~~The Taiwanese-American Occultation Survey~~

The Trans-neptunian Automated Occultation Survey (TAOS II)

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ASIAA

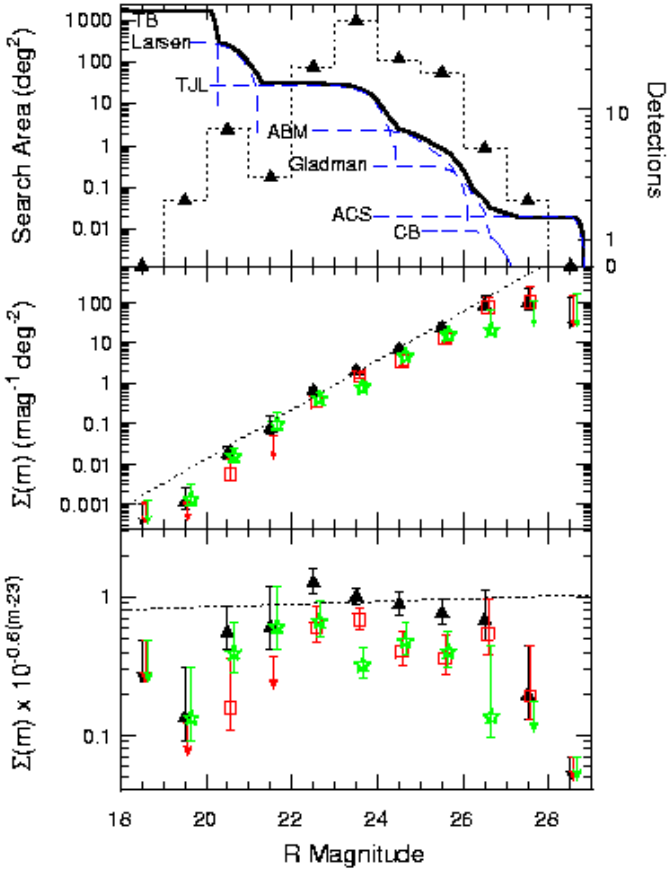
The TAOS II Partners:

Academia Sinica Institute of Astronomy and Astrophysics

Universidad Nacional Autónoma de México

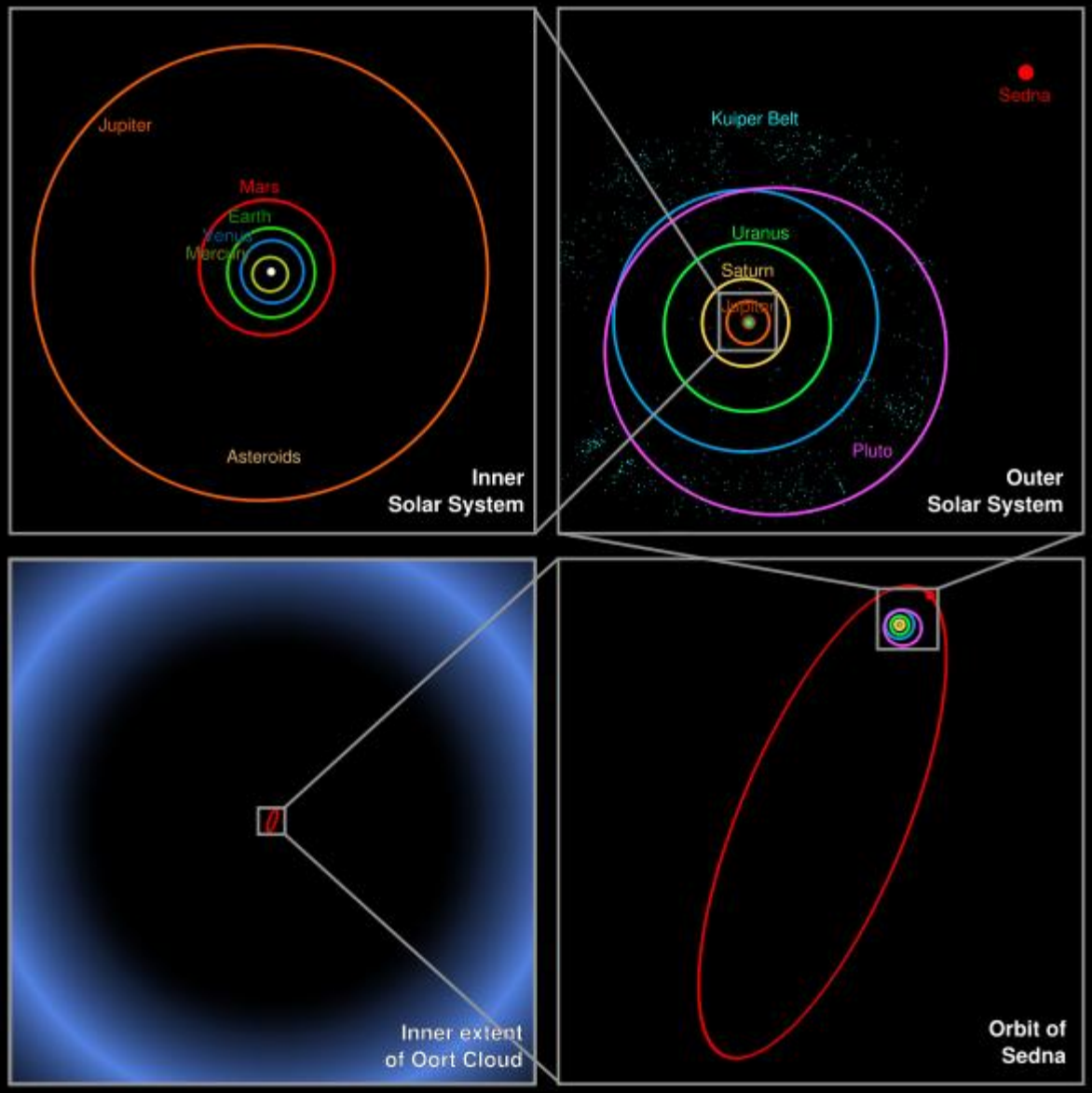
Harvard-Smithsonian Center for Astrophysics

Size Distribution of Kuiper Belt

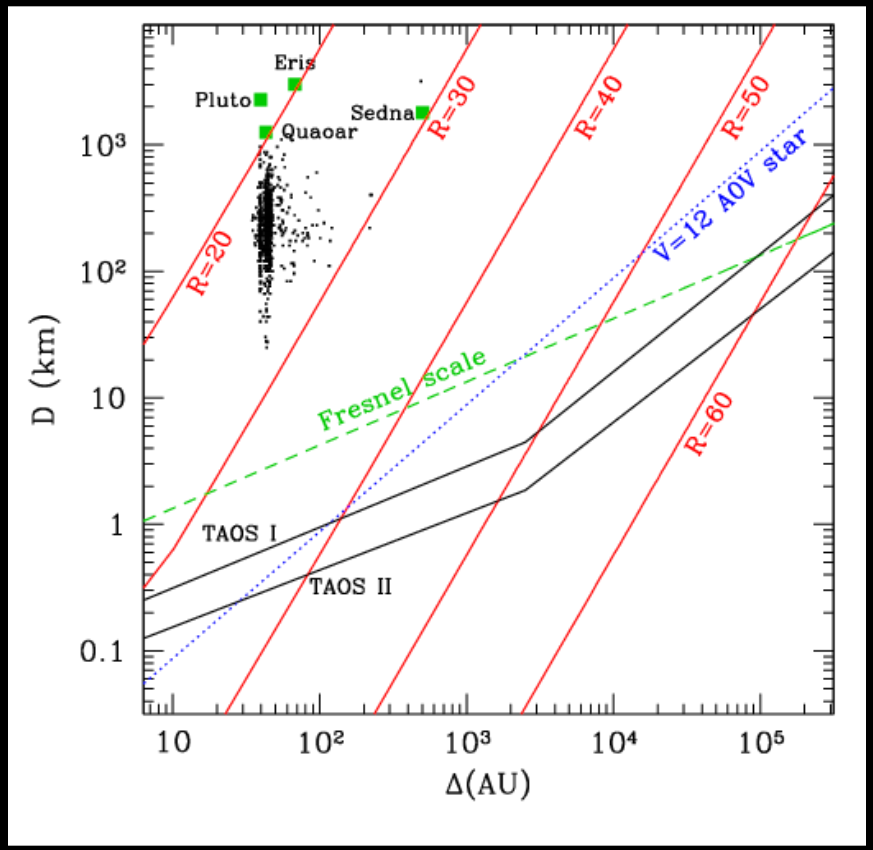


Bernstein et al. (2004)

Beyond the Kuiper Belt



Why attempt an occultation survey?



- Direct searches well-suited to objects larger than R ~30 km
- Occultations of bright stars can reveal smaller and/or more distant objects
- No orbital information
  - Can measure inclination distribution if enough events.

Occultation Events

Fresnel Scale:

$$F = \sqrt{\lambda \Delta / 2}$$

F = 1.5 km at 43 AU

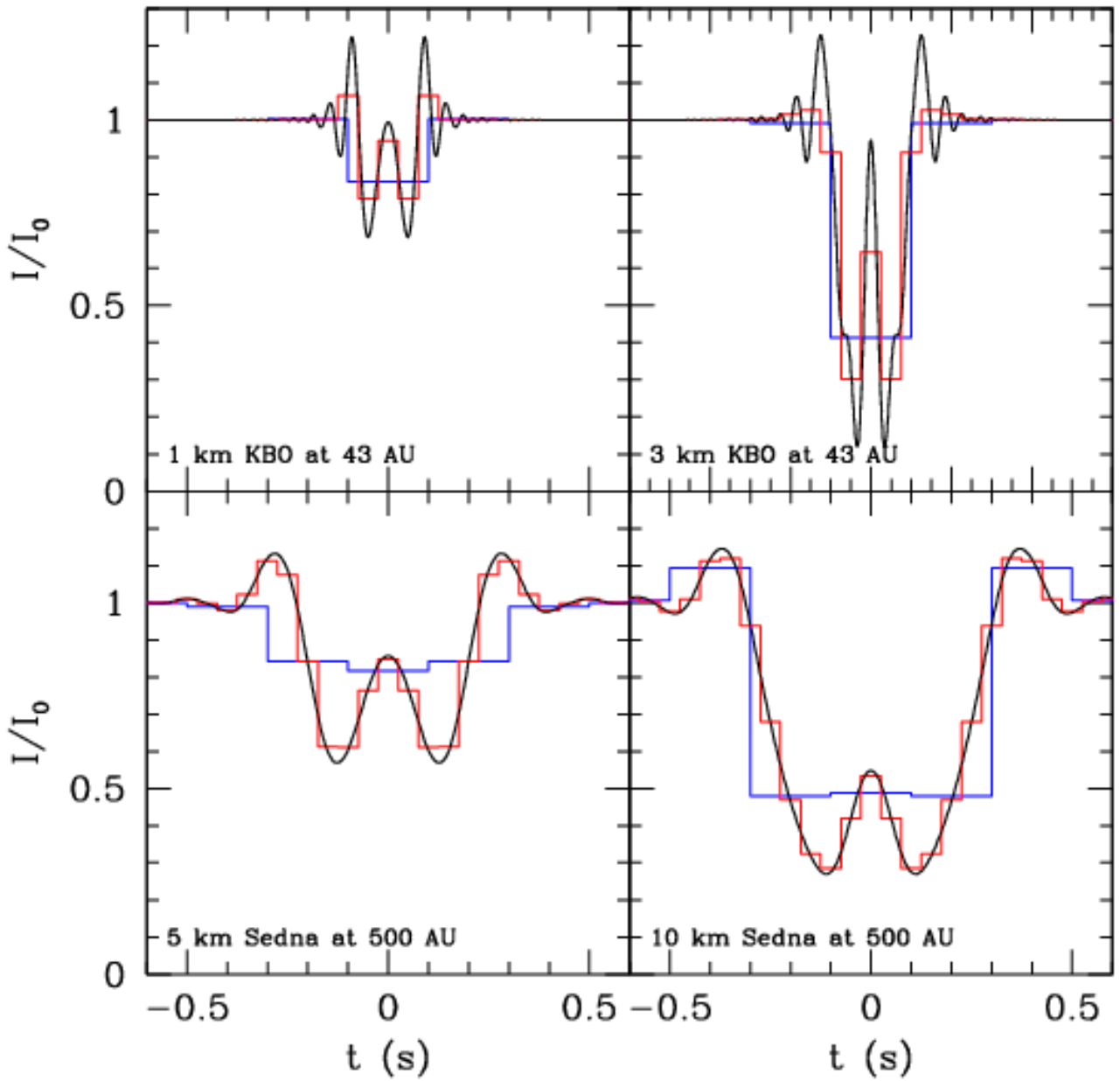
Minimum event width:

$$W = 2\sqrt{3}F$$

Objects in relative motion,

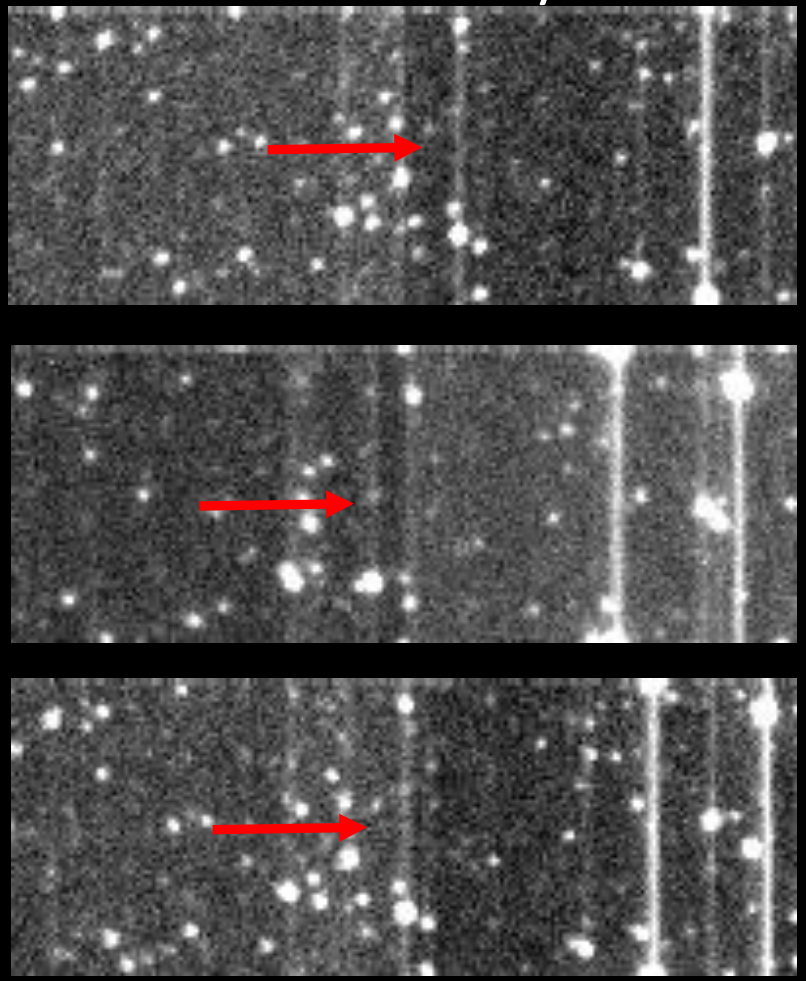
$v \sim$ 25 km/sec

Event timescale ~200ms!


1 km KBO at 43 AU
3 km KBO at 43 AU
5 km Sedna at 500 AU
10 km Sedna at 500 AU
I/I0
1
0.5
0
−0.5
0
0.5
t (s)

TAOS I

Occultation by (286) Iclea
2006 February 6



- Four 50cm telescopes at Lulin
- Strongest upper limits to data on D > 700m
- Bad weather
- Poor optical quality of telescopes
- Number of stars limited
- Not sensitive enough to measure expected surface density

TAOS II

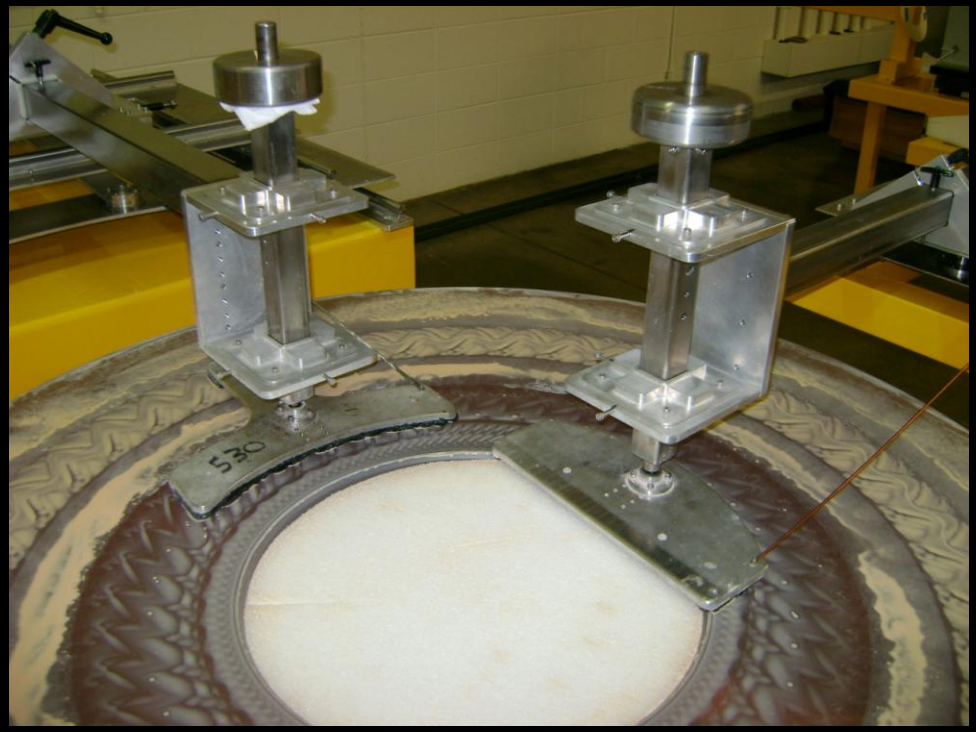
- Next generation occultation survey
- Design Goal: 100 times the event rate of TAOS I
- Better site (more data)
- Better telescopes (higher SNR)
- 20 Hz sampling cadence (better temporal resolution)

A factor of 100

- 7 times more of observing time
  - 250 observable nights/yr
- 1-10 times higher event rate (model dep.)
  - 20 Hz sampling, higher S/N
  - smaller objects
- 20 times more stars monitored
  - R_{limit}= 16.5
  - 40 times higher SNR needed
    - Larger aperture
    - Better seeing & sampling

Telescopes

- 3 telescopes from DFM Engineering
- F/4 1.3m modified Richey Chretien
  - Single Schmidt corrector plate
- 1.7° FOV over 154 mm diameter
- <1 arcsec tracking error over 20 minutes
- 5 axis focus housing
- First delivery late 2012/early 2013



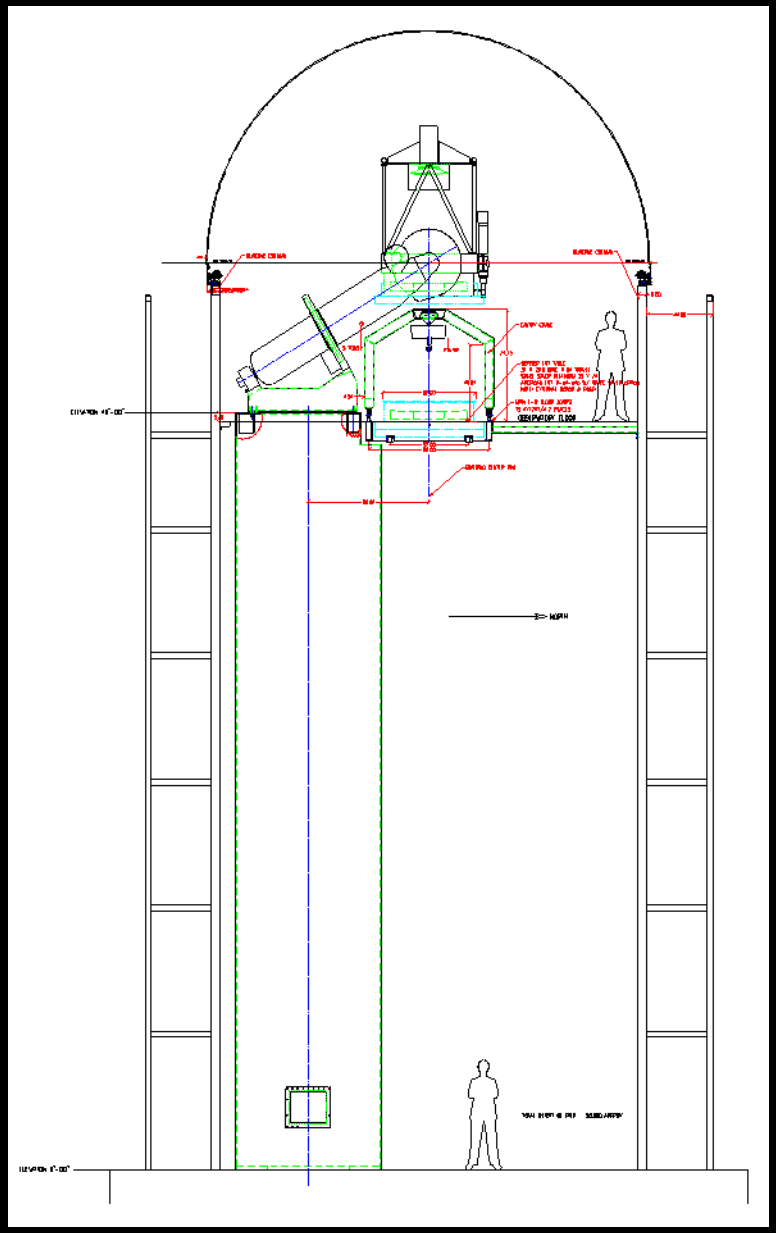
Telescope #1 Primary

USNO Telescope

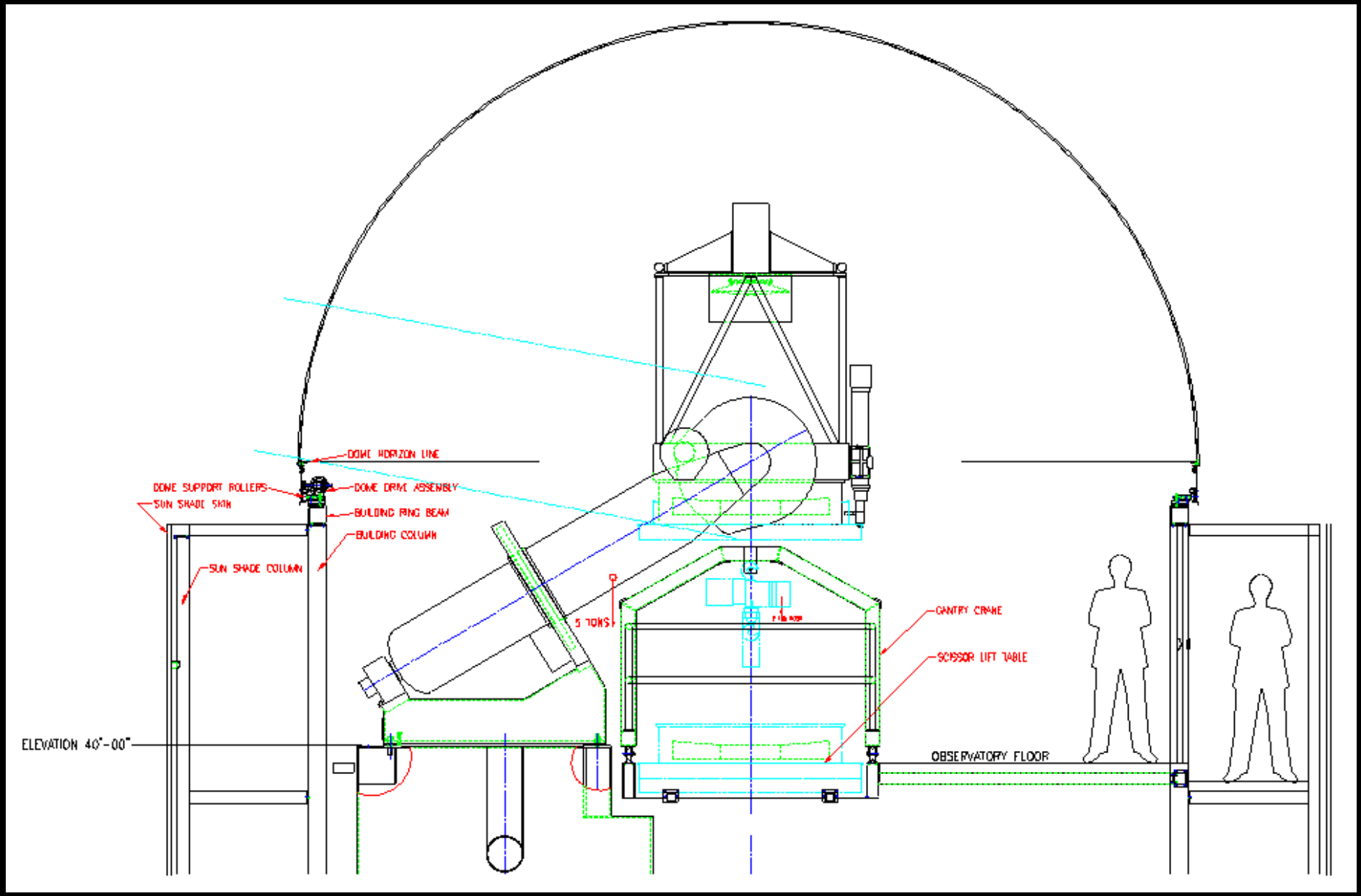
Telescope #1

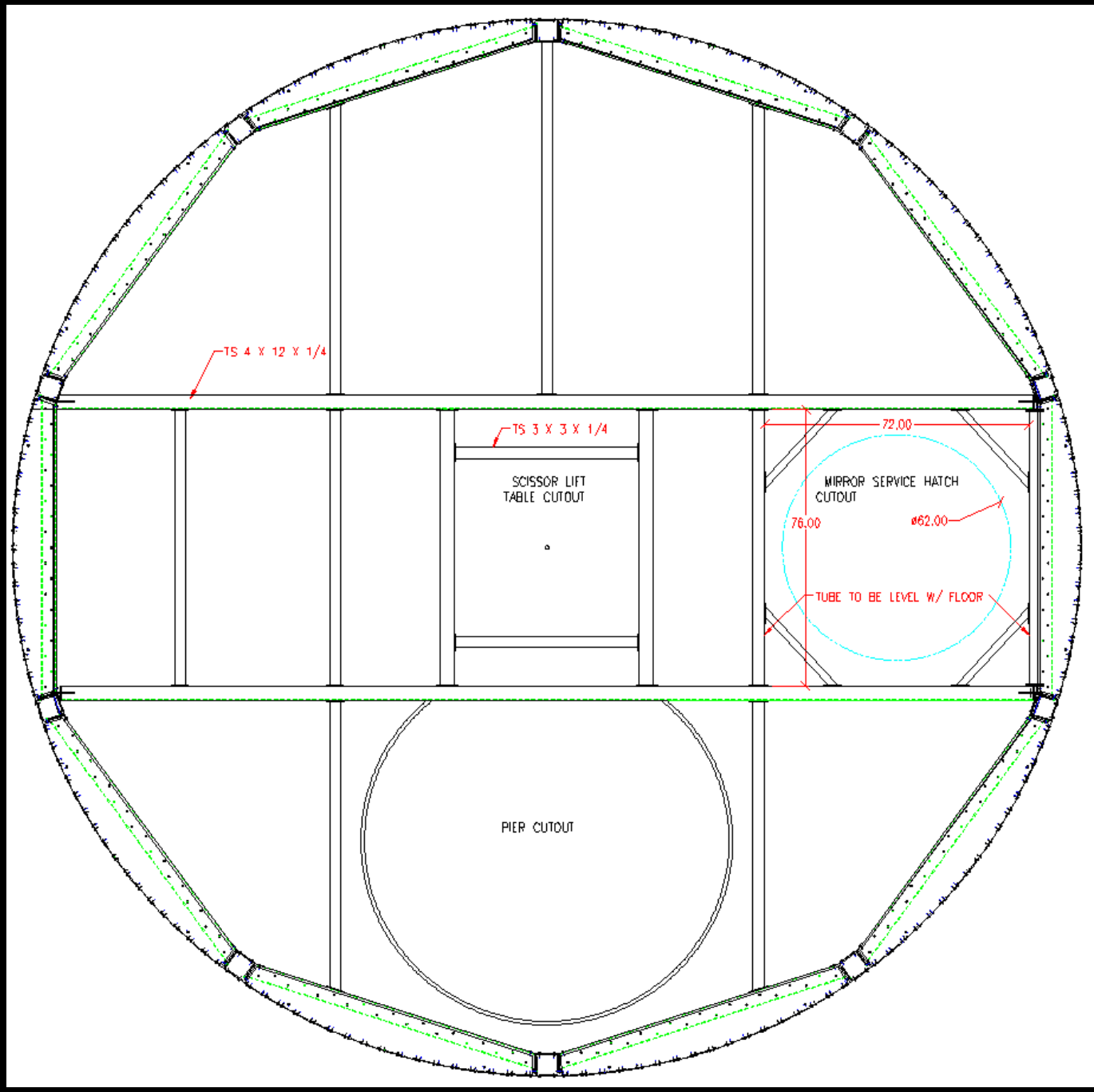
Dome #1

Enclosures



- Observing floor at 12m
- 8’ diameter steel pipe for pier
- Low thermal mass
- Separate electronics vault
- Passive cooling, sun shade
- 24’6” Ash dome
- Mirror handling

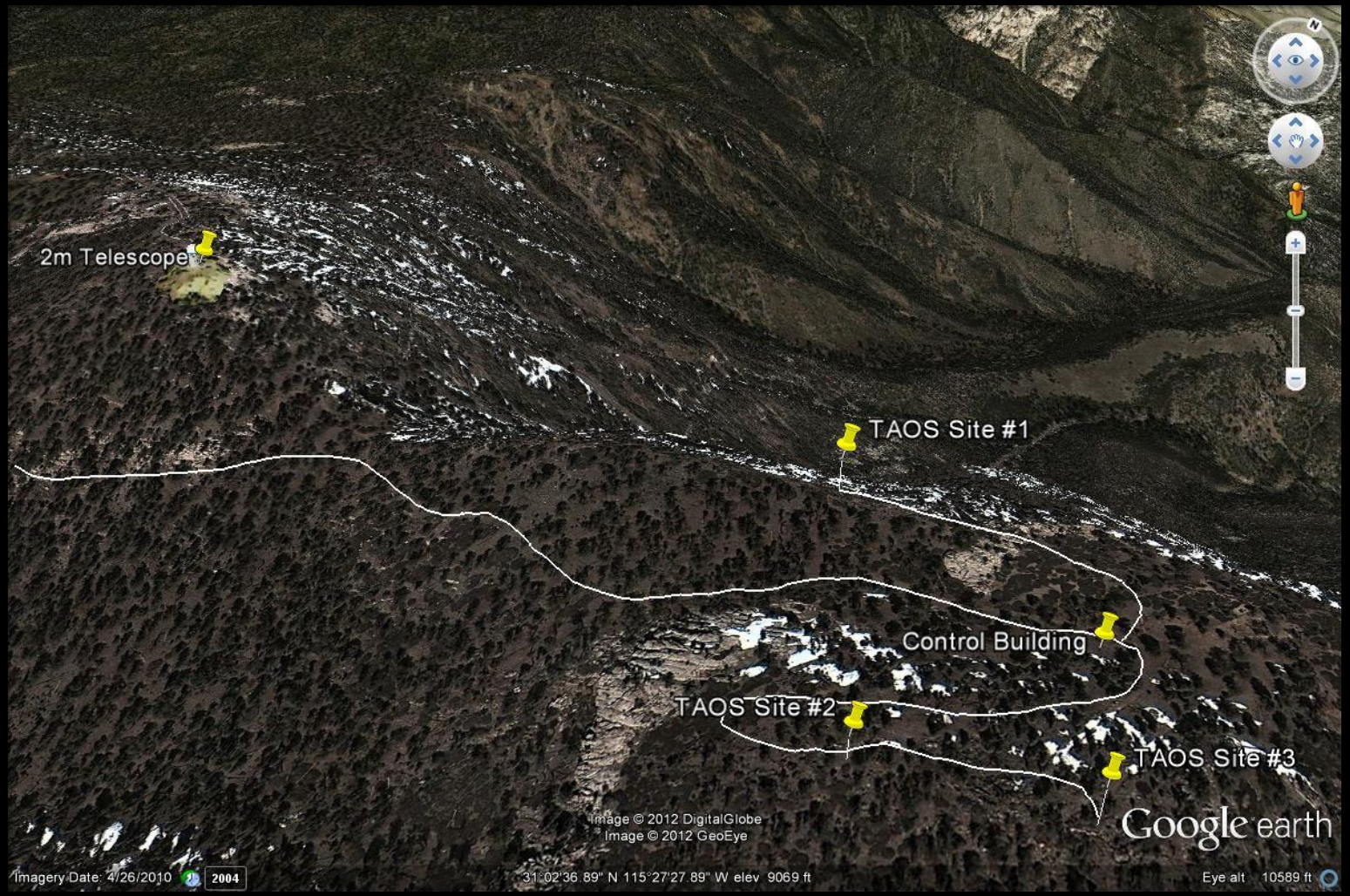

DOME HORIZON LINE
DOME SUPPORT ROLLERS
SUN SHADE SKIN
DOME DRIVE ASSEMBLY
BUILDING RING BEAM
BUILDING COLUMN
SUN SHADE COLUMN
5 TONS
GANTRY CRANE
SCISSOR LIFT TABLE
ELEVATION 40'-00"
OBSERVATORY FLOOR


TS 4 X 12 X 1/4
TS 3 X 3 X 1/4
SCISSOR LIFT
TABLE CUTOUT
72.00
MIRROR SERVICE HATCH
CUTOUT
76.00
ø62.00
TUBE TO BE LEVEL W/ FLOOR
PIER CUTOUT

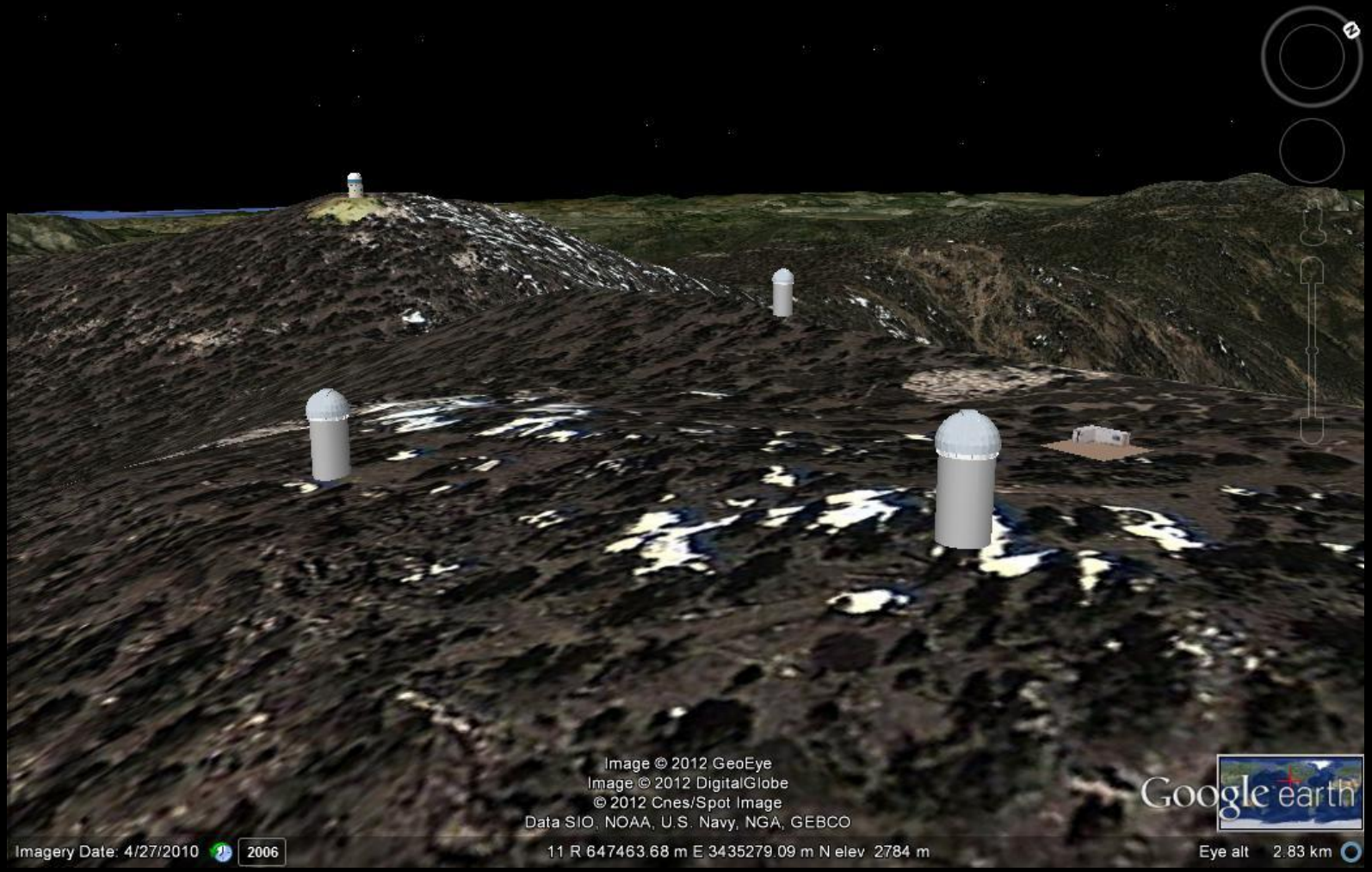
TAOS II Site

- High quality astronomical site needed
- >250 clear nights per year
- <1” median seeing
- large baseline (>100 m)

San Pedro Mártir



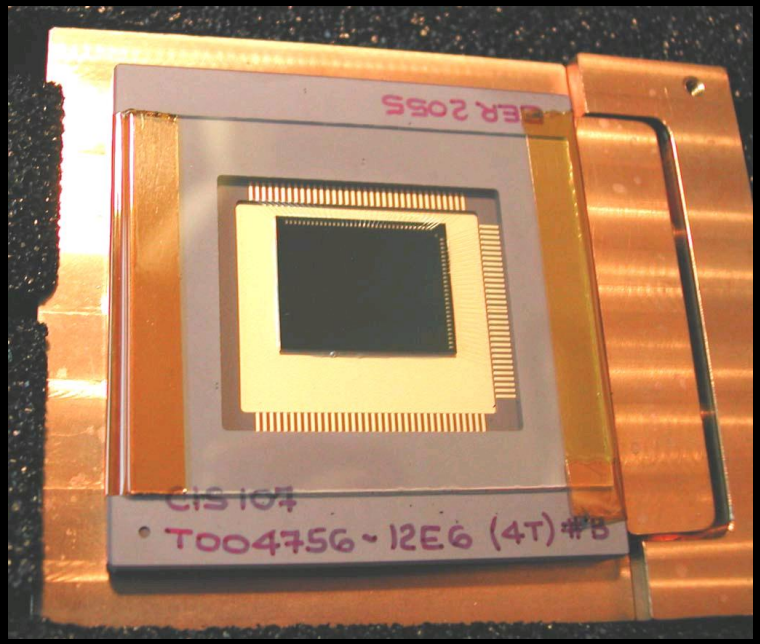
San Pedro Mártir

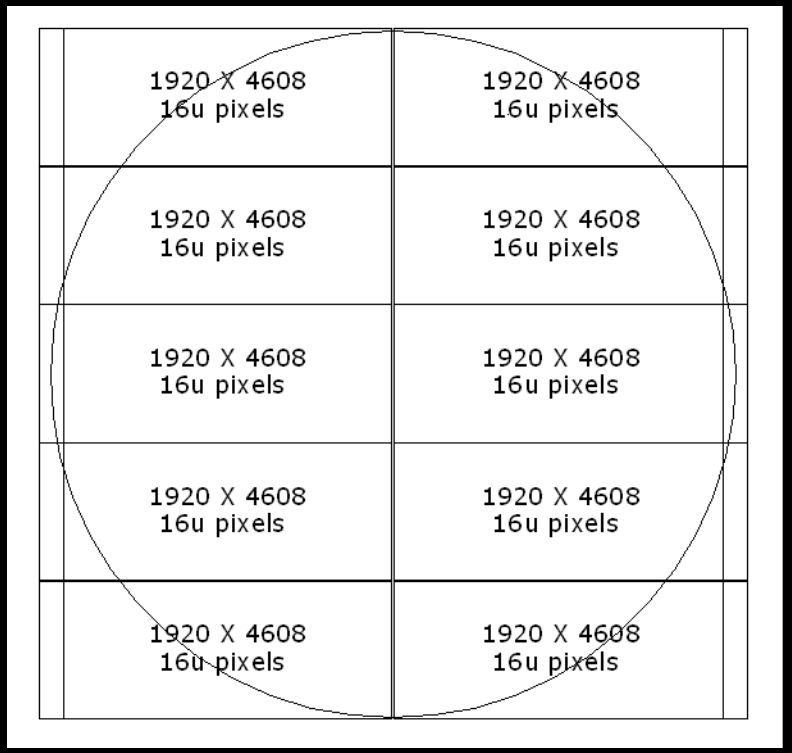


San Pedro Mártir

Camera

- High speed readout with ultra low noise
- Custom back-illuminated CMOS from e2v
- Sub-aperture readout, onboard CDS (<5e$^-$ read noise)
- 12k stars at 20 Hz





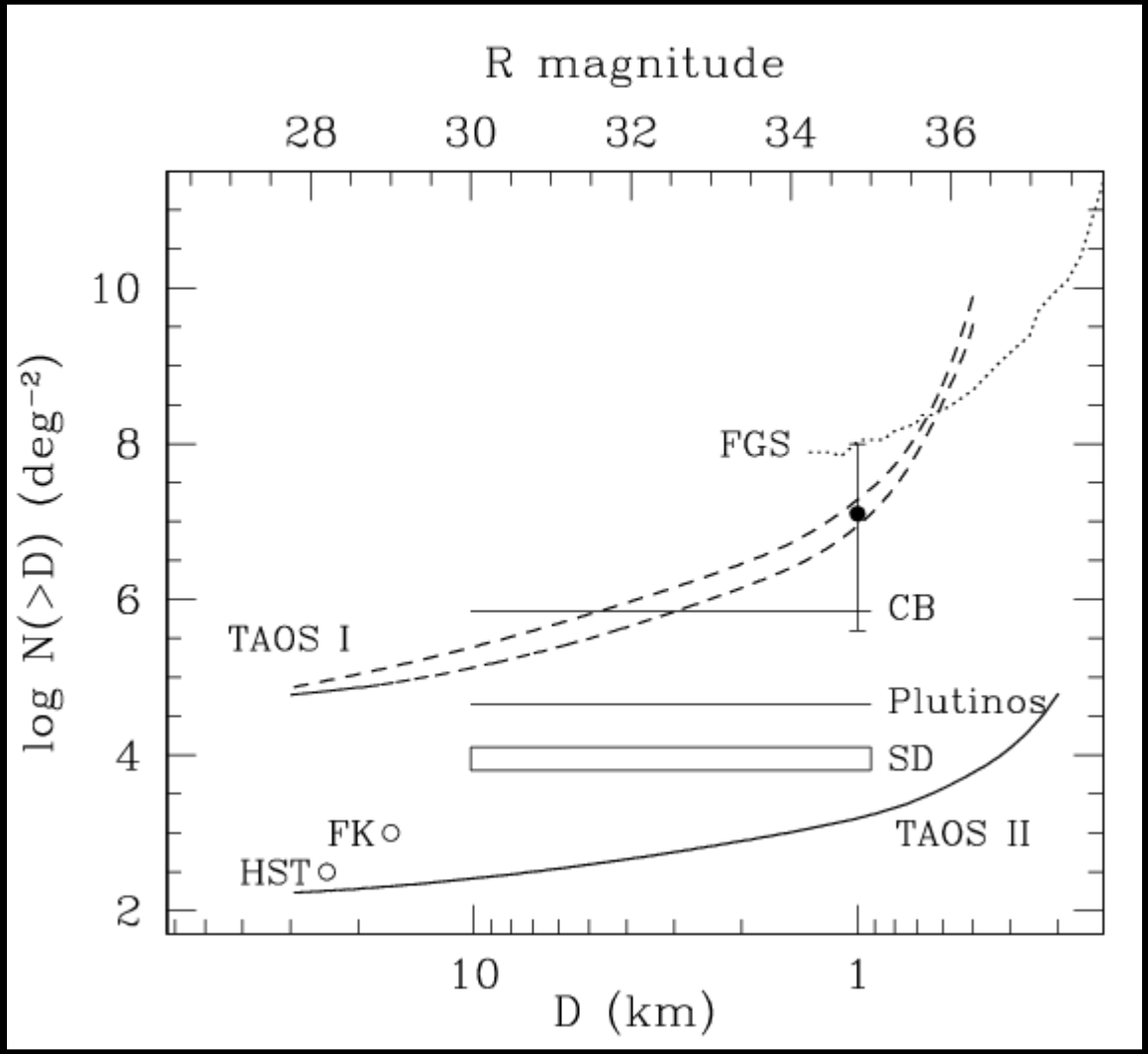
Data Rates

- 70 Mpix camera (3 of them)
- 20 Hz readout
- 250 TB of raw image data per night!
  - Sub-aperture readout
  - Image data rate a factor of 200 lower
  - 3 - 4 TB/night image + lightcurve data
  - similar to LSST

Data management

- 1 PB/year of image and lightcurve data
- Where?
  - Ensenada? San Diego? Taipei?
- Need to keep track of many files
  - Xrootd? FUSE + SQL?
  - Data integrity
- Public access
  - Raw files? VOTables? No access?

Sensitivity of survey



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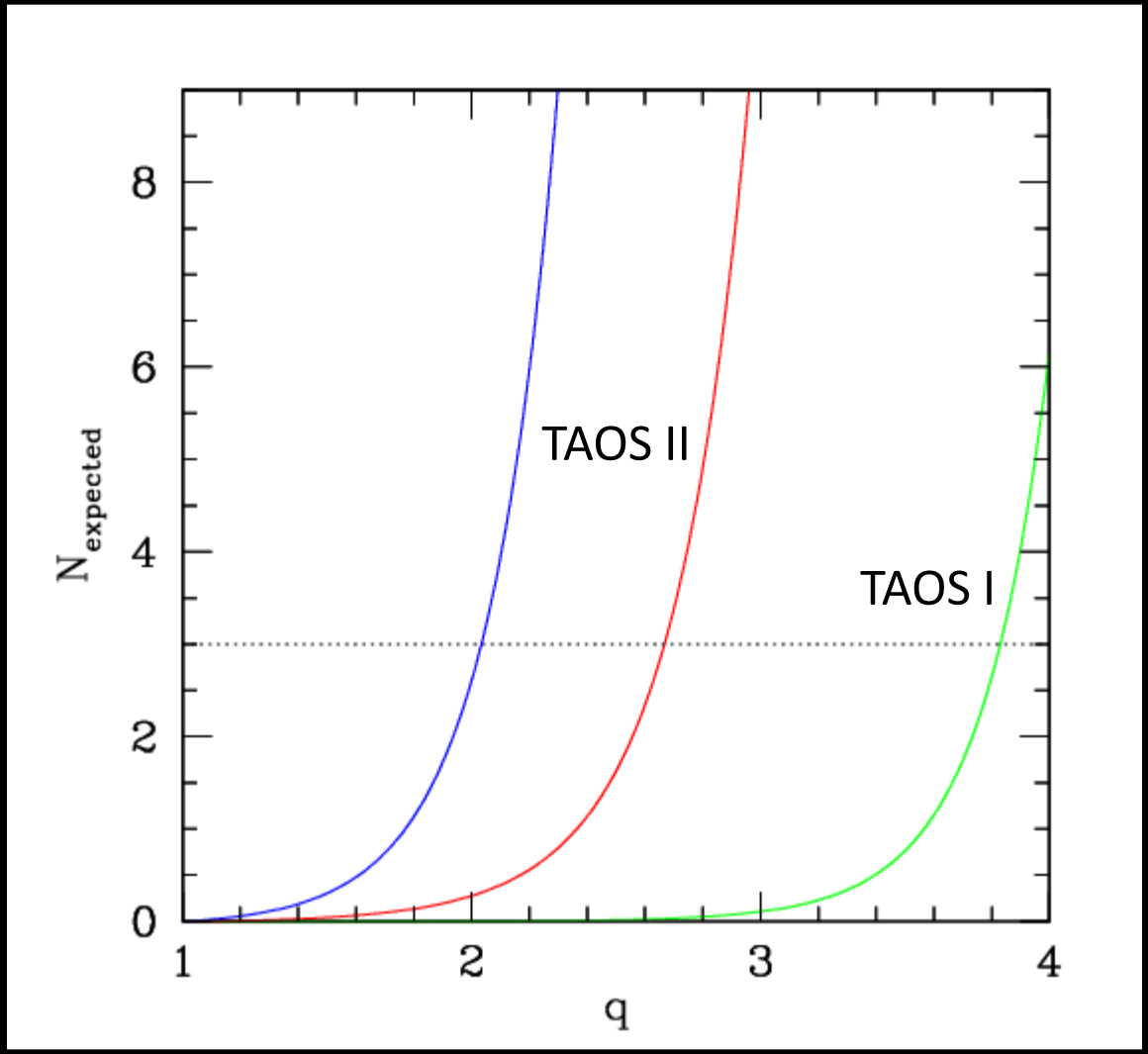


TAOS II: Schedule

- Site preparation to begin in this year
  - Roads, foundations for enclosures
- Telescopes delivered by June 2013
- Prototype camera this autumn
- Completed system operation mid 2015

“Robotic” Observatory

- What are we really talking about?
  - Automated scheduling of observations, standard operations, remote observations
  - Automatic “safe mode”, close up in bad weather, recovery from hardware, software problems
- No human intervention
  - Some intervention inevitable
  - Amount of intervention inversely proportional to cost, complexity

Automated Scheduling

- Maximize observing time
- Use complex algorithm when many observations in queue
- Minimize slewing, filter changing
- No dead time
- Minimize chance of human error
- TAOS: motivation is boredom
  - Pick a field
  - Image for 90 minutes
  - Repeat

“Safe Mode” and Recovery

- Automatically close domes during bad weather
- Need to alert staff in case of hardware problem (like if the dome fails to close)
- System needs to be robust in case of software, hardware failures
  - Daemons go into safe mode, shutdown if hardware problem
  - Automatically restart daemons in case of shutdown or crash
  - But not always….

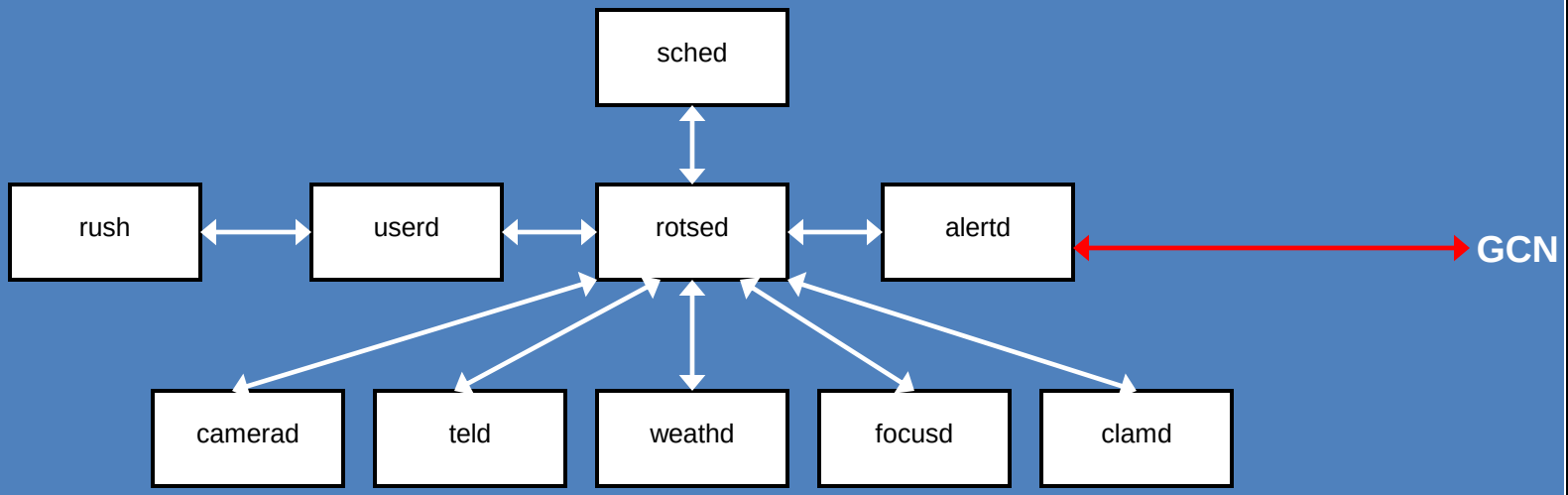
Automatically close domes during bad weather

- Need reliable domes
  - Resist the urge to reinvent the wheel
- Need reliable weather monitoring
  - Want quality sensors (Vaisala WXT520)
  - No moving parts
  - *Need to keep weather stations calibrated!*
  - Redunancy
  - Rain detection
    - Total area of sensors << 1% of the area of our telescopes and electronics
    - Looking into cloud sensors

Robust control software

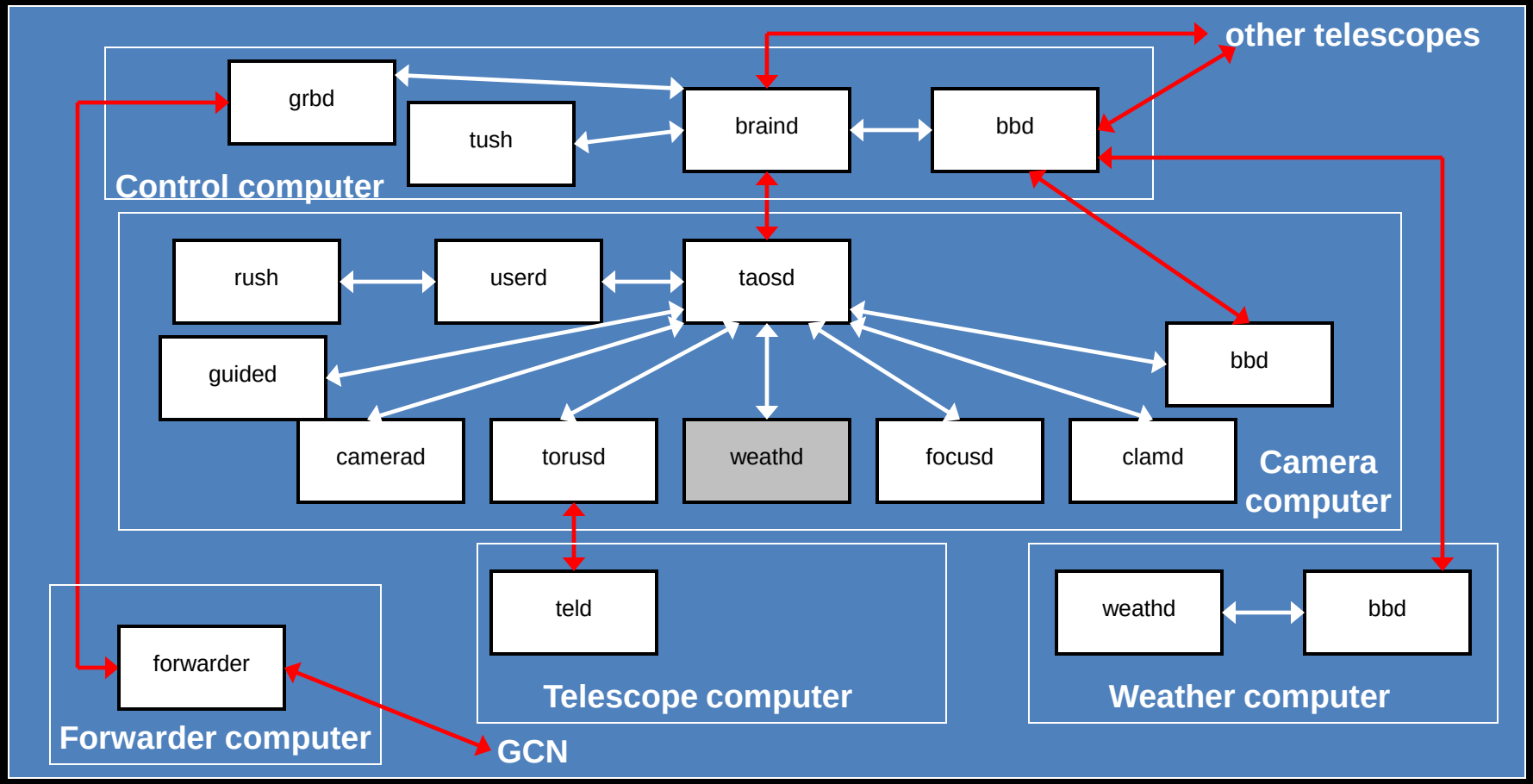
- Watchdog timer
  - Automatically close domes using hardware override in case of computer crash
- Scheduler can automatically restart crashed or shutdown daemons
  - Best thing is to write daemons that don't crash!
- Auto-recovery from hardware failures
  - Depends on the failure mode
  - Only possible when you have the same problem repeatedly (in which case you fix the problem!)

TAOS I Software



Courtesy of ROTSE

TAOS I Software



Lessons Learned

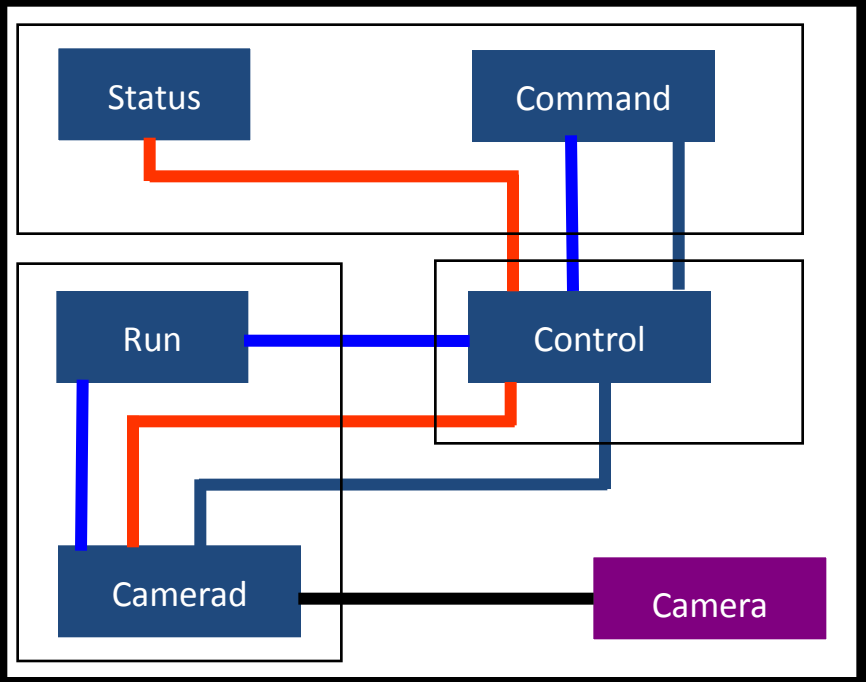
- Quality software design
  - Robust IPC
  - Error checking on every system call
  - Verbose logging (log every command)
    - Use __FILE__, __FUNCTION__, and __LINE__ macros
  - Stick with POSIX compatible code
    - Makes system upgrades much easier
    - Avoid third party software packages if possible
  - Simple macro facility
- Run-able in gdb
- Control software will take much longer than you think

TAOS II Control Software

- Many daemons
  - Scheduler
  - Master Control
  - Camera Daemon (×3)
  - Telescope/Dome Daemon (×3)
  - Archive Daemon (×3×2+)
  - Weather Daemon (×3)
  - Watchdog Daemon (×4)
- At least 14 computers

Control Software

- TAOS I
  - IPC using shm
  - User space polling using kernel timer as trigger
  - Could not test individual pieces
  - Could not run in debugger
- TAOS II
  - Sockets for IPC
  - Let kernel do polling
  - Can run in debugger
  - Can test pieces individually



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