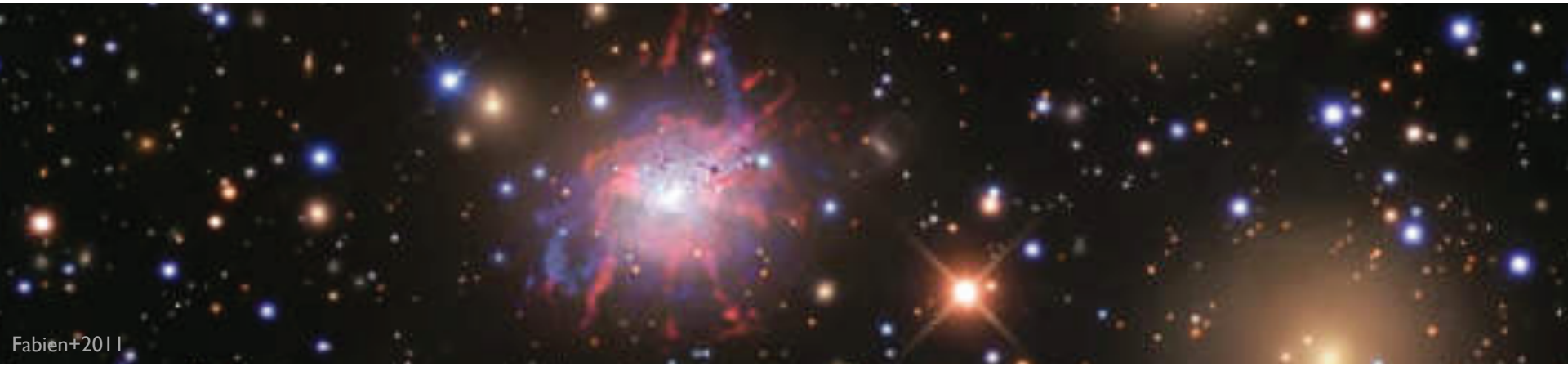
High-dynamic-range 21 cm JVLA observations of the Perseus Cluster



Chat Hull

NAOJ Fellow —

National Astronomical Observatory of Japan
NAOJ Chile Observatory
Joint ALMA Observatory

Many thanks to my collaborators: *Rick Perley, Mike McCourt, James McBride, the galaxy cluster experts at the CfA, and the CASA experts at the NRAO!*

15 May 2018

Perseus in Sicily
Noto, Sicily, Italy

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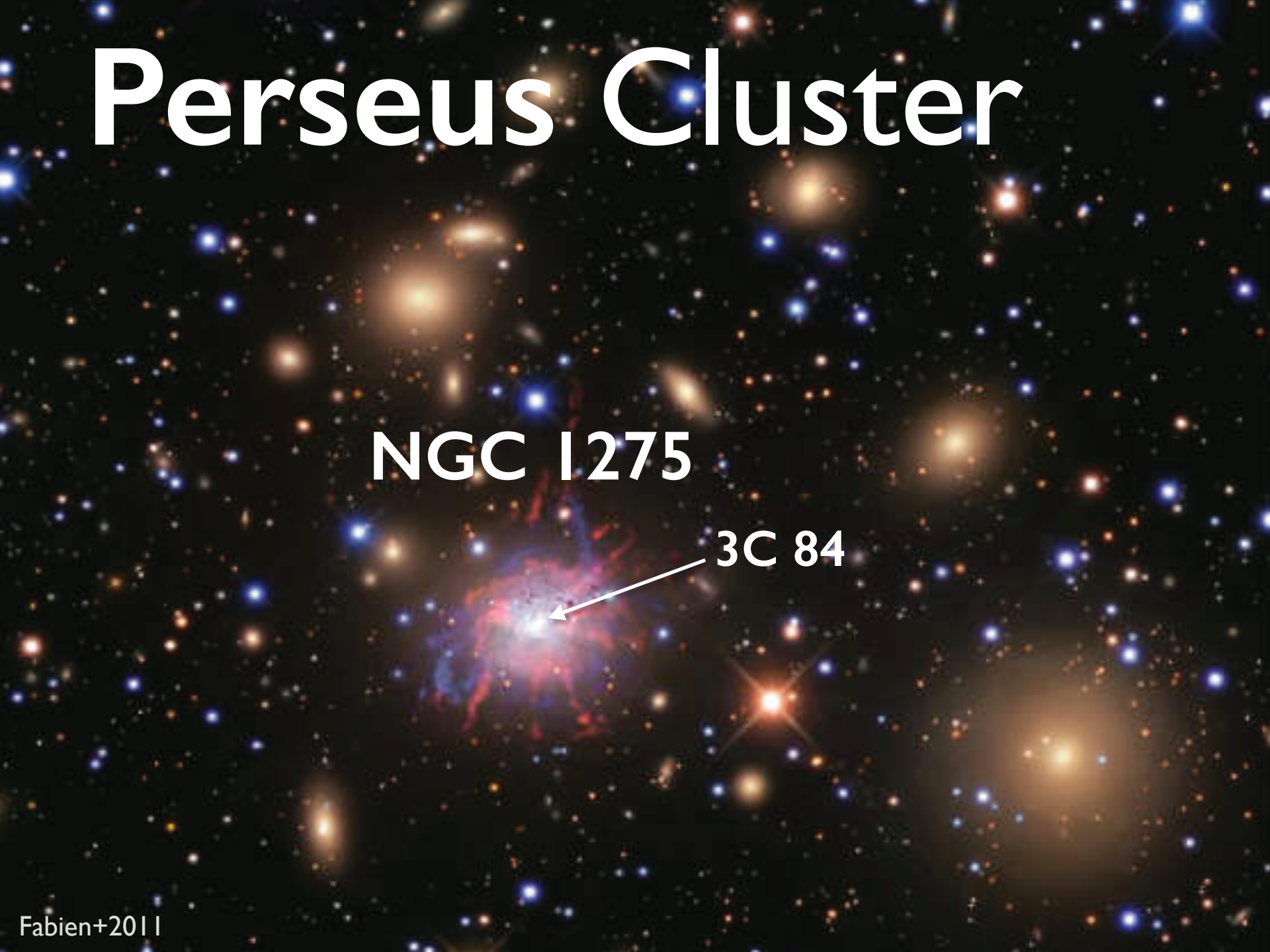
Perseus Cluster



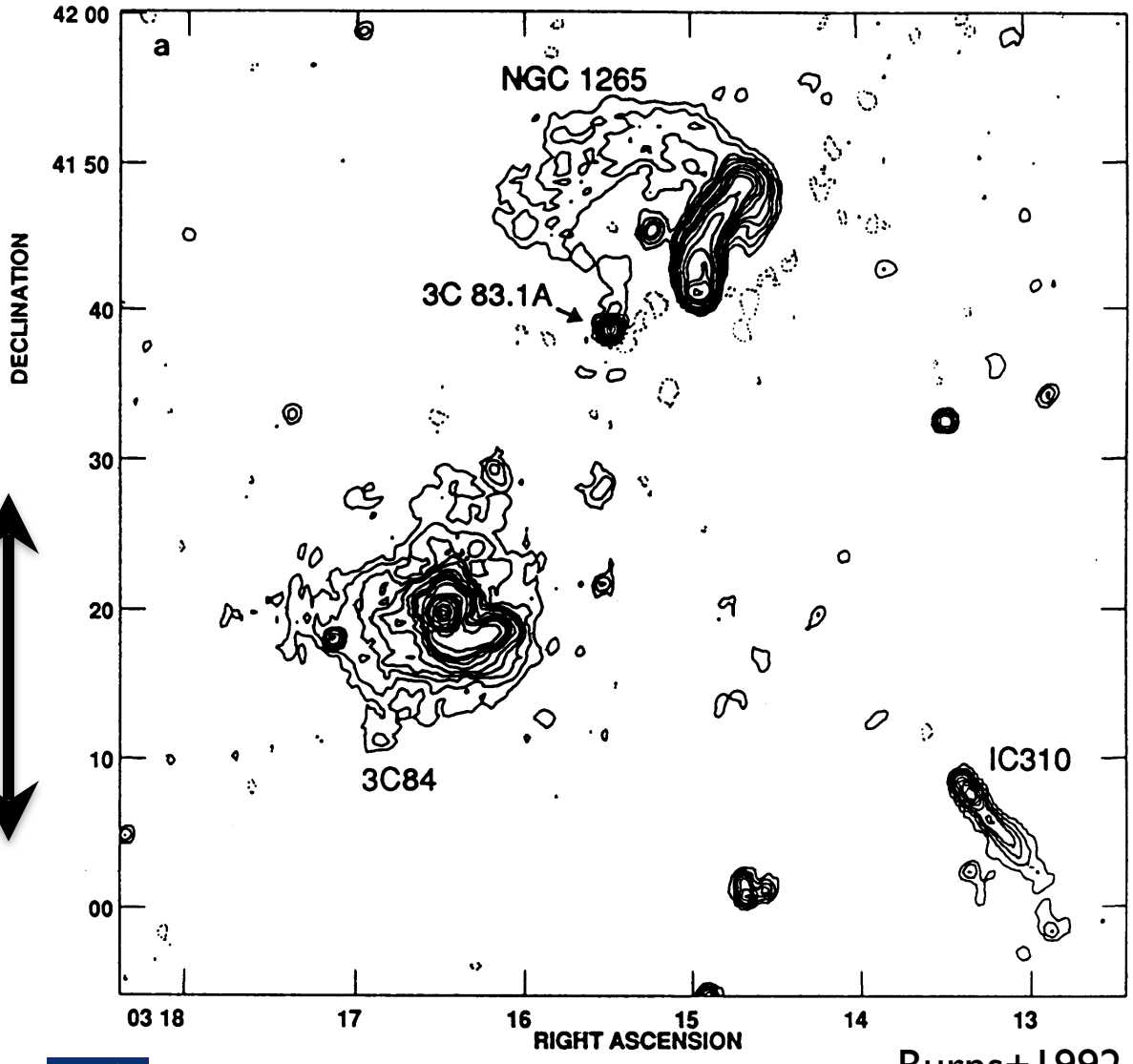
Fabien+2011

Cluster info

- Cluster mass ~10^{15} solar masses
- Mass in gas **~20%**
- Mass in stars **~2%**
- There's < gas in all of the galaxies combined than there is in the ICM!

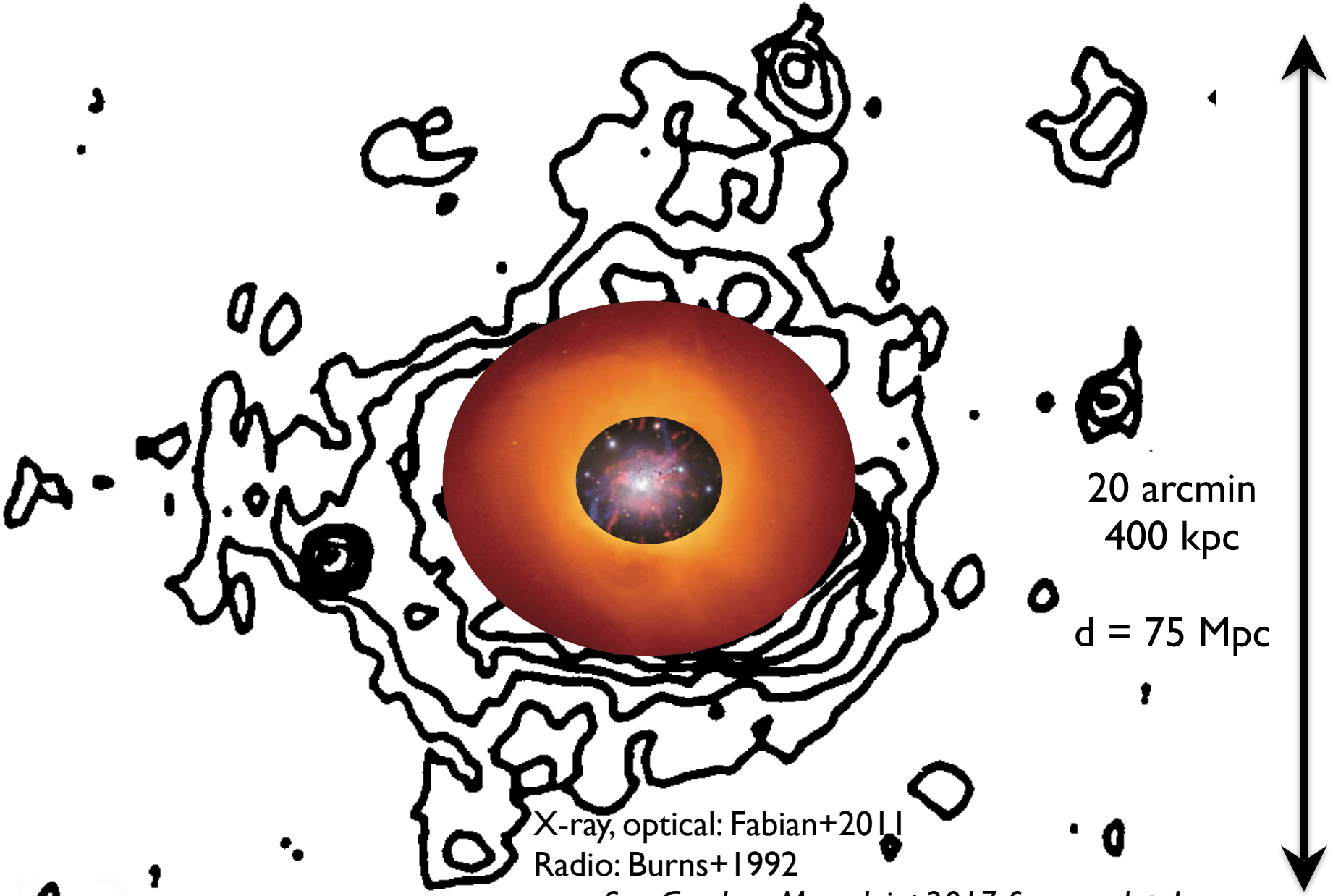
- BCGs / cD galaxies: most massive galaxies in the Universe

3C84: minihalo (VLA 330 MHz data)



20 arcmin
400 kpc

Burns+1992



X-ray, optical: Fabian+2011
Radio: Burns+1992

See Gendron-Marsolais+2017 for new data!

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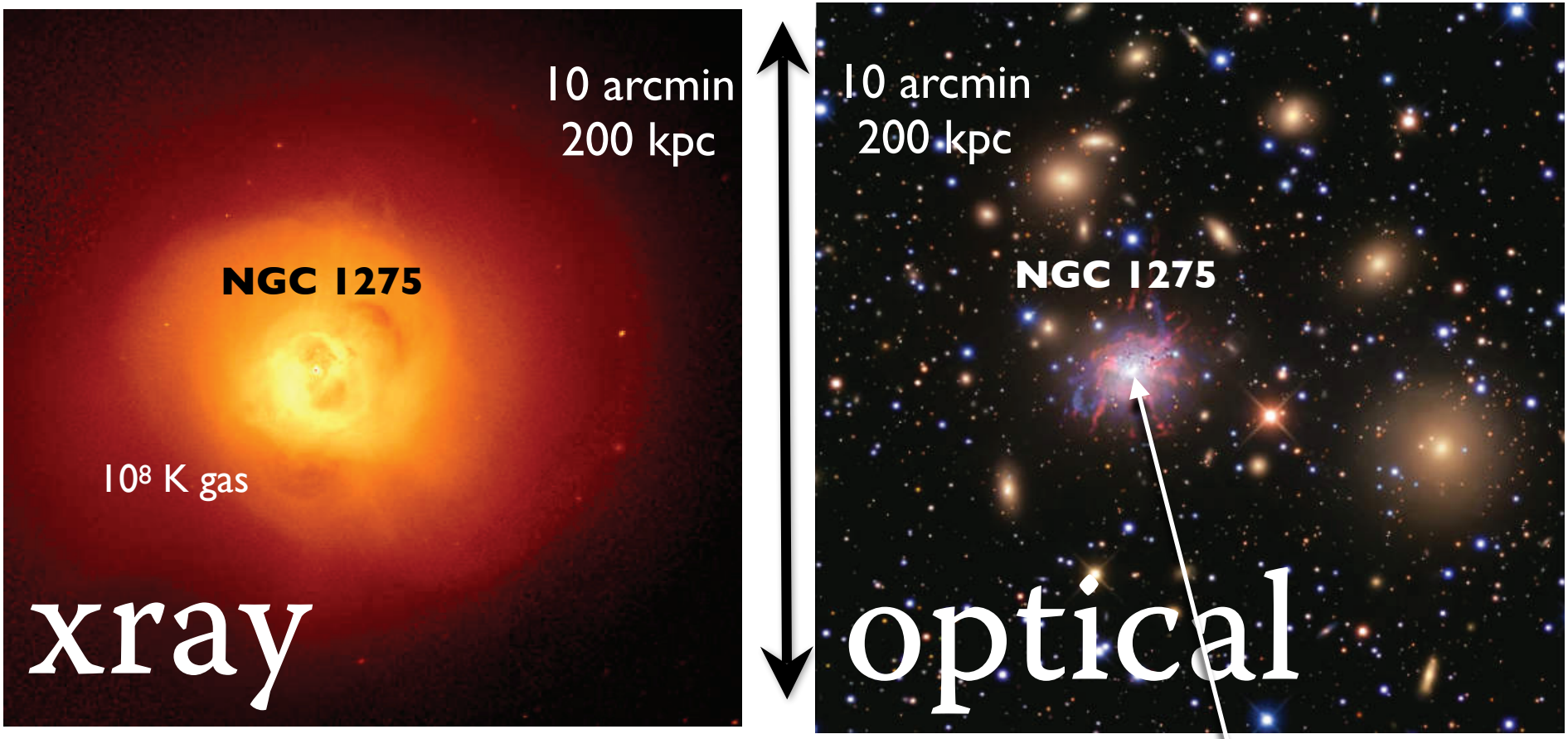
H-alpha filaments in the Perseus cluster



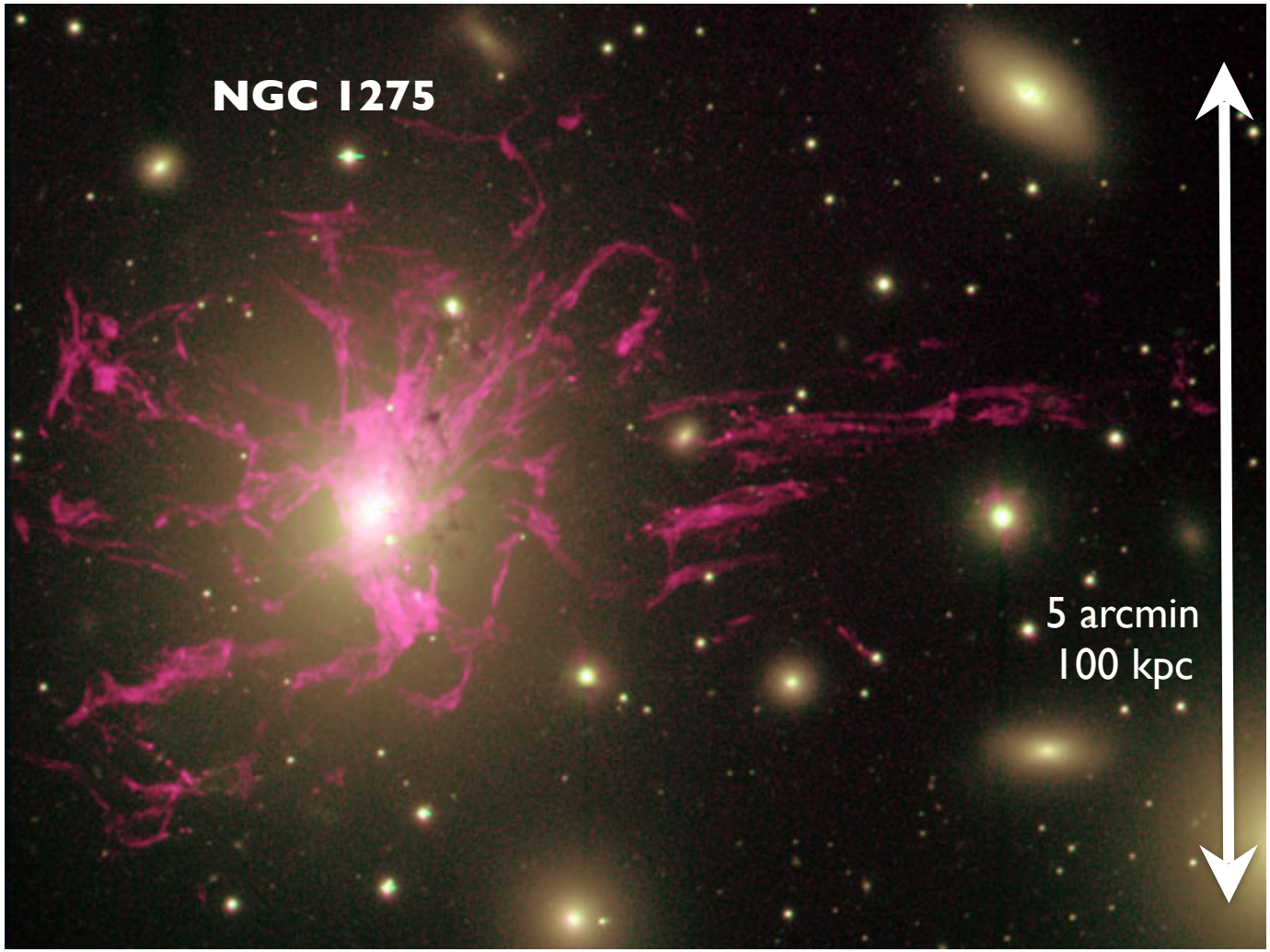
Fabian+ 2011

H-alpha filaments around 3C84
(10^4 K gas)

H-alpha filaments in the Perseus cluster

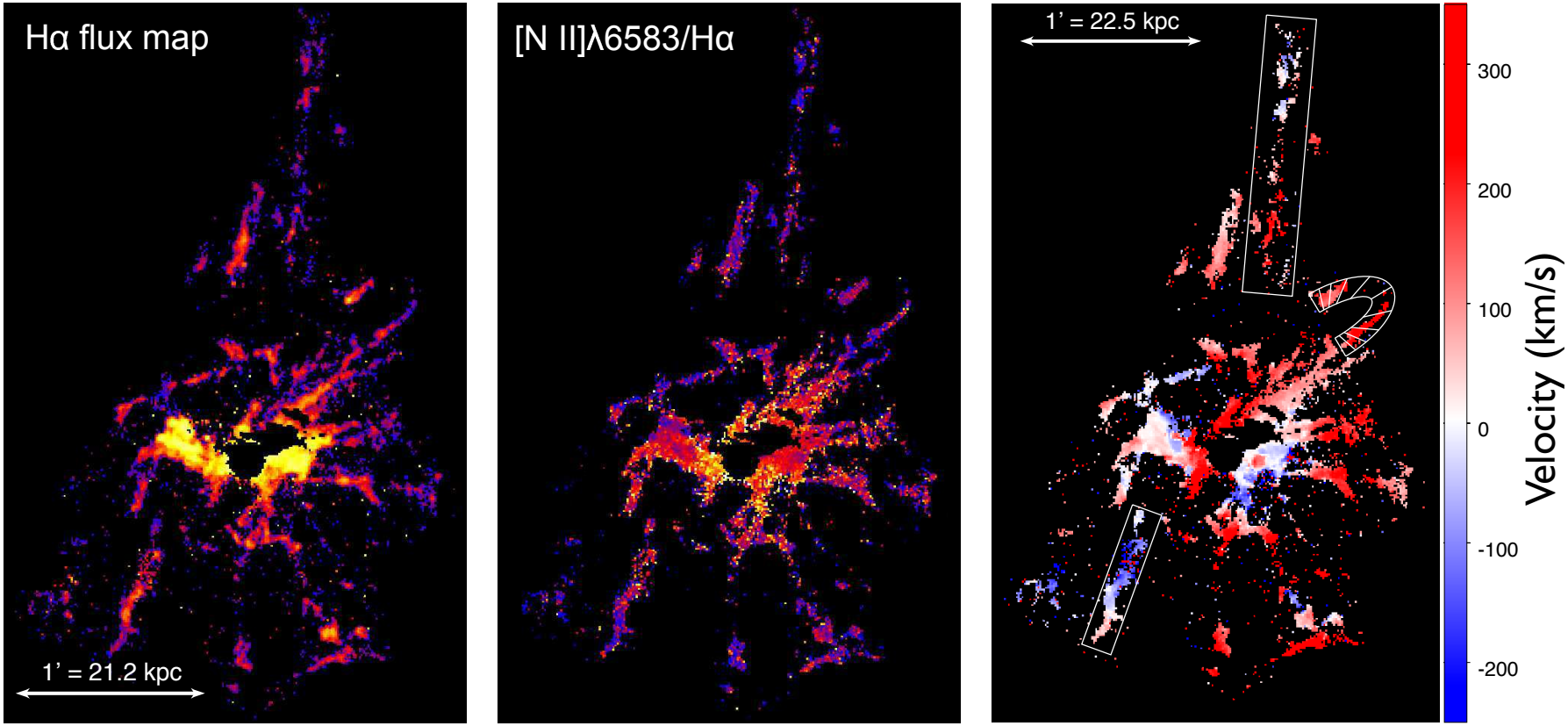
H-alpha filaments:

- 10–100 **kpc** long
- < 70 **pc** thick
- How do they not evaporate in ~100 yr?!



Conselice+2001

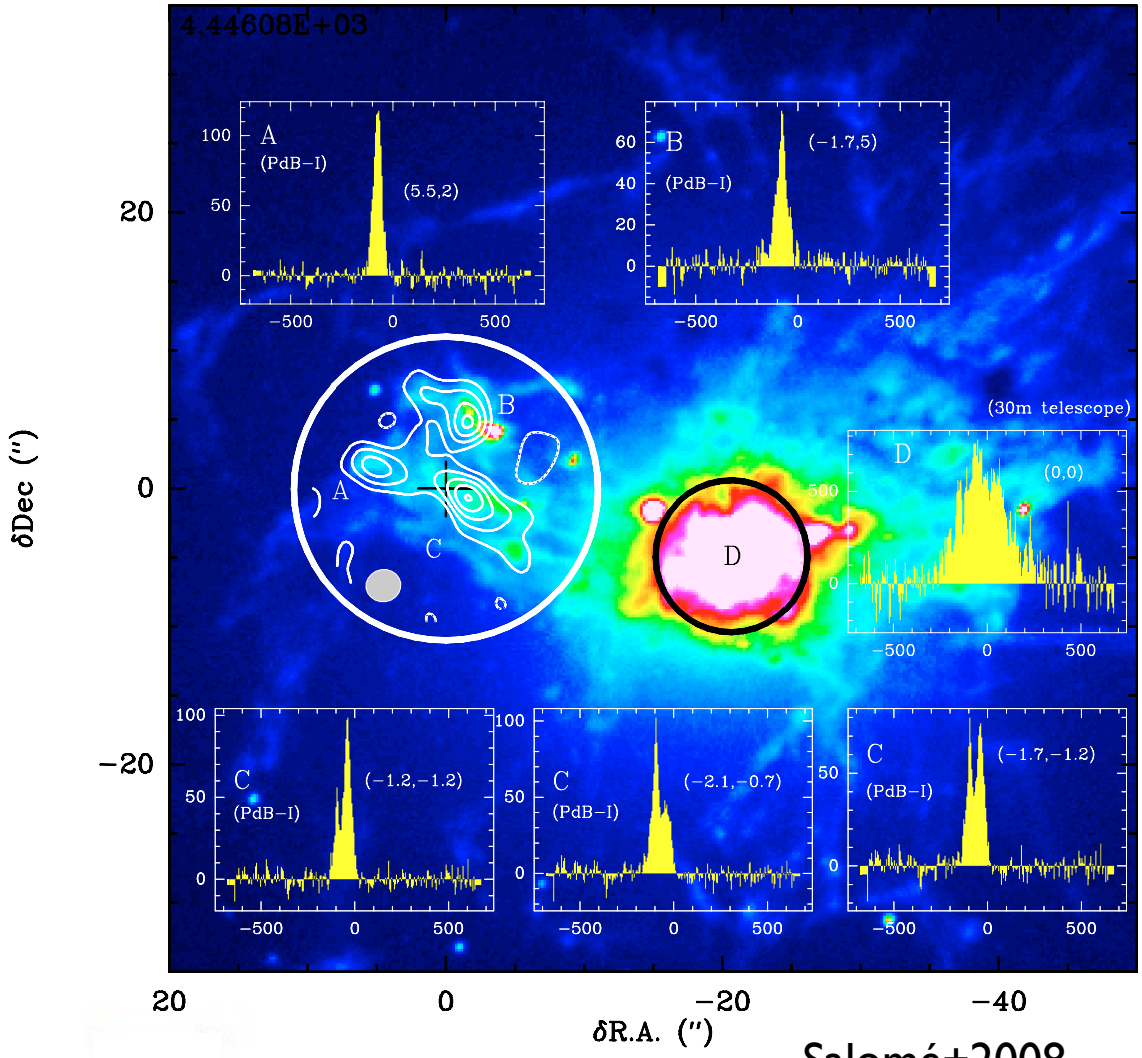
H-alpha filaments in the Perseus cluster



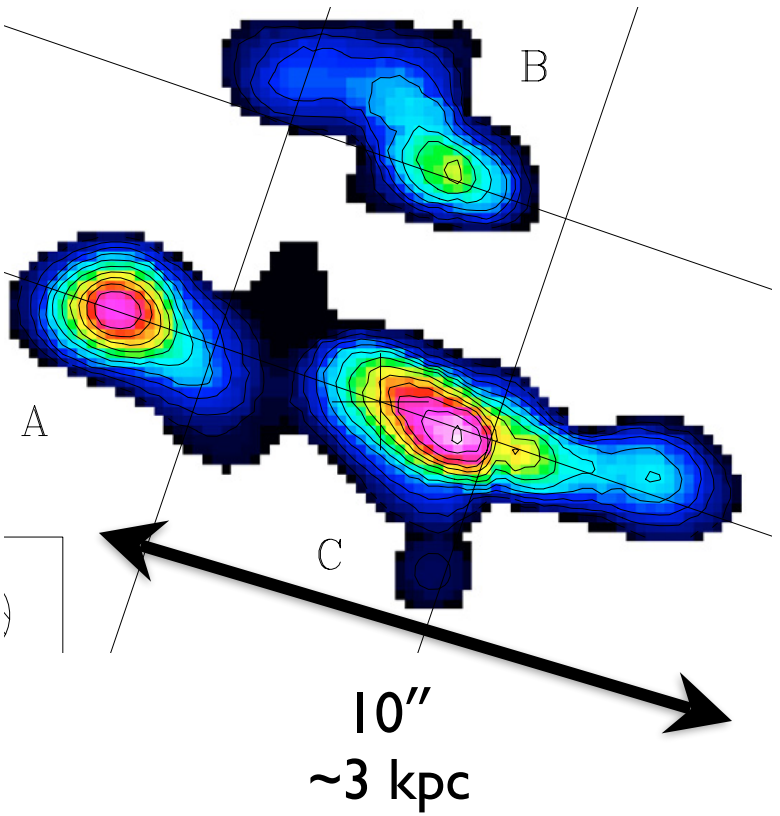
Gendron-Marsolais+2018

3C84: molecular gas in the filaments

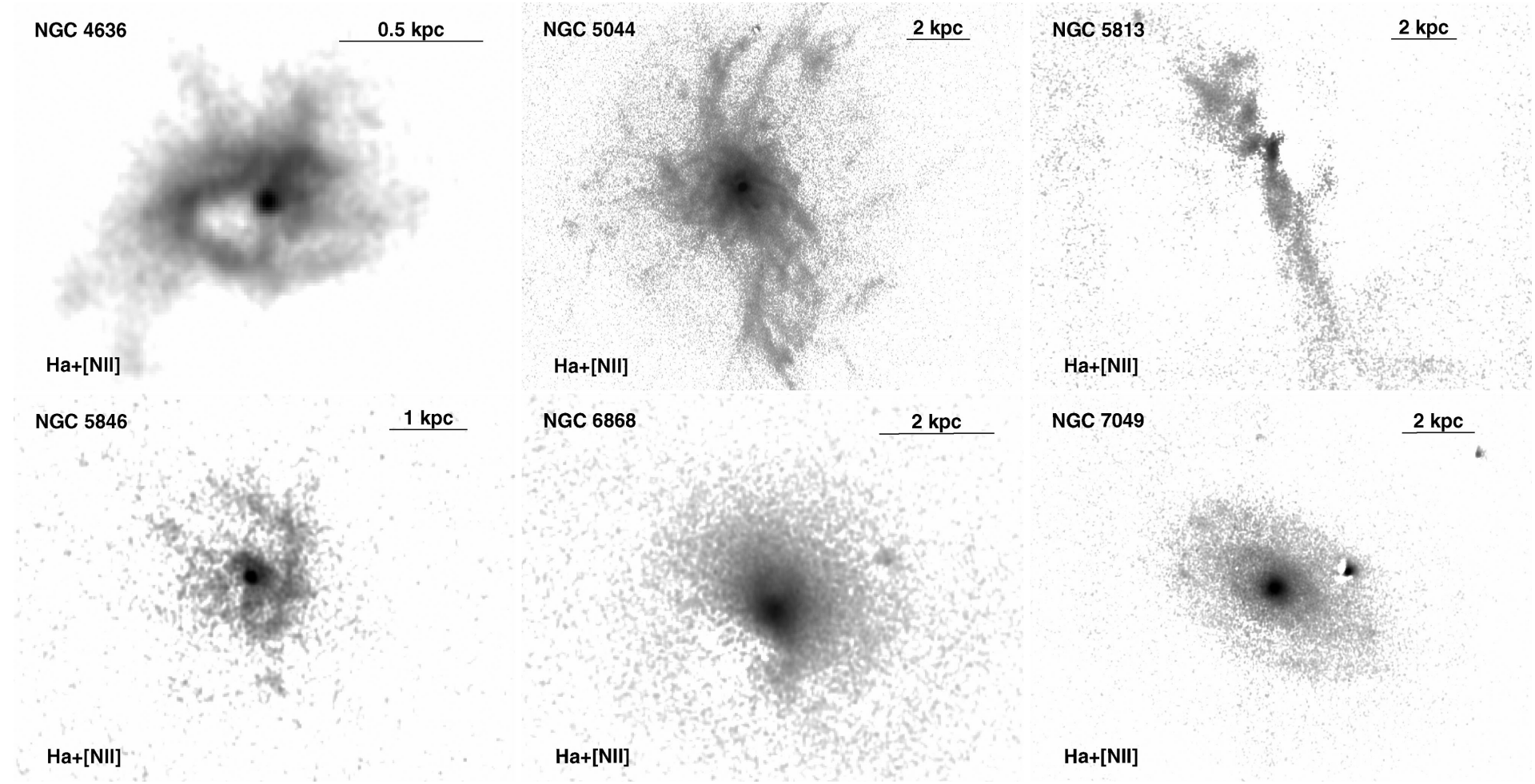
See more in talk by Françoise Combes



Salomé+2008



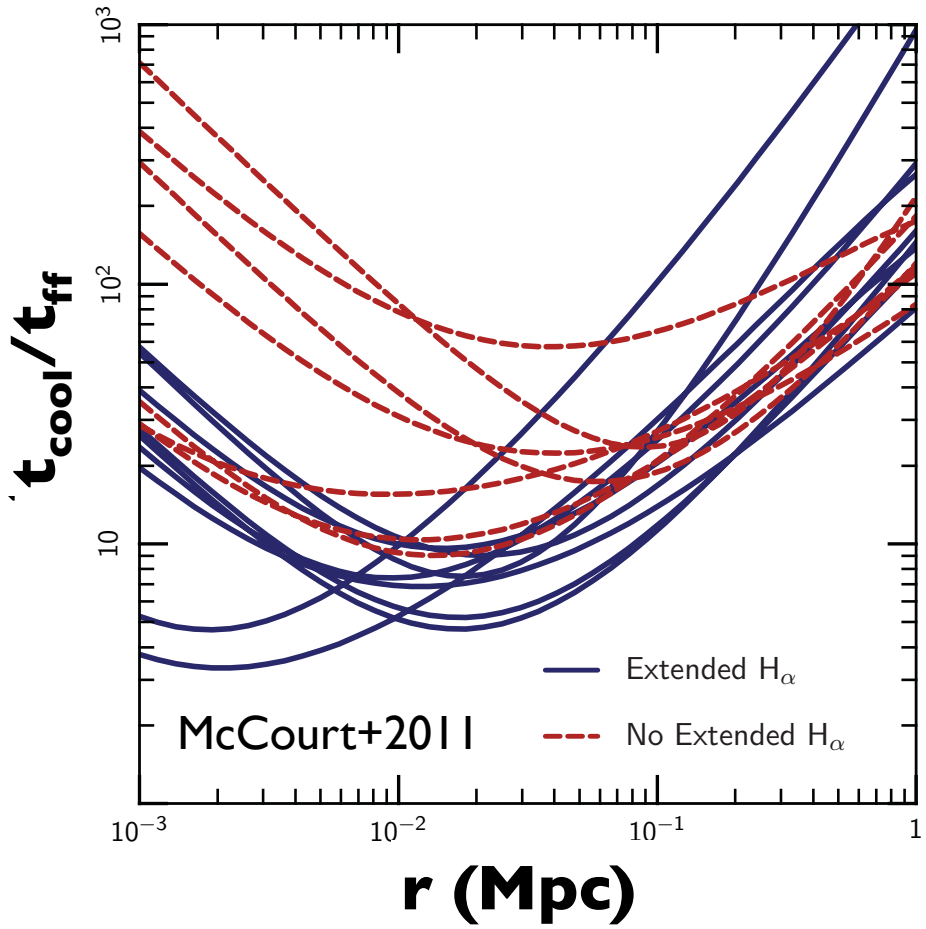
Filaments in other brightest cluster galaxies (BCGs)

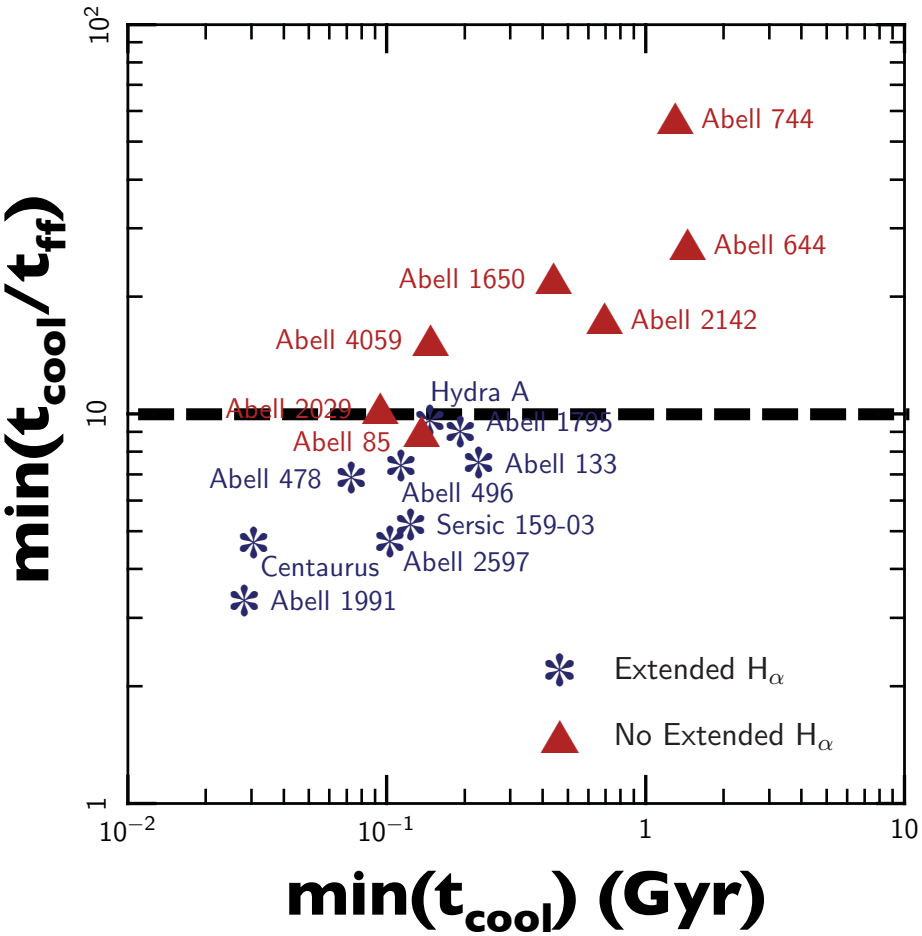


Filaments are common in BCGs!

Above: H-alpha + [NII] emission from the SOAR telescope (Werner+2014)

Possible filament origin: thermal instability





- Filaments tend to form when $t_{cool}/t_{ff} < 10$

Filament importance

- **Star formation:** regions where stars are forming *outside* of a galaxy
  - Do they still fall on the radio-FIR correlation?

- **Galaxy formation:** M_{gas} in filaments can be > M_{gas} in the central galaxy
  - Filaments are probably the source of gas for the central galaxy
  - Probing the formation of the largest galaxies in the Universe

- **Cluster formation:** galaxy mass function falls off at high masses (> 10^{11} solar masses)
  - Thermal instability → filaments → AGN activity → cutoff

- **B-fields:** Investigating importance of B-fields in extragalactic star formation
  - Filaments are thought to be extremely magnetically dominant

Our goal: measure synchrotron

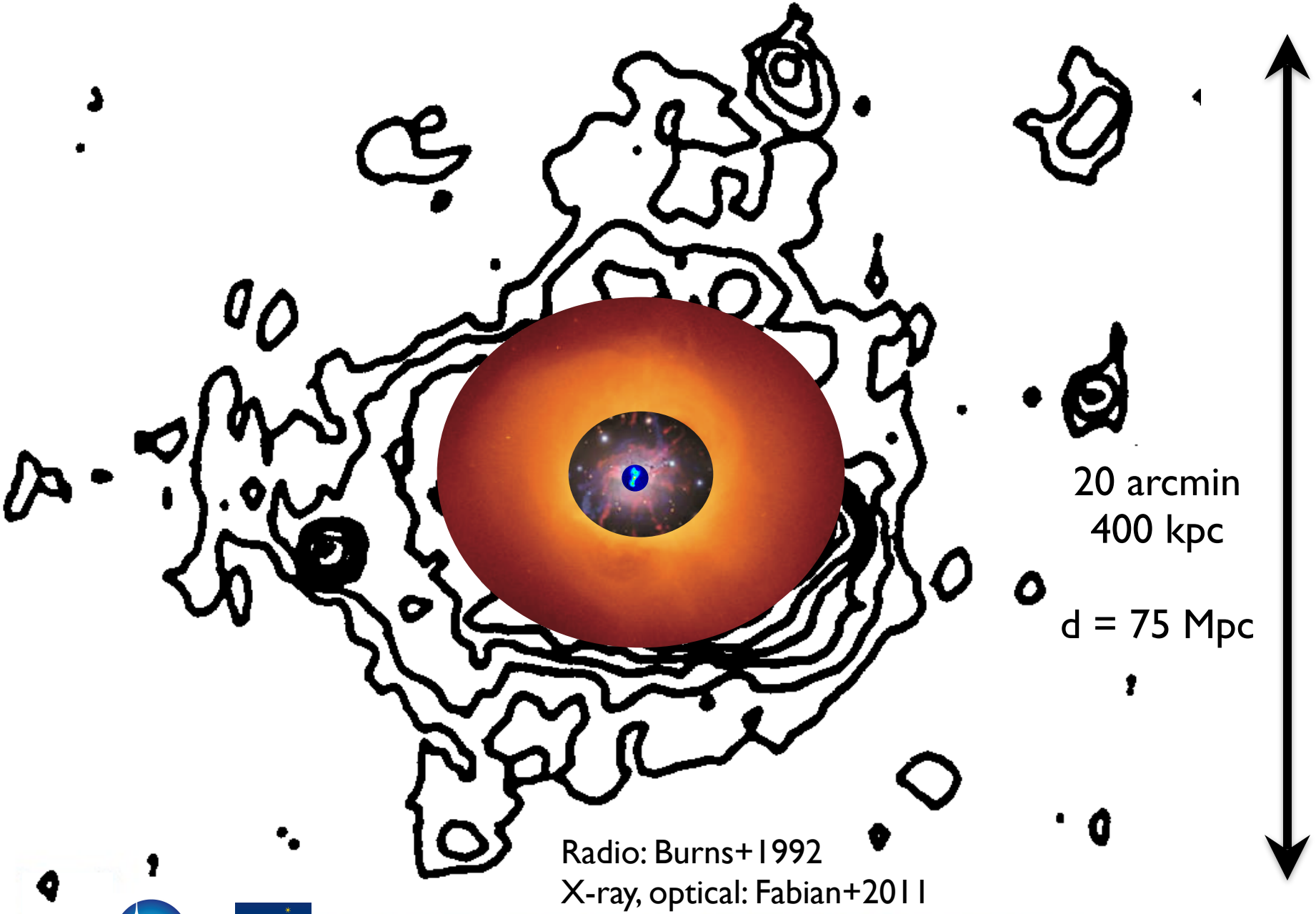
Collaborators:

Rick Perley (NRAO, Socorro)

Mike McCourt (UC Berkeley → CfA → consultant)

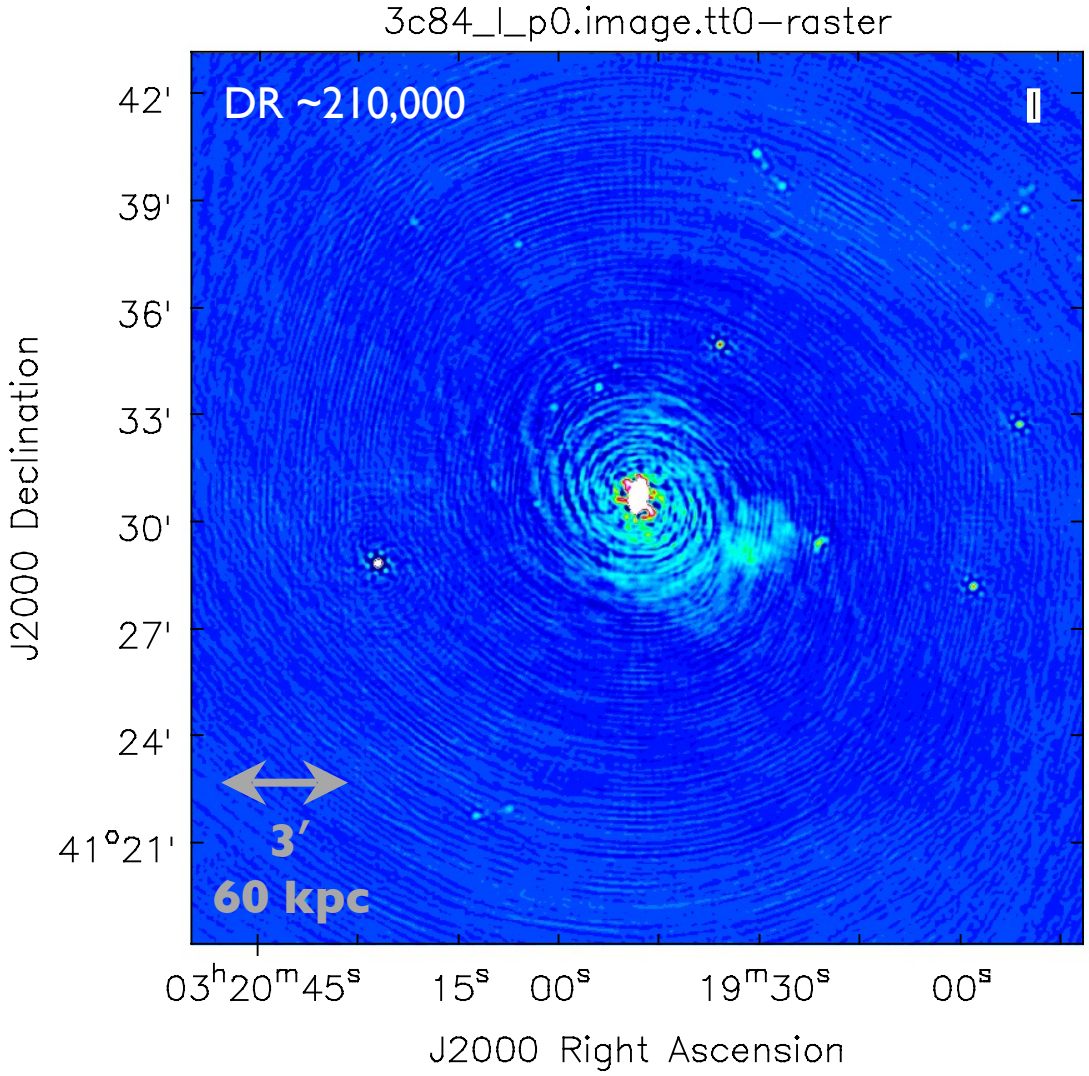
James McBride (UC Berkeley → Ceres Imaging)

- Test properties of the only known SF regions outside of a galaxy



Radio: Burns+1992
X-ray, optical: Fabian+2011

3C 84 / NGC 1275: VLA C+D-config at L-band



The wonders of

multi-term,

multi-frequency,

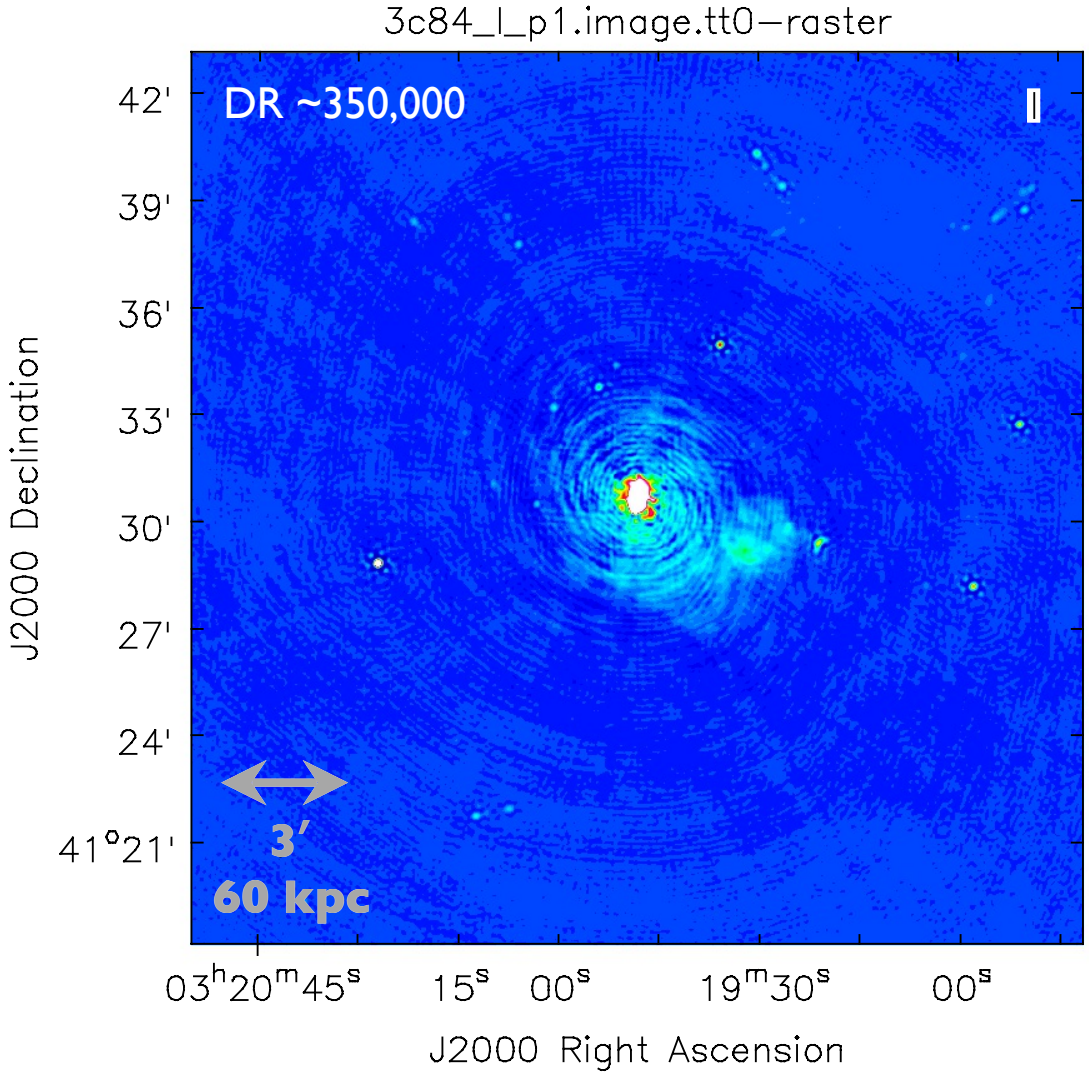
w-projected,

multi-processor

CASA with TCLEAN()…

…and selfcal

3C 84 / NGC 1275: VLA C+D-config at L-band



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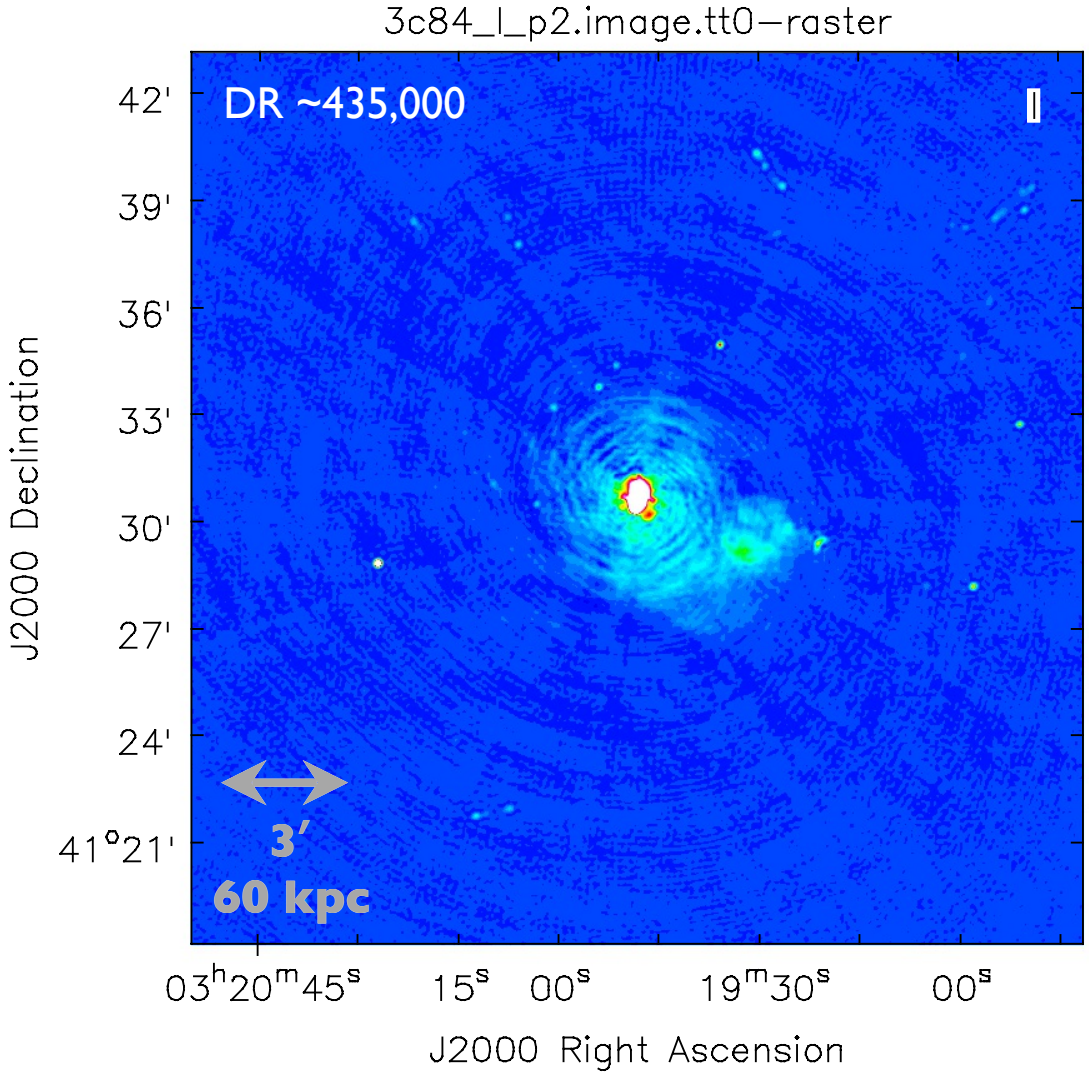

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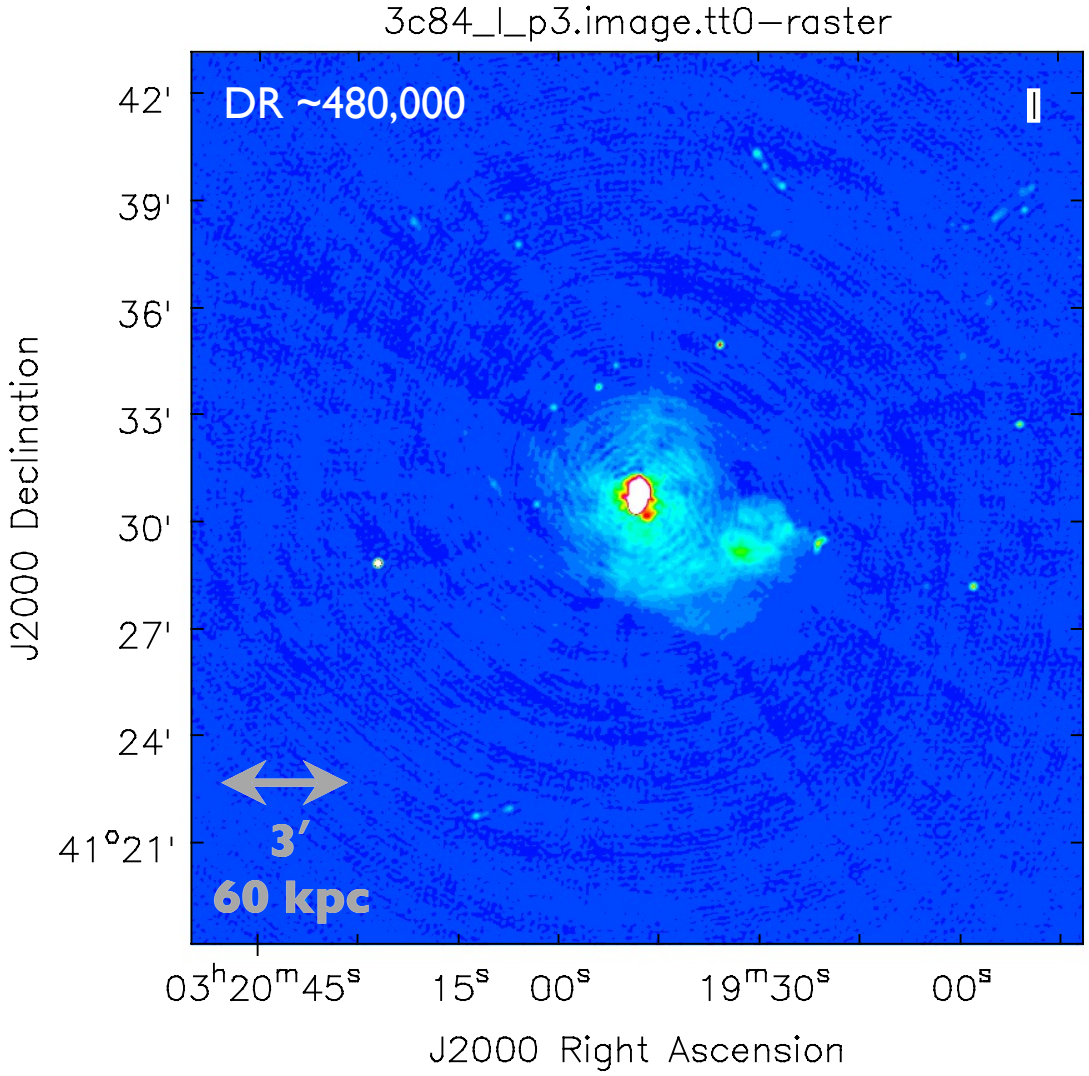

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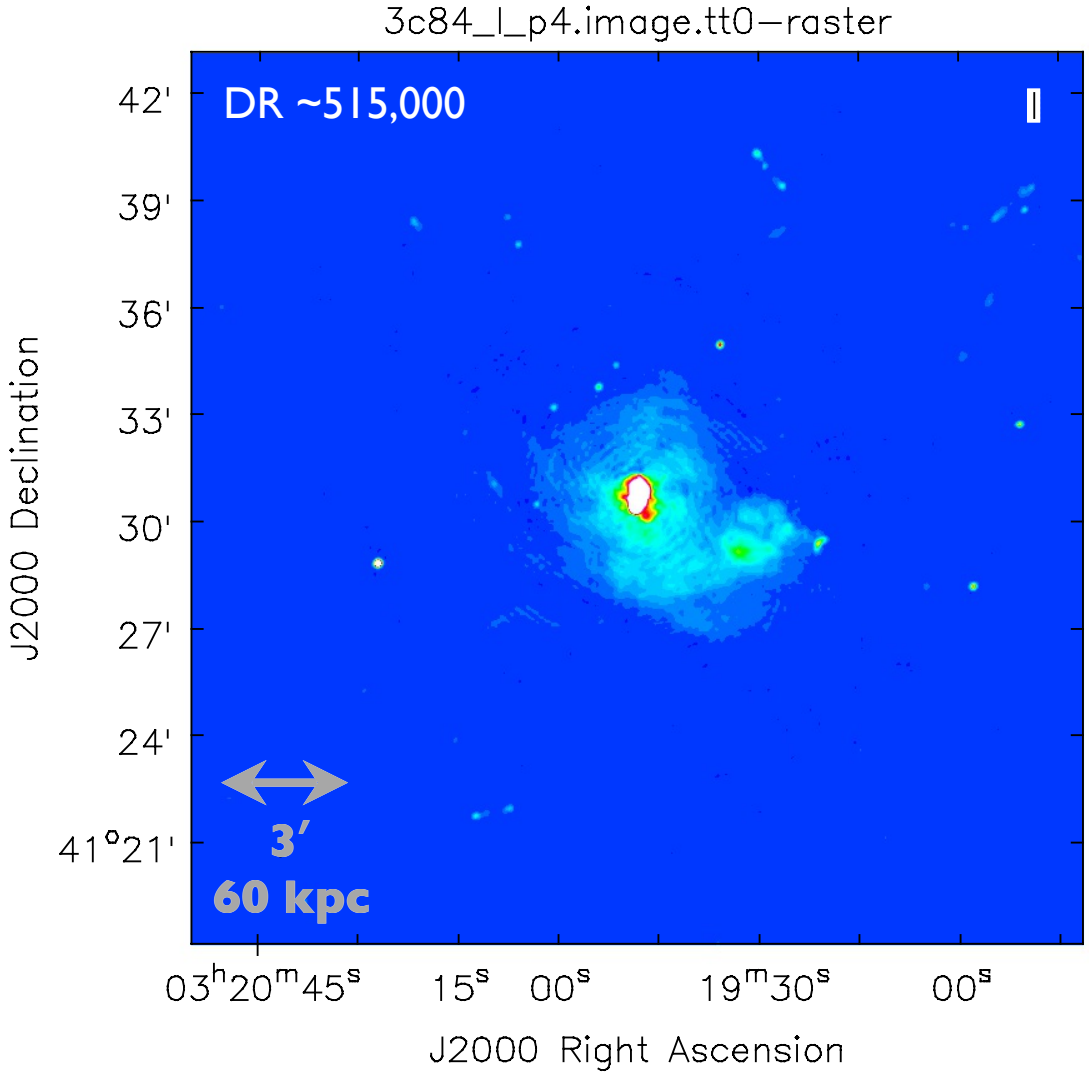

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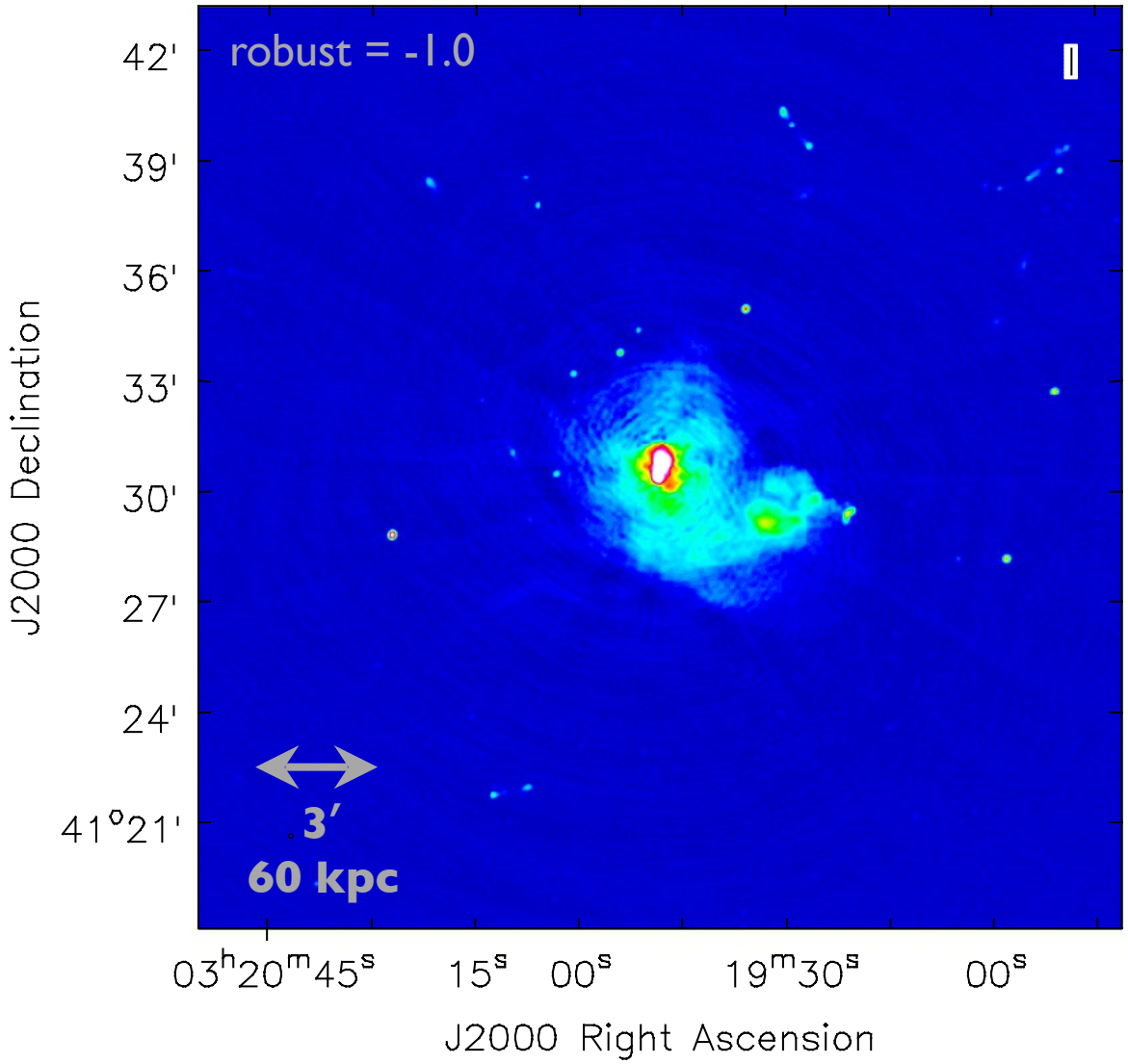
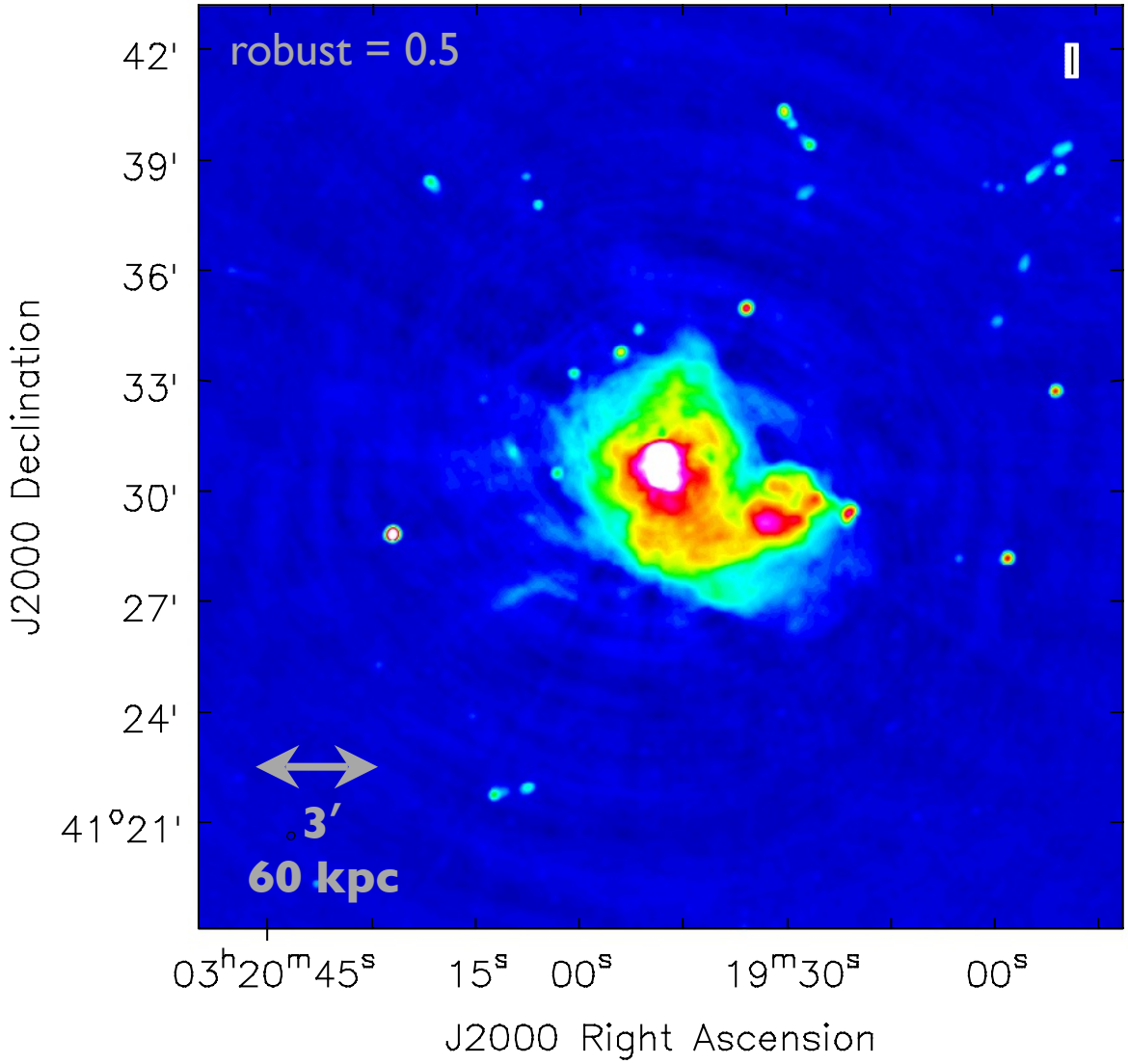


Recovery of different scales with different weighting in the imaging process

3C 84 / NGC 1275: VLA C+D-config at L-band



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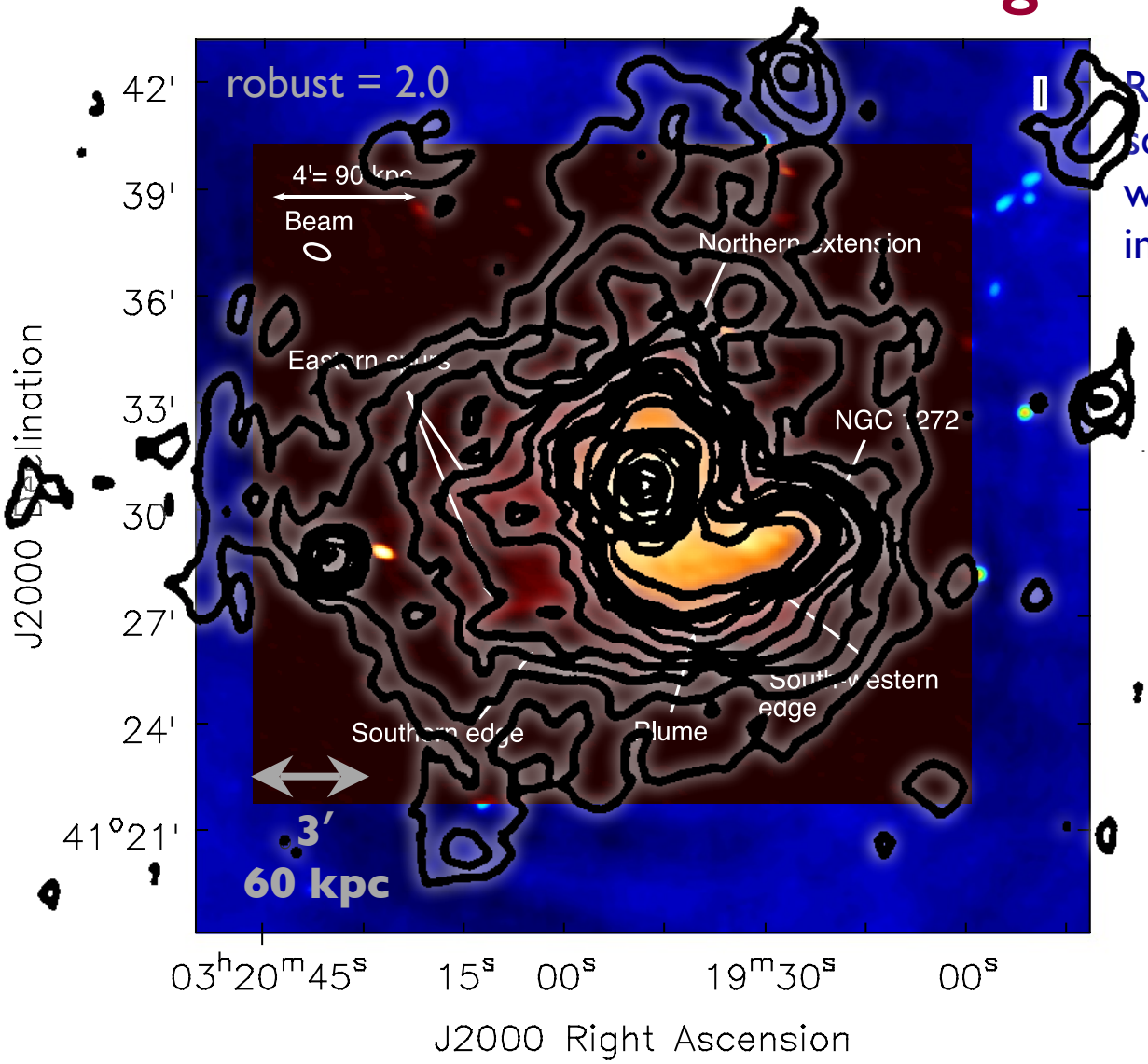
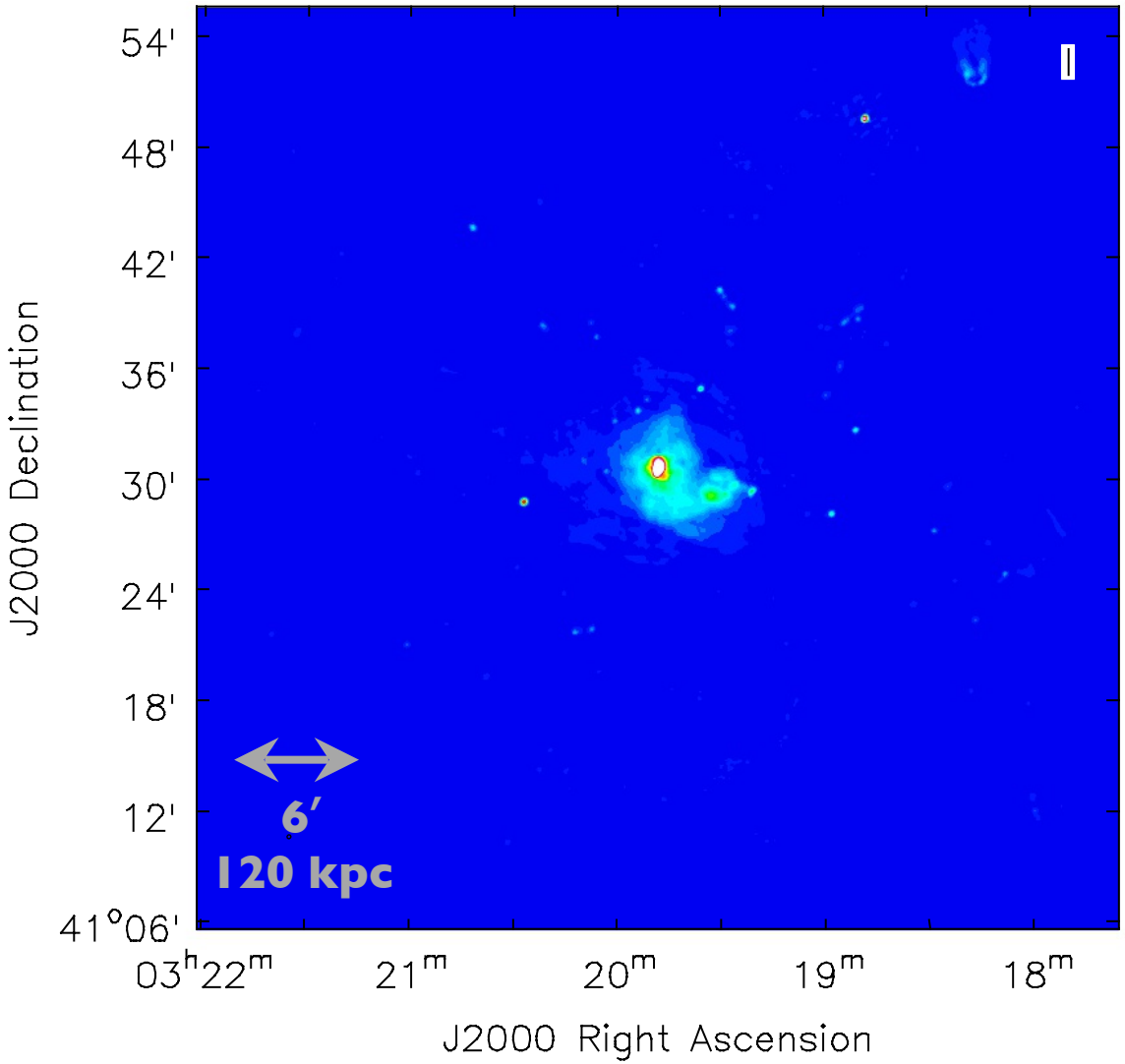
3C 84 / NGC 1275: VLA C+D-config at L-band



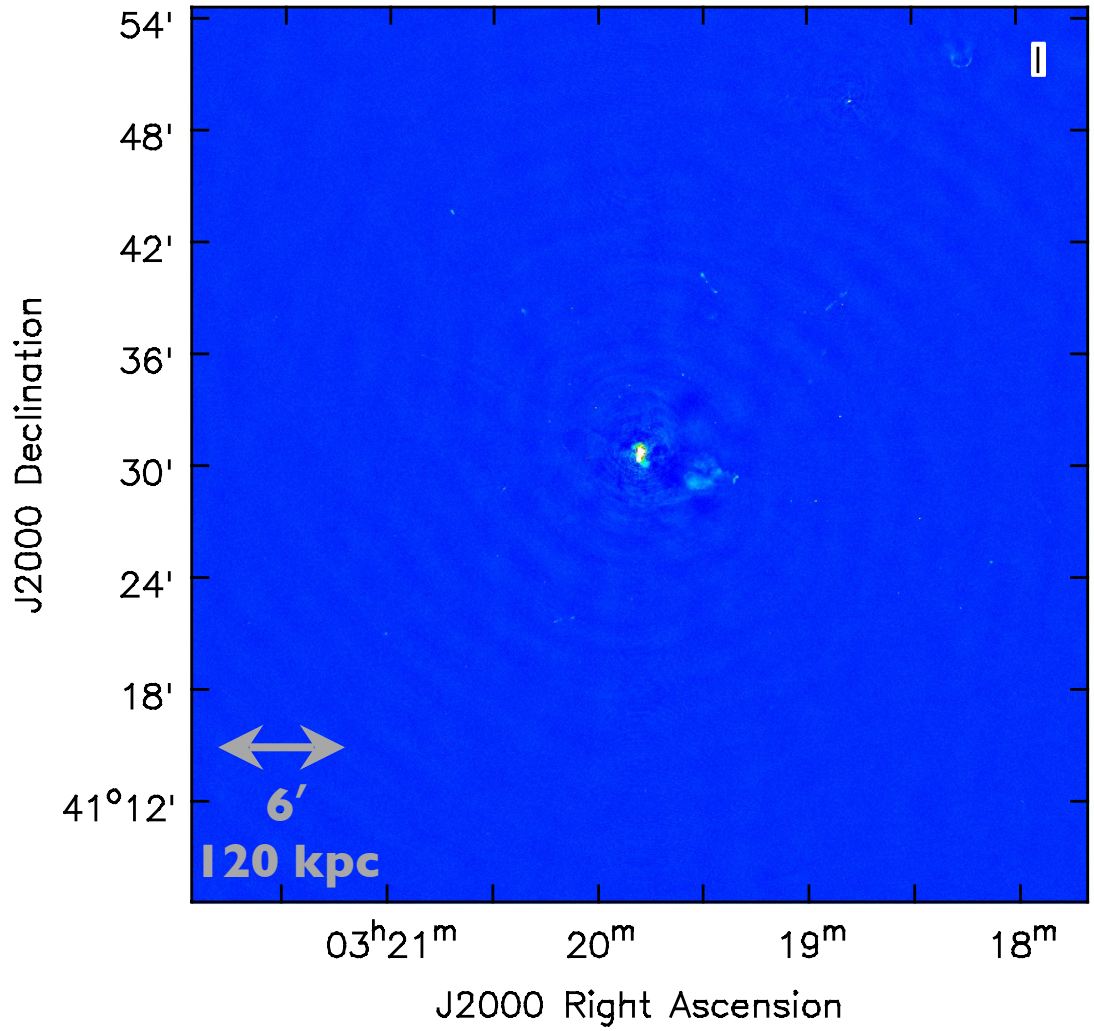
Recovery of different scales with different weighting in the imaging process

P band: colorscale (Gendron-Marsolais+2017); contours (Burns+1992)

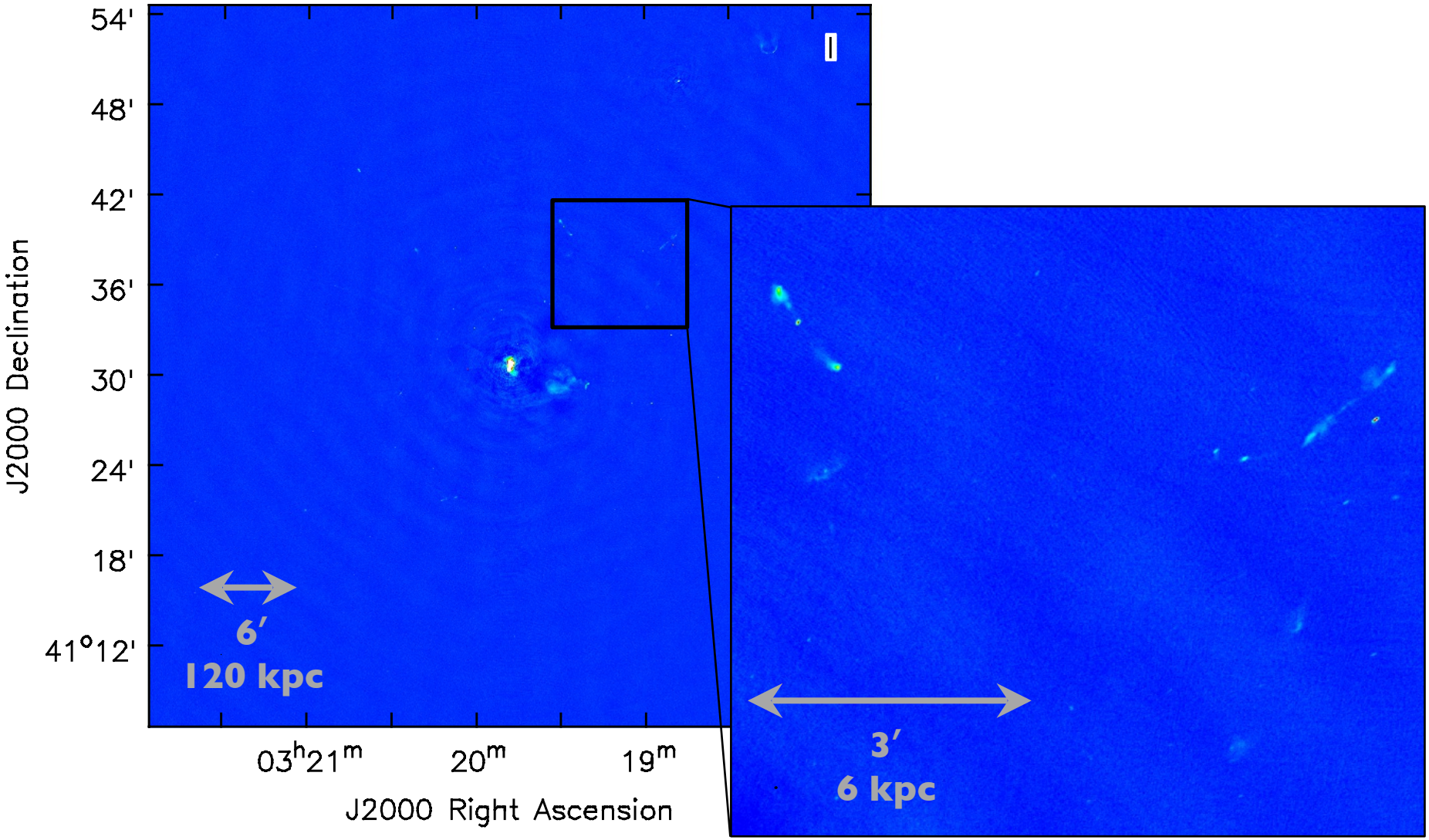
3C 84 / NGC 1275: VLA C+D-config at L-band



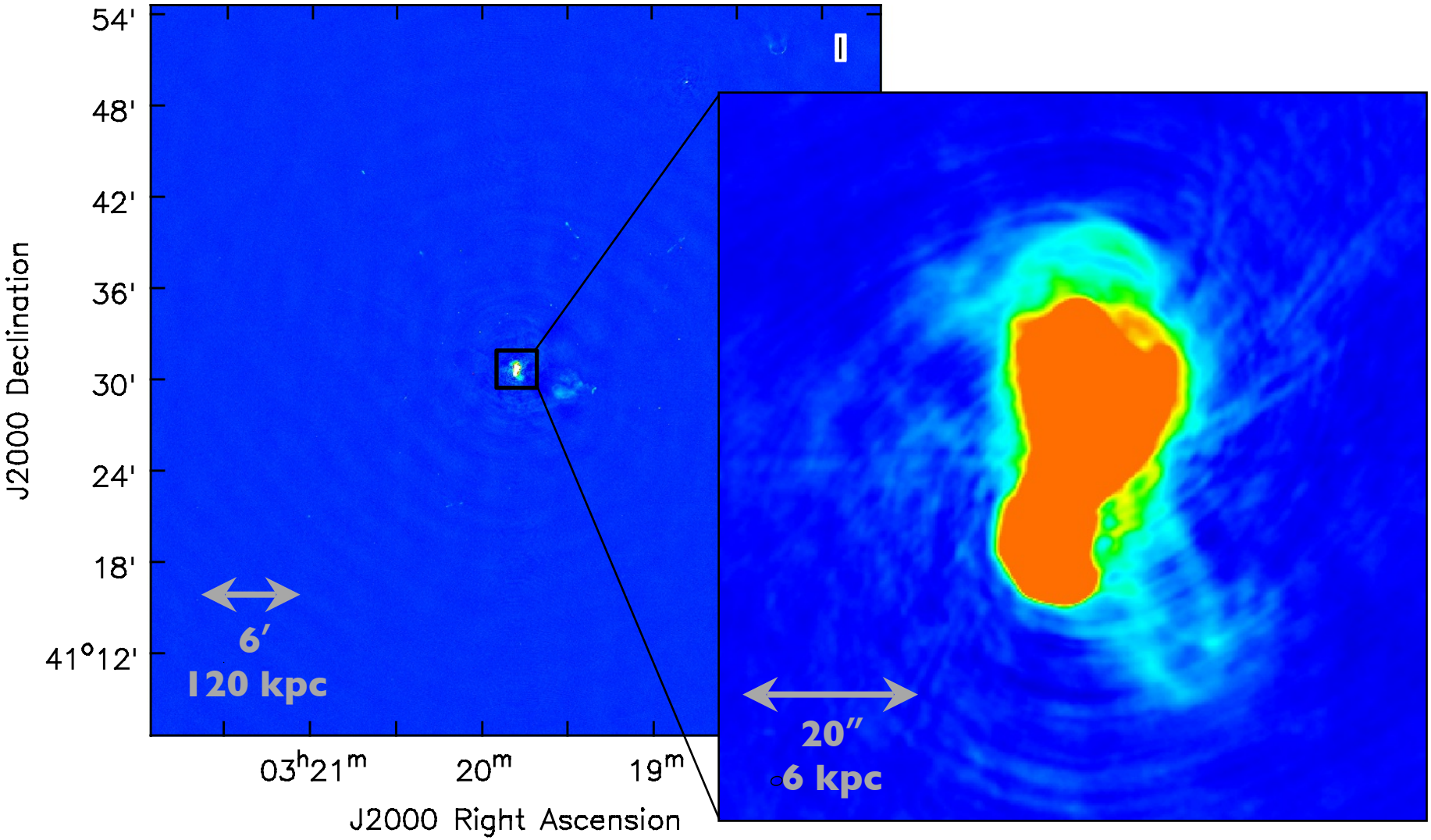
3C 84 / NGC 1275: VLA A+B-config at L-band



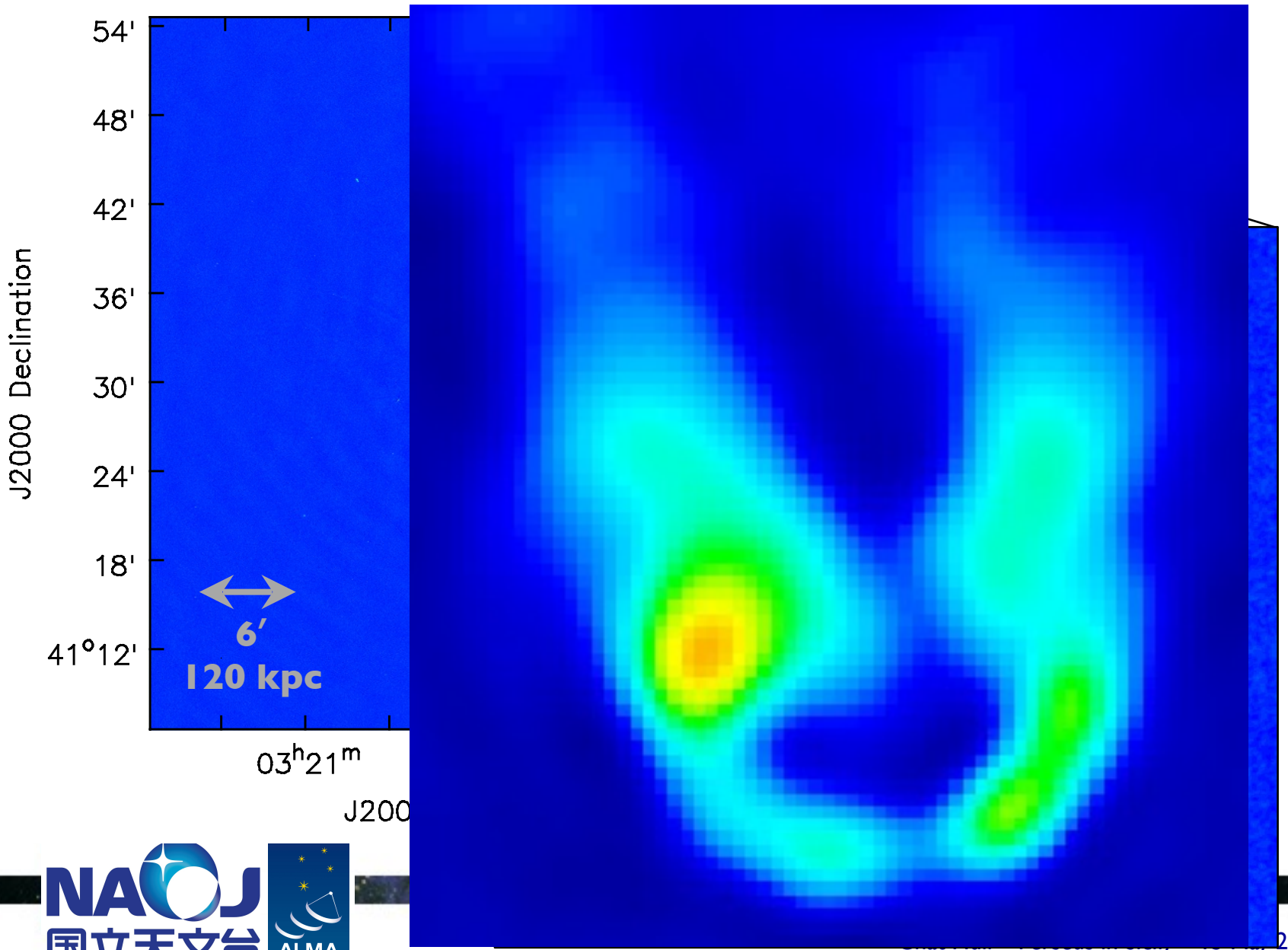
A zillion background sources



3C 84 (central quasar)

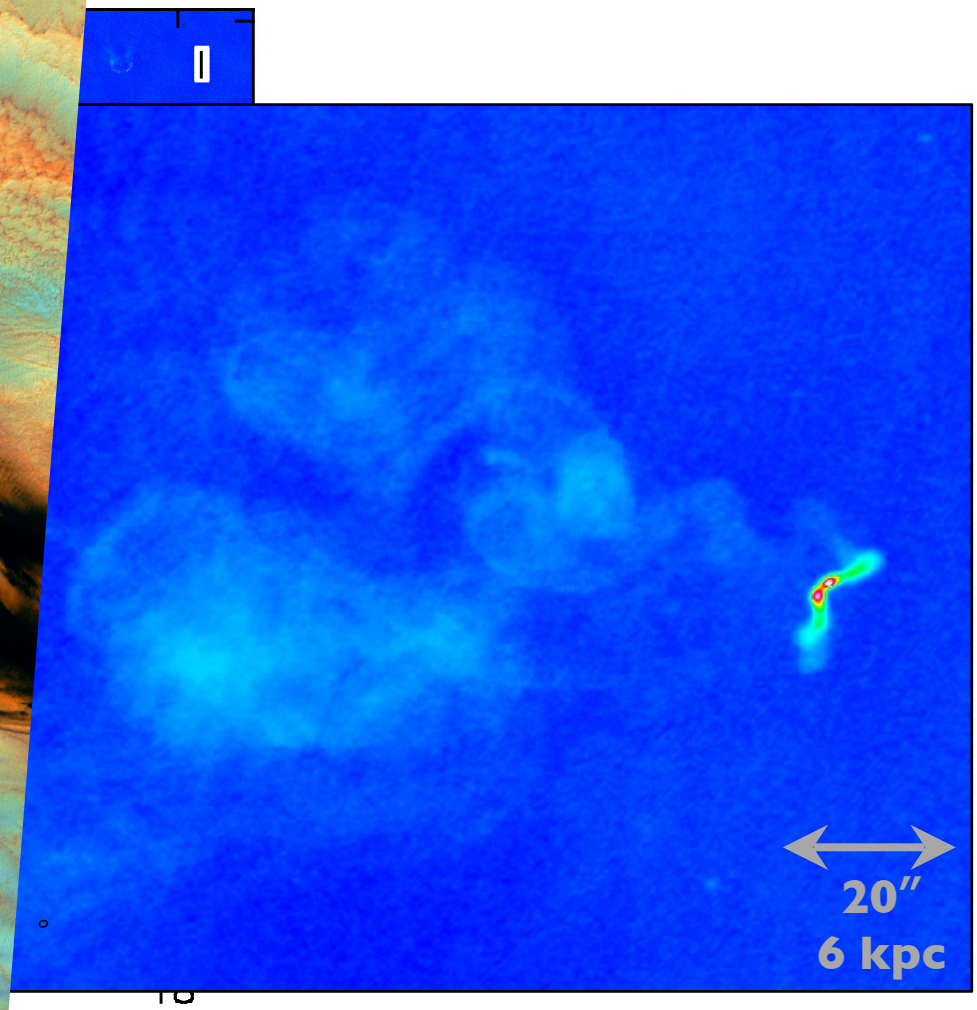


Head-tail galaxy (with bandwidth smearing)



von Kármán vortex streets over the Aleutian Islands

xy with flocculent tail)

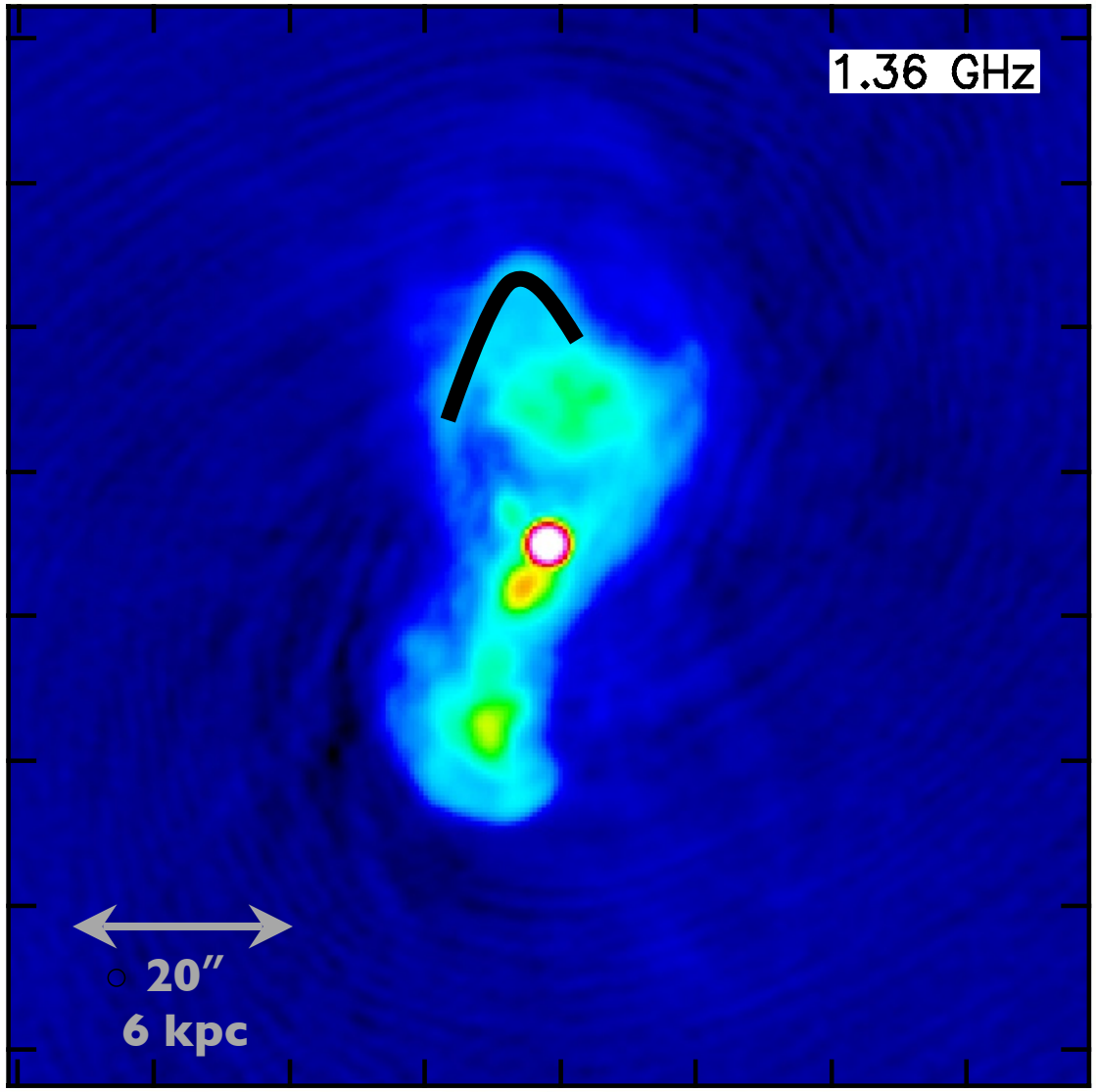


See also McBride & McCourt 2014

Vortices: https://eoimages.gsfc.nasa.gov/images/imagerecords/4000/4718/landsat_vonkarman_artII_lrg.jpg

3C 84: VLA A+B-config at L-band

- ~2,500,000 dynamic range
- rms ~6 uJy/bm at map edge



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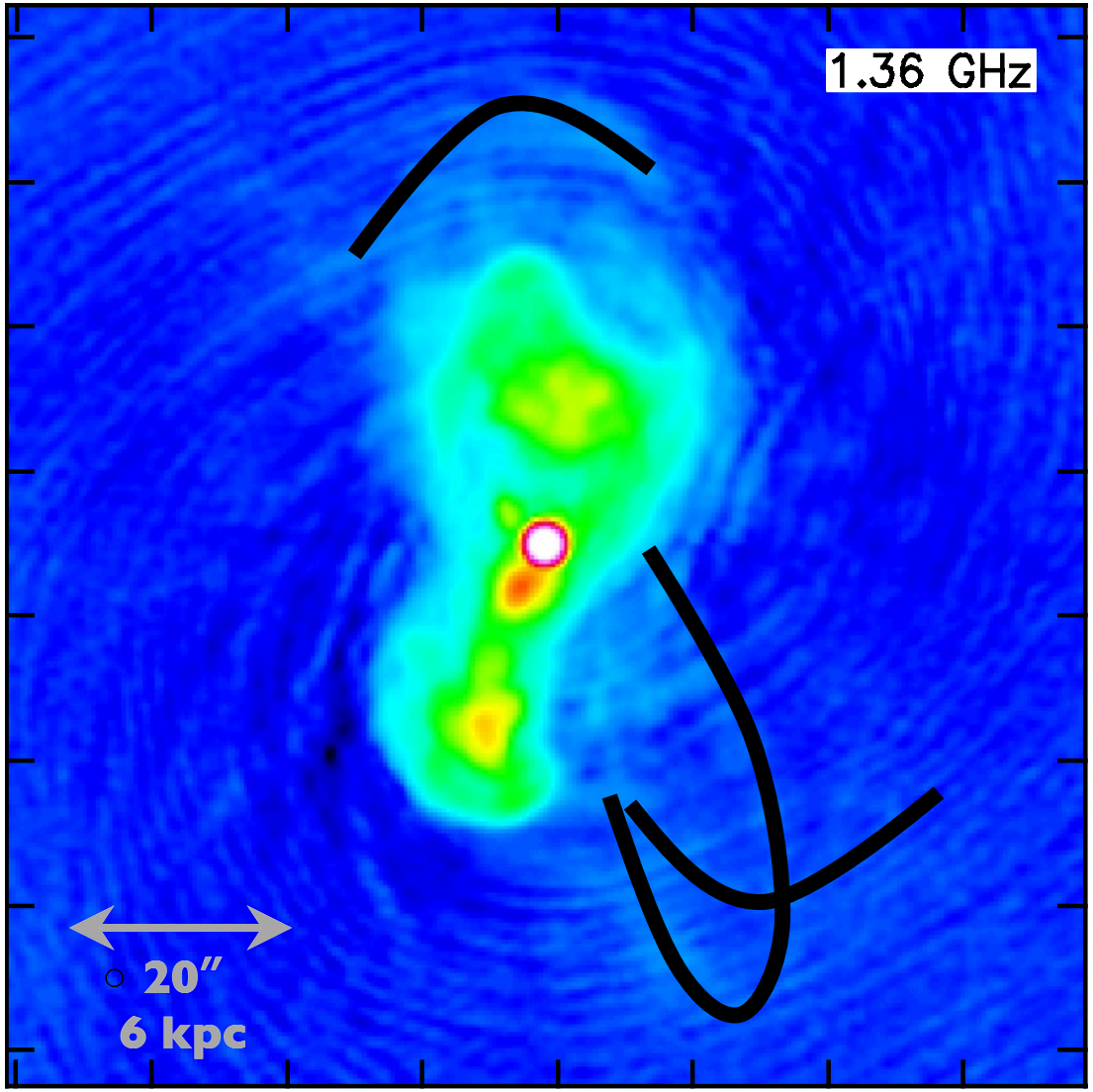
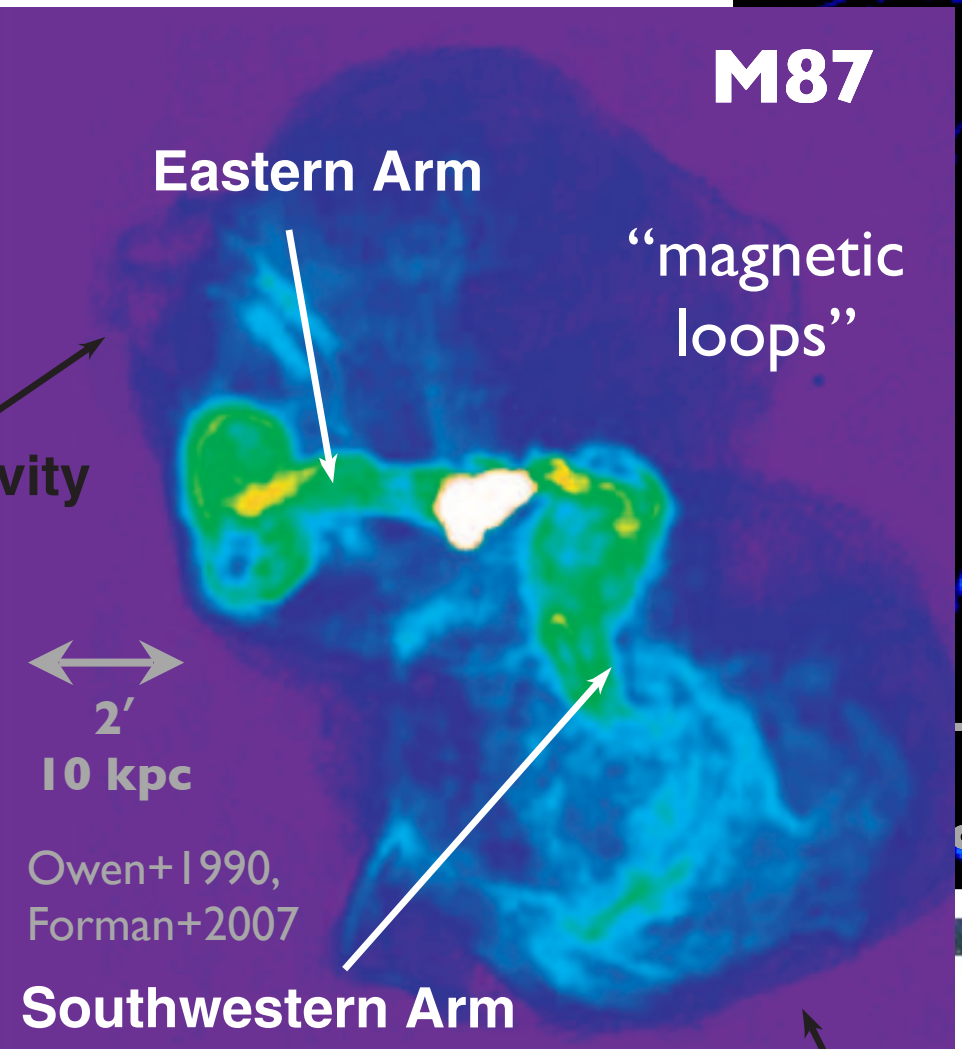
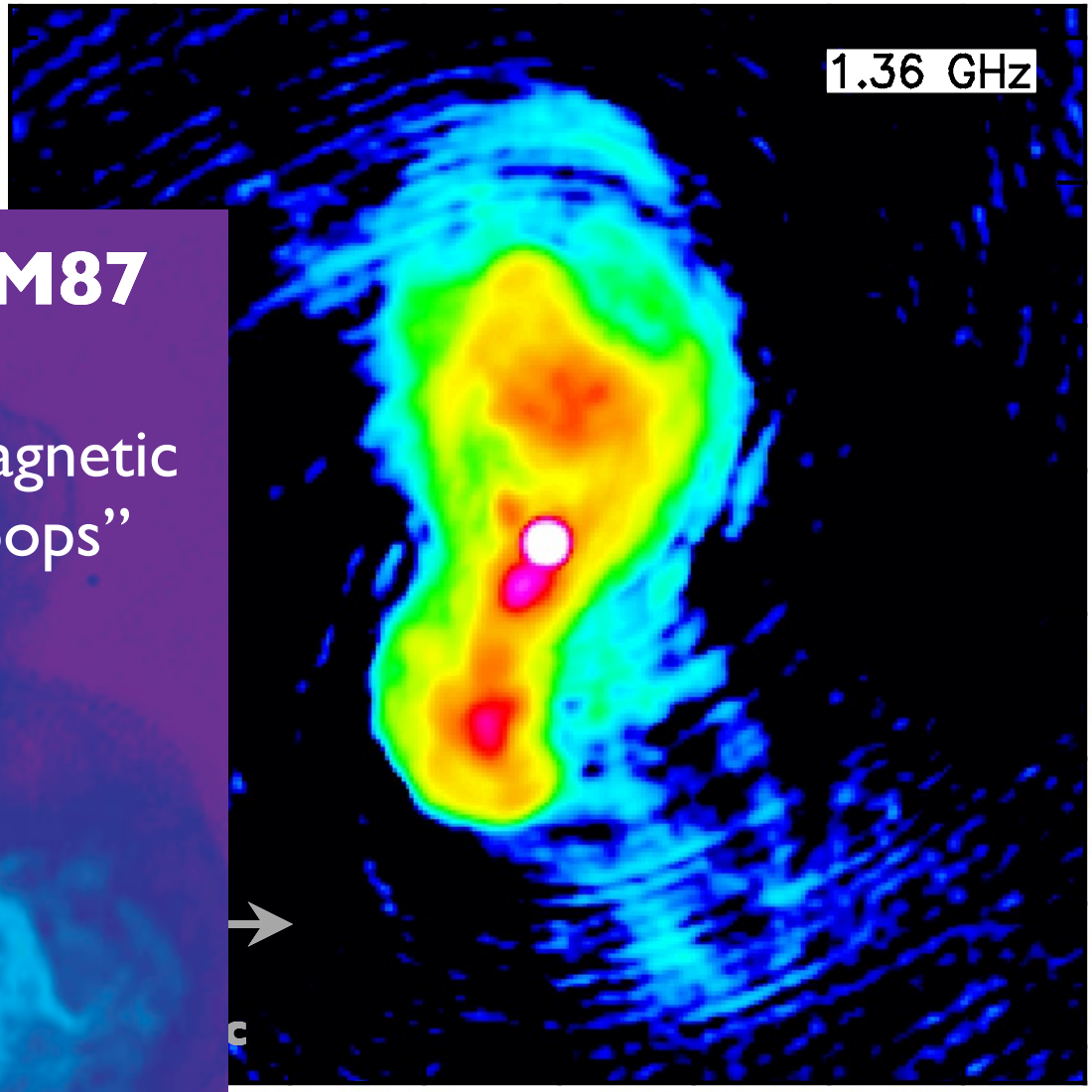


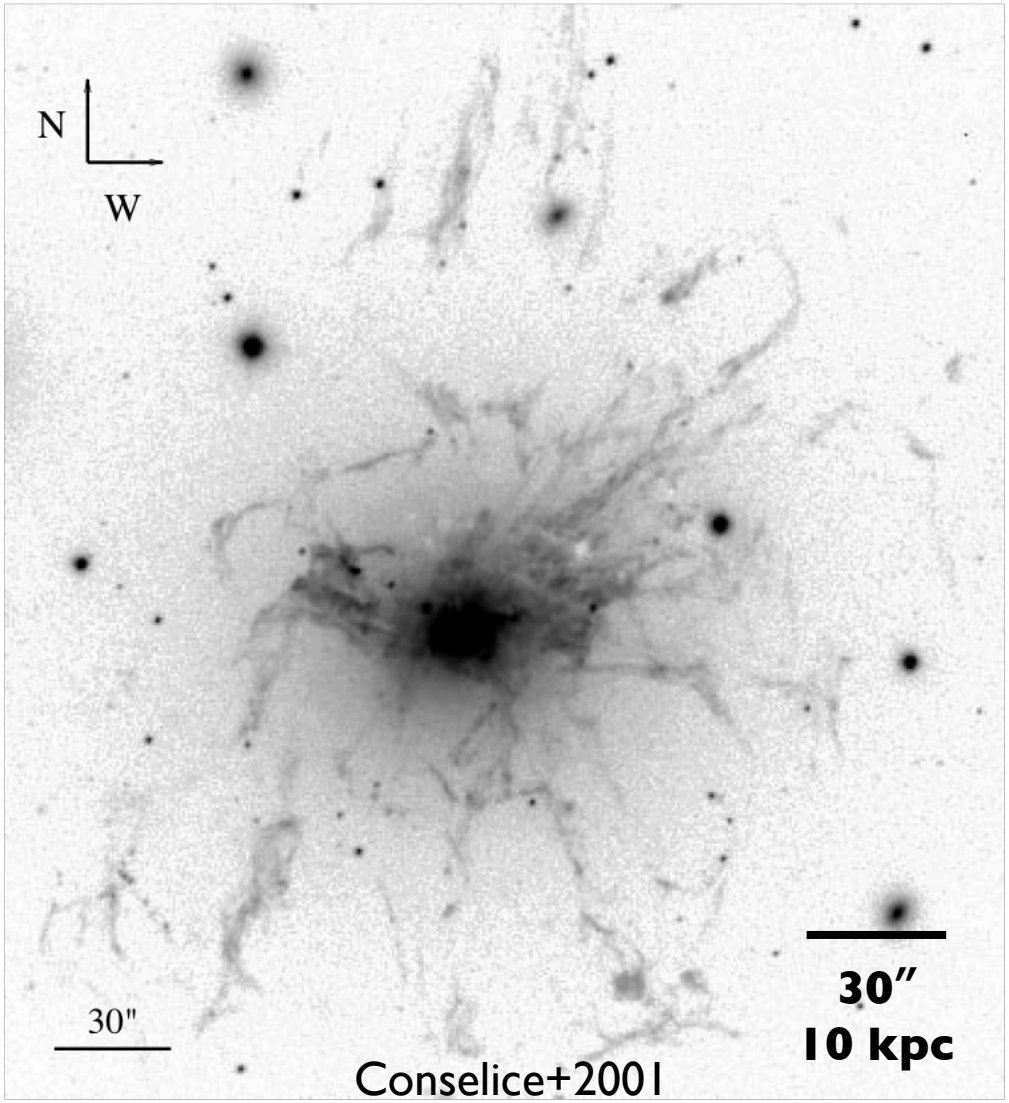
3C 84: VLA A+B-config at L-band

- Outer filaments: 200–300 uJy/bm



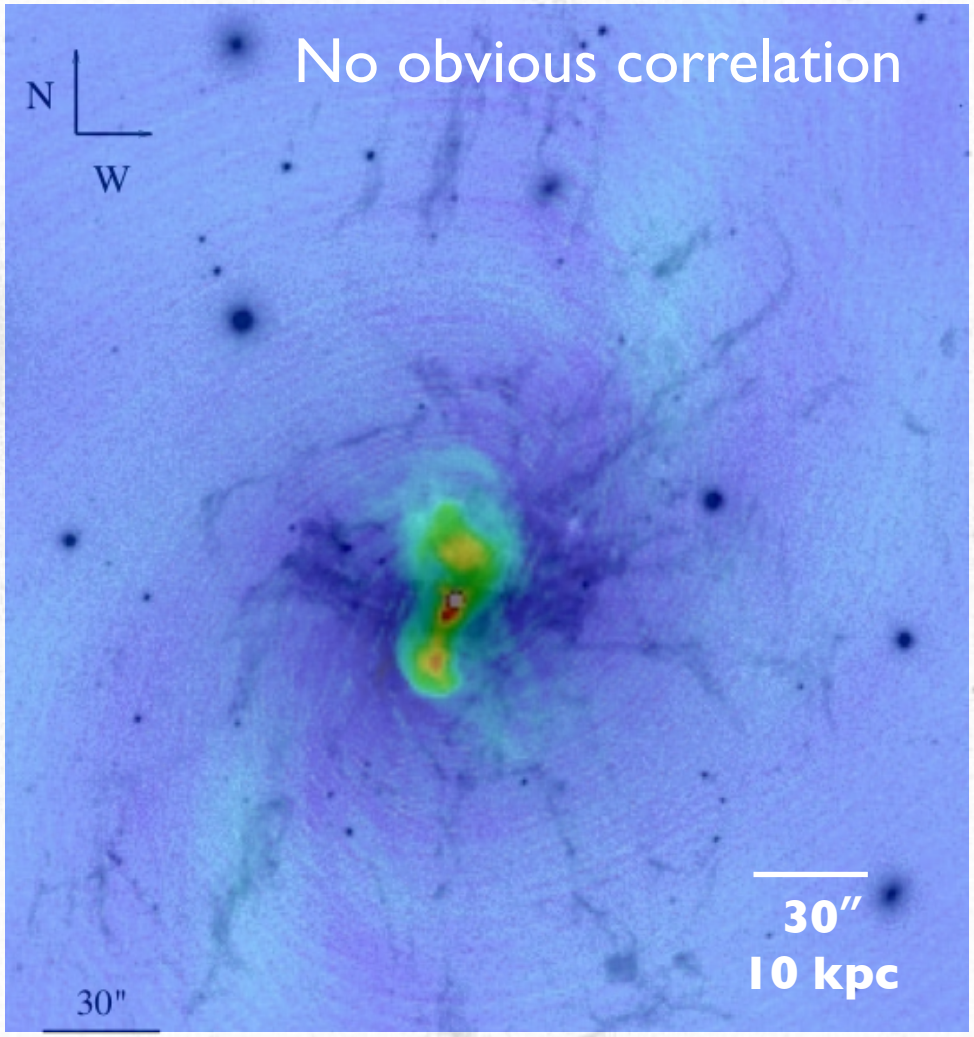


Comparison with H-alpha filaments



Conselice+2001

Comparison with H-alpha filaments



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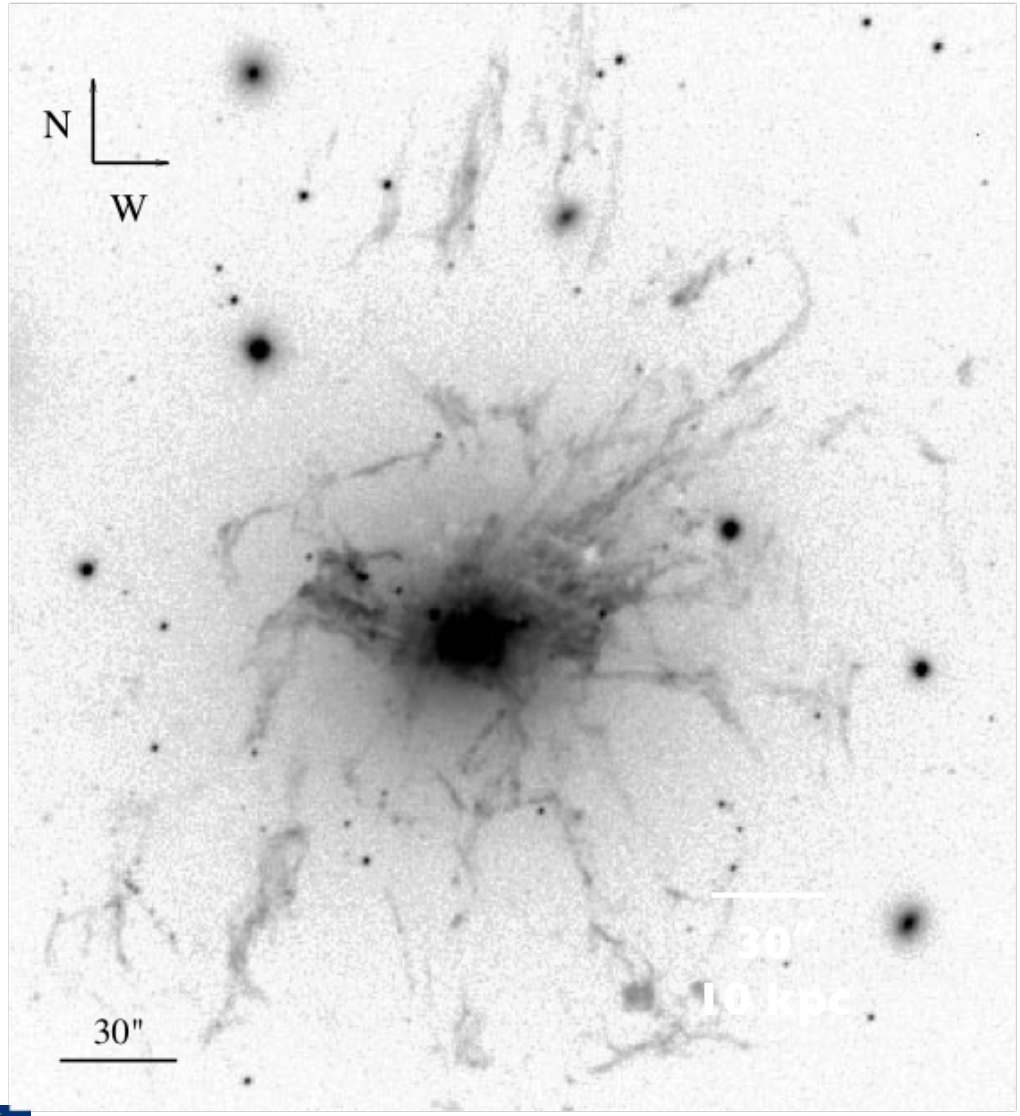

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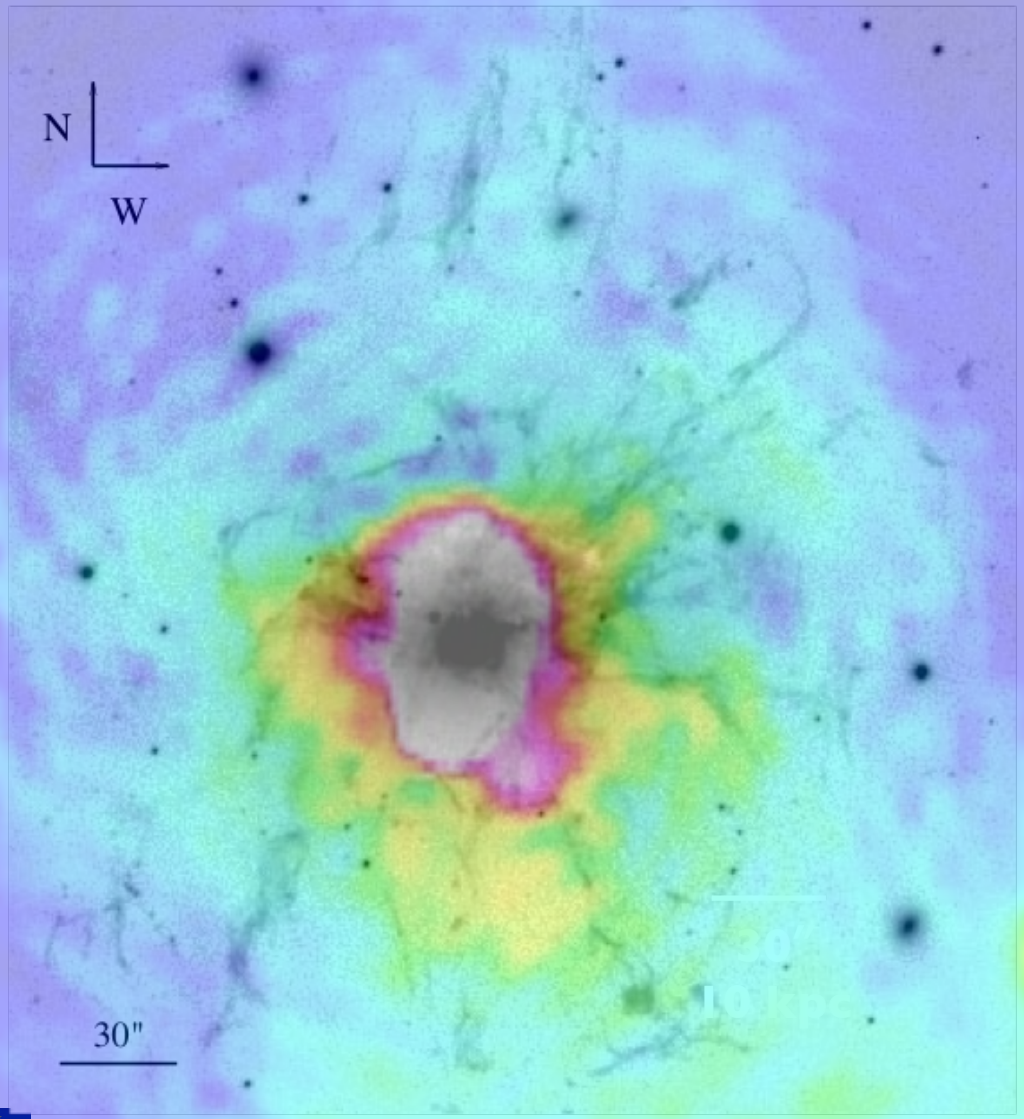

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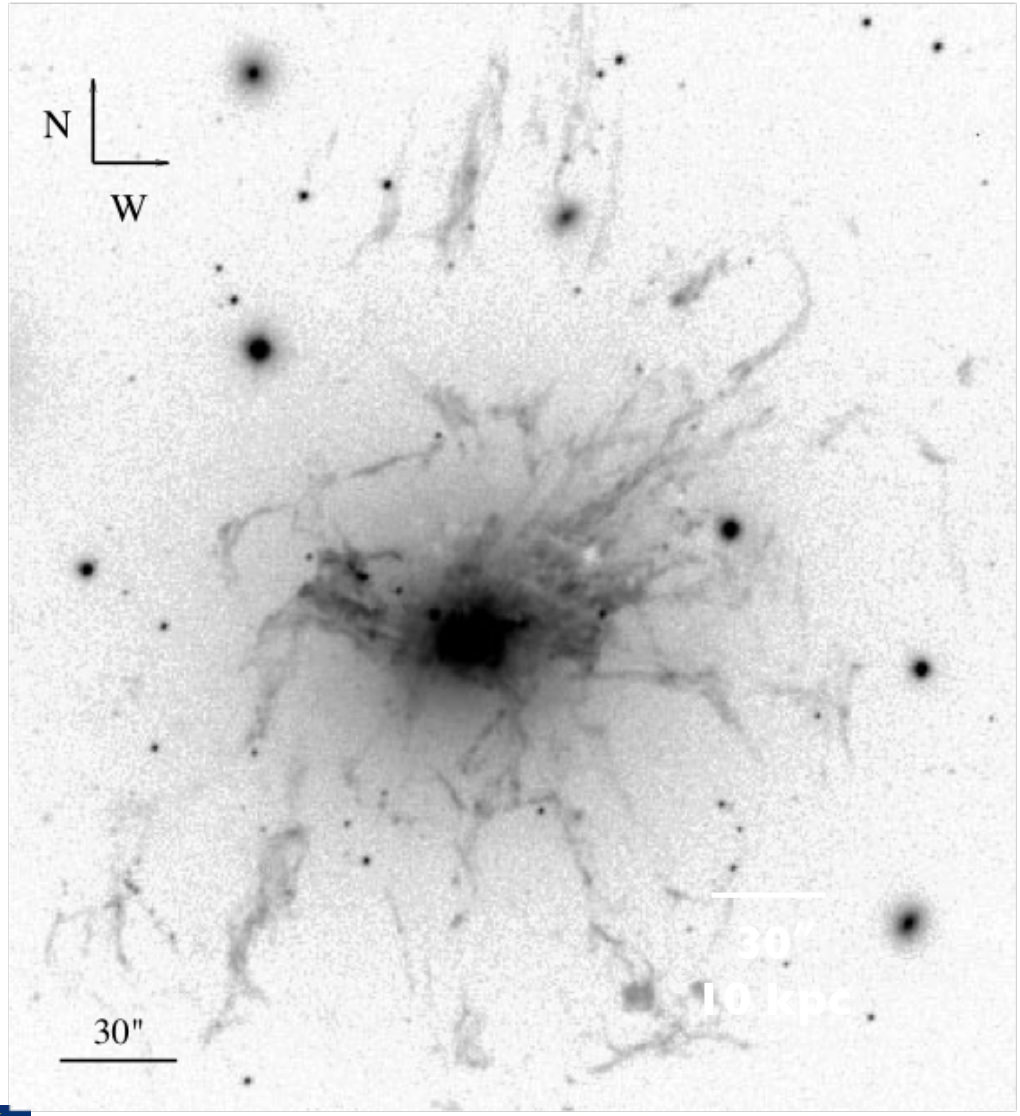

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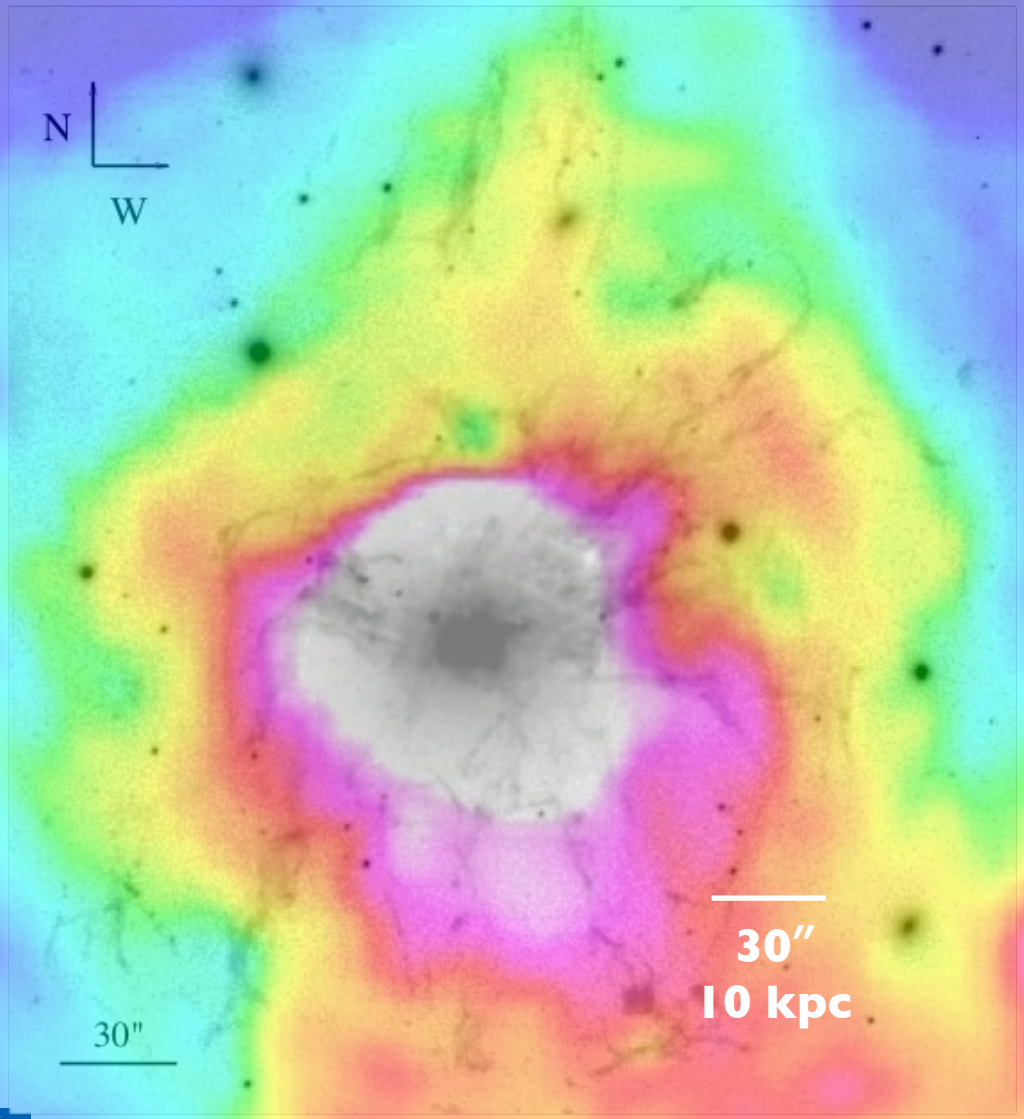
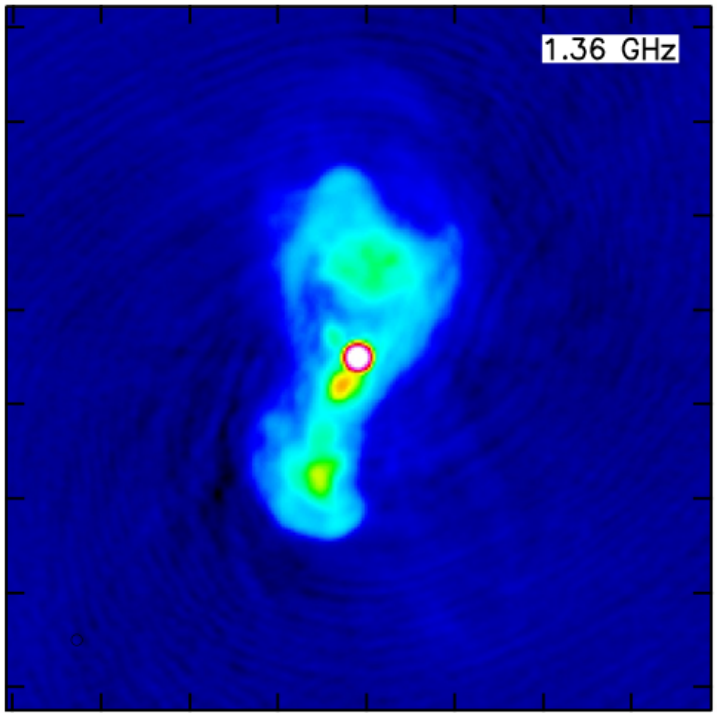


The diffuse synchrotron emission seems to trace the extent of the H-alpha filaments (also seen in P band by Gendron-Marsolais 2018)

Summary

Filaments around NGC 1275



- High dynamic range imaging of 3C84 is in progress
  - A+B image dynamic range: achieved **2,500,000 : 1**
  - Hopefully higher with A+B+C
- Filaments have been seen! But they don't coincide with H-alpha…
- We'll answer (and ask more!) questions about star, galaxy, and cluster formation

Fin