Full-sky surveys with WEAVE and 4MOST in the Gaia era

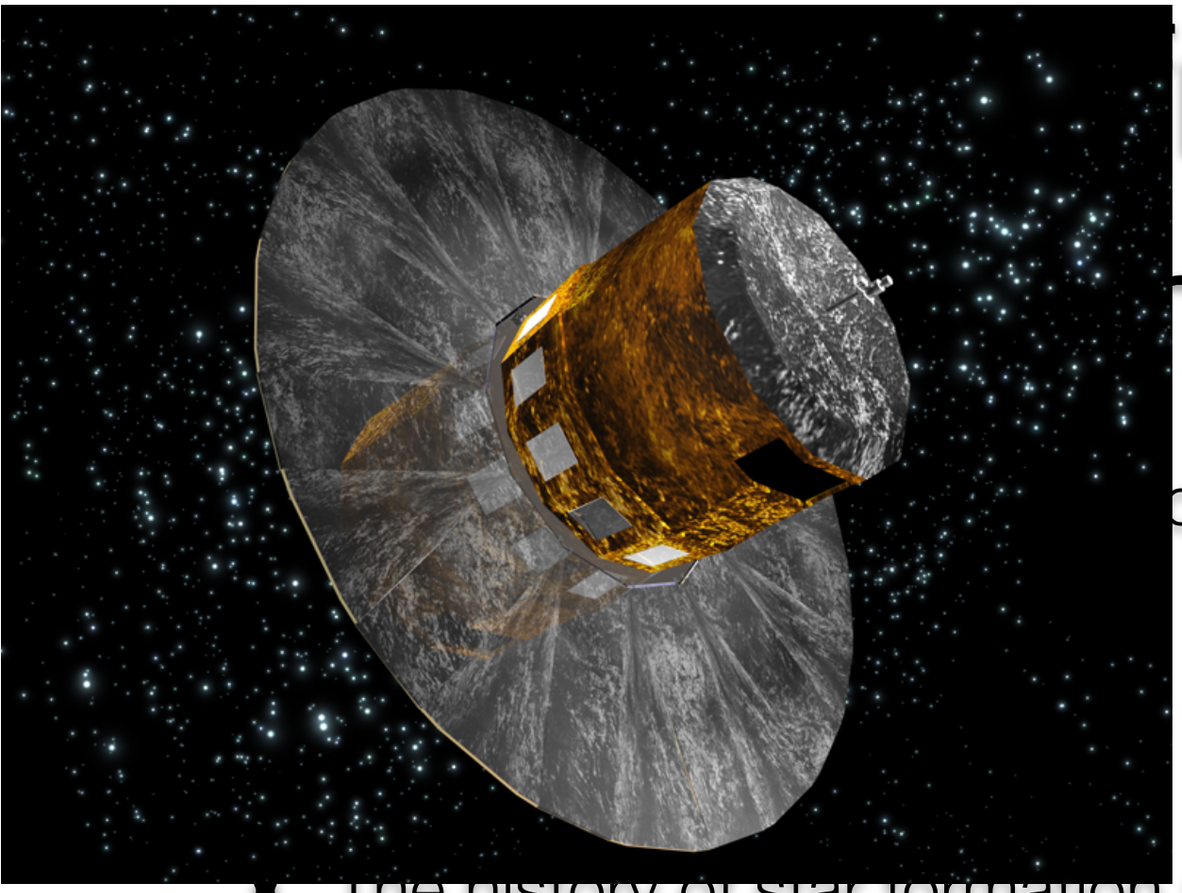
S.C. Trager (WEAVE PS + NL PI)

with thanks to the WEAVE+4MOST science teams

university of groningen / faculty of mathematics and natural sciences / astronomy

New survey frontiers from new survey instruments

- Gaia: Astrometry at microarcsecond precision
  - The history of the Milky Way
- SKA Pathfinders:
  - The history of star formation and AGN in the Universe
  - HI at cosmological distances
  - Precision cosmology
- eROSITA
  - This history of X-ray-selected AGN and clusters in Universe
  - Precision cosmology



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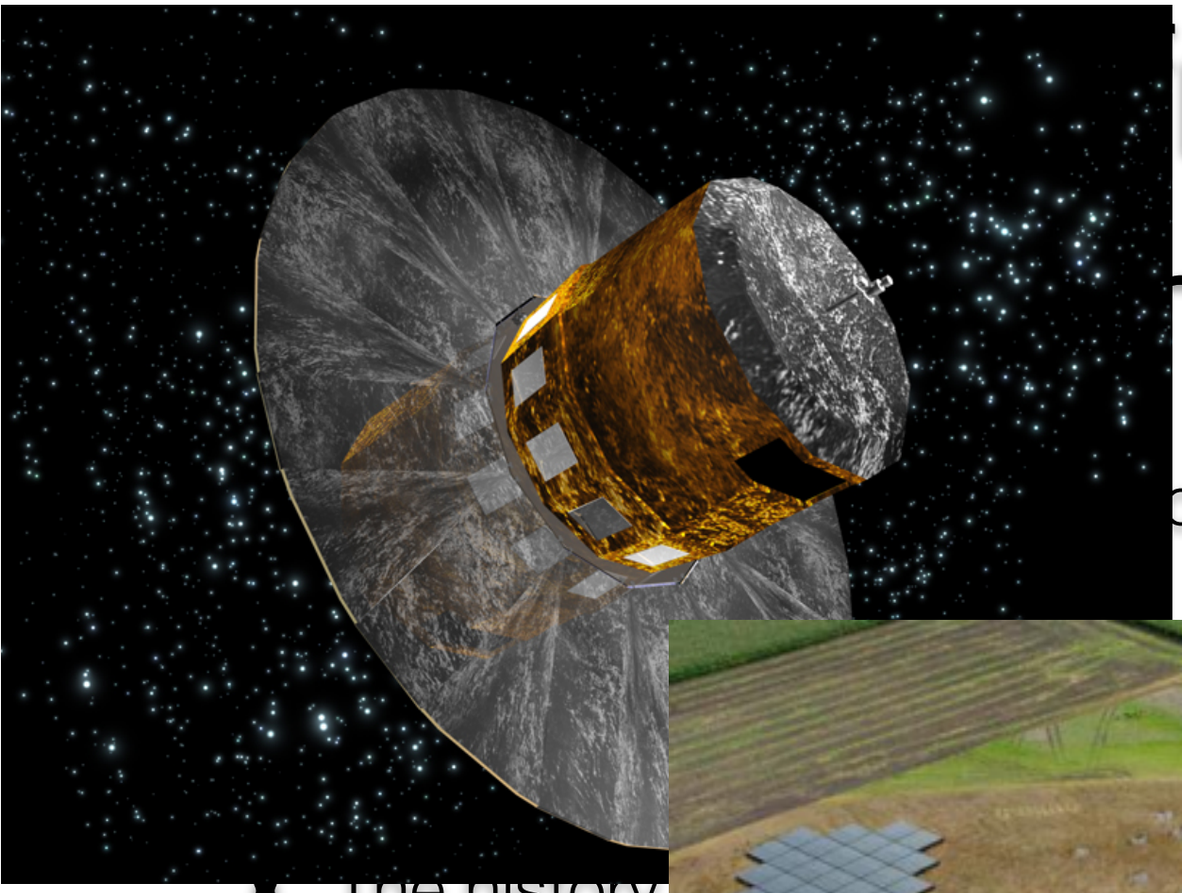

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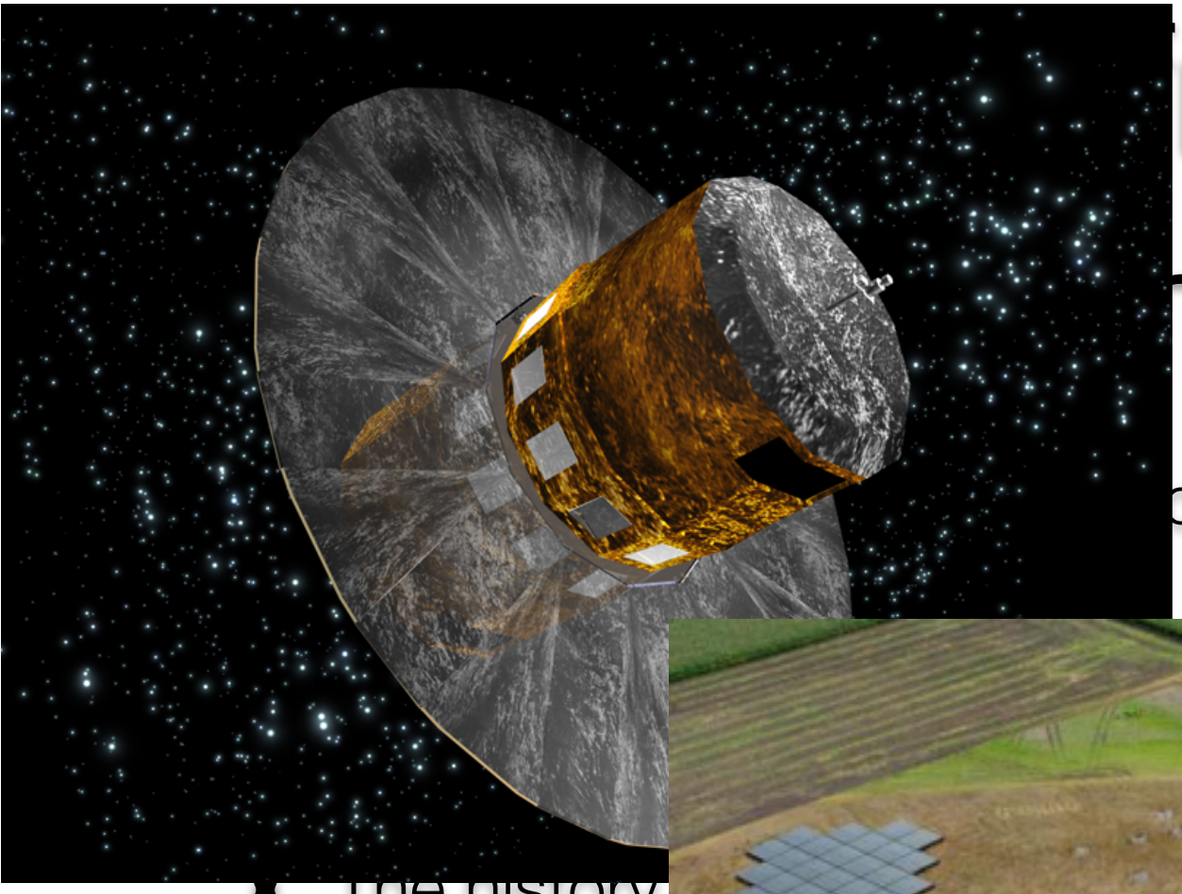

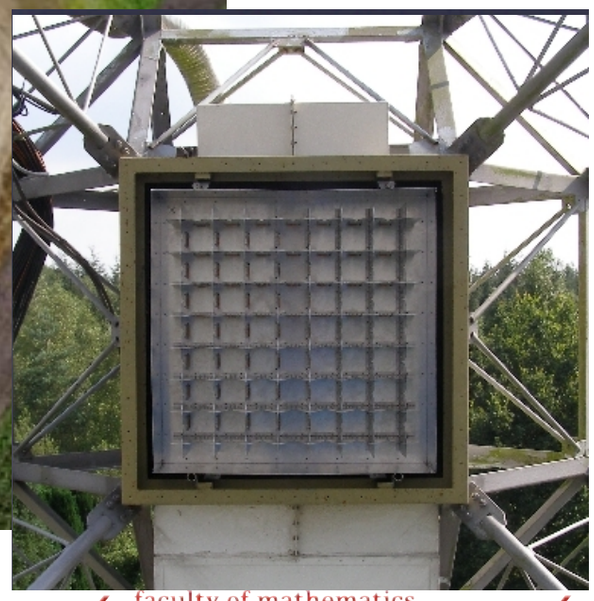

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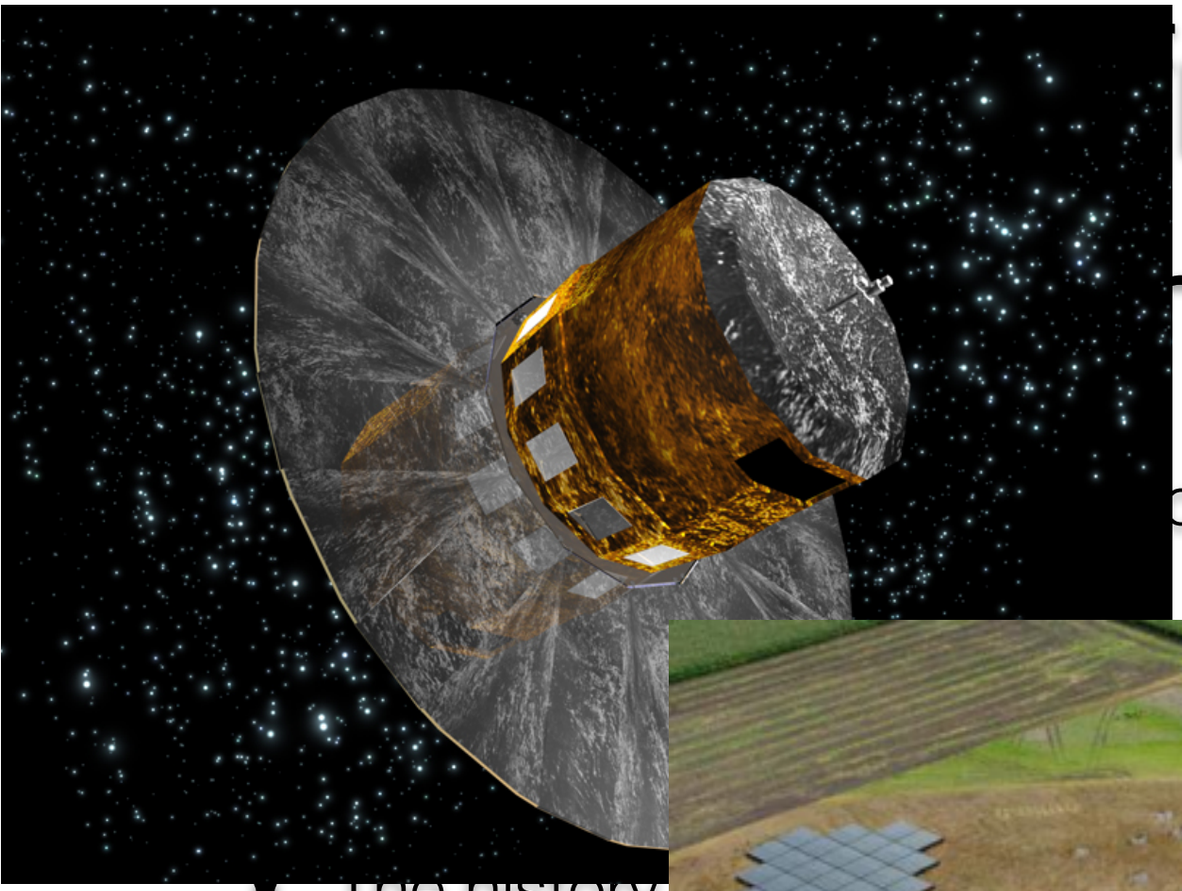

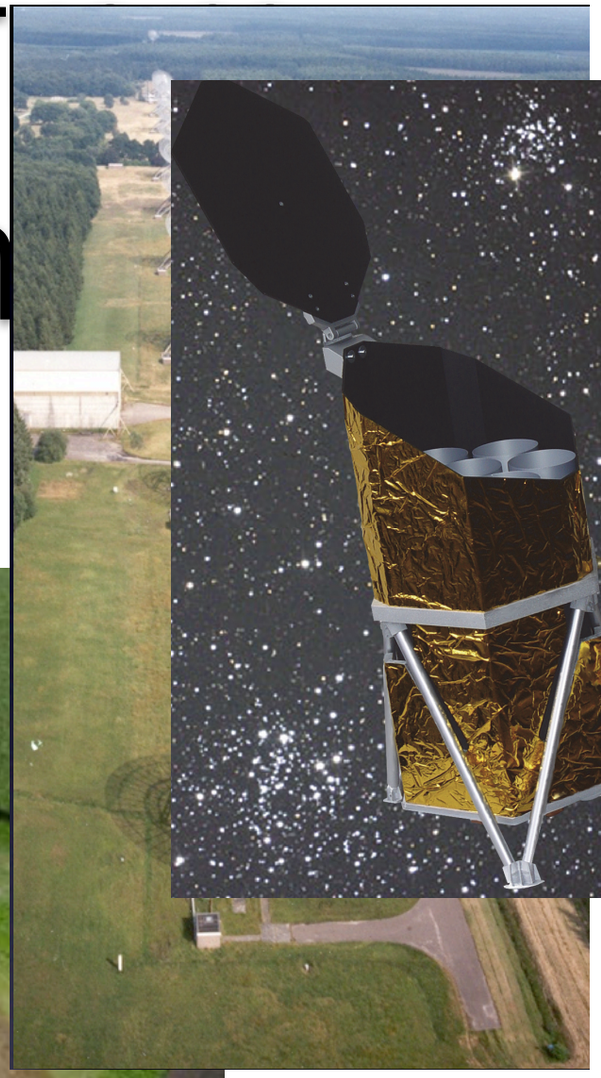

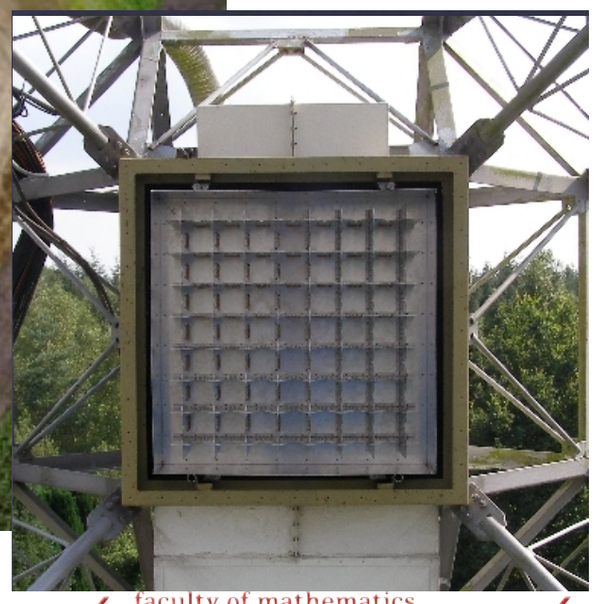

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New survey frontiers from new survey instruments

- All of these are, by themselves, incomplete!
  - Gaia: no radial velocities at V>17 mag (only 15% of stars), no abundances at V>12 mag (only 0.1% of stars)
  - LOFAR + ASKAP+MeerKAT continuum surveys: just continuum, no redshifts
  - Apertif + ASKAP+MeerKAT HI surveys: just neutral gas kinematics, limited (SDSS) or no stellar info
  - eROSITA: just X-ray fluxes

Galactic archaeology surveys: exploiting Gaia's scientific return

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Galactic archaeology: *How did our Galaxy form?*

- The Galactic halo:
  - how was it formed? accreted or in-situ?
  - what is the total mass of the Milky Way?
  - what is the shape of the Milky Way's gravitational potential?
  - how much substructure does the halo have?
  - where are the most metal-poor stars in the Milky Way, and what are their properties?

Galactic archaeology: *How did our Galaxy form?*

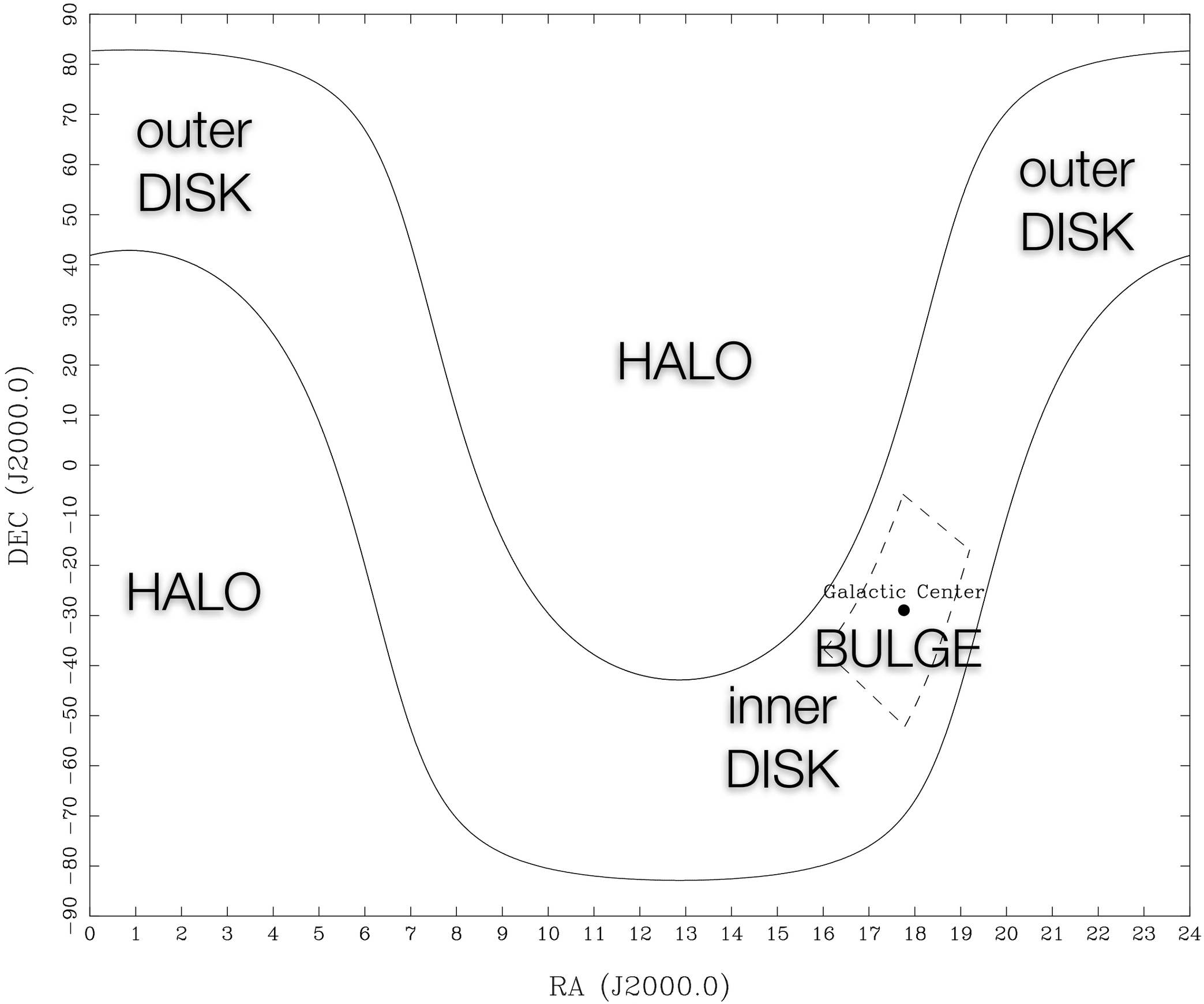
- The Galactic disk(s):
  - how many disks are there really? what are their relationships with the bulge, the halo, and each other?
  - did they form through accretion or secular processes – is radial migration important?
  - what is the metallicity gradient in the disk(s)?

Galactic archaeology: *How did our Galaxy form?*

- The Galactic bulge and bar:
  - when and how did the bulge form?
  - how is the bar related to the disk(s) and the bulge?

The need for full-sky Galactic surveys

- No single instrument on the ground can survey **all** of the Galactic populations
  - The Galaxy is *asymmetric* when seen from the ground
- Southern Hemisphere facilities — like 4MOST — are excellently positioned to get the Galactic bulge, bar, and inner disk, as well as some of the Galactic halo
- Northern Hemisphere facilities — like WEAVE — get the outer disk and (more of) the halo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outer
DISK
HALO
HALO
Galactic Center
BULGE
inner
DISK
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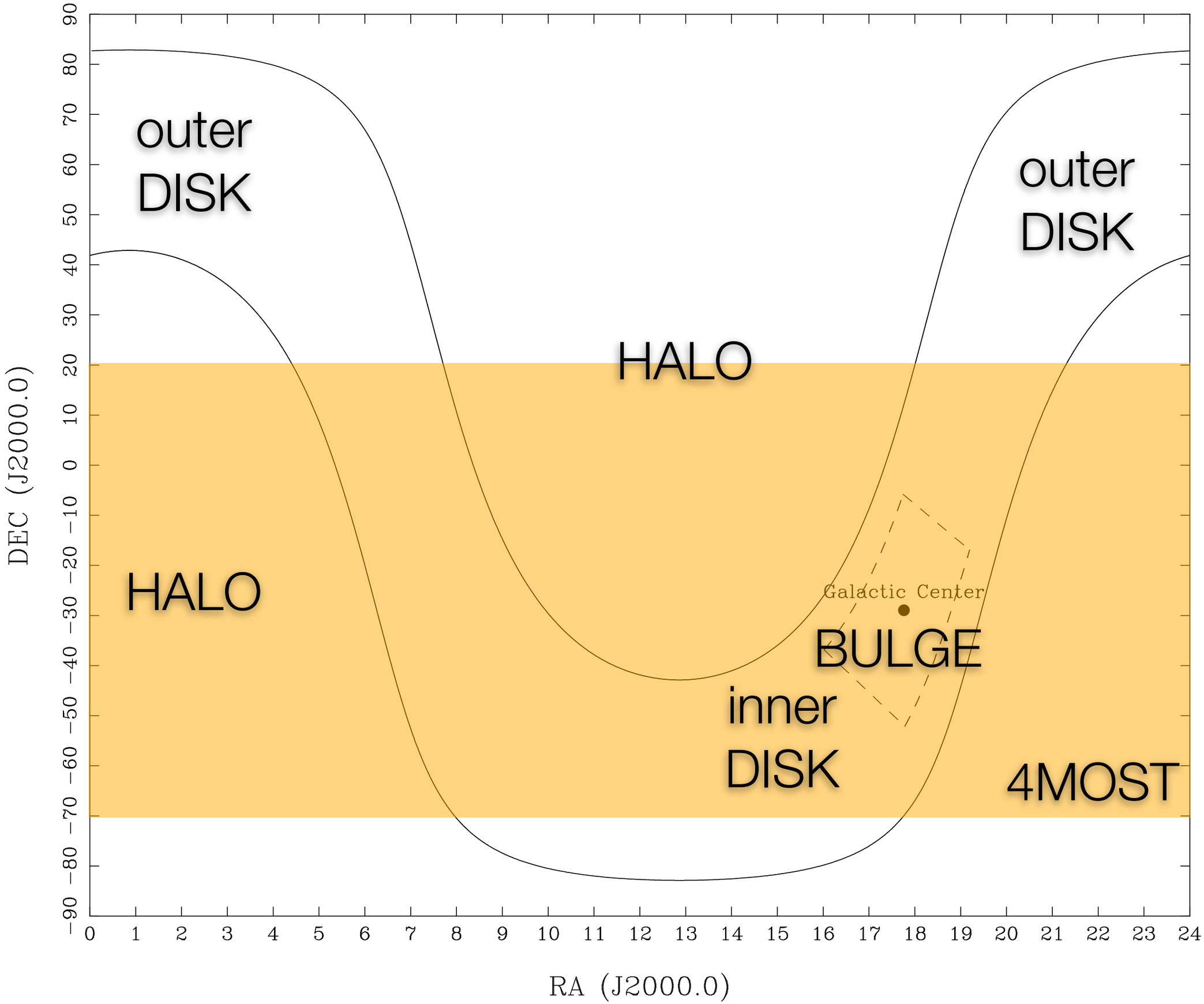

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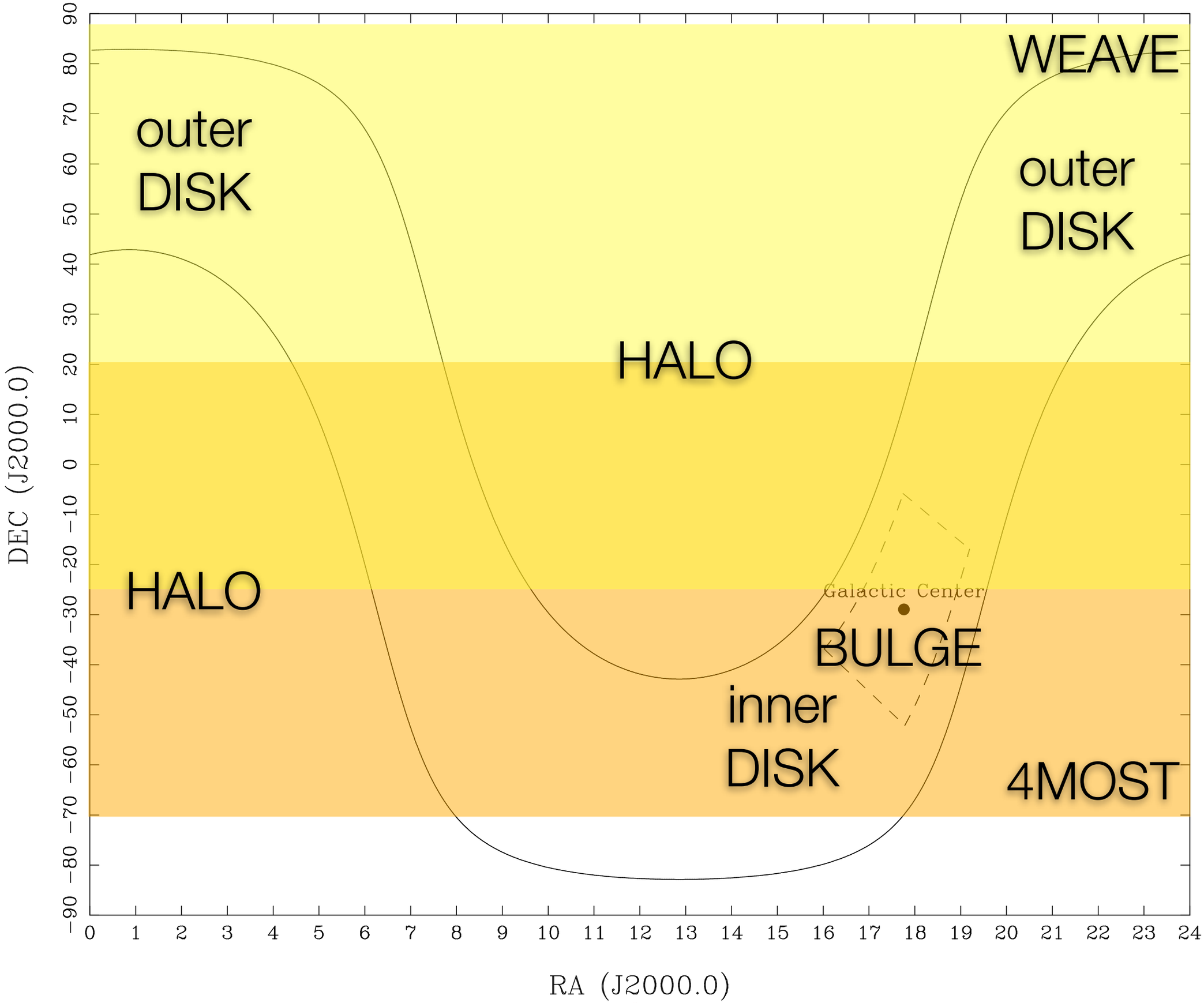

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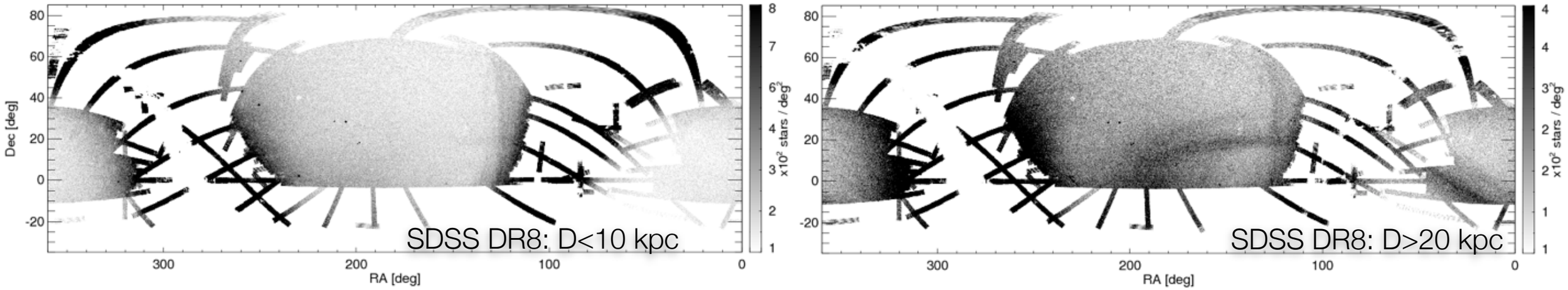
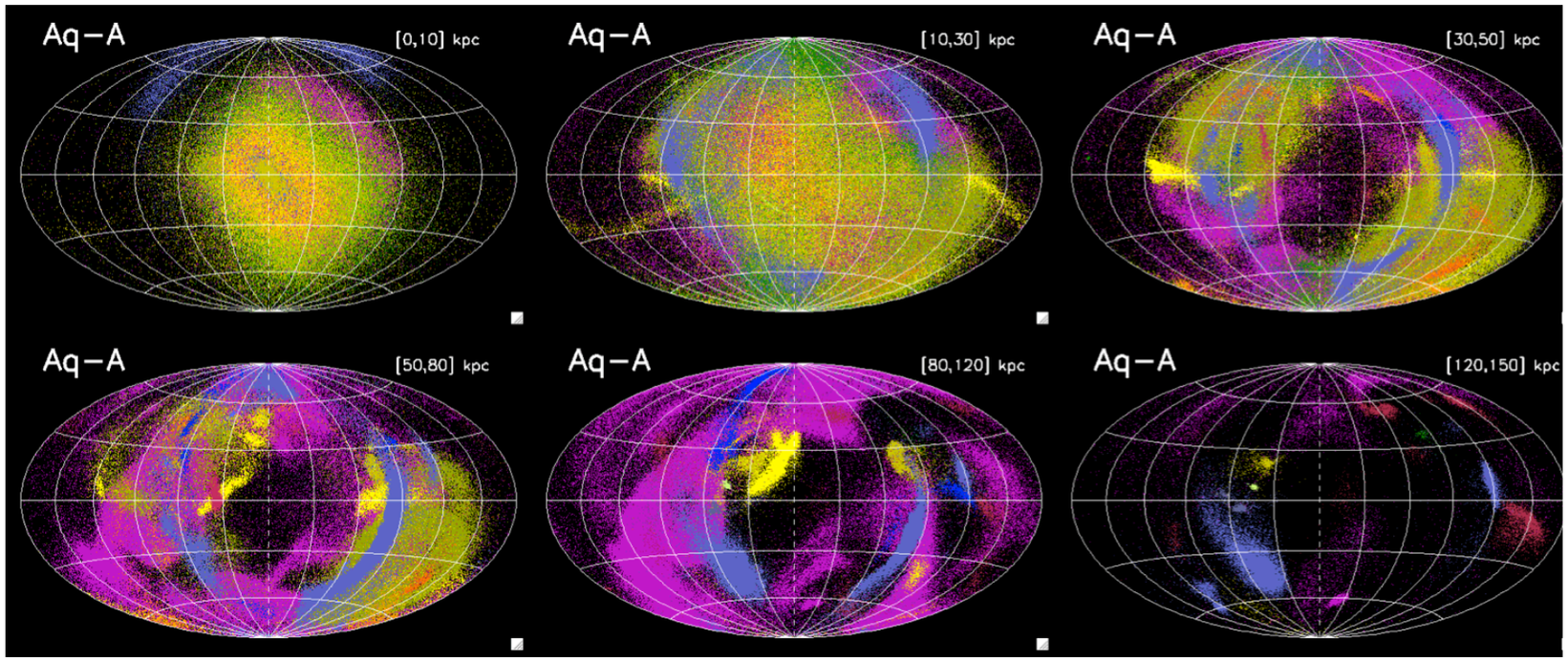
The Galactic halo



- The halo records the **formation history** of the MW
  - at large distances, mixing timescales are long: ancient substructure *readily discernible* with all-sky surveys
    - outer halo (>20 kpc): streams detected as overdensities
    - inner halo (10-20 kpc): need chemodynamics

The Galactic halo



- The halo is **intrinsically asymmetric** due to its formation process
  - need to observe **both** (equatorial) hemispheres to get full picture of halo formation!

The Galactic disks

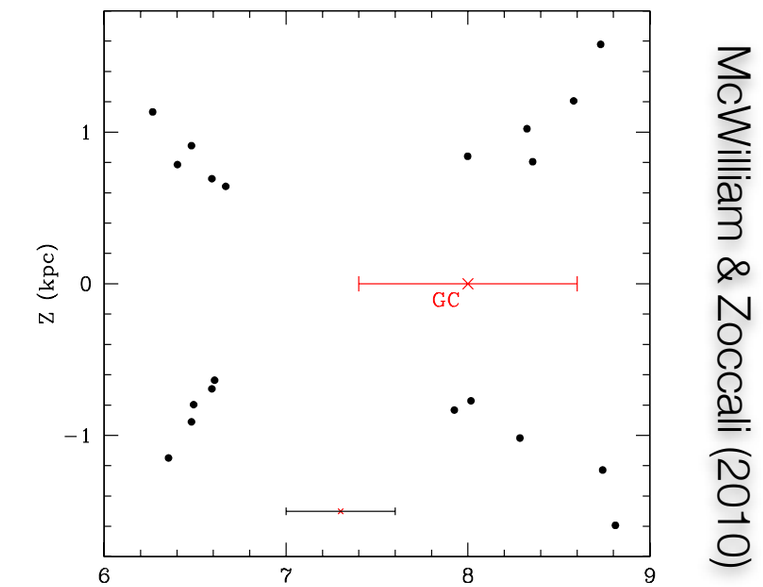
- Disk formation and evolution appears to be a complex interplay of multiple processes, such as
  - smooth baryon accretion
  - secular evolution of clumpy, turbulent gas disks
  - sporadic satellite accretion
  - spiral-driven radial stellar migration
  - bar-halo and bar-spiral angular momentum coupling

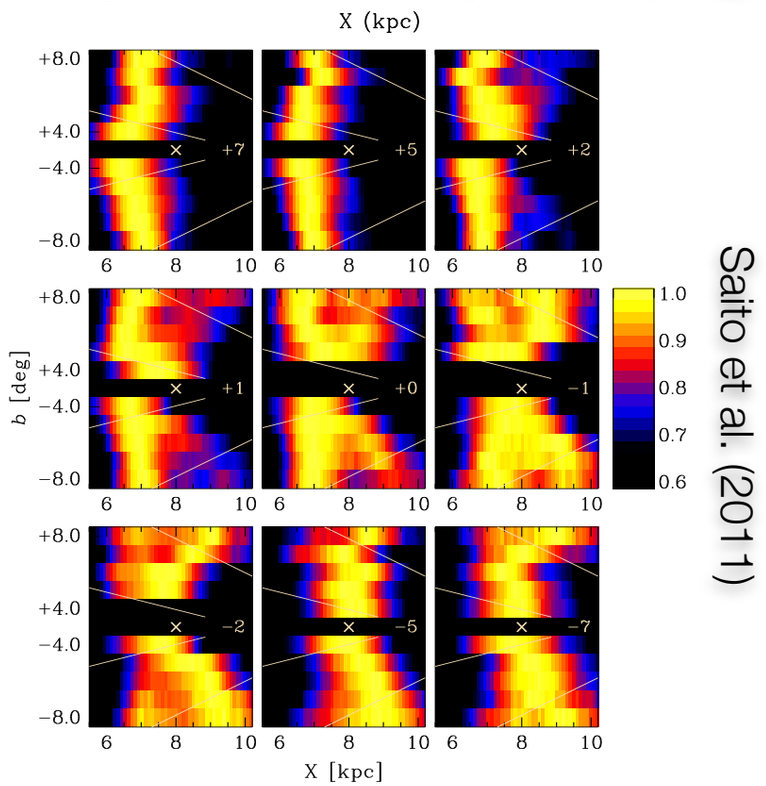
The Galactic disks

- The Galactic disks are not (severely) asymmetric, *but* the formation processes likely **vary with radius**
  - The *inner disk* — best seen from the South — is likely dominated by *in-situ* star formation and secular processes
  - The *outer disk* — best seen from the North — is likely a combination of *accreted* populations on top of *in-situ* star formation, with secular processes playing a complicated role
    - for example, may be easier to trace *radial migration* in outer disk (Roskar et al. 2008, 2010)

The Galactic bulge and bar

- The bulge *may* be symmetric, but it appears that the bar is complex, with a distinct *X*-shape
- How does this come about? What are the populations of these components – their compositions and kinematics? How did they form?
- As already discussed, this is best tackled from the South





Chemical labeling vs kinematics in the Milky Way

- Of course, all of these questions should be answered using all of the tools at our disposal
  - Dynamics inferred from kinematics: phase-space information at the ~2 km s^{-1} level
  - Chemical composition of the populations: abundances at the [X/H]~±0.1 dex level

Chemical labeling vs kinematics in the Milky Way

- Dynamics inferred from kinematics: phase-space information at the ~2 km s^{-1} level
  - R≥5000 + Gaia parallaxes and proper motions
    - V>17: need 4MOST and WEAVE
- Chemical compositions: abundances at the [X/H]~±0.1 dex level
  - R≥20000
    - V>12: need 4MOST and WEAVE (and HERMES at bright end)

Galactic archaeology survey strategy: WEAVE

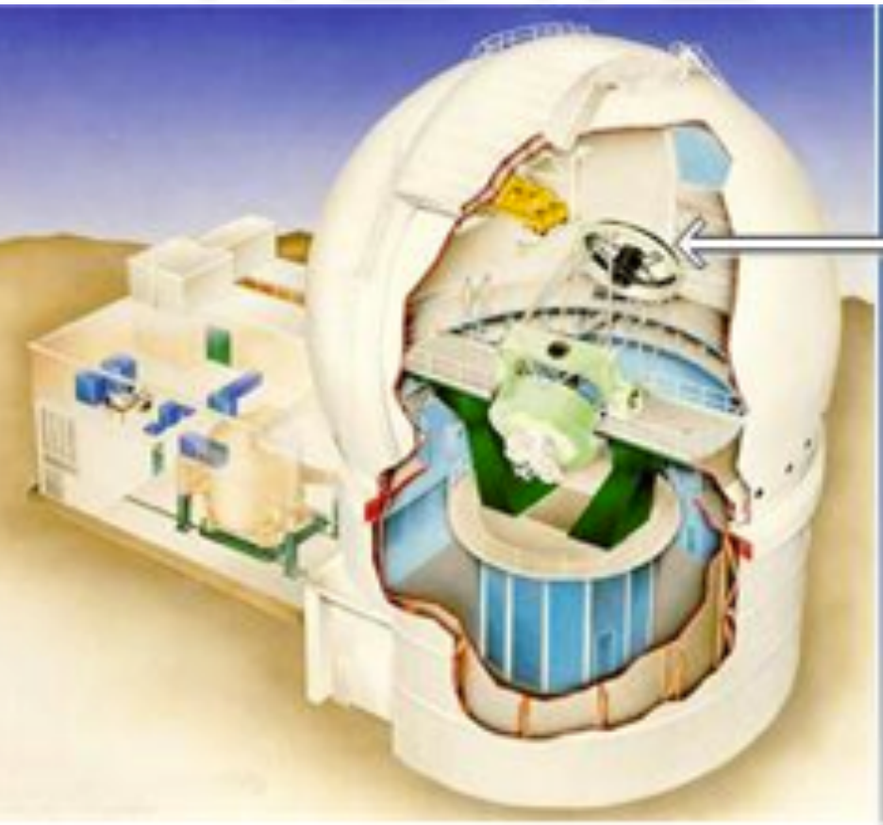
	log(N)	Area (deg^2)	R	Depth
Halo	6	6500	5000	V≤20
Disks	6.7	2000	5000	V≤20
Chemical labeling	4.7 (halo) 5.7 (disk)	2500 2000	20000	V≤17
Open clusters	4.7	150	20000	V≤17

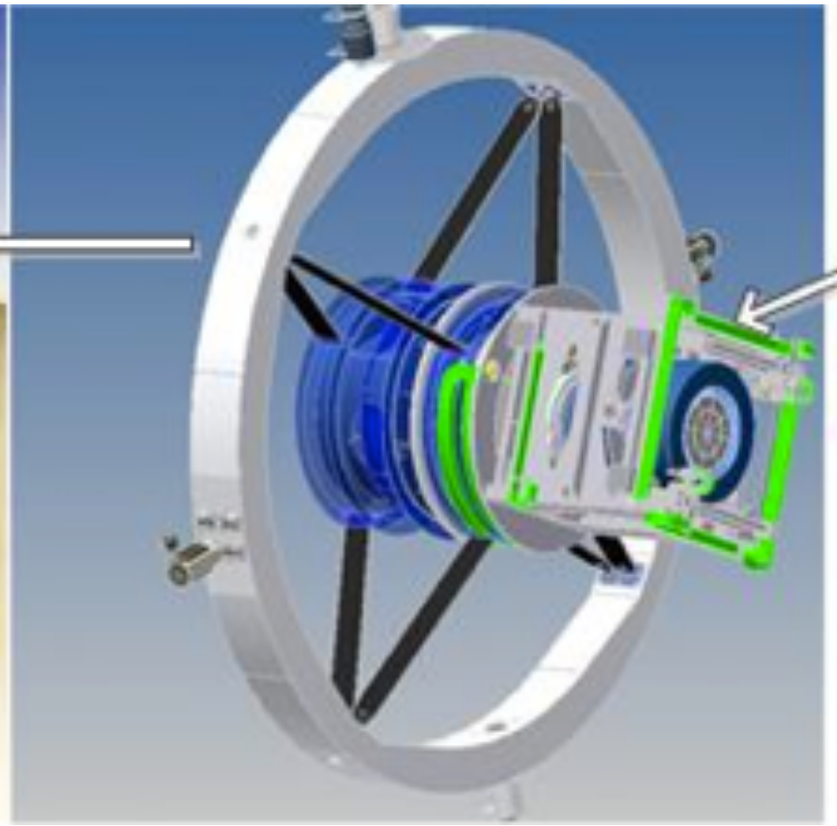
Total survey time: 4 years
@ 7 hours/night

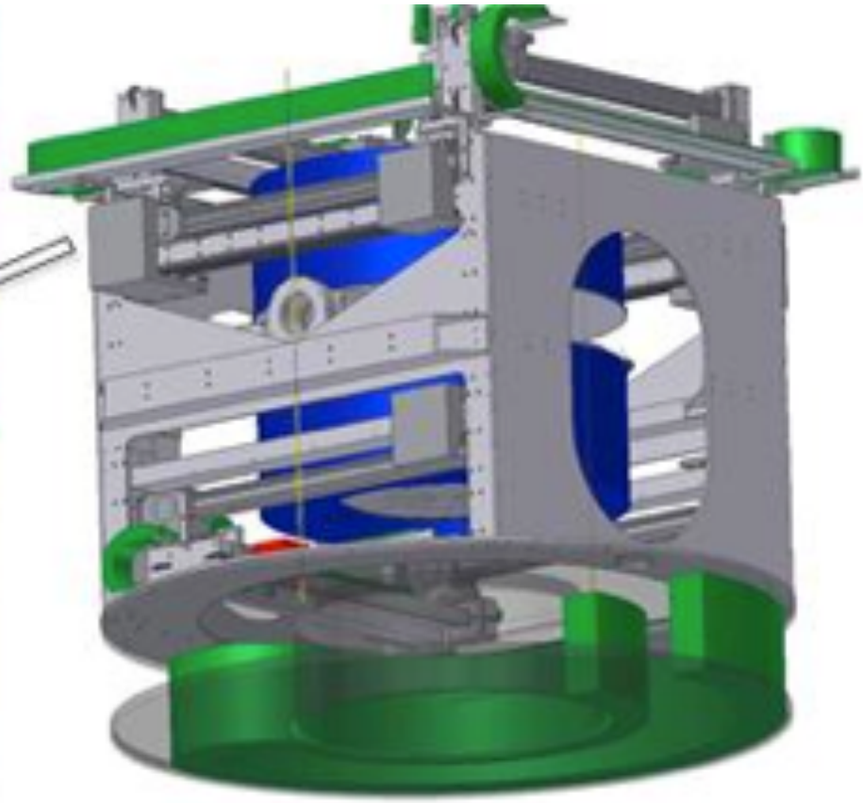
WEAVE's additional Galactic Archaeology science cases

- Hunting the rarest stellar phases
- Dating Galactic populations with white dwarfs
- Pulsating variable stars
- Massive (blue) stars in the MW and Local Group
- IMF of low-mass stars and sub-stellar objects
- Chemodynamics of MW dwarf satellites
- Ultra-faint dwarfs

WEAVE







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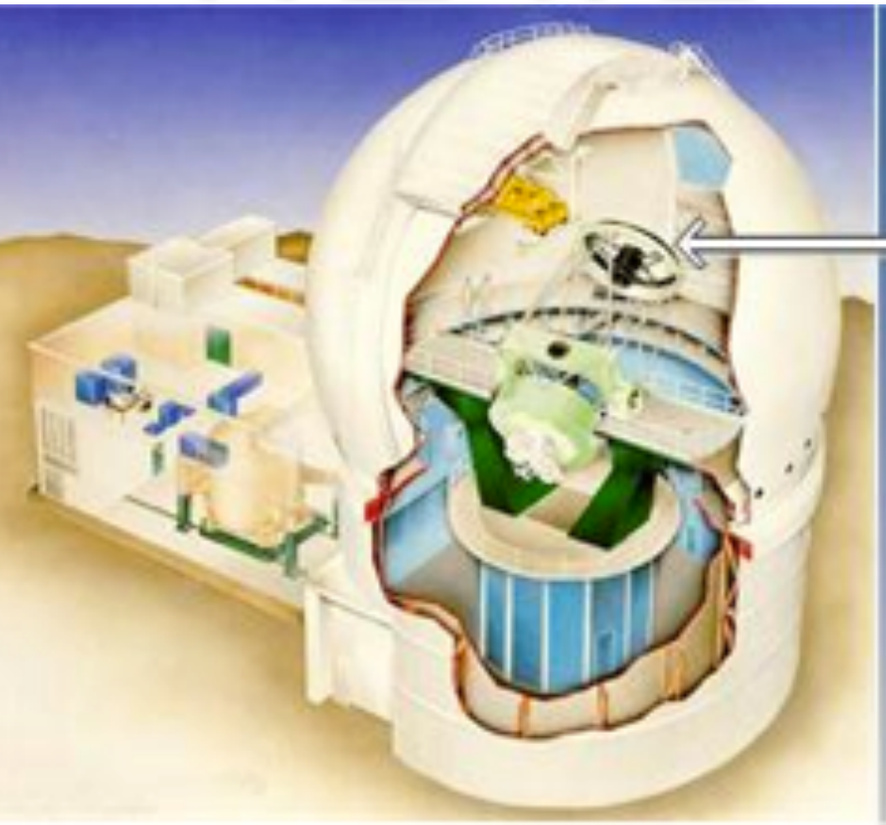

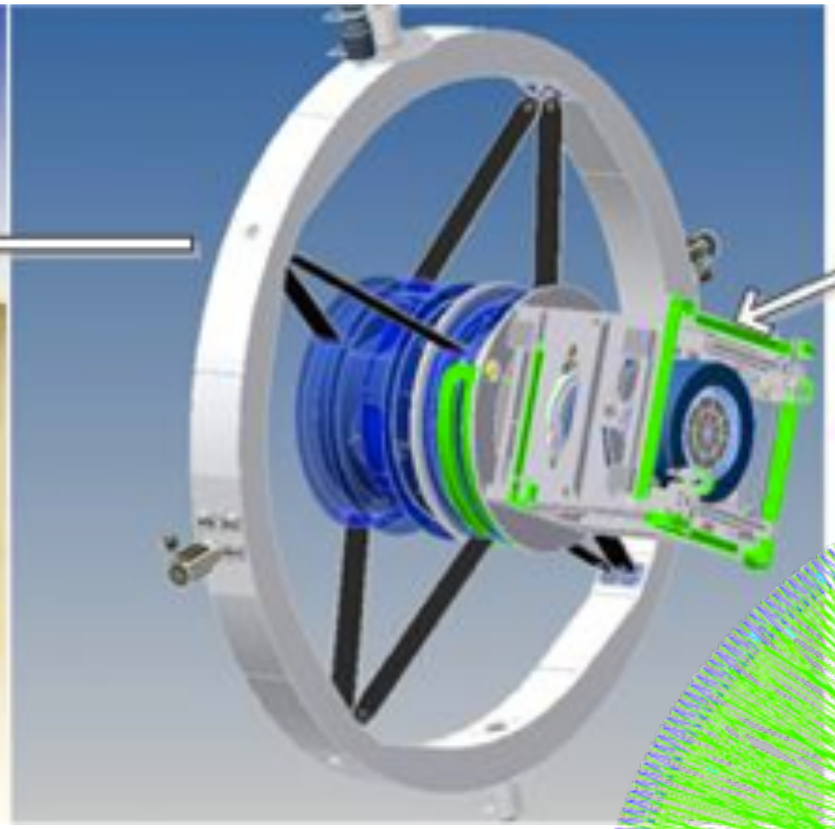

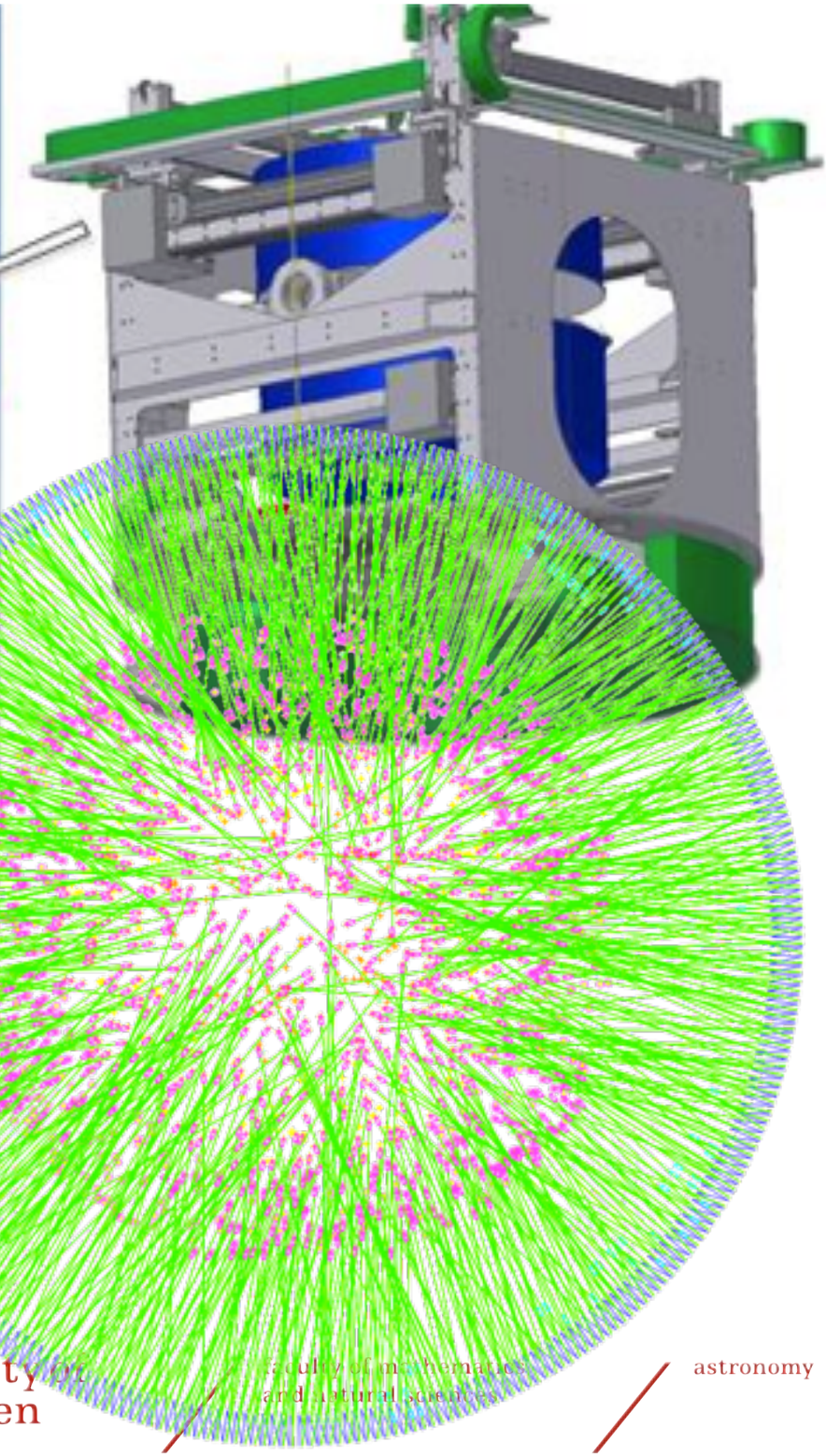

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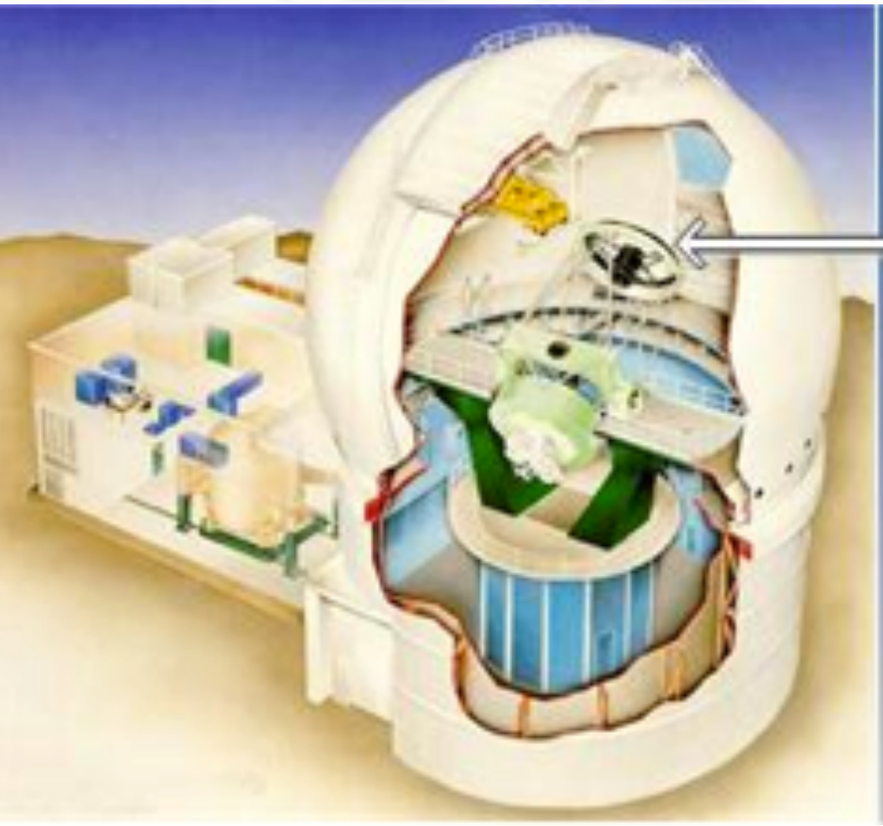

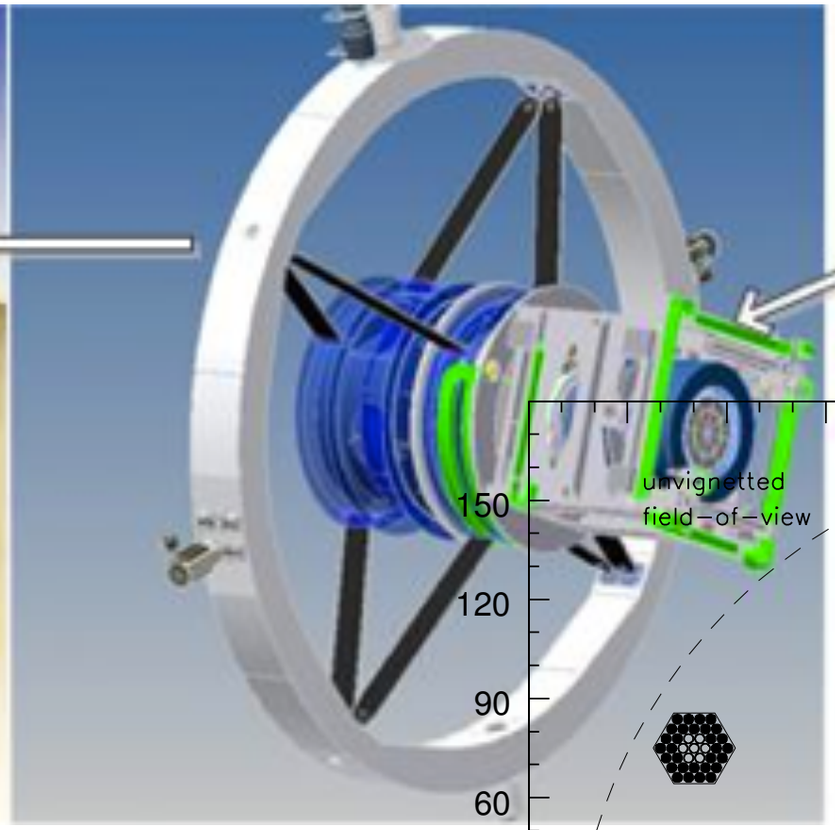

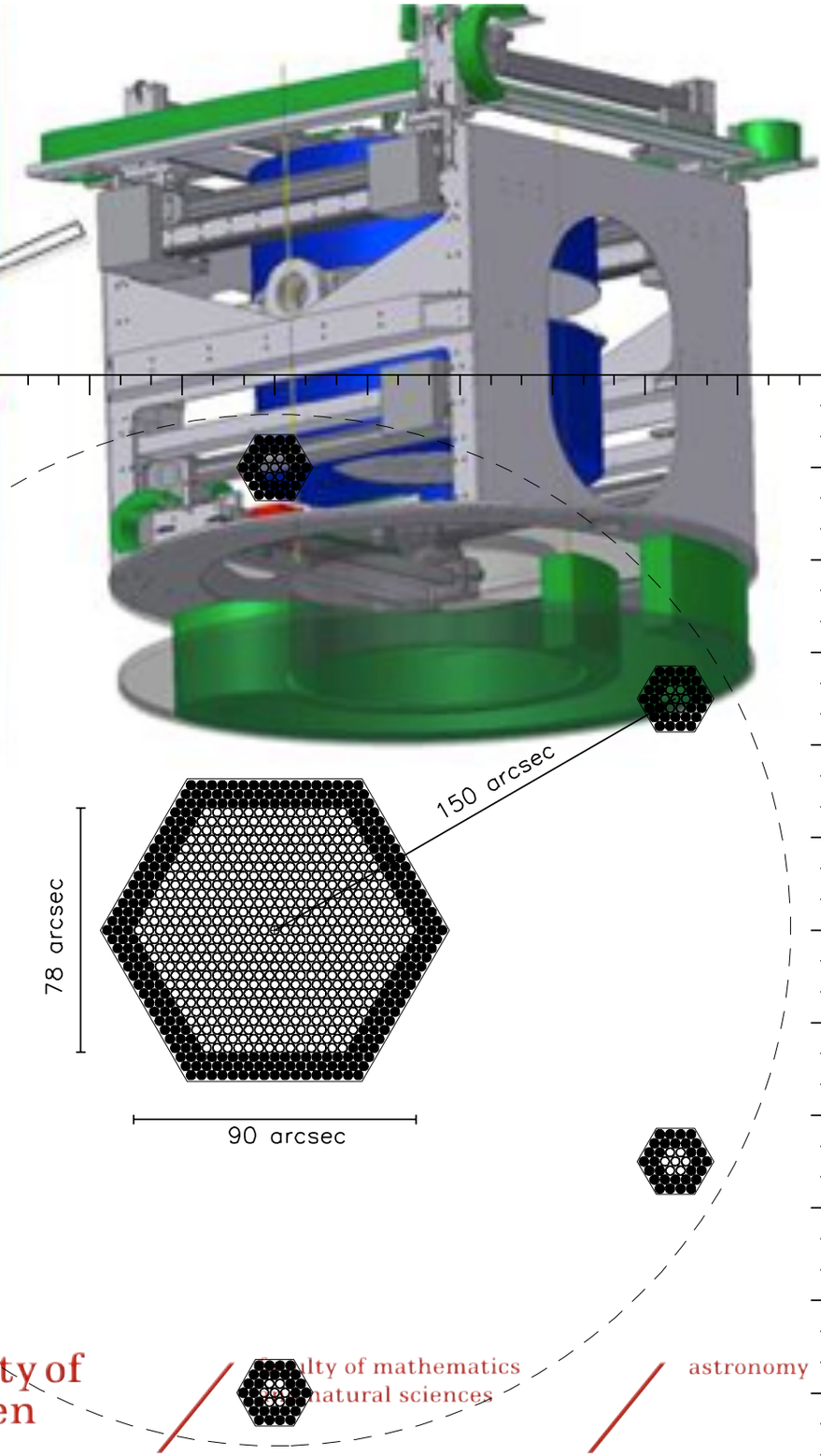

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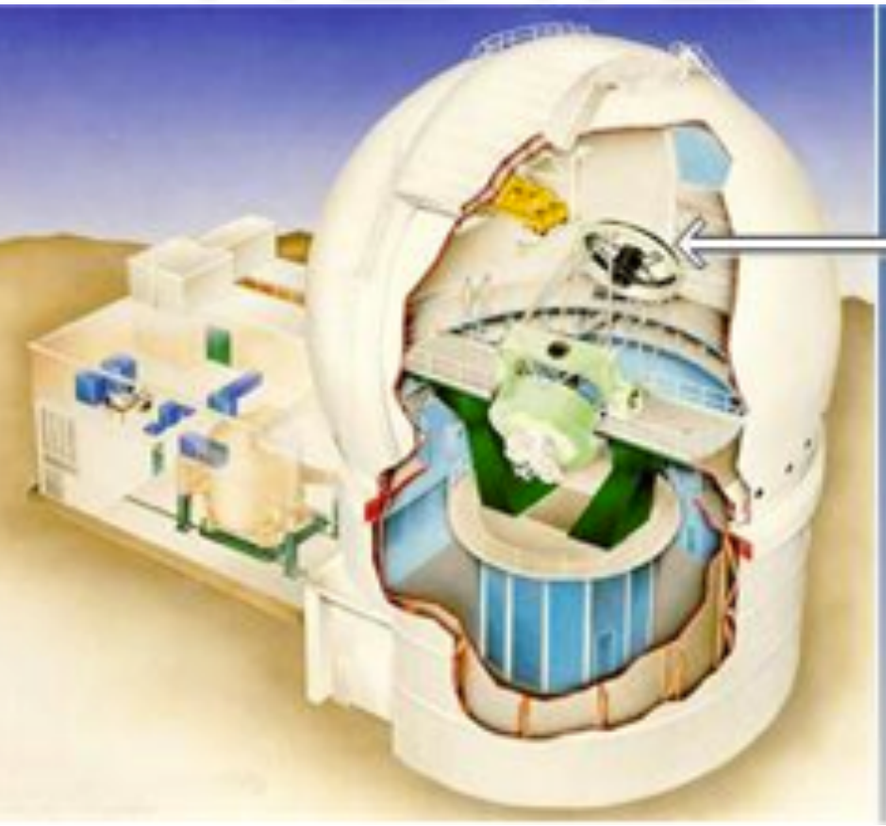

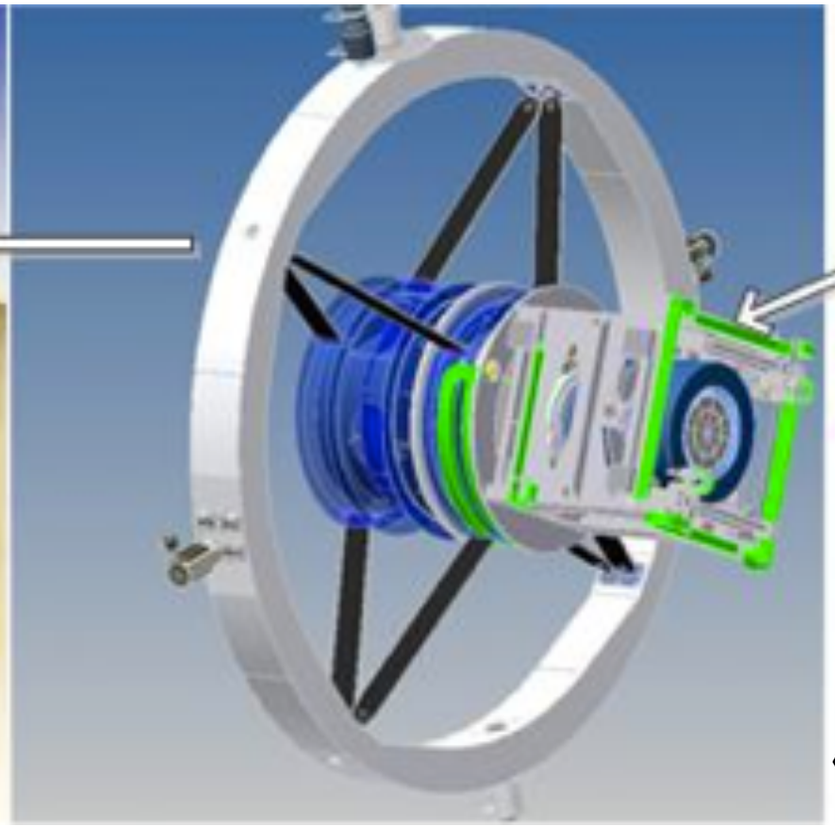

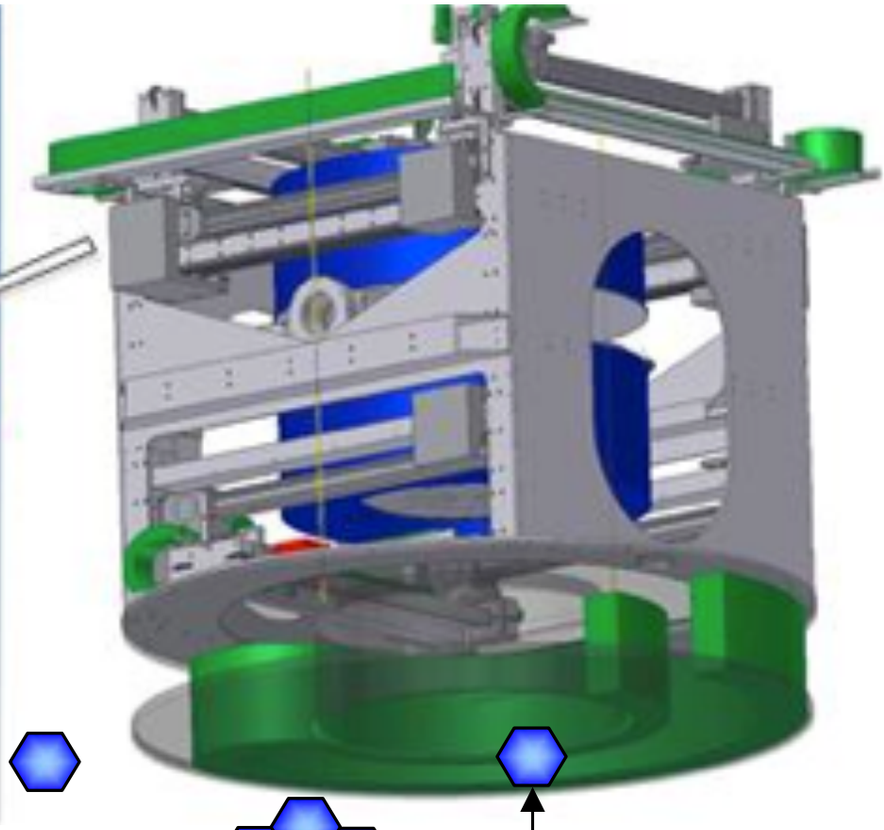

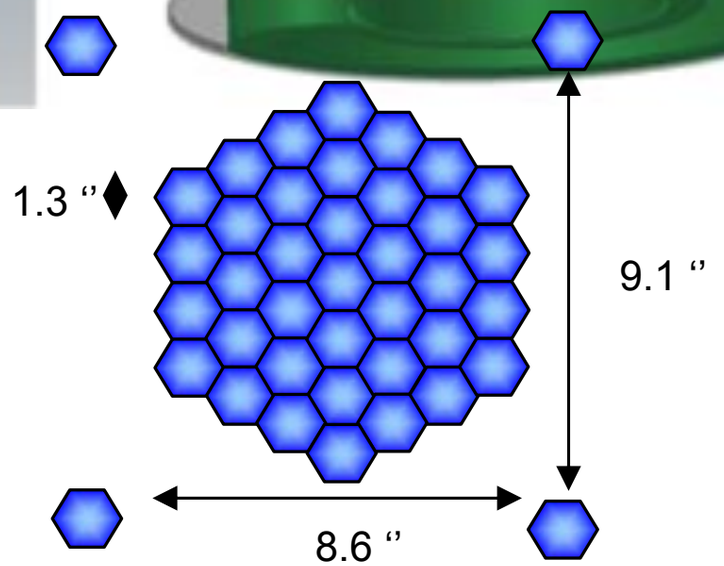

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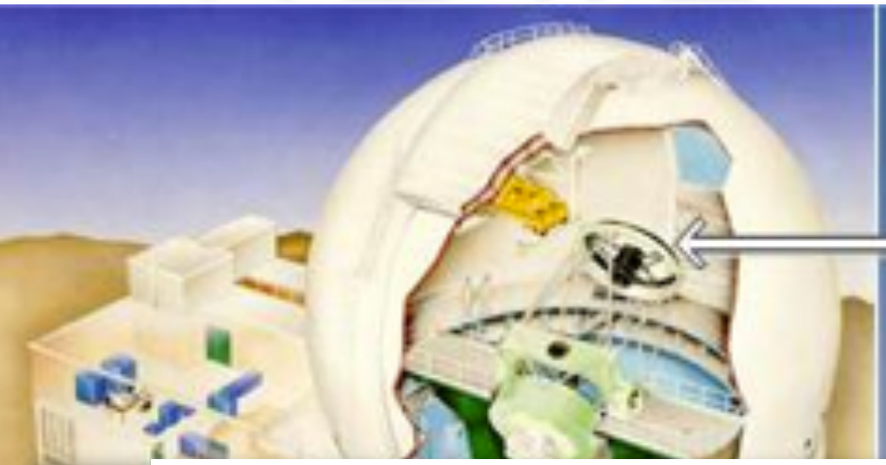
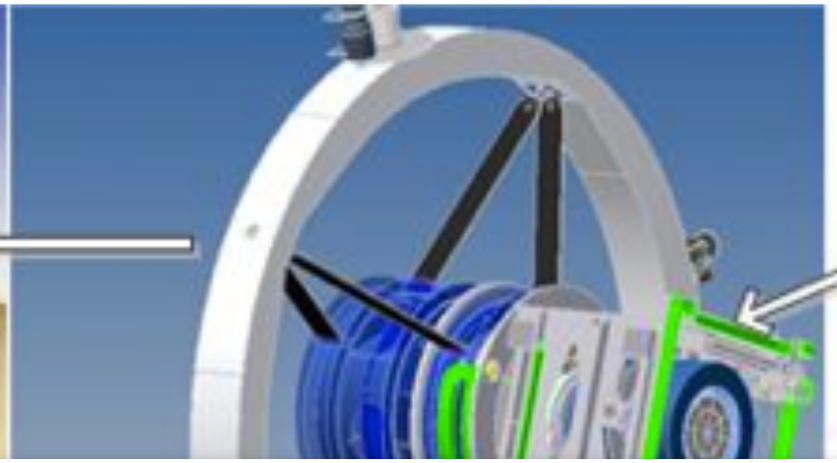
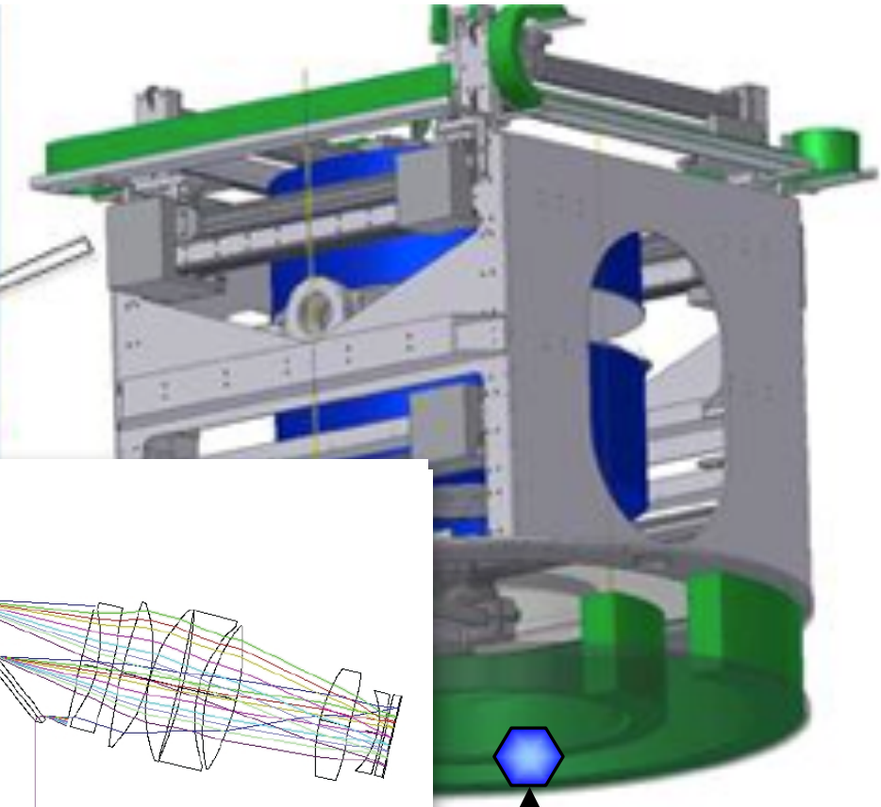
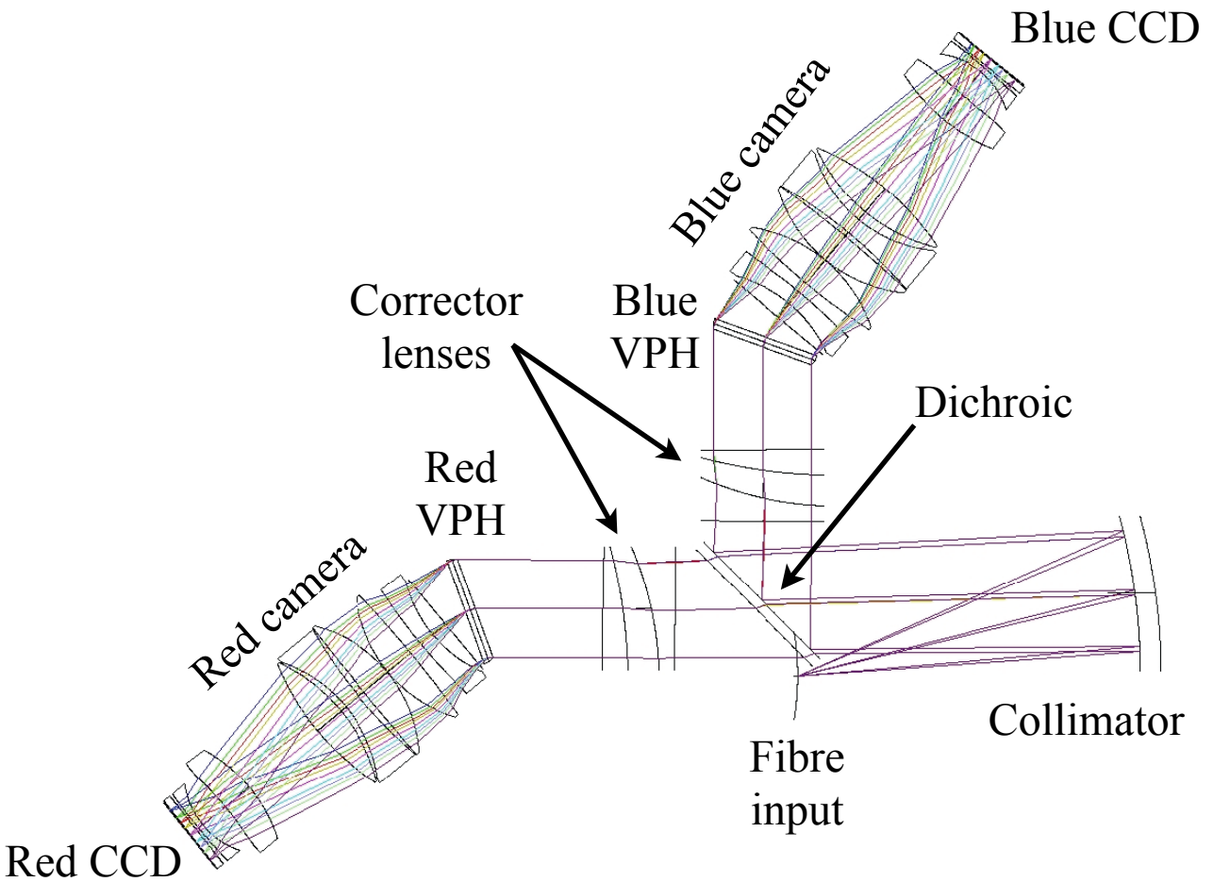
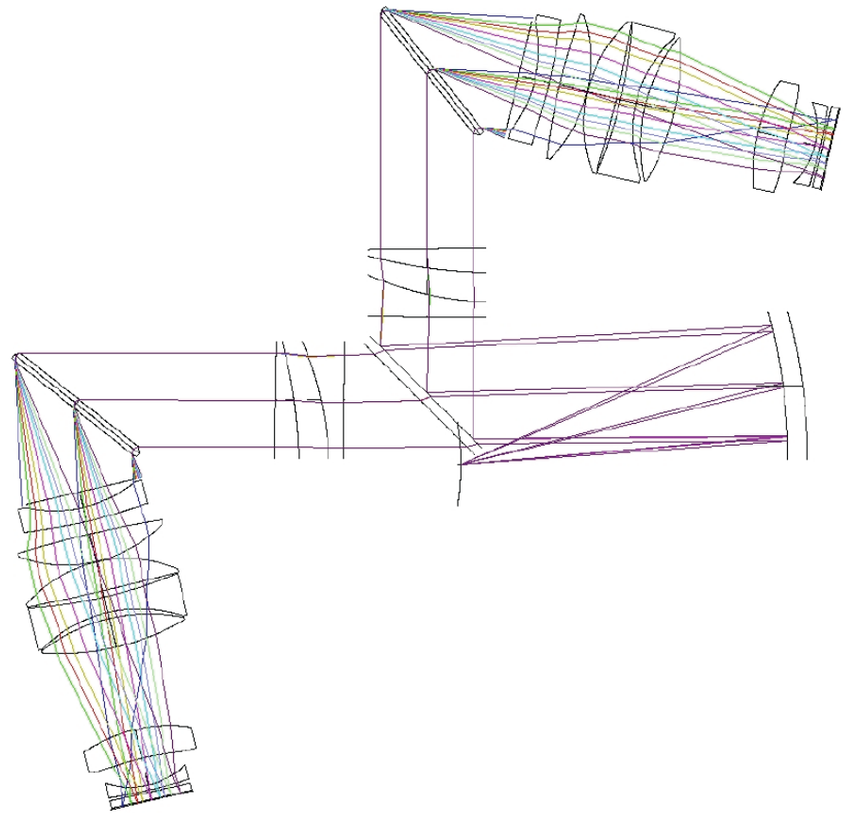




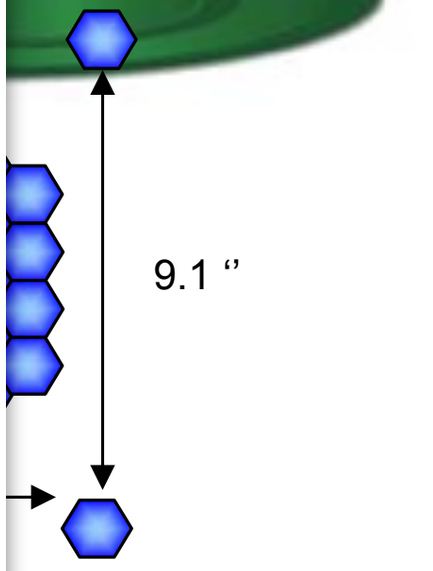




Low-resolution mode



High-resolution mode



WEAVE characteristics

Telescope, diameter	WHT, 4.2m
Field of view	2º
Number of fibers	1000
Fiber size	1.3”
Number of small IFUs, size	~25, 9”x12” (1.3” spaxels)
LIFU size	~2‘x1.5’ (2.6” spaxels)
Low-resolution mode resolution	4300–7200
Low-resolution mode wavelength coverage (Å)	3660–9840
High-resolution mode resolution	18560–21375
High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

WEAVE throughput

WEAVE organization

- PI: Gavin Dalton (Oxford/RAL)
- Deputy PI: Dave Carter (LJMU)
- Project Scientist & Dutch PI: SCT (Kapteyn)
- French PI: Piercarlo Bonifacio
- Spain PI: J. Alfonso Aguirre Lopez
- Project Manager: DC Abrams (ING)
- Systems Engineer: Mike McIntosh (UKATC)
- Instrument Scientist: Chris Evans (UKATC)
- Contributions from RAL, UKATC, LJMU, NOVA, GEPI, ING, Cambridge
- Financial contributions (expected) from UK, NL, E, F

WEAVE status

- Full WEAVE PDR in 2013 Q1 (March)
  - Prime focus corrector optics PDR successful on 4 November 2012
- Funding in progress
  - Positive funding outlook in NL, UK, E (+ ING and in-kind contributions from F)
    - NL: secured M€2, M€1,4 requested and under review

Conclusions

- A **complete** understanding of our own Galaxy *requires* full-sky coverage of its kinematics and chemical composition

- The **requires** moderate resolution wide-field spectroscopic facilities in **both hemispheres**

Conclusions

- **4MOST** on ESO's VISTA telescope in the South and **WEAVE** on the WHT in the North are *ideal* for such full-sky surveys
- Complementary surveys on *nearly identical* instrumentation
  - multiplex and field size only significant differences!

Other survey complementarities

- SKA pathfinder follow-up surveys
  - HI-driven galaxy evolution surveys
    - stellar and ionized gas content at cosmological distances
  - Continuum surveys
    - AGN and SF evolution
    - Finding the *rarest* objects: e.g., *z*~6–7 AGN and radio-selected galaxy clusters

Other survey complementarities

- Full-sky eROSITA follow-up
  - Finding the *rarest* objects: high-*z* AGN and the richest clusters at *z*<1
- Full-sky cosmology surveys