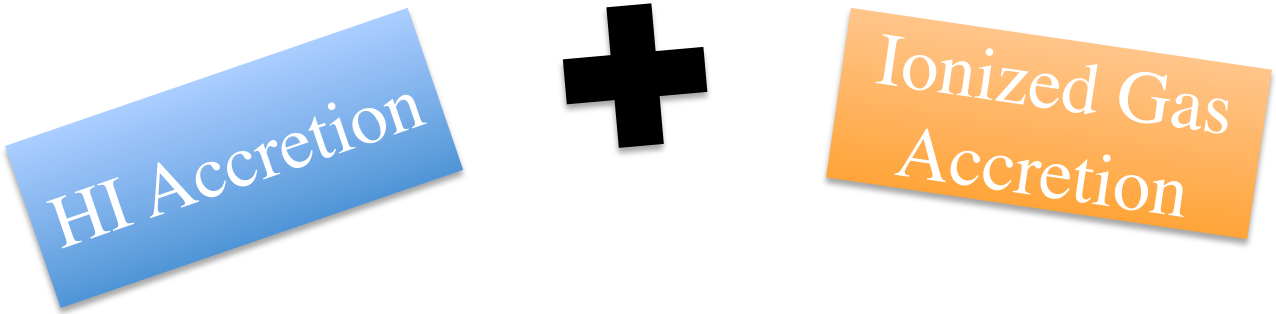
Evidence of Gas Accretion at the Disk-halo Interface of M33

Yong Zheng[1], Josh Peek[2], Jess Werk[3], Mary Putman[1]

1. Columbia University; 2. Space Telescope Science Institute; 3. University of California, Santa Cruz



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Why Gas Accretion?

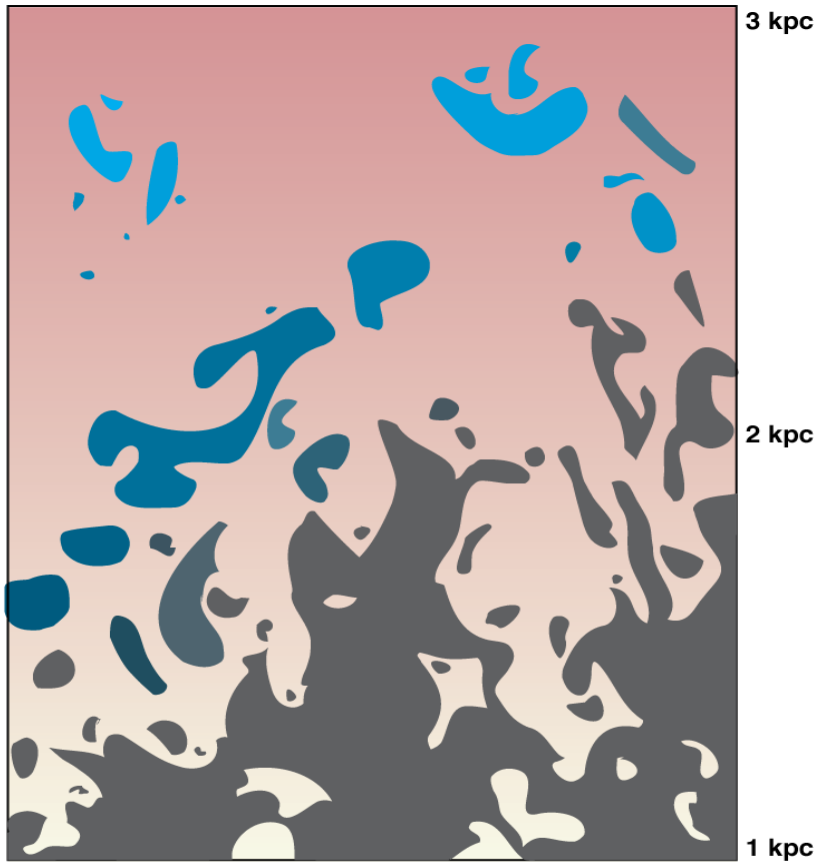
- The gas consumption problem
  - Additional fuel is needed to sustain the star forming activities for both the Milky Way and external galaxies

Galaxy	SFR (M_{sun}/yr)	M_{HI}(disk) (M_{sun})	HI accr. rate (M_{sun}/yr)	Ionized Gas Accr. Rate (M_{sun}/yr)
Milky Way	1-2 [a]	~ 5x10^9 [h]	~ 0.2 [b]	0.8-1.4 [c]
NGC 891	3.8 [f]	4.1x10^9 [g]	> 0.1 [g]	
M33	0.7 [d]	2.5x10^8 [e]		

HALOGAS (Erwin de Blok's talk)

a-Robitaille and Whitney 2010; b-Wakker et al. 2007; Peek et al 2008; c-Lehner & Howk 2011; d-Biltz and Rosolowsky 2006; e-Putman et al. 2009; f-Popescue et al. 2004; g-Osterloo et al. 2007; h-Simith et al. 1978

Why Disk-halo Interface?

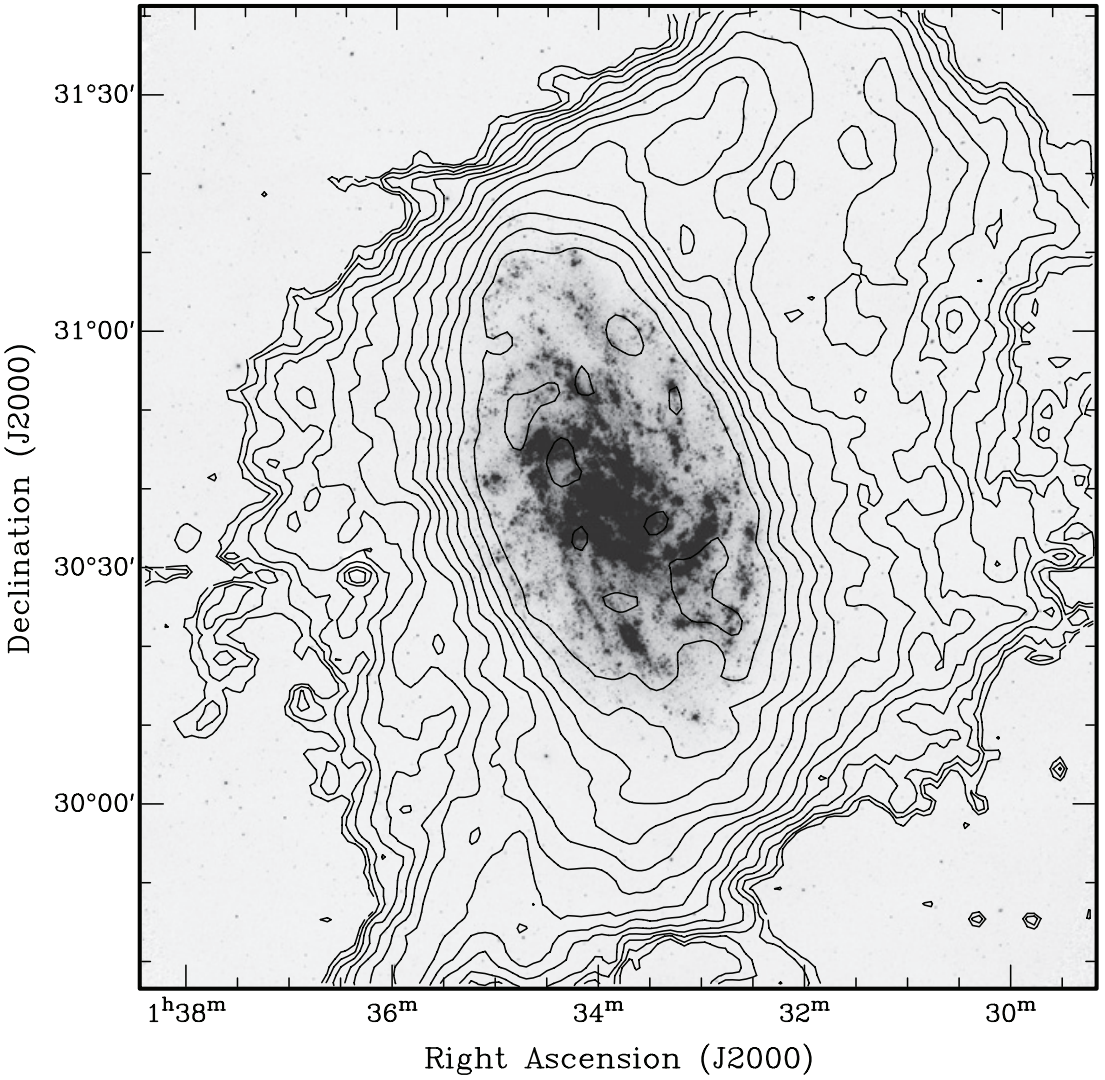


(Putman et al. 2012)

- Key Transition regions
  - Multiphase
  - A hierarchy of increasing temperature and ionization state (Dickey and Lockman 1990)
  - Kinematic gradient: co-rotating/ halo lagging
- What people have observed
  - MW: HVC, ionized HVC, IVC
  - External galaxies: Reynolds layer/ extraplanar gas (Heald et al. 2007; Fraternali et al. 2005)

How does the ionized halo gas become cold material feeding the star formation?

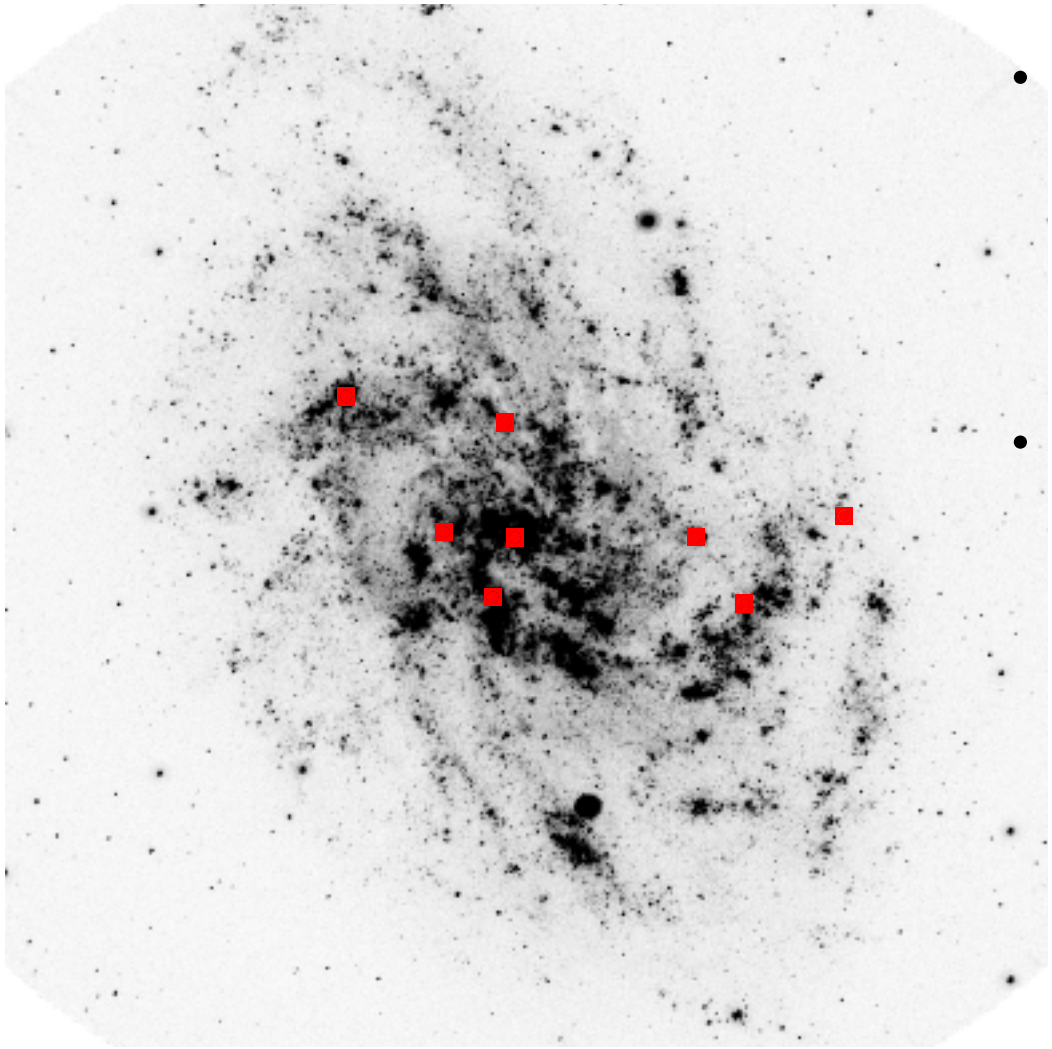
Why M33?



(Putman et al. 2012)

- Why not MW?
  - Galactic absorption/emission blocks the view
  - Galactic rotation complicates the kinematic (Zheng et al. 2015)
- Why M33?
  - Small dwarf galaxy
  - Active star forming: SFR ~ 0.7 M_{sun}/yr (Biltz & Rosolowsky 2006)
  - Nearby: D ~ 840 kpc (Freeman et al. 1991)
  - Free from MW contamination: V_{LSR} (M33) ~ -179 km/s (Corbelli & Schneider 1997)
  - Inclination (49): study of both gas accretion and halo lagging

M33 Observations

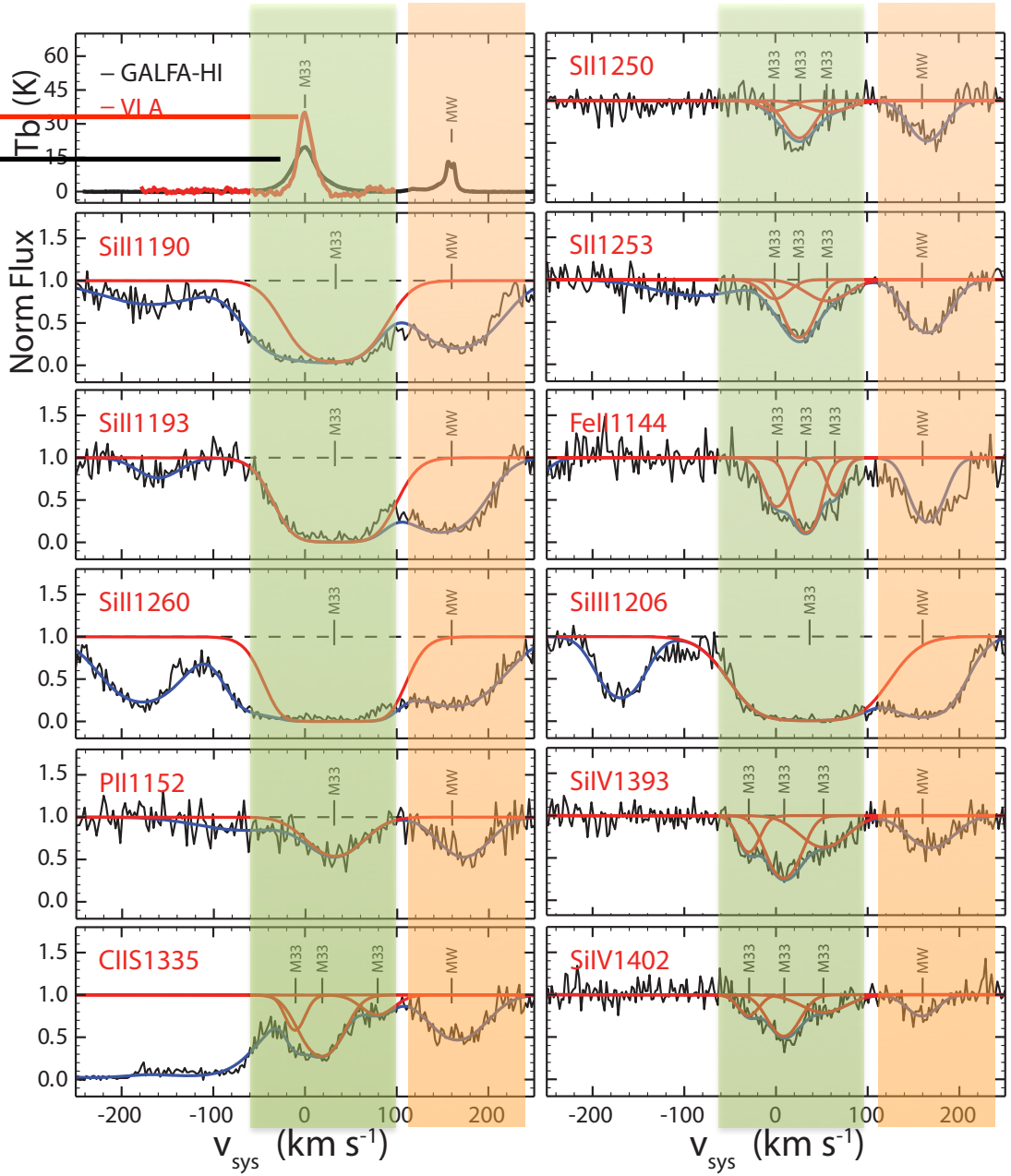


- Neutral hydrogen
  - GALFA-HI: 4 arcmin; 0.74 km/s (Putman et al. 2009)
  - VLA: 25 arcsec; 1.29 km/s (Graiter et al. 2010)
- COS observations
  - 8 O type stars
  - Resolution: 10-15 km/s
  - SII 1250, 1253, 1259, CII 1334, CIIS 1335, Fe II 1144, PII 1152, NI 1199, SiII 1190, 1193, 1260, SiIII 1206, SiIV 1393, 1402
  - Temperature range
    - Warm gas: T ~ 10^4 K
    - Warm-hot gas: T ~ 10^5 K

Example Spectra: NGC 592

VLA
Compact HI

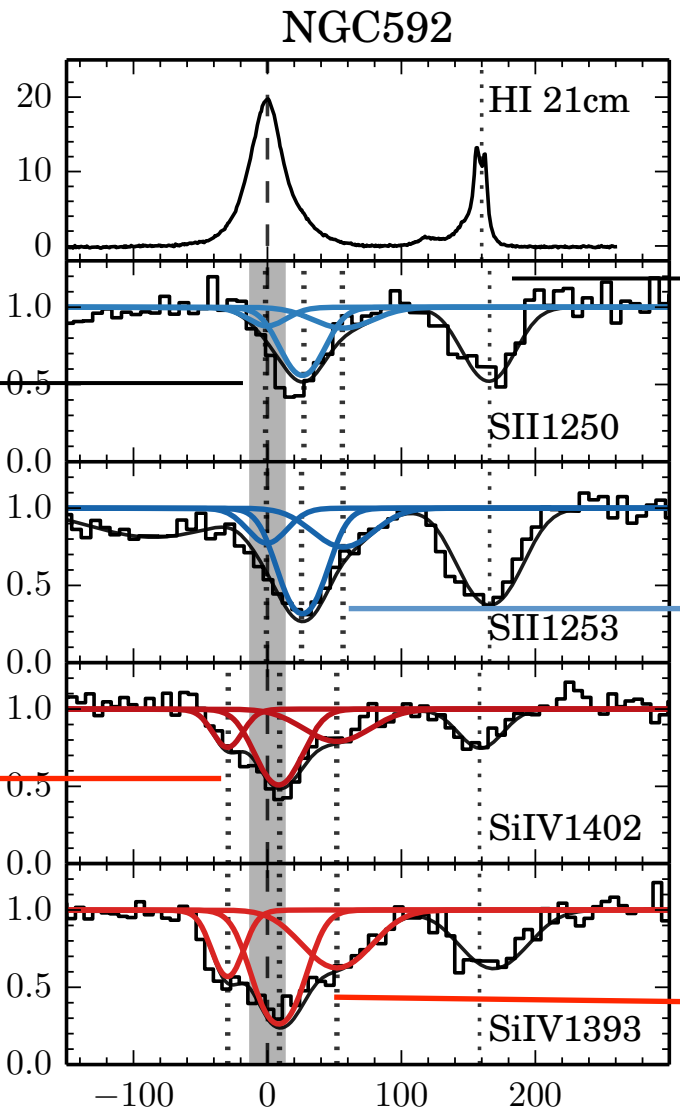
GALFA-HI
Diffuse HI



MW absorption

M33 absorption

Absorption Features of Accreting/Outflow Gas



MW absorption

± 10-15 km/s,
M33 systemic

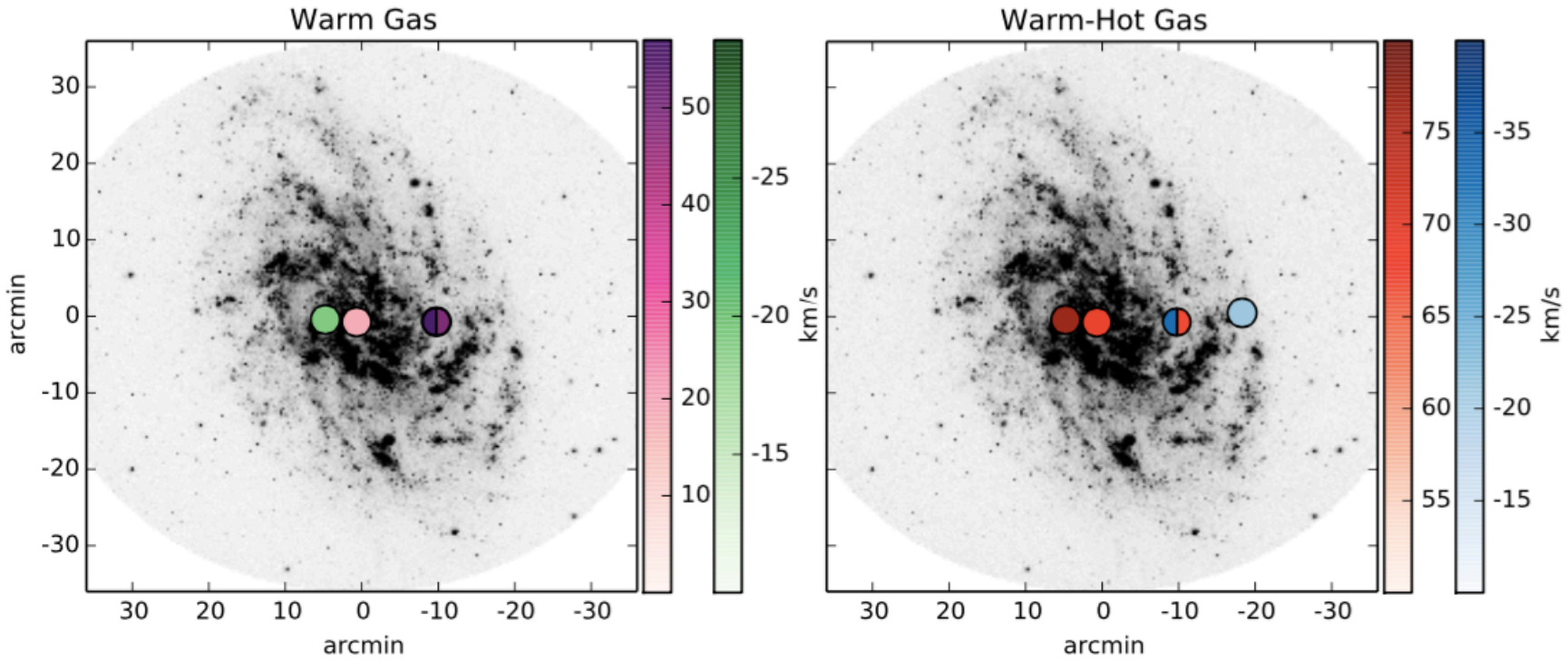
Warm Accretion
57 km/s

Warm-Hot
Outflow
-30 km/s

Warm-Hot
Accretion
52 km/s

Continuum fitting,
Voigt profile fitting
- Tumlinson et al. 2013

Distribution of Accretion/Outflow Over the Disk



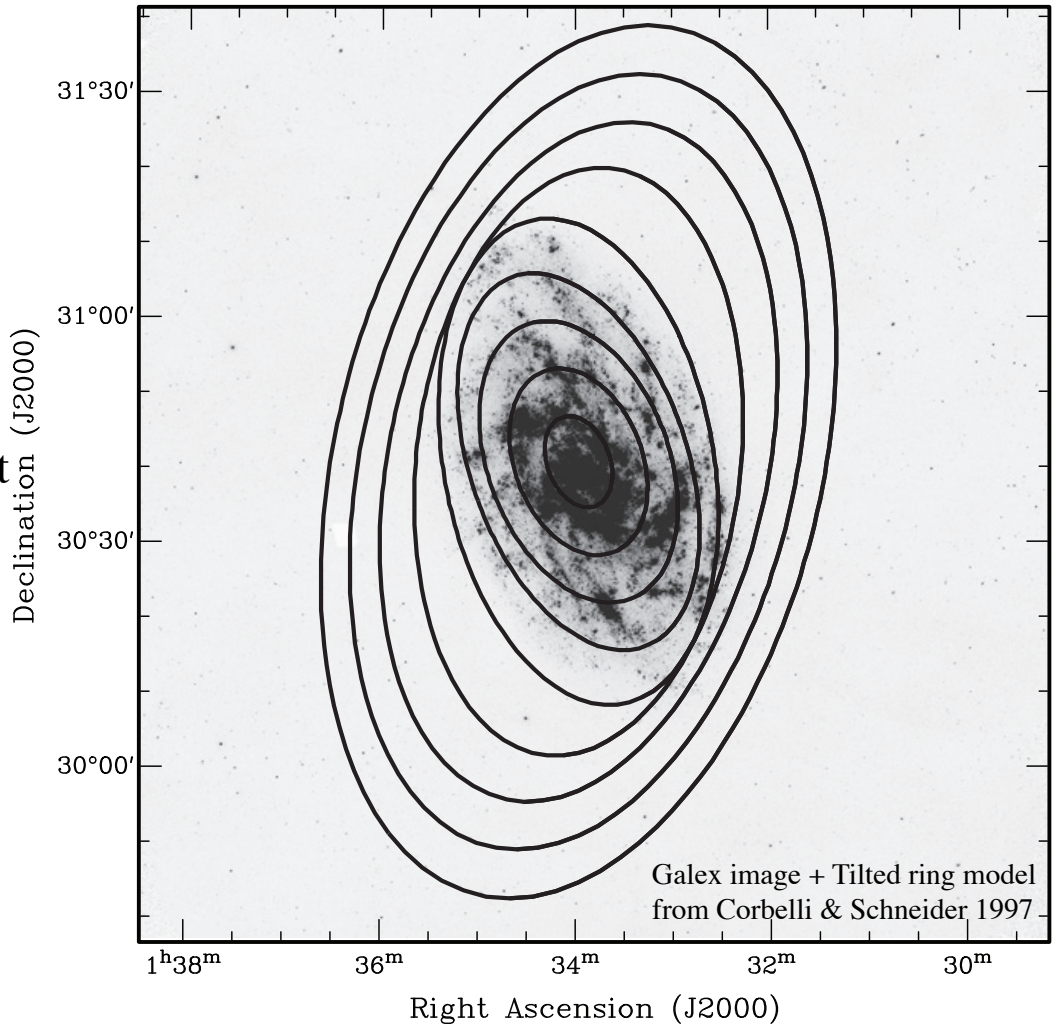
→ Warm-hot gas has higher accretion velocities that those of warm gas, if detected

→ Warm gas is probably more affected by local activities in the disk

→ Inclination and projections complicate the interpretation of the velocity

Modeling of Gas Kinematics at the DH interface

- Tilted ring model
  (Corbelli & Schneider 1997)
- Warm/hot layer
  - A layer of warm gas, z_w
  - A layer of warm-hot gas, z_{wh}
  - Accretion velocity, v_w, v_{wh}
  - Accretion velocity is constant or exponentially decreasing: $v_w, v_{wh} \sim e^{-r/h}$
  - Halo lagging



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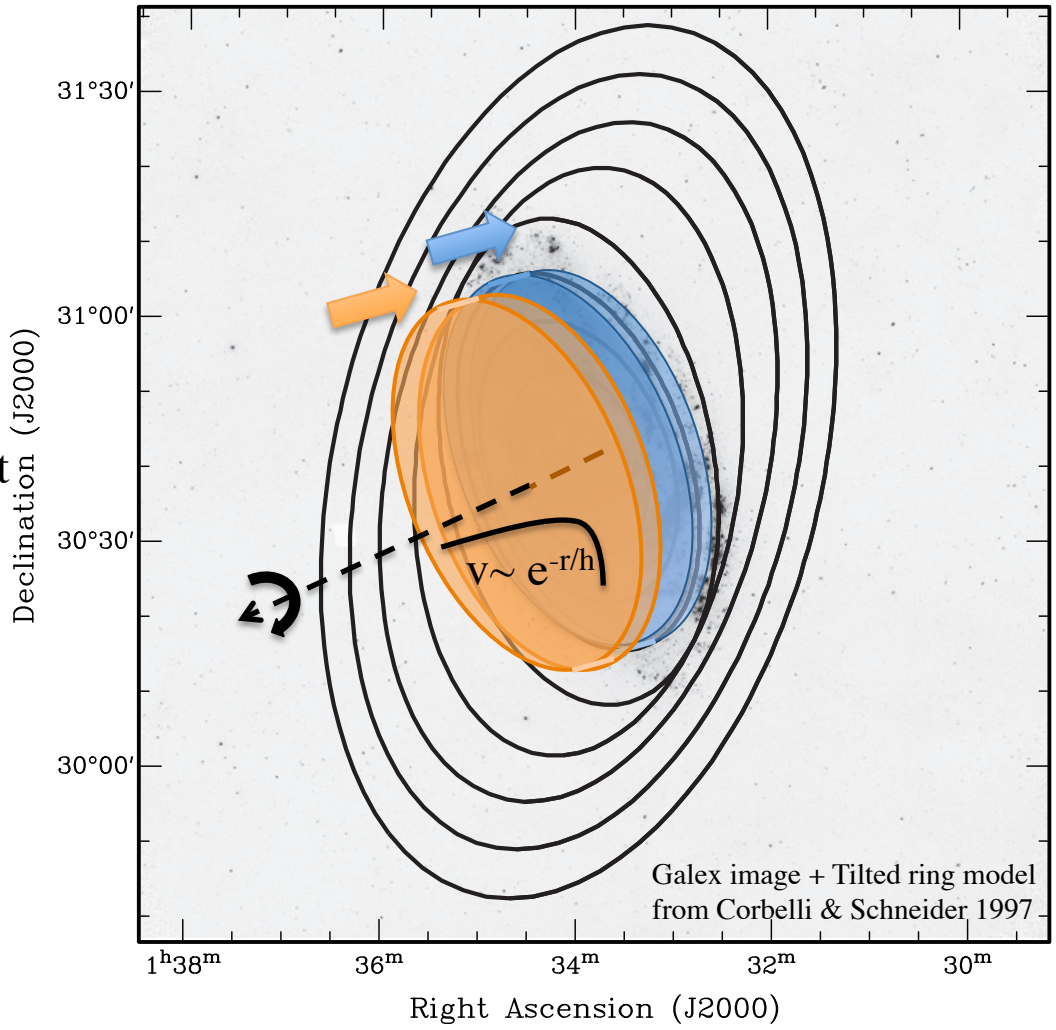
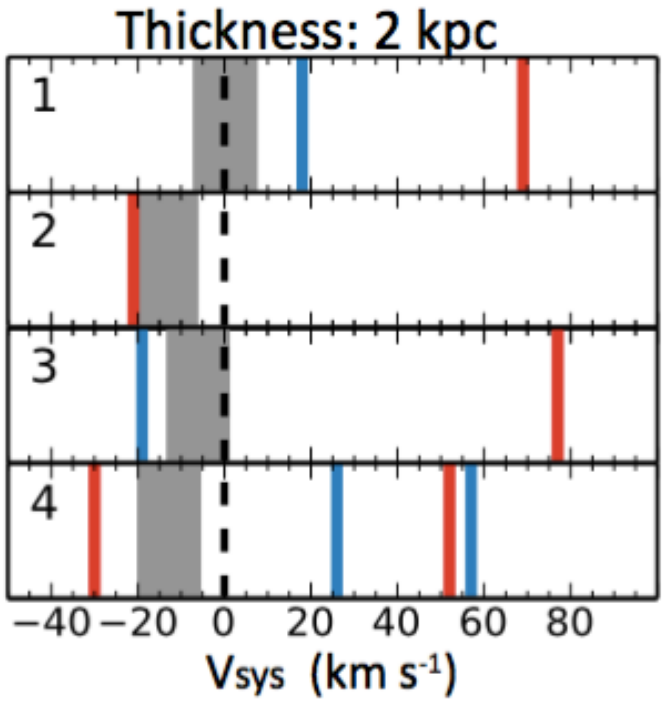
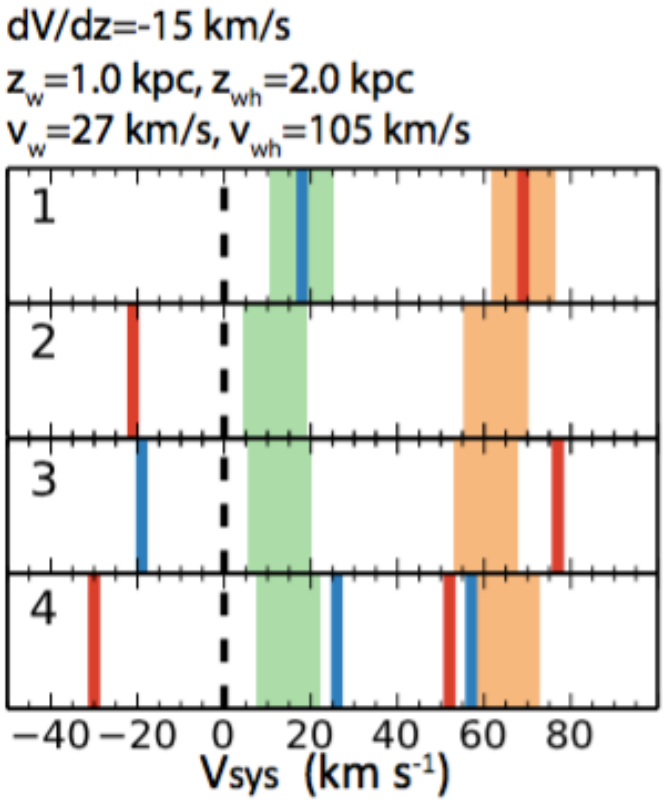


Compare observed velocities with predicted ones





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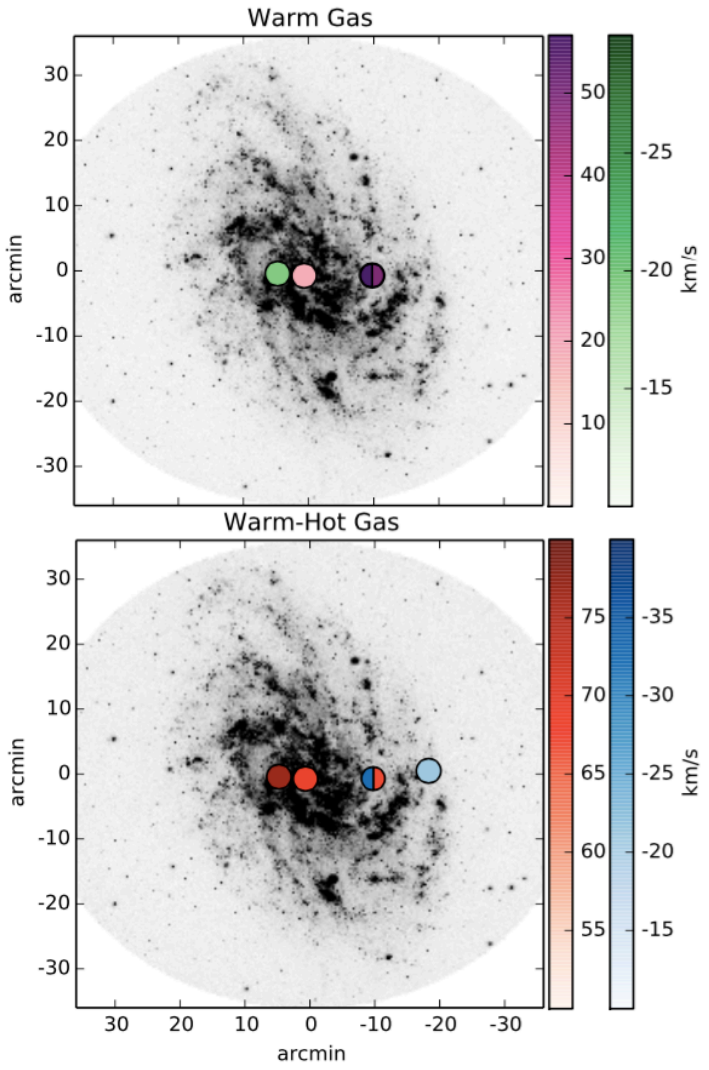
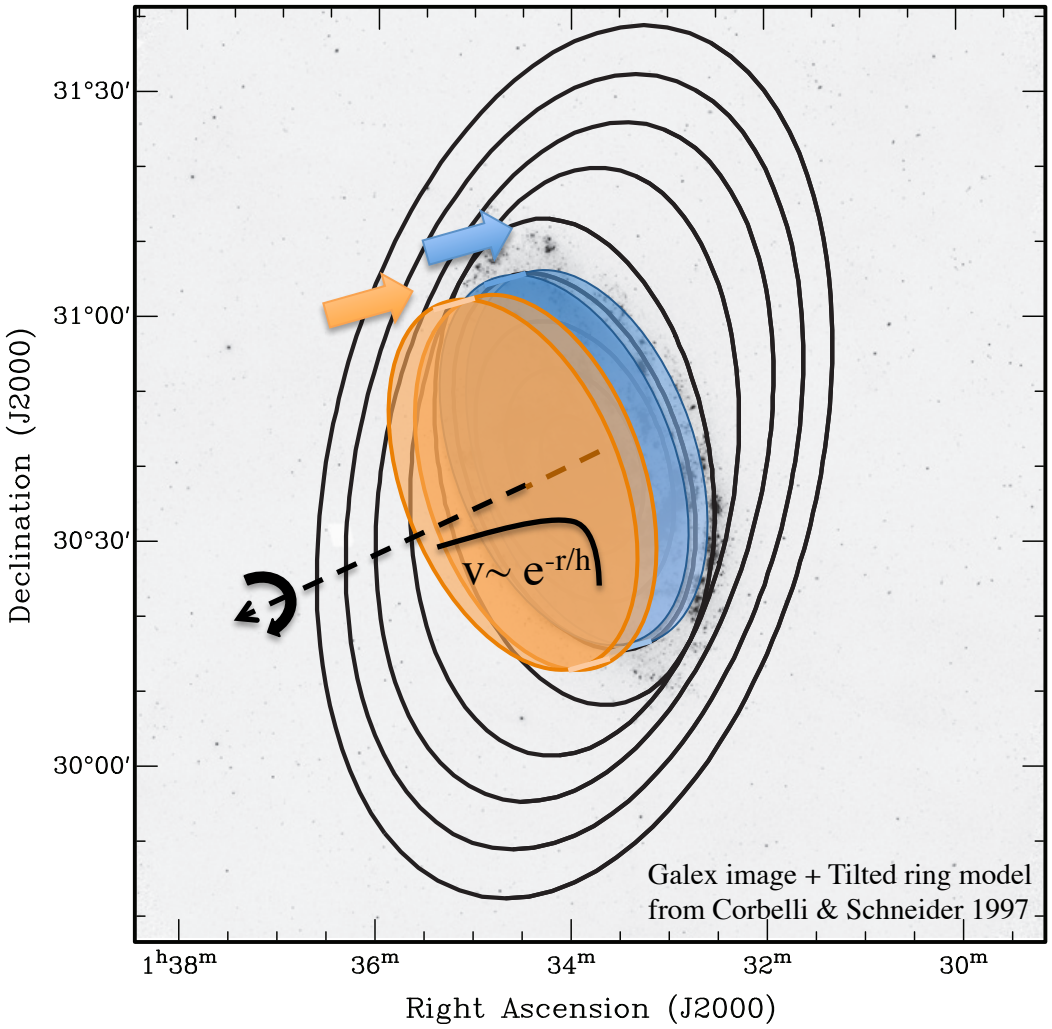
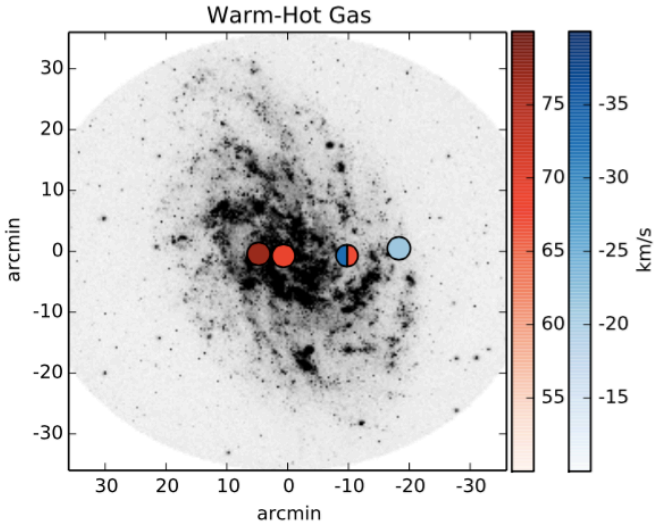




Summary

Evidence of gas accretion at the disk-halo interface of M33

- → Will do: kinematic modeling / Cloudy modeling/ HI interpretation (Putman et al. 2009)
- → **Accretion rate**



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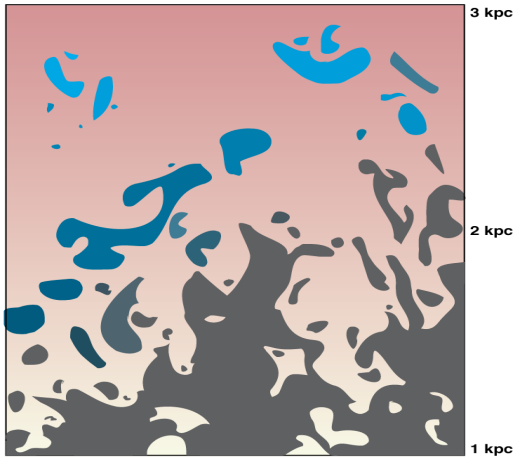

(Putman et al. 2012)