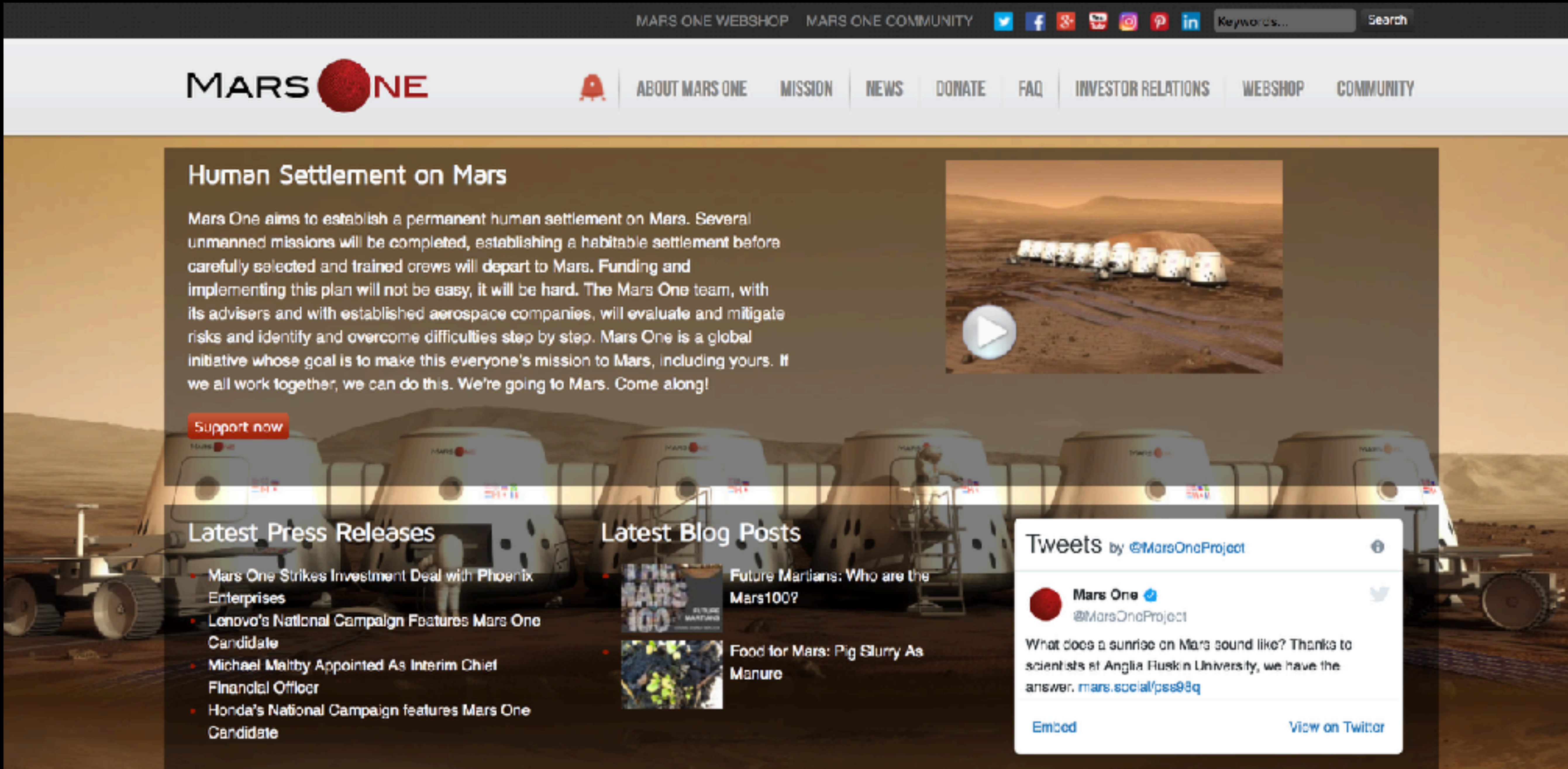


Reality TV [edit]

A proposed global reality-TV show was intended to provide funds to finance the expedition, however, no such television show has emerged and no contracts have been signed. The astronaut selection process (with some public participation) was to be televised and continue on through the first years of living on Mars.[88][89]

HDTV From Mars

- What would it take to send HDTV from Mars?
- What bit rate do we need?
- How much information can we transmit across a noisy channel?
- What would we listen with on Earth?
- What would it take to transmit from Mars?

HDTV Bandwith

- “standard” HDTV 1080p is 1080 by 1920 pixels
- 8-12 bits per color per pixel (*3 colors)
- 24-60 frames/s
- Total rate: 1080*1920*8*3*24=1.2 Gb/s
- But, things get compressed…

Netflix Recommended Speeds

Internet Connection Speed Recommendations

Below are the internet download speed recommendations per stream for playing TV shows and movies through Netflix.

- 0.5 Megabits per second - Required broadband connection speed
- 1.5 Megabits per second - Recommended broadband connection speed
- 3.0 Megabits per second - Recommended for SD quality
- 5.0 Megabits per second - Recommended for HD quality
- 25 Megabits per second - Recommended for Ultra HD quality

Compression factor ~50 typical.
So, let’s go for 25 megabits/s

Bit rate/noise scaling

- For fixed bandwidth B, how many bits/s can I send?
- Take high-SNR case first. Say signal level was 8 times noise level. Could send (0,1,..7) each 1/B time period. Takes 3 bits to specify 0..7.
- In high SNR limit, bit rate is $B*\log_2(S/N)$
- This is why wifi bandwidth drops w/distance to router.
- Of course, Mars communications may not be high SNR

Various Theorems

- Noisy-channel coding theorem (Shannon). Communications channels have some capacity. If we're smart enough, we can error-correct to get arbitrarily close to that capacity.

- Shannon-Hartley theorem: for Gaussian noise, that capacity is $B*\log_2(1+S/N)$ where B is bandwidth, S is signal power, N is noise power.

Power/Bandwith Scaling

- Let's fix information content rate r we need to send, and background noise power N (in e.g. Watts/Hz.)
- At fixed SNR, total power=B*S=B*N*SNR
- $r=B\log_2(1+SNR)$, $SNR=2^{(r/B)}-1$. Power=$BN(2^{(r/B)}-1)$
- For r>B, power requirement scales exponentially!
- For r<<B, $2^{(r/B)}=e^{(\log(2)r/B)}\sim 1+\log(2)r/B$.
- Power=$BN(1+\log(2)r/B-1)=\log(2)rN$
- High noise needs high power. High rate needs high power. More bandwidth doesn't help, as long as we have enough.


MARS STATION
NASA
JPL
Jet Propulsion Laboratory
The Mars Station is the site of the largest antenna at the Goldstone Complex, a 70-meter (230 ft) diameter antenna that dwarfs its surrounding support buildings. Originally built as a 64-meter antenna in 1966, it was expanded to 70 meters in 1988 in support of the Voyager missions. The total structure stands approximately 24 stories high and weighs 7.2 million kilograms (16 million pounds). The rotation portion, which weighs nearly 4 million kilograms (8.4 million pounds), floats and moves on a thin film of hydraulic oil about 25 millimeters (.010 inch) thick. Despite its size, the antenna with its complex electronic equipment and unique mechanical systems, is a precision instrument capable of communicating with spacecraft at the edge of the solar system and beyond into interstellar space. Though this antenna was the first of its size to be built as part of NASA's Deep Space Network, identical antennas were later built in Spain and Australia. Besides being used to support deep space missions, the high gain and multiple frequency capability of this antenna makes it an extremely valuable tool for radio astronomy and radar experiments.

Table 2-2. DSN Goldstone large ground antennas downlink performance for 25-percent weather and zenith antenna-pointing elevation angle.

Antenna	Freq. Band	Gain (dBi)	Noise Temp. (K)	G/T (dB)	HPBW (deg)
34-m BWG	S	56.8	36.8	41.1	0.23
	X	68.0	33.0	52.9	0.063
	Ka	78.5	31.0	63.6	0.017
34-m HEF	S	56.0	38.0	40.2	0.23
	X	68.1	19.8	55.1	0.063
	Ka	NA	NA	NA	NA
70-m	S	63.4	22.0	50.0	0.11
	X	74.4	20.6	61.3	0.031
	Ka	NA	NA	NA	NA

Aside: Radio Bands

Standard Radar Frequency Letter-Band Nomenclature(IEEE Standard 521-2002)		
Band Designator	Frequency (GHz)	Wavelength in Free Space (centimeters)
HF	0.003 to 0.030	10000 to 1000
VHF	0.030 to 0.300	1000 to 100
UHF	0.300 to 1	100 to 30.0
L band	1 to 2	30.0 to 15.0
S band	2 to 4	15 to 7.5
C band	4 to 8	7.5 to 3.8
X band	8 to 12	3.8 to 2.5
Ku band	12 to 18	2.5 to 1.7
K band	18 to 27	1.7 to 1.1
Ka band	27 to 40	1.1 to 0.75
V band	40 to 75	0.75 to 0.40
W band	75 to 110	0.40 to 0.27
mm	110 to 300	0.27 to 0.10

- Supposedly picked during WW2 to be maximally confusing in case of spies.

K-band Requirements

- Let's say 500 MHz of bandwidth. SNR required is log(2)25/500 = 0.035.
- T_{sys}=31K. So, T_{signal}=0.035*31=1.1K.
- How many Jy is that?
- g(34m)=A_{eff}/2k, A_{eff}~0.7*πr^2~6.3e6 cm^2.
  g~6.3e6/2*1.36e-16=2.3e22=0.23 K/Jy
- 1.1K/.23K/Jy=5Jy over 500 MHz
- power rate at Earth=5e-23*500e6=2.5e-14 erg/cm^2/s=2.5e-17 W/m^2/s

Transmitting Requirements

- Mars is 228 million km from sun. Take as typical Earth-Mars distance (sometimes closer, sometimes further)
- Isotropic power requirement $2.5e\text{-}17 * 4\pi(228e6*1000)^2$=16 MW. Probably won't have 16 MW transmitter on Mars…
- Most signal being sent out into space. Why not send towards Earth?

MRO

- Mars Reconnaissance Orbiter transmits signals from e.g. rovers back to Earth. Has antennas/transmitters for this.

Antennas

High-gain Antenna

The high-gain antenna is a 3 meter- (10 foot-) diameter dish antenna for sending and receiving data at high rates.

The high-gain antenna was deployed shortly after launch (see launch configuration), and will remain deployed for the remainder of the mission. It serves as the primary means of communication to and from the orbiter.

The high-gain antenna must be pointed accurately and is therefore steered using the gimbal mechanism.

Amplifiers

Located on the back side of the high-gain antenna is the enclosure for the Traveling Wave Tube Amplifiers, which boost the power of the spacecraft's radio signals so they are strong enough to be detected by the Deep Space Network antennas. Mars Reconnaissance Orbiter has three amplifiers on board:

- two for the X-band radio frequency that transmit radio signals at a power of 100 watts (the second one is a backup to provide communications if the first one fails)
- one for the Ka-band radio frequency that is capable of transmitting at 35 watts.

MRO Beam Size

- X-band, wavelength is 3 cm. Ka, wavelength is 1 cm.
- Beam radius ($1.22\lambda/D$) $\sim 2.5\lambda/D$. Solid angle $\sim 1.5\pi\lambda^2/D^2$. Fraction of sphere is solid angle/$4\pi \sim 0.35(\lambda/D)^2$. $A_{dish}=\pi(D/2)^2$ so fraction of sky covered scales like dish area in wavelengths.
- Dish diameter is 100λ (X-band)/300λ (Ka-band), so fraction of sky covered by beam is 3.5e-5/4e-6.
- HD power requirements are then 16 MW*(3.5e-5/4e-6) =500/65W.
- Factor of a few away - would need to build a larger telescope and/or higher power transmitter.
- We've also been a bit optimistic…

With its large-dish antenna, powerful amplifier, and fast computer, Mars Reconnaissance Orbiter can transmit data to Earth at rates as high as 6 megabits per second, a rate 10 times higher than previous Mars orbiters. This rate is quite high considering that Mars Reconnaissance Orbiter achieves it while 100 million kilometers (62 million miles) from Earth. The spacecraft has already provided more than 50 Terabits -- that's 50 million million bits. To put it another way, that's more than all the data transmitted by all previous JPL spacecraft put together!

The orbiter's radio operates in the X-band of the radio spectrum, at a frequency of around 8 gigahertz. That means that the electromagnetic

- At 100e6 km, we would have guessed ~100W at X-band to get 25 Mb/s, they get 6 in practice, so we've been a factor of a few optimistic.

Final Requirements

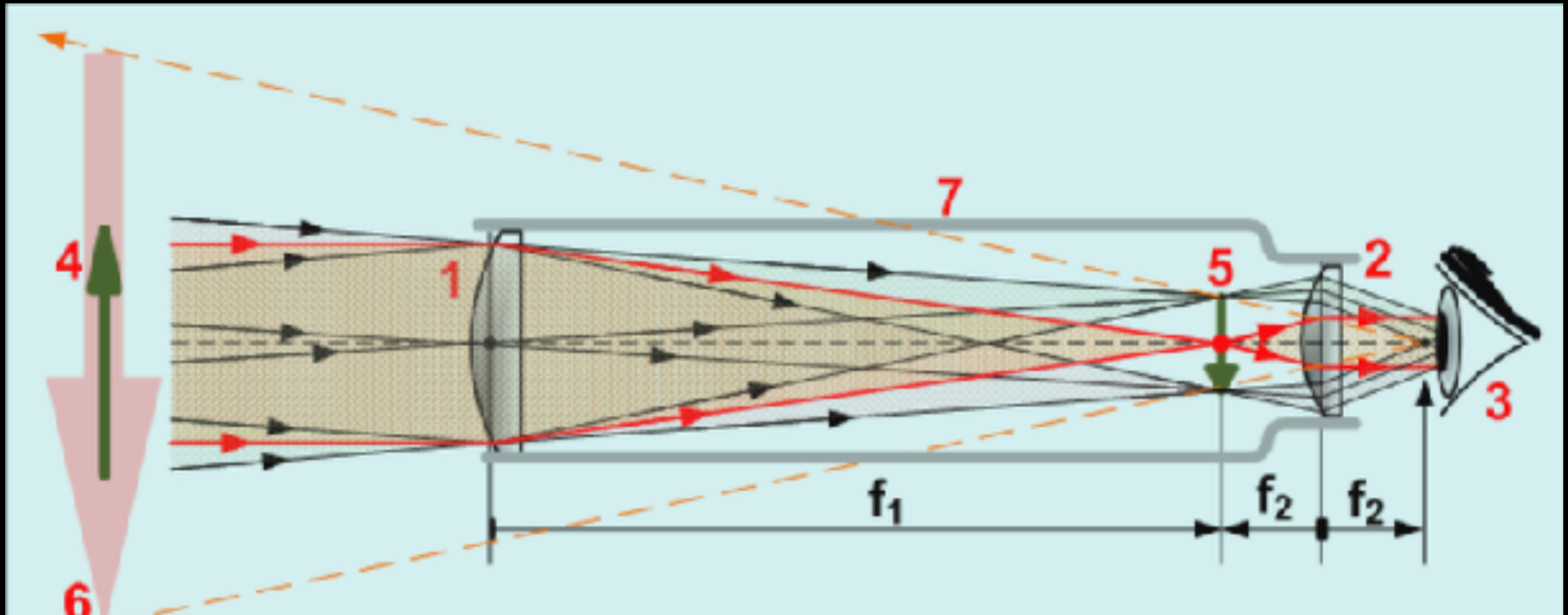
- Typical distance w/ current setup is ~1 megabit.
- So, build 25 MROs. Or build antenna with 25 times area/ 5 times radius=15m. Or build higher-power transmitter.
- On Earth, build larger dishes - gain goes like area as well, so 34m -> 170m would also work. But, need 3 to always see Mars. Lower noise would help as well.
- Current DSN: “By this measure, a 1-K reduction at X-band throughout the DSN is worth about $91M” by the time construction, operations costs added together.

New Horizon

- Pluto flyby has 2.1m antenna, 12W transmitter. d=40 AU
- Bit rate vs. mars=$(2.1/3)^2*(12/100)*(0.7/40)^2*6$ mbit=100 bits/s. They claim 1 kbit, so probably using Ka-band, not X-band.
- Total data “stored on a pair of 32-Gbit hard drives” - 64e9/1000=6.4e7 ~2 years to send back the data.
- This is why Pluto data took so long to get back.
- Also why a lot of image compression done by Galileo after high-gain (large) antenna failed to open.

Optical Telescopes

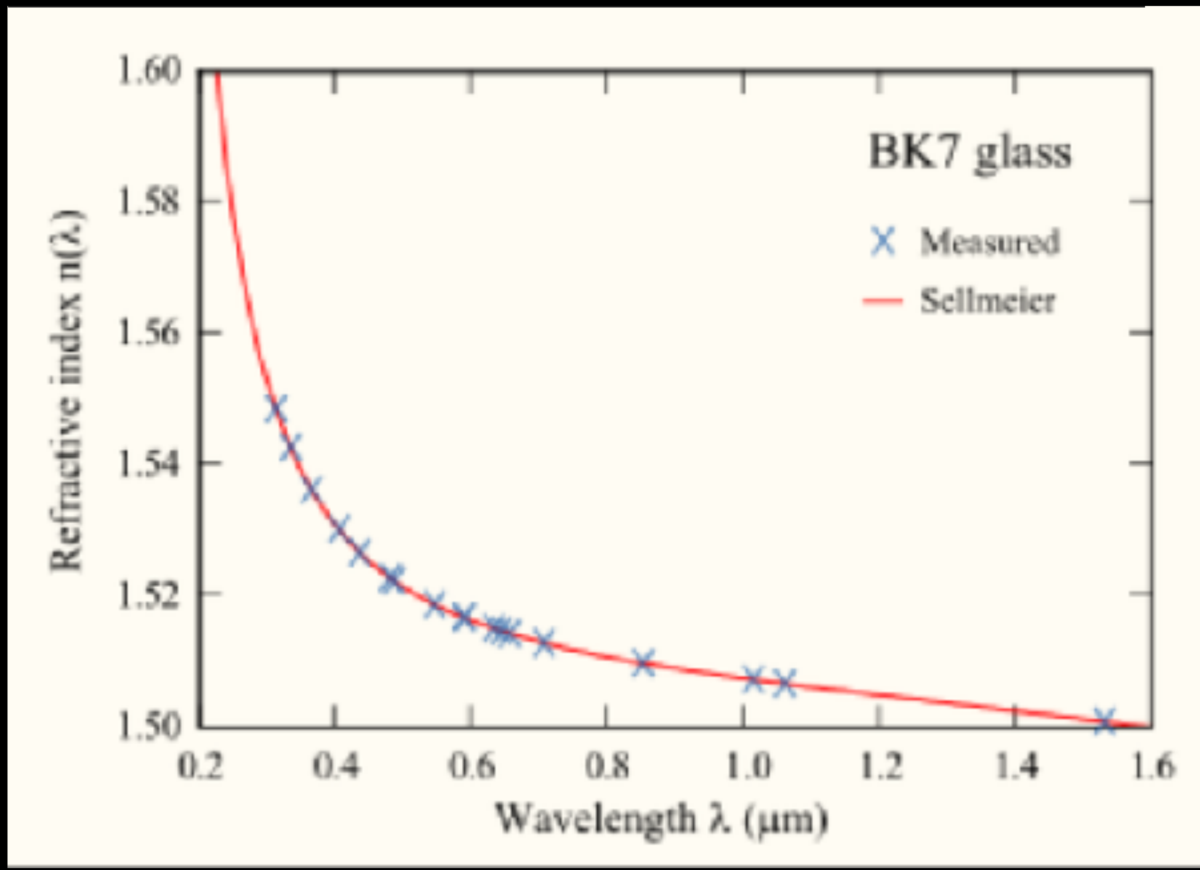
- Telescopes invented in early 1600s in Netherlands (by spectacle makers). Galileo heard, made his own, first to look upwards.
- Old telescopes were refractors - used (glass) lenses to bend light. Not ideal…



Schematic of **Keplerian** refracting telescope.

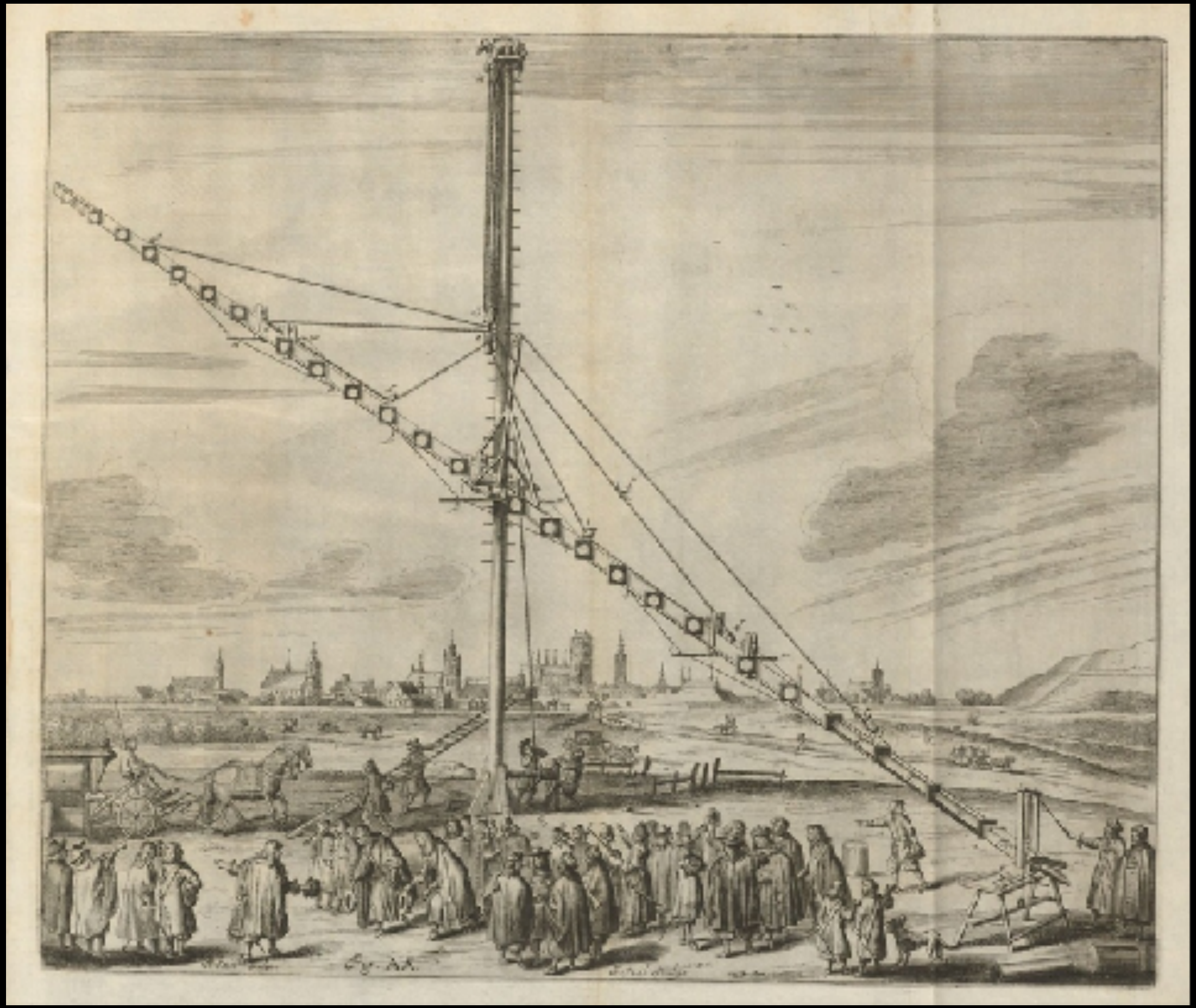
Aberrations

- Refractors not great. Glass bends different wavelengths differently. (Achromatic/ apochromatic get around with multiple kinds of glass)
- Different incoming angles go through different glass thickness, leads to spherical aberration.

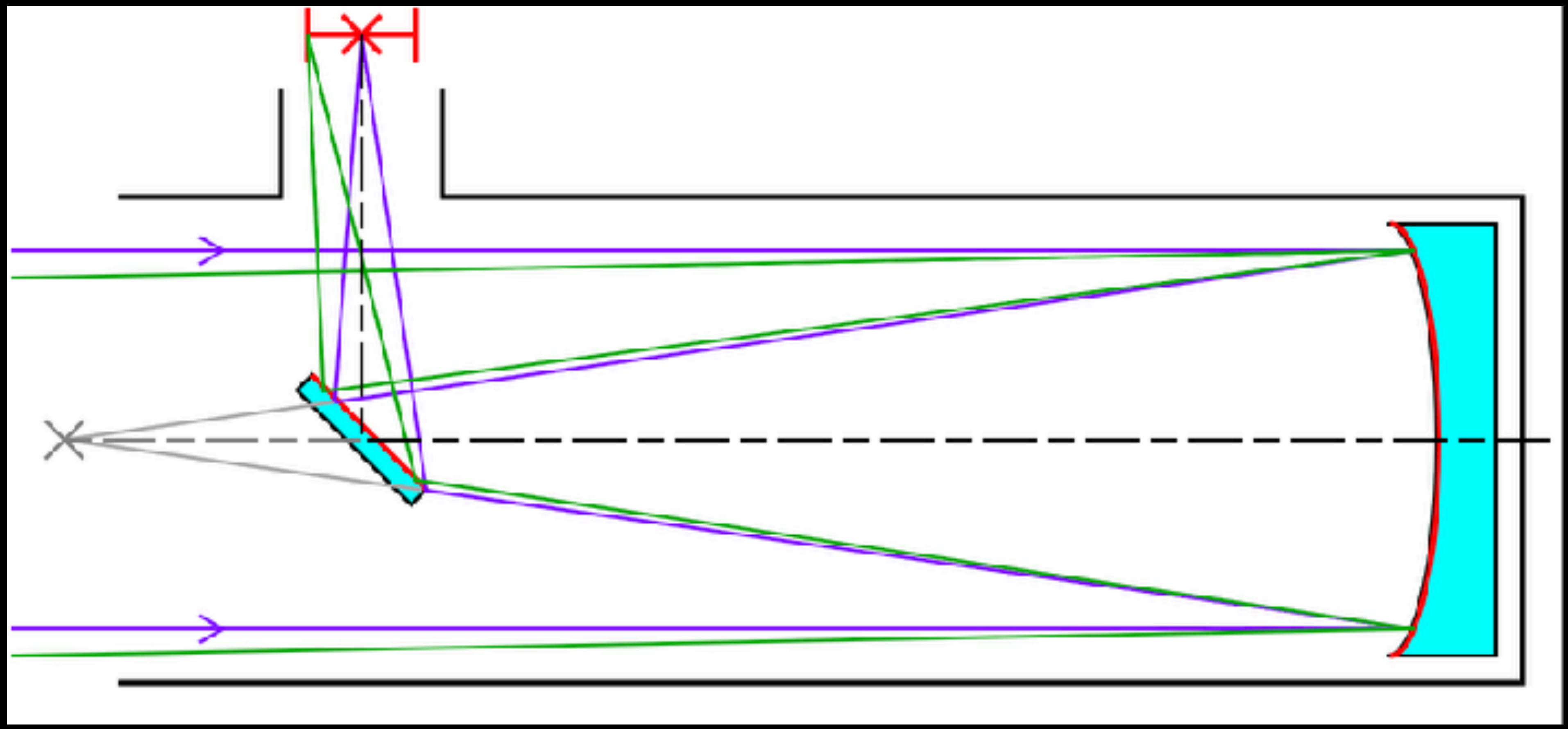


Early Refractors

- Long telescopes bend light less - smaller differences across FOV.
- Early refractors got ludicrously long…
- Right: 45m focal length telescope from 1673
- This was not sustainable…



Reflecting Telescopes



- Newton invented the reflecting telescope.
- Put a parabolic mirror (achromatic!), which will focus light.
- To avoid putting your head in front of mirror, use a diagonal pickoff mirror. and look at that.

Plate Scale

- If I put a camera at focus, what is the relation between position on the sky and position in the camera?
- Rays bouncing off center of dish would need to go to center of beam. So, if I move an angle θ away from center of field, those rays would move an angle of θ in the opposite direction.
- Dish is in focus at focal length f, so linear distance moved is $f\theta$.
- Palomar 200 inch has focal length of 55.5 feet. Keck has focal length of 57 feed. How big should my CCD pixels be?
- Could I use an iPhone camera? (12 megapixels)

Plate Scale

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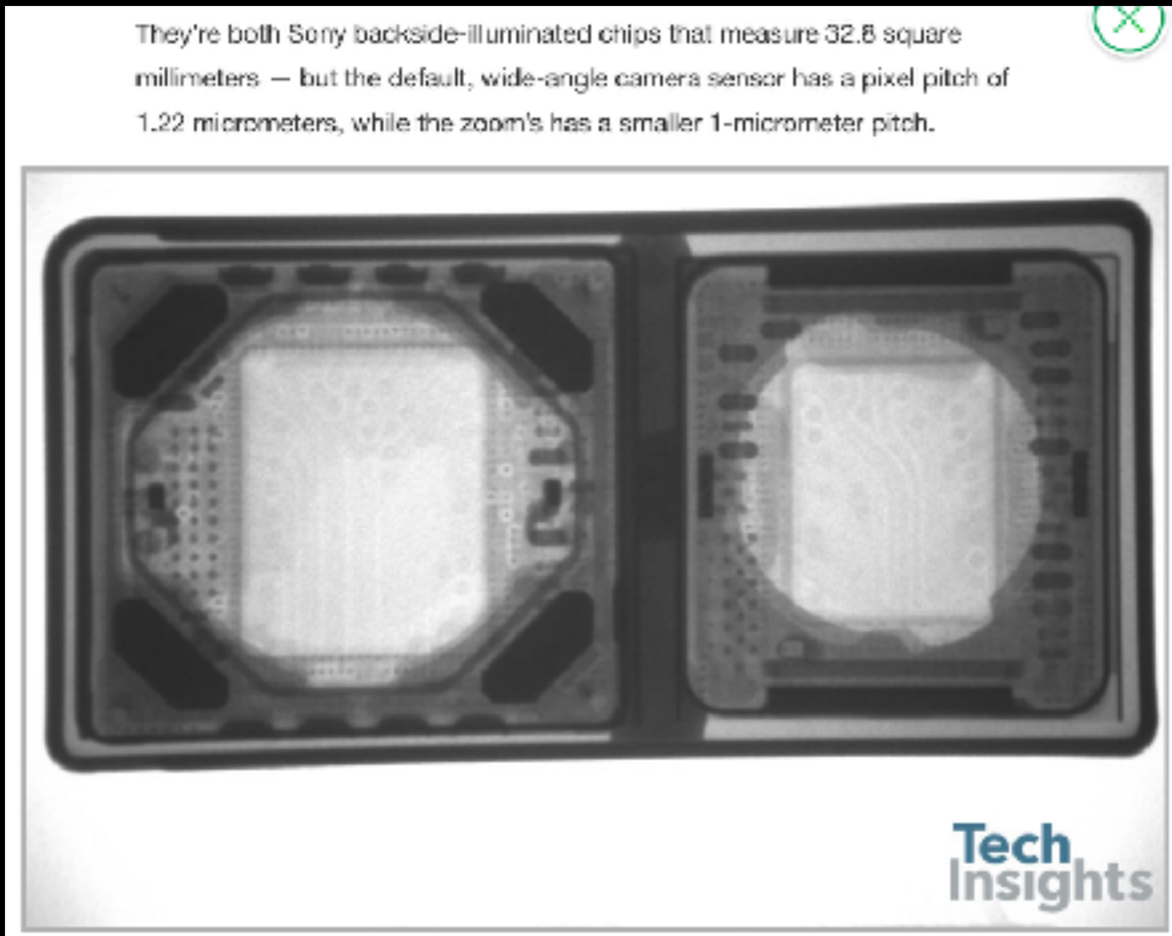
- Rays bouncing off center of dish would need to go to center of beam. So, if I move an angle θ away from center of field, those rays would move an angle of θ in the opposite direction.
- Dish is in focus at focal length *f*, so linear distance moved is *f*θ.
- Palomar 200 inch has focal length of 55.5 feet. Keck has focal length of 57 feed. How big should my CCD pixels be?
  - Best seeing ~0.5". Want to Nyquist sample, so is θ of 1.2e-6 radians. *55.5 feet(=17000mm)=20 μm.
- Could I use an iphone camera? (12 megapixels)

Nope



- iPhone pixels way too small.
- SBIG camera has $16e6^*(0.009)^2$ mm^2=1296 mm^2, 40x area of iPhone.
- Big pixels also mean more light holding capacity, higher dynamic range…

Aberration

- If I move source off-axis, what happens?
- Light ray along center will stay in phase. Off-center changes, though.
- This will lead to out-of-phase errors, or smearing out of signal.

Phase Errors

```
import numpy as np
from matplotlib import pyplot as plt
#figure out how far away an off-axis source focuses, and what phase errors look like
D_dish=0.5
f_ratio=10
f=D_dish*f_ratio;
th_deg=0.5;th=th_deg*np.pi/180 #are we in focus at a distance of th_deg from center?

rdish=D_dish/2.0
a=0.25/f #equation for parabola
lamda=500e-9

x=np.linspace(-rdish,rdish,20)
d=np.linspace(0.95,1.05,100001)*f

dtot=np.zeros([len(d),len(x)])


xf=-d*np.sin(th)    #x/y coordinates of possible focal points
yf=d*np.cos(th)

for  i in range(len(x)):
    x0=x[i]
    y0=a*x0**2
    d1=-(np.cos(th)*y0+np.sin(th)*x0) #distance from infinity to dish
    d2=np.sqrt((yf-y0)**2+(xf-x0)**2) #distance from dish to focus

    dtot[:,i]=d1+d2


plt.ion();
plt.clf();
mystd=np.std(dtot,axis=1)
ii=np.argmin(mystd)
print 'min scatter at angle ',th_deg, ' degrees is ',mystd[ii]
print 'in wavelengths that is ',mystd[ii]/lamda
print 'distance from dish center of focus is ',d[ii]
plt.clf();plt.semilogy(d,mystd)
```

- As we go further off-axis, errors get bigger
- As dish gets bigger, errors get bigger
- As focal length gets bigger, errors get smaller.

Seeing.

- Stars twinkle. Phase is changing across mirror.
- Twinkle time ~5 ms.
- Atmosphere height ~10 km (scale height)
- Wind velocities ~10 m/s
- What does this tell us about ground-based resolution?
- Isoplanatic patch - phase constant across region. Typical size ~wind velocity times coherence time ~10 cm
- Ground-based resolution ~1”.

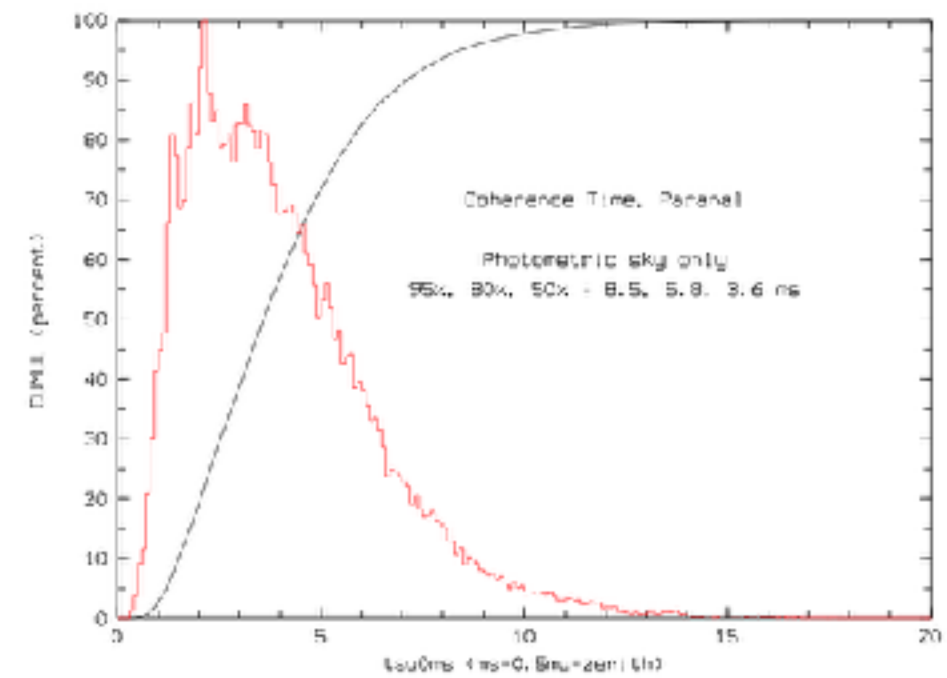
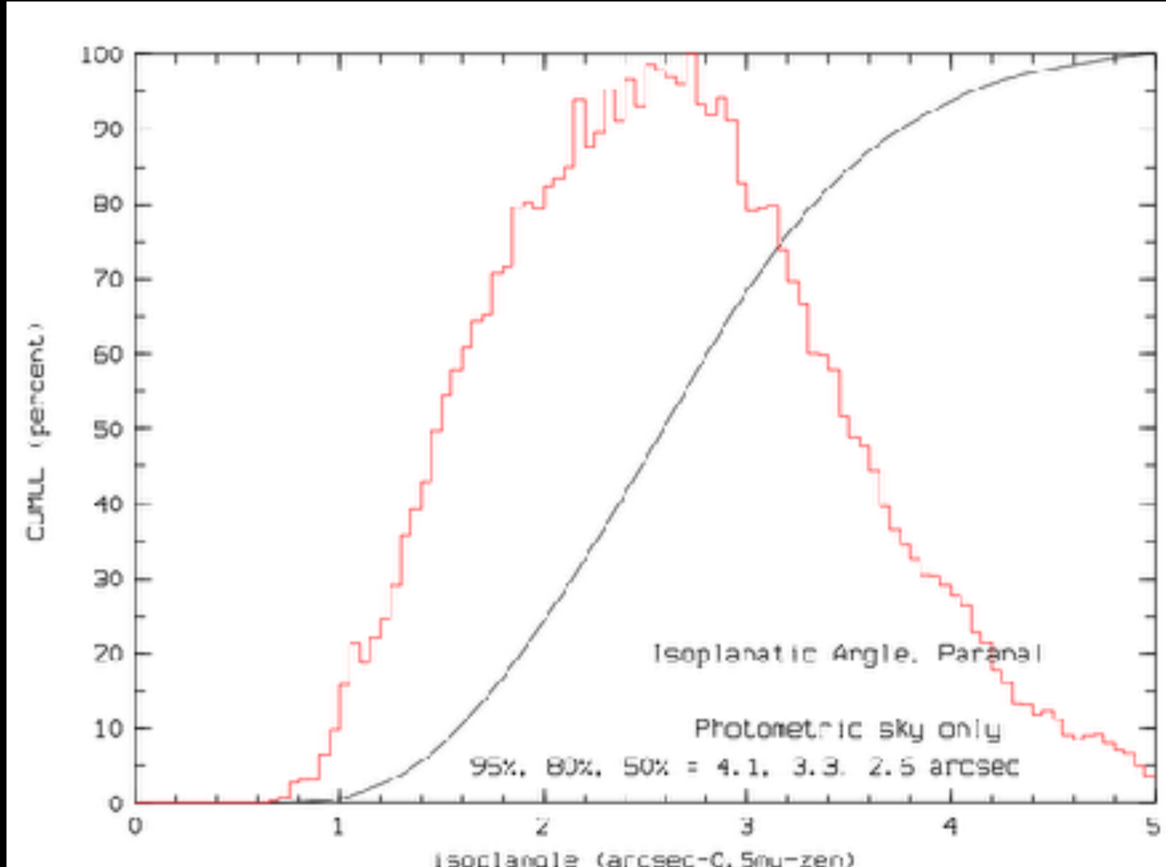


Figure 6. Statistics of the coherence time τ_0 at Cerro Paranal for the year 2000 (ms at 0.5 μm at zenith).



Resolution of Telescope

- HST has 2.4m primary. Optical wavelengths ~500 nm. Resolution ~$1.22\lambda/D = 0.05''$.
-