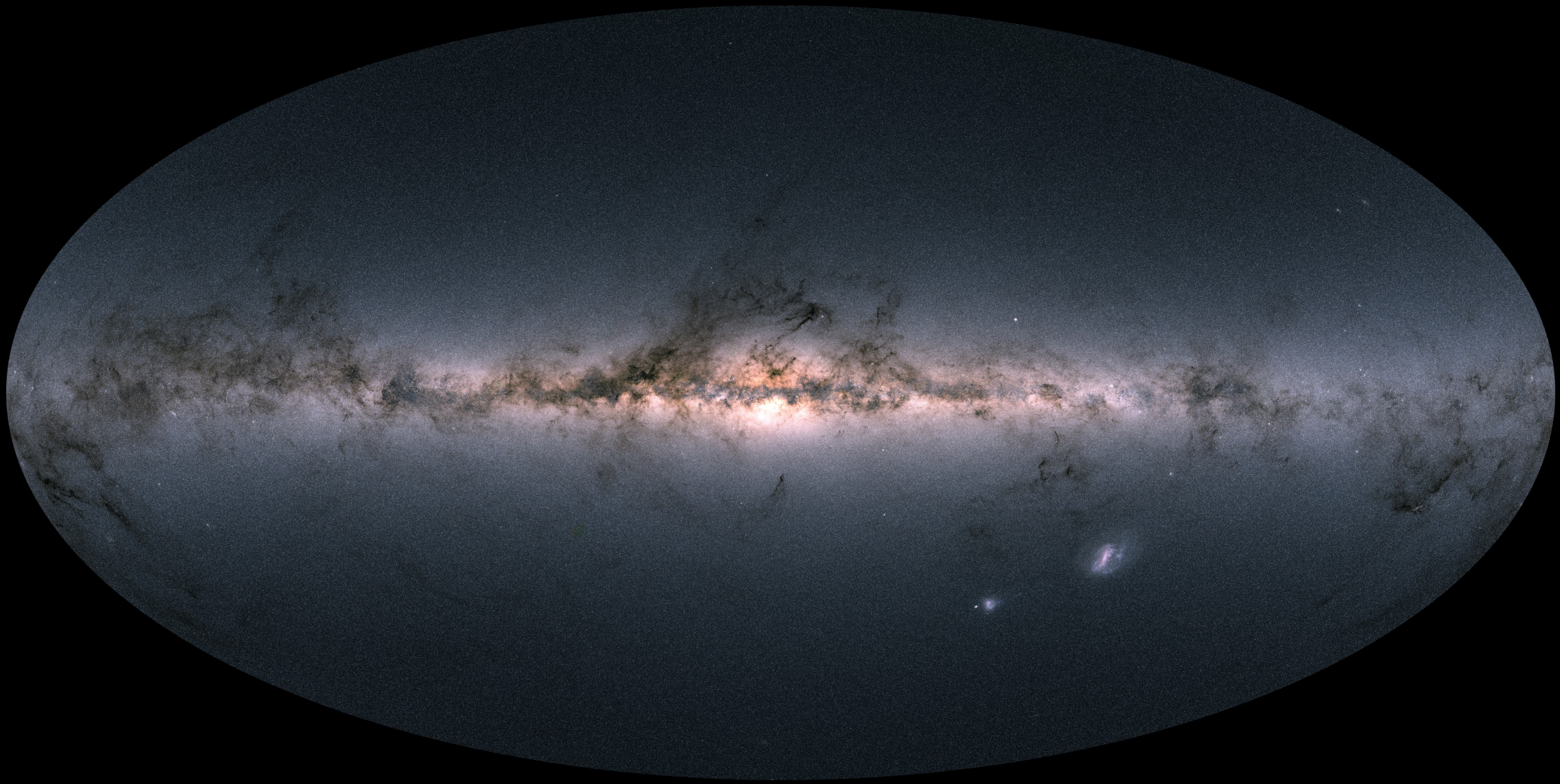
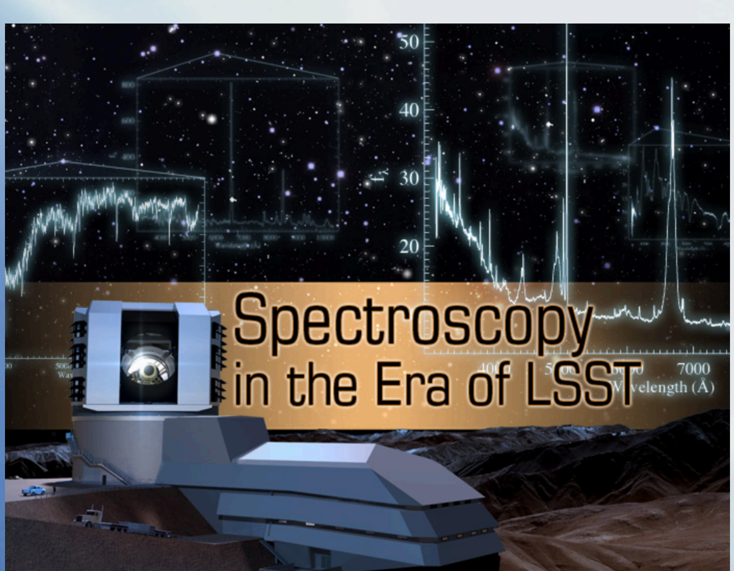
MegaMapping Dark Matter

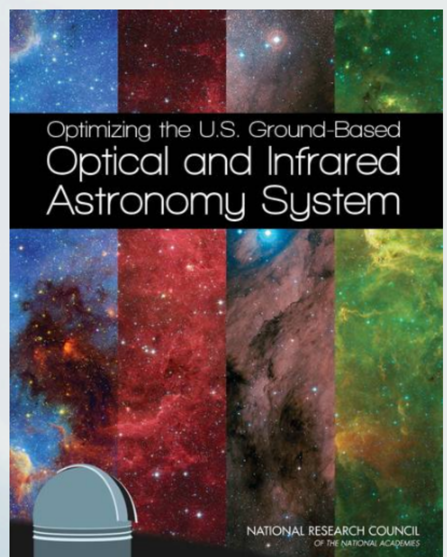


Josh Simon (Carnegie Observatories)

Need for massively multiplexed spectroscopy is clear

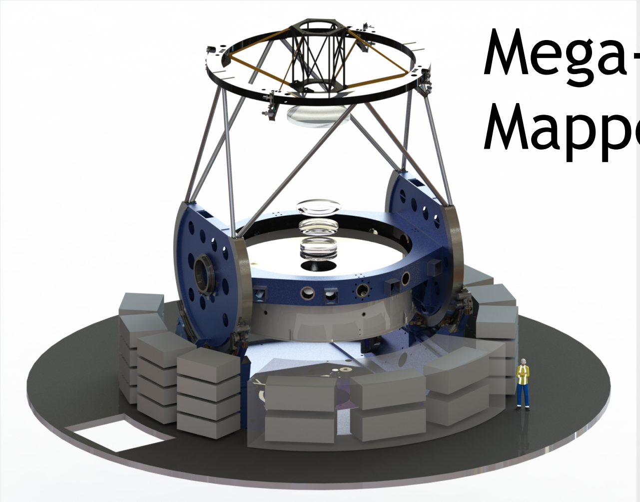
- LSST will detect ~10 billion stars and ~20 billion galaxies over ~20000 deg^2
- Maximizing the science obtained in many fields will require extensive follow-up



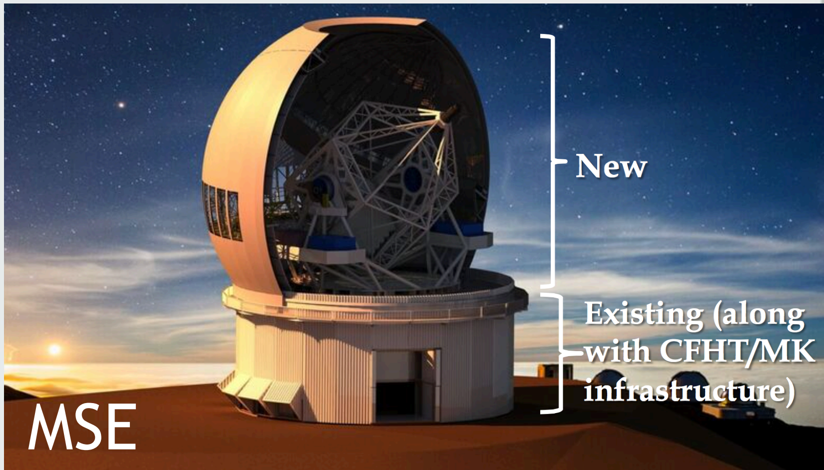


Multi-Object spectroscopy parameter space

- Spectroscopic survey speed depends on:
  - collecting area
  - field of view
  - multiplexing



MSE: 11.25m diameter, 1.5 deg^2, 4332 fibers
SpecTel: 11.4m diameter, 5 deg^2, 15000 fibers
MM: 6.5m diameter, 7 deg^2, 20000 fibers



MegaMapper delivers 10× DESI survey speed

(exceeds any other cost-effective future designs)

Instrument (year)	Primary/m^2	Nfiber	Reflections	Product	Speed vs. SDSS
SDSS (1999)	3.68	640	0.9^2	1908	1.00
BOSS (2009)	3.68	1000	0.9^2	2980	1.56
DESI (2019)	9.5	5000	0.9^1	42,750	22.4
PFS (2020)	50	2400	0.9^1	108,000	56.6
4MOST (2022)	12	1624	0.9^2	15,800	8.3
MegaMapper	**28**	**20,000**	$\mathbf{0.9^2}$	**454,000**	**238**.
Keck/FOBOS	77.9	1800	0.9^3	102,000	53.6
MSE	78	3249	0.9^1	228,000	119.
LSSTspec	35.3	8640	0.9^3	222,000	116.
SpecTel	87.9	15,000	0.9^2	1,070,000	560.

Table 1: Survey speeds for multi-fiber spectrographs as measured by the product of the telescope clear aperture, number of fibers and losses from mirror reflections. This speed assumes a dedicated program, which would not be possible in all cases. Keck/FOBOS [9], MSE [10], SpecTel [11] and MegaMapper are proposed experiments. LSSTspec [12] is a notional number using MegaMapper positioners on the LSST focal plane, if optical design limitations could be overcome injecting f/1.2 light into fibers.

Schlegel et al. (2019)

MegaMapper concept

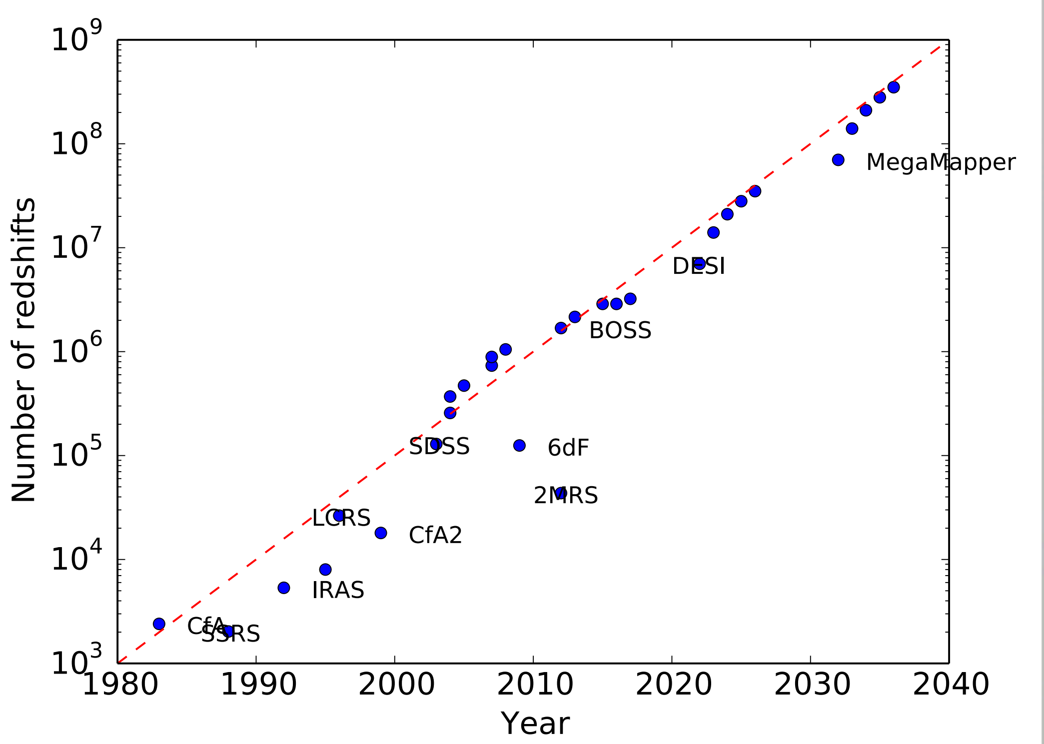
- Copy of Magellan telescopes
  - Modify primary mirror shape to increase FOV
  - Straightforward to construct, 15+ years of operating experience
  - Much cheaper than a custom 11m telescope
- Use 32 DESI spectrographs
  - 16 will already exist from DESI+SDSS-V
- Shrink DESI fiber positioners
  - Reduce pitch from 10.4mm to 6.2mm to allow 20K to fit in the focal plane

Cosmology survey

- 5-year redshift survey at z>2 proposed as a next-gen DESI-like experiment

MegaMapper DESI

Parameter	σ(parameter) Fid./Ideal.	DESI
Curvature $\Omega_K/10^{-4}$	6.6 / 5.2	12.0
Neutrinos $\sum m_\nu$	0.028 / 0.026	0.032
Spectral index n_s	0.0026 / 0.0026	0.0029
Running α_s	0.003 / 0.003	0.004
Rel. species N_{eff}	0.069 / 0.069	0.078
Gravitational slip	0.008 / 0.008	0.01
D.E. FoM	398 / 441	162



Ferraro et al. (2019)

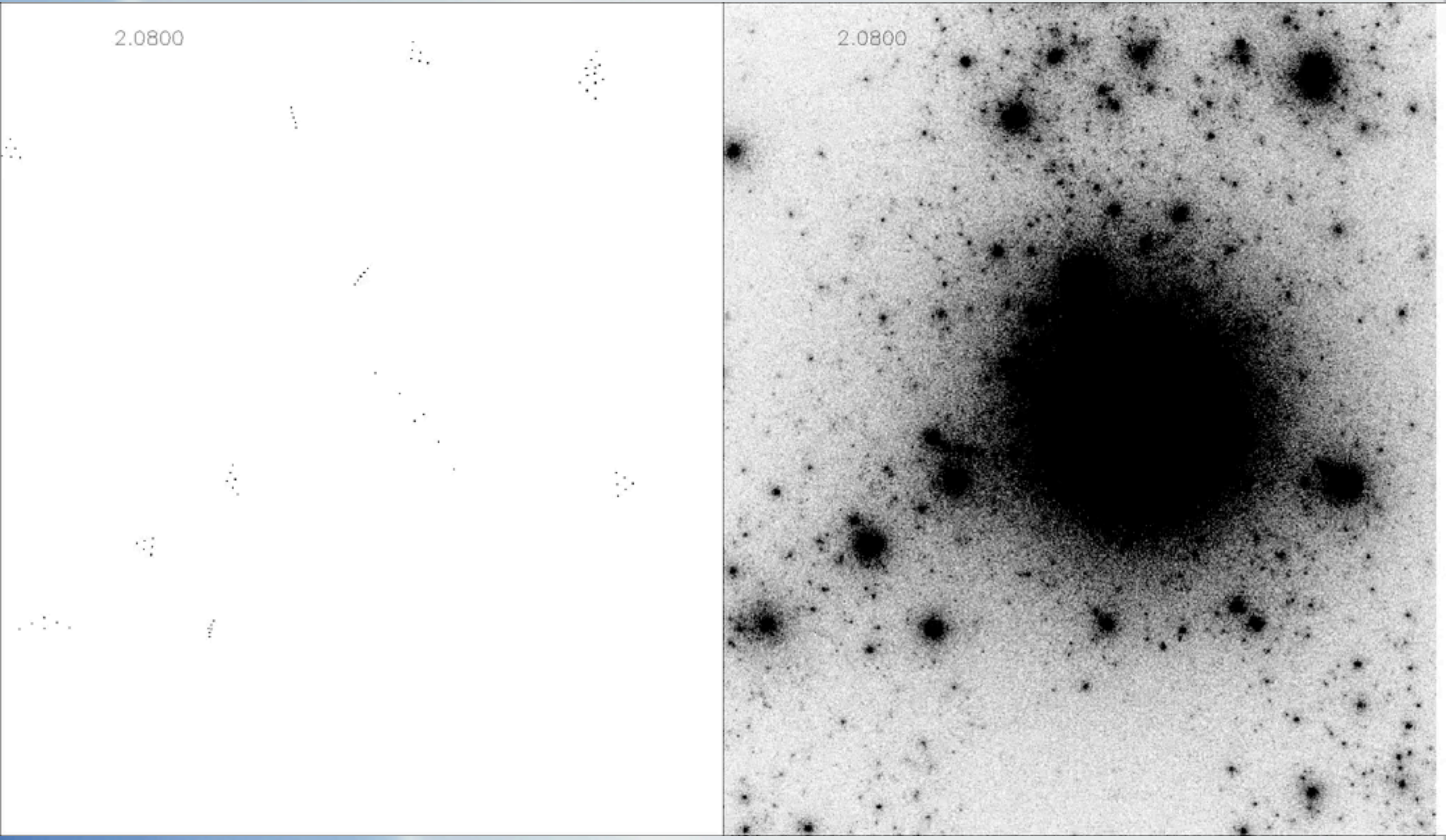
Schlegel et al. (2019)

Enormous range of applications

- Dwarf galaxy/stellar stream spectroscopy
- Chemodynamical survey of 10^6 halo stars
- Stellar evolution survey of clusters to measure rotation and magnetic fields
- Supermassive BH demographics from AGN monitoring
- IGM tomography
- LSST photo-z training sets
- . . .

Najita et al. (2016)

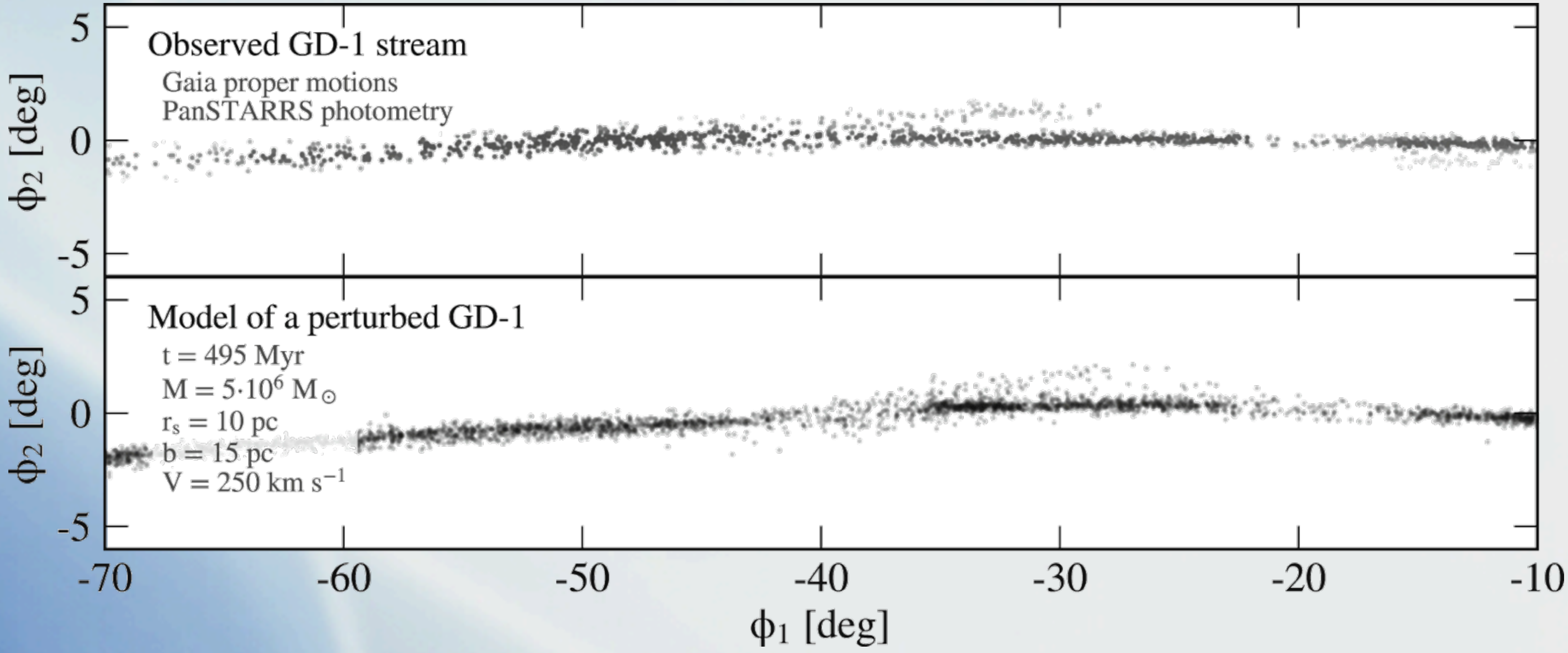
Dark matter with MegaMapper



Movie courtesy of Ray Carlberg

Dark matter with MegaMapper

- Dynamics of stellar streams are sensitive to dark matter substructure



Bonaca et al. (2019)

Dark matter with MegaMapper

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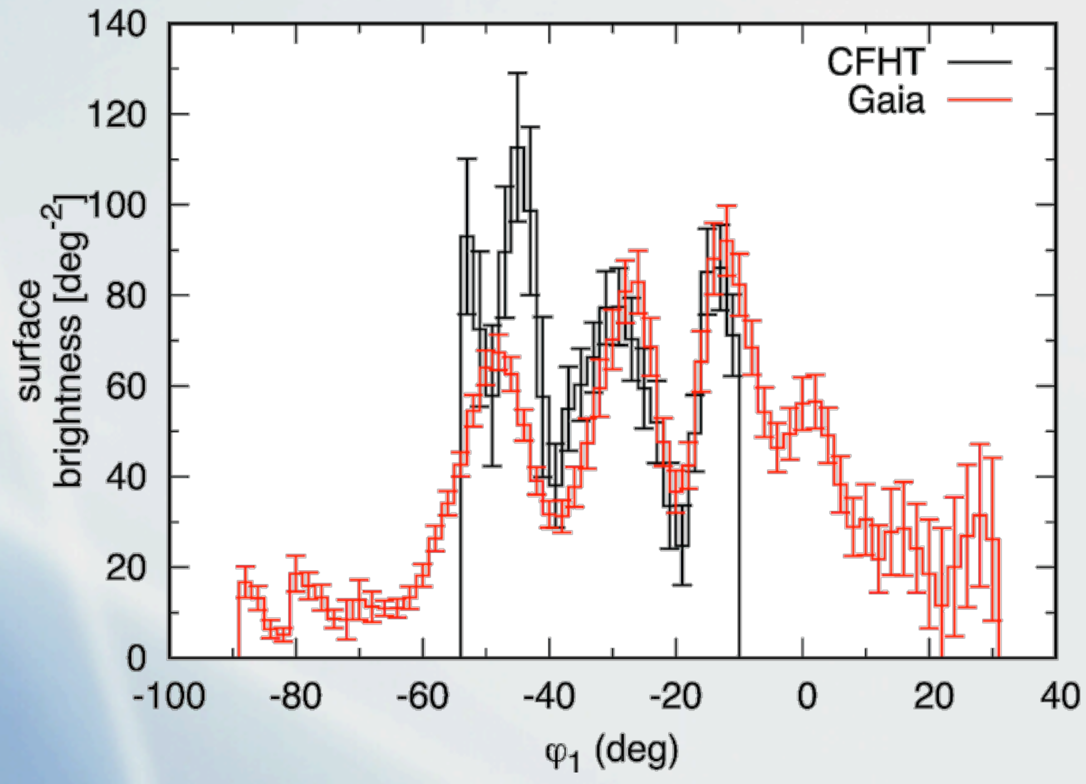
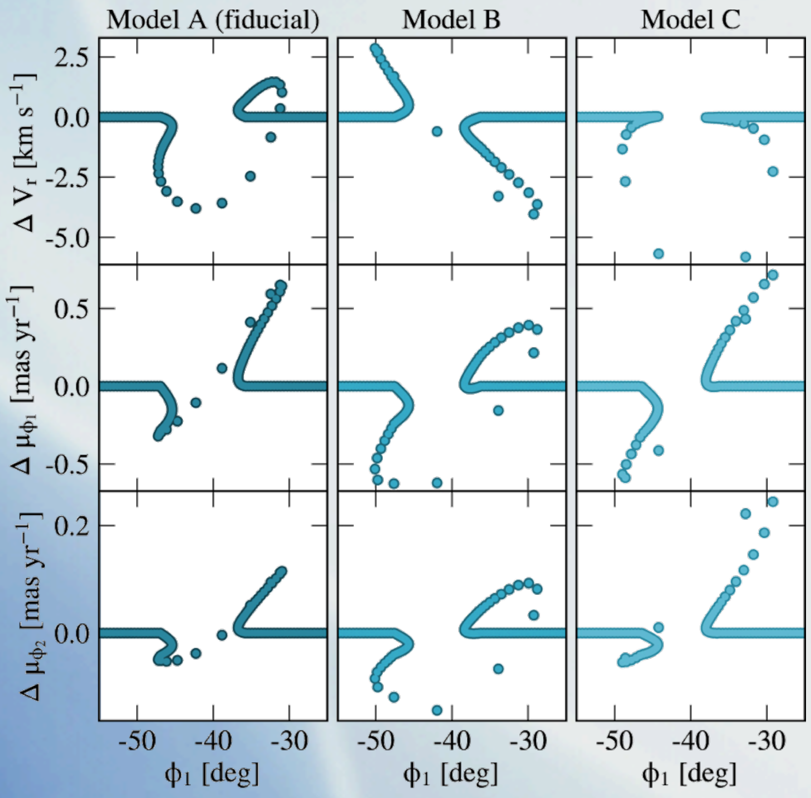


de Boer et al. (2020)

Dark matter with MegaMapper

- Kinematics of stellar streams depend on perturber properties

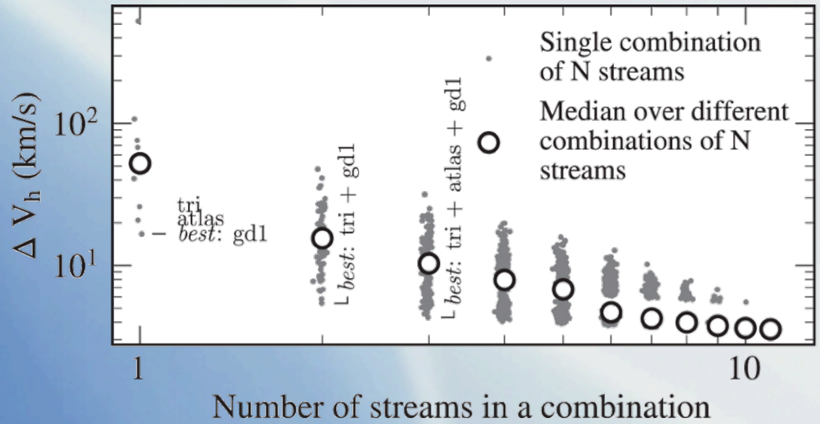


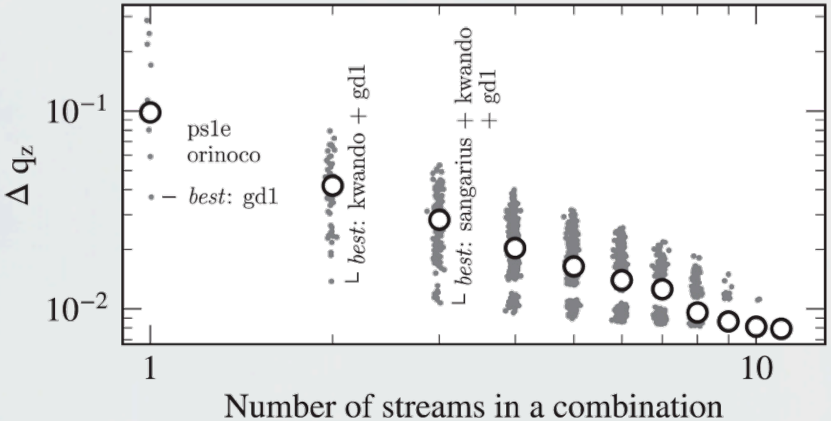
– Need ~1 km s^{-1} velocities
– MegaMapper will increase available sample size/ surface density by >10× relative to AAT

Bonaca et al. (2019)

Dark matter with MegaMapper

- Streams can substantially improve mass measurements for the Milky Way
  - Current uncertainties ~50%
  - Affects predicted DM density near Sun and MW satellite population

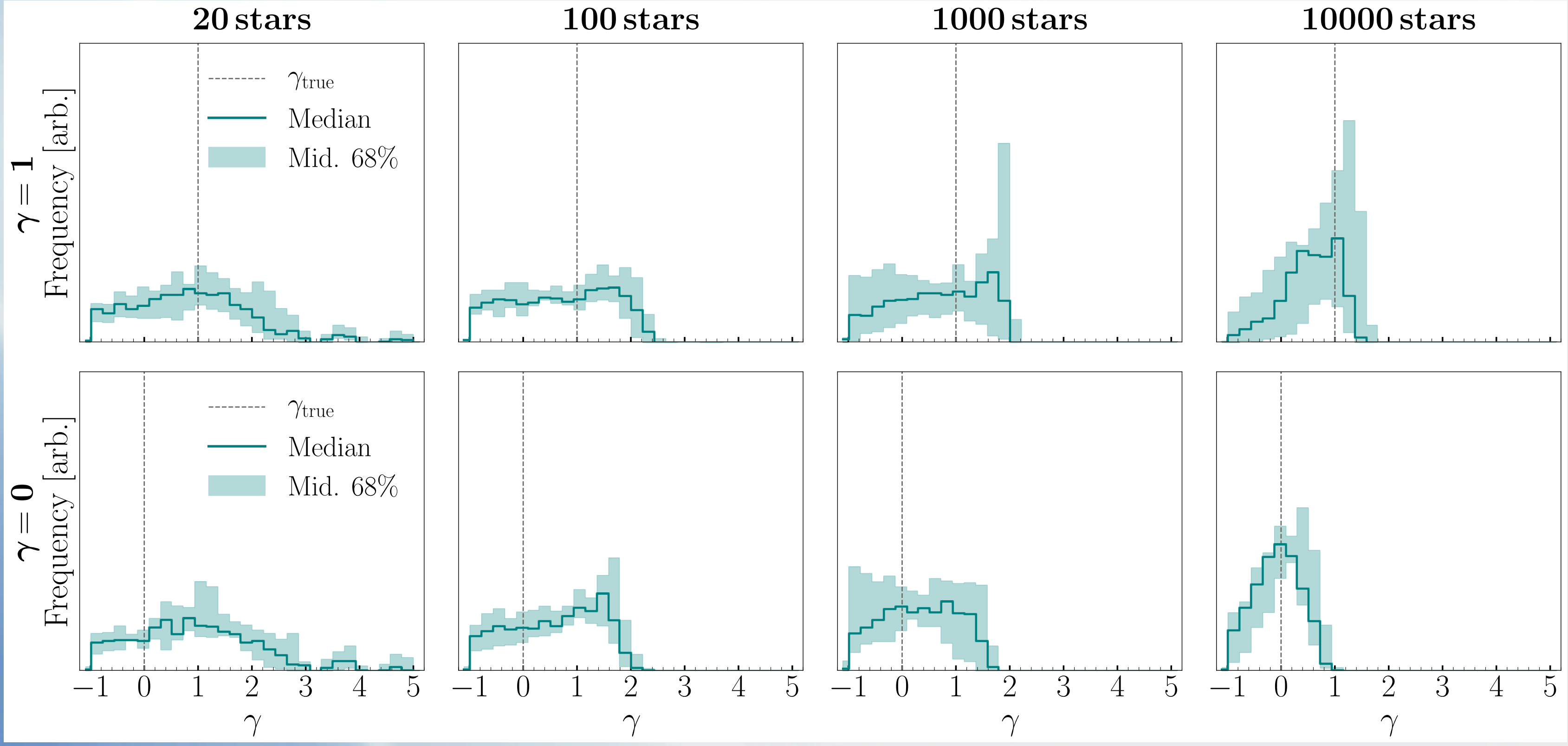




Bonaca & Hogg (2018)

Dark matter with MegaMapper

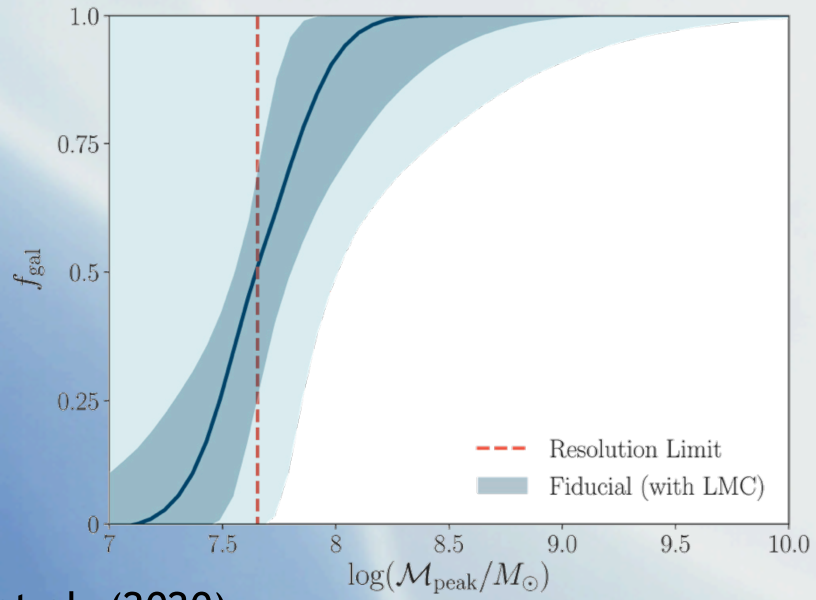
- Dwarf galaxy density profiles
  - Measuring with RVs alone requires 10^4 stars



Chang & Necib (2020)

Dark matter with MegaMapper

- Confirming/measuring masses of newly discovered dwarf galaxies
  - Tightens minimum halo mass constraints
  - Improves J-factors for γ–ray observations



Confirming Rubin dwarf candidates will require: ~1 yr of wide-field MOS observations OR an ELT

Nadler et al. (2020)

Najita et al. (2016), Simon et al. (2019)

Summary

- Wide-field multi-object spectroscopy can have a significant impact on DM models
  - Velocity measurements for stream stars will:
    - Constrain the mass function below $10^7\ M_\odot$
    - Determine the mass of the Milky Way
  - Velocity measurements of dwarf galaxies will:
    - Tighten constraints on minimum halo mass
    - Determine dark matter density profiles
- MegaMapper will be the most cost-effective facility with these capabilities