HI Distributions of Virgo Cluster Galaxies: Ram Pressure Stripping and Galaxy Evolution

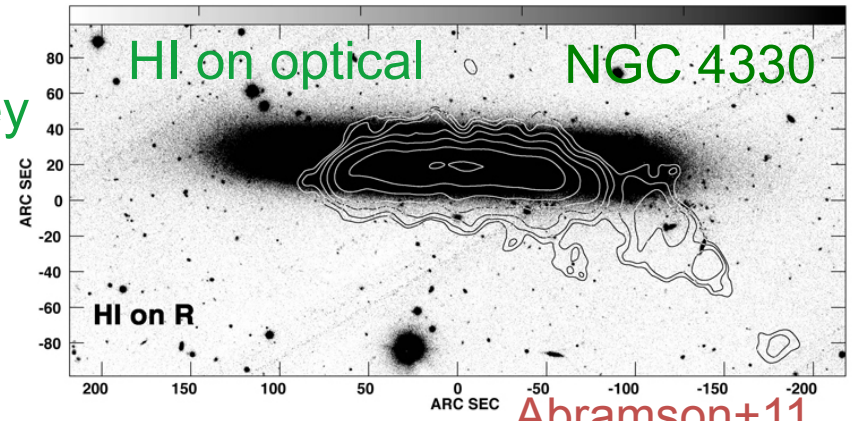
Jeff Kenney (Yale U.)

EWASS 2017 Prague

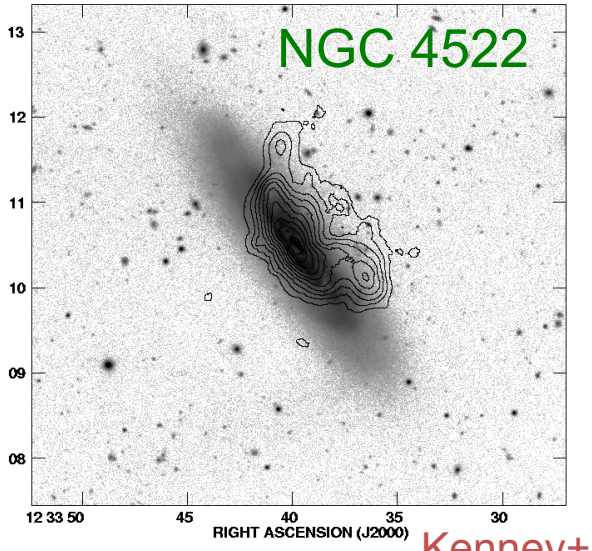
Diagnostics of active ram pressure stripping:

Gas not Stars, outside-in, one direction

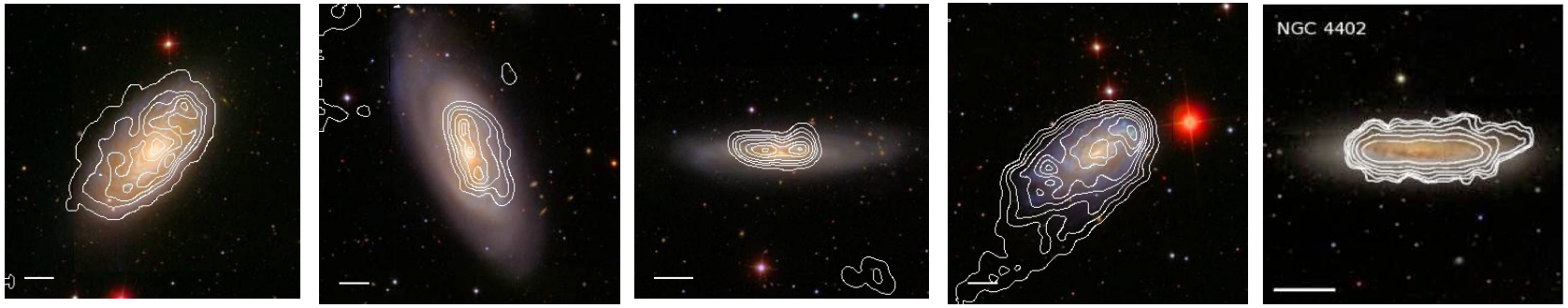
Virgo Cluster
VIVA HI survey
~50 spirals



Abramson+11



Kenney+04



Large fraction of Virgo spirals have truncated gas disks with normal stellar disks & one-sided extraplanar gas features

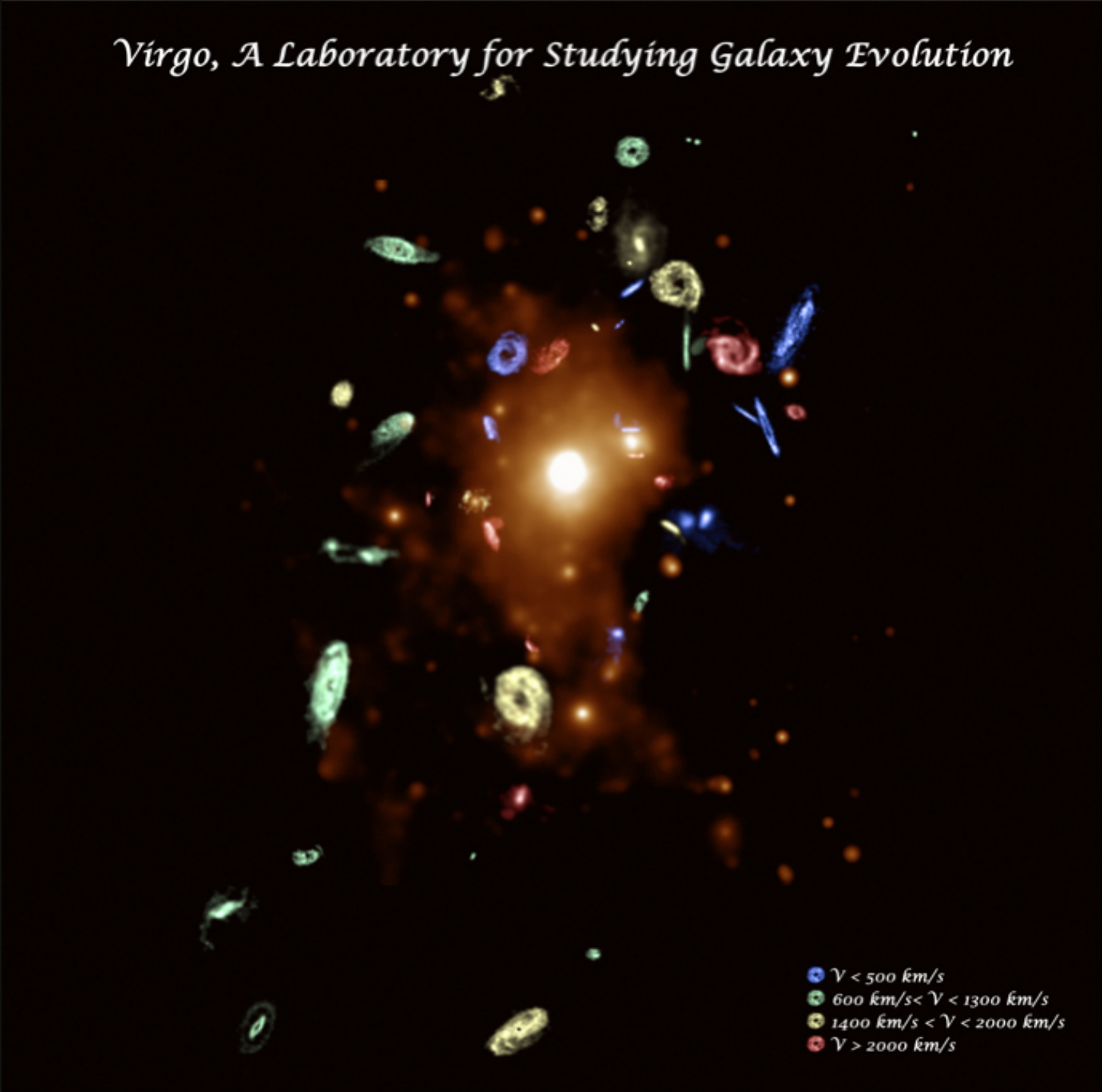
Chung+09

but! …. we don't yet have objective quantifiable measures of gas distribution to indicate active ram pressure stripping … until now (?)

… new analysis of VIVA HI data

Kenney + in prep

collaborators:
Elijah Mas
Michael Warrener
Aeree Chung
Jacqueline van Gorkom
Hugh Crowl
Bernd Vollmer



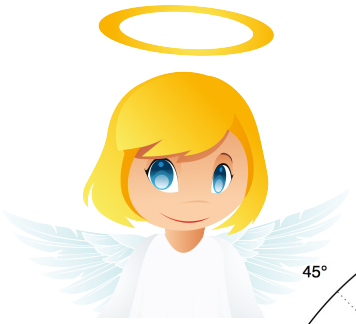
VIVA!

VLA
Imaging of
Virgo Galaxies in
Atomic Gas

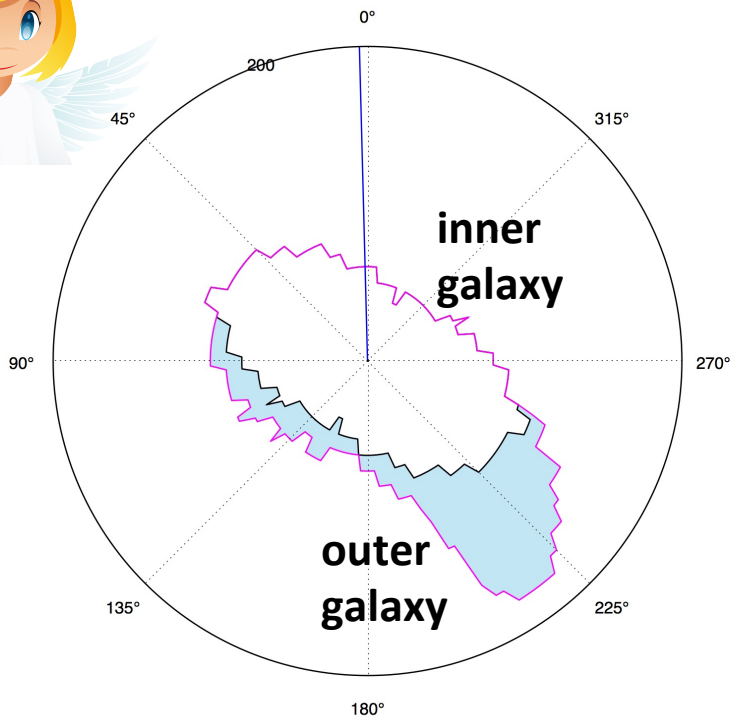
Aeree Chung
Hugh Crowl
Jacqueline van Gorkom
Jeff Kenney
Bernd Vollmer
(Chung etal 2009)

50 spiral & peculiar galaxies
(~50% of late type galaxies $M_* > 10^9$ M_{sun})

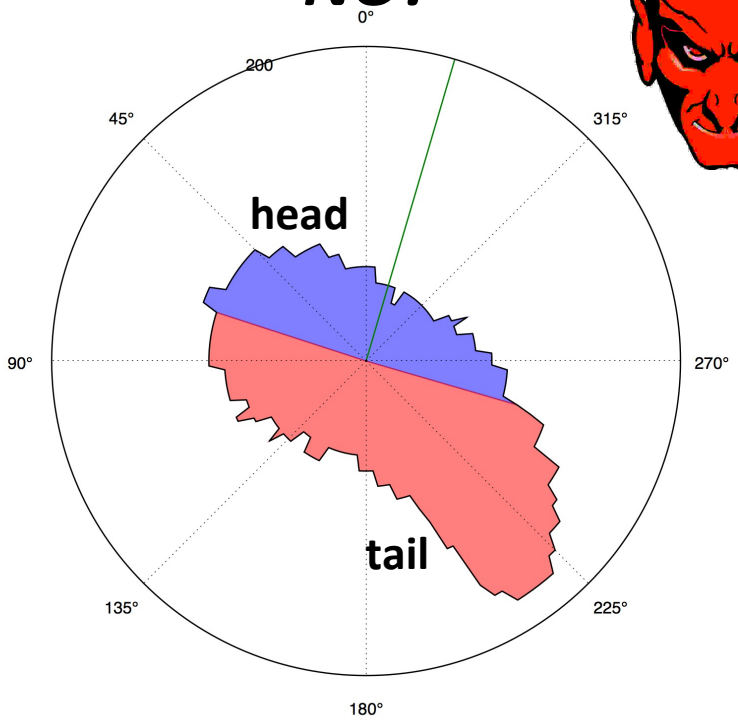
VLA HI maps
on X-ray
HI maps blown up
10x



YES!



NO!

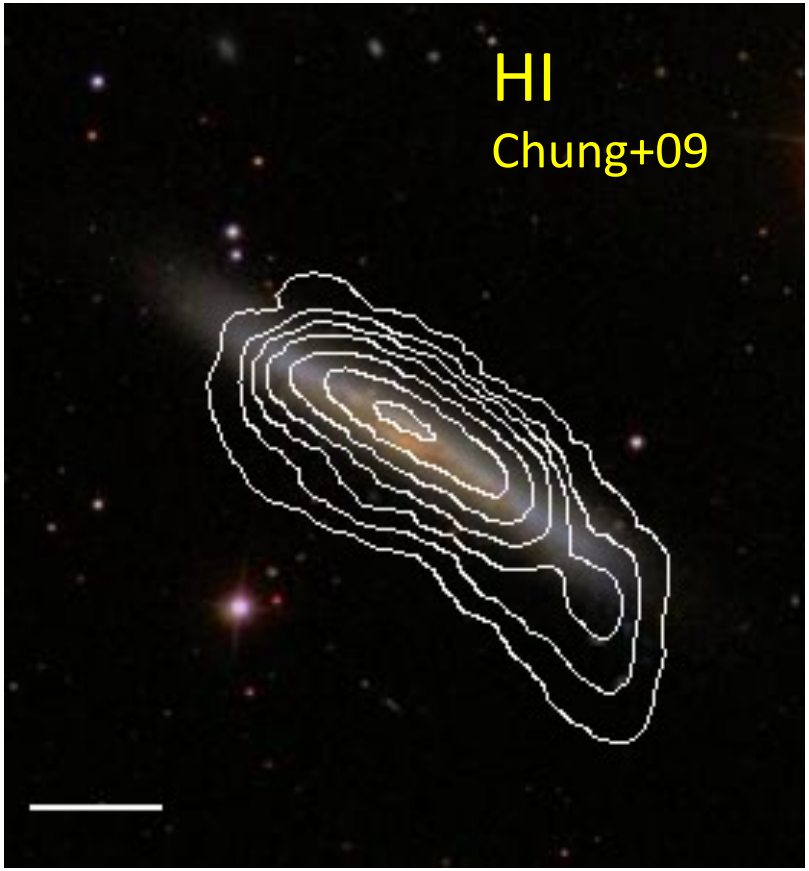


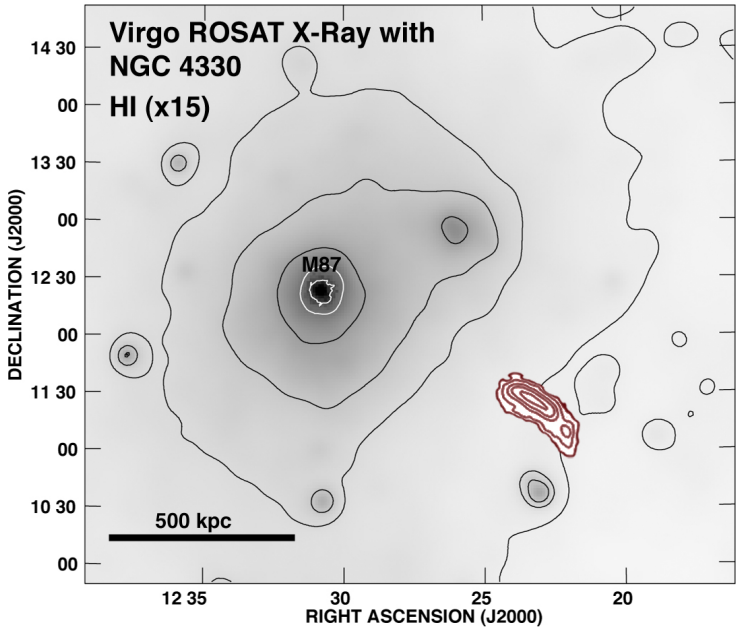
want to measure something from HI map that traces active rps

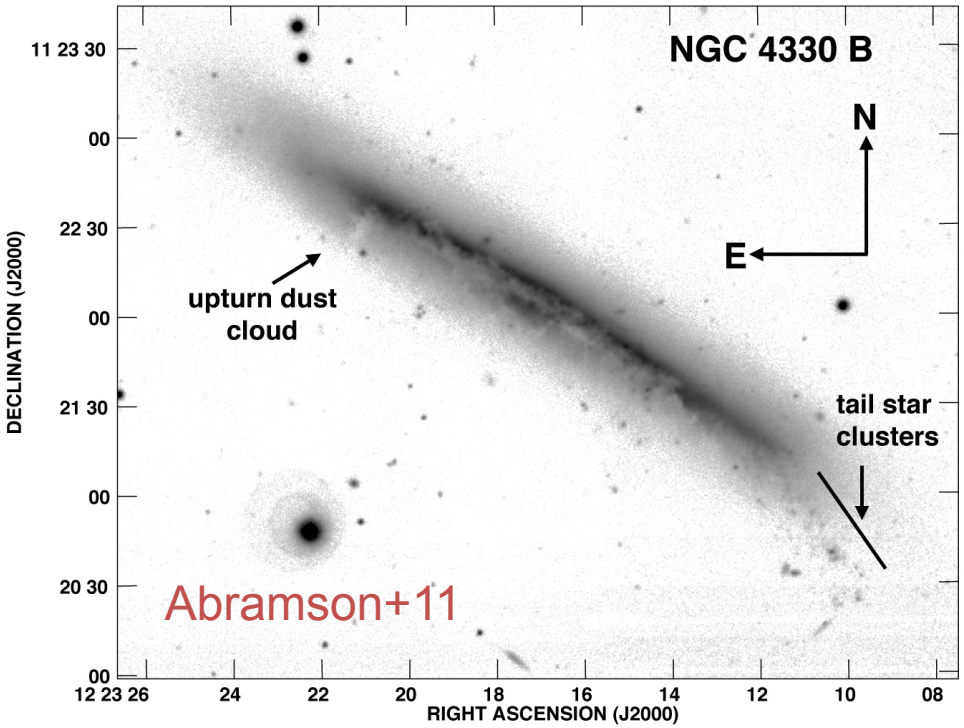
→ global head-tail **asymmetry (of all the gas)** doesn't work well

→ head-tail **asymmetry of *outer* gas** works well

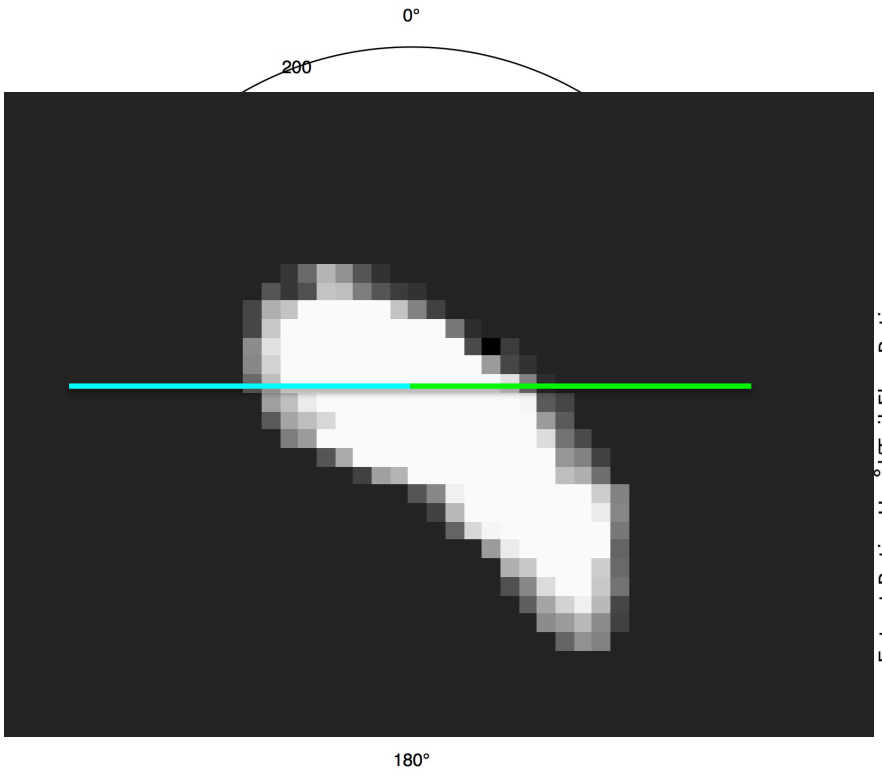
NGC 4330

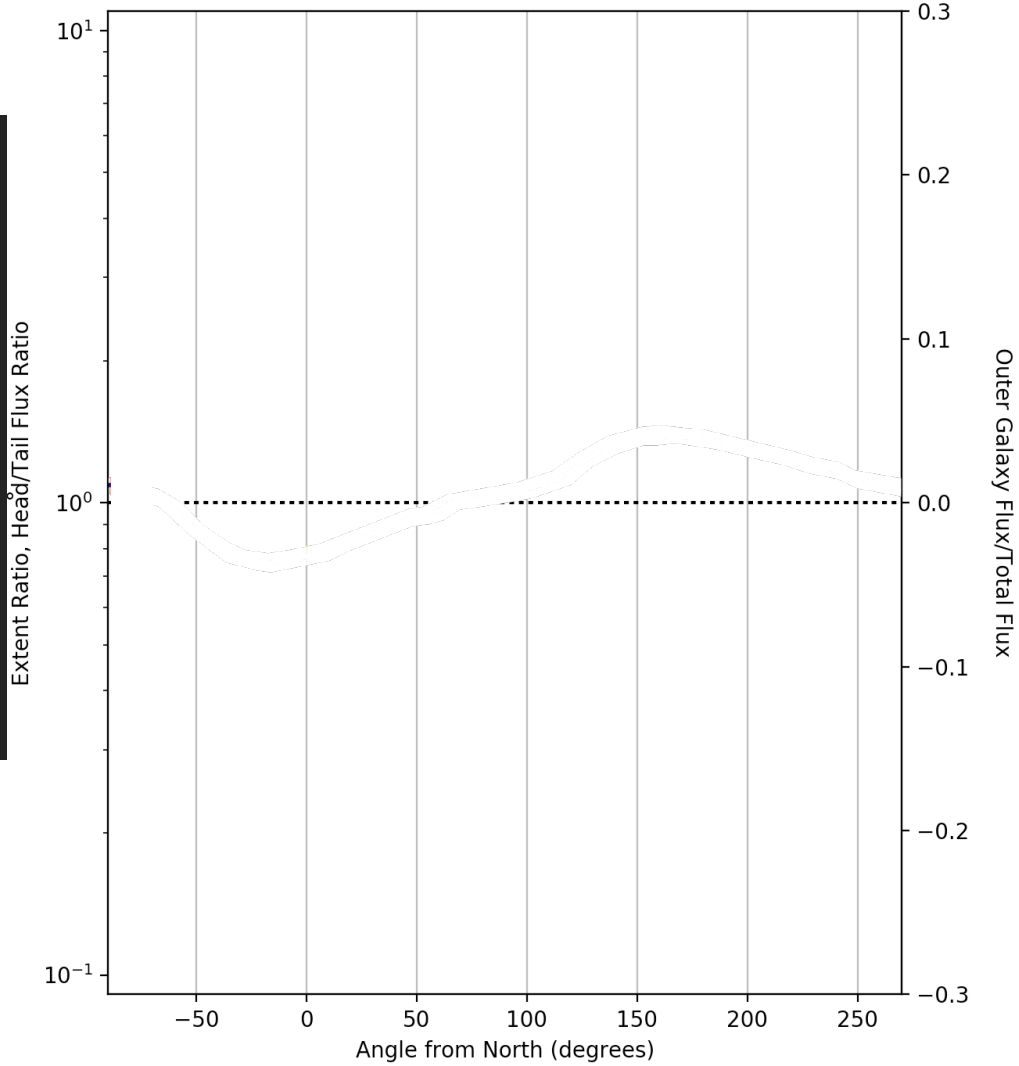

HI
Chung+09


Virgo ROSAT X-Ray with
NGC 4330
HI (x15)
M87
500 kpc
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
14 30
00
13 30
00
12 30
00
11 30
00
10 30
00
12 35
30
25
20

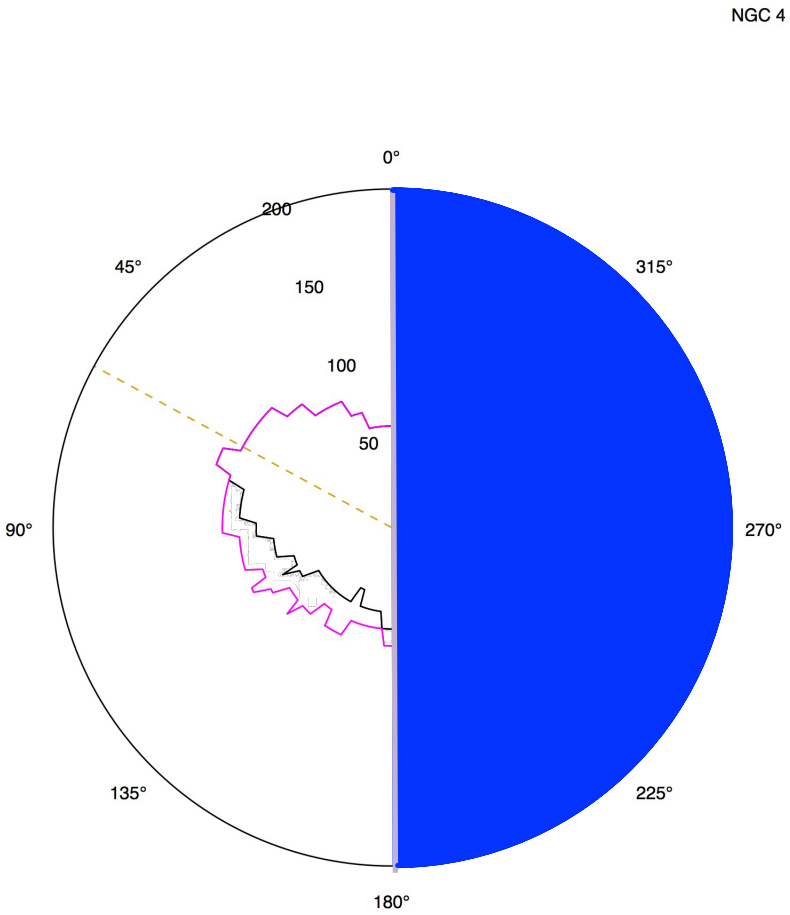

NGC 4330 B
N
E
upturn dust
cloud
tail star
clusters
Abramson+11
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
11 23 30
00
22 30
00
21 30
00
20 30
00
12 23 26
24
22
20
18
16
14
12
10
08

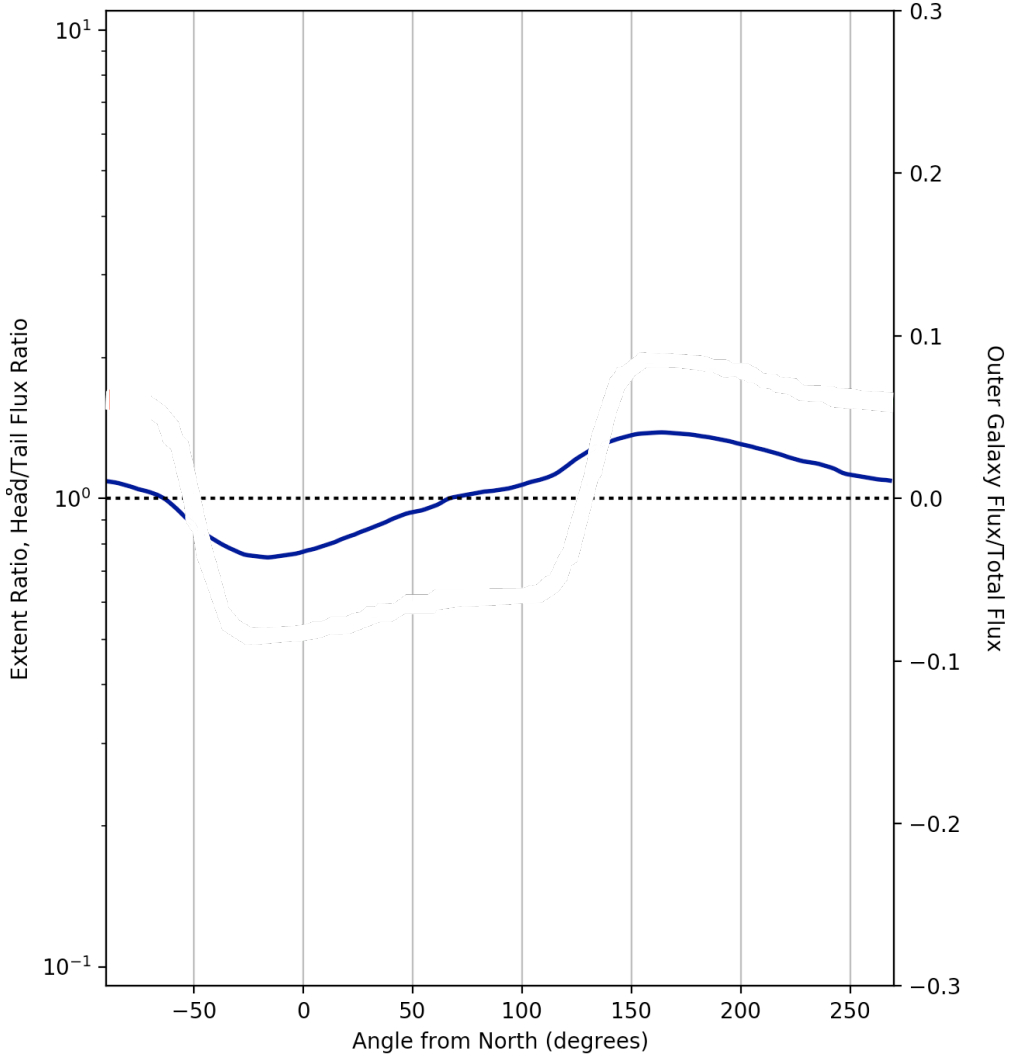
extent ratio & defining the inner galaxy



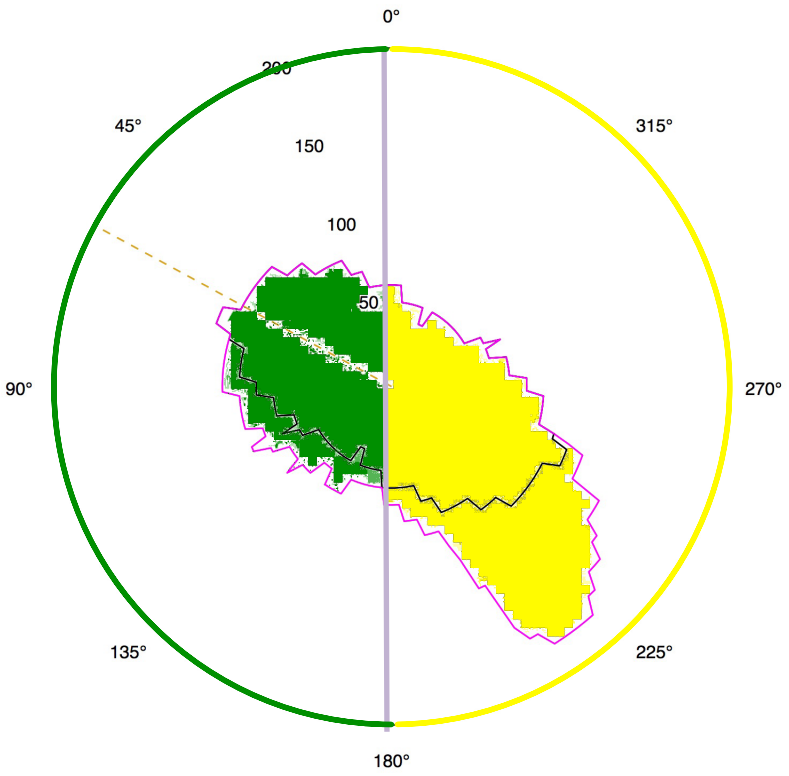


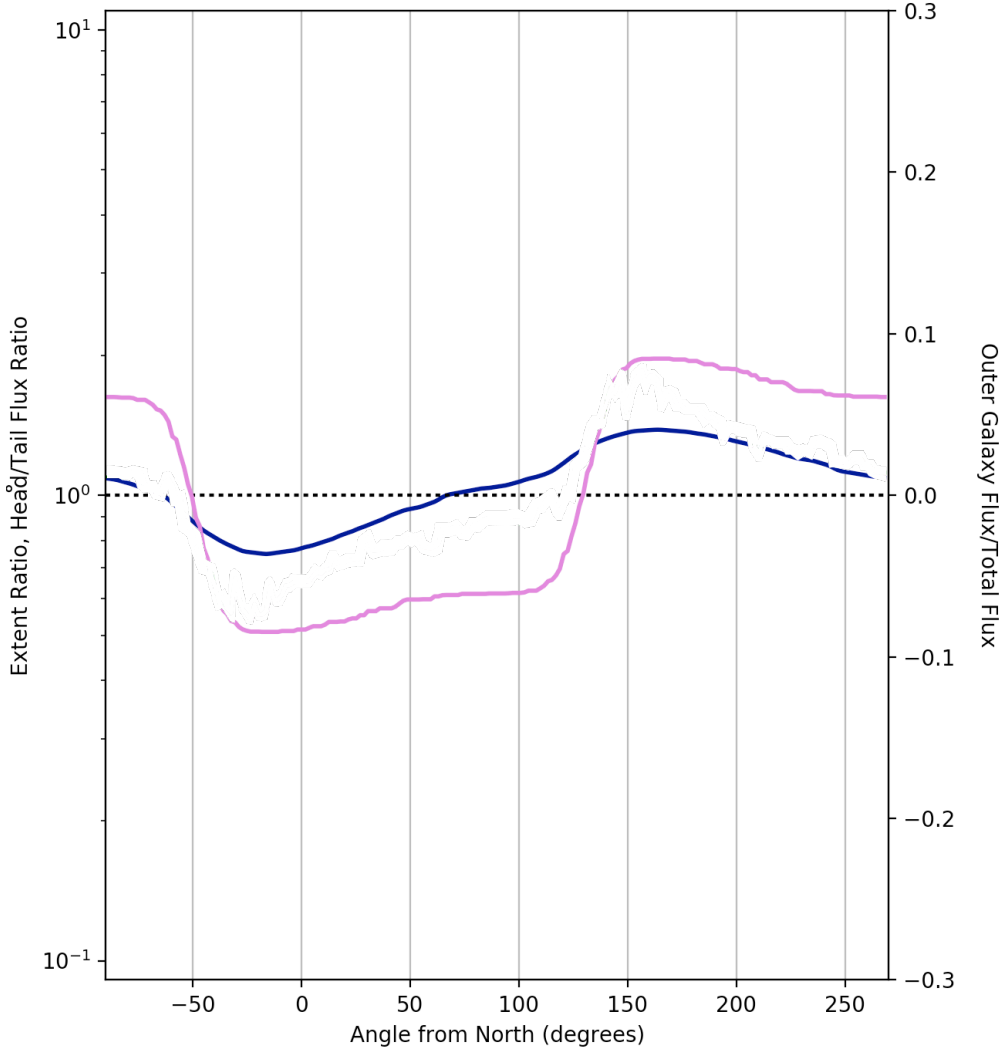
outer tail-to-total flux ratio



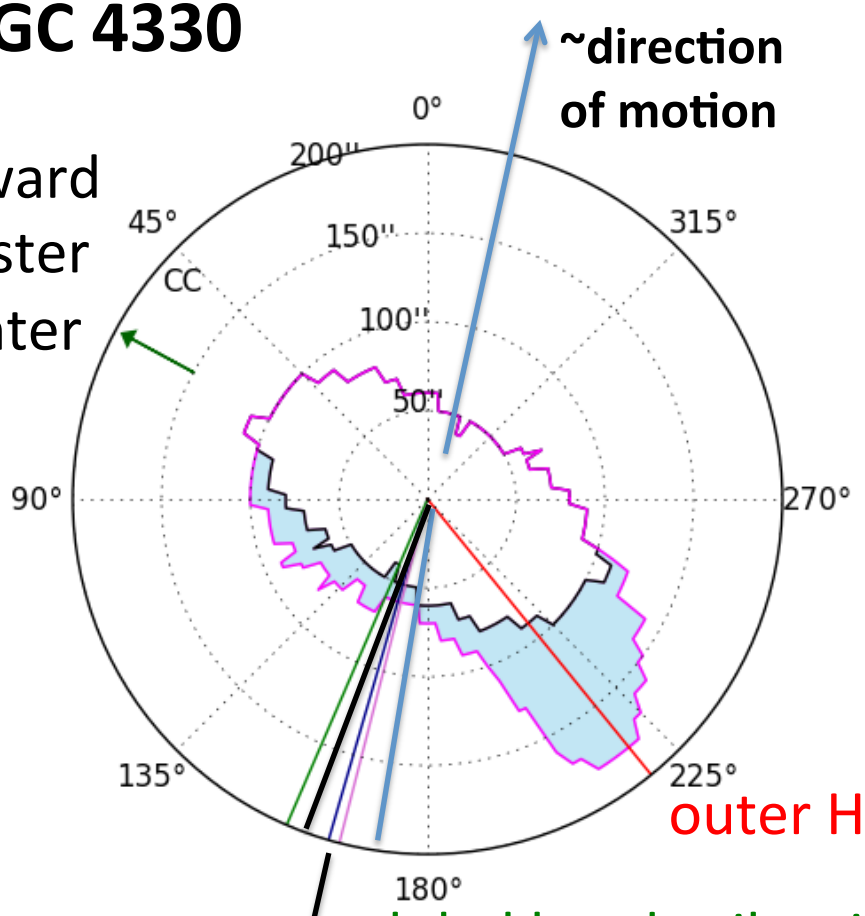


global head-tail ratio





NGC 4330



projected wind direction

extent ratio and outer flux ratio give accurate measures of ***projected wind direction***, since they do good job identifying compressed & extended sides

outer HI angle

global head-tail ratio angle

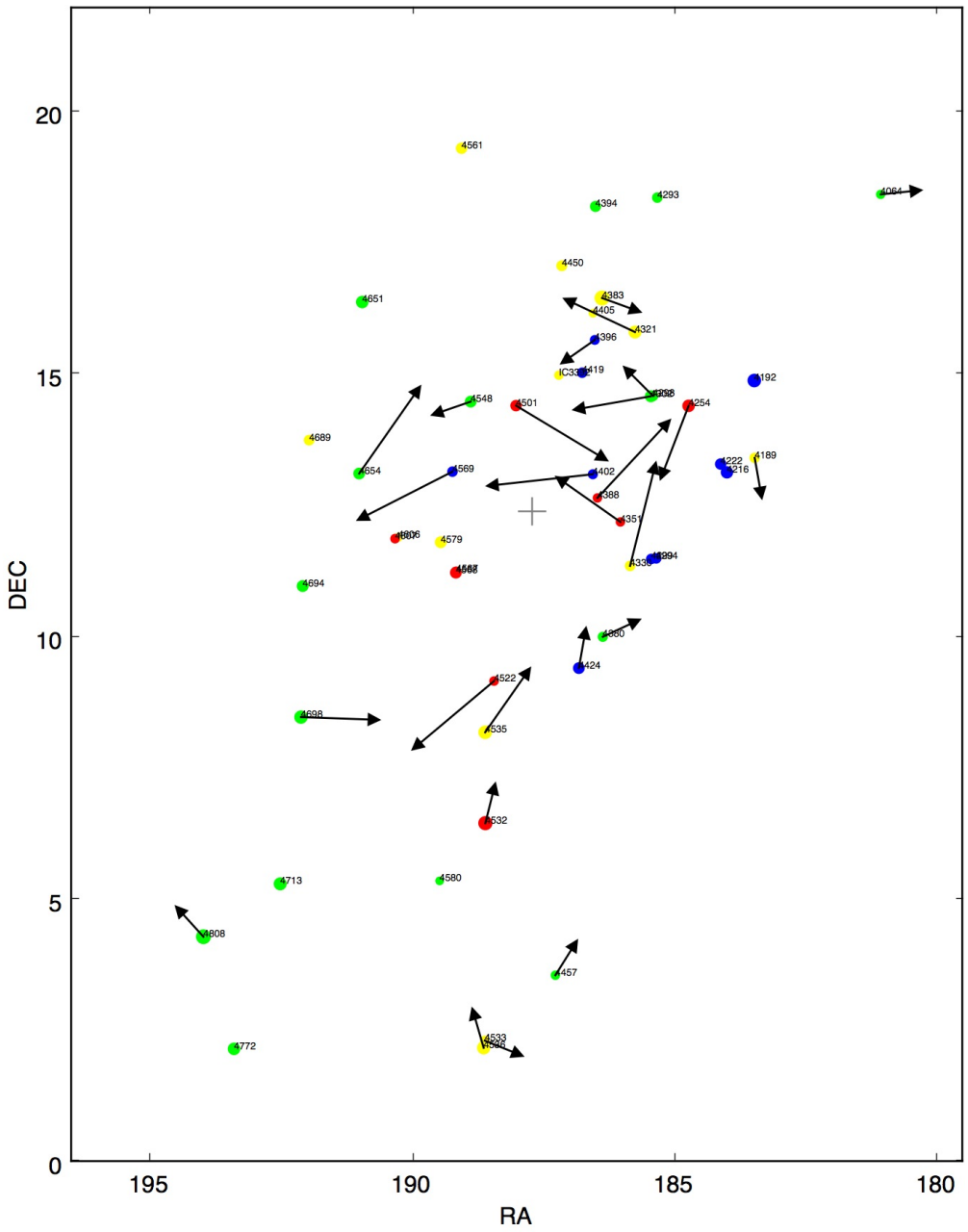
simulation angle (Vollmer+12)

extent ratio angle

outer flux ratio angle

radio deficit angle

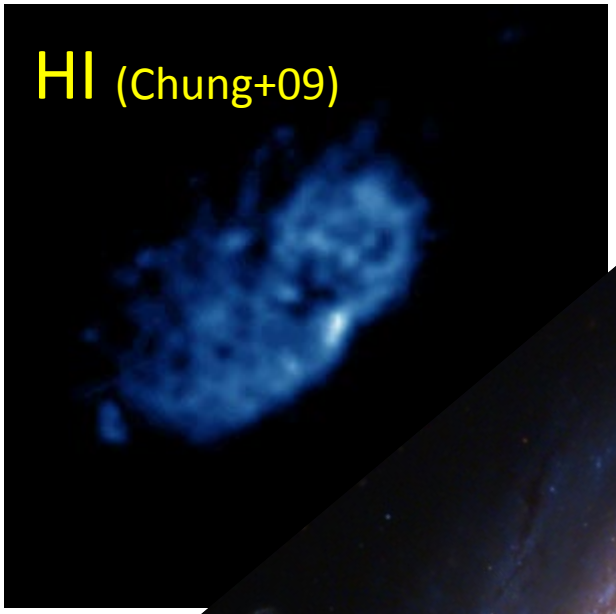
radio deficit region on radio map (Murphy+09)

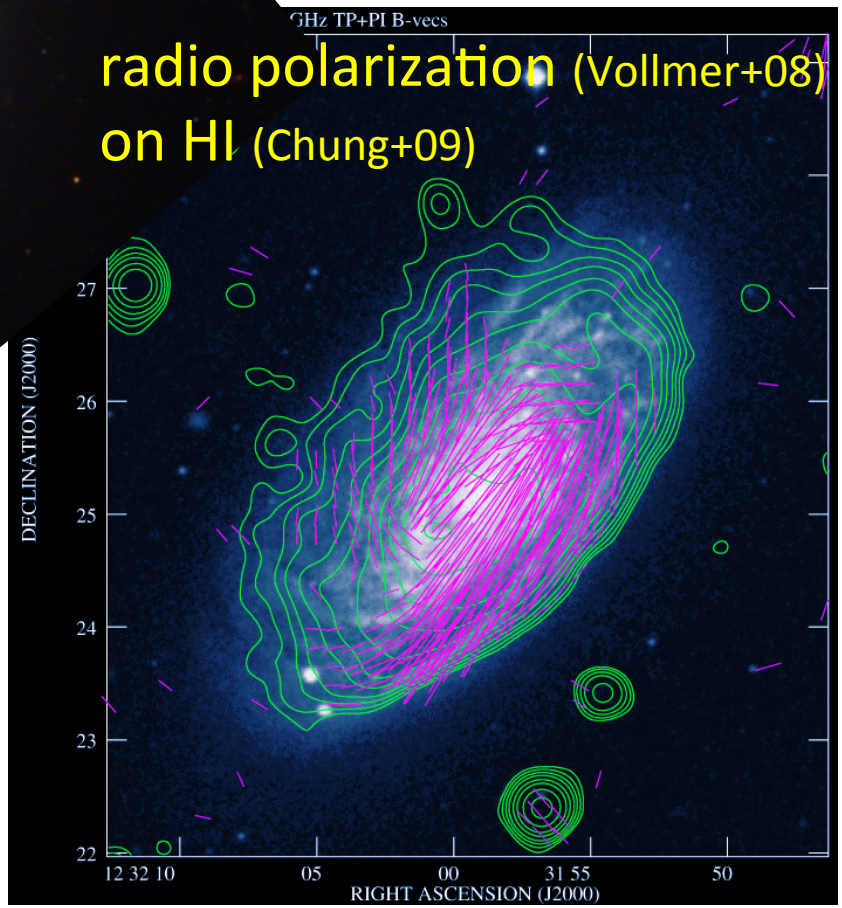


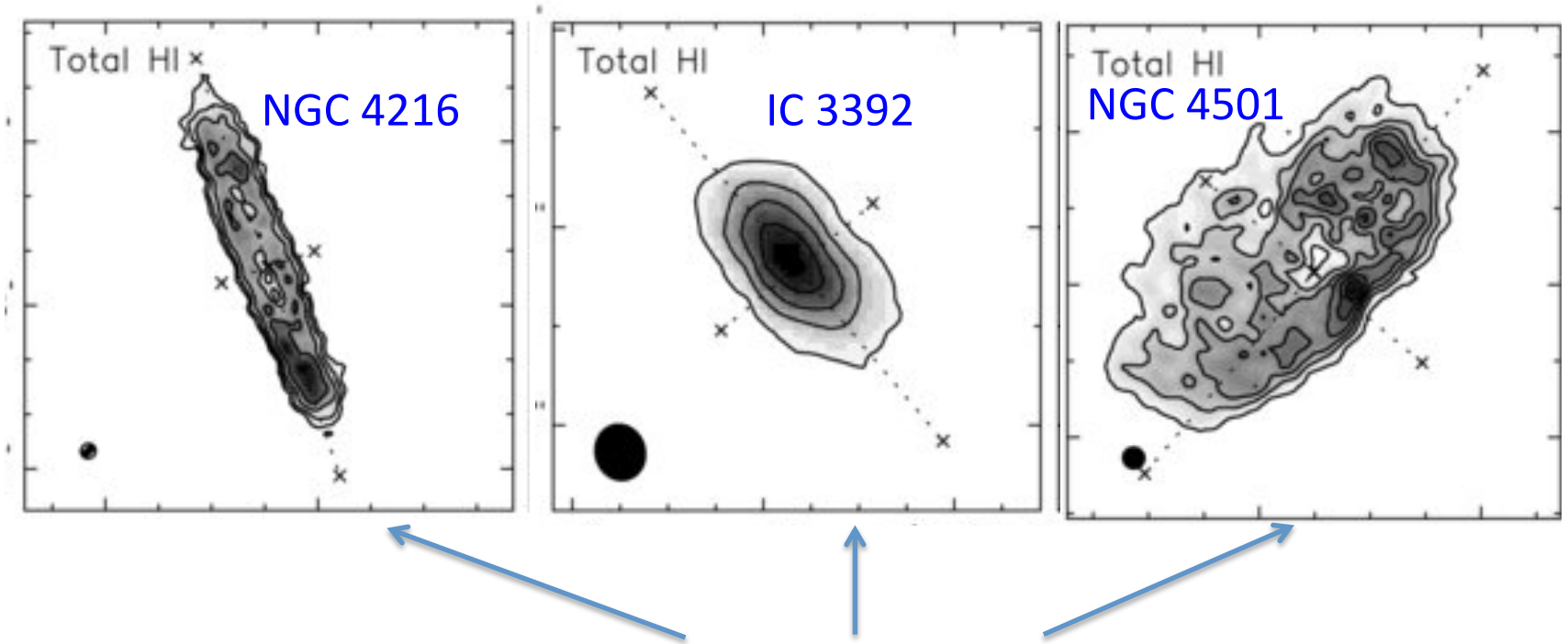
Virgo cluster

map of directions of sky motion
(preliminary)

clear ongoing rps in NGC 4501

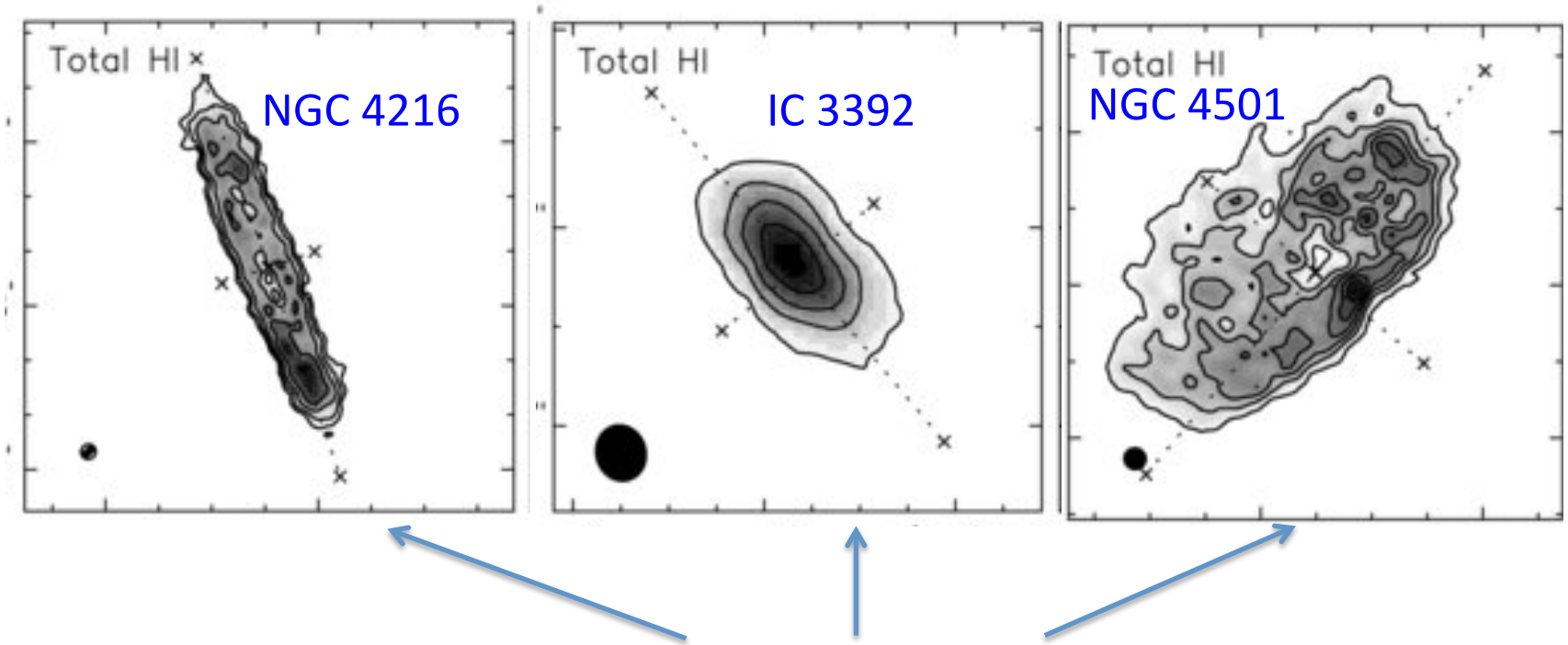






global head-tail ratio: 0.78 0.70 0.79 (1.00 is symmetric)

NGC 4501 has a clear head-tail morphology but its global head-tail ratio is the same as galaxies with no head-tail morphology ?!?!?

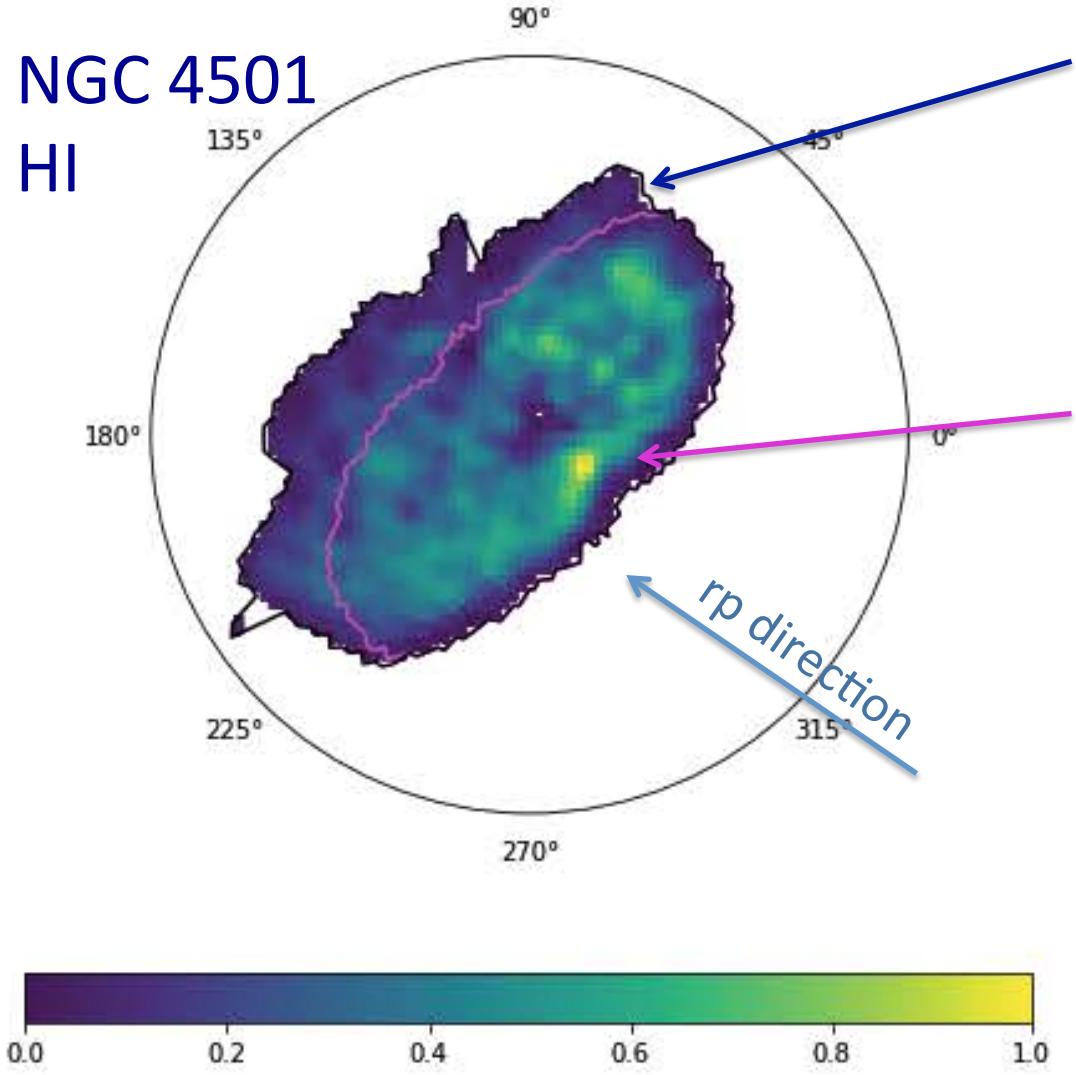


global head-tail ratio:	0.78	0.70	0.79 (1.00 is symmetric)
outer tail flux ratio:	0.01	0.01	0.13 (0.00 is symmetric)
head-tail extent ratio:	1.04	1.05	1.46 (1.00 is symmetric)

the extent ratio and outer tail-to-total flux ratio are much higher in NGC 4501

asymmetries of inner & outer galaxy are typically opposite or unrelated

NGC 4501
HI

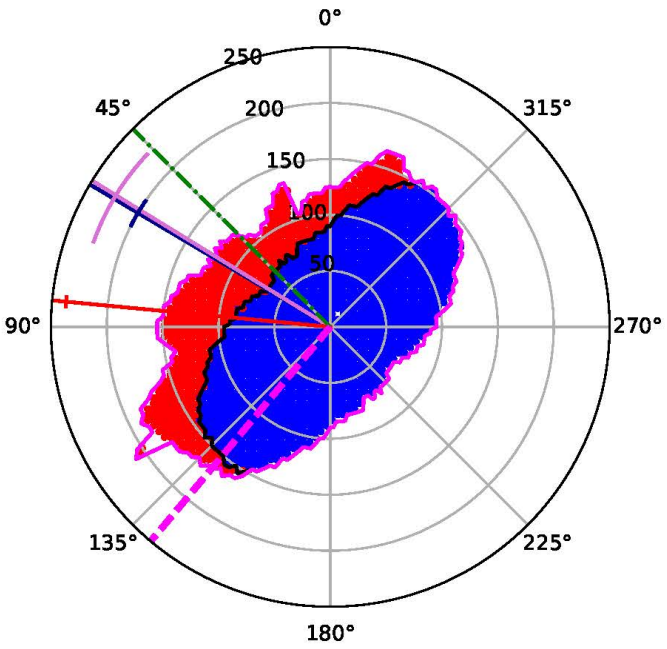


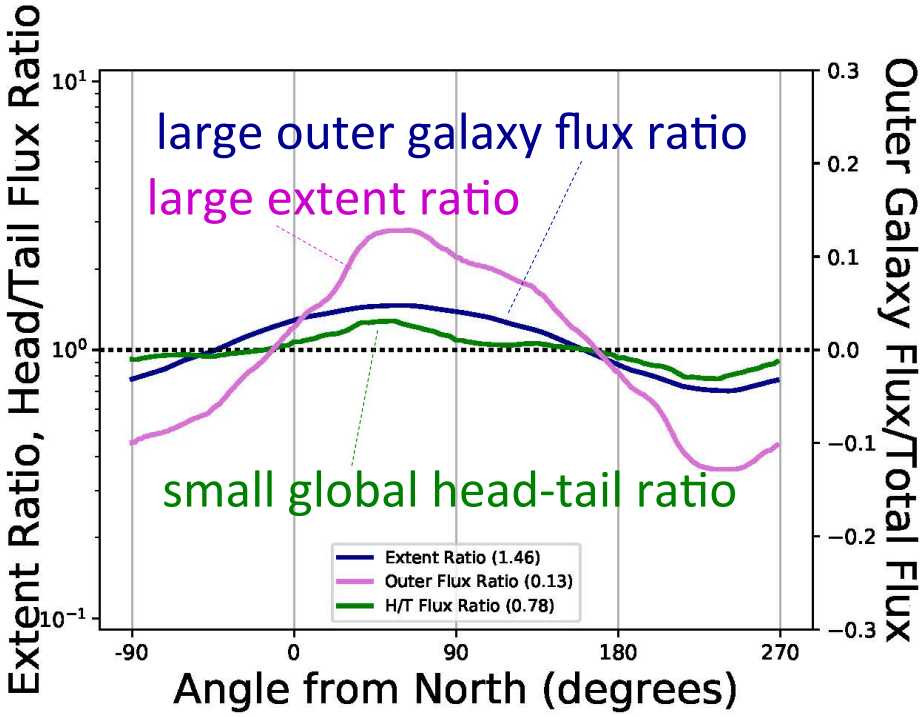
outer galaxy has more HI flux on trailing side (tail) due to r.p.

inner galaxy has more HI flux on leading side (head) due to r.p. compression

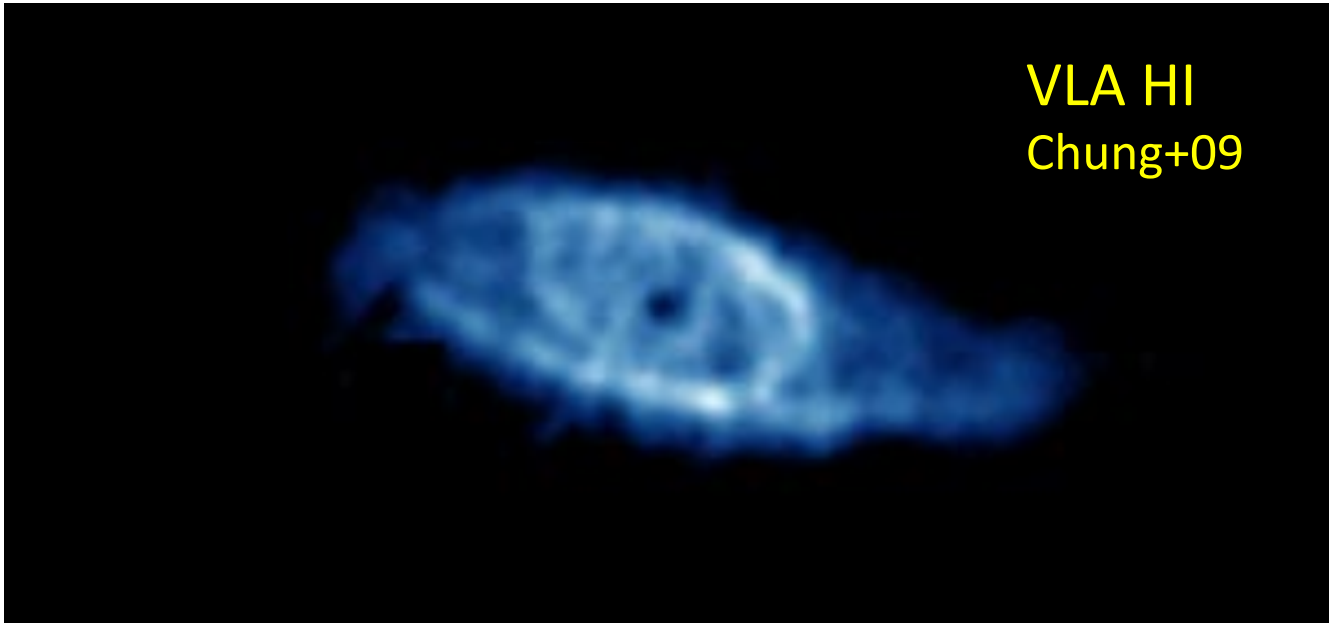
2 effects tend to cancel each other out so total head-tail flux ratio is poor indicator of the asymmetry

NGC 4501


0°
45°
90°
135°
180°
225°
270°
315°
250
200
150
100
50

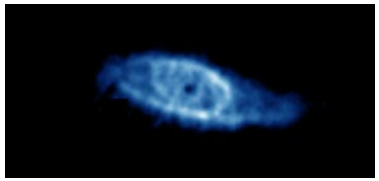

large outer galaxy flux ratio
large extent ratio
small global head-tail ratio
Extent Ratio (1.46)
Outer Flux Ratio (0.13)
H/T Flux Ratio (0.78)
Extent Ratio, Head/Tail Flux Ratio
Outer Galaxy Flux/Total Flux
Angle from North (degrees)
-90
0
90
180
270
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3

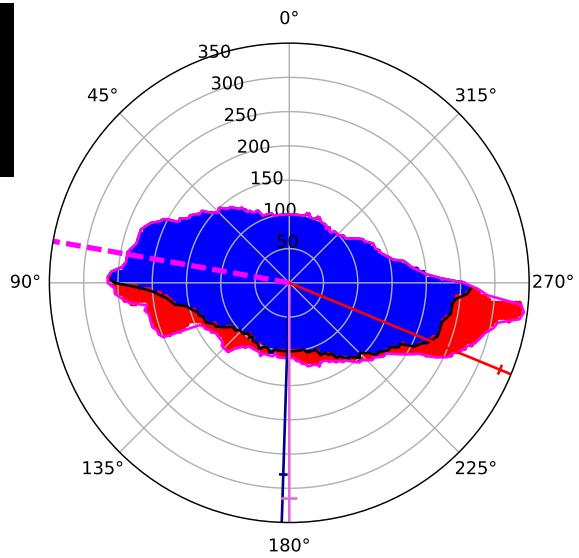
NGC 4651 "Umbrella Galaxy"

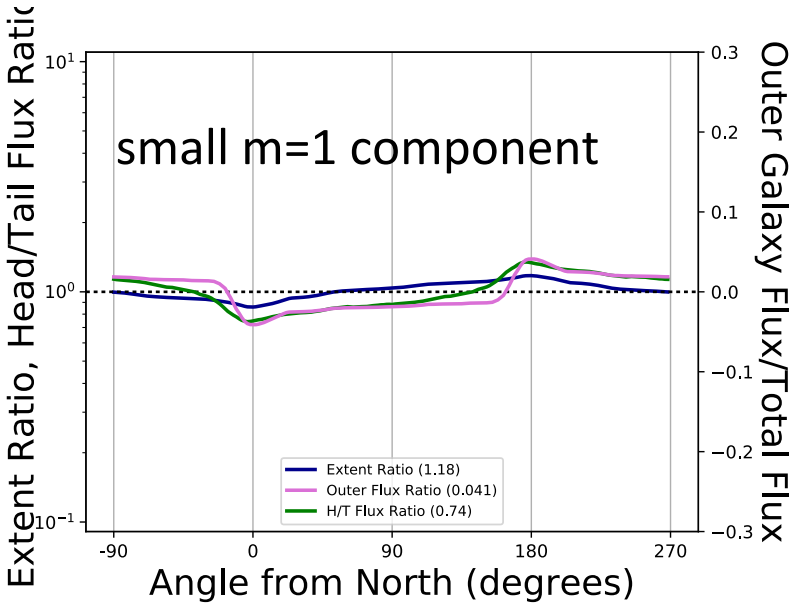


NGC 4651

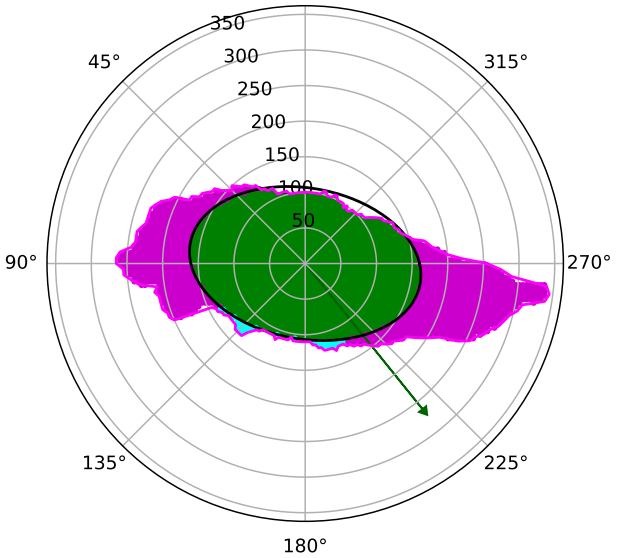
large m=2 component due to minor merger
small m=1 component – irregularity in accreted thing?

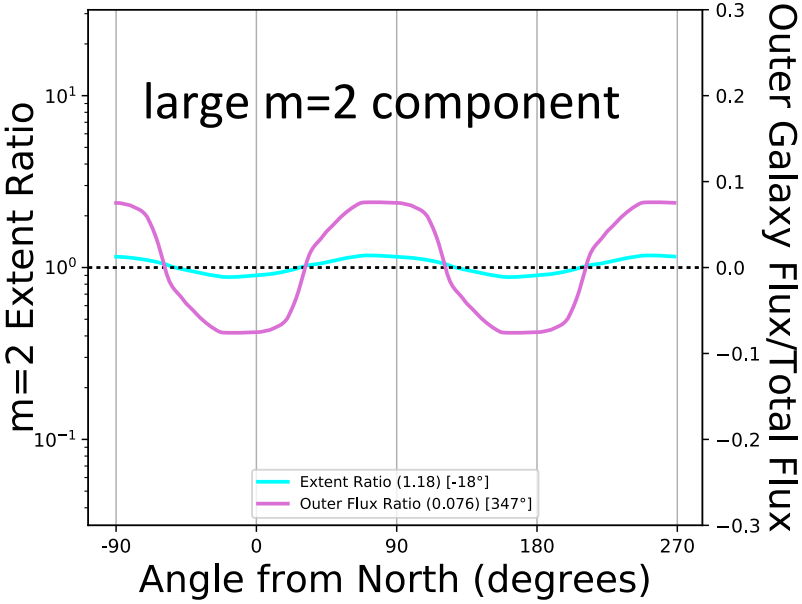


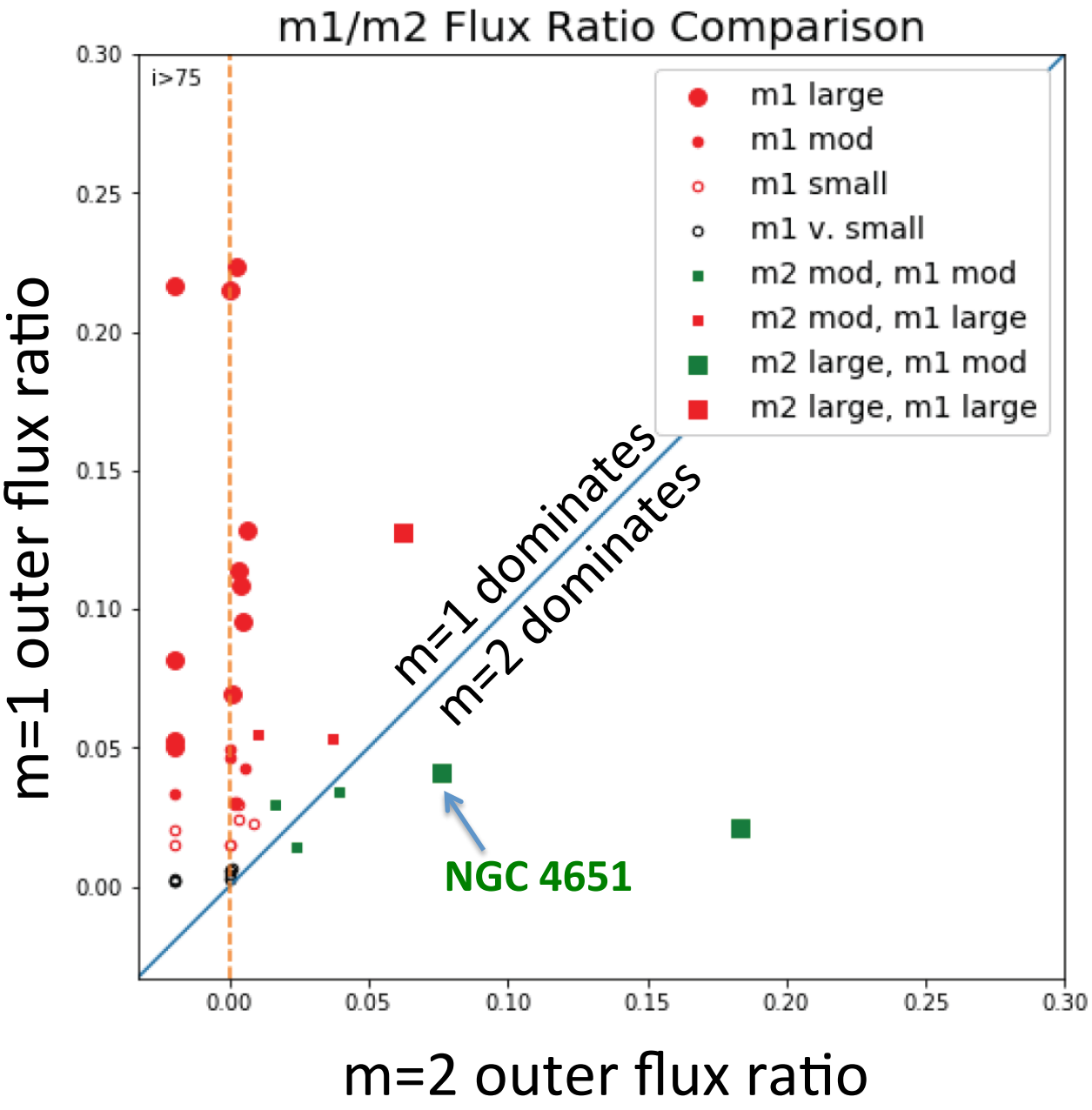




need to check for m=2 as well as m=1 components to be sure about rps

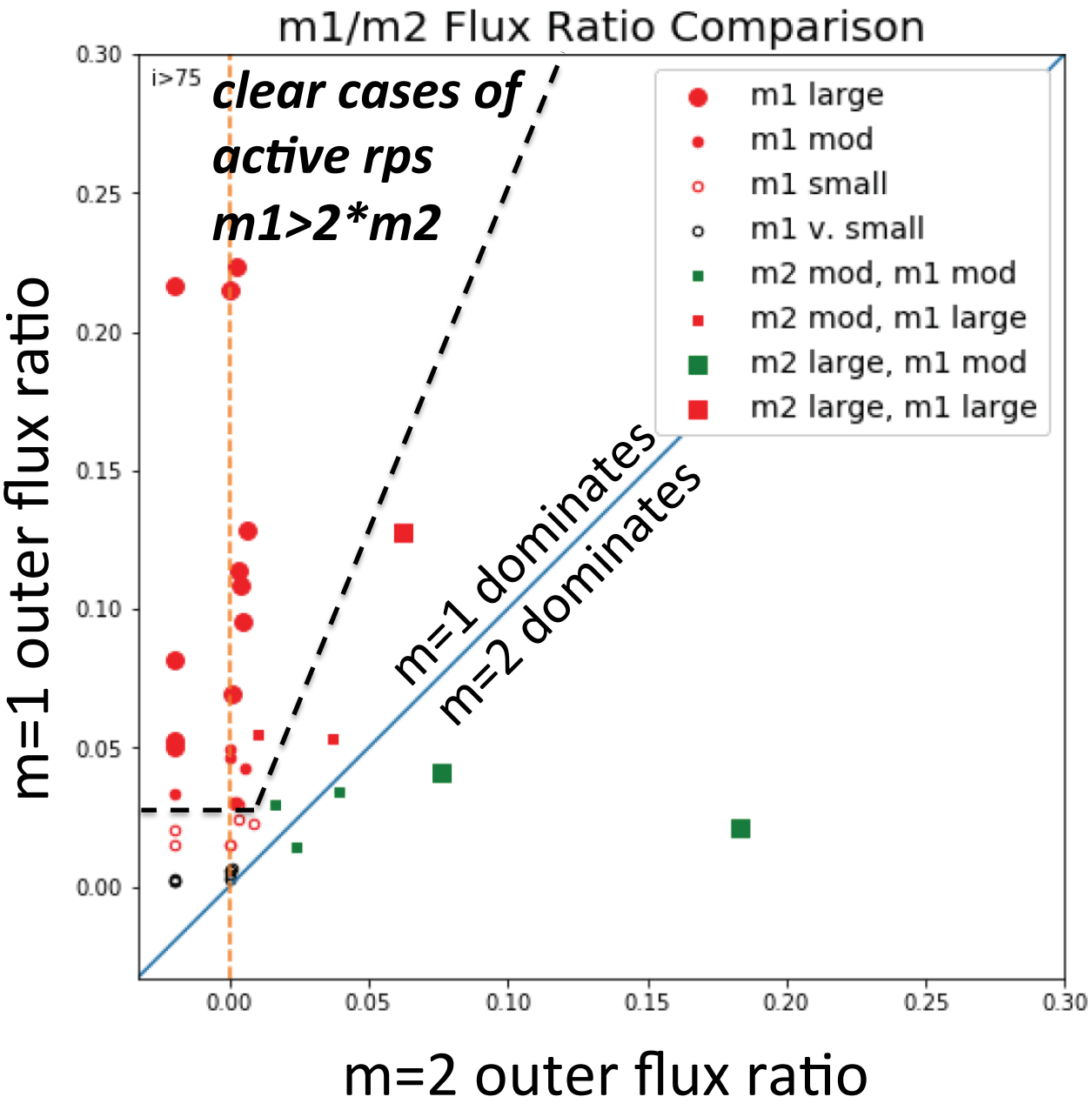






head-tail (m=1) vs m=2 components of outer HI gas distributions

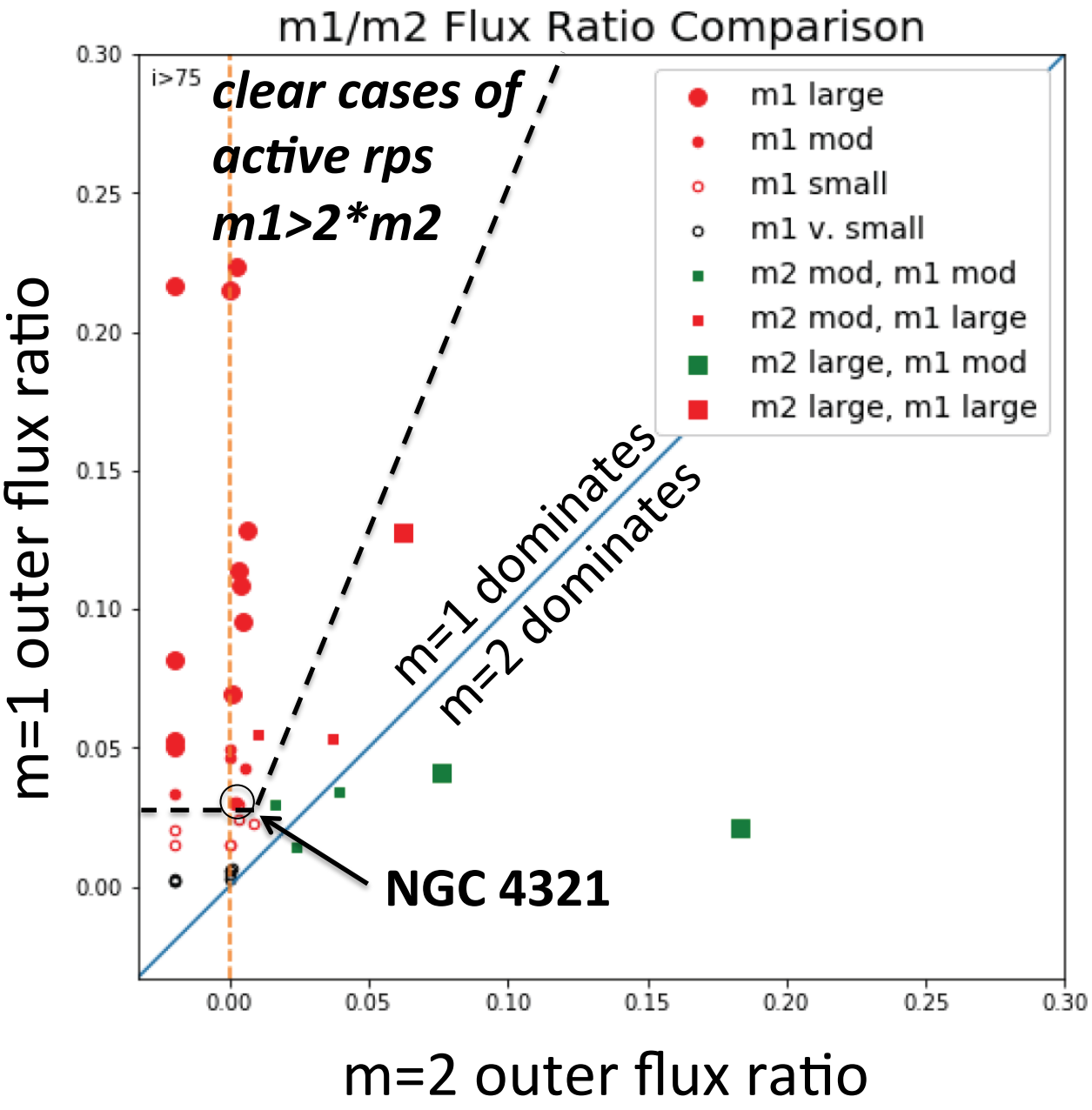
m=1 dominates in most Virgo spirals



head-tail (m=1) vs m=2 components of outer HI gas distributions

m=1 dominates in most Virgo spirals

>18/50 Virgo galaxies show clear evidence for ongoing rps



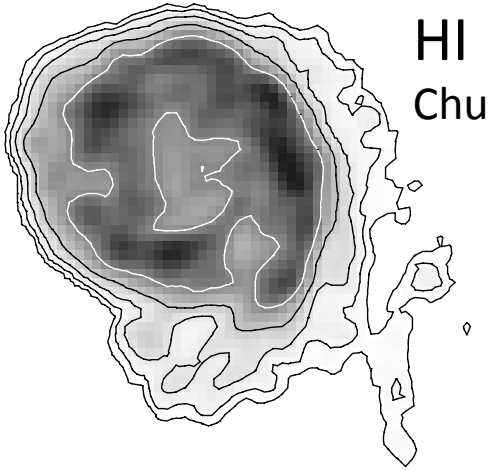
head-tail (m=1) vs m=2 components of outer HI gas distributions

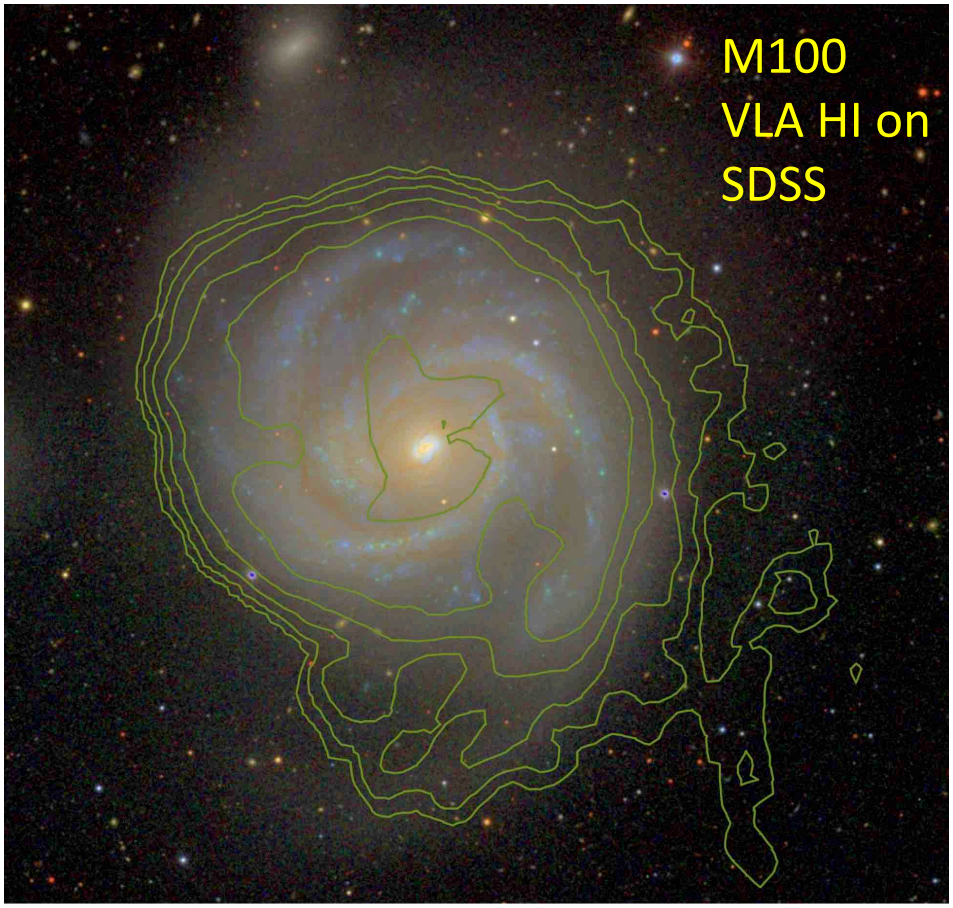
m=1 dominates in most Virgo spirals

>18/50 Virgo galaxies show clear evidence for ongoing rps

M100 = NGC 4321

clear head-tail gas morphology &
stellar arm without dust or young stars
extends beyond gas truncation radius in NE

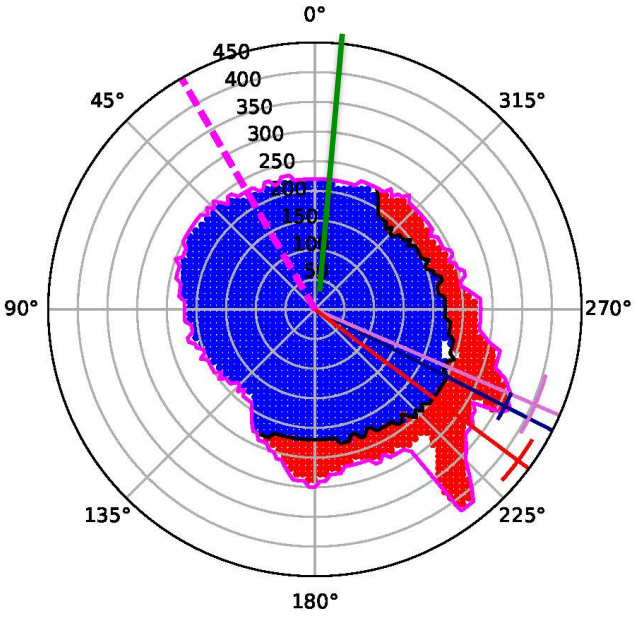


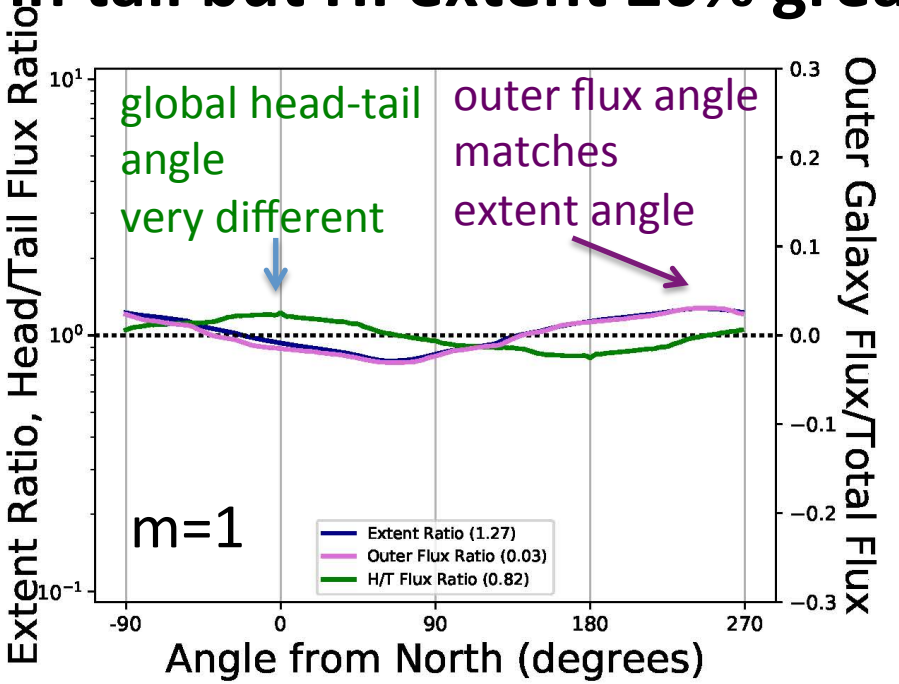


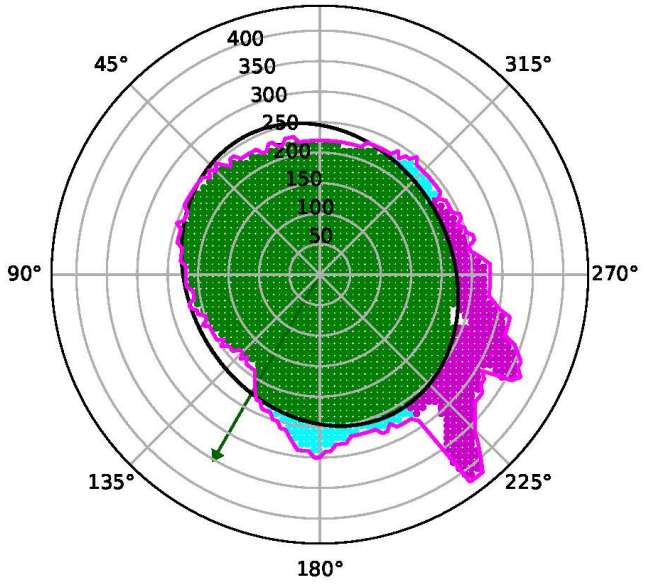
gas disk truncated in NE at r= 1.0 R_{25}

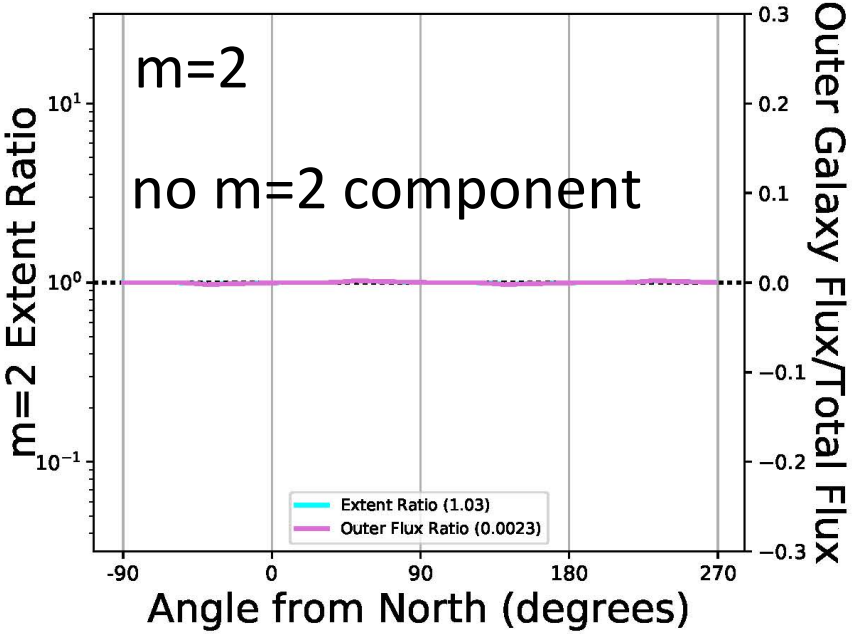
far out so not previously recognized as clear case of rps

M100: only 3% of HI flux in tail but HI extent 20% greater

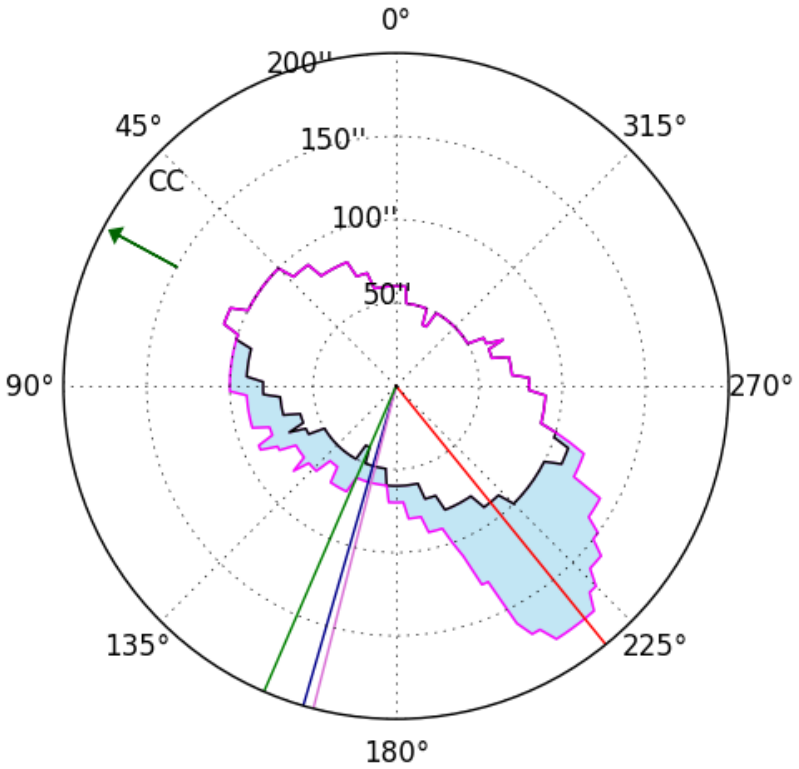




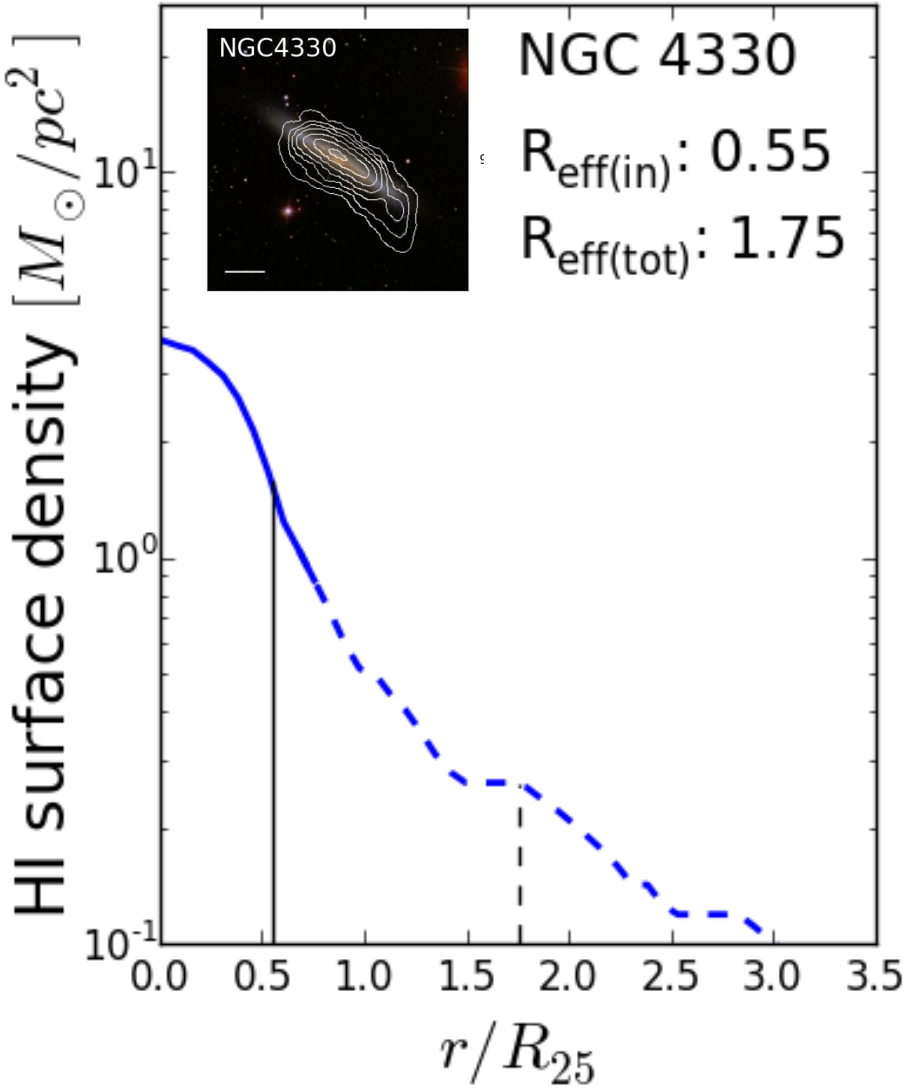




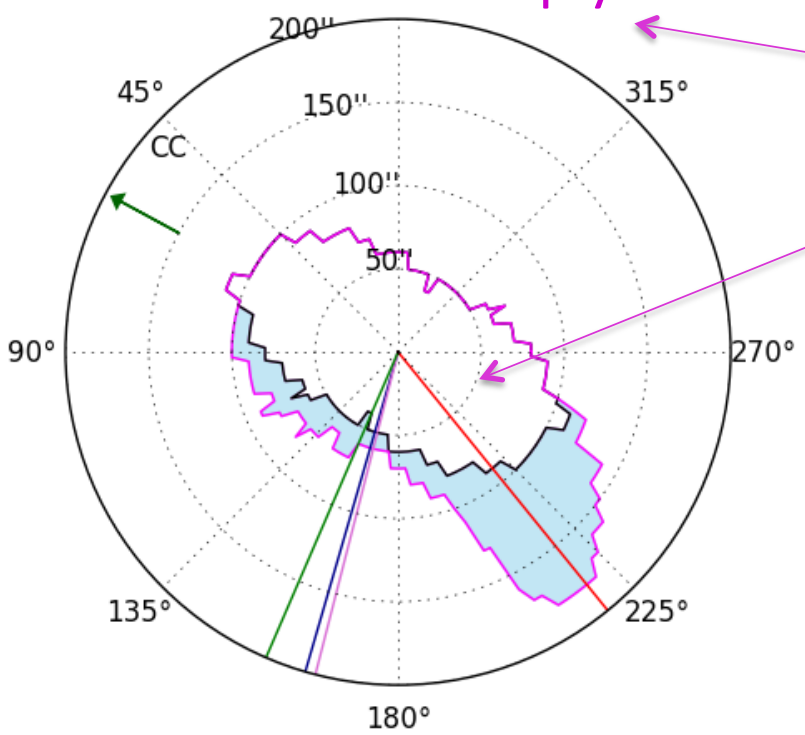
radial gas distributions help trace evolutionary state of galaxies



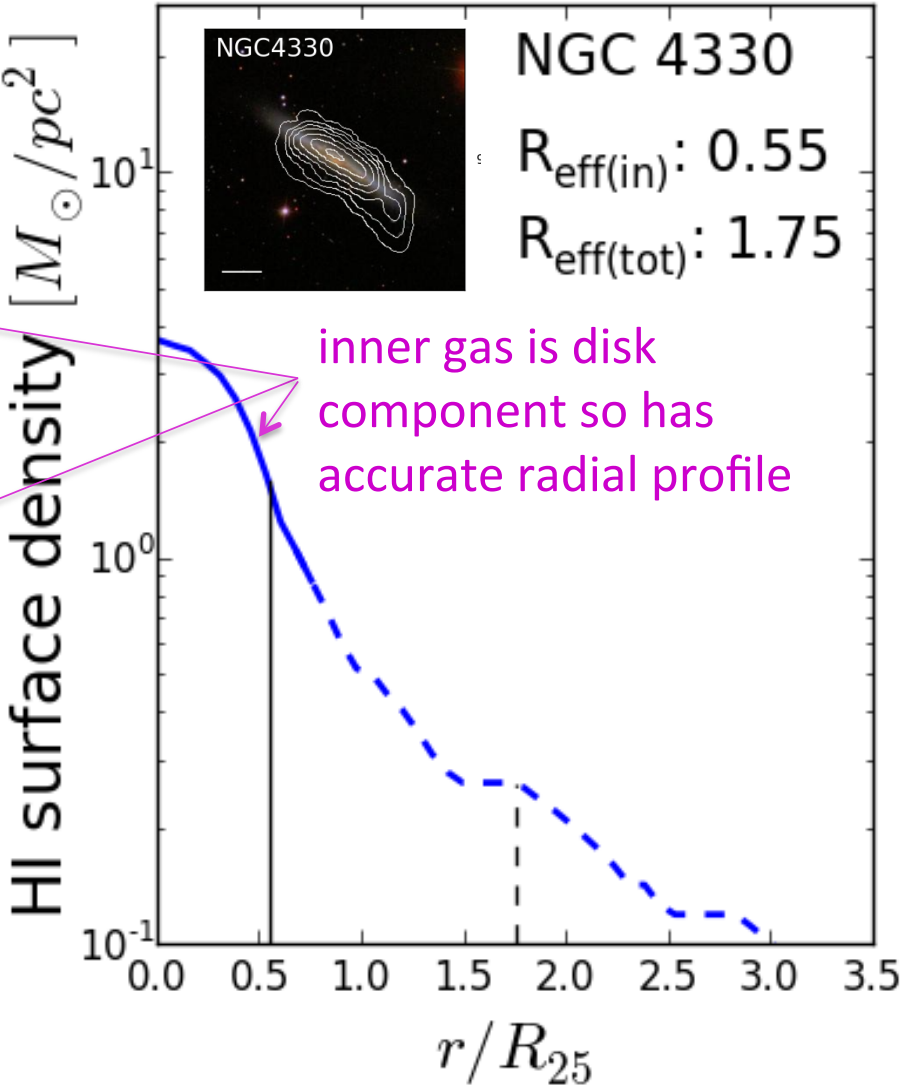
radial gas distributions from tilted ring models



radial gas distributions help trace evolutionary state of galaxies

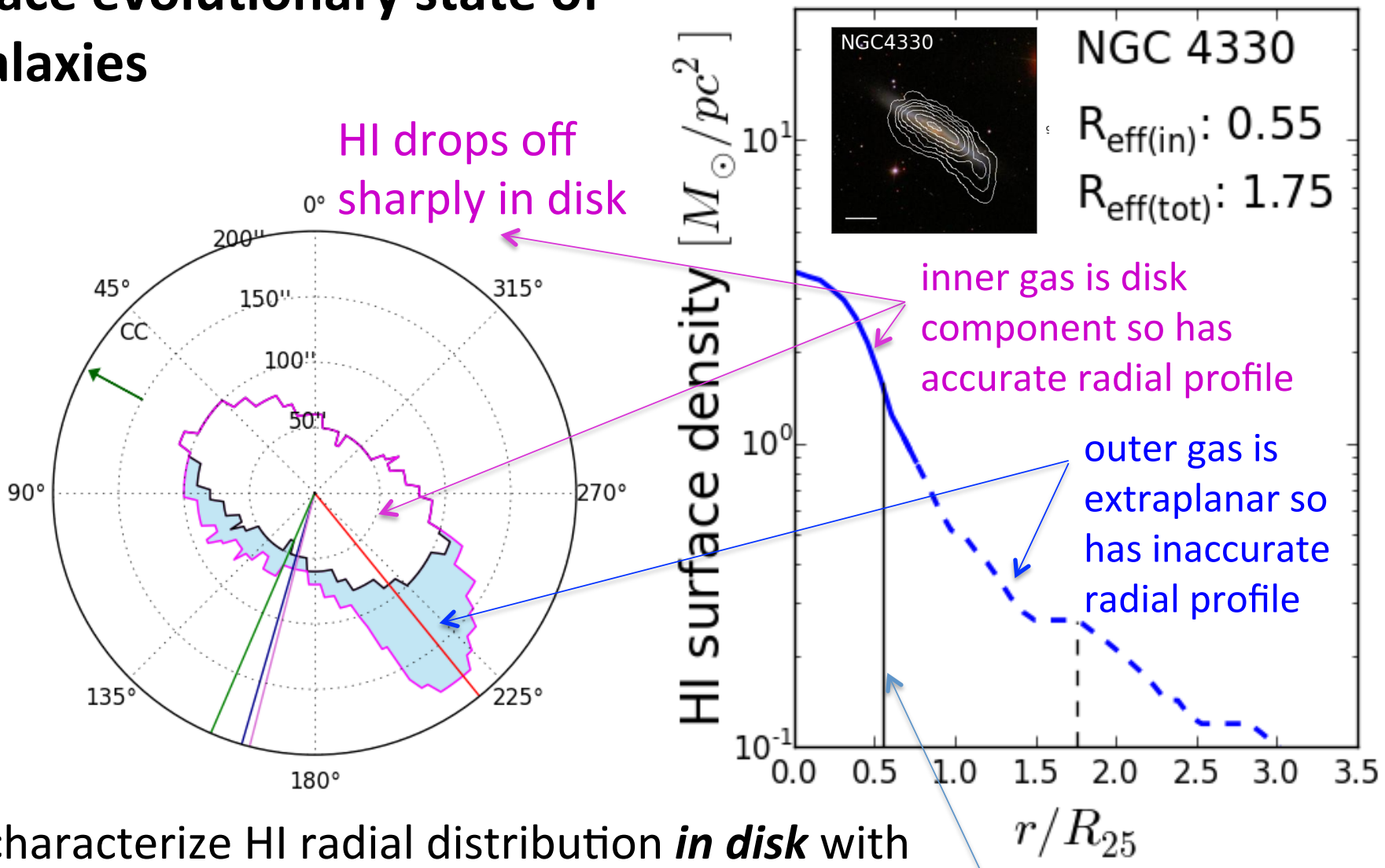


radial gas distributions from tilted ring models



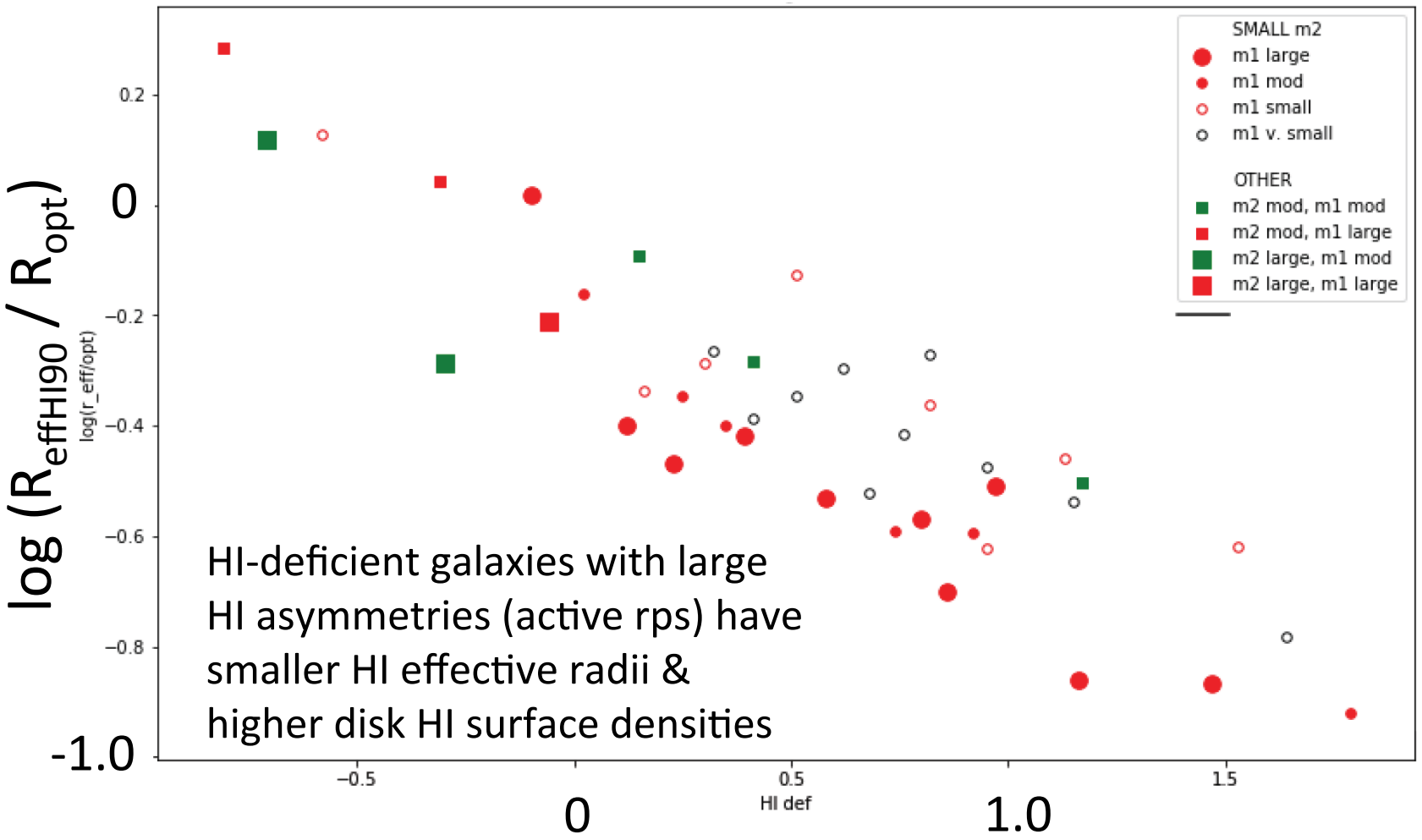
radial gas distributions help trace evolutionary state of galaxies

radial gas distributions from tilted ring models



characterize HI radial distribution ***in disk*** with $R_{eff90(in)}$, the effective radius that contains ***90% of the disk HI***.

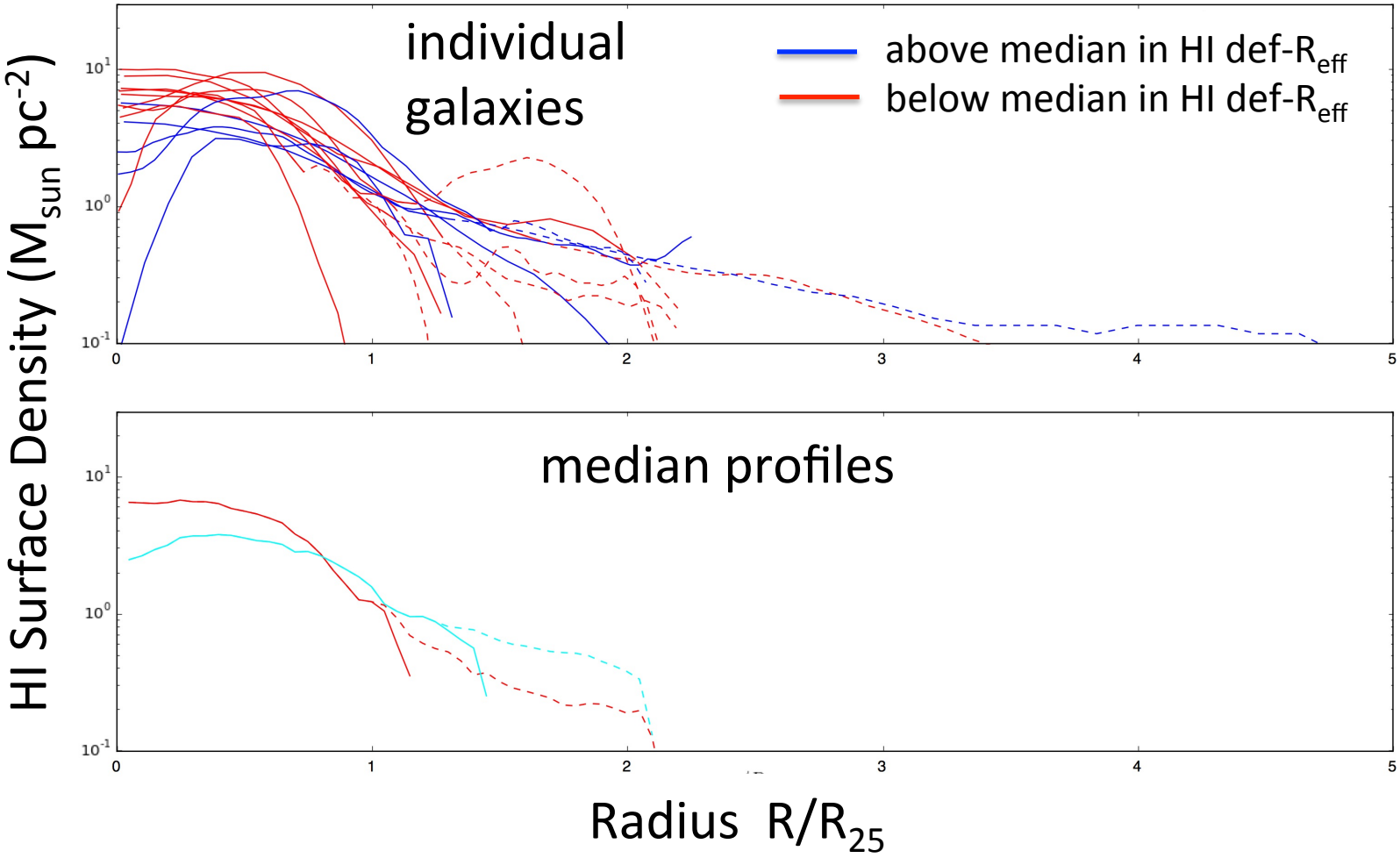
HI effective radius in disk vs. HI deficiency



HI deficiency = log ($M_{HI\ normal}$) – log (M_{HI})

Virgo spiral HI radial profiles

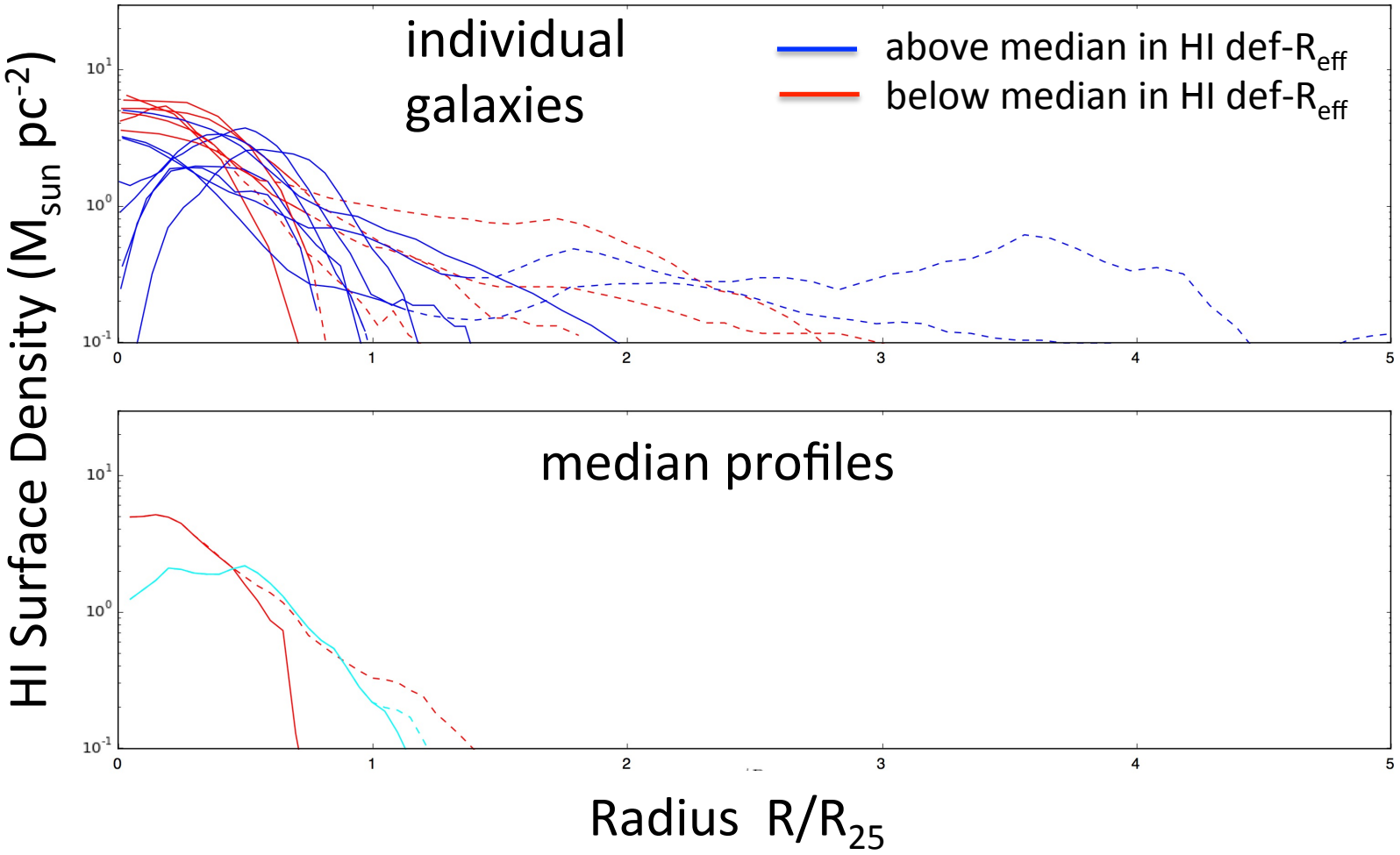
HI def = 0.2 - 0.7 (deficient by factors of 1.5-5)



HI-deficient galaxies with **large HI asymmetries** (active rps) have **higher disk HI surface densities**

Virgo spiral HI radial profiles

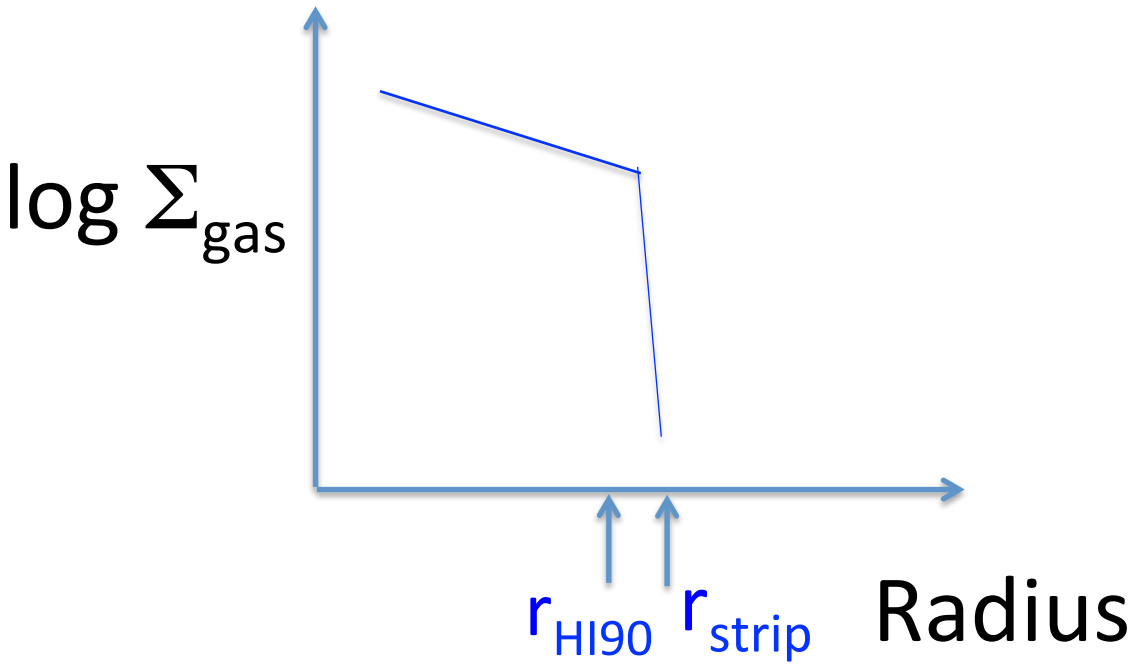
HI def = 0.7 – 1.2 (deficient by factors of 5-20)



HI-deficient galaxies with **small HI asymmetries** (post rps) have **lower disk HI surface densities**

disk gas distributions before & after peak pressure

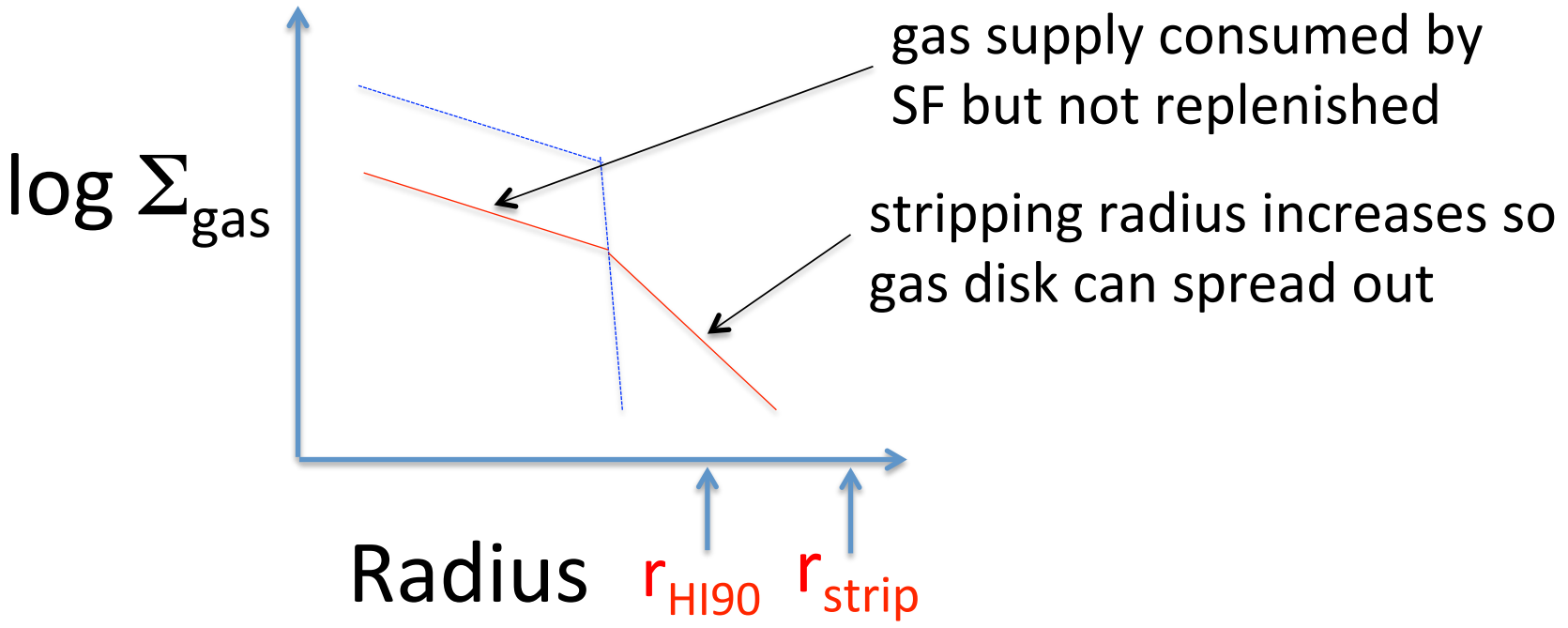
galaxy during active stripping stage (pre-peak pressure)



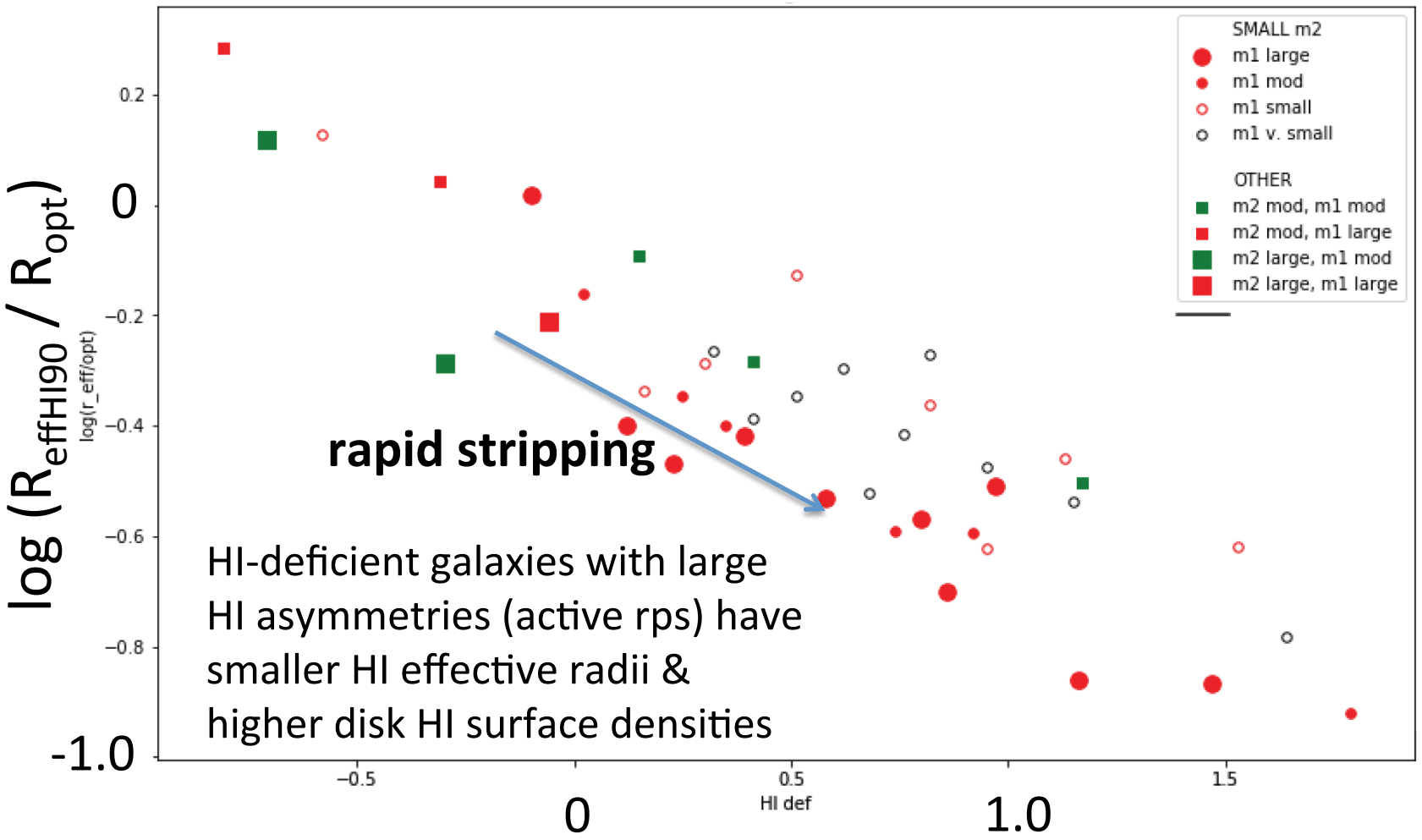
disk gas distributions before & after peak pressure

galaxy during active stripping stage (pre-peak pressure)

galaxy after active stripping stage (post-peak pressure, starvation phase)

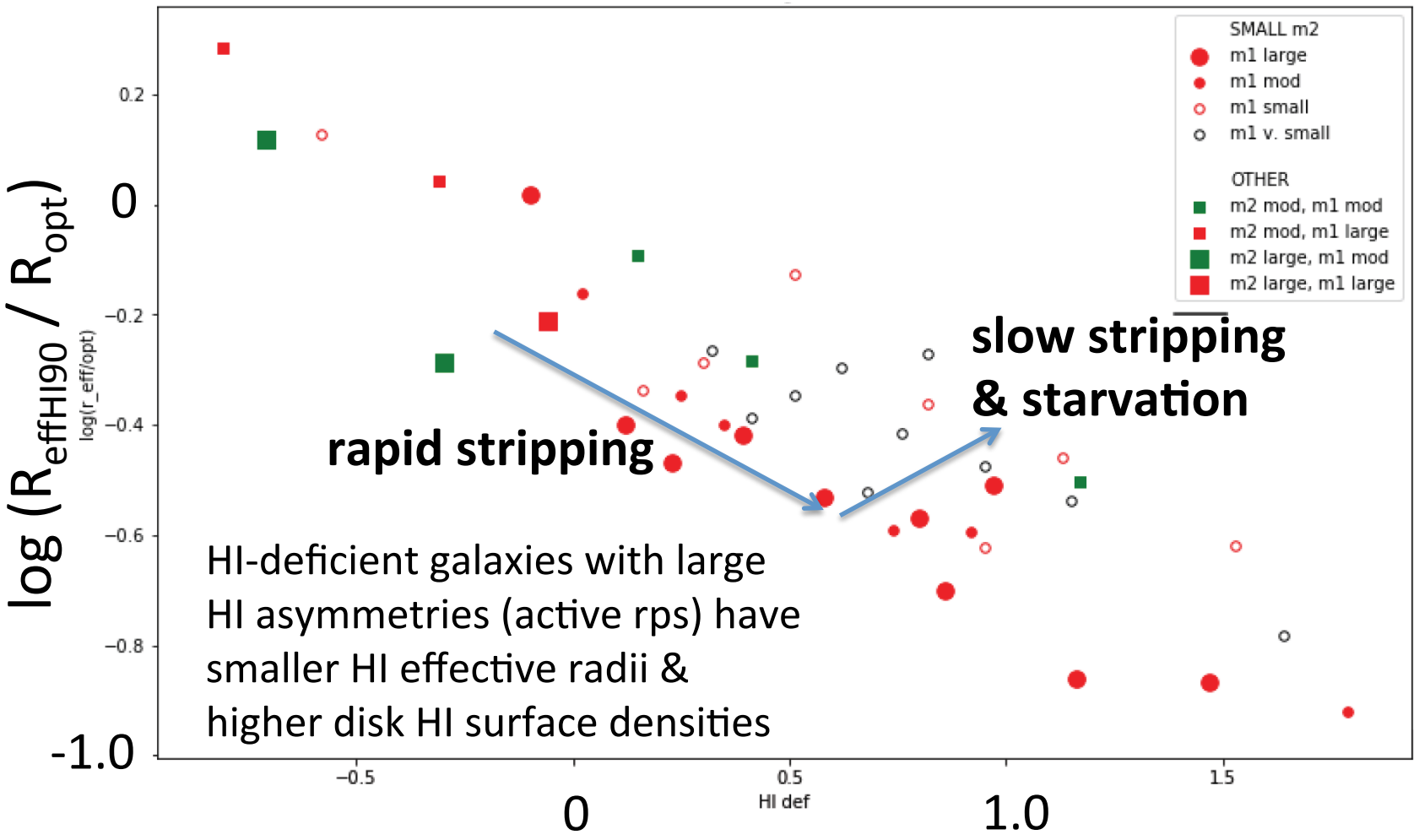


HI effective radius in disk vs. HI deficiency



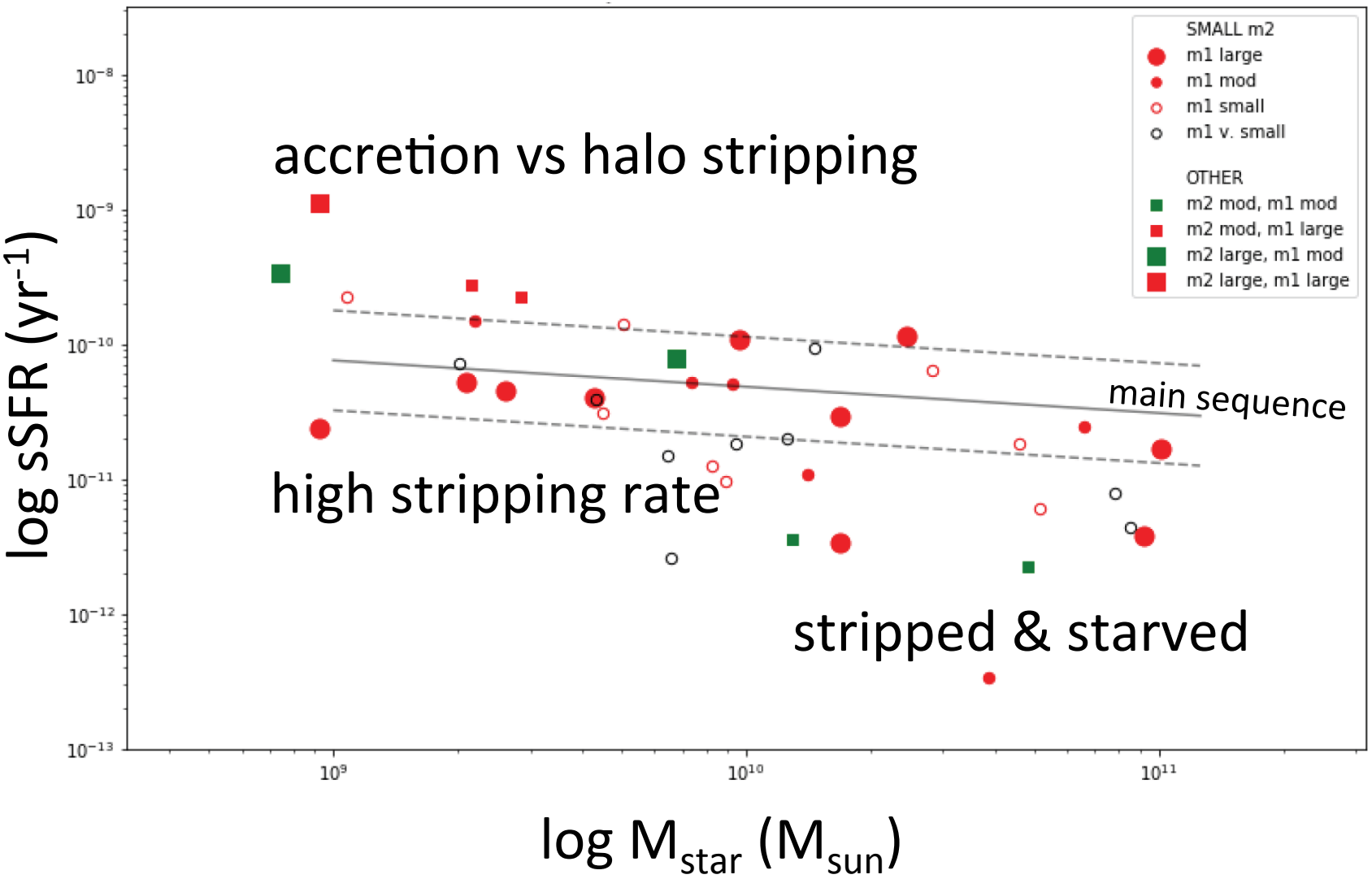
HI deficiency = log ($M_{HI\ normal}$) – log (M_{HI})

HI effective radius in disk vs. HI deficiency



HI deficiency = log ($M_{HI\ normal}$) – log (M_{HI})

stripping & evolution of SFR



summary

- good diagnostic for active stripping*:*
  outer galaxy head-tail HI asymmetry
  traces recent stripping rate

- good indicator of stripping vs. starvation evolutionary stage:
  effective radius of gas ***in disk (inner galaxy)***
  post-stripped galaxies are starved & have lower disk gas surface densities