Mapping the Dark Matter in the Local Universe

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April 10, 2012

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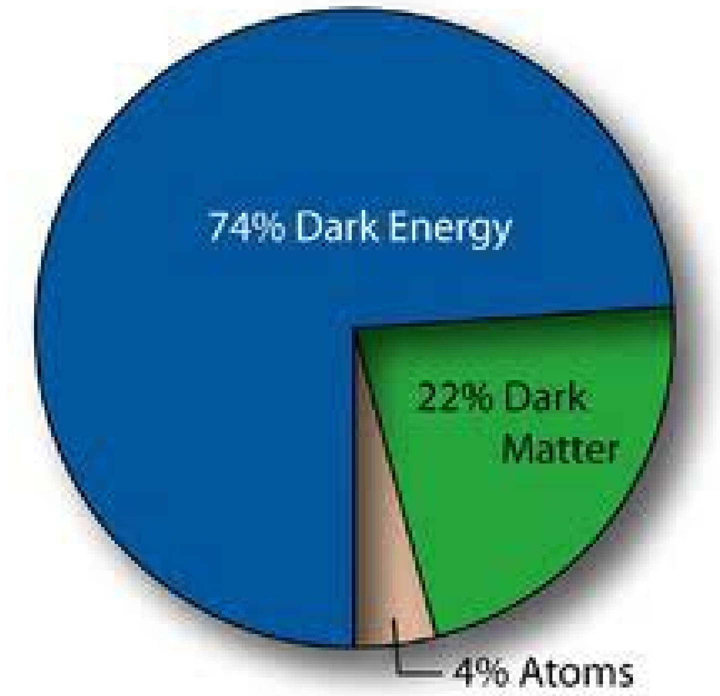
Dark Matter

Detected in regions where M/L > 100

- –Outer parts of spiral galaxies
- –Dwarf spheroidal galaxies
- –Clusters of galaxies



Not detected in the lab yet, but see

http://www.cfa.harvard.edu/events/2010/dyn/

Mapping Dark Matter

Use the gravitational effect of matter on light

- Weak lensing

Measure the motions of galaxies induced by dark matter

- Peculiar velocities

The bullet cluster

Credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.;
Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

Mapping the Dark Matter in the Local Universe

Conventional wisdom is that the distribution of dark matter in the Universe follows the distribution of galaxies.

Detailed models of the evolution of structure, such as the Millenium Simulation, embody that assumption.

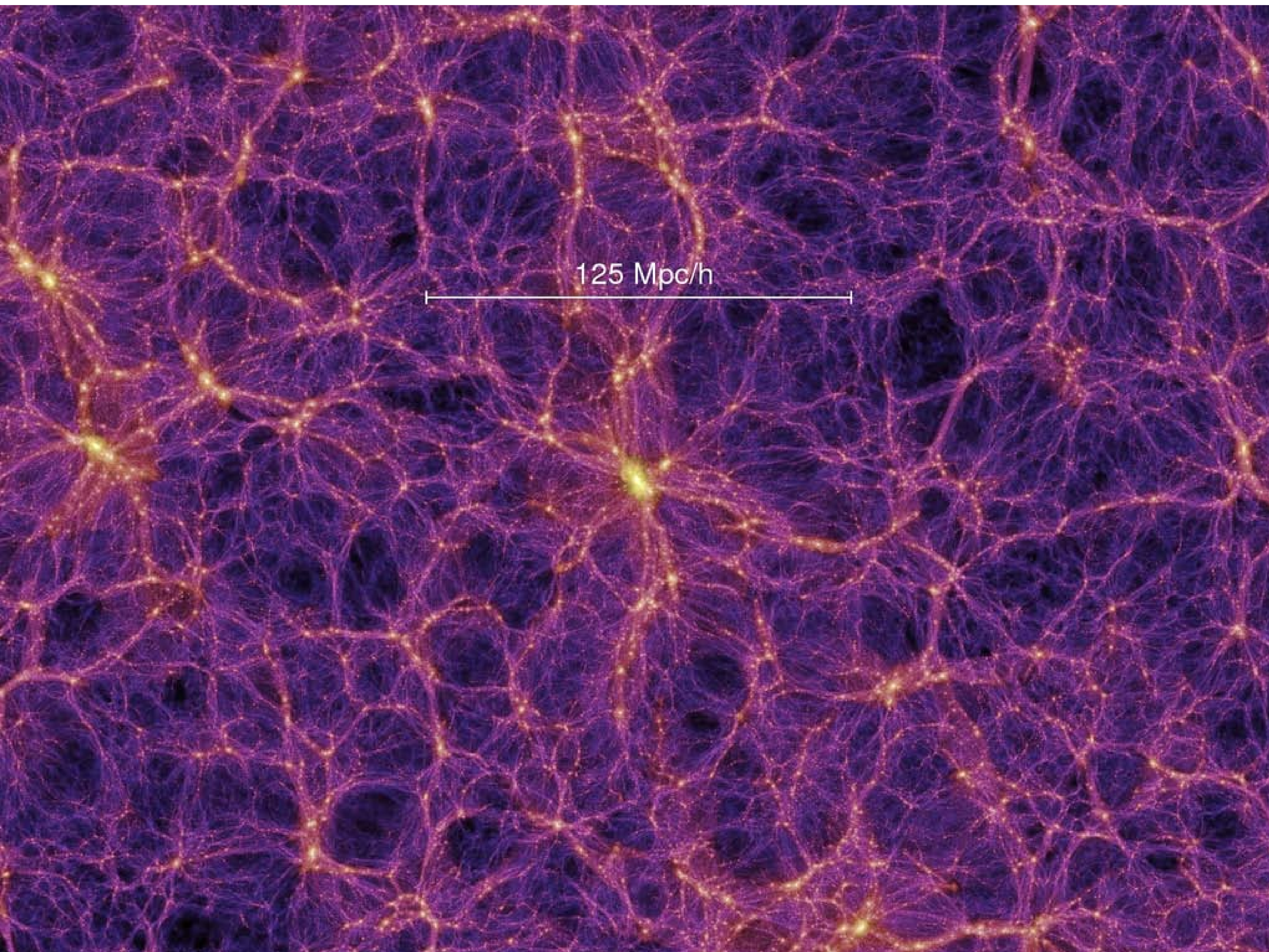
Redshift surveys such as 2dFGRS and SDSS appear to be consistent with this relationship.

An observational test of the assumption is possible and is potentially very informative about the nature of dark matter.

Measurement of galaxy distances allows non-Hubble-expansion velocities of galaxies to be determined

How can these data can be integrated to provide a map of the dark matter on 100 Mpc scales ?

Both current projects (using the 6dF galaxy redshift survey) and future projects using the Australian Square Kilometre Array Pathfinder (due to operate in 2014) are relevant.


125 Mpc/h

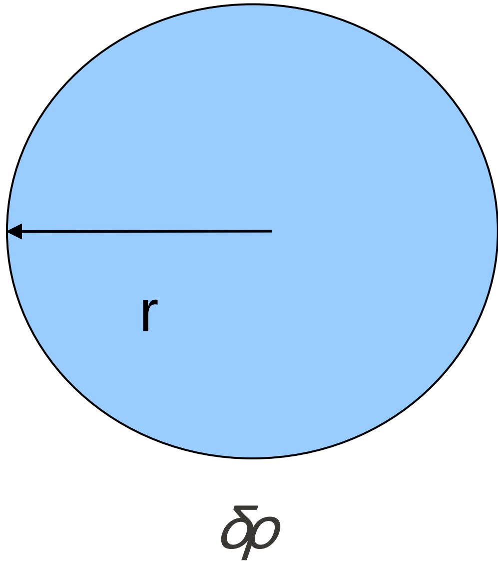
Density perturbations: Newtonian cosmology

$$\ddot{r} = -G\frac{4\pi}{3}r^3\frac{\delta\rho}{r^2}$$

$$\Omega = \frac{8\pi G\rho}{3\mathrm{H}^2}$$

$$\frac{\ddot{r}}{v} = -\frac{1}{2}H\frac{\delta\rho}{\rho}\Omega$$

$$\frac{\delta v}{v} = -\frac{\delta\rho}{\rho}\Omega$$



Calculate the velocity field from the density field

$$\vec{v} = \frac{Hf}{4\pi}\int \frac{\delta(\vec{x}\,')(\vec{x}-\vec{x}\,')d^3x'}{(|\vec{x}-\vec{x}\,'|)^3}$$

It is also possible to go in the reverse direction and calculate the density field from the velocity field

- Smooth and integrate the velocity field to get the potential
- Then recover the density field from the potential

$$v = \nabla \Phi$$

Summary of cosmic flow (linear approximation)

$$\vec{\nabla}.\vec{v} = -\frac{\delta\rho}{\rho} f(\Omega)H \qquad \vec{\nabla}\times\vec{v} = 0$$

Measuring galaxy peculiar velocities

Measure redshift (*cz*) and distance (*r*),
get velocity

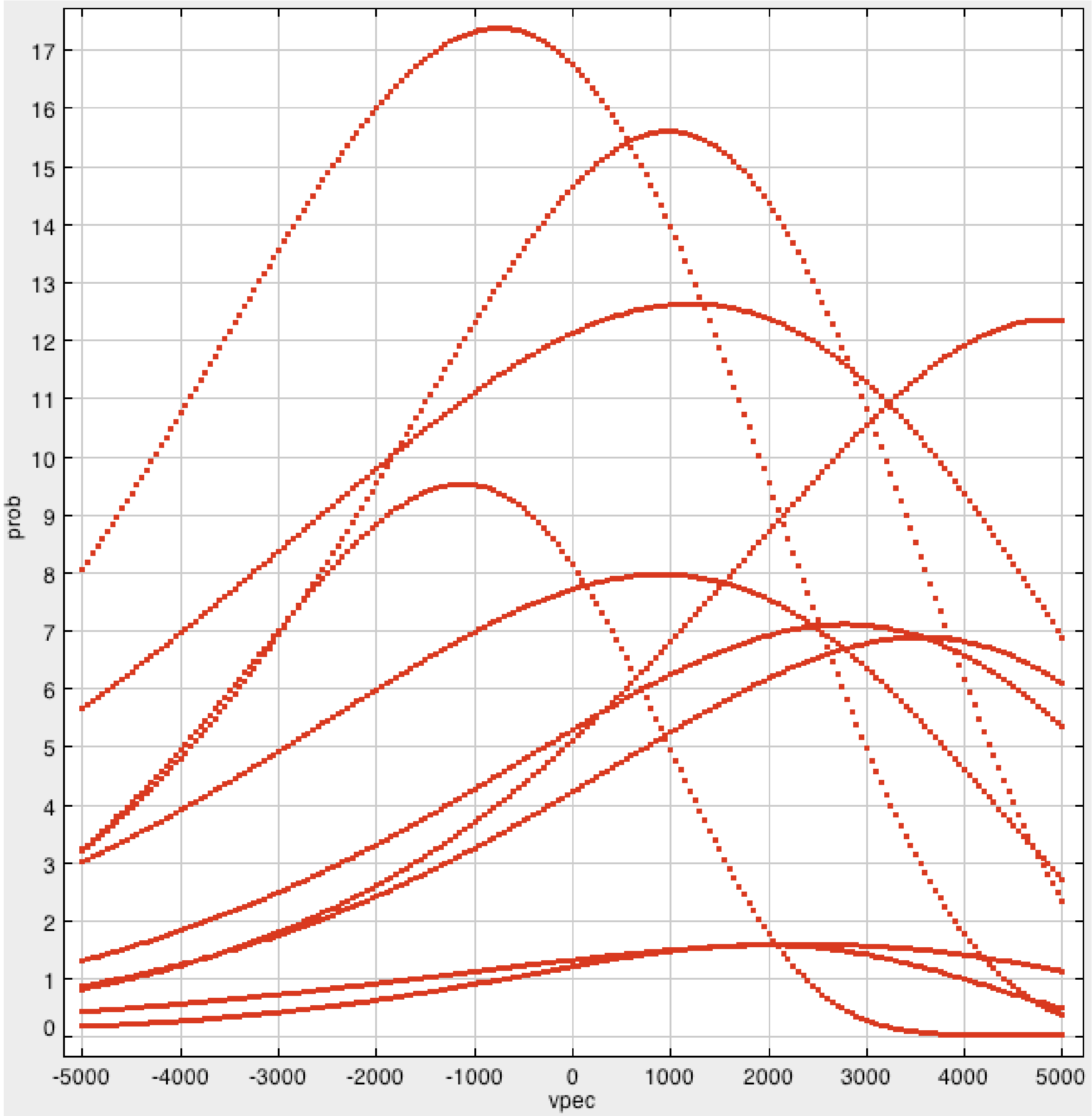
$$v = cz - H_0 r$$

6dFGS peculiar velocity sample

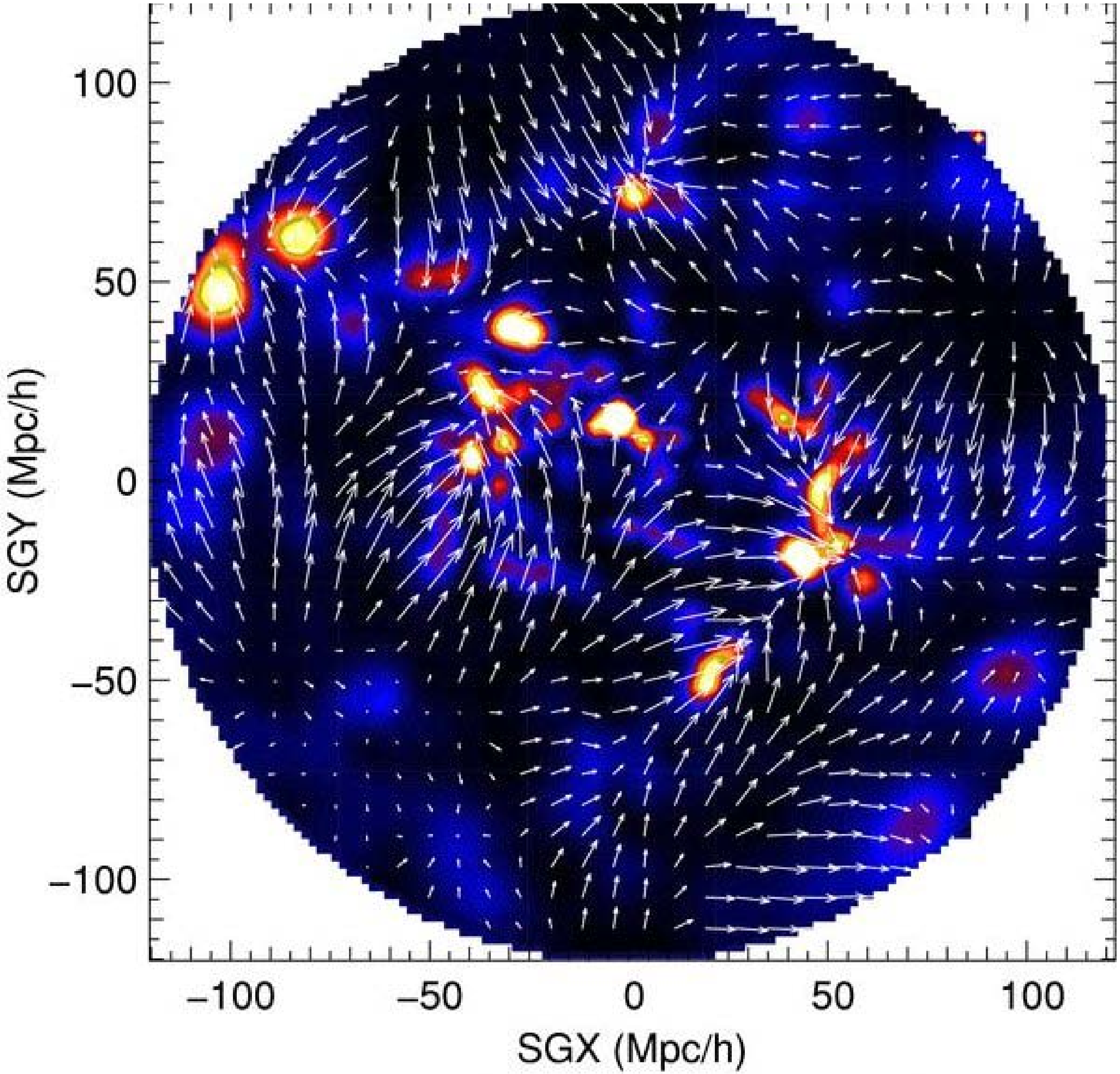
- 10000 early-type galaxies with cz<16500km/s with Fundamental Plane distances
- Covers the whole southern hemisphere (|b|>10)
- Deriving Bayesian posterior peculiar velocity probability distributions rather than 'peculiar velocities'
- The assumed prior is important as the likelihood distributions are broad (due to the large distance uncertainties):
    - Uninformative priors: uniform? Gaussian?
    - Peculiar velocity model: Tonry? from z-survey?

Posterior velocity distributions

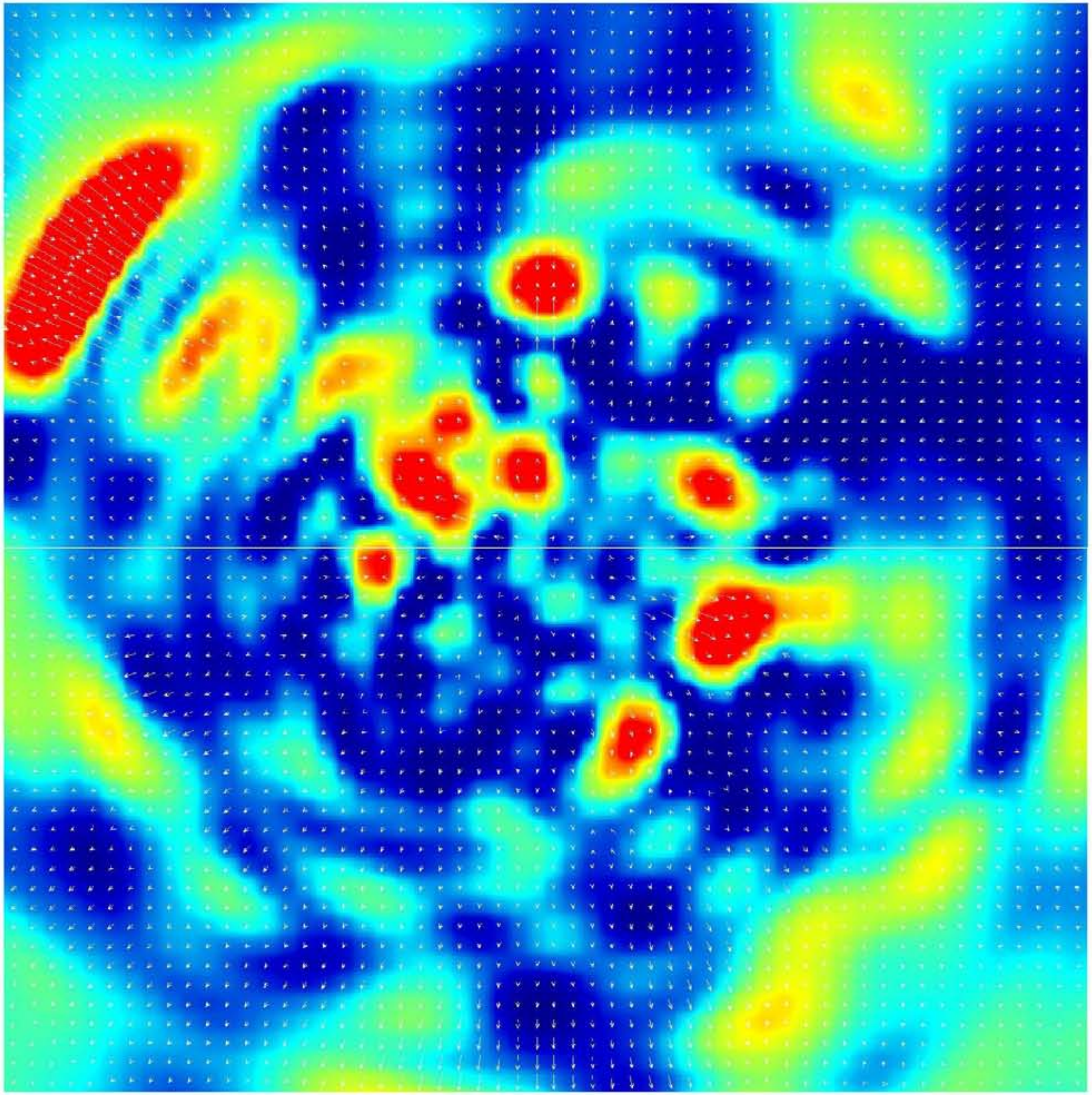
- Some examples of posterior peculiar distributions (with a uniform prior) for individual galaxies
- Distributions are very broad (due to uncertainties in distance estimates)
- To construct the velocity field, use adaptive spatial smoothing of PVs



2MRS predicted flowfield

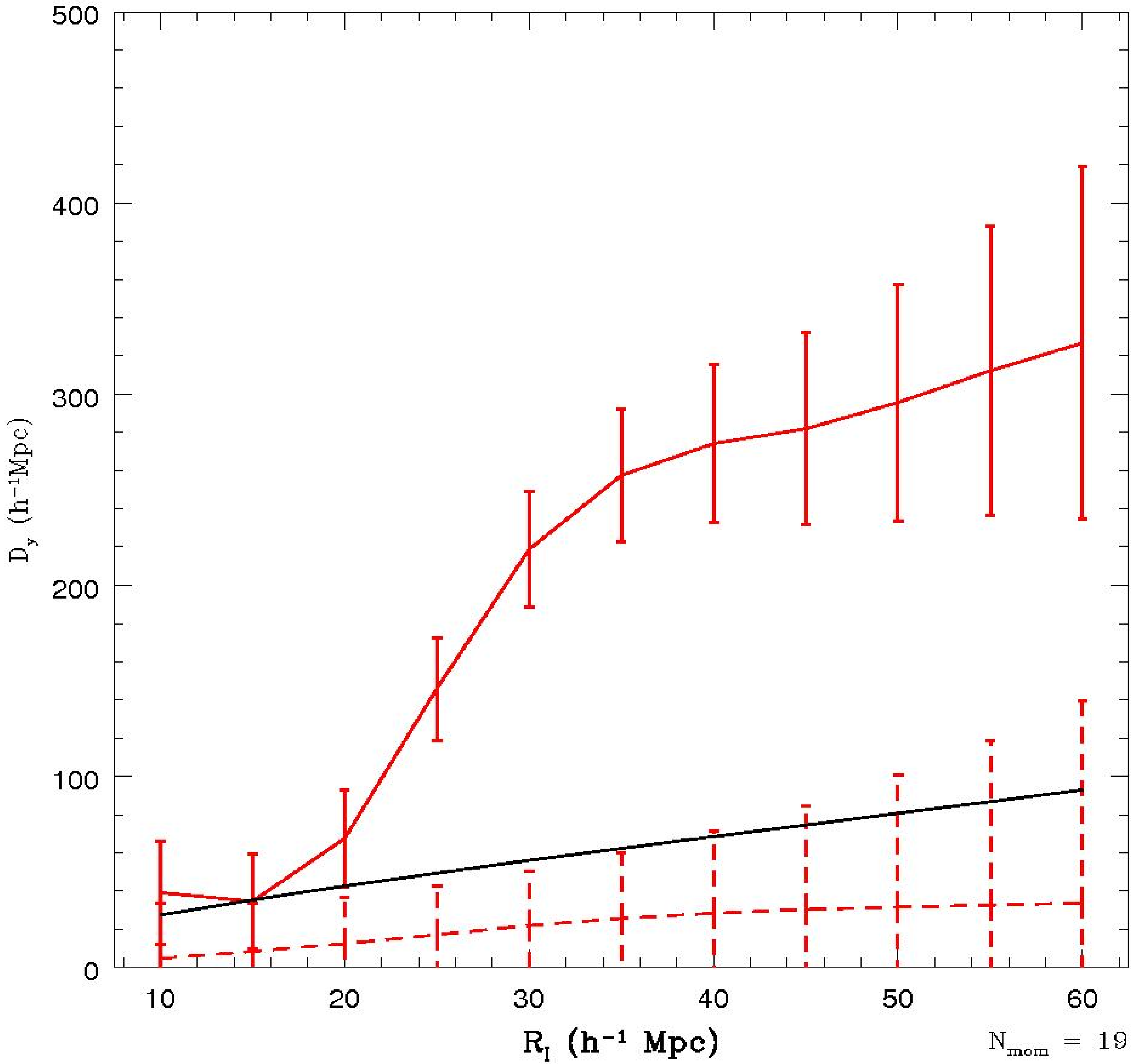


Lavaux & Tully 2010

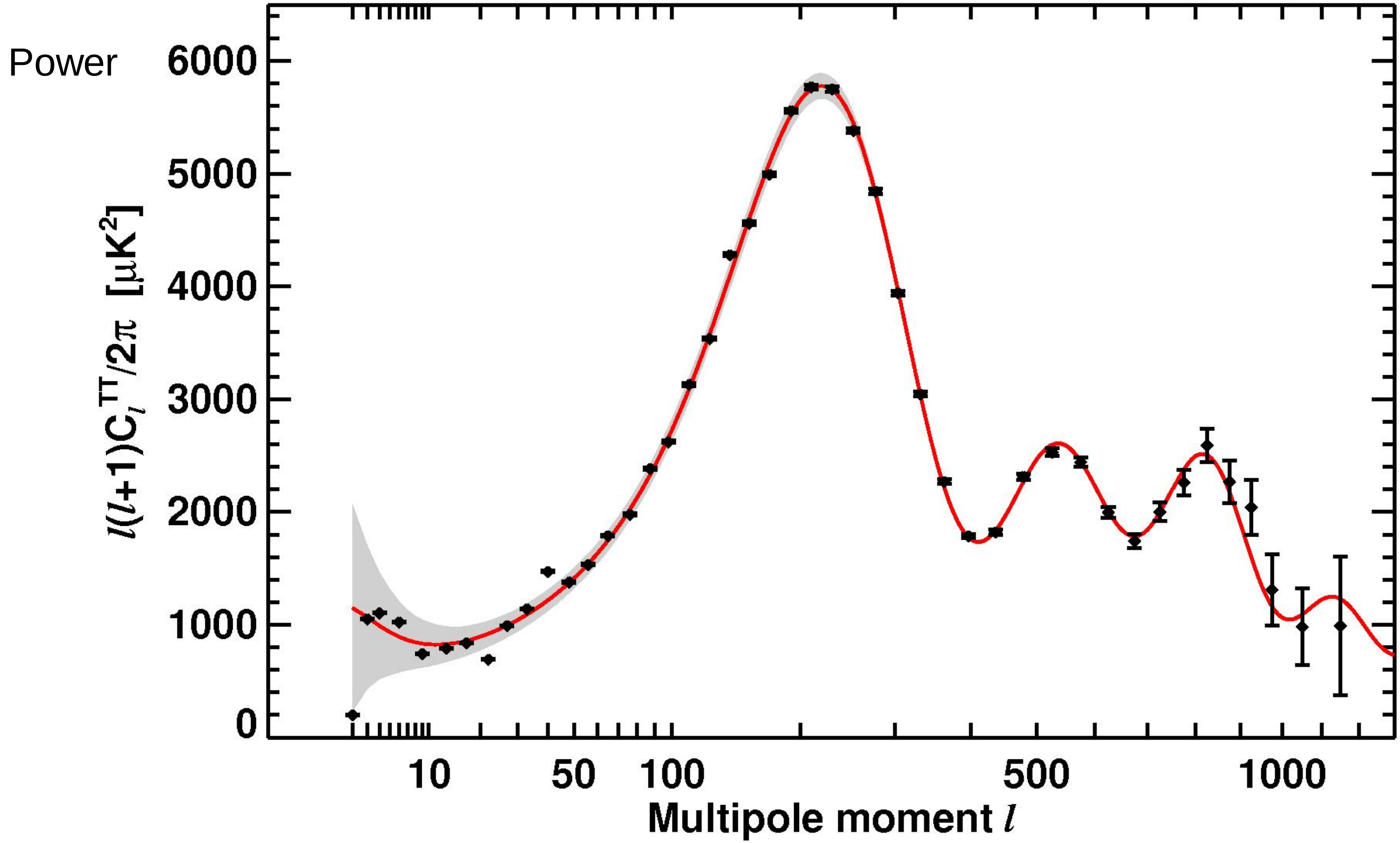


Pirin
Erdogdu

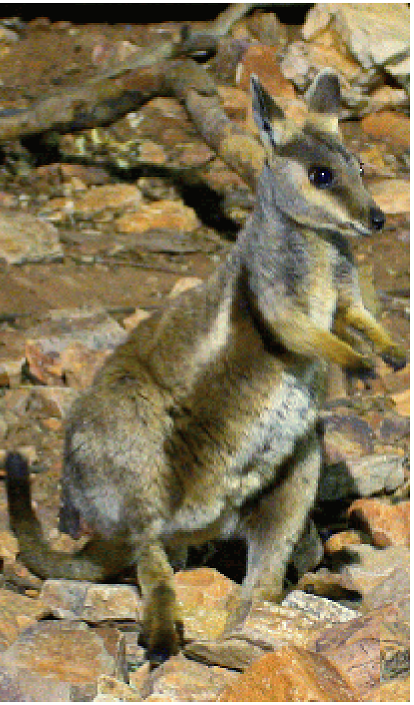
Expected distance to the dominant gravitational source

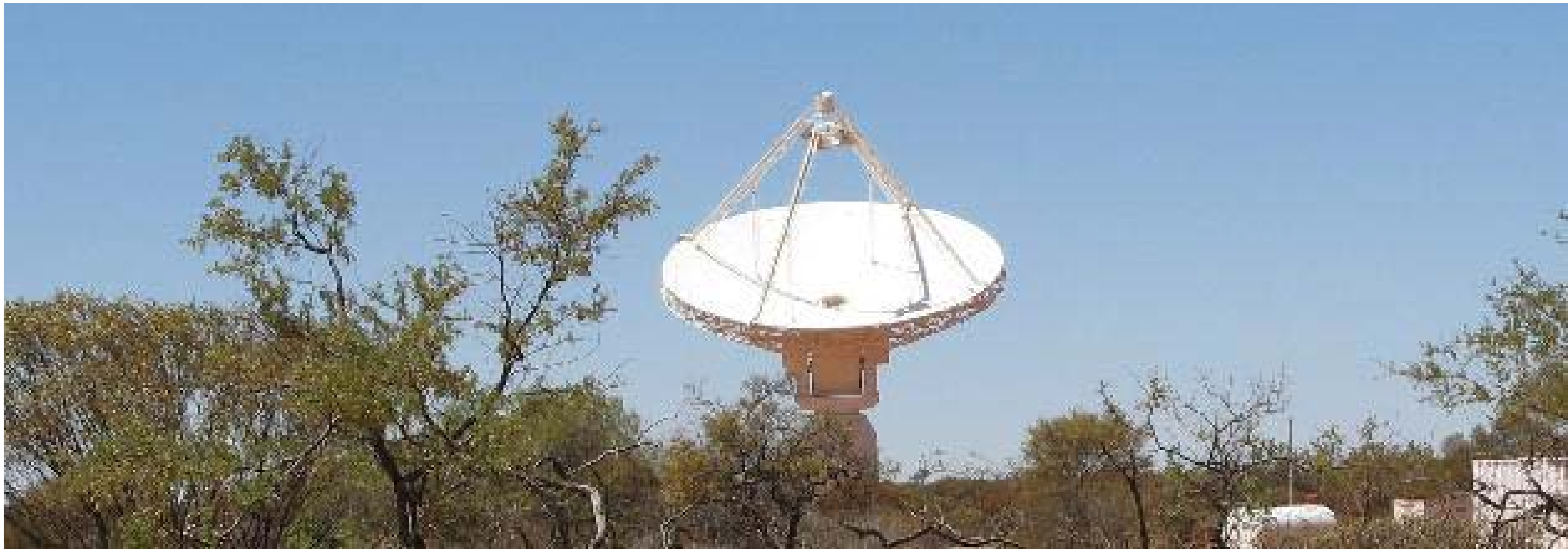


Cosmic Microwave Background
WMAP 7 yr



WALLABY - the ASKAP HI All-Sky Survey





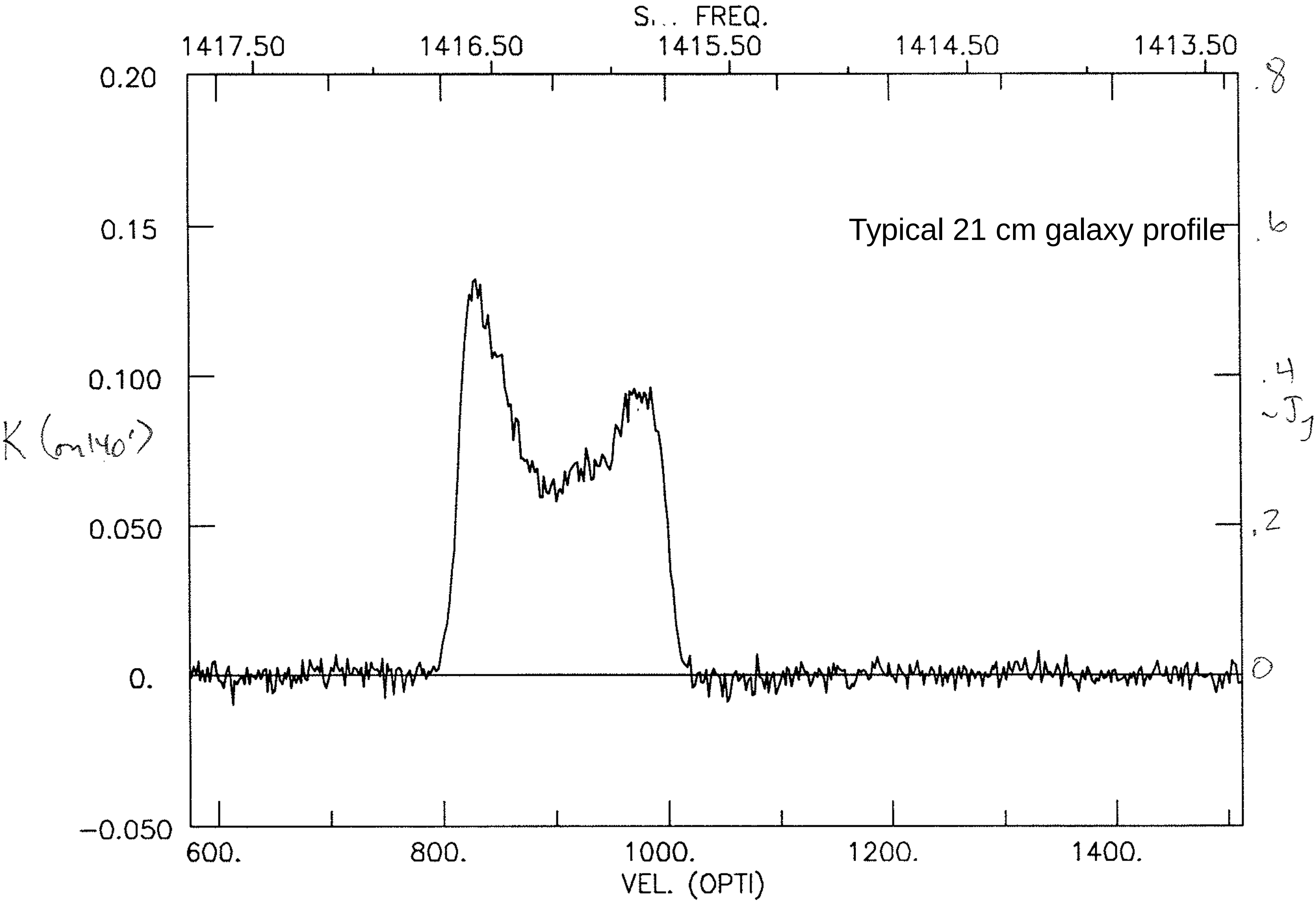
- ASKAP **36 x 12-m antennas** (4072 sq m)
- focal plane arrays
- field-of-view **5.5 deg x 5.5 deg** (= 30 sq deg)
- 0.7 - 1.8 GHz, i.e. ideal for large HI and 20-cm continuum surveys.
- inner 30 antennas (3400 sq m) of ASKAP optimally arranged in a 2-km configuration, delivering an angular resolution of 30".
- further six antennas at larger distances (max. baseline = 6-km), giving an excellent angular resolution of around 10".

CSIRO

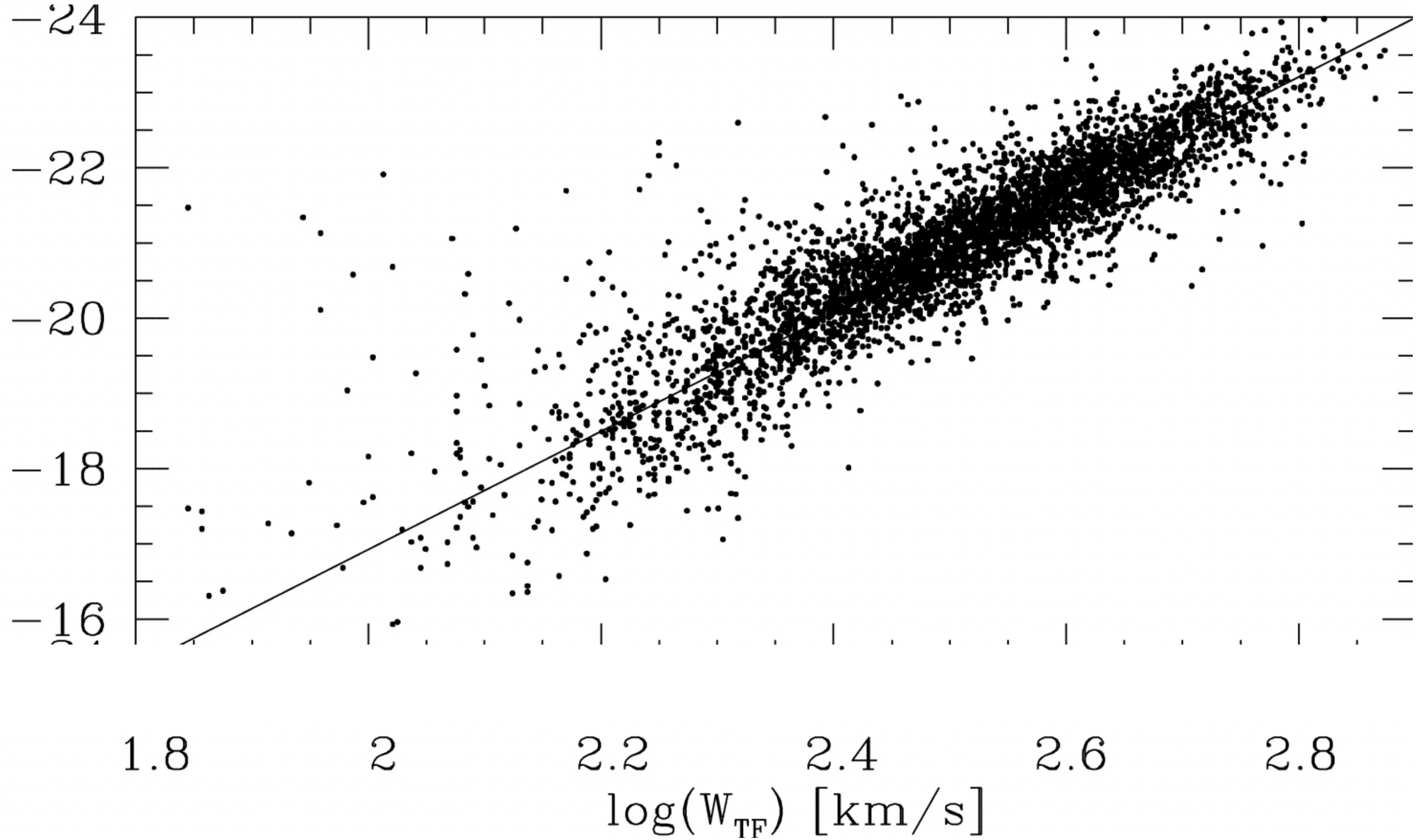
A comparable Dutch survey is WNSHS in the North

WALLABY: Widefield ASKAP L-band Legacy All-sky Blind surveY
Principal Investigators: Baerbel S. Koribalski (ATNF) and Lister Staveley-Smith (UWA)

- flux sensitivity ~20 times better than the HI Parkes All-Sky Survey (HIPASS)
- velocity resolution ~4 times better
- dwarf galaxies (M_{HI} = 10^8 M_*) out to a distance of ~60 Mpc,
- massive galaxies (M_{HI} = 6 x 10^9 M_*) to ~500 Mpc
- super-massive galaxies like Malin 1 (M_{HI} = 5 x 10^{10} M_*) to 1 Gpc.
- mean sample redshift is expected to be z = 0.05 (200 Mpc).
- For the ~3 x 10^4 galaxies expected to be larger than 1.5‘
    - simple structural, mass and angular momentum parameters.
- automated parameter pipeline.



S... FREQ.
1417.50
1416.50
1415.50
1414.50
1413.50
0.20
0.15
0.100
0.050
0.
−0.050
K (on 140')
.8
.6
.4
~Jy
.2
0
Typical 21 cm galaxy profile
600.
800.
1000.
1200.
1400.
VEL. (OPTI)



Springob et al

Tully Fisher relation for spiral galaxies

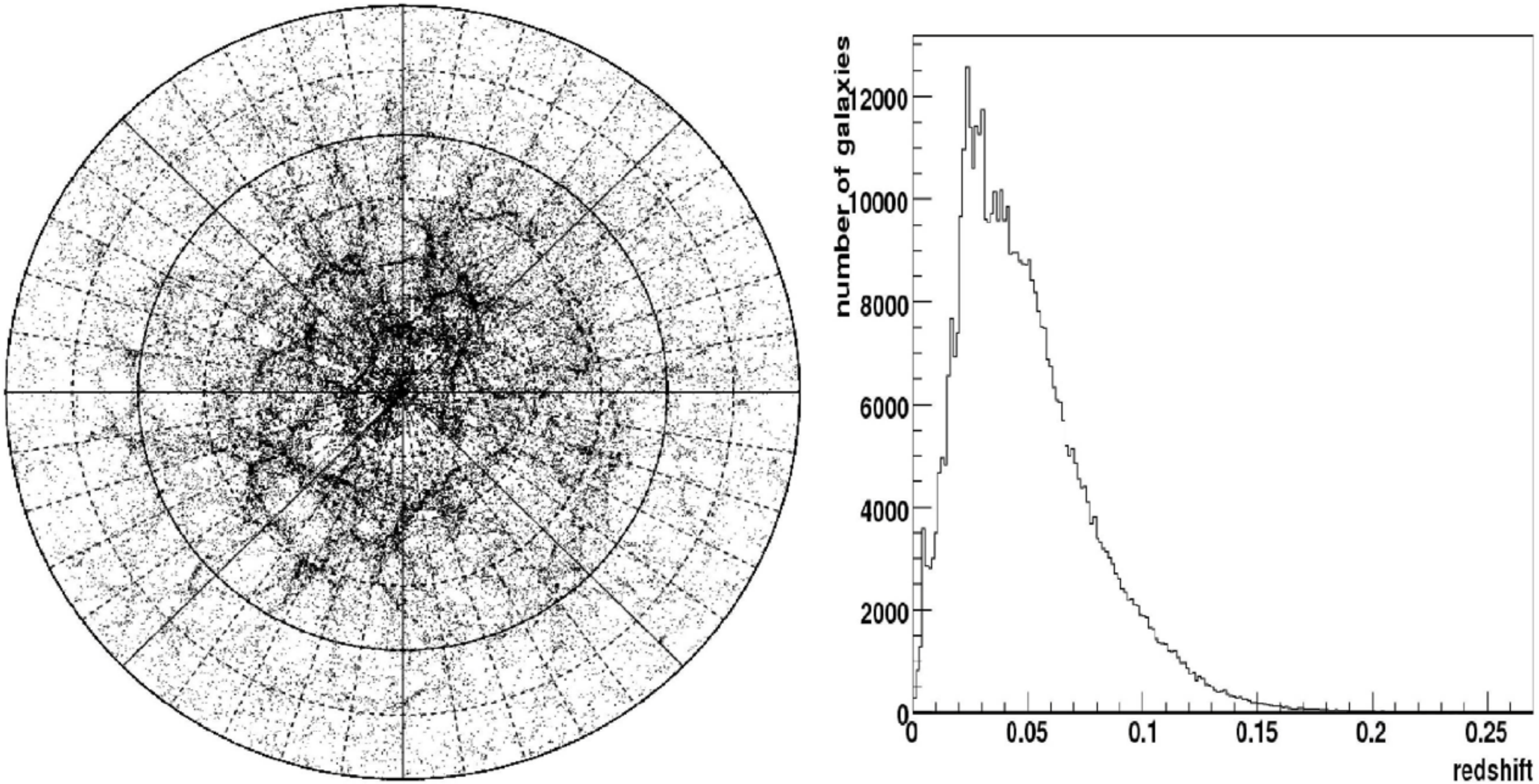
The Skymapper Survey

THE AUSTRALIAN NATIONAL UNIVERSITY

***CAASTRO* will combine the WALLABY and Skymapper galaxy databases**

CAASTRO

Wallaby: Simulated sky and redshift distribution (Beutler)



500,000 galaxies

How many of these are detectable, *i* > 45º, ΔV > 80 km/s ?

Skymapper galaxy magnitudes for Peculiar Velocity sample

CAASTRO postdoc David Lagattuta has now started

Galaxy magnitude pipeline will be developed

Typical extant software is the ARCHANGEL package

- 2007astro.ph 3646 Jim Schombert
- Lachlan Hislop MSc thesis Melbourne 2010

Fits elliptical isophotes

Integrates the flux to give a total magnitude

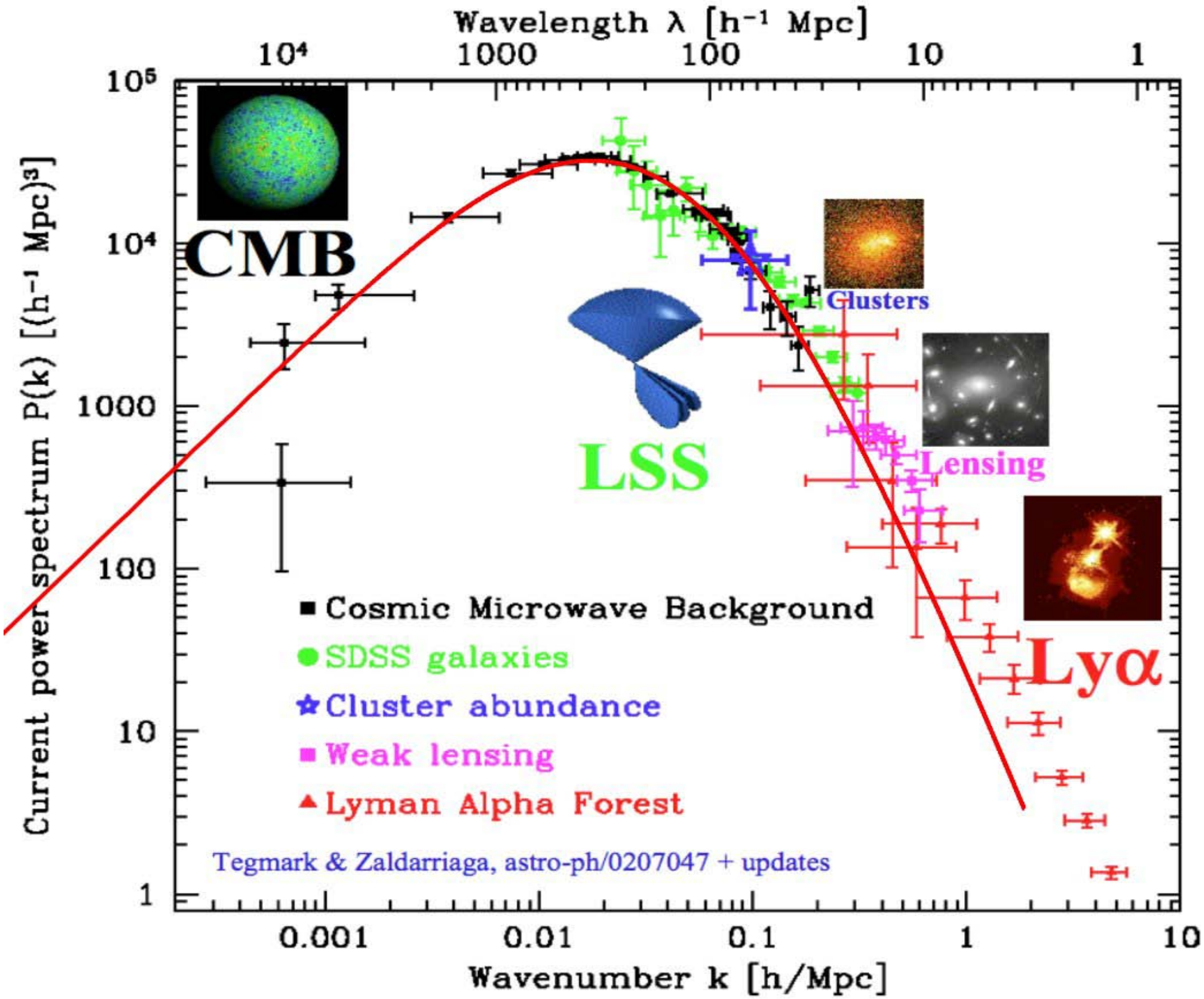
Interesting to see which of *i,y,z* magnitudes is best

Traditional to use blue images for disk inclinations

Constraints on large scale structure

Will the WALLABY peculiar velocity Survey require more power on large scales than WMAP ?

Does the dark matter follow the light distribution ?

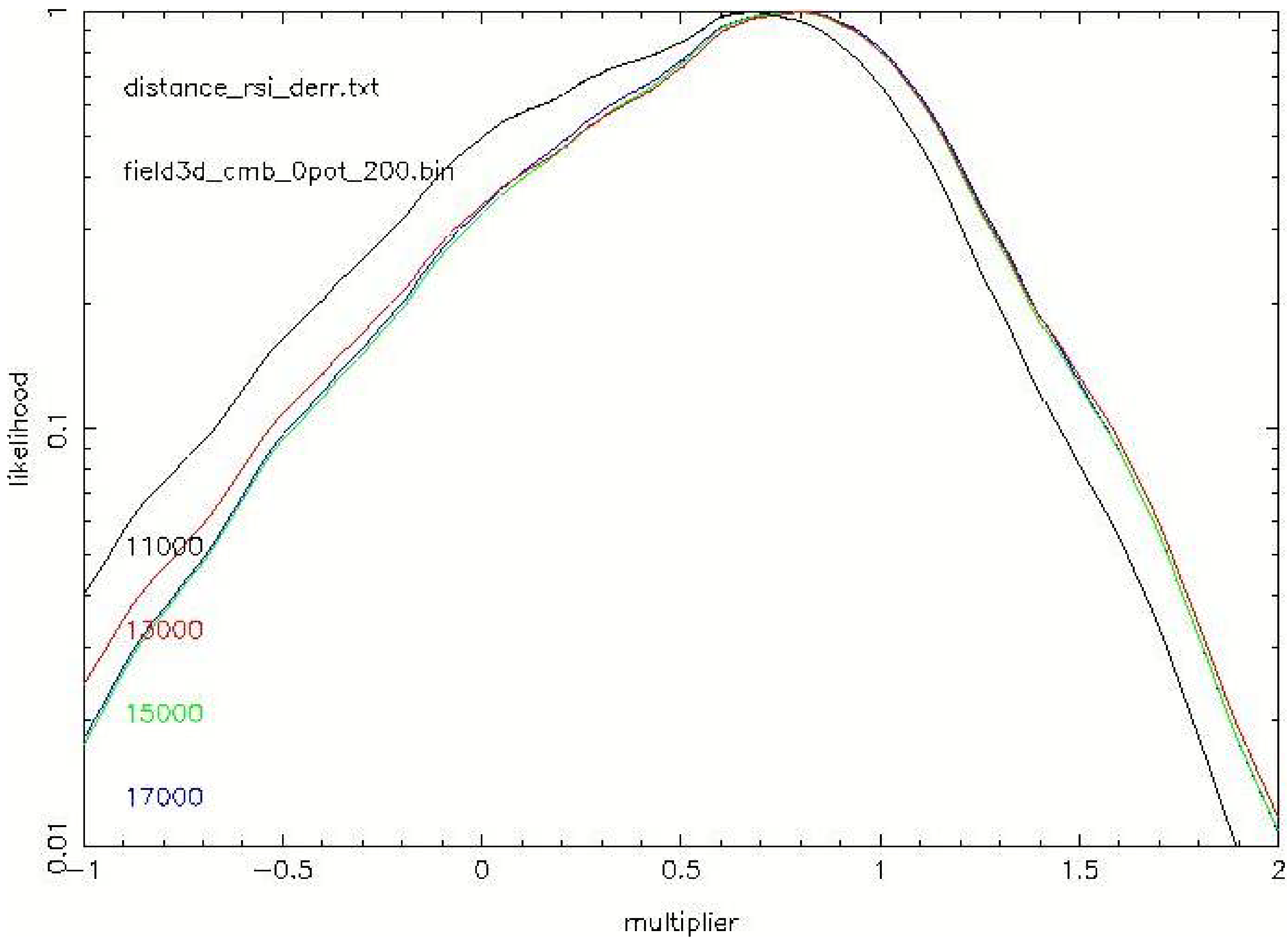


Cosmic Flow: In The Rainforest

With so much recent activity on measurements of motion in the universe it is timely to announce our upcoming workshop, “Cosmic Flow in the Rainforest”. Over February 20th-22nd, 2012, we hosted a small workshop-style conference at O’Reillys Rainforest Retreat, in the beautiful Gold Coast Hinterland, focusing on present and upcoming measurements of cosmic flows.

Cosmic flow refers to any coherent motion in the universe including the common Hubble flow due to the expansion. It can be used to probe the dynamics of our local universe as well as provide new insights into cosmology and gravitational theory. Local flows are particularly useful for studies of dark energy, since models of gravity that can explain the acceleration of the expansion of the universe may fail in explaining the growth of structure within it.

6dF Magoulas fundamental plane and Erdogdu reconstructed peculiar velocities



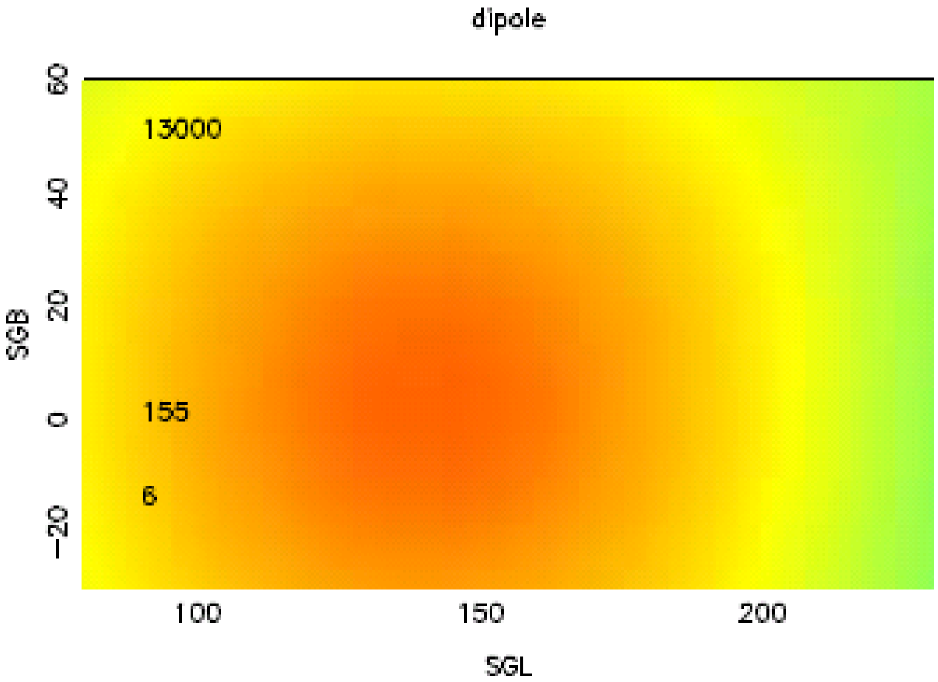
Density $\Omega = \Omega_m$

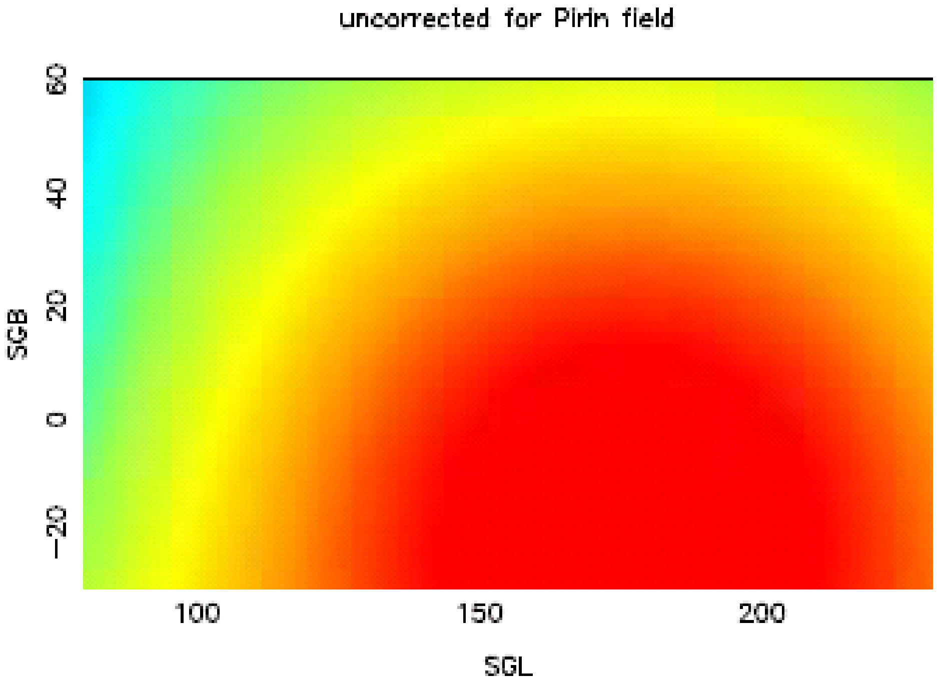
- In linear theory $\nabla.\mathbf{v} = -\beta\, H_0\, \delta\rho/\rho$
- b = $\langle \delta g/\delta dm \rangle$ galaxies are a biased tracer of m
- Erdogdu assumed $\beta = \Omega^{4/7}/b = 0.4$
- Our fit to 6dF is β = (0.73 ⌖ 0.1) x 0.4 = 0.29
- This gives b = 1.7 for WMAP7 matter density
- Lavaux et al. found Ω = 0.31 ⌖ 0.05 with b = 1
  - astro-ph 0810.3658
  - i.e. β = 0.51 ⌖ 0.05
- Davis et al β = 0.33 ⌖ 0.04 (SFI++)
- Bilicki et al β = 0.38 ⌖ 0.04

Future Work: FP & TF

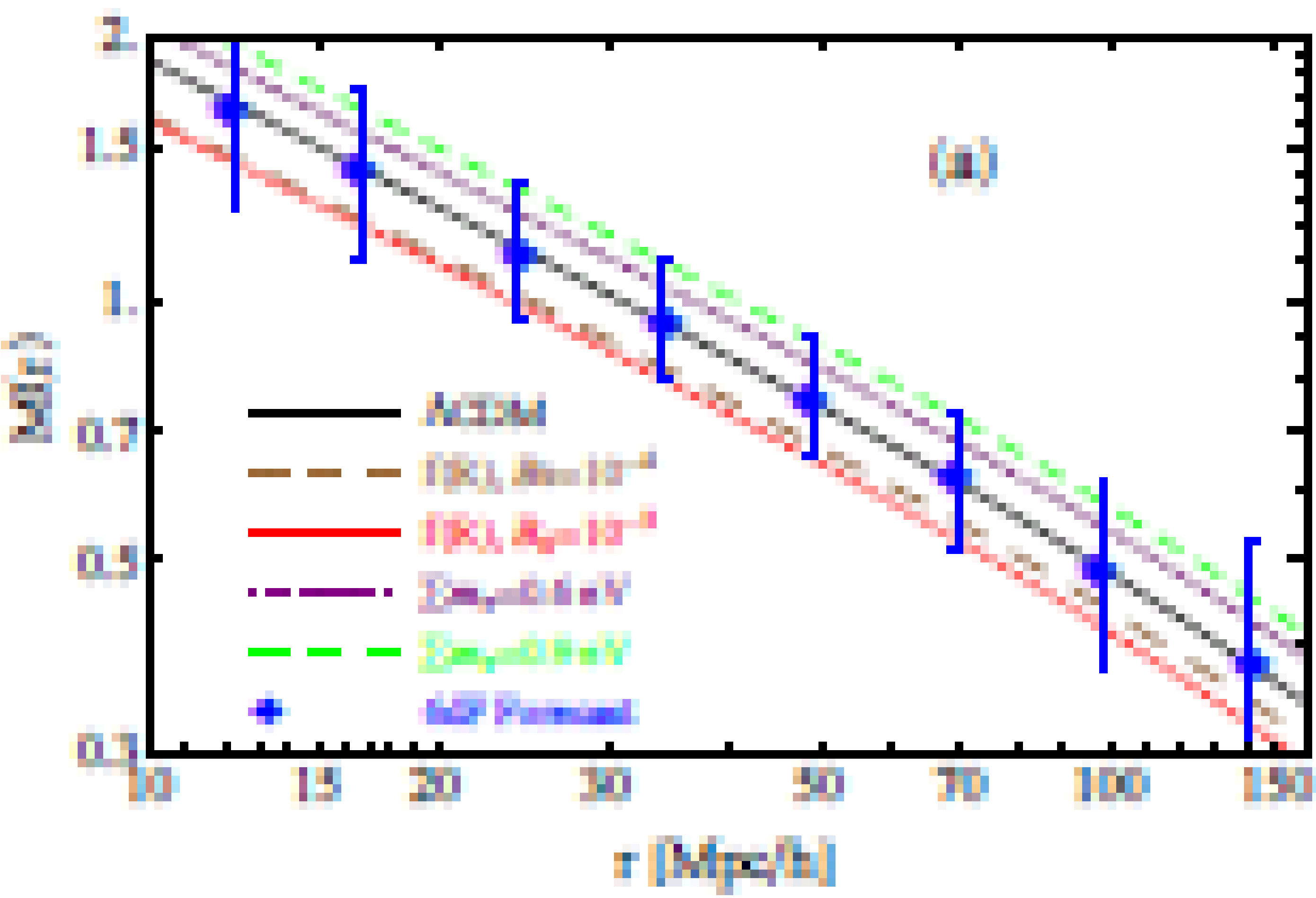
- Add SDSS data (Graves) to cover π sr of the northern hemisphere (NH)
- Enlarge the reconstruction
  - improve the incompleteness correction,
  - peculiar velocities key to improving redshift distances
- Extend the SH sample volume, using ASKAP and SkyMapper (Lagattuta)
- Extend the NH sample volume, using WNSHS and PanSTARRS
- Improve Tully-Fisher relation $v = (\sigma^4 + \Delta V^4)^{1/4}$

Dipole is reduced by correction for the individual peculiar velocities predicted by Erdogdu





Cosmic Mach Number
Ma, Ostriker, Zhao 2011



$M = v / \sigma$

Andrew Hopkins

Australian Astronomical Observatory

Australian Government
Department of Innovation
Industry, Science and Research

TAIPAN

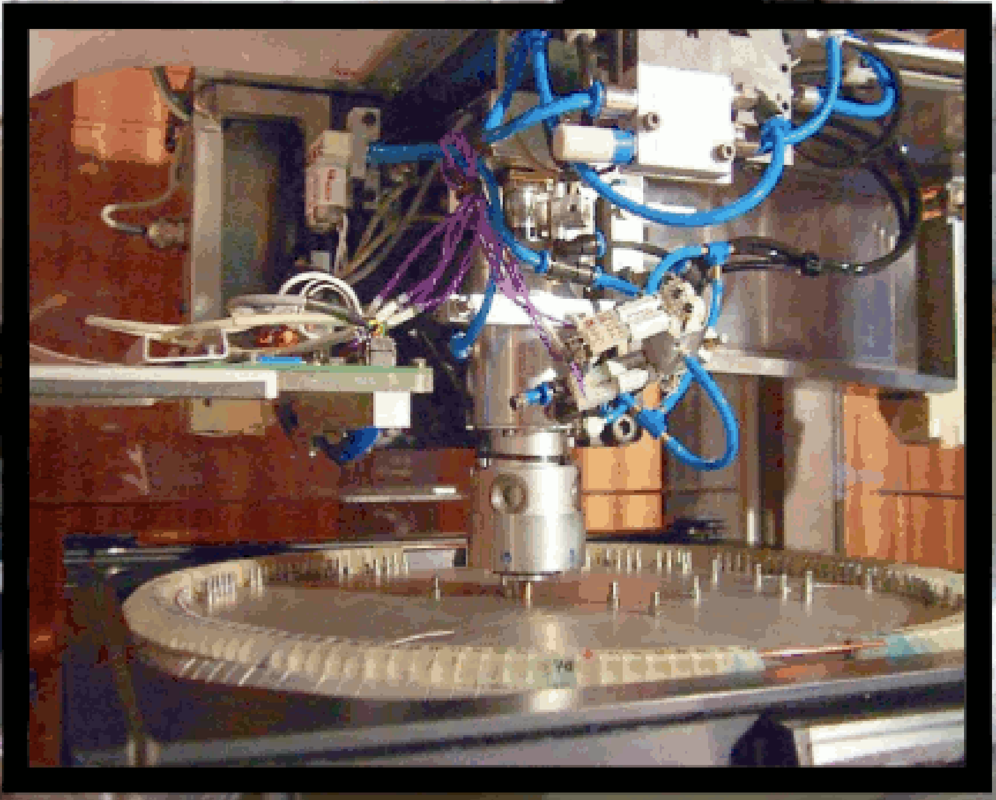
- Transforming Astronomical Imaging-surveys through Polychromatic Analysis of Nebulae
- Survey with the UK Schmidt Telescope at Siding Spring, following in the footsteps of the 6dF Galaxy Survey (Jones et al., 2004, 2009)
- All southern sky multi-object spectroscopic survey, ~500000 galaxies
- 30 authors on the original expression of interest to the AAO

Acronym grade 1/10 Committee for Ridiculous Acronym Prevention
Alternative: Tokyo Astronomy I_* P_* A_* N_*

The 6-Degree Field instrument (6dF)

- The 6-Degree Field is a floor-mounted spectrograph for the AAO's UK Schmidt Telescope:
  - commissioned in 2001
  - 5.7º field (25.5 deg^2)
  - up to 150 objects at a time

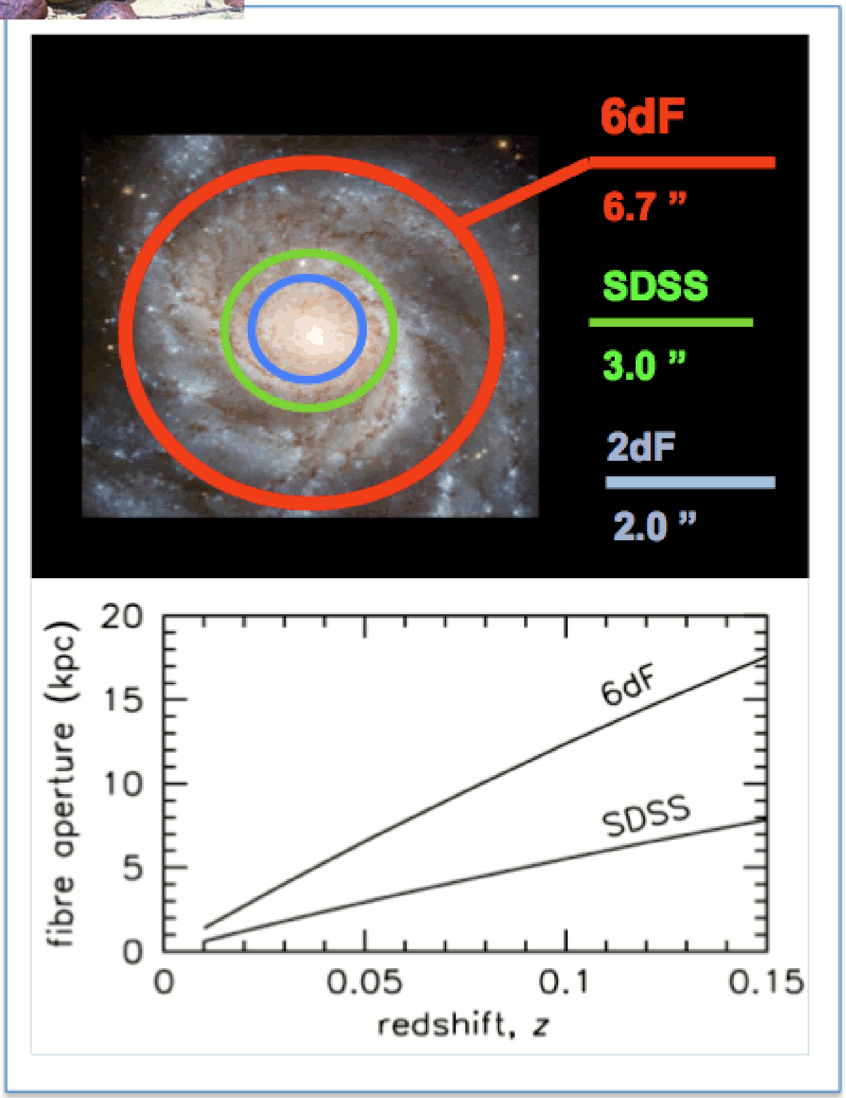
- 6dF has *by far* the largest F.O.V. of any multi-object spectrograph in the southern hemisphere…
  - 6dFGS: 110,256 new galaxy redshifts (2001 – 2005)
  - RAVE: 292,665 stellar radial velocities (2005 – present)

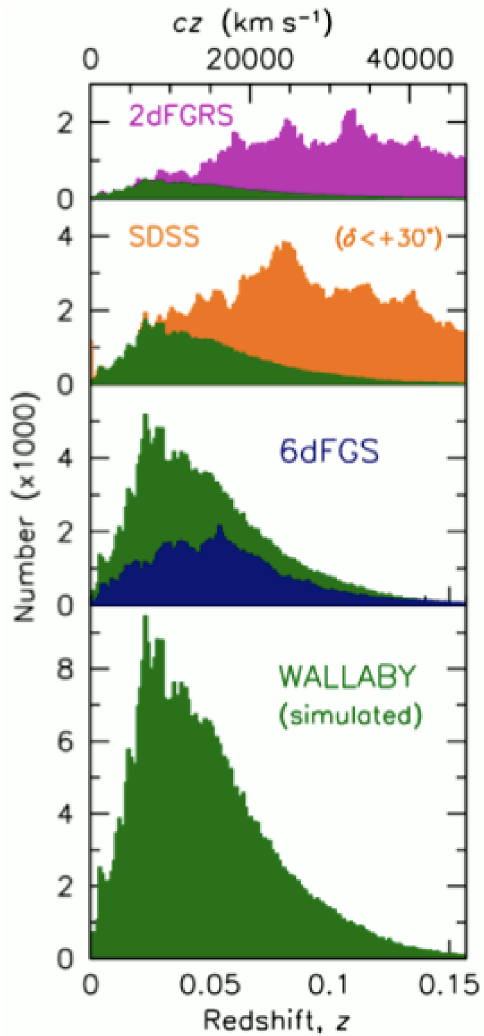


TAIPAN status

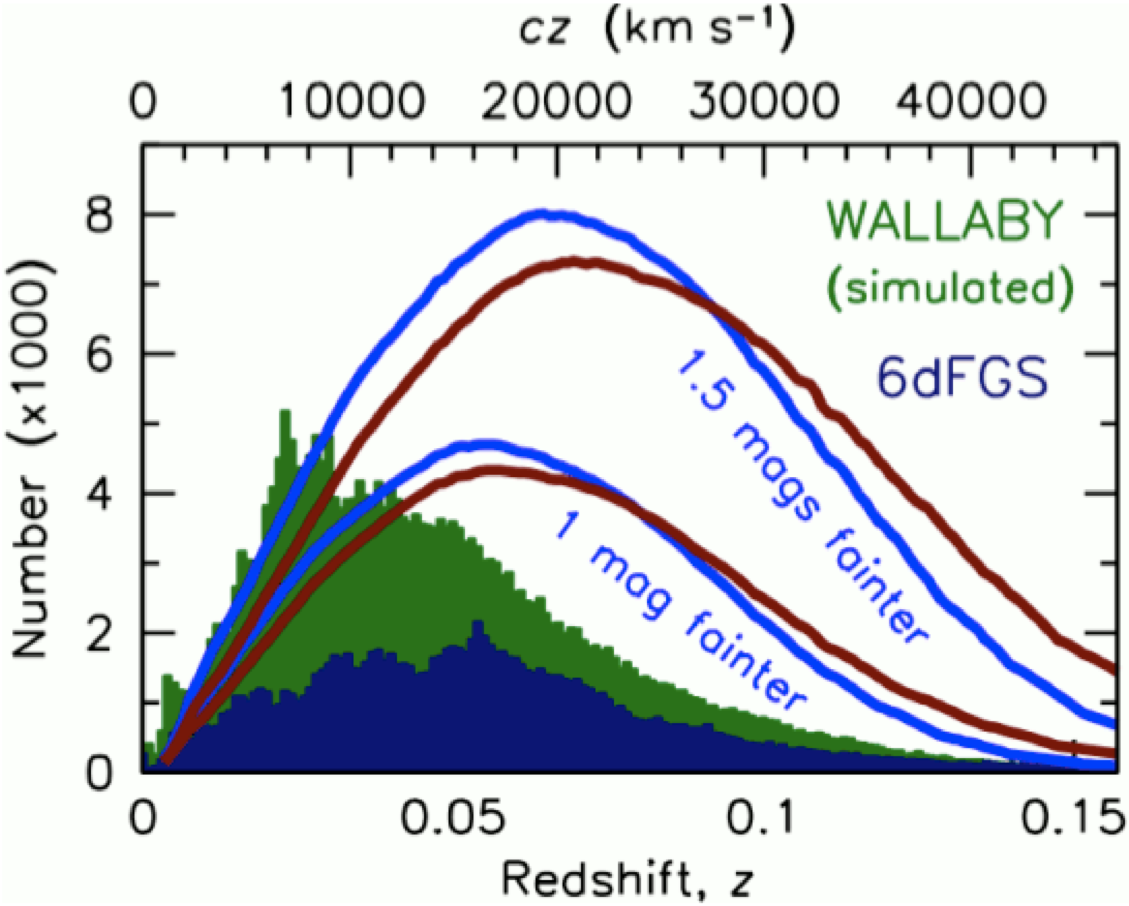
- Survey is not currently funded
- Several survey models are being refined, to anticipate different potential funding scales
  - Modest upgrades to 6dF, 50% efficiency gain: r<16.5 (~1 mag fainter than 6dFGS)
  - Major upgrade (new spectrograph), ⋖2 efficiency: r<17
  - New instrument (UKidna-style), ⋖4 efficiency, plus significant multiplex gain: r<18

6dF and WALLABY





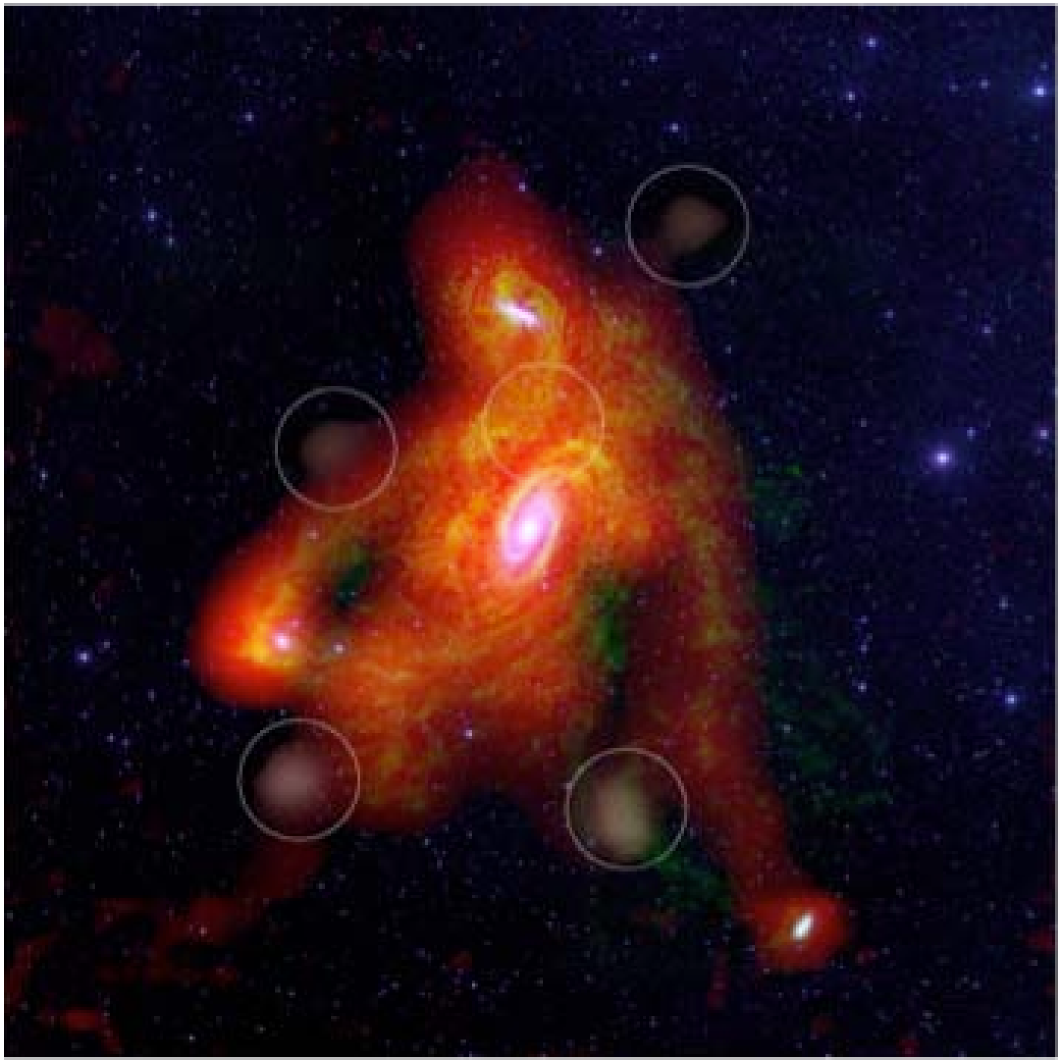
TAIPAN and WALLABY



Scientific Goals

- The connection between gas and stars
  - TAIPAN and WALLABY together
- The impact of environment and mergers
- Stellar and halo mass functions
- Star formation and AGN
- Mapping the Dark Matter to $z = 0.1$
- Legacy value

Stars and Gas



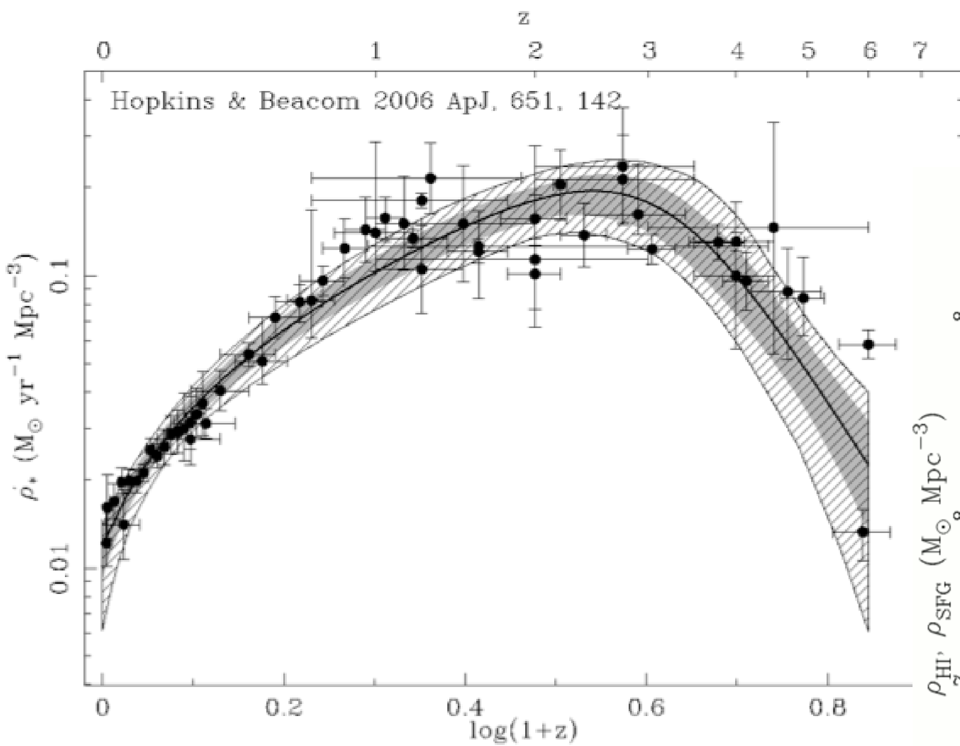
Katie Chynoweth & NRAO

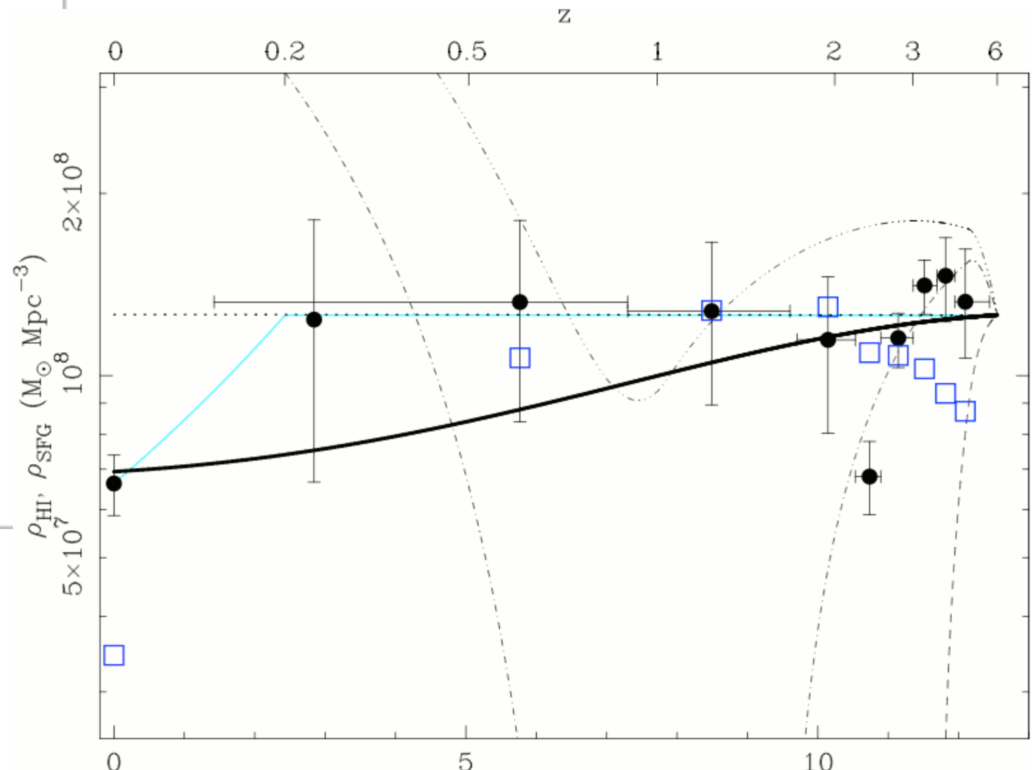
Stars and Gas

M81 galaxy group

Thanks to Katie Chynoweth for the individual fits files

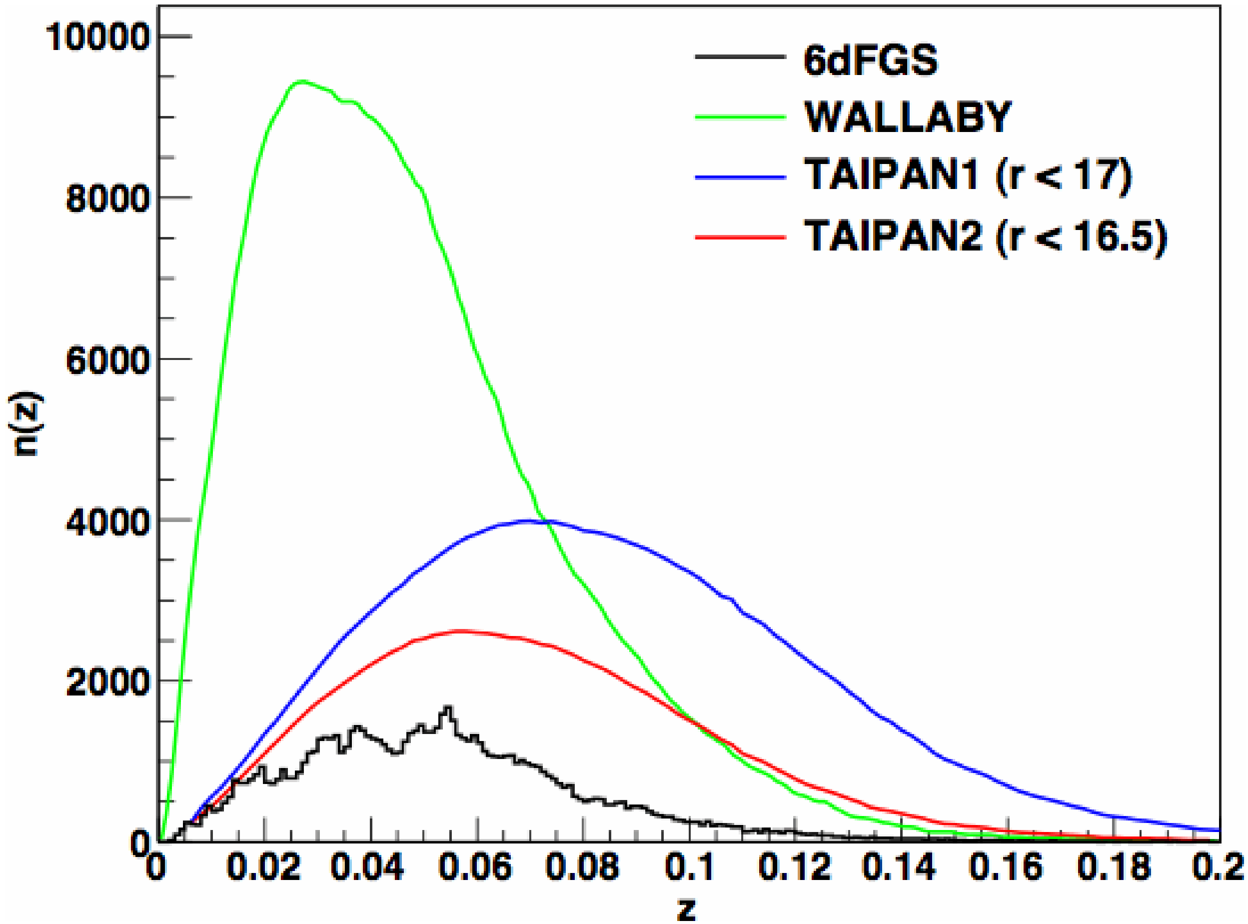
Evolution of HI vs SFR





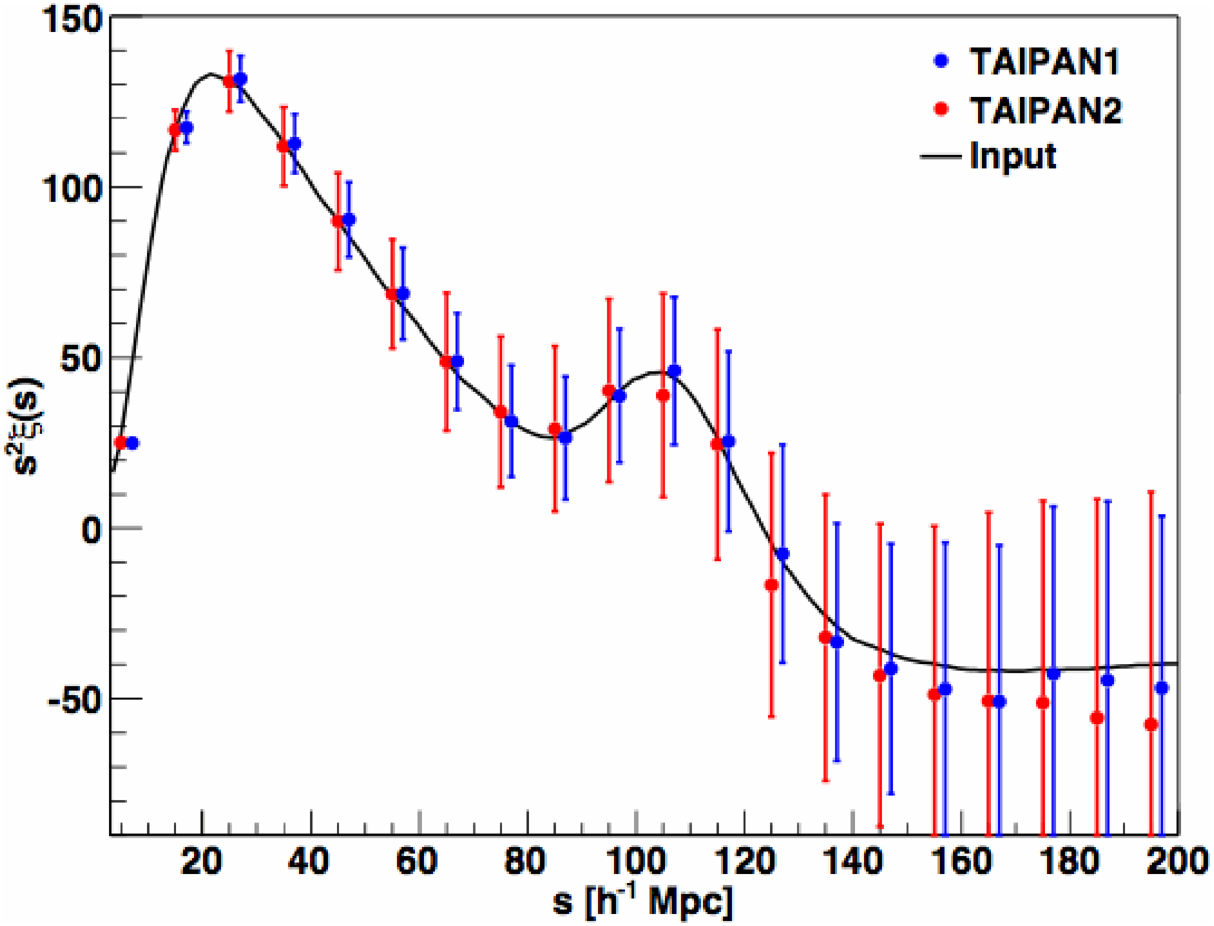
Hopkins, McClure-Griffiths & Gaensler, 2008, ApJ, 682, L13

TAIPAN cosmology



Beutler et al., 2011, MNRAS, 416, 3017

TAIPAN cosmology



Beutler et al., 2011, MNRAS, 416, 3017

Survey design

- Survey to r<17 (c.f. SDSS at r<17.7)
- Assumes ≺2 spectrograph efficiency improvement compared to 6dF
- Assumes 300 “starbug” fibre probes
- ~700000 targets, (~1000 per 6dF field)
- 50 min exposures S/N~10, 3.3 visits per field
- 2.2 year survey

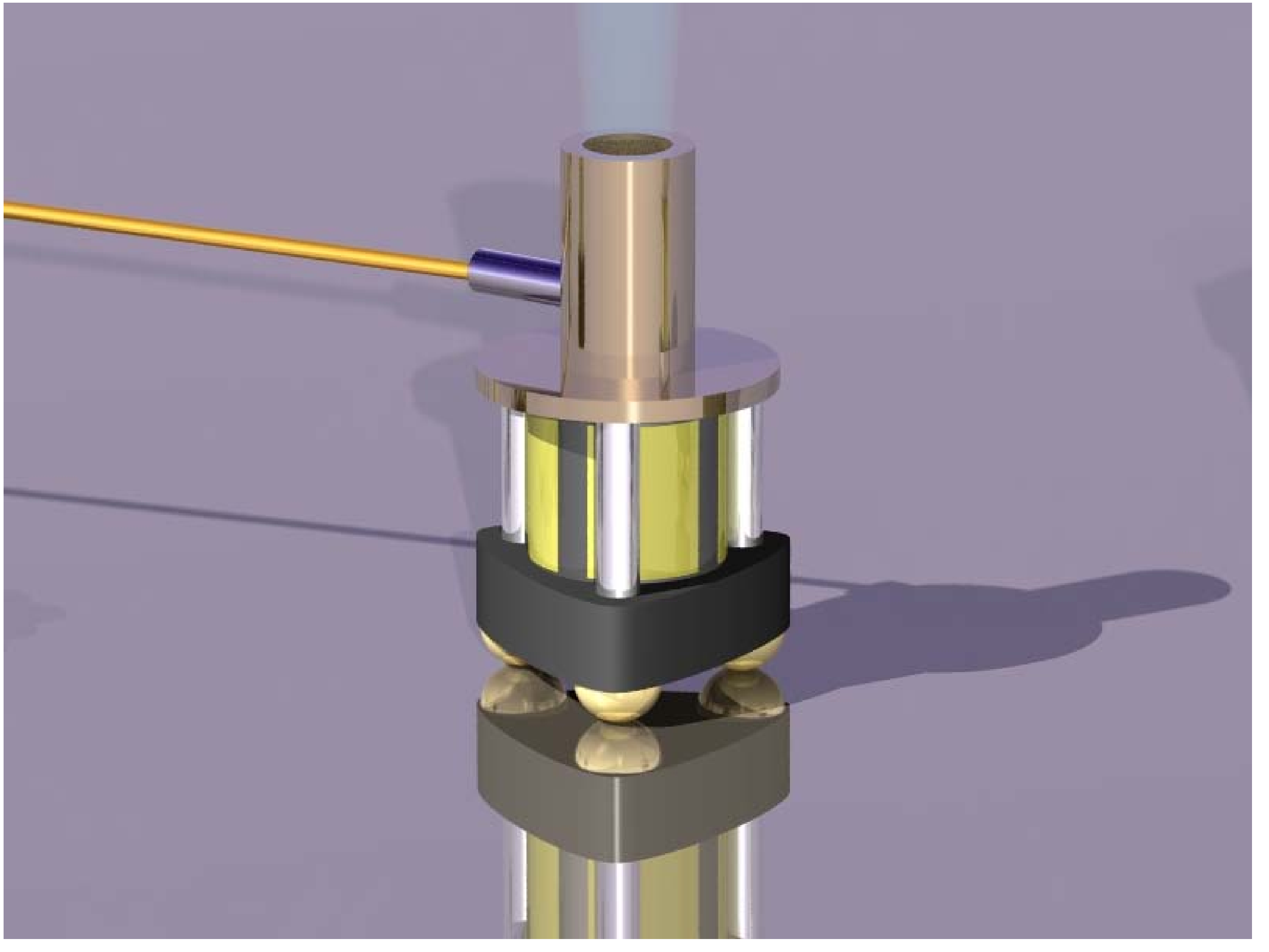
Survey design

- Scaled from 6dFGS
- Desirable wavelength range: 3700-7500 Å
- [OII], Hβ, [OIII], Hα, [NII], [SII], (Hα to $z<0.14$)
- Resolution: $R>3000$, to allow 1 pixel=100 km/s sampling

Spectrograph outline

- With a 4K x 4K CCD, 3800 Å wavelength range can be accommodated with ~1 Å per pixel.
  - This would provide a resolution of R~4000 at the blue end of the spectrum.
  - The same could be achieved with two 2K x 4K devices and a dichroic, similar to AAOmega.
- With 300 starbug probes, each target spectrum has ~13 pixels, allowing for a good PSF with minimal overlap.
  - This is more separated than spectra from 2dF with the AAOmega spectrograph, which accommodates 392 targets in 4K pixels.

Starbugs



The Starbug concept uses magnetic buttons similar to those carrying the fibres for OzPoz, FMOS and other pick-and-place positioners, but mounted on micro-robotic actuators that can be independently and simultaneously positioned by ‘walking’ across the field plate.

TAIPAN and WALLABY

Basis for possible collaboration

- AAO: modify the 6dF robotic positioner
- CAASTRO:
  - fund UKST upgrade from ARC LIEF
  - fund visitors
  - employ a TAIPAN postdoc 2015-17
- Partner: build spectrograph
- Timeline: ARC proposal due March 2013
  - funding would start January 2014

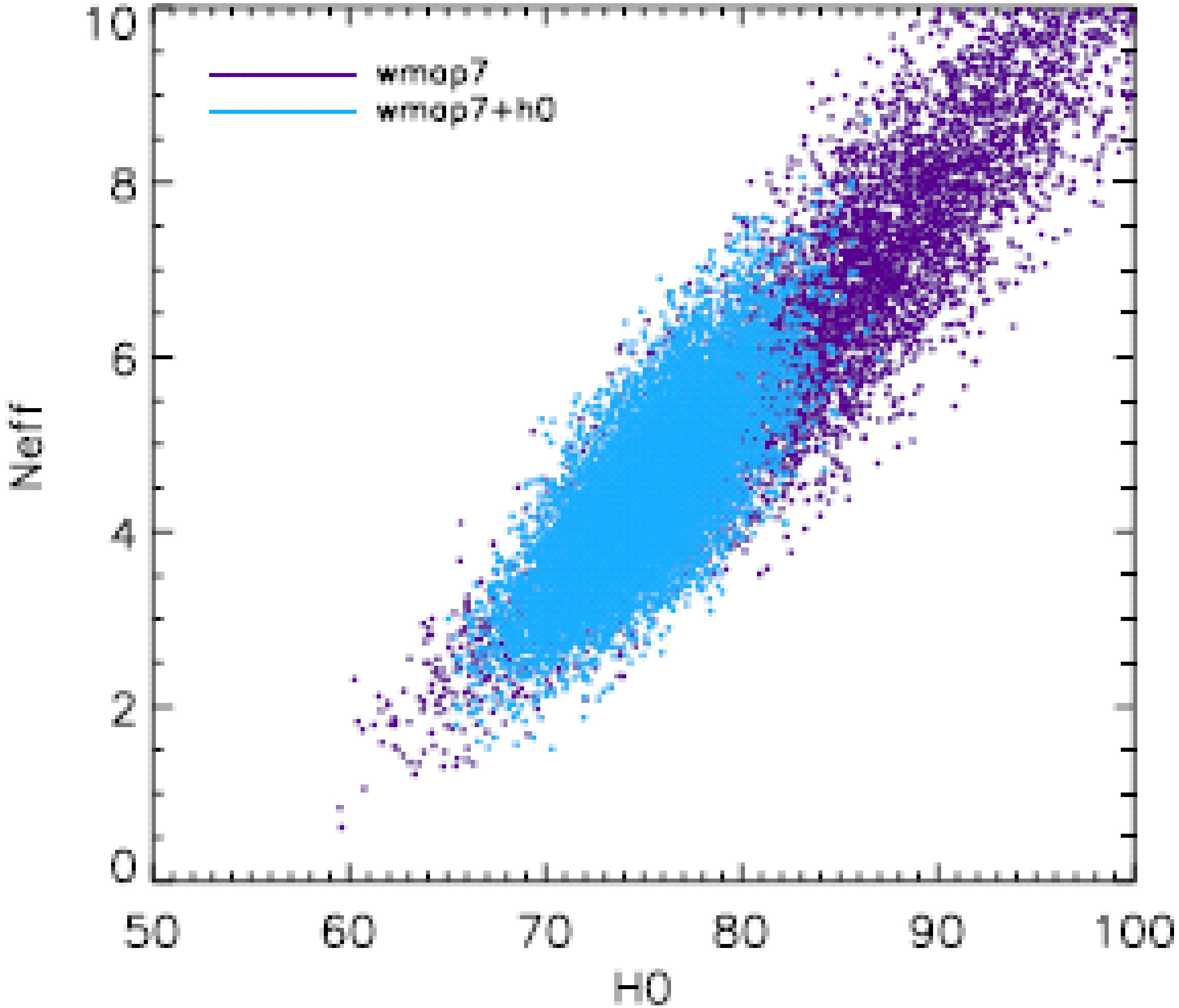
3-day workshop on the Hubble constant (H0) **arXiv:1202.4459**

February 6-8 2012 at Kavli Institute for Particle Astrophysics & Cosmology, Stanford University.

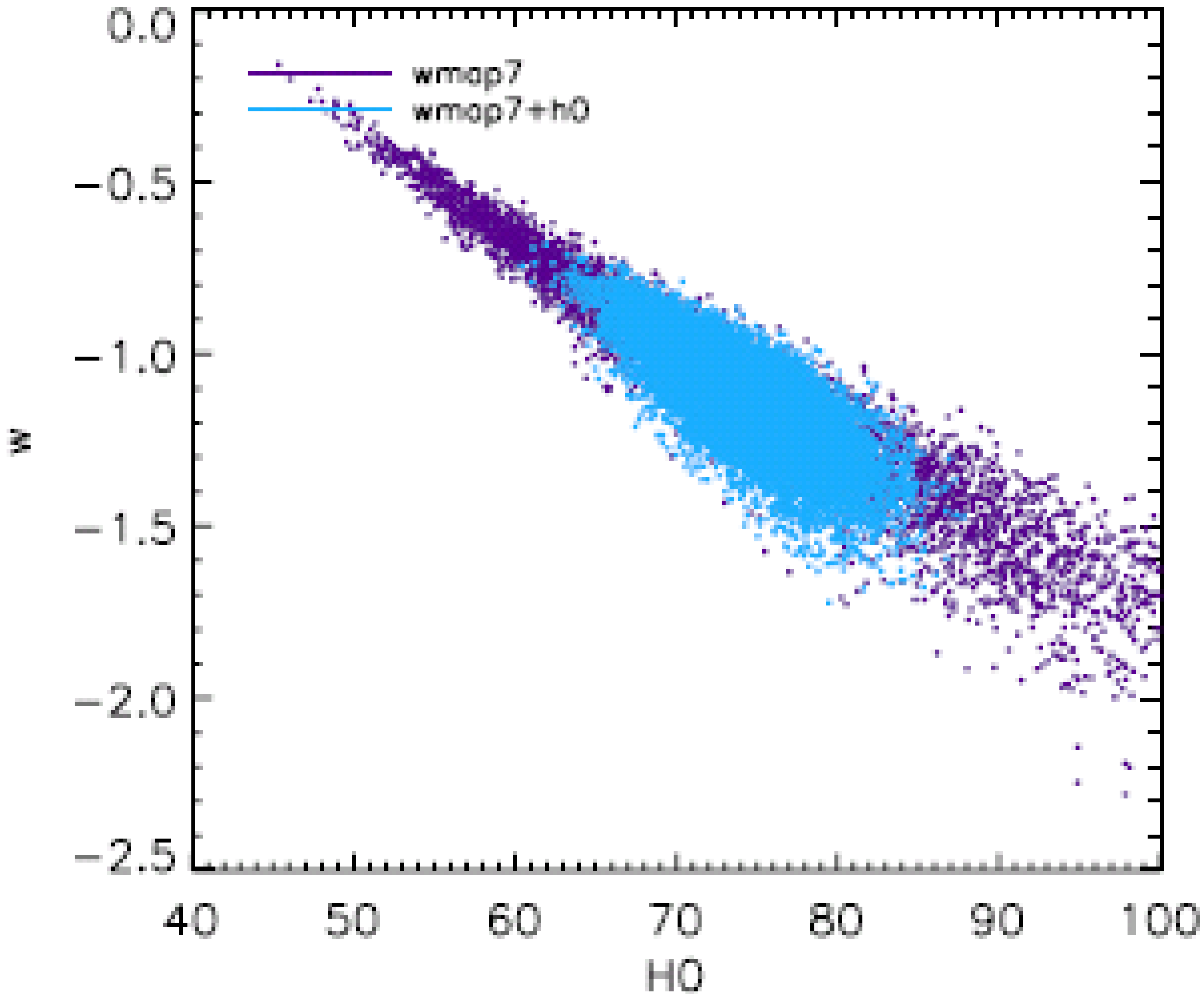
Are there compelling scientific reasons to obtain more precise and more accurate measurements of H0 than currently available? If there are, how can we achieve this goal?

<u>Answers</u> (1) better measurements of H0 provide critical independent constraints on dark energy, spatial curvature of the Universe, neutrino physics, and validity of general relativity

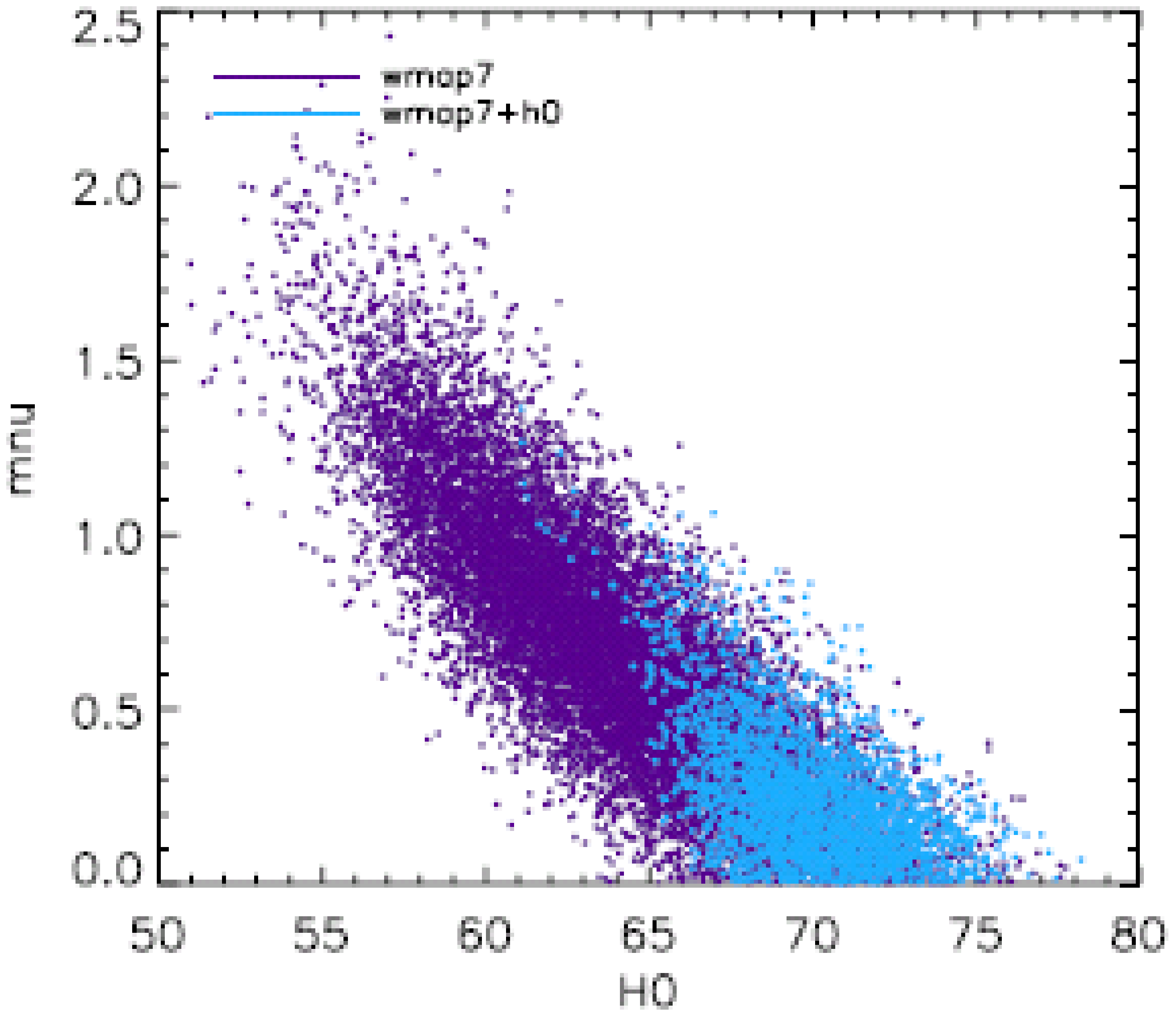
Neutrino species – Joanne Dunkley



Dark energy



Total mass of neutrinos in eV



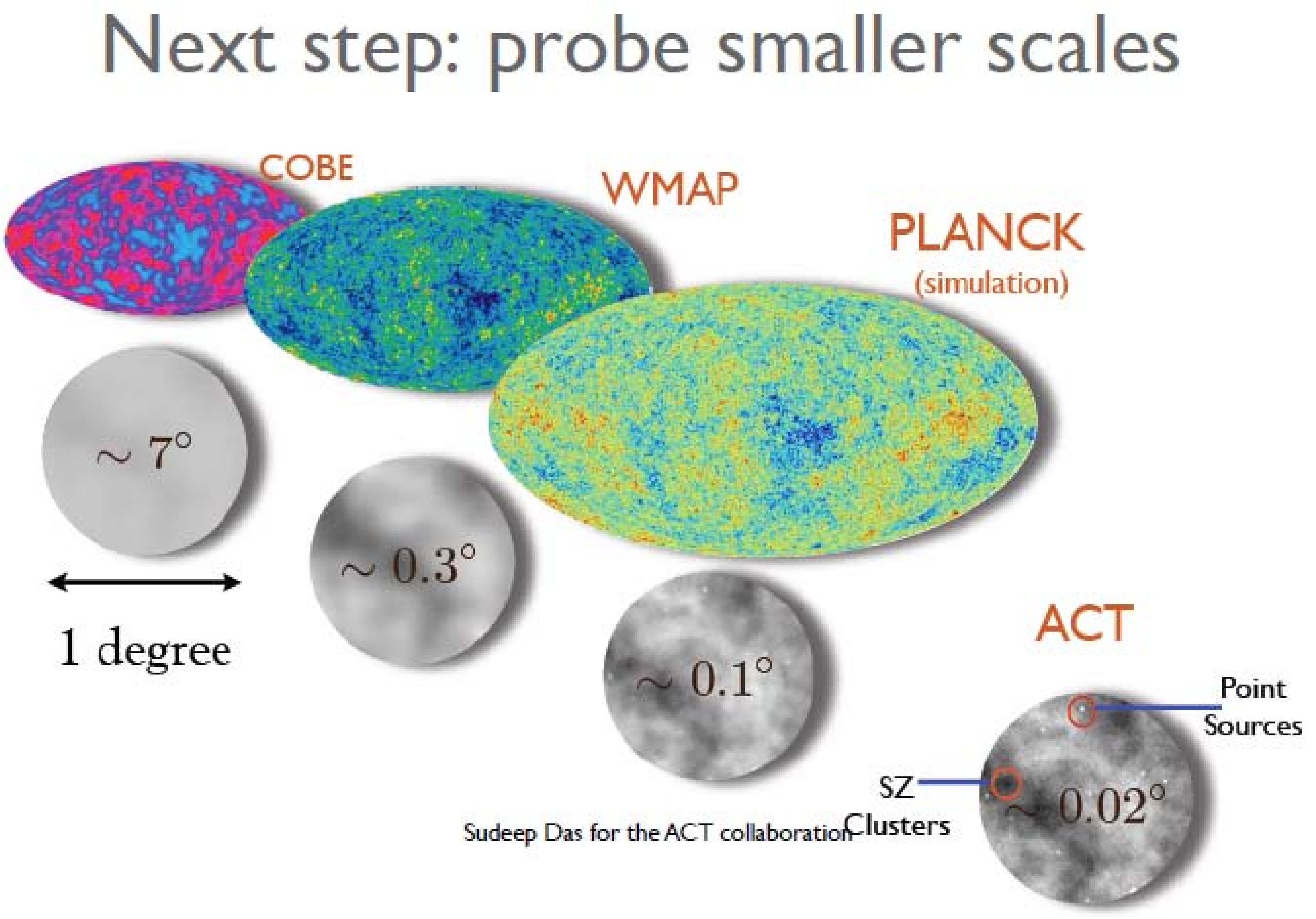
How ?

(2) a measurement of H_0 to 1% in both precision and accuracy, supported by rigorous error budgets, is within reach for several methods

- Key-Project-&-Sandage-like: Cepheids and SNIa
- Mega-Masers plus SBF
  - only northern hemisphere (VLBI in SH said to be weak)
  - SBF claims 1.5% accuracy, more realistically 3%
- BAO plus CMB

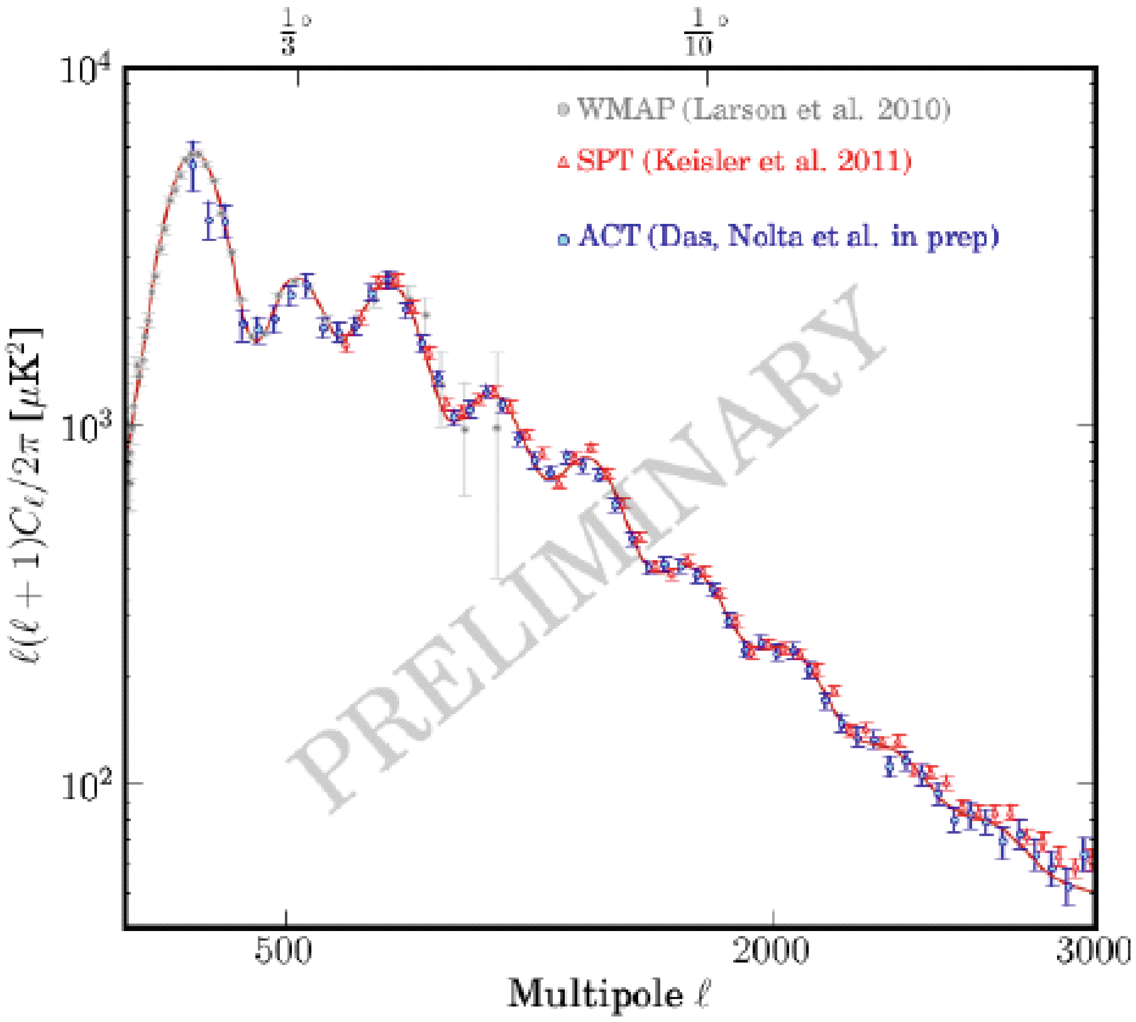
(3) multiple paths to independent determinations of H_0 are needed in order to access and control systematics.

The CMB future

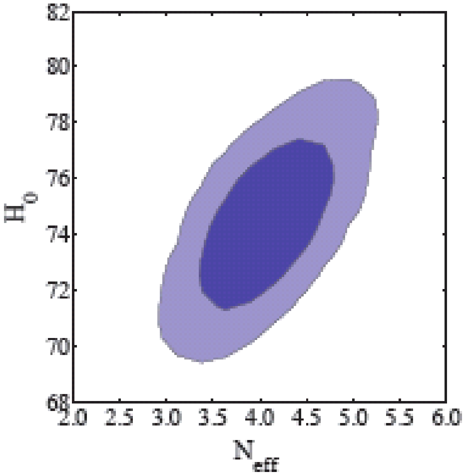


Yes, there seem to be 4 'neutrinos'

Small-scale spectrum: SPT+ACT

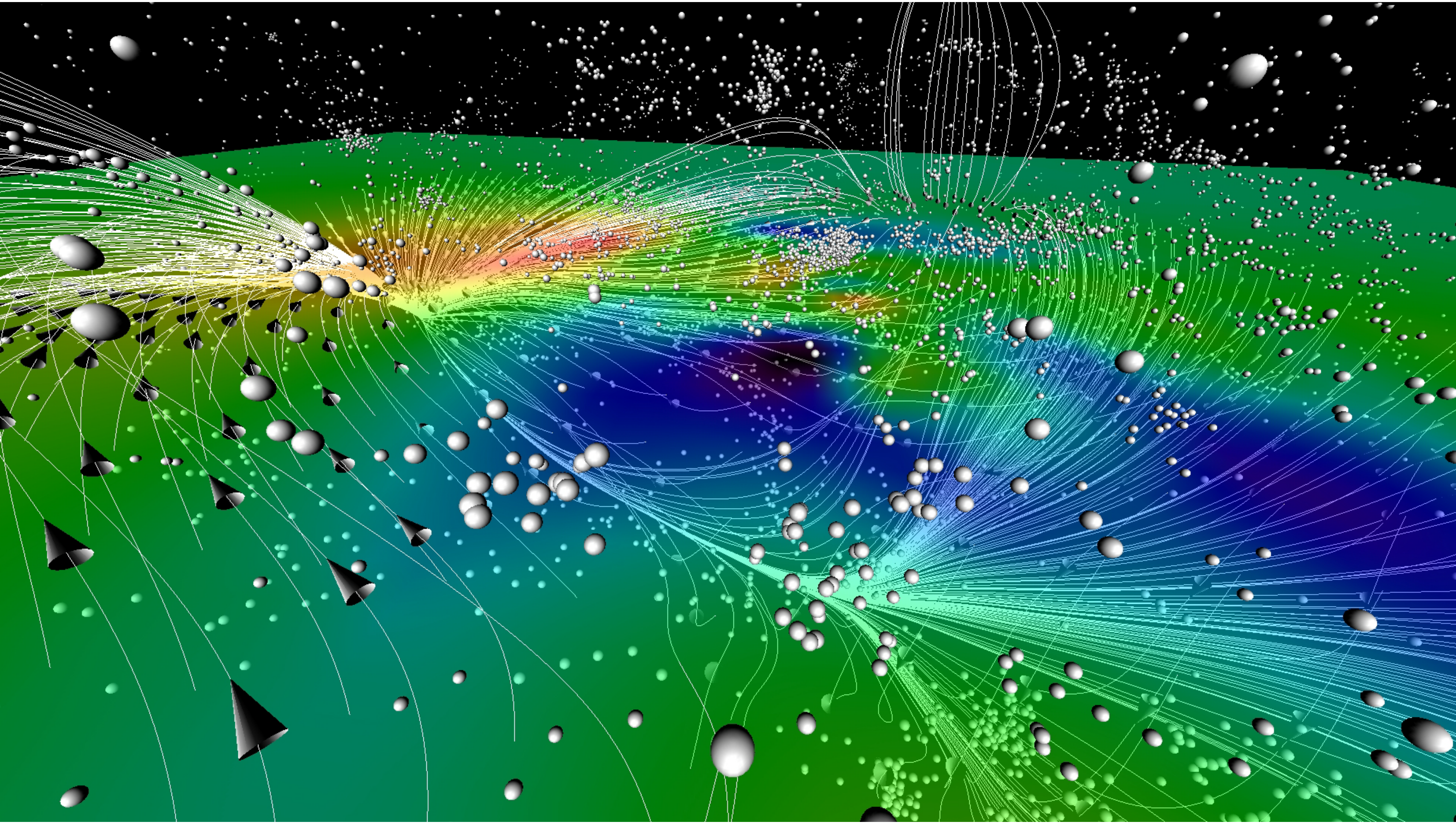


ΛCDM really works.
Constraints on H_0 improved for extended models with tail.



Calabrese et al 2011

The flow towards the Great Attractor : the red zone in the background, as reconstructed using Tully's cosmicflows-1 catalog.
The Great attractor is seen located outside the ZOA.



Summary

- We can now map the dark matter for $z < 0.05$

  TAIPAN redshifts would extend this to $z = 0.1$

- Observations and CDM are fairly compatible, although excess power on large scales still seems likely

  TAIPAN project to $z = 0.1$ would be decisive

- Knowing the velocity field makes Hubble constant measurements more accurate

- Reaching $\delta H_0/H_0 = 0.01$ is possible in the next few years and may yield a surprise in the number of neutrinos (relativistic species)