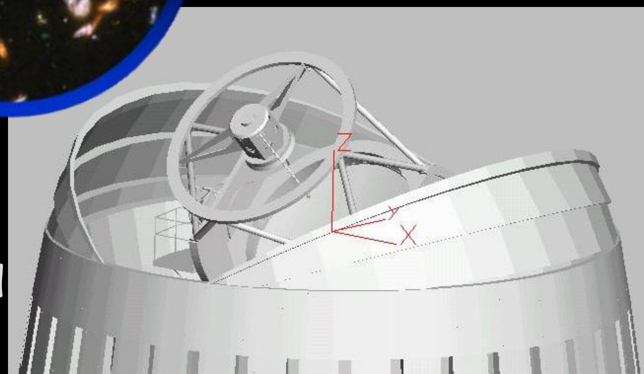
SASIR

Synoptic
All-**S**ky
Infrared
Survey



Telescope Optical Design
(preconcept issues)

J. Jesús González (IA-UNAM)

Guillermo Haro Workshop
Aug 13-20 2008
INAOE, Tonanzintla, Mexico

SASIR Proposal

Survey, synoptically, the entire northern sky at infrared wavelengths to unprecedented depths (y, J, H & K)

- Dedicated wide-field 6.5-meter telescope in SPM
  - 1st Operation phase: 4-yr SASIR project
  - Afterwards: optical/NIR spectroscopic Survey, General Purpose telescope, etc

Final 4-yr synoptic survey ~1,000 more sensitive than 2MASS covering a volume >30,000 times larger

⇒ Enormous impact in the study of rare, faint, red and obscured objects in two domains:

Time-resolved (synoptic) survey, unique in the IR

Moving objects (local low-mass stars); Distance ladder (RR Lyrae, Cepheids, Miras), SNe surveys (Ia, II-N, PP) ; High-z transients (GRBs); Grav Wav & Neutrino missions counterparts ; Fast transients (orphan GRB afterglows?)

Static Sky (single pointing & accumulated) survey

Significantly deeper or wider than any ongoing or planed (≤4 m)

SASIR dedicated telescope

A new large-telescope facility is needed for SASIR

- 6-10m class telescopes (~8 VLTs per hemisphere):
  - ✓ Each with a full site of traditional instrumentation
  - ✓ The majority with relative narrow fields (< 20′)
  - ✓ Optimal for faint or high-dispersion spectroscopy

- 4m-class telescopes:
  - ✓ Growing emphasis on large-scale programs and/or wide-field Vis&IR imagers: 2DF, SDSS, UKIDSS, VISTA, MOSA, ODI
- 2m-class telescopes:
  - ✓ Innovation is in fully automated, rapid-response systems, primarily for IR and optical imaging and spectroscopy

A 6.5 m aperture: x2.6 step in NIR imaging (LSST comparable)

We do not start from scratch

- SASIR builds up from Mexico's developments and long term goals towards the optimal exploitation of the SPM virtues, in particular through a competitive world-class optical/IR facility

- INAOE & UA partnership for a polished primary mirror, schedule for casting this year

- The Magellan telescopes are indeed an excellent reference for a proven efficient design
  - In particular the telescope and building, allowing us to concentrate on the new areas that need special attention or development (e.g. optimal optical design for the NIR)
  - Risks and unknown cost mitigated

SPM-Twin: Competitiveness based on optimized cost-effective concepts (Magellan/MMT)

Large Grasp Concept:

SPM-Twin large grasp (product of aperture, efficiency, multiplex advantage, field of view and pass-band) makes it possible to explore unique discovery spaces in the ELT era.

Integrated Design:

telescopes will be designed simultaneously with their major instrumentation, guaranteeing robust performance and minimization of overheads and compromises in each telescope.

Risk mitigation:

by exploiting these highly successful existing designs the SPM-Twin facility performance is guaranteed.

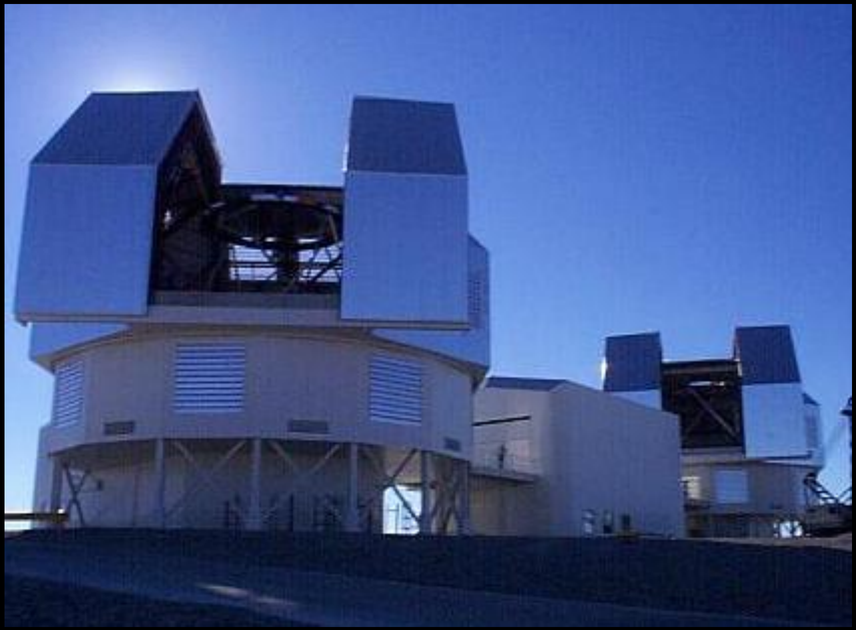
Fast Schedule:

focusing efforts mostly on the new developments required for the science programs, the schedule to build SPM-Twin should be relatively short (five to seven years).

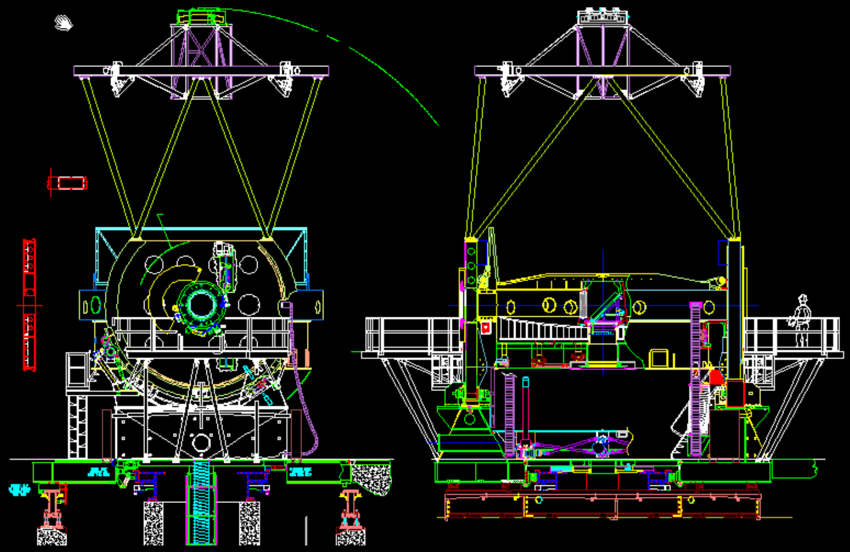
Economy:

By maximally exploiting existing designs, non-recurring engineering costs are minimized. The integrated engineering approach will simplify operations once scientific observations commence, saving operations costs.

SPM-Twin: WF-Spectroscopic Telescope

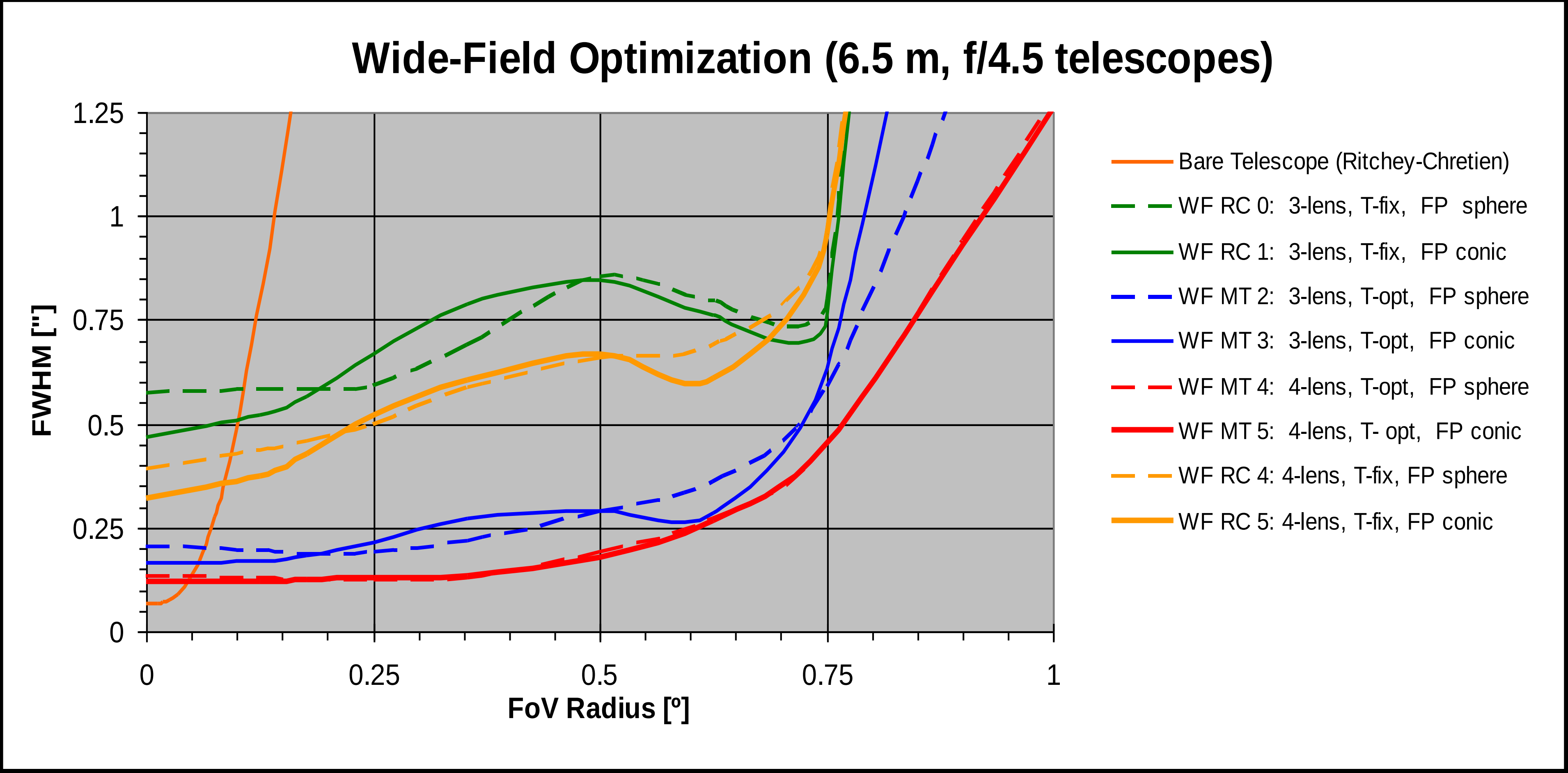


Fields ≥ 1.5°
with a Magellan-like 6.5 m telescope ?



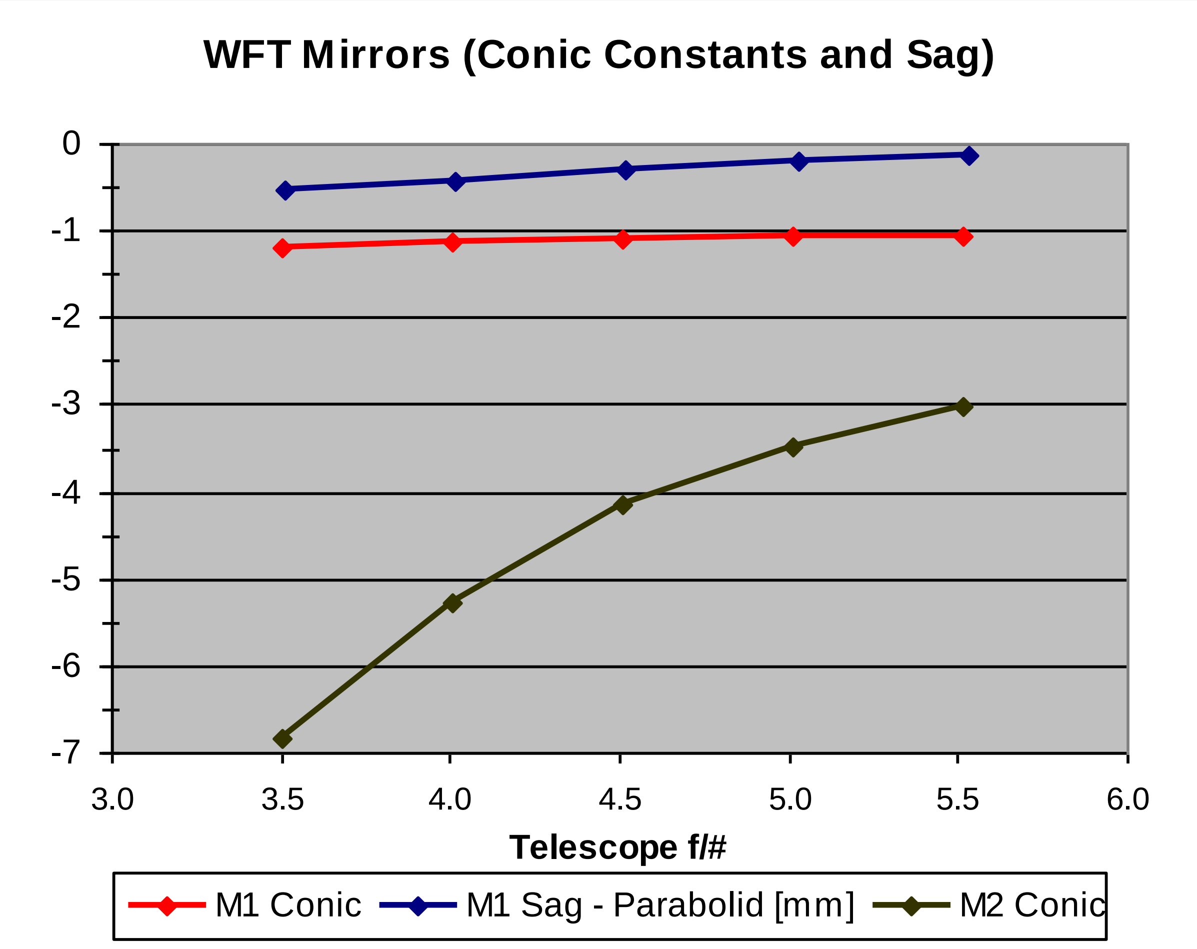
- Strategy and tools developed to design, compare and identify optical concepts
- Minimal structural modifications
- Viable optical elements
- Integral system optimization
  - Telescope + WFC + ADC
  - Field Integration suitability
  - Spectral R & Δλ matching
  - Spectra packing, etc.

SPM-Twin:
1.5°-2° fields with a Magellan-like 6.5 m ?
...Yes !



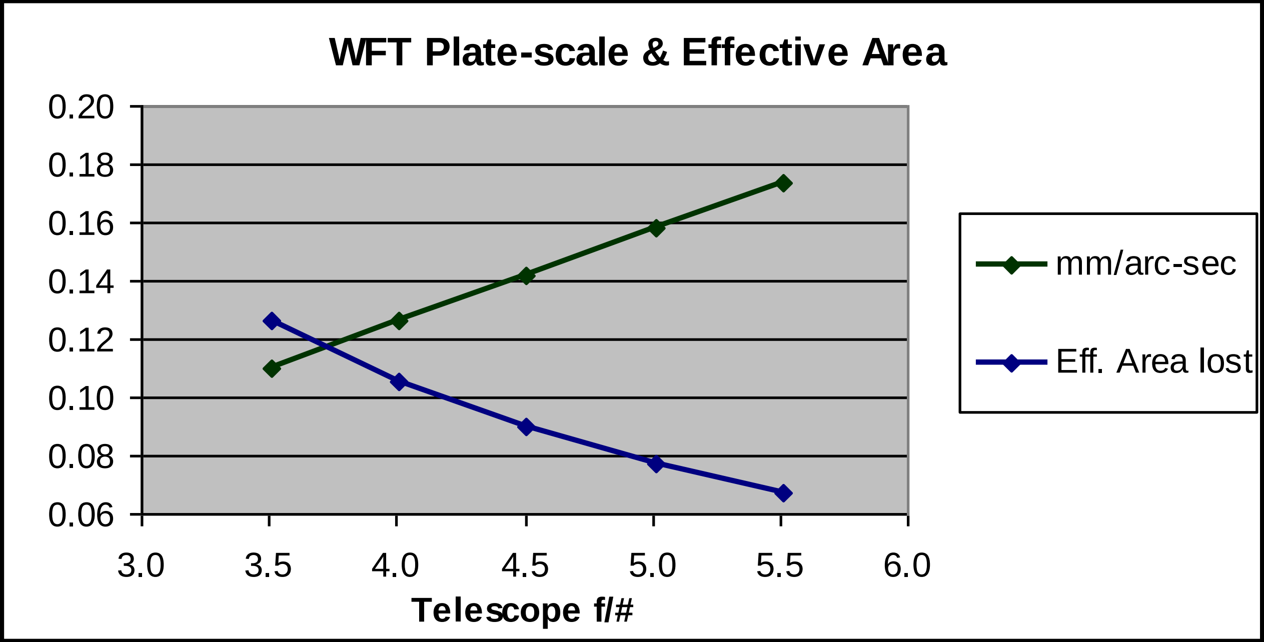
SPM-Twin: WF Telescope focal ratios

Mirror Feasibility

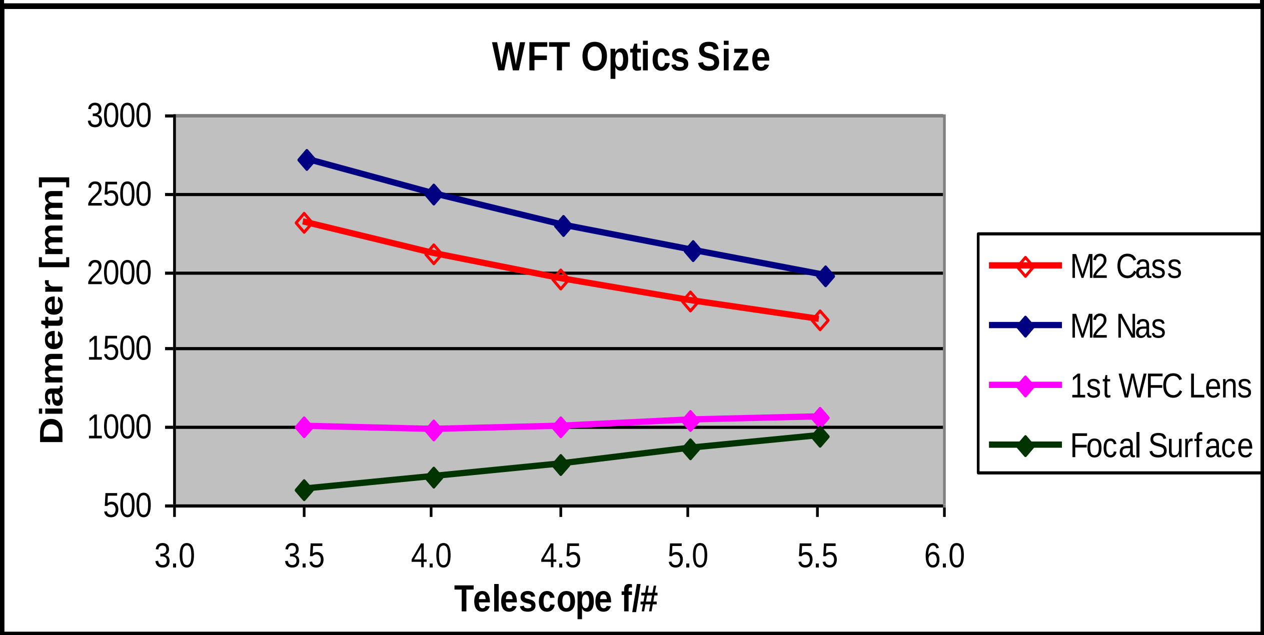


- ✓ Non-parabolic Primary (M1)
- ✓ Glass to remove
- ✓ Secondary figuring

SPM-Twin: WF Telescope focal ratios (II)

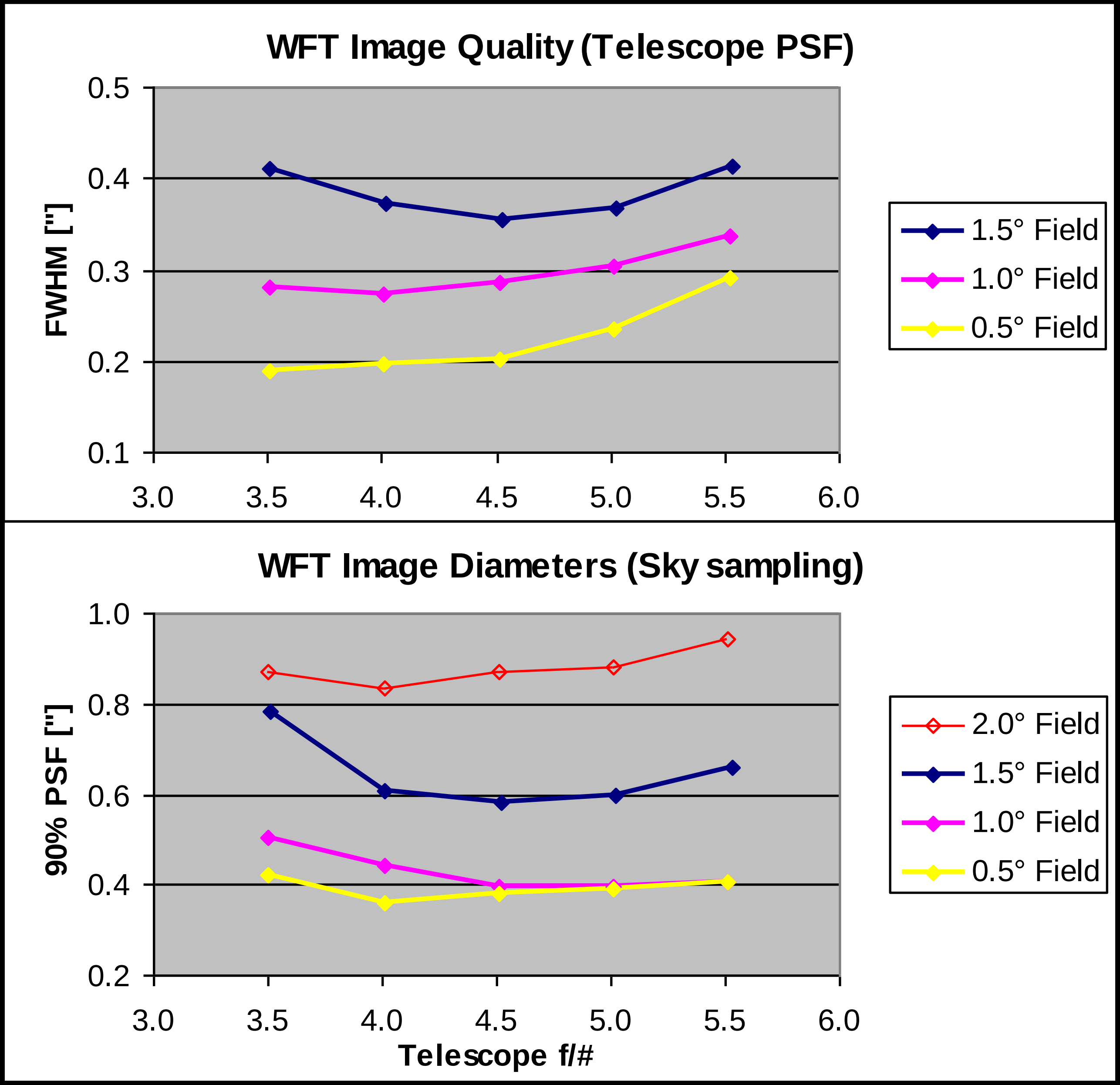


Focal plane should couple naturally to fiber scale and NA demands



Dimensions of secondary and corrector optics may be limiting factors

SPM-Twin: WF Telescope focal ratios (III)



IF Spectroscopy:
PSF extent is relevant
(not just FWHM)

SPM-Twin: WFT Atmospheric Dispersion Correction

Performance (Z=60° over 1.5° field of view)

Circles:

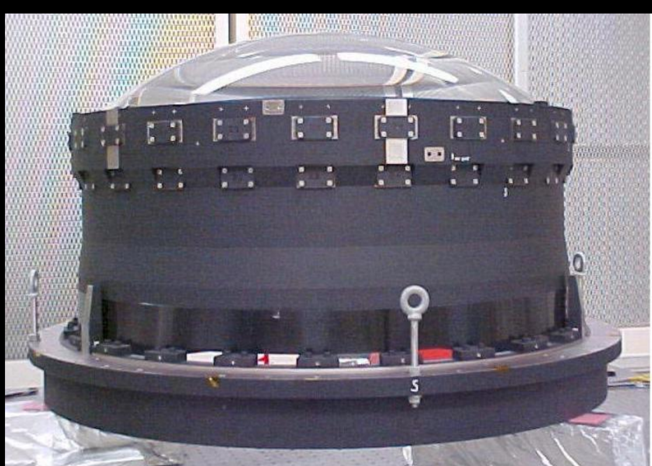
2” aperture (Spaxel)

SPM-TWIN WFT 1.5° Corrector

1″
Central
spaxel

WF+ADC
Performance
(Z=60°)

1″
@ 1.5° FoV
spaxel



MMT & Magellan 1° FoV (Fabricant et al, 2003)

SPM 6.5m f/4.5 WFT

Effective aperture: 6.2 m
M1 to M2: 6.02 m
Plate scale 0.142 mm/arcsec

Primary mirror

Conic = -1.07198
Curv. radius = 16,255 mm
Hole diameter ≥ 1,100mm

Secondary mirror

Conic = -3.78412
Curv. radius = 5,813 mm
Diameter: 1.9 - 2m (1.°5 - 2° fields)

WF+ADC Field

3 silica lenses
(all-spherical surfaces)
ADC: 2 double prisms
Largest lens (Silica meniscus)
Aperture: 1.03 m (1.°5 field)
1.25 m (2° field)
Thickness: 75 to100 mm
Curv. radii: 1.5 m & 4.0m (front, back)

WFC Lenses: 3 Silica (all spheres)

100 cm

80 cm

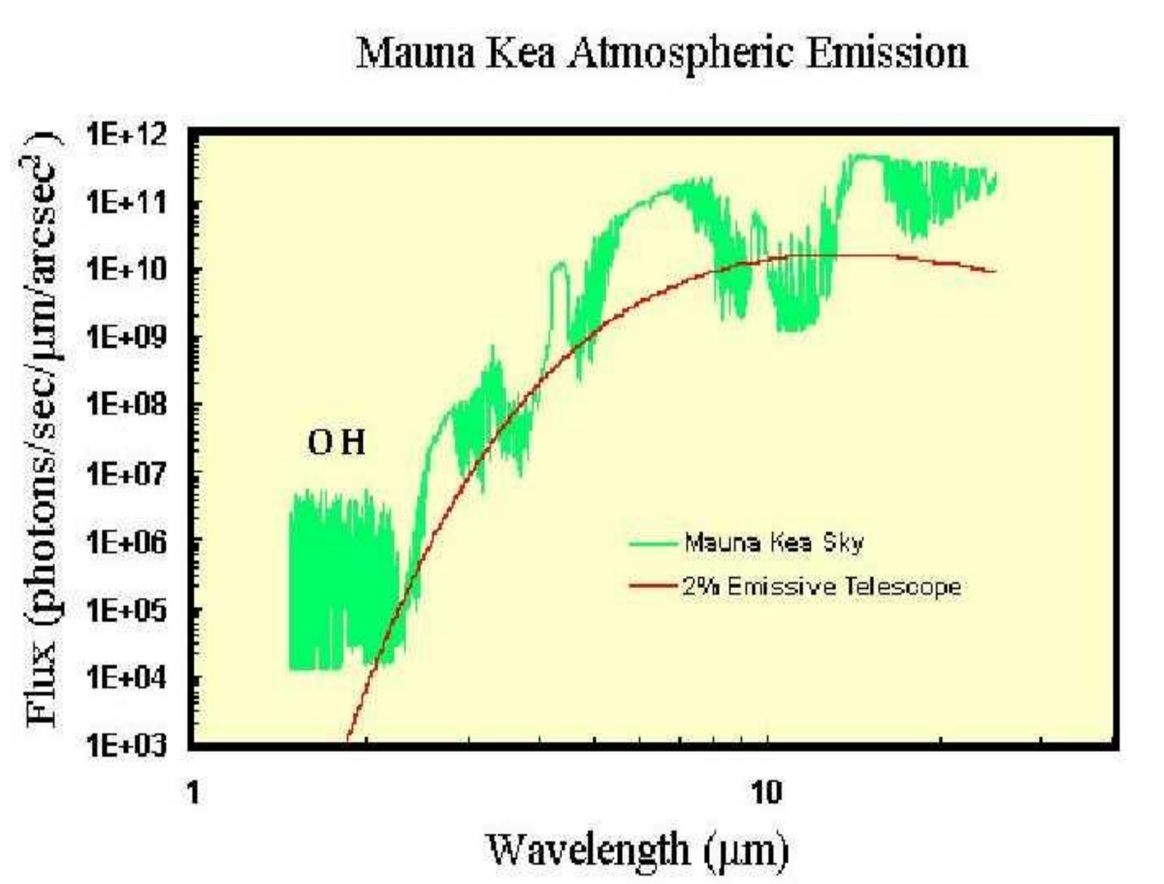
ADC Double prisms: 2 (K10 + N-Pk52A)

Nevertheless, a lot is different for SASIR

- Near Infrared instead of a visible wide-field system
- Thermal emission becomes quite relevant in K
  - Large cryogenics
  - White pupil and/or elaborated baffling
  - Heat transfer, emissivity & temperature gradients
- Significantly better image quality
- Limited availability of optical materials (CaF_2, BaF_2, etc)
- Pixel scale calls for a faster system (~f/2.5)
- Need to divide the field or to split the beam in 4

- What is simpler?
  - No need for ADC
  - Some freedom on back focal & focal station
  - May consider other kind of telescope systems

Infrared emission



Mauna Kea atmospheric transmission compared to the emissivity of a 2% emissive telescope for 2-mm of water vapour. Note how a mid-IR instrument is limited by the telescope emisivity over a significant part of the 10 micron window. Image: University of Florida Astronomy Group.

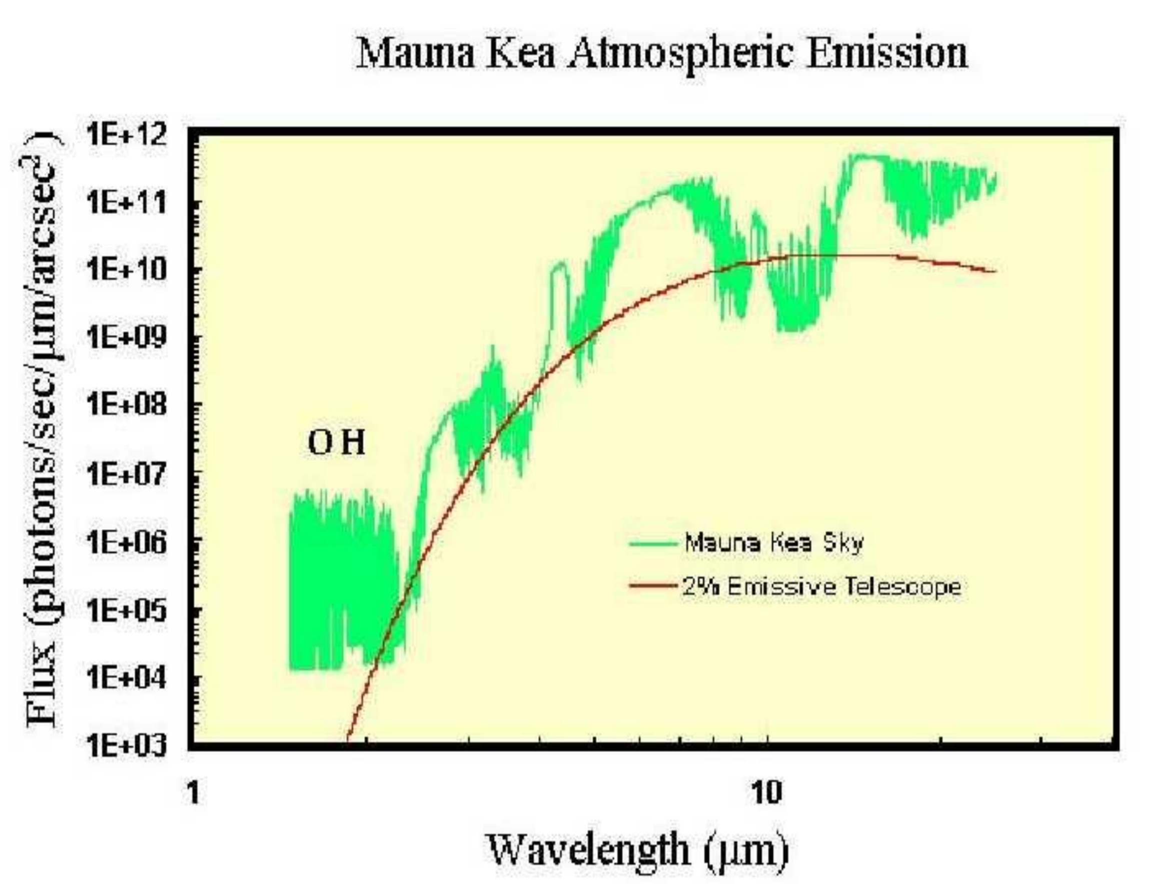
Relative contributions of background light from the sky (green line) and a perfect telescope (red line), assuming 2-mm of water vapour and a telescope 98% reflectivity (an optical telescope may not pass 80% unless it has recently been cleaned and 95% is very difficult to attain). By making the optics as clean and reflective as possible (telescope mirrors and mirrors inside CanariCam) the radiation from the atmosphere can be the deciding factor in many cases, but in the best parts of the 10-micron window what limits us is the optical path.

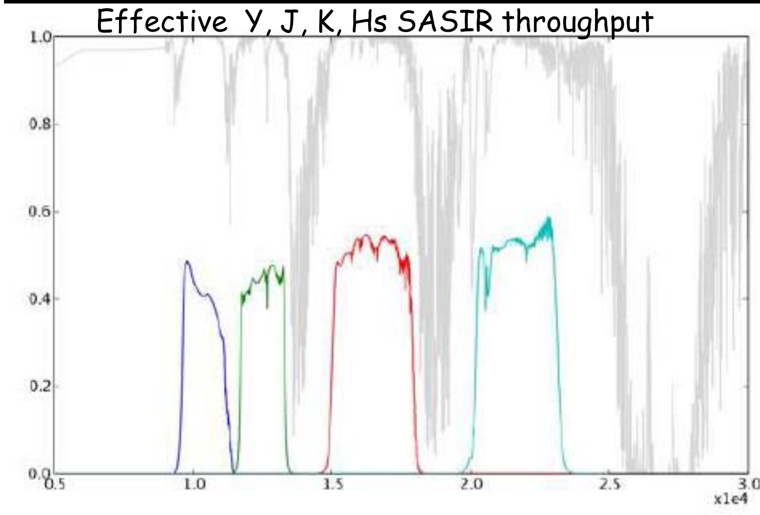
Telescope contribution minimized by making the structure as light as possible (to "see" minimum o support structure) and by taking measures to maintain the mirrors very clean, including segment removal from the GTC every week to clean them on a cyclical basis (every six months approx the entire mirror surface is renewed). Giving the telescope a gold-coated secondary mirror may make another improvement in the future, as gold reflects infrared light very efficiently - much more so than aluminium or silver. These factors are beyond the control of CanariCam.

CanariCam Gold mirrors, each 99% reflective for infrared light are used. The detector and mirrors are cooled to below 30K (-245°C) and a special shield (a light baffle) cooled to the same temperature blocks out all light that does not come from the telescope mirror.

We can also improve the instrument's sensitivity significantly by observing in cold and very dry conditions to reduce the background still further. By scheduling the most critical observations in queue observing mode we can take advantage of the very best conditions in the observatory, whenever they happen.

Infrared emission





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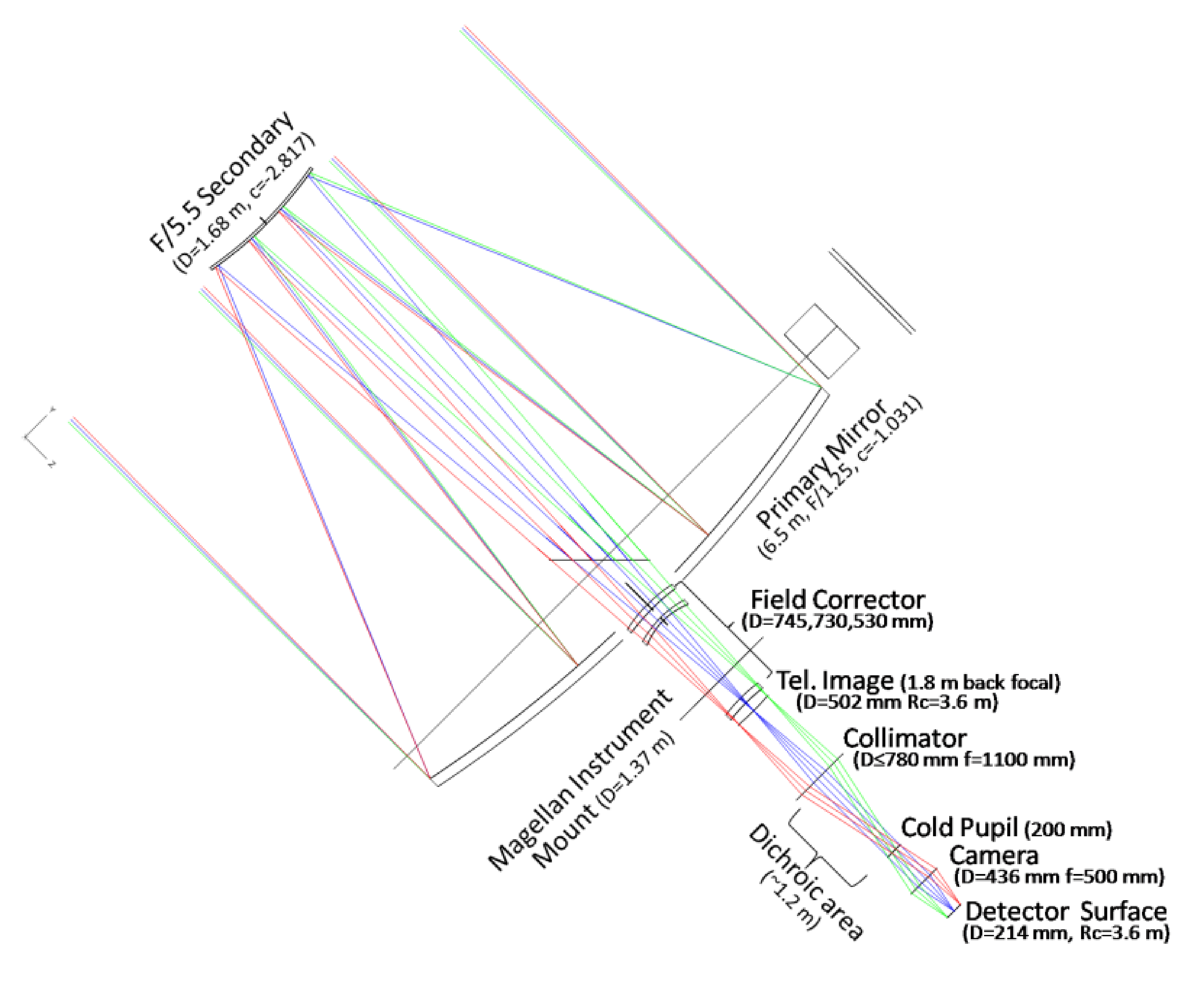
SASIR pre-conceptual design



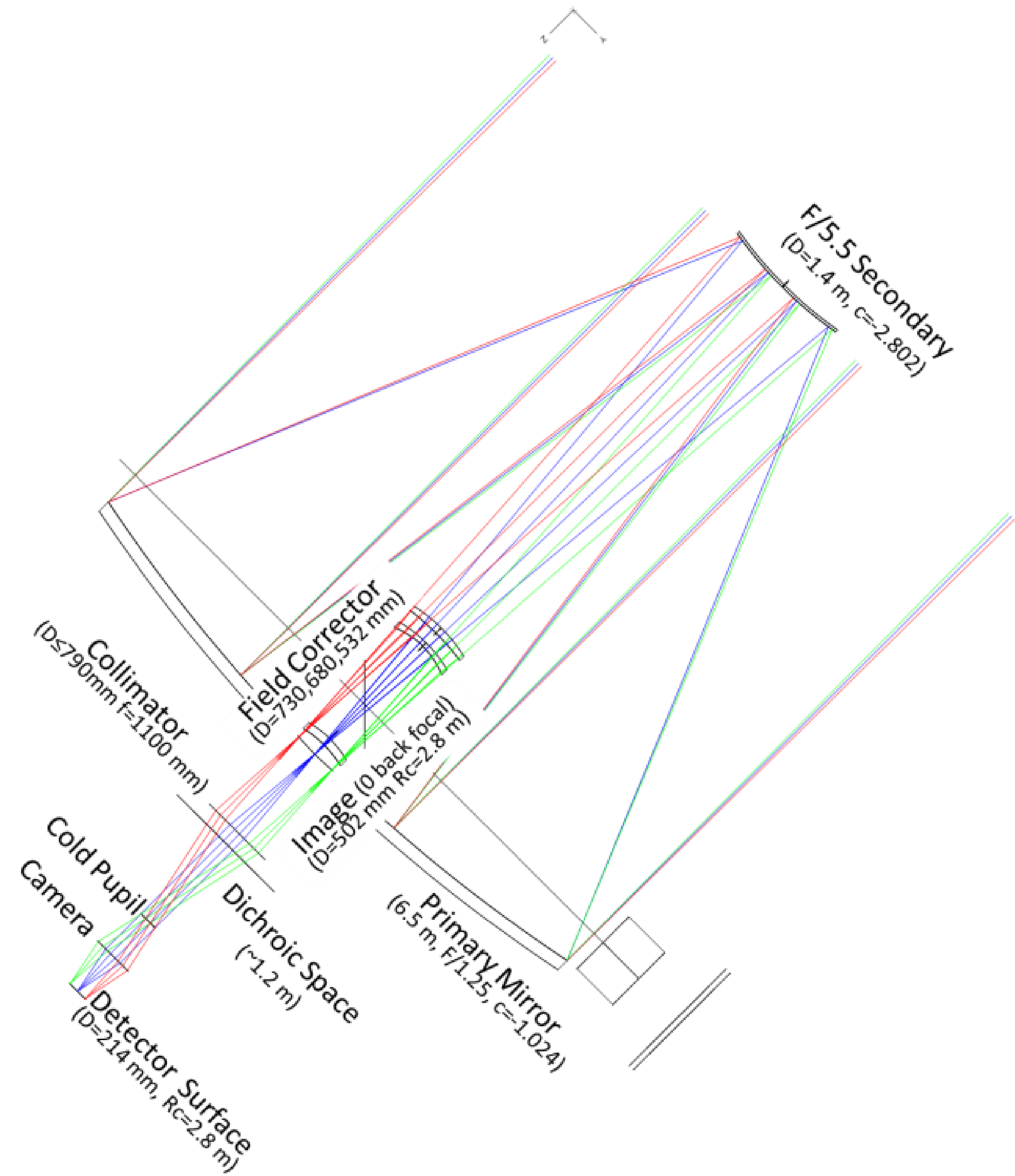
Tels explored:
f/3.0 – f/9.0

D2: 2.6 – 1.15 m
Rc2: 10.1 - 2.8 m
C2: -8.7 to -1.82
C1: -1.2 to -1.01

WFC:
D1: 850 – 917mm
R1: 1.67 – 1.18 m

Collimator:
D = 515 – 1148 mm
F = 600 – 1800 mm

Camera (F=500 mm)
D = 457 – 426 mm


F/5.5 Secondary
(D=1.4 m, c=-2.802)
Field Corrector
(D=730,680,532 mm)
Collimator
(D≤790mm f=1100 mm)
Image (0 back focal)
(D=502 mm Rc=2.8 m)
Cold Pupil
Camera
Dichroic Space
(~1.2 m)
Primary Mirror
(6.5 m, F/1.25, c=-1.024)
Detector Surface
(D=214 mm, Rc=2.8 m)

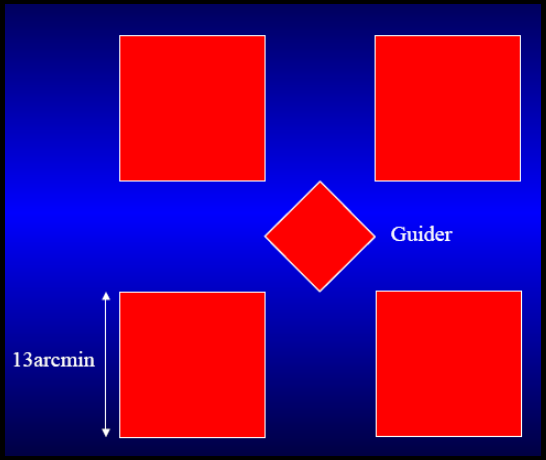
f/5.5 Classic & Gregorian systems
M2 becomes too large at f/# < ~8

Normal Field
9' FoV (0.075)

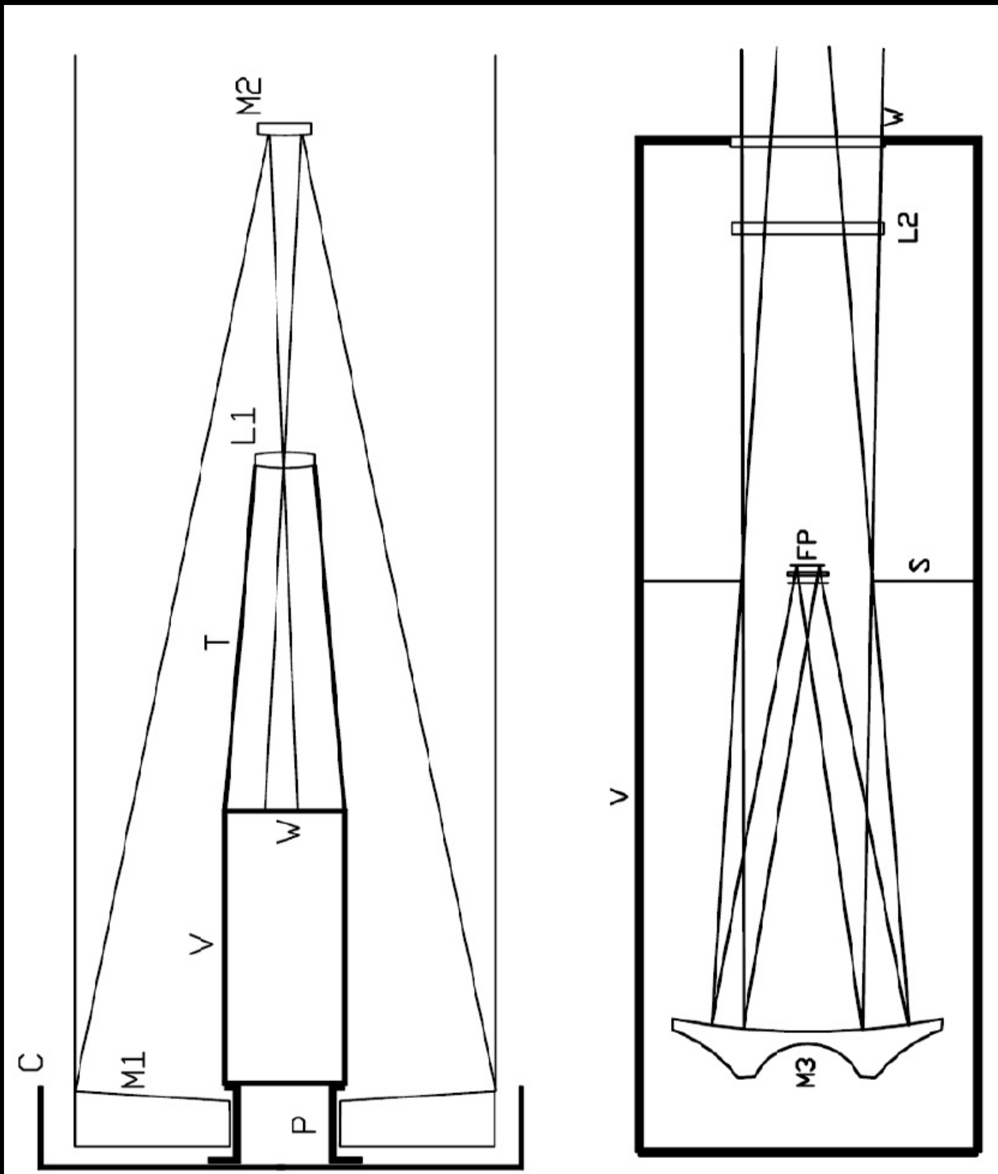
Wide-field
0.8 FoV

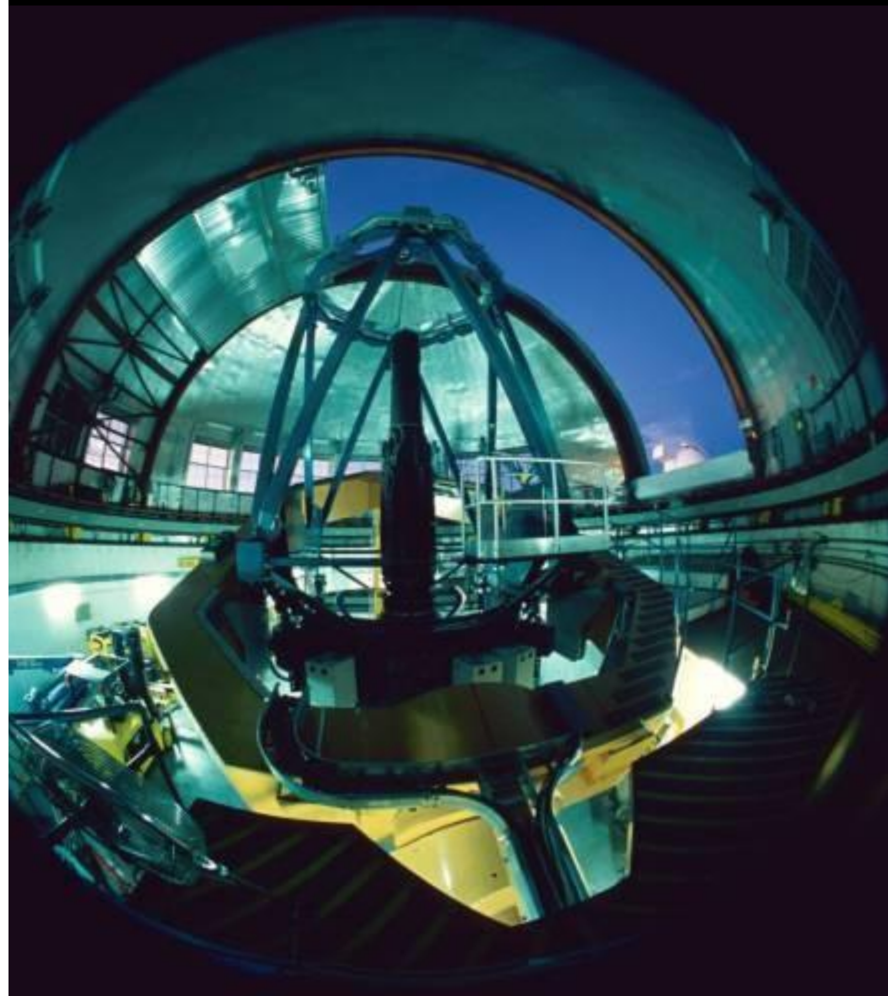
WFCAM (UKIDSS)

- 3.8 m UK InfraRed Telescope
- Started operations in May 2005
- Built by the ATC (Edinburgh)
- 4 2048^2 Rockwell detectors (0.4"/pixel)
- 0.21 square degree/exposure
- ZYJHK filters
- Data release 3 (2007)



Schmidt like solution

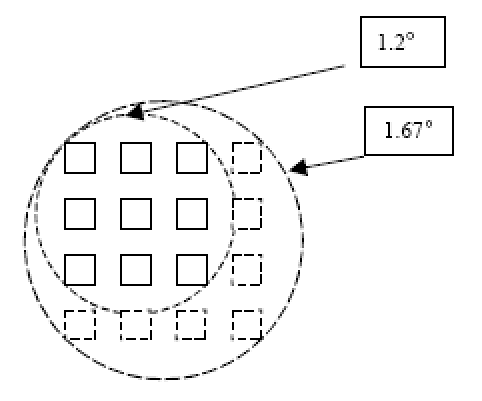


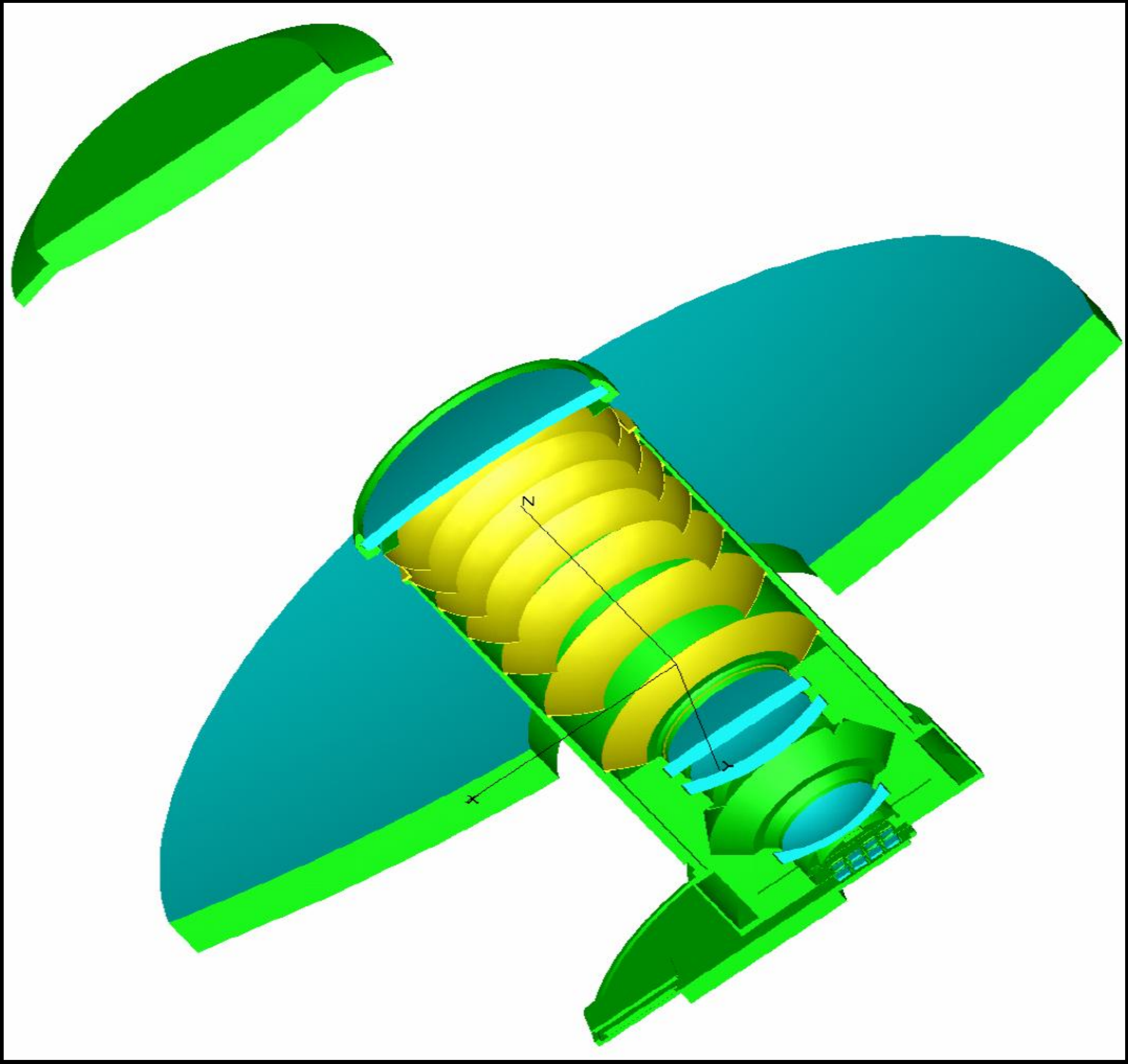


f/2.5

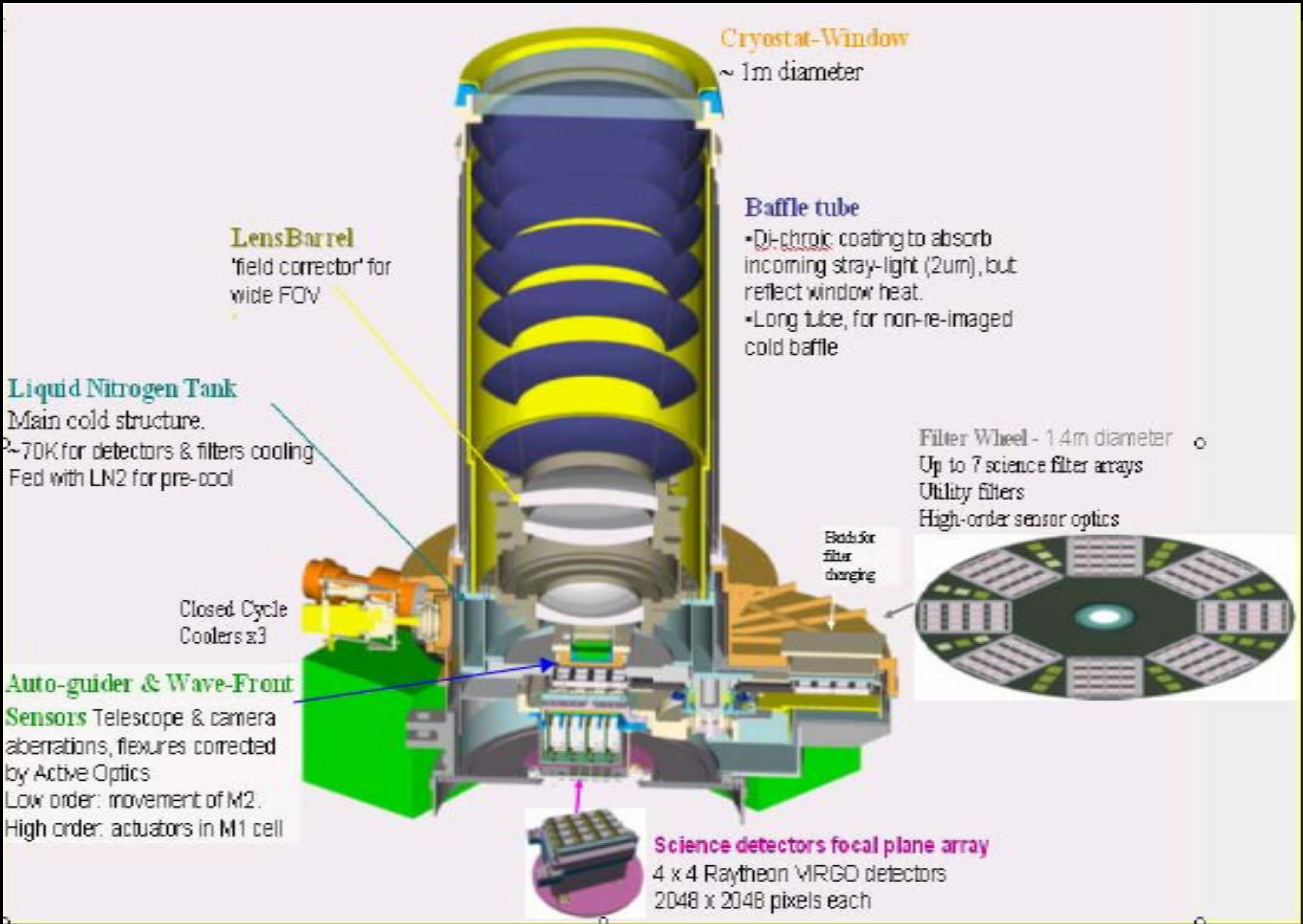
VISTA Infrared Camera

- VISTA 4.1 m telescope
- 1.65 degrees FoV, f/3.25
- 16 Raytheon VIRGO 2048^2 HgCdTe
- 0.34"/pixel, FoV=0.6 sq.deg/ex
- Being commissioned





Z
Y
X


Cryostat-Window
~ 1m diameter
Baffle tube
•Di-chroic coating to absorb incoming stray-light (2um), but reflect window heat.
•Long tube, for non-re-imaged cold baffle
LensBarrel
'field corrector' for wide FOV
Liquid Nitrogen Tank
Main cold structure.
~70K for detectors & filters cooling
Fed with LN2 for pre-cool
Filter Wheel - 1.4m diameter
Up to 7 science filter arrays
Utility filters
High-order sensor optics
Closed Cycle Coolers x3
Auto-guider & Wave-Front Sensors Telescope & camera aberrations, flexures corrected by Active Optics
Low order: movement of M2.
High order: actuators in M1 cell
Science detectors focal plane array
4 x 4 Raytheon VIRGO detectors
2048 x 2048 pixels each

Relevant issues to cover by the optical conceptual design study

- Best pixel scale (0.2”-0.35”)
- Best pixel size (10-22μm)
- Definitive conclusions of field vs. beam spliting
- Base optical design (2-3 mirror, WFC, focal station, etc). M1 conic constant
- Collimator & Camera concepts
- Impact to telescope structure and building
- Post-survey phases of the facility
- Integral error-budget (telescope, optics, site conditions & operations) for optical design
- Precise cryogenic indices of refraction

Conclusions

- A 6.5m high-image quality wide-field NIR imaging telescope is quite feasible under a range of design configurations
- A WF-corrected classical system looks particularly attractive, given its fewer uncertainties and its natural compatibility with the telescope structure and with 2nd phase operations (integral field spectroscopy, general purpose telescope, etc.)
- The main challenge is to be able to accommodate up to four focal planes under reasonable design, physical and performance constrains
- Proposal Phase funding seek this year: will finance the conceptual design, we must then continue working hard to summarize the main science requirements while gauging realistic technical constrains

Thanks!

Feedback from the community

- SASIR survey(s) definitions
- Synergies with present & future facilities

- MexCal broader collaborations
- Required and potential follow-up projects & collaborations

- Long-term plans for the facility

- Input from the community (diversity & interests)
  - What SASIR should do for your science ?
  - How the present sketch of SASIR science should change/mature
  - Brainstorm of ideas and concerns
- Involvement areas
  - Surveys definition
  - Data products exploitation
  - Follow-up & parallel science
- List of specific requirements from specific science cases
- Synergies & complementary projects
- Extend access/exchange with other facilities
- Science for 2nd phase and beyond
  - General purpose telescope? some degree of specialization?
  - Other kind of NIR survey
  - WF optical/NIR spectroscopic survey
- Workgroups for specific milestones

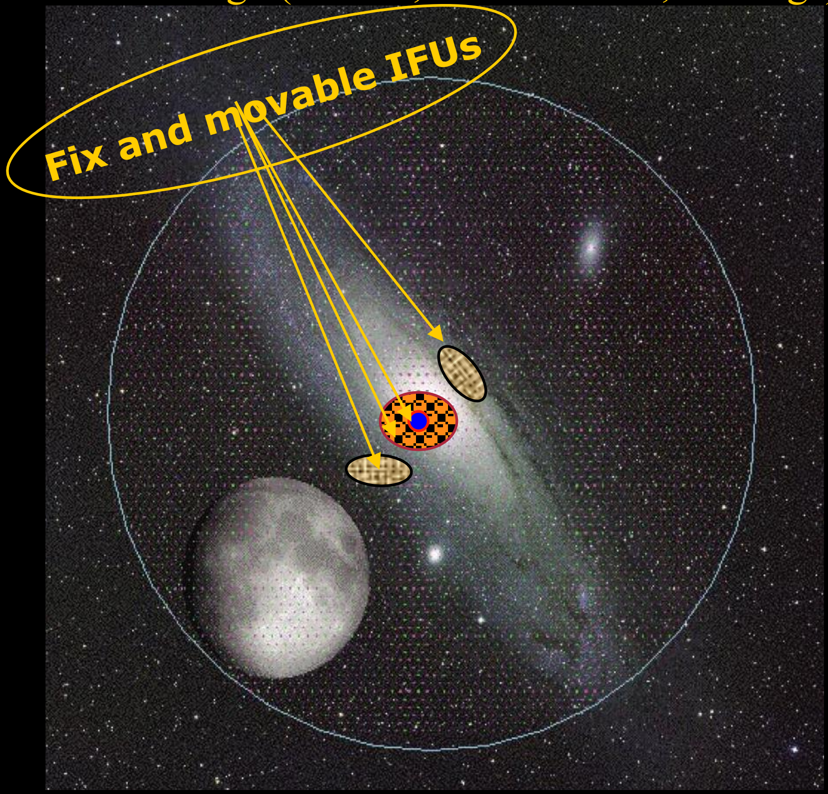
Some relevant milestones

- US/Mex proposals to fund the design phase (NSF, CONACyT
  - NNN
  - Formalization of an specific CONACyT “red”
- M1 Casting

SPM-Twin: *Wide-Field Sampling & Integration (complementary limitations)*

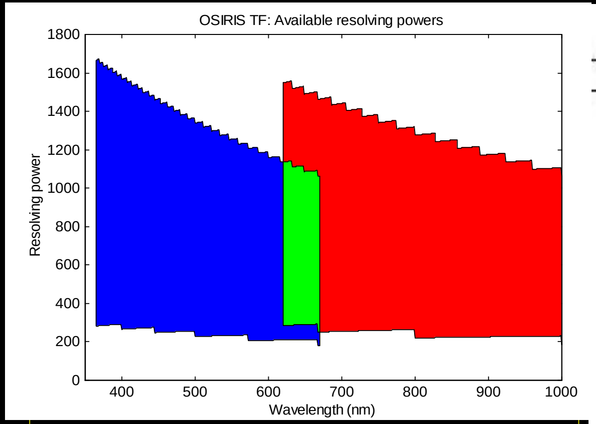
1.5° Field of View (5400”) = 1.77 square degrees
Lots of sampling elements (“spaxels”): 2.4×10^7 squared arcsecs

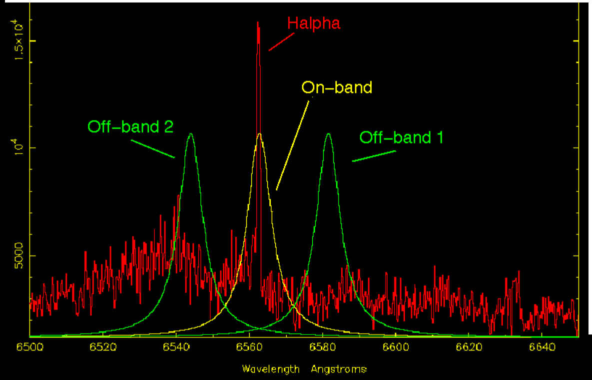
a) Full wavelength range with well-chosen spatial coverage (d-IFUs, fiber-bundles, starbugs)

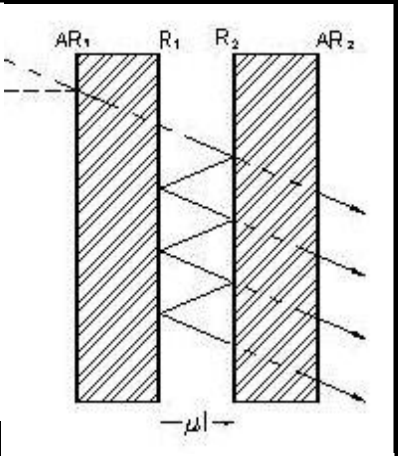


K.A.O.S. Purple Book 2002

b) Full spatial coverage with a finite wavelength range (WFT tunable imager)







$m \lambda = 2 \mu \, l \cos \theta$

$R = m N$

$dR/R = dm/m = dl/l$

R: 100 - 1000

m: 4 – 40

l : 1.5 – 15 μm

GTC-OSIRIS

SPM-Twin WFT:
3 Spaxel Distributions for Spectroscopy

High-Z & Stellar objects

a. Super sloan-like surveys (DE, LSS, etc. basically redshifts)
b. Stellar surveys (thick disk, Local group systems)
c. GC & PN systems
d. HII Regions in local galaxies

Very large number of individual spaxels (sparse sampling) with limited patrol fields each)

The Intermediate-z Universe and semi-crowded fields

a. Indicative galaxy dynamics, gradients and size
b. Indicative structure (notches, pair interaction, etc)

A number of relatively small IFUs (sparse with limited-continuous sampling), relatively large patrol fields

The "local" 150 Mpc Universe

a. Large galaxies
b. galactic extended sources

Single Large IFU (continuous sampling), fixed patrol field

Sitios privilegiados para el visible y el Infrarrojo

Norte de Chile

Antu	8.2m	Europa
Kueyen	8.2	Europa
Melipal	8.2	Europa
Yepun	8.2	Europa
Gemini	8.1	USA UK Canadá Brasil Chile Australia Argentina
Baade	6.5	USA
Clay	6.5	USA
Soar	4.1	Brasil USA
Blanco	4.0	USA 74
"360"	3.6	Europa 77
NTech	3.5	Europa
duPont	2.5	USA 75
MPG-E	2.2	Europa

Construcción: 1,200 M$
Operación: 71 M$/año

Islas de Hawai

Keck I	10m	USA
Keck II	10	USA
Subaru	8.3	Japón
Gillet	8.1	USA UK Canadá Brasil Chile Australia Argentina
UKIRT	3.8	UK 79 Canadá, Holanda
AEO	3.7	USA-AF
CFHT	3.6	Canadá Francia USA 79
IRTF	3.0	USA
UH	2.2	USA 70

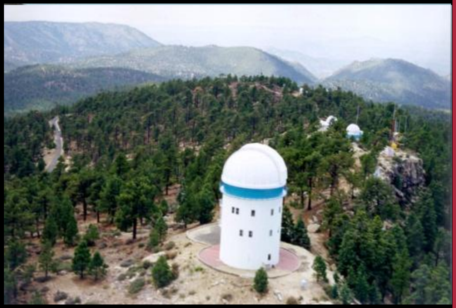
Construcción: 1,000 M$
Operación: 76 M$/año

Islas Canarias

GTC	10.4m	España México USA
Herschel	4.2	UK España Holanda
Galileo	3.6	Italia España
Newton	2.5	UK España Holanda
Nordic	2.5	Dinamrca Islandia Noruega Finlandia Suecia
Liverpool	2.0	Universitario

Construcción: 300 M$
Operación: 15 M$/año

San Pedro Mártir



SPM	2.1m	México 79
SPM	1.5	México
SPM	0.8	México

Construcción: 5 M$
Operación: 1.0 M$/año

Inversión de Construcción: sólo considera los telescopios (y edificio) listados <u>sin sus instrumentos</u>.
Presupuesto de Operación (reportes anuales oficiales 2006): telescopios para Visible e Infrarrojo únicamente.

Se excluyen radio, solar, altas energías, etc. así cómo presupuestos y desarrollos fuera del observatorio en centros de administración, investigación o del consorcio o de socios

Otros Telescopios (visible e infrarrojo)

En EEUU continental

HET	9.2	USA Alemania
LBT	2x8.4	USA Italia Alemania
MMT	6.5	USA
Hale	5.0	USA 48
Mayall	3.4	USA 73
ARC	3.5	USA
WIYN	3.5	USA
Starfire	3.5	USA Militar
Shane	3.0	USA 59
H. Smith	2.7	USA 68
Hooker	2.5	USA 17
SLOAN	2.5	USA Europa Japón
CHARA	2.4	USA Francia
MRO	2.4	USA
Hiltner	2.4	USA
WIRO	2.3	USA
Bok	2.3	USA 69
KP2.1	2.1	USA 61
Struve	2.1	USA 69

Construcción: ~800 M$
Operación: ~60 M$/año

En sitios diversos

SALT	9.8	Sudáfrica UK USA Alemania Polonia N. Zelanda
Bolshoi	6.0	Rusia 76
LZT	6.0	Canadá USA Francia
LAMOST	4.2	China USA
AAT	3.9	Australia UK 75
MPIA	3.5	Alemania España
ByAO	2.6	Armenia 76
Shajn	2.6	Ucrania 76
duPont	2.4	Francia
Lijiang	2.4	China
ANU	2.3	Australia
V. Bappu	2.3	India
MPIA	2.2	Alemania España
Beijing	2.2	China
Sahade	2.2	Argentina
HCT	2.1	India
Lyot	2.0	Francia
Faulkes-S	2.0	Australia

Construcción: ~310 M$
Operación: ~40 M$/año

En construcción

VLT-Int	4^{+}x8.4m	Europa (en Chile)
Keck-Int	2x10	USA (en Hawai)
LSST	8.0	USA (en Chile)
Lamost	6.4	China USA UK
DCT	4.2	USA (en USA)
VISTA	4.0	Europa (en Chile)
VST	2.6	Europa (en Chile)
Aristarcos	2.5	Grecia
APF	2.4	USA (en USA)
Pan-STARRS	4x1.8	USA (en Hawai)
MRO-I	2.4+10x1.4	USA (en USA)

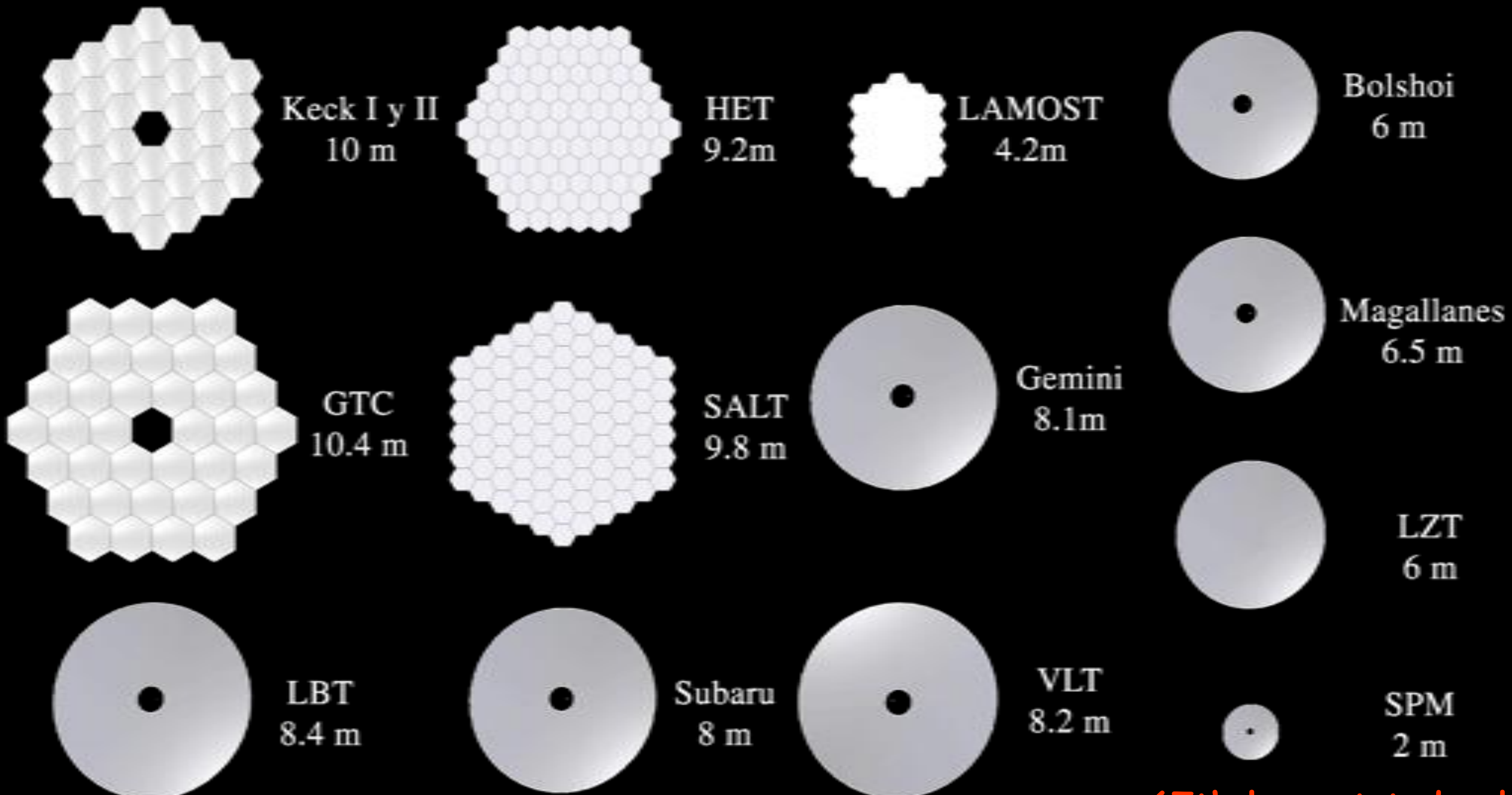
Inversión: ~730 Musd

Planeados

E-ELT	42m	Europa (en Chile o Canarias)
TMT	30m	USA (en Hawai, Chile o SPM)
GMT	24m	USA (en Chile)

Inversión: ~2,700 Musd

Algunos de los primarios de hoy



67th largest today !

Static-Sky Sensitivities

Significant advances over planned and existing surveys

- 1st full sky IR coverage in the Northern sky
  - UKIDSS only 1/5 of the SASIR area
  - VISTA covers a similar area in two filters only (JK)
  - Both are much shallower
- Premier program for identifying the faintest, rarest, reddest objects

Filter	Point Source Sensitivity				Extended Source Sensitivity	
	Single Epoch (5-σ)		Survey (5-σ)		Survey (5-σ per pixel)	
	[AB mag]	[μJy]	[AB mag]	[μJy]	[AB arcsec^{-2}]	[μJy arcsec^{-2}]
Y	23.49	1.45	24.47	0.59	23.32	1.71
J	22.95	2.40	23.93	0.97	22.78	2.82
H	22.60	3.30	23.57	1.35	22.42	3.89
K_s	22.47	3.74	23.44	1.52	22.29	4.40

Based on a preliminary simulation of a four band survey (Y and 2MASS filters J,H,Ks) with 75% clear weather fraction and average seeing of 0.6 arcsec and 18 micron pixels. Each epoch assumes 80 sec total integration with 6 epochs per field over the entire survey (24,000 sq. deg.).

Basic Survey

- ~ 20 sec dithered exposures => total on-source dwell of 80 sec
- 2 visits per night of 2 integrations each

- Cover ~140 sq deg per 9hr night (6 sec slew time)
- Entire SPM visible sky imaged every 3 mnths

- ~0.05" Paralaxes (10-sigma) for a K=20 mag nearby sky

SASIR comparison with other significant IR surveys already completed (×) or planned (o). Left: point source K-band sensitivity versus sky coverage. Right: point source sensitivity versus wavelength for wide-area surveys. Survey data compiled by D. Stern (JPL).

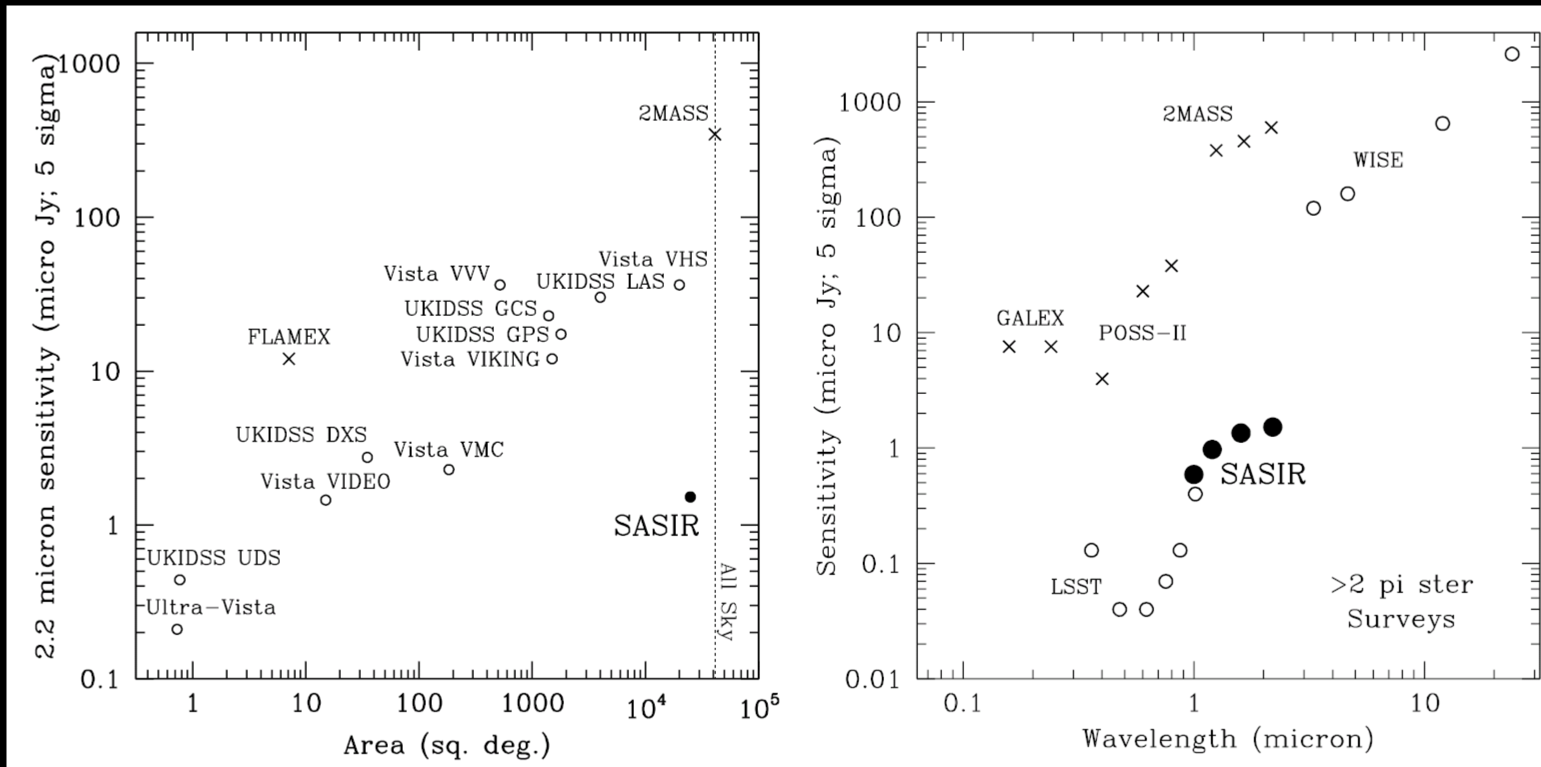


Table 1. Sensitivities of the SASIR Survey

Filter	Point Source Sensitivity Single Epoch (5-σ) [AB mag]	Single Epoch (5-σ) [μJy]	Survey (5-σ) [AB mag]	Survey (5-σ) [μJy]	Extended Source Sensitivity Survey (5-σ per pixel) [AB arcsec^{-2}]	Survey (5-σ per pixel) [μJy arcsec^{-2}]
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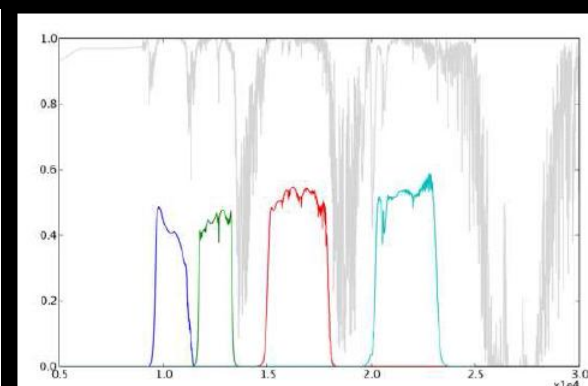
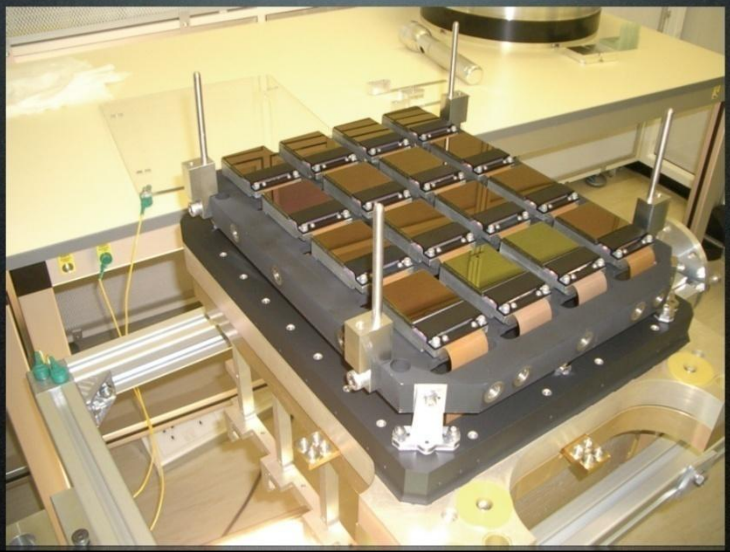


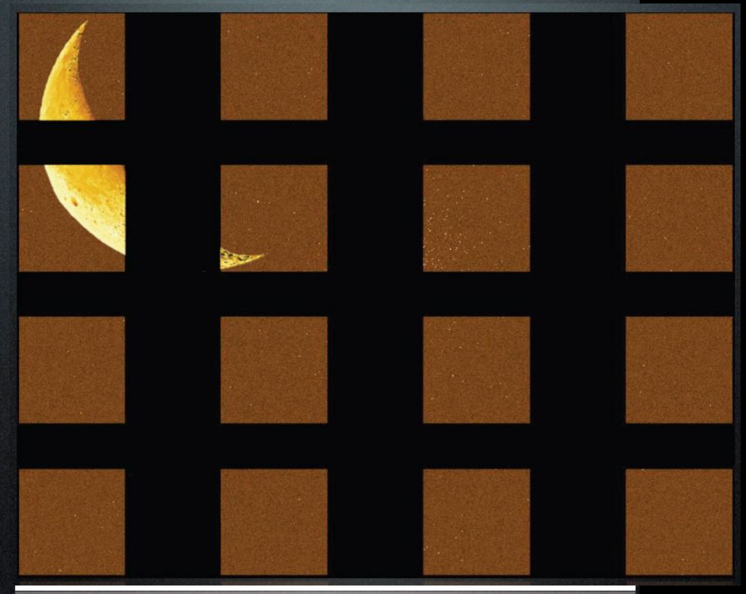
Absolute Y, J, K, Hs SASIR throughput

Technical Concept (Detectors)

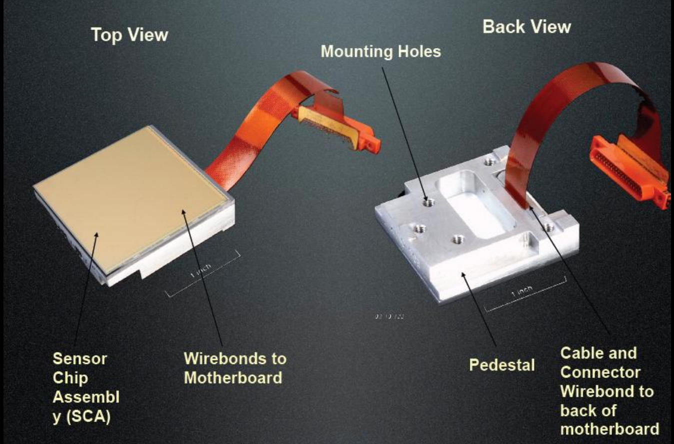
VISTA: 16x Raytheon VIRGO 2k x 2k



16x Raytheon VIRGO 2k x 2k

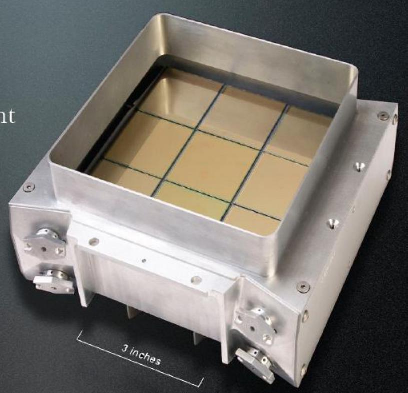


Modules for Minimum Edge Gaps

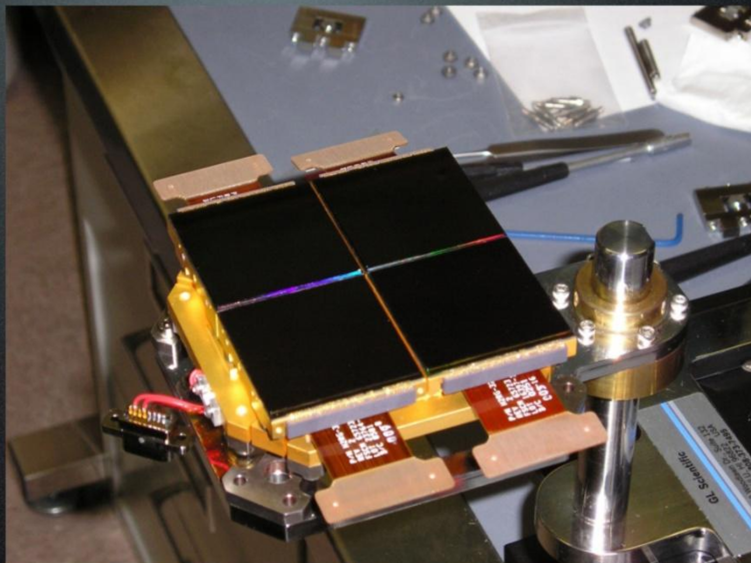


9 Modules in Thermal Isolating Housing

- Provides Convenient Mounting of Modules
- Provides accurate alignment
- Inner cold structure insulated from outer housing for minimum headload
- Design space qualified



WIRCAM/CFHT: 4x H2RG Teledyne



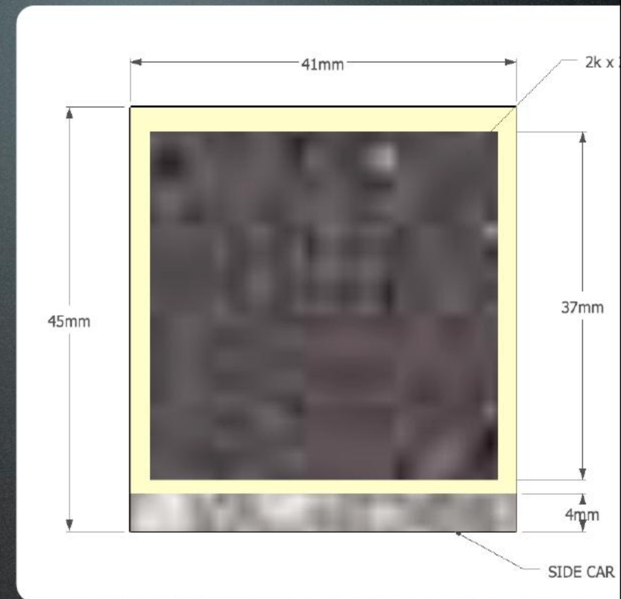
also, WFC3,
WIRE,
MOSFIRE,
JWST,
SNAP

Hawaii-2 RG

18 μm pixels
= 0.228”/pix (@ f/2.5)
= 0.163”/pix (@ f/3.5)

2040 x 2040 live pixels

fill factor = 0.757



Hawaii-2 RG

- 100,000 e “full-well” (95% linearity)
- < 30 e readnoise (CDS)
- 16 bit A/D (+ 12 bit A/D for fast reads)
- 1 of 32 channels can be used for fast reads of sub-arrays during exposure -> on-chip guiding! cf. WIRCAM/CFHT

Heat load:

1/2 Watt per ASIC at running at capacity x 80 ~ 40 Watt * 5% duty cycle ~ <2 Watt>

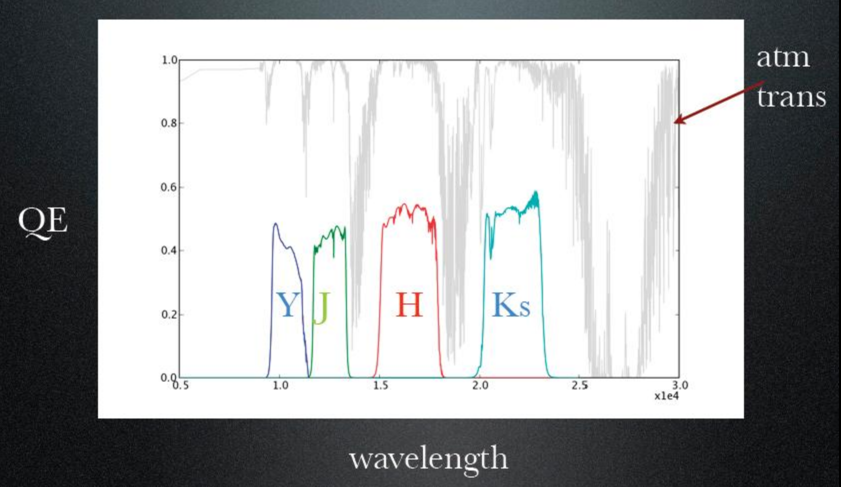
IR Detectors

Basic Costs

science grade — 1x 2k x 2k array = $350,000 (H2RG; Teledyne)
= $380,000 (VIRGO: Raytheon)

(Teledyne) { + *$25k readout circuit*
+ *$42k sidecar ASIC kit (USB interface)* }

- Yield is key to cost & time:
  we "buy the distribution"
  e.g., engineering grade H2RG = $50k



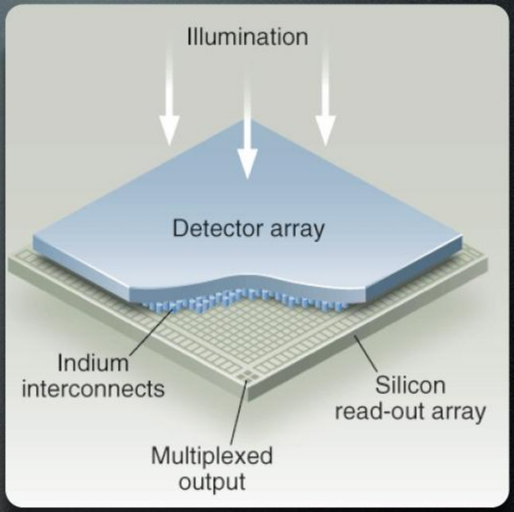
Overall Costs & Timeline

distribution discount: avg. ~$200k/unit (including sidecar, electronics...)

~($16M to $24M) + $2M focal plane assembly ~ $18M - $26M (5 - 8 cent/pixel)

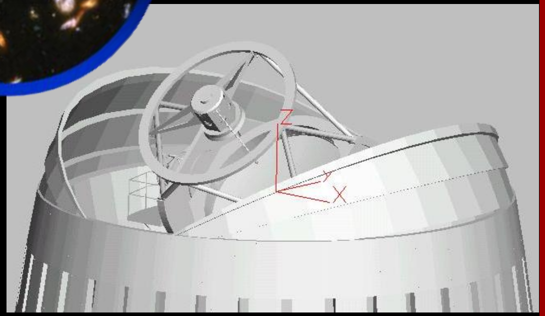
3 - 4 yr timescale for delivery is ok with milestone payments beginning ~start of 2009

removal of CdZnTe substrate gives sensitivity to 400 nm (improves yield)



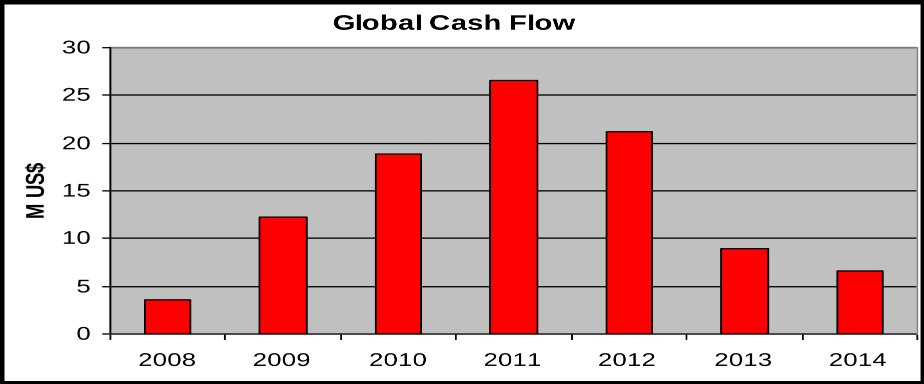
1st order estimate
Need IR-Camera Concept

SASIR
SPM WFT



Budget (MUS$)

Feasibility Study	0.250
Conceptual Design	0.600
Science Act., Dcf. & Sup.	0.250
Management	4.540
System Engineering	1.500
Enclosure & Civil work	11.200
Telescope Structure	10.290
Telescope & IR Optics	23,000
Support facilities	1.500
Control System	8.000
IR Detectors	22.000
Total	82.520
Contingency (15%)	12.378
TOTAL	94.898



Other relevant subjects

- Budget & financing strategy
  - ~ 150 M$ (facility+survey)
  - Broader than Astro autreach (education, industry, science connections)
  - Mostly California & Mexico private donor with a seed from public funding (NSF, CONACyT and alike)
  - Reasonable 1st-light goal: late 2013
- Mexican astronomy benefits
  - Survey & data products design & science
  - Significant increase of Large-Tel time:
    - ✓ SASIR Telescope itself during and after IR survey
    - ✓ Follow-up science (presnet & future): GTC, GTM, ESO, Space, ELTs, etc
  - Potentiate SPM as a world-class observatory
- GH meeting (Aug 13-22)
  - further definitions of the SASIR science, technical, management & financing aspects

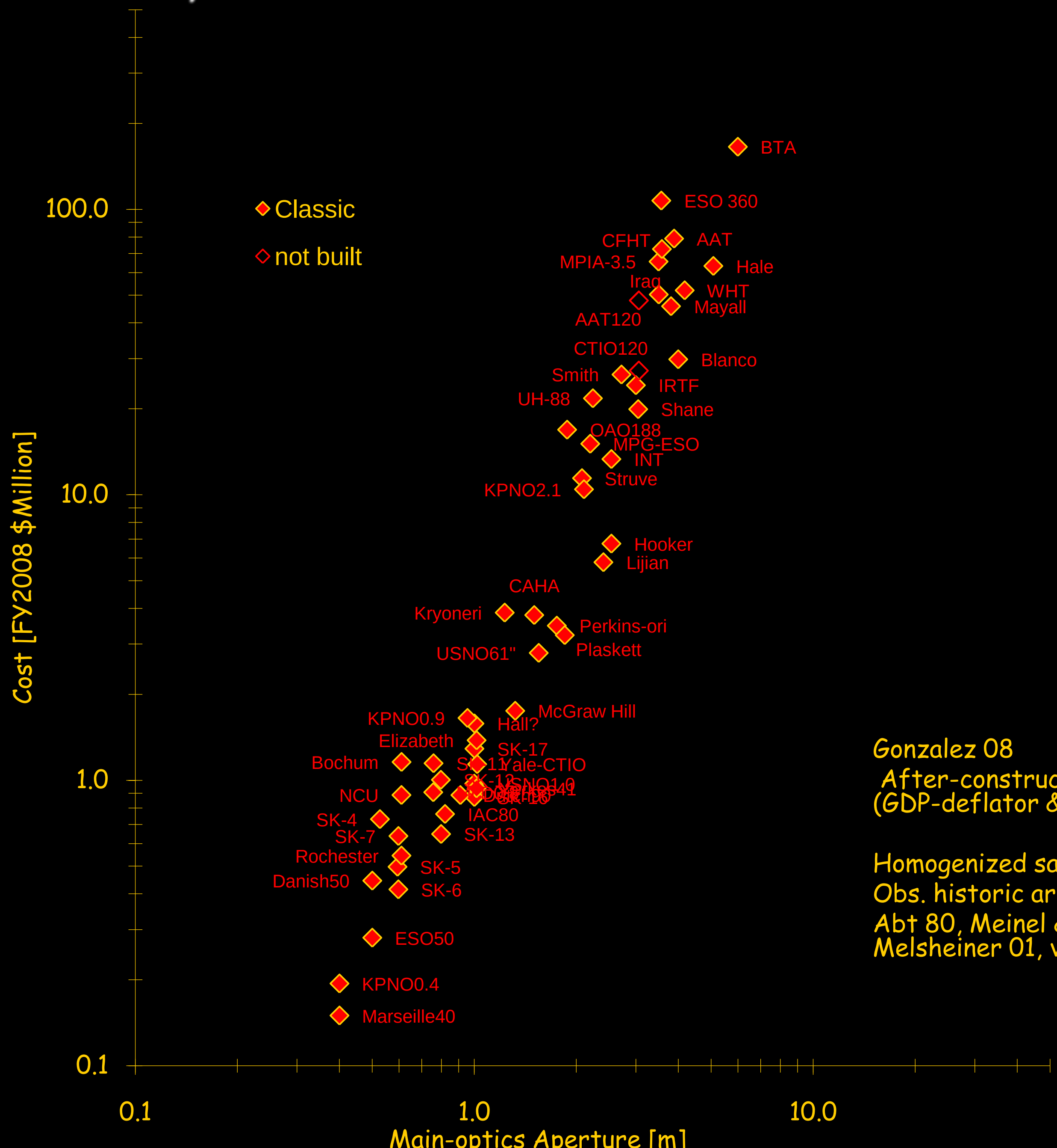
Detectors

- The cost of large format science-grade IR arrays is plummeting. The current price (as of Feb 2008) appears to be $350k for a single 2k x 2k MgCdTe from Teledyne (according to Chris Bebek). [Bulk rate now we might be able to get $300k per…in one year from now perhaps $250k]. There are two main vendors Raytheon and Teledyne/Rockwell each with experience building IR array systems for astronomy. They can deliver the arrays themselves or the arrays pre-mounted in whatever focal plane configuration we specify.

Segunda parte

- Los telescopios y sus costos
  - Relación costo apertura
    - Distribución de costes
  - Instrumentos
  - Operación

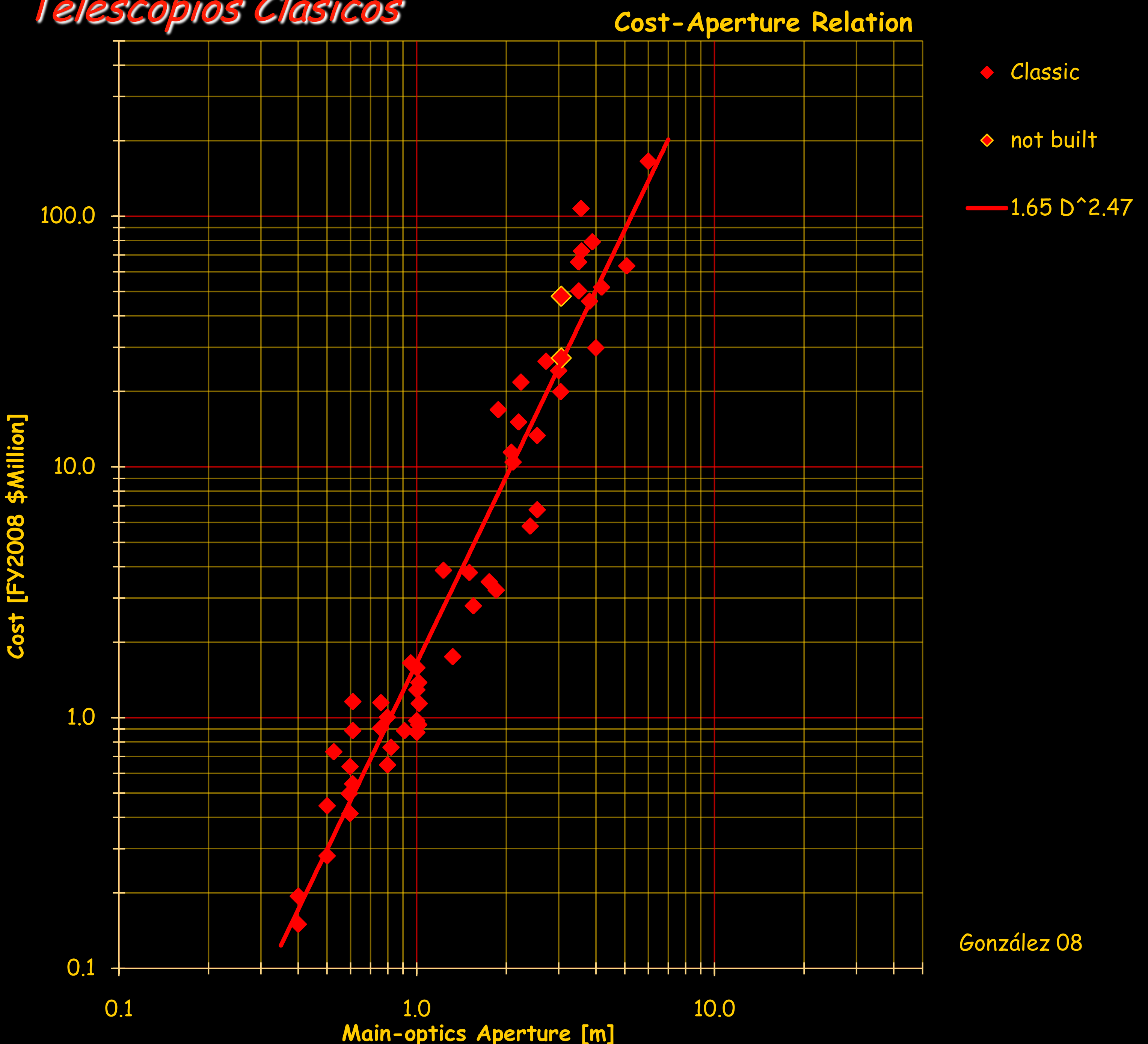
Telescopios Clásicos



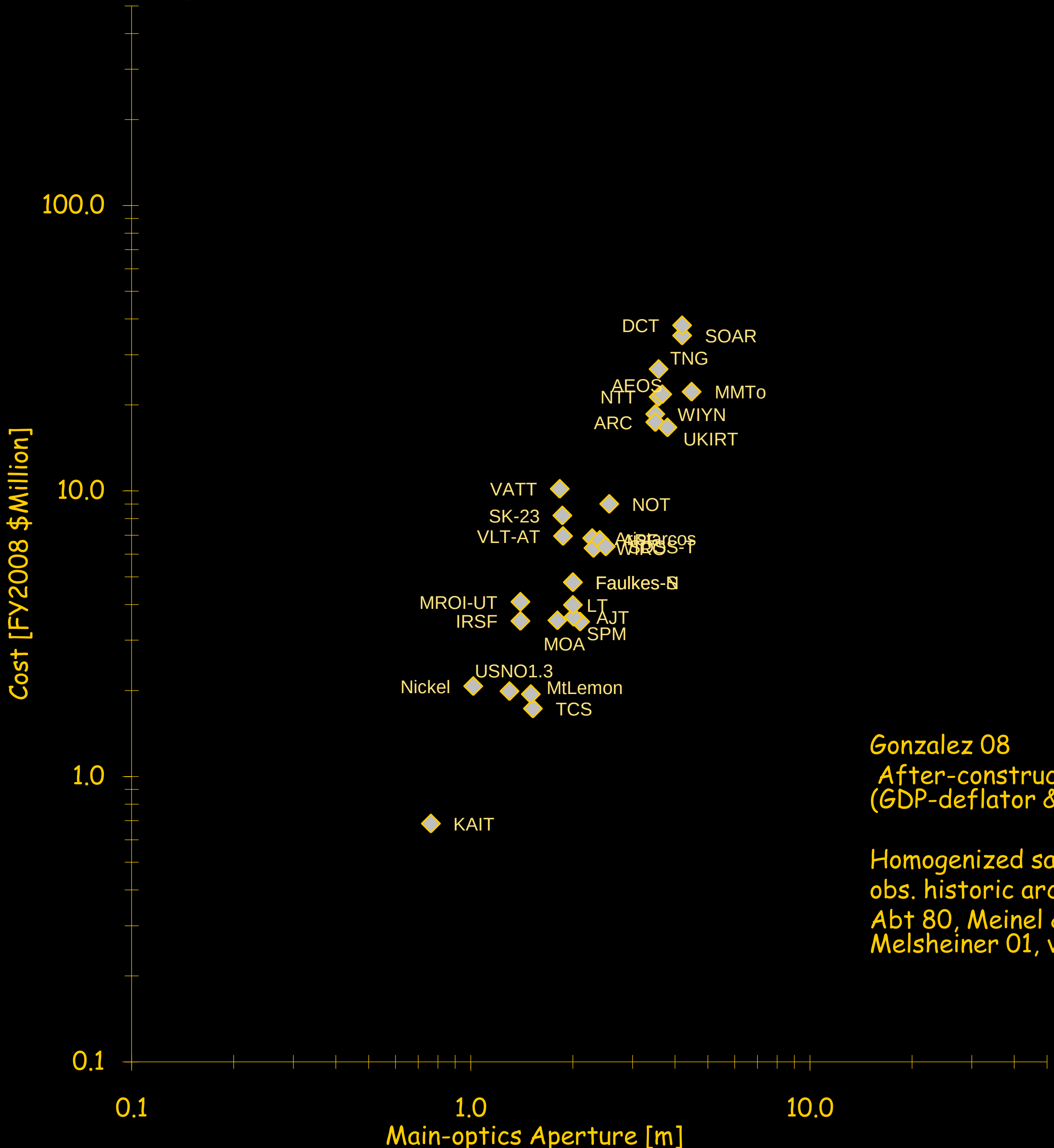
Gonzalez 08
After-construction project cost. Telescope & Building only.
(GDP-deflator & exchange rates at completion date)

Homogenized sample from very many kinds of sources:
Obs. historic archives, Press, obs. & gov. web pages,
Abt 80, Meinel & Meinel 80, Schmidt-Kaler & Rucks 1998,
Melsheiner 01, vanBelle et.al 03, etc.

Telescopios Clásicos



Telescopios Modernos



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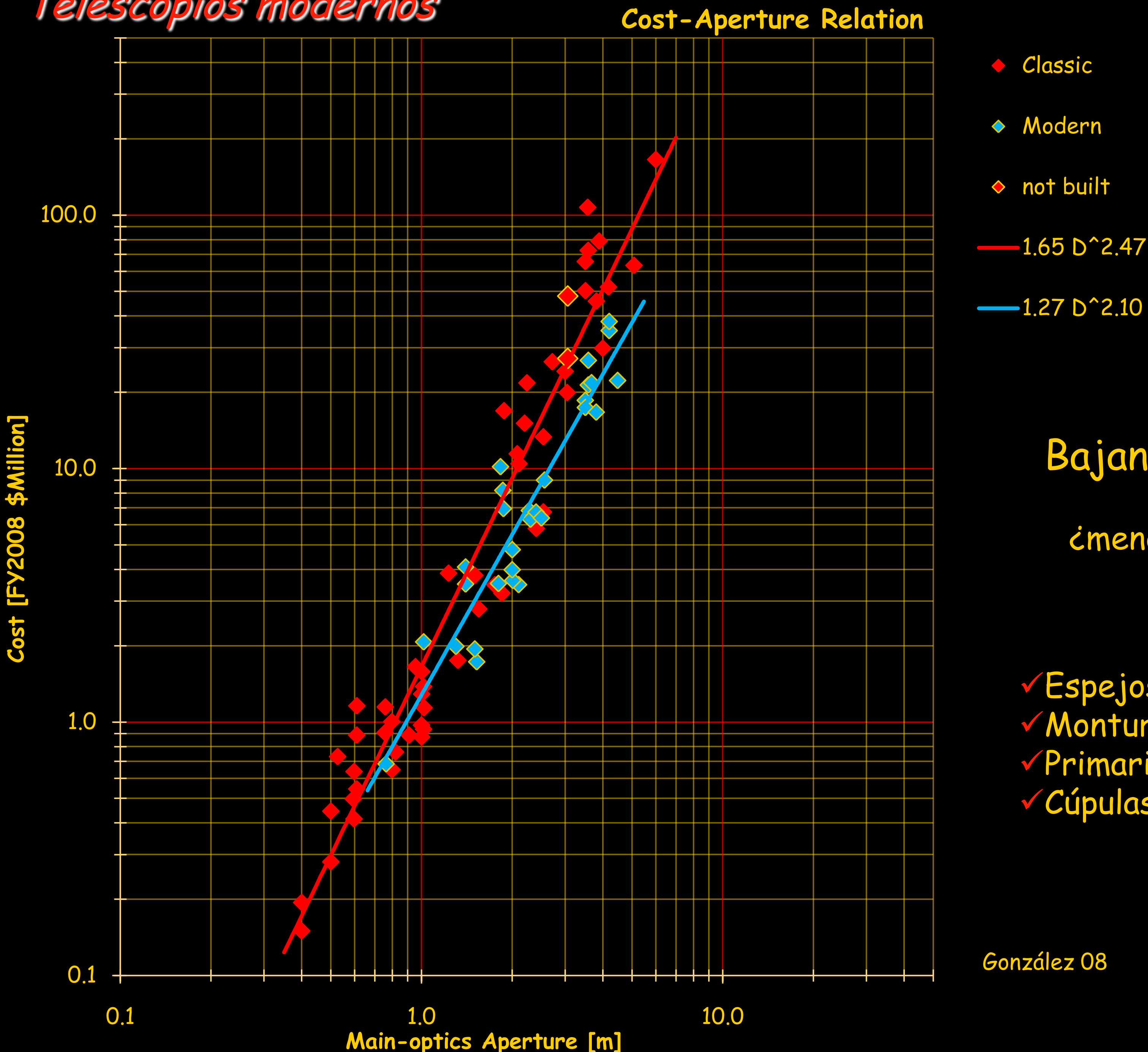
Telescopios modernos



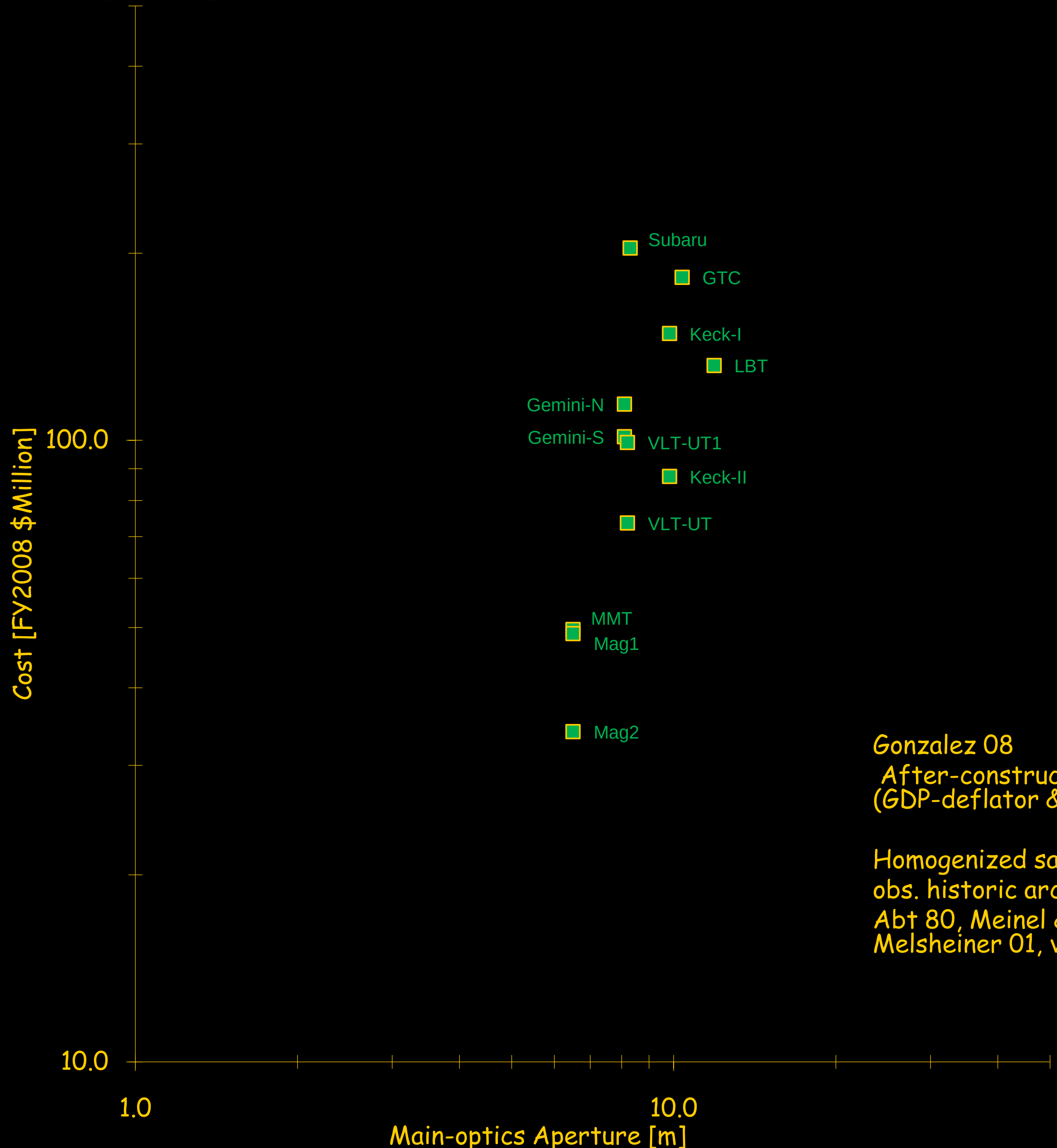
Bajan costos ~77%

¿menor pendiente?

- ✓Espejos más ligeros
- ✓Monturas Alt-Az
- ✓Primarios más rápidos
- ✓Cúpulas menos sobradas

González 08

Very Large Telescopes



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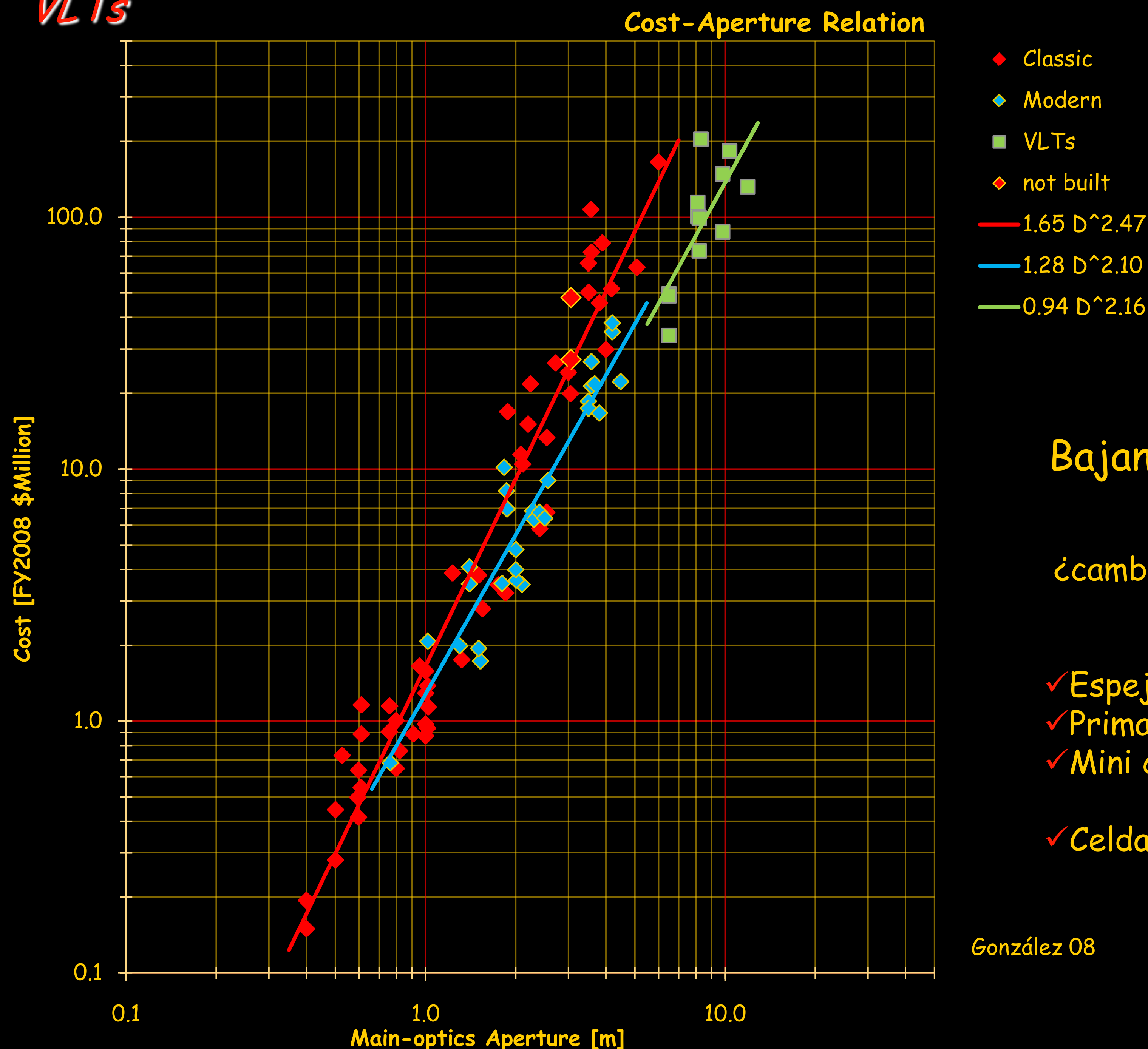
VLTs



Bajan más el coste
~74%

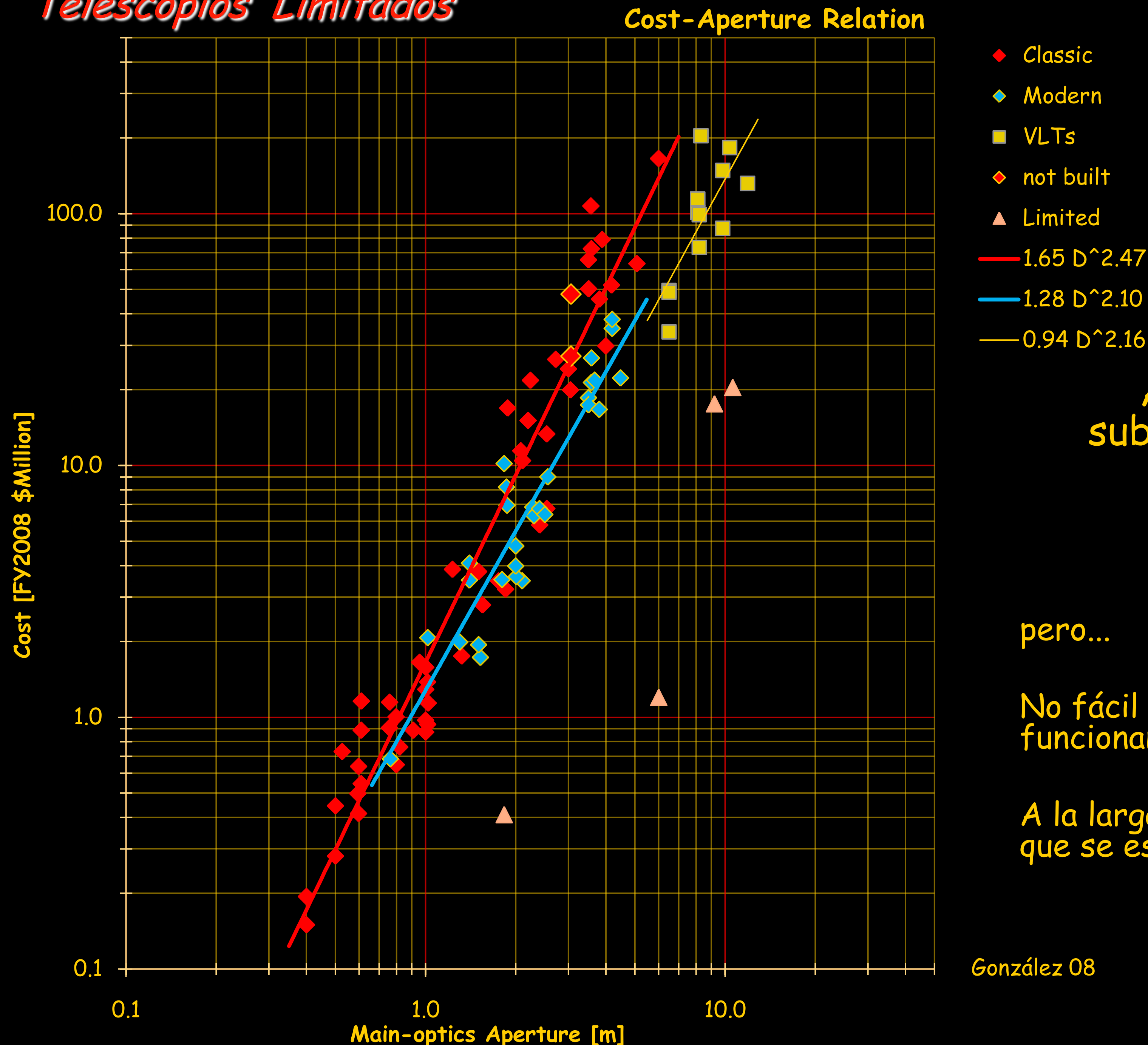
¿cambio en pendiente?

- ✓Espejos súper ligeros
- ✓Primarios súper rápidos
- ✓Mini cúpulas

- ✓Celdas más complejas

González 08

Telescopios Limitados



Ahorros substantivos !

SALT

HET

LZT

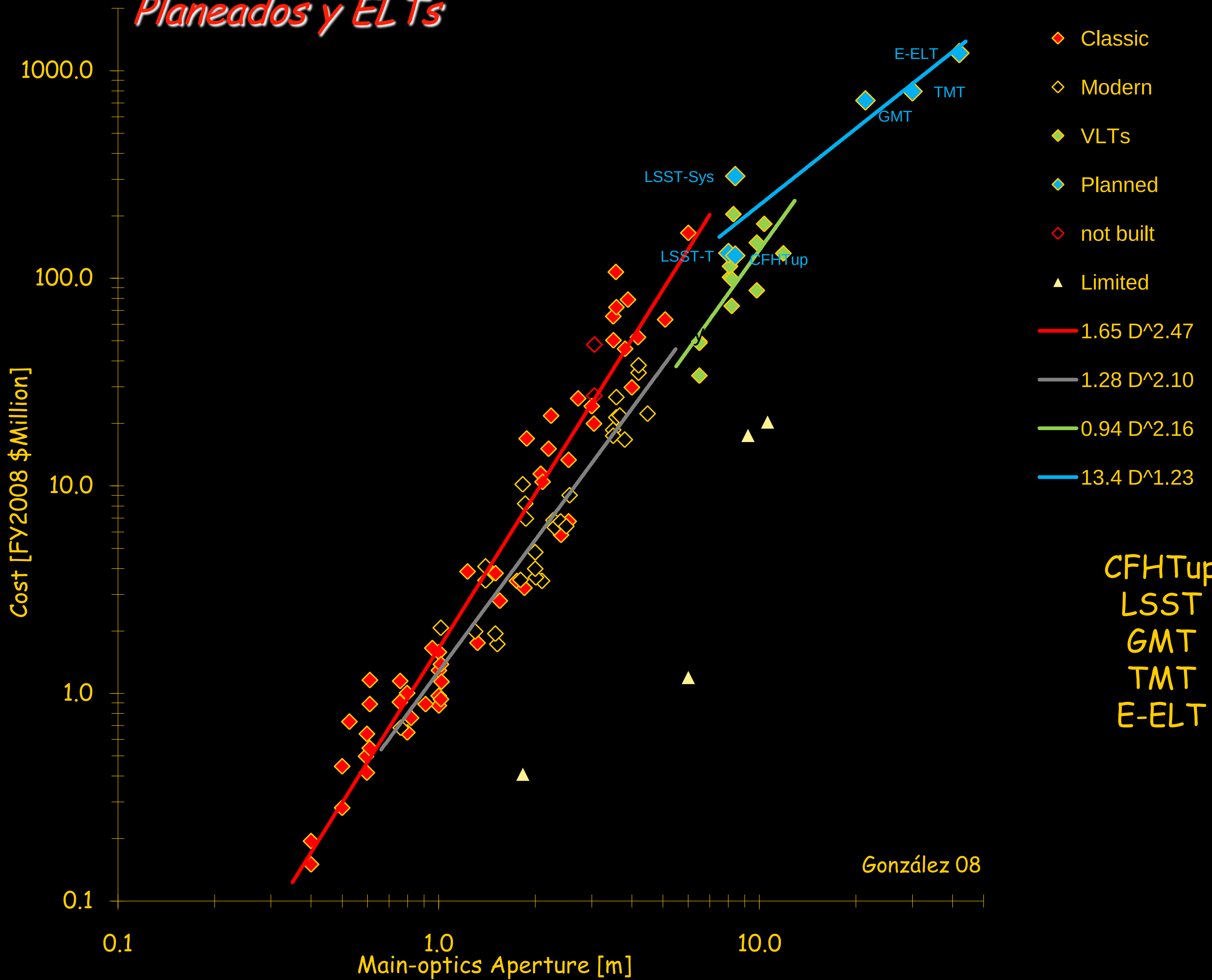
OSETI

pero...

No fácil ni rápidamente funcionan

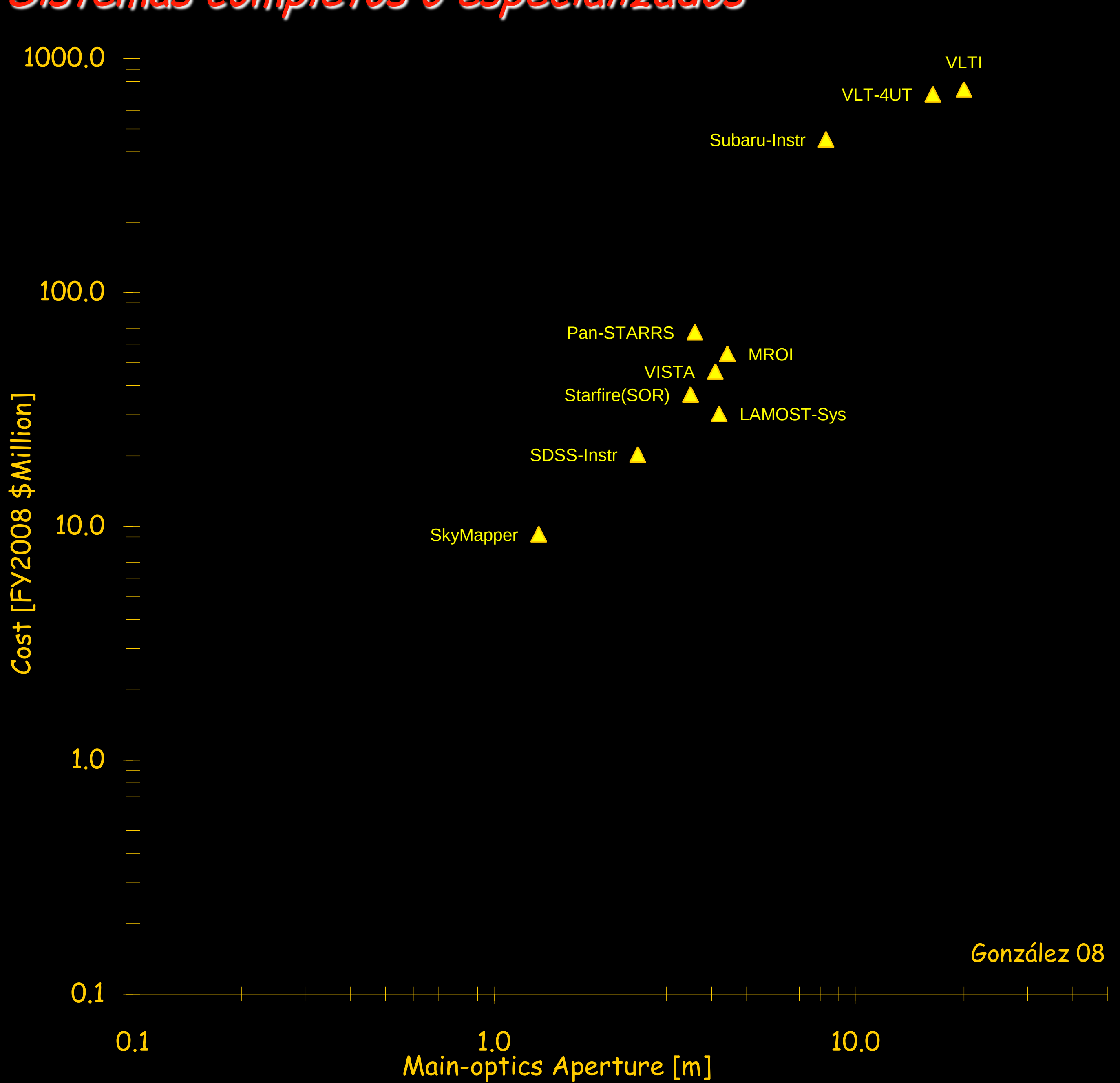
A la larga pierden a menos que se especialicen

Planeados y ELTs



CFHTup
LSST
GMT
TMT
E-ELT

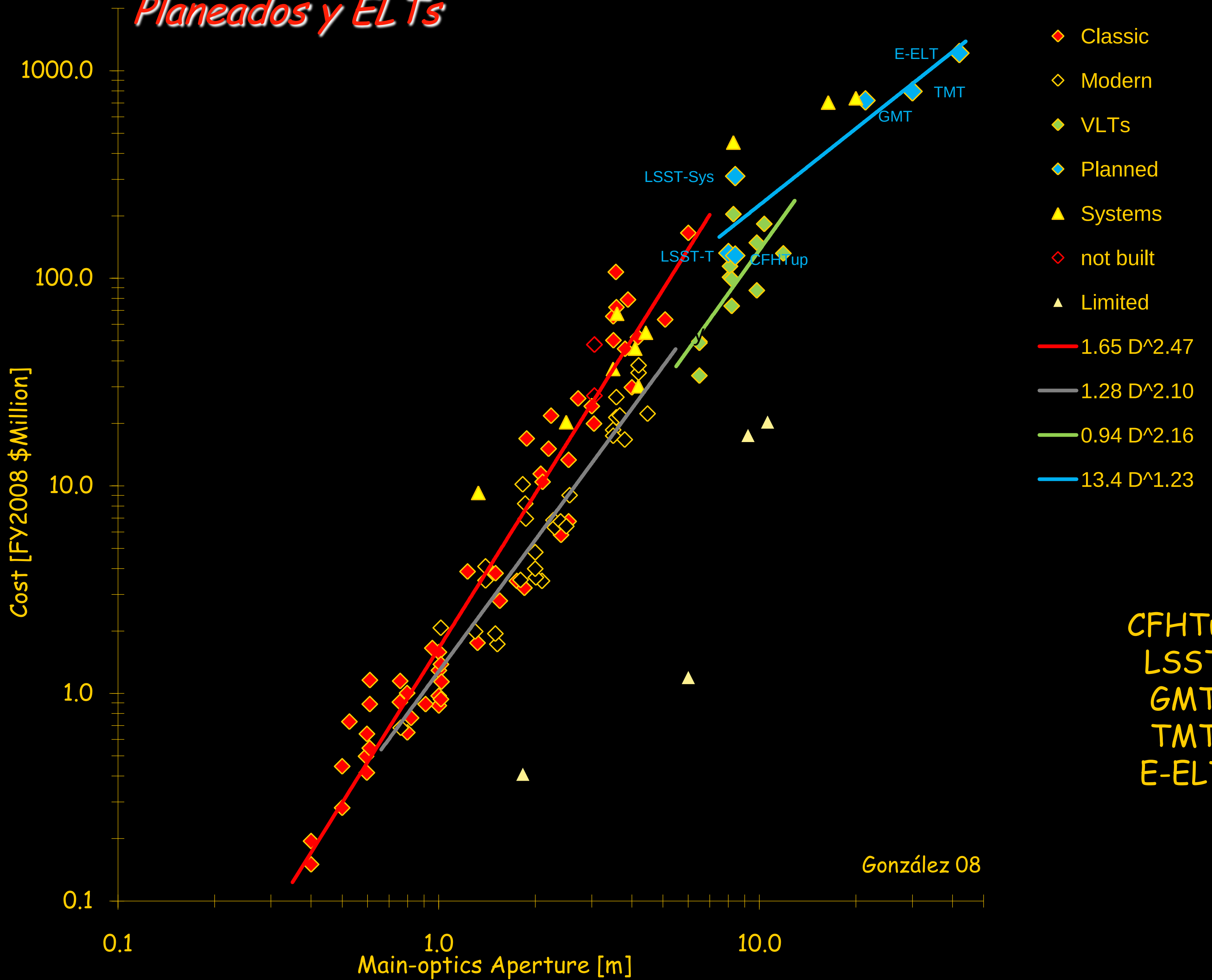
Sistemas completos o especializados



SkyMapper
SDSS
Starfire
Pan-STARRS
MROI
Subaru-Instr
VLT-4UT
VLT-I
Vista

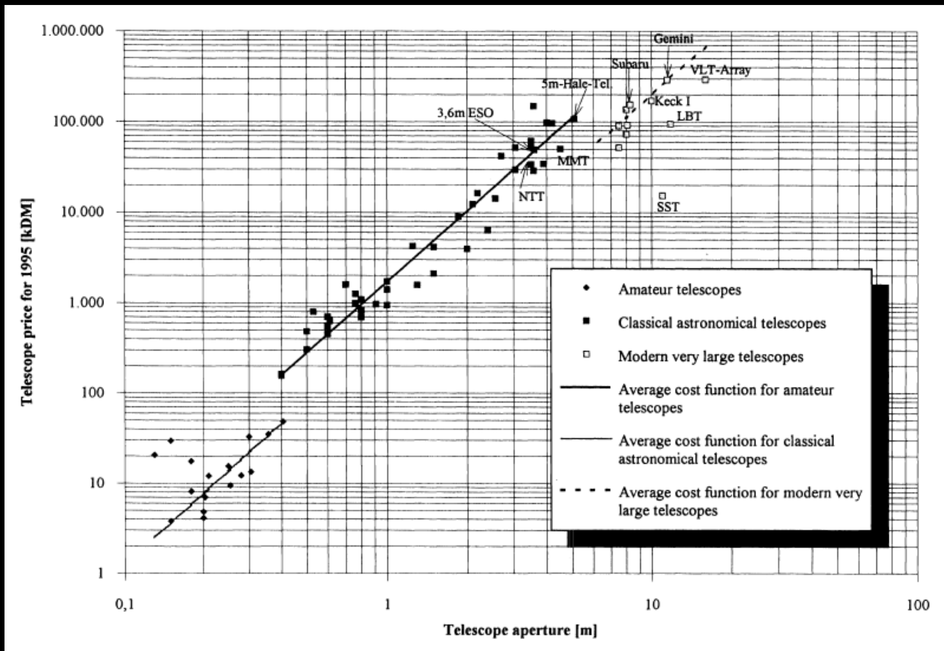
LSST
APF

Planeados y ELTs



CFHTup
LSST
GMT
TMT
E-ELT

Previous work



$\$ \sim D^{2.6}$ (Smith-Kaler & Ricks 1997)

$\sim D^{2.1}$ (Melsheimer 2001)

$\sim D^{2.4}$ (vanBelle & Meinel² 2004)

¿Quién eres?

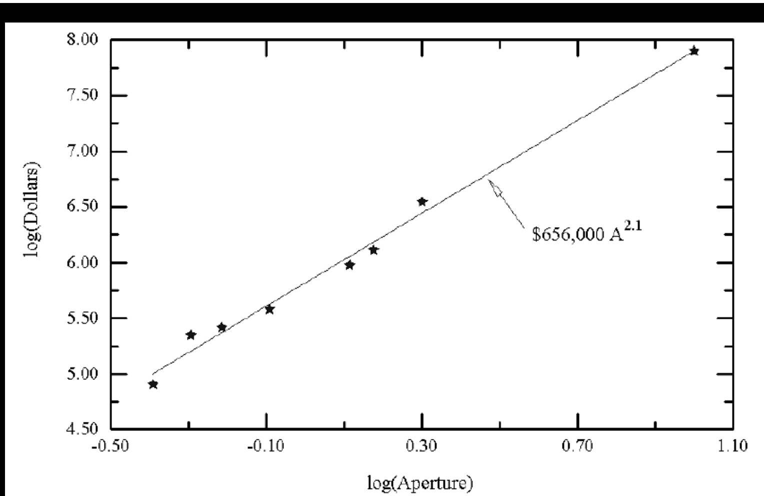


Figure 1. Current telescope construction costs (from Melsheimer, 2001.) Related costs, such as building or instruments, are not included.

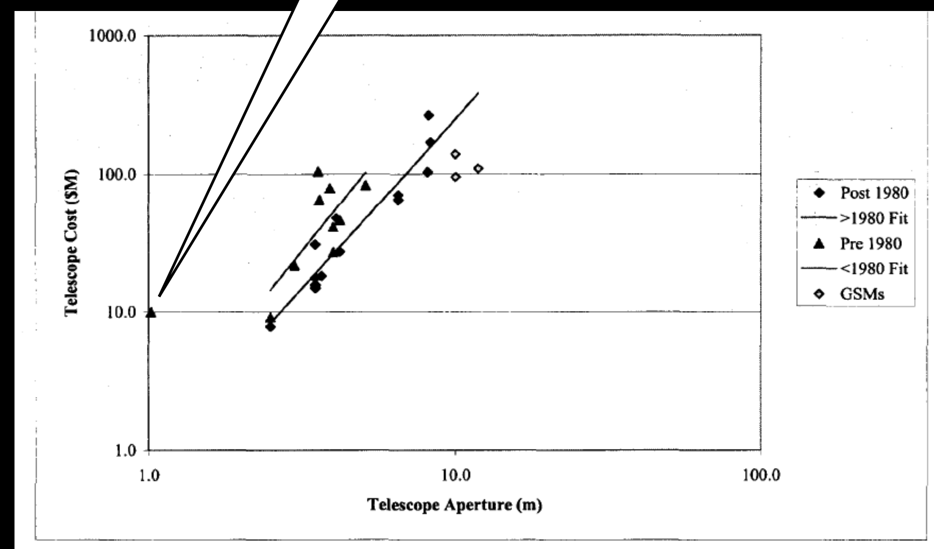
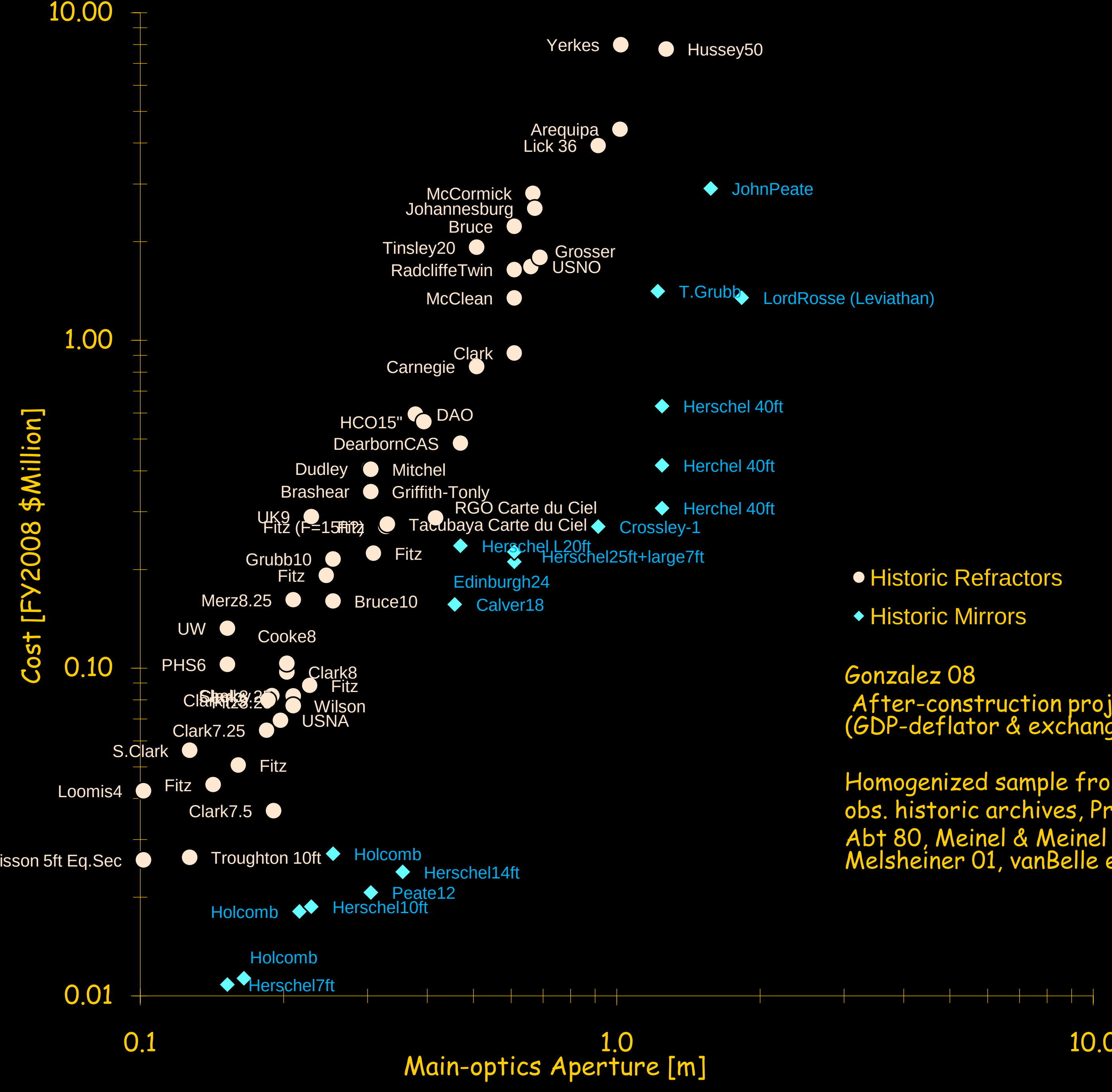


Fig. 1.— Cost versus aperture diameter for optical telescopes built before and after 1980. For the pre-1980 fit, cost $\propto D^{2.77}$, and for the post-1980 fit (exclusive of the giant segmented mirrors), cost $\propto D^{2.45}$.

Van Belle, Meinel & Meinel, 2004

Reflactores y reflectores historicos



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After-construction project cost. Telescope & Building only.
(GDP-deflator & exchange rates at completion date)

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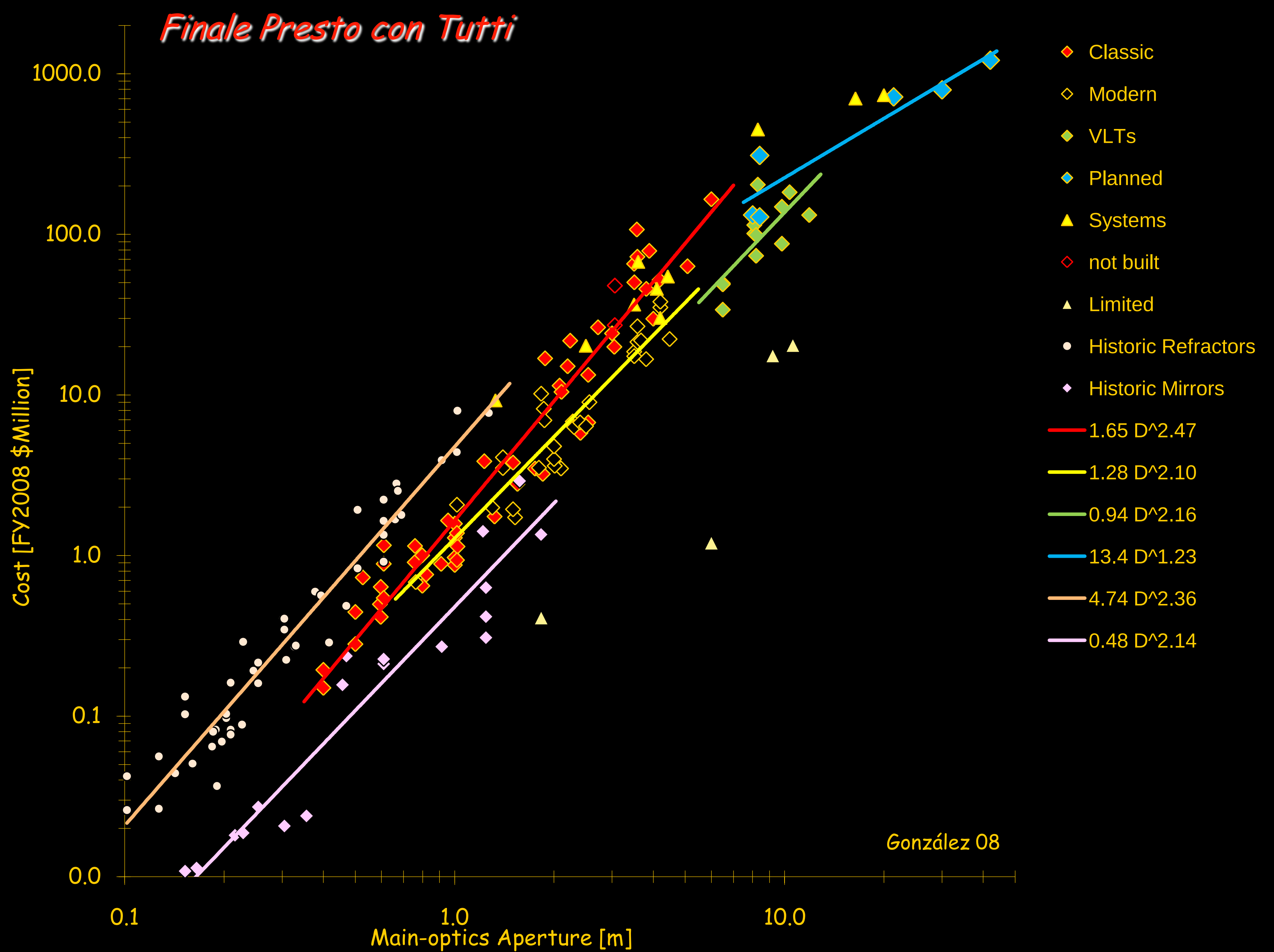
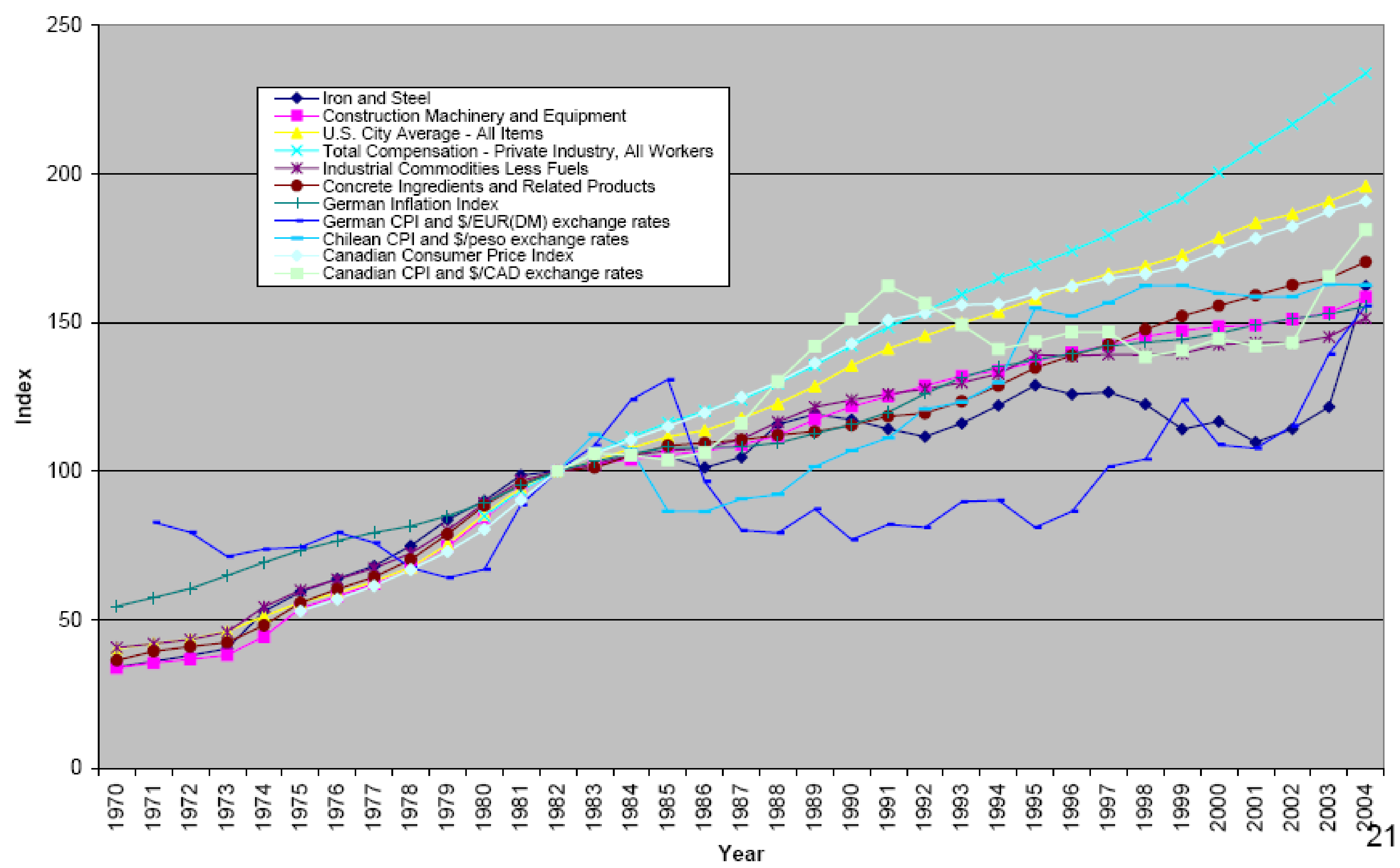


Finale Presto con Tutti
Cost [FY2008 $Million]
1000.0
100.0
10.0
1.0
0.1
0.0
0.1
1.0
10.0
Main-optics Aperture [m]
Classic
Modern
VLTs
Planned
Systems
not built
Limited
Historic Refractors
Historic Mirrors
1.65 D^2.47
1.28 D^2.10
0.94 D^2.16
13.4 D^1.23
4.74 D^2.36
0.48 D^2.14
González 08

Índices económicos (?)



We used GDP – deflator for Present-day project cost estimate (not value nor just inflation)

Distribución de costos de inversión

Tipical Cost Distribution 8-m Telescope (FY 2006, mean of VLT, Gemini, LSST)

System Management	**8.56**			**7.7%**		
Telecope devolopment		5.56			5.0%	
System Management		3.00			2.7%	
System Engineering	**0.94**			**0.8%**		
Performance Assurance	**0.38**			**0.3%**		
Hardware/Software Dekiverables	**96.68**			**87.4%**		
Facilities & Infraestructure		16.00			14.5%	
Telescope Mount		16.20			14.6%	
Dome		10.60			9.6%	
Mirrors		31.00			28.0%	
M1			22.60			20.4%
M2			8.40			7.6%
WFS & aligment		1.13			1.0%	
Calibration System		4.63			4.2%	
Software & Control		3.88			3.5%	
Obs Monitoring		1.13			1.0%	
Equipment & Support Subsystems		12.13			11.0%	
Telescope Integration and Test	**3.25**			**2.9%**		
Observatory Integration, Test & Commision	**0.81**			**0.7%**		
Total	**110.61**					

Instrumentos

- Rangos espectrales
  - Visible
  - Infrarrojo cercano (NIR)
  - Infrarrojo térmico (MIR)
- Resoluciones espaciales:
  - Limitada por difracción
  - Limitada por seeing
  - Limitada por muestreo
- Resoluciones espectrales
  - Imagen (BB-NB)
  - Flujos
  - Redshifts
  - Perfiles y alta densidad de líneas

- Costos indicativos
  - MTs (1-4m): 1/2-2.5 M$
  - VLTs (6-8m): 5-15 M$
  - ELTs (>20m): >20 M$ (?)
  - Muy dependiente de:
    - Rango espectral
    - Número de detectores
    - Número de modos
    - Grado de Replicación e Innovación
- Distribución de gastos
  - Hardware/software: 50%
  - Caballos de Fuerza (M/M): 50%
  - Varía con:
    - Diámetro del Tel y de campo
    - Complejidad del instrumento
    - Grado de Replicación

Operación

- Varían entre el 7% y el 5% del costo de inversión

- Distribución de gastos:
  - Salarios: 70-80%
  - Mantenimiento: 5-15
  - Servicios: pocos %
  - Todo lo demás: pocos %

- Costos dependen mucho
  - Número de telescopios
  - Número de instrumentos
  - Número de sitios

- Basado en los reportes anuales (2006) de:

Keck:	24 M$/yr
Gemini:	34
UKIRT:	4.3
CFHT:	6.3
IRTF:	3.4
NOAO:	24
ESOchile	39
ING:	3.1
NOT:	1.8
AAT:	11.5
Magellan:	3.8
MMT:	2.2
Subaru, Francia, Italia: ?	