International
Centre for
Radio
Astronomy
Research

The bearded spiral NGC 3521

searching for extra-planar gas

Gas in Galaxies
June 2011
Kloster Seeon

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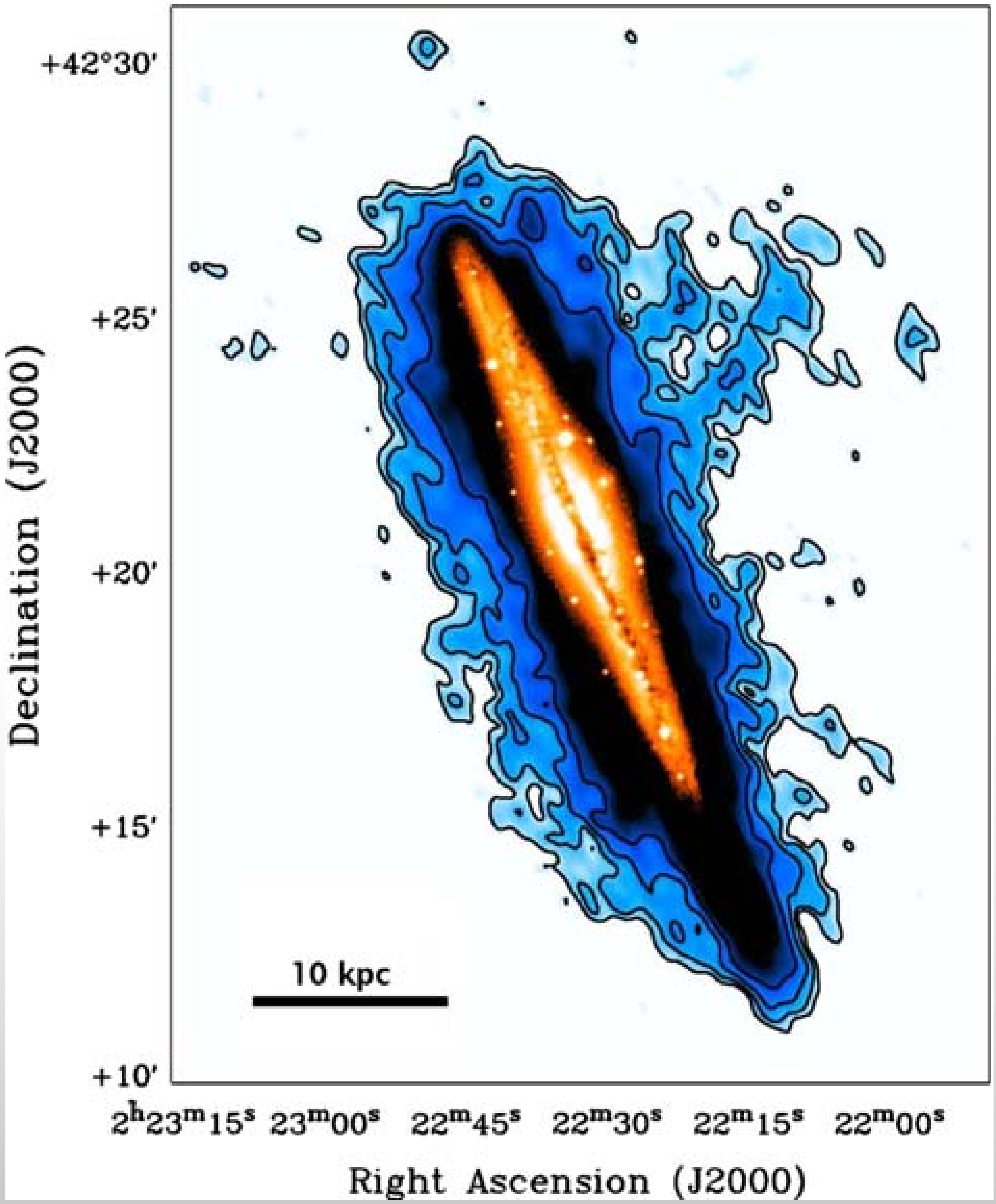
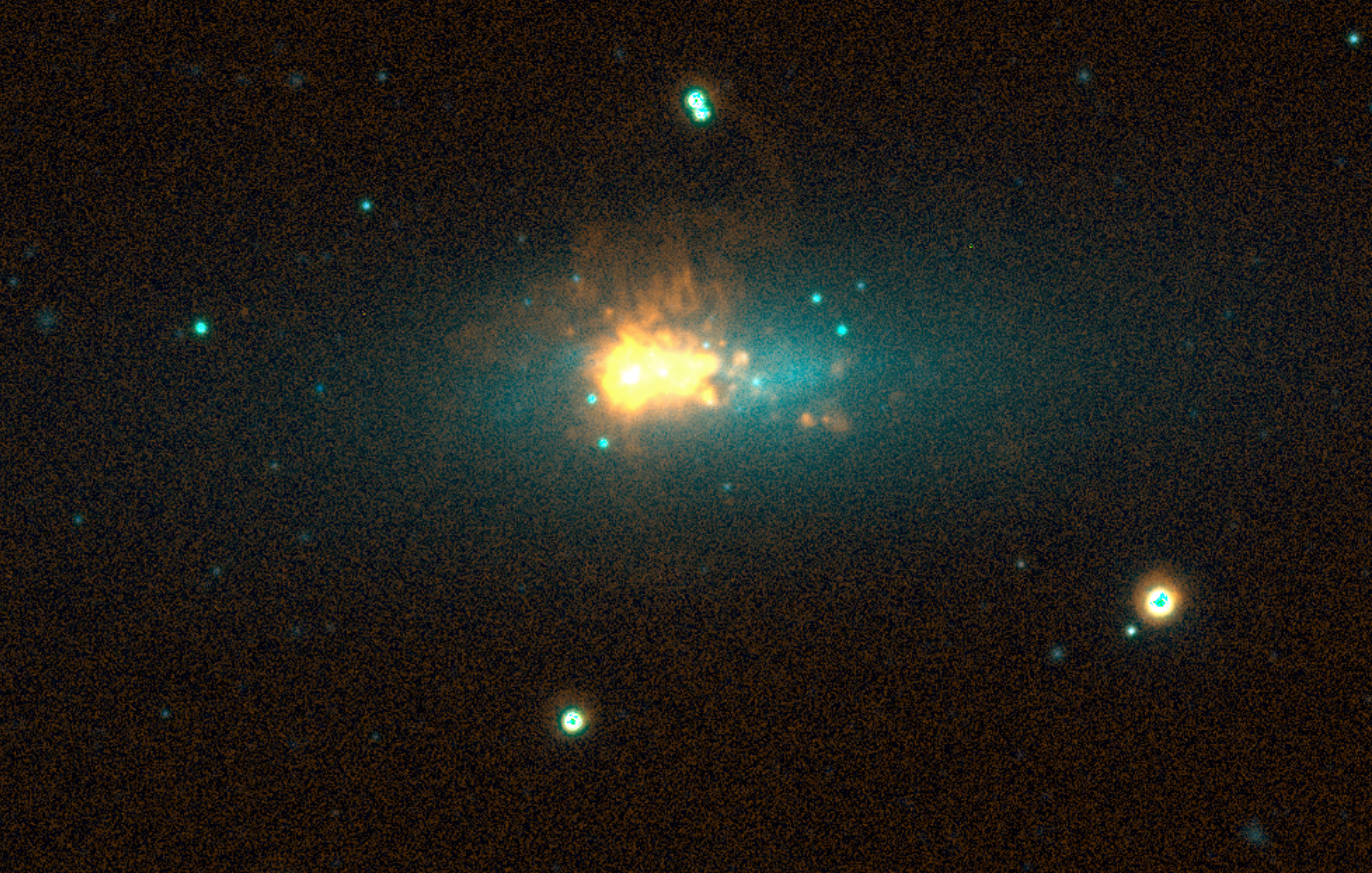
Introduction



NGC 891, Oosterloo et al. (2007)

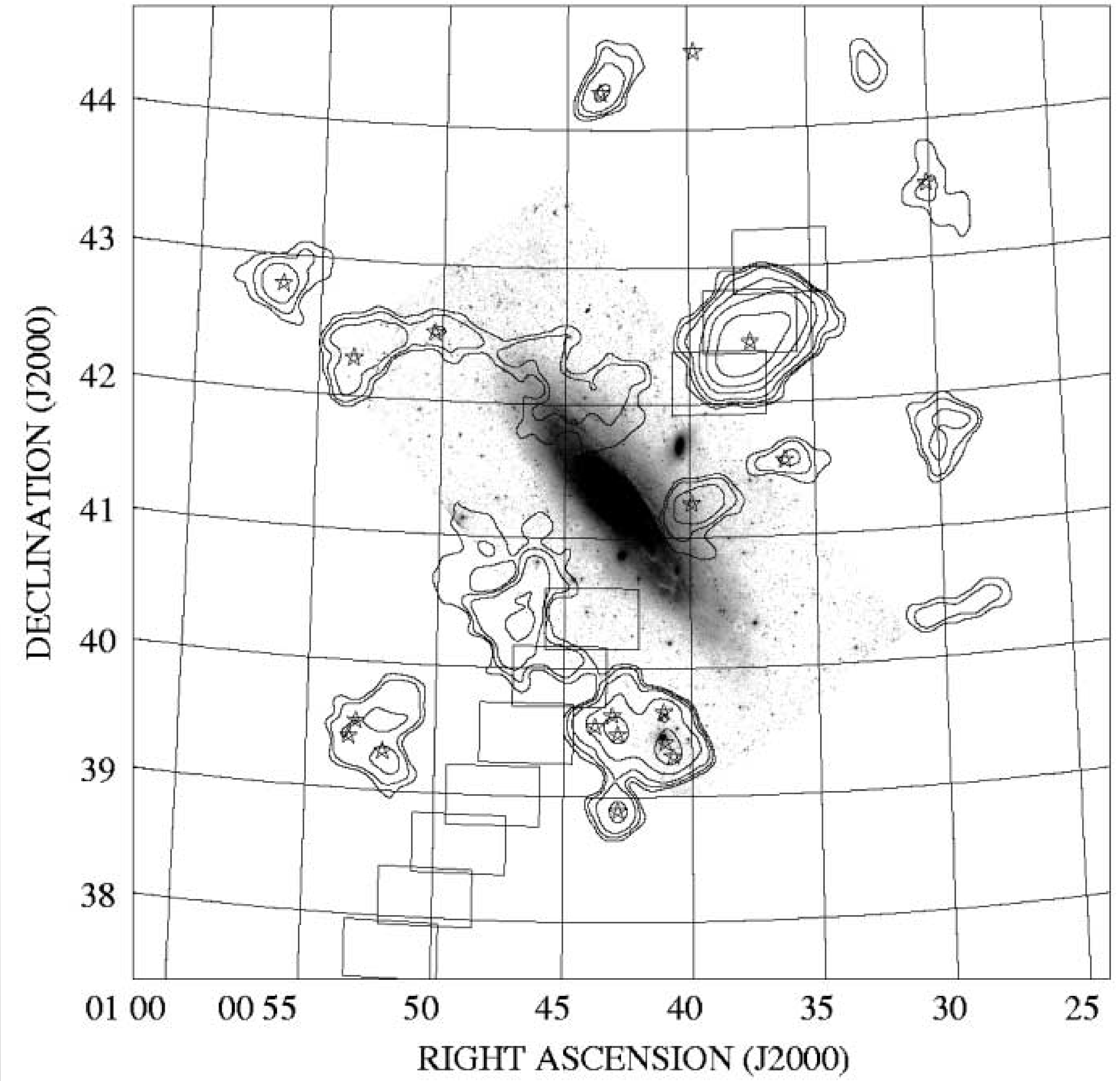
- Cold gas in the halo region of disk galaxies is well established
- Origin of extra-planar gas?
  - Star formation (galactic fountain)
  - Accretion from IGM

Galactic fountain scenario (Shapiro & Field, 1976)



NGC 625, upcoming SINGG data release

Introduction



M31, Thilker et al. (2004)

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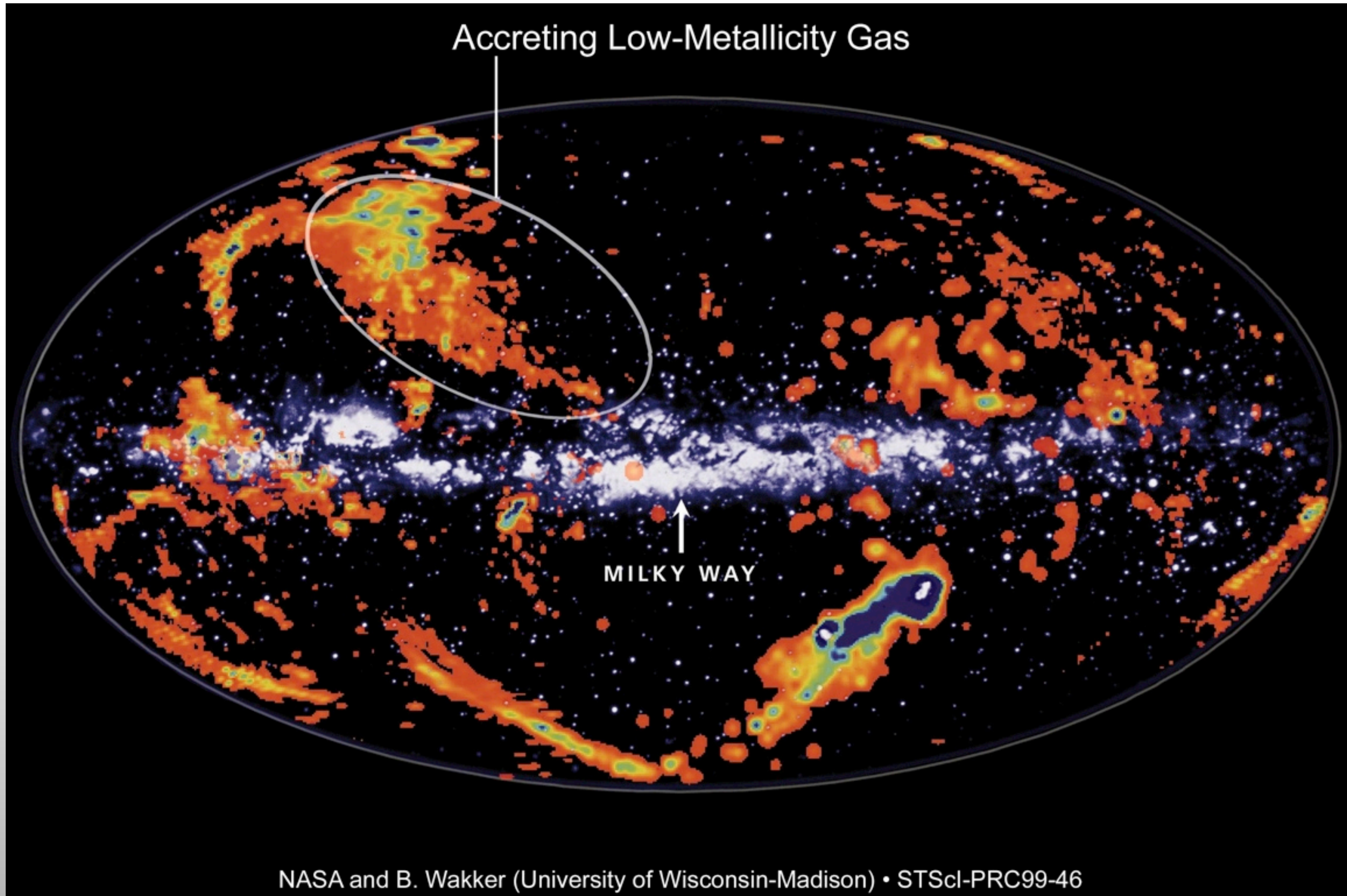
Cold gas accretion

- A significant fraction of extra-planar gas must be infall from inter-galactic space



Only a few galaxies have had their extra-planar gas studied in detail:

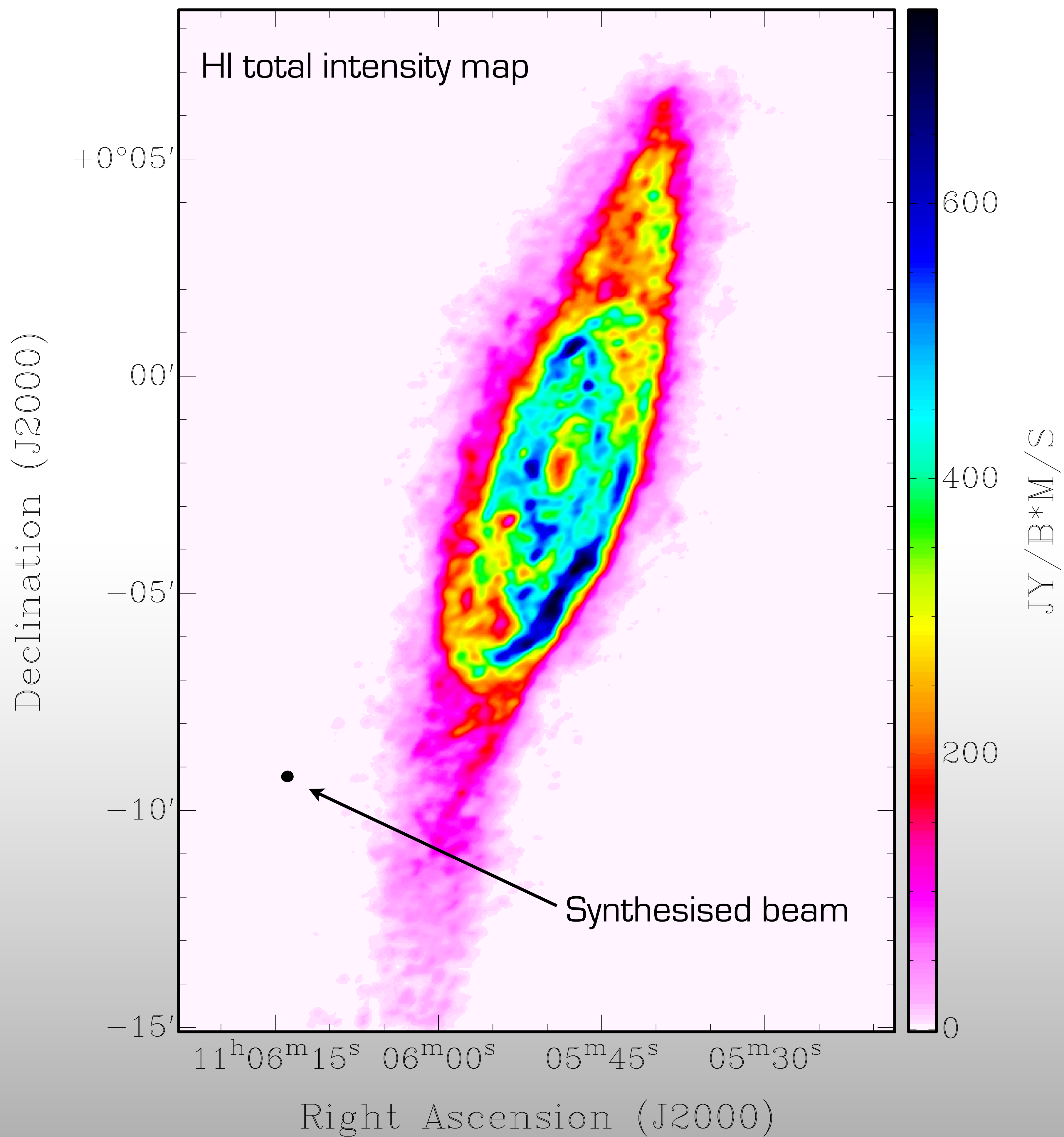
Galaxy	Type	Incl (°)	v_{flat} (km s^{-1})	$M_{HI_{halo}}$ (10^8 M$_\odot$)	$\frac{M_{HI_{halo}}}{M_{HI_{tot}}}$ (%)	References
Milky Way	Sb	–	220	>0.2	>1[a]	Wakker et al. (2007)
M 31	Sb	77	226	>0.3	>1	Thilker et al. (2004)
NGC 891	Sb	90	230	12	30	Oosterloo et al. (2007a)
NGC 6946	Scd	38	175	>2.9	>4	Boomsma et al. (2005b)
NGC 4559	Scd	67	120	5.9	11	Barbieri et al. (2005)
NGC 2403	Scd	63	130	3	10	Fraternali et al. (2002)
UGC 7321	Sd	88	110	$\gtrsim$0.1	$\gtrsim$1	Matthews and Wood (2003)
NGC 2613	Sb	~80	~300	4.4[b]	5	Chaves and Irwin (2001)
NGC 253	Sc	~75	~185	0.8	3	Boomsma et al. (2005a)

Taken from Sancisi et al. (2008)

NGC 3521

- Nearby (10.7 Mpc) disk galaxy
- Intermediate inclination ~ 72°
- Flocculent HI distribution
- M_B = -20.94, M_{HI} ~ 8 x 10^9 $M_\odot$
- Observed as part of THINGS
  - 14.14'' x 11.15'' spatial res.
  - 5.2 km/s spectral res.

Walter et al. 2008



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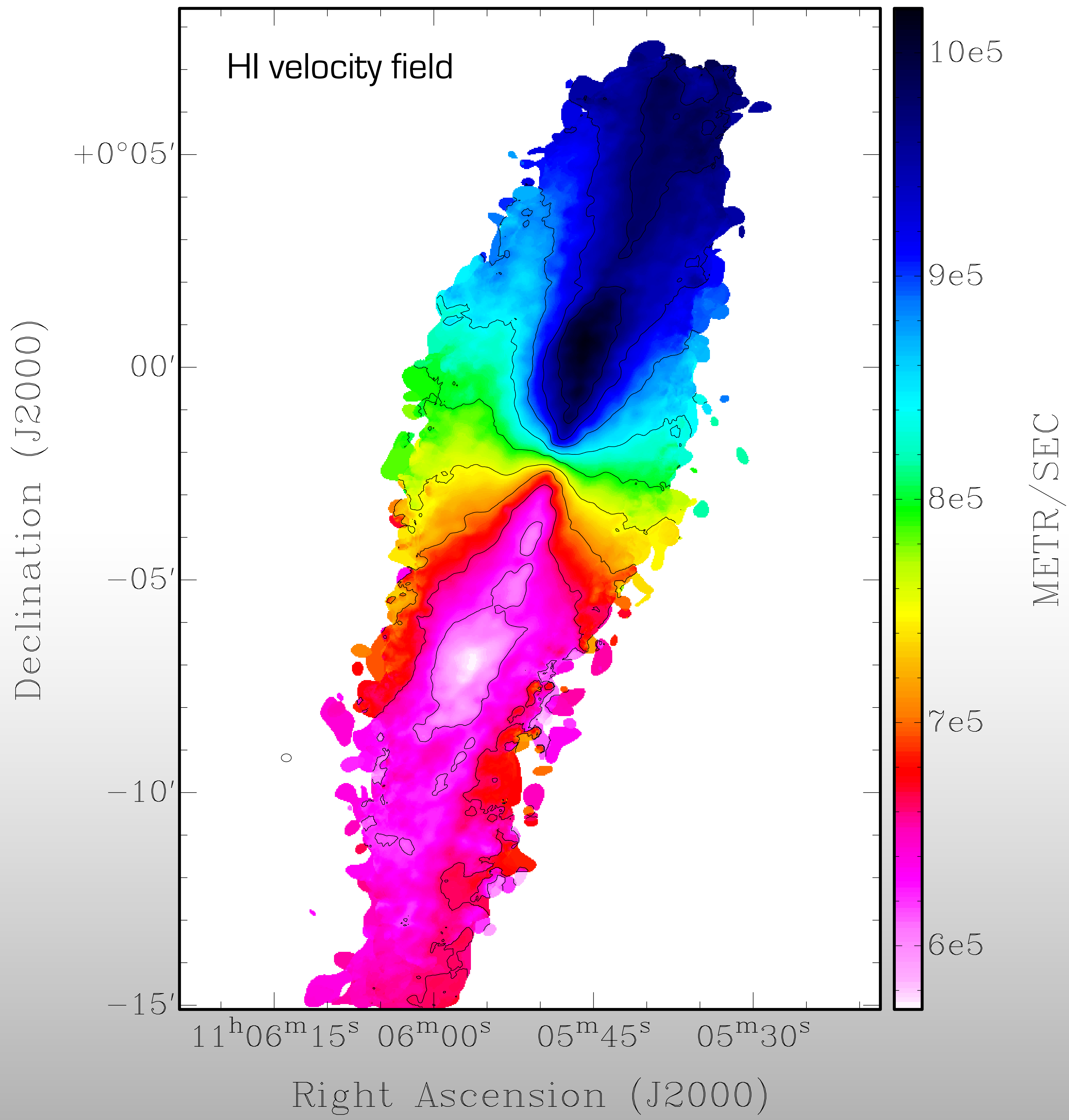

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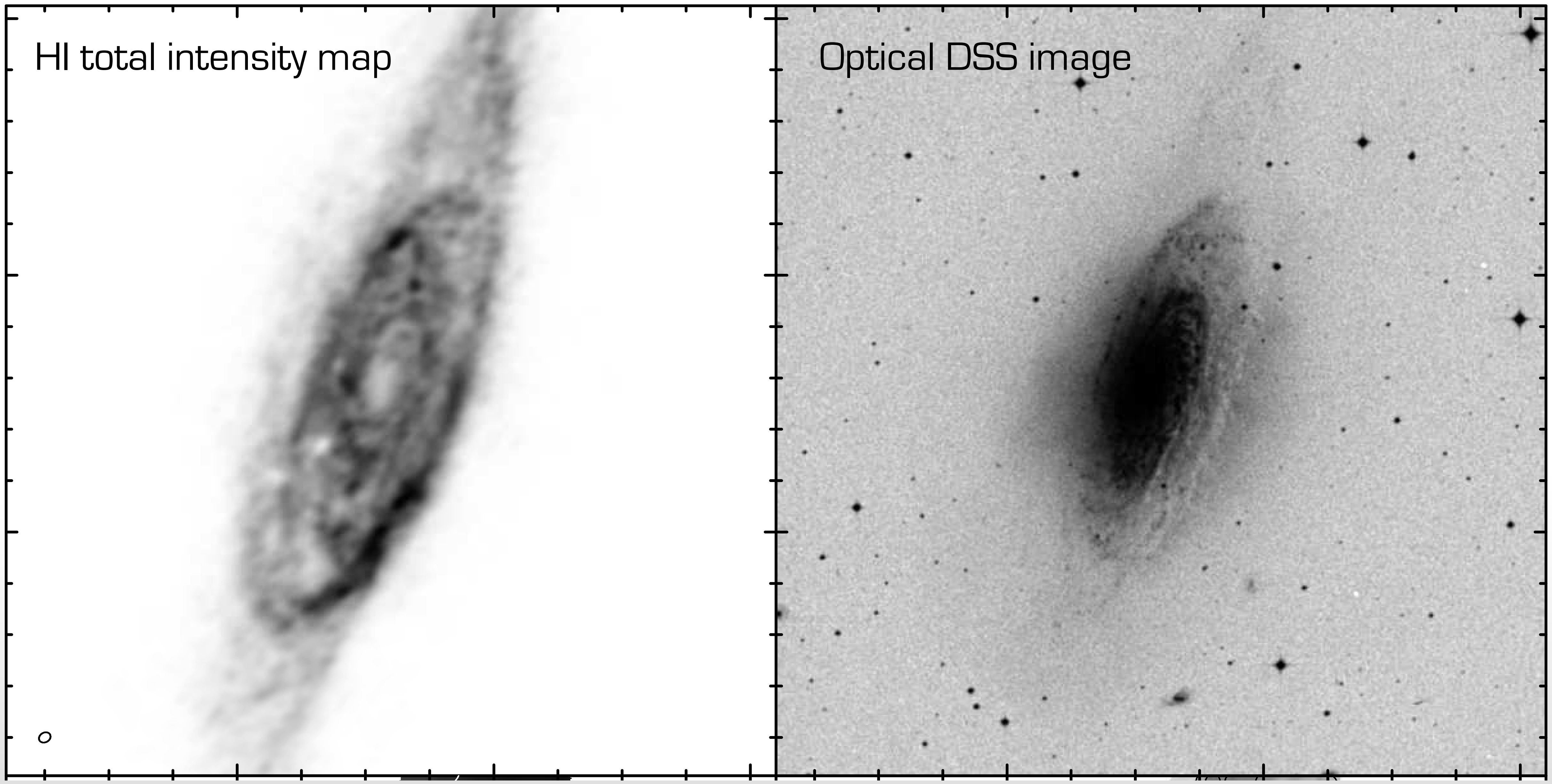
NGC 3521



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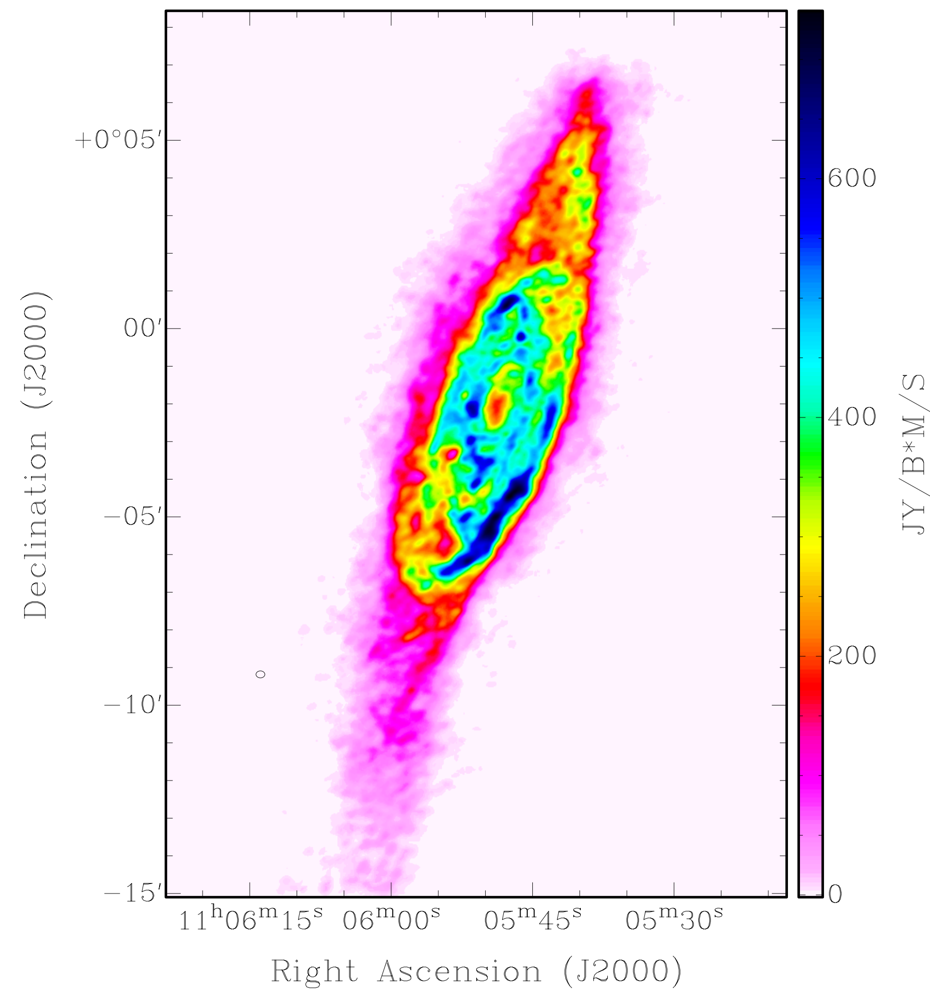
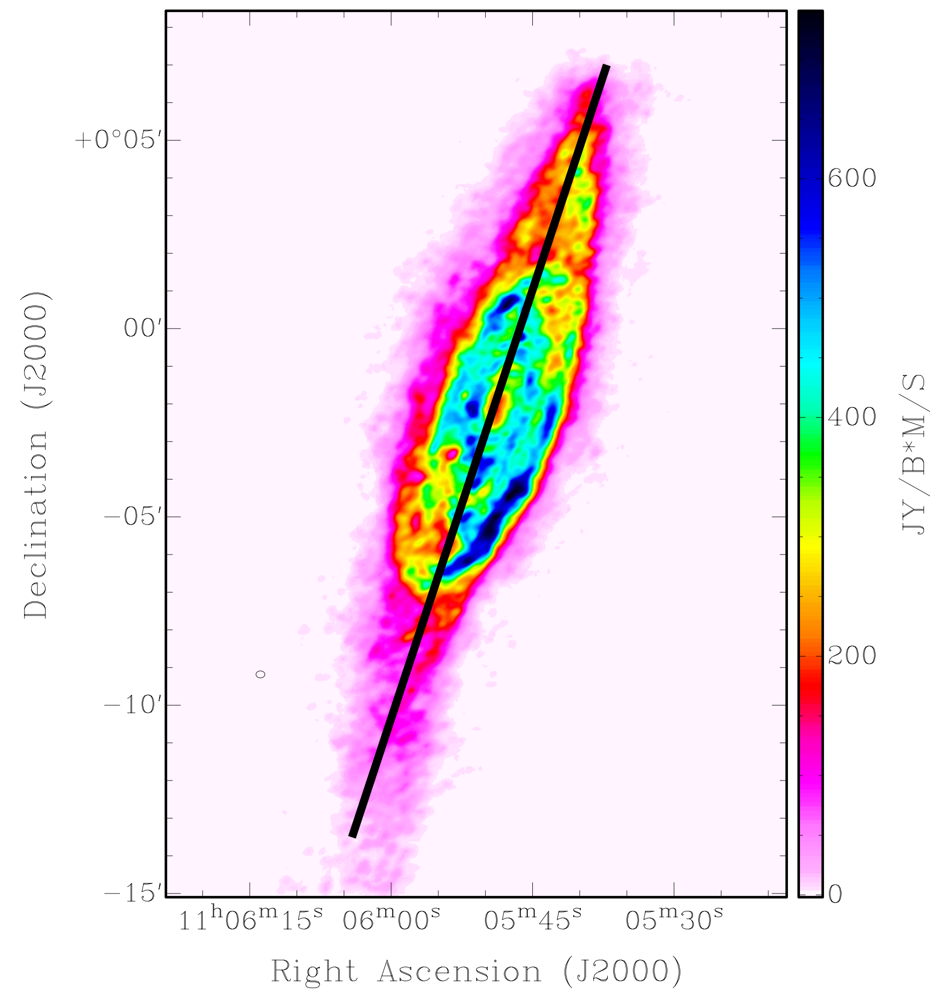
NGC 3521- kinematics



NGC 3521- kinematics



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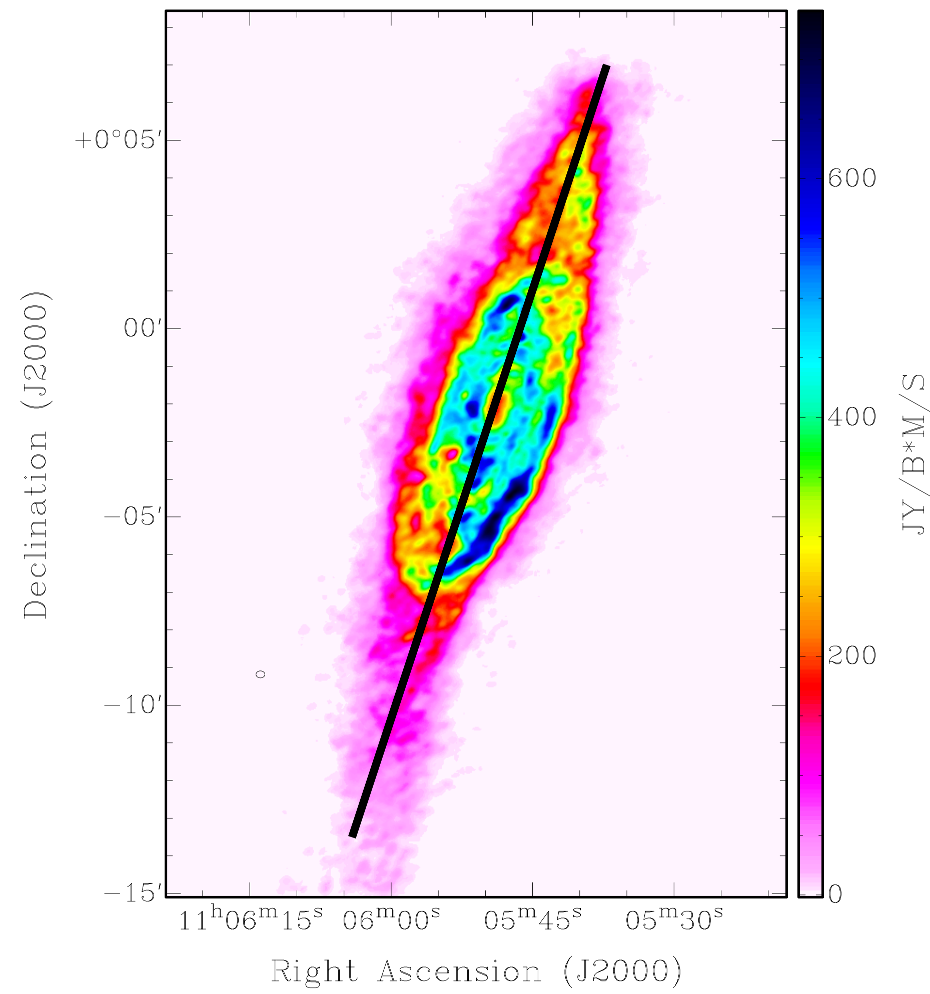

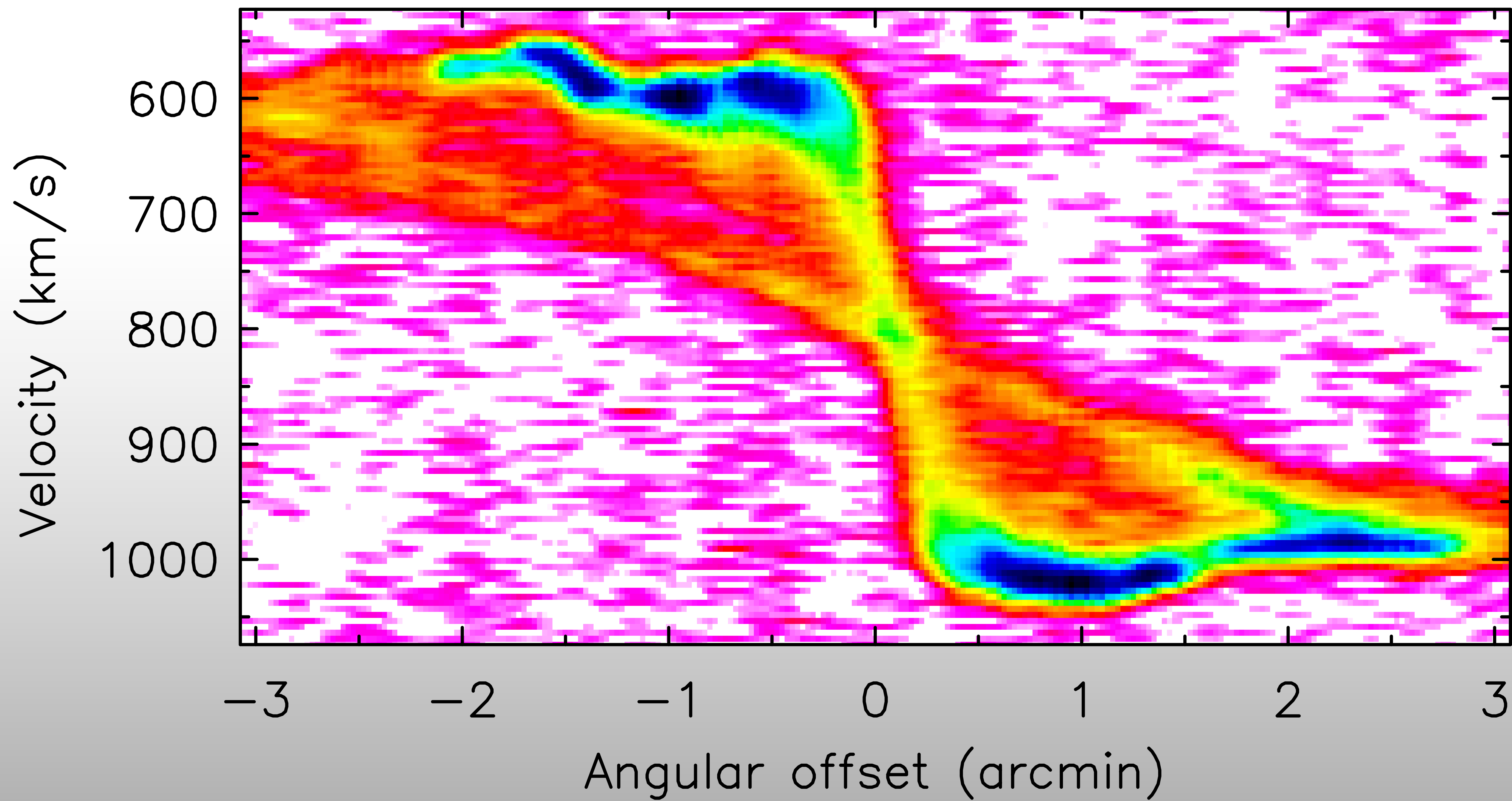

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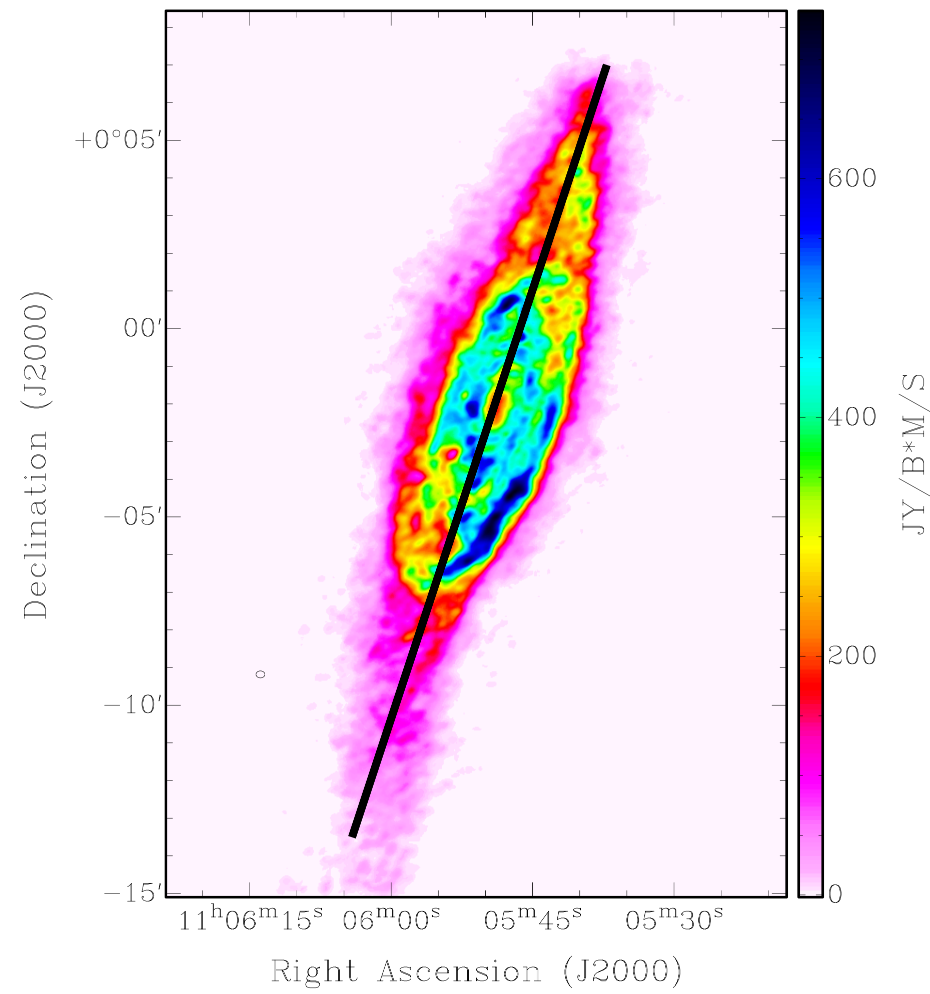
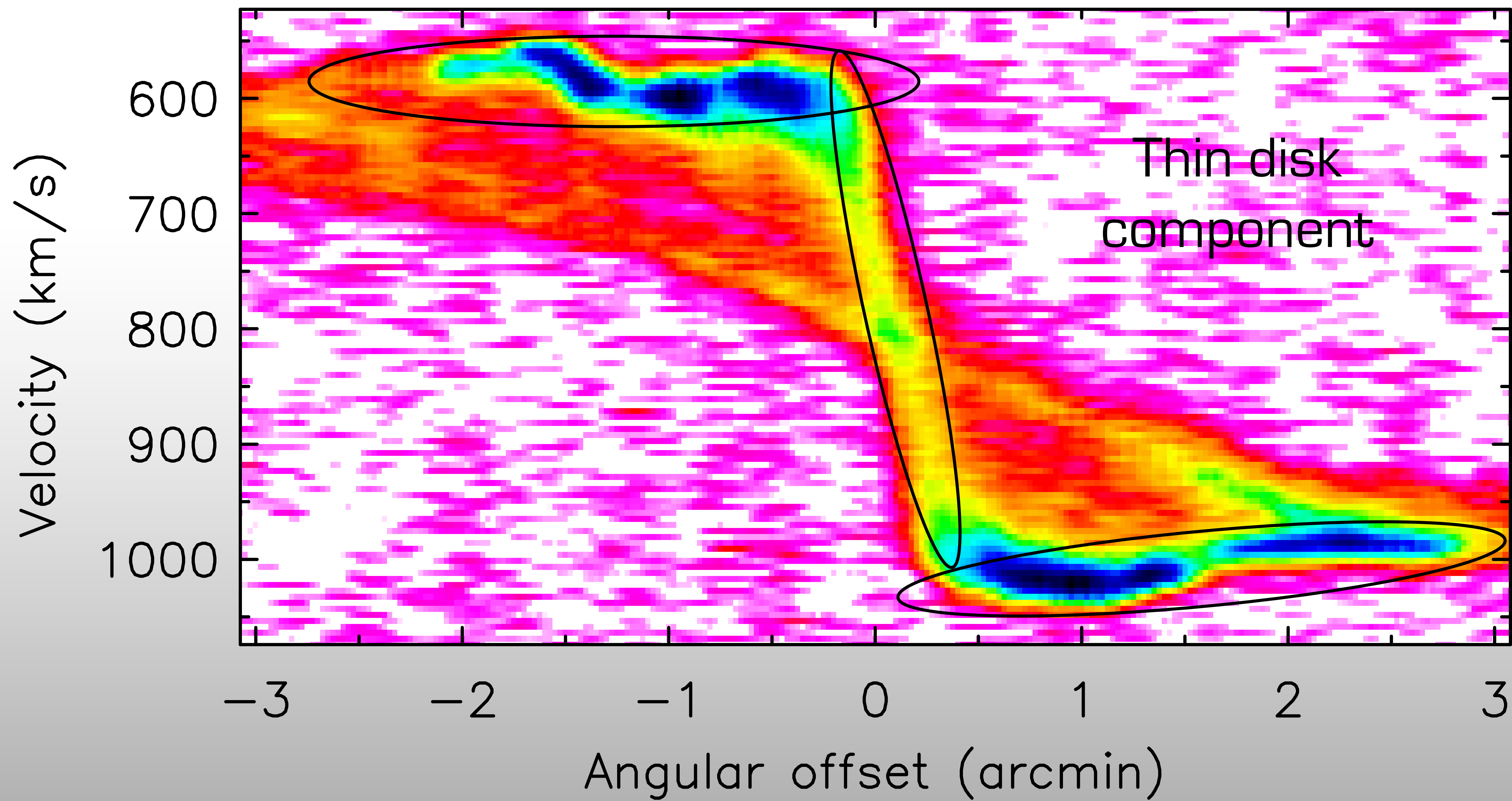


Two dynamical components are clearly seen in the data



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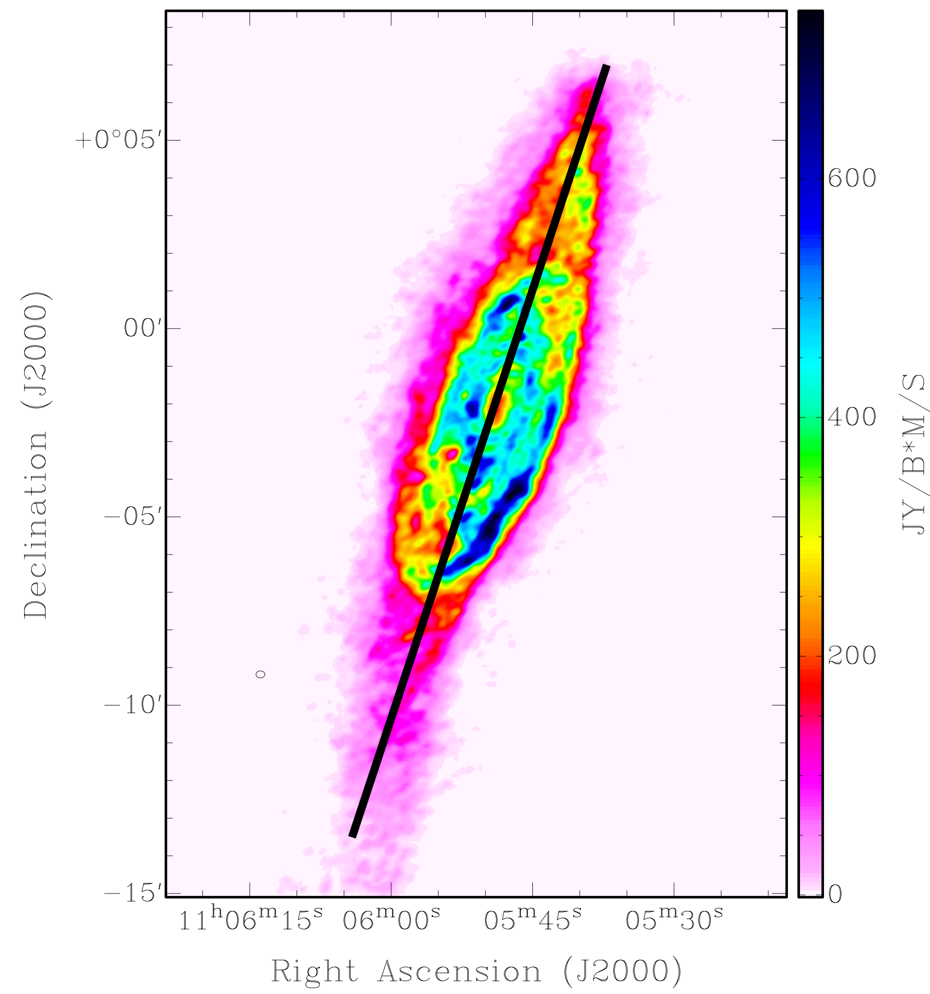

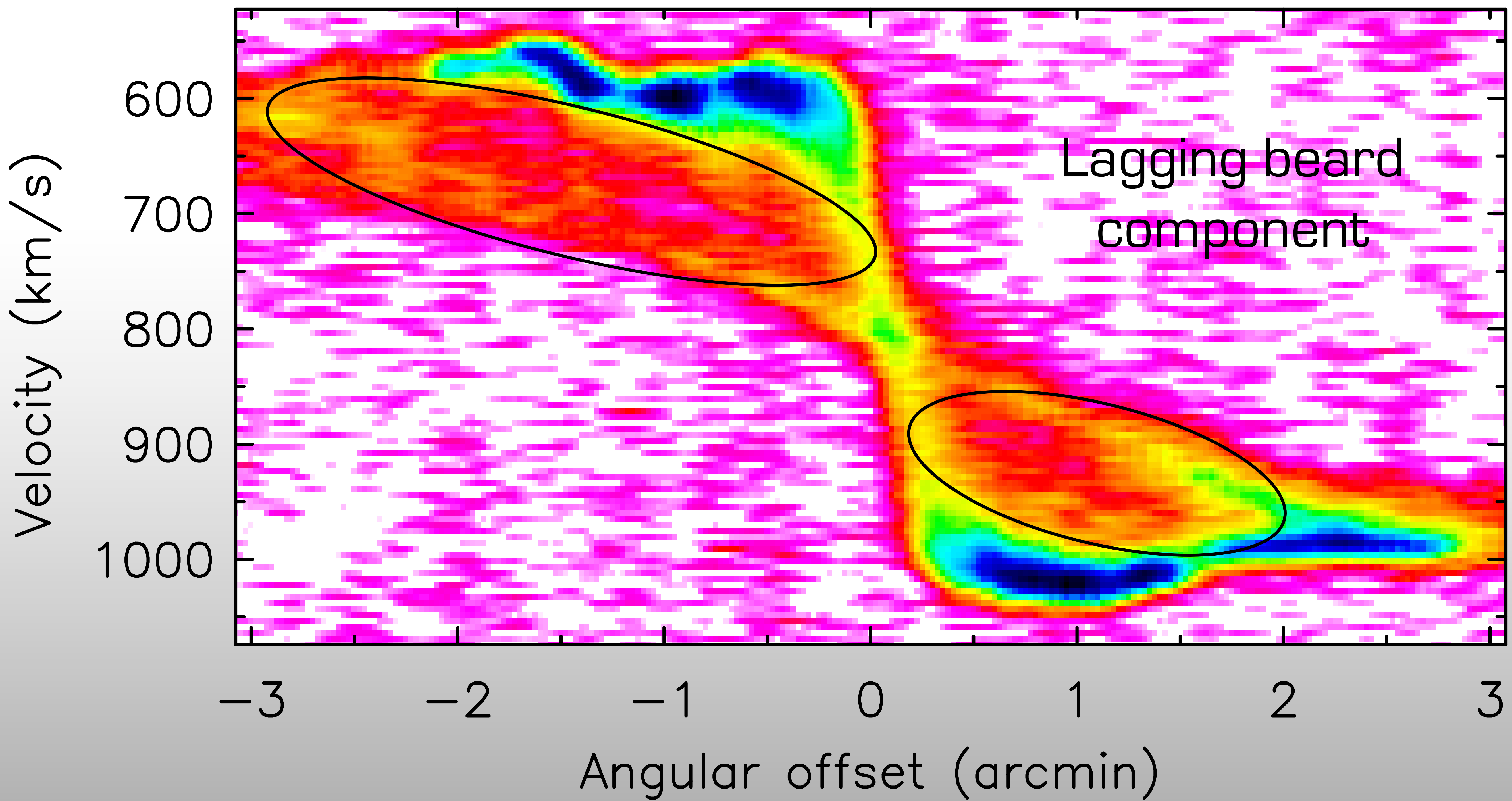

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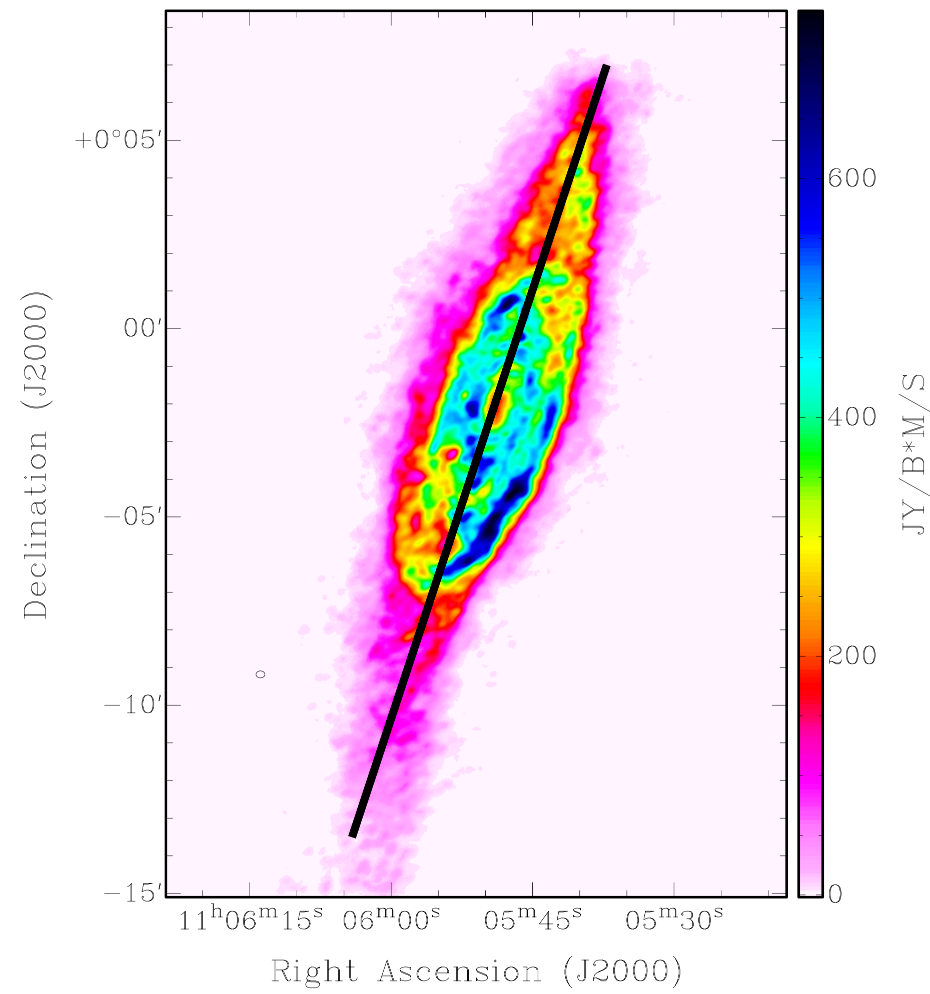

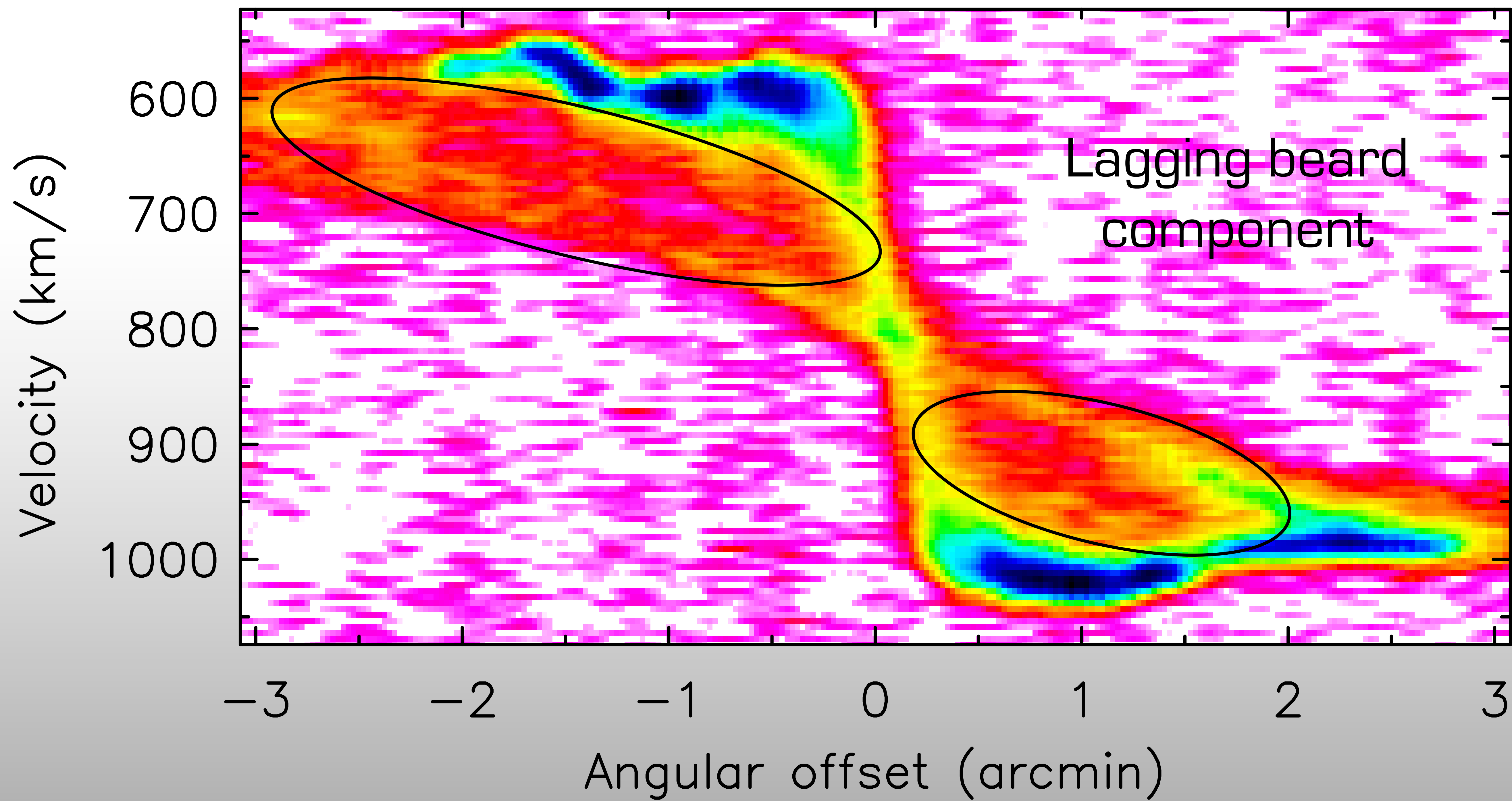

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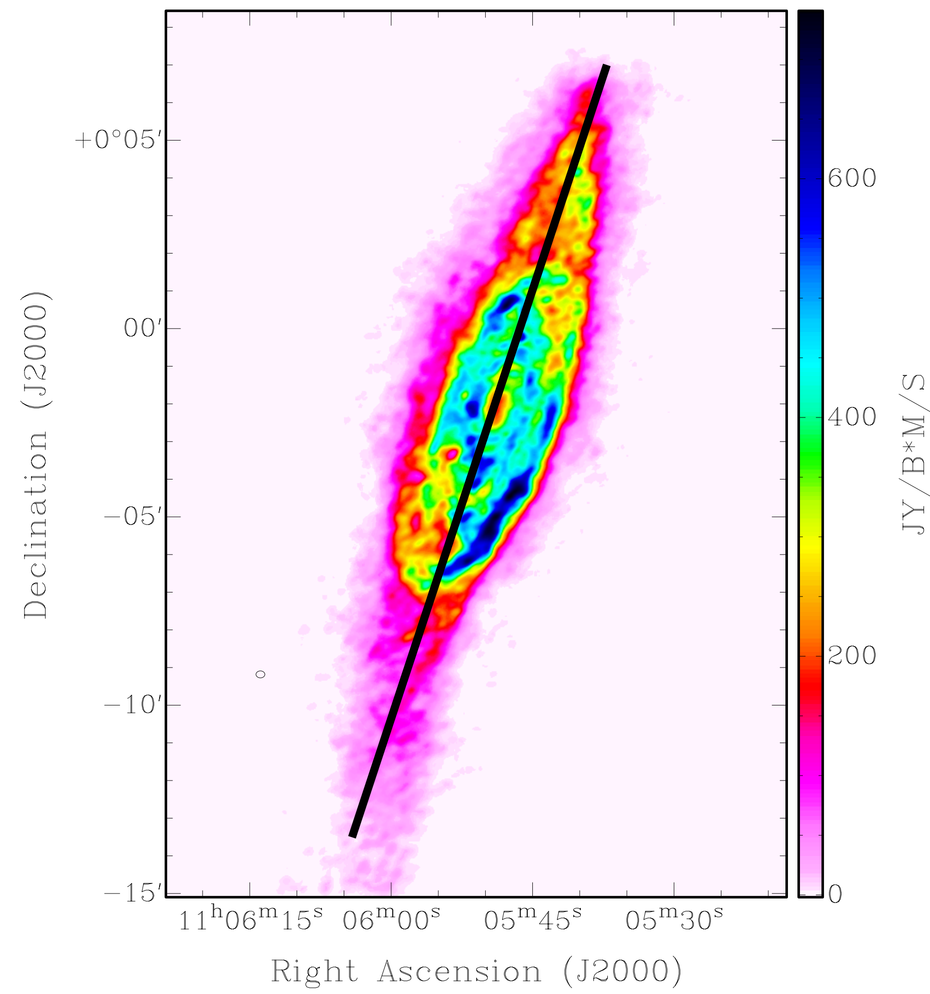

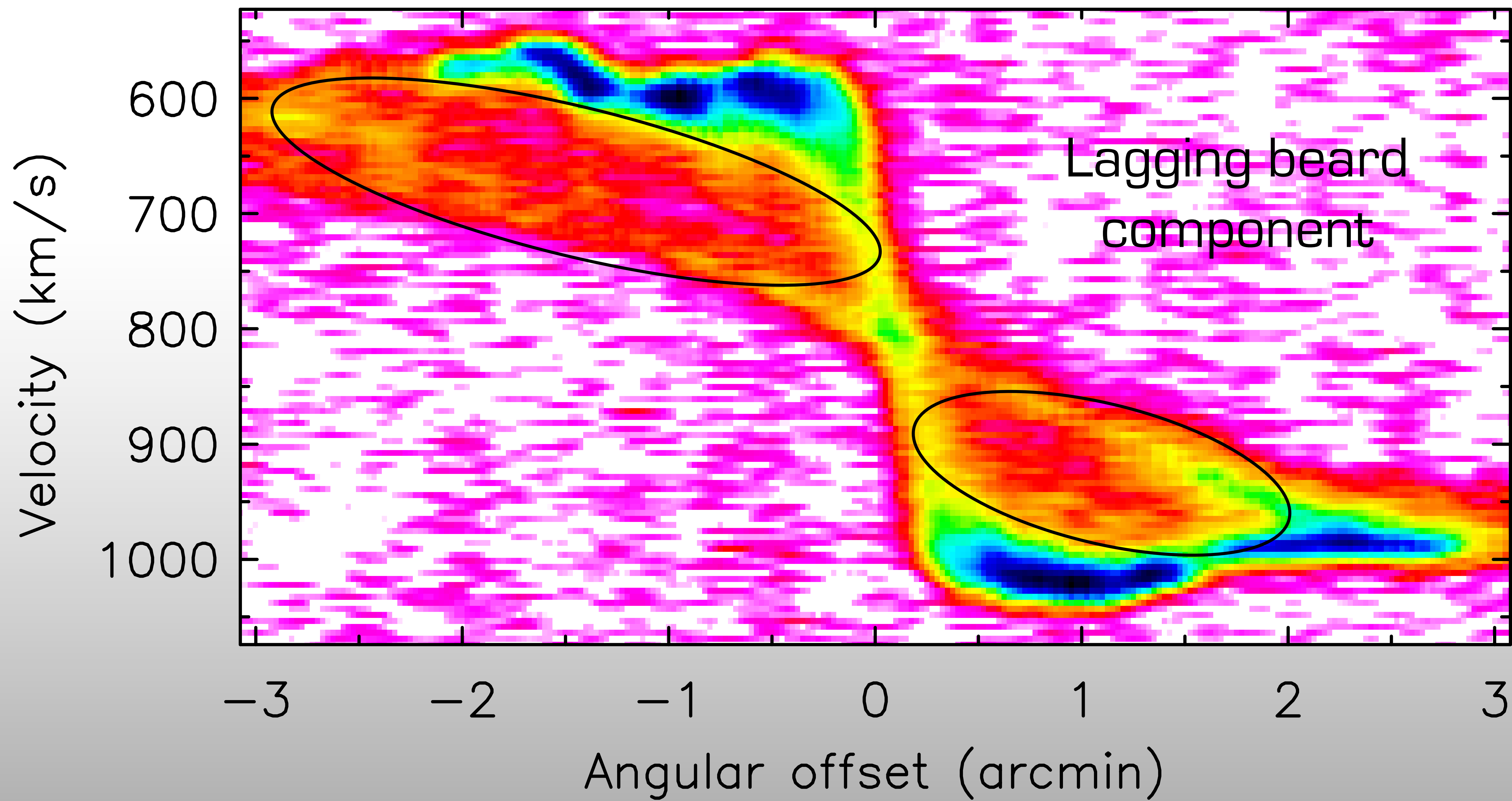

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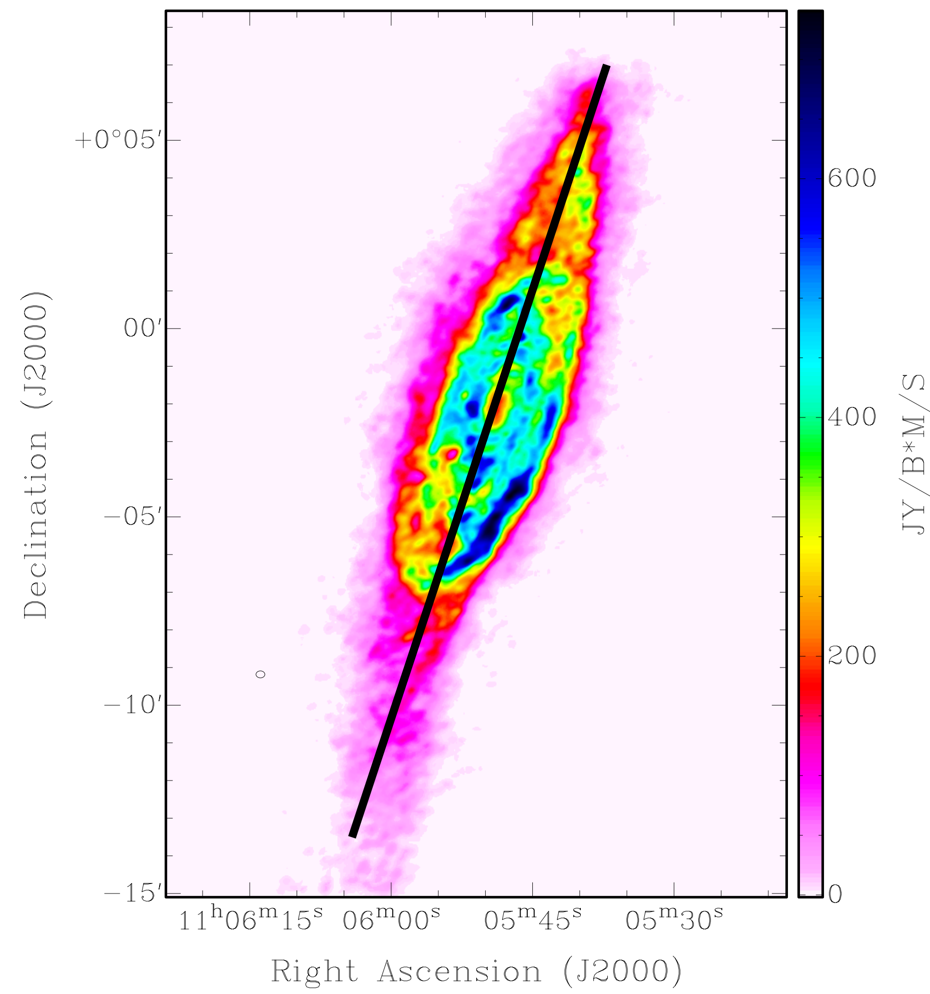
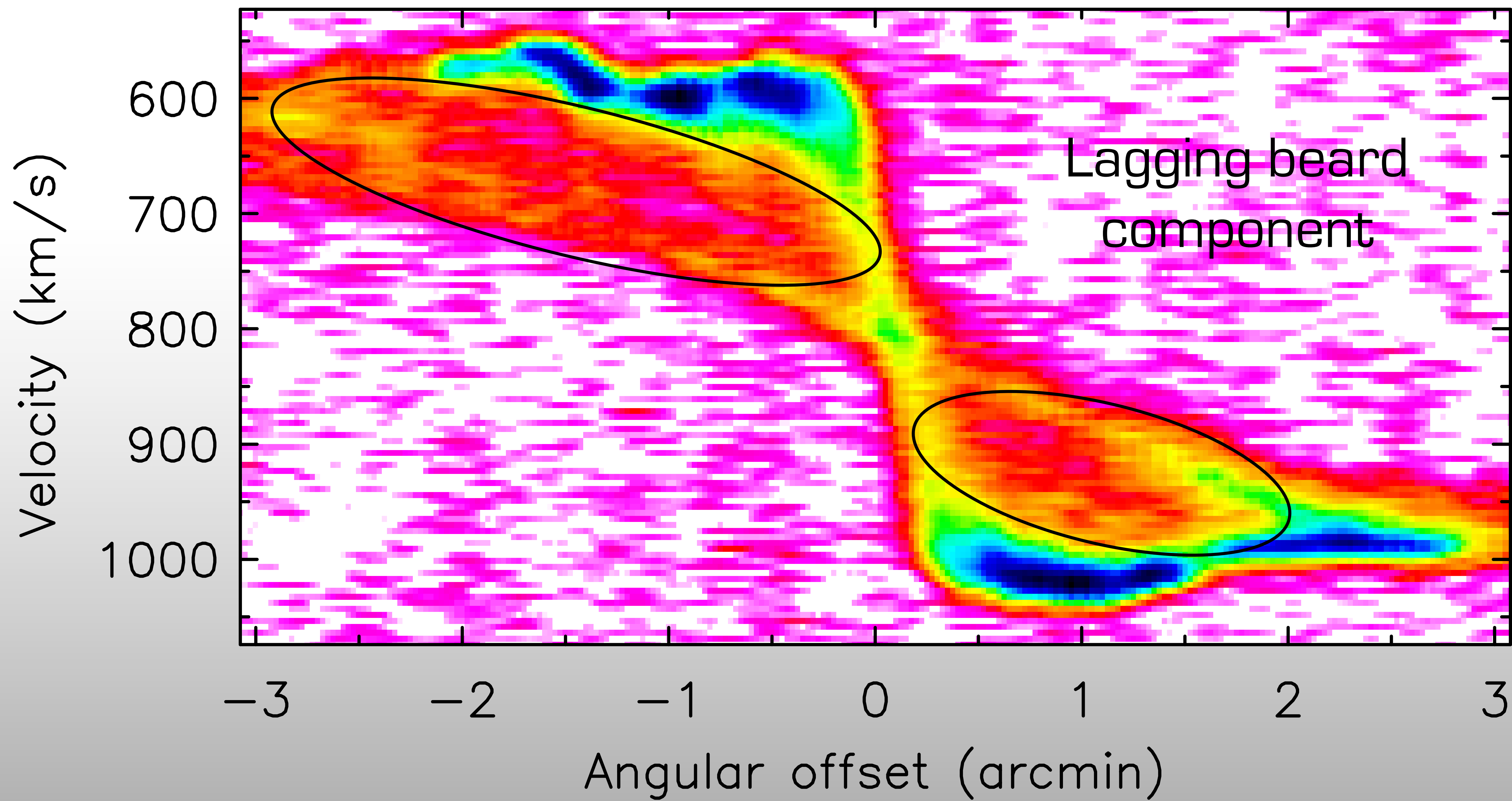


What is the HI beard in NGC 3521?



Dynamical analyses - separating the kinematic components

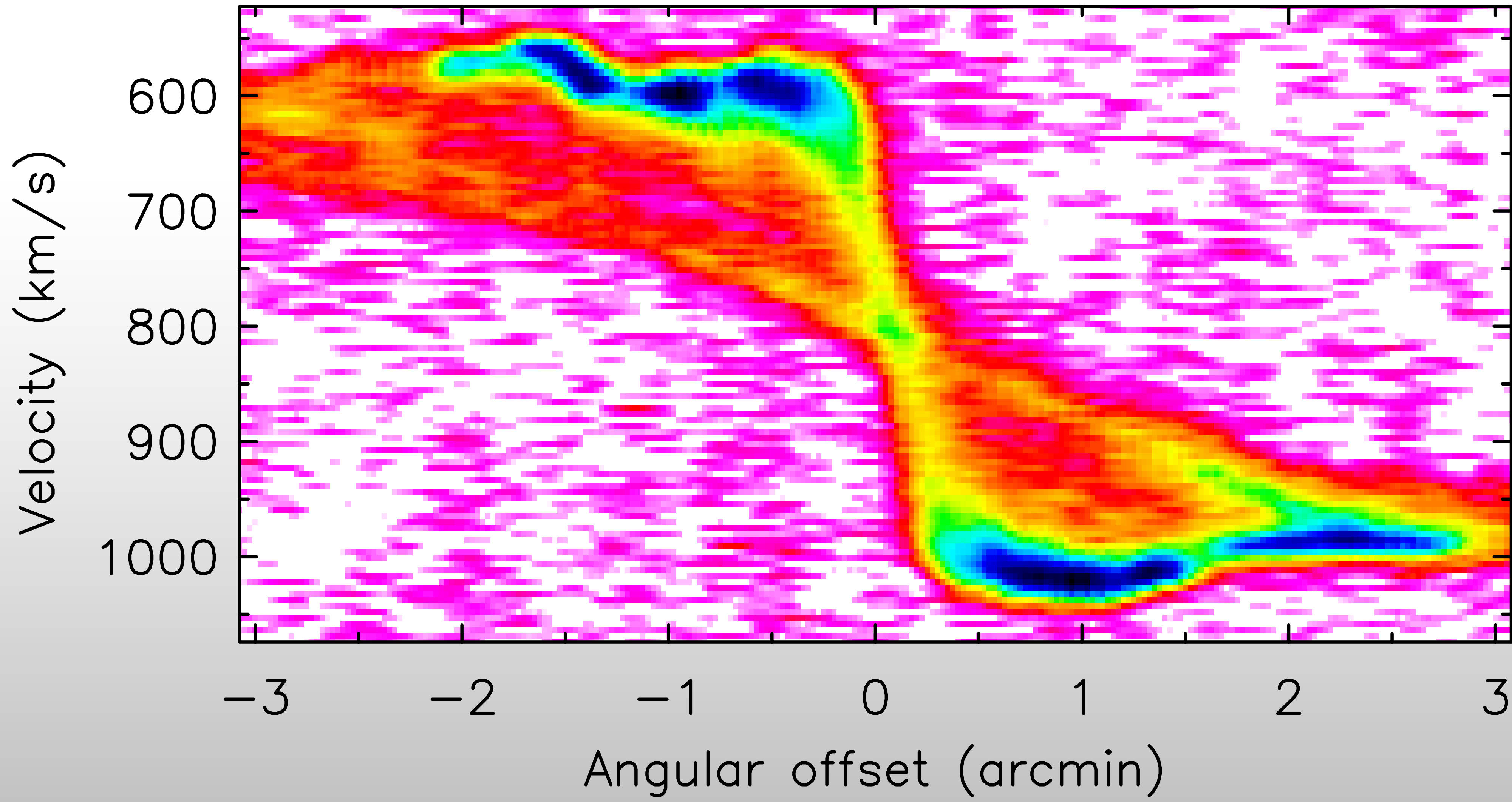
- Line profiles are clearly skewed towards V_{sys}.

- Separate the disk and beard emission:

1. Parameterise each line profile as a double Gaussian

2. Organise fitted Gaussians according to velocity

3. Build new cubes for each set of Gaussians



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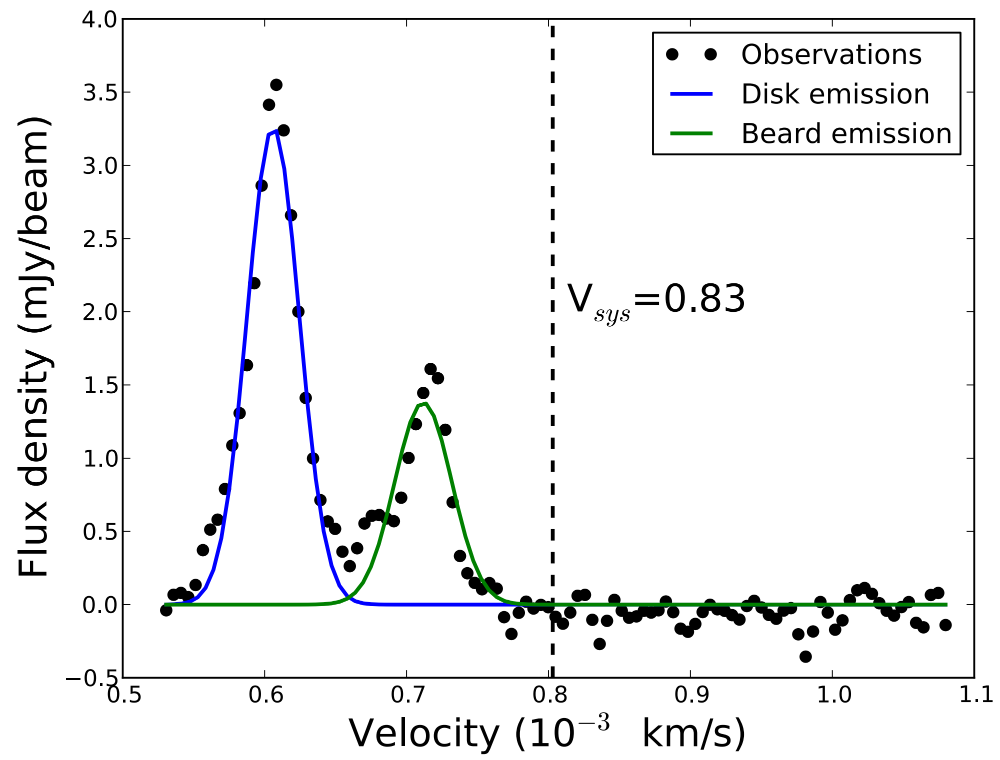

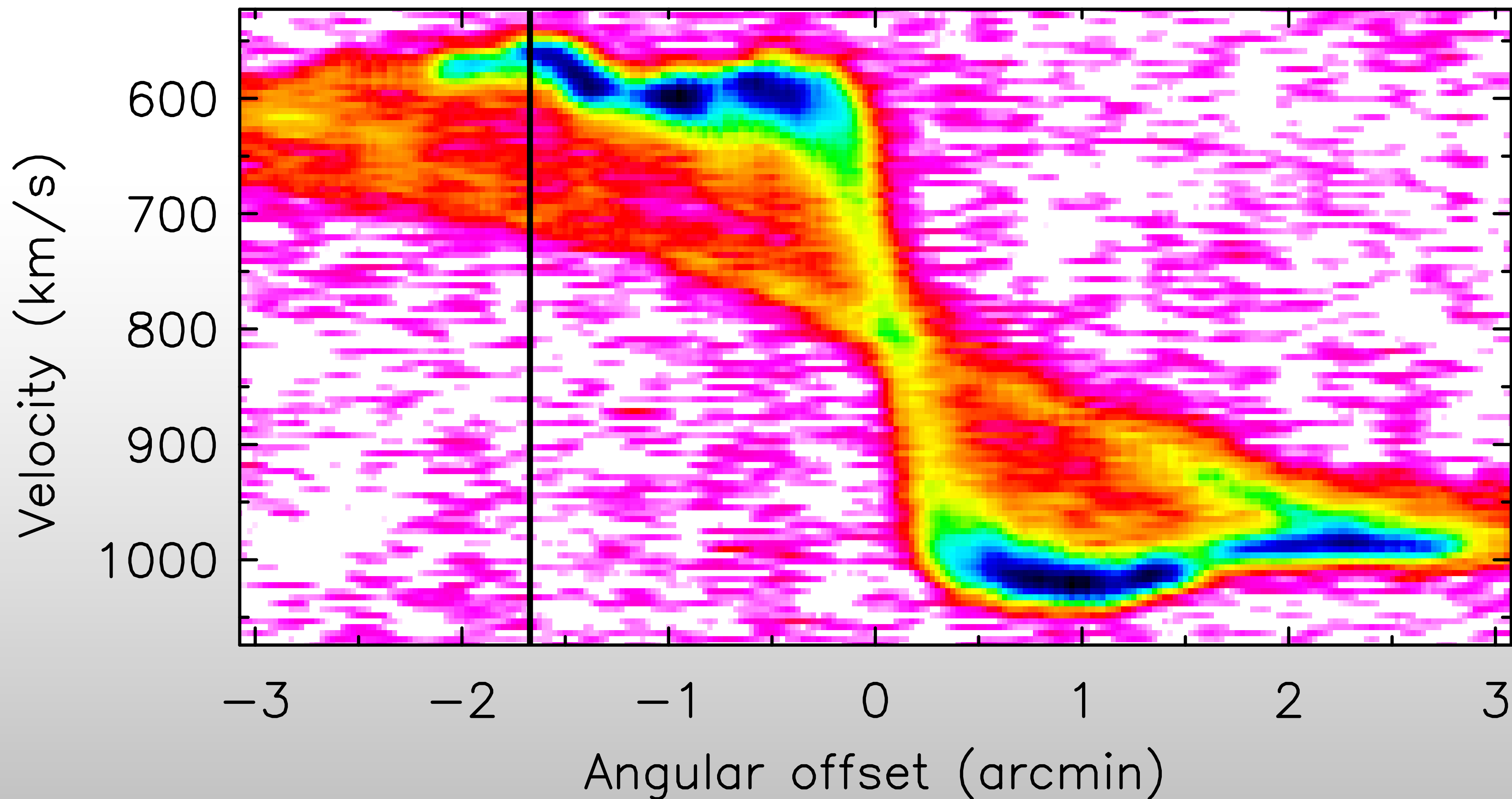

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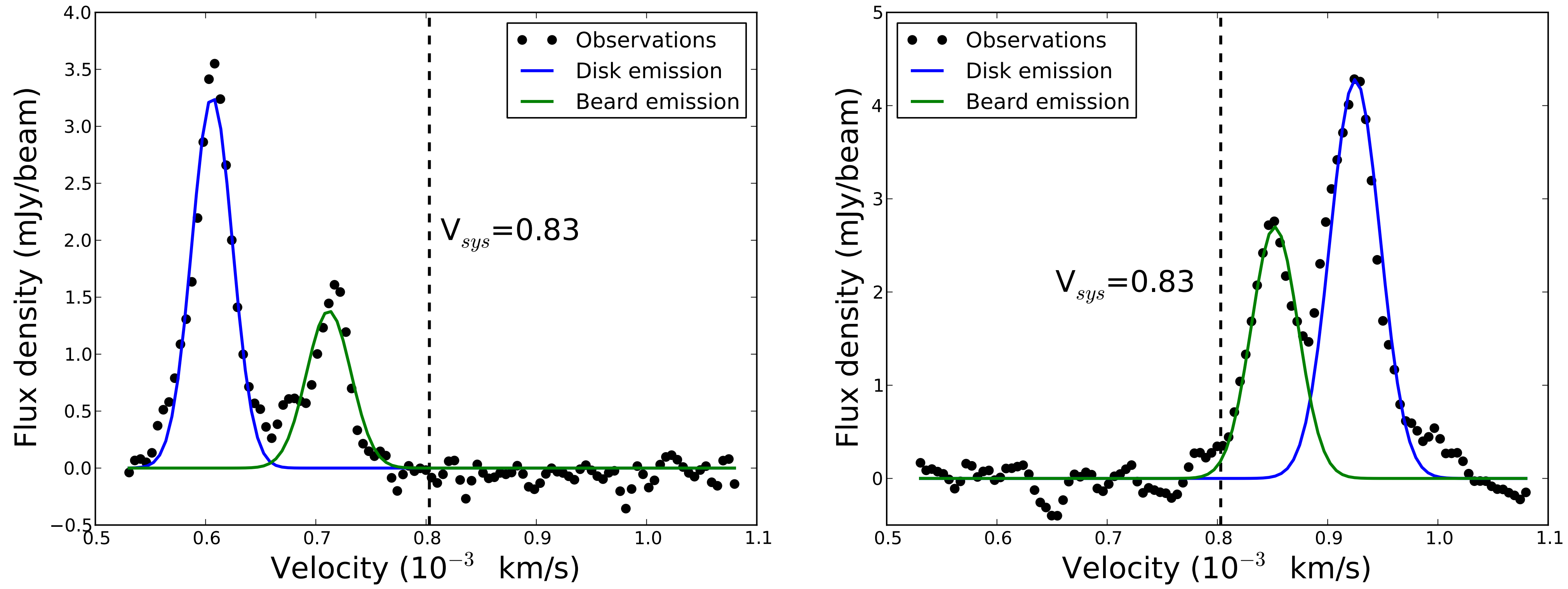

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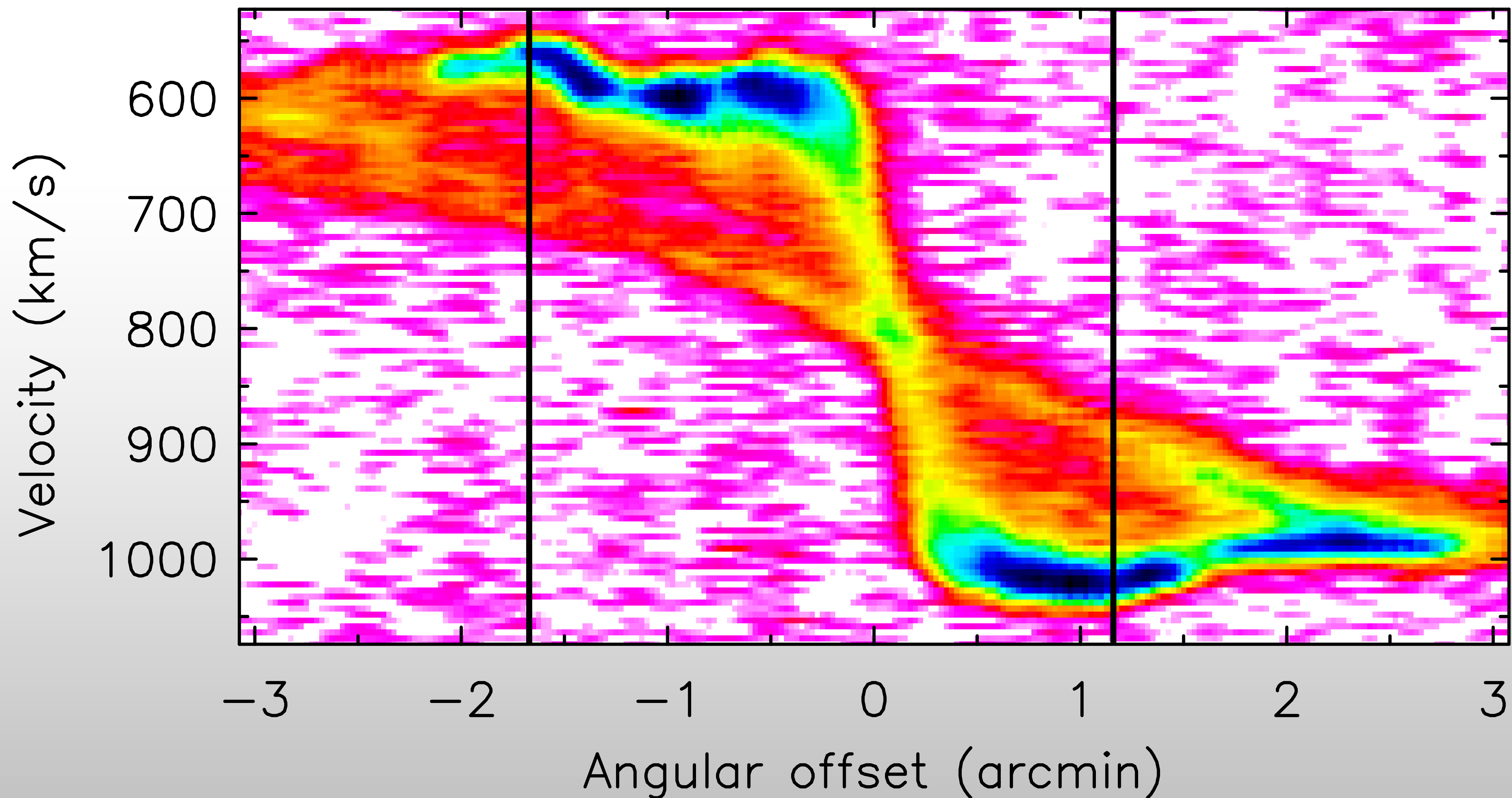

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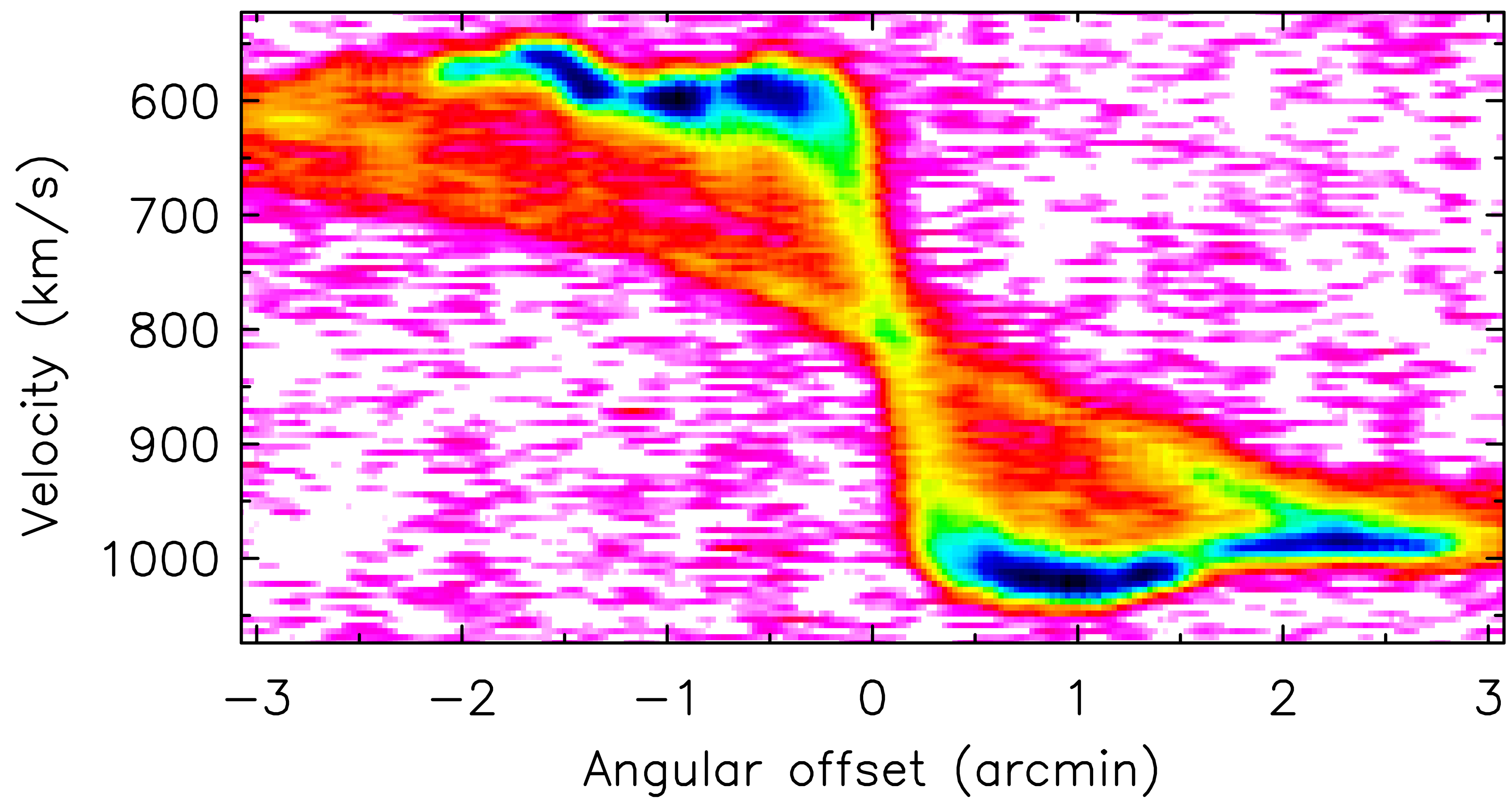

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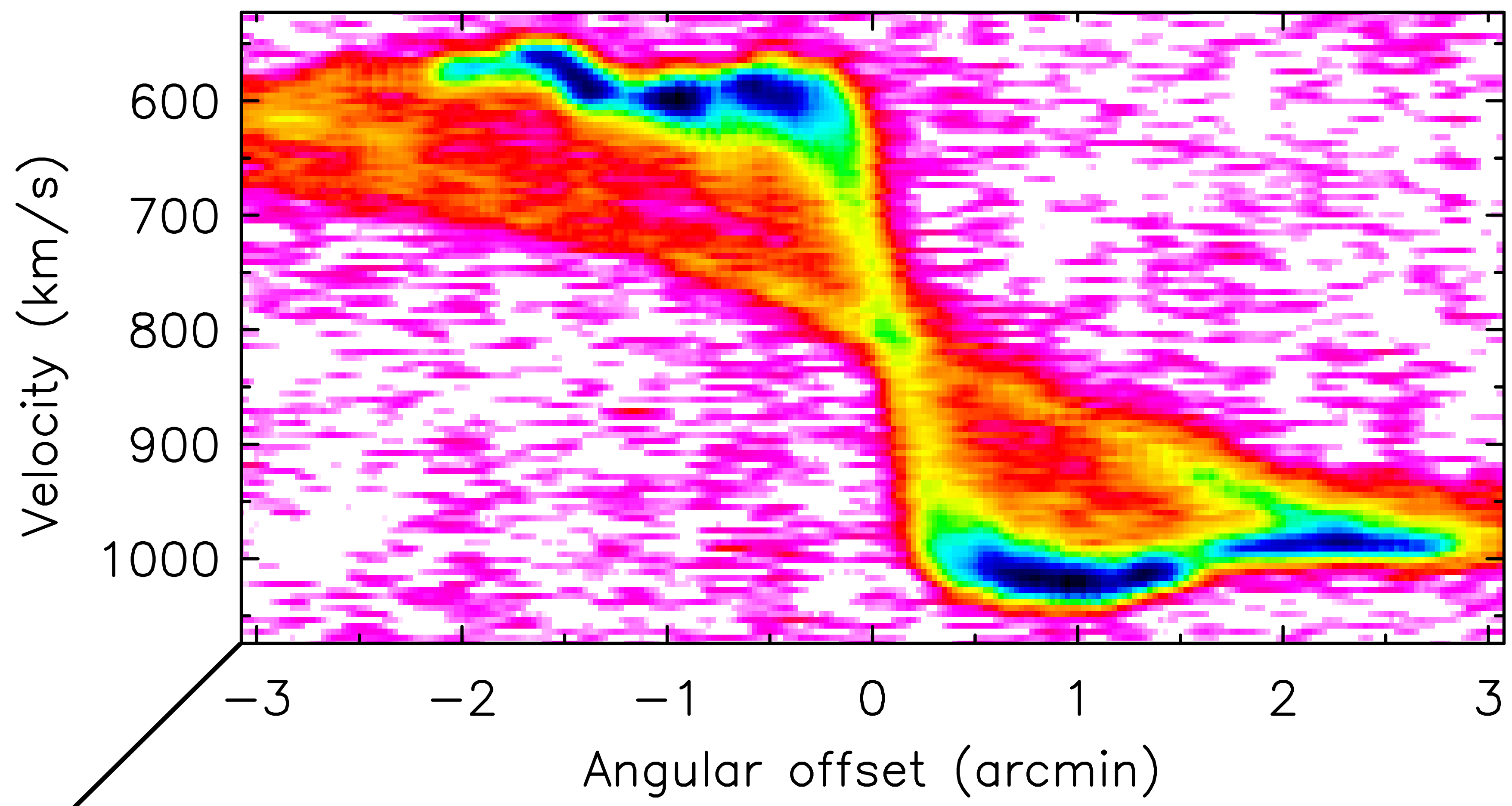
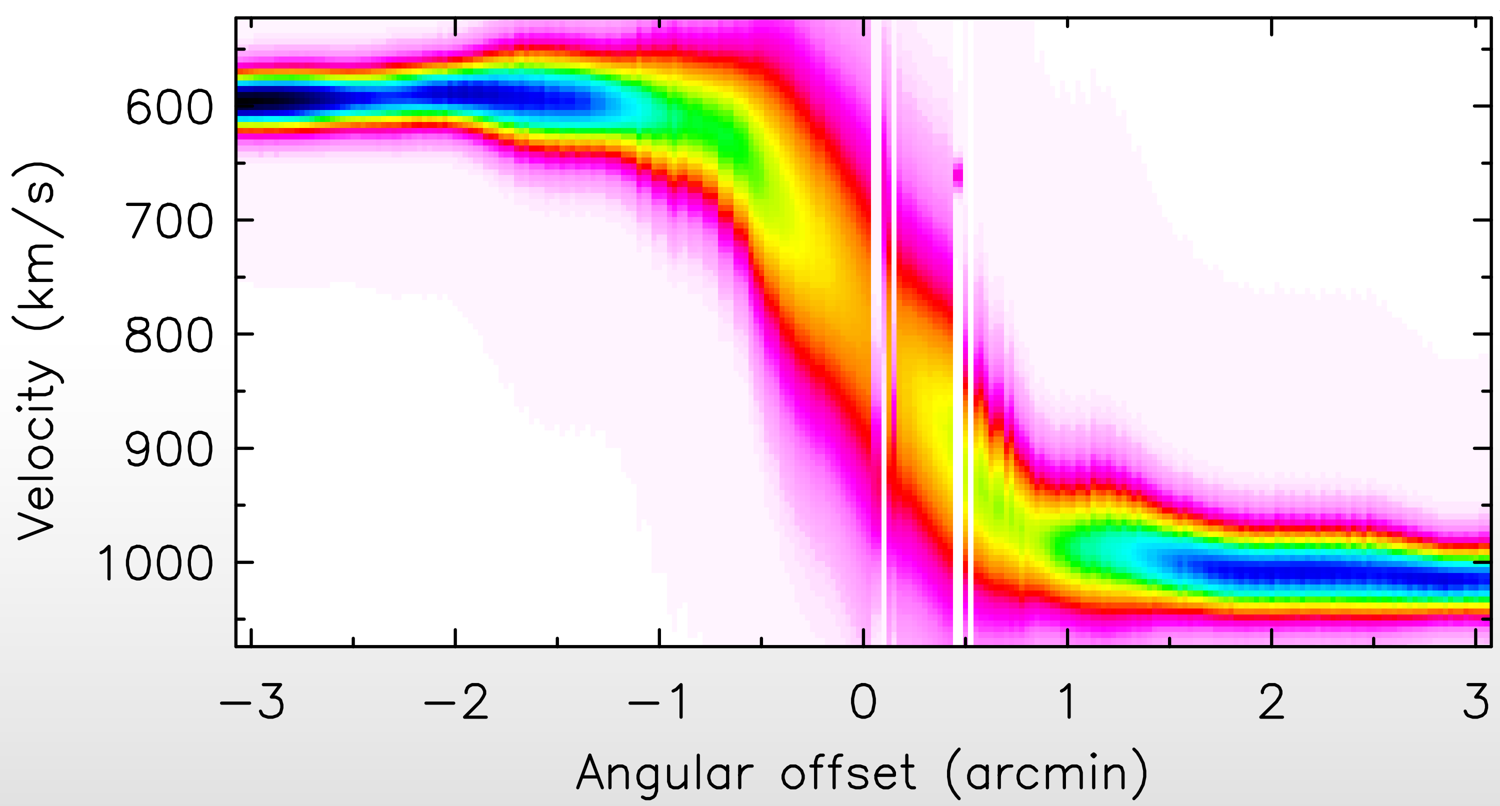


Thin disk HI component



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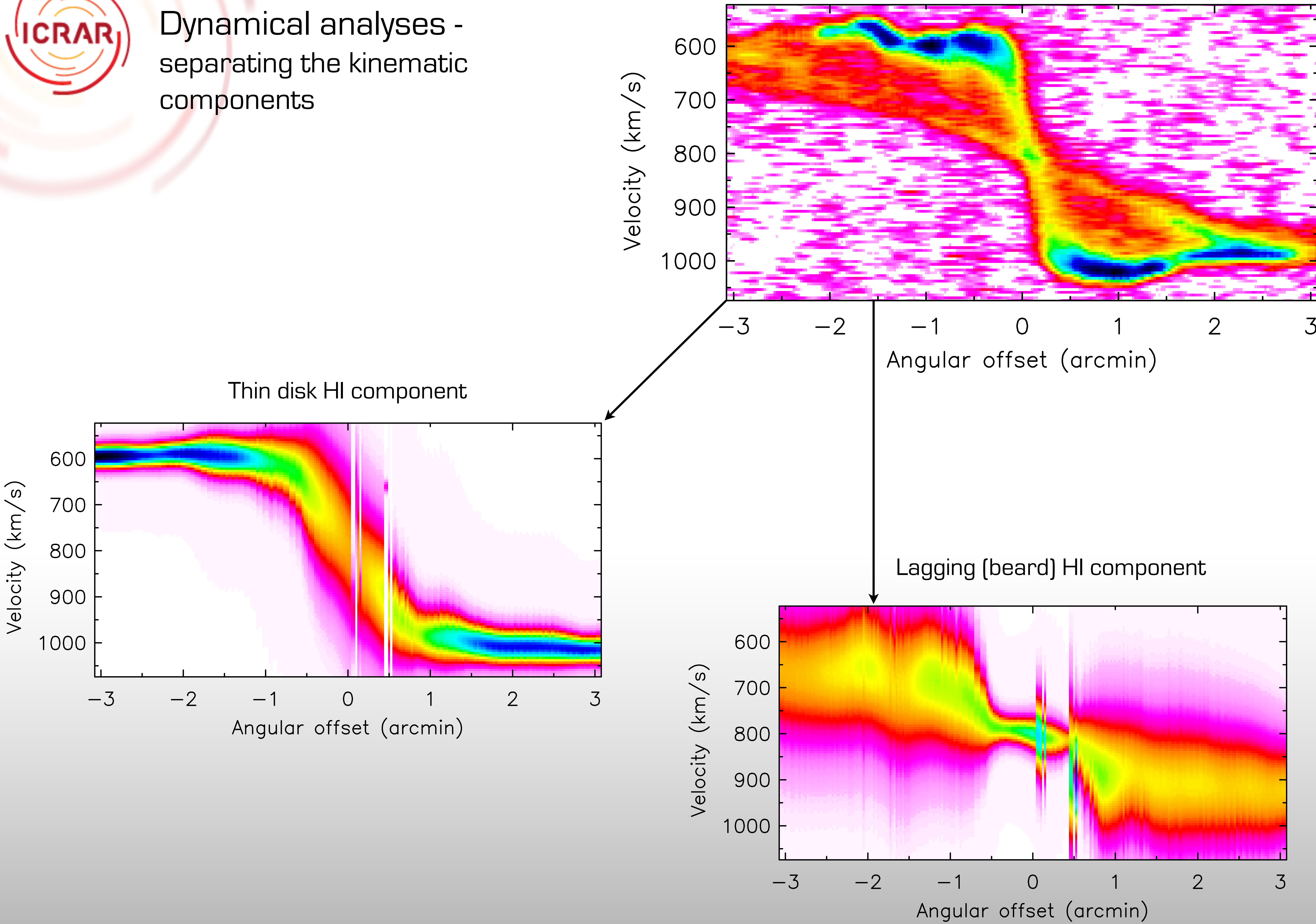
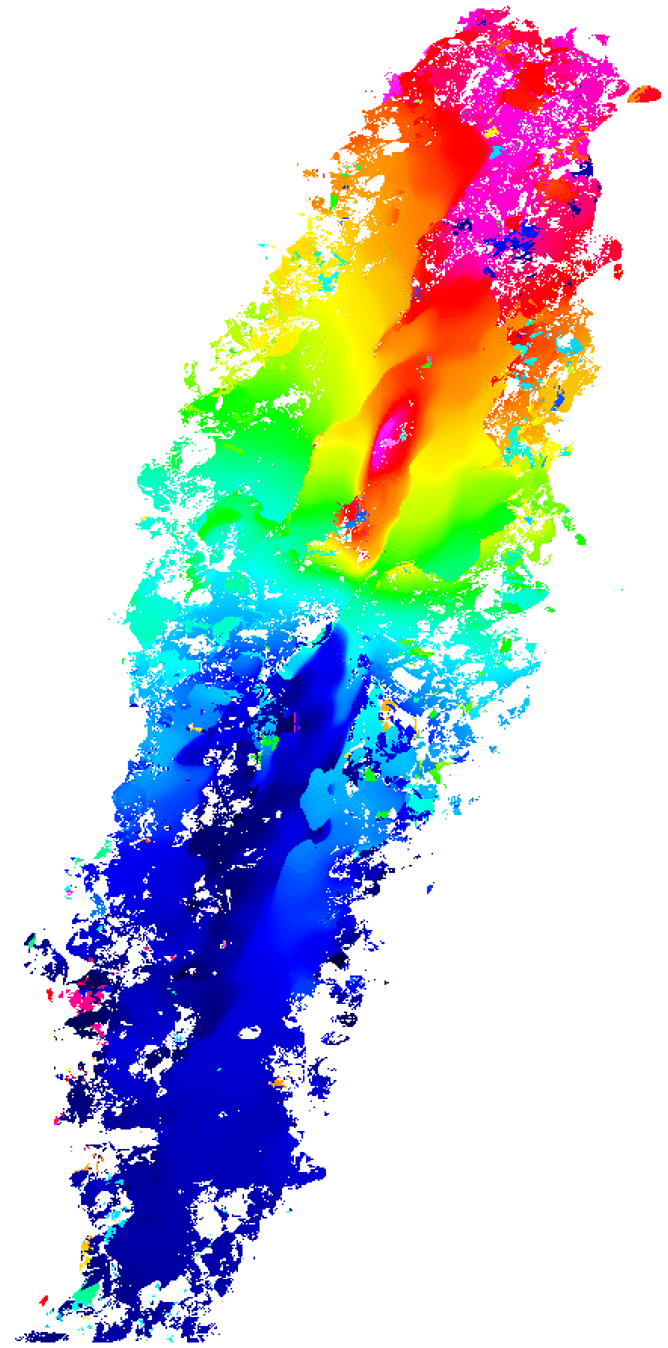
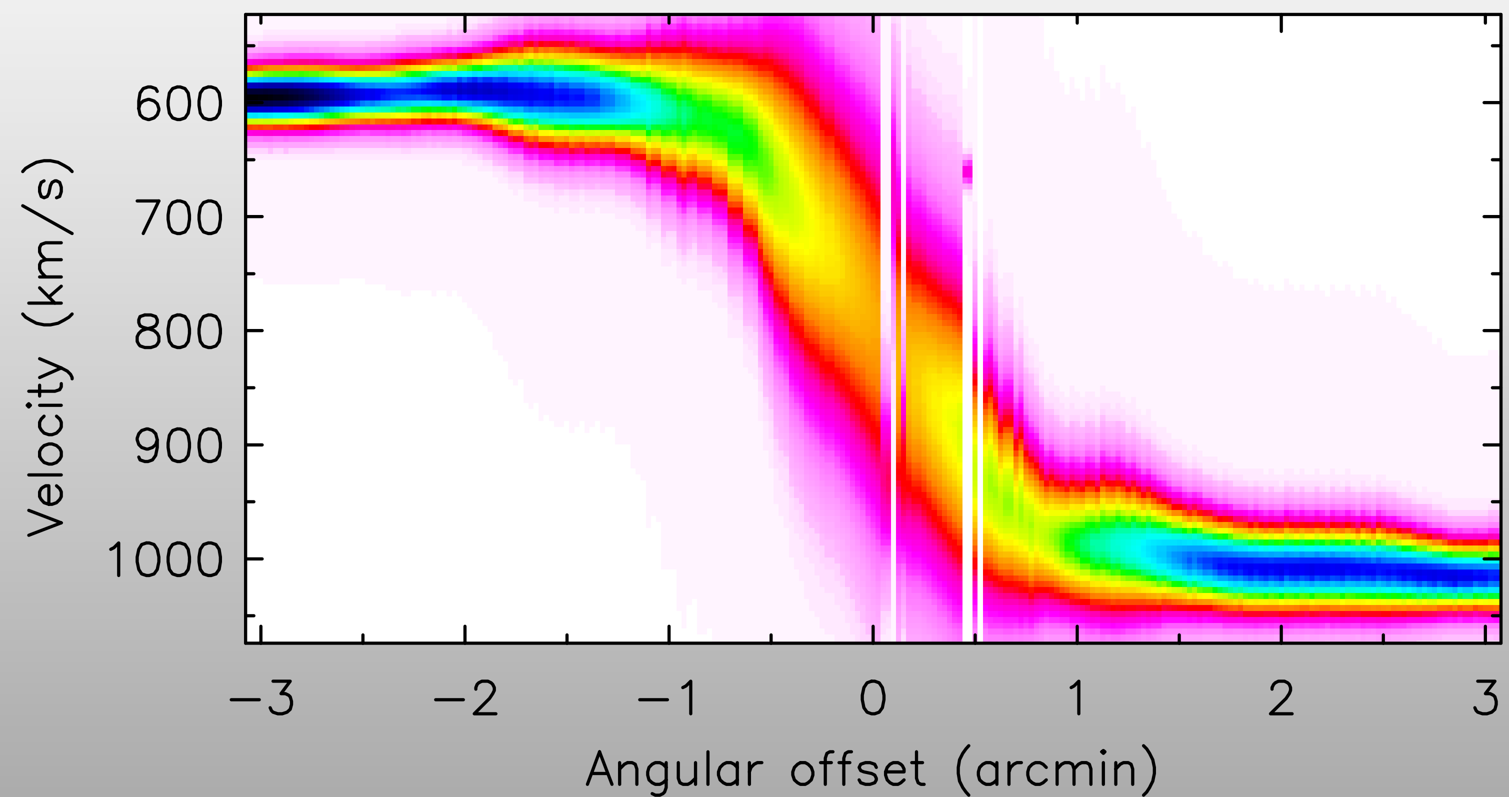


IWM vel fields



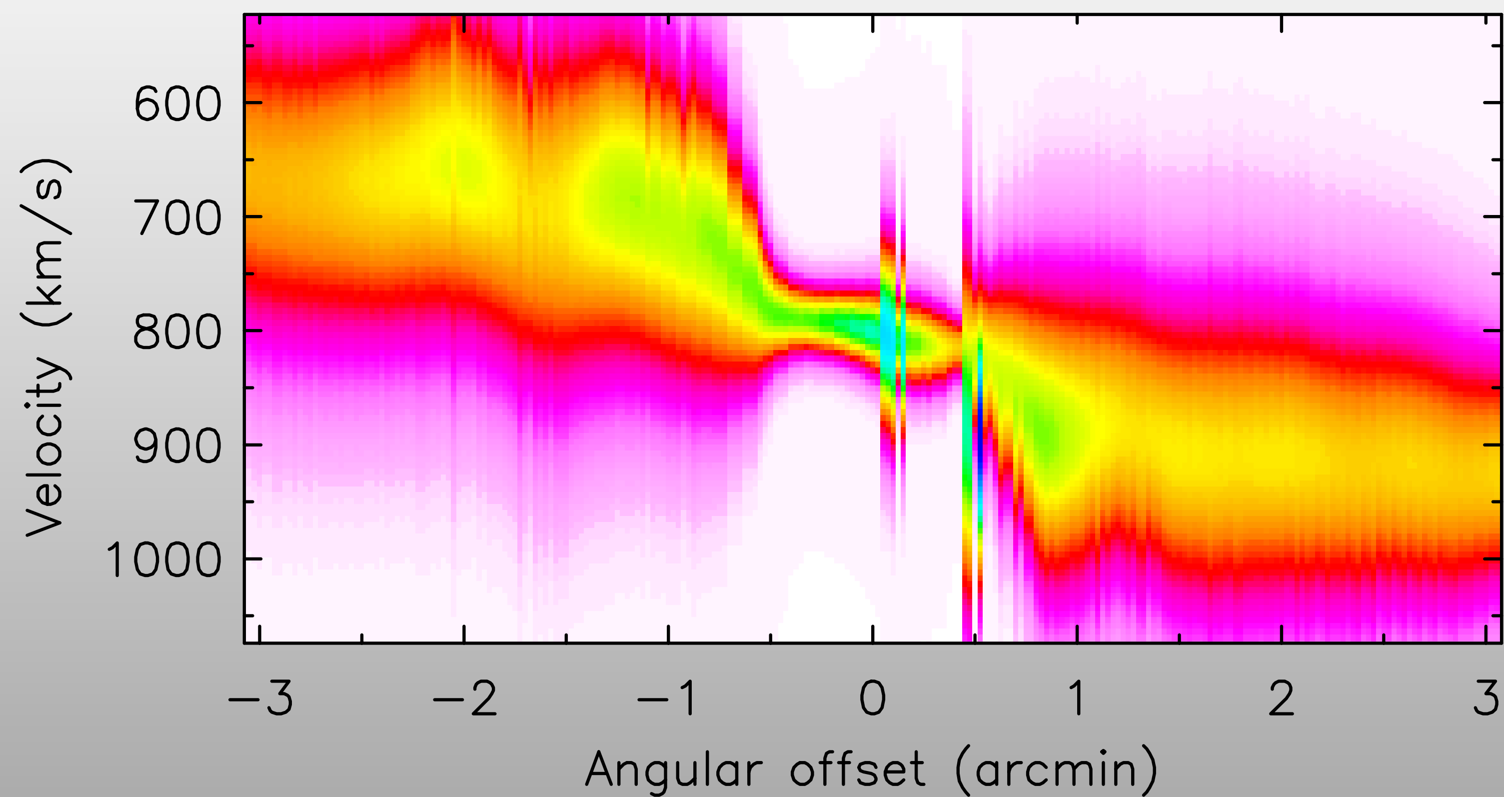
Thin disk HI component

$M_{HI} \sim 6.5 \times 10^9 M_\odot$

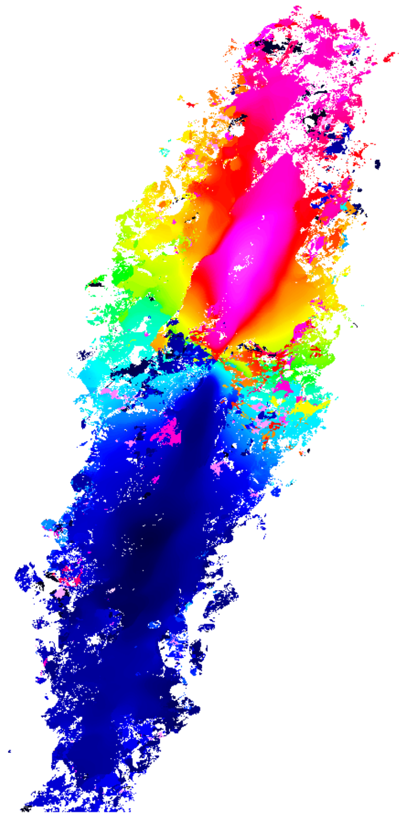


Lagging (beard) HI component

$M_{HI} \sim 1.5 \times 10^9 M_\odot$

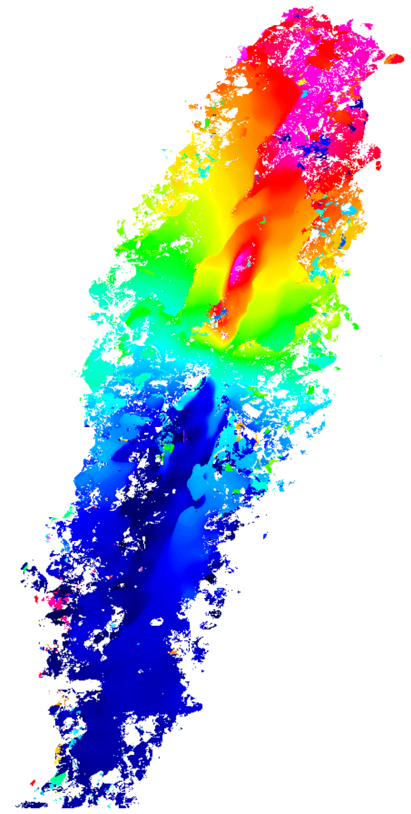


Dynamical analyses - separating the kinematic components



Thin disk HI component

IWM vel fields

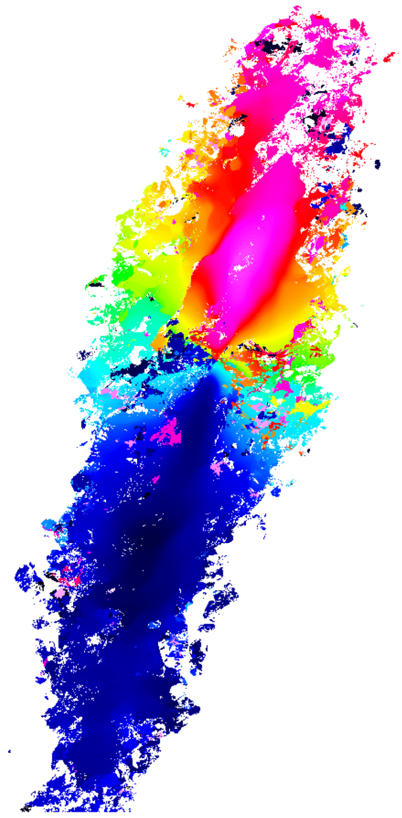


Lagging (beard) HI component

Fit tilted ring models to the HI velocity fields to extract rotation curves:

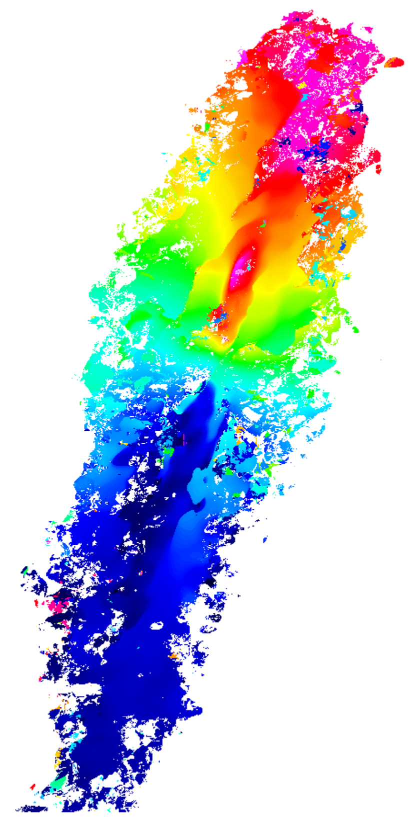
$$V_{los}(x, y) = V_{sys} + V_{rot}\sin(i)\cos(\theta)$$

Dynamical analyses -
tilted ring modeling



Thin disk HI component

IWM vel fields



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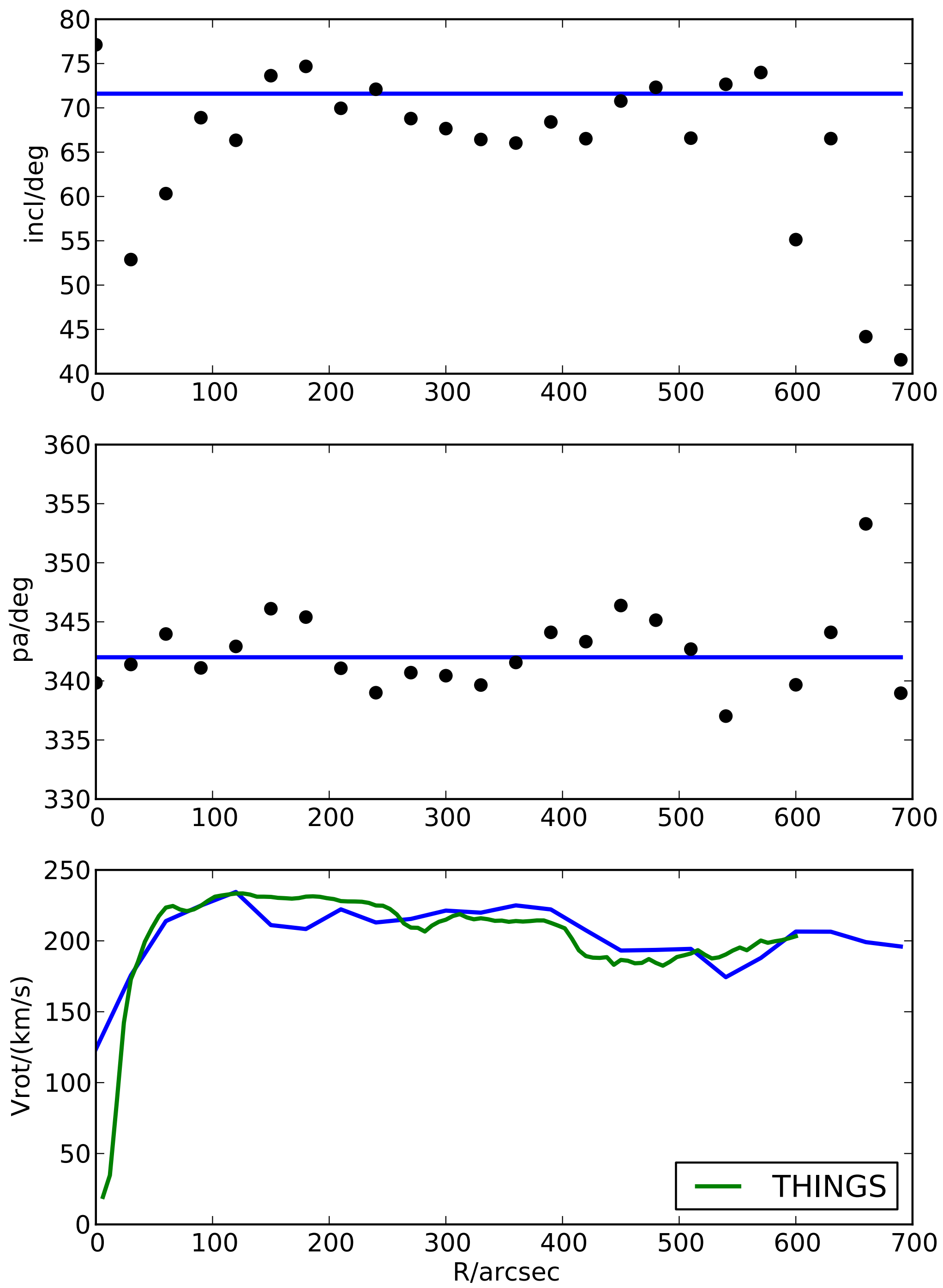
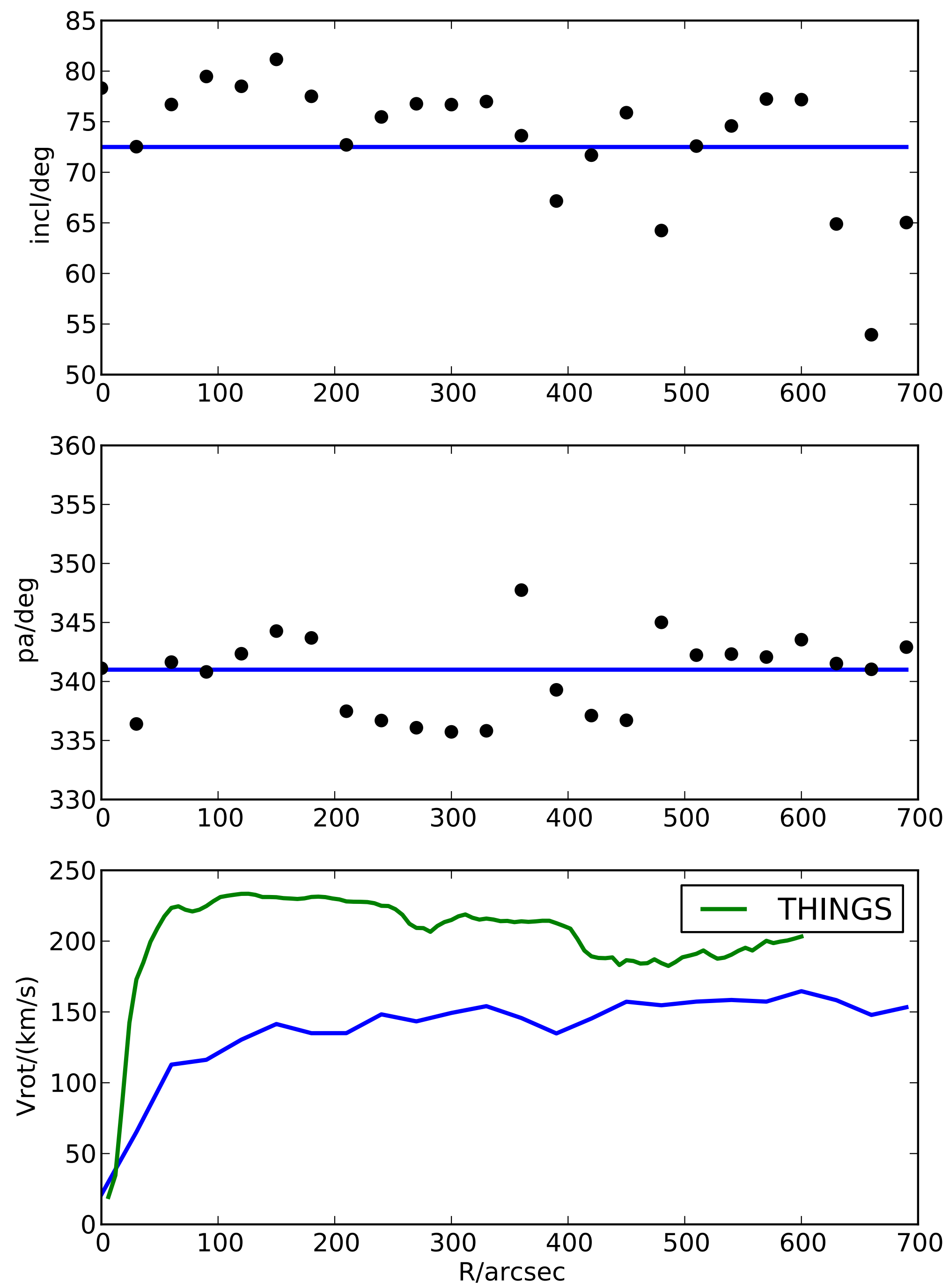
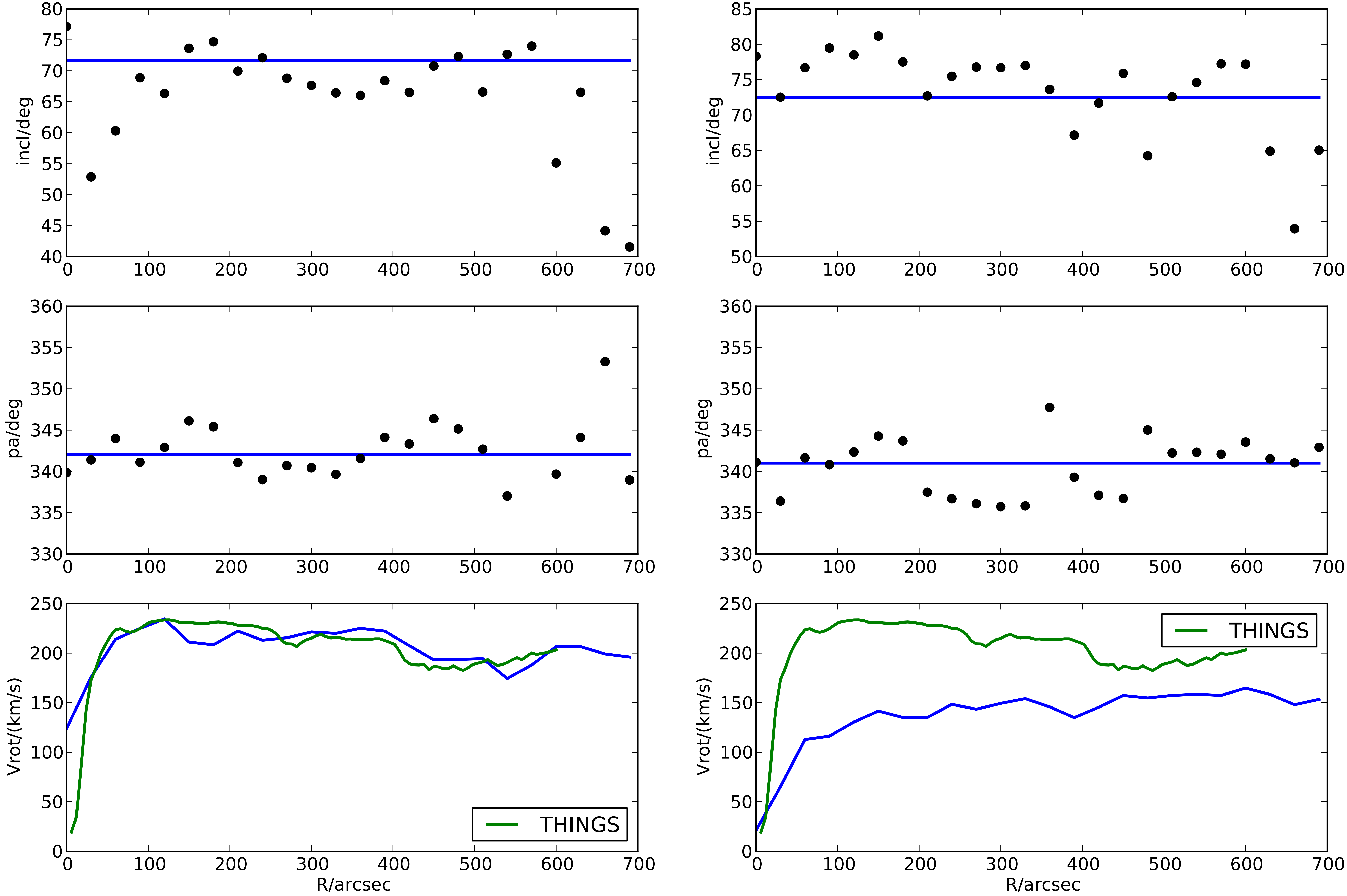




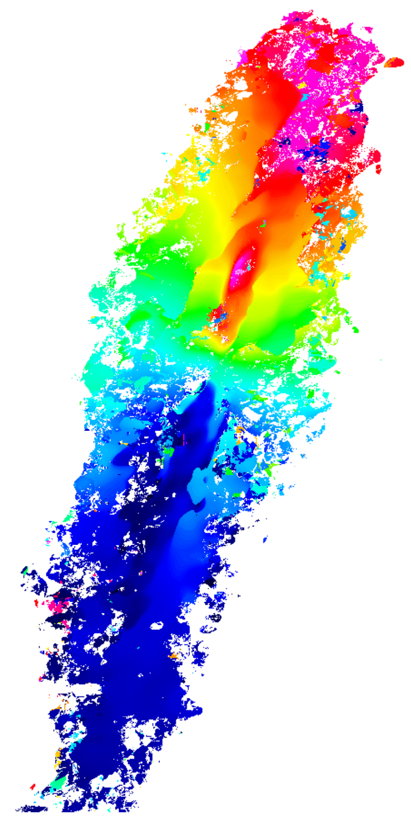


incl/deg
pa/deg
Vrot/(km/s)
R/arcsec
THINGS
THINGS

Dynamical analyses - tilted ring modeling

Thin disk HI component

IWM vel fields



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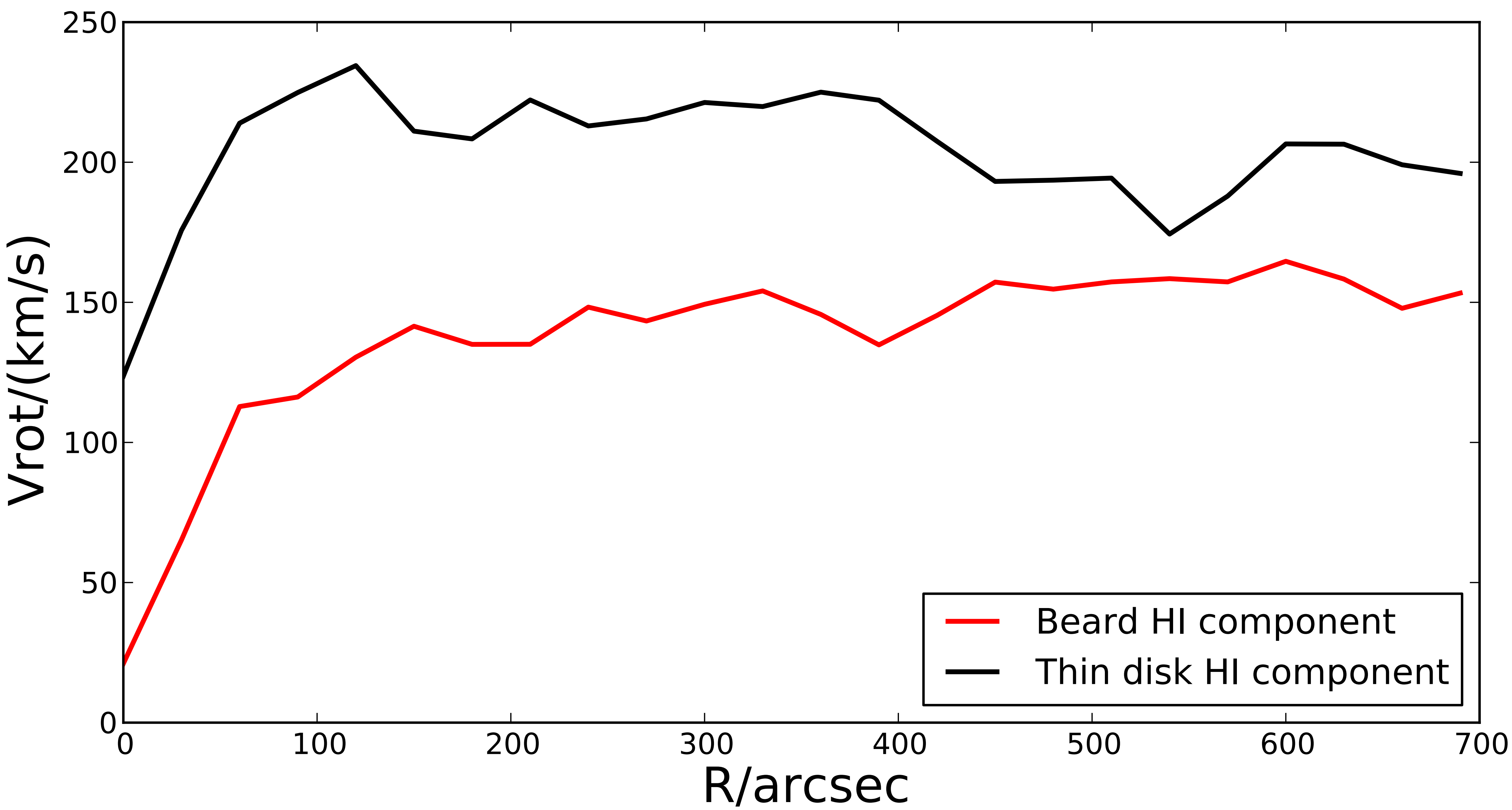

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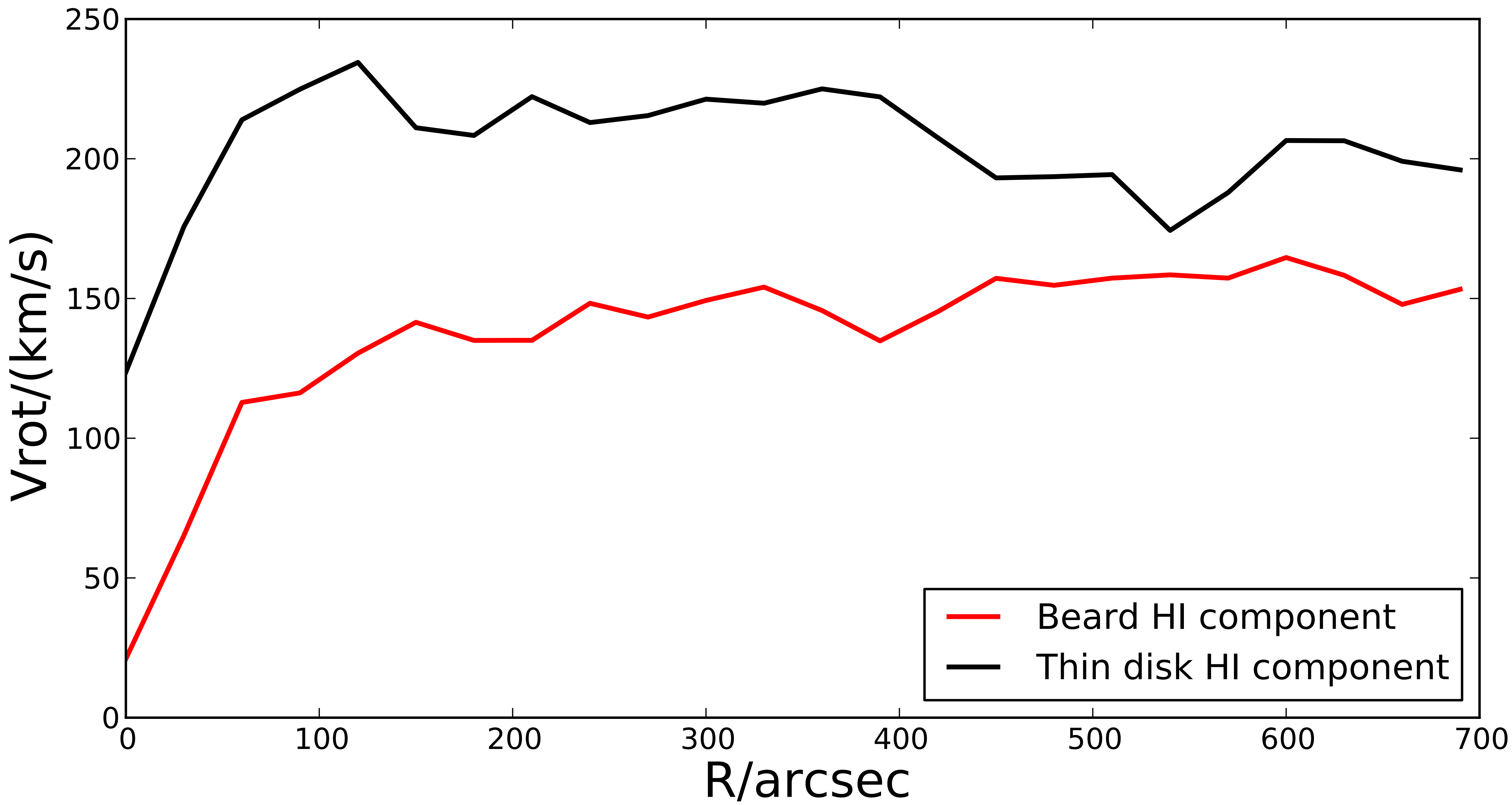
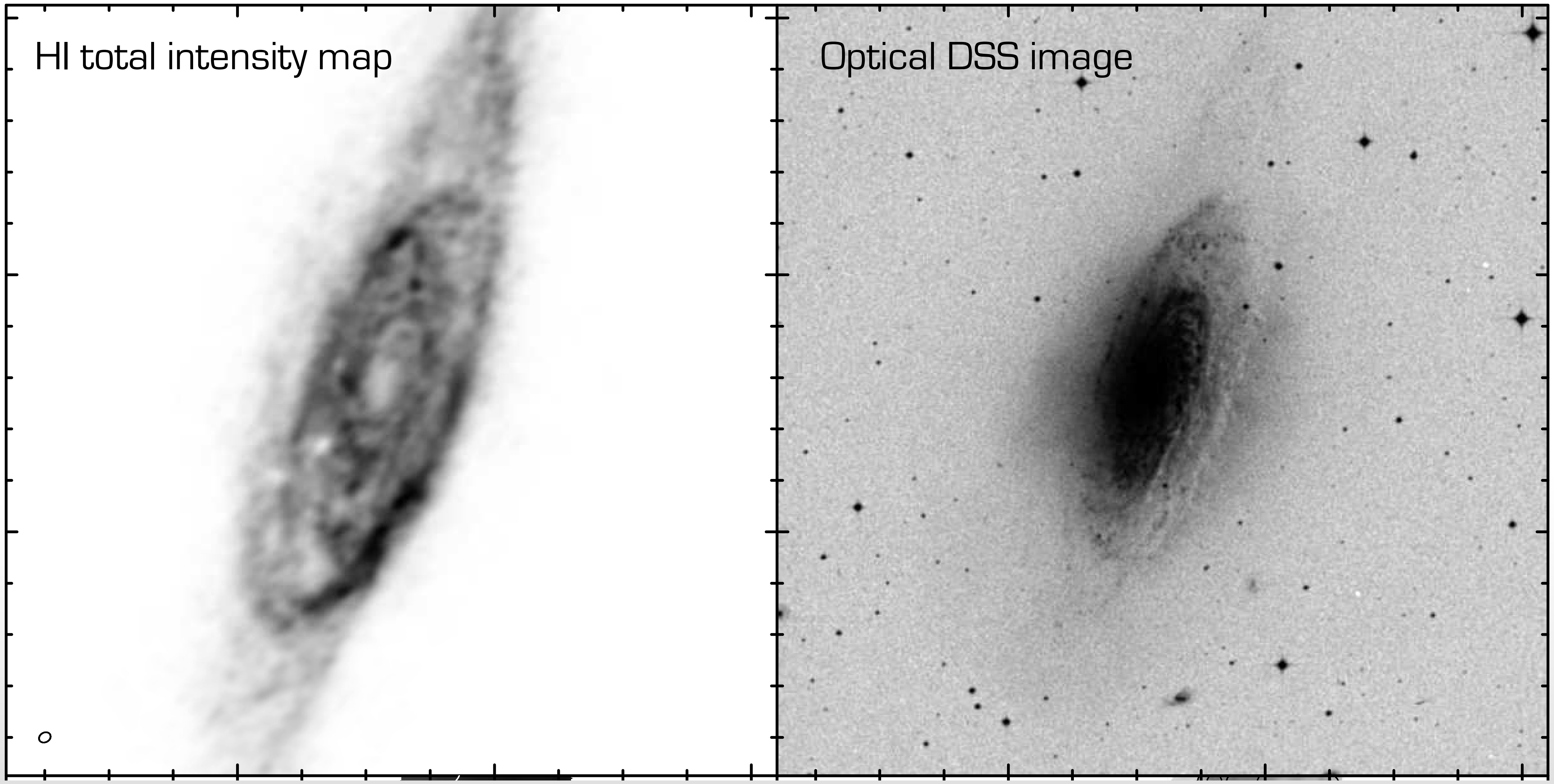


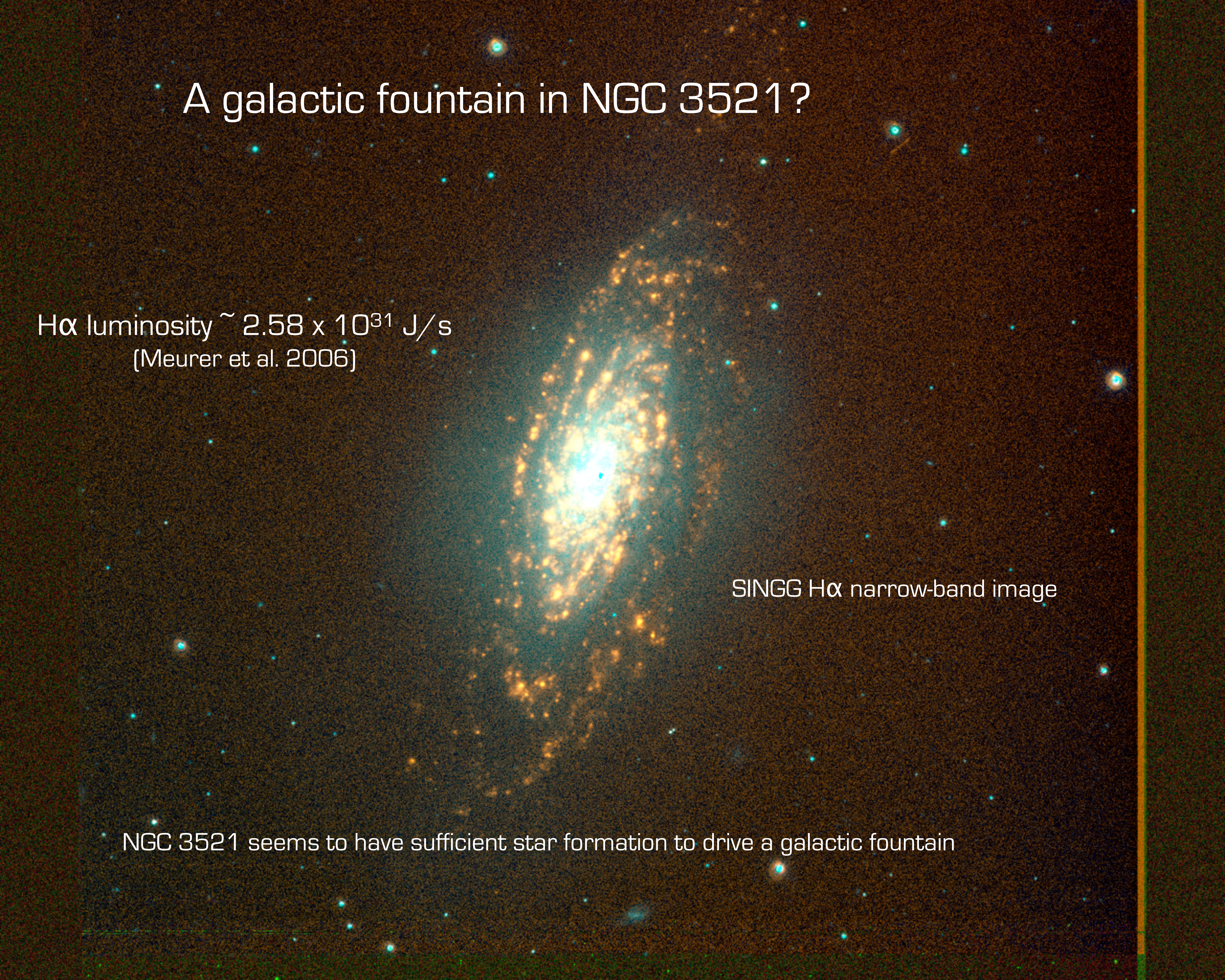
Anomalous gas rotates ~50 - 75 km/s slower than thin HI disk

Could the slow-rotating beard emission be distributed in a thick HI layer?

A galactic fountain in NGC 3521?



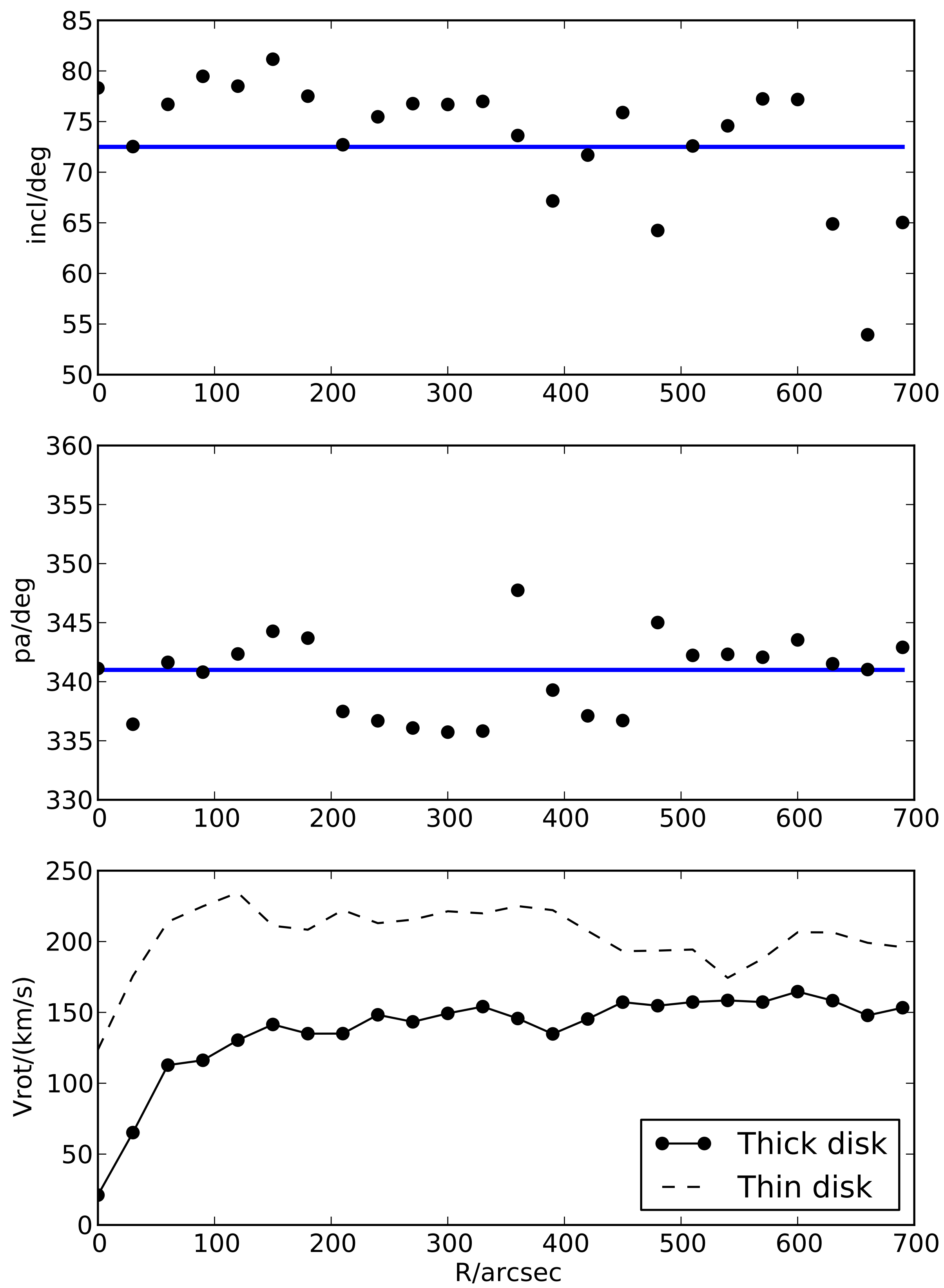
Walter et al. (2008)


A galactic fountain in NGC 3521?
Hα luminosity ~ 2.58 x 10^31 J/s
(Meurer et al. 2006)
SINGG Hα narrow-band image
NGC 3521 seems to have sufficient star formation to drive a galactic fountain

3D modeling of 2-component structures

- Generate separate 3D models of thin & thick disks
- Add thick & thin structures together to form a 2-component model

TR model of 2D HI vel field, used as input for 3D model of HI cube



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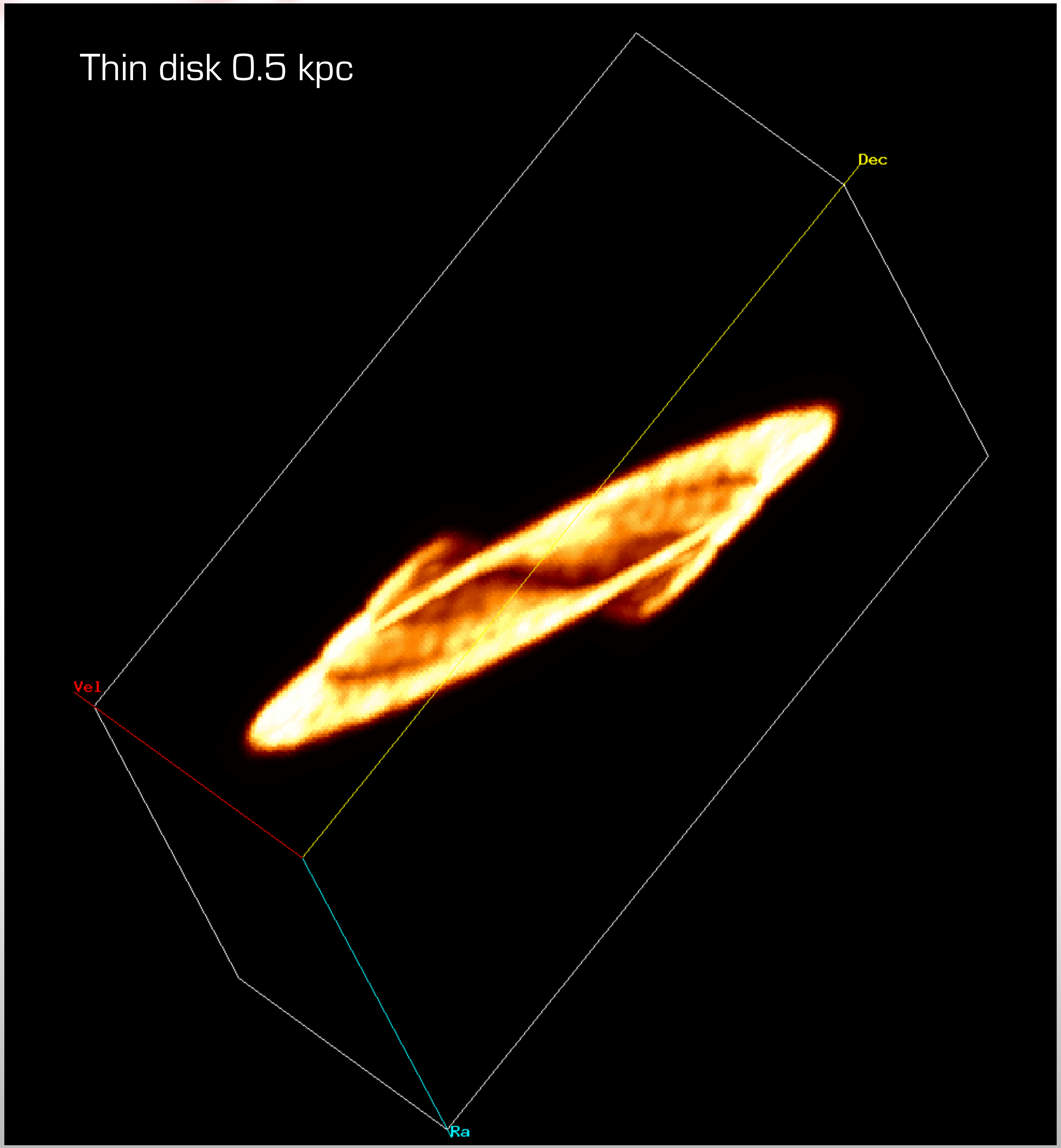

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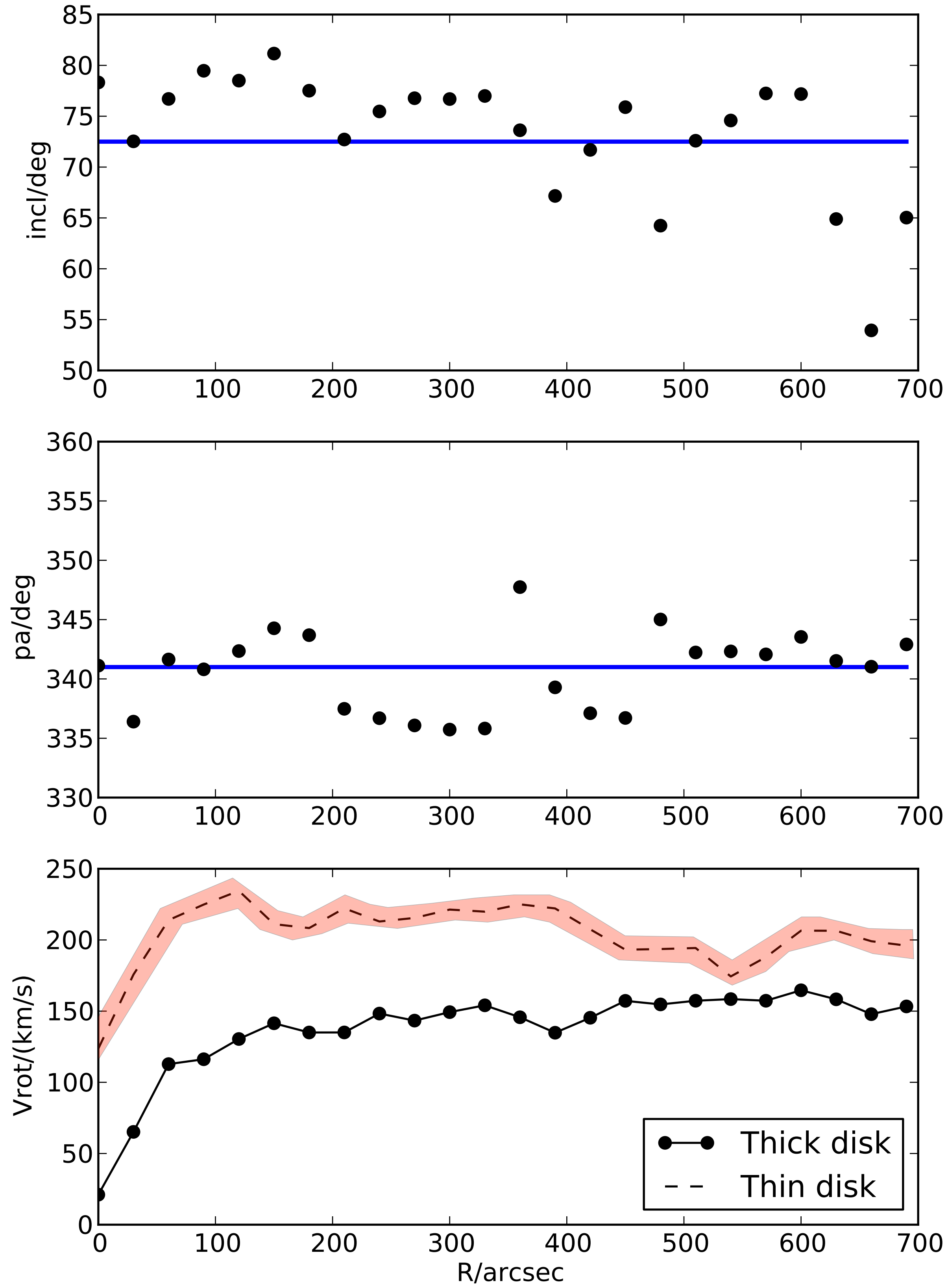
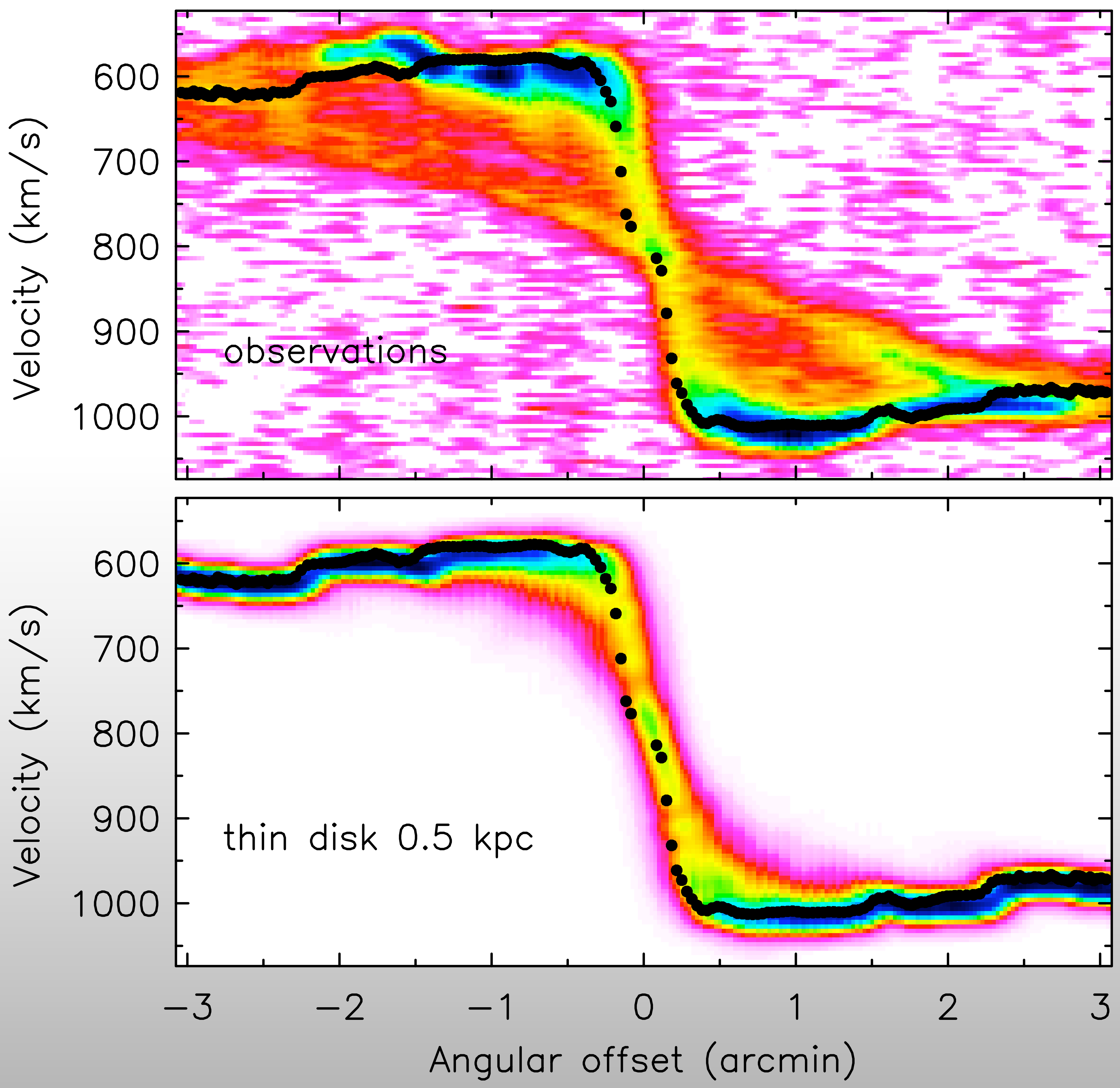


3D modeling of 2-component structures

Thin rotating disk (1 component)



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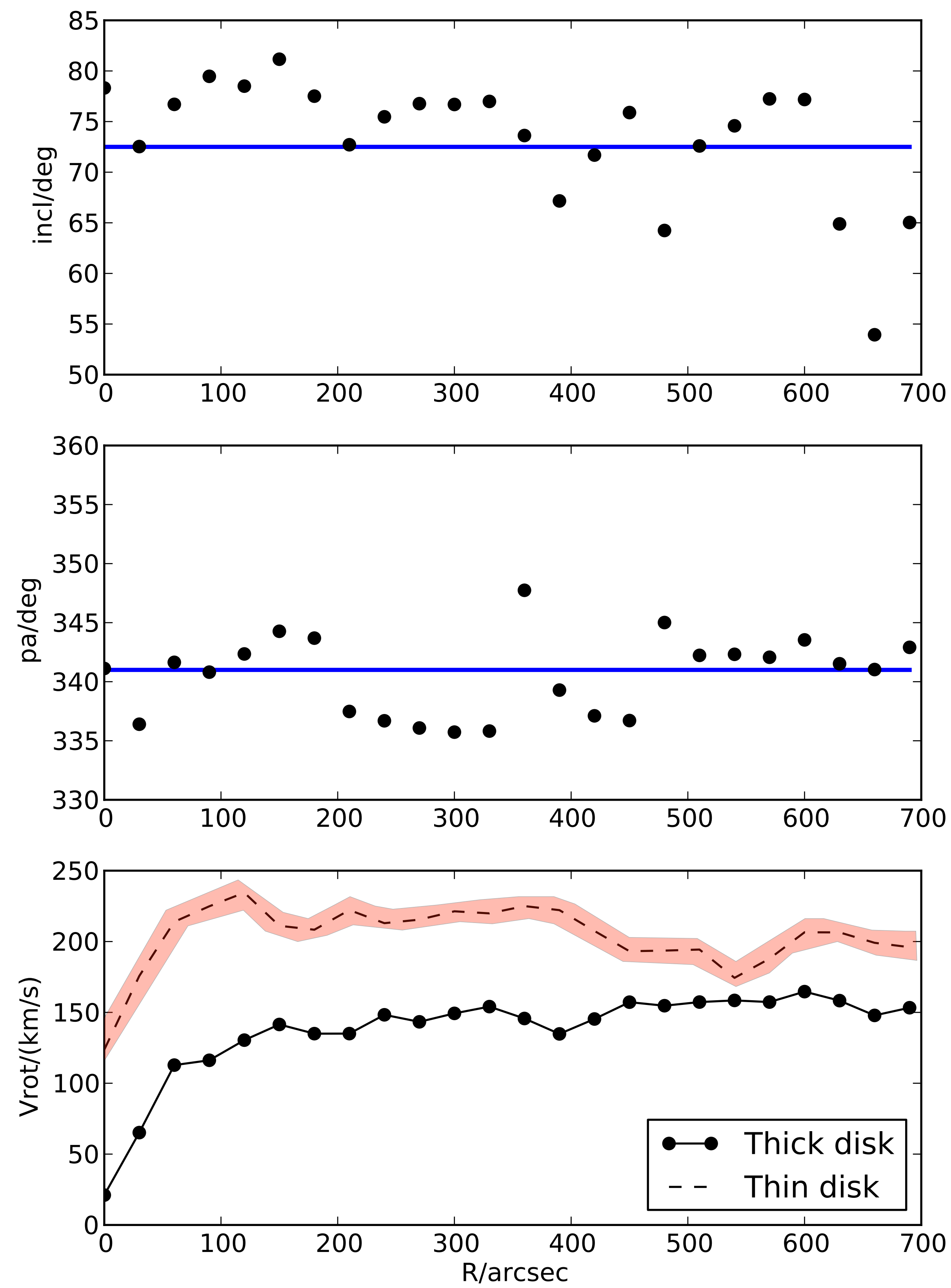

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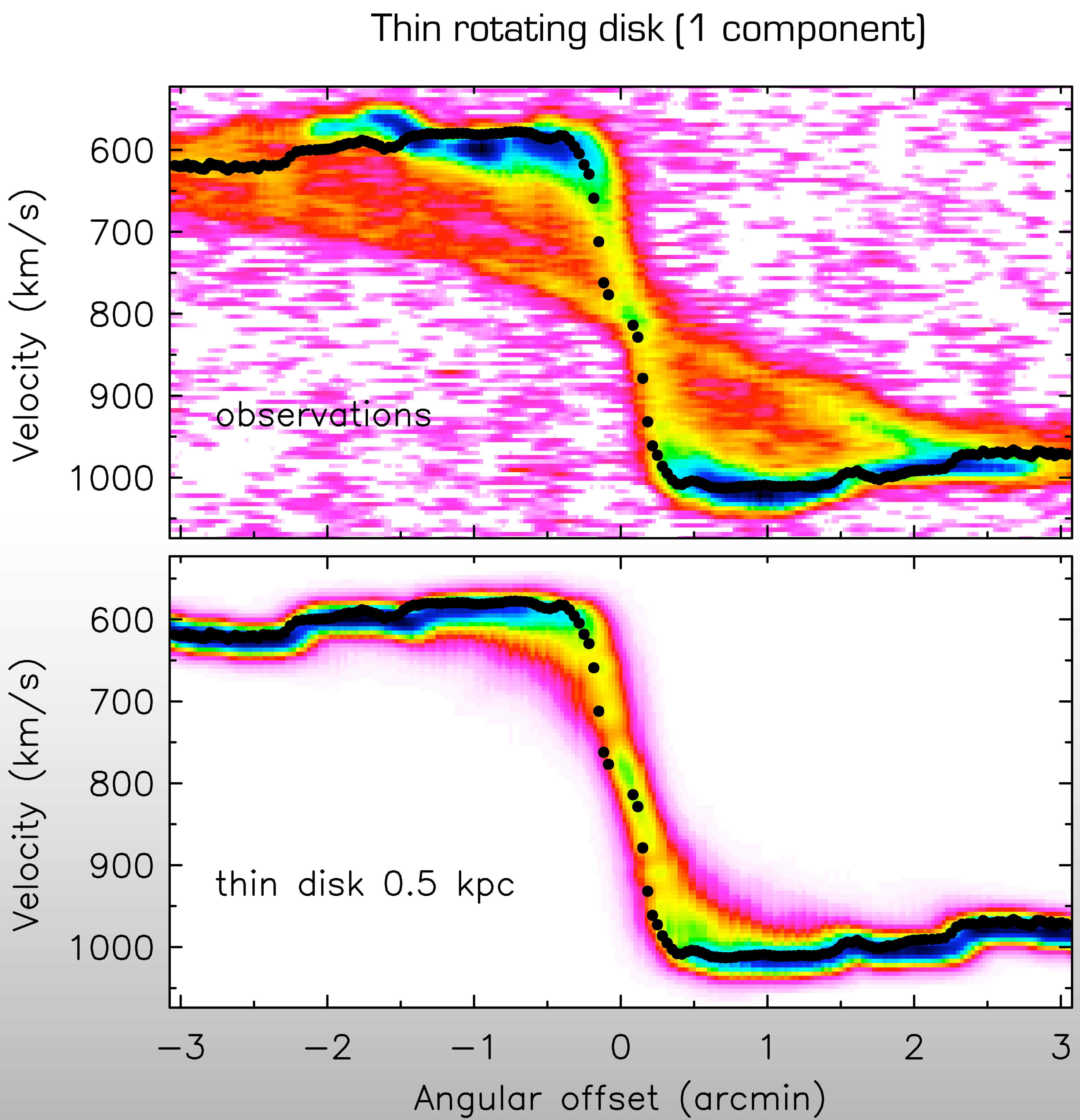

- A thin disk model alone cannot reproduce the observed asymmetric line profiles
- Combine thin disk model with thick disk models

3D modeling of 2-component structures

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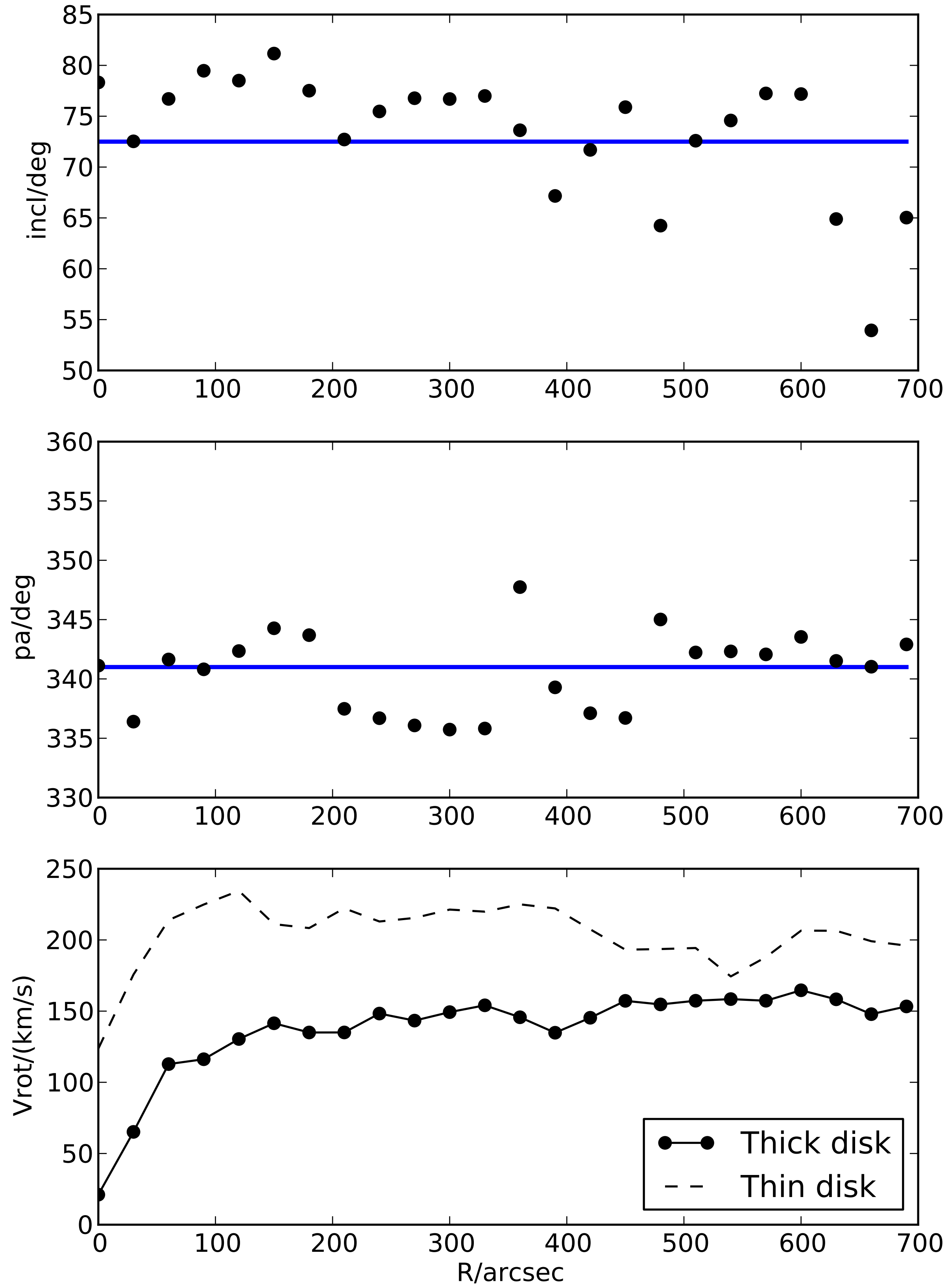
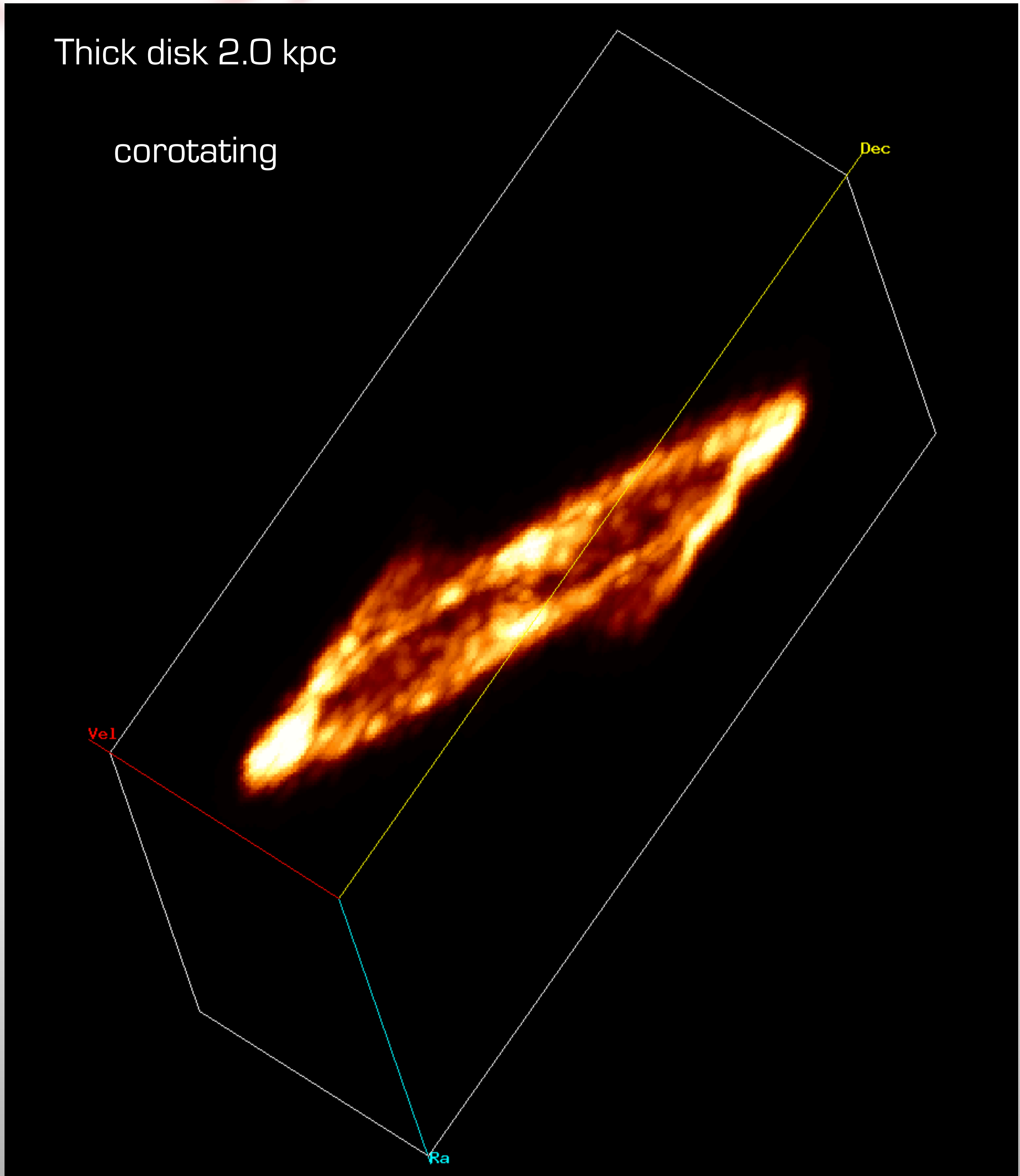


- Thick disk models:
  - Use same inputs as for thin disk model, but use larger FWHM for vertical Gaussian density profile
  - Thick disk HI mass = 1/5 thin disk HI mass
  - Add to thin disk model to generate 2-component galaxy model

3D modeling of 2-component structures



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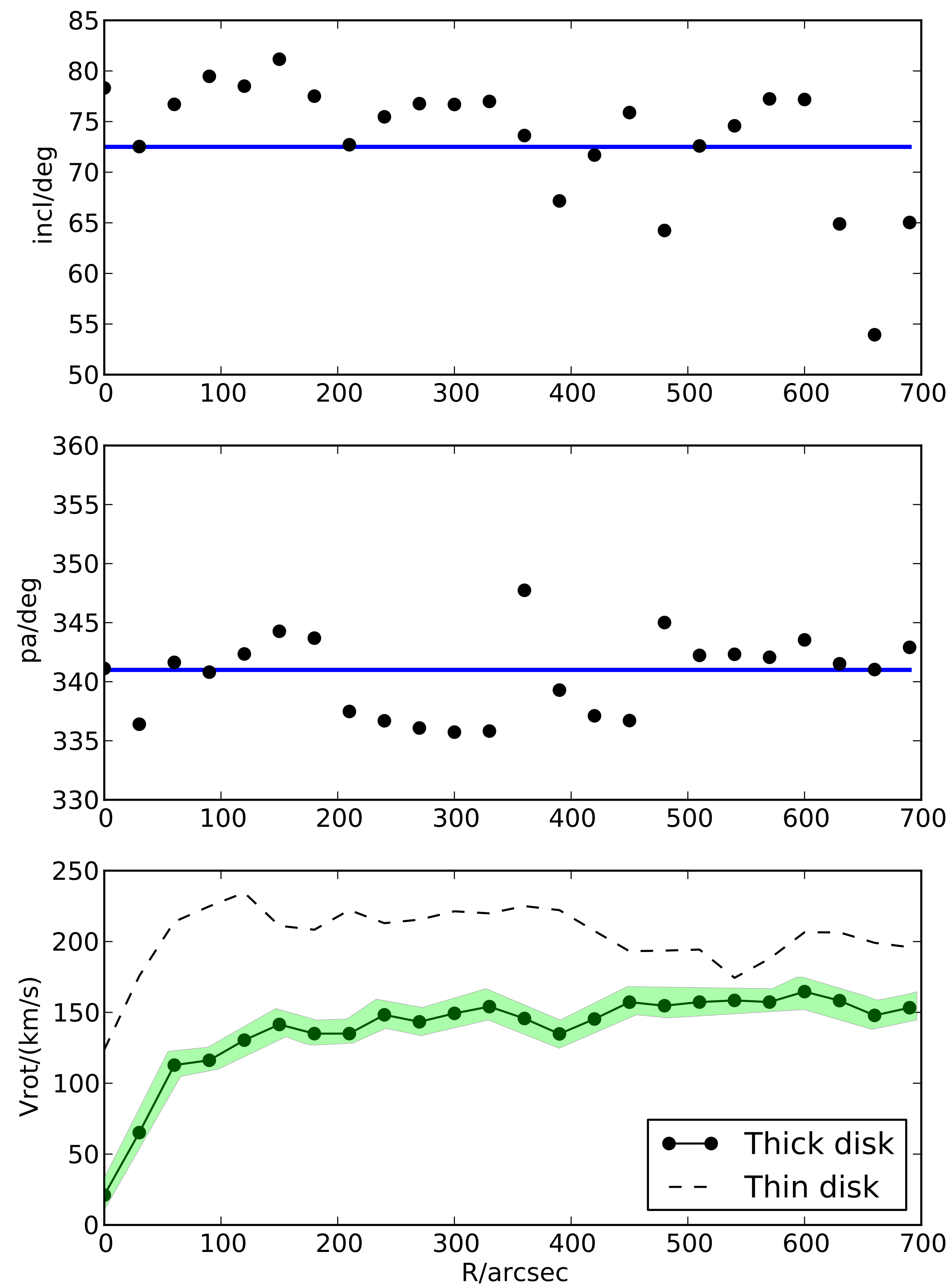

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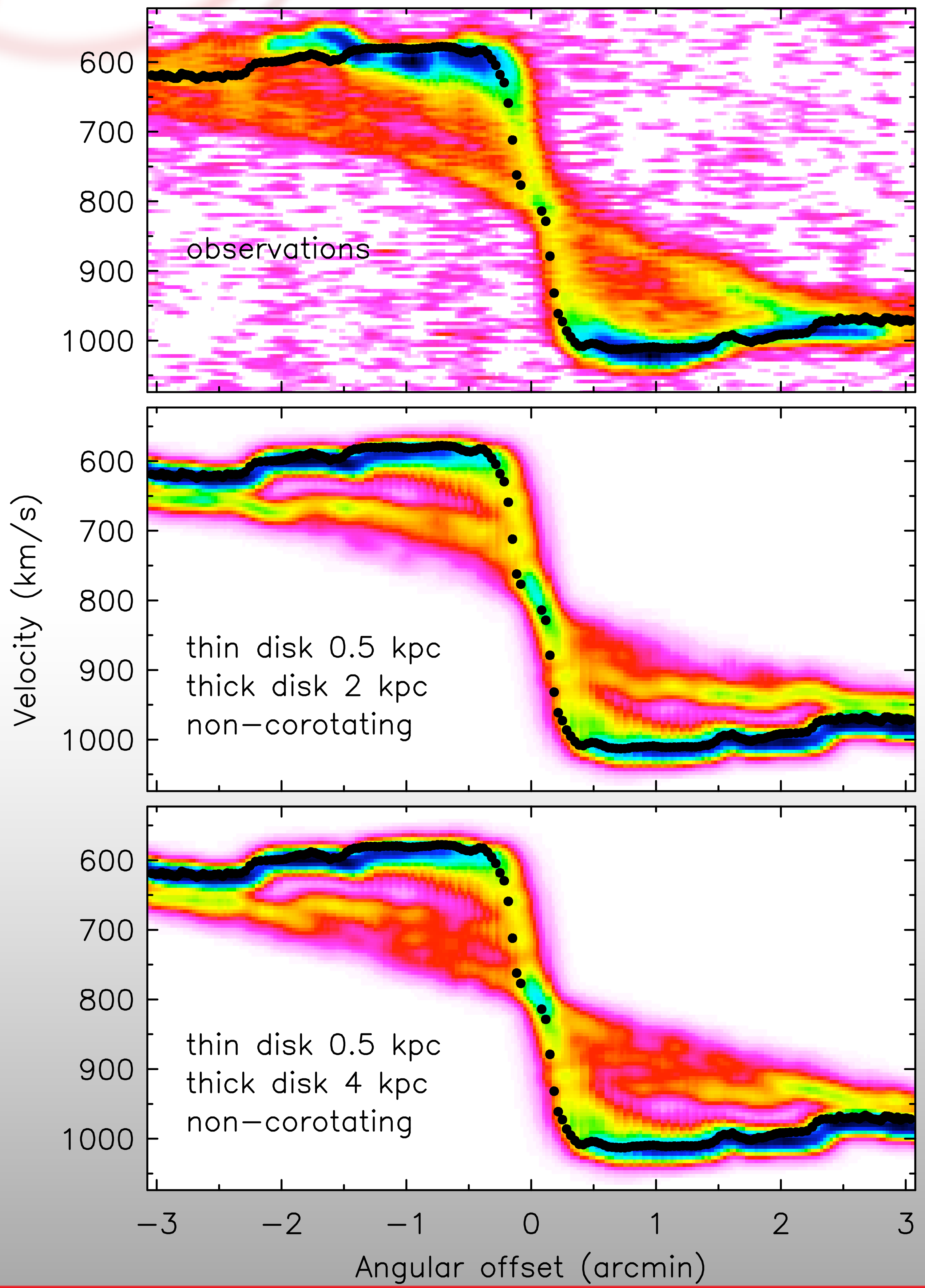

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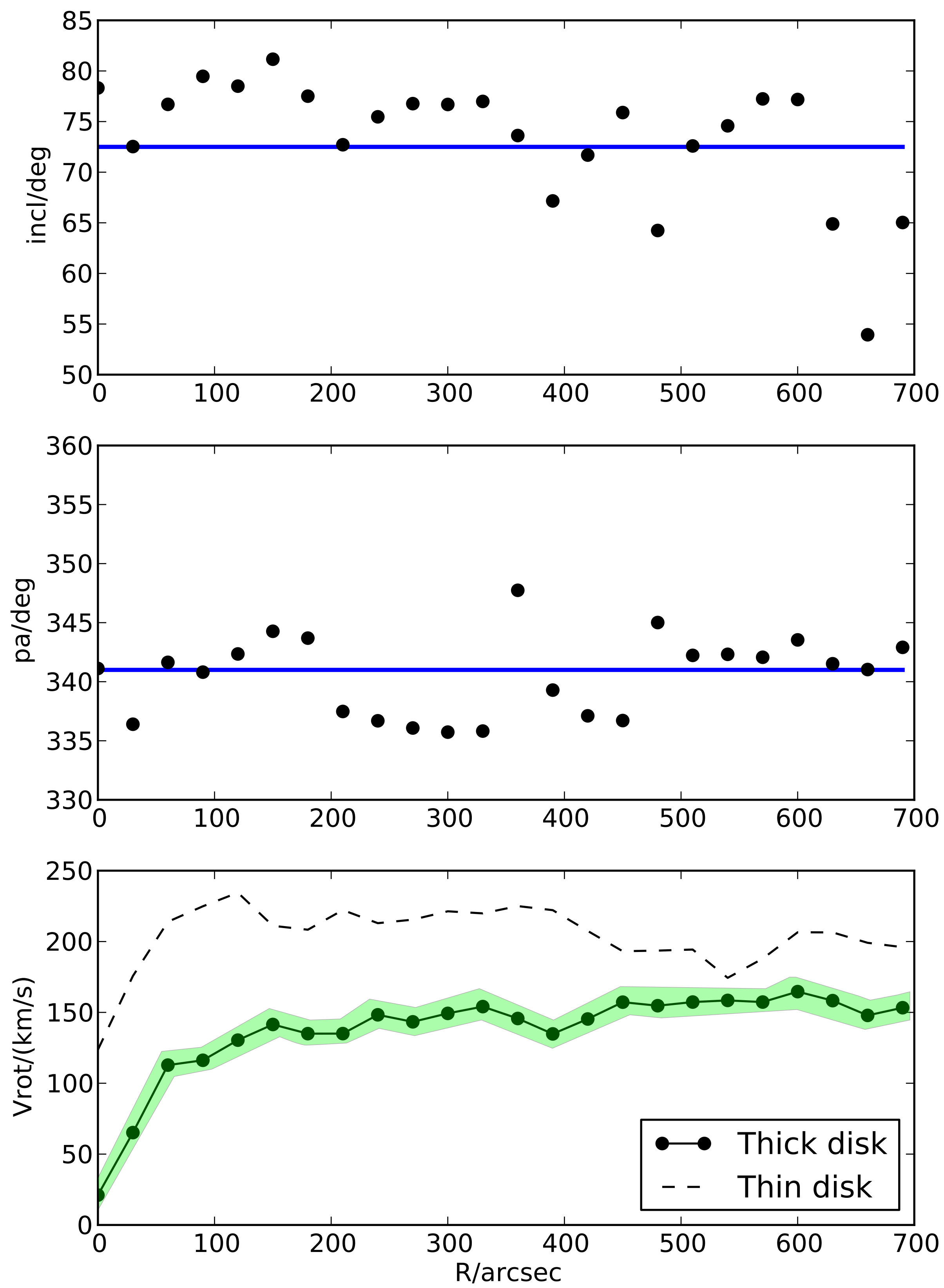
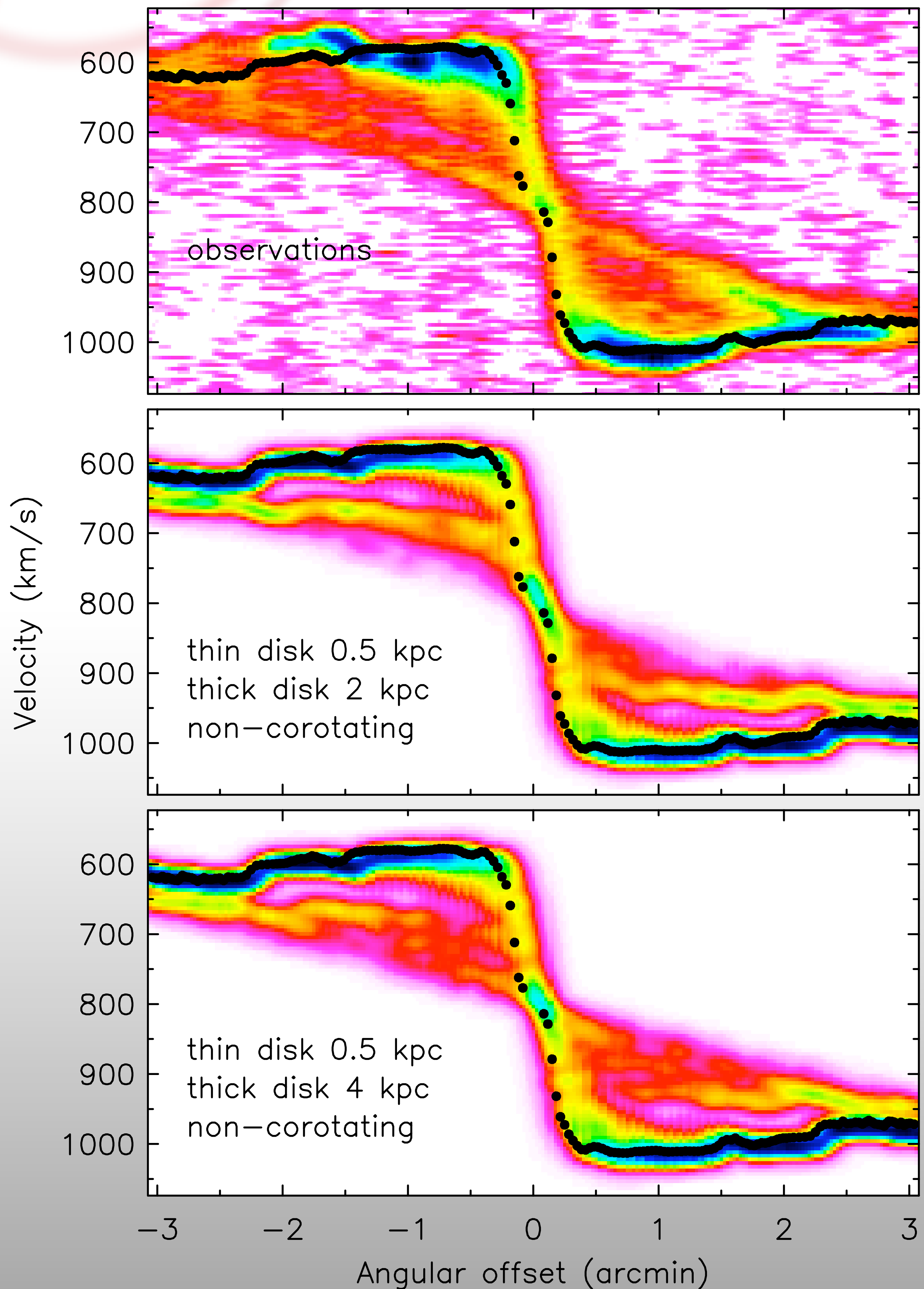


3D modeling of 2-component structures



- Observations are consistent with a **slow-rotating thick** (2 - 4 kpc) HI layer of lower density

Conclusions

- Star formation can displace disk gas into the halo
- HI observations of NGC 3521 provide evidence of a slow-rotating gas component
- Modeling suggests the beard emission to be lagging the thin disk HI by

~ 50 - 75 km/s

- High mass SF in NGC 3521 should be enough to drive a galactic fountain
- ~ 20 % of NGC 3521's HI may be extra-planar and slow-rotating