The continuing formation of early-type galaxies: an HI view

HI observations of SAURON galaxies

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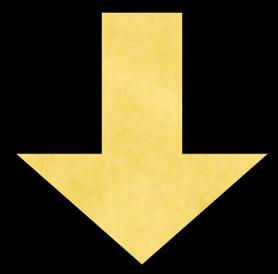
Gas and early-type galaxies

- Early-type galaxies: diversity of properties that goes beyond simulations ➠ do not constitute a uniform class
- Hierarchical galaxy formation:
  - ✳ mass ratio of the merging components
  - ✳ feedback on the gas
  - ✳ amount of dissipation during the merger



Is gas (partly) responsible for this?

Cold accretion important?

H I-rich early-type galaxies: shallow survey (HIPASS & ATCA)

Morganti et al. 1997

Oosterloo, Sadler, Morganti
Serra, van der Hulst A&A 2007

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- 5-10% (in field galaxies) have 10^9-10^{10} $M_\odot$ on scale of hundred kpc
- M_{HI}/L_B ~0.1 - 1 (i.e. like spirals!)
- **Regular structures (disks), very large, more than 10^9 yr old**;
- Often strongly warped
- Dark matter content; similarity with spirals
- Low surface density (0.5-1 $M_\odot/pc^2$)

so do not form (many) stars (i.e. the H I is not used up quickly),
these H I structures can stay around for a very long time!

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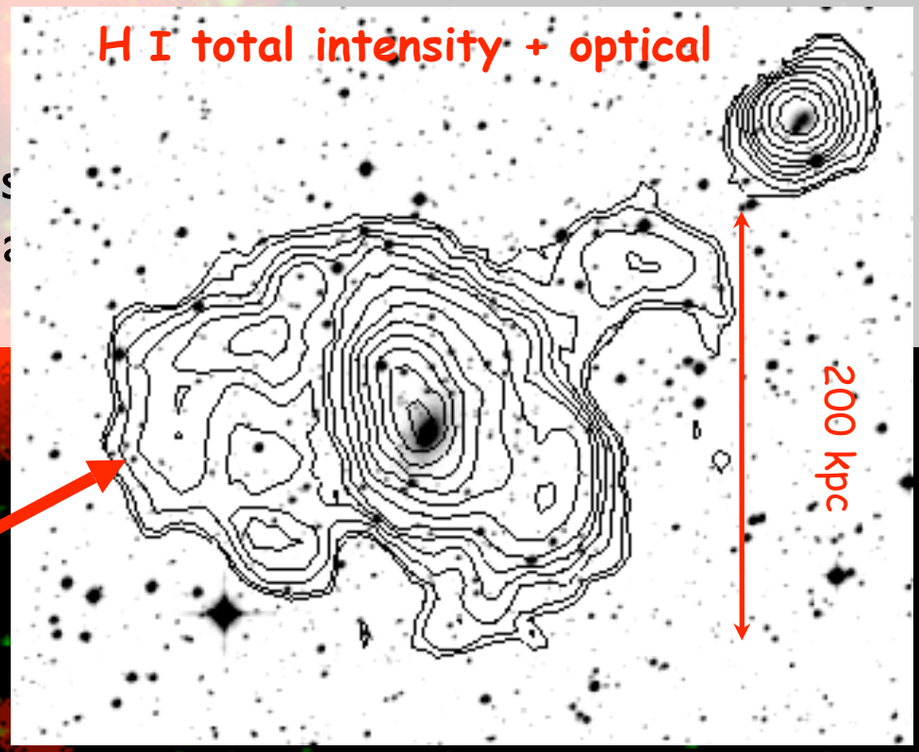


These early-type galaxies likely form through a major merger

IC4200: Event that happened about 2 Gyr ago and originated both the H I structure and the central starburst: major merger – time not long enough for accretion of IGM.
Serra et al. A&A 2006

What is the next step?

Higher sensitivity for deeper HI observations

Complementary information on the ionised/molecular gas and stellar population ➠ essential for a complete picture

WSRT observations of galaxies of the SAURON sample (dec>10°)

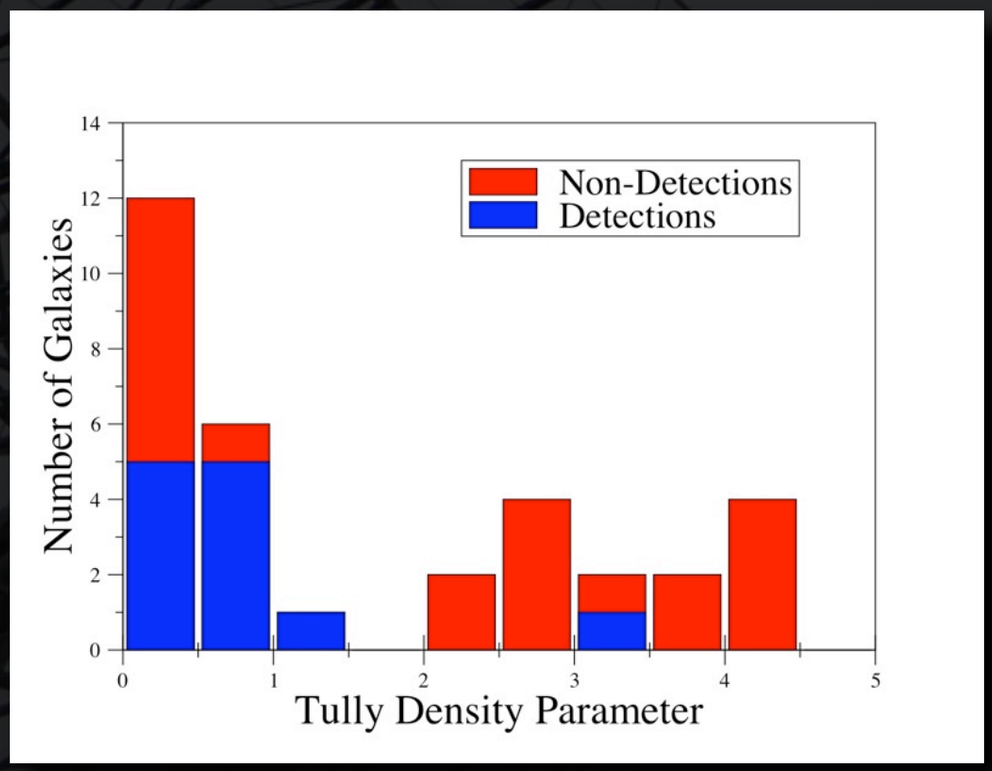
- 12h spent on each target
- resolution few kpc (at the distance of typical SAURON galaxies)
- follow-up (additional 3x12h) for the HI detected galaxies

The WSRT-HI survey of SAURON galaxies

- **detection rate in field ~60%**
- strong dependence on the environment:

  20 field galaxies ➠ 12 (+2?) detections

  13 cluster galaxies➠ 1 detection
- mass limit few x 10^6 $M_\odot$
- variety of HI morphologies: information about morphology important

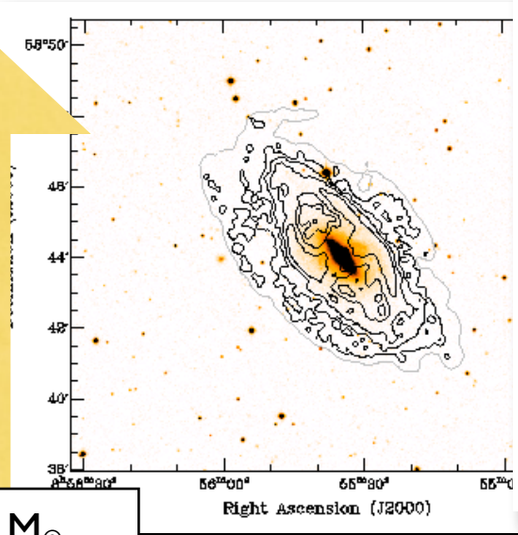


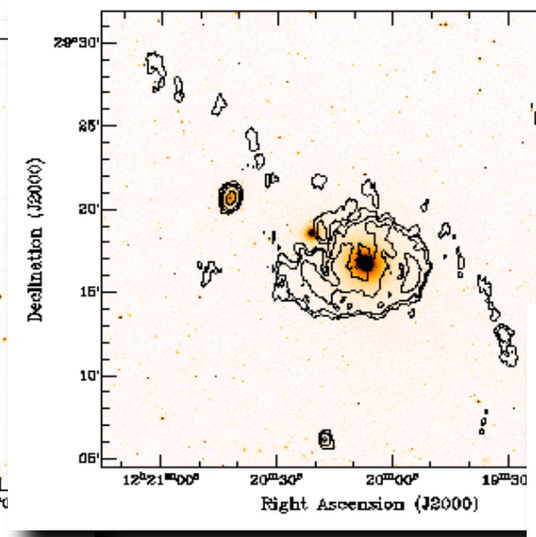
- Morganti R. , deZeeuw T. , Oosterloo T. ,McDermid, R. M.; Krajnović, D.; Cappellari, M.; Kenn, F.; Weijmans, A.; Sarzi, M (2006)
- Oosterloo et al. in prep

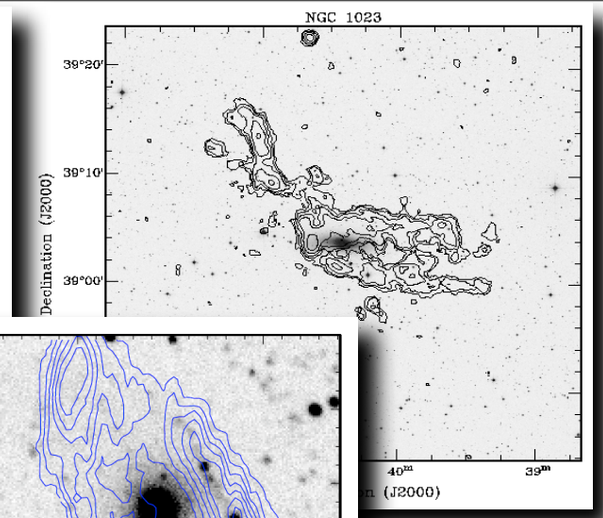
HI mass

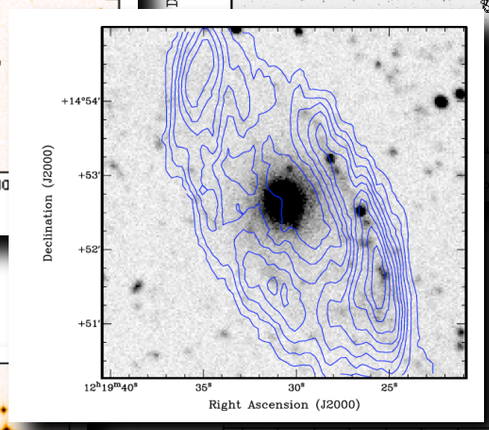
~5x10^8 M$_\odot$

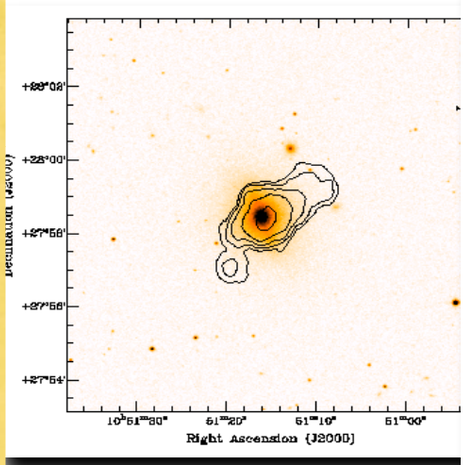
~5x10^7 M$_\odot$

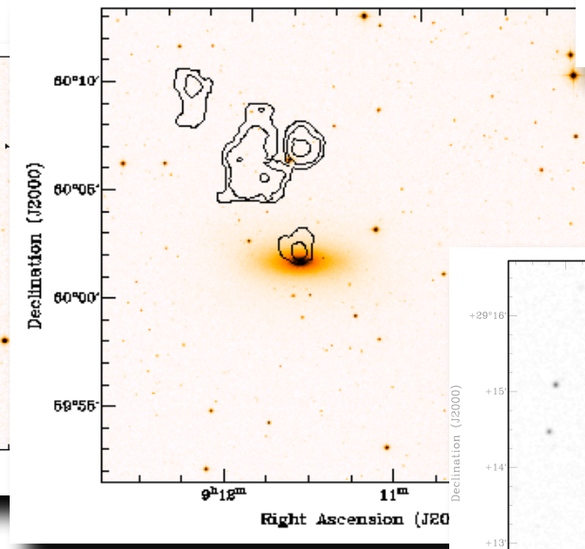


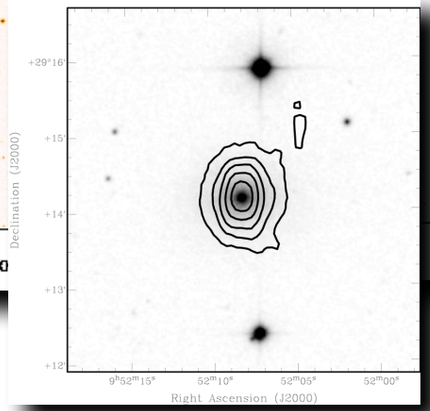


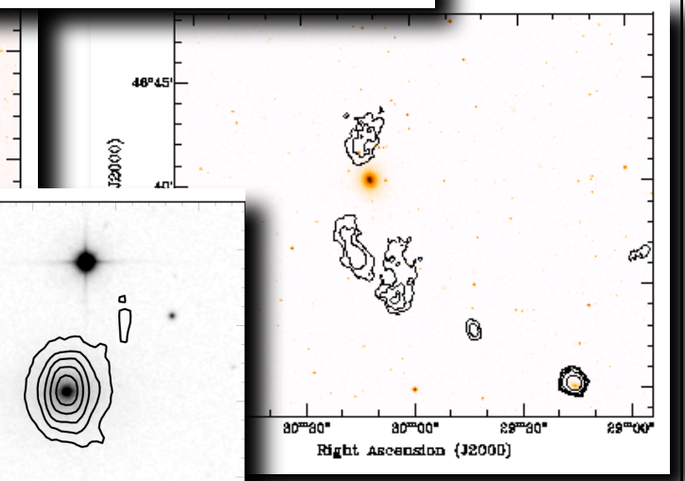


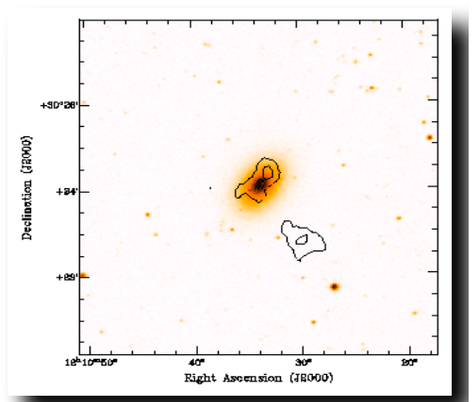


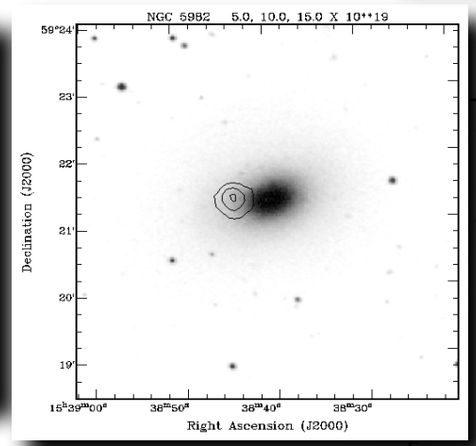


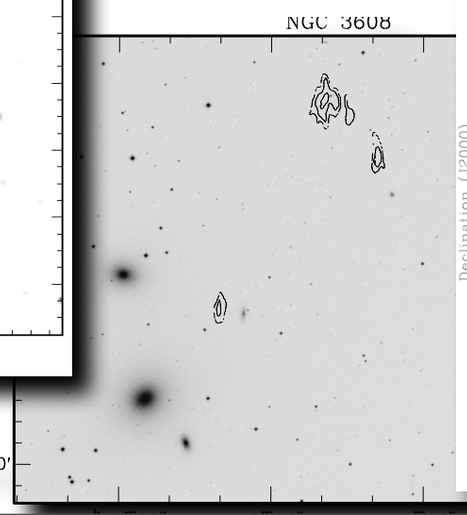


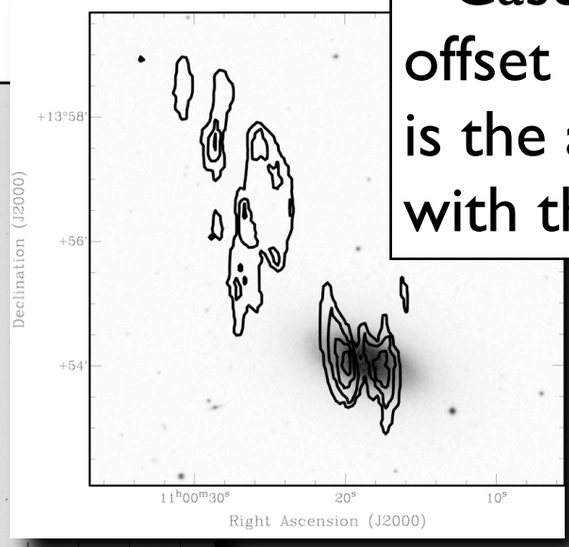












- Half of the HI detected early-type galaxies have the gas distributed (mainly)in disk/ring structures
- Some of them have also tails suggesting on-going accretion or interaction
- The remaining show unsettled structures ➠ HI does not manage to form a disk
- Cases with large offset HI-target: what is the actual relation with the target?

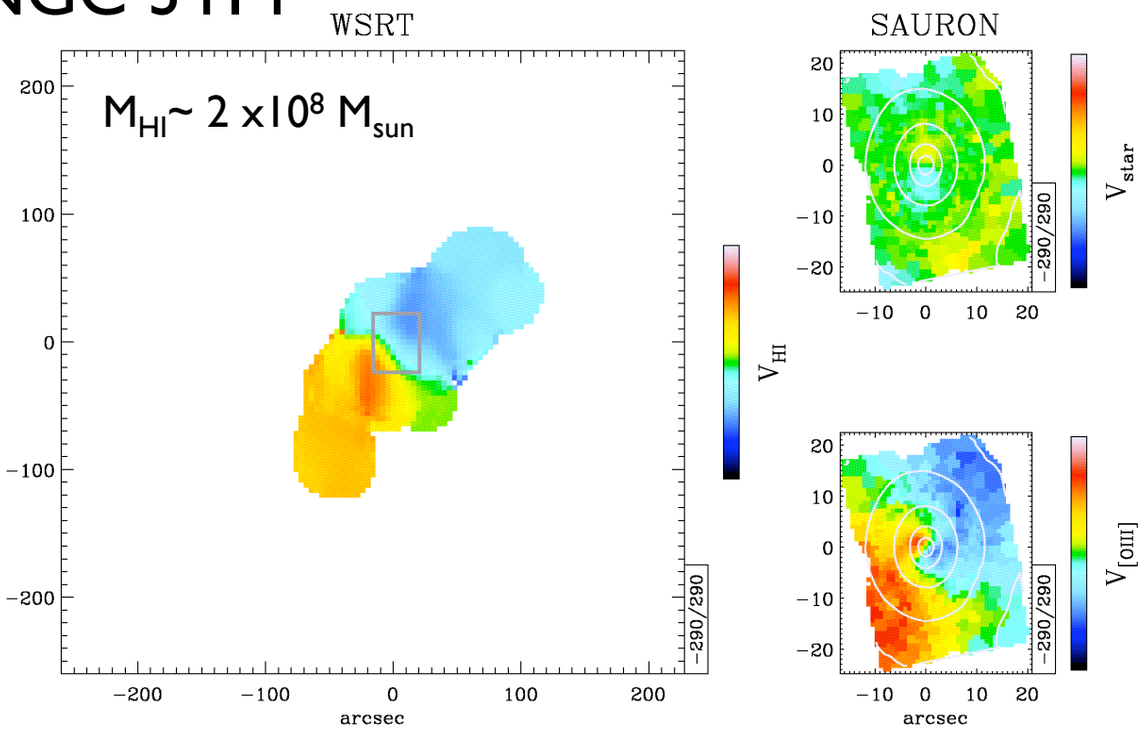
Unique dataset to compare/correlate with other 3D datasets ➠ optical and CO data

- Ionised data occurence/morphology/kinematics
- Stellar population
- Host galaxy properties
- Dark matter
- CO data
- Radio AGN

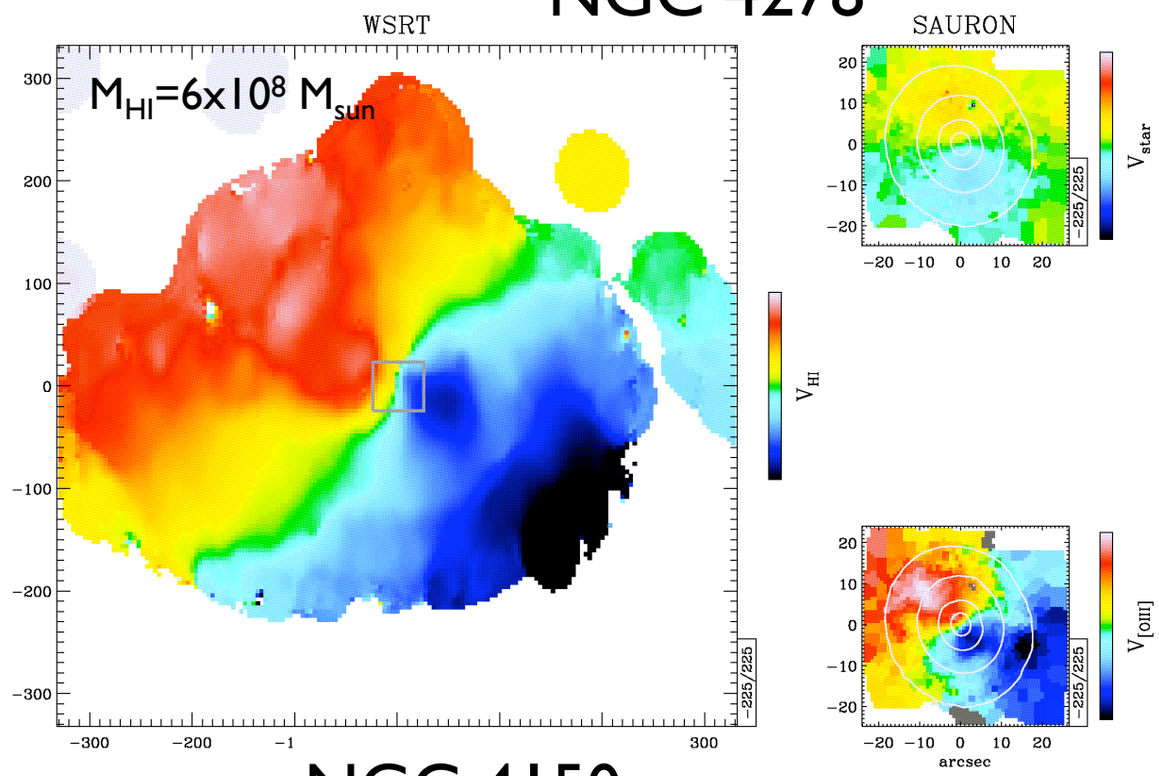
as function of HI occurrence but also HI morphology

Kinematics of the gas and the stars:
galaxies with regular HI disks also have extended, kinematically regular structures in the ionised gas

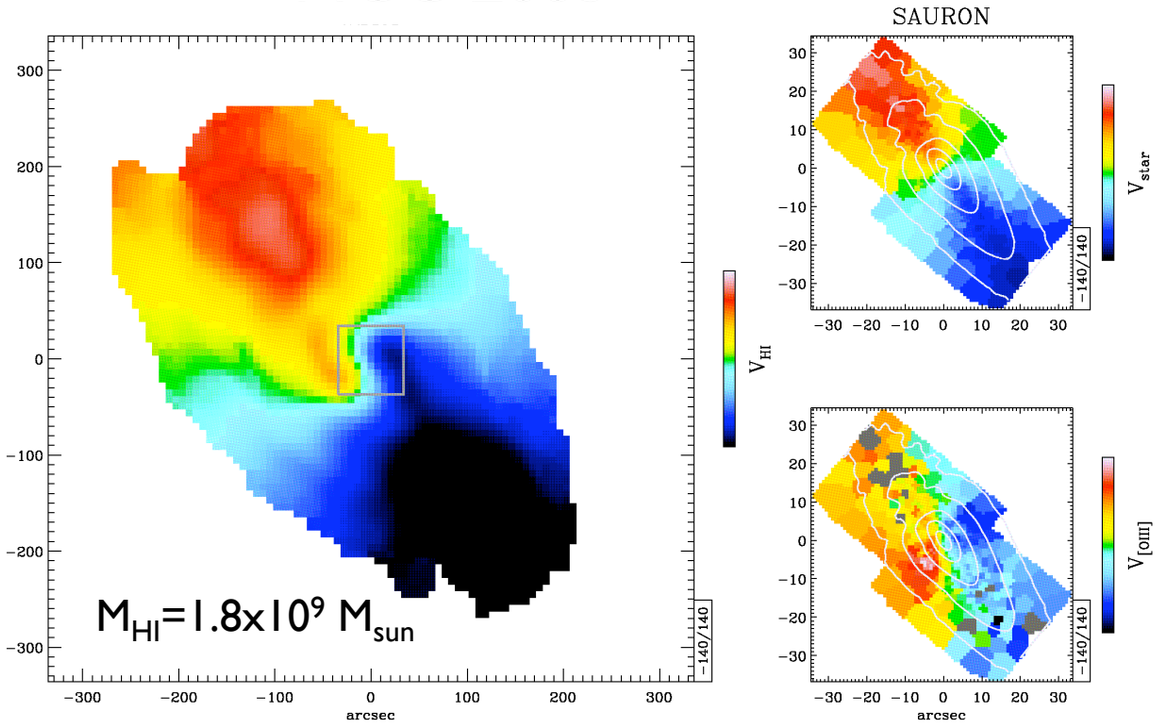
NGC 3414



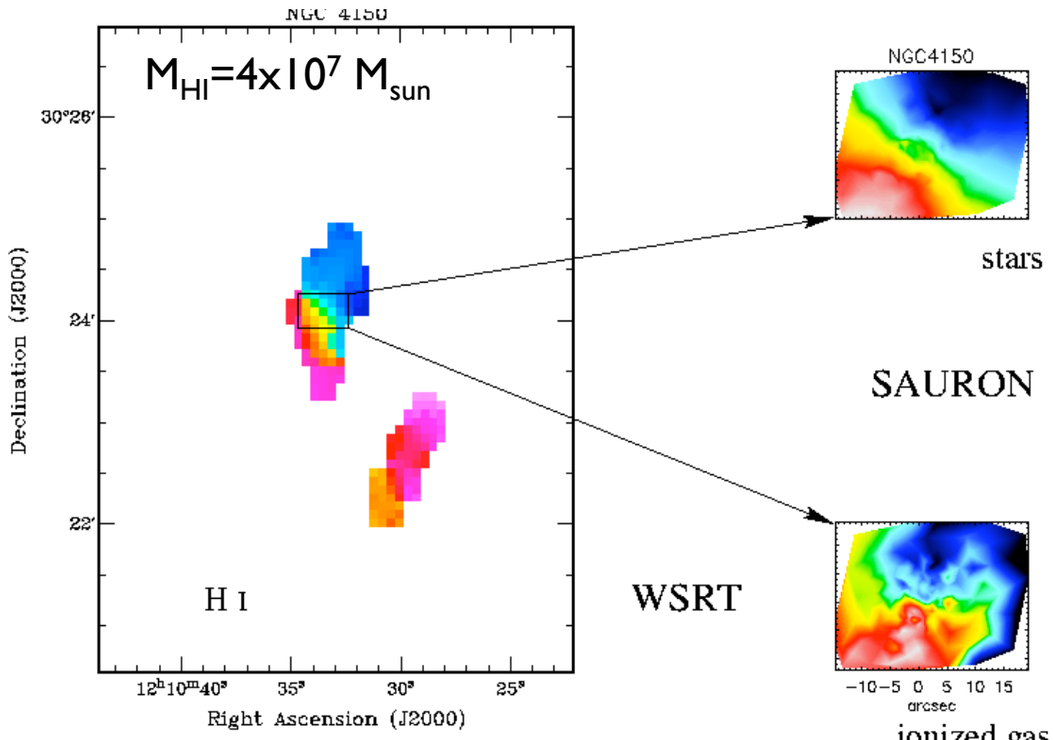
NGC 4278



NGC 2685



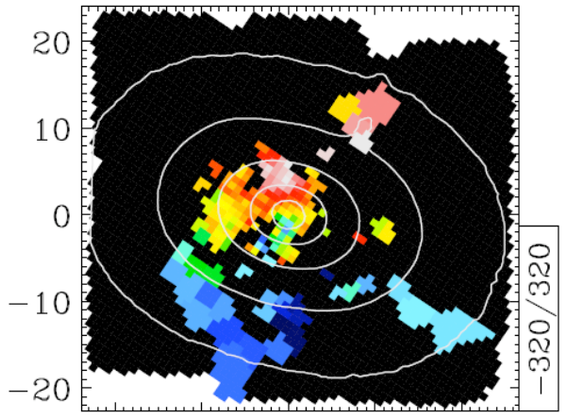
NGC 4150



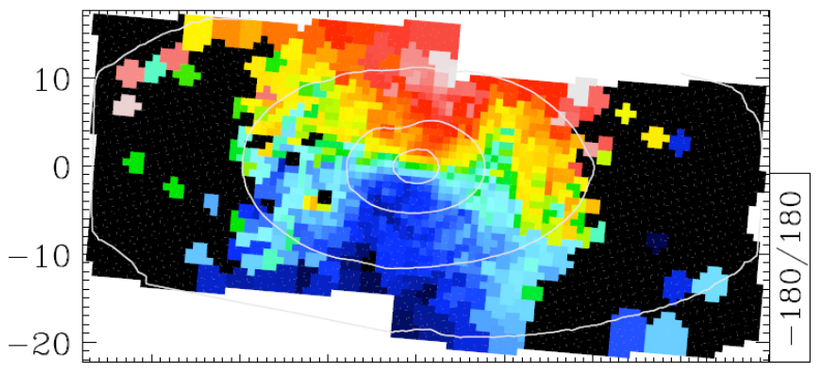
Morganti et al. 2006

Galaxies with offset (or complex) HI

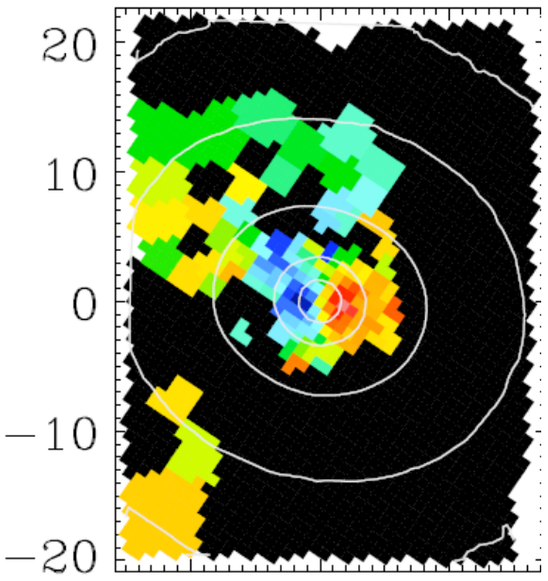
NGC 5982



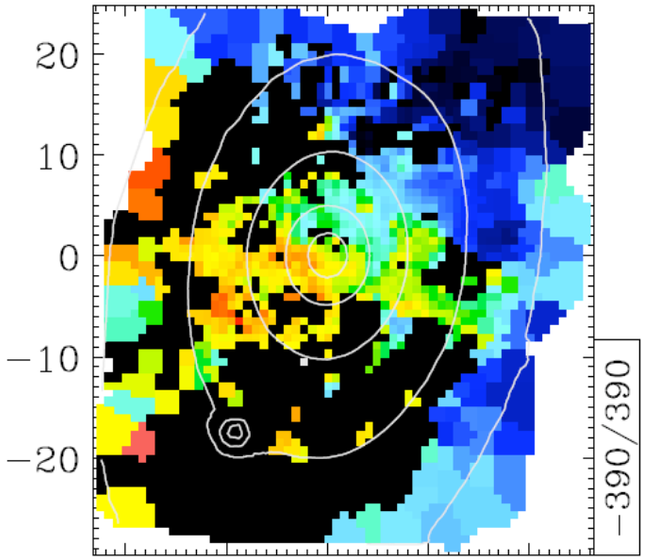
NGC 2768



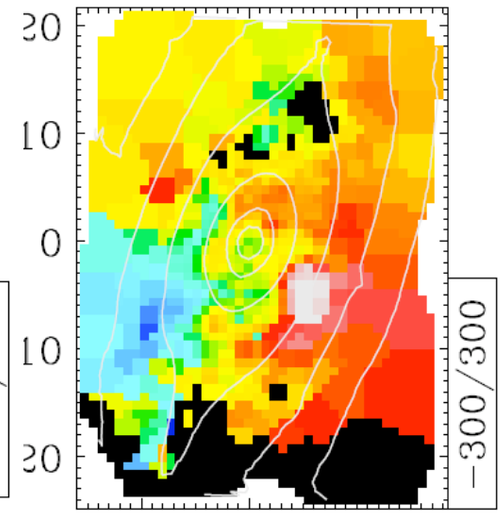
NGC 5198



NGC 1023

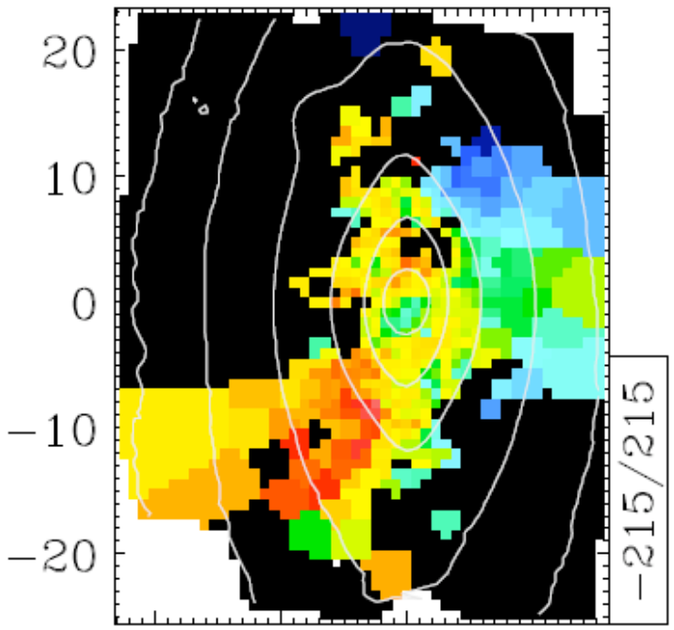


NGC 7332

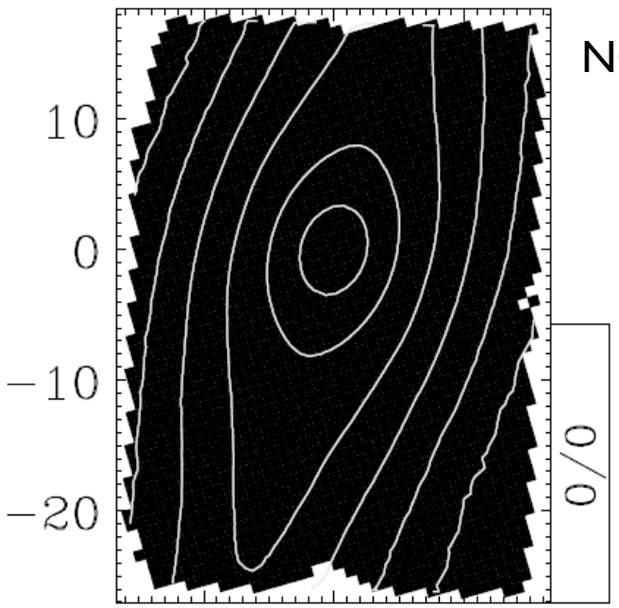


Galaxies with no HI

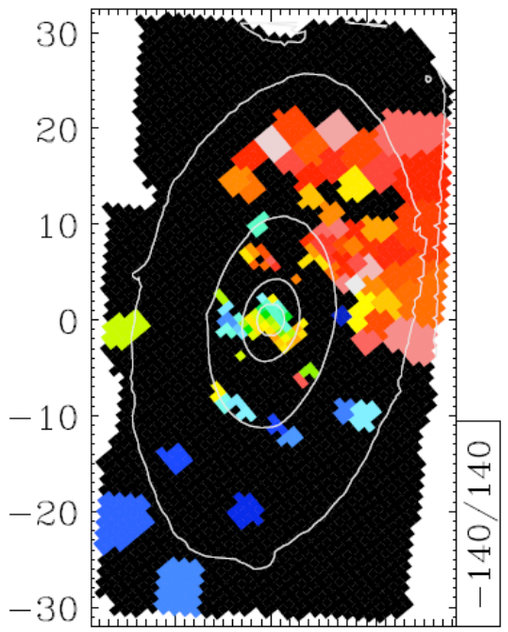
NGC 2549



NGC 5308

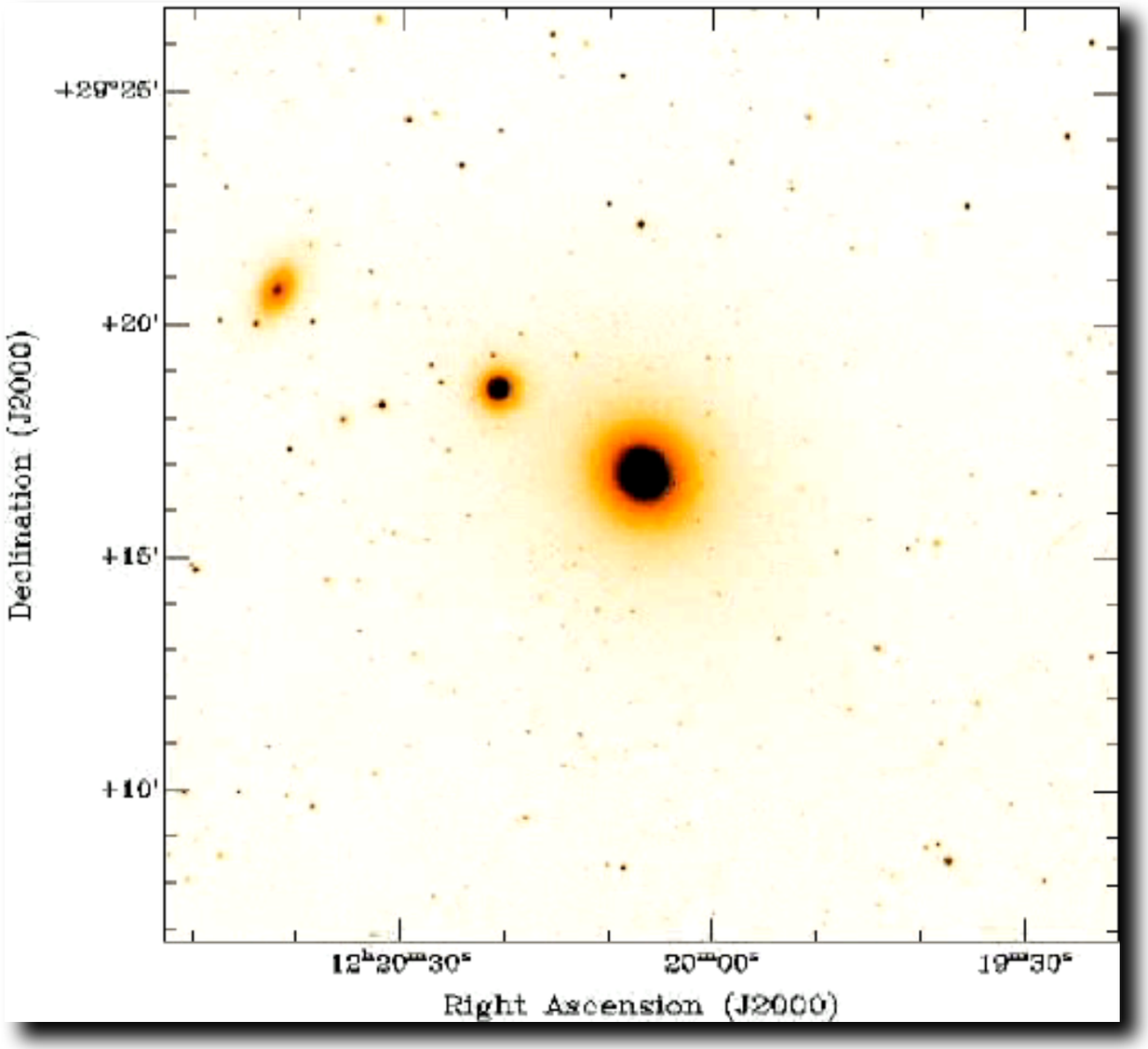


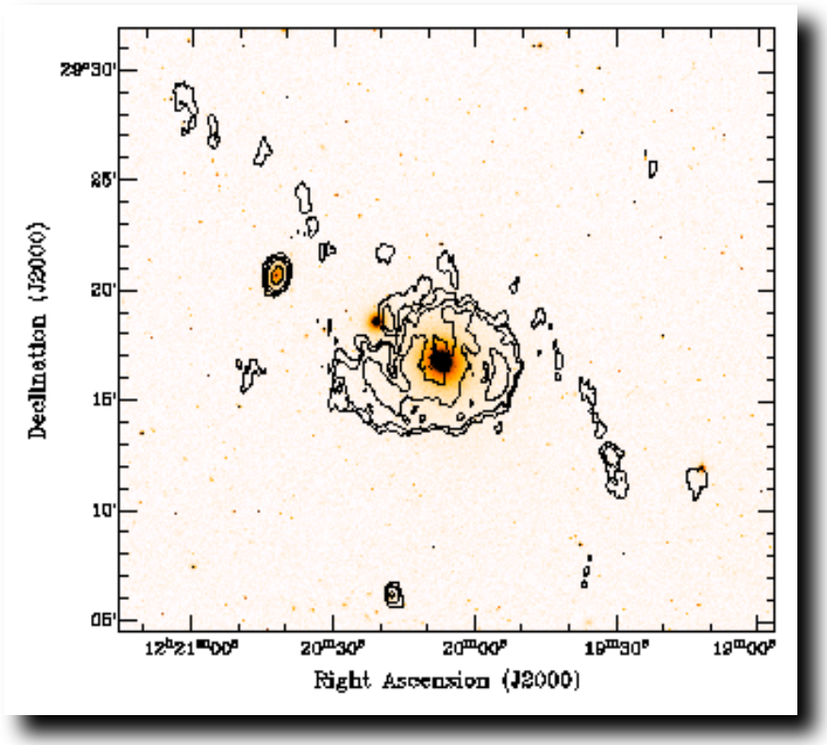
NGC7457



There is more in the data: looking at the full datacube

NGC4278





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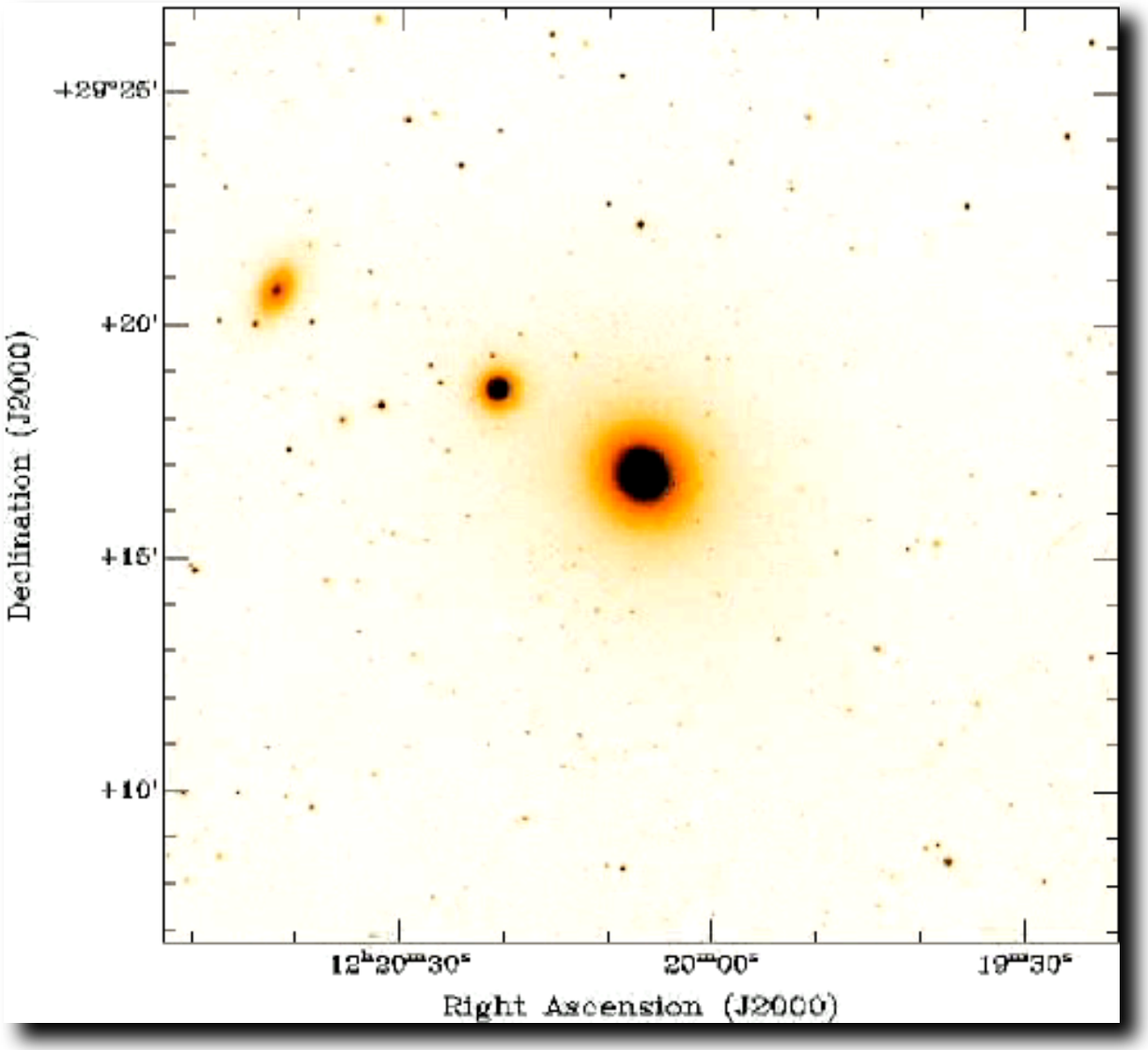
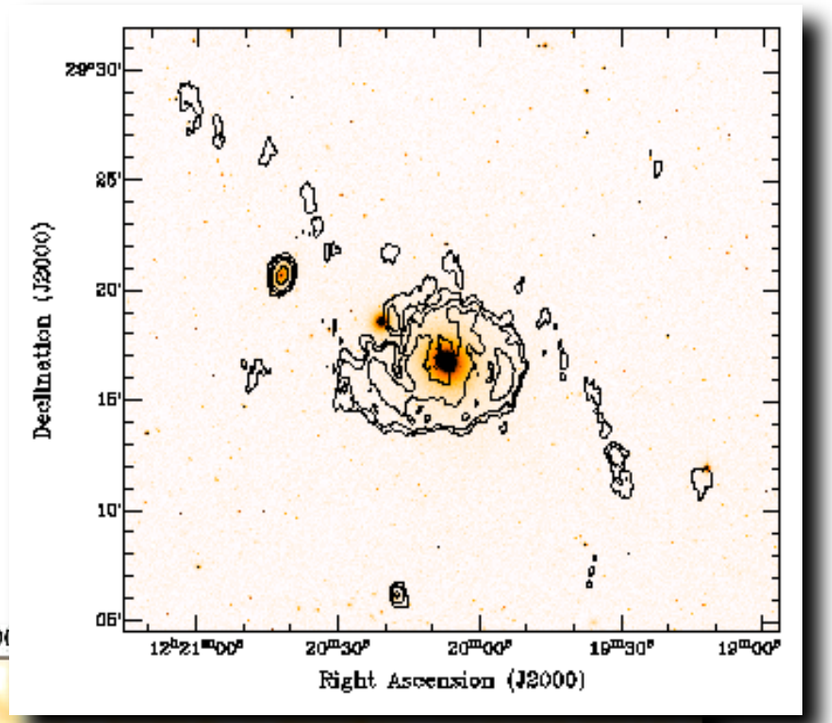
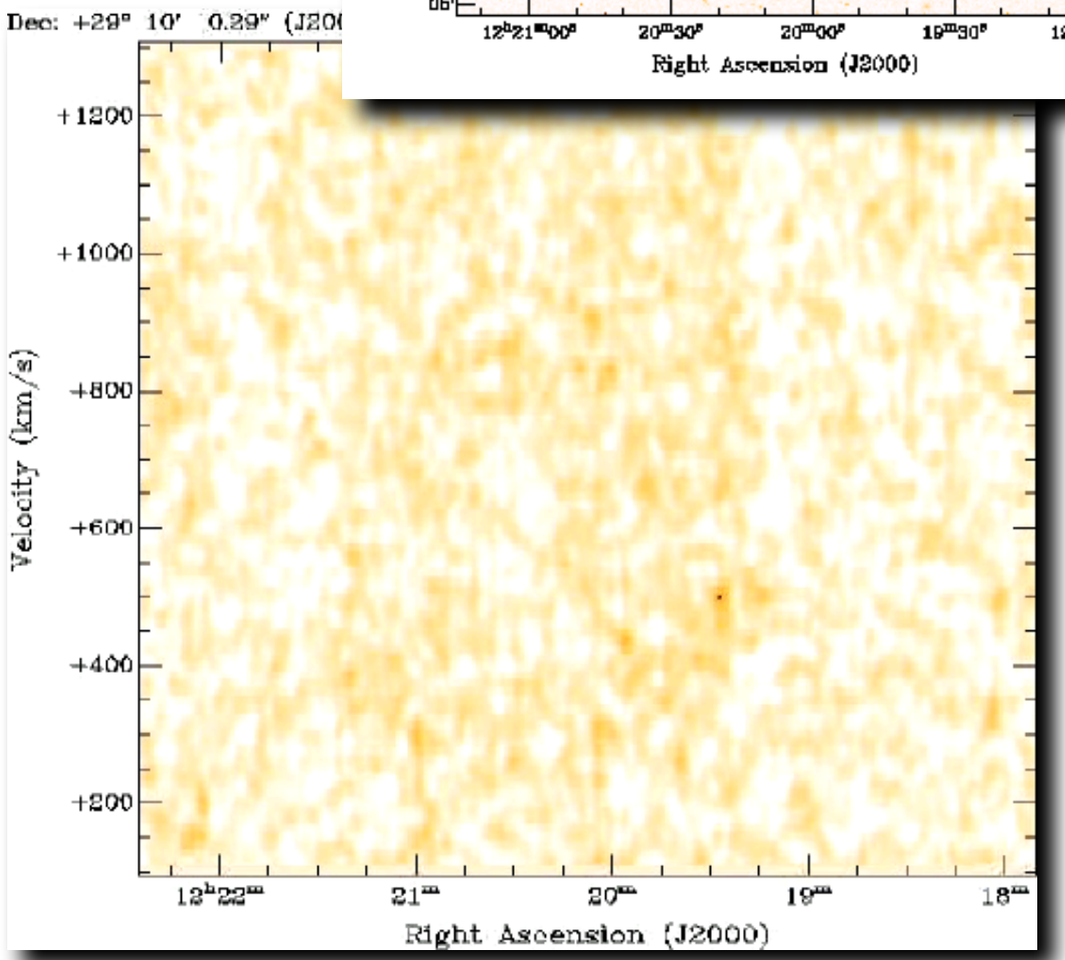


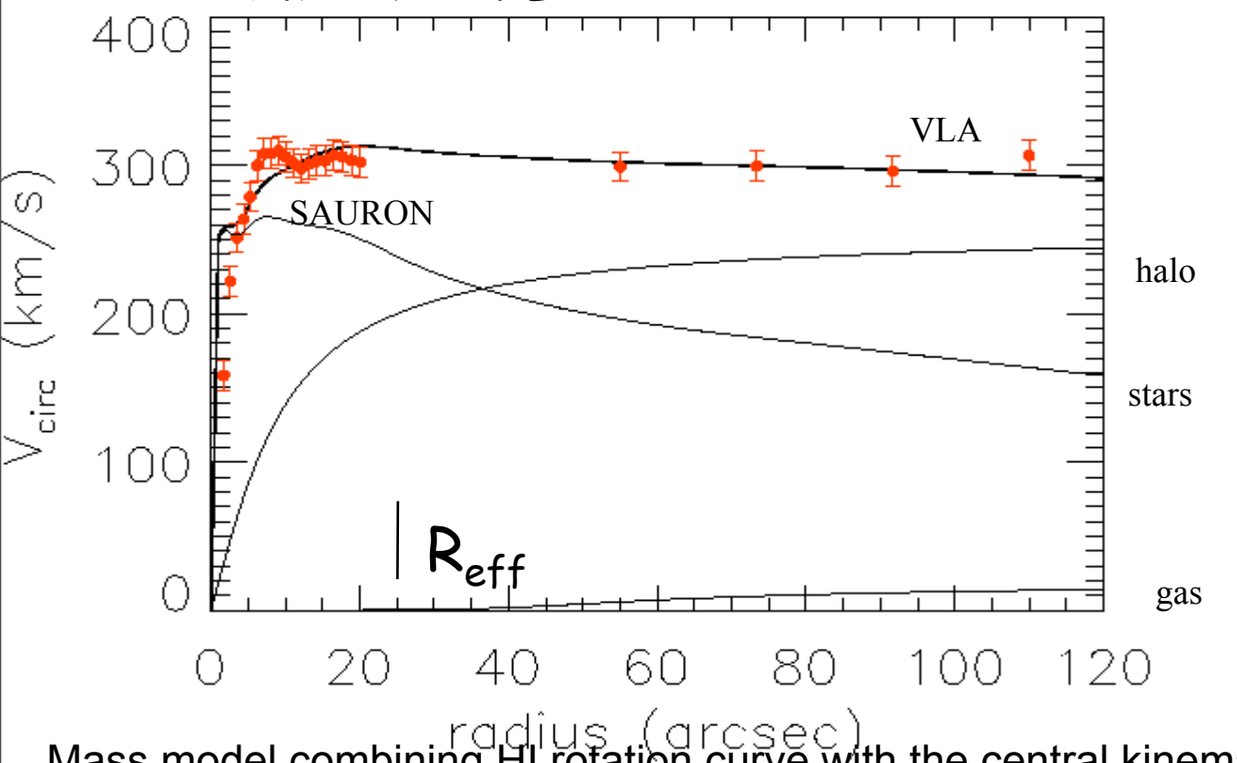




Example of what we can do with these data: NGC 2974

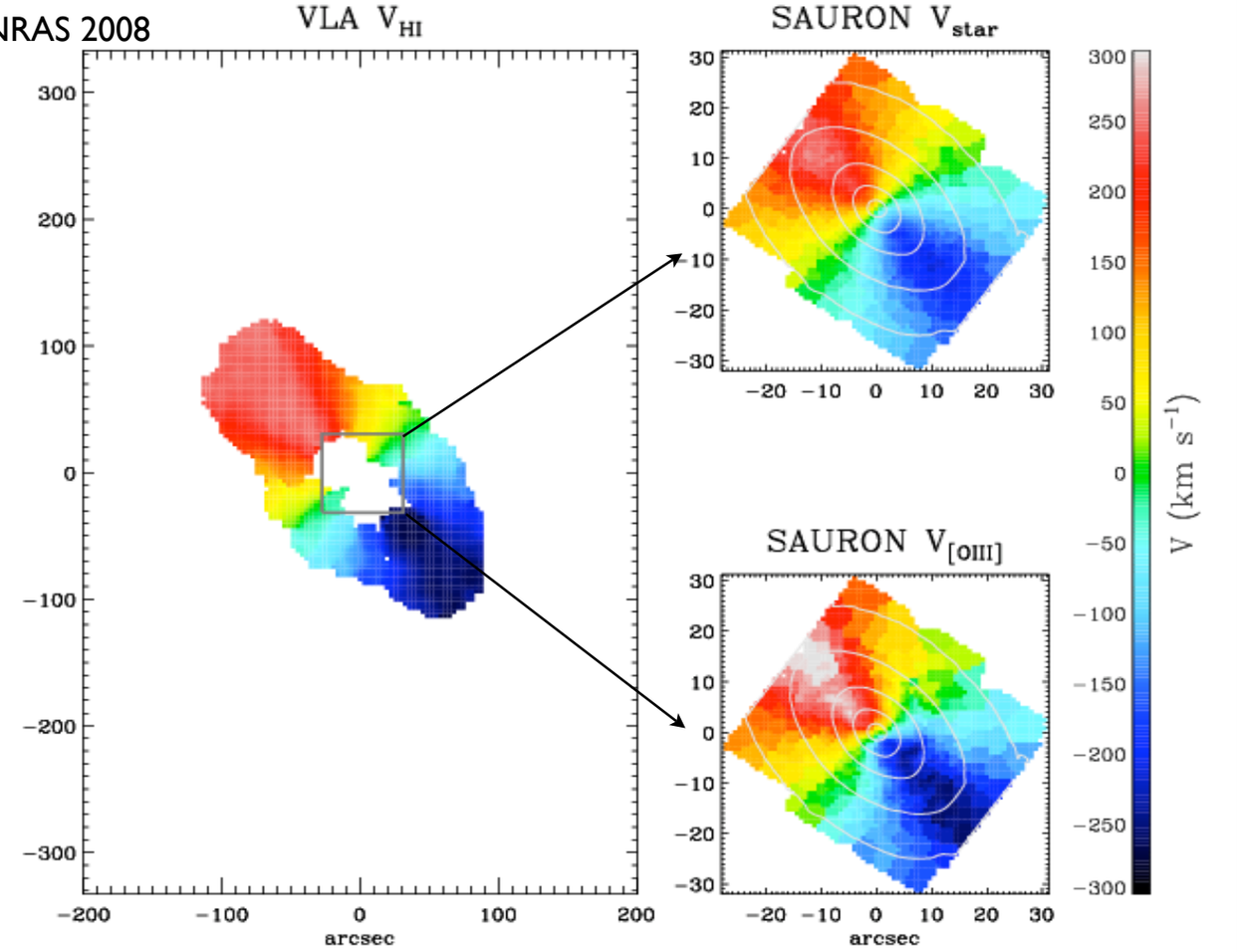
Weijmans A.-M., Krajnovic D., van der Ven G., Oosterloo T., Morganti R., de Zeeuw T. MNRAS 2008

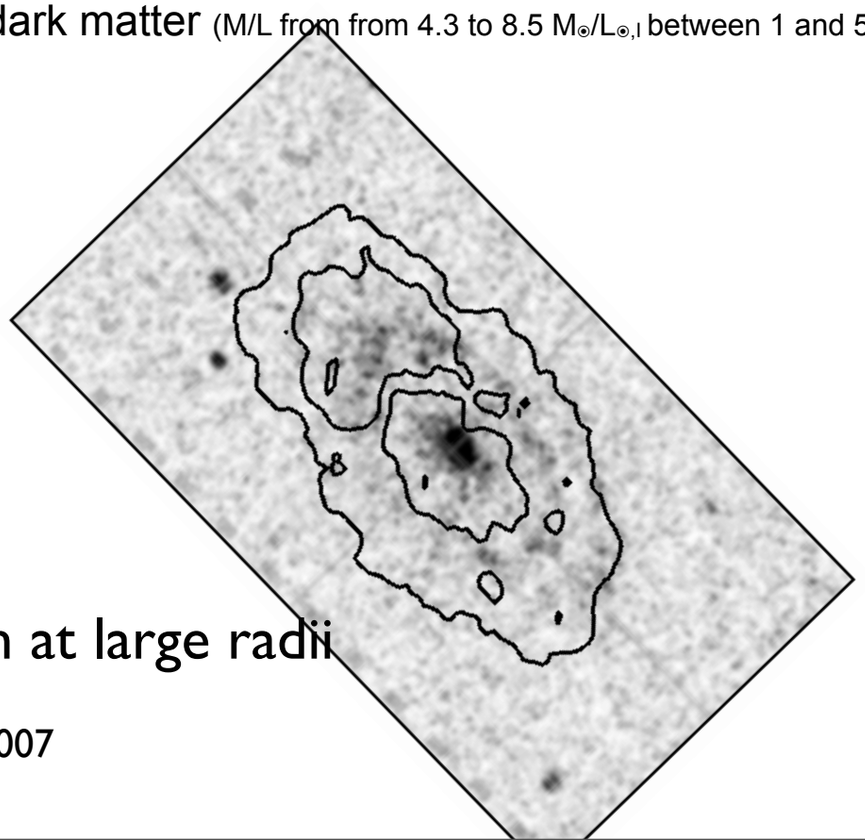
Sauron + VLA



Mass model combining HI rotation curve with the central kinematics of the ionised gas.

Increase M/L ⇒ dark matter (M/L from from 4.3 to 8.5 $M_\odot/L_{\odot,I}$ between 1 and 5 R_e)

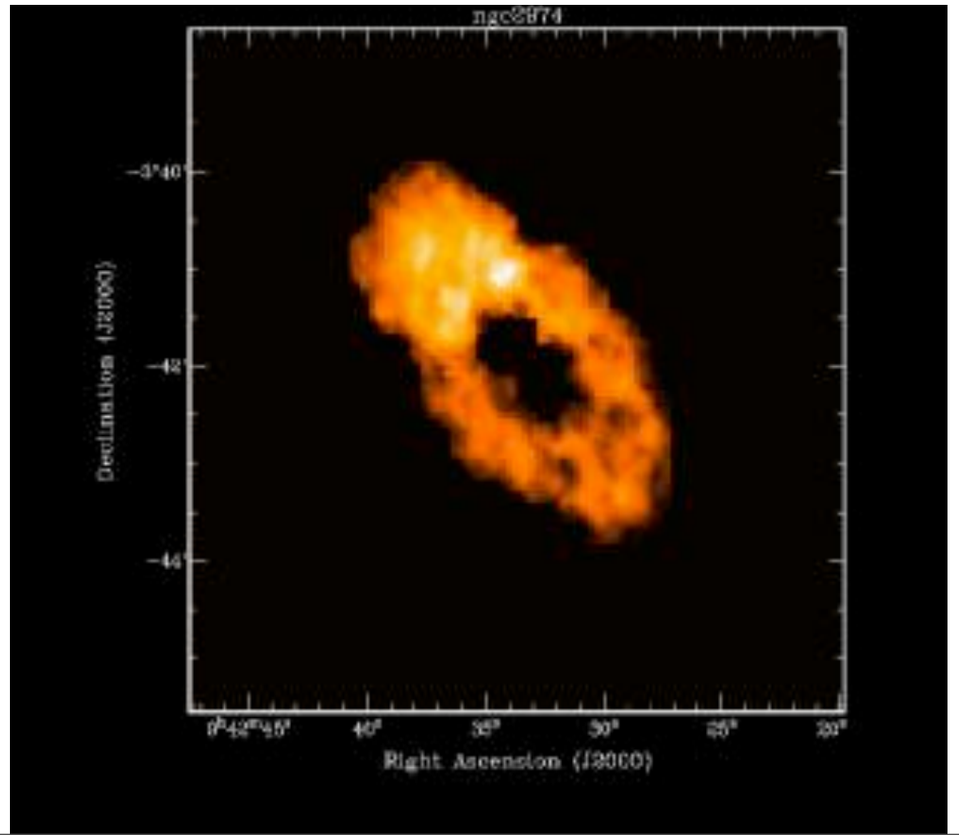




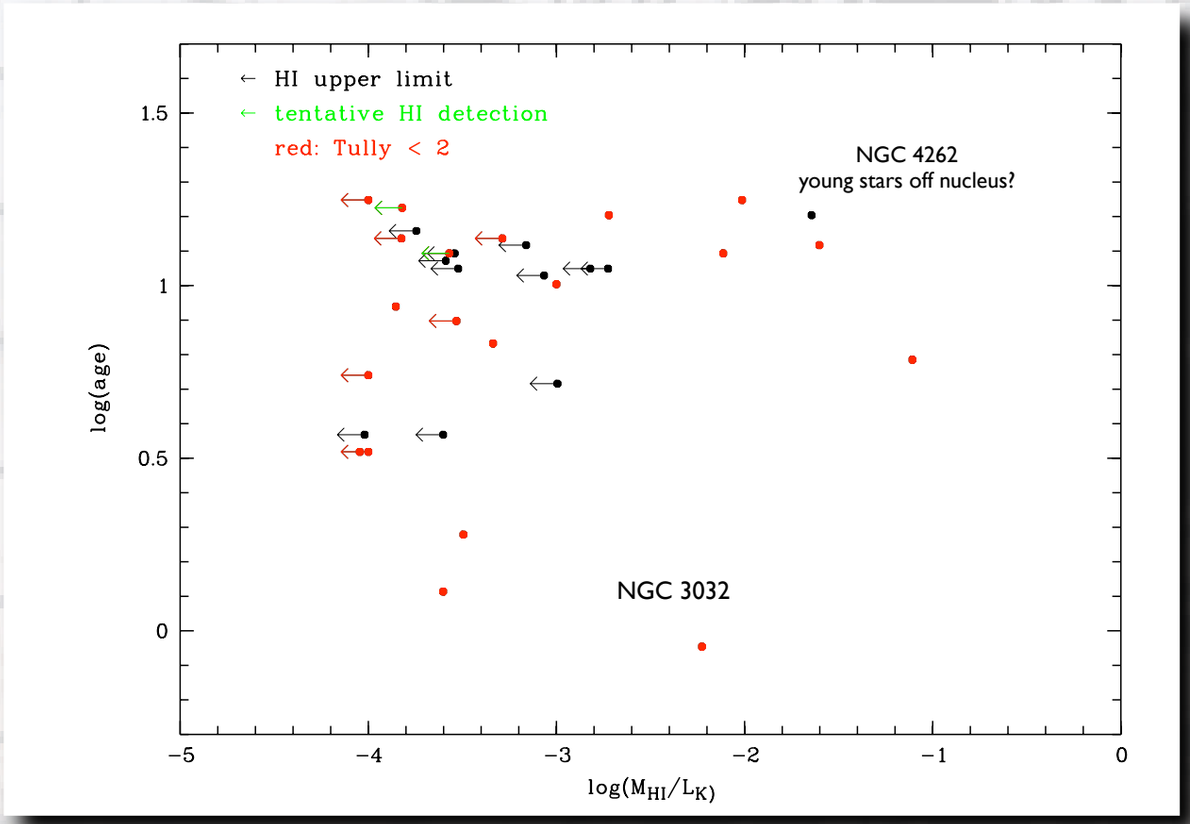
Galex & H I

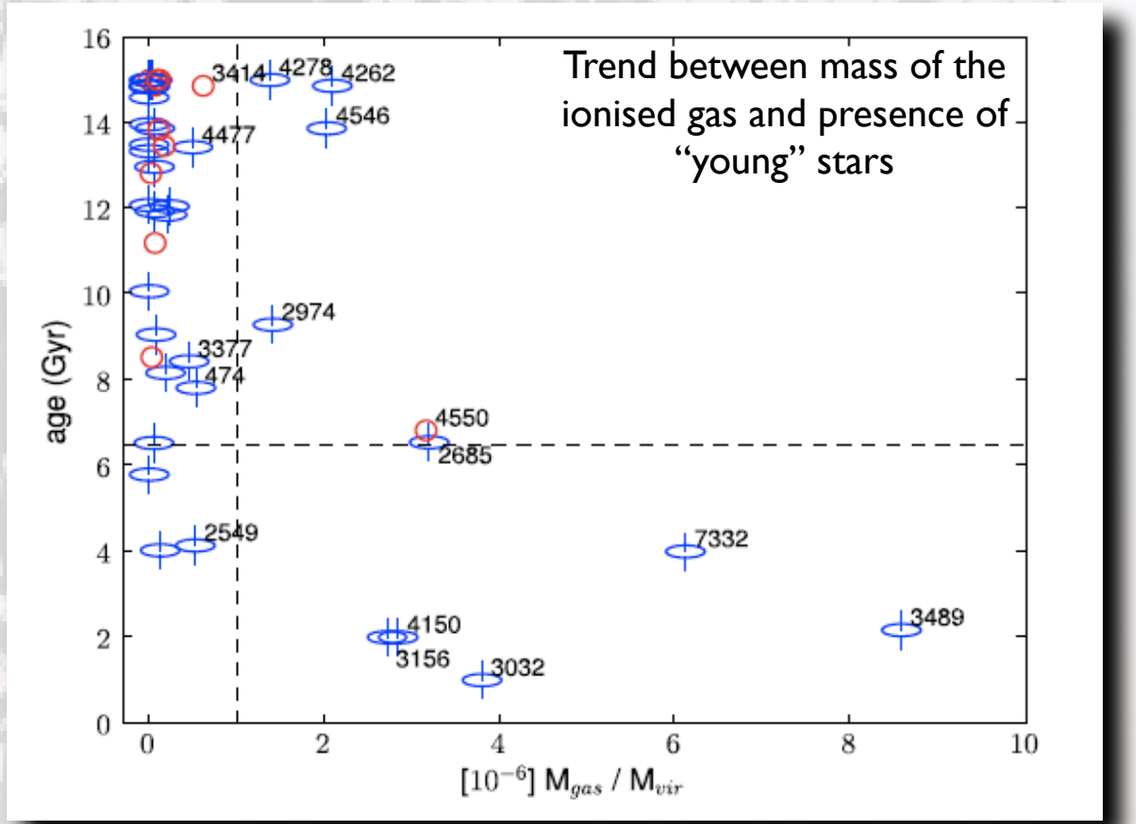
Star formation at large radii

Jeong, Bureau et al. 2007



HI and Stellar population: no trivial link!





Values of the (luminosity weighted) stellar age from Harald Kuntschner

HI

Ionised gas (Emsellem et al. 2006)

- Very different region sampled by the HI and the optical data
- Large radial gradients in stellar populations
- Efficiency with which gas is turned in stars varies strongly with details of interaction/accretion (see e.g. de Matteo et al. 2007)
- From GALEX data: young at large r in some objects

see also talk of Paolo Serra

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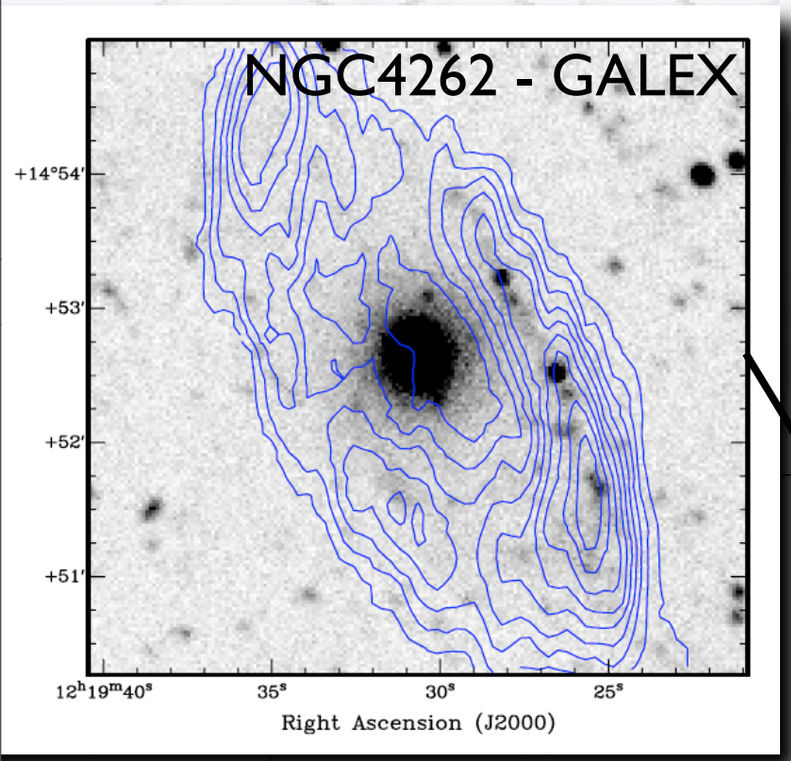

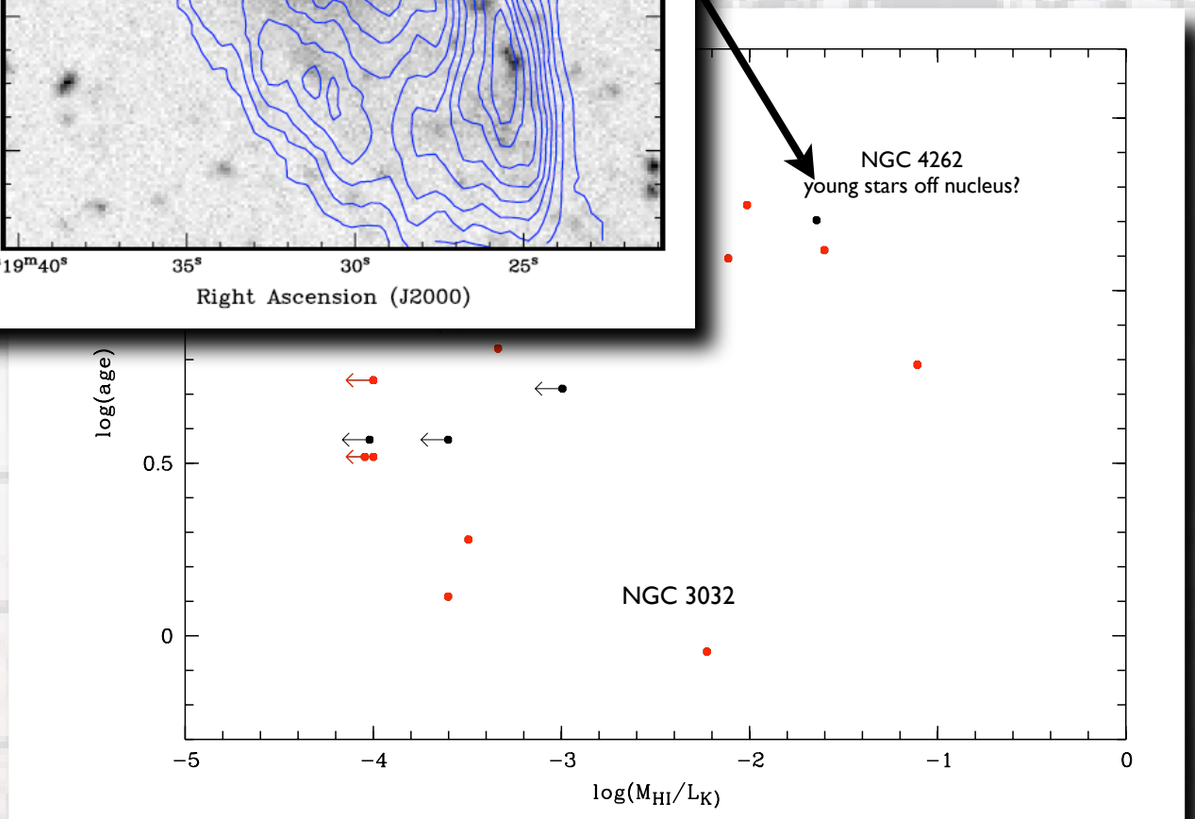

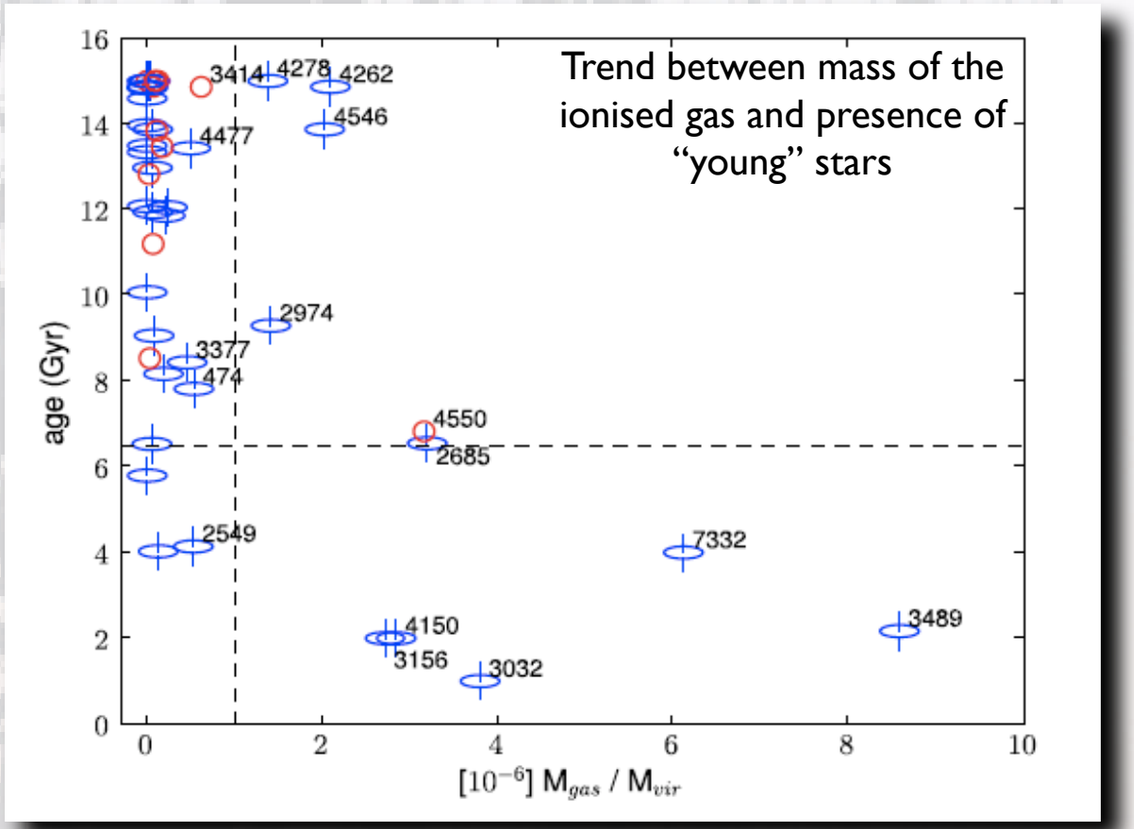

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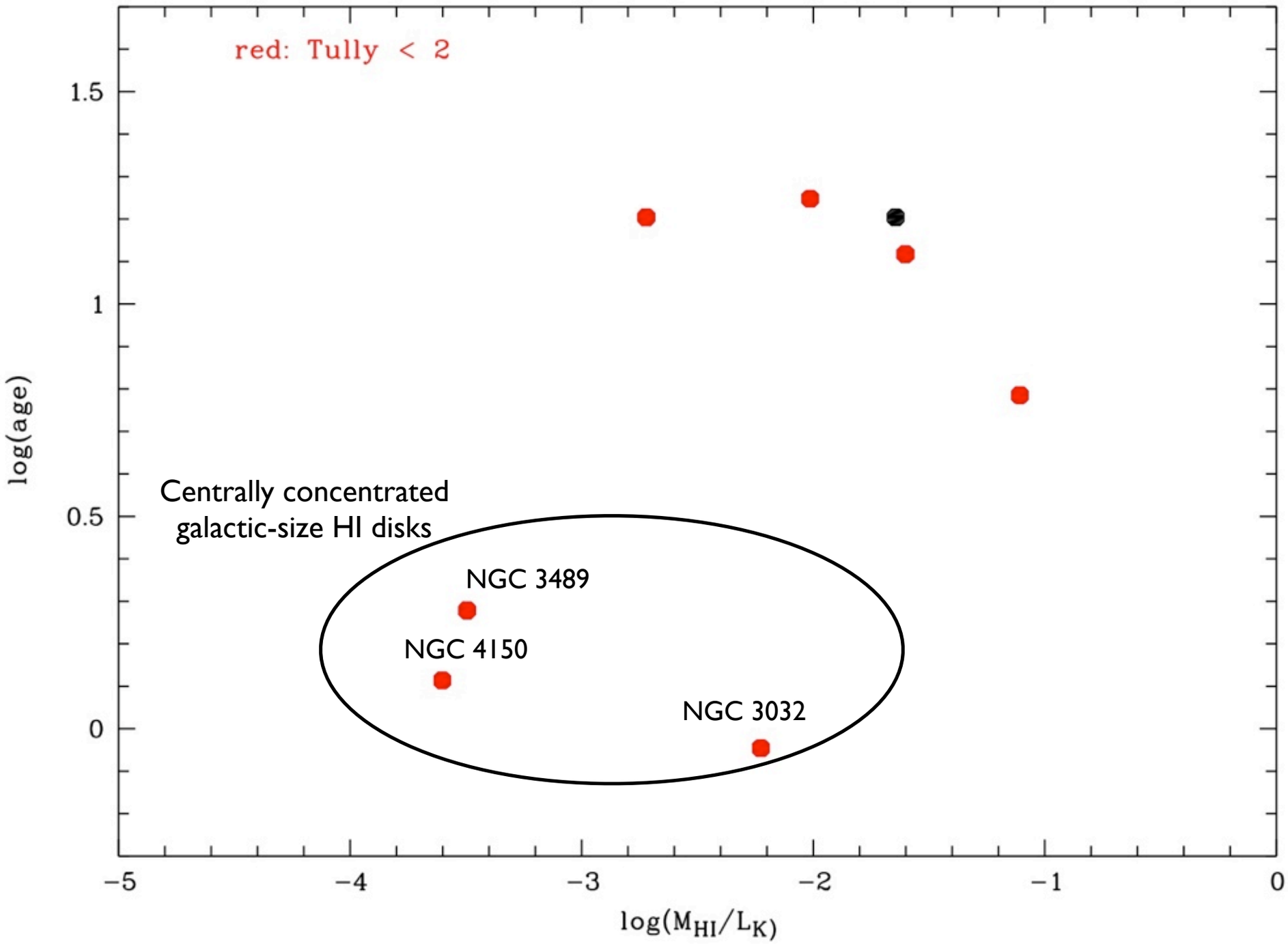
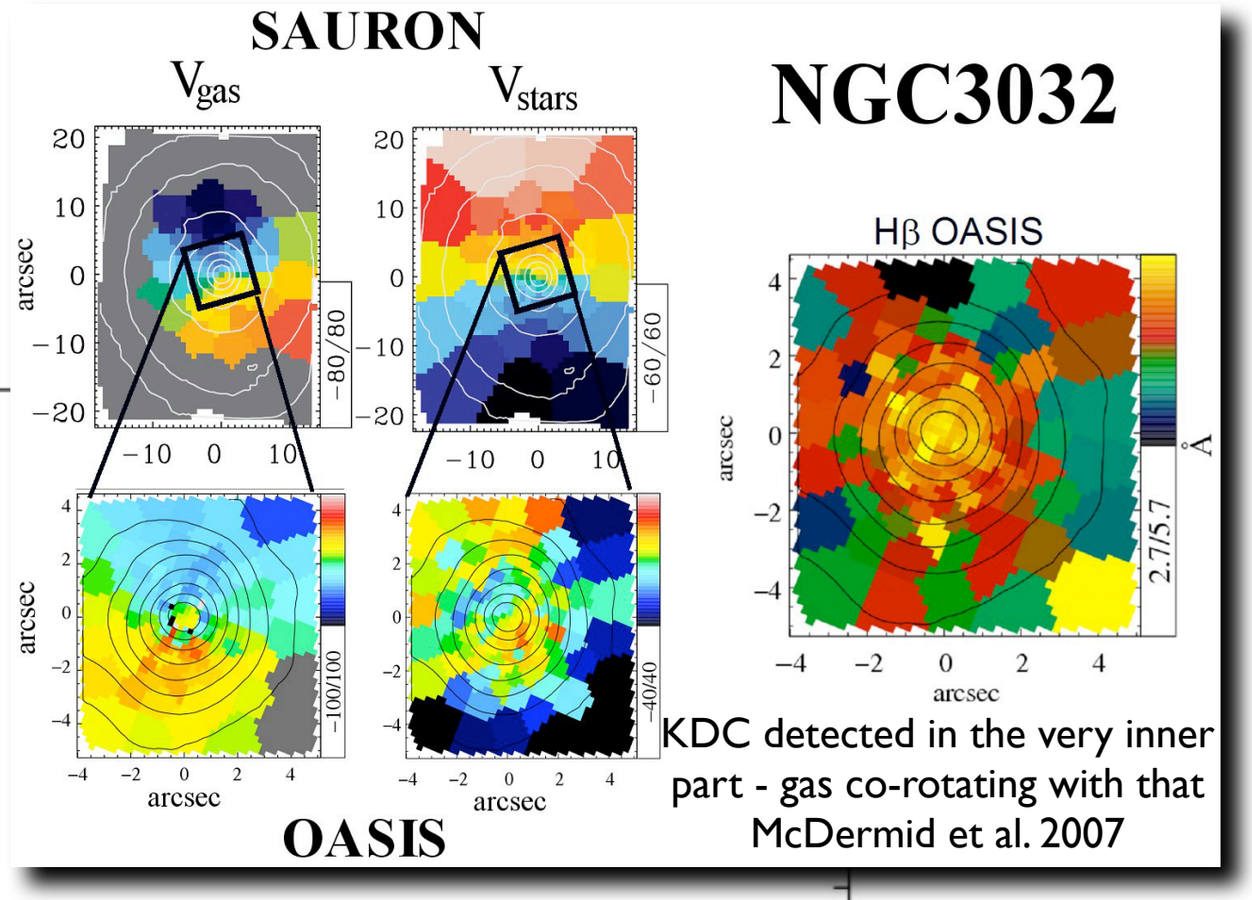
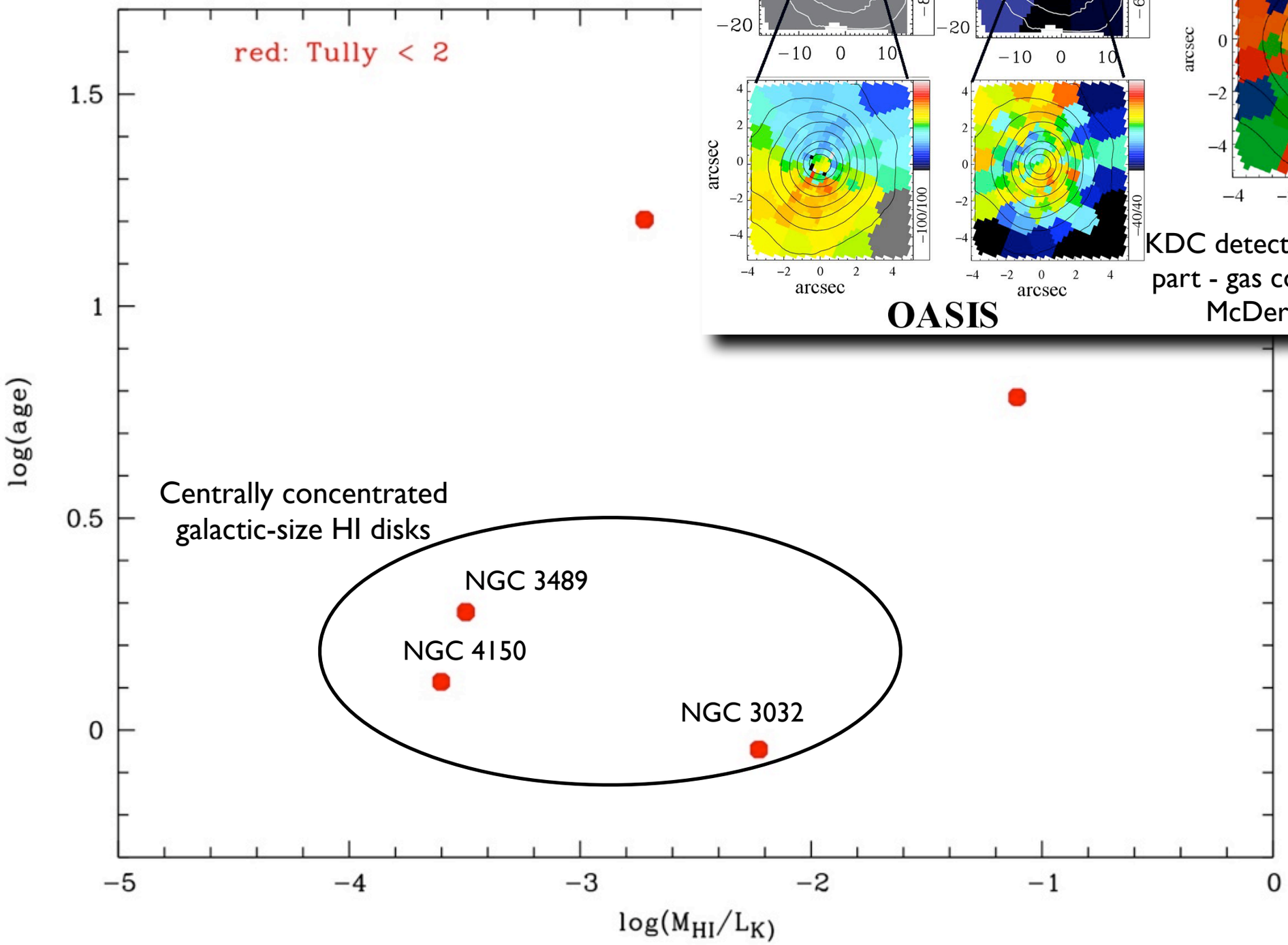
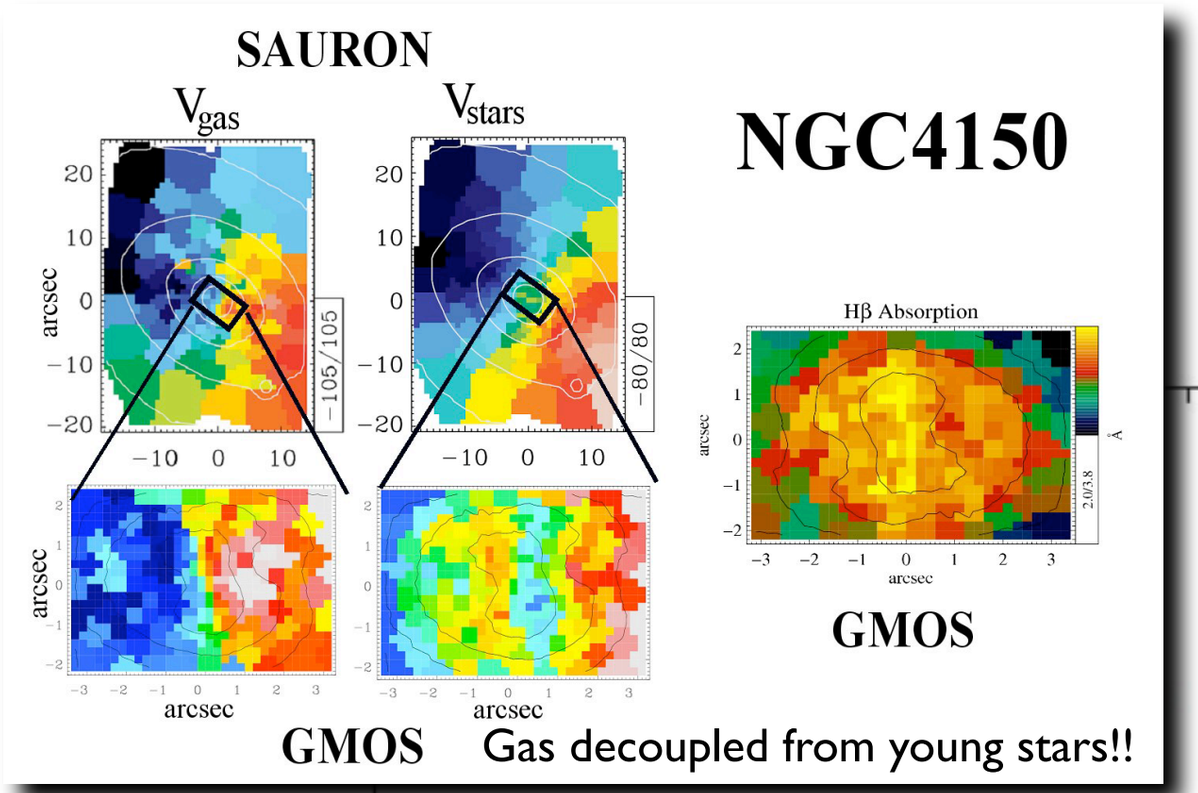
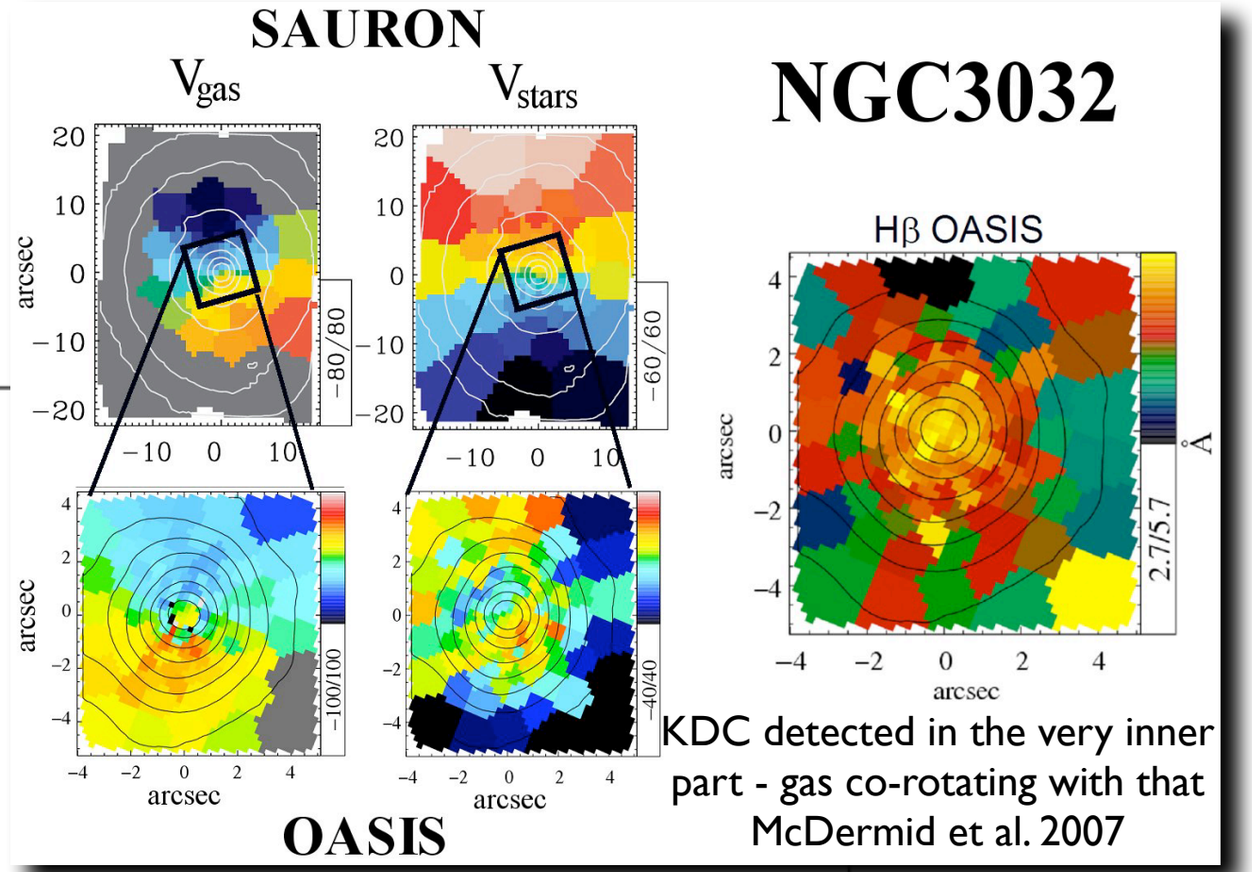

red: Tully < 2
Centrally concentrated
galactic-size HI disks
NGC 3489
NGC 4150
NGC 3032
log(age)
log(M_HI/L_K)
1.5
1
0.5
0
−5
−4
−3
−2
−1
0



KDC detected in the very inner part - gas co-rotating with that McDermid et al. 2007




SAURON
Vgas
Vstars
arcsec
−105/105
−80/80
NGC4150
Hβ Absorption
Å
2.0/3.8
GMOS
GMOS Gas decoupled from young stars!!


SAURON
Vgas
Vstars
arcsec
−80/80
−60/60
−100/100
−40/40
NGC3032
Hβ OASIS
Å
2.7/5.7
OASIS
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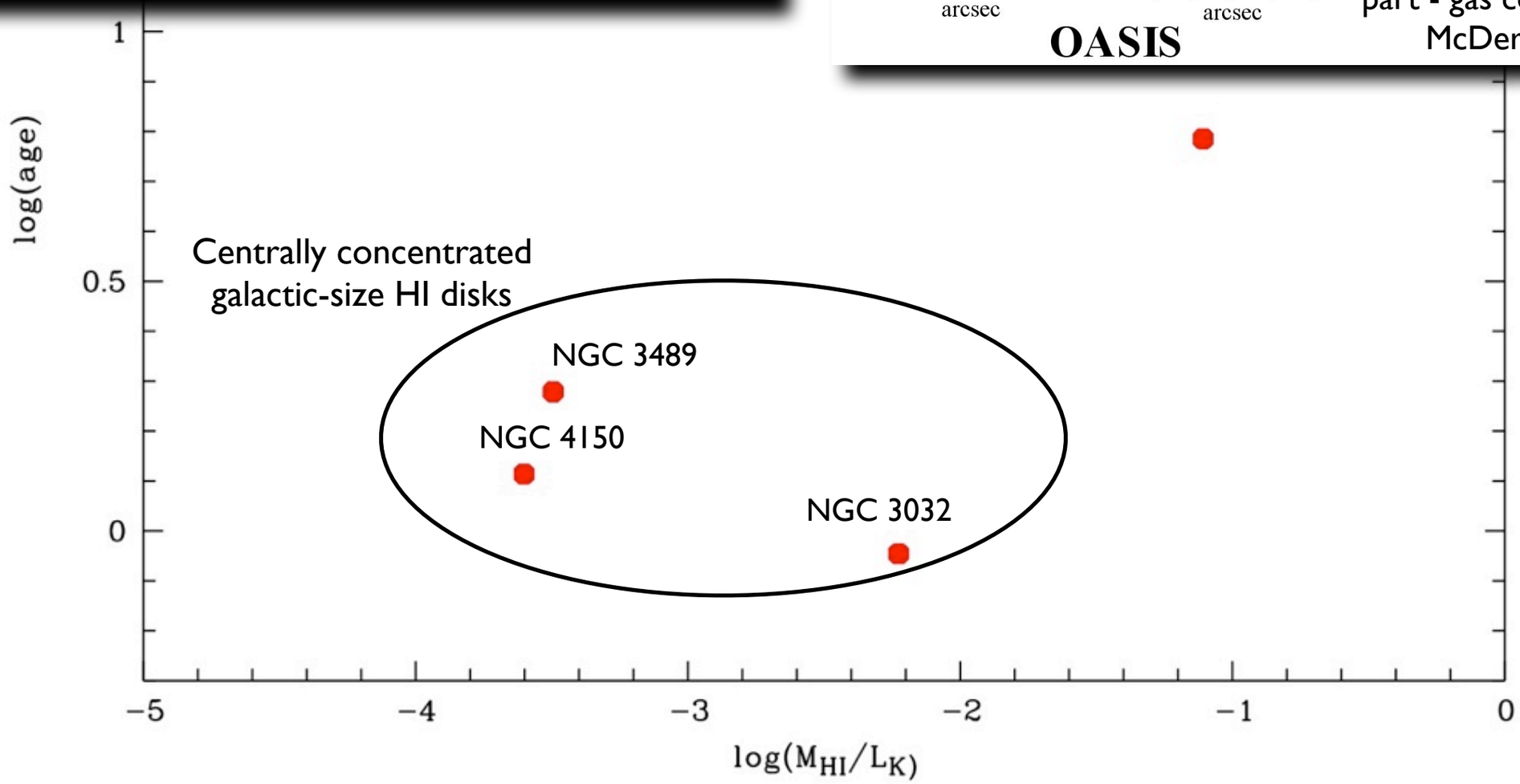
log(age)
log(M_HI/L_K)
Centrally concentrated galactic-size HI disks
NGC 3489
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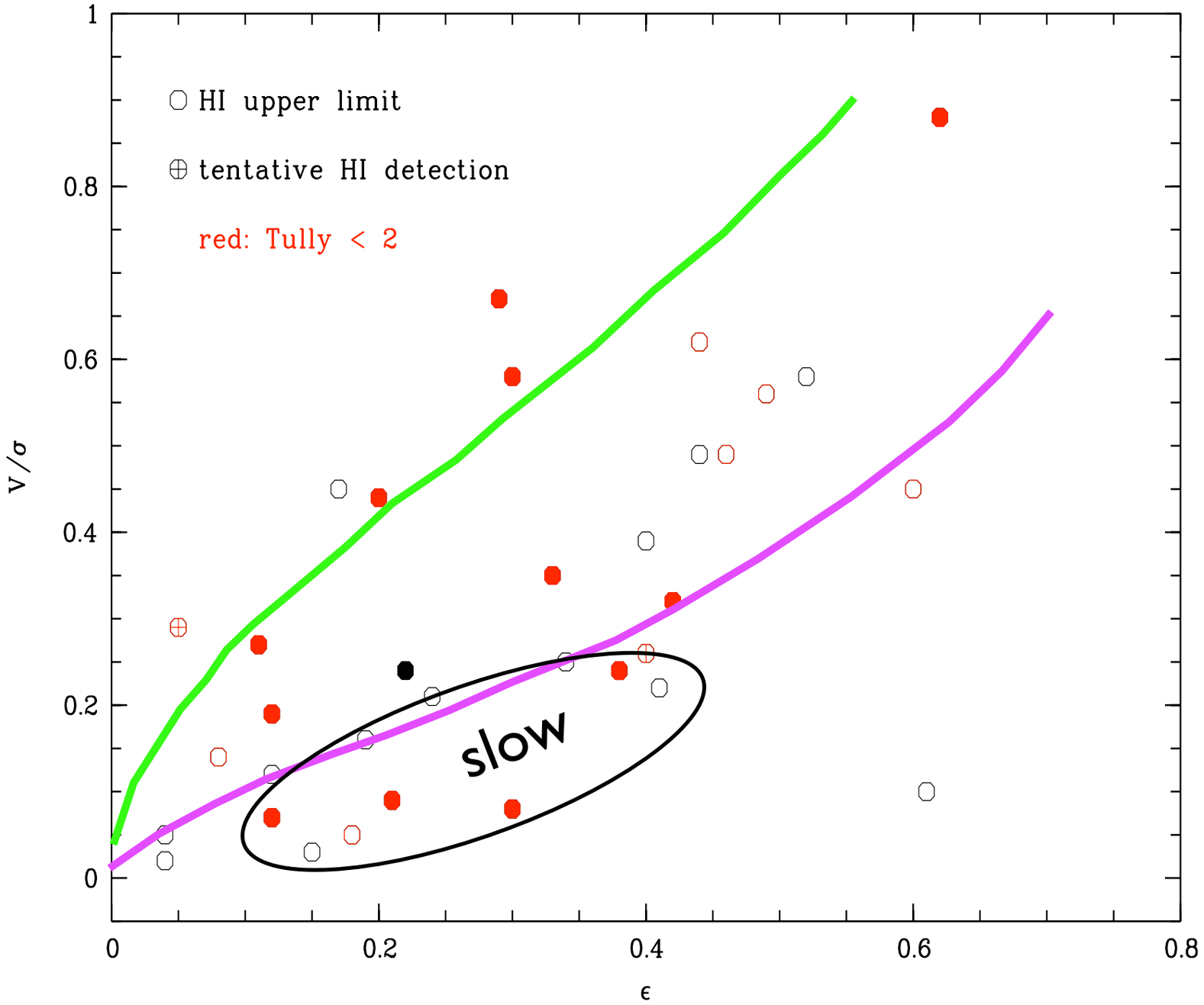
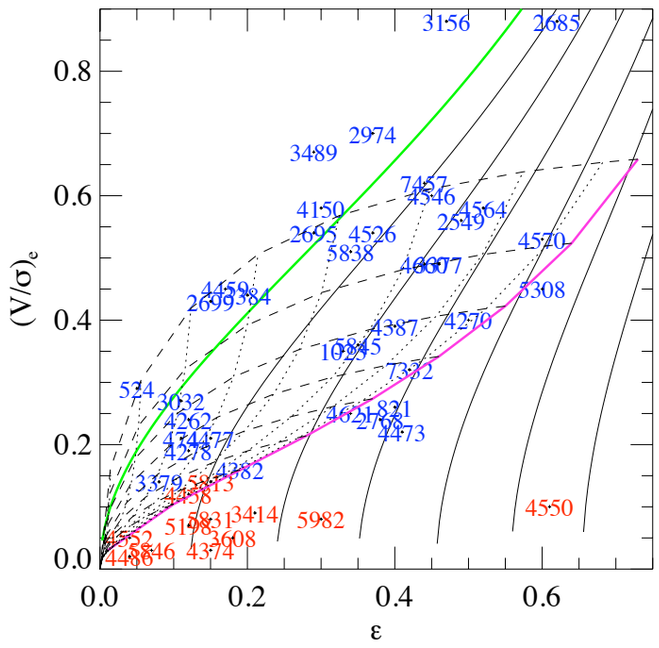
NGC 3032

HI and the host galaxy

- from SAURON stellar kinematics: fast- and slow-rotator classification (Cappellari et al. 2007)
- presence AND morphology of the HI





from Cappellari et al. 2007

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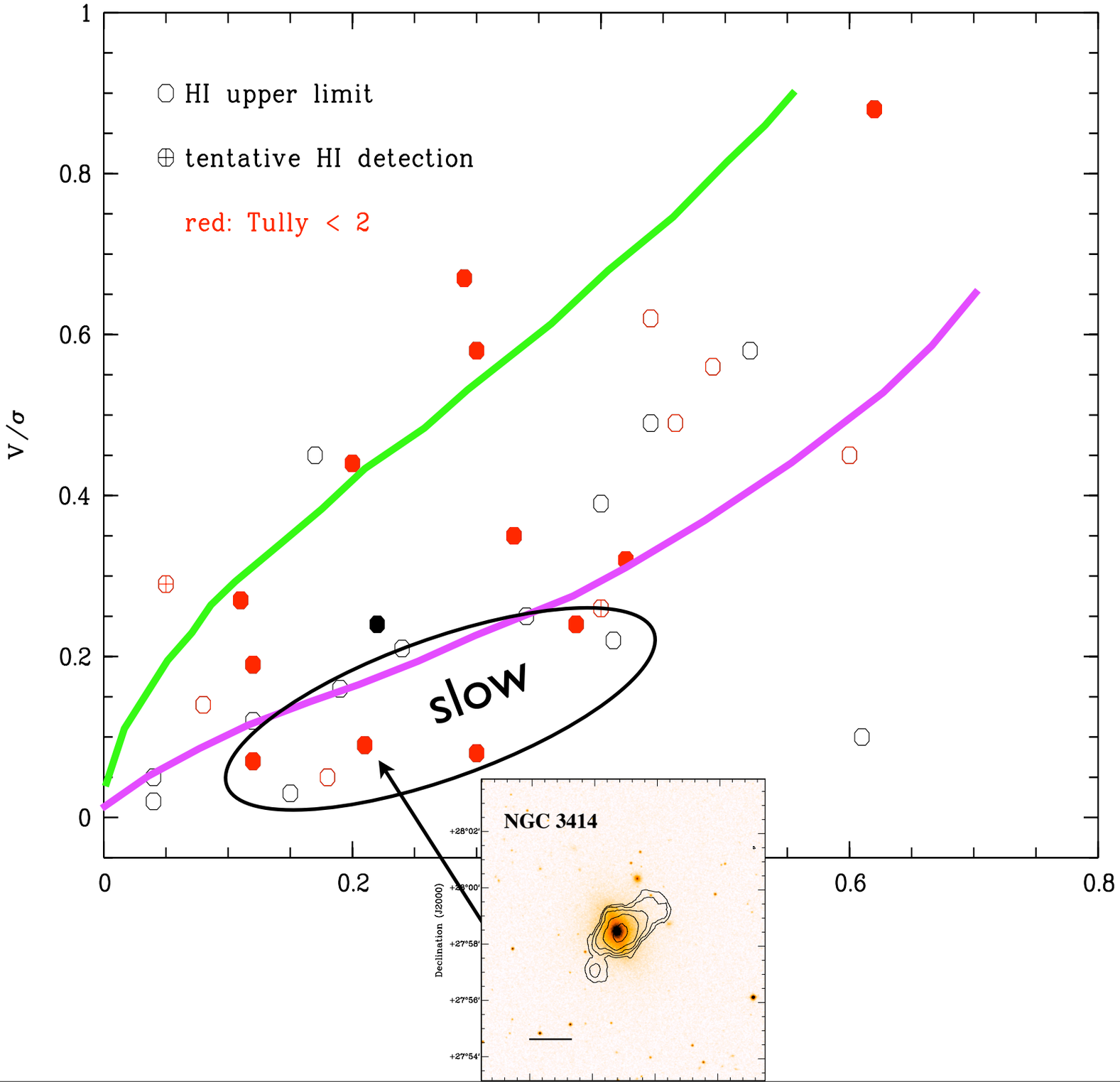
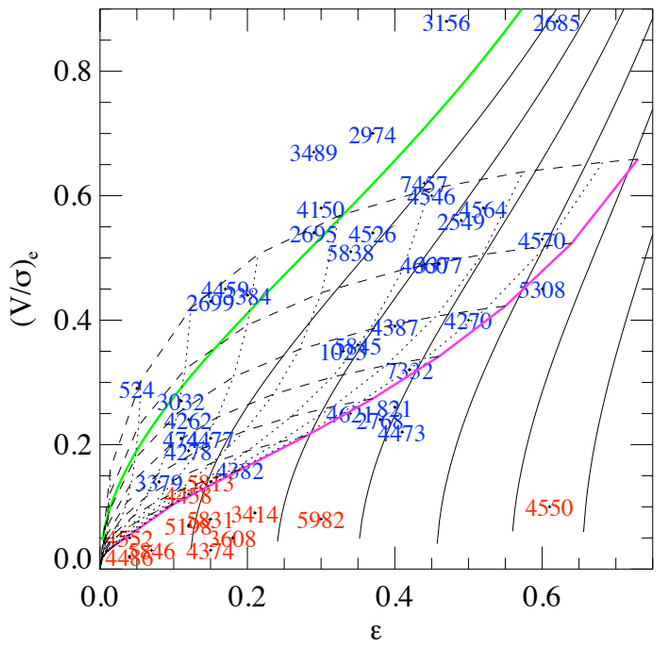




from Cappellari et al. 2007

HI presents both in slow and fast rotators

BUT

Possible trend with the HI morphology

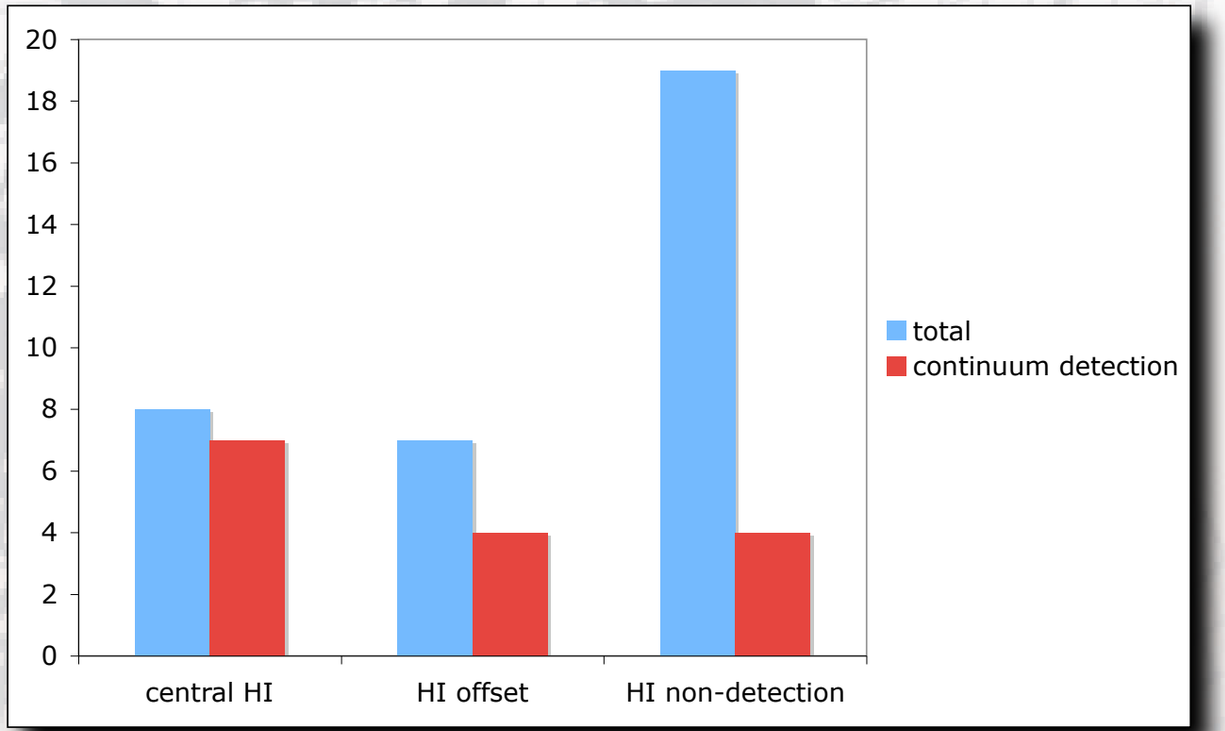
Slow rotators do not have regularly rotating structures of HI?

Origin of these galaxies?

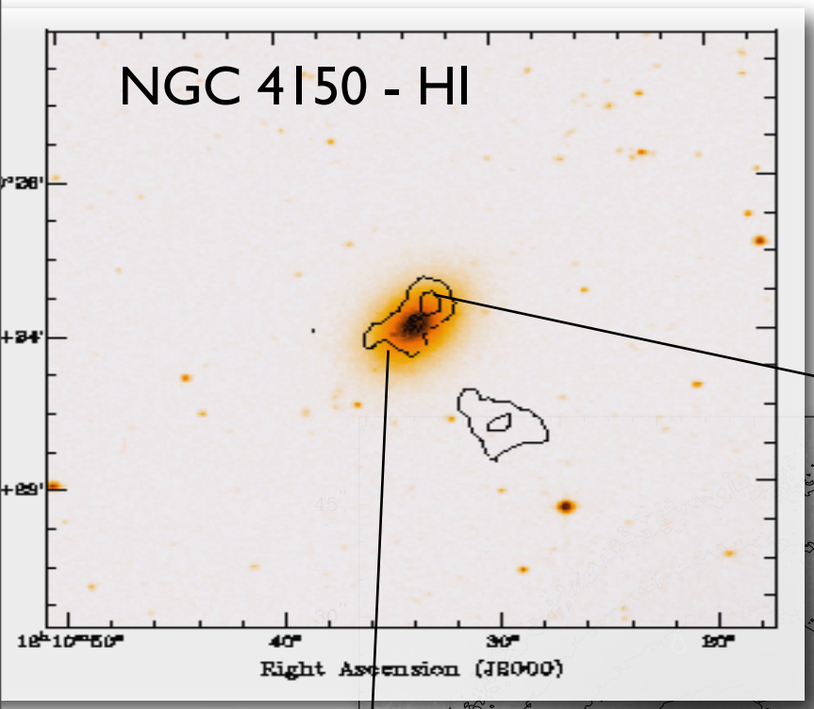
Too few cases of slow rotators to derive some clear conclusions ➠ ATLAS3D

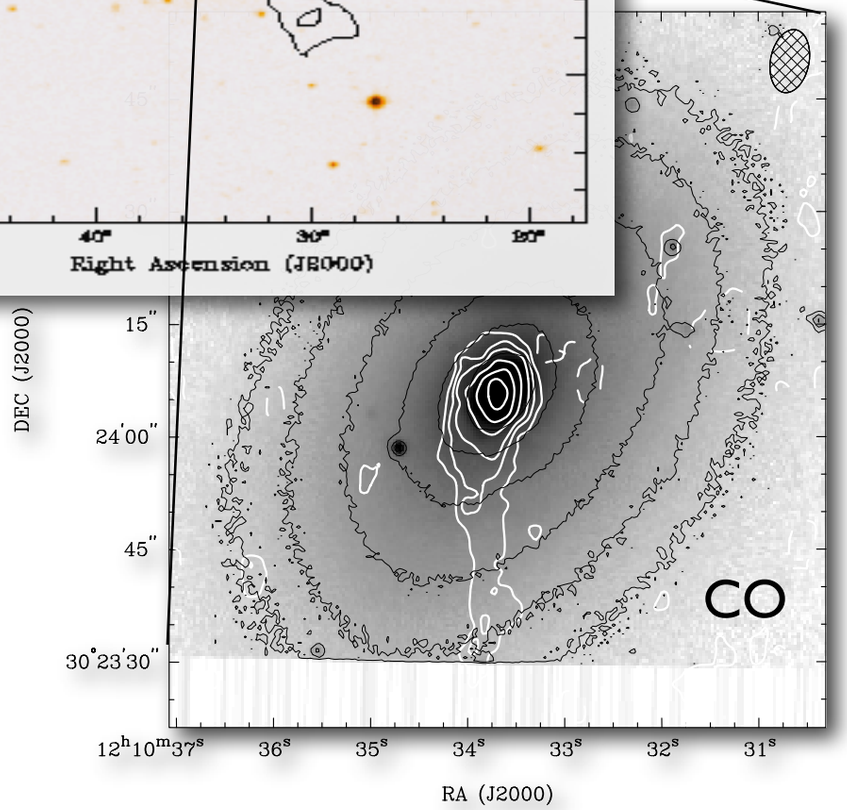
Preliminary result: relation to radio continuum

- Detection rate higher for galaxies with HI
- Independent from the HI morphology



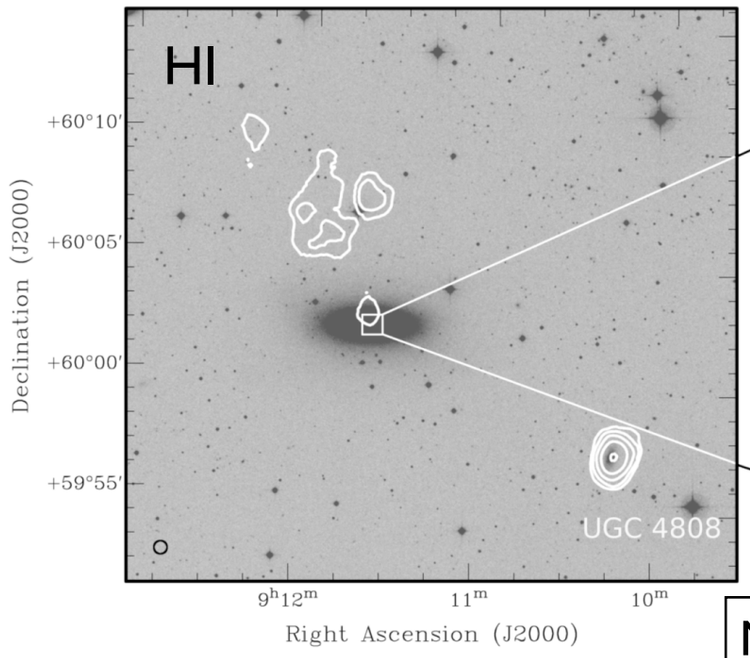
Comparison with the molecular gas

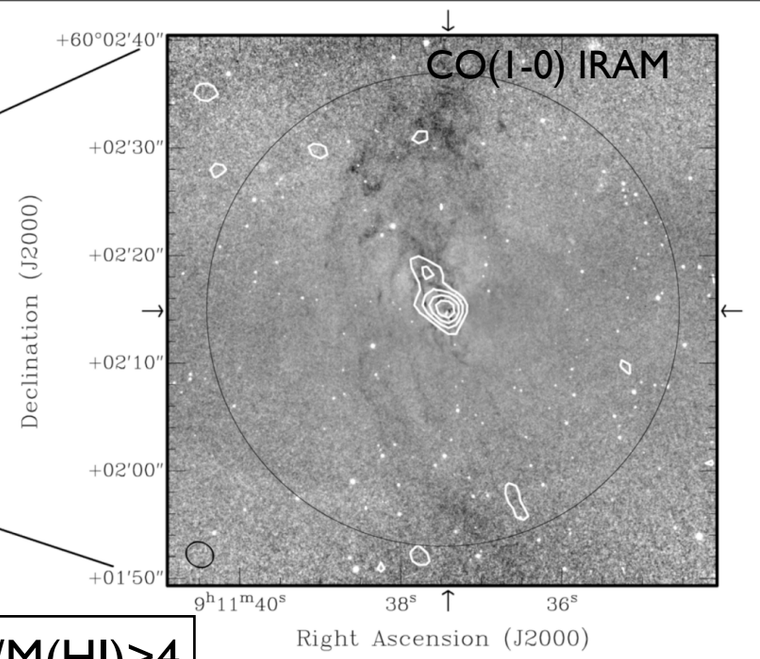




$M(H_2)/M(HI)=23$

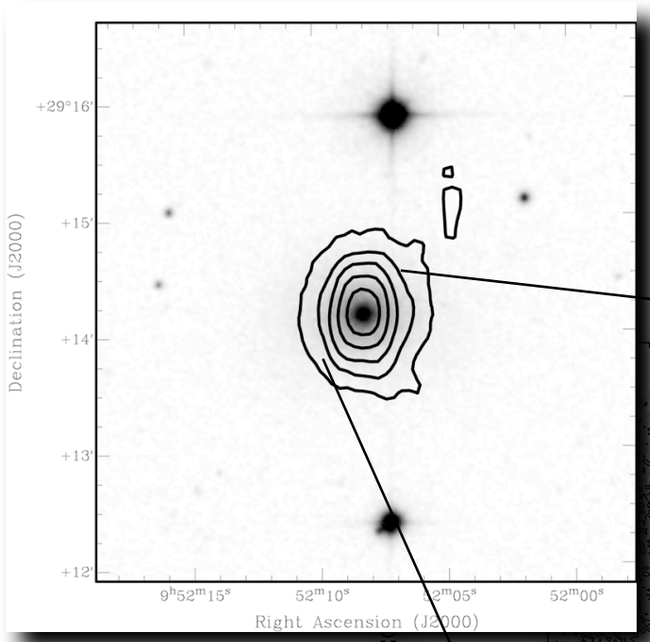
Young, Bureau, Cappellari ApJ 2007



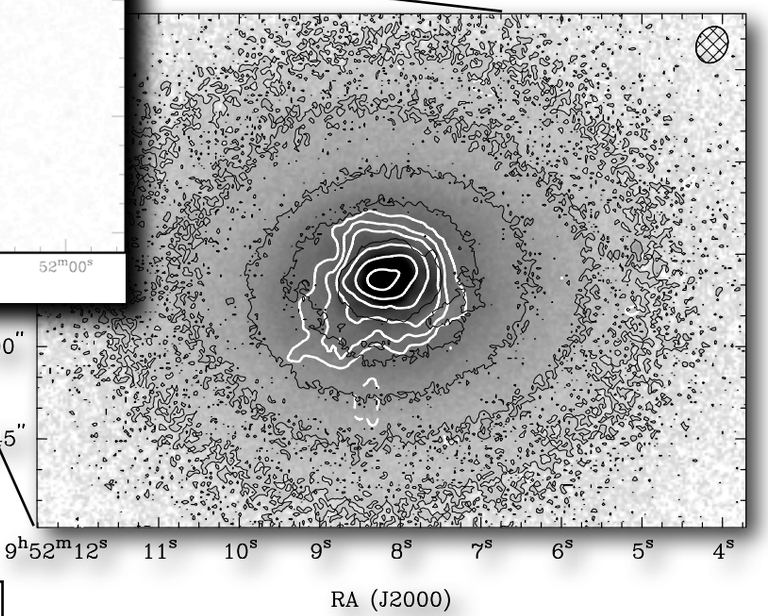


$M(H_2)/M(HI)>4$

Crocker et al. MNRAS 2008

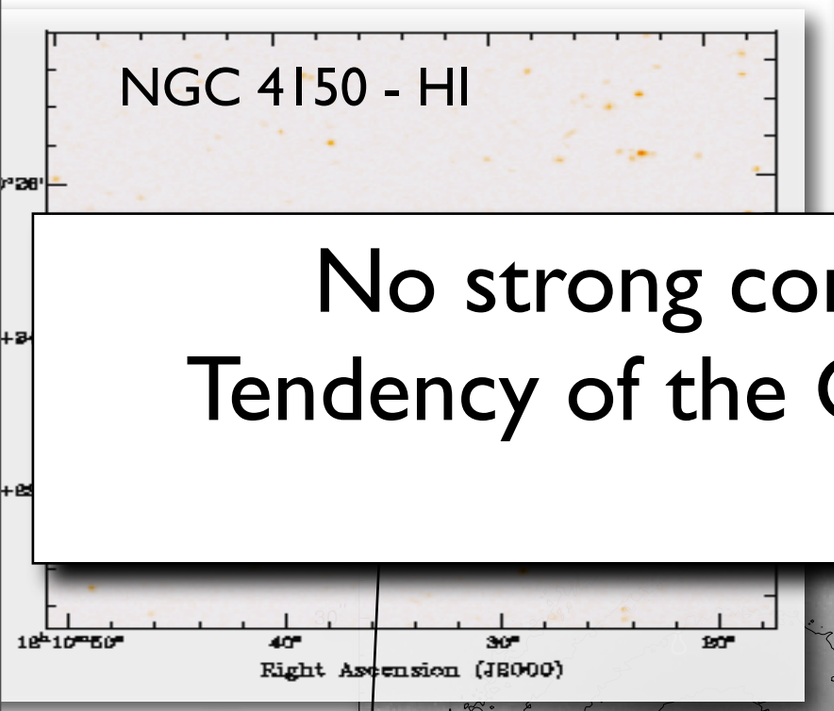


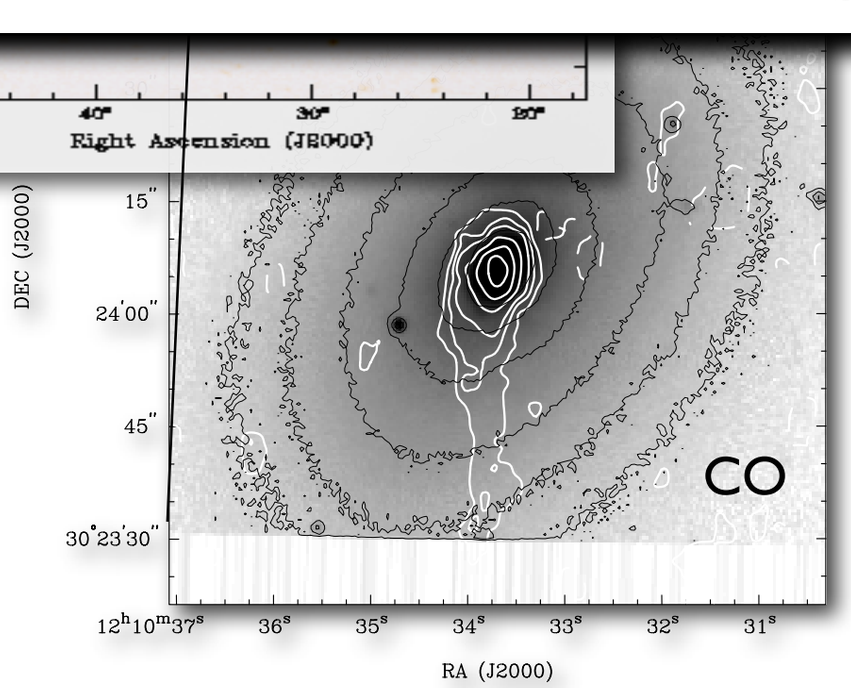
NGC 3032 CO



$M(H_2)/M(HI)\sim6$

Comparison with the molecular gas





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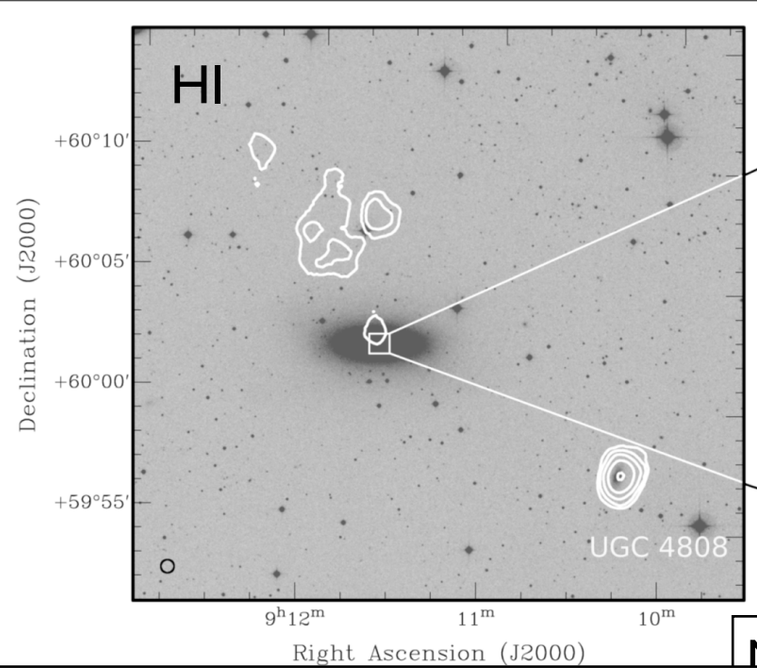

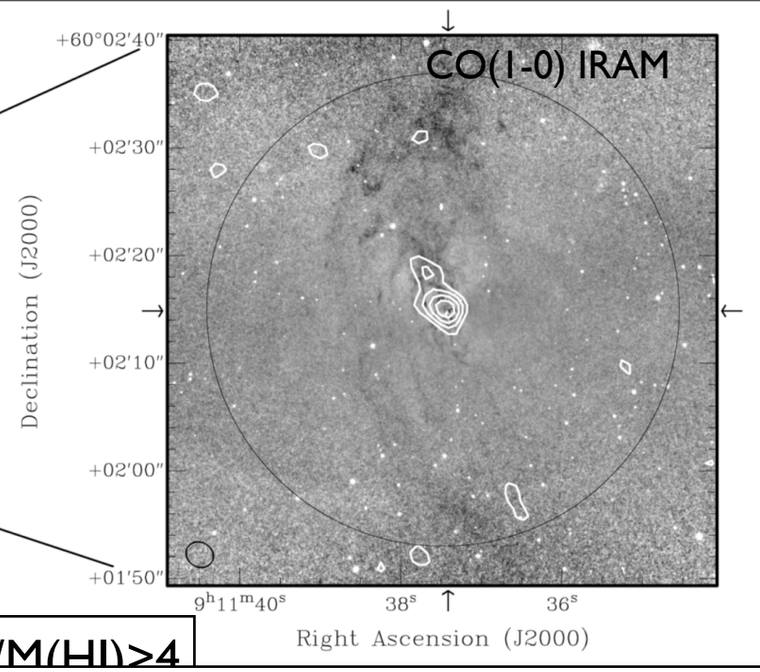

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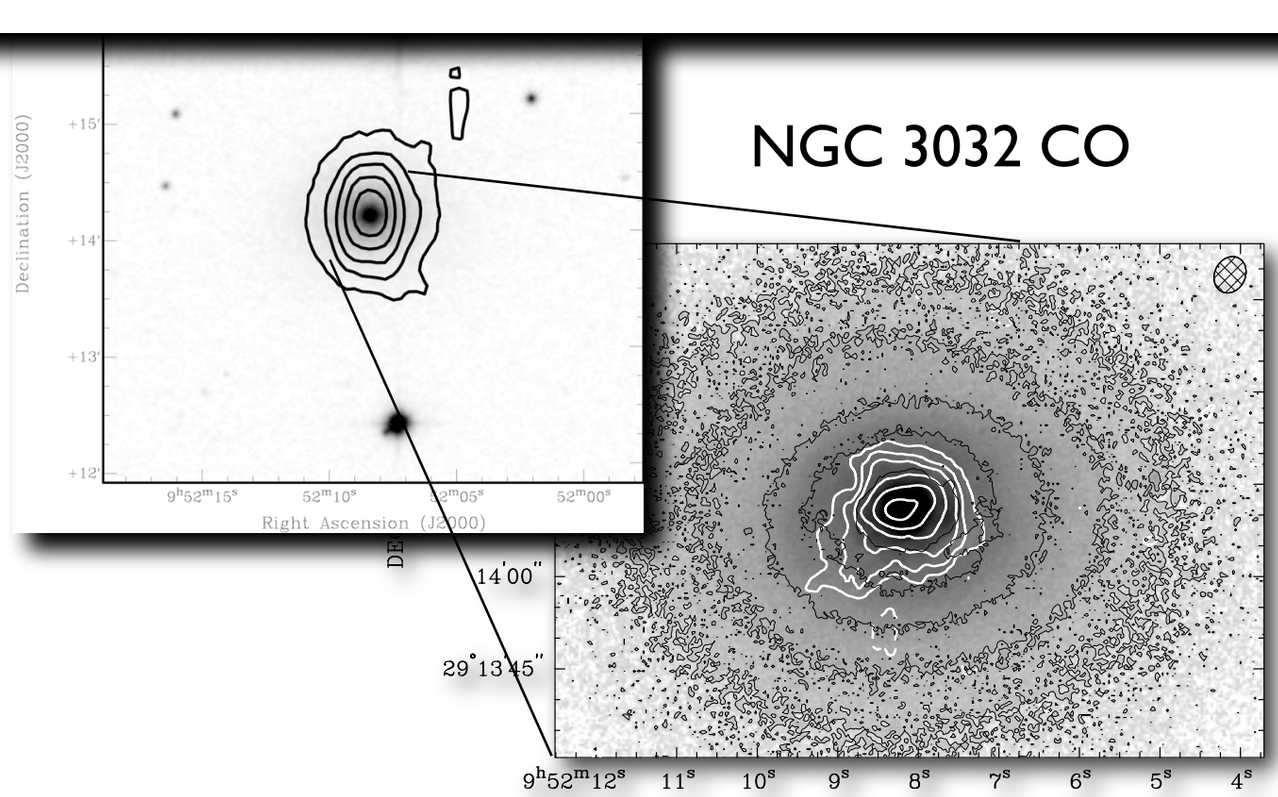
No strong correlation in the detection of CO and HI.
Tendency of the CO to be detected in system with centrally concentrated HI



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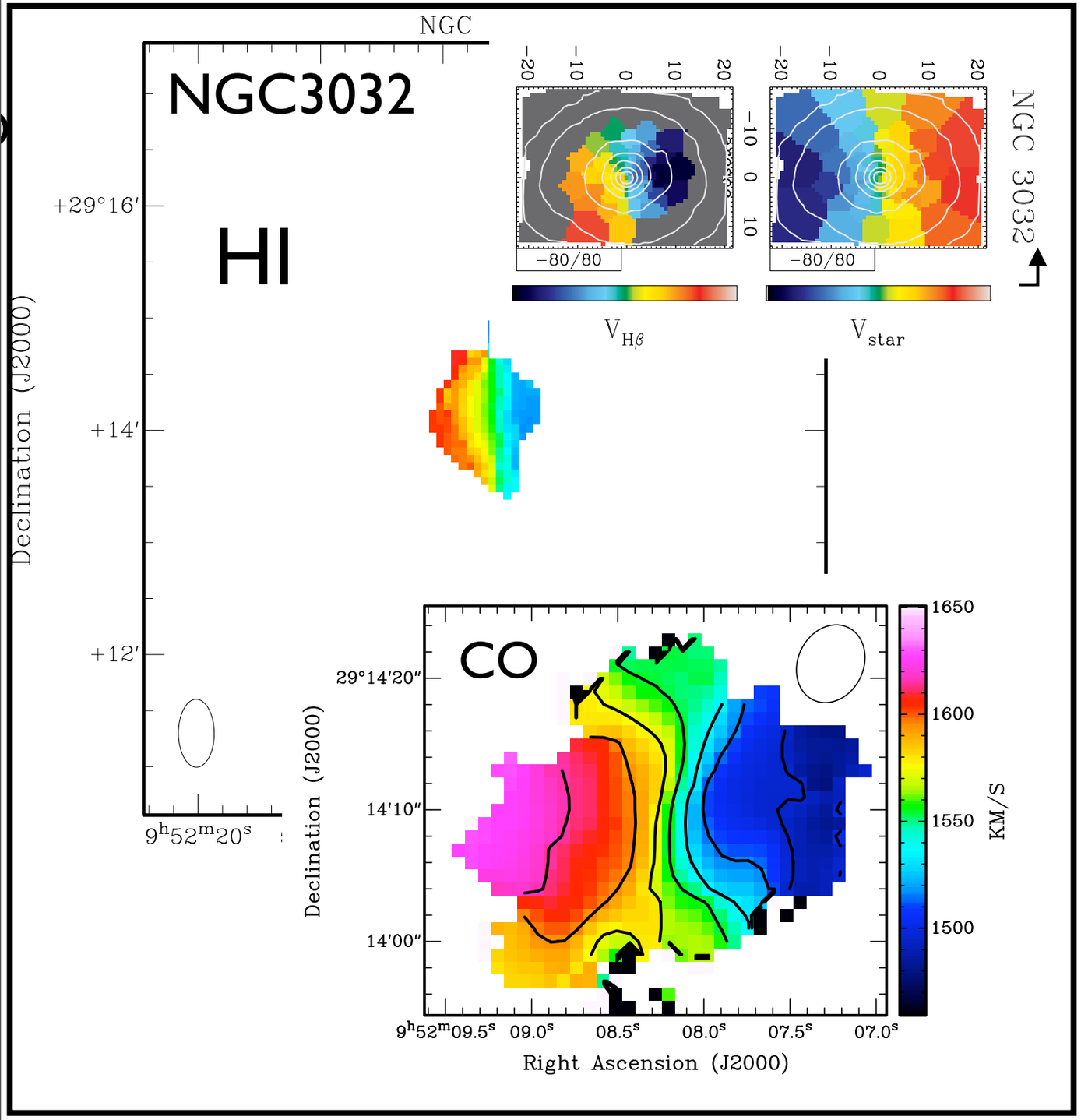

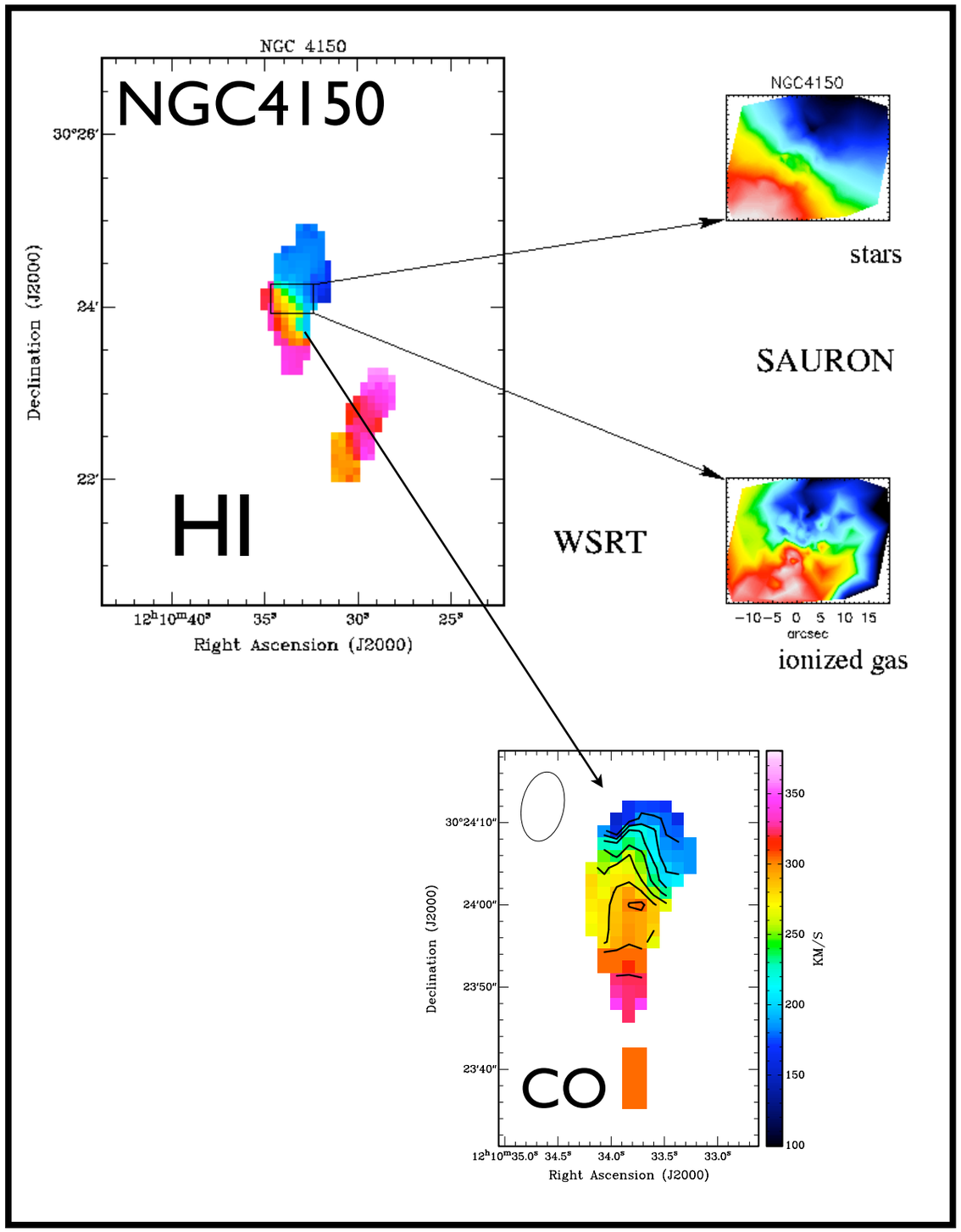

- CO(1-0) data from Young et al. 2008
- Optical data from Sarzi et al. 2006
- HI from Morganti et al. 2006 and Oosterloo et al. in prep..

Conclusions

- HI common characteristic of early-type galaxies in field
- In half of the detections, HI in regular structures (wide range of HI mass)
- HI nicely connected to the ionised gas (morphology and kinematics)
- Galactic-size HI disks found in galaxies with the younger stellar population - cases of young stars at large-r associated with peaks of HI
- Possible difference in HI morphology between fast and slow rotators?
- Detection of radio continuum (AGN?) higher in galaxies where also HI is detected (regardless morphology)
- Comparison with CO - cases of high values of $M(H_2)/M(HI)$

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Machinery (and time allocation!) in place for the study of a much larger sample ➠ ATLAS^{3D}