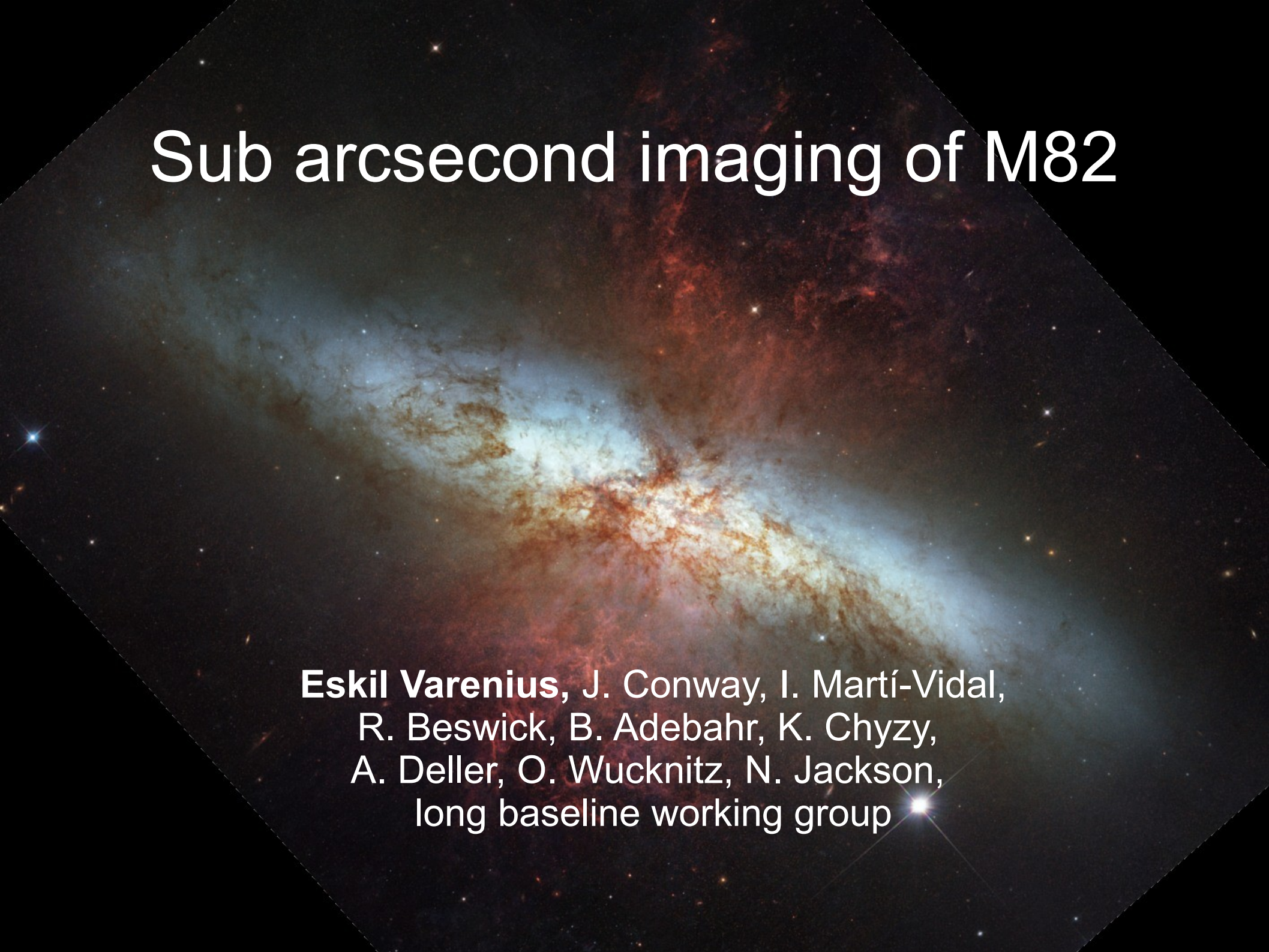


Sub arcsecond imaging of M82

Eskil Varenius, J. Conway, I. Martí-Vidal,
R. Beswick, B. Adebahr, K. Chyzy,
A. Deller, O. Wucknitz, N. Jackson,
long baseline working group

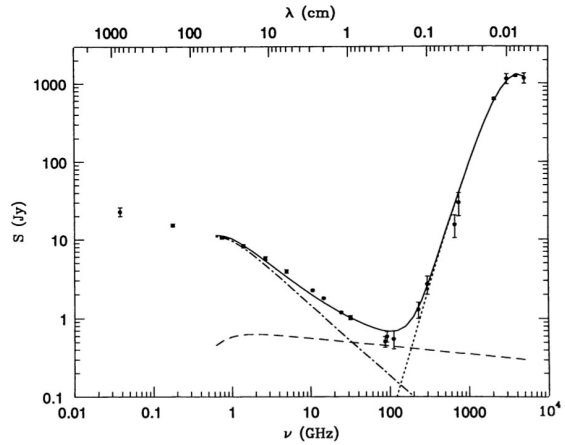
Outline

- Short background on M82
- Pretty LOFAR picture of M82
- Observations summary
- Science goals
- Calibrating the long baselines
- First results
- Outlook
- Summary

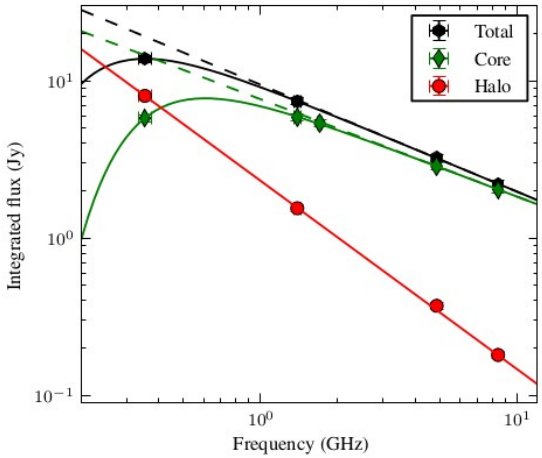
M82

- M82 is a nearby (3.6Mpc), bright and well studied (nuclear) starburst galaxy.
- Large scale outflows present, connected to central region.
- We are interested in low frequency spectra of starburst galaxies.
- International LOFAR baselines= high-resolution images!

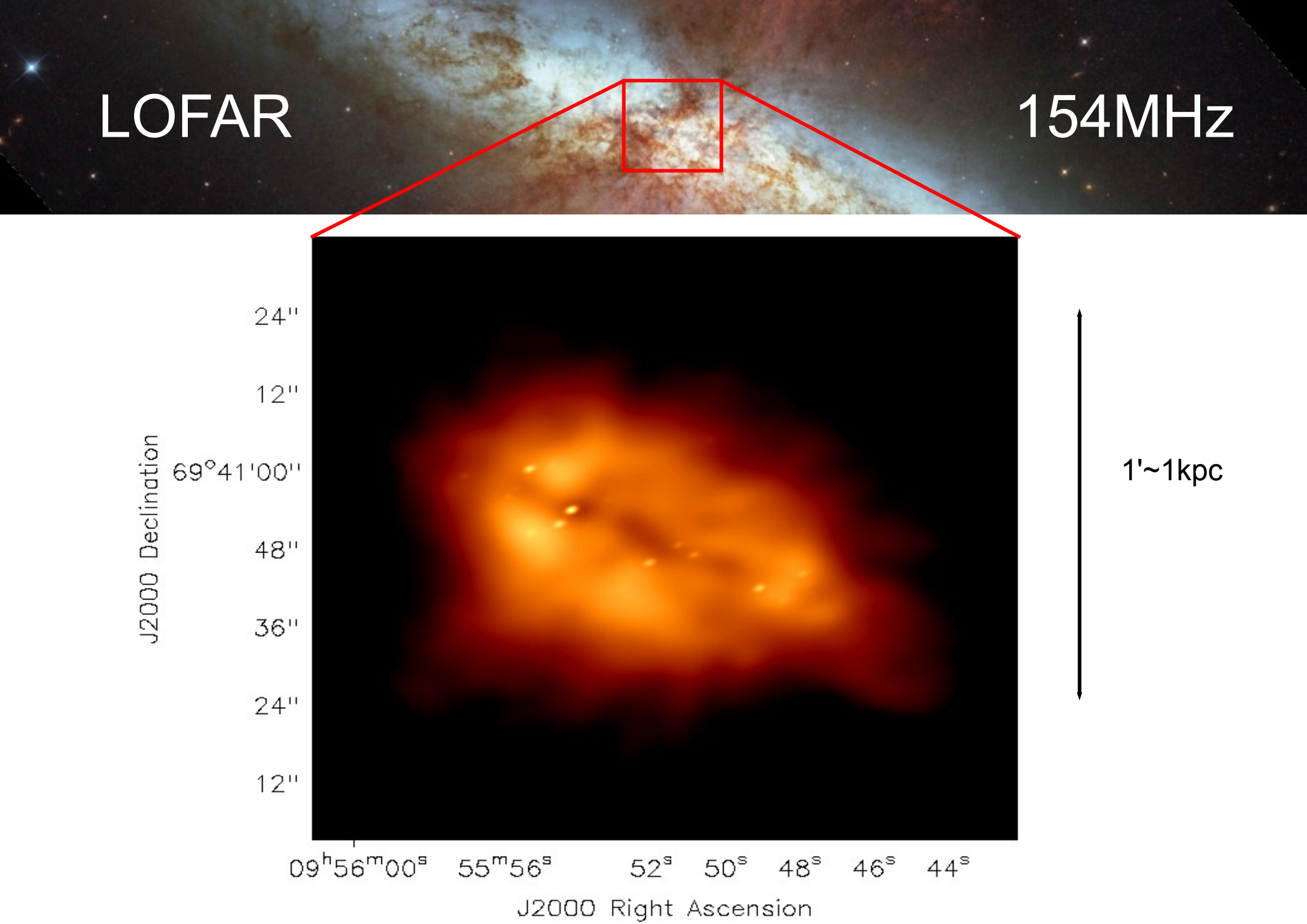
Top image credit: NASA, ESA and the Hubble Heritage Team STScI/ AURA). Acknowledgment: J. Gallagher (University of Wisconsin), M. Mountain (STScI) and P. Puxley (NSF).



Integrated spectrum of M82 (Condon 1992).



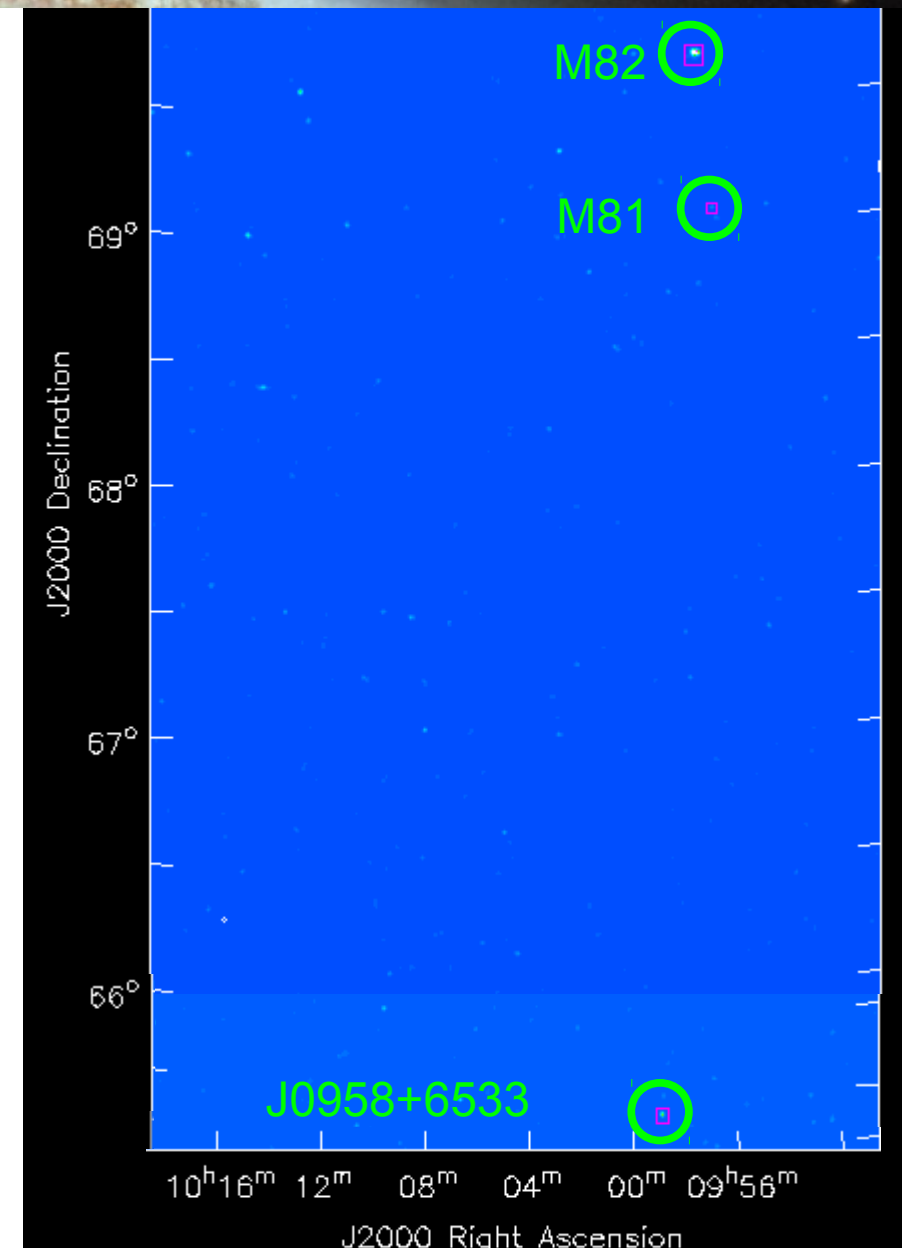
Resolved low frequency spectrum (Adebahr et. al 2013).



Combined image (*feather* in CASA) of two images.

Observations

- Project LC0_026, HBA
- 10 hours 2013-03-26
- 6 hours 2013-04-05
- 16 MHz bandwidth at 154 MHz
- Three simul. beams:
  - M82
  - M81 (0.6º)
  - J0958+6533 (4.1º)
- 2 min/hour on 3C196 (22º)



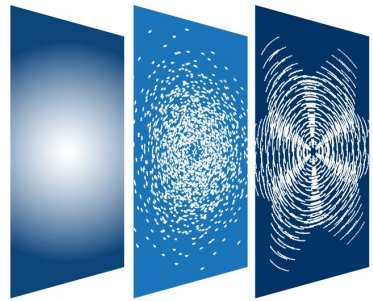
NVSS 1.4GHz

Science goals

- Test models of free-free and ionisation losses for core of M82.
- Study spectra of known compact objects in M82 (>40).
- Check special objects:
  - In M82: SN2008iz and transient source 43.78+59.3.
  - In M81: M81* and the SN1993J.
- Look for exotic steep spectrum sources.
- **NOTE:** We focus on the core and compact sources. We also collaborate with B. Adebahr et. al to image the more extended halo.

Calibrating the long baselines

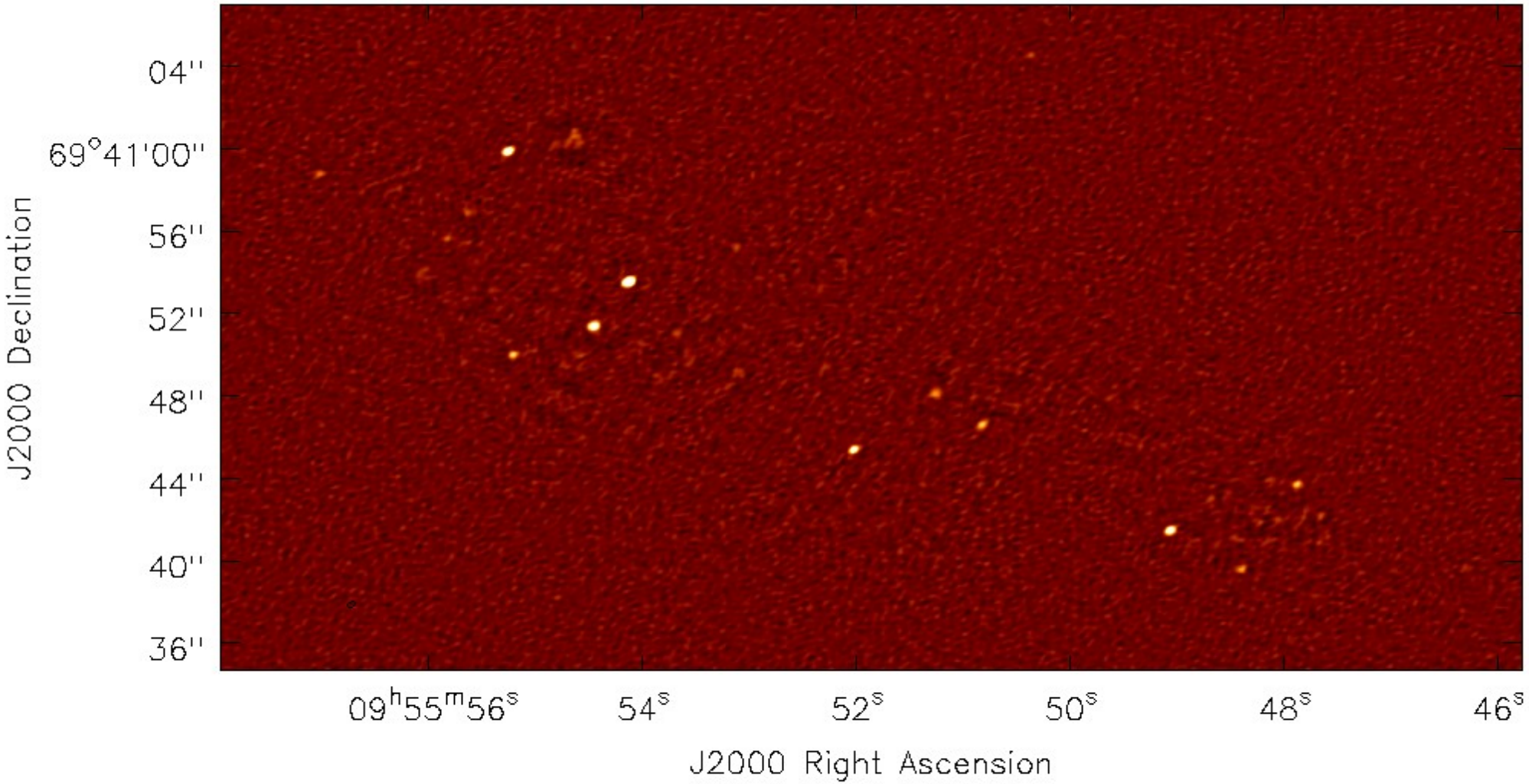
- Standard LOFAR software does not currently allow for correction of residual delays and rates. So, we use AIPS.
- AIPS cannot deal with large FoV, but we image only 2'.
- Data were averaged to 10s, 1ch/SB using NDPPP.
- Then converted to circular polarisation using *mscorpol* (T. Carrozzi), and to UVFITS (*importuvfits* in CASA).
- Delay and rate corrections derived using J0958+6533, and phase corrections using M81* and M82 itself.
- Absolute flux scale anchored to 3C196.
- Imaging with Multi-Scale Multi-Frequency Synthesis CLEAN in CASA 3.4.



CASA

Common Astronomy Software Applications

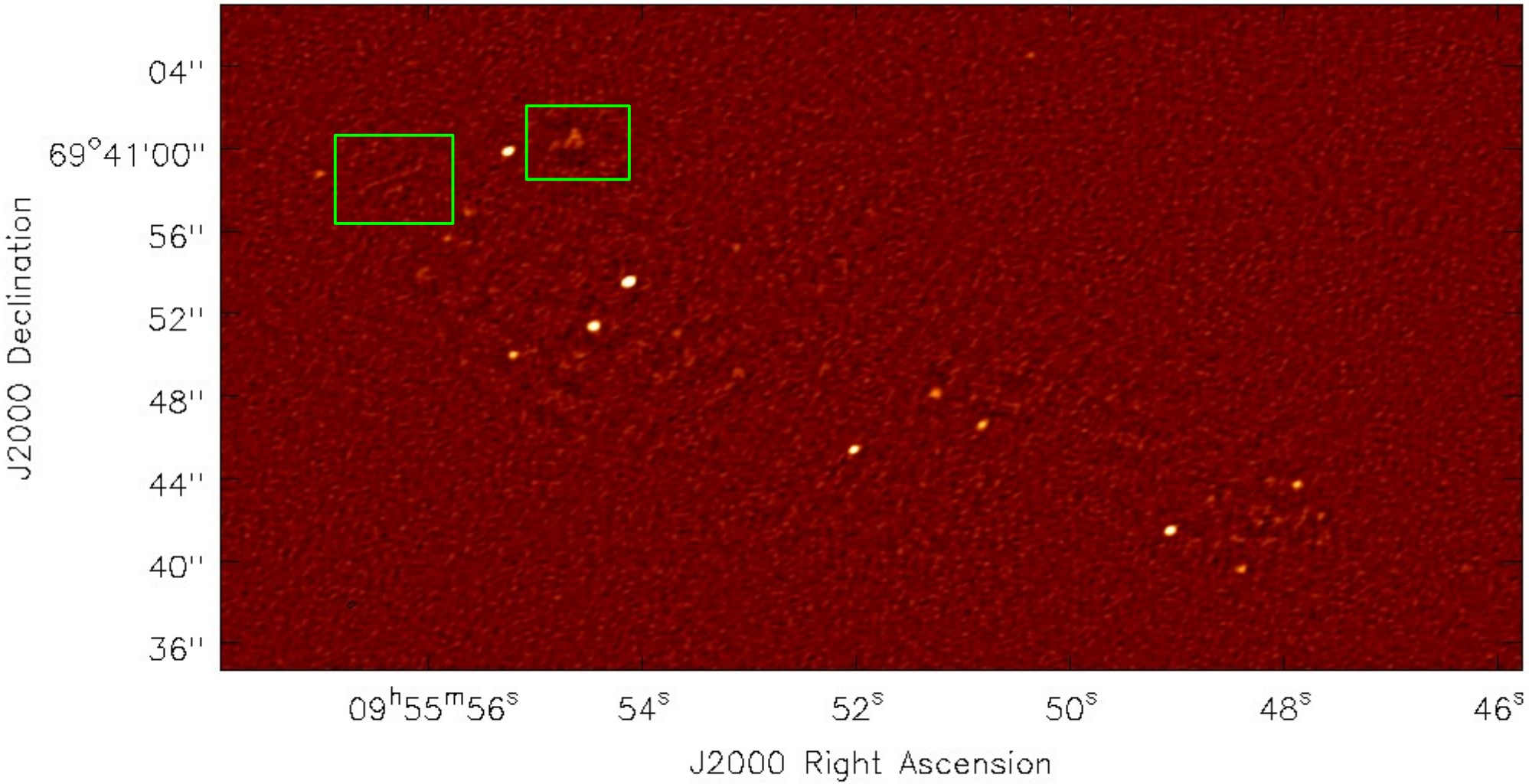
International LOFAR image



(Varenius et al. 2014, in preparation)

Using baselines longer than 75kλ.
Resolution 0.39"x0.24". RMS noise σ=0.17 mJy/beam.
We detect ~77mJy in 22 compact sources > 5σ.

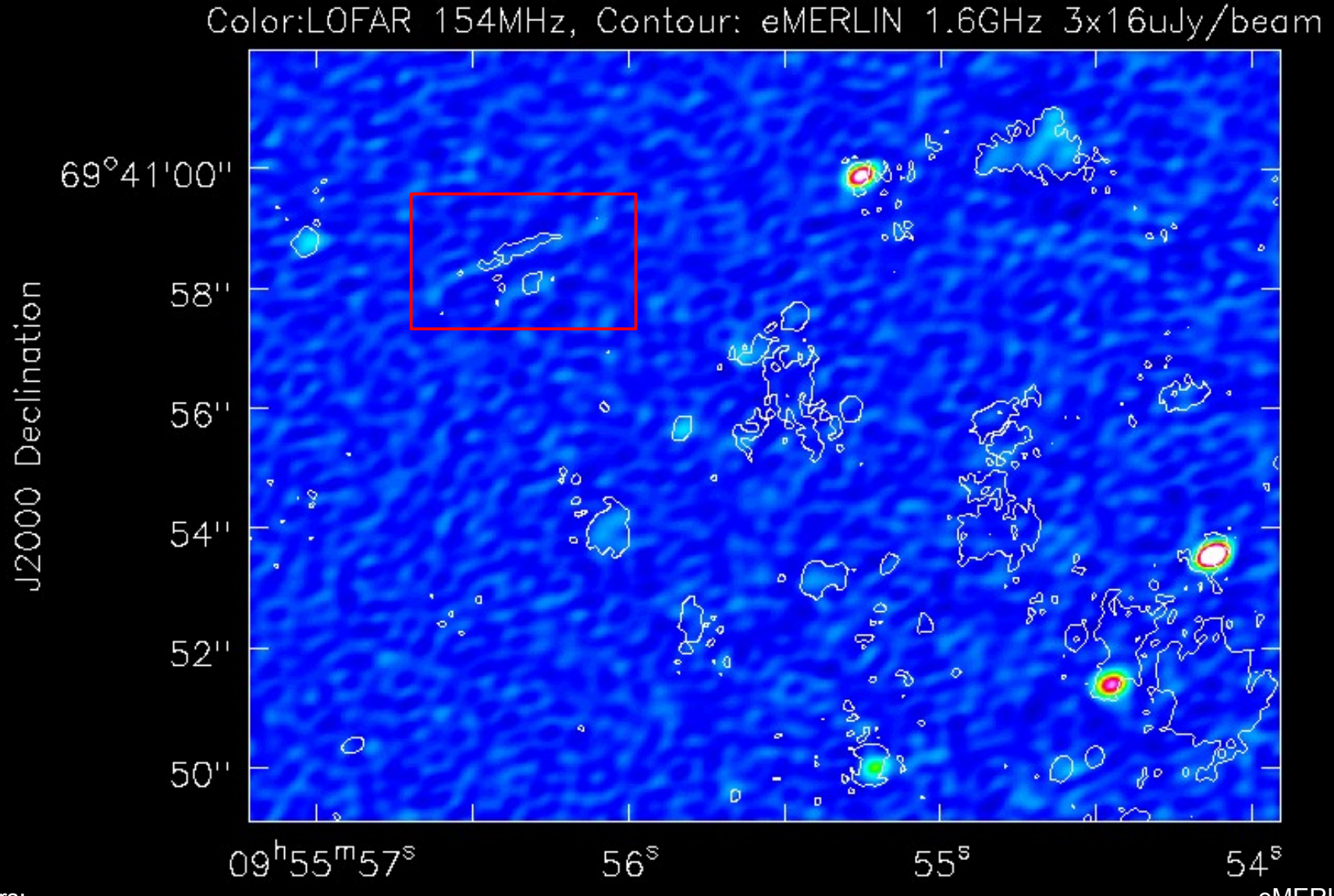
International LOFAR image



(Varenius et al. 2014, in preparation)

Using baselines longer than 75kλ.
Resolution 0.39"x0.24". RMS noise σ=0.17 mJy/beam.
We detect ~77mJy in 22 compact sources > 5σ.

Compare with eMERLIN at 1.6 GHz



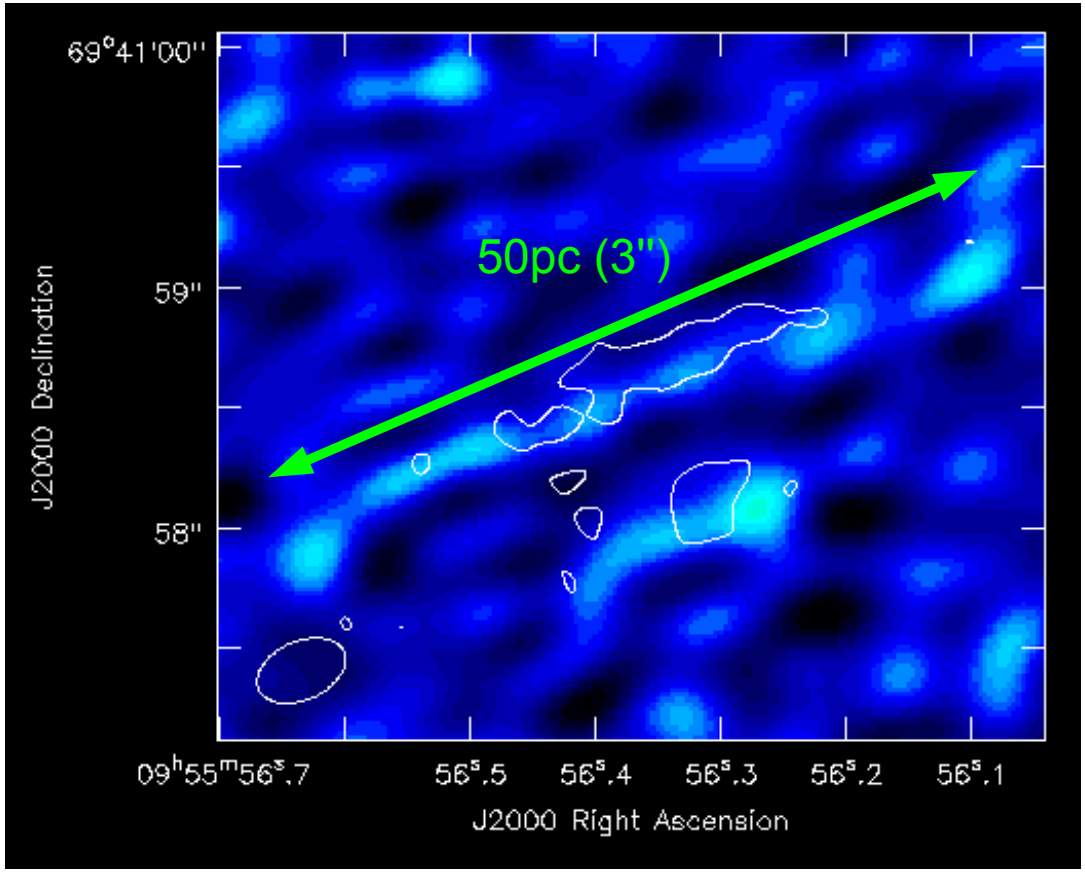
LOFAR colors:
Varenius et al. 2014, in preparation.

eMERLIN contour:
R. Beswick et al, in preparation.

A peculiar linear source

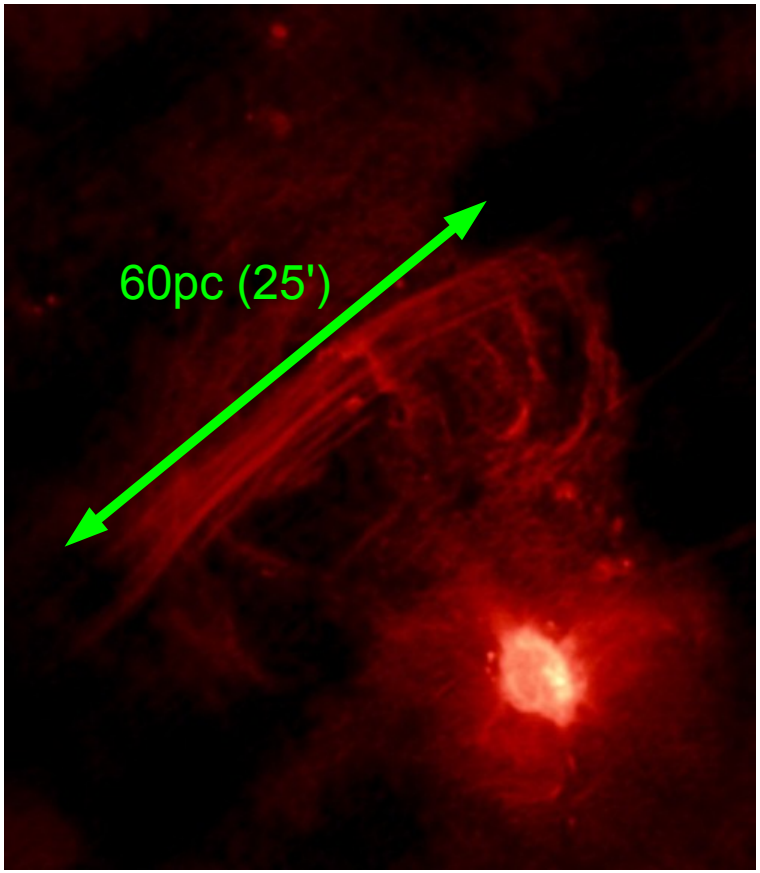
Above 2σ along 3". Flux density 0.3mJy at 154MHz, 1.8mJy at 1.6GHz (α=0.8).
R. Beswick suggested magnetically constrained shocks, as in seen with VLA in SGR A*.

M82



LOFAR colors: Varenius et al. 2014, in preparation.
eMERLIN 3σ contours: R. Beswick et al, in preparation.

SGR A*

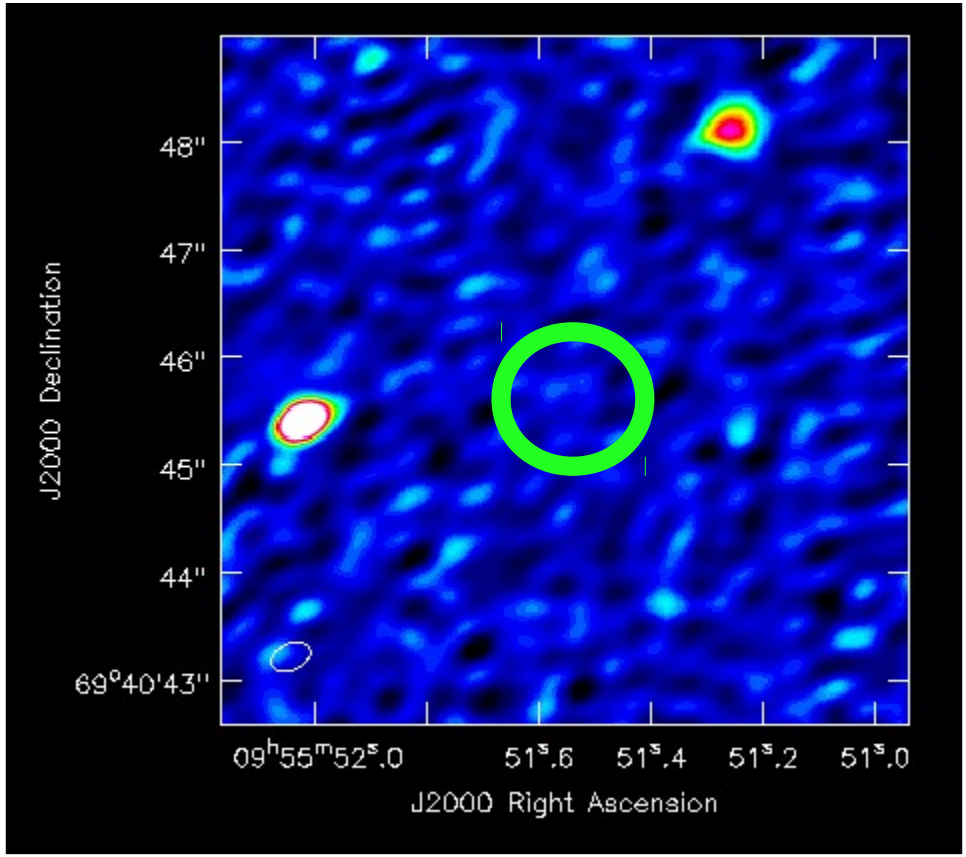


VLA (Yusuf-Zadeh et al. 1984 and later papers)

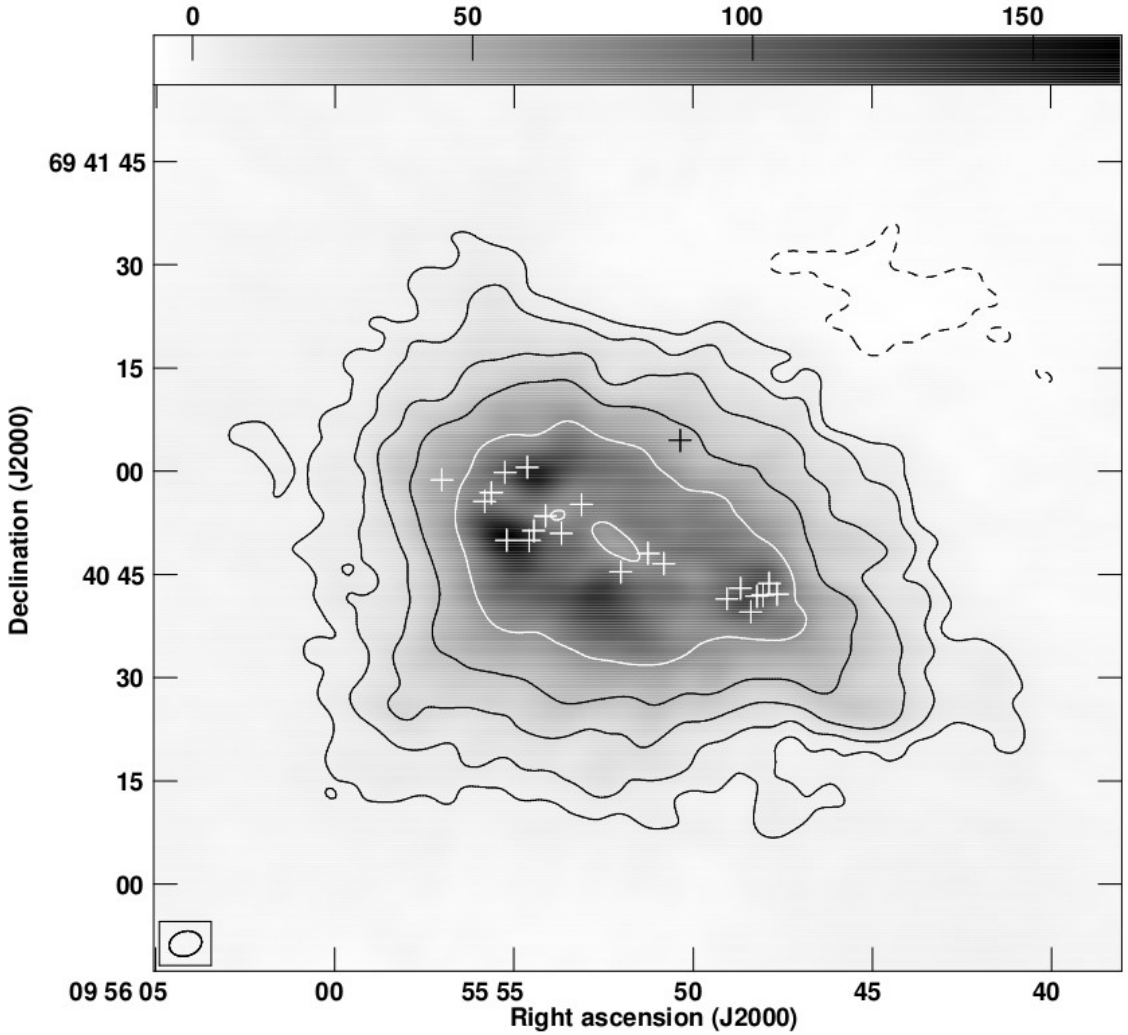
Where is supernova SN2008iz?

- SN2008iz in M82 was modelled to be ~140mJy at 154MHz (Jan 2013, I. Martí-Vidal).
- Undetected (weaker than 2σ).

- Why?
  Pehaps free-free absorbed:
  - Far-away side of M82?
  - Clumpy strong absorption at this line of sight?



Remote baseline image



Resolution
4.79"×3.57"

RMS noise
σ=0.44mJy/beam

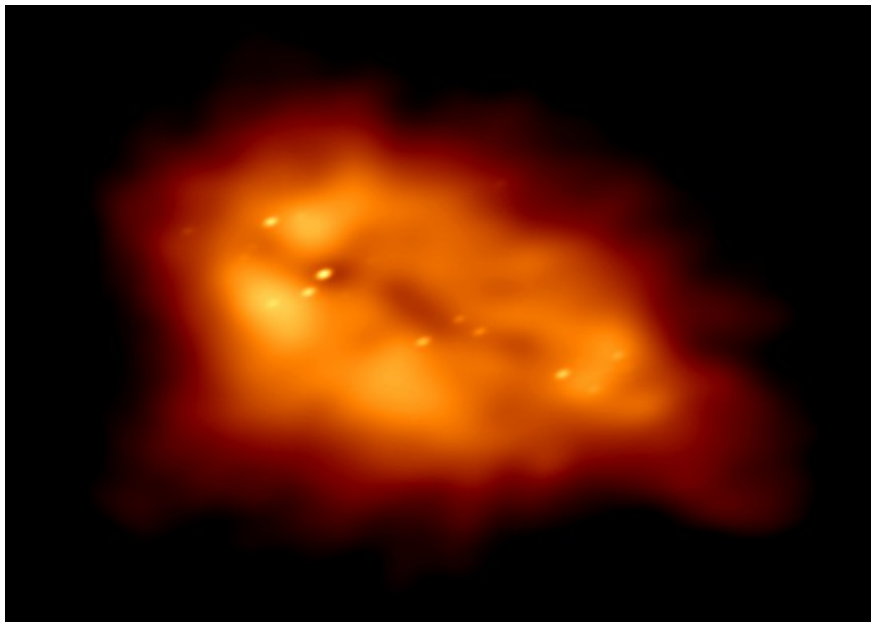
Varenius et al. 2014,
in preparation

Using baselines of length between 2 kλ and 75 kλ (RS).
Contours at (-10, 10, 20, 40, 80, and 160) times σ, grey scale in mJy/beam.

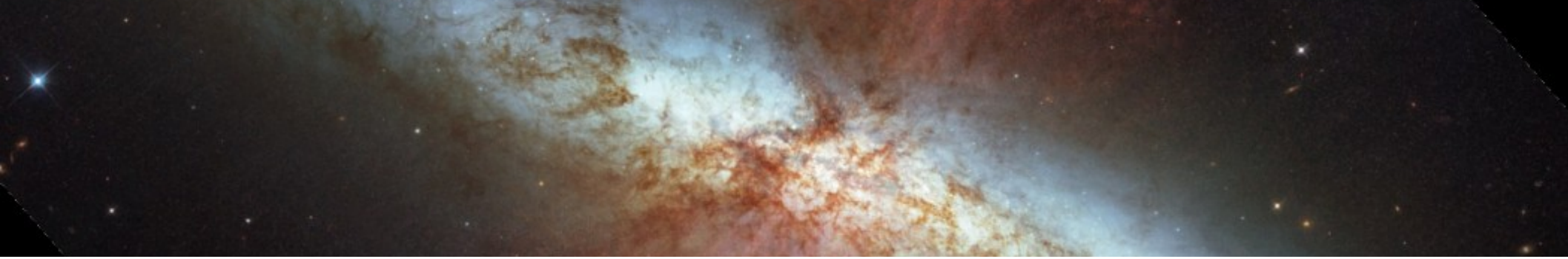
Outlook

- Model the spectra of all 22 detected sources.
- Extract and model flux densities of M81* and SN1993J.
- Model the core emission and the outflow around the core.
- Eventually:
  - New observations with more bandwidth (~<0.1mJy RMS).
  - The future Hamburg station to include intermediate (between INT and RS) baselines.

Summary

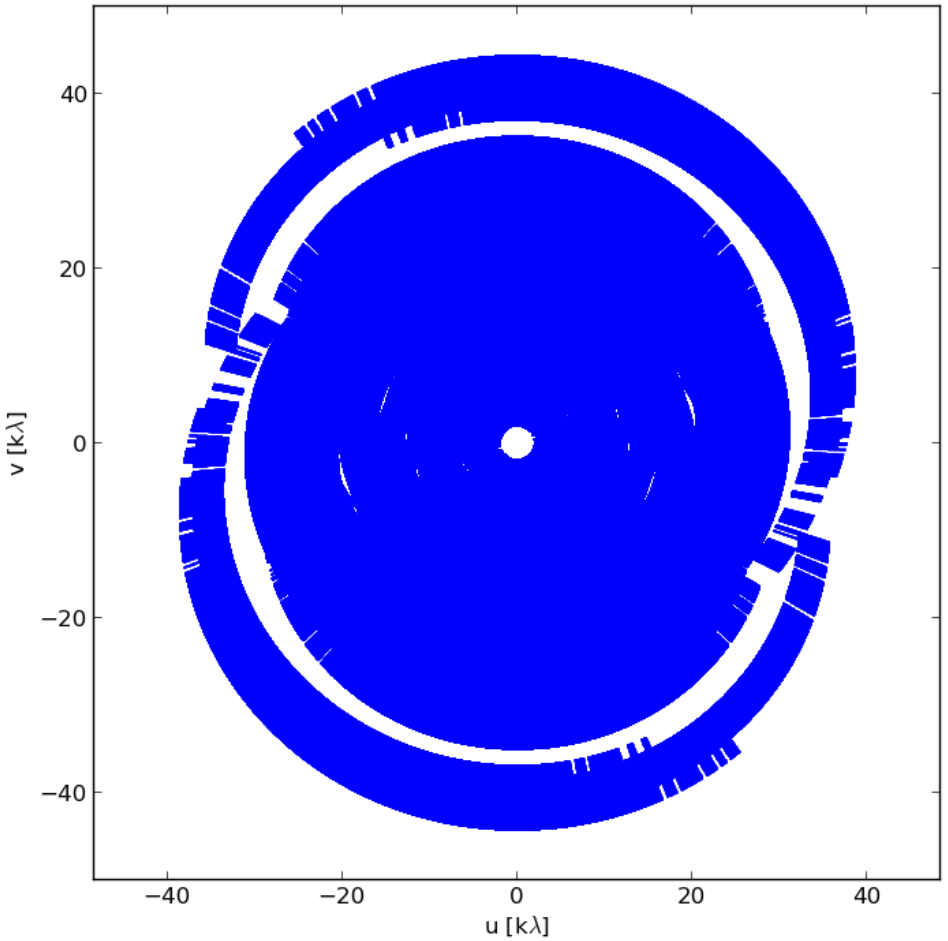


- New record in resolution at 154MHz and lower frequencies.
- We see compact sources and more extended outflow with deep absorption in the central star forming disk.
- We hope that future modeling of these results can help interpreting LOFAR survey observations of high-redhift galaxies.

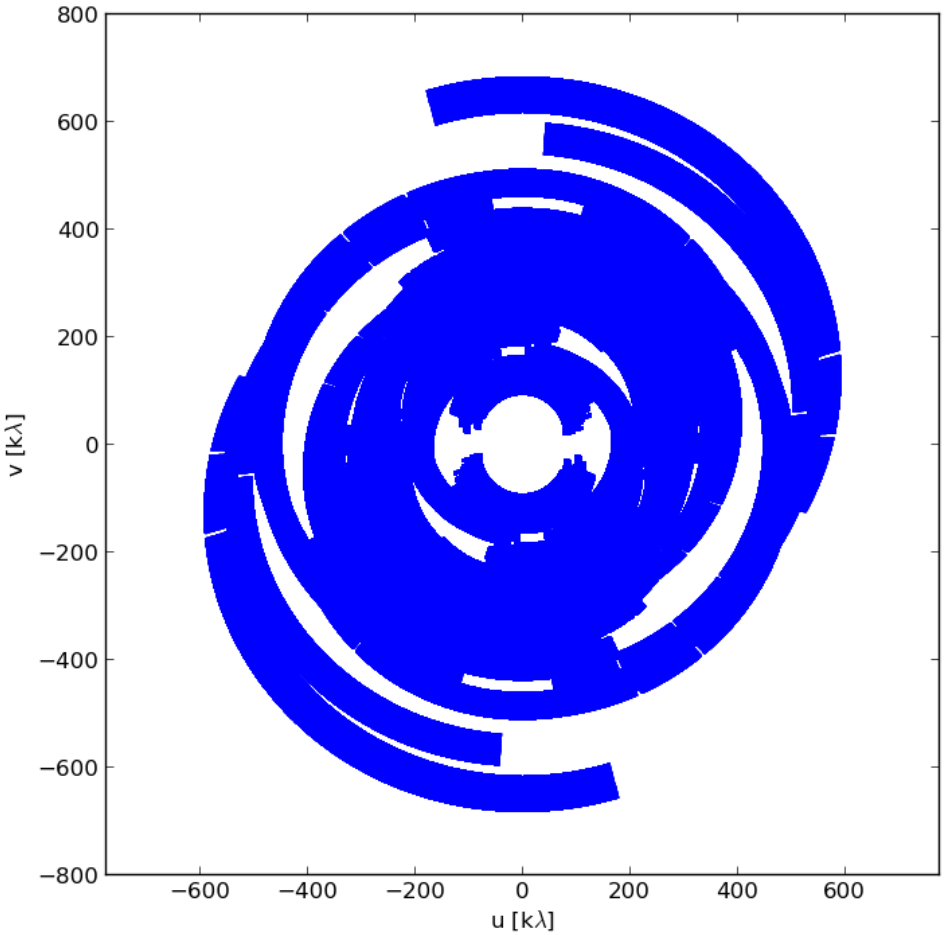


Extra: UV-coverage for M82 LOFAR observations

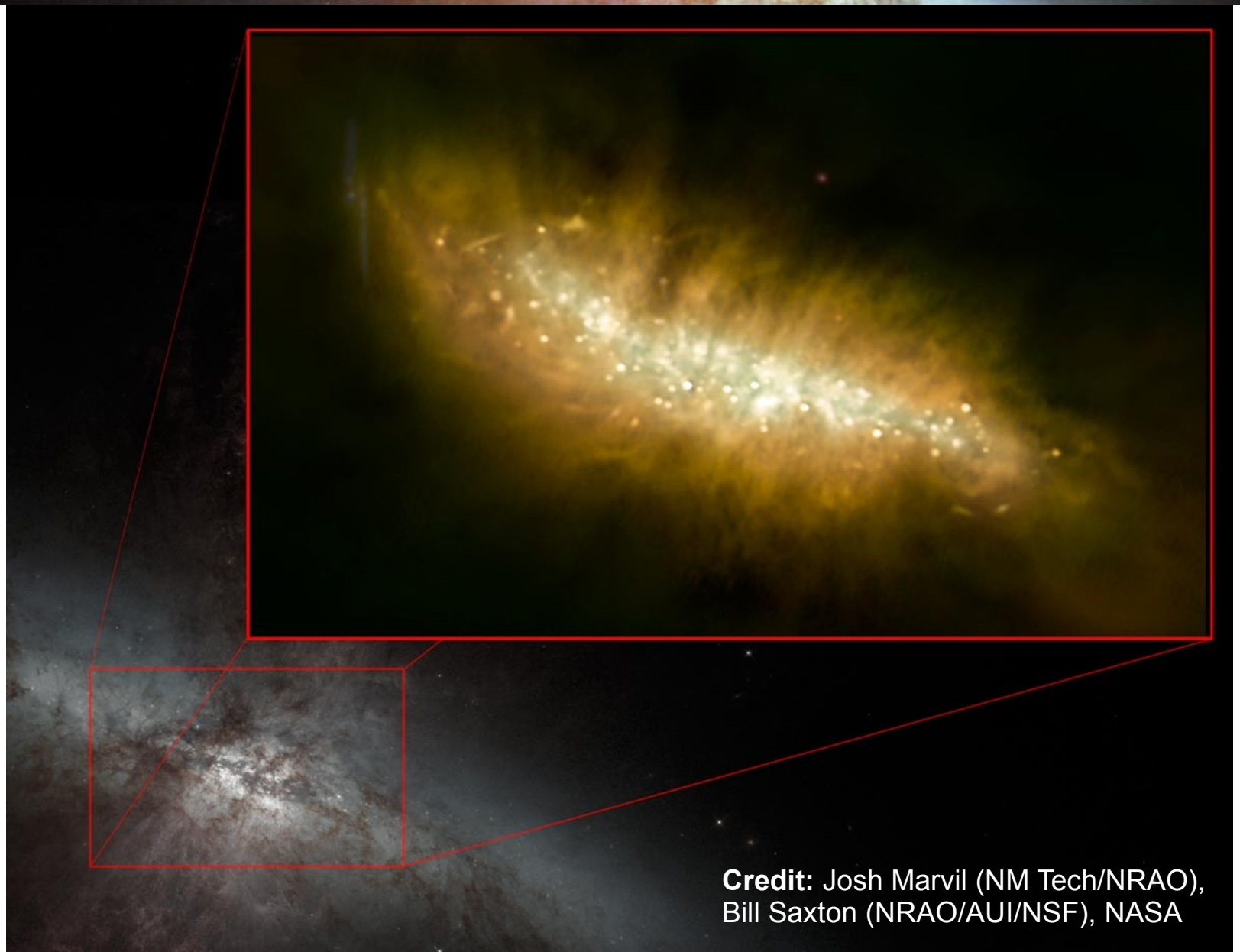
M82 UV coverage RS (2kλ<data<75kλ)



M82 UV coverage INT (data>75kλ)



Extra: Comparison with unpublished JVLA map (5GHz?)



Credit: Josh Marvil (NM Tech/NRAO), Bill Saxton (NRAO/AUI/NSF), NASA