Atacama Submillimeter Telescope Design Issues

David Woody

Caltech

Owens Valley Radio Observatory

January 2005

outline

- General discussion
  - Major issues
  - Performance limits
- General approaches
- A design concept

First order decisions

- Collecting area
  - 500 m^2
- Shortest wavelength
  - 200 μm ? (15 μm surface RMS)
- Budget
  - $70M ??
- Site
  - Atacama, but where exactly???

Performance Issues

- Imaging quality
  - Pointing
  - Field of view
  - Sidelobes
  - Polarization purity
  - Beam shape (surfaces RMS and aberrations)
- Operating conditions (dome?)
  - Weather
  - Maintenance
  - Instrument packages
  - Solar loading
- Detector performance (loading, Tsys)
  - Blockage
  - Scattering
  - Spillover

What effects performance

- Environment
  - Wind
  - Sun
  - Gravity
- Materials
  - Steel
  - Aluminum
  - CFRP
- Geometry
  - Symmetric
  - Off-axis
  - ?
- Fabrication

Basic limits

- Gravity
- Thermal
- Wind
- Survival

Von Hoerner limits

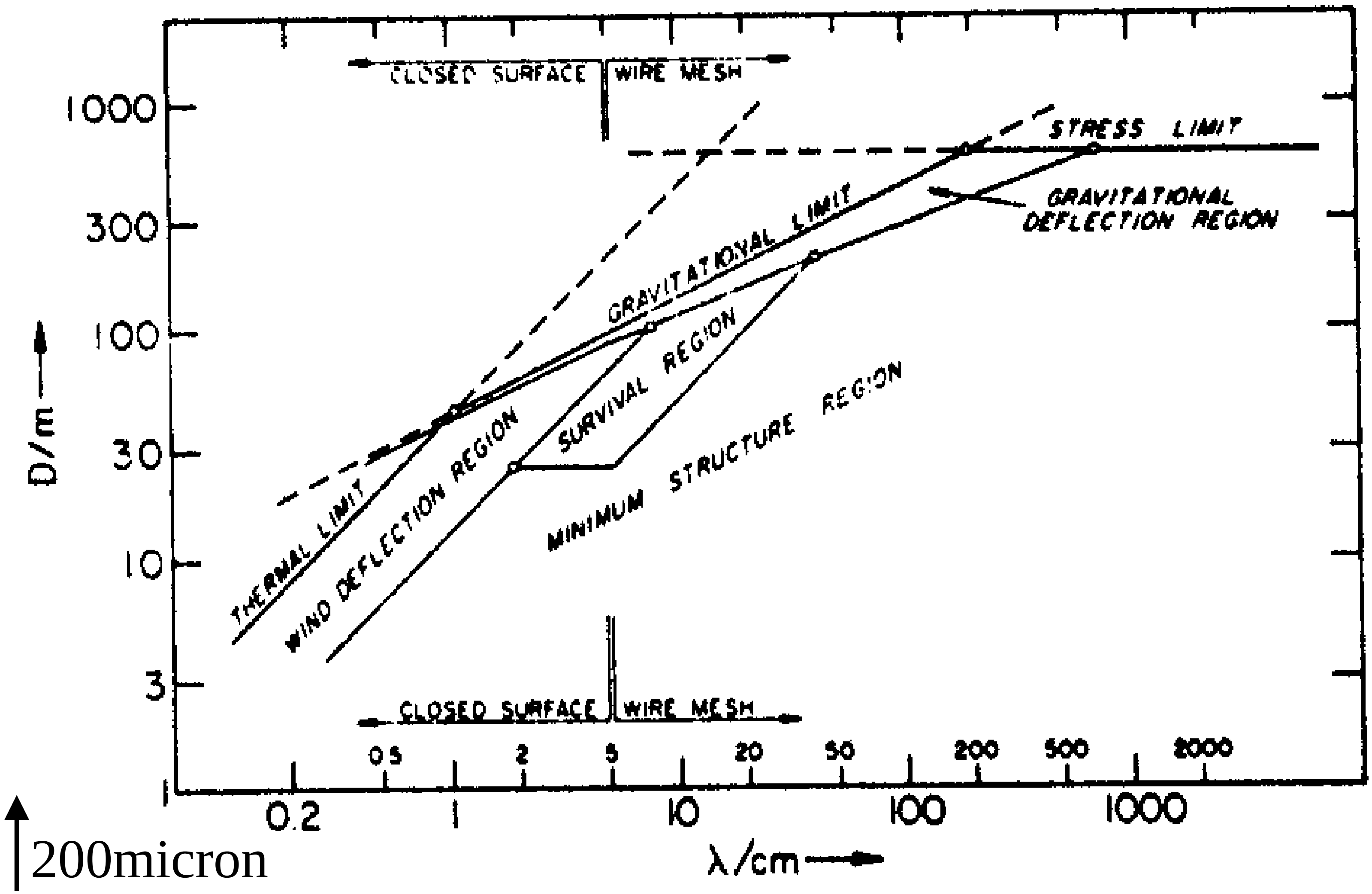


FIG. 3. Regions of diameter D and wavelength λ, in which the weight of the structure is defined by different conditions, and the three limits of Fig. 2.

Material parameters

	Steel	CFRP	Aluminum	Invar
Density [lb/in^3]	0.283	0.061	0.097	0.291
Modulus [10^6 lb/in^2]	30	17	10	22
CTE [10^{-6}/K]	12	0.2	23	1.6
Y/ρ [10^8in]	1.1	2.8	1.0	0.8

CFRP

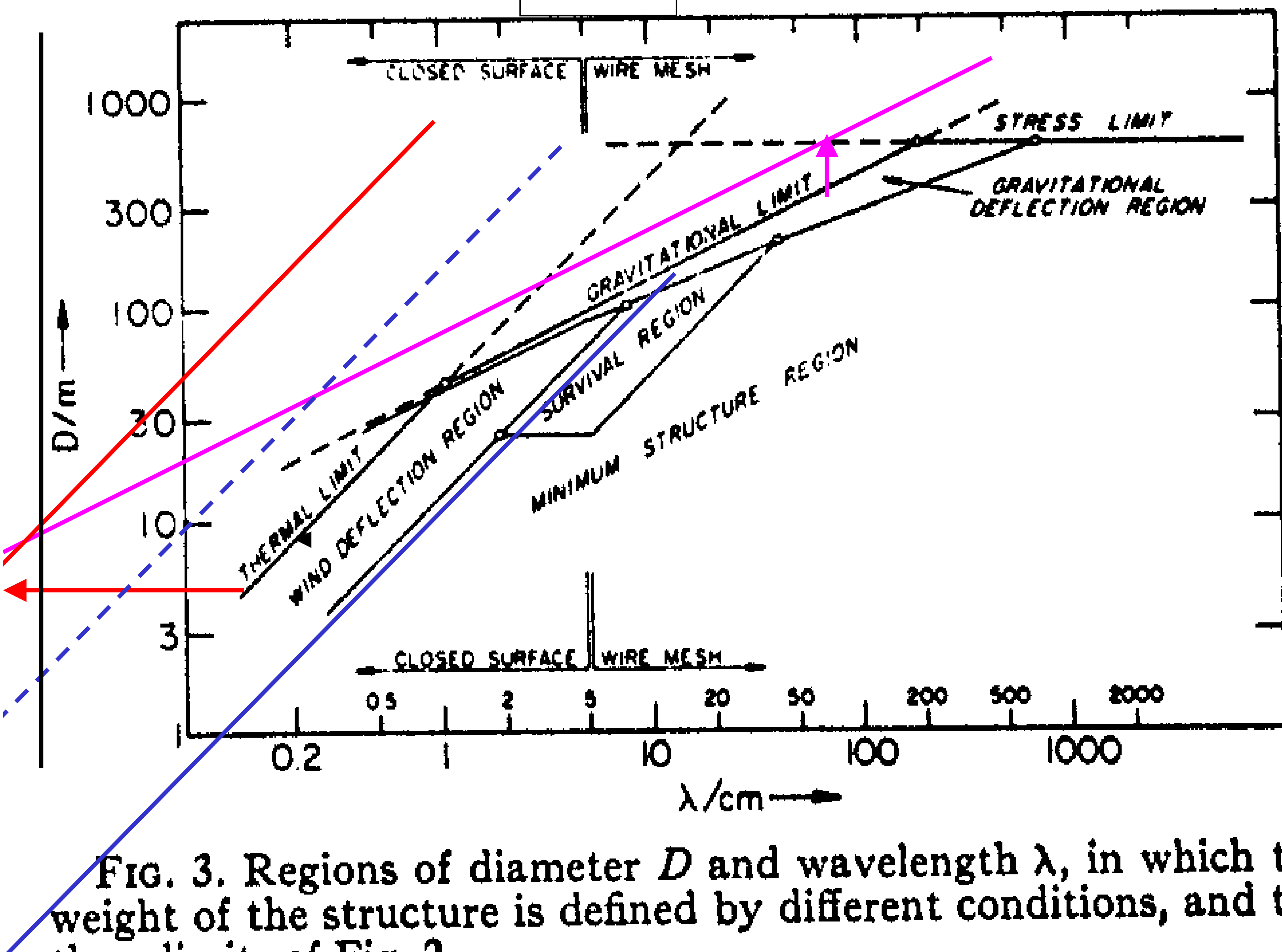


FIG. 3. Regions of diameter D and wavelength λ, in which the weight of the structure is defined by different conditions, and the three limits of Fig. 2.

So we need tricks

- Homology can beat gravity by ~10
- Actuators can beat thermal and gravity if
  - Stable measuring system
  - Stable reference system
- But wind is a major problem
  - First order => pointing errors
    - Pointing reference system or guide stars
  - Higher order distortions are very difficult

  => Dome

Steel in dome and homology

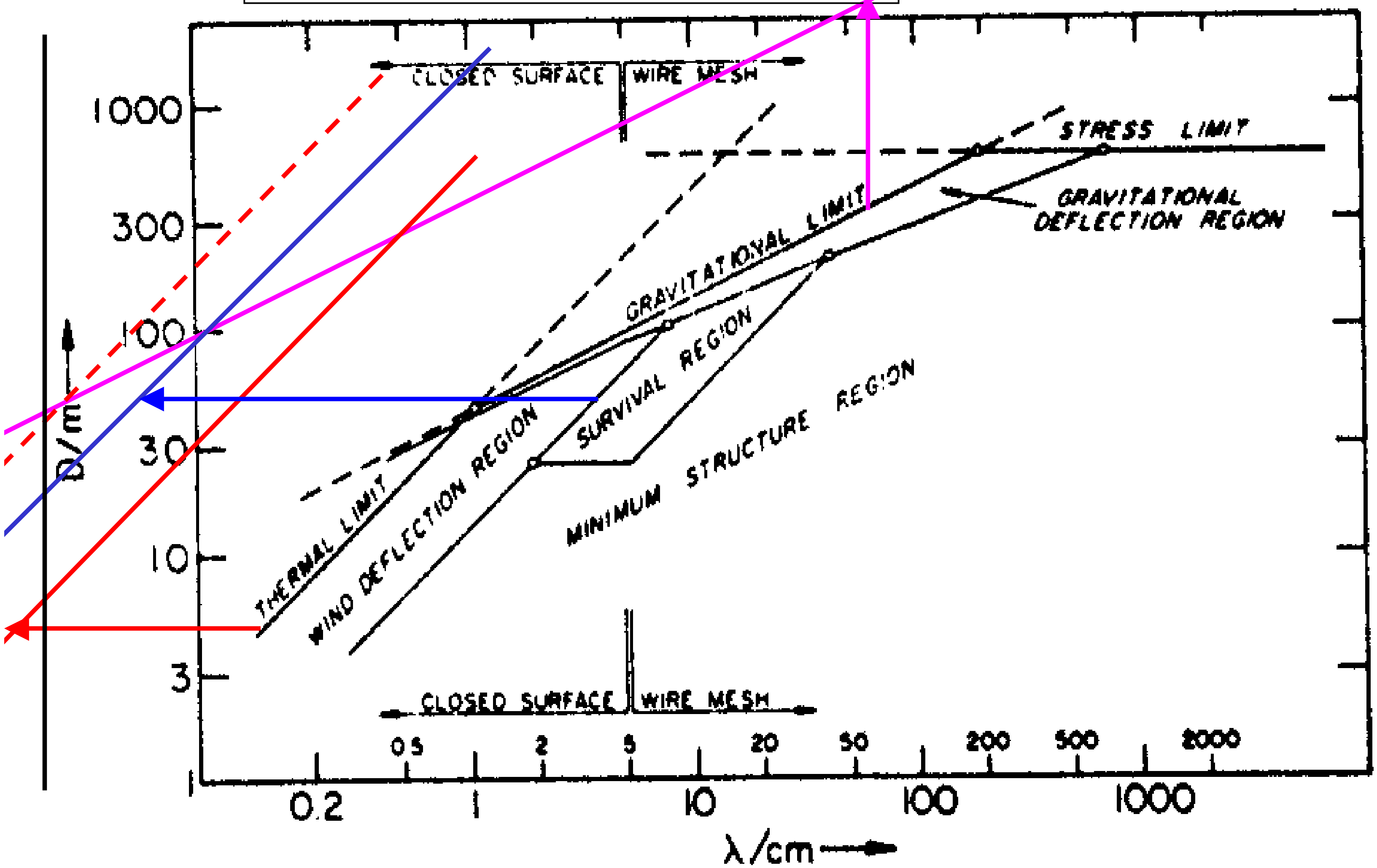


FIG. 3. Regions of diameter D and wavelength λ, in which the weight of the structure is defined by different conditions, and the three limits of Fig. 2.

Dome

- \+ Decrease wind by 10
- \+ Better Survival
- \+ Good working conditions
- \+ Keep panels and structure dry
- \+ Less dust!!!
- Thermal?
  - Requires insulation
  - Good air circulation during day when closed

Steel vs. CFRP structure

- Steel structure
  - + Well understood
  - + Cheap
- Aluminum panels
  - + Well understood
  - + Cheap

- CFRP structure
  - + Excellent CTE
  - + Light weight
  - - Still requires research
- + CFRP panels
  - + Excellent CTE
  - + Light weight
  - - Still requires research
  - - Surface layer problems

Geometry

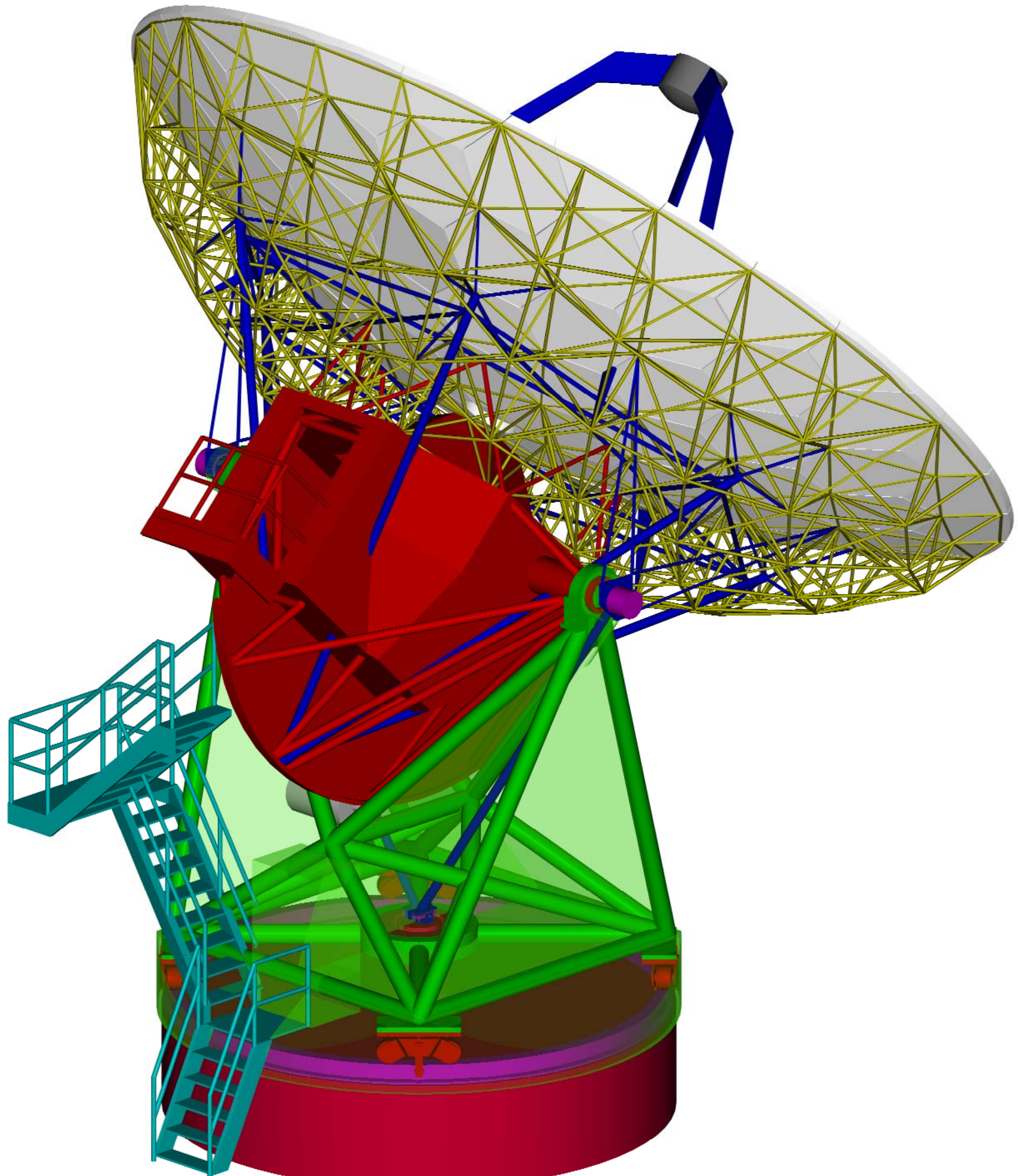
- Symmetric
  - + Best surface
  - + Best pointing
  - + Lowest cost
  - - ~2% Feedleg blockage
  - Polarization
    - + Symmetric optics
    - - Feedleg scattering
    - ? Effect of panel gaps
- Off-axis
  - + Best beam
  - + No feedleg blockage
  - - Higher cost
  - ? Homology
  - Polarization
    - + No feedleg scattering
    - - asymmetric optics
    - ? Effect of panel gaps

Accuators

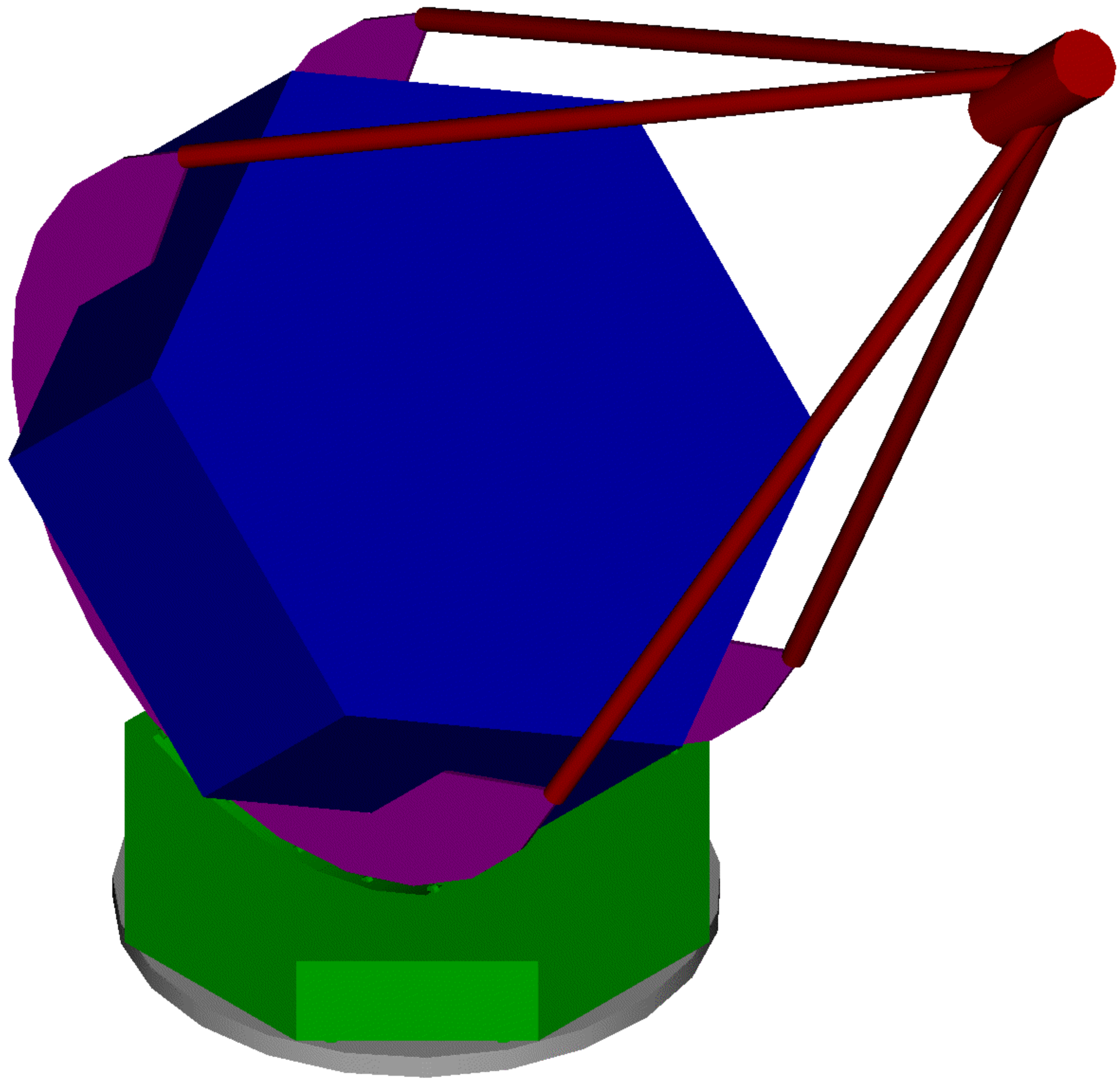
+ Relaxes homology, may be essential
+ Might help with thermal
+ Easy to adjust surface

- High costs
- Needs research
- No good reference structure available
- Software
- Maintenance

An ALMA concept

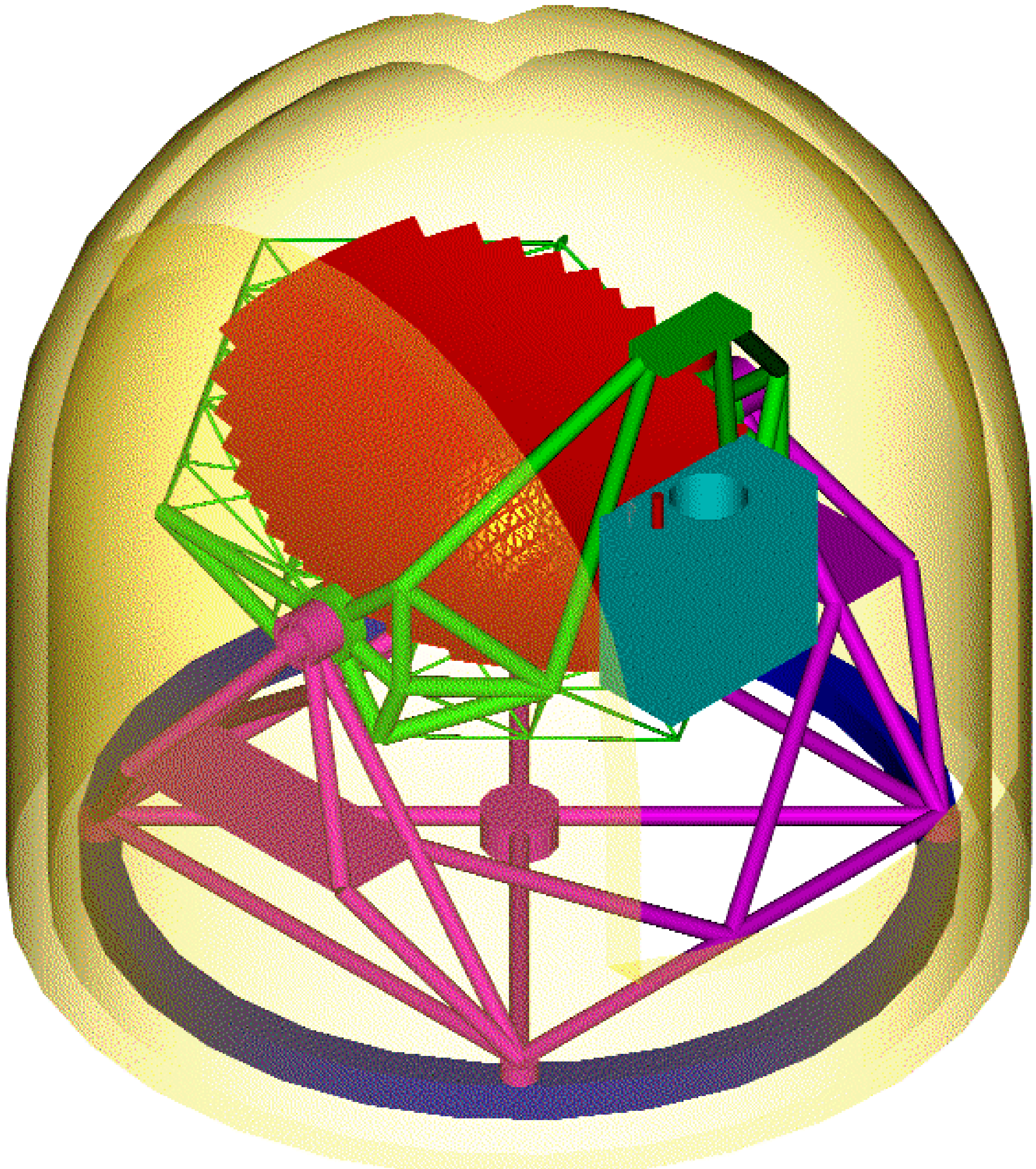


A previous CELT concept



Investigate an off-axis design

- Better imaging
- No blockage
- Receivers
  - Large volume with no relay optics
    - (large $A\Omega$ requires huge mirrors)
  - Nasmyth platforms?



Optics

- 25 m clear aperture
- Disk from 50 m f/d=.4 parabaloid
  - Effective f/d=1
- Compact structure
  - Swept volume 21.5 m radius
  - Tipping structure can rotate 360 deg in elev.

Panels

- Bulk or cast aluminum
  - Machined surface
  - Heavy
  - Proven
- CFRP (CFRP or Al honeycomb)
  - Molded surface
  - Light weight
  - Low CTE
  - Surface unproven
- Electroplated Nickel
  - Replicated surface
  - Light weight
  - Can have optical surface finish or diffuse scattering
  - CTE probably limits size to 1 m^2 (insulate backside)

Raft concept

- Put 10-20 panels on a subframe
  - Fixed adjusters for the panels
  - Set panels on the raft in lab
- Raft ~10 m^2
  - 50 rafts
  - 3 actuators per raft
  - Stiff
    - Small gravity and wind distortions
  - Thermally stable
    - CFRP frame or insulated steel

Surface control

- Keck style edge sensors
  - On thermally stable rafts
- Laser interferometry
  - Many fixed sight lines

- Modulated laser absolute measuring system
  - Few scanning systems
  - Just beyond current state-of-the-art
- Wavefront sensor system
  - IR stars
- Shearing interferometer system
  - CSO has used this very successfully
- Out of focus holography

Drive system

- Critical for fast scanning and pointing
- Bearings
  - Hydrostatic
    - Smooth
    - Low friction
    - Messy
  - Wheels and roller bearings
    - Cheap?
    - Standard

Motors

- Commercial motors and standard gear trains (COTS)
  - Limited bandwidth
  - Torque ripple
  - Gear noise
  - May limit tracking performance
- Commercial motors friction drives
  - Difficult to develop high enough torques
  - Torque ripple
- Direct drive
  - Develop a standard ~2 m diameter on-axis motor
    - Use several identical motor on each axis
  - High bandwidth
  - Very smooth tracking (torque ripple within bandwidth)
  - expensive

Telescope concept

- Off-axis
- In dome
- Electroplated Nickel panels on CFRP rafts
- Modulated laser metrology
  - (corner reflectors formed into panels)

  + shearing interferometer absolute meas. system
- Hydrostatic bearings
- Modular direct drive motors
- Optics details TBD

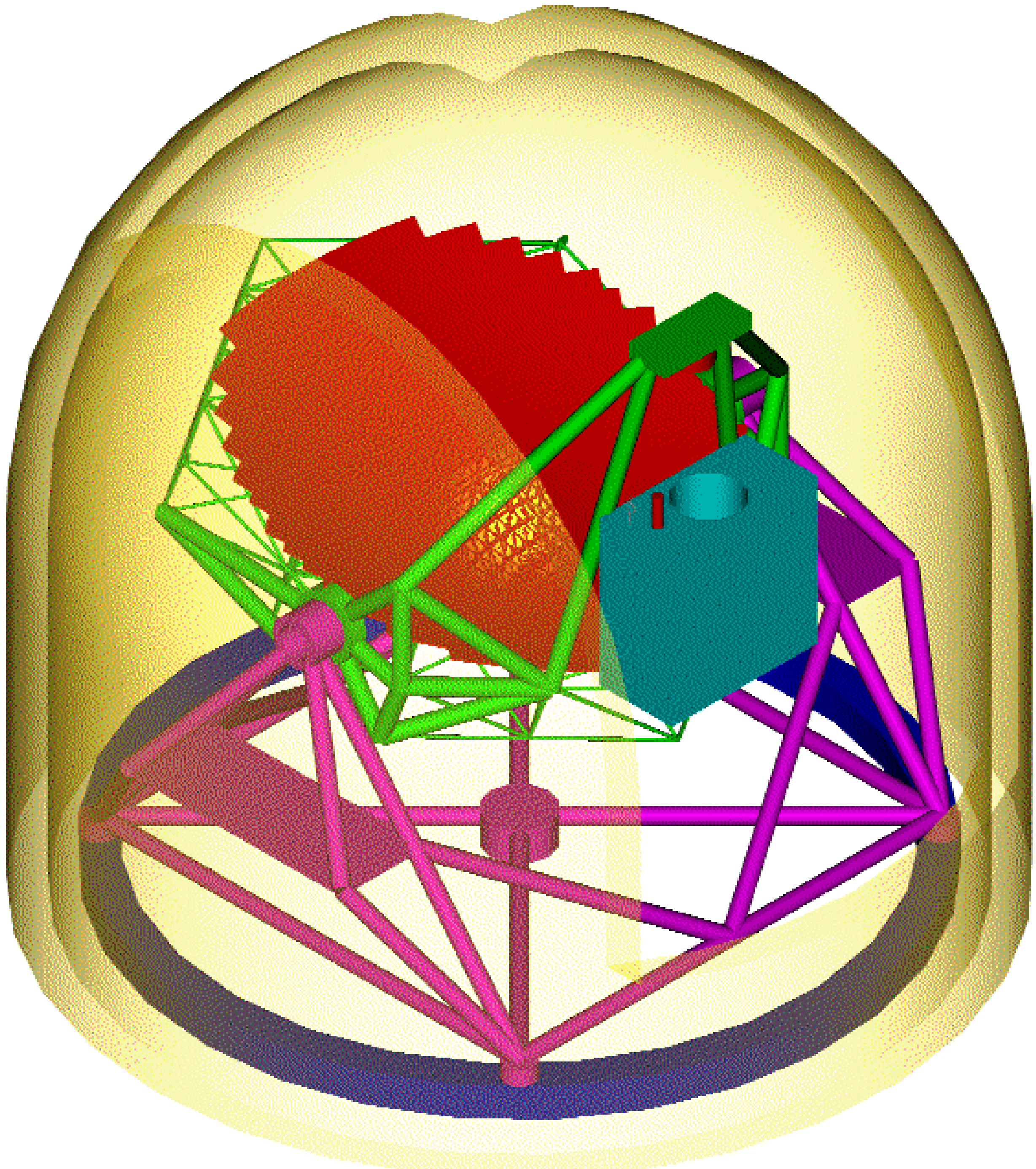


TABLE I: . FINITE ELEMENT ANALYSIS SUMMARY FOR REPRESENTATIVE LOAD CASES.

Case	Path Change	Path Error	Pointing Change	Pointing Error	½ WFE	½ WFE after fit
1 Gravity, zenith	494.0	-2.1	0.5	0.6	15.2	9.5
2 Gravity, horizon	-11.1	-7.2	9.1	16.2	21.5	7.2
3 Wind, zen., X-axis	0.0	0.0	0.6	0.1	0.3	0.1
4 Wind, zen., Y-axis	0.1	0.0	1.1	0.1	0.3	0.1
5 Wind, hor., X axis	0.0	0.0	0.3	0.3	0.5	0.2
6 Wind, hor., Z axis	81.2	3.3	2.7	0.0	3.7	1.2
7 Temp., zen., uniform 10 C	-348.0	-29.0	0.0	0.3	6.0	0.7
8 Temp., hor., uniform 10 C	382.0	-15.1	8.3	0.0	6.3	2.0
9 Temp., hor., dT/dX=1C/m	0.0	0.0	1.0	0.1	0.4	0.3
10 Temp., hor., dT/dY=1C/m	93.3	-4.0	0.7	0.4	5.0	0.5
11 Temp., hor., $T(R)=.2R[m]^2$	111.0	-3.9	2.2	0.0	5.0	0.4
12 Temp., zen., meas. [**Error! Bookmark not defined.**]	2.2	0.7	1.1	0.1	1.5	0.6

TABLE I: SURFACE ERROR BUDGET

	Effective surface error [μm]
Backing structure	
Gravity (ideal)	6
Gravity (departure from ideal)	3
Absolute temperature	6
Temperature gradient	5
Wind	4
Subtotal	**11.0**
Panel and supports	
Manufacturing	10
Absolute temperature	4
Temperature gradient	4
Gravity	5
Wind	5
Aging	3
Panel location in plane	2
Panel adjustment perpendicular to plane	3
Subtotal	**14.0**
Secondary mirror	
Manufacturing	5
Absolute temperature	2
Temperature gradient	2
Gravity	2
Wind	2
Aging	2
Alignment	5
Subtotal	**8.4**
Surface setting (holography)	
all contributions	10
Subtotal	**10.0**
Total (rss)	**22.1**

TABLE I: POINTING ERROR BUDGET

	Pointing error [arcsec]
Gravity (departure from ideal)	0.1
Wind	0.3
Absolute temperature	0.3
Temperature gradient	0.4
Encoders (24-bit)	0.1
Metrology (tiltmeters and gap sensors)	0.1
Reference structure (bearing slop and friction)	0.1
Total	**0.6**

Simple FEA

- Weight
  - Tipping weight 510,000kgm
  - Glass 150,000kgm
- Deflection of 250um p-p
- Remove glass => 176um p-p
- RMS => ~40um
- Improved homology expect => ~20um

Main issues

- Performance
  - Collecting area
  - Surface error
  - Pointing
  - Detector loading/Tsys
    - Scattering
    - Emission
  - Beam
    - Sidelobes
    - Polarization purity
- Cost
  - Design
  - Construction
  - Operations