DESCRIPTION FOR A SUBMILLIMETER SPECTROMETER FOR SOFIA – *S3*

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INTRODUCTION

DEVELOP A VERY SENSITIVE SUBMILLIMETER SPECTROMETER FOR USE ON SOFIA.

CHOOSE ONE FREQUENCY AND OPTIMIZE THE SENSITIVITY.

METHODS

ADOPT TECHNIQUES USED IN HERSCHEL HIFI.

DESIGN AND CONSTRUCT NEW DETECTORS WITH BETTER NOISE TEMPERATURES.

APPLY NEW TECHNIQUES FOR DATA COLLECTION.

EXAMPLE SCIENTIFIC STUDIES

EMPLOY THIS SPECTROMETER TO STUDY SIGNALS THAT WOULD OTHERWISE BE TOO WEAK TO MEASURE.

HERSCHEL MADE A NUMBER OF OBSERVATIONS THAT COULD NOT BE FOLLOWED UP DUE TO CONSUMABLES. THIS SPECTROMETER WILL ALLOW THESE FOLLOW UP MEASUREMENTS TO BE MADE.

Doppler Tomography of $H_2^{18}O$ & NH_3 in HAeBe Disks

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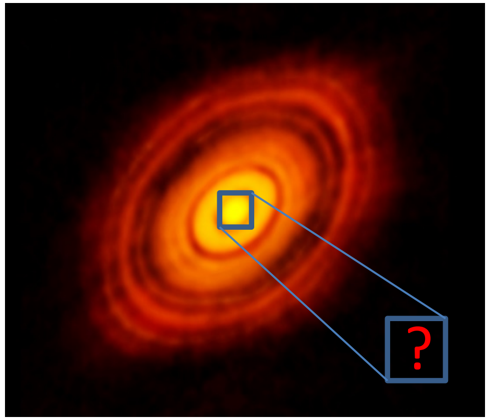
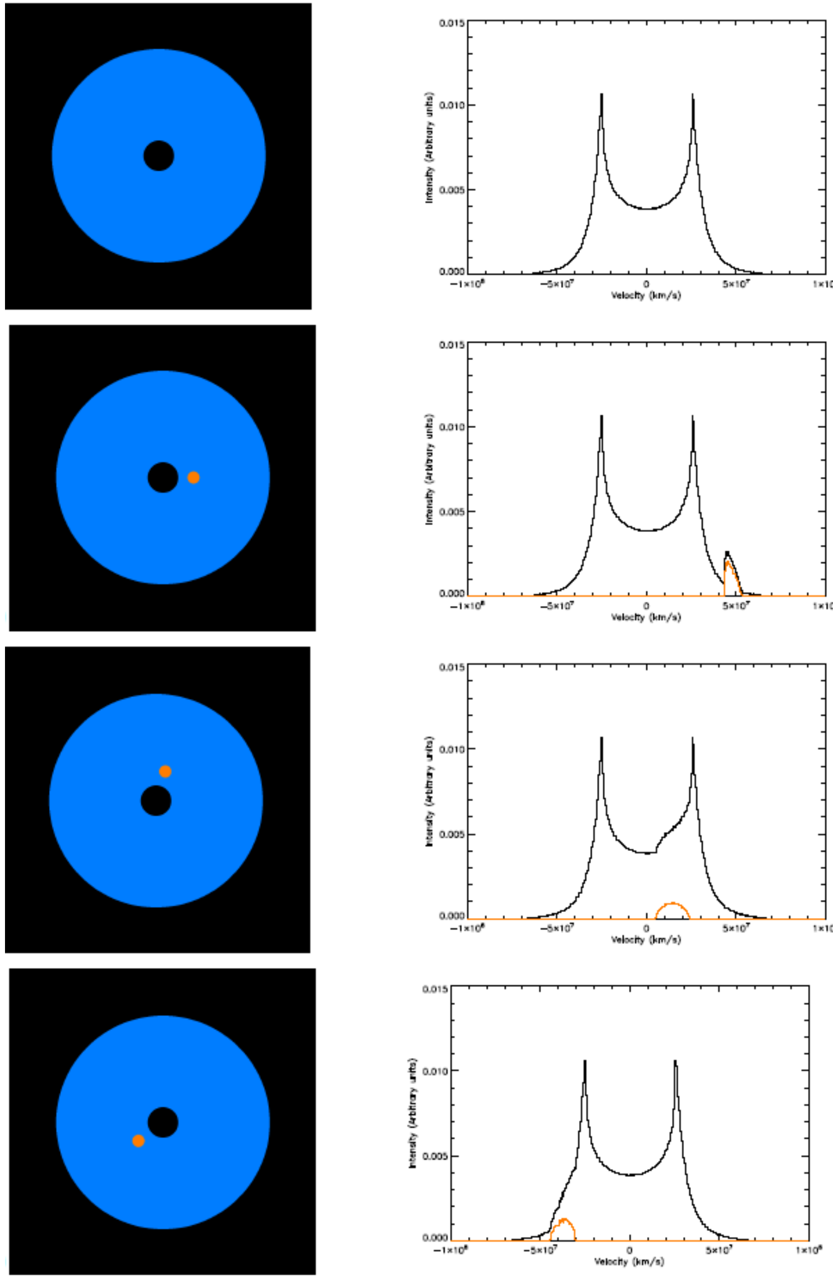
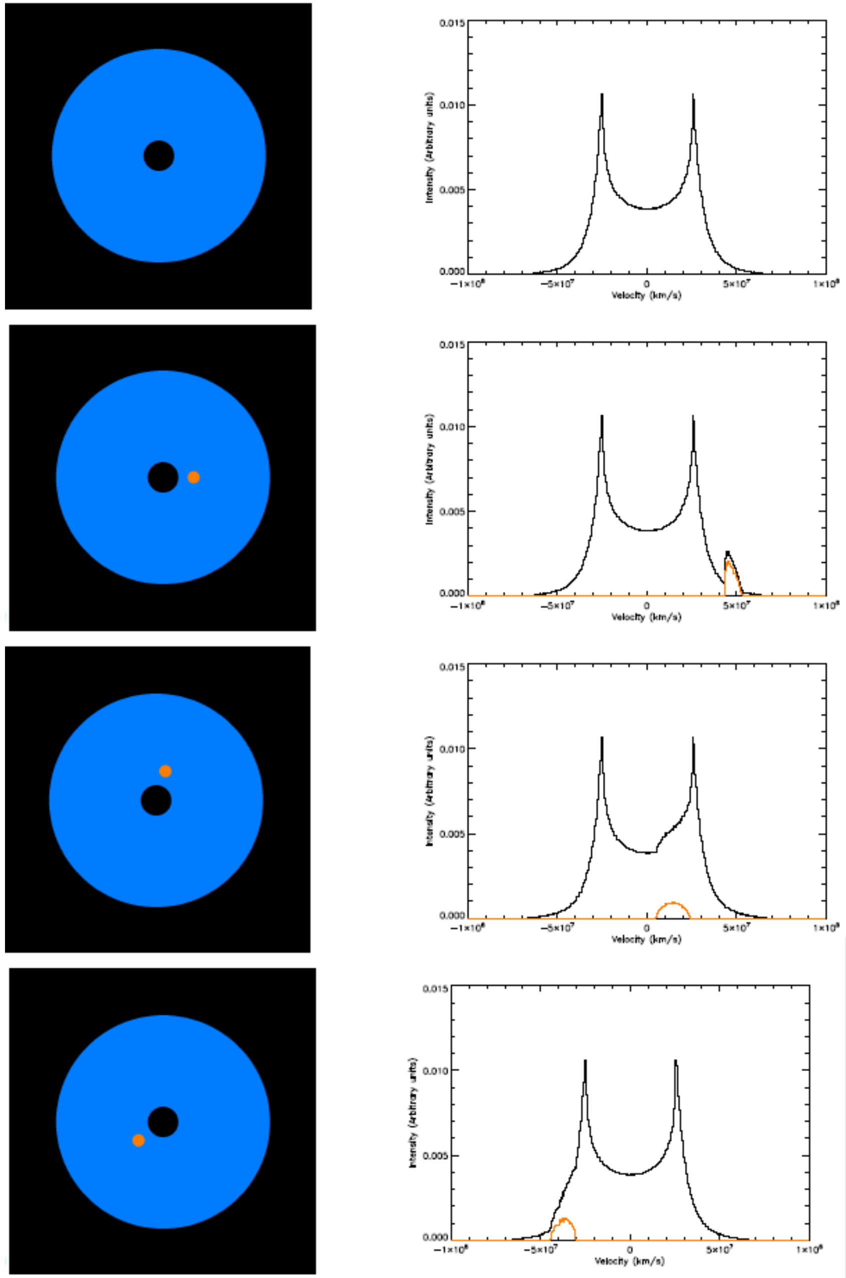




Doppler Tomography of $H_2^{18}O$ & NH_3 in HAeBe Disks

- ***Intensive time-domain study of inner disk structure in a few objects***
  - Repeated observations of line profiles in protoplanetary disks *and their changes* over the course of 3 years

- **Only a SOFIA/*S3* Legacy program would have both the observing time required & the ability to make cryogenic measurements over many disk rotation periods**

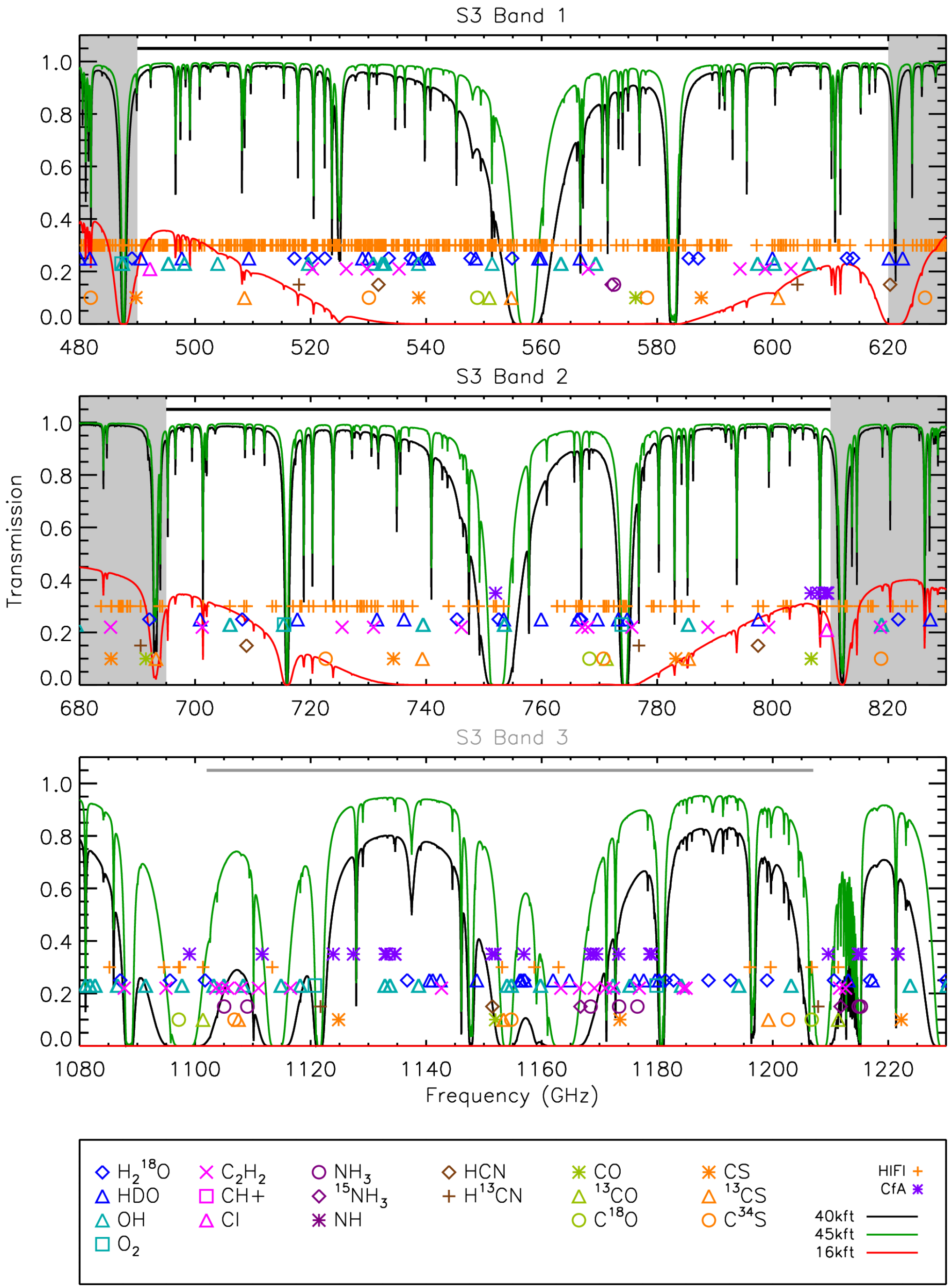


S3 Enabling Capabilities:

- High Sensitivity
- High Spectral Resolution
- Long-term Status

Additional Science Topics:

- CII at moderate Z
- B fields
- Mol. Gas in MW & Exg. SFRs
- Solar system obs, …
- ▪ Time-domain studies

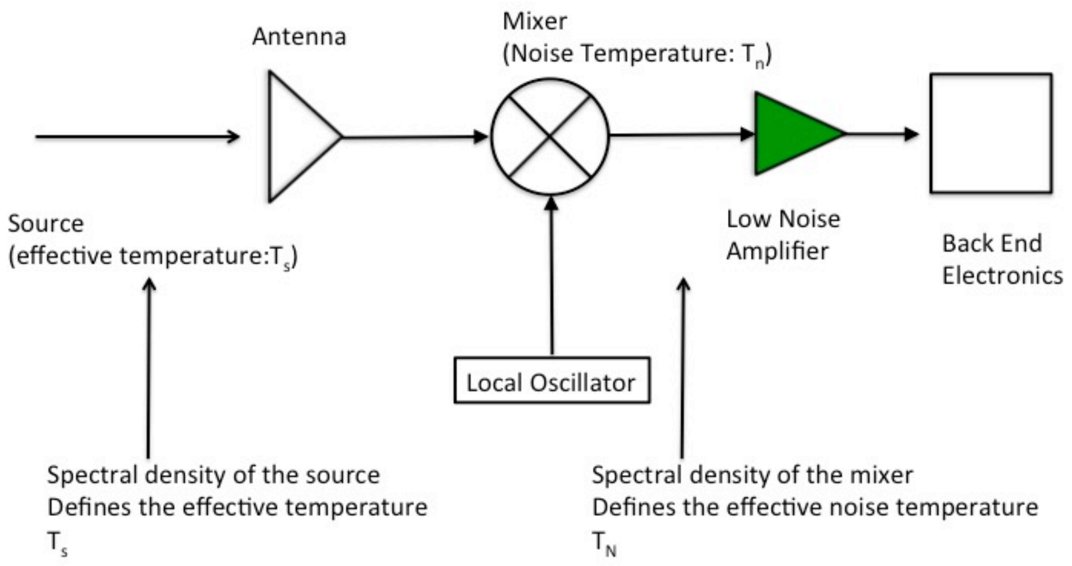


S3: OPTIMIZE PERFORMANCE

CONSTRUCT DEVICES AND OPTICAL DESIGNS TO MAXIMIZE SENSITIVITY

- Design and manufacture SIS mixers with minimum noise temperatures.
- Maximize the use of the detected power from the source.
- Optimize the optical design to permit maximum time integration

COHERENT RADIOMETER

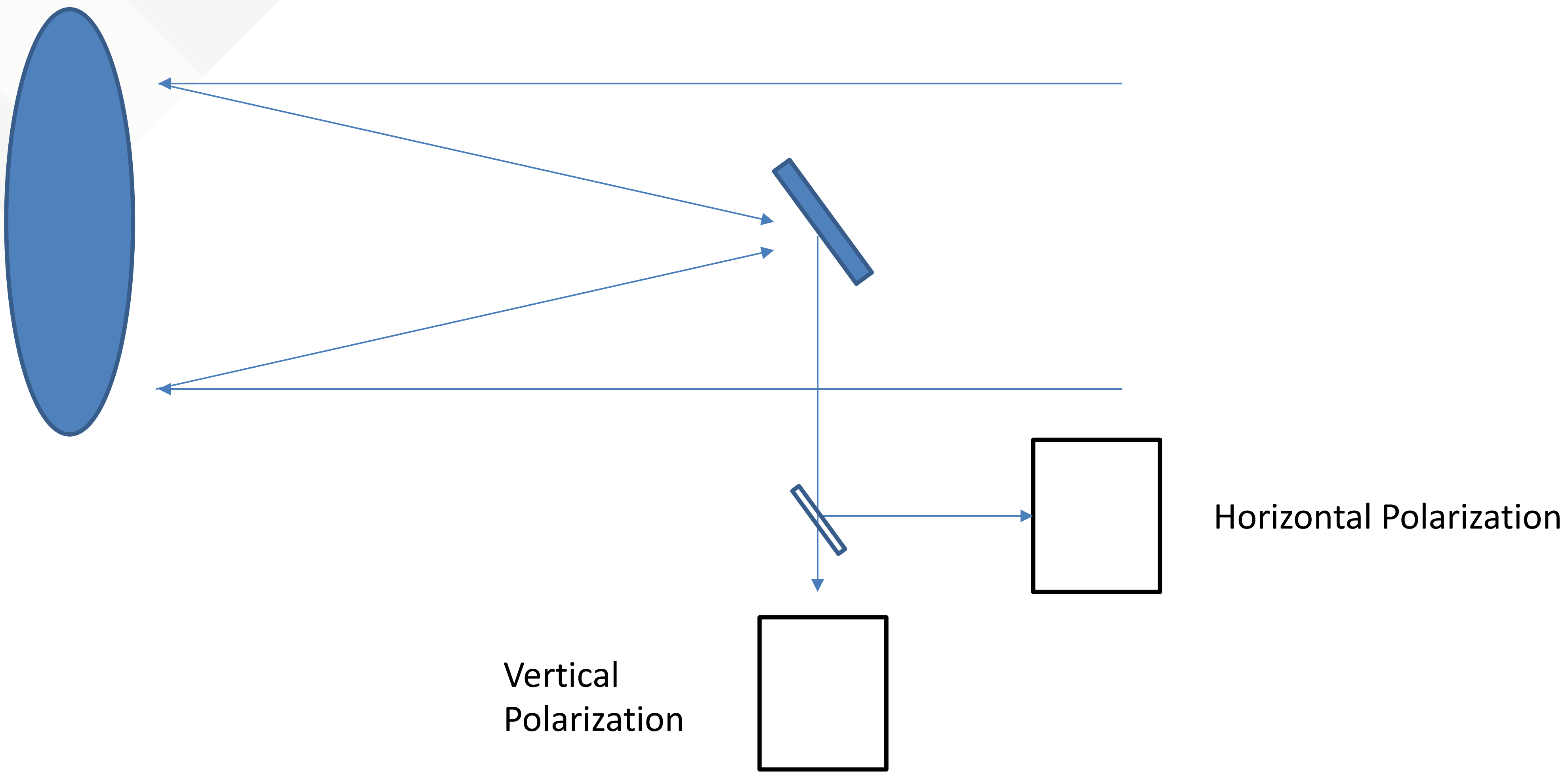


Block diagram of a heterodyne receiver system

- Antenna collects the source signal and directs it to the mixer.
- Model the mixer and amplifier as ideal devices with noise sources after them.
- Noise is modeled as an ideal resistor and has an effective temperature T_n.
- Source signal is also modeled as a black body with an effective temperature T_s.
- It can be shown that the minimum detectable temperature difference is;
- $\Delta T = \frac{T_N}{\sqrt{B\tau}}$

SOFIA (SIMPLIFIED)

HETERODYNE DETECTORS ARE POLARIZATION SENSITIVE



MINIMUM DETECTABLE TEMPERATURE DIFFERENCE: ΔT

$$\Delta T = \frac{T_N}{\sqrt{B\tau}}$$

T_n: **Noise temperature** of the detector.
Directly affects the sensitivity
Set by the design and construction of the detector.
Limited by the quantum noise limit.

B: **Detection bandwidth**.
Varies depending on the velocity resolution needed.
Set by the type of measurement being made.

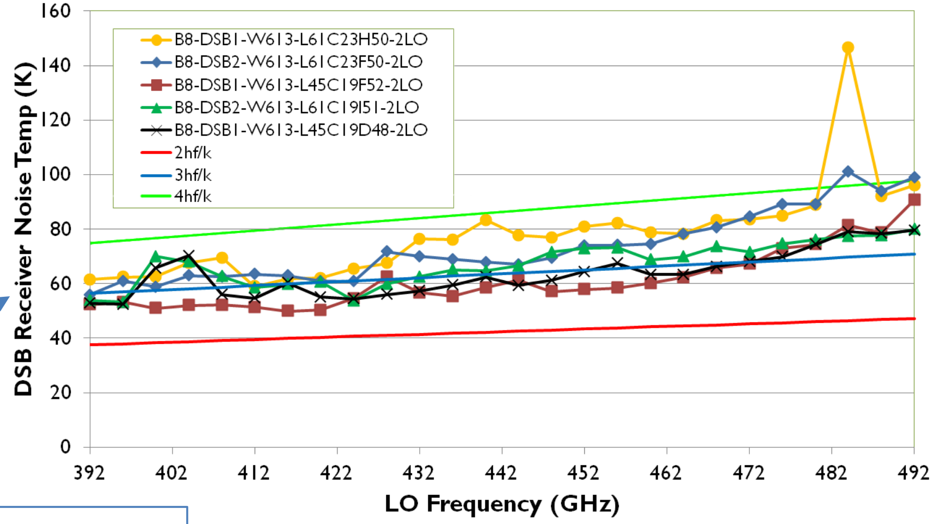
τ: **Integration time**.
Varies depending on the sensitivity needed.
Limited by the flight time and tracking ability.

S3: MINIMIZE NOISE TEMPERATURE

T_n: **Reduce Noise Temperature**

$$\Delta T = \frac{T_N}{\sqrt{B\tau}}$$

Measured DSB noise temperatures of UVa SIS mixers in the 400—500 GHz band. For comparison, noises temperature at 2, 3, and 4 times the quantum limit are shown.



UVA has already built mixers with noise temperatures on the order of 60K

Caltech has designed new mixers with **50K** noise temperatures

T_n = **50K** in the 500-600 GHz region

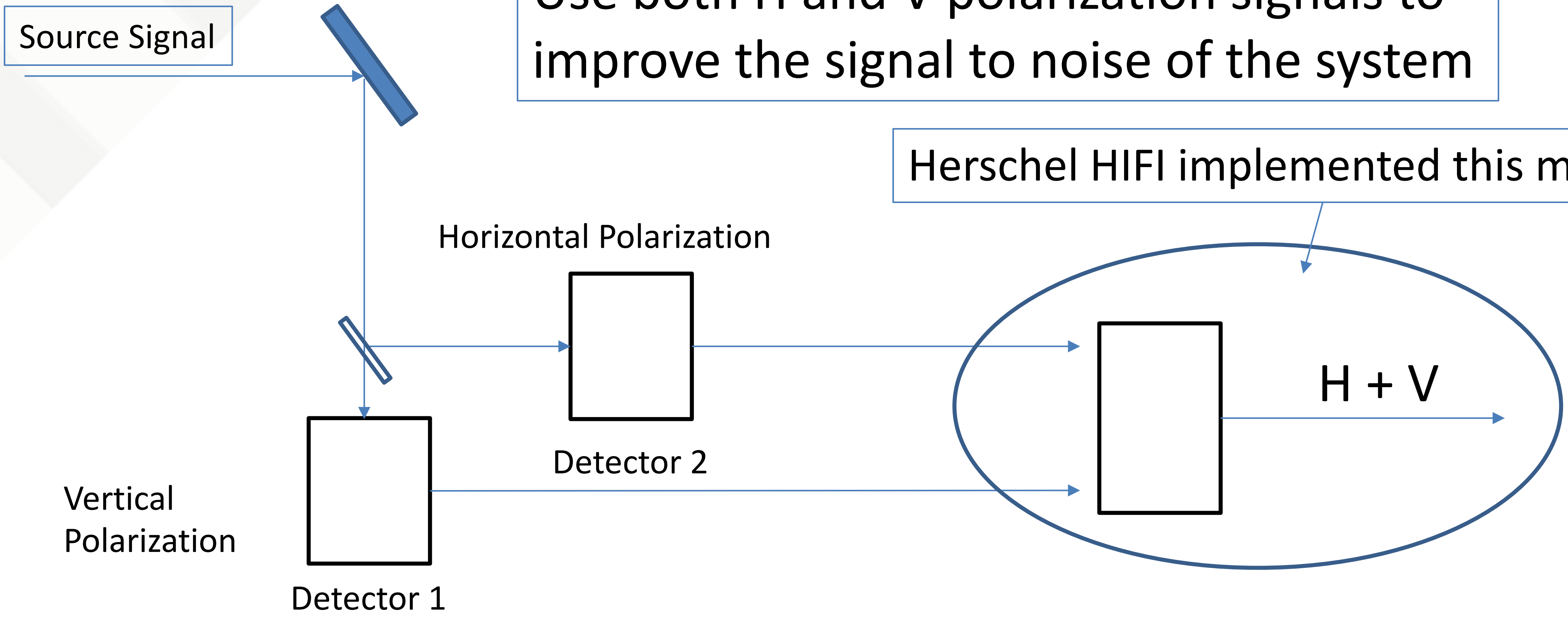
NOISE TEMPERATURES OF DIFFERENT SYSTEMS

- Herschel HIFI: 500 GHz: 80K DSB (from paper)
- GREAT: 500 GHz: 140K DSB (from website)
- *S3*: 500 GHz: **50K** DSB (predicted)

S3: MAXIMIZE SIGNAL
COMBINE H AND V DETECTORS

Use both H and V polarization signals to improve the signal to noise of the system

Herschel HIFI implemented this method

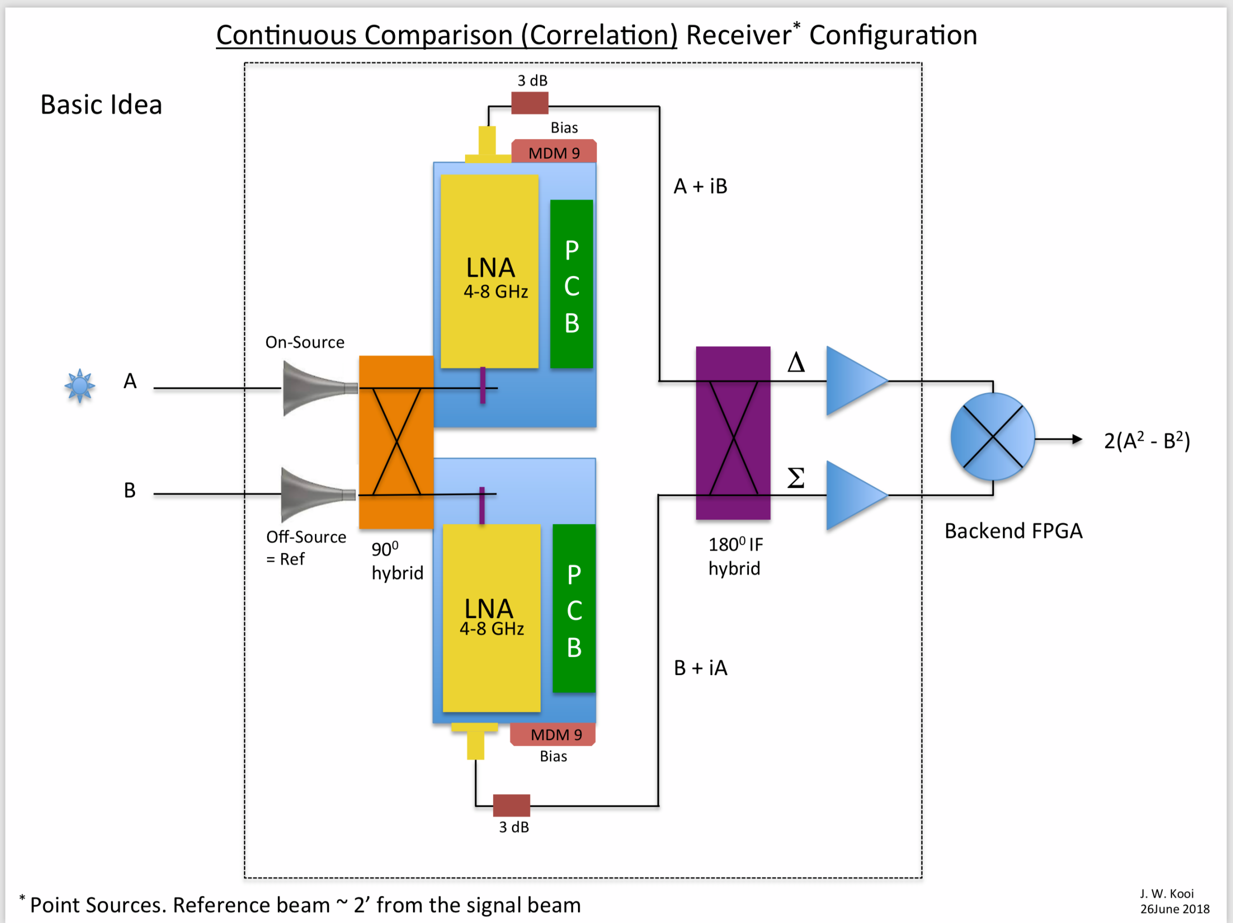


Benefit: Direct improvement to the Signal-to-Noise of the system

S3: CONTINUOUS COMPARISON CORRELATION

Use 2 detectors simultaneously for each polarization:

Detector A: On-Source
Detector B: Off- Source



This method allows the On-Source and Off-Source channels to be collected simultaneously.

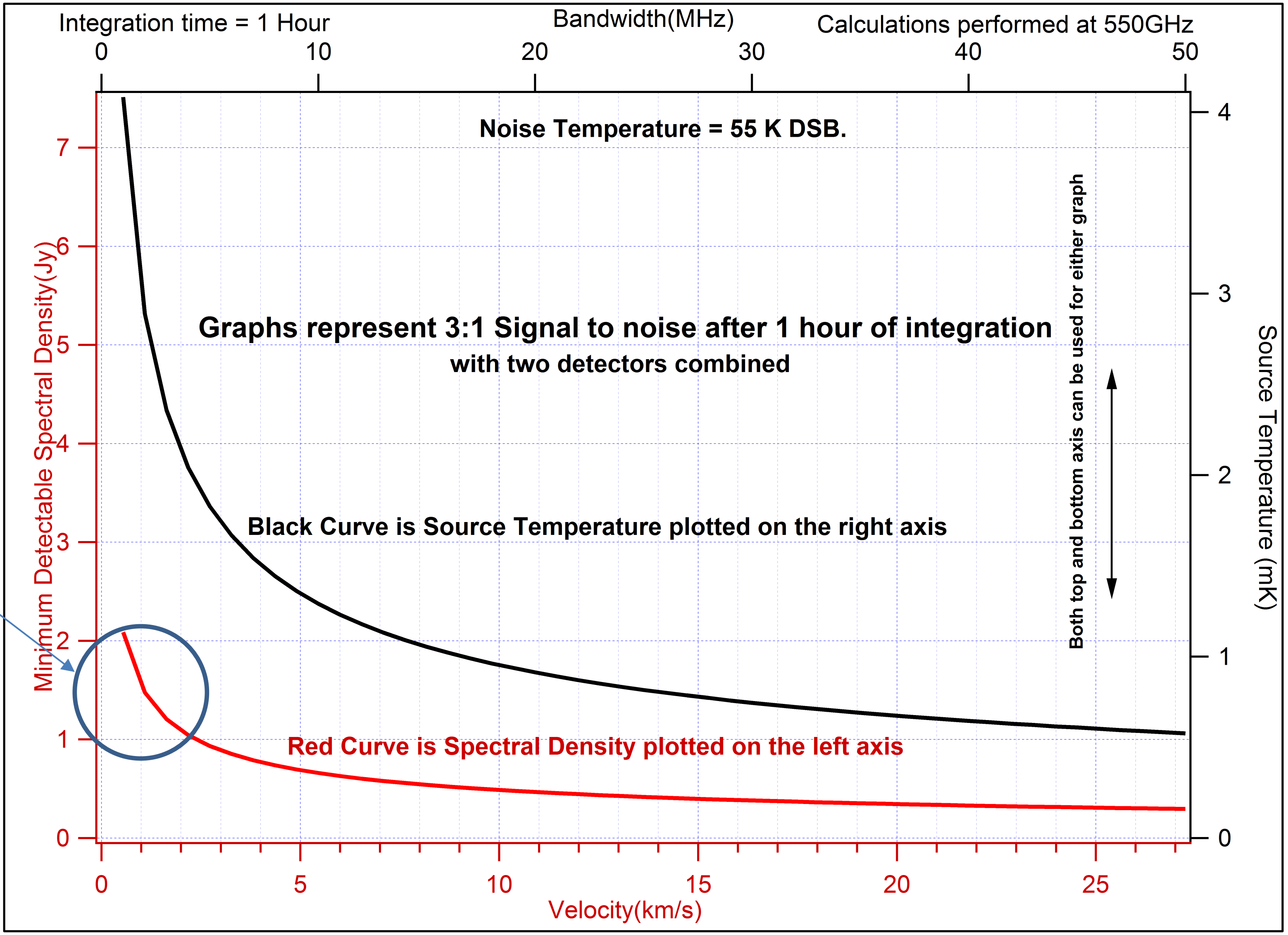
We have developed an optical design that allows the Continuous Comparison Correlator to be implemented on SOFIA.

S3 IS MOST SIMILAR IN COMPARISON TO HERSCHEL HIFI

- *S3* and HIFI both make use of very low noise temperature SIS detectors.
- *S3* and HIFI would both use the combination of H and V polarizations in order to improve the Signal-to-Noise.
- *S3* would add the Continuous Comparison Correlator.
- Herschel used a larger primary mirror and no atmospheric losses, therefore *S3* would require more integration time to achieve similar measurements (but HIFI of course isn't making any measurements now)

PREDICTED INSTRUMENT RESPONSE FOR S3 USING 1 HOUR INTEGRATION TIME

Herschel achieved measurements in this region with 14 minutes of integration time.



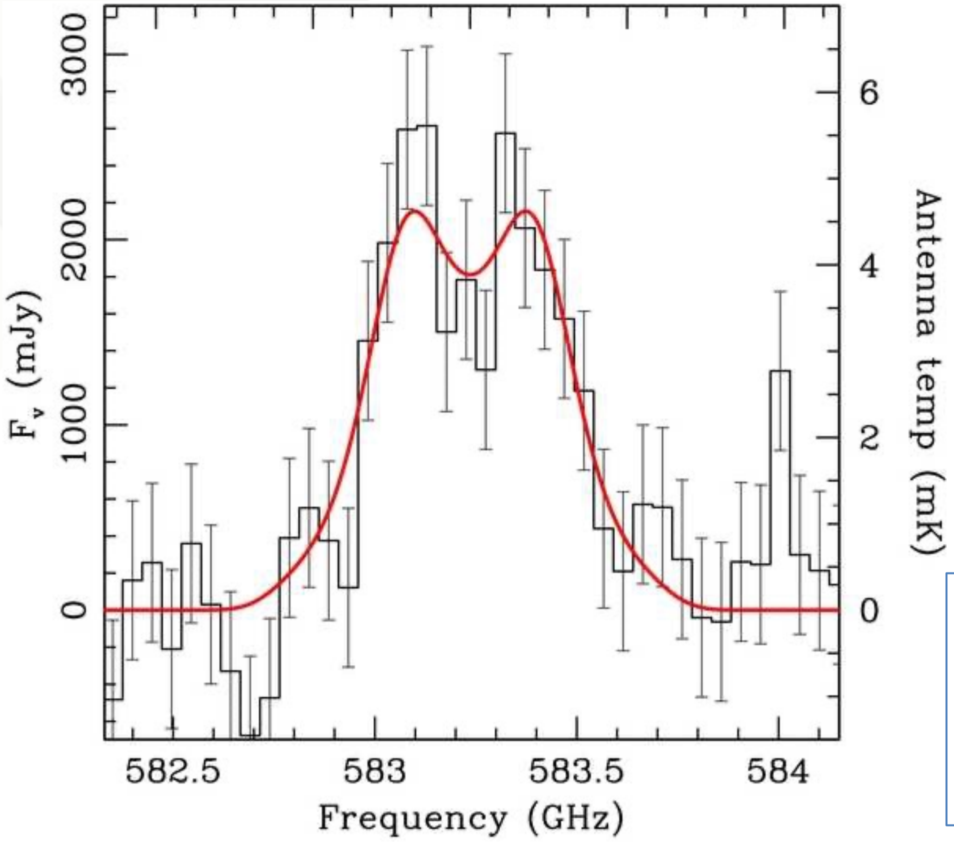
COMPARISON TO HERSCHEL MEASUREMENTS

HOW DO THE INSTRUMENT RESPONSE CURVES COMPARE TO MEASUREMENTS MADE BY HERSCHEL HIFI?

HERSCHEL MADE MEASUREMENTS IN THIS FREQUENCY REGION THAT CAN BE USED AS EXAMPLES FOR THIS COMPARISON.

MEASURED DATA FROM HERSCHEL HIFI

Data reported from the HIFI spectrometer on the Herschel satellite.



(Rhoads, J. E., Malhotra, S., Allam, S., et al. 2014, ApJ, 787, 8)

- S3's high spectral resolution would enable measurements of the C II line profile. The two peaks are a signpost of a rotating disk in a z=2.26 galaxy, otherwise undetectable in this spatially unresolved galaxy

HIFI Wide-Band Spectrometer (WBS) with 1.10 MHz resolution.
14-minute integration time on source

S3 SUMMARY

- The *S3* instrument would use 4 modern SIS mixers with noise temperatures of 50K (lower than similar instruments, both past & current).

- *S3* would combine the H and V polarization channels in order to improve the sensitivity of the instrument.

- *S3* would add a Continuous Comparison Correlator optical design to allow the on and off source beams to be collected simultaneously.

➢ *S3*'s high sensitivity & high spectral resolution would uniquely enable numerous astrophysical studies such as Doppler tomography of protoplanetary disks & CII in distant galaxies with SOFIA