Astronomy with the new antenna array technology

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Radioastronomy is an important part of astronomy

Strong role of radioastronomy (partly) driven by technological advances.

5 radioastronomy Nobel prizes: 3K, Pulsars, Binary Pulsars, Cobe, Aperture Synthesis

Current telescopes approaching their limits. Progress stalling.

There is need and opportunity for something really bigger & better

SKA

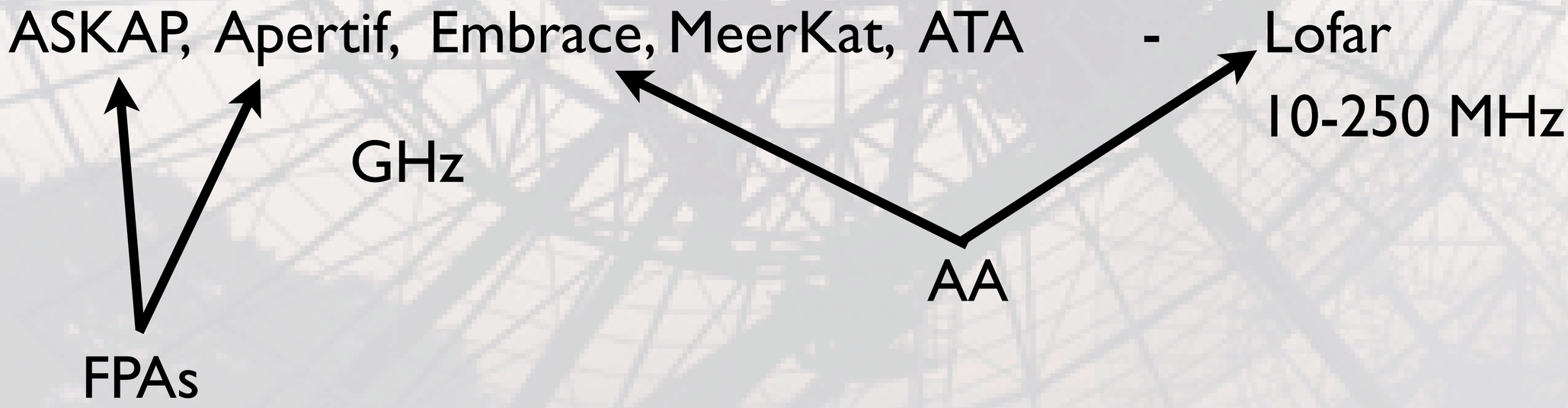
"Two orders of magnitude bigger & better"

- Much larger collecting area (1 km^2) → much more sensitive
  - fainter objects
  - more distant
  - higher spatial/spectral resolution (factor 10)
  - …
- large field of view (FoV) with high spatial resolution
  several FoVs of 1 deg^2 with sub-arcsecond resolution (@21 cm)
  → can make detailed images entire sky
- …

Road to SKA

- 1 km^2 collecting area is expensive and we'll have to wait until 2020
- Larger/multiple field of view is possible now with antenna arrays!!!

Several SKA Pathfinders (SKAPs) planned that have larger FoV

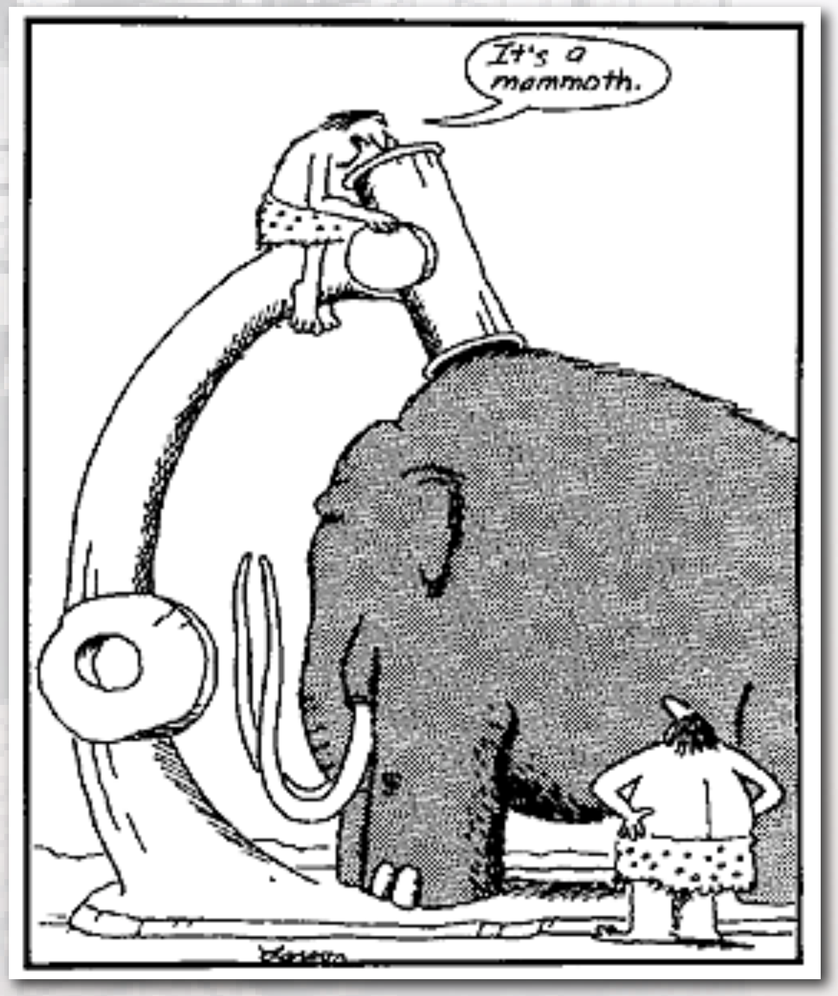


The limitations of science cases

None of the major astronomical facilities (past and current) is/will be remembered for the science as planned in their science cases

Building a telescope is different from preparing an experiment

It's about opening up discovery space



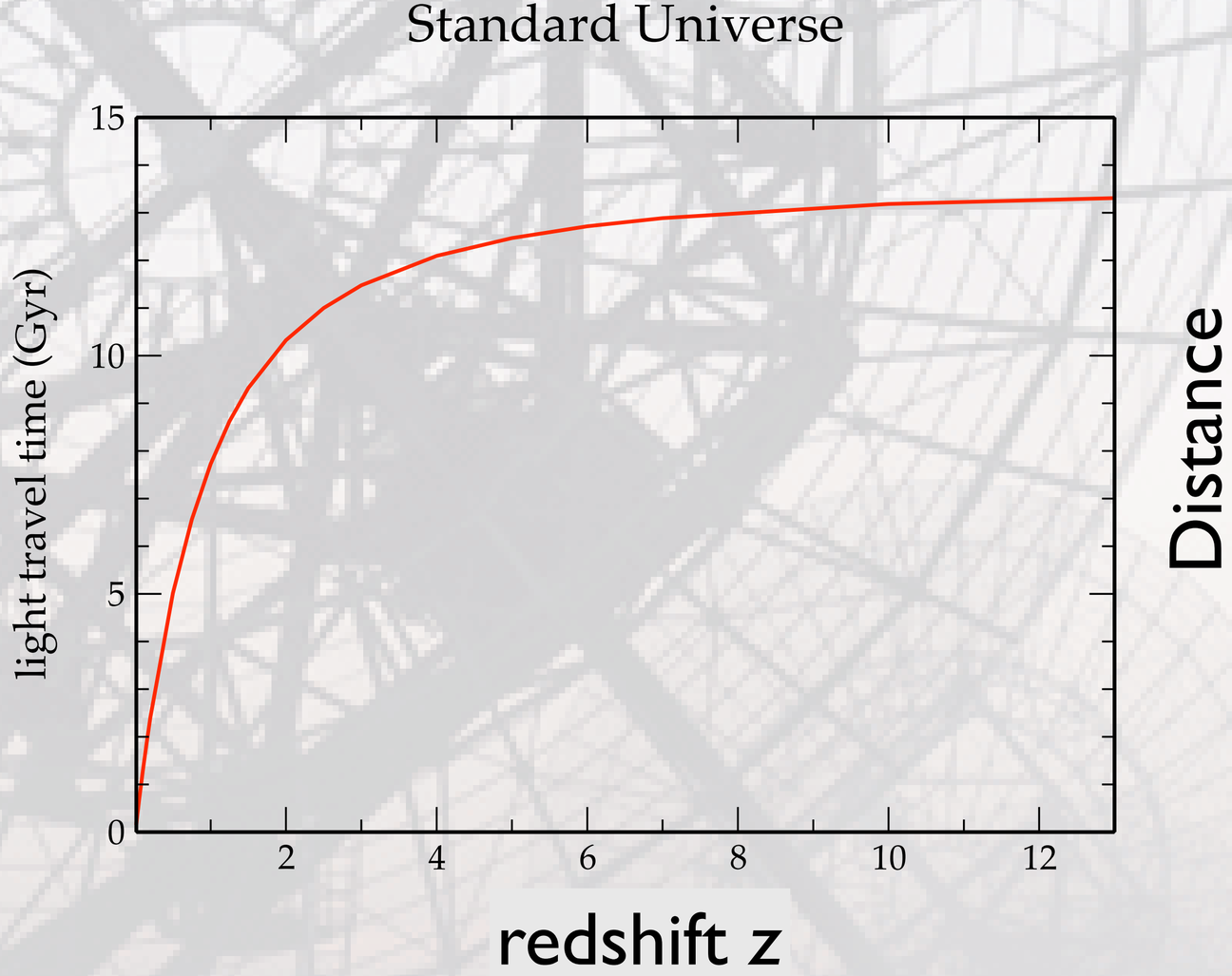
Gary Larson

Intermezzo: cosmology

Due to the expansion of the Universe, radiation of distant objects is *redshifted* to lower frequencies

redshift $z = \Delta\lambda/\lambda_o$

measure of distance and of lookback time



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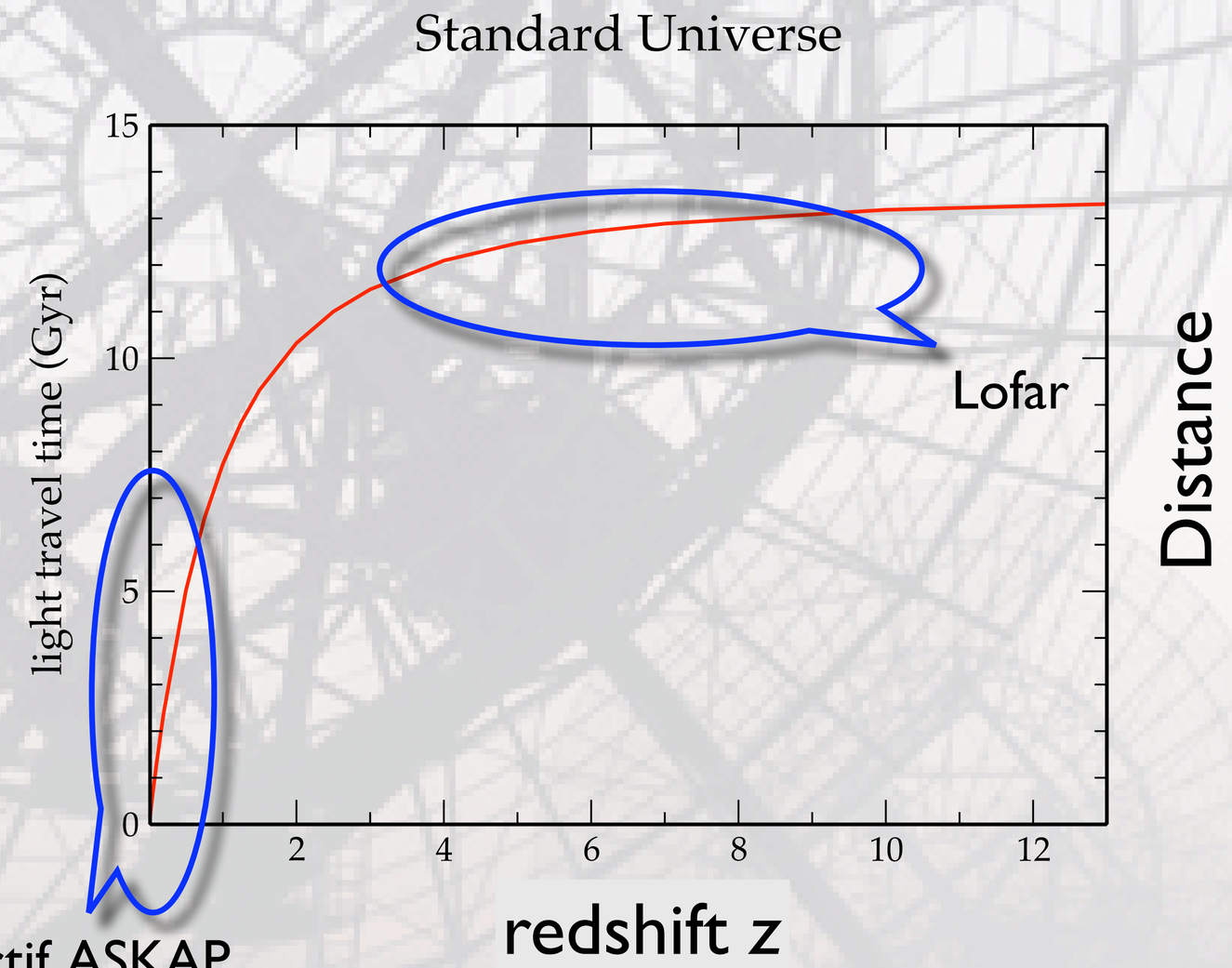

Large FoV means: deep surveys

	MeerKat	Apertif	ASKAP	WSRT
A/T	3	1	0.5	1
FoV	3	25	120	1
Survey speed	25	30	80	1

- All-sky survey of neutral hydrogen in galaxies
- All-sky galaxy continuum survey
- Imaging of Cosmic Web
- All-sky pulsar surveys
- All-sky rotation-measure grid
- Find transient sources

Exciting times ahead for H I work

- *Large field of view* and *large bandwidth*.
  given collecting area, the spatial resolution of SKAPs is near optimum for deep surveys of neutral hydrogen (H I)

- Major new opportunity: can image the *entire* sky at high resolution, high sensitivity and out to large distances

- Current state: HIPASS with ~5500 galaxies out to $z = 0.04$ with 15 arcmin resolution.
  We know about H I in ~10^4 galaxies, ~100 above $z = 0.1$

- Future: 10^6 galaxies, out to $z \geq 0.6$, most above $z = 0.1$, with 15 arcsec resolution.

- 10^7 sources as H I absorption candidates

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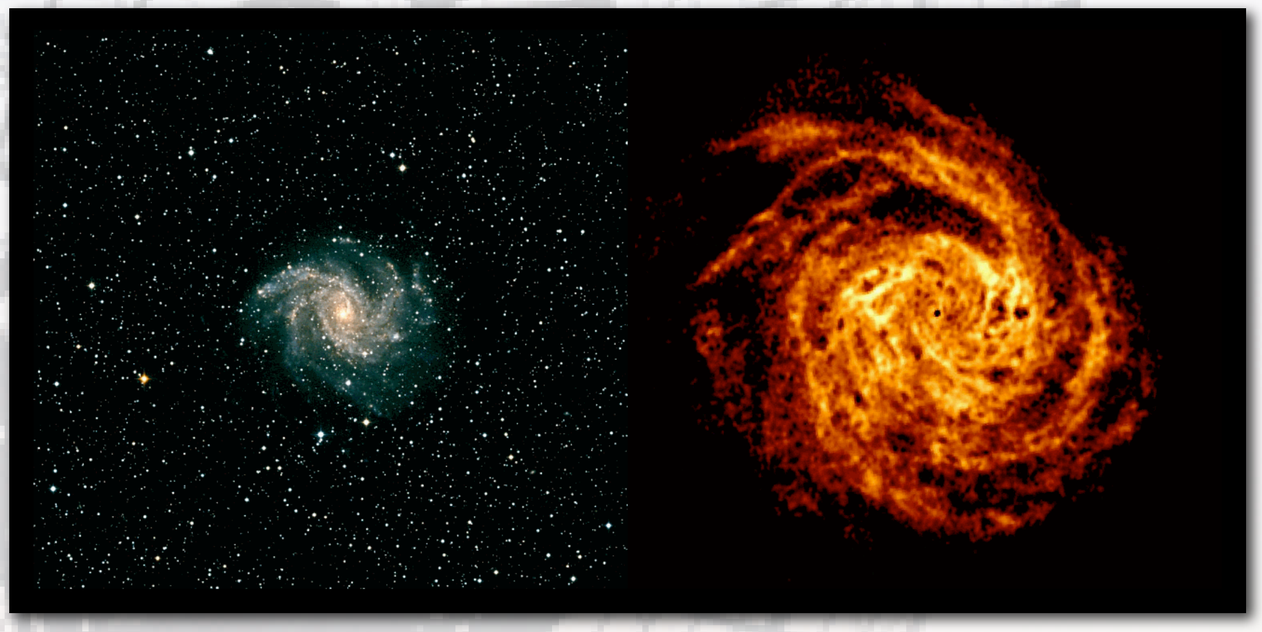
Why H I?

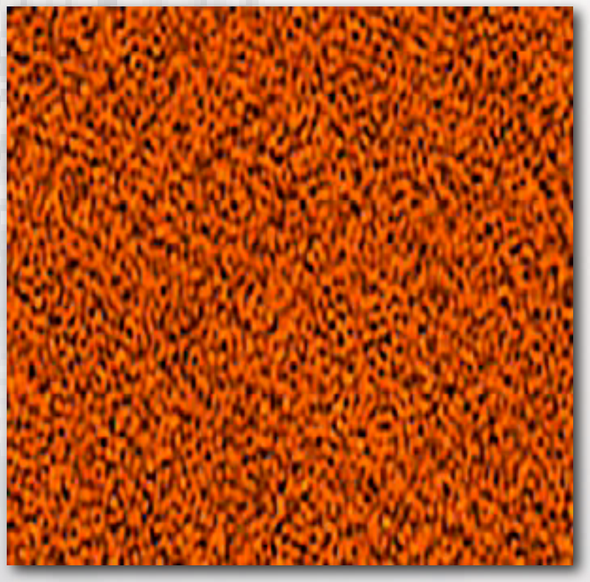
- Hydrogen most abundant element
  - H I major constituent of interstellar medium (ISM)
  - Stars form from gas
- Gives kinematics



NGC 6946 Boomsma et al

- Galaxies look different in H I, complementary information

Cannot understand galaxies and their evolution without knowing about their H I and of their environment

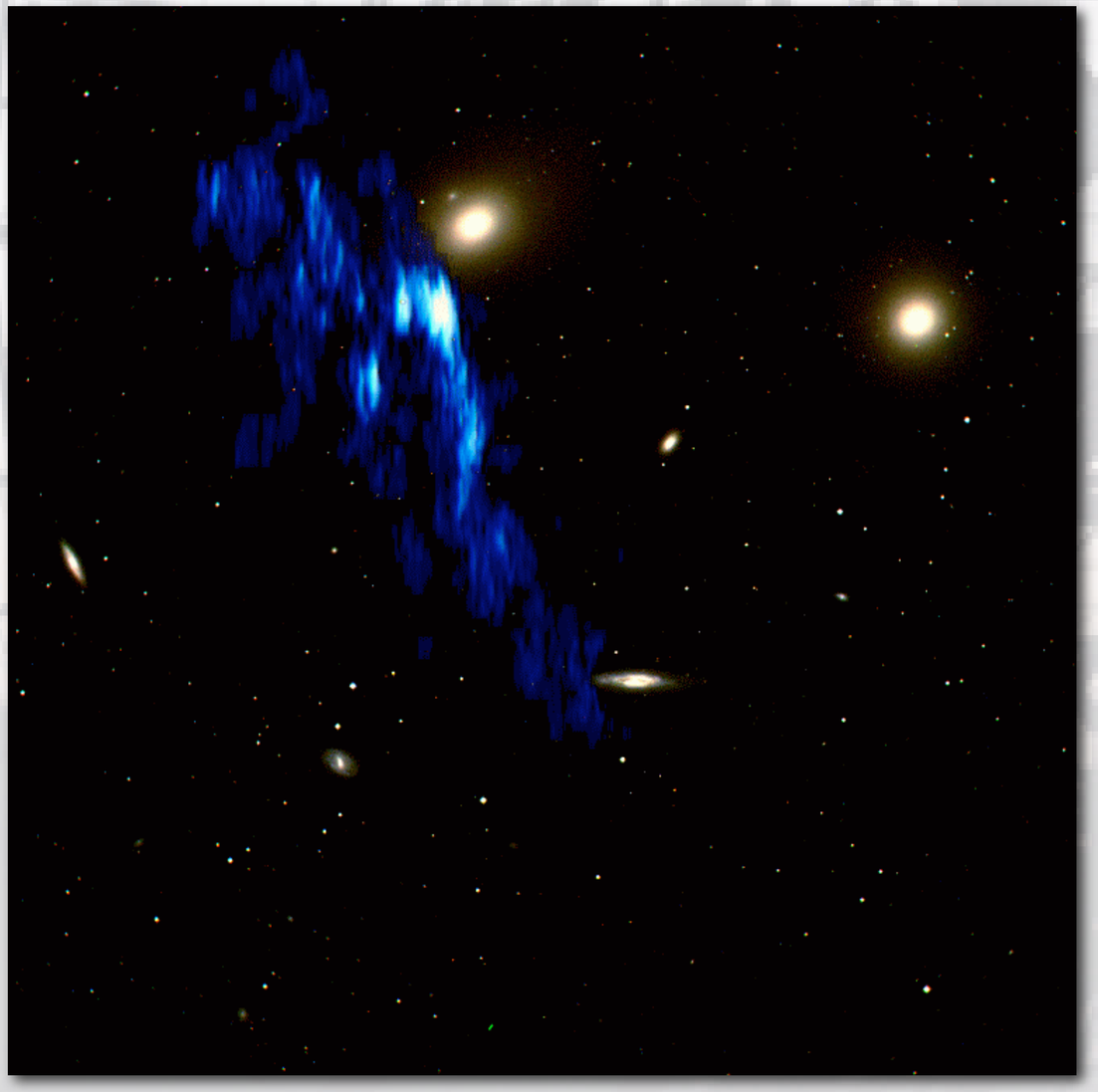


NGC 4414 Oosterloo

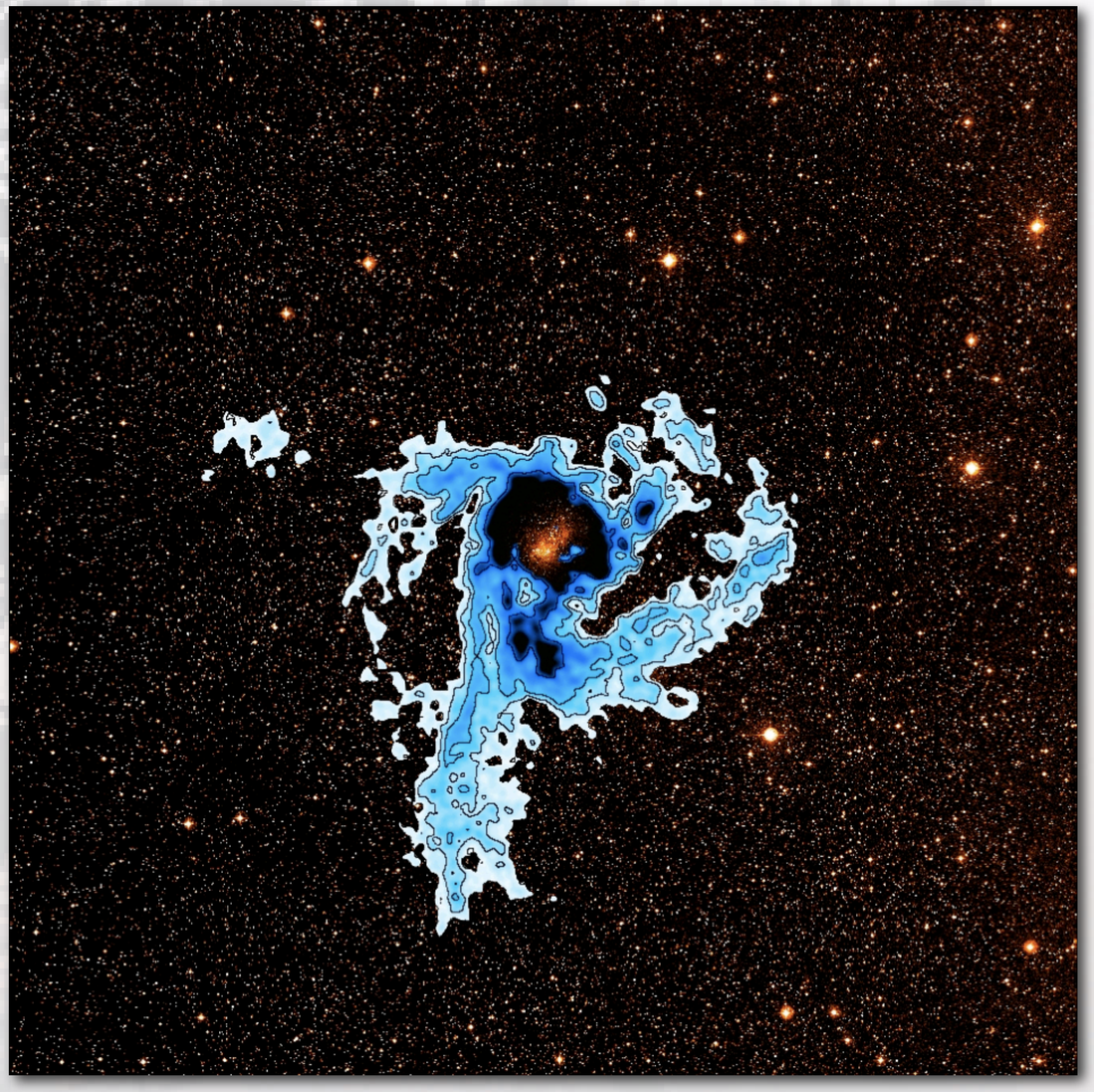
First mentioning of SKA: “The Hydrogen Array”

All sky: H I in galaxies

Detailed studies of structure of different kinds of galaxies in different environments
Statistics as function of environment



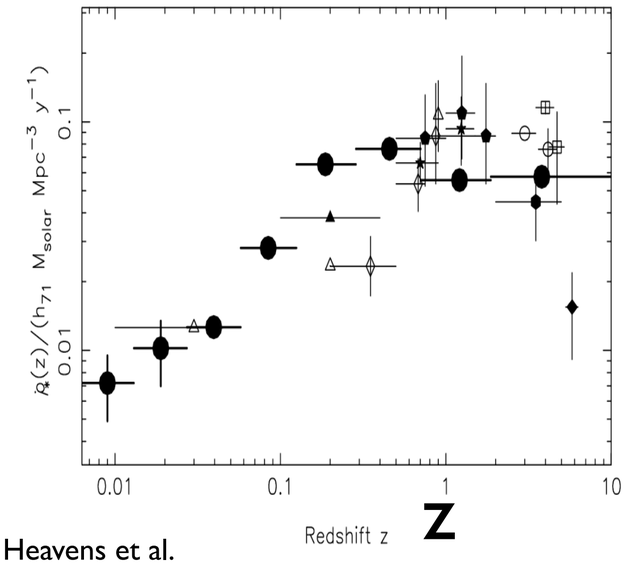
NGC 4388 in Virgo; Oosterloo & van Gorkom



IC 10; Manthey & Oosterloo

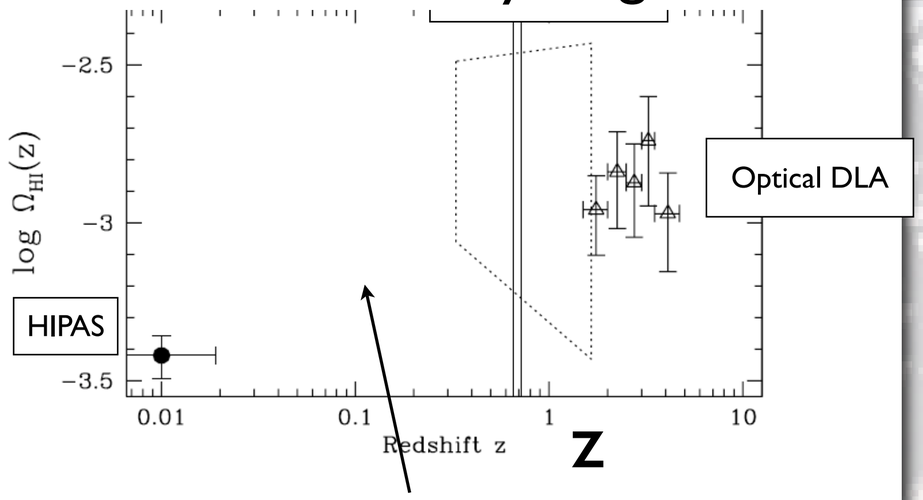
The issue: evolution of gas content & star formation

Star formation density



Heavens et al.

Cosmological density of neutral hydrogen



unprobed!!!!

Strong evolution of star formation and gas density.
Universe is slowly turning off the light?

WHY????

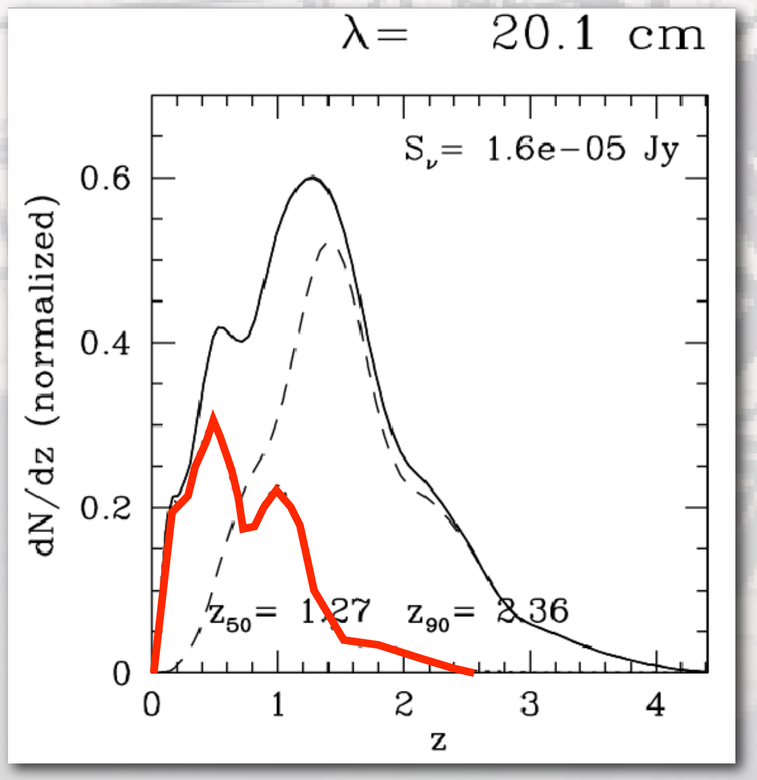
Stars form from gas so we need to observe the gas to understand this

NGC 6946 Boomsma et al

Combine with continuum (for free..)

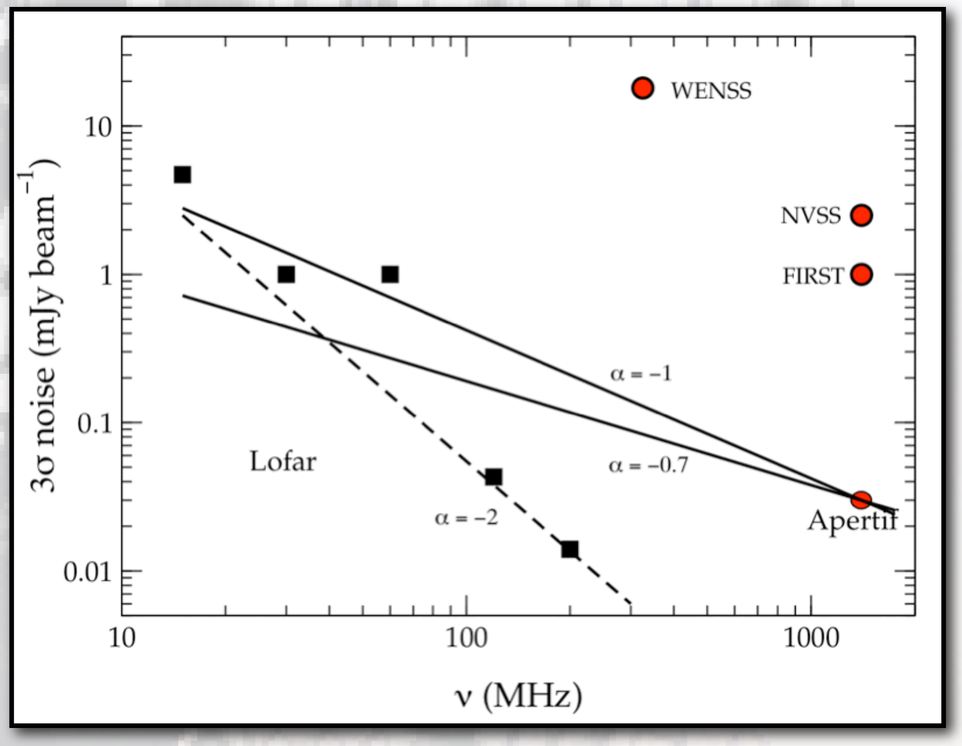
Continuum emission comes from
- Relativistic electrons in magnetic field
- Thermal emission from 10^4 K plasma

Both are connected to star formation
Will detect 10^7 sources



Baugh et al

Continuum images will be confusion limited



Apertif & Lofar complementary

Fainter sources detected in continuum survey
will be normal star forming galaxies up to z = 1
i.e. similar population as detected in H I.

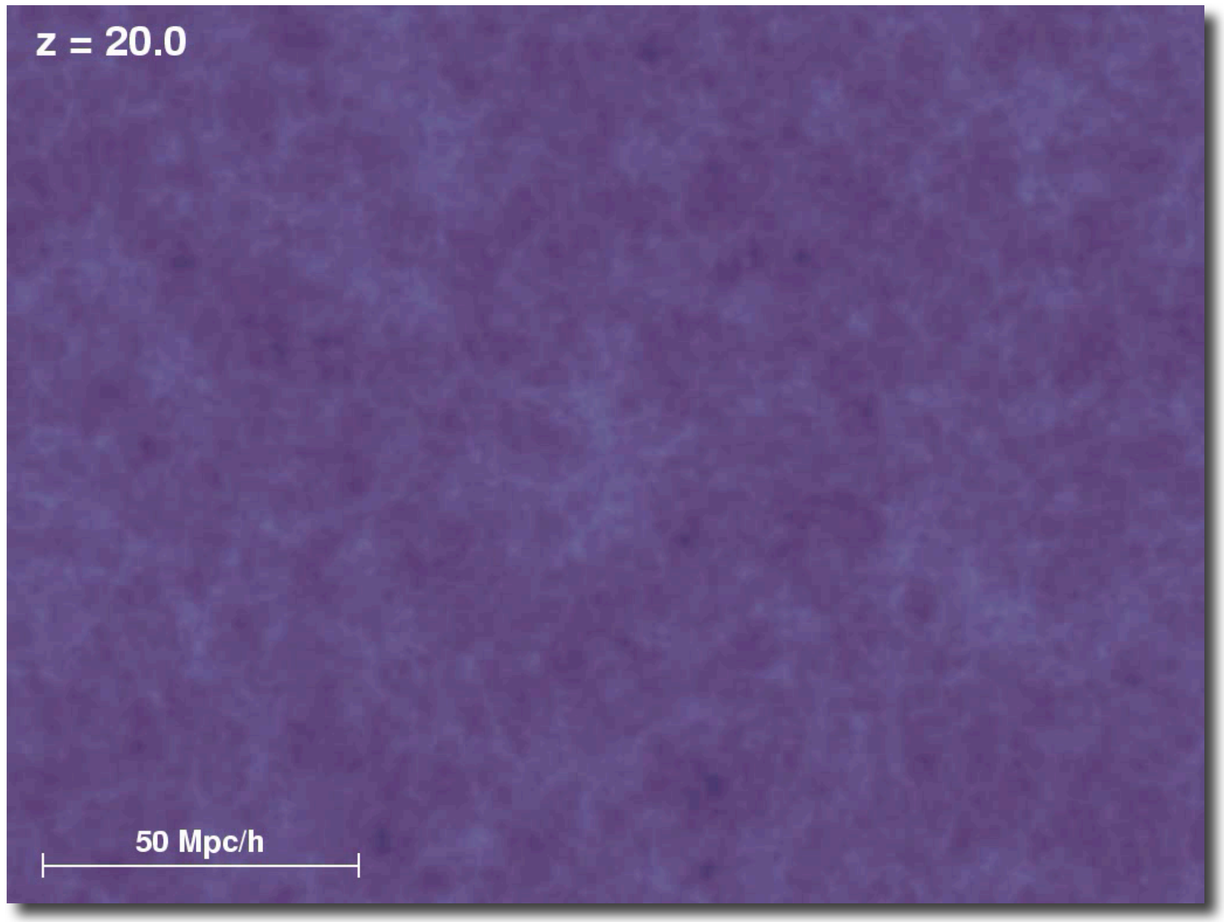
Survey measures both star formation & gas suply
over important cosmological period

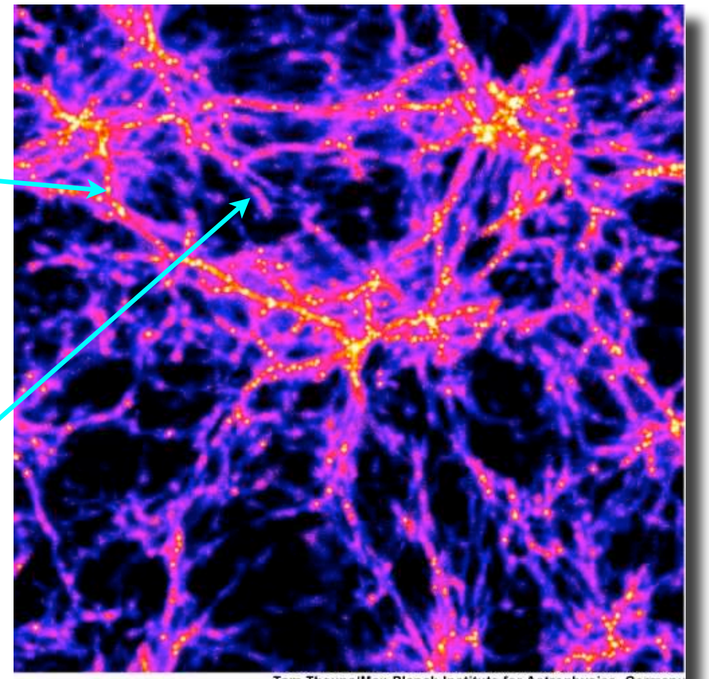
Galaxies form through gravitational collapse & accretion

- Movie of formation of structure over large volume

  (many many many galaxies)

Redshift $z = \Delta\lambda/\lambda_o$: measure of time/distance
z = 20: 13.5 Gyr ago. Universe is then 0.2 Gyr old
z = 5: 12.5 Gyr
z = 1: 7.7 Gyr
z = 0.1: 1.2 Gyr





endresult: Cosmic Web

The Cosmic Web

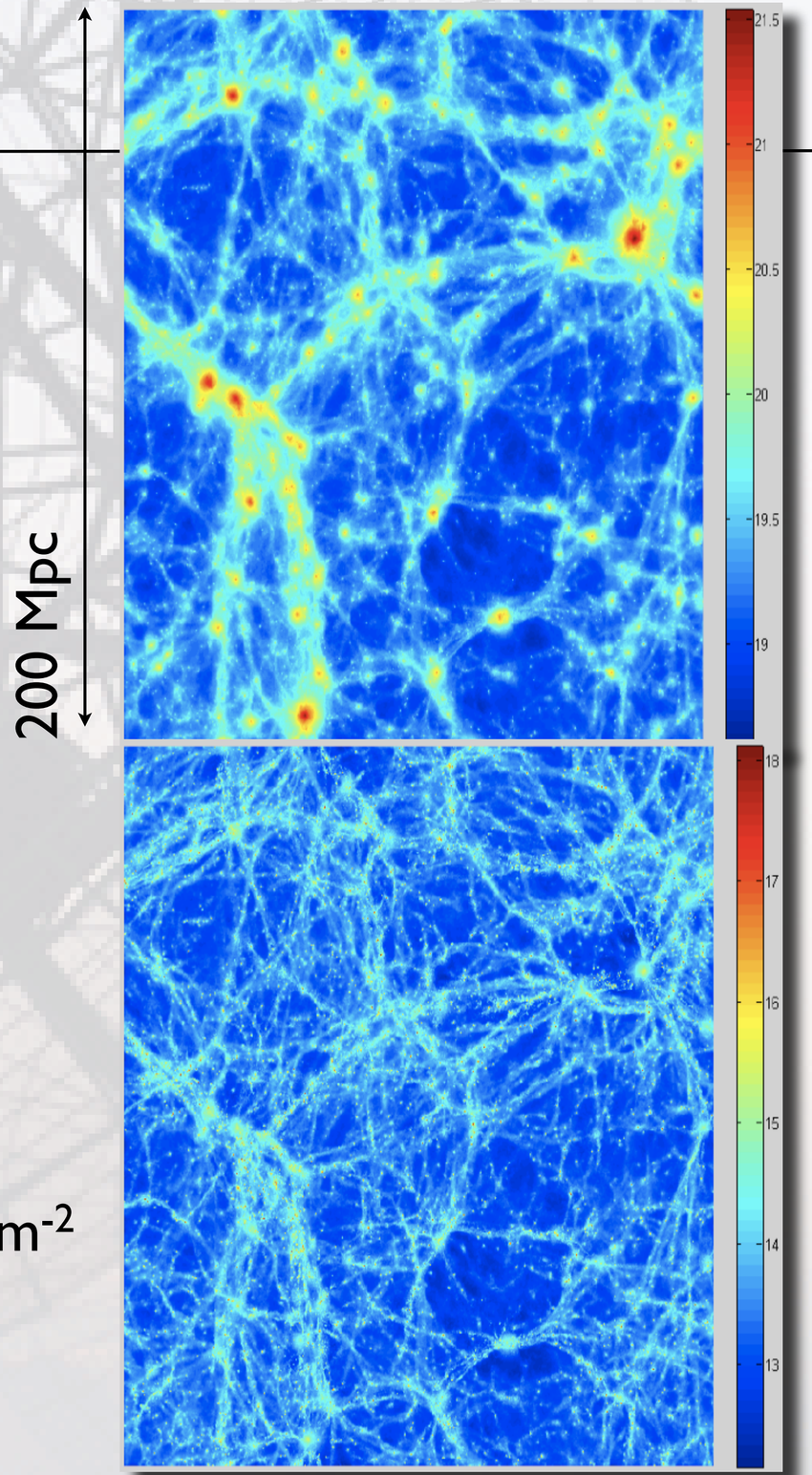
Inventory of cosmic energy density

75% Dark Energy (don't know what it is)
21% Dark Matter (don't know what it is, not baryons)
4% Baryonic matter

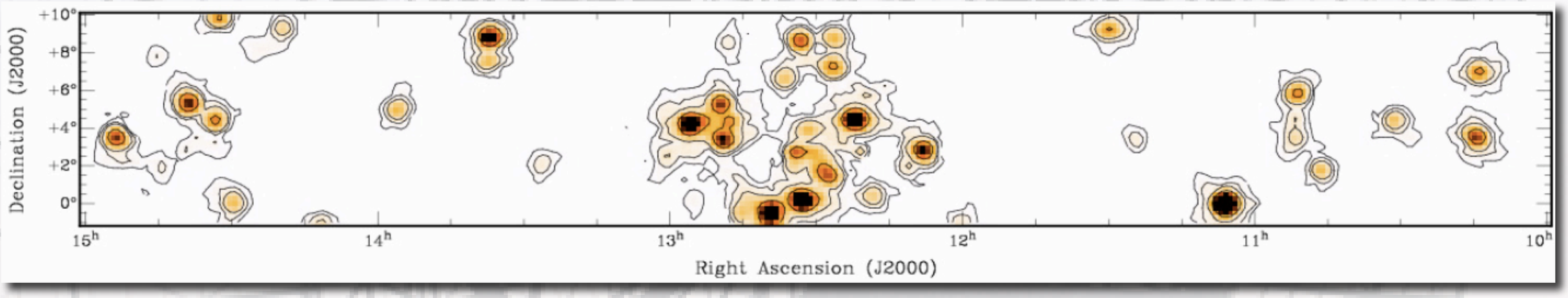
Of the baryonic matter, only 10-15% is in galaxies
(so only 0.5% of all mass/energy!!!!)

The rest of the baryons are "out there"
in the Cosmic Web as warm & hot gas (10^4-10^7 K).
Is very hard to detect!!!!

Does contain a small fraction of neutral gas.
Column density below 10^{19} cm^{-2} - Normal galaxies > 10^{20} cm^{-2}
This we can detect with deep, large-FoV surveys
Also gives kinematics



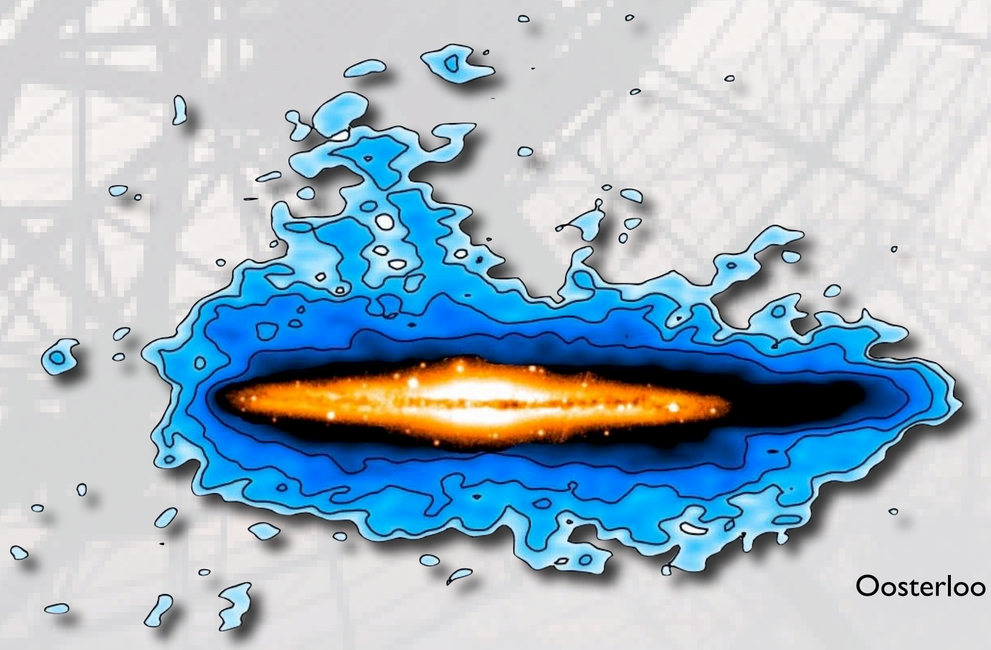
First tentative detections



Filaments in Virgo

Popping & Braun (WSRT)

Filaments around NGC 891
20 nights integration...



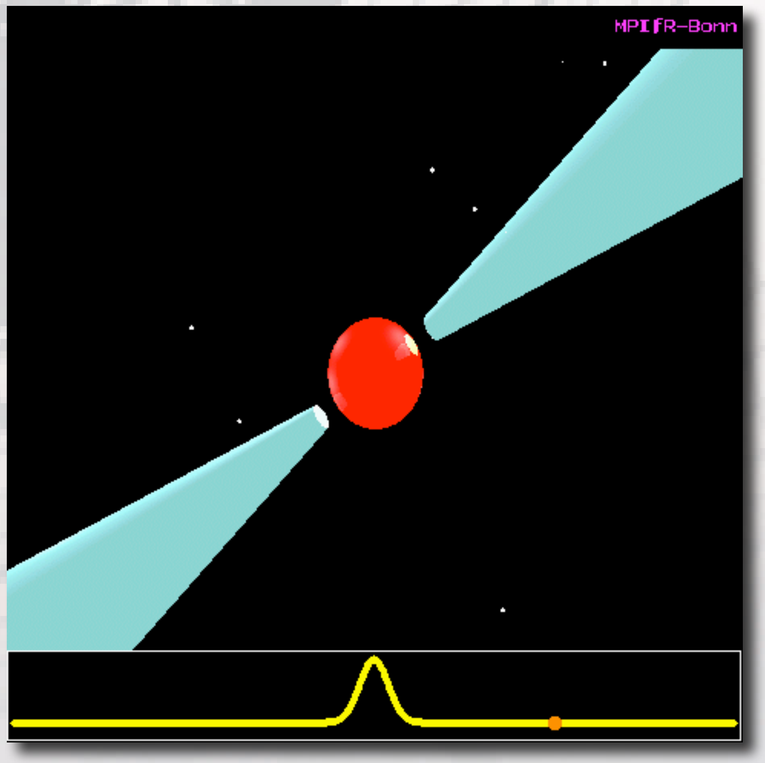
Oosterloo et al. (WSRT)

Pulsars

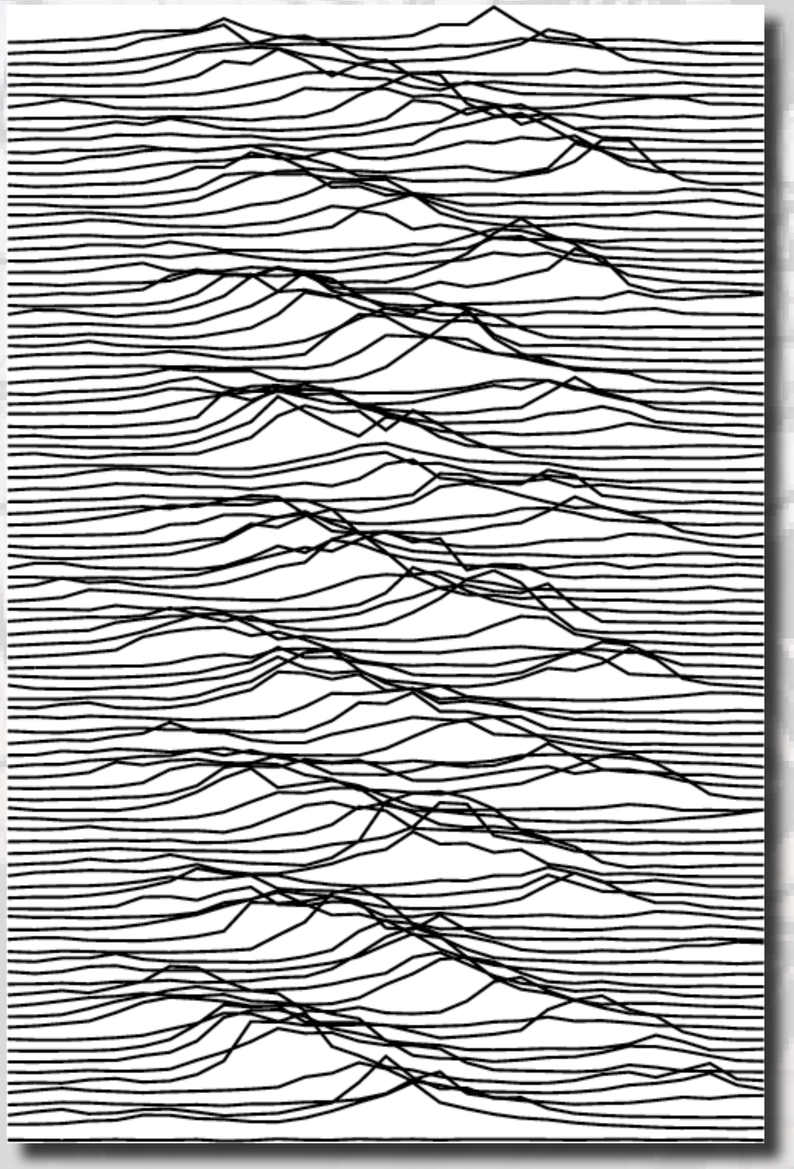
Pulsars are highly magnetised rotating neutron stars which emit a beam of electromagnetic radiation.
Their observed periods range from 1.5 ms to 8.5 s

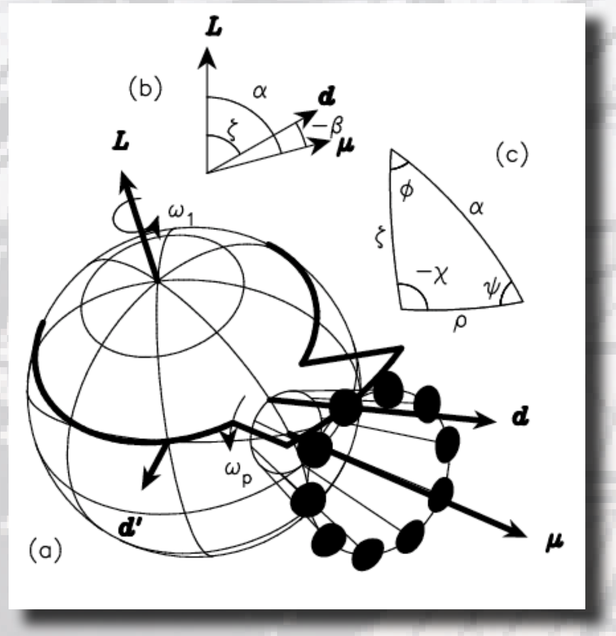
A neutron star is formed from the collapsed remnant of a supernova.
Mass 1.4 times the sun, diameter 10-15 km (!!!).
Density compares with that of atomic nuclei.
One teaspoon weighs 5×10^{12} kg ...
Magnetic fields 10^{12} - 10^{13} Gauss

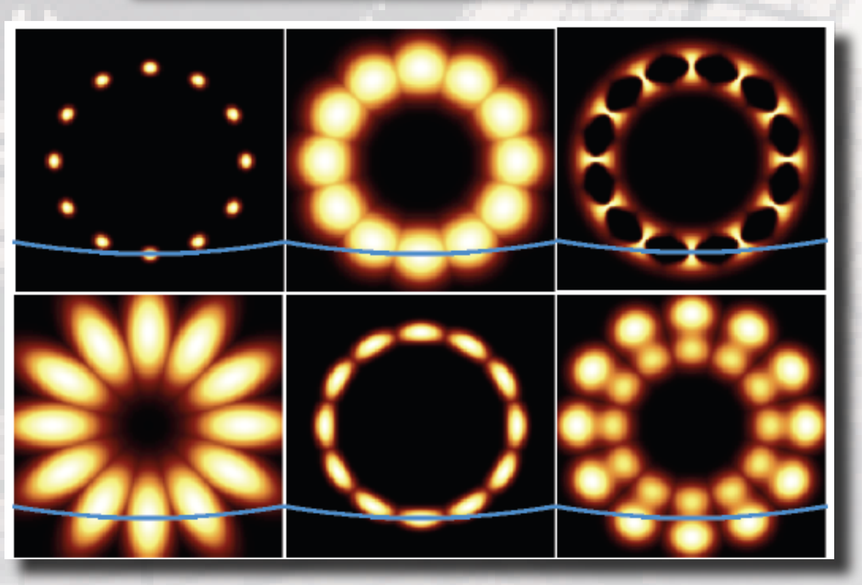
- Extreme (quantum)physics
- Tests of general relativity (binaries)
- Detection of gravitational waves
- ISM in Galaxy (through pulse dispersion)
- Radiation mechanism



Example: drifting sub-pulses







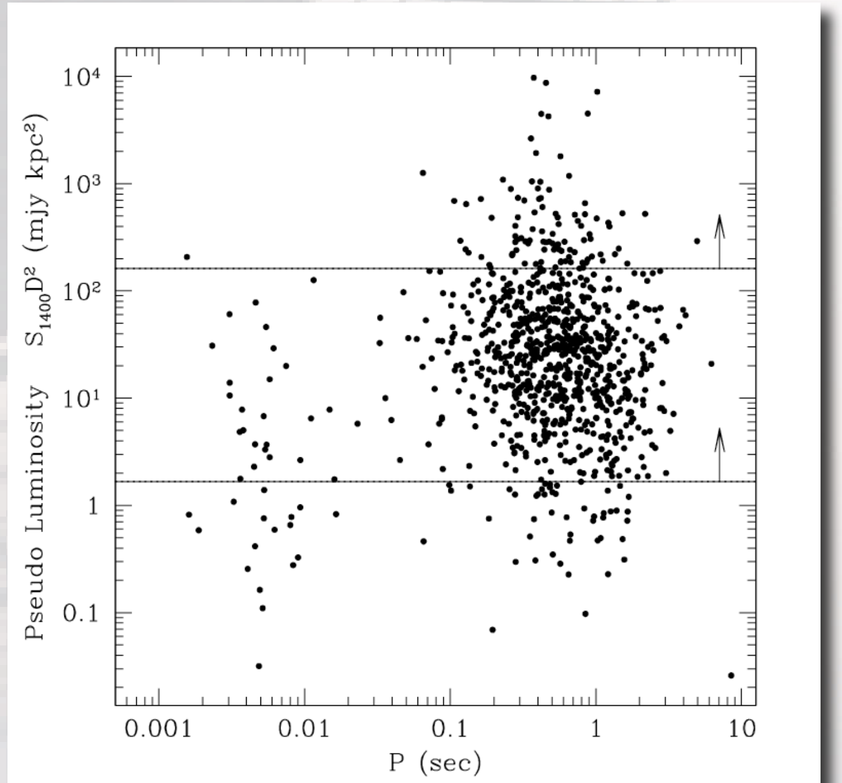
Sub-km imaging of polar cap of neutron stars

Pulsar surveys

- Lofar & Apertif will double the number of known pulsars
  Apertif the more distant ones
- On *northern* sky, important for timing experiments
- Galactic census of pulsars
- Search for pulsars in globular clusters, many expected.
  Probe stellar evolution
- Rare objects, e.g. MSP-Black Hole binary

10σ detection limit
at 100 kpc

10 kpc



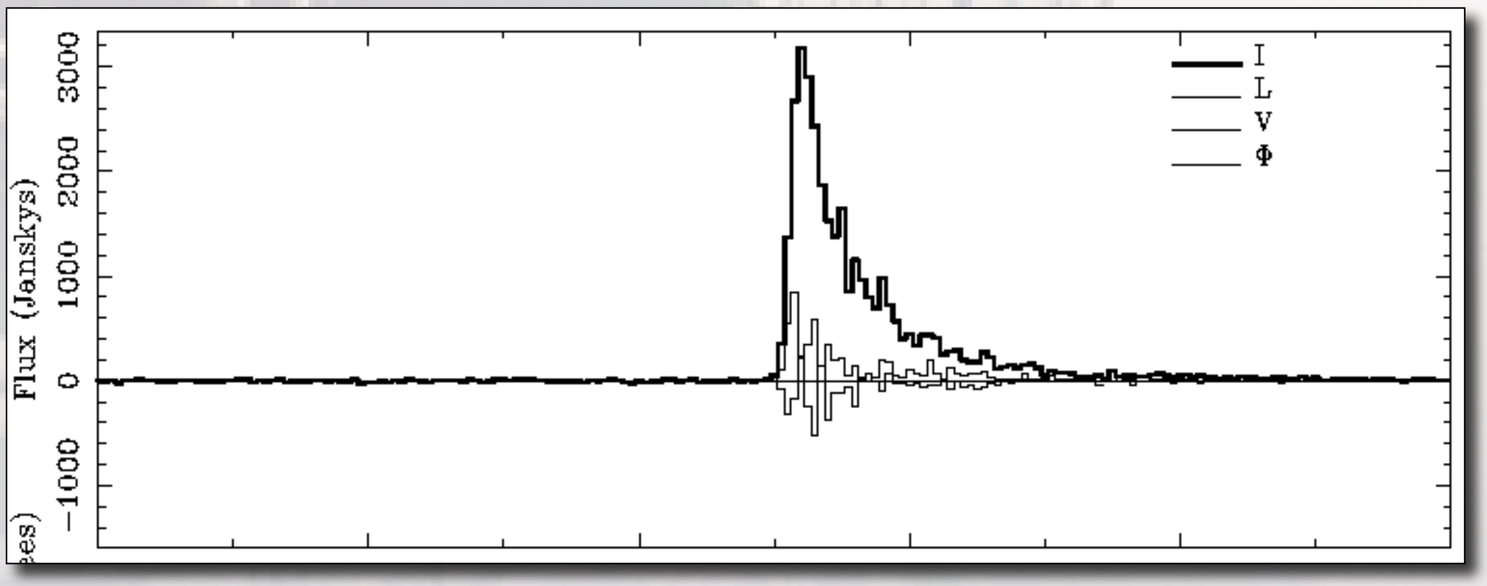
Transients

Large FoV allows to scan the sky quickly
example: NVSS continuum survey of northern sky (VLA) took 3 years

ASKAP can do the same in 1 (one) day....

So we can image same part of sky often and search for transient sources
This opens up new discovery space and could lead to a lot of new astronomy

- Flare stars
- Giant pulses
- Orphan Gamma-Ray Burts
- New types of objects



Giant pulse from Crab pulsar

Summary

Radio astronomy needs application of new technology to stay alive

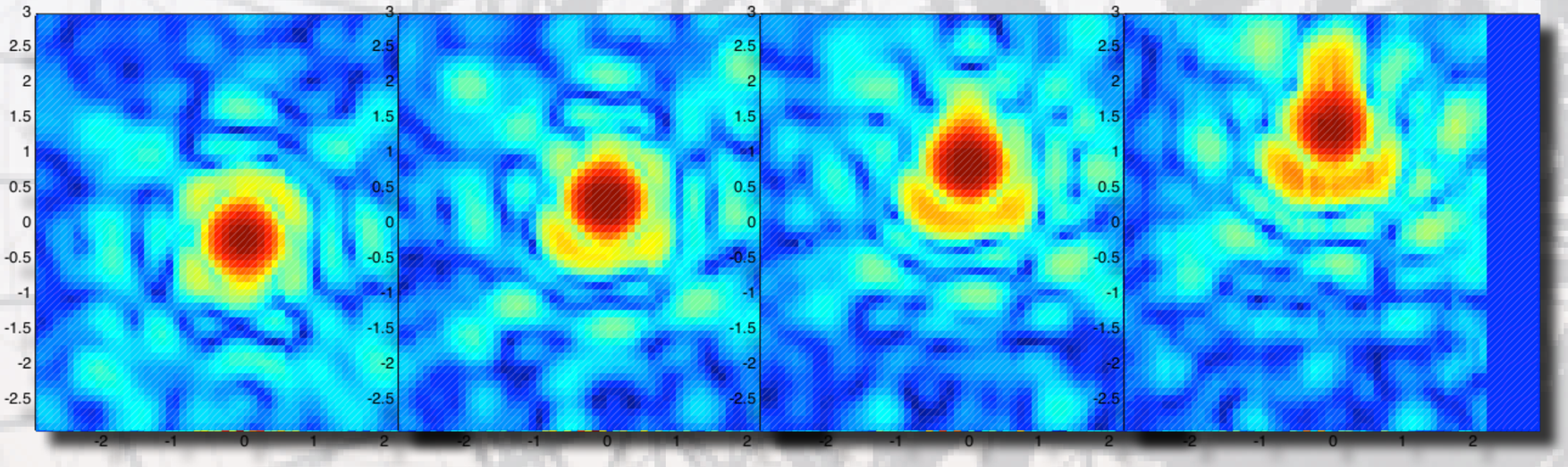
The large field of view offered by antenna arrays will enable significant progress on many important problems

- Evolution of star formation & gas content
- Kinematics of Cosmic Web
- Pulsars
- Cosmic magnetic fields (Galaxy)
- Transients
- ....

Observational astronomy is still about exploration.
Antenna arrays open up large discovery spaces so they will give us lots of

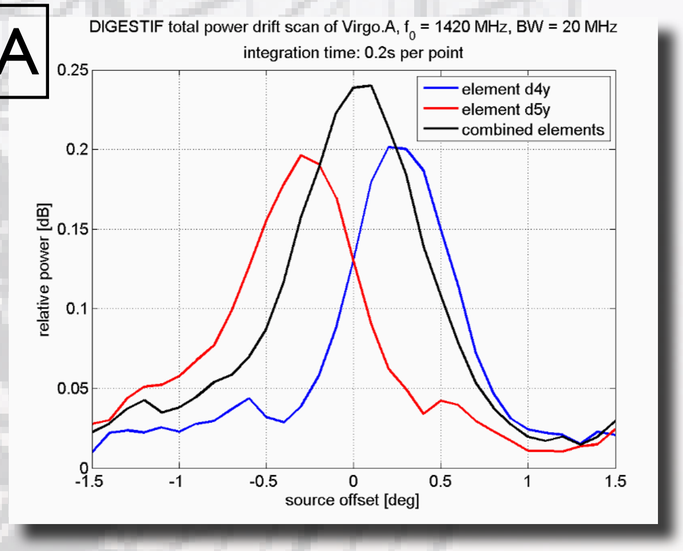
new astronomy

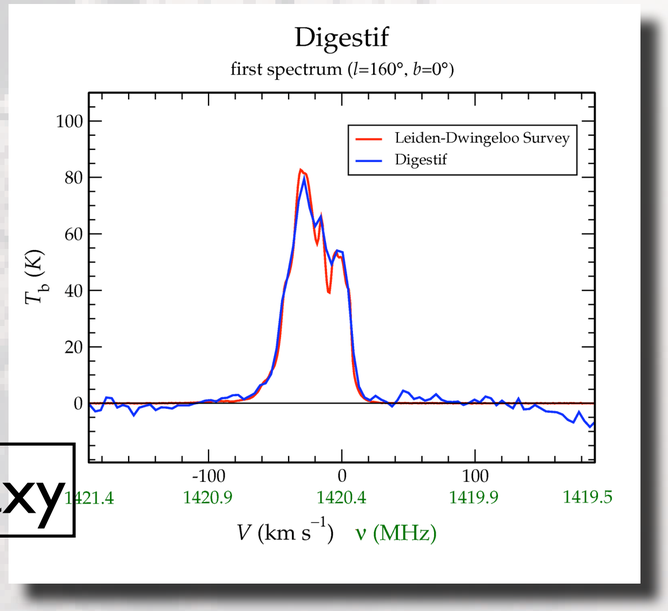
First astronomical observations with DIGESTIF



beam patterns measured in sky

Virgo A





H I in Galaxy

Prototype of a prototype of Apertif FPA on WSRT dish

Wim van Cappellen (friday)