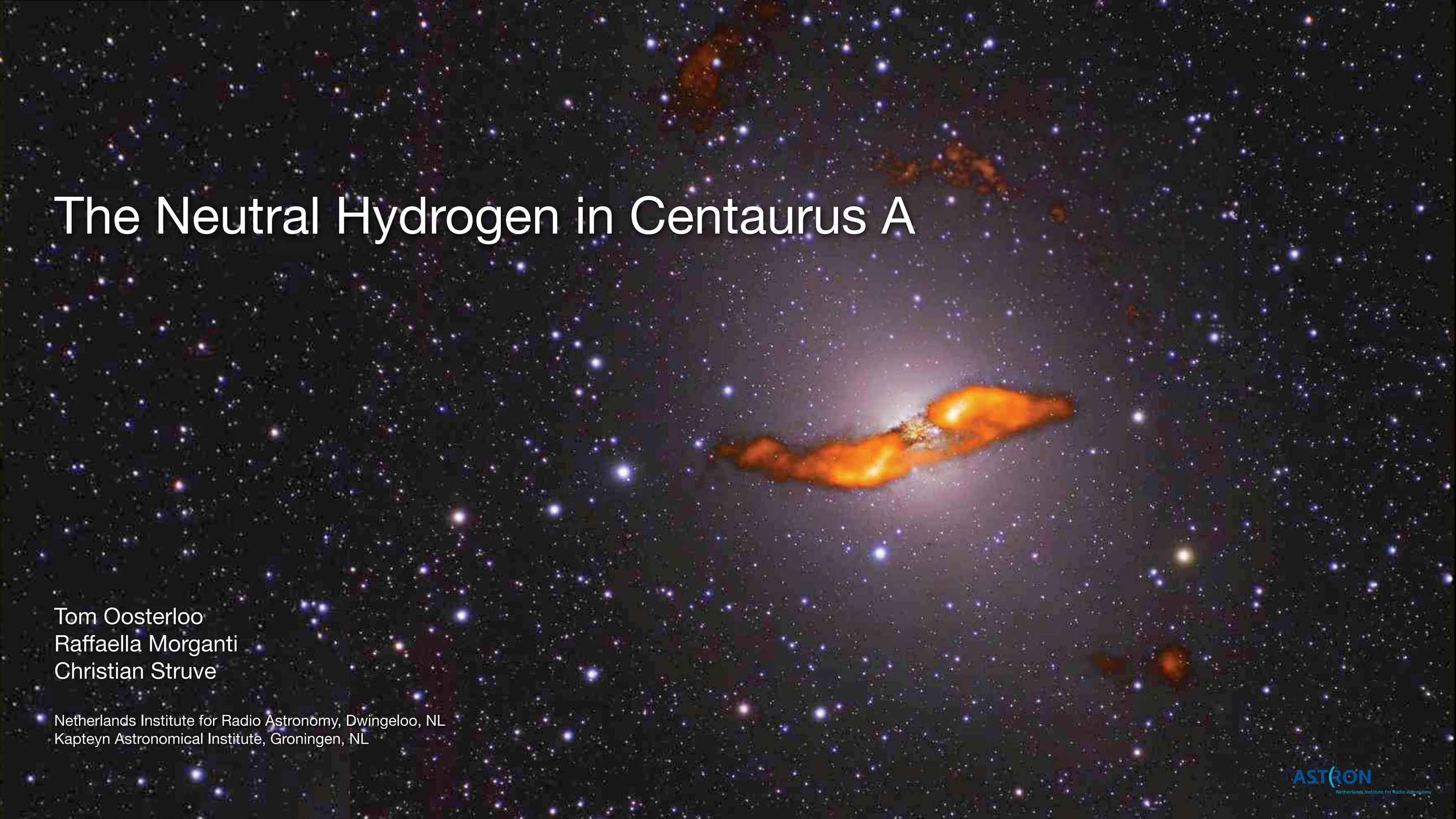
The Neutral Hydrogen in Centaurus A



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ASTRON
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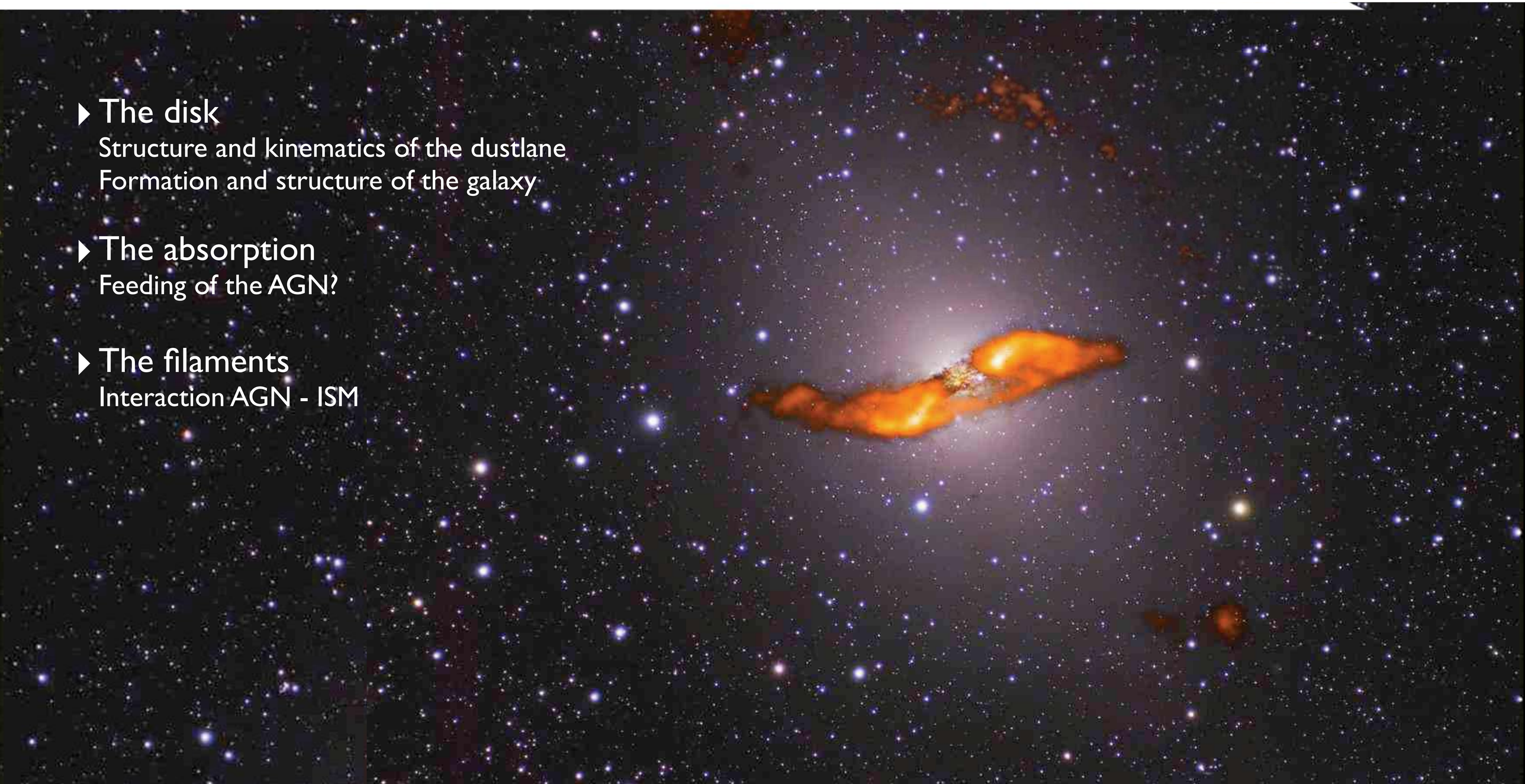
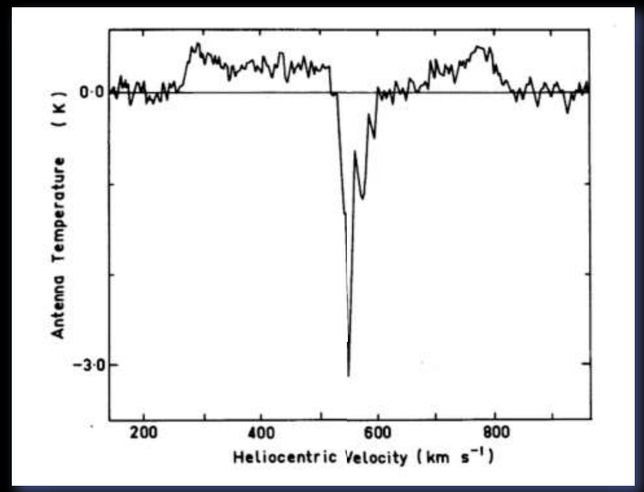
Outline

- **The disk**
  Structure and kinematics of the dustlane
  Formation and structure of the galaxy
- **The absorption**
  Feeding of the AGN?
- **The filaments**
  Interaction AGN - ISM

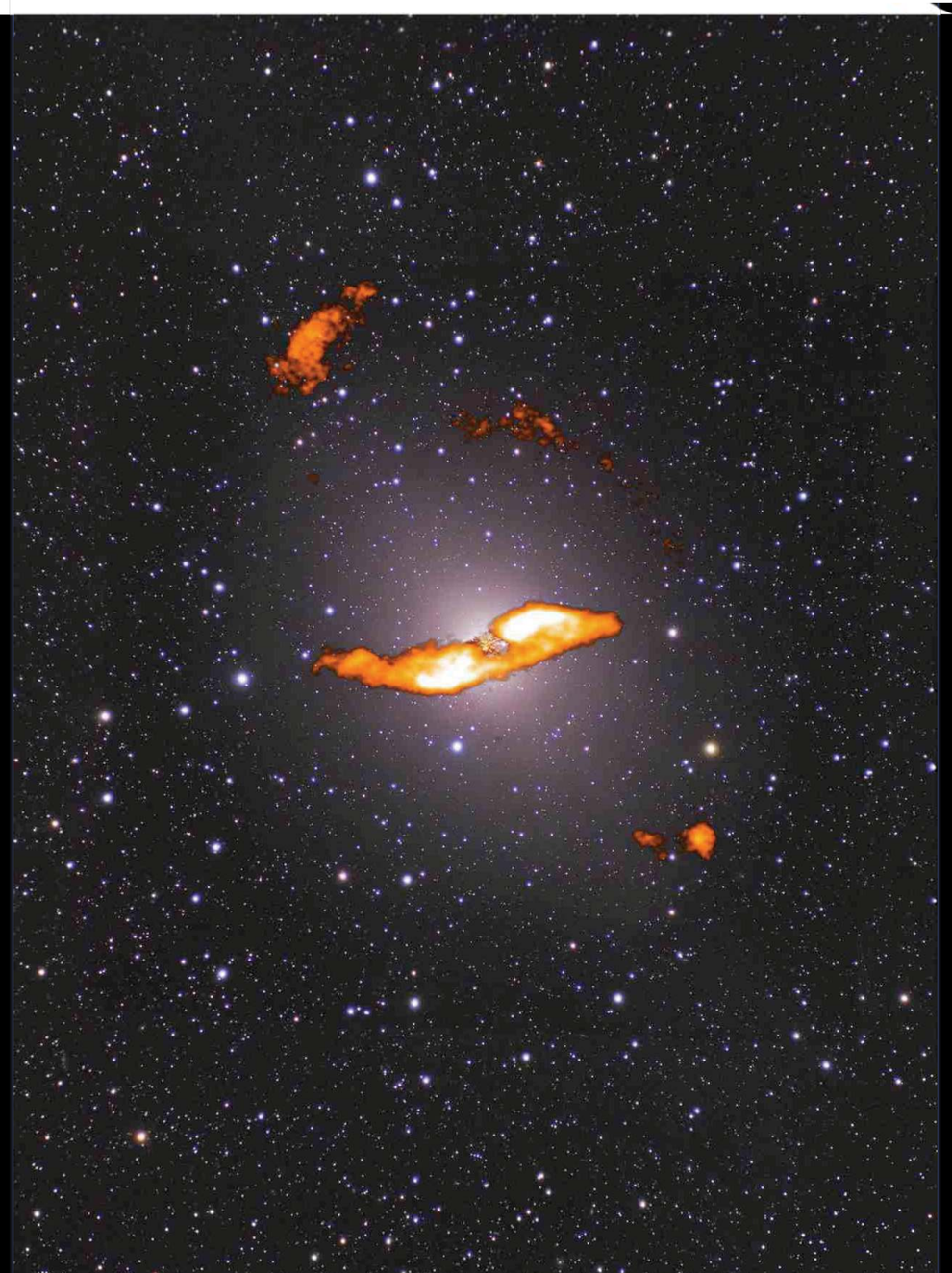


The disk

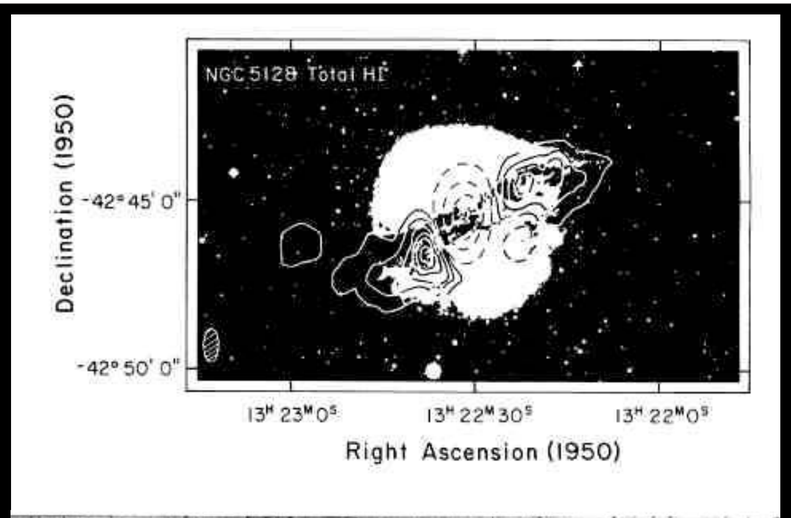
- First elliptical in which H I was detected
  (absorption Roberts 1970; emission Gardner & Whiteoak 1976)



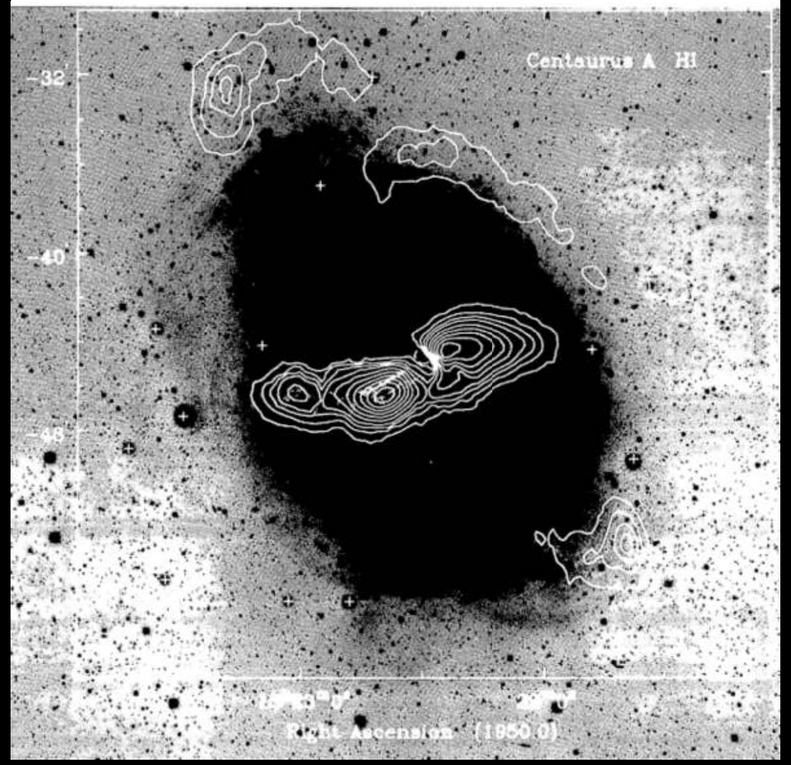
- H I disk is often associated with merger that led to AGN activity. Which activity?
- Do we see signs that AGN is fed by H I disk?
- How common is H I in early-type galaxies and how often does it look like the H I in Cen A?



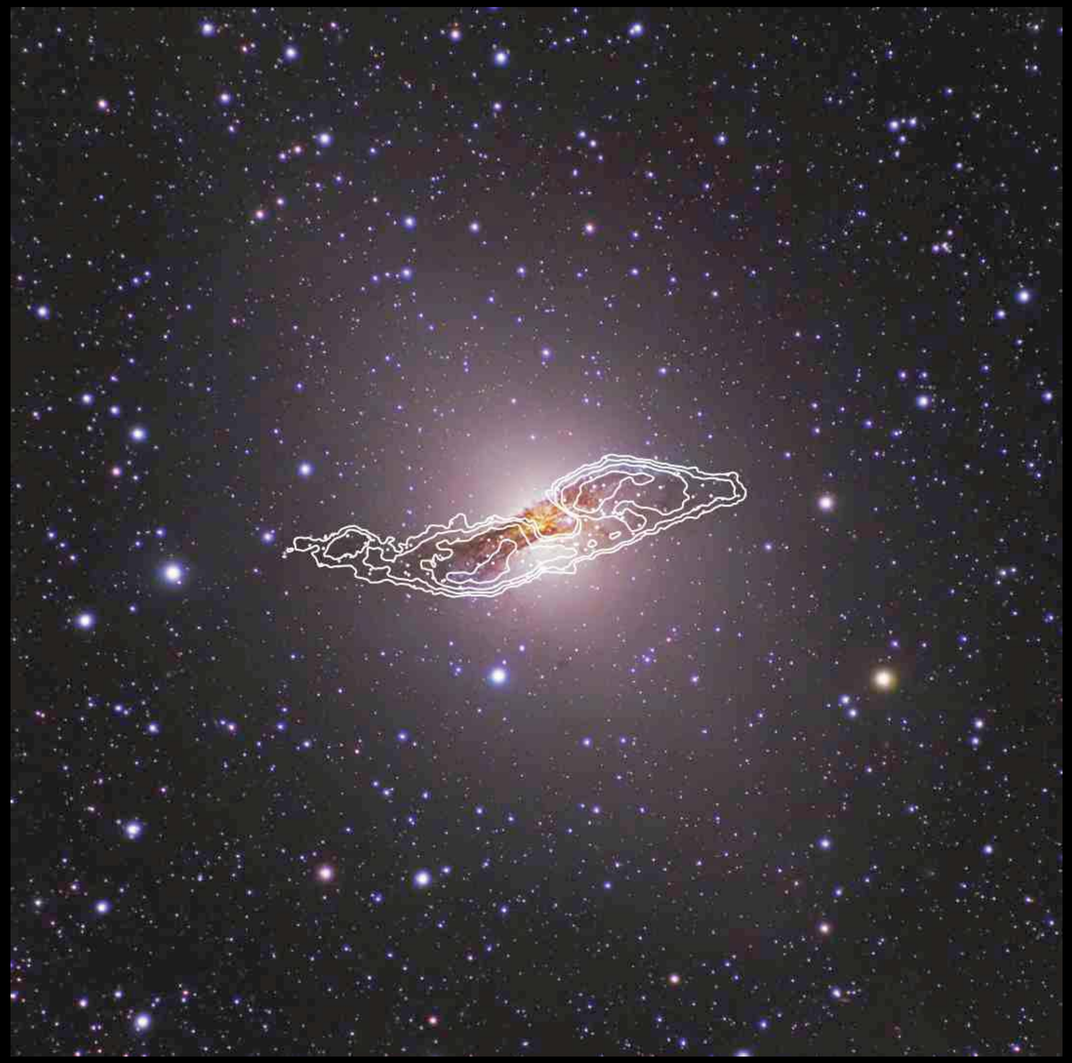
The disk



van Gorkom+ 1990



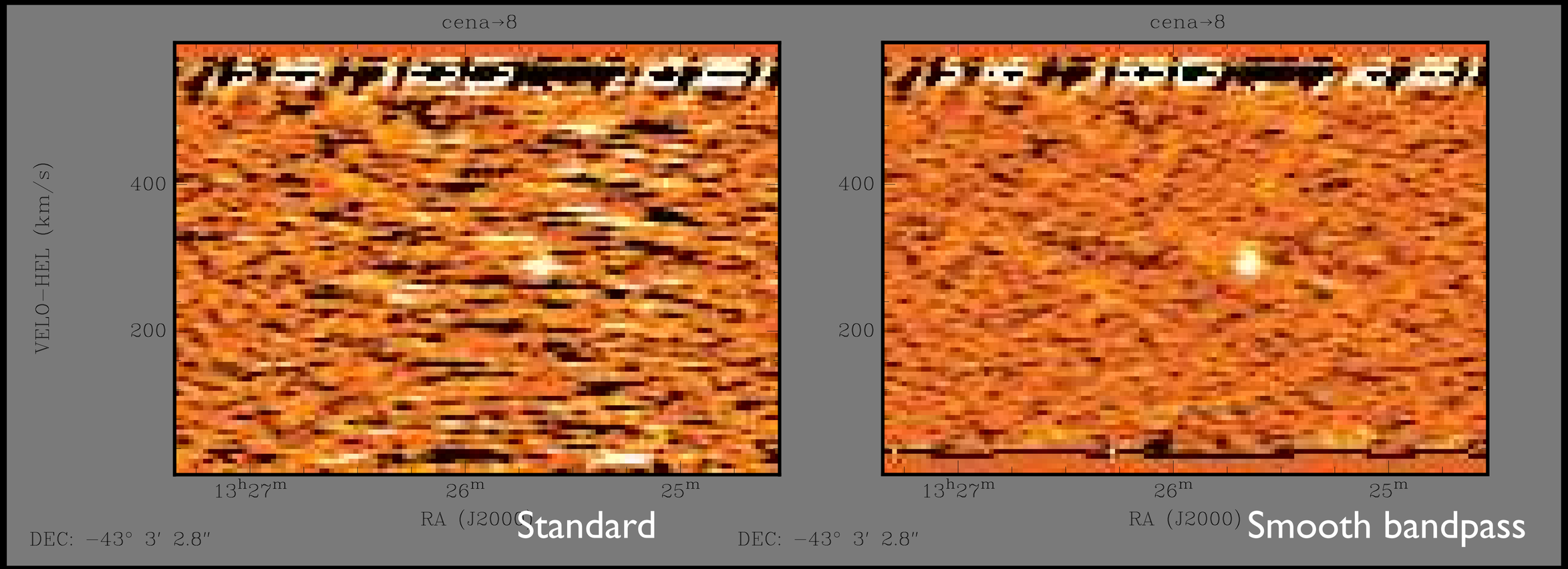
Schiminovich+ 1994

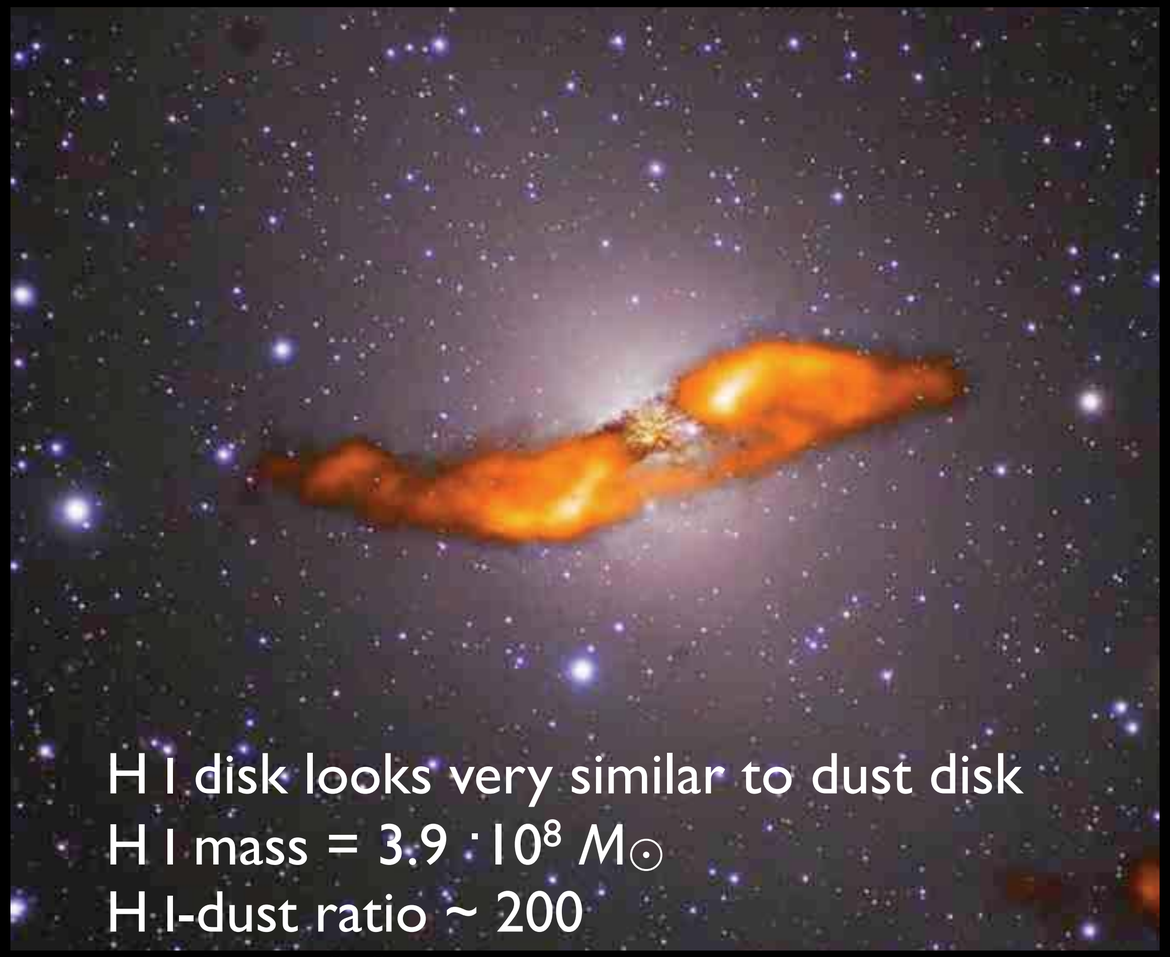


Latest observations: ATCA (Morganti, Struve, Oosterloo)
8”-18” resolution
16 MHz bandwidth

Difficult observations

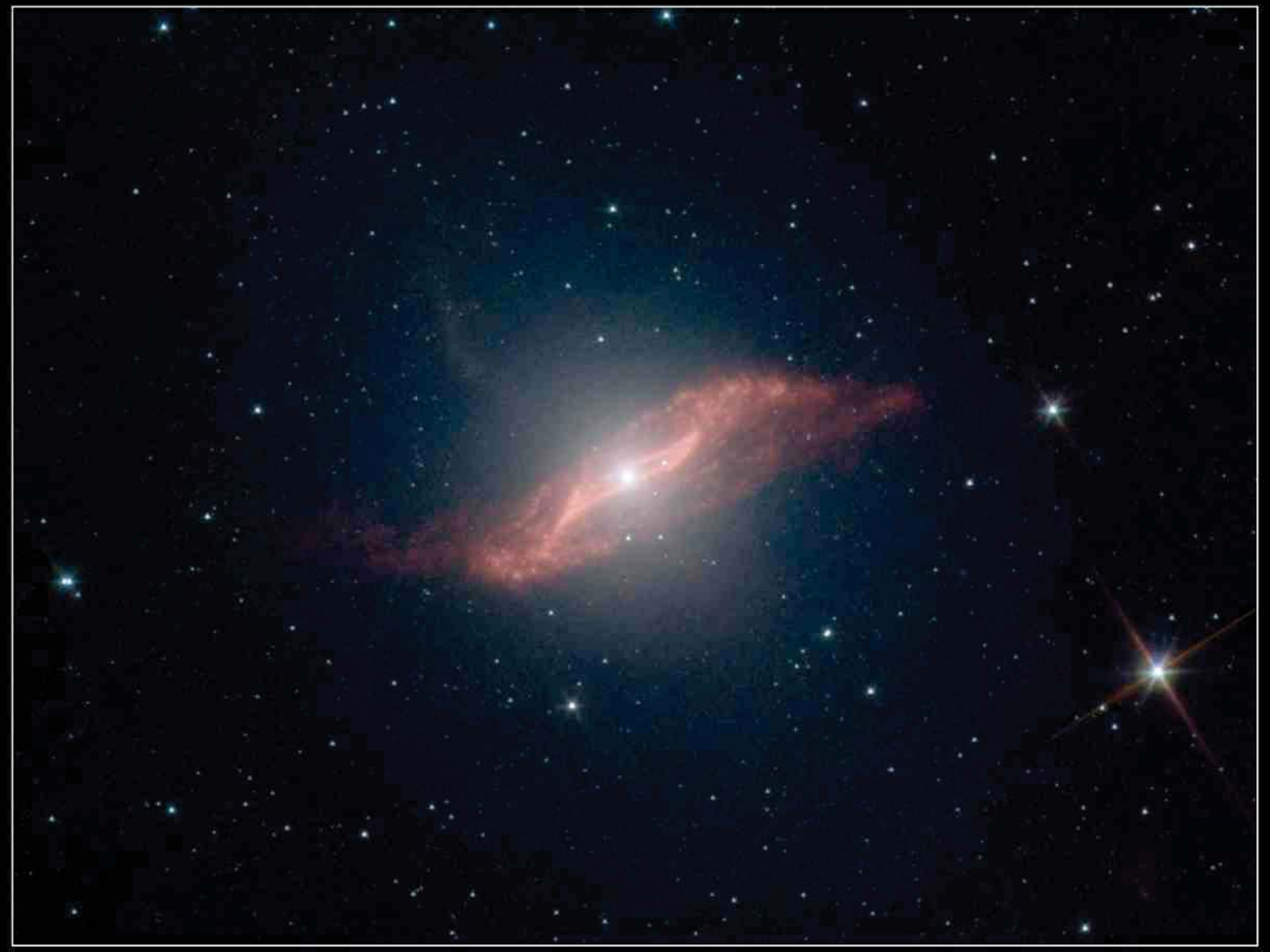
- Due to very strong continuum, bandpass calibration is essential for spectral line work
- Standard bandpass calibration introduces extra noise



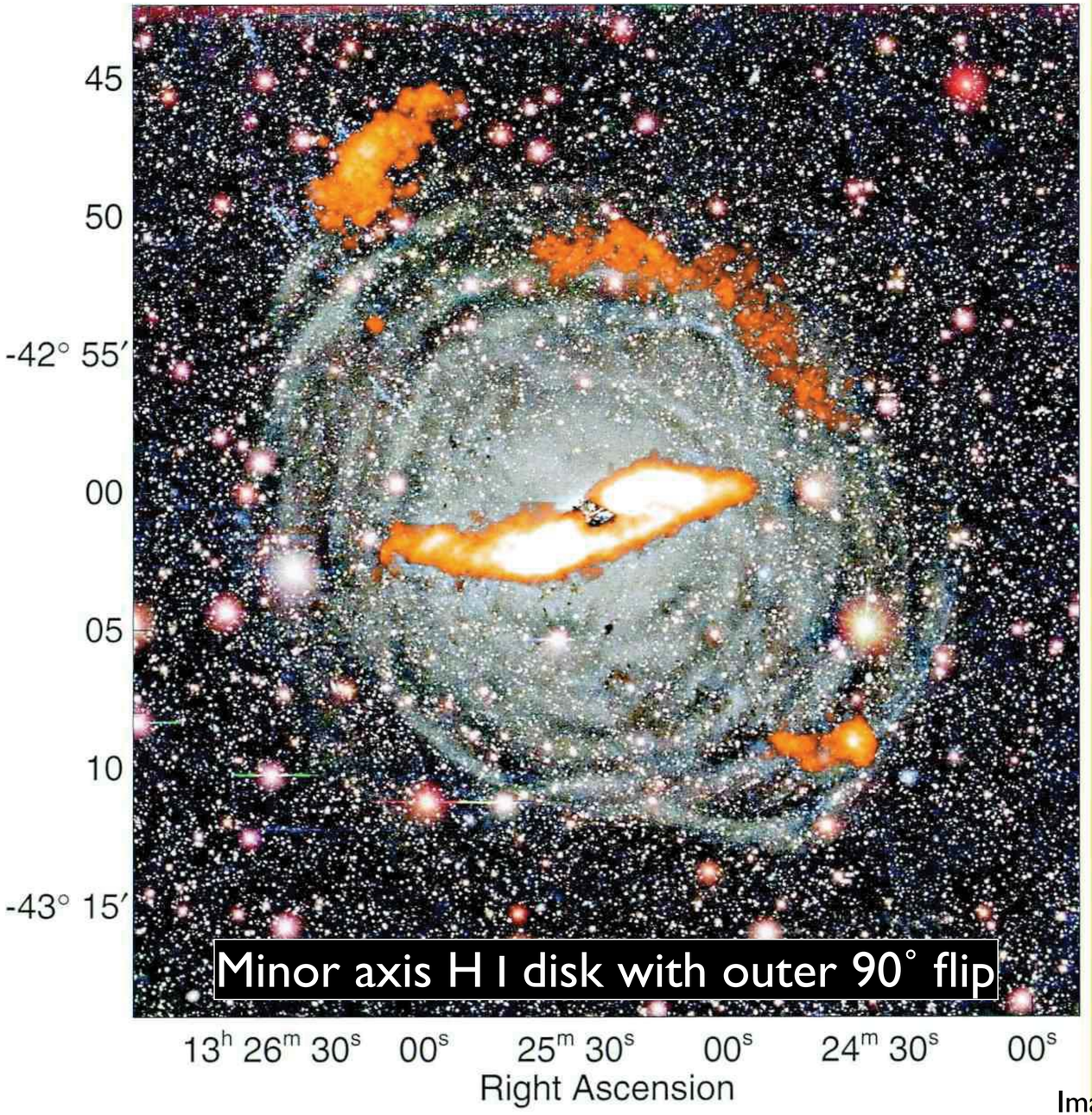


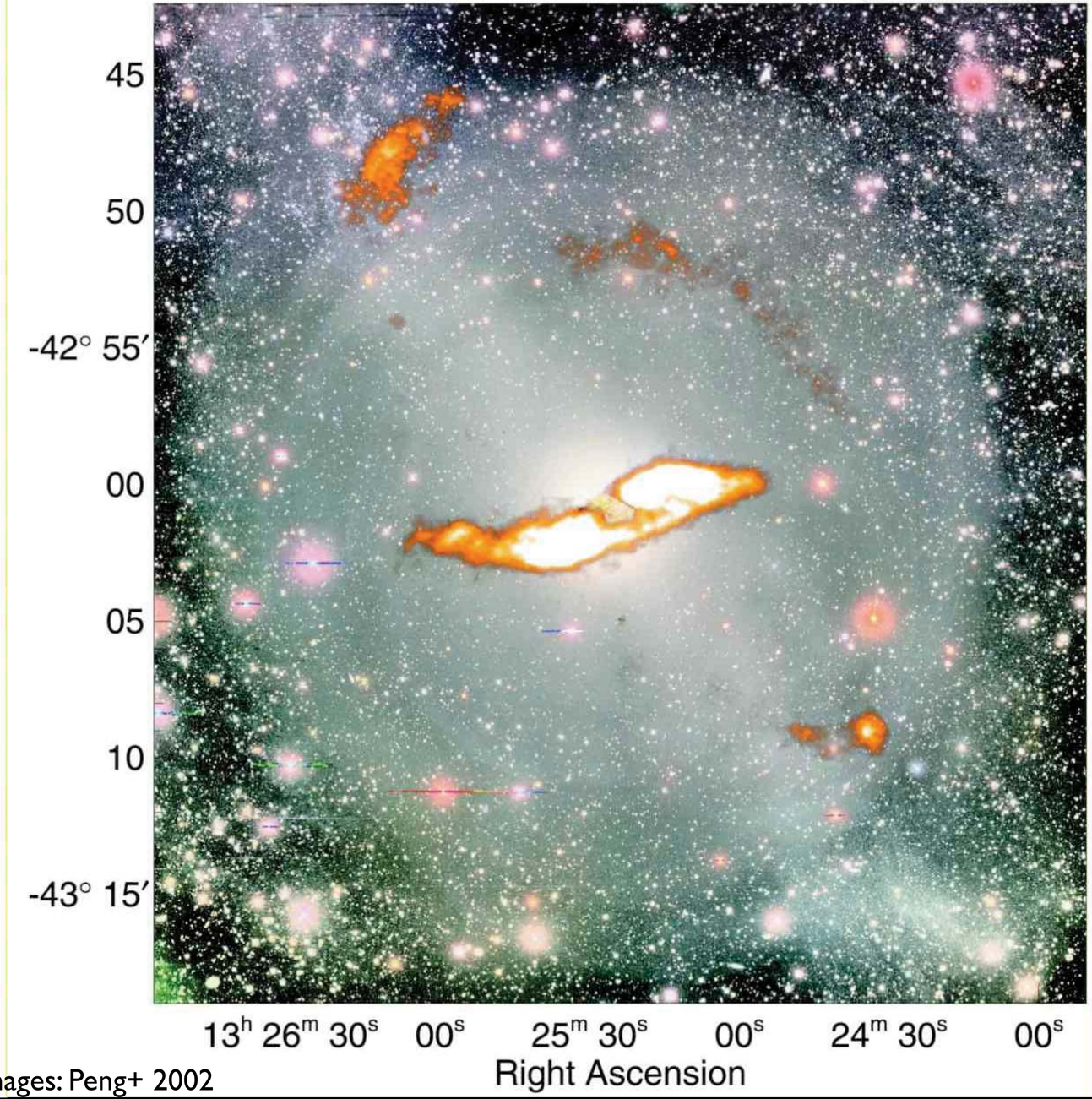
H I disk looks very similar to dust disk
H I mass = $3.9 \cdot 10^8\ M_\odot$
H I-dust ratio ~ 200
$M_{HI}/L_B = 0.01$

Asymmetries in outer regions



Dusty Elliptical Galaxy Centarus A
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / J. Keene (SSC/Caltech)
ssc2004-09a





Images: Peng+ 2002

Inner disk

- Disk been modelled as warped disk (Nicholson, Quillen, Sparke…), precessing in tri-axial potential
- Used ATCA data to model kinematics of H I disk, using Spitzer image as additional constraint

The Warp

Warp model reproduces H I and Spitzer data with realistic rotationcurve

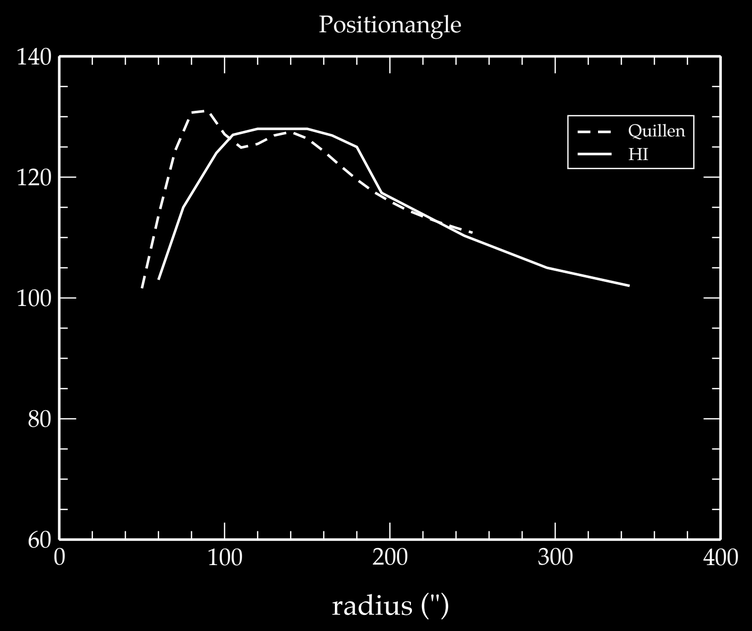
Not a strong warp

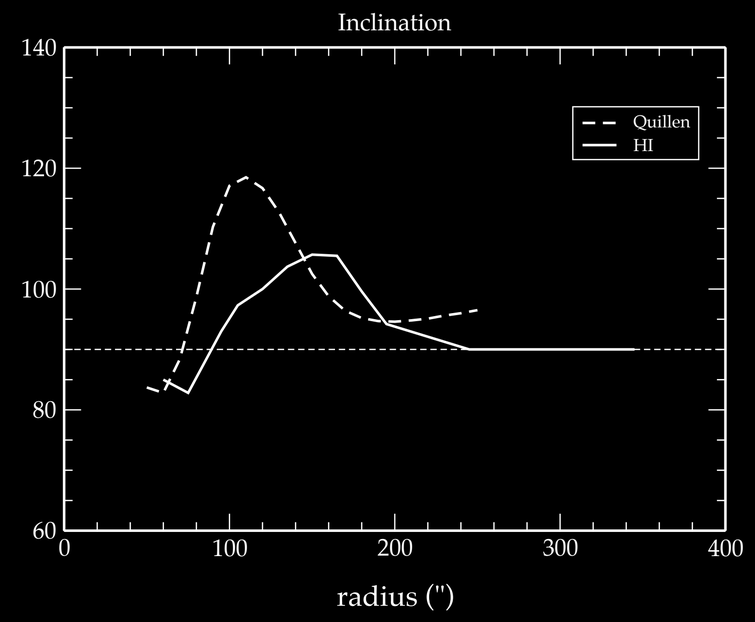
“No” H I inside 1 arcmin

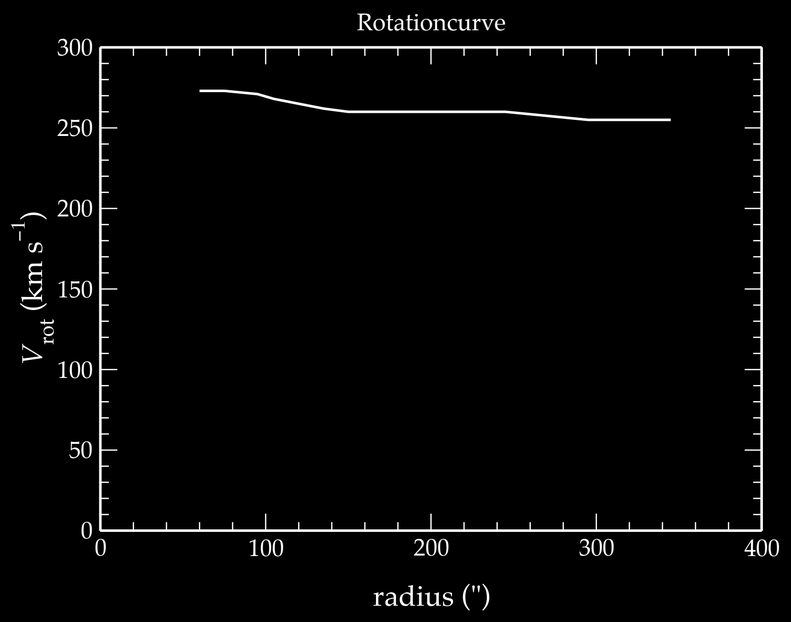
Similar to Quillen model,
disk more edge on in inner region

Shape of rotationcurve is what you would expect for bulge-dominated galaxy

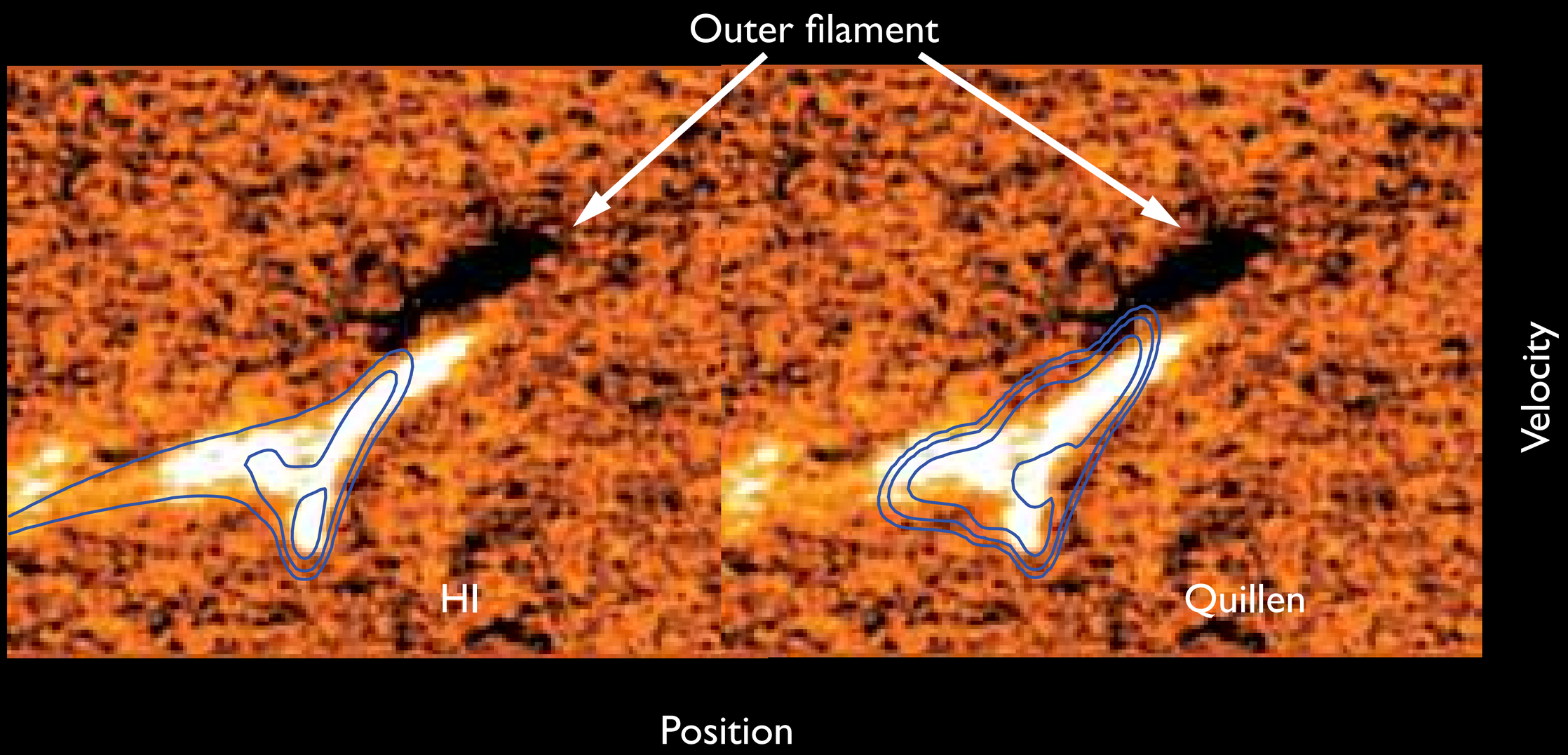
No evidence for non-circular motions at kpc scales



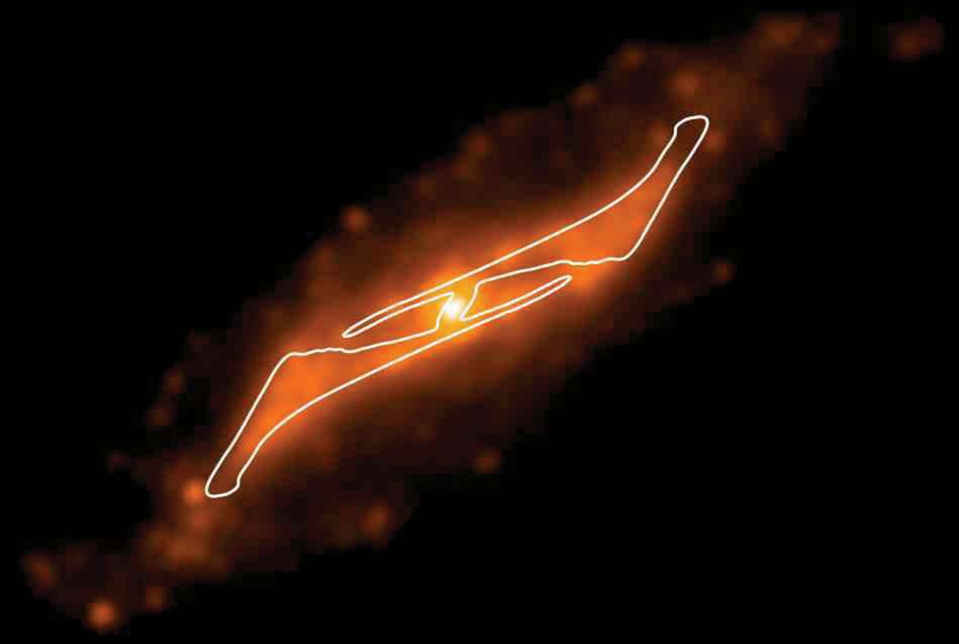


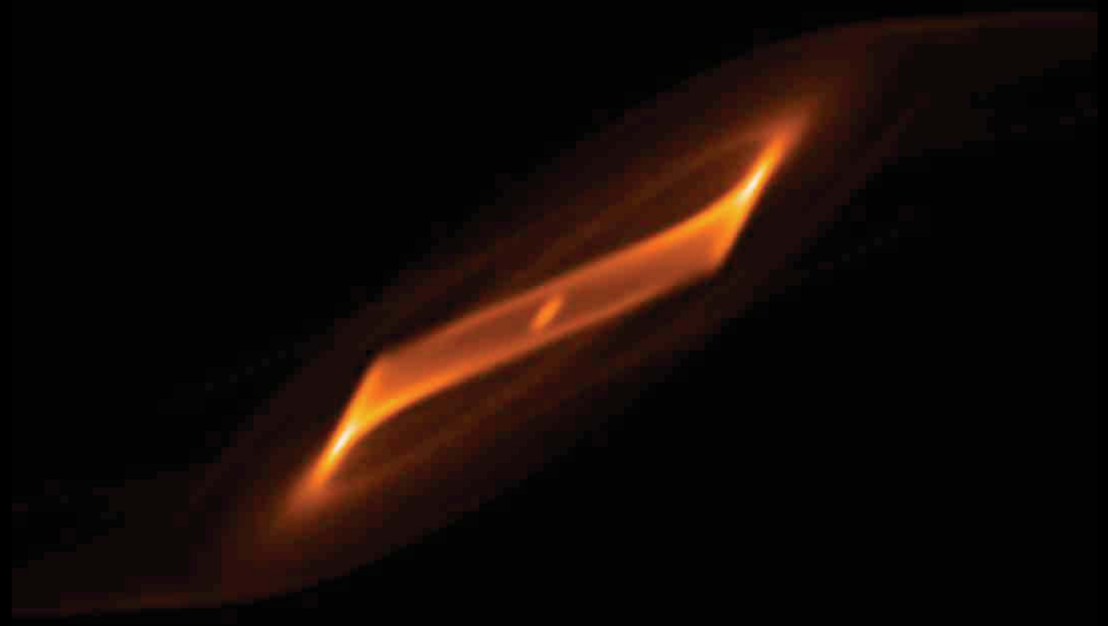


Inner disk more edge on



- H I model reproduces Spitzer image

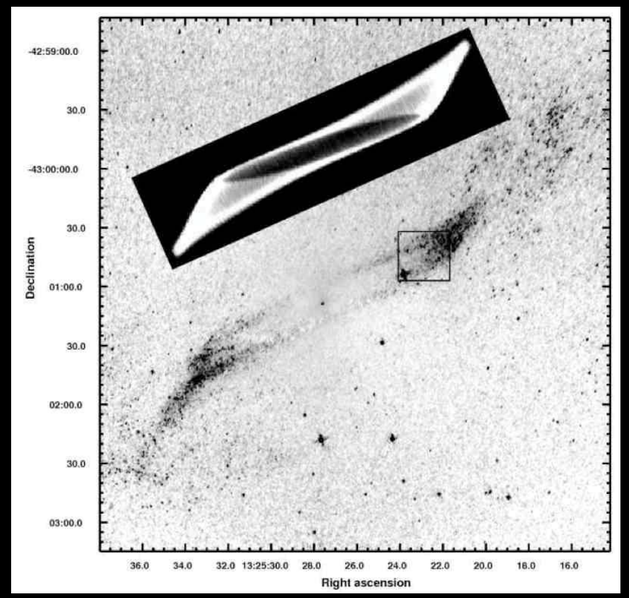


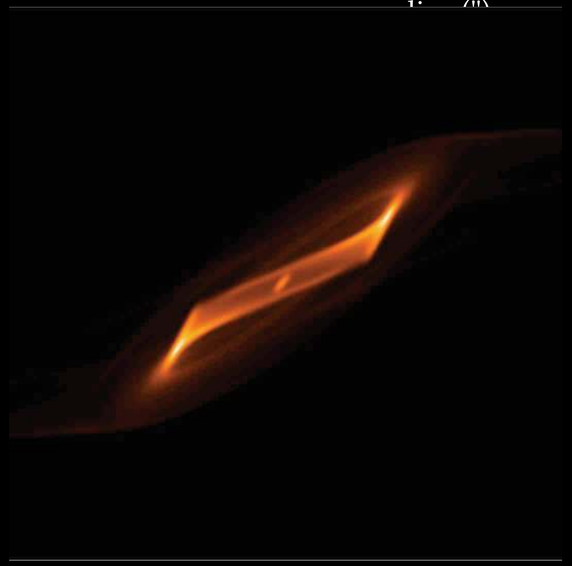


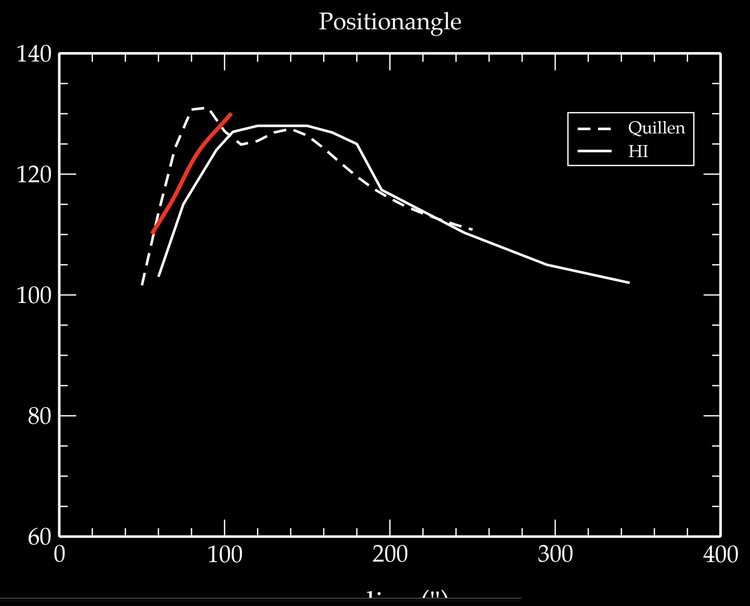
The Warp

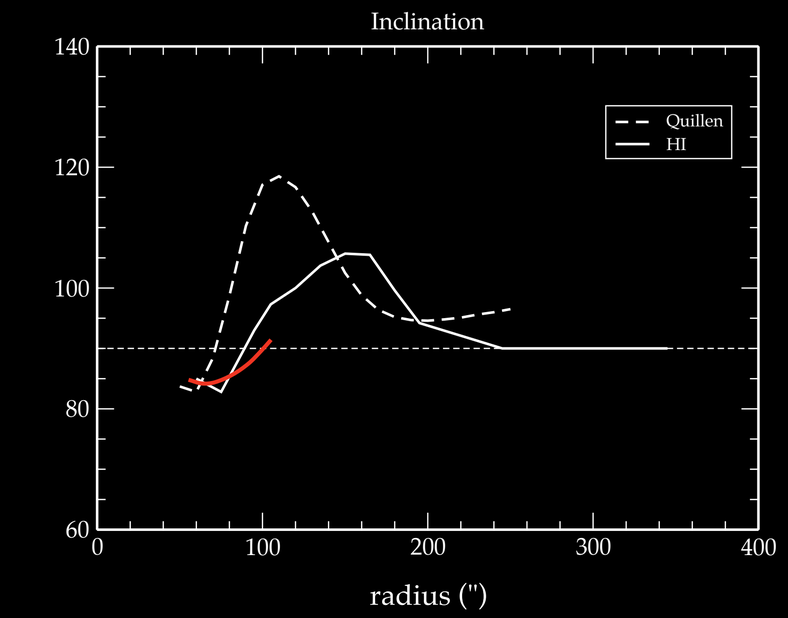
Warp model reproduces H I and Spitzer data with realistic rotationcurve

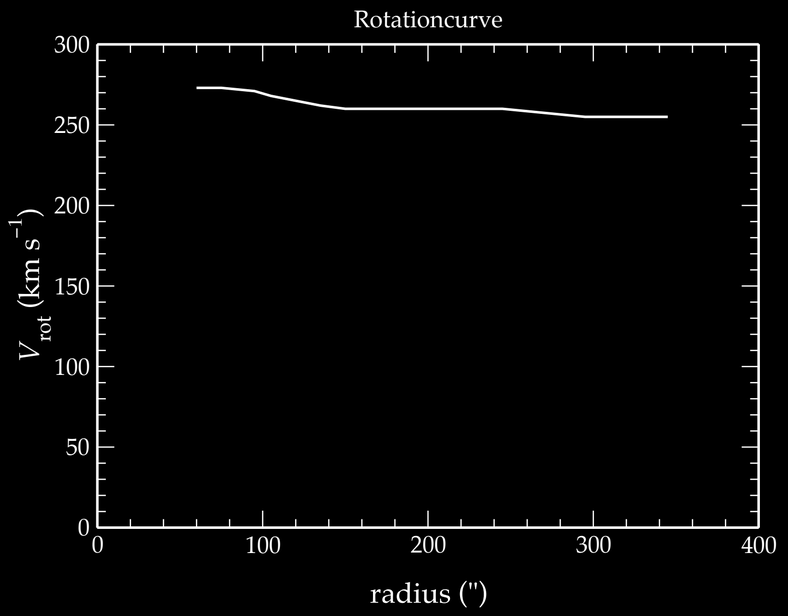
Kainulainen+ find similar result for stellar ring





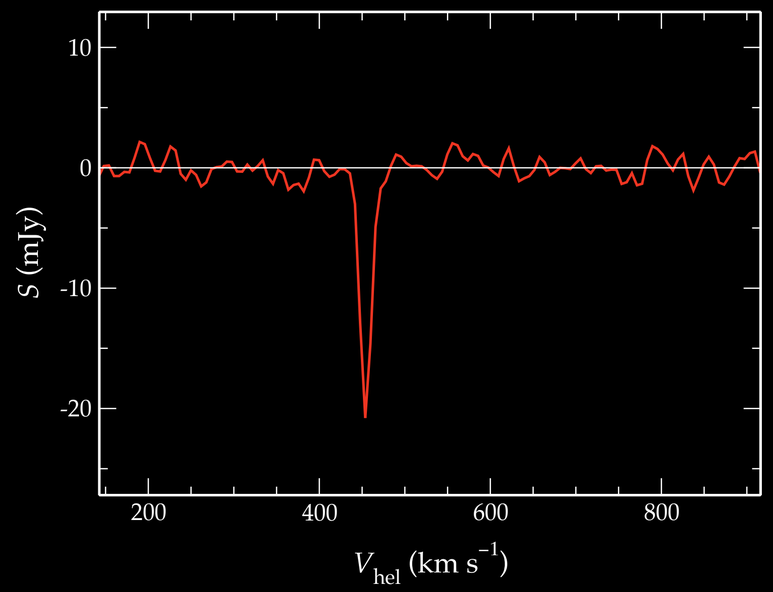


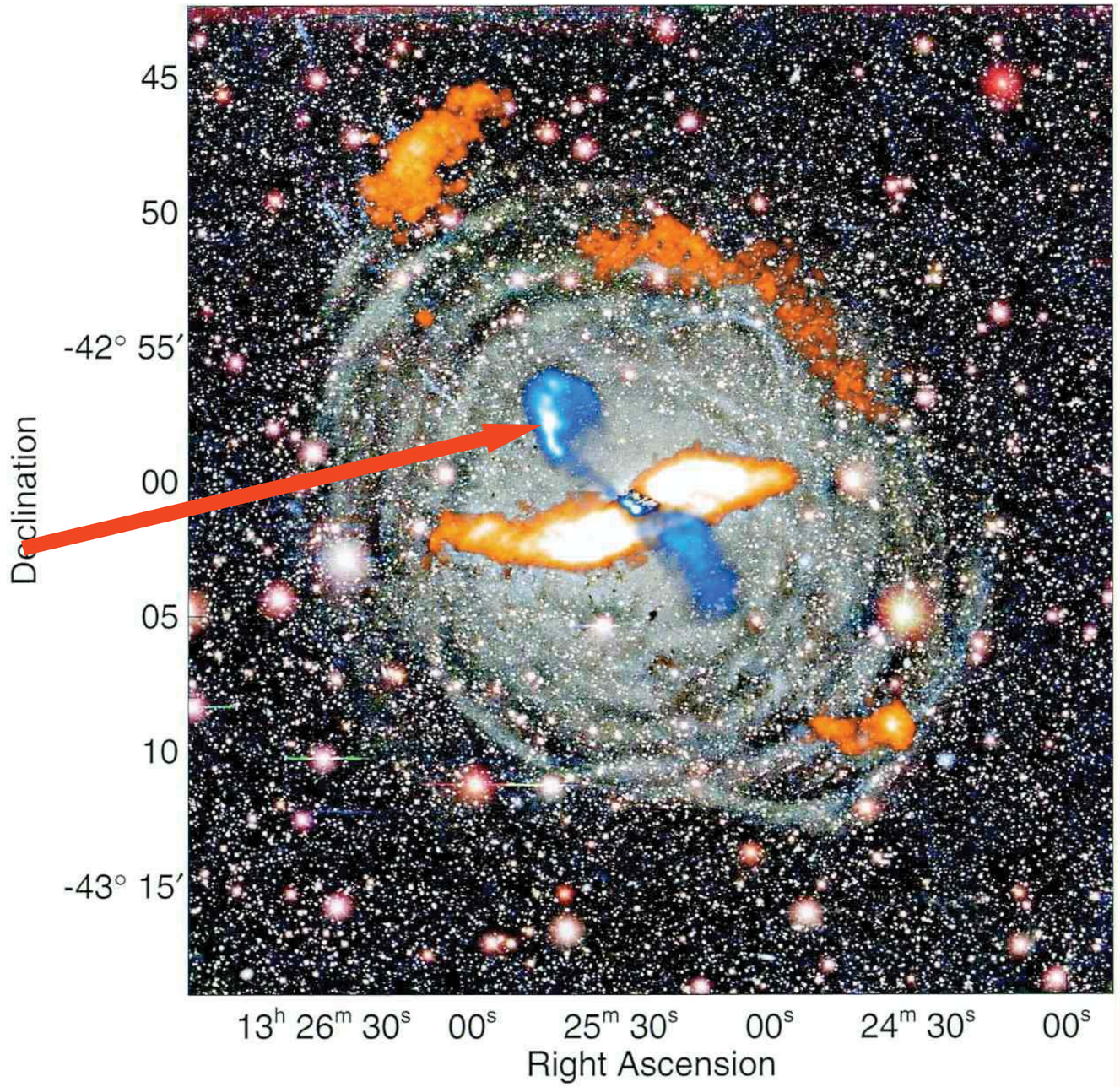




Lots of fluffy stuff at large radius

- regular disk for $r < 5$ kpc
  but H I is unsettled at larger radii





How settled is the disk?

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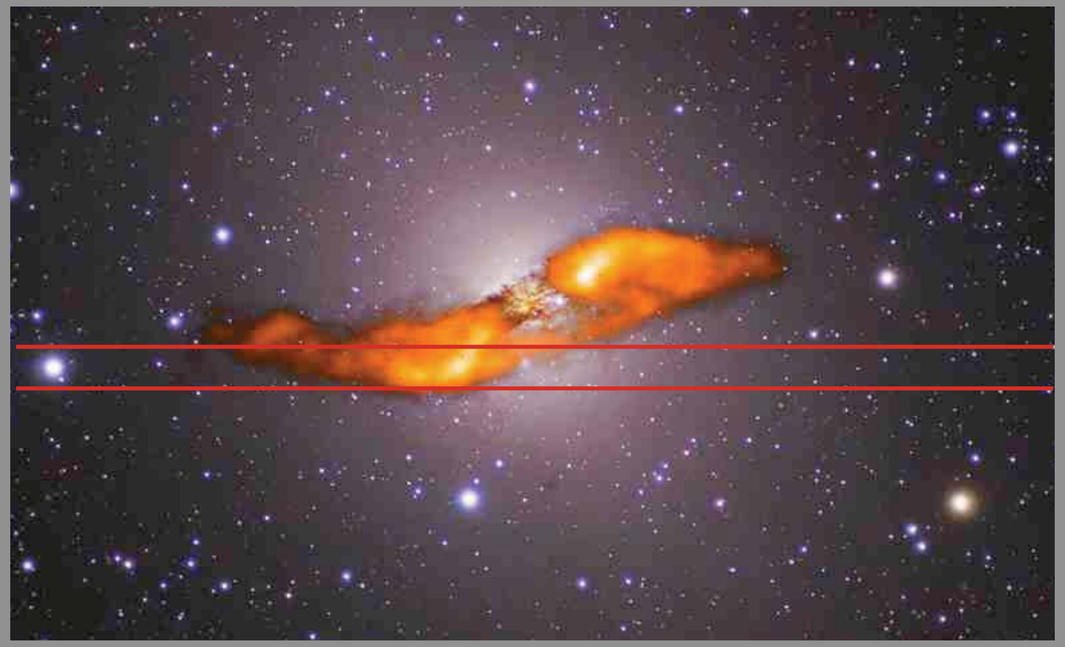
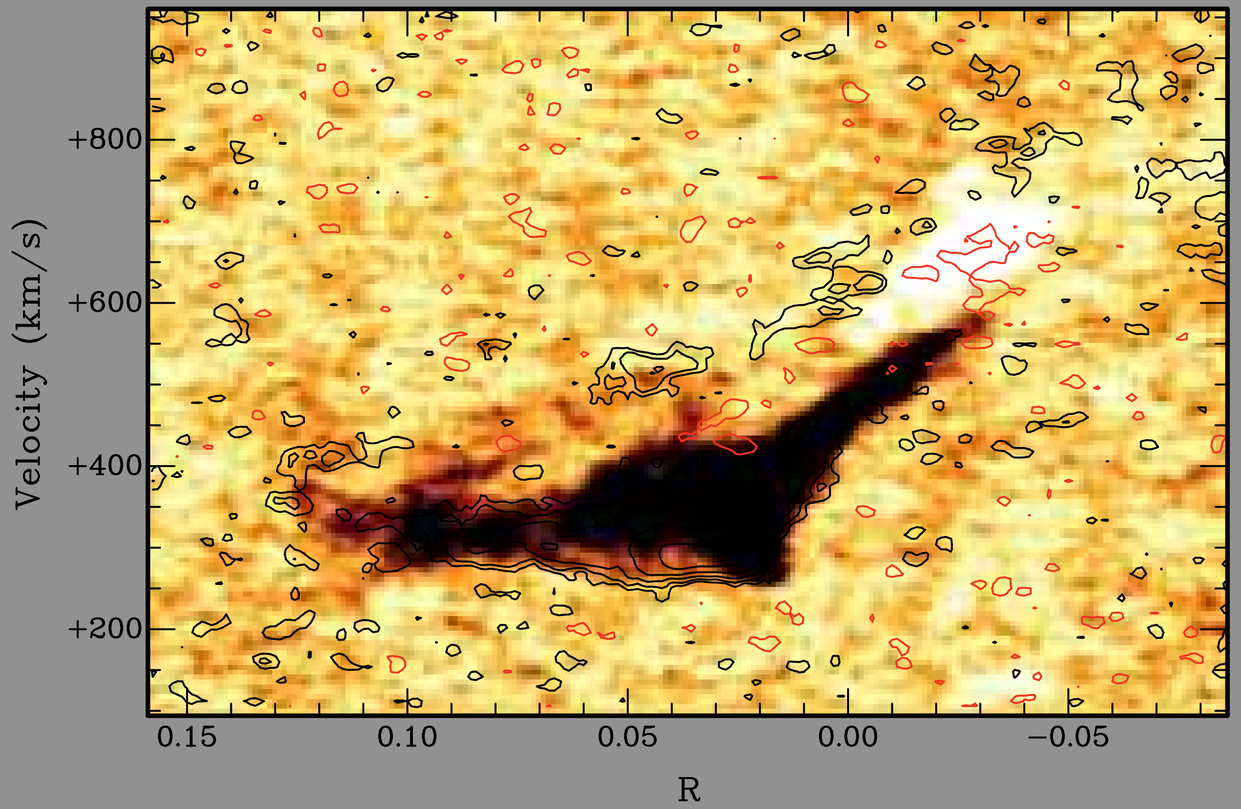
- Asymmetries in outer disk
- Filaments with unsettled kinematics in outer regions (> 5 kpc)
- Rotation period at 5 kpc ~ 10^8 yr ➪ age of disk few x 10^8 yr





The Disk

ASTRON

- 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

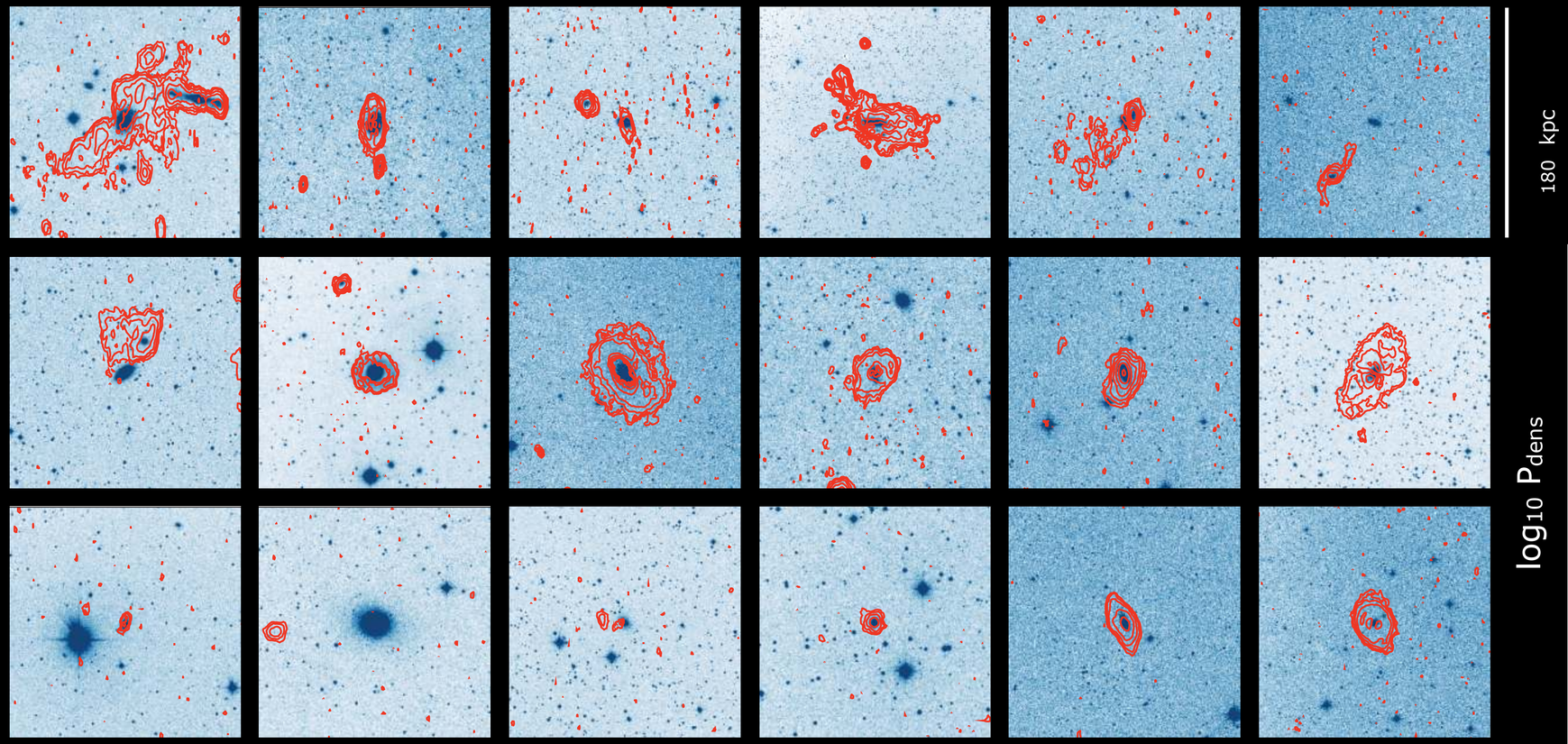
- Regular kinematics inside 5 kpc
  Asymmetries and filaments at larger radius
  No need for non-circular orbits between 1-5 kpc
  Reproduces H I kinematics & shape dust disk (and stellar ring)

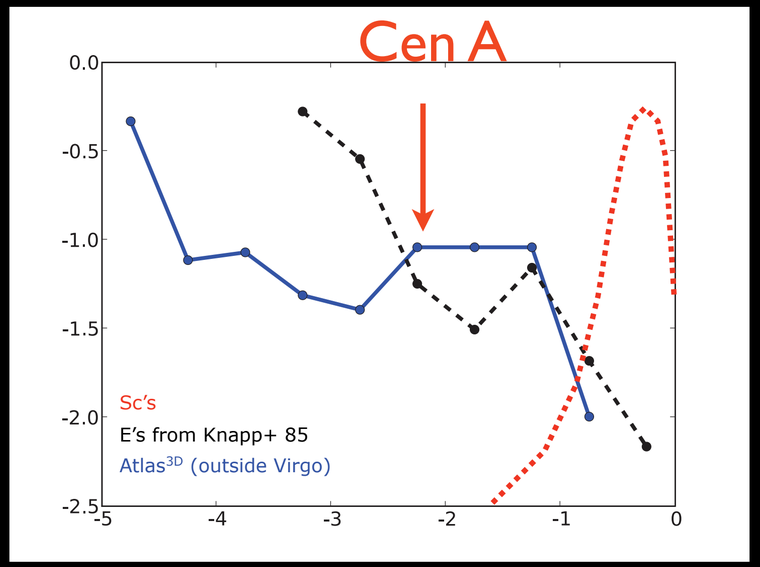
- Age few x 10^8 yr
  Too old for triggering recent AGN activity (10^7 yr)
  Connected to previous episode of AGN activity? Disk has ~same age as middle lobes, younger than outer lobes?

- M_{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

How unusual is the HI disk in Cen A?

- It is not!!
- >50% of non-cluster early-type galaxies have H I, ranging from 10^6 to 10^{10} $M_\odot$



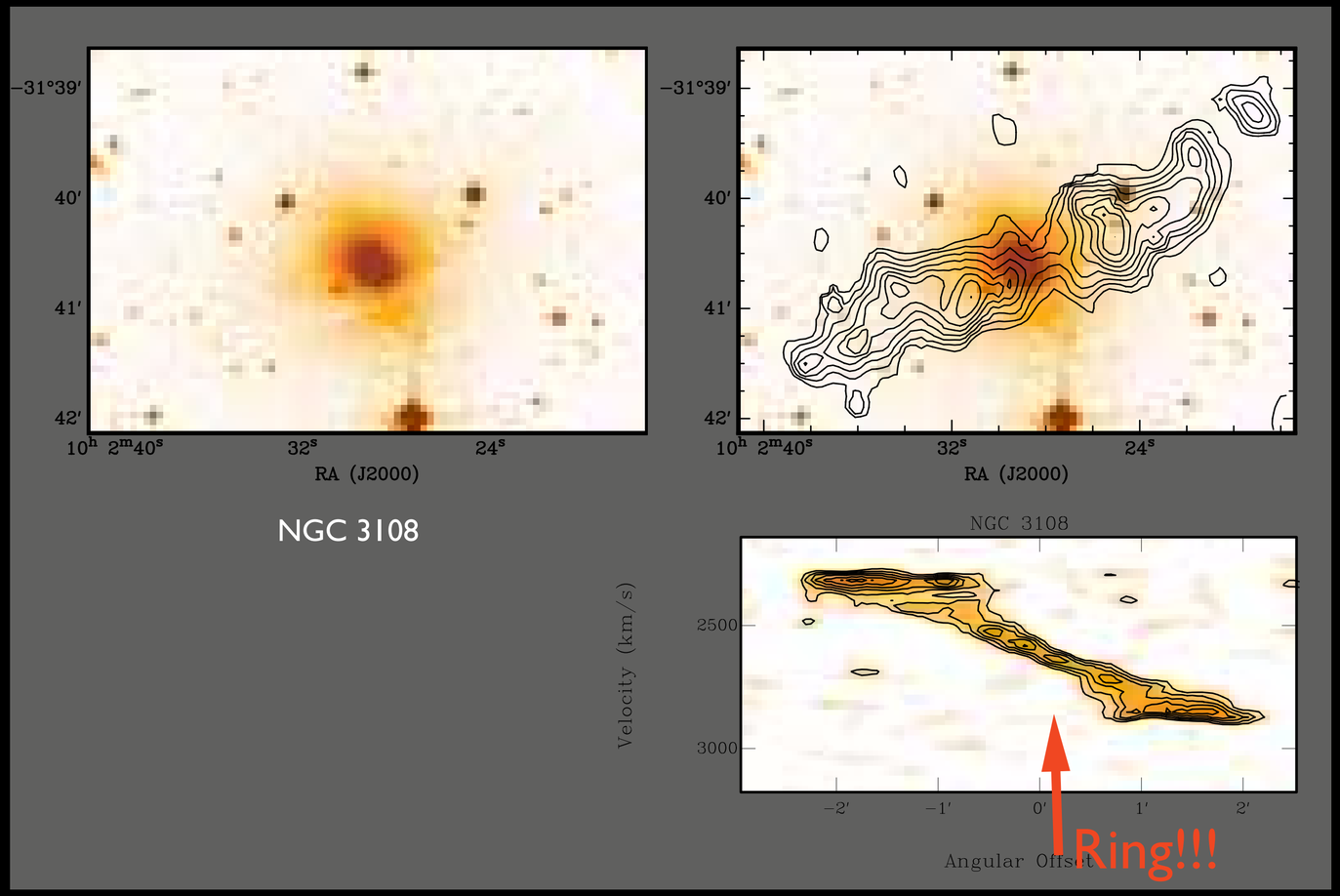


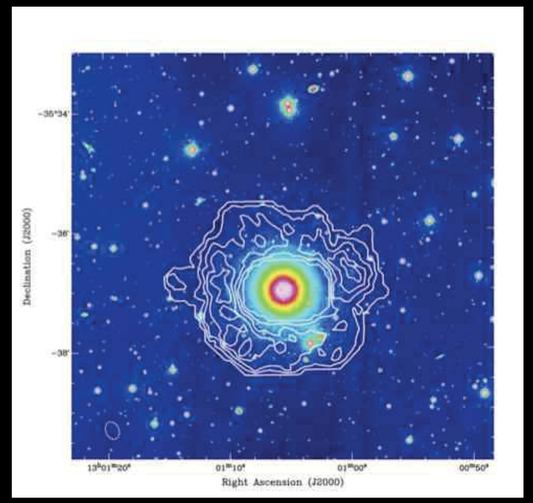
WSRT survey of Atlas^{3D} sample (100 ET galaxies; Serra, Oosterloo, Morganti)

K

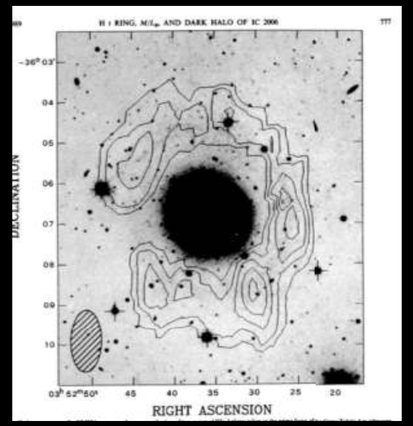
How unusual is the HI disk in Cen A?

- It is not!!
- Many galaxies have regular H I rings, not always related to bar





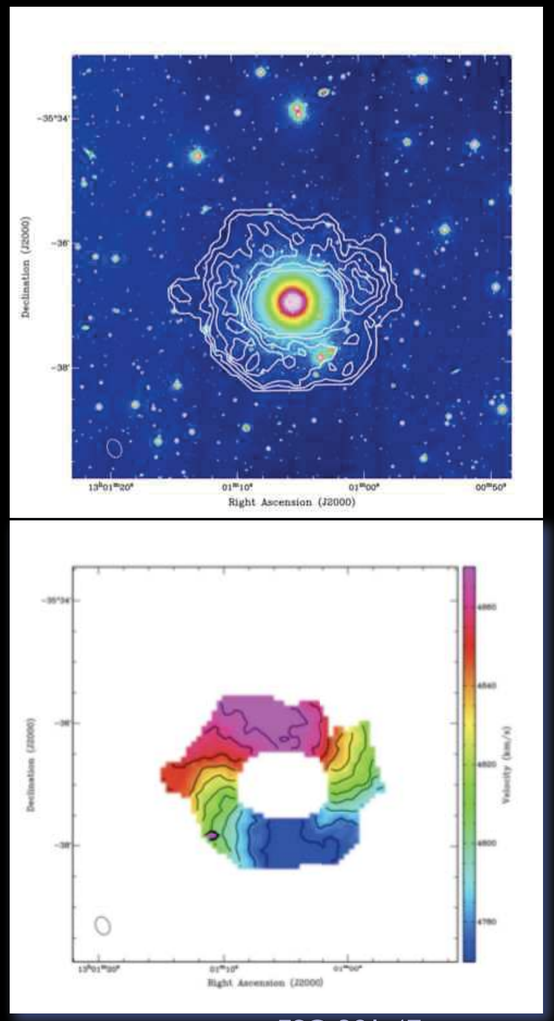
ESO 381-47
(Donovan+ 2009)



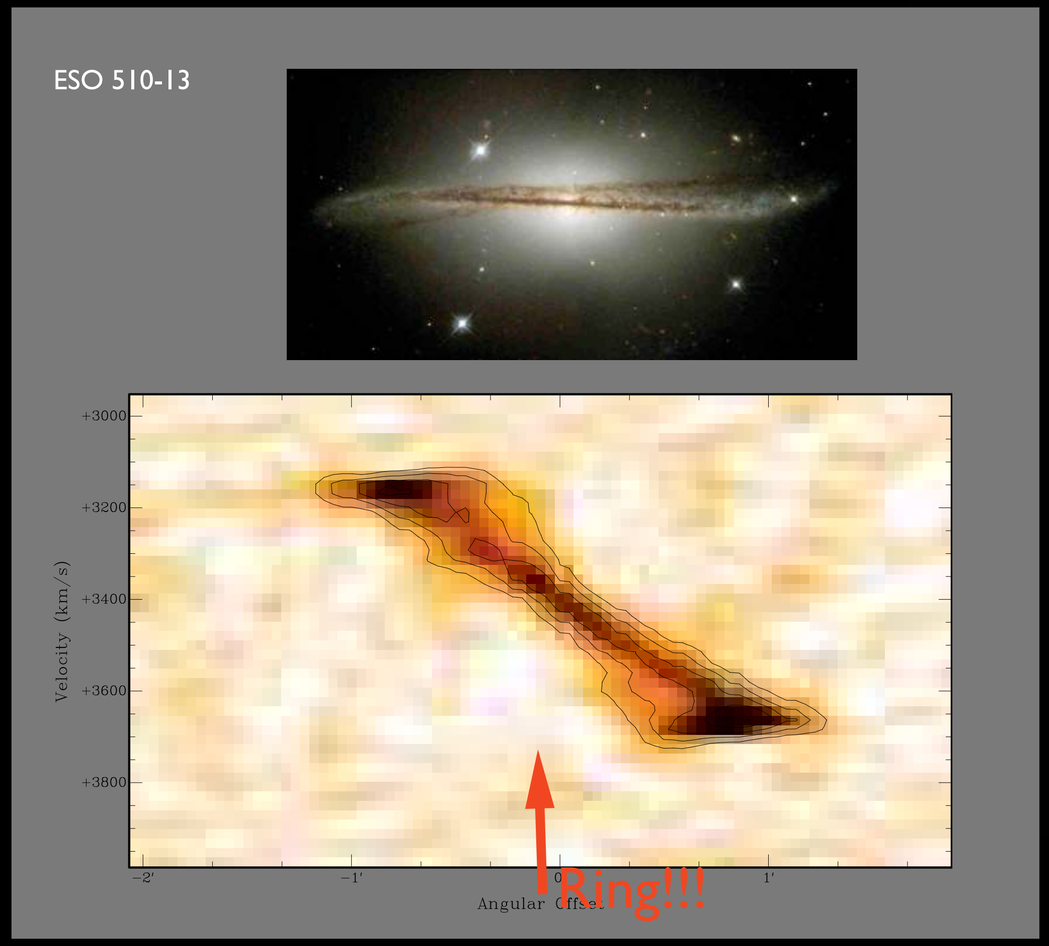
IC 2006
Schweizer+,
Franx+

How unusual is the HI disk in Cen A?

- It is not!!
- Almost every H I disk/ring in an early-type galaxy is warped, sometimes strongly warped

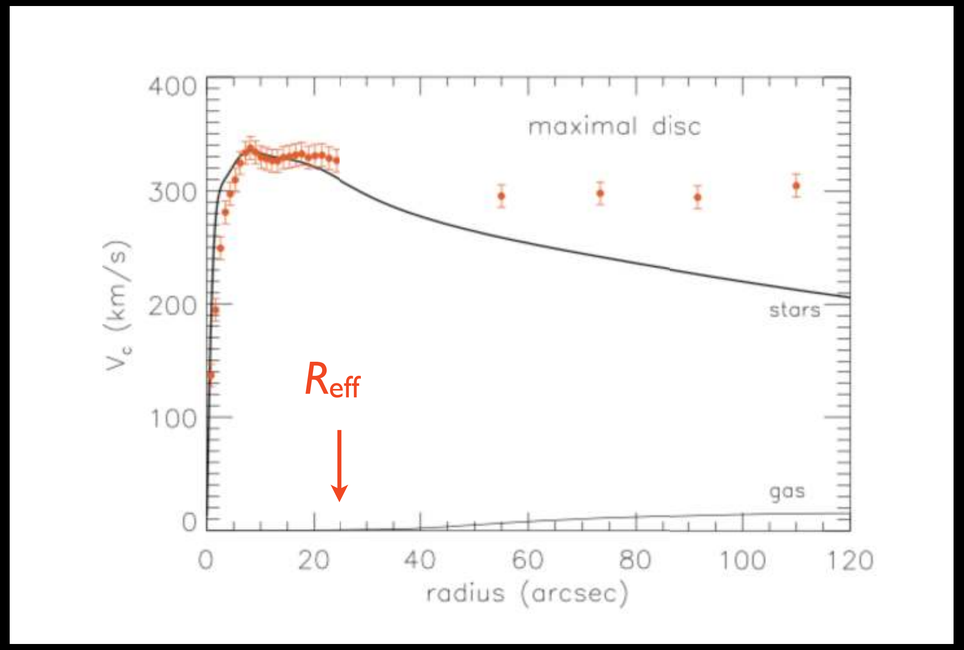


ESO 381-47
(Donovan+ 2009)



NGC 2685
(Jozsa+ 2009)

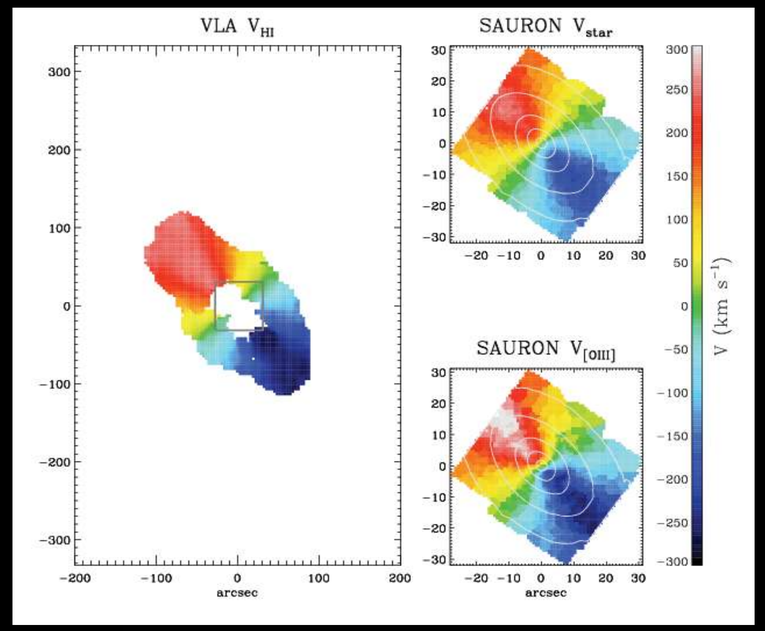
Rotationcurve of Cen A

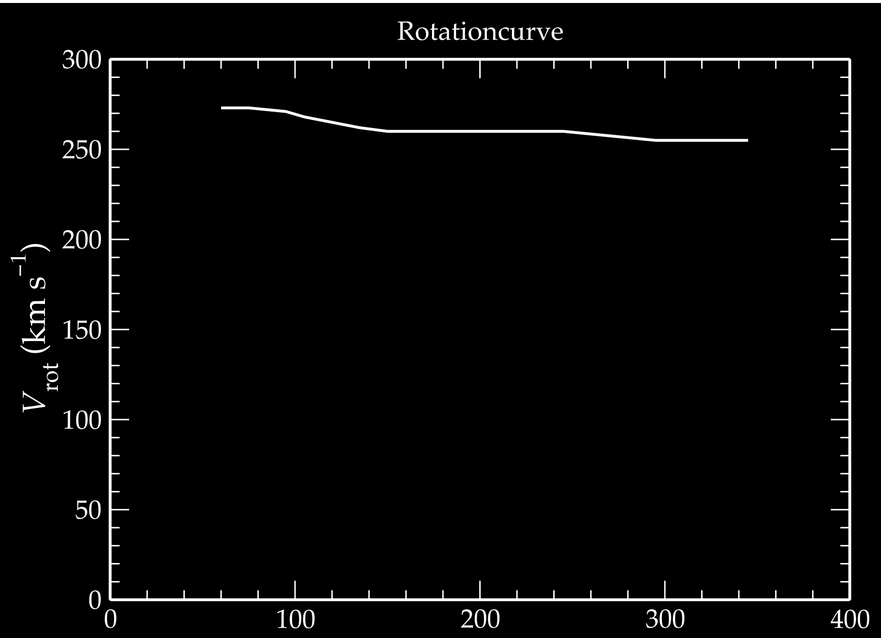


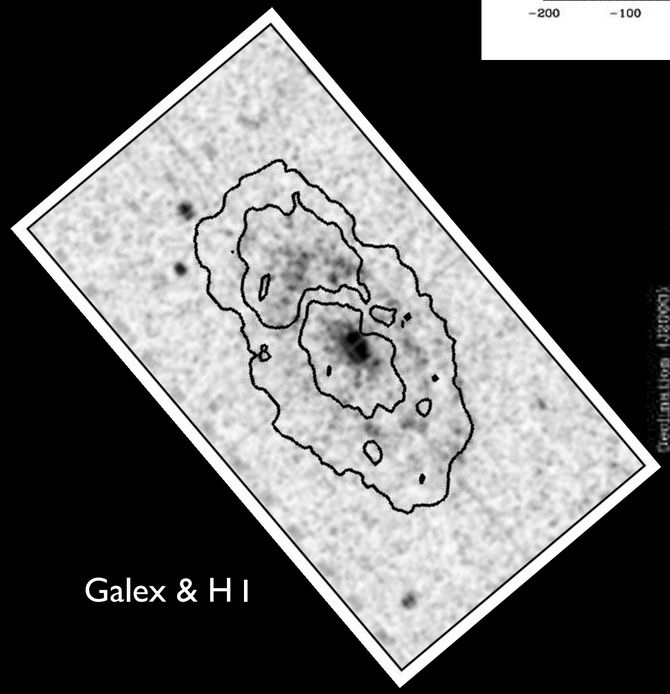
Sauron + VLA

NGC 2974 (E4 galaxy)
Weijmans+ 2008

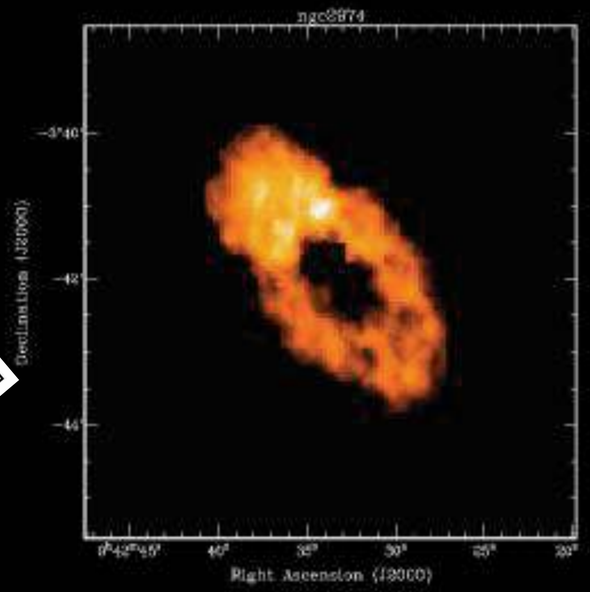
Ring due to small bar?





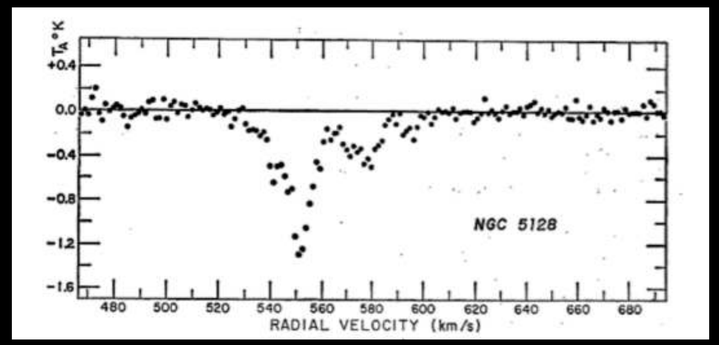


Galex & H I



The absorption

- First radiogalaxy in which H I absorption was detected (Roberts 1970)

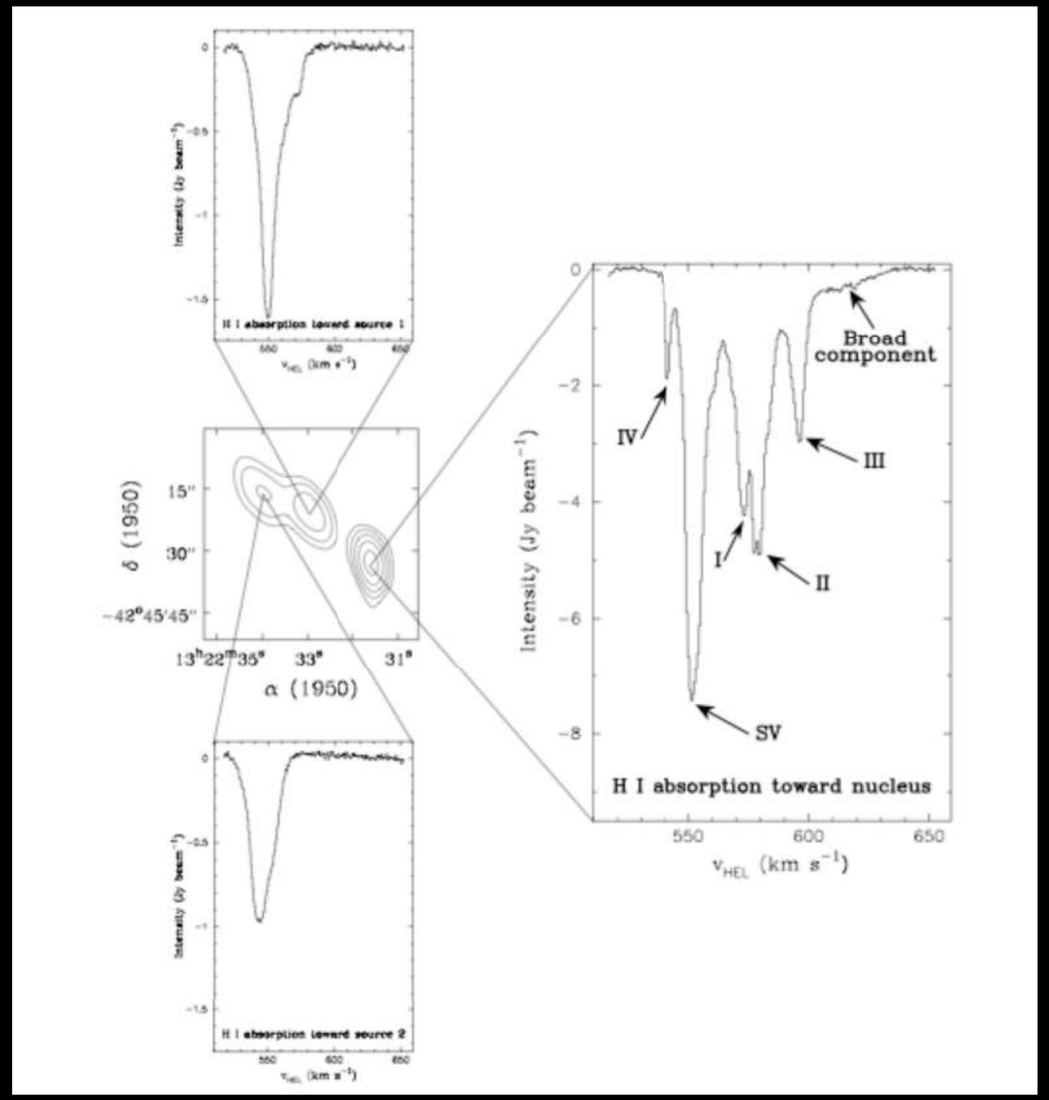


- Redshifted absorption against AGN is often interpreted as evidence for infall into AGN

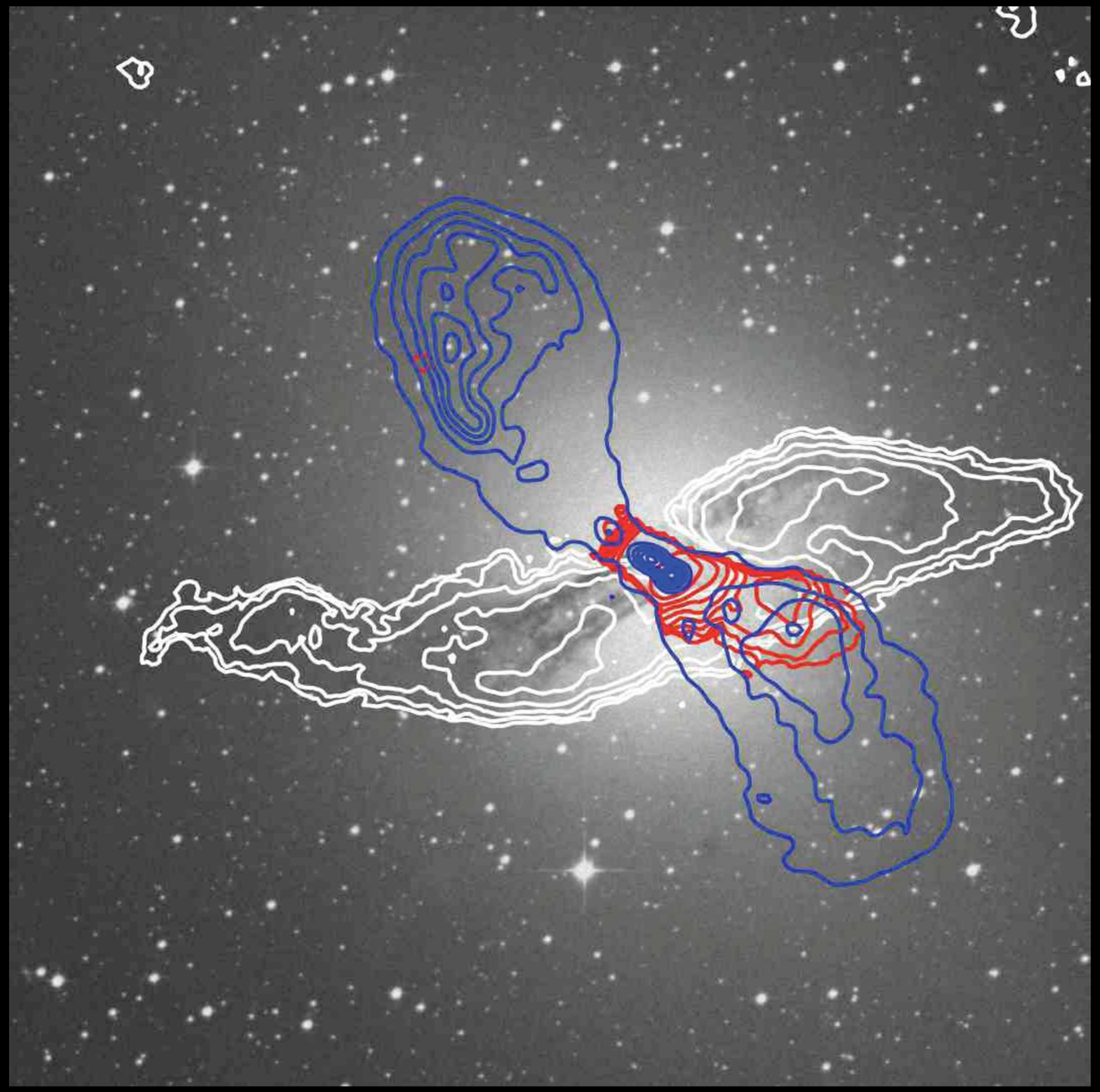
- But things are more complicated...

Note: no radio core at 21 cm (obscured by torus of ionised gas) so absorption is against environment of nucleus

Sarma+ 2002

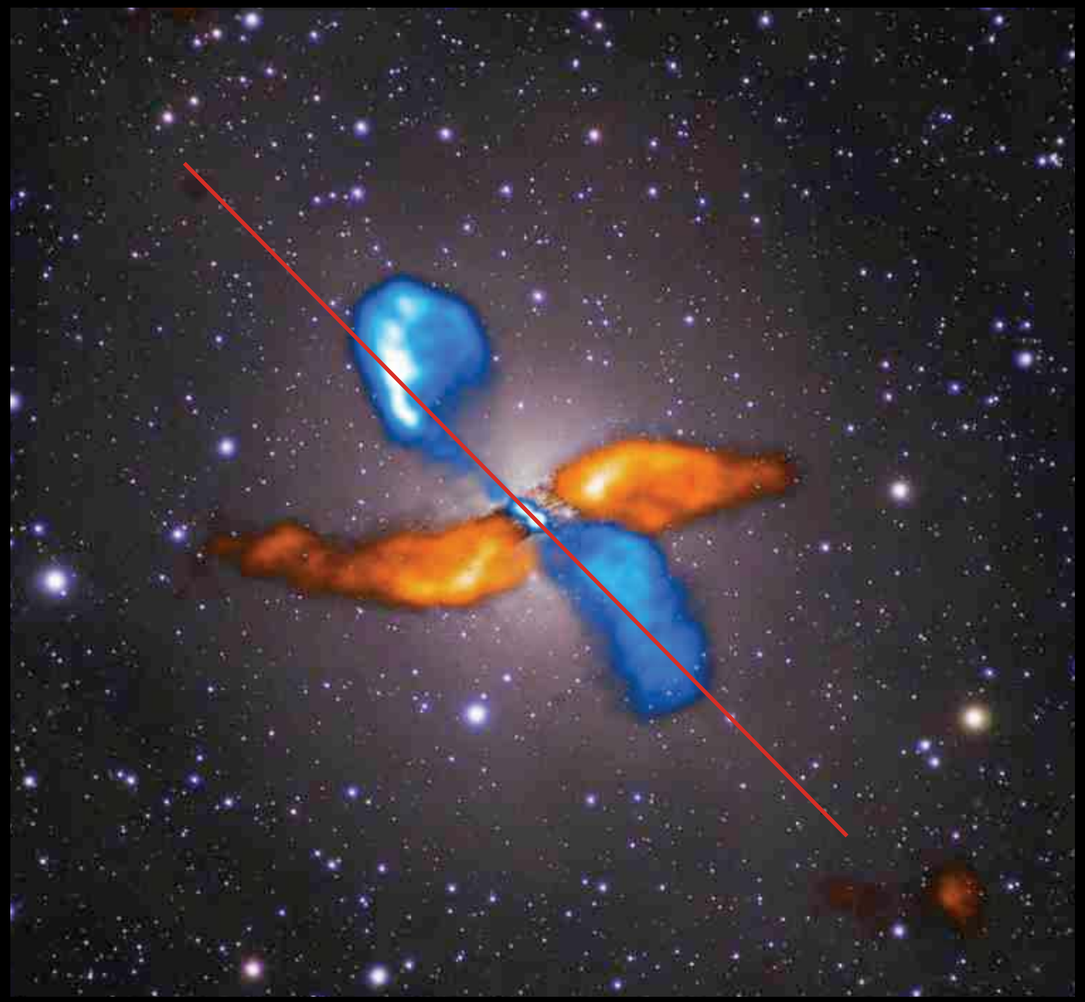


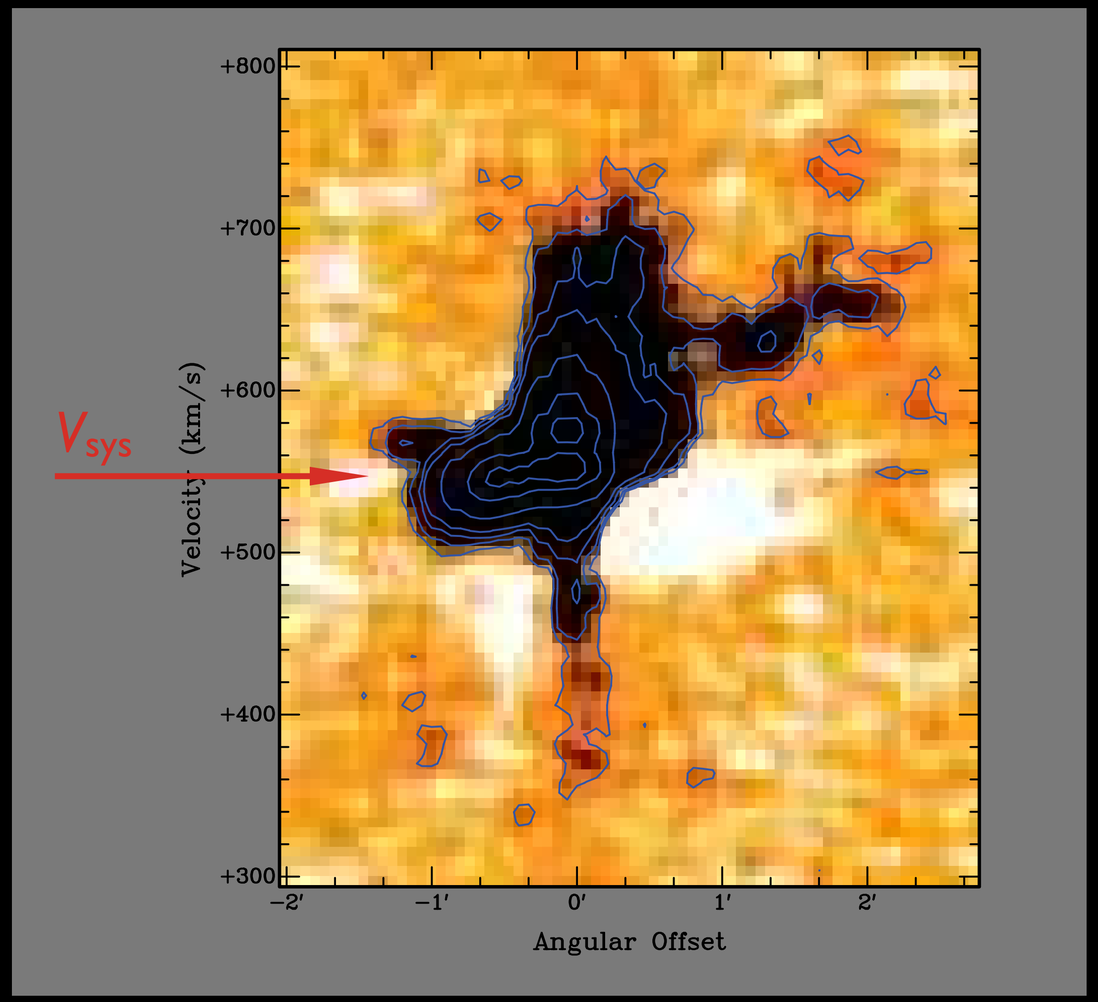
H I absorption



The Absorption

- There is redshifted absorption everywhere. Filament at large radius is redshifted and in front of nucleus
- And blueshifted absorption against the core as well, symmetric in velocity wrt redshifted absorption
- Blueshifted absorption not seen in earlier observations due to small bandwidths

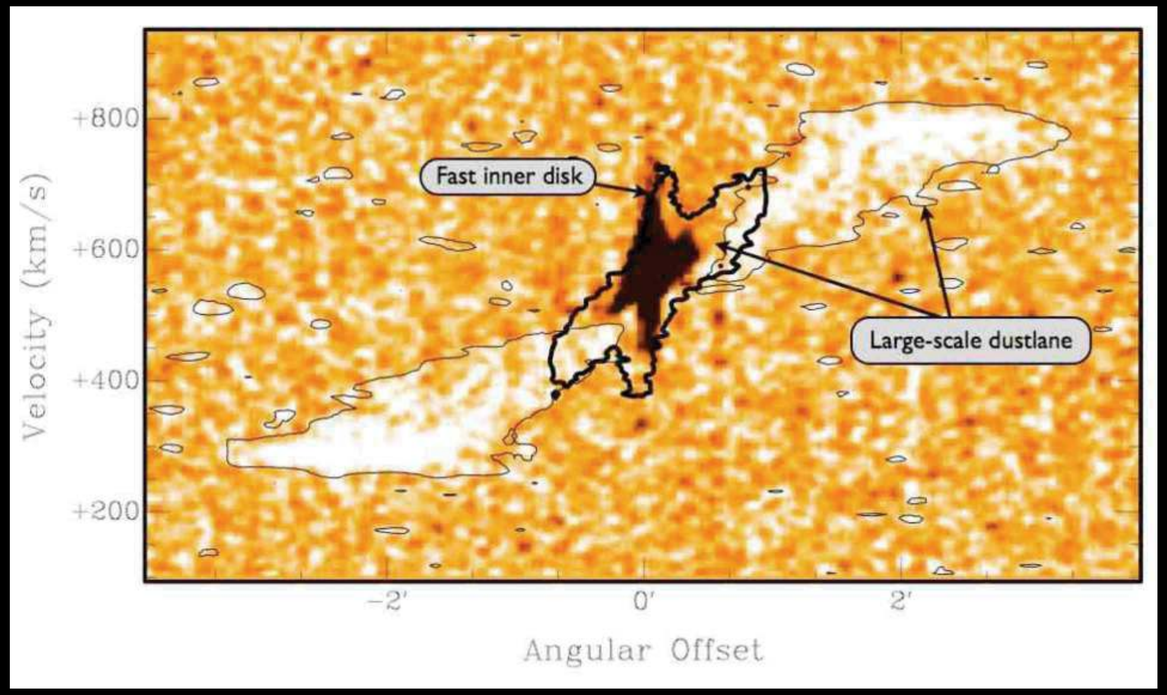




The Absorption

- Blueshifted nuclear absorption is associated with inner disk (r < 200 pc)
- Not straightforward to show that part of the redshifted H I absorption is connected to infall

H I & CO J=3-2 Liszt

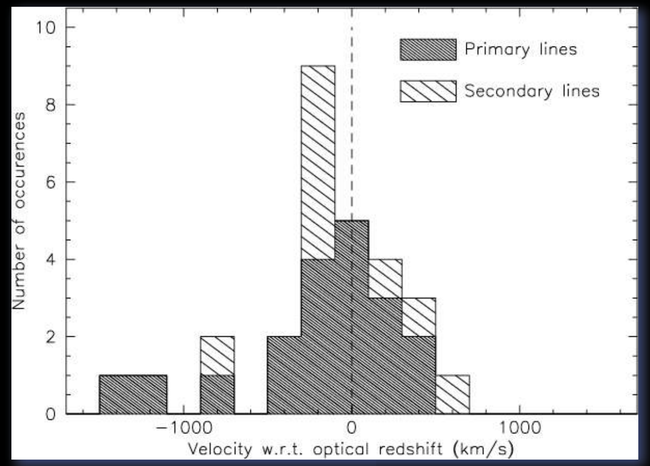


High-resolution H I data

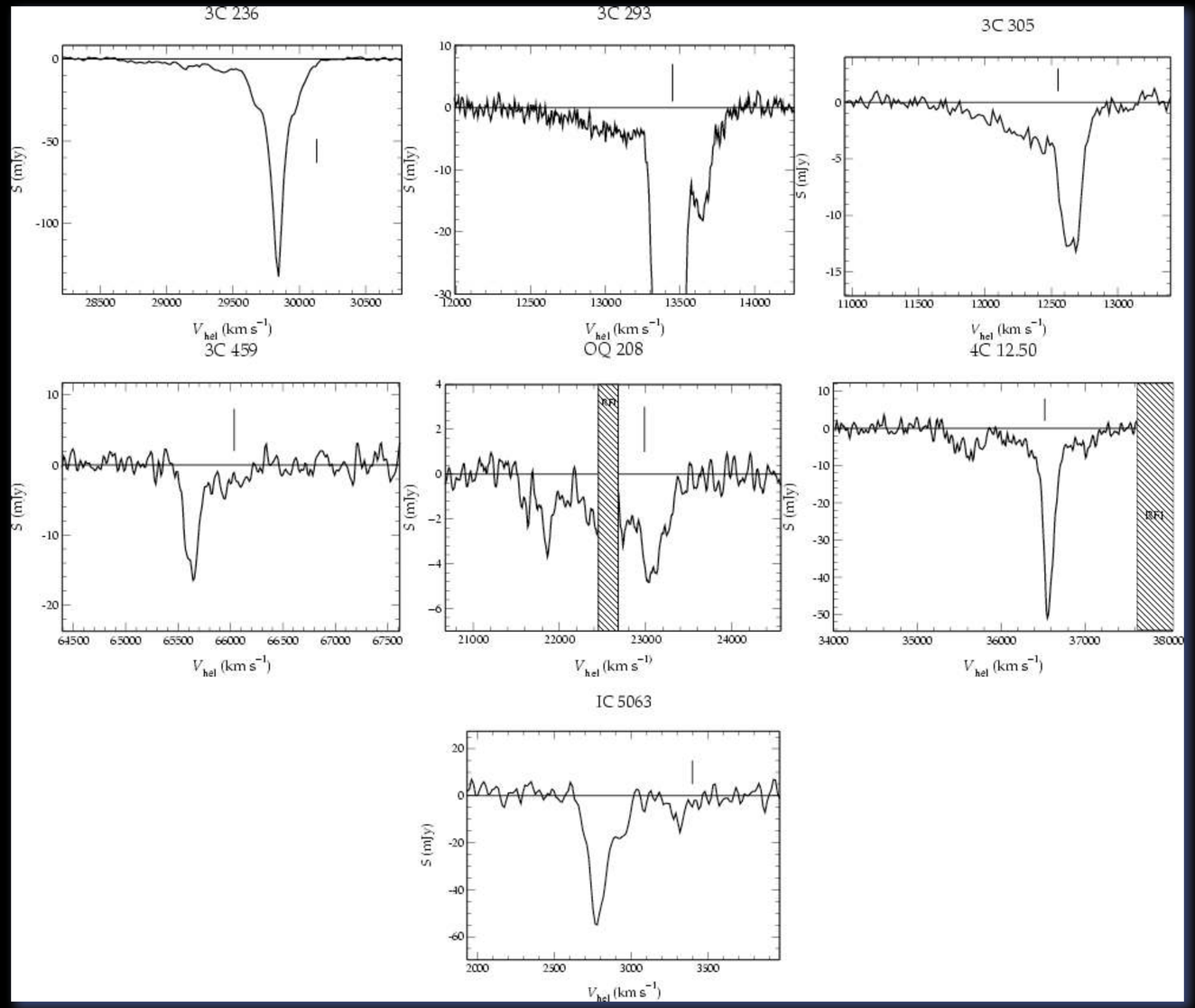
Note smaller velocity range of blueshifted absorption in high-resolution H I data
Blueshifted absorption against extended source

How unusual is the absorption?

- Older data seemed to suggest that H I absorption against AGN is often only redshifted
- Newer data show that blueshifted absorption is seen very often as well
- Blueshifted absorption is often not associated with disk, but with, e.g., outflows
- **Solid** evidence from H I absorption for circumnuclear disk is rare
- Cen A is best case to study circumnuclear disk



Vermeulen+ 2005



Morganti+ 2005

The filaments

- Set of filaments of ionised gas NE of Cen A
- Very turbulent kinematics
- Not ionised by starformation

- Evidence for interaction of jet with ISM

- Does the H I has anything to do with these filaments?

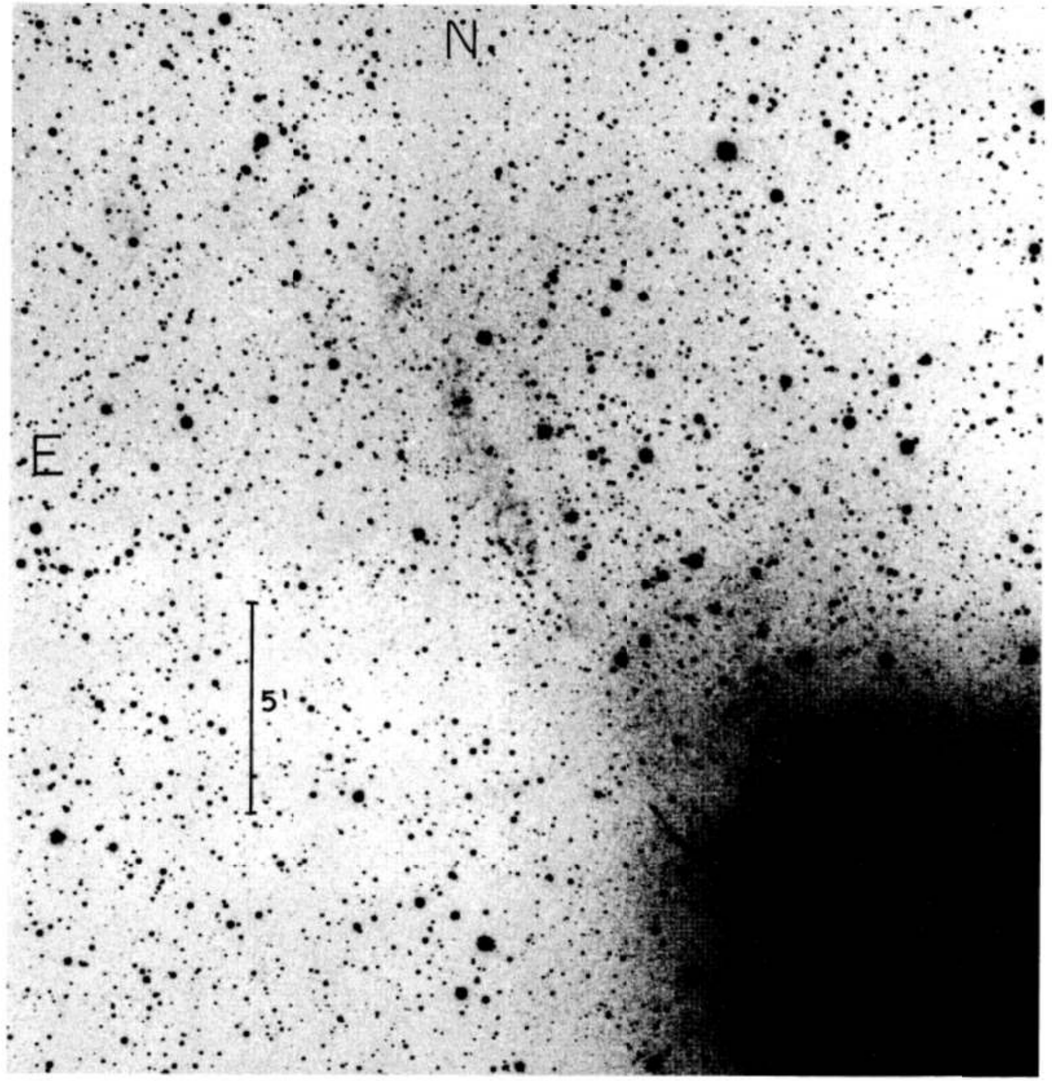


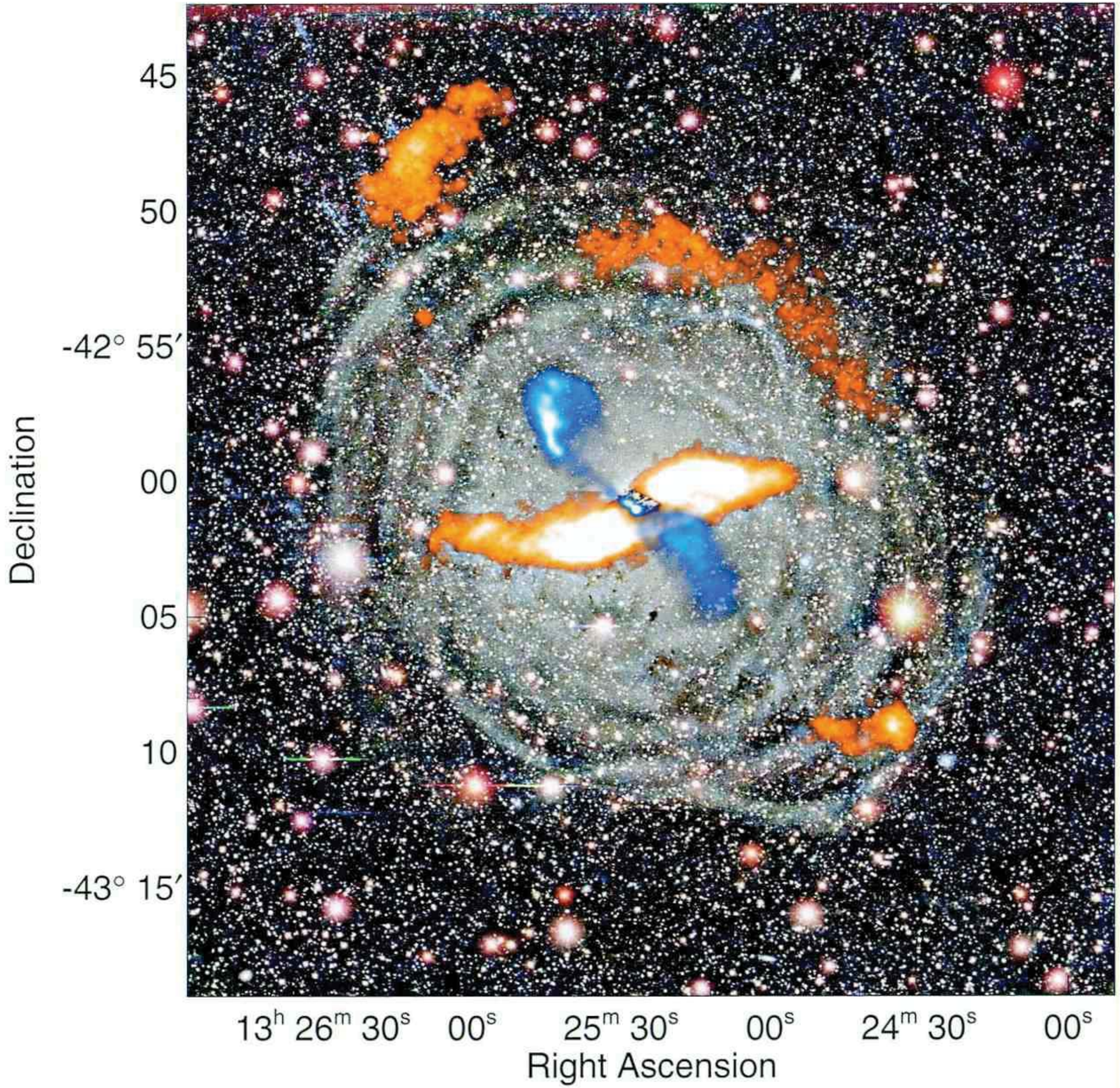
FIG. 1.—Hα interference filter photograph of the filamentary structure extending from NGC 5128

BLANCO *et al.* (*see* page L63)

Keel

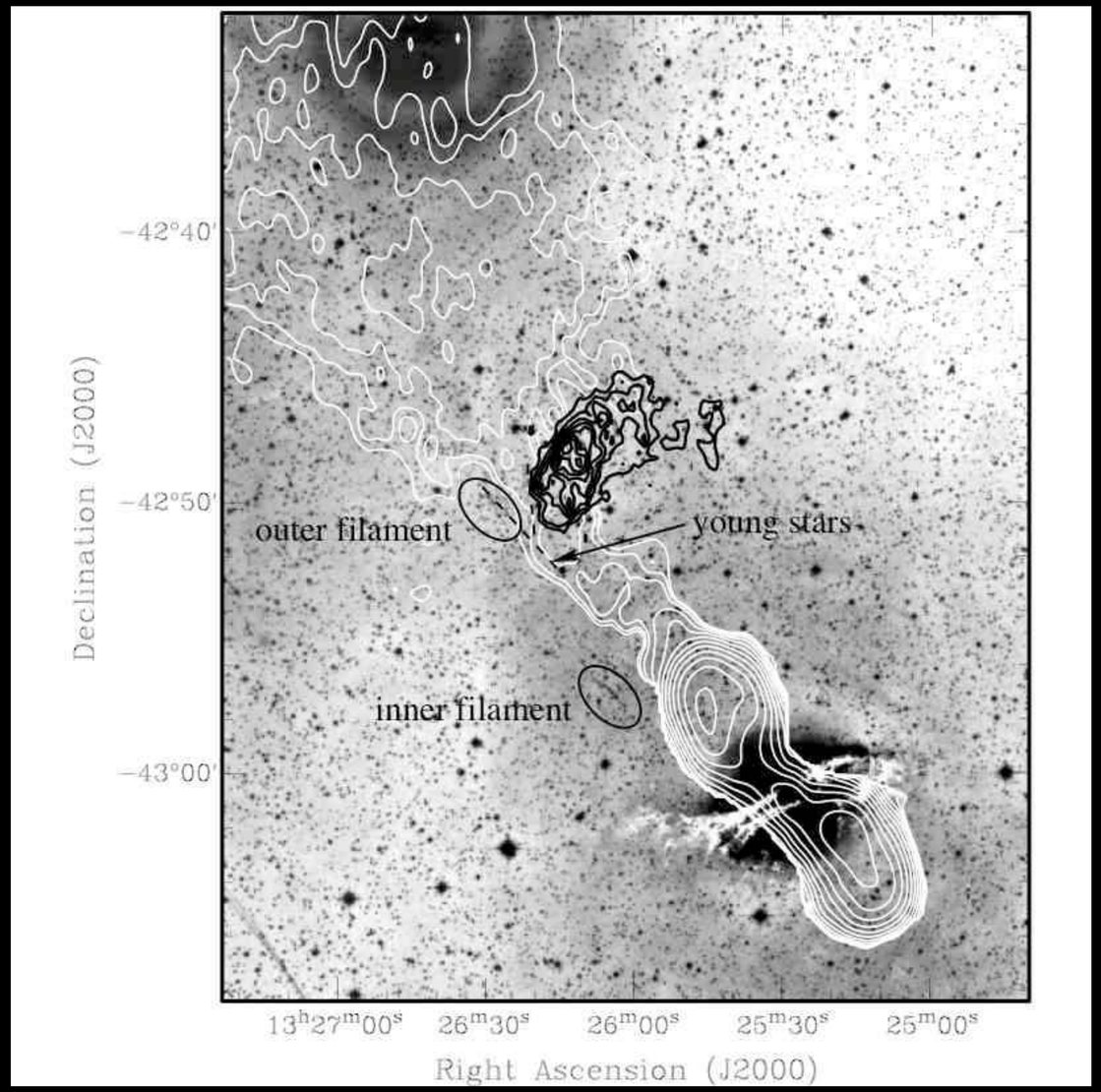
The outer H I

- Many gas clouds at large radius



- Jet to NML passes near filaments and H I

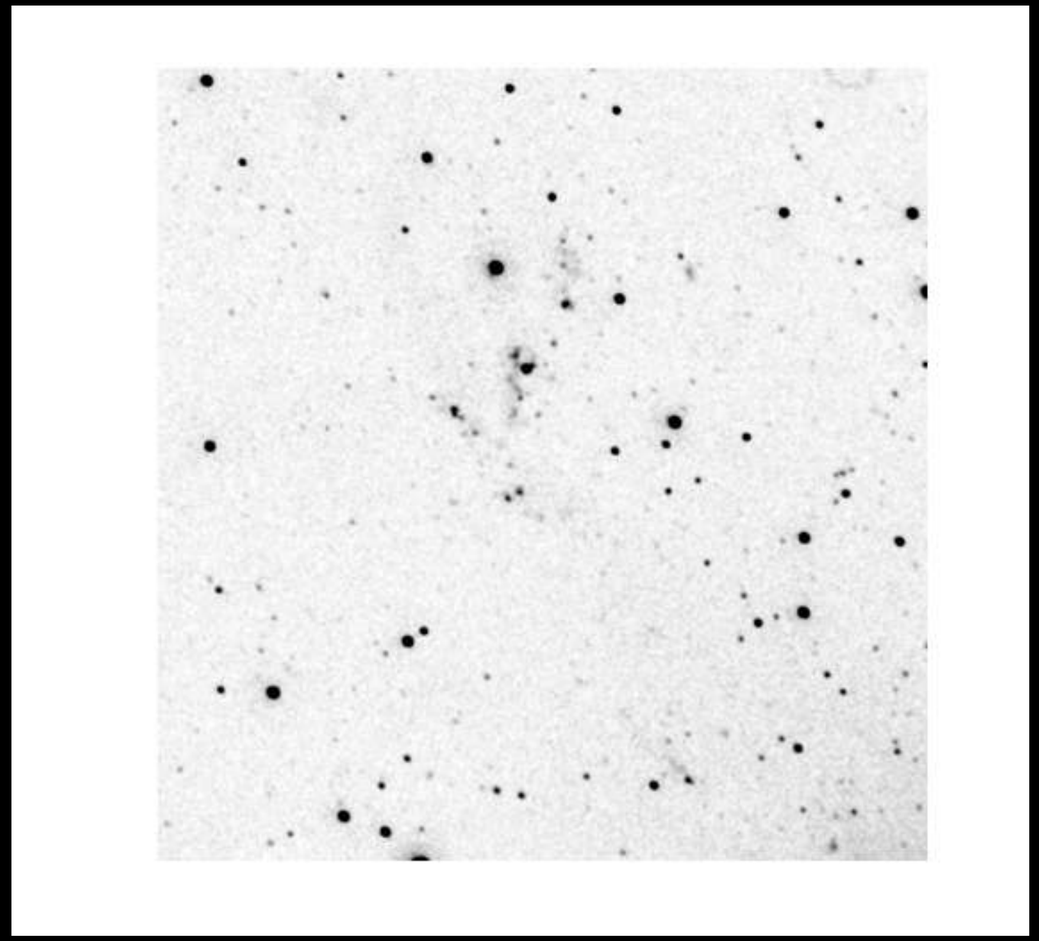
- There is no SML and associated jet
  This is why there are no filaments S of Cen A?



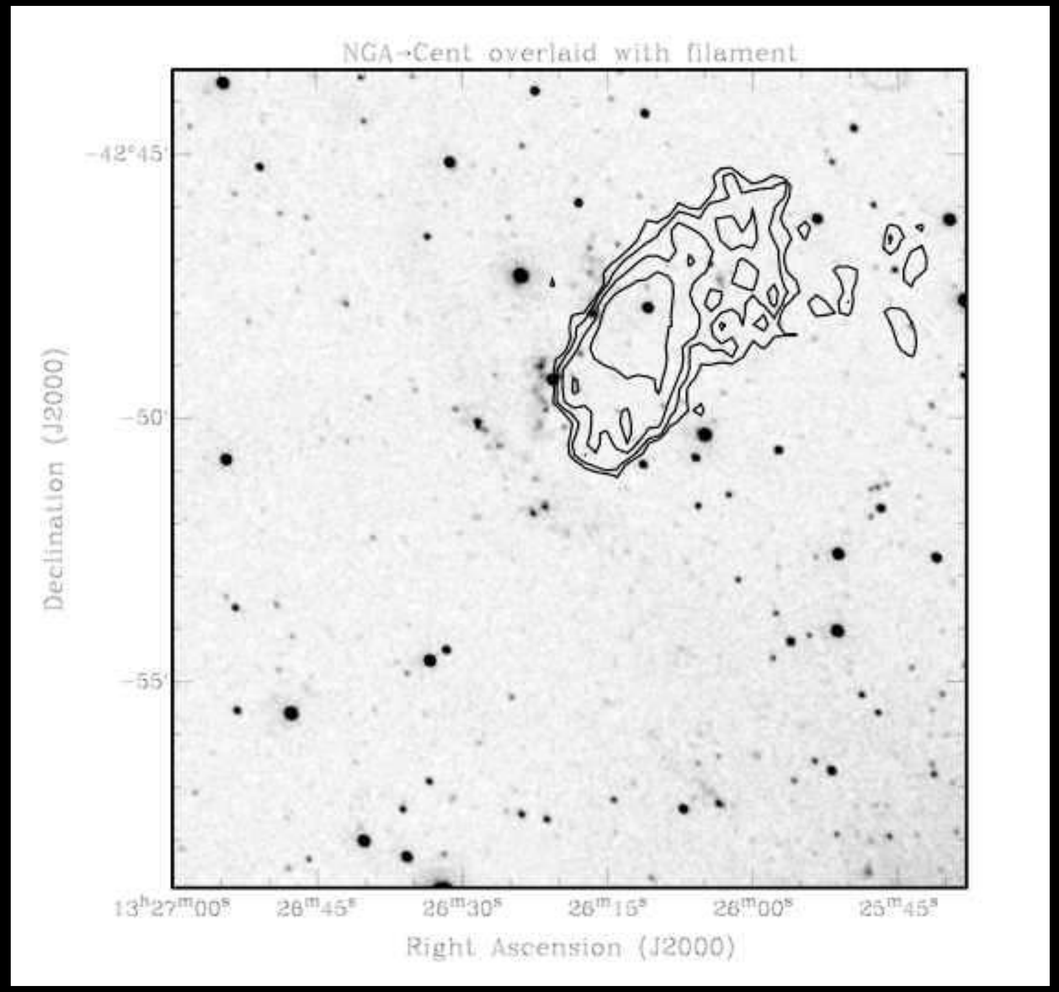
Oosterloo & Morganti

HI near outer filament

- Outer filament coincides with edge H I cloud



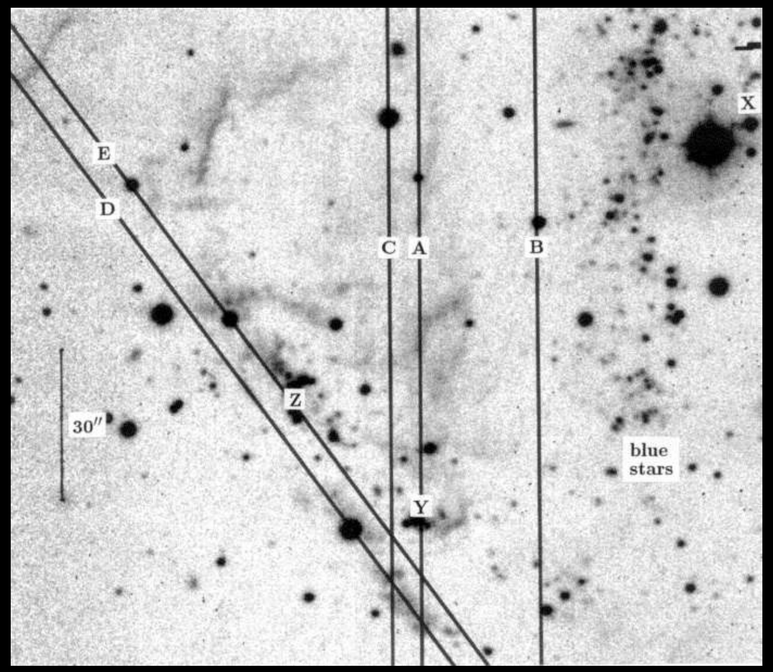
Galex



Young stars in outer filament

Jet-induced star formation?

Rejkuba

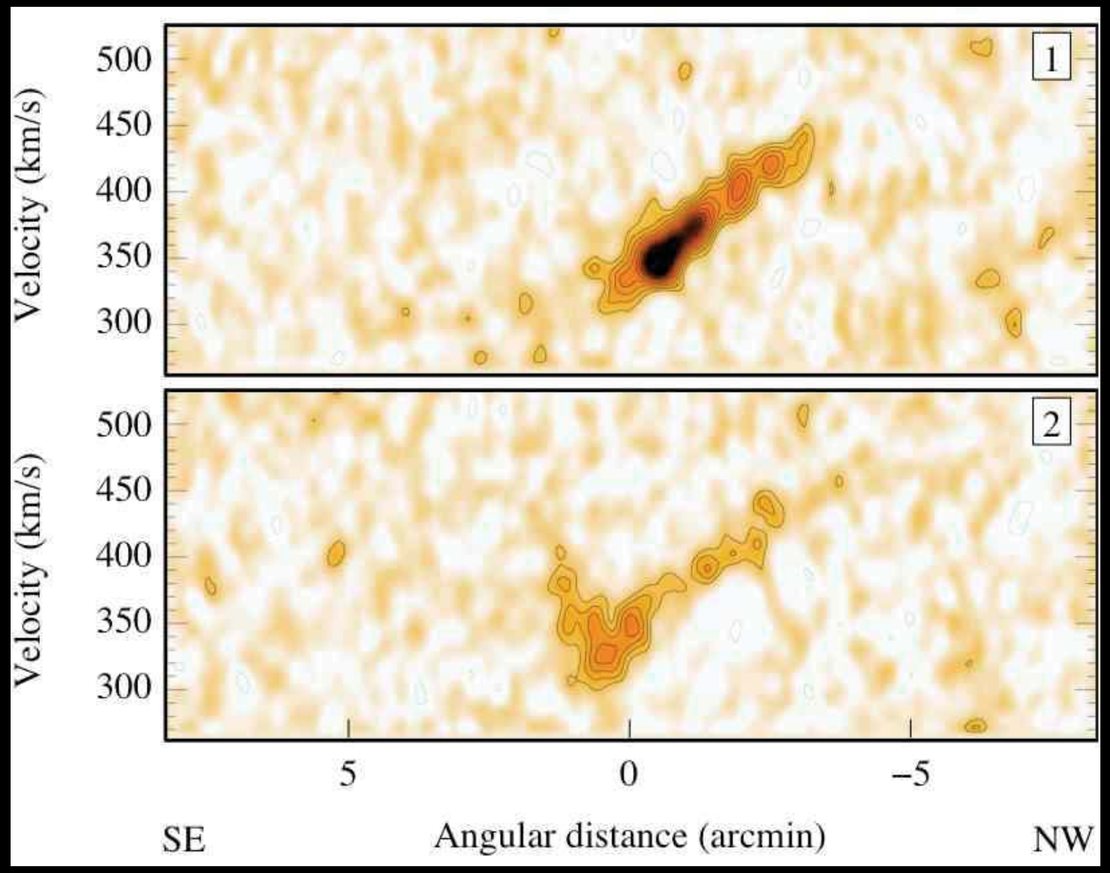


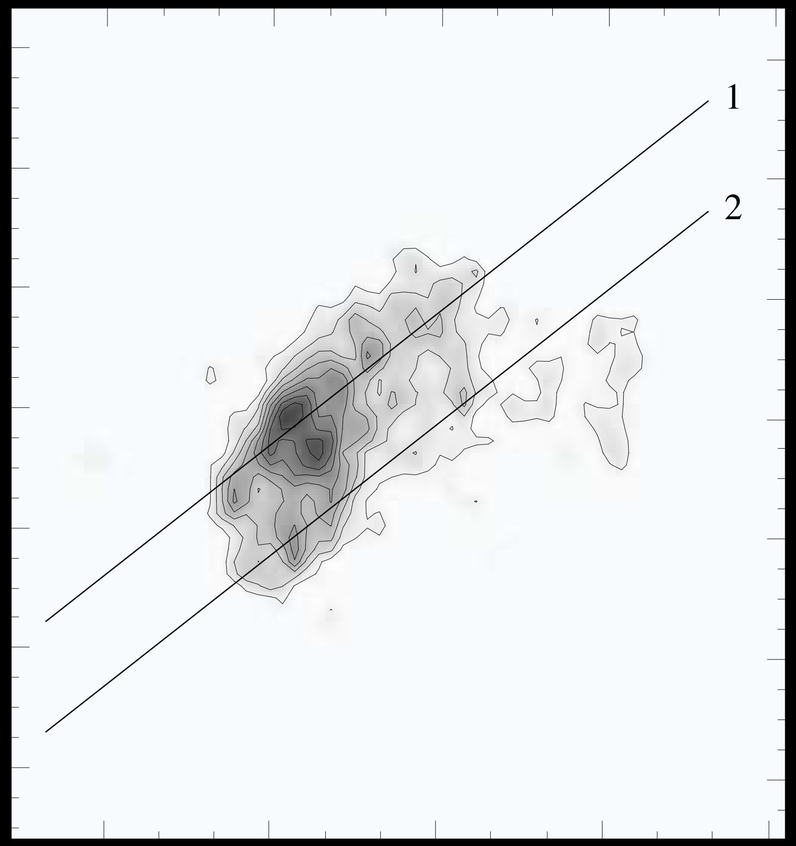
Graham

Filaments contain young stars (10 Myr)

Velocity anomaly in S tip of HI cloud

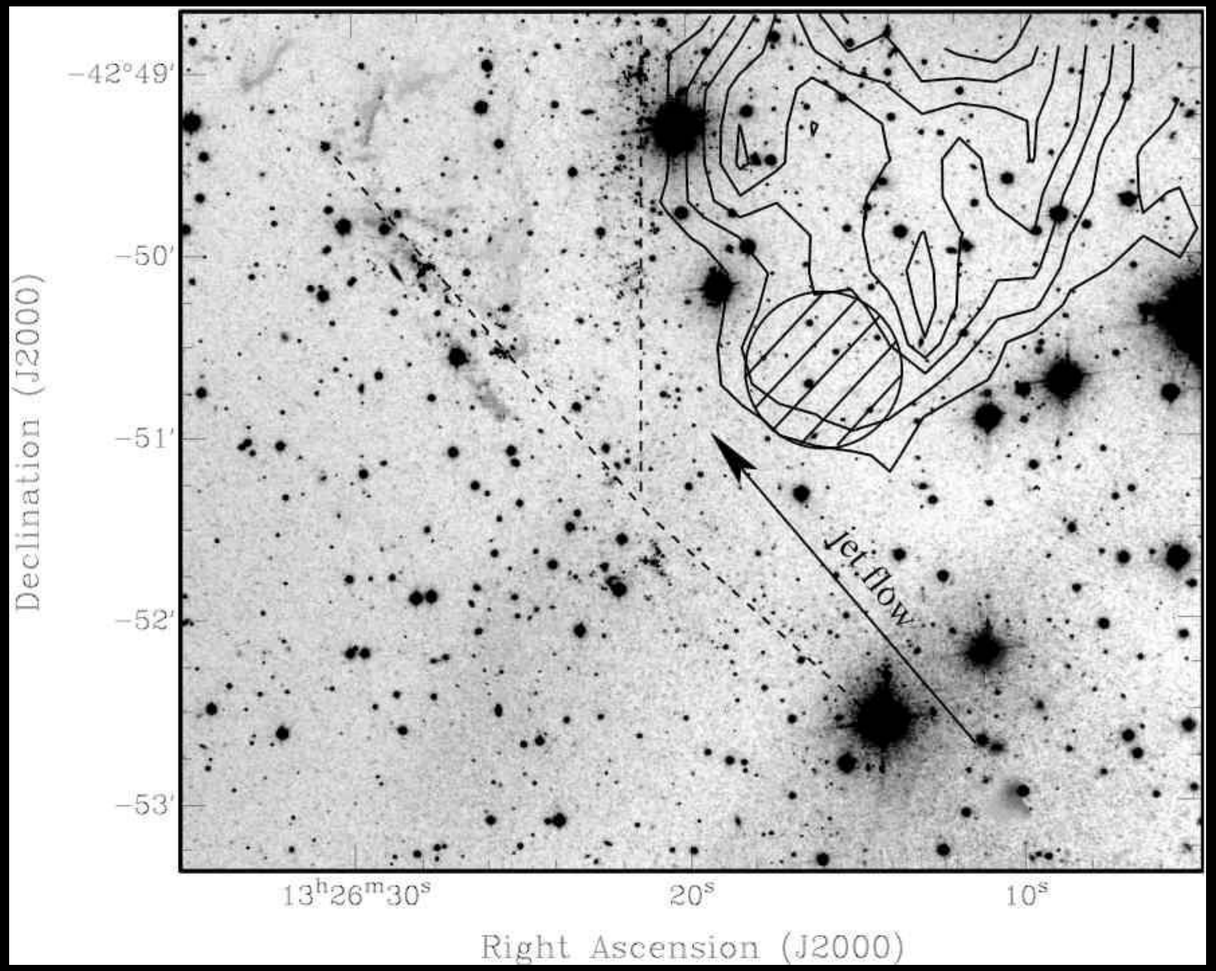
- 100 km s^{-1} over 1 kpc, is not gravitational
- Jet hitting HI cloud?



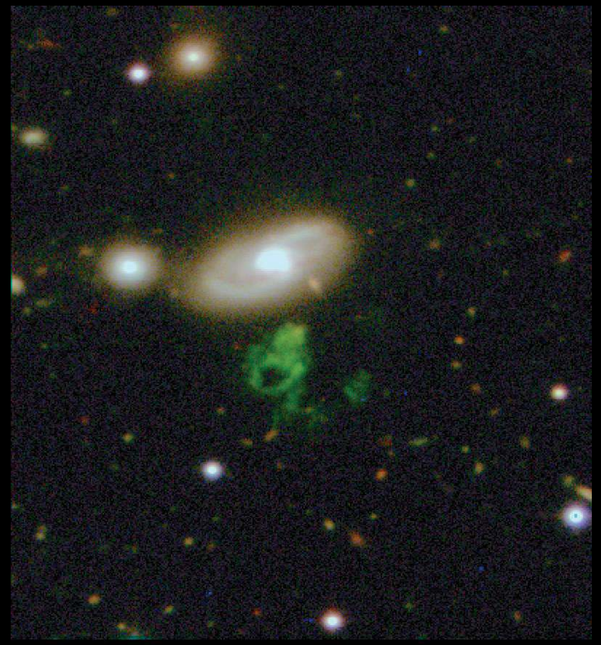


- Jet hits S tip of H I cloud
  inducing star formation
  and creating turbulent ionised filament

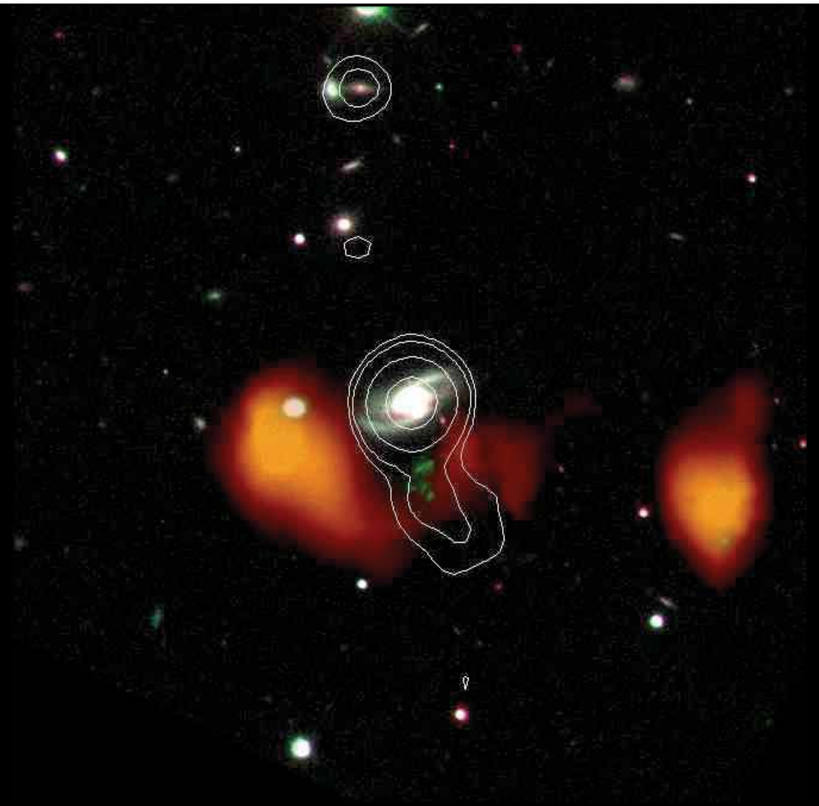
- Puzzle: column density in H I cloud is above
  10^{21} cm^{-2}. Why no star formation in cloud?



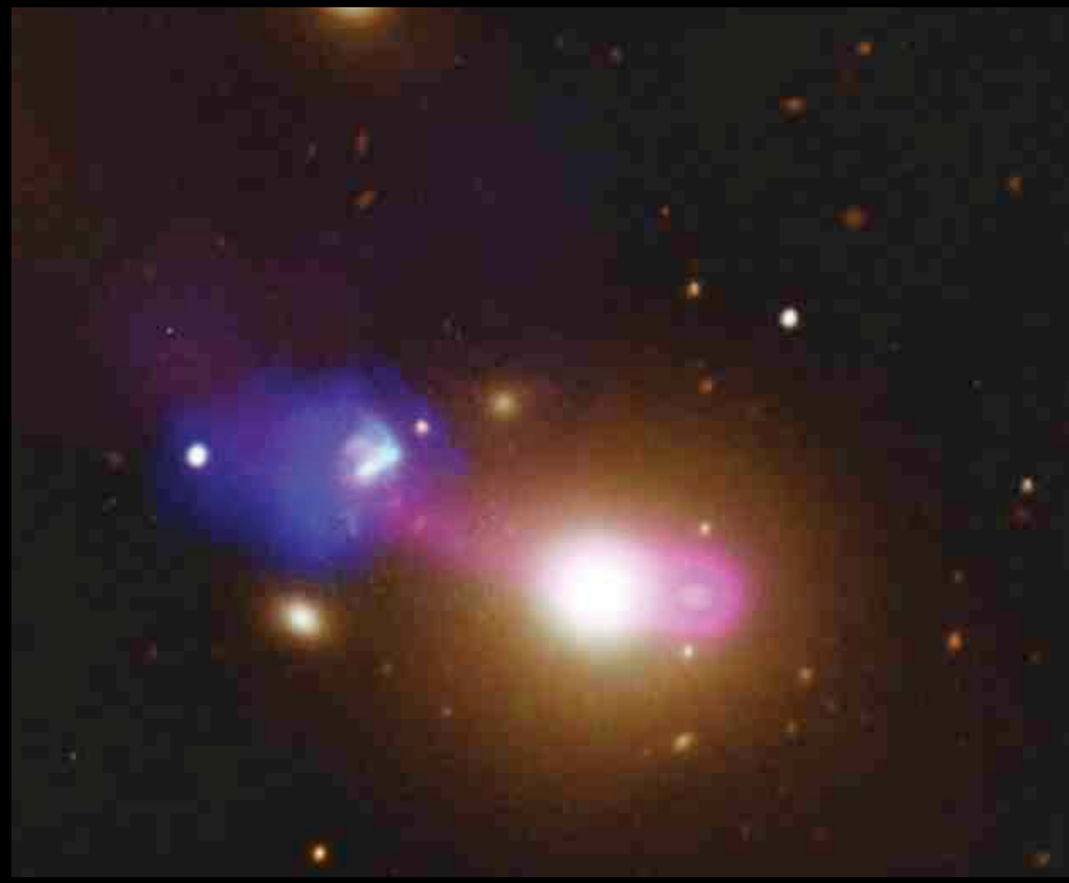
Other examples of "filaments"



Hanny's Voorwerp



Jozsa+ 2009

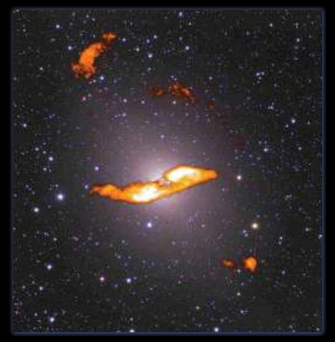


Minkowsky's Object

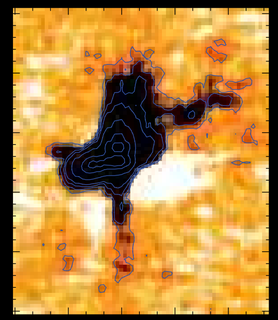
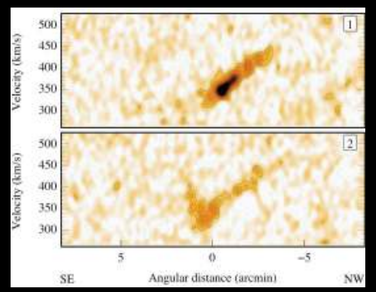
Jet-cloud interactions are rare, but other cases are known
Filaments near Cen A are weak

Summary

- Cen A has regular H I disk out to 5 kpc, very similar to what is seen in other early-type galaxies
  - Can be modelled, together with dust disk, as mildly warping disk, gives "flat" rotation curve
  - At larger radius significant non-circular motions and filaments
  - Accretion of gas rich (small) galaxy a few 10^8 yr ago
  - Large-scale disk is not connected to feeding current episode of AGN activity



- Extensive H I absorption, against centre, jet and lobes
  - Blueshifted H I absorption against centre, due to circumnuclear disk (r < 200 pc)
  - Not straightforward to interpret redshifted H I absorption as evidence for infall



- Jet to NML is interacting with ISM
  - Anomalous velocities in northern H I cloud
  - Jet induced starformation