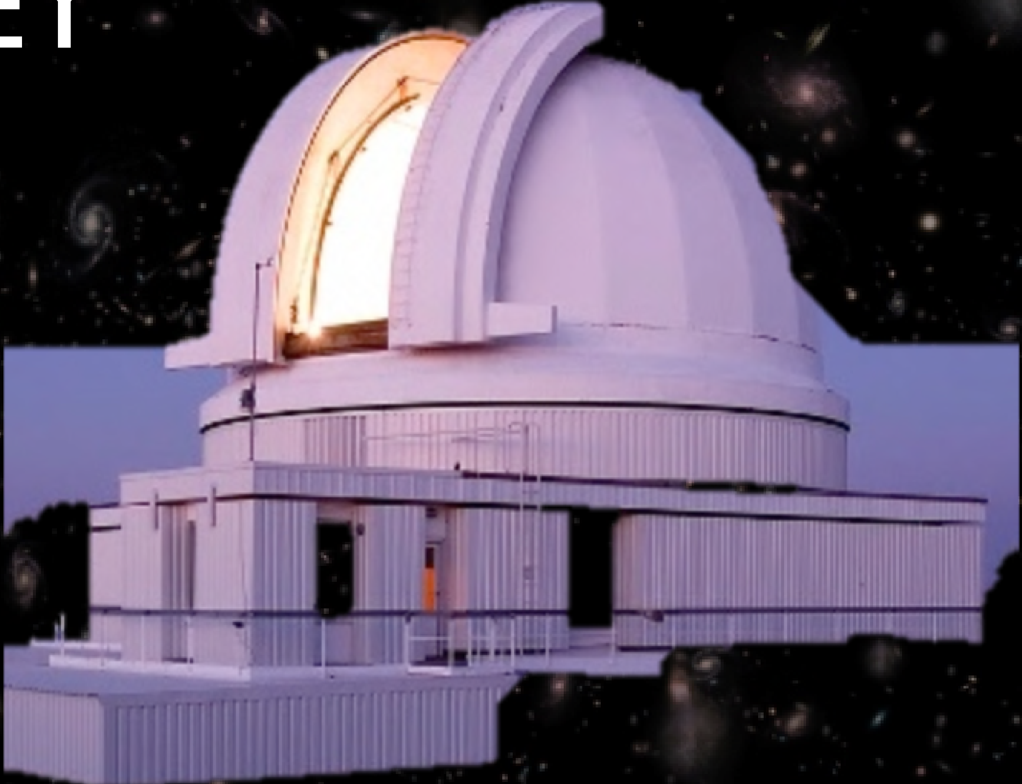
STRUCTURE, MOTIONS AND COSMOLOGY FROM THE TAIPAN SURVEY



Matthew Colless

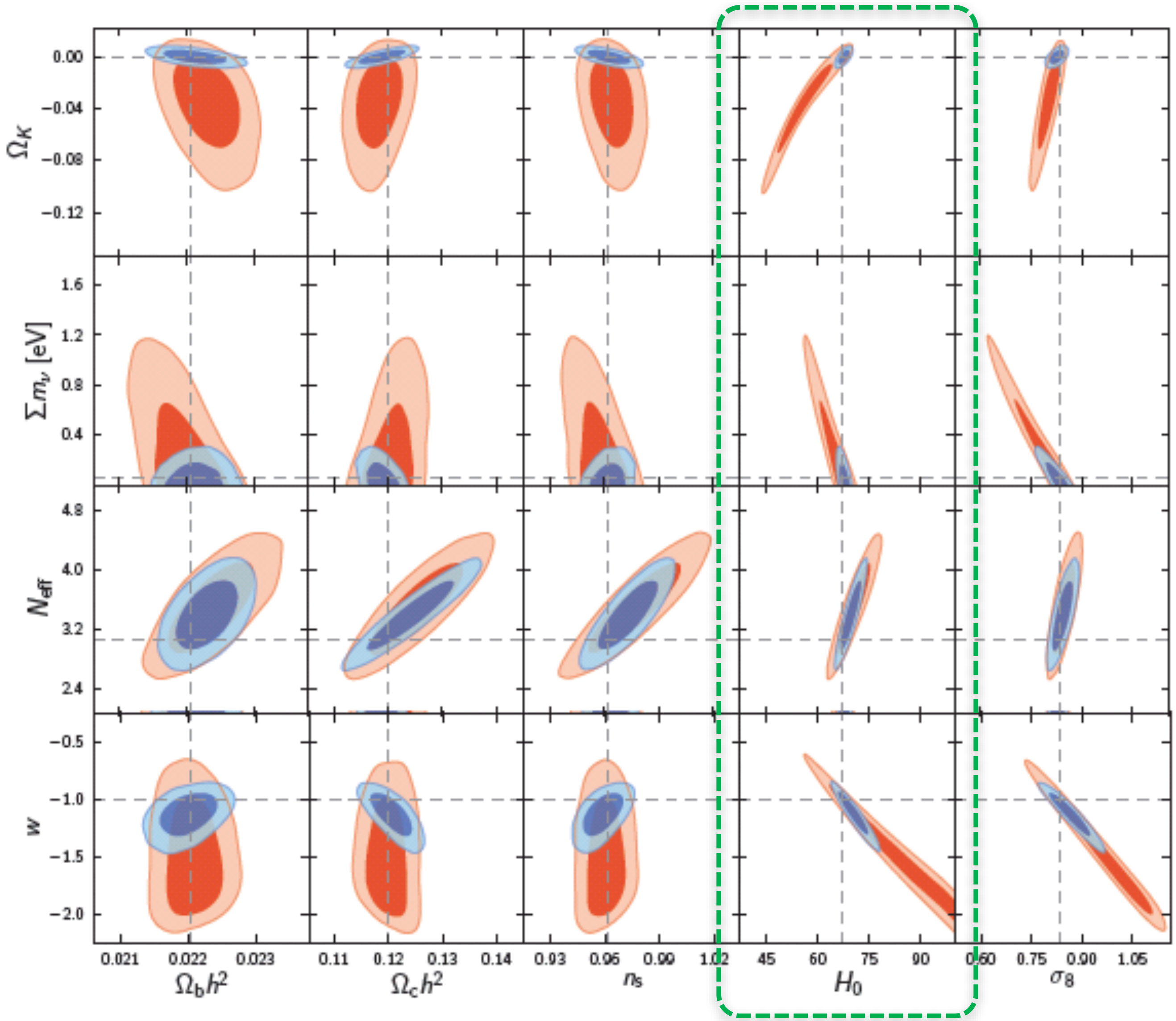
Large Scale Structure and Galaxy Flows

Quy Nhon, 4 July 2016

Why measure H_0? *(with emphasis on the '0')*

- H_0, the local (i.e. zero-redshift) expansion rate, is a fundamental cosmic parameter ($\Longrightarrow$ age of universe)
- Assuming a flat ΛCDM universe, Planck determines H_0 to ~1.5% – but this is a model-dependent result

CMB H_0 is model-dependent



Planck results

Red : CMB only

Blue : CMB+BAO

The H_0 from the CMB is an extrapolation to low z of measurements at high z that depends on other parameters of the cosmological model

Why measure H_0?

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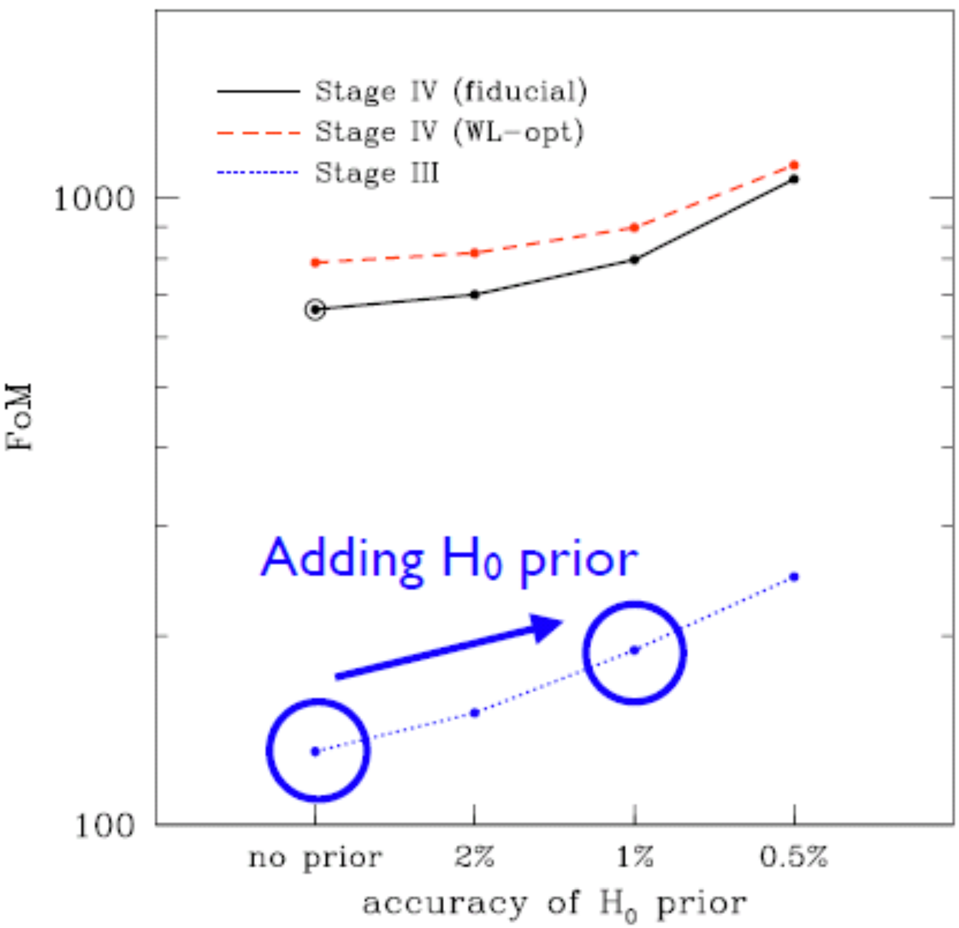
- Assuming a flat ΛCDM universe, Planck determines H_0 to ~1.5% – but this is a model-dependent result
- An independent determination of H_0 is a key prior that improves the constraints on other parameters (e.g. dark energy, neutrino numbers/mass)

H_0 is key prior for dark energy

Weinberg et al. (2012)



- Assuming (w_0, w_a) model, 1% H_0 measurement adds about 40% to Stage III dark energy experiments [e.g. BOSS, DES, etc.]
- Adds very little to Stage IV experiments [e.g. LSST, SKA, etc.]

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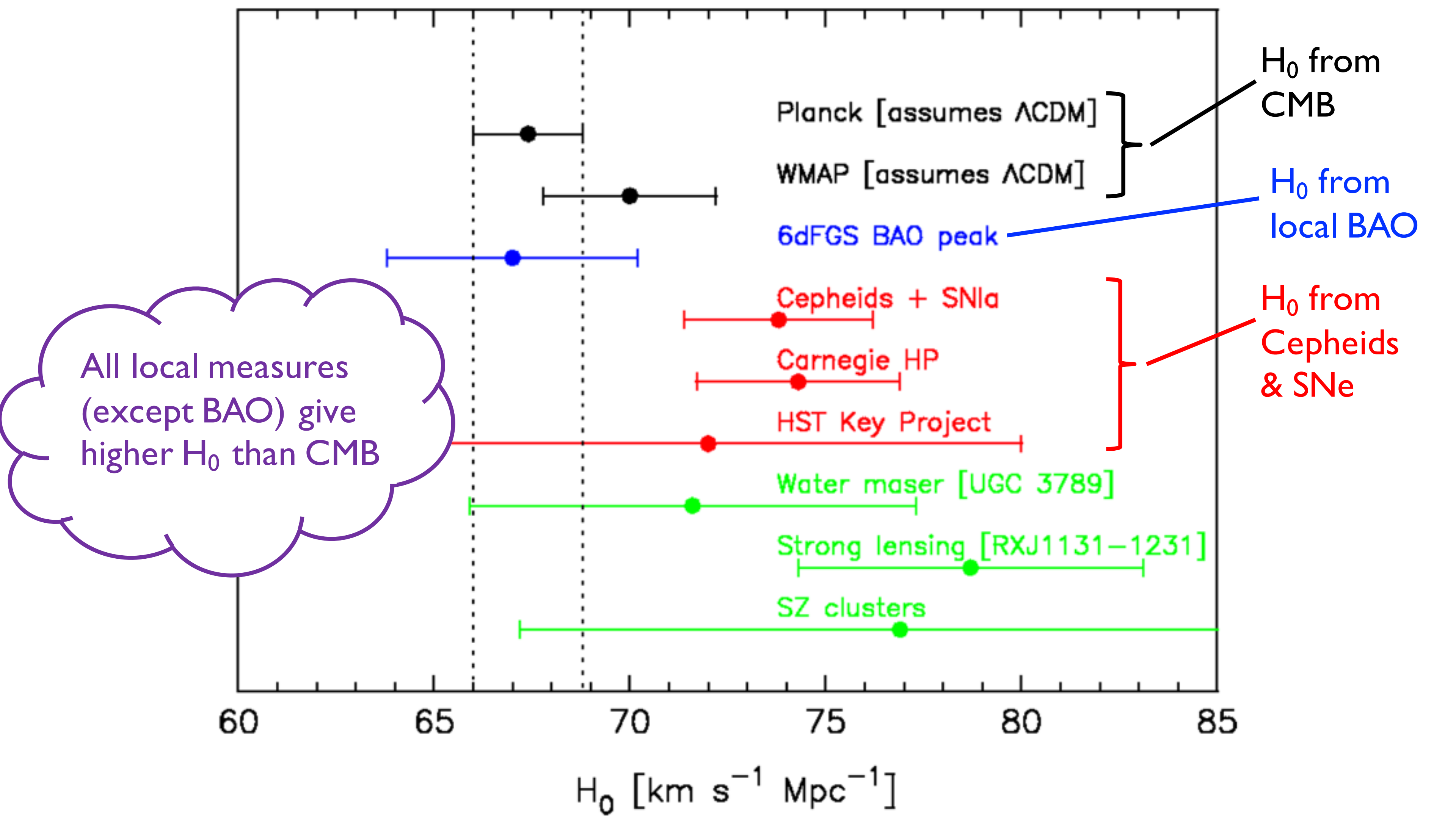
- An independent determination of H_0 is a key prior that improves the constraints on other parameters (e.g. dark energy, neutrino numbers/mass)
- Currently, there are systematic discrepancies between H_0 determined from the CMB and local measurements (via Cepheids, masers, SNe) – tension at ~3σ level

Local and CMB H_0 are discrepant



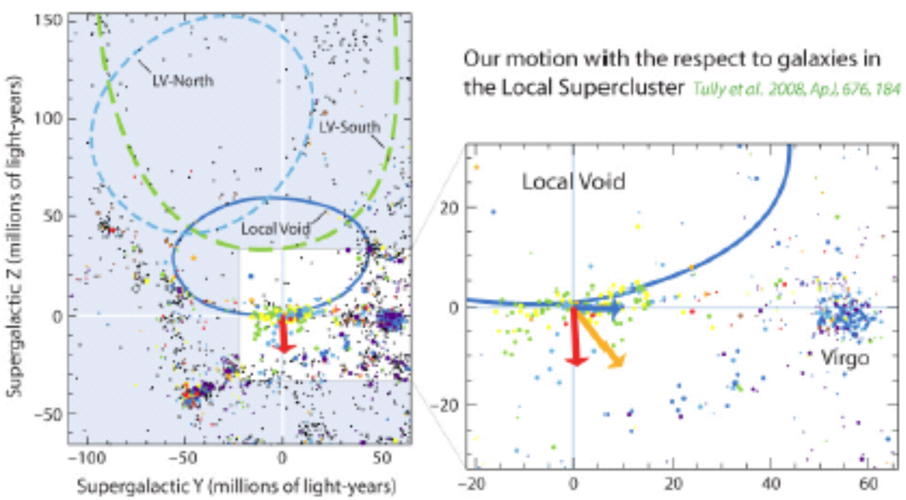
Local and CMB H_0 are discrepant

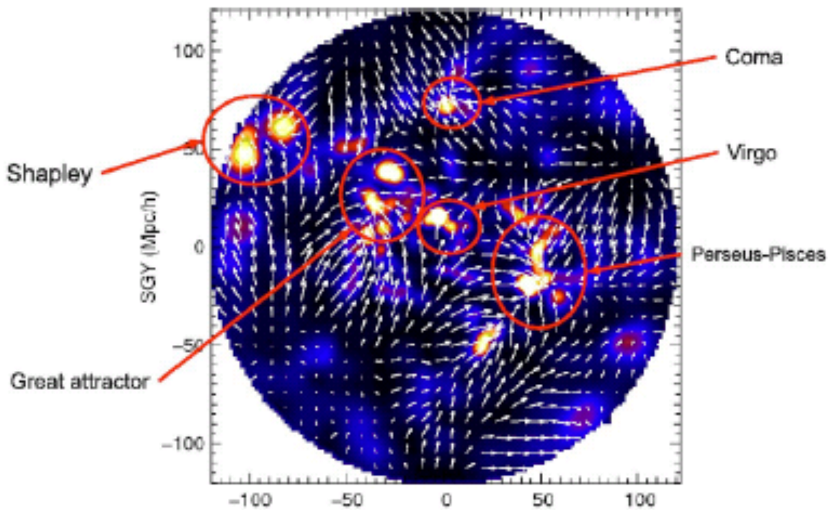
Discrepancies could be…

… systematic errors in the local or CMB measurements

… signature of non-LCDM physics in cosmological model

… signature of gravitational physics due to inhomogeneity and back-reaction



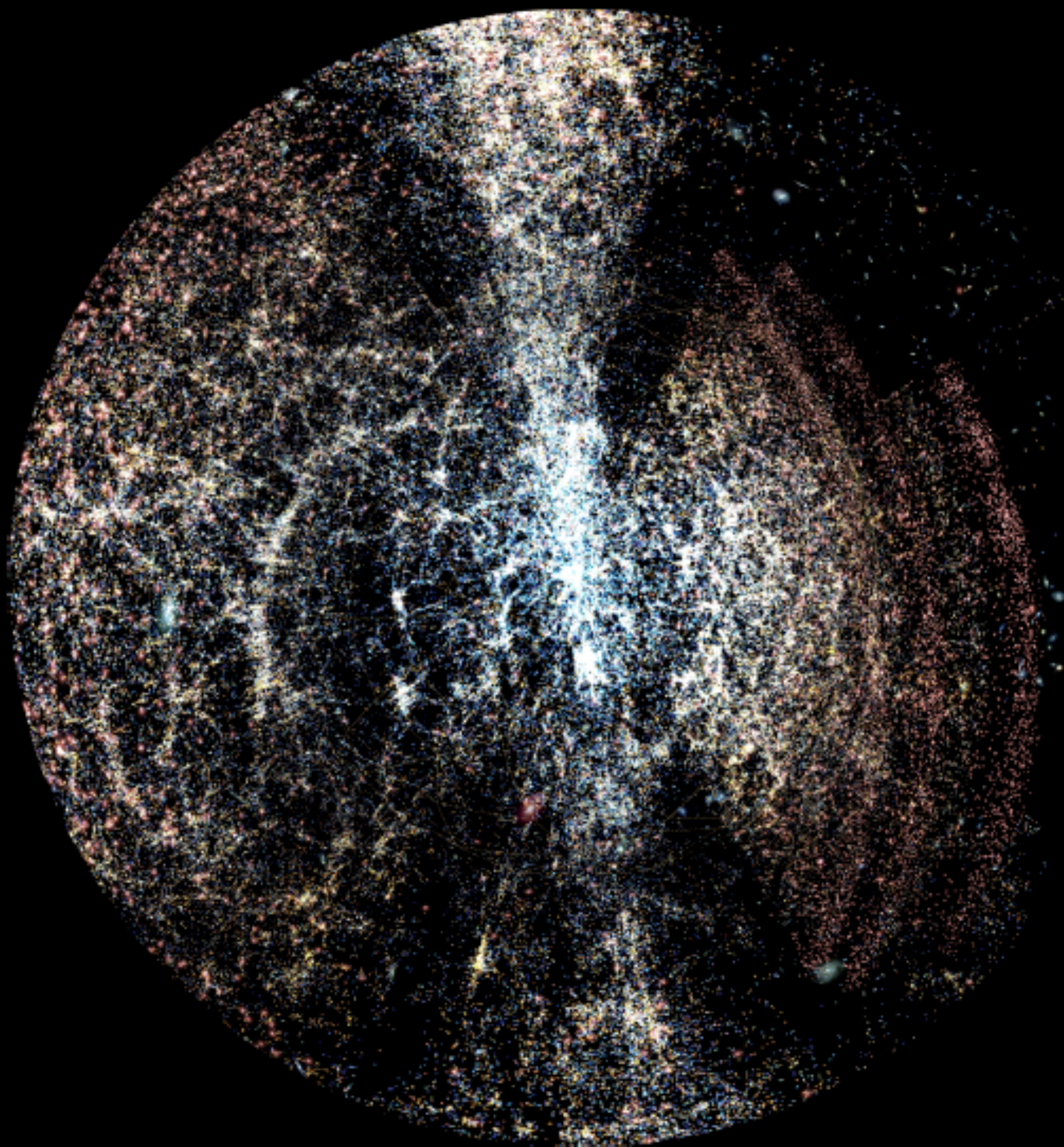


Tests of large-scale gravity

- Is the growth rate of structure consistent with the cosmic expansion history?

- Is the gravitational physics of the homogeneous and inhomogeneous Universe consistent?

- Need to measure galaxy velocities …



Goals of the Taipan survey

1. **What is the expansion rate of the universe?**
   Aim to measure the local Hubble constant, H_0, with 1% precision from the large-scale distribution of galaxies
2. **What are the density and velocity fields in the local universe?**
   Map the both density *and* velocity fields over a greater volume and with more galaxies than previous surveys
3. **What is the correct theory of gravity?**
   Test gravity models using both the *peculiar velocities* of galaxies and the *redshift-space distortions* of their large-scale distribution

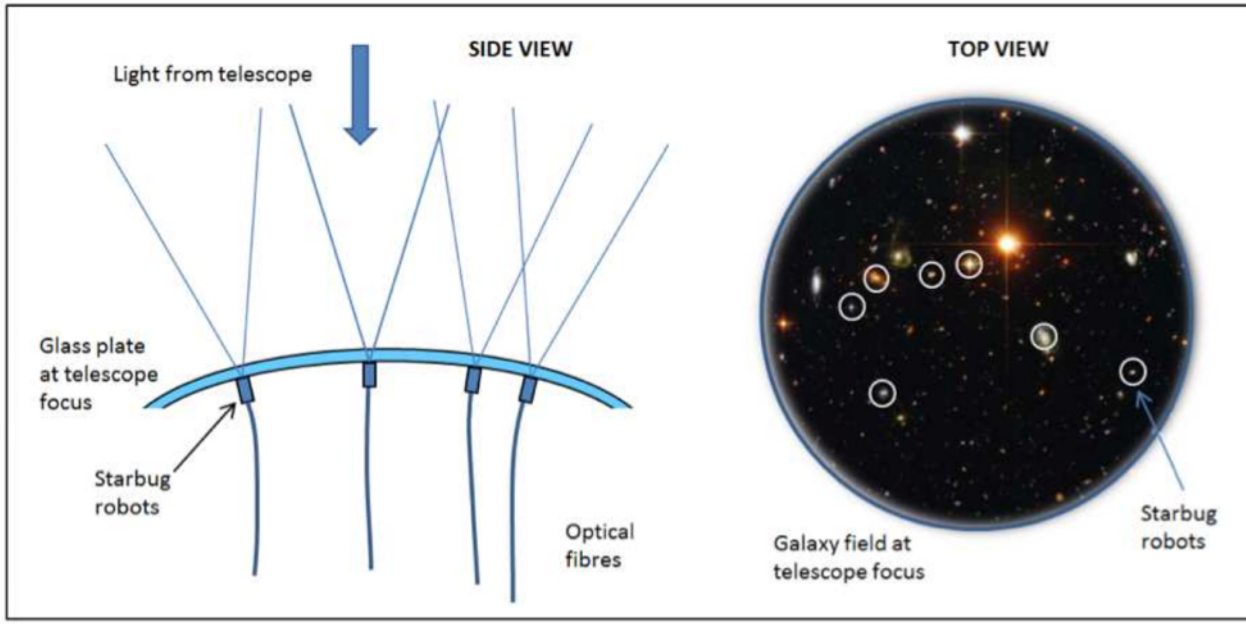
UKST-TAIPAN instrument system

- The Taipan survey will employ the new TAIPAN multi-fibre spectrograph on a rejuvenated UKST…
  - The 1.2-metre UK Schmidt Telescope at Siding Spring Observatory is being completely refurbished so that it can operate in an automated mode, substantially increasing efficiency and reducing operating costs
  - A new 150-fibre Starbugs positioner is being built by AAO to provide rapid automated reconfigurations (a prototype for the MANIFEST system on the Giant Magellan Telescope); a proposal to upgrade this to 300 fibres is under review
  - A new TAIPAN spectrograph is being built by AAO to provide high-throughput, fixed-format spectroscopy over the full visible range from 370nm to 870nm at R~2100

The UK Schmidt Telescope (before)

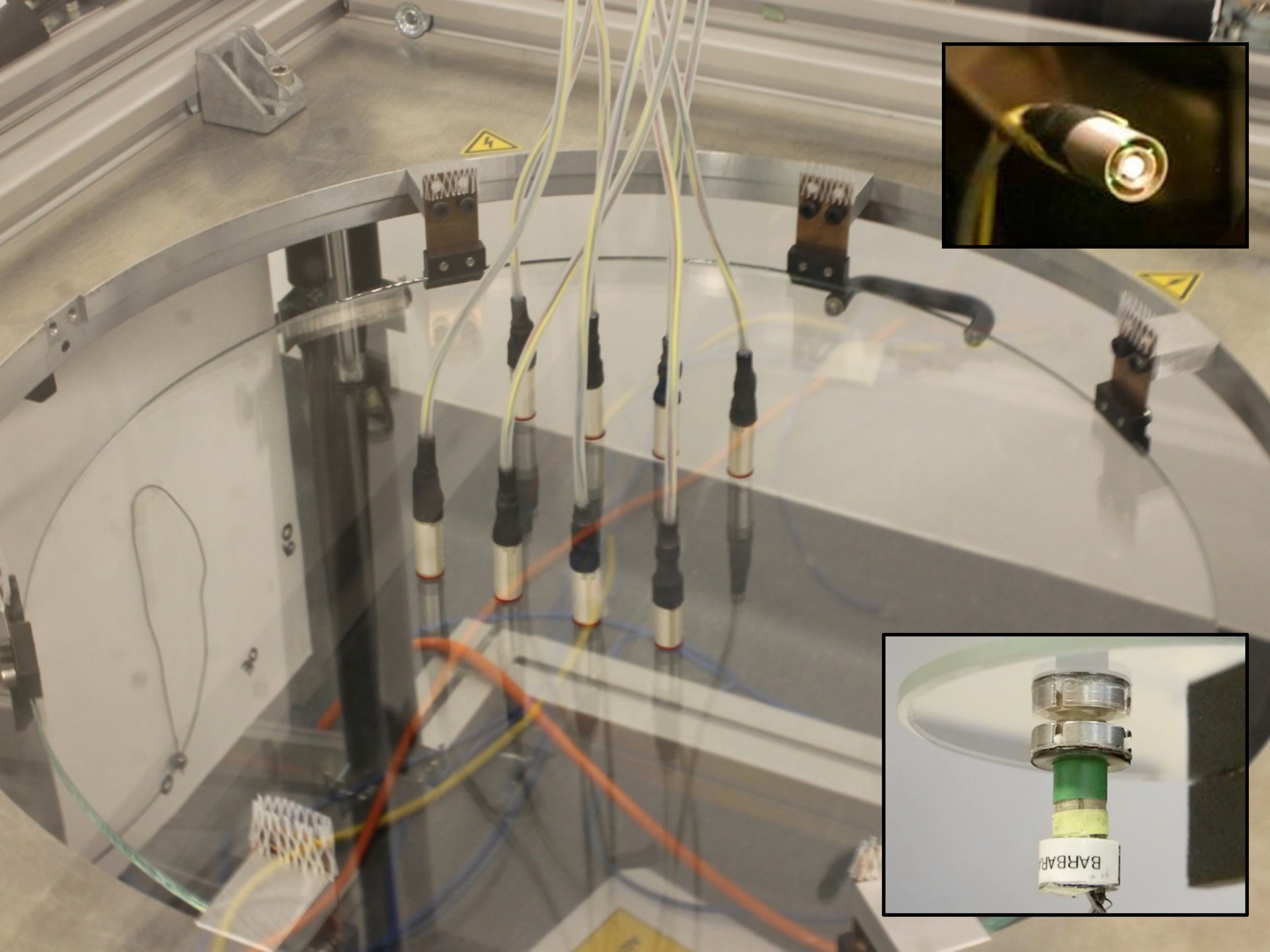
Starbugs fibre positioner

- Starbugs are piezoelectric micro-robots providing an elegant way to position fibres in telescope focal planes



- A prototype Starbugs system for the UKST has already seen first light; the full system will be completed by late 2016

- Starbugs will also be used in the MANIFEST fibre system that will feed spectrographs on the Giant Magellan Telescope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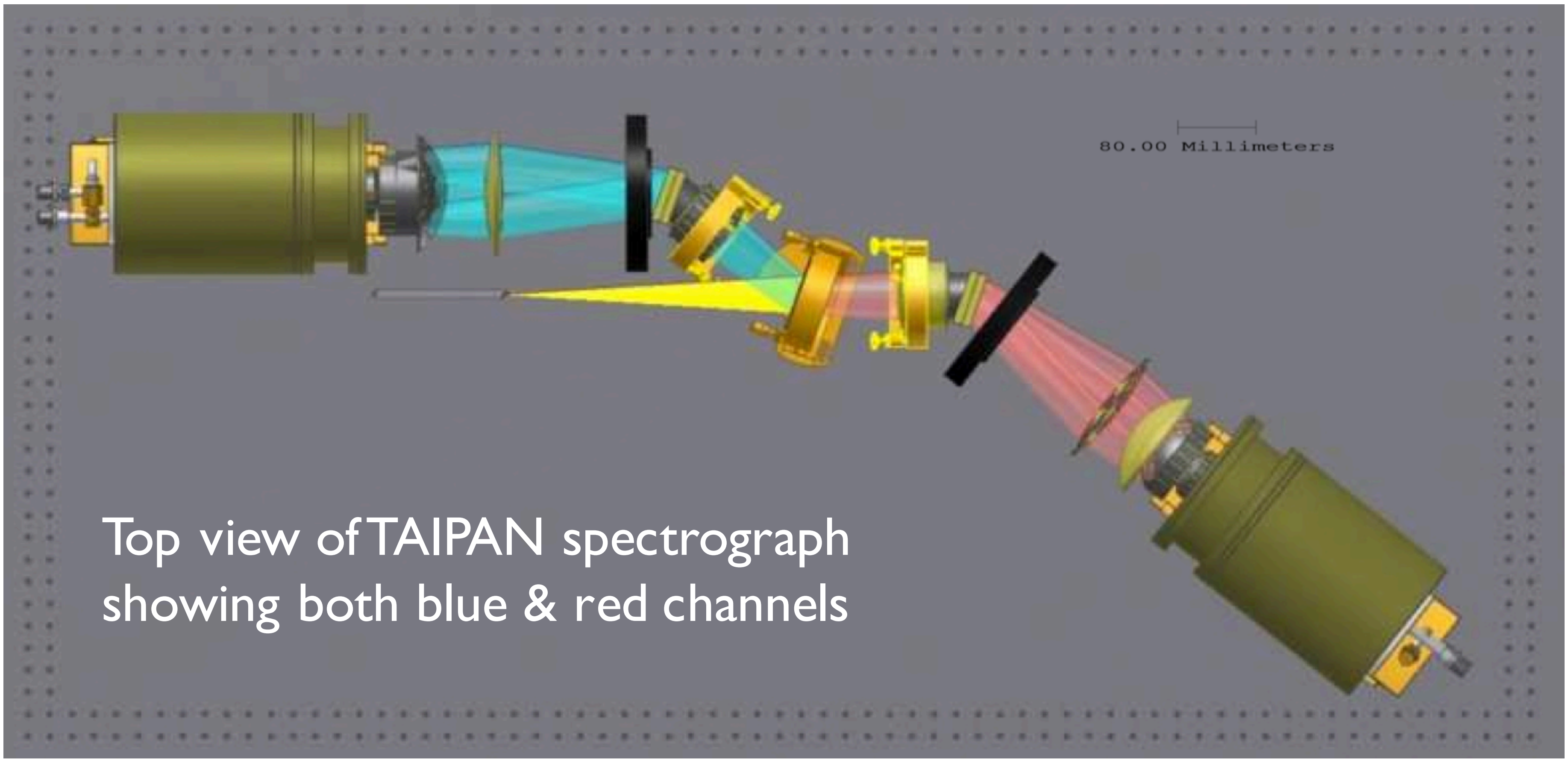
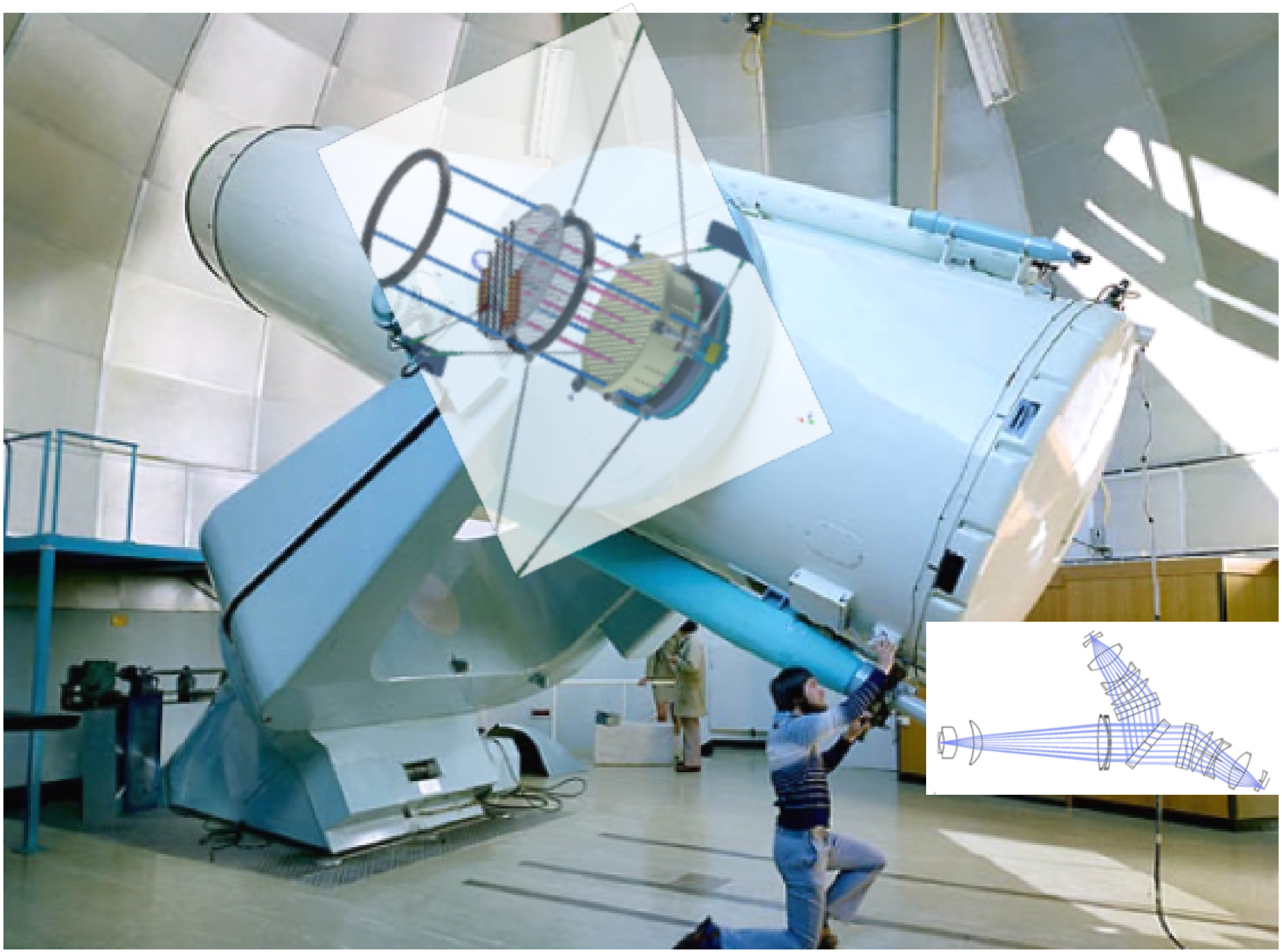
TAIPAN spectrograph

- The TAIPAN spectrograph is a two-channel, fixed format design
- Covers 370-870nm at R~2100 with 3.3" diameter input fibres



The UK Schmidt Telescope (with TAIPAN)



TAIPAN technical specifications

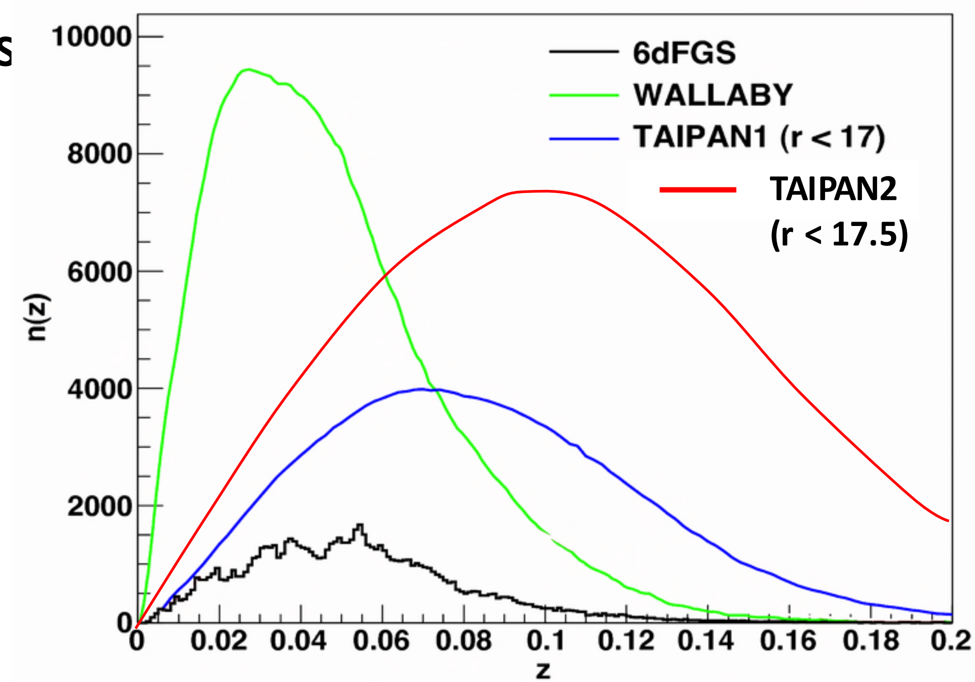
Field of view	6 degree diameter
Number of fibres	150 (upgrade to 300)
Fibre diameter	3.3 arcsec
Wavelength range	370 – 870 nm
Resolving power	1960 (blue) to 2740 (red)

The Taipan survey

- Taipan will measure redshifts for ~1,00,000 galaxies to r≈17.5 (K≈14.5) with <z> ≈ 0.1 over V_{eff} ≈ 1Gpc^3
  - cf. 6dFGS: 125,000 redshifts to K ≈ 12.65 and <z> ≈ 0.05 over V_{eff} ≈ 0.24 Gpc^3 (so Taipan is ~8x number, ~4x volume)
- Taipan will measure peculiar velocities for ~100,000 galaxies using the Fundamental Plane distance estimator
  - cf. 6dFGS: 9000 velocities (so Taipan is ~10x bigger)
- Bright time: *FunnelWeb* survey of 3x10^6 stars with 5.7<V<12.5 and $\delta < +30^\circ$ targeted in future exoplanet searches (e.g. TESS)
  - expands on legacy of RAVE (Steinmetz+ 2006, Siebert+ 2011) which observed ~0.5x10^6 stars with lower R and λλ coverage
  - requires the rapid fibre positioning of the Starbugs technology to acquire an average of 5 fields/hour (a spectrum every 2s !)

Taipan & WALLABY

- WALLABY is an all-sky HI survey that will measure redshifts for ~500,000 HI galaxies using the Australian SKA Pathfinder: $b \approx 0.7$, $\langle z \rangle \approx 0.04$, $V_{eff} \approx 0.35\ Gpc^3$
- WALLABY will also obtain HI Tully-Fisher distances and peculiar velocities for a large sample of spirals
- WALLABY TF peculiar velocities for spirals will complement the Taipan FP peculiar velocities for early-types, sampling more densely the nearer half of the Taipan survey volume

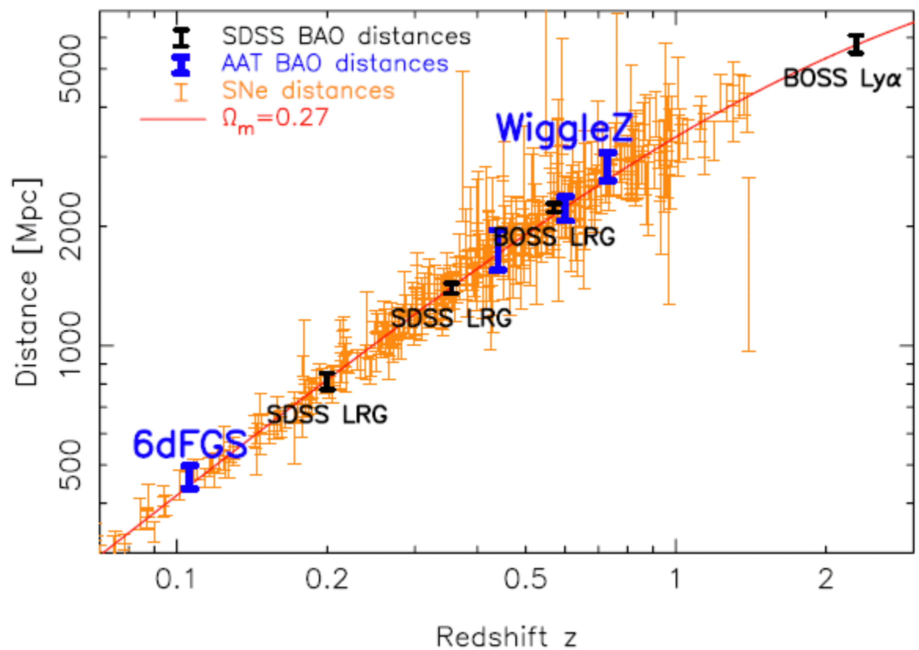


A combined all-sky survey

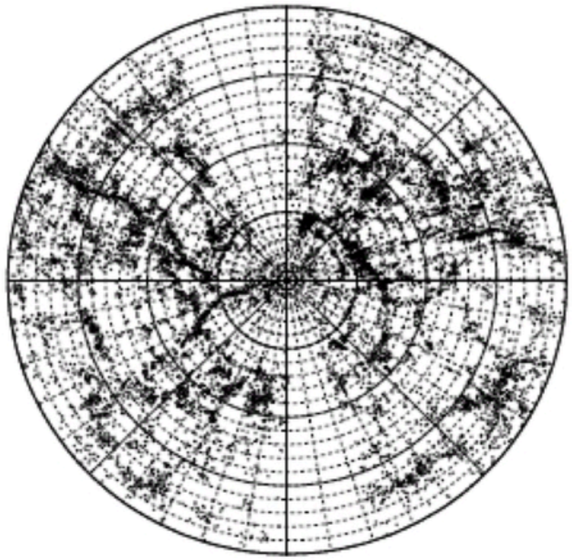
- Strong arguments for an all-sky survey of local universe:
  - to completely characterize the local velocity field, especially the monopole (local Hubble constant) and dipole terms
  - to map the foreground large-scale structure for cross-correlation with deeper observations (particularly all-sky CMB surveys)
  - to make a definitive database of optical spectra for local galaxies
- This can be achieved by combining the SDSS, Taipan and LAMOST surveys into an all-sky (|b|>10) survey to r ≈ 17.5
  - Taipan will cover southern hemisphere (+ perhaps some of the north)
  - SDSS/BOSS cover $\gtrsim\pi$ steradians of north (+ some overlap in south)
  - LAMOST could cover the remaining $\lesssim\pi$ steradians of north
  - All surveys can provide good S/N spectra to r ≈ 17.5 at R~2000
  - Need consistent selection criteria (pre-/post-selection of sample) based on SDSS + SkyMapper + Pan-STARRs imaging

Measuring H_0 with BAO

- Baryon acoustic oscillations (BAO) imprint co-moving scale of 146 Mpc on matter distribution (calibrated to 0.3% by Planck)
- BAO scale is well within the linear regime of gravitationally growing fluctuations, so is a standard ruler seen at all redshifts that allows mapping of cosmic distances and geometry
- First detected in z-surveys by 2dFGRS (Cole+2005) & SDSS (Eisenstein+2005)
- Key application of BAO in low-redshift surveys is measuring H_0



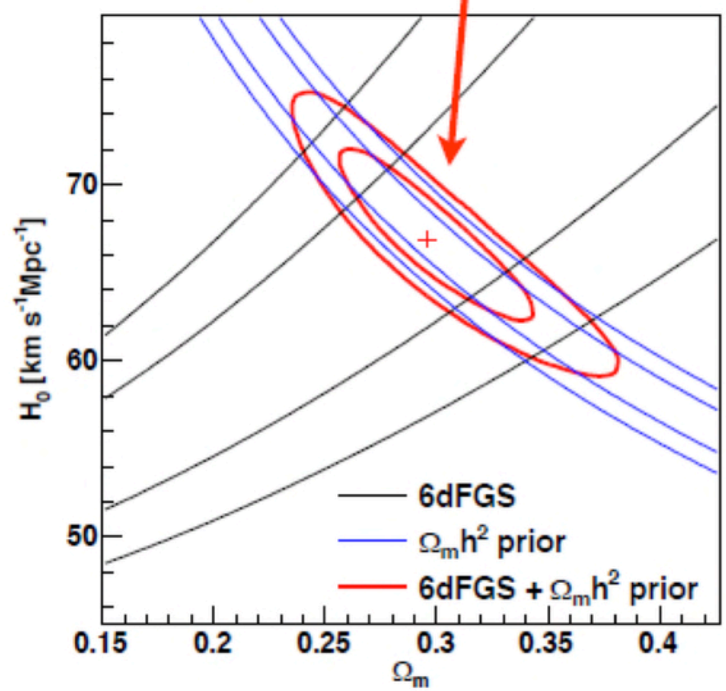
Existing low-z BAO H_0 measurement



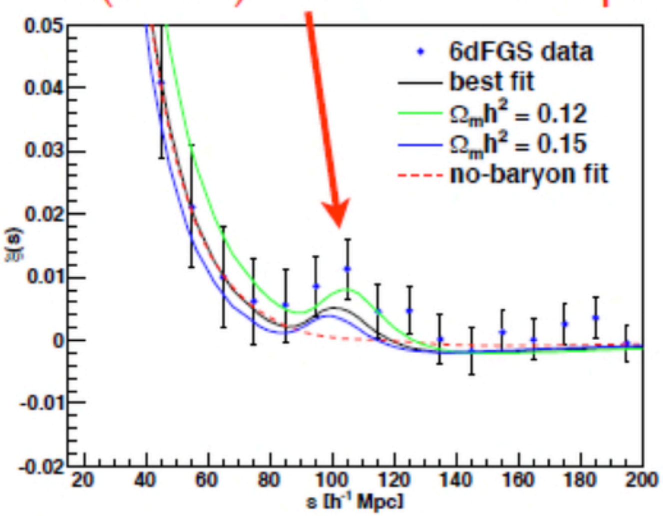
6dF Galaxy Survey

Beutler et al. (2011)

H_0 = 67.0 +/- 3.2 km s^{-1} Mpc^{-1}



D(z=0.1) = 456 +/- 27 Mpc



Hubble constant from 6dFGS

At low z, distance measurements only constrain H_0 – but are *model-independent*!

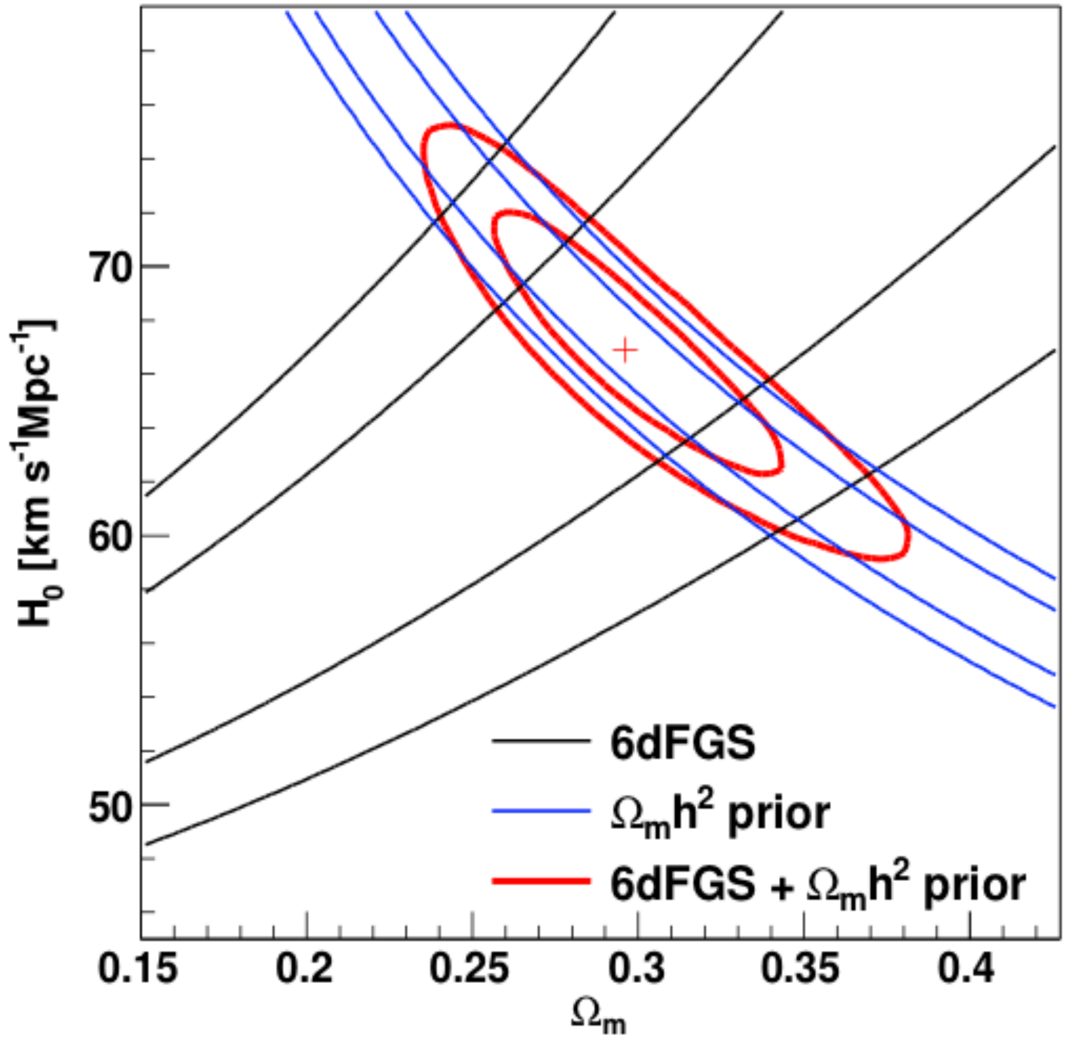
low-z

Beutler+ 2011 (6dFGS, BAO)
$H_0 = 67 \pm 3.2$ km/s/Mpc

Riess+ 2016 (Cepheids, SNe)
$H_0 = 73.0 \pm 1.8$ km/s/Mpc

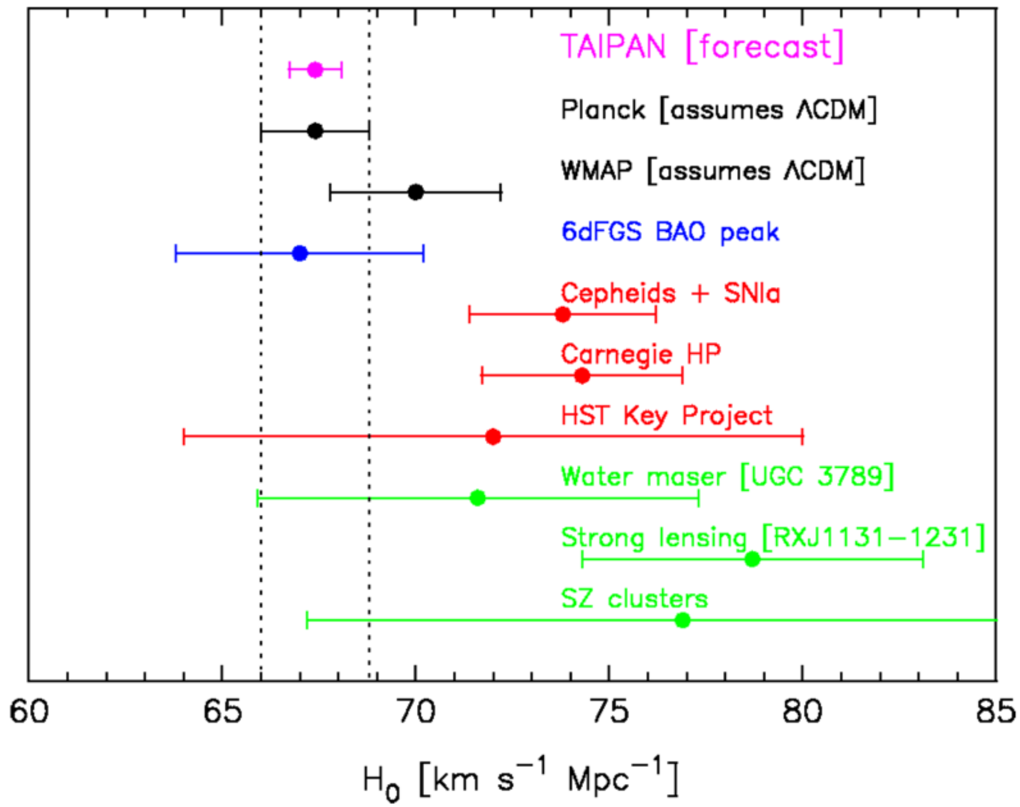
high-z

Planck 2015 (CMB, BAO)
$H_0 = 67.3 \pm 0.7$ km/s/Mpc
(*model-dependent*)



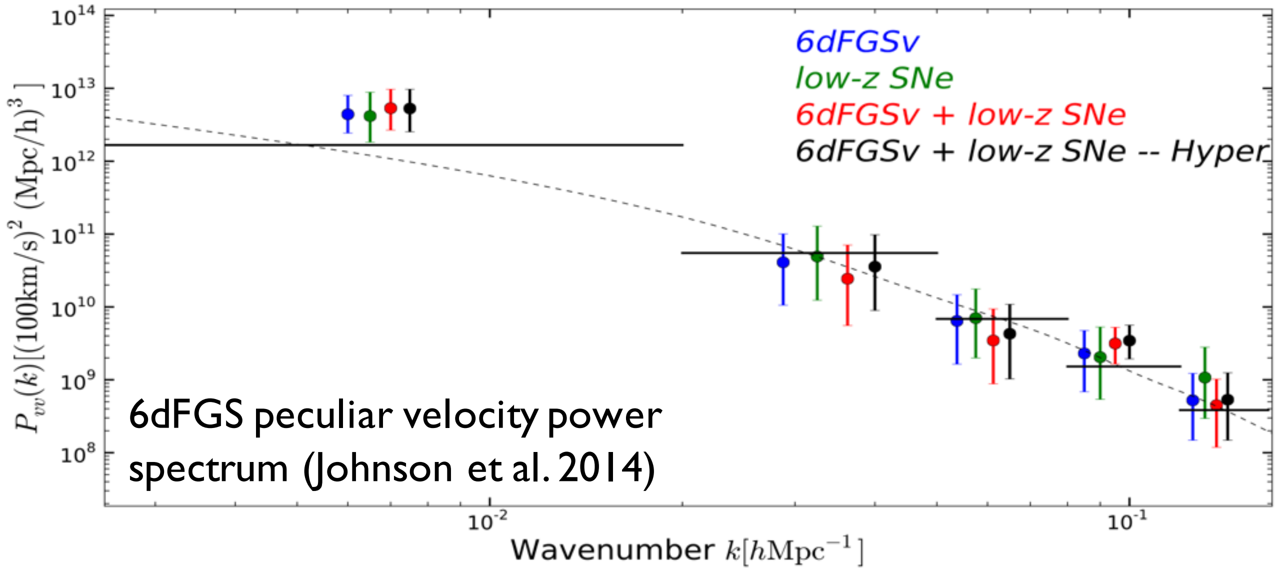
Hubble constant from Taipan

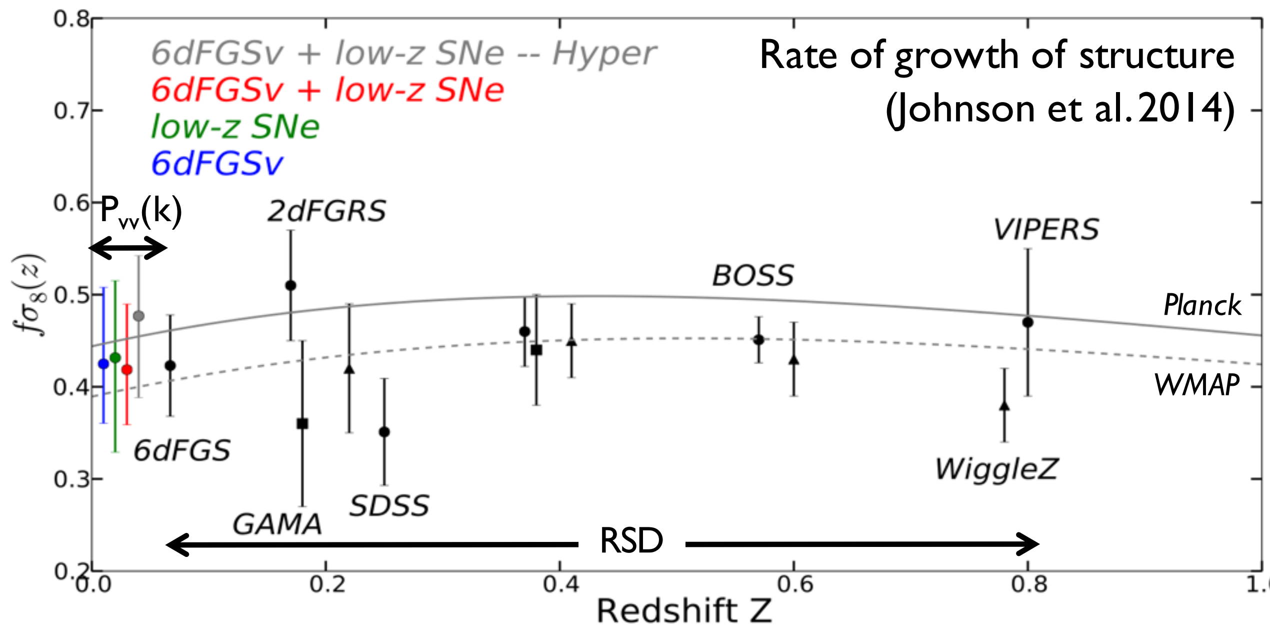
- With redshifts for ~1,000,000 galaxies at <z> ≈ 0.1 over a volume V_{eff} ≈ 1Gpc^3, simulations indicate Taipan will measure H_0 with ~1% precision
- This is a 4x better than 6dFGS:
  - Gain a factor of ~2 from larger sample size and volume of TAIPAN cf. 6dFGS
  - Gain another factor of ~2 from better BAO reconstruction



Cosmology from velocities – 6dFGS

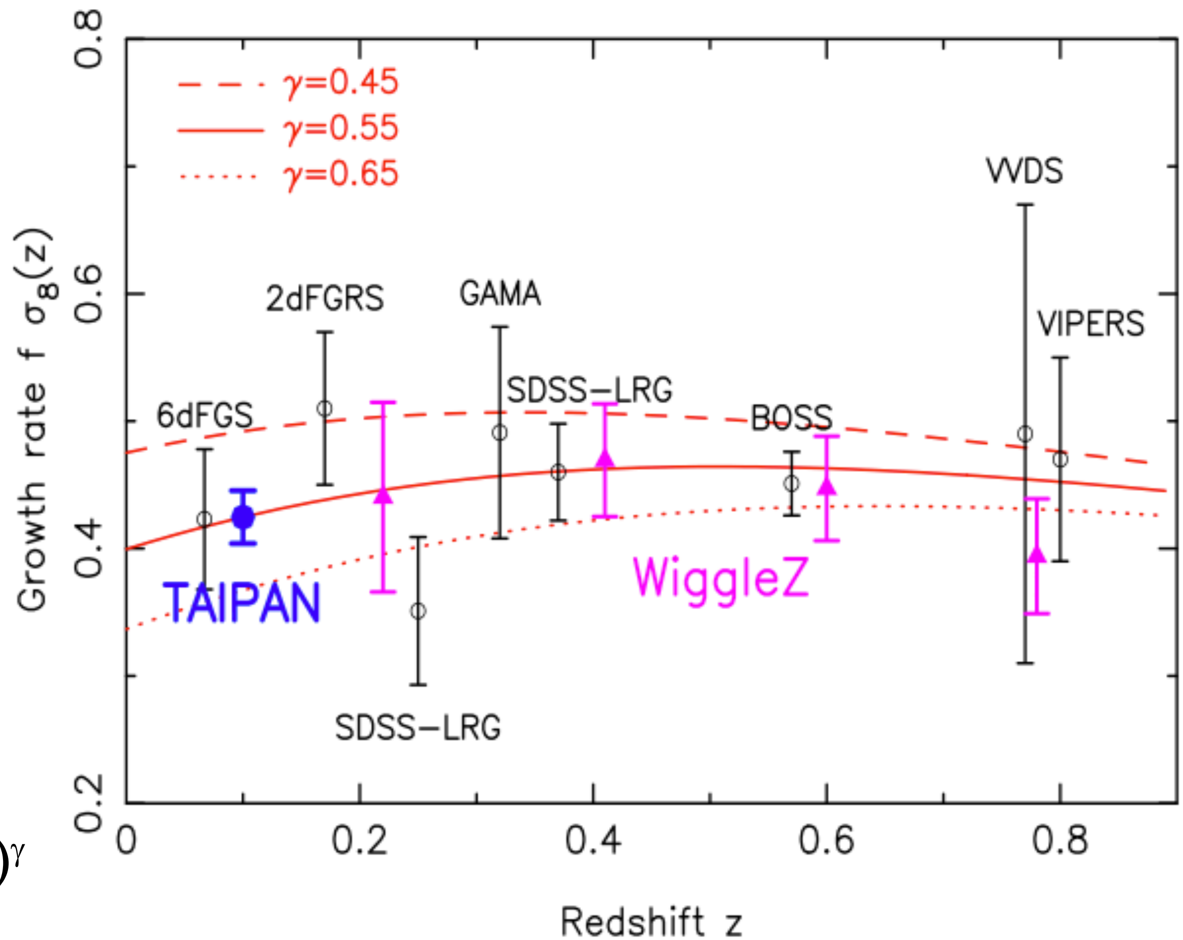
- Analysis of peculiar velocity power spectrum $P_{vv}(k)$ provides additional new constraints on parameters that are degenerate in $P_{gg}(k)$
- 6dFGS has measured $P_{vv}(k)$ and the growth rate of structure $f\sigma_8$:
  - The growth rate is scale-independent for scales <300 Mpc/h
  - Overall growth rate at z~0 from $P_{vv}(k)$ is consistent with higher-z estimates from RSD, and with Planck/WMAP LCDM models





Cosmology from velocities – Taipan

- The Taipan velocity survey improves on 6dFGS by having…
  - ~2x the volume
  - ~10x sample size
  - smaller peculiar velocity errors
- Taipan will constrain the growth rate of structure at z~0 to 5% from RSD & $P_{vv}(k)$
- Can distinguish models of gravity with $f\sigma_8 \sim \Omega(z)^\gamma$ and $\gamma - \gamma_{GR} > 0.05$



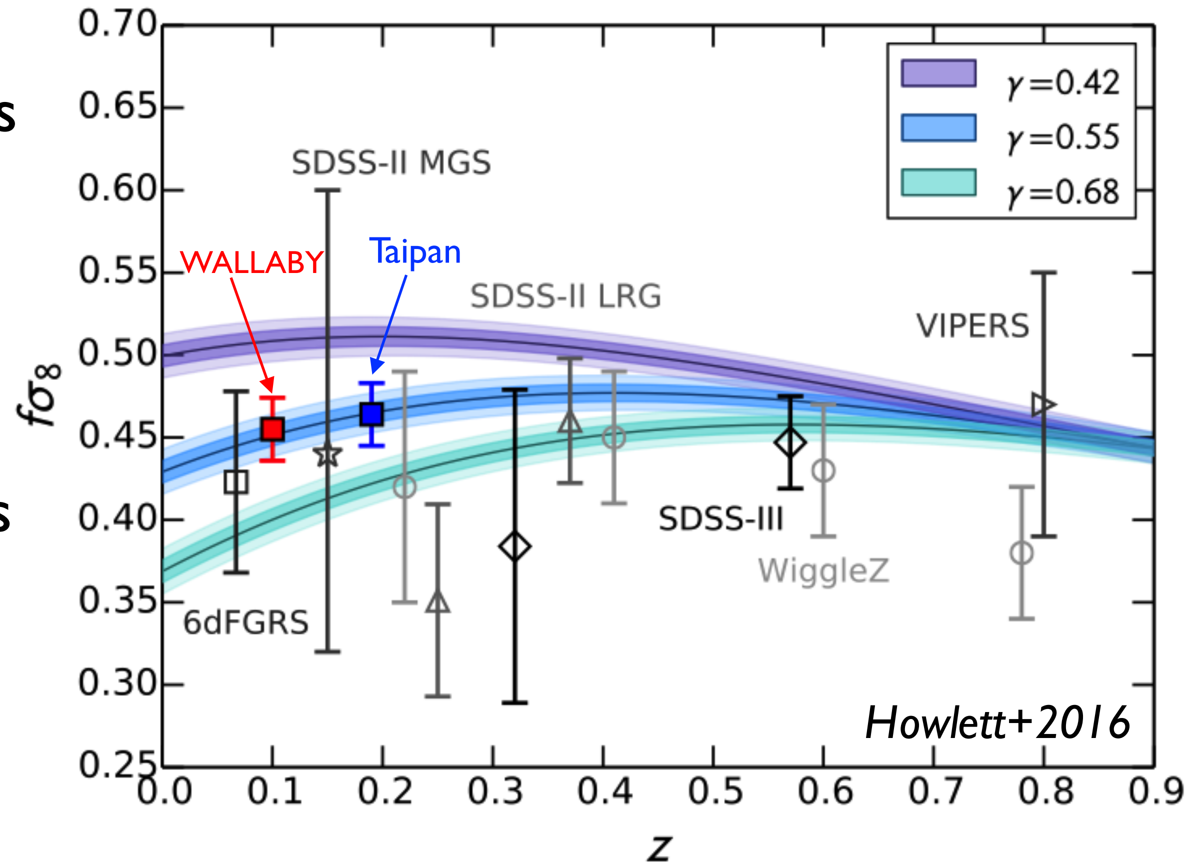
- Potential to combine the optical Taipan survey with the HI WALLABY survey to provide cross-checks and multi-tracer analysis of velocity field

Joint fits to density & velocity fields

- The density fluctuations sources the large-scale velocity field, so sample variance cancels
- Combining z & v tightens constraints on $\beta = f/b = \Omega^\gamma/b$
- If β varies on large scales, implies non-standard physics such as non-Gaussianity or modified gravity
- Combining z & v reduces degeneracy due to galaxy bias
- Burkey+Taylor(2004), Koda+(2014) & Howlett+(2016) provide full density & velocity Fisher matrix forecasts for Taipan, both alone & combined with other surveys (incl. effects of primordial non-Gaussianity, scale-dependent density/velocity biases, & zero-point offsets)

Growth rate of structure constraints

- Taipan and WALLABY jointly provide significantly improved constraints on the growth rate of structure parameter
- The combination of the two surveys can measure $f\sigma_8$ to <3% precision
- The low redshifts of the WALLABY and Taipan samples allow for a much more stringent test of deviations from GR, as it is at low z where differing γ produce the largest changes in $f\sigma_8$



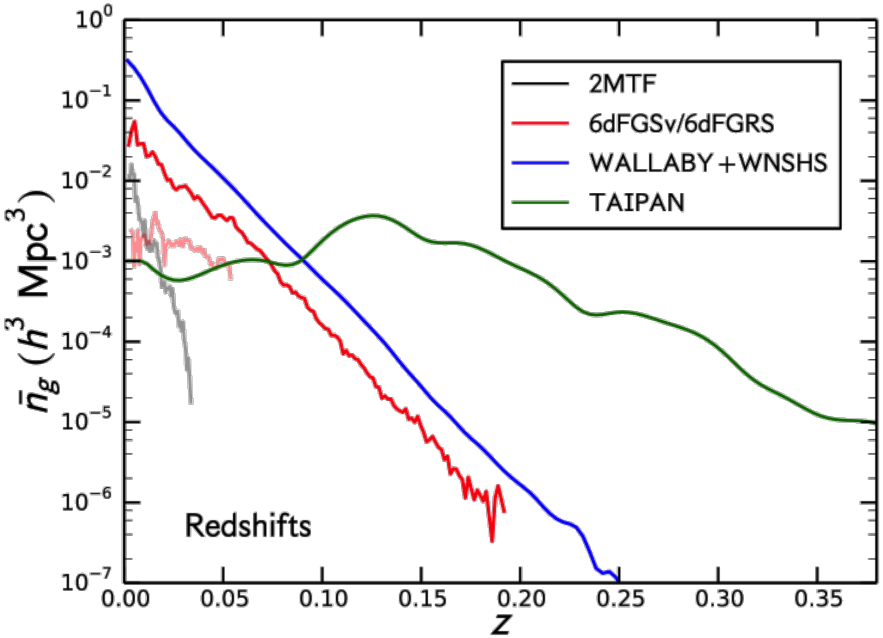
Taipan survey - summary

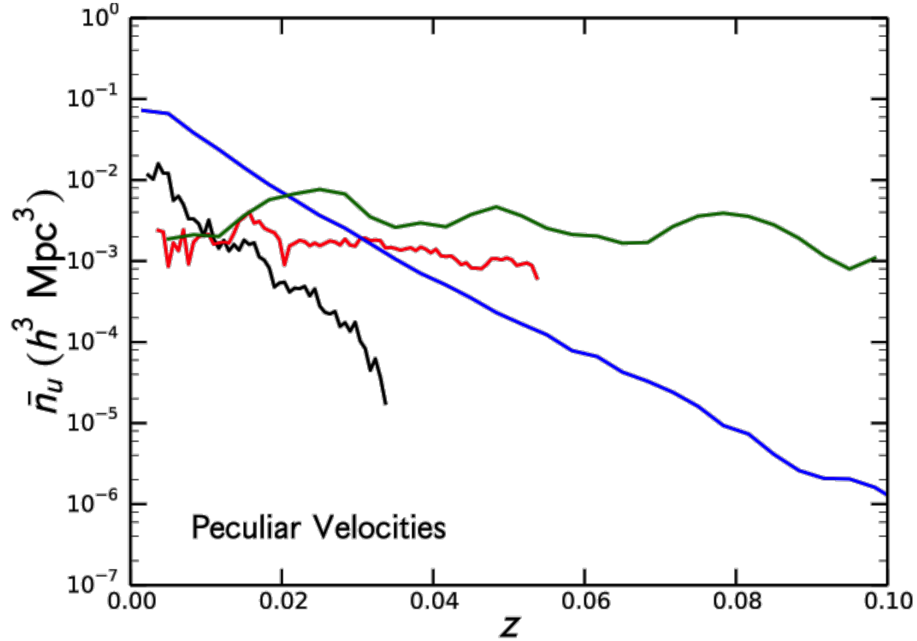
- Starting in early 2017, the Taipan survey will use a refurbished UKST with a new fibre positioner and a new spectrograph to measure 1,000,000 redshifts and 100,000 peculiar velocities for southern hemisphere galaxies over ~1Gpc^3 of the nearby universe

- The Taipan survey will…
  - provide a definitive map of the local southern large-scale structure and a legacy database to combine with other all-sky surveys
  - increase the number of measured peculiar velocities by ~10x and the mapped volume of the velocity field by ~2x
  - provide precise measures of the galaxy & velocity power spectra and the correlation between the distributions of galaxies & DM
  - yield a model-independent measure of the local Hubble constant to 1% precision and of the growth rate of structure to 5%
  - combining Taipan with WALLABY will tighten these constraints

Redshift sampling of surveys

Howlett+2016





Forecast constraints

Predictions from Fisher matrix analysis by Howlett+(2016) for results from combining various redshift and velocity surveys…

Combined Density and Velocity Fields		$100 \times \sigma(\theta_i) \,/\, \theta_i$				
Survey	Parameters	$f\sigma_8$	β	r_g	σ_u	σ_g
						$k_{max} = 0.2\,h\,\mathrm{Mpc}^{-1}$
2MTF	$f\sigma_8$, β	14.8	16.5	-	-	-
	$f\sigma_8$, β, r_g, σ_u, σ_g	20.8	21.2	3.5	27.4	92.6
6dFGSv	$f\sigma_8$, β	12.8	14.0	-	-	-
	$f\sigma_8$, β, r_g, σ_u, σ_g	17.6	17.9	4.7	32.8	45.7
6dFGSv +	$f\sigma_8$, β	8.0	8.9	-	-	-
6dFGRS	$f\sigma_8$, β, r_g, σ_u, σ_g	11.7	12.1	1.8	29.2	21.5
2MTF +	$f\sigma_8$, β	9.7	11.4, 10.6	-	-	-
6dFGSv	$f\sigma_8$, β, r_g, σ_u, σ_g	13.3	14.3, 13.5	3.2, 3.0	23.5, 30.3	71.6, 42.3
2MTF +	$f\sigma_8$, β	6.8	8.6, 7.5	-	-	-
6dFGSv + 6dFGRS	$f\sigma_8$, β, r_g, σ_u, σ_g	9.7	11.2, 10.0	2.6, 1.0	22.0, 28.3	59.5, 20.0
TAIPAN	$f\sigma_8$, β	2.3	2.6	-	-	-
	$f\sigma_8$, β, r_g, σ_u, σ_g	4.1	4.2	2.3	12.1	6.8
WALLABY +	$f\sigma_8$, β	2.7	3.3	-	-	-
WNSHS	$f\sigma_8$, β, r_g, σ_u, σ_g	4.2	4.4	0.3	6.8	12.9
TAIPAN +	$f\sigma_8$, β	1.8	2.2, 2.0	-	-	-
WALLABY + WNSHS	$f\sigma_8$, β, r_g, σ_u, σ_g	2.8	3.0, 3.1	1.1, 0.3	10.9, 6.4	5.7, 9.7

γ constraints	$100 \times \sigma(\gamma) \,/\, \gamma$	
Survey	Velocity Only	Velocity + Density
2MTF	40.4	24.0
6dFGSv	37.4	20.3
6dFGSv + 6dFGRS	37.4	13.6
2MTF + 6dFGSv	28.4	15.5
2MTF + 6dFGSv + 6dFGRS	28.4	11.3
TAIPAN	15.2	5.2
WALLABY + WNSHS	16.4	5.3
TAIPAN + WALLABY + WNSHS	11.5	4.0

Cullan Howlett will describe these results in detail in his talk later in this meeting