Lessons from local AGN

Gas (neutral and ionised) and radio-loud galaxies:
formation of extended structures and outflows

Raffaella Morganti

ASTRON, Dwingeloo

Kapteyn Inst. Groningen

with the help of: Clive Tadhunter, Tom Oosterloo, Joanna Holt, Bjorn Emonts, Christian Struve

Lessons from local radio-loud AGN through the gas

connection with some of the topics that will be covered in the next days!

- large gas structures:

  characteristics - origin - AGN vs radio quite

- gas on nuclear scales: evolution of young radio sources and outflows - obscuration from the host galaxy

Radio-loud AGN -> host by early-type galaxies:
GAS: important and common component

We use the morphology and kinematics of the gas to trace the formation/evolution of the host galaxy (radio quiet vs radio-loud) and what is happening in the central regions of active galaxies

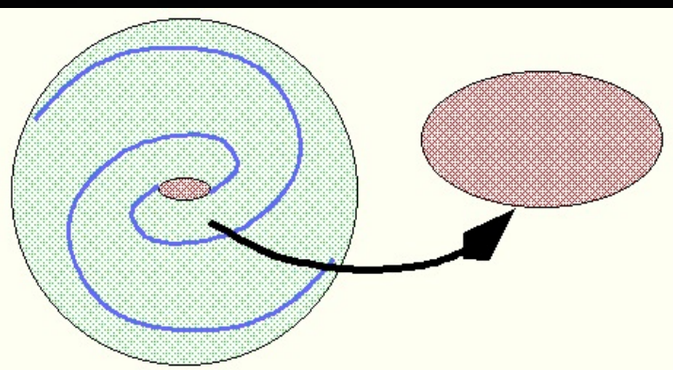
complementary information

HI(21-cm) and ionised gas

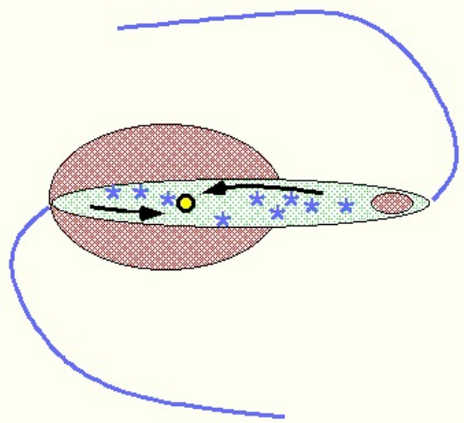
can only be studied in detail in the local Universe

onset of radio activity related to accretion or merger -> but variety of conditions in the merger

from Clive Tadhunter



Start of merger
-1 billion yr



Advanced merger: gas driven towards nucleus; starburst
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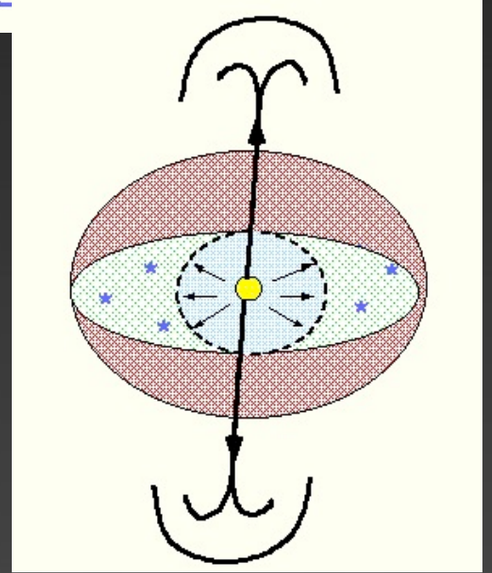
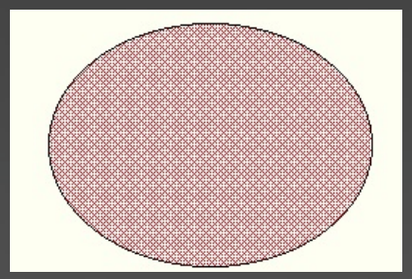


Quasar and jet activity drives gas out of galaxy
Now

Following a hierarchical scenario:
evolution of AGN vs host galaxy



Relaxed
E-galaxy
+1 billion yr

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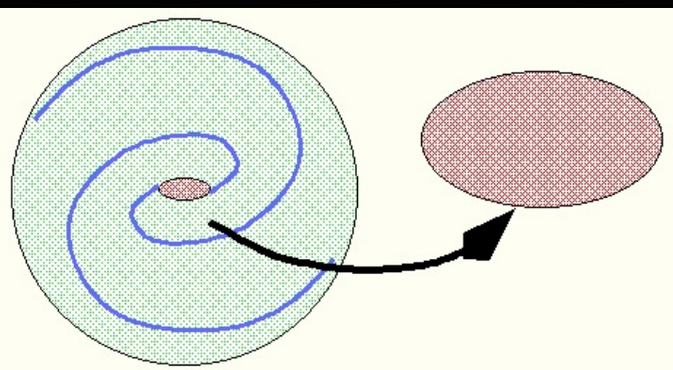

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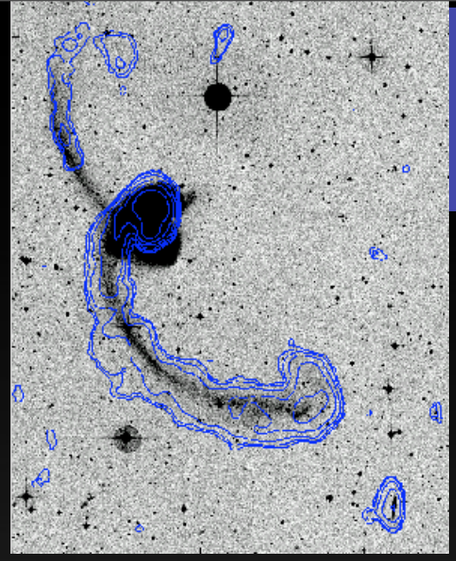

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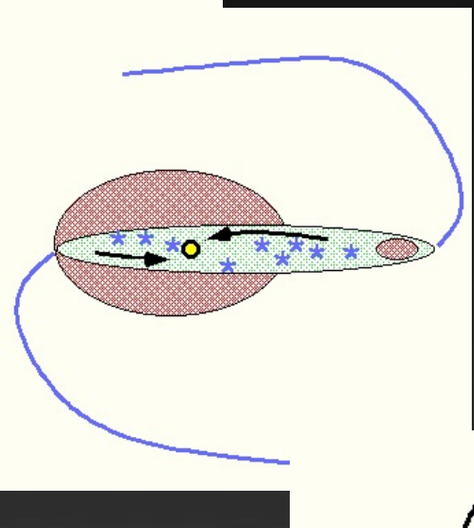

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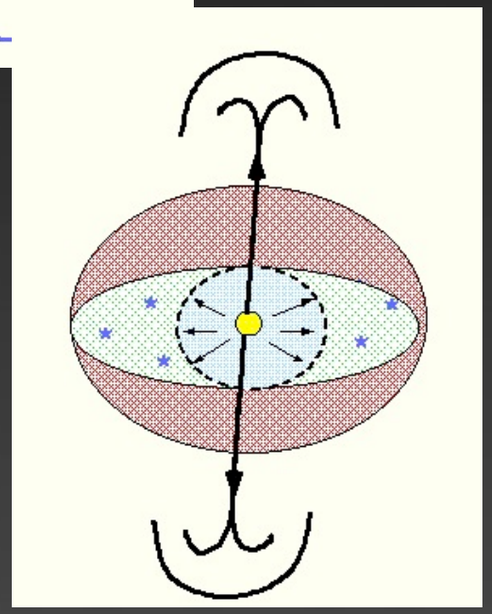

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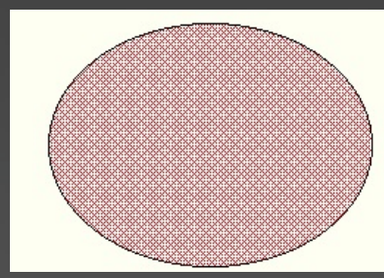

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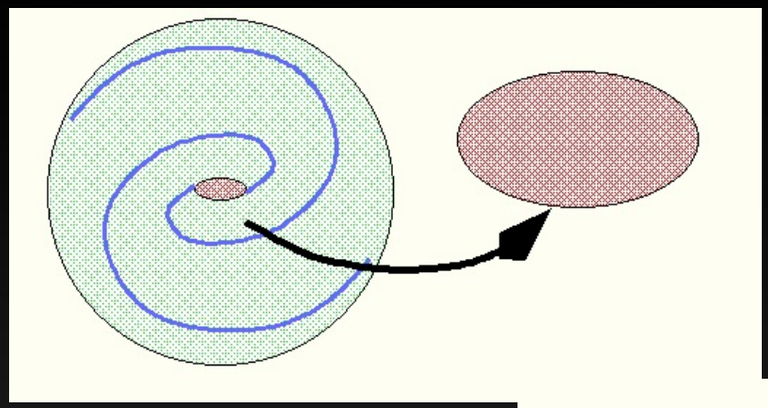

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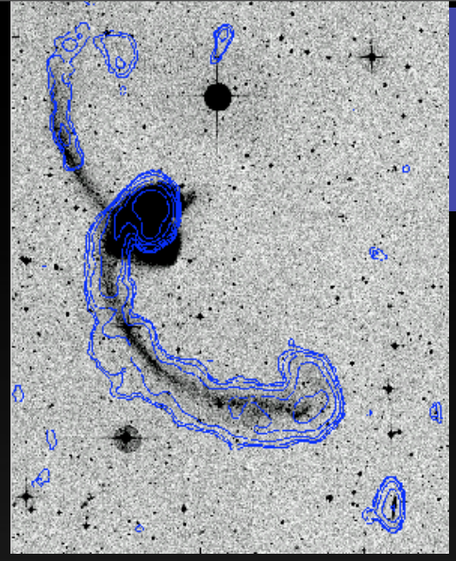

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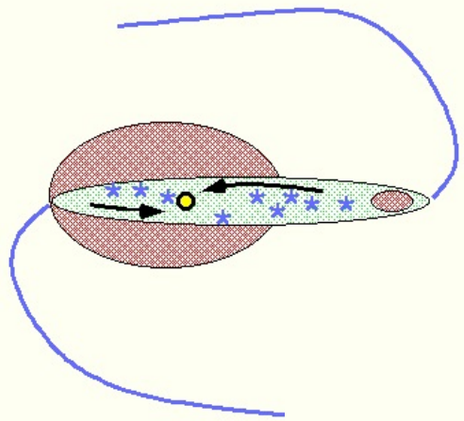

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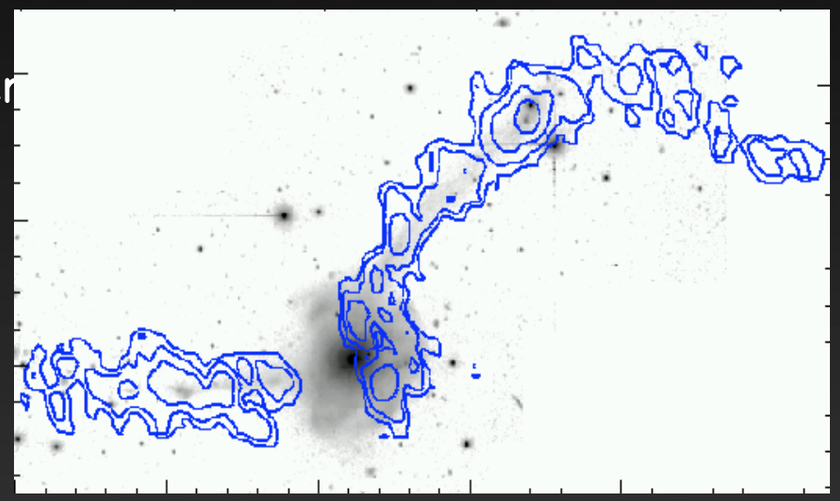

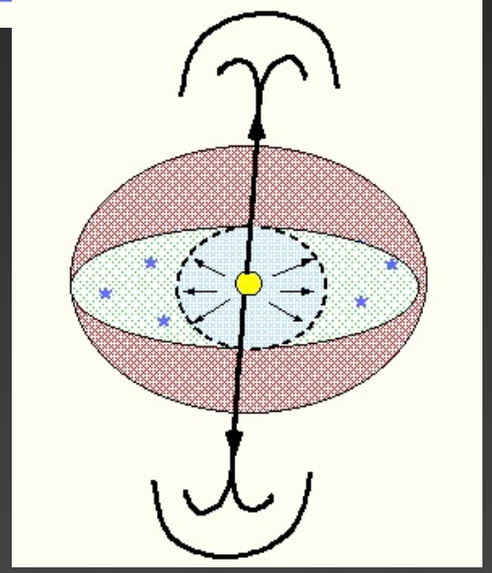

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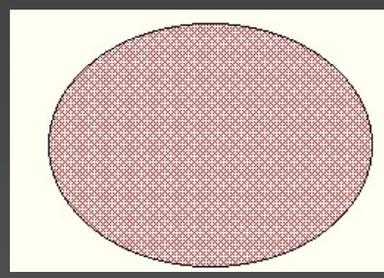

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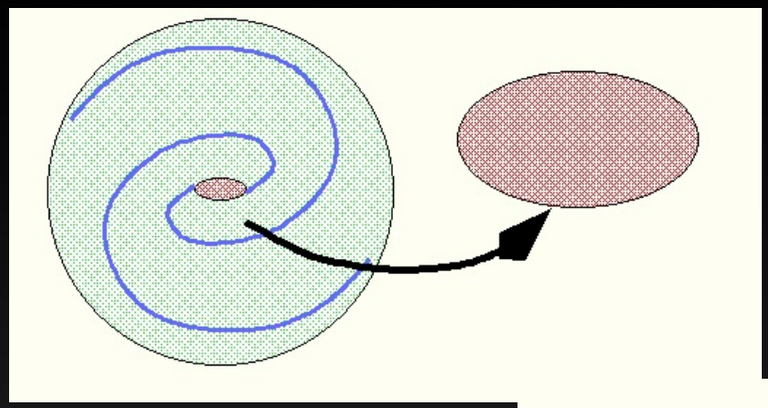

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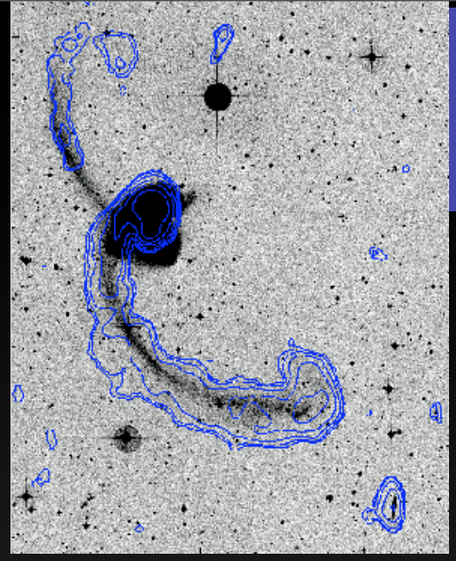

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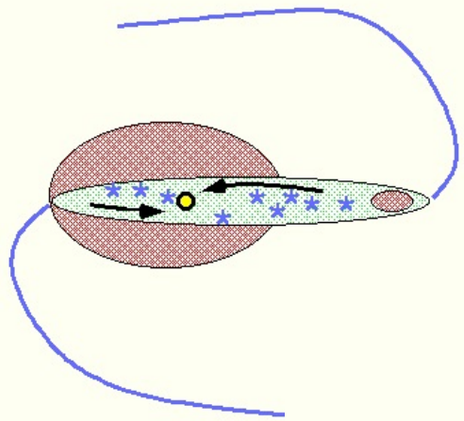

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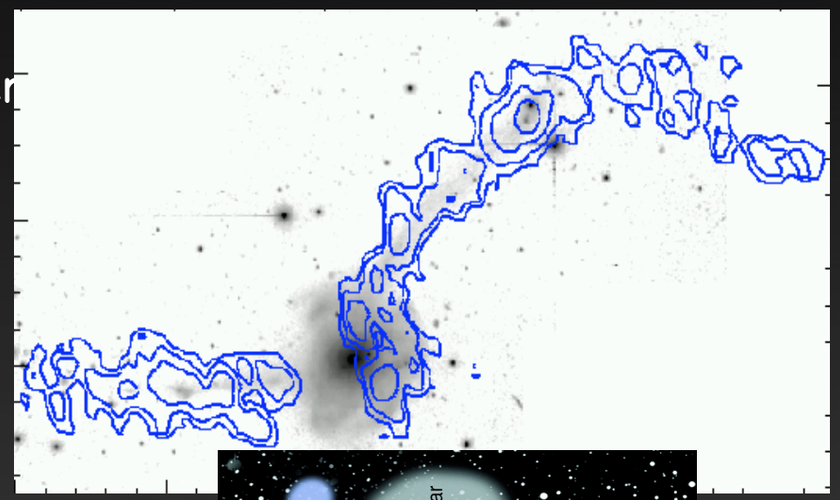

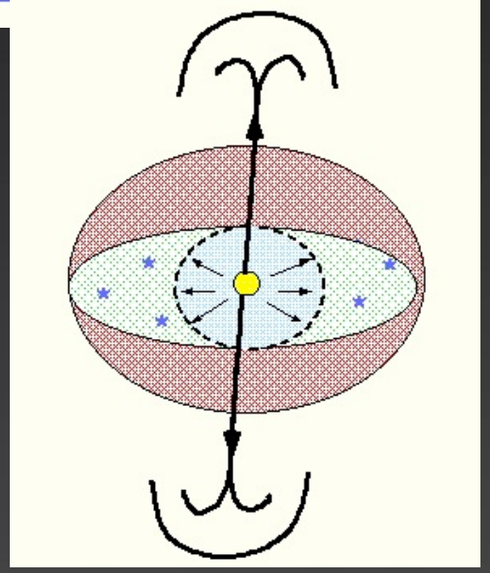

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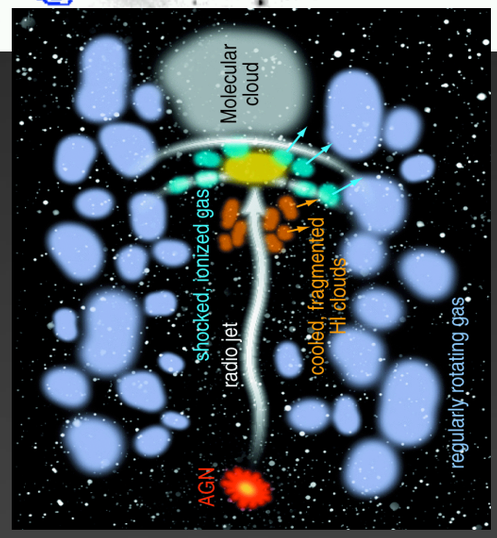

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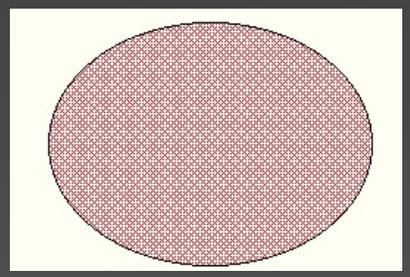

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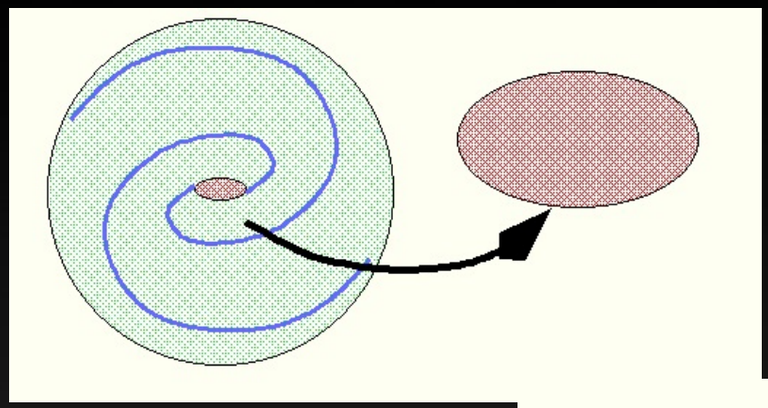

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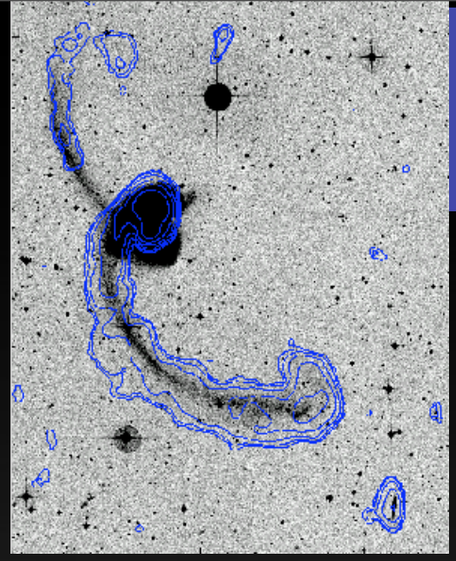

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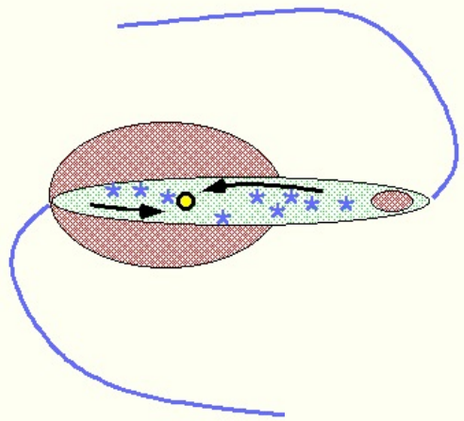

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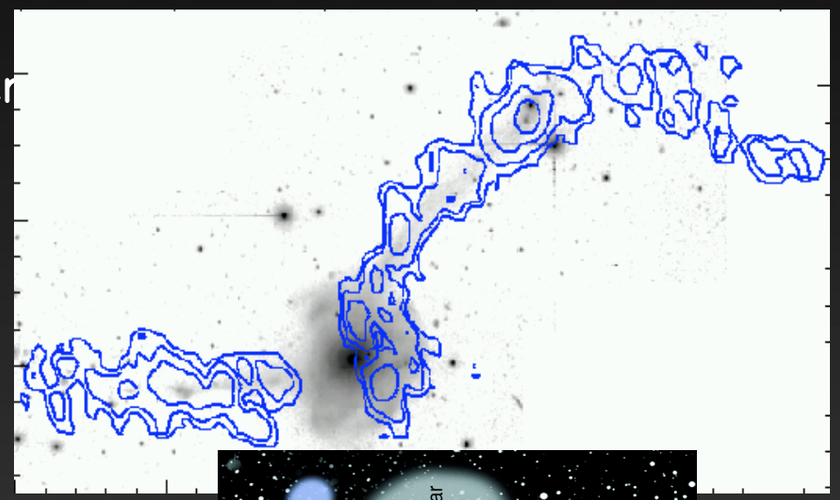

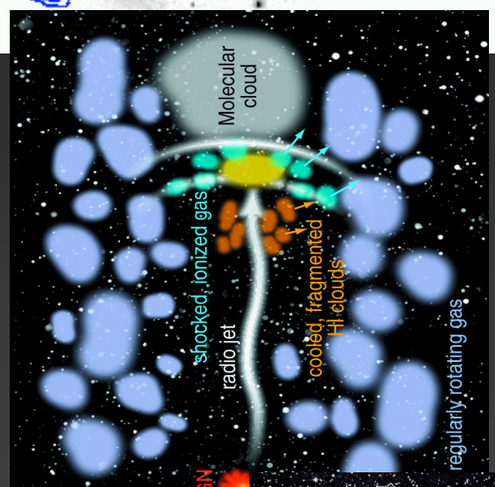

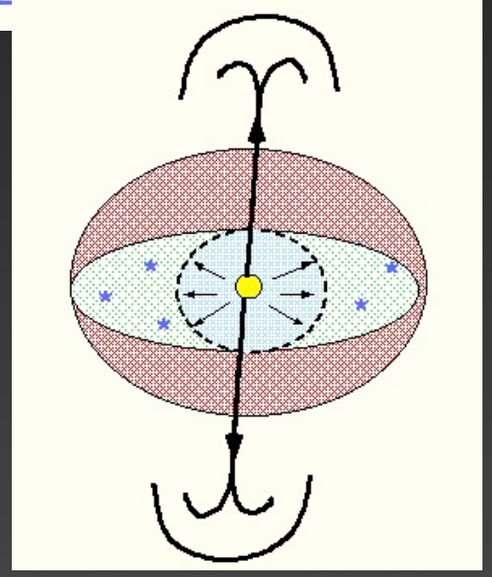

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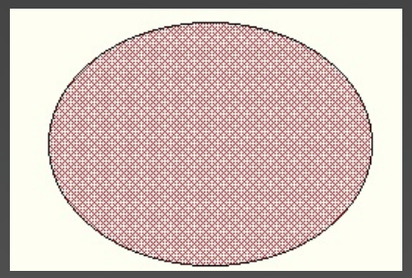

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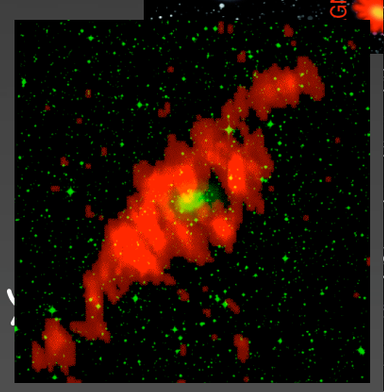
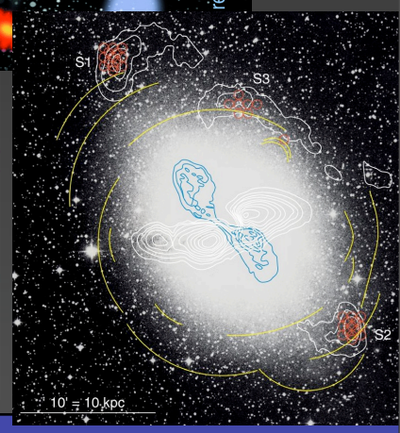
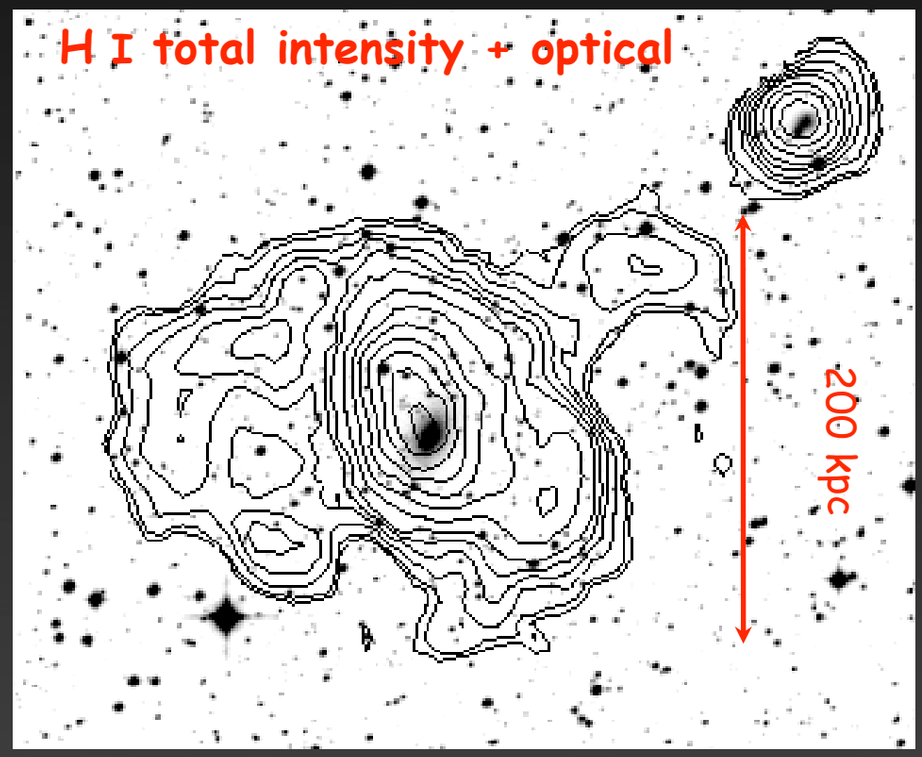




Can we find HI in early-type galaxies?

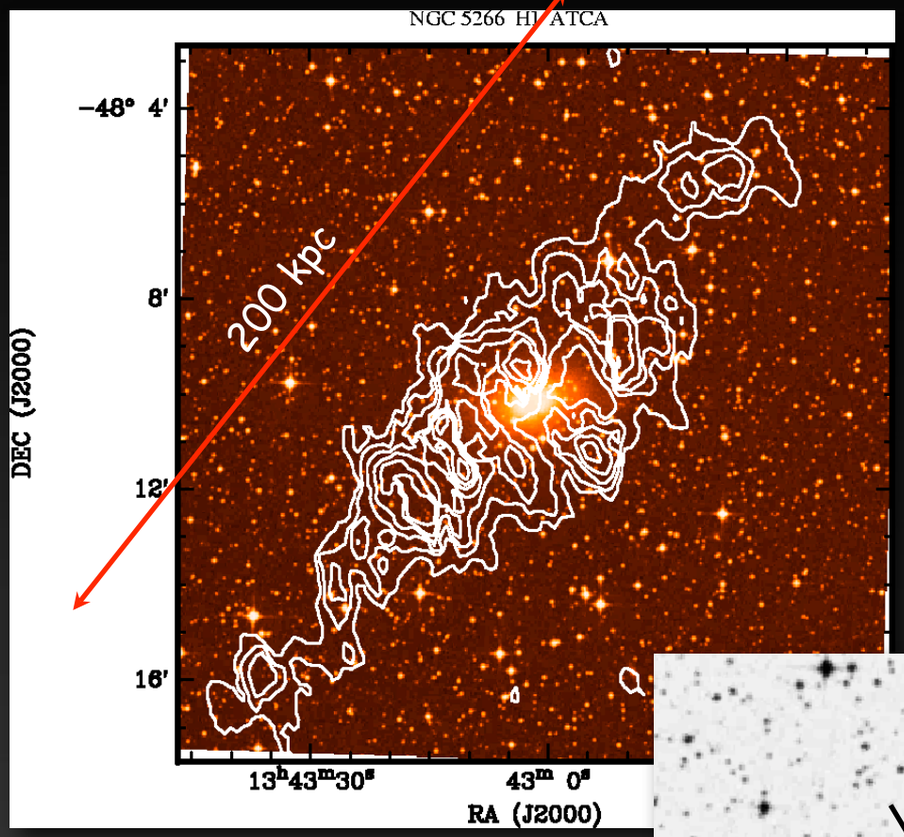
- in 5-10% the HI is in large (up to 200 kpc!!!), rich (more than 10^9 M_{sun}) disks
- many cases are clear results of major mergers: e.g. IC4200
- Stellar counterpart in other cases, e.g. NGC5266
- large regular HI structures, low column density-> old mergers

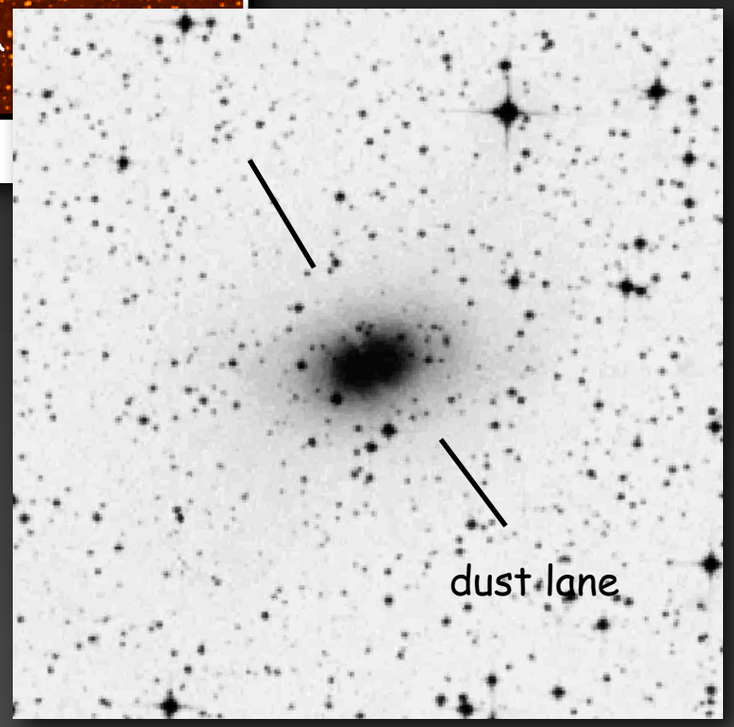


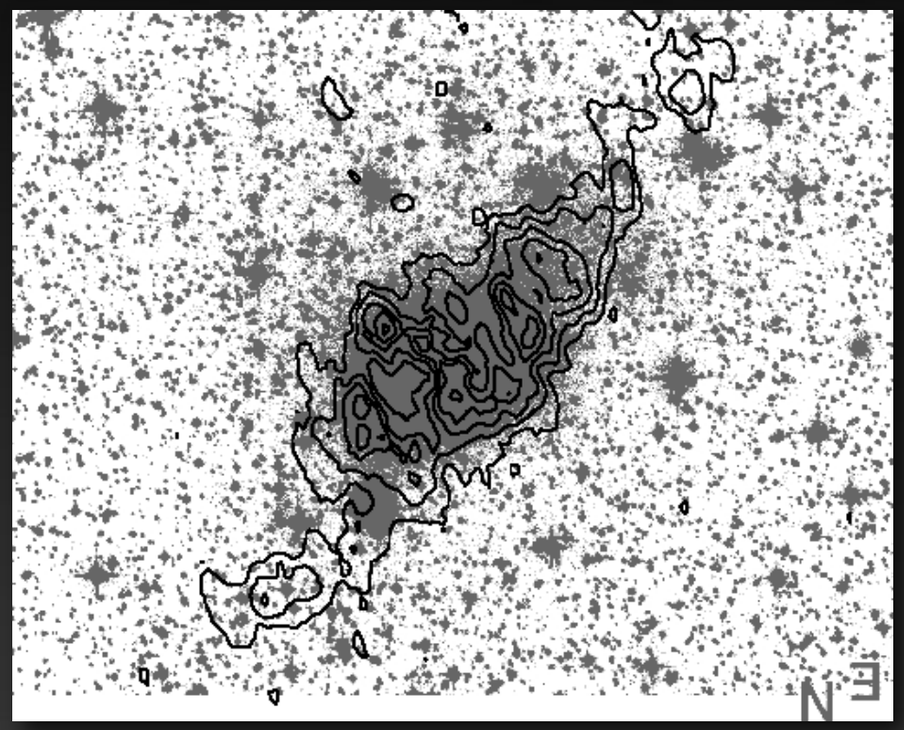
IC4200: Event that happened about 2 Gyr ago and originated both the H I structure and the central starburst: major merger – time not long enough for accretion of IGM.
Serra et al. A&A 2006, astro-ph/0602621

NGC 5266

Minor-axis dust-lane elliptical with large, semi-regular H I disk of 10^{10} $M_\odot$







deep image D. Malin

remnant of major gas-rich merger

Morganti et al. 1996

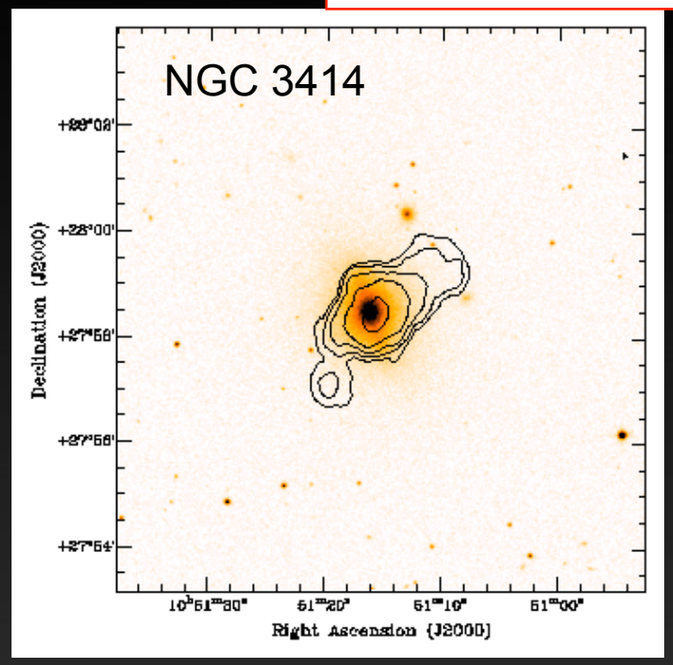
other nice cases:
van Gorkom et al.
Schiminovich et al. 1998

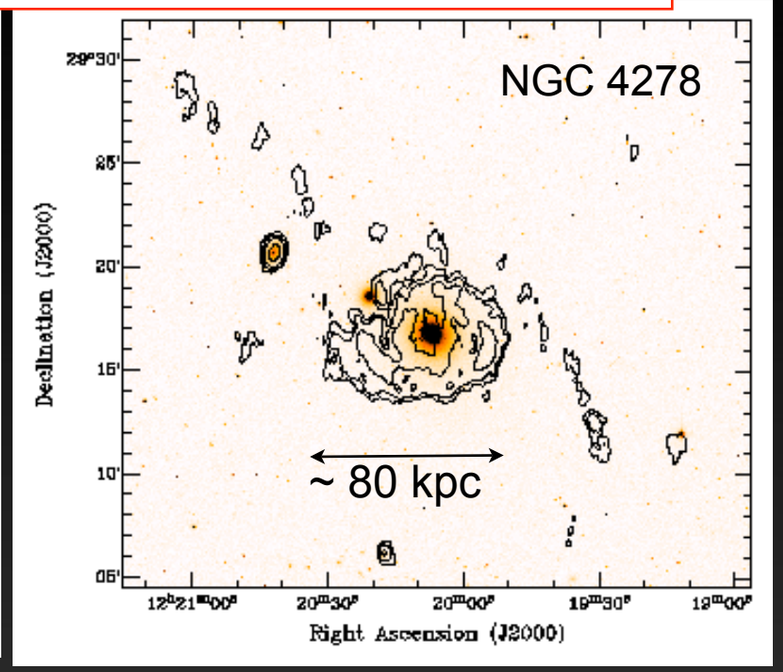
Up to 70% of early-type galaxies are detected in HI

IF

we go as deep as few 10^6 M_{sun}:
a variety of structures is fund

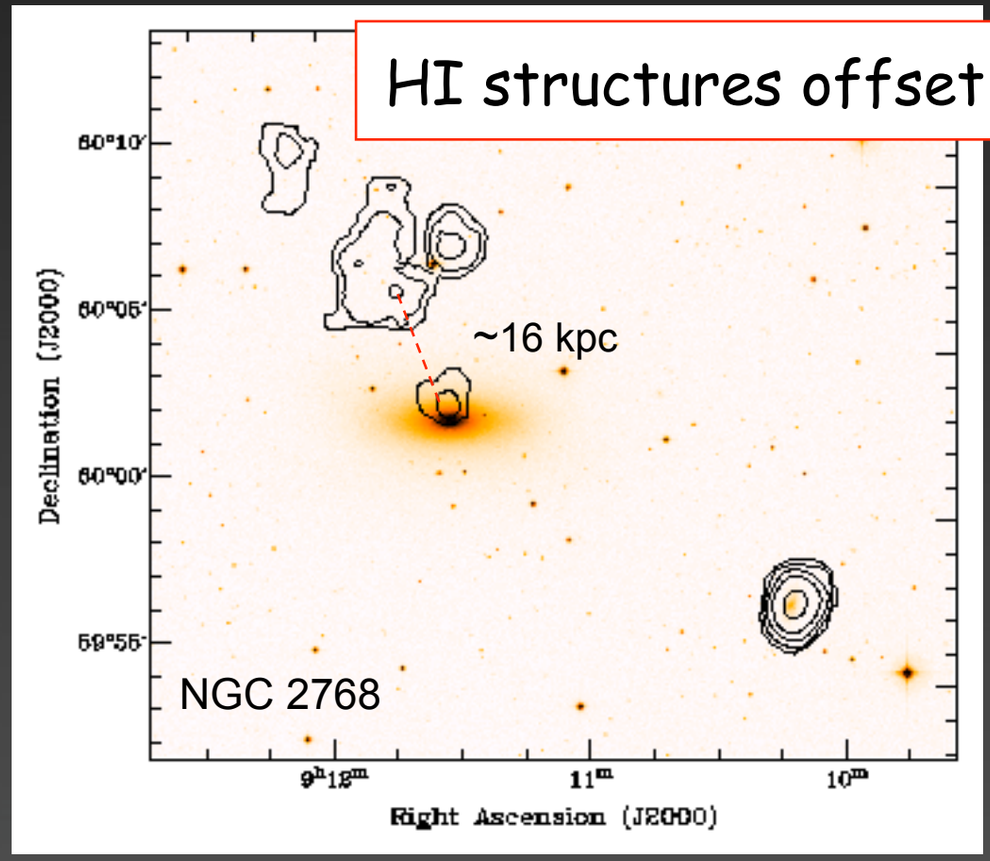
Regularly rotating HI structures

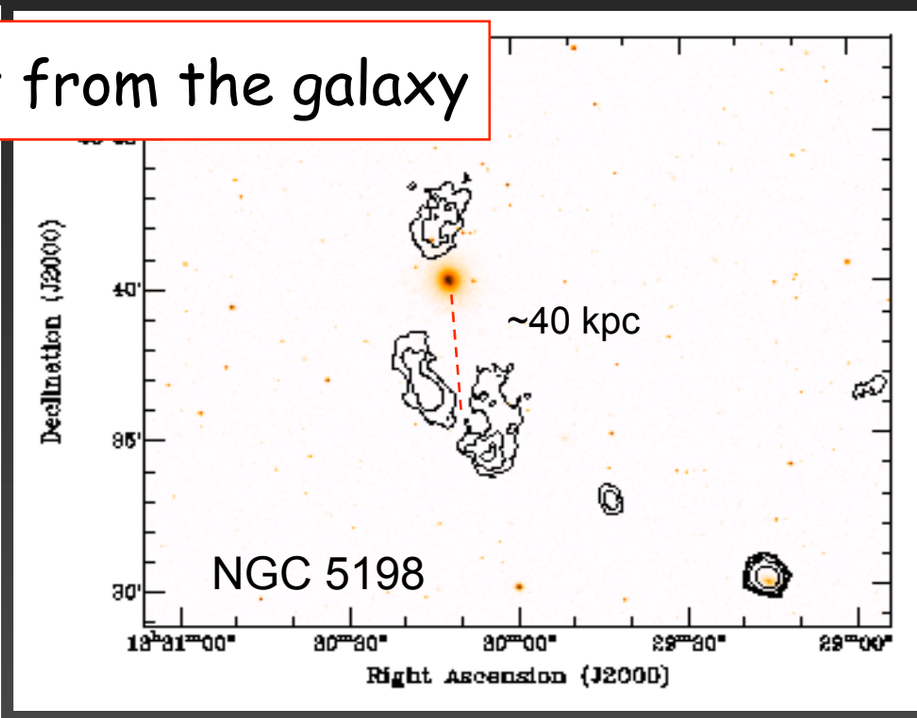




on the low HI-mass end the origin of the gas can be interaction but also cold accretion!

HI structures offset from the galaxy

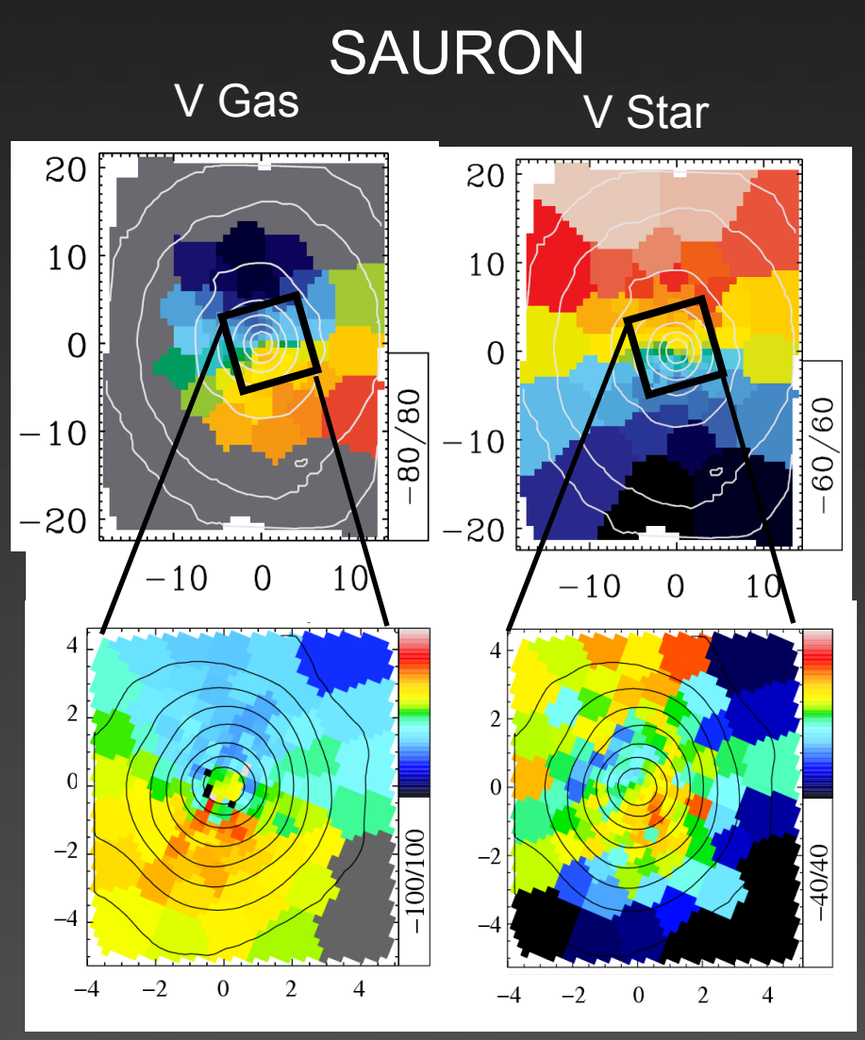




Morganti et al. 2006

Ionised gas in early-type (field) galaxies

- About 75 % galaxies detected in ionised gas (Sarzi et al. 2006)
- Comparable detection rate between H I and ionised gas despite the very different regions observed
- Gas NOT ionised by star formation

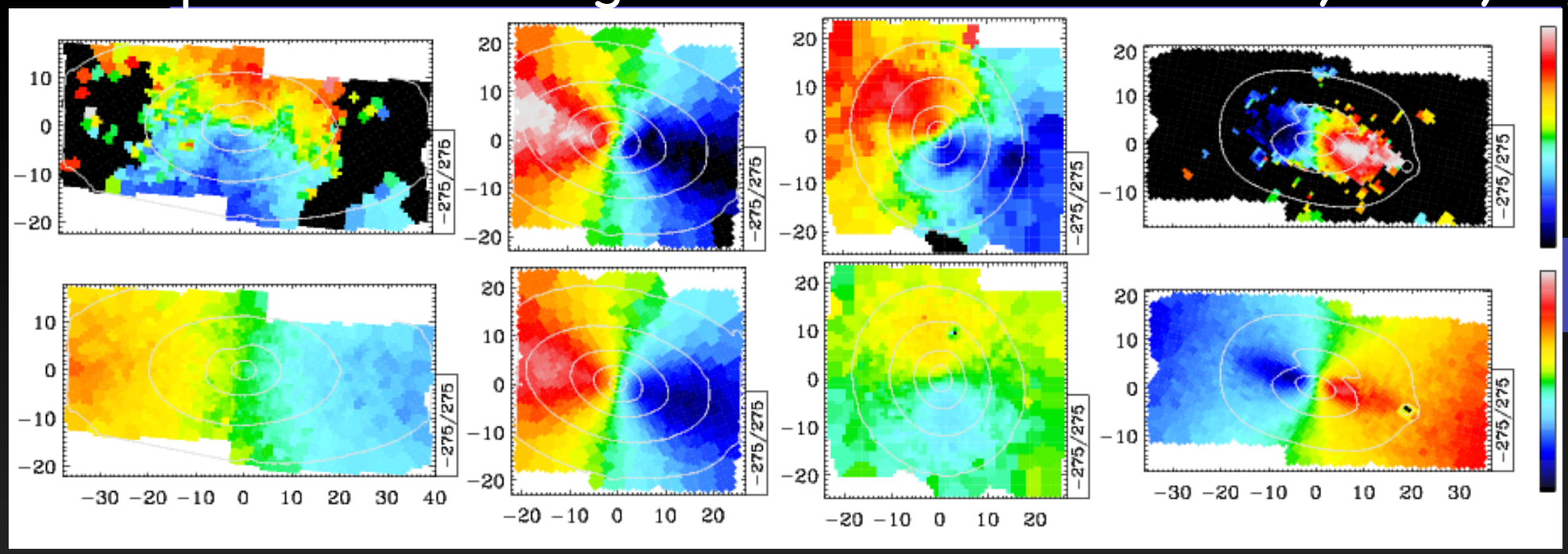


- Kinematical decoupled cores (the kinematics changes in the very inner parts
- Ionized gas linked to recent SF

McDermid et al. using Sauron and OASIS integral field spectrographs

linear scale, between 50 and 100 pc/arcsec

Examples of ionised gas in the centre of nearby early-type galaxies

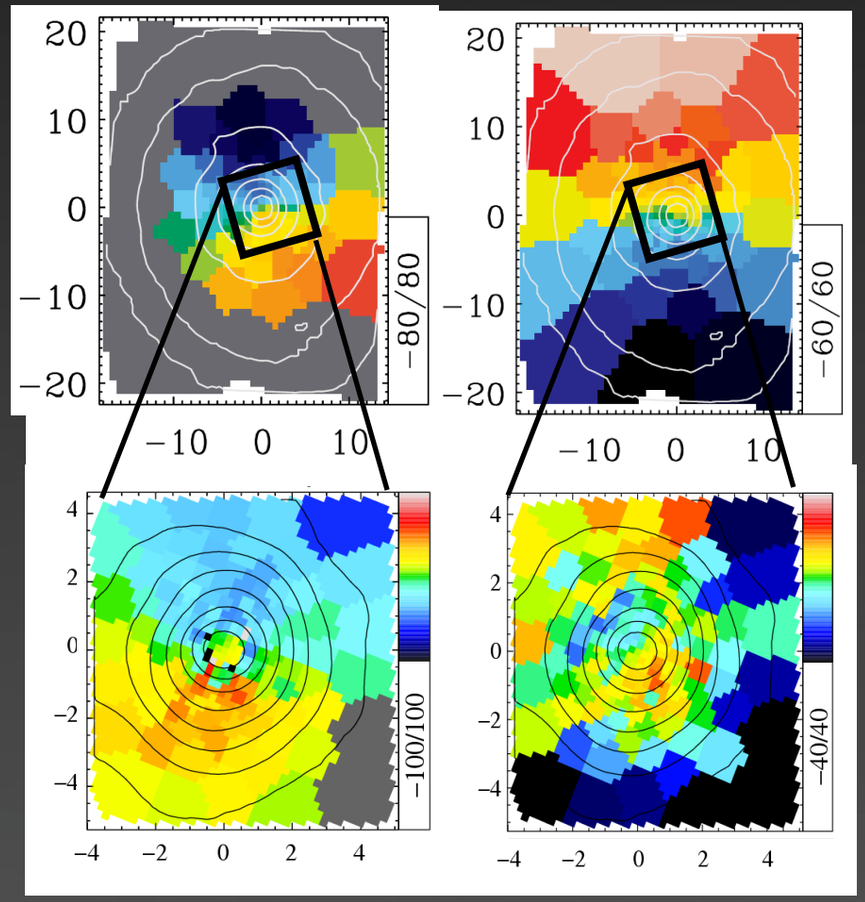


Integral field spectrograph
SAURON

SAURON

V Gas

V Star



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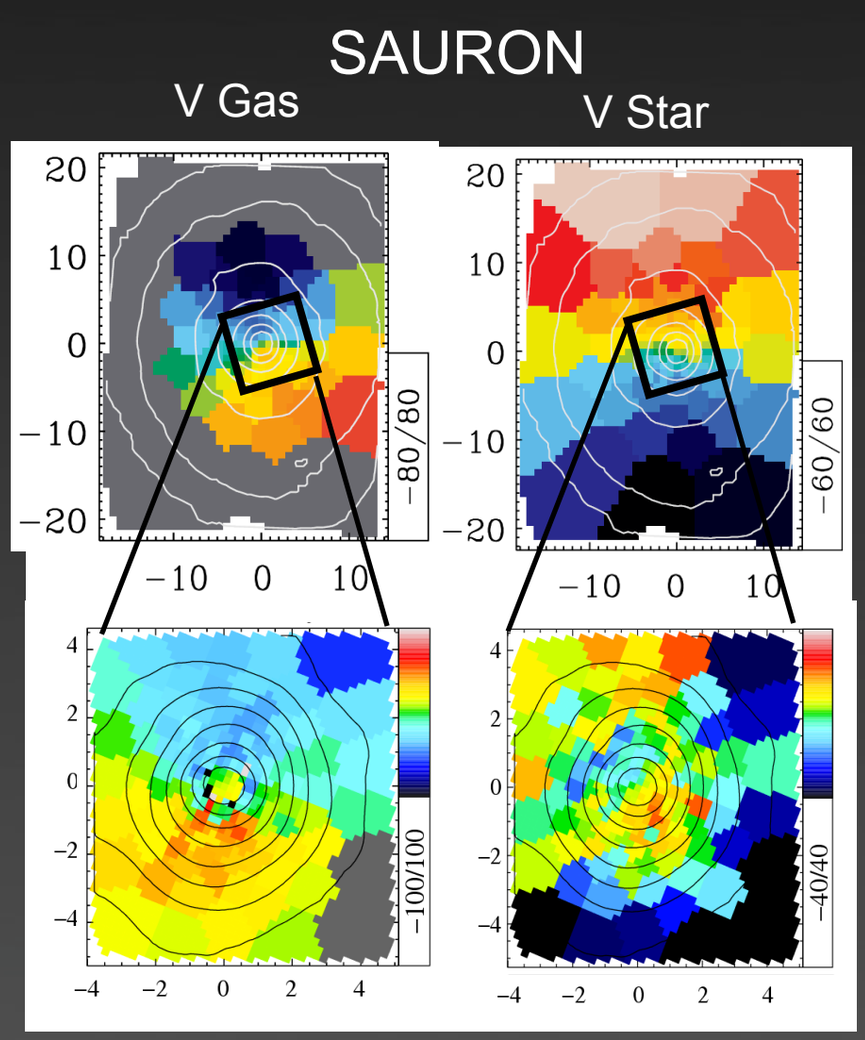

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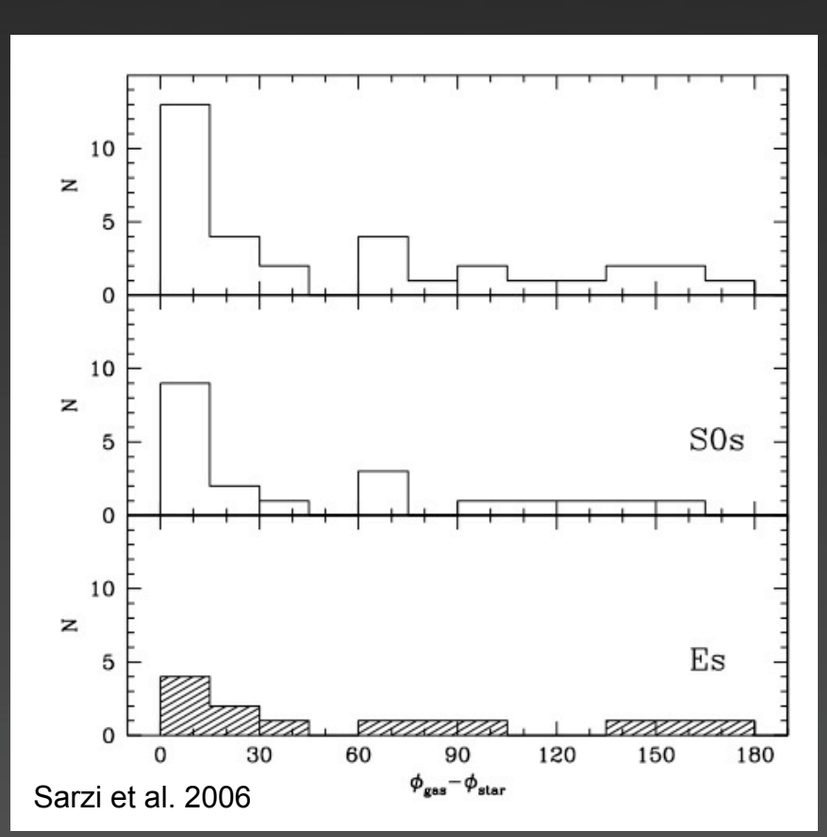
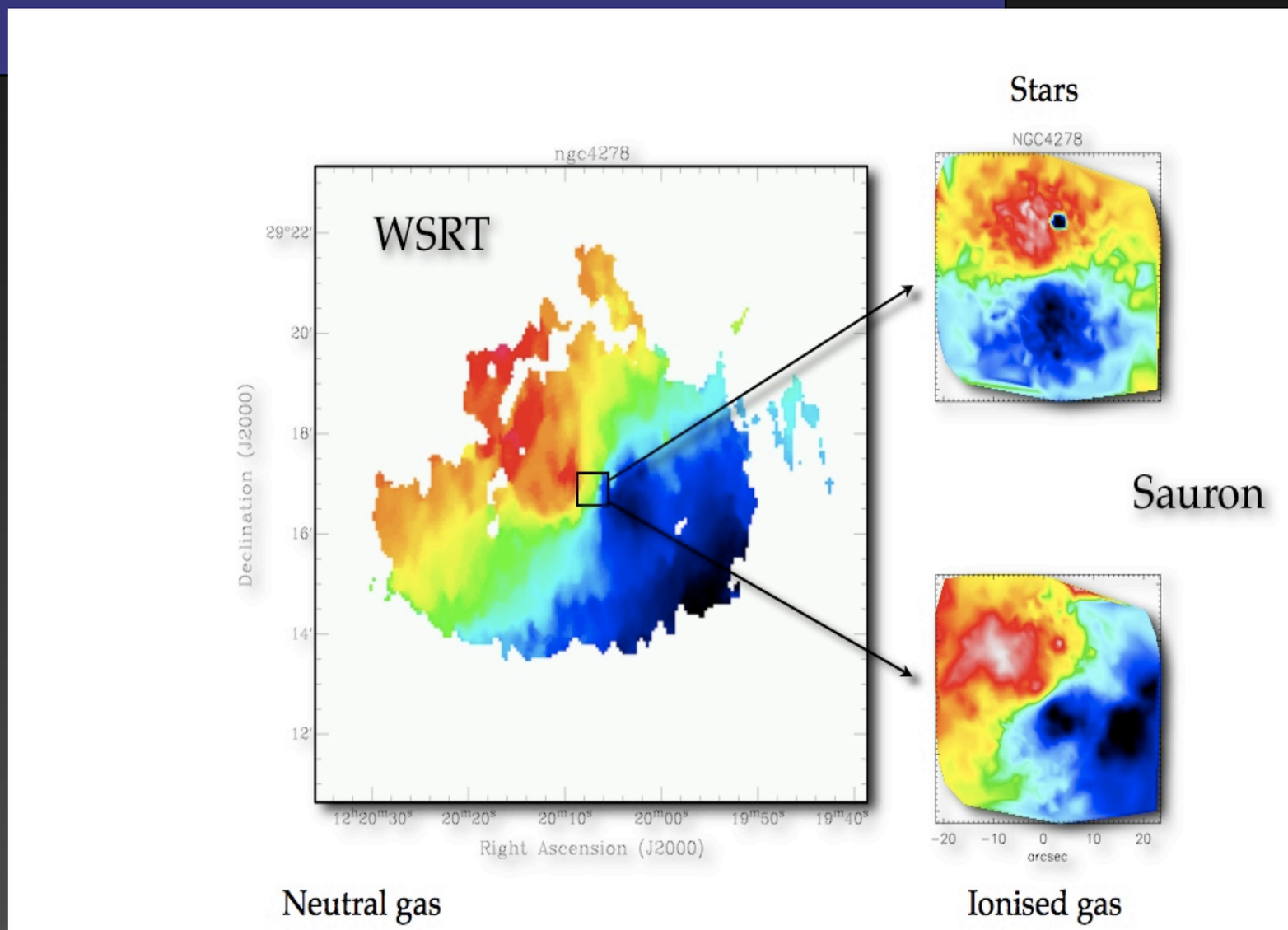
Galaxies with regular H I disks also have extended, kinematically regular structures of ionised gas

External origin for the ionised gas in the majority of the cases



Sarzi et al. 2006



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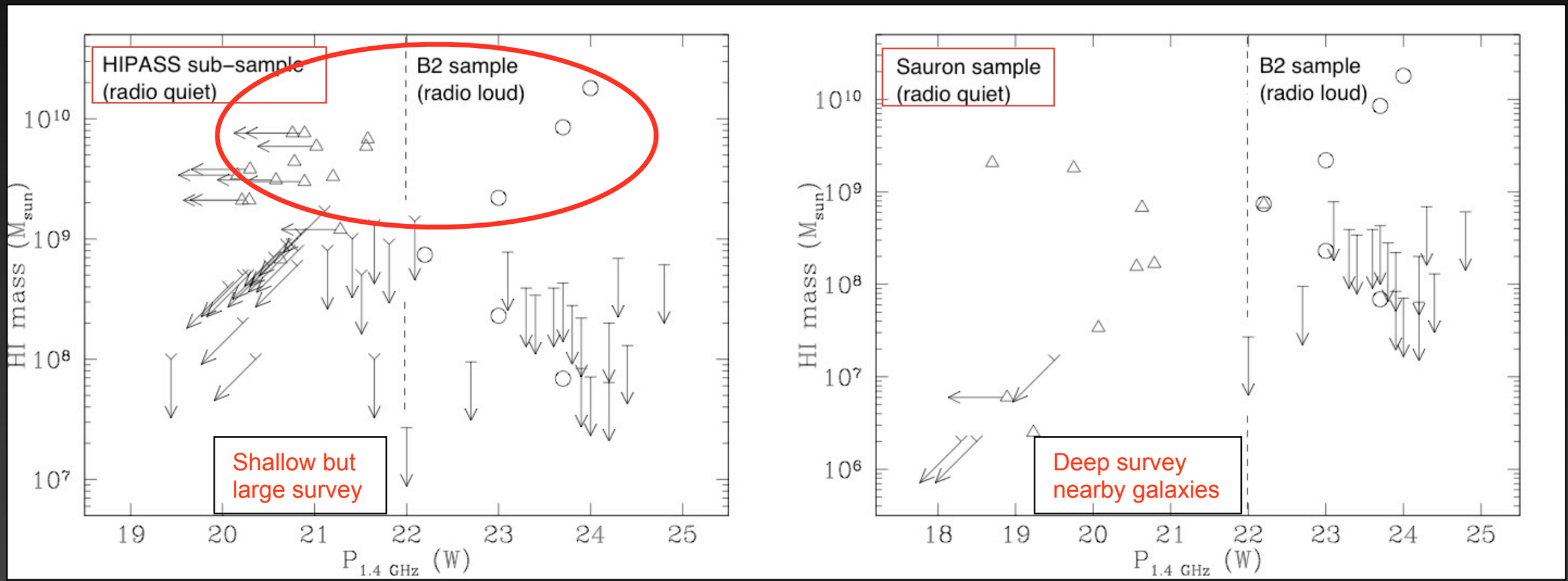

Emonts 2006 (PhD thesis)

Large-scale (>100 kpc) HI-rich disks (M_{HI} > few x 10^9 M_{sun}) also observed in radiogalaxies

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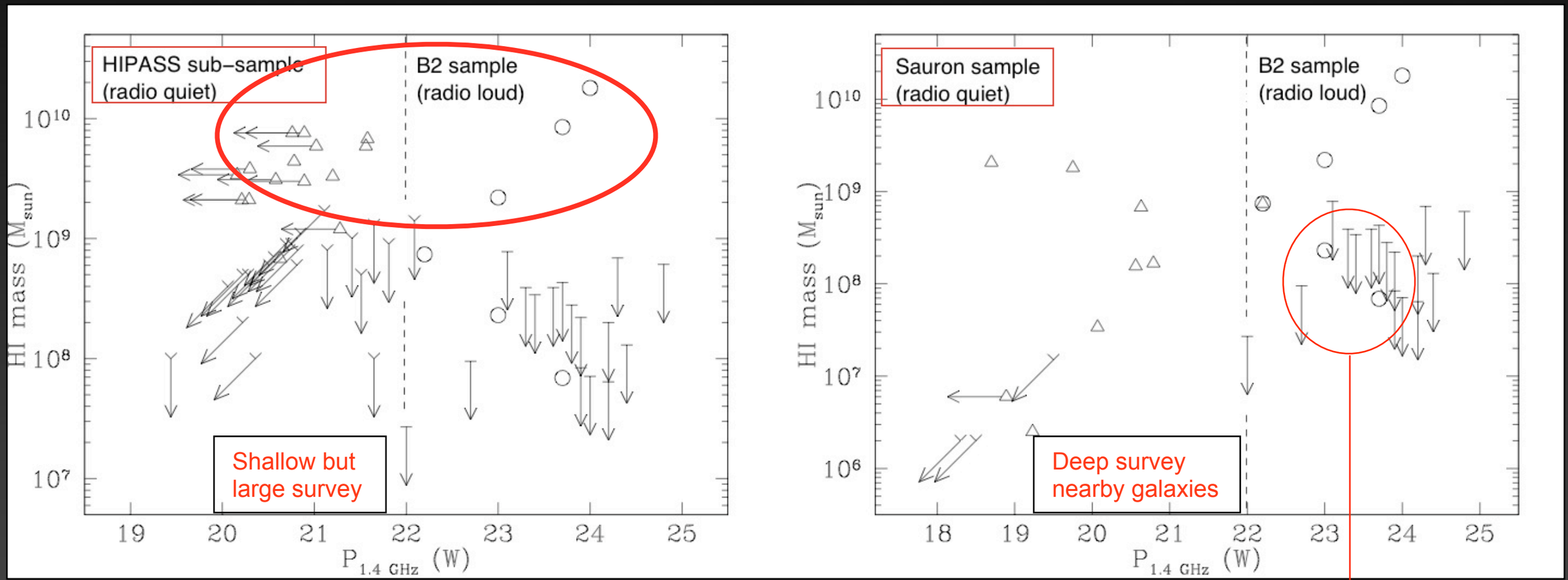

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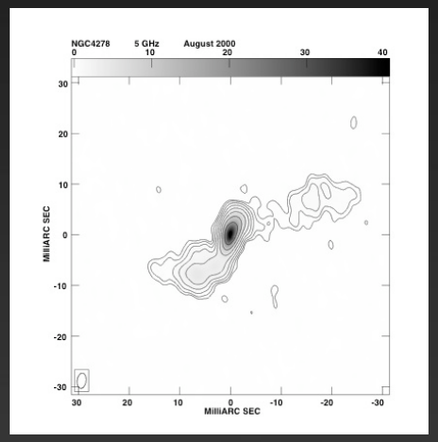
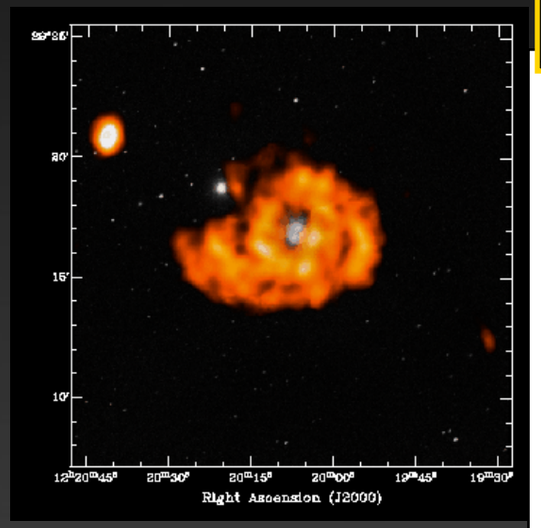
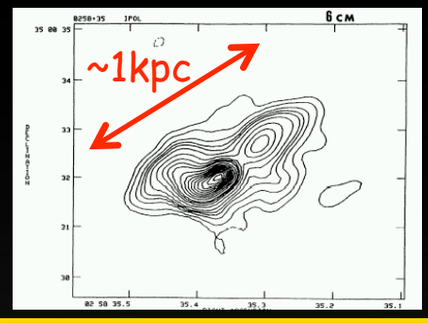
different structures?

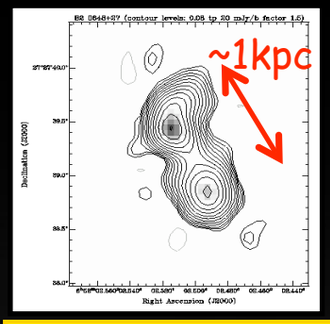
Remarkable trend:
radio galaxies with large amounts (M_{HI} >10^9 M_{sun}) of extended (many tens of kpc up to 200 kpc!) HI disks all have a **compact** radio source



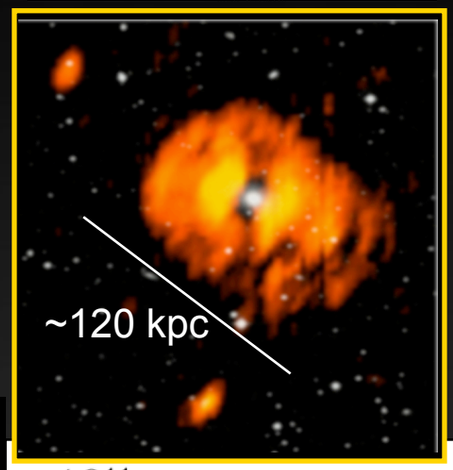
Giroletti et al. 2004

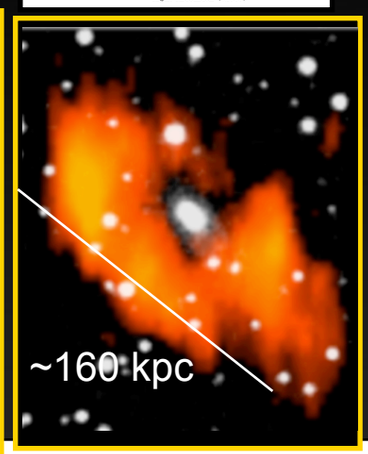


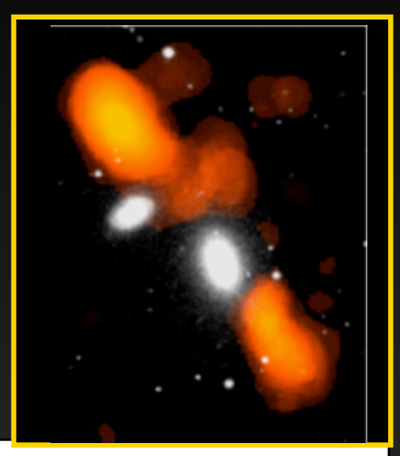


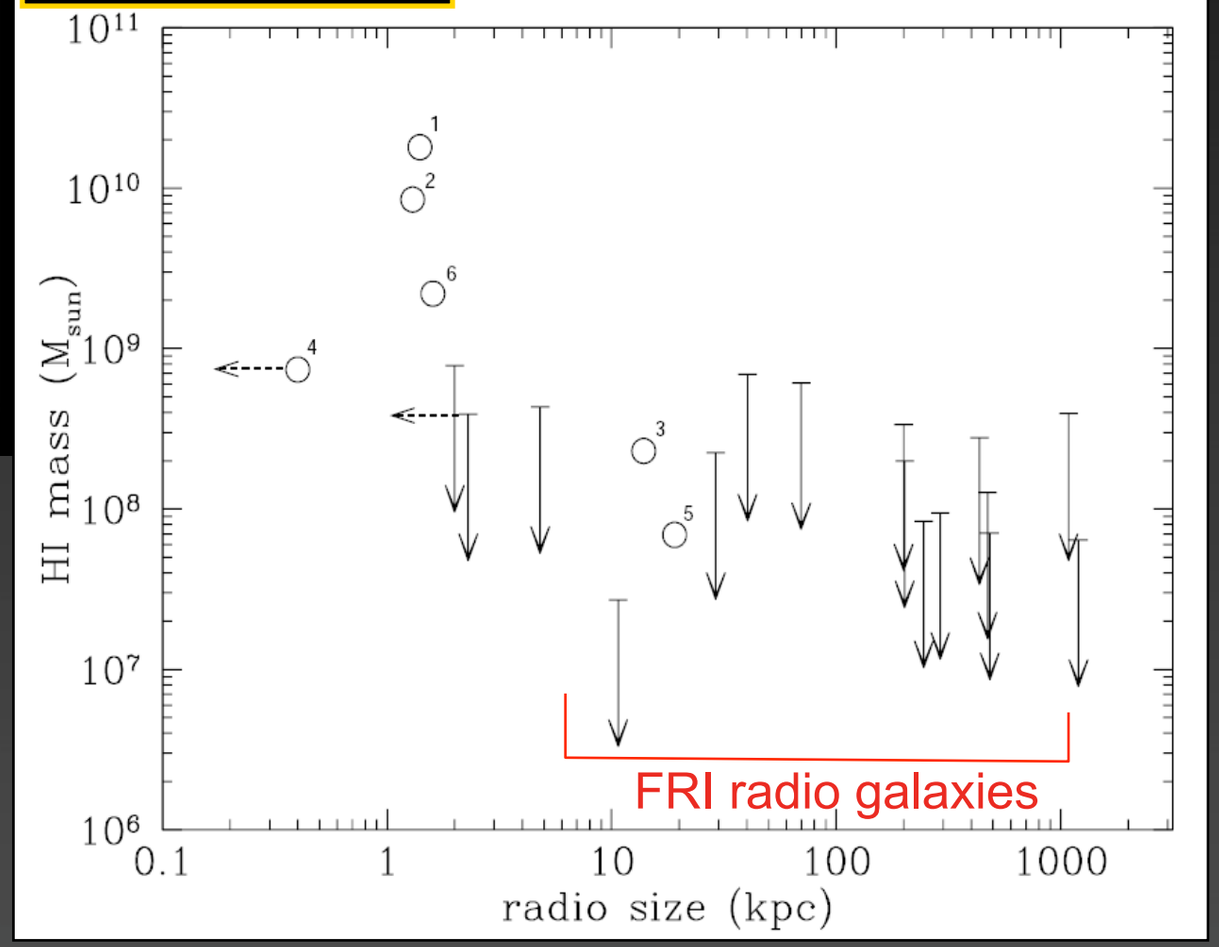


NGC 3894





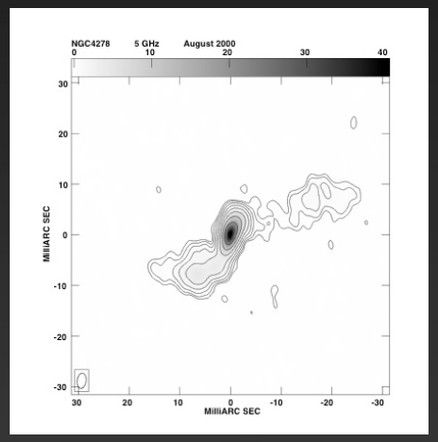




Emonts et al. 2006, astro-ph/0701438

Low luminosity radio galaxies

Remarkable trend:
radio galaxies with large amounts (M_{HI} >10^9 M_{sun}) of extended (many tens of kpc up to 200 kpc!) HI disks all have a **compact** radio source



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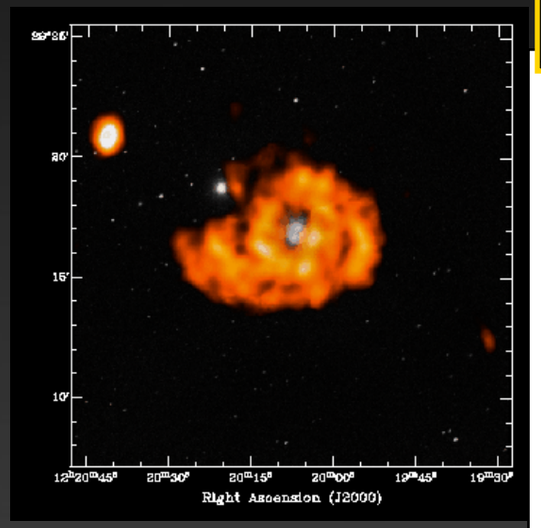

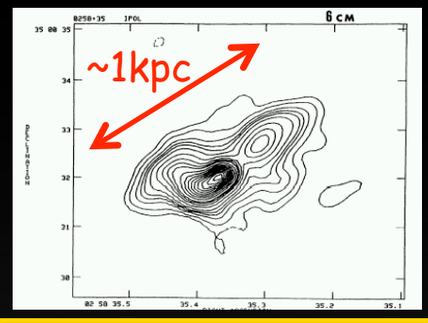

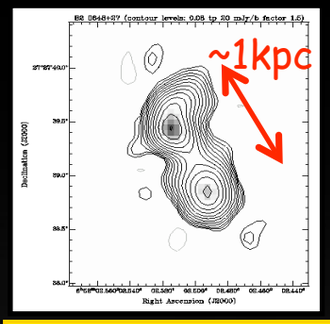

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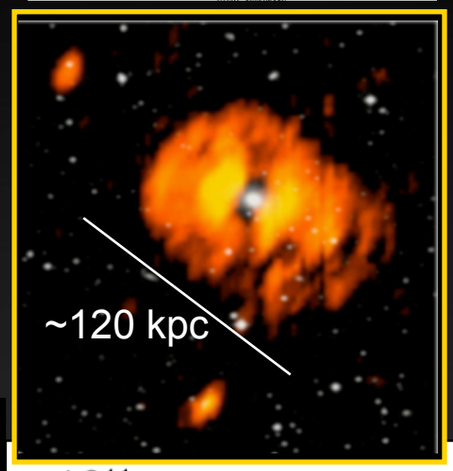
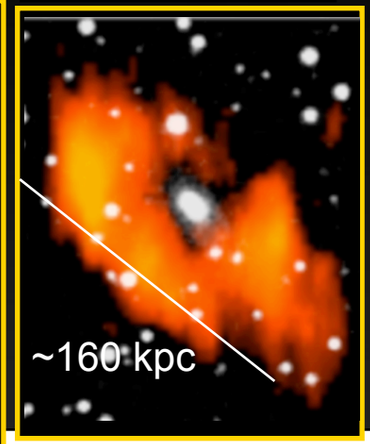
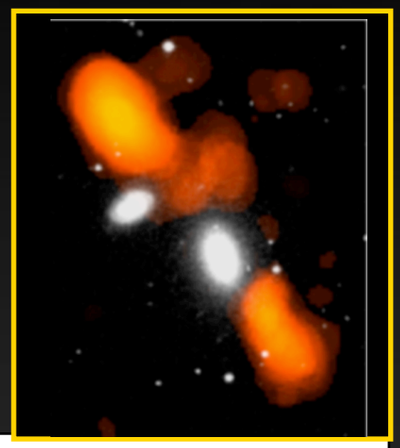
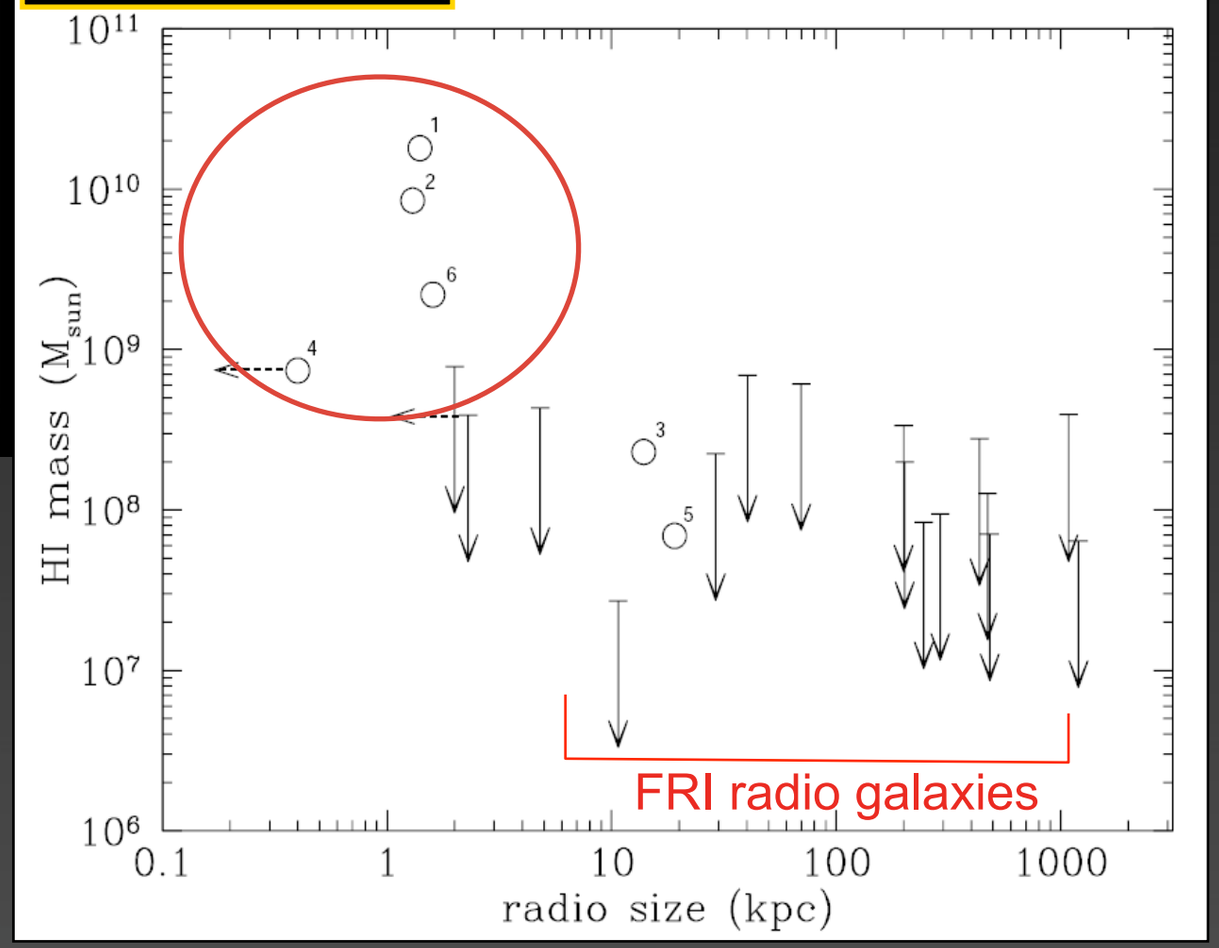




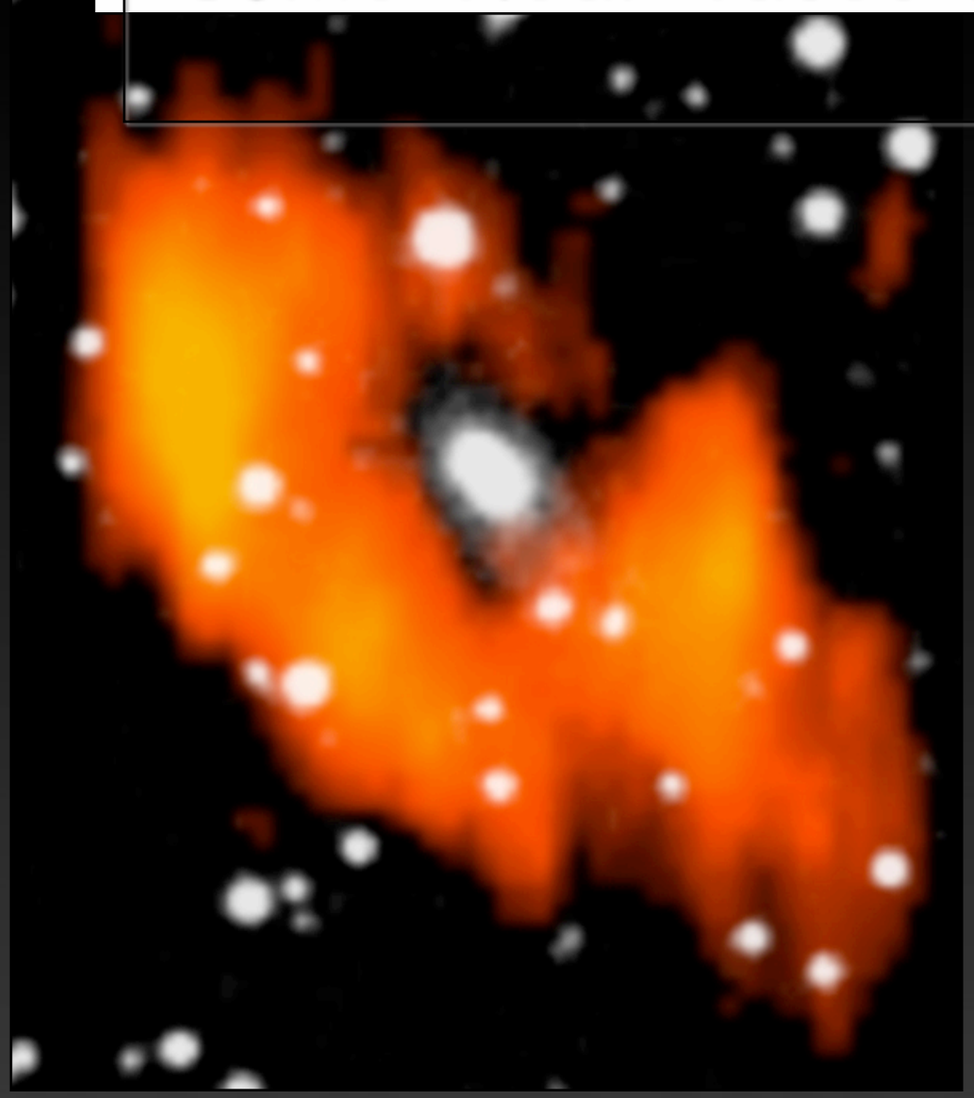


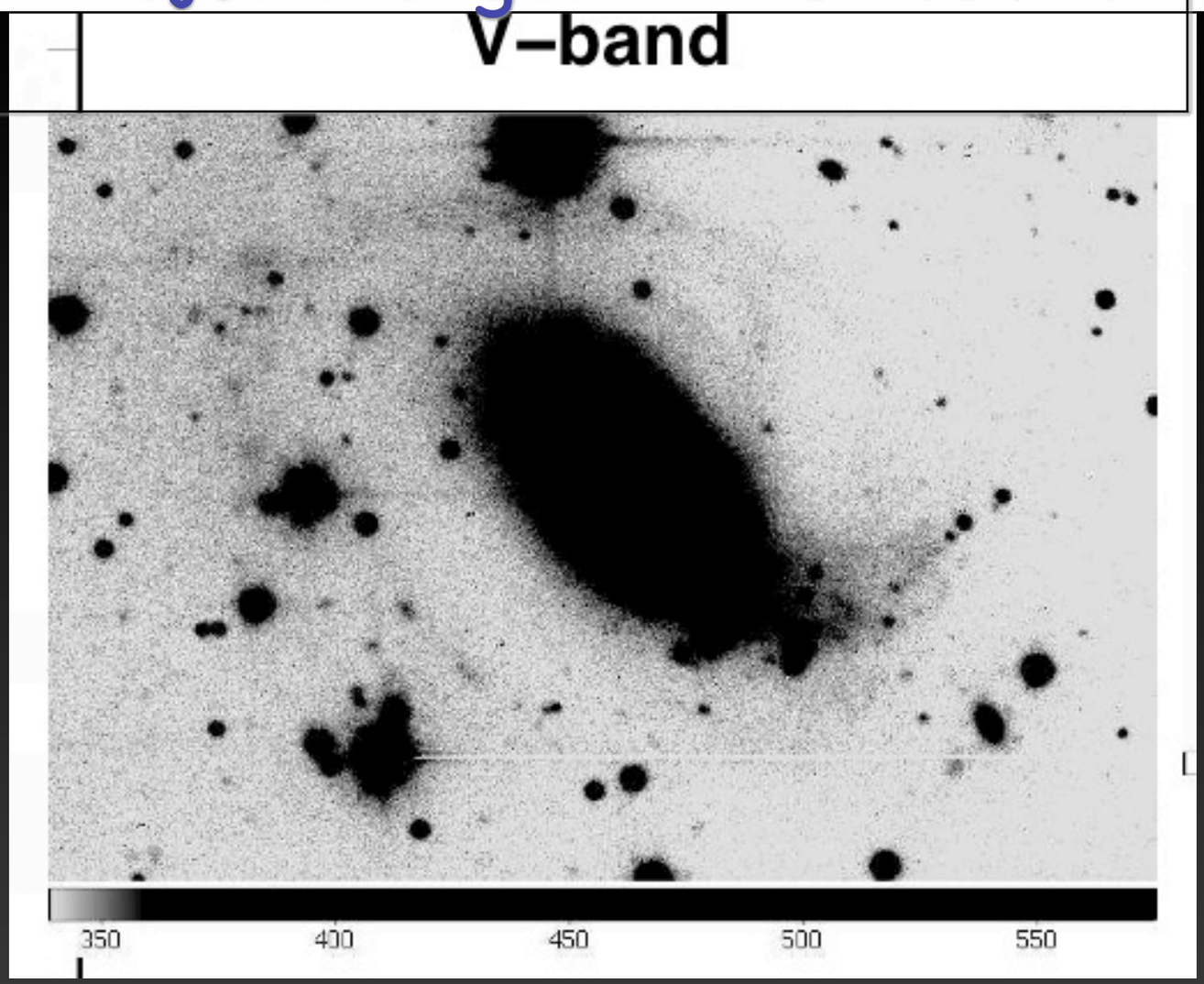


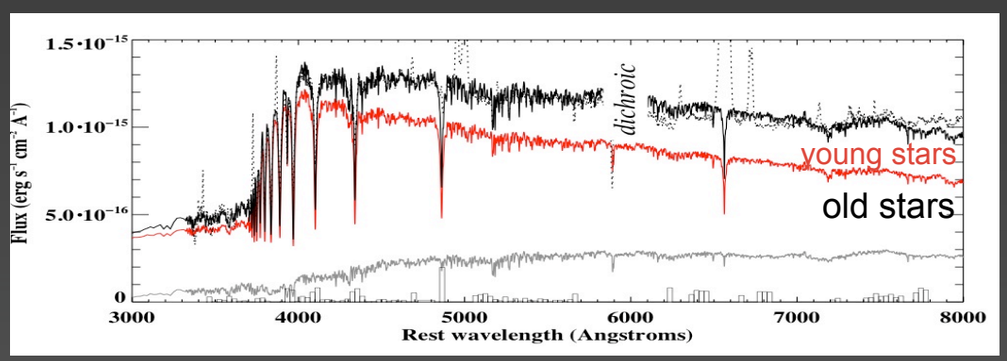
Emonts et al. 2006, astro-ph/0701438

Low luminosity radio galaxies

Some clear cases of major merger: B2 0648+27







- HI ring (~1.5 Gyr)
- Young Stellar Population (~0.3 Gyr)

⇓

relatively old merger but stars and radio source appear more recently

HI-rich (> 10^{10} M_{sun} of HI) large (> 100 kpc) disks only in compact radio galaxies: **why** ?

- Large-scale HI and type of radio sources both depend on the properties of the host galaxy
- the radio source heat/ionises the gas when jet/lobes propagate outward

-> BUT not much ionized gas at large radii for FRI!

-> more likely in the case of FRII (also in these radiogalaxies we also do not seem to find large amount of HI -> preliminary results!)

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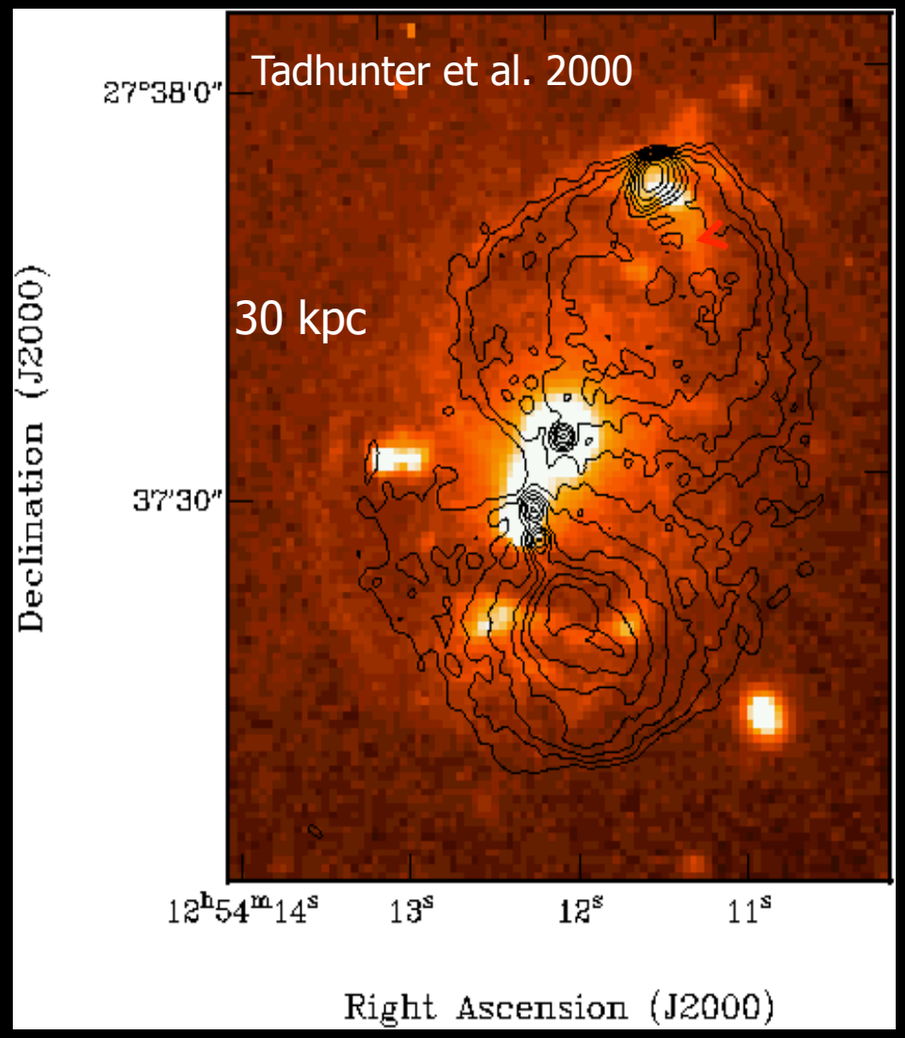
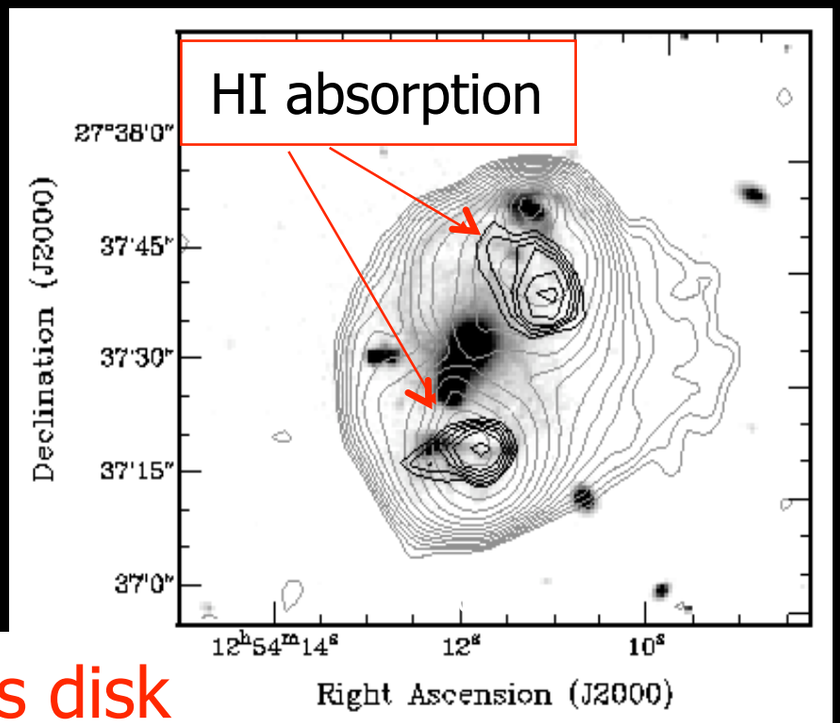


Complex morphology of the ionized gas and neutral hydrogen (with similar kinematics)



Radio lobes expanding into gas disk

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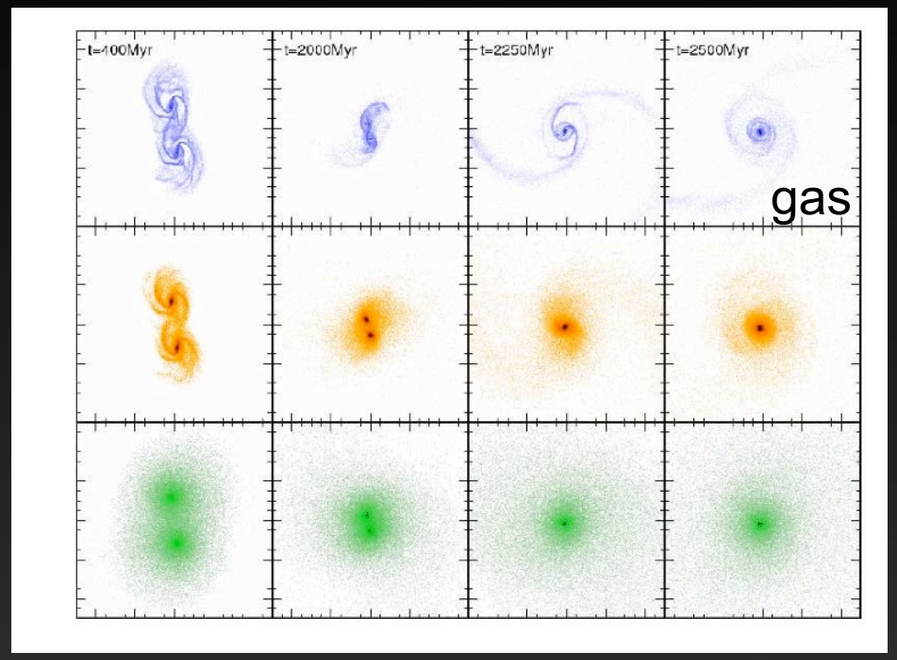
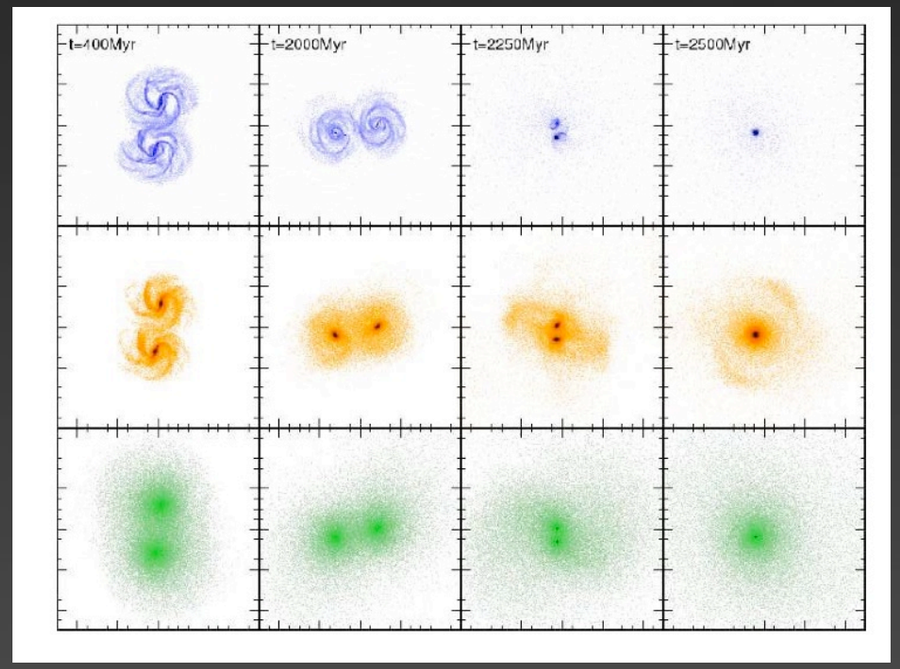


Direct merger



Retrograde merger

Di Matteo, Combes et al. 2007

but also: Mihos et al. , Volker et al.
and suggested for other HI-rich like NGC5266

Summary for radio-loud (mainly compact and FRI) galaxies

- Gas (HI and ionised) observed in a high fraction of early-type galaxies BOTH radio-quiet and radio-loud -> important component
- The HI can form very extended structures with mass well above 10^9 M_{sun} BOTH in radio-quiet and radio-loud!

- Convincing cases of major mergers (at least some type of..)
- Only small/young(?) radio sources have associated large HI disks -> different evolution for these objects?
- So far no FRI (and FRII) with such HI-rich structures -> gas ionised by the radio source? different type of merger?
- no one-to-one correlation gas-young stars
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relevant for the high-z extended structures?

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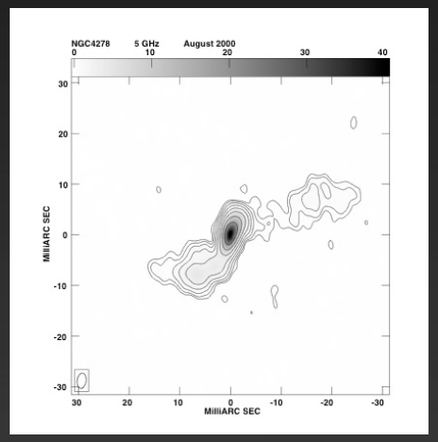
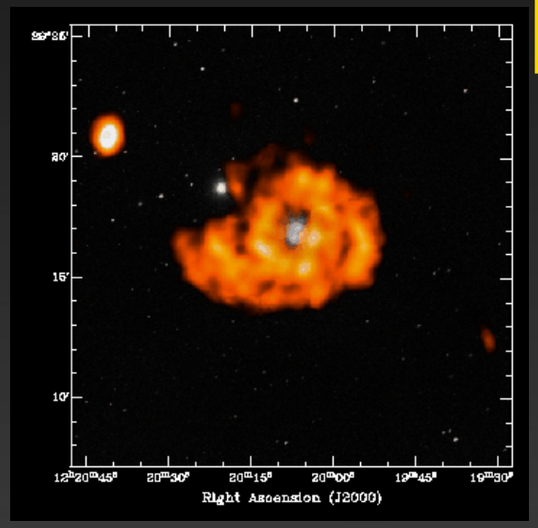
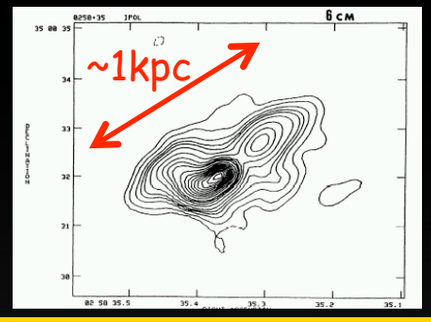
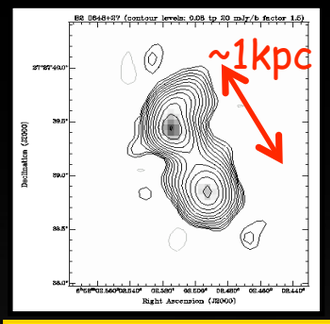


Giroletti et al. 2004







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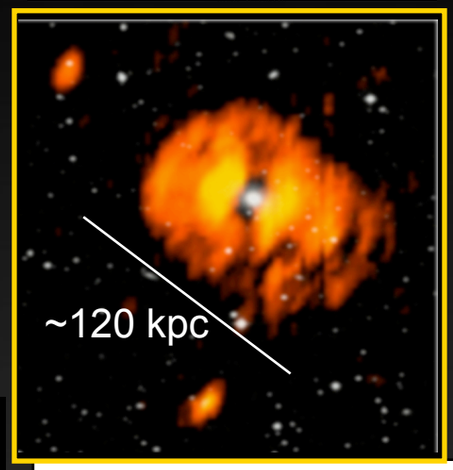
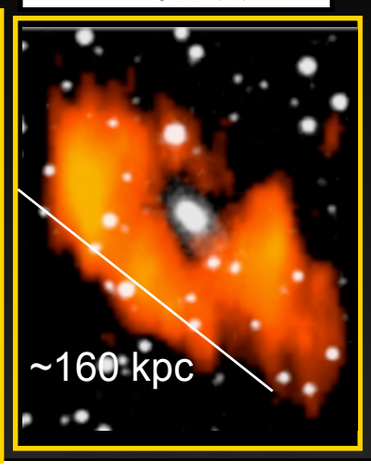
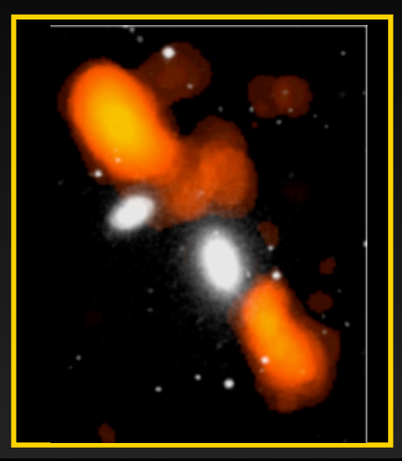
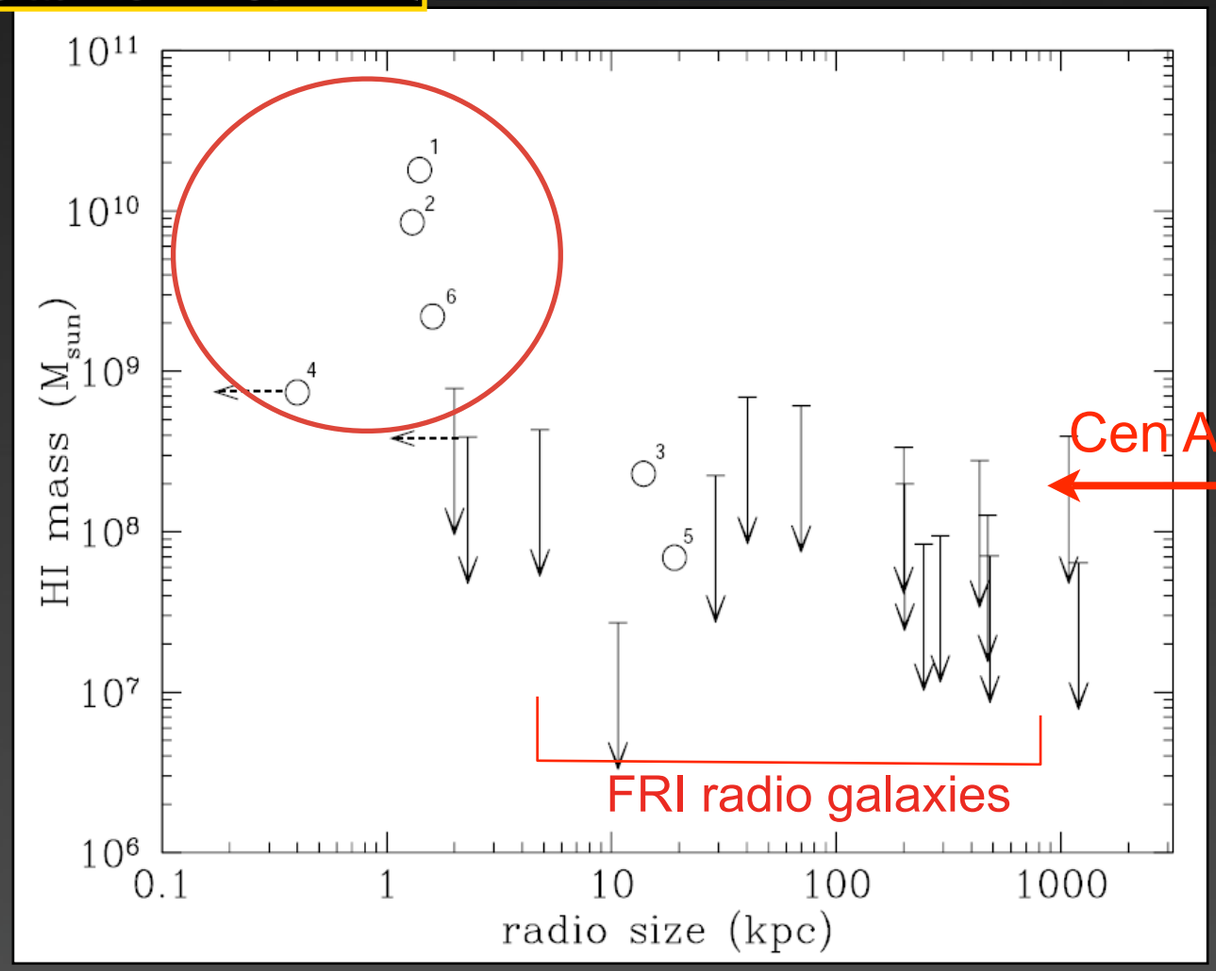


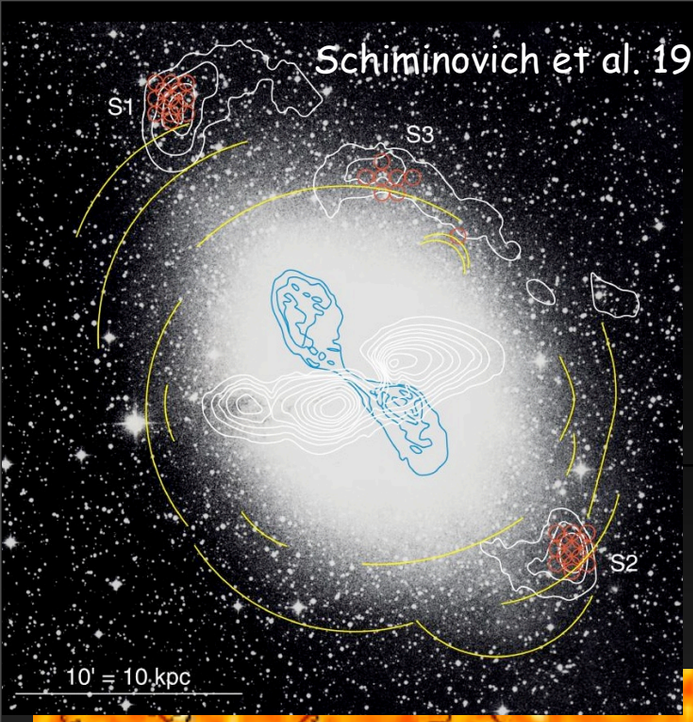




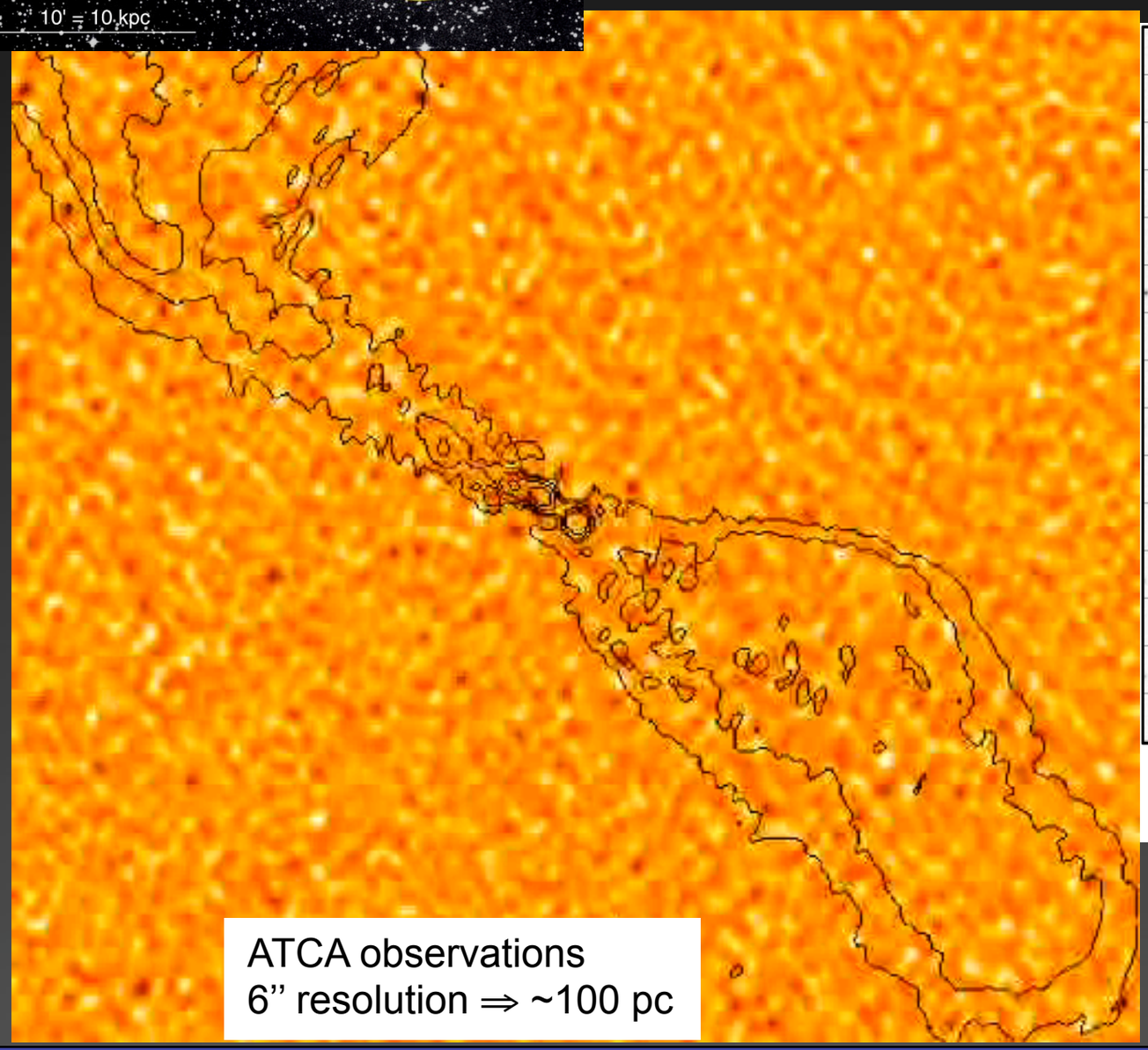


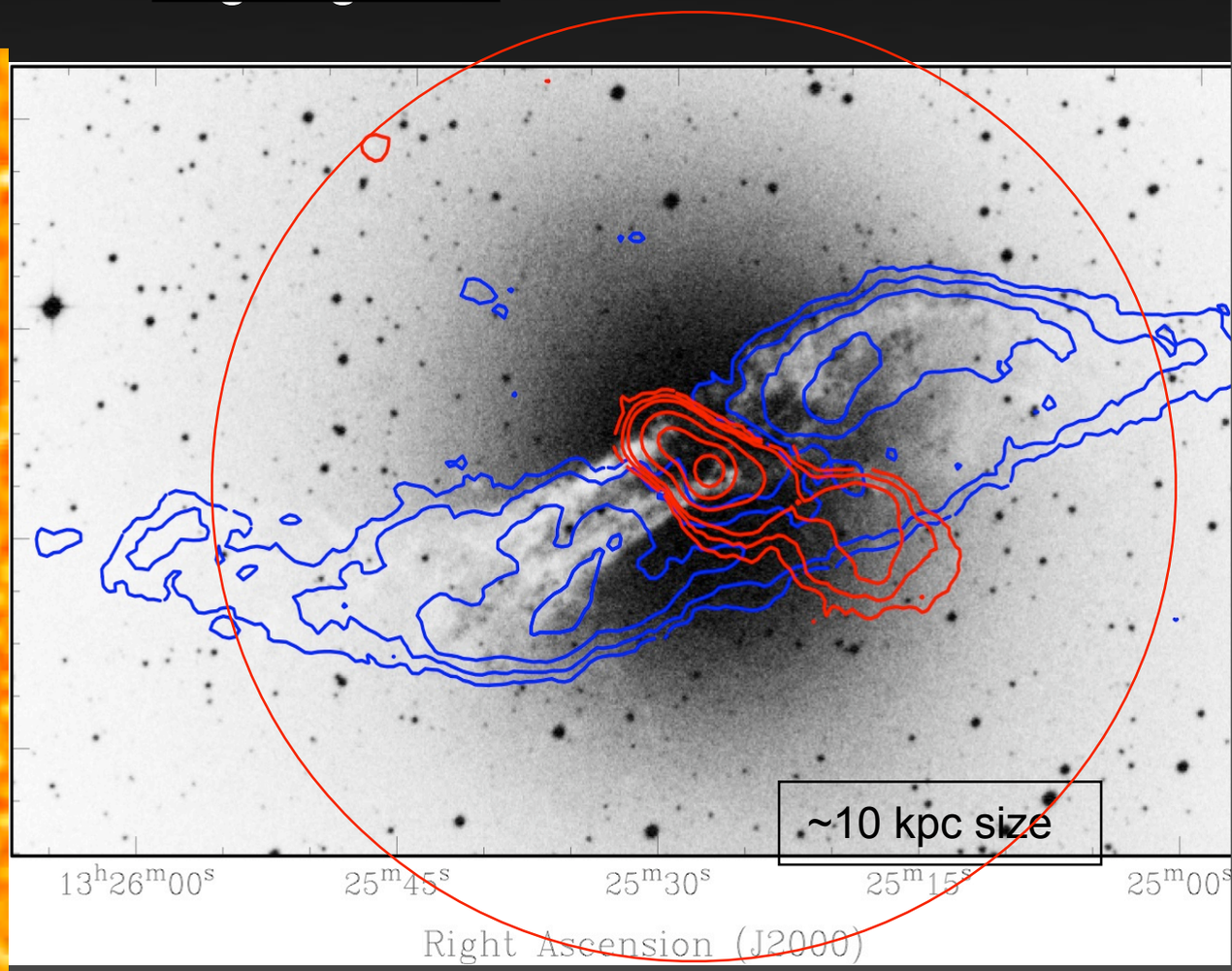
Case of Centaurus A: the story becomes more complicated

(emission, absorption and the effects of the central AGN)



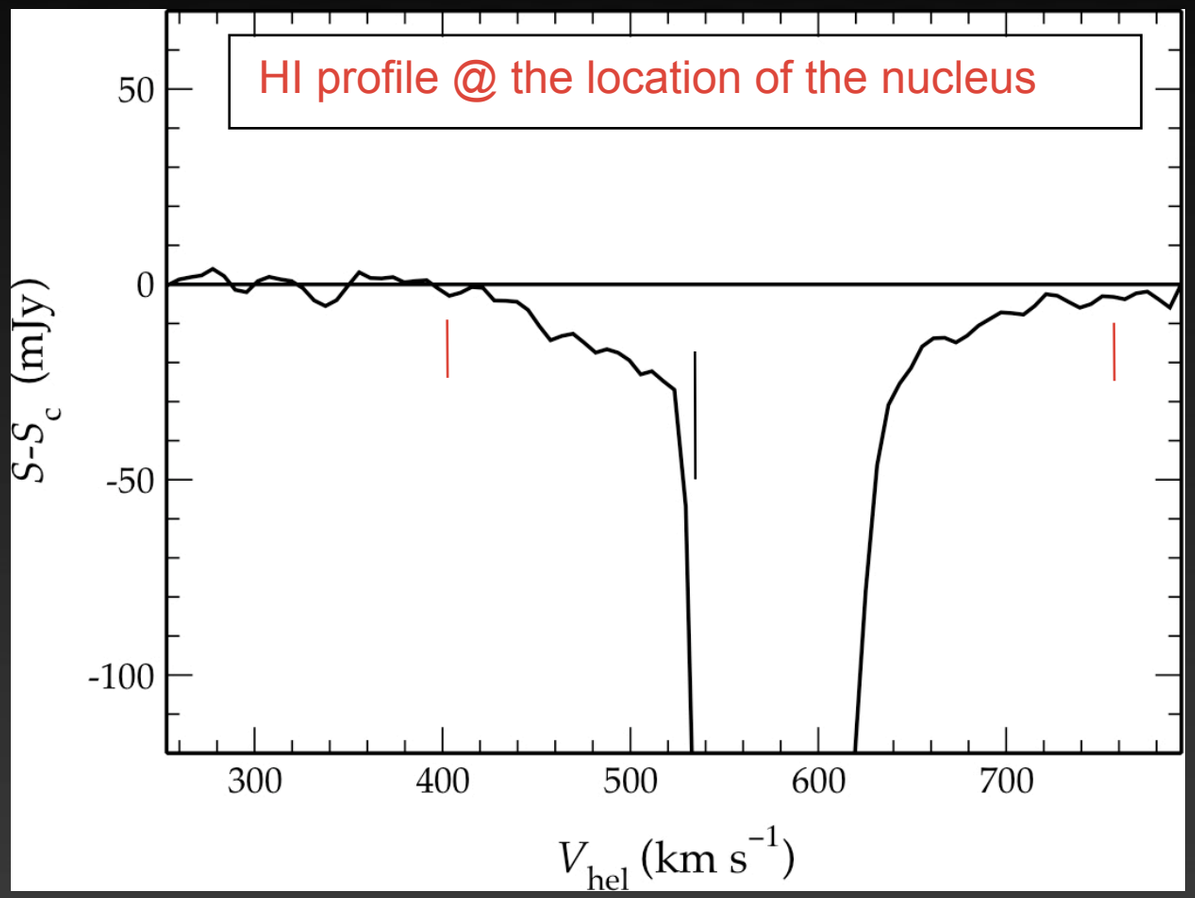
Nearby radio galaxy where the HI can be studied in detail (maybe too many details!)
⇒ ongoing work!

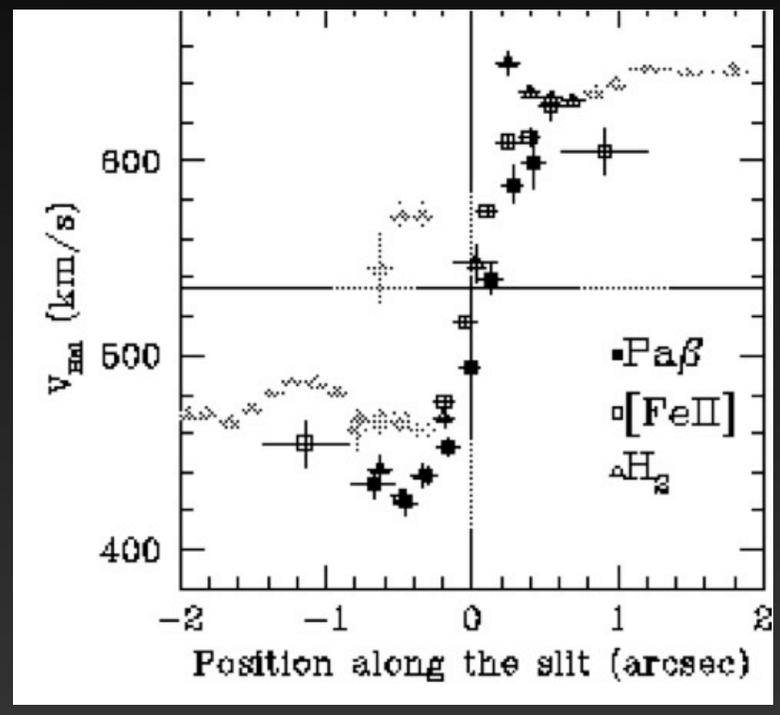




C. Struve PhD project (RuG)

The central absorption: gas close to the AGN



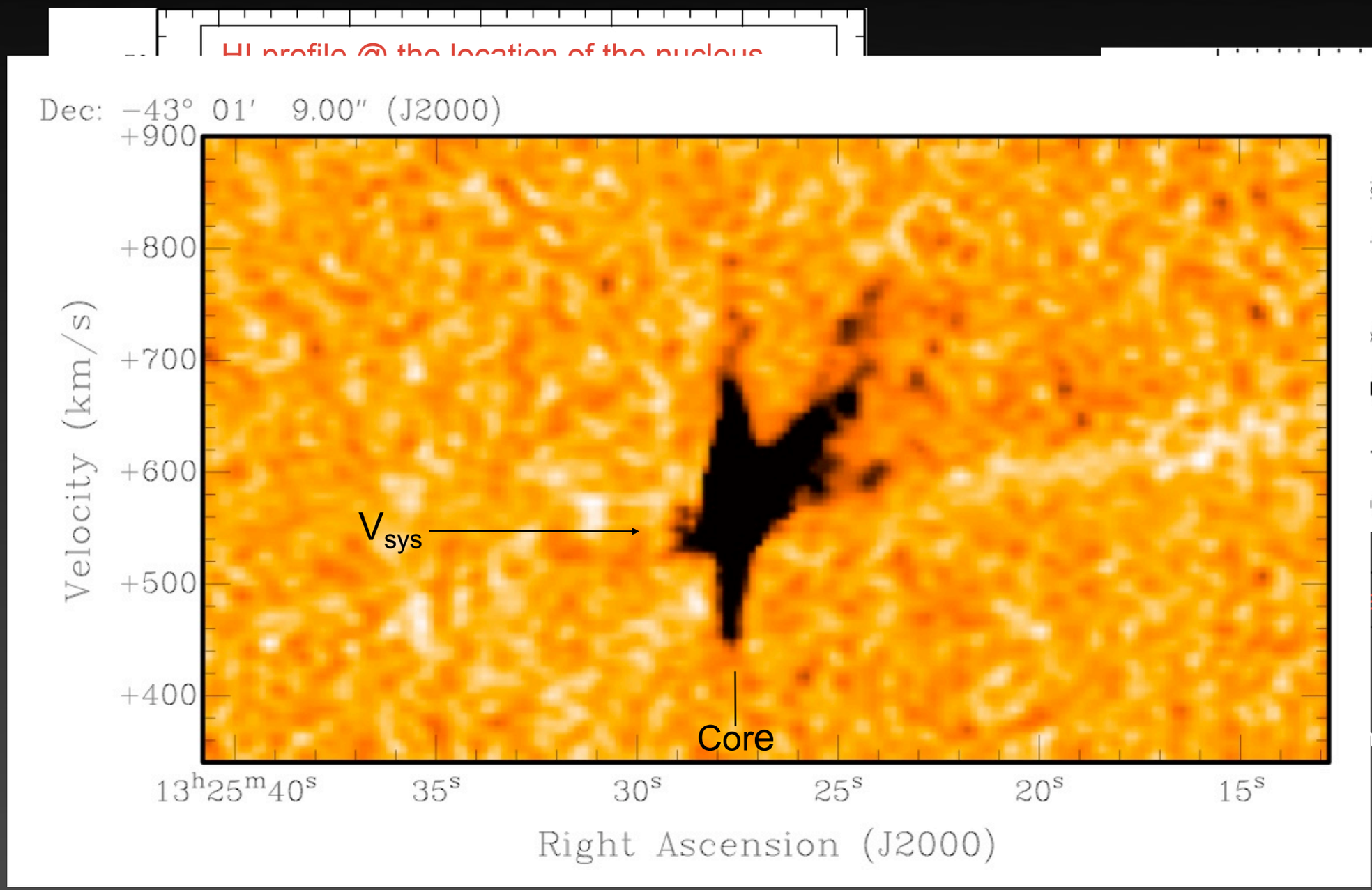


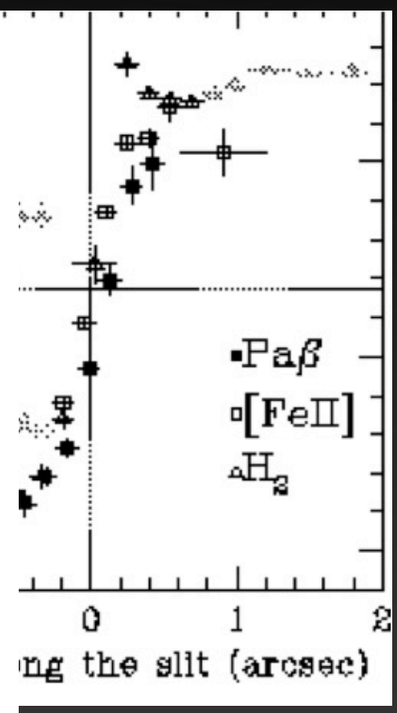
Marconi et al. 2001

- part of the redshifted component was known:
  inflow? feeding the monster (van der Hulst et al., van Gorkom et al.)
- broader redshifted + broad blueshifted component now also observed
- circumnuclear disk counterpart of what seen in the infrared (~30pc)?
  if so, it will tell us about the physical conditions
- non-circular orbits? inflow/outflow?

The central absorption: gas close to the AGN

HI profile @ the location of the nucleus





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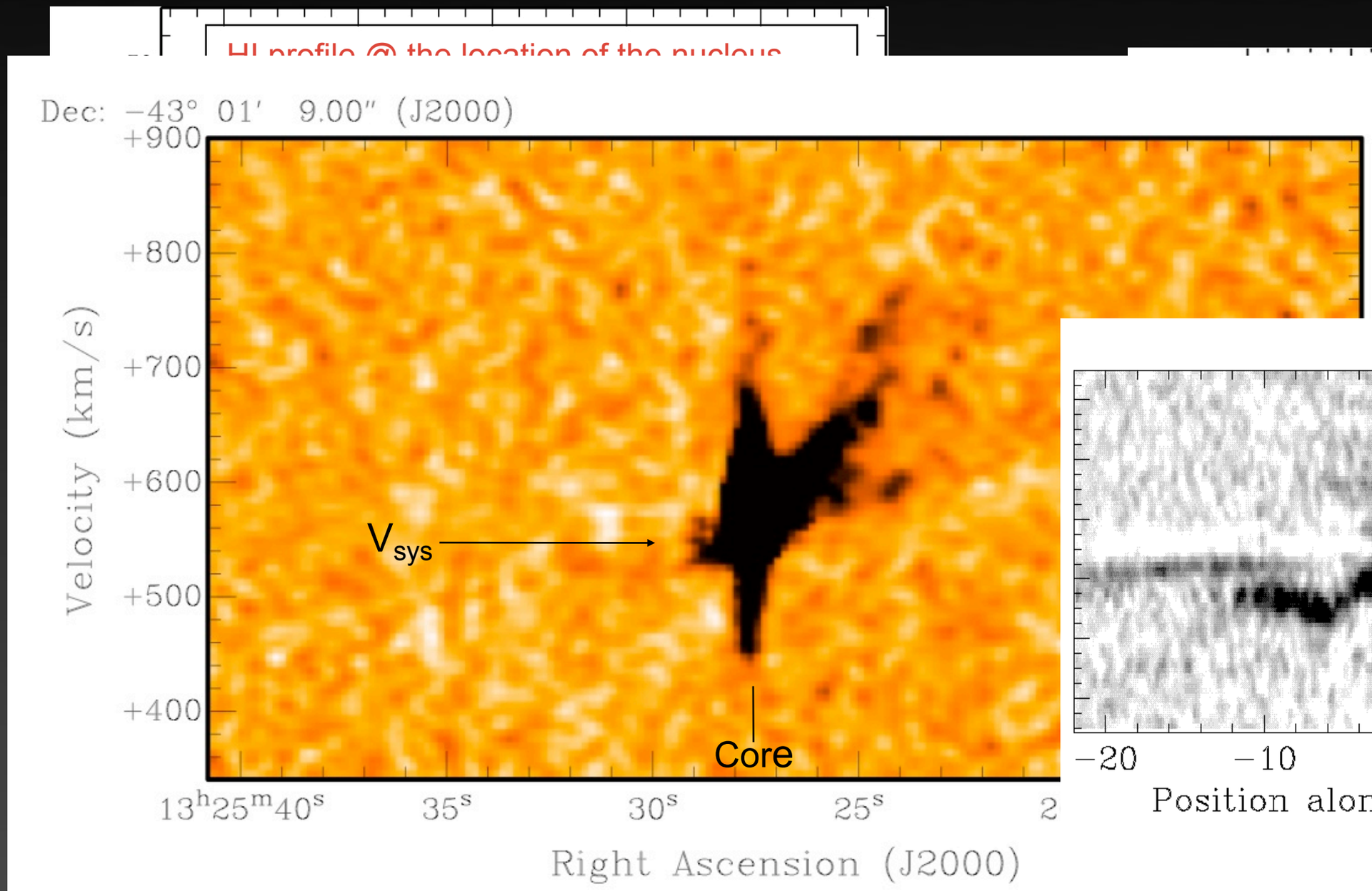

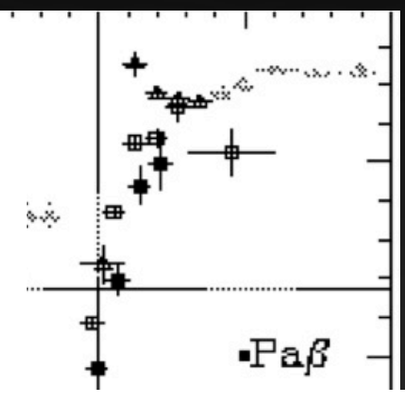

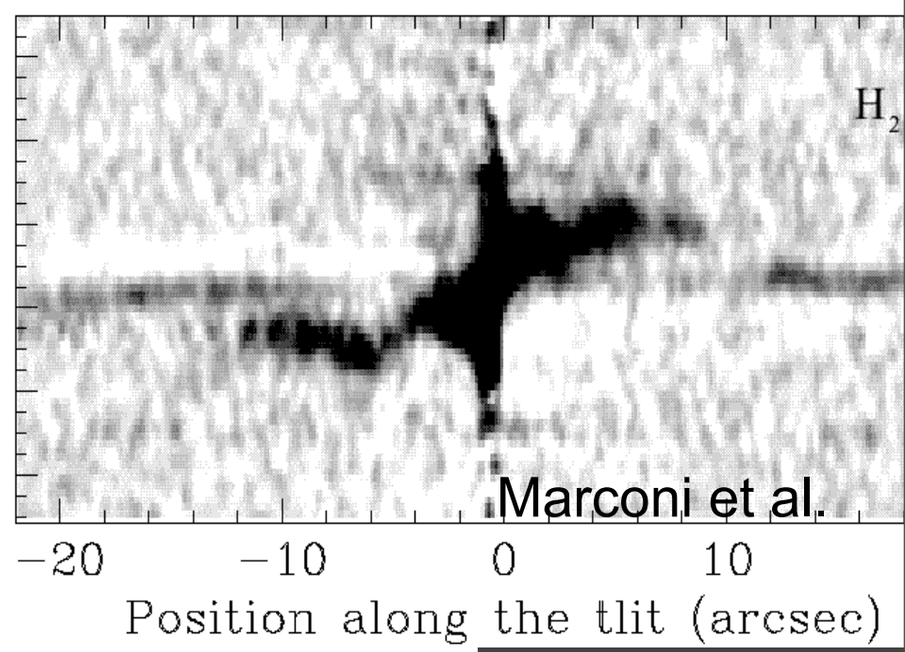

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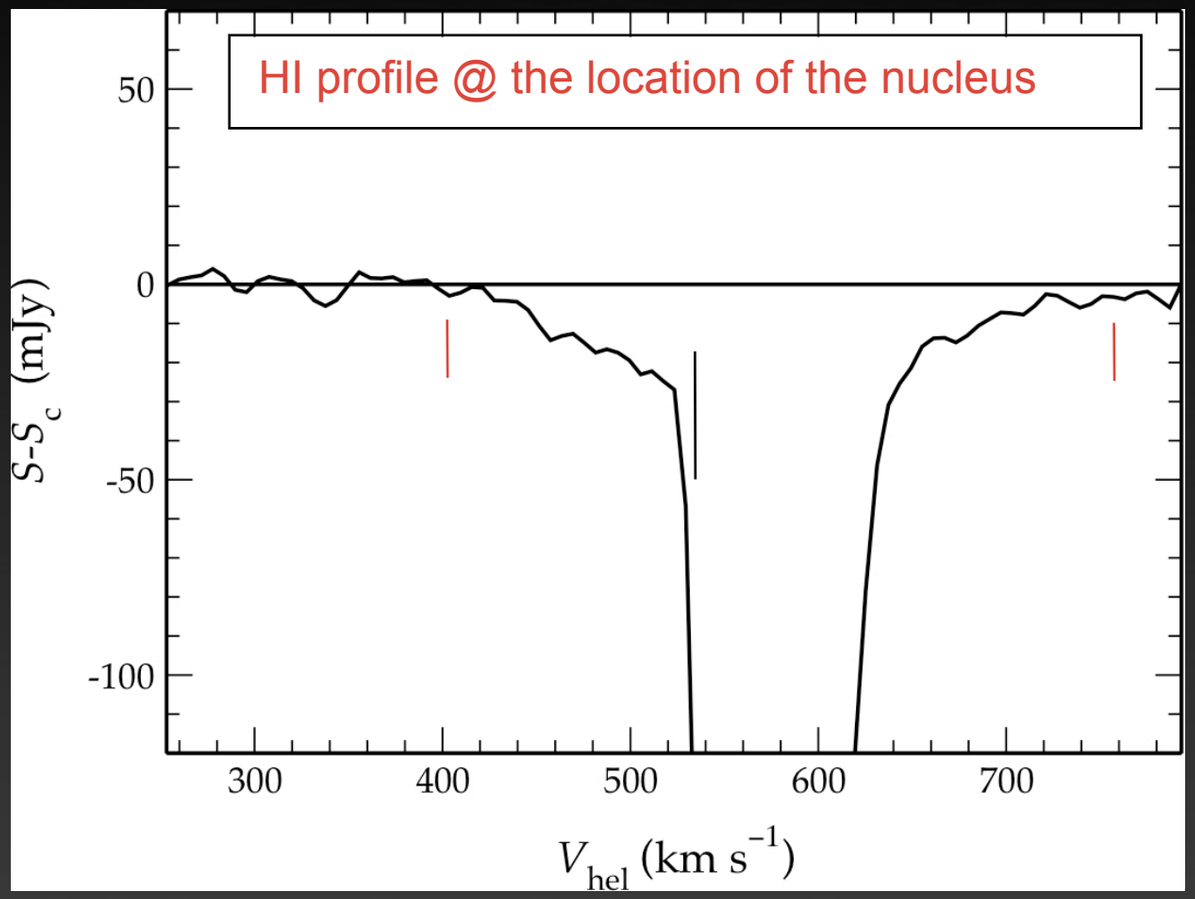

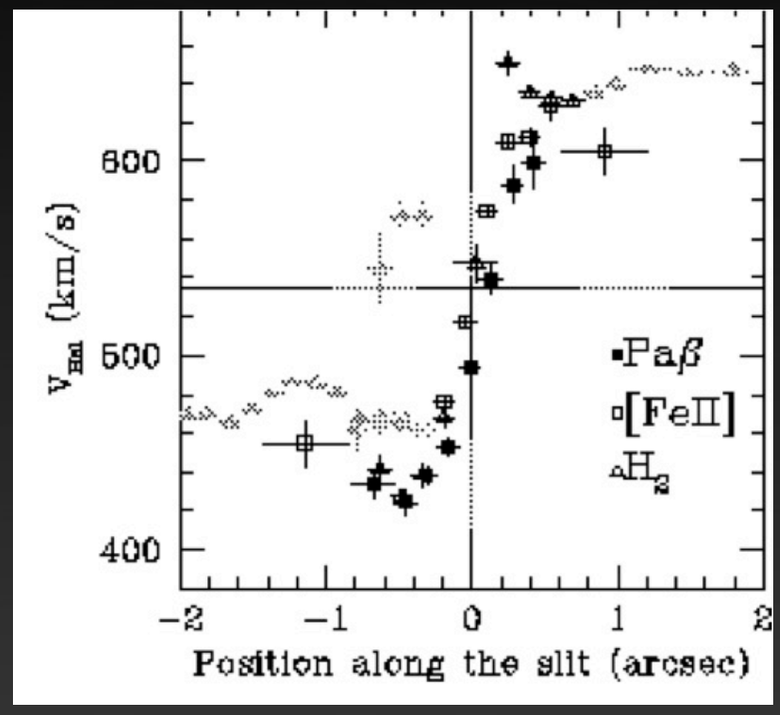

Marconi et al. 2001

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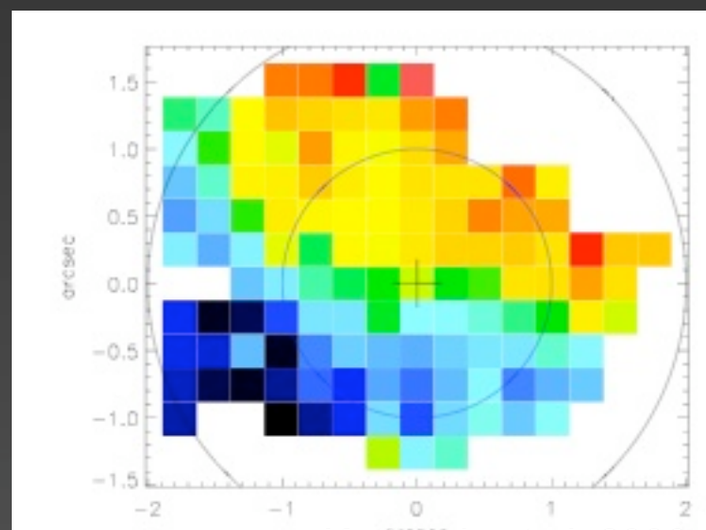

Krajnovic et al. 2006

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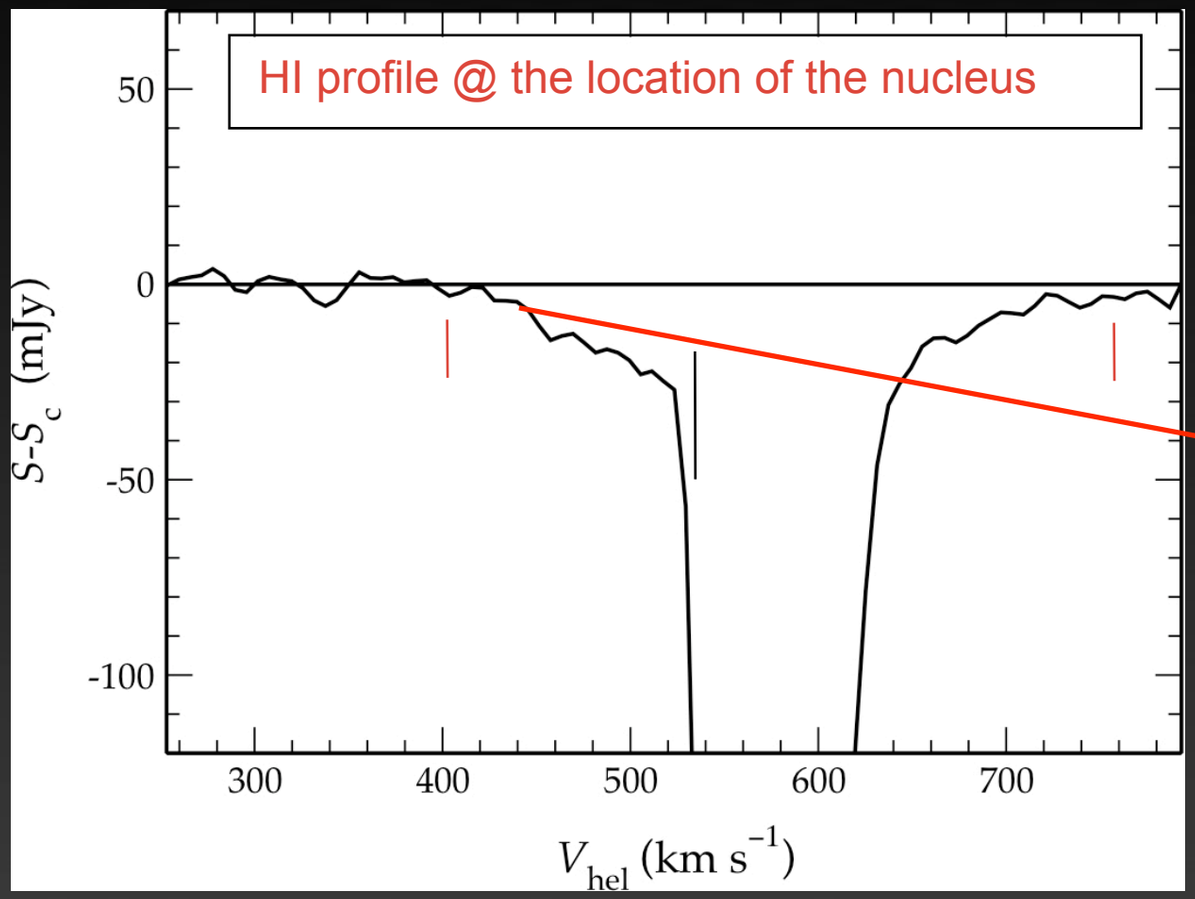

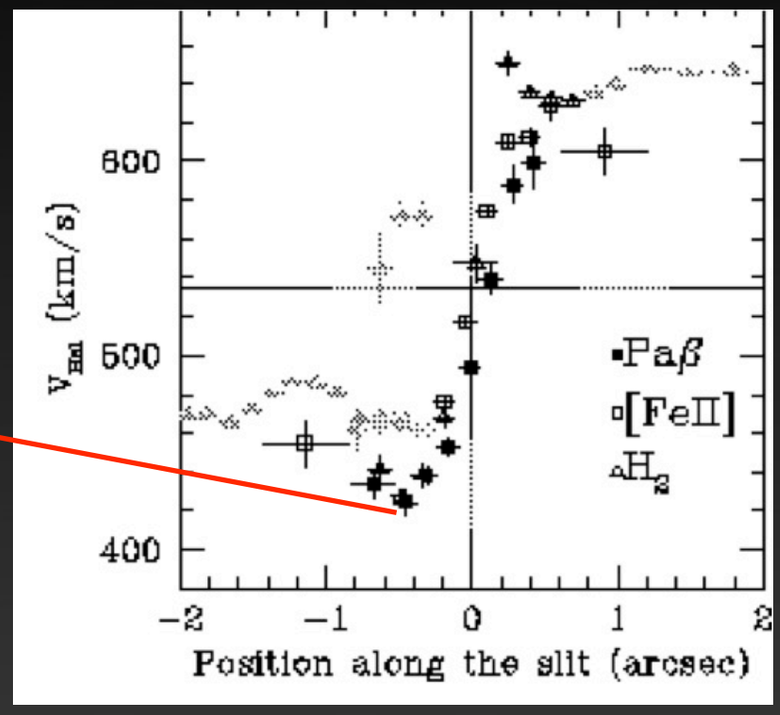

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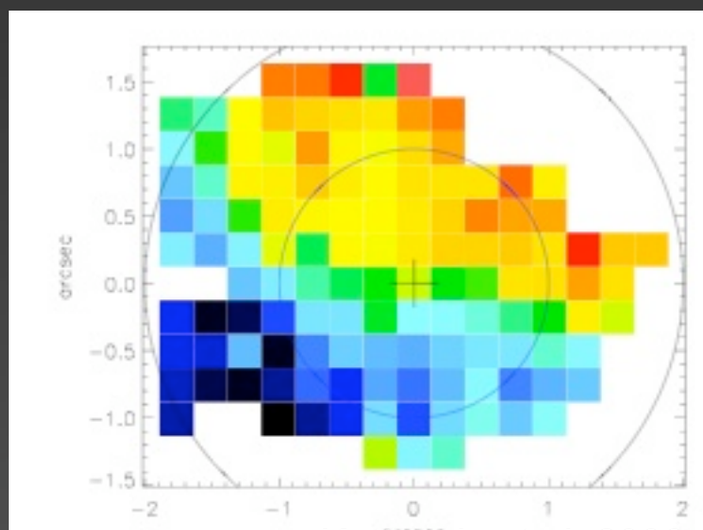

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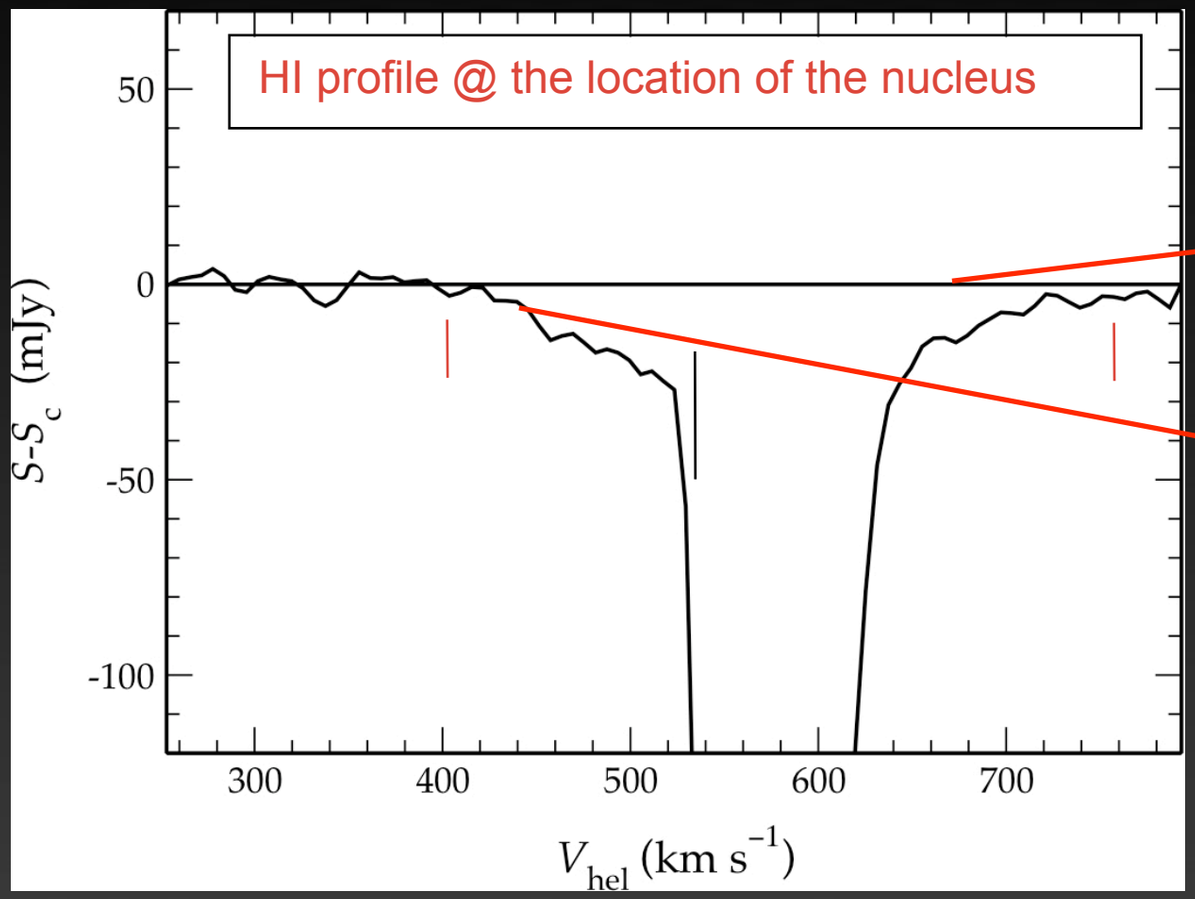

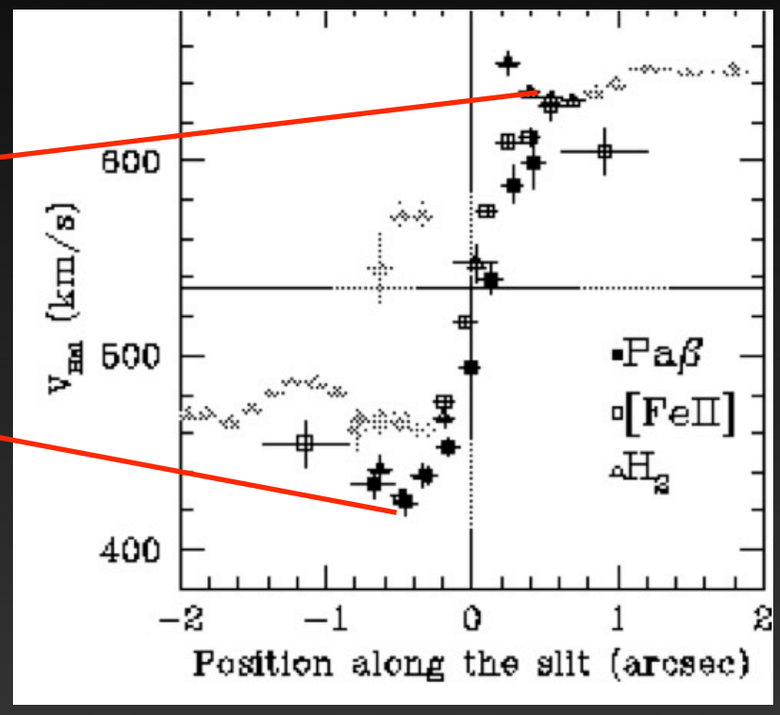

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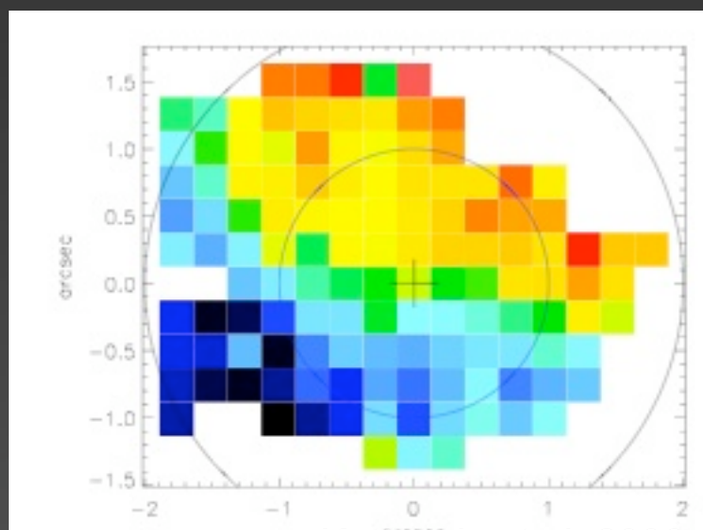
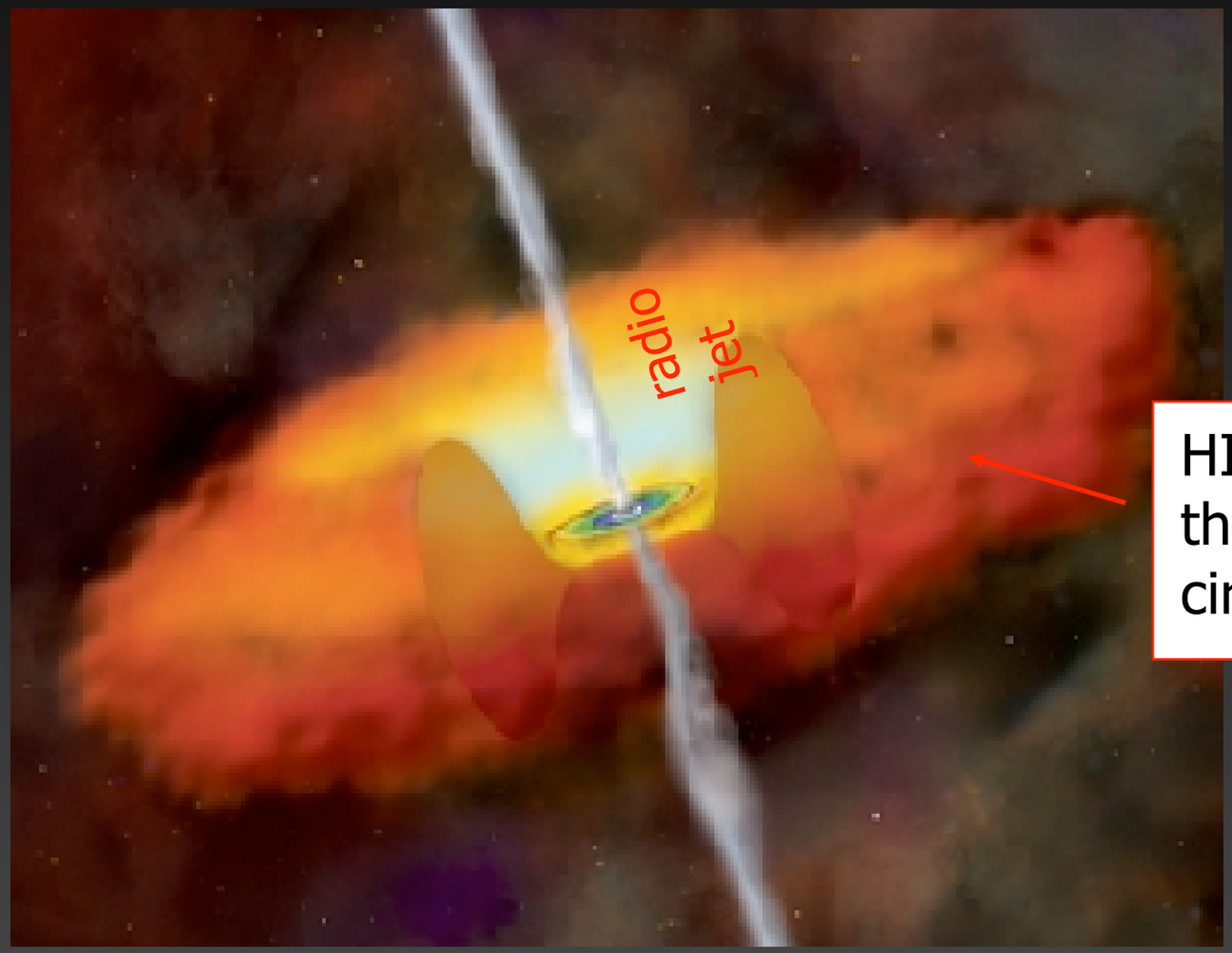
- non-circular orbits? inflow/outflow?

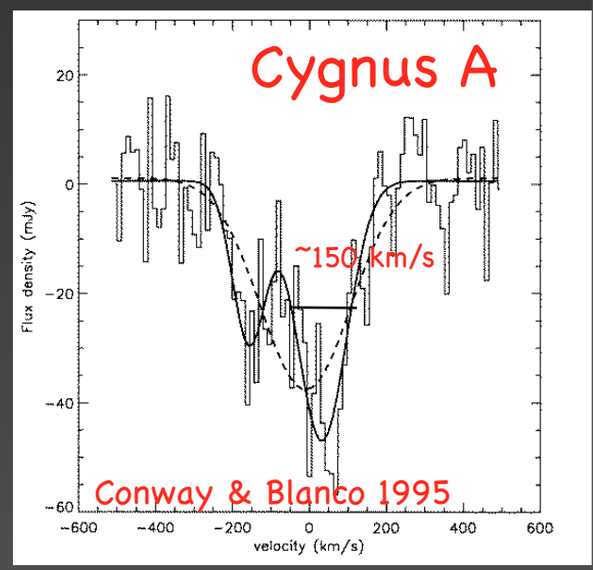


Krajnovic et al. 2006

The nuclear regions probed by the gas



HI absorption from the torus or from circumnuclear disks



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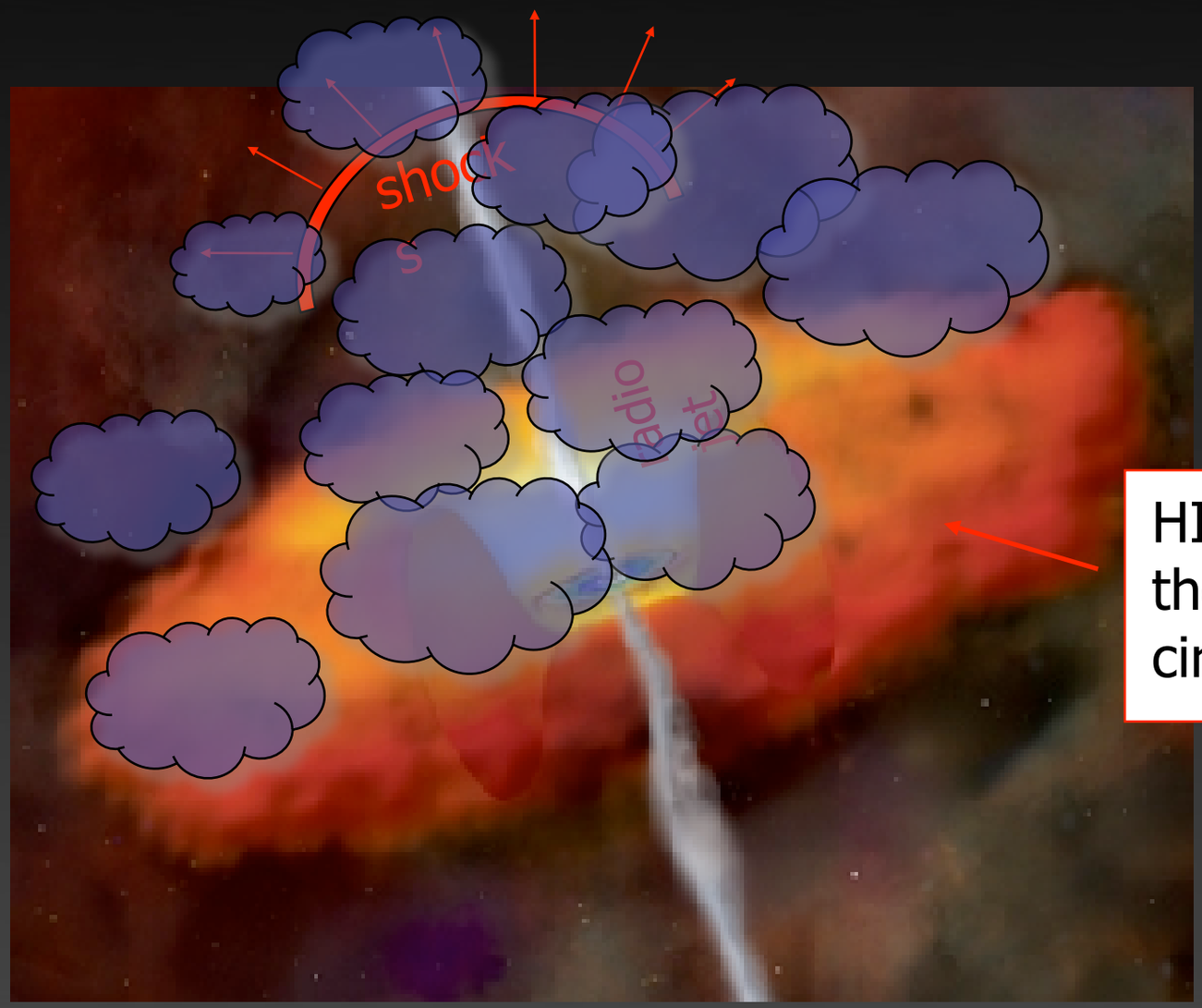

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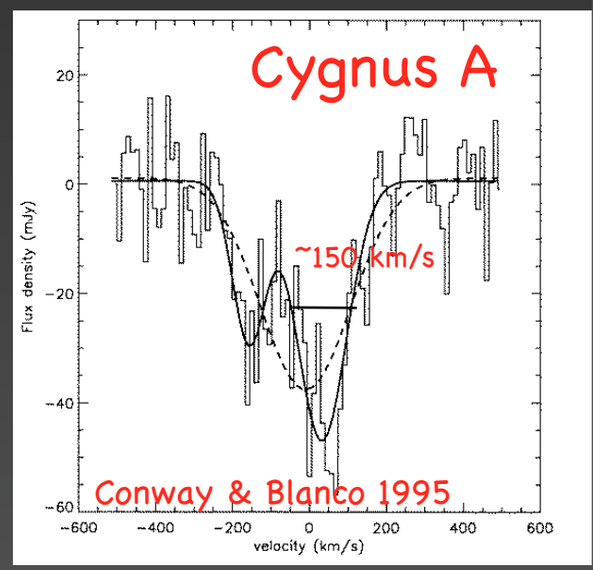
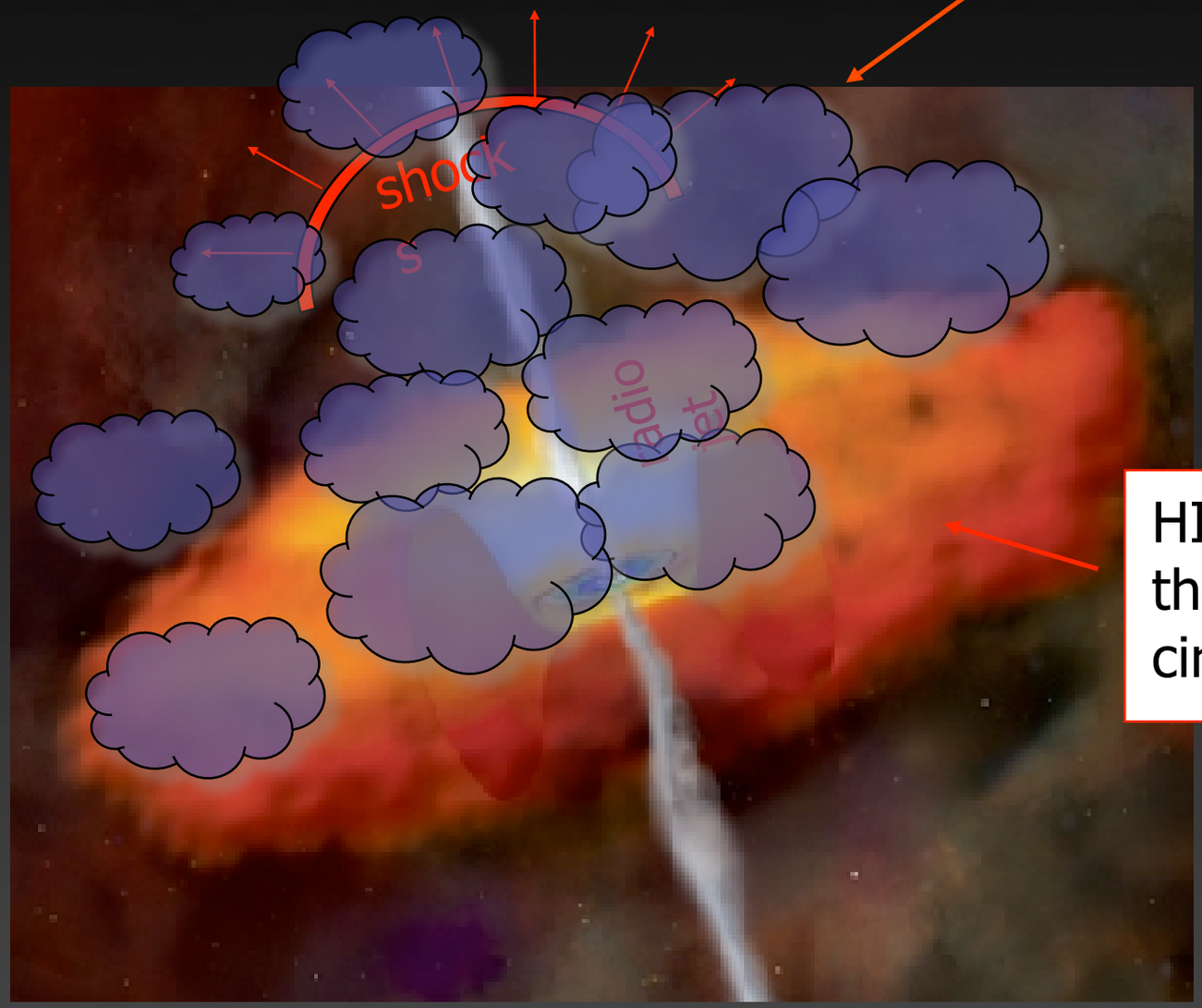


The nuclear regions probed by the gas

extra-gas surrounding the AGN, e.g. left over from the merger that triggered the AGN



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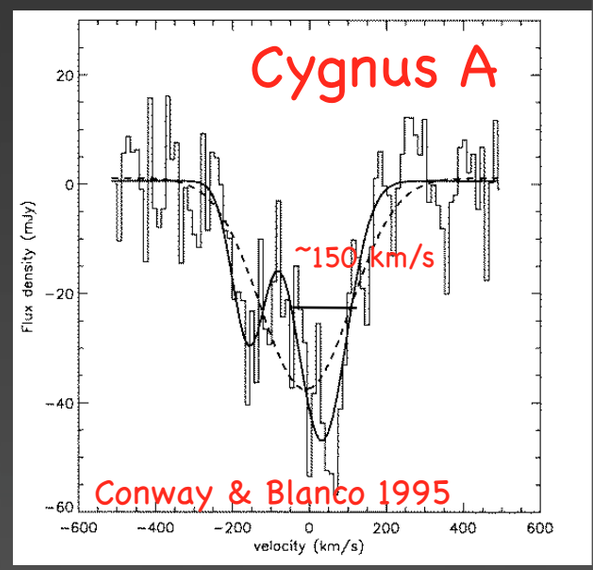
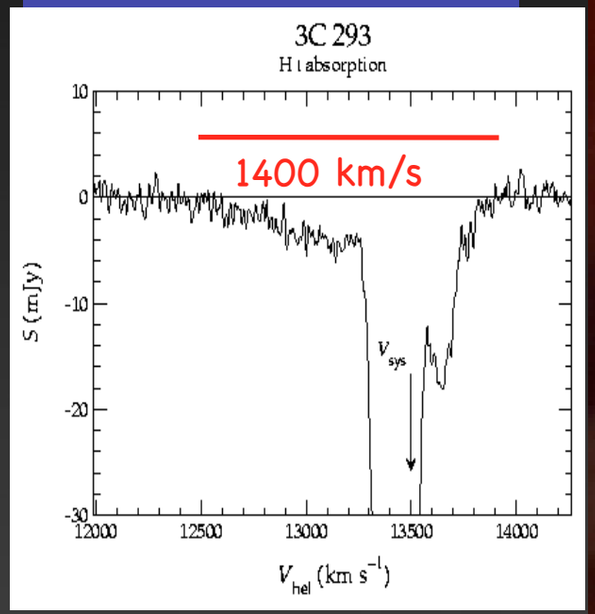
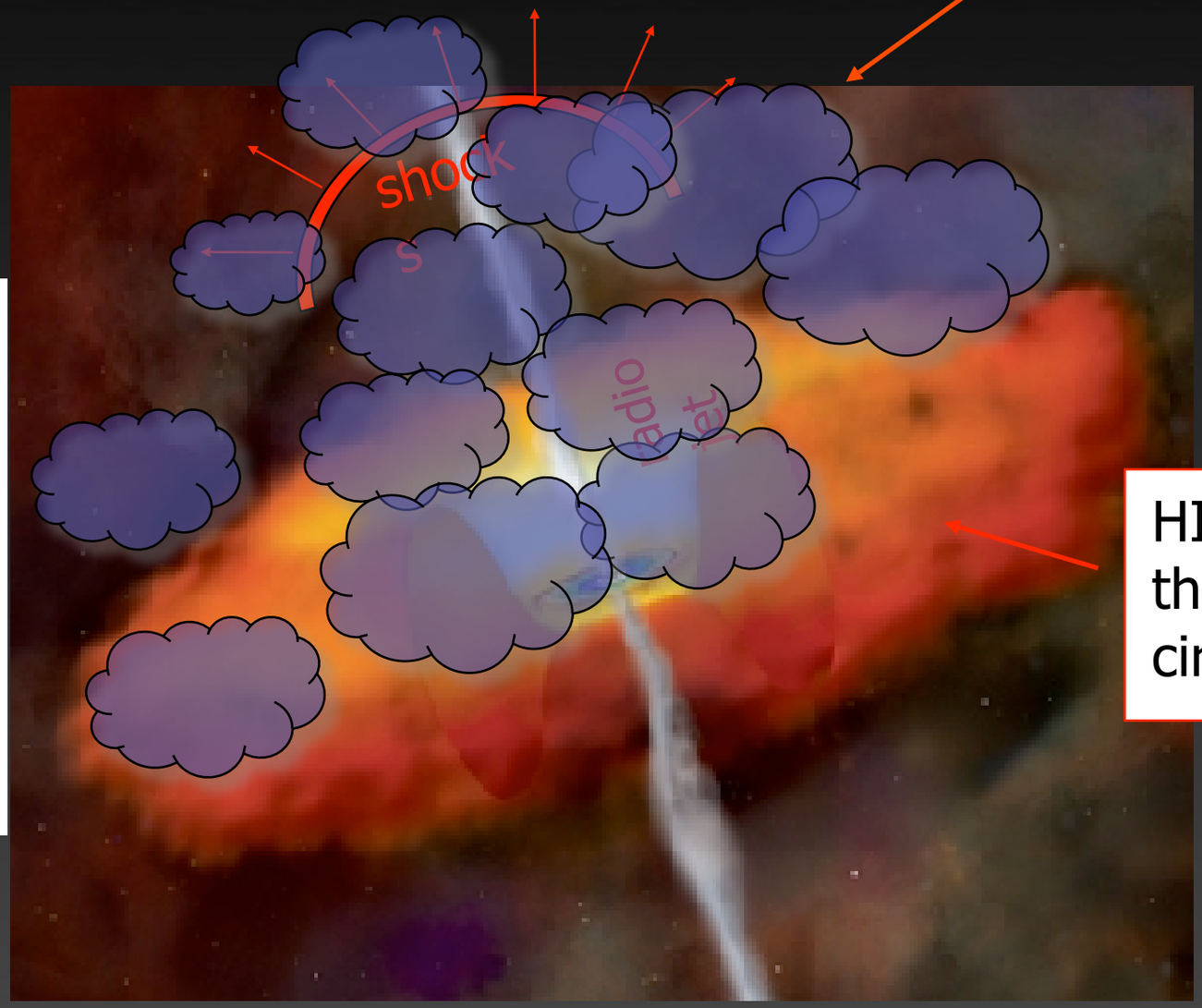


The nuclear regions probed by the gas

extra-gas surrounding the AGN, e.g. left over from the merger that triggered the AGN

Fast outflows: observed in ionised gas and HI
How important is the radio jet?





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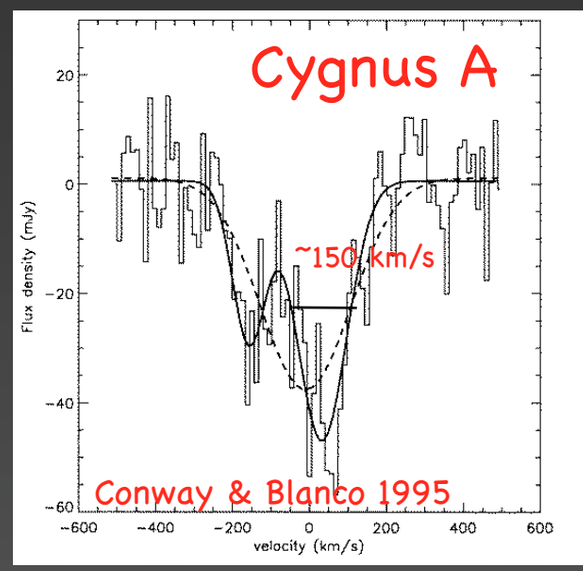
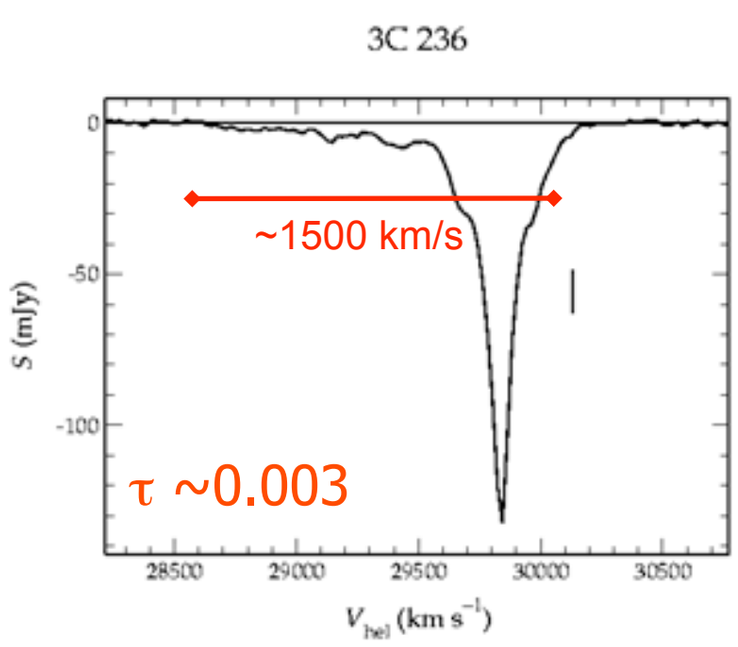
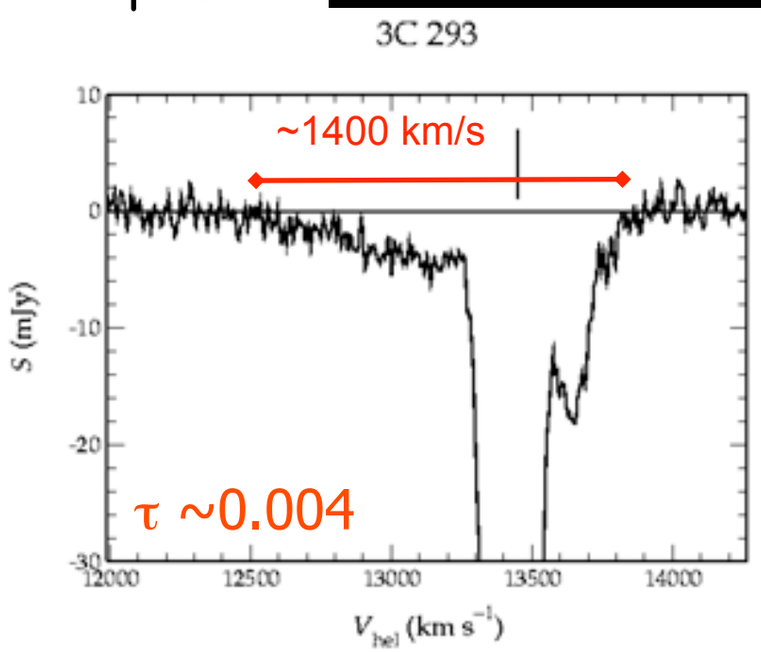
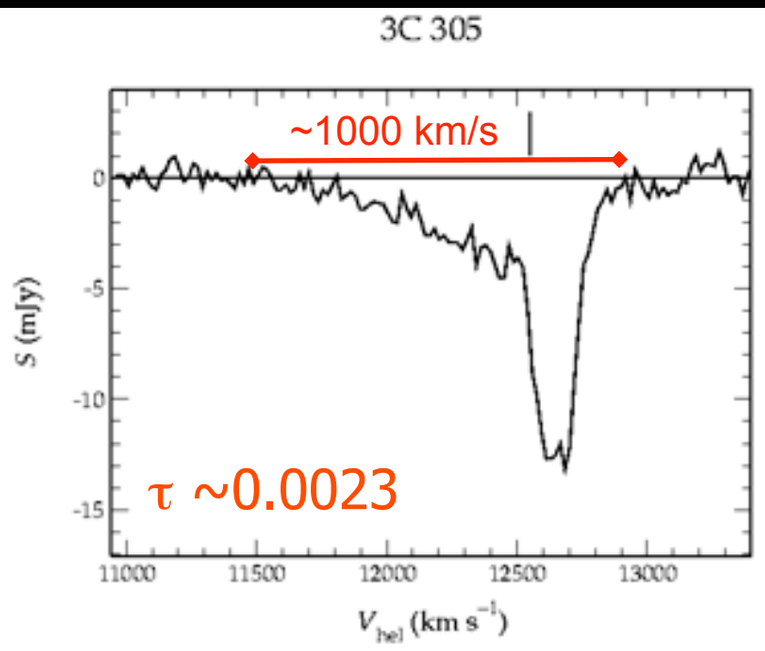
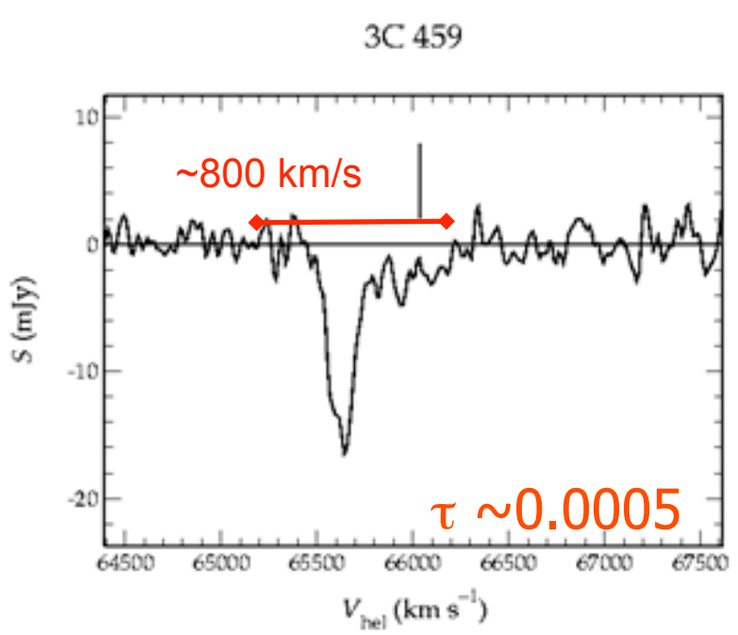


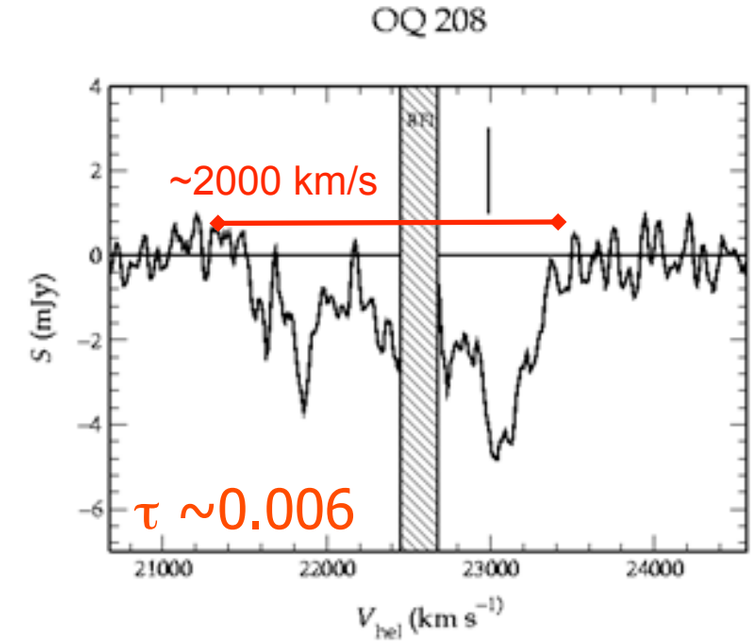
WSRT observations of broad HI absorption

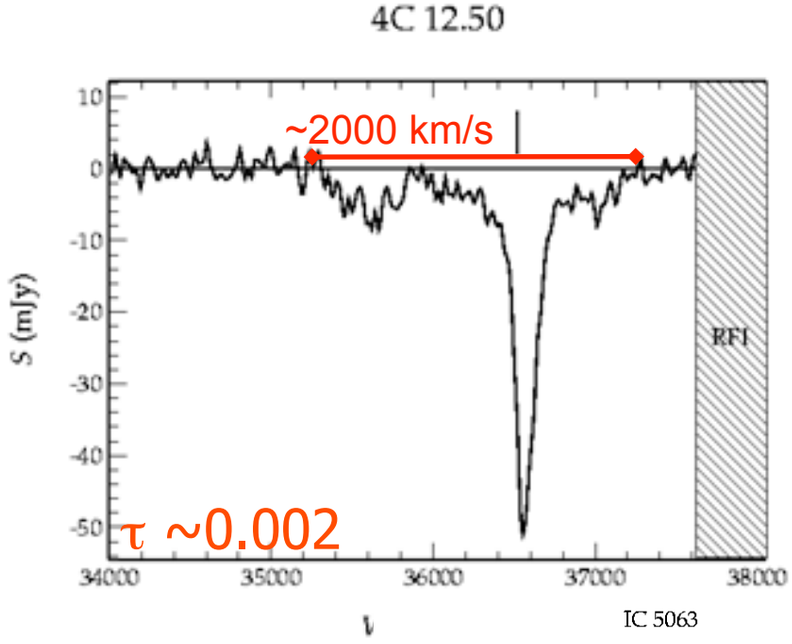


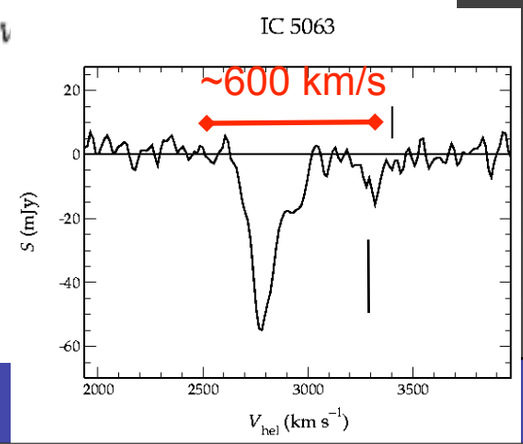












Up to 2000 km/s width, optical depth <<1%

Column density few times 10^{21} cm^{-2} (for T_{spin} = 1000 K)

Mostly blueshifted HI outflows – Morganti, Oosterloo, Tadhunter A&A 2005

- Radio sources with detected fast HI outflows are either compact/young
or
large with steep-spectrum cores

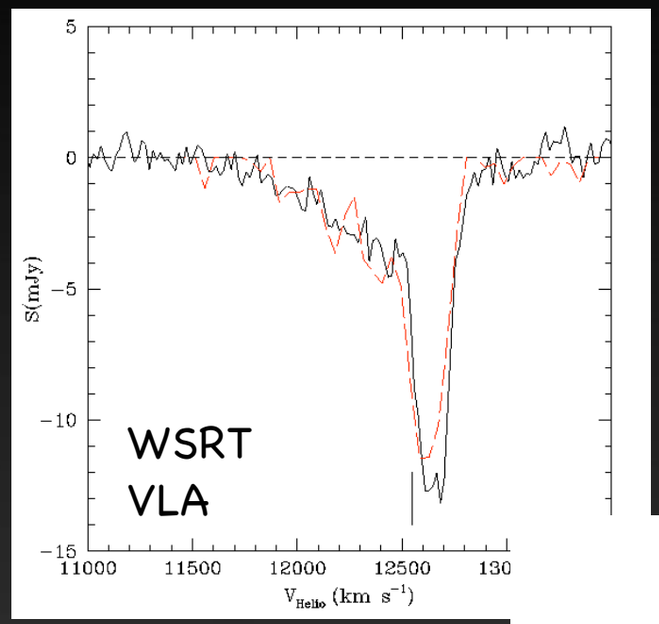
(considered to be objects with **restarted** radio activity: 3C293 and 3C236)

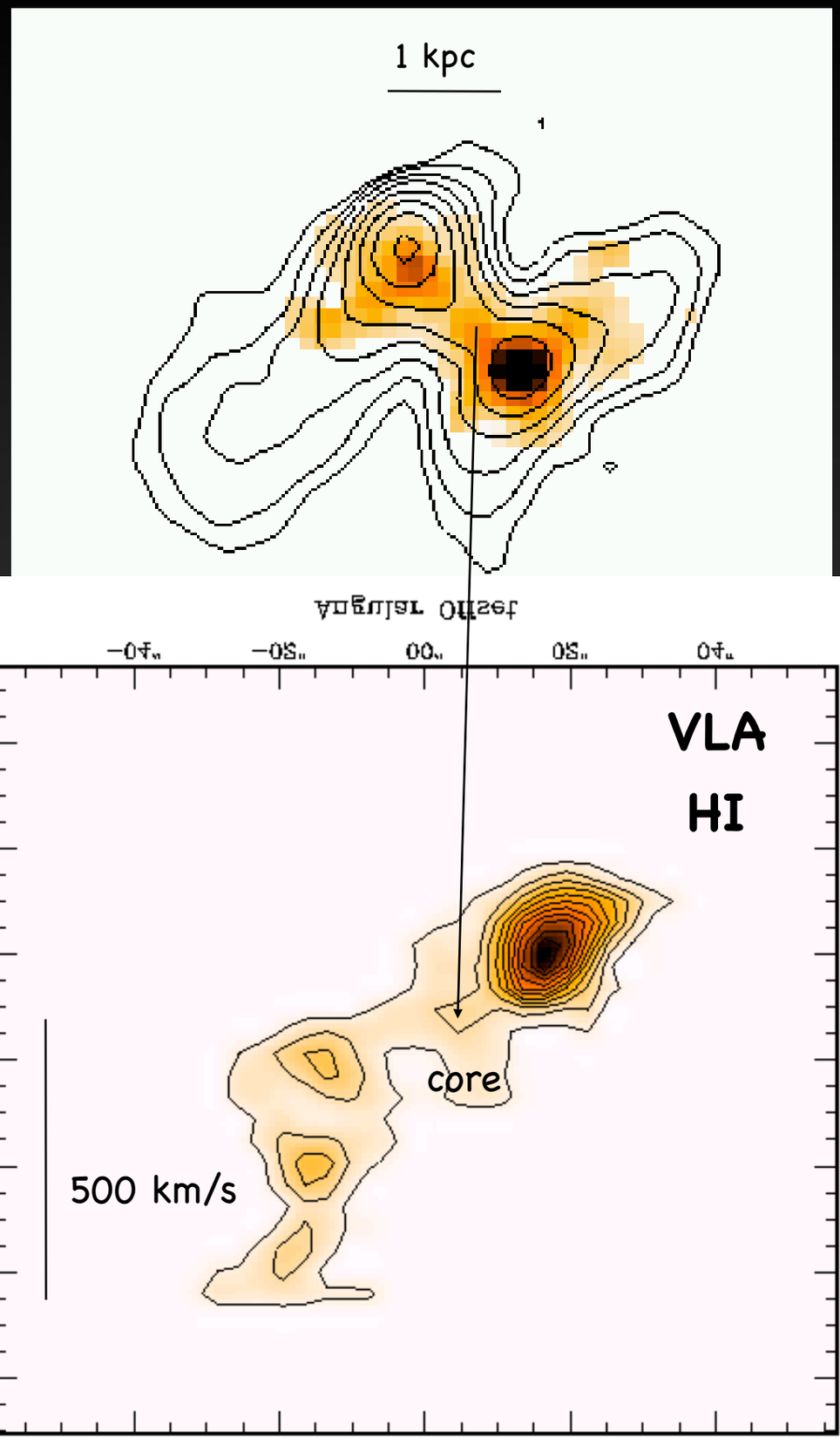
- Outflows detected in off-nuclear regions:

jet-ISM interaction originating the outflow

Outflows detected (with similar kinematics) both in ionised AND neutral gas!

The case of 3C305





- The broad HI absorption is found **off-nucleus** at the location of the radio lobe (about 1.6kpc from the nucleus)
- column density 2×10^{21} cm^{-2} (for T_{spin}=1000K)
- Mass outflowing gas ~10^6 M_{sun}

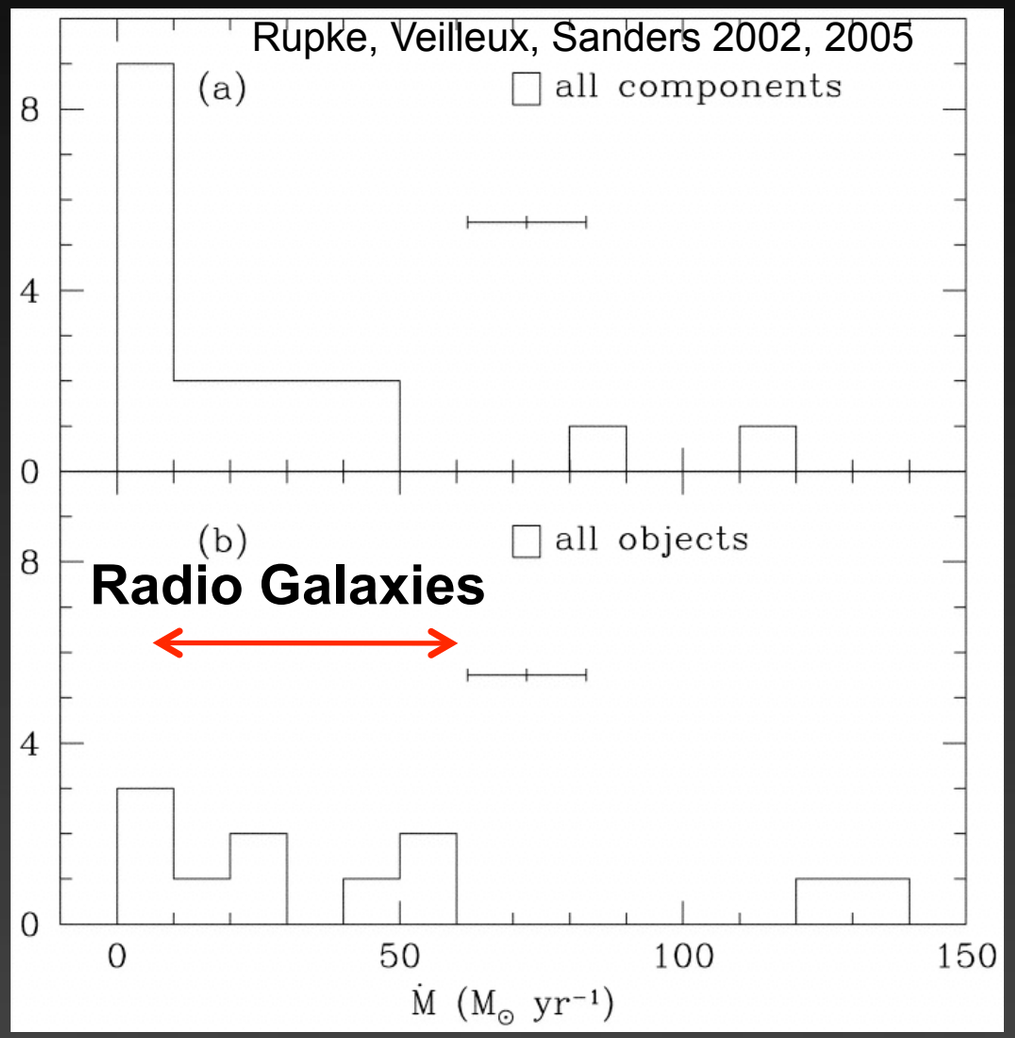
Morganti, Oosterloo, Tadhunter, van Moorsel & Emonts 2005 A&A

Mass outflow rate (from HI) ranges between a few and ~50 M_{sun}/yr

comparable (lower end) to that found in Ultraluminous IR galaxies

Relevant impact in the evolution of the galaxy?

- Bulk kinetic energy:
  ~ few x 10^{57} erg
  (over a lifetime of a radio jet)



Jet-driven outflows can have an impact on the evolution of a galaxy comparable to starburst-driven superwinds

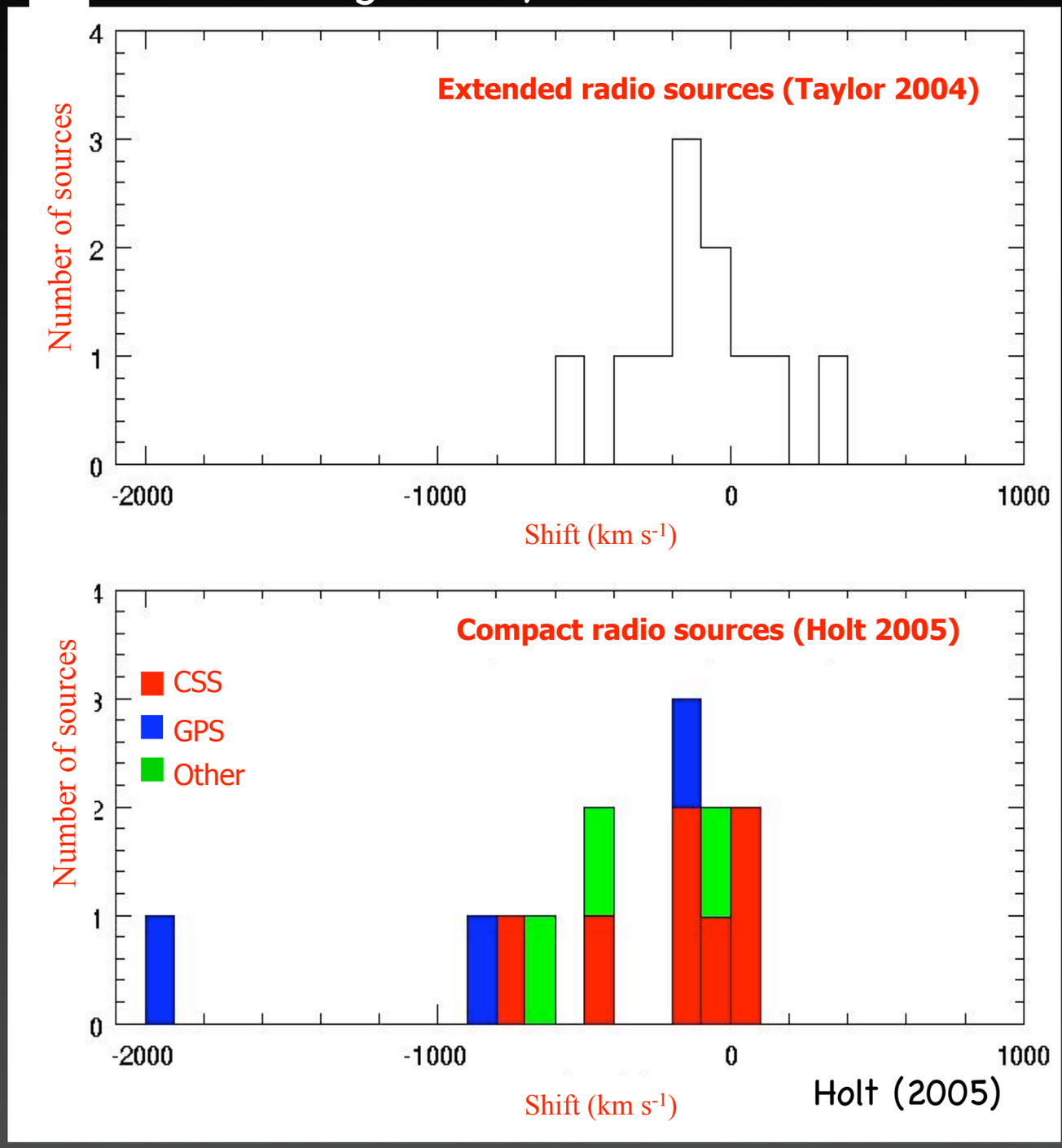
Comparison between young (compact) and extended radio sources

Ionised gas

- 14 powerful CSS/GPS from 3C/4C-2Jy samples
- 11/14 show evidence for fast outflows
  - systemic to broadest component
  - different distributions: K-S test significance: 99.9%

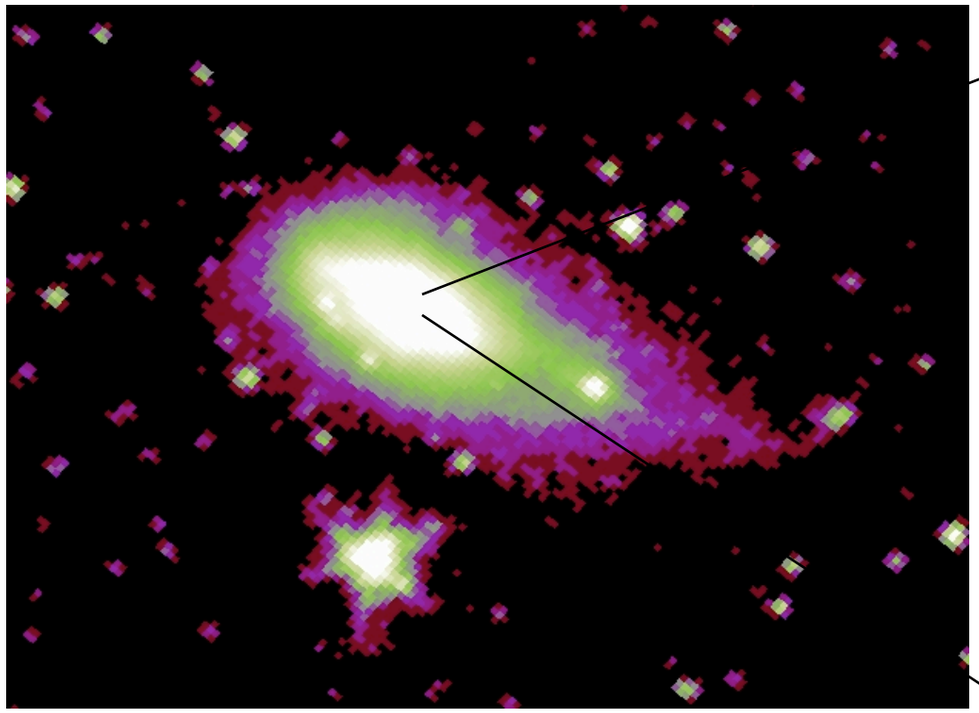
In the first phase of evolution the radio-loud AGN has effect on the surrounding medium

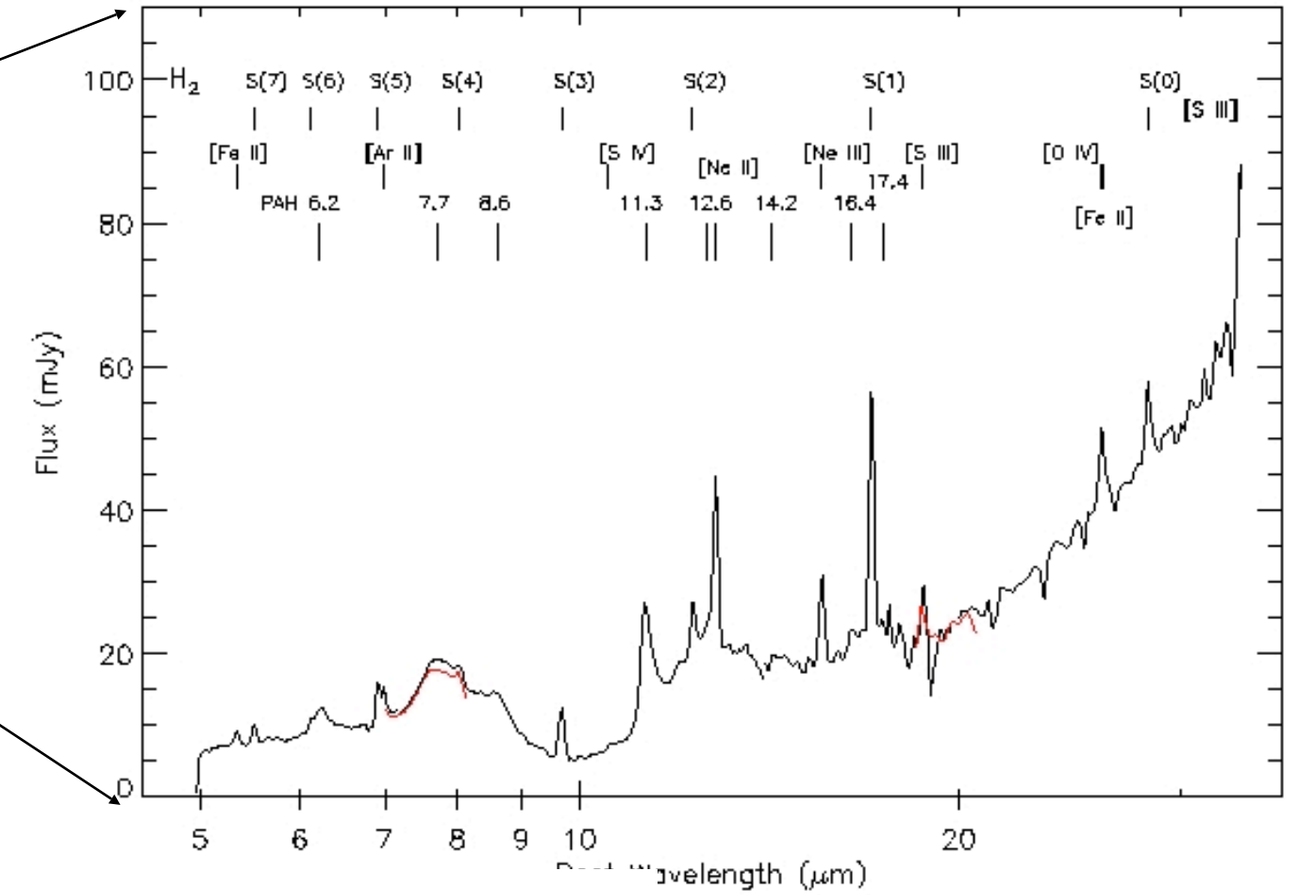
Histograms: systemic-broadest



PhD work of Joanna Holt

Shocked H2 Emission in 3C 293



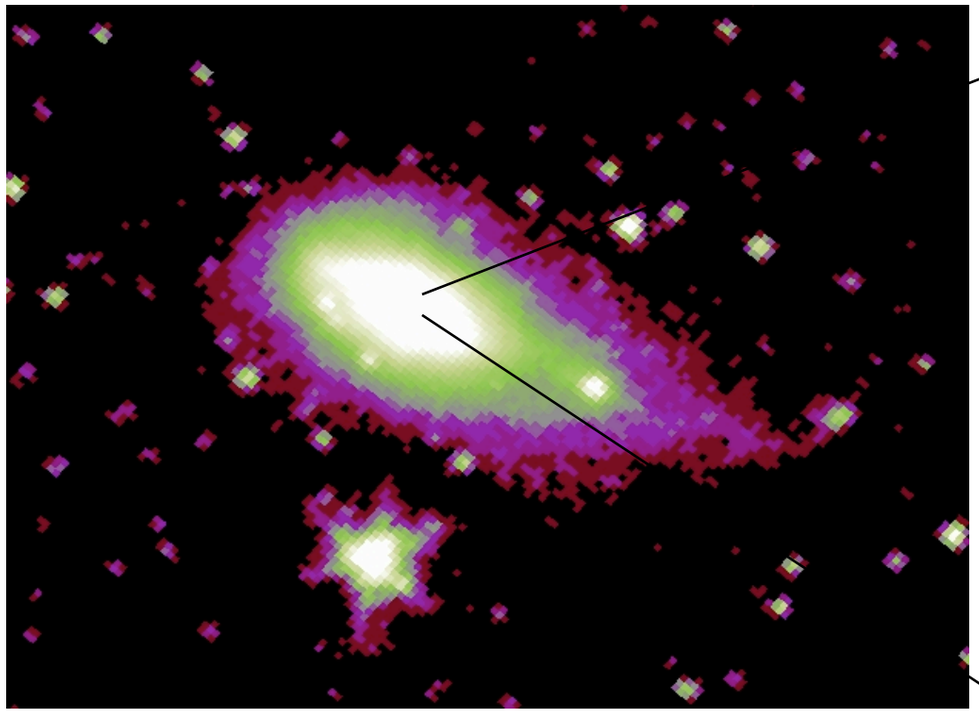


Spitzer IRAC and IRS

- L(H2)=6E41 erg/s,
- L(178 MHz)=1E41 erg/s
- M(H2, warm; cold)=1E9; 1.5E10 Msun
- HI and ionized outflows (Morganti et al. 03,05)

Ogle et al. 2007b

Shocked H2 Emission in 3C 293



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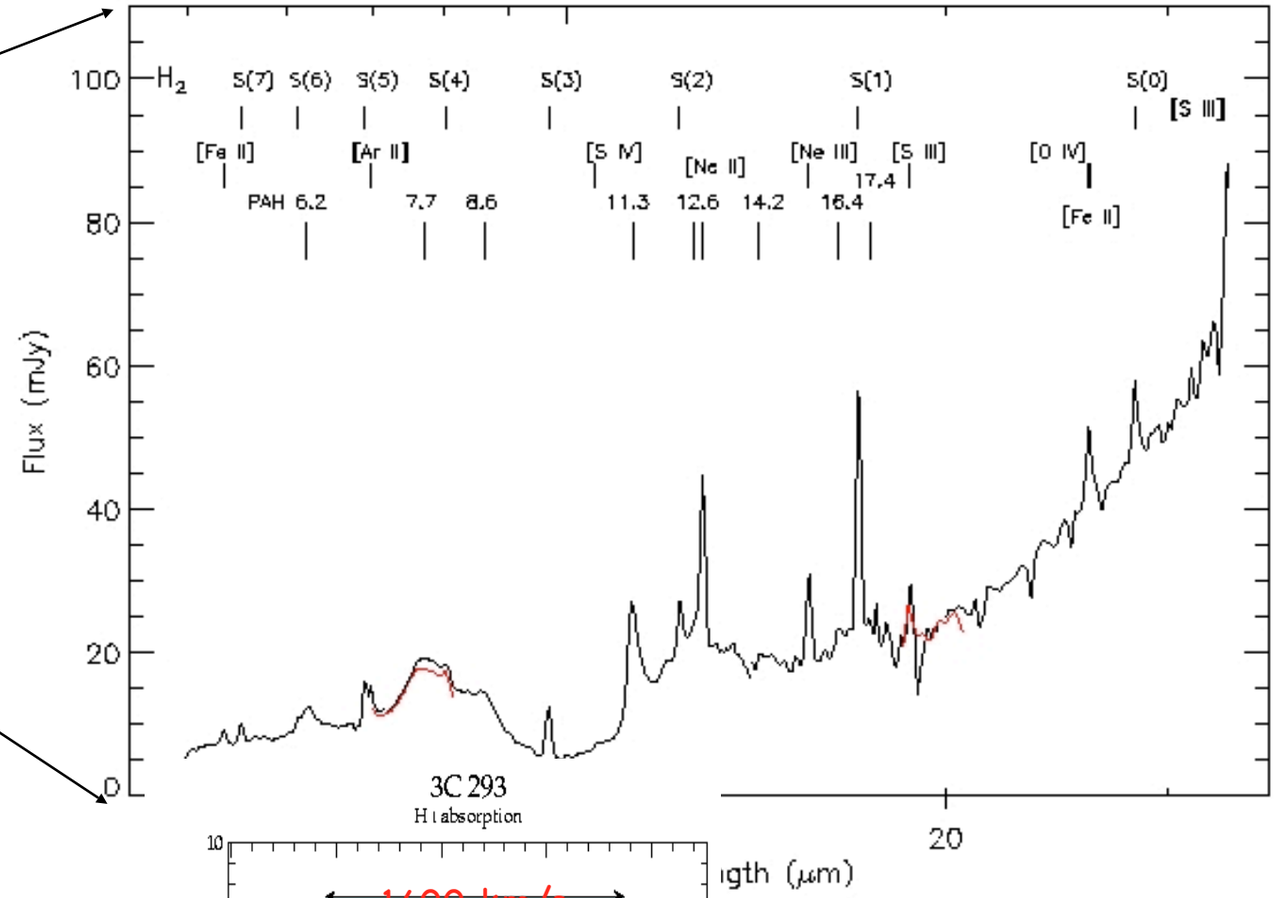

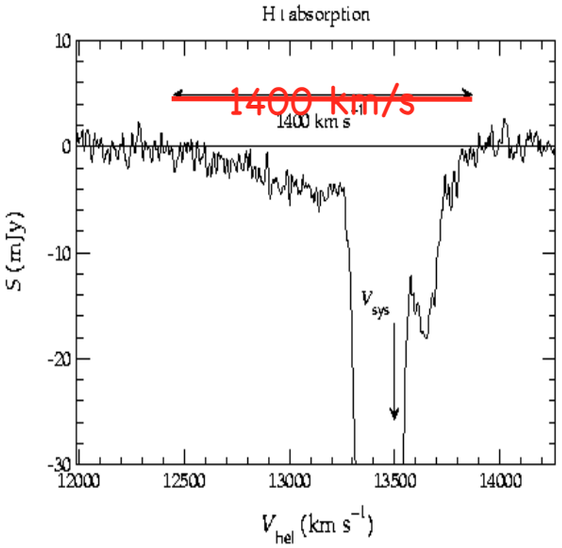

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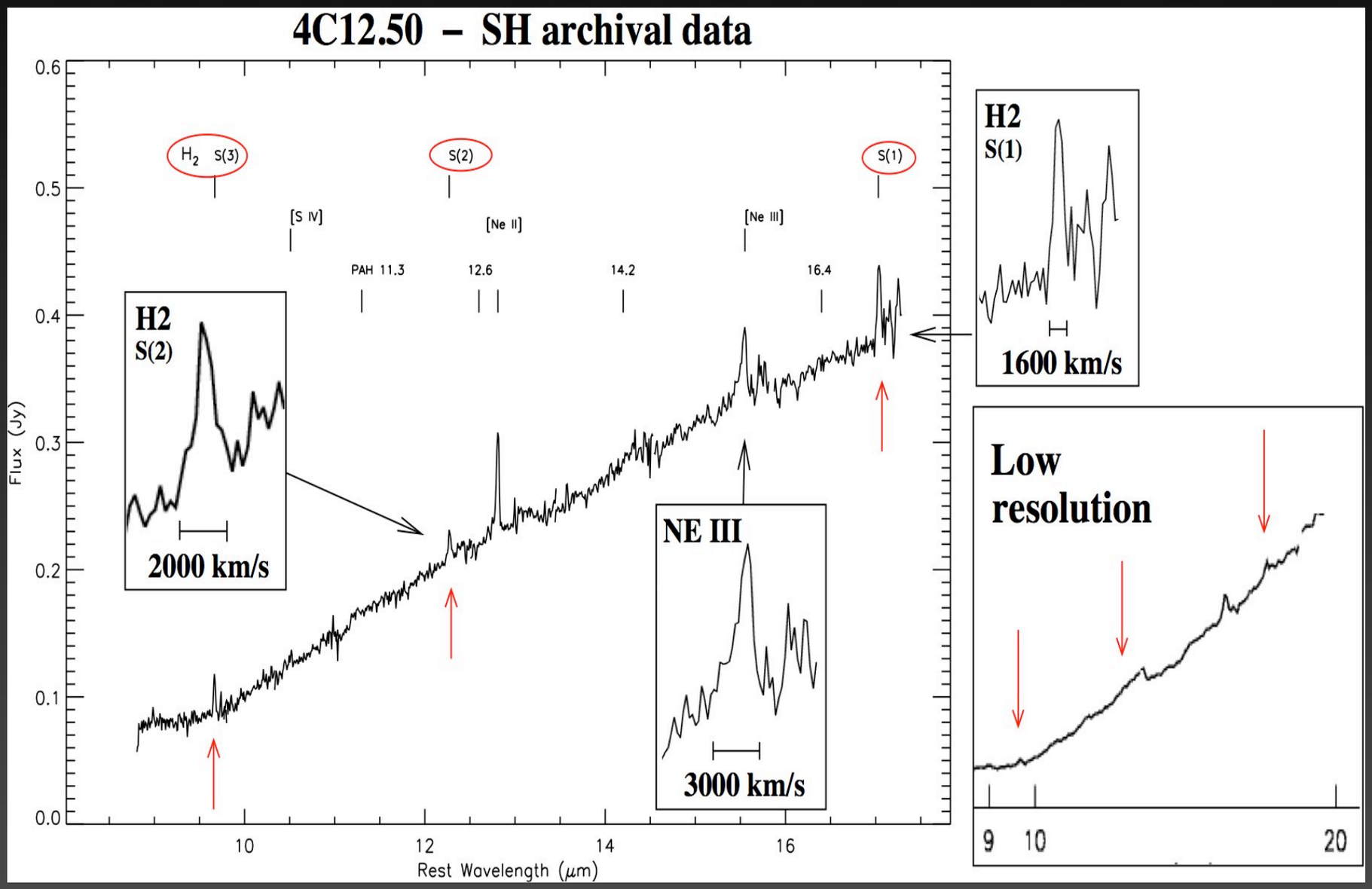
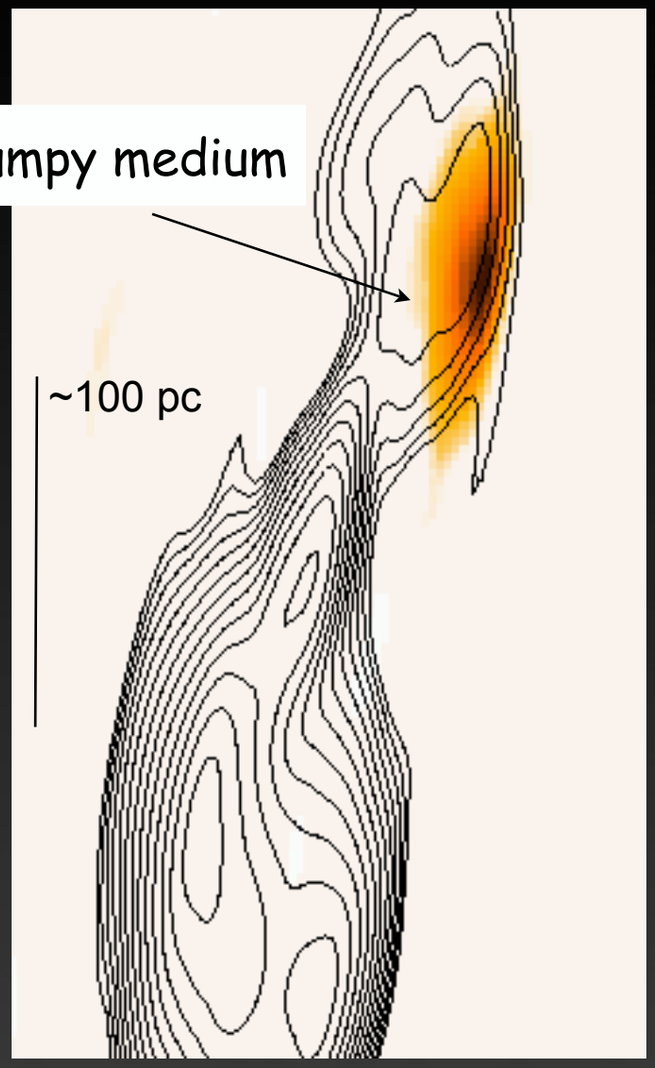
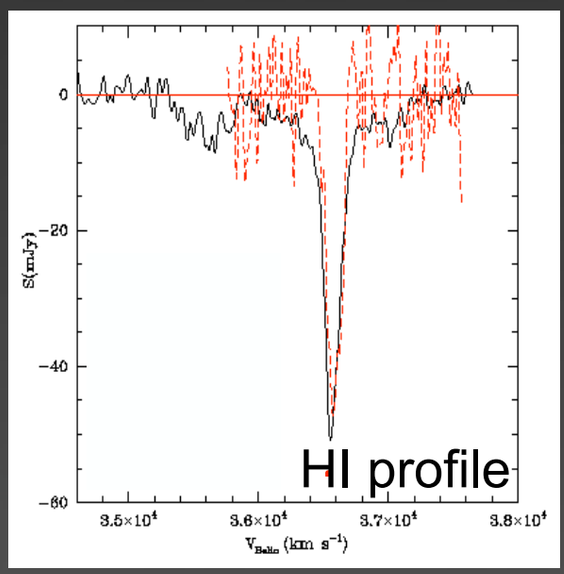
Spitzer results: strong H2 lines in all the galaxies with broad HI and sign of jet/ISM interaction (Ogle et al.)







Ogle, Emonts et al. (from Spitzer archival data PI. Armus)

PKS 1549-79: an example of obscured radio source in the early-stage of its evolution

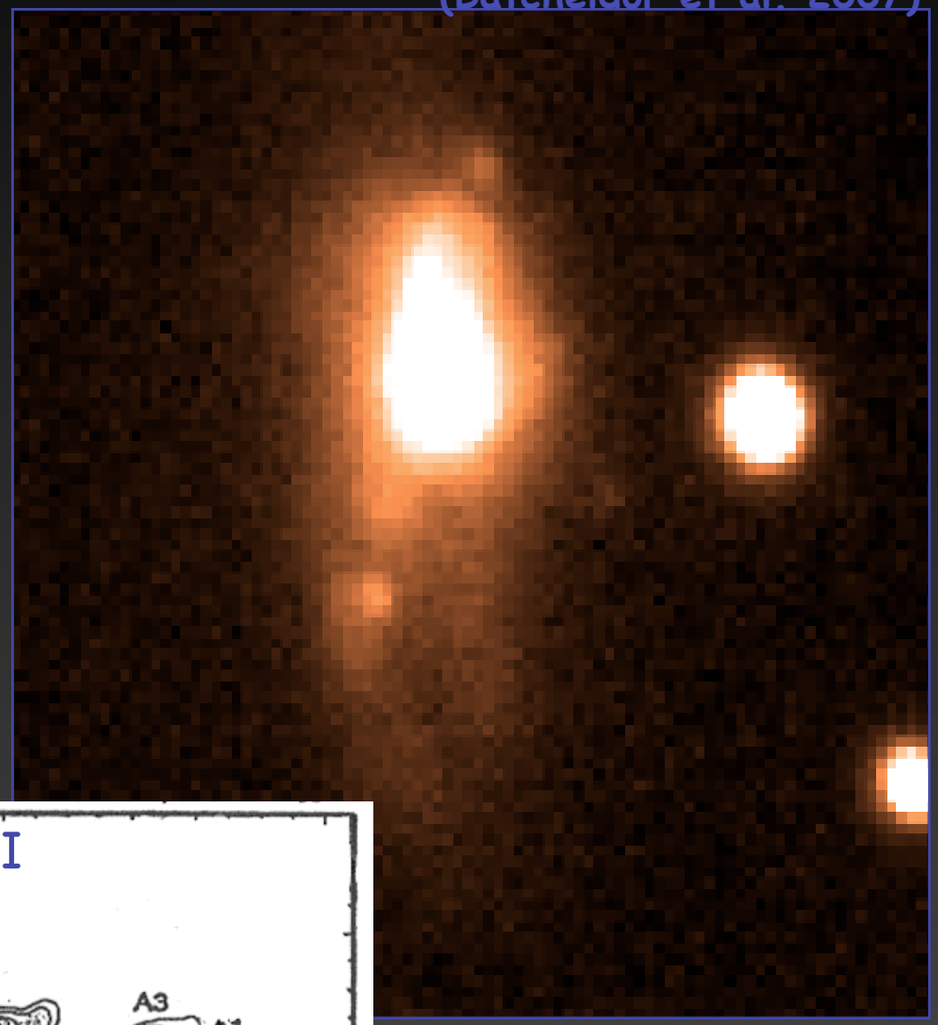
- Core-jet radio structure: close to the line-of-sight
- Recent major merger:

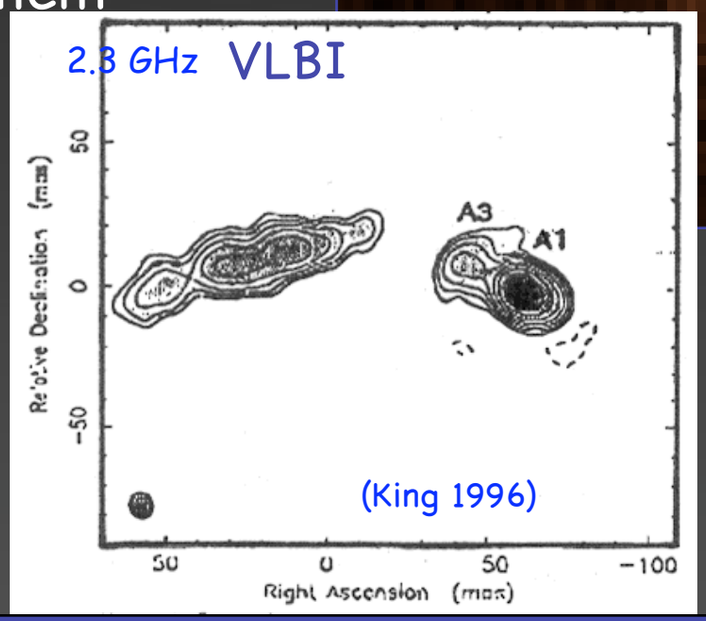
  tidal tails in optical, young stellar population (50-250 Myr)
- <u>HI absorption surprisingly present</u>
- No broad permitted (optical) lines but

  Paα in NIR
- Broad blueshifted (outflowing) component e.g. [OIII]5007

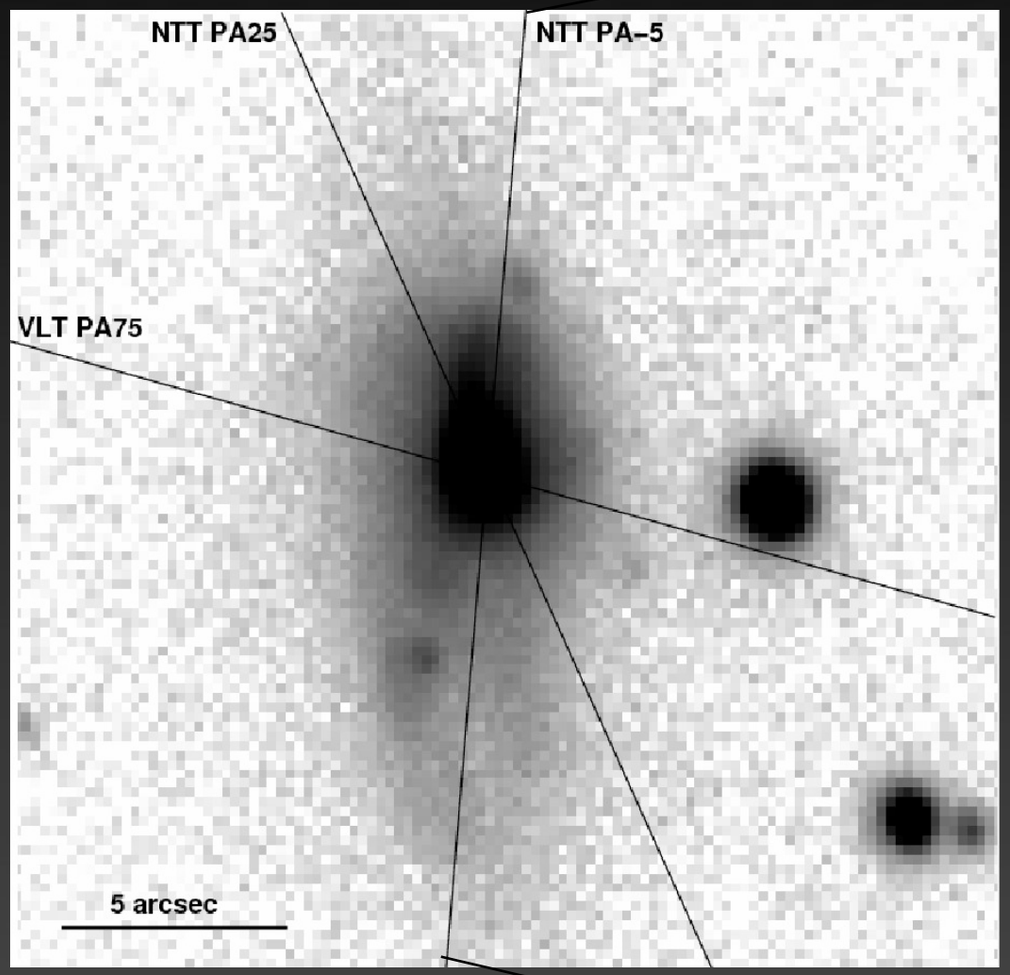
Tadhunter et al. 2001, Holt et al. 2006

VLT+FORS1: Gunn r
(Batcheldor et al. 2007)

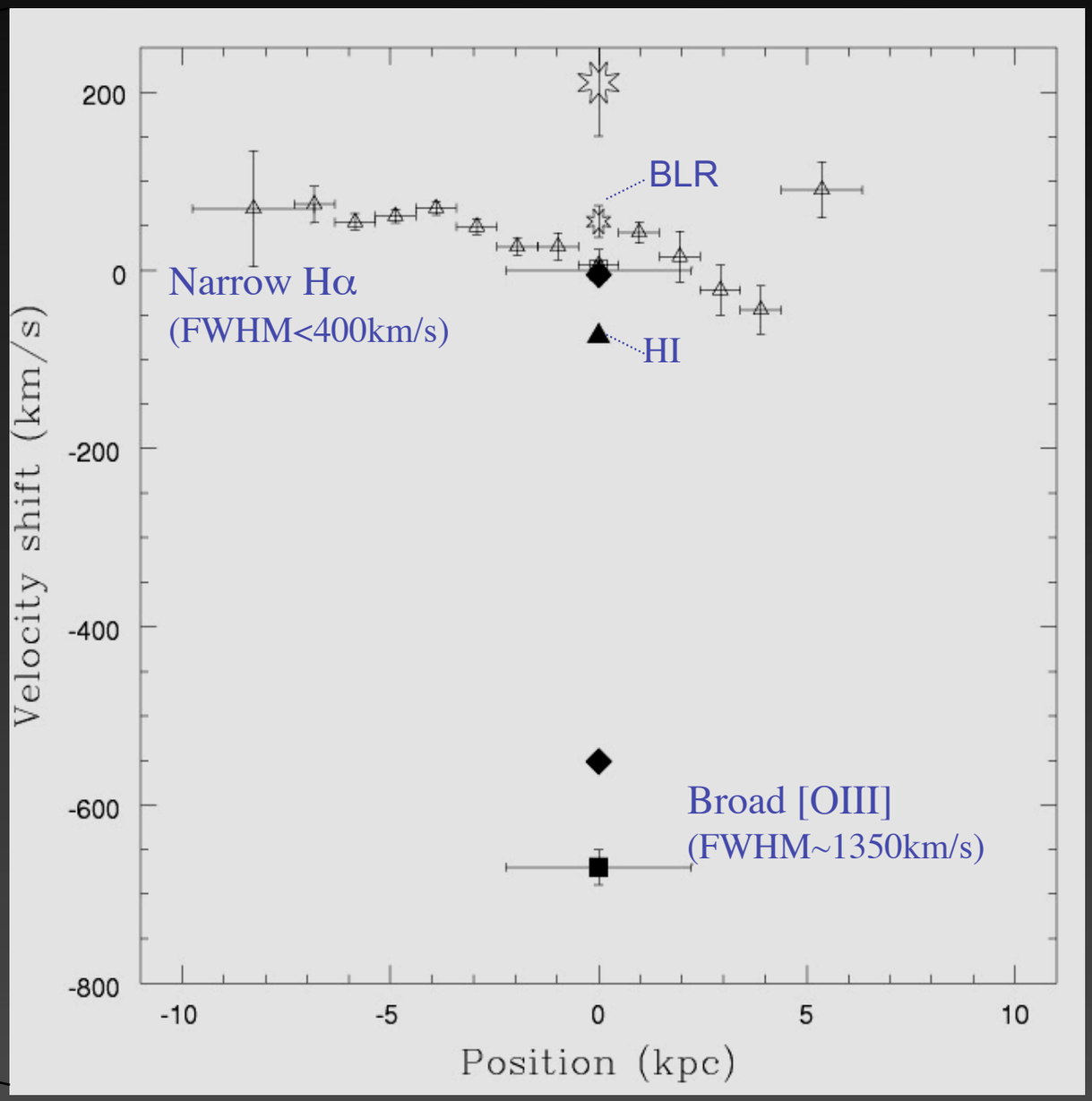




Emission line kinematics in PKS1549-79



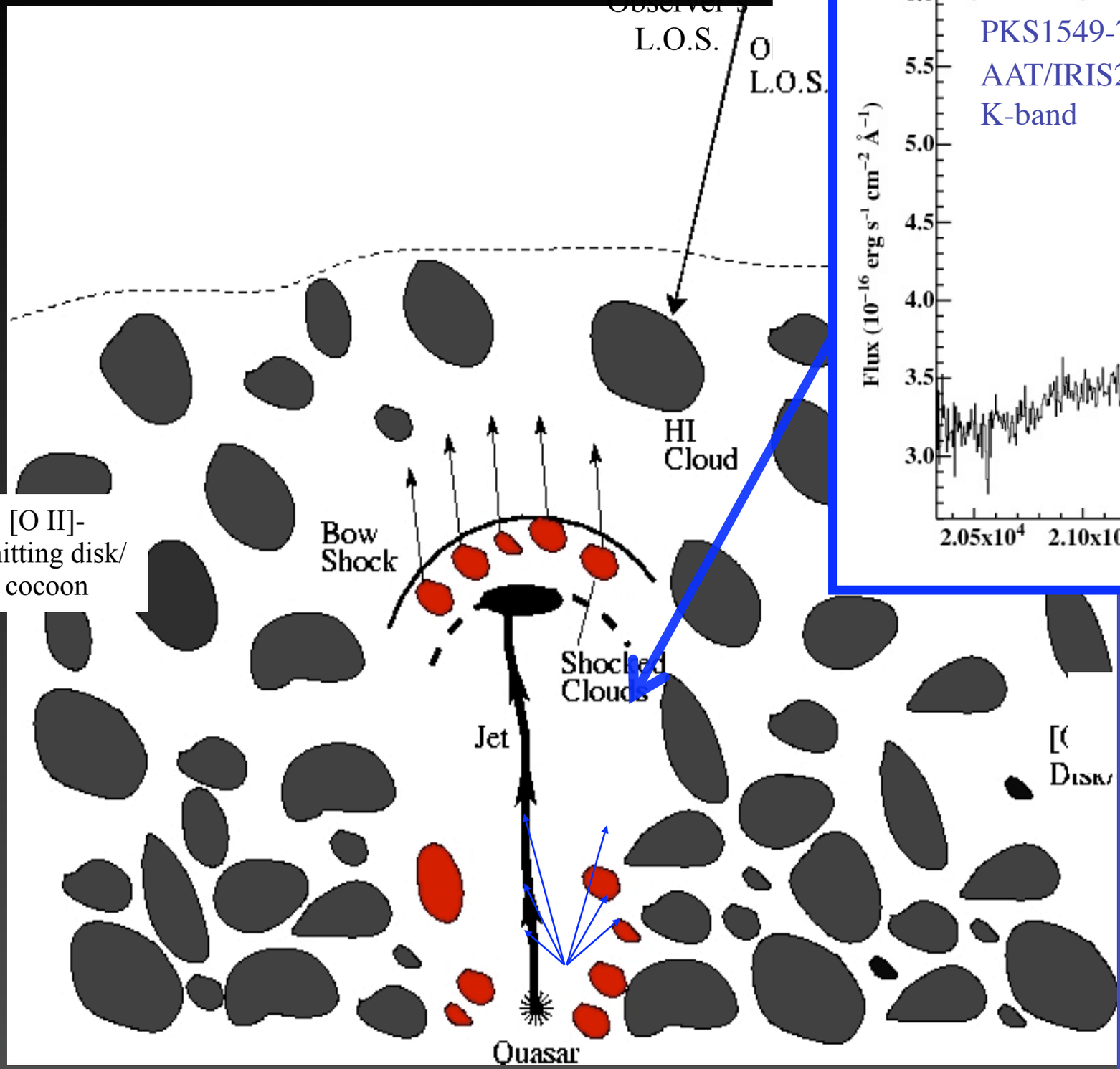
VLT+FORS1
Gunn r

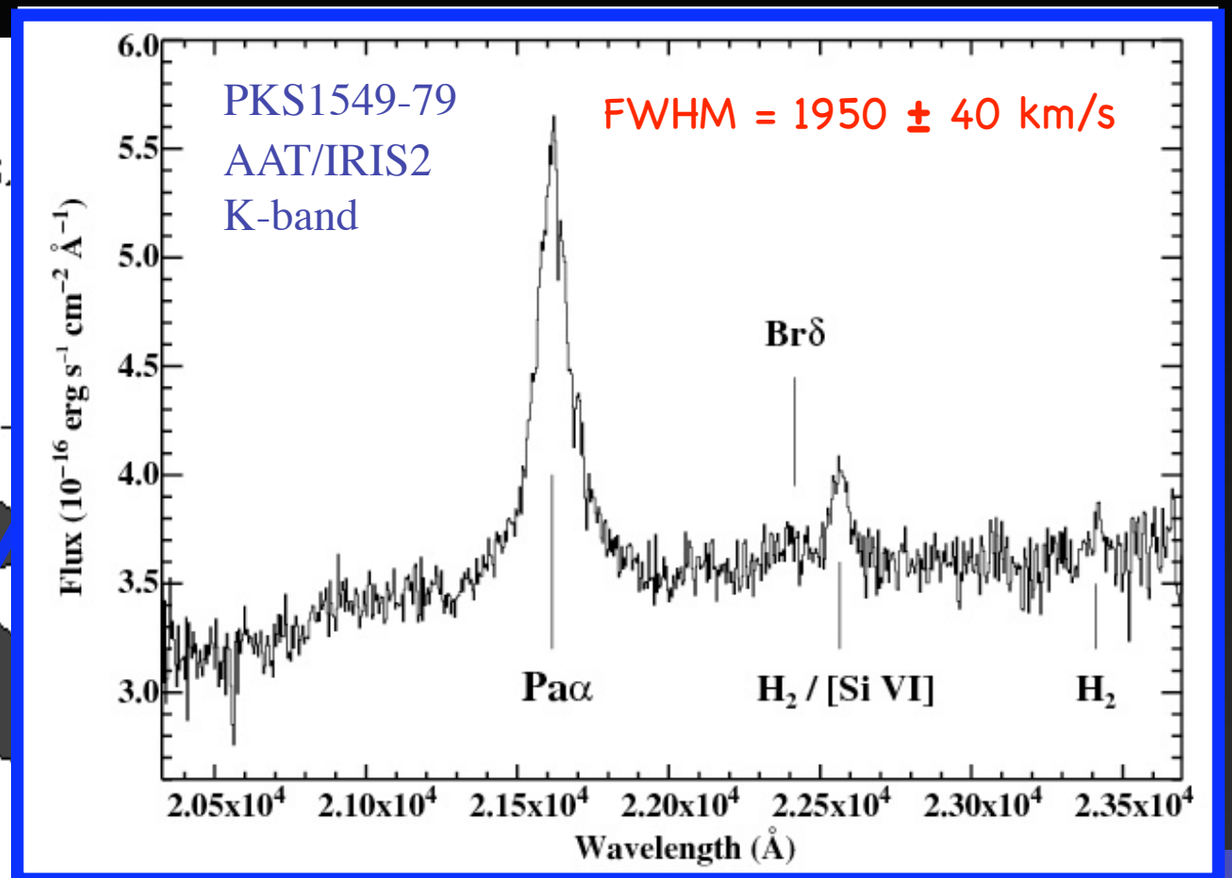


VLT+FORS2

Holt et al. (2006)

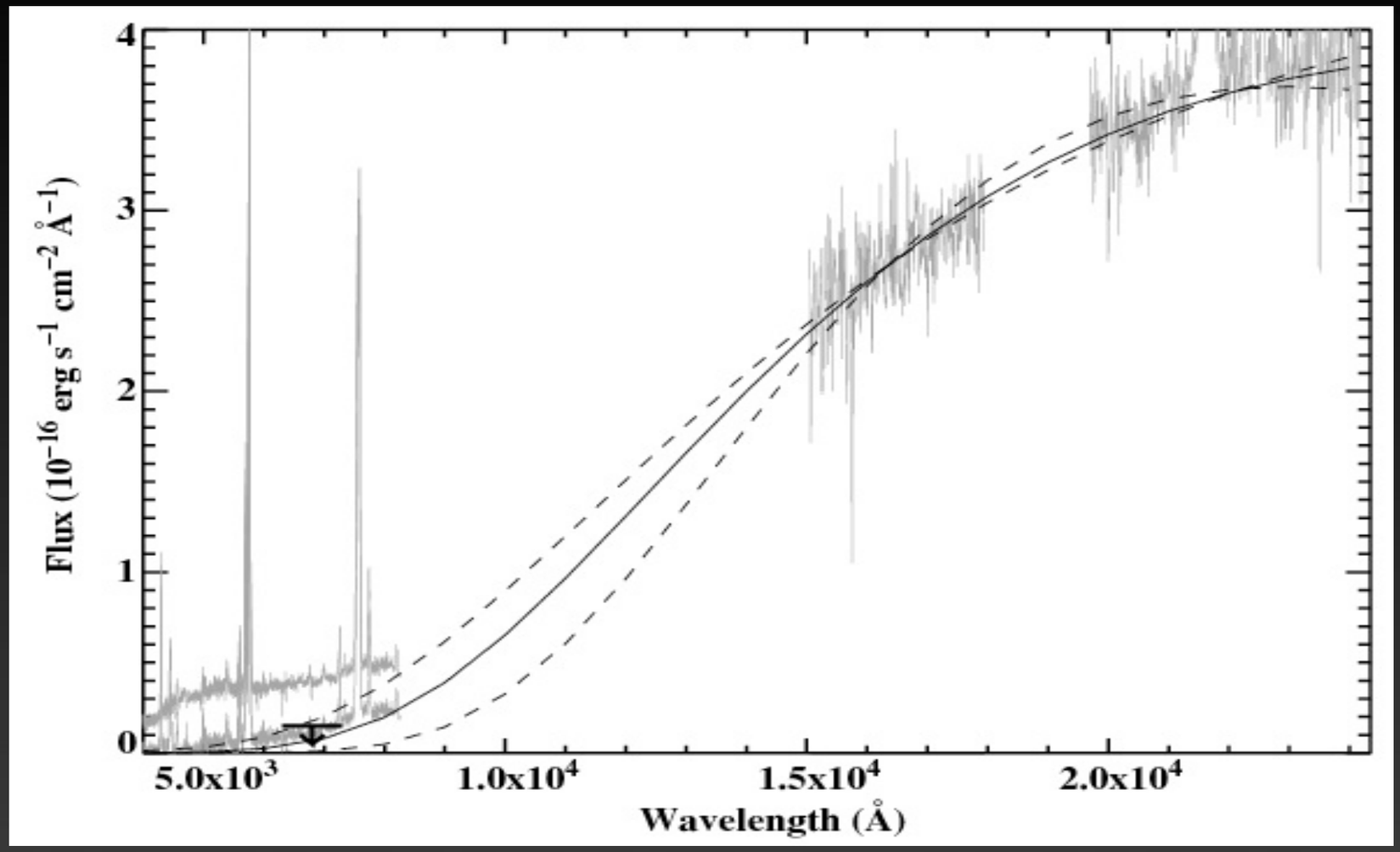
PKS 1549-79: in a stage where the nucleus is still hidden (in the optical) by the gas/dust coming from the merger that triggered the radio source





- young, small scale radio jets
- expanding through dense cocoon
- sweep aside gas and dust
- AGN driven outflow will eventually remove the gas

Optical/near-IR continuum SED



NTT+
SOFI

VLT+
FORS2

Quasar properties: $-27.56 < M_v < -23.5$

$6.4 < A_v < 13.2$

Holt et al. (2006)

- Black hole mass: 3.6×10^7 -- 2.4×10^8 M_{sun}

  (virial) (from M_r)

- High Eddington ratio: $0.3 < L_{bol}/L_{edd} < 35$

Main problem: relatively modest warm gas outflow

relative modest warm outflow

mass outflow rate: $0.12 < \dot{M} < 12\ M_\odot\ yr^{-1}$

mass of ionised gas in the outflow: $1.9 \times 10^4 < M_{sun} < 1.6 \times 10^6$

energy flux: $5.1 \times 10^{40} < \dot{E} < 5.1 \times 10^{42}$ erg s^{-1}

$1.5 \times 10^{-6} < \dot{E}/L_{edd} < 1.5 \times 10^{-4}$

Only small fraction of accretion power

- the warm-gas outflow is not large! more in cold/hot gas?
- not as large as expected in the quasars feedback model
- it will not be able to clear all gas
- amount of ionised gas: not large enough to stop the jet

Holt et al. 2006

Results from the gas outflow in young radio sources

- Interaction jet/ISM important in young radio sources - many effects seen
- Obscuration from the ambient medium in young radio sources
- complex, stratified structure of the ionised gas outflow
- the gas masses do not seem to be large enough to confine the (powerful) young radio sources
- but likely slowing down the evolution of the jets.

Summary for radio-loud (mainly compact and FRI) galaxies

- Gas (HI and ionised) observed in a high fraction of early-type galaxies BOTH radio-quiet and radio-loud -> important component
- The HI can form very extended structures with mass well above 10^9 M_{sun} BOTH in radio-quiet and radio-loud!

- Convincing cases of major mergers (at least some type of..)
- Only small/young(?) radio sources have associated large HI disks -> different evolution for these objects?
- So far no FRI (and FRII) with such HI-rich structures -> gas ionised by the radio source? different type of merger?
- no one-to-one correlation gas-young stars
- lack of HI on the large scale does not mean that there is no gas on the small scale (see later this talk)

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relevant for the high-z extended structures?

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