CO Intensity Mapping – Considerations for a Feed Array Experiment

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The First Billion Years
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Outline

General considerations for CO intensity mapping experiment as presented in:

- Righi, Henandez-Monteagudo, & Sunyaev, A&A 489, 489 (2008)
- Carilli, ApJL (2011)
- Gong et al., ApJL 728, 46 (2011)
- Lidz et al., ApJ (2011)
- Discussion at KISS FBY workshop (August 2010)

What would a feedhorn array experiment look like?

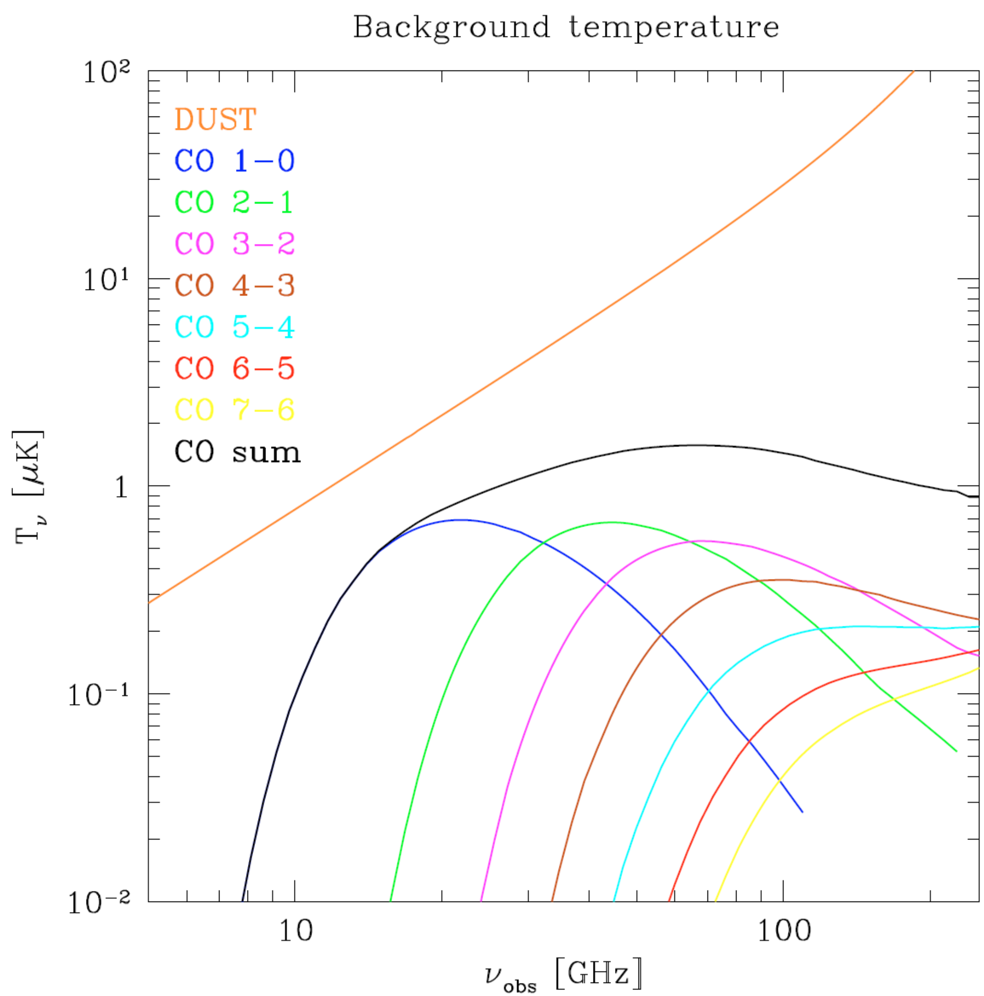
- One line or two? Which lines?
- Number of feeds
- Receiver topology
- Estimated sensitivity

Can we get extra mileage out of this experiment for CMB studies?

How big are the mean signal and fluctuations?

Righi, Hernandez-Monteagudo, & Sunyaev 2008:

"At 30 GHz, most of the contribution to the background in the first CO transition is due to low-flux sources, which cannot be detected directly."



How big are the mean signal and fluctuations?

Carilli 2011:

"Order of Magnitude" estimate of emission calculated from cosmic SFR required to reionize (and keep ionized) the IGM.

Standard relations for
Cosmic SFR -> IR Luminosity -> CO Luminosity

Estimate is for mean emission, not structure, but assume rms is of order the mean.

$$T_B{}^{\mathrm{CO}} \sim 1.1 \left(\frac{C}{5}\right)\left(\frac{f}{0.1}\right)^{-1} \ \mu\mathrm{K} \quad (z=8)$$

Consider: z=8, CO(2-1) (25.6 GHz observing frequency), 5 arcmin angular res.
Δz=0.044 corresponds to 1500 km/sec

How big are the mean signal and fluctuations?

Gong et al. 2011:

CO Luminosity estimated as a function of halo mass from simulations of Obreschkow et al. (2009). Add estimate of halo mass function and cosmology to get CO brightness temperature. Consider CO (1-0) at z=6-8.

Mean ${T_B}^{\mathrm{CO}} \sim 0.5\ \mu\mathrm{K}$ (z=6)
(1 sigma uncertainty is +1.0, -0.4 $\mu\mathrm{K}$)

RMS fluctuations $\sim 0.1\ \mu\mathrm{K}$ on 30 arcmin scales

Suggests ${T_B}^{\mathrm{CO}(2-1)} \sim 0.6\ {T_B}^{\mathrm{CO}(1-0)}$

How big are the mean signal and fluctuations?

Lidz et al. 2011:

Star Formation Rate (SFR) estimated as a function of dark matter halo mass.
CO Luminosity estimated as a function of SFR. Measurements at $z<3$ are applied to $z=7$. Estimates broadly consistent with previous.

Explicitly considered an interferometer experiment with

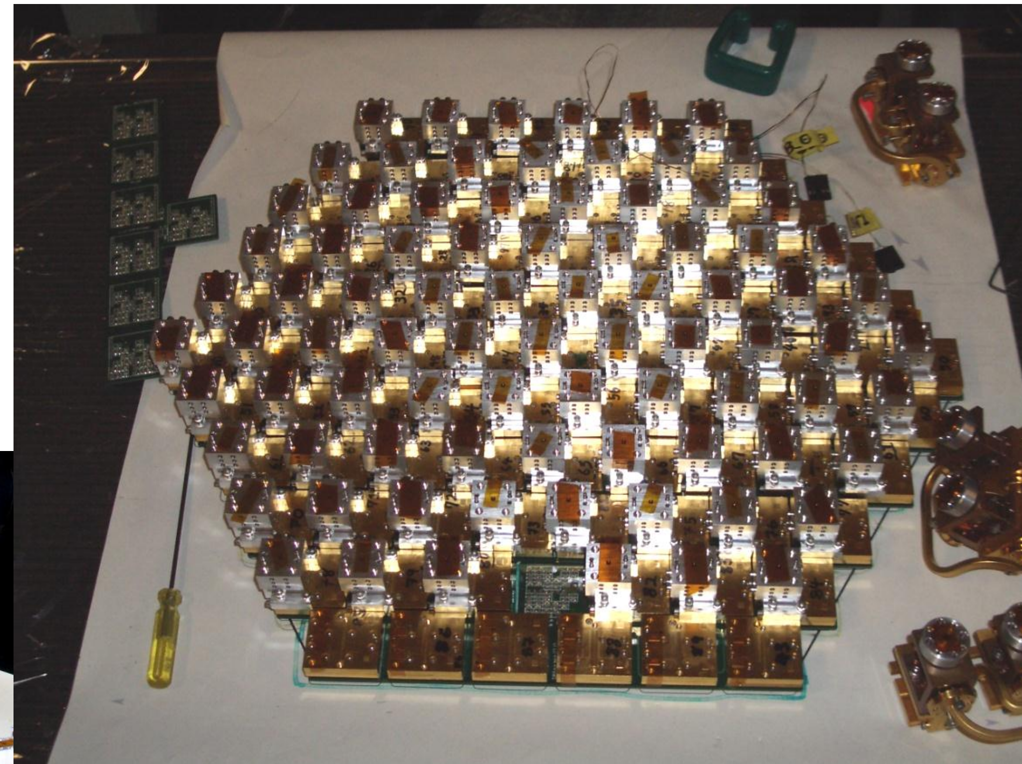
- 25 deg^2
- angular resolution ~ 6 arcmin
- Noise per 6 arcmin pixel 4 μK
- 50 MHz spectral resolution bins
- Tsys 30K, 900 antennas, 1000 hours.

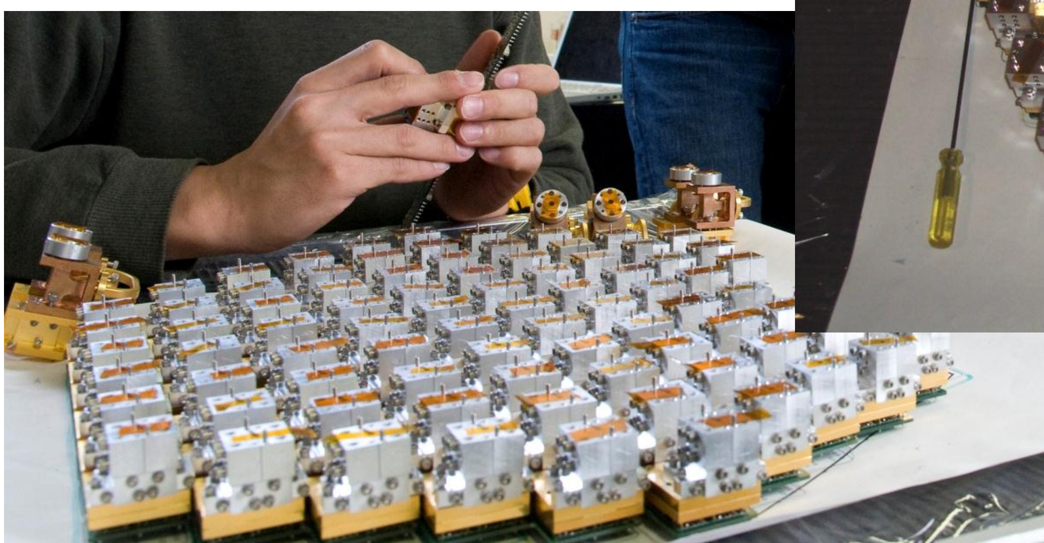
Emphasizes the power of cross correlating with HI, CII, more than one CO line

What would such an experiment look like?

90 GHz QUIET array for CMB polarization

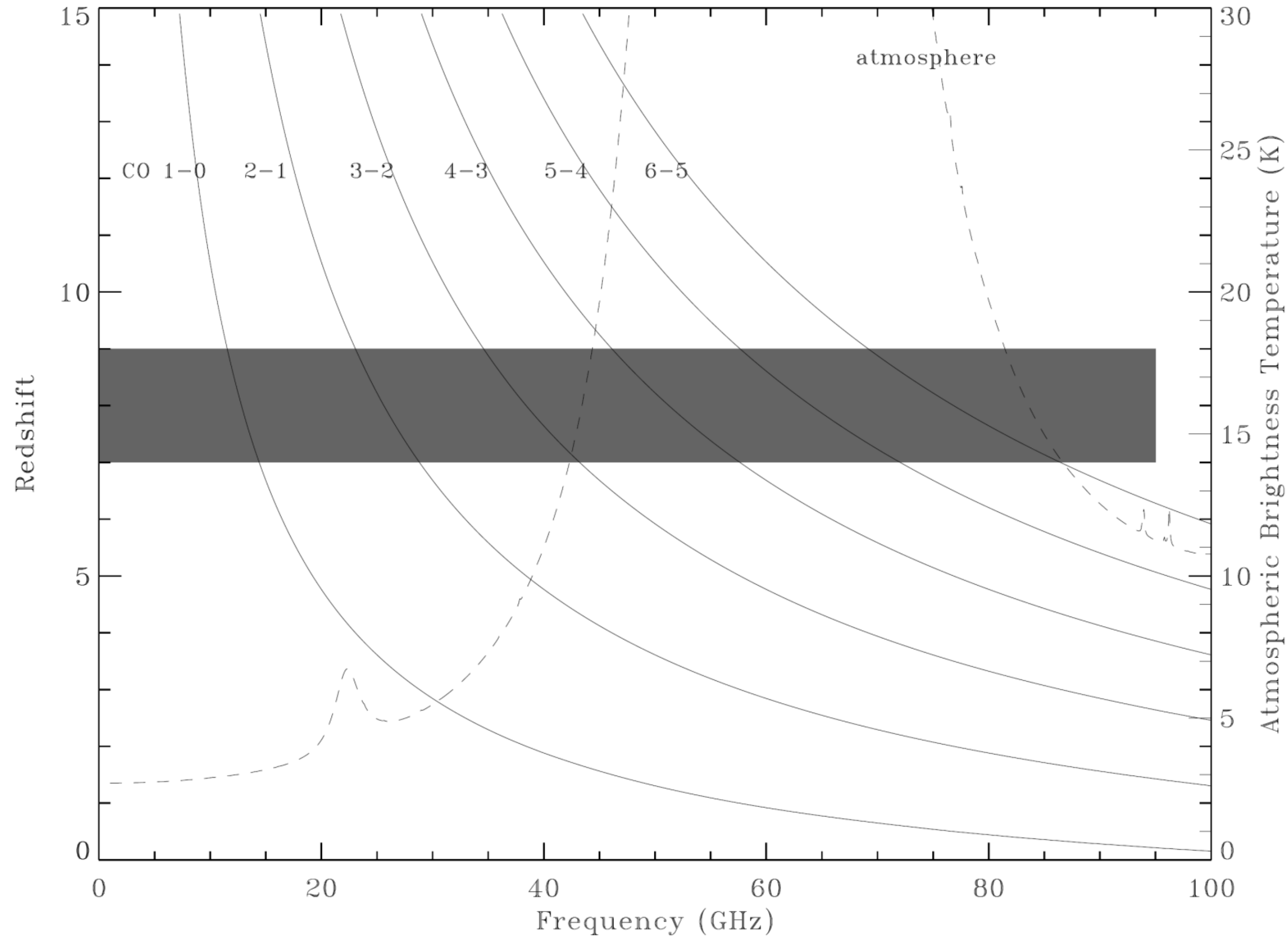
Existence proof of a reasonably large array of compact receiver modules



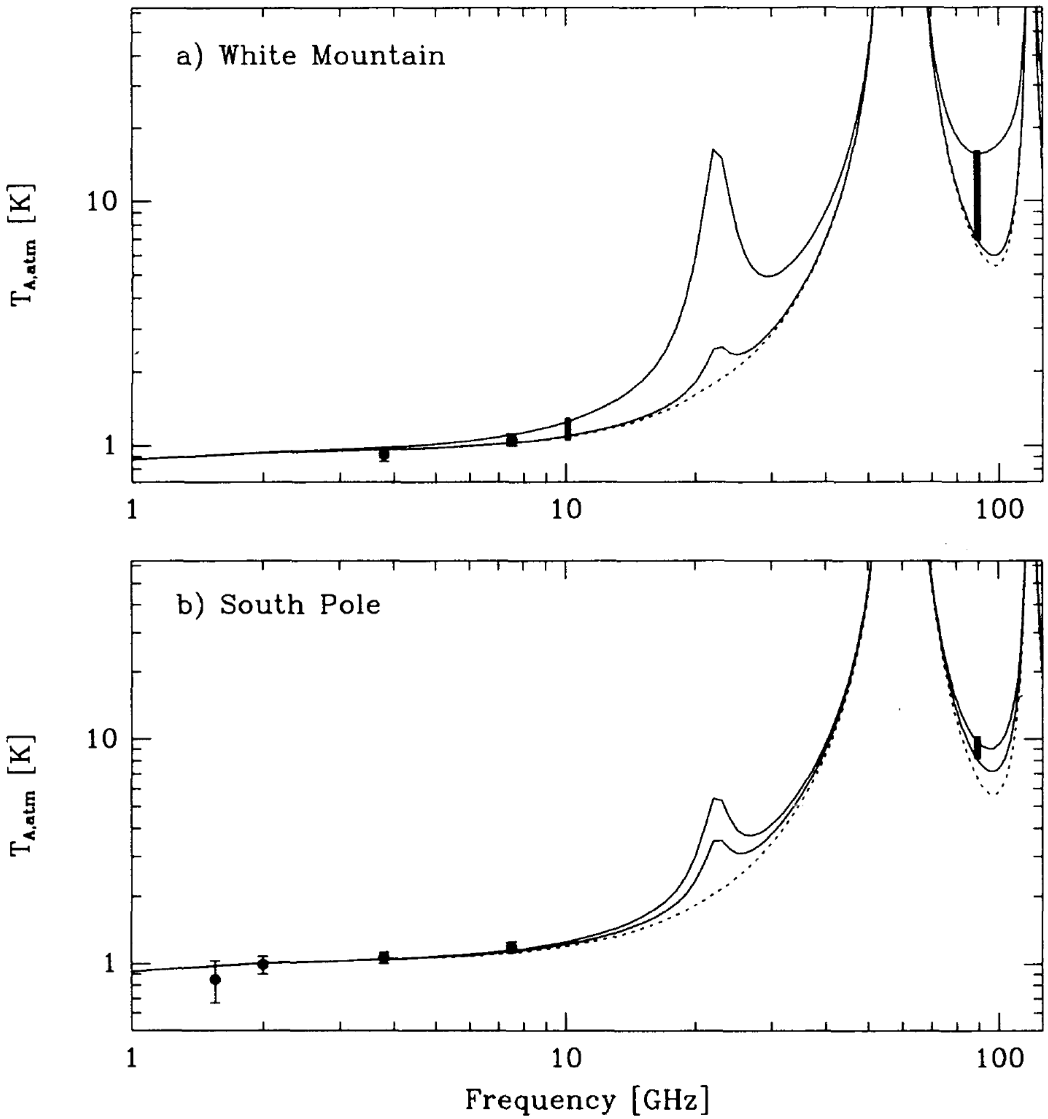


Array sensitivity ~60 mK·√s in 15 GHz bandwidth

What would such an experiment look like? Landscape of emission lines



Atmospheric contribution limits ground-based measurements



Measured and modeled atmospheric emission.

Dashed line is dry atmosphere emission model.

Solid lines represent range of water vapor contributions.

Bersanelli et al., ApJ, 448, 8 (1995)

Raw sensitivity for CO intensity mapping instrument

$$\Delta T = \frac{T_{sys}}{\sqrt{N}\sqrt{\beta\tau}}$$

$$T_{sys} \approx 20\text{K}$$

$$\Delta T \approx 1\,\text{uK}$$

$$\beta \approx 50\,\text{MHz}$$

$$N\tau \approx 8\text{x}10^6$$

So, this is for one pixel. So, perhaps we can imagine a "precursor" experiment with ~ 100 feeds, with ~ 1 year observing and restricted sky coverage.

Telescope size and angular resolution

Generally, we will want to push on the angular resolution so that the beam does not excessively smear out the fluctuating signal.

Consider 10 arc min at 26 GHz.
Scaled from the QUIET optics (designed for good beam quality and sidelobe control over a large field)

We find a system with:
6.2 m aperture
2.5 degree FOV
accommodates ~ 260 feeds

Switching strategy

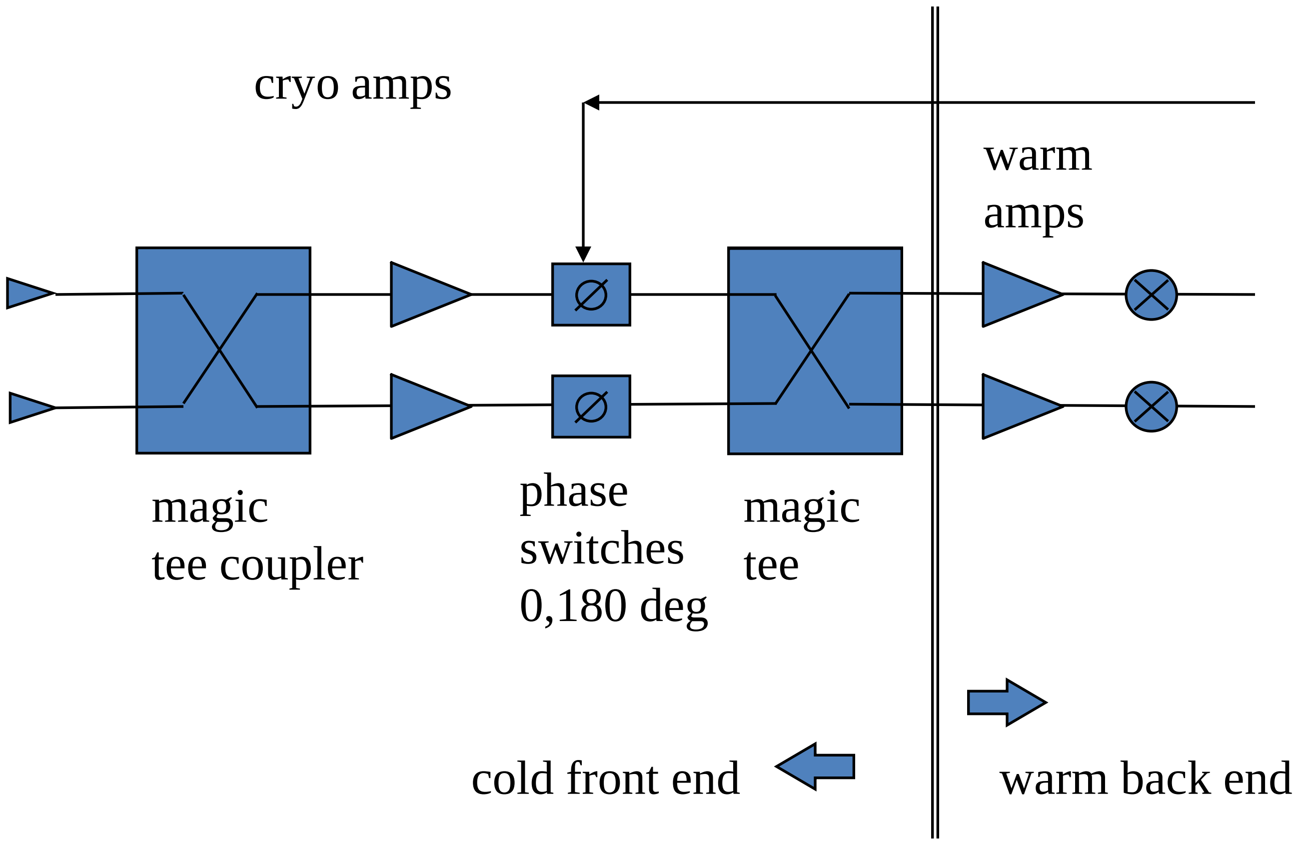
Rapid modulate of the sky signal “Dicke switching” overcomes gain fluctuations in the receiver system.

Key difference with CMB experiments is that we will subtract a smooth foreground spectrum from each spatial pixel. Also helps with receiver gain fluctuations.

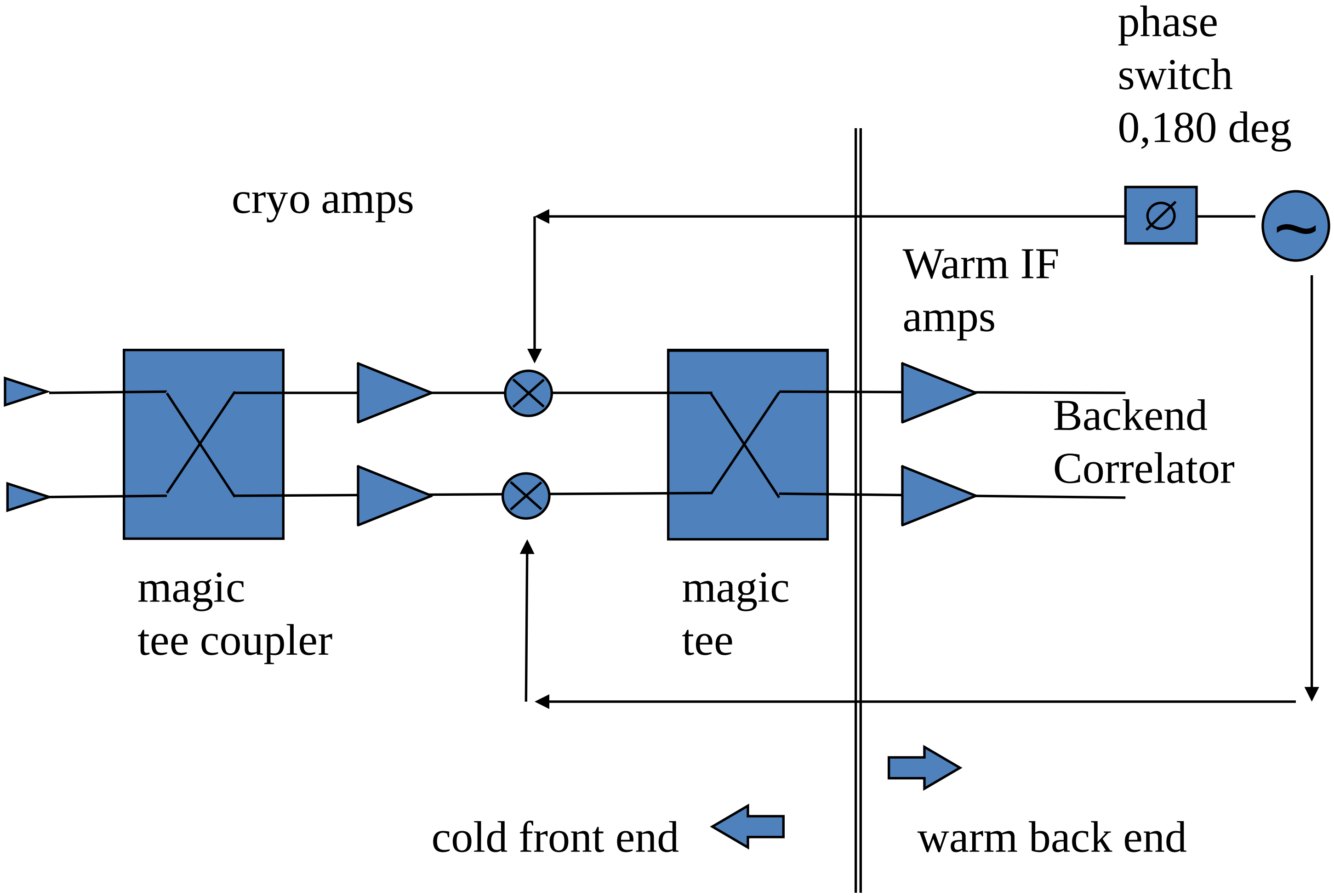
Several options:

- Modulation by the scanning of the receiver only
  - rapid (e.g. BEAST)
  - slow – telescope motion only
- Beam switching the receiver

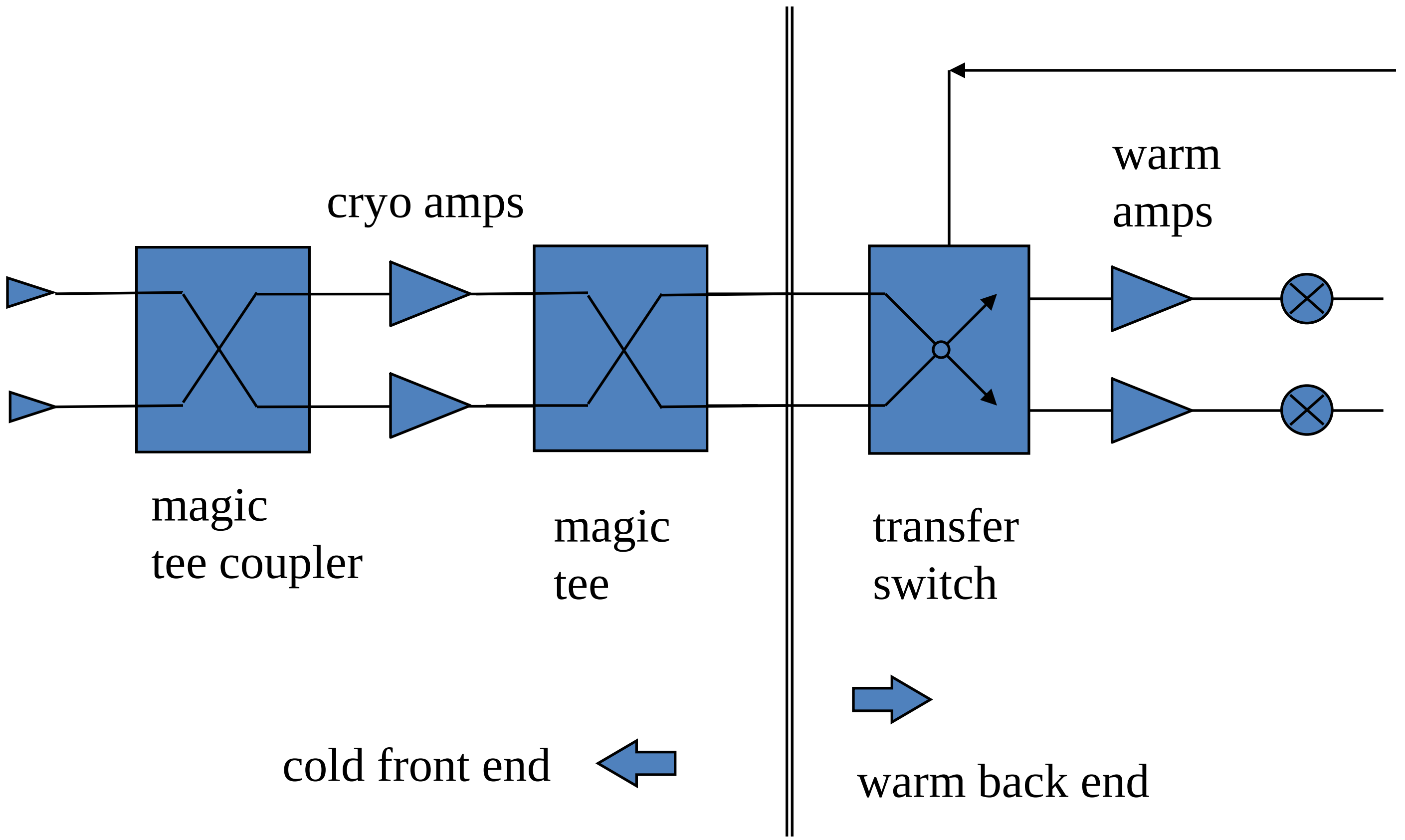
Receiver topology
Planck - like front end



Receiver topology with cold mixers



Backend switch Receiver topology



Topics for discussion:

Can we make such an experiment do double duty as a CMB polarization experiment? OMTs at the front end. Difference between horns in orthogonal polarizations?

Merits of a feedhorn array versus an inteferometer:

Optimal S/N strategy – SN~1 per spectral-spatial bin? Sky area and sensitivity for a stage 1 experiment.

Two lines or just one? CO(2-1) or CO(1-0)

Is there a need or utility for space?

Switching or modulation strategy for a feedhorn array:

(a) Optics Modulation
(b) Beam Switching