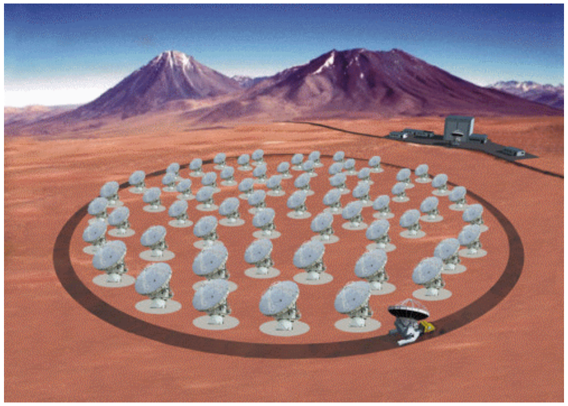
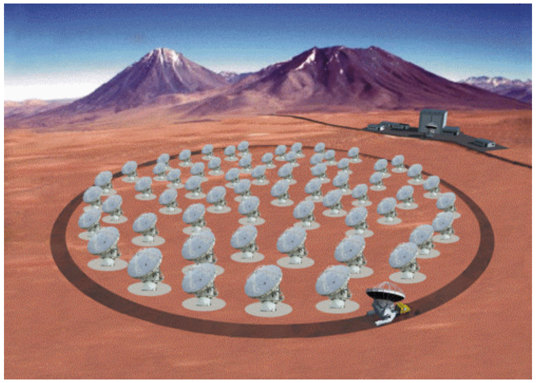


Phase Calibration

Al Wootten

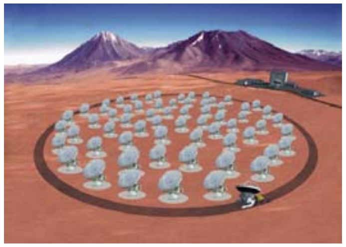
(based on work by many)

ALMA Week 2003 Victoria, B. C.



Purpose

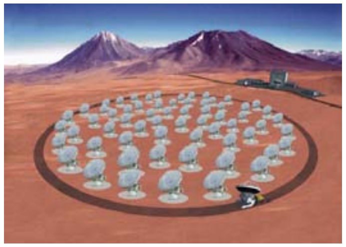
- Phase errors limit ALMA’s resolution, the dynamic range of its images, its sensitivity and they may introduce artifacts into ALMA images
- Address this through periodic calibration
  - Baseline and geometric errors--well-defined f(t,<)
  - Slow temporal errors, from electronics, antenna— calibrated f(t,<) on hundreds of seconds scales
  - Frequency dependent phase errors—bandpass calibration f(t,<) on hundreds of seconds scales, though atmosphere contributes too
  - Slowly varying atmospheric phase errors, which apply for only some of the time at some bands on the shortest baselines



Atmospheric Phase Compared to Other Phase Error Sources

- Phase calibration discussed in Woody et al. 1995; Memo 144
- This Memo set specifications for the Millimeter Array; subsequently the project became the ALMA Project.
- Woody et al. was planned to achieve 90% coherence only 50% of the time at 300 GHz
- The proposed error budget at 300 GHz was:

Conditions	Net Gain	Atmosphere	Antenna	Electronics
'Best'	98%	6° =17μm	5° =14μm	3° =7μm
'Median'	90%	14° =38μm	11° =31μm	6° =16μm
80^{th} %ile	50%	36° =100μm	28° =79μm	14° =40μm

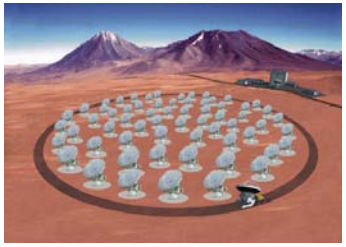


Cont…

- Project Book, Ch. 7, D'Addario revised these budgetary goals to be 'greater than 90% interferometric coherence at 950 Ghz (77 fsec rms), after all calibrations and corrections, on all time scales from 1 s to 10000 s, with absolute visibility calibration to 0.1 radian (16.8 fsec) at 950 Ghz. In that chapter, the phase error goals were divided into systematic and random parts.
- **PB Table 7.4: Phase Error Goals**

	Atmosphere f(t,<**)**	Electronics f(<**)**	Structure f(<**)**	Total, per antenna
systematic	8.4	6.9	4.8	11.9
Random (rms)	38.5	31.4	22.2	54.5

t 6 **tens of seconds**



Cont…

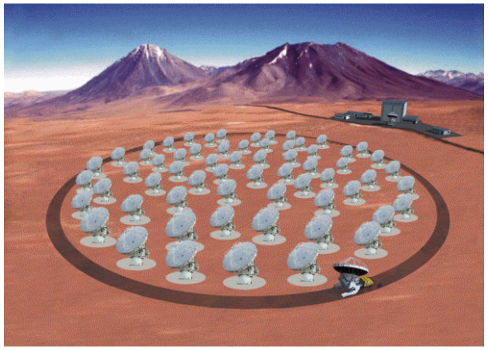
- Draft calibration plan revises these budgetary goals. Butler defines the total system delay at the ith antenna as:

$$\Phi_i = \varphi_{gi} + \varphi_{ai} + \varphi_{si} + \varphi_{ei} + \varphi_{fi}$$

Proposed **Phase Error Goals**

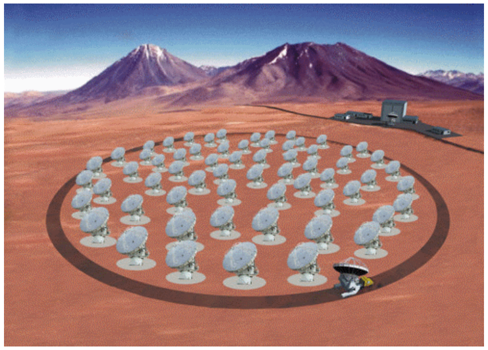
	Geometric f(t,<)	**Atmosphere f(t,<)**	**Electronics f(<, ~t)**	**Structure f(<, ~t)**	Total, per antenna
Systematic	5	10	7	7	15
Random (rms)	0	**40*(1.25 +PWV)**	50	30	$\sqrt{5900 + 3600\,\mathrm{PWV} + 1440\,\mathrm{PWV}^2}$

t 6 tens of seconds; ~t 6 longer timescales



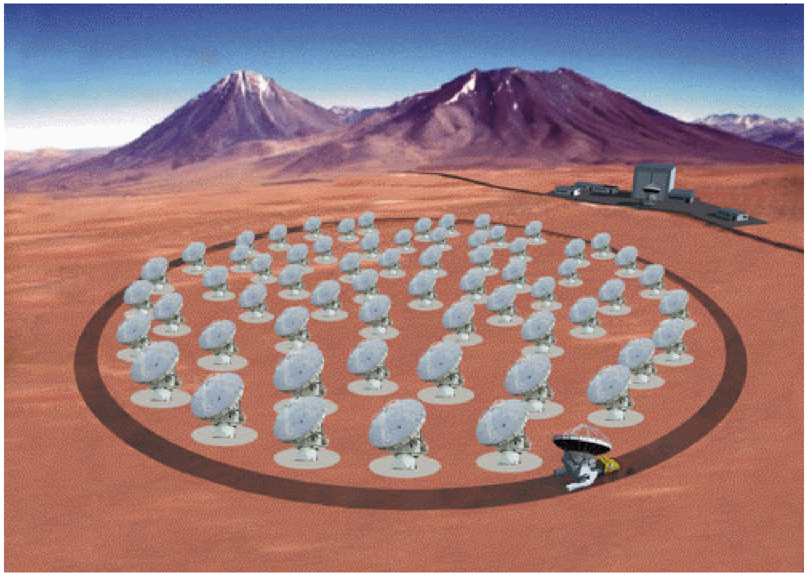
Discussion

- Geometric – many components, accurate positions to 1 mas using J2000, corrections standard to e.g. CALC package.
- Atmospheric –
  - Troposphere –
    - bulk atmospheric per antenna
    - Fluctuating part (dry and wet)
  - ionosphere.
- Antenna Location:
  - 1/3 radian phase difference across the band requires a baseline accuracy of about 1mm.
  - Butler takes 10^{o} as the maximum allowable phase error at the highest observing frequency (650 GHz for the baseline project).
  - error in the baseline must be less than about 130 μm; each antenna location to 65 μm.



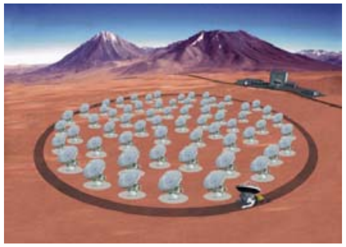
Continued

- Antenna structure
  - Repeatable: Estimate about one tenth of the repeatable residual delay will result in true systematic delay offsets ~7fsec
  - Non-repeatable: Adopt RFP number of 15 μm, or 50 fs at 650 GHz
- Electronics
  - Should not dominate other errors



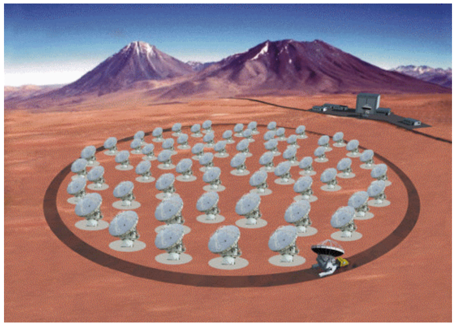
Atmospheric Correction--Critical to Achieving ALMA Science

- Owing to the critical need of ALMA science for achieving its science goals, a combination of fast switching and water vapor radiometry will be used to correct for the atmospheric phase fluctuations.
- Even then, achieving the goals will be challenging for the highest frequencies and longest baselines
- Method of employing these two methods together remains unclear, to evolve with time—although each has been used, they have never been used in concert, and 183 GHz radiometry is relatively untested.
- First attempts to be undertaken at ATF

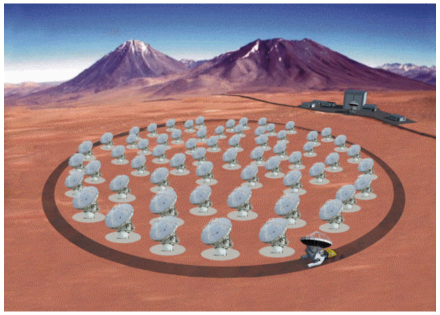


Atmospheric terms

- Stringency Σ – the ratio of the total available observing time to the total time under which conditions are appropriate for a particular observation.
- 'Traditional' phase calibration every several minutes – low Σ all bands, instrumental phase cal
- For atmospheric errors, particularly where water vapor contributes, φ~f(t,<**);** more frequent calibration is needed – high Σ; all bands for the larger arrays
  - – Fast switching (position, interband) (Holdaway) ~10 s
  - – Water vapor radiometry (Friday session) to 1s
    - Phase at 183 GHz scaled, through modeling, to other frequencies.
  - – Considerable overlap in deployment regimes suggests development of a strategy on conditions to deploy a particular method



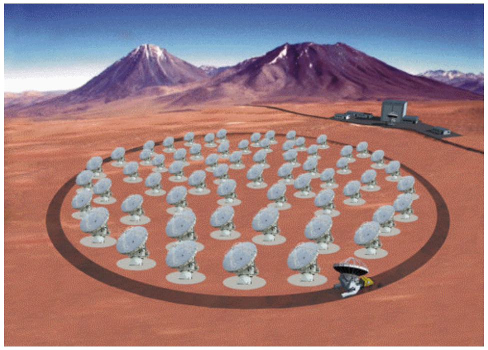
- Phase stable observations are possible only for low Σ
  – – long wavelengths or short baselines 6
  Compensatory actions needed for other λ, B, high Σ
- ASAC Oct 2002 report on stringency confronts site data with ALMA needs to start exploring the concept of Σ and its relationship to how we observe with ALMA—three variables, wind (yes/no), ϑ(225GHz), φ_{rms} considered.



Chajnantor Phase Stability

	φ_{rms}		< limit	(GHz)	345	GHz
	μm		30°	70°	B_{max}m	θ_{sec}
75%	394	5.3°	63	148	52	2.40”
50%	187	2.5°	134	313	181	0.69”
25%	89	1.2°	281	655	625	0.20”
10%	49	0.7°	510	1189	1681	0.07”

Φ_{rms} From site testing interferometer, scaled; $<_{limit}$ for observations with specified Φ_{rms} for B=300m after Holdaway and Owen ’95; B_{max}m and θ_{sec} after Masson ’94 using Holdaway and Pardo ’01 mean structure function exponent.



Template Slide

- Here go words.