How to capitalize the unique Antarctica site performance for astronomy.

Gil Moretto
CRAL/CNRS, Lyon, France

On behalf of French Antarctic Astronomy Community
Lyu Abe, Eric Aristidi, Marcel Carbillet, Nicolas Epchtein, Farrokh Vakili, Aziz Ziad (Nice)
and
Maud Langlois, Gil Moretto, Isabelle Vauglin (Lyon)

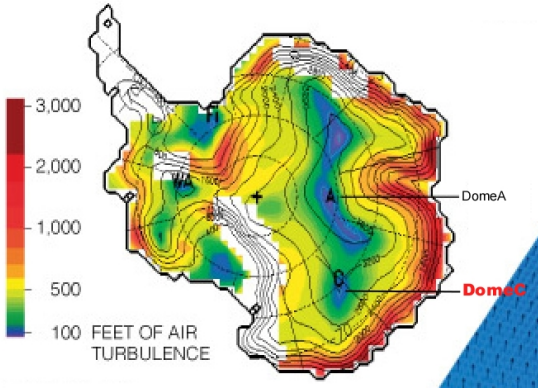
Photo © J. Zaccaria

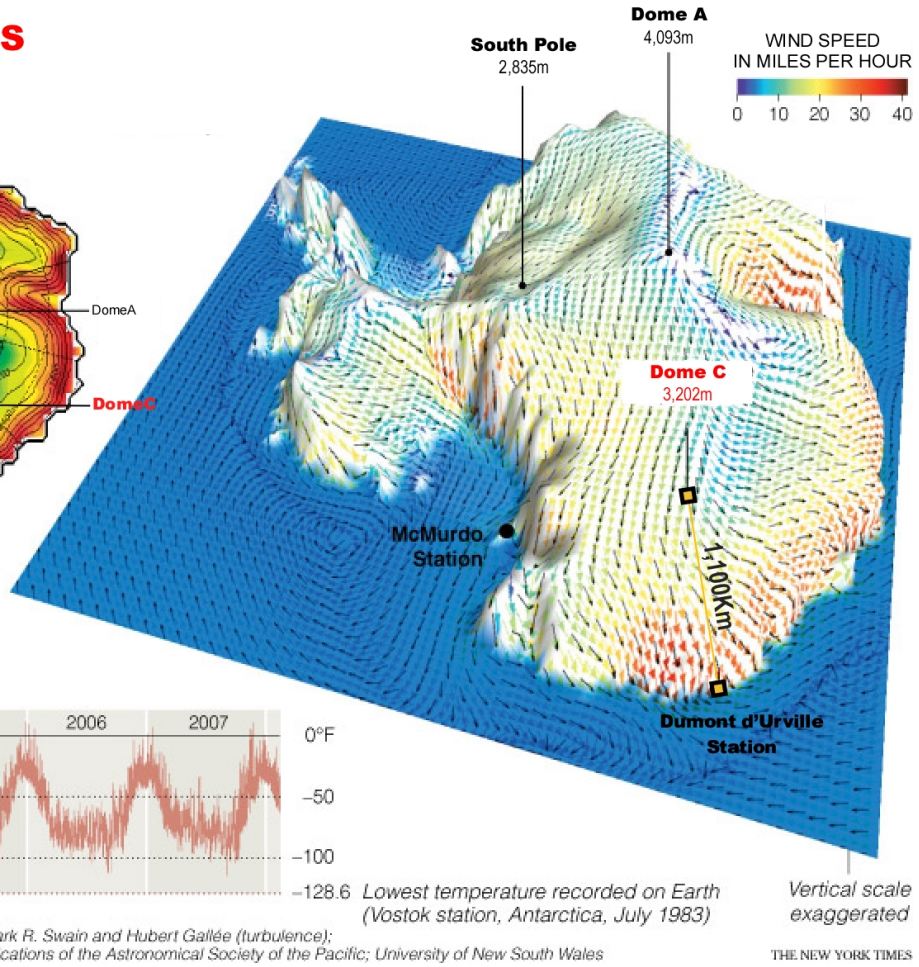
Astronomy and Astrophysics from Antarctica
Third Workshop of the SCAR AAA
7-10 August 2015, Kilauea Military Camp, Hawaii, USA

DOME C might be among the most studied sites!

HIGH ALTITUDE & CALM WINDS

DomeC is at 3,202m and one of the least windy.





CLEAR & STABLE SKIES

The only turbulence at Dome C is close to the ground!

LOW TEMPERATURES

At -50°C to -90°C for Dome C, one the coldest places on Earth

Lowest temperature recorded on Earth (Vostok station, Antarctica, July 1983)

Sources: Andrew J. Monaghan (wind speed); Mark R. Swain and Hubert Gallée (turbulence); Australian Antarctic Division (temperature); Publications of the Astronomical Society of the Pacific; University of New South Wales

THE NEW YORK TIMES

DRY & CLEAN

Low Precipitable Water Vapor (PWV) and Reduced Particulate Content

TRANSPARENT, STABLE, COLD, DRY & CLEAN
LOW THERMAL BACKGROUND
LOW SKY BRIGHTNESS

Winter Scenario

Turbulent Boundary Layer = 23m

Above 23m Seeing ~ 0.”36

	Seeing	Isop.	Coh. time
DIMM/GSM	0.4 ‘’	4.1 ‘’	
SSS	0.3 ‘’	6.9 ‘’	10.2 ms
Balloons	0.4 ‘’	2.7 ‘’	6.8 ms
AASTINO 2004[1]	*0.3 ‘’*	*5.7 ‘’*	*7.9 ms*
Simulations[2]	0.3 ’’		

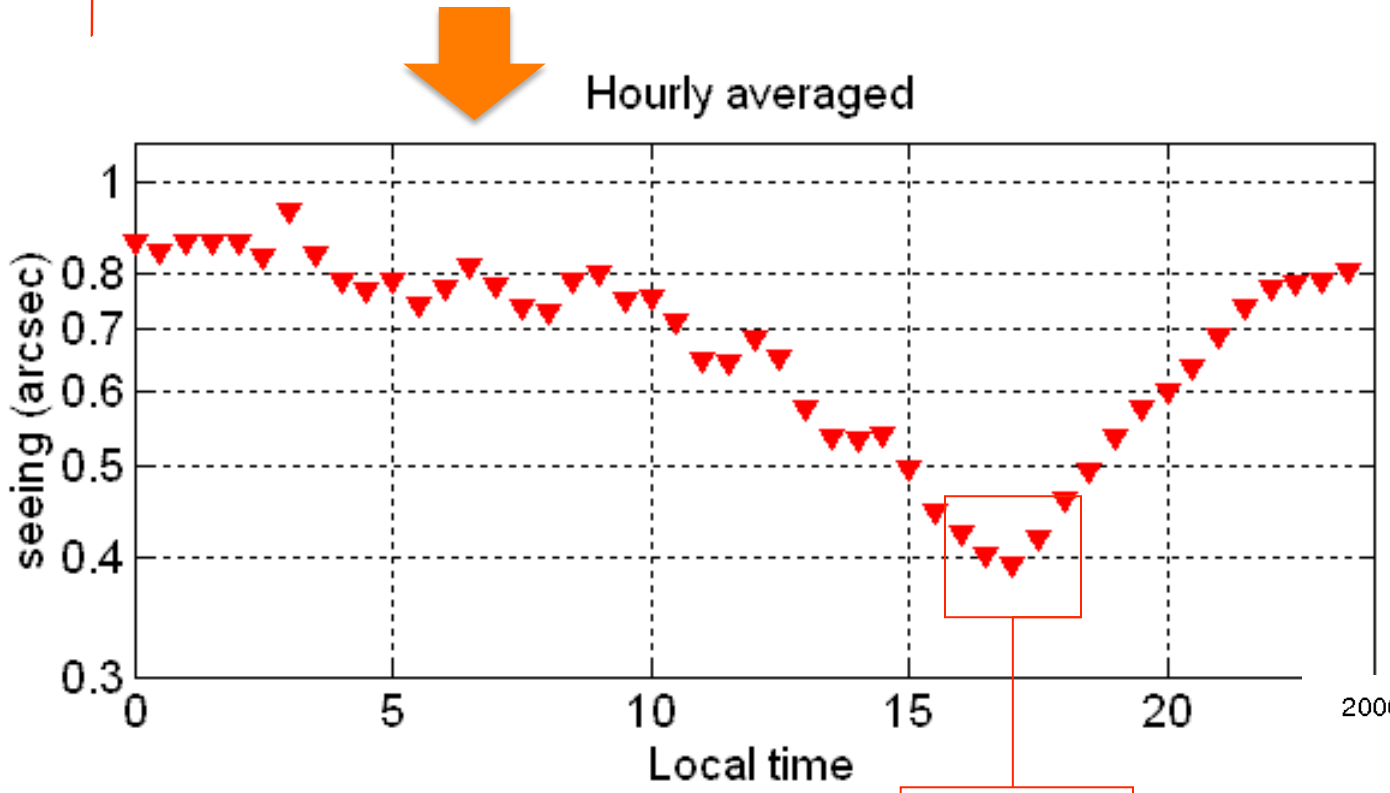
Mauna Kea	0.6 ‘’	1.9 ‘’	2.7 ms
Paranal	0.8 ‘’	2.6 ‘’	3.3 ms

@Ground

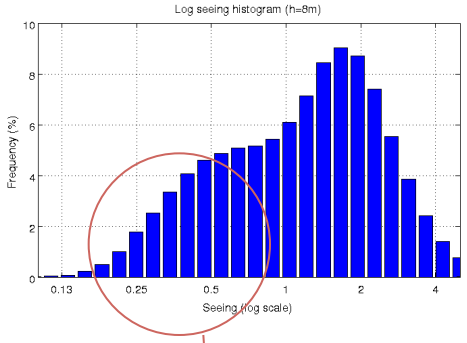
[1]Lawrence et al 2004
[2]Lascaux et al 2011

Summer Scenario

DIMM@8m Seeing (Dec. – Jan.)

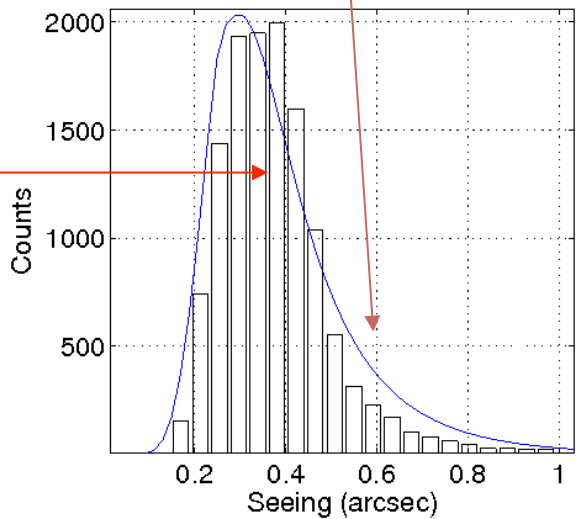


Seeing Histogram

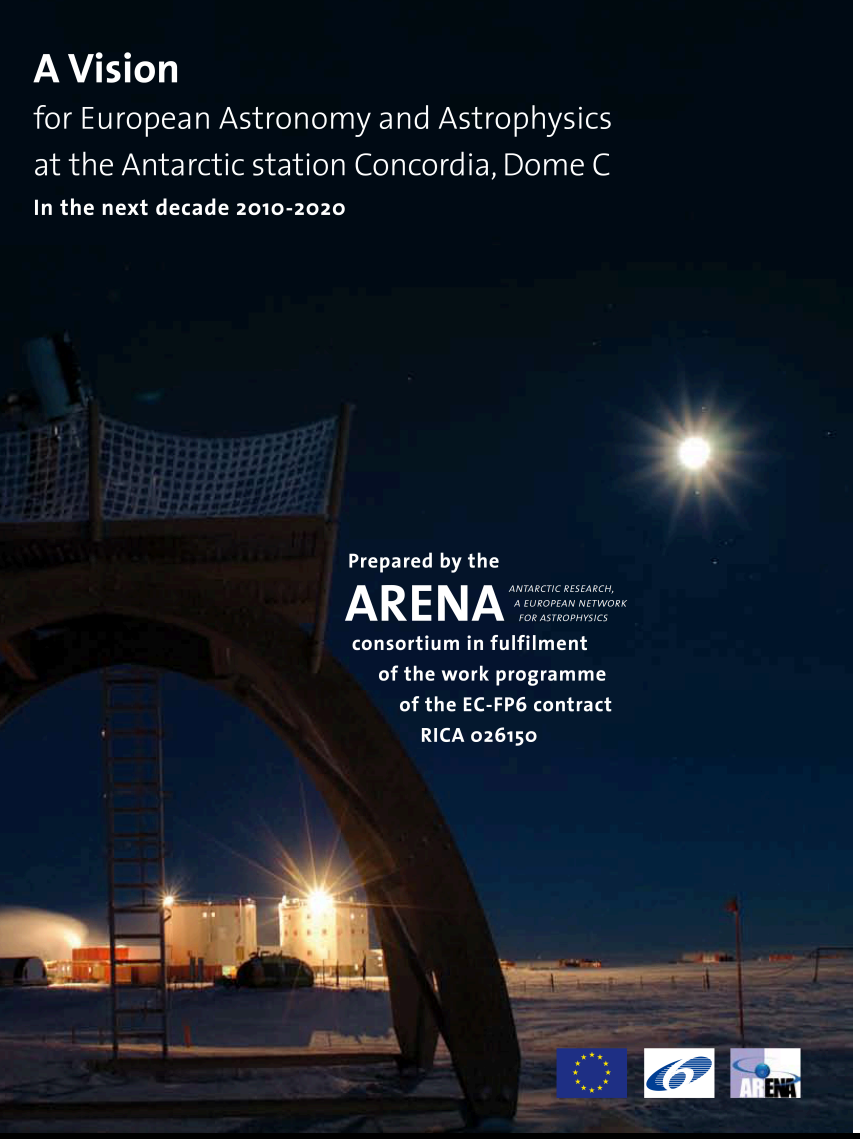


Free atmosphere bump of the histogram

Seeing Histogram (4pm—6 pm)



SUMMER
SEEING = 0’’.40
[0.3 – 0.5]



PRECIPITABLE WATER VAPOUR (PWV):

1. Monthly average range from 0.72(+/-0.20)mm in December to 0.26(+/-0.1)mm in March/April period.
2. Observations in the 200μm window opens at a transmission level about 20% during 25% of the time.
3. Observations at 350μm and 450μm are possible all year round!
4. Low PWV means higher transmission in the NIR and MIR windows and an extended wavelength coverage.

SKY BRIGHTNESS (IR):

At wavelength above 2.3μm, the dominant factor is the temperature of the atmosphere (-50°C to -90°C).

SKY BRIGHTNESS (OPTICAL):

Sky is dark at solar elevation of -12° result in a total of 2506 dark hours per year. The fraction of clear nights is of the order of 80-85% during the winter.

TEMPERATURE AND WIND PROFILES:

1. Quasi-periodic ground temperature oscillation during summer and winter months.
2. Winter dT/dt up to 30°C/week.
3. Summer dT/dt > 10°C/hour.
4. Wind speed are very low (Aristidi et al 2005).
5. Ground layer wind profile do not show any strong diurnal variation.

ARENA: DOME C AN UNIQUE GROUND SITE FOR ASTRONOMY

http://www.arena.ulg.ac.be/upload/100126_ARENA_EUROPEAN_VISION.pdf

How to CAPITALIZE
Such Unique Performance?

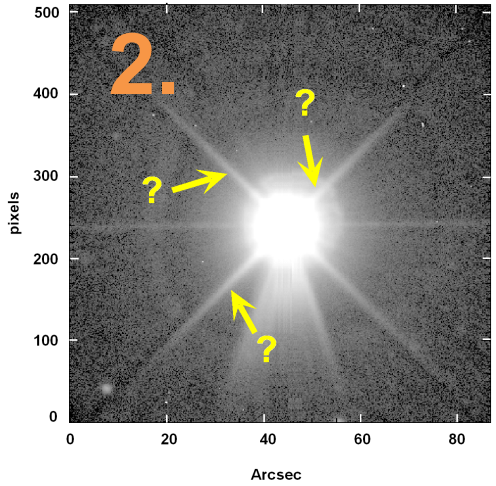
Astronomy from Antarctica
needs
High Dynamic Range Telescopes!

Off-Axis Telescopes!!!

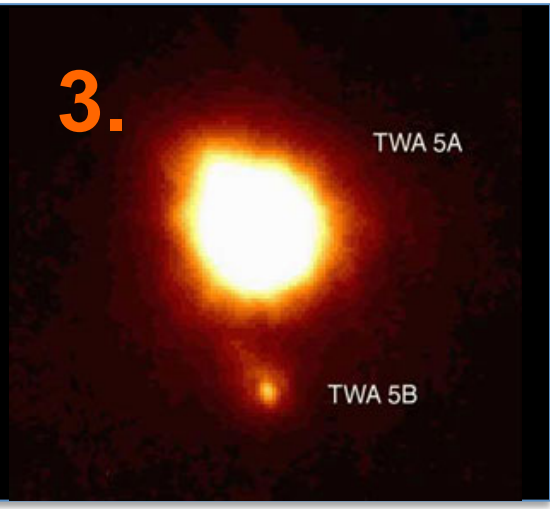
WHY OFF-AXIS TELESCOPES?

1. **It has no obstruction = minimizing scattered light**
= far superior constrast

2. It allows to **observe an important part of universe where current concentric telescopes are blind** because of scattered light.



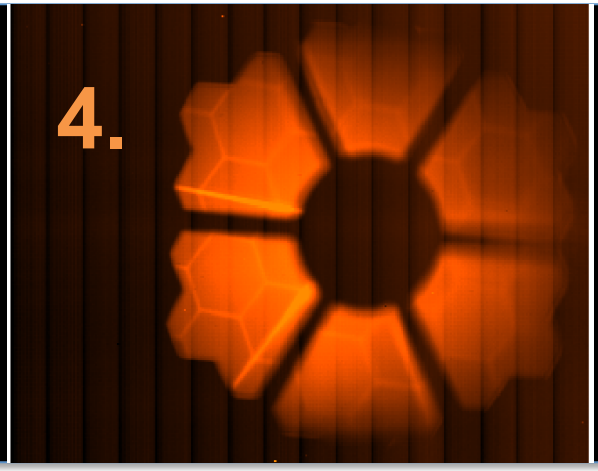
3. It minimizes light scattering = **a tremendous advantage for studies and detections of faint planets near bright stars and faint nebulosity surrounding young stars, where planets may be forming;**



WHY OFF-AXIS TELESCOPES?

4. It **reduces the sources self thermal emissivity**. A MUST for infrared astronomy!

Gran Telescopio CANARIAS (GTC) – Pupil image showing some of the warm components of the telescope emission. In light orange we can see the emission from the interspace between M1 segments and from the M2 support structure spider. The "Rose Petal" Lyot mask within CanariCam was used.



5. Off-axis telescopes turn out **a natural-filled-aperture** =

no azimuthal PSF structure;

no missing or interpolated wavefront errors;

a natural advantages **for interferometry** and **adaptive optics** performance!!

OFF-AXIS

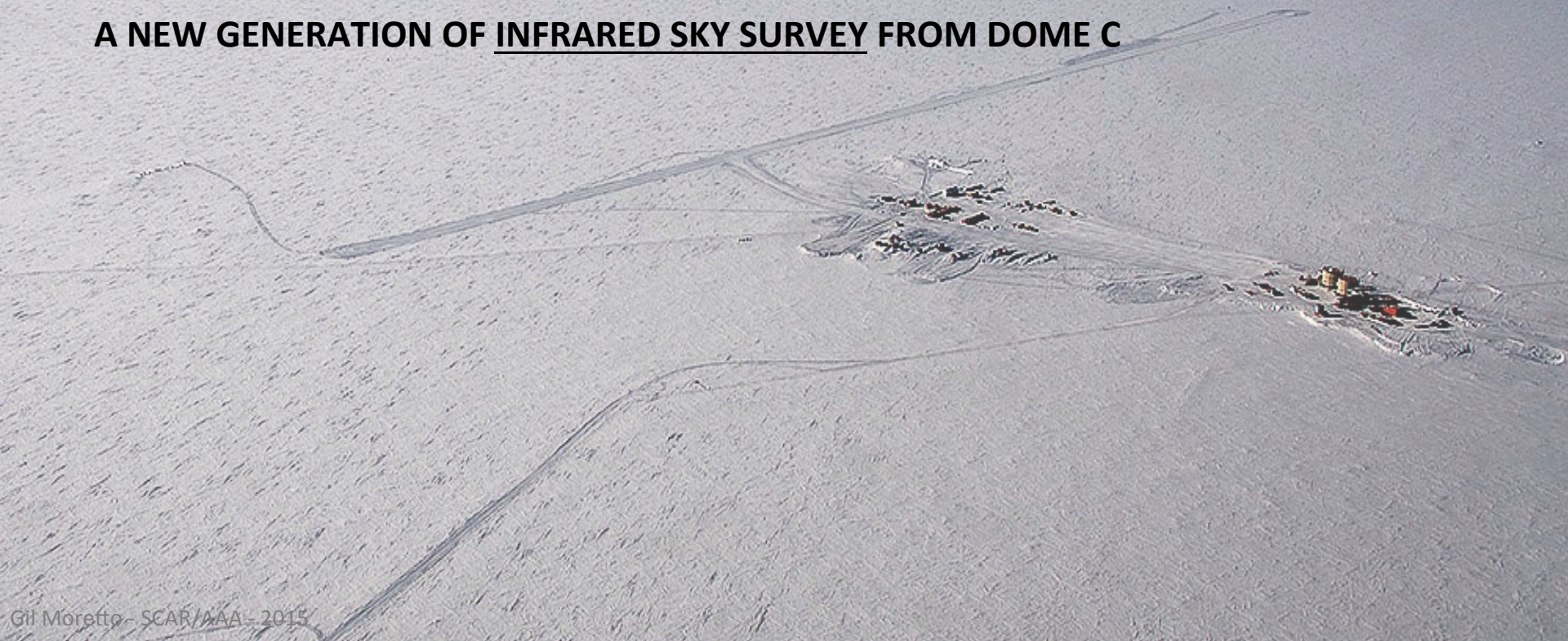
Telescopes Concepts for Antarctica

KEOPS

A KM INTERFEROMETER @DOME C

ANGISS

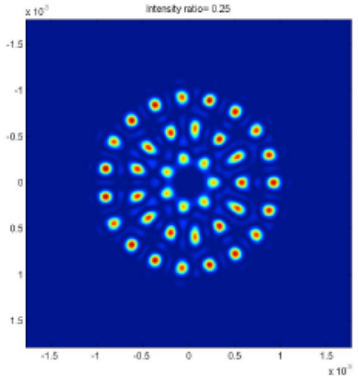
A NEW GENERATION OF INFRARED SKY SURVEY FROM DOME C

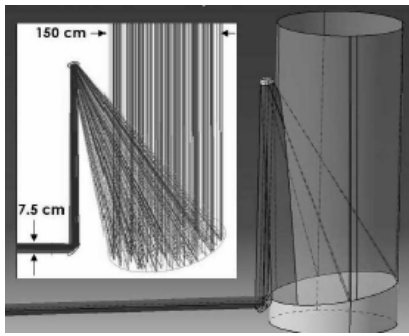


KEOPS

KILOPARSEC EXPLORER FOR OPTICAL PLANET SEARCH: A KM INTERFEROMETER @DOME C

Vakili et al (Nice), 2003

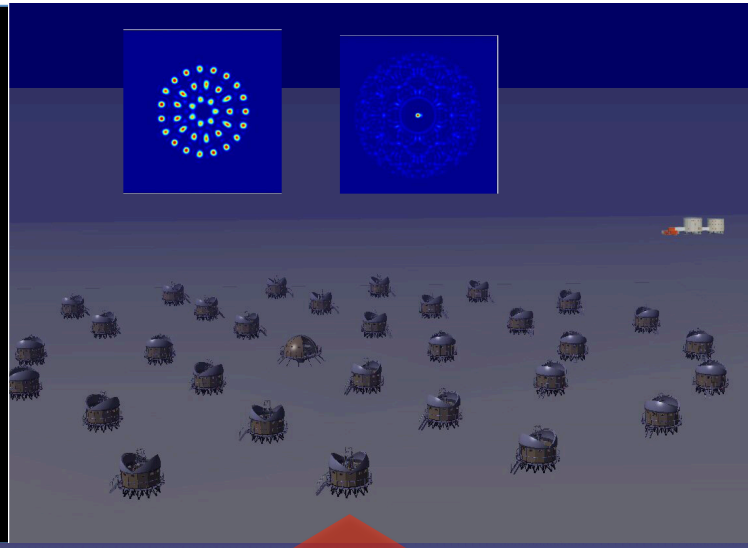


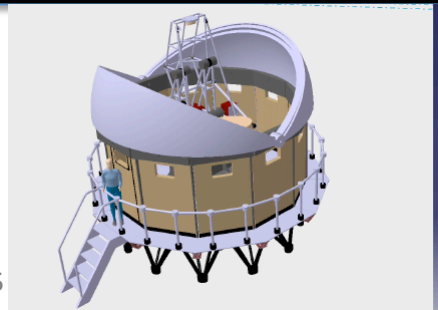


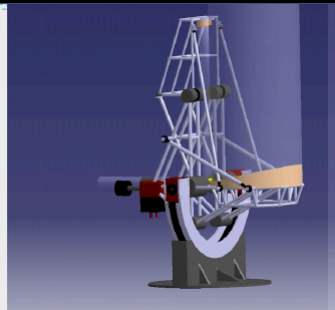
1. 36x1.5m off-axis optical/thermal IR telescopes on 3 rings of 300m (6T), 500m (12T) and 1000m (18T);
2. Collecting Surface ~ Keck;
3. Snap-shot Imaging (530 simultaneously u,v points);

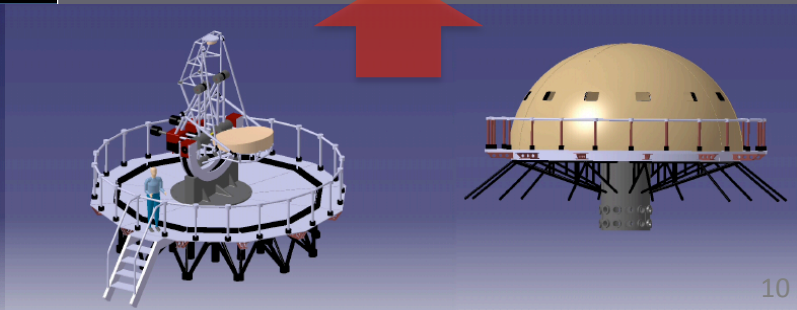
TECHNOLOGICAL CHALLENGES

1. Antarctica Operations (energy, data transmission, maintenance, …
2. 1.5m Off-Axis telescope mechanical stability (T/T) at seeing quality (0.2") ,
3. Coherent Transport over 1km (open-air, tunnels + partial vacuum),
4. Metrology & Sideral OPD on 1km,
5. Co-phasing + aperture synthesis (36T).





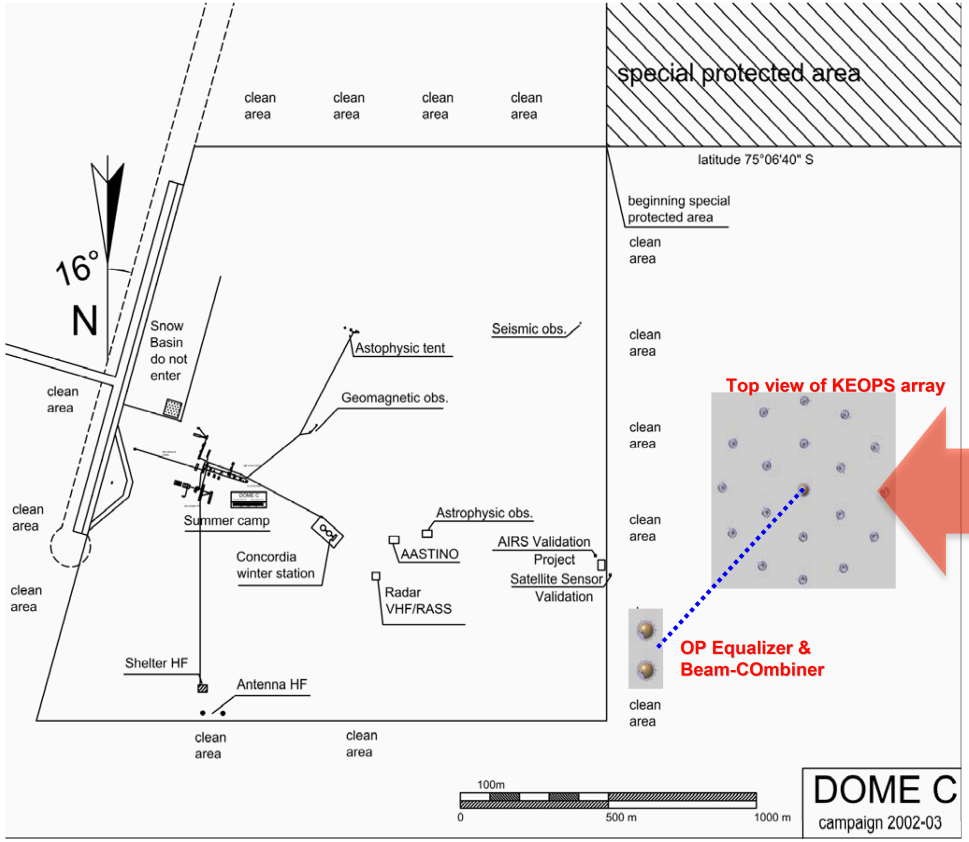




KEOPS

KILOPARSEC EXPLORER FOR OPTICAL PLANET SEARCH: A KM INTERFEROMETER @DOME C

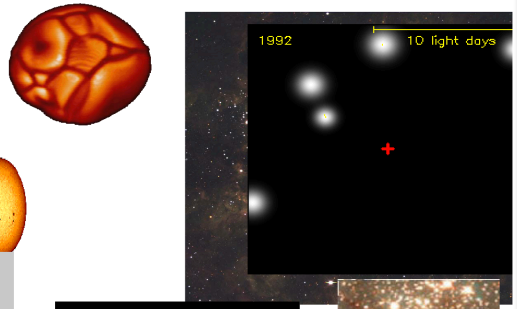
Vakili et al (Nice), 2003

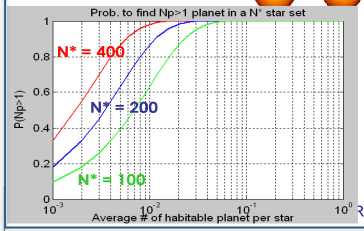


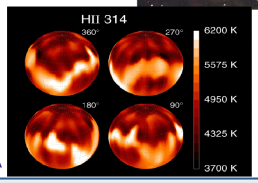
SCIENCE WITH KEOPS:

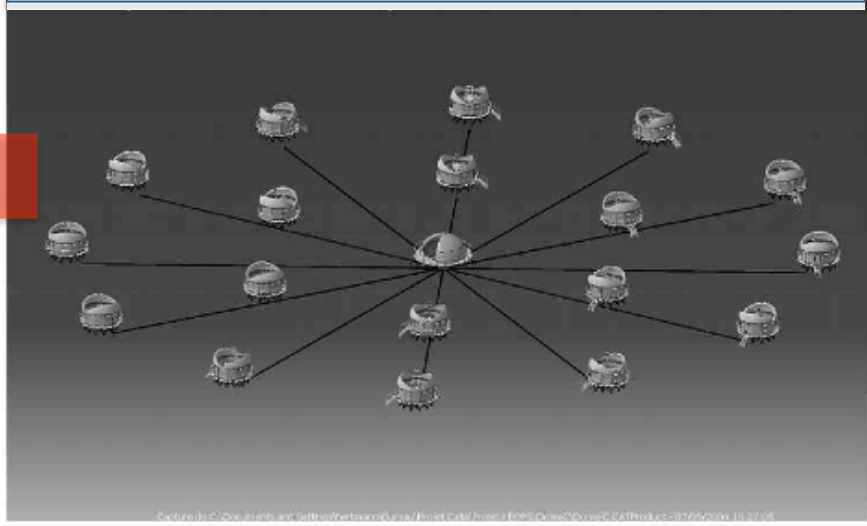
Detection of exo-Earth
Imaging of stellar surfaces
- Activity
- Convection
- Oscillations

Clusters
Stellar formation
Dynamic of galactic cores
Distances of quasars









(WAS) A DARWIN/TPF challenger but at a much lower cost!

http://www.arena.ulg.ac.be/upload/100126_ARENA_EUROPEAN_VISION.pdf

ANGISS

ASSESSMENT OF

A NEW GENERATION OF INFRARED SKY SURVEY FOR THE E-ELT AND EUCLID ERA

(Lyon) M. Langlois, G. Moretto, I. Vauglin; (Nice) E. Aristidi, M. Carbillet, L. Abe and N. Epchtein

1. **In support of the science key programmes** of the current on-going projects of extremely large optical/IR telescopes from the ground and major space missions, such as the **E-ELT**, **JWST** and **EUCLID**.

2. It addresses the technical feasibility of a New Generation Infrared Sky Survey from Antarctica

1. An assessment study and development of an innovative 2-4m class telescope, heading to a proof-of concept and prototype construction.

2. It proposes innovative technologies in the conception of:

    A. a telescope low emissivity;
    B. the AO techniques matching the Dome C atmospheric properties;
    C. an overall system winterization.

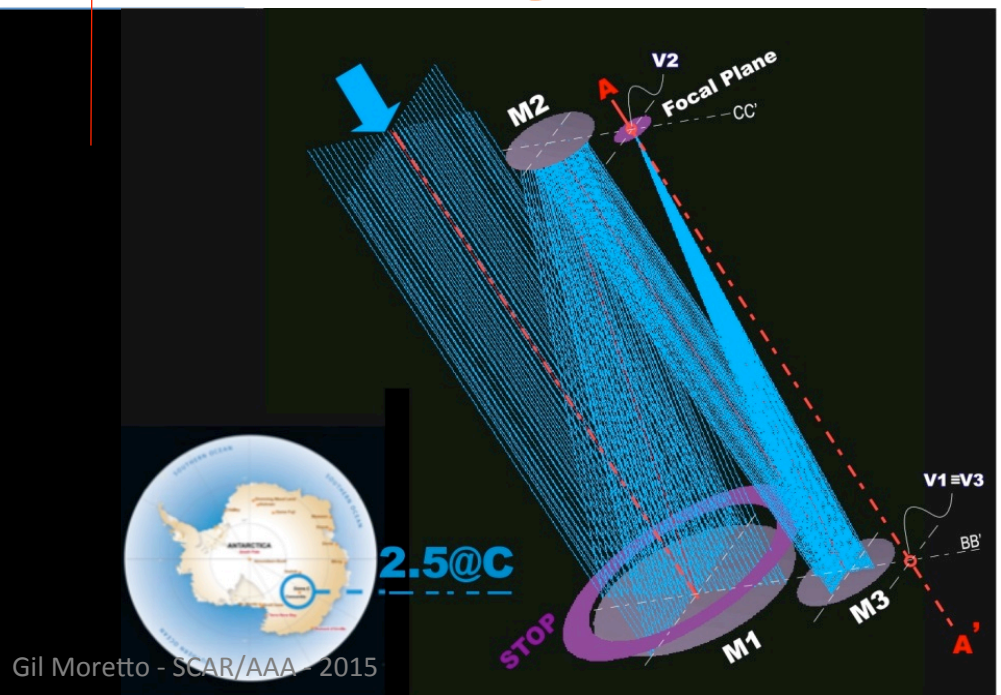
ANGISS

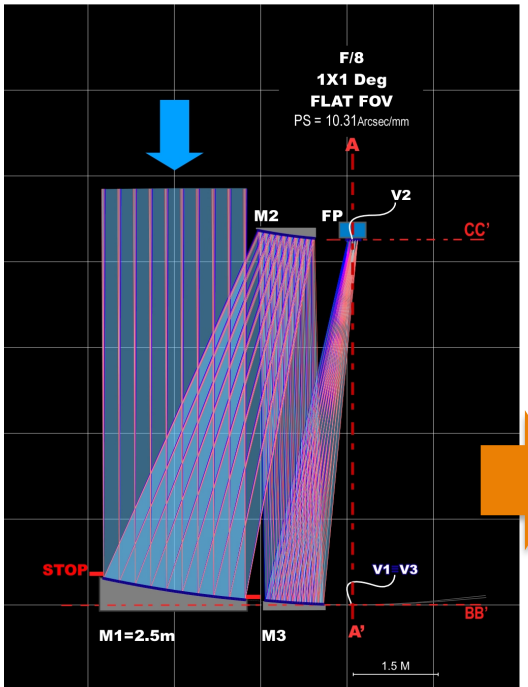
Science Driver Cases:

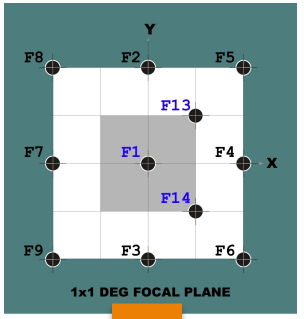
1. **Highest possible dynamic range for photometry and angular resolution.**
2. **Wide-field imaging** mode**.**

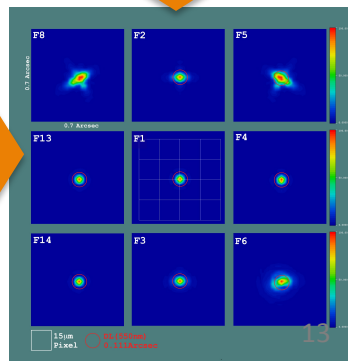
1. Calls for an **OFF-AXIS DESIGN** optimized for **low scattered light** and **low emissivity**.
2. Calls for a **THREE MIRRORS DESIGN** optimized for a **wide 1x1 Deg FOV**.

1.+ 2. = 2.5@C









ANGISS Proposal

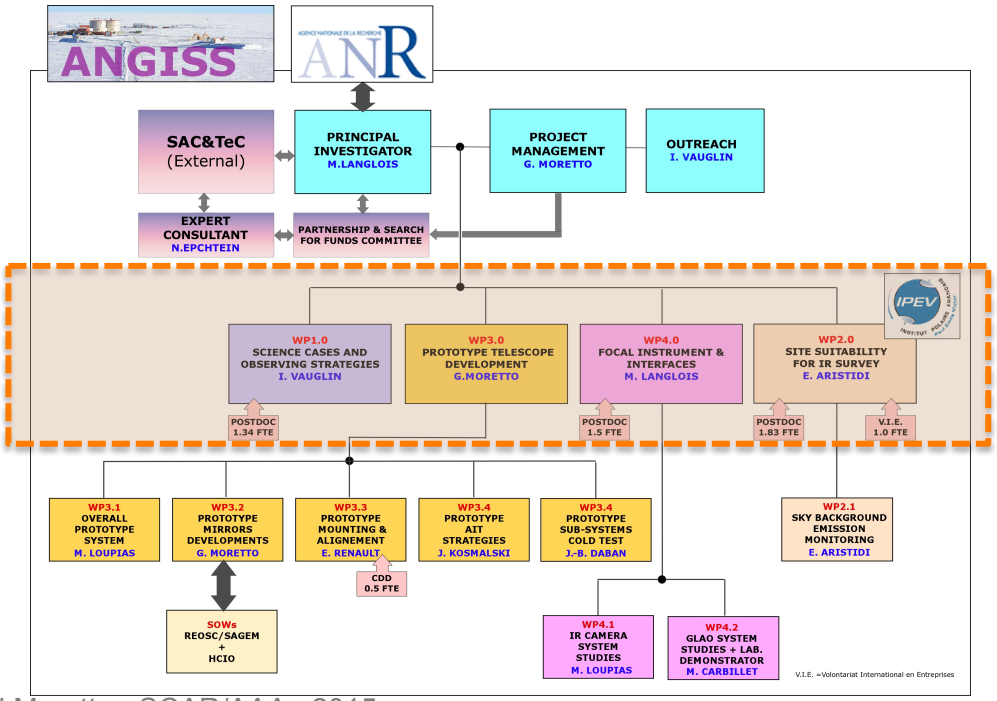
100% French-Français Proposal

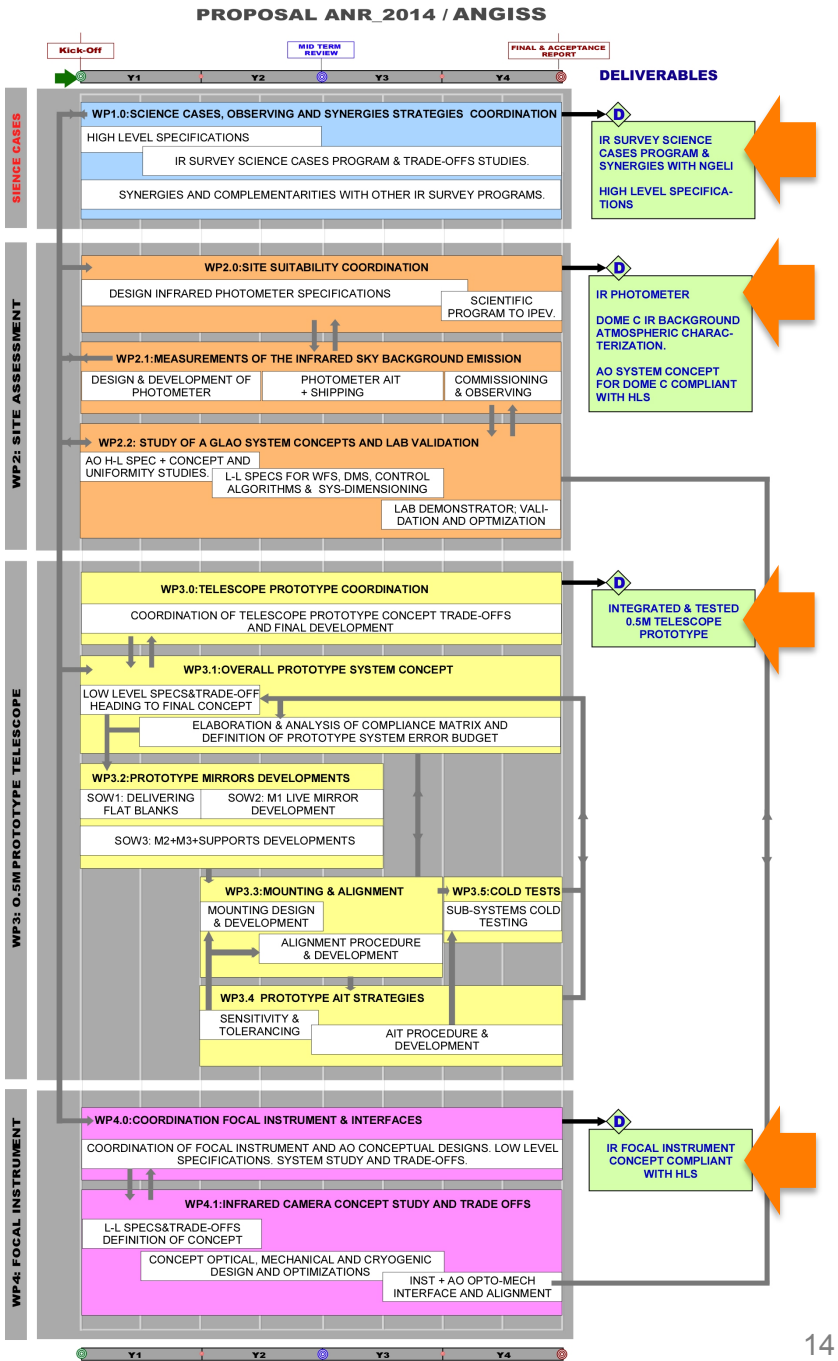
Input 4.3M€ 246P/M (CNRS LABS+UNIVERSITIES)

Request 1M€ 74P/M

4 Years Project

Agence Nationale de la Recherche ANR	Sigle du partenaire	Coût Complet (€)	Aide Demandée (€)	Personnel permanent (pers/mois)	Personnel non permanent AVEC financement ANR demandé (pers/mois)	Personnel non permanent SANS financement ANR demandé (pers/mois)
Centre de recherche astrophysique de Lyon (Coordinateur)	CRAL - CNRS	2 917 880,00	605 280,00	157,00	40,00	25,00
Laboratoire JL Lagrange (OCA/CNRS/UNS)	LAGRANGE (OCA/CNRS/UNS)	1 402 435,80	391 844,96	89,00	34,00	8,00
Totaux	Totaux	4 320 315,80	997 124,96	246,00	74,00	33,00





OFF-AXIS

Telescopes Concepts for Antarctica

KEOPS

A KM INTERFEROMETER @DOME C

ANGISS

A NEW GENERATION OF INFRARED SKY SURVEY FROM DOME C

Proposed to ANR (French Research Agency).
Well ranked but not selected for financial support!
French (and EU) grants for AAA is not a priority!

An OFF-AXIS Telescope for Antarctica

LIVE MIRROR™ FET/H2020 Proposal

Zero-Polishing Scalable Dynamic Opto-Electronic Mirrors

Future and Emerging Technologies (FET):
Calls FETOPEN and FETPROACT

Research and Innovation Actions (RIA)

Consortium: France + Germany + USA

cnrs dépasser les frontières CRAL

KIS Kiepenheuer-Institut für Sonnenphysik

Institut für Technische Optik

Institute for Astronomy / Advanced Technology Research Center
University of Hawaii

LIVE MIRROR™ FET/H2020 Proposal

Zero-Polishing Scalable Dynamic Opto-Electronic Mirrors

Model, optimize and **create:**

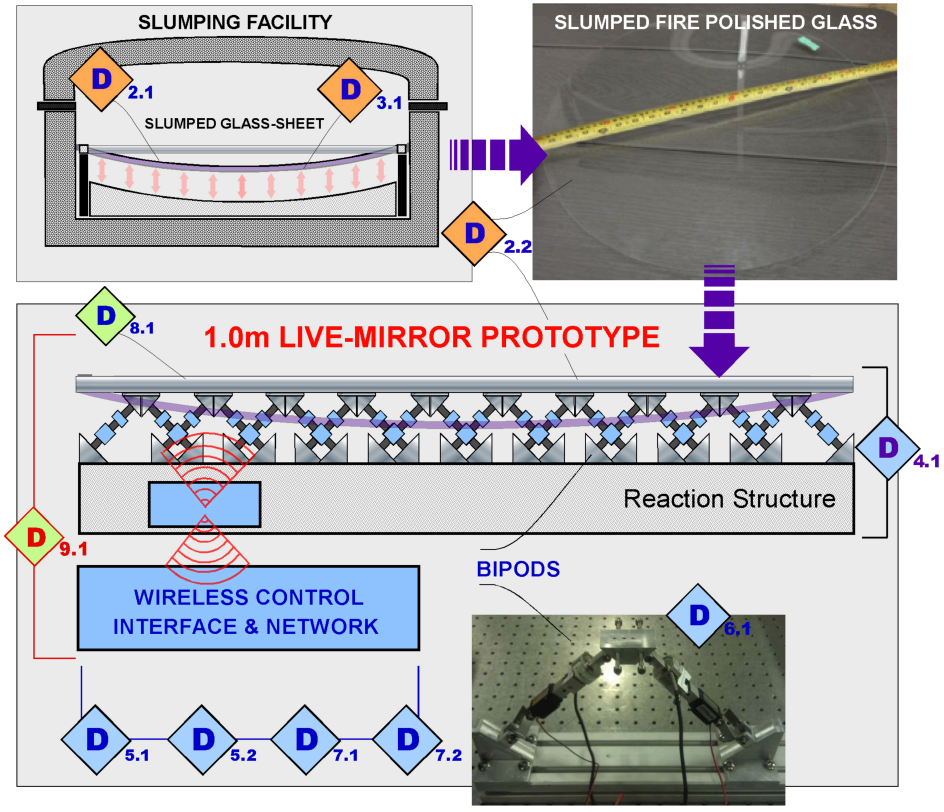
- **LARGE,**
- **LIGHTWEIGHT and**
- **PRECISE ASPHERIC OPTICAL SURFACE.**

New shaping mirror concept is based on:

- **Kirchoff-Love plate deformation theory;**
- A **controlled active 3D-printed force actuators and sensors**.

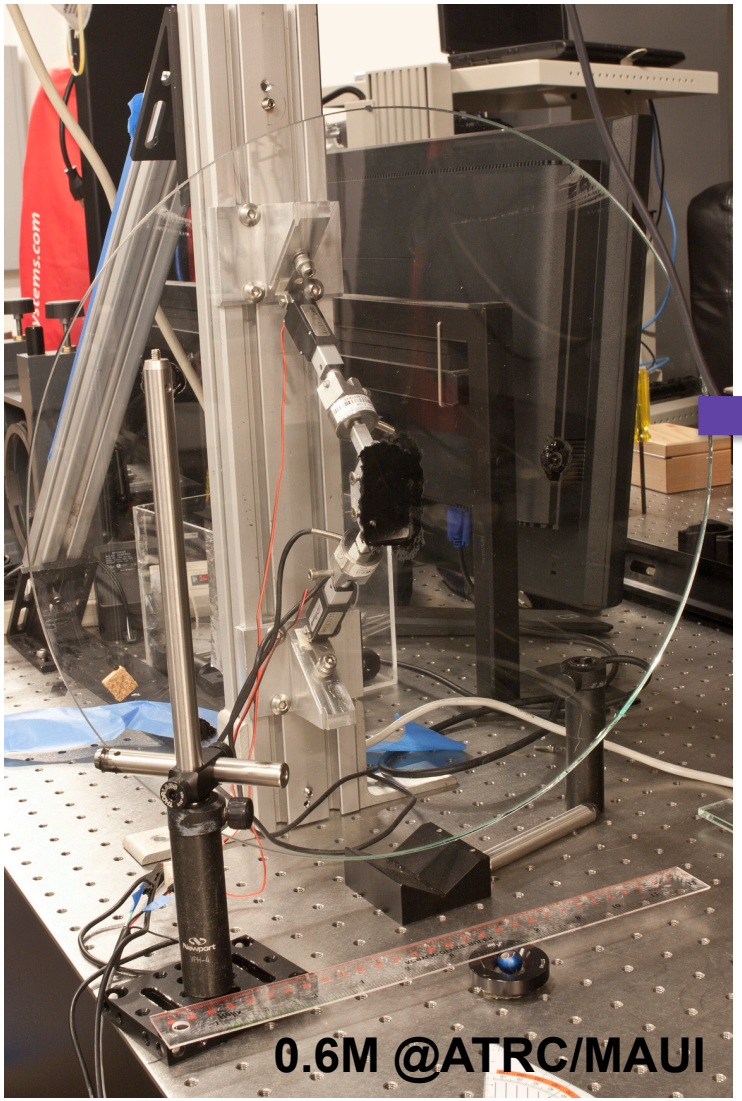
Deliverables:

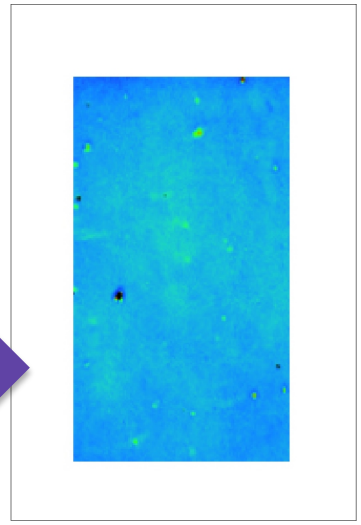
- **Large Precise Aspheric Optical Surfaces = Off-axis Parabolic Mirrors.**



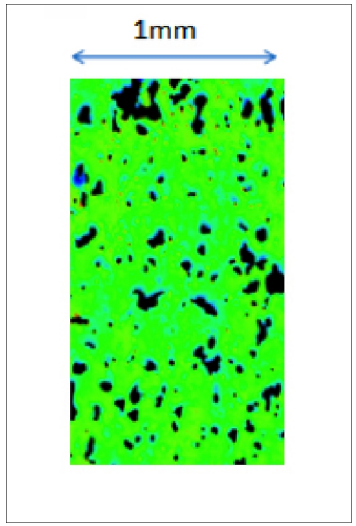
LIVE MIRROR™ FET/H2020 Proposal

Zero-Polishing Scalable Dynamic Opto-Electronic Mirrors



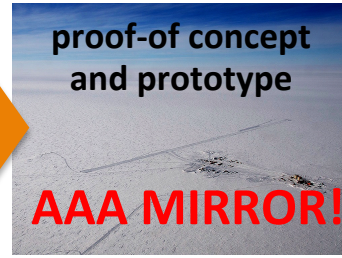


Fire Polished Surface
0.4nm microroughness



Ground and Polished Surface
1.3nm microroughness

0.5–1.0m OFF-AXIS PARABOLIC MIRROR PROTOTYPE



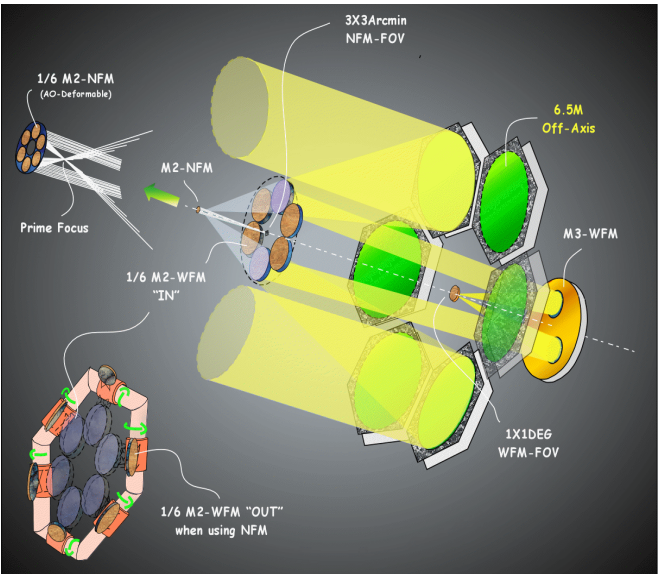
An OFF-AXIS Telescope for Antarctica

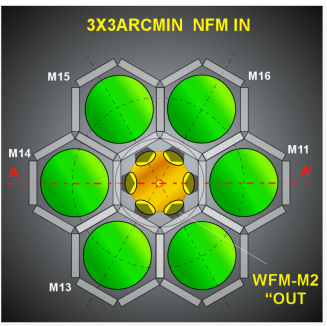
Rationale: A medium/large aperture telescope **on the Antarctic Plateau has the potential to undertake tasks previously thought to be possible only in space**, for example **the imaging and crude spectroscopy of Earth-size extra-solar planets.**
(Angel, Lawrence and Storey, 2004).

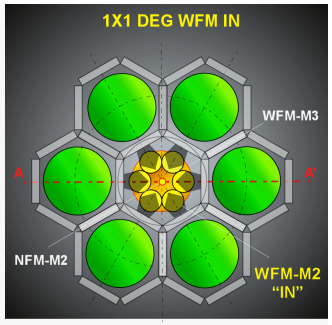
… and/or **a new generation of IR sky survey.**

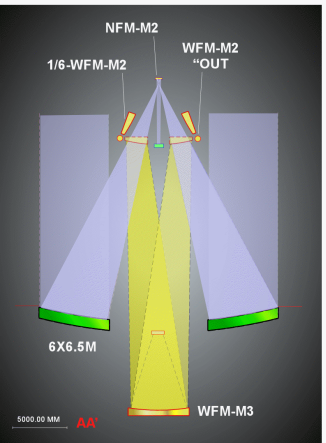
High Dynamic Range Telescope

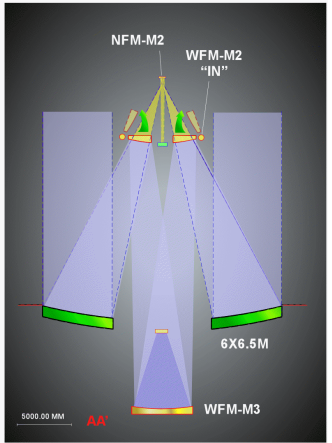
An unique Opportunities for observing ExPNs and to special-purpose surveys.



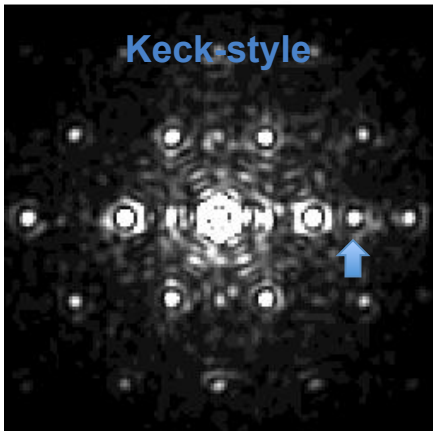


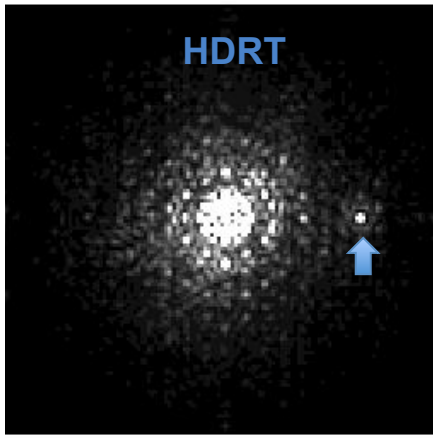






- 6x6.5m Off-Axis Mirrors
- 22m Effective Clear Aperture
- Two Modes:
  - 3x3 Arcmin NFM (ExPNs)
  - 1x1 Degree WFM (Surveys)
- CFHT Replacement (2000)



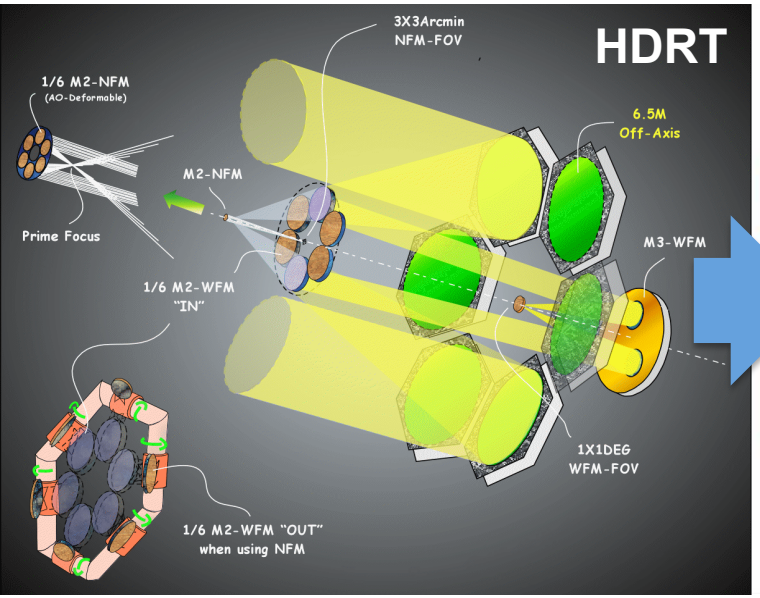


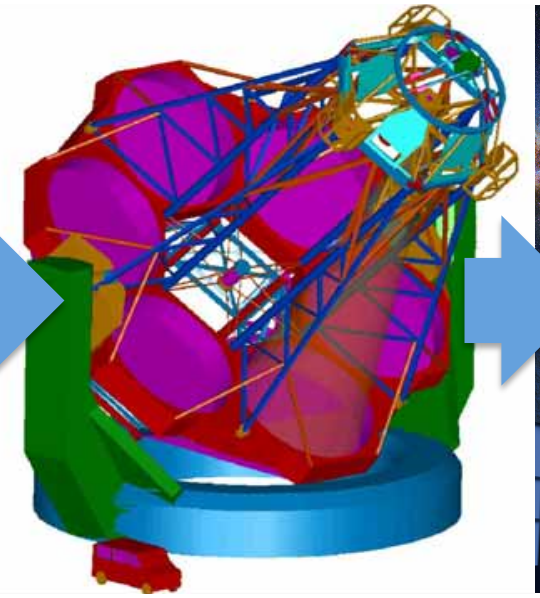
The angular field in each image is 1".1 and **a faint stellar companion has been added 0".36 to the right of the central star** in each image. Atmosphere with r_0 = 1m @1micron and using a 400 degree-of-freedom AO system.

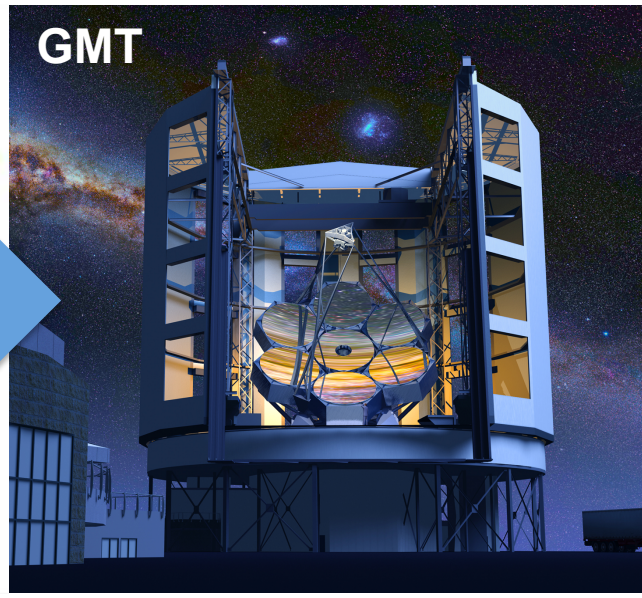
(Kuhn, Moretto, Racine, Roddier and Coulter, PASP, 2001)

High Dynamic Range Telescope

Concept for an Off-Axis Telescope in Antarctica







GMT: Giant Magellan Telescope

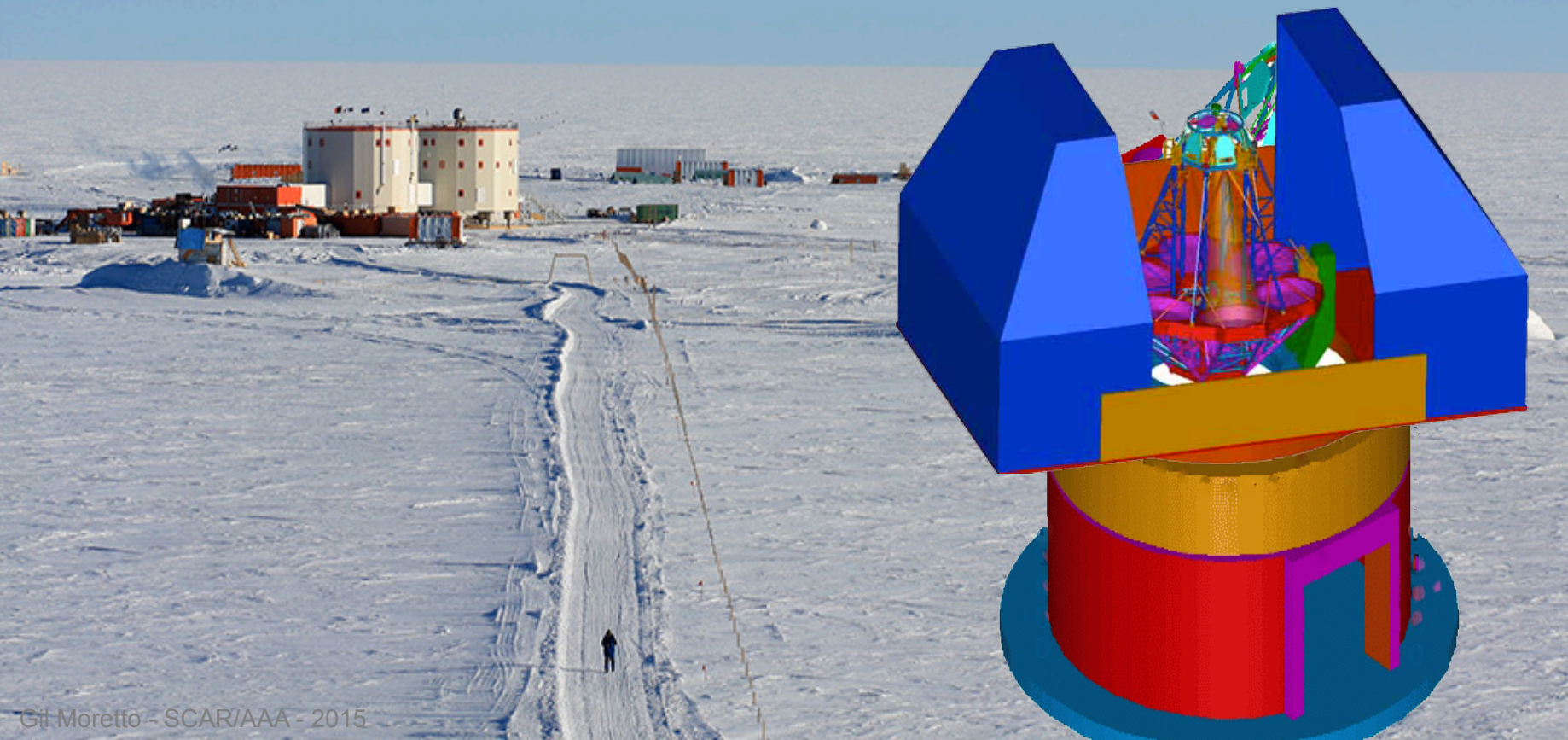
6X8.4m OFF-AXIS

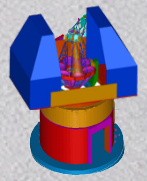
24.5m COLLECTING AREA

AT THE END OF THE DAY

Concept for an Off-Axis Telescope in Antarctica

AN OFF-AXIS TELESCOPE CONCEPT WOULD CAPITALIZE SUCH UNIQUE ANTARCTICA SITE PERFORMANCE!





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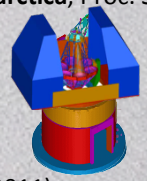


+SE NECESSÁRIO

ANGISS Proposal

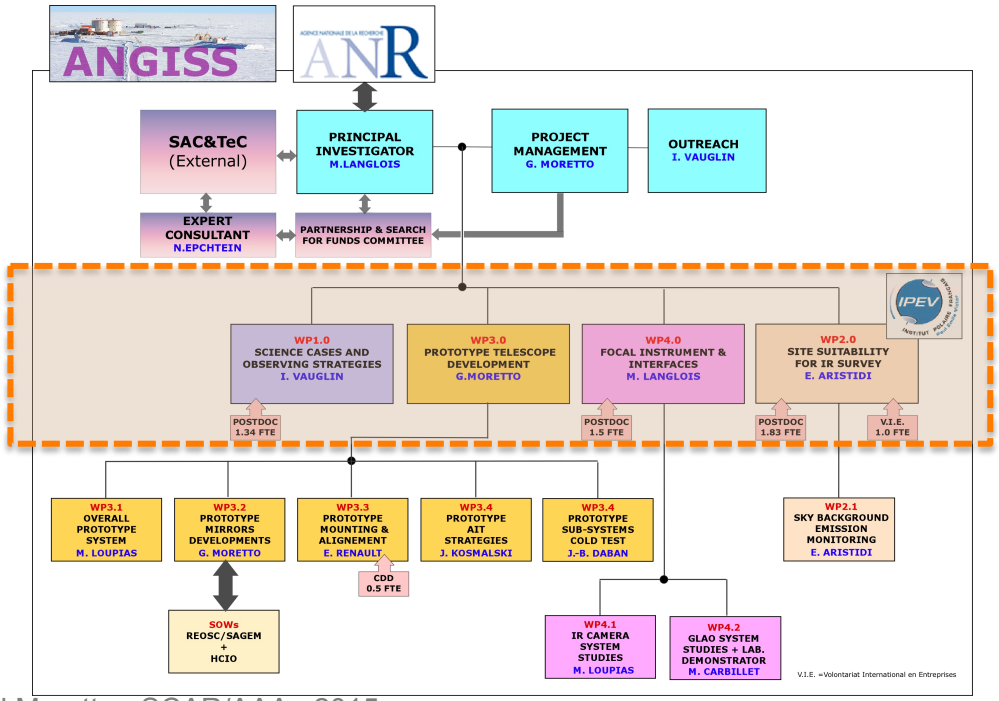
100% French-Français Proposal

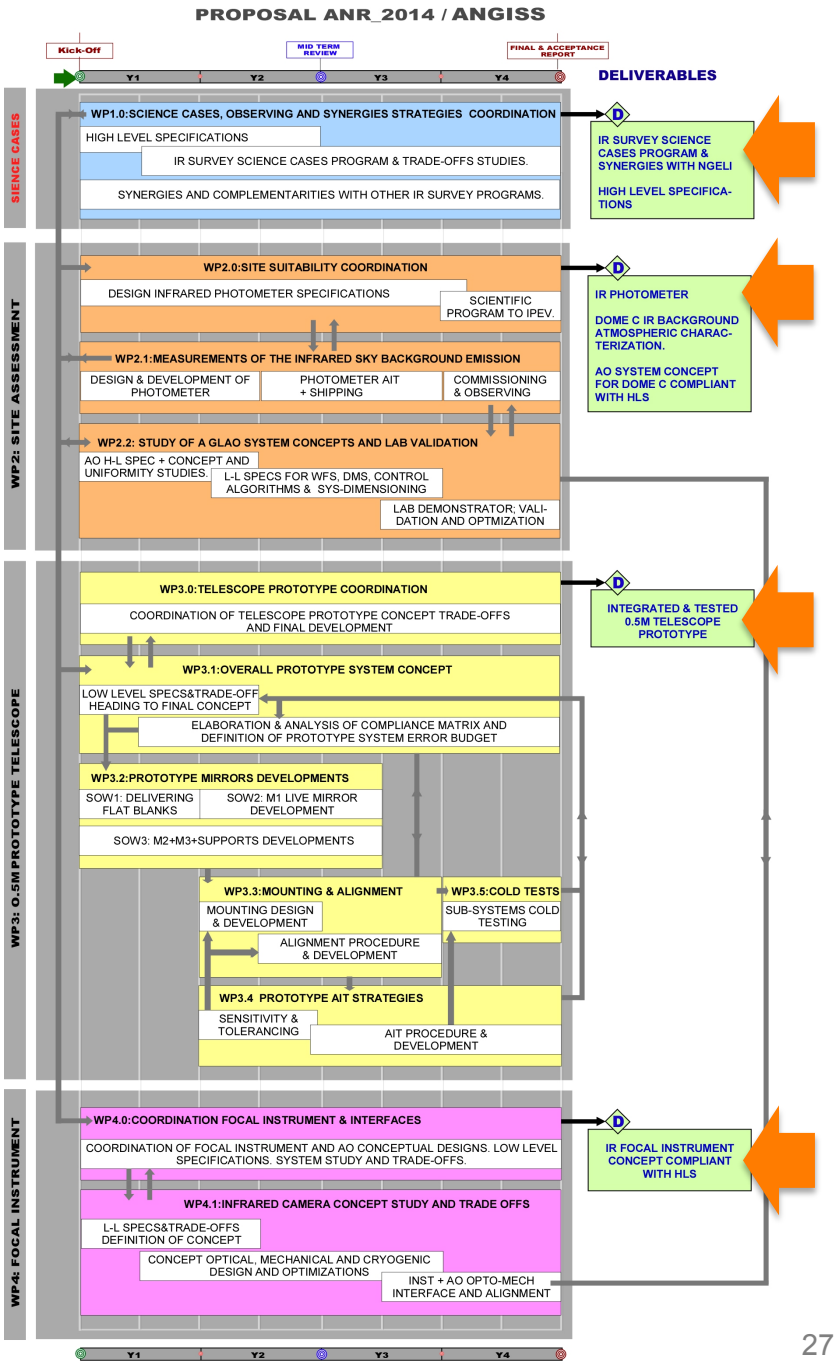
Input 4.3M€ 246P/M (CNRS LABS+UNIVERSITIES)

Request 1M€ 74P/M

4 Years Project

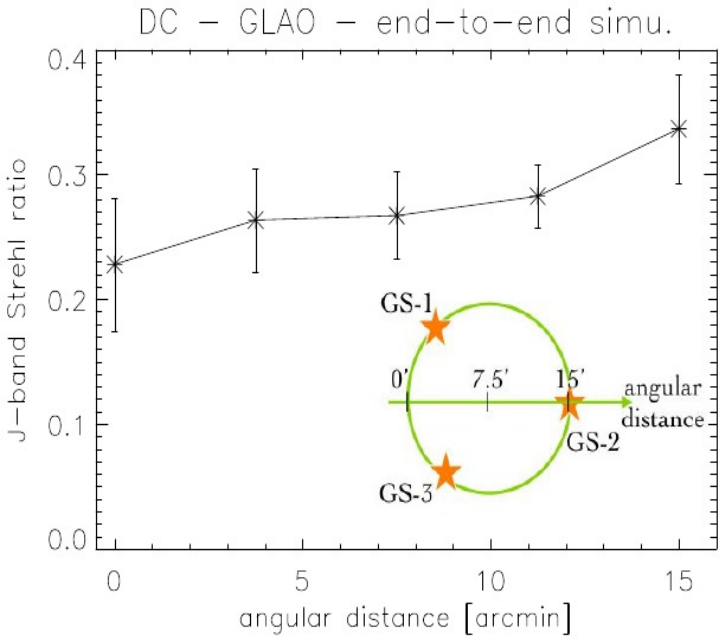
Agence Nationale de la Recherche ANR	Sigle du partenaire	Coût Complet (€)	Aide Demandée (€)	Personnel permanent (pers/mois)	Personnel non permanent AVEC financement ANR demandé (pers/mois)	Personnel non permanent SANS financement ANR demandé (pers/mois)
Centre de recherche astrophysique de Lyon (Coordinateur)	CRAL - CNRS	2 917 880,00	605 280,00	157,00	40,00	25,00
Laboratoire JL Lagrange (OCA/CNRS/UNS)	LAGRANGE (OCA/CNRS/UNS)	1 402 435,80	391 844,96	89,00	34,00	8,00
Totaux	Totaux	4 320 315,80	997 124,96	246,00	74,00	33,00

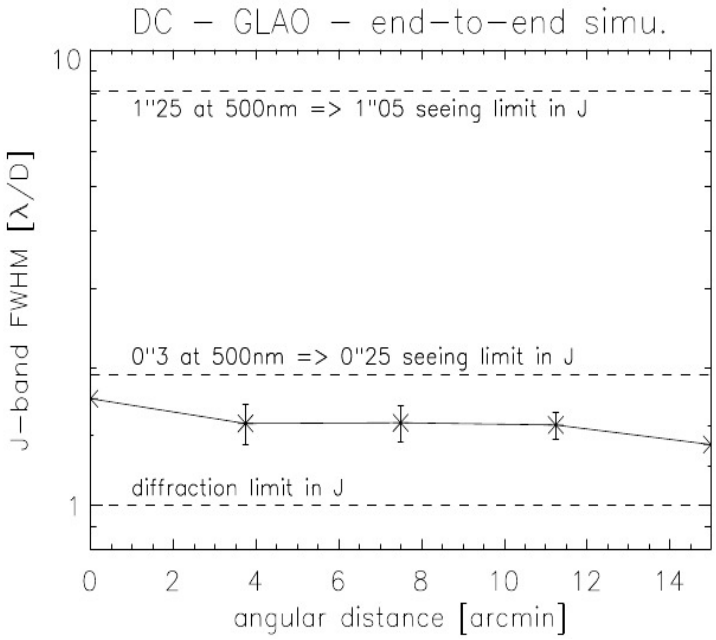




ANGISS GLAO PERFORMANCES @DOME C

A 2m class telescope located 8m above the ground and using a median turbulence profile from at of radio-soundings (Carbillet et al, 2009)





Strehl ratio in J band as a function of the angular distance from the target, using **3 reference stars.**

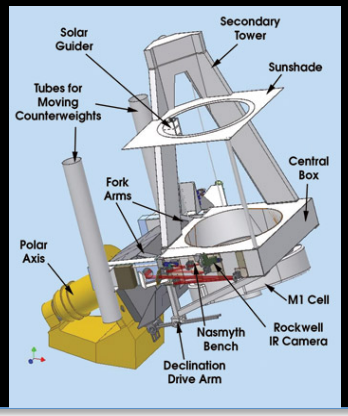
PSF FWHM as a function of the angular distance, in units of λ/D.

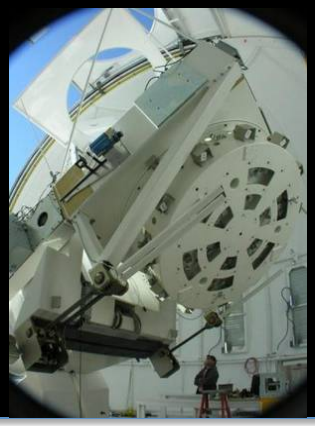
BY NOW

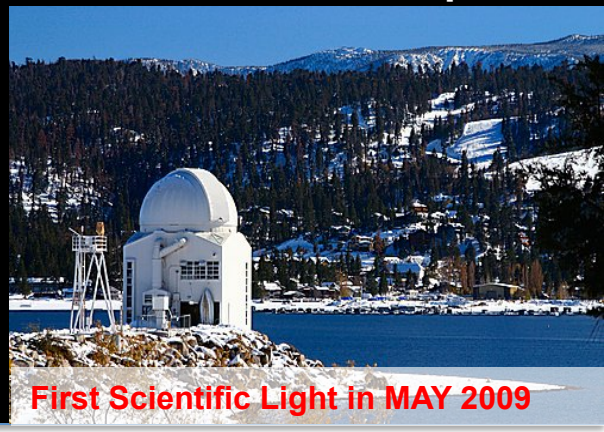
A NUMBER OF OFF-AXIS TELESCOPE DESIGNED, BUILT, OPERATING AND FUNDED!

NST - New Solar Telescope is a 1.6m clear (off-axis) aperture solar telescope - the largest of its kind in the world - has seen first scientific light in May 2009: it's now operational. The NST the pathfinder for future, large ground-based off-axis telescopes.

M1 off-axis figuring at the Steward Observatory Mirror Lab. - Arizona

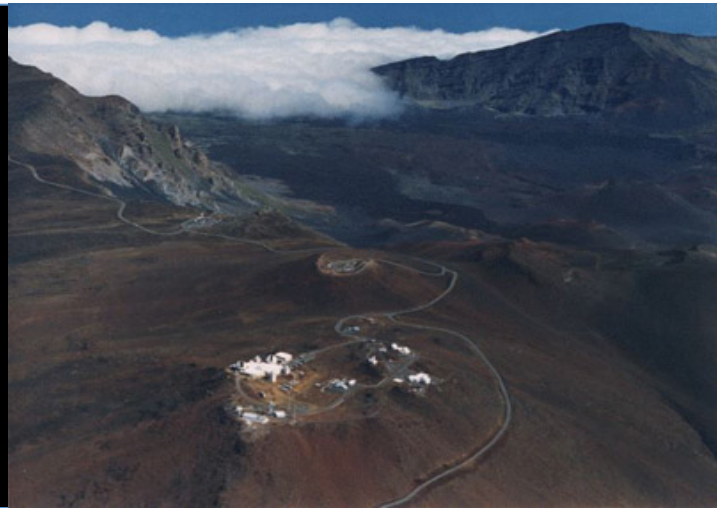






First Scientific Light in MAY 2009

PLANETS – Japan Hawaii Europe Telescope - will be a 1.9m off-axis telescope and is similar in design to the 1.6m NST. Project funded in 2011. The telescope will be constructed on Haleakala, a 3000m volcano on the island of Maui, HI.

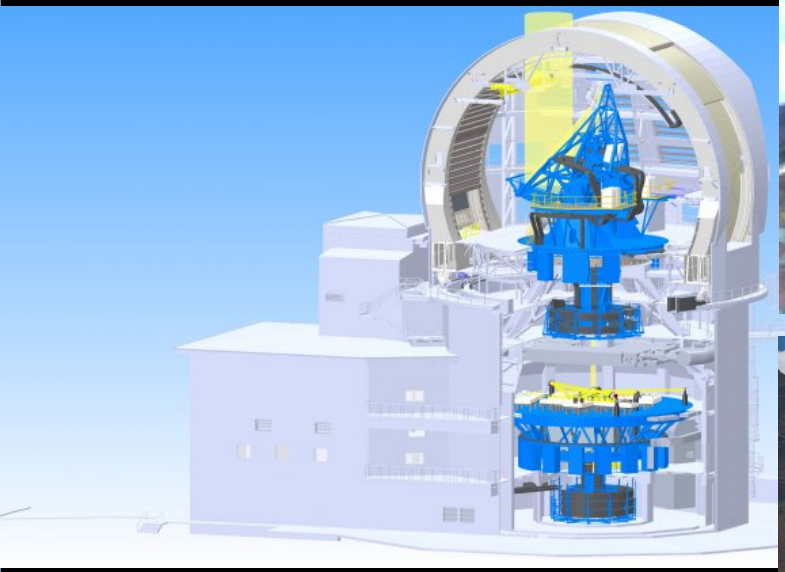


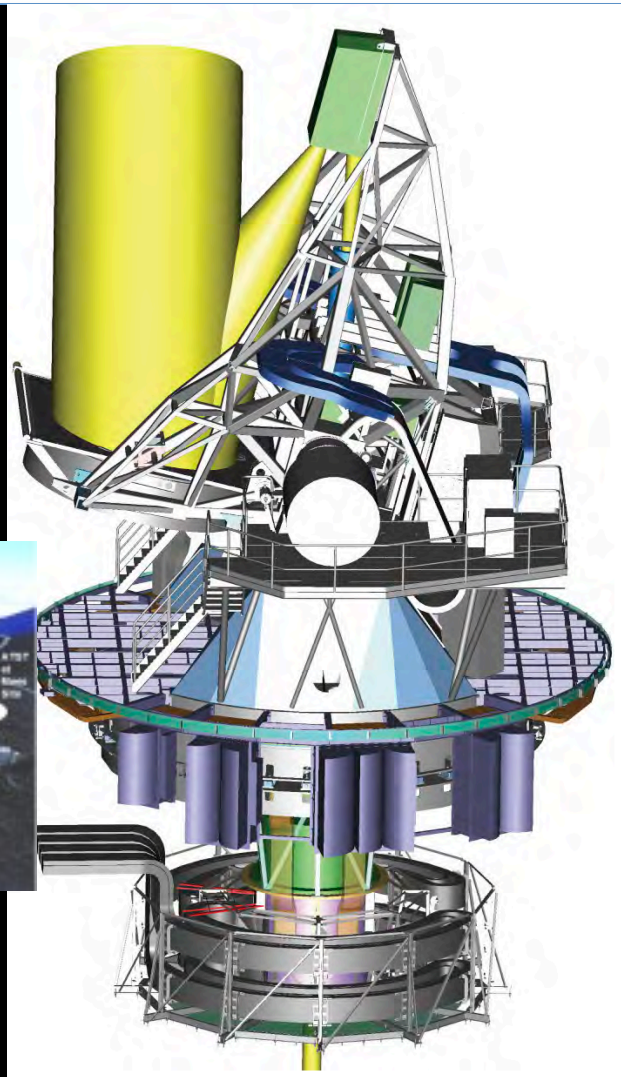
BY NOW

A NUMBER OF OFF-AXIS TELESCOPE DESIGNED, BUILT, OPERATING AND FUNDED!

ATST – Advanced Technology Solar Telescope –

will be a 4m class off-axis optical telescope that will serve the solar physics community. The goal for the FOV is 5 Arcmin on the spectral range 0.3 – 28 μm. Project will begin construction in the near future and AURA/NSO and SCHOTT have been working to develop the primary mirror blank; a 4m off-axis paraboloid. Site: Haleakala, Maui.





BY NOW

A NUMBER OF OFF-AXIS TELESCOPE DESIGNED, BUILT, OPERATING AND FUNDED!

GMT – Giant Magellan Telescope - will be one of the next class of super giant earth-based telescopes. It is a segmented mirror telescope that employs seven of today's largest stiff monolith mirrors as segments. Six off-axis 8.4 meter segments surround a central on-axis segment, forming a single optical surface with a collecting area of 24.5 meters in diameter.