

## The never ending story of Centaurus A

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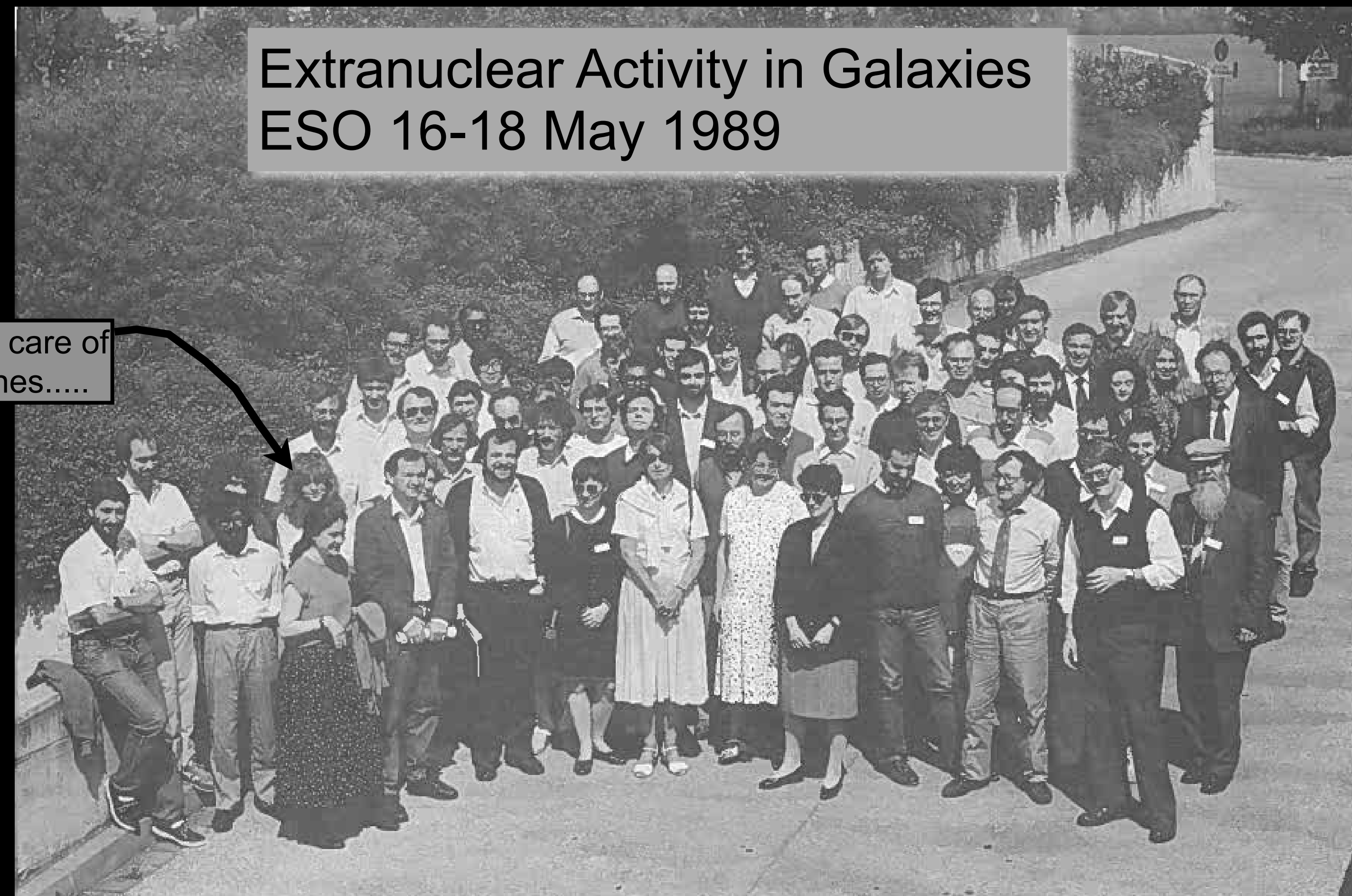
# Some key ingredients .....

- ▶ great supervisor - guidance and patience - chance to finally learn some english

- ▶ no chance to work on radio data! only focus on optical data!!!

- ▶ extremely lively group ...

....at the time when Active Galactic Nuclei were exciting objects to study not only for their feedback!!!





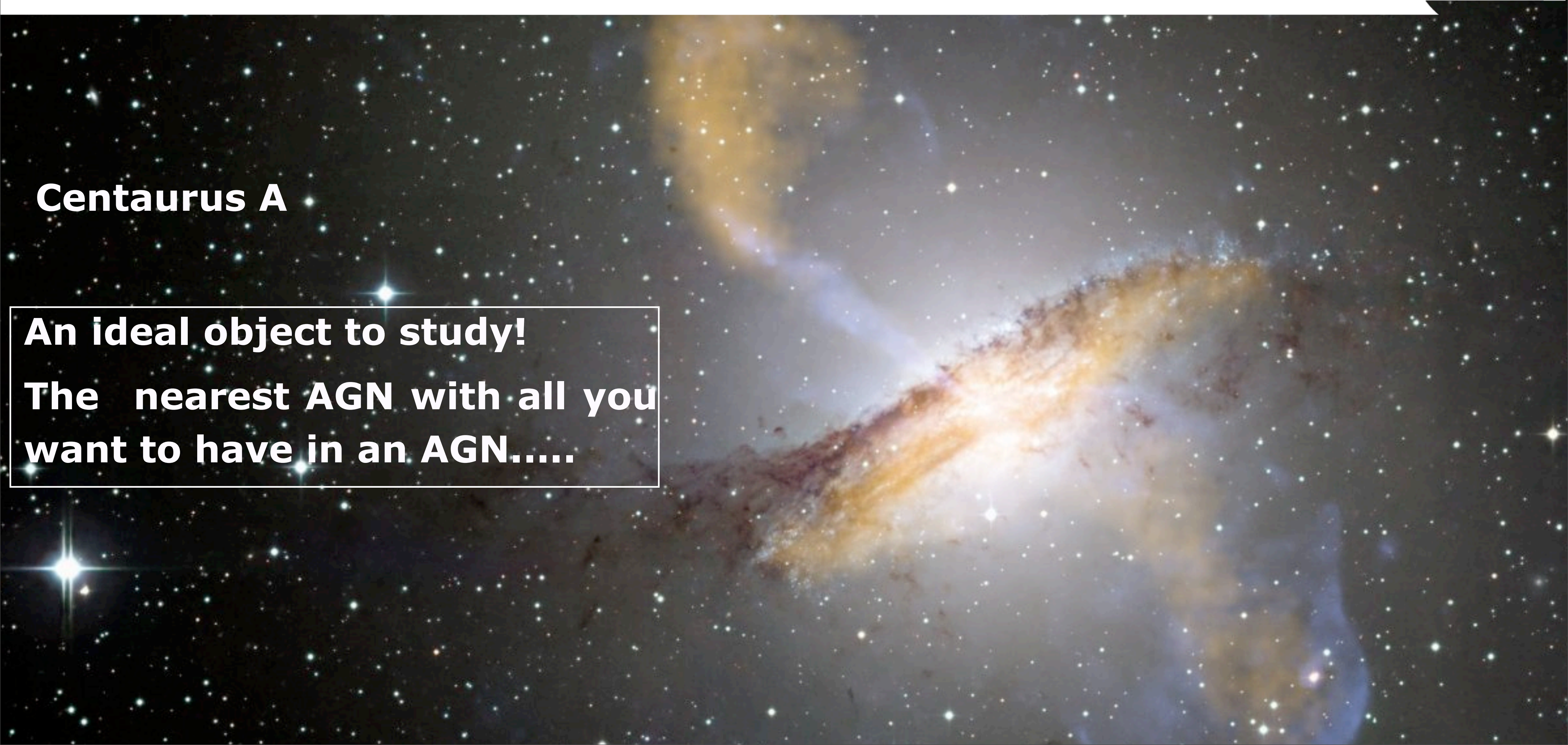
More key ingredients.....

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## **Centaurus A**

**An ideal object to study!**

**The nearest AGN with all you  
want to have in an AGN.....**





- ▶ Many different phases of the gas spread across many different scales
- ▶ Hot → warm → cold (atomic, molecular - variety of lines/transitions)

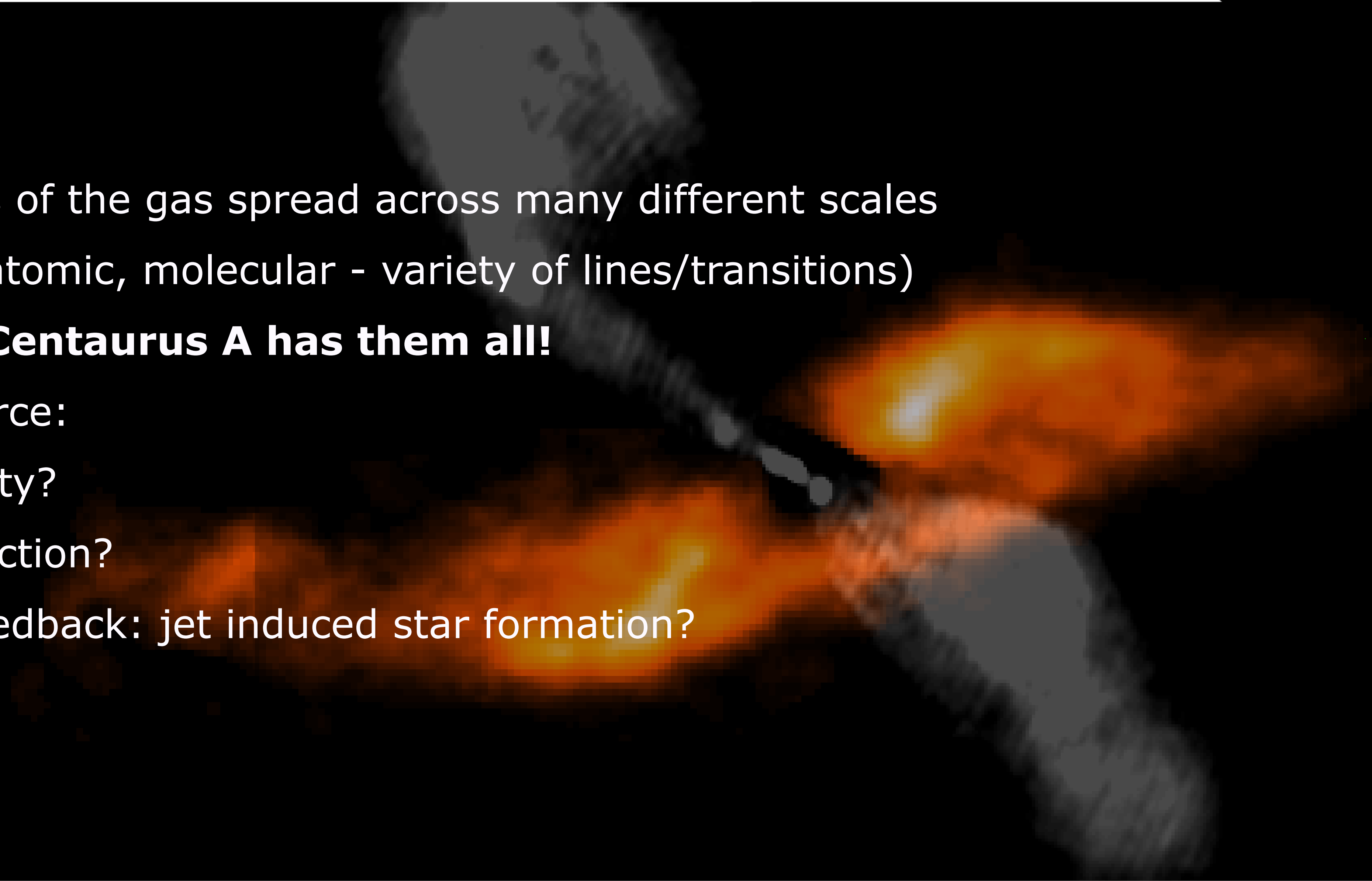
**Centaurus A has them all!**

- ▶ Interesting radio source:

Restarted activity?

Jet/cloud interaction?

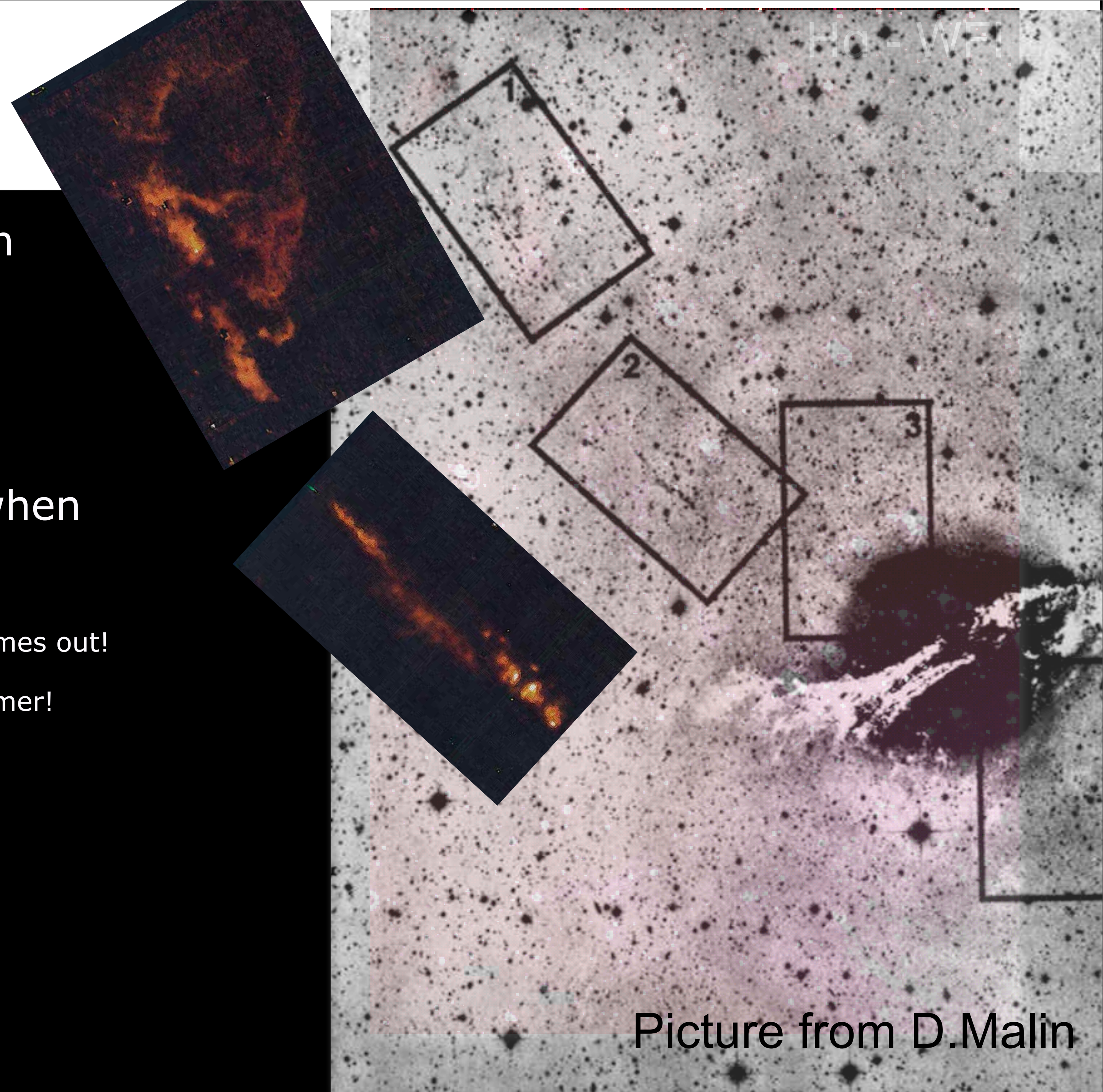
Constructive feedback: jet induced star formation?





# How everything started.....

- ▶ “The nature of the optical filaments in Centaurus A. Evidence for a beamed ionizing continuum”
- ▶ I don't know what Bob had in mind when he gave me these data:
  - the data are so old, doesn't really matter if nothing comes out!
  - let's see whether we can discourage this radio astronomer!
  - finally the right person for this project!
- ▶ Why interesting.....?

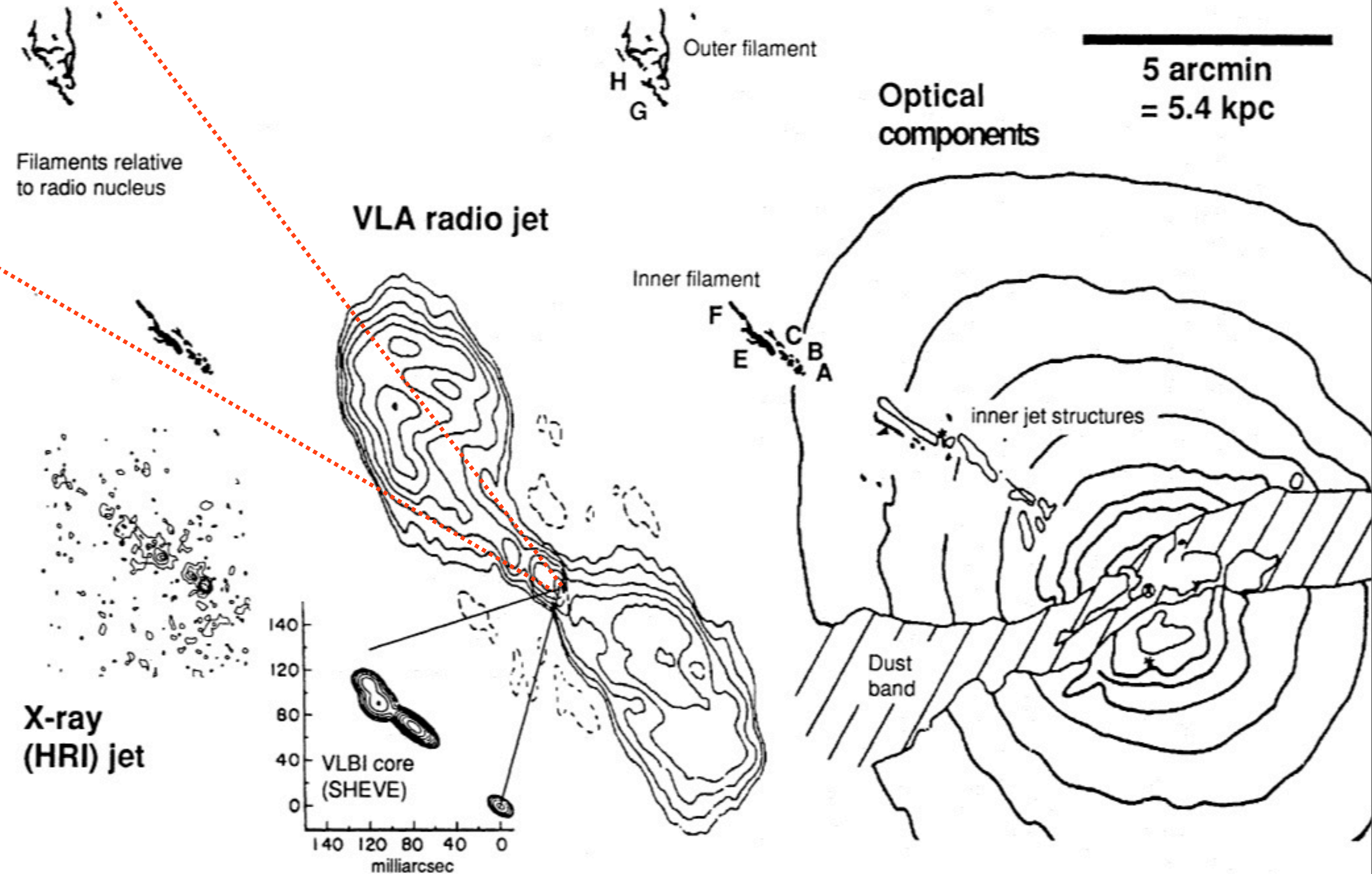
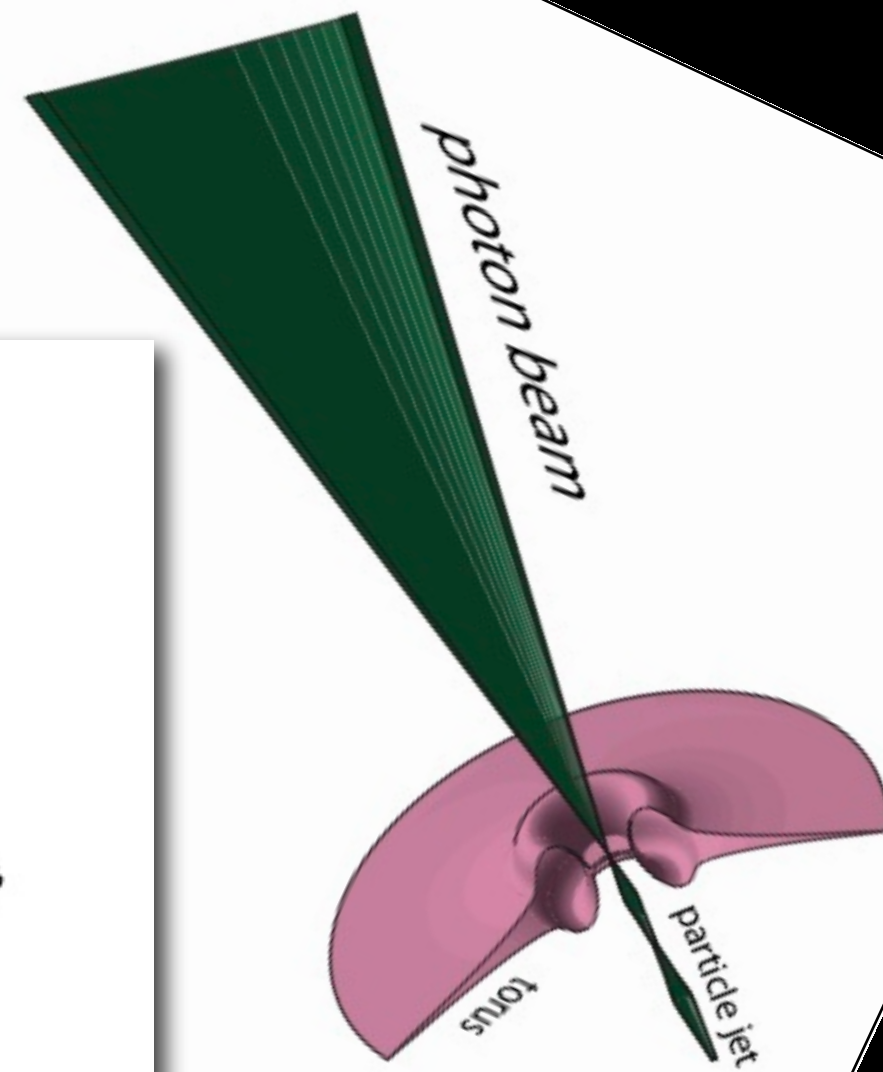
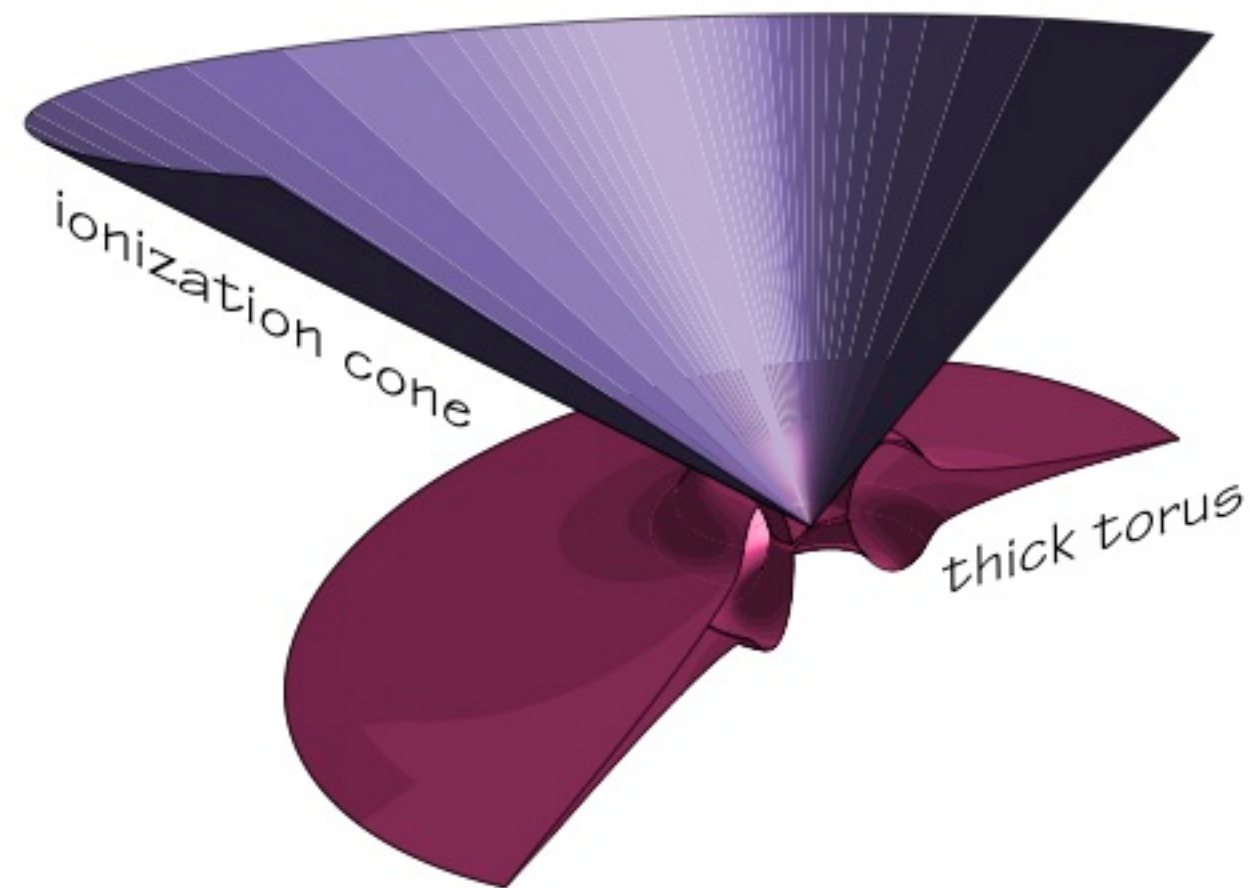


Picture from D.Malin



# The optical filaments and the nucleus....

Anisotropic radiation from AGN:  
looking far away from the AGN  
to understand what is happening  
in the central regions!



“Disentangle the complex physical processes which represent the interaction between the active nucleus and the outer part of its host galaxy”



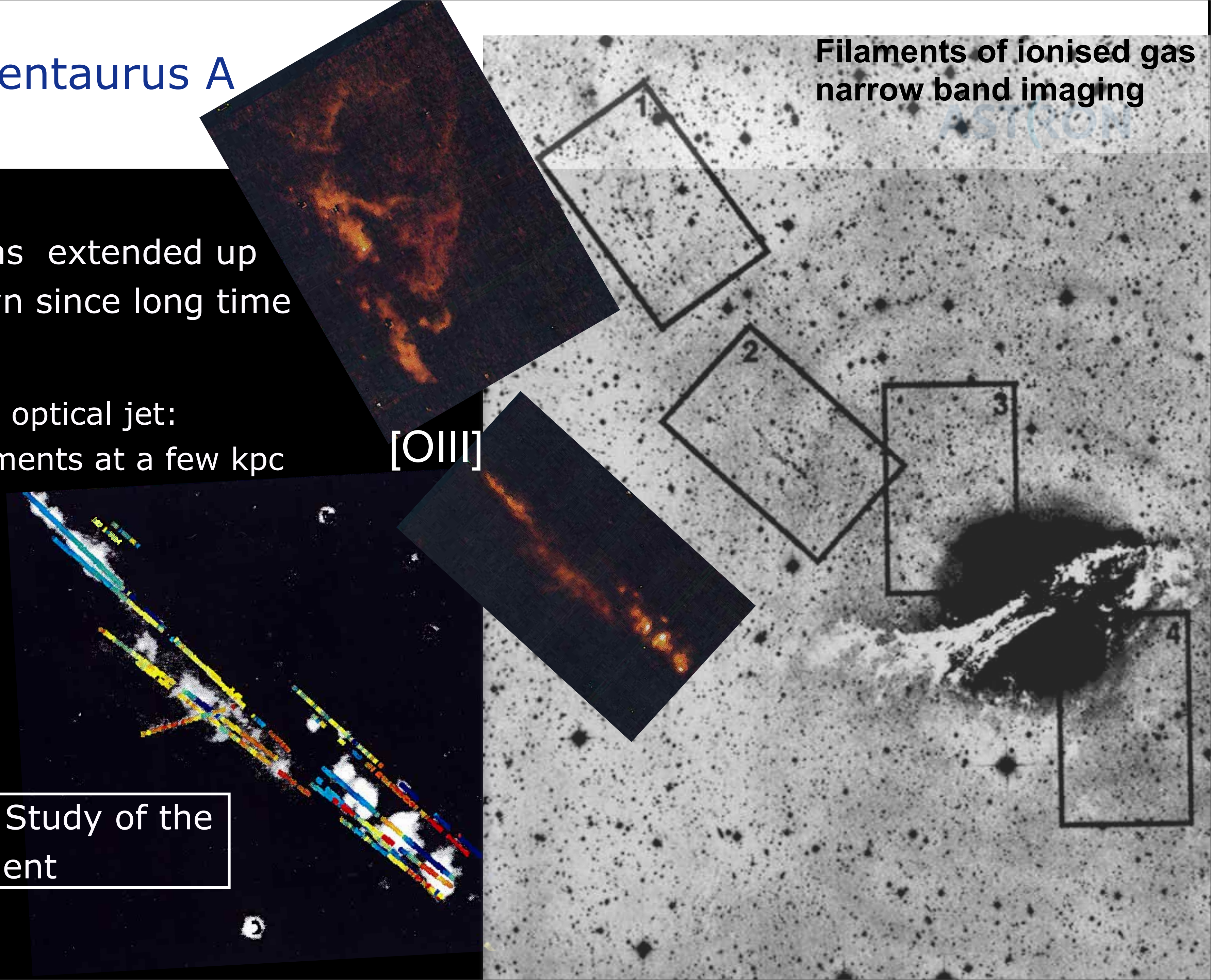
# Gas @ large scale in Centaurus A

- Presence of filaments of gas extended up to 20 kpc (and more?) known since long time (Blanco et al. 1975)
- Dufour & van den Bergh 78 → optical jet: compact knots and diffuse filaments at a few kpc from the centre

EFOSC @ 3.6m telescope - Study of the line ratios and velocity gradient

[OIII]

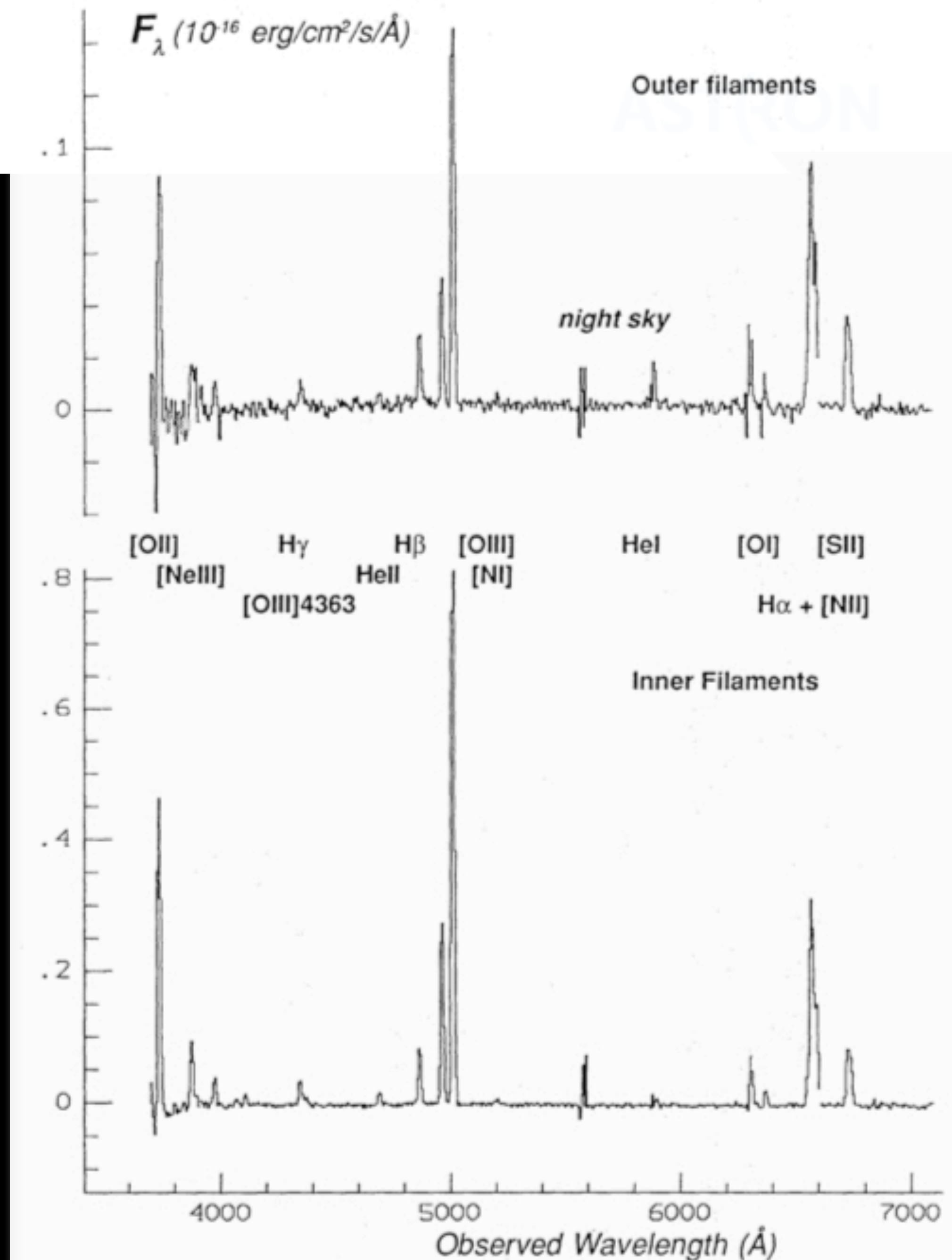
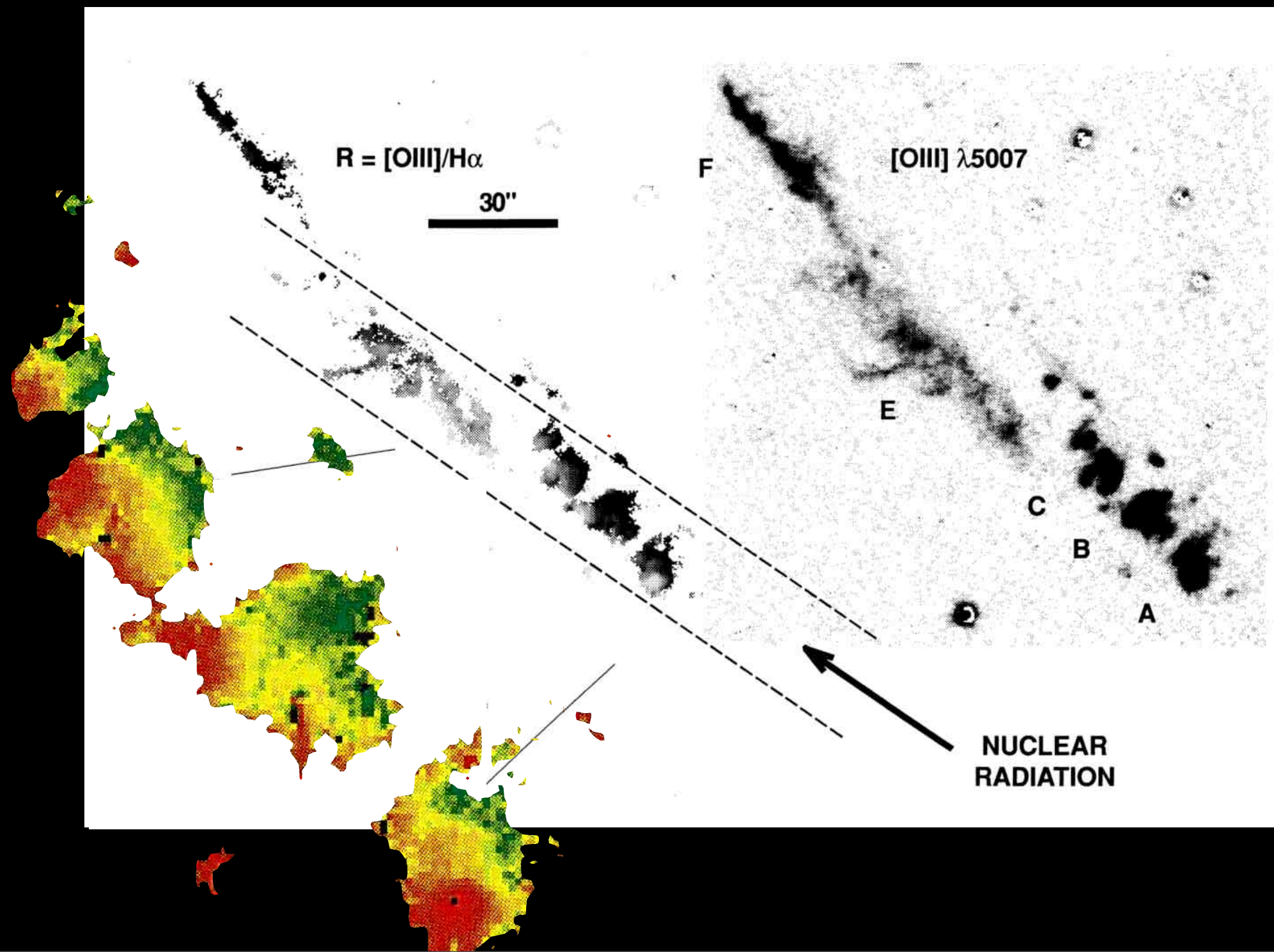
Filaments of ionised gas  
narrow band imaging





# Ionised gas in the filaments

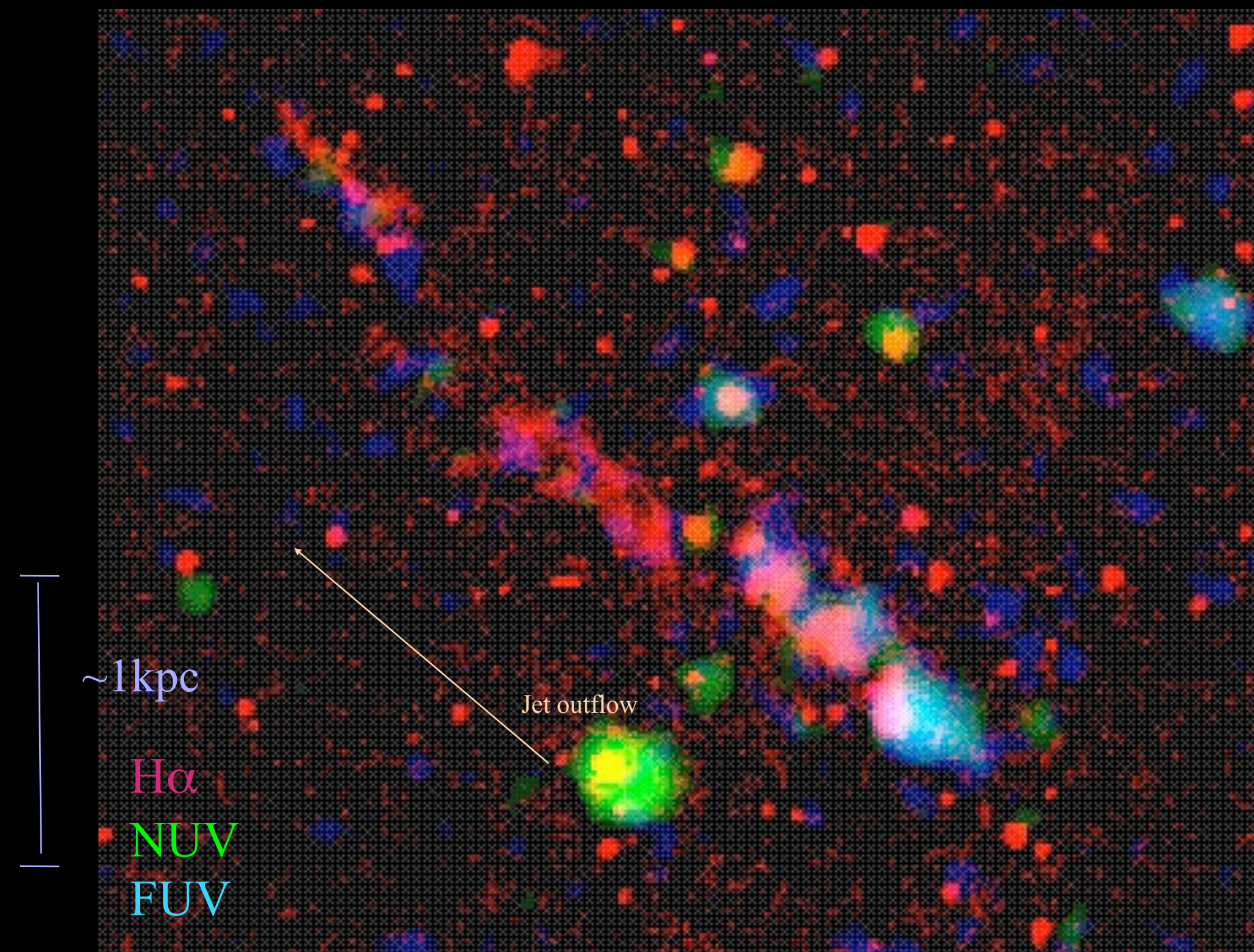
- ▶ High excitation and turbulent gas in filaments (between ~6 and 20 kpc from centre - only northern side). Velocity variations of 100-200 km/s in a few hundred pc. Ionisation gradient.
- ▶ Comparison with predictions of photionisation models => UV photoionisation from the nucleus
- ▶ Similarities of the continuum with BL Lac (confirmed by the near-IR study) + interaction with the jet => shocks to explain the turbulence?



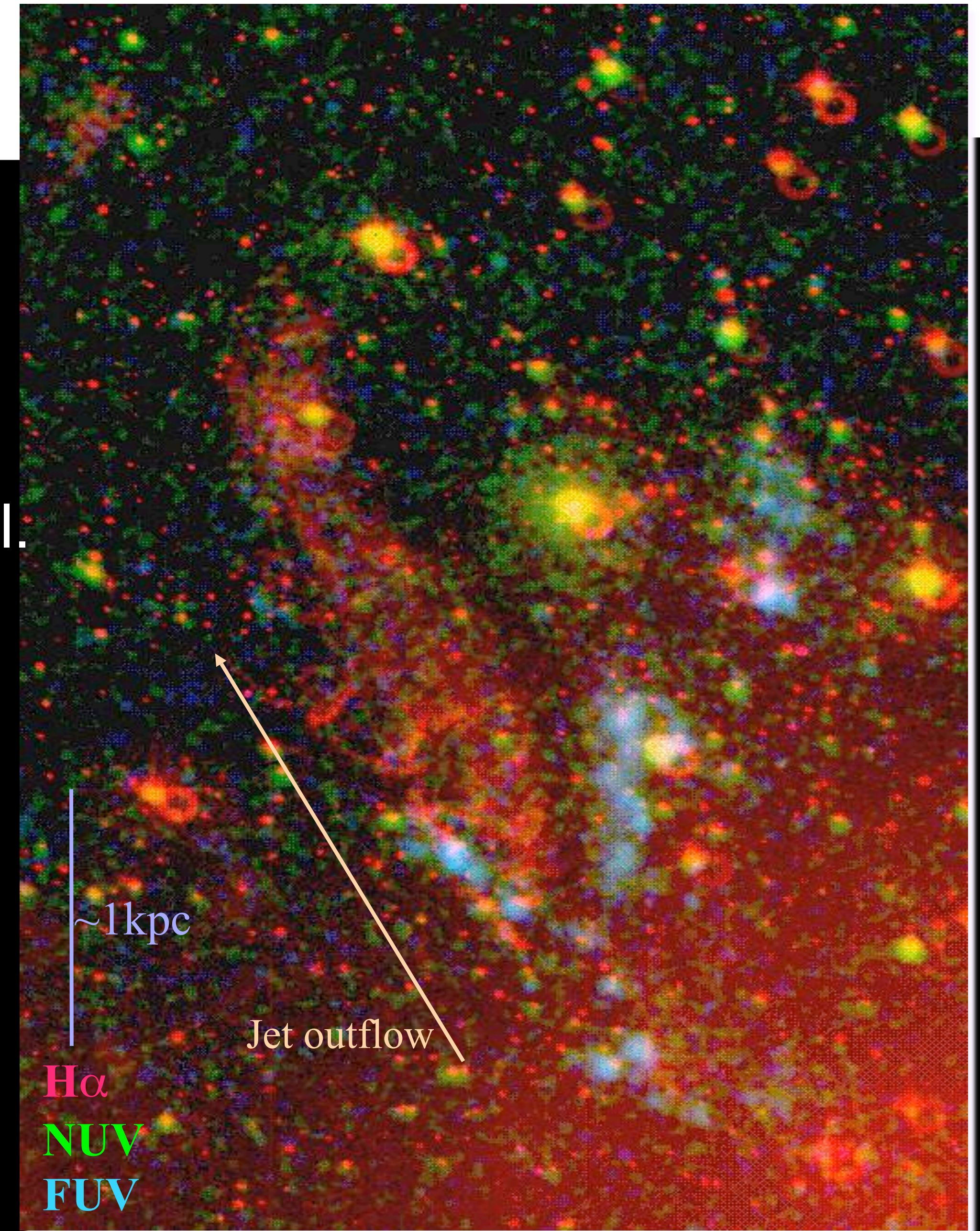


....also GALEX data

- ▶ UV from young/blue stars
- ▶ Far-UV emission from shocked gas?
- ▶ Star formation associated with the interaction



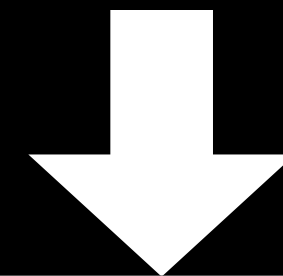
Neff et al.





- ▶ high ionisation => dominant source: photoionisation from AGN not from shocks (but big discussion about this!)
- ▶ gradient in ionisation....
- ▶ beamed radiation => BL Lac
- ▶ extra component to produce the turbulent velocity (radiation pressure not enough): jet interaction?

**Many open questions that kept me busy since then....**



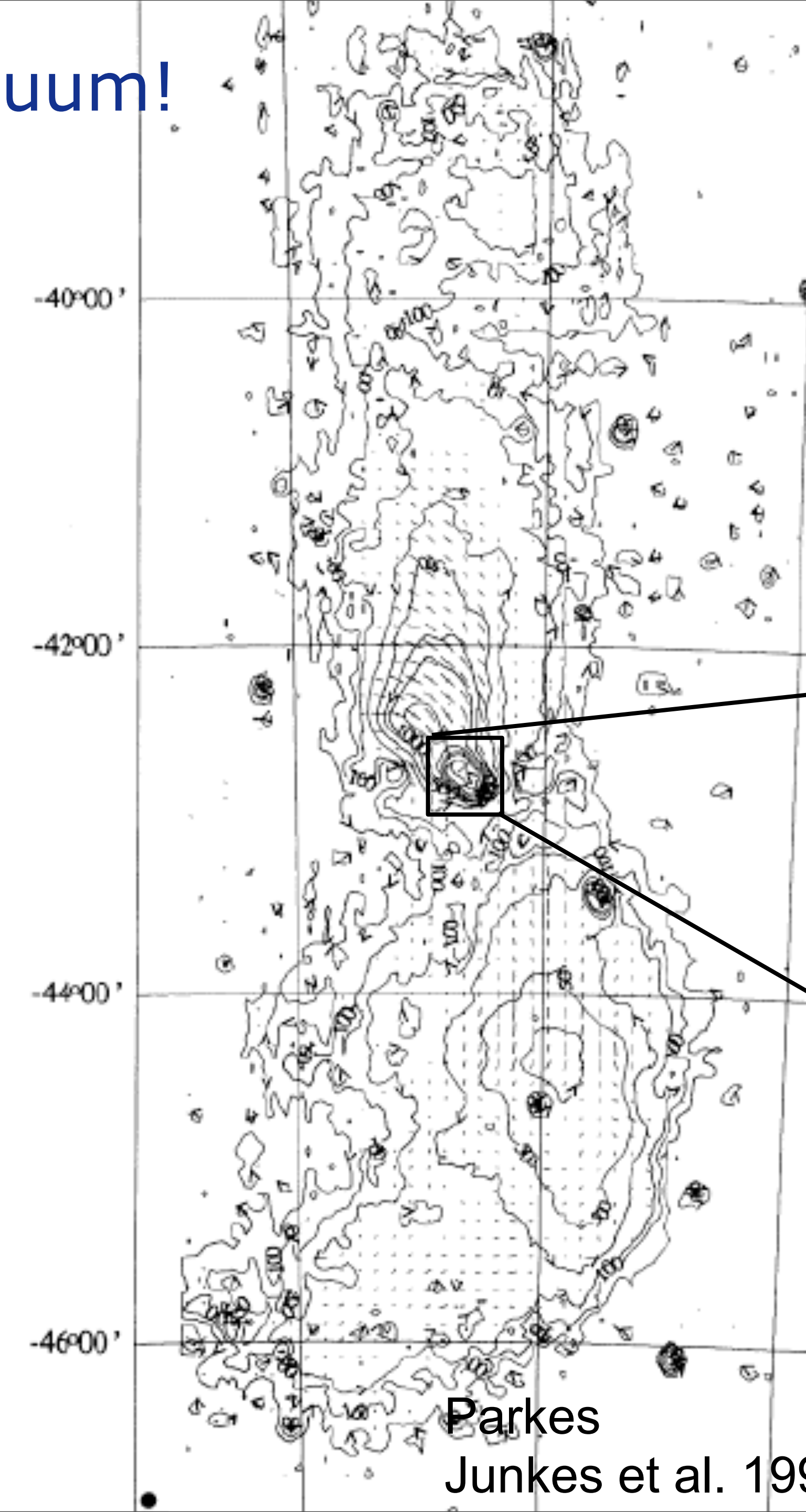
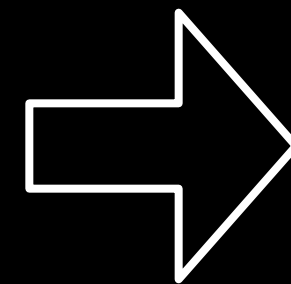
- is there a large-scale radio jet?
- interaction (what kind?) between gas and radio plasma
- origin of the filaments
- ....



The next step: improve the radio continuum!

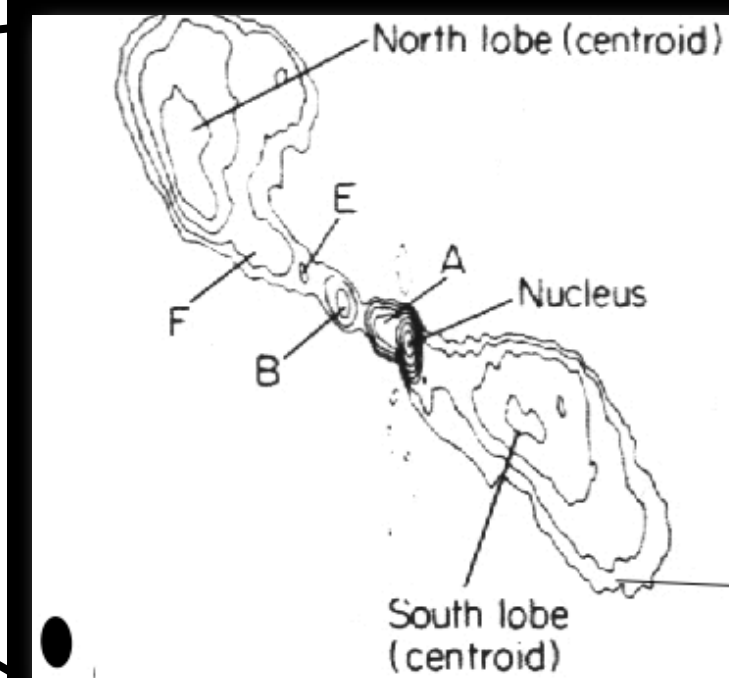
Need for relatively high resolution radio images for the region co-spatial with the optical filaments: is it plausible the presence of a jet-cloud interaction? Is there a jet?

Radio images available then



Parkes  
Junkes et al. 1993

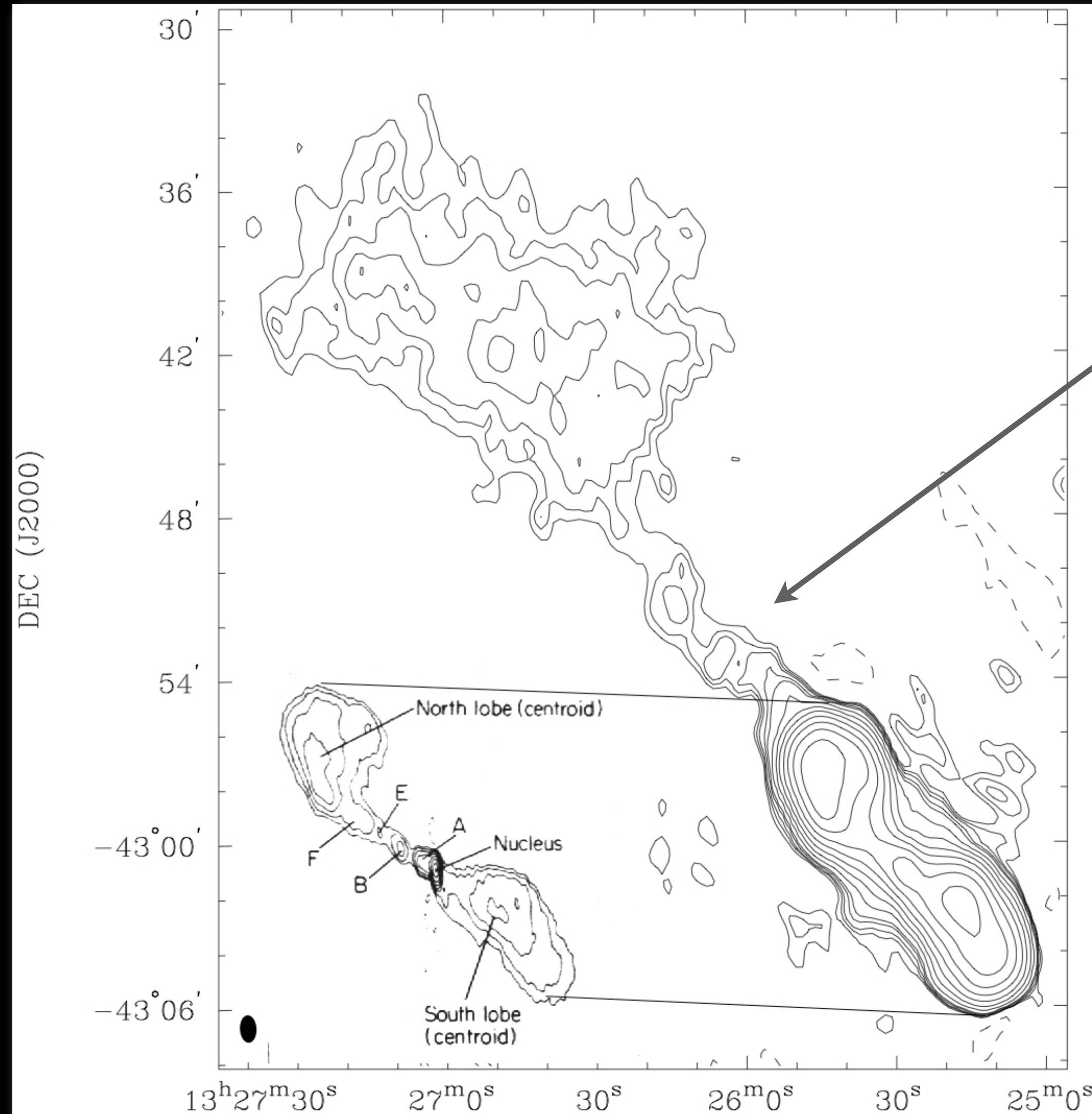
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VLA  
Burns et al. 1993

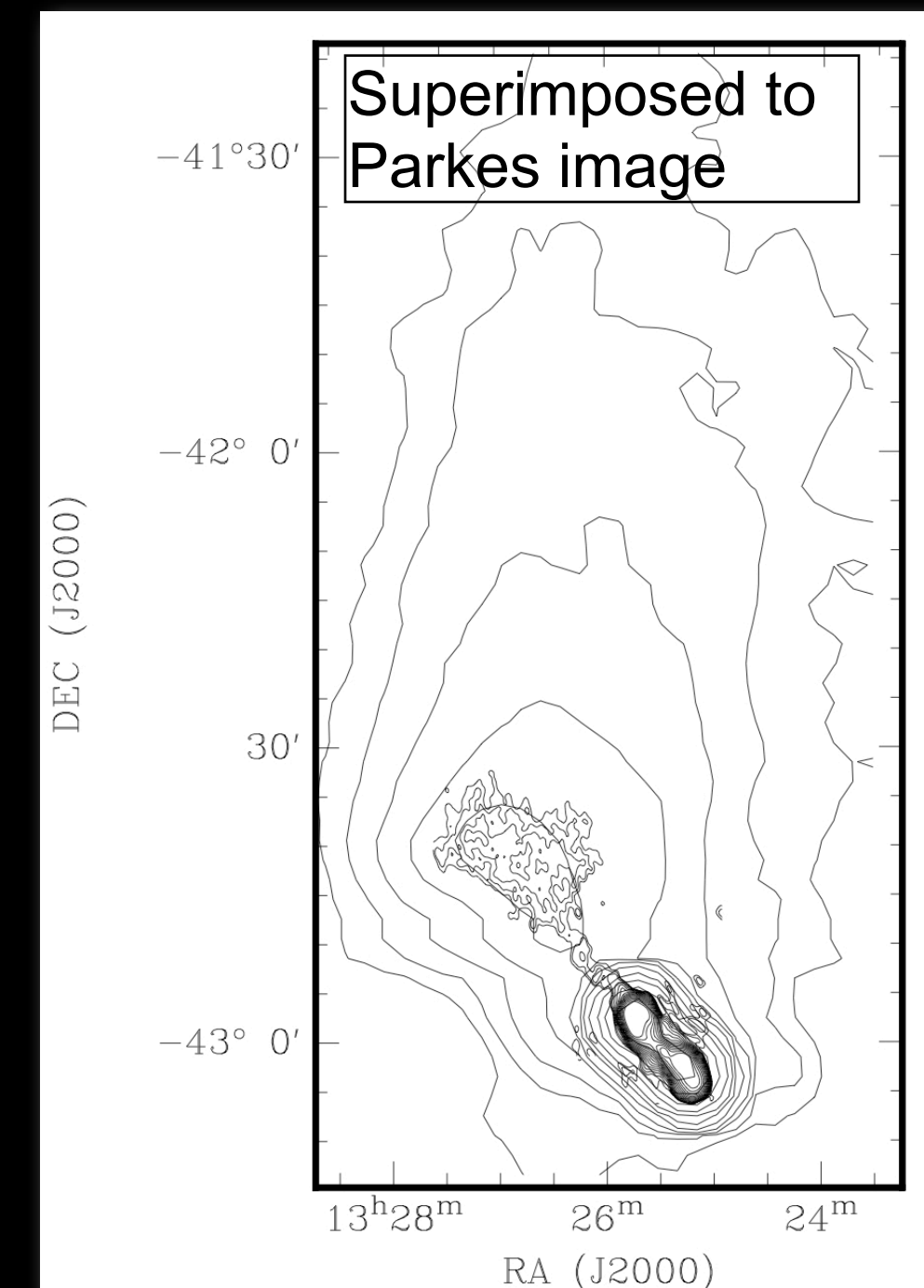


# New radio observations: the bursting bubble



Morganti, Killeen, Ekers, Oosterloo 1999

- ▶ Mosaic using ATCA - about 1kpc linear resolution
- ▶ Detected jet-like structure connecting inner and middle radio lobes
- ▶ Multiple outbursts? Need to explain the large drop in brightness observed
- ▶ Bursting bubble idea? plasma accumulated in the inner lobe would "burst" through one nozzle
- ▶ ...or created by old episod of activity interrupted by the merger (and now raising buoyantly) - Saxton & Bicknell (2001)



Radio spectral index?



# An even larger mosaic of Centaurus A

Feain et al. - APoD

- ▶ recent image (Feain et al.): central part is still taken from our ATCA mosaic
- ▶ note asymmetry: many interesting things seem to happen only in the northern lobe



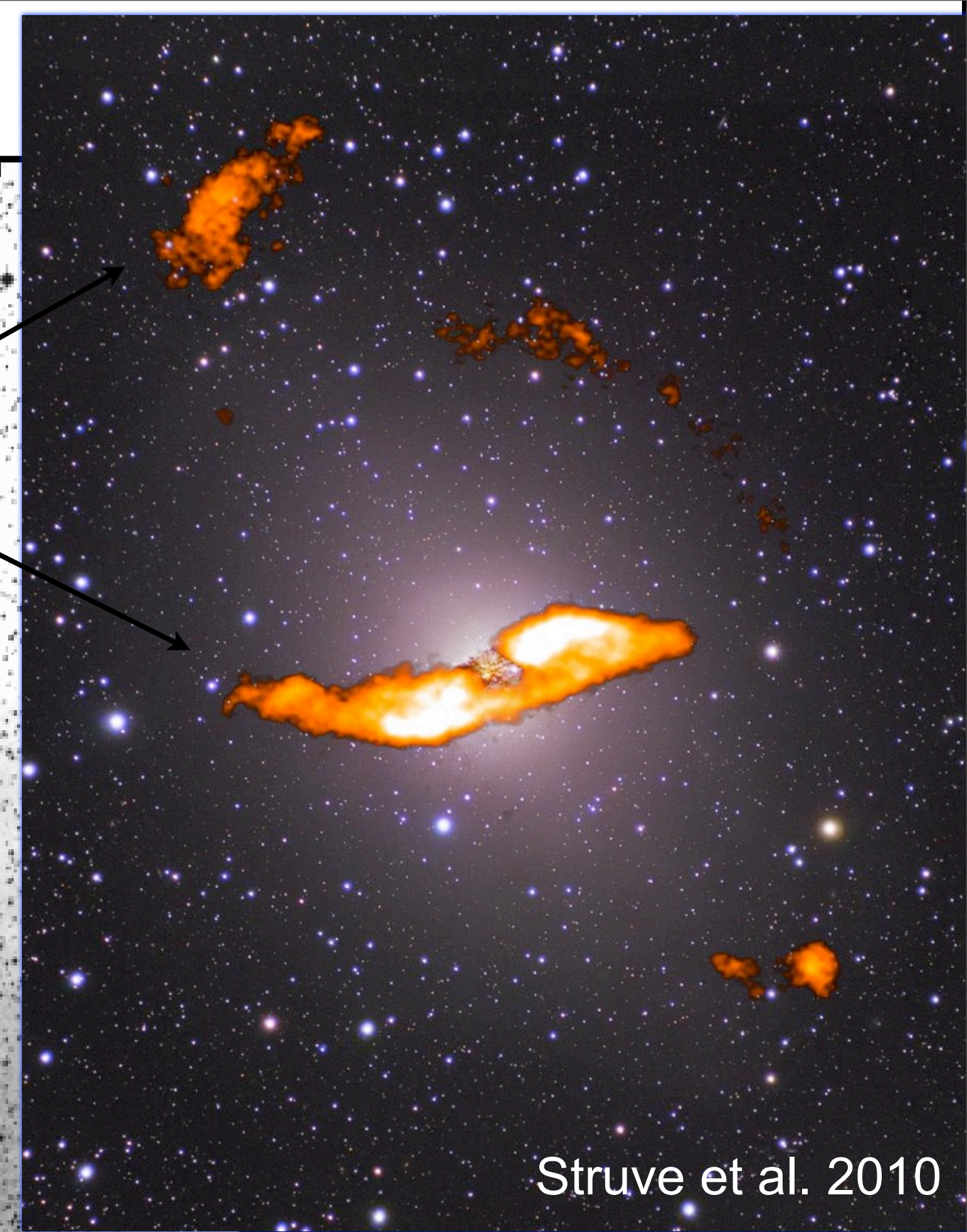
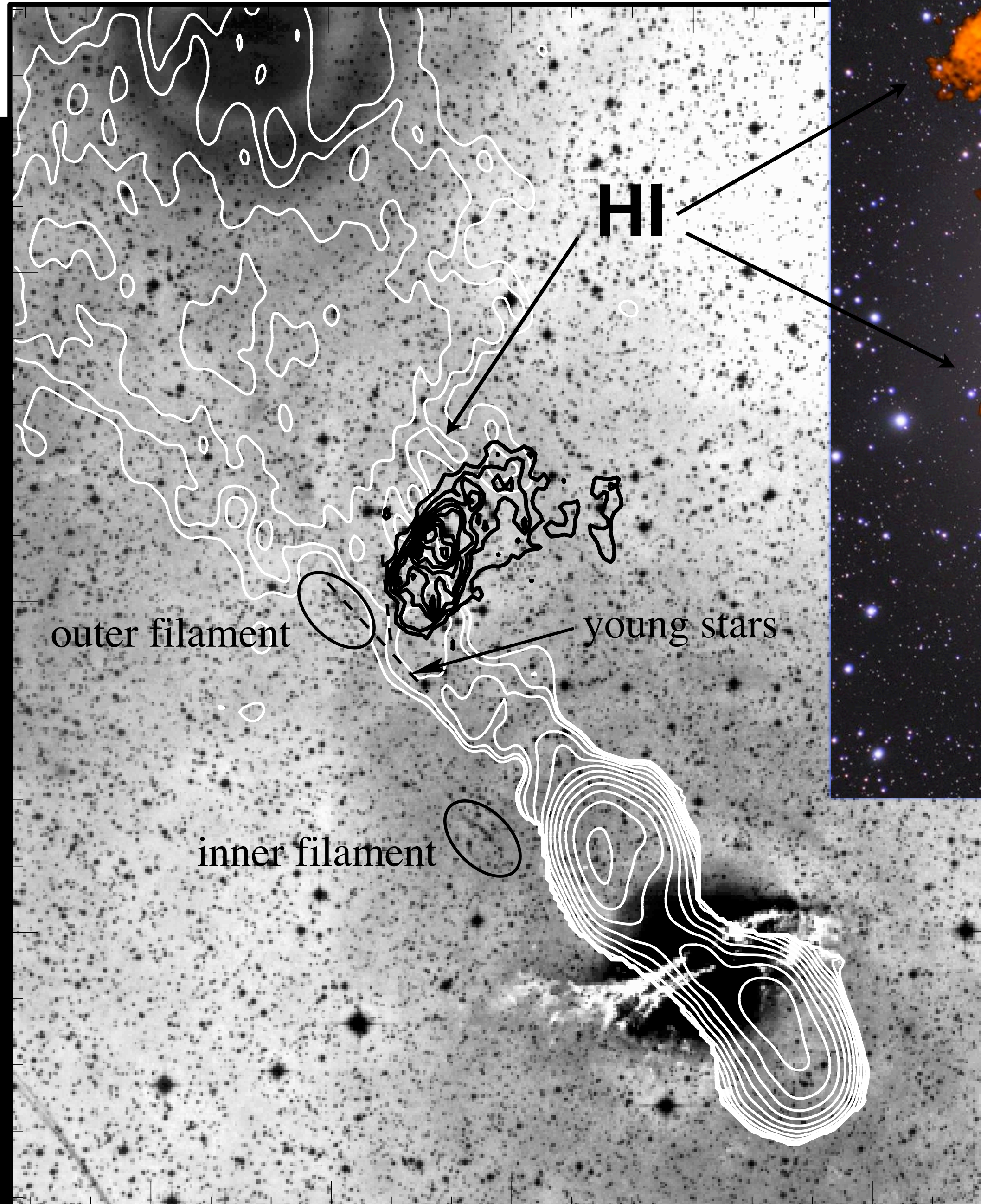


# Radio continuum and HI: jet induced star formation?

- HI next to the filament and velocity gradient



Filaments contain young stars (10 Myr)  
Rejkuba et al (2002), Mould et al. (2000)

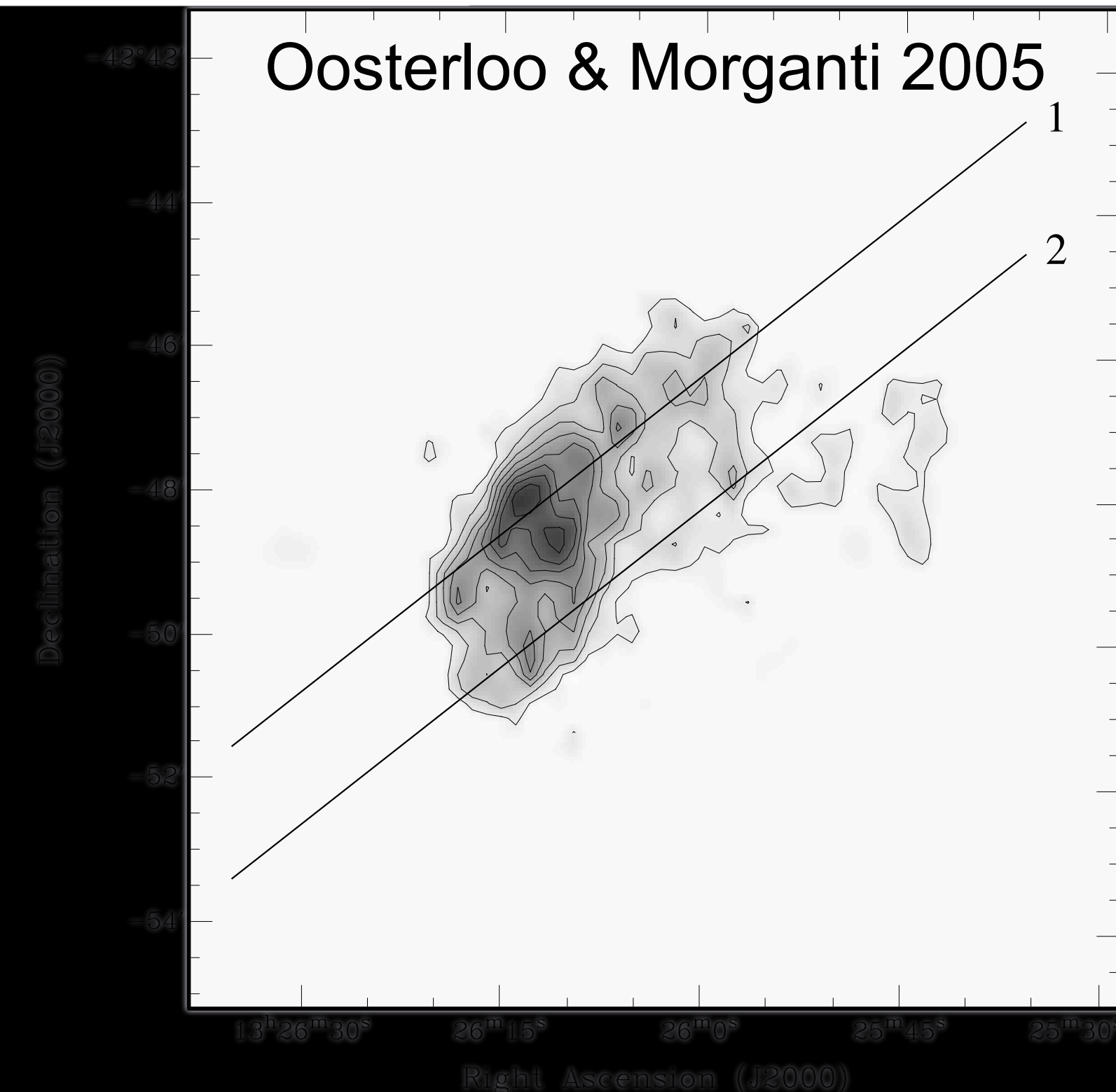
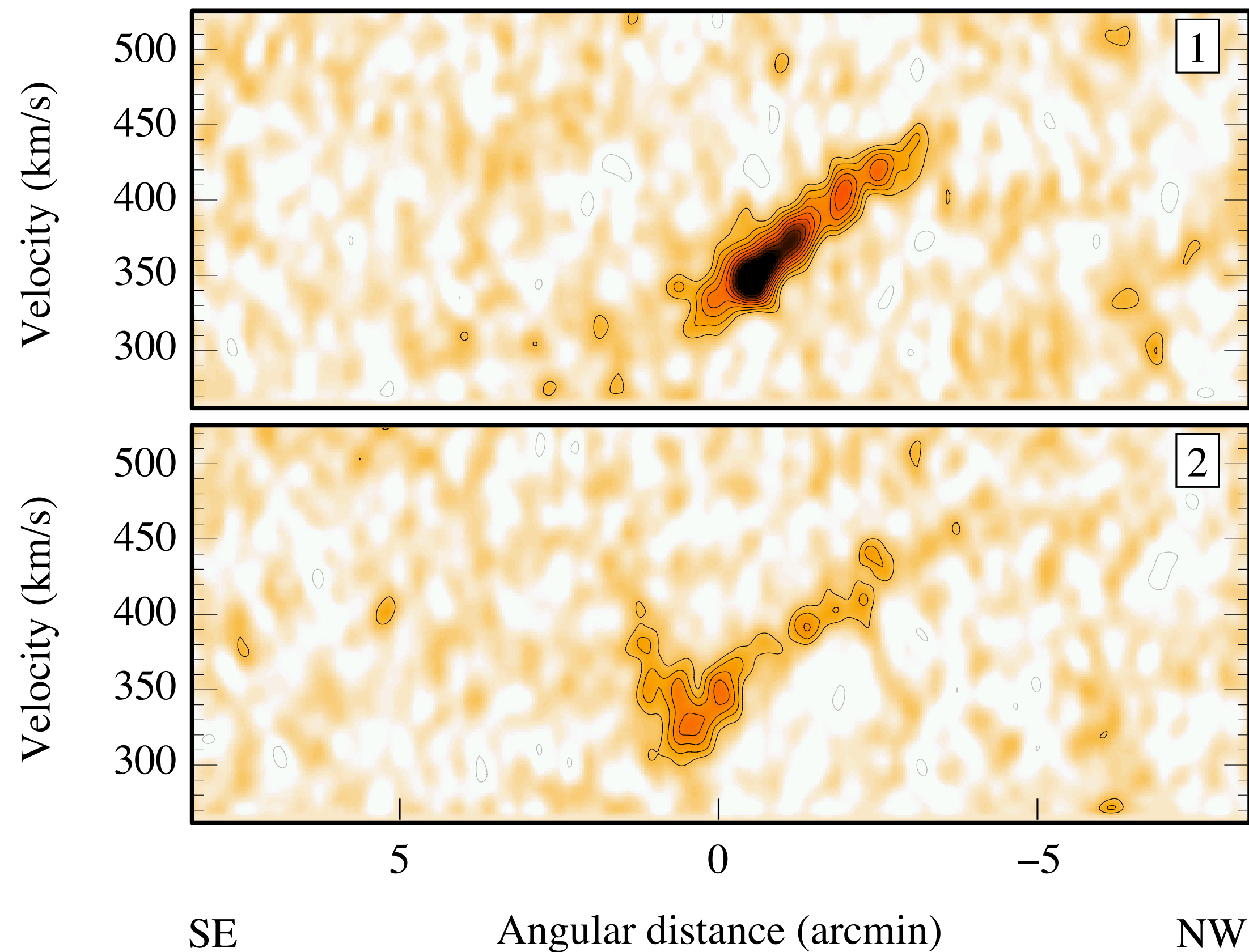


Struve et al. 2010



# Velocity anomaly in S tip of HI cloud

- ▶  $100 \text{ km s}^{-1}$  over 1 kpc, is not gravitational

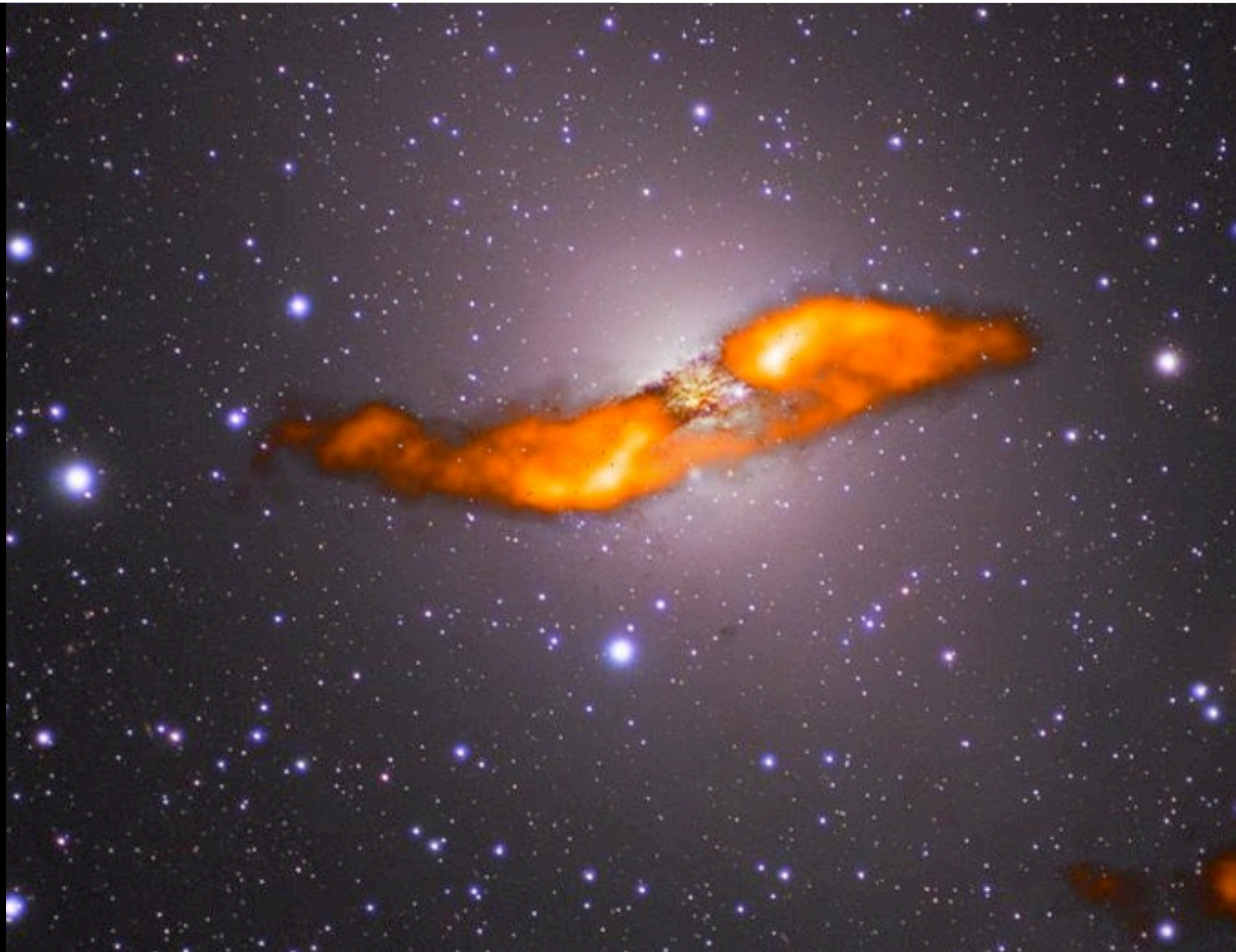


- ▶ Jet hits S tip of H I cloud inducing star formation and creating turbulent ionised filament
- ▶ Puzzle: column density in H I cloud is above  $10^{21} \text{ cm}^{-2}$ . Why no star formation in cloud?



# HI disk: a look into the history of the galaxy

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HI disk looks very similar to dust disk

HI mass =  $3.9 \cdot 10^8 M_{\odot}$

HI-dust ratio  $\sim 200$

$M_{\text{HI}}/L_B = 0.01$



**Dusty Elliptical Galaxy Centarus A**

NASA / JPL-Caltech / J. Keene (SSC/Caltech)

**Spitzer Space Telescope • IRAC**

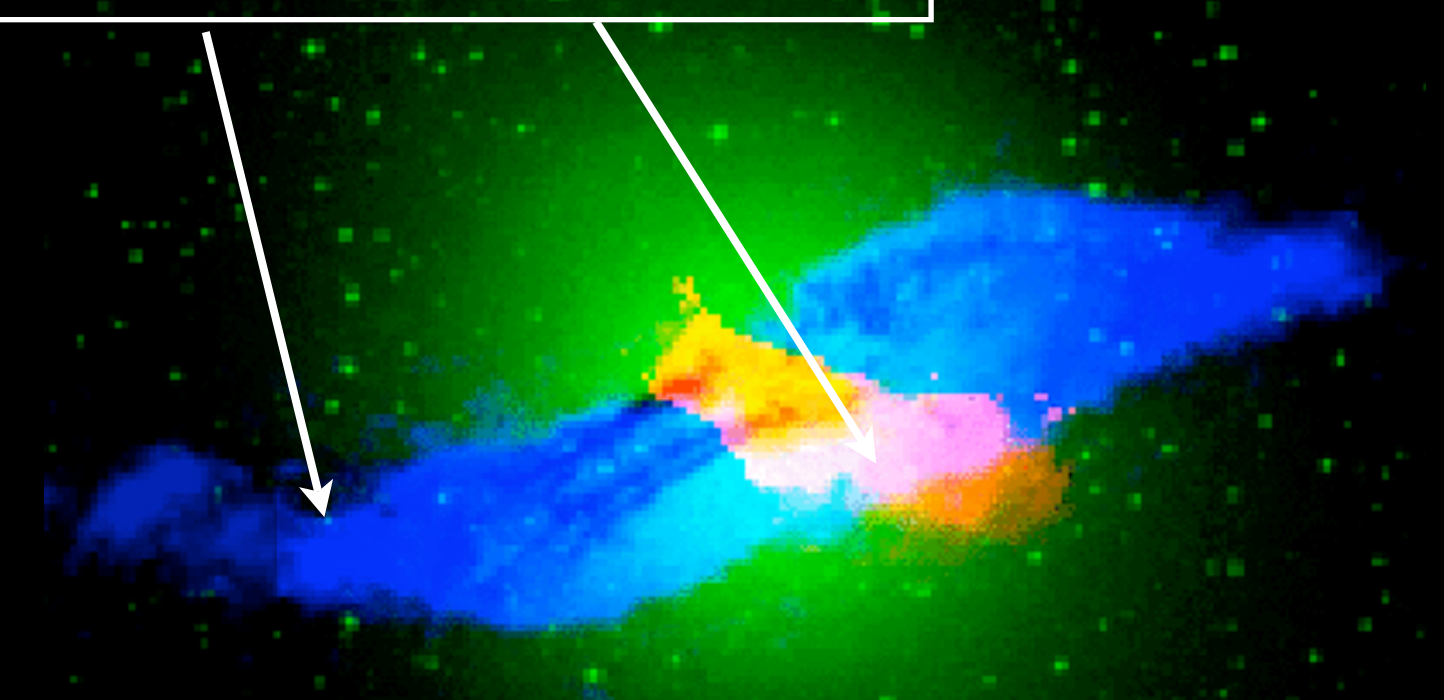
ssc2004-09a



# Large disk : HI along the dust-lane

- ▶ HI observations with ATCA
  - Relatively high spatial ( $6'' \sim 100$  pc) and velocity resolution
  - High sensitivity and large bandwidth
- ▶ Settled gas except for the outer regions ( $\geq 5$  kpc)
- ▶ Warped disk with gas in circular orbits describes well the observed HI structure

HI emission & absorption



Few  $\times 10^8 M_{\odot}$  of HI

~ 2 kpc



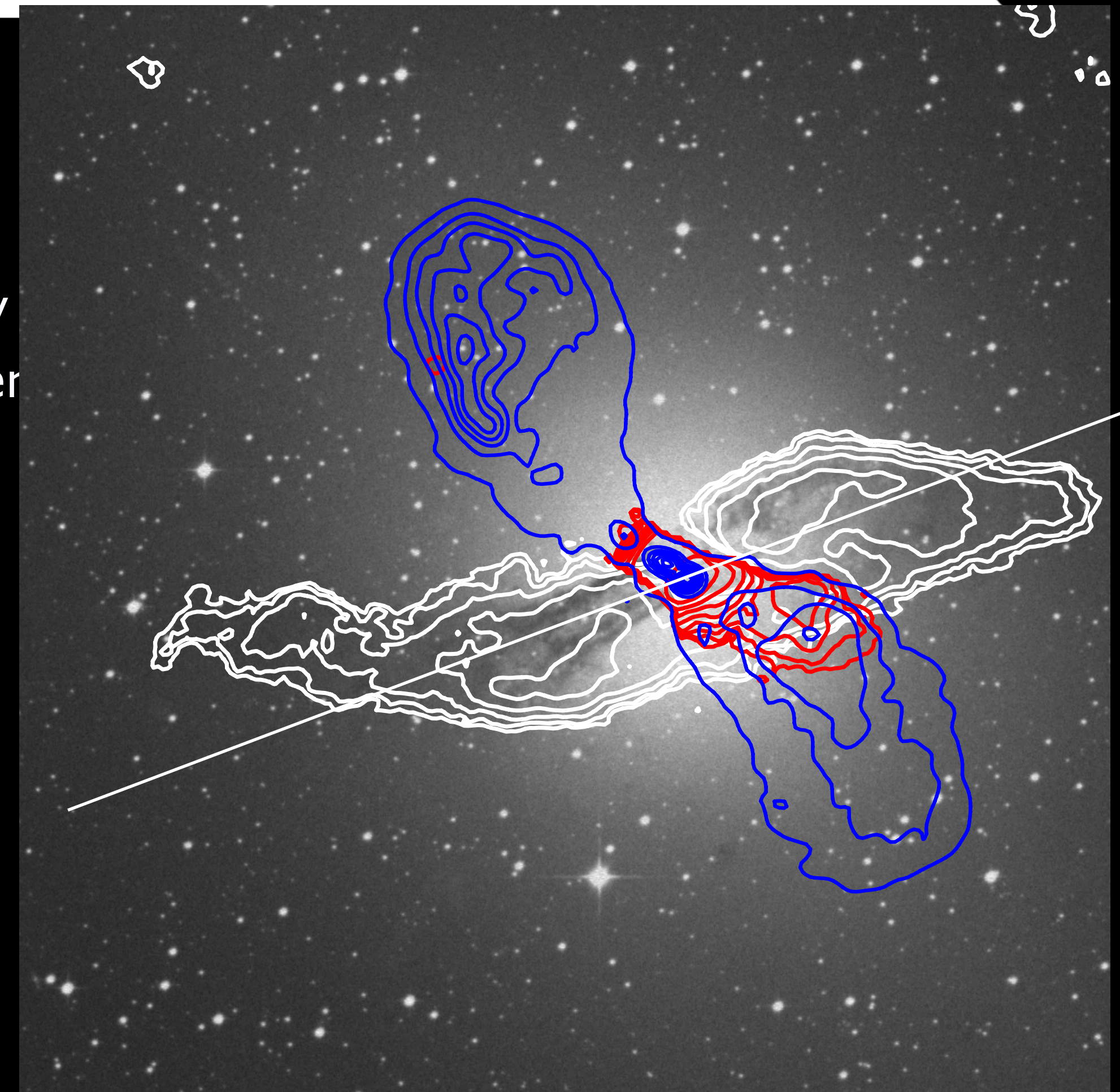
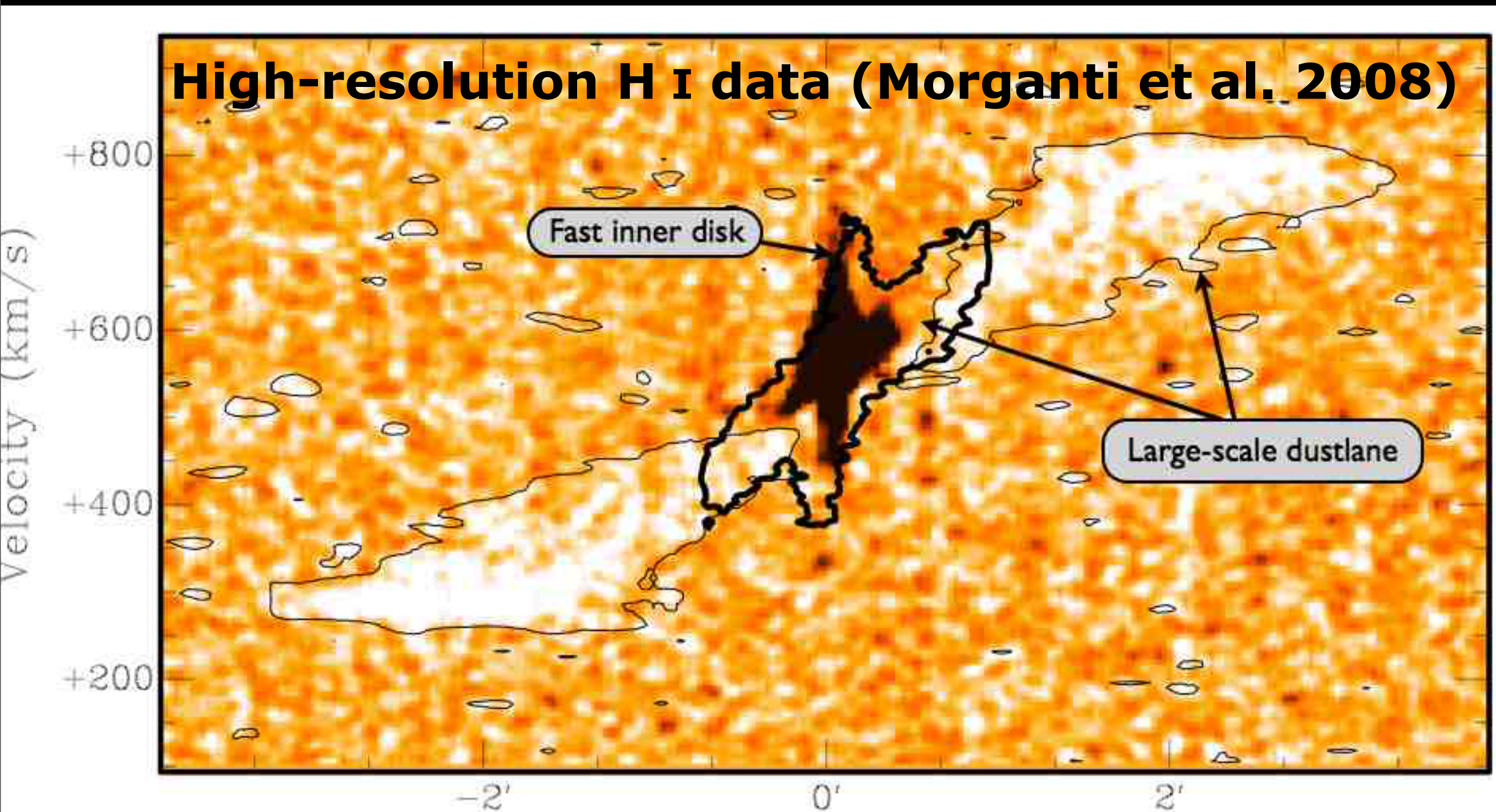
- ▶ Cen A has warped H I disk along minor axis, warp is very modest  
Partial outer H I ring perpendicular to inner disk  
“No” H I inside 1 kpc
- ▶ Regular kinematics inside 5 kpc  
Asymmetries and filaments at larger radius  
No need for non-circular orbits between 1-5 kpc  
Reproduces H I kinematics & shape dust disk (and stellar ring)
- ▶ Age few  $\times 10^8$  yr  
Too old for triggering recent AGN activity ( $10^7$  yr)  
Connected to previous episode of AGN activity? Disk has  $\sim$ same age as middle lobes, younger than outer lobes?
- ▶  $M_{\text{HI}}/L_B = 0.01$ , so H I disk might well be the result of accretion of small (SMC-like?) galaxy  
Not connected to “major merger” of 5 Gyr ago

Conclusions about the origin of gas and AGN activity: no direct indication it is a merger that trigger the activity, different time scales etc.



# The HI absorption: gas in the centre

- ▶ Main argument: redshifted absorption → gas infalling, feeding AGN?
- ▶ Deeper HI observations (ATCA) show also a blueshifted component of the HI absorption (Morganti et al. 2008) → not only infalling gas! Blueshifted nuclear absorption is associated with inner disk ( $r < 200$  pc)

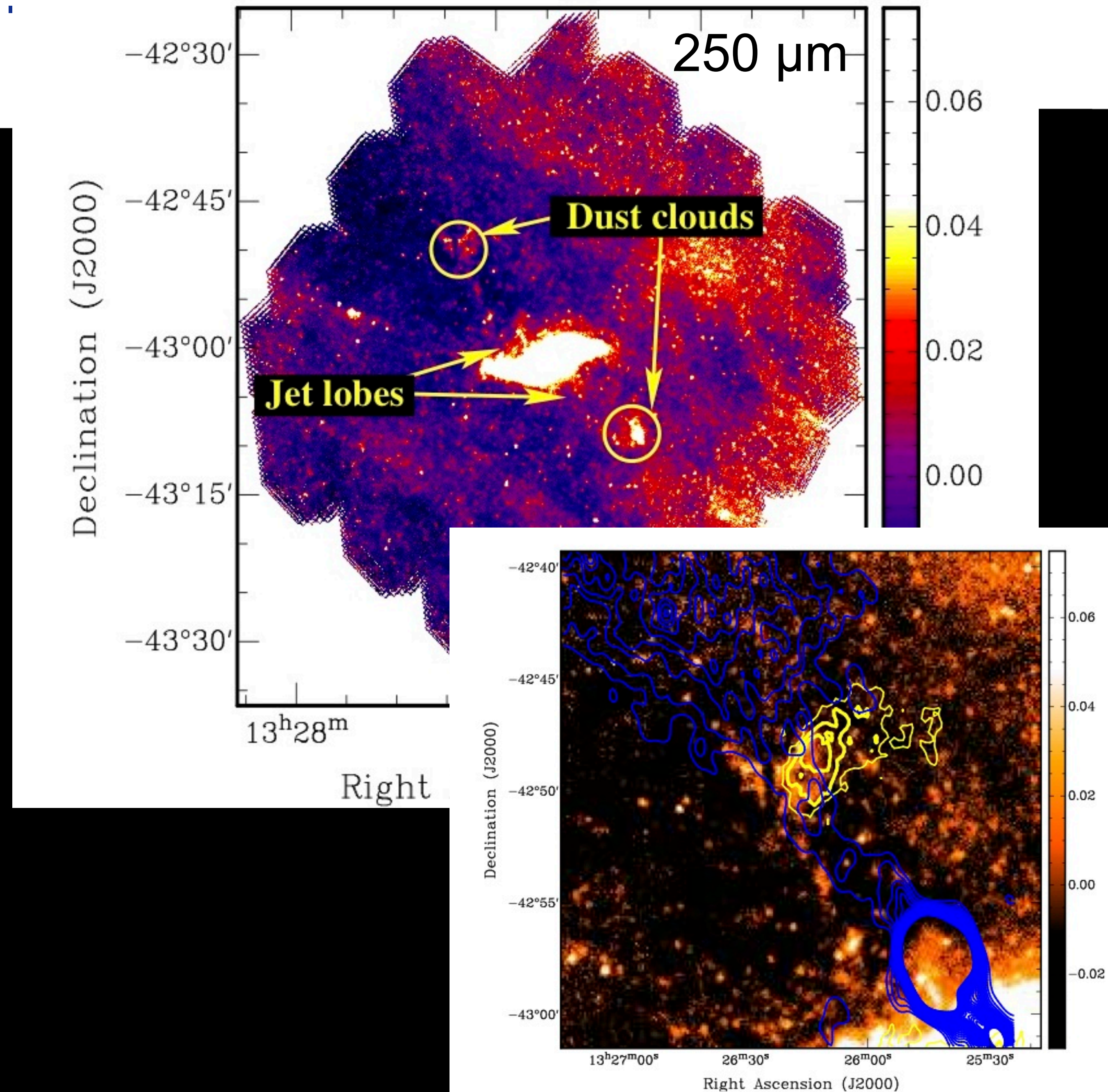


PV plot of the HI + CO(J=3-2) contour (Liszt)



....at last, back to the filaments...

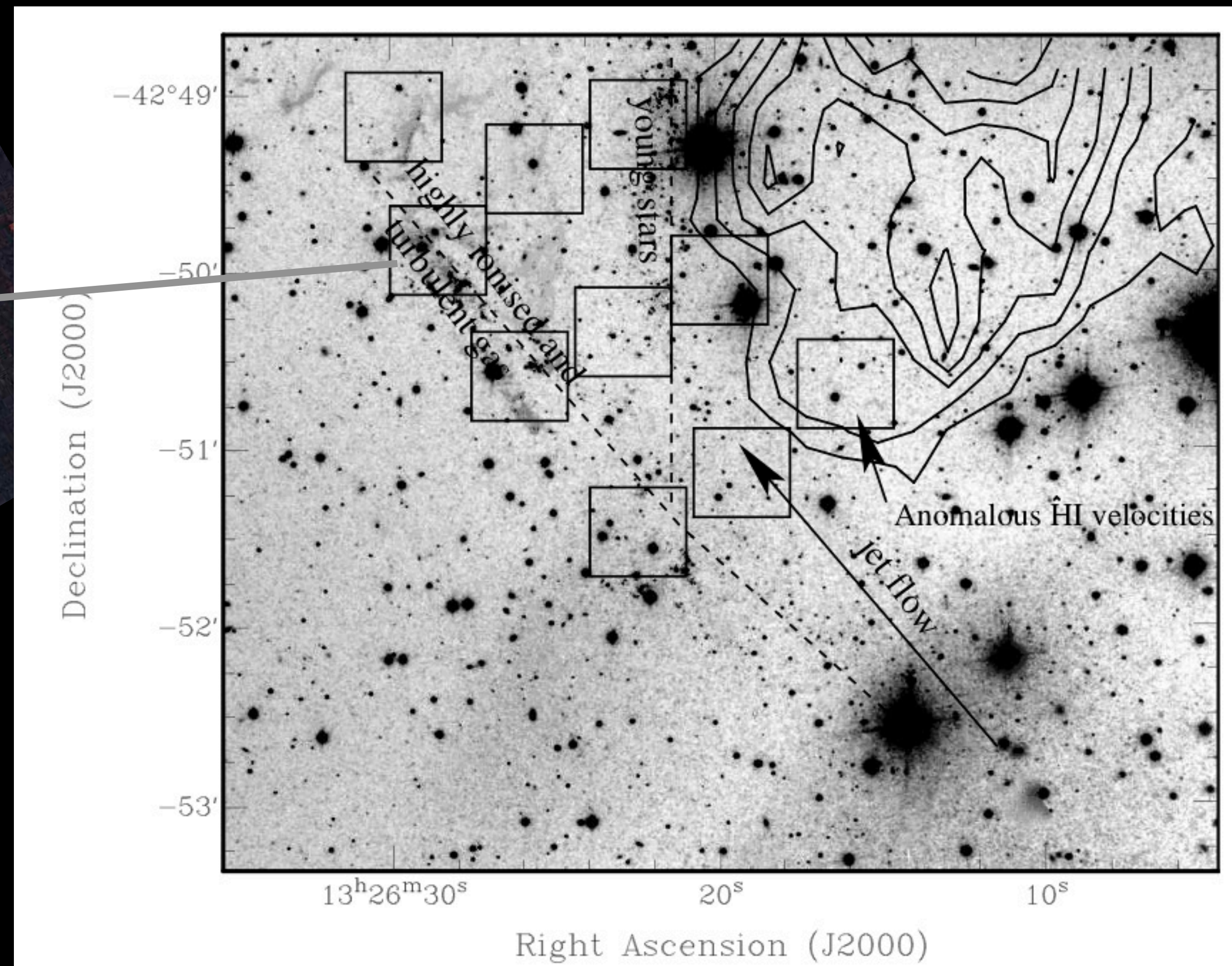
- ▶ missing ingredient: dust! Herschel - SPIRE data (SPIRE 250, 350, 500  $\mu\text{m}$ ): work of Auld et al.
- ▶ Two dust clouds co-aligned with the axis of the radio jet (again related to interaction? enhanced column density? but remember asymmetries in radio!)
- ▶ dust temperature  $\sim 13\text{-}14\text{ K}$
- ▶ SFR too low to produce the inferred dust mass ( $\log M \sim 5.6 M_{\odot}$ )
- ▶ dust originate in a late-type progenitor galaxy that merged with Cen A





....at last, back to the filaments.....OPTICAL DATA!

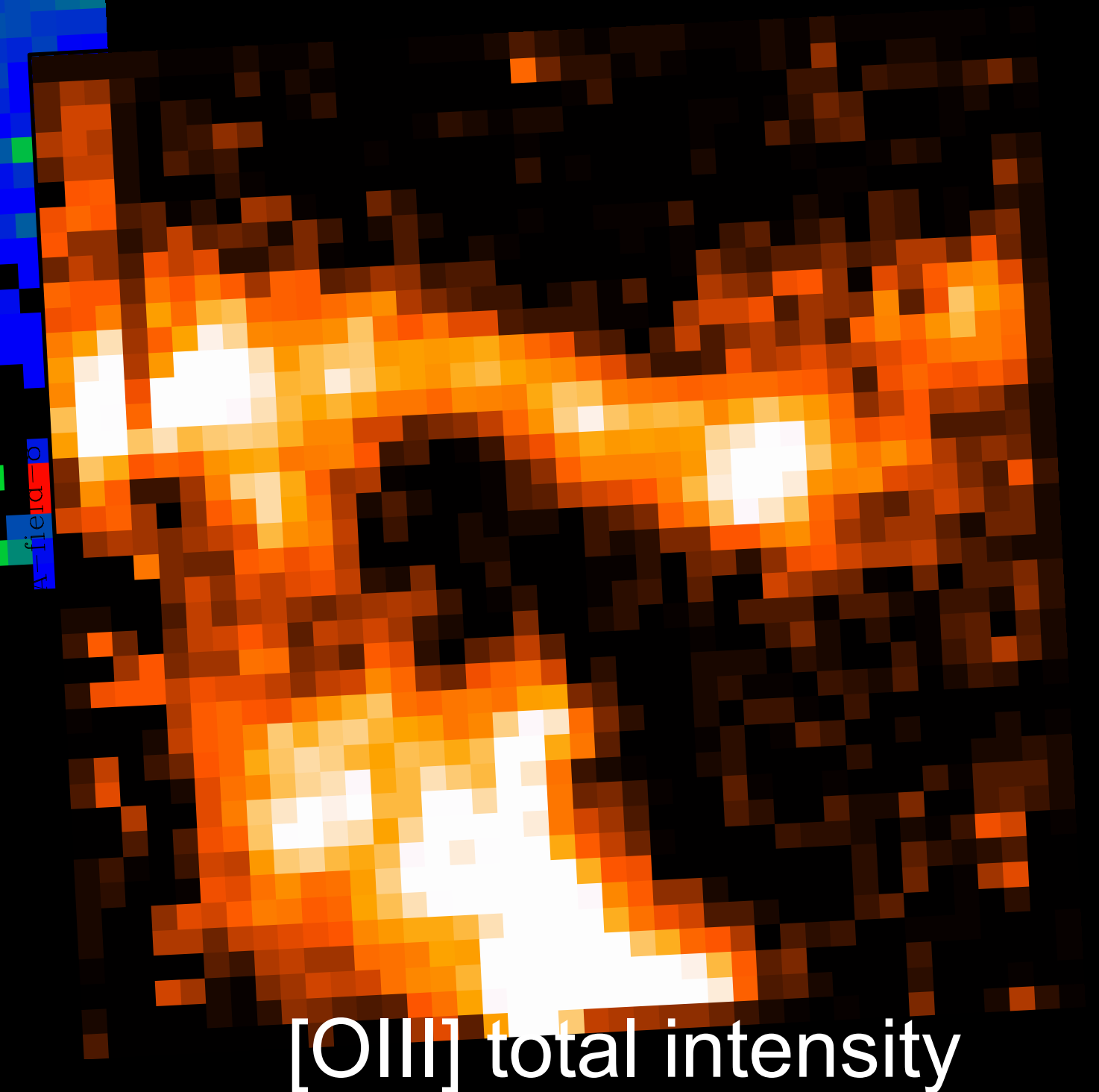
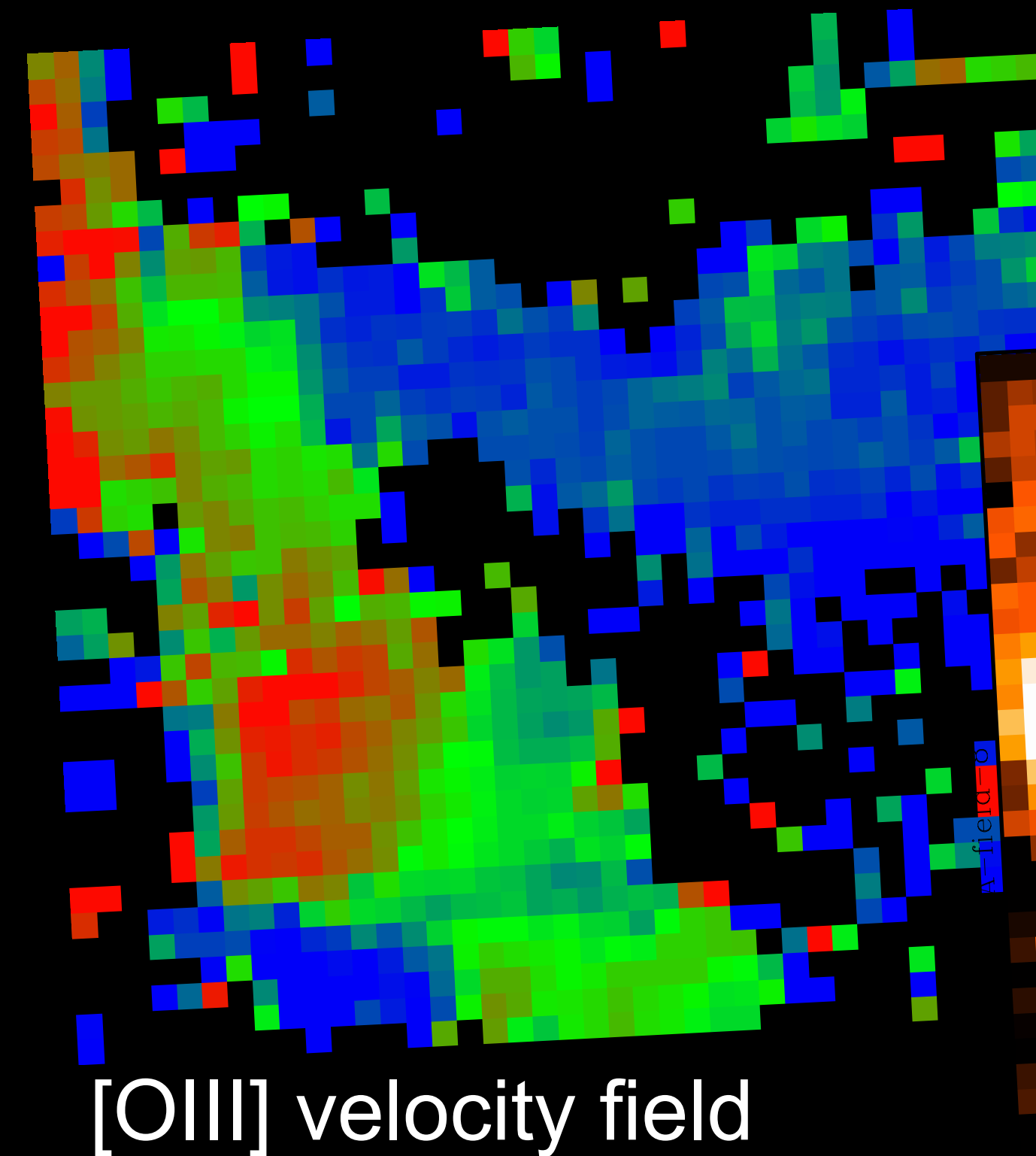
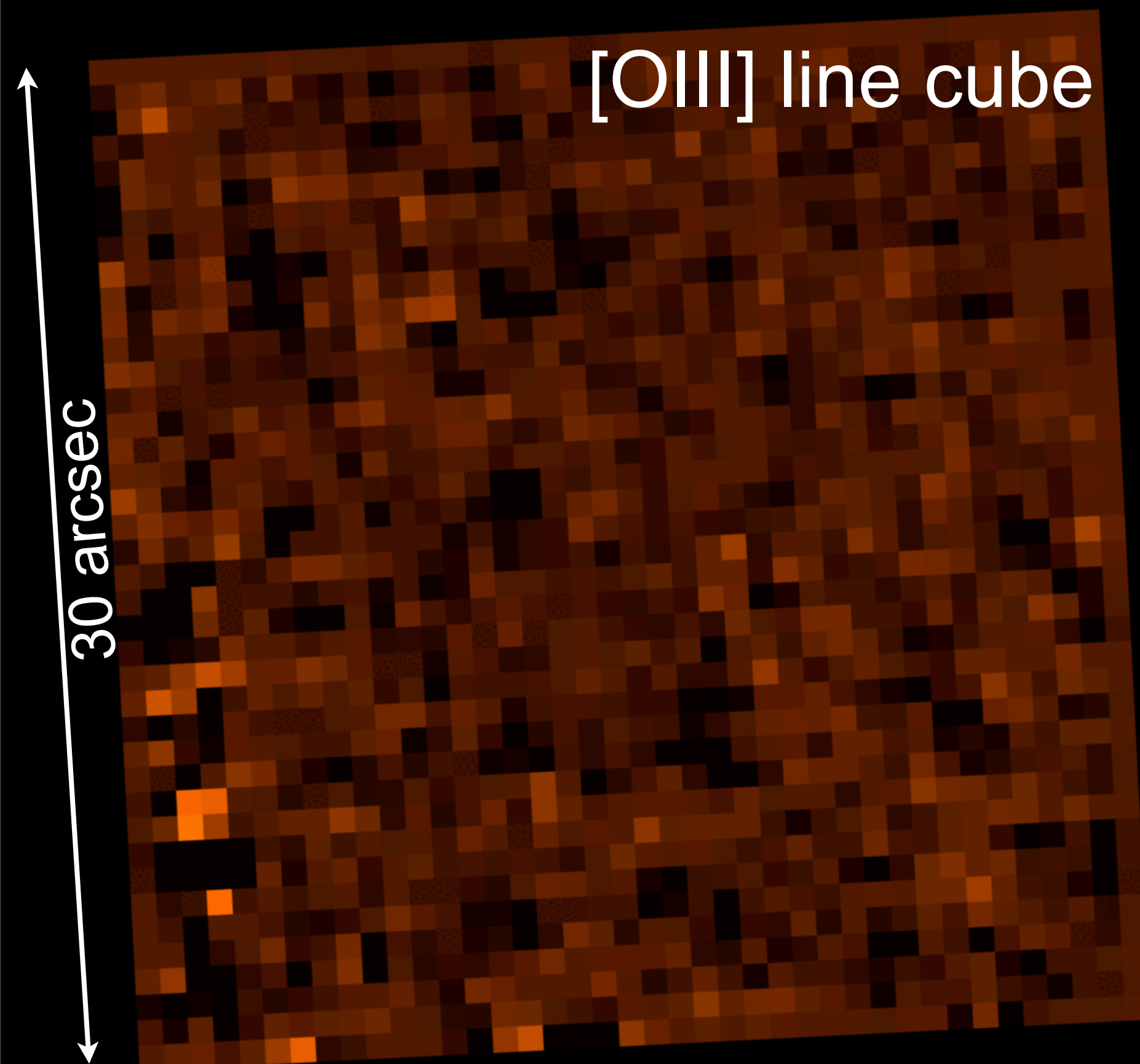
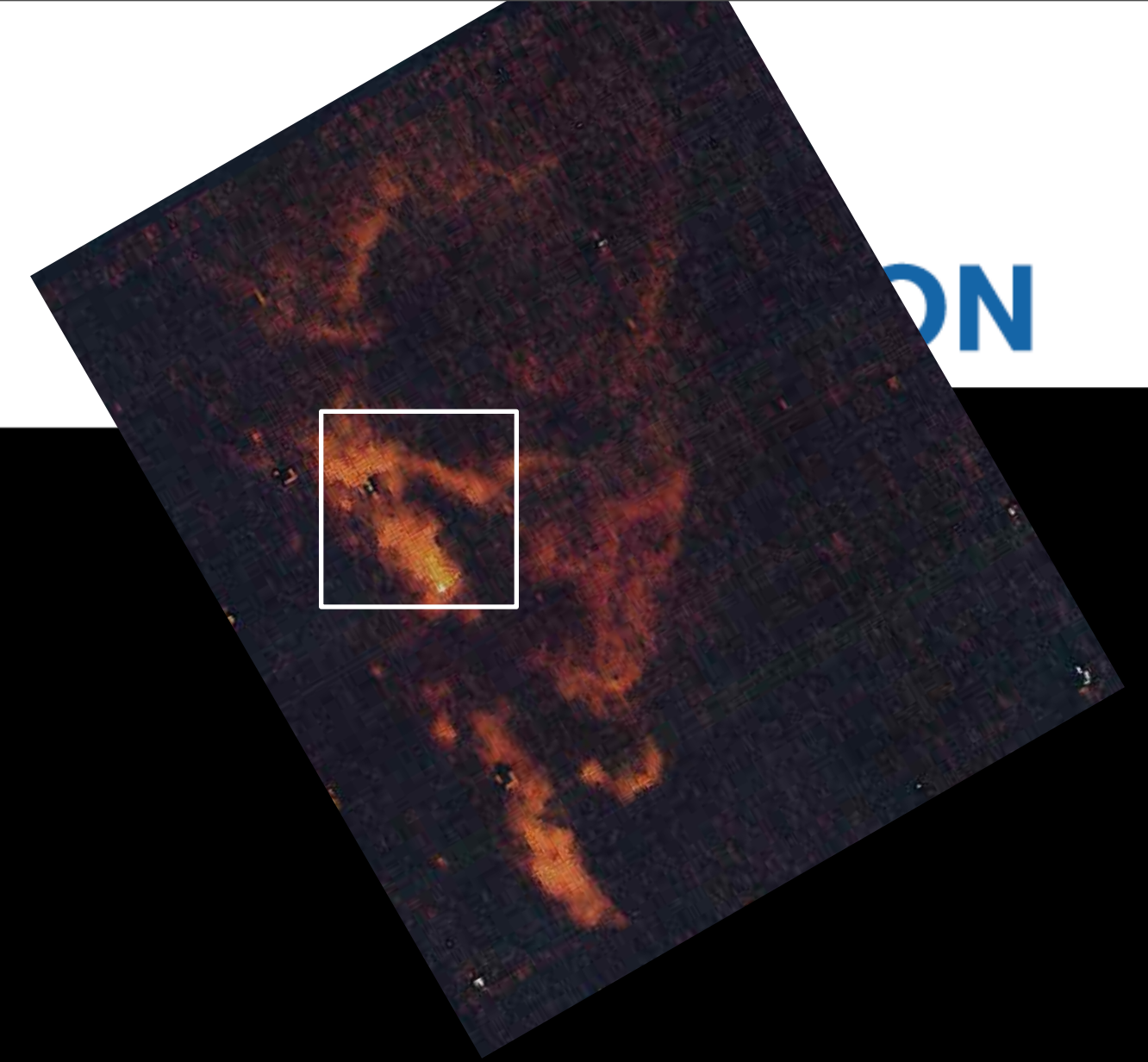
- ▶ This time with **Integral Field spectroscopy** (VIMOS data)
- ▶ detect any change in conditions along the flow that would allow to study the time evolution of the gas after the interaction.....





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# What did I learn and what next?

- ▶ Wonderful object: in this epoch of mega-surveys, studies of single objects can illuminate (or confuse!) on many important aspects!!!!
- ▶ Connection merger  $\longleftrightarrow$  nuclear activity far from clear!
- ▶ Effects of radio jet on the ISM
- ▶ Importance of multi-wavelength data: *"there is nothing so boring as a radio source"* (Bob Becker, FIRST)

Plenty of new radio telescopes in the southern hemisphere: Cen A is one of the prime targets..... a lot of fun ahead!!!