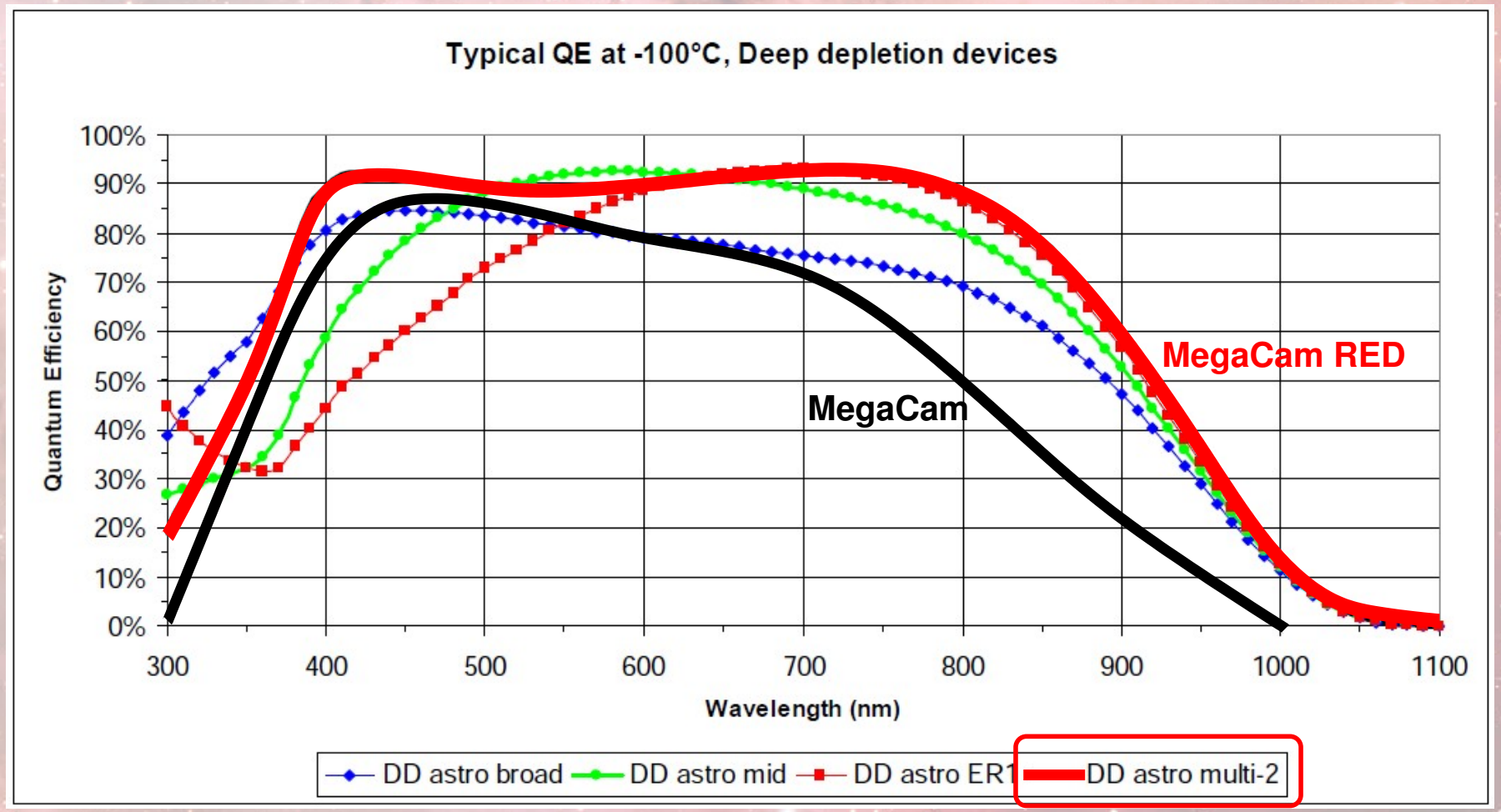
MegaCam

RED

Red Enhanced Detectors

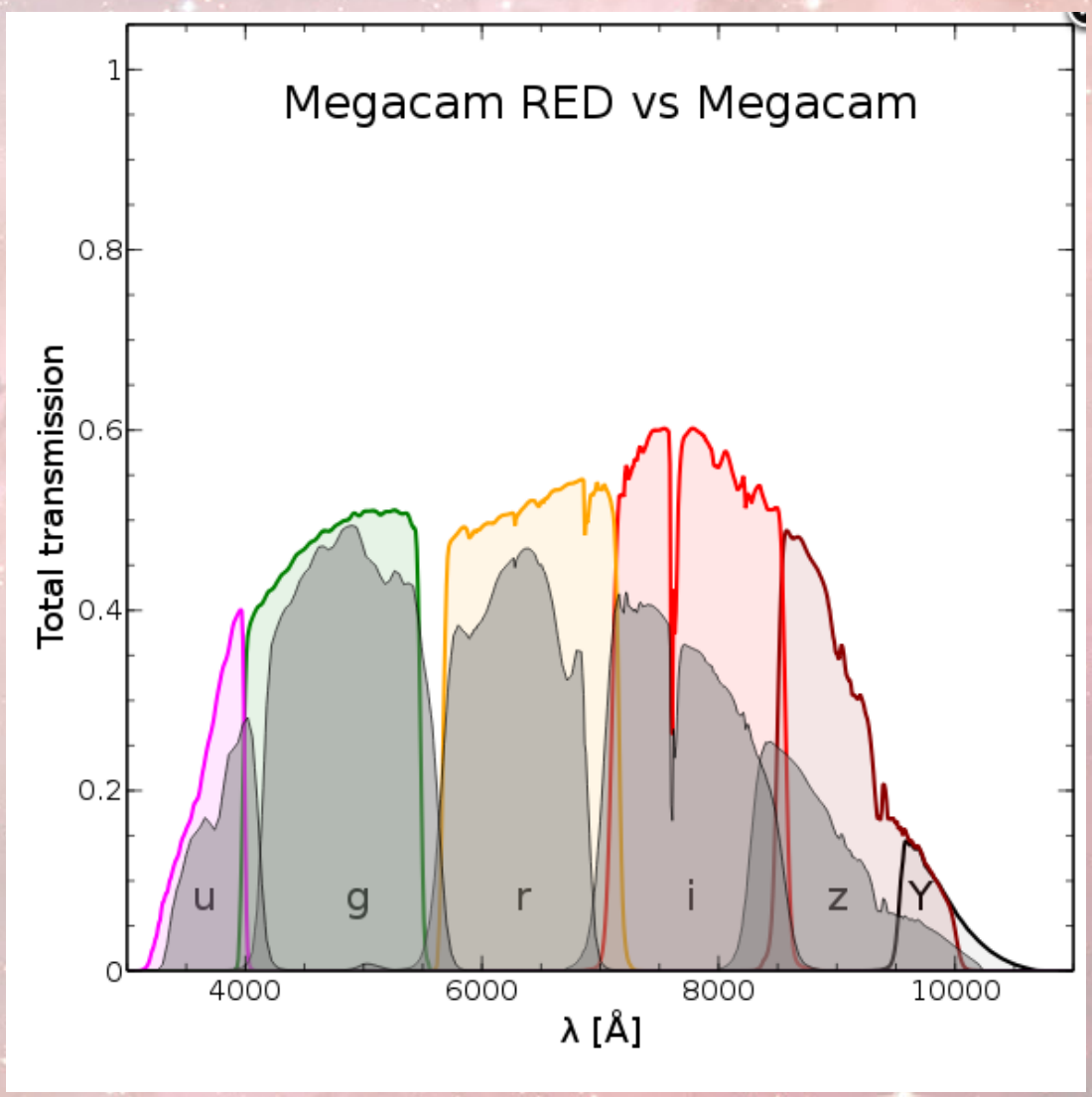
... and Euclid

Advances in detector & coating technology over the past decade



e2v 42–90 deep depletion: pin, electrically, and mechanically 100% identical to 1998 version

Advances in filter technology over the past decade

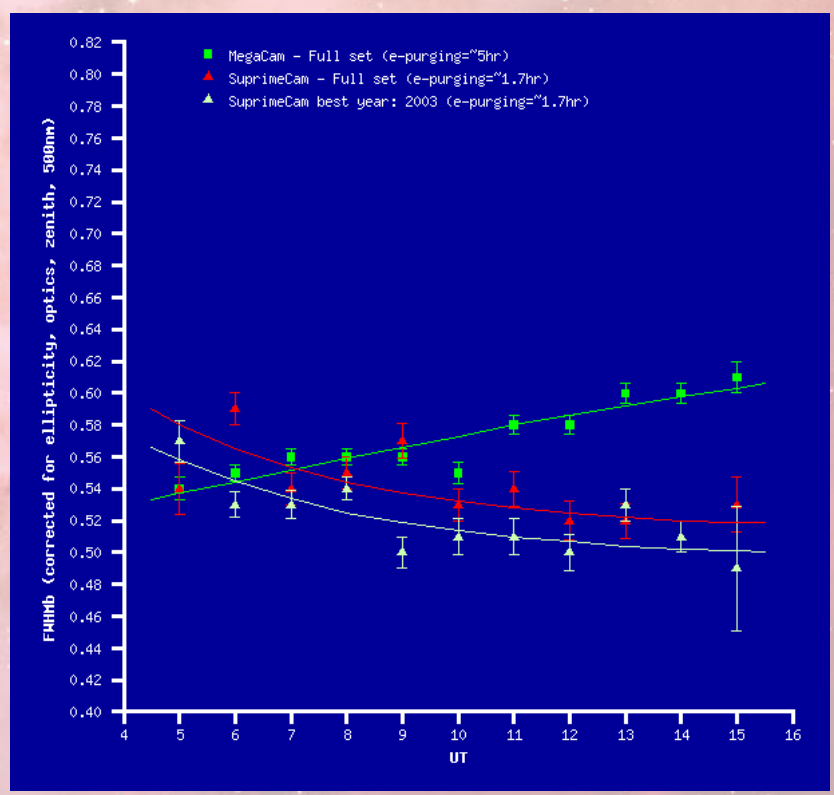


DECam filters response used for MegaCam RED

Overall gain in zero–points: u=0.2, g=0.1, r=0.4, i=0.5, z=0.6 mag.

Dome venting (2013)

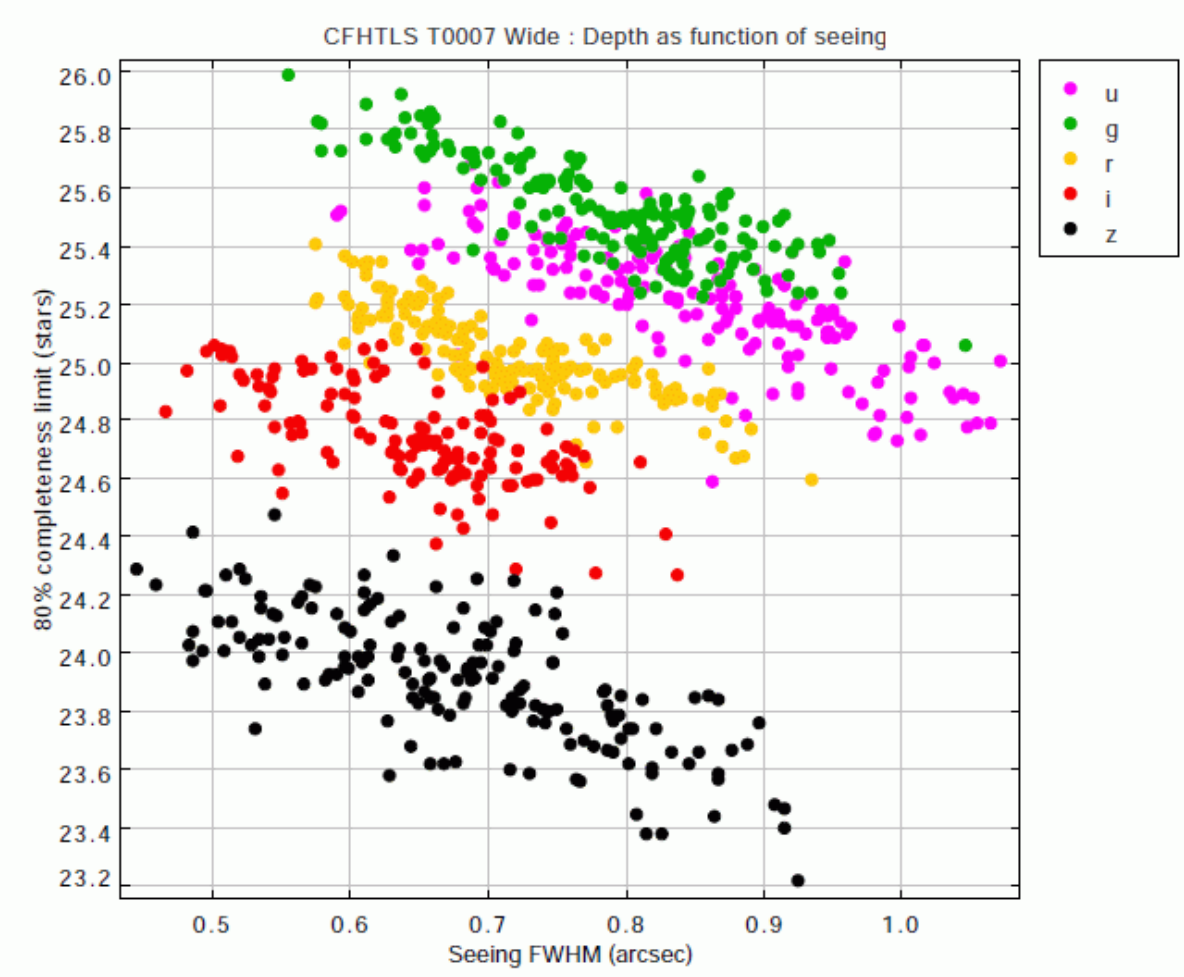
Full integration: fall 2013



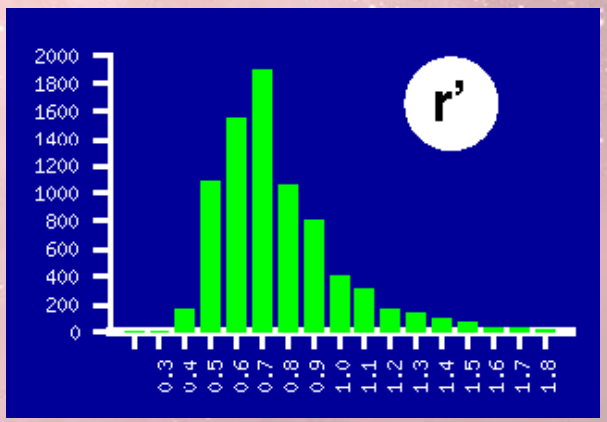
Matching Subaru's performance: 0.1" gain

Not just a gain in absolute: the IQ will get far more uniform throughout the night

Optimization of the observing process (SNR QSO, 2013)



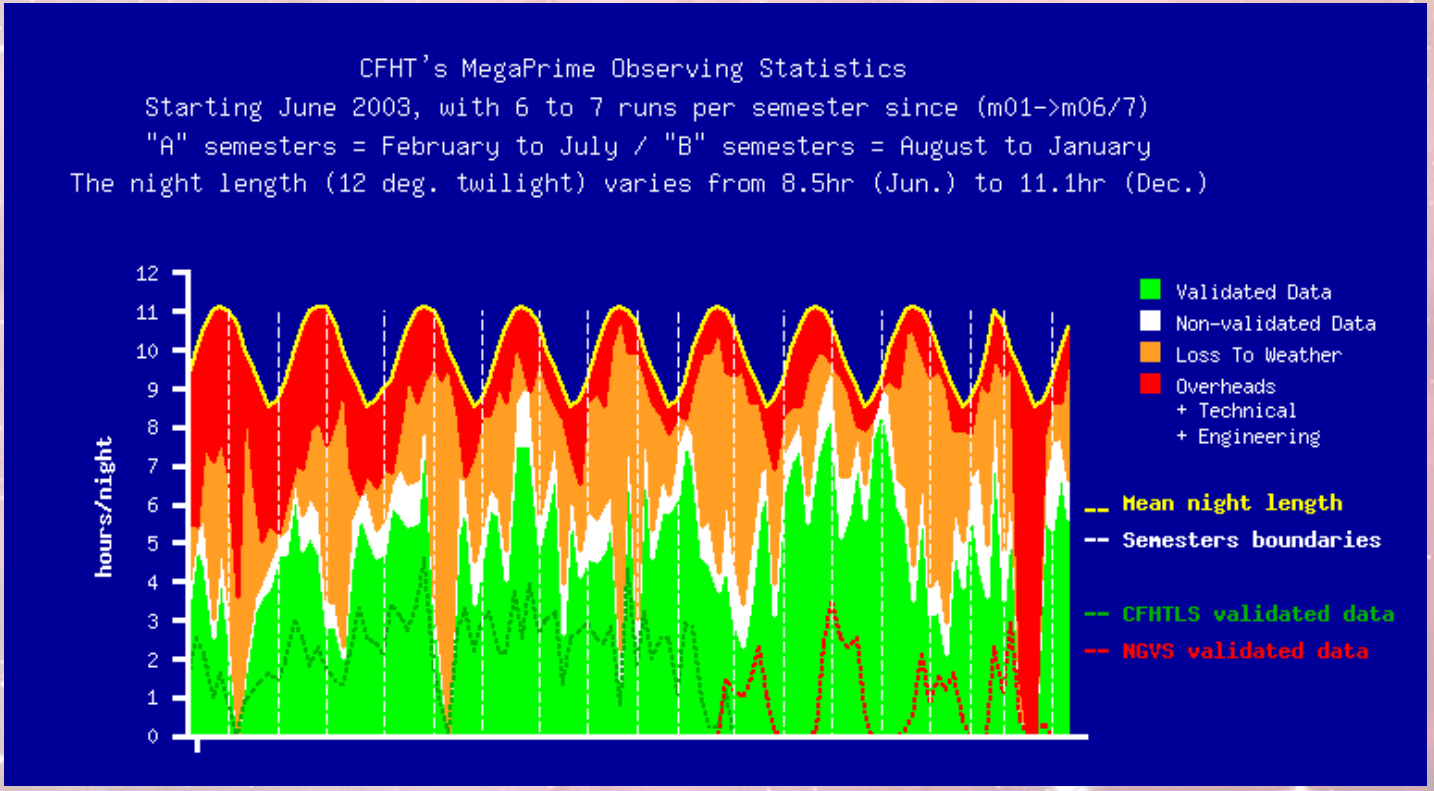
CFHTLS Wide depth vs image quality at fixed exposure times



MegaCam IQ distribution

The end result is a uniform depth for a survey designed with the median IQ

Planning with real weather statistics



10 years of MegaCam observing: 5 hours per night of validation PIs/LPs

Considering the past decade conditions, mapping a large contiguous sky area with limited slews lead to 6.3 hours per night of QSO validation.

Mapping the Euclid north galactic cap: 7,500 sq.deg. in g, r, i, z

Filter	Extended sources SNR=7	Point sources SNR=5
g	24.7	25.5
r	24.0	25.0
i	23.3	24.4
z	22.9	23.9

Depth requirements for the Euclid ground survey

	g	r	i	z	Intg.	Nights	Years	Fraction 6 Years
MegaCam	1250	1000	1075	1800	5125	2064	5.7	94% (No venting)
MegaCam Vented	1041	819	926	1428	4214	1746	4.8	80% z' compromised
MegaCam RED	939	694	537	437	2607	1117	3.1	51% (x 1.6 MC vented)

Global time envelope

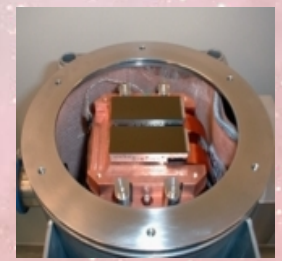
MegaCam RED could use bright time in extended observing runs (months)

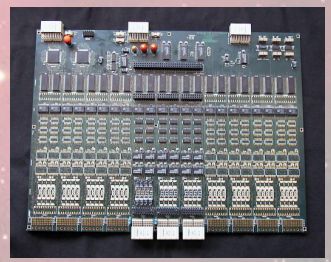
Adding a u–band component (24.1 SNR=5) adds ~700 hours (+25%)

MegaCam RED: distribution of tasks in the CEA/CFHT project

MegaCam upgrade (MegaCam RED)

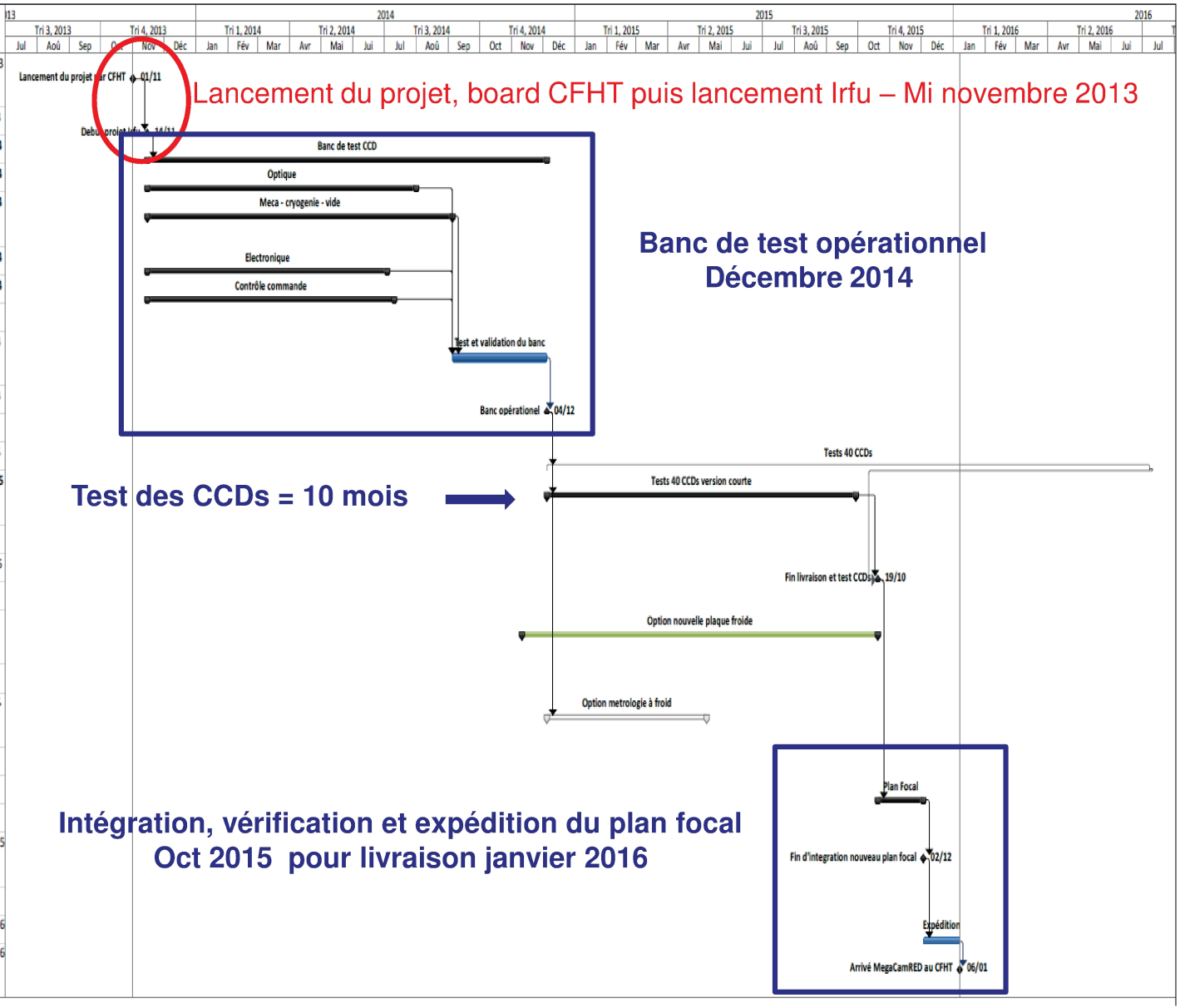
- **CCD Testing** (cea)
  - CCDs procurement (CFH)
  - Test bench (cea)
  - Test & metrology (cea)
- **Integration** (cea)
  - Cryostat delivery (CFH)
  - Integration Metrology (cea)
- **Readout speed optimization** (CFH)
  - Test bench (CFH)
  - Code optimization (CFH)
- **Filters** (CFH)
  - Procurement (CFH)
  - New frames (CFH)





Schedule at CEA IRFU: November 2013 – January 2016

N°	Nom de la tâche	Durée	Début	Fin
1	Lancement du projet par CFHT	0 jour	Ven 01/11/13	Ven 01/11/13
2	Debut projet Irfu	0 jour	Jeu 14/11/13	Jeu 14/11/13
3	**Banc de test CCD**	**235 jours**	**Ven 15/11/13**	**Jeu 04/12/14**
4	**Optique**	**170 jours**	**Ven 15/11/13**	**Jeu 31/07/14**
12	**Meca - cryogenie - vide**	**175 jours**	**Ven 15/11/13**	**Jeu 04/09/14**
27	**Electronique**	**150 jours**	**Ven 15/11/13**	**Jeu 03/07/14**
35	**Contrôle commande**	**155 jours**	**Ven 15/11/13**	**Jeu 10/07/14**
43				
44	**Test et validation du banc**	3 mois	Ven 05/09/14	Jeu 04/12/14
45	**Banc opérationel**	0 jour	Jeu 04/12/14	Jeu 04/12/14
46				
47	~~Tests 40 CCDs~~	~~18 mois~~	~~Ven 05/12/14~~	~~Jeu 07/07/16~~
48	**Tests 40 CCDs version courte**	**177 jours**	**Ven 05/12/14**	**Lun 28/09/15**
212				
213	Fin livraison et test CCDs	0 jour	Lun 19/10/15	Lun 19/10/15
214				
215	Option nouvelle plaque froide	205 jours	Mar 11/11/14	Mar 20/10/15
223				
224	~~Option metrologie à froid~~	~~95 jours~~	~~Ven 05/12/14~~	~~Jeu 07/05/15~~
231				
232	**Plan Focal**	**27 jours**	**Mar**	**Mer**
239				
240	**Fin d'integration nouveau plan focal**	0 jour	Mer 02/12/15	Mer 02/12/15
241				
242	**Expédition**	1 mois	Jeu 03/12/15	Mer 06/01/16
243	**Arrivé MegaCamRED au CFHT**	0 jour	Mer 06/01/16	Mer 06/01/16



CEA IRFU cost center

Coût en k€

Systèmes	2014	2015	2016
Banc de test	222	8	0
Integration Plan Focal	0	20	
Garantie - assurance	0	17,4	0
Missions			
Relation industrielle	2,5	0,5	0
CDD			
Developpement electronique	35	0	0
TOTAL :	259,5	45,9	0
Options			
Nouvelles plaque froide	0	28,5	0
Métrologie mosaïque à froid	0	5,5	0
TOTAL avec les options :	259,5	79,9	0

à confirmer

305 = $400k

~~339~~

Main d'œuvre CEA	60	257	174

491 = $642k in–kind

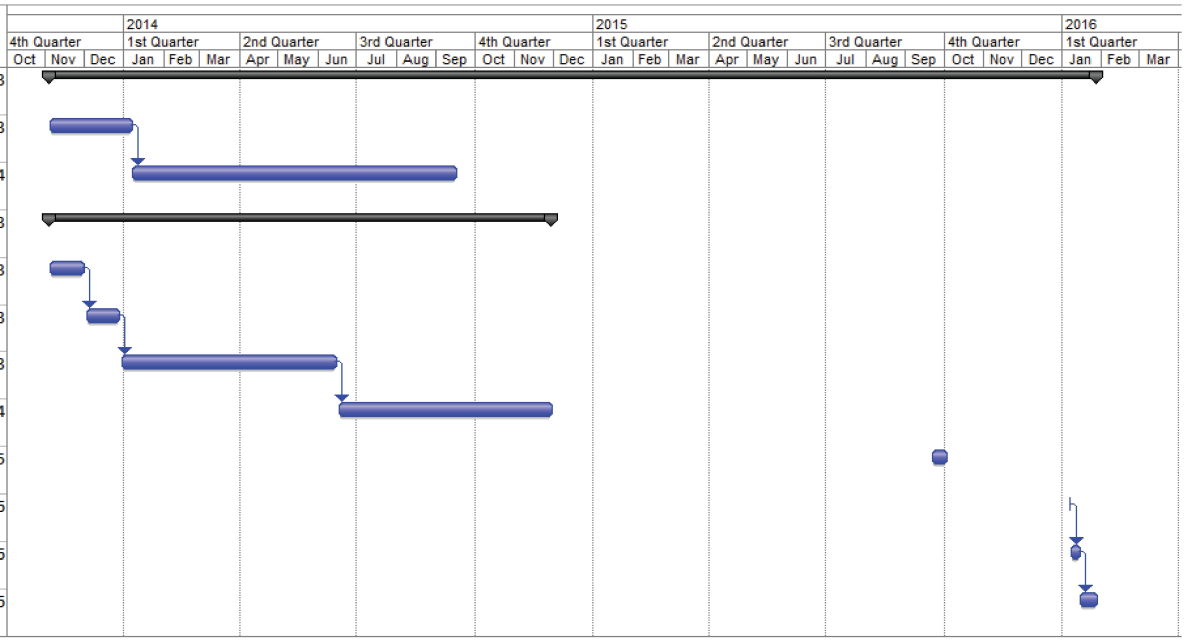
Provision pour risque			
Franchise assurance CCD *	0	**14,5**	0

*Cours du dollard considéré 0,7637

Schedule and manpower at CFHT: November 2013 – January 2016

CFHT manpower estimate			
FTE estimates	per month	duration (months)	man months
Project management	0.2	27	5.4
CCD procurement	1	2	2
Filter procurement	1	2	2
Readout speed improvement -software	0.5	12	6
Readout speed improvement -hardware	0.5	13	6.5
MegaCam disassembly/shipping prep	2	0.4	0.8
MegaCam assembly	2	0.25	0.5
MegaCam test	2	0.5	1
Total manpower (man months)			24.2

ID	Task Name	Duration	Start
1	Project management	583 days	Mon 11/4/13
2	CCD contract and procurment	46 days	Mon 11/4/13
3	Filter procurement and delivery	180 days	Tue 1/7/14
4	Readout speed improvement	280 days	Mon 11/4/13
5	PCB fabrication	20 days	Mon 11/4/13
6	PCB asssembly	20 days	Mon 12/2/13
7	SLINK interface dvelopment	120 days	Mon 12/30/13
8	Readout optimization/ test	120 days	Mon 6/16/14
9	MegaCam disassembly/shipping to CEA	10 days	Mon 9/21/15
10	MegaCam return	1 day	Wed 1/6/16
11	MegaCam reassembly	5 days	Thu 1/7/16
12	MegaCam test	10 days	Thu 1/14/16



CFHT cost center

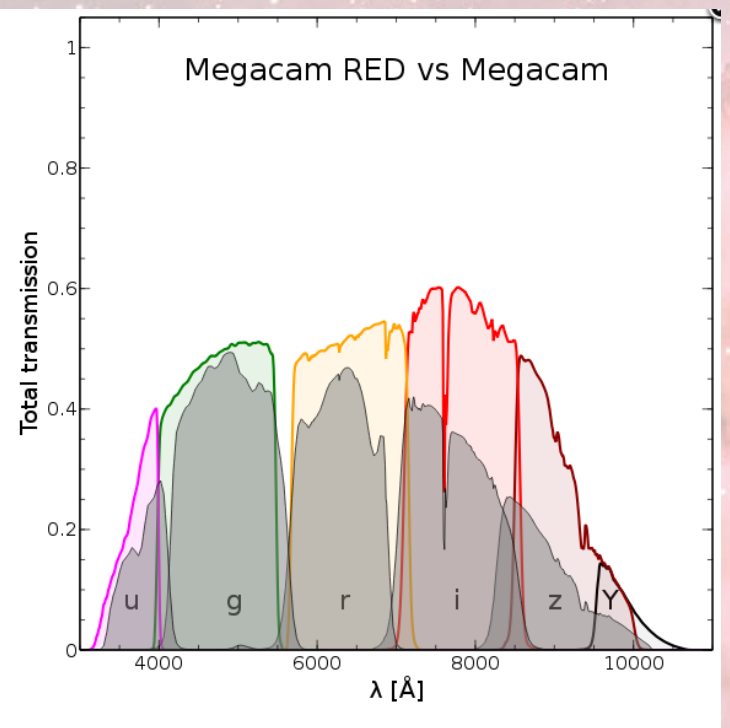
	CFHT cost estimate			
Test cryostat	Equipment	Qty	Price	Cost
	Driver PCB	2	500	1000
	SHARC PCB	2	250	500
	Readout PCB	2	300	600
	Parts/cables/connector/chassis	lot	1000	1000
	Next gen SLINK	1 pair	1000	1000
	Computer	1	1000	1000
	Contingency			4000
	Subtotal			**9100**
Filters	u	1	70000	70000
	g	1	35000	35000
	r	1	35000	35000
	i	1	35000	35000
	z	1	35000	35000
	Y	1	19000	19000
	filter holders	6	100	600
	Subtotal			**229600**
CCDs	CCD42-90 science grade DD G1-AM2	40	47500	1900000
	Subtotal			**1900000**
Travel	Integration & test @ CFHT	2	6200	12400
	Meeting @ CEA	2	6200	12400
	Meeting @ e2V	3	500	1500
	Subtotal			**26300**
Shipping to and from CEA		2	2000	4000
	Subtotal			**4000**
	Total cost (USD)			**2169000**

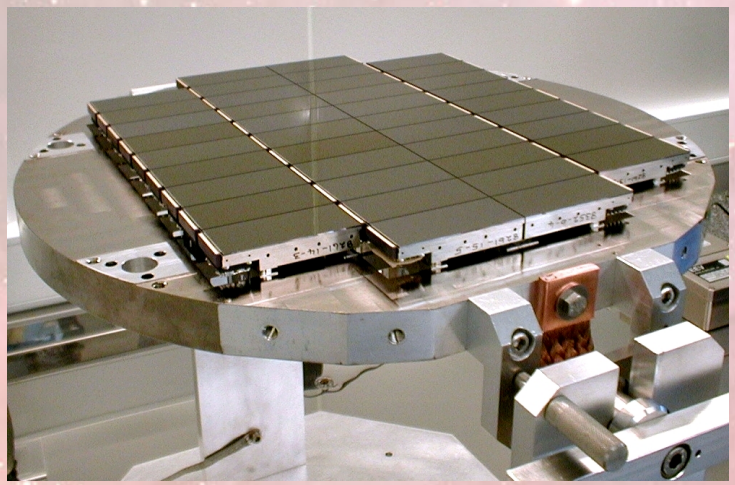
MegaCam RED grand total:

CEA+CFHT: $2,569,000

including 10% contingency for low risk

MegaCam RED: a CEA/CFHT project building on CFHT's strengths





MegaCam RED grand total:

CEA+CFHT: $2,569,000

- Low risk
- Low complexity
- Fast track: first light Jan. 2016
- No MegaCam for 3 months in 15B
- High scientific return potential
- Superb 0.6" survey machine
- Large established community

Project lead: J.–C. Cuillandre
Project manager CEA: R. Granelli
Project manager CFHT: K. Ho
Inst. scientist CEA: O. Boulade
Co–I Canada: R. Carlberg
Co–I France: Y. Mellier

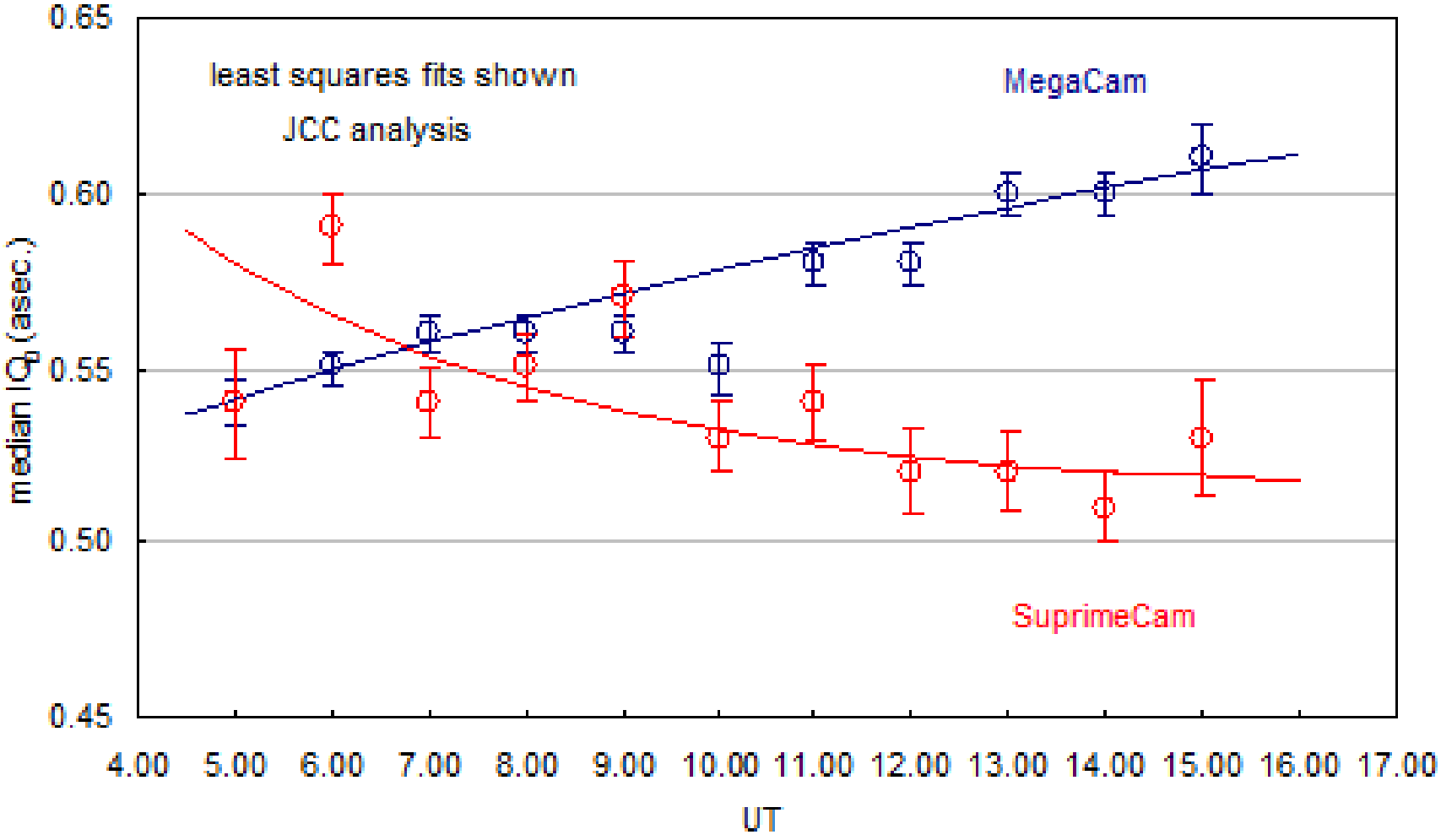
Megacam RED Science

Megacam RED QE
Every band gets Better

Camera/CCD	u	g	r	i	z	Y
MegaCam e2v	55%	85%	80%	55%	25%	0%
MegaCam e2v AM2	60%	90%	90%	90%	65%	15%
PS1/2 MIT/LL	0%	50%	85%	95%	90%	40%
DECam LBNL	20%	70%	85%	90%	85%	20%
HSC Matsushita	15%	85%	95%	90%	75%	15%
LSST (e2v base)	25%	85%	92%	90%	65%	15%

No other current or planned camera has comparable u band response. A unique capability for at least a decade.

Dome venting will improve IQ



Site Figure of Merit: **natural seeing** (TMT site testing data) M~clear/IQ^2

	Visible
Tololo	**0.343**
Mauna Kea* (TMT)	**0.675**
Armazones	**1.000**

Has interesting implications for DECam vs CFHT

CFHT Megacam-Red: Everyone wins

- Dome venting (at last):
  - Conservatively, Subaru quality images
  - Possibly better.
- Chip upgrade: no losers
  - i band gain is 2.5x science speed (with IQ)
  - Low cost, low risk in the single most used capability of CFHT.
- Important to keep CFHT productive

A Wide Field ugriz survey now

- Along with DES provides the first ever deep, all high latitude sky imaging, CFHT: unique u band.
- Science is very broad
  - Milky Way tomography (u implements [Fe/H])
    - 30x volume of SDSS in north
    - Hot stars (WDs, OB stars in other galaxies)
  - Galaxy clusters (photo-z, strong lenses, Planck)
    - w indicator, cluster physics, galaxy environments at redshift
  - Galaxy evolution (with u band SFR, drop-outs)
    - Study to z~3, vast increase beyond SDSS low z.
  - AGN: search for the rare in the sky
    - Fainter than SDSS at z~6+, TMT/E-ELT relevant for IGM
  - Weak lensing (better IQ?, better photo-z with u)
    - First glimpse of Euclid science
  - Supernovae* (SNLS to z~1.1)
    - add-on survey? DE and Sne science, metal evolution
  - The biggest possible legacy dataset
  - Participation in the international all-sky OIR mapping program.

Opportunities for collaboration with other telescopes

- Subaru, PS & DES (efficiency, calibration)
- CHIME (low res HI mapper, BAO) LOFAR?
- MS-DESI Spectra ~BigBOSS (2019)
- eROSITA soft x-ray (Russia has north)
- Possible route into LSST
- Targets for JWST (2018)
- Euclid

A significant CFHT time decision

Euclid Ground @ CFHT

	g	r	i	z	Intg.	Nights	Years	Fraction 6 Years
MegaCam	1250	1000	1075	1800	5125	2064	5.7	94% (No venting)
MegaCam Vented	1041	819	926	1428	4214	1746	4.8	80% (Subaru perf.)
MegaCam RED 0	1068	820	614	498	3000	1254	3.4	57% (No venting)
MegaCam RED 1	939	694	537	437	2607	1117	3.1	51% (Subaru perf.)
MegaCam RED 2	850	621	477	388	2336	1022	2.8	47% (CFHT best)
MegaCam RED 3	781	578	431	349	2139	954	2.6	44% (Full optimal)

Adding u band adds 0-25% more time.

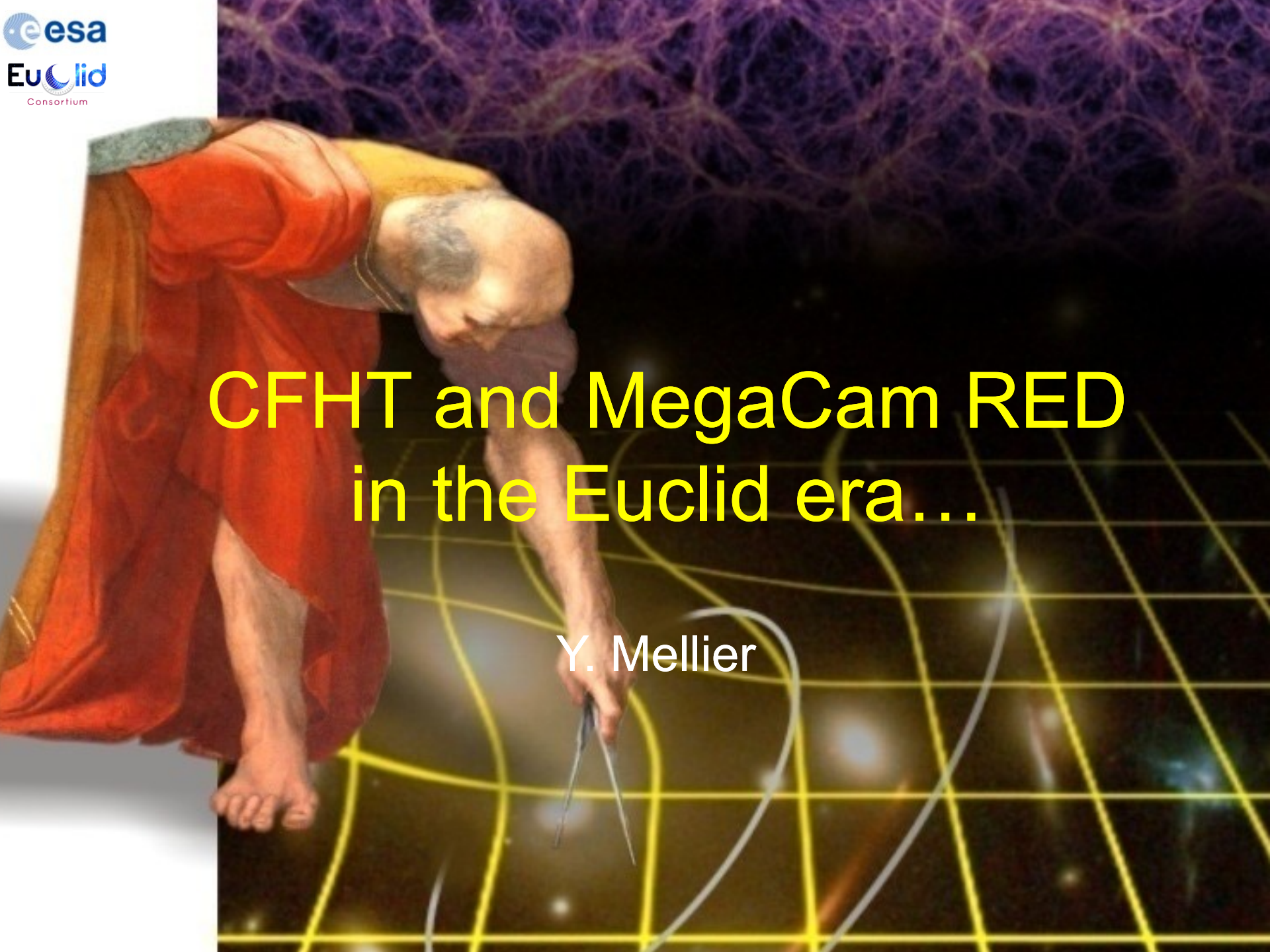
Euclid analysis needs to be re-evaluated with u

Total is ~3.5 yrs, 100% allocation if at Subaru IQ

Should leave some time for PI science (leveraging)

CFHT Survival Issues

- National astronomy programs elsewhere are sacrificing 4m telescopes
- Survivors (AAT) are largely survey dedicated.
- In Canada, NRC supports:
  - TMT funding request for 2014 (first light 2022)
  - SKA request expected in 2016
  - No short term transformation opportunity
  - Important to keep CFHT for students, PDFs



CFHT and MegaCam RED in the Euclid era…

Y. Mellier

Digging the dark in the Planck universe

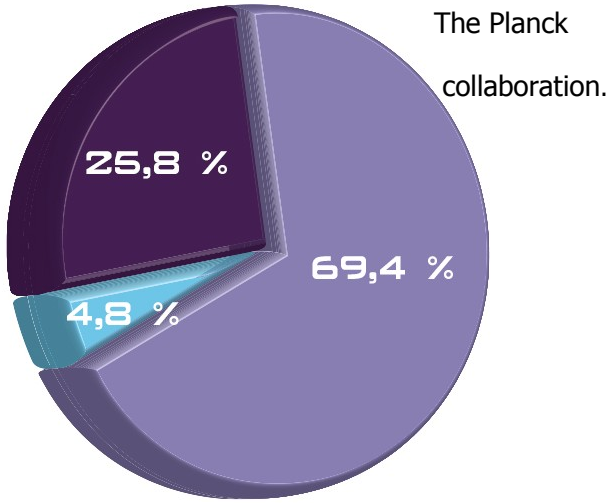
- Why a Universe in accelerating expansion?
  Origin: dark energy ? modified gravity ?

- When did the DE-DM transition happen?

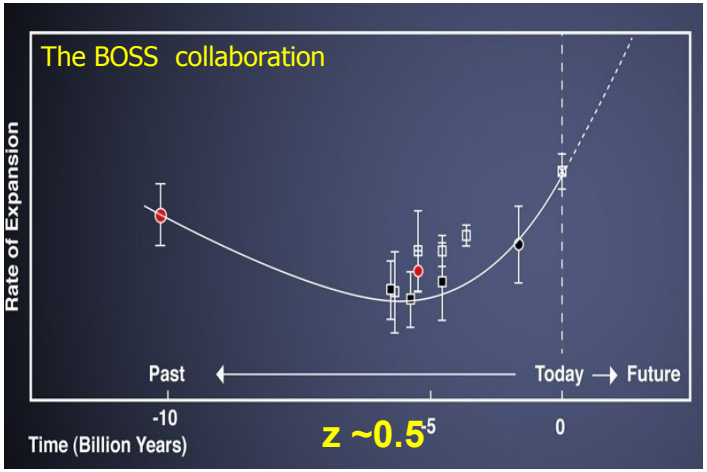
→ Distinguish DE, MG, DM effects by:

- Using >2 independent probes (Euclid=5)
- Tracking signatures on
  - Geometry of the Universe:
    - Weak Lensing, Galaxy Clustering,
  - History of structure formation:
    - WL, Redshift-Space Distortion, Clusters of Galaxies

→Need:control very accurately systematics.



The Planck collaboration.

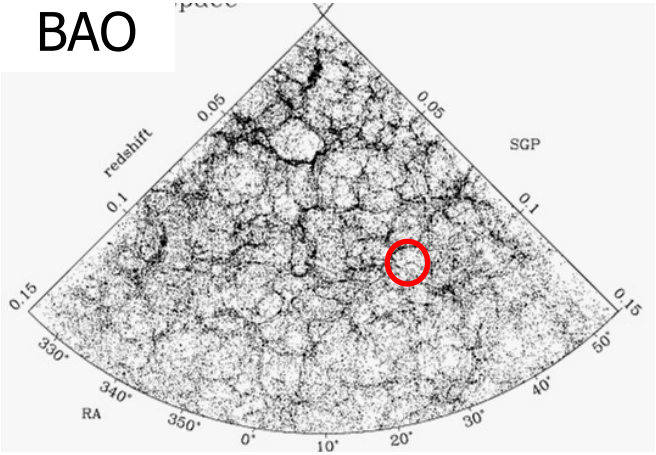


Transition very late, can be explored with visible+NIR telescopes → Euclid

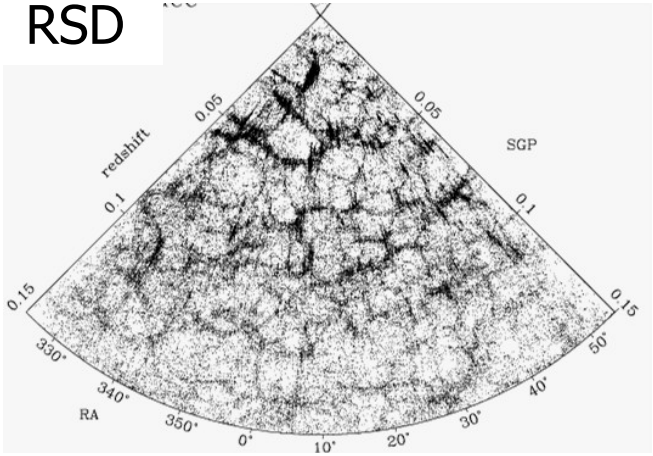
BAO, RSD and WL over 15,000 deg^2

50 million galaxies with redshifts

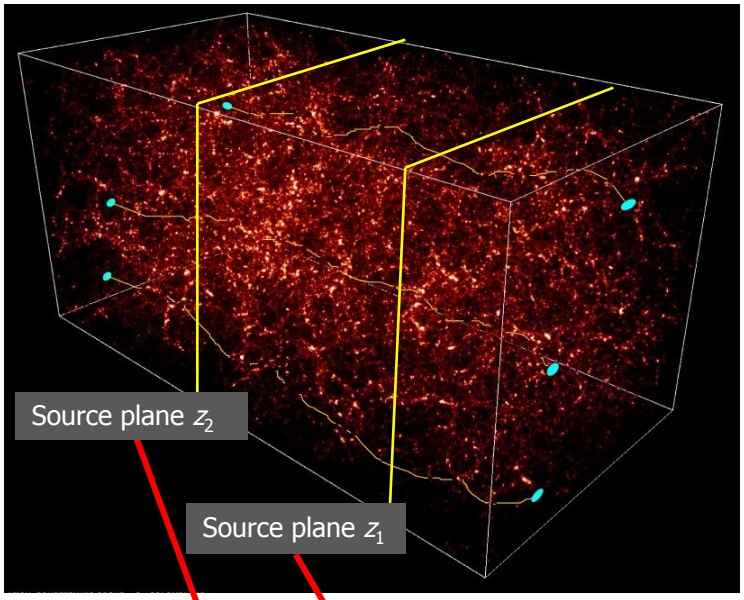
BAO

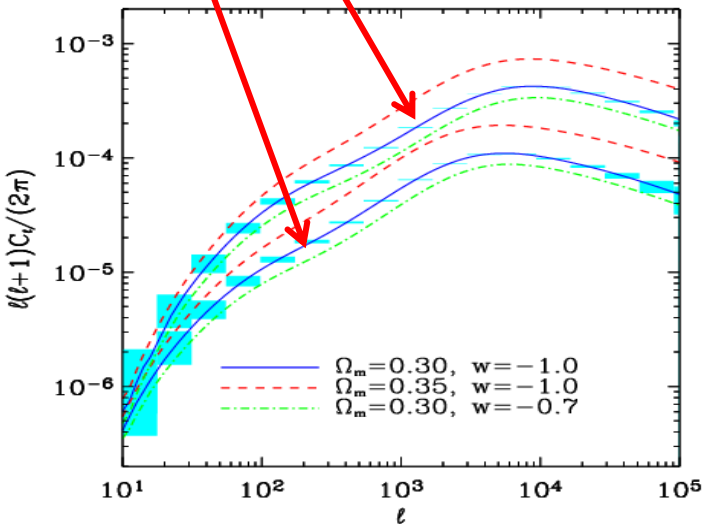


RSD



1.5 billion sources with shapes, 10 slices





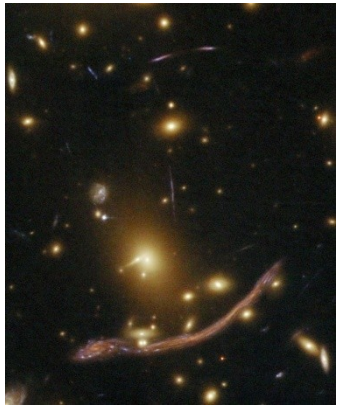
Visible + NIR data needed for Euclid

- Weak Lensing : redshifts of 2 10^9 sources to
  - Slice the universe
  - Control contamination by intrinsic alignments of galaxies

HST/ACS credit NASA/ESA

Galaxy halos

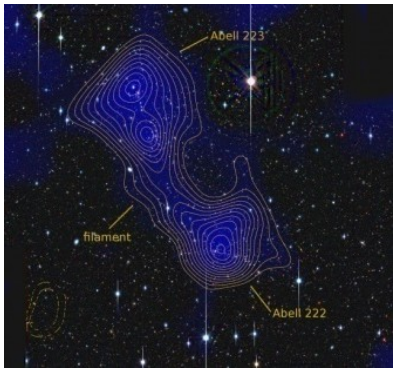
HST/ACS; credit NASA/ESA



Clusters of galaxies

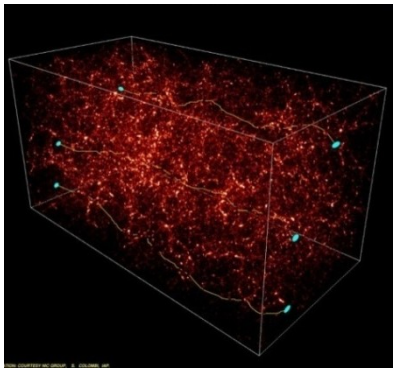
- Redshifts of Euclid clusters: (60,000 clusters, 5,000 giant arcs)
→ synergy with Planck and eROSITA

Dietrich et al 2012



Filaments between clusters

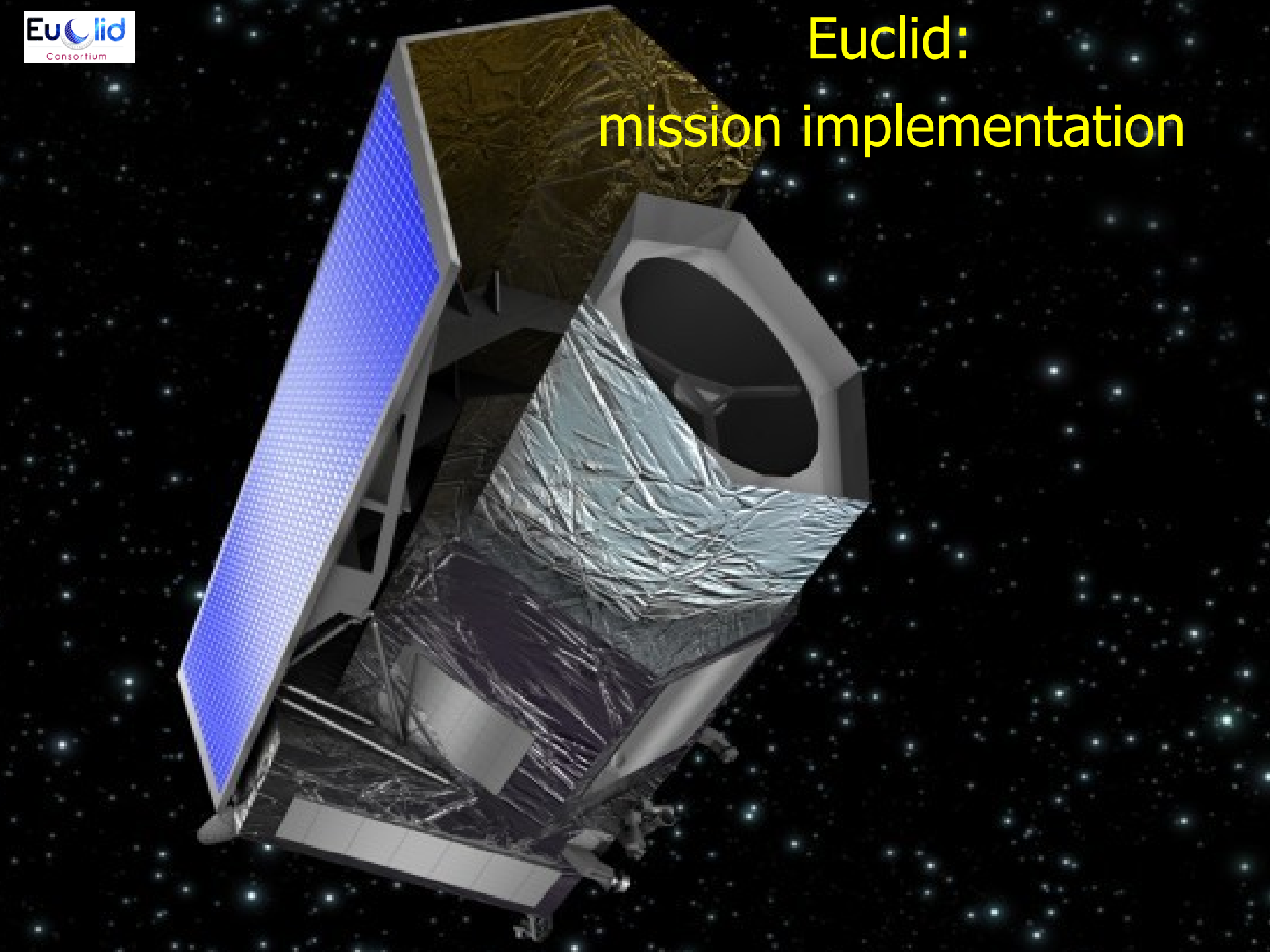
Colombi/Mellier



Cosmic shear

- Redshifts of sources and lenses needed at least in the range 0.2<z<2

→ Photo-z necessary, but with both Optical+NIR data



Euclid: mission implementation

Euclid mission baseline: Launch in 2020

Photo-z: Ground based Photometry and Spectroscopy

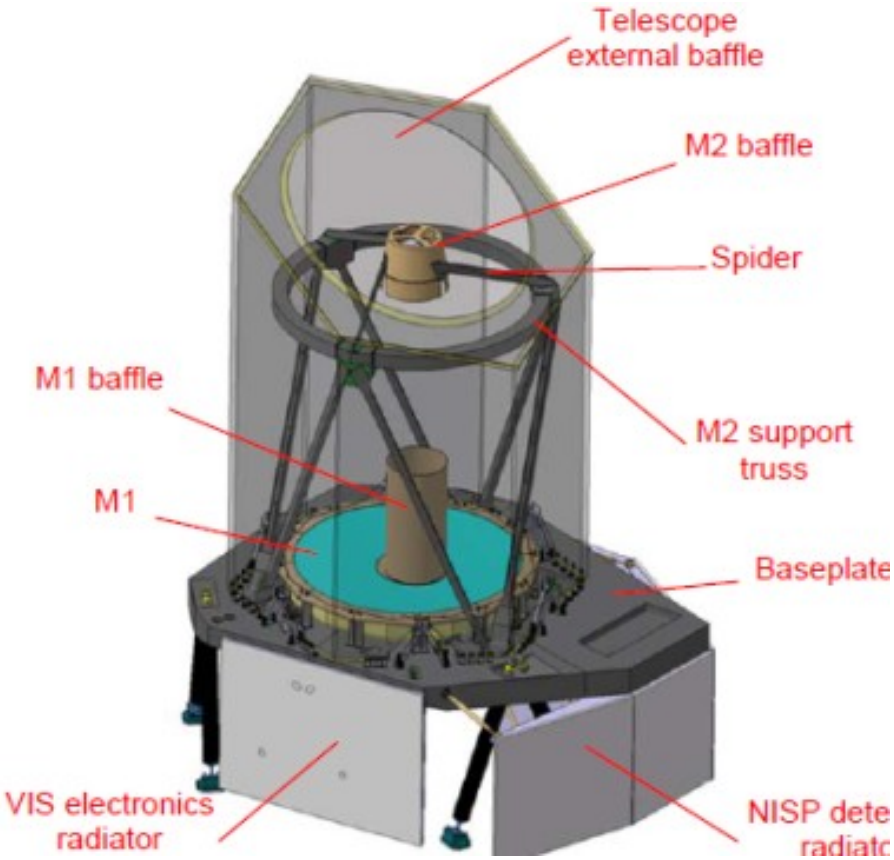
SURVEYS **In ~6 years**					
	Area (deg2)	Description			
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.			
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey			
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg²	0.763×0.722 deg²			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	$3\ 10^{-16}$ erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of n = 1.5 x10⁹ galaxies			**z of n=5x10⁷ galaxies**	

Possibility other surveys: SN and/or μ-lens surveys, Milky Way ?

Ref: Euclid RB Laureijs et al arXiv:1110.3193

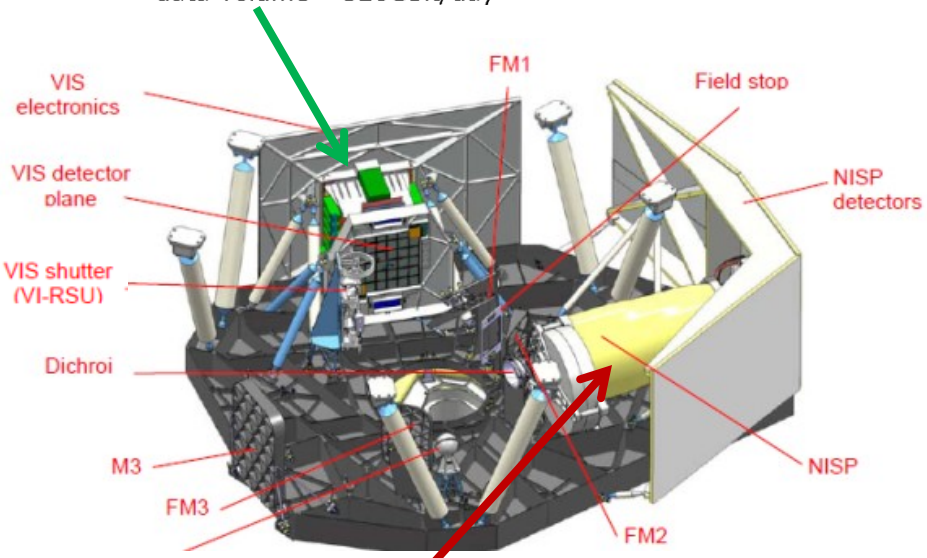
Euclid: telescope and instrument

Courtesy: Astrium and ESA Project office



VIS:

large area imager – a 'shape measurement machine'
36 4kx4k CCDs with 12 micron pixels
0.1 arcsec pixels on sky
bandpass 550-900 nm – narrow band channel
limiting magnitude for wide survey of magAB = 24.5 for 10σ
data volume – 520Gbit/day



NISP:

16 2kx2k H2GR NIR detectors , 0.3 arcsec/pixel

3 NIR filters: H,J,H, 4 Grisms (2 « B»; 2 « R »)

Lim. mag: AB 24.0 ; 5 σ pt source

Data volume:180 Gbit/day

- Stabilisation: pointing error x,y axes= 25mas over 700 s.
- FoV: Common visible and NIR Fov = 0.54 deg^2

Simulation of M51 with VIS

SDSS @ z=0.1

Euclid @ z=0.1

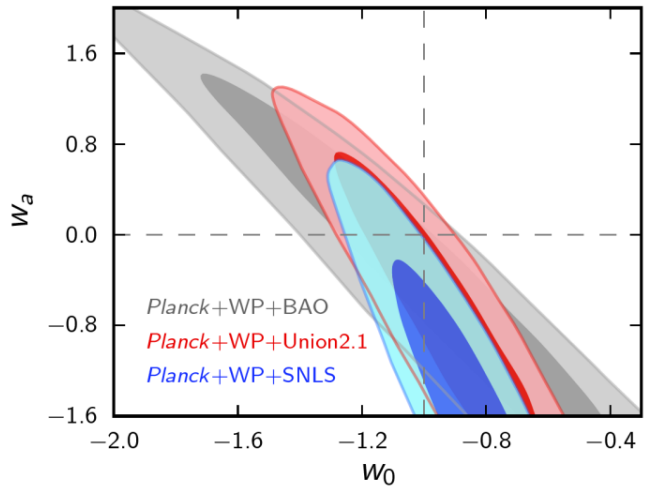
Euclid @ z=0.7

Euclid will get the resolution of Sloan Digital Sky Survey but at z=1 instead of z=0.05.

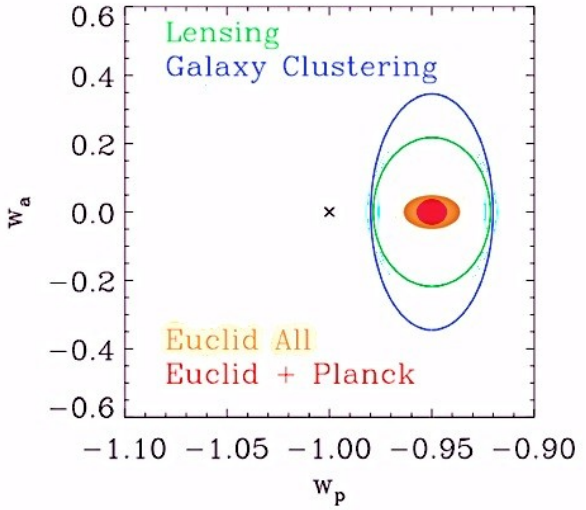
Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

Forecasts: Euclid cosmology programme

The Planck Collaboration. Ade et al 2013



68% confidence contours in (w_p, w_a).



	Modified Gravity	Dark Matter	Dark Energy		
Parameter	γ	m_ν /eV	w_p	w_a	*FoM*
Euclid primary (WL+GC)	0.010	0.027	0.015	0.150	430
Euclid All	0.009	0.020	0.013	0.048	1540
Euclid+Planck	0.007	0.019	0.007	0.035	4020
Current (2009)	0.200	0.580	0.100	1.500	~10
Improvement Factor	**30**	**30**	**>10**	**>40**	**>400**

Ref: Euclid RB arXiv:1110.3193

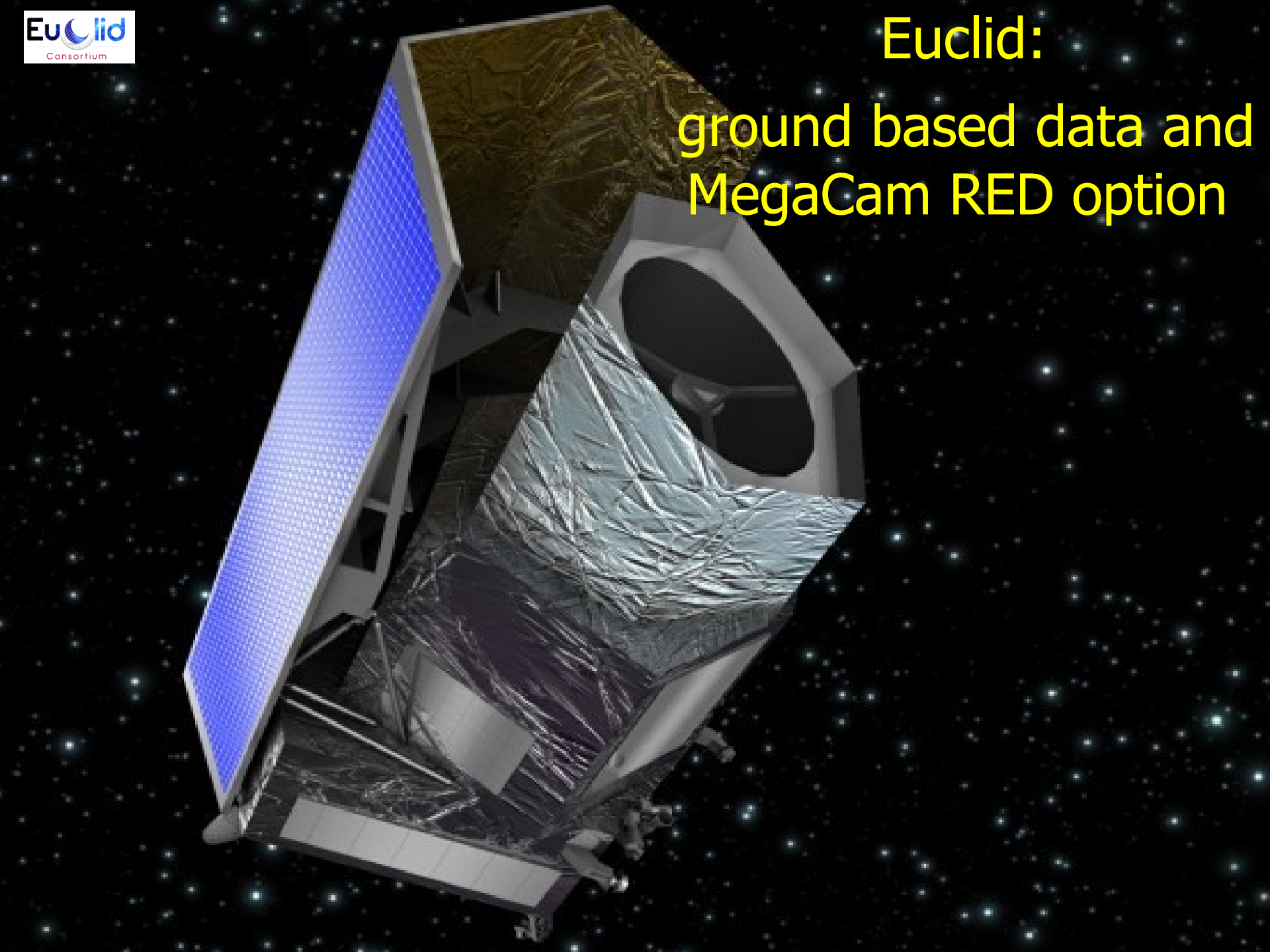
Assume systematic errors are under control

Euclid Legacy

- 12 billion sources ,3-σ
- 50 million redshifts;
- A mine of images and spectra for the community for several decades;
- A reservoir of targets for JWST, GAIA, E-ELT, TMT, ALMA, Subaru, VLT, ngCFHT, etc…
- Synergy with LSST, e-ROSITA, SKA

Objects	Euclid	Before Euclid
Galaxies at 1<z<3 with precise mass measurement	~2×10^8	~5×10^6
Massive galaxies (1<z<3))	Few hundreds	Few tenss
Hα Emitters with metal abundance measurements at z~2-3	~$4\times10^7/10^4$	~10^4/~10^2 ?
Galaxies in clusters of galaxies at z>1	~2×10^4	~10^3 ?
Active Galactic Nuclei galaxies (0.7<z<2)	~10^4	<10^3
Dwarf galaxies	~10^5	
T_{eff} ~400K Y dwarfs	~few 10^2	<10
Lensing galaxies with arc and rings	~300,000	~10-100
Quasars at z > 8	~30	None

Gravitational arcs and rings in Euclid


Euclid
Consortium
Euclid:
ground based data and
MegaCam RED option

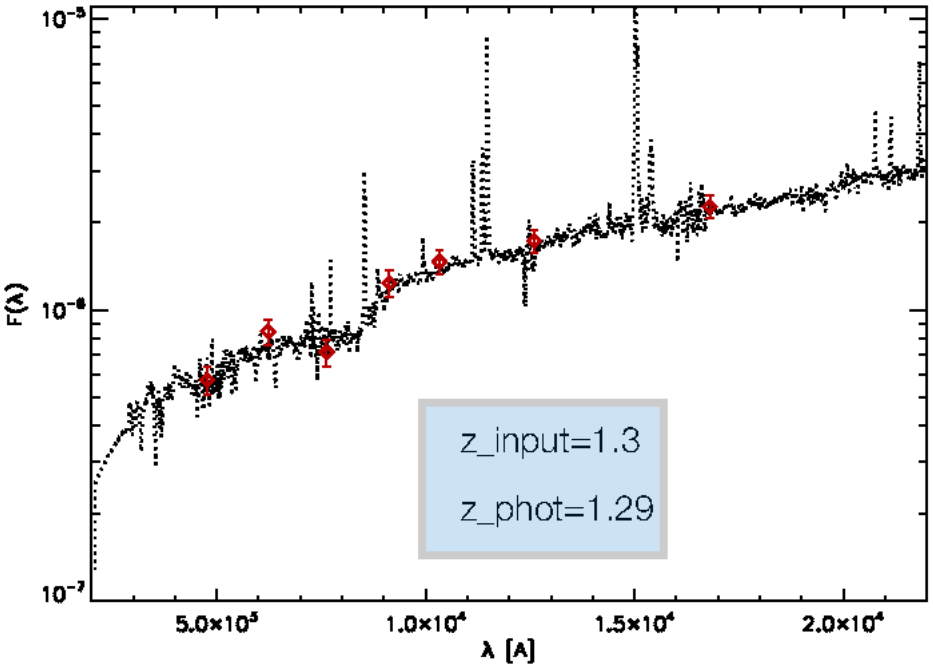
Ground Based Data: photo-z with Euclid

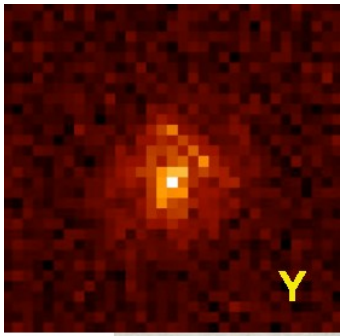
Requirements:

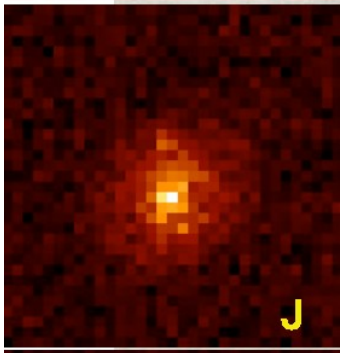
accuracy = 0.05x(1+z)

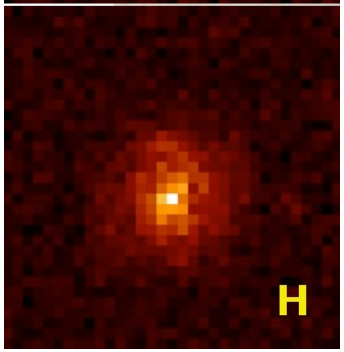
→ 4 optical band needed

→ u-band not needed.

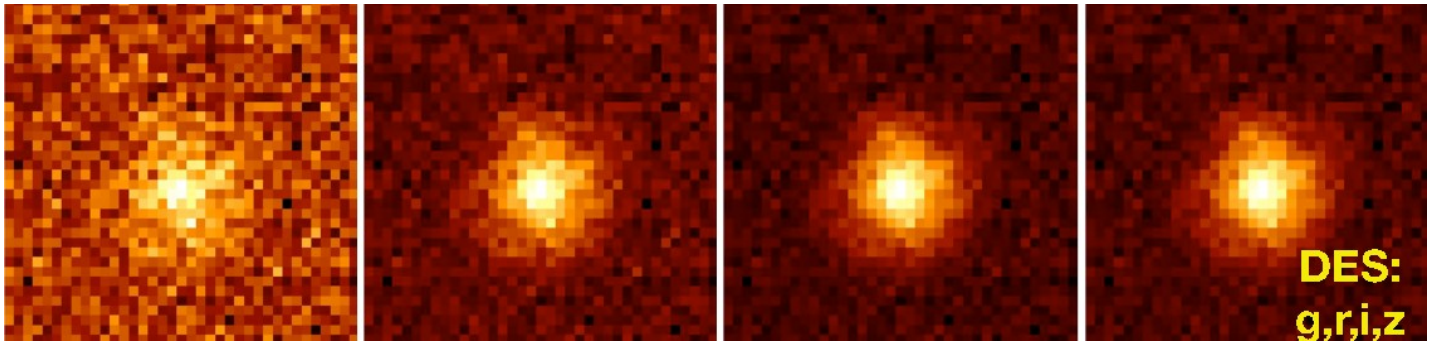








NIR data from Euclid NIR images.

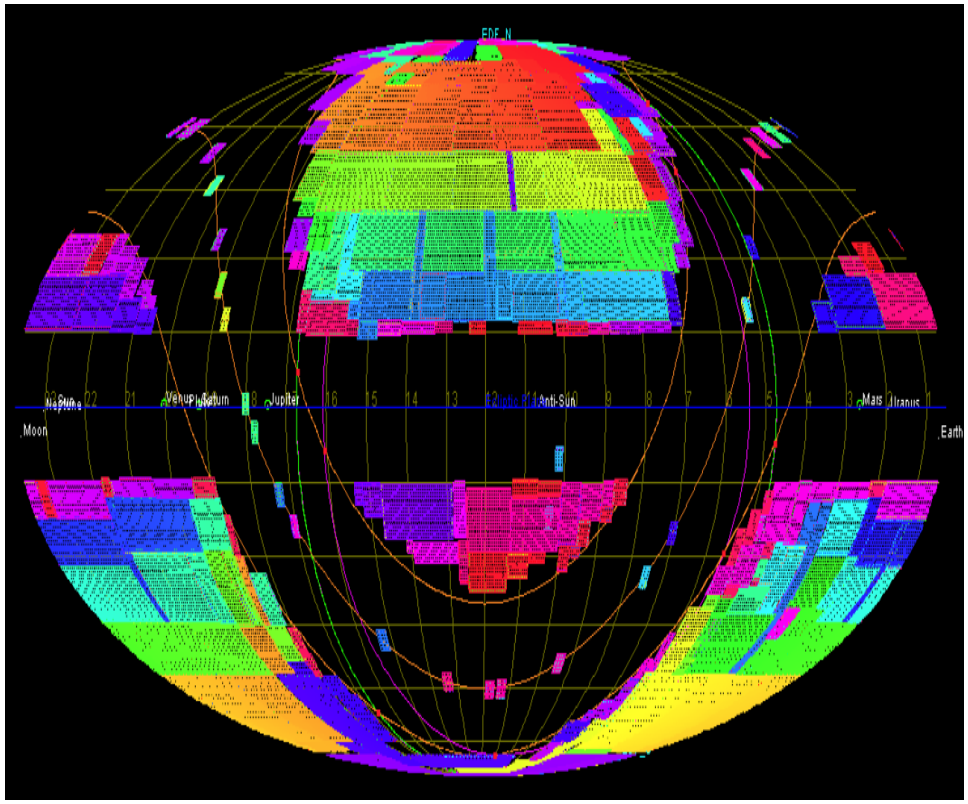


Visible data obtained from ground based telescopes

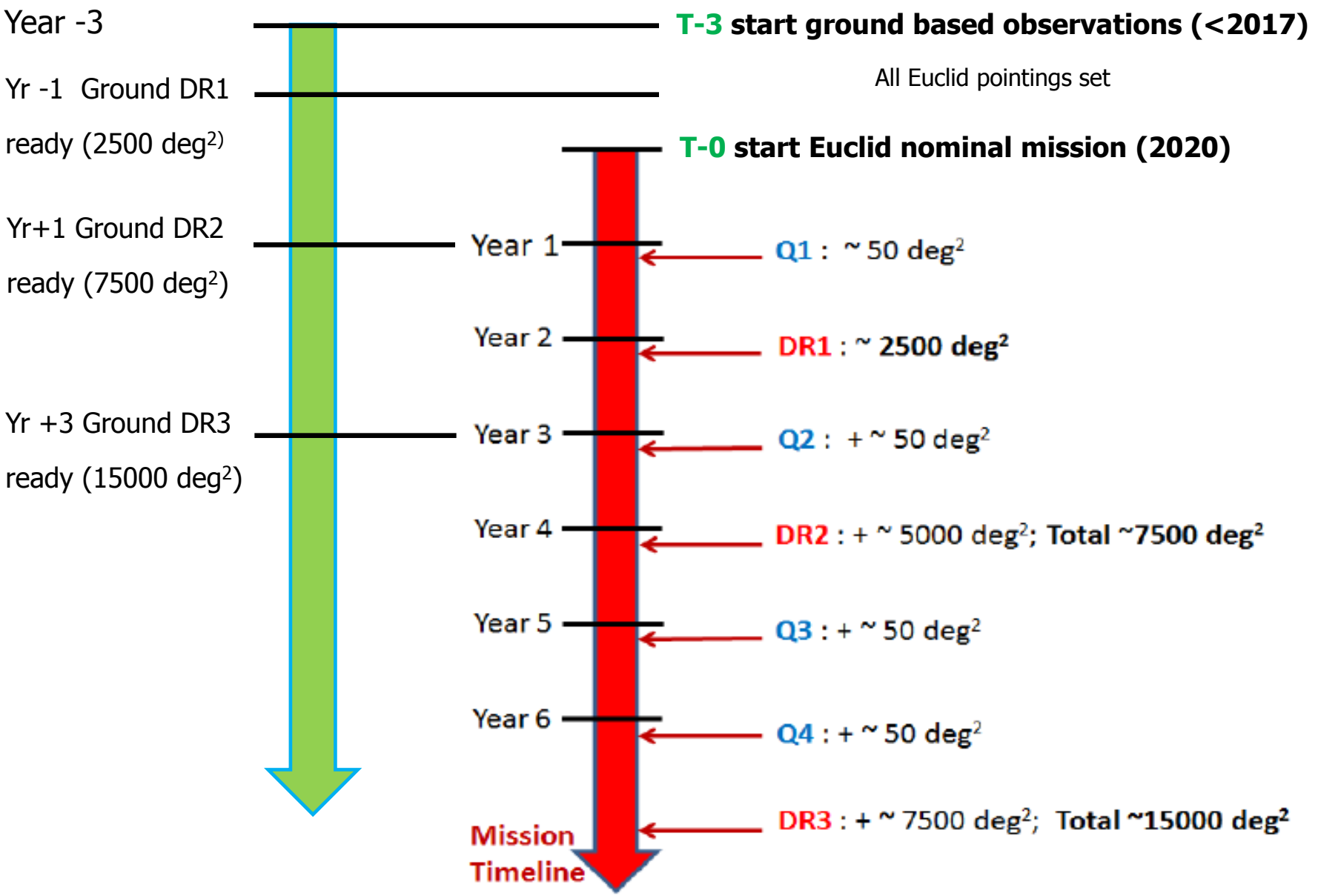
Ground Based Data: photo-z

- South: consolidated:
  - DES data deep enough in g,r,i,z . Suits Euclid needs;
  - EC will reprocessed DES data after the 1yr-proprietary period

- North: Not consolidated:
  - Pan-STARRS: CCD procurement problems, less time allocated to Euclid. If Canada in , then PS still needs 8 M USD from Euclid;
  - MegaCam-RED: looks promising C+F project → RECOMMENDED by Euclid Board → Canada interested?
  - HSC/Subaru→ Conflicts with PFS?



Data release model: Euclid + ground



MegaCam RED, Euclid and Canada

- What could be the contribution of Canada?
  - Participation to MegaCam RED survey(grey + dark) time for ~7yrs
  - MegaCam RED survey archived at CADC
  - Participation to the processing of the MegaCam RED survey

- Interesting option:
  - Canada leads a survey comprising some photometric data that are not essential to Euclid, but most useful for MegaCam RED stand alone science :

  → u-band?

  → Euclid to meet 0.03x(1+z) accuracy on photo-z.