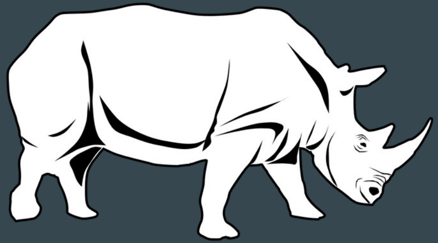
# RHINO

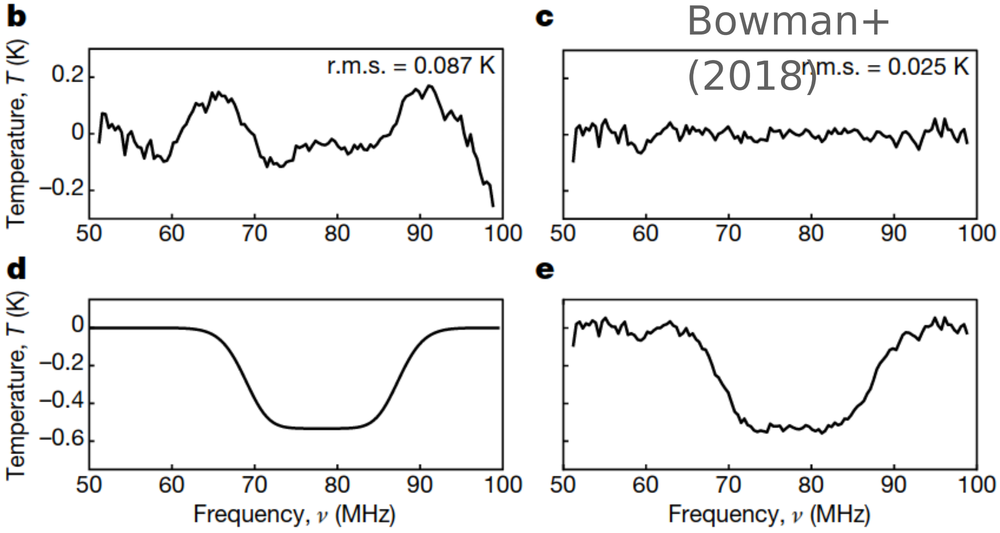
## Detecting the 21cm global signal with a giant horn antenna


Phil Bull, Hugh Garsden
Jodrell Bank Centre for Astrophysics

***RHINO: R**emote **HI***
*e**N**vironment **O**bserver*

# The EDGES result




Bowman+ (2018)

Current experiments all tend to have compact antennas (mostly dipole derivatives, but also monopole/discone etc.)

***If we measured the same signal with a radically different type of antenna, would we be convinced the signal was real? I think yes!***

# So why a horn antenna?

Horn antennas have appealing properties for precision spectrometry:

- High suppression of sidelobes and backlobes
- Good control over beam shape, cross-pol. etc.
- In-built shielding from the environment (RFI, groundspill); easier to model
- Non-resonant design – reduced risk of standing waves etc.

Horn antennas have a compelling heritage for precision spectrometry (particularly CMB).


# Why *not* a horn antenna?

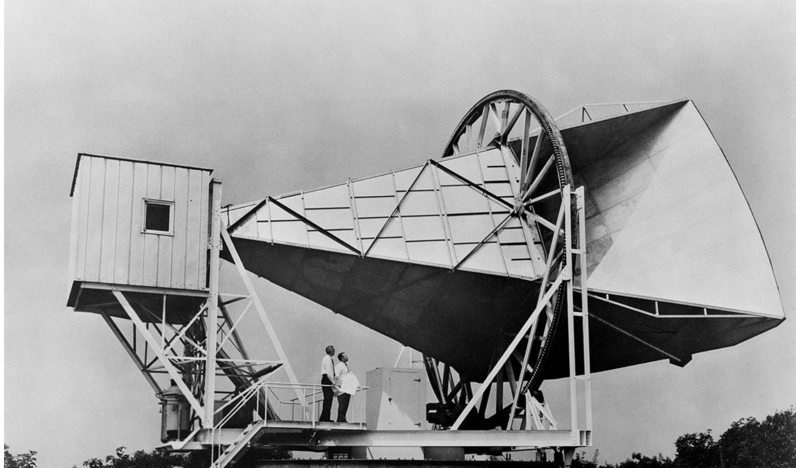
EDGES-like band. At 70MHz (λ ~ 4m), a minimal horn design has:

- ~3λ aperture = 12m
- >3λ height = 12m
- Surface area (pyramidal) > 350 $m^2$

Big and unwieldy; heavy and moderately expensive. Hard to point. Wind loading.

Corrugations etc. (maybe needed inside) even more unwieldy.

Where can you put something that is >12m high with (a) low RFI; (b) stability/weather protection?



# Potential sites

Need a *very* remote location to avoid FM radio. Logistics would be very difficult! Find somewhere closer to home?

Northern hemisphere is desirable to contrast with southern/equatorial experiments.

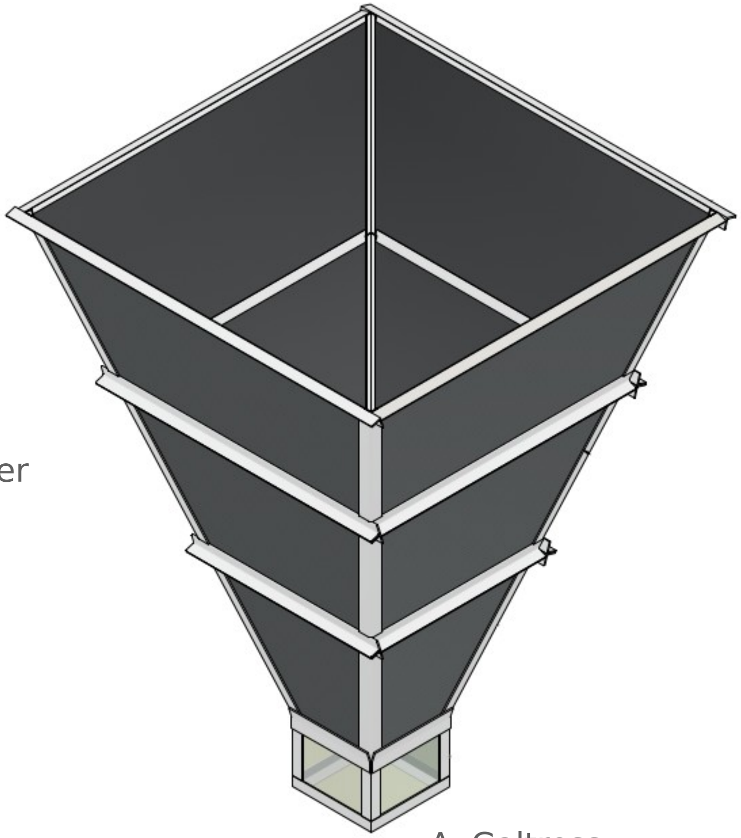
- Svalbard Ny-Ålesund VLBI station (78.9°N) *[no FM radio in Norway!]*
- Greenland Telescope (76.5°N)
- Unst spaceport, Scotland (60.8°N) *[far from nearest FM transmitter]*
- Llanbedr spaceport site, Wales (52.8°N) *[nearby valleys are in FM shadow]*
- *Jodrell Bank is at 53.2°N*
- Engineering challenge of building a ~12-15m tall horn is straightforward, but strongly contingent on site properties (foundation, wind etc.) Ground screen!?

If we go far enough north, we can observe the North Celestial Pole close to zenith, which has nice properties for a drift-scan field.

# Let’s build a protoype first!

We want to build a **prototype horn** to test fabrication methods, detailed design, beam characterisation methods etc. before we build a giant one!

- 5:1 scale model
  - Use similar materials and methods, but still much smaller
  - The design can simply be scaled down
  - Can use essentially the same receiver (except filters)
- Shift 100MHz observing band up to 350 MHz (~80cm)
  - Quite low RFI around 350 MHz (aero navigation at 328 – 335 MHz; meteorology/space ~400 MHz; UK digital TV 470 – 860 MHz)



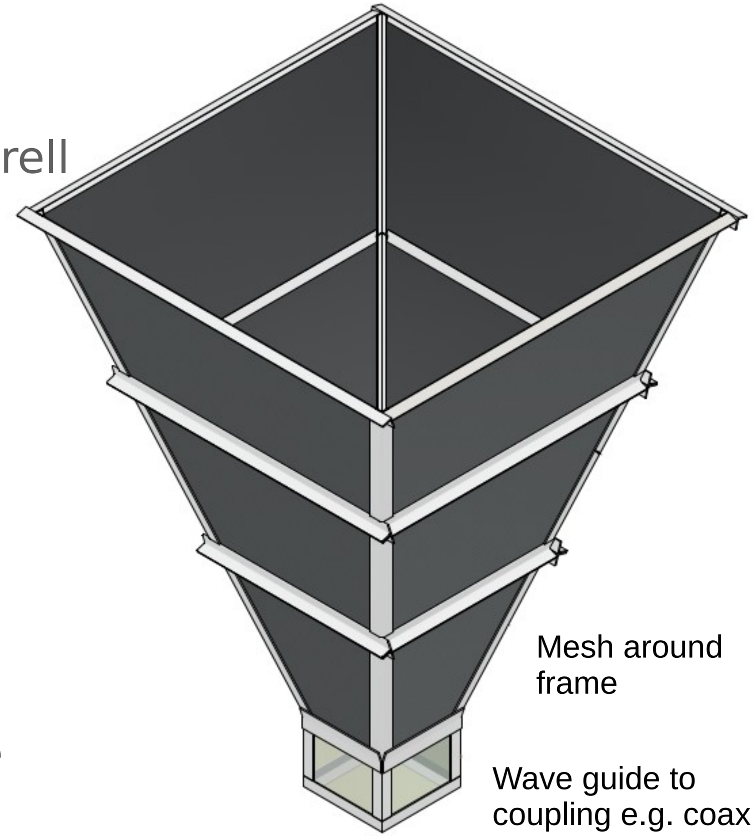
A. Galtress

# Basic prototype horn

“Version 0” prototype: wood frame on site at Jodrell Bank; mesh surface, built in modular sections

Planned experiments:

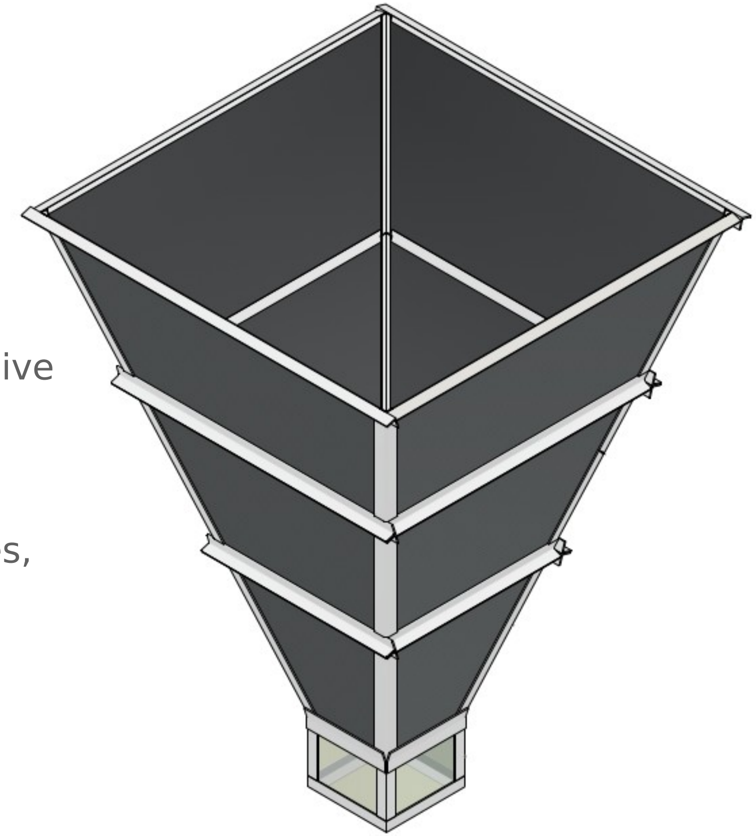
- Attach chokes at aperture (to suppress backlobe)
- Experiment w. twisted waveguide (“diagonal horn”)
- Small enough to move/rotate/tilt for beam pattern measurements (far field at >12.4m)
- Test different methods for joining conductive panels  (mesh)



# Horn prototyping roadmap

After the “Version 0” horn:

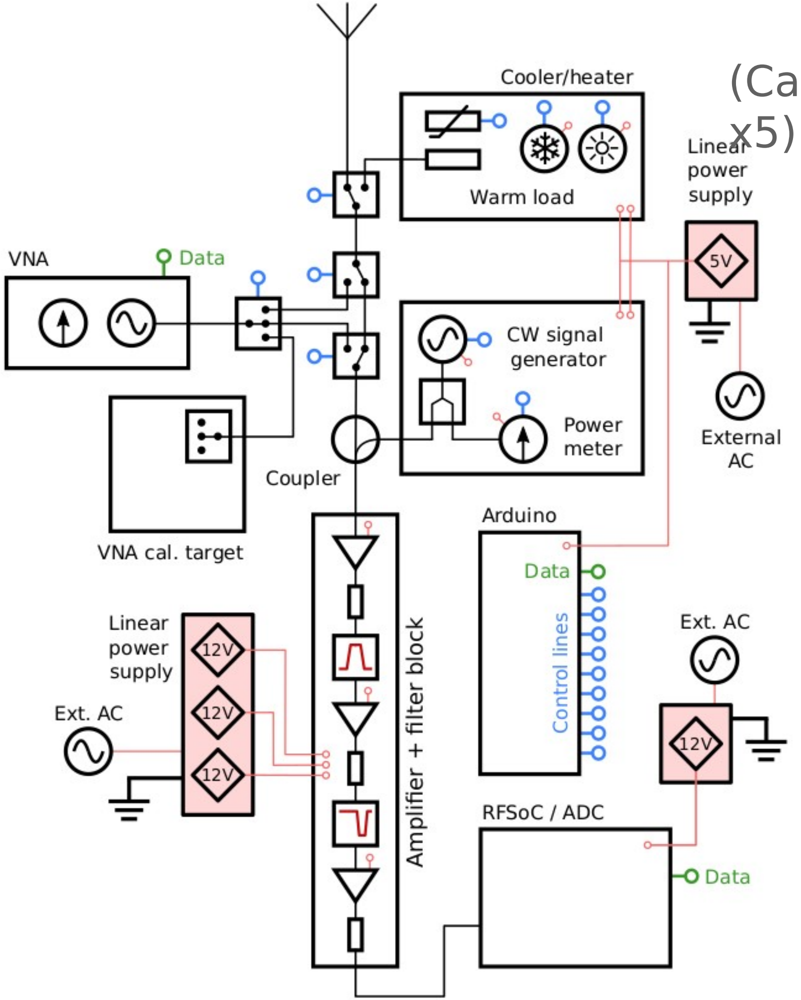
- Improved EM modelling and design optimisation
  - Limited by what can be fabricated without excessive cost
- Is a conical (circular aperture) feasible?
  - Better beam symmetry and polarisation properties, but harder to build
- Are corrugations, ridges, or multi-taper feasible?
  - Better beam shape, reduced side/backlobes, but harder and more expensive to build



# System diagram

(bit out of date now)

- Use **continuous wave** calibration for gain drifts (instead of noise diodes)
- Temperature-controlled reference loads (like other expts), absolute scale
- Use **built-in VNA** for in-situ reflection measurements (like other expts)
- Use off-the-shelf components where possible to get up and running quickly
- Rely on filtering rather than seeking very radio-quiet site (difficult logistics)




(Cal. load x5)

# Continuous wave calibration

Inject a constant, pure sine wave source via a signal generator + coupler

- No switching required; the CW is always present in the data. No changes in signal path reflection characteristics etc.
- CW amplitude can be very large (high SNR)
  - Only lose a single narrow frequency channel
  - *Total power* injected is still low; no issues with linearity etc.
- Monitor CW source using a power detector to ensure stability
- Need to assume that gain fluctuations are strongly correlated across the band
  - This *should* be the case, but can test for deviations by shifting CW frequency and/or injecting a comb instead of a single frequency spike

# Gibbs sampler pipeline

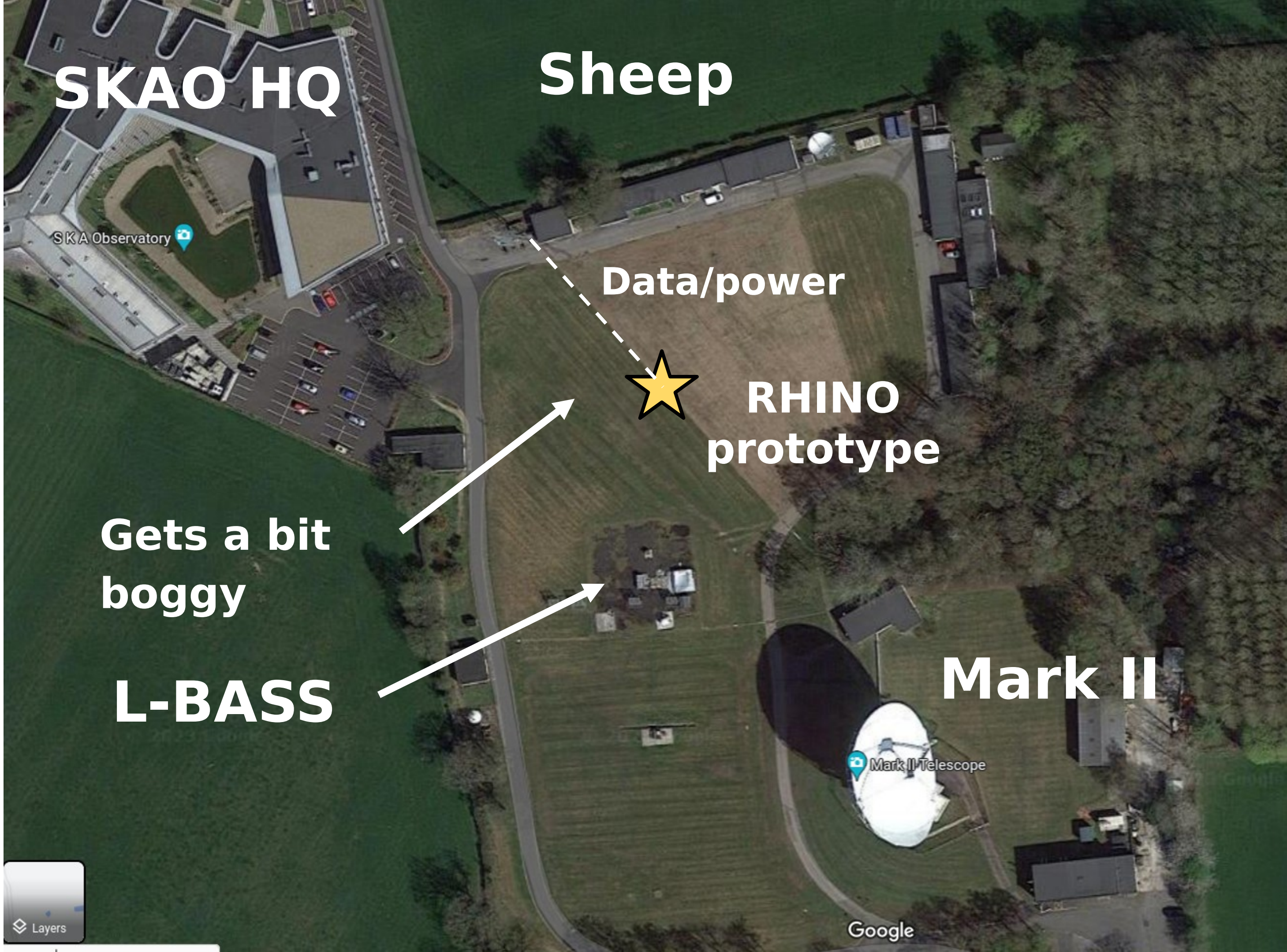
As well as making the hardware systematics independent, it would be nice to have an independent approach to the data analysis pipeline too!

- Bayesian approach is perhaps unavoidable for such a high dynamic range problem
- **Hydra Gibbs sampler** developed for HERA
  - Ultra-high dimensionality via Gibbs sampling approach *(breaks posterior into more tractable conditional distributions and samples iteratively)*
  - Global signal is a simpler special case – one antenna, autocorrelation etc.
  - Can sample complex beam pattern, diffuse sky model, point sources, gains…
  - Need to add noise-wave (reflection parameters)
- Ultimately, would also like to cross-check results using other pipelines

# Prototype at Jodrell Bank

Spectrum continually monitored (mostly for e-Merlin)

RFI exists though

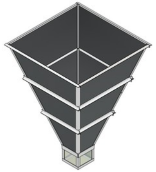


Current status (Sep 2023):

- Shielded box with power + network on site, horn sits on top
- Horn side panels fully built, need to assemble, and stand it up
- All the necessary components for a basic receiver have been acquired
- Basic DAQ software written

Katrine, Jacob, Melvyn, Hugh

Phil, Jacob



Hugh

All side panels completed

# Summary

- **Horn antennas** have great properties for this kind of experiment, and can offer an important cross-check of other measurements
- They are unwieldy at 70 MHz, but ultimately tractable
- Other design choices (e.g. CW calibration, Gibbs sampling) increase independence of systematics etc.
- We are trying to get a working prototype as fast as possible to test out these ideas
  - Ready in a couple of months!
- There is a Google group - rhino-experiment