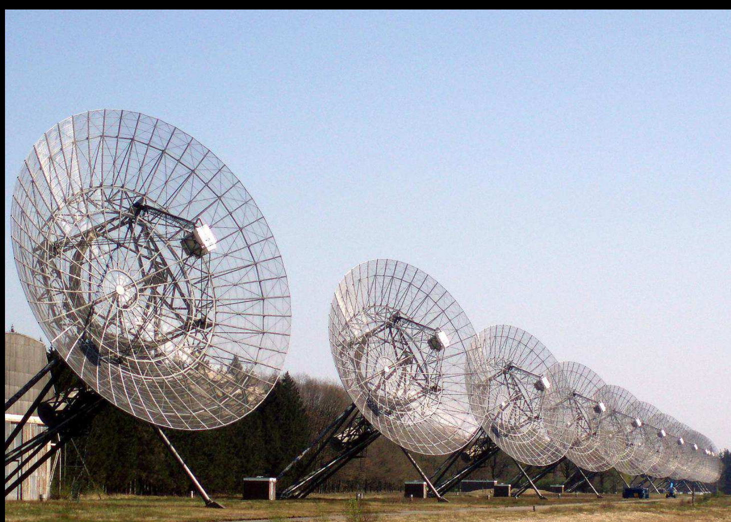
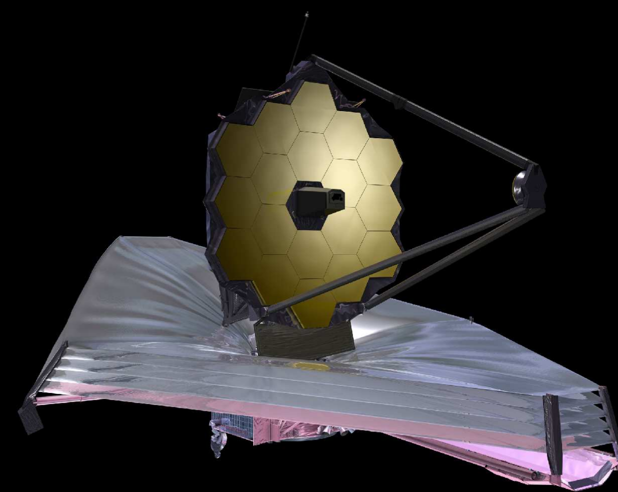
Deep Surveys with the Westerbork Synthesis Radio Telescope
Cosmic Star Formation & Supermassive Blackhole Growth

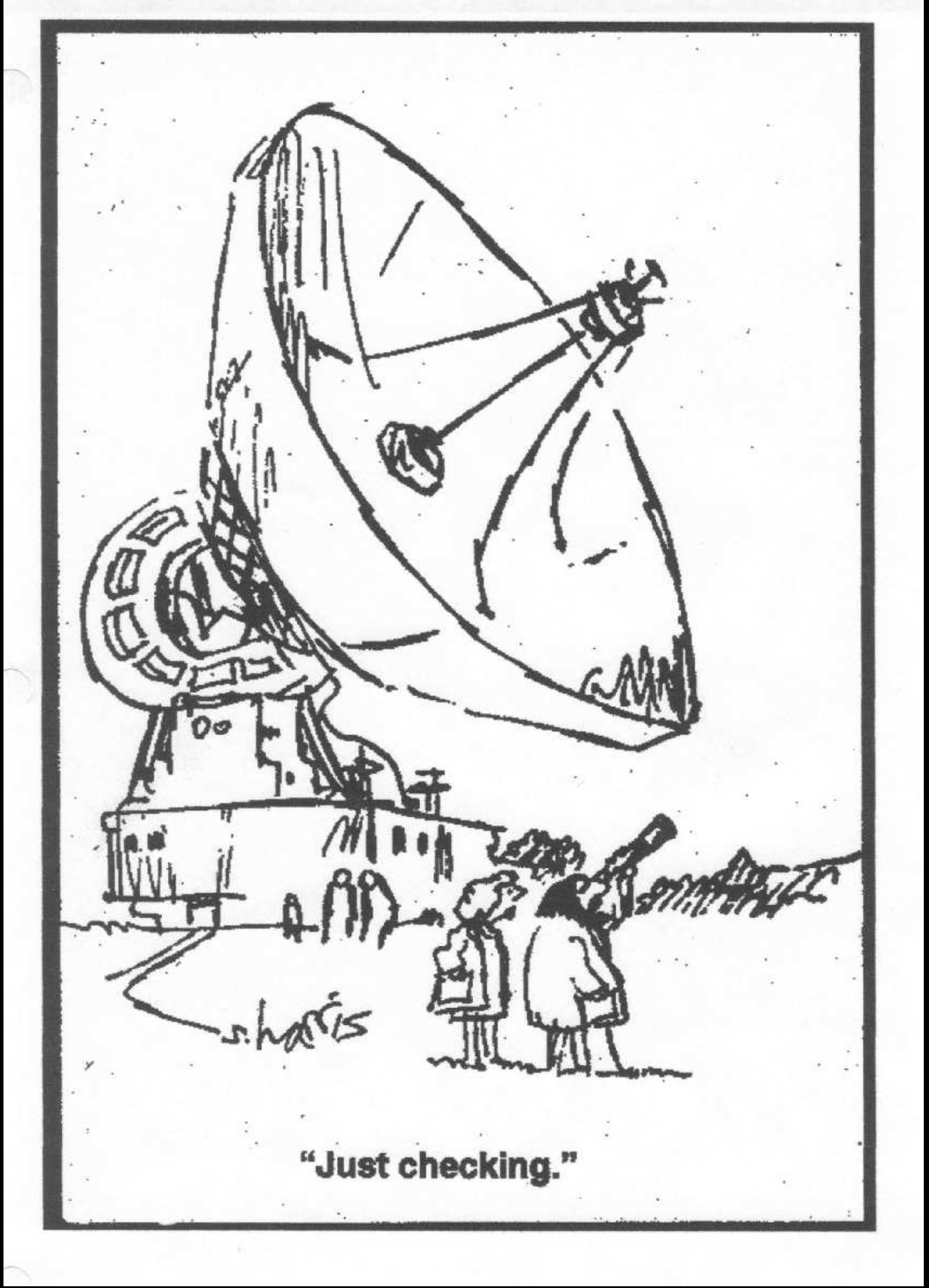
Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist





Symposium honoring Prof. Wim Brouw's 77th birthday

Radiosterrewacht Dwingeloo; The Netherlands, Friday, July 7, 2017



After my dissertation on WSRT, I worked on smaller telescope: HST & JWST.

- Wim Brouw has taught us the perfection of Radio Interferometry
- His work laid the foundation of Dutch Radio Astronomy
- It had other unintended, but beneficial side-effects: ...
- Unbeknownst to Wim, he is responsible for recruiting me into astronomy:

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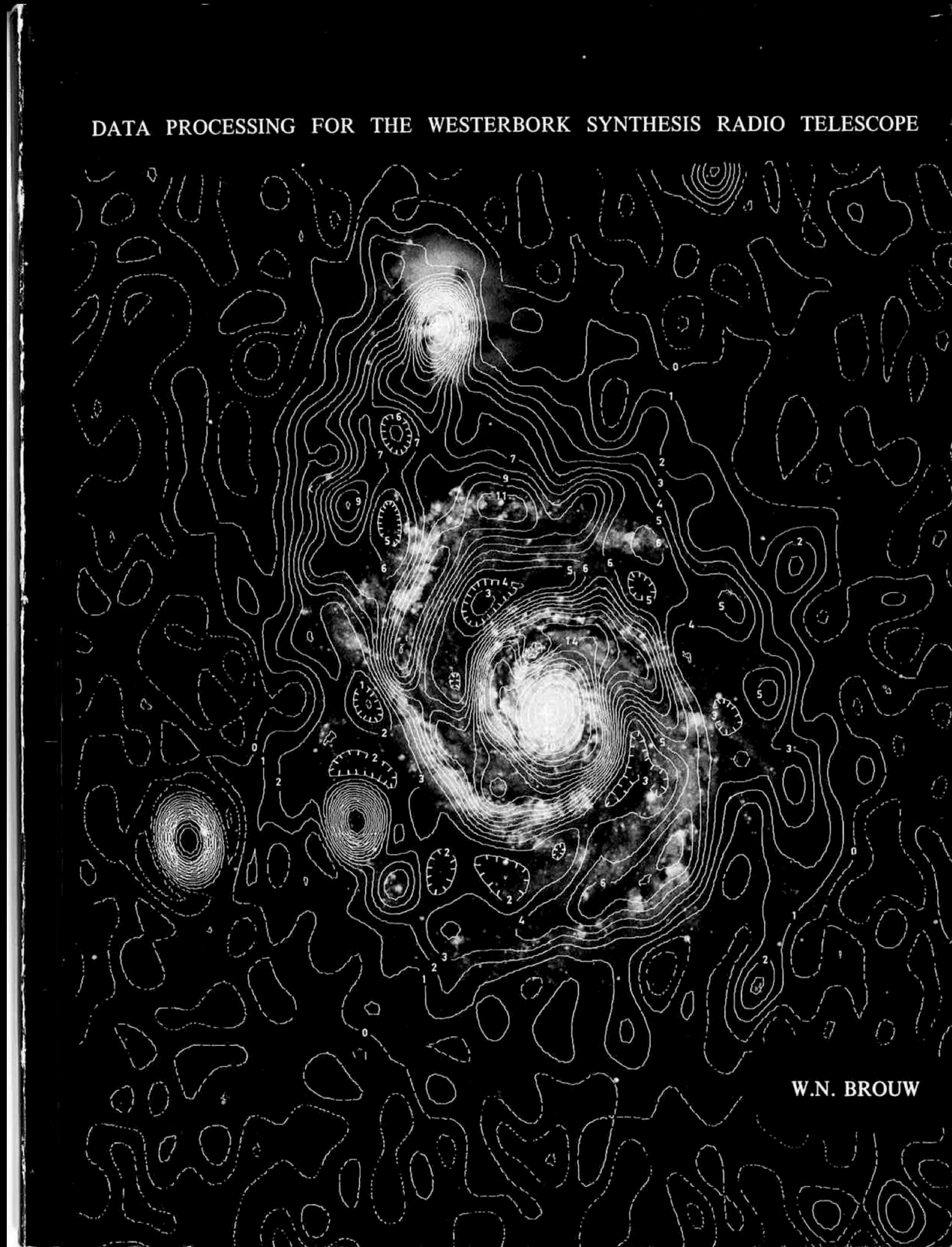
- Unbeknownst to Wim, he is responsible for recruiting me into astronomy:
- Wim and I went to the same highschool: Christelijk Lyceum in Dordrecht.
- In Sept. 1971, highschool teachers showed me the work of alumnus Wim:



- This caused a major phase transition in my life, and in their lives:

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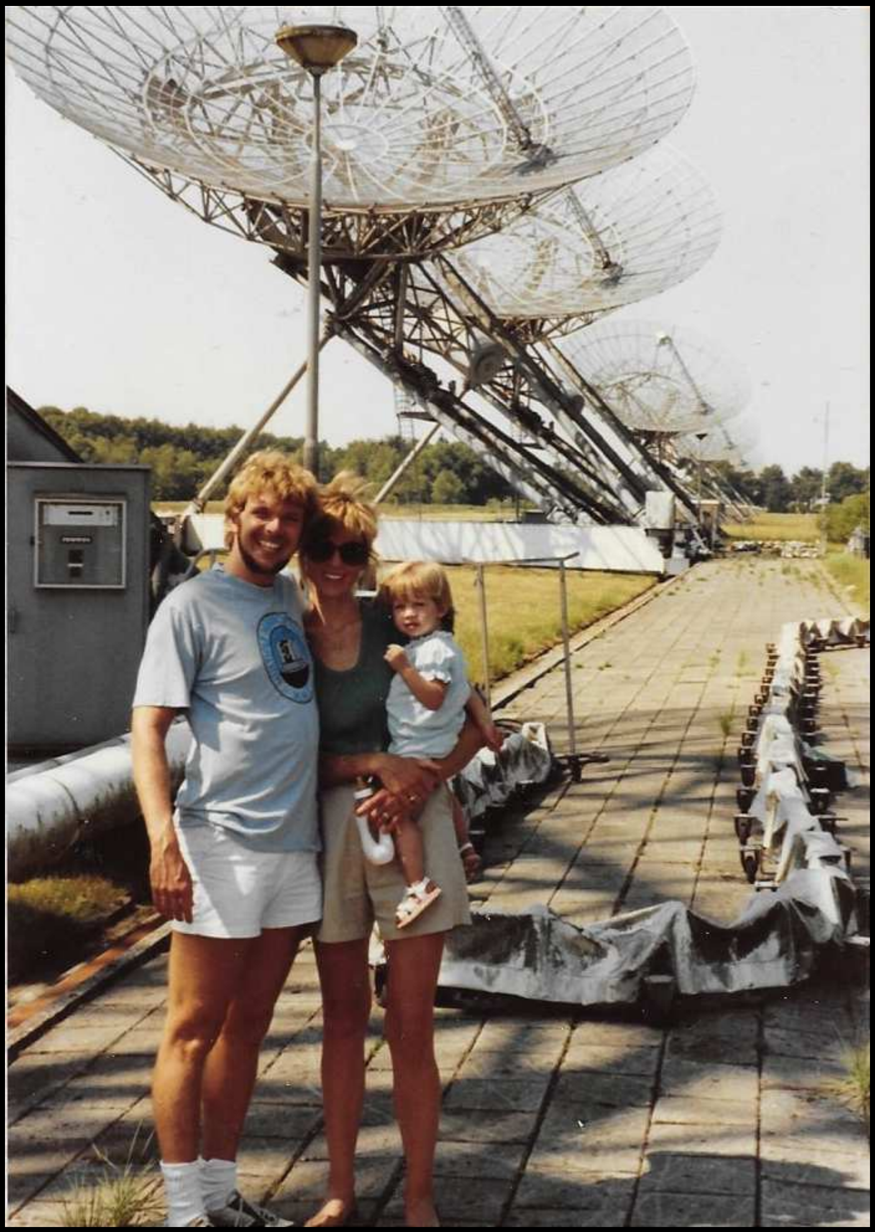
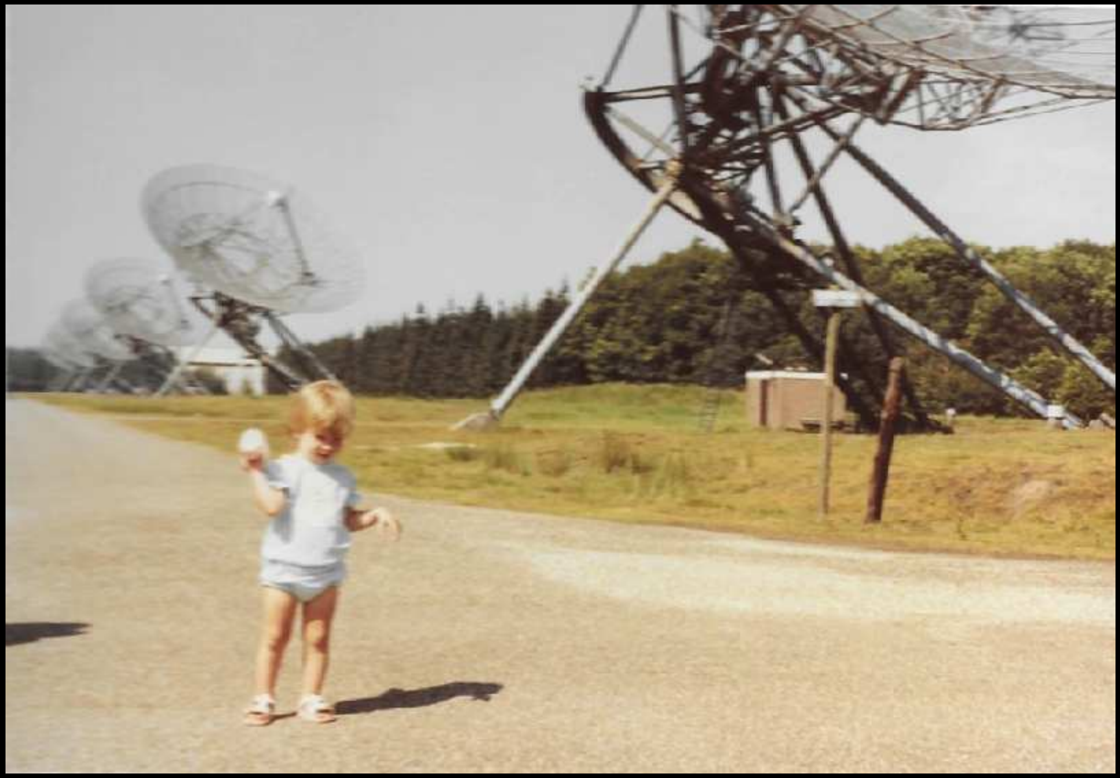
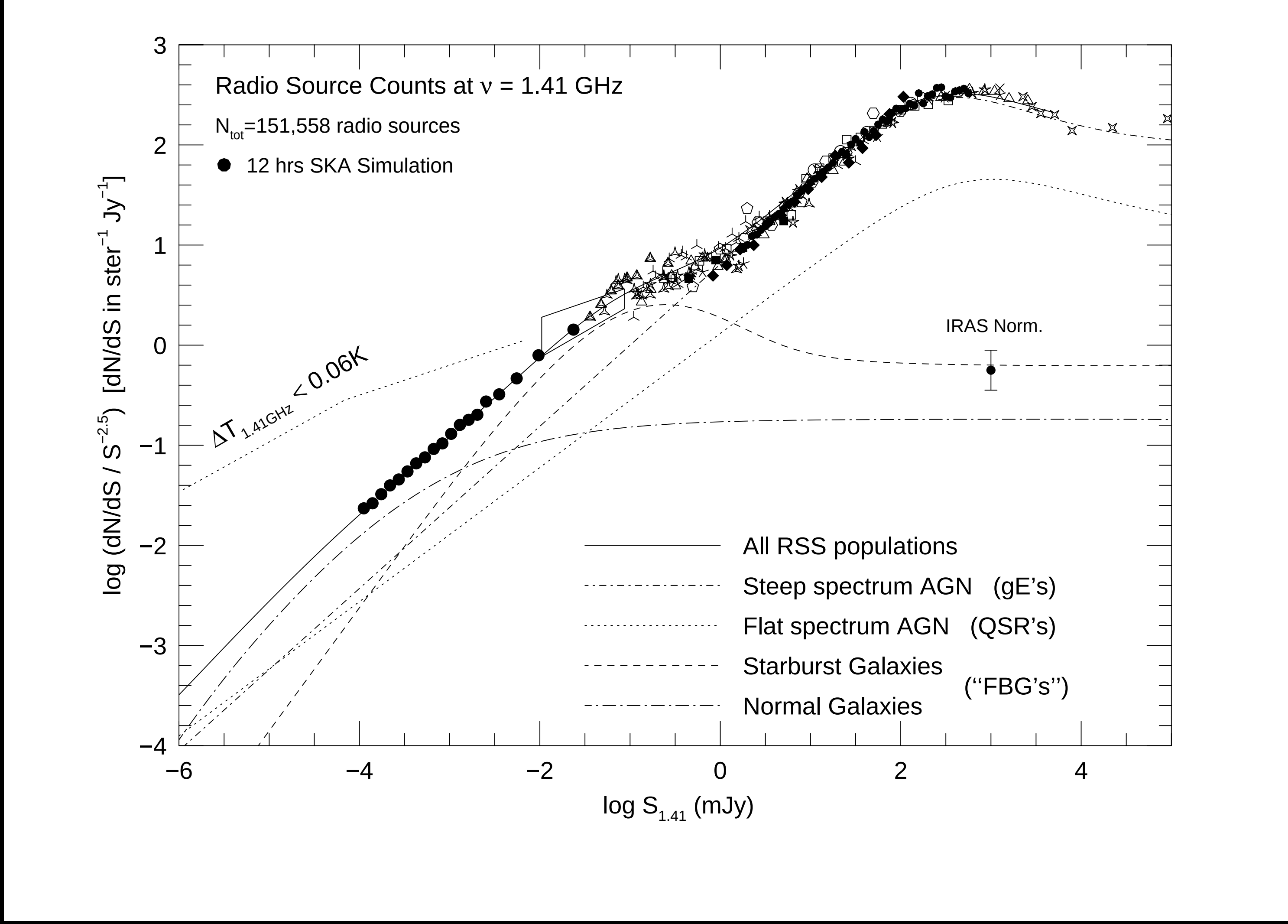
Drs. J. ten Hope (Physics):	"You ought to follow in Brouw's footsteps: Go work for Oort & van der Laan in Leiden."





Westerbork traced Cosmic Star Formation and Actively Galactic Nuclei:

- Young Objects and Old objects with redshift, or
- Stellar Birth and Stellar Demise over cosmic time.



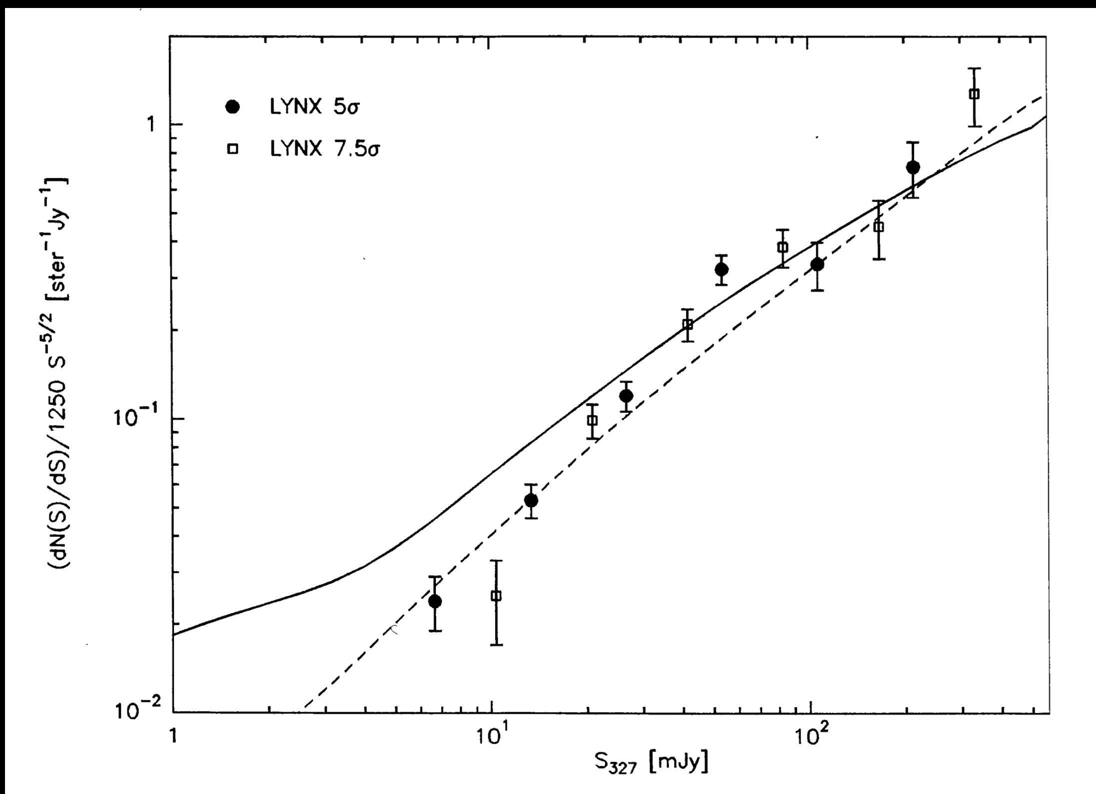
Normalized differential 1.41 GHz source counts (Windhorst et al. 1985, 1993, 2003; Hopkins et al. 2000) from 100 Jy to 100 nJy. Filled circles below 10μJy : 12-hr SKA simulation of Hopkins et al. (2000).

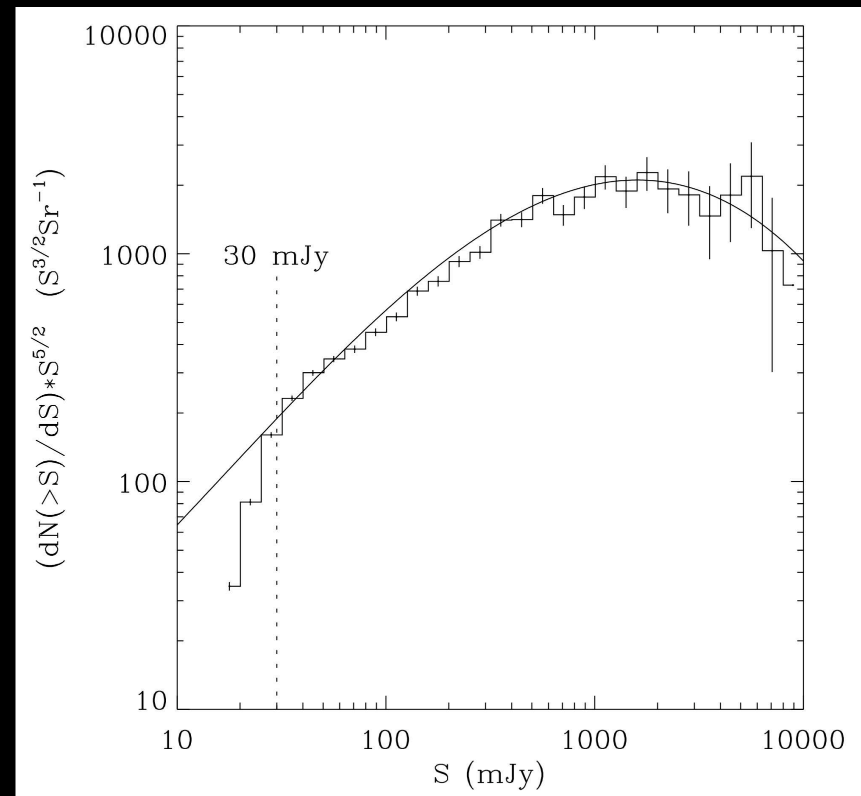
Models: giant ellipticals (dot-dash) and quasars dominate the counts to 1 mJy, starbursts (dashed) below 1 mJy. Normal spirals at cosmological distances (dot-long dash) will dominate the SKA counts below 100 nJy.

The Westerbork Northern Sky Survey (WENSS)

I. A 570 square degree Mini-Survey around the North Ecliptic Pole*

R.B. Rengelink[1], Y. Tang[2], A.G. de Bruyn[2,3], G.K. Miley[1], M.N. Bremer[1,4], H.J.A. Röttgering[1,4,5], and M.A.R. Bremer[1,6]





Upturn below 1 mJy in 1.4 GHz source counts not seen in WENSS and other WSRT 327 MHz surveys → upturn due to a flatter spectrum population?

- All such surveys only possible with WSRT's fantastic dynamic range thanks to Wim Brouw's perfected calibration methods (Rengelink et al. A&A Supp., 124, 25).

Go to page 1
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Upper Limits on the 21 cm Epoch of Reionization Power Spectrum from One Night with LOFAR

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Abstract

We present the first limits on the Epoch of Reionization 21 cm H I power spectra, in the redshift range $z = 7.9$–10.6, using the Low-Frequency Array (LOFAR) High-Band Antenna (HBA). In total, 13.0 hr of data were used from observations centered on the North Celestial Pole. After subtraction of the sky model and the noise bias, we detect a non-zero $\Delta_{\rm I}^2 = (56 \pm 13\ {\rm mK})^2$ (1-σ) excess variance and a best 2-σ upper limit of $\Delta_{21}^2 < (79.6\ {\rm mK})^2$ at $k = 0.053\ h\ {\rm cMpc}^{-1}$ in the range $z = 9.6$–10.6. The excess variance decreases when optimizing the smoothness of the direction- and frequency-dependent gain calibration, and with increasing the completeness of the sky model. It is likely caused by (i) residual side-lobe noise on calibration baselines, (ii) *leverage* due to nonlinear effects, (iii) noise and ionosphere-induced gain errors, or a combination thereof. Further analyses of the excess variance will be discussed in forthcoming publications.

Key words: dark ages, reionization, first stars

Due to Wim's — & Ger's — dedicated efforts to perfect LOFAR calibration, we're now getting close to an HI Reionization power-spectrum detection!!

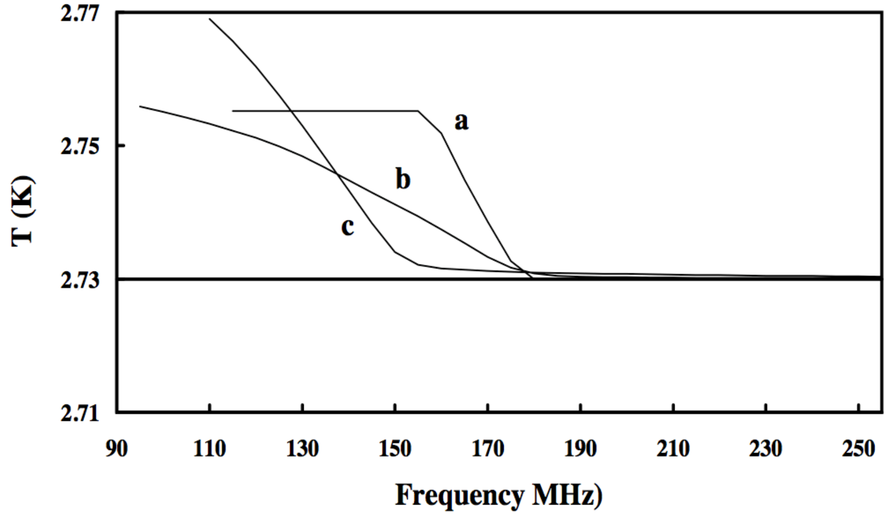

Fig. 1. Expected brightness temperature of the cosmic background in the vicinity of the H I reionization edge as a function of observing frequency. Three cases are shown for the H I step, (a): the case from Eq. (5) with $z_{ion} = 7, \Delta z = 1$ and $h = 0.7$, (b) and (c): revised results provided by N. Gnedin (private communication) from the simulations by Gnedin & Ostriker (1997) and Baltz et al. (1998) case A respectively, with $\Omega_M = 0.35, \Omega_\Lambda = 0.65$, and $h = 0.7$.

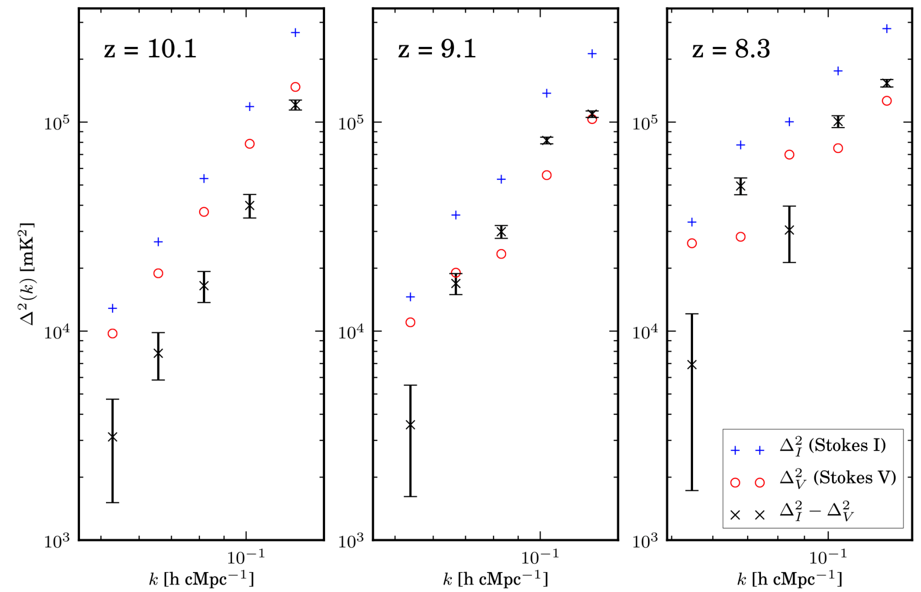

Figure 8. Spherically averaged Stokes I and V power spectra after GMCA for L90490. From left to right are shown the redshift ranges $z = 9.6$–10.6, $z = 8.7$–9.6, and $z = 7.9$–8.7 from left to right, respectively. The mean redshifts are indicated in the panels.

Table 3
Δ^2_{21} Upper Limits at the 2-σ Level

k (h cMpc^{-1})	$z = 7.9$–8.7 (mK^2)	$z = 8.7$–9.6 (mK^2)	$z = 9.6$–10.6 (mK^2)
0.053	$(131.5)^2$	$(86.4)^2$	$(79.6)^2$
0.067	$(242.1)^2$	$(144.2)^2$	$(108.8)^2$
0.083	$(220.9)^2$	$(184.7)^2$	$(148.6)^2$
0.103	$(337.4)^2$	$(296.1)^2$	$(224.0)^2$
0.128	$(407.7)^2$	$(342.0)^2$	$(366.1)^2$

beam. With the current 20,800 component model, we still notice improvements when new sources are added.

2. Include diffuse Stokes Q, U, and (if possible) diffuse Stokes I emission in the sky model and (if possible) avoid the split-baseline approach. This should reduce the excess variance as tests have shown, due to the elimination of *leverage*, while not suppressing diffuse emission.
3. Improve GMCA foreground subtraction, or replace it by a spectrally smooth diffuse foreground model and subtract it in the *uv*-plane on short baselines.

In Shaver et al. (1999), I never thought we'd see the z$\gtrsim$8 Reionization signal in redshifted Lyα — it's too close to the Geocoronal 1.083 μm He-line.

(see Shaver, Windhorst, Madau, & de Bruyn, 1999, A&Ap, 345, 380).

However, in redshifted HI, the Reionization signal may be tractable, if one can subtract all extragalactic sources and bright diffuse Galactic foreground.

- With state-of-the-art LOFAR calibration — first pioneered for WSRT by Wim Brouw — we're getting close to an HI Reionization power-spectrum detection! (see Patil, Yatawatta, Koopmans, de Bruyn, et al. (incl W. N. Brouw), 2017, ApJ, 838, 65).

Thank you, Wim, for everything you did for Dutch (Radio) Astronomy:

- For mailing a copy of your career-changing Dissertation to Dordrecht!
- For your state-of-the-art, triple-blackbelt calibration pipelines!
- For enabling WSRT (and LOFAR) to obtain the very best dynamic range.
- For enabling WSRT to do very high-fidelity, deep radio surveys.
- For your excellent, sustained leadership in Dutch Radio Astronomy!

SPARE CHARTS