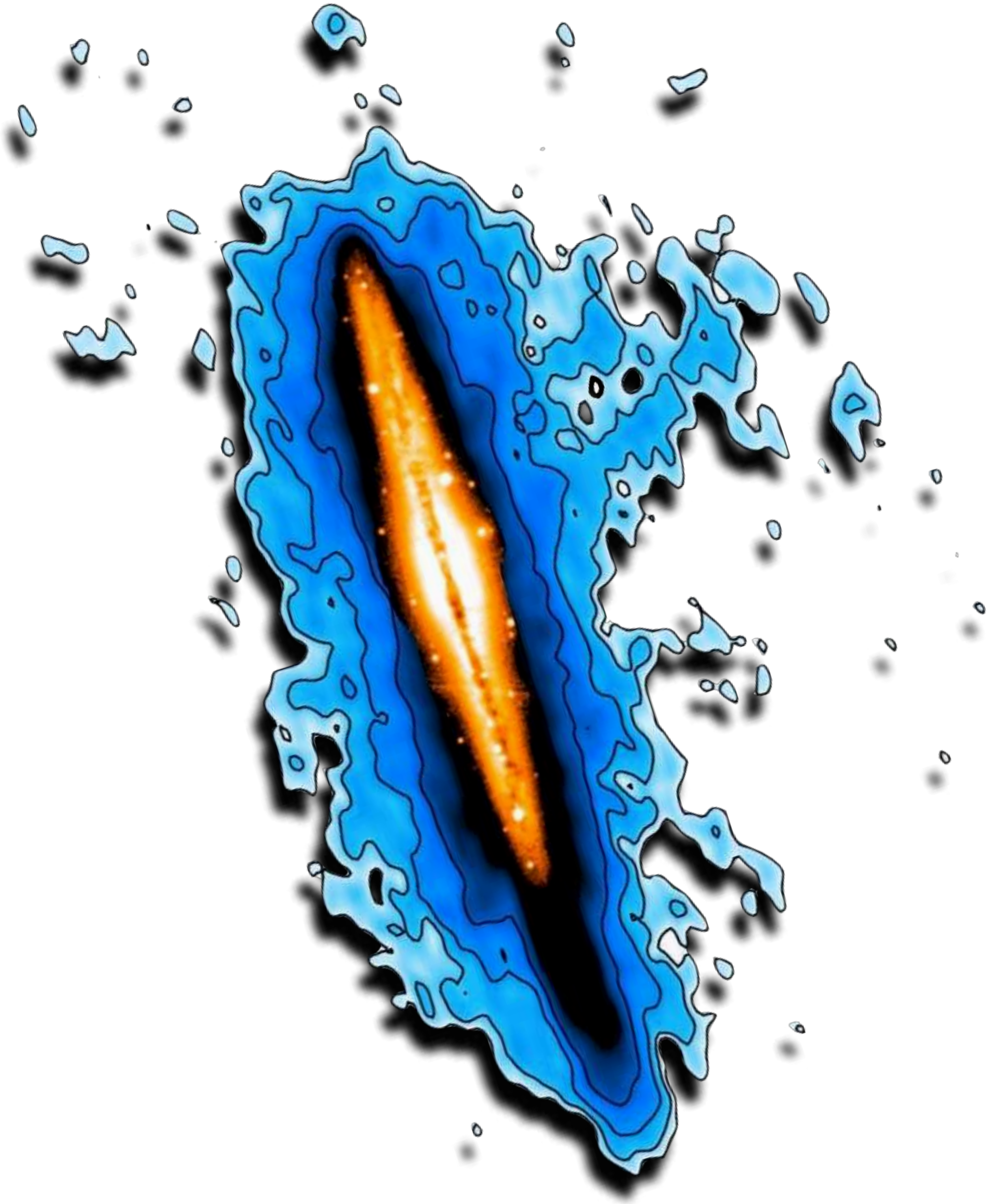
Cold gas accretion in galaxies, an update



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REVIEW ARTICLE

Cold gas accretion in galaxies

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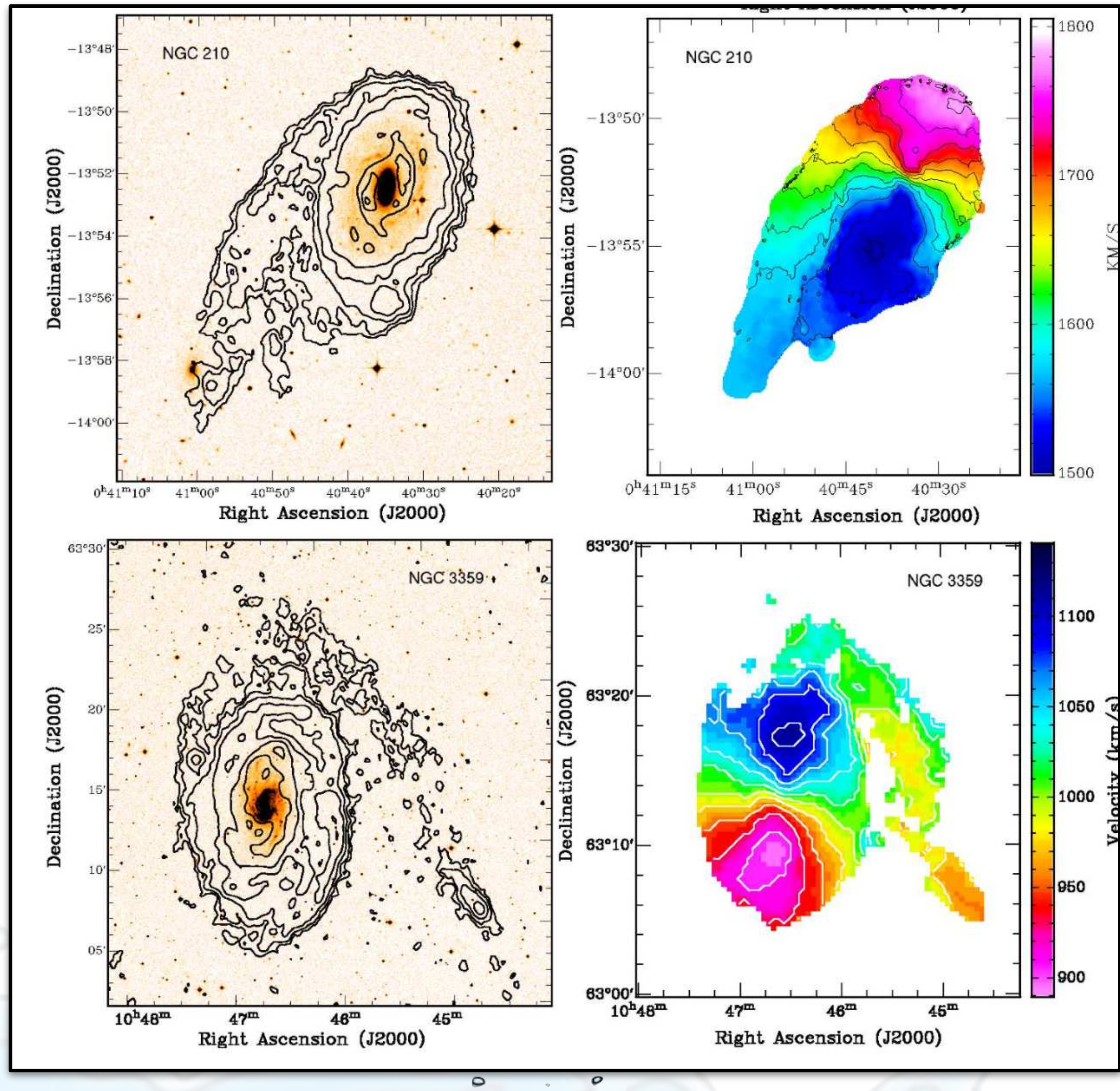
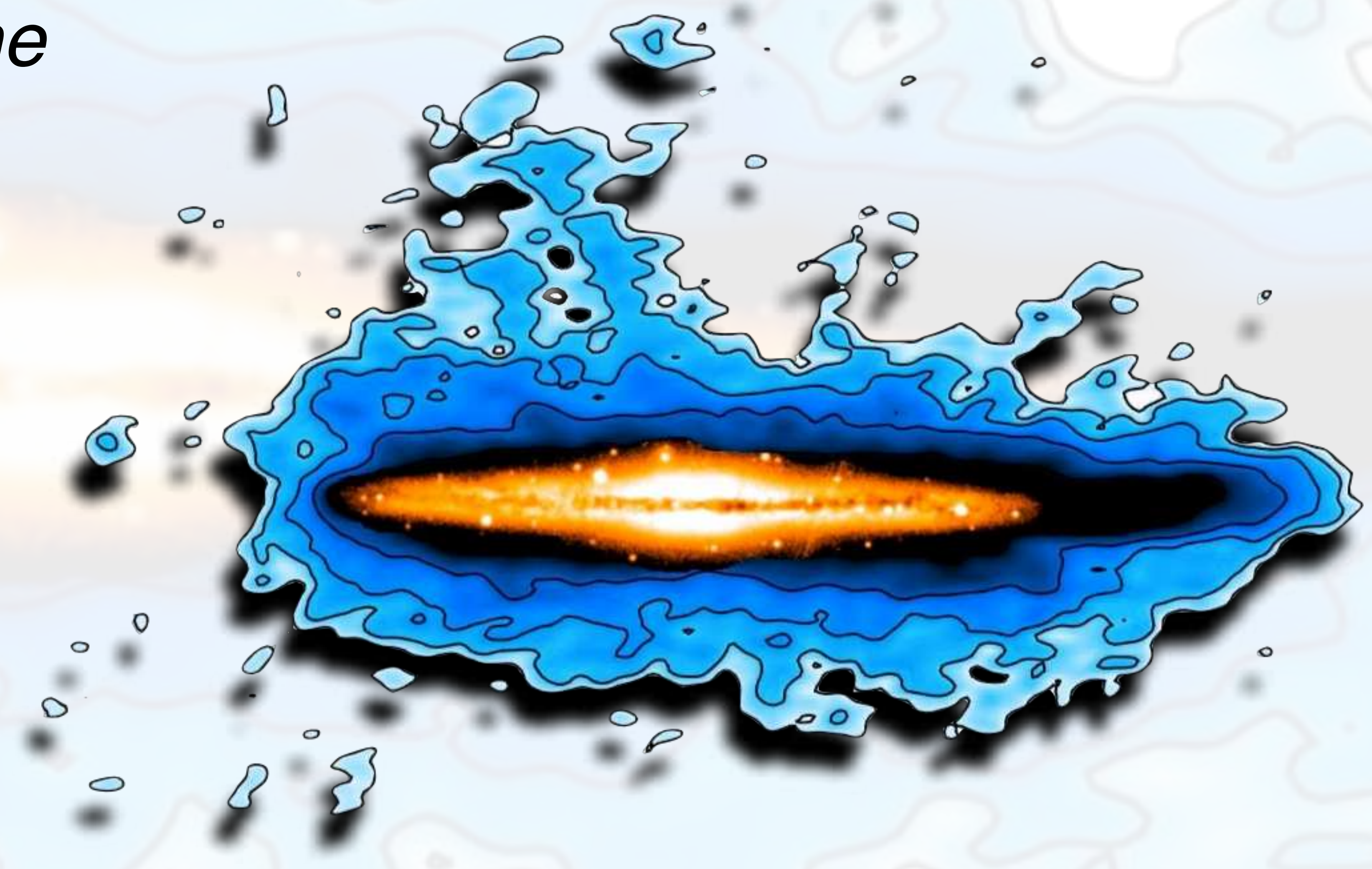
2008 review - main conclusions

‘A large number of galaxies are accompanied by gas-rich dwarfs or are surrounded by HI cloud complexes, tails and filaments. This suggests ongoing minor mergers and recent arrival of external gas. It may be regarded, therefore, as direct evidence of cold gas accretion in the local Universe.

Considerable amounts of extra-planar H I have been found in nearby spiral galaxies. While a large fraction of this gas is undoubtedly produced by galactic fountains, it is likely that a part of it is of extragalactic origin.

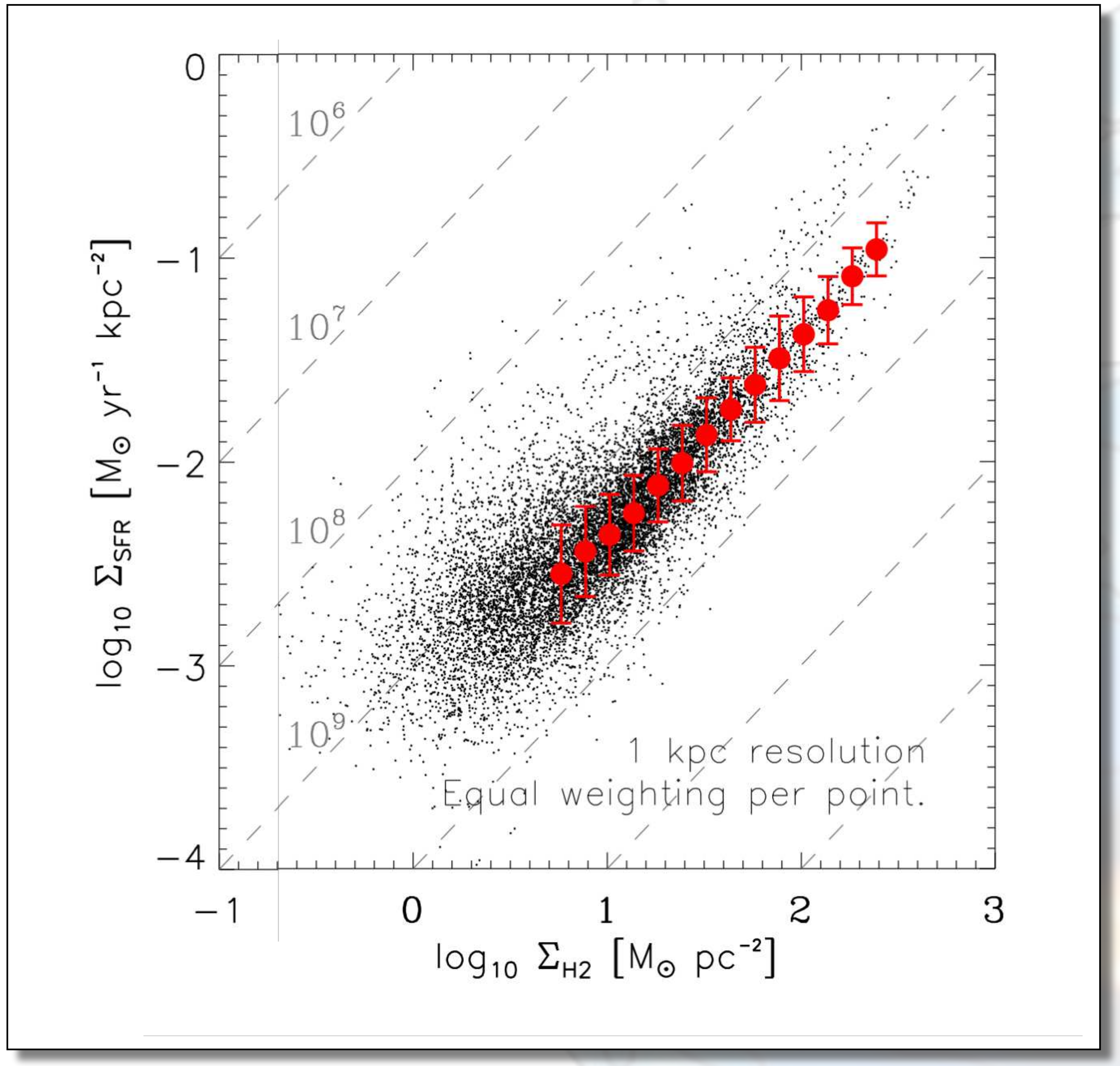
We infer a mean “visible” accretion rate of cold gas in galaxies of at least 0.2 $M_{\odot}\ yr^{-1}$. In order to reach the accretion rates needed to sustain the observed star formation (≈ 1 $M_{\odot}\ yr^{-1}$), additional infall of large amounts of gas from the IGM seems to be required.’



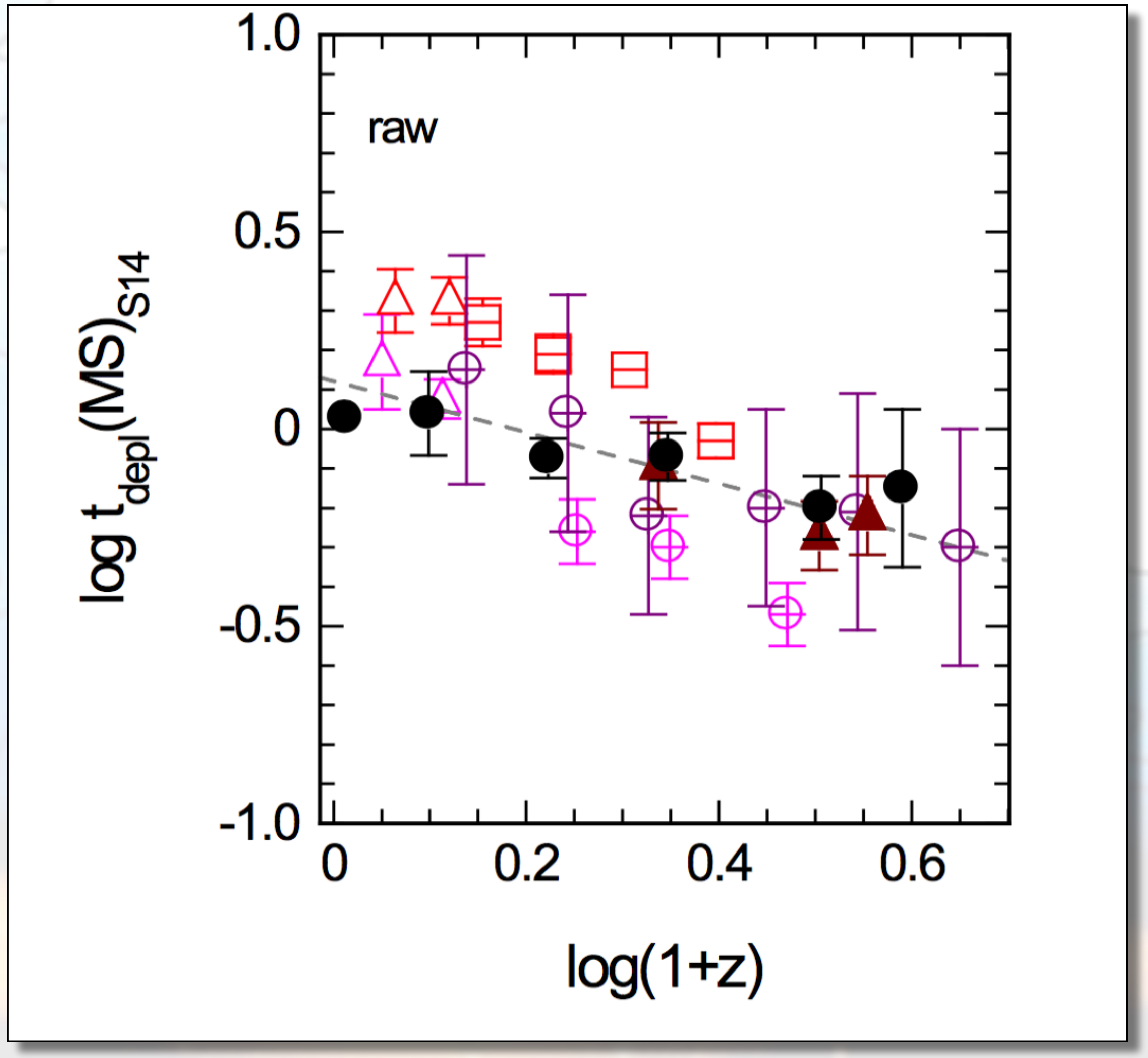


Why should galaxies accrete gas?

Star formation consumes all the gas in a few Gyr.
Even quicker at higher redshift



Bigiel et al. 2011



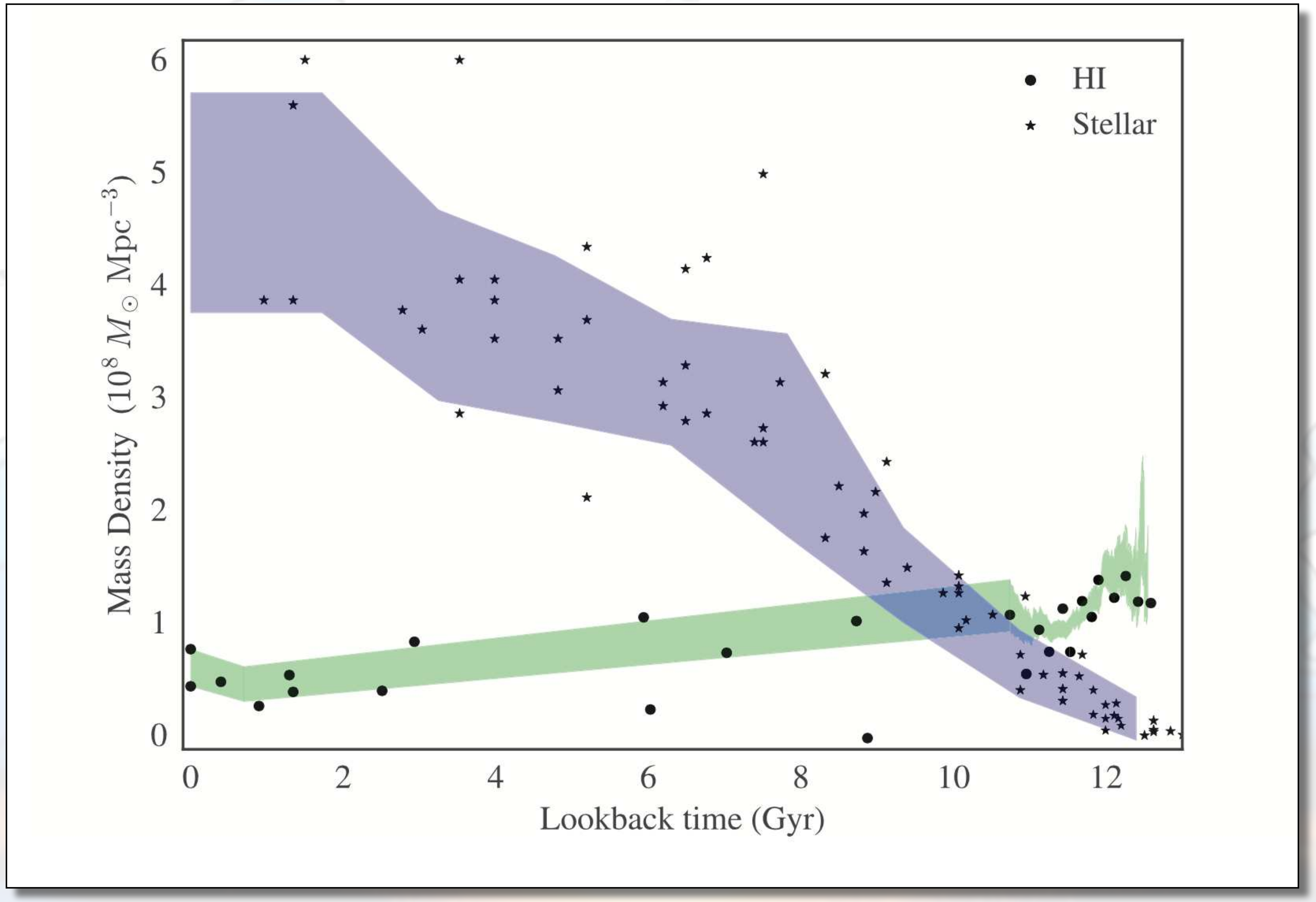
Tacconi et al. 2018

Why should galaxies accrete gas?

The evolution of the number of stars and of the amount of HI do not trace each other

HI cannot provide the gas to compensate for decrease of molecular gas due to star formation

Must be dynamic process involving cooling from ionised CGM



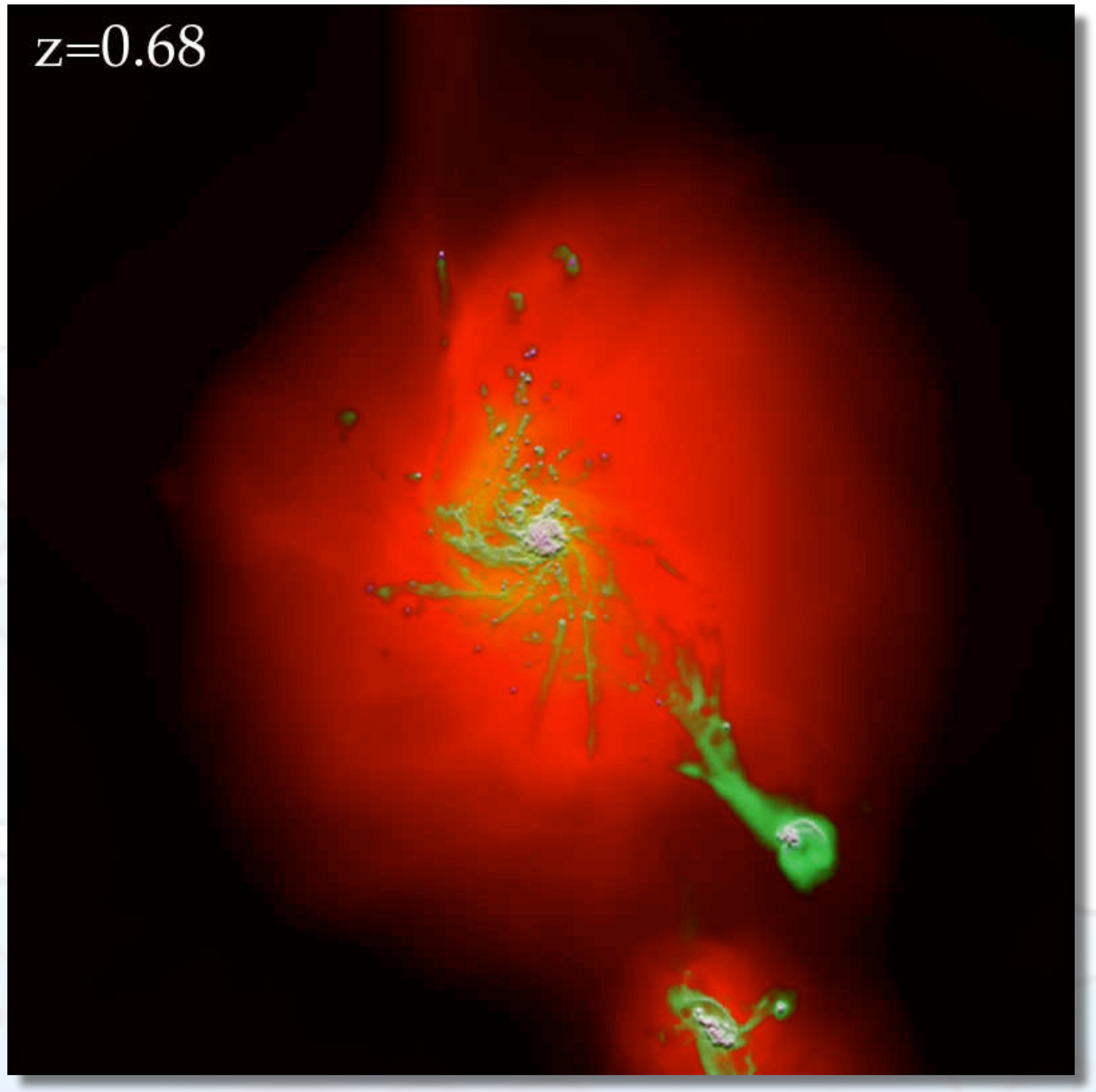
Putman 2016

Accretion

- accretion of gas-rich companions
- reservoir of hot gas cooling onto galaxy
- streams of ‘cold’ gas

- Much observational effort has been done to detect the accreting CGM in HI

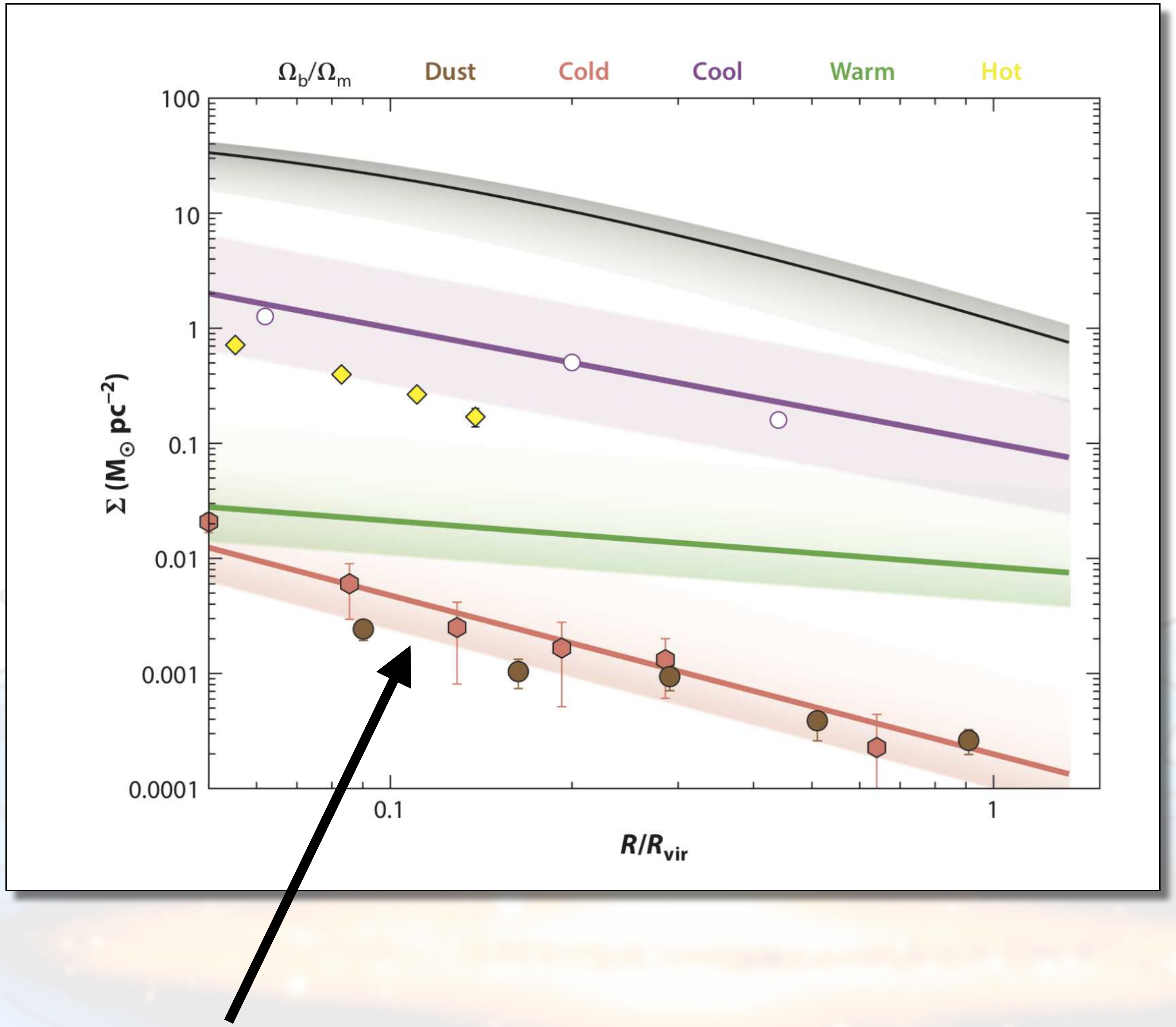
- With some success, but observed accretion rates are small



FIRE simulations - Hopkins et al. 2017

There is a lot of CGM that (could) accrete

but is not HI!!

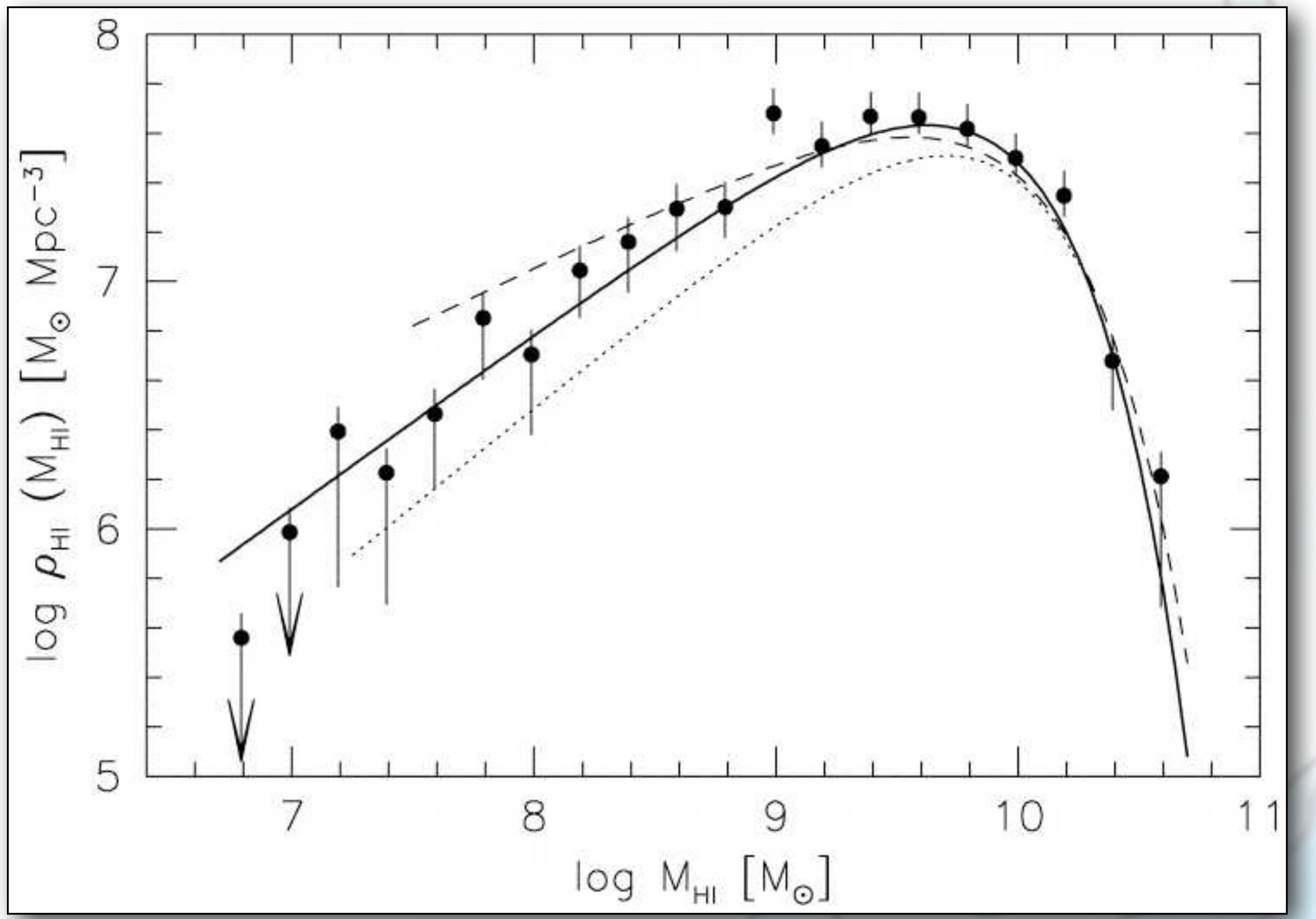


Tumlinson, Peeples & Werk 2017

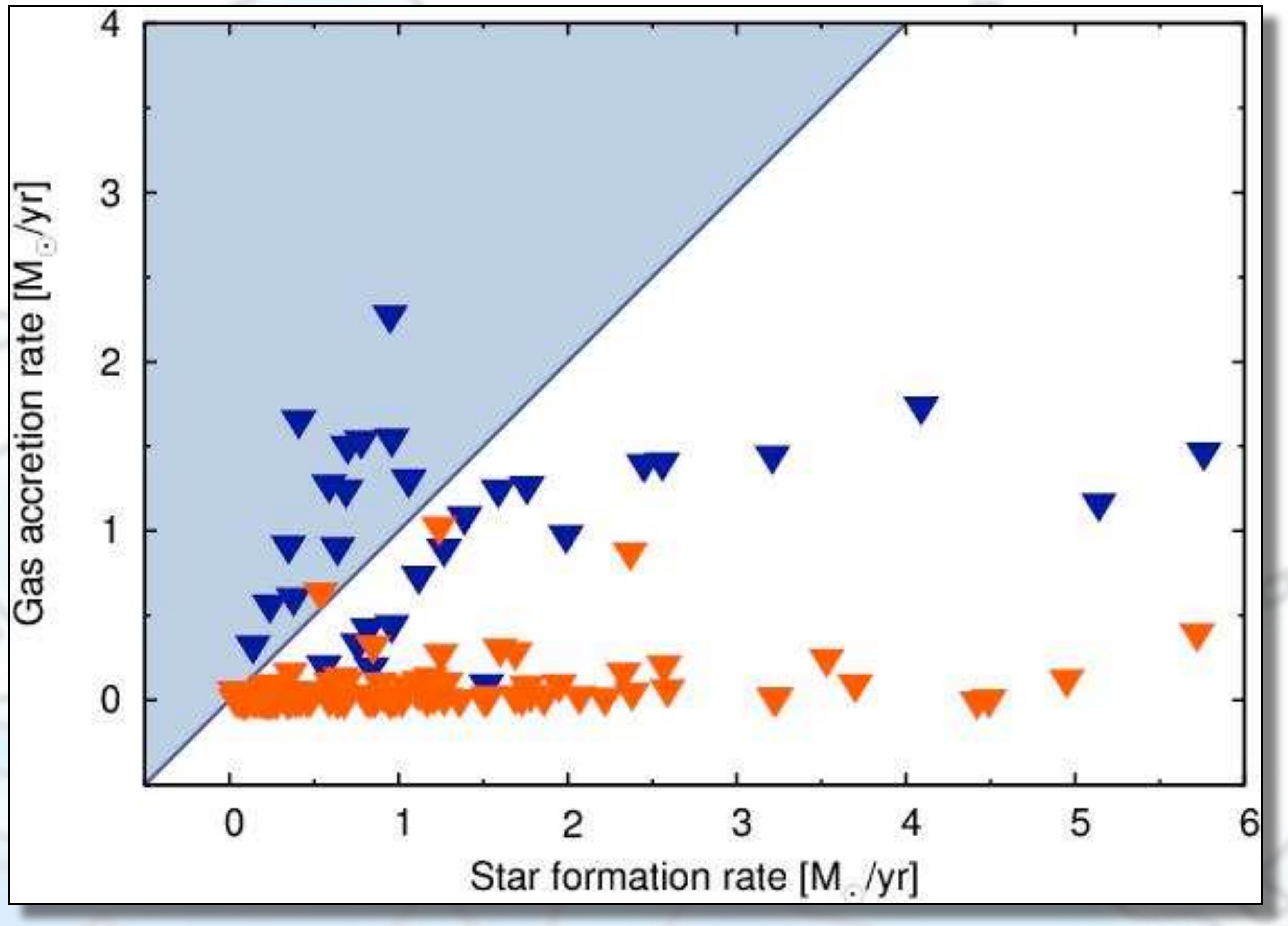
Minor mergers are very common, and bring in fresh HI, but:

Accretion of companions cannot solve the problem: most HI in galaxies is already in large galaxies.

There is not enough HI in companions to keep on feeding large galaxies for a long time.



Zwaan+ 2005

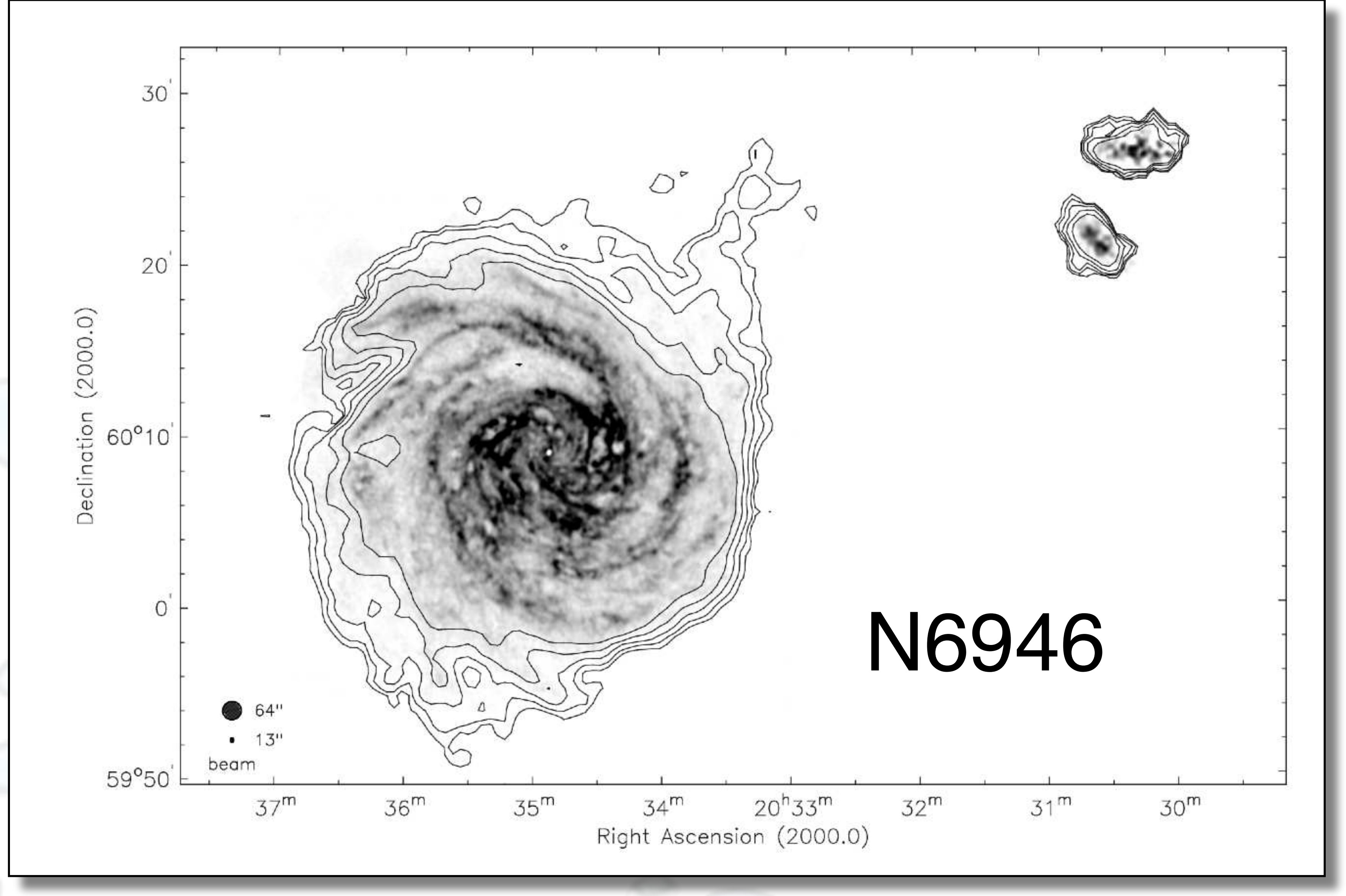


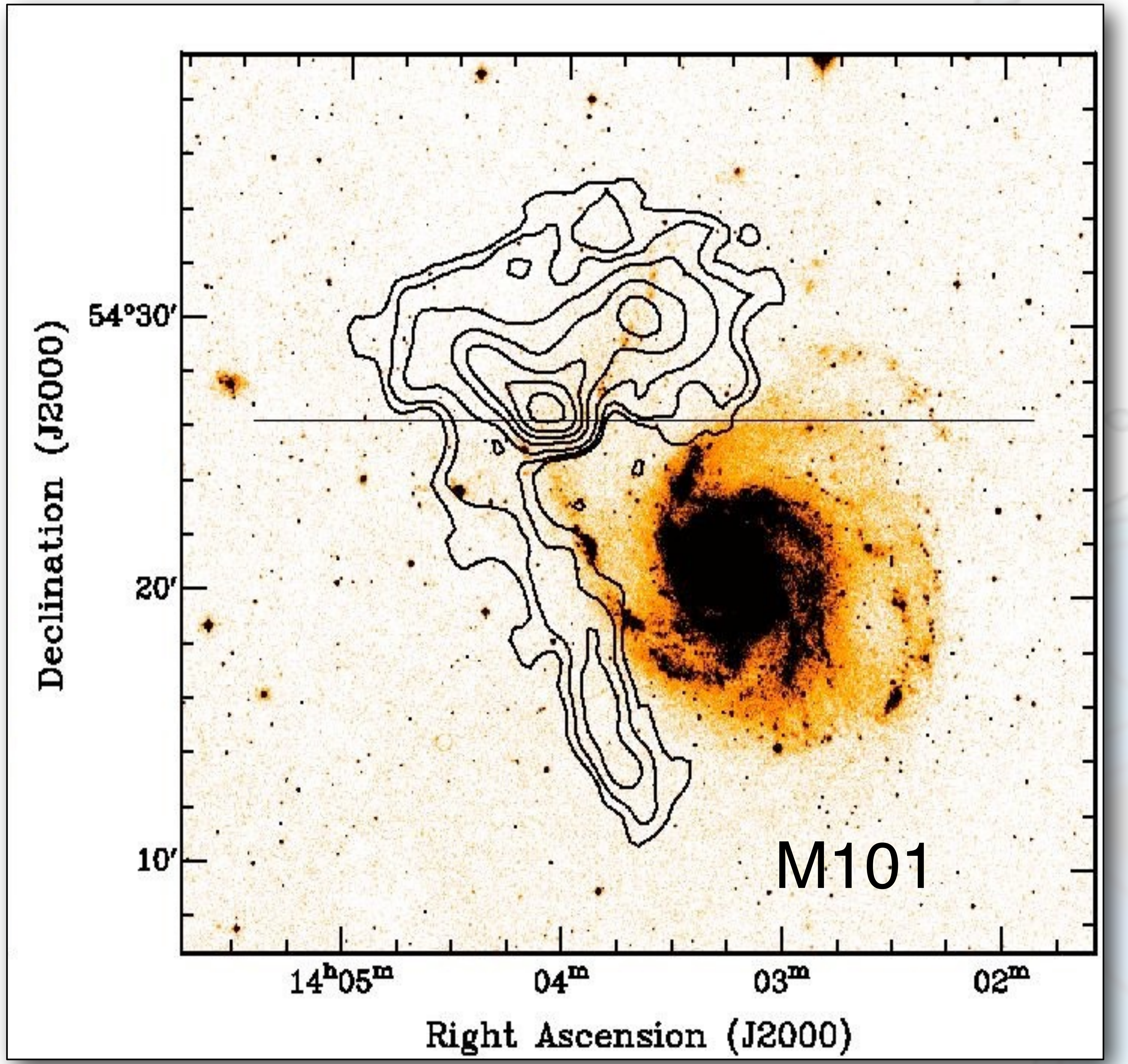
maximum gas accretion rate of 0.28 $M_\odot$ yr^{-1}

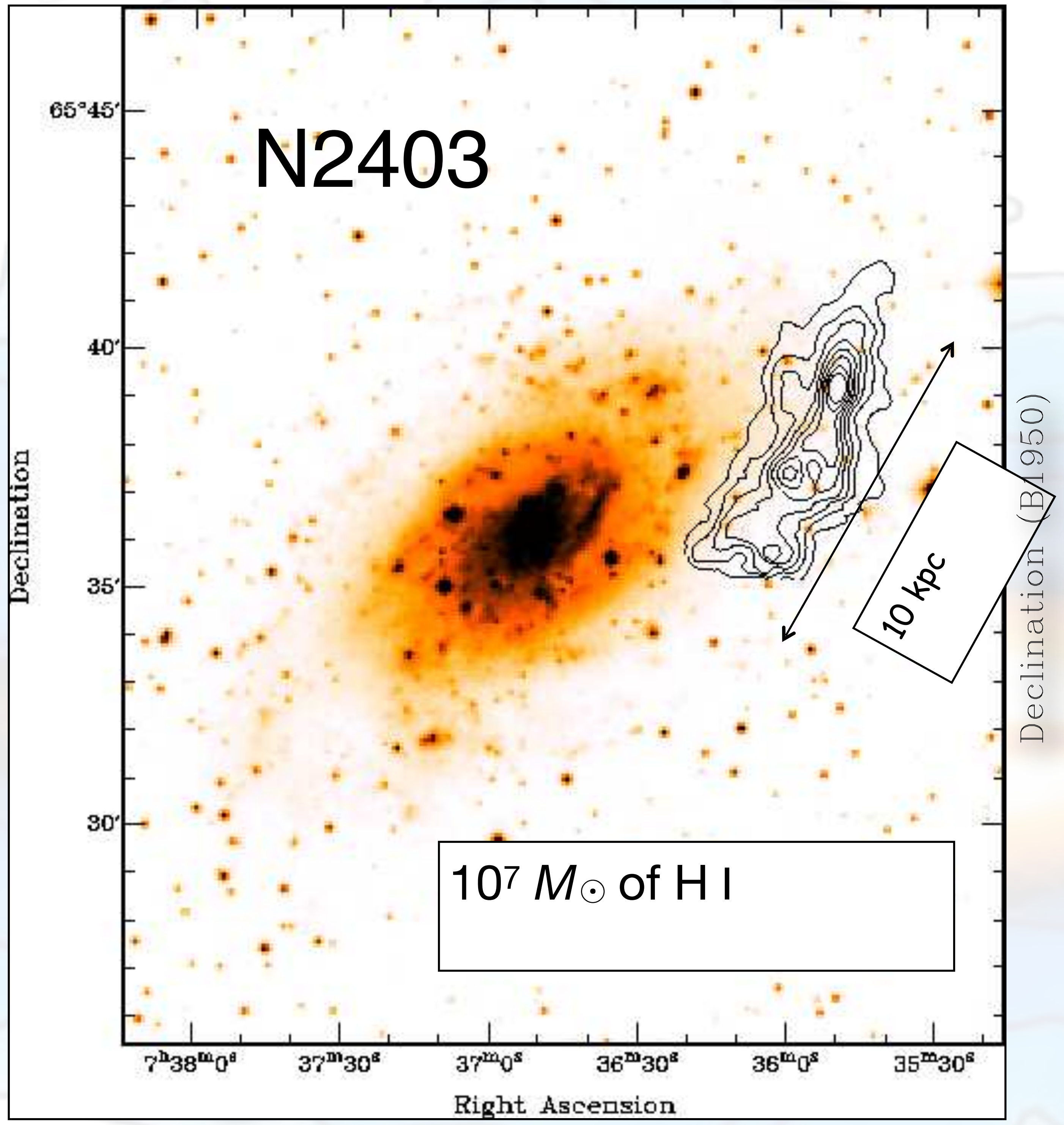
di Teodoro & Fraternali 2014

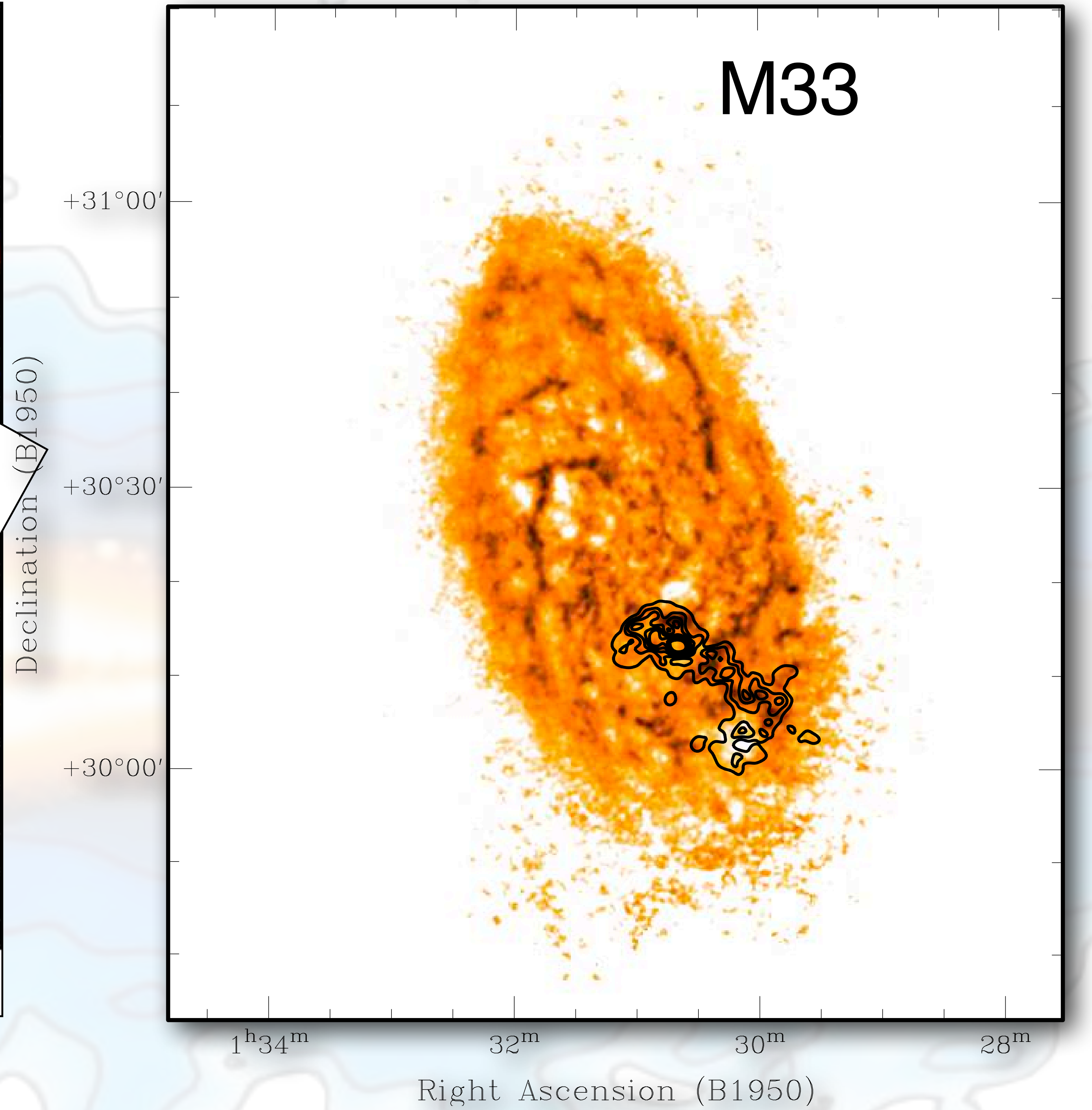
Same is true for large, dark(?) HVC complexes similar to Complex C

A number are known, but not enough to provide sufficient HI

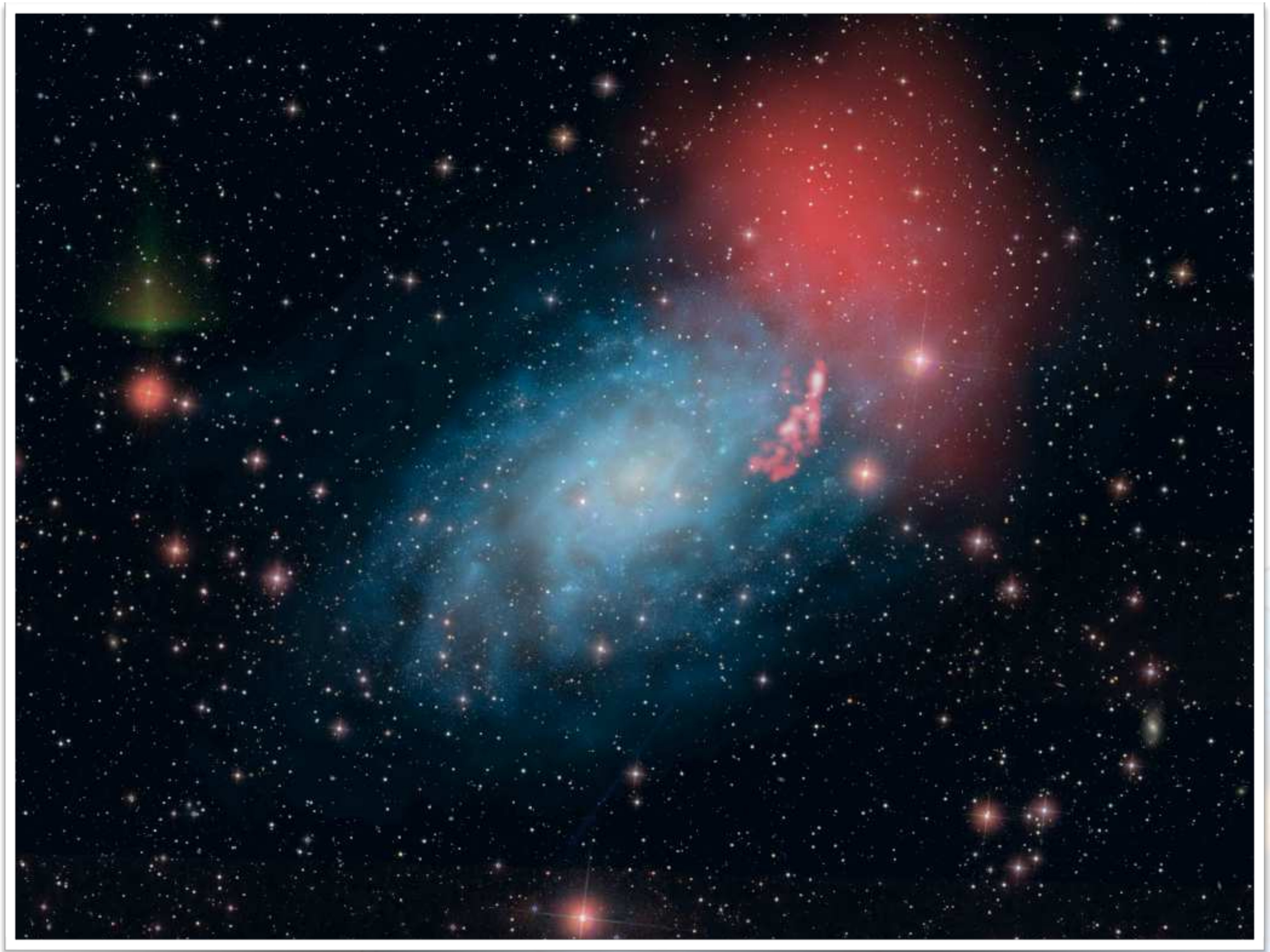






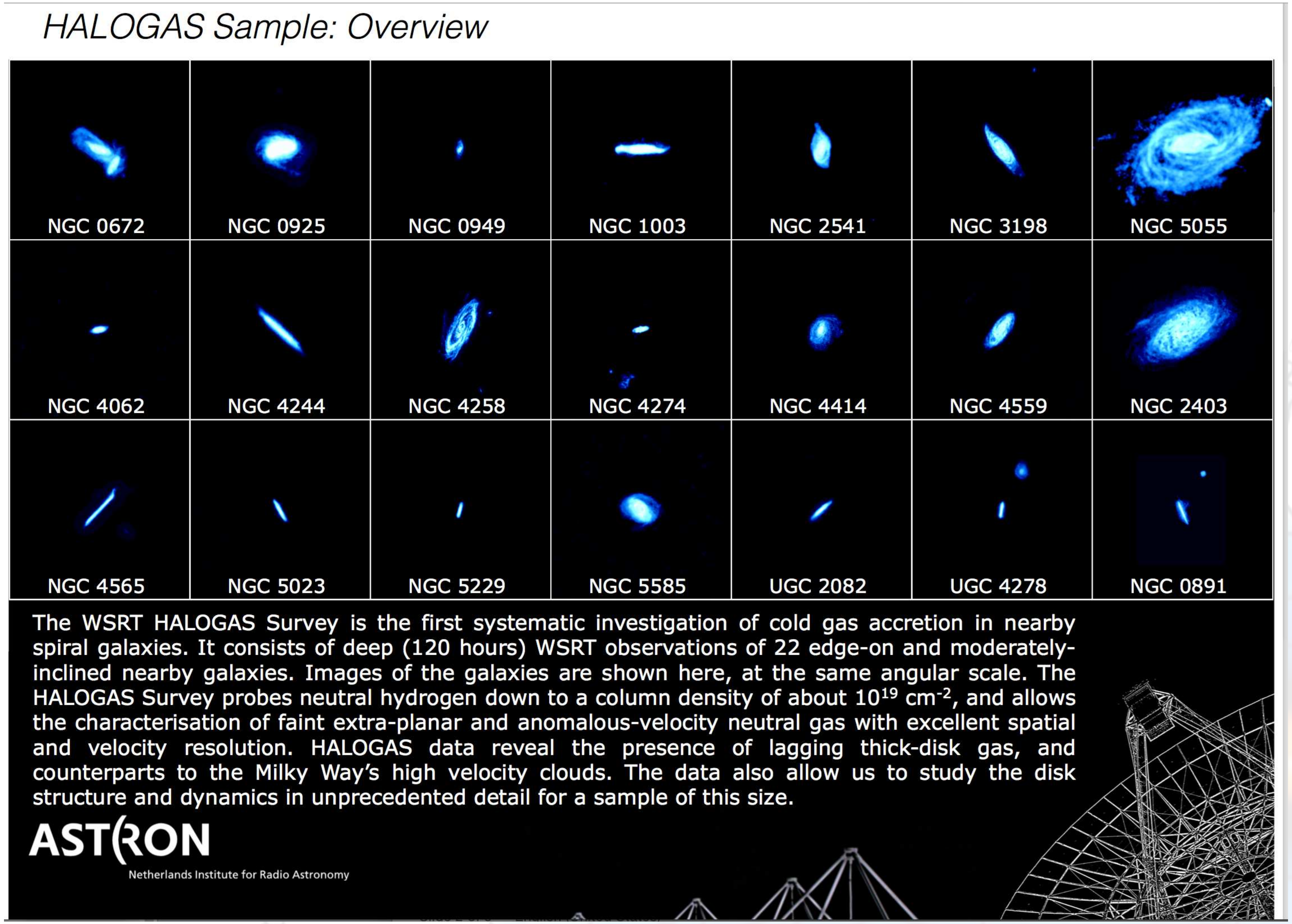


van de Hulst, Sancisi, 1988

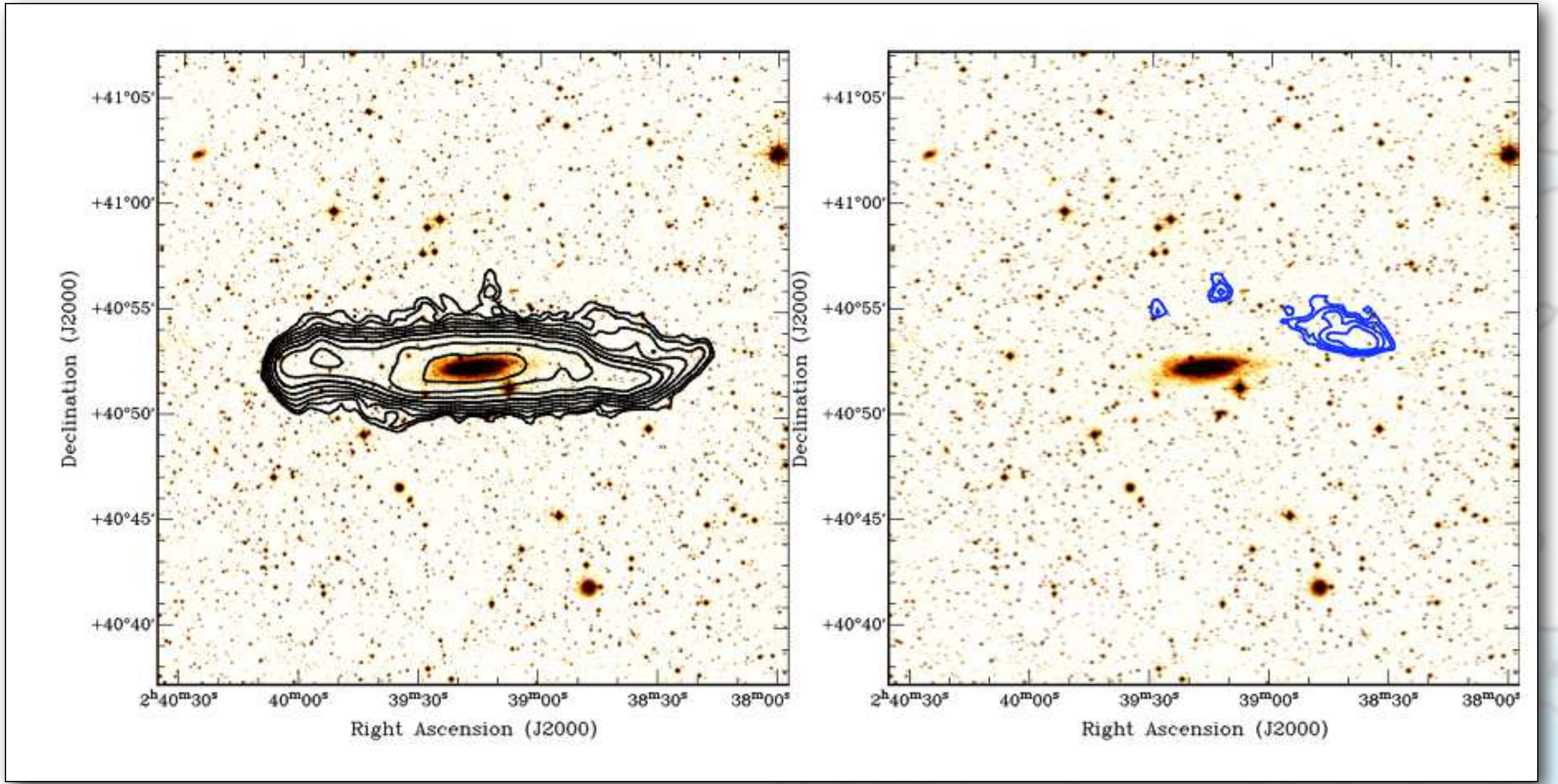


New GBT observations show the complex in N2403 is even larger
de Blok+ 2014

Halogas survey (Heald et al.)



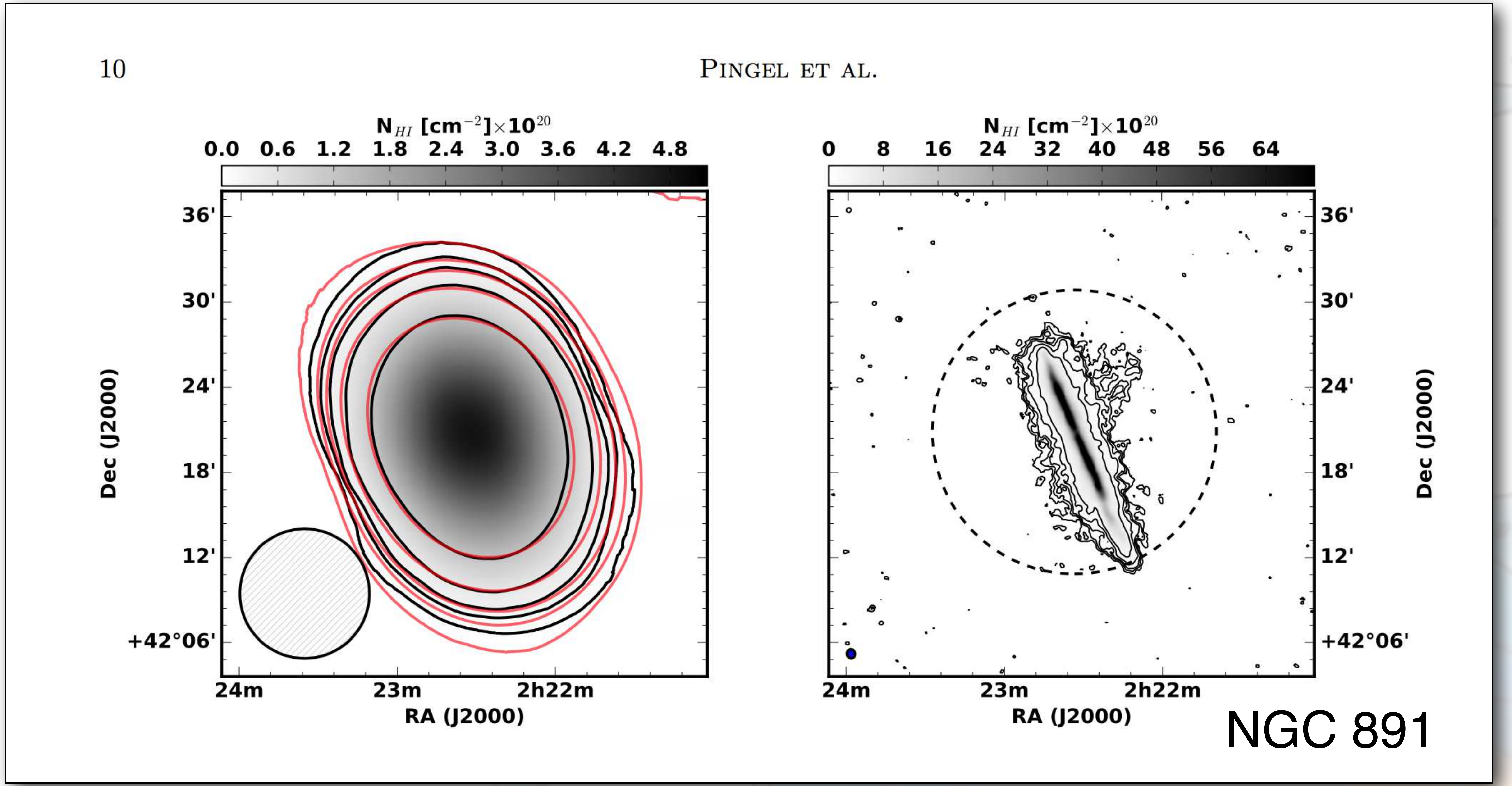
Halogas survey has found some but not many new large HVCs

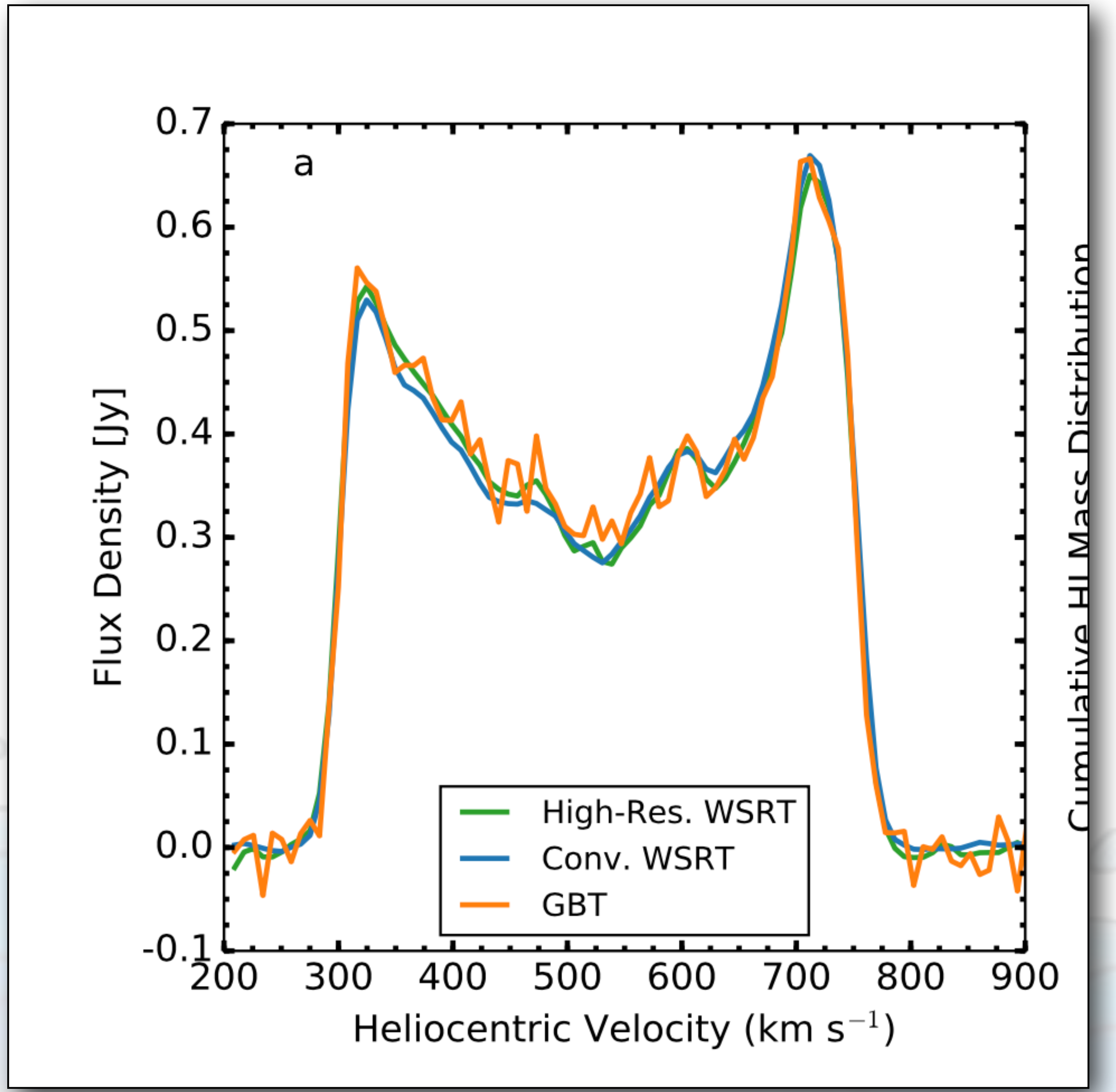


NGC 1003

No evidence of a large population of large HVCs, sufficient to feed star formation

No evidence for extended, diffuse gas on 10 kpc scales





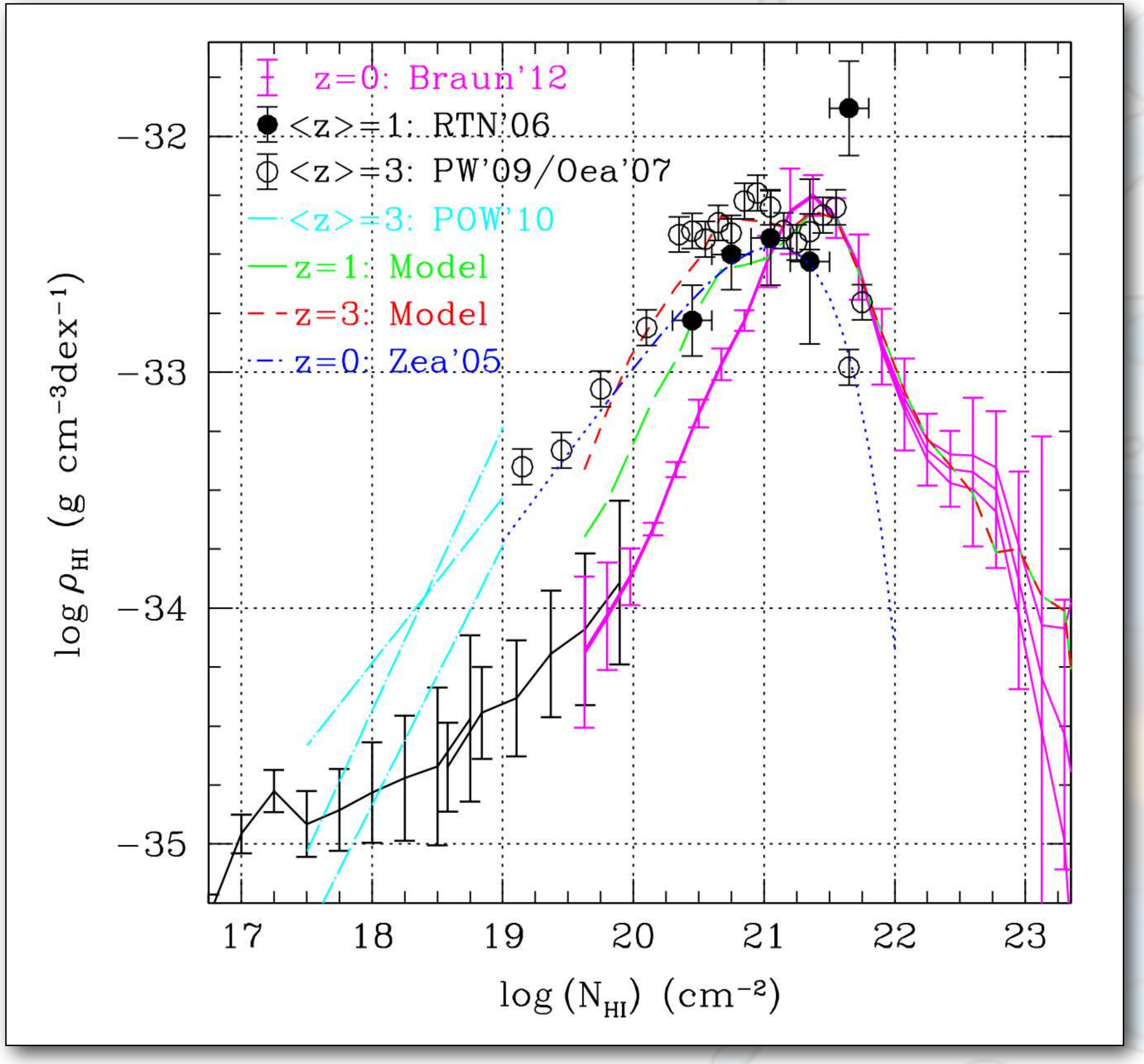
Pingel et al. 2018

GBT observations of Halogas sample detect the same flux as the WSRT

Very tricky to do…. Early versions of this work concluded the opposite…

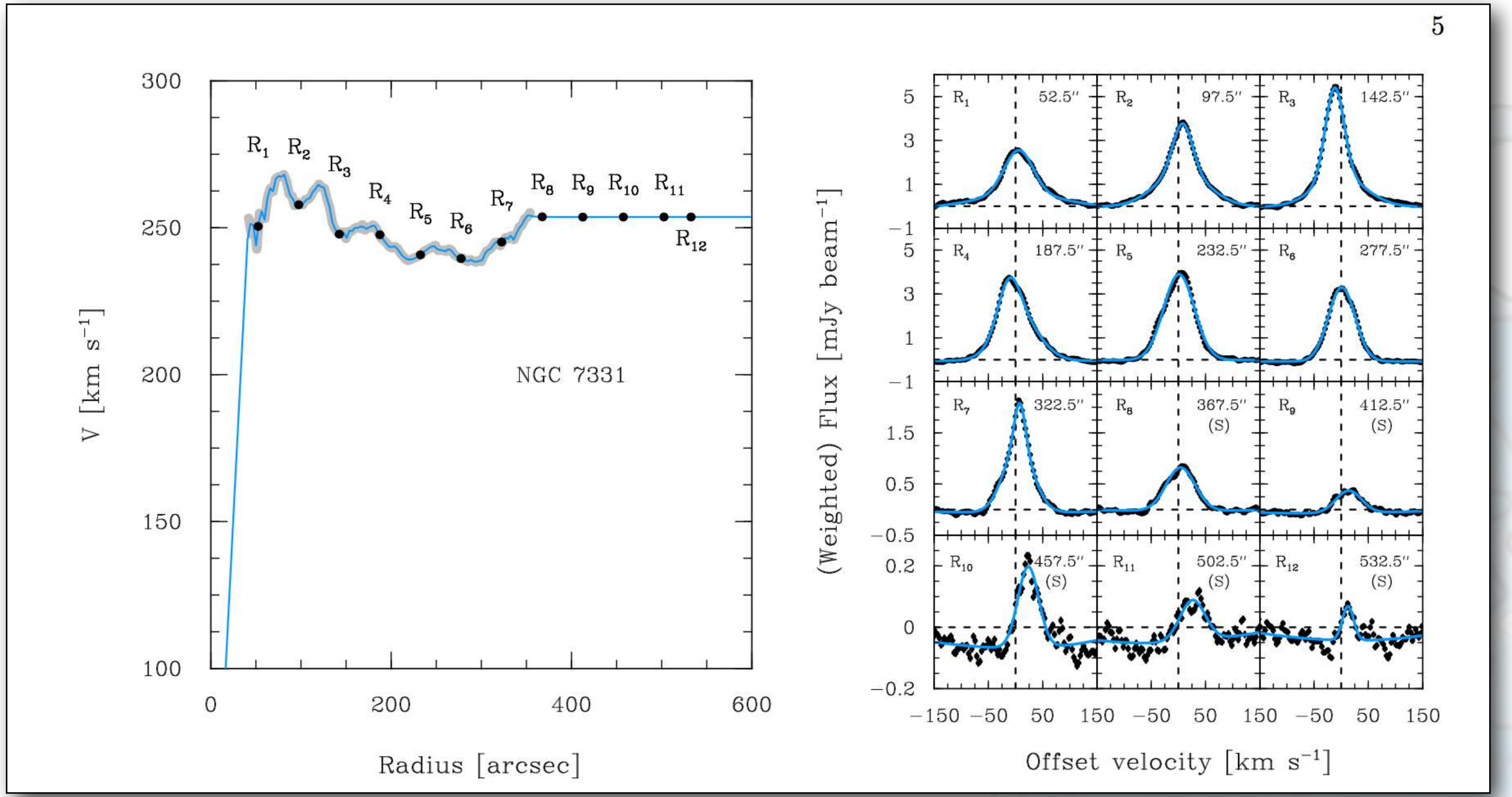
Most of the HI in the Universe is at high column densities

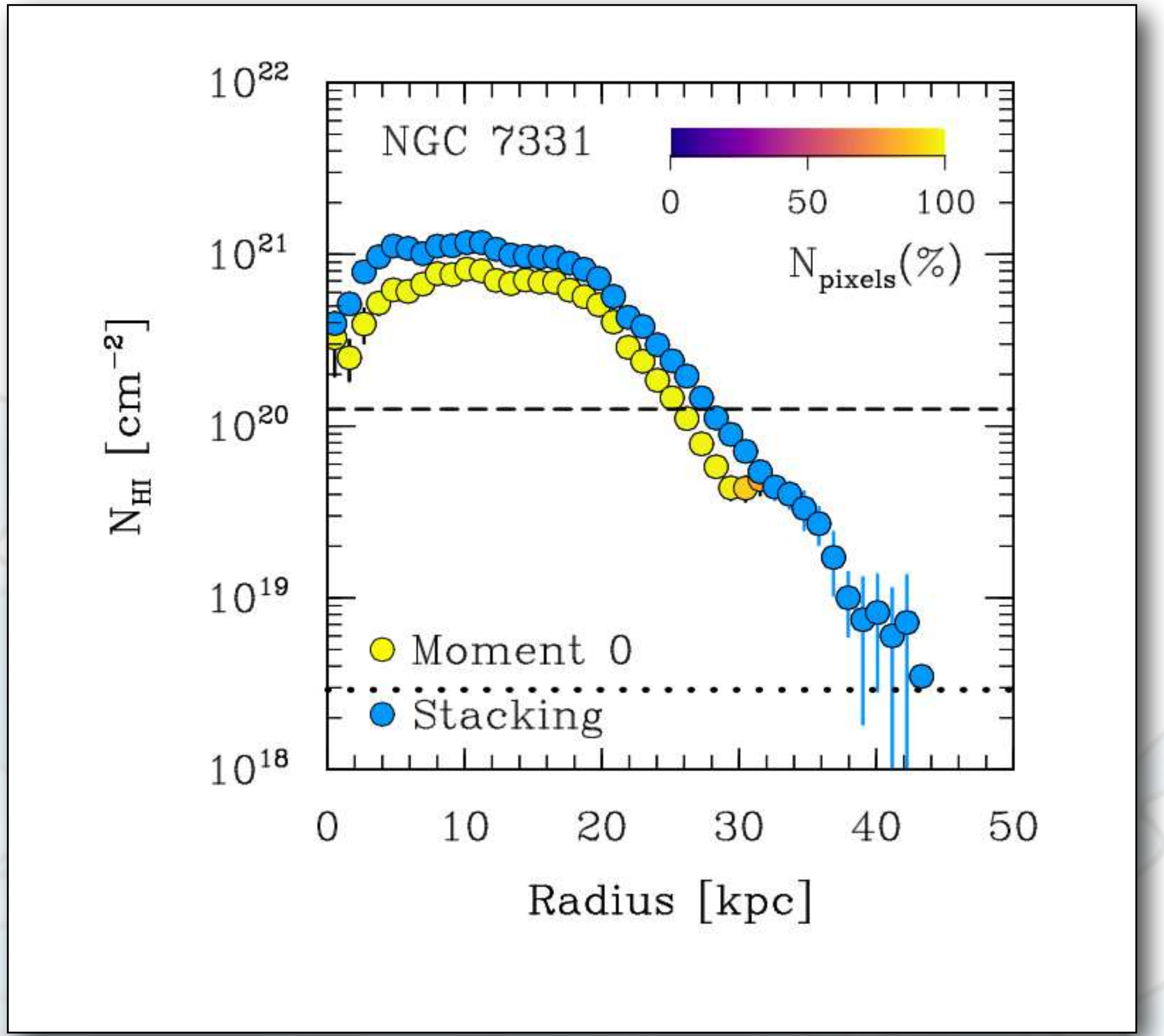
no room for substantial amounts of low column density HI around galaxies



Braun 2012

But stacking reveals low column density gas on smaller scales





Ianjamasimanana et al. 2018

No edges to the disk. Gas below photo-ionisation limits.

Gas must be clumpy / filamentary, on scales of ~1 kpc.

Resolution GBT is too low

So maybe it is like M83

filaments of ~1 kpc width out to very large radius

Meerkat should be great for detection this!

Same sensitivity as GBT but at resolution matching the structures

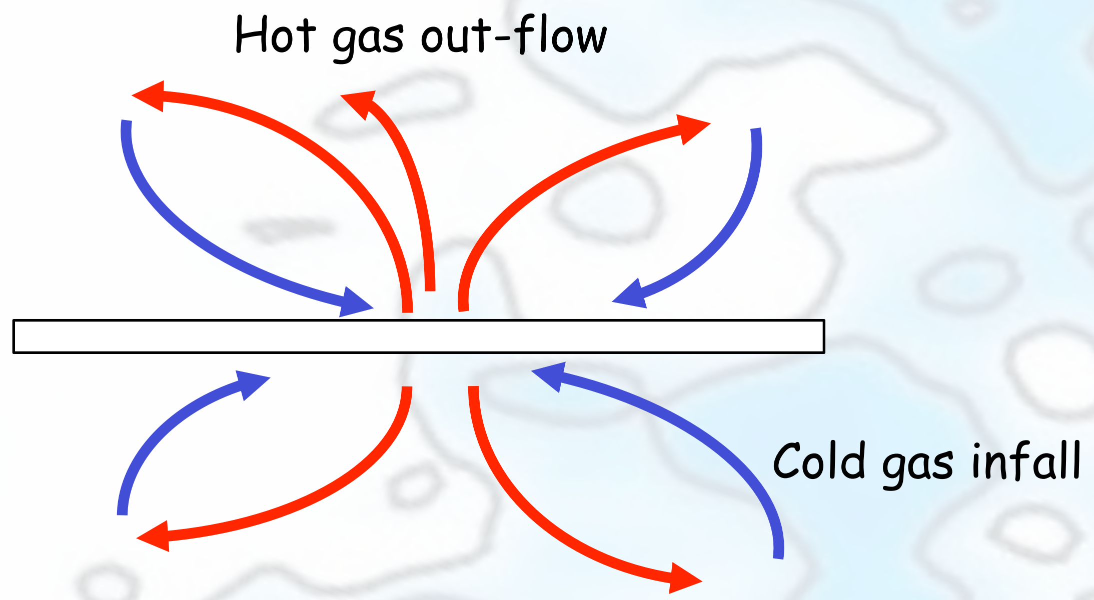
2008 review

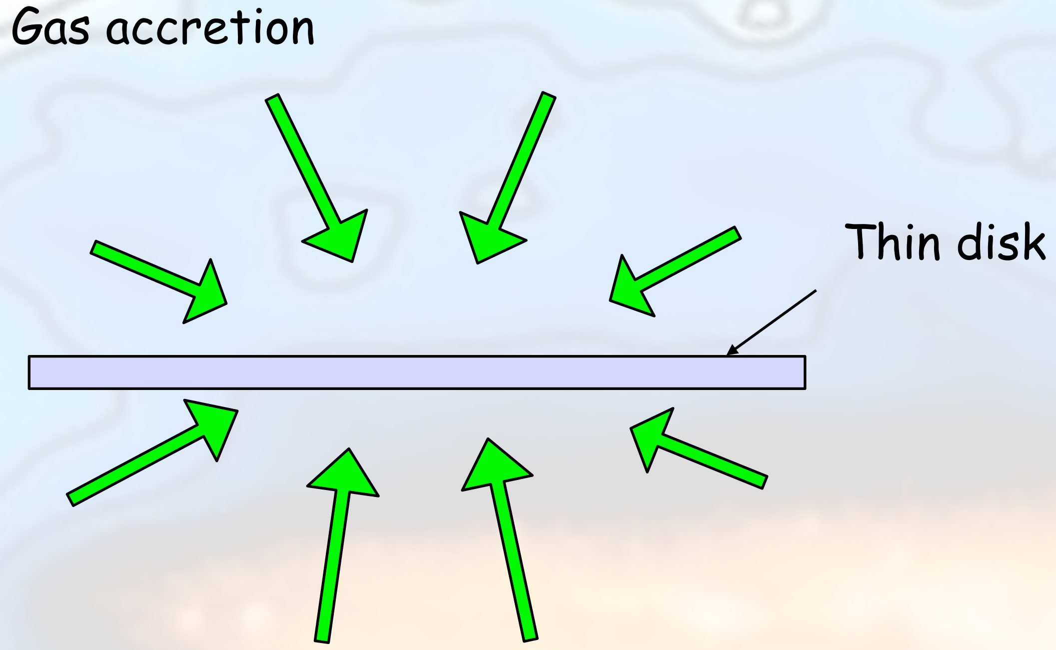
'Considerable amounts of extra-planar H I have been found in nearby spiral galaxies. While a large fraction of this gas is undoubtedly produced by galactic fountains, it is likely that a part of it is of extragalactic origin.'

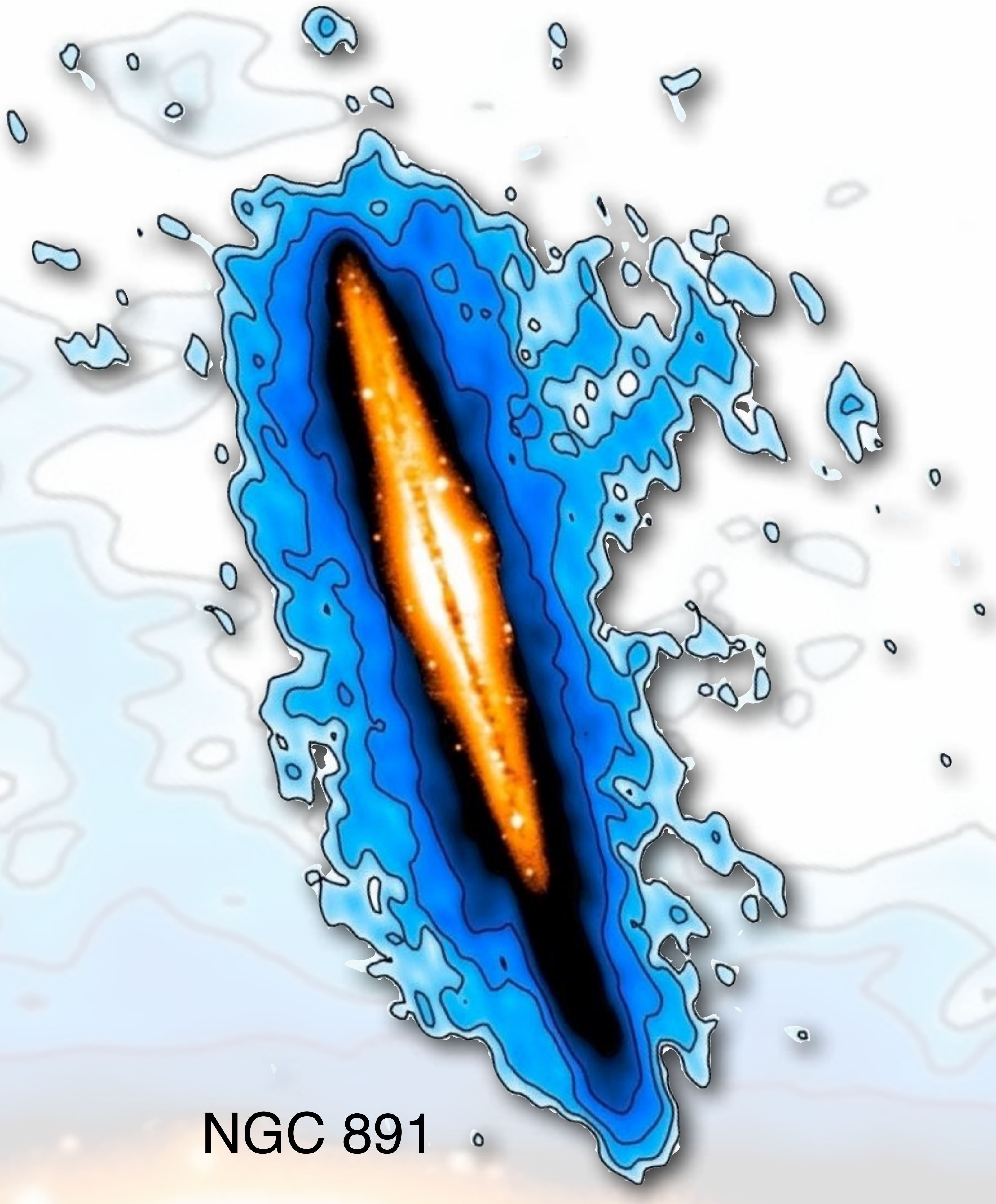
Important to understand the origin of this HI

(Now re-discovered as outflows in the optical…)

- Two components:
  - Galactic fountains (IVC)
    few kpc thick
    lagging rotation
  - Accretion (HVC)

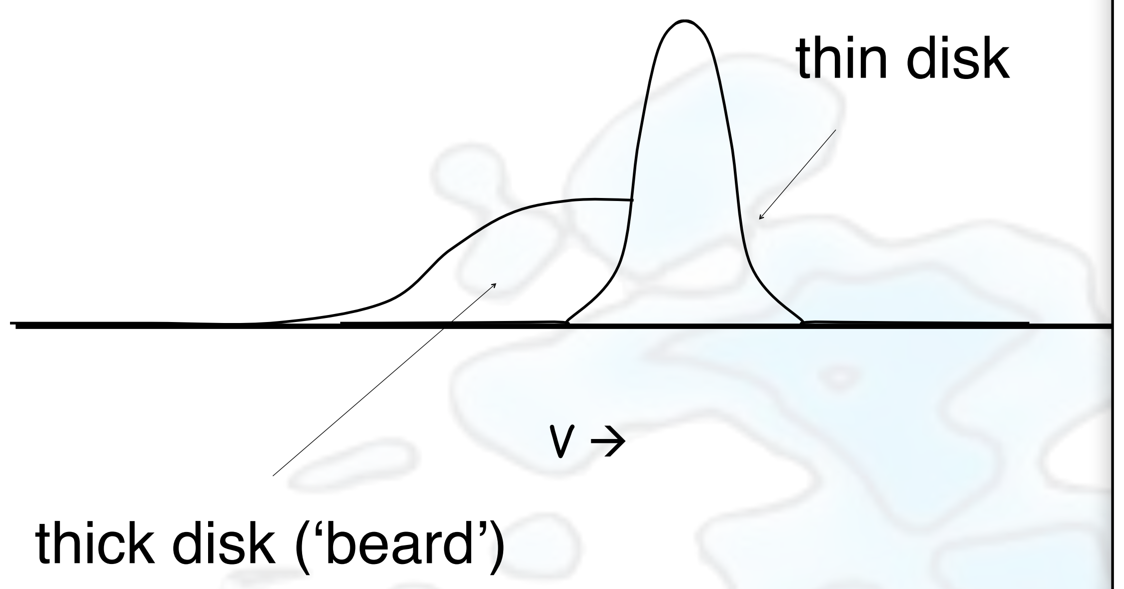


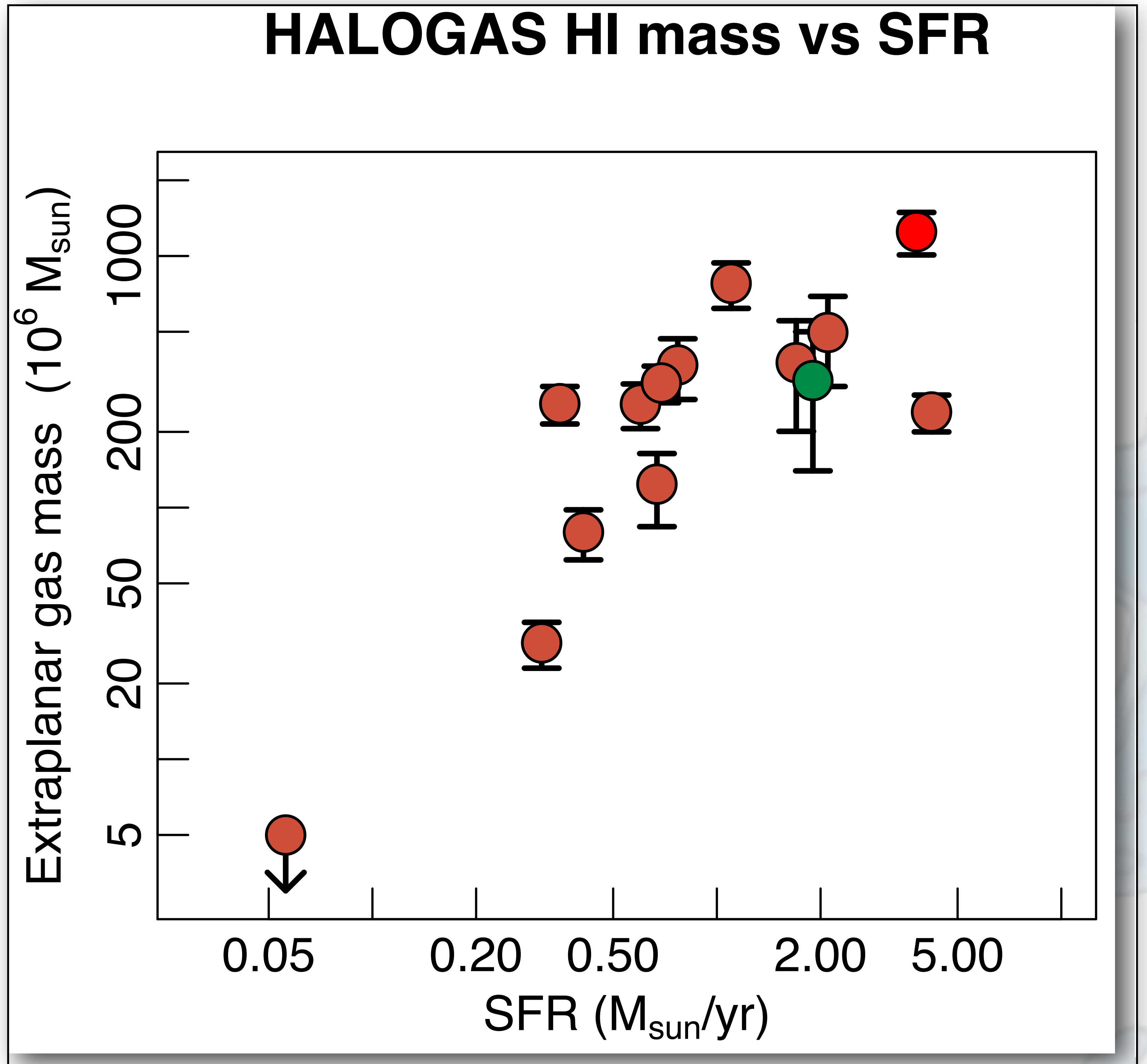



NGC 891

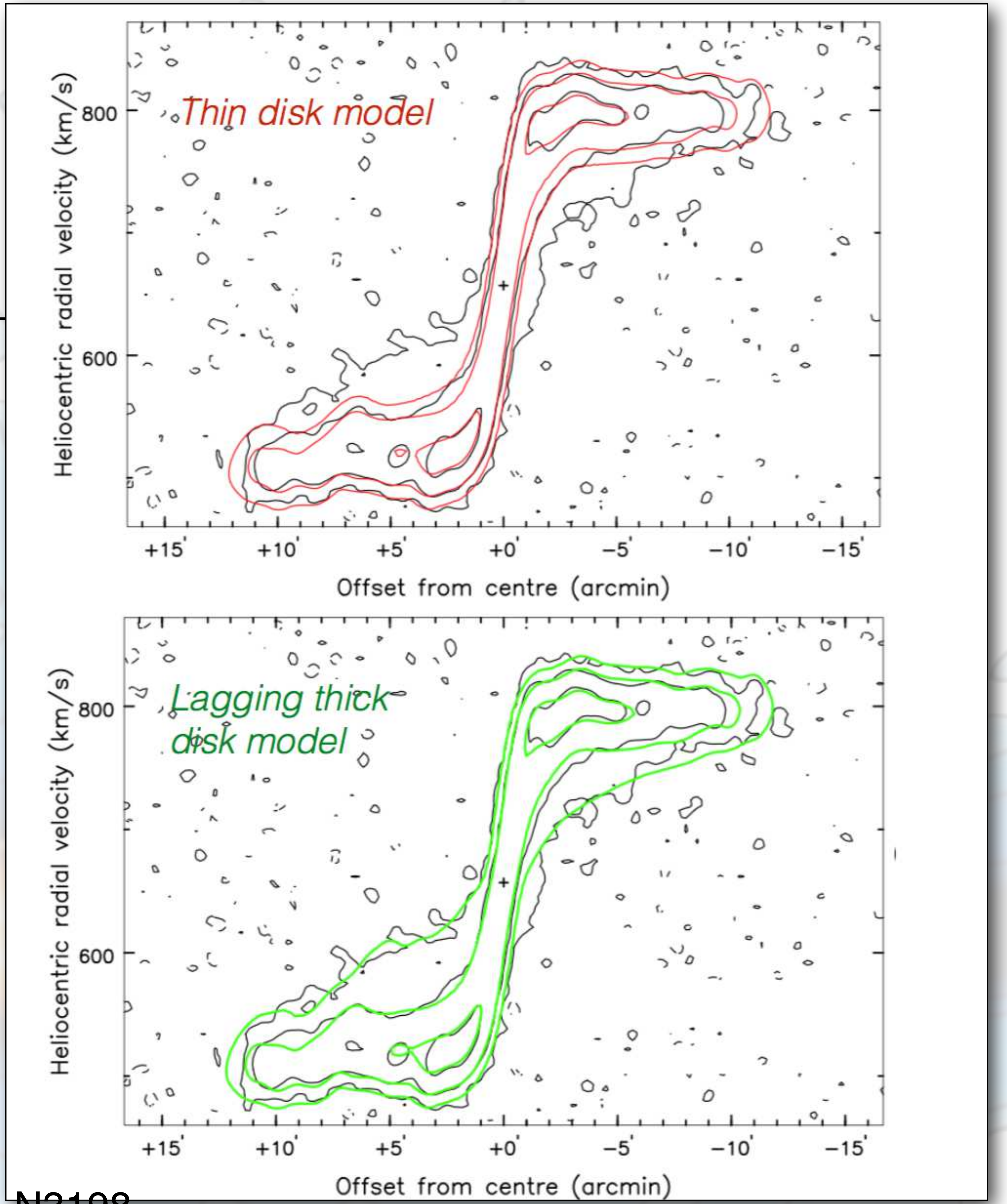
HALOGAS survey shows that lagging, thick HI disks are common and that their properties correlate with star formation.
But N891 is unusual!!!

Separate thin disk H I from thick disk H I



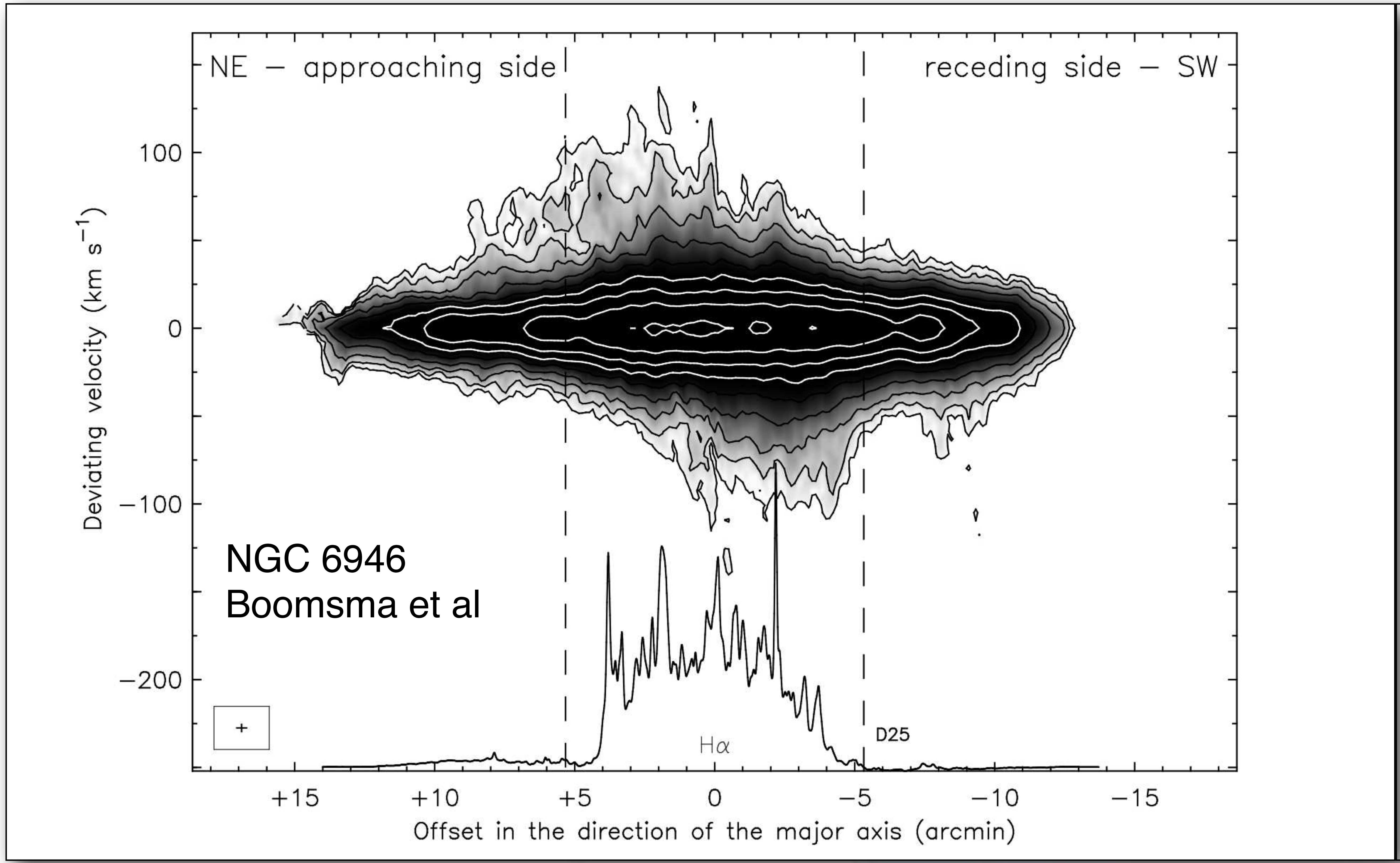


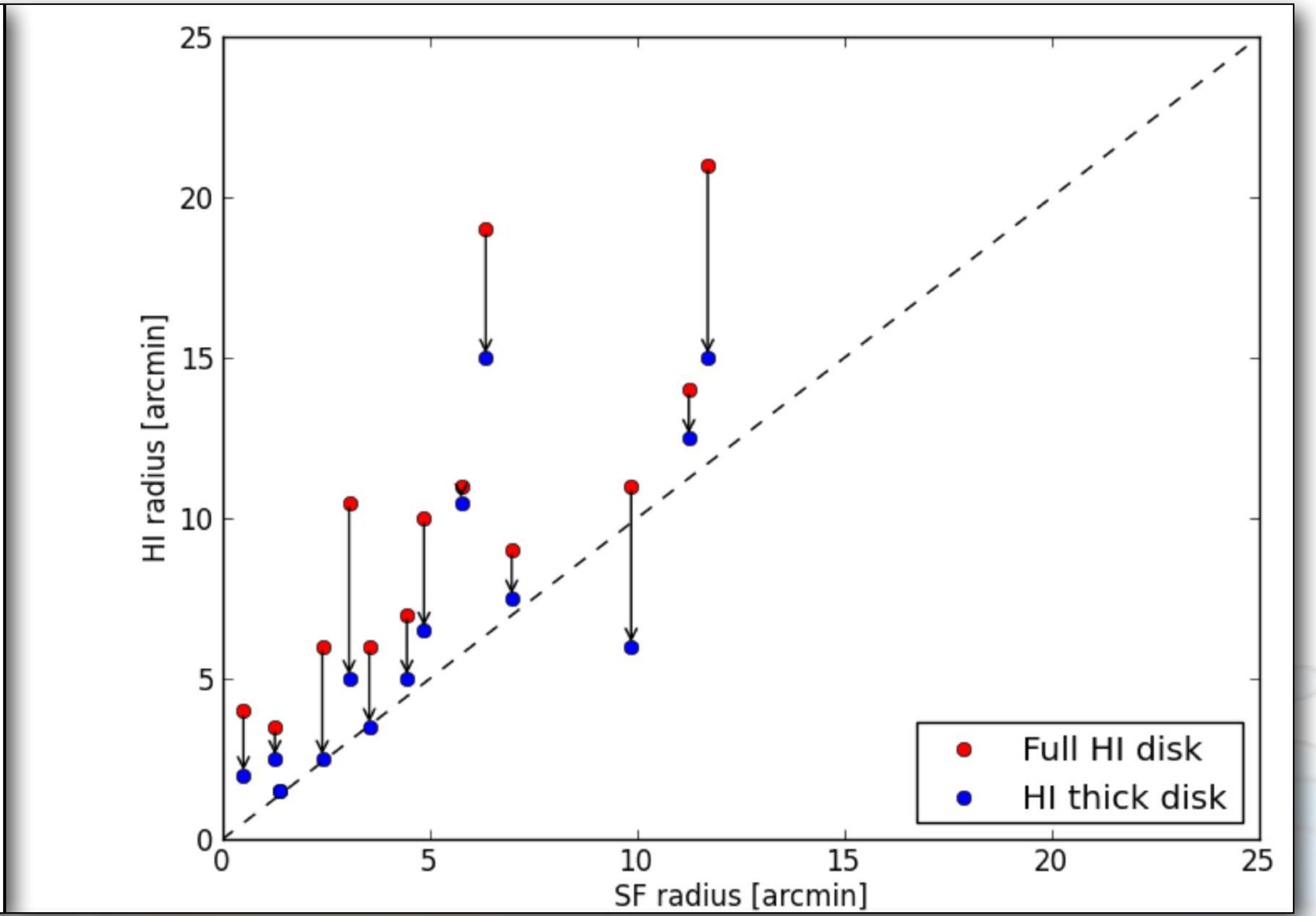
Gentile et al 2013.



N3198

Radial extent of thick HI disk is about the same as that of the star formation





Thick disks indicate very significant gas circulation

Halogas

Typical HI masses of thick disks are 10^8 M_{sol}
so gas circulation of at least 10 M_{sol}/yr

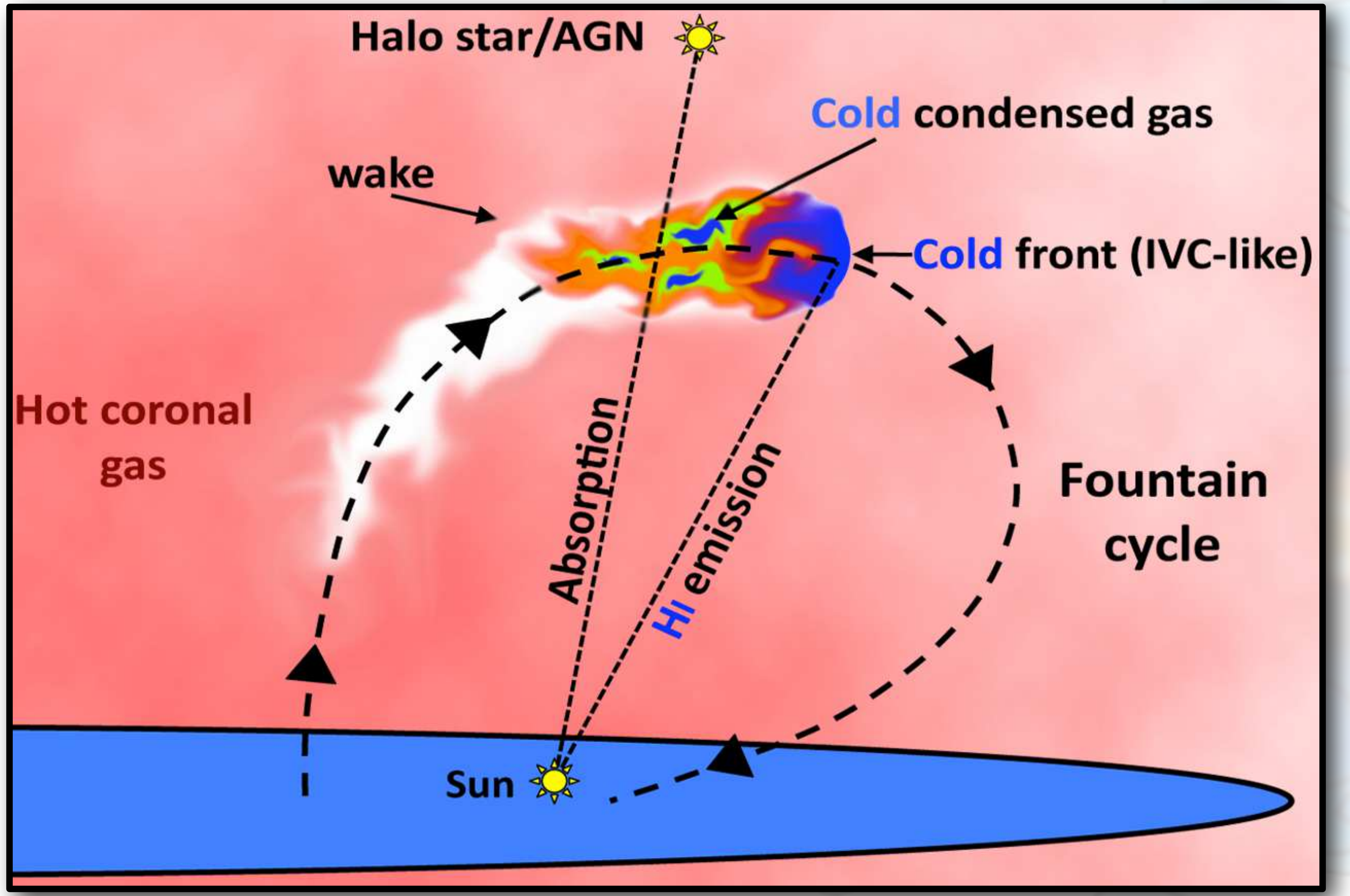
The role of thick HI disks in accretion

Basic idea: star formation blows gas into halo, gas cools and falls back to disk

Interaction with hot halo induces cooling of hot gas.

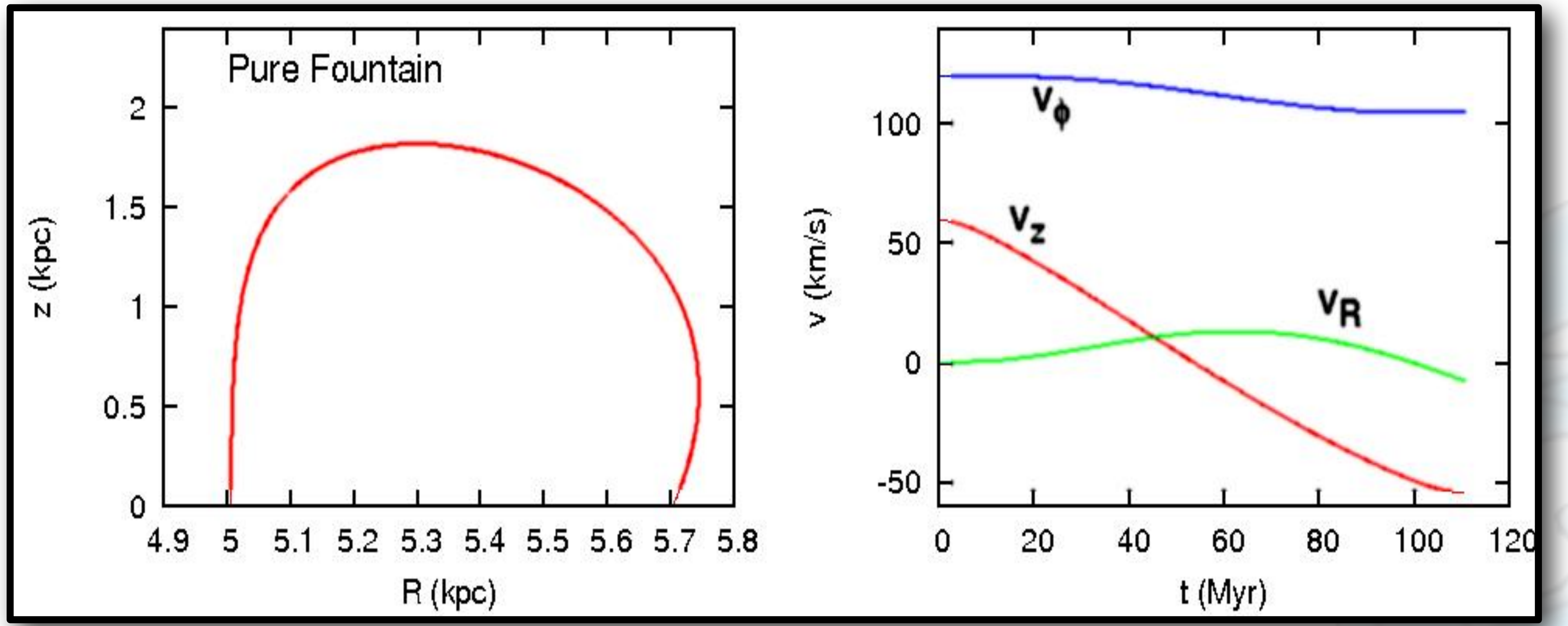
More cold gas rains down that was shot up!

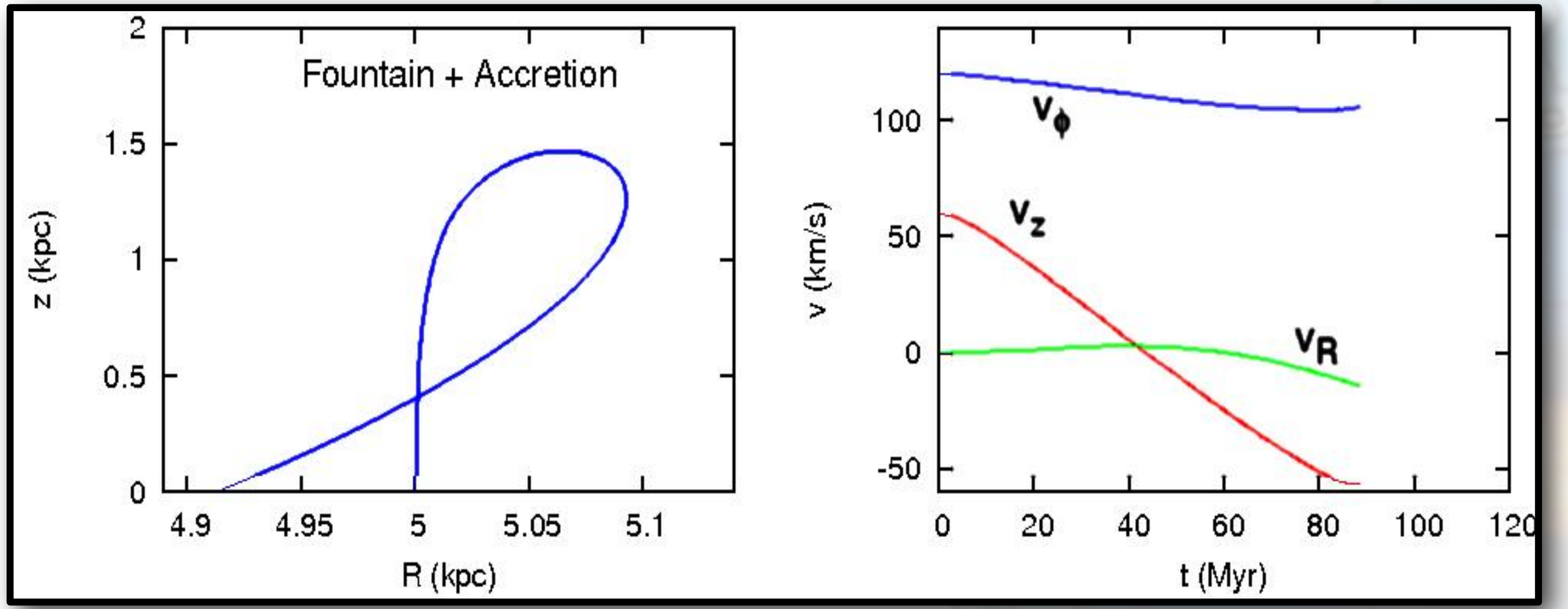
Induced accretion at rates sufficient to maintain star formation



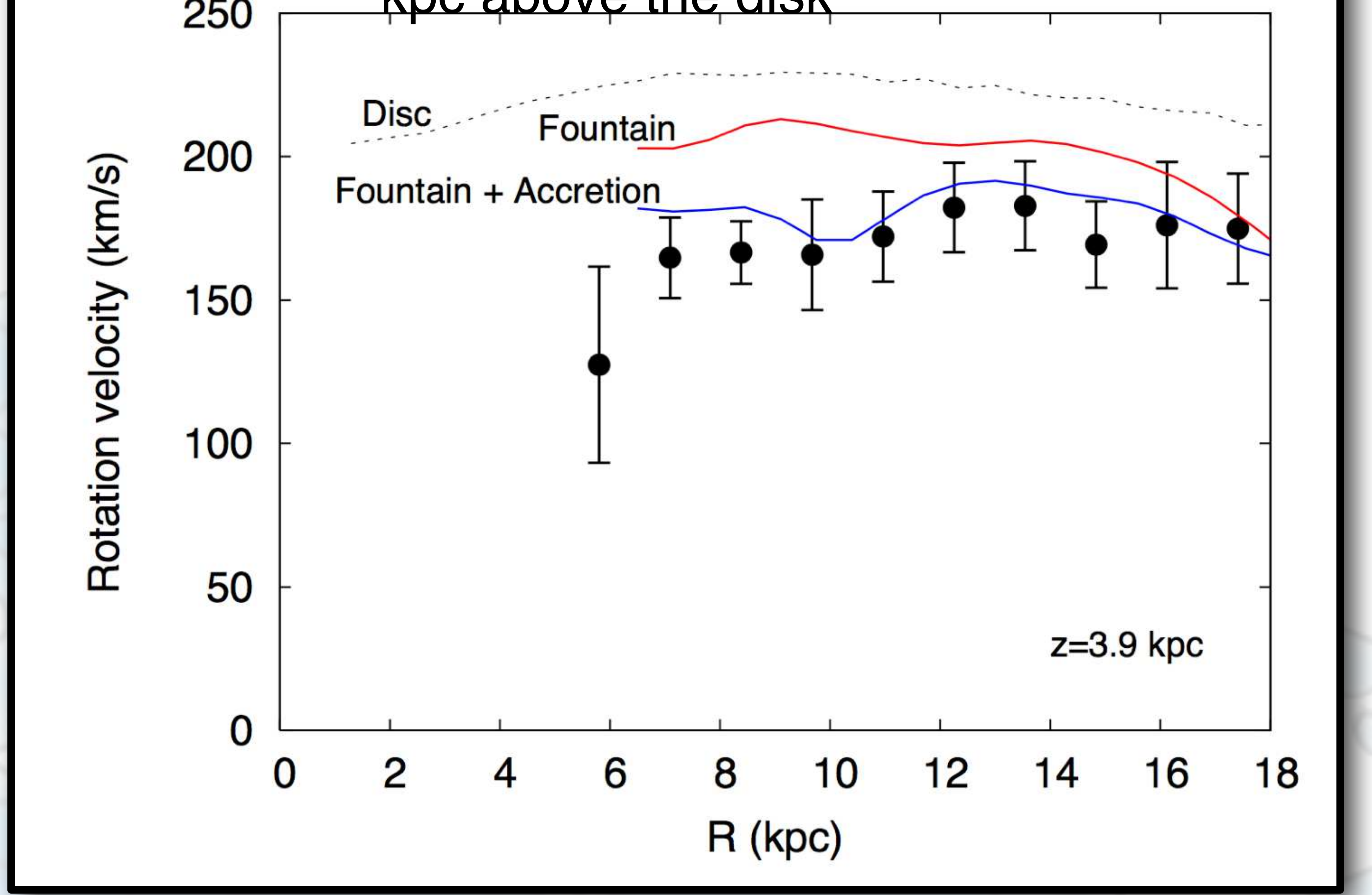
Fraternali, Marinacci, Marasco, Armilotta,… many papers

Testable using kinematics





~~N891 rotation curve of thick disk 3.9 kpc above the disk~~



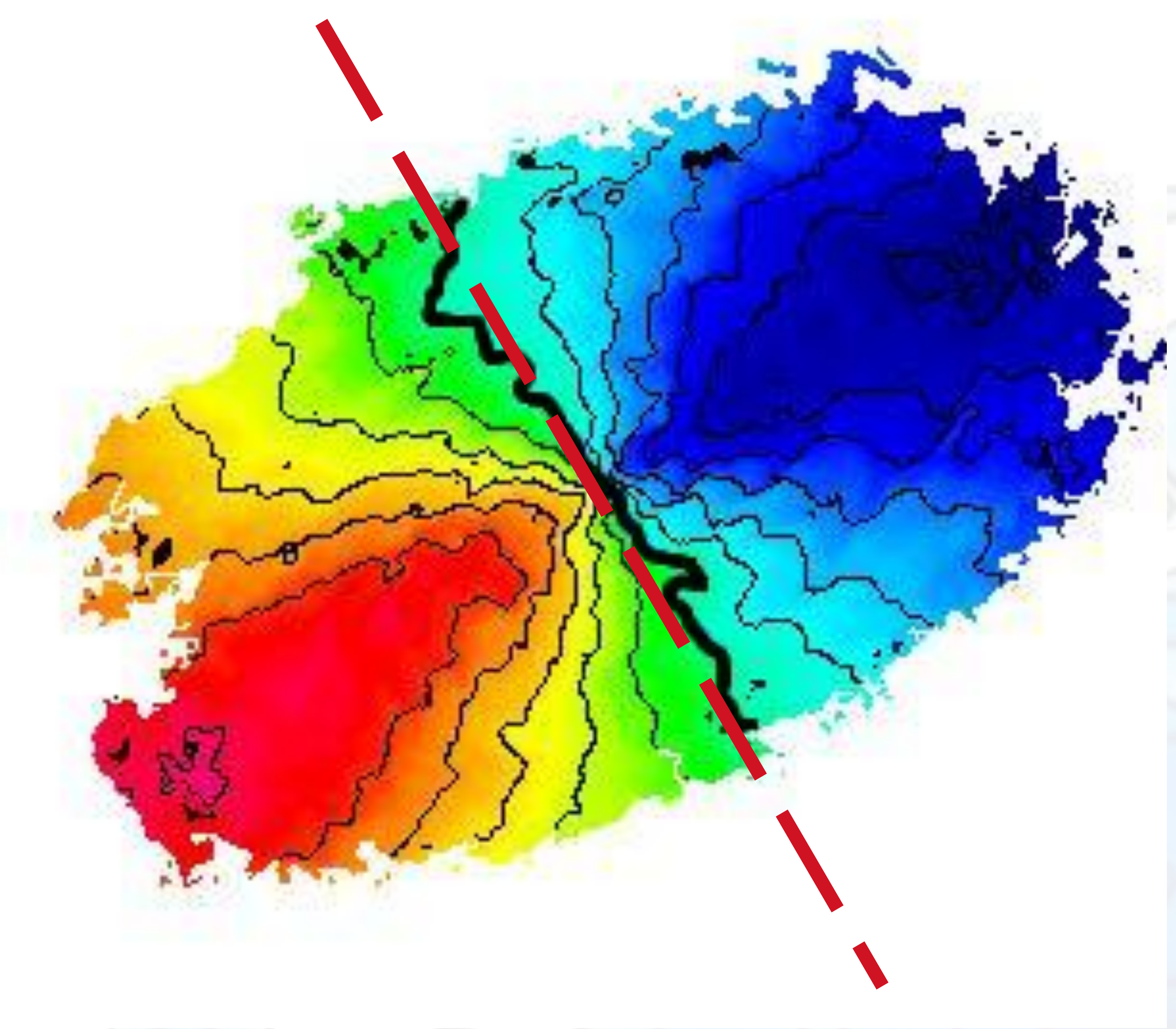
Fountain only model without accretion does not fit rotation of thick disk

Fountain+accretion does fit and provides the right amount of accretion

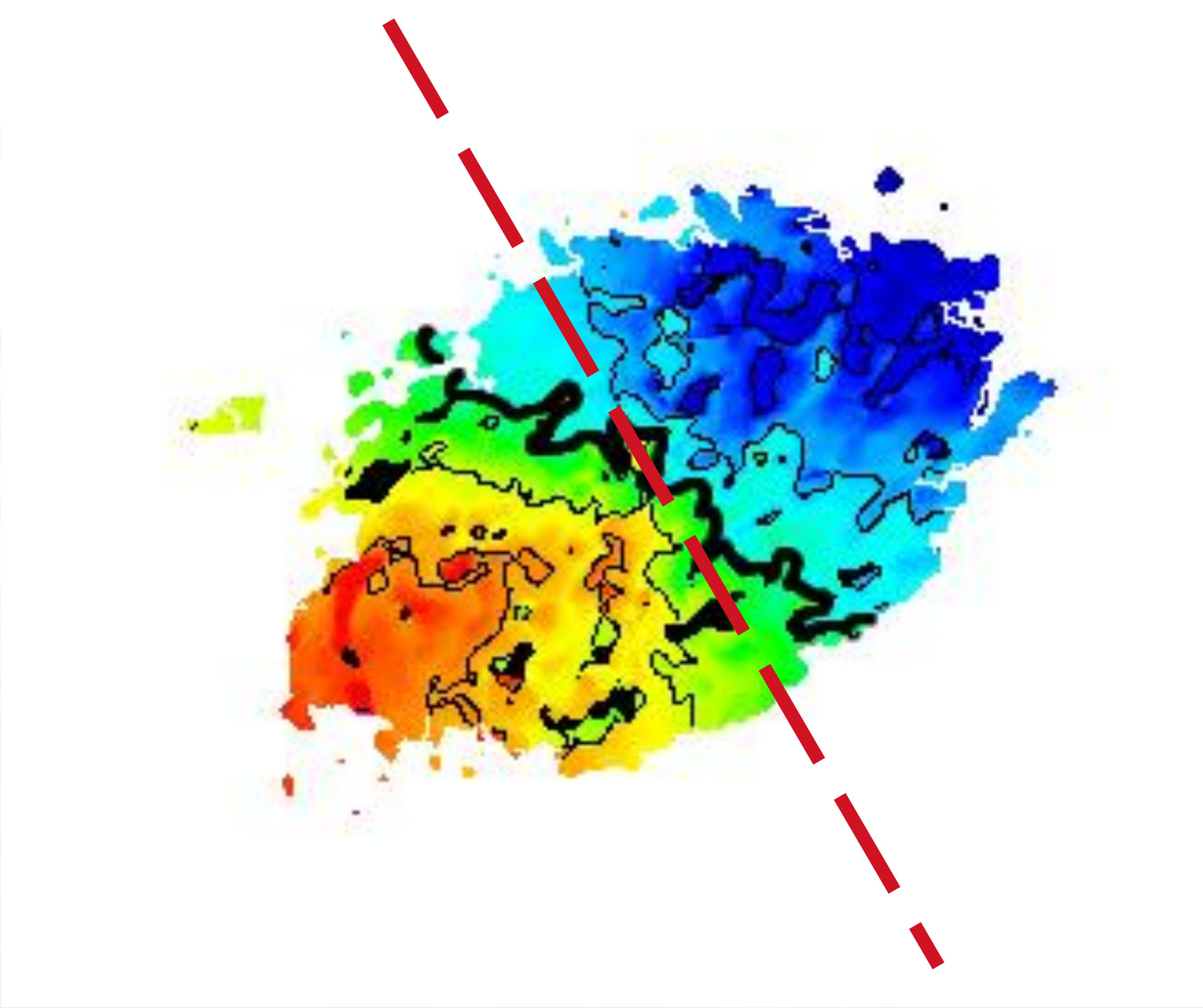
Fountain + accretion: thick disk has radial inflow

Radial motions are detected in thick disk

Disc gas



Extraplanar gas gas



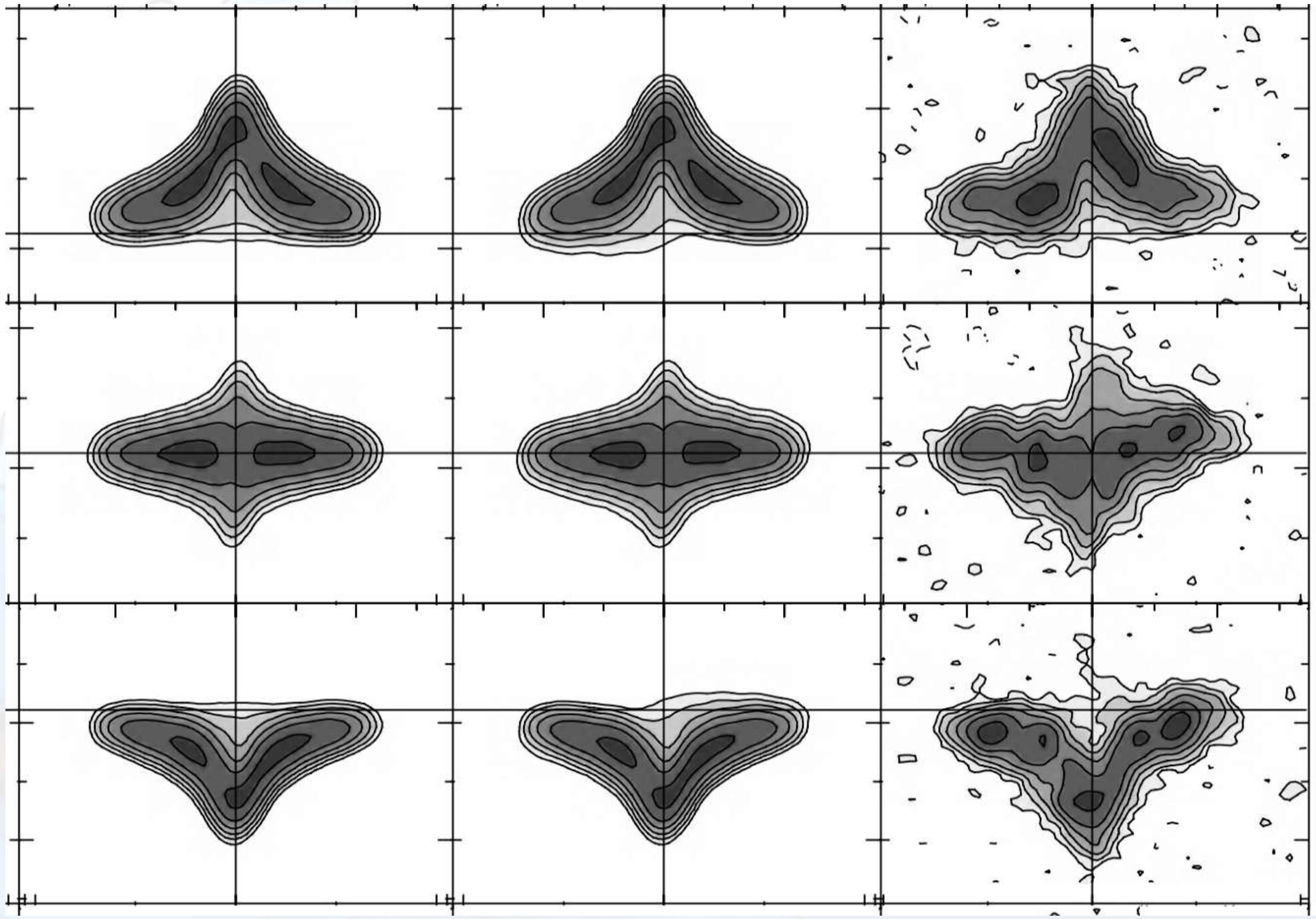
Fraternali et al. 2004

But not in every galaxy

Radial inflow of thick disk in N4559

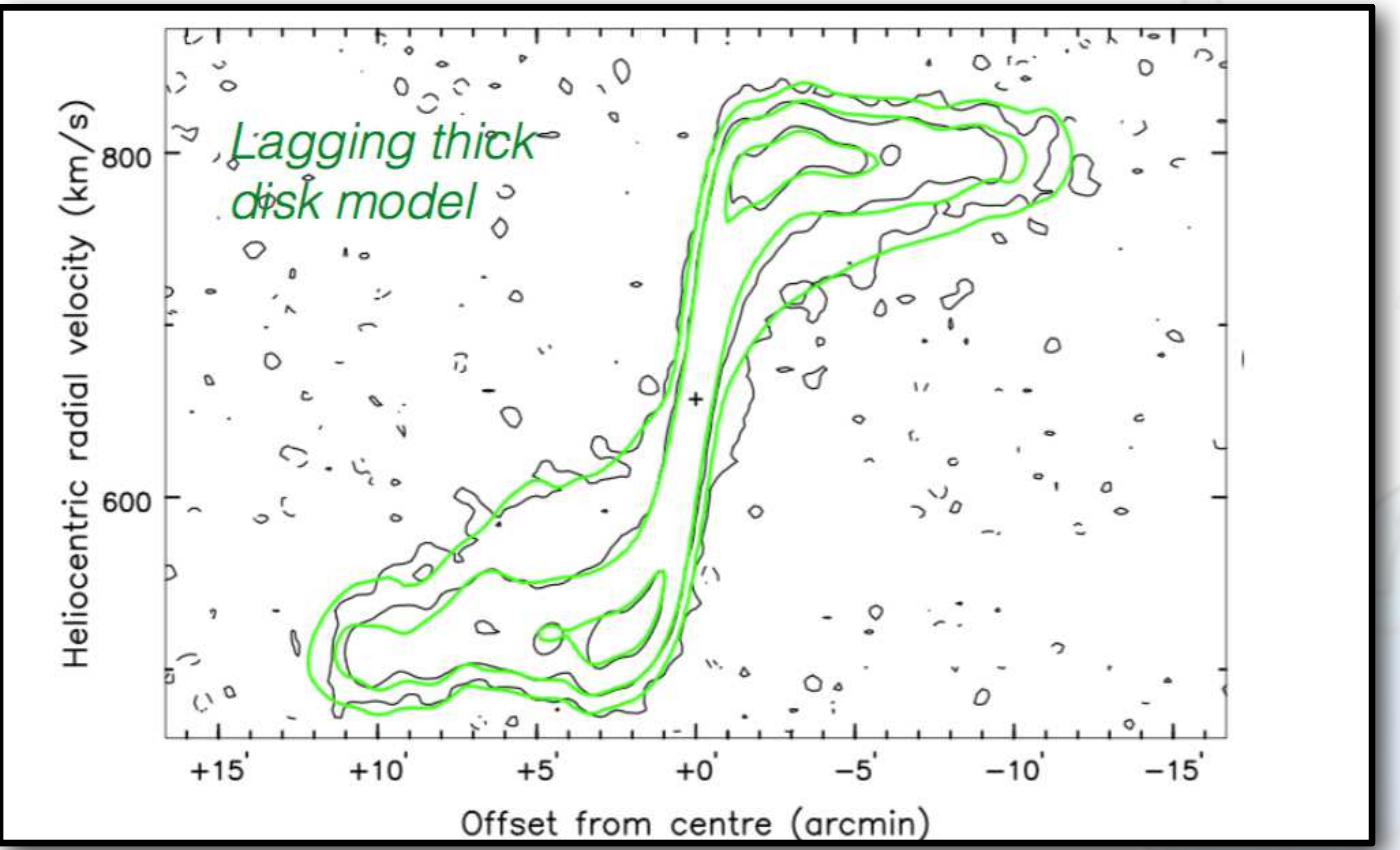
(Barbieri et al. 2005)

V



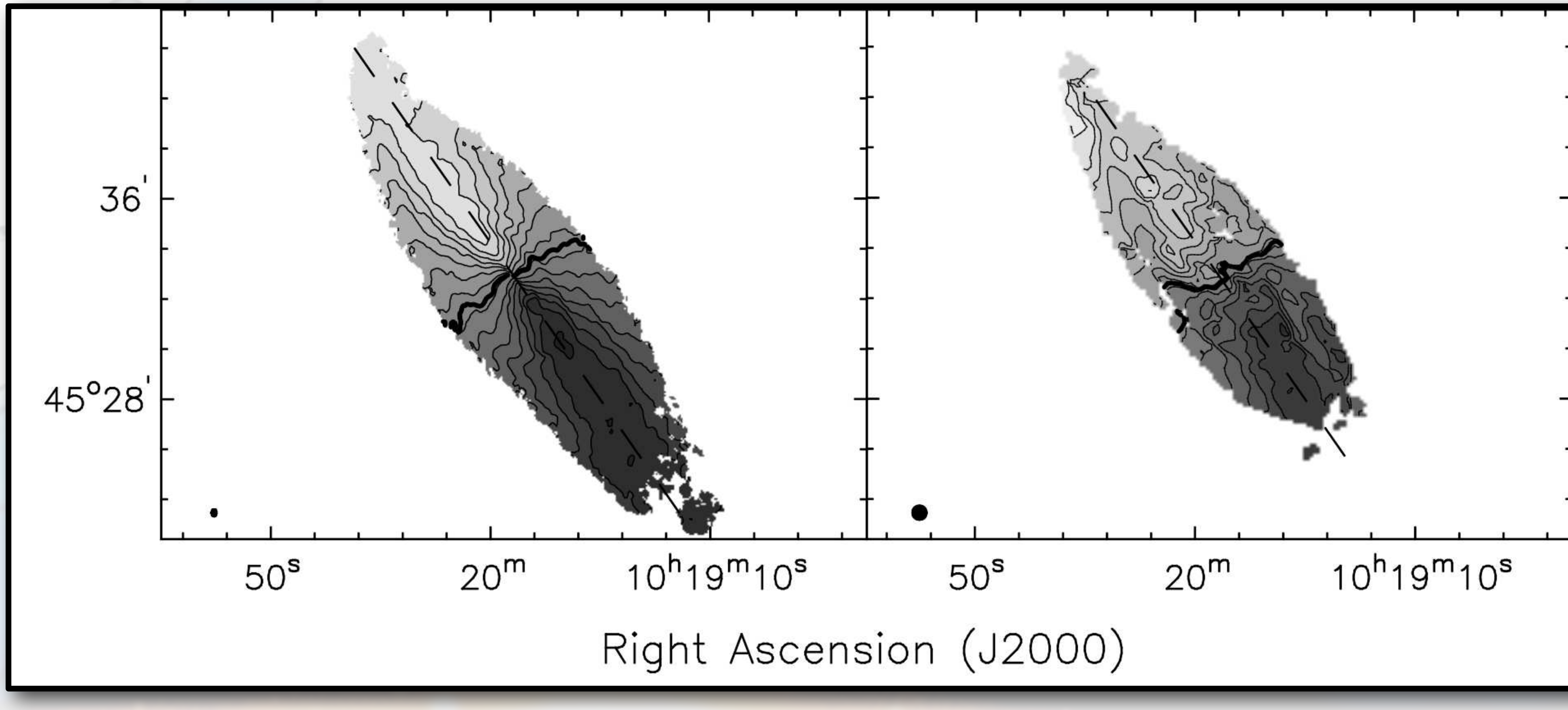
X

PV slices along minor axis



Disc gas

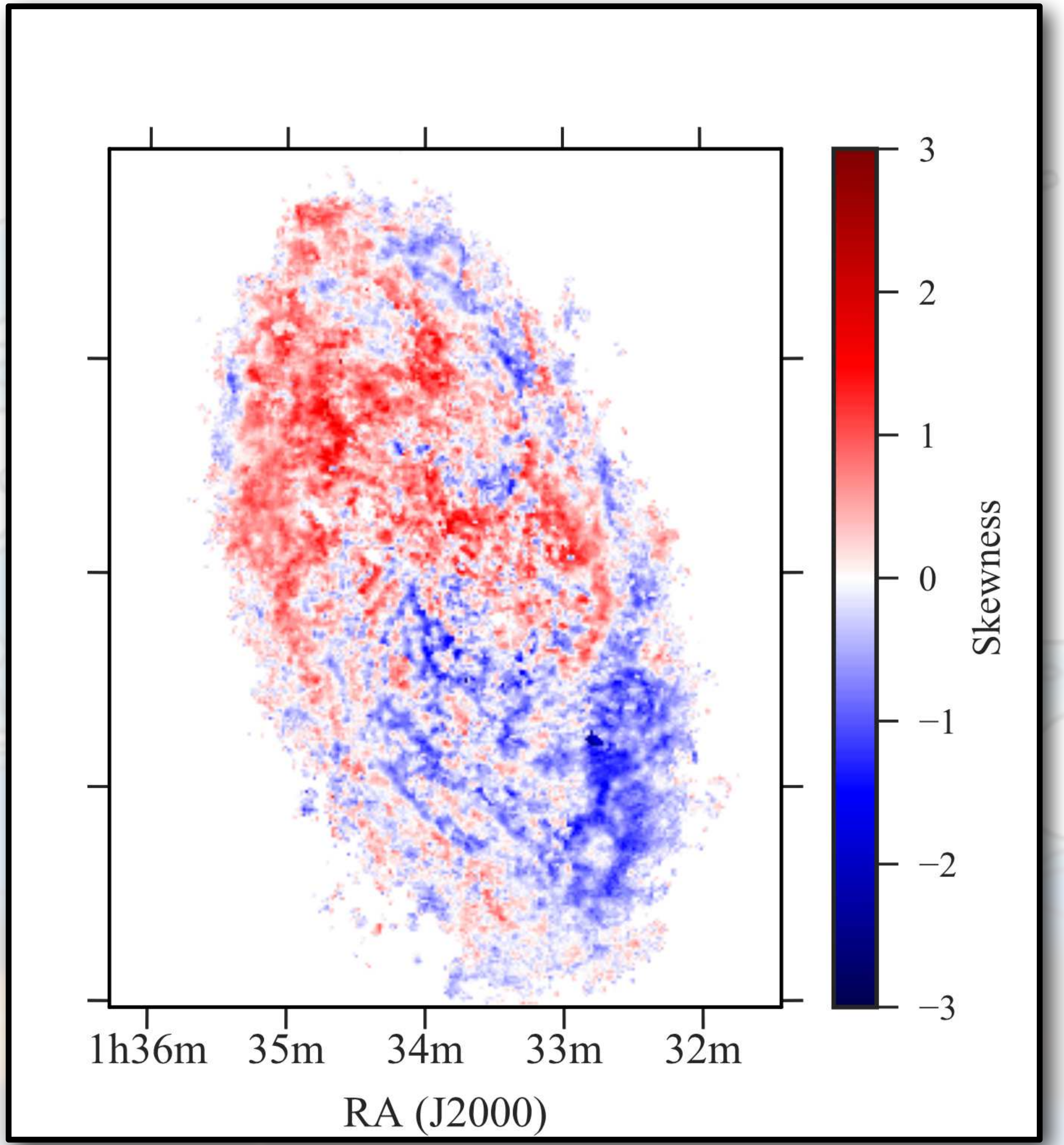
Extraplanar gas



NGC 3198 (Halogas)

prominent thick disk but at most subtle signs of inflow…

Perhaps radial motions in M33



Koch et al.2018

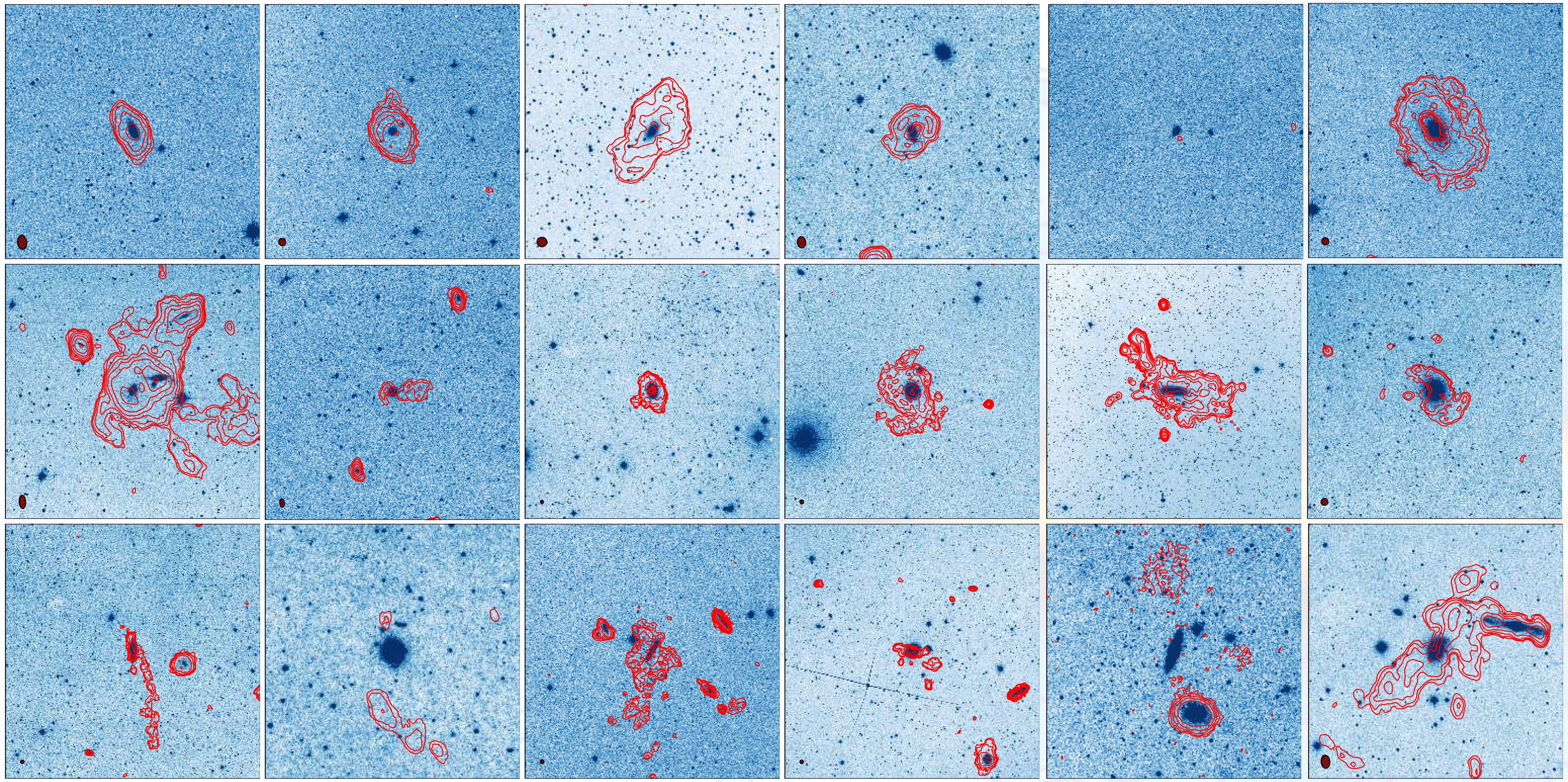
How about accretion in early-type galaxies?

Atlas^{3D} survey (Serra et al. 2012)

HI detection rate 40% in field, 10% in Virgo. HI is of low column density, too low for star formation.

Large range in morphology: disks/rings (large and small), strong warps, polar rings, tails, clouds.

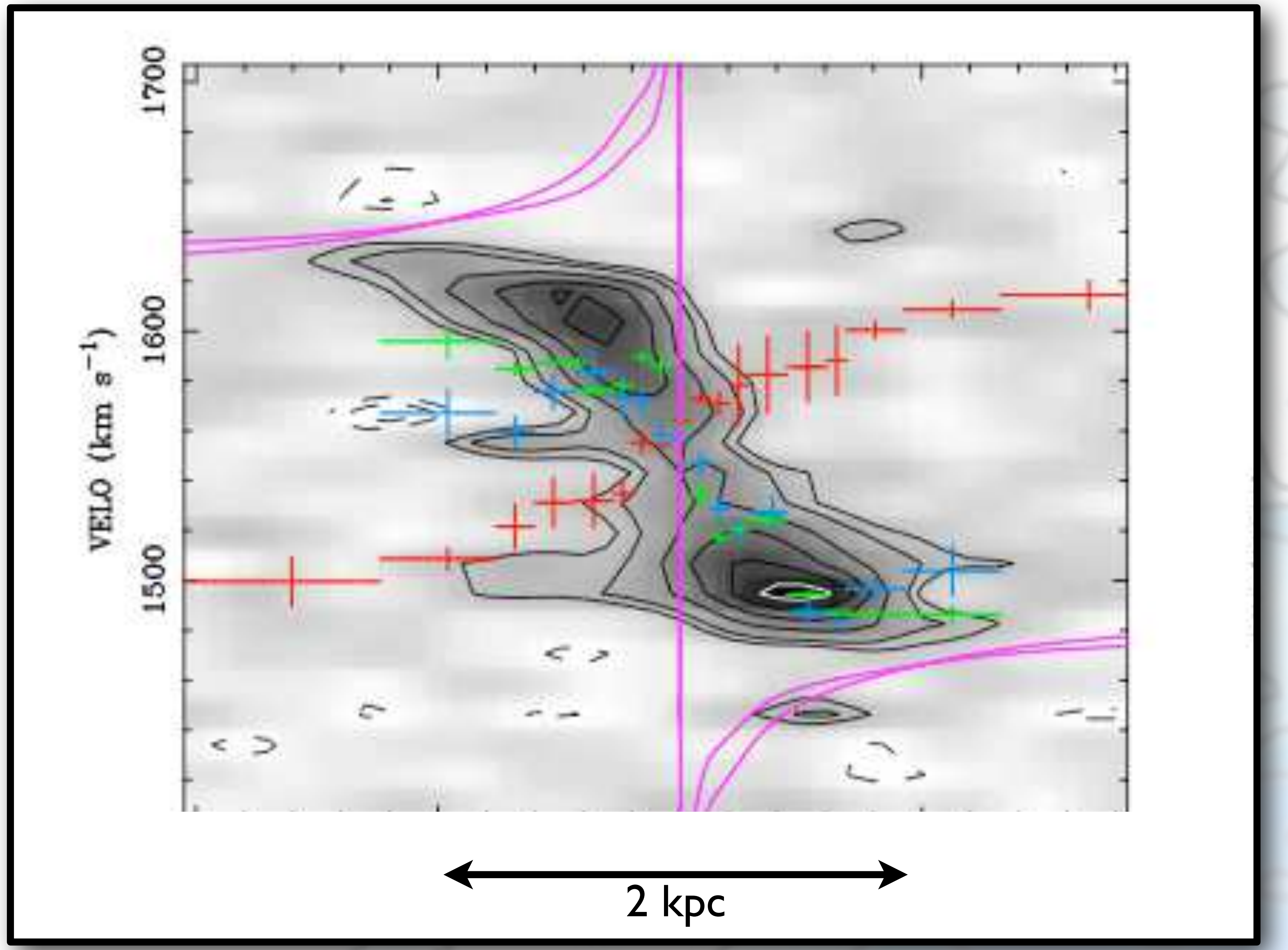
Many signs of ongoing accretion, interaction, stripping



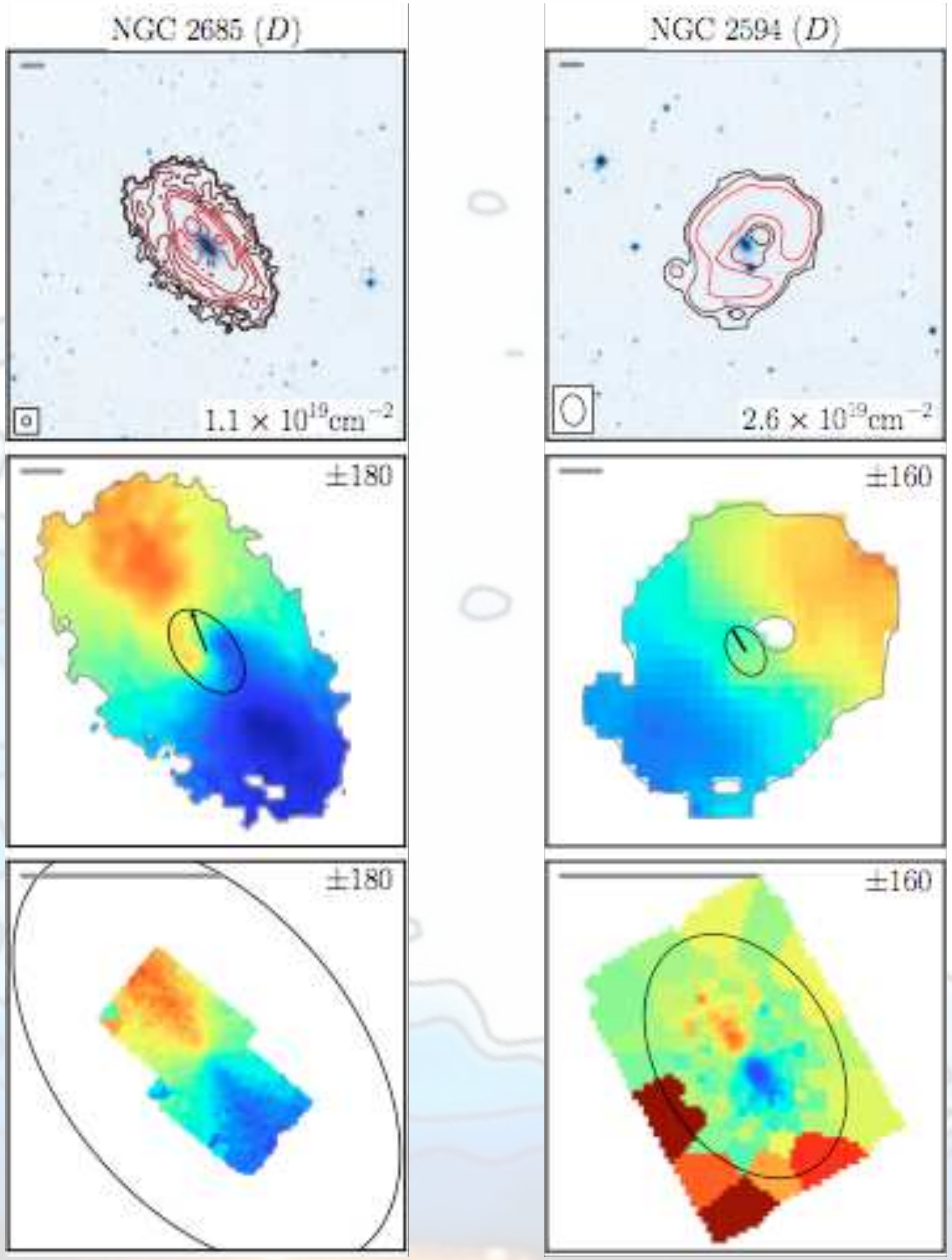
Accretion in early-type galaxies

- many early-type galaxies in the field are also accreting small companions. Accretion of small amounts of HI, only small impact on galaxy

- Many field ETGs have gas disks (seen in HI, CO and ionised gas),
- many HI disk are counter rotating, polar or strongly warped

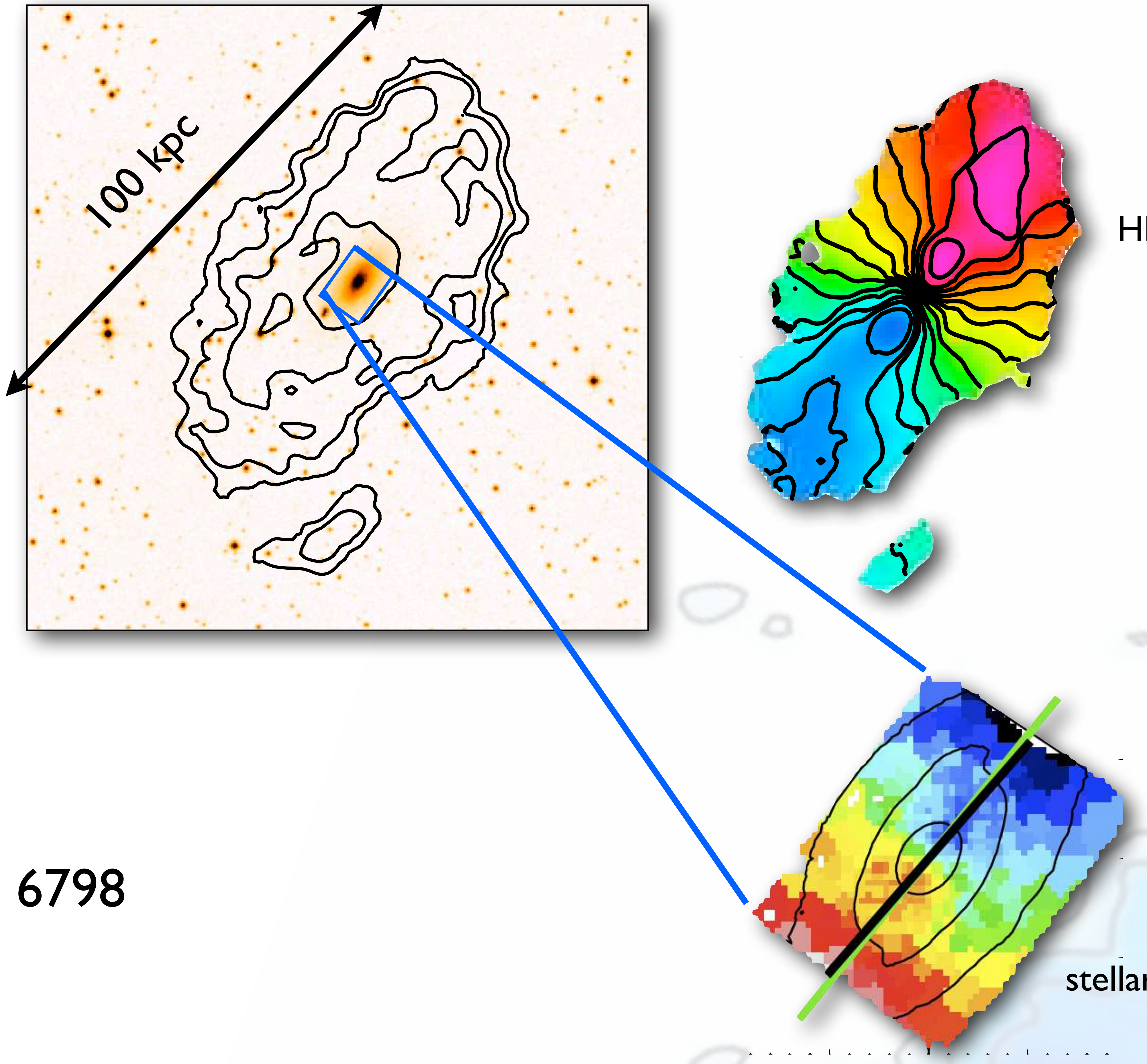


NGC 3032.
Contours gas, red symbols stars
green ionised gas



Early-type galaxies

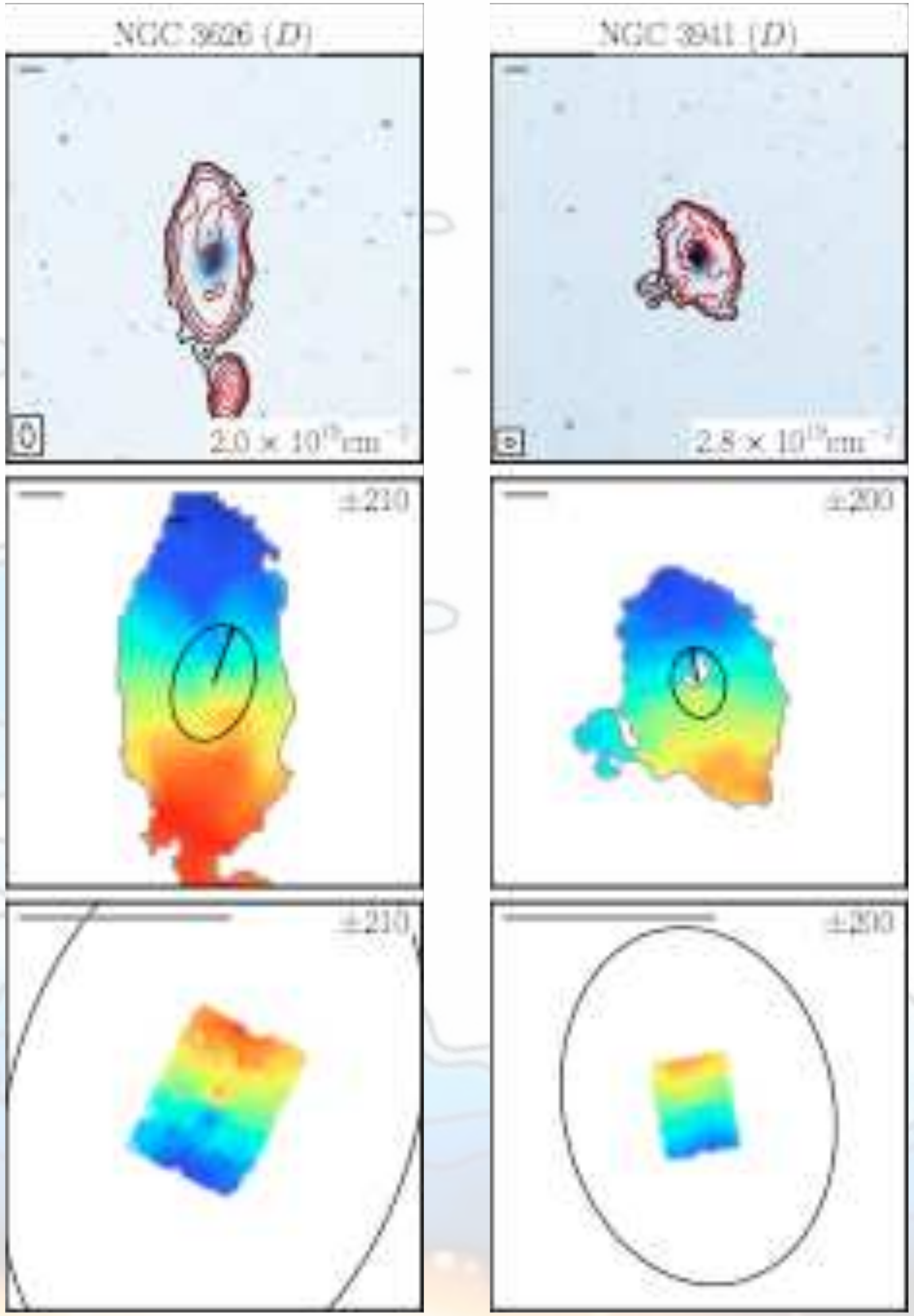
- Surprisingly often these (counter-rotating) disks are huge!!!



HI velocity field

stellar velocity field

NGC 6798

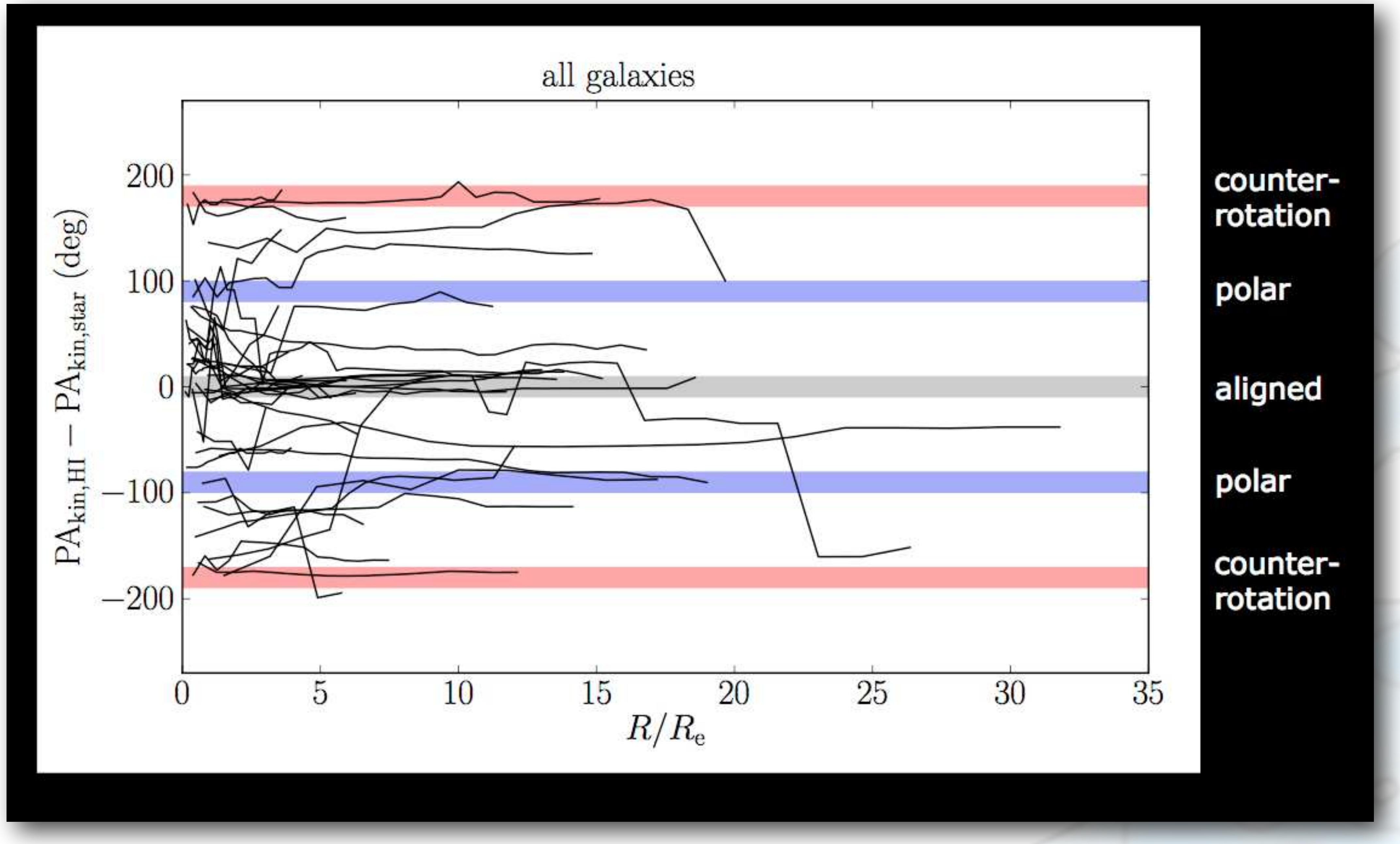


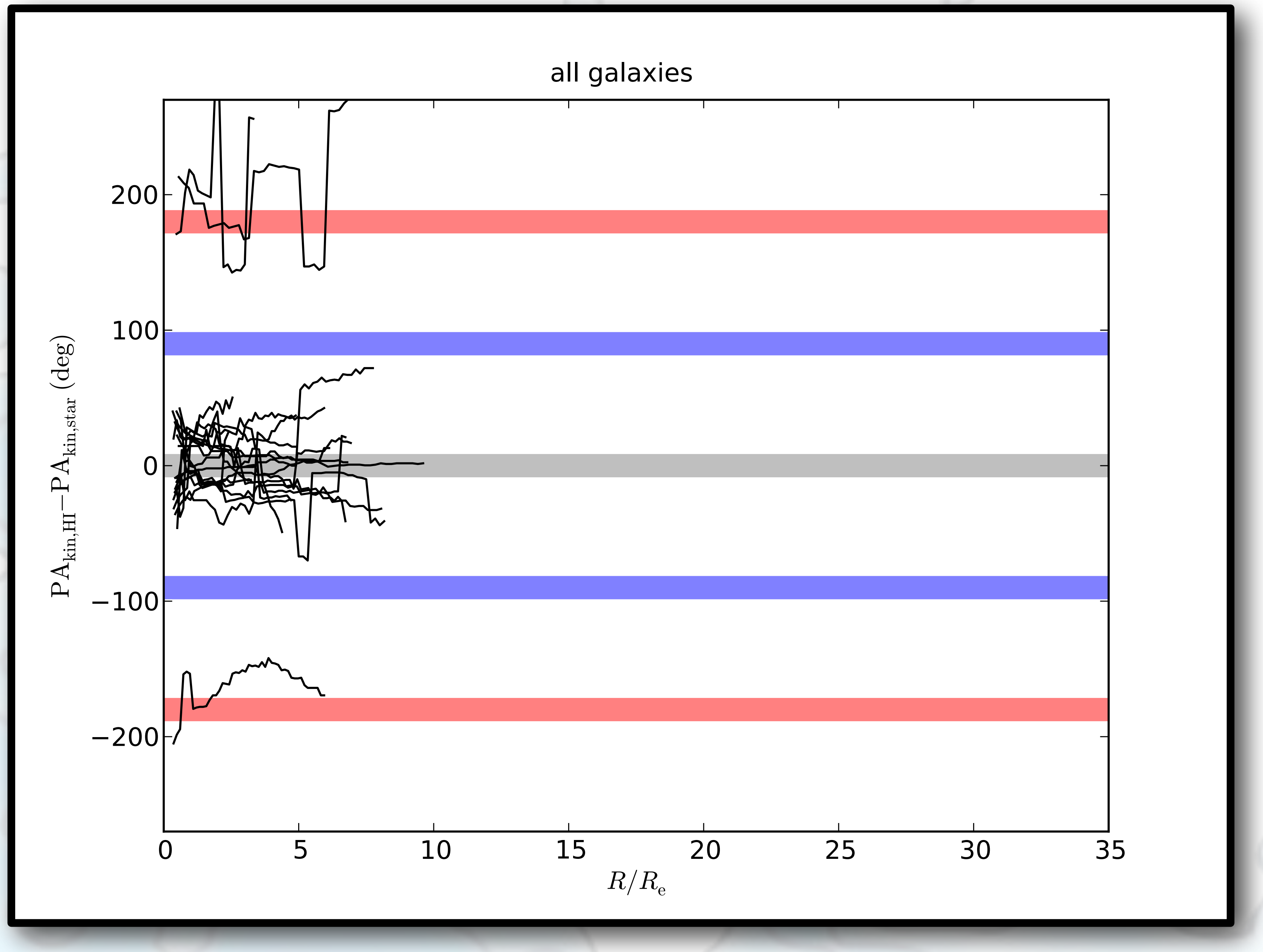
HI disk (100 kpc diameter) counterrotating containing 4 10^9 Msol of HI.

HI column density is low ($<10^{20}$ cm^{-2}),
so no star formation in these disks, despite the large HI mass.
These disks must be quite old
Such large HI disks are fairly common

Distribution of misalignments is a good test for simulations

Serra+ 2014



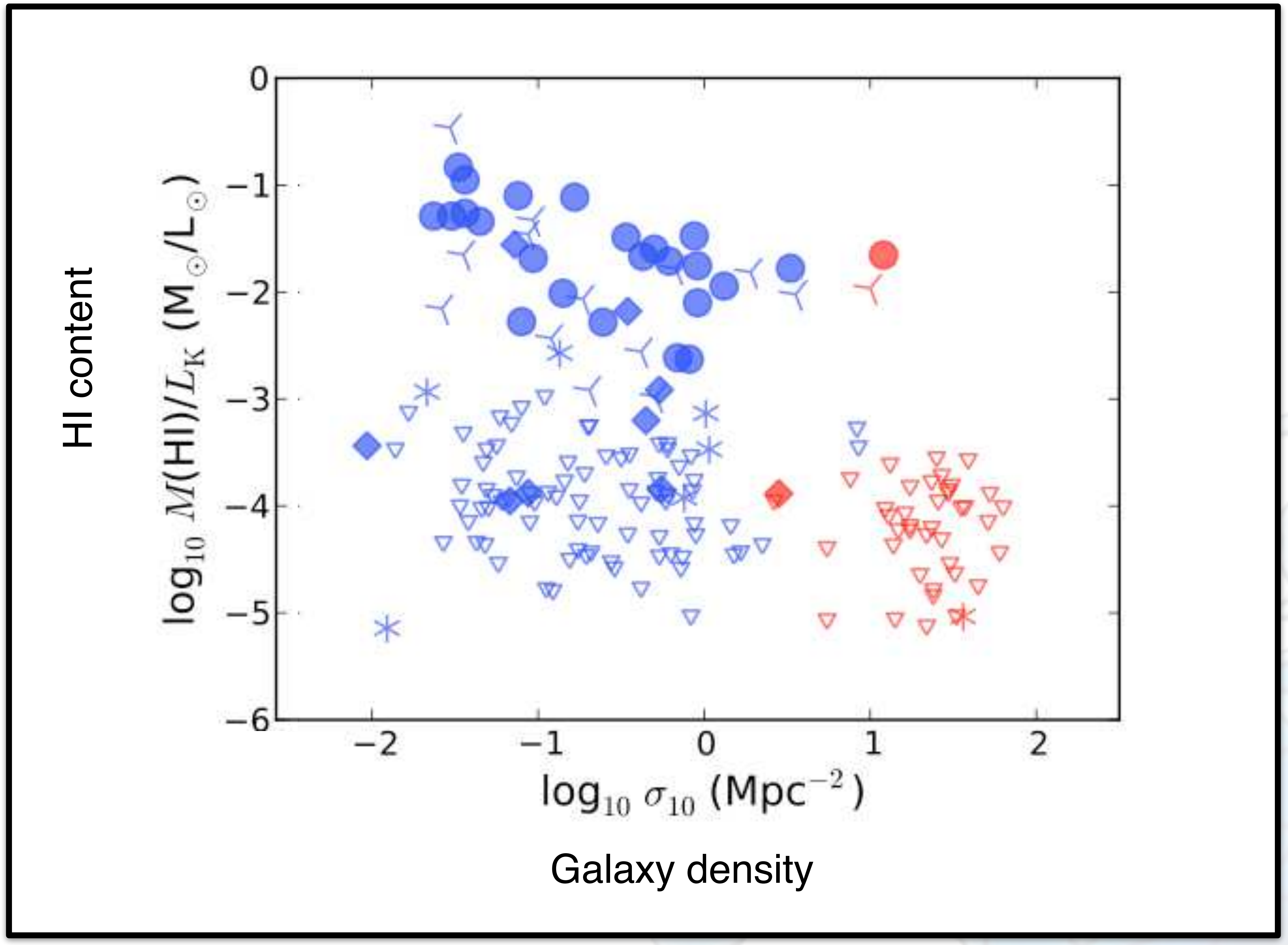


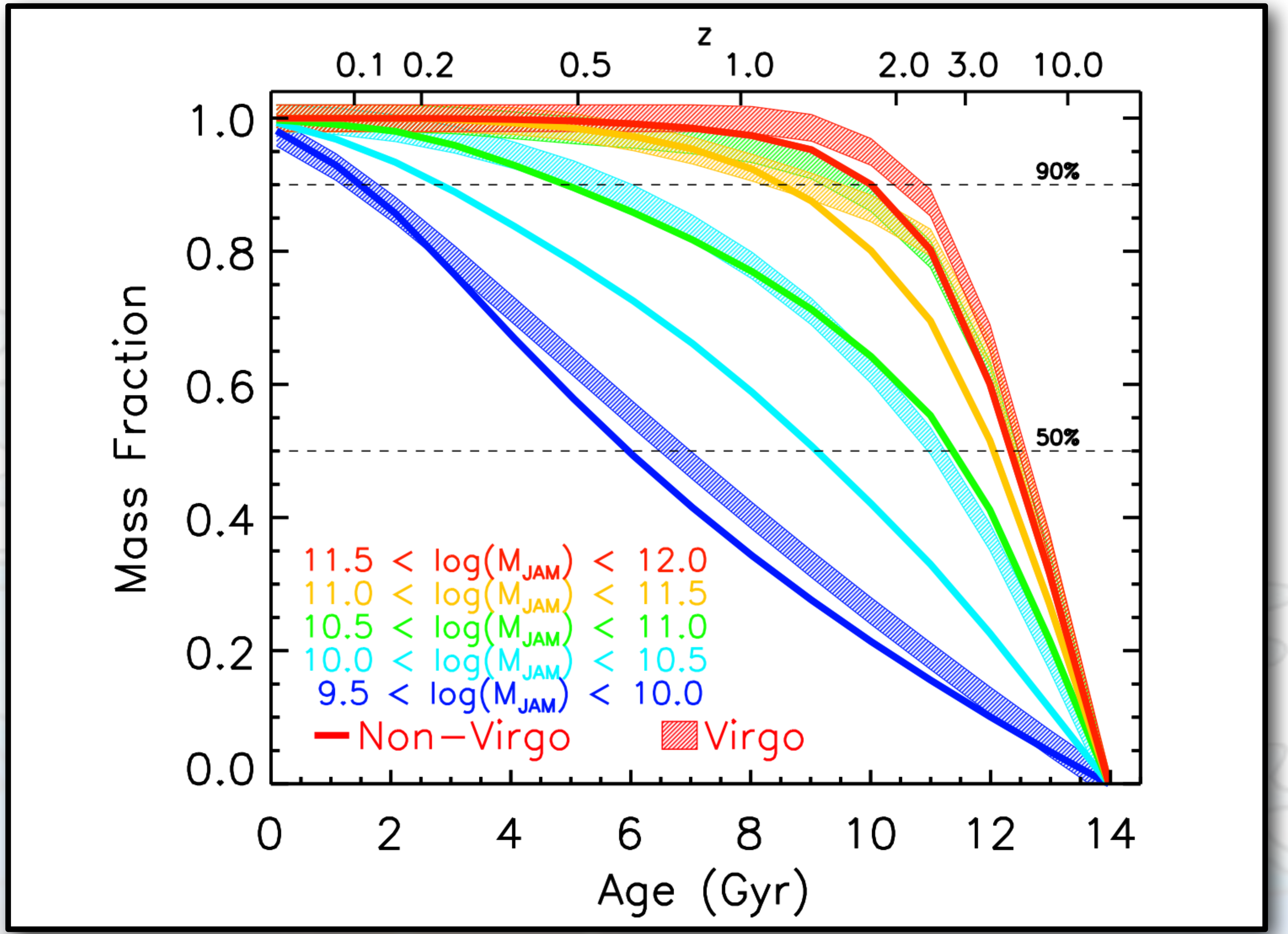
Fraction of simulated, aligned galaxies too large

Although this simulation seemed to reproduce the stars,
it did not do a good job on the gas,…

Eagle simulations much better. Mainly due to better implementation of feedback (Serra, in progress)

Virgo ETG are HI poor





Differences in star formation history caused by differences in accretion of gas

McDermid et al. 2015

The Future 1

ASKAP & Apertif
Phased array feed front end
very large field of view (~30x larger)
at sensitivity of old WSRT

High survey speed and high resolution

Will be able to image the large ares at 15-30 arc sec resolution with (much) better sensitivity than Alfalfa and HIPASS

Excellent for imaging the HI environment of galaxies and study the changes of HI content

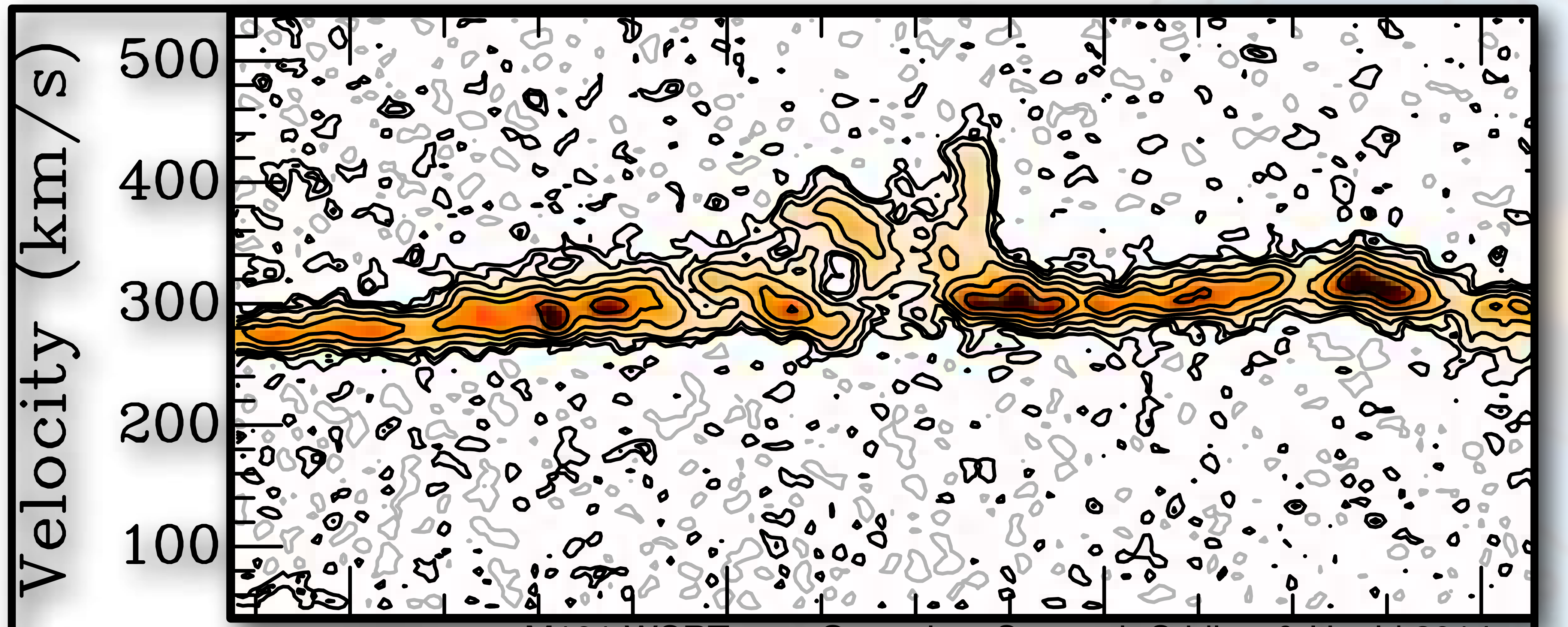
The Future 2

MeerKat and SKA1-Mid

1x resp. 3x sensitivity of EVLA, larger field of view, excellent uv coverage, good resolution (few arcsec) but many short baselines

To better understand the galactic fountains/beards, radial motions and their relevance for accretion, we need something like Halogas survey, but at resolution of a few arc sec .

Much bette study on relation star formation and HI halos

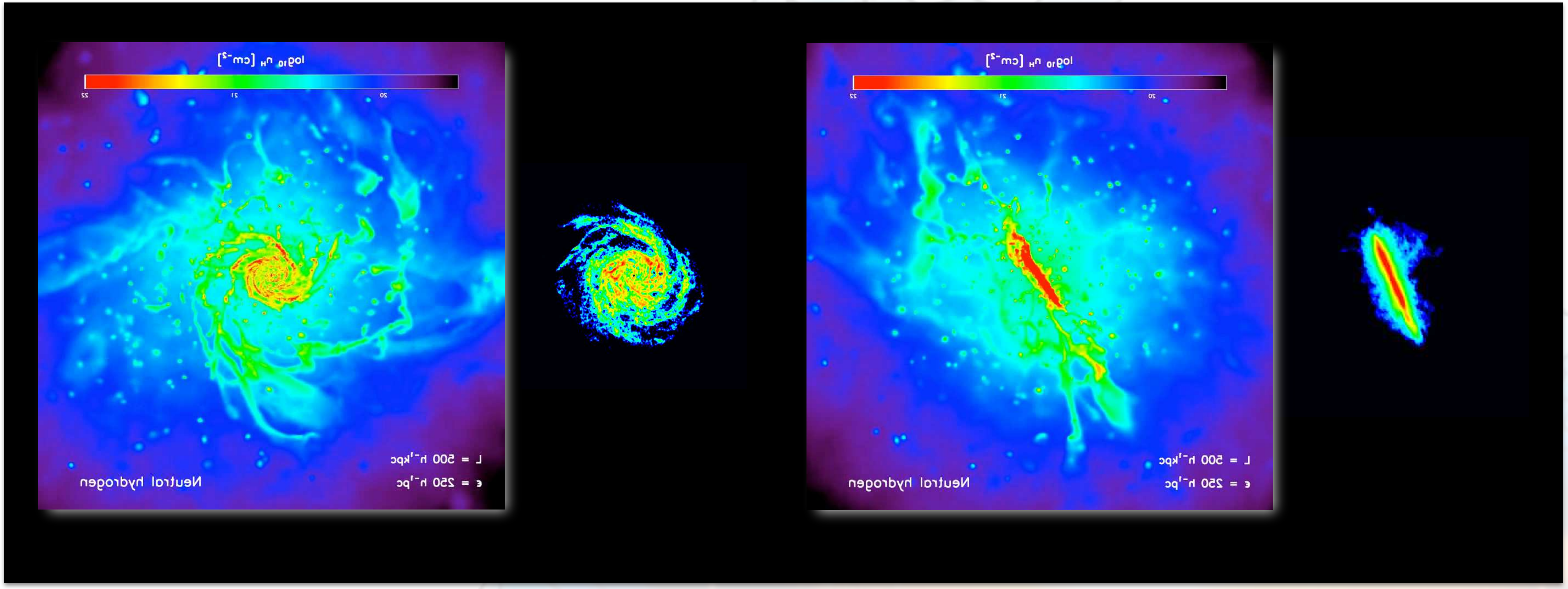


M101 WSRT   Oosterloo, Sarrvesh, Sridhar & Heald 2014,
Combine with L band & LOFAR continuum

The Future 3

SKA1-Mid: 500 m core with high filling factor (‘Imaging Arecibo’)

Will be able to image column densities well below 10^{18} cm^{-2} at arcmin resolution



Detect the very faint HI interface with the IGM,
Study gas accretion

Summary

- Plenty of observational evidence for cold gas accretion in galaxies
- But the observed HI accretion rates are below the star formation rates
- Spiral galaxies have thick HI disks, with lower rotation
  - related to star formation (galactic fountains)
  - very significant circulation of gas
  - still some puzzles about the kinematics (radial inflows)
- Many early-type galaxies have accreted gas
- Lack of accretion for Virgo galaxies causes different star formation histories
- Significant progress can be expected from SKA pathfinders
- Relatively modest progress in the last decade
  - will change with the new telescopes soon operational