# High-Impact Infrared Science with 4m telescopes


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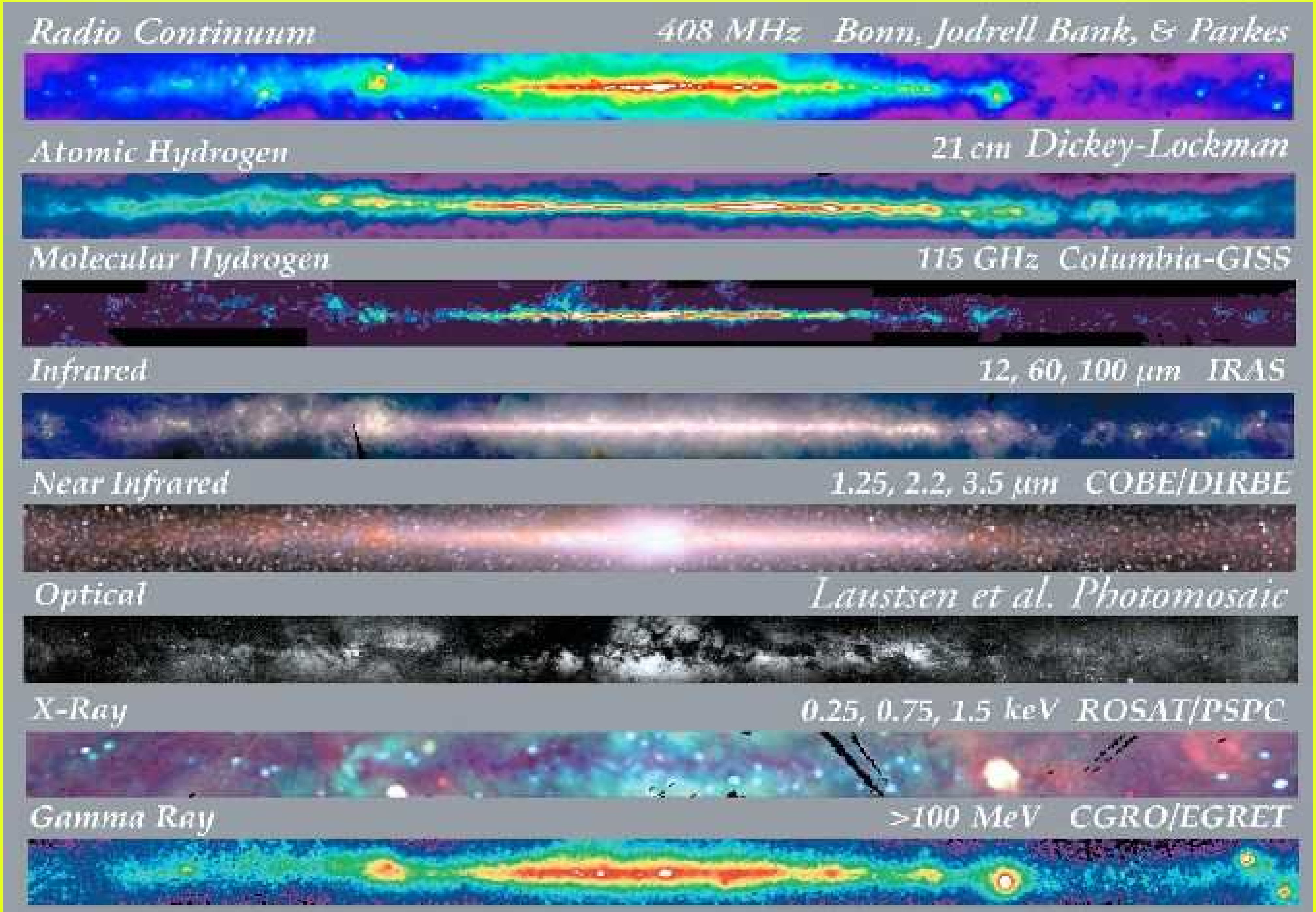
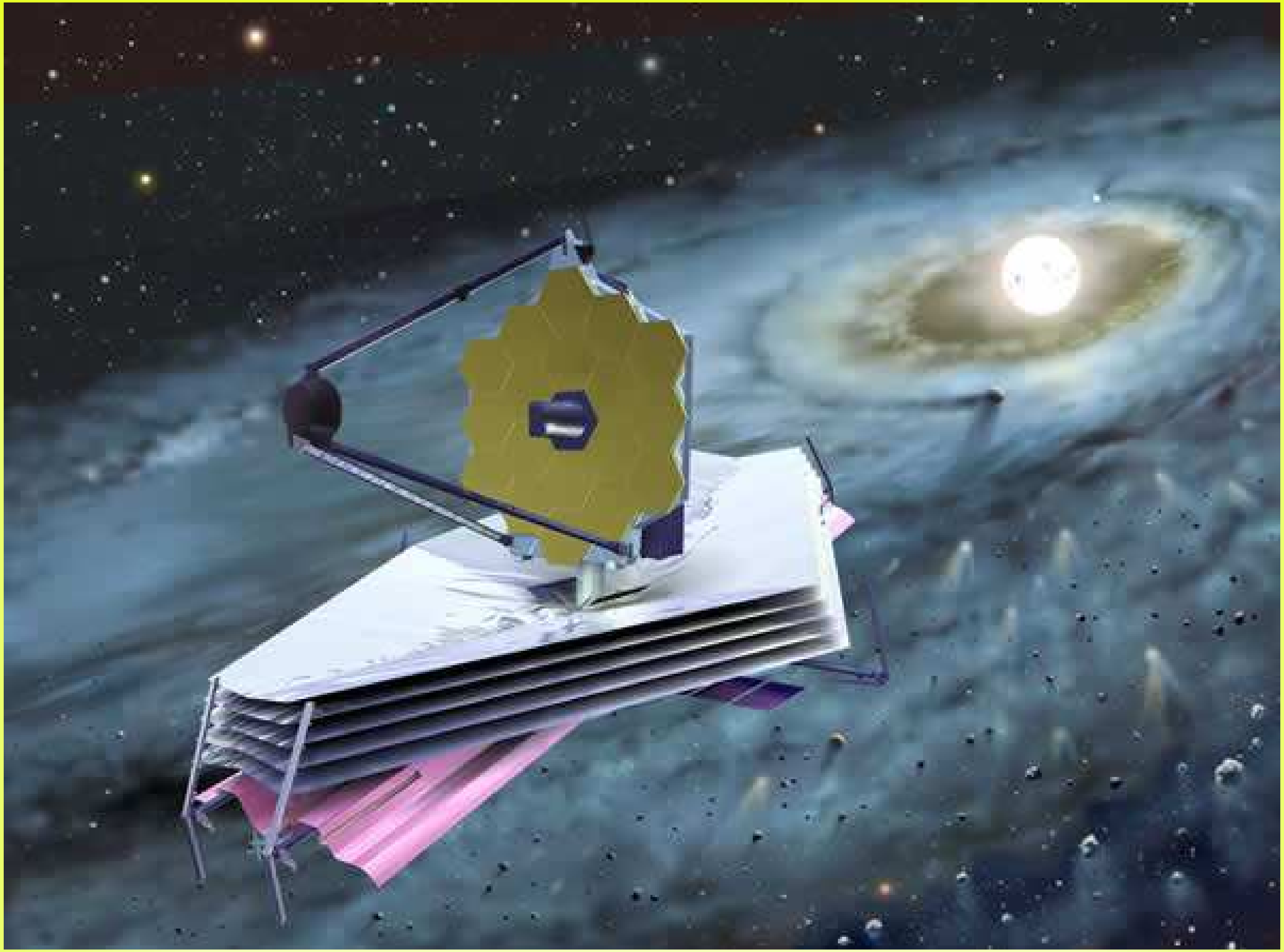
# The Milky Way at Various Wavelengths





The James Webb Space Telescope (launched in 2014), the next Hubble Space Telescope, will be an Infrared telescope.

## Why in the near-infrared?

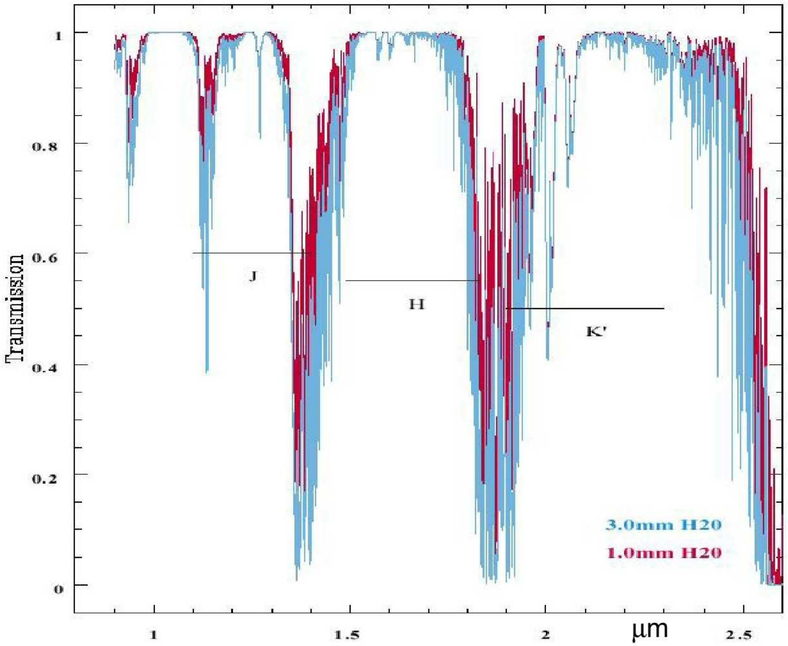
- to detect galaxies at very high redshift
- to detect planets (cool objects)
- to study star formation (looking through the dust)

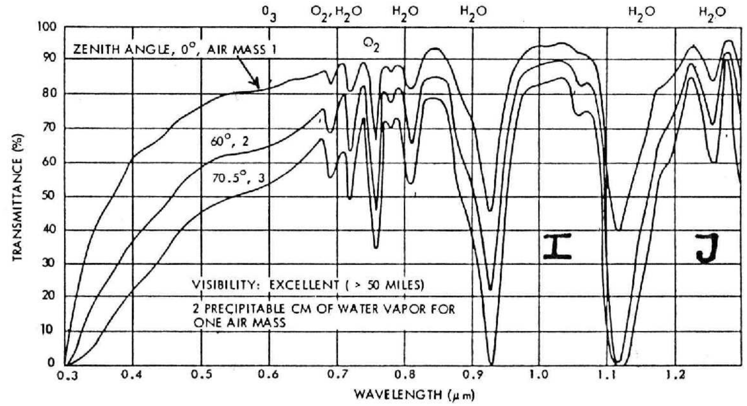
One problem:

The sky in the IR is bright and variable.

This is not a problem any more in the NIR.

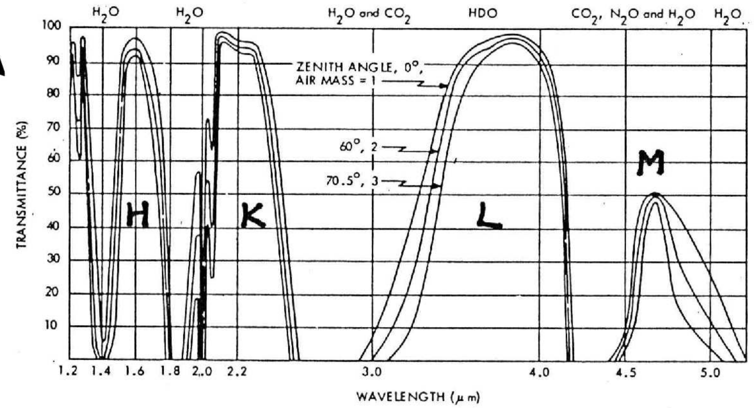
**infrared extinction is dominated by molecular absorptions, mostly of $H_2O$ and $CO_2$** ➔
**observations are only possible in a number of 'windows', designated by I, J, K, L, M, N, Q**

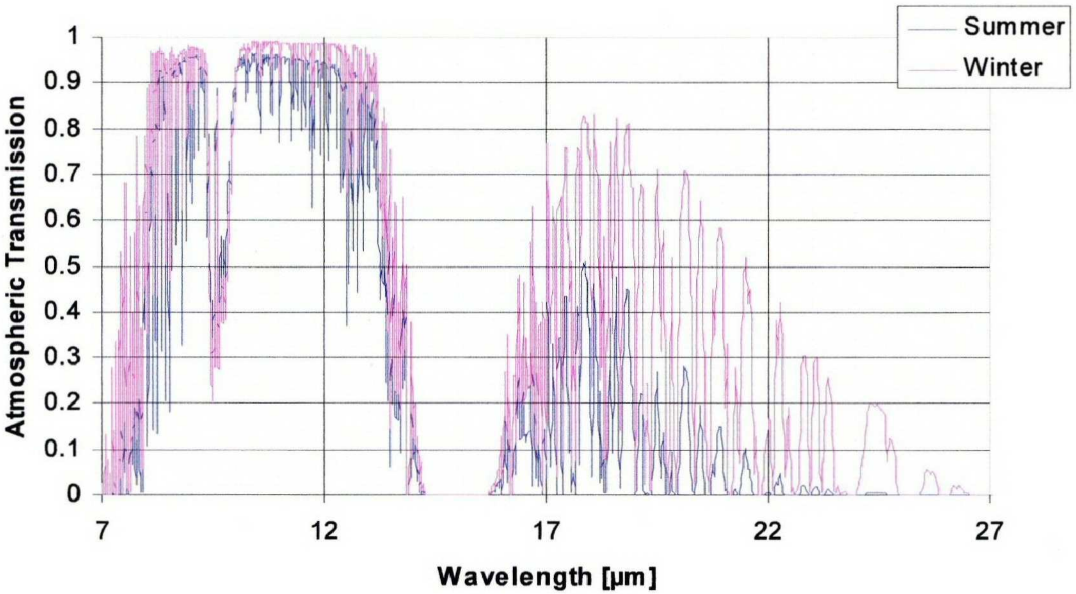


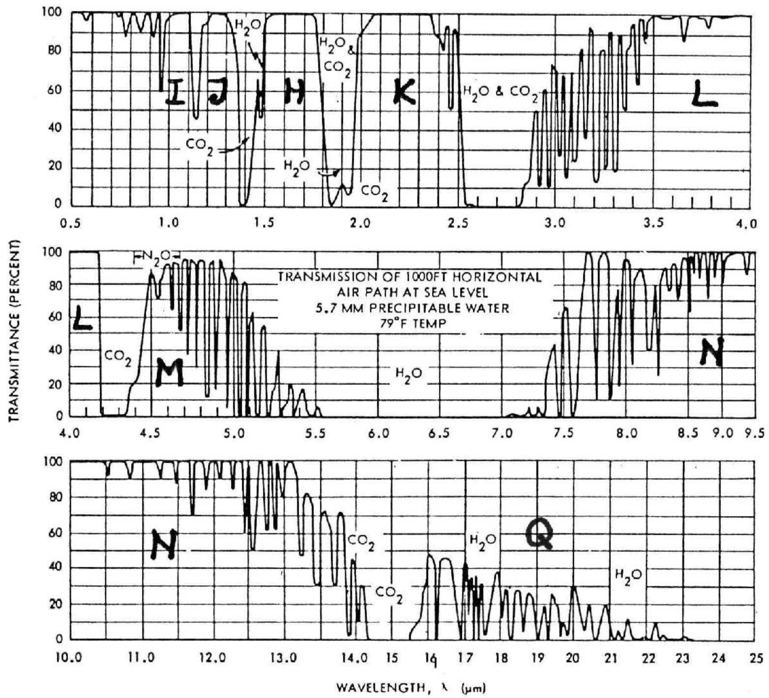




**$H_2O$ absorption depends strongly on humidity ➔ highly variable !**

**requires high and very dry observatory sites**



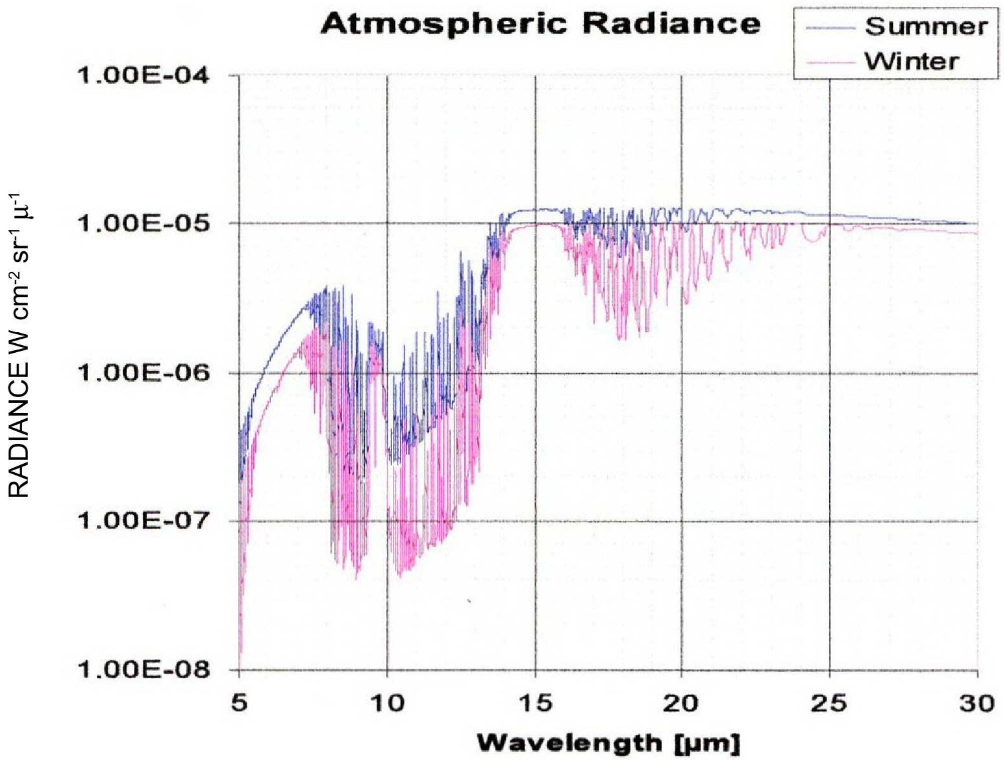



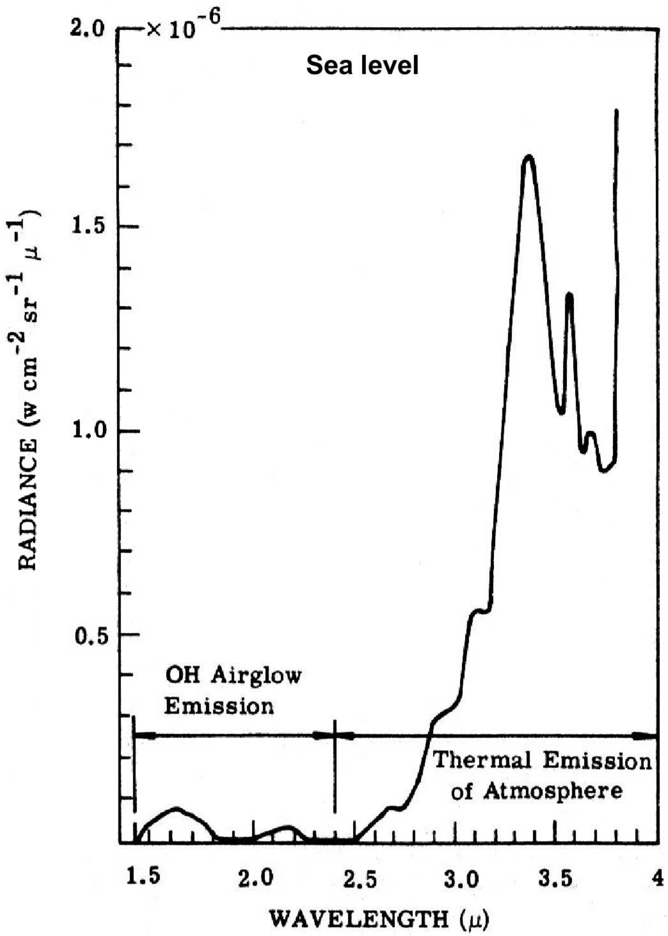



# thermal atmospheric emission

**for $\lambda > 2.5\ \mu m$ thermal radiation from the atmosphere becomes the dominant sky background (hence: the 'thermal infrared')**

**$T_{eff}$(atmosphere) ≈ 250 K ➔ peak at $\lambda \approx 12\ \mu m$, but note: atmosphere is not a black body !**



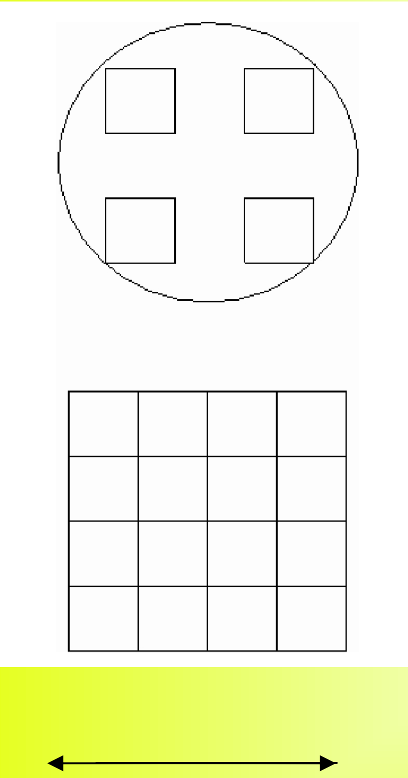

**Kirchhoff: in thermal equilibrium emissivity = absorptivity ➔ IR sky emissivity is 'mirror image' of IR atmospheric transmission curve this hits us twice: $\kappa_{atm.}$ high ➔ large fraction of source photons removed *and* high sky background**

**consequence for ground-based observations in the thermal IR: nearly all astronomical sources are very faint w.r.t. sky background**

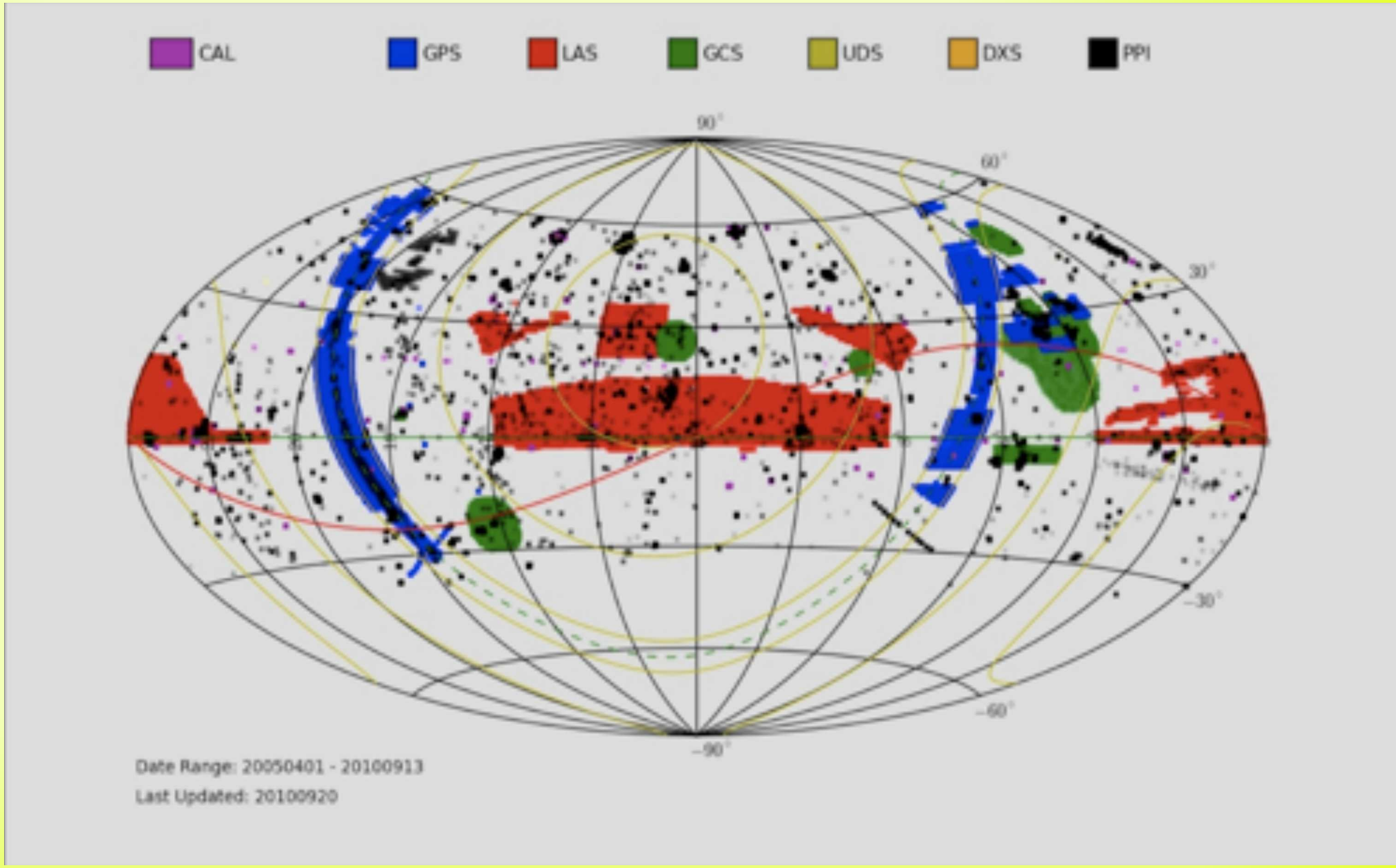
# Large Modern Infrared Facilities:

| Telescope | Instrument | Field Size | Completion Year |
|---|---|---|---|
| UKIRT | WFCAM | 40' | 2005 |
| ESO/VISTA | Nircam | $1.5^o$ | 2009 |
| ESO/VLT | HAWK-I | 14' | 2007 |
| SDSS III | APOGEE NIR Spectrograph | $3^o$ | 2011 |

# UKIRT- a telescope used for Surveys



40'

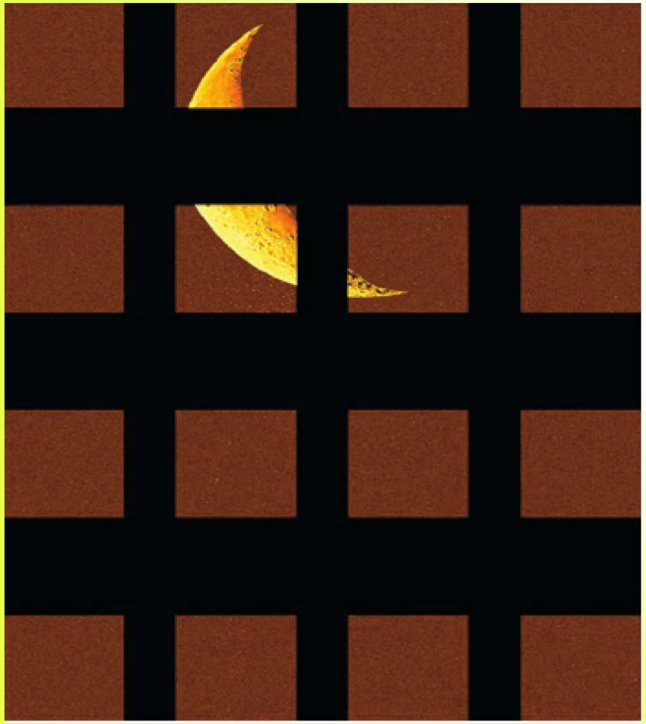


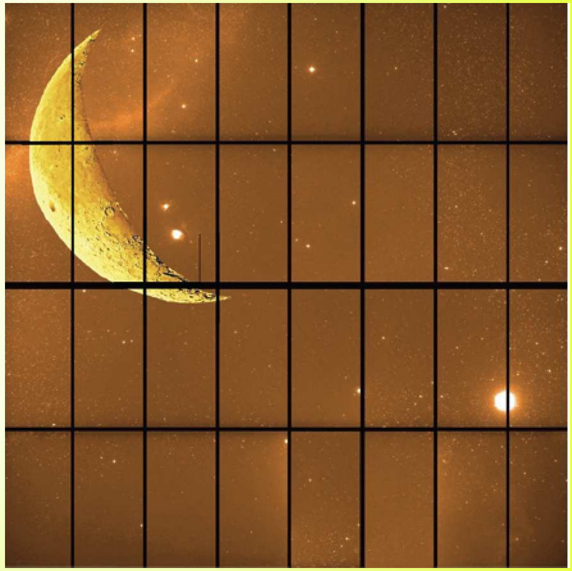
# DR8: UKIDSS is 60% released, 75% observed

| | | | | | | |
|---|---|---|---|---|---|---|
| Large Area Survey | LAS | YJHK | 18.2K | 3792 s.d. | 262n | ExGal |
| Deep Extragalactic Survey | DXS | JK | 20.8 | 31 | 118 | ExGal |
| Ultra Deep Survey | UDS | JHK | 22.8 | 0.77 | 296 | ExGal |
| Galactic Plane Survey | GPS | JHK | 18.8 | 1851 | 186 | Gal |
| Galactic Clusters Survey | GCS | ZYJHK | 18.5 | 1069 | 84 | Gal |

| | |
|---|---|
| Large Area Survey | SDSS near-ir photom, Y dwarfs, z=7 quasars |
| Deep Extragalactic Survey | Multiwavelength fields, the Universe at $1<z<1.5$ |
| Ultra Deep Survey | Multiwavelength field SXDS, the Universe at z=3 |
| Galactic Plane Survey | Galactic-plane atlas $-5<b<+5$ |
| Galactic Clusters Survey | Universality of the stellar IMF |

# Survey telescopes at ESO

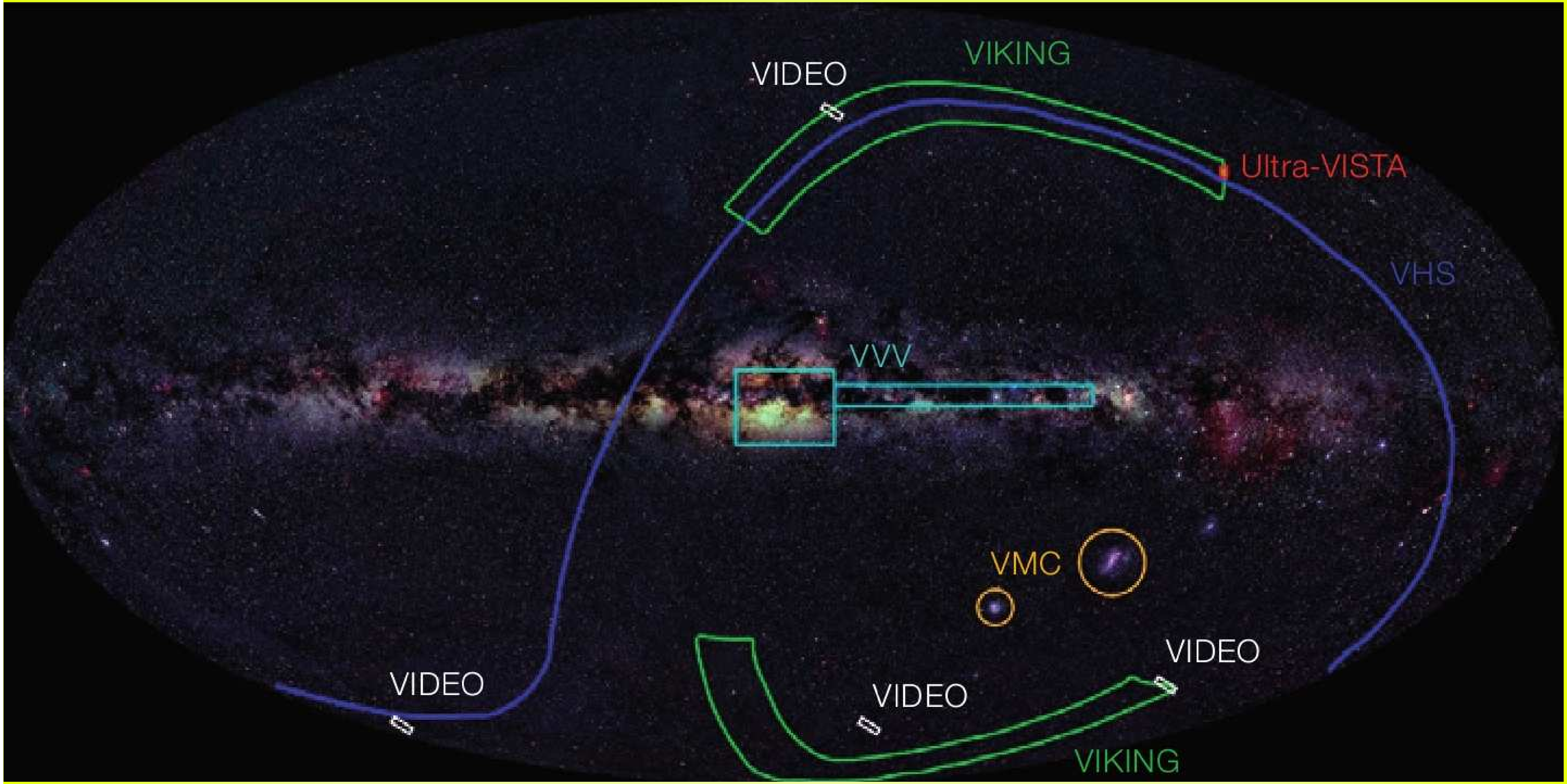




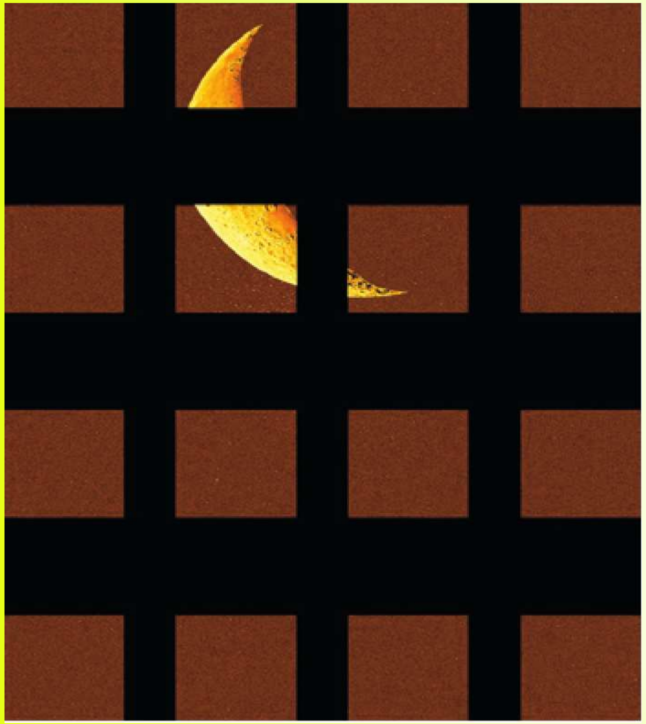
OmegaCAM, Optical

VISTA, Infrared

# VISTA Surveys

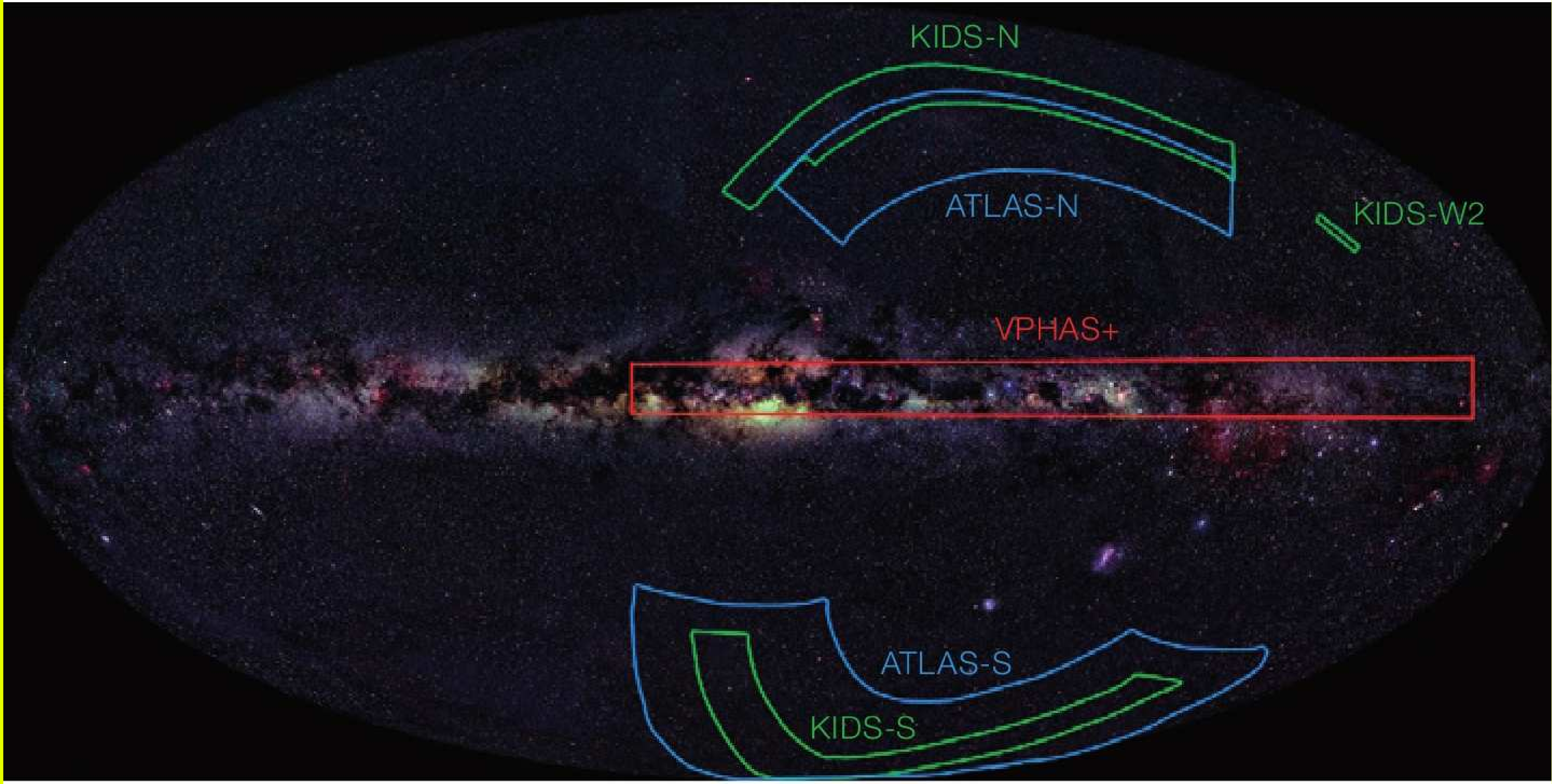


# VISTA (dedicated 4m in Paranal, Chile)

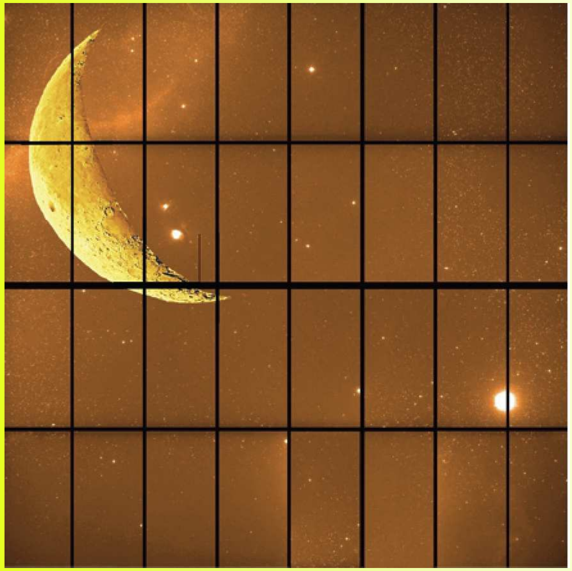


| Survey | Area [$deg_2$] | Filter | Magnitude limit | Limit Measure |
|---|---|---|---|---|
| Ultra-VISTA | 0.73 (ultra-deep) | *Y* | 26.7 | 5σ (AB) |
| | | *J* | 26.6 | |
| | | *H* | 26.1 | |
| | | $K_s$ | 25.6 | |
| | | *NB* | 24.1 | |
| VHS | 20000 | *Y* | 21.2 | 5σ (AB) |
| | | *J* | 21.1 | |
| | | *H* | 20.6 | |
| | | $K_s$ | 20.0 | |
| VIDEO | 15 | *Z* | 25.7 | 5σ (AB) |
| | | *Y* | 24.6 | |
| | | *J* | 24.5 | |
| | | *H* | 24.0 | |
| | | $K_s$ | 23.5 | |
| VVV | 520 | *Z* | 21.9 | 5σ (Vega) |
| | | *Y* | 21.2 | |
| | | *J* | 20.2 | |
| | | *H* | 18.2 | |
| | | $K_s$ | 18.1 | |
| VIKING | 1500 | *Z* | 23.1 | 5σ (AB) |
| | | *Y* | 22.3 | |
| | | *J* | 22.1 | |
| | | *H* | 21.5 | |
| | | $K_s$ | 21.2 | |
| VMC | 184 | *Y* | 21.9 | 10σ (Vega) |
| | | *J* | 21.4 | |
| | | $K_s$ | 20.3 | |

# VST Surveys



# VST (dedicated 2.5m telescope at Paranal)

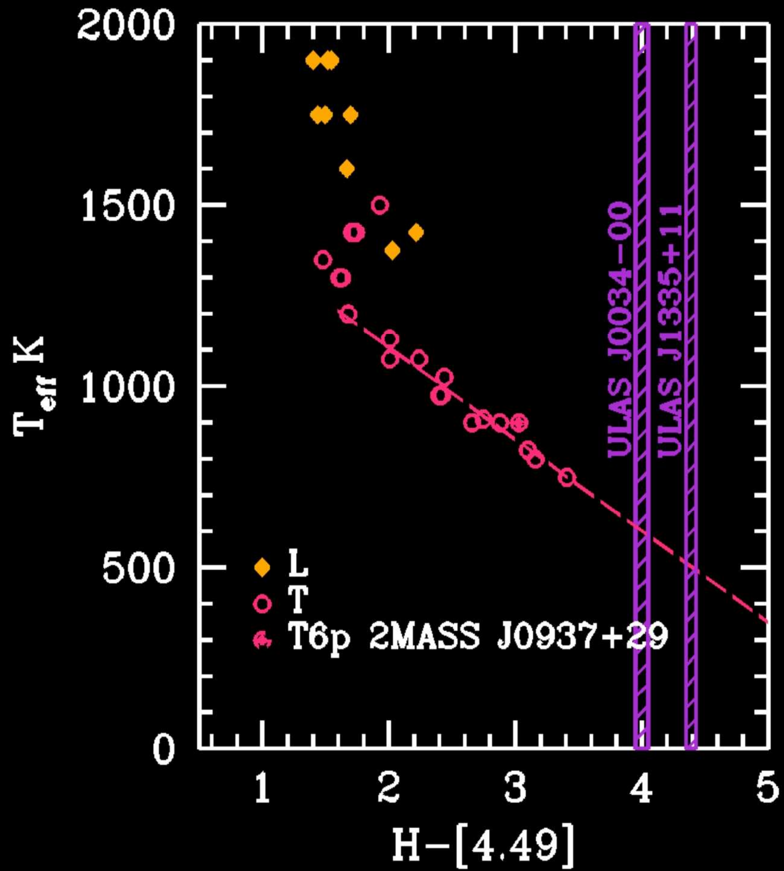


| Survey | Area [$deg_2$] | Filter | Magnitude limit | Depth Measure |
|---|---|---|---|---|
| KIDS | 1500 | u′ | 24.1 | 10σ (AB) |
| | | g′ | 24.6 | |
| | | r′ | 24.4 | |
| | | i′ | 23.4 | |
| ATLAS | 4500 | u′ | 22.0 | 10σ (AB) |
| | | g′ | 22.2 | |
| | | r′ | 22.2 | |
| | | i′ | 21,3 | |
| | | z′ | 20.5 | |
| VPHAS+ | 1800 | u′ | 21.8 | 10σ (AB) |
| | | g′ | 22.5 | |
| | | Hα | 21.6 | |
| | | r′ | 22.5 | |
| | | i′ | 21.8 | |

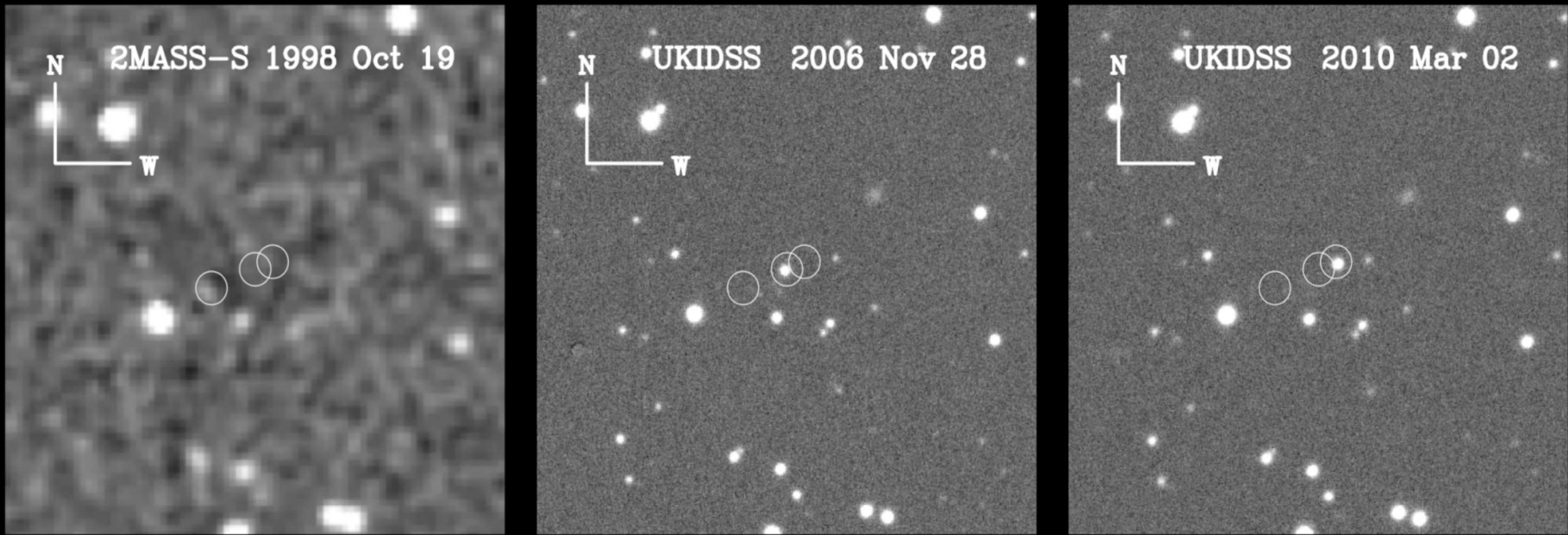
# UKIDSS Surveys – science highlights

i The coolest brown dwarfs (LAS, GPS)
ii The low-mass end of the stellar IMF (GPS)
iii Bimodal galaxy colors $0<z<2.5$ (UDS)
iv The galaxy luminosity function $5<z<6$ (UDS)
v Detection of Ly $\alpha$ emitters $7<z<9$ (Narrow band)

# i – The coolest Brown Dwarfs

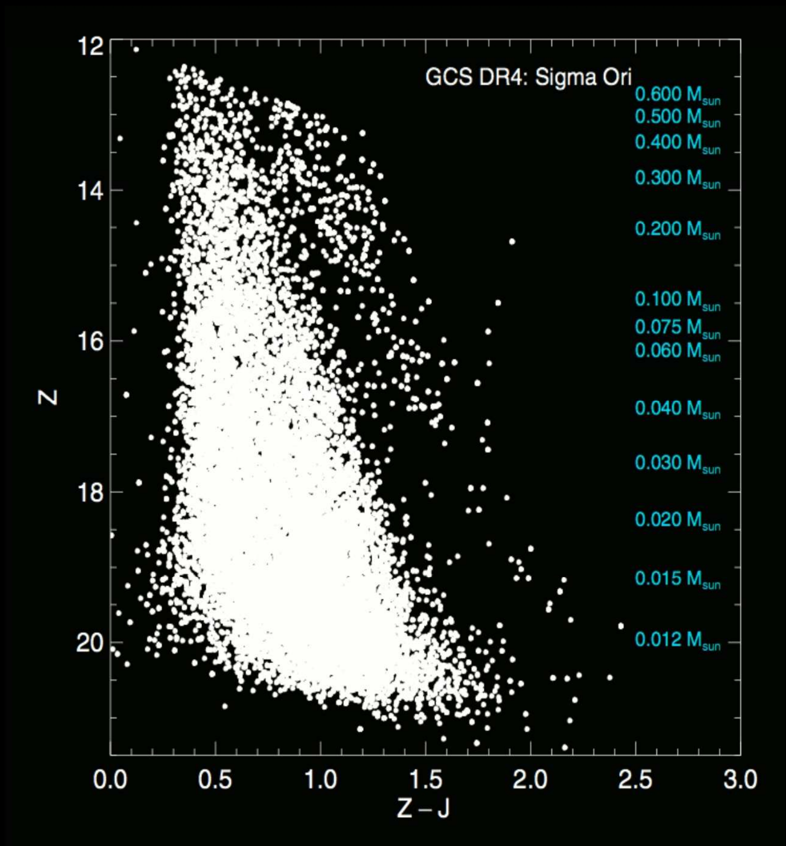


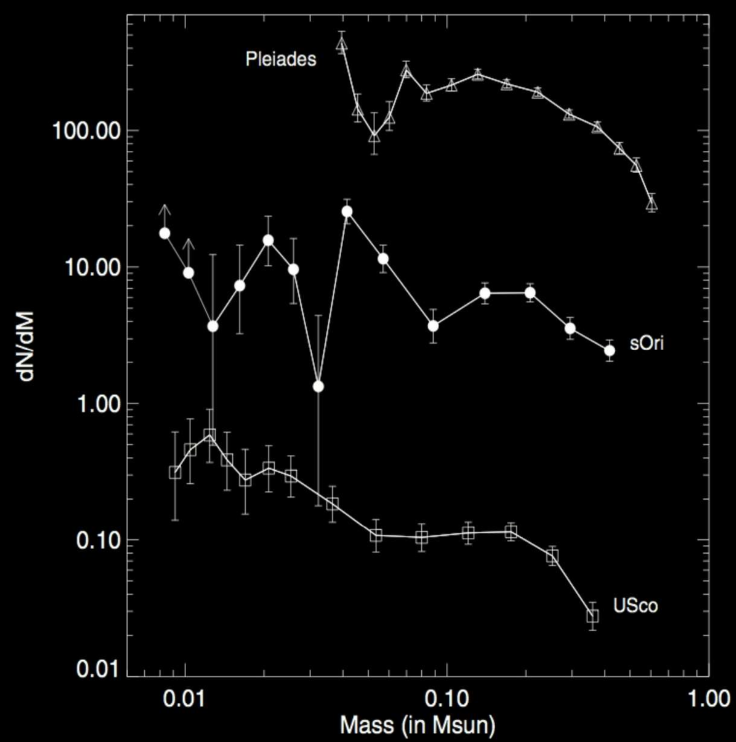
# The coolest brown dwarf UGPS 0722




Distance 4pc, 480K<$T_{eff}$<560K

# ii. The low mass end of the stellar IMF

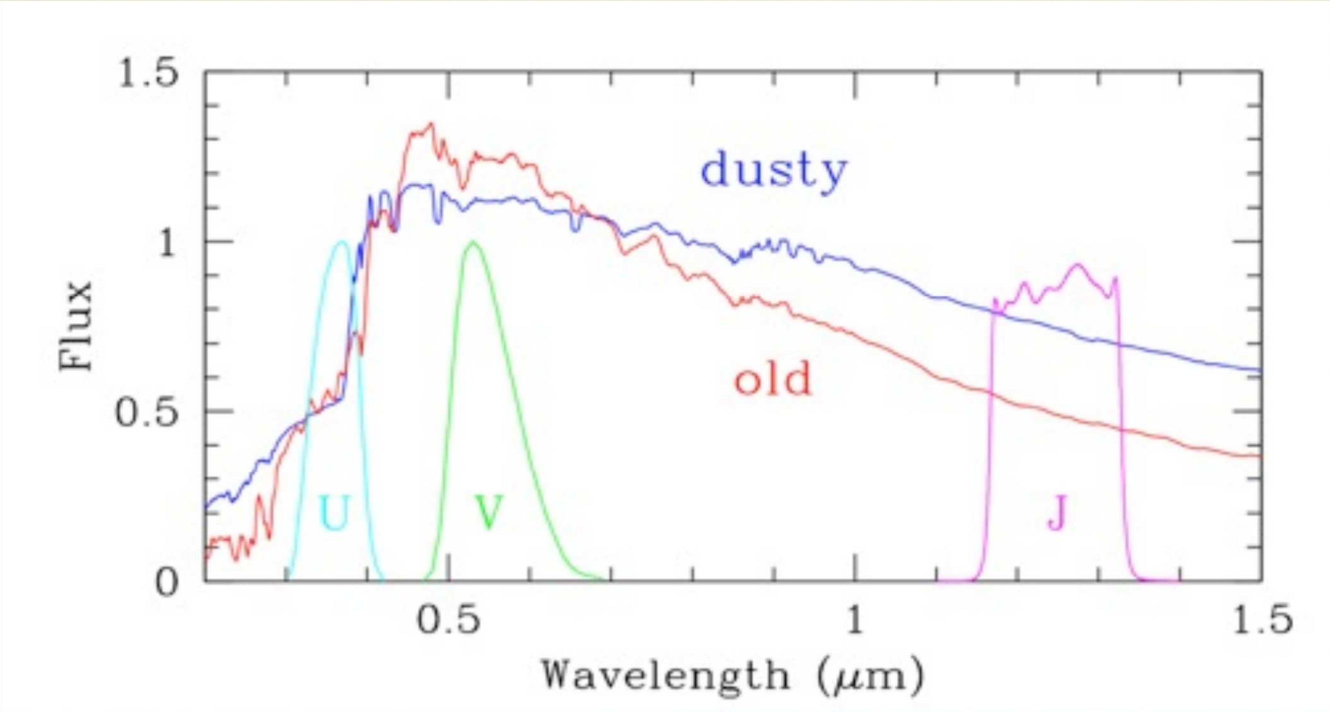


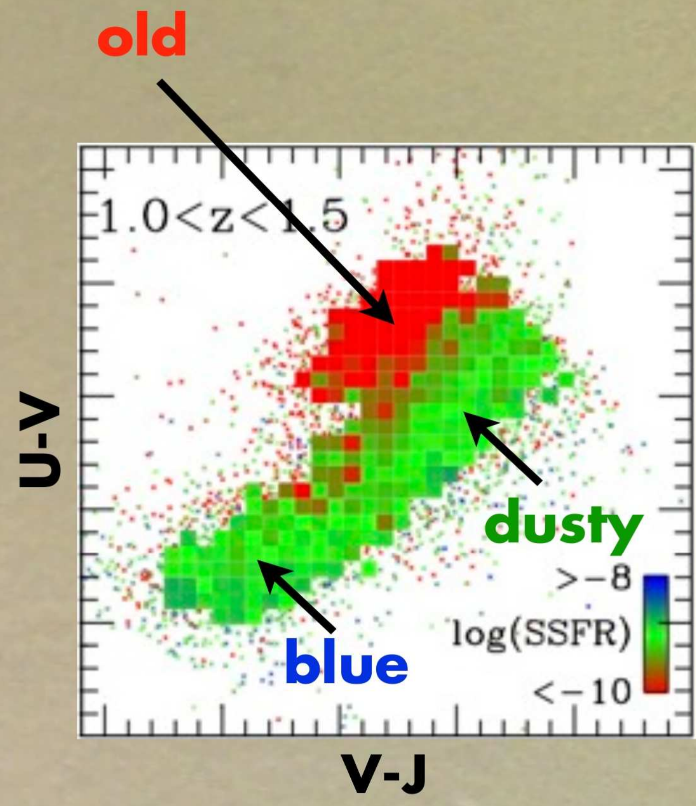



iii – Bimodal Galaxy Colors

# Quiescent galaxies to z=2

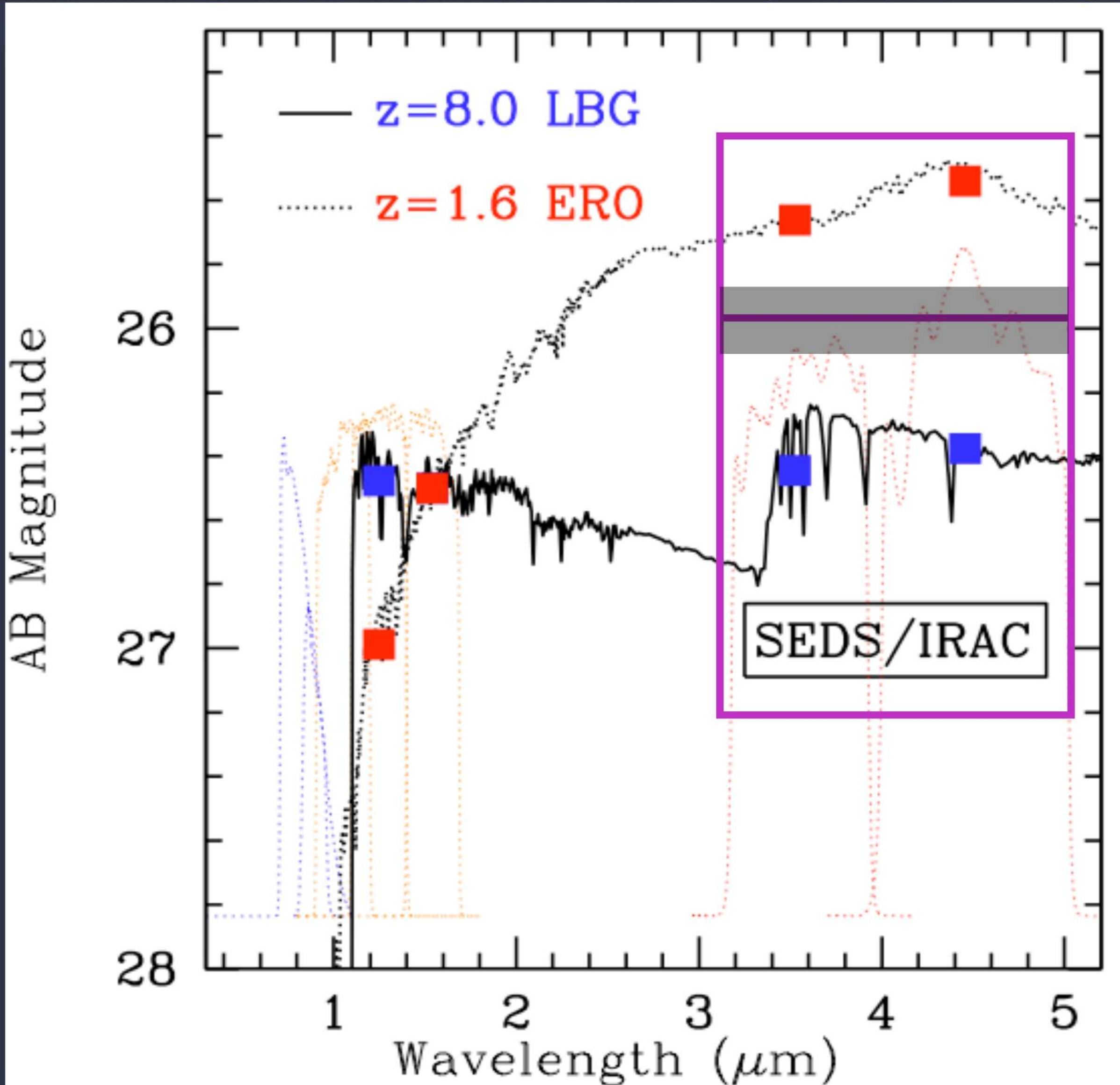
**Red galaxy rest-frame SEDs**



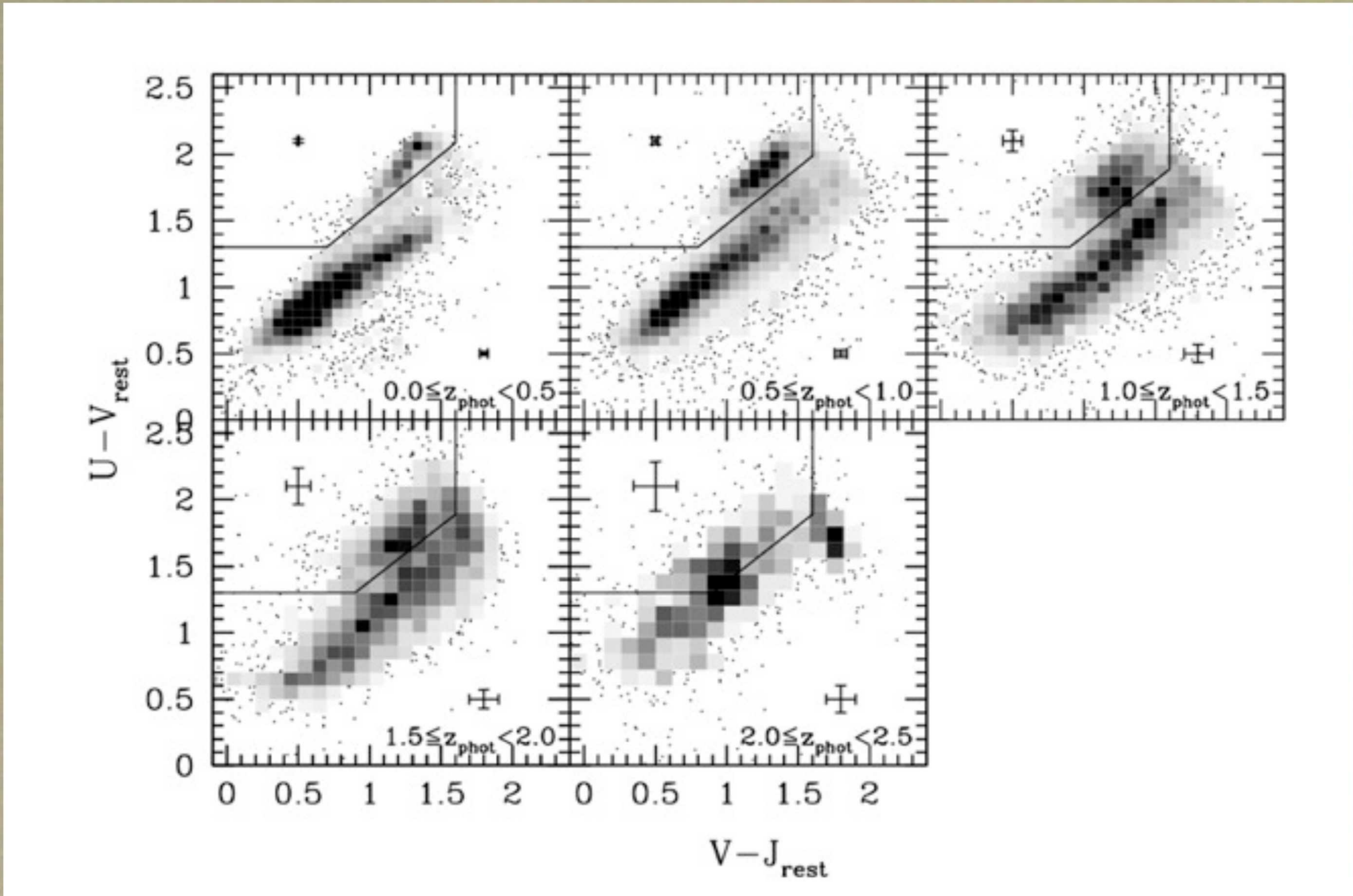




**Williams, Quadri, et al. 2009, ApJ, 691,1879**

# Importance of SEDS/IRAC

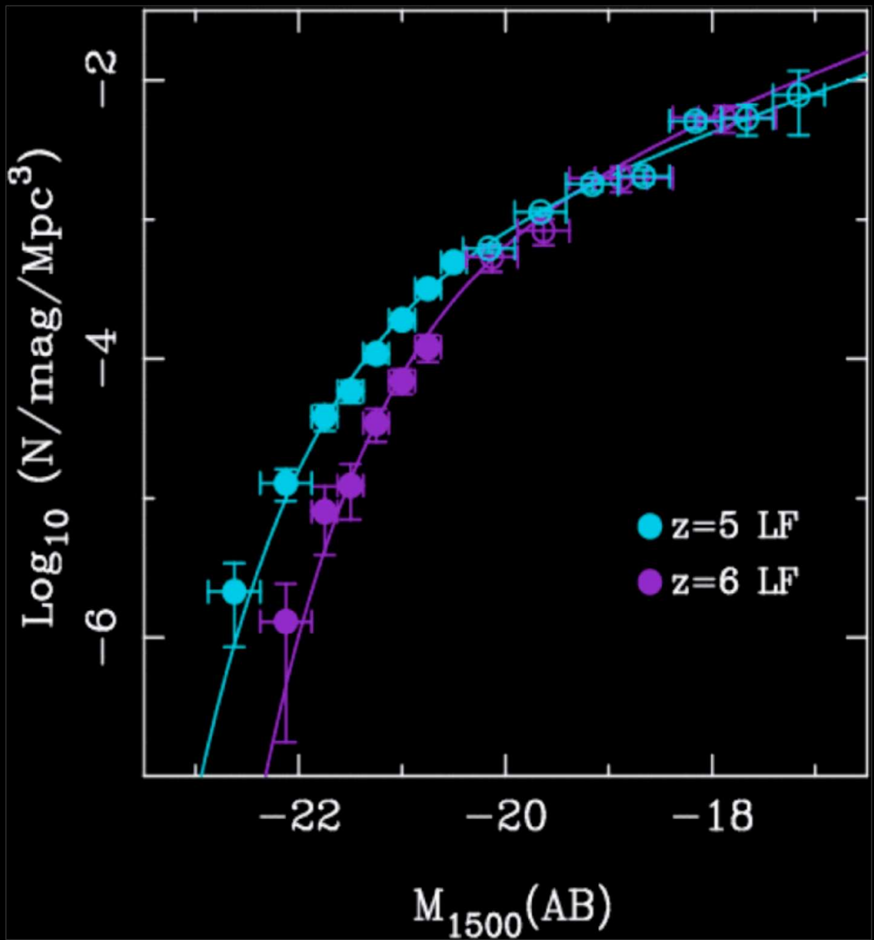


# Quiescent galaxies to z=2




Williams, Quadri, et al. 2009, ApJ, 691,1879

# iv. The galaxy luminosity function 5<z<6




McLure et al. 2009 bright end of the high-reshift galaxy LF, from the UDS K=22.7 over 0.8 $deg^2$

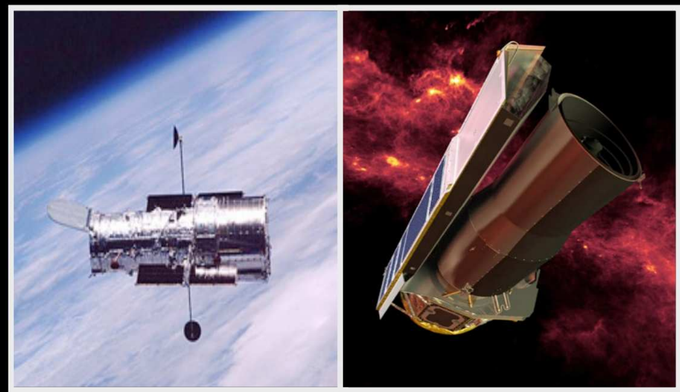
# Future Prospects at 7.0<z<9.0

## 1. Ground-based

- UDS/VISTA surveys
- VLT HAWK-I YK imaging
- Suprime-cam z-band imaging

## 2. Space-based

- CANDELS survey (HST)
- SEDS survey (Spitzer)



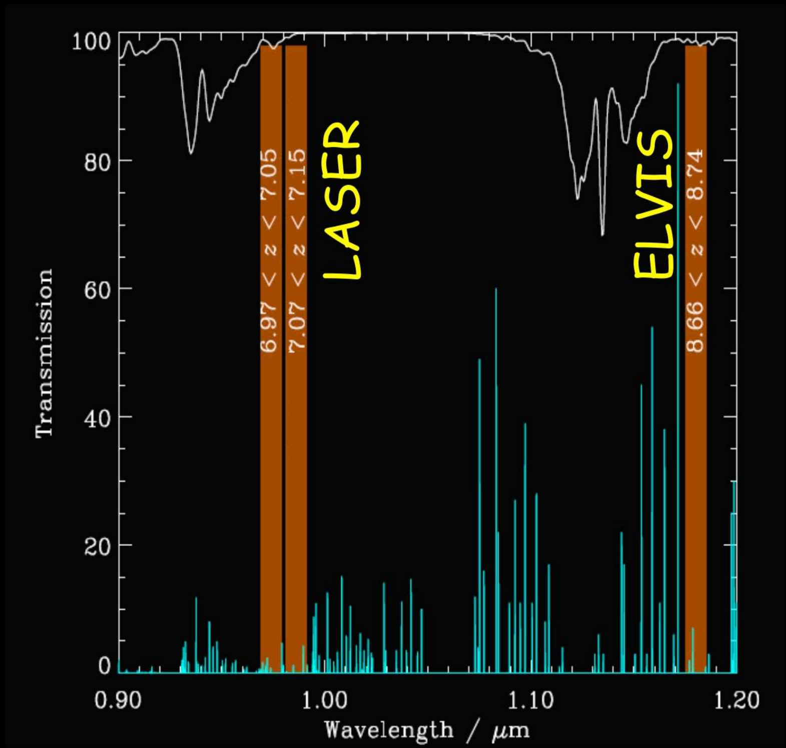
# New ground-based data in the UDS

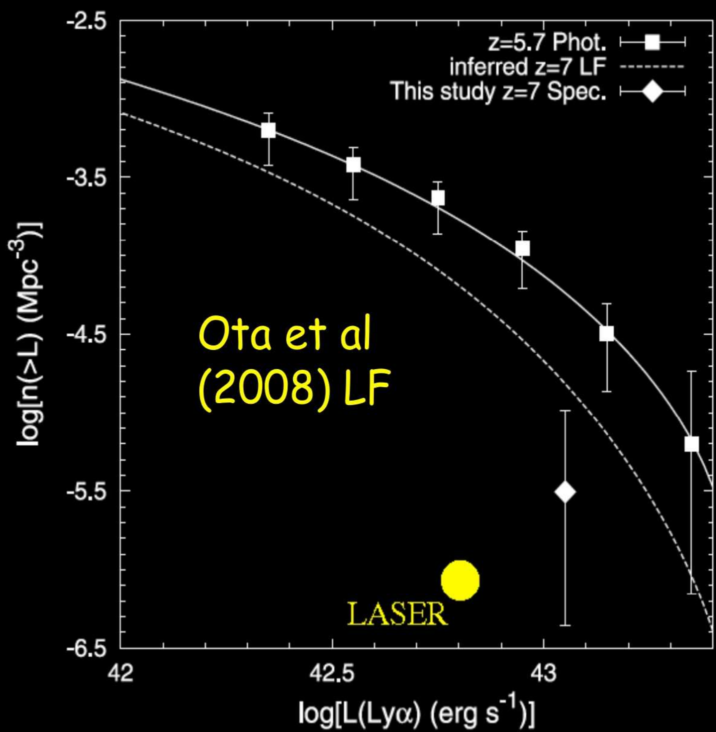
Y-band imaging as part of VISTA/VIDEO survey (PI M. Jarvis)
final depth of Y=24.6(AB); key for LBG/dwarf separation at high-z

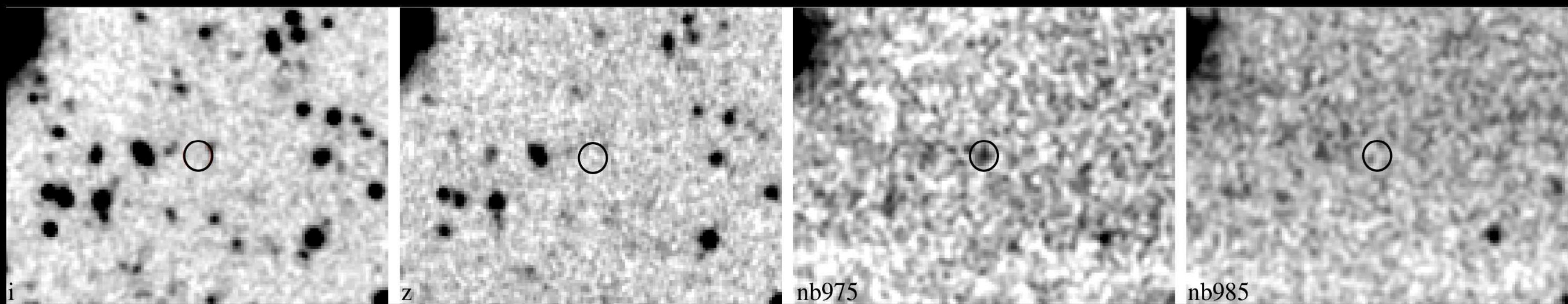
VISTA narrow-band imaging of the UDS to identify
z=7 Lyman-alpha emitters (LASER)

# LASER: Ly-Alpha Sources in Epoch of Reionisation

(PI M. Jarvis; Herts, Oxford, Edinburgh, Liverpool)

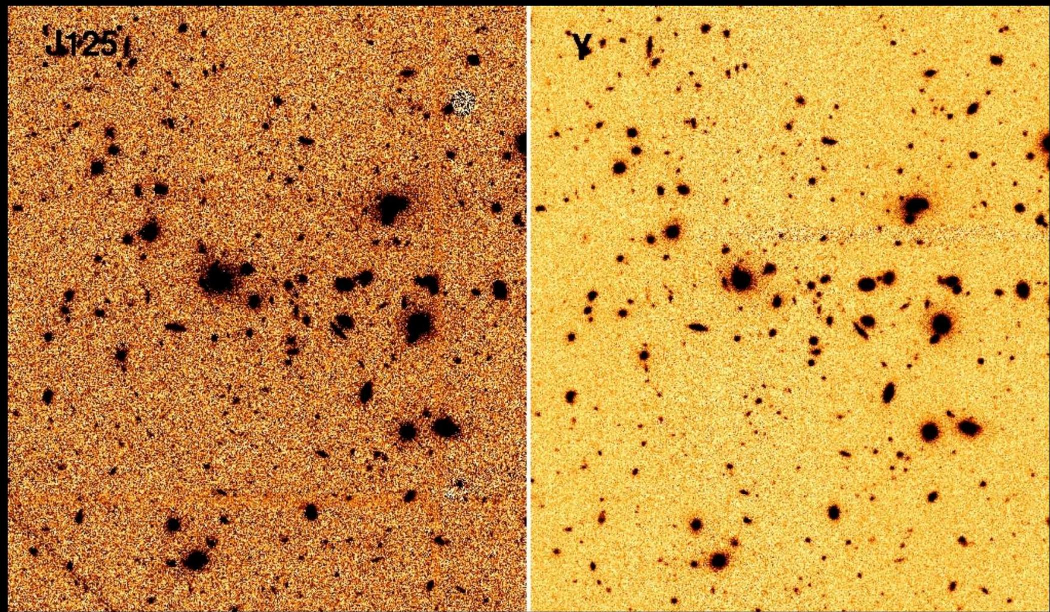



First z=7 candidate from LASER

# New ground-based data in the UDS




HST WFC3/IR HAWK-I

New VLT/HAWK-I YK imaging campaign in the UDS (PI A. Fontana)
pushing to YK=26 (5σ, AB) over 150 sq. arcmins

# The SDSS Surveys

# The Sloan Digital Sky Survey: I, II, III

SDSS-I (2000-2005):

- Imaging of 8400 deg$^2$, *ugriz* photometry of 230M objects
- Repeat imaging (~25 epochs) of 300 deg$^2$
- Spectra/redshifts of $10^6$ galaxies, $10^5$ quasars, $10^5$ stars

SDSS-II (2005-2008):

- Legacy spectroscopy (fill the gap in north)
- SEGUE: 240,000 stellar spectra, 3500 deg$^2$ new imaging
- Supernova: ~75 scans of 300 deg$^2$, >500 confirmed Type Ia SNe

SDSS-III (2008-2014):

- BOSS: extragalactic redshift survey
- SEGUE-2, APOGEE: Structure and formation of the Milky Way
- MARVELS: Extra-solar planets

# SDSS-III: Massive Spectroscopic Surveys of the Distant Universe, Milky Way Galaxy, Extra-Solar Planetary Systems

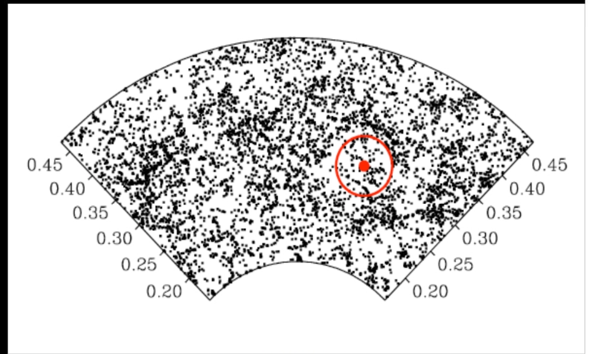
## Four surveys on three scientific themes:

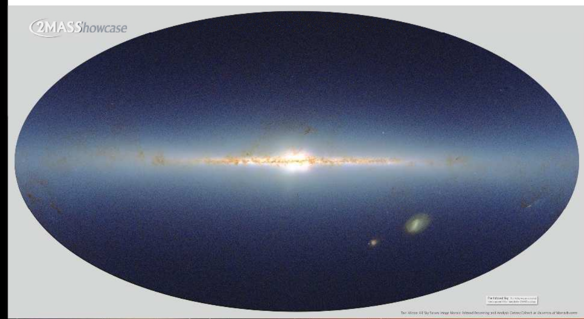
**BOSS:** Measure cosmic expansion via baryon acoustic oscillations (BAO). Redshifts of 1.5 million LRGs to z=0.7. Ly$\alpha$ forest spectra of 150,000 QSOs at z~2.5.

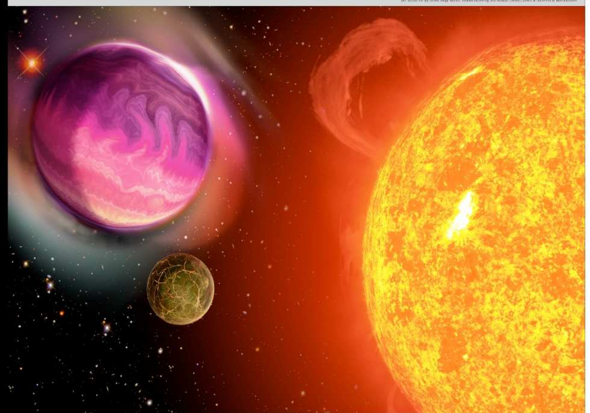
**SEGUE-2:** Optical spectra of 124,000 stars to r ≈ 20, 5 km $s^{-1}$ radial velocities, 0.2-dex bulk metallicities.

**APOGEE:** H-band spectra of 100,000 stars to H ≈ 12.5, 0.5 km $s^{-1}$ radial velocities, abundances of ~15 chemical elements per star.

**MARVELS:** Radial velocity monitoring of 8,000 FGK stars, average 24 visits per star, ~10-40 m $s^{-1}$ precision.



Six-year program, started July 08, with funding from the Sloan Foundation, NSF, DOE, Participating Institutions.

SDSS-III is fully funded

# Status of SDSS-III

51 institutional partners (including UK, Spain, Germany, France, Japan, Brazil) with over 500+ scientists

SEGUE-2: Observations complete.  Pipeline development complete.  Science analysis underway.  DR8 bonanza!

MARVELS: Observations on schedule with 74k observations of 2500 stars. First discovery papers in process.

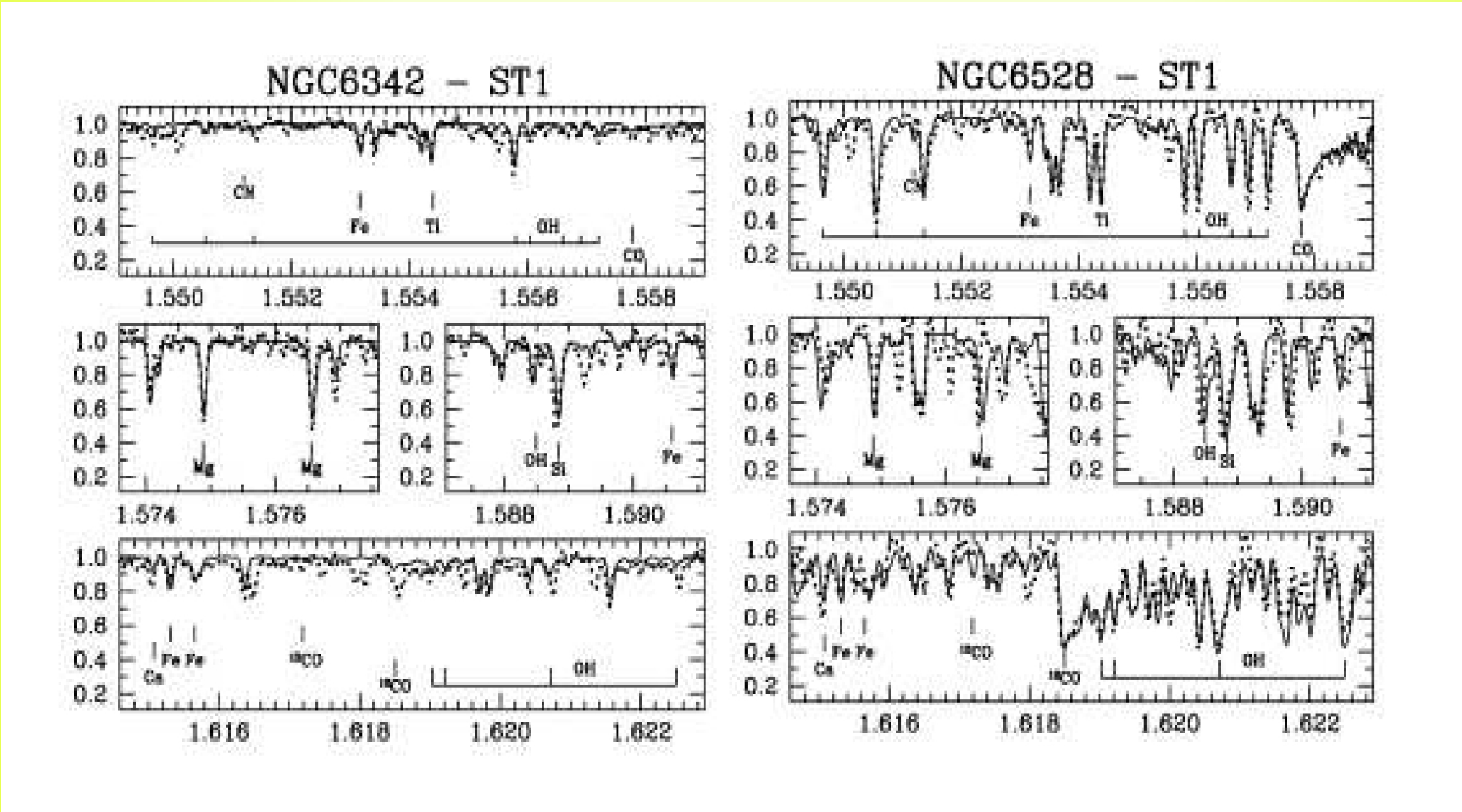
APOGEE: Spectrograph construction done and first light in lab.  Work on target selection, data pipeline underway. Commissioning and survey start in 2011.

BOSS: New imaging complete and part of DR8 bonanza! Full operations since January 2010, with 290,000 LRG spectra and 29k $z>2.2$ quasars

# APOGEE: H-band spectra, R=20000

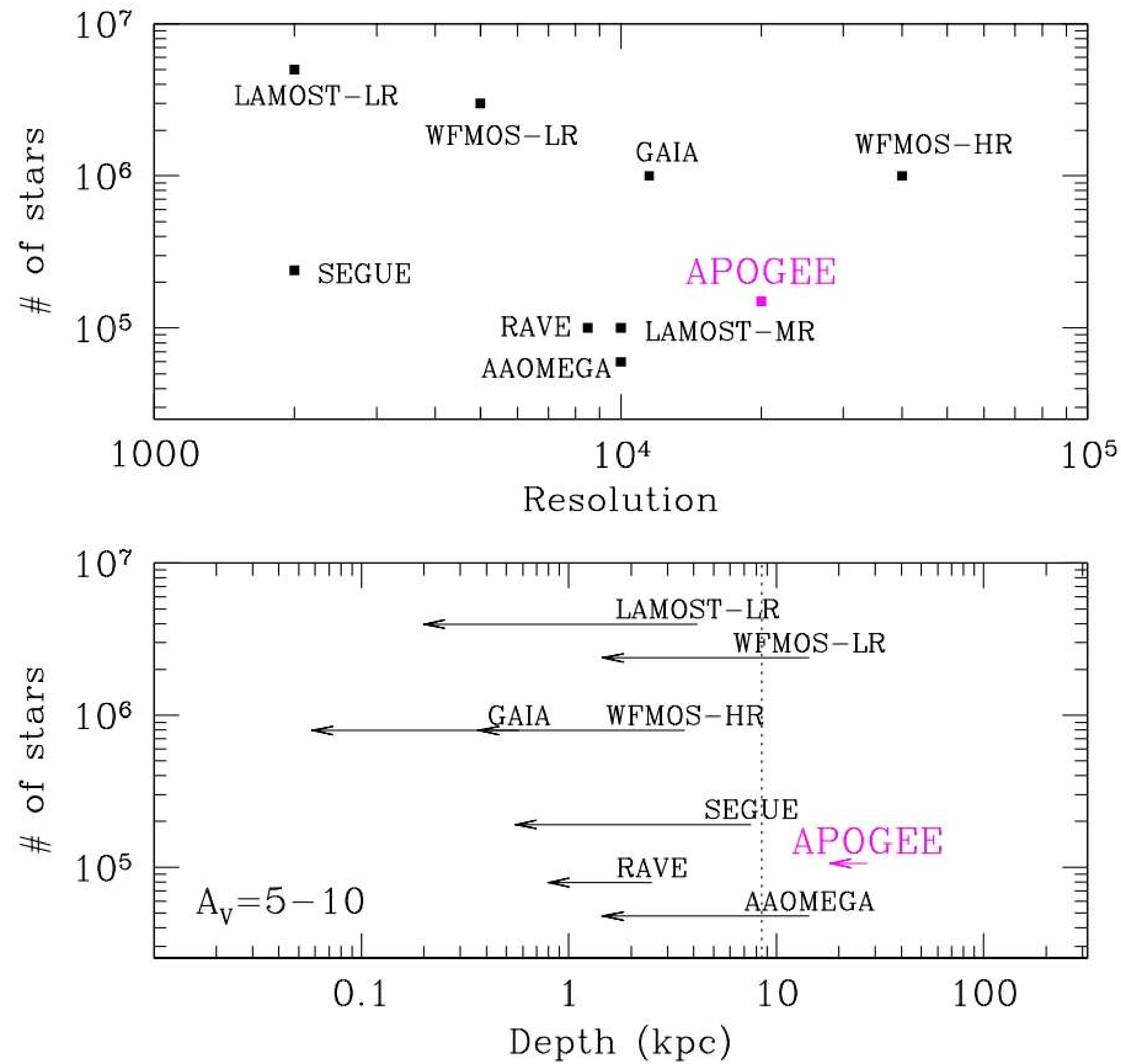
Sample to observe: H<13.5

300 spectra to be observed at the same time



# Science with APOGEE:

- Galactic stellar populations
- Formation of the Bulge and the Inner Galaxy
- Population III stars
- Halo stars (kinematics!)
- Study of Inner Bar
- Star cluster study
- Star Formation



LAMOST−LR
WFMOS−LR
GAIA
WFMOS−HR
SEGUE
APOGEE
RAVE
LAMOST−MR
AAOMEGA
# of stars
Resolution
1000
10^4
10^5
10^7
10^6
10^5
LAMOST−LR
WFMOS−LR
GAIA
WFMOS−HR
SEGUE
APOGEE
RAVE
AAOMEGA
A_V=5−10
# of stars
Depth (kpc)
0.1
1
10
100

# How to make an impact in IR astronomy?

Specialize! Be the best at something!

Examples of specializations:

- Large field of view
- Narrow band filters
- Good image quality
- Low sky background (high altitude)
- High resolution spectroscopy
- Most creative science topic
- Robotic telescope specialization

# Is it a good idea to observe in N or Q (10 or 20 micron)?

At 10 micron a 4 or 8m telescope is diffraction limited (the FWHM of the airy disk is 0.1" at 10 micron on an 8m).

So for a point source the amount of background light that one gets when one observes a point source is 2x2 = 4 times smaller on an 8m than on a 4m.

One also collects 2x2 = 4x as much light on an 8m.

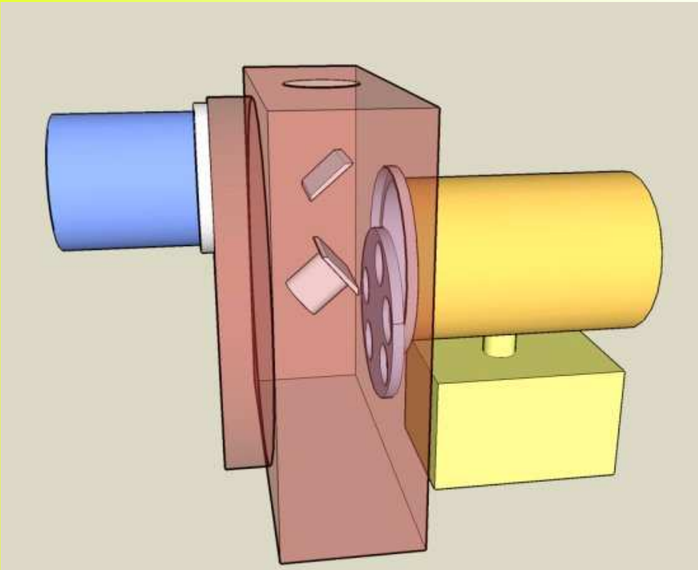
So the S/N goes up for backgroundlimited observations (almost all) by a factor of sqrt(2x2x2x2) = 4 in the same amount of time.

→ it is hard to compete with 8m telescope in the thermal IR

# The Liverpool Telescope at La Palma

A robotic 2m telescope offering various instruments, amongst which an optical images, spectrograph and an infrared imager.

New: plans to build a new camera, the IO Camera.



- optical imager with 10'x10' field
- infrared JH imager with 6'x6' field
- Y-band filter
- small pixels (0.2")
- tip-tilt correction

# Conclusion:

There is a lot still to be done in the infrared, but it will not be easy to make a large impact, since several studies are already on its way.

However, the area of infrared spectroscopy is relatively unexplored.

In any case, wide-field, multi-object capabilities are very important.