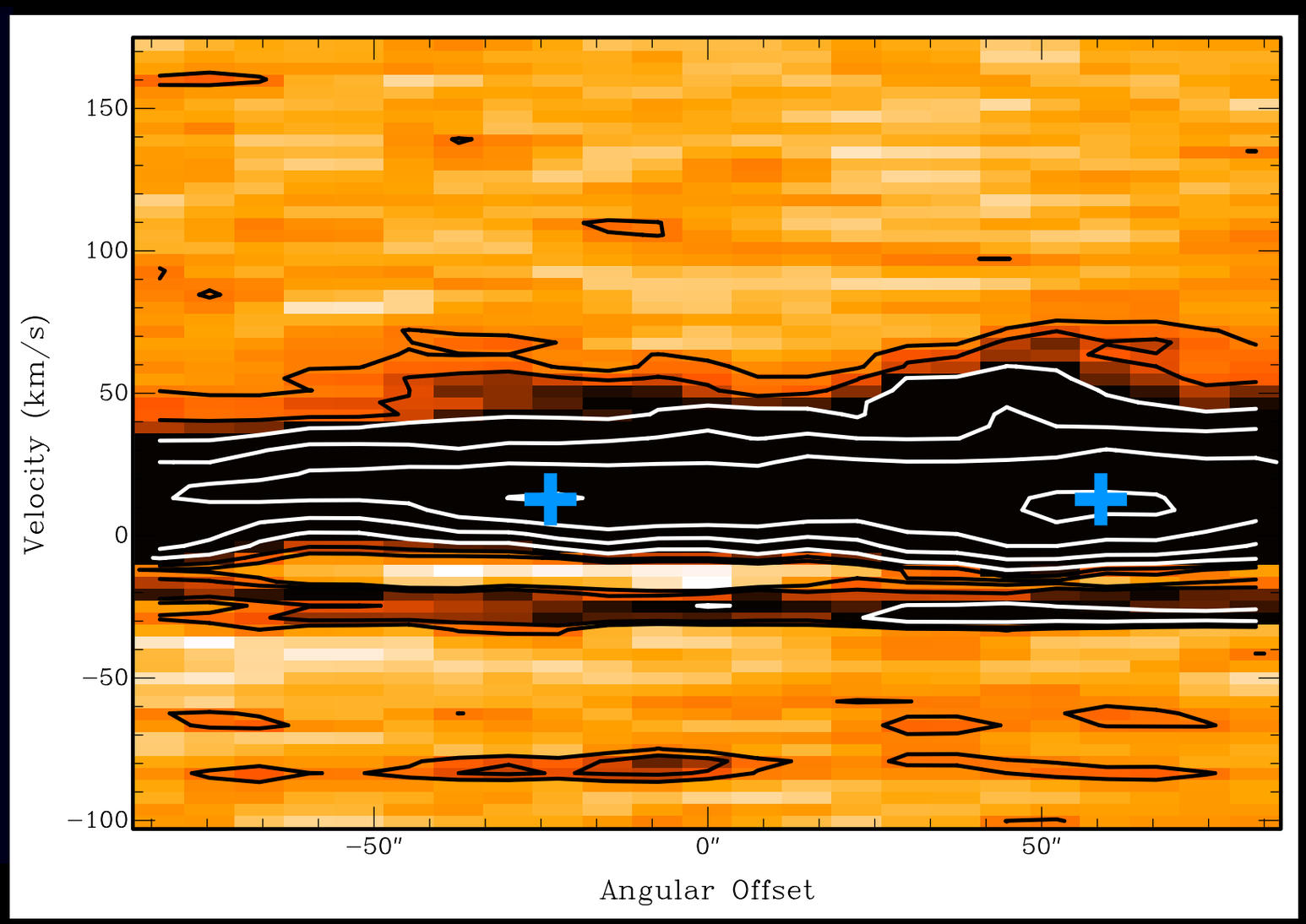

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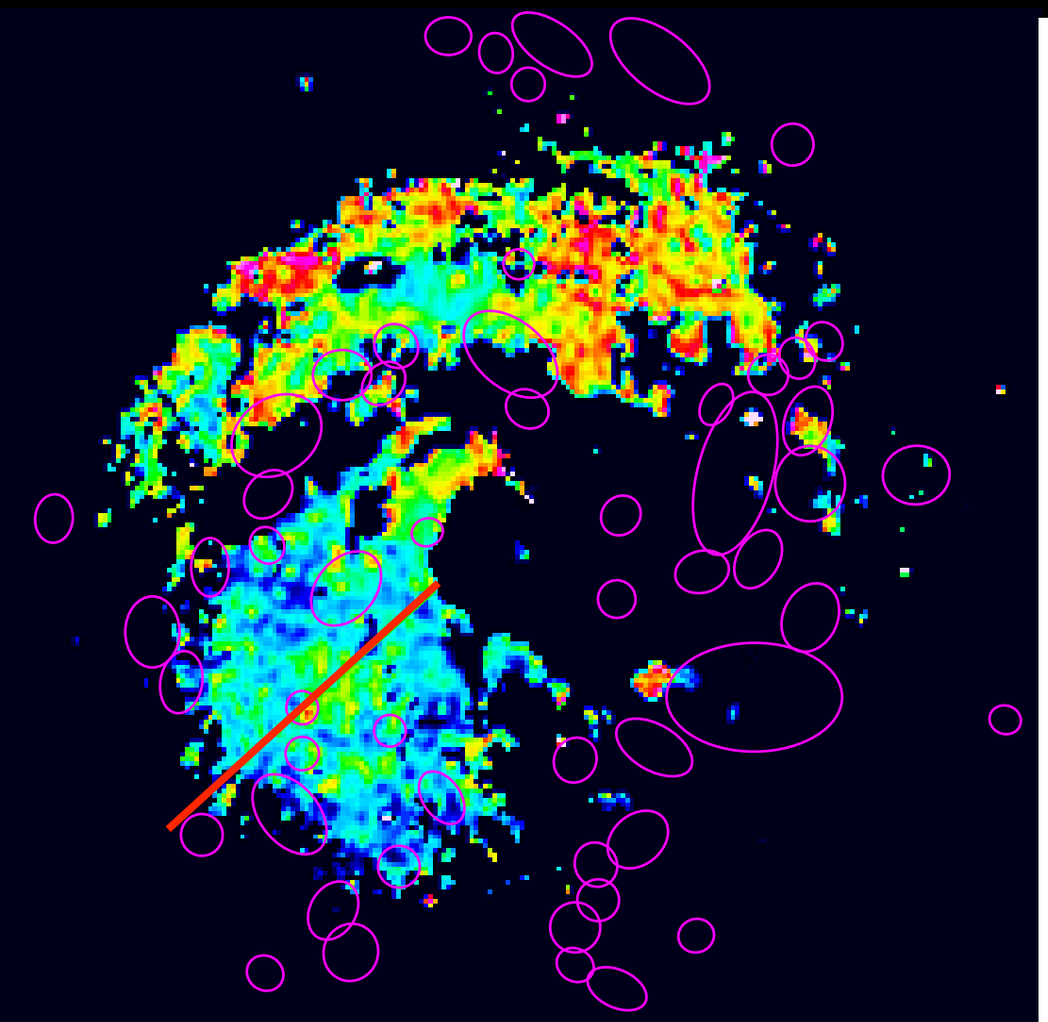

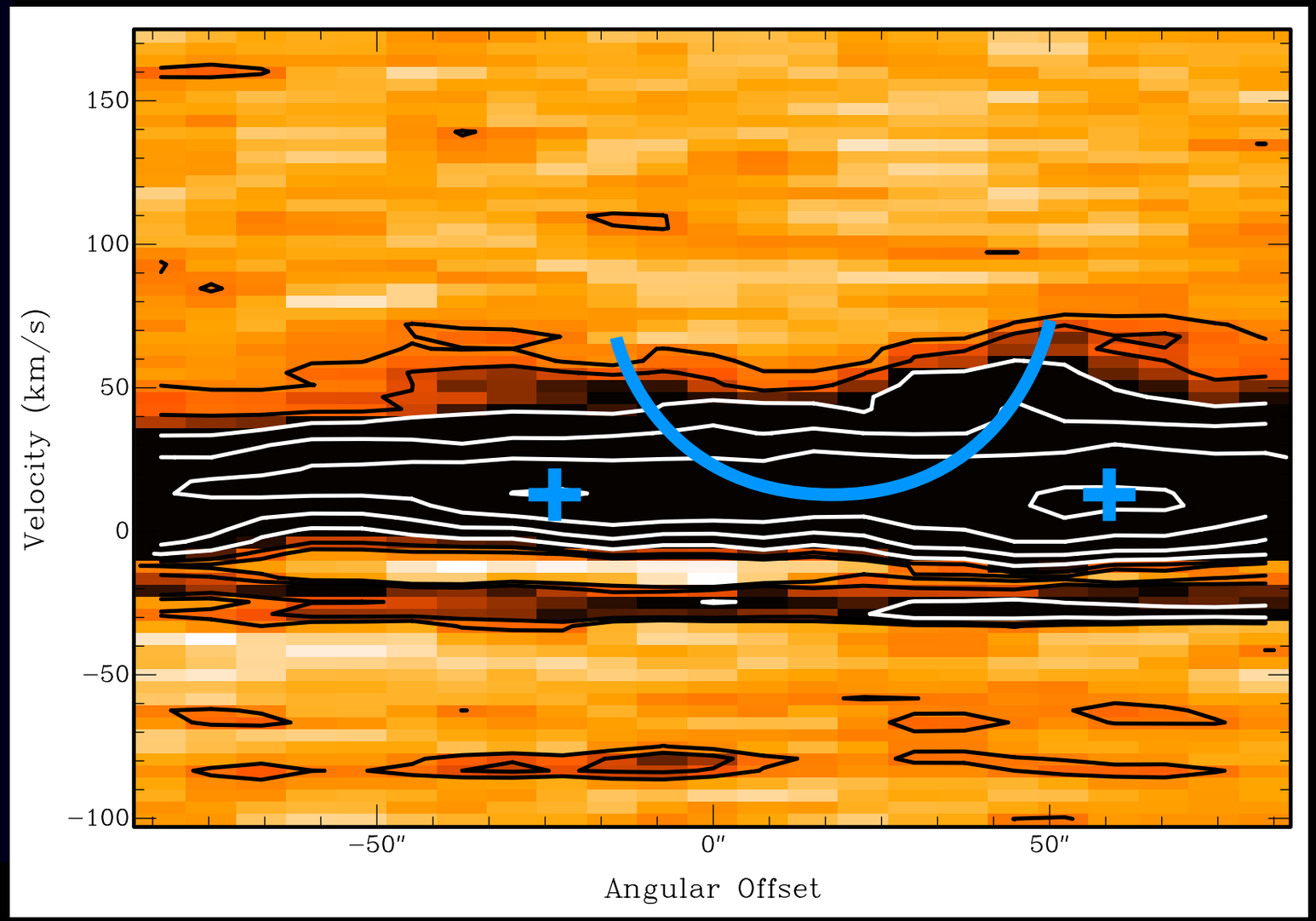

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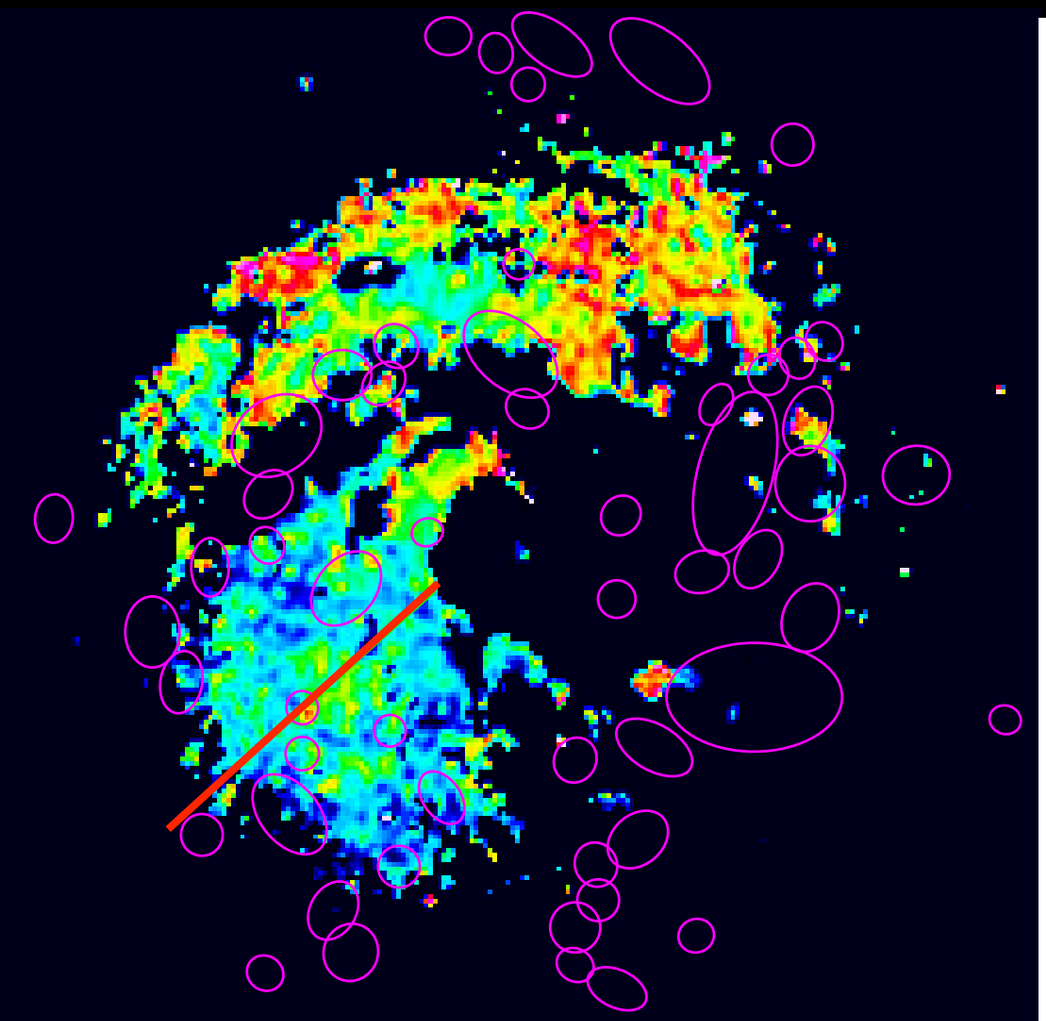
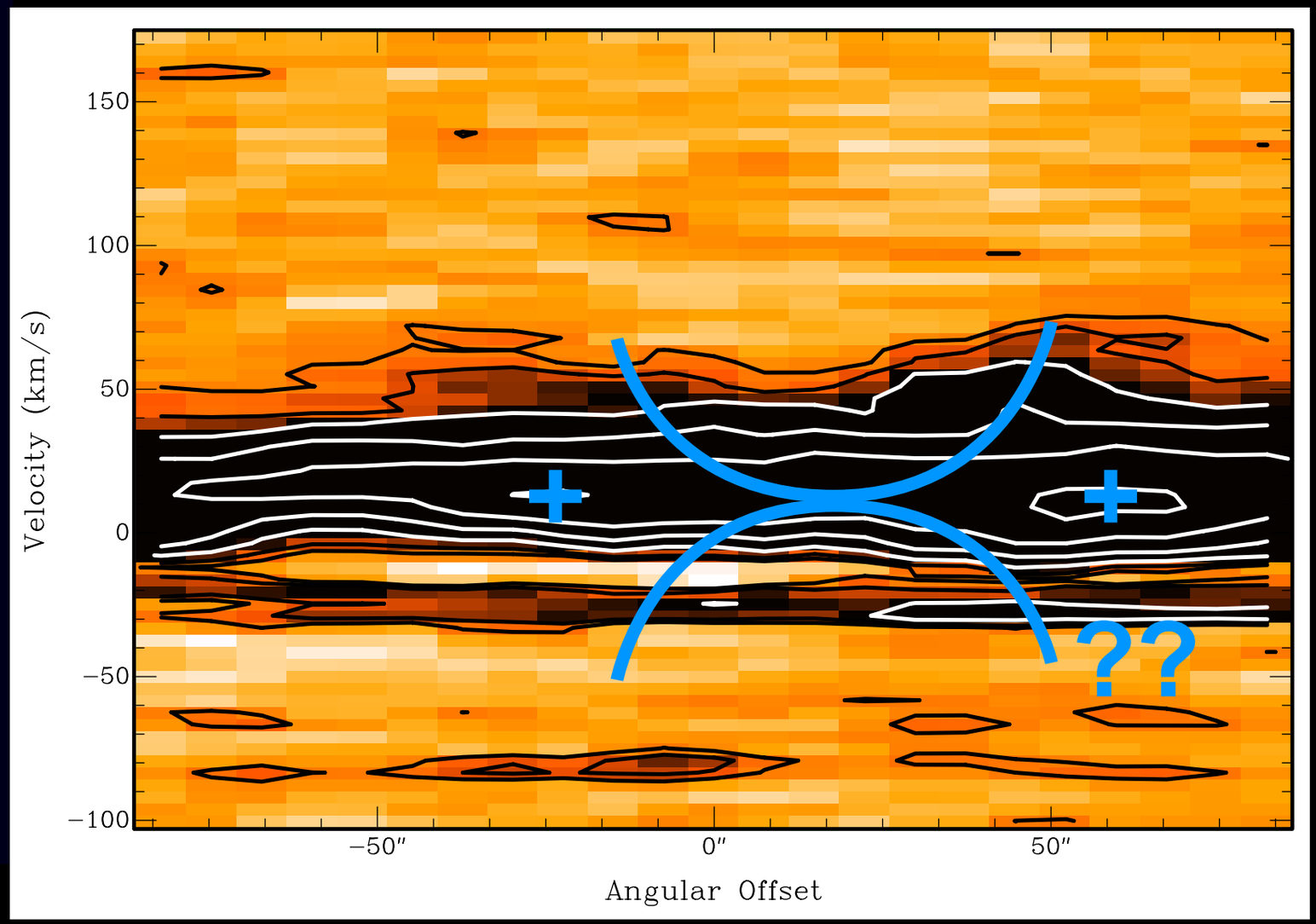


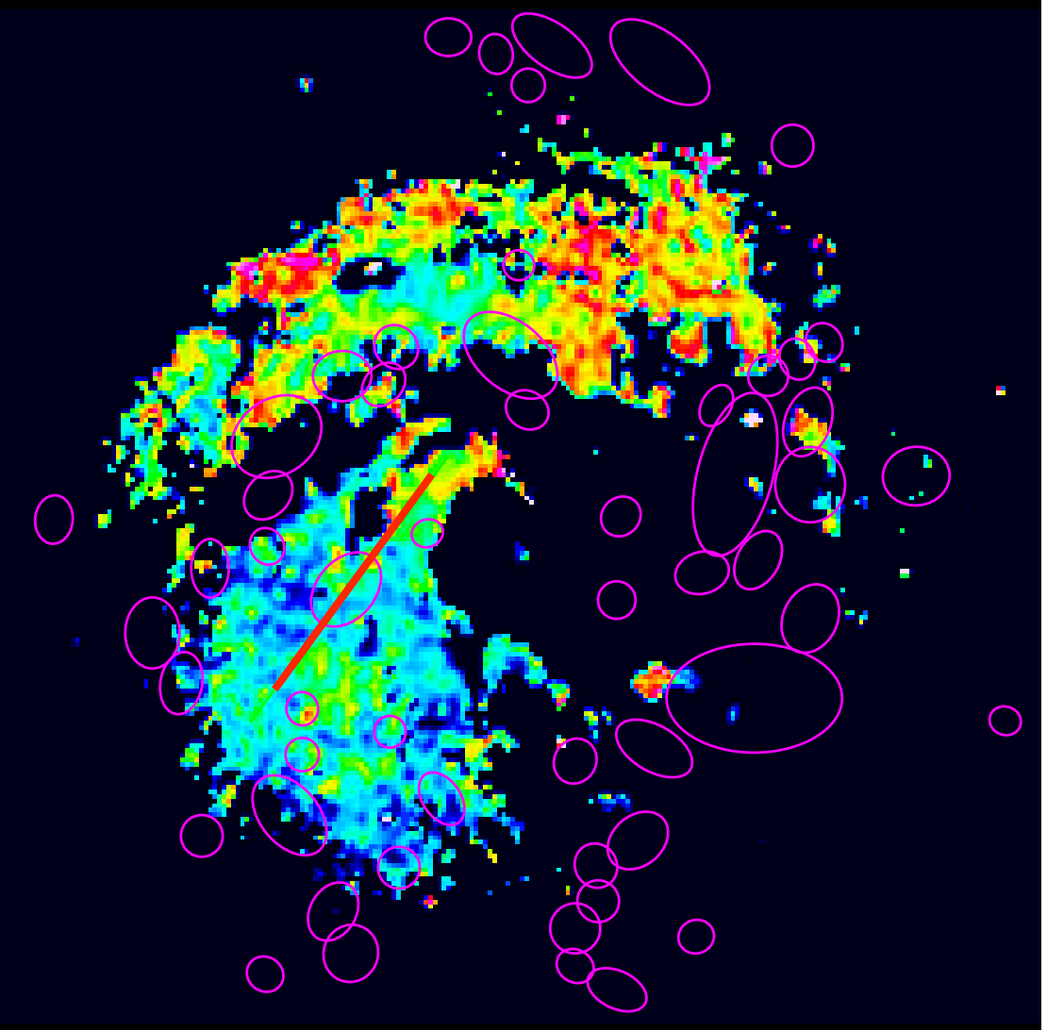


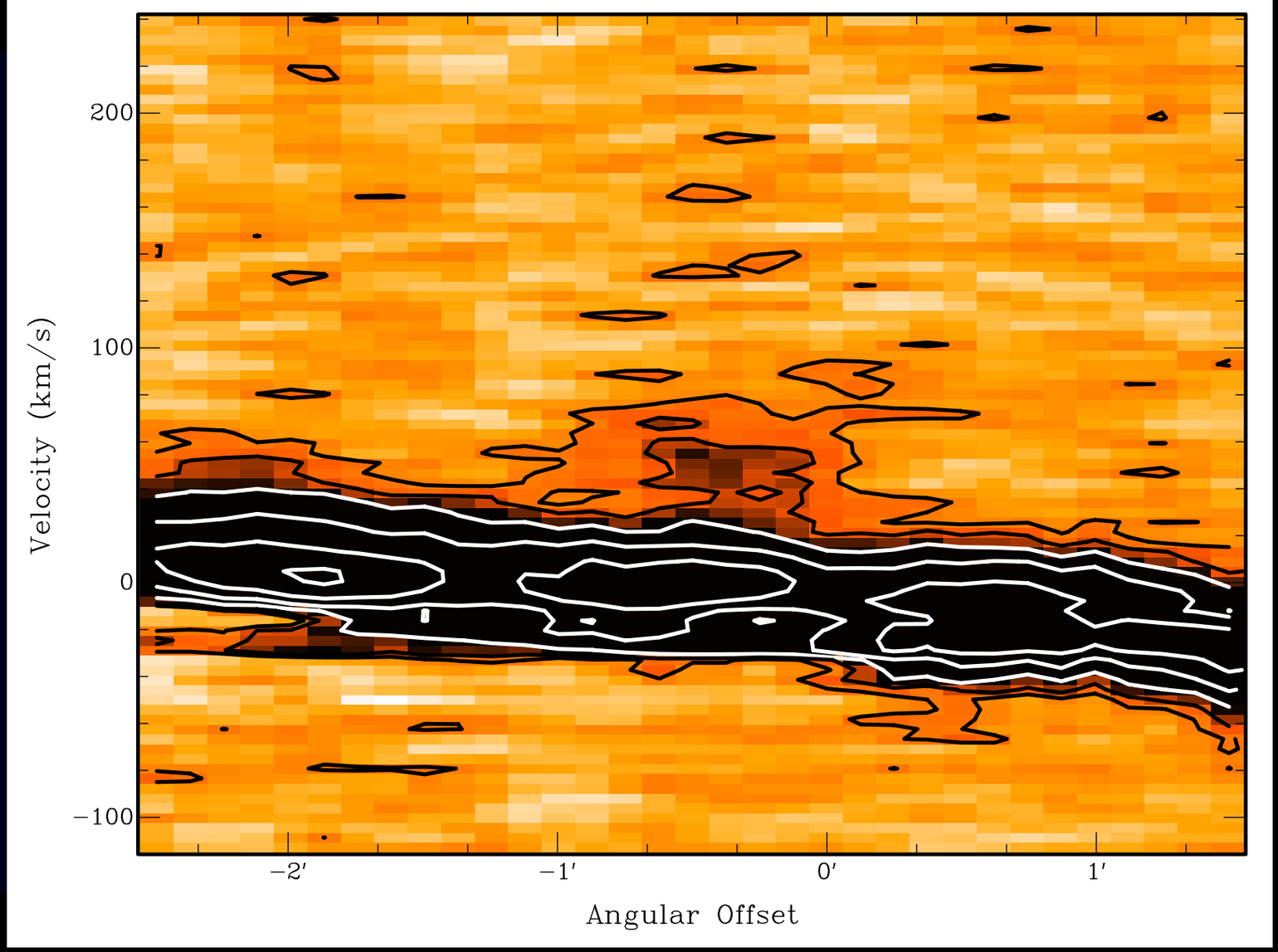
- (Note that negative-velocity emission, if present, is confused with MW HI at the same velocity range)

HI data courtesy R. Boomsma

Hole 30

- Anomalous HI gas clearly detected at position of hole





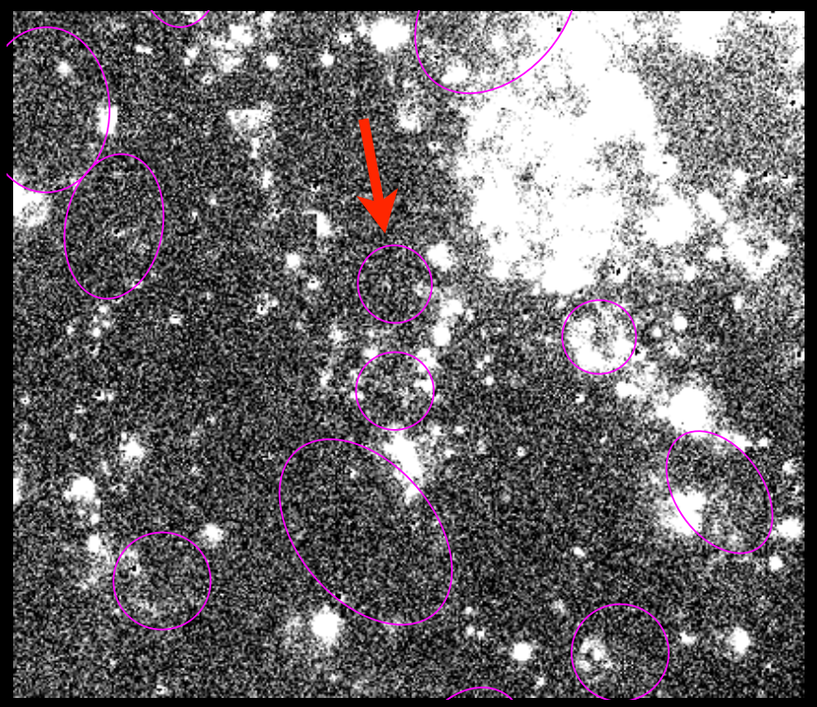
- RM gradient at this location less obvious than in Hole 22 ...

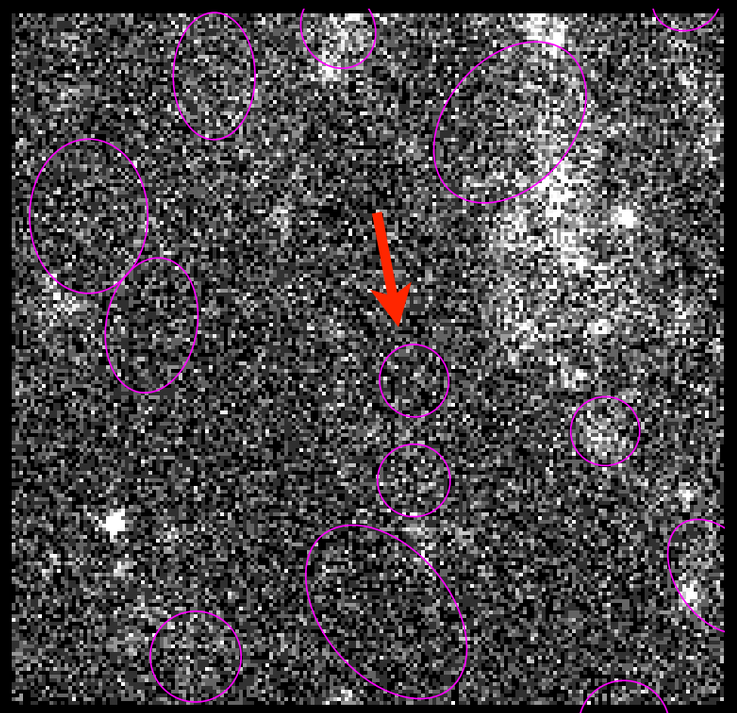
HI data courtesy R. Boomsma

Star formation in the holes?

- Should we see star formation in the holes? For example, hole 22 does not show clear signs (from Hα or GALEX):

Hα image courtesy A. Ferguson



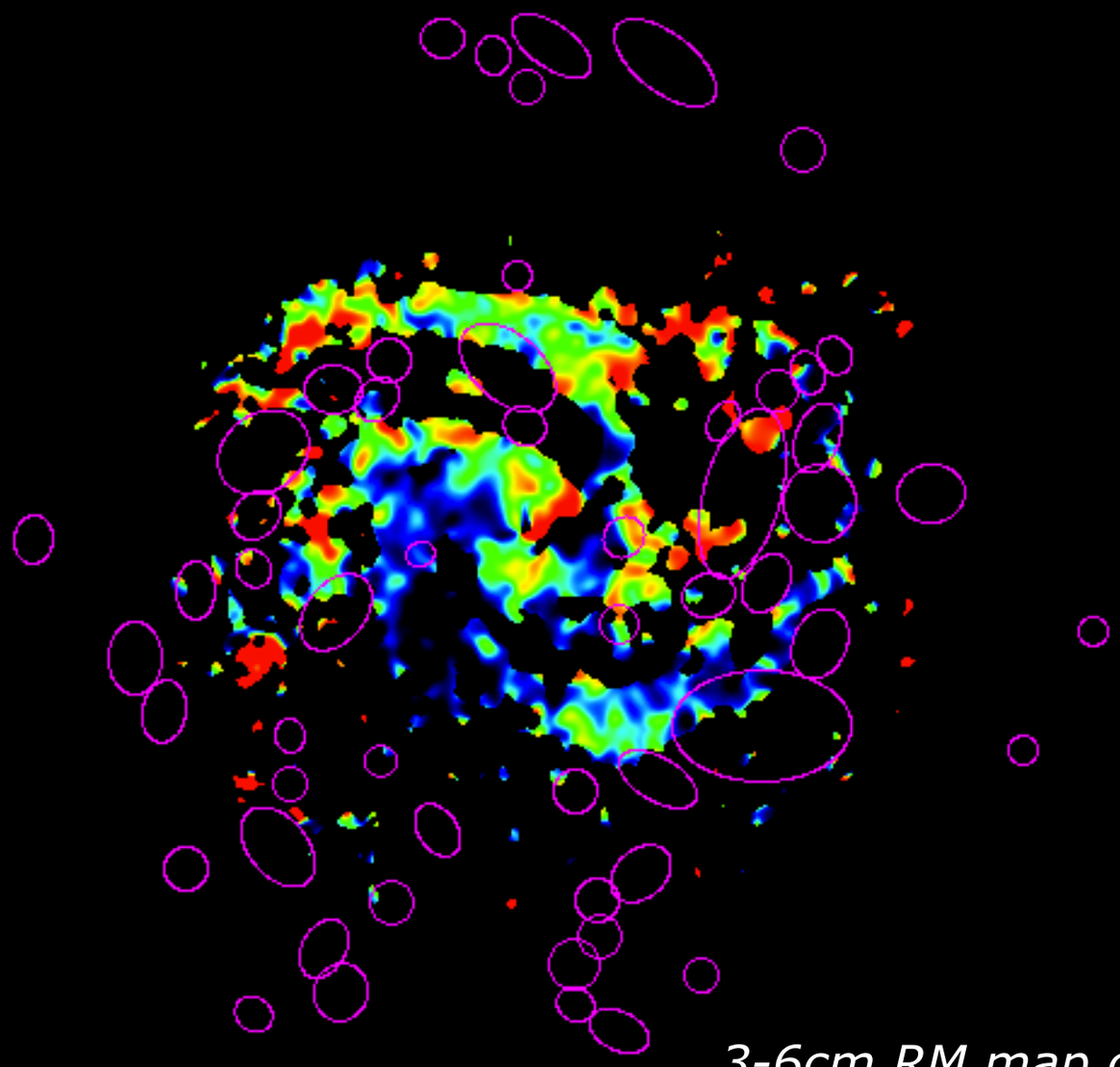


GALEX FUV (NGS)

- Timescale for disruption due to shearing is estimated ~10^8 yr
- Note that Hα is only sensitive to star formation within ~10^6 yr; GALEX within ~10^8 yr - but at NGS sensitivity, we could only detect clusters with initial mass ~2600-6600 $M_\odot$ (for ages 10-100 Myr; Thilker+ 2007)
- Nominal energy needed for Hole 22 is $4x10^{53}$ erg, so smaller clusters could do the job of clearing the HI hole - would need deep observations

RMs at higher frequency

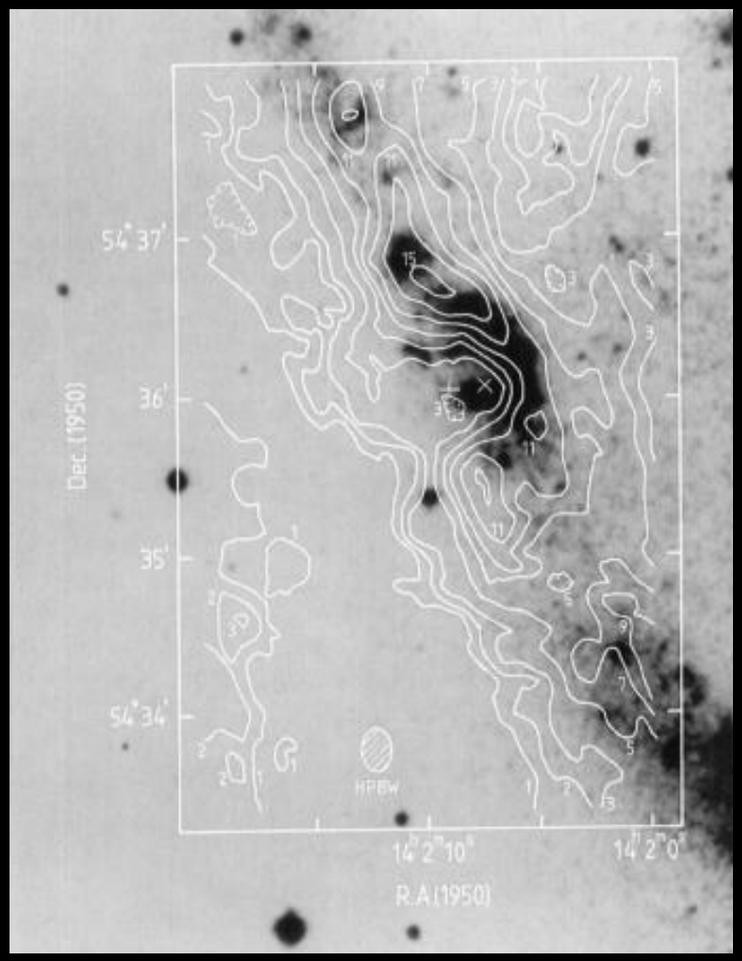
- At higher frequency turbulent depolarization should be less important, does this give a clearer picture in the vicinity of holes? Seems not.

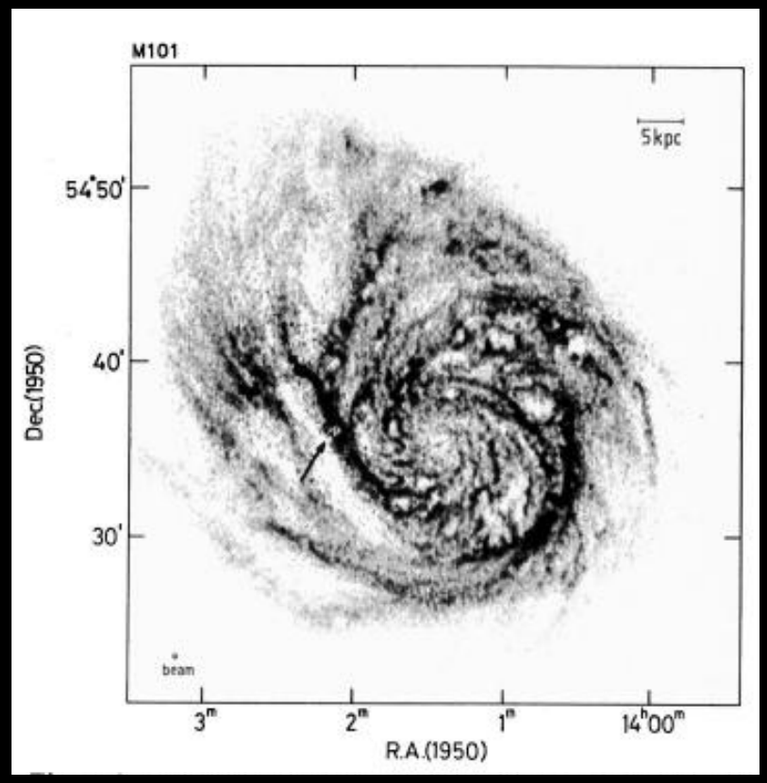


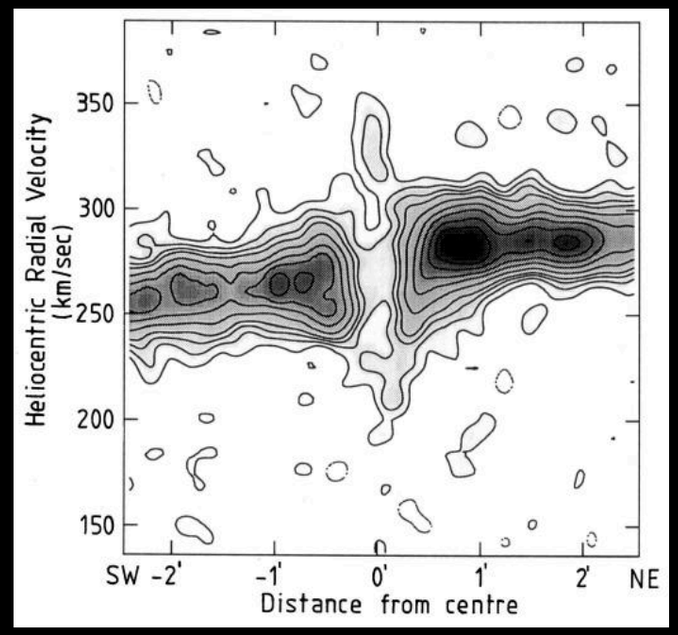
3-6cm RM map courtesy R. Beck

M101: the most obvious place to look...

- HI superbubble (Kamphuis et al. 1991)
  - 1.5 kpc diameter, expansion 50 km/s
  - at least 1000 SNe required







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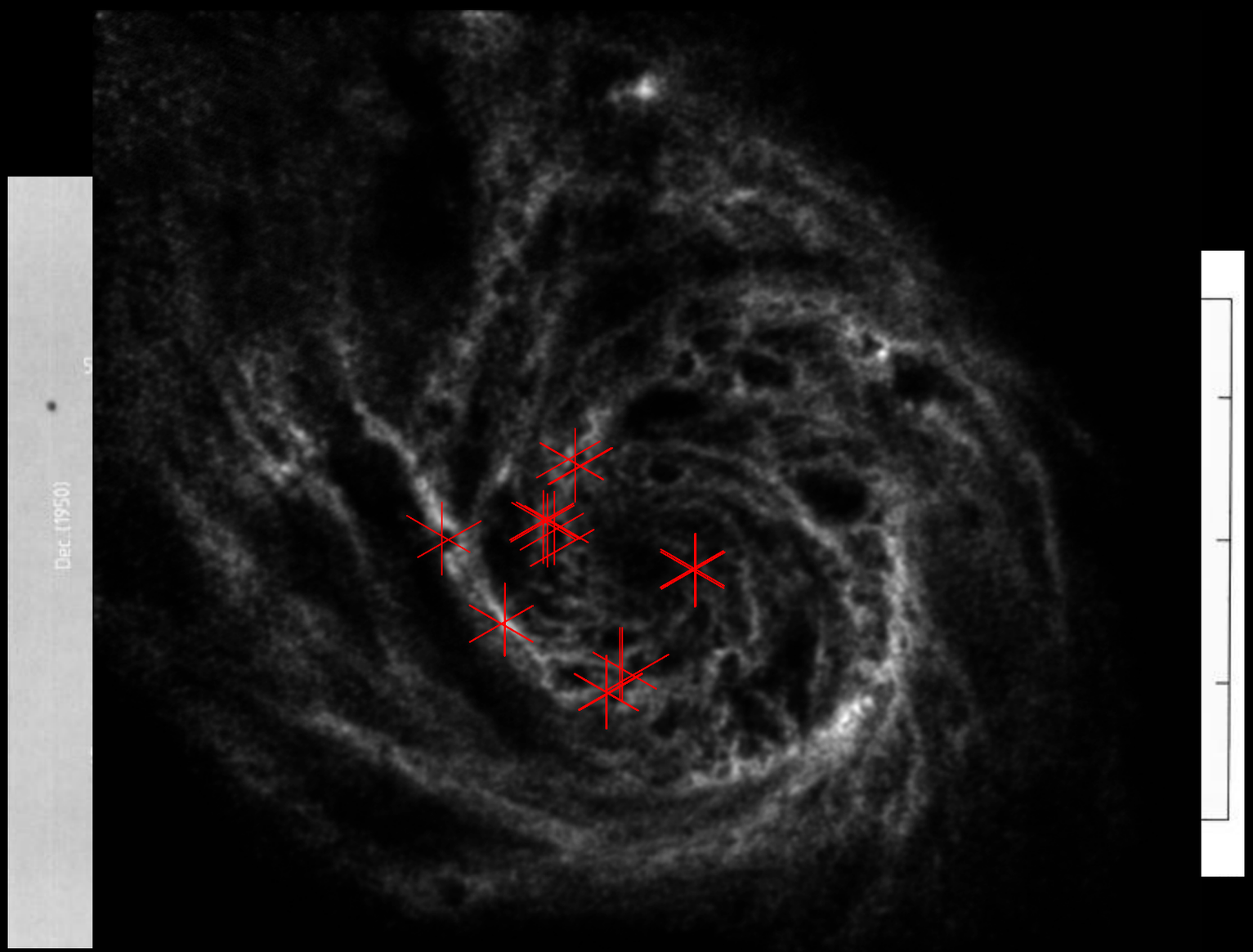
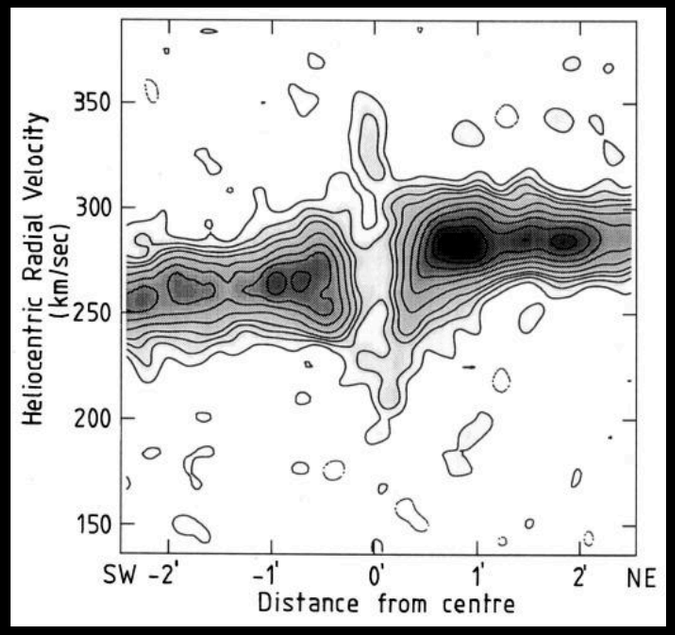
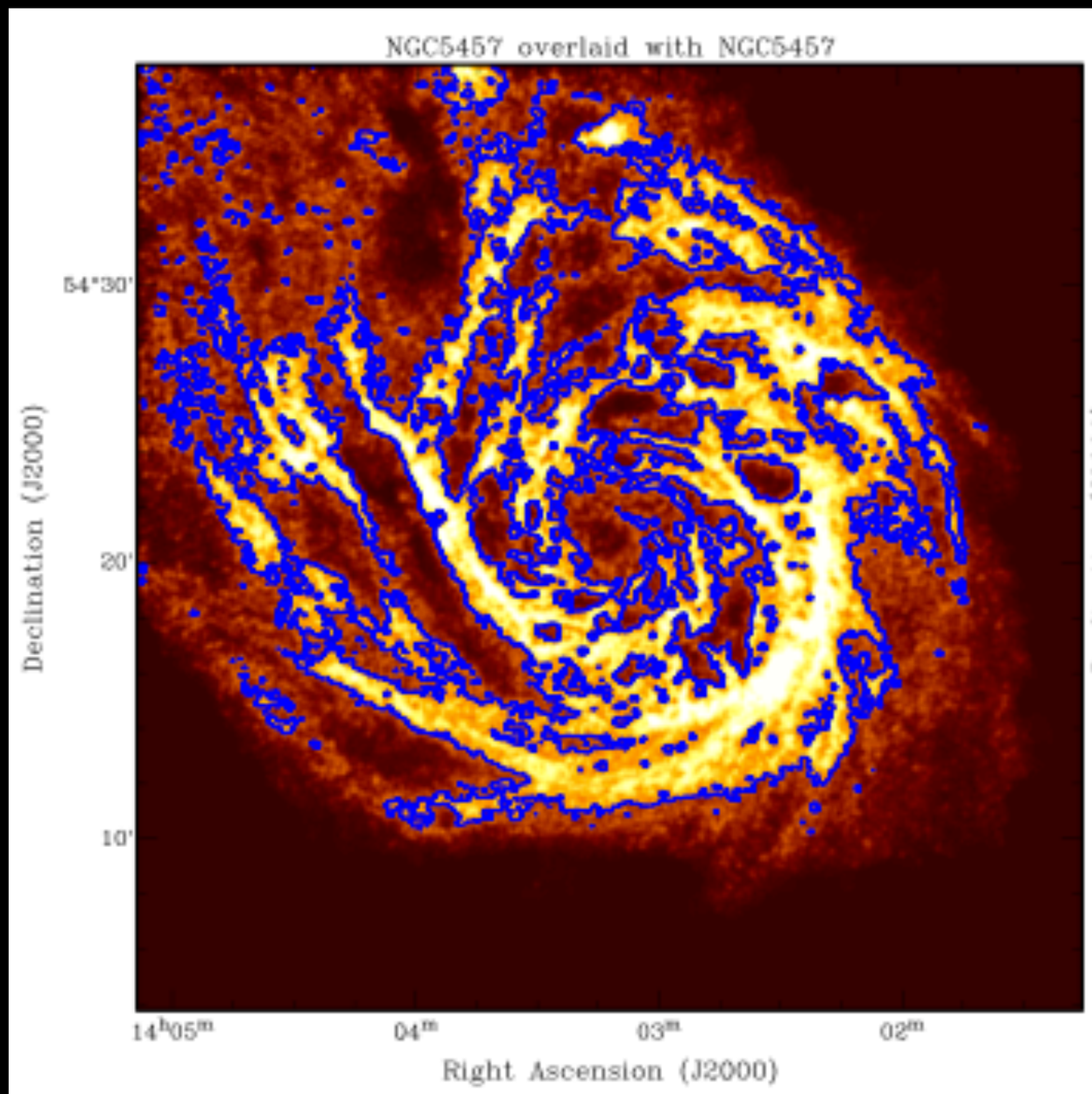


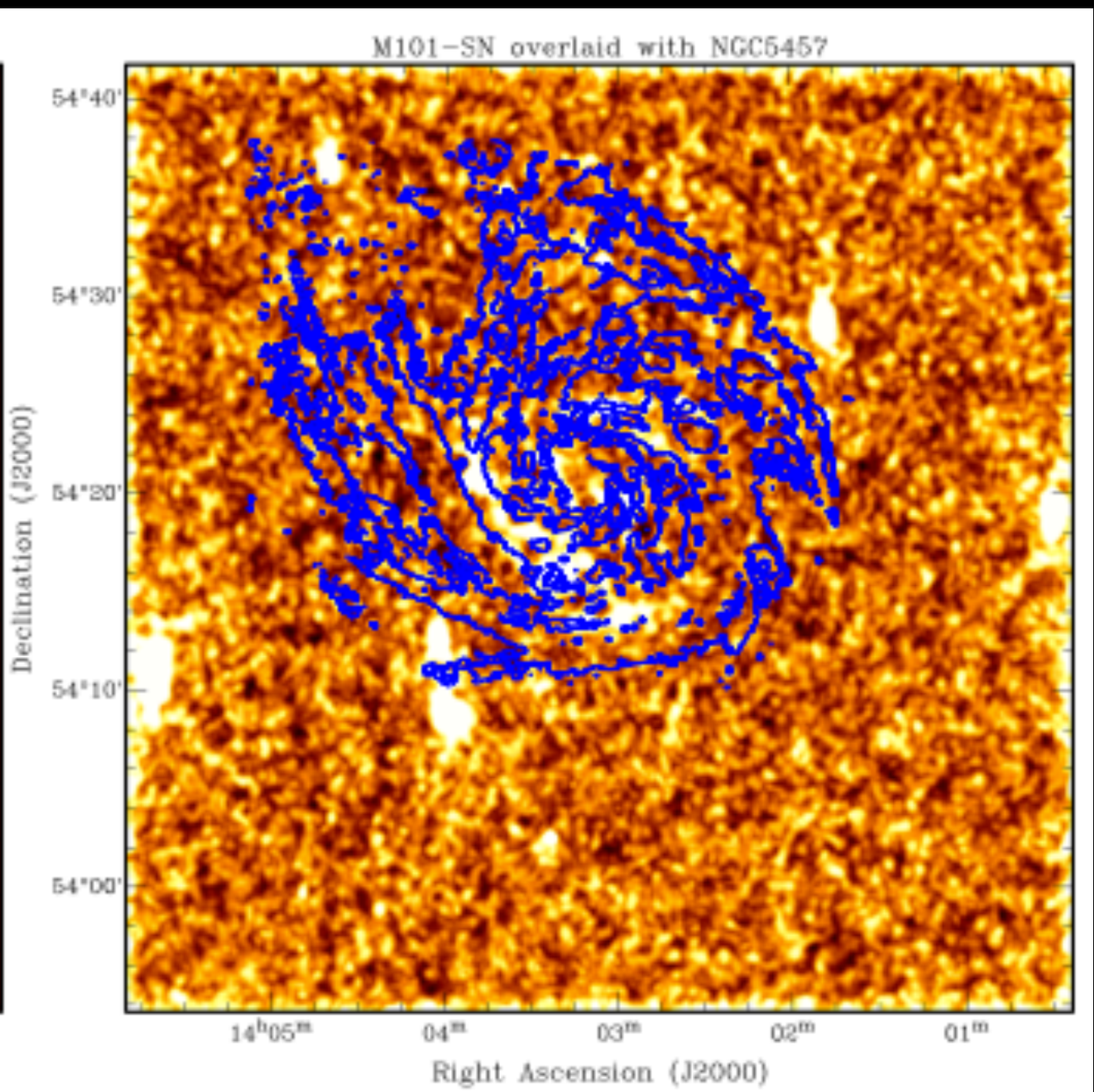


Hα data: Heald & Rand (in prep)

M101 superbubble in RM?

- Substantial depolarization, but still some signal there ....



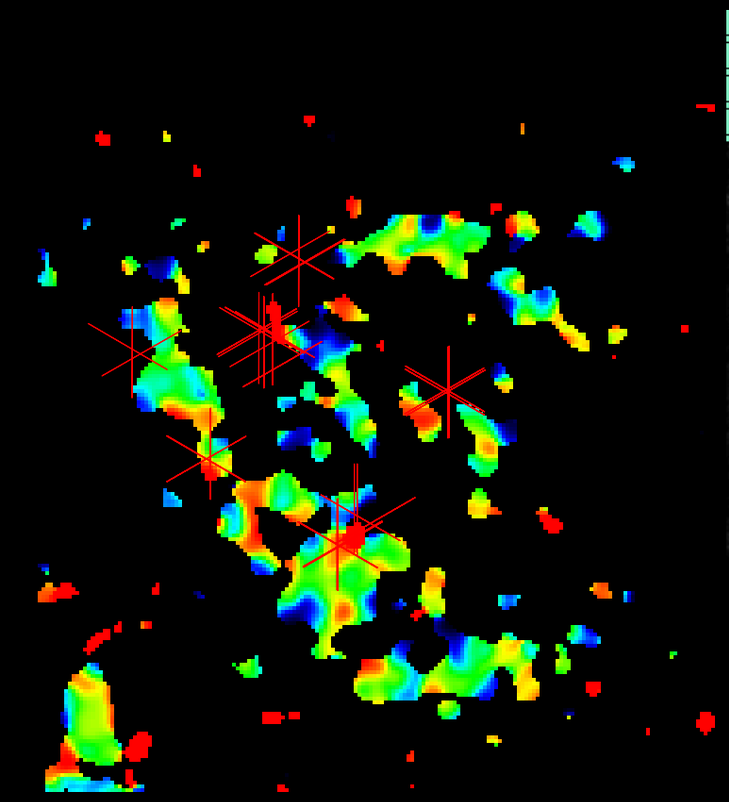


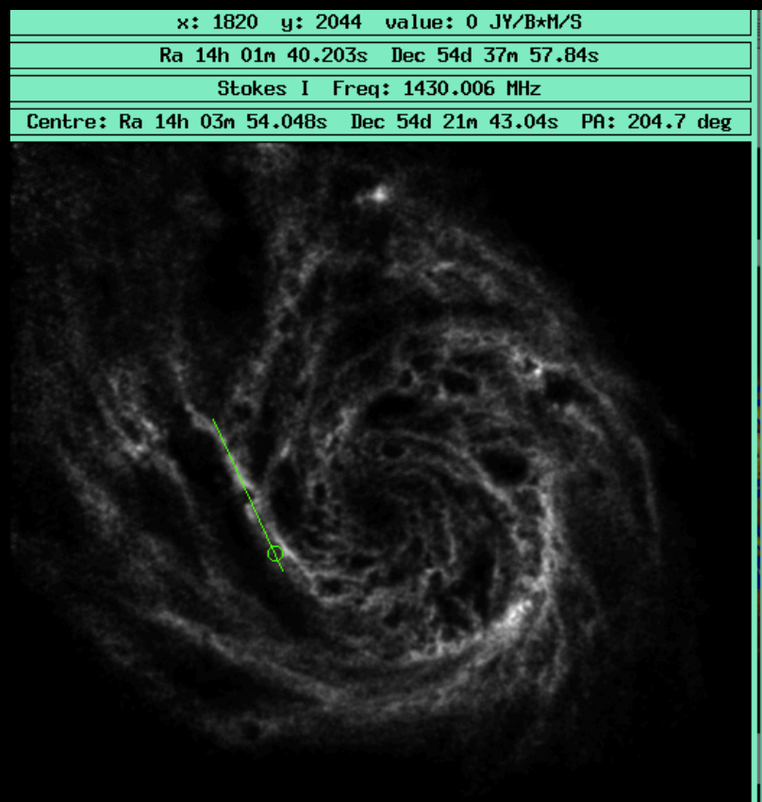
HI data from THINGS

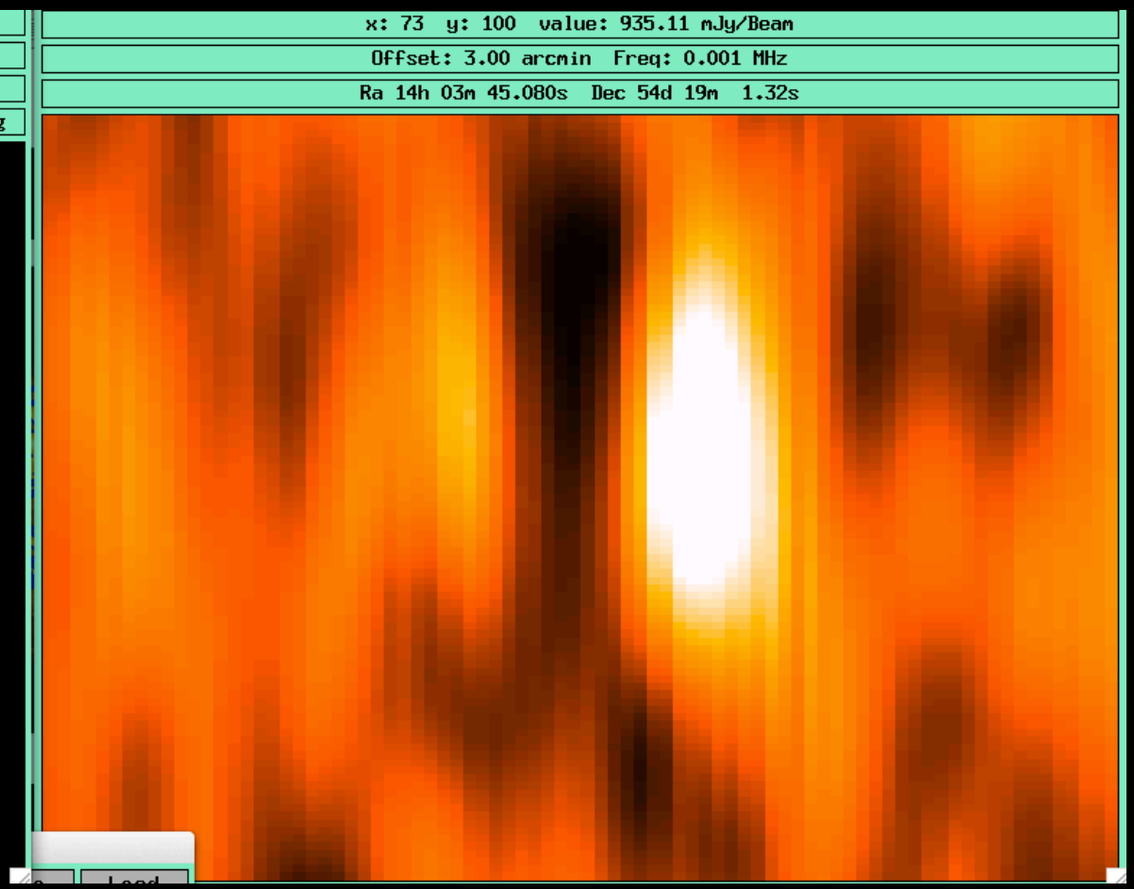
Polarization data courtesy G. de Bruyn

M101 superbubble in RM?

- Possibly a RM gradient of order 40-50 rad/m^2, but lots of other structure in the RM map ... need better sensitivity and most importantly better RM resolution in order to make progress







Polarization data (RM cube) courtesy G. de Bruyn

Summary & Prospects

- Magnetized component of disk-halo connections may be traced by a combination of sensitive HI observations and polarimetry
- May be giving us a first handle on magnetic chimneys!
- Role for LOFAR?
  - Signs of superbubble caps in the high disk-halo interface region?
  - Tracing CR transport and B-field structure in *edge-on* galaxies, and relation to under-lying SF regions