Science from the astronomy group

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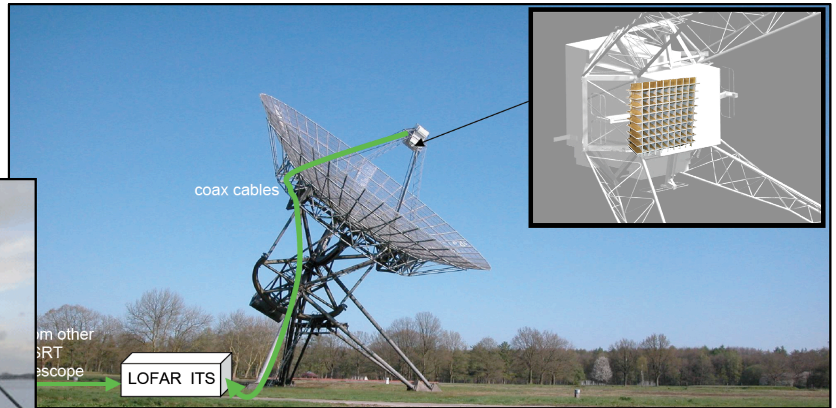
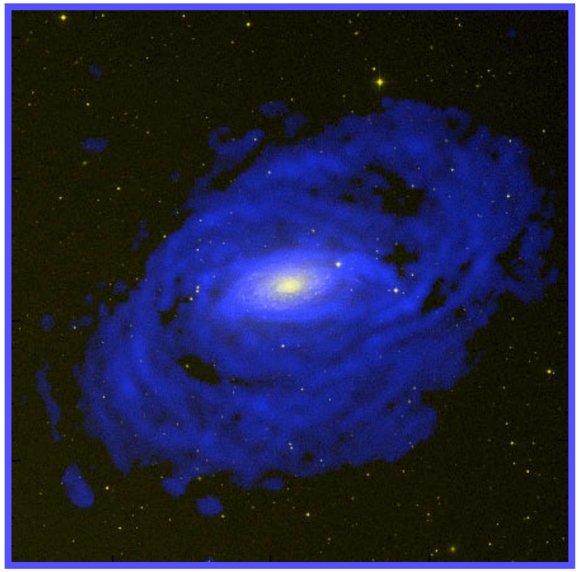
These are exciting times!

- Using the existing facilities at their limits: Westerbork Synthesis Radio Telescope again a world-class radio telescope after the upgrade
- Commissioning of the new facilities: making LOFAR a success
- Looking at the future: Focal-Plane Array and Square Kilometer Array



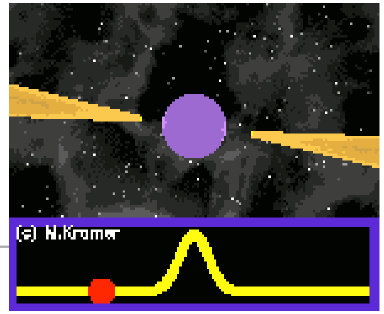
Main science topics

- **Broad range of science topics**
- Nearby compact objects (in our galaxy), e.g. pulsars
- Galaxies in the Local Group and far away: galaxy structure and evolution, the interstellar and intergalactic medium

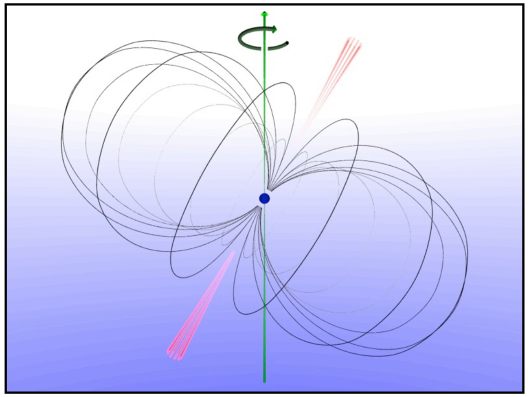


- Galaxies with an active central black-hole
- Gravitational lensing
- Study of the distant Universe
- **Many more topics covered in collaborations with other institutes in and outside The Netherlands....**

Inside our Galaxy: exotic pulsars



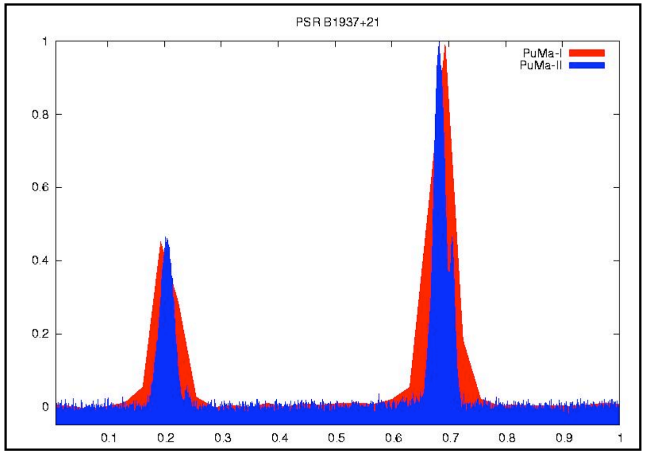
- Radio pulsars are weak point-like radio-sources with periodic signals which are remarkably stable (ranging from milliseconds to seconds). Pulsars are neutron stars, which have an extremely high mass density and strong dipolar magnetic field.



Smits 2007

- The regularity of the pulsation is sometimes as accurate as what can be achieved by an atomic clock.
  How the radio emission is created?

- **PuMa II at the WSRT: one of the best pulsar machines in the world. The timing that we can do at the WSRT is now amongst the most precise in the world due to the great pulsar machine and the great telescope!**



Pulse profiles from the original millisecond pulsar, obtained simultaneously with PuMa and PuMa-II showing the improved sharpness of the pulse profile achieved using the coherent de-dispersion of PuMa-II. This improvement leads directly to an order of magnitude improvement in the accuracy to which the arrival time of the pulses can be measured.

- Coherently de-dispersing pulsar machine. Correct for delay (pulses arrive later at lower frequencies) due to the effect of interstellar medium.

- Significantly sharper pulse profiles and much higher timing precision

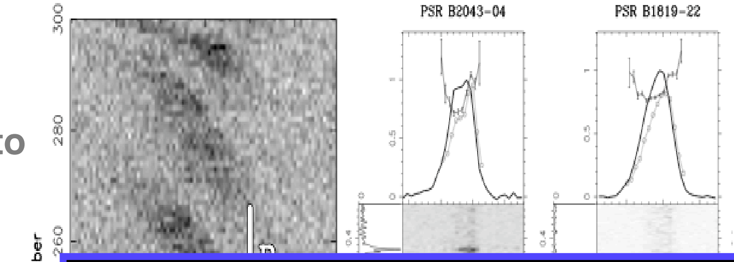
Every pulse is different:
Largest Ever Drifting-Subpulse Survey

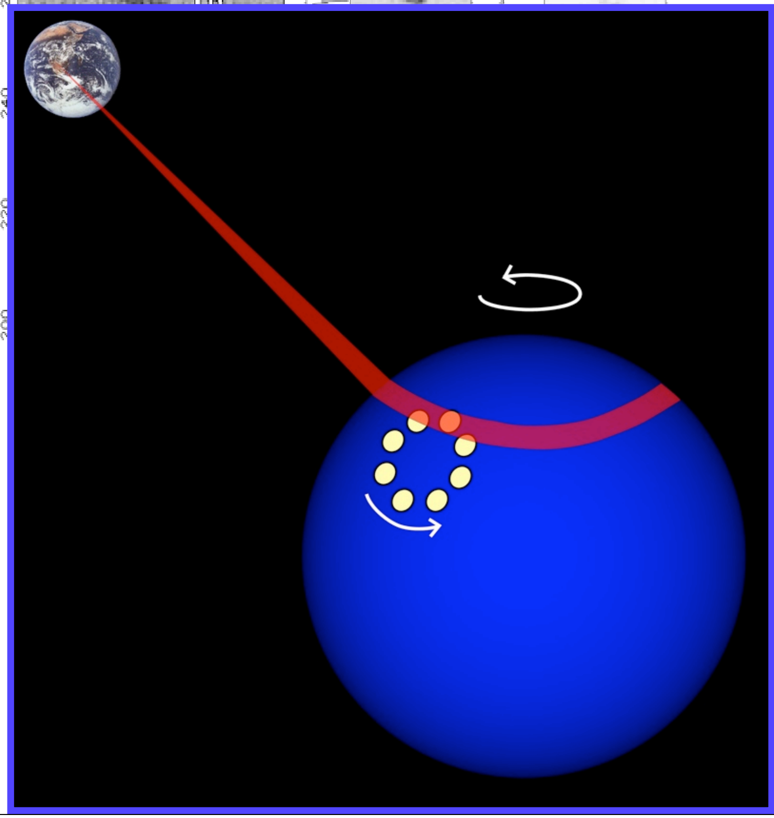
- More than 55% of the pulsars show “drifting” sub-pulse. **The survey of drifting subpulses done with the WSRT is the largest ever! The first to be able to prove statistically the importance of drifting.**

- So common that cannot be very different from the emission mechanism of radio pulsar. Sub-pulse drift is an intrinsic phenomena of pulsar emission mechanism phenomenon is intrinsically linked to the emission mechanism

- Beam of emission segmented into smaller sub-beams that rotate around the magnetic axis: **carousel**

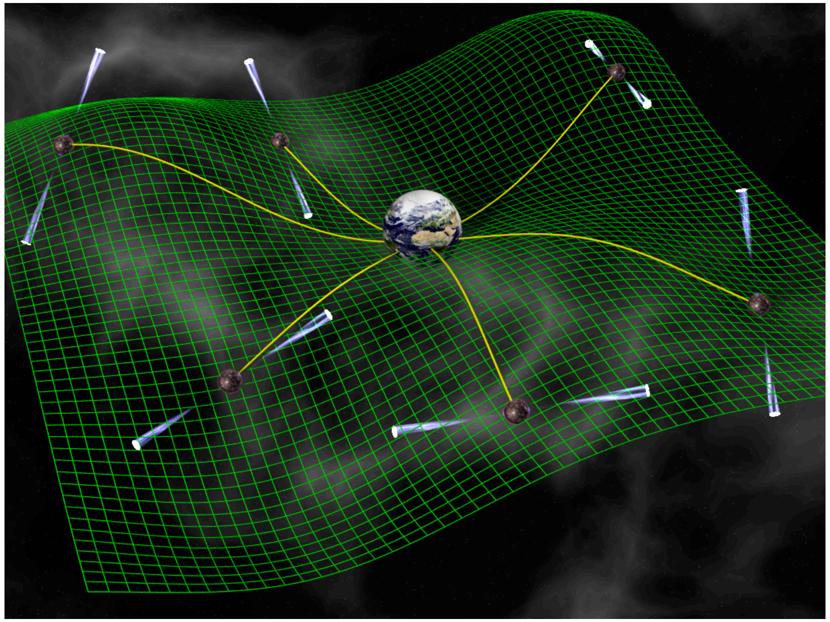
- Model the height above the star’s surface from which the emission is generated: each height the radiation is emitted at different frequency(emission heights range between 2 and 14 km)

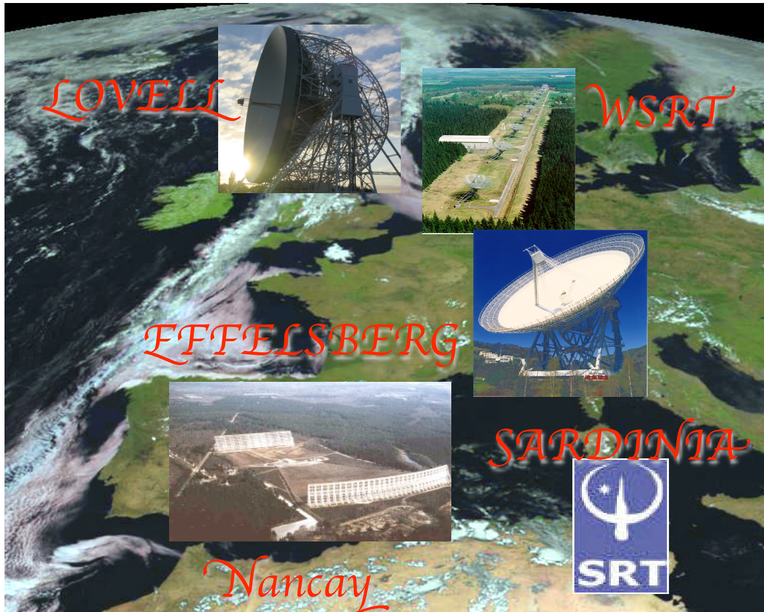




European Pulsar Timing Array: EPTA

- AIM: To combine pulsar timing data from 5 large European telescopes to detect gravitational waves
- Using an ensemble of pulsar distributed over the sky - as arms of a very long interferometer - **it will be possible to measure the correlated variations in spin-down rates of the pulsars**
- Variations caused by gravitational waves with periods of the order of years -> thought to originate from the very early Universe (e.g. orbiting super massive black-holes).
- Need to measure pulsar arrival times to better than 100 nanoseconds.
- **The WSRT and ASTRON are playing a leading role in this project!** Because of the size of the telescopes involved and frequency of observation should enable us to be best in world.

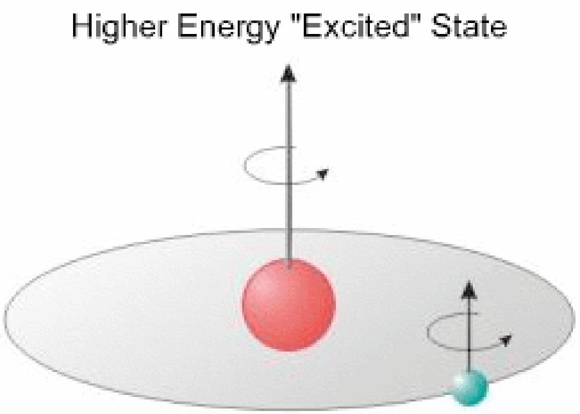




The most common element in the Universe

- Hydrogen most common element in the Universe and main ingredient for galaxy formation

- Fundamental work in this field done by the Westerbork Synthesis Radio Telescope [one of the main reasons why the WSRT was planned and constructed] and by the dutch astronomical community (line predicted by van de Hulst, 1944)



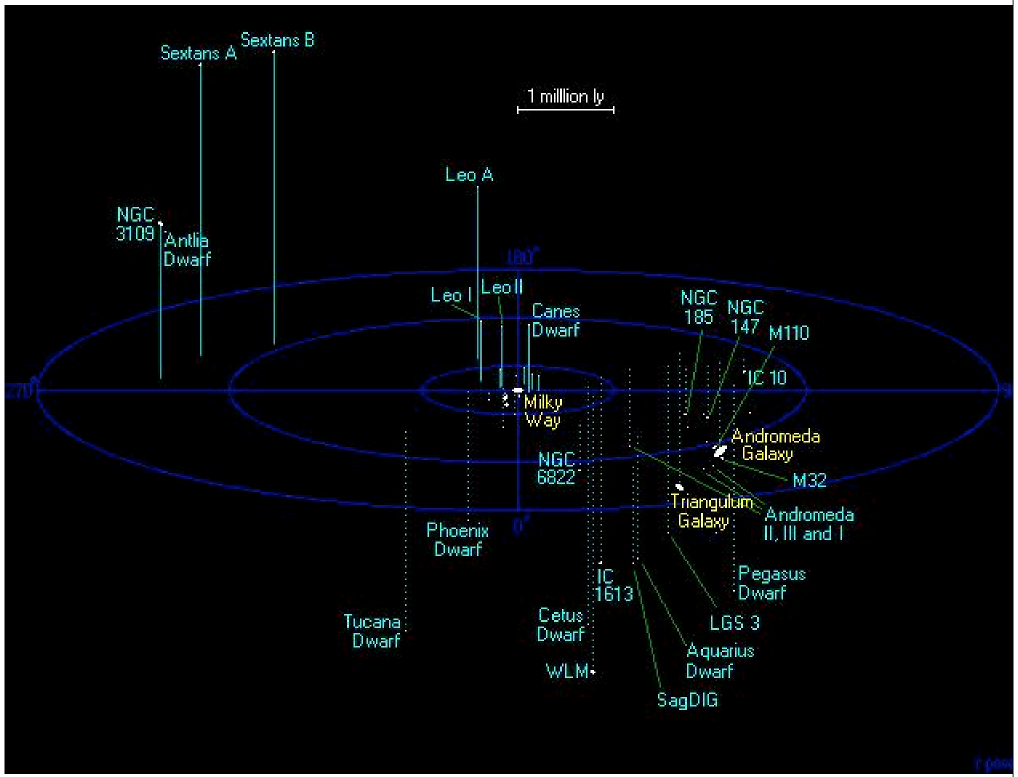
The Universe around our Galaxy

- **Dwarf galaxies “building blocks” of large galaxies.**

- According to models/simulations, the Milky Way has fewer dwarf companions than predicted (missing satellite problem)

- Solution: small galaxies are less efficient in converting gas into stars, making them fainter than predicted

- To form stars, the gas in a galaxy has to cool to very low temperatures. Do we see this gas?



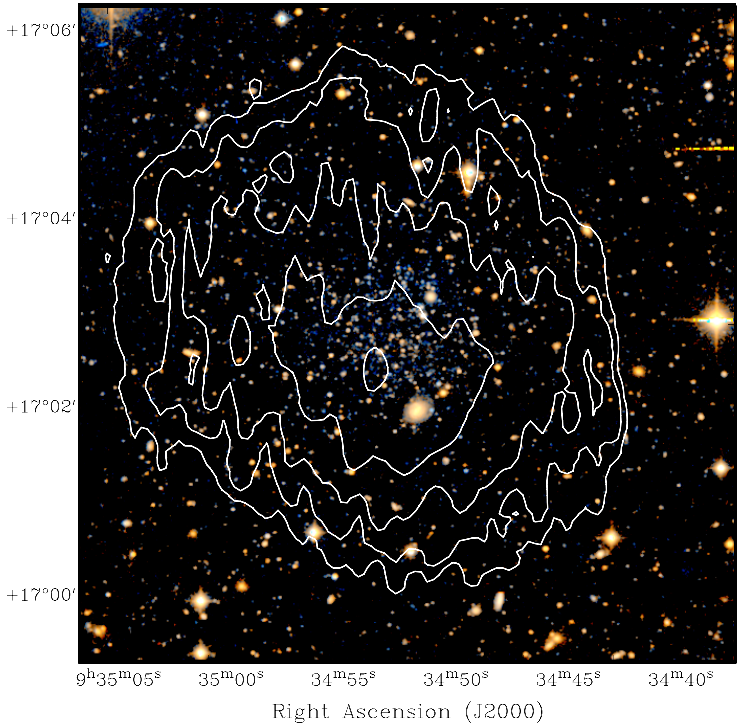
Yes, sometimes a lot of it!

Dwarf galaxies around us

- The recently discovered dwarf galaxy LeoT is a key object: it is (by far) the smallest galaxy that has a *nice* disk of hydrogen gas

- Best case to study properties of interstellar medium in relation to star formation

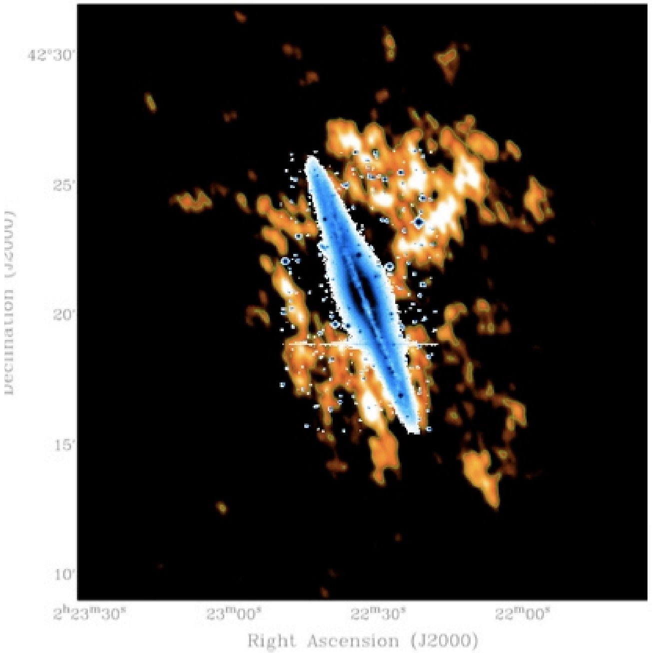
- Why is this less efficient in small galaxies? Effect of re-ionisation? Effect of supernovae?



Distribution of hydrogen gas (contours) in the dwarf galaxy LeoT as observed by the WSRT

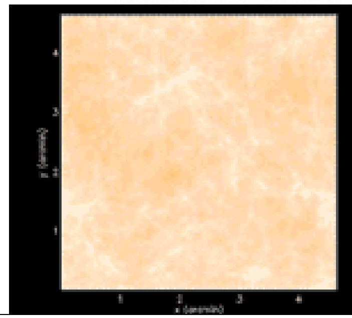
Cosmic Drizzle

- All stars, gas and dust together account for only 1/3 of all normal matter in the Universe.
- The other 2/3 is in warm and hot, primordial gas floating in the large space between galaxies. There has to be a continuous "drizzle" of this intergalactic material onto galaxies because otherwise all galaxies would have no gas (and would not be able to form stars!)
- The infalling clouds are quite small and extremely difficult to observe.
- **20 days of WSRT observations of the nearby galaxy NGC 891 have allowed to detect such gas for the first time**



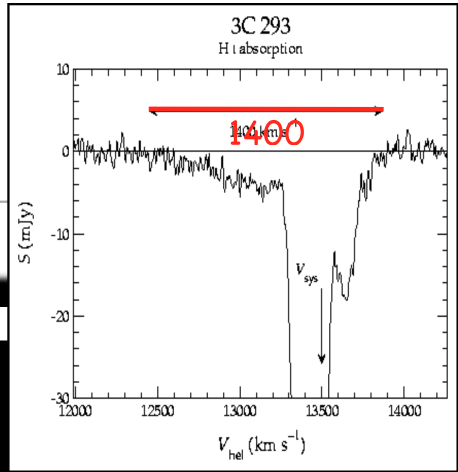
The cold gaseous halo of NGC 891 Oosterloo, Fraternali & Sancisito appear in The Astronomical Journal

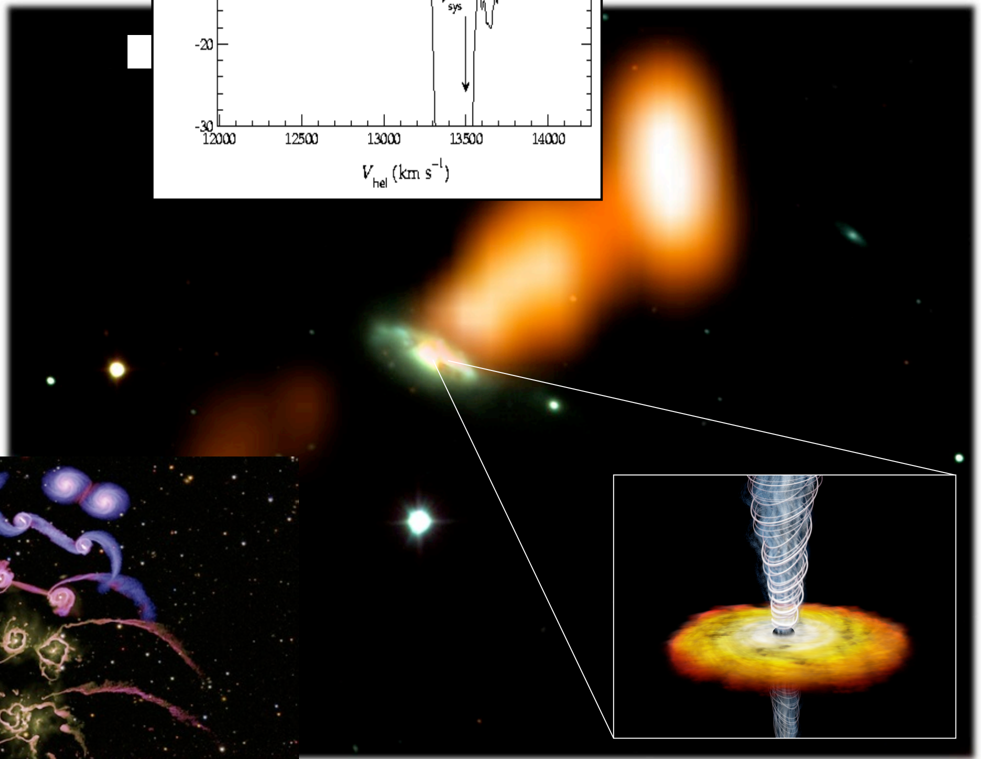
The gas falling onto NGC 891 as detected with the WSRT



Simulations of the neutral hydrogen in the Universe evolving with time(from Steve Furlanetto,)

Like ice cubes on the Sun!





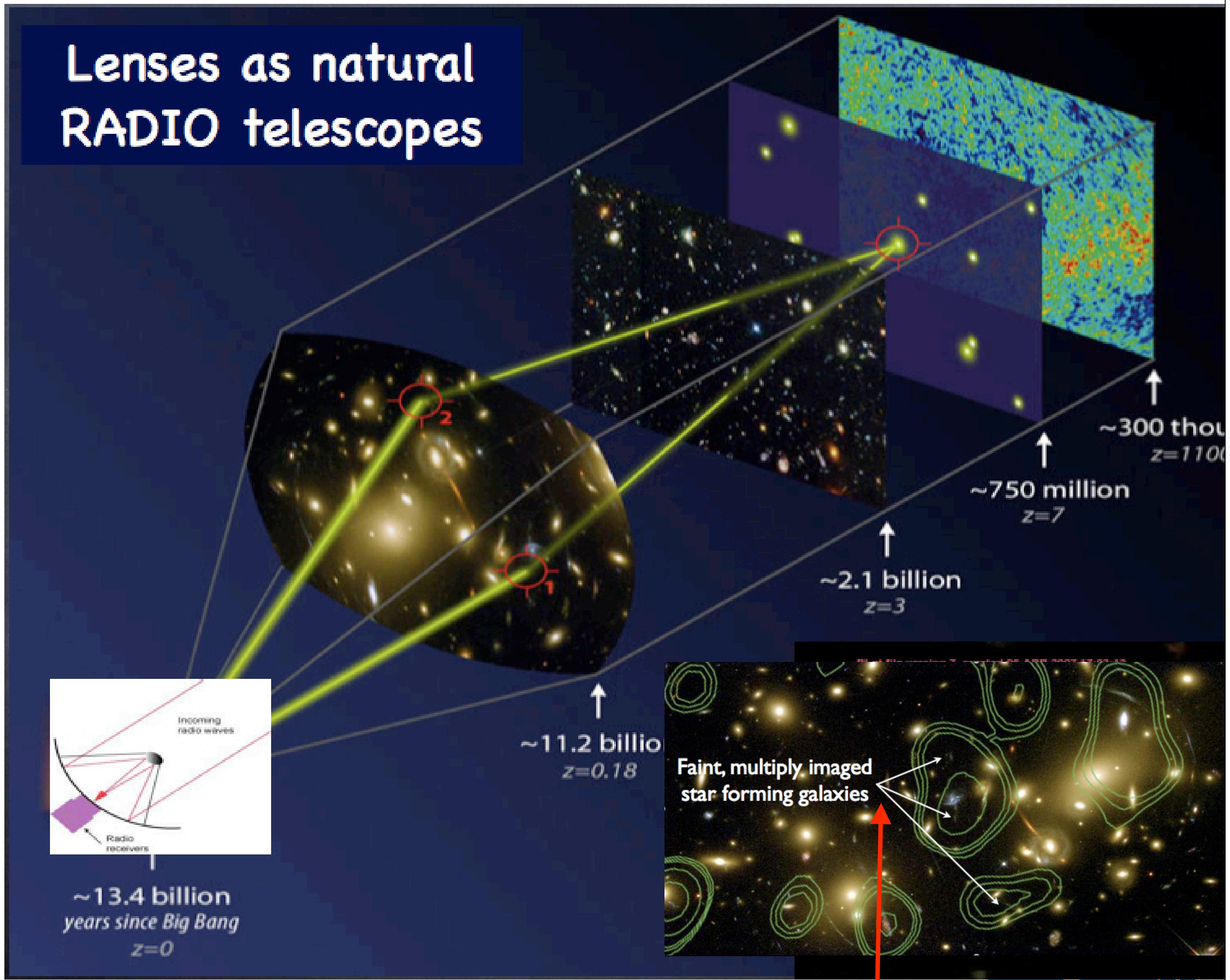
- Active nuclei: extended radio emission (up to many hundreds/ thousand light yr)
- Fast outflows of neutral hydrogen
- **Discovered thanks to the broad band of the upgraded WSRT!**
- cosmological implications

also part of Emonts PhD project

Under the magnifying glass: the most distant radio sources

- Gravitational lensing (by individual galaxies and massive galaxy clusters) can magnify the light of background galaxies and quasars by a factor of 10-100

- **The WSRT has provided the first case of multiply lensed radio emission from a star forming galaxy**



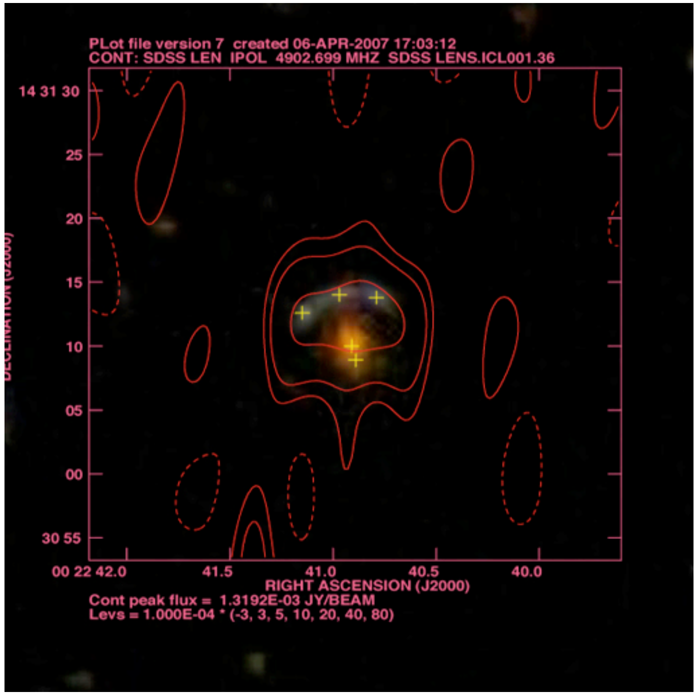
Under the magnifying glass: the most distant radio sources

- The magnification from gravitational lenses makes possible a detailed study of extremely **distant** systems otherwise too faint

- What kind of galaxies inhabit the early Universe? How different was the Universe then?

- At which rate these galaxies are forming stars?

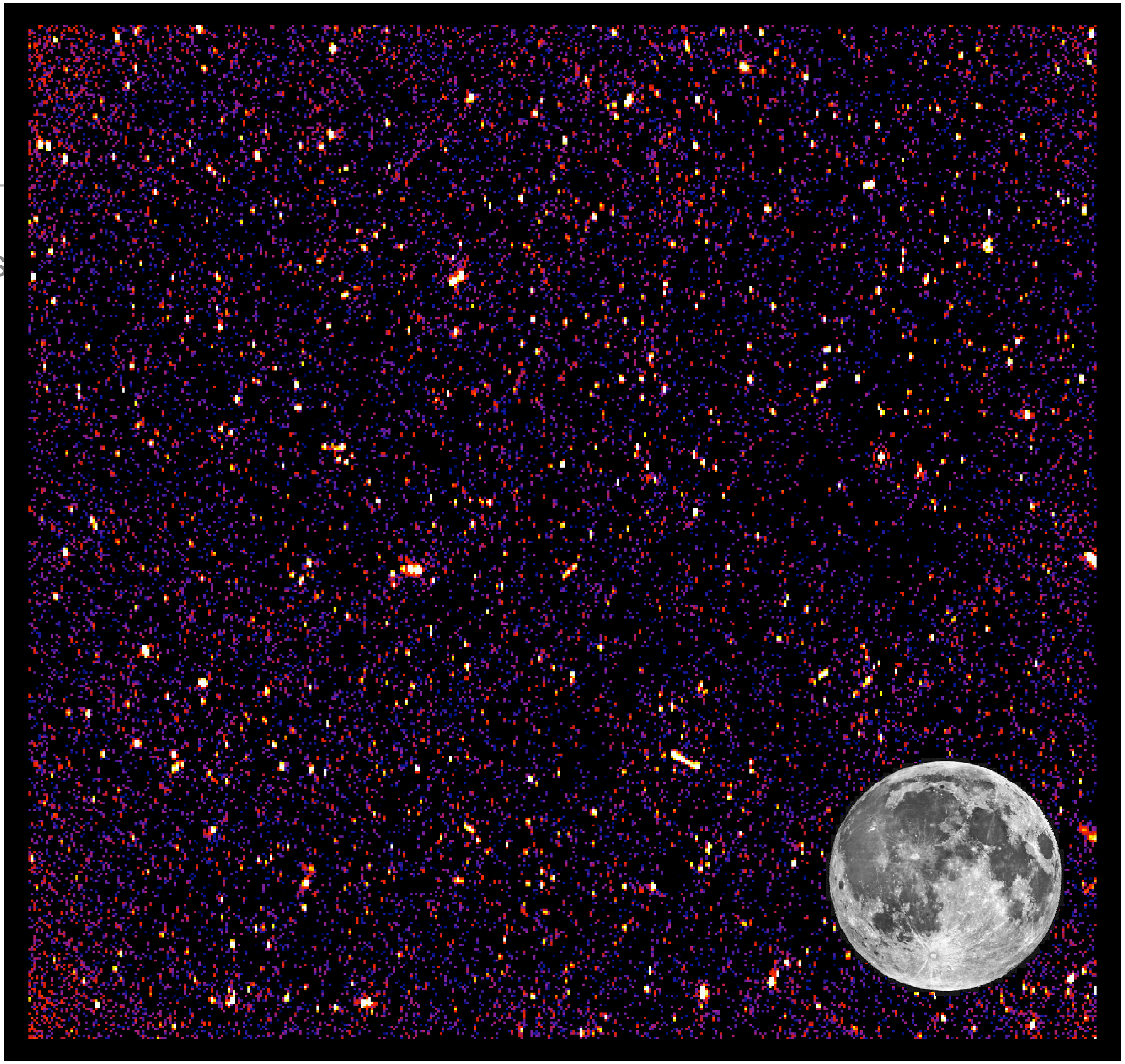
- Do they have different characteristics than the nearby galaxies?



8 o'clock arc - galaxy at z=2.7 2.4 Gyr from BigBang
(today is 13.6 Gyr from BigBang)

Deep look at the radio sky

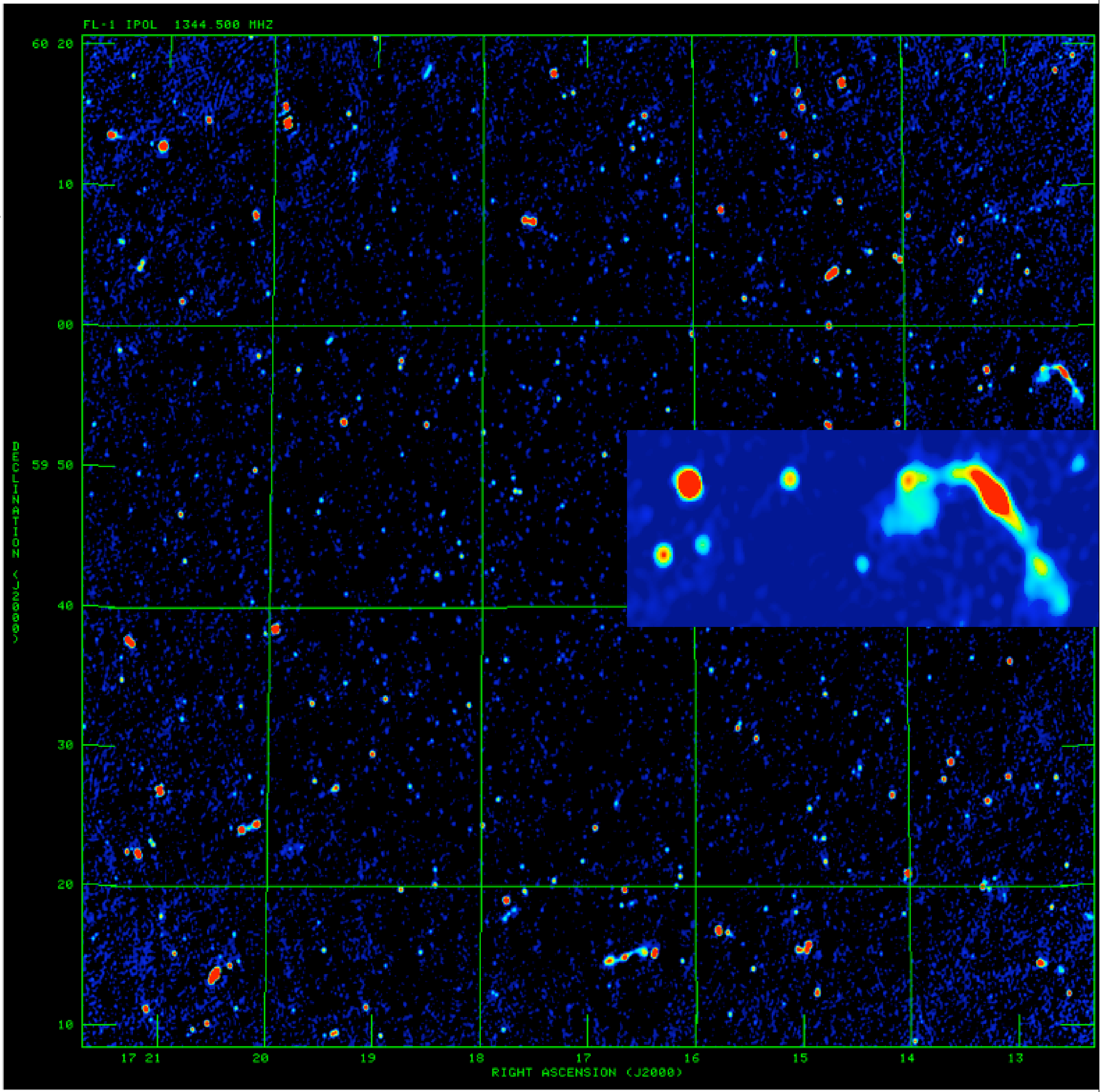
- Lensing technique allows us to study the most extreme cases.
- With deep surveys of large pieces of sky we can study (in a statistical way) the nature of radio sources
- How do the properties change in the life of the Universe



ASTRON

Deep look at the radio sky

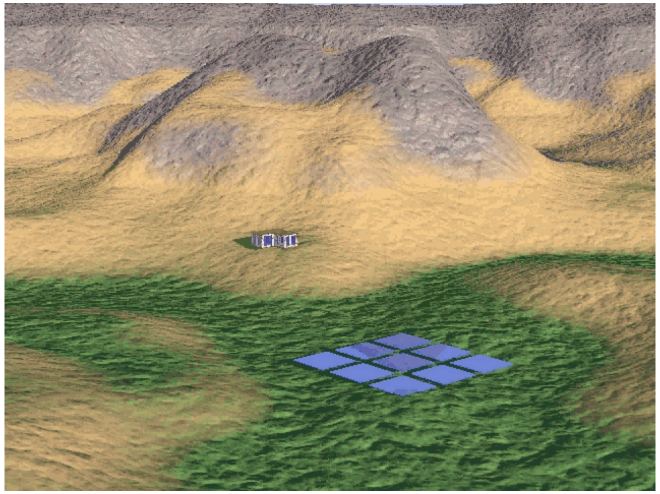
- Very time consuming for present day radio telescopes
- Complementary to what we will obtain from LOFAR
- LOFAR has the ideal capabilities



LOFAR progress

- Commissioning of the first station CS1 and first image - together with the technical people the astronomers are busy trying to understand the complex system. More technical part for the visit on-site

- Why is it *cool*? LOFAR will open a new parameter space so far unexplored (at the resolution that LOFAR will allow): huge field of view (many objects in one pointing!), novel multi beam capability!



Simulation (done for SKA by M. Kramer) of multi-beam capability!

- **Astronomers at ASTRON deeply involved given the great expertise in the field (strong collaboration with Universities)**

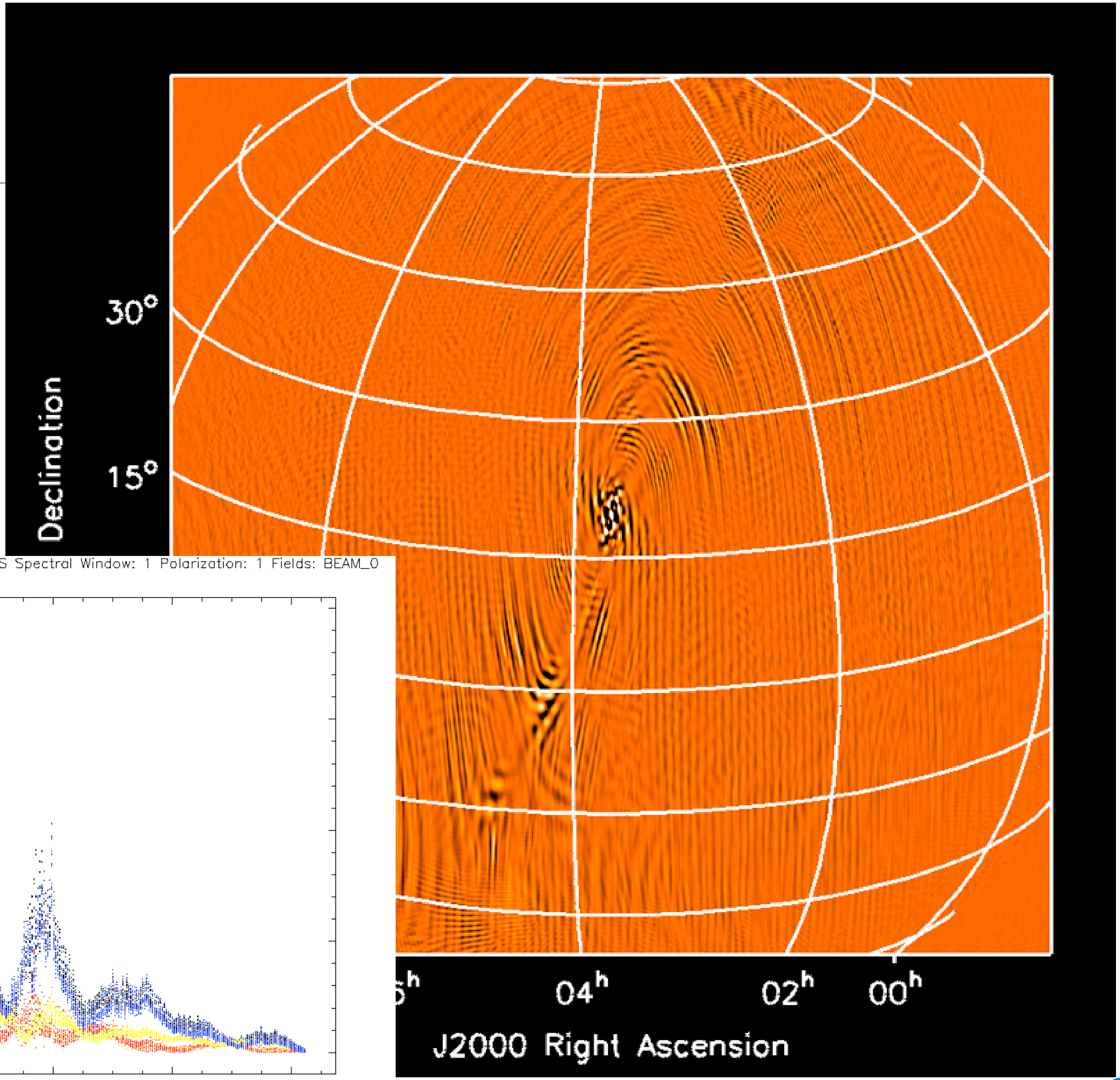
- Members of the astronomy group in every key project:

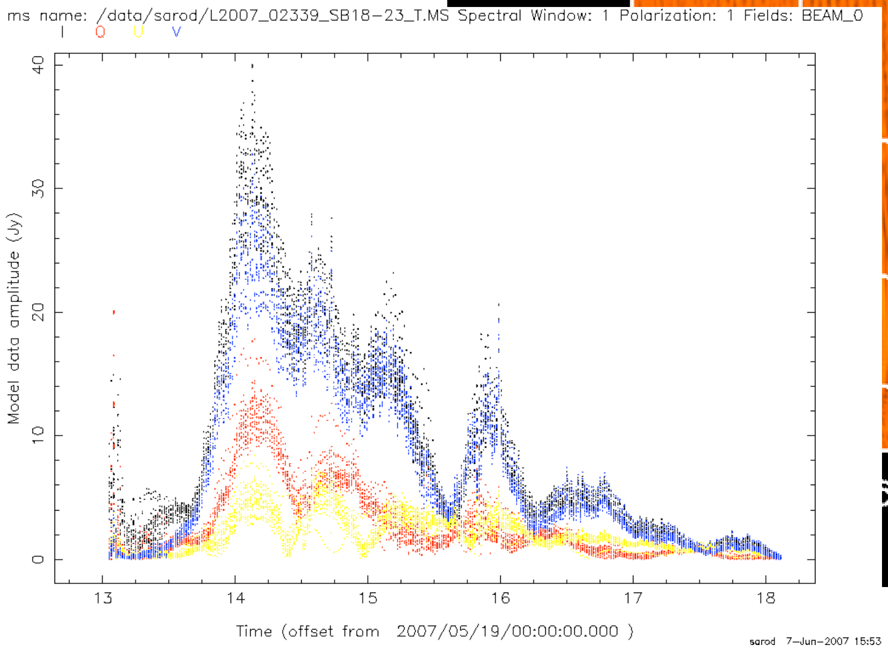
  Epoch of Reionisation - Deep Extragalactic Surveys - Transient Sources - Ultra High Energy Cosmic Rays

ASTRON

The system works!

- Sun flare....
- Solar fringes: how the radio data look like!

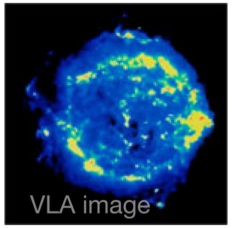




ASTRON

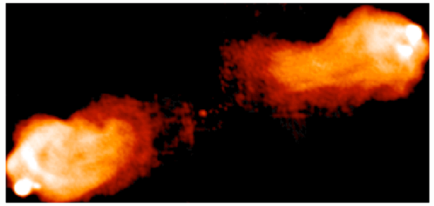
First high quality 'large-sky' CS-1 image

- 24 Feb 2007 (29h observation)
- Frequency <44 - 60> MHz
- Sub-bands at 44, 52, 57 & 60 MHz
- 15 dipoles + one full (48 dipole) station
- 48-dipole beam on CasA: stronger radio source, peak 20,000 Jy **subtracted**



- Resolution ~ 0.5° - Image noise ~ 3 - 5 Jy
- About ~ 40 (known) sources visible!

In the future!!! (VLA image)



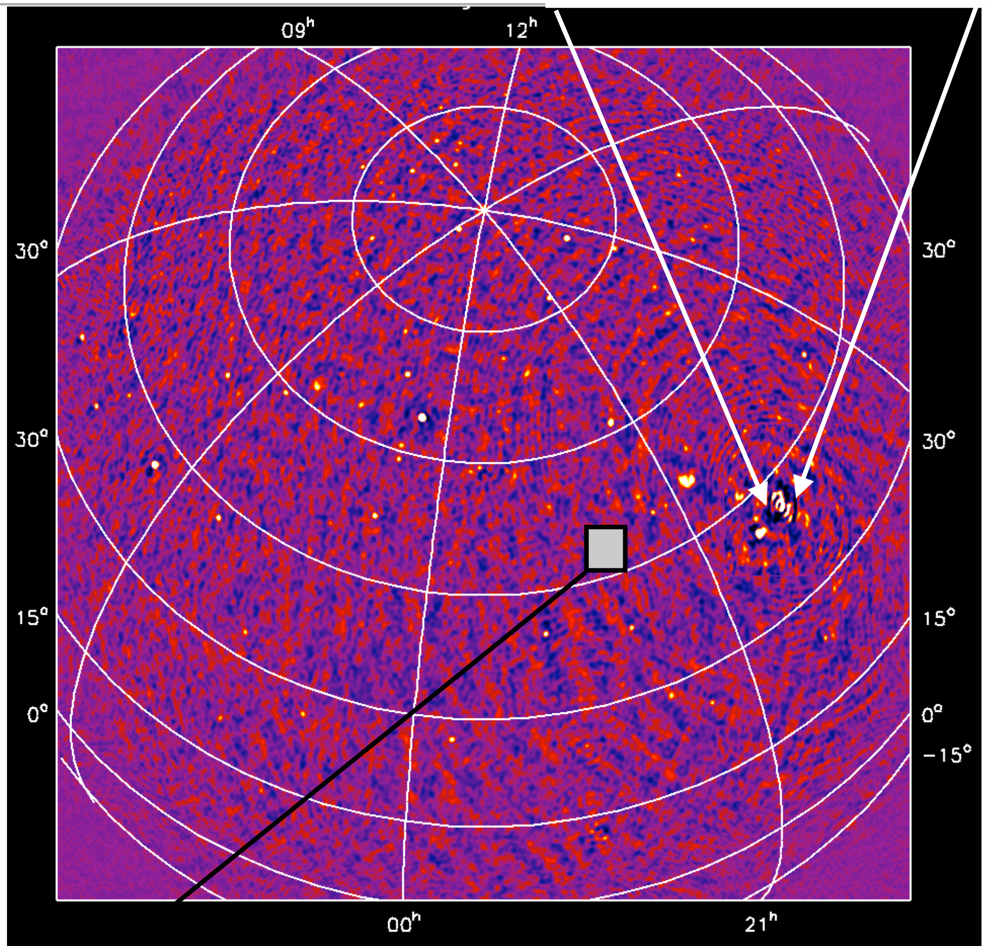


Image obtained by Sarod Yatawatta & Ger de Bruyn

Example of "large" field with present days radio telescopes
The large field-of-view of LOFAR will be crucial for the discovery of new transient phenomena!

Blow up near Cas A (subtracted)

3C10,

Tycho's SNR

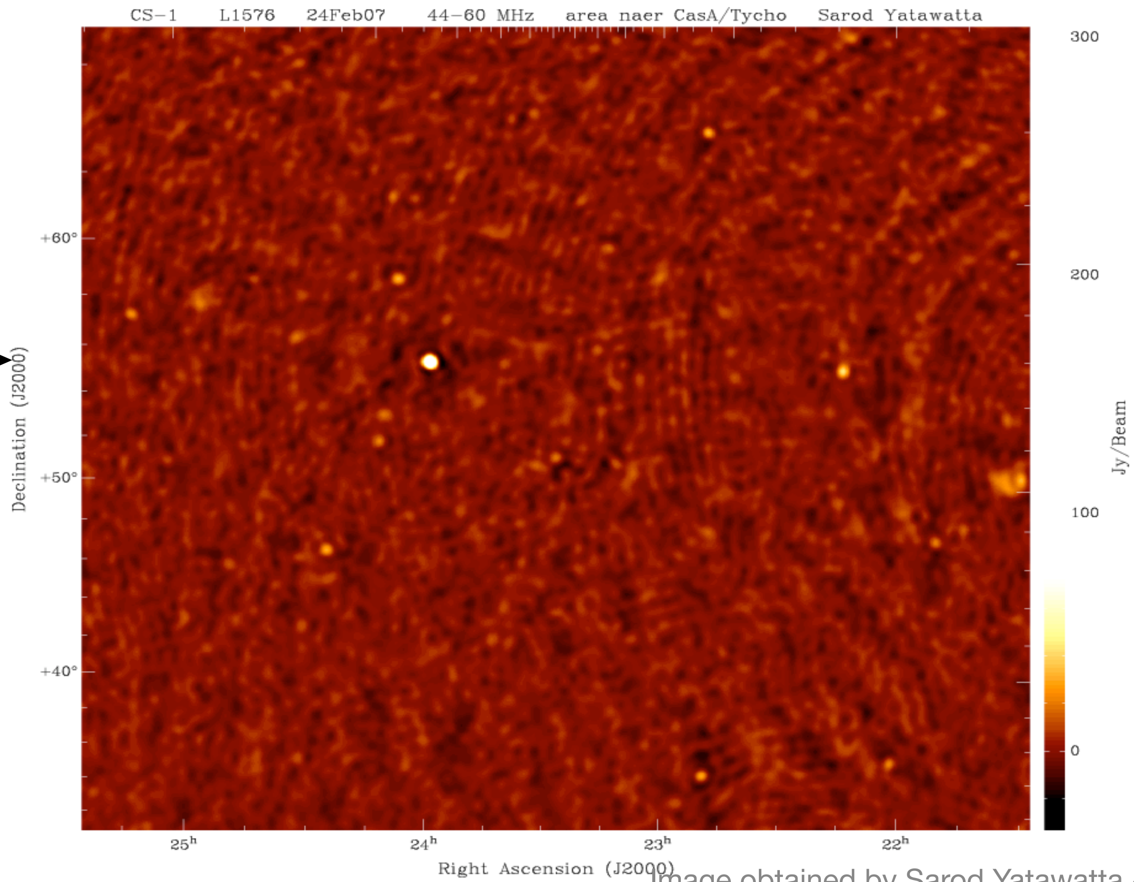


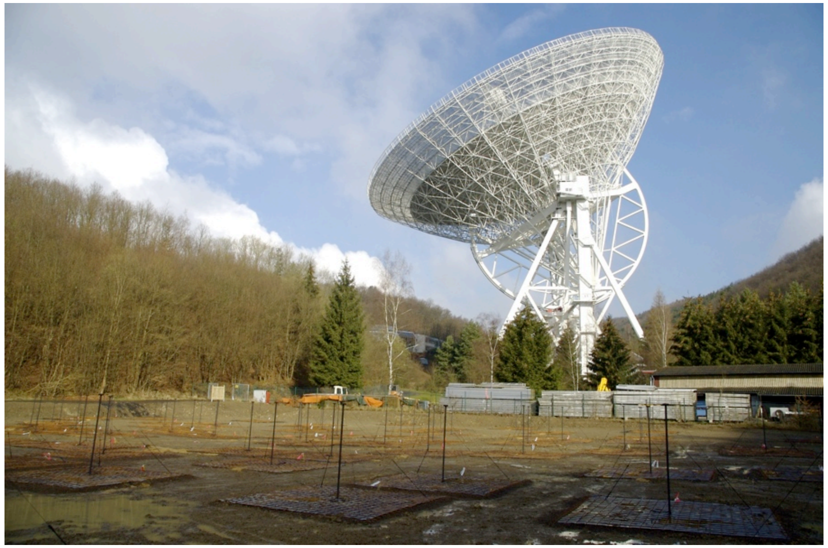
Image obtained by Sarod Yatawatta & Ger de Bruyn

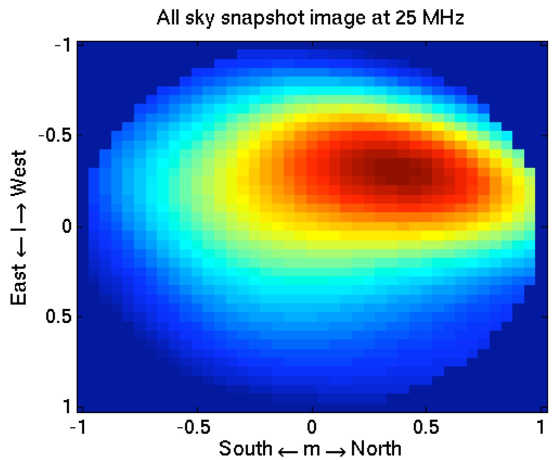
Preliminary conclusions CS-1 commissioning

- **End-to-end signal processing achieved!!!**
- All sampling/frequency modes tested
- Beam-forming/tracking works
- Station hardware functions well; gain/phase stable to few %,$^{\circ}$
- Signal transport reliable
- RFI levels as expected
- Off-line data reduction

We need more......E-LOFAR!!!!

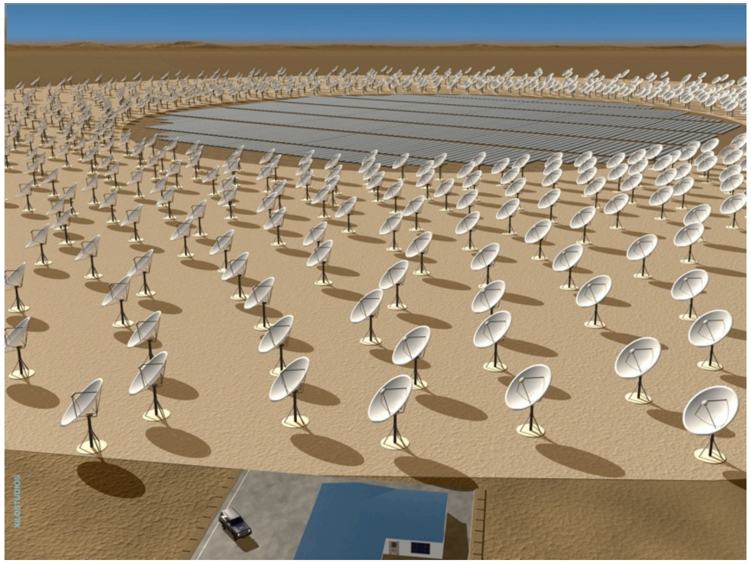
- The longer the distances between station, the sharper we can make the images
- A lot of exciting science needs this!
- Growing interest for LOFAR all around Europe: E-LOFAR
- First station in Effelsberg (*IS GE-1*). Two more planned in Germany (Munich & Postdam)
- Connection high speed from Effelsberg to Groningen ready end of 2007
- Two stations planned in UK
- Strong interest from France, Italy, Poland, Ukraina





First image(at 25 MHz) from the *IS GE-1* station.

...and the future ....



- SKA and SKA pathfinders (SKA Phase 1 in 2011)
- Contributing to the science case
- APERTIF (Focal Plane Array) on the WSRT