# 4MOST: 4-meter Multi-Object Spectroscopic Telescope

A design study for an ESO spectroscopic follow-up facility for Gaia, eROSITA, Euclid and other all-sky surveys

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on behalf of

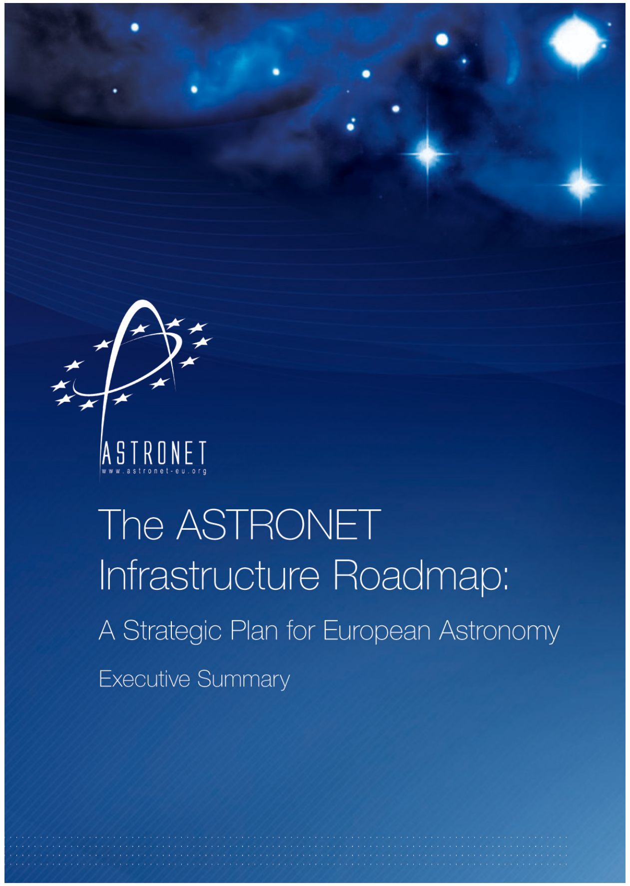
Roelof de Jong (AIP)

# Conceptual Design Study for ESO

- Now: start Conceptual Design study, completed by Feb 2013
- Goal: start all-sky spectroscopic survey early 2018
- Telescope: 4m-class telescope, either on VISTA or NTT
- Science: space mission follow-up: Gaia, eROSITA, Euclid
- Data: yearly public data releases with higher level data products
- Goal specs:
  - Very high multiplex: >3000 fibers
  - Full optical wavelength coverage: 390-1000 nm
  - Large field-of-view: $\varnothing=3°$
- 4MOST provides in a 5 year survey
  - $>20 \times 10^6$ spectra @ R~7000 to $m_V$~20 mag at S/N=20
  - $> 1 \times 10^6$ spectra @ R~20,000 to $m_V$~16 mag at S/N=50

# Background

- 2008: ASTRONET Infrastructure Roadmap
  „A smaller project, but again of high priority, is a wide-field spectrograph for massive surveys with large optical telescopes.“
- 2008: ESA-ESO Working Group on Galactic populations, chemistry and dynamics
  „Blue multiplexed spectrograph on 4 or 8m class telescope“



ASTRONET
www.astronet-eu.org

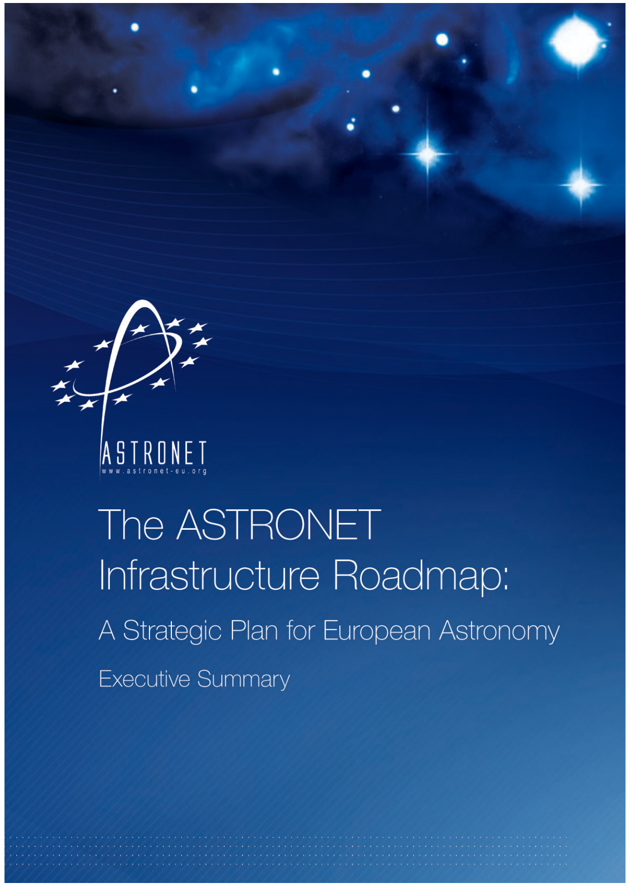
The ASTRONET Infrastructure Roadmap:

A Strategic Plan for European Astronomy

Executive Summary

# Background

- September 2010:
  Call for LoI for a Wide-Field Spectroscopic Survey Facility
  - Invitation to submit proposal
- March 1, 2011:
  proposal deadline
- May 2011:
  ESO selects two phase A studies
  - MOONS (IR MOS spectrograph for VLT)
  - 4MOST
- May 2012: VISTA/NTT decision
- Spring 2013: decision by ESO



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Executive Summary

# 4MOST facility consortium

- Instrument Institutes
  - Leibniz-Institut für Astrophysik Potsdam (AIP) (D)
  - MPI für Extraterrestrische Physik, München (D)
  - Ludwig-Maximilian Universität, München (D)
  - Zentrum für Astronomie, Univ. of Heidelberg (D)
  - Institute of Astronomy, Cambridge University (UK)
  - Rutherford Appleton Laboratory, Oxford (UK)
  - L'Observatoire de Paris, GEPI, Paris (F)
  - NOVA, Dwingeloo (NL)
  - ESO, Garching (EU)
- Science Institutes
  - University of Lund (S)
  - University of Uppsala (S)
  - University of Groningen (NL)

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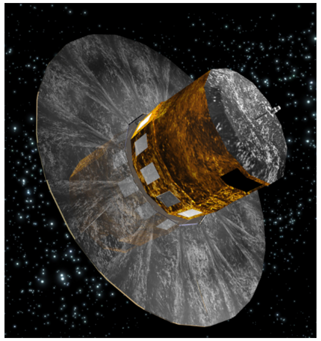
# One size fits all, all the time

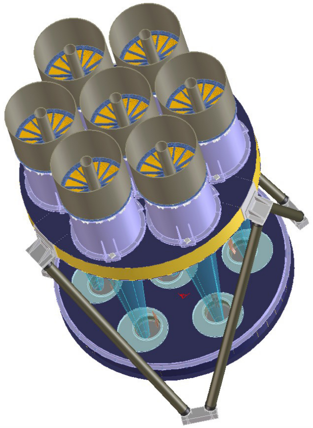
4MOST can do many science cases at the same time

- Large Field-of-View of 3–7 □° enables all-hemisphere surveys
  - 20,000□°/ 7□°=~3000 pointings
  - 5 pointings/night x 300 nights/year = 2 years
- Large multiplex of >1500 (goal 3000) enables massive surveys, repeat observations
- 4MOST combine 3 spectral regimes in one facility
  - R~1000-2000 for redshift surveys of faint objects
  - R~5000 for radial velocities, [Fe/H], and [α/Fe]
  - R>20,000 for abundances
- Doing all at the same time, all the time creates opportunities otherwise not possible
  - Targeting object densities 1-100s / degree$^2$ all-sky, 1k – 10M samples

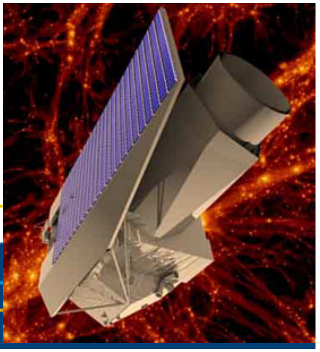
# Science drivers



- **Gaia** follow-up:
  - Stellar radial velocities, parameters and abundances ($15 < m_G < 20$ mag)
  - Chemical tagging ($m_G < \sim 16$ mag)

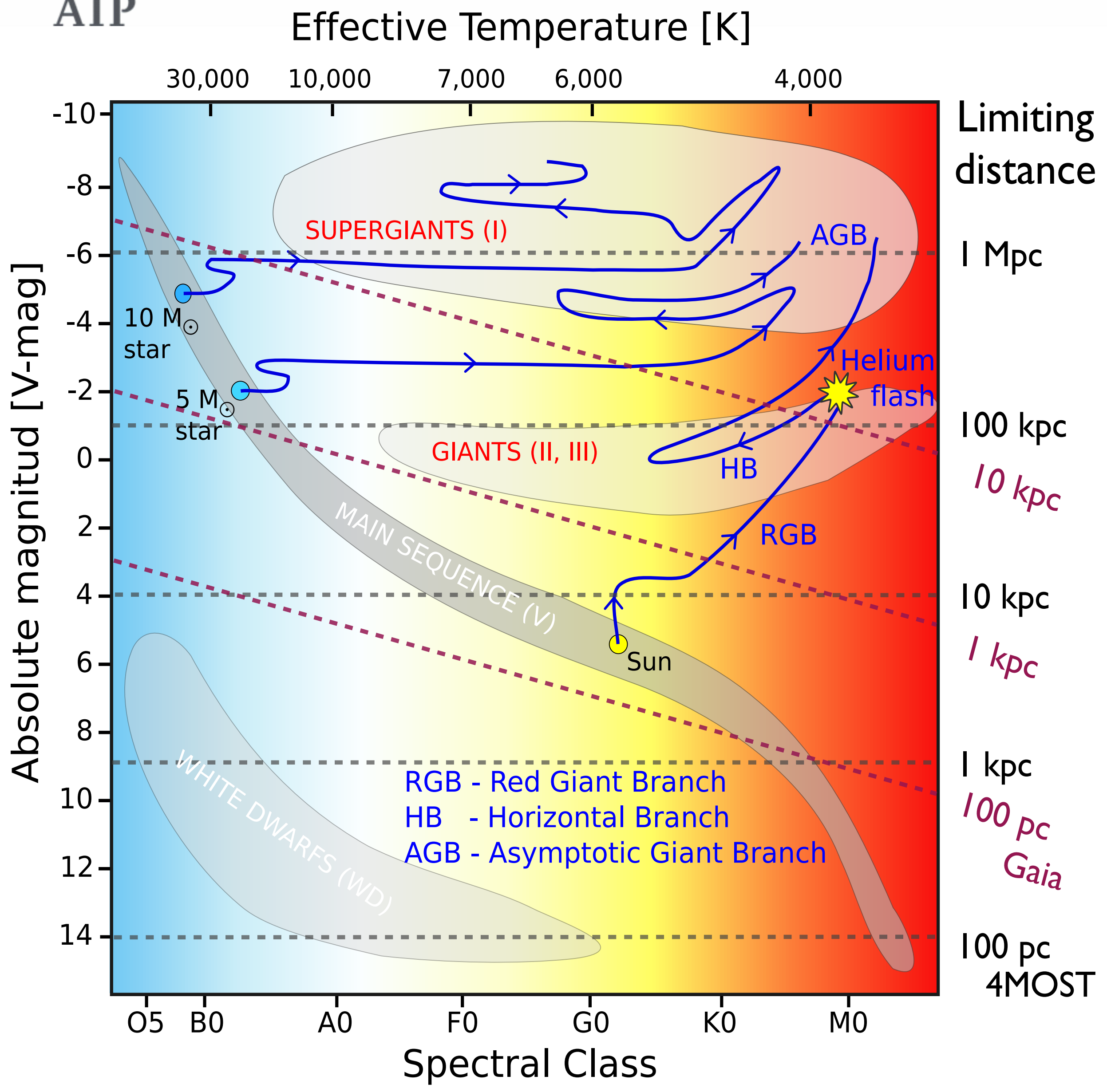


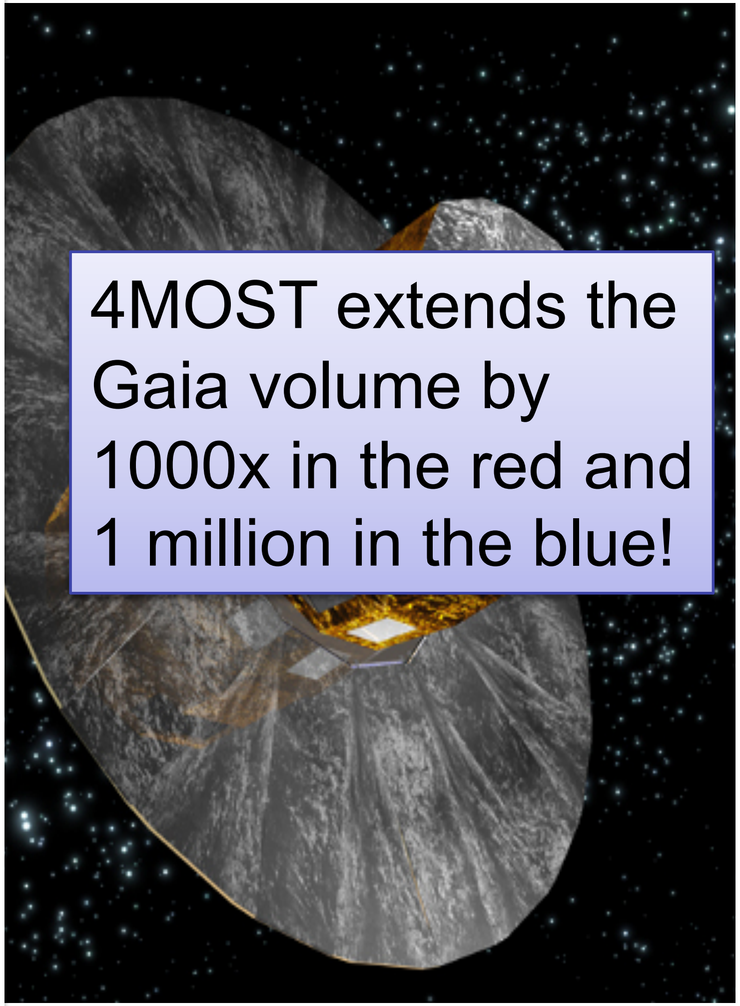
- **eROSITA** follow-up:
  - Cosmology with x-ray clusters of galaxies ($z < \sim 0.6$, $r < 22.5$ mag)
  - X-ray AGN/galaxy evolution to $z \sim 5$
  - Galactic X-ray sources



- **Euclid** (and other imaging surveys) follow-up:
  - Dark Energy from BAO
  - Galaxy evolution

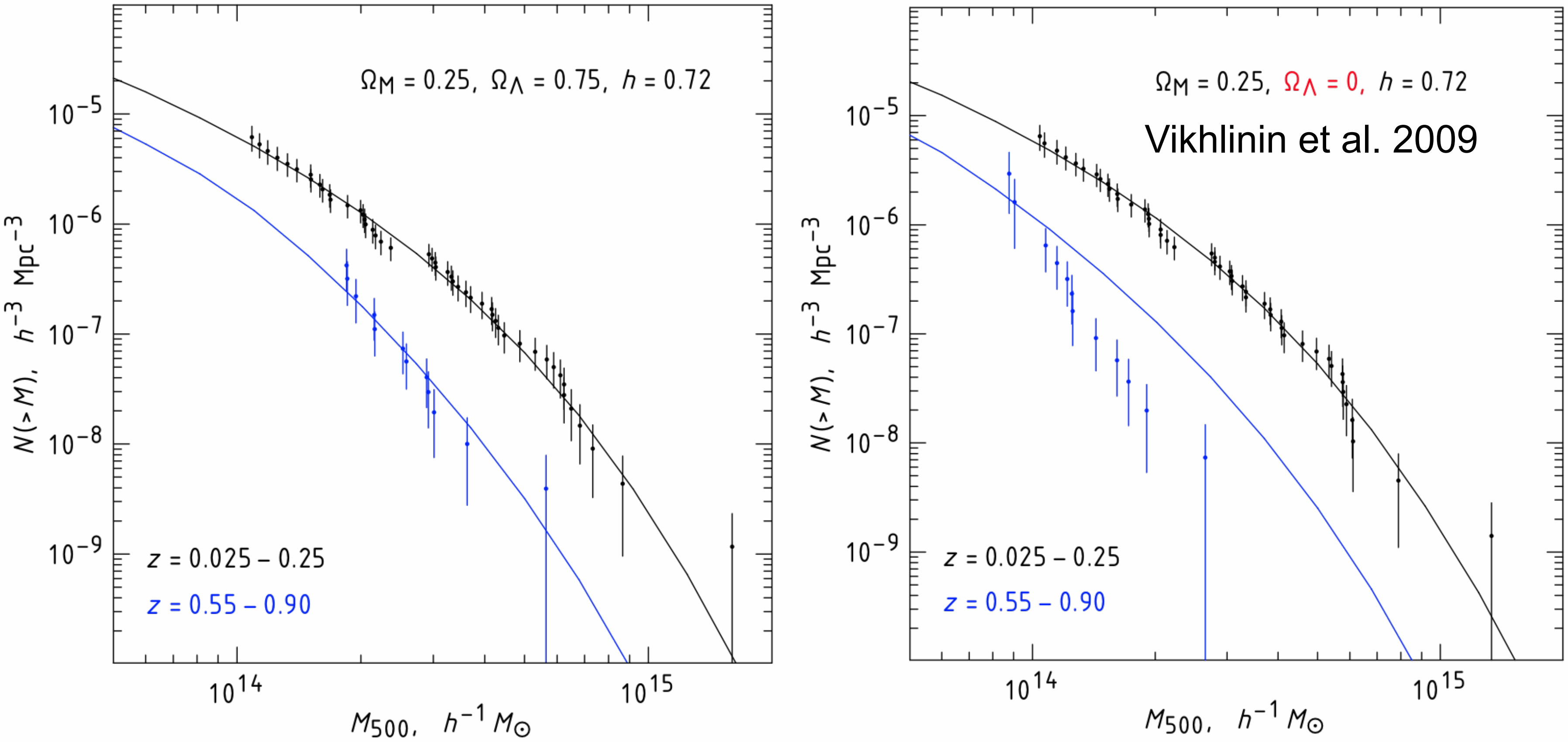
# Gaia needs spectroscopic follow-up to achieve its full potential





4MOST extends the Gaia volume by 1000x in the red and 1 million in the blue!

# Cluster mass function vs. cosmological model

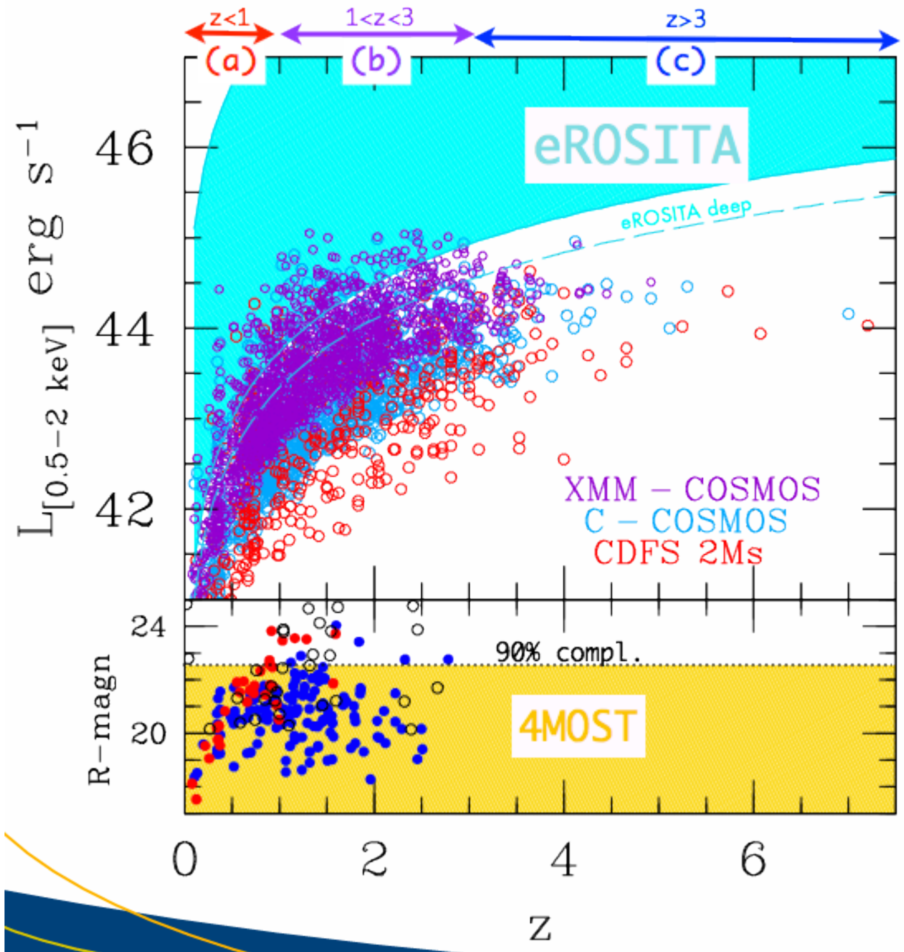


Vikhlinin et al. 2009

ROSAT discoveries, Chandra follow-up, 88 objects

- With eROSITA & 4MOST: ~50,000 clusters, 10 redshift bins → $\Omega_\Lambda$ = f(time)

# The AGN-Galaxy connection as f(z)



- 4MOST will obtain R~3000 spectra for >1 million eROSITA AGNs:
  - z<1 BH accretion versus galaxy properties
  - 1<z<3 Feedback in action through outflow absorption lines of $\sim 10^4$ AGNs
  - z>3 Search and characterization of the first accreting black holes (>$10^4$ AGNs over a range of masses)
  - 0<z<5 The evolution of the SMBH-galaxy scaling relations
  - 0<z<3 AGN in dark matter halos: triggering and lifetime using 3D correlation functions

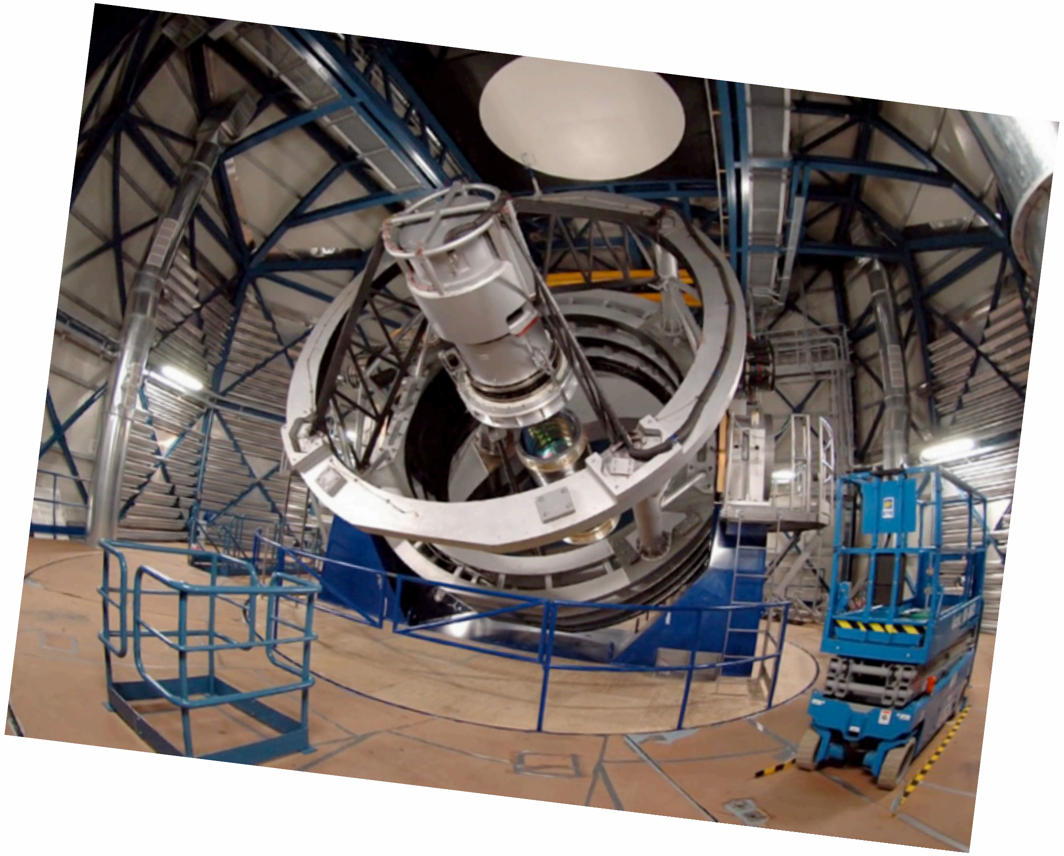
# Large discovery space for Galactic X-ray sources

- Expect 0.5 million Galactic point source
- Constraining evolutionary channels (especially when combining 4MOST+eROSITA+Gaia)
  - coronal X-ray emitters
  - X-ray binaries of all sorts (CVs, XRBs, etc.)

# Instrument Specification

| Specification | Baseline | Goal |
|---|---|---|
| Field-of-View (FoV) | 3 degree$^2$ | **>5 degree$^2$** |
| Multiplex fiber positioner | 1500 | >3000 |
| Spectrographs – blue arm | | |
| resolution @ 500 nm | R~5000 | R~5000 |
| passband | 400-650 nm | 390-650 nm |
| Spectrographs – red arm | | |
| resolution @ 850 nm | R~5000 | R~7000 |
| passband | 650-900 nm | 650-1000 nm |
| High resolution mode (10-20% of all fibers) | R>20,000,<br>λ=393-459 & 585-676 nm | R>20,000,<br>λ=393-459 & 585-676 nm |
| # of fibers in ⌀=2' circle | >3 | >7 |
| Reconfigure time | <8 min | <4 min |
| Area (5 year survey) | 2x15,000 deg$^2$ | **>2x~20,000 deg$^2$** |
| Objects (5 year survey) | 6x10$^6$ | **>20x10$^6$** |
| Start operations | | end 2017 |

# Telescope choice between NTT and VISTA



- Mainly a policy decision by ESO

# Telescopes pros and cons

| | VISTA | NTT |
|---|---|---|
| Effective primary mirror diameter | 3.7m (3.95m) | 3.58m |
| Telescope site | Paranal ++ | La Silla + |
| Modern survey telescope | ++ | + |
| Preliminary corrector FoV | ⌀=3° | ⌀=2° |
| Rotator | + | - |
| Easy access focus | ++ | -- |
| Total costs to create large FoV | ++ | -- |
| Space for spectrographs | ++ | ++ |
| Community reluctance | - ? | + |

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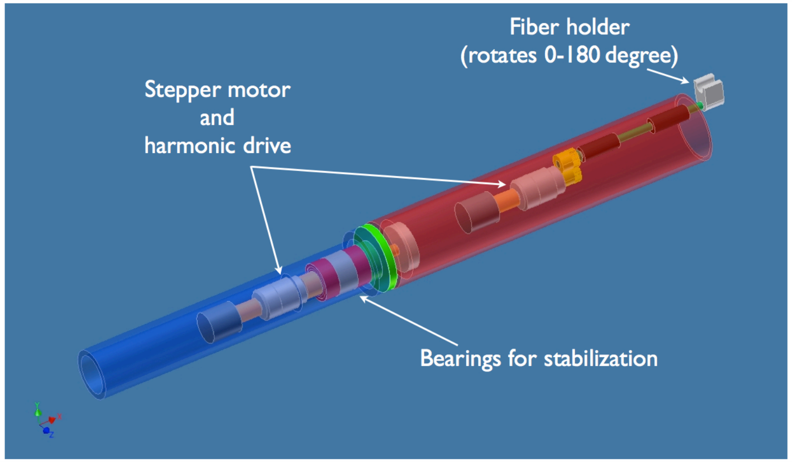
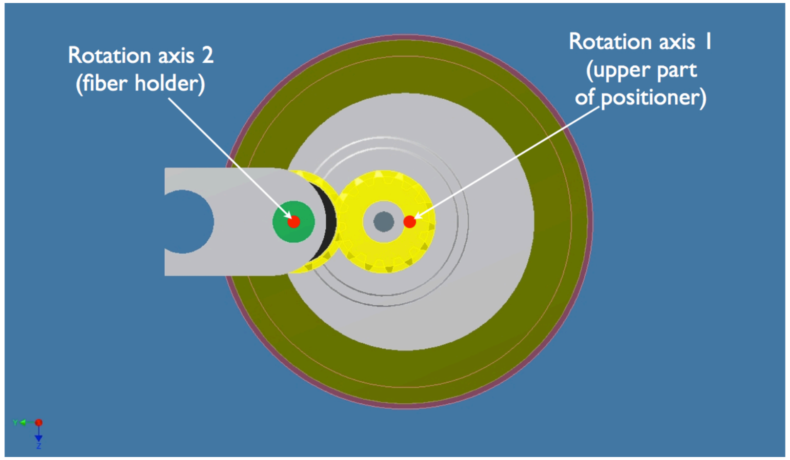
# Fiber Positioner concepts

| Concept | Advantages | Disadvantages |
|---|---|---|
| Plug plates (e.g. SDSS) | High density, low complexity, low build cost, close ~~target proximity, curved~~ focal surfaces | ~~Handling, offline~~ machinery requirements, labor intensive – high operations cost |
| Pick and place (e.g. 2dF) | Flexible, fair target proximity, relatively cheap | Single point failure mode, limit to multiplex, space for multiple field plates required |
| Locally sampling (e.g. LAMOST) | Scalable, robust, high density, uniform areal sampling, curved focal surfaces acceptable | Complexity, high cost, less flexibility assigning targets, hard feeding different spectral resolutions simultaneously |

# LAMOST-style positioner





# ECHIDNA style positioner

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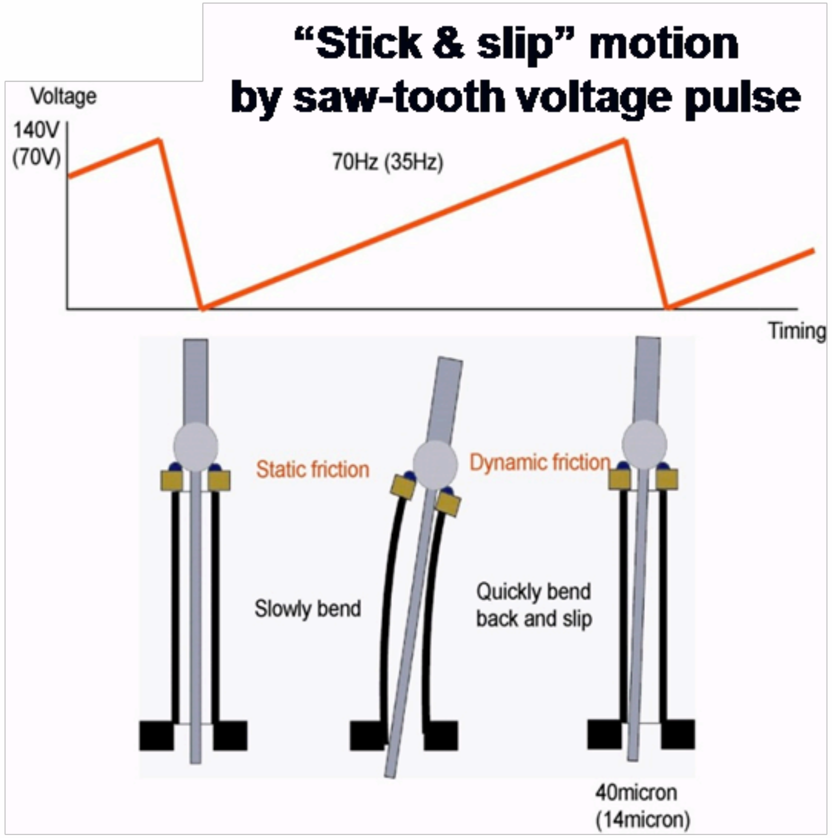
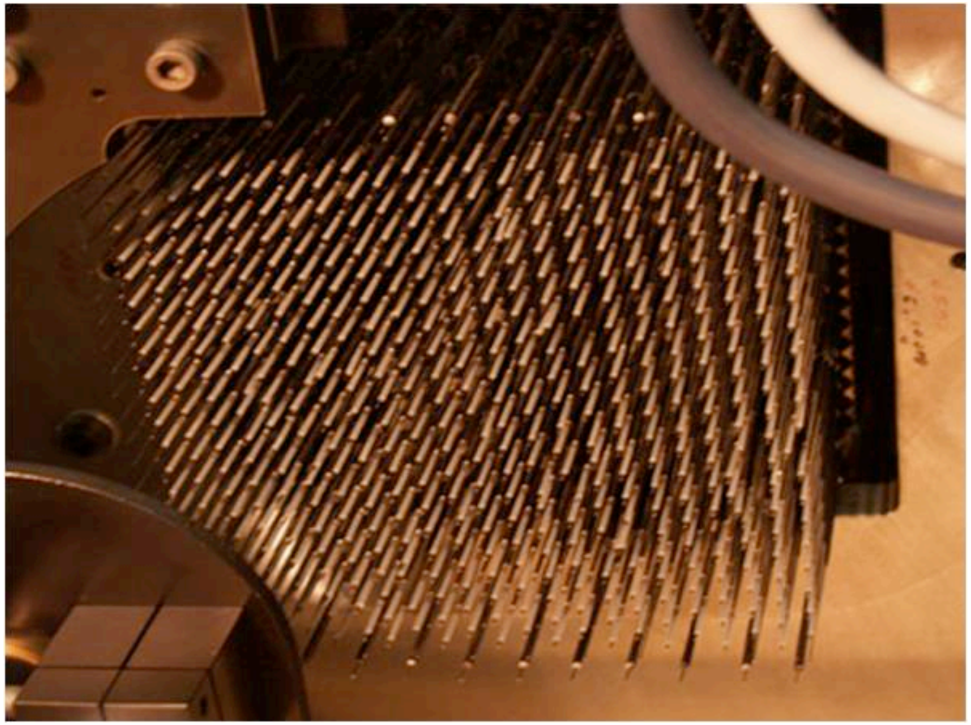
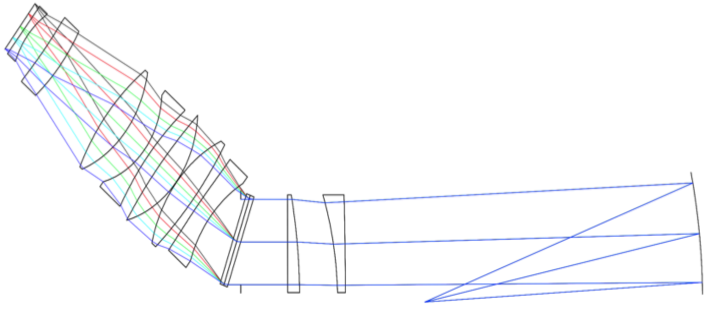
# Echidna-style positioner (SUBARU FMOS)

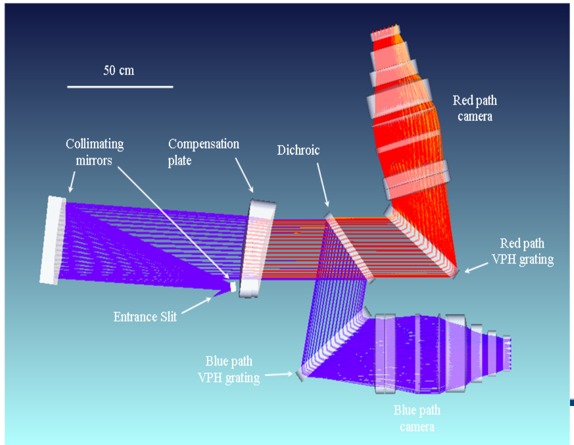


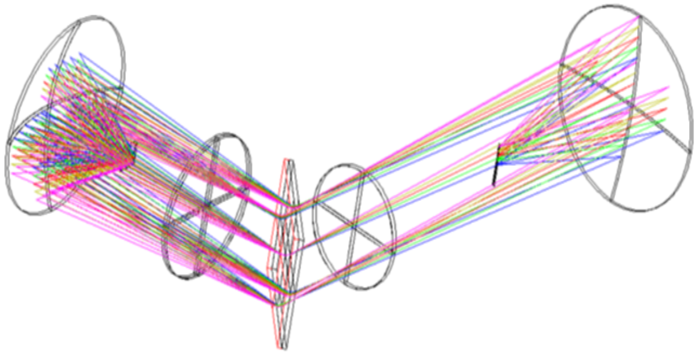


# Spectrographs

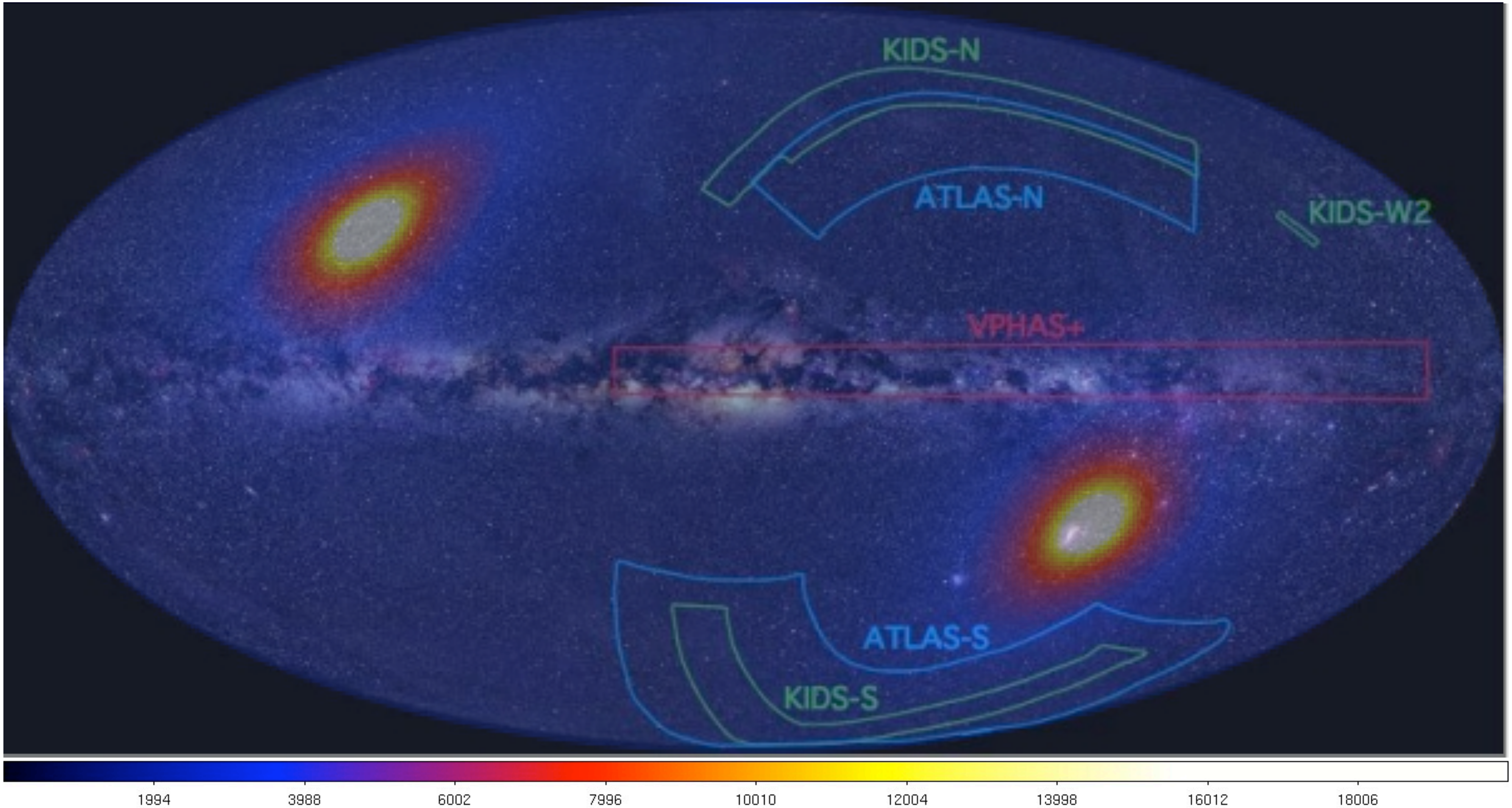
- Single configuration spectrographs, high throughput with VPH gratings
- Replicate R~5000 spectrographs to fiber count of positioner Dedicated R~20,000 spectrograph for ~10-20% fibers
- Minimize cross-talk between fibers as we have large dynamic range in science goals
  - If FoV >3 degree$^2$ we can repeat sky in different magnitude ranges
- Multiple designs currently being considered, building on earlier developments: WEAVE, WFMOS, GYES

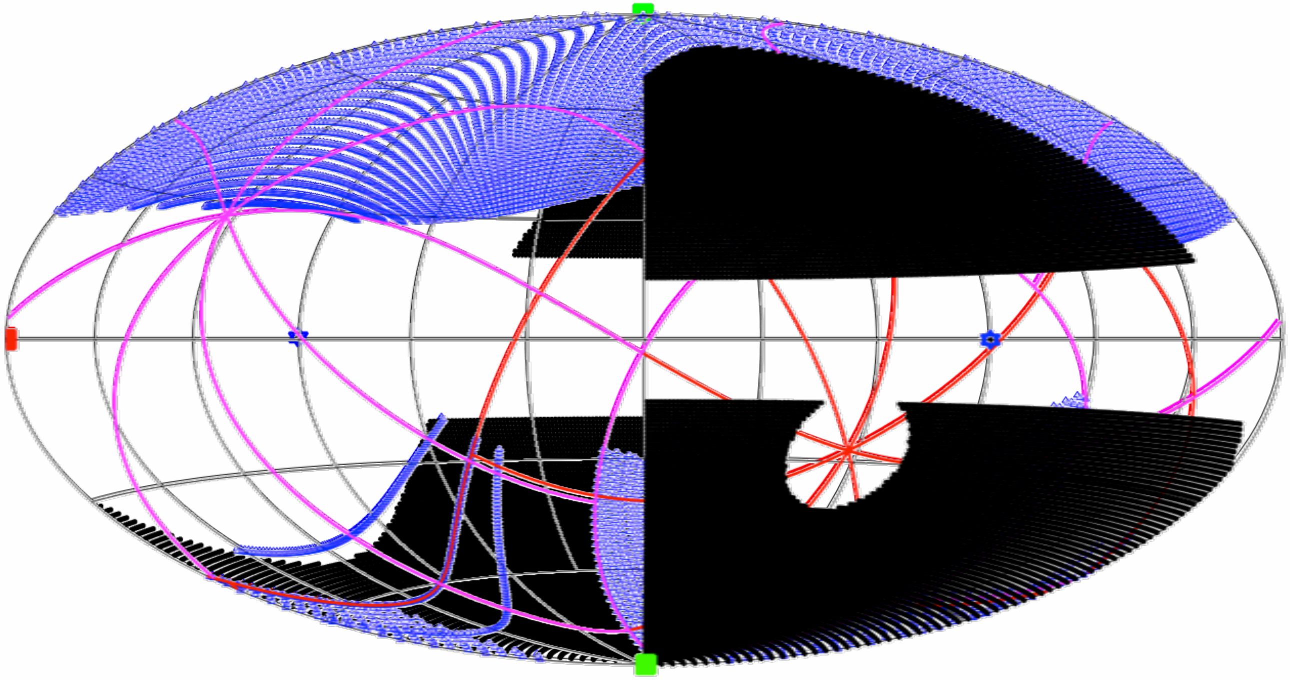






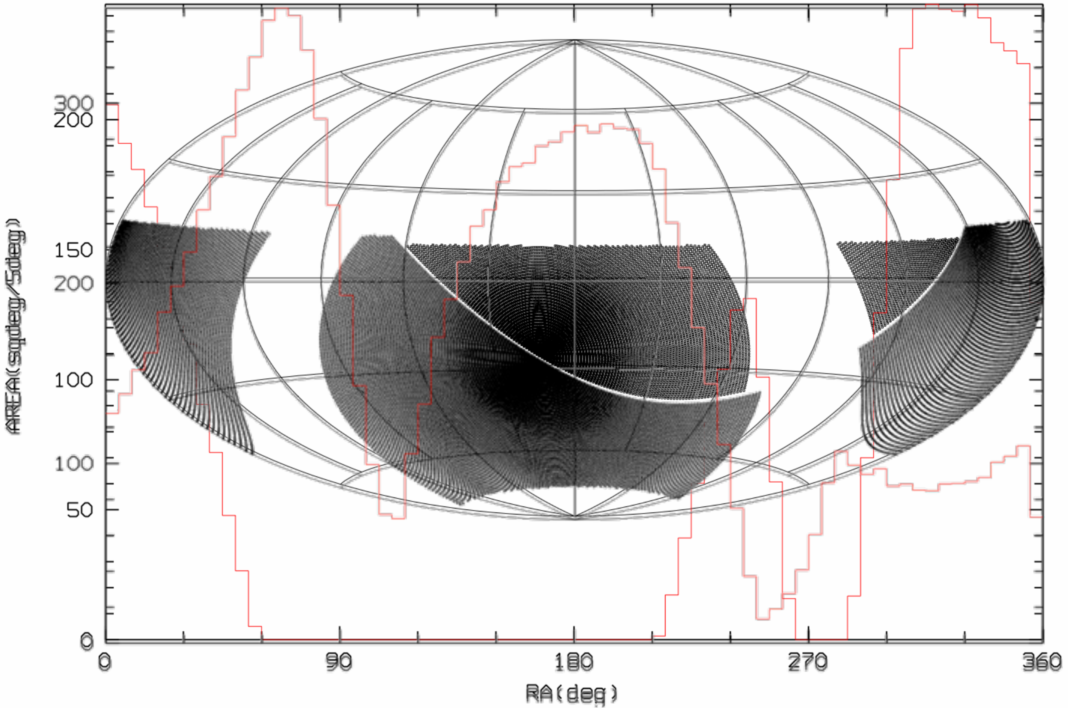
# Exposure map in galactic coordinates





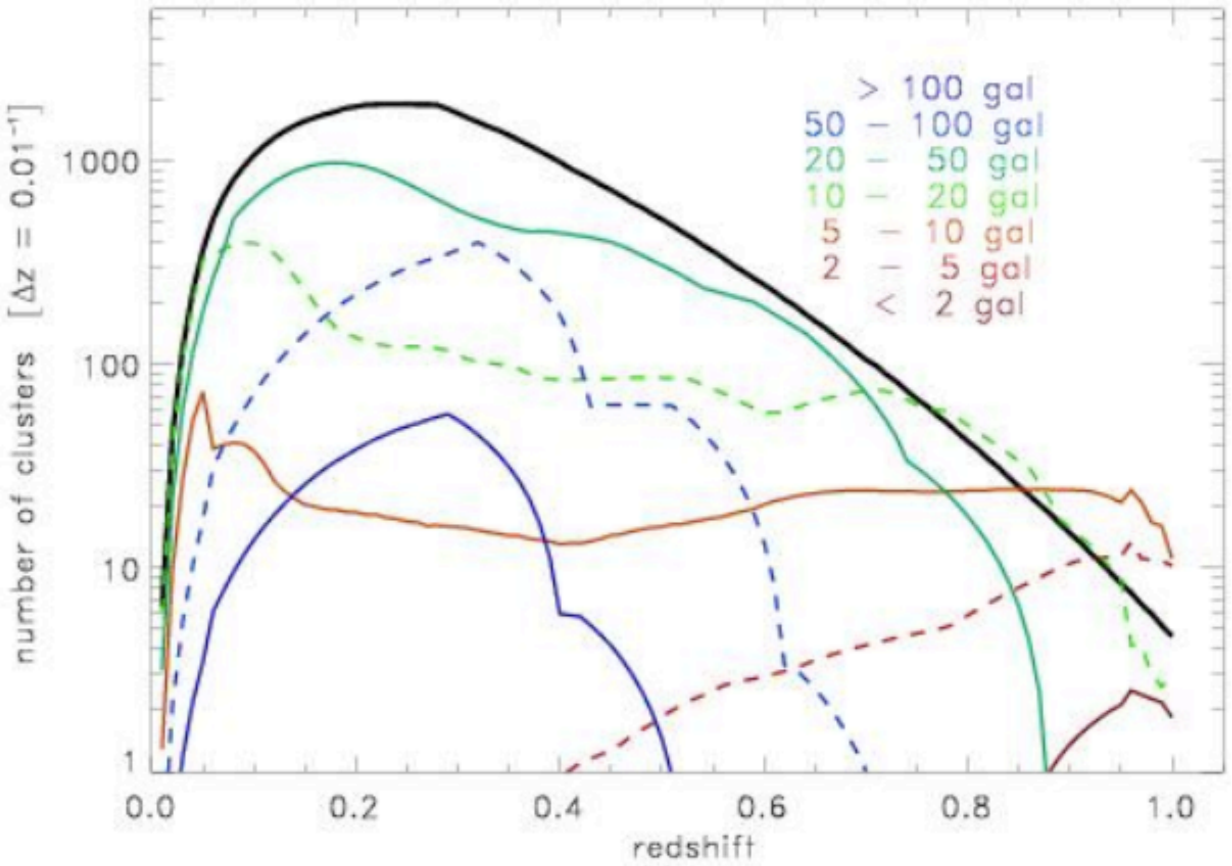
| West | \|b\| > 15 | \|b\| > 20 |
|---|---|---|
| NTT | 12570 | 11090 |
| VISTA | 12730 | 11270 |

| East | \|b\| > 15 | \|b\| > 20 |
|---|---|---|
| NTT | 5530 | 5090 |
| VISTA | 6210 | 5720 |



# Observable galaxies per cluster

Magnitude range = 18.5 to 20.5 in i-band (< 22 in r-band)



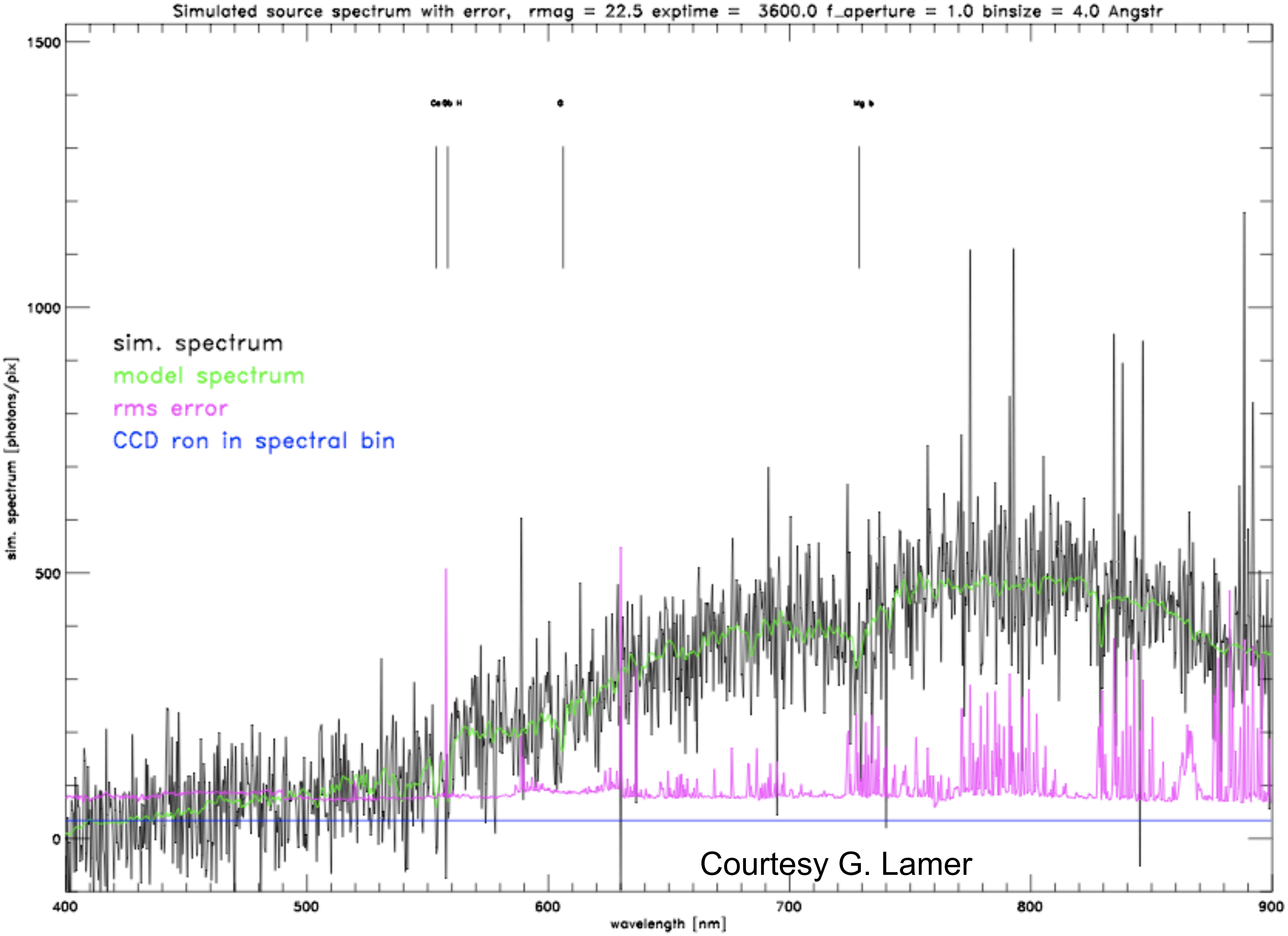
# Number summary

For a 15000 deg$^2$ survey:

- 50000 galaxy clusters
- 50 galaxies/cluster = 2.5 Million galaxies
- Selection efficiency 50%
- Targeting overhead x2

→Total 2.5 Million spectra

→Challenge: strong clustering of target galaxies

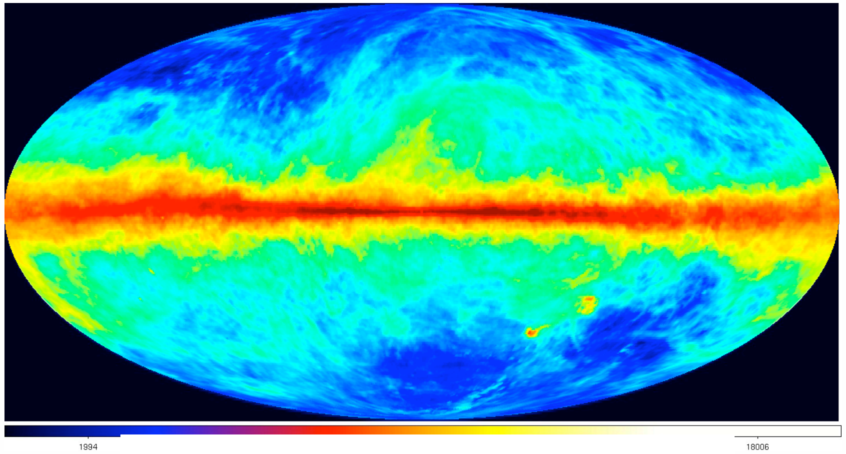


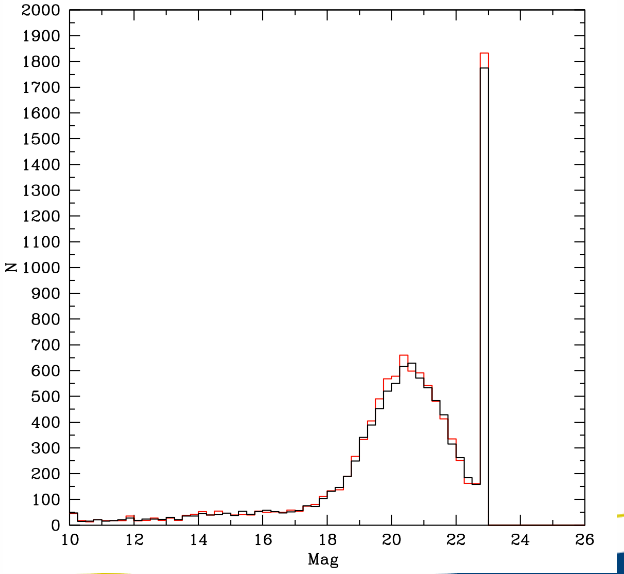
Courtesy G. Lamer

# Mock catalogues, obs strategy

- Exposure map +
  Galactic extinction map
  → limiting flux $F_{x,lim}$@ E
- logNlogS → #/deg$^2$
  (100 – 300)
- FoV → #sources
  (~1.3 Mio)
- $F_x/F_{opt}$ → optical targets
  (~1.2 Mio)

- Completeness (90%)
- Depth (16-22.5 mag)
- Red sensitivity (400-1000nm)





# Preliminary ETC

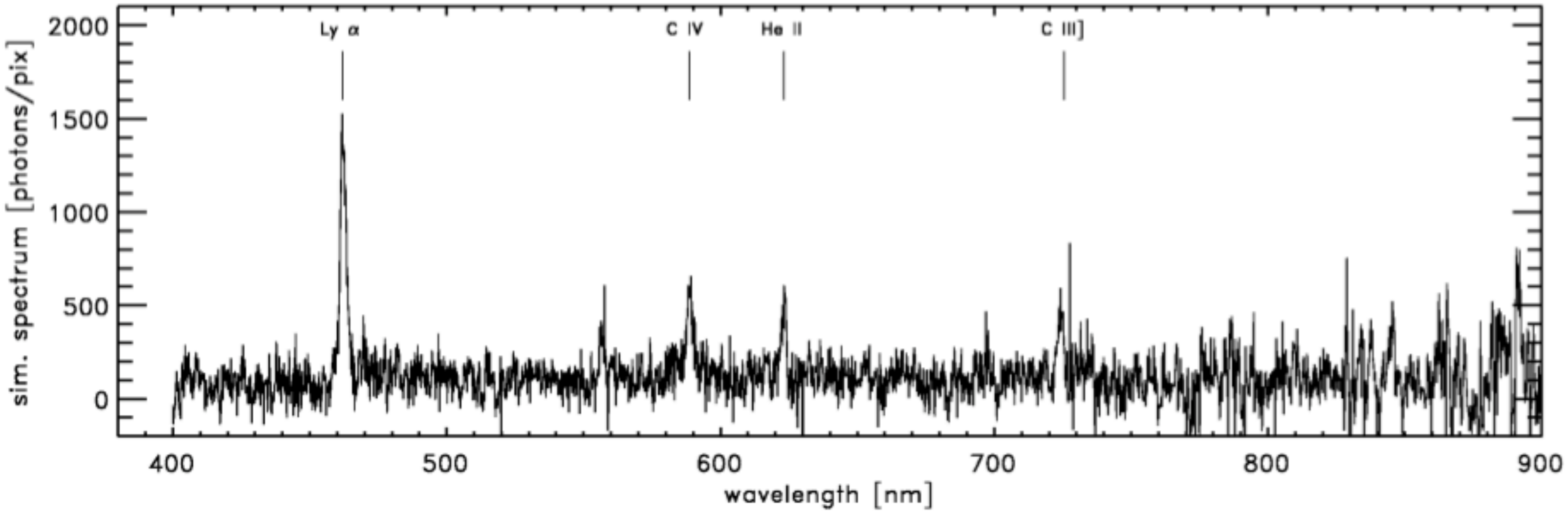


Figure 12: Simulation of an obscured QSO spectrum using a preliminary 4MOST exposure time calculator. The input spectrum is based on an observed low-resolution spectrum of an X-ray selected obscured QSO at $z = 2.8$ with magnitude $m_{\mathrm{R}} = 23.2$ and line flux $f_{\mathrm{HeII}} = 1.5 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$. The simulation includes photon and read-out noise based on a 4MOST exposure of 2 hours under realistic Paranal sky conditions.

Courtesy G. Lamer

# ESO decision spring 2013