Future Surveys

Fundamental Limits and Global Site Statistics

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NBI – August 20, 2014

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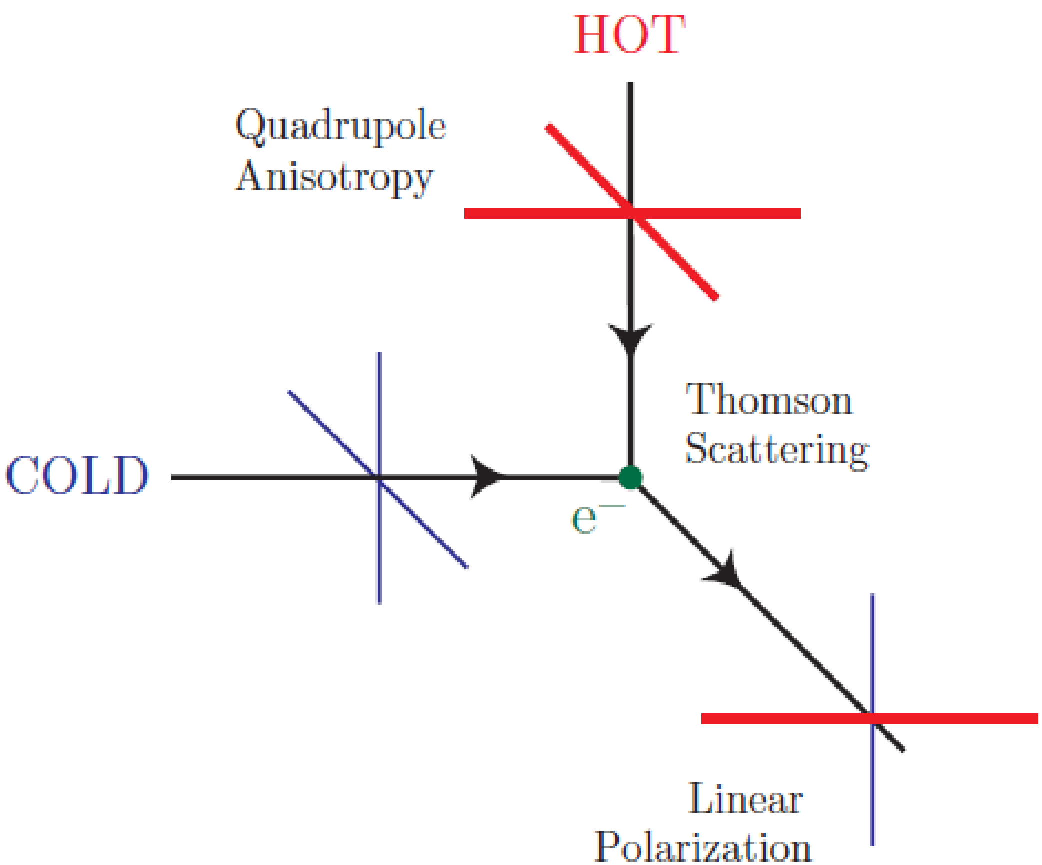
Known Knowns, Known Unknowns, Unknown Unknowns

- We **definitely** have evidence for NEW Physics
- No theory of QG
- No understanding of DE
- No understanding of DM
- No understanding of origin of universe
- ….
- Patent office not closed quite yet

Creating Polarization in the CMB



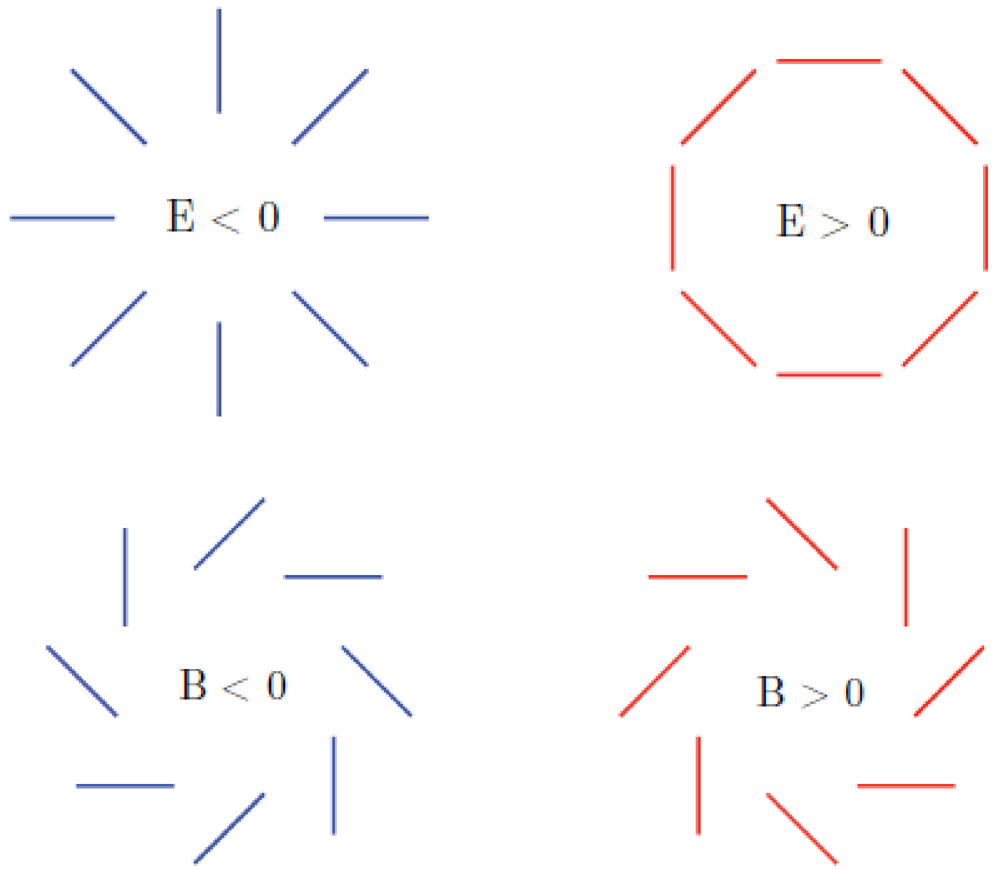
Nomenclature

$$(Q \pm iU)(\hat{n}) = \sum_{\ell,m} a_{\pm 2,\ell m}\,{}_{\pm 2}Y_{\ell m}(\hat{n})$$

$$a_{E,\ell m} \equiv -\frac{1}{2}\left(a_{2,\ell m} + a_{-2,\ell m}\right)$$

$$a_{B,\ell m} \equiv -\frac{1}{2i}\left(a_{2,\ell m} - a_{-2,\ell m}\right)$$

E and B Modes



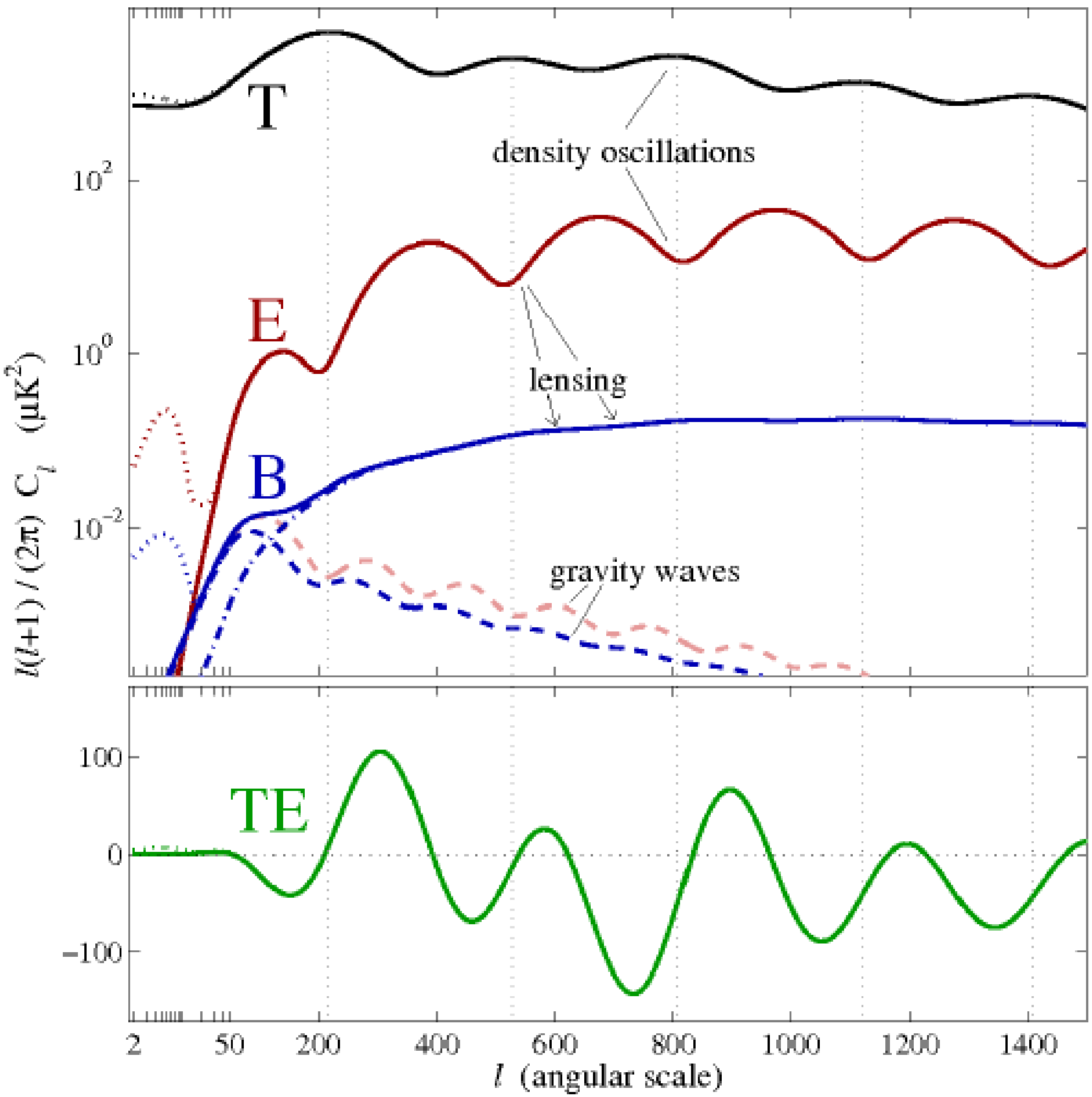
Power Spectra

$$C_\ell^{XY} \equiv \frac{1}{2\ell+1}\sum_m \langle a^*_{X,\ell m} a_{Y,\ell m}\rangle\,, \qquad X,Y = T,E,B$$

$$a_{X,\ell m} = 4\pi(-i)^\ell \int \frac{\mathrm{d}^3k}{(2\pi)^3}\,\Delta_{X\ell}(k)\,\{\zeta_{\vec{k}}, h_{\vec{k}}\}\,Y_{\ell m}(\hat{k})$$

$$C_\ell^{BB} = (4\pi)^2 \int k^2 \mathrm{d}k\ \underbrace{P_h(k)}_{\text{Inflation}}\ \Delta^2_{B\ell}(k)$$

Intensity and Polarization E and B modes



What do we learn

- No other known mechanism produces super horizon tensor fluctuation
- Inflation potential

$$V^{1/4} \sim \left(\frac{r}{0.01}\right)^{1/4} 10^{16}\,\mathrm{GeV}$$

- Super Planckian field variation

$$\frac{\Delta\phi}{M_{\mathrm{pl}}} = \mathcal{O}(1) \times \left(\frac{r}{0.01}\right)^{1/2}$$

Spectral Index (Tilt) , Running and Slow Roll Parameters

$$n_s(k) = n_s(k_0) + dn_s/d\ln k \ln\left(\frac{k}{k_0}\right)$$

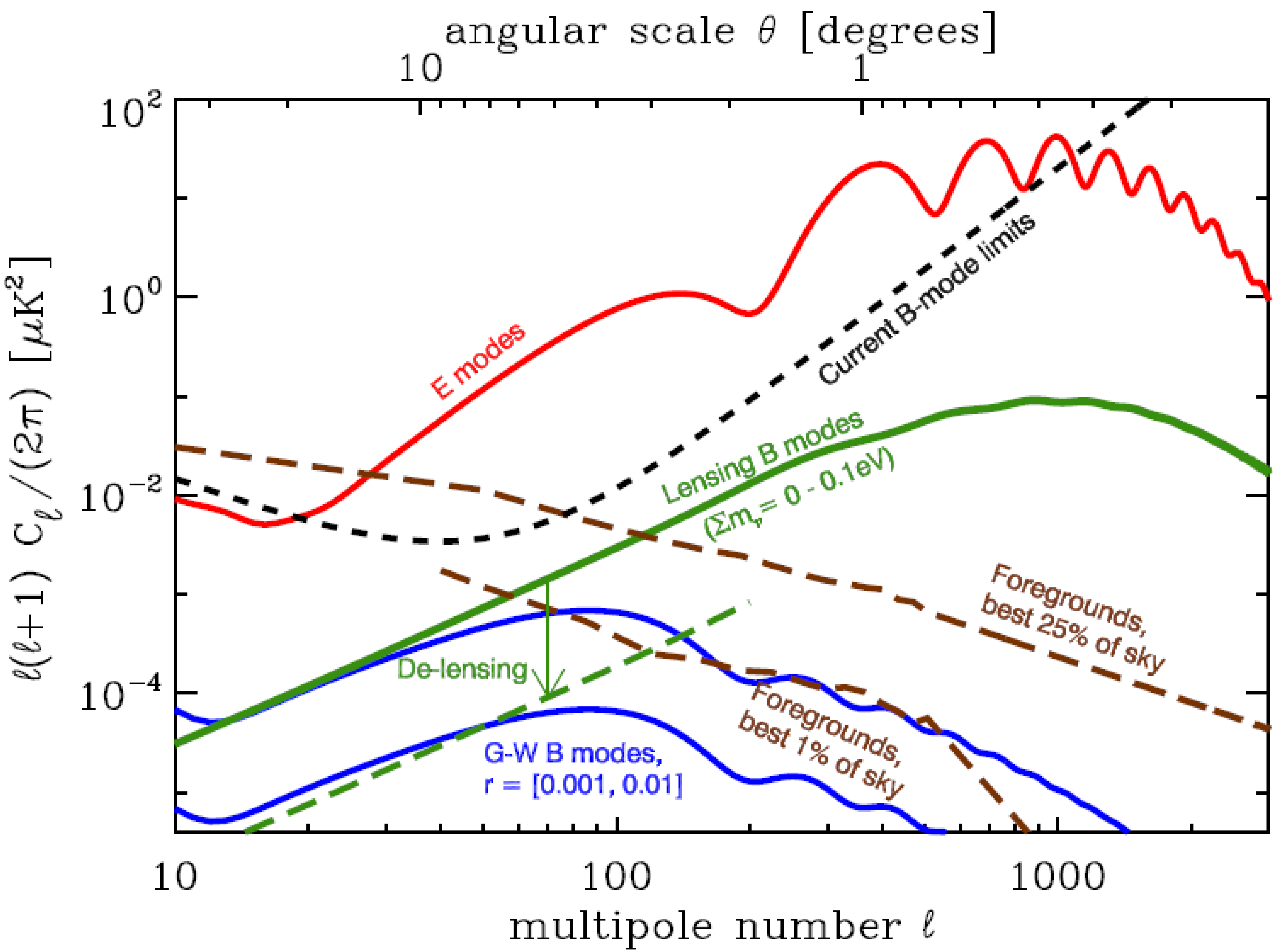
$$k^3\langle\zeta_k\zeta_{-k}\rangle \propto k^{n_s-1}$$

$$n_s = 0.960 \pm 0.0073$$

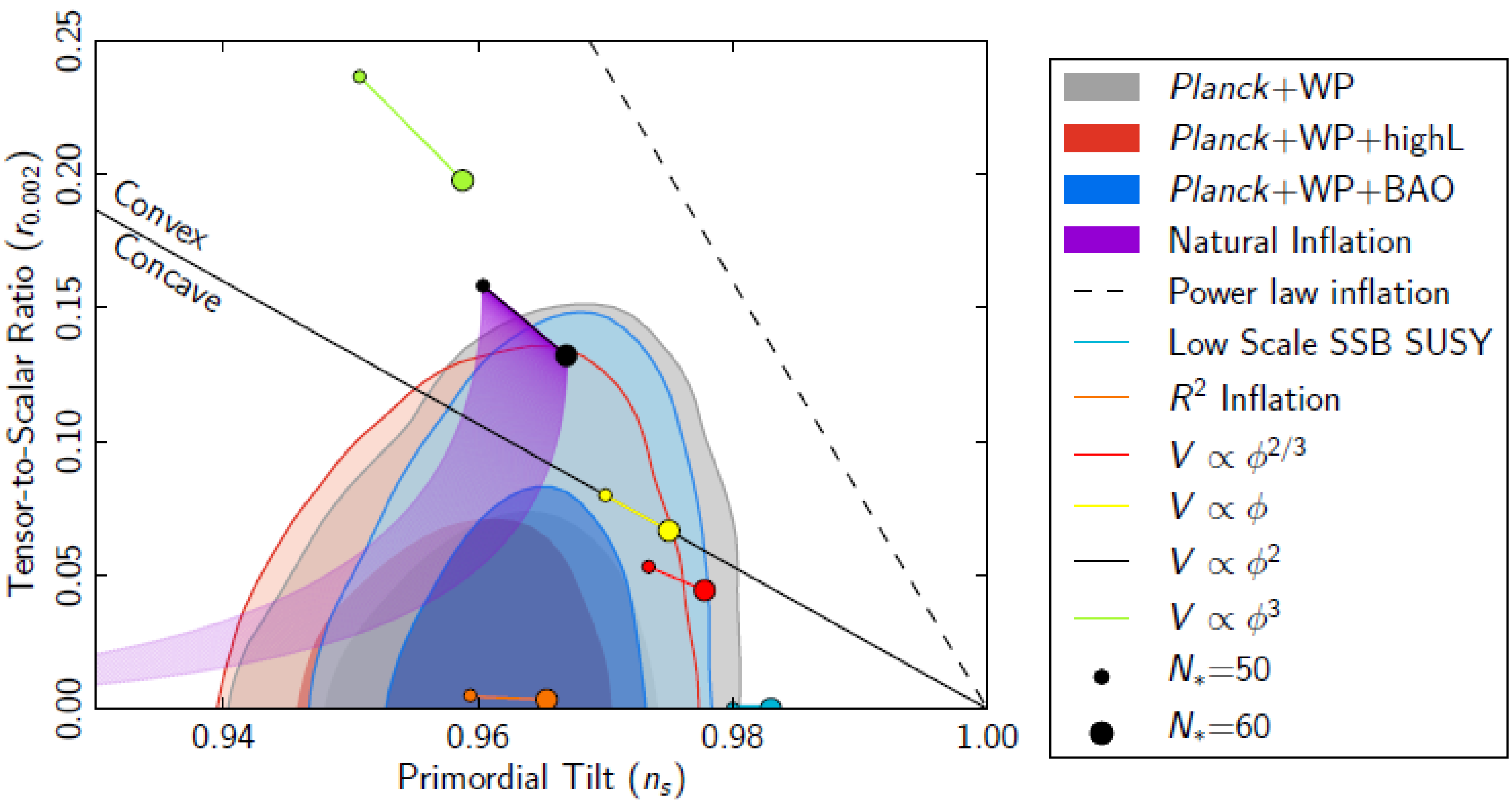
$$n_s - 1 = -6\epsilon + 2\eta$$

$$\epsilon = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2 \qquad \eta = M_P^2\frac{V''}{V}$$

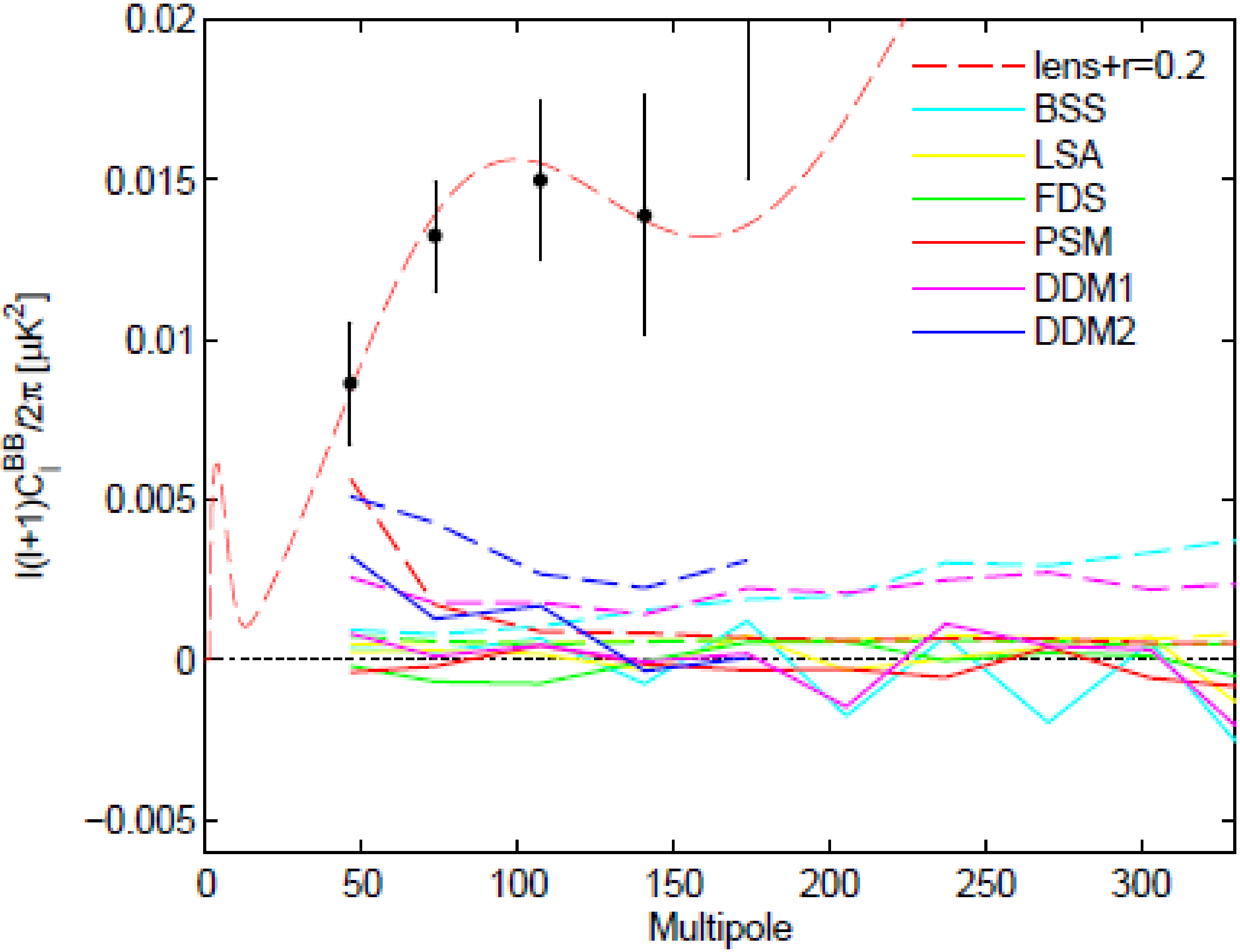
E (expected) & B (unknown)
BBC – Before Bicep



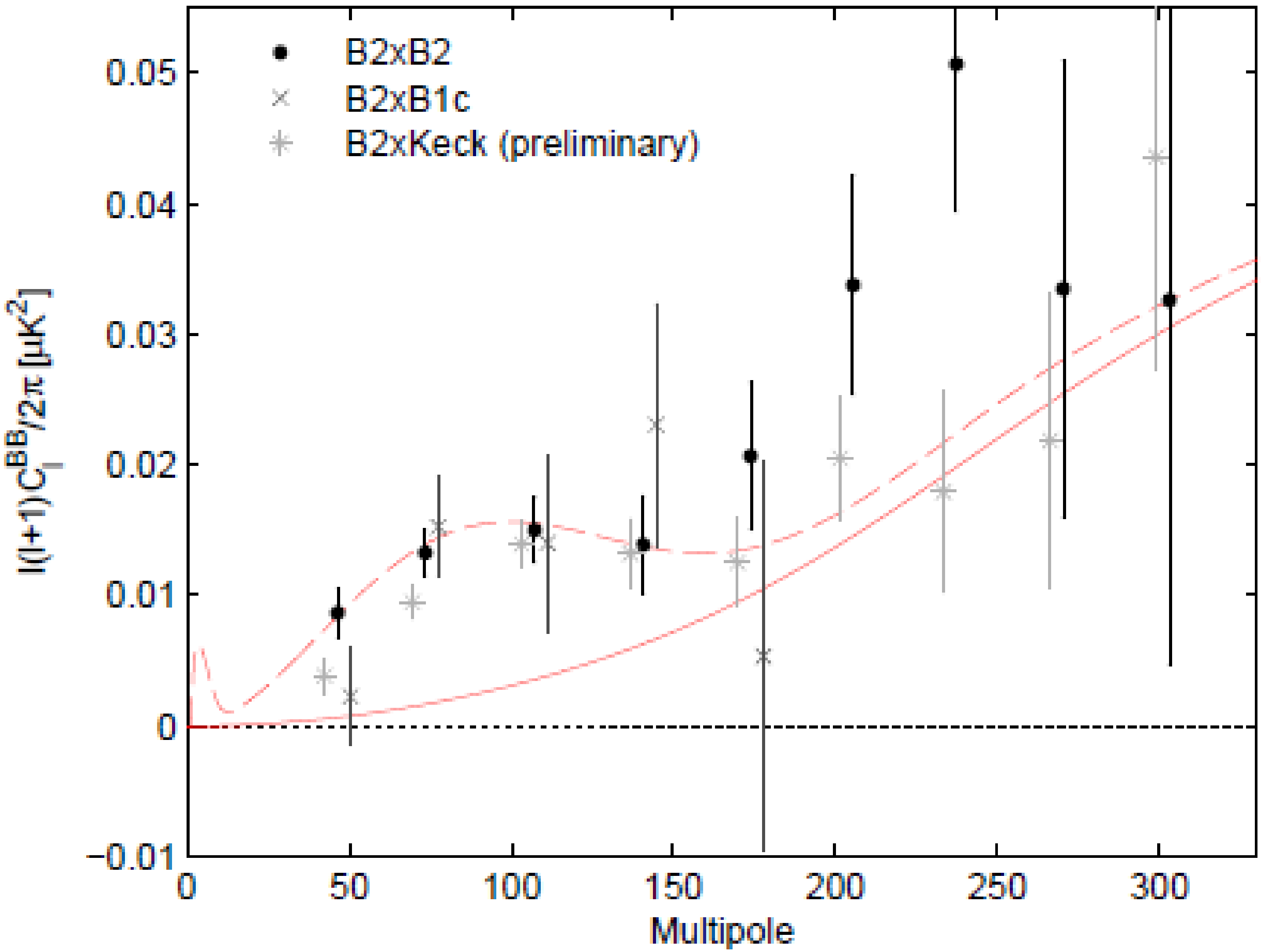
Current Limits – BBC r<0.11 (2σ)
Assumes no running of n_s



Harvard March 19 – Inflation Discovered!?

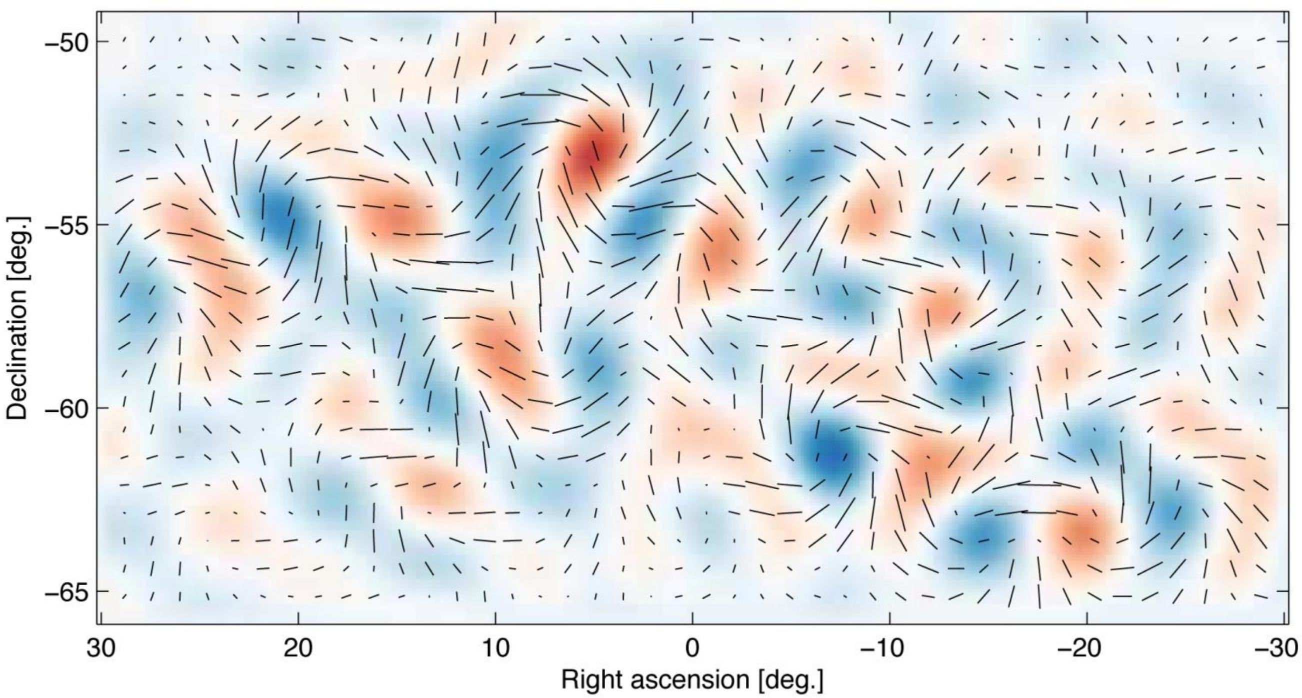


BiCEP2 – March 2014



Harvard March 17 10:45 – Inflation Detected?

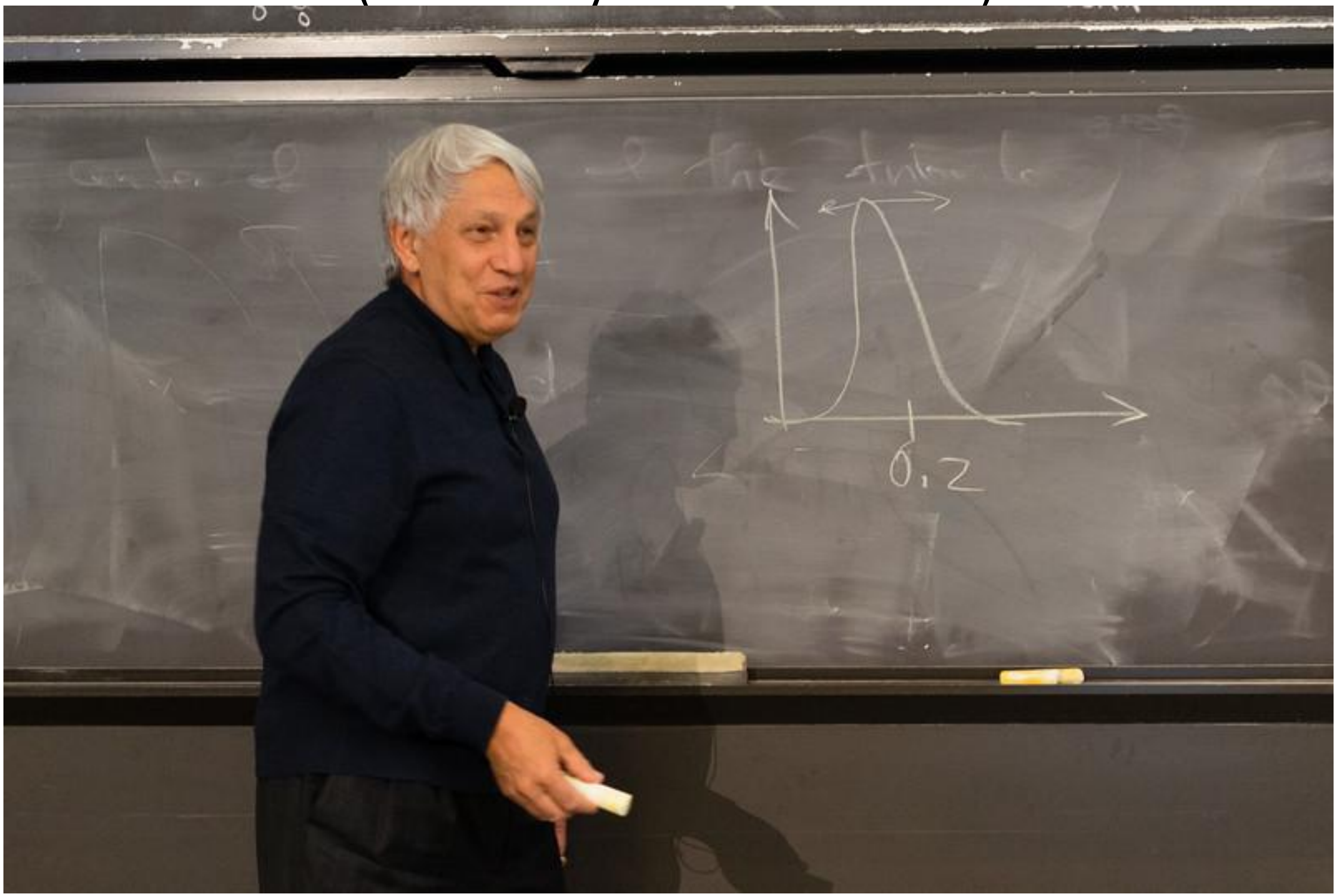
- http://www.cfa.harvard.edu/news/2014-05
- First Direct Evidence of Cosmic Inflation
- **Release No.:** 2014-05
- **For Release:**
- Monday, March 17, 2014 - 10:45am



r=0.2? or r<0.2?

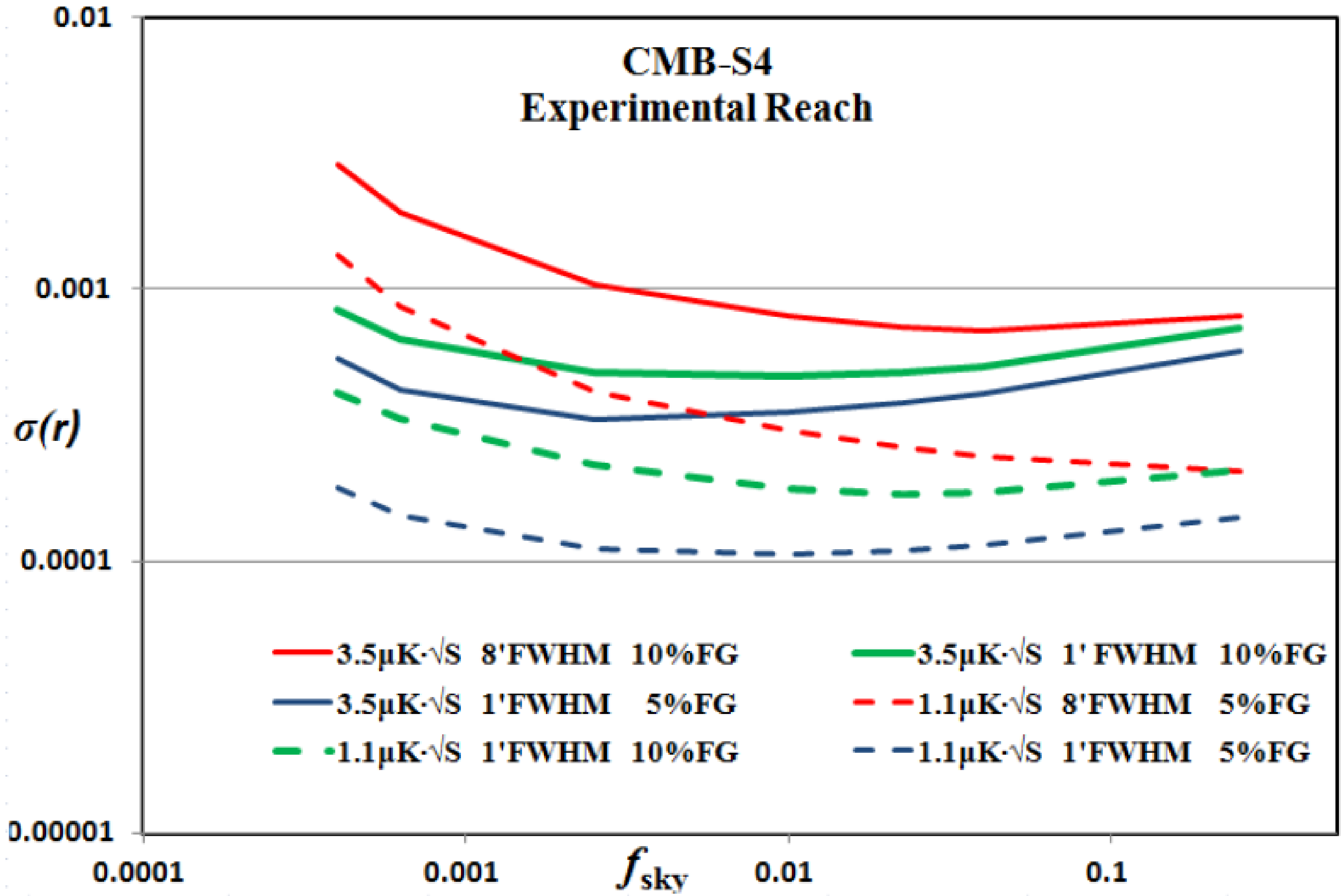
Luckily Andrei has a good sense of humor

(which may be needed soon)

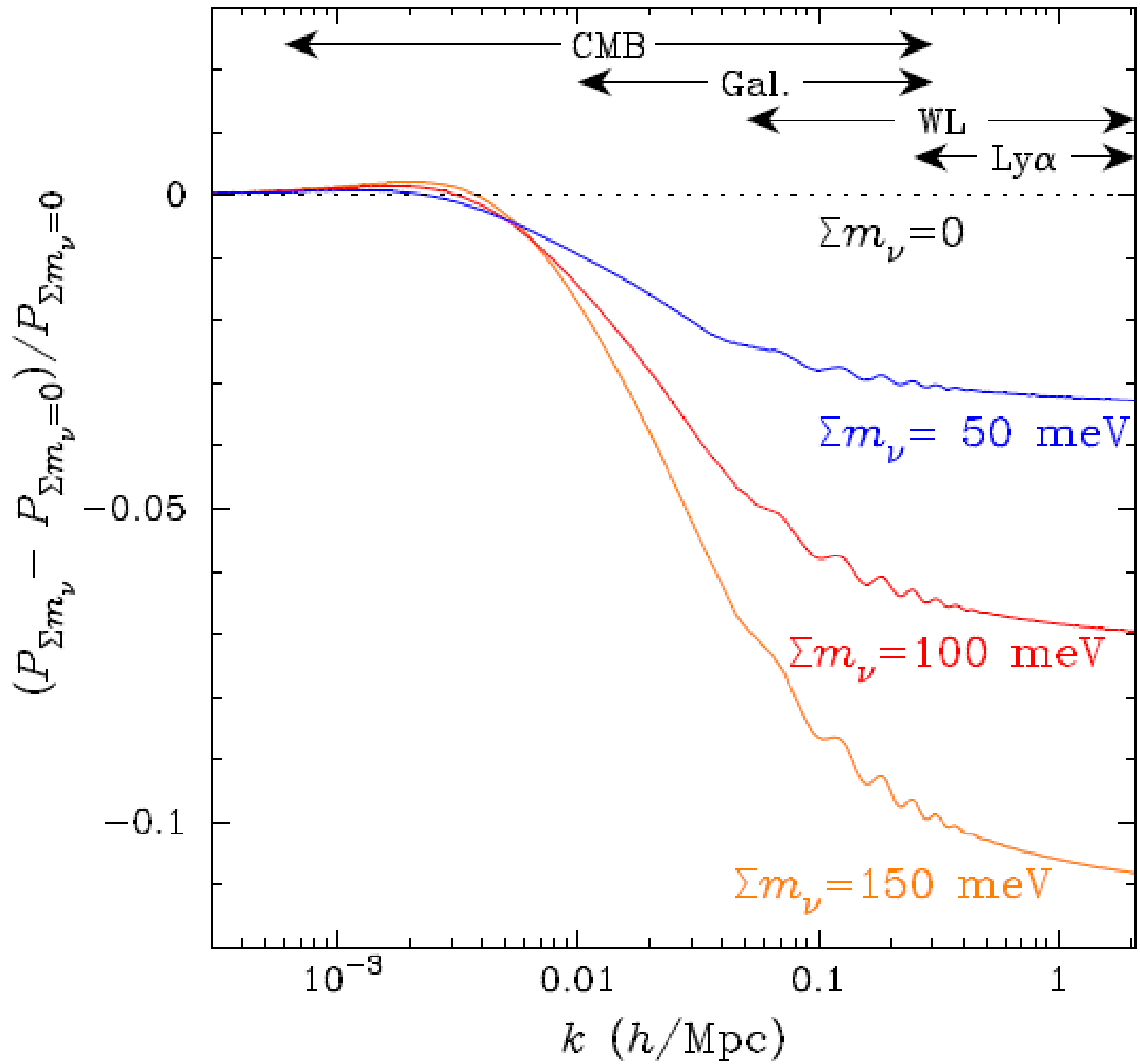


BICEP Press release – Harvard March 17 2014 www.youtube.com/watch?v=Iasqtm1prlI

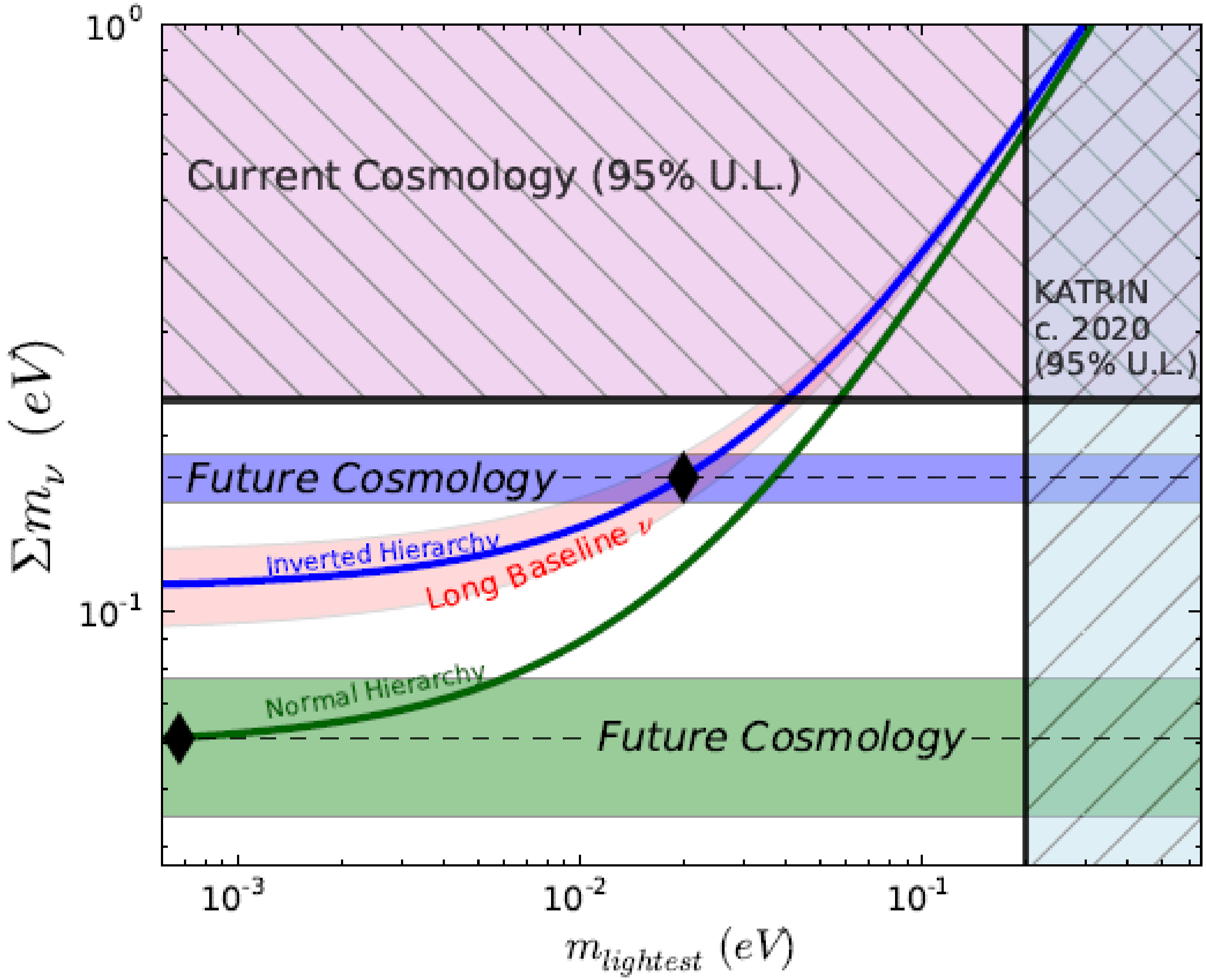
Future Forecast – 4th Gen Experiments



Effect of Neutrino Mass on Matter Power Spectrum



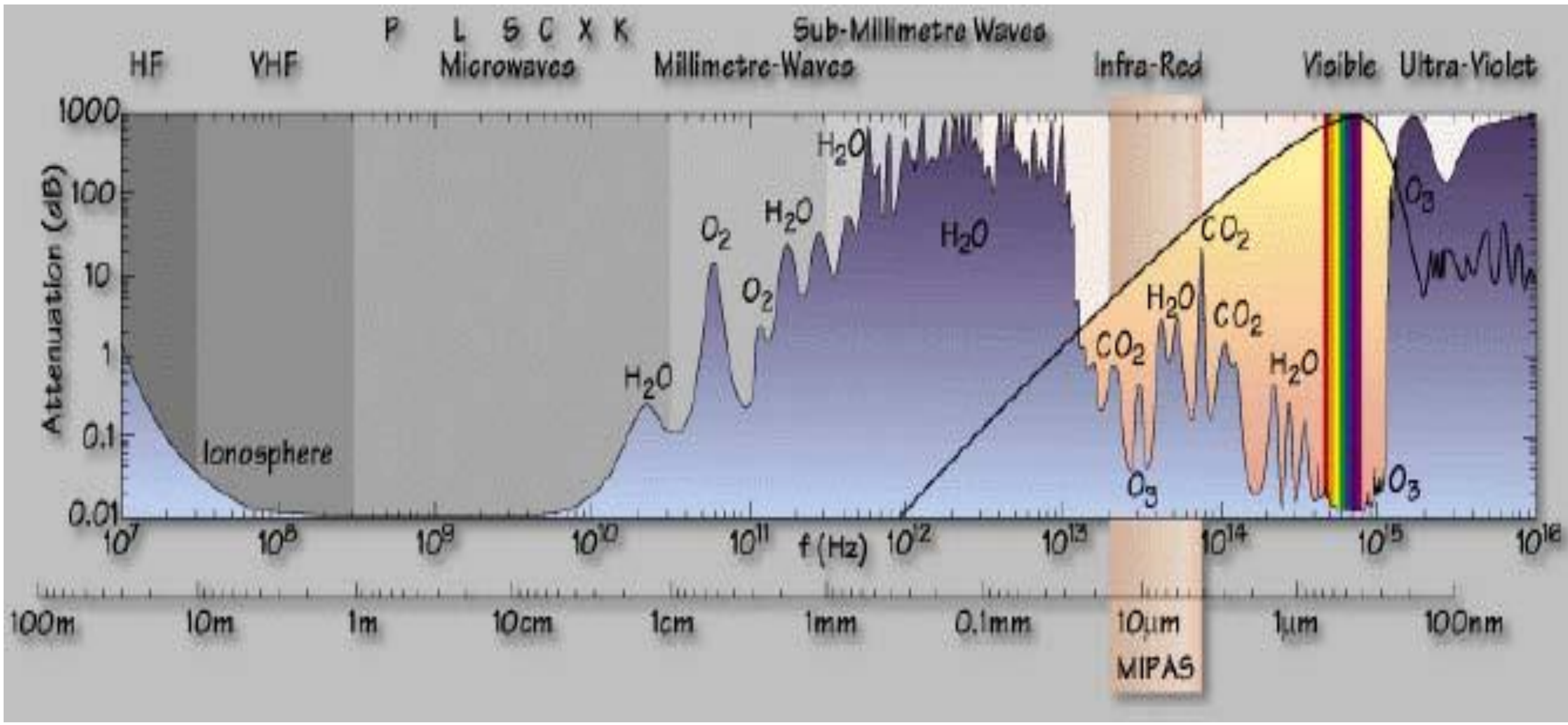
Forecast for Neutrino Mass Sensitivity



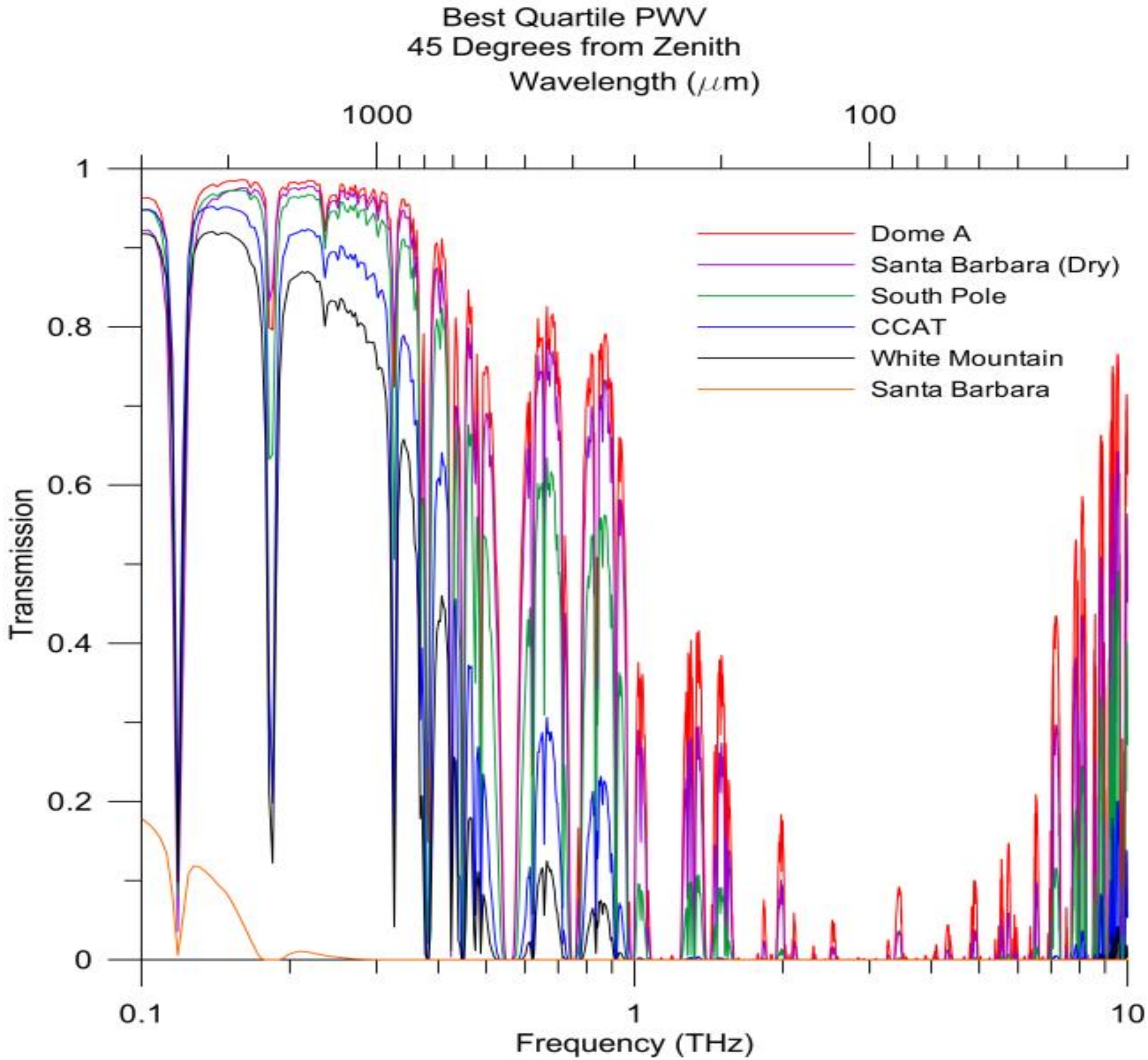
Current, Planned , Future Neutrino Sensitivity

Dataset	$\sigma\left(\sum m_\nu\right)$ [meV]	$\sigma\left(N_{\rm eff}\right)$
Galaxy Clustering (current CMB):		
Planck + BOSS BAO	100	0.18
Planck + BOSS galaxy clustering	46/68	0.14/0.17
Planck + eBOSS BAO	97	0.18
Planck + eBOSS galaxy clustering	36/52	0.13/0.16
Planck + DESI BAO	91	0.18
Planck + DESI galaxy clustering	**17/24**	0.08/0.12
CMB Lensing (current galaxy clustering):		
Stage-IV CMB	45	**0.021**
Stage-IV CMB + BOSS BAO	**25**	0.021
CMB Lensing + Galaxy clustering:		
Stage-IV CMB + eBOSS BAO	23	0.021
Stage-IV CMB + DESI BAO	**16**	0.020
Stage-IV CMB no lensing + DESI galaxy clustering	15/20	0.022/0.024
Galaxy Weak Lensing:		
Planck + LSST [51]	23	0.07
Planck + Euclid [48]	25	NA†

EM spectrum from the Ground – The Big Picture

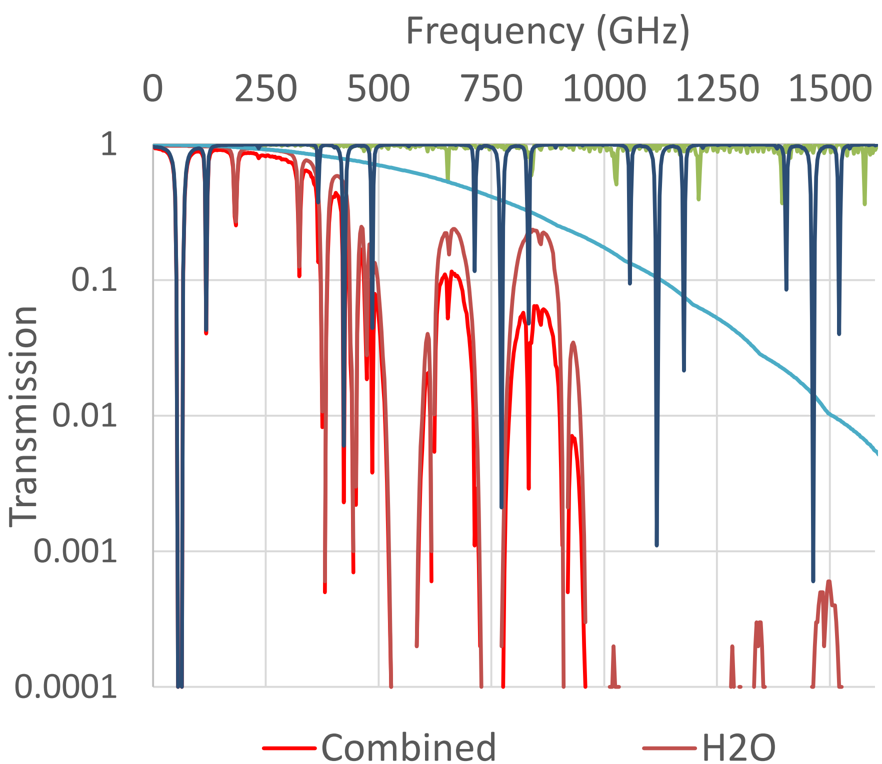


Transmission vs Frequency vs Site



Water Vapor – The Enemy

- Most of the atmospheric lines in the THz regime are from water vapor.

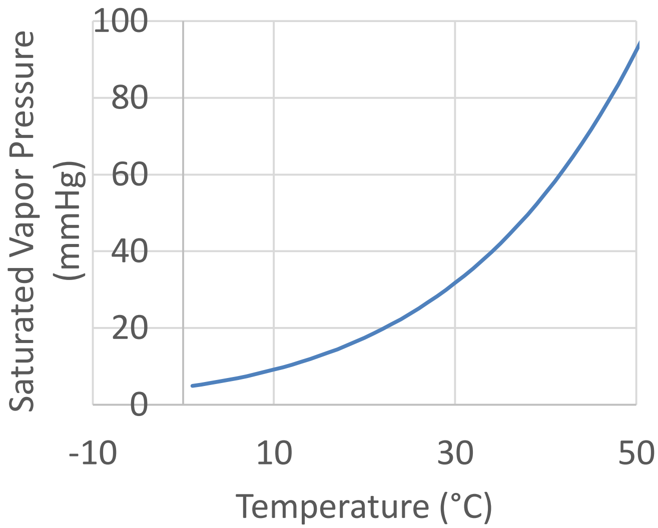


- Oxygen has a number of discrete lines
  - 60 GHz band (Magnetic dipolar)
  - Regular structure

- Negligible until the IR: CO, CO_2, CH_4, NOX (N_2O, $HNO_{3,4}$, NO, NO_2…), NH_3
- (in gas phase)

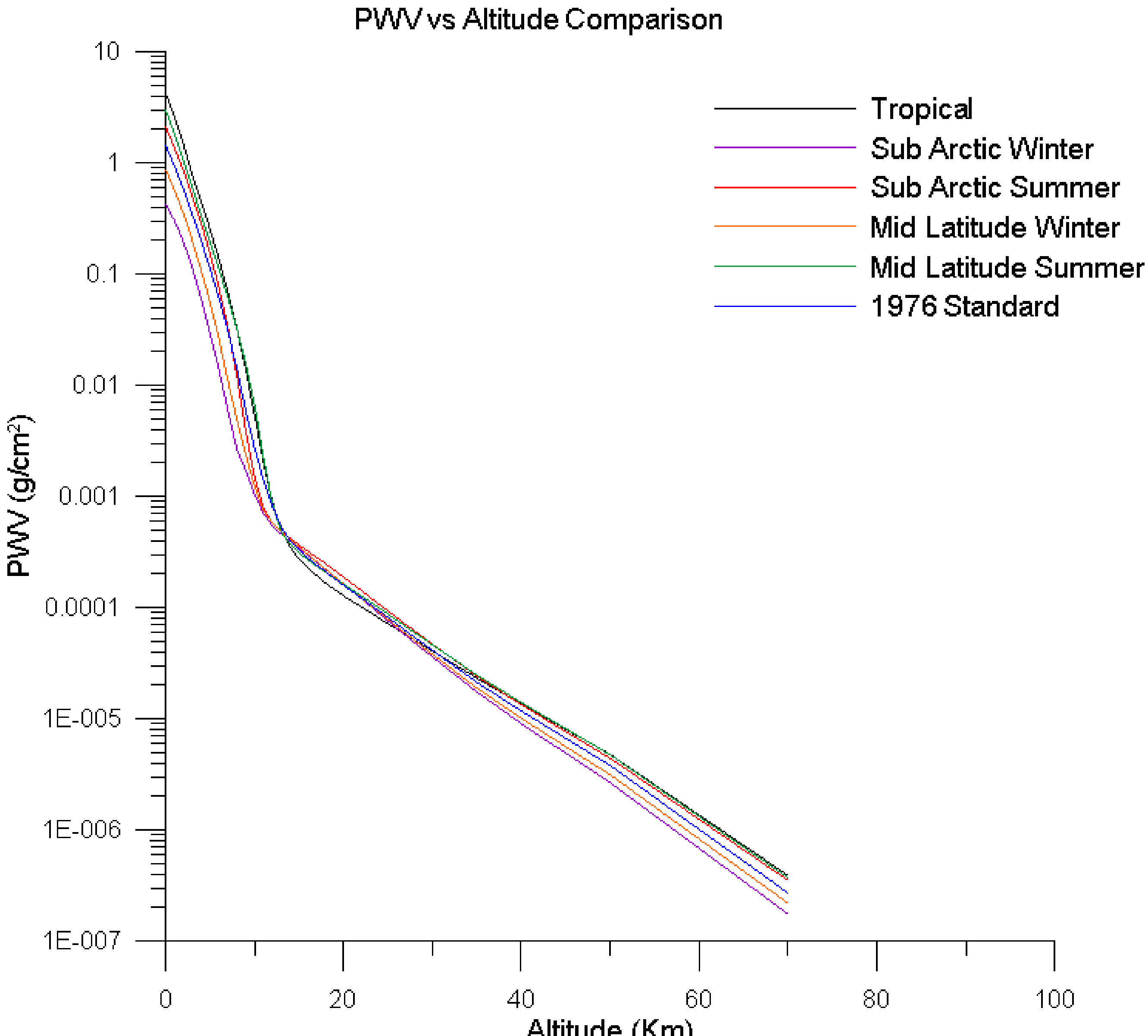
Distribution of Gasses

- Water distribution is a heavy function of temperature.

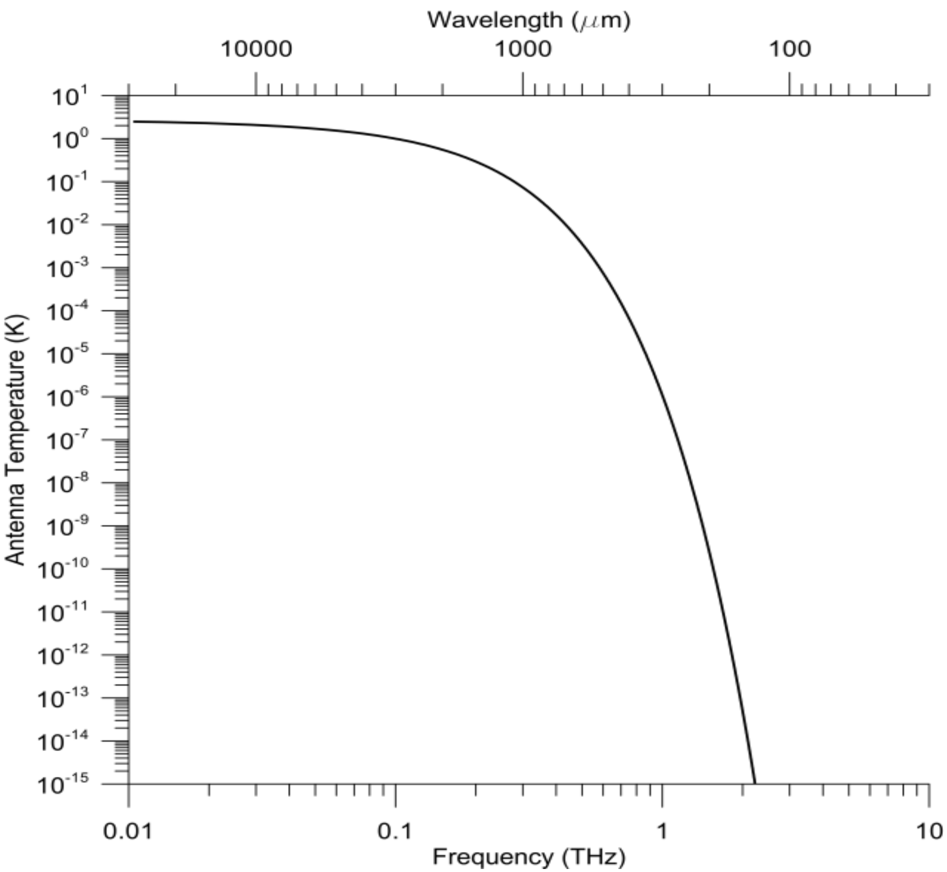


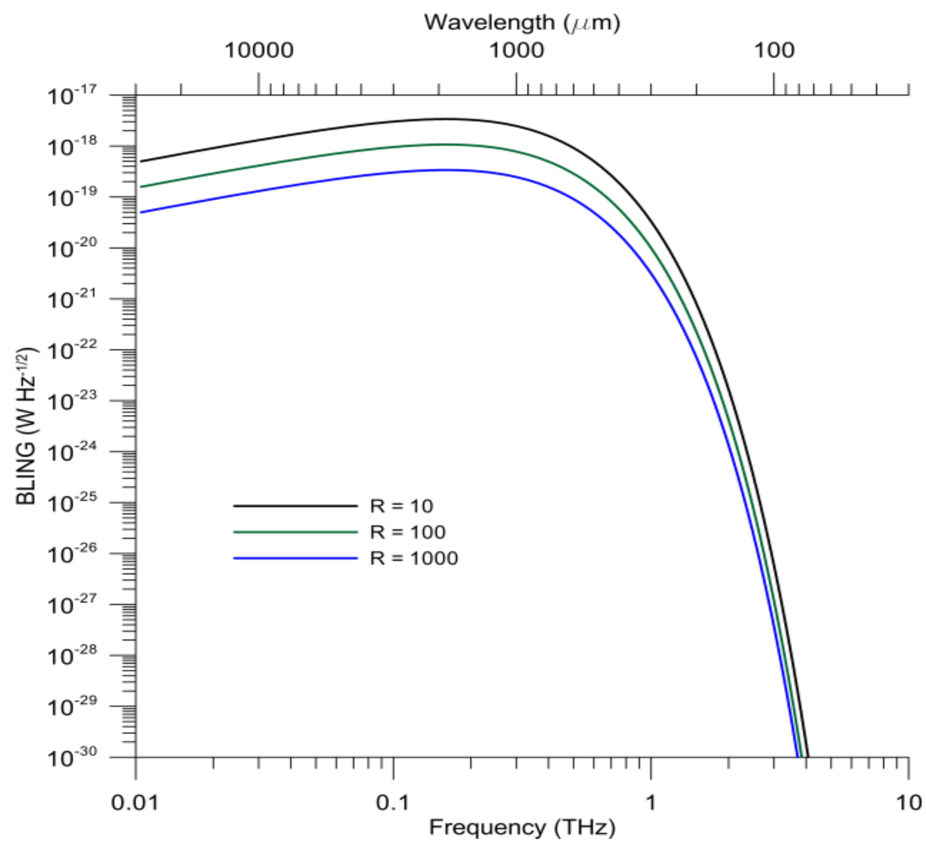
- Scale height (1/e distance) of water is much smaller than other atmospheric gasses
  - H2O = 1.5 km
  - Whole atmosphere = 7.6 km
- Mixing of O_2, N_2, Ar uniform until ~80 km.
- Very little atmosphere by 100 km.

For the Atmosphere
Water Vapor is THE ISSUE

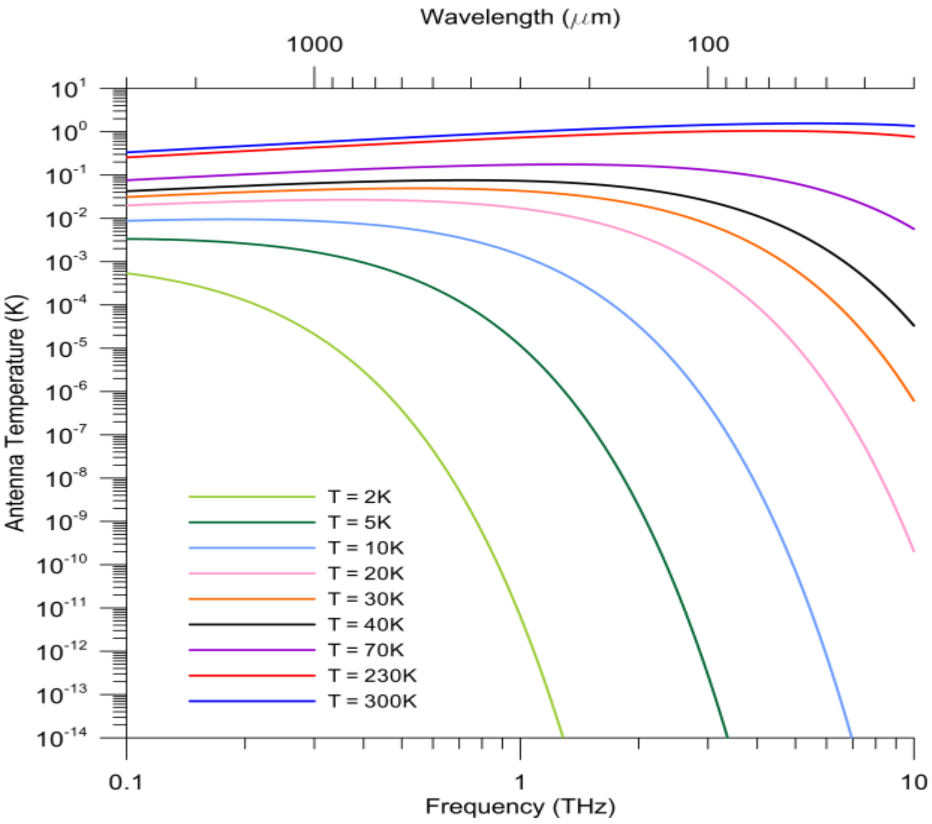


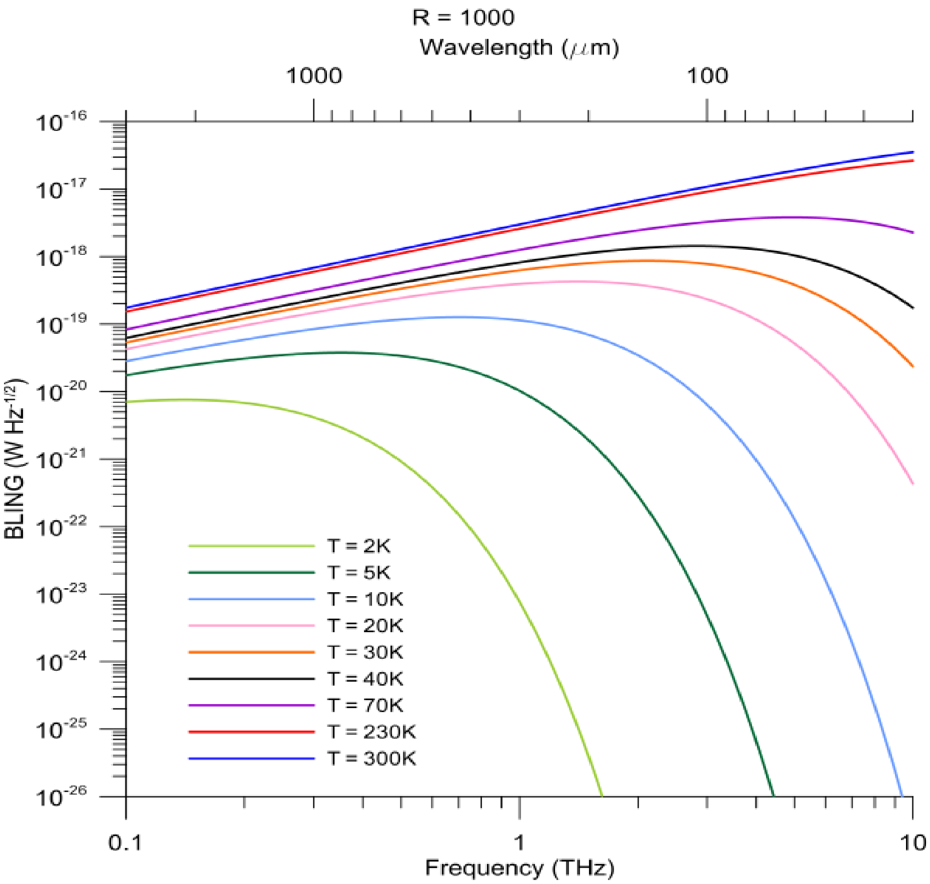
CMB in Ta and BLING



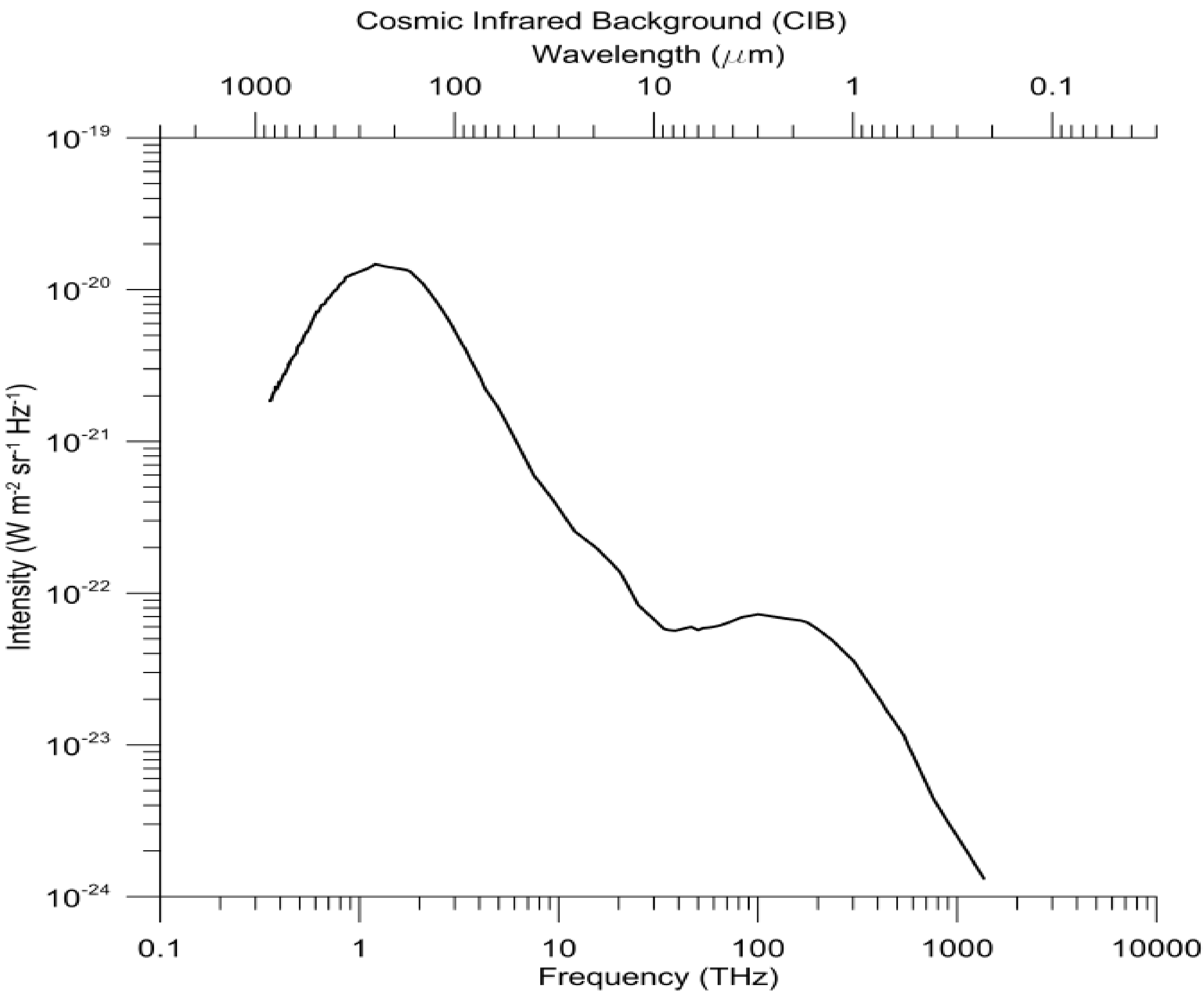


Mirror Emission vs Temp

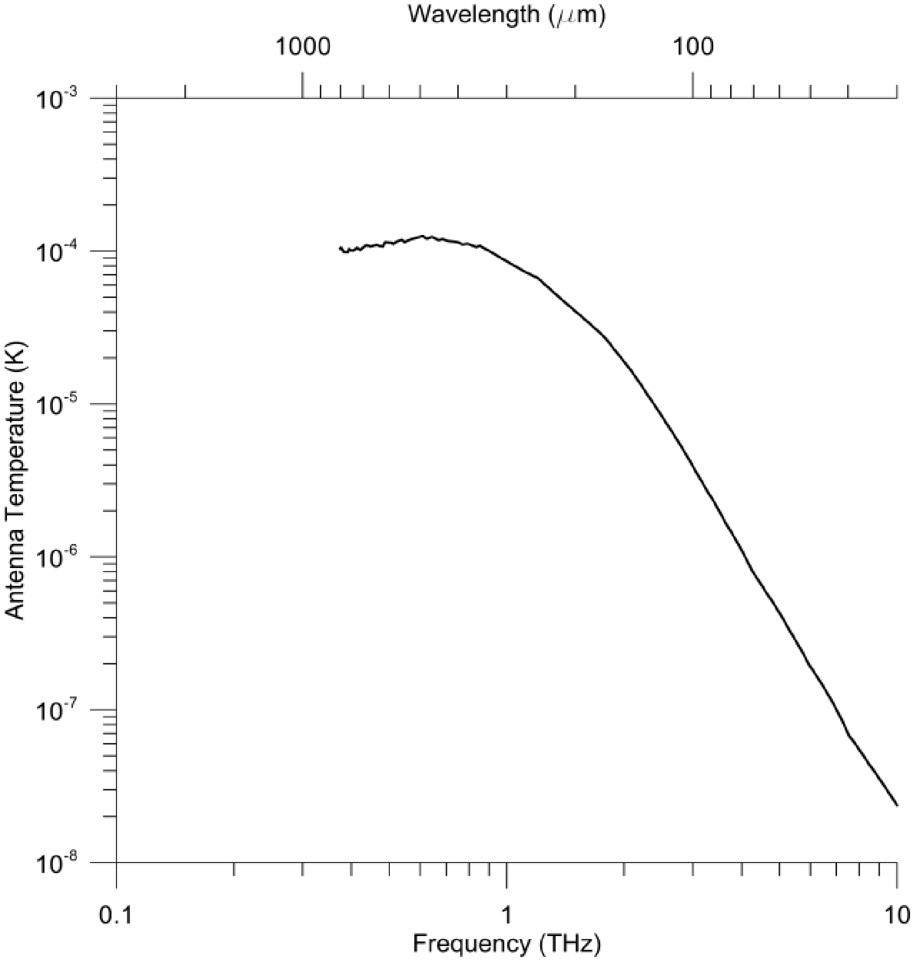




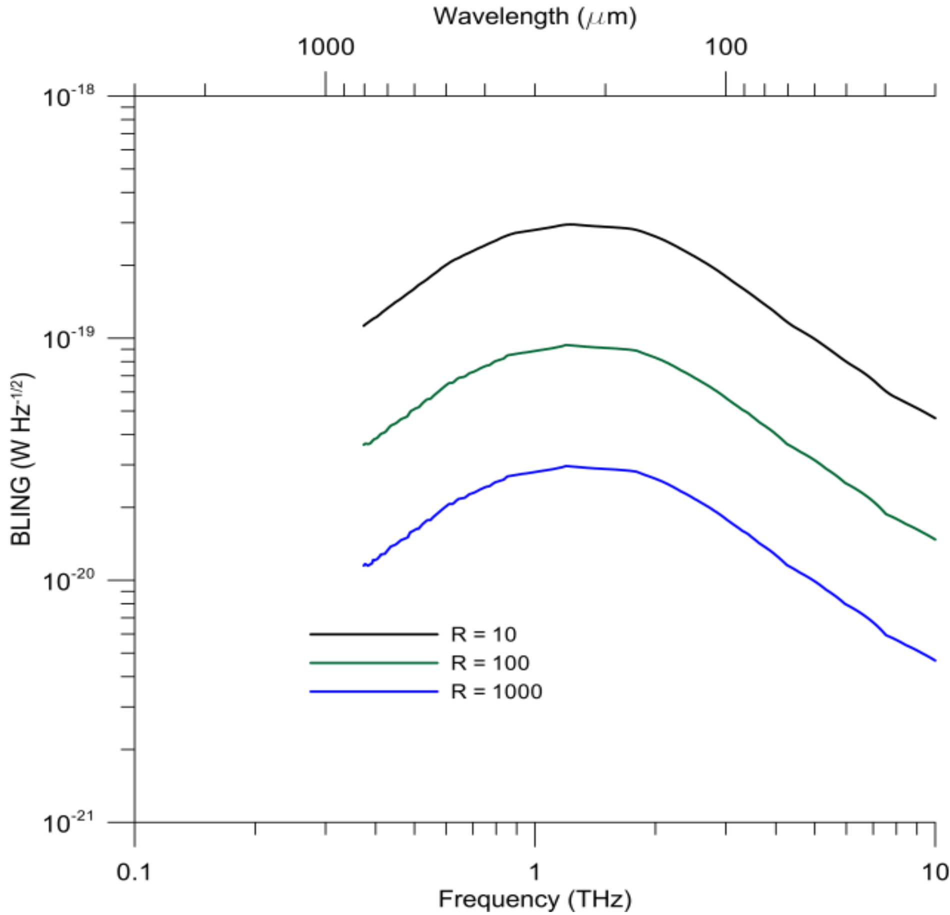
Cosmic IR Background - CIB



CIB in far IR

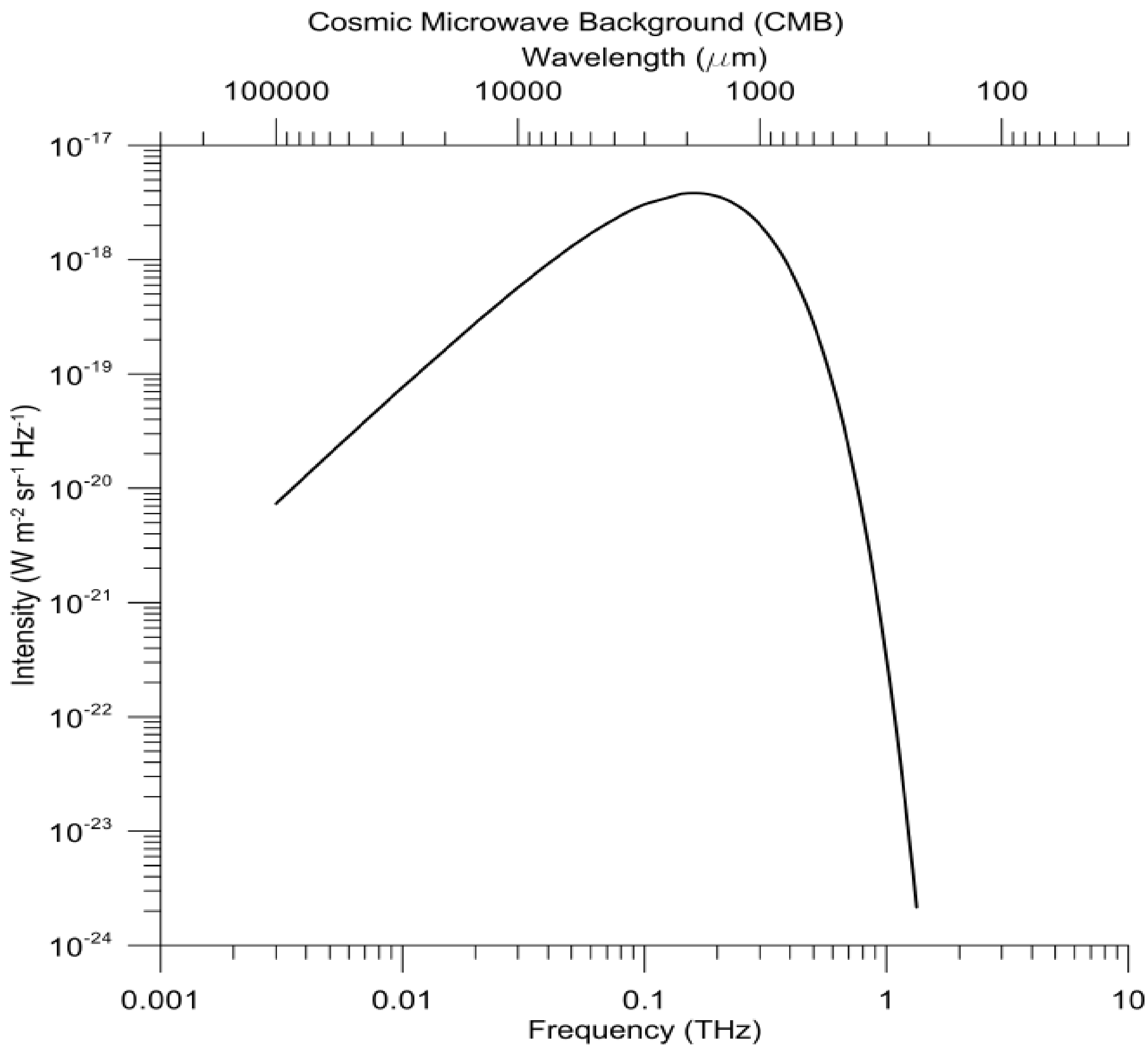


Wavelength (μm)
1000
100
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Antenna Temperature (K)
0.1
1
10
Frequency (THz)

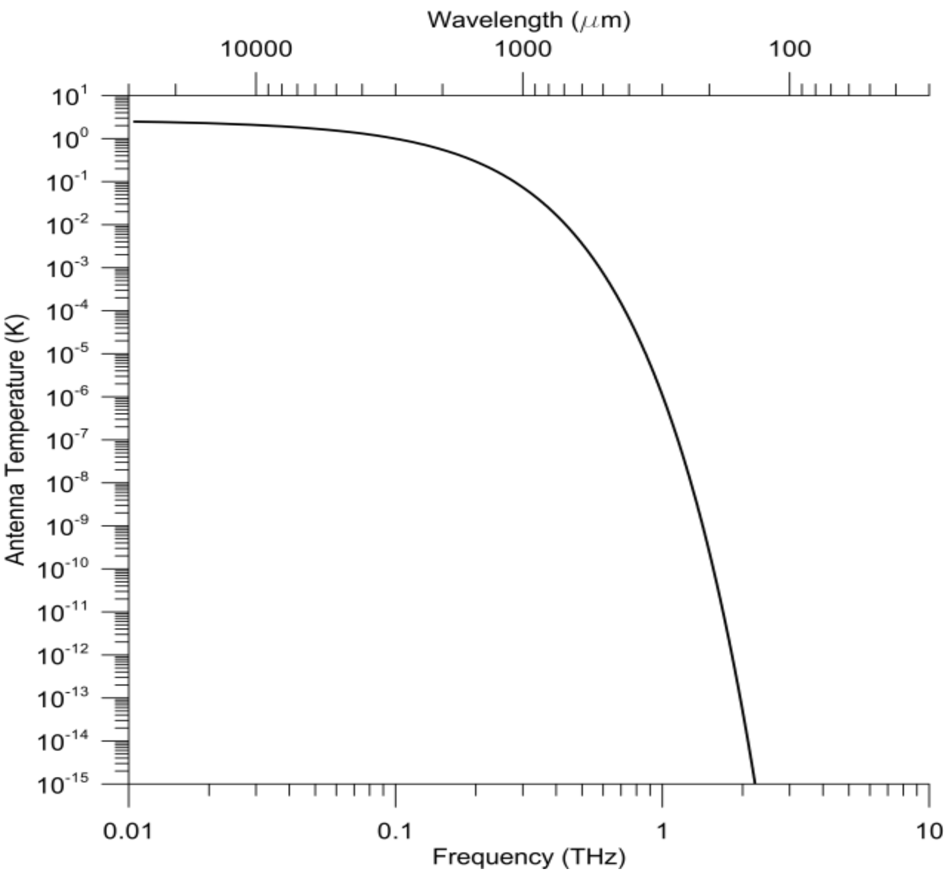


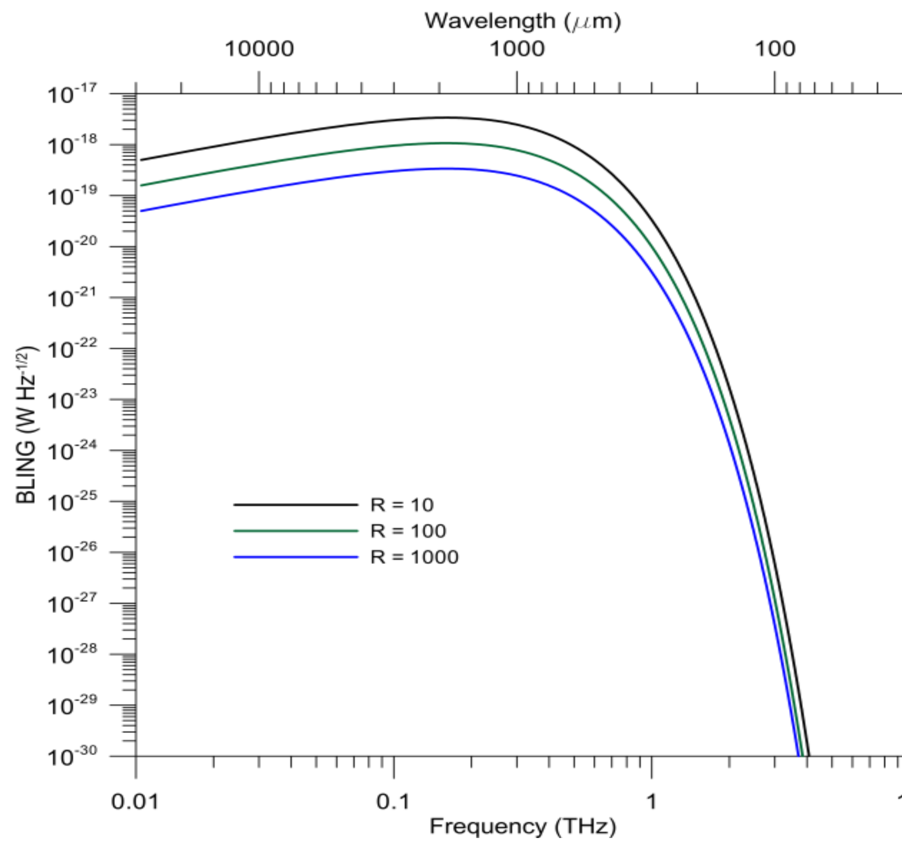
Wavelength (μm)
1000
100
10^{-18}
10^{-19}
10^{-20}
10^{-21}
BLING (W Hz$^{-1/2}$)
R = 10
R = 100
R = 1000
0.1
1
10
Frequency (THz)

CMB Contribution

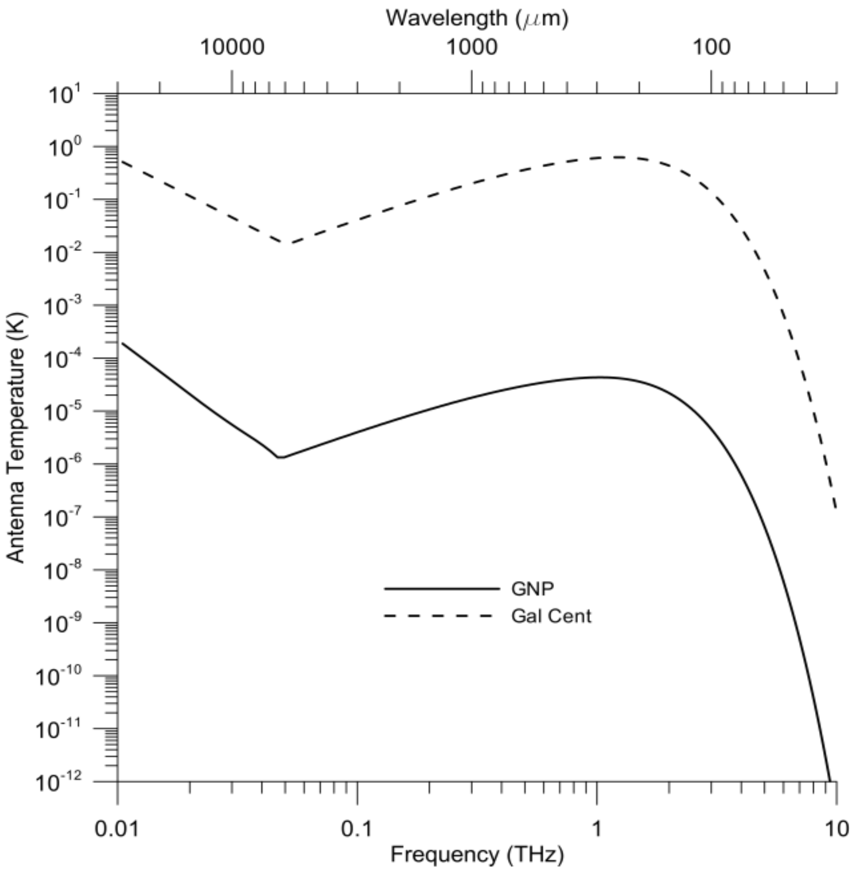


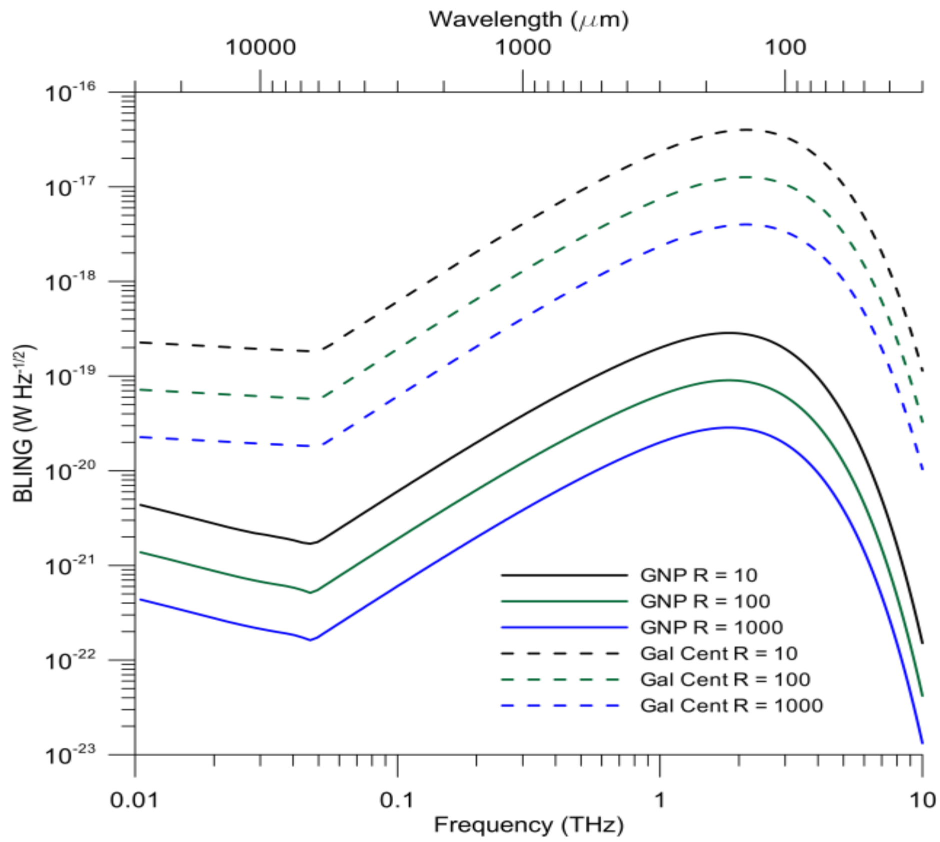
CMB in Ta and BLING



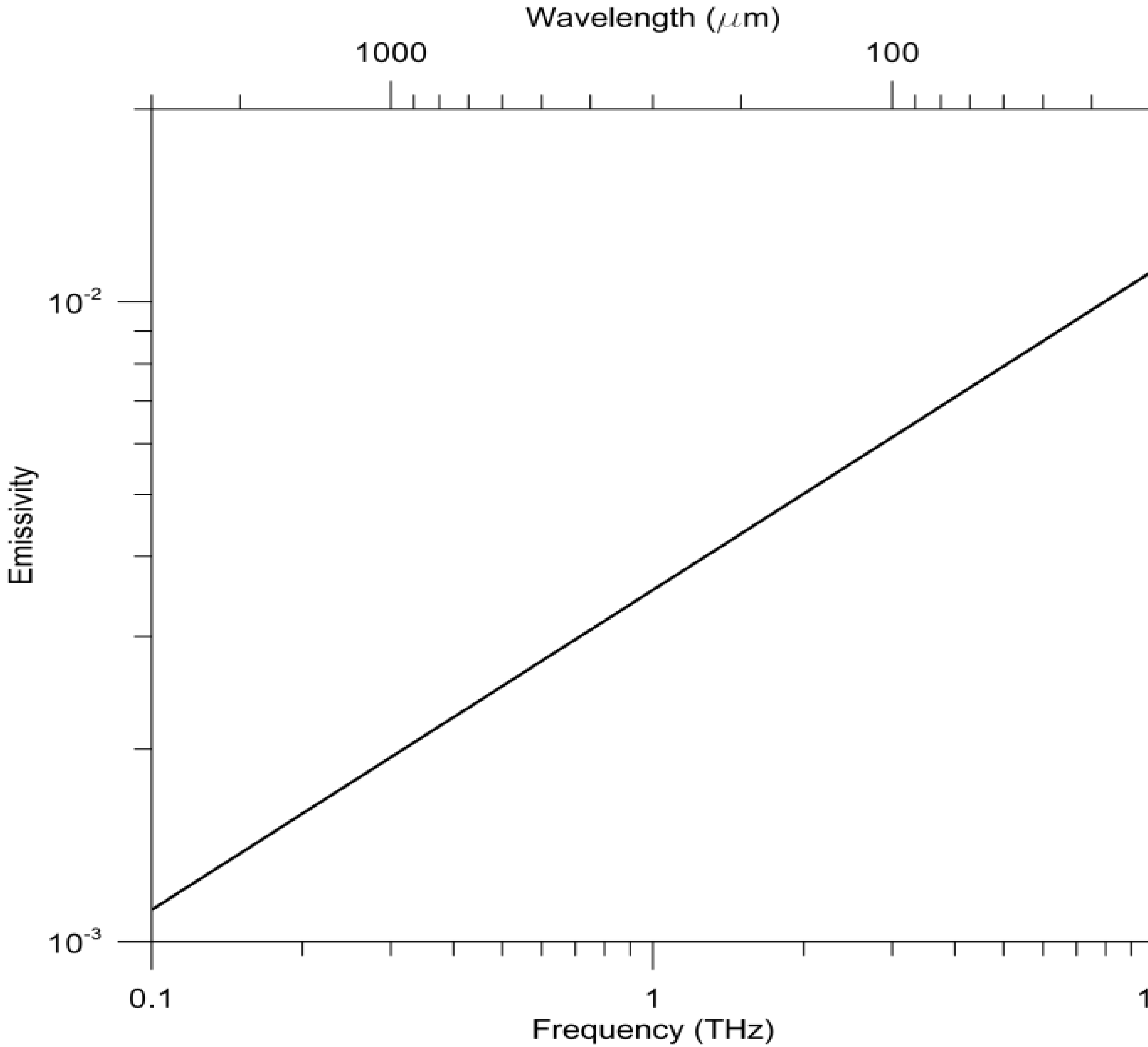


Galaxy in Synchrotron, Brem and Dust

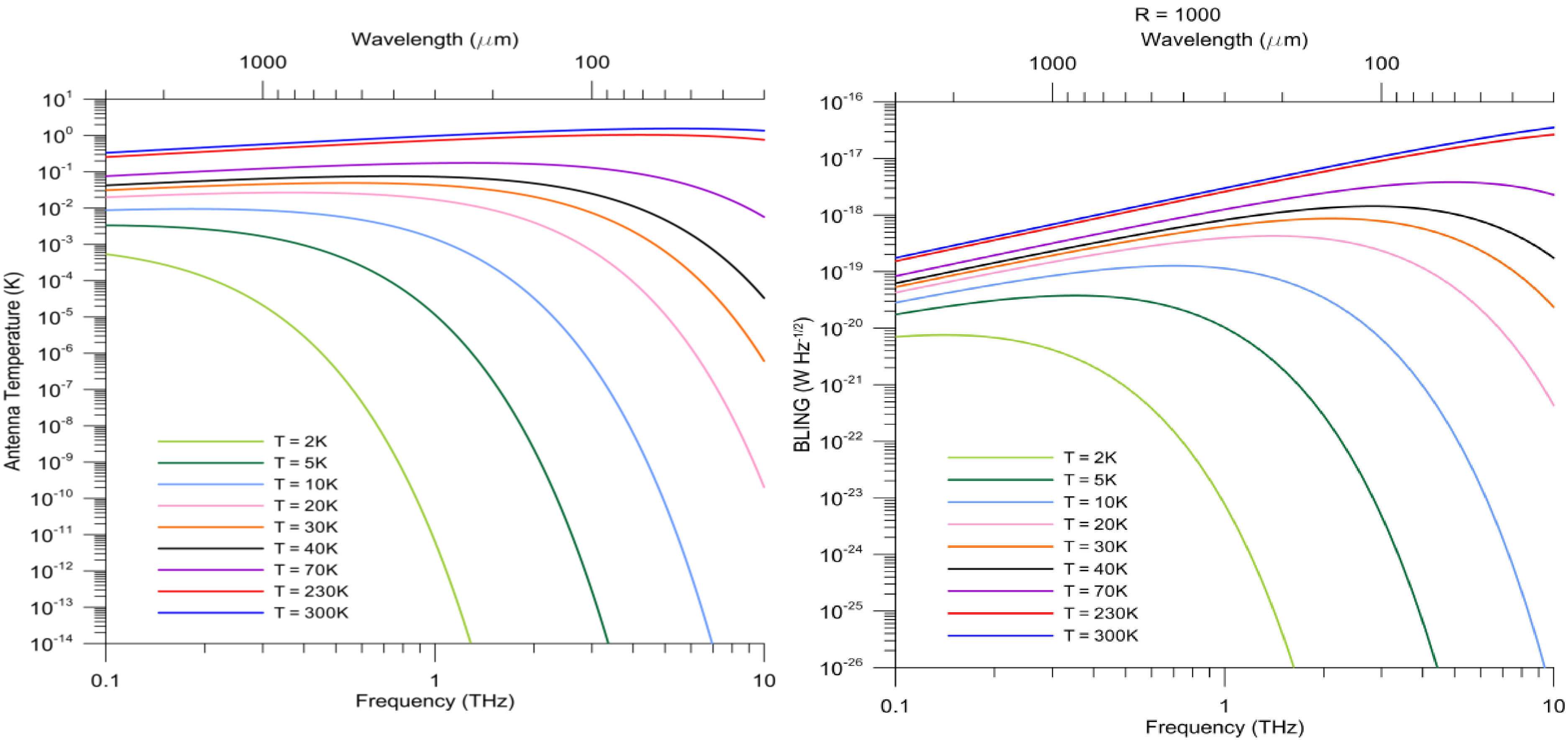




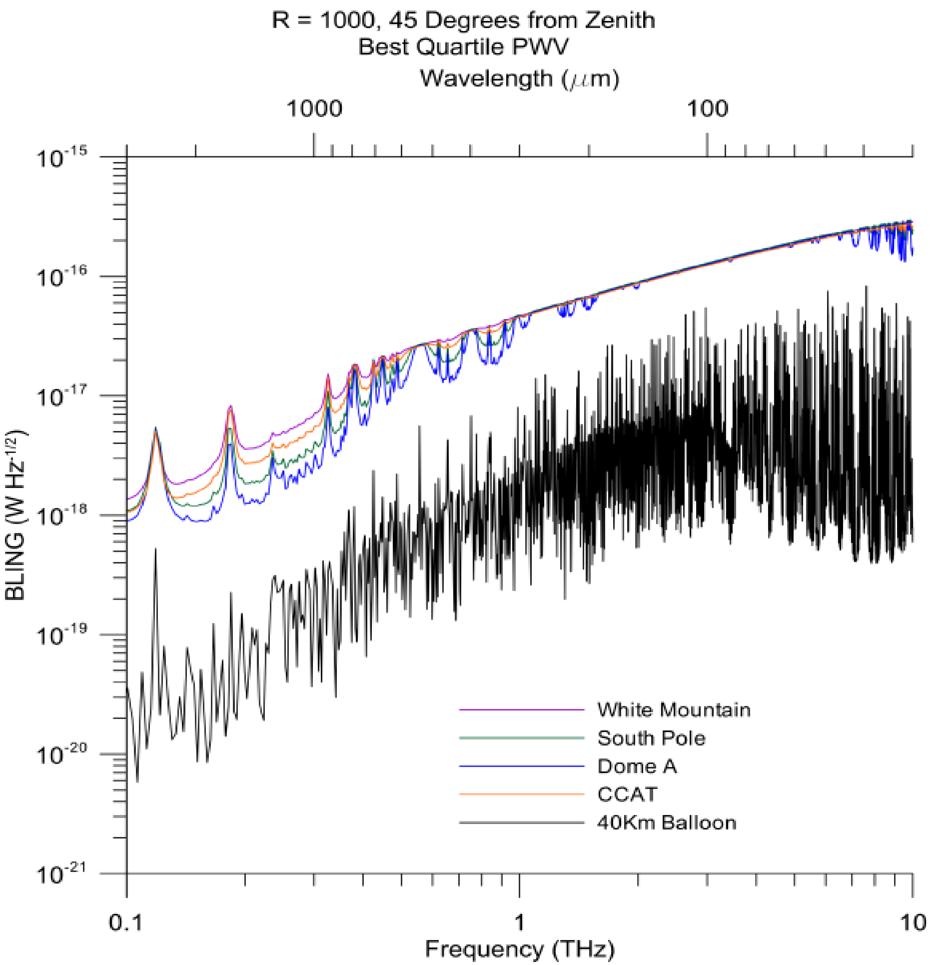
Mirror Emissivity - Al

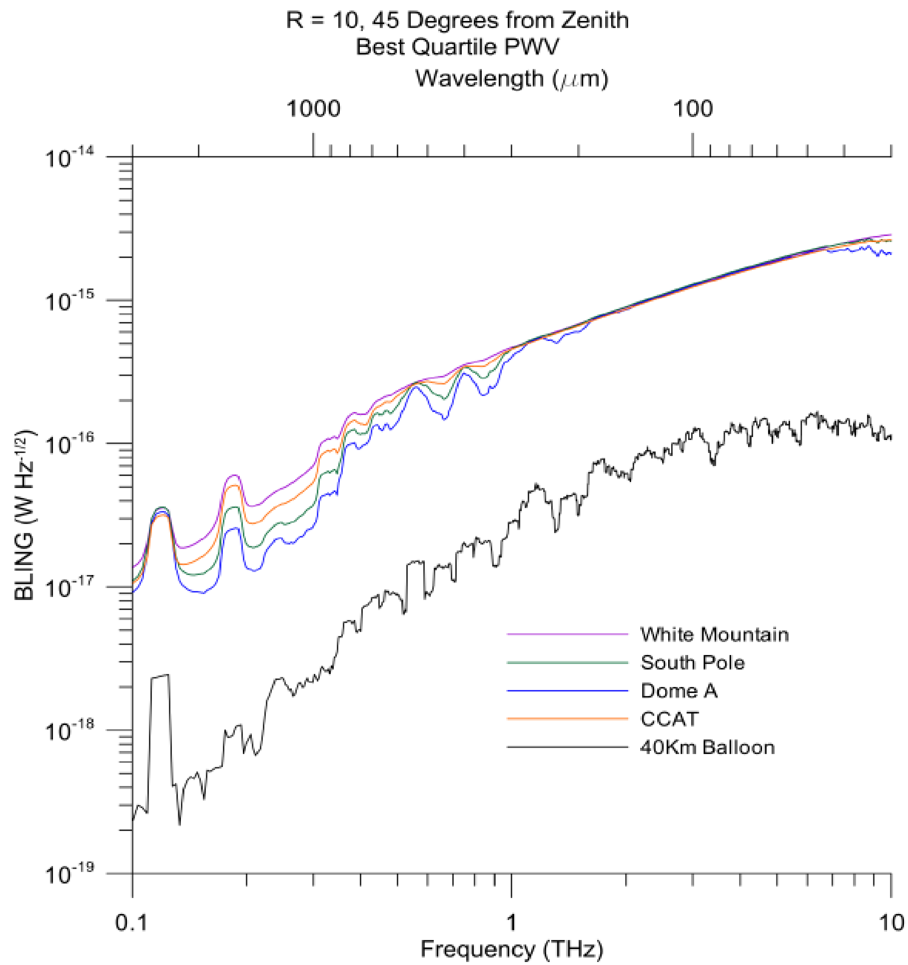


Mirror Emission vs Temp

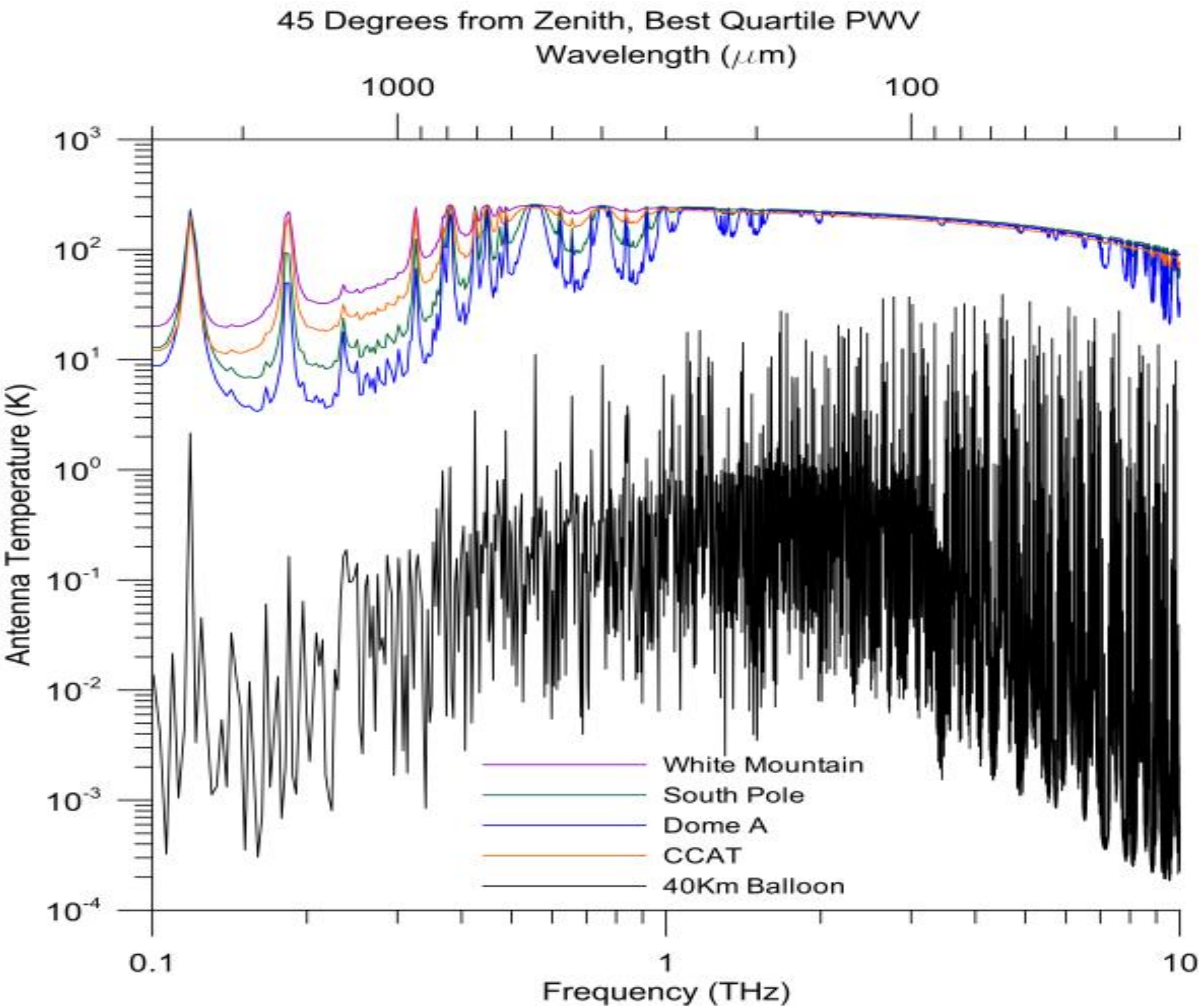


Effect of Spectral Resolution

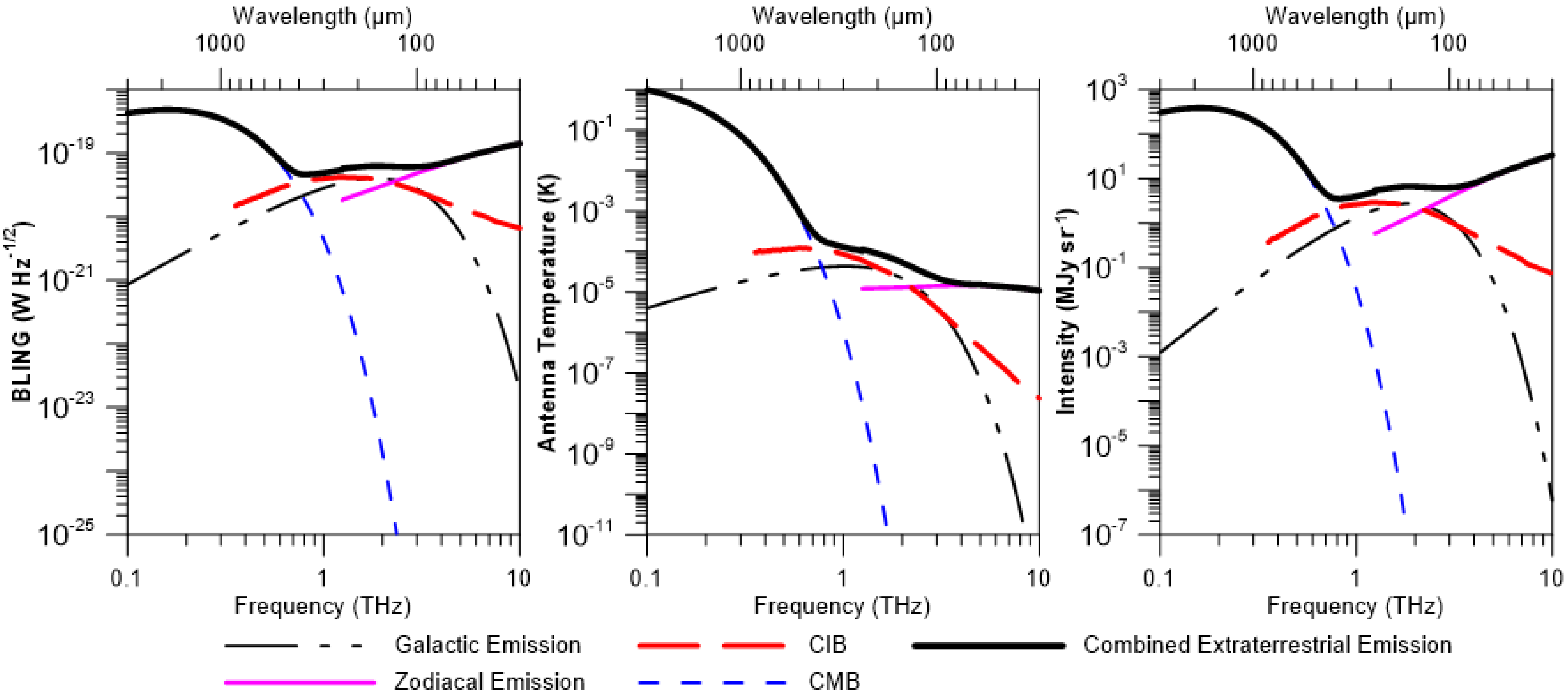




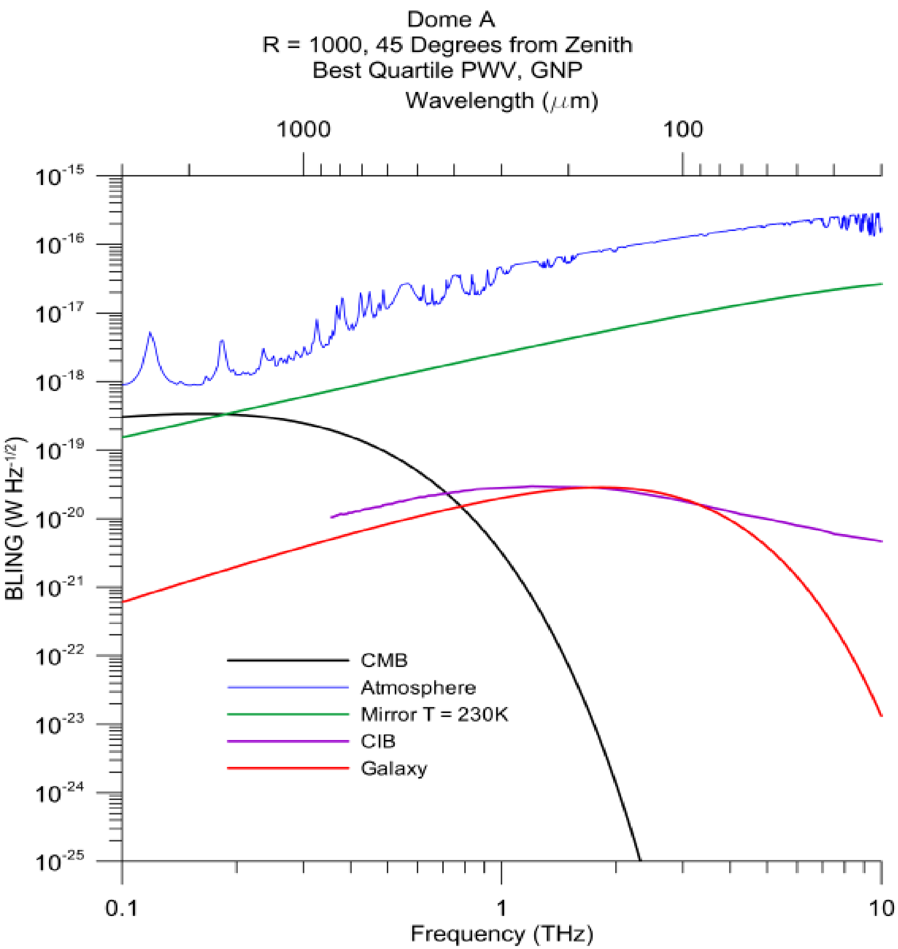
Ground vs Air

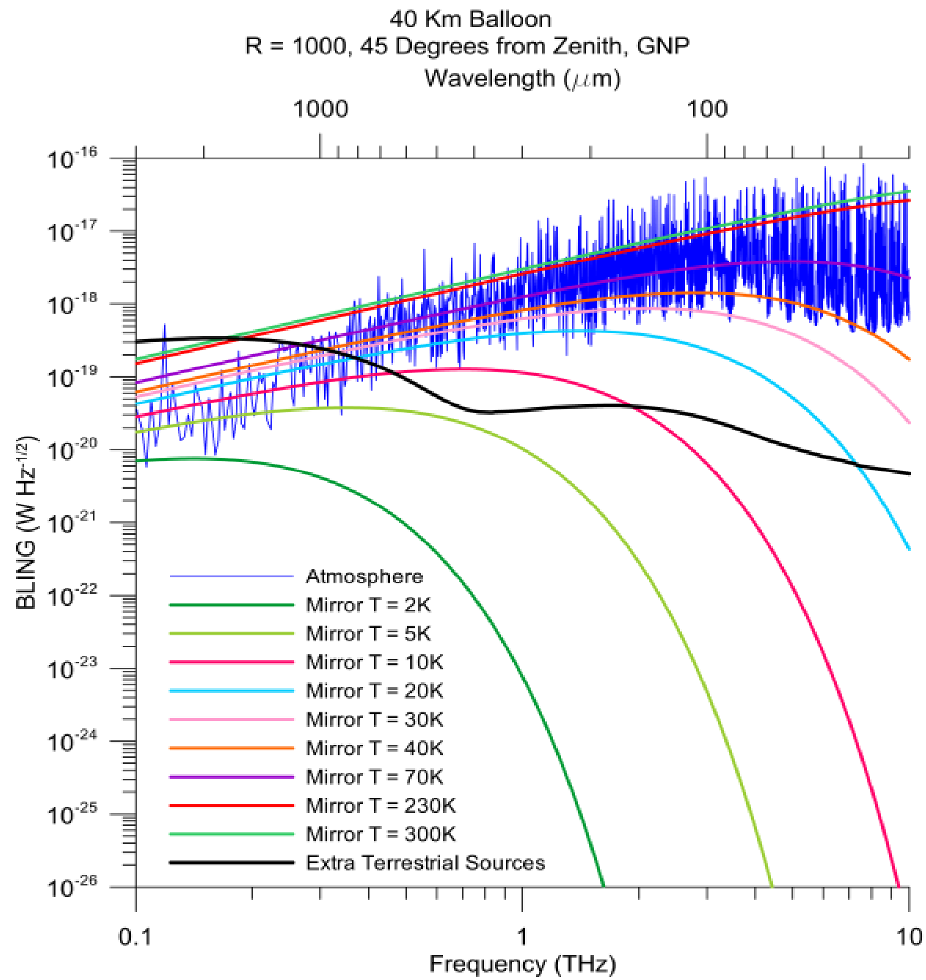


Galaxy-Zodi-CIB-CMB Foregrounds

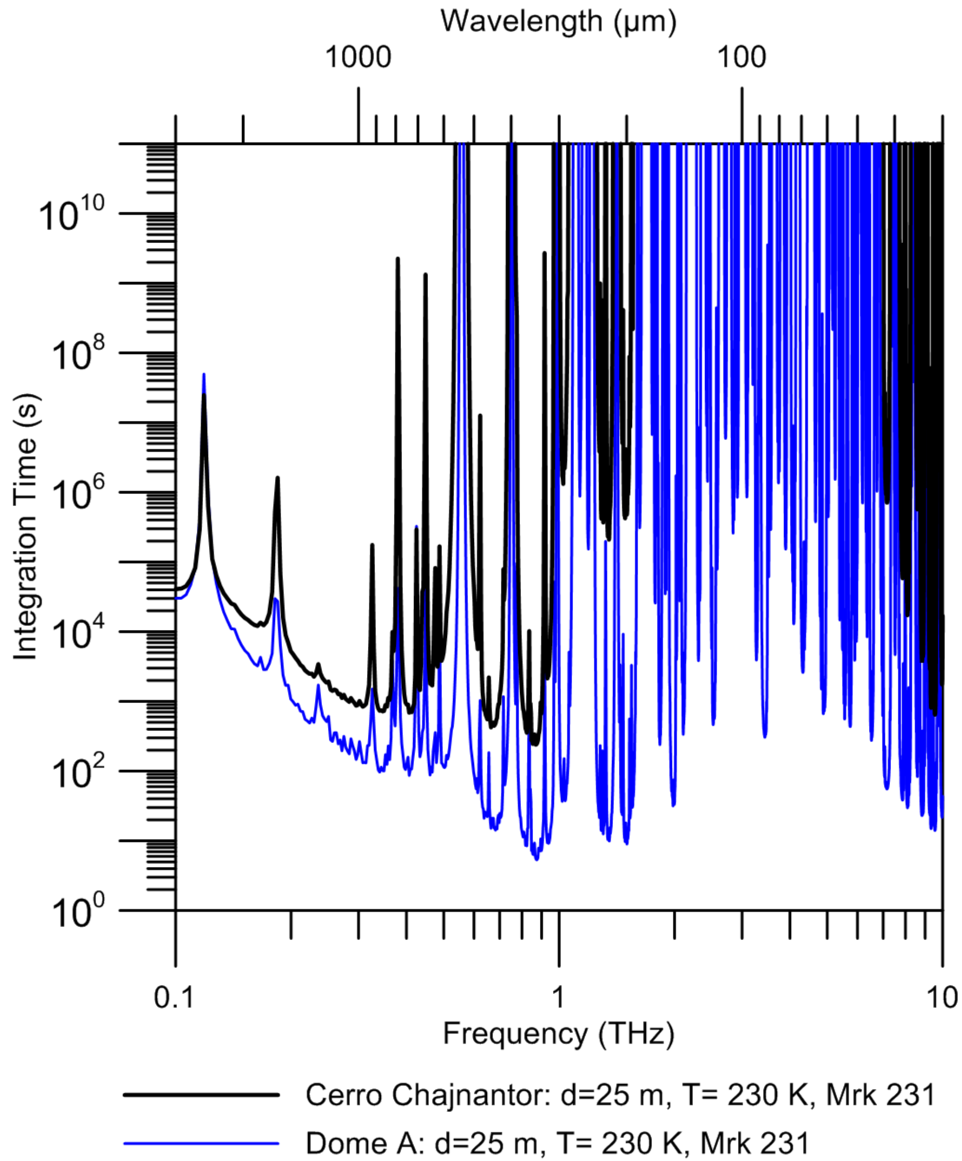


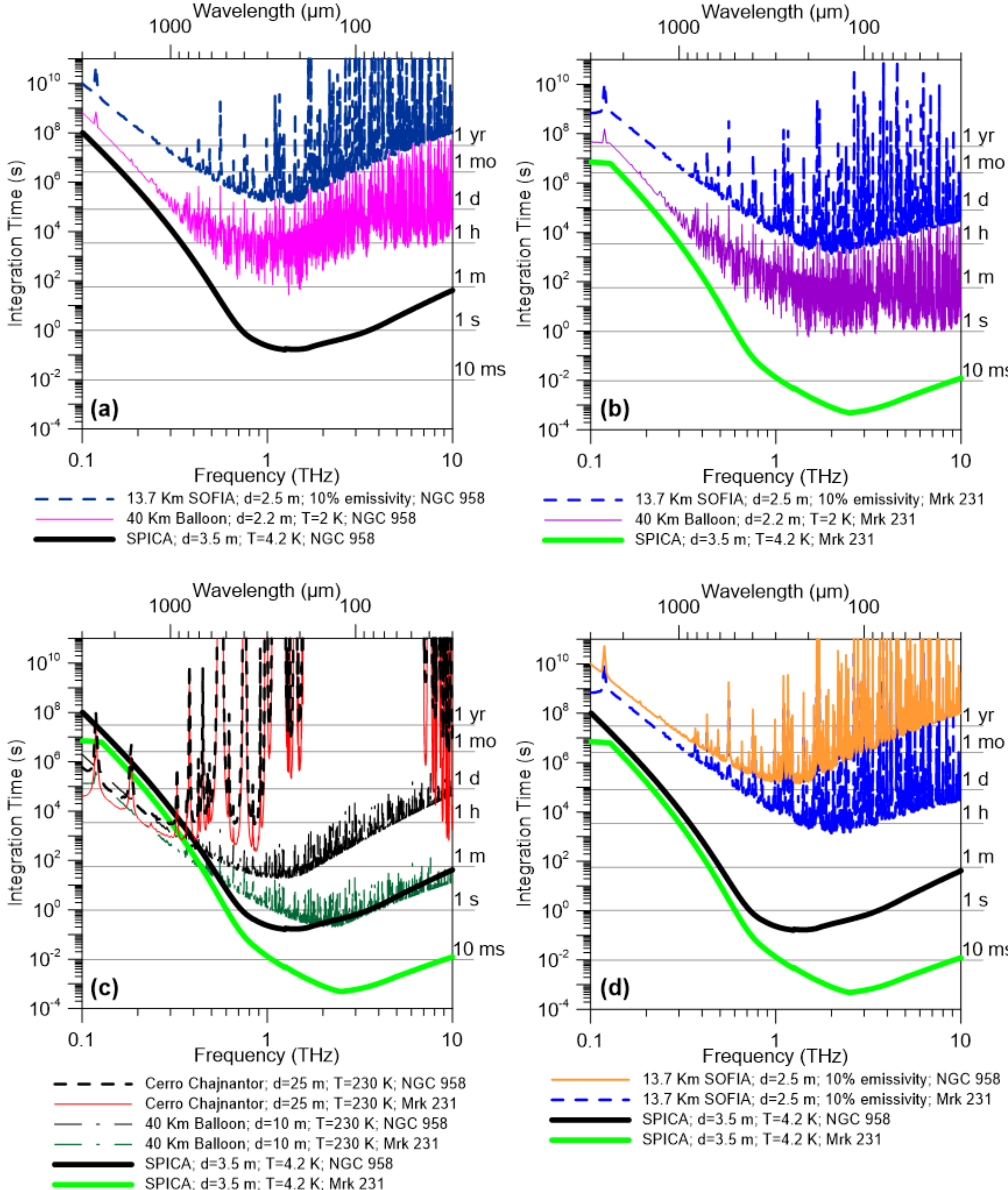
Mirror, Atmosphere, CMB, Gal, CIB





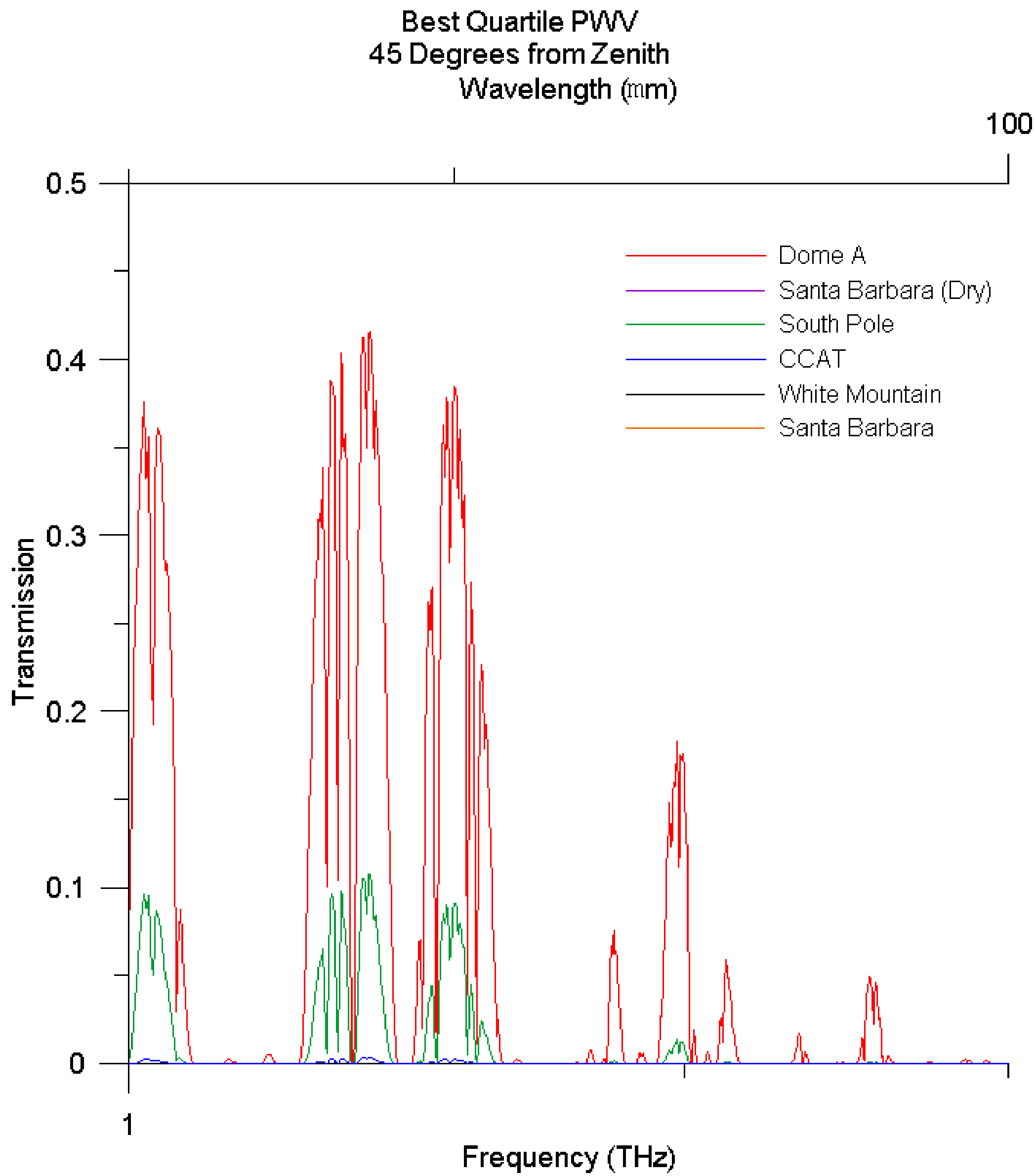
CCAT Class (25m) and Integration vs Site



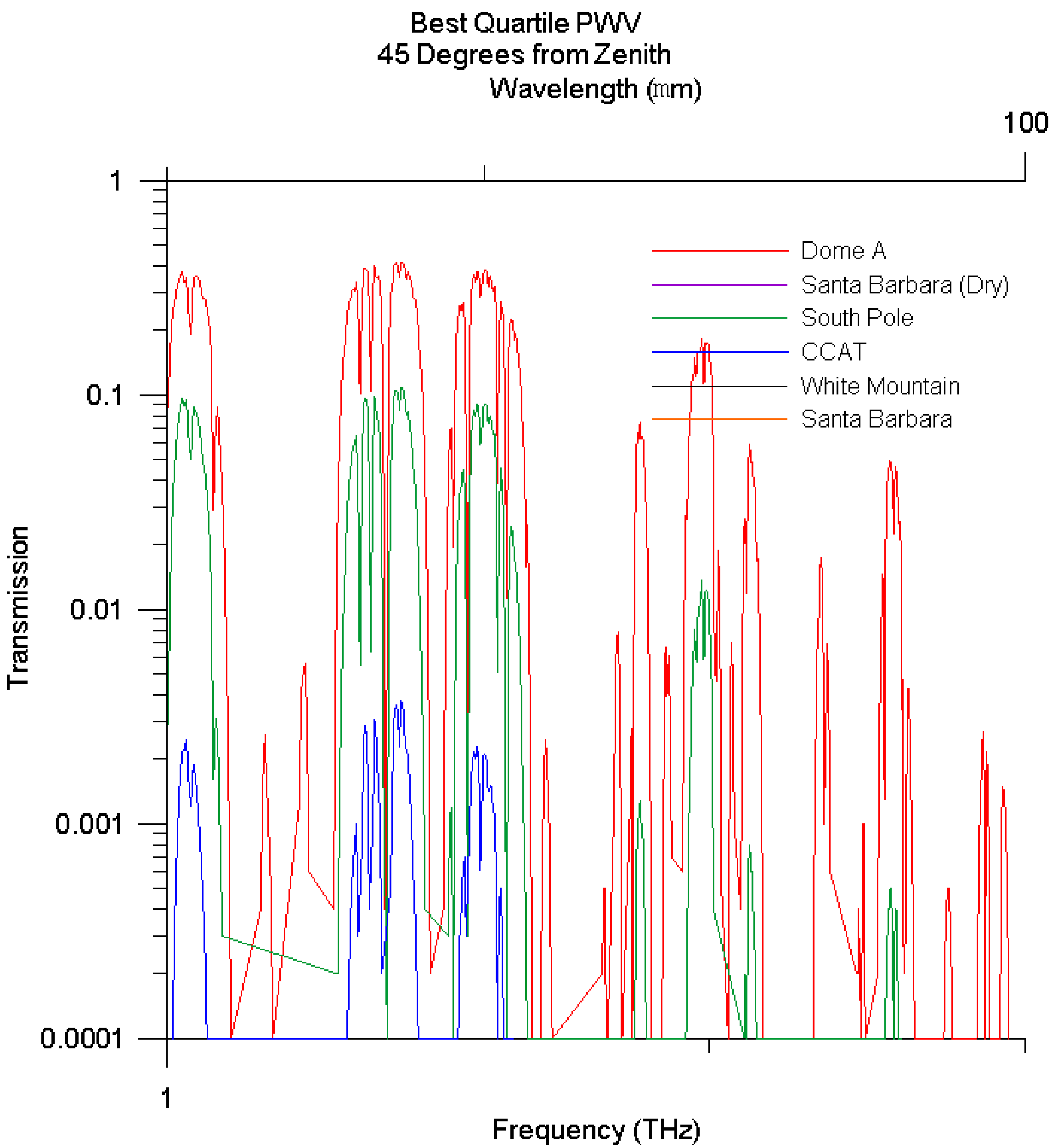


Wavelength (μm)
1000
100
Integration Time (s)
Frequency (THz)
0.1
1
10
1 yr
1 mo
1 d
1 h
1 m
1 s
10 ms
(a)
13.7 Km SOFIA; d=2.5 m; 10% emissivity; NGC 958
40 Km Balloon; d=2.2 m; T=2 K; NGC 958
SPICA; d=3.5 m; T=4.2 K; NGC 958
(b)
13.7 Km SOFIA; d=2.5 m; 10% emissivity; Mrk 231
40 Km Balloon; d=2.2 m; T=2 K; Mrk 231
SPICA; d=3.5 m; T=4.2 K; Mrk 231
(c)
Cerro Chajnantor; d=25 m; T=230 K; NGC 958
Cerro Chajnantor; d=25 m; T=230 K; Mrk 231
40 Km Balloon; d=10 m; T=230 K; NGC 958
40 Km Balloon; d=10 m; T=230 K; Mrk 231
SPICA; d=3.5 m; T=4.2 K; NGC 958
SPICA; d=3.5 m; T=4.2 K; Mrk 231
(d)
13.7 Km SOFIA; d=2.5 m; 10% emissivity; NGC 958
13.7 Km SOFIA; d=2.5 m; 10% emissivity; Mrk 231
SPICA; d=3.5 m; T=4.2 K; NGC 958
SPICA; d=3.5 m; T=4.2 K; Mrk 231

Extreme Sensitivity to PWV (Ex: λ = 100-300μ)
Dome A (0.1 mm), SP (0.23 mm), CCAT site (0.73 mm)

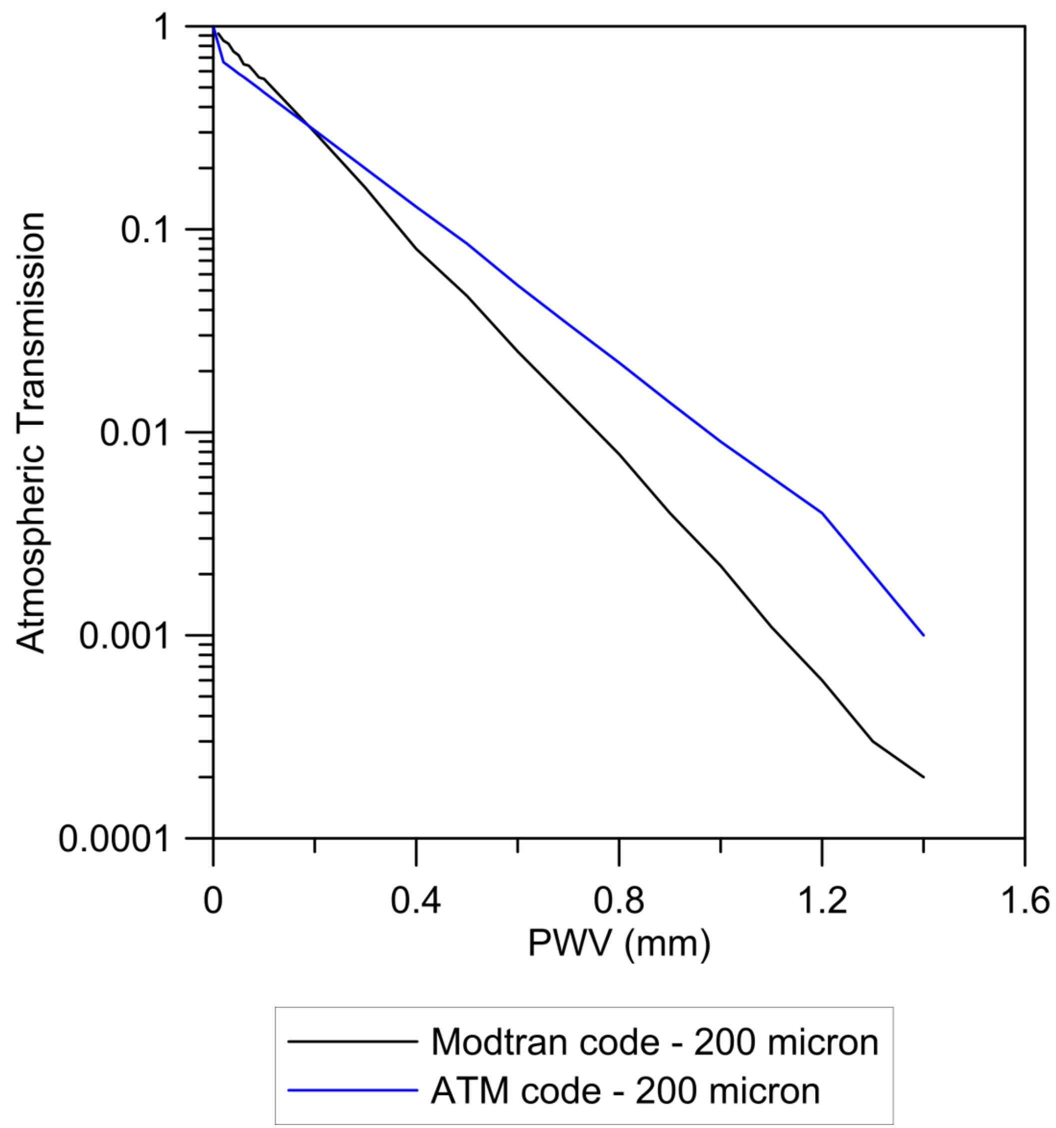


Log Scale



Best Quartile PWV
45 Degrees from Zenith
Wavelength (mm)
100
1
0.1
0.01
0.001
0.0001
Transmission
Dome A
Santa Barbara (Dry)
South Pole
CCAT
White Mountain
Santa Barbara
1
Frequency (THz)

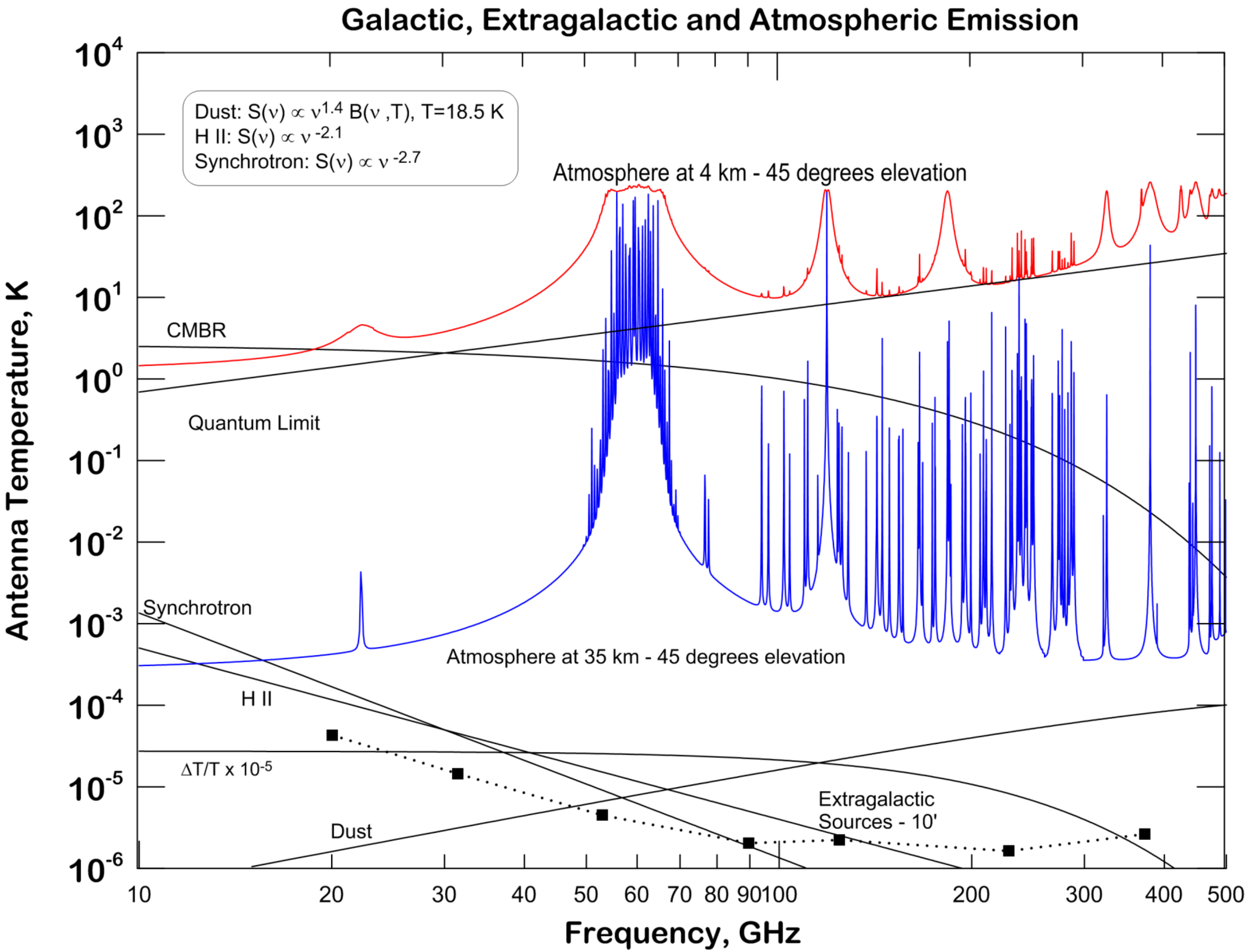
Extreme Sensitivity to PWV for Sub mm Windows



PWV (g/cm^2)– Best 25 and 50%

% Time with PWV	**Dome A (4100m)**	**Dome C (3250m)**	**South Pole (2850m)**	**CCAT (5600m)**	**White Mountain (3800m)**	**Mauna Kea (4100m)**
25%	0.010	0.015	0.023	0.0732	0.115	0.10
50%	0.014	0.024	0.032	0.0978	0.175	0.15

Dome A, Dome C, South Pole, and Mauna Kea values are from Yang et al. 2010. CCAT values are for Chajnantor in Herter and Radford 2005. White Mountain values are from Marvil et al. 2005.



Galactic, Extragalactic and Atmospheric Emission
Dust: S(ν) ∝ ν^1.4 B(ν ,T), T=18.5 K
H II: S(ν) ∝ ν^-2.1
Synchrotron: S(ν) ∝ ν^-2.7
Atmosphere at 4 km - 45 degrees elevation
CMBR
Quantum Limit
Synchrotron
Atmosphere at 35 km - 45 degrees elevation
H II
ΔT/T x 10^-5
Extragalactic
Sources - 10'
Dust
Antenna Temperature, K
Frequency, GHz
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10
20
30
40
50
60
70
80
90
100
200
300
400
500

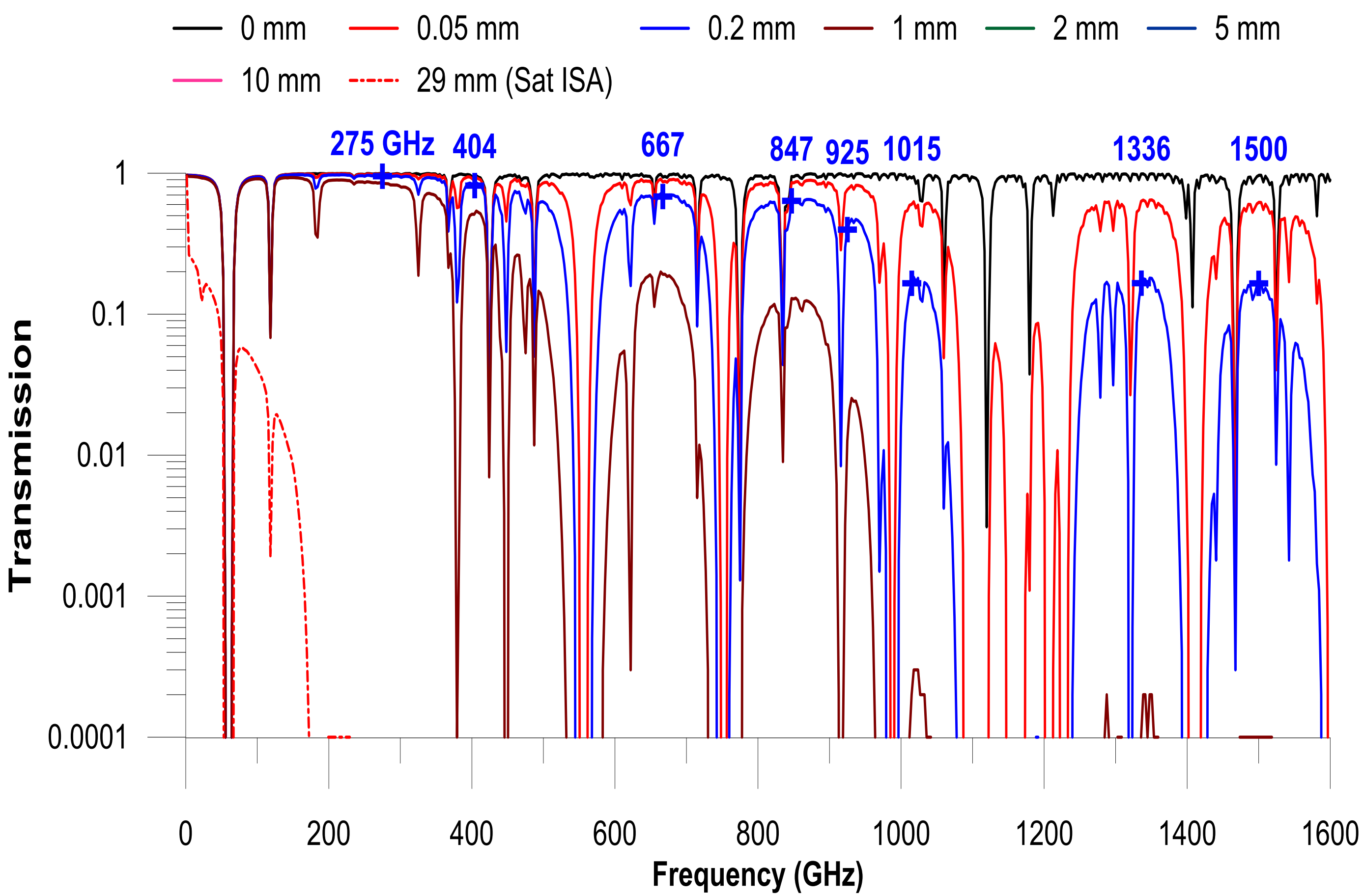
Fundamental Background Limits

- Fundamental limits set by photon shot noise-incoher
- Fundamental limit set by quantum limit - coherent
- NEP (noise equiv power) = $kT_{A\text{-total}}\ \beta^{0.5}$
- P= $kT_{A\text{-total}}\ \beta$ (~ Υ/s)
- $T_{A\text{-total}}$ = total "flux" temperature β = bandwidth (~30%)
- $k\Delta T_A\ \beta$ = NEP – single polarization mode
- Convert to ΔT_{CMB} $\Delta T_A = K\ T_{A\text{-total}} / \beta^{0.5}$ (1 sec)
- $T_{A\text{-total}}$ = T(atm) +T(CMB) + T(galaxy)+T(optics)+....
- Typ T(atm)~ 5 K ground 45 GHz, 10K 100 GHz …
- T(atm) increases w freq. T(CMB) decreases w freq
- Ground $T_{A\text{-total}}$ ~ 10 K (45 GHz – HEMT) ~ 15K(100 GHz-bolo – assumes 100% eff) ~ 50K (100 GHz – HEMT)
- NEP ~ 10^{-17} w-s$^{-0.5}$ ground HEMT <100 GHz, bolo >100

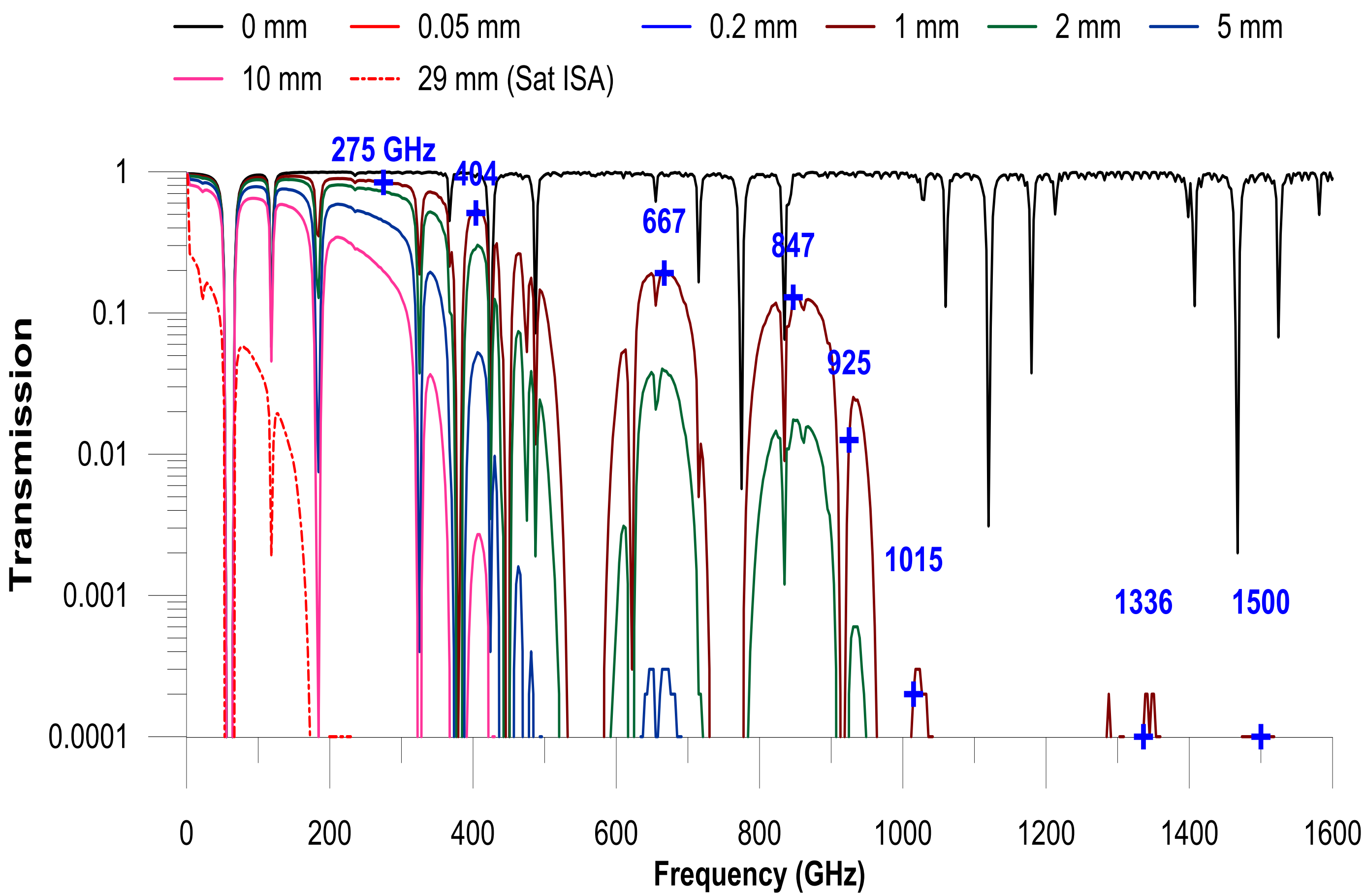
Ground vs Space

- Two types of issues:
  - Statistical - no atmosphere, lower optics T -> less emission, no vac window, no weather, 100% duty cycle
  - Systematic – no weather -> constant loading, better scanning options, can get far from Earth – lower pickup
- Below 100 GHz with HEMT;s small only modest statistical (noise T) between space and ground
- Above 100 GHz significant difference between space and ground due to atmosphere transmission and radiance (loading). Above 200 GHz – difficult
- Systematics – atm known important for T not as much P
- Space ~30μK-$s^{-0.5}$ Ground ~ 150-300μK-$s^{-0.5}$ HEMT 45 GHz and bolo 150 GHz possible optimum ΔT_{CMB}

Water Vapor in the THz
Good sites



Water Vapor in the THz
Not so good sites



Characterizing water vapor

- Dependence of transmission to water column is basically Beer-Lambert

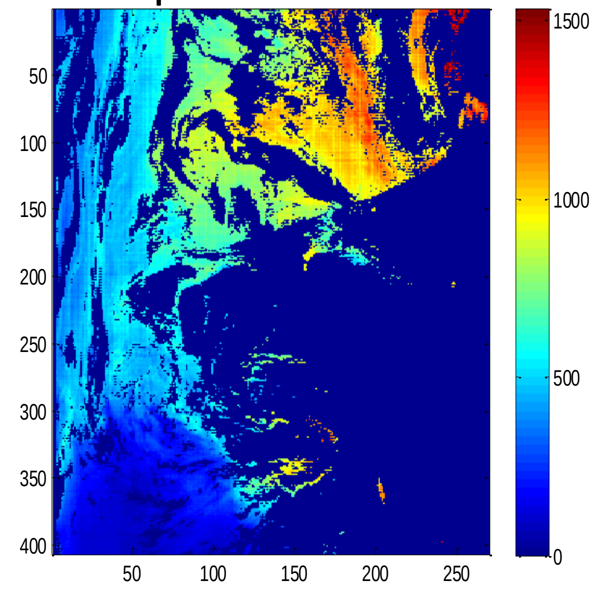
Freq. (GHz)	α (Exp,/mm)
30	0.0232
275	0.162
404	0.560
667	1.50
847	1.89
925	4.12
1015	8.08
1336	8.70
1500	8.45

- 86, 225, 857 GHz Tipping radiometers
- Availability limited
- Clouds have low water vapor (0.2 mm) but high scattering

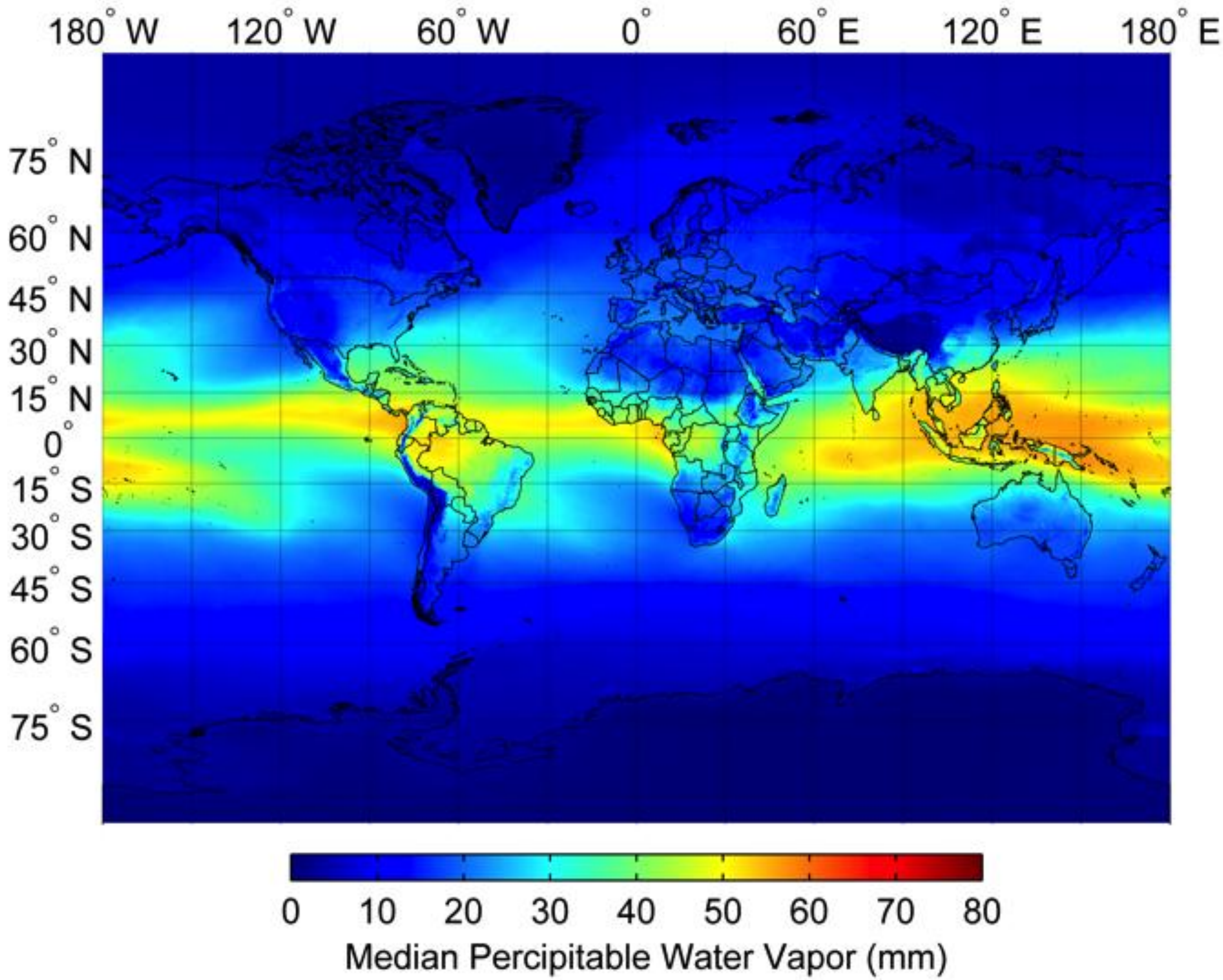
- Desired Coverage:
- Global Scale
- High Resolution
- Continuous Coverage
- Cloud Information

MODIS

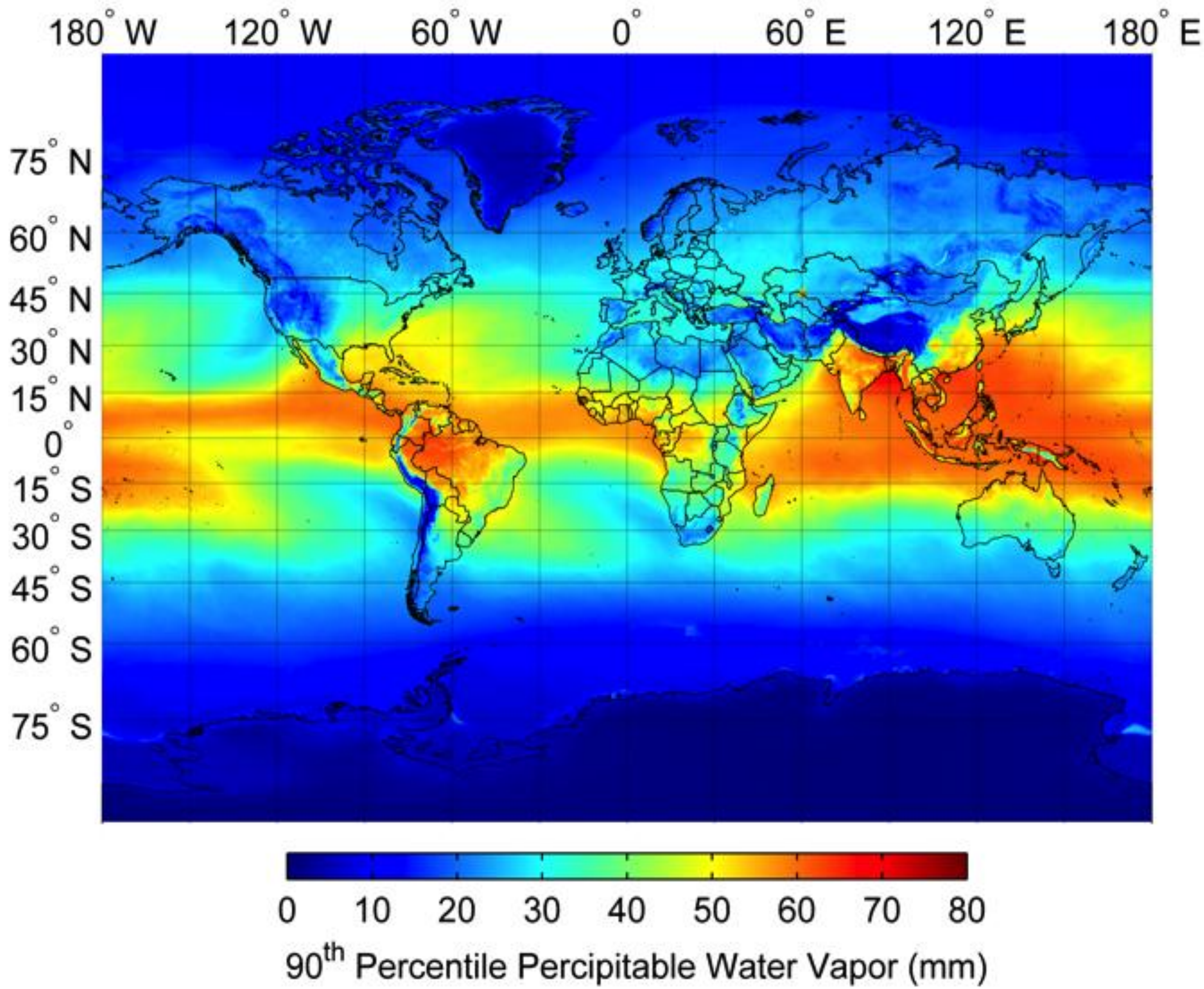
- Moderate Resolution Infrared Spectrometer
  - 1-km pixel scanning radiometer
  - 36 channels: 620 nm – 14.3 µm
- NOAA EOS Satellites: Terra and Aqua
- Polar Sun-synchronous orbits
  - Mid-latitudes Aqua passes around 10:30 AM Local Time
  - Terra around 1:30 PM Local
  - Same 12 hours later
- MOD07_L2
  - Regression retrieval algorithm
  - 6.7, 7.3, 8.6 µm, at 5 km resolution
  - MOD35 IR cloud mask: 9 of 25 pixels cloud-free

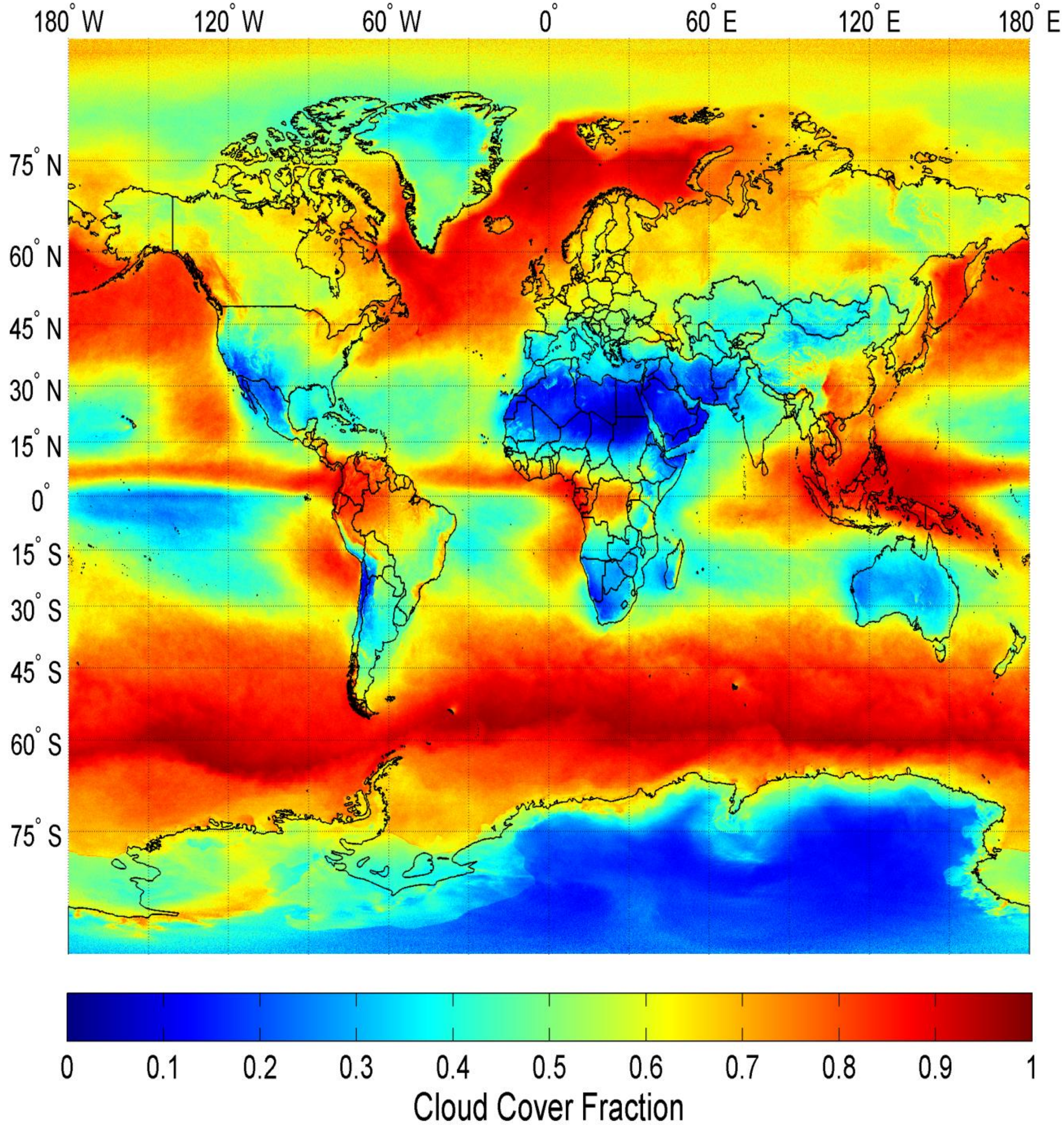


Median (50%) PWV



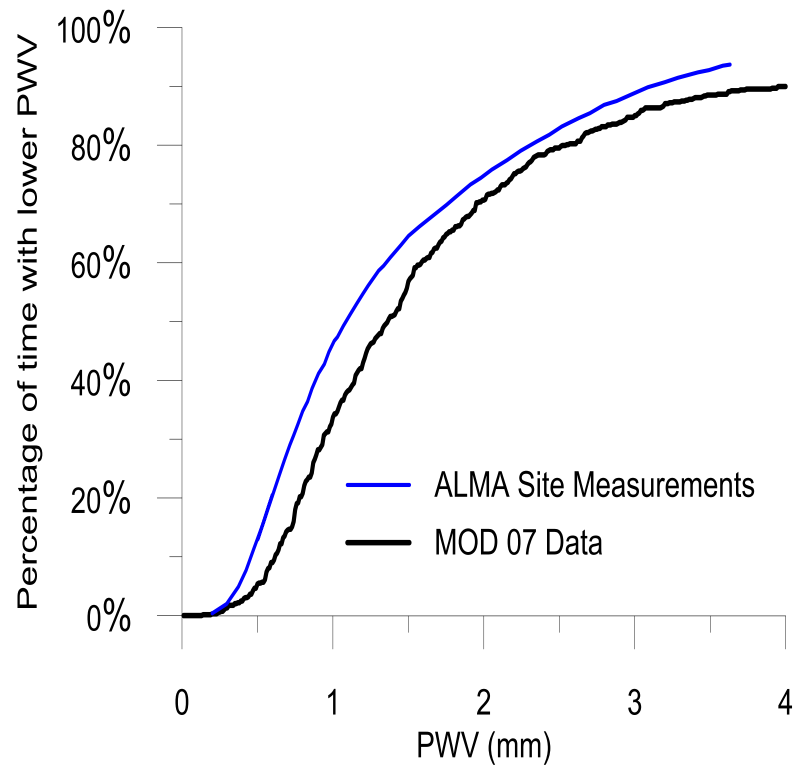
90% PWV

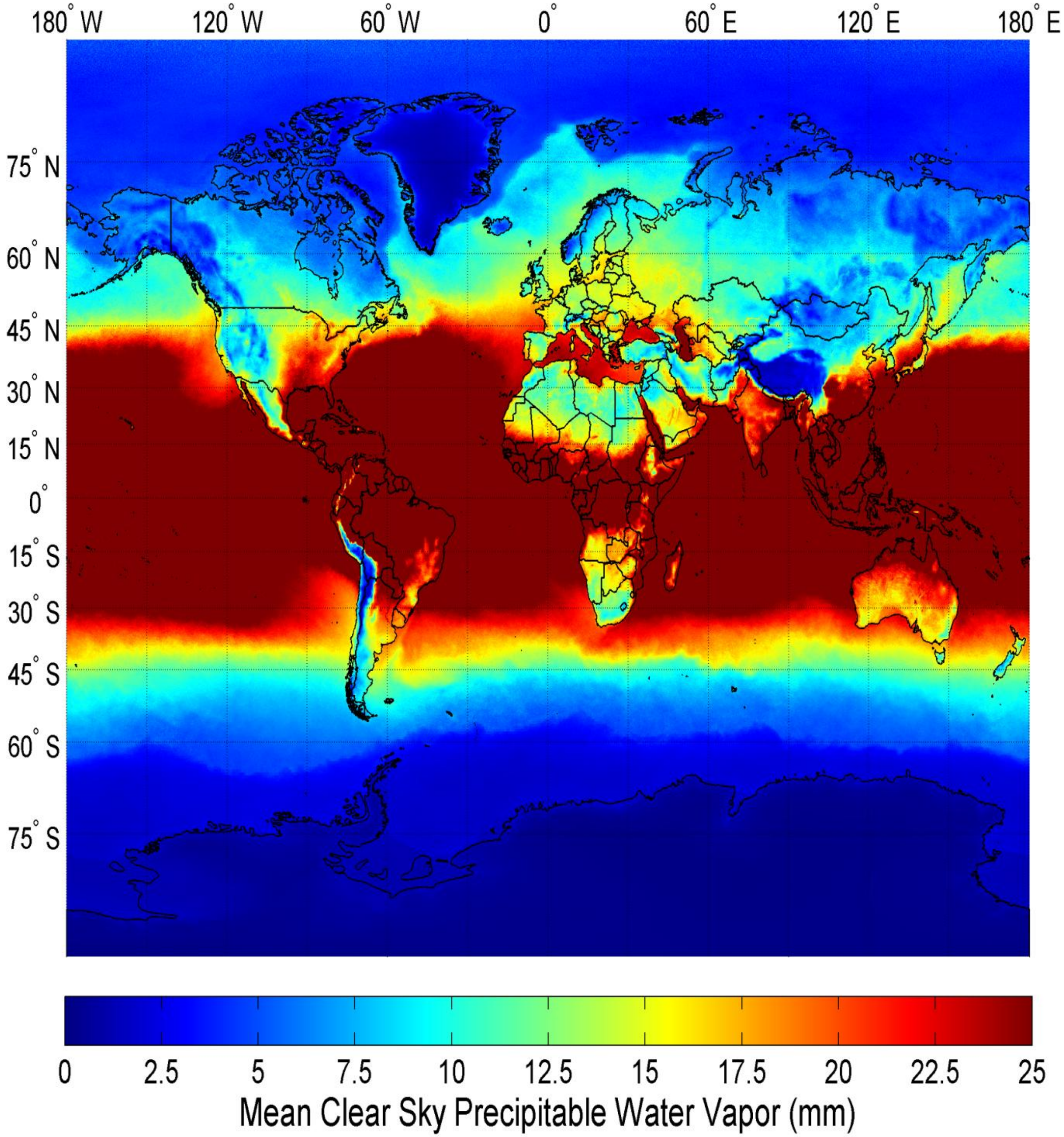

180° W
120° W
60° W
0°
60° E
120° E
180° E
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S
0
10
20
30
40
50
60
70
80
90th Percentile Percipitable Water Vapor (mm)


180° W
120° W
60° W
0°
60° E
120° E
180° E
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Cloud Cover Fraction

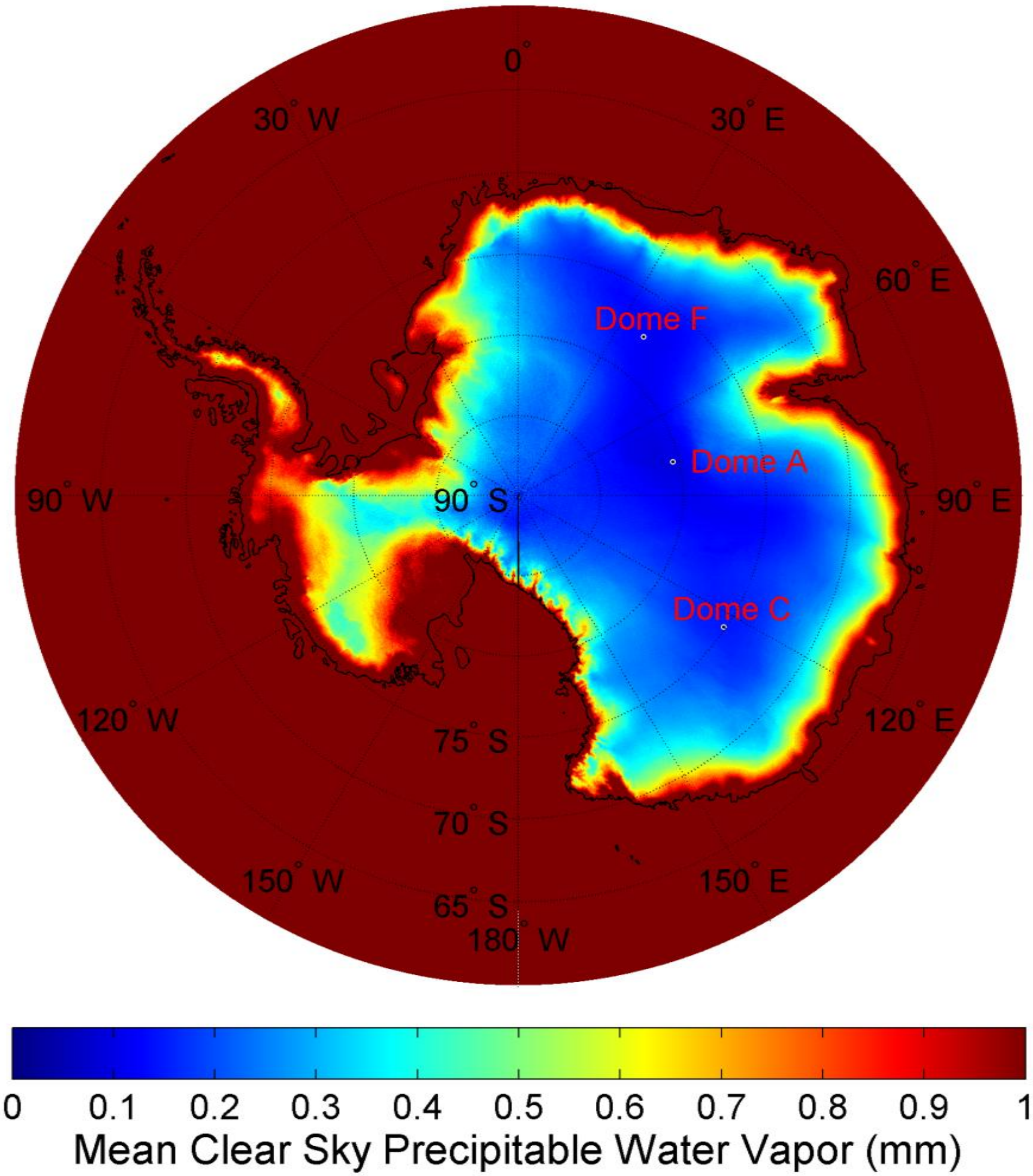
MOD07_L2 Atmosphere Profile

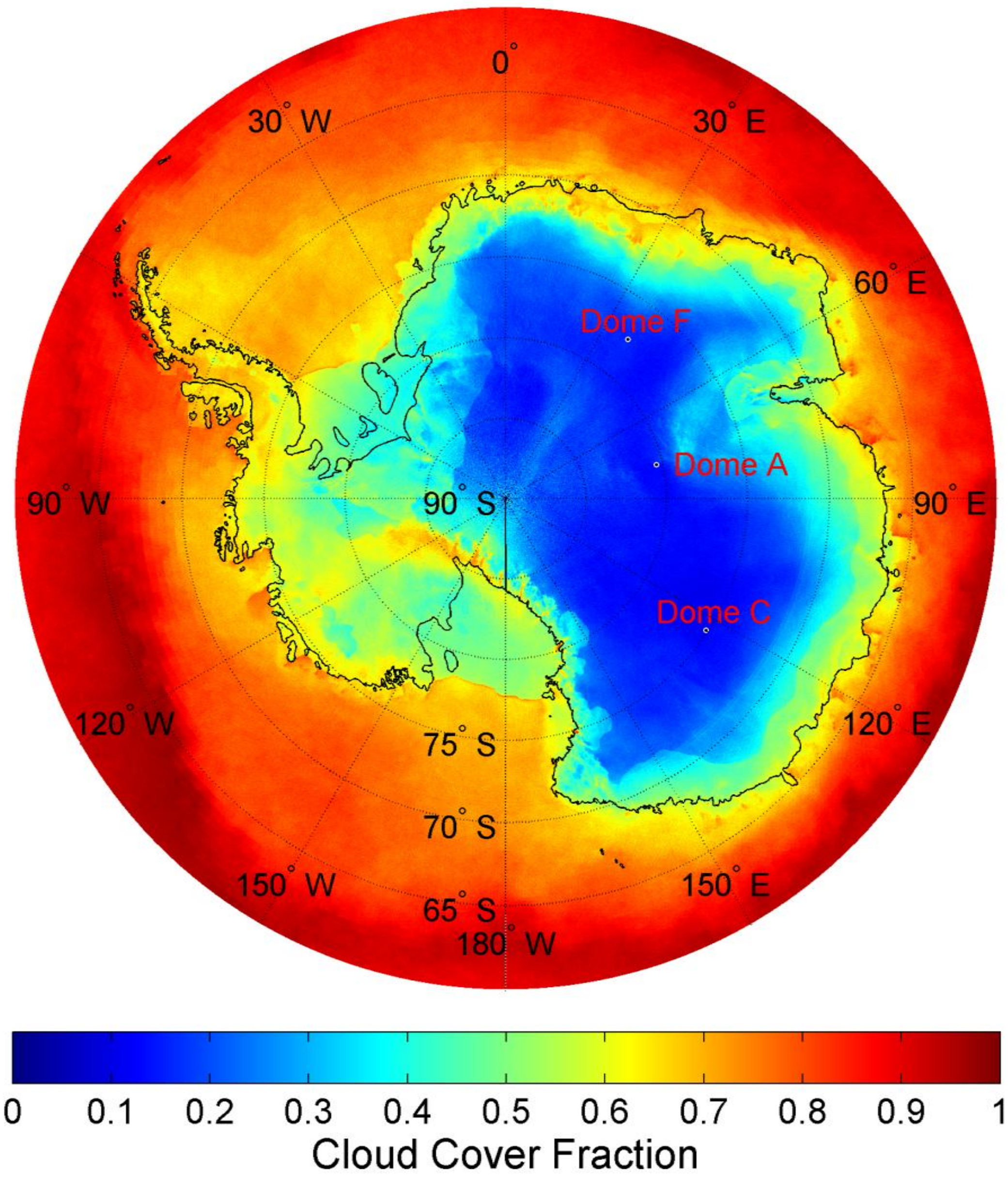
- Dataset used was CY 2011
- MOD07 Validation (ATBD)
  - RMSE (<15 mm) = 2.2 mm
  - Bias 0.7 mm mornings, 0.3 mm afternoons
- Difficult to get exactly the same data
  - Dome A, Antarctica 0.07 mm median MOD07 vs. 0.14 mm site
  - South Pole 0.10 mm MOD07 vs 0.24 mm site
  - ALMA 1.37 mm MOD07 vs 1.1 mm site
  - OVRO 5.36 mm MOD07 vs 5 mm site
  - Mauna Kea, 14.55 mm vs 1.5 mm site

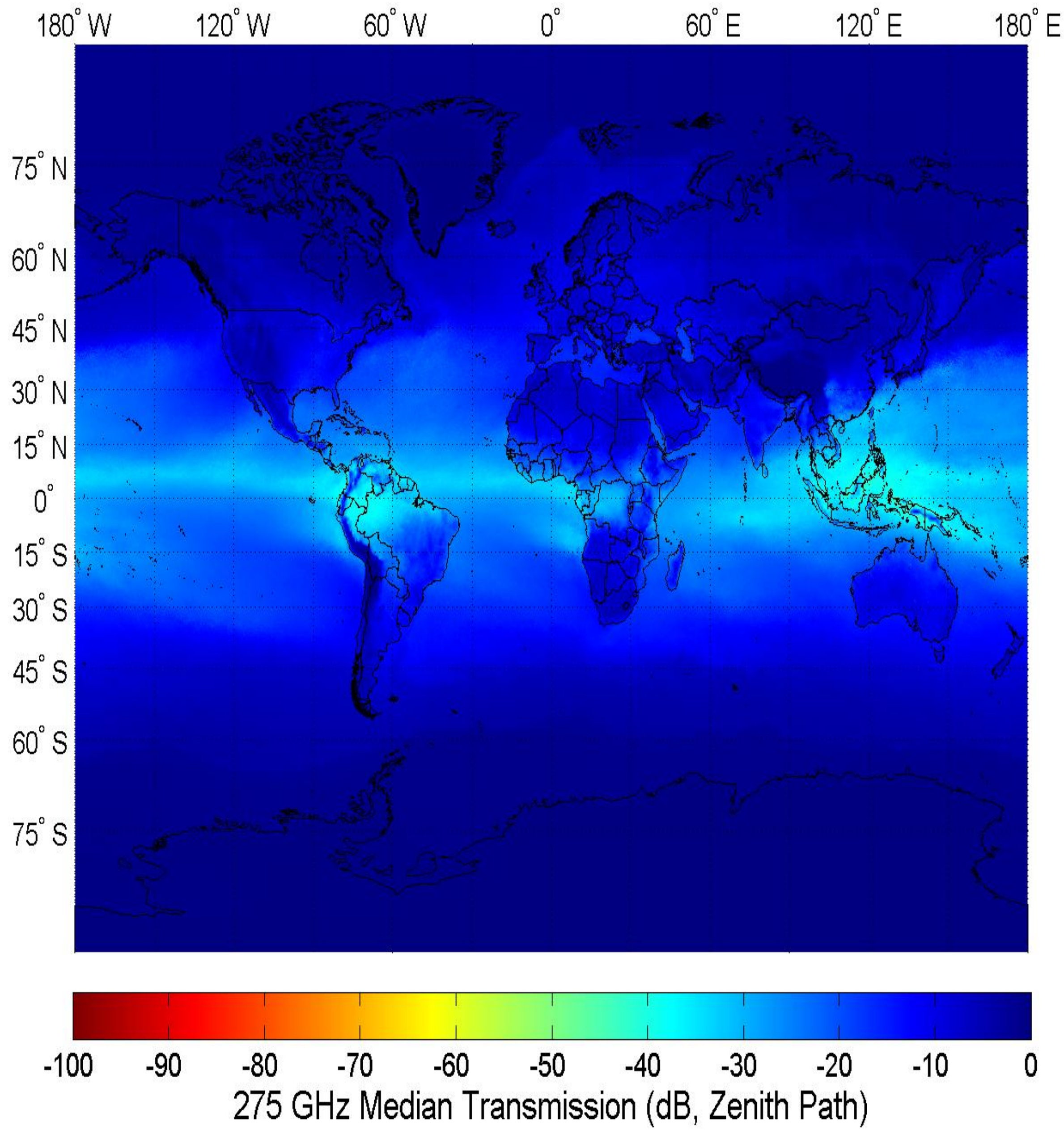


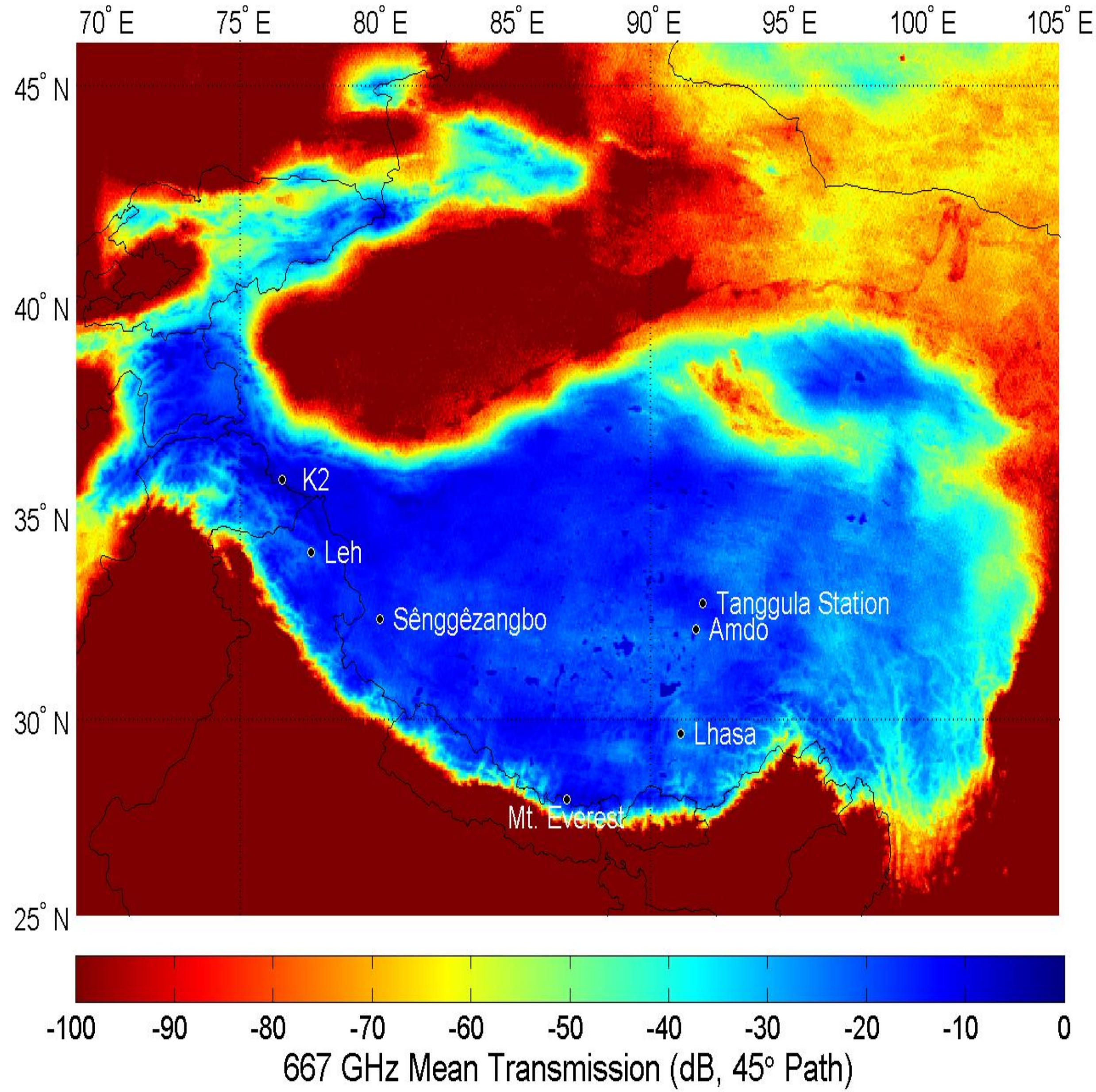


180° W
120° W
60° W
0°
60° E
120° E
180° E
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
Mean Clear Sky Precipitable Water Vapor (mm)

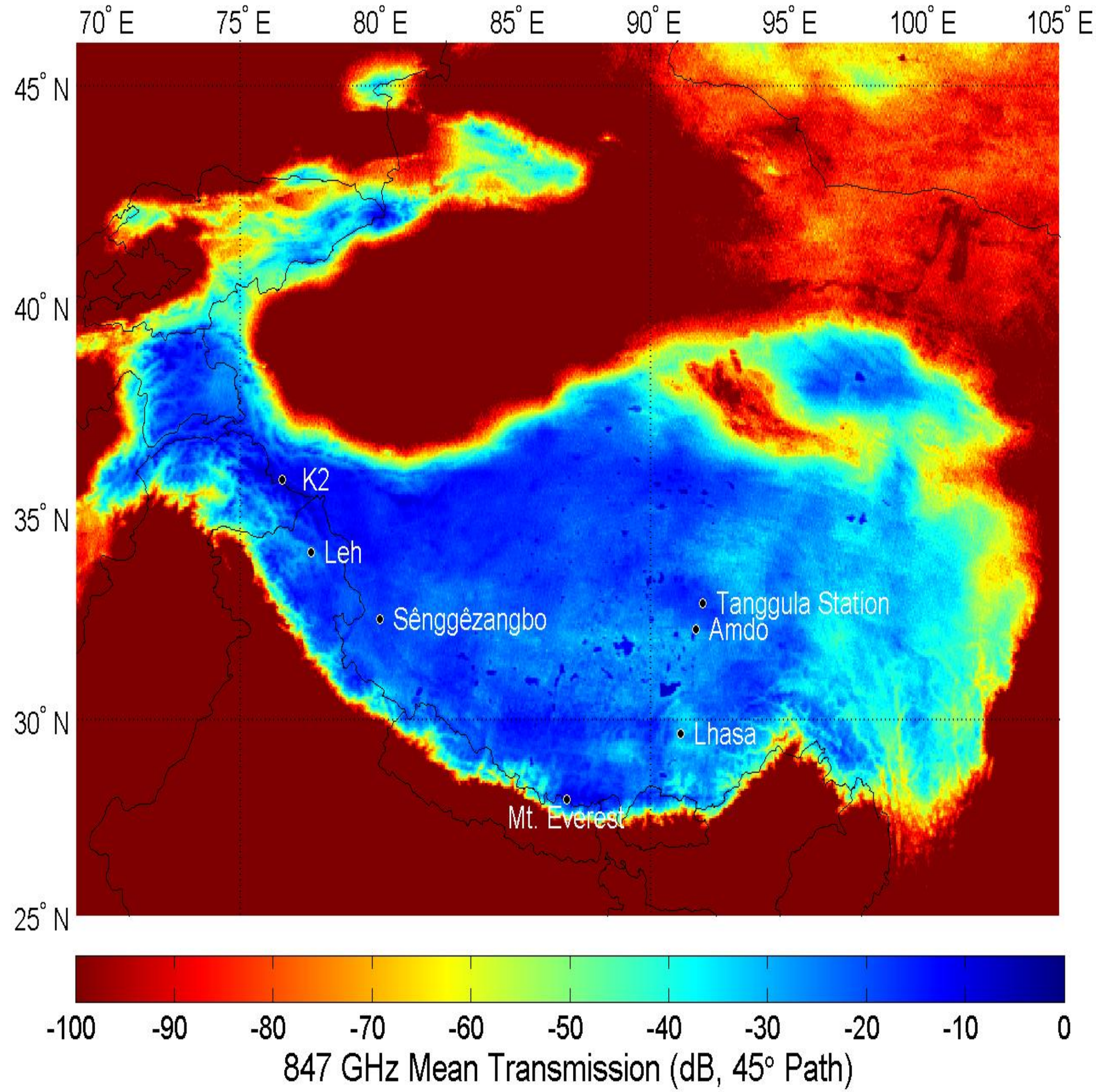

0°
30° W
30° E
60° E
Dome F
Dome A
90° W
90° S
90° E
Dome C
120° W
120° E
75° S
70° S
150° W
150° E
65° S
180° W
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Mean Clear Sky Precipitable Water Vapor (mm)


0°
30° W
30° E
60° E
Dome F
Dome A
90° W
90° S
90° E
Dome C
120° W
120° E
75° S
70° S
150° W
150° E
65° S
180° W
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Cloud Cover Fraction

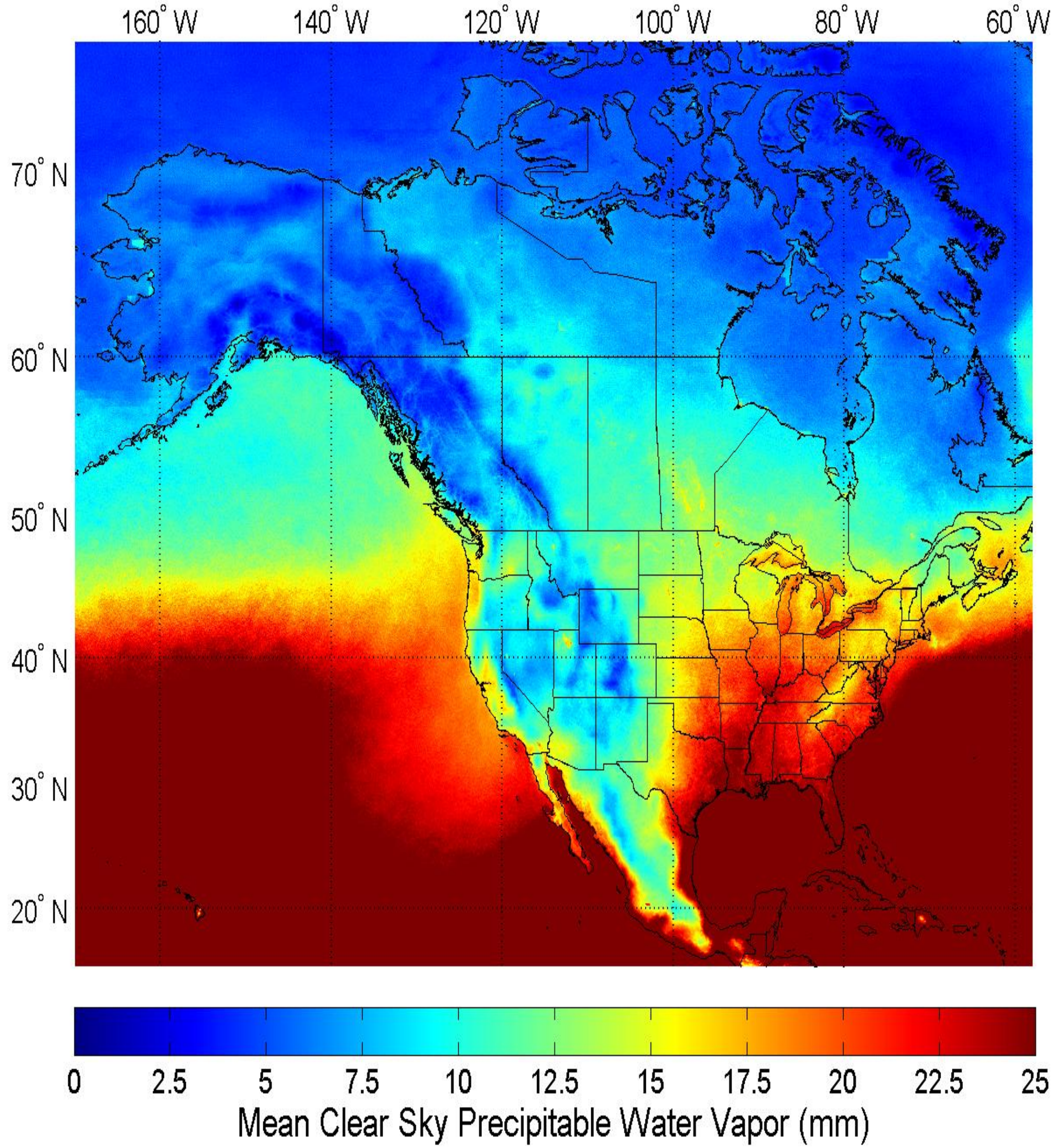

180° W
120° W
60° W
0°
60° E
120° E
180° E
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
275 GHz Median Transmission (dB, Zenith Path)

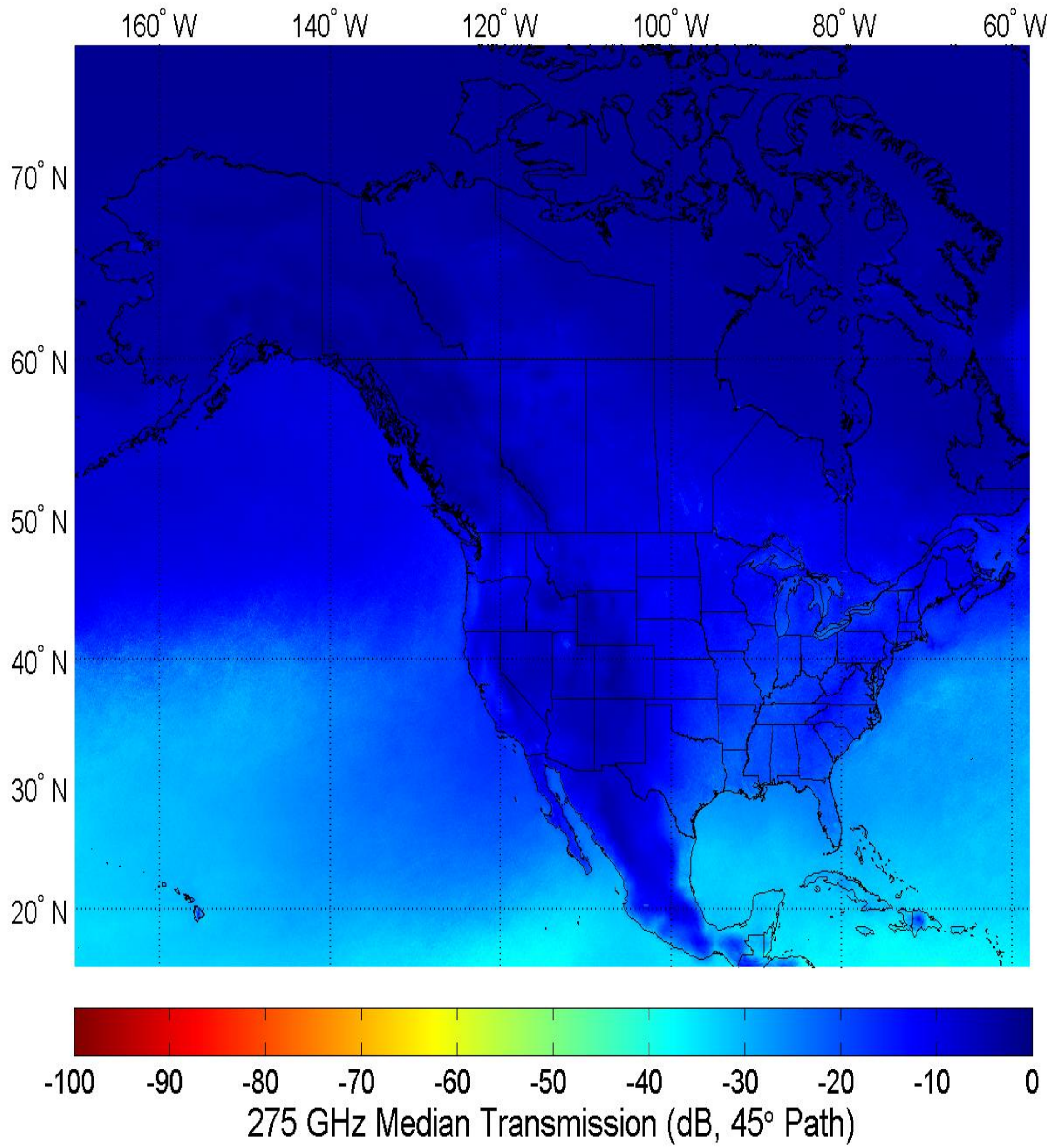


70° E
75° E
80° E
85° E
90° E
95° E
100° E
105° E
45° N
40° N
35° N
30° N
25° N
K2
Leh
Sênggêzangbo
Tanggula Station
Amdo
Lhasa
Mt. Everest
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
667 GHz Mean Transmission (dB, 45° Path)

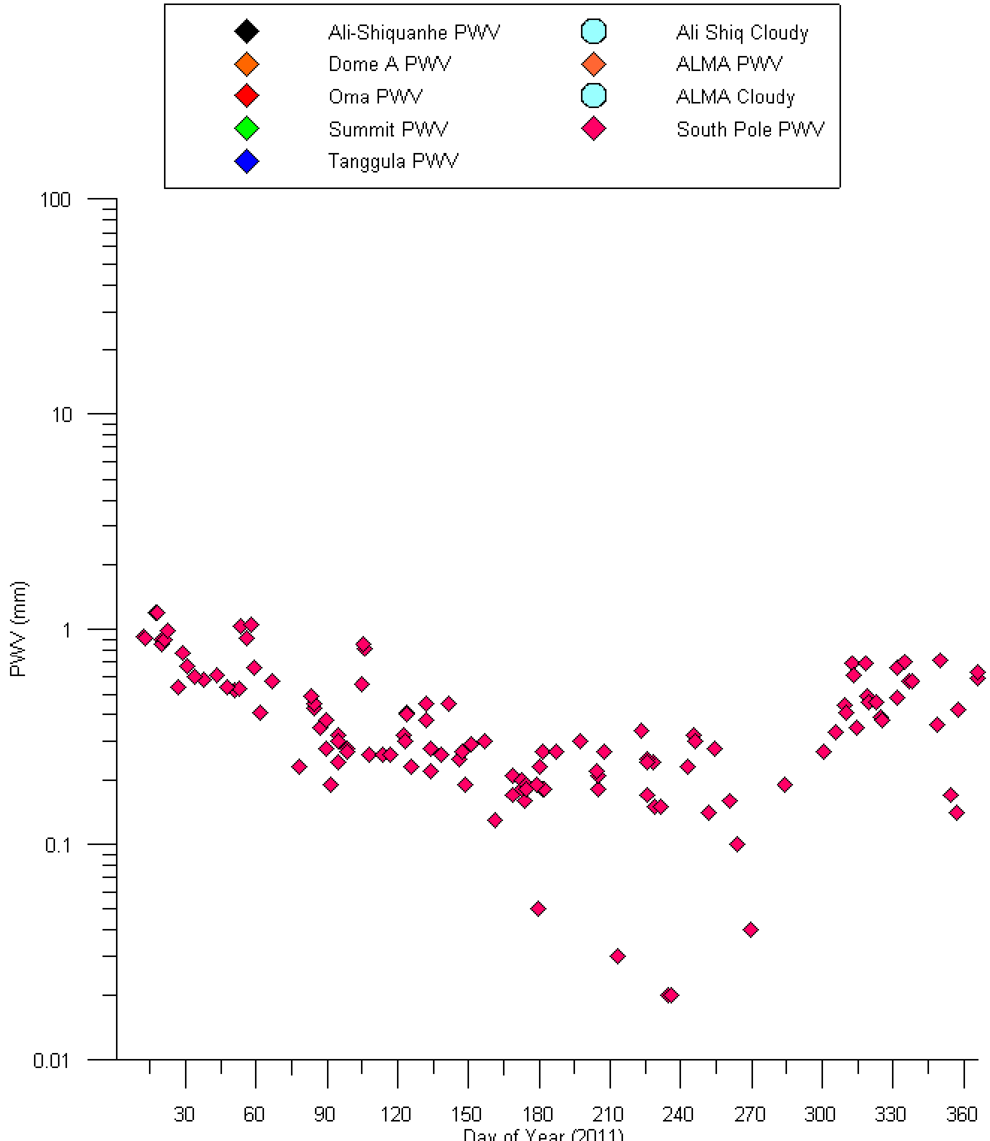


70° E
75° E
80° E
85° E
90° E
95° E
100° E
105° E
45° N
40° N
35° N
30° N
25° N
K2
Leh
Sênggêzangbo
Tanggula Station
Amdo
Lhasa
Mt. Everest
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
847 GHz Mean Transmission (dB, 45° Path)

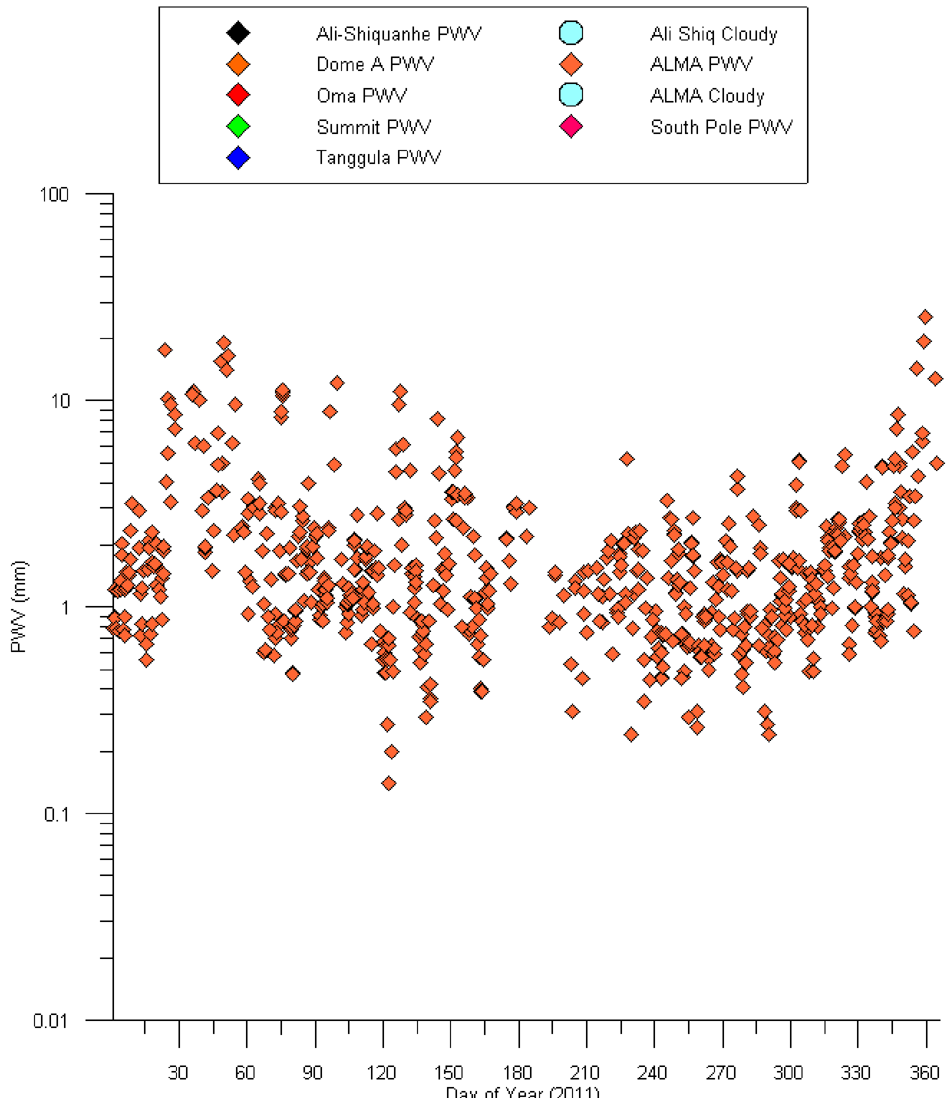

160° W
140° W
120° W
100° W
80° W
60° W
70° N
60° N
50° N
40° N
30° N
20° N
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
Mean Clear Sky Precipitable Water Vapor (mm)


160° W
140° W
120° W
100° W
80° W
60° W
70° N
60° N
50° N
40° N
30° N
20° N
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
275 GHz Median Transmission (dB, 45° Path)

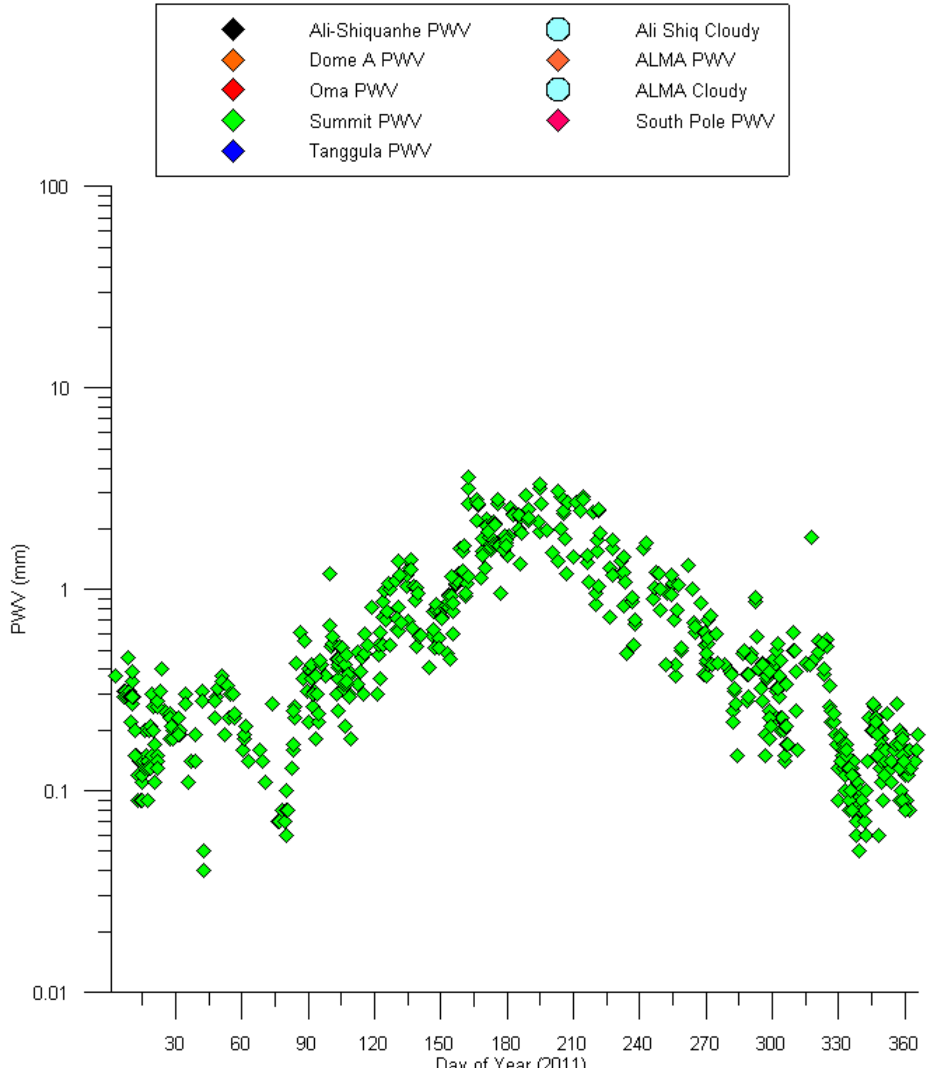
PWV Clear South Pole 2011 Time series



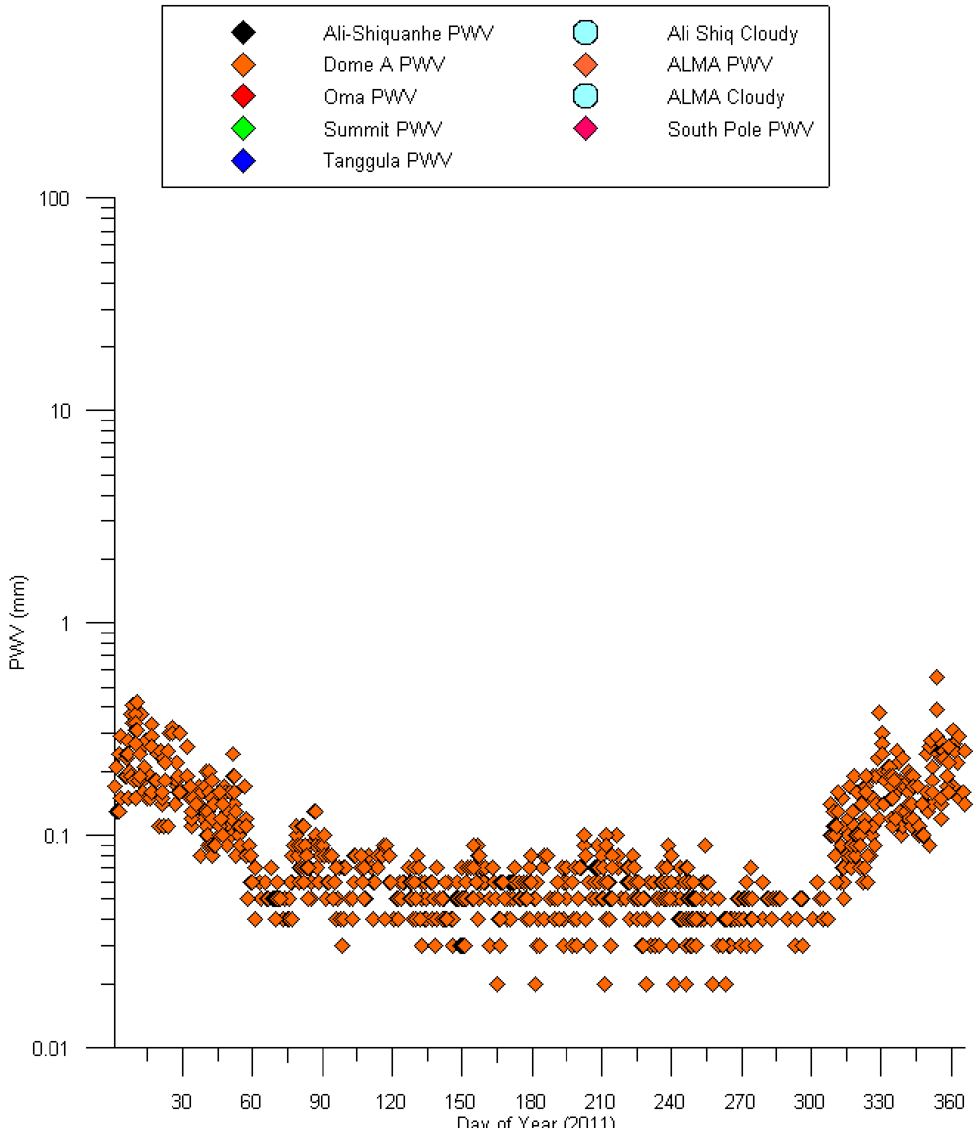
PWV Alma2011 Time series



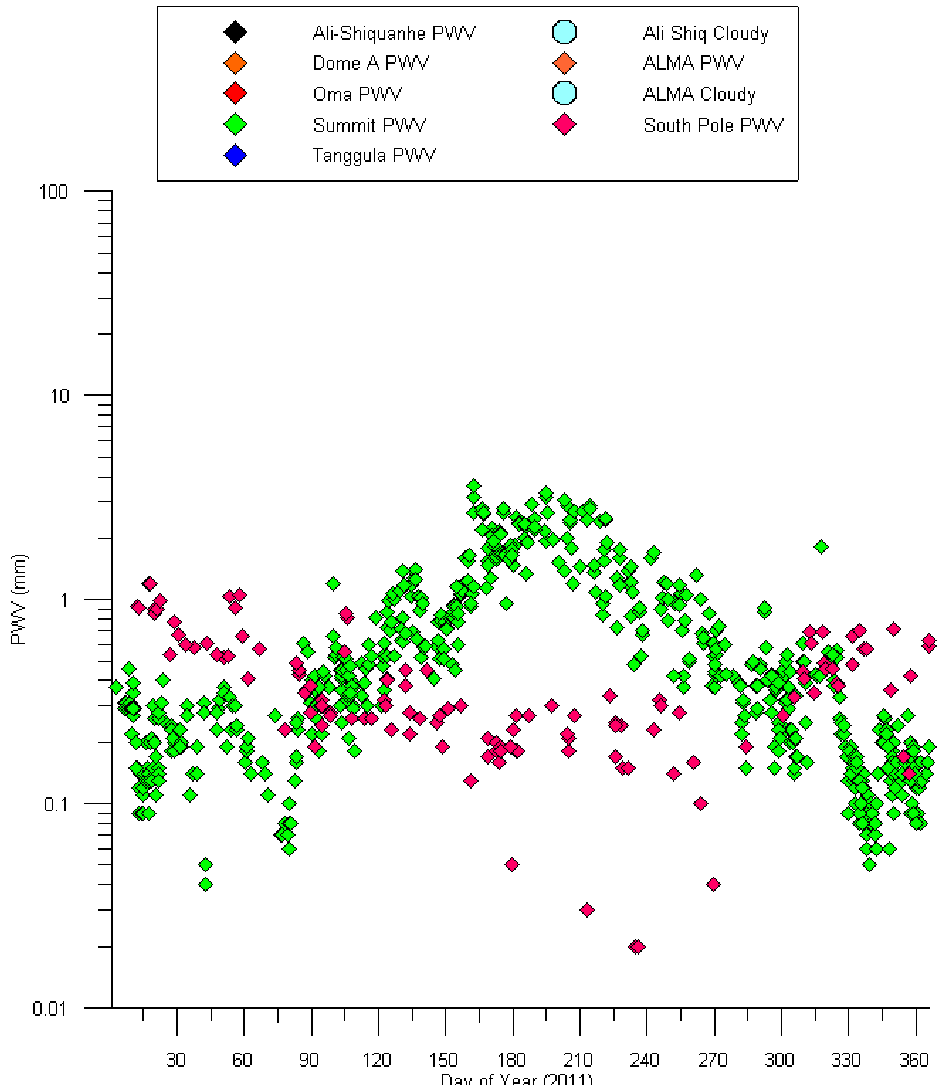
PWV Summit Greenland 2011 Time series



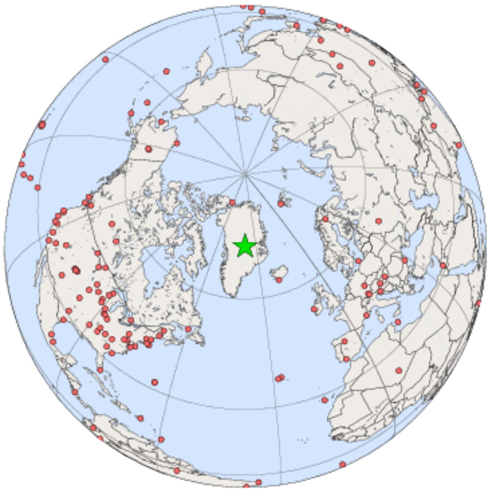
PWV Dome A 2011 Time series



PWV - Summit and S. Pole

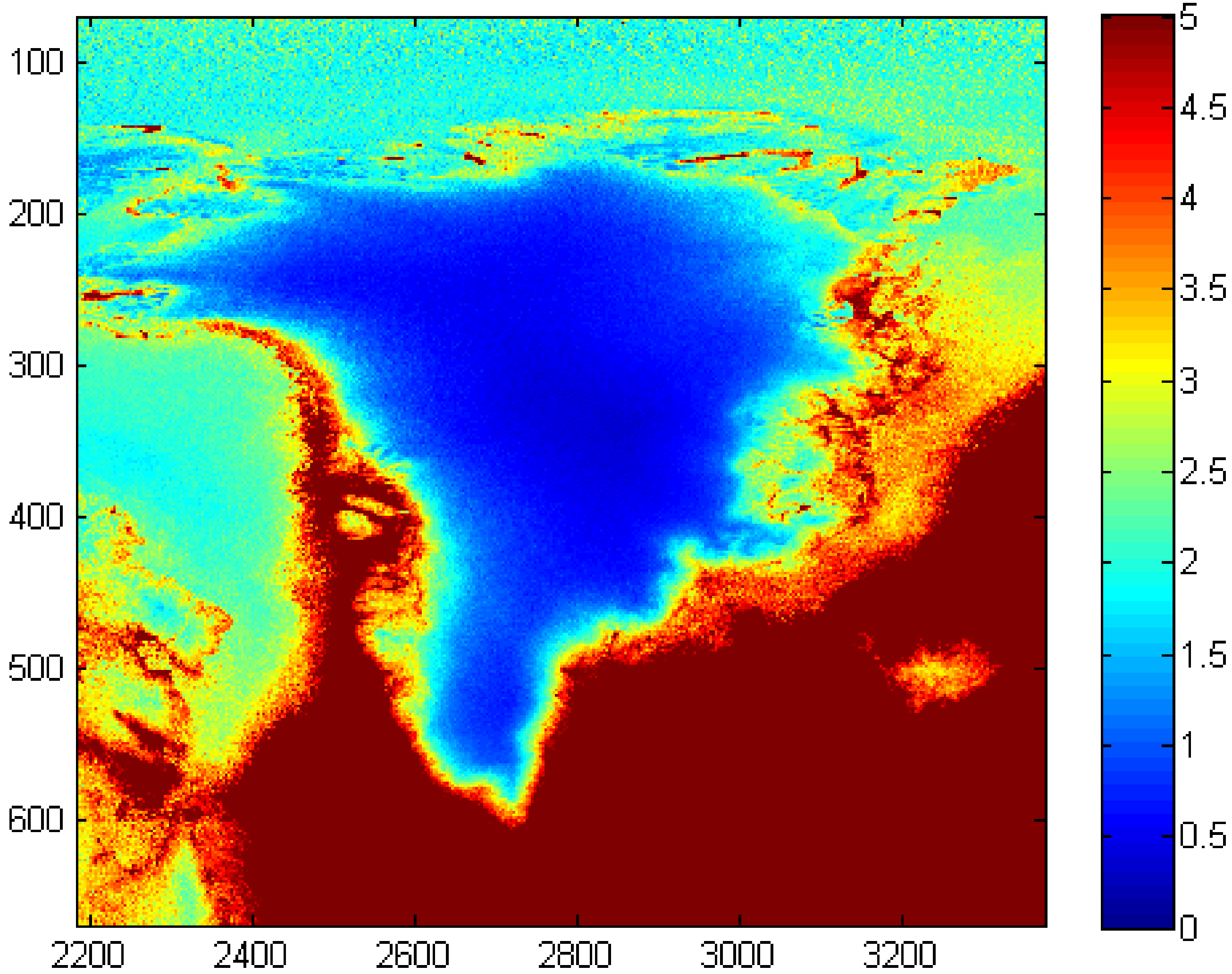


Summit Site Greenland

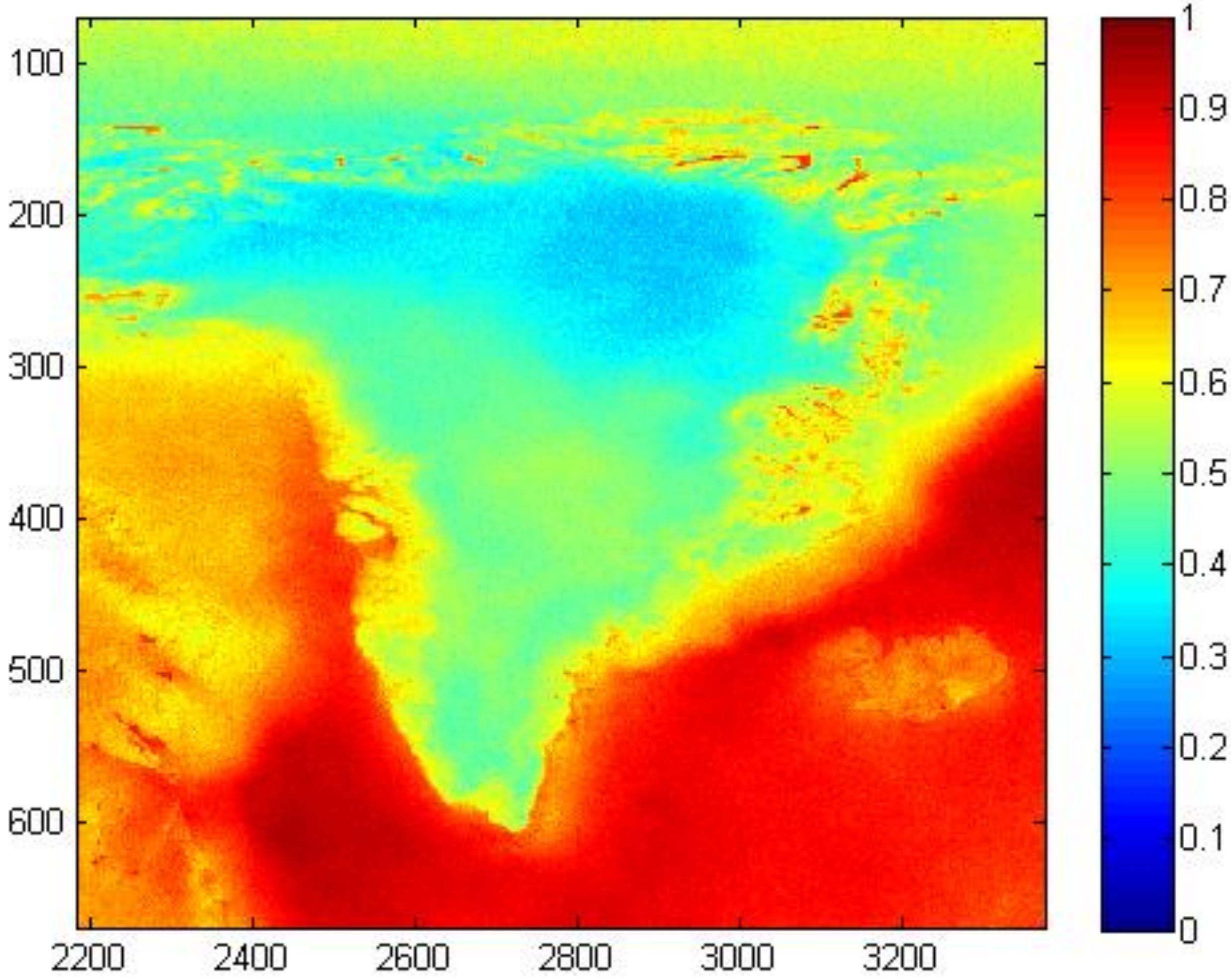


- •Long: 38.48° W
- •El: 3216.00 masl
- •Lat: 72.5800° N
- •Danish Com for Sci Res
- • NSF-OPP

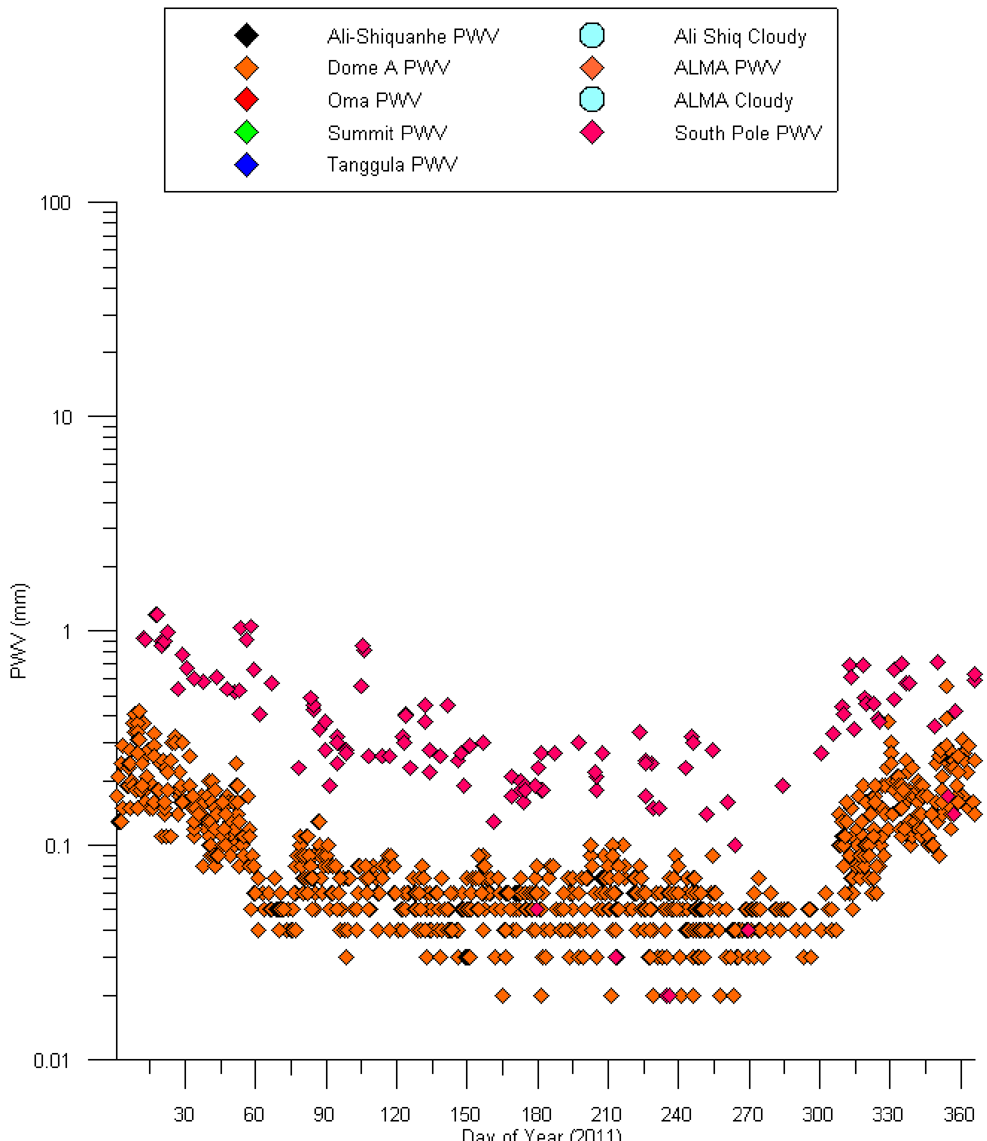
Greenland PWV



Greenland Cloud Fraction



S. Pole and Dome A



Sufficiency and Necessity

- What is good enough
- What is necessary and what is sufficient
- Lets rank some potential sites:
  1. Extragalactic – clearly desired
  2. Outside the solar system
  3. Moon
  4. L2
  5. LEO, GEO
  6. Balloon
  7. Dome A
  8. S. Pole
  9. Greenland
  10. ALMA/ Chile
  11. White Mountain, Mauna Kea etc
  12. Copenhagen

How do you know what is good enough

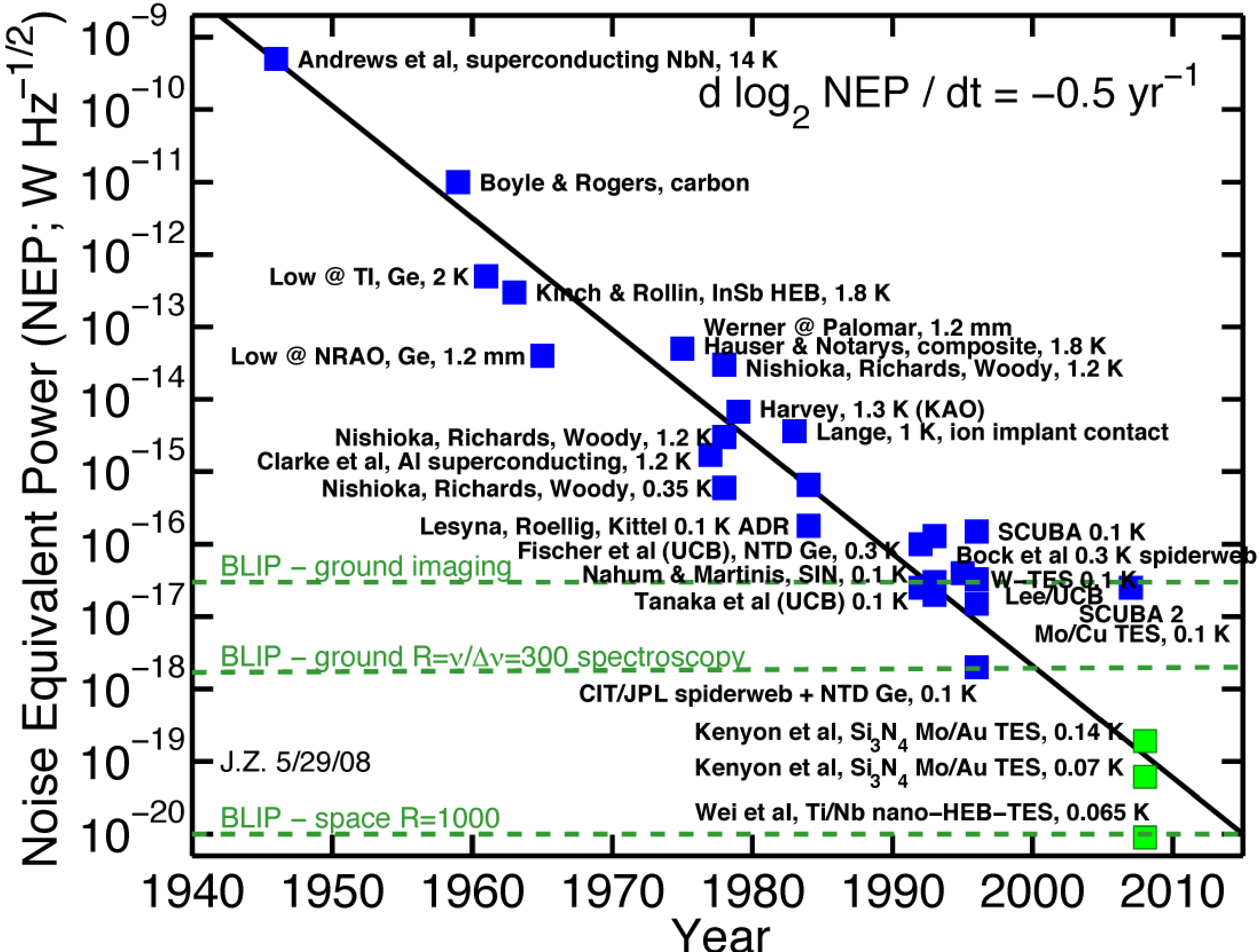
- You have to define the problem
- For CMB transmission and atmospheric radiance
- Set fundamental limits of integration time
- High freq (sensitive) >200 GHz hard from the ground
- Dust at high freq is complex – eg BiCEP?
- Low freq <100 GHz much easier from the ground
- Is synchrotron less complex than dust? More predictable?
- Go green – go where there is money to go! -> S Pole in US
- In general you don't know what is necessary nor sufficient
- Except transmission -> this is a rational argument
- Have done vastly better from the ground than anyone thought

Higher vs Lower Freq

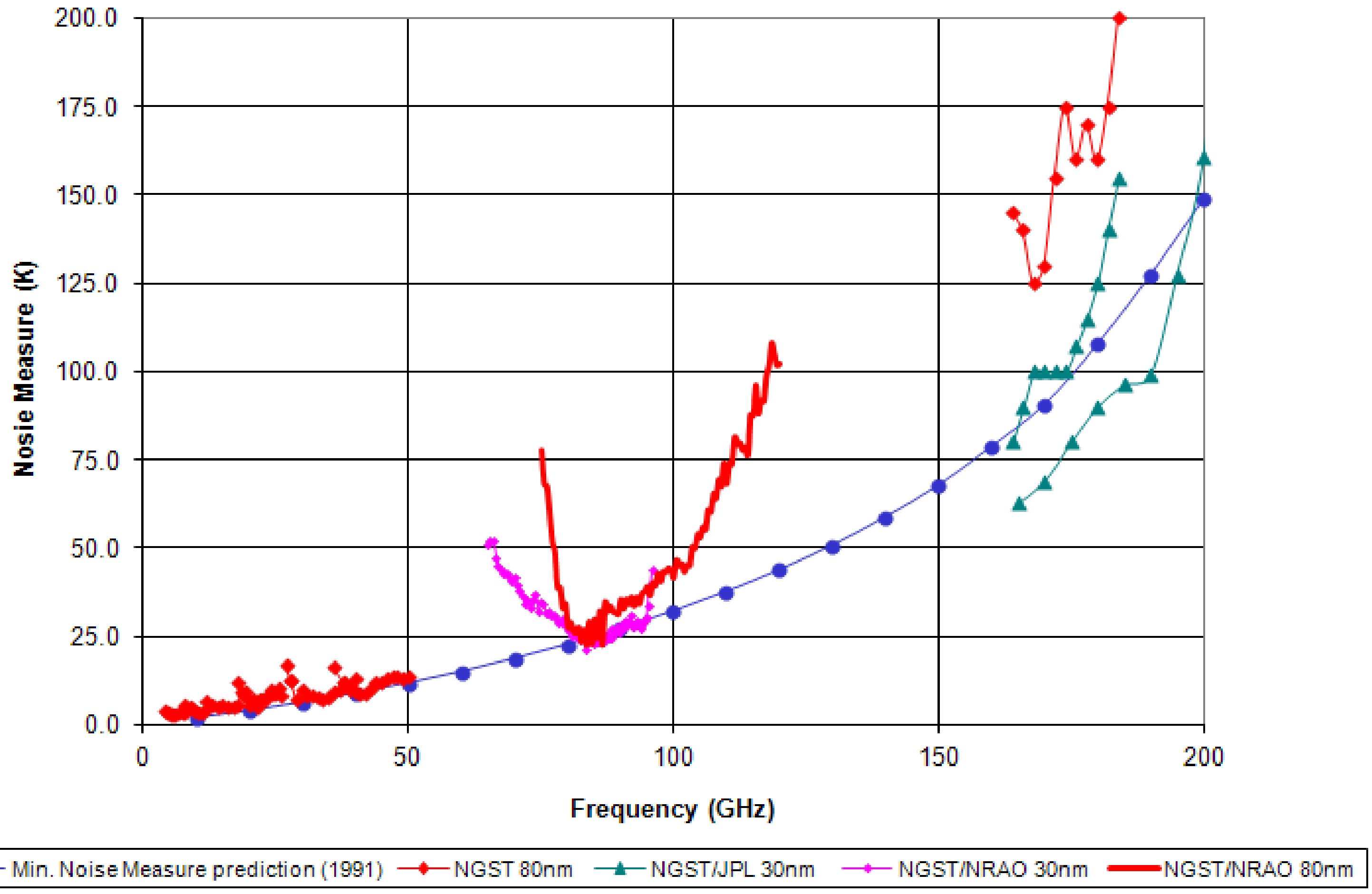
- High freq >100 Ghz – more detectors per area
- Above 200 Ghz hard to get sensitivity
- Lever arm limited – sensitivity falls <>150
- Choose your weapon – bolometers
- Issues, issues, issues
- Lower freq <100 GHz – need more area/ telescopes to get same sensitivity
- Choose your weapon – InP etc HEMT
- Much longer lever arm on galaxy 0-100 ~ open
- 60 GHz O2 line etc
- In the end you need both – ie BiCEP problem
- Lower freq needs to be emphasized now
- Per detector on ground -> $\Delta T_{CMB} \sim 200\text{-}400\ \mu K\text{-}s^{1/2}$

Historical View- Moore would be proud

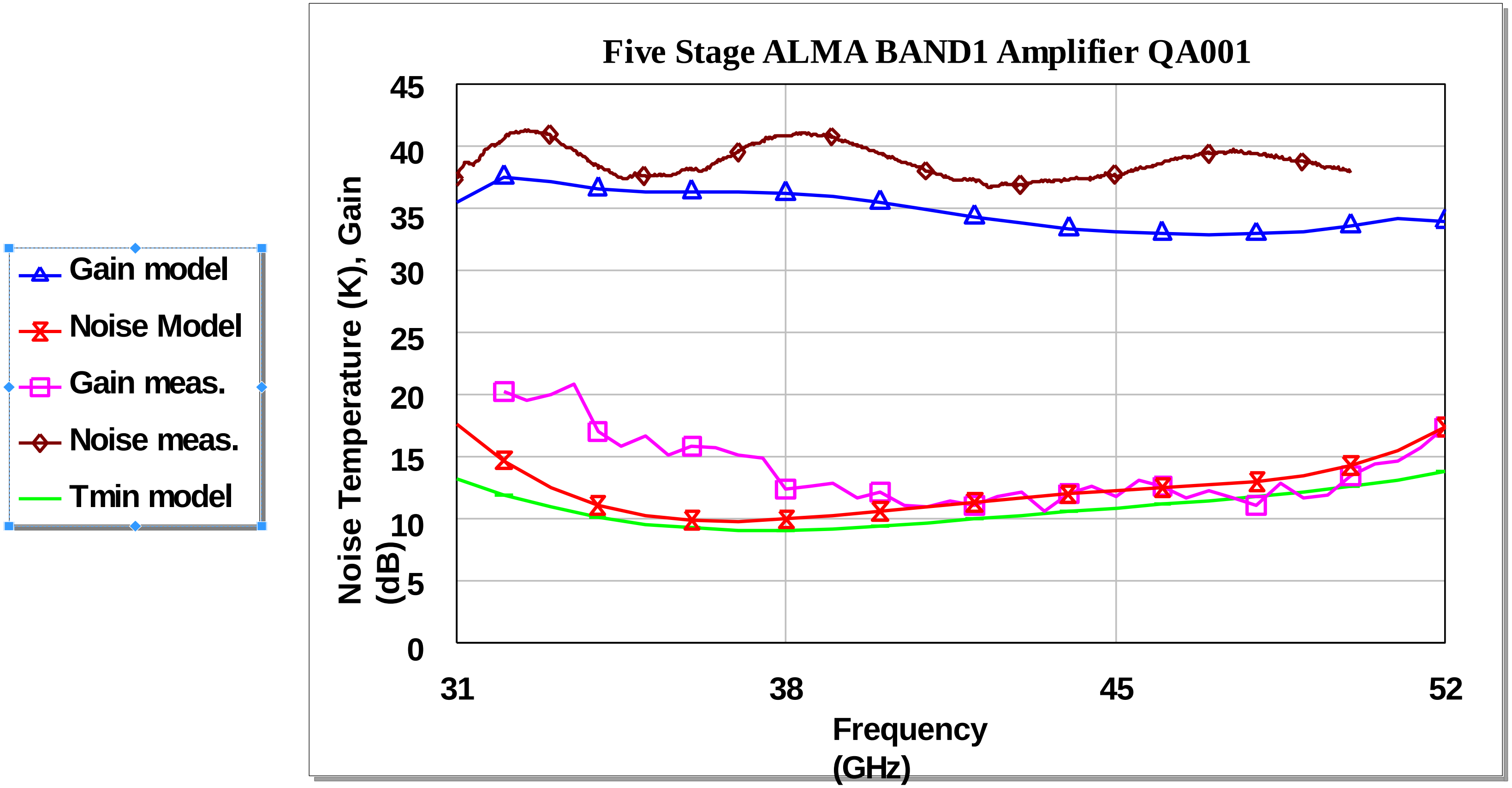
but reality intervenes



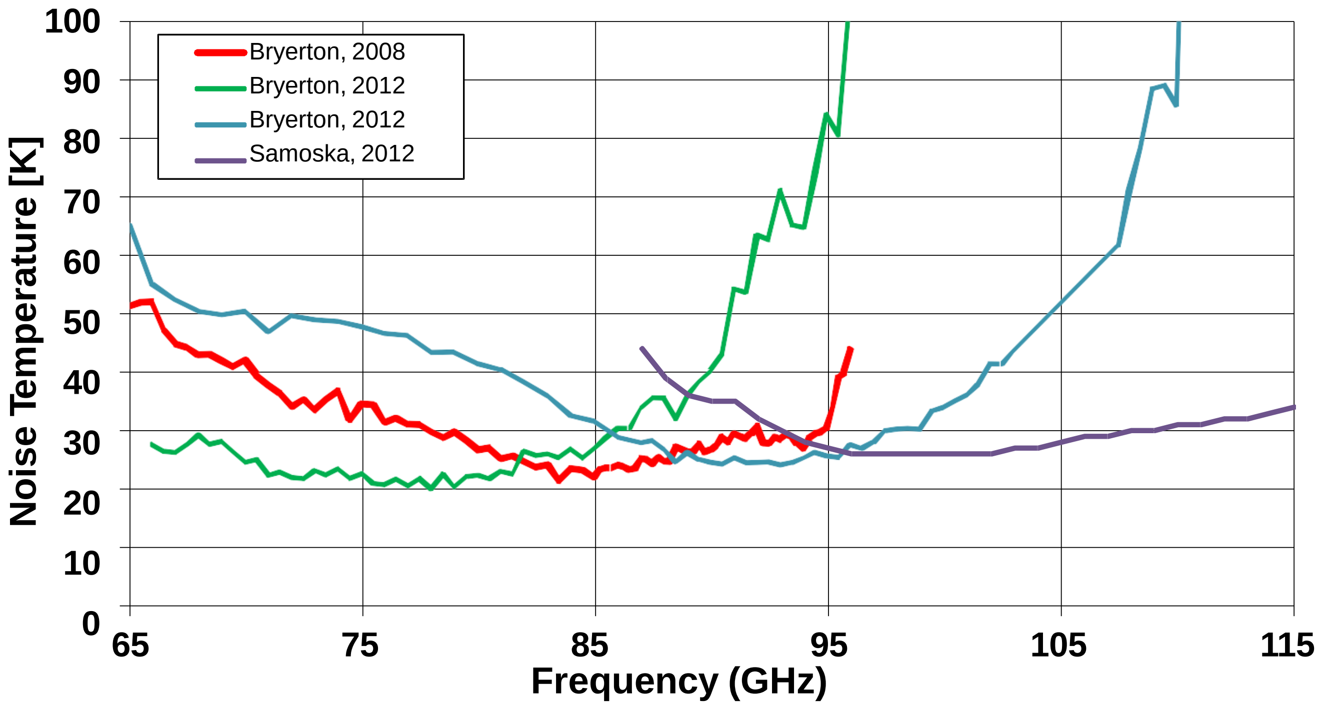
Noise Temperature Summary of Cryogenic HEMTs



5 stage 33-52 GHz amplifier: model and measured results at 20 K (QA001)



Packaged 35nm MMIC Test Results



- Measurements above at 20K operating temperature
- 4 different MMIC designs shown, packaged in either WR-12 or WR-10 modul
- Typical gain of 30dB for 3-stage MMIC
- Noise temperature at 297K typically 10-15x higher

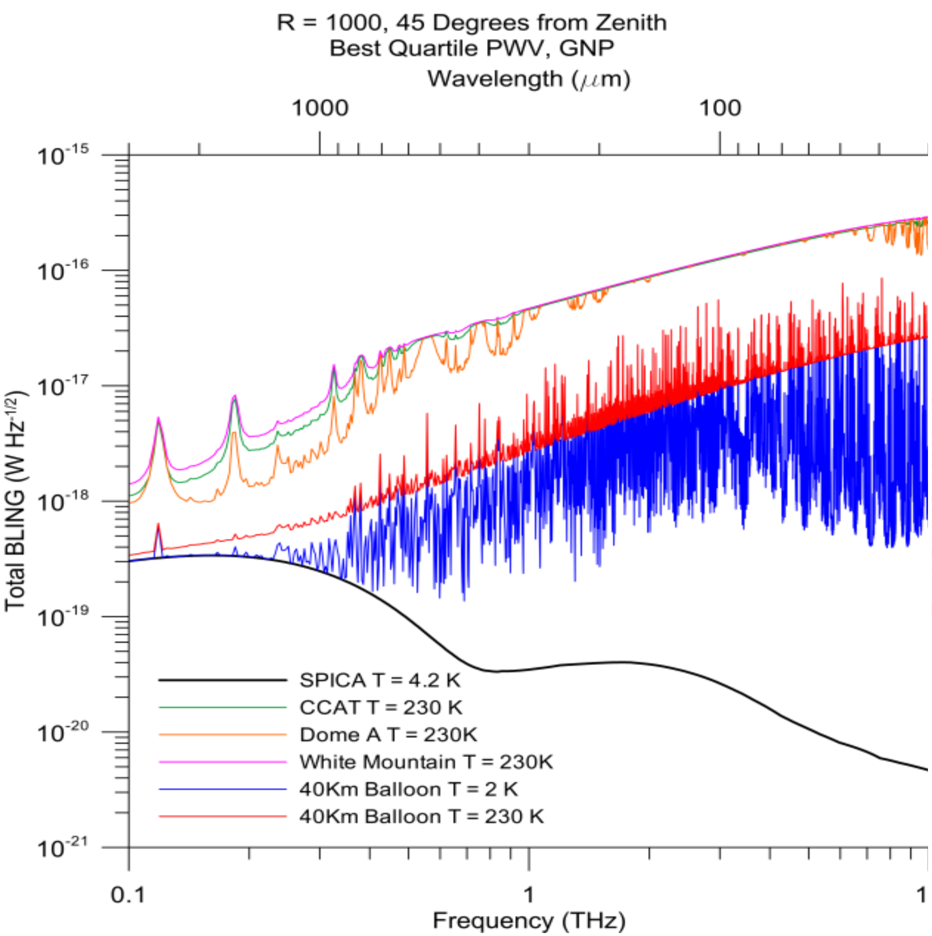
Sensitivity Needs

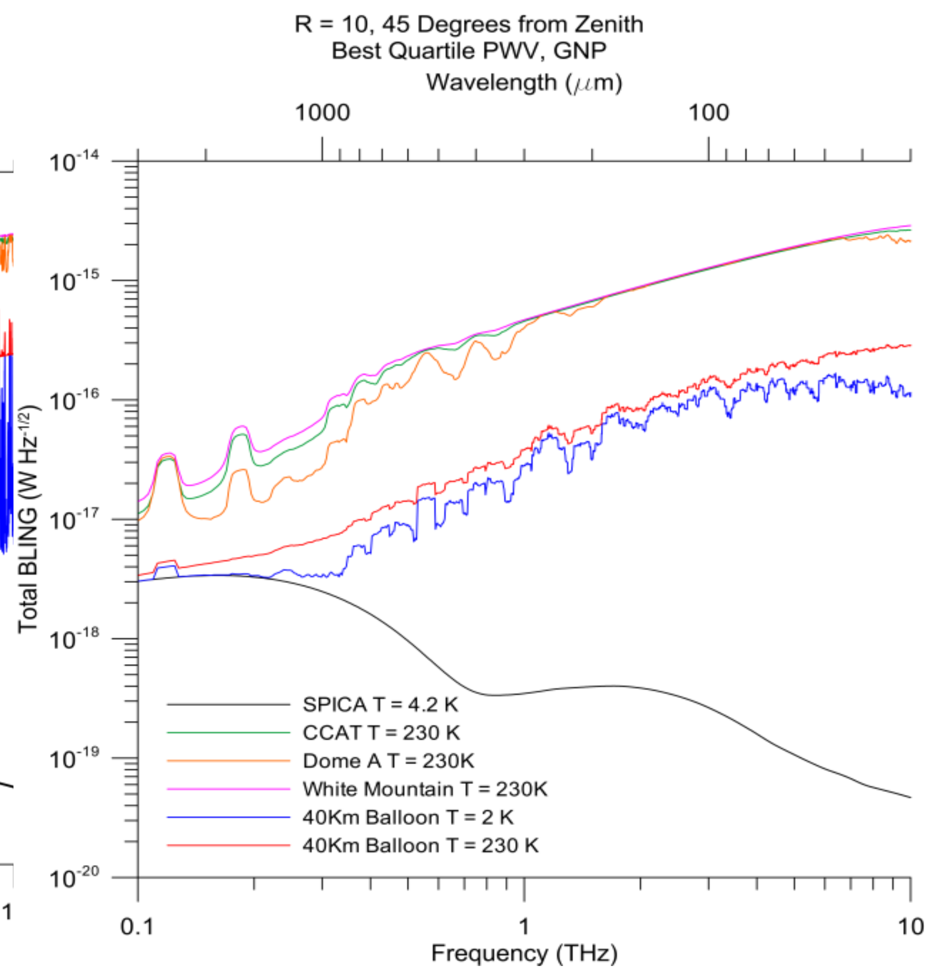
- Complicated discussion – depends on l range and B goal
- But figure of merit –> desire ~ 1 nK total integrated across t and det
- Assume 300 μK-s$^{1/2}$ -> (300 μK/1nK)^2 ~ 10^{11} s-detectors
- Assume 3 years good data -> 10^8 s -> ~ 6+ years clock time
- -> 1000 detectors -> 10,000 in works -> 100,000 ~10 years
- Hard but doable
- Focal plane area -> K* N_{det} λ^2 where K ~ O(1) (1-10 typ $F^{\#2}$)
- λ=2(150 GHz),3(100),6(50) mm – decent bands – λ>6 open
- Ex N_{det} =1000 K=10 ->A ~ 10^4 4,9,36 mm^2 4 λ horn -> tighter packing OK
- Not that large -> size (diam) ~ (K* N_{det})$^{1/2}$ λ -> 200-600 mm
- Ex N_{det} =10^6 K=3 -> 300x area -> size ~ 17 x larger -> multiple telescope
- Cost of telescopes, cryogenics, detectors
- Cryo needs are different – bolo ~ 0.1-0.25K, HEMT ~ 15K
- Bolo -> 4K 2 stage pulse tube driver, HEMT 15K 2 stage GM cooler
- Mass produce telescopes, cryogenics, detectors
- 1/f issues – bolo – lower 1/f , HEMT higher 1/f -> different detector layout

Issues - Reality

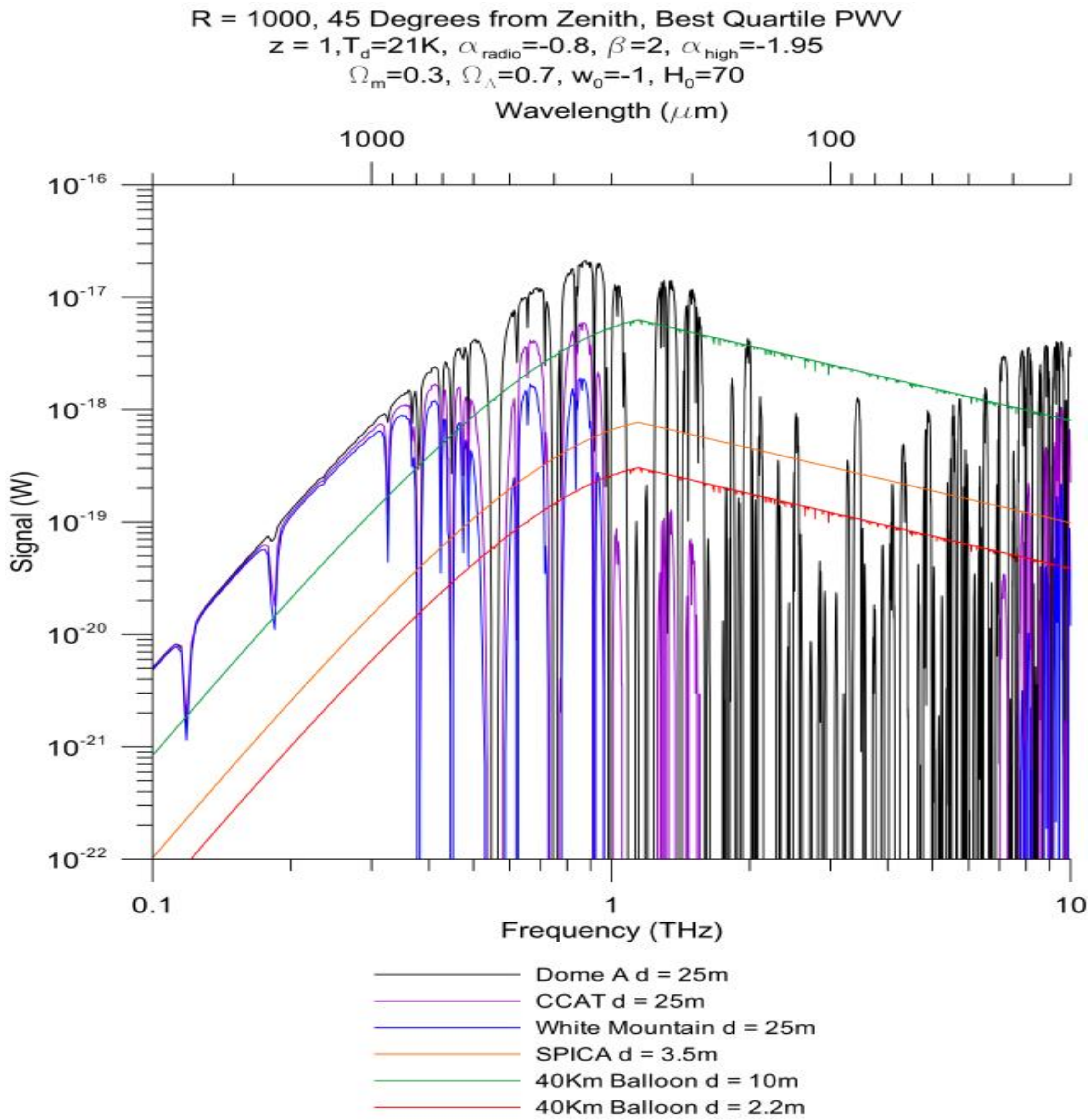
- We are now entering the foreground limited arena
- All eggs in one (bolometer) basket is not wise
- Space is required for high freq systems for best sens
- Space not obvious for <100 GHz observations
- Foregrounds will likely push us to 10-200 GHz ground as well as possible push to space BUT plan is needed to deal with foregrounds
- Are ~ background – photon noise limited – gnd bolo/HEMT
- Are ~background limited from space for >100 GHz bolo
- **We do NOT know what signal we are trying to detect**
- **Mass production is key for ground based systems - future**

Ground, Air and Space R=1000, 10

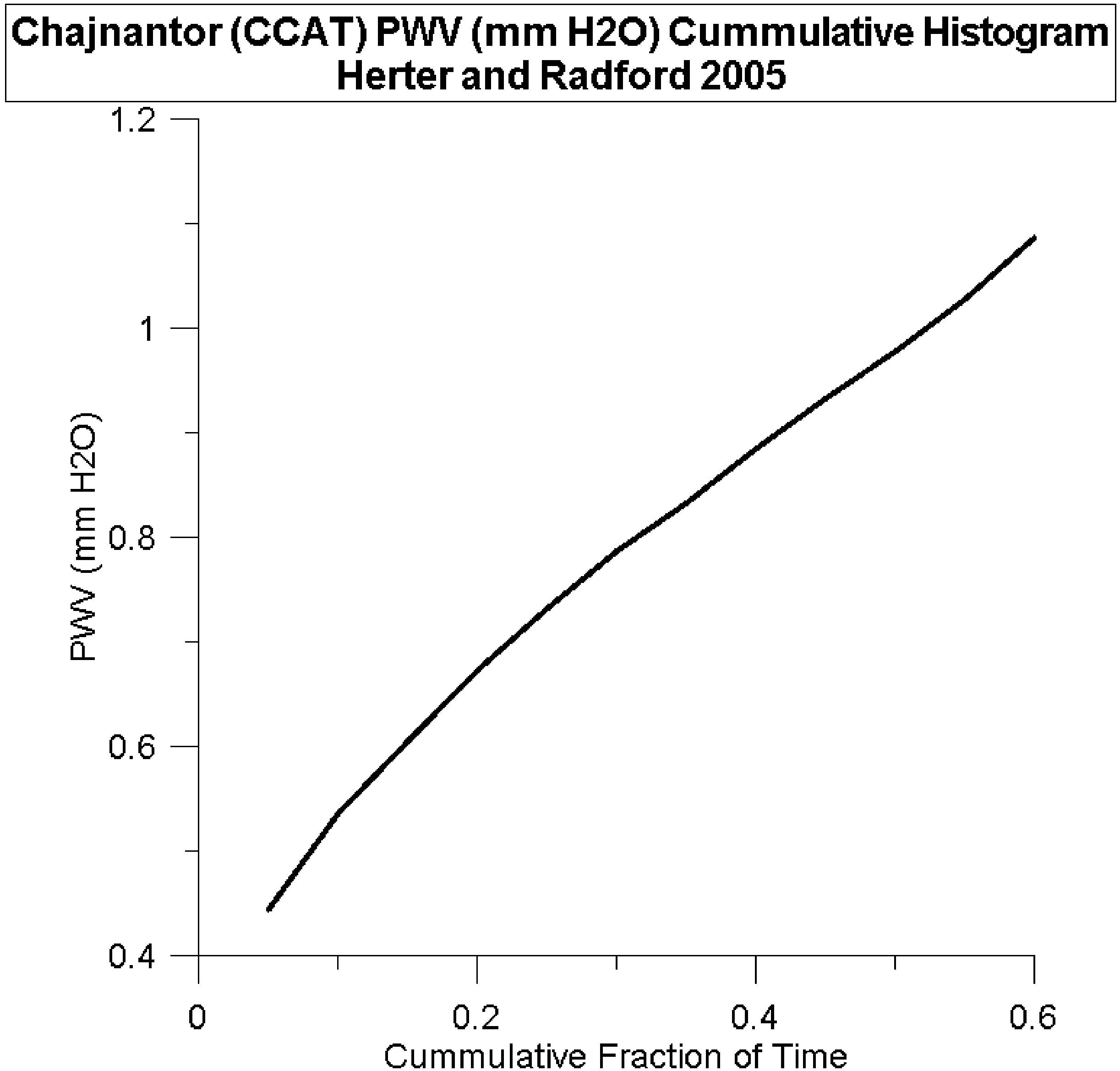




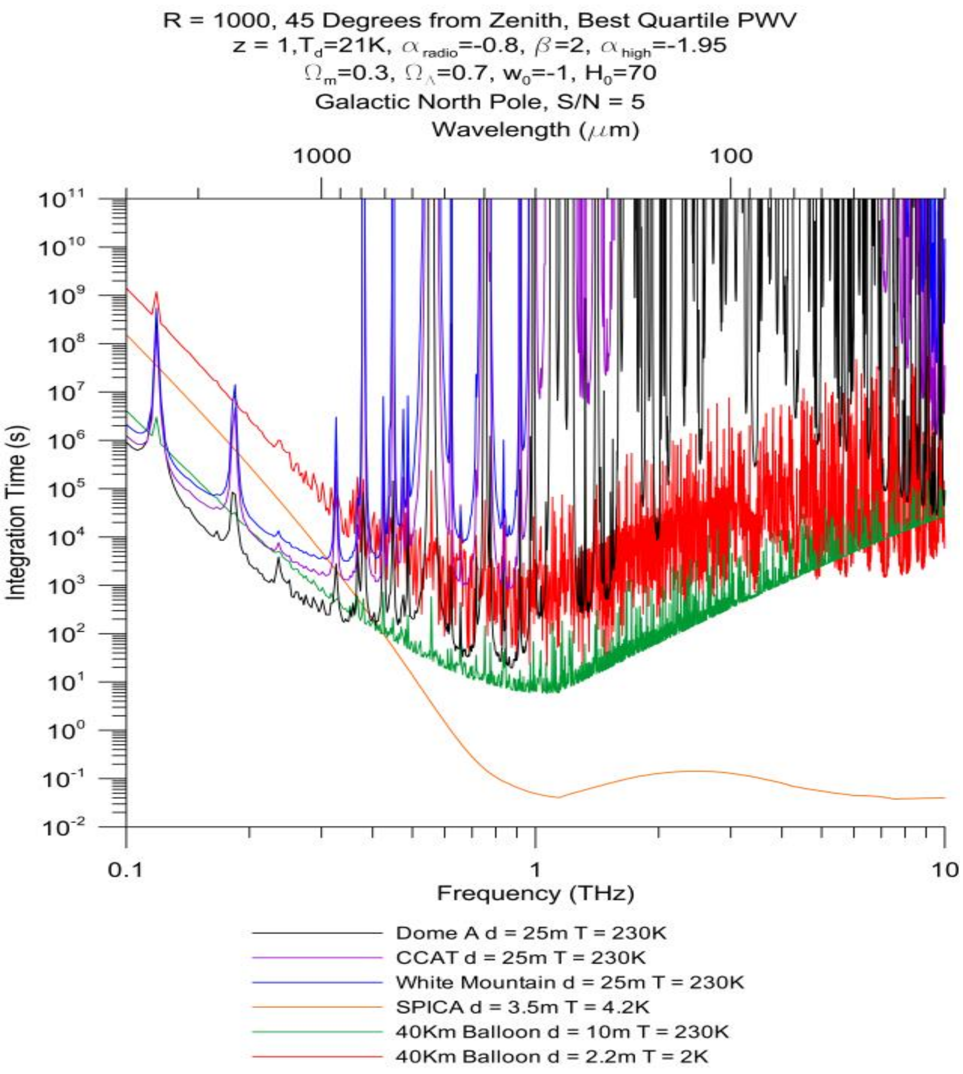
Dusty Galaxy @ Z=1 vs Obs. Platform – R=1000

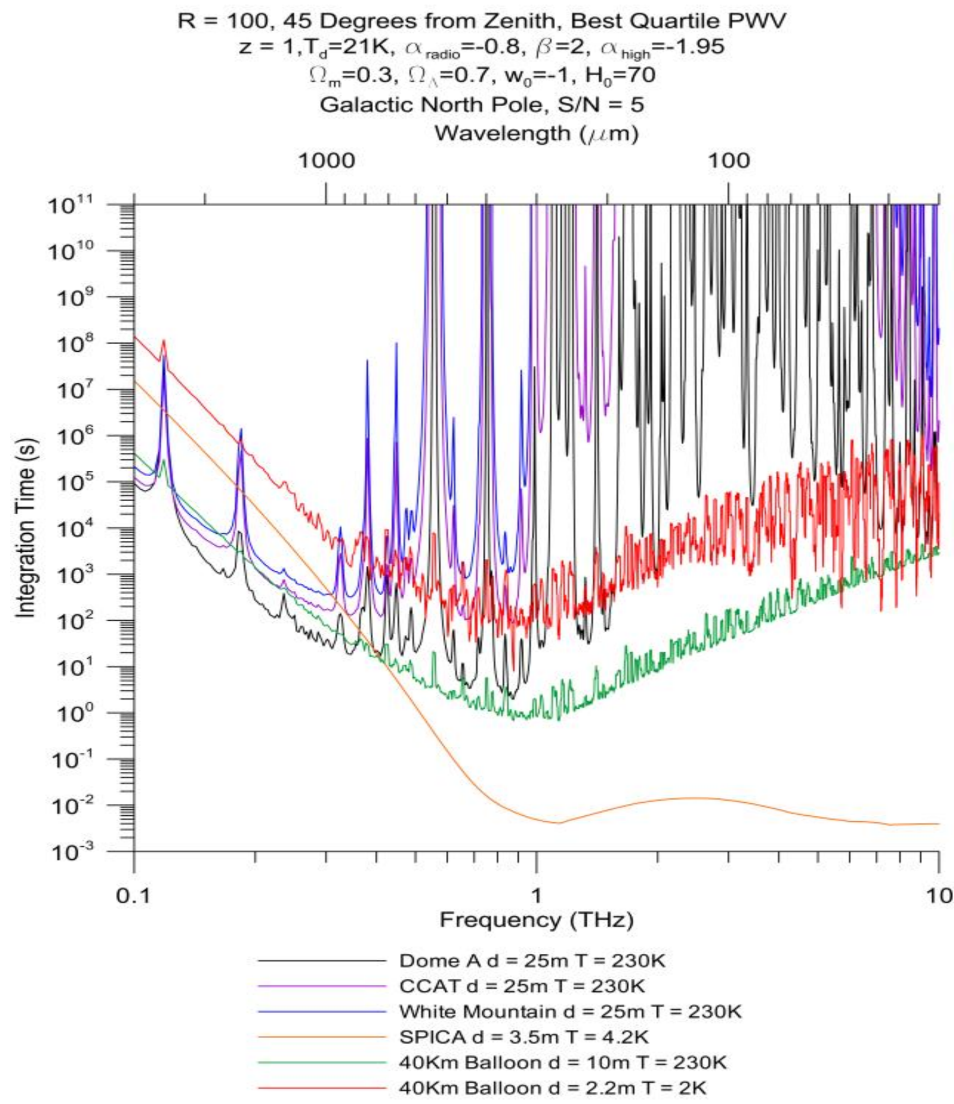


CCAT Site PWV Histogram Example
The tails of the Distribution are Important

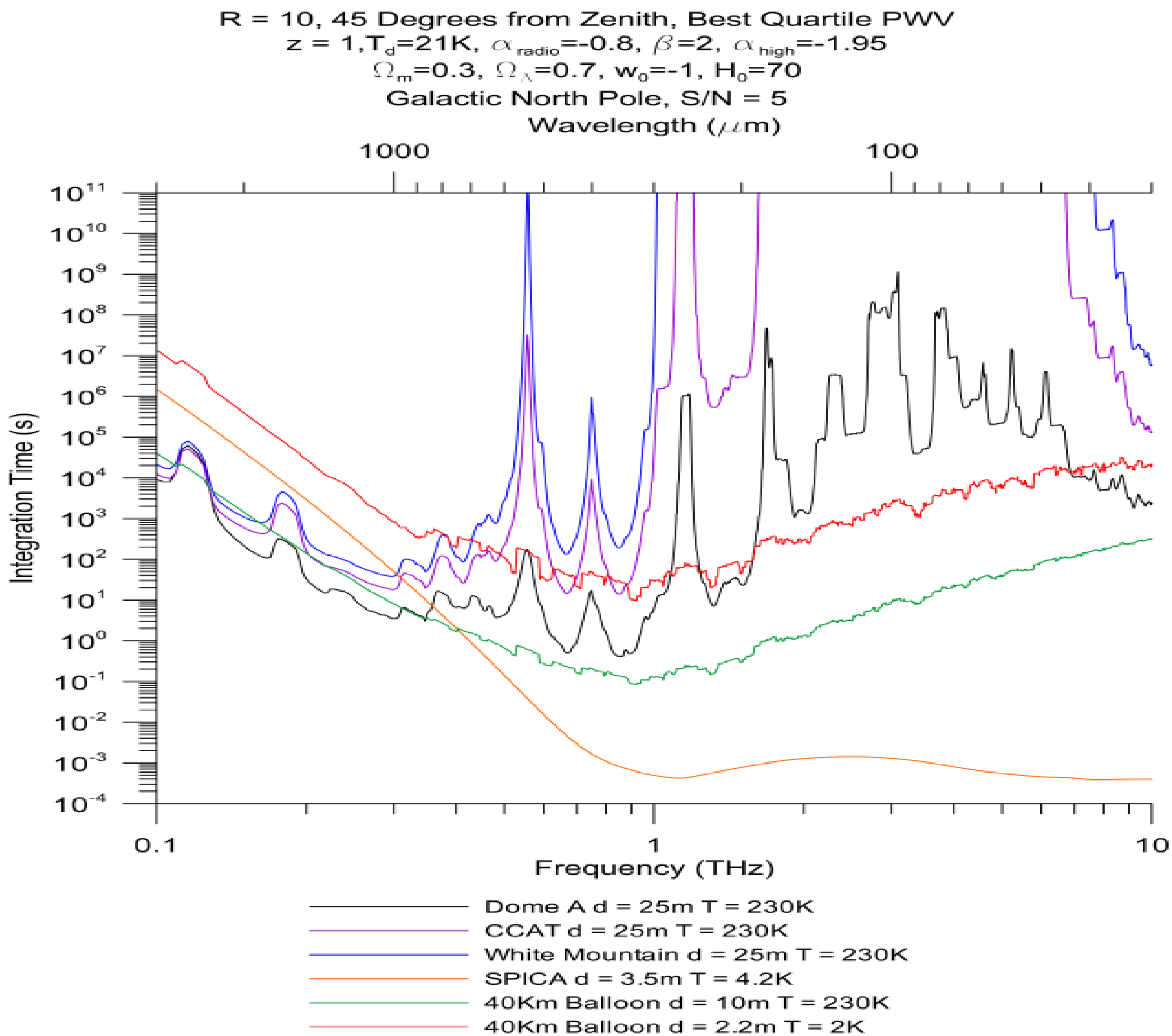


Obs Time SNR=5 - Z=1, R=1000, 100 vs Platform

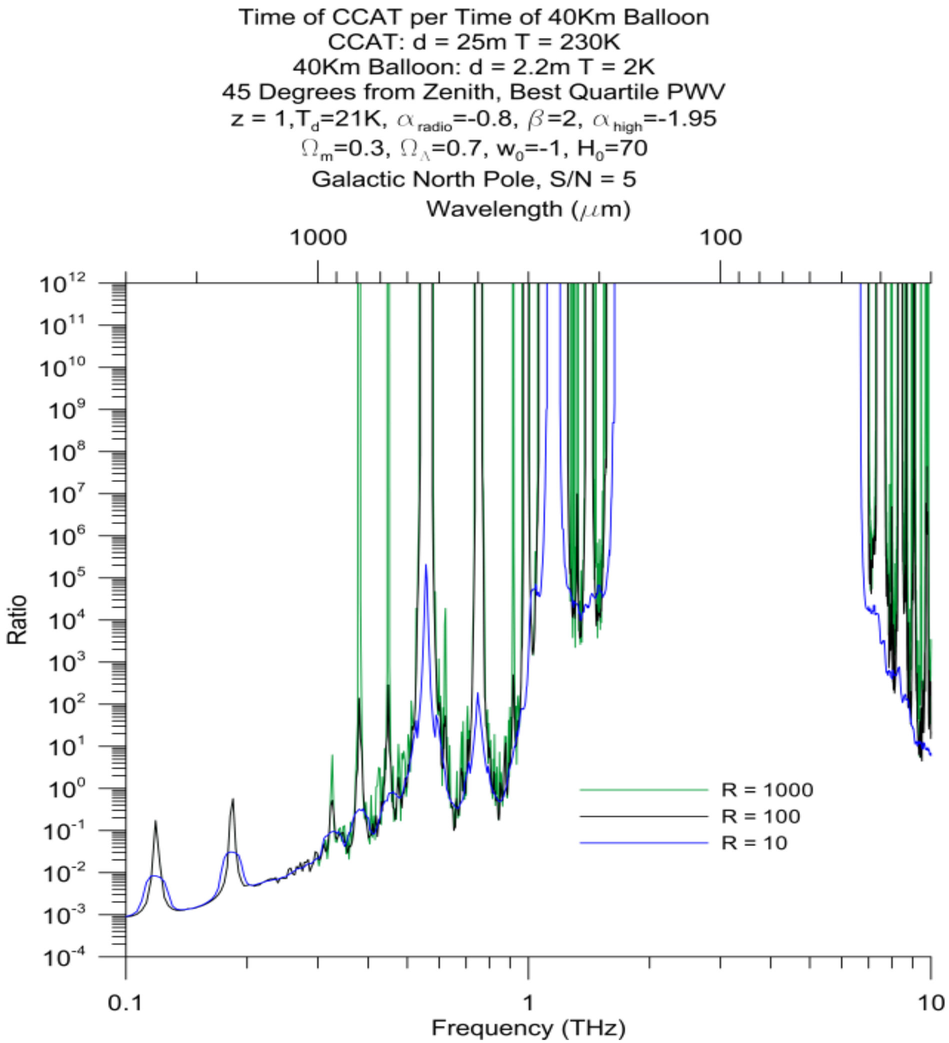


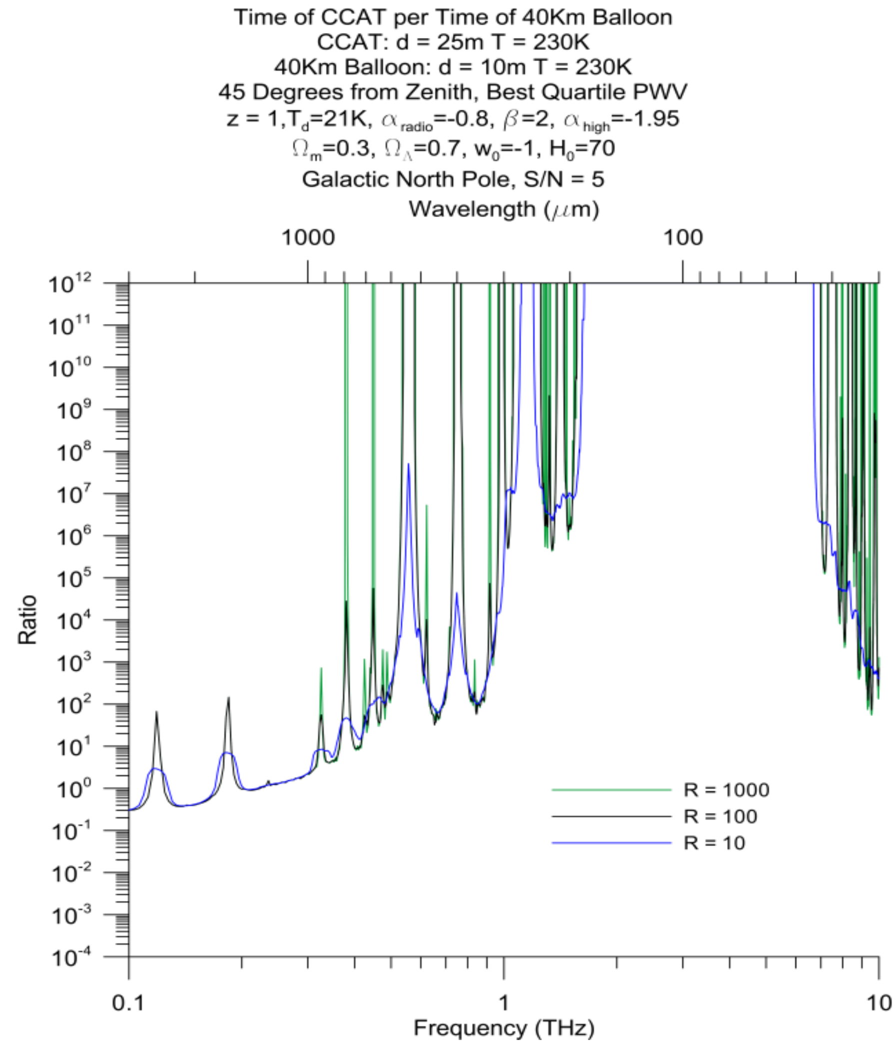


Obs Time SNR=5 - Z=1, R=10 vs Platform



Observing Time Ratio vs CCAT (best quartile) Multiply x4 to get "Clock time" Ratio





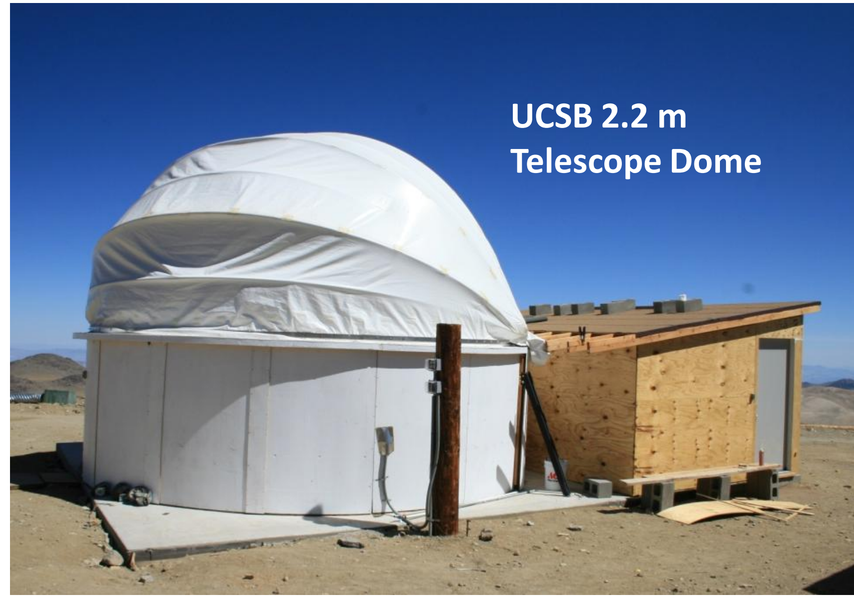
UCSB 2.2 m Carbon Fiber THz Mirrors good to > 500 GHz

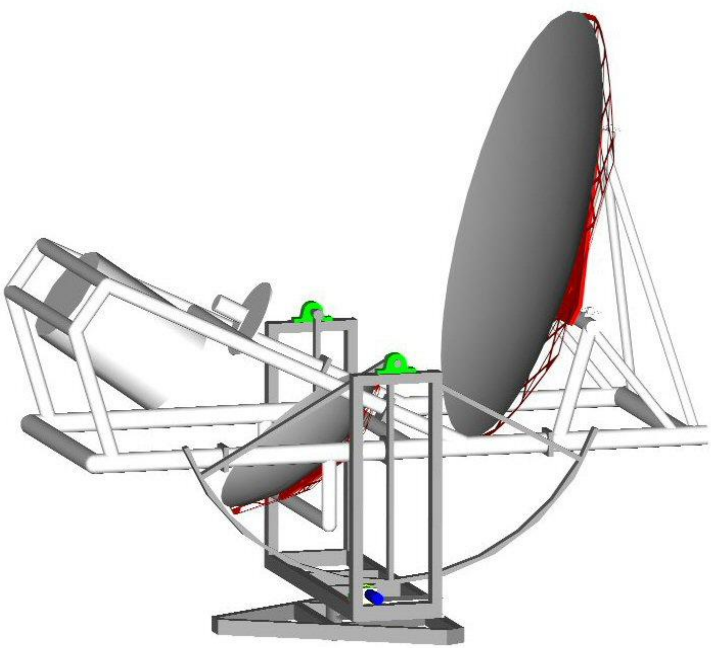
Carbon fiber mm wave telescope fabrication using 2.4 Meter mold, First mirror during layup, computer measurement at ATK (Santa Barbara).

We would start with our 0.9 meter elliptical CFRP mirror or custom machine an aluminum mirror

Very lightweight 2.2 meter telescope
Hernia Operation 1 week later!


UCSB 'White
Mountain site'


UCSB 2.2 m
Telescope Dome




Secondary
CAUTION

Possible plan for Greenland

- Start by deploying one 2.2 m telescope pathfinder with HEMT array with 20,30,45 GHz focal plane array options – 15 K cryo – 2 kw
- Use B Machine as prototype
- Same can be used with MKID focal plane array at 100, 150 GHz if desired – 4 K pulse cooler – 5-10kw
- Telescopes can be mass produced relatively cheaply
- Replicated optics
- Key is mass production of focal plane

Conclusions

- Everyone has a favorite poison
- We usually like to do what we did
- Scientists are not always so scientific
- Politics and money play a major factors in decisions
- Logic is not always operational
- WE have a problem now ->galaxy
- Extragalactic mission required -> will require some time
- Fallback -> space (is it needed?) -> we do not know
- Do not know the signal level for B modes from (IF) inflation
- We are starting to better understand the galactic enemy
- Longer baseline desired -> Go Long λ to help
- Greenland is not green but it is white and it is good
- Array of 2m telescopes – low cost high performance option to cover 20-45 Ghz with HEMT' and 100,150 GHz with MKID's
- Possible deployment of larger mm/ sub mm telescope for N Hemisphere – 7-10 m class.