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Netherlands Institute for Radio Astronomy

Gas and radio galaxies: a story of love and hate

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ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

YERAC - Jodrell Bank, 19 July 2011

Don’t underestimate the YERAC!

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- 1986 - YERAC Havelte (just a few km from Dwingeloo - organised by ASTRON)
- Many of them still around....
- Not all of them are doing the same things now.....there is hope!

My favorite topic: radio jets

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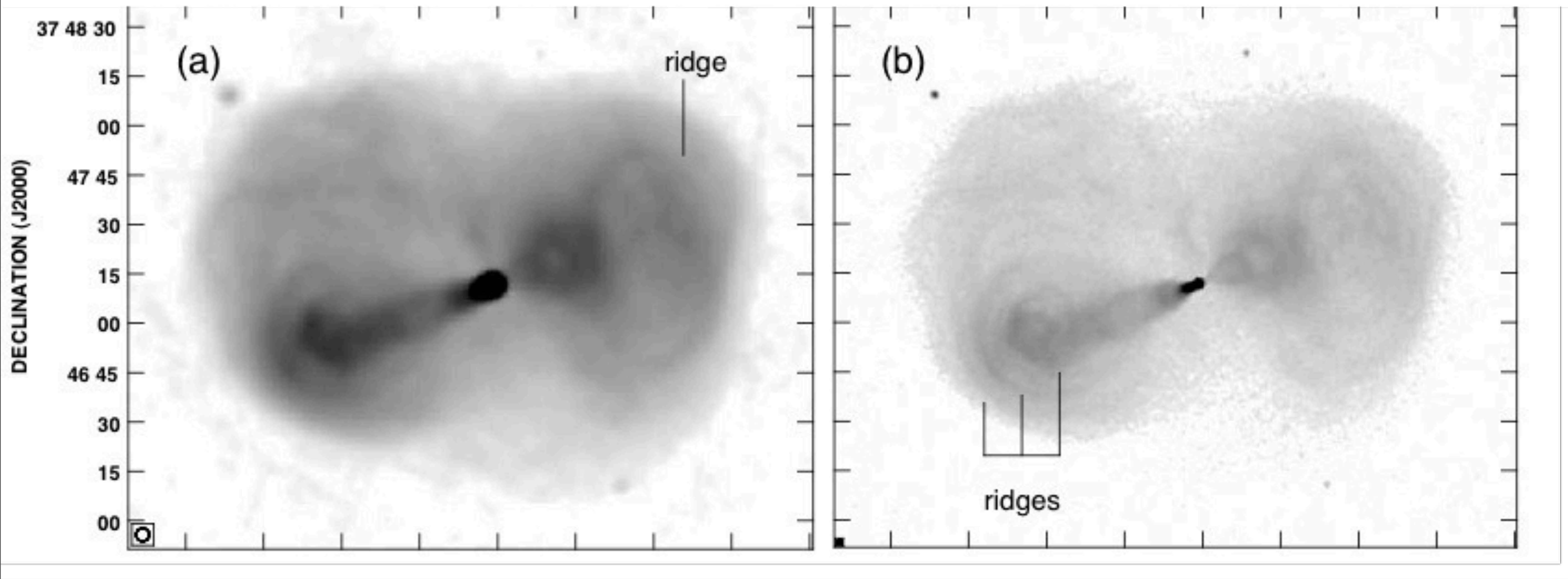
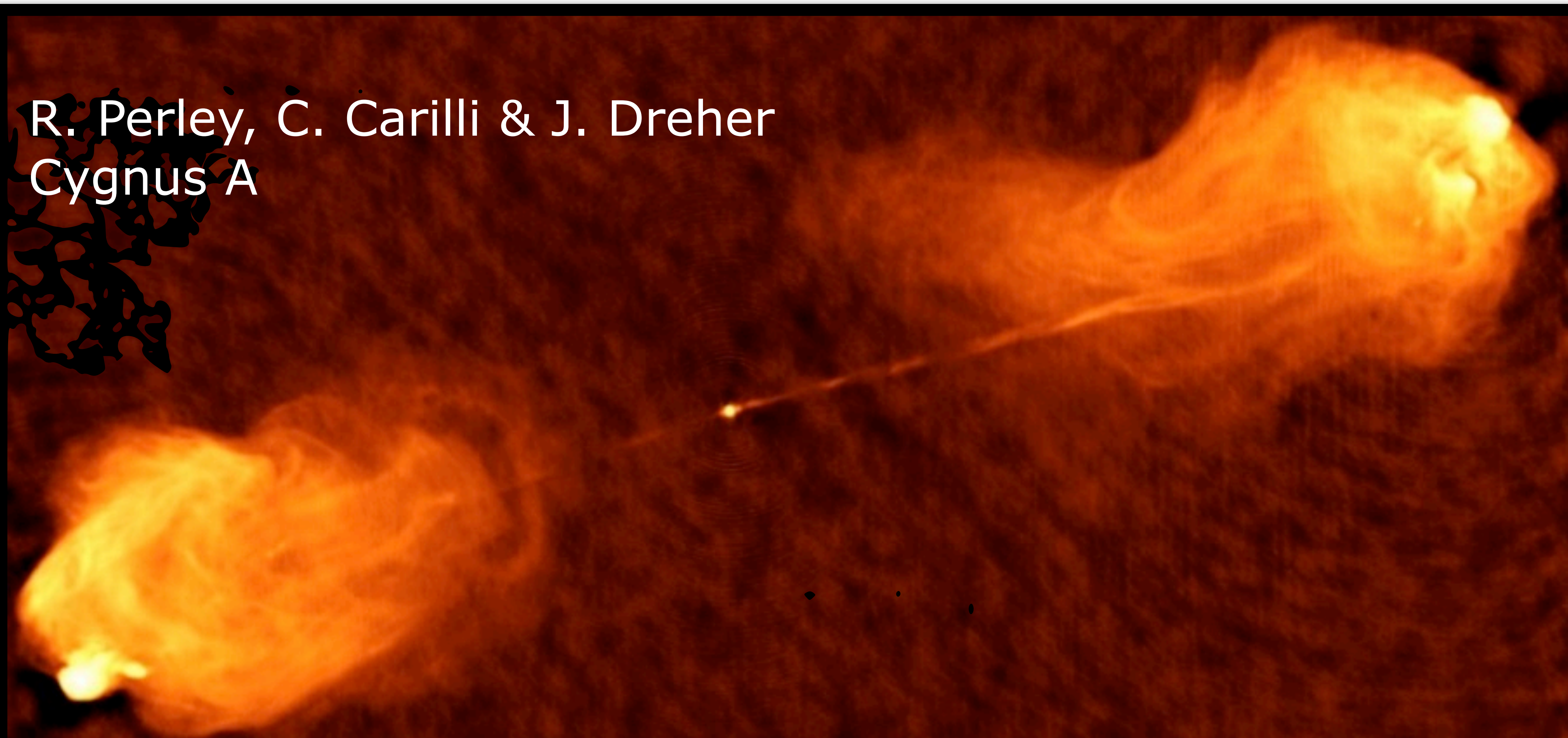
My favorite topic: radio jets and gas

Radio jets and gas: the perfect combination

Laing et al. astro-ph/1107.2511




R. Perley, C. Carilli & J. Dreher
Cygnus A


Feain et al. astro-ph/1104.0077
Centaurus A

Radio jets and gas: the perfect combination

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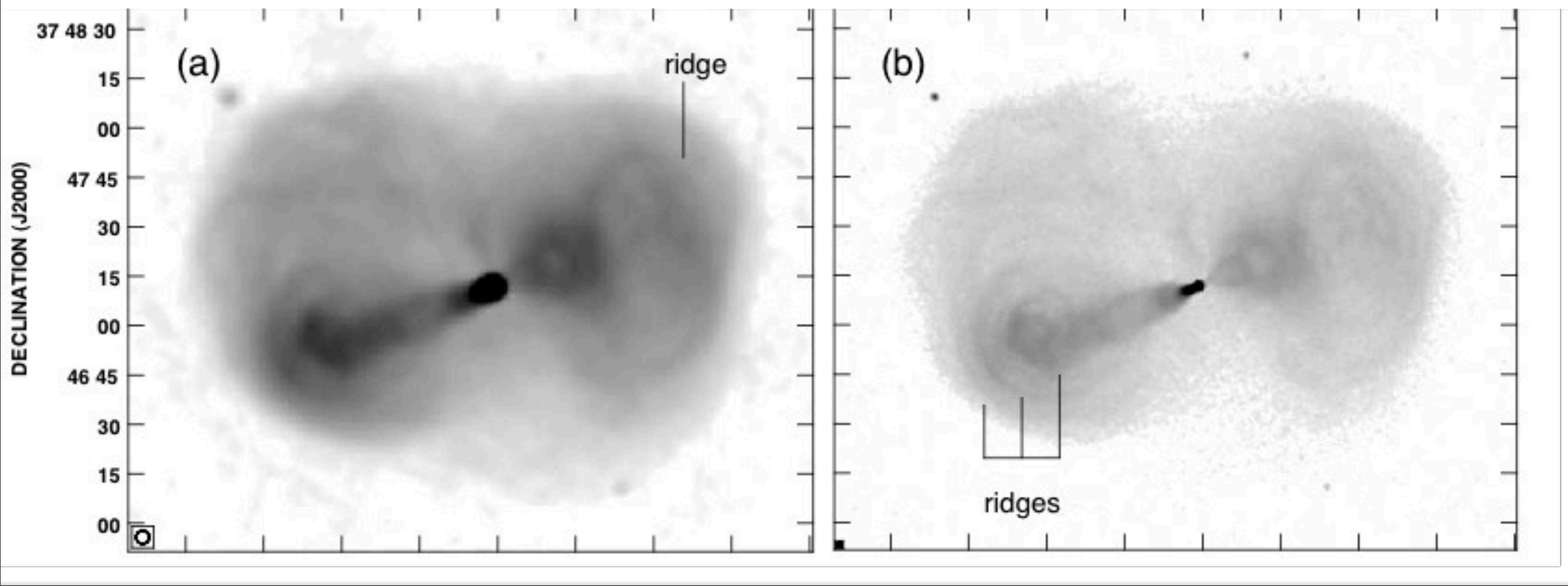
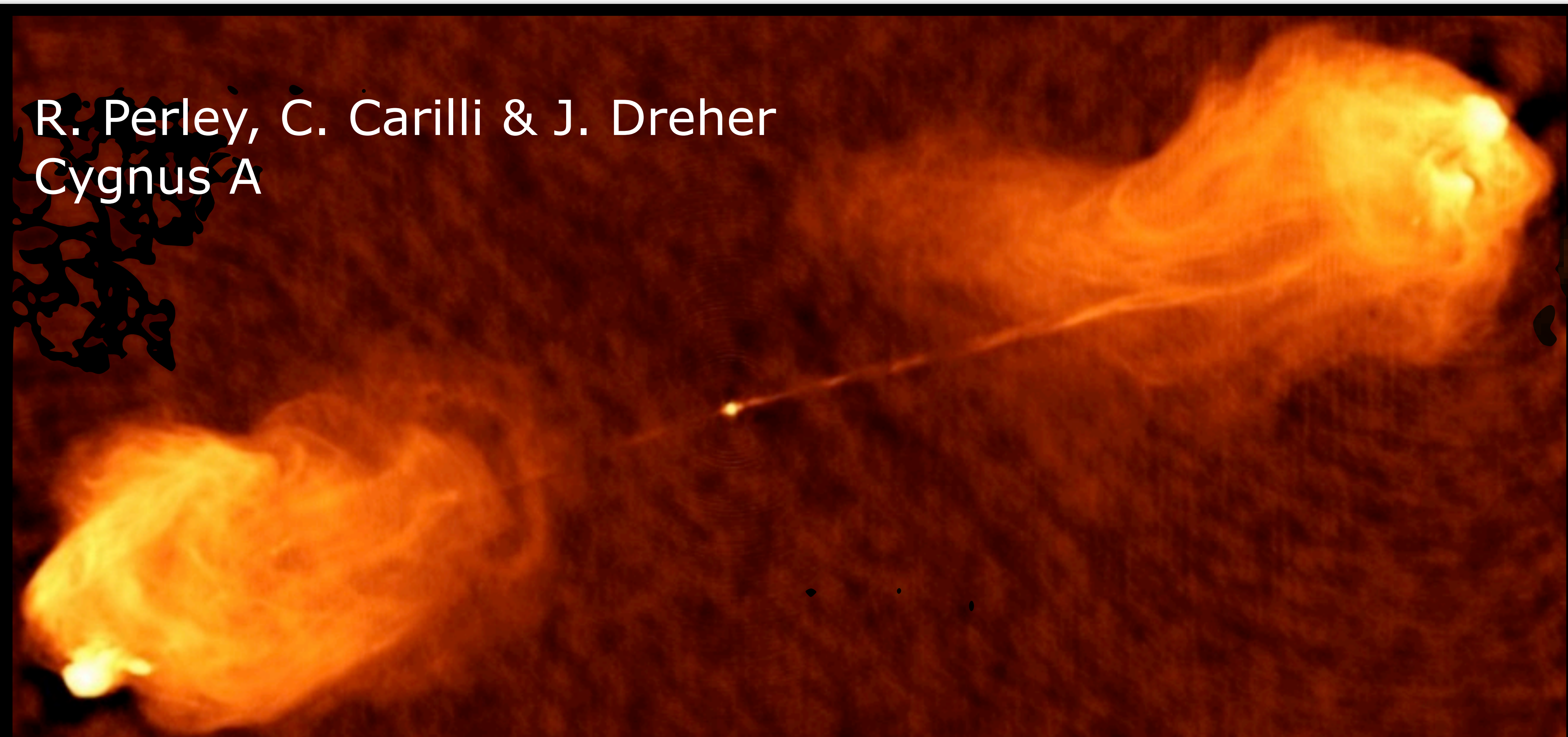
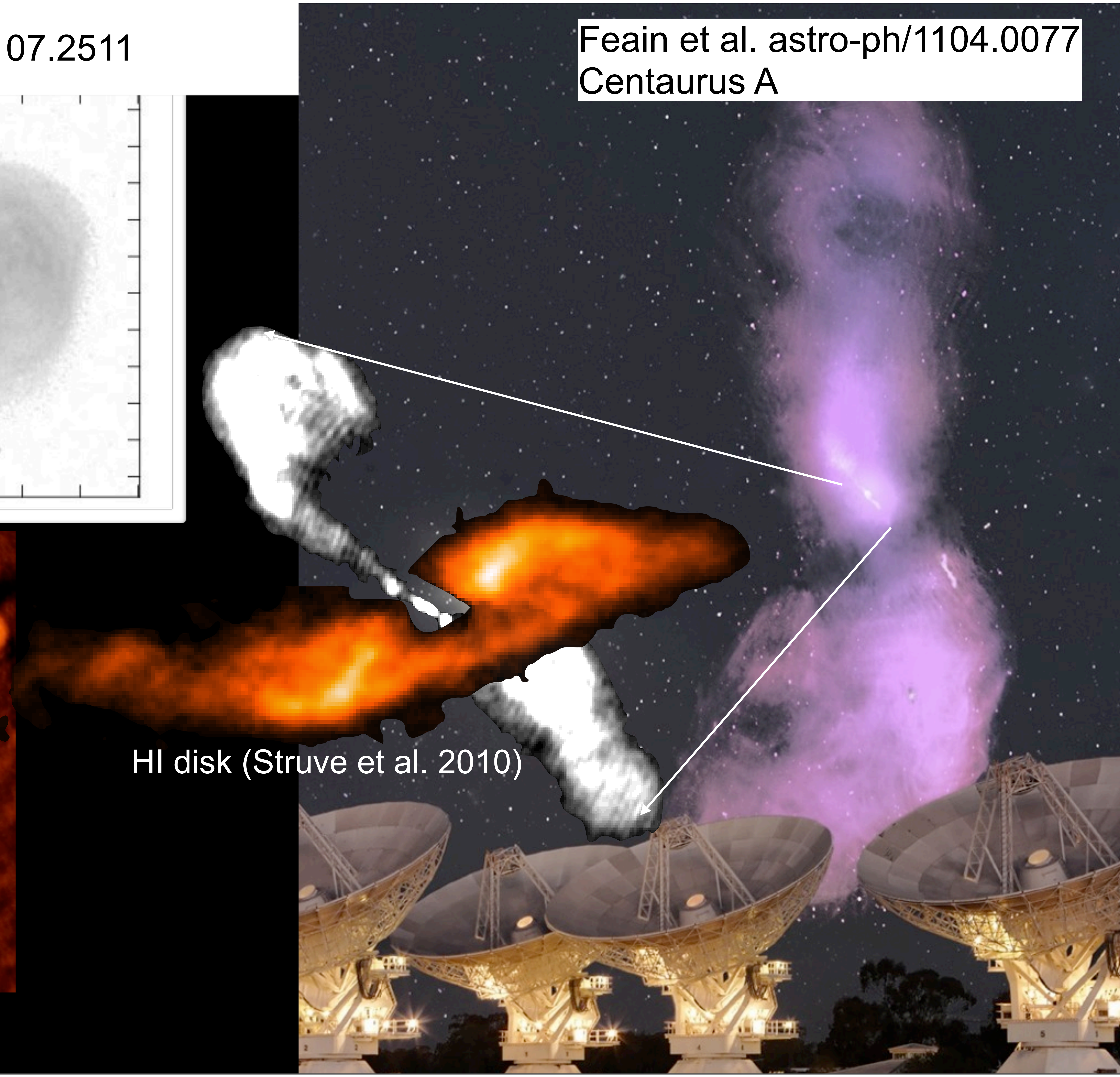






Why AGN are **now** so popular?

- they can limit the growth of the black-hole (self-regulating via feedback): BH - bulge mass relations
- they can inhibit star-formation by expelling gas from the central regions
- importante for orientation-independent obscuration, again by expelling the gas that obscure the AGN in the initial phase

Galaxy collisions awaken dormant black holes (T. Di Matteo, V. Springel, L. Hernquist)

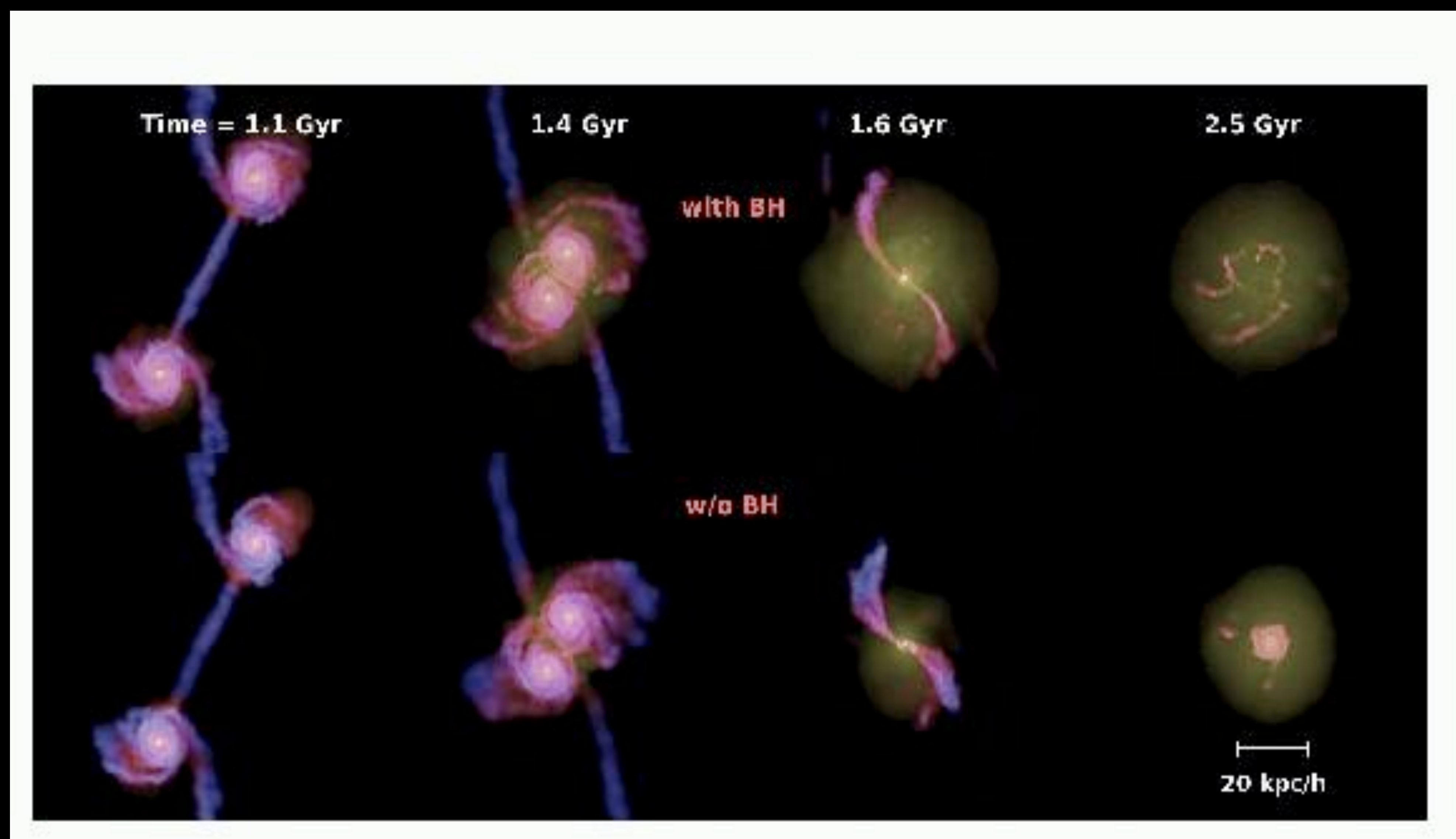
- Energy input from quasars regulates the growth and activity of black holes and their host galaxies

Figure: Snapshots of the time evolution of a collision of two spiral galaxies with black holes at their center from a computer simulation.

Color indicates temperature and brightness the gas density. When the galaxies and their black holes collide a quasar is ignited which expels most of the gas in a strong wind. The remaining galaxy contains very little gas but a large supermassive black hole.

With BH => no condensation of gas in the centre

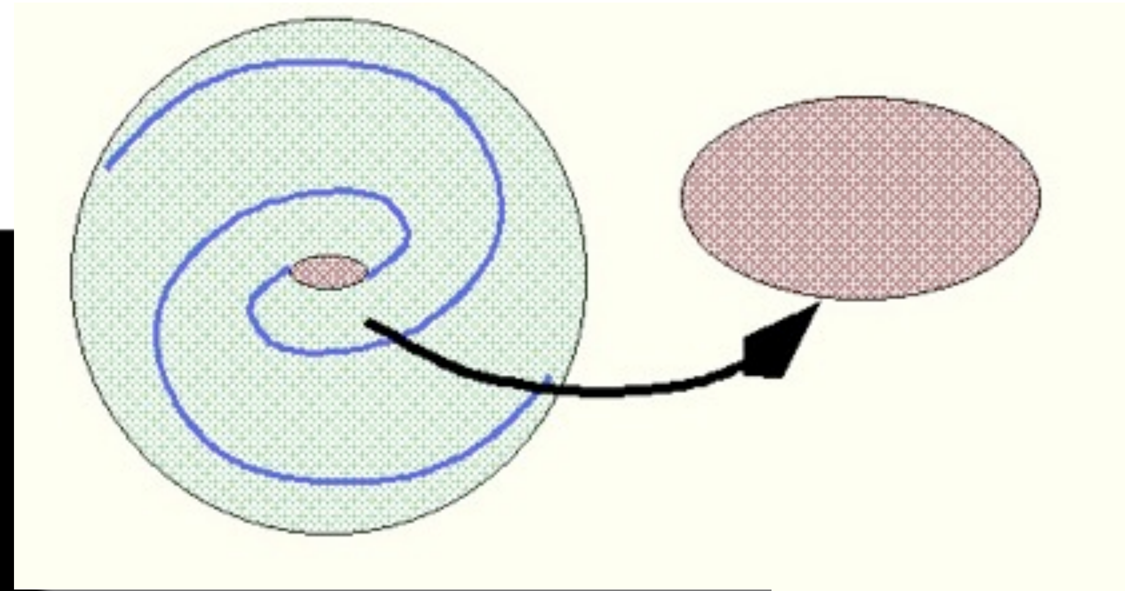
Without BH => condensation of gas in the center



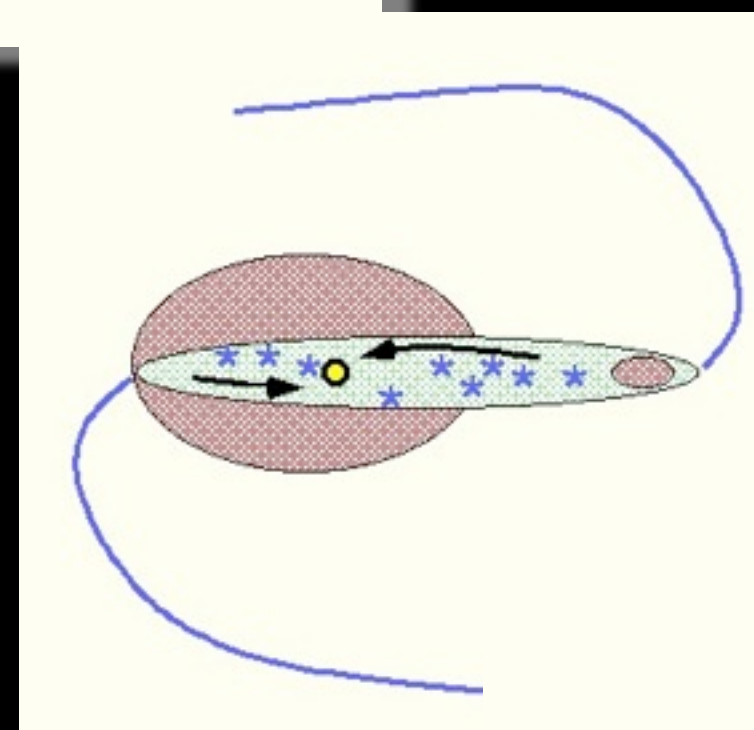
Nature, 10 February 2005

Possible life of an early-type galaxy hosting an AGN

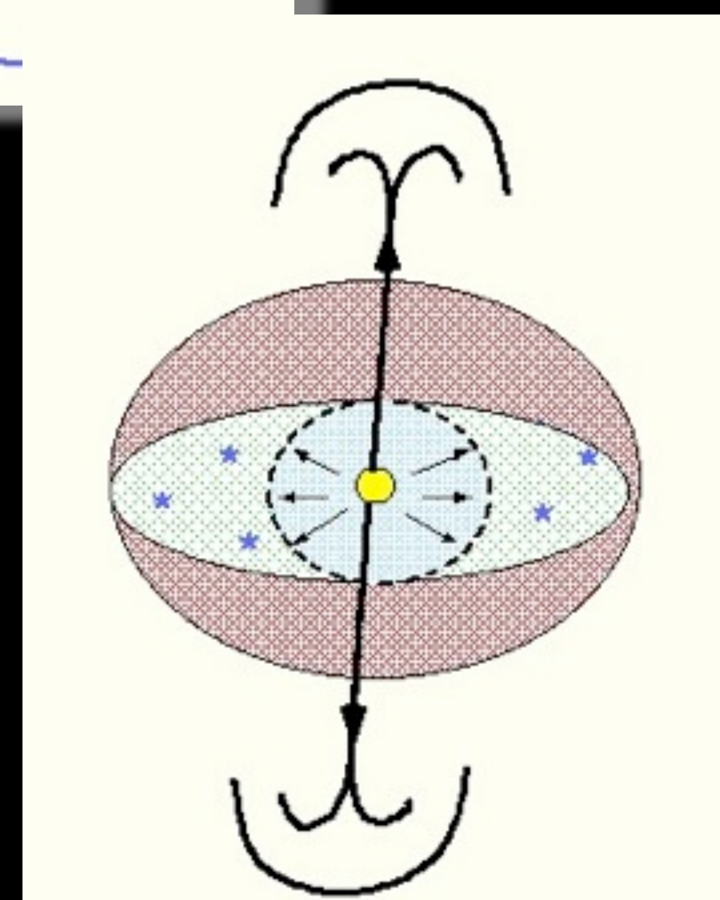
from Clive Tadhunter



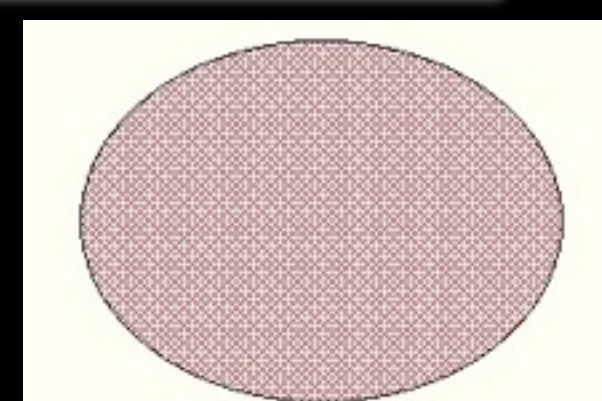
Start of merger
-1 billion yr



Advanced merger: gas driven towards nucleus; starburst
-0.5 billion yr



Quasar and jet activity drives gas out of galaxy
Now



Relaxed E-galaxy
+1 billion yr

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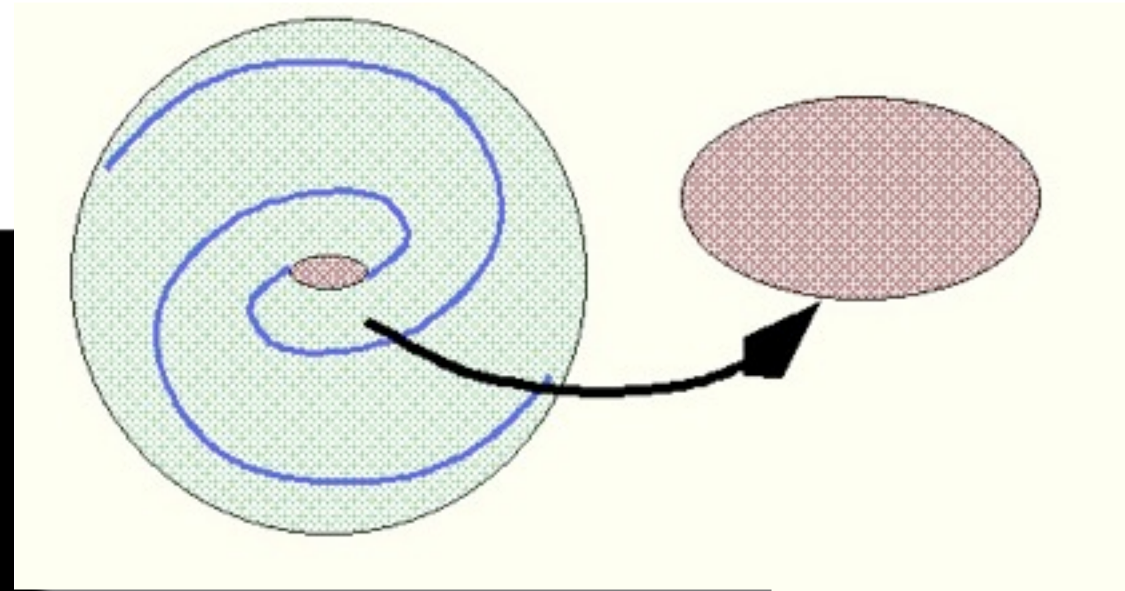

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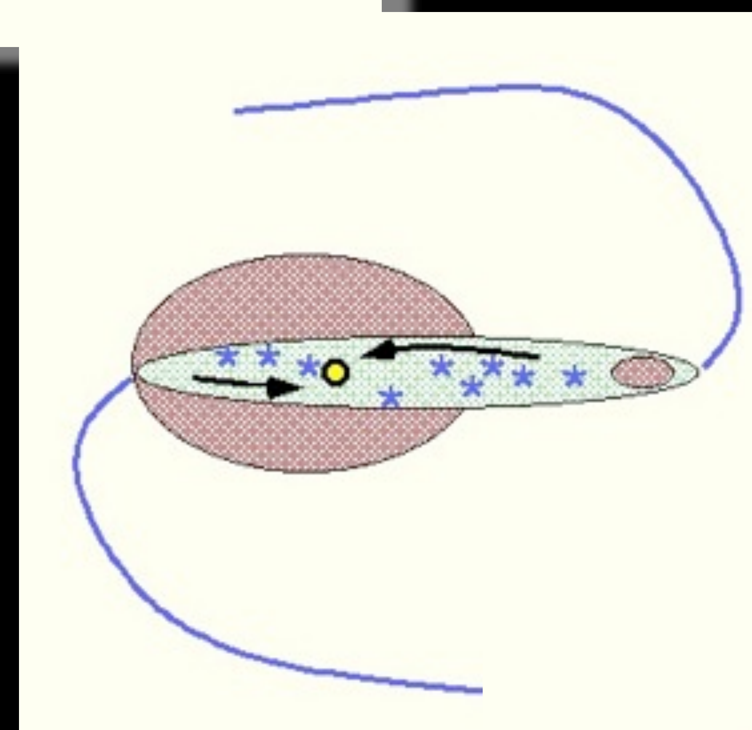

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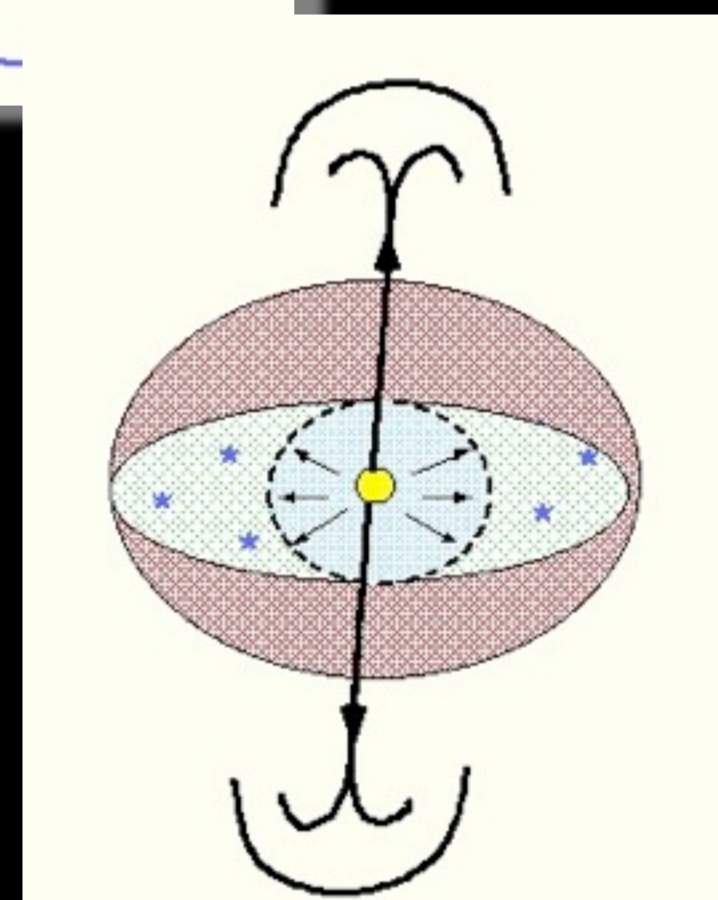

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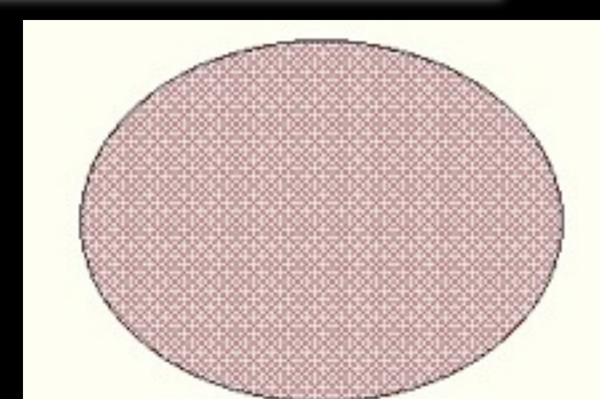

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We can use the gas to trace all these stages!

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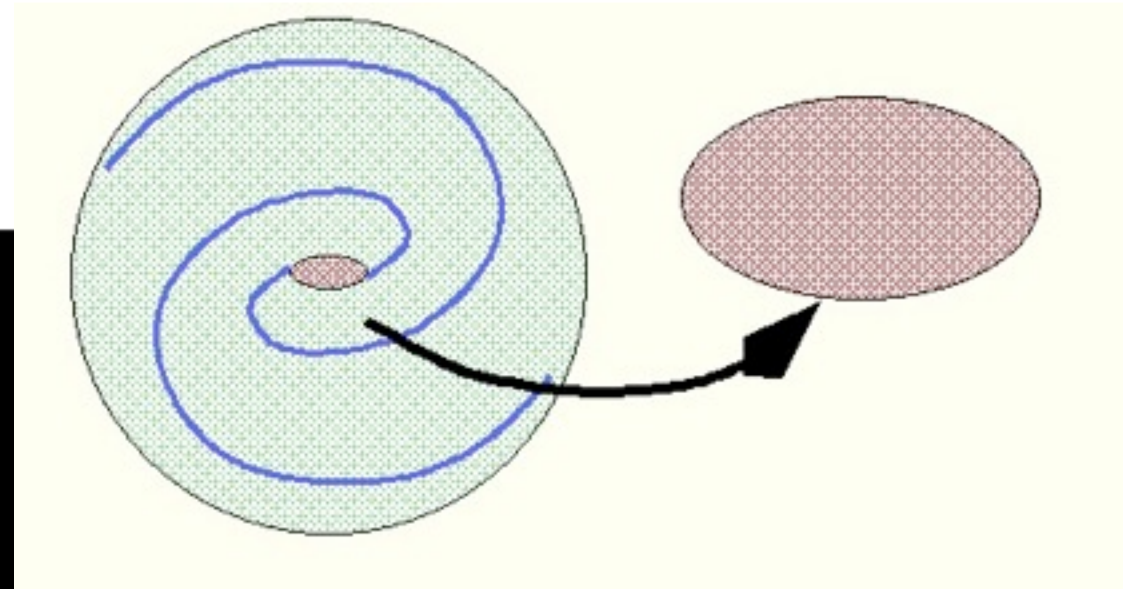

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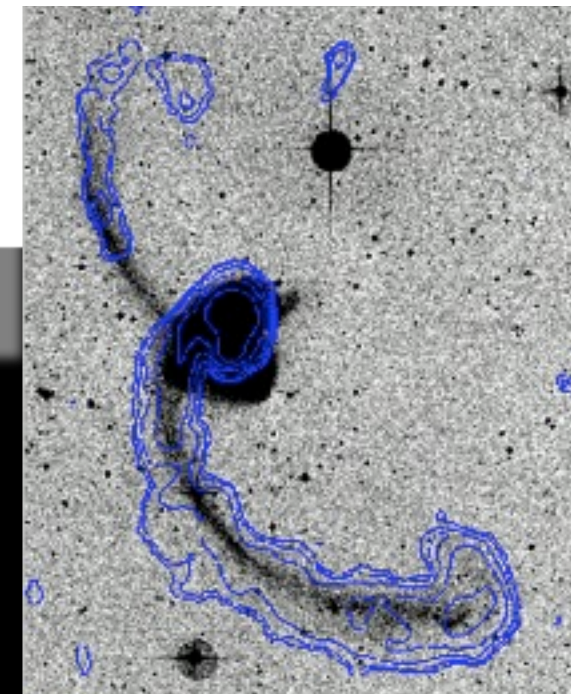
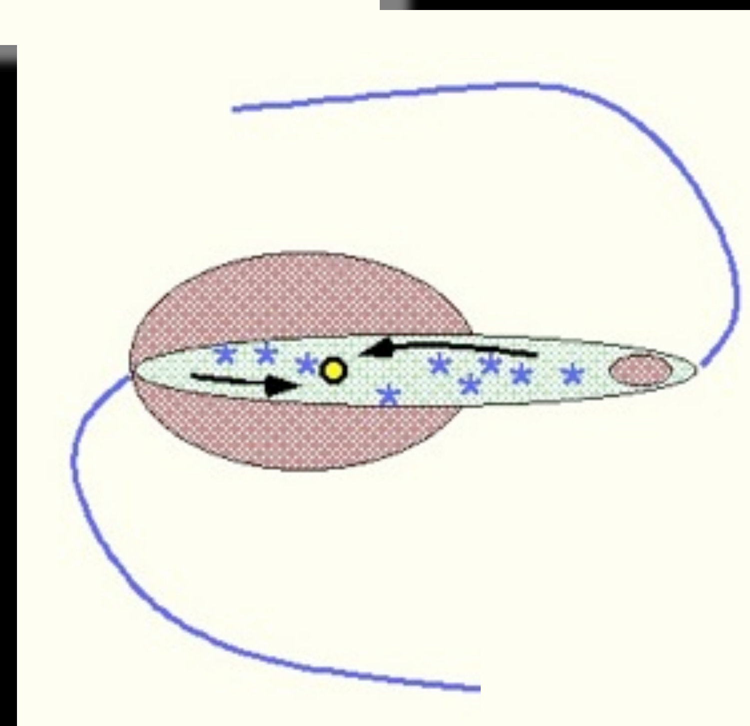


Optical image+HI contours



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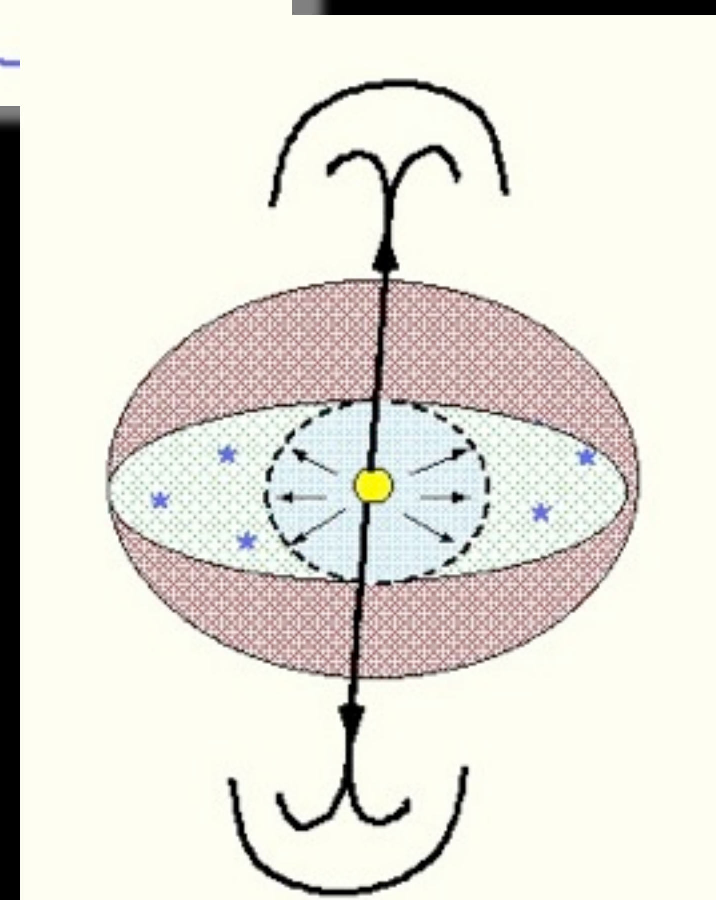

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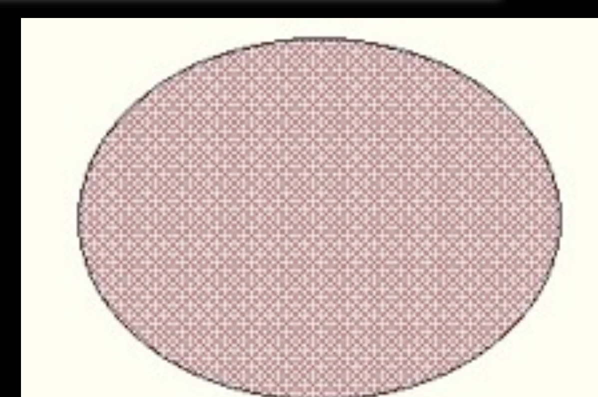

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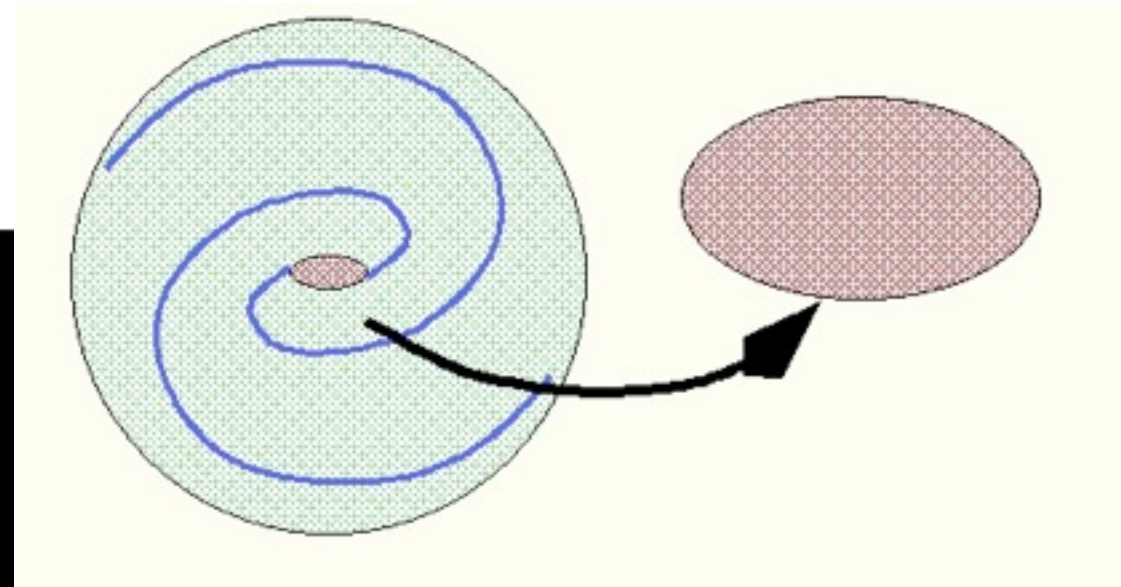

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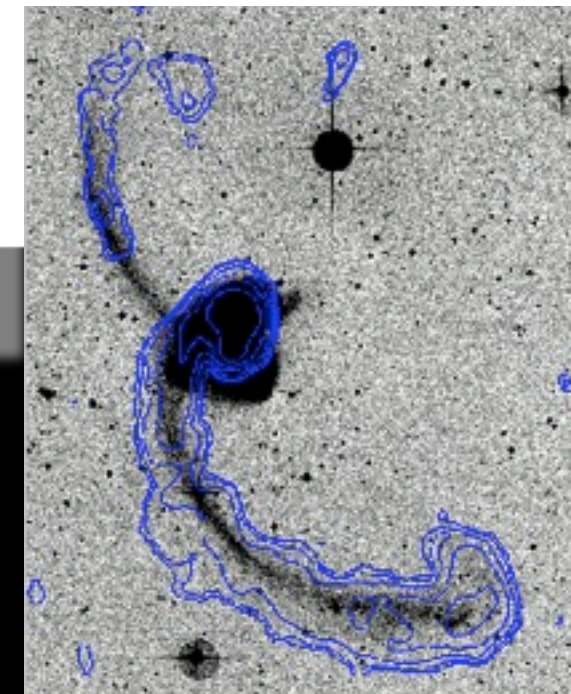

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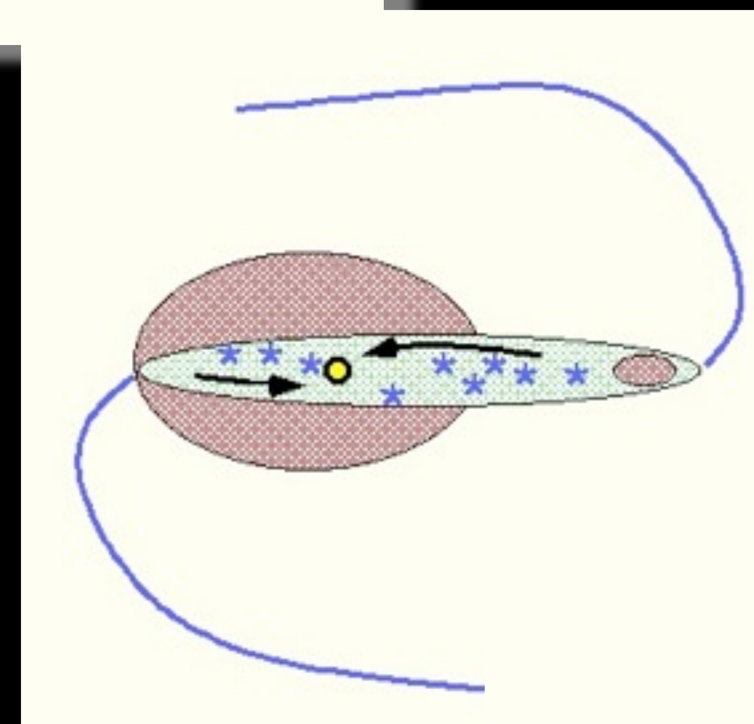

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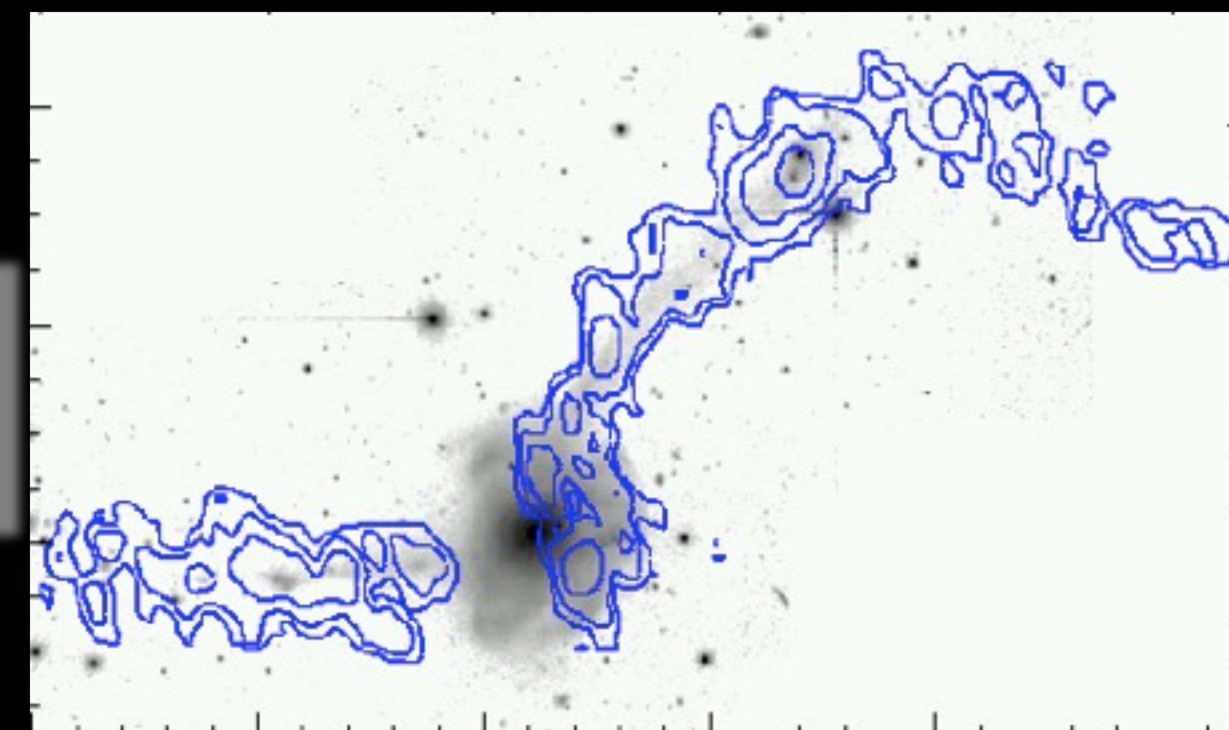

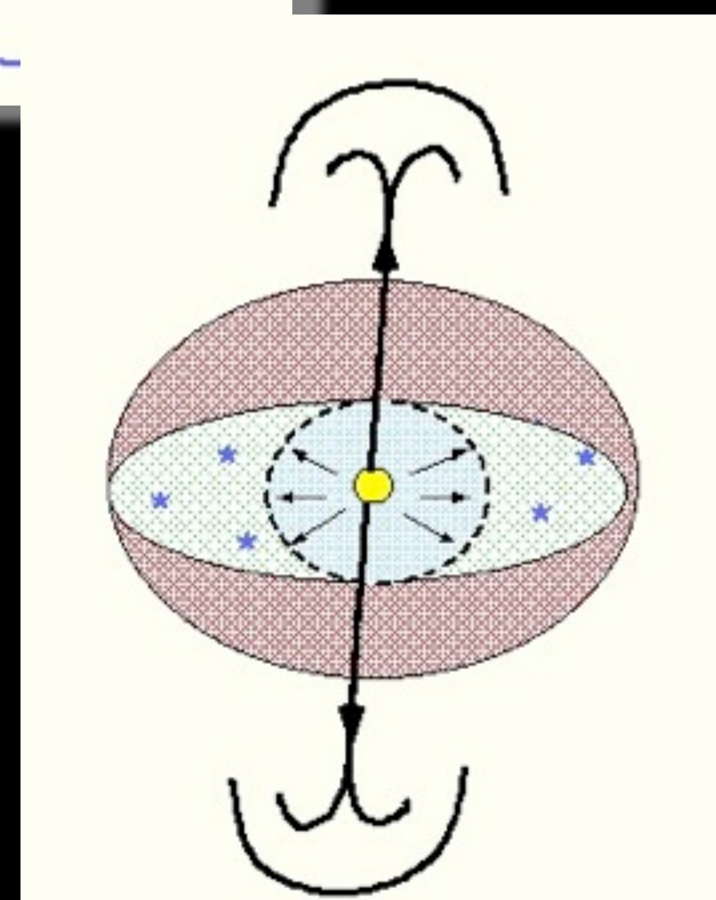

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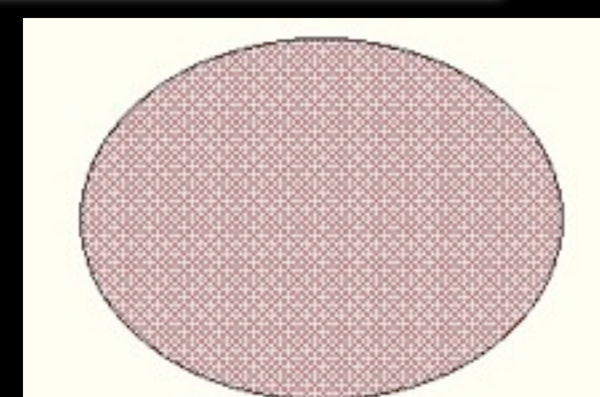

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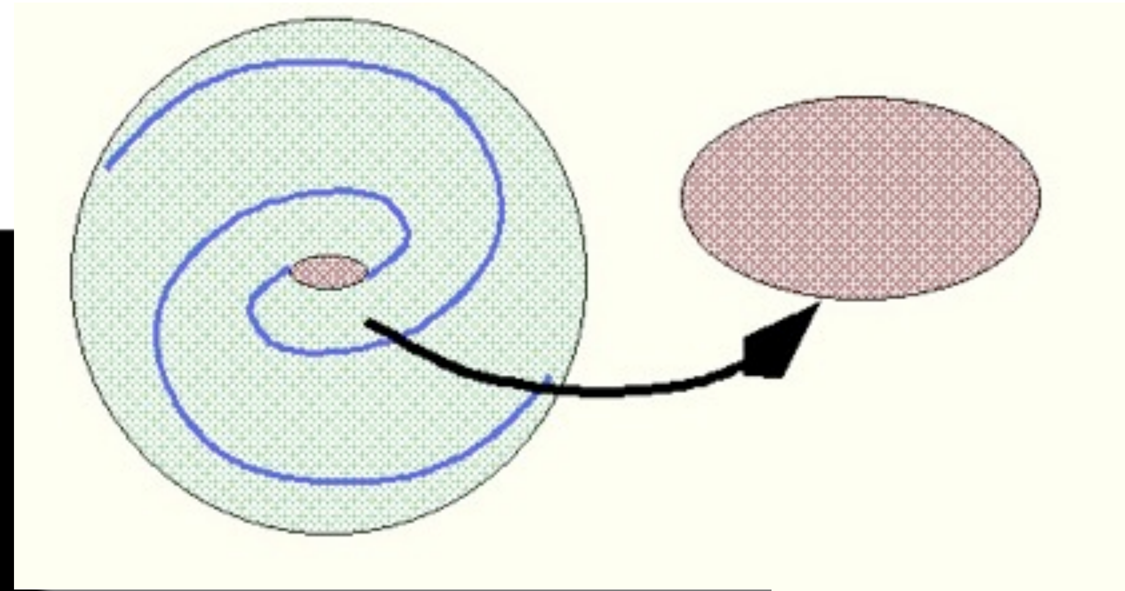

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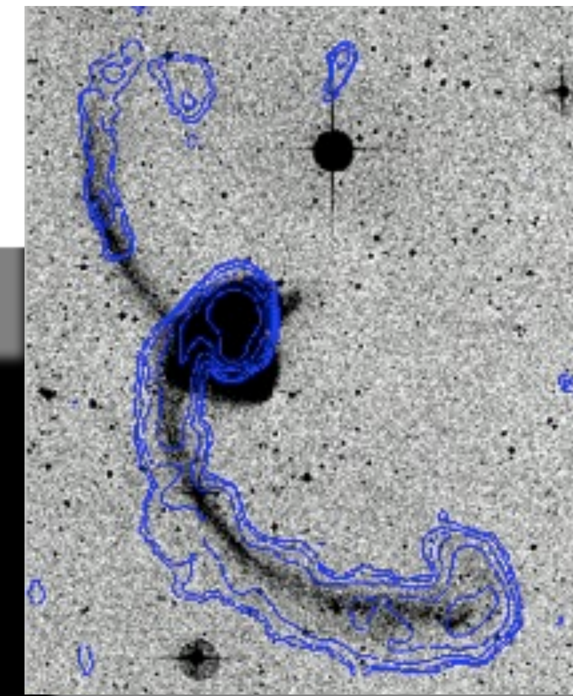

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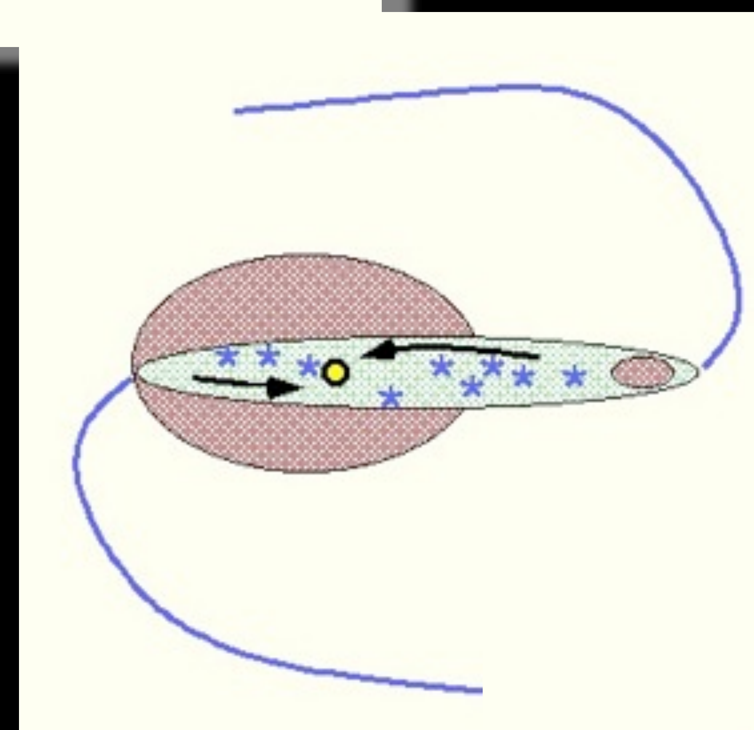

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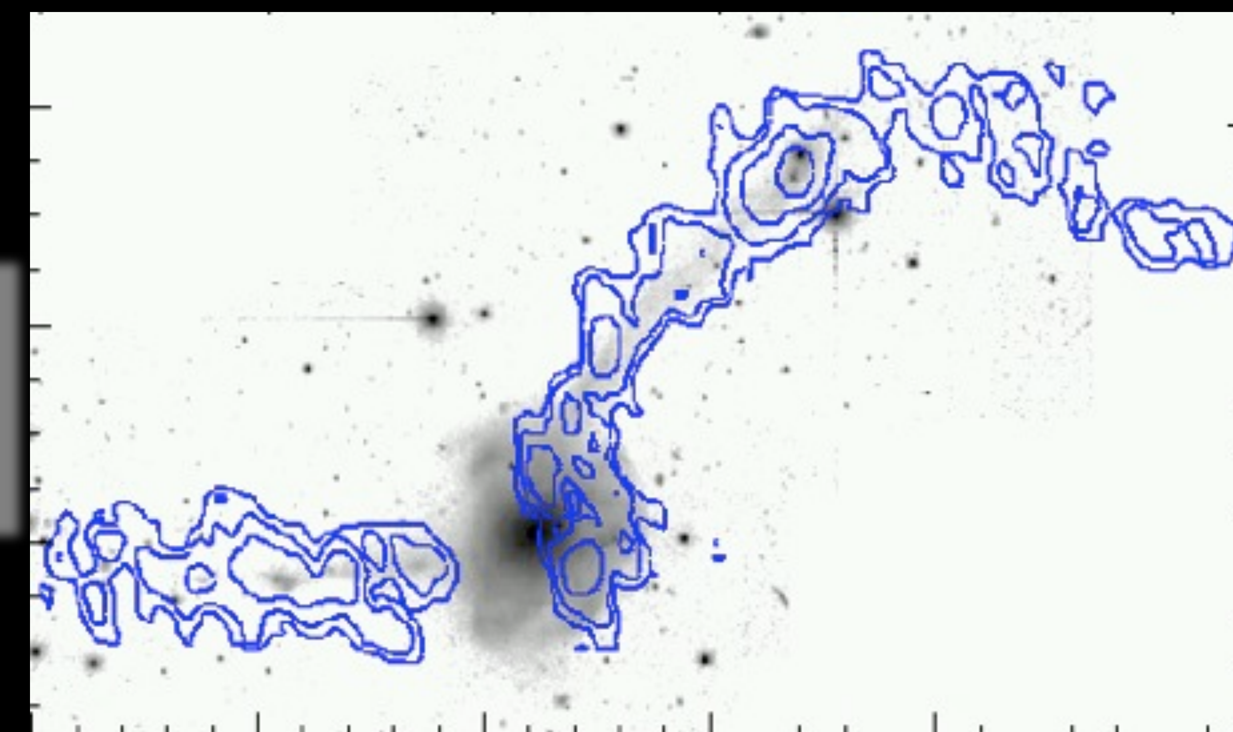

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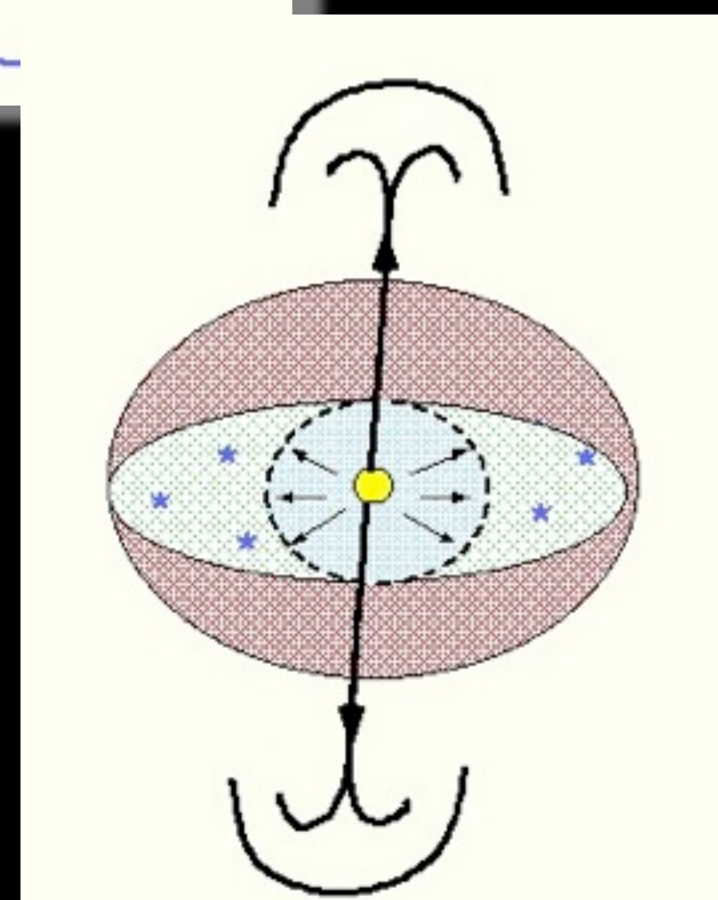

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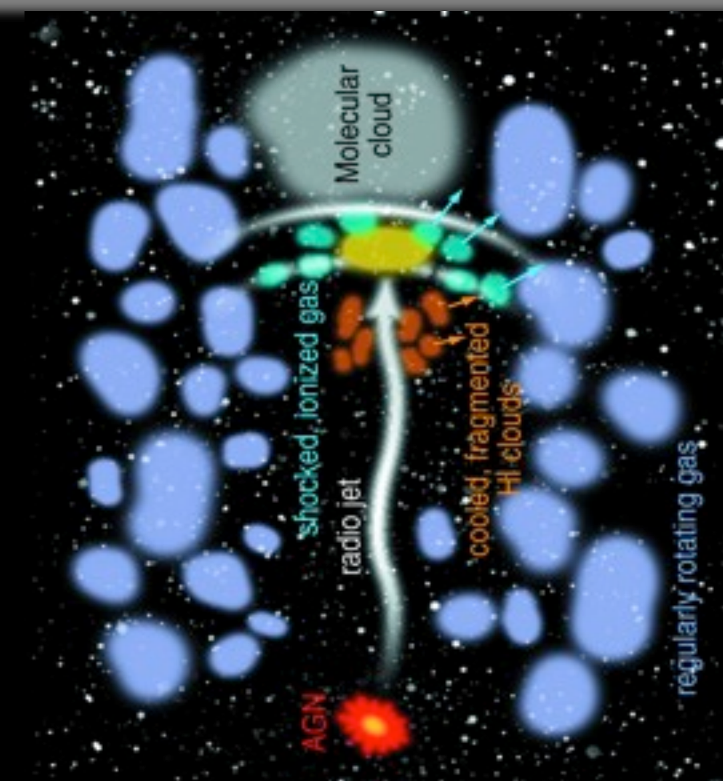

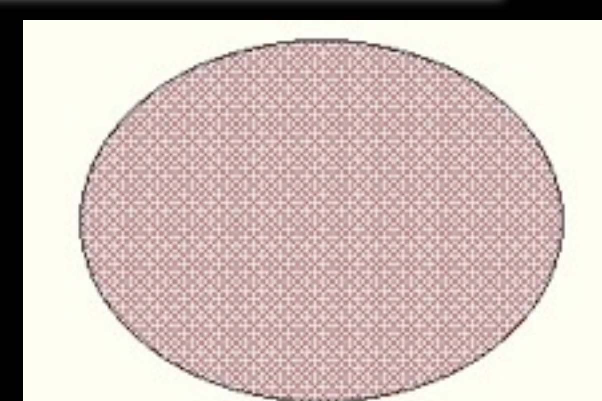

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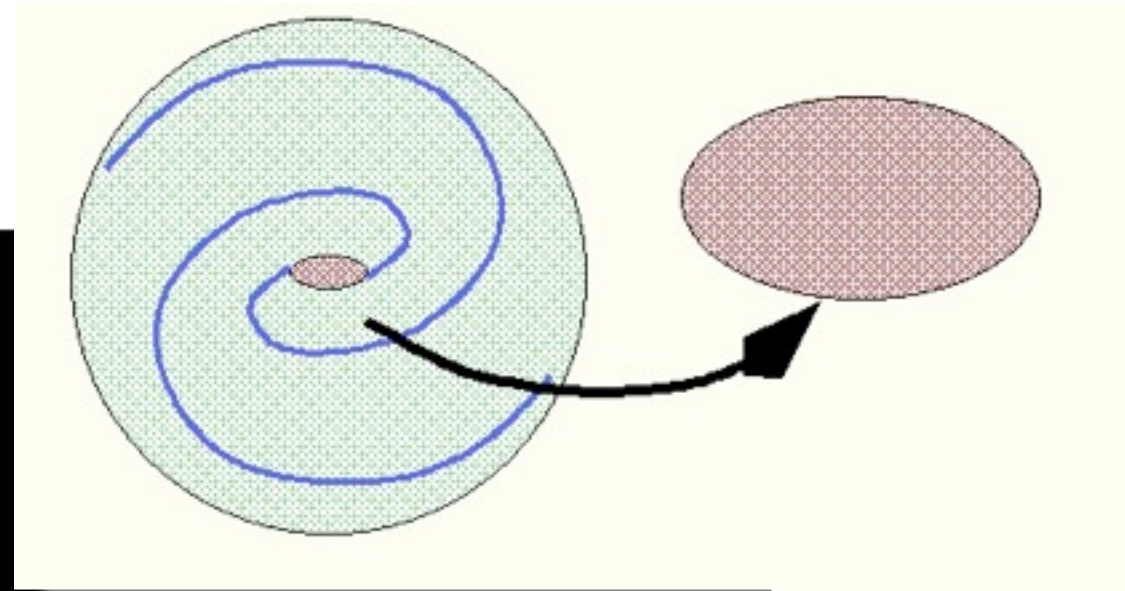

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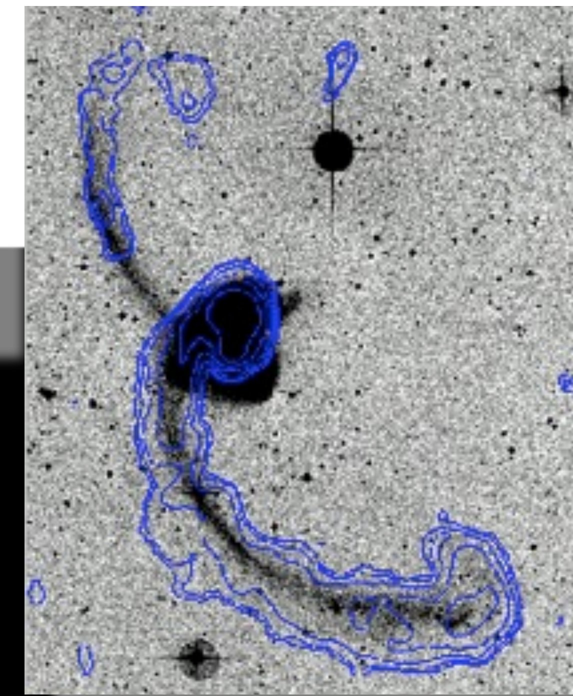

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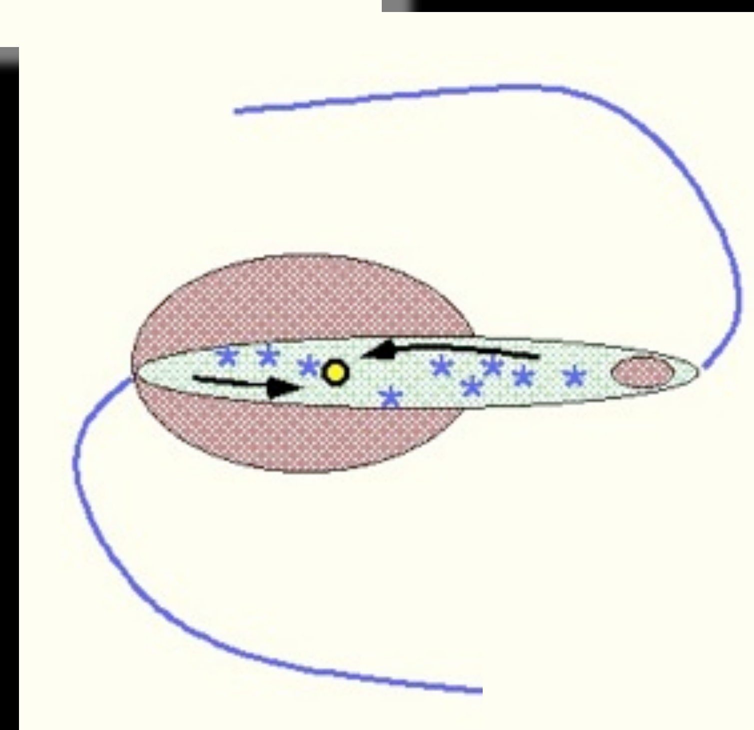

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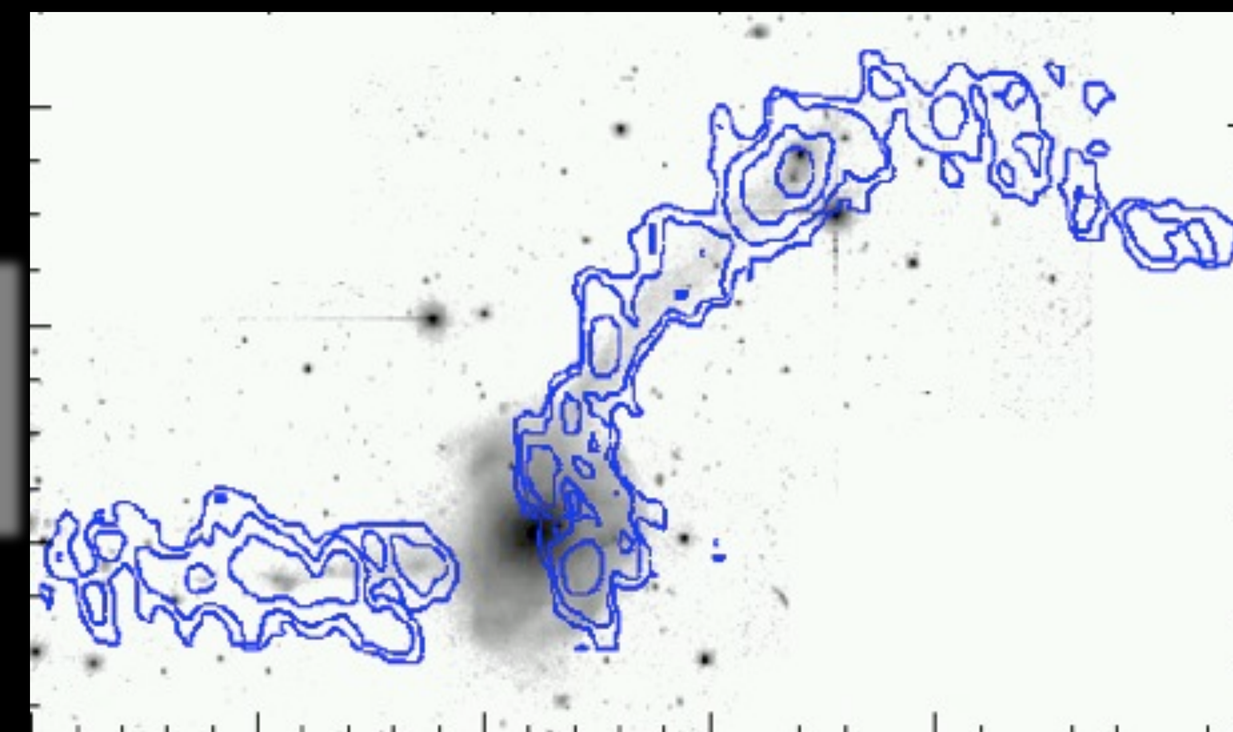

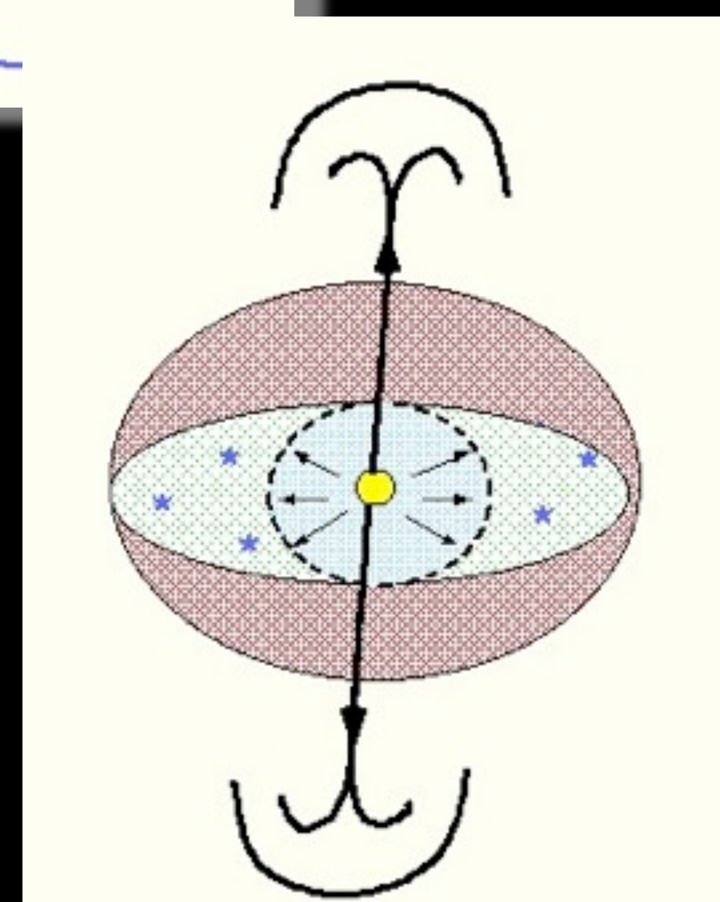

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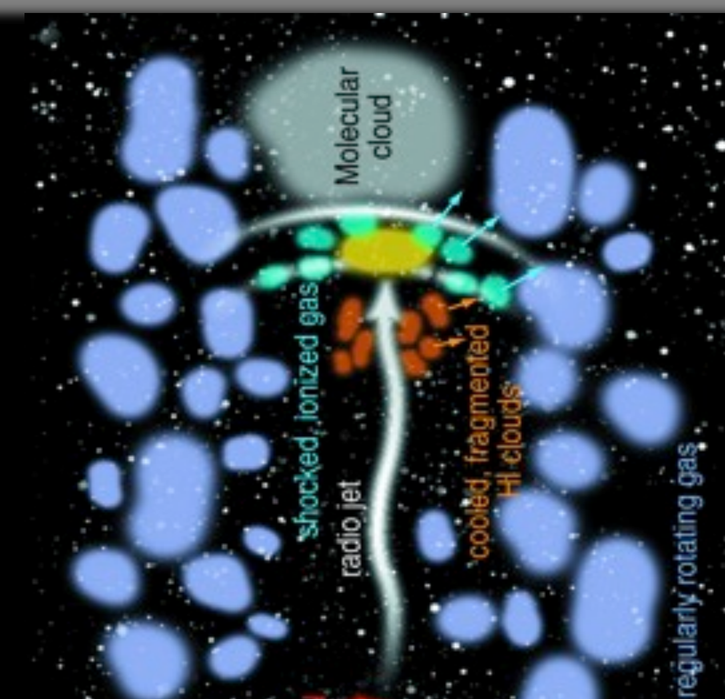

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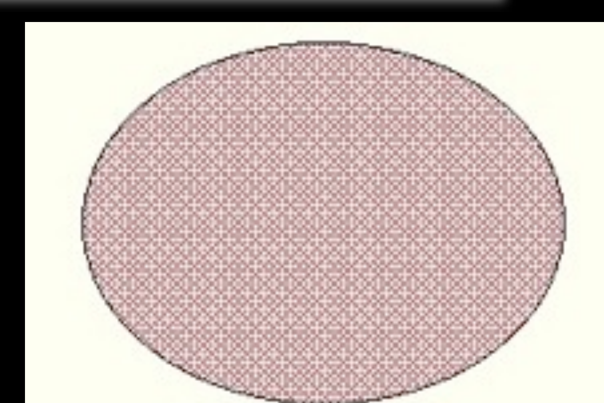

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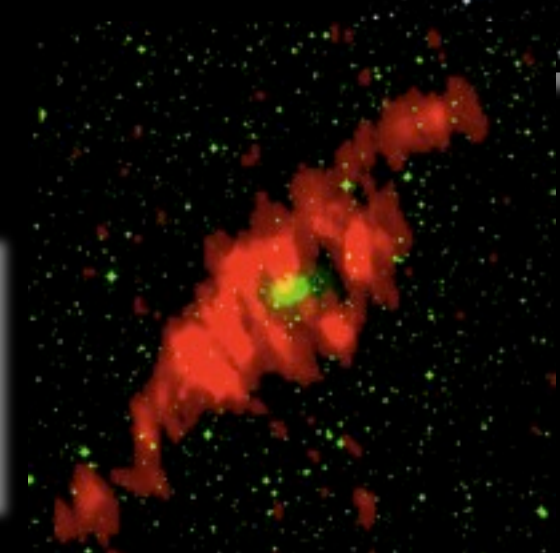

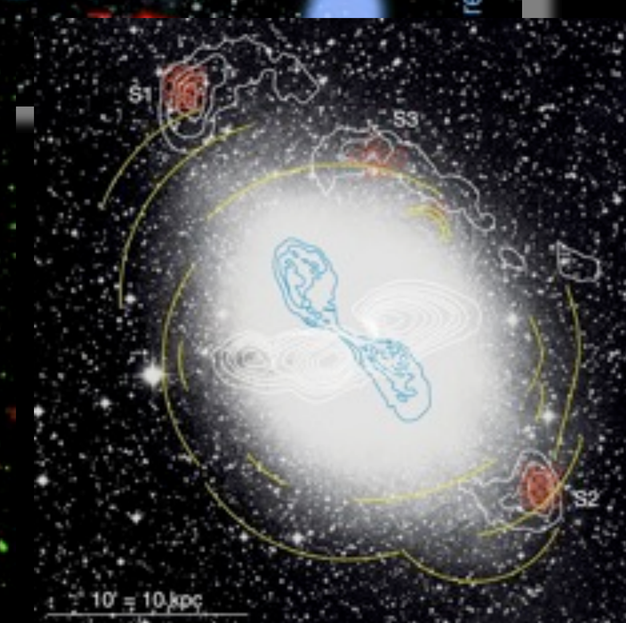

Why radio-loud AGN? recurrent activity

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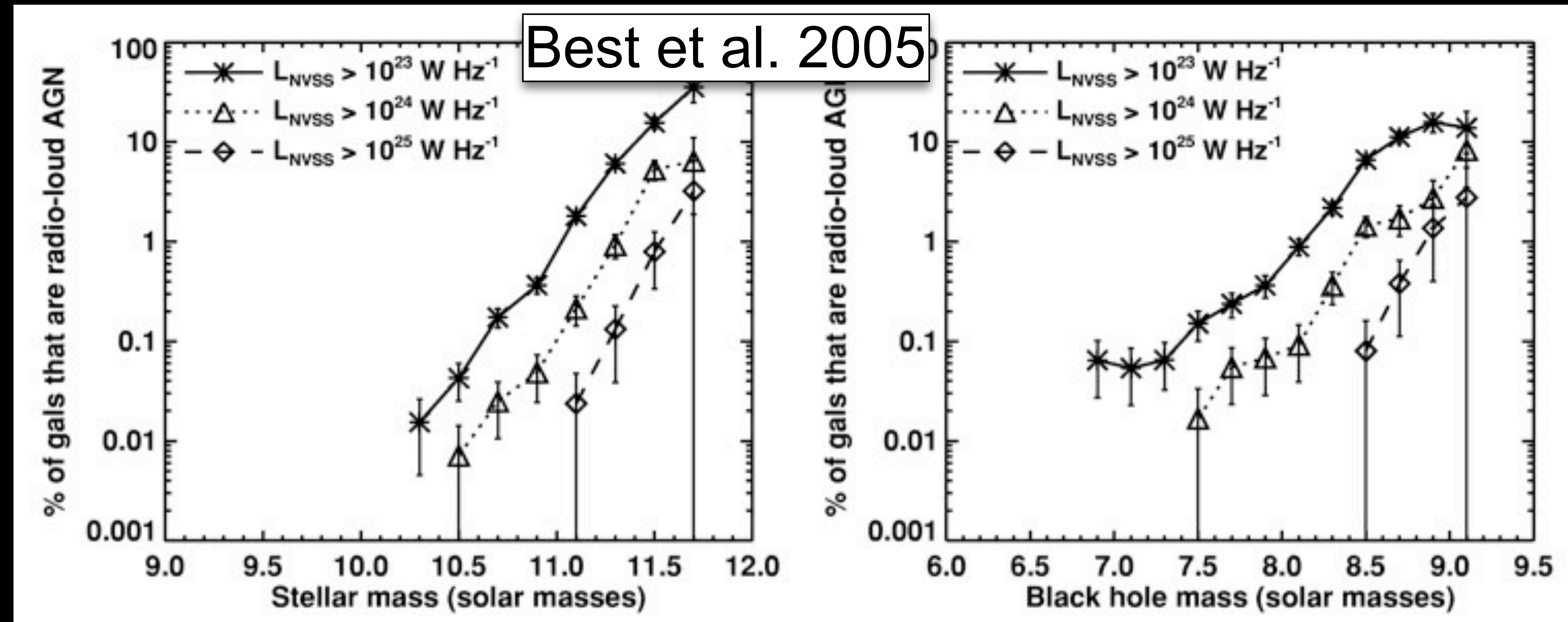
➢ Radio-loud AGN are preferentially hosted by massive early-type galaxies

➢ An interesting fraction of these galaxies are radio loud.

➢ Fraction of radio-loud increasing with mass: for the highest masses, fraction of galaxies that are radio sources > 25% (Best et al. 2005)

➢ Considering that radio-loud AGN live for only 10^7 - 10^8 yr, the radio source activity **must be constantly re-triggered**
(Kauffmann et al., Best et al. 2005)



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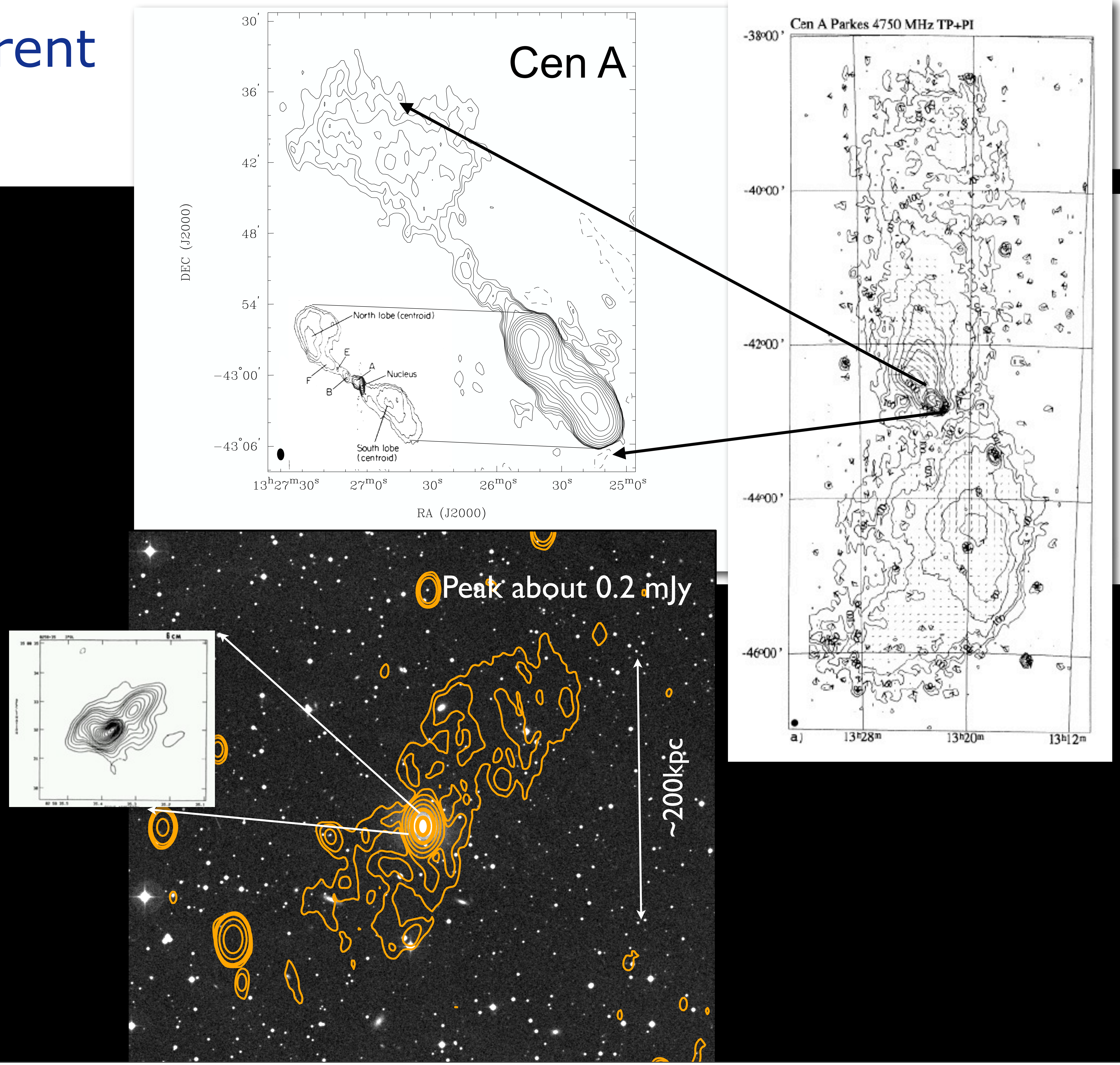

Powerful radio galaxies: energetics

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Powerful radio galaxies → $P_{radio} > 10^{23}$ W/Hz

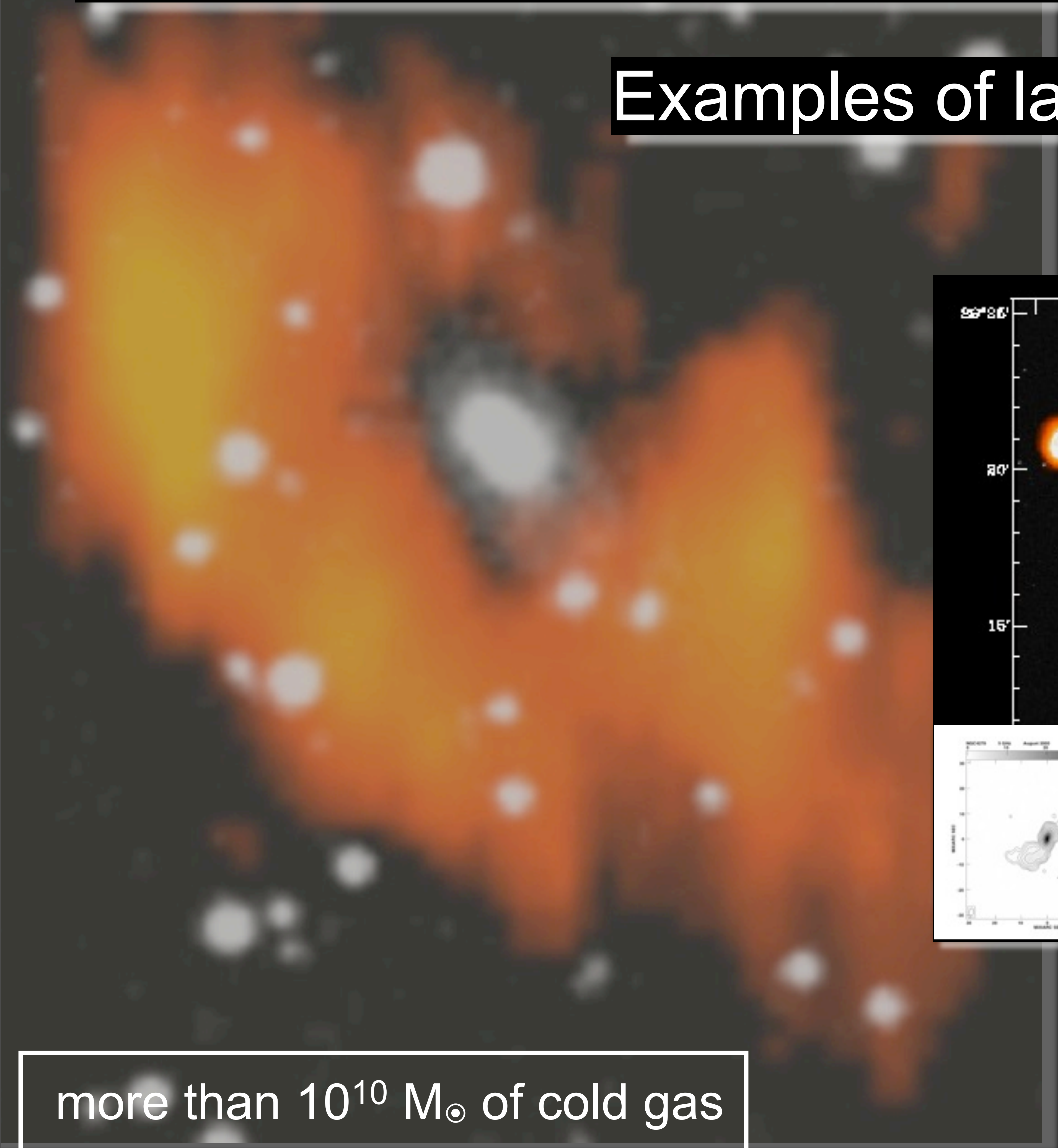
Radiation	Quasar luminosity: 10^{44} — 10^{47} erg s^{-1} Luminosity integrated over lifetime: 10^{57}—10^{62} erg
Jets	Jet power: 10^{43} —10^{47} erg s^{-1} Jet power integrated over lifetime: 10^{57} — 10^{62} erg
Winds	Total wind power: ~$0.1 L_{bol}$ (from models)? Wind power integrated over lifetime: 10^{56} — 10^{61} erg

Comparison:
Luminosity of hot ISM in a cluster: 10^{44} — 10^{45} erg s^{-1}
Grav. binding energy of gas in spiral: 10^{58} —10^{60} erg

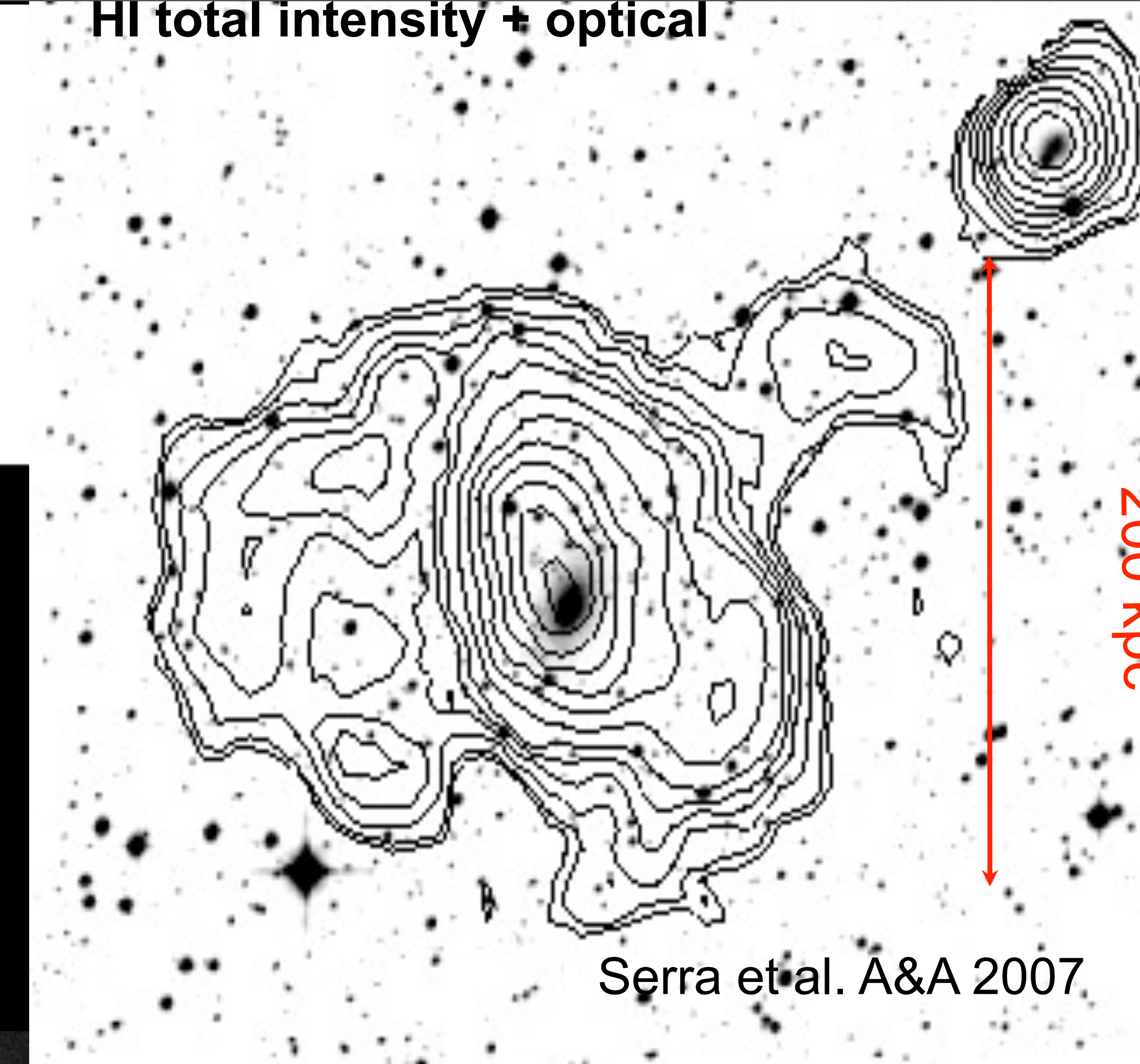
From Tadhunter 2008

....the gas is there!

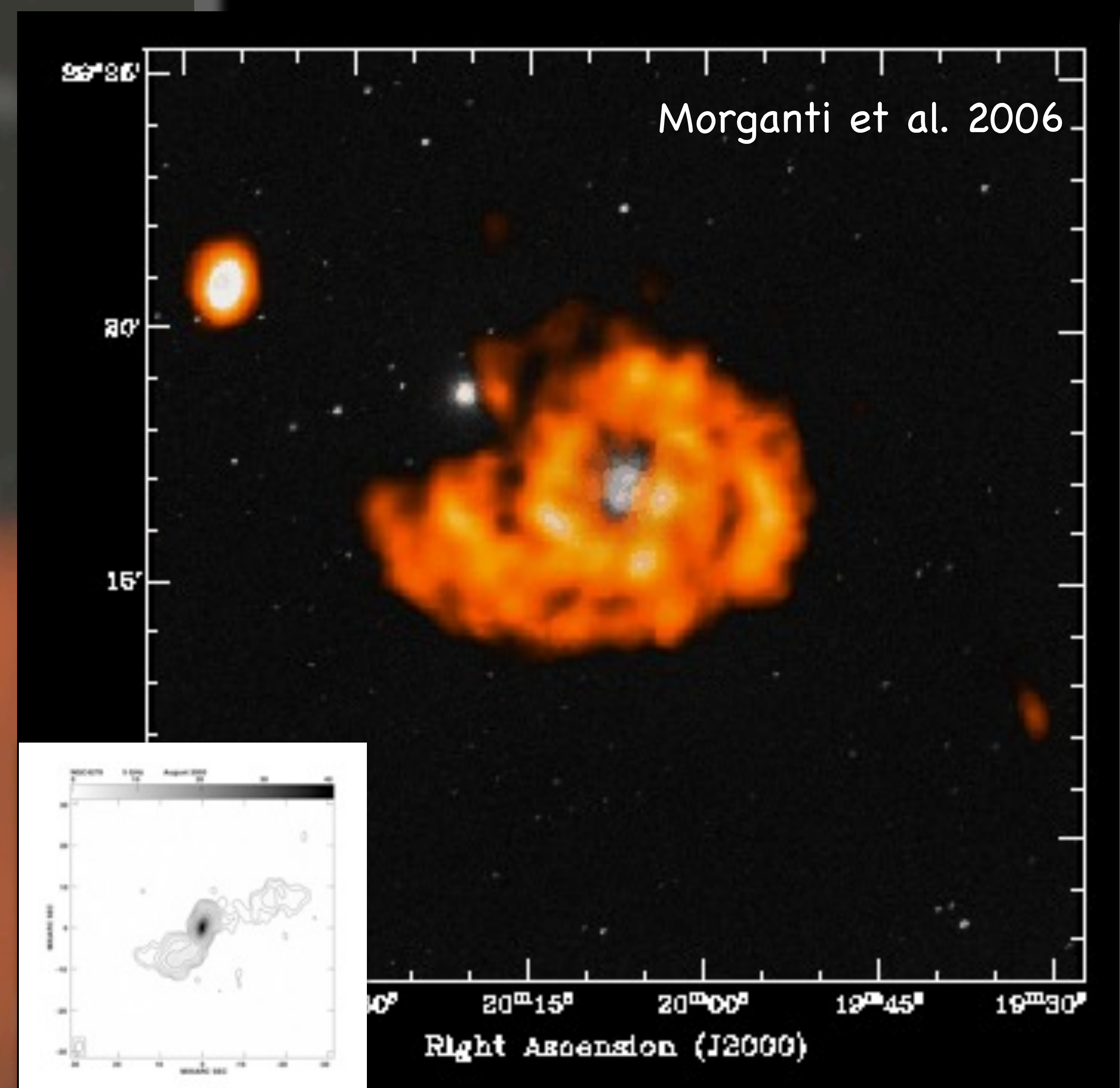
- Early-type galaxies (with or without AGN) with gas ➔ red galaxies can have a lot of gas: cold (HI, molecular), warm ionised and hot gas

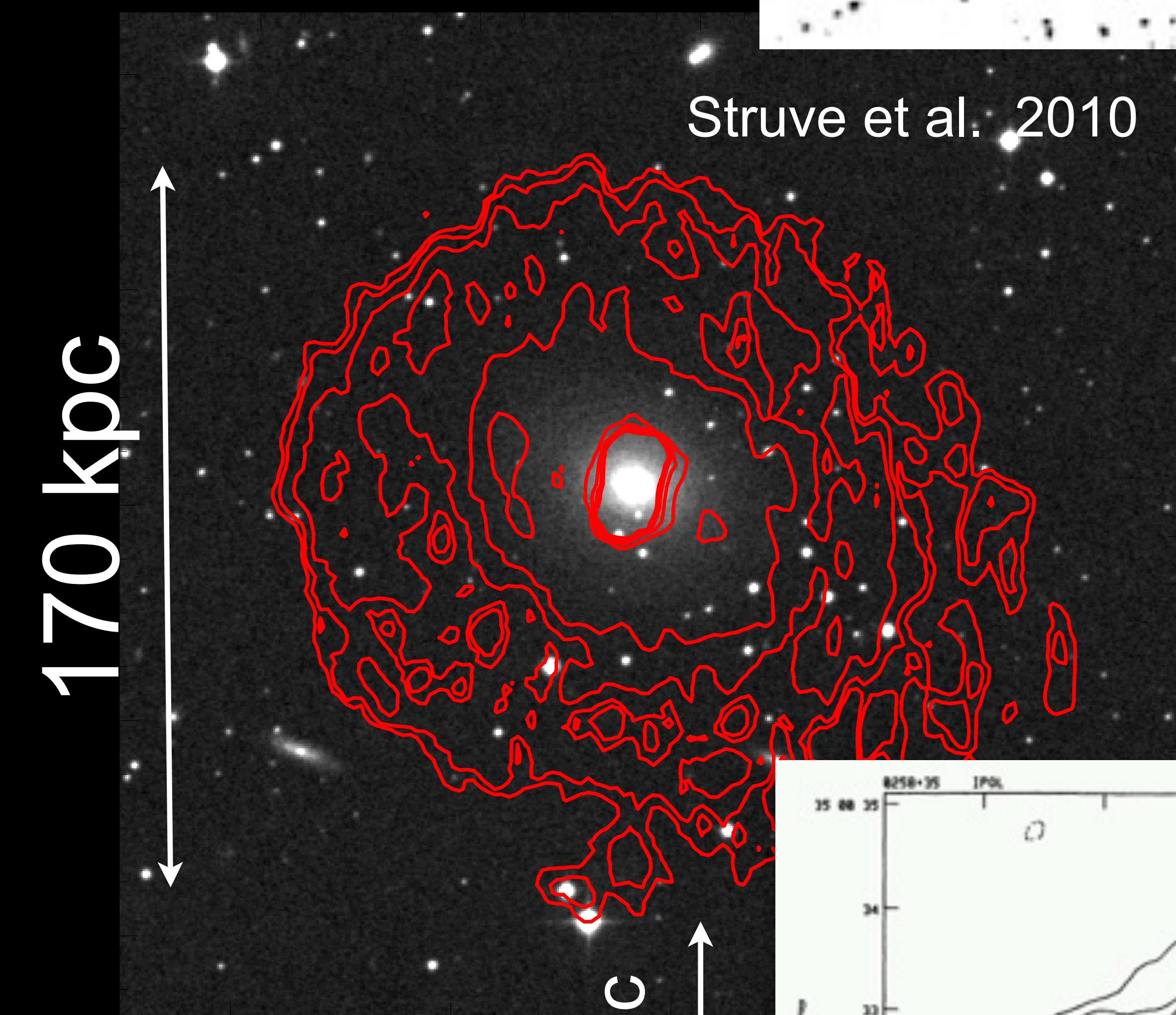


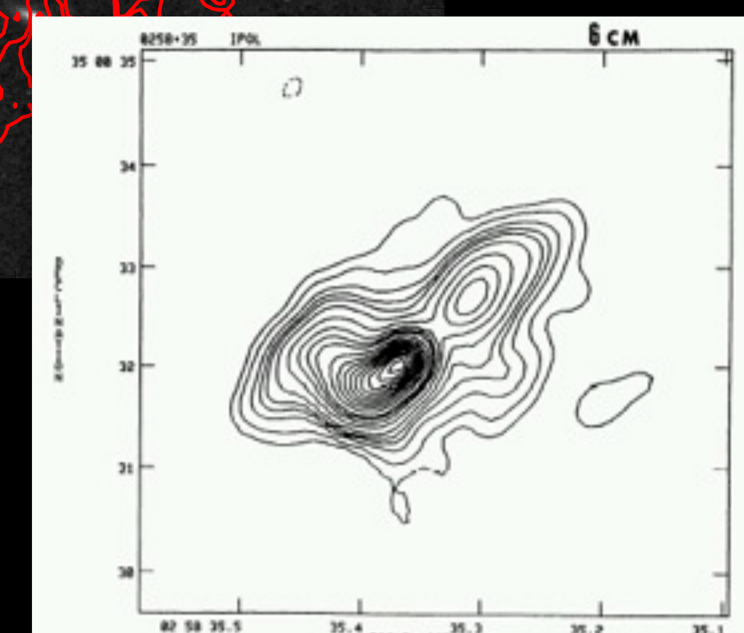
more than 10^{10} $M_\odot$ of cold gas



Examples of large HI disk in early-type galaxies







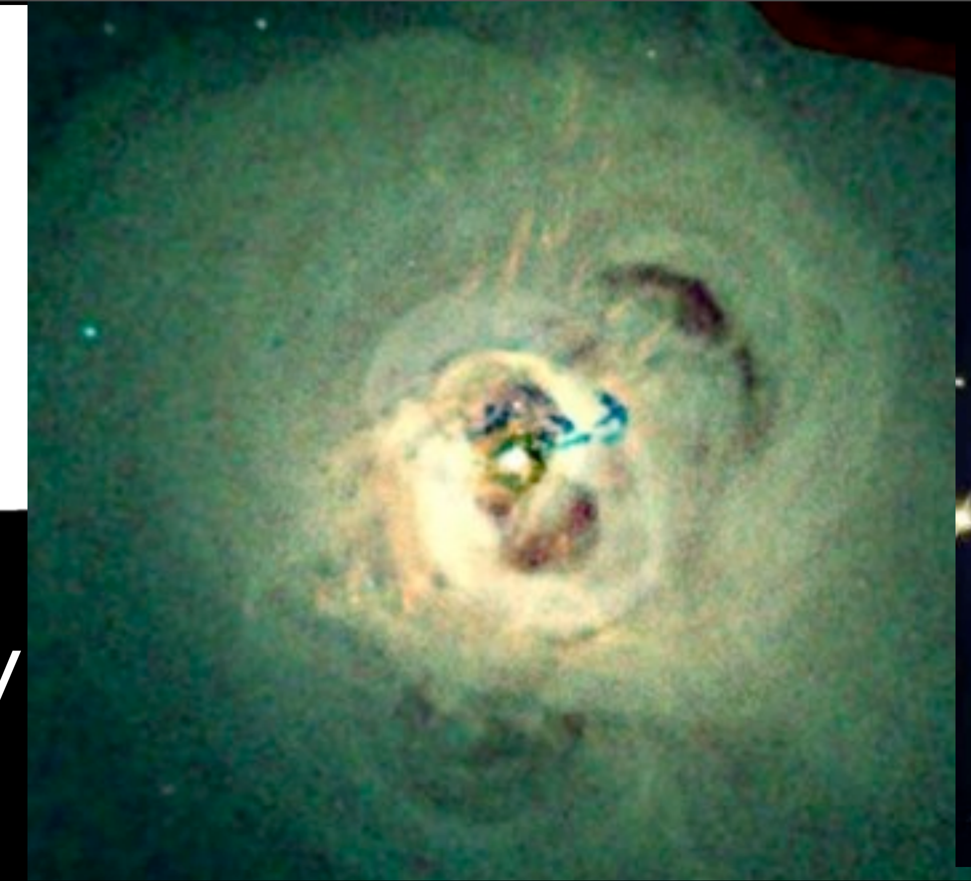
Morganti et al. 2006, Emonts et al. 2010,Oosterloo et al. 2010, Serra et al. 2011 and many others ...

..... signs of merger are also there ....

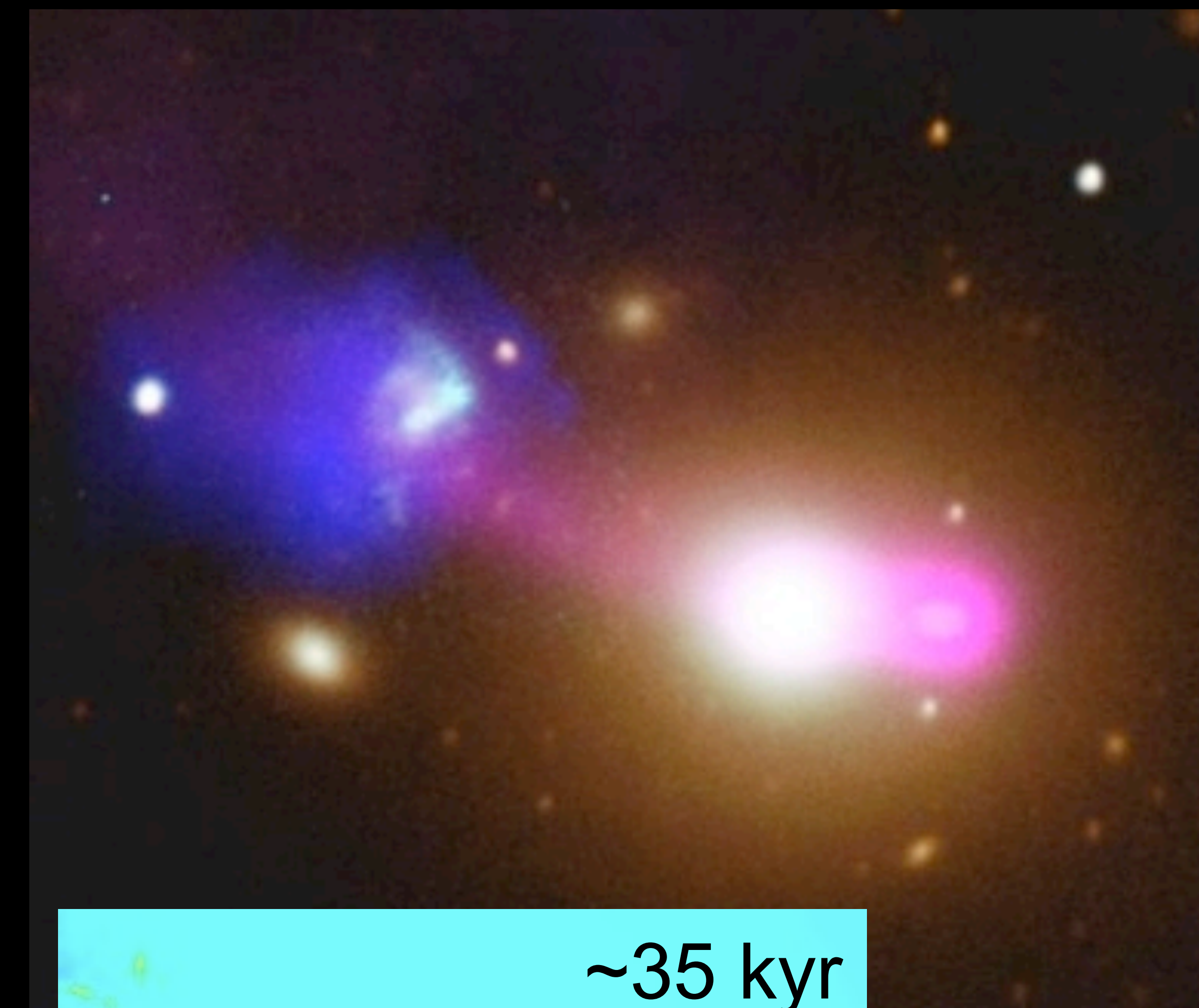
......although not very case is a major (gas-rich) merger (about 30%)

Heckman et al. 1986
Ramos Almeida et al. 2011

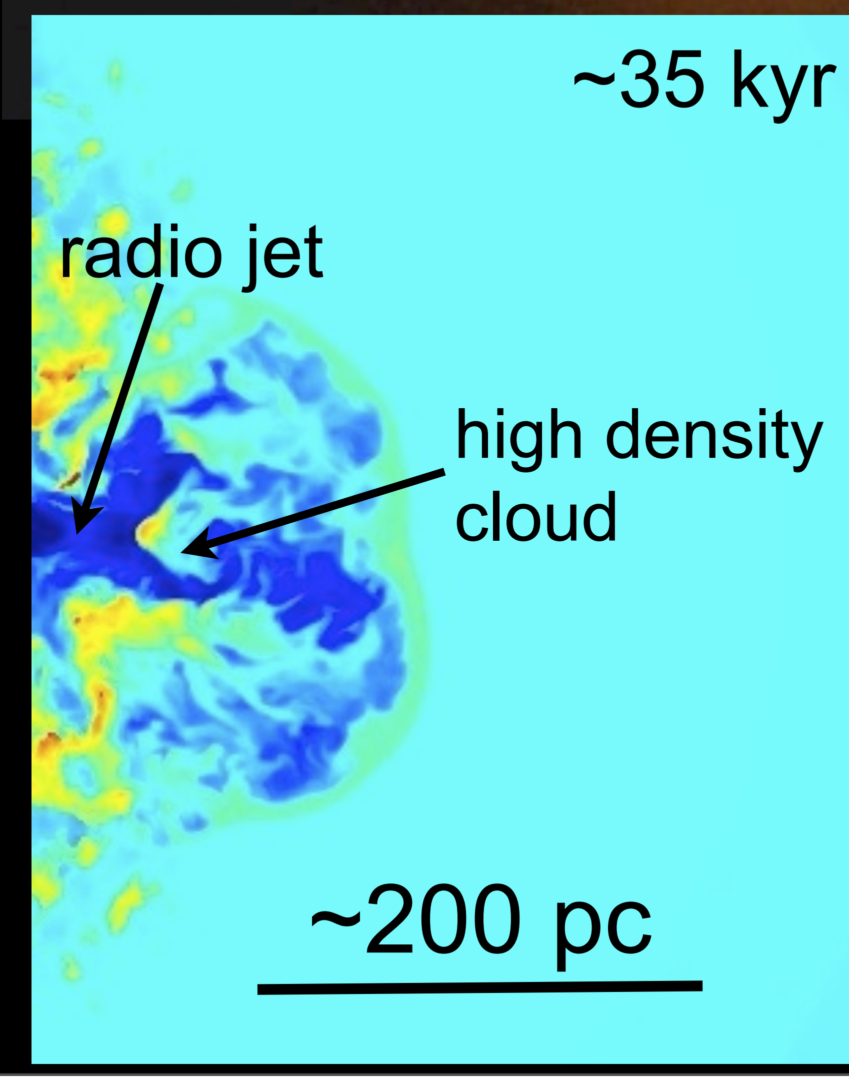
The many (often competing) roles for radio jets



- Jets provide a way of transporting the energy out: they couple efficiently to the ISM/IGM and inject energy into the large-scale ISM/IGM medium => therefore *preventing gas to cool to form stars* (leaving signatures like X-ray cavities, McNamara & Nulsen 2007, Birzan et al. 2008).
- Jets can help in *triggering star formation* via the effects of shocks and compression of clouds in the ISM (Mellema et al. 2004, Fragile et al. 2004, Croft et al. 2007).



- They can *produce fast gaseous outflows* from the central regions as seen in young radio galaxies, *removing gas* from the centre of a galaxy
- BUT a particularly dense ISM surrounding an AGN can have the opposite effect by blocking the expansion of the AGN, or even destroying the jets therefore strongly *limiting the region over which the AGN has influence* (Wagner & Bicknell 2011).



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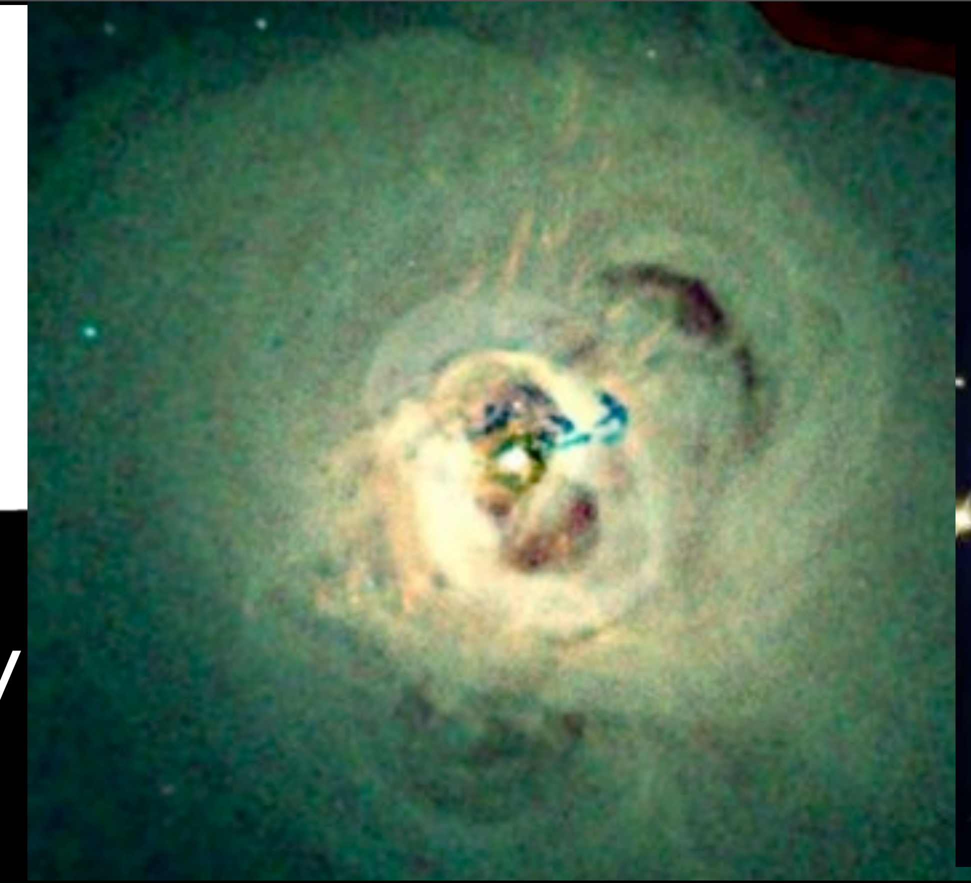

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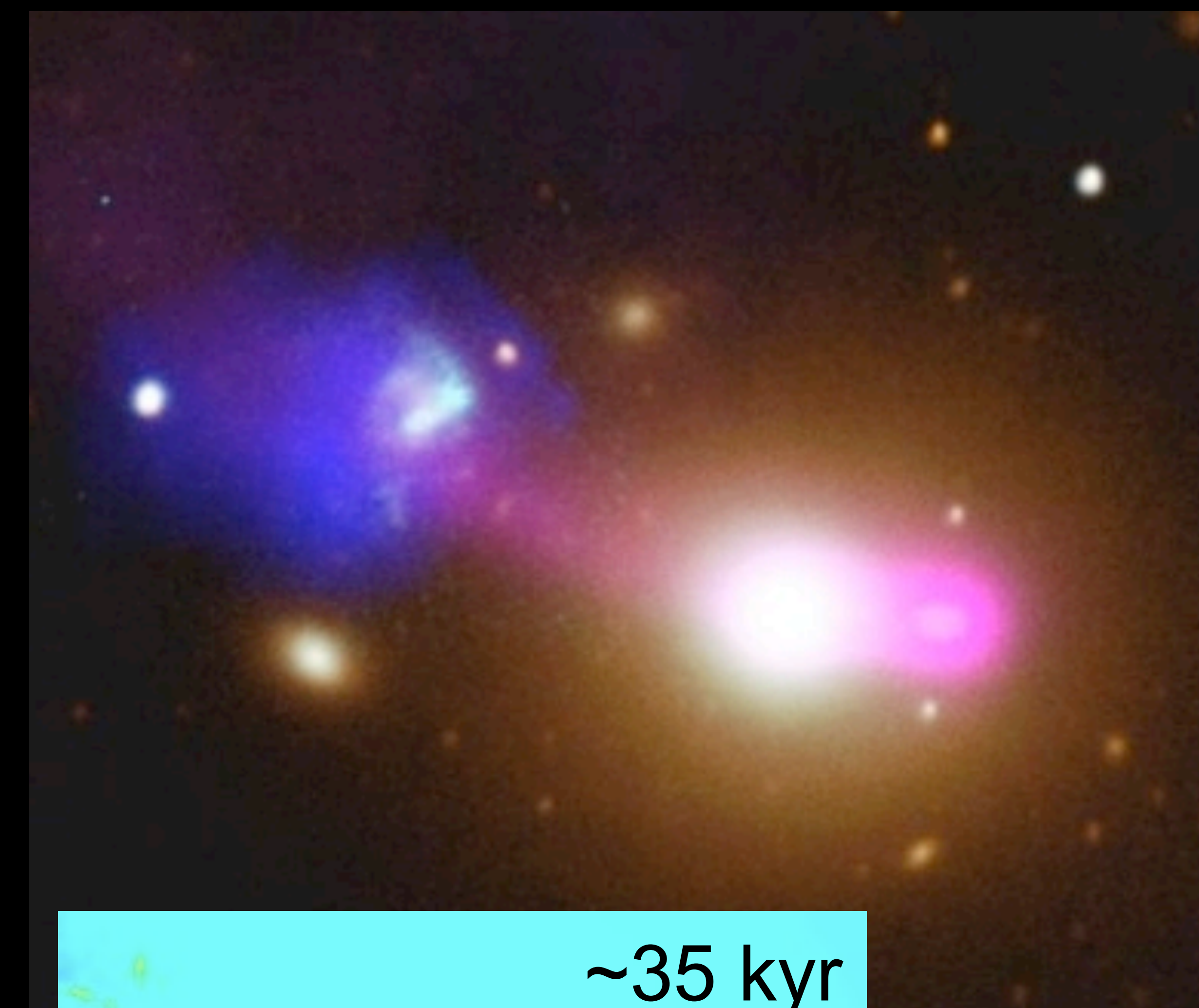

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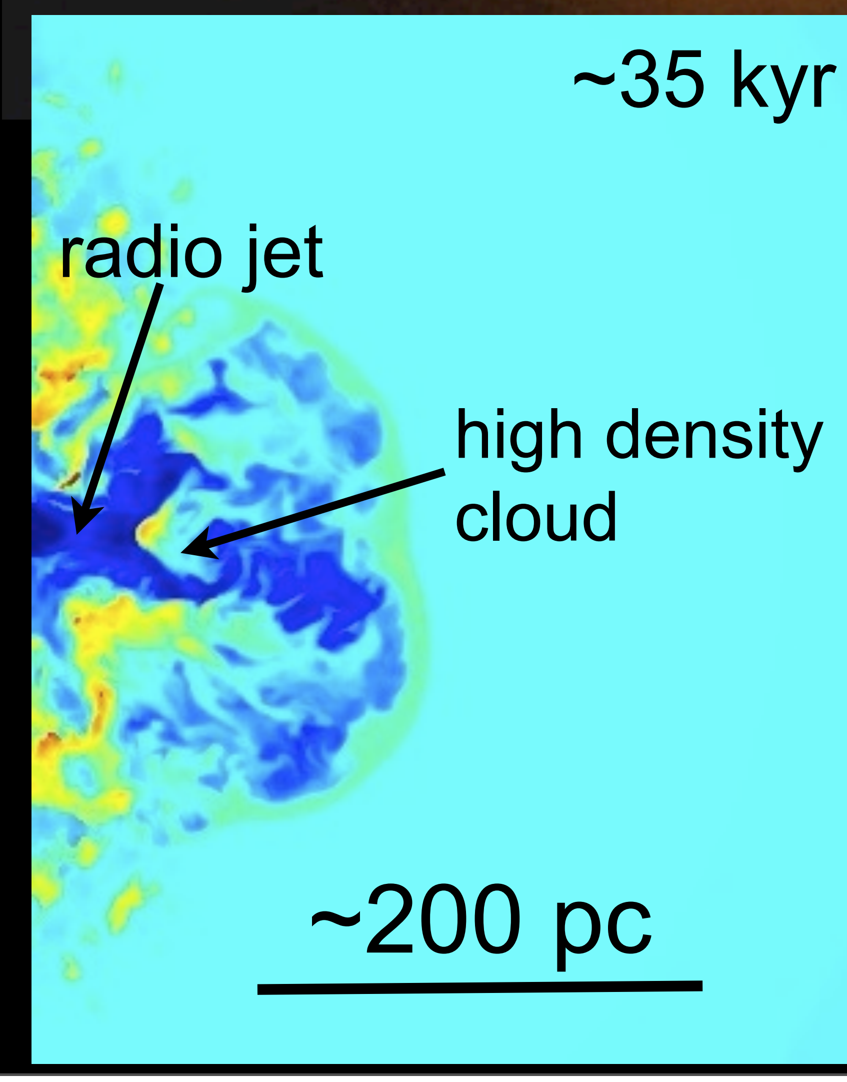


Simulations of radio jets - impact on ISM

- Importance of radio jets on the ISM ➔ cocoons around the jet (not only the narrow radio jet but shocked/disturbed gas over a large region)
- Energy associated with the jets: wide range ➔ enough to be relevant?
- Various phases of the gas traced in the interaction - fast gaseous outflows **including cold gas! atomic neutral (HI) an molecular (recent finding!)**

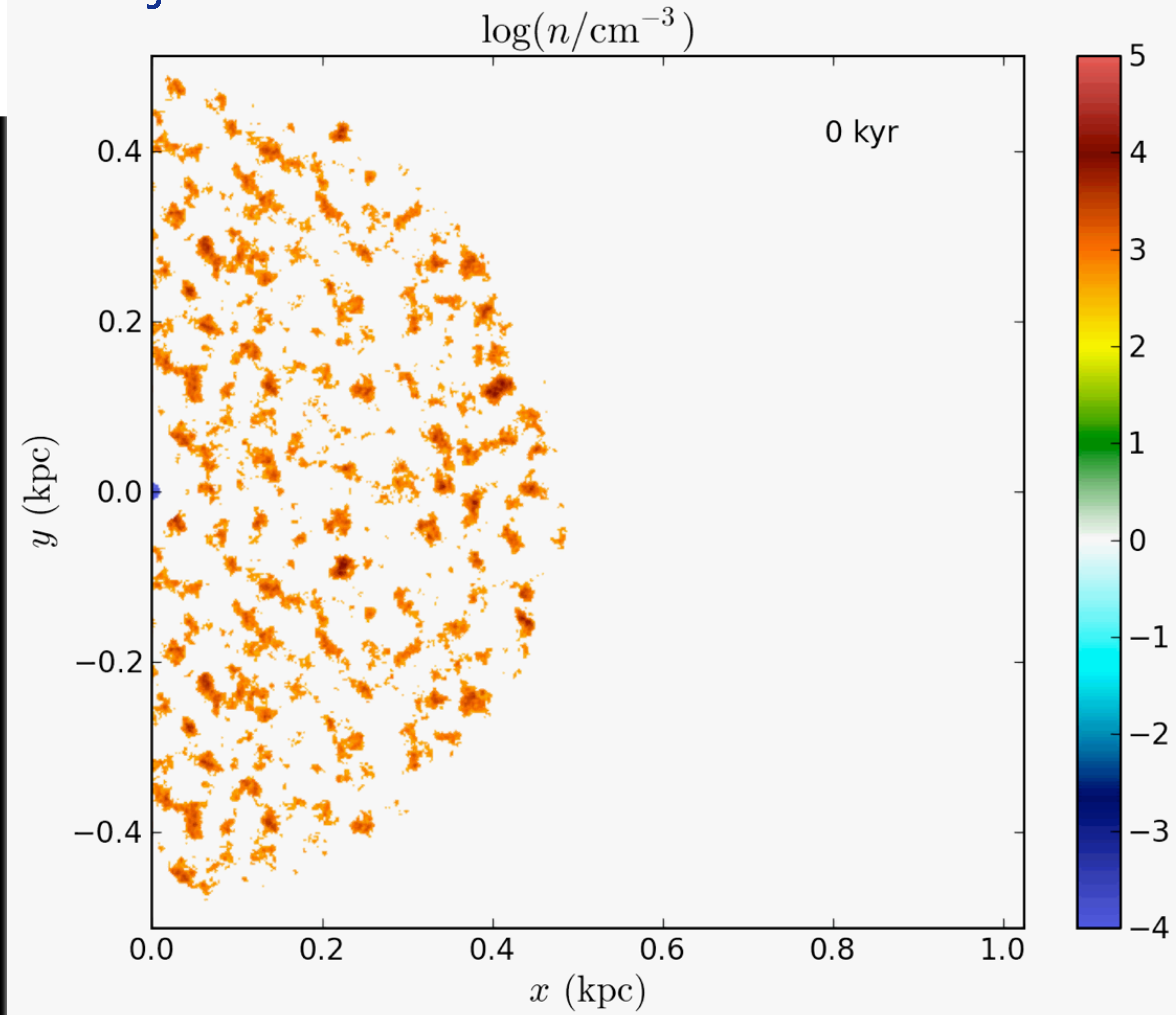
Importance of the first phase of the jet

Powerful, relativistic jet

Jet power = 10^{45} erg/s

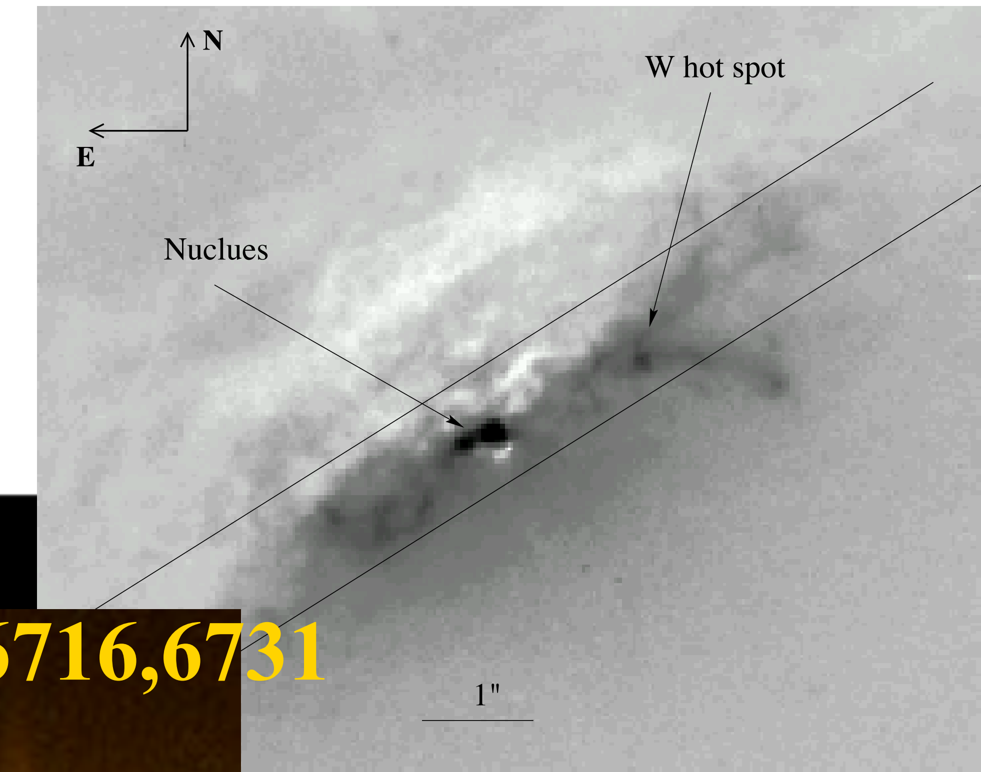
the jet is very light and overpressured

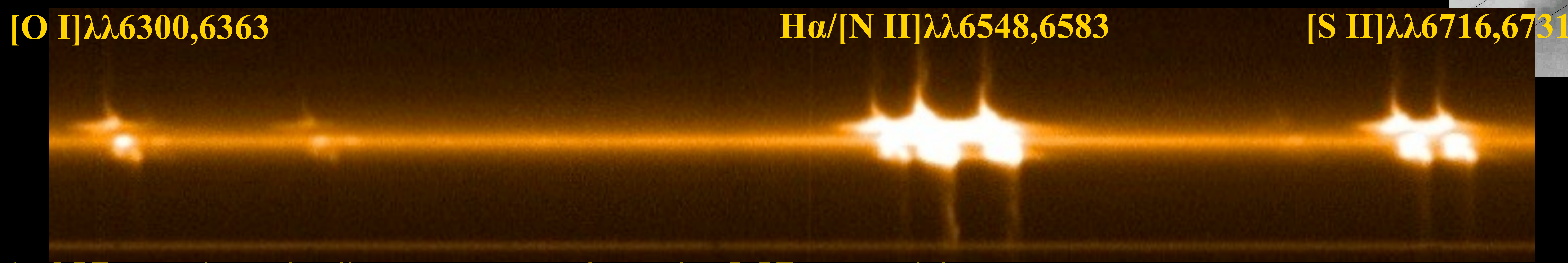
simulations from:
Wagner & Bicknell 2011 ApJ 728, 29



How can we trace this with real data?

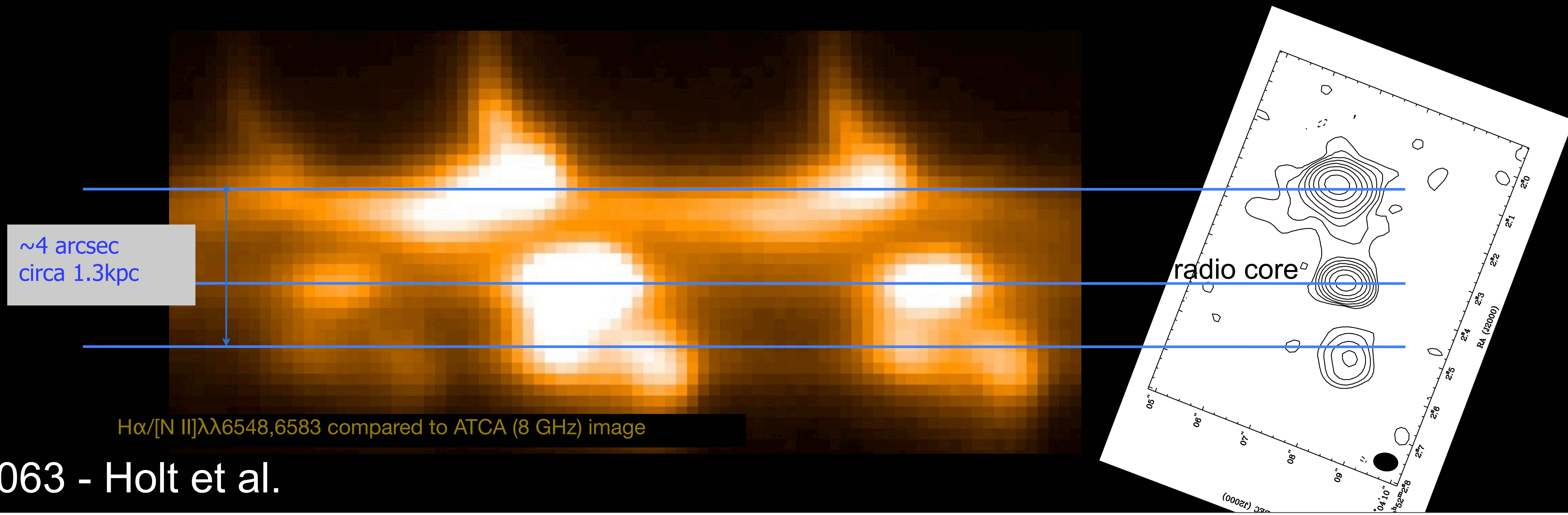
Outflows in warm (ionised) gas....expected from the shocks





part of 2D spectrum (red)

pix scale: 0.27 arcsec/pix



Hα/[N II]λλ6548,6583 compared to ATCA (8 GHz) image

IC5063 - Holt et al.

Cold gas (HI) detected in absorption

Cold gas (HI) detected in absorption

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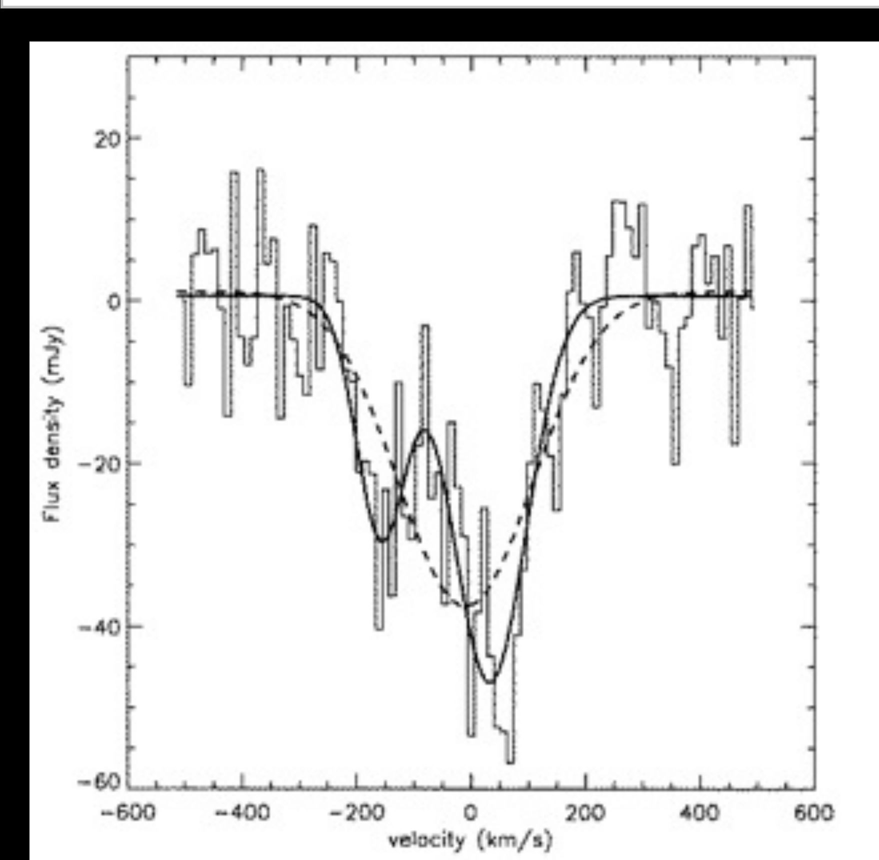
HI absorption from the torus or from circumnuclear disks



Cygnus A

~150 km/s

Conway & Blanco 1995

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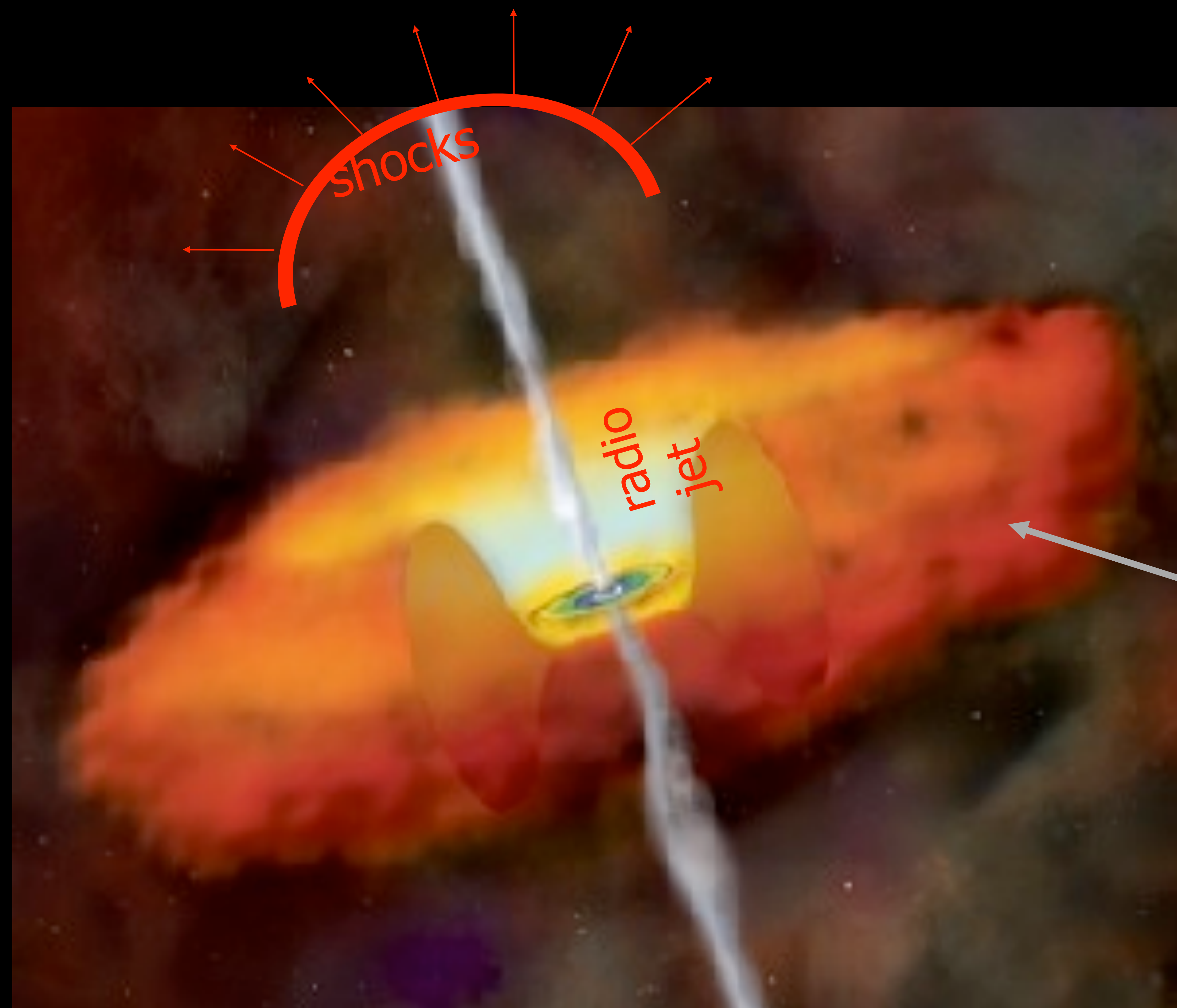

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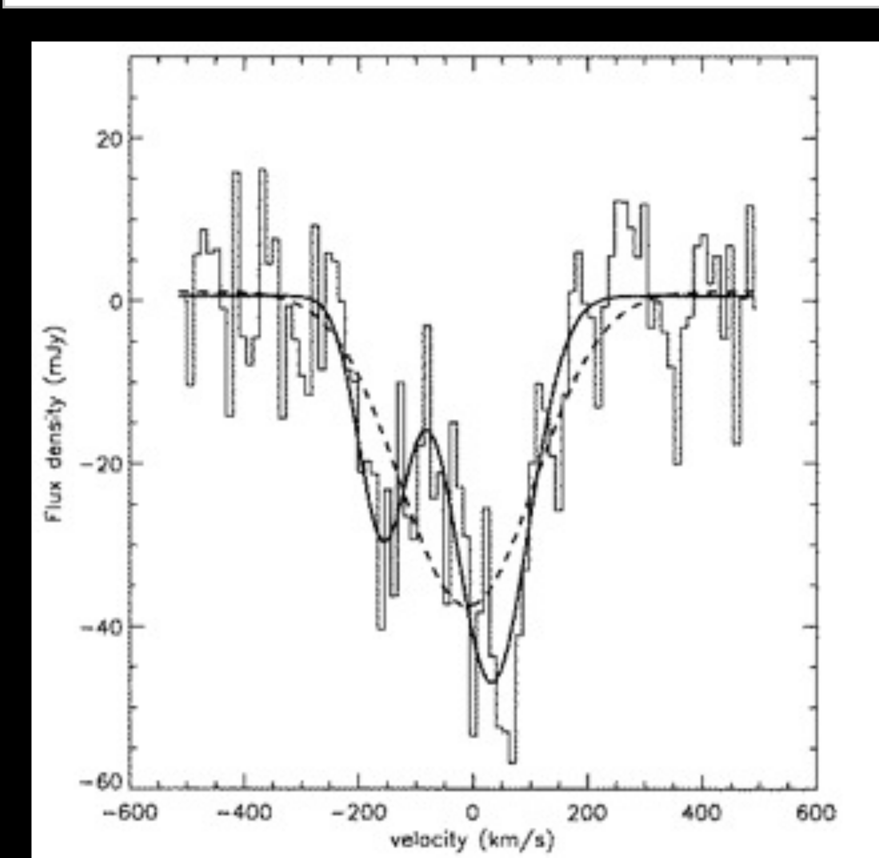

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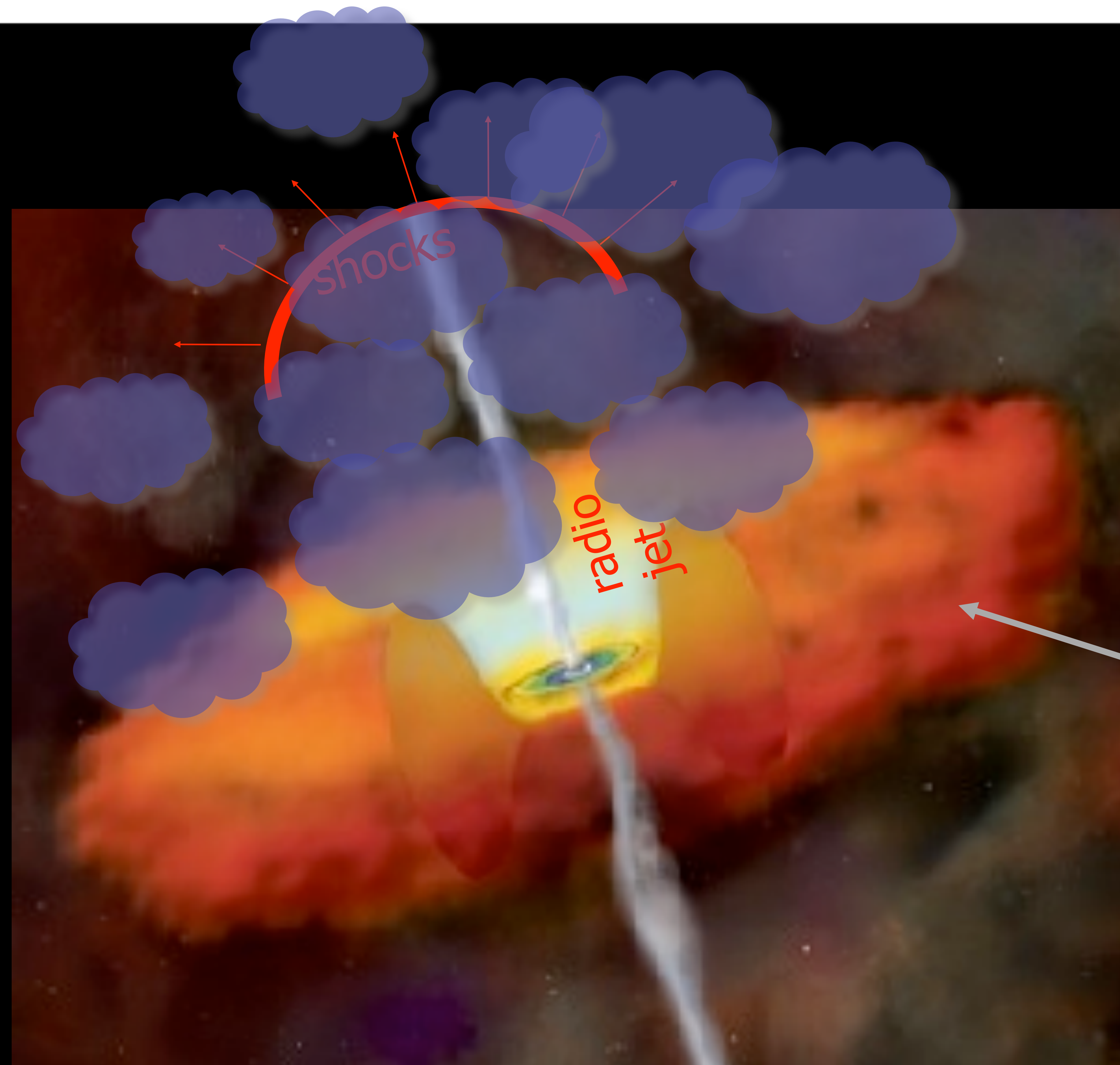
ASTRON



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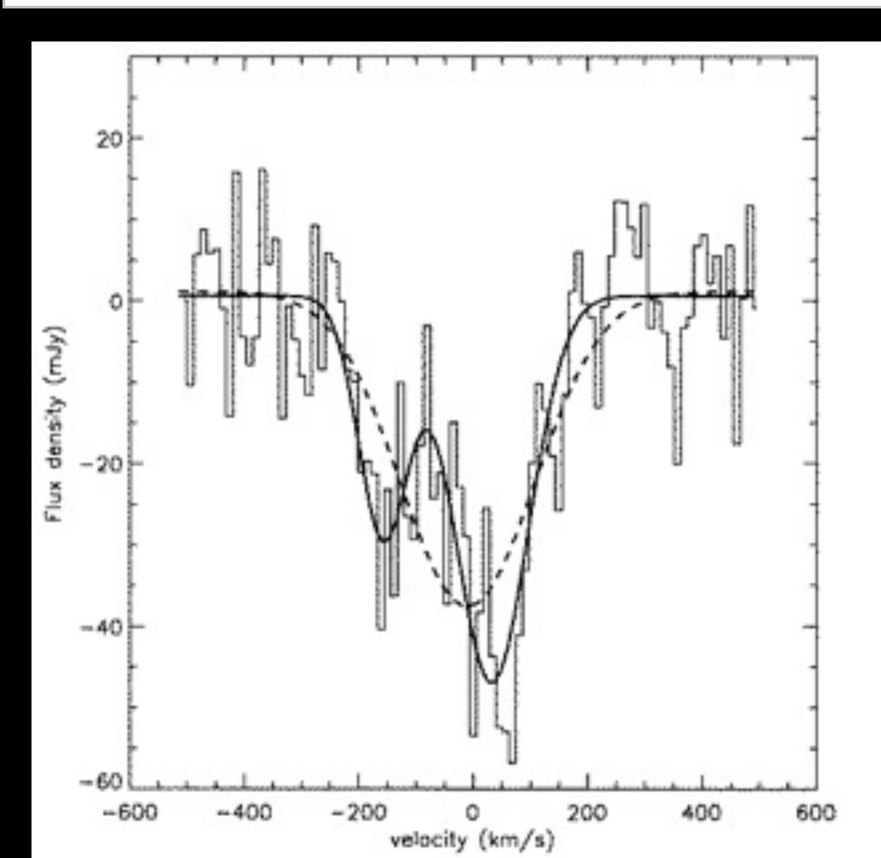

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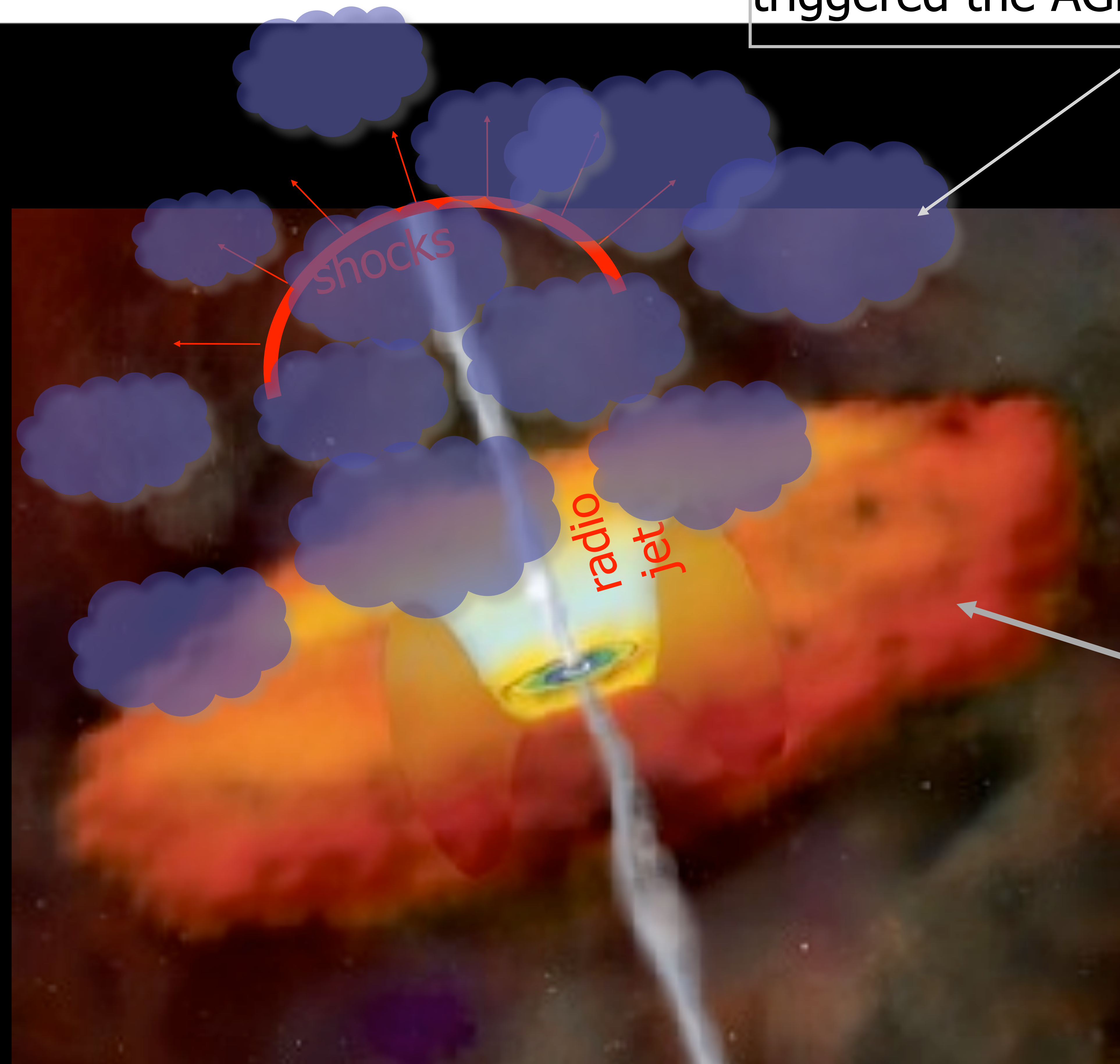
Cold gas (HI) detected in absorption

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



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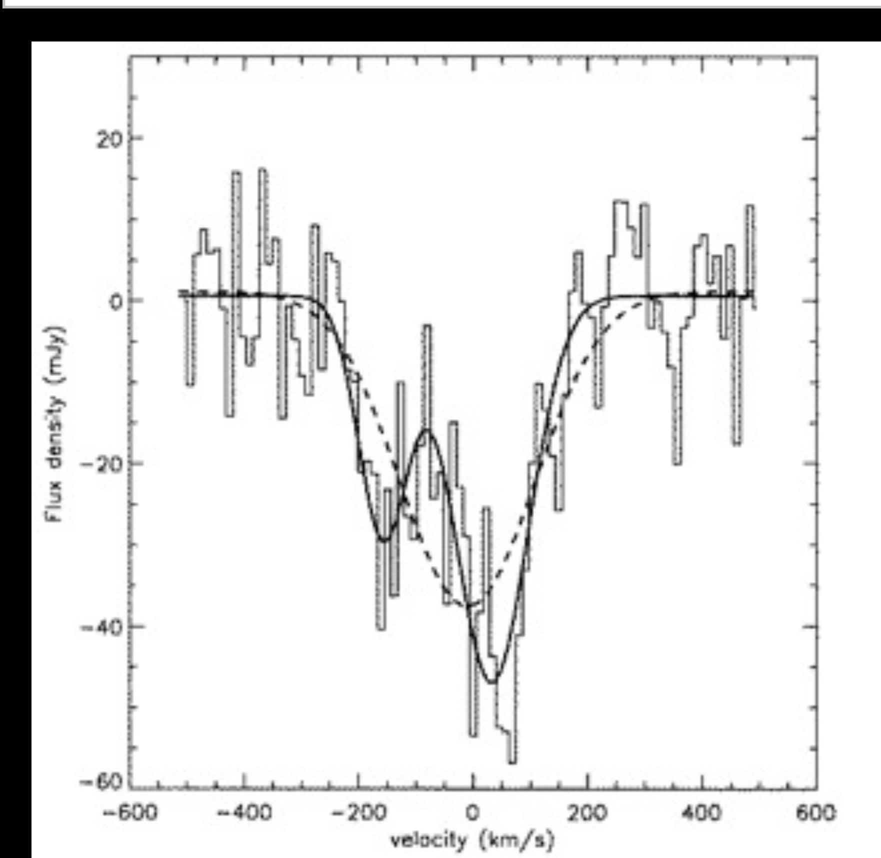

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Conway & Blanco 1995

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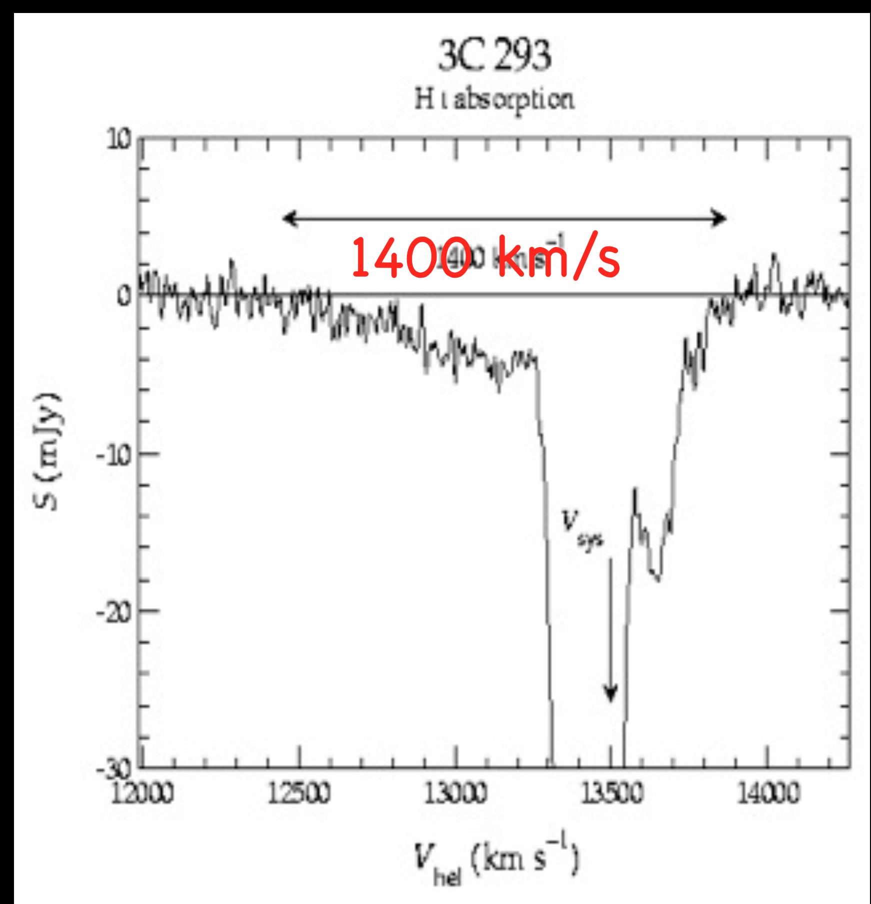
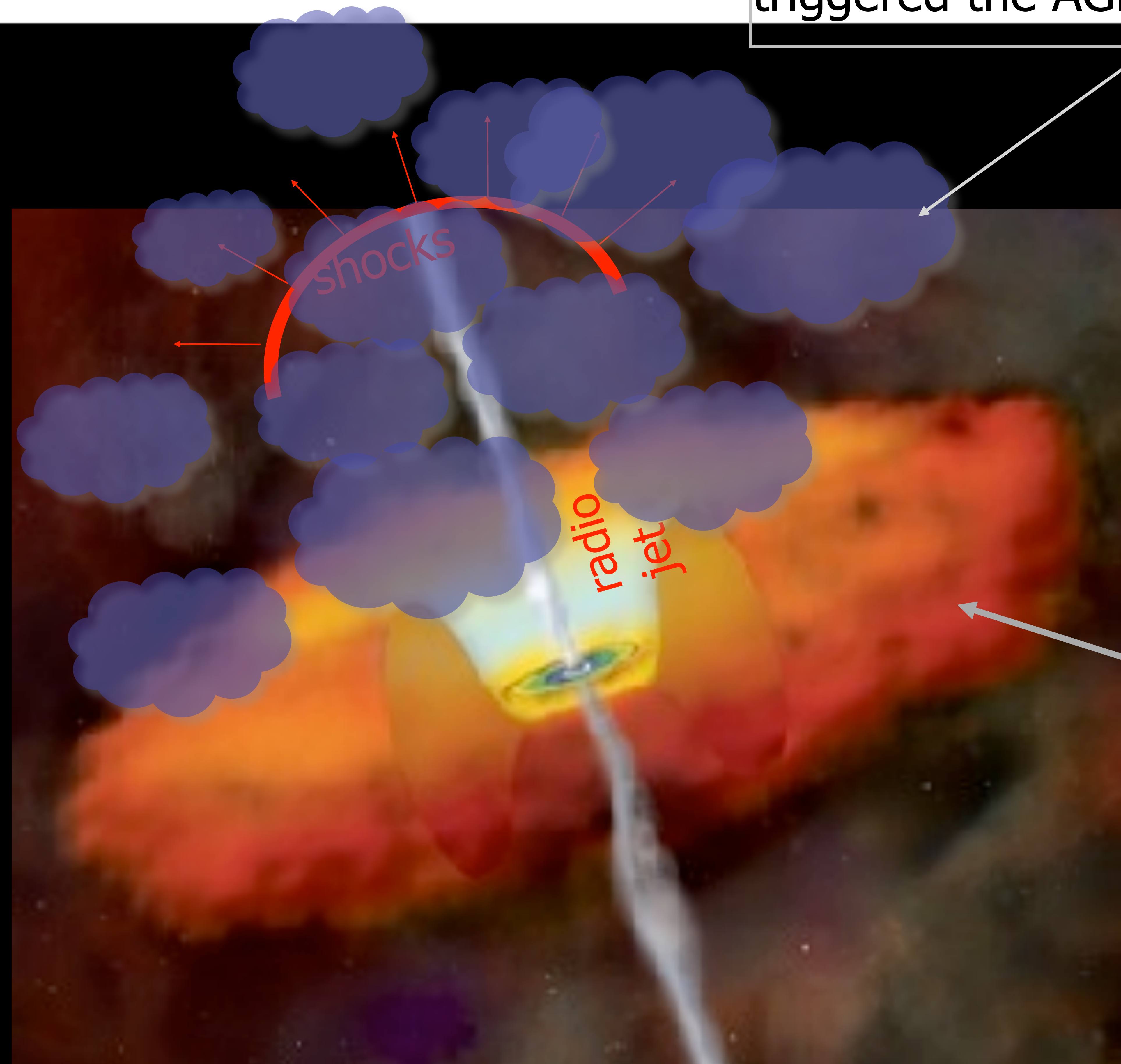
Fast outflows: observed in ionised gas and HI
How important is the radio jet?





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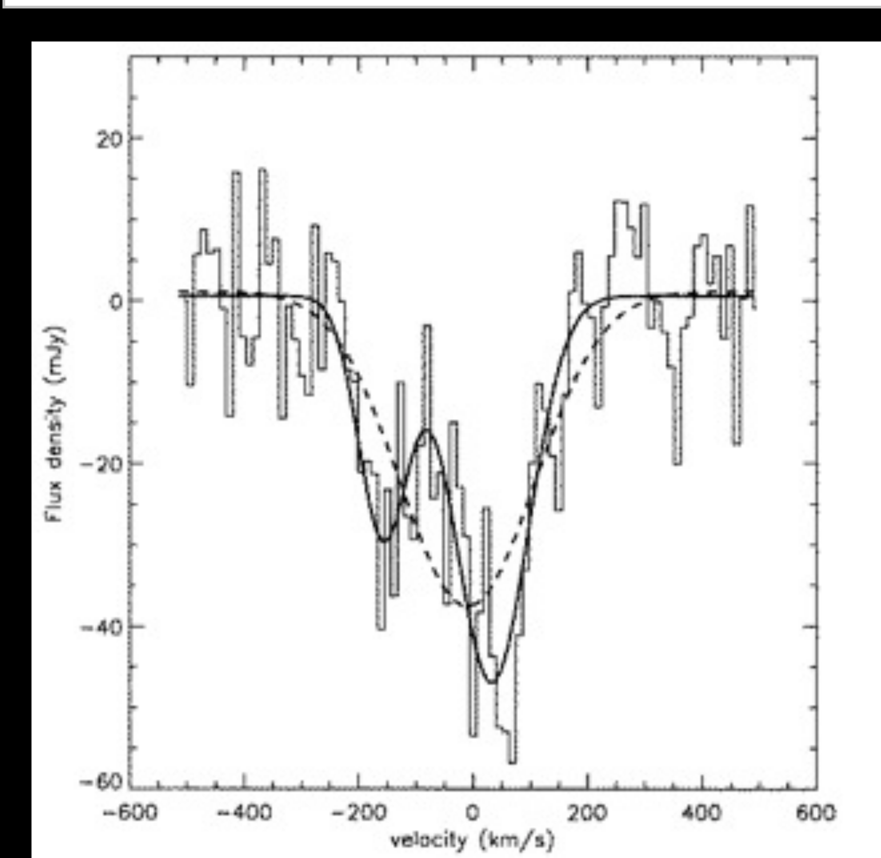

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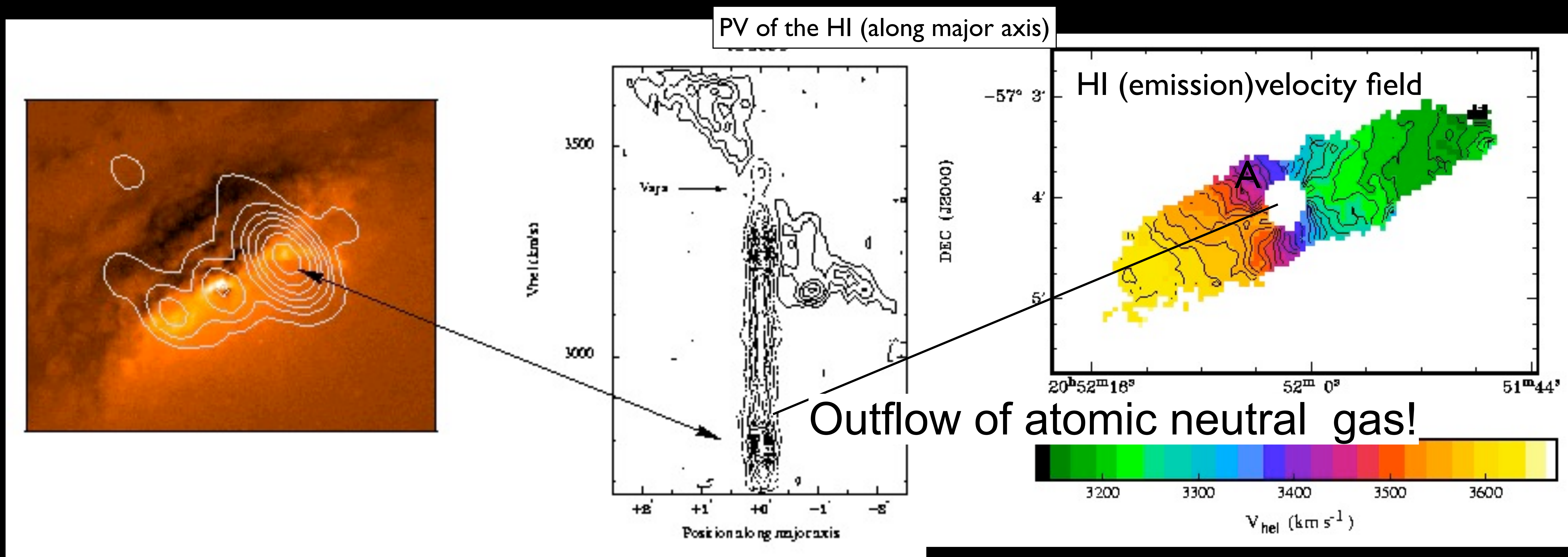
~150 km/s

Conway & Blanco 1995

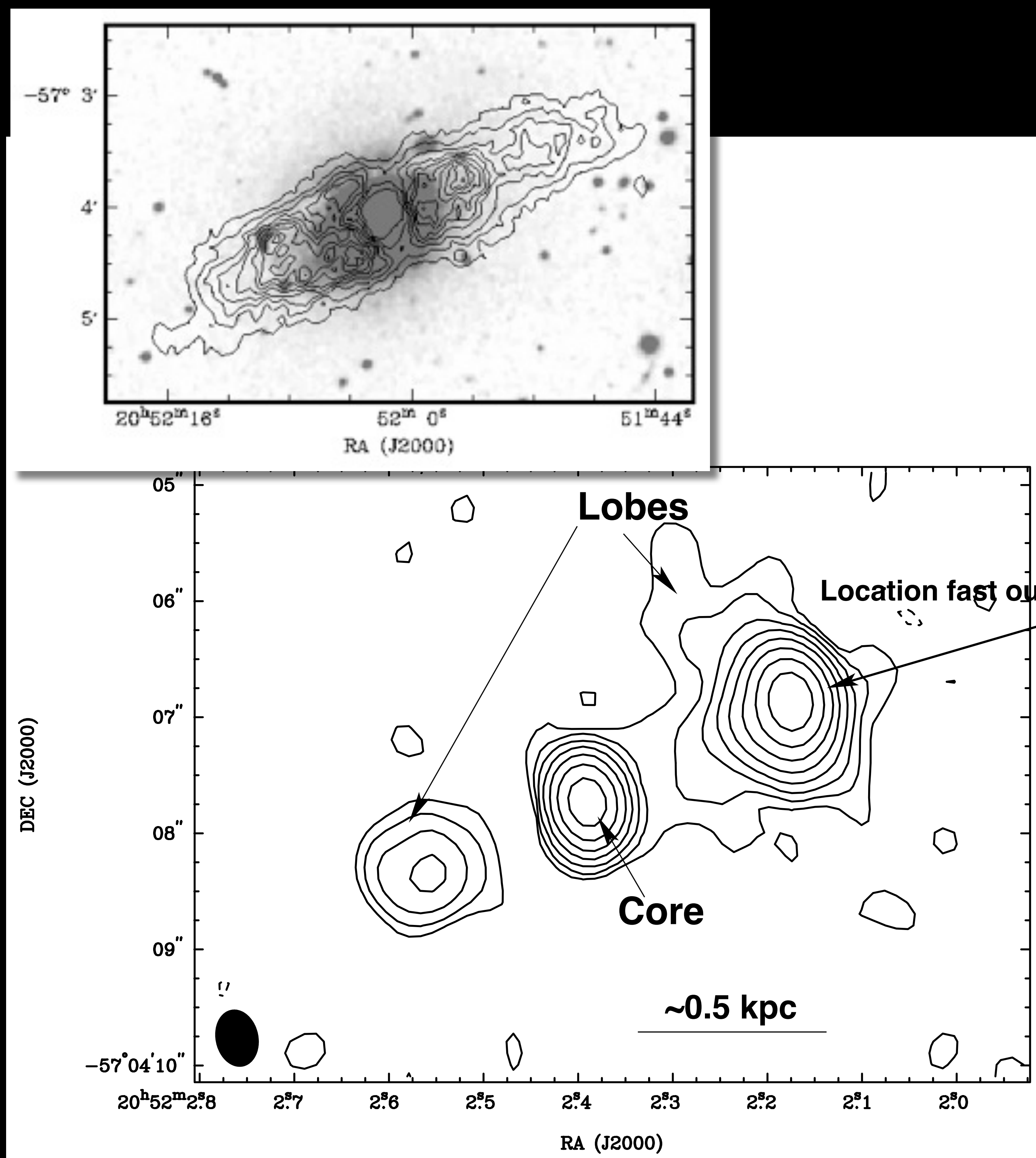
IC5063: off-nuclear HI outflows

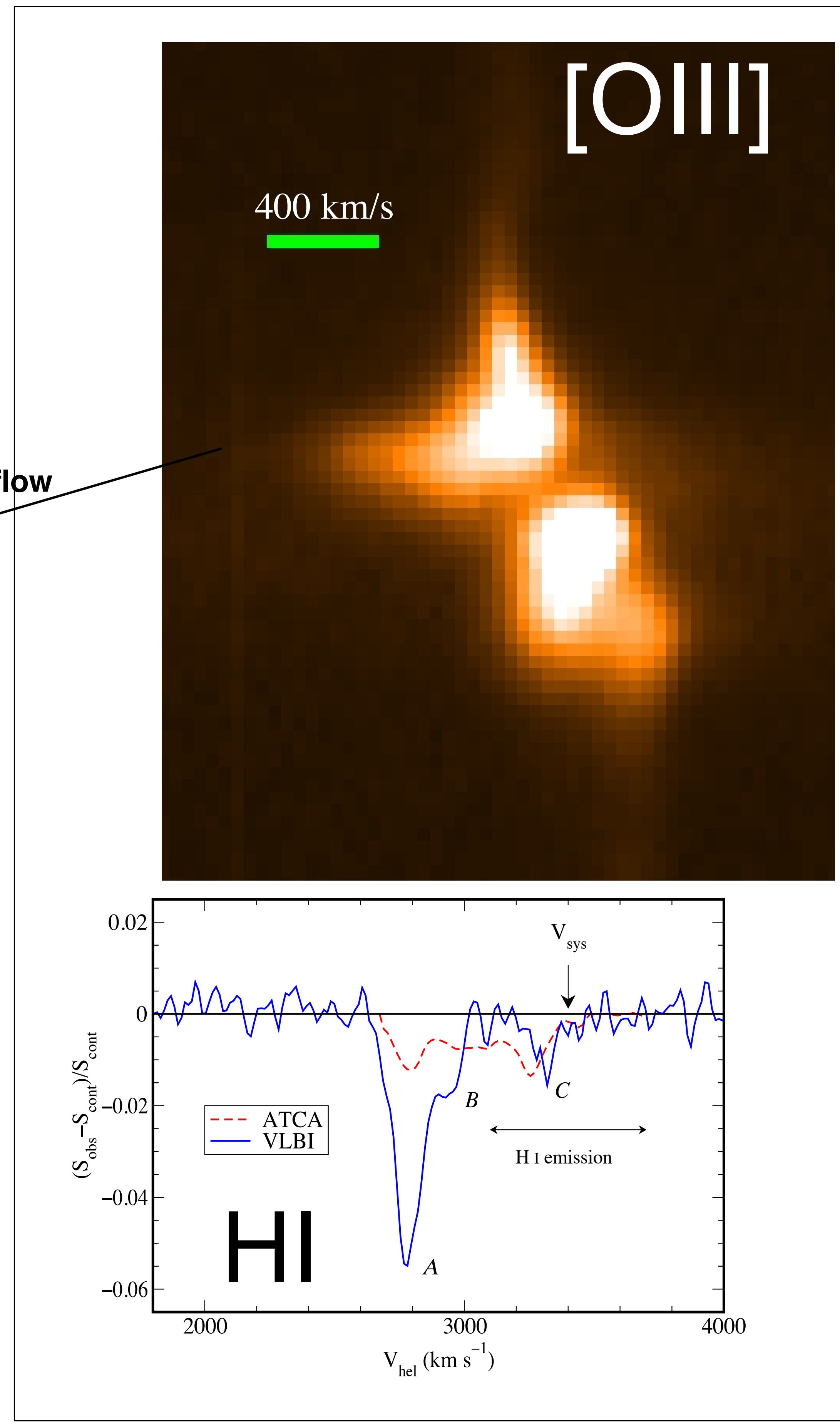
- First case of **fast outflow (700 km/s) of neutral hydrogen** (Morganti et al. 1998, Oosterloo et al. 2000)
- One of the clearer examples of jet/cloud interaction: outflow **at the location of the bright radio lobe**



At the same location as the outflow of ionised gas

Multiphase gas outflow: ionised, atomic neutral, molecular





Mass outflow rate HI gas ~ M_{dot}= 12 $M_\odot$/yr

ionised gas ~ M_{dot}= 0.08 $M_\odot$/yr

(Morganti et al. 2007)

Multiphase gas outflow: ionised, atomic neutral, molecular

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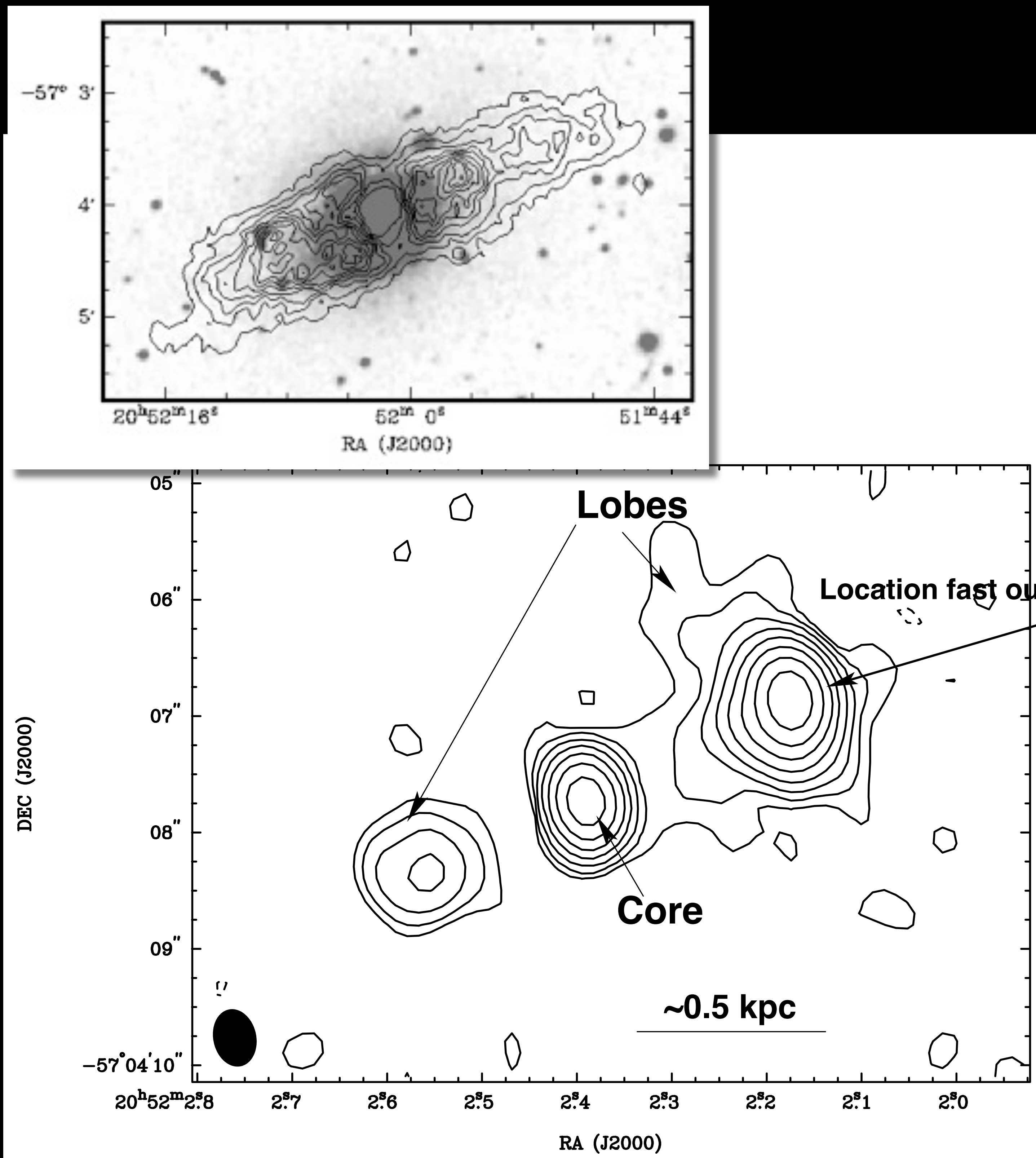

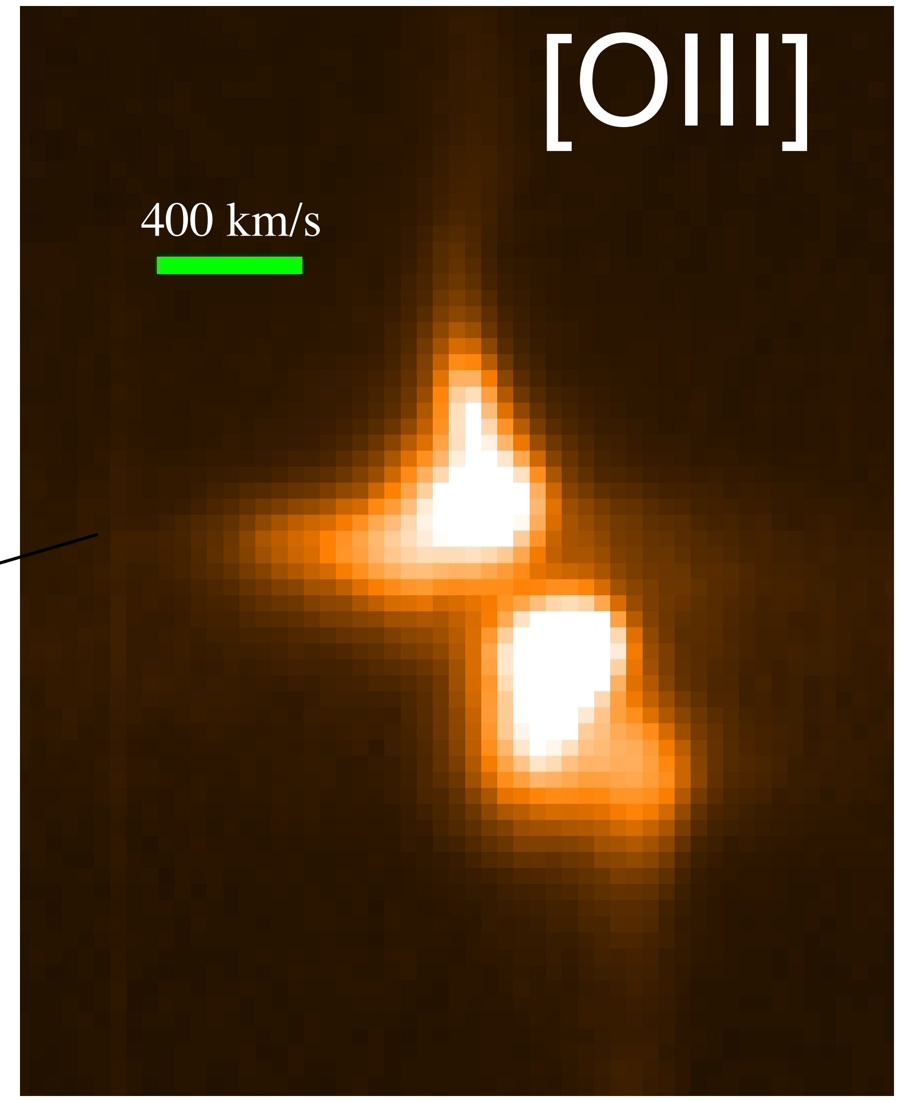

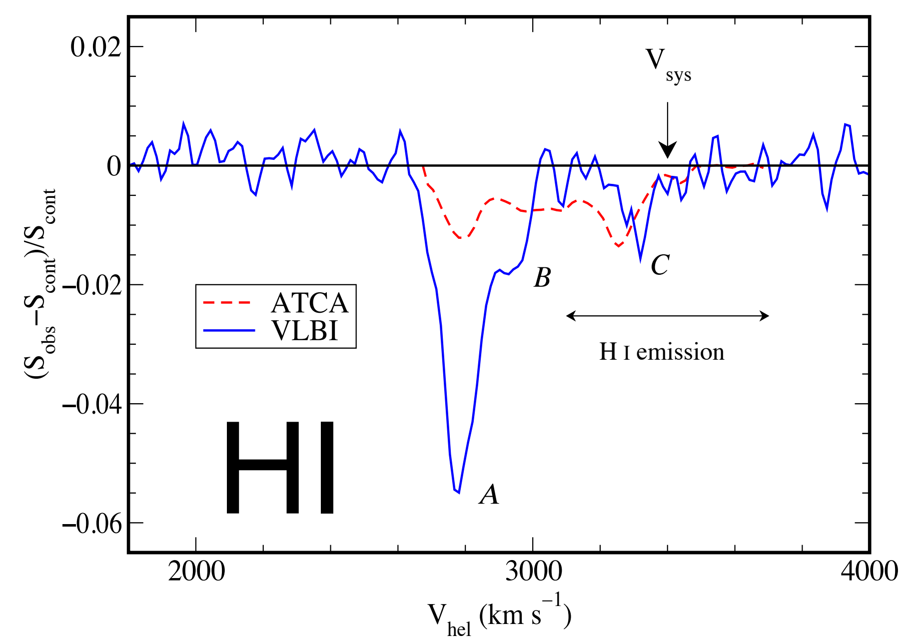

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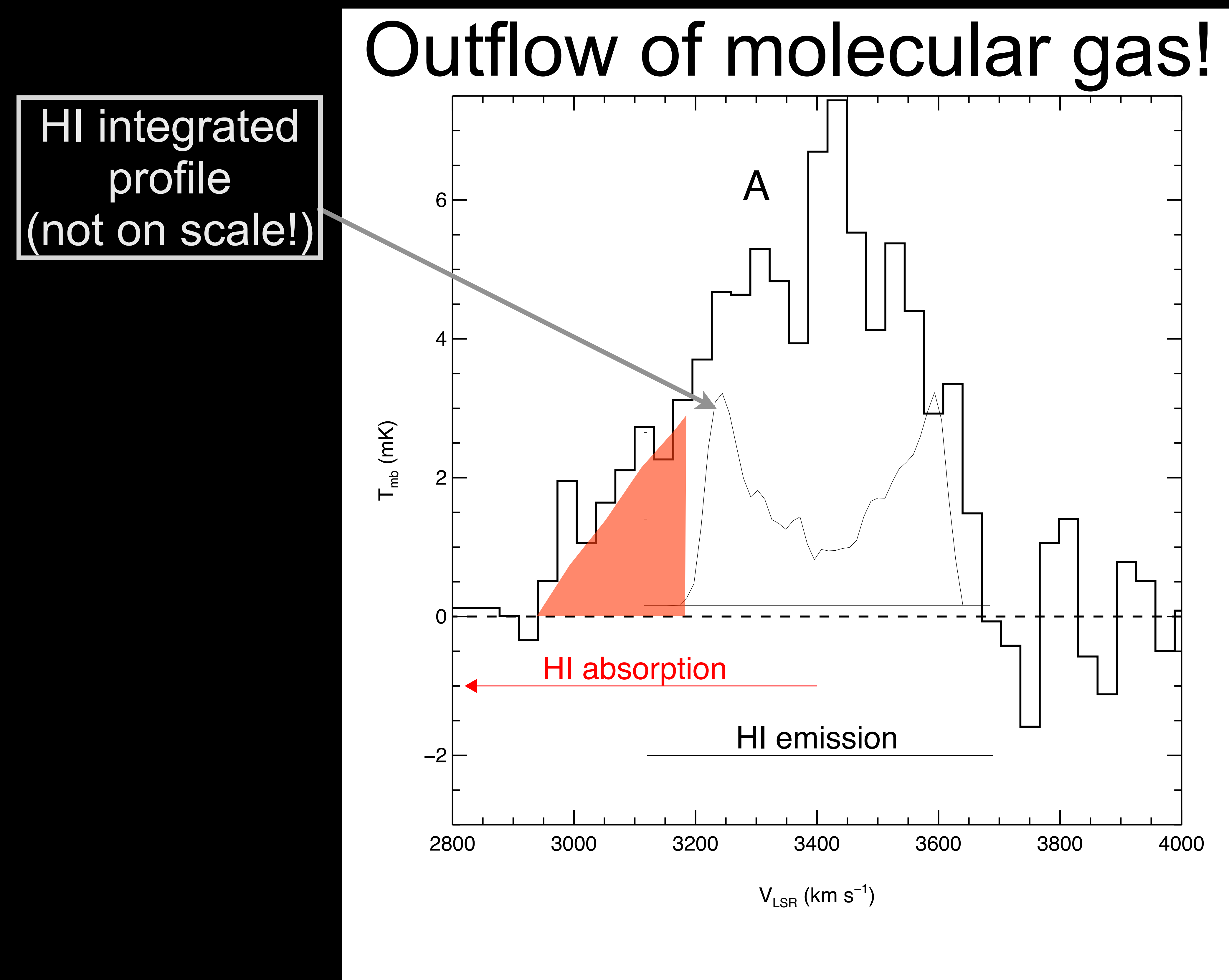
APEX CO (2-1) profile



More off-nuclear HI outflows: 3C305

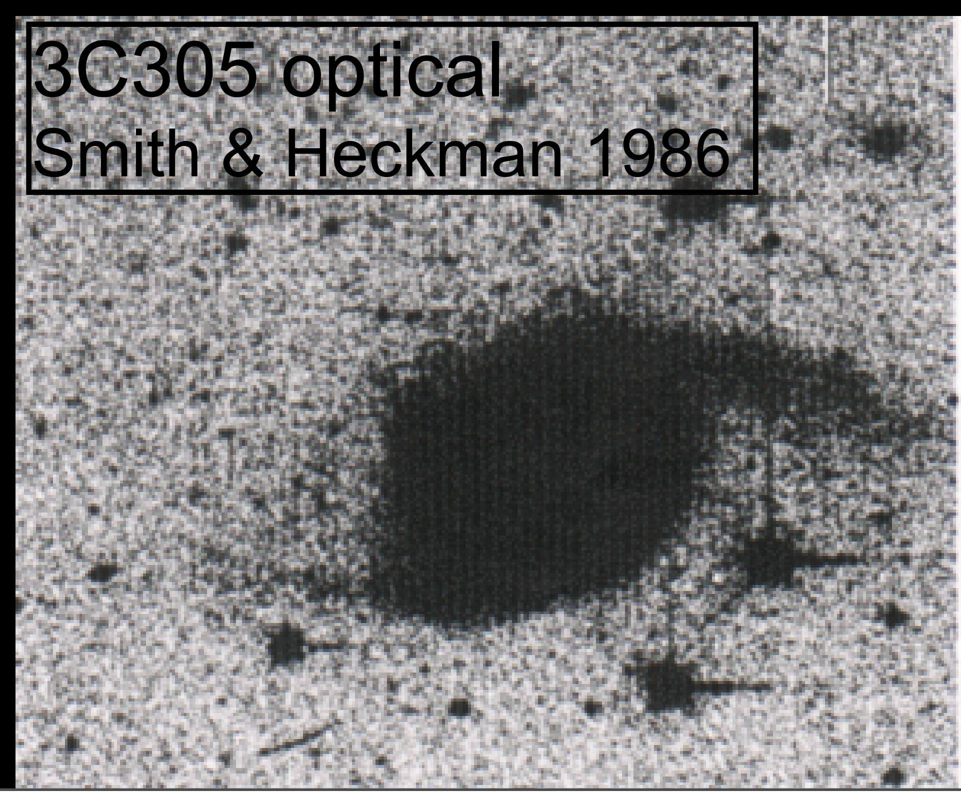
- The broad HI absorption is found **off-nucleus** at the location of the radio lobe - same location for the outflow of ionised gas

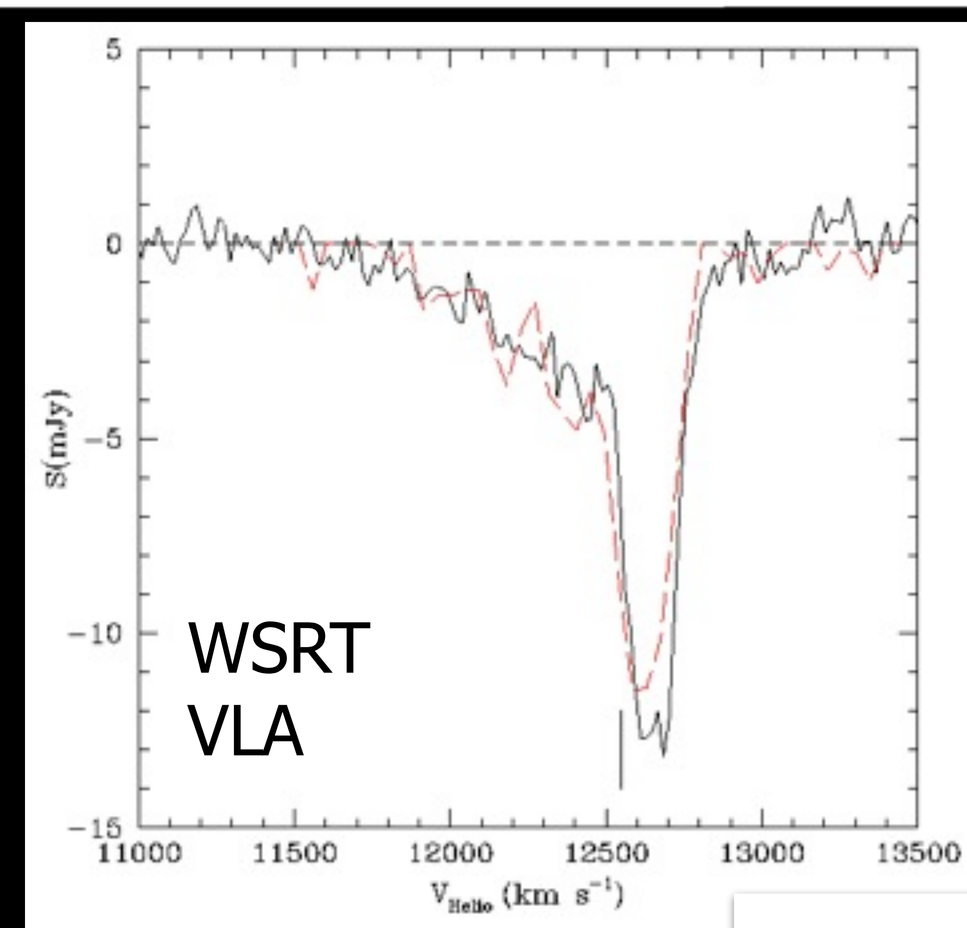
HI **outflow occuring about 1.6 kpc from the nucleus)**

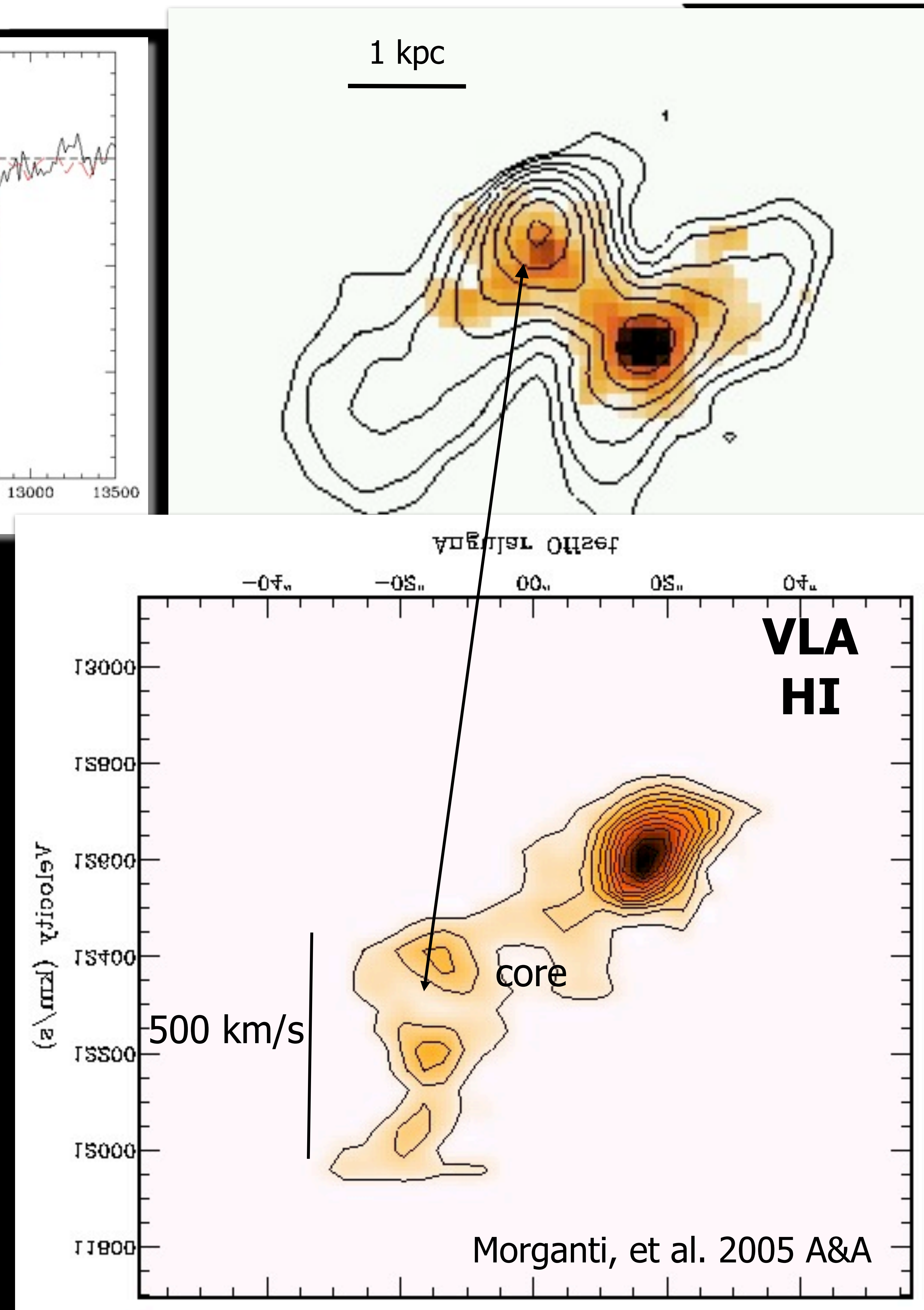
- column density 2x10^{21} cm^{-2} (for T_{spin}=1000K)
- Mass outflowing HI gas ~10^{6} M_{sun} (M_{dot}= 12 $M_{\odot}$/yr)

ionised gas ~10^{5} M_{sun}

The two components of the gas are the result of a gaseous outflow produced **by the same mechanism**







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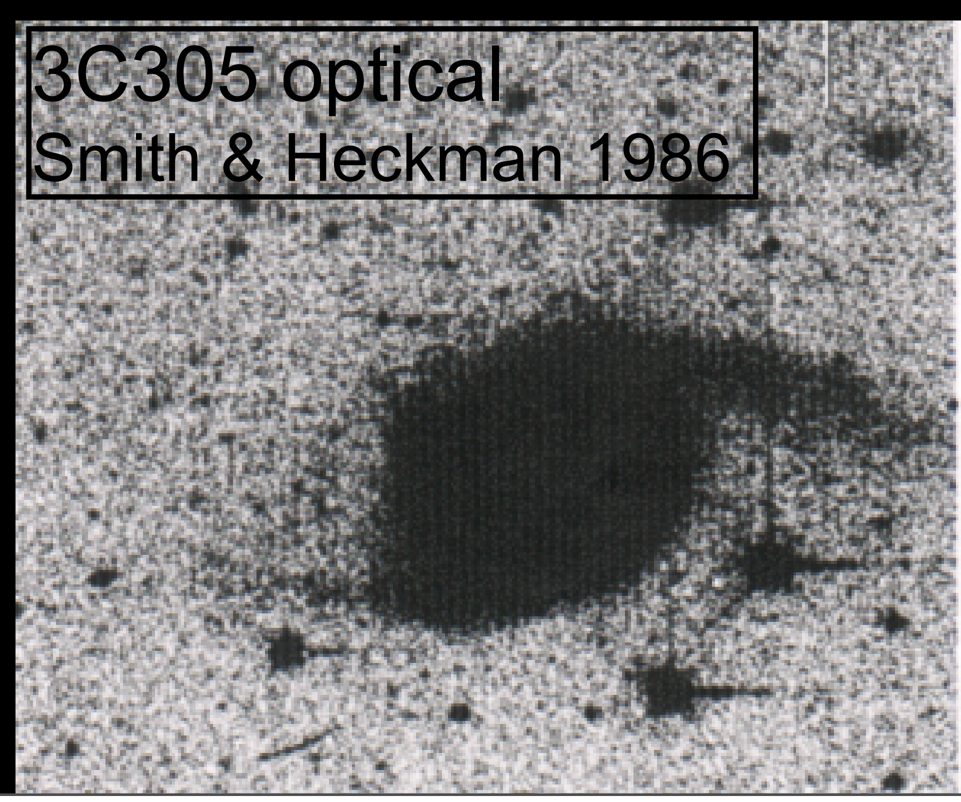
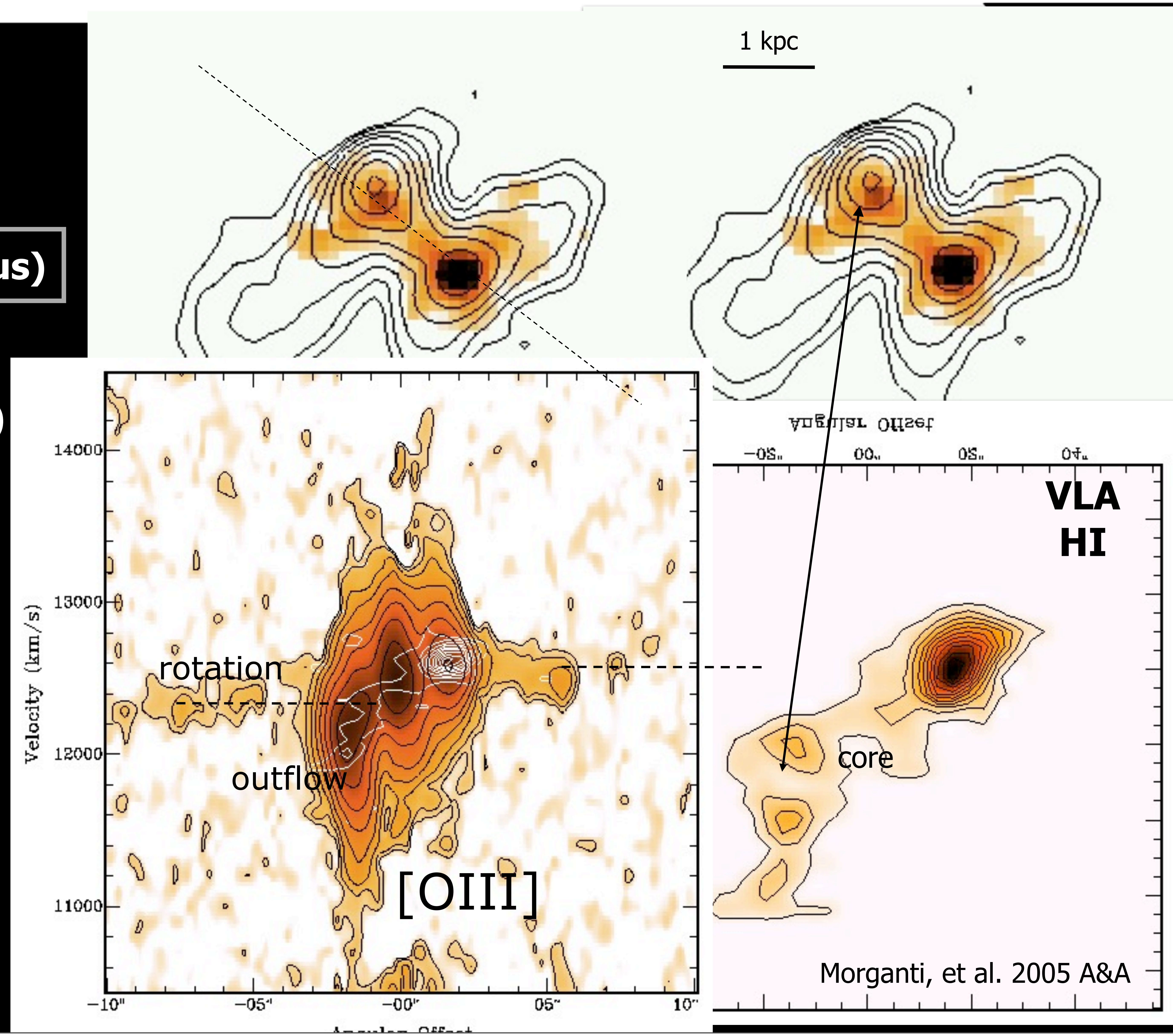
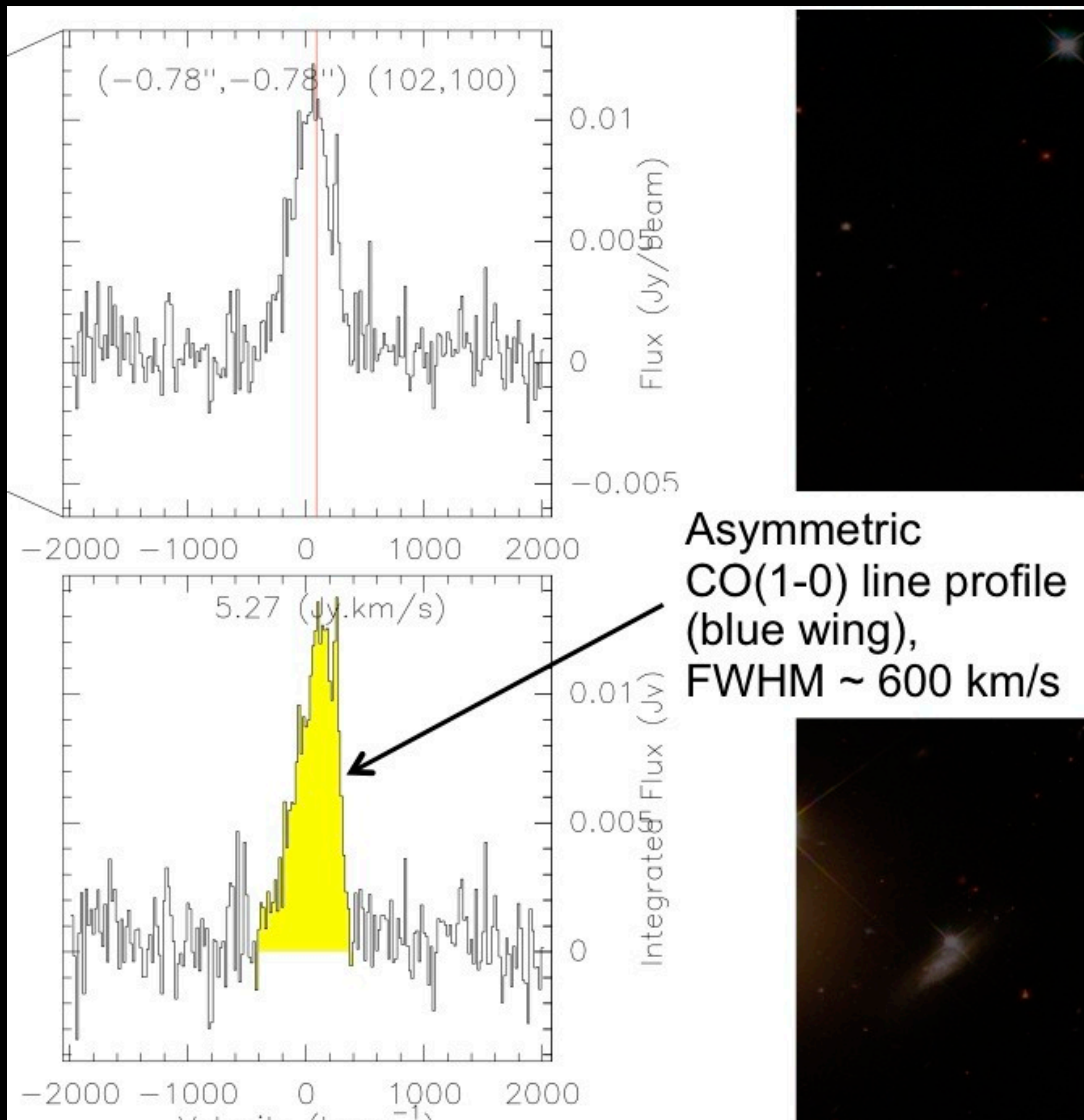
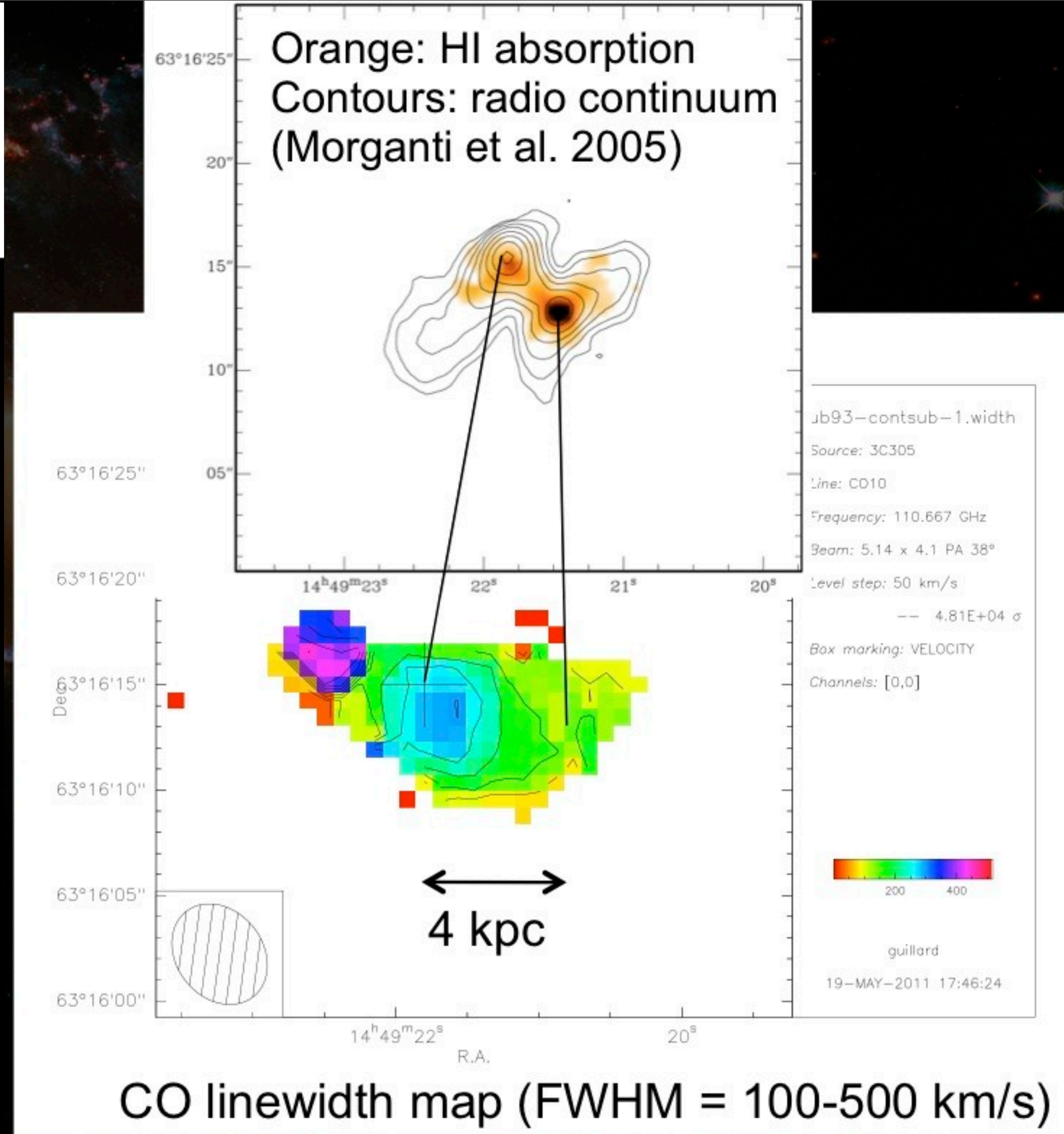




Outflow of molecular gas

- PdB CO(1-0) observations

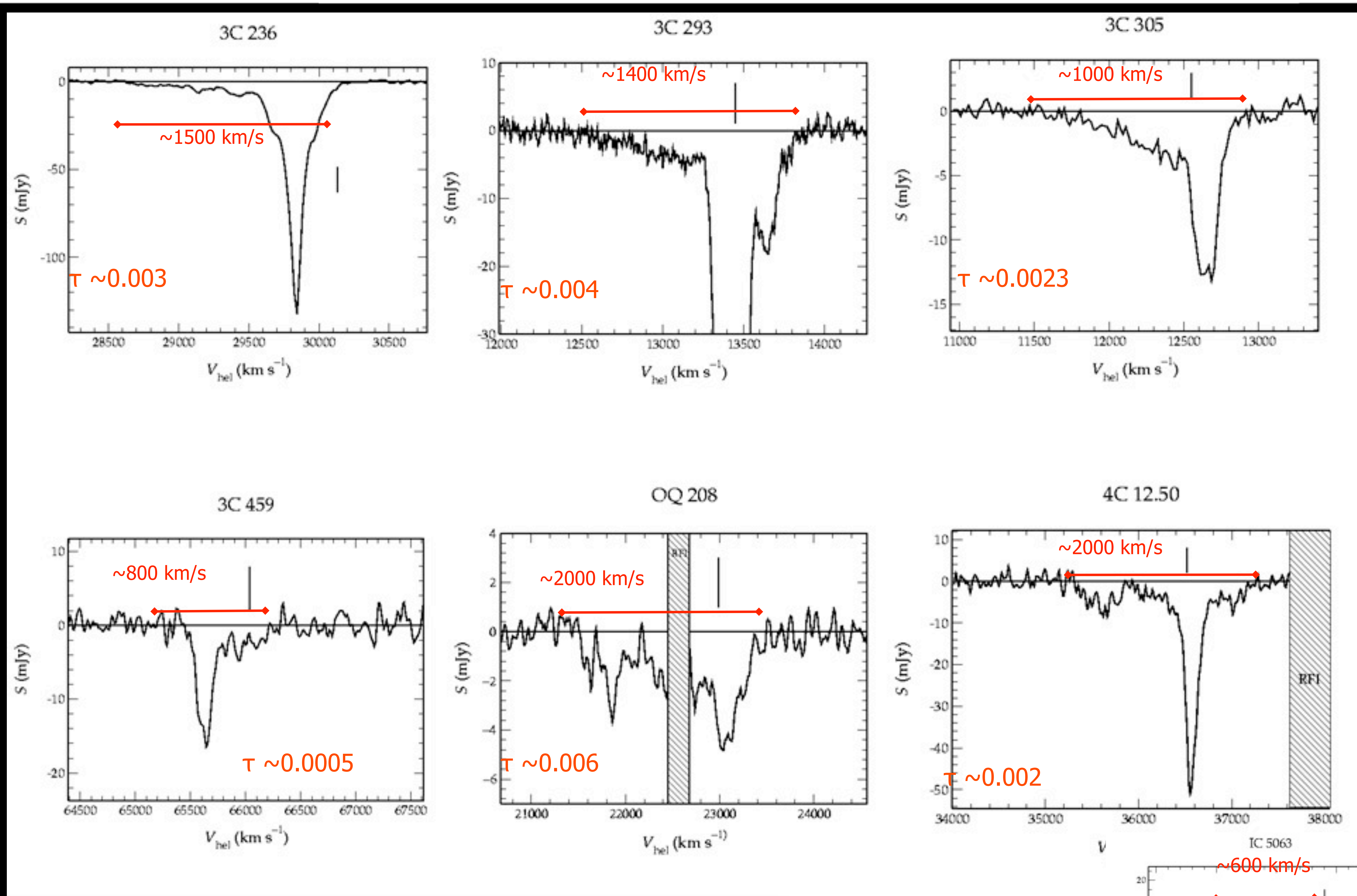


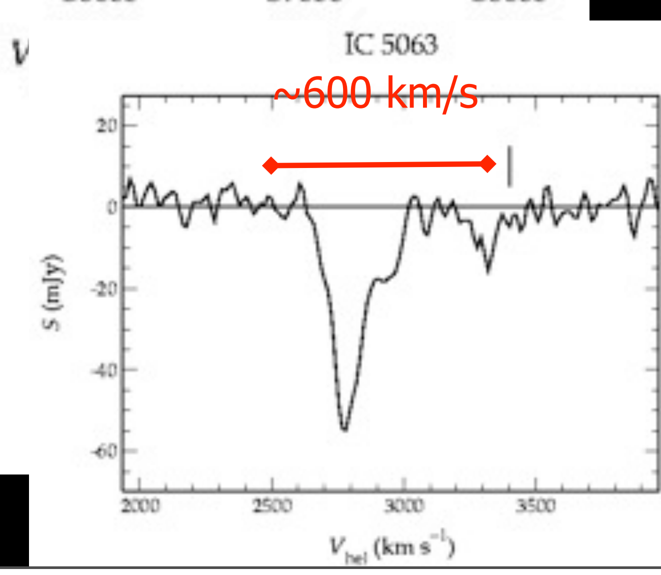


Guillard et al., in prep

CO resolved well beyond HI absorption (bias of these measurements) - total M(H2) = 2.1×10^9 M_{sun}

Many examples of HI outflows...





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

⬇

a number of cases of fast HI outflows revealed by broad & blueshifted HI absorption

- all resulting from jet/cloud interaction? perhaps not!

- Radio sources with fast HI outflows are either compact/young or objects with restarted radio activity (3C293 and 3C236)

- All with rich ISM (CO, farIR....)

Many examples of HI outflows...

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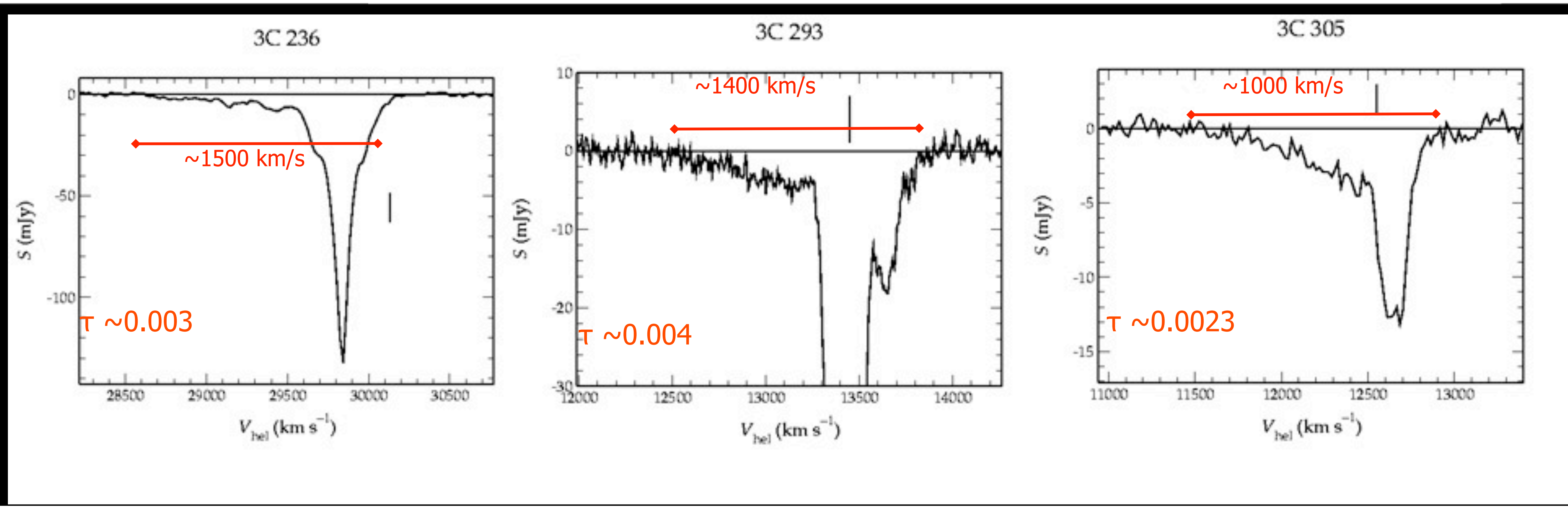
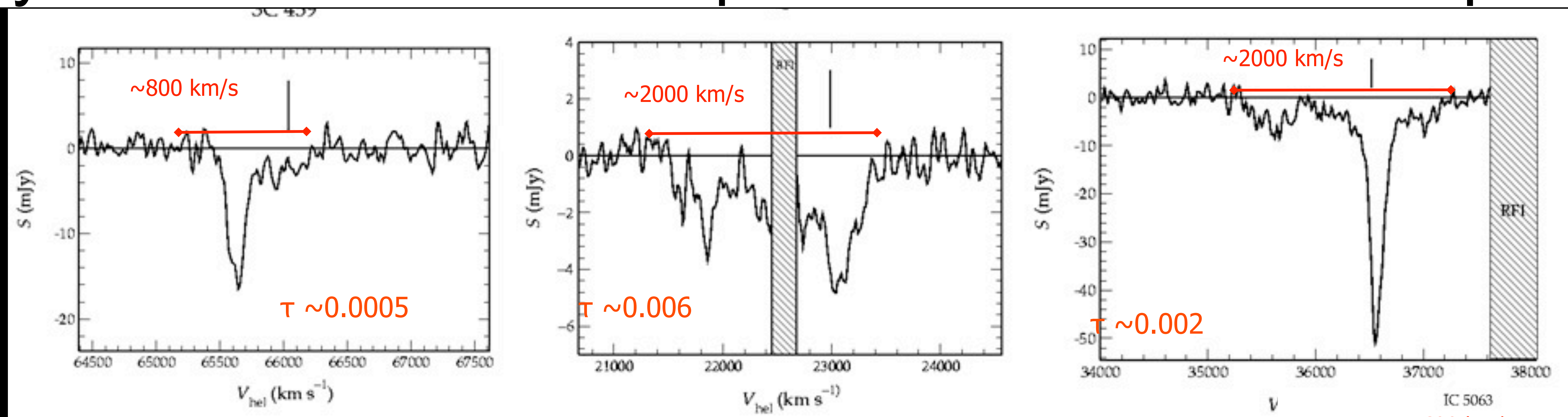
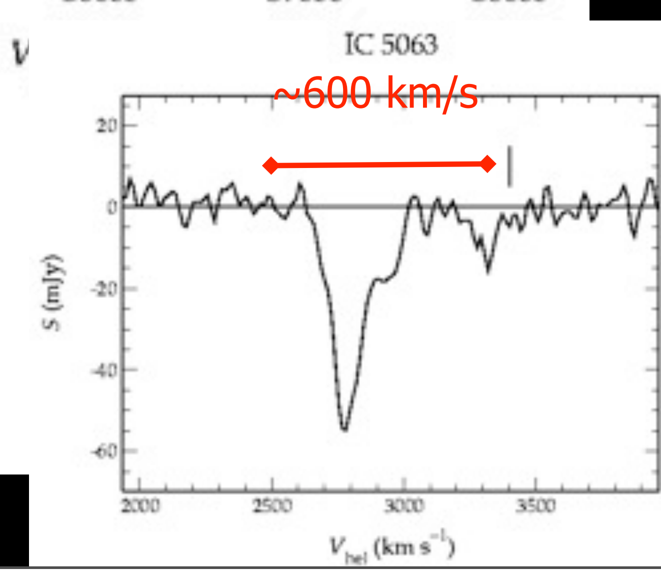


a number of cases of fast HI outflows revealed by broad & blueshifted HI absorption

Very tricky to detected: the absorpton is shallow and low optical depth!





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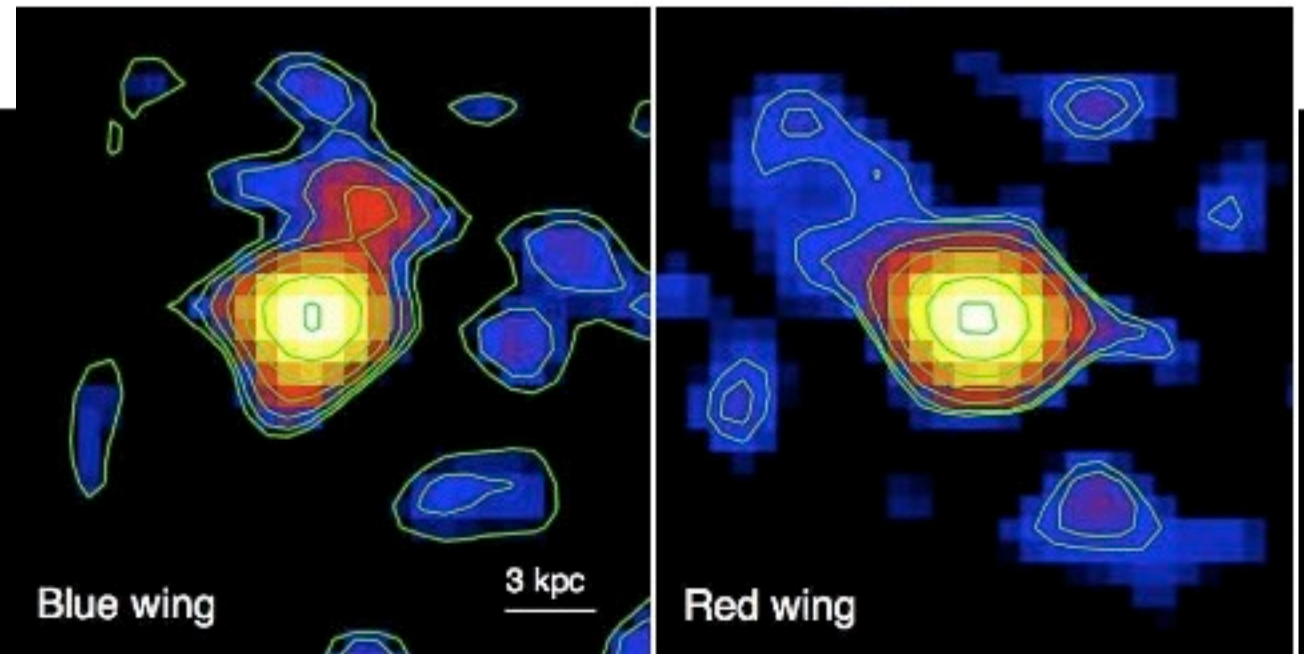
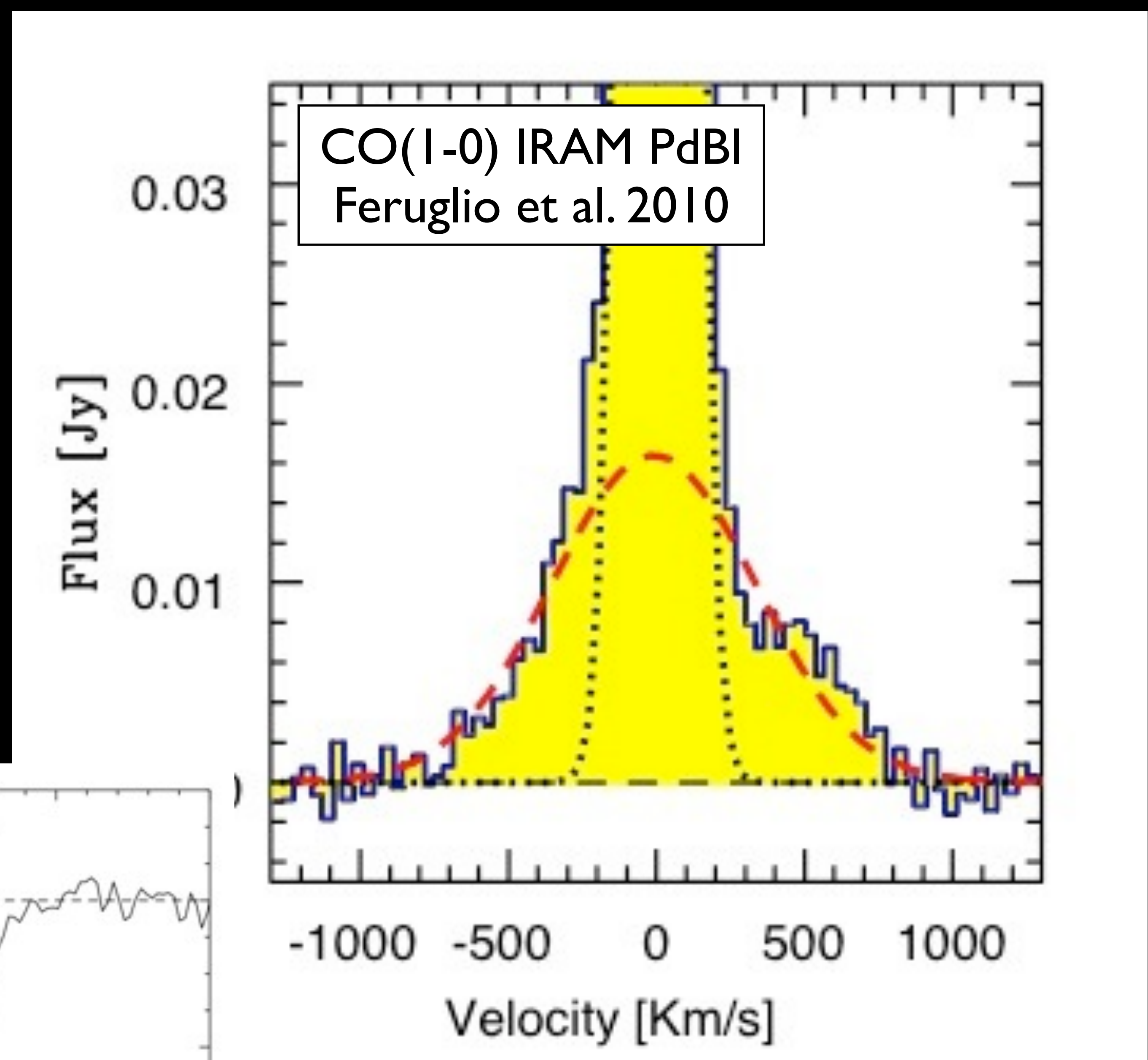
Mostly blueshifted HI outflows - Morganti, Oosterloo, Tadhunter A&A 2005

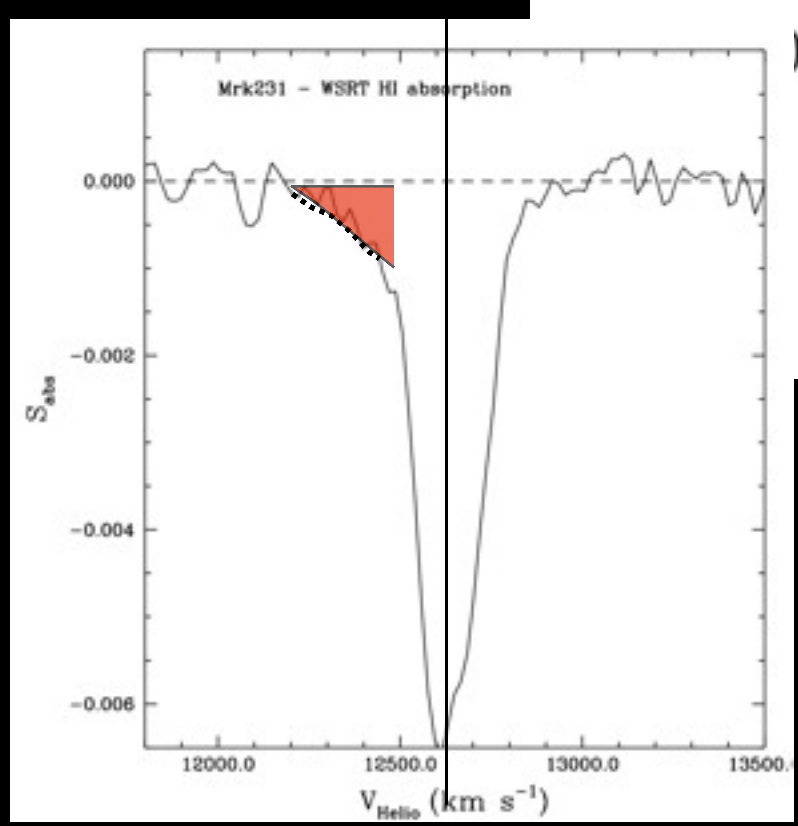
Molecular gas outflows also start to be detected ...perfect timing (ALMA coming...)!

Mrk 231 -
Feruglio et al. 2010

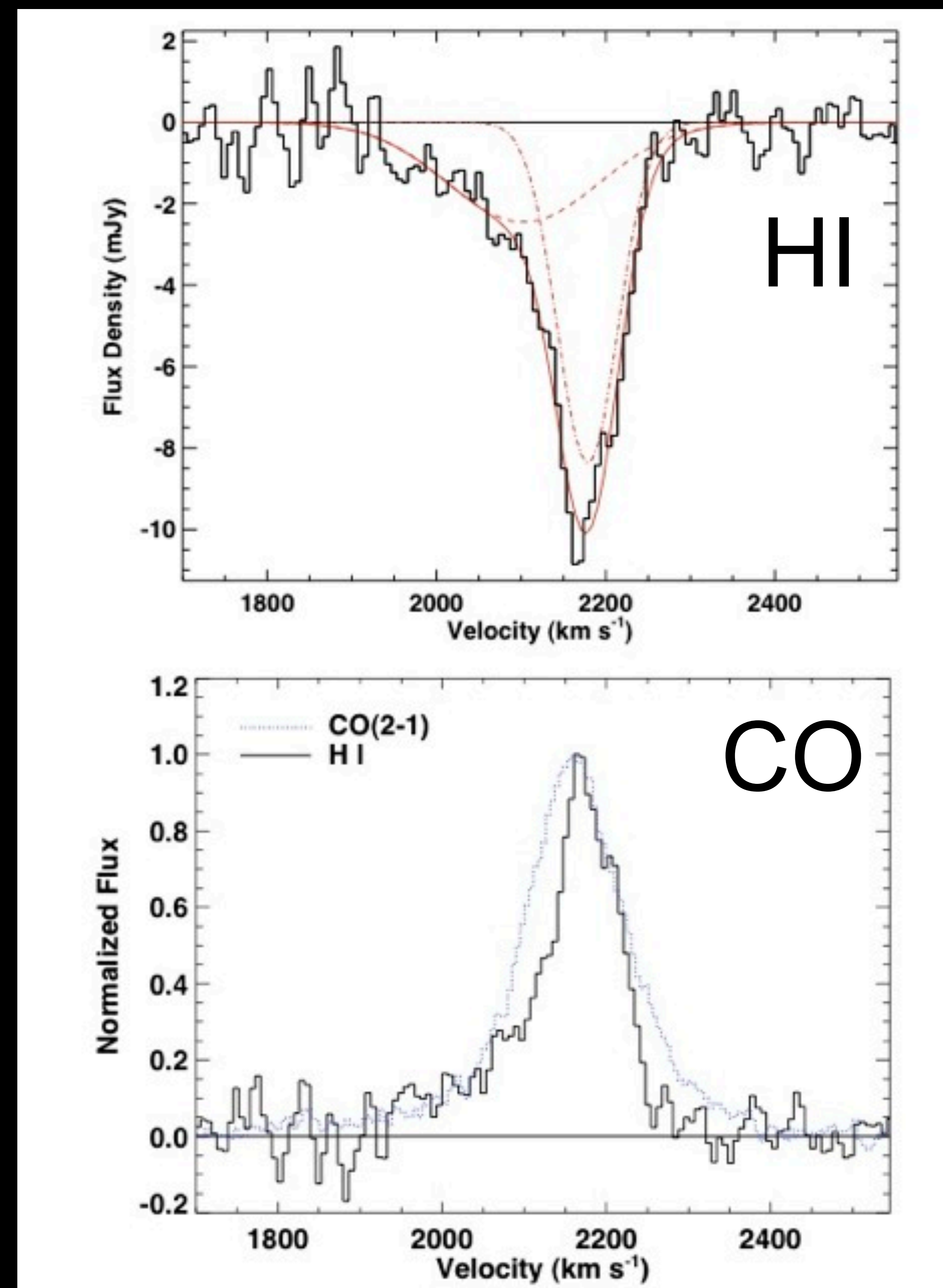


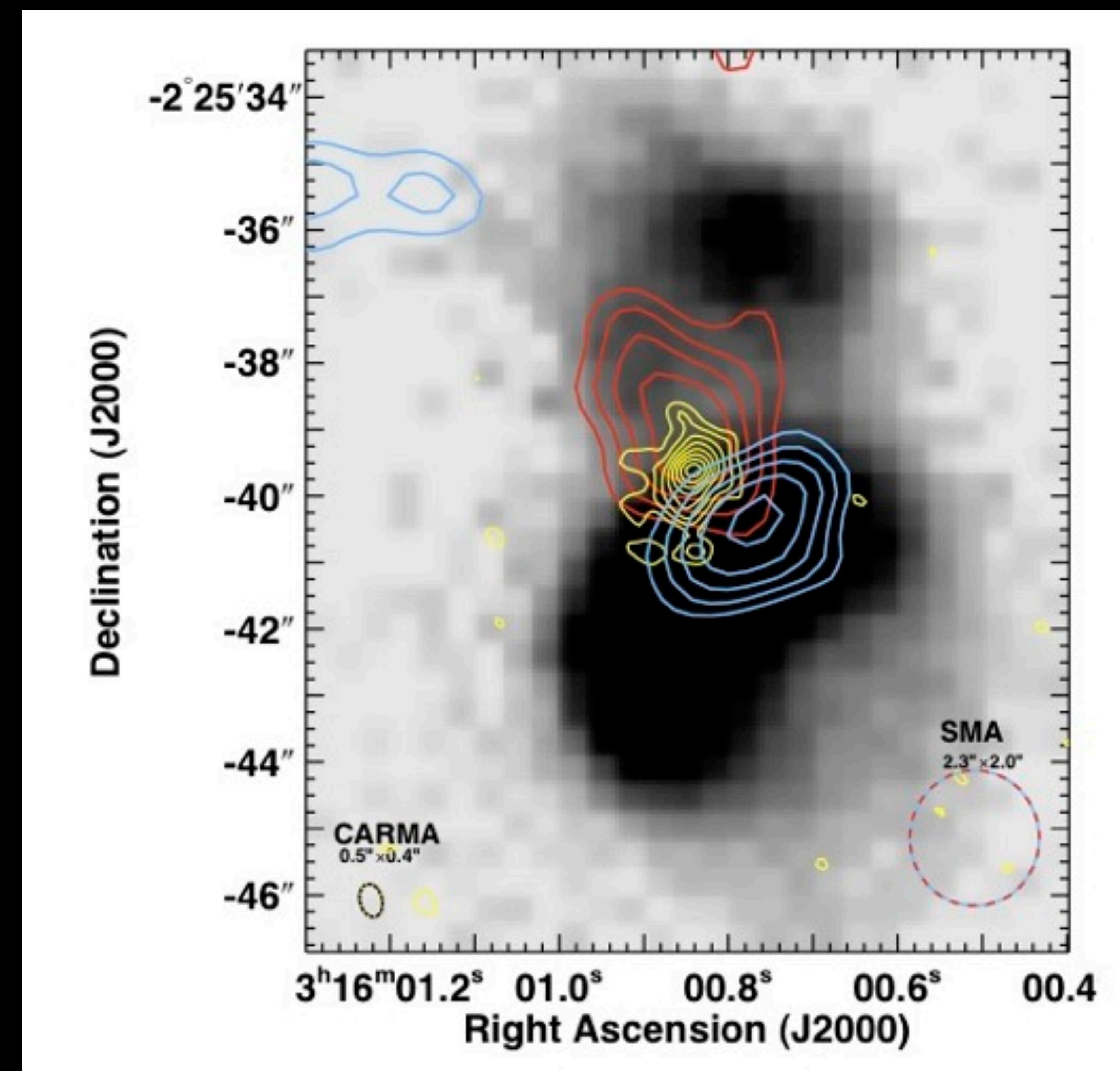
Molecular gas may carry the majority of the mass outflow rate!





Evidence of a blueshifted component also in HI
(Morganti et al. in prep)





NGC1266 -
Alatalo et al. 2011

....but what is the impact?

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	warm (ionised)	cold (HI)
Mass outflows	10^5 Msun	>10^6 Msun
Mass outflow rate	0.1-10	1-50 Msun/yr
E_{kin}/L_{edd}	10^{-5} - 10^{-6}	(few x) 10^{-4}

comparable to the lower end of starburst superwinds (Rupke et al. 2002)

✓ HI and molecular outflows seem to do better than warm outflows but still not quite enough compared to the standard model?

✓ these outflows are nevertheless important for understanding the evolution of the radio jets

Conclusions

- Radio jets have a clear influence on the galactic ISM (and vice versa?)

- Clear evidence for interaction between radio jets and the surrounding nuclear interstellar medium: jets and gas are a perfect combination!

- Fast outflows of cold gas (despite the high energy carried by the jets) => **HI and molecular gas => can be studied at radio frequencies!!!**

- Relevant for the evolution of the host galaxy? ...not yet clear!

- At the limit of what we can do with current radio telescopes.......

but new radio telescope are coming!!!

Importance of the new radio facilities

Many facilities planned or in the process of becoming available: ALMA, EVLA, eMerlin, ASKAP, MeerKat, Apertif.....

- **ASKAP/Aperif**: large surveys to detect more systems/outflows in HI and increase the statistics...but they will not go much deeper than now
- **EVLA/eMerlin/MeerKat**: deep and high resolution follow up of interesting objects
- **ALMA**: detailed study of molecular outflows , physical conditions
- **LOFAR:** → sensitive to steep spectrum structures: looking for relicts of past activity (also in galaxies that are not radio loud now!)
- **SKA:** major step forward - what will it bring to this field?
  - a more complete census of HI in radio sources
  - detailed study of the kinematics of the gas close to the nucleus
  - possibility of looking for outflows in weaker sources: complete census of occurrence and characteristics