# Ground-Based Multi-Object Spectroscopic Facilities

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# Ground-Based Multi-Object Spectroscopy has a long tradition

- Multi-object spectroscopy has been a cornerstone of observational astronomy for over 100 years

Annie Jump Cannon ca. 1930

- Others have used slitless spectroscopy, primarily surveys using Schmidt telescopes with objective prism

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# The modern era: SDSS

- SDSS set the stage for modern massive spectroscopy


- Subsequent generations of SDSS science and instrumentation have expanded on the original
- SDSS-V will add robotic fiber positioners to APOGEE infrared spectrographs

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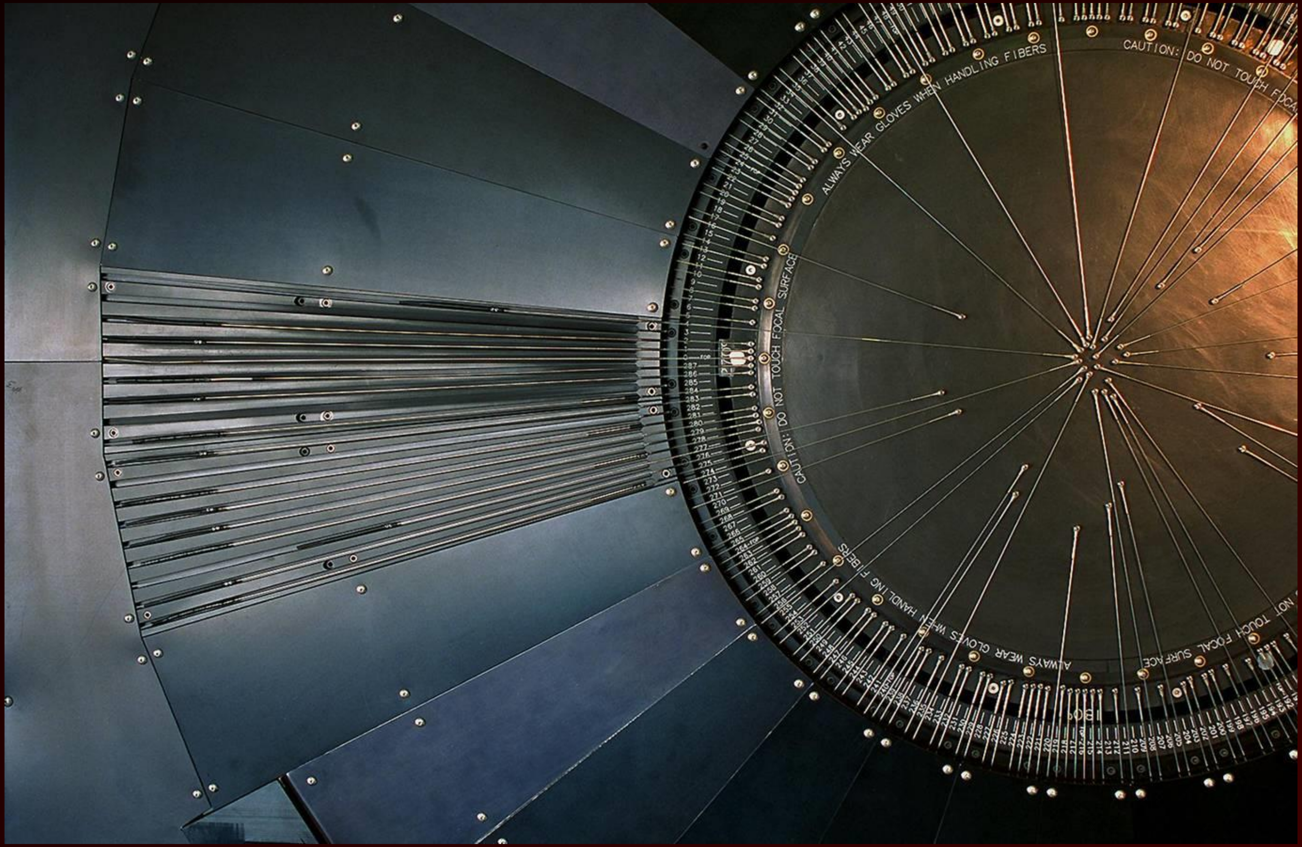
# Hydra spectrographs

- Radial fiber positioner spectrographs built for 4m KPNO, CTIO, and WIYN telescopes in the 1990s




- Decommissioned in favor of more modern technology

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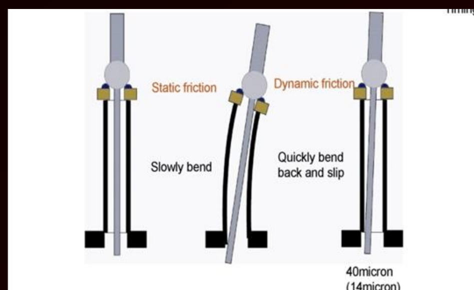
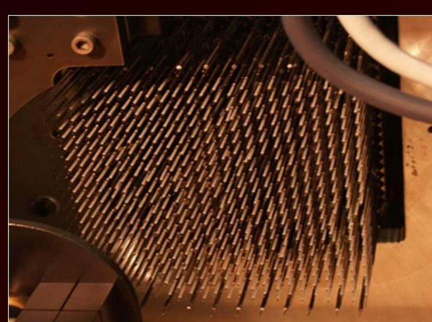
# Modern fiber positioner architectures

## Echidna-style

- Tilting spines




- Built for 2dF, Subaru, VLT, SOAR, others



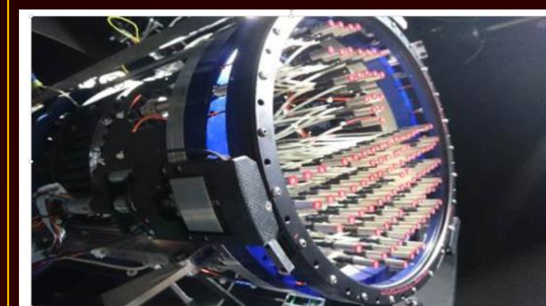
## Cobra-style

- Theta-phi

- Will be used in DESI, PFS

## Starbugs

- Fibers “walk” across glass field plate

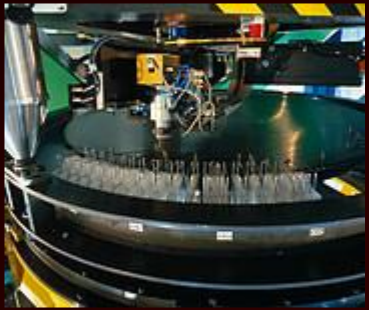


- MANIFEST: 1000s of Starbugs in the 20 arcmin focal plane of GMT that will feed all facility spectrographs

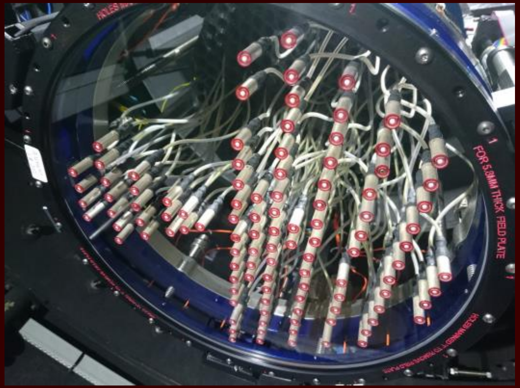
# Fiber positioner-fed spectrographs

2dF: 4m AAT, 392 fibers, echidna positioner, 2 sq deg FOV
AAOmega: R~1k to R~10k
Hermes: R~50k

LAMOST: 4m telescope, 4000 fibers, R=500, 1000, 1500

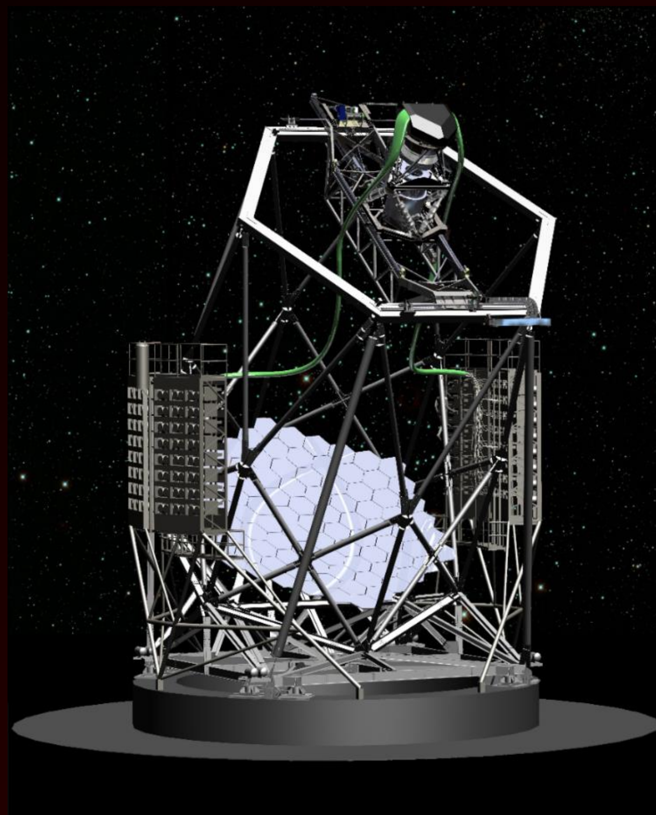


FLAMES: 8m VLT, OzPos positioner
UVES: 8 fibers, hires spectrograph
Giraffe: 130 fibers, moderate resolution

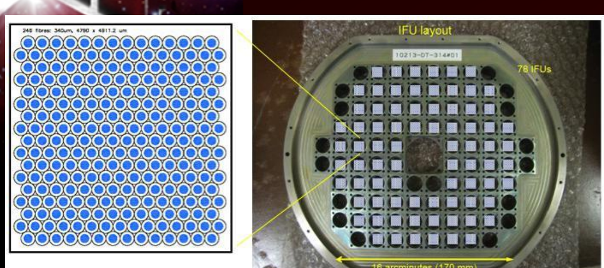


TAIPAN: 150 fibers on Starbugs, 1.2m telescope,R~2100

# HETDEX/VIRUS



- HETDEX: blind 420 deg$^2$ spectroscopic survey
  - Constrain expansion history over $1.9 < z < 3.5$
  - Line flux limit 3.5e-17, continuum detection at $m_{AB}$~22
- VIRUS: first highly-replicated instrument in optical astronomy
  - 156 fixed spectrographs
  - 350 – 550 nm with R~700
  - 33,600 spectra per exposure

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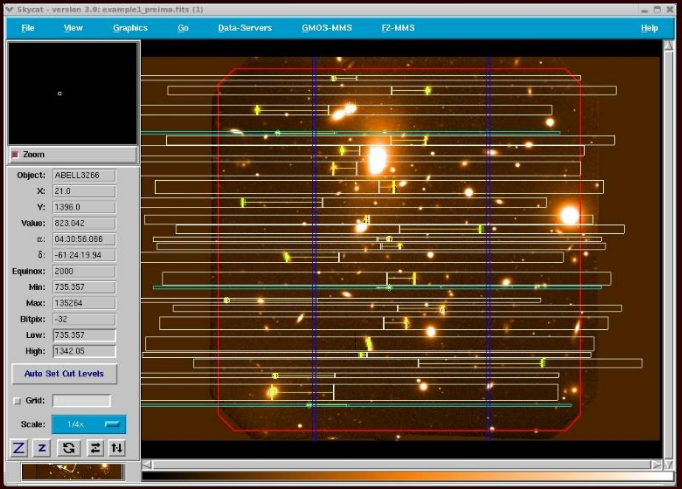
# Slit mask-fed spectrographs

- Not massively multiplexed (lower A-$\Omega$), but still multi-object
- Nearly every 10m-class telescope has at least one:
  - Gemini: GMOS
  - Magellan: IMACS, LDSS3
  - Keck: LRIS, DEIMOS
  - VLT: VIMOS
  - LBT: MODS
  - GTC: OSIRIS
  - SALT: RSS
- These are generally the most subscribed instruments on their telescopes




GMOS mask design software

IMACS slit mask production

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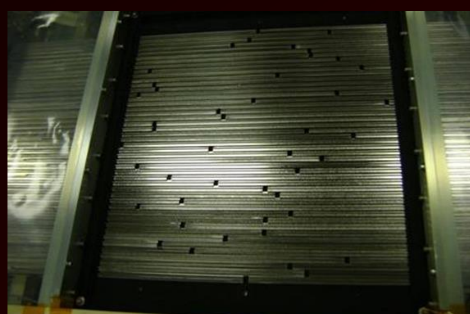
# Infrared multi-object spectrographs

## MOSFIRE

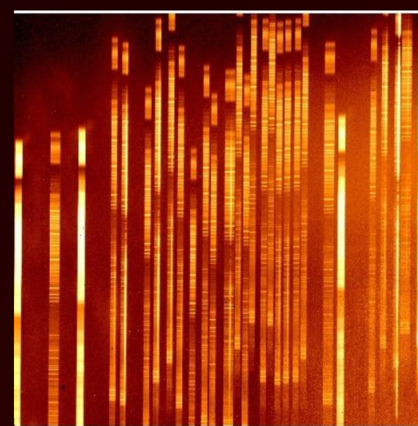
- 10m Keck telescope
- 46 slits in a cryogenic Configurable Slit Unit



- Same technology as JWST/NIRSpec, GTC/EMIRS
- 0.9–2.5 μm
- 2200 < R < 4800

## MMIRS

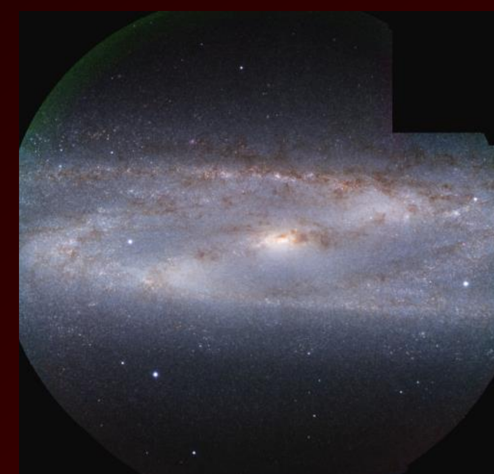
- 6.5m MMT/Magellan
- Cryogenic slit mask



- Based on Flamingos/ Flamingos-2 design

## Flamingos-2

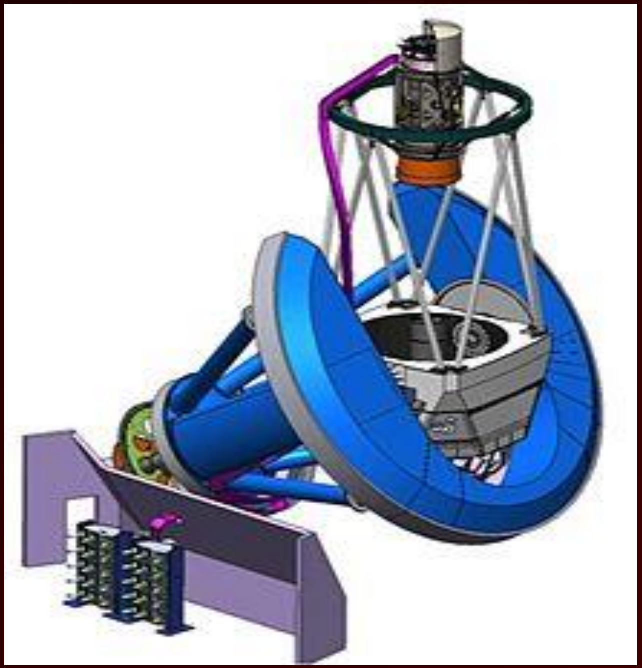
- 8m Gemini
- 6 arcmin FOV
- Imaging and longslit



- Multioobject mode awaiting commissioning

# The future: DESI

- 4m Blanco telescope
- 5000 fiber cobra-style positioner feeds 10 3-arm spectrographs
- $360 < \lambda < 980$ nm
- $2000 < R < 5000$

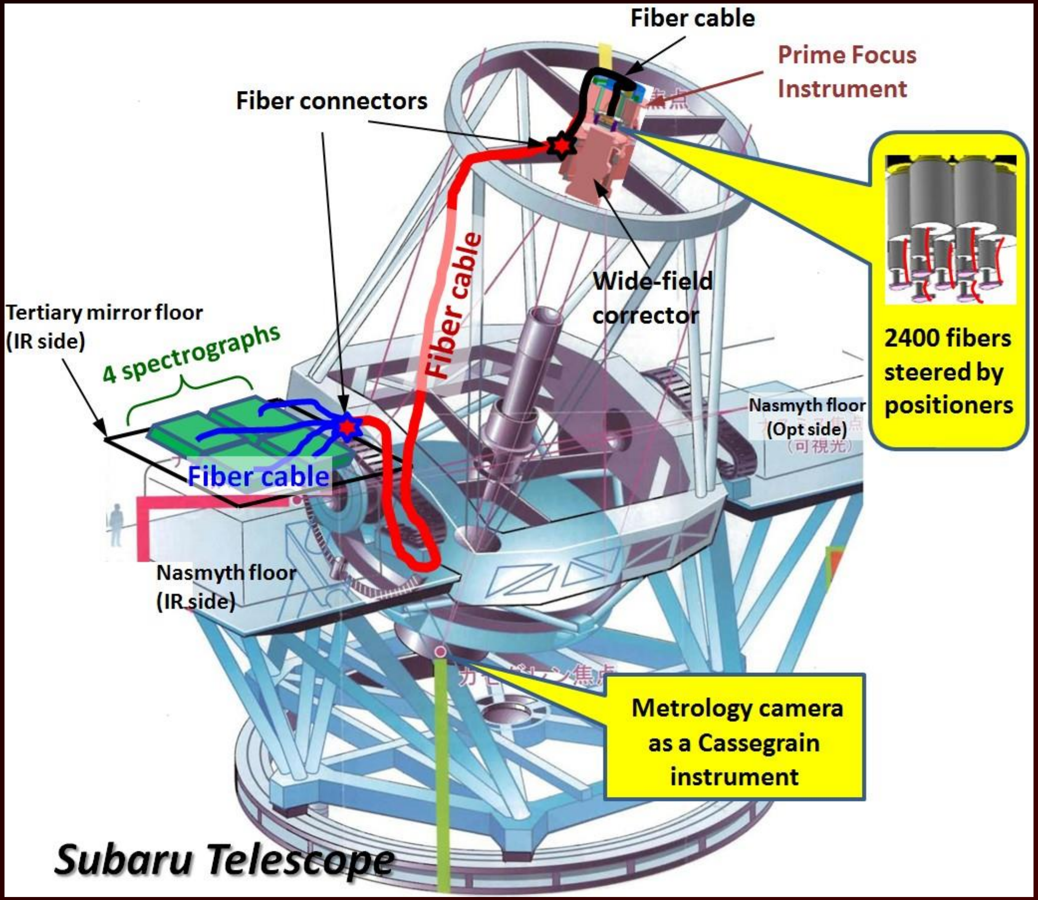


- First light: 2019
- Science: will enable a Stage IV dark energy measurement

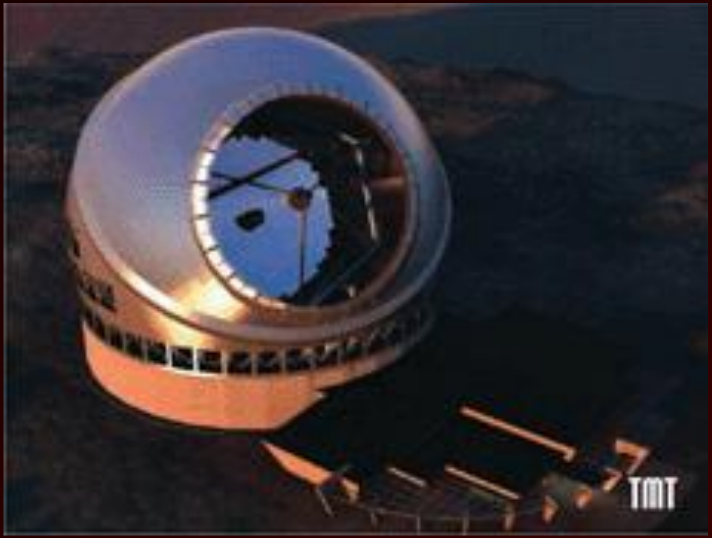
# The future: PFS

- 8m Subaru telescope
- 2400 fibers with Cobra-style positioner feeds four 3-arm spectrograph
- 380 nm < λ < 1.26 micron
- 2000 < R < 4000

- First light: 2019
- Science: cosmology



# The future: GMT/TMT


MANIFEST positioner will feed 10s to 1000s of fibers to facility instruments

- GMACS, optical moderate resolution spectrograph
- G-CLEF, optical hires spectrograph
- GMTIFS, infrared moderate resolution spectrograph
- GMTNIRS, infrared hires spectrograph

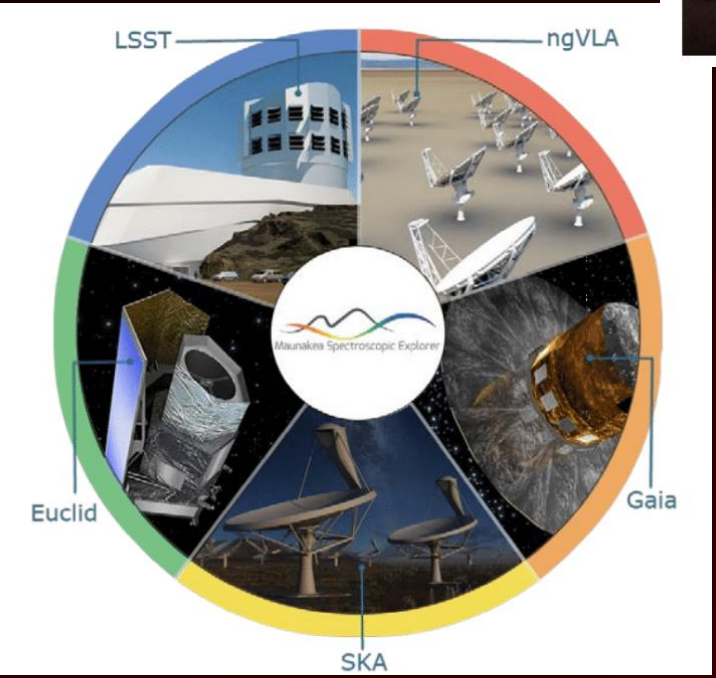
TMT also has 20 arcmin field of view

- WFOS is a first light moderate resolution optical wide field spectrometer

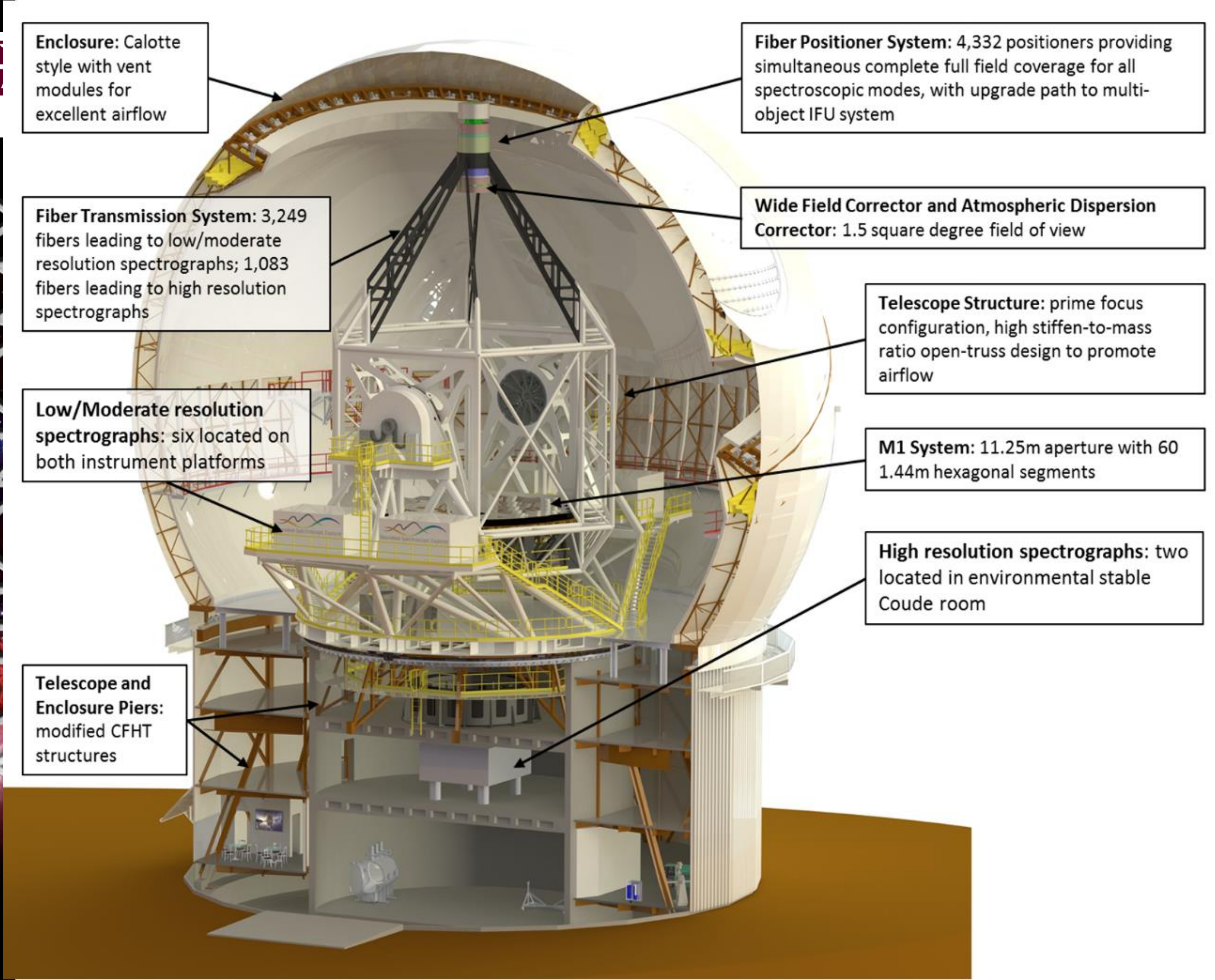
First light: ???

# The future: MSE

- Maunakea Spectroscopic Explorer
- 11.25m transformed CFHT telescope


- First light: 2026
- Science: everything!



**Enclosure:** Calotte style with vent modules for excellent airflow
**Fiber Positioner System:** 4,332 positioners providing simultaneous complete full field coverage for all spectroscopic modes, with upgrade path to multi-object IFU system
**Fiber Transmission System:** 3,249 fibers leading to low/moderate resolution spectrographs; 1,083 fibers leading to high resolution spectrographs
**Wide Field Corrector and Atmospheric Dispersion Corrector:** 1.5 square degree field of view
**Telescope Structure:** prime focus configuration, high stiffen-to-mass ratio open-truss design to promote airflow
**Low/Moderate resolution spectrographs:** six located on both instrument platforms
**M1 System:** 11.25m aperture with 60 1.44m hexagonal segments
**High resolution spectrographs:** two located in environmental stable Coude room
**Telescope and Enclosure Piers:** modified CFHT structures

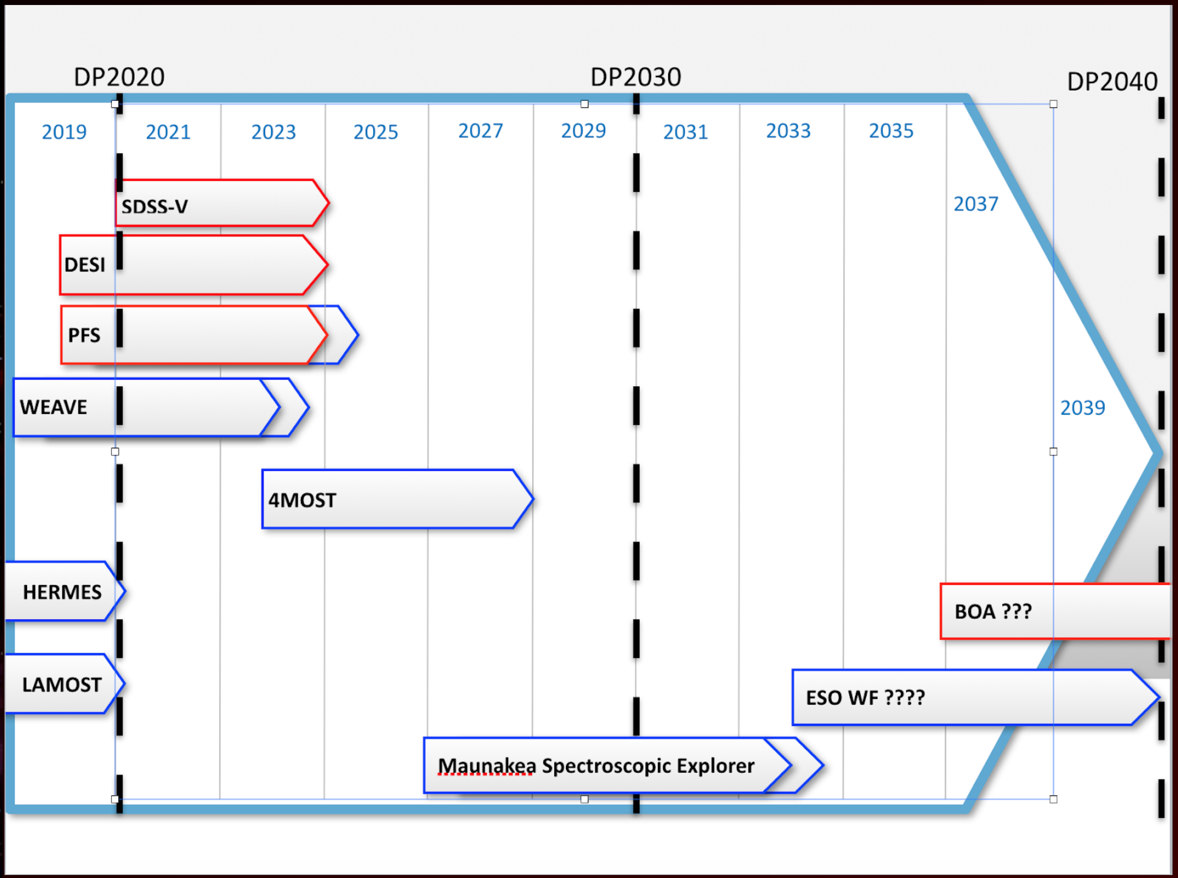
# MSE science

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Accessible sky | 30000 square degrees (airmass < 1.55) | | | | | | |
| Aperture (M1 in m) | 11.25m | | | | | | |
| Field of view (square degrees) | 1.5 | | | | | | |
| Etendue = FoV x $\pi$ (M1 / 2)$^2$ | 149 | | | | | | |
| Modes | Low | | Moderate | High | | | IFU |
| Wavelength range | 0.36 - 1.8 µm | | 0.36 - 0.95 µm | 0.36 - 0.90 µm # | | | IFU capable; anticipated second generation capability |
| | 0.36 - 0.95 µm | J, H bands | | 0.36 - 0.45 µm | 0.45 - 0.60 µm | 0.60 - 0.90 µm | |
| Spectral resolution, R = $\lambda_c/d\lambda$ | 2500 *(3000)* | 3000 *(5000)* | 6000 | 40000 | 40000 | 20000 | |
| Multiplexing | >3200 | | >3200 | >1000 | | | |
| Spectral windows | Full | | ≈Half | $\lambda_c/30$ | $\lambda_c/30$ | $\lambda_c/15$ | |
| Sensitivity ★ | m=24 @ SNR=2 | | m=23.5 @ SNR=2 | m=20.0 @ SNR=10 | | | |
| Velocity precision ★ | 20 km/s @ SNR=5 | | 9 km/s @ SNR=5 | < 100 m/s @ SNR=30 | | | |
| Spectrophotometic accuracy | < 3 % relative | | < 3 % relative | N/A | | | |

- MSE is capable of conducting multi-object spectroscopy on science targets on three-quarters of the entire sky:
  - 1.5 square degree science field of view
  - Operate at three different resolutions, from R~2,500 (low), R~6,000 (moderate) to R~40,000 (high)
  - >3200 spectra per exposure at low or moderate resolution per telescope pointing
  - >1000 spectra per exposure at high resolution per telescope pointing
  - Wavelength range stretching from blue-optical to the near-infrared

See MSE Science Book 2018 for more details

# SnowPAC2018: Roadmaps to Wide Field Spectroscopic Surveys




The future of wide field survey spectroscopy, adapted from Jeff Newman. Disclaimer: dates are rough and preliminary.

In the landscape of future LSST (even DES) spectroscopic followup, there is a lot missing:

- Aperture
- Hemisphere
- The future