Dome A – what is it good for?

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Dome A cosmology workshop
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1. Site comparison
2. KDUST capabilities
3. PILOT science drivers

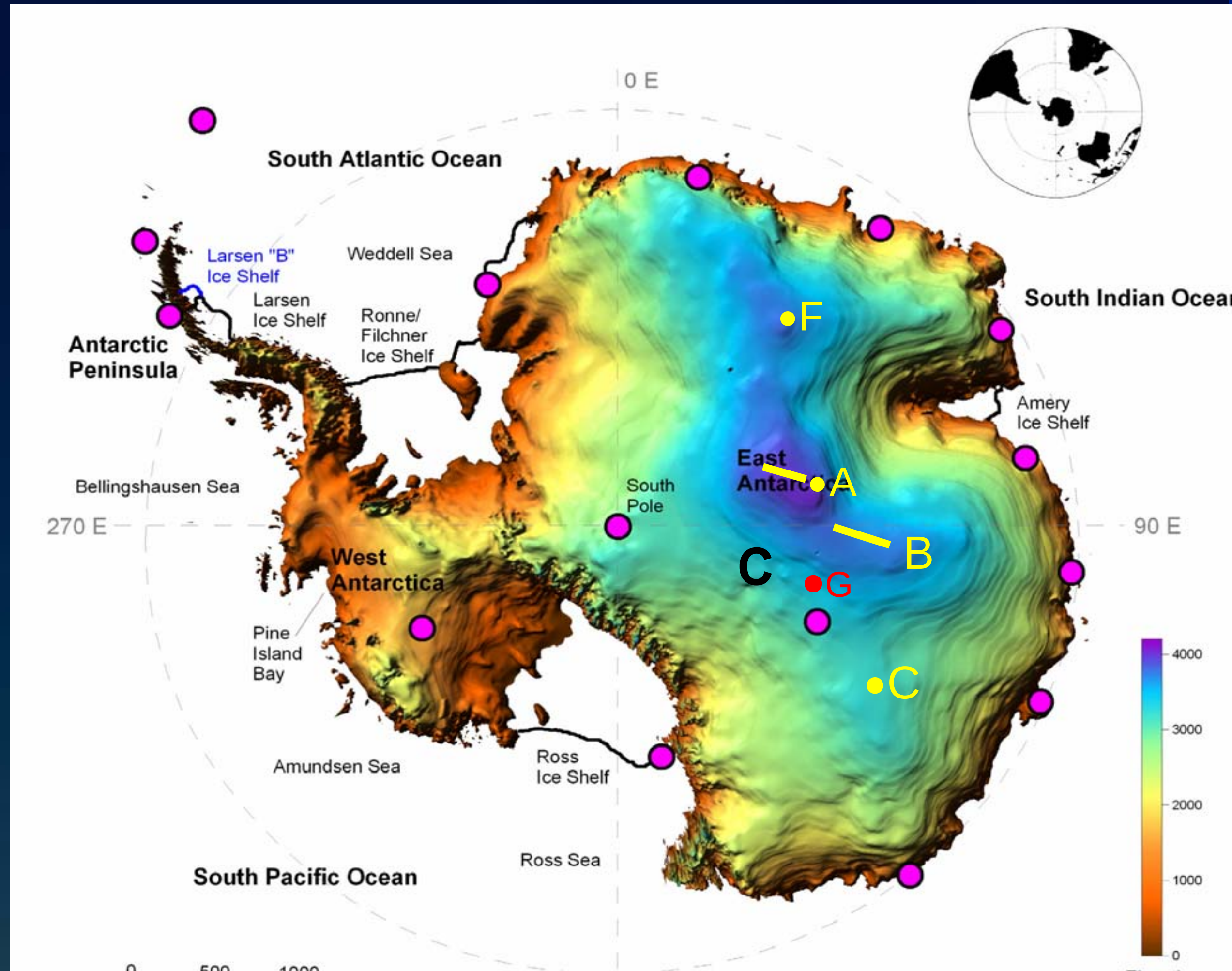
Saunders *et al.* (2009, astro-ph 0905.4156, *PASP* almost in press) attempted systematic comparison of Antarctic sites.

Looked at:

- **Boundary layer thickness**
- **Cloud cover**
- **Auroral emission**
- **Airglow**
- **Atmospheric emission**
- **Precipitable water vapour**
- **Surface temperature**
- **Free atmospheric seeing**

Didn't look at

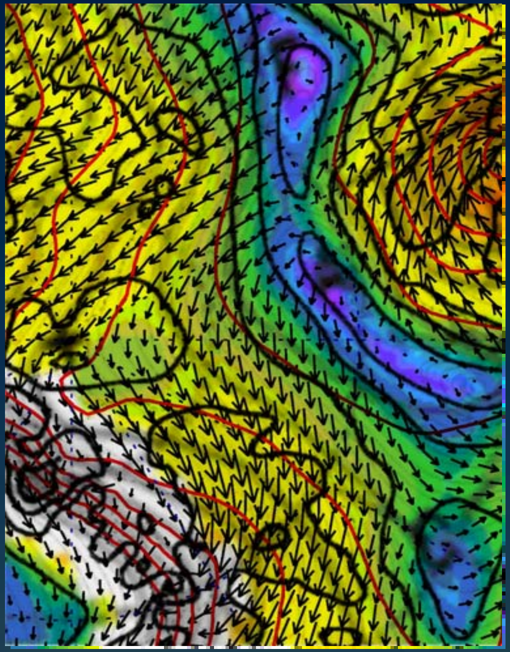
- **Non-winter use**
- **Sky coverage**
- **Dark time**
- **Infrastructure**
- **Non-astronomical uses**

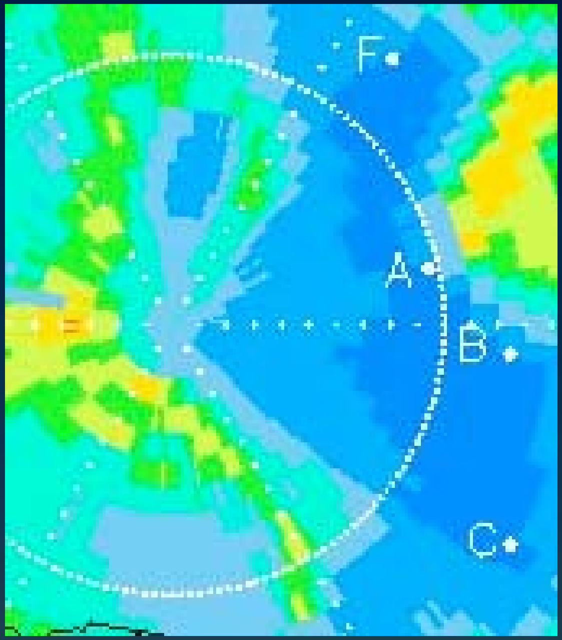


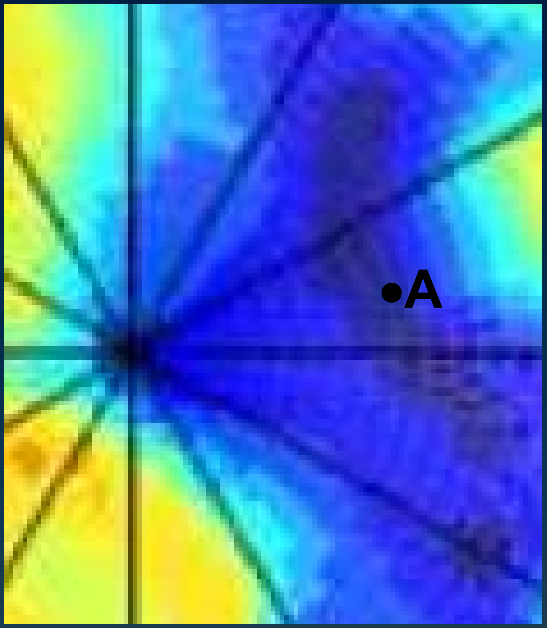
Site	Latitude	Longitude	Elevation	Λ(2010)
Dome A	80.37S	77.53E	4083m	-84.9°
Dome C	75.06S	123.23E	3233m	-84.1°
Dome F	77.19S	39.42E	3810m	-77.0°
Ridge B	76-79°S	97-93°E	3700-3809m	-85.4° -87.1°
South Pole	90°S	0°E	2800m	-80.0°

BOUNDARY LAYER THICKNESS, CLOUD COVER, SURFACE TEMPERATURE

All favour a site slightly to south of Dome A.







Swain & Gallee prediction for boundary layer thickness at Kunlun is 30m!
Dome A is not quite on `katabatic ridge', which passes 1-2° south.
BL thickness on katabatic ridge is 21m.

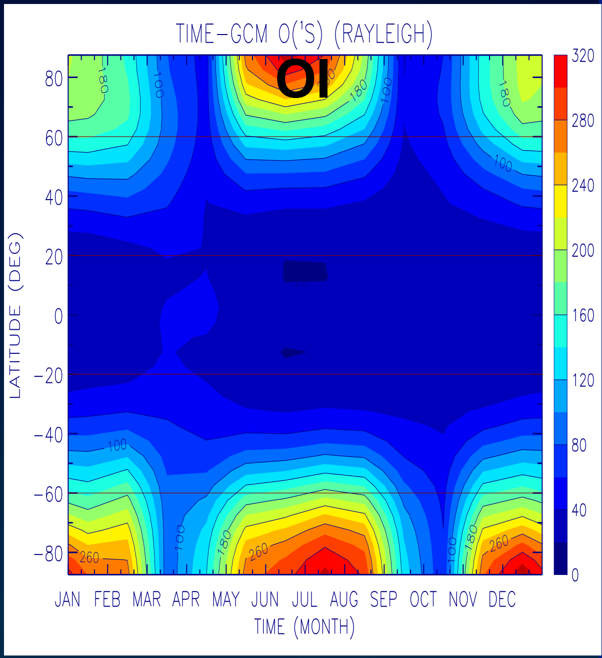
AURORAE, AIRGLOW

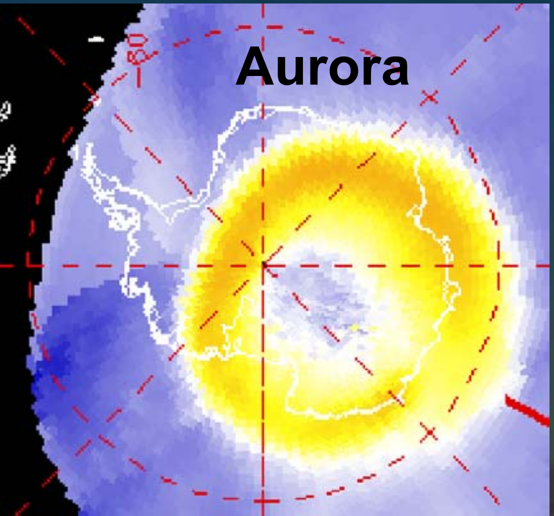
All Antarctic sites suffer from Aurora, at all times in solar cycle.

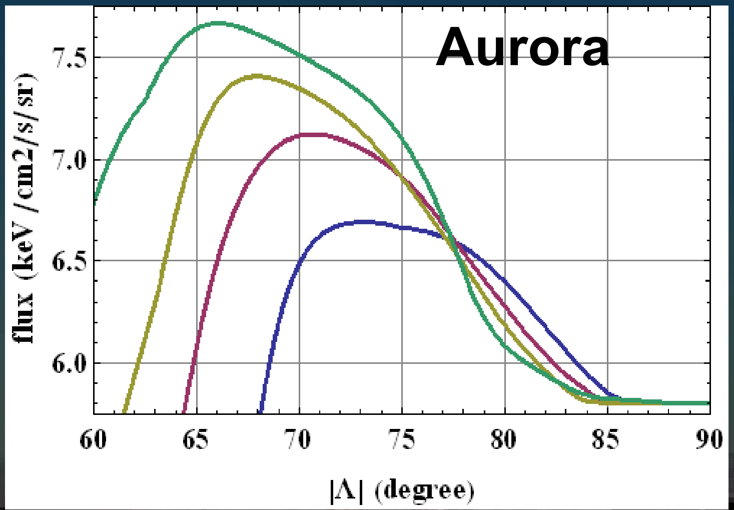
OI airglow is predicted to be much higher than temperate sites. But narrow lines.

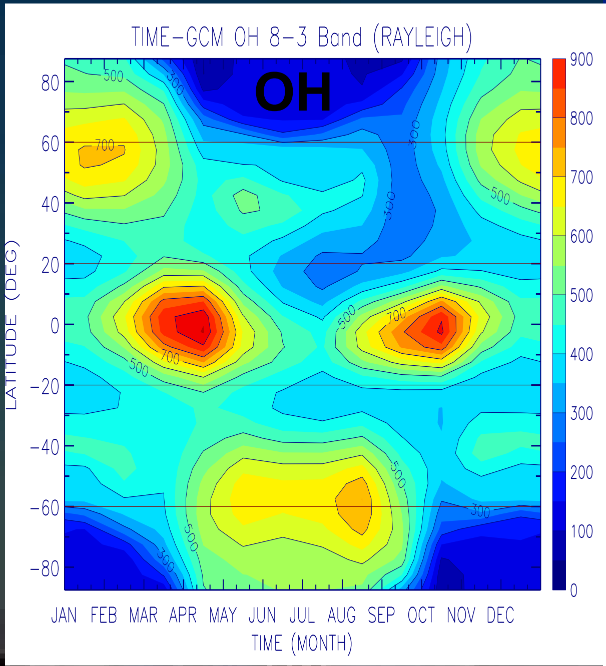
OH emission slightly higher than temperate sites.

Overall, optical sky brightness in Antarctica is predicted to be higher than at temperate sites, by ~25%, in *grizYJH*









ATMOSPHERIC THERMAL EMISSION

Temperature data from NCAR/NCEP reanalysis

Coldest between South Pole and Dome A

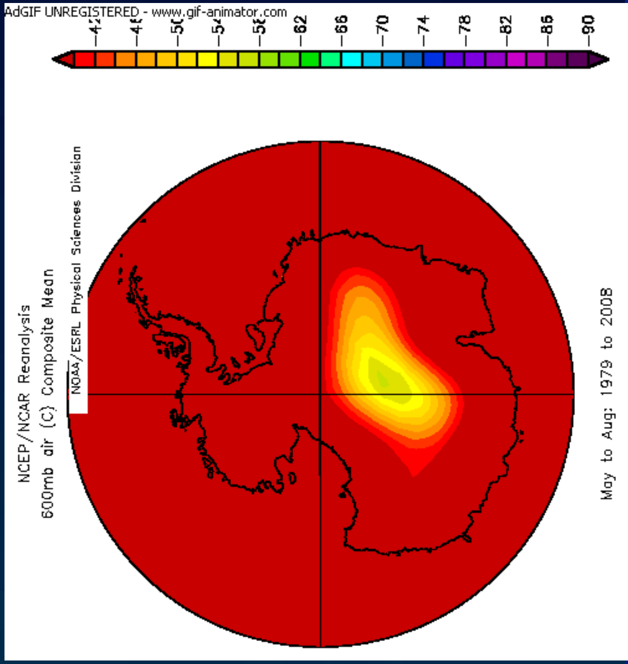
Colder site ⇒ wider K_{dark}, can reach to 2.5μm.

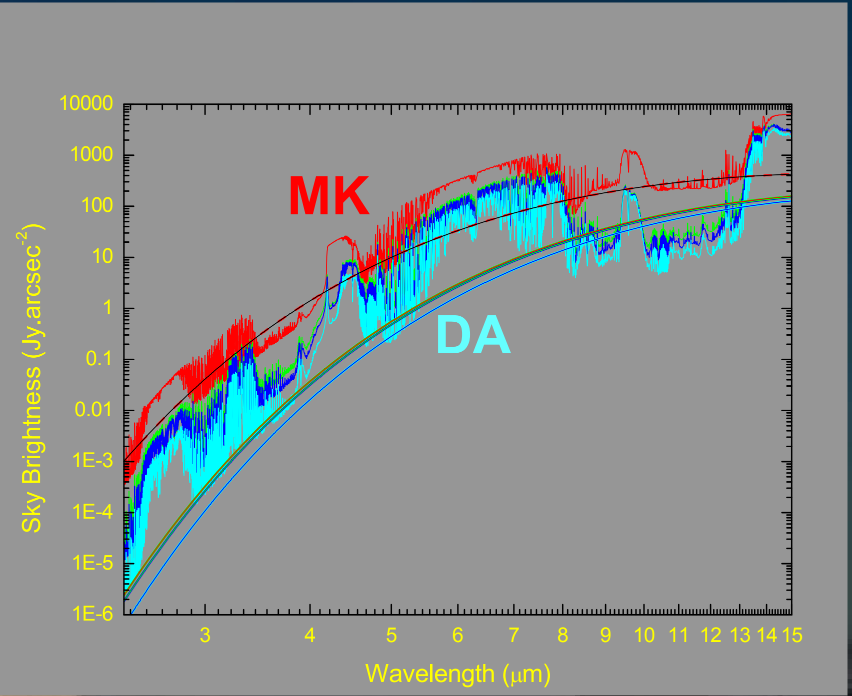
Factors of 1.5-3 variation between Antarctic sites

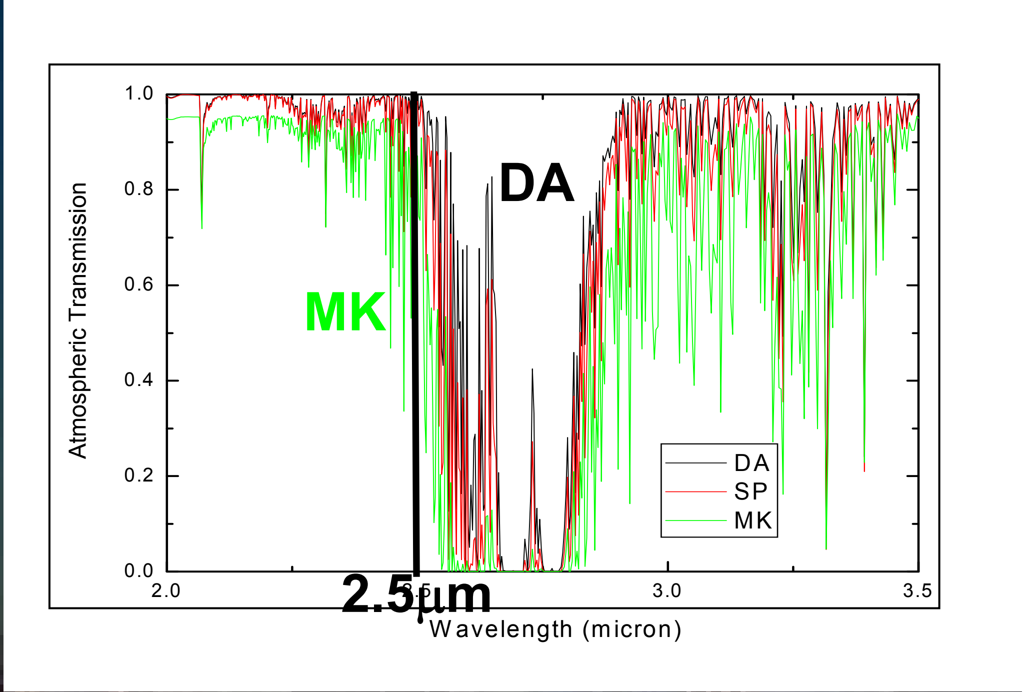
Only measurement of K_{dark} is at South Pole!

Origin of K_{dark} background unknown!

Measurement at Dome A needed!



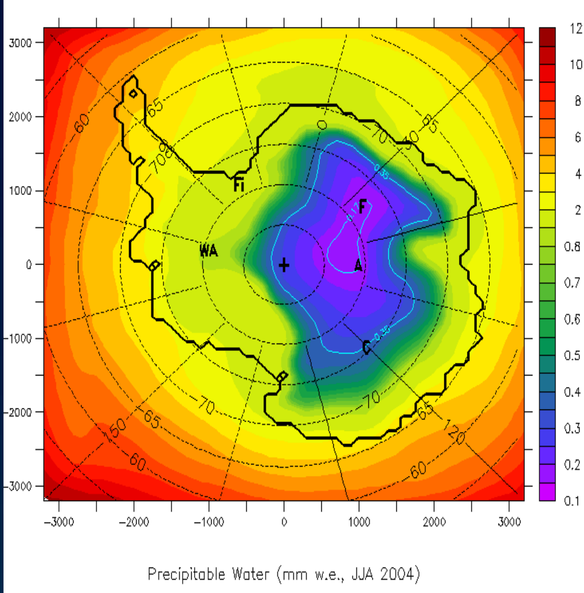




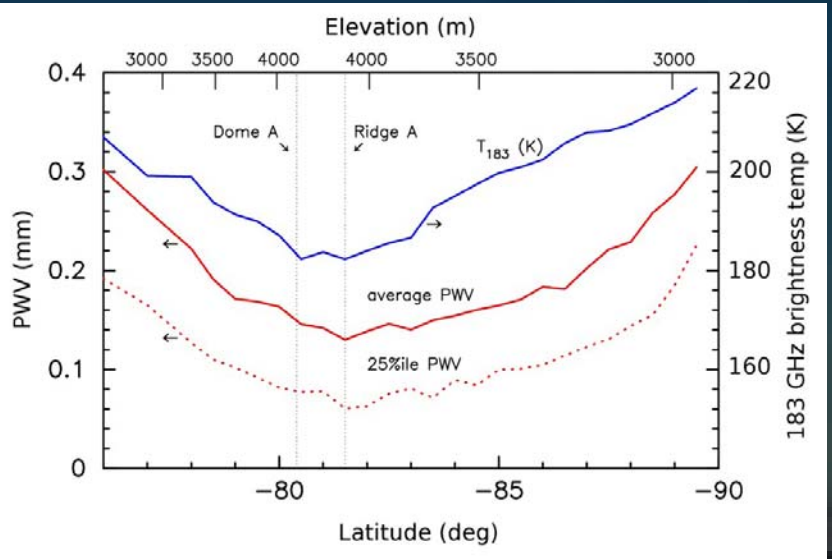
PRECIPITABLE WATER VAPOUR

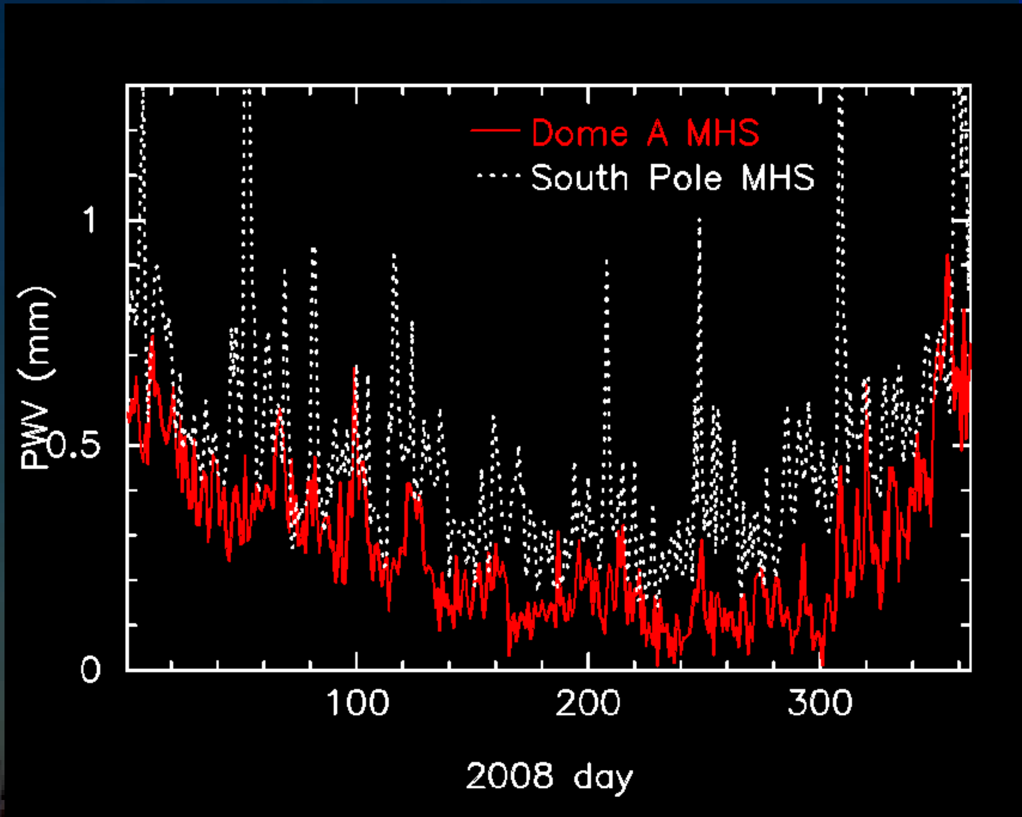
Prediction from Swain and Gallee 2006, measurements from MHS sensor on NOAA-18 satellite.

- **In winter, Dome A has 2.5 x less PWV than SP**
- **Best PWV between South Pole and Dome A**
- **Ridge A looks superb**



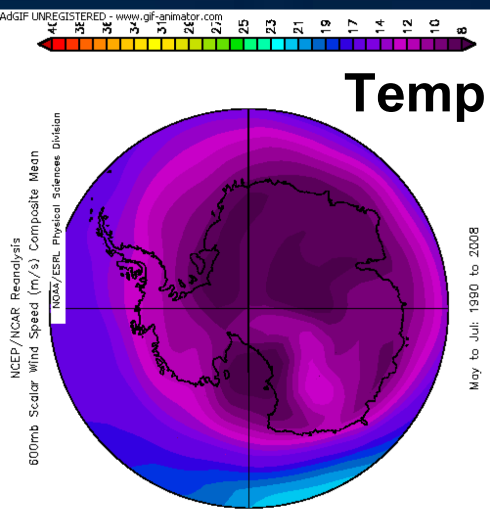
	SP	DC	DA	RA	DB	DF
Annual med.	437	342	233	210	274	279
Winter med.	324	235	141	118	163	163
Winter 25%	258	146	103	77	115	114
Winter 10%	203	113	71	45	83	90
Winter σ	133	122	65	64	67	98

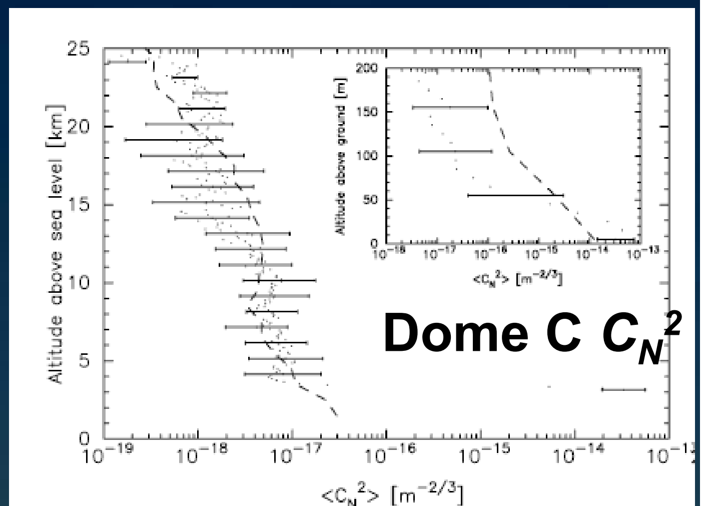


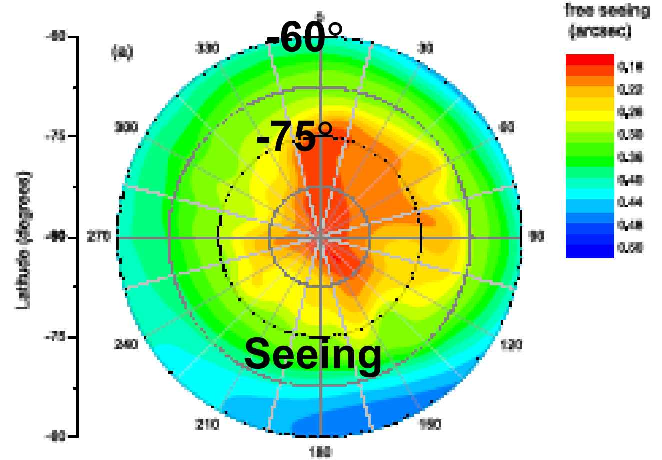


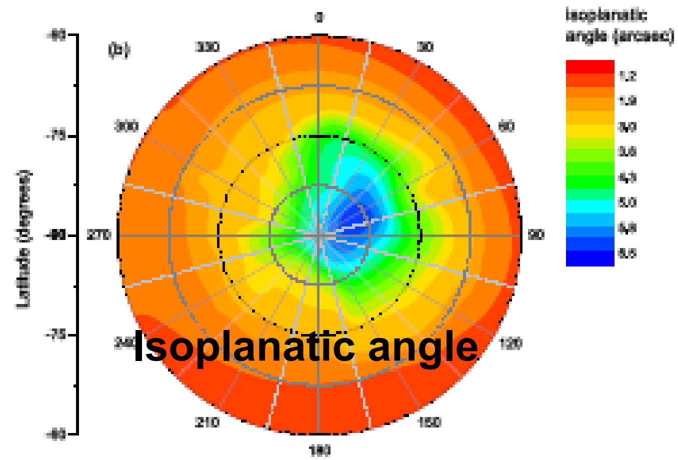
FREE ATMOSPHERIC SEEING (above B.L.)

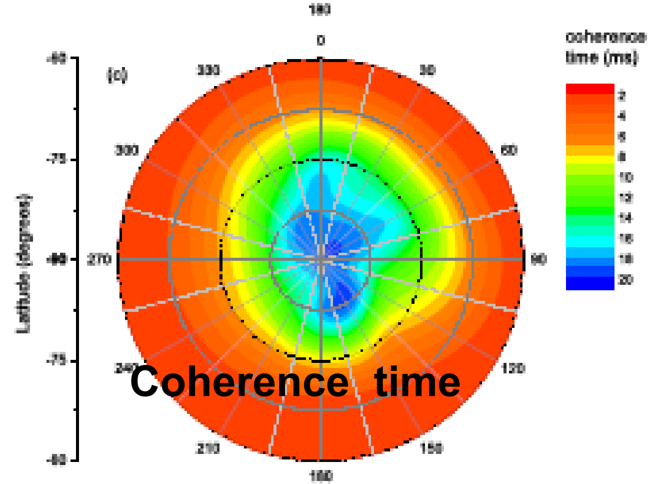
- Assume $|dV/dz| \propto V$ (self-similar)
- Use C_N^2 data from Dome C as template
- Scale C_N^2 according to wind speed
- Very crude model, can do better!
- Best between SP and DA
- Large factors (x10!) in 'coherence volume'









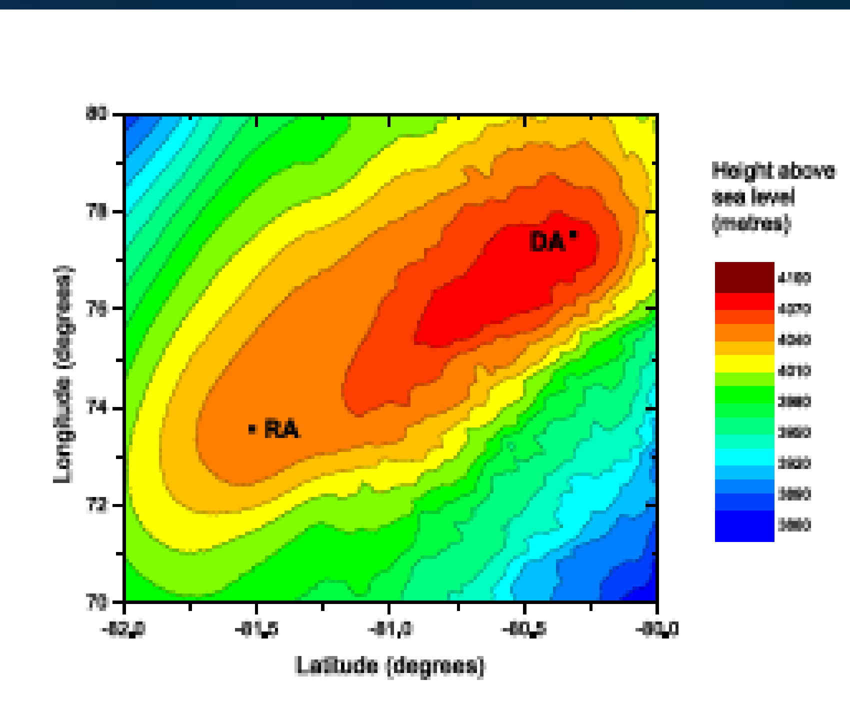


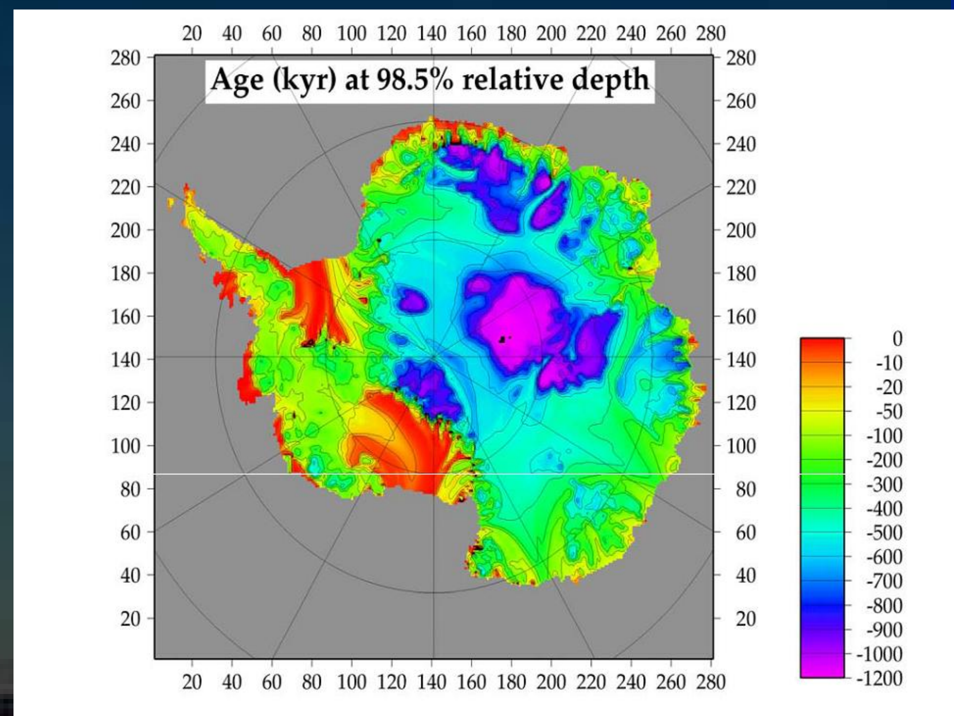
Site	ε_0 ('')	θ_0 ('')	τ_0 (ms)	$\tau_0(\theta_0/\varepsilon_0)^2$ (s)
S. Pole	0.19	5.43	18.8	16.0
Dome A	0.22	5.57	16.0	10.4
Ridge A	0.21	6.29	17.6	16.1
Dome C	0.26	3.39	8.44	1.42

Real measurement needed!

- **DOME A versus 'RIDGE A'**
- Boundary layer, weather, free atmospheric seeing, atmospheric thermal emission, PWV, surface temperature ALL favour a site nearer South Pole.
- Obvious candidate is at the end of 'Ridge A' at (81.5°S 73.5°E 4053m
- Ice core drilling for oldest CO_2 record is also likely to favour a site between Dome A and South Pole.

Keep in touch with ice core projects!





'SUMMARY TABLE'

	SP	DA	RB	DC	DF	RA
Cloud Cover	×	√	√√	√√√	√√	√√
Boundary Layer	×	√	√√	√	√√√	√√√
Aurorae	×	√	√	√	××	√
Free seeing	√√√	√√	√	√	√√√	√√√
IR sky brightness/PWV	√	√√√	√√	√	√√√	√√√
Surface temperature	×	√√√	√√√	√√	√√	√√√

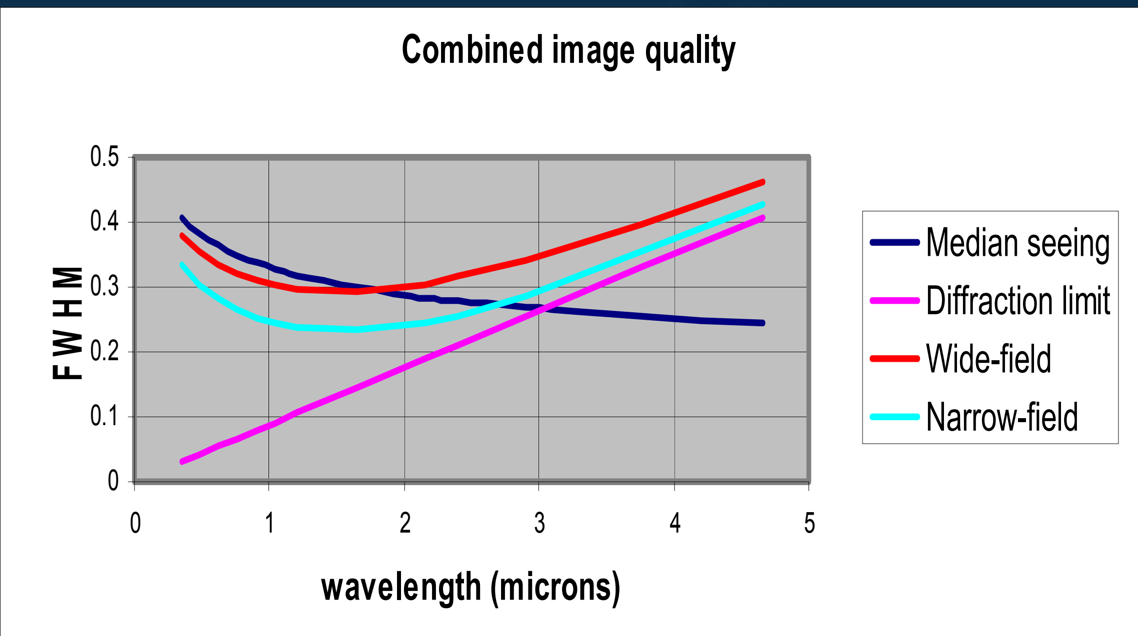
Delivered image quality

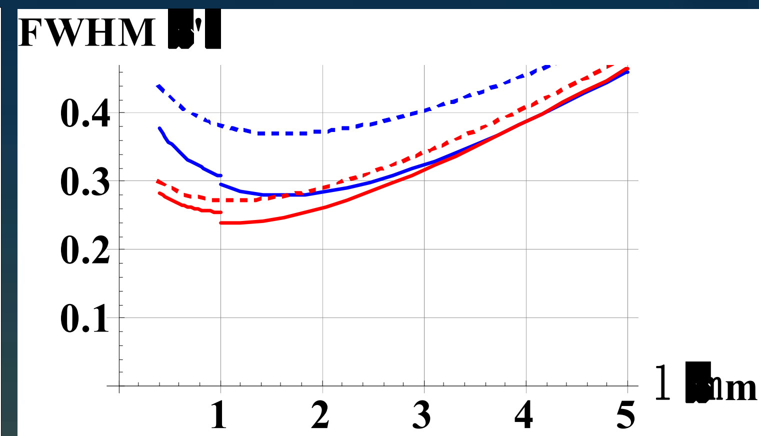
Tip-tilt removes most windshake and residual ground-layer turbulence. Using balloon or MASS/SNODAR values makes little difference to delivered image quality.

Budget for entire PILOT system is 0.3" d_{80} (~0.2" FWHM)

Median delivered wide-field image quality ~0.3" for izYJHK

Median delivered narrow-field image quality < 0.25" for izYJHK





All ÷ 1.5 for KDUST

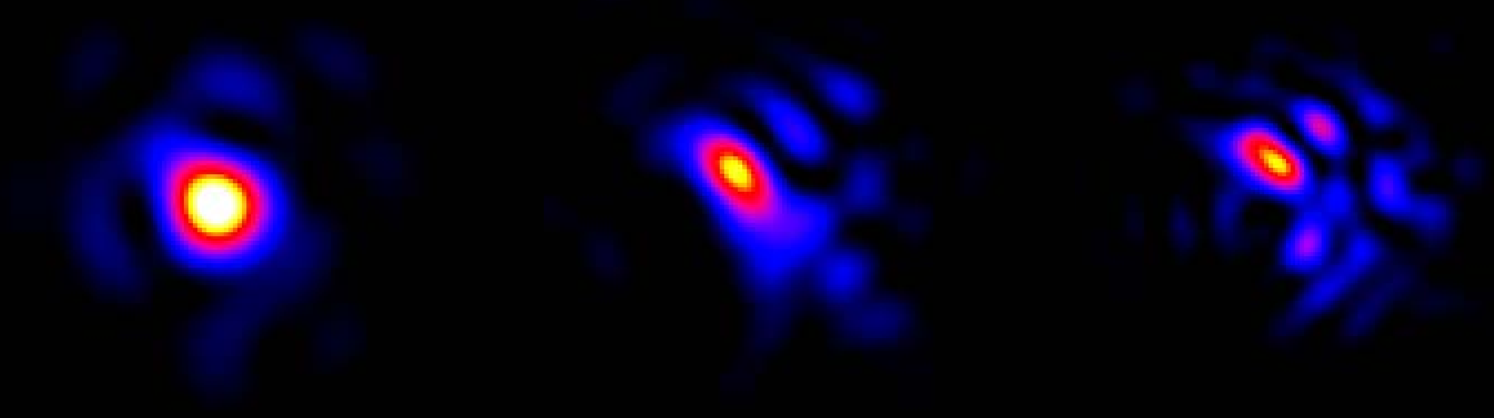
Tip-tilt correction

For an ideal telescope without Adaptive Optics, image quality is

PSF = diffraction ⊗ instantaneous seeing ⊗ image motion

Scales uniquely with D/r_0

Simulations by Nick Kaiser (http://www.ifa.hawaii.edu/~kaiser/wfhri/)



$D/r_0=2.5$	$D/r_0=3.75$	$D/r_0=5.0$
z	i	r

can correct for low-level turbulence over wide fields

can correct for high-level turbulence over arcminute fields

Sensitivities

Sensitivity similar to existing 8m-class telescopes for wide-field optical/non-thermal IR work, and for narrow-field thermal IR.

Greatest sensitivity gains for wife-field thermal IR.

At K, background is 30-40 times less than best temperate sites, image quality twice as good. =>10 times faster than VLT to given depth. 10 times faster survey speed than VISTA.

Only possibility to get high resolution NIR data of depth comparable to big optical surveys.

Only possibility to get high resolution matching photometry for Spitzer warm mission (3.6μm, 4.5μm).

No comparison with JWST => wide-field

Optical science cases depend on high resolution over wide-fields.

Band	Point Source AB, 5 σ, 1hr
g	27.6
r	27.1
i	26.7
z	25.8
Y	25.5
J	25.0
H	24.6
K_{dark}	25.3
L	21.2
M	19.6

All + 1^m for KDUST

SPECTROSCOPY – Why Antarctica?

Many thanks to Jamie Lloyd!

Consider a telescope with diameter D, at a site with seeing θ

The required integration time to fixed (point source) magnitude is $t \propto (D/\theta)^2$

So for fixed integration time, $D \propto \theta$

Cost of telescope $T \propto D^{2.3} \propto \theta^{2.3}$

But spectrograph beam size is $B \propto D\theta \propto \theta^2$

And cost of spectrograph optics $O \propto B^3 \propto \theta^6$

So, gain of factor of 2 in seeing $\Rightarrow$ factor 64 gain in spectrograph costs!

e.g., for LAMOST, with 0.5° fibres, would need only 5 spectrographs (vs 16)
f/2.5 vs f/1.3 cameras, with 2.5 x spectral resolution!

SPECTROSCOPY – OH suppression

Can suppress OH emission using Bragg grating structure imprinted into optical fibres.

Currently only half of H-band, but only prototype so far.

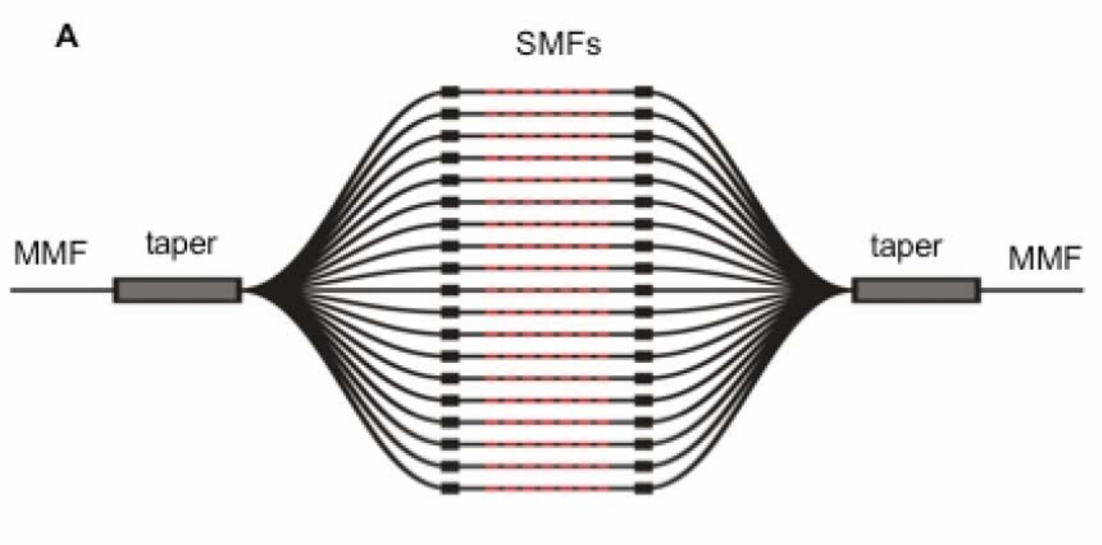
Can only do on single mode fibre! But can split normal multimode fibres into multiple single-mode fibres, and vice versa.

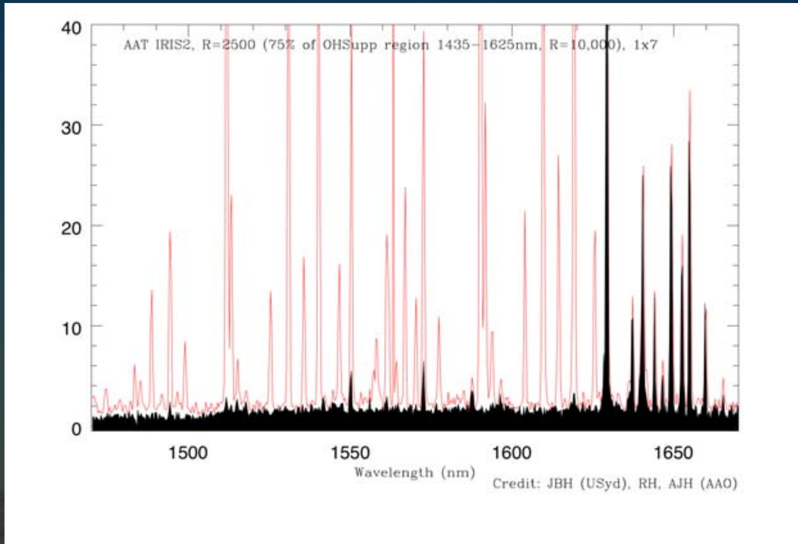
Number of modes is ~8 $(D/\theta)^2$ per aperture – e.g. 500 for FMOS/SUBARU

Cost is currently $2000/mode ! e.g. for FMOS, 500 x $2000 x 400 = $400M !

Cost/mode will come down with multiple imprinting, but go up to do Y+J+H bands.

Number of modes $\propto (D/\theta)^2 \propto \theta^4 \Rightarrow$ factor of 2 gain is seeing gives factor 16 reduction in OH suppression costs!



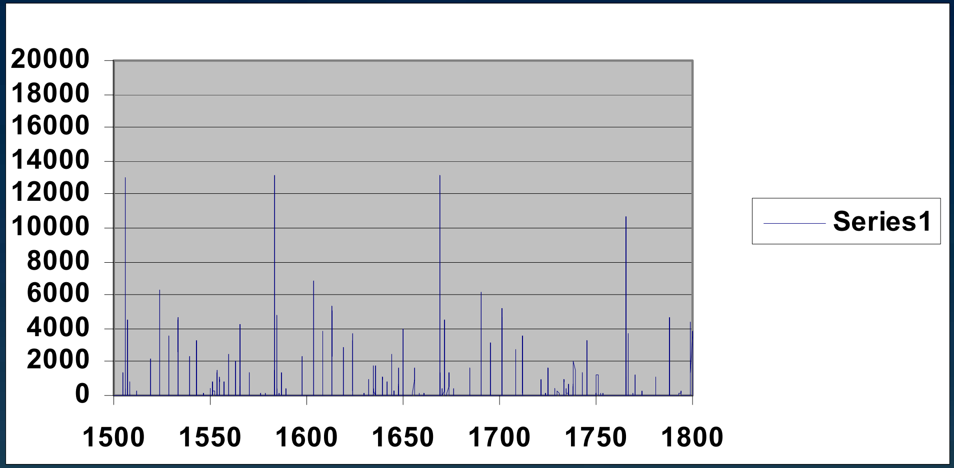


SPECTROSCOPY – wavelength coverag

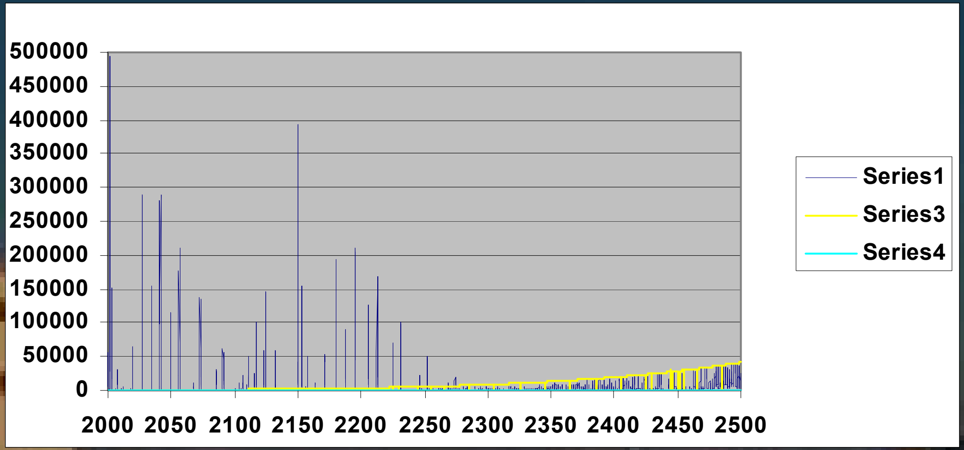
Can cover 1-2.5μm with almost no breaks – comparable to optical range 0.37-0.9μm in both range and sensitivity!

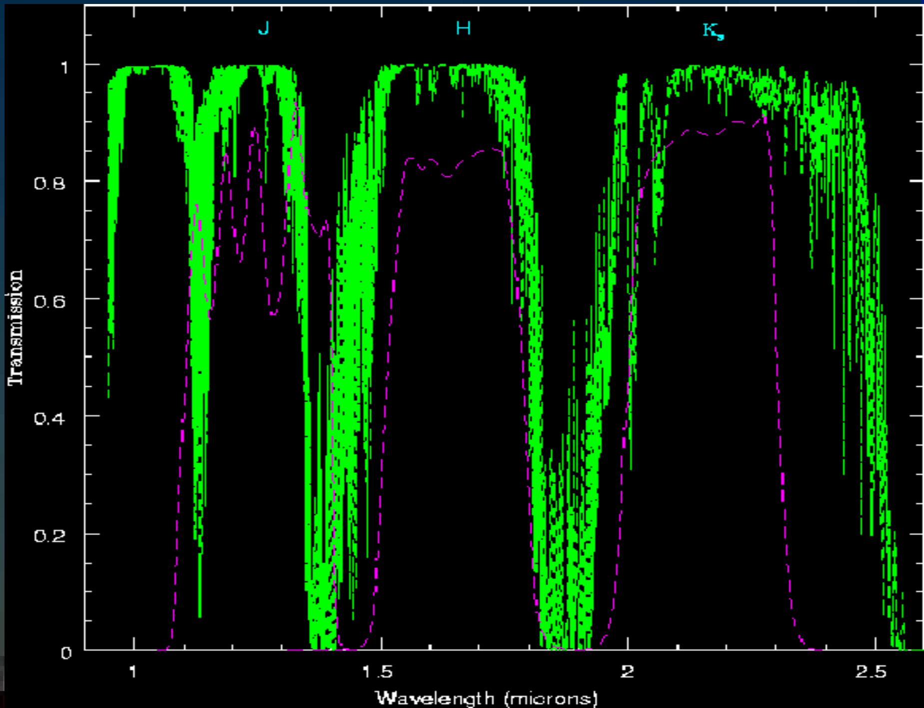
Can use non-thermal techniques (like FMOS) over wide fields.

Uniquely fills in 'redshift desert' between z=1.75 (Hα leaves H-band) and z=2.3 (Lyα enters optical range). Extends Hα coverage to z=2.8.



BAO at z~2?





Science Driver Drivers for PILOT:

Science drivers must be driven by at least one of:

– resolution over wide fields
– low IR background
– photometric stability
– continuous coverage

4 identified big science drivers so far:

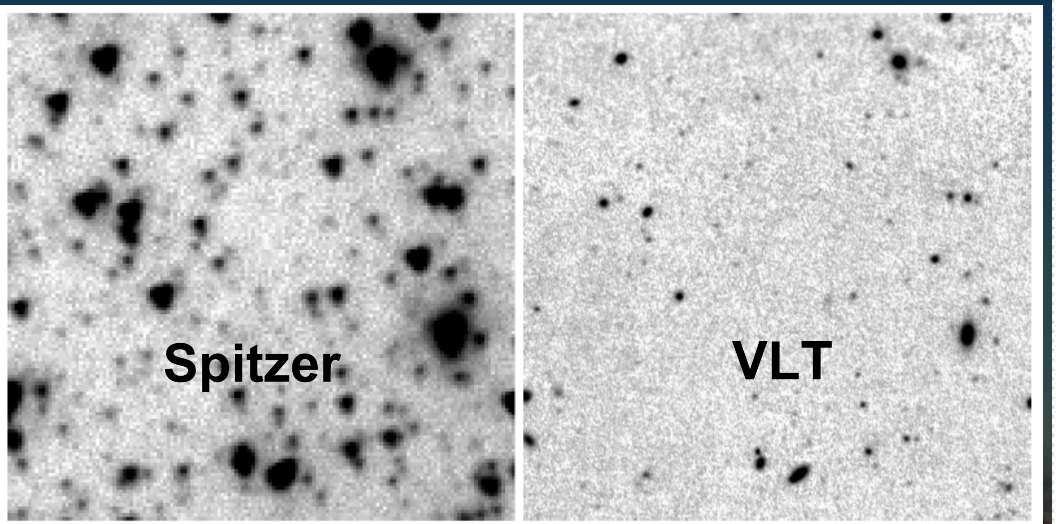
– H_2 in our Galaxy
– The first light in the Universe
– The earliest stellar populations
– The equation of state of the Universe

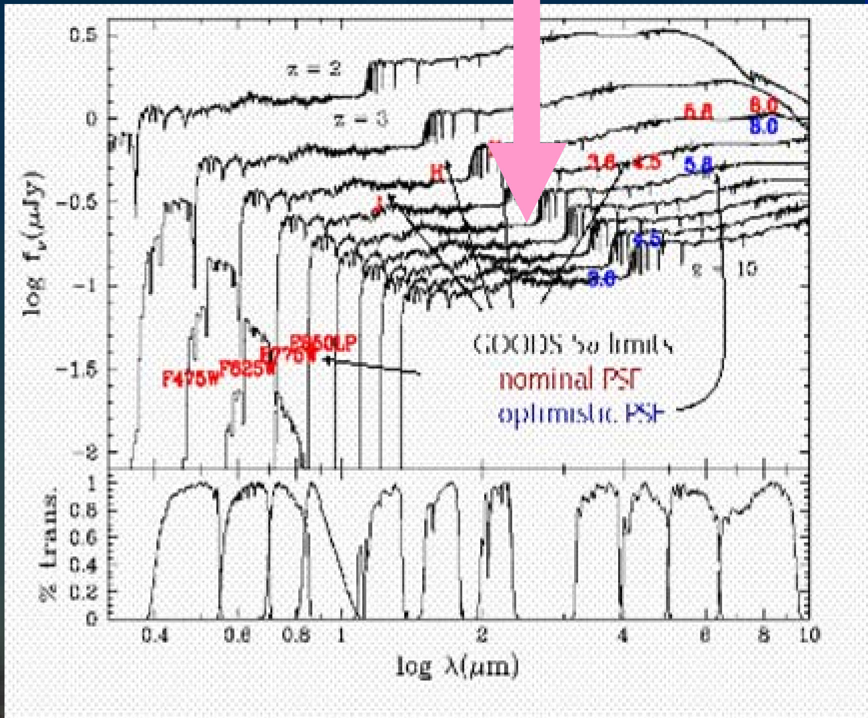
Science Driver: The first stellar populations

PILOT K_{dark}-band data is perfectly matched to find Balmer break in oldest galaxies at z=5-7. Too hard for VISTA. Strong synergy with Spitzer warm mission and MWA.

Takes few hundred Myear to develop 4000Ǻ break. Detection at z~6-7 pushes => galaxy formation at z~10 – Re-ionisation epoch, Population III. Expect 10^3-10^4 gals

PILOT *K_{dark}* Deep Field





Science Driver: First light in the Universe

Gamma Ray Bursters:

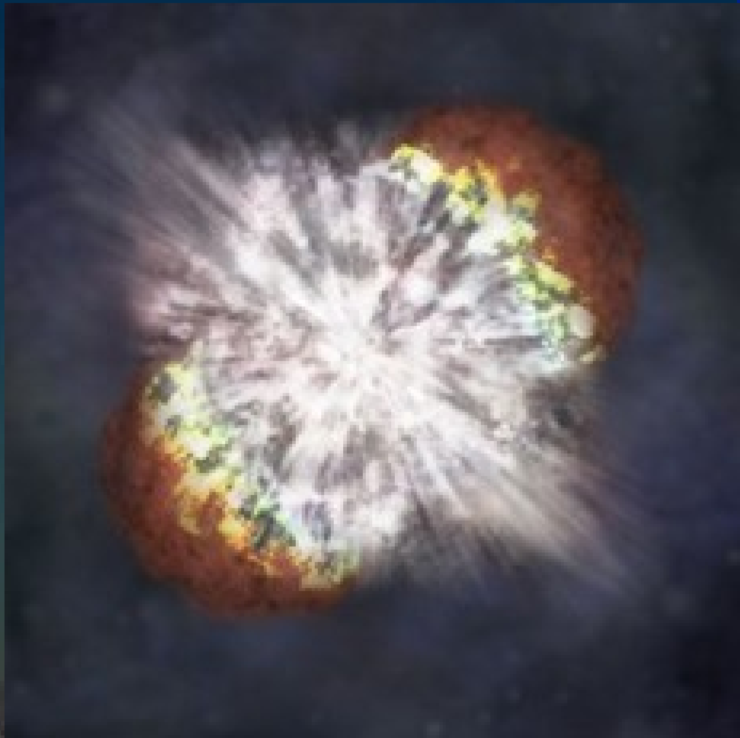
Gamma-ray bursters are most distant objects seen in Universe.
Detected by satellites. Large error box – 10' or more.

Most distant bursters expected to have afterglow only in NIR.

Wide-field, wide wavelength range, low background gives PILOT unique opportunity to catch these. Must have ID for JWST followup!

Population III supernova:

SN2006gy brightest supernova ever detected
Pair-creation supernova.
Expect many similar supernovae from Pop III.



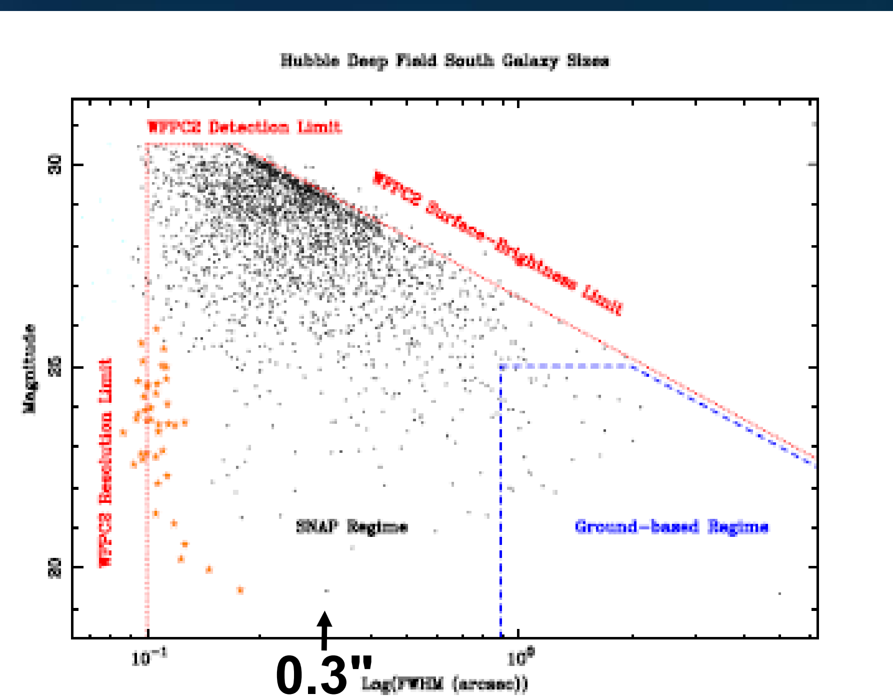
Can see 250M_{sol} in 1 hour at K_{dark} to z=15
Expect few/deg^2/year
Lifetimes (Δm < 1) ~ few days

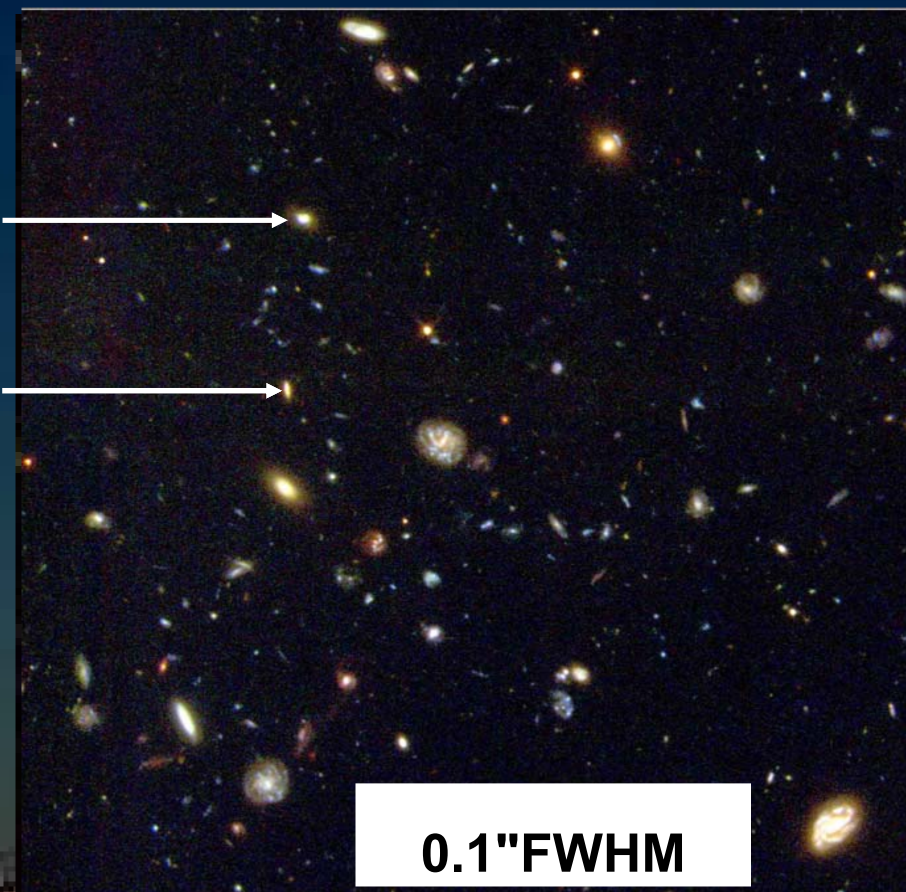
PILOT would see ~ few per winter

PILOT and weak lensing

- Weak Lensing is most promising route to understanding Dark Energy (NASA, NSF, ESA…)
- Need large sky coverage,
- Modest depth
- Need very stable PSF
- Resolution limited

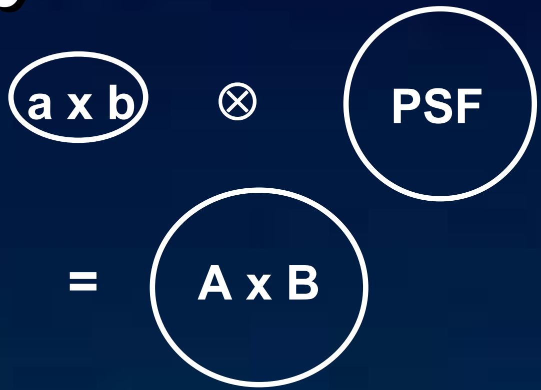
A LOT of other lensing surveys planned – PILOT must be better or faster or both





Weak Lensing and image quality

Weak lensing signal ~ 1% change in ellipticity
Seeing makes galaxies look
(a) rounder, need higher S/N to see distortion
(b) smeared out, so more skylight mixed in

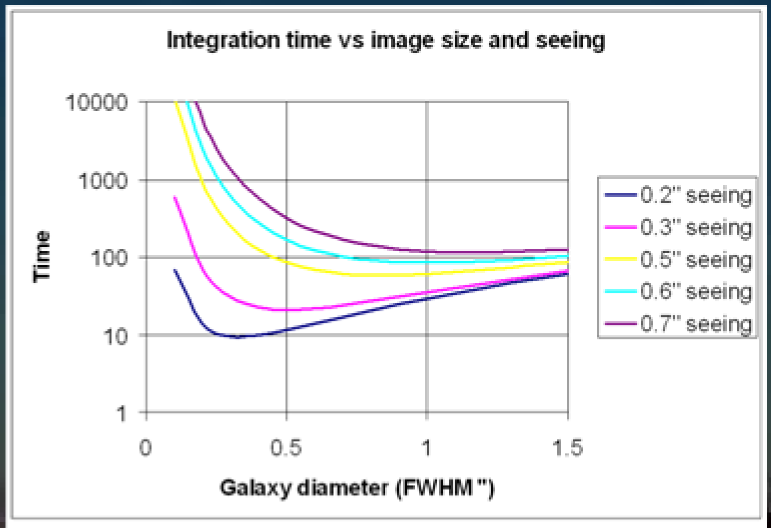


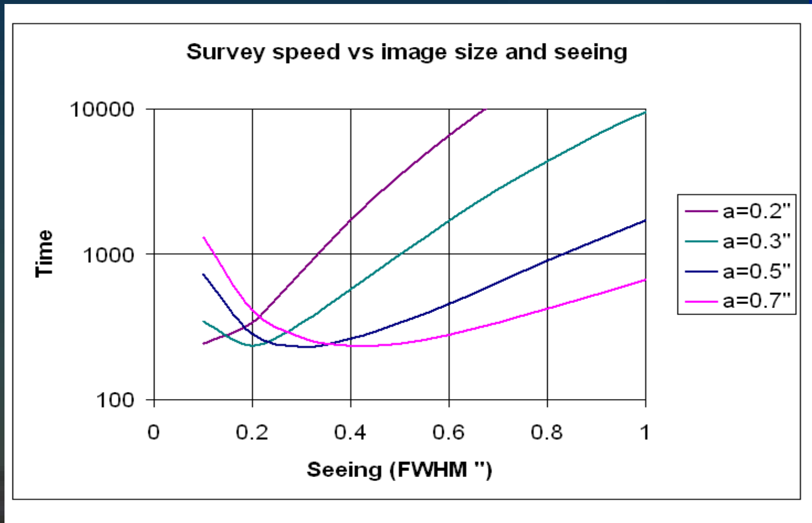
$t_{req} \propto AB\,(A^2+B^2)/(A-B)^2$

Overall, time required to measure shape varies as sixth power of observed size

For typical galaxy, t_{req} at Dome-C is 20 times less than at Mauna Kea

Survey speed varies as fourth power of observed size





PILOT and other surveys:

PILOT allows a surface density of ~40 gals/arcmin^2, compared with ~15 gals/arcmin^2 from temperate sites. Comparable image quality and survey speed as DUNE/EUCLID.

Much easier control of systematics than other ground-based sites: larger lensing signal, and slow diffraction-limited optics.

	Diam	Gpix	Seeing	Signal	Speed	Year
MegaCam	3.6	0.34	0.7	0.16	0.11	2003
VST	2.6	0.28	0.8	0.12	0.03	2009
DES	4.0	0.5	0.9	0.10	0.08	2009
PanSTARRS	1.8	1.4	0.6	0.20	0.18	2009
PanSTARRS4	3.6	1.4	0.6	0.20	0.73	2012
PILOT	2.5	1.1	0.2	0.69	3.29	2013
HSC	8.2	1.0	0.7	0.16	1.62	2013
LSST	6.5	3.0	0.7	0.16	3.05	2014
DUNE	1.2	0.65	0.23	0.63	3.71	2018
SNAP	1.8	0.45	0.15	0.80	9.33	2018

Wide-field fast guiding with OTA CCD's?

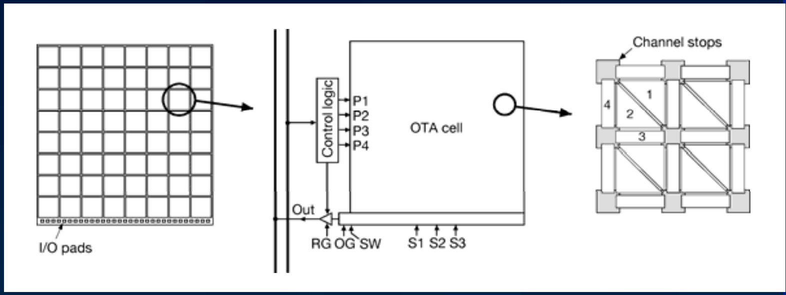
At Dome C, r_0,θ_0,ε_0 all twice as good as best other sites.

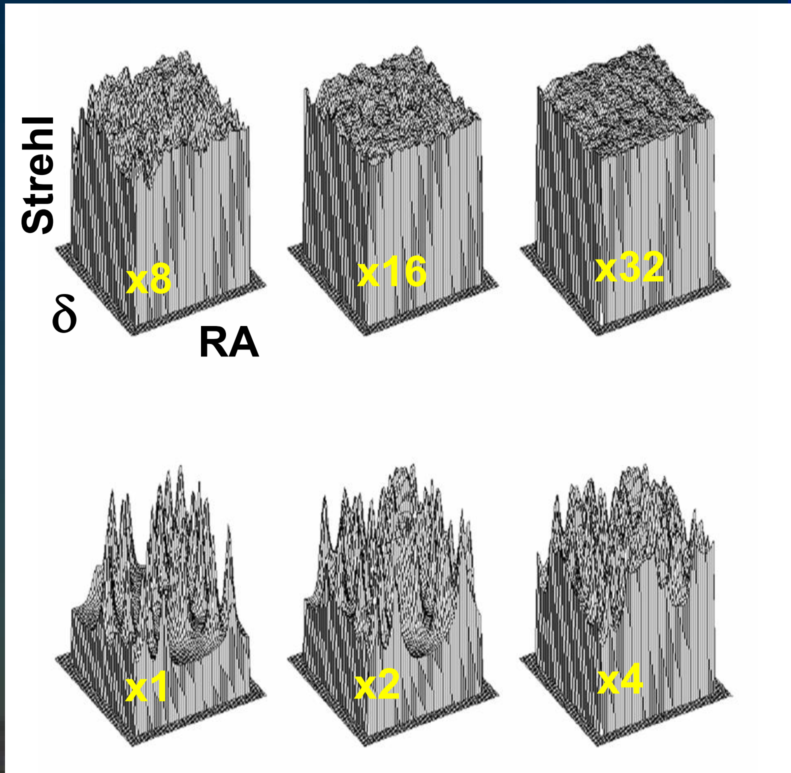
=> density of suitable guide stars per isoplanatic patch is twenty times more favourable than Mauna Kea

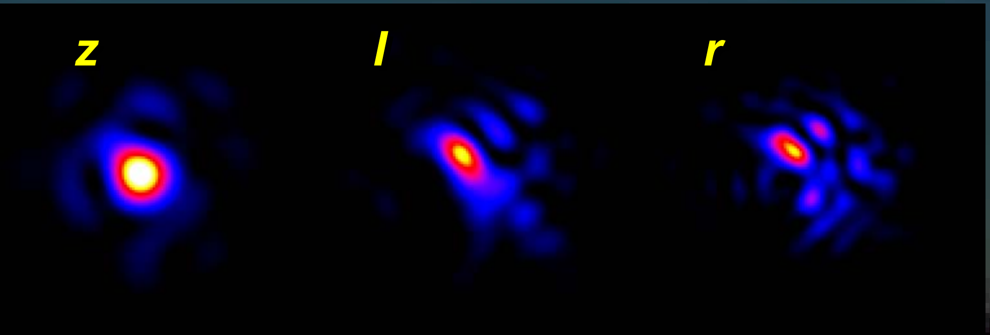
Could use multiple guide stars (400!) and OTA CCDs to correct image motion caused by atmospheric turbulence.

Median delivered image quality 0.25" (but variable)

PanSTARRS camera $5M.

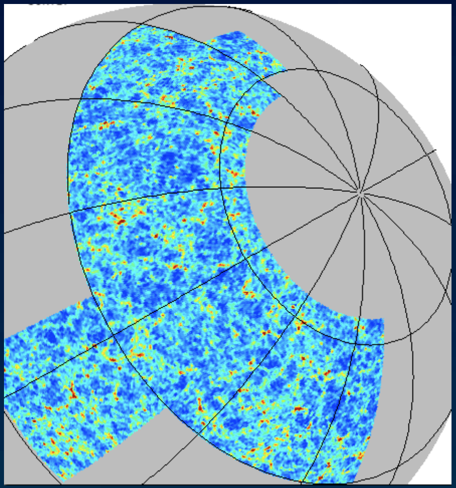






Proposed PILOT weak lensing survey

– 4000 deg^2 over 3 years, use 50% best seeing only
– Dark Energy Survey area
– riz ultra-broad-band filter
– 1/2 hour per field
– S/N = 10 for i_{AB}=25.6^m
– Photometric redshifts from DES griz – limits redshifts to z~1.2. 40% hit compared with EUCLID. Take Y data separately? Also have K_d (2.4μm) data



Cosmological constraints ~2 times worse than EUCLID
Better than LSST !