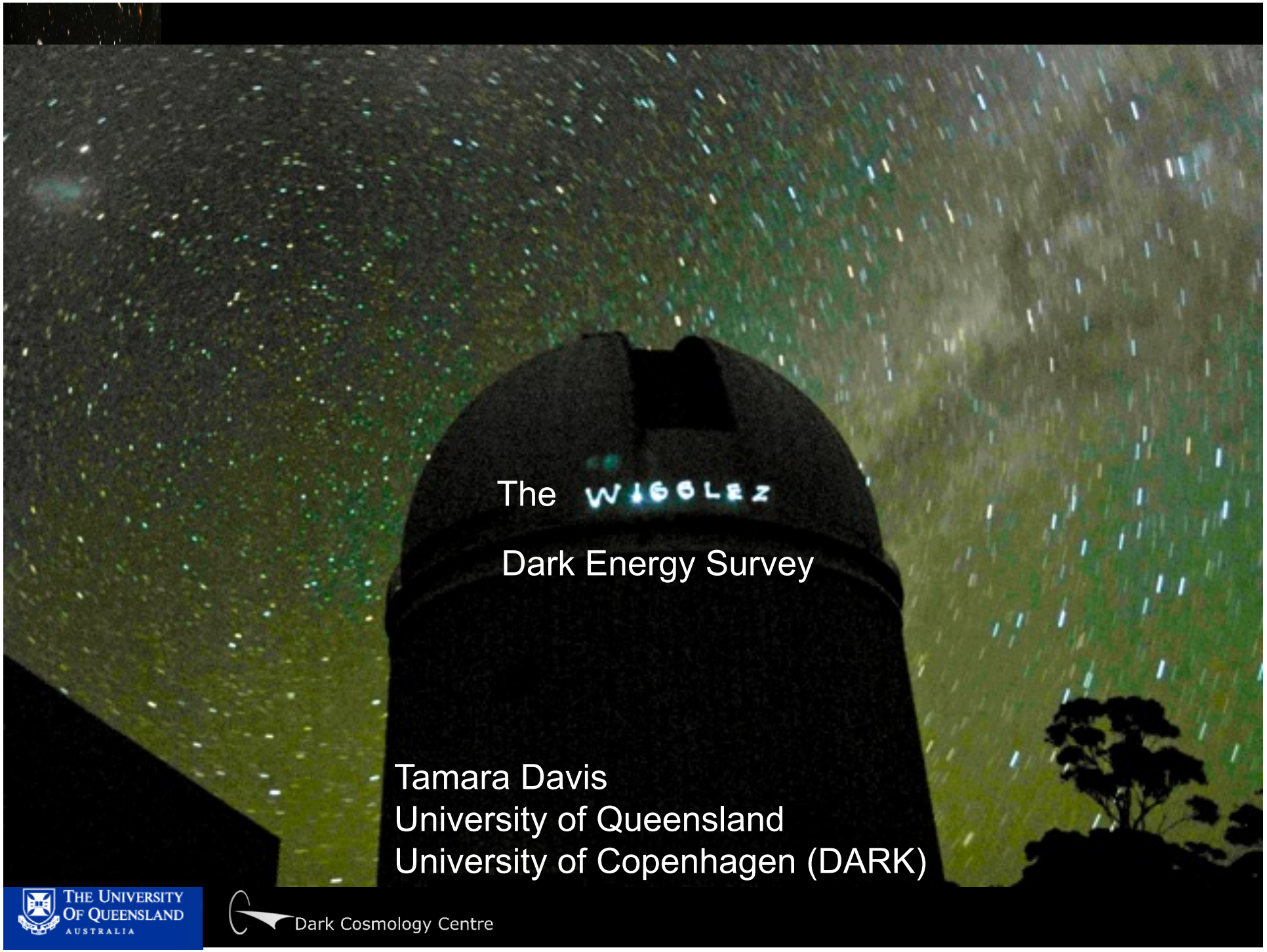
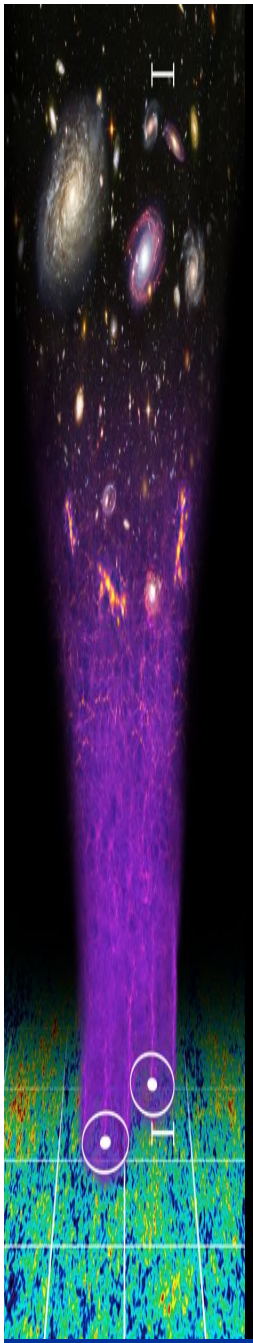


Tamara Davis
University of Queensland
University of Copenhagen (DARK)

The University Of Queensland AUSTRALIA

Dark Cosmology Centre

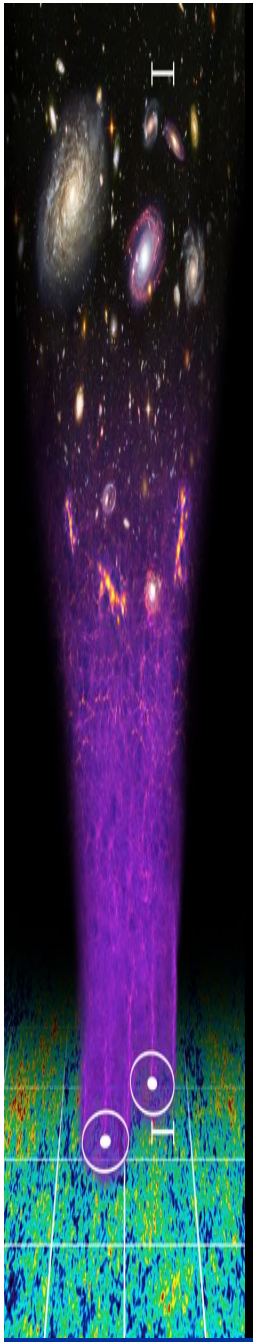


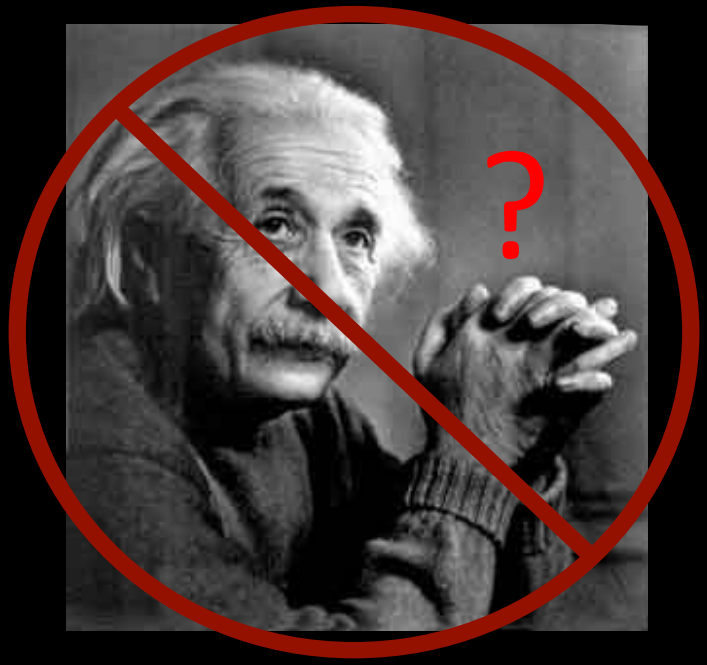
Cosmic Conundrums - motivation

- What are the fundamental rules that govern our universe?
  - Is general relativity the correct theory of gravity?
  - If so, what form does the dark energy take?
  - If dark energy is Λ, measure the other cosmological parameters of the universe.
- What initiated the expansion?
  - Test predictions of inflation
- How did galaxies form and how do they evolve?
  - Test structure formation and galaxy evolution

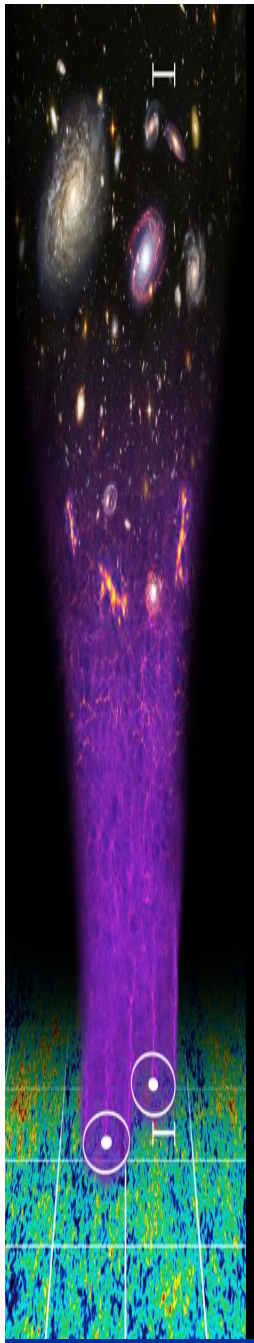
Was Einstein wrong?

- Is general relativity the correct theory of gravity?





"Its easy to identify crackpots, just listen for: 'Einstein was wrong'!"



WiggleZ Aims

- Map 1 Gpc^3 at much higher redshift than existing surveys
- Extend baryon acoustic oscillation distance data to z=1, to test the properties of dark energy
- Measure the rate of structure growth from z=1 to z=0 to test beyond-standard theories of gravity
- Lots of other science connected with star-forming galaxies at high redshift

The WiggleZ Survey Team

University of Queensland: Tamara Davis, Michael Drinkwater, Signe Riemer-Sorensen, David Parkinson (soon)

Swinburne: Chris Blake, Carlos Contreras, Warrick Couch, Darren Croton, Karl Glazebrook, Tornado Li, Greg Poole, Emily Wisniowksi

AAO: Sarah Brough, Matthew Colless, Mike Pracy, Rob Sharp

Scott Croom (U.Syd), Ben Jelliffe (U.Syd), David Woods (UBC), Kevin Pimbblet (Monash), Russell Jurek (ATNF)

Galex Team: Karl Forster, Barry Madore, Chris Martin, Ted Wyder

RCS2 Team: David Gilbank, Mike Gladders, Howard Yee

Associate: Berian James (DARK)

WiggleZ Vital Statistics

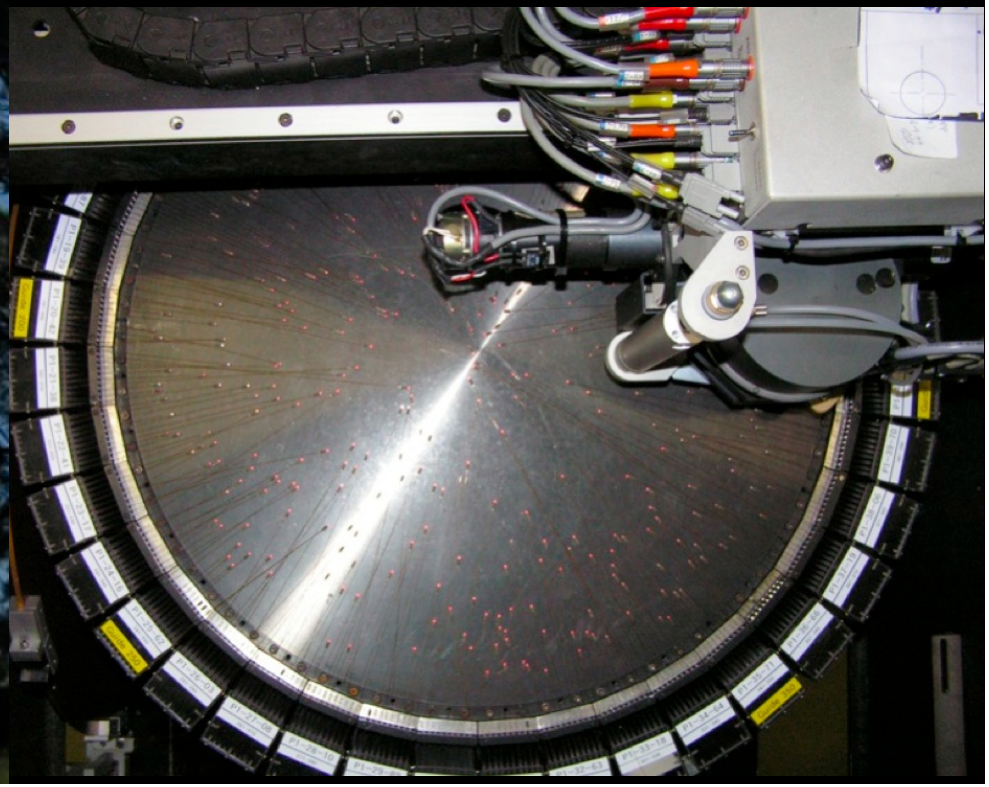
1000 square degrees

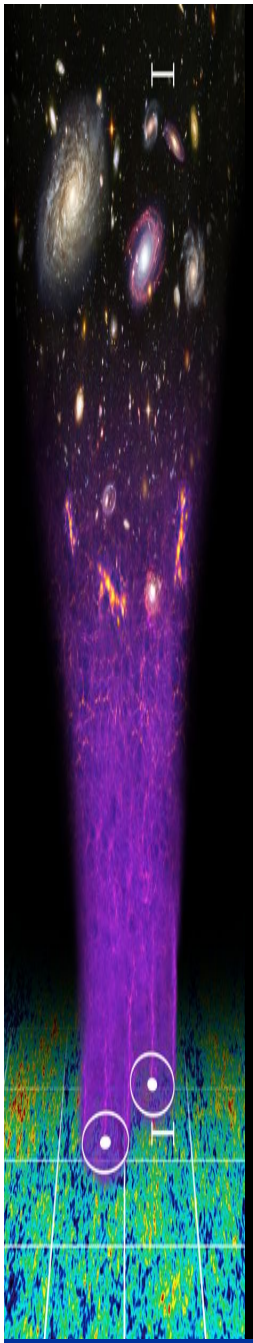
$0.2 < z < 1.0$

~250,000 redshifts

Blue star-forming galaxies

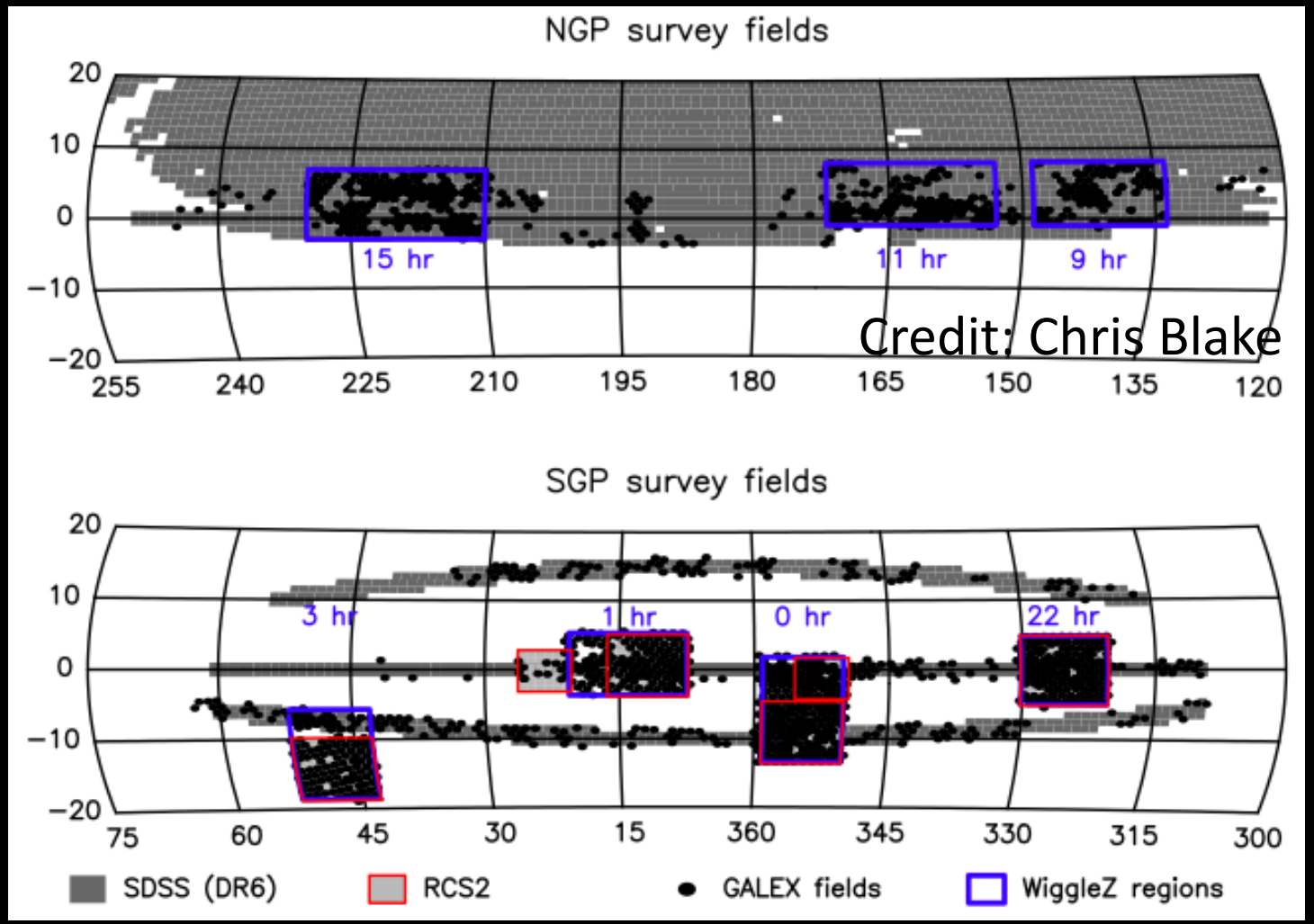
2006-2010(11)





WiggleZ survey fields

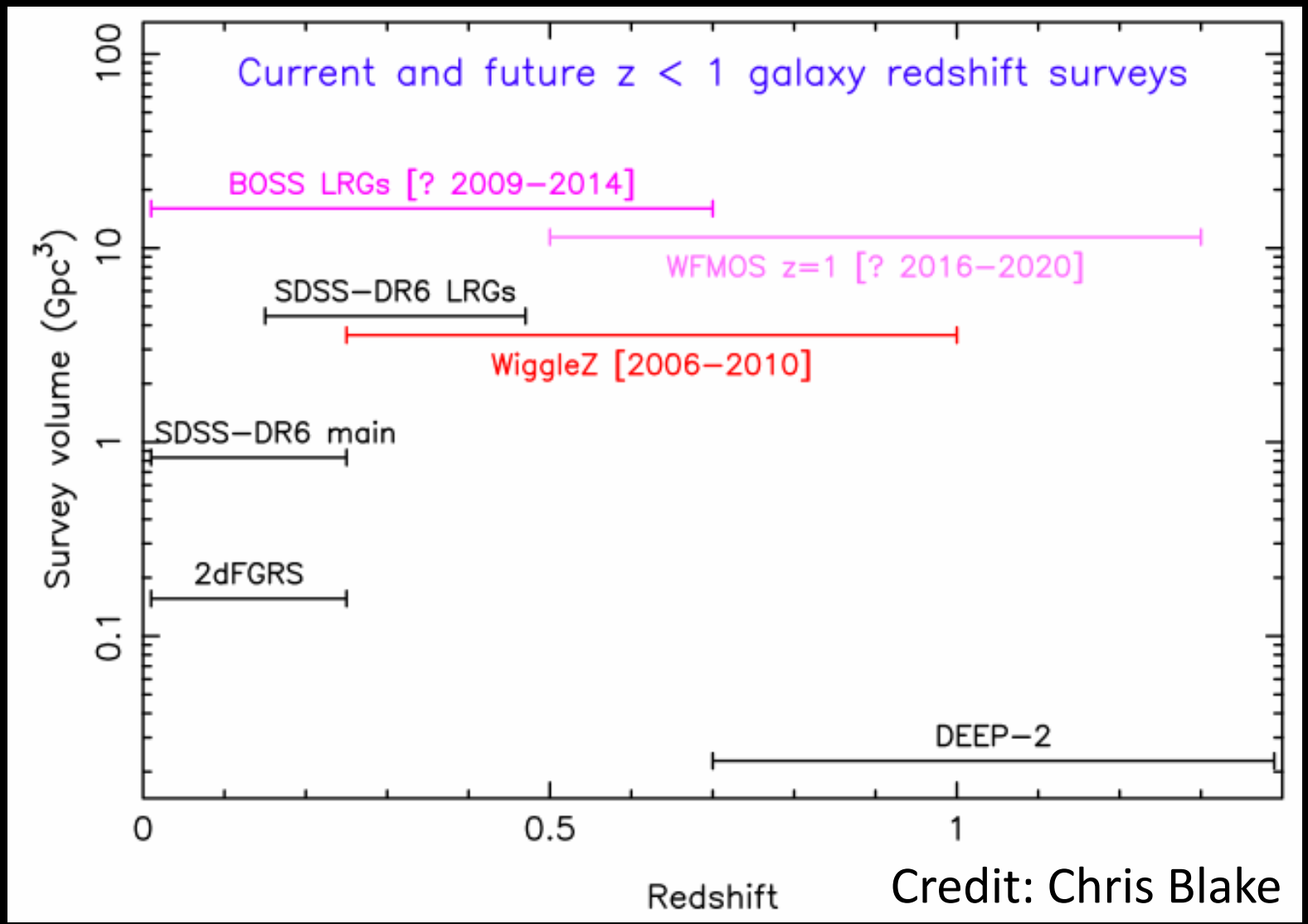
7 equatorial fields, each 100-200 deg^2
>9° on side, ~3 x BAO scale at z > 0.5
Physical size ~ 1300 x 500 x 500 Mpc/h



The University Of Queensland AUSTRALIA

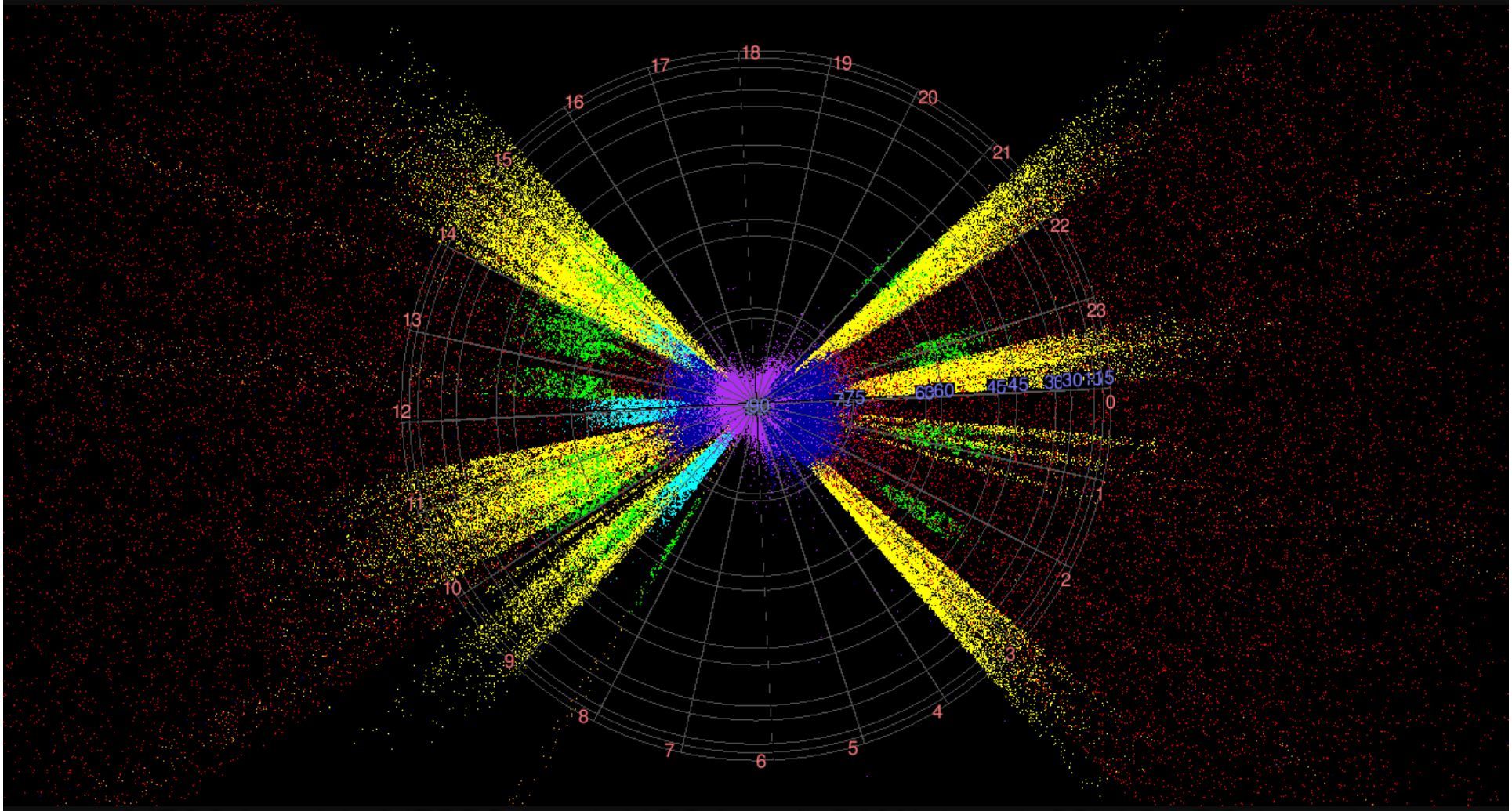
Dark Cosmology Centre

Comparison to other surveys



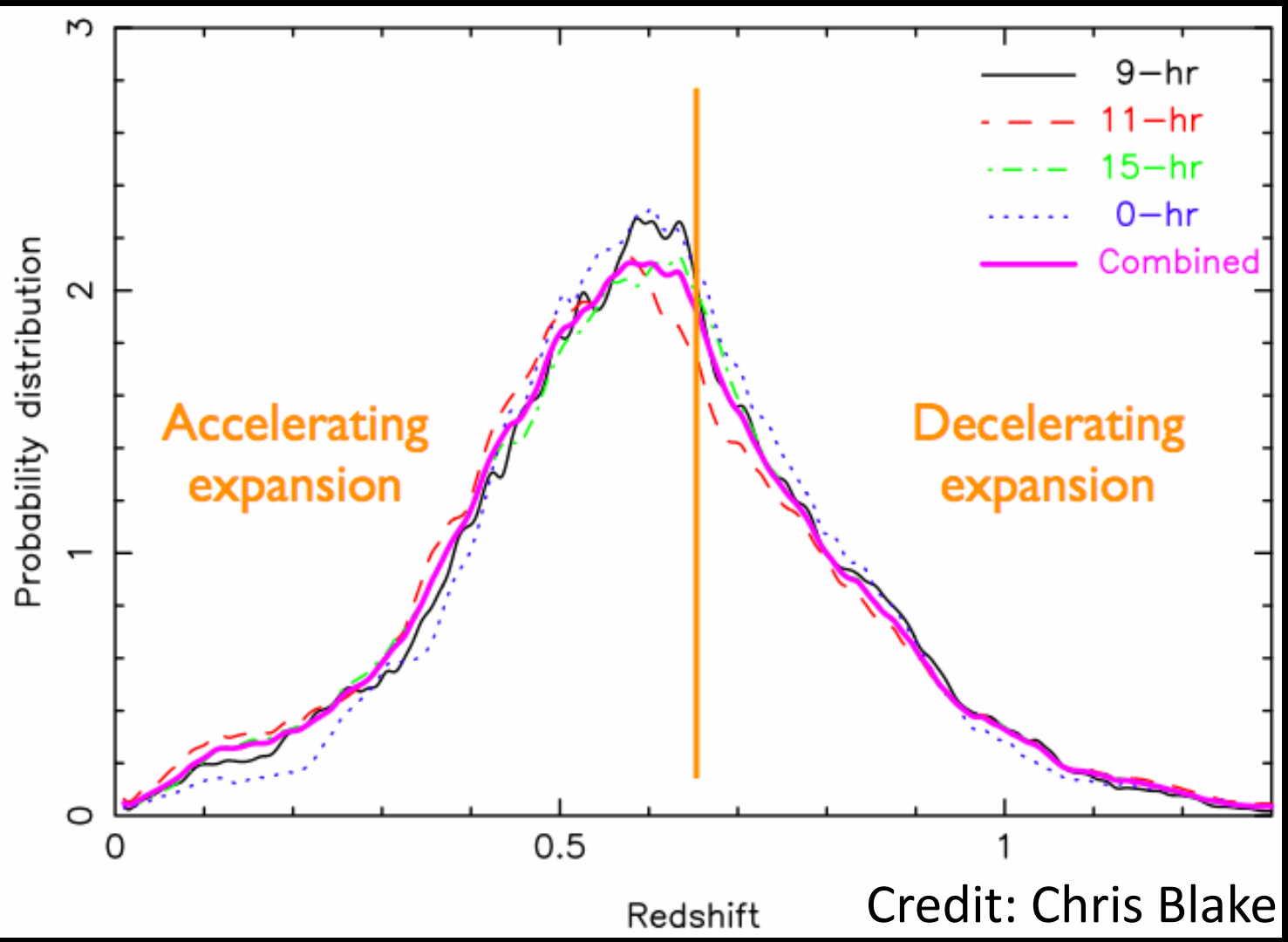
Credit: Chris Blake

AAT and UKST redshift surveys



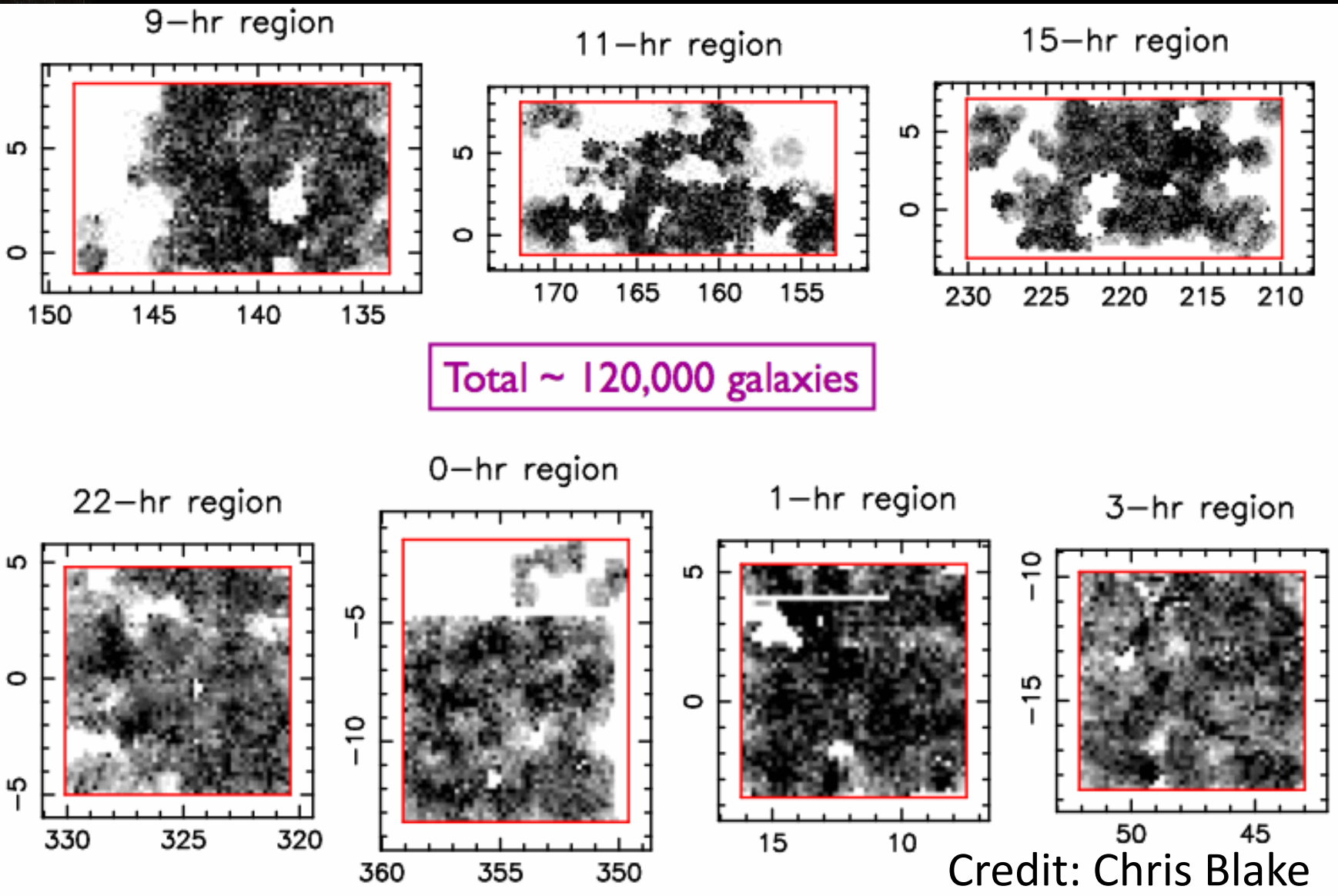
6dFGS (purple), 2dFGRS (blue), MGC (navy), GAMA (cyan), 2SLAQ-LRG (green), WiggleZ (yellow), 2SLAQ-QSO (orange), 2QZ (red); the celestial sphere is at z=1.

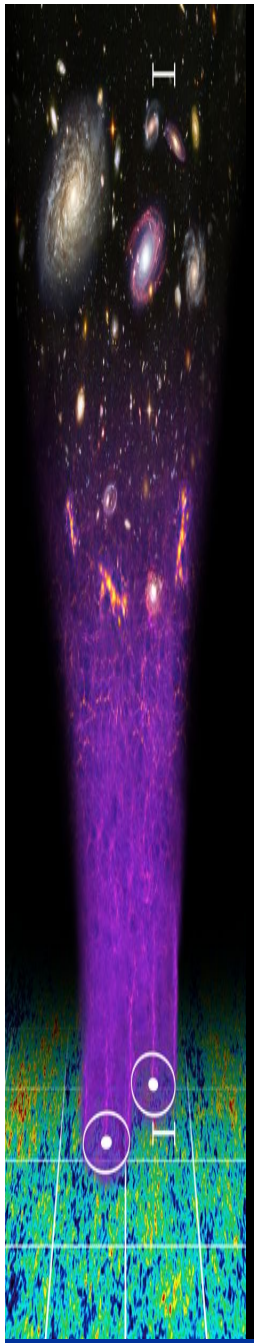
Redshift distribution



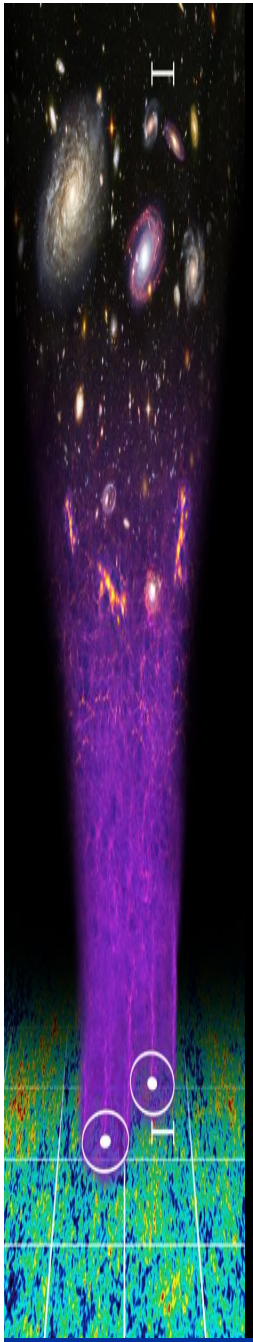
Credit: Chris Blake

Current analysed sample



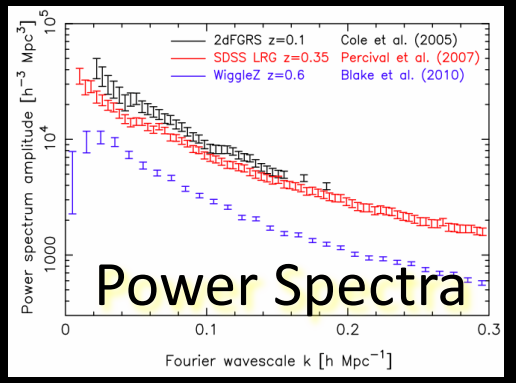


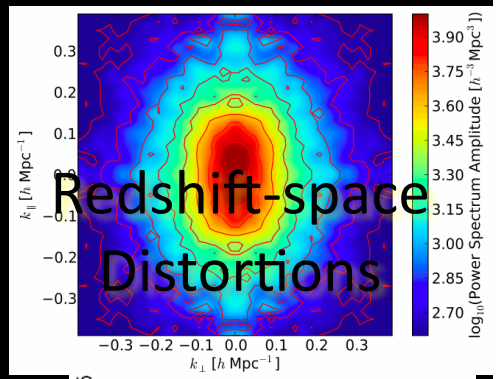
Chris Blake (Swinburne) has been leading the cosmology analysis and many of the plots I'm showing are from his work

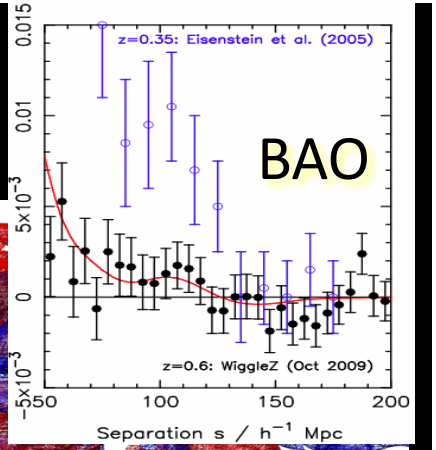


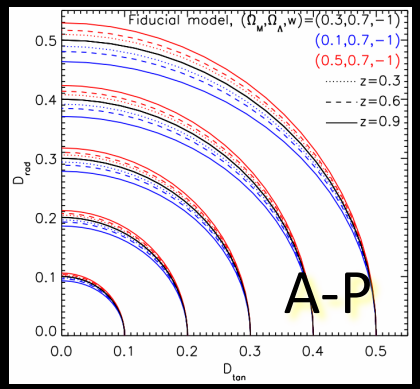
This talk

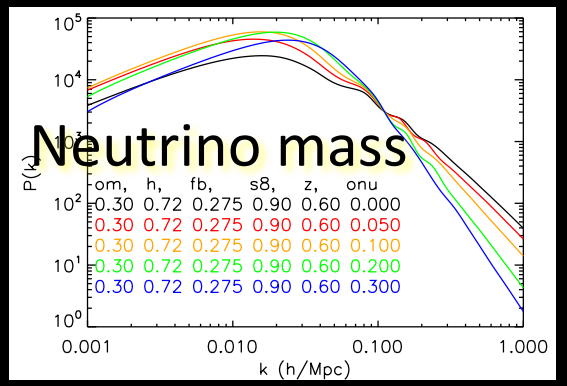
- Preliminary results
  - Power spectra
  - Growth (redshift-space distortions)
  - Baryon Acoustic Oscillations
  - Topology
  - Bispectrum
- Plans
  - Alcock-Paczynski effect
  - Neutrino Mass
- Database







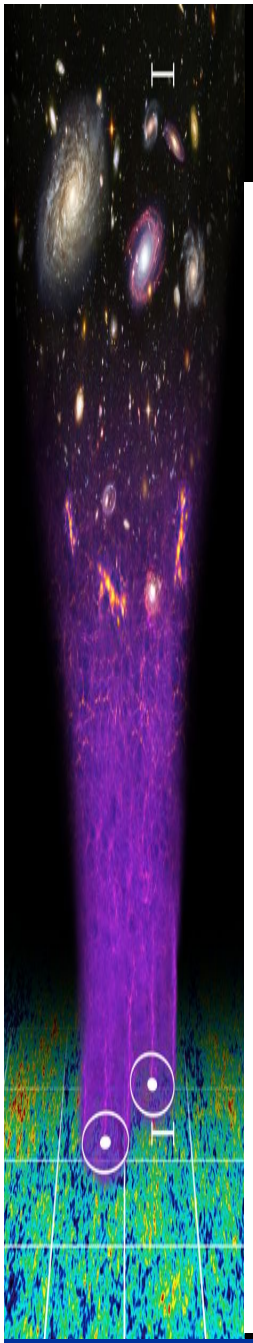


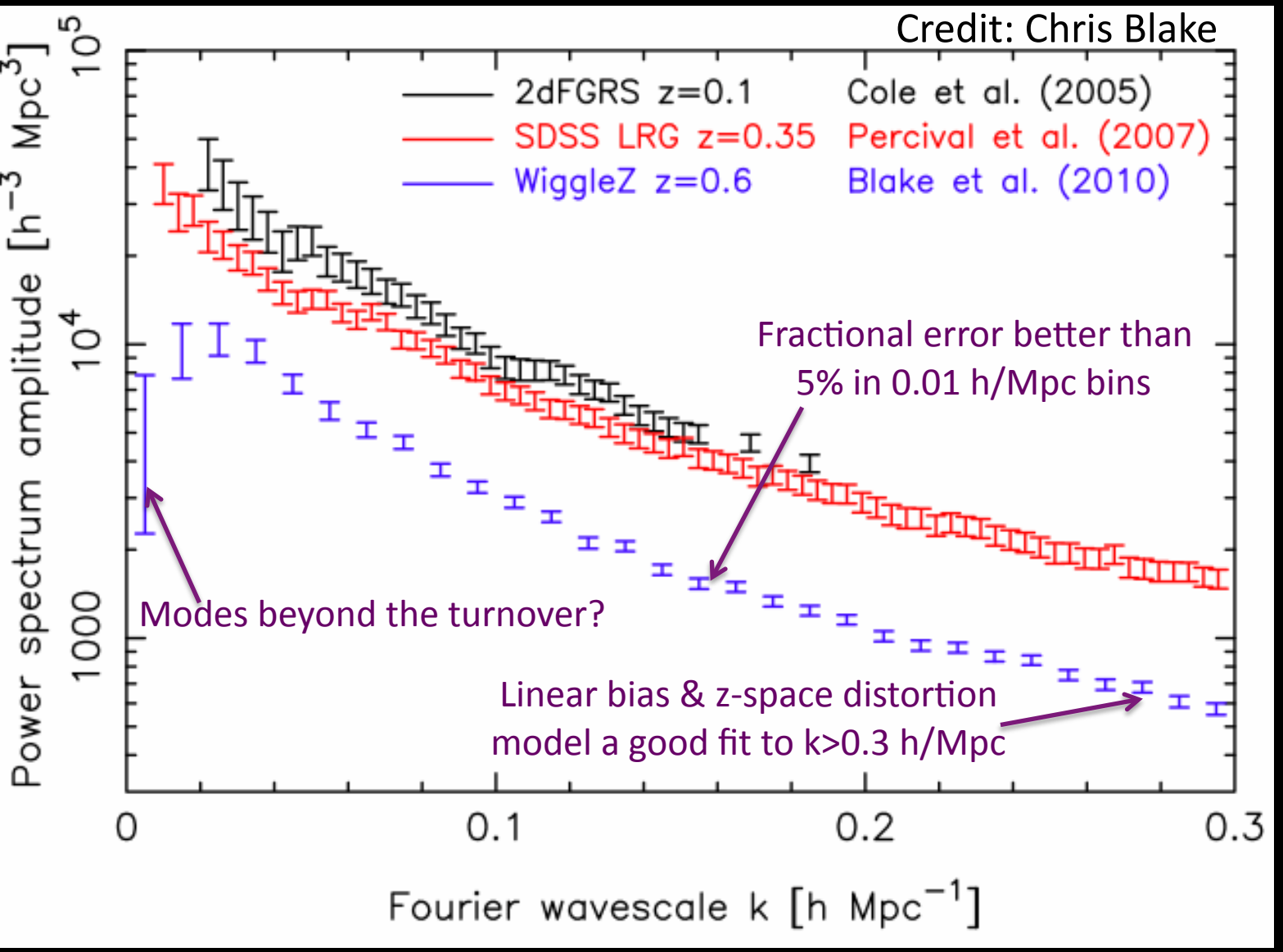


THE UNIVERSITY OF QUEENSLAND AUSTRALIA

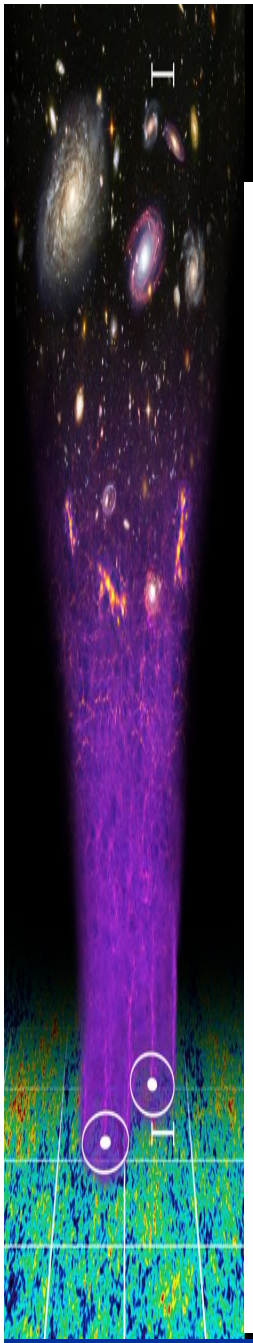
Dark Cosmology Centre

WiggleZ power spectrum (blue)

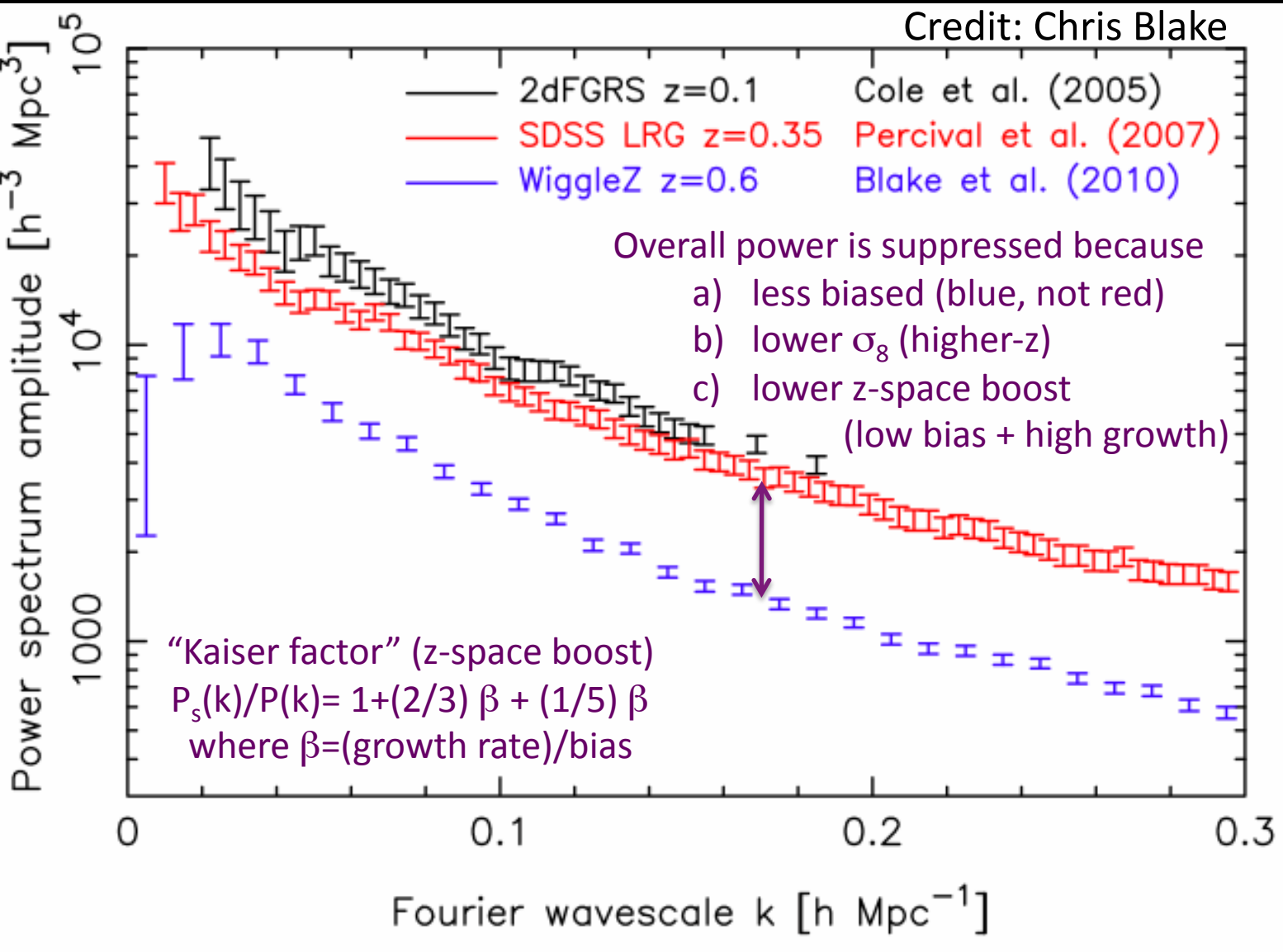




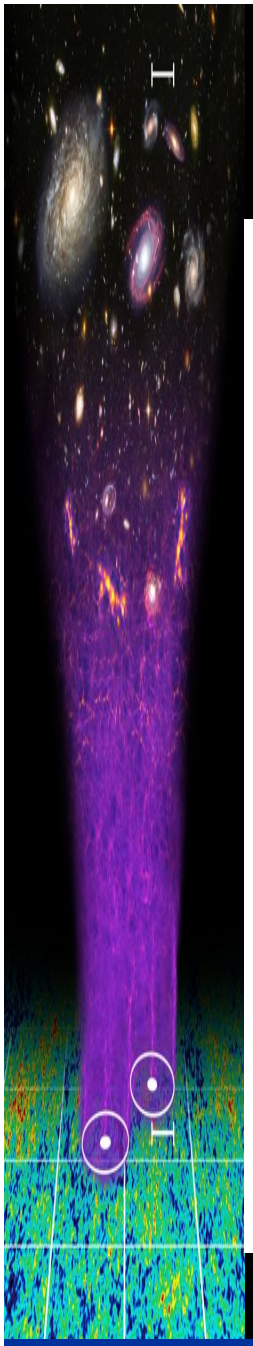
WiggleZ power spectrum (blue)

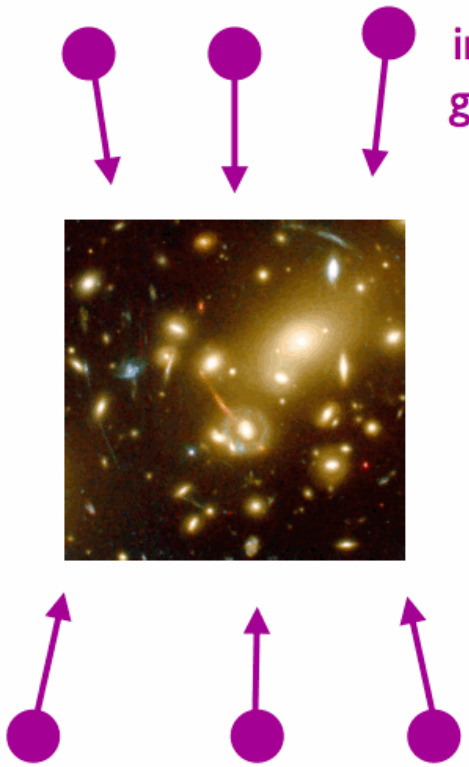


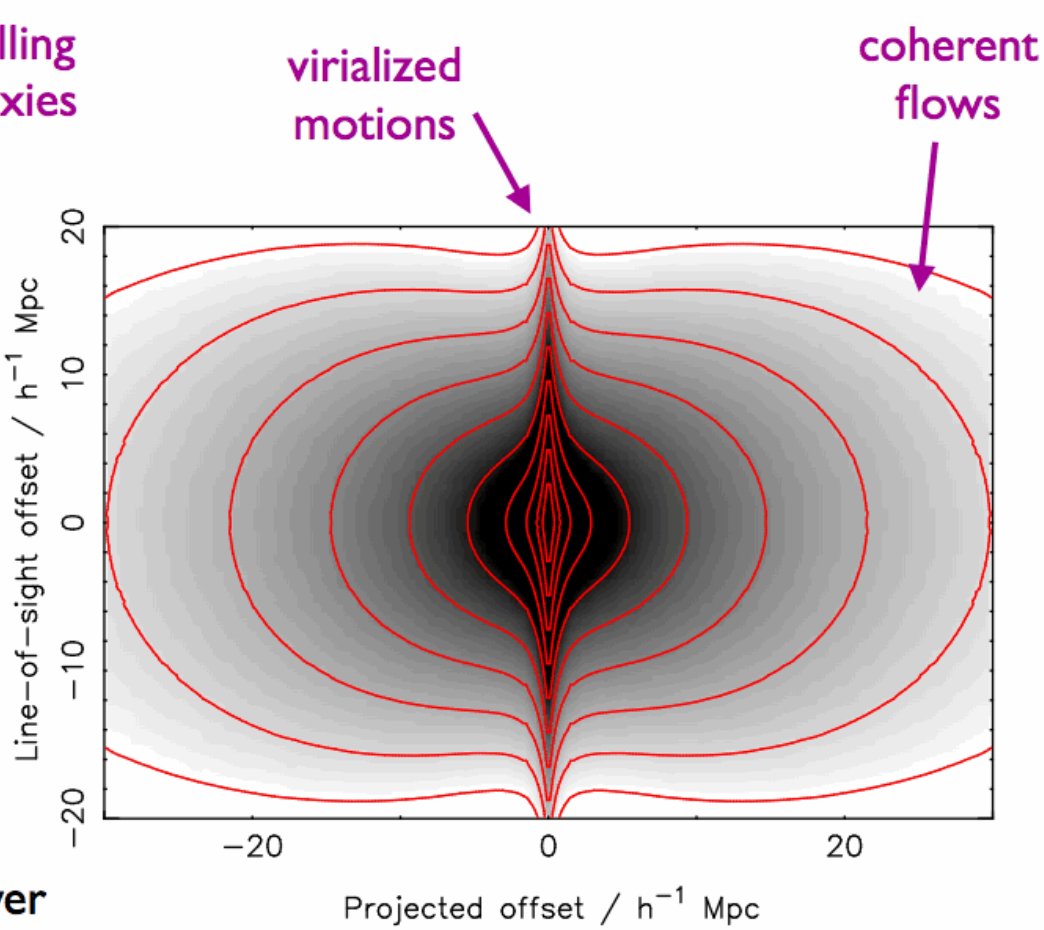
Credit: Chris Blake



Redshift space distortions

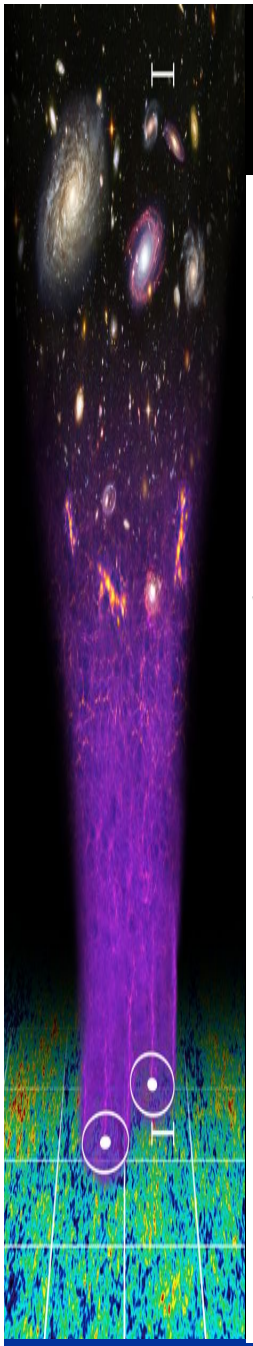


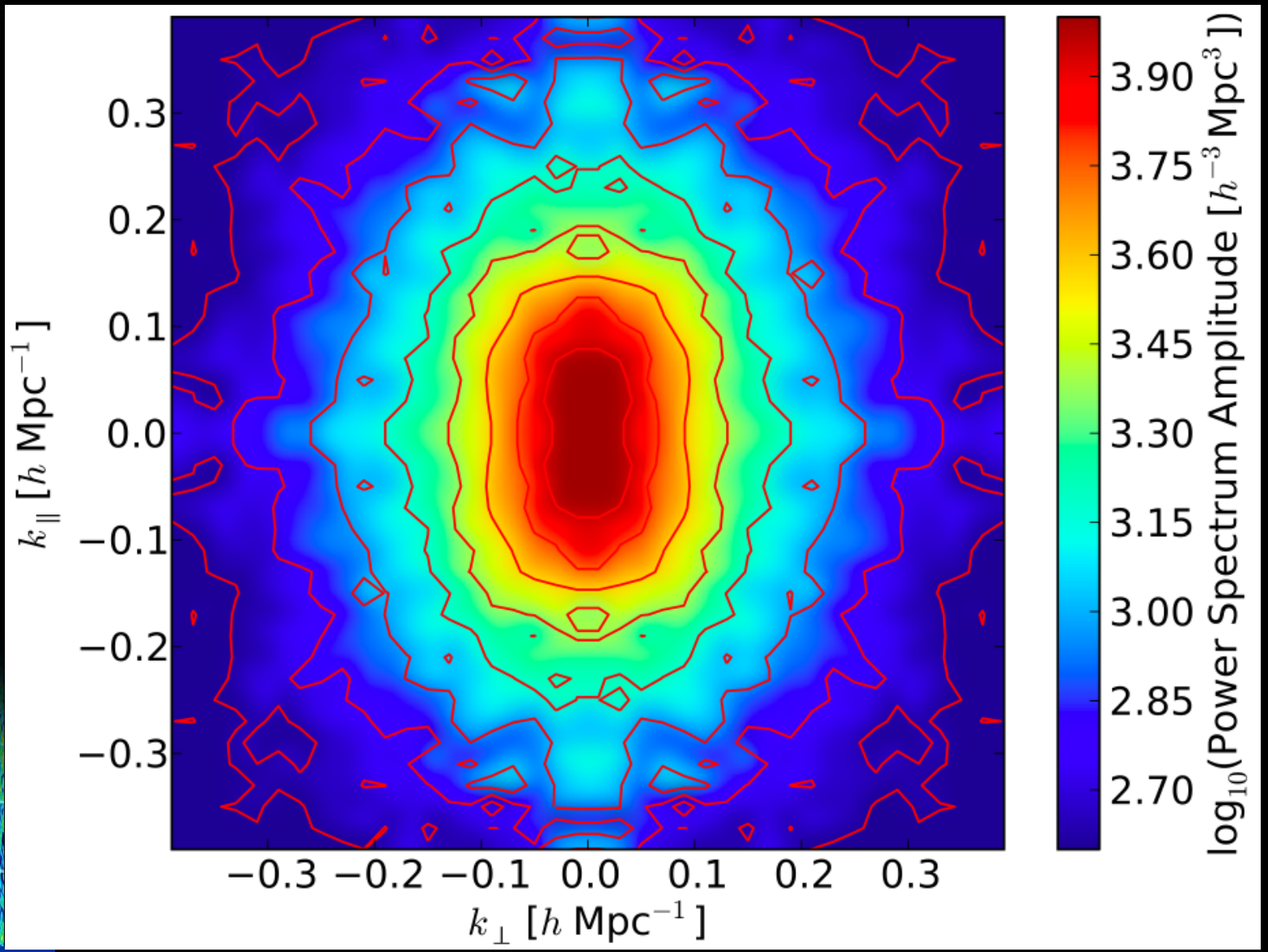




Credit: Chris Blake

Redshift space distortions





Redshift space distortion model

Image credit: Chris Blake

Amplitude of Fourier mode

Growth rate

Angle to the line-of-sight $\mu = \cos\theta$

Redshift

Real

$$\delta_s(\vec{k}) = \delta_r(\vec{k})(1 + f\,\mu^2)$$

$\gamma \approx 6/11$ (ΛCDM)

$\gamma \approx 11/16$ (DGP)

$$f = \Omega_{\rm m}(z)^{\gamma}$$

Galaxy power spectrum

Bias factor

Matter power spectrum

Anisotropy depends on f/b

$$P_{\rm g}(k,\mu) = b^2\,P_{\rm m}(k)\left(1 + \frac{f}{b}\mu^2\right)^2$$

b also appears in normalisation

3 fitted parameters

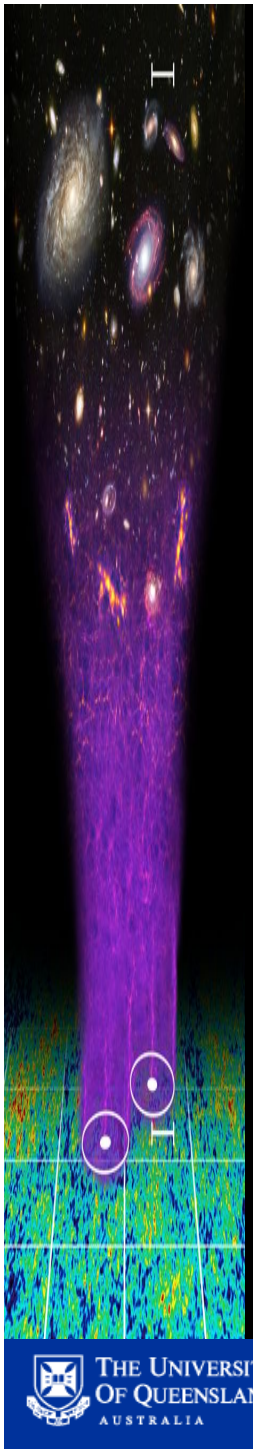
Pairwise velocity dispersion

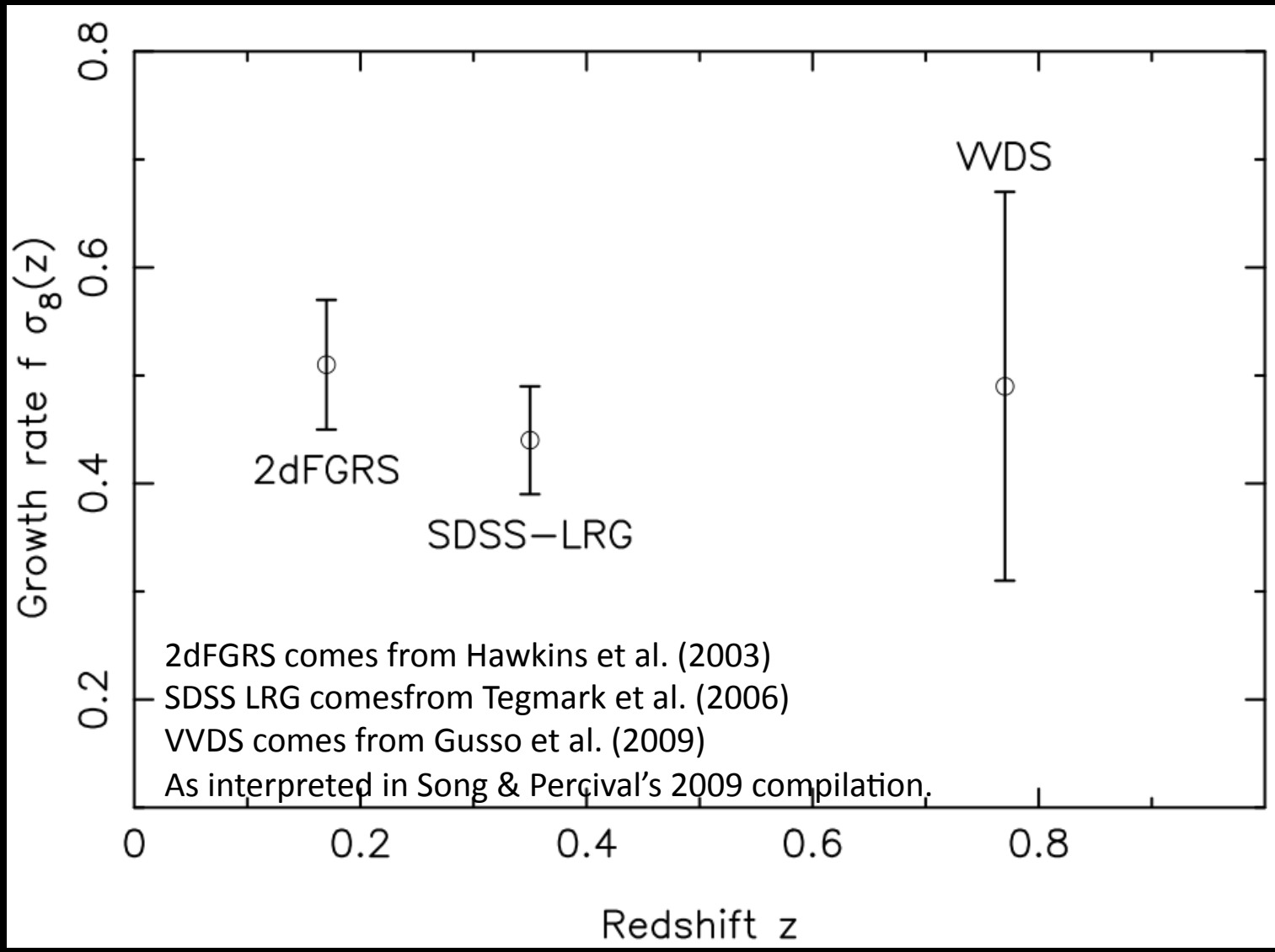
$$P(v) \propto e^{-|v|/\sigma_v}$$

$$P_{\rm g}(k,\mu) = b^2\,P_{\rm m}(k)\frac{[1 + (f/b)\mu^2]^2}{1 + (\sigma_v H_0 k\mu)^2}$$

Therefore observations are sensitive to $f\,\sigma_8$

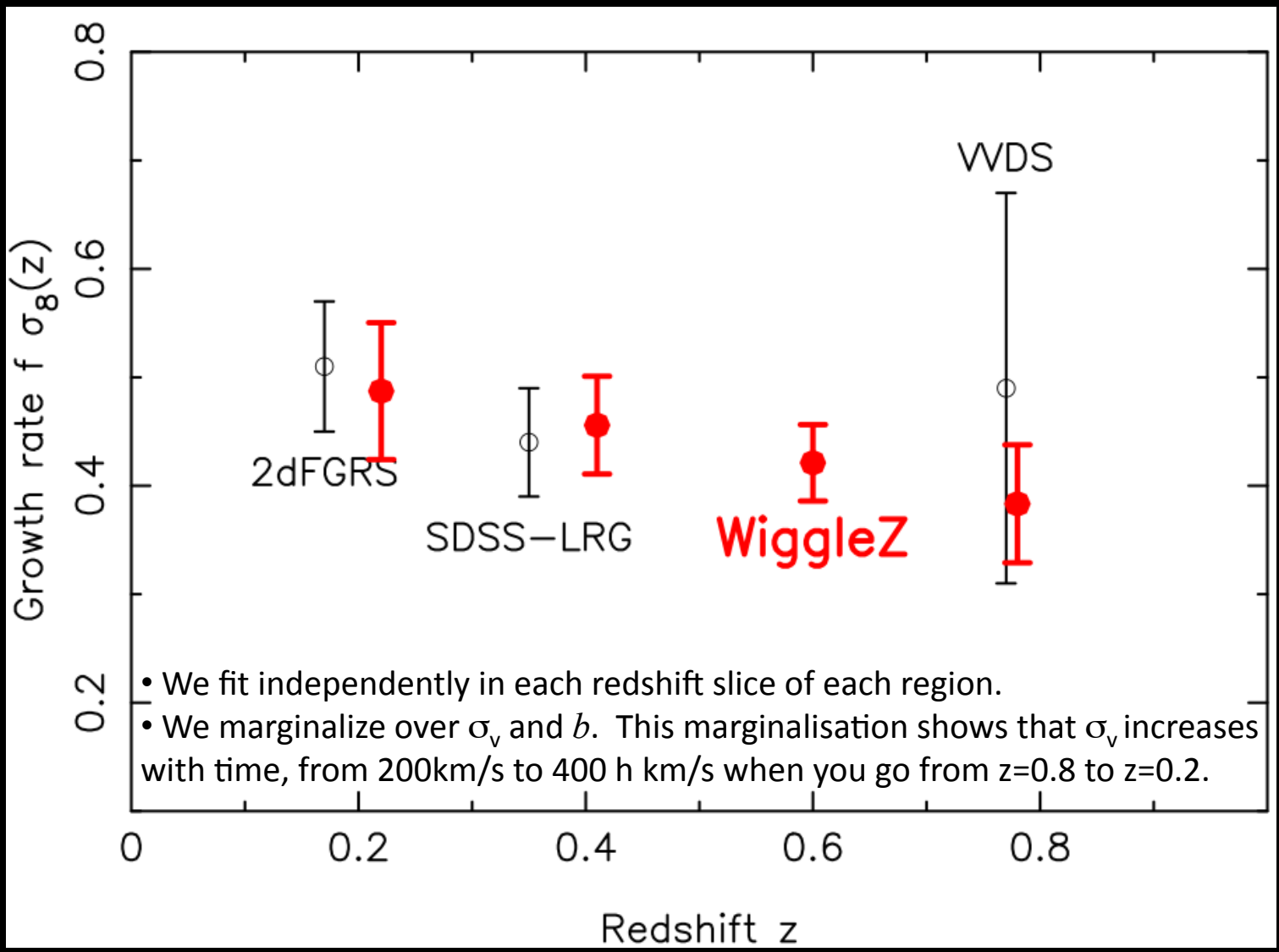
Growth rate – existing measurements



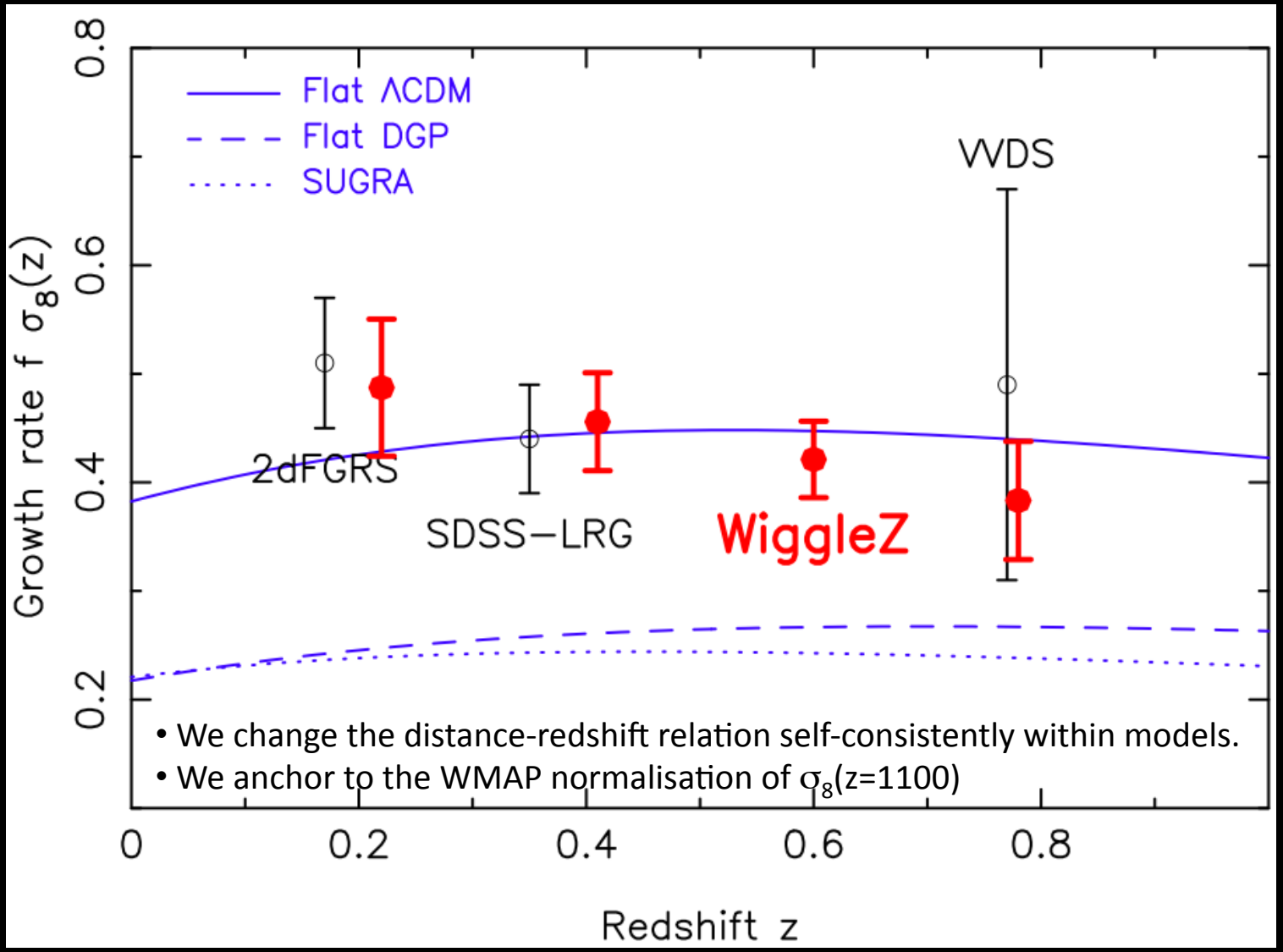


2dFGRS comes from Hawkins et al. (2003)
SDSS LRG comesfrom Tegmark et al. (2006)
VVDS comes from Gusso et al. (2009)
As interpreted in Song & Percival's 2009 compilation.

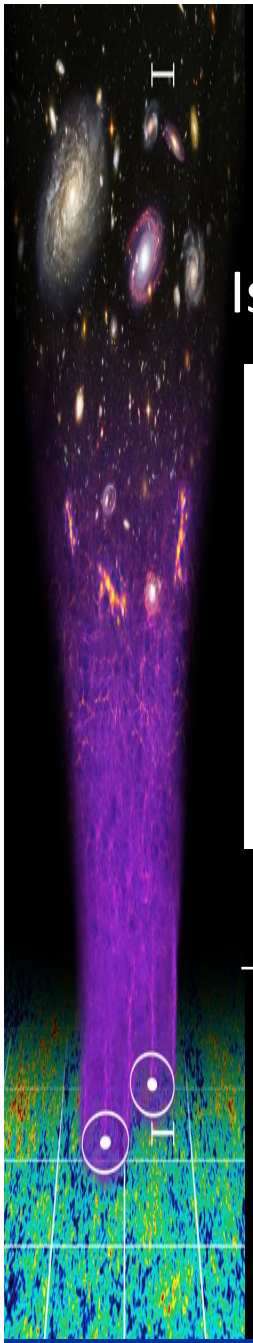
Growth rate – adding WiggleZ



Distinguishing dark energy models



Distinguishing Dark Energy models



Is ΛCDM self-consistent?

Fiducial Parameters

$$\Omega_M(0) = 0.27$$

$$f_b = 0.166$$

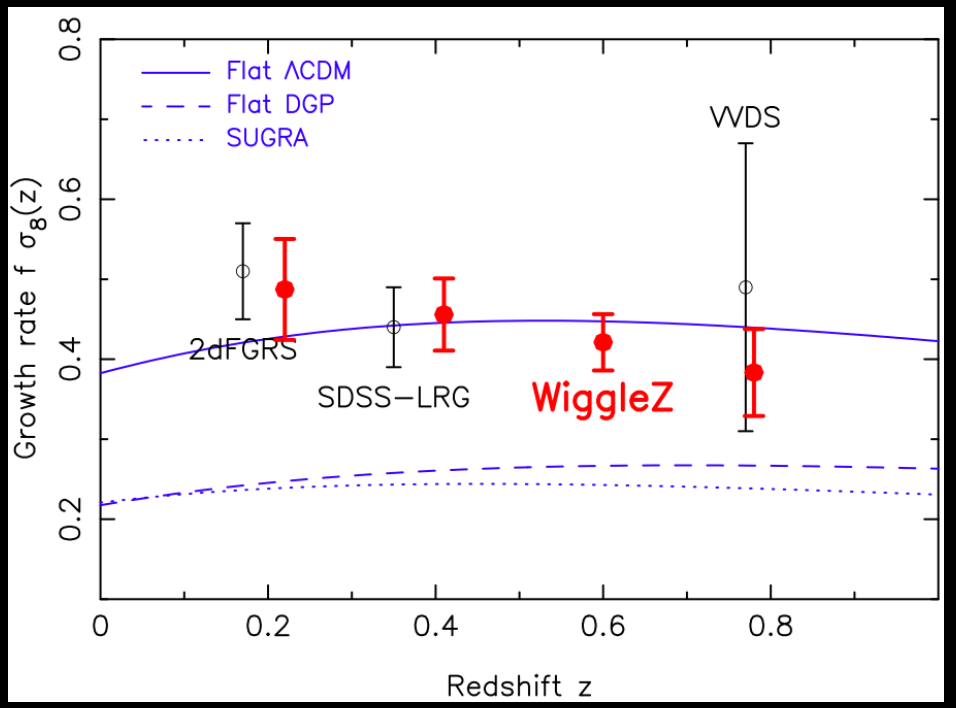
$$H_0 = 72 kms^{-1} Mpc^{-1}$$

$$n_s = 0.96$$

$$\Omega_K = 0$$

Model	χ^2/dof	
ΛCDM	1.2	good fit
SUGRA	8.6	rejected ~5σ
DGP	11	rejected ~6σ

Tentative!



$$f = \Omega_{\rm m}(z)^{\gamma}$$

- For a ΛCDM model : $\gamma = 0.60 \pm 0.10$ [prediction 0.55]
- For a DGP model : $\gamma = 0.30 \pm 0.08$ [prediction 0.69]

The University Of Queensland AUSTRALIA

Dark Cosmology Centre

Baryon Acoustic Oscillations

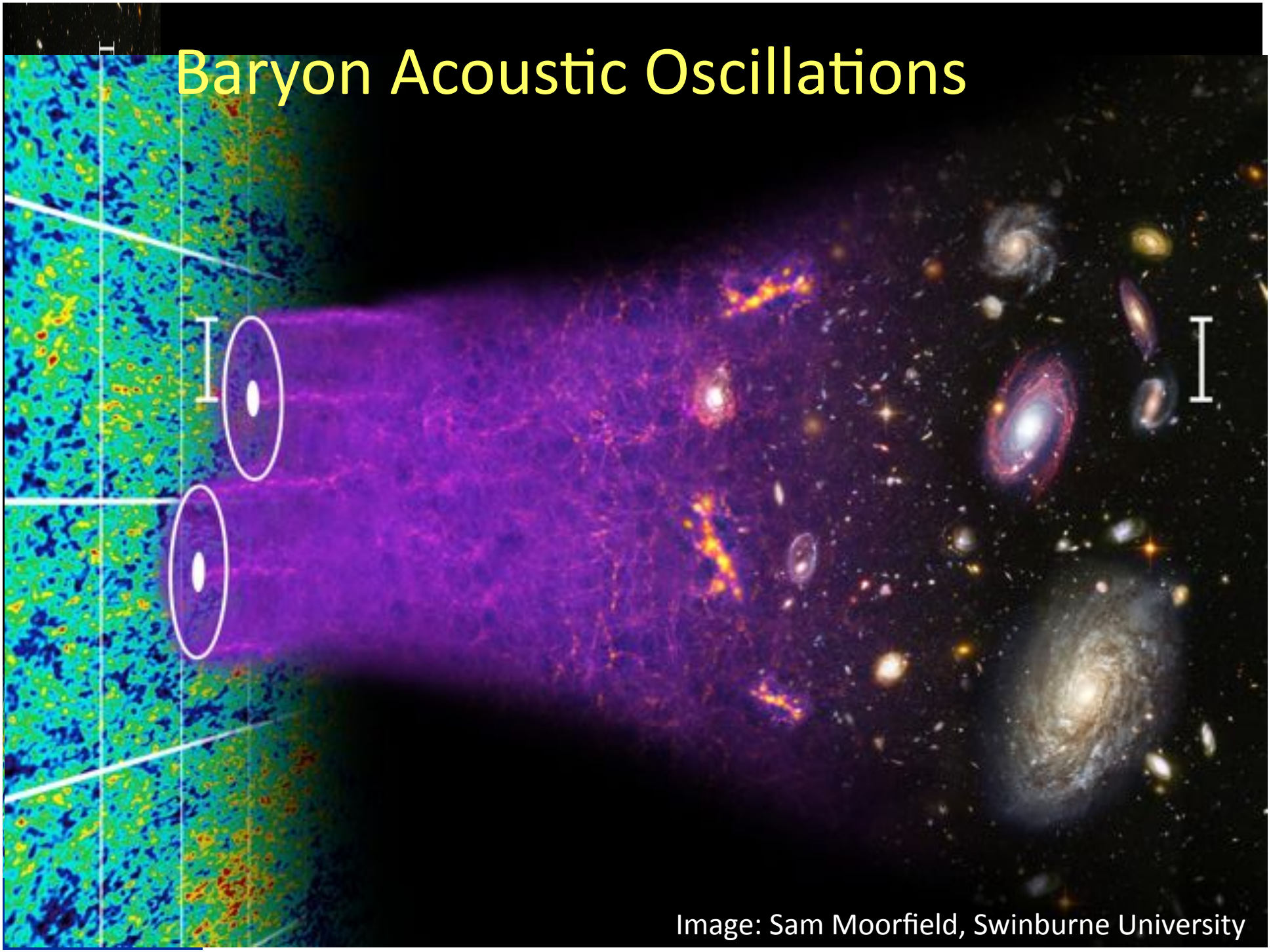
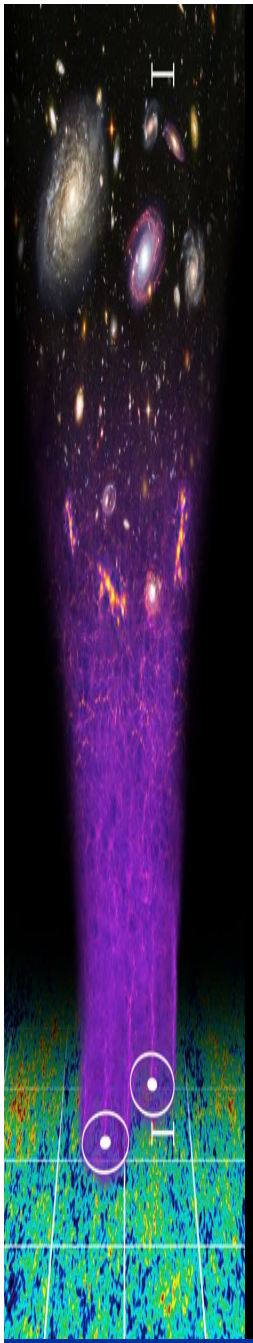
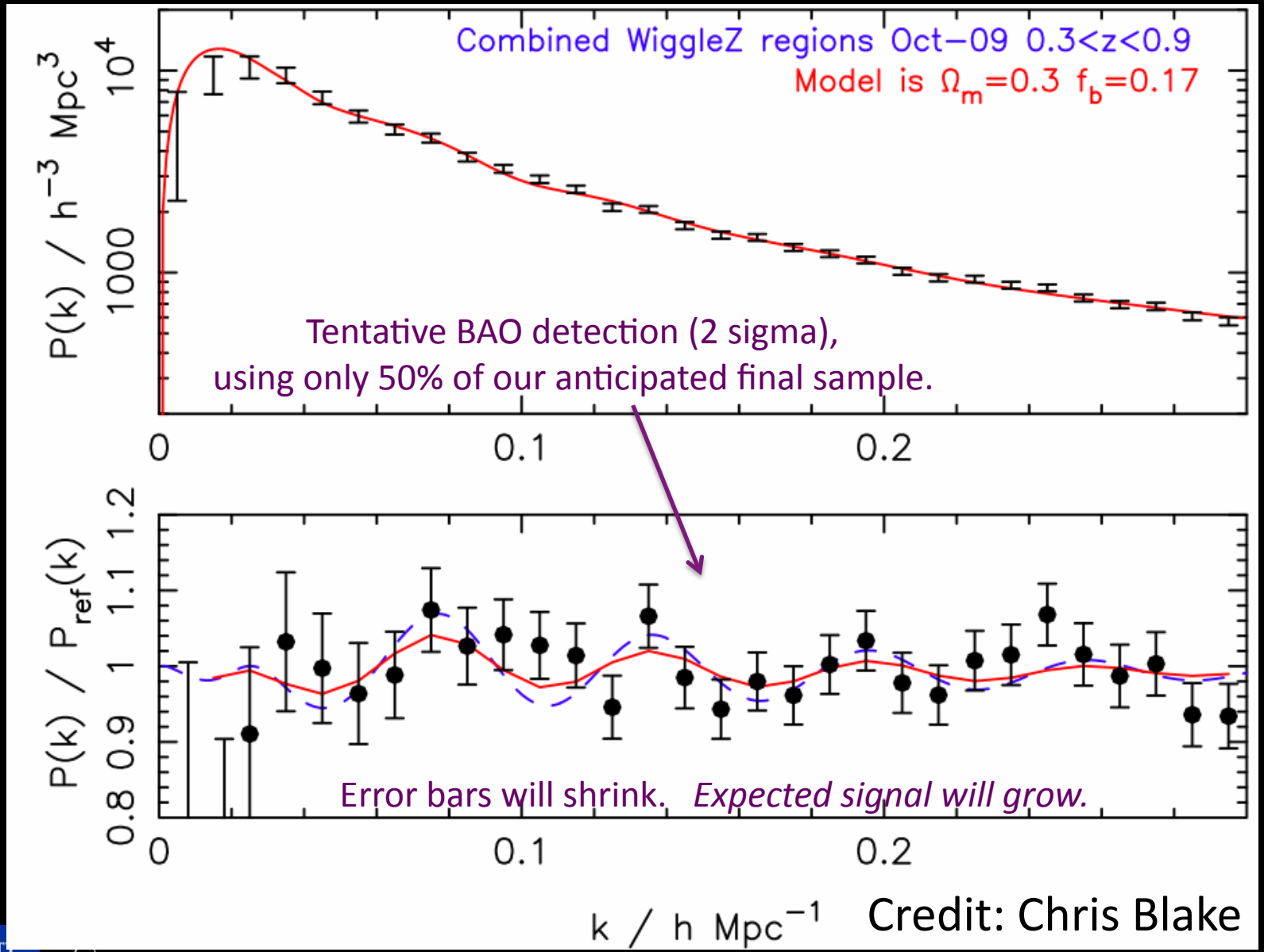


Image: Sam Moorfield, Swinburne University

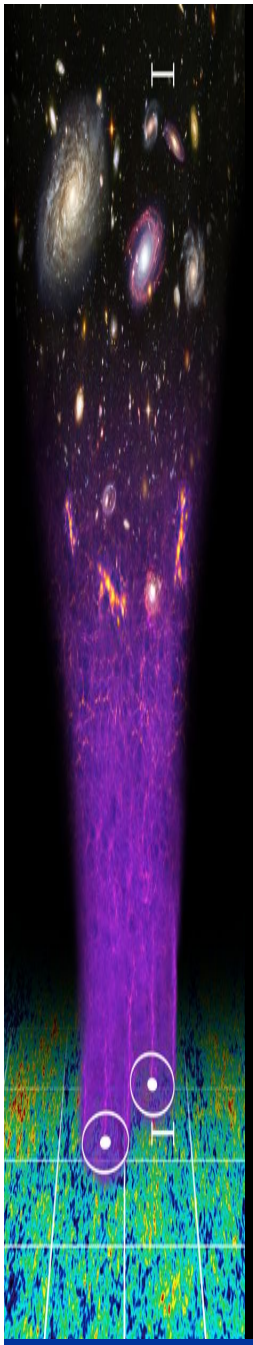
Baryon Acoustic Oscillations

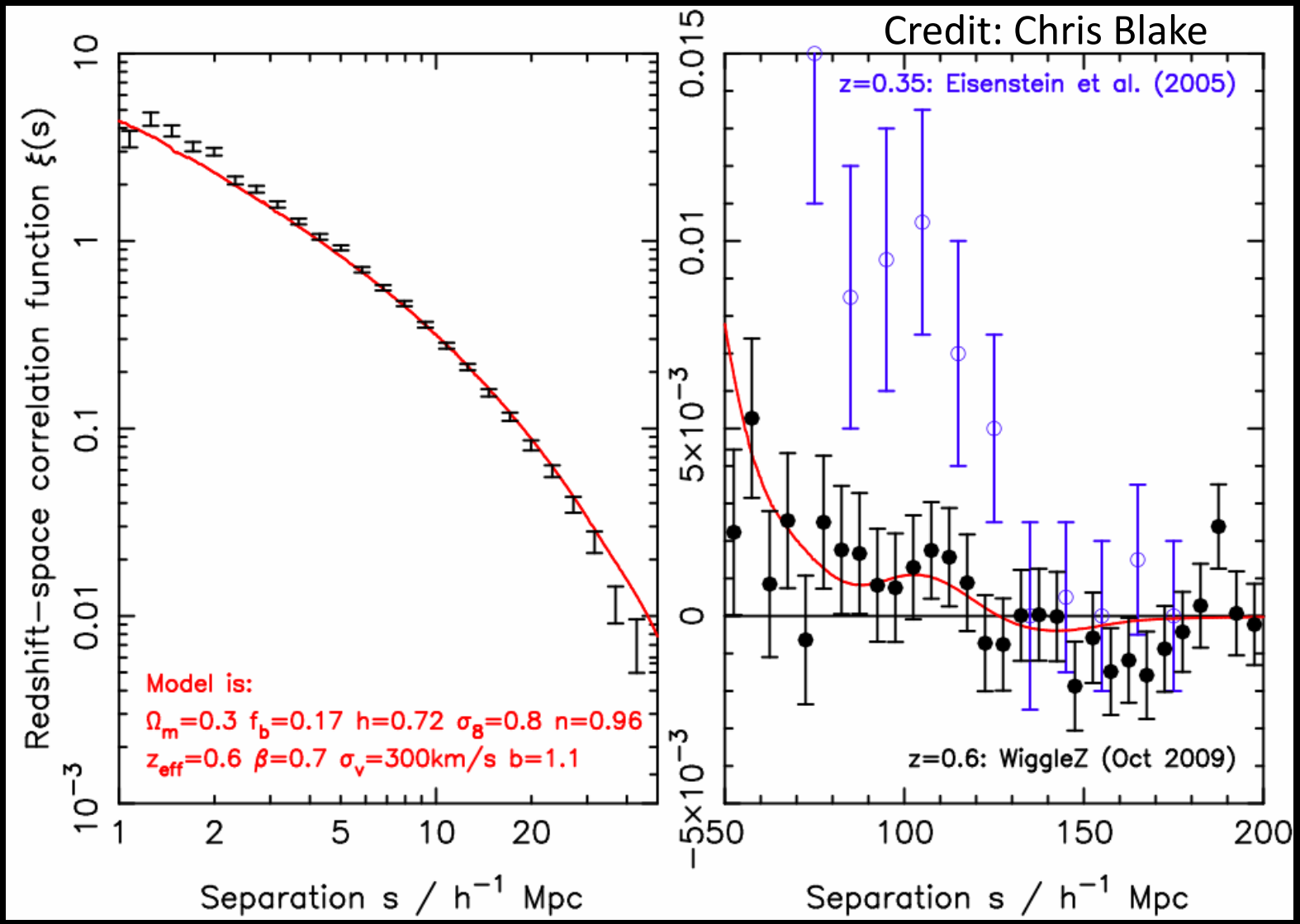




Credit: Chris Blake

BAO Correlation Function

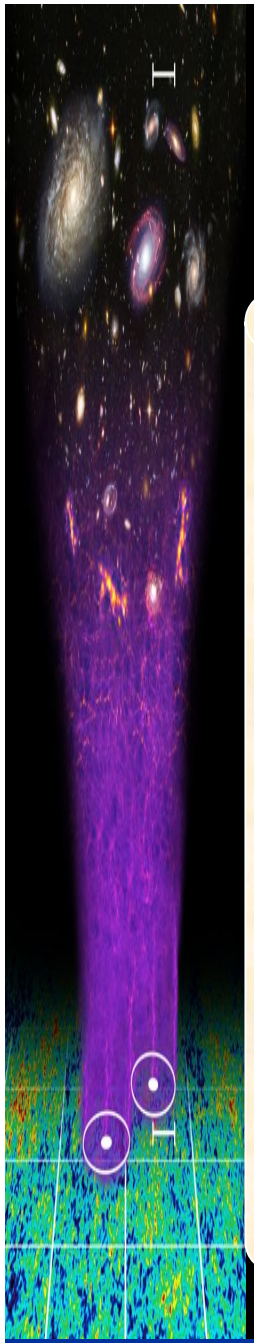




Expect 2% precision on standard ruler scale.

The University Of Queensland AUSTRALIA

Dark Cosmology Centre



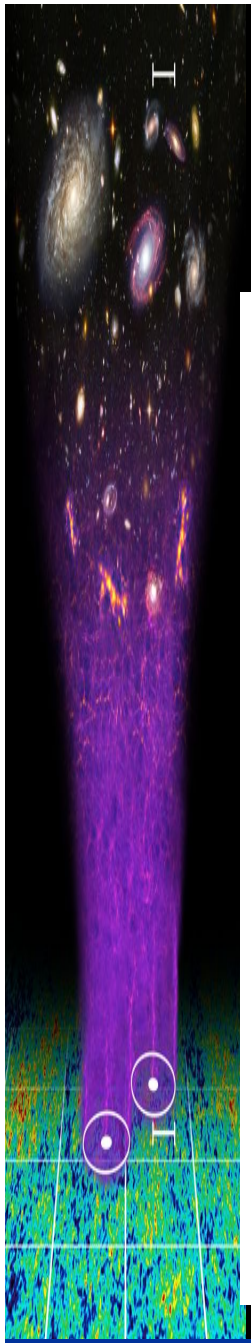
The brave souls…

"It is not the critic who counts, or how the strong man stumbled, or whether the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood, who strives valiantly, who errs and comes short again and again; who knows the great enthusiasm, the great devotion, and who spends himself in a worthy cause, and if he fails, at least fails while daring greatly, so that he'll never be with those

cold and timid souls

who never know either victory or defeat."

Teddy Roosevelt



Bispectrum theory

- Higher-order clustering statistic - measure of skewness
- Zero for Gaussian fields

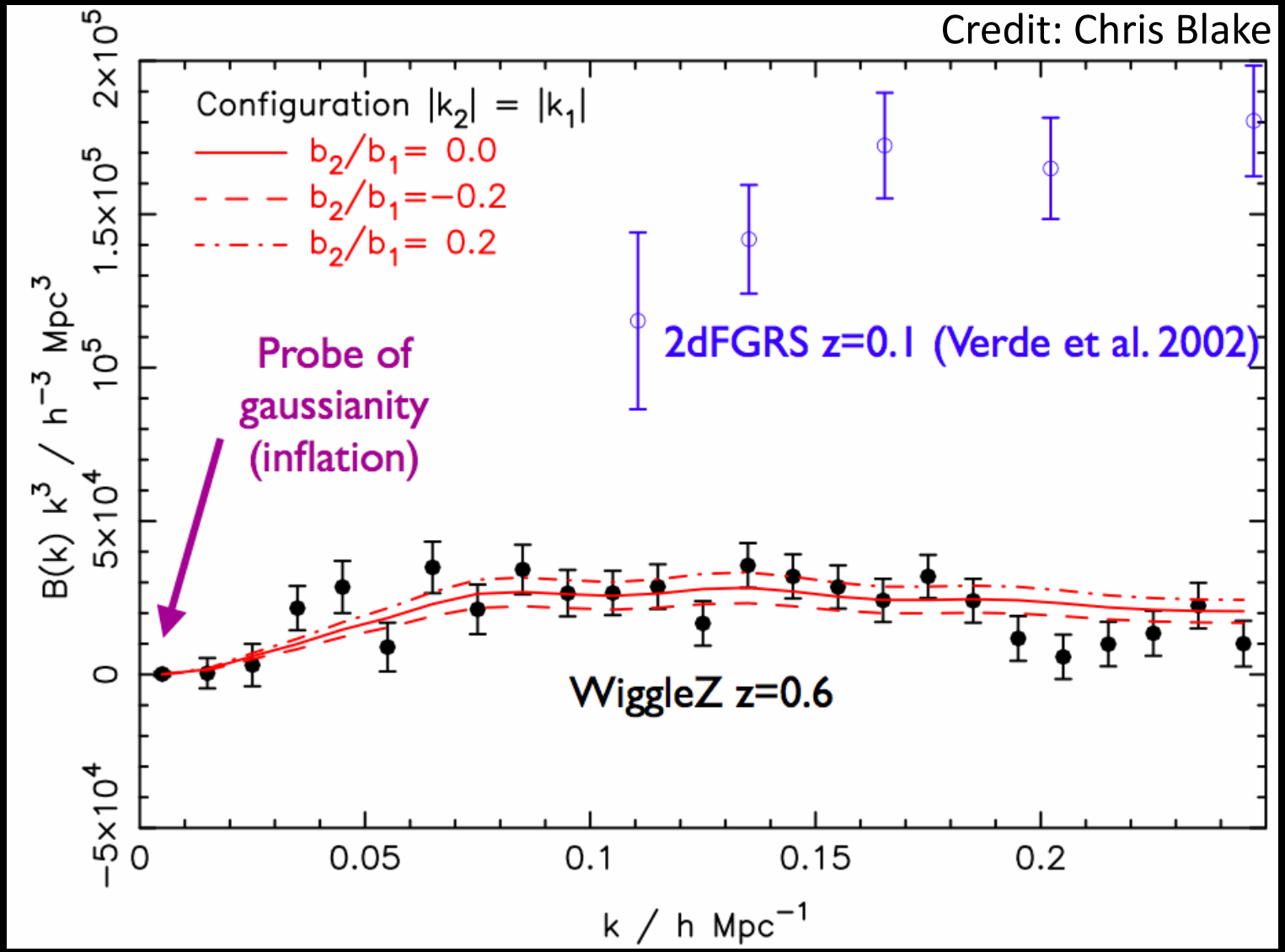
Fourier amplitudes

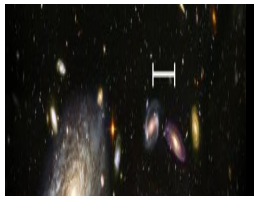
$$B(\vec{k_1},\vec{k_2},\vec{k_3}) = < \delta_{\vec{k_1}} \delta_{\vec{k_2}} \delta_{\vec{k_3}} >$$

$$\vec{k_1} + \vec{k_2} + \vec{k_3} = 0$$

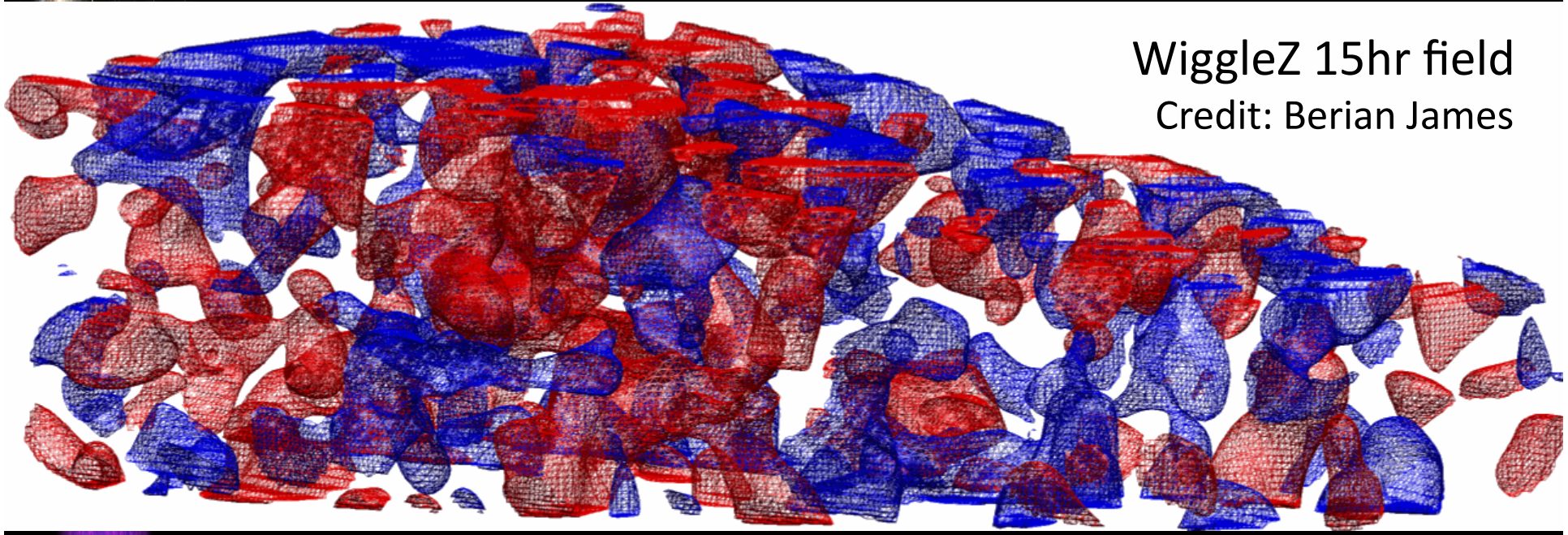
$$\delta_g = b_1 \delta_m + \frac{1}{2} b_2 \delta_m^2$$

Bispectrum

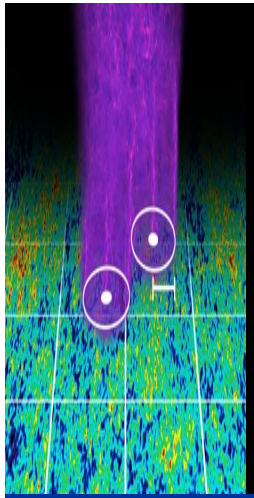

Credit: Chris Blake
Configuration $|k_2| = |k_1|$
$b_2/b_1 = 0.0$
$b_2/b_1 = -0.2$
$b_2/b_1 = 0.2$
Probe of gaussianity (inflation)
2dFGRS z=0.1 (Verde et al. 2002)
WiggleZ z=0.6
$B(k)\ k^3 / h^{-3}\ Mpc^3$
$k / h\ Mpc^{-1}$
2×10^5
1.5×10^5
10^5
5×10^4
0
-5×10^4
0
0.05
0.1
0.15
0.2



Topology, genus, and gaussianity



WiggleZ 15hr field
Credit: Berian James



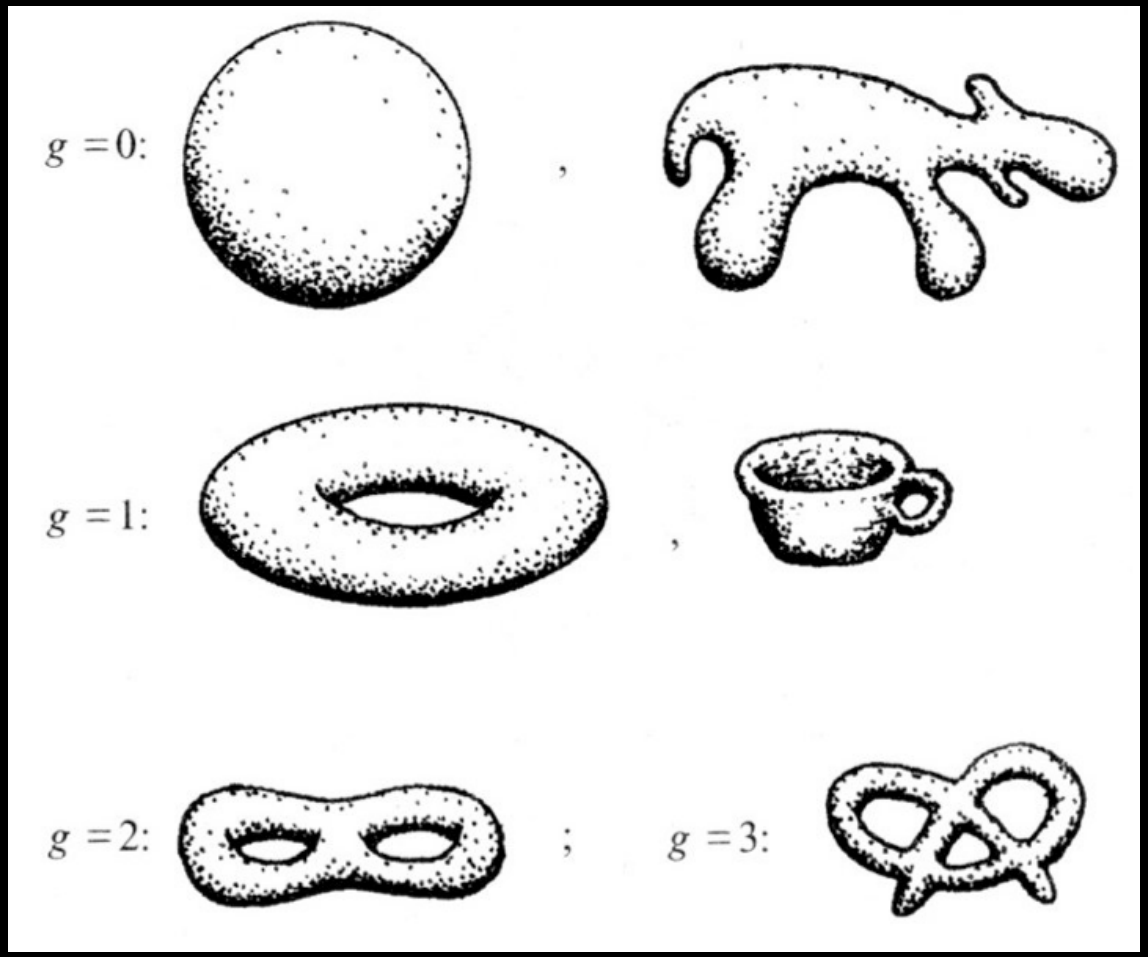
After smoothing the point distribution of galaxies cordon off the highest density (red) and lowest density (blue) regions (each 10% by volume).

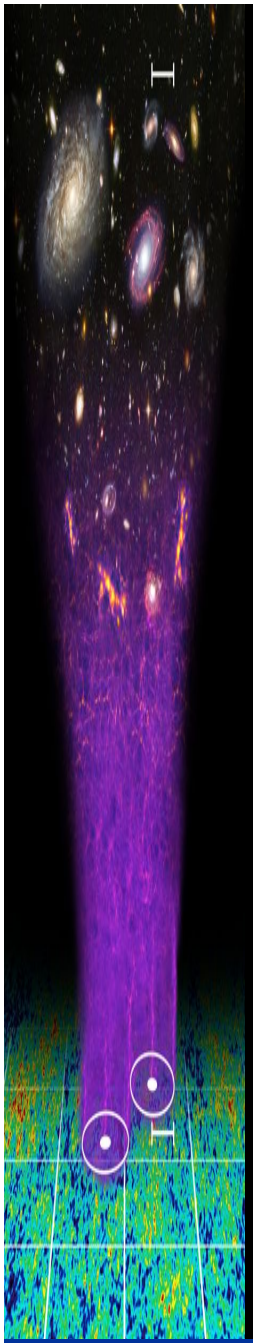
The University Of Queensland
AUSTRALIA

Dark Cosmology Centre

What is genus?

Genus is a measure of topology





The genus statistic

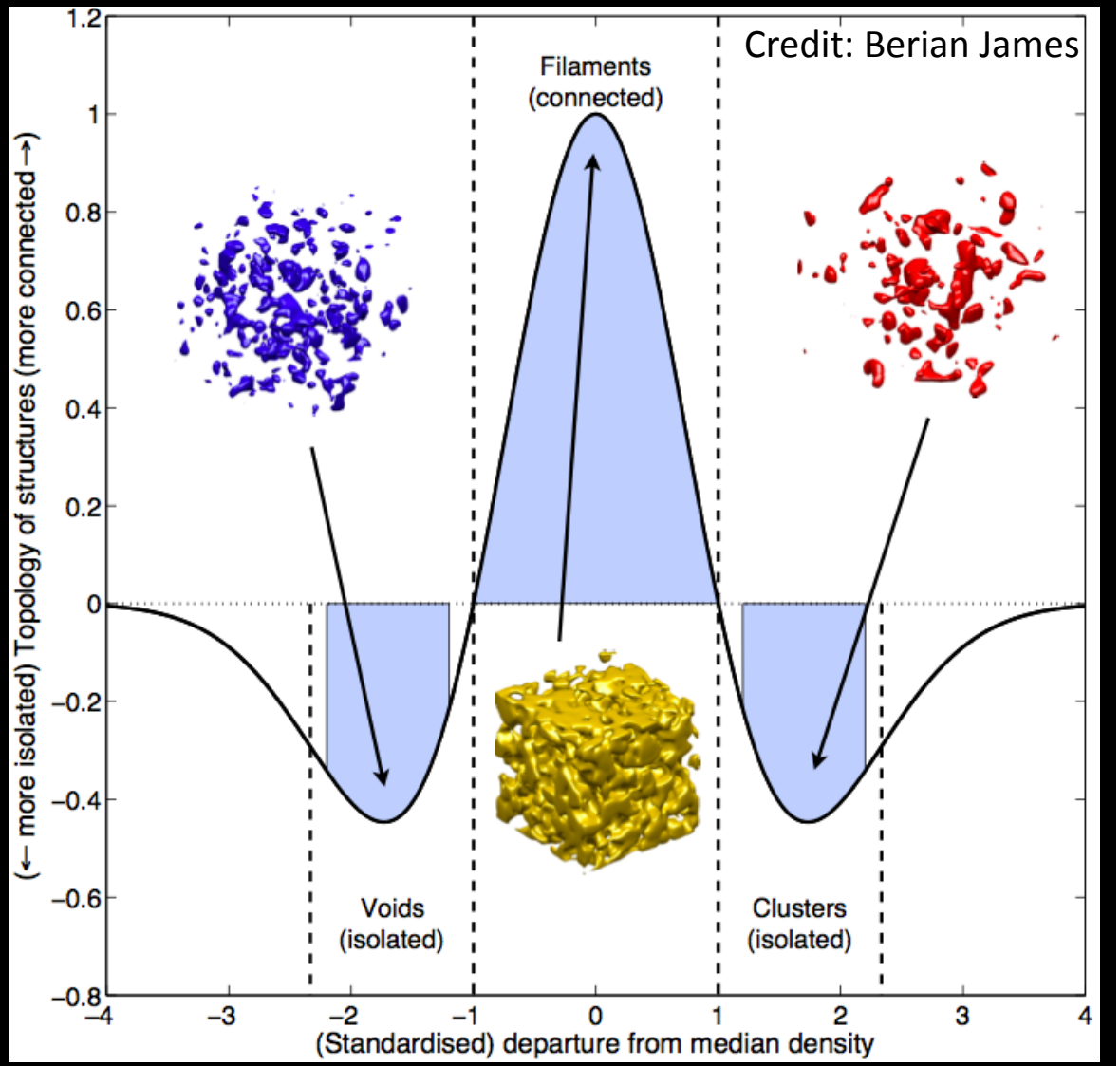
The genus statistic measures the topology of structure

Gaussian random fields have a specific topology

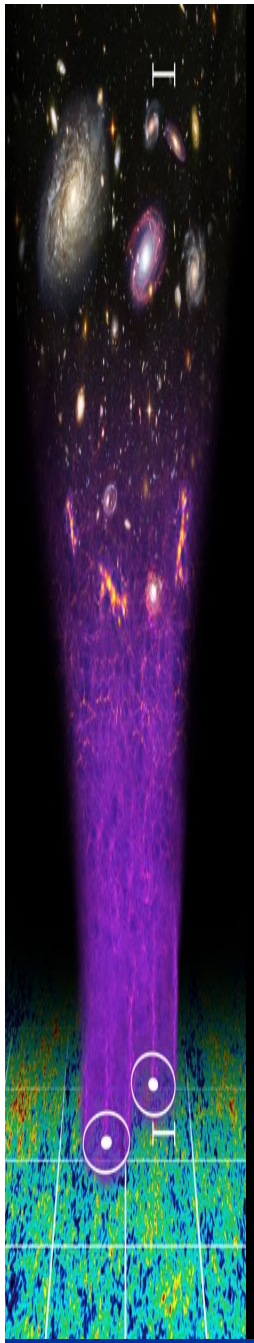
By measuring the genus we can detect non-gaussianity

Large scales – primordial non-gaussianity

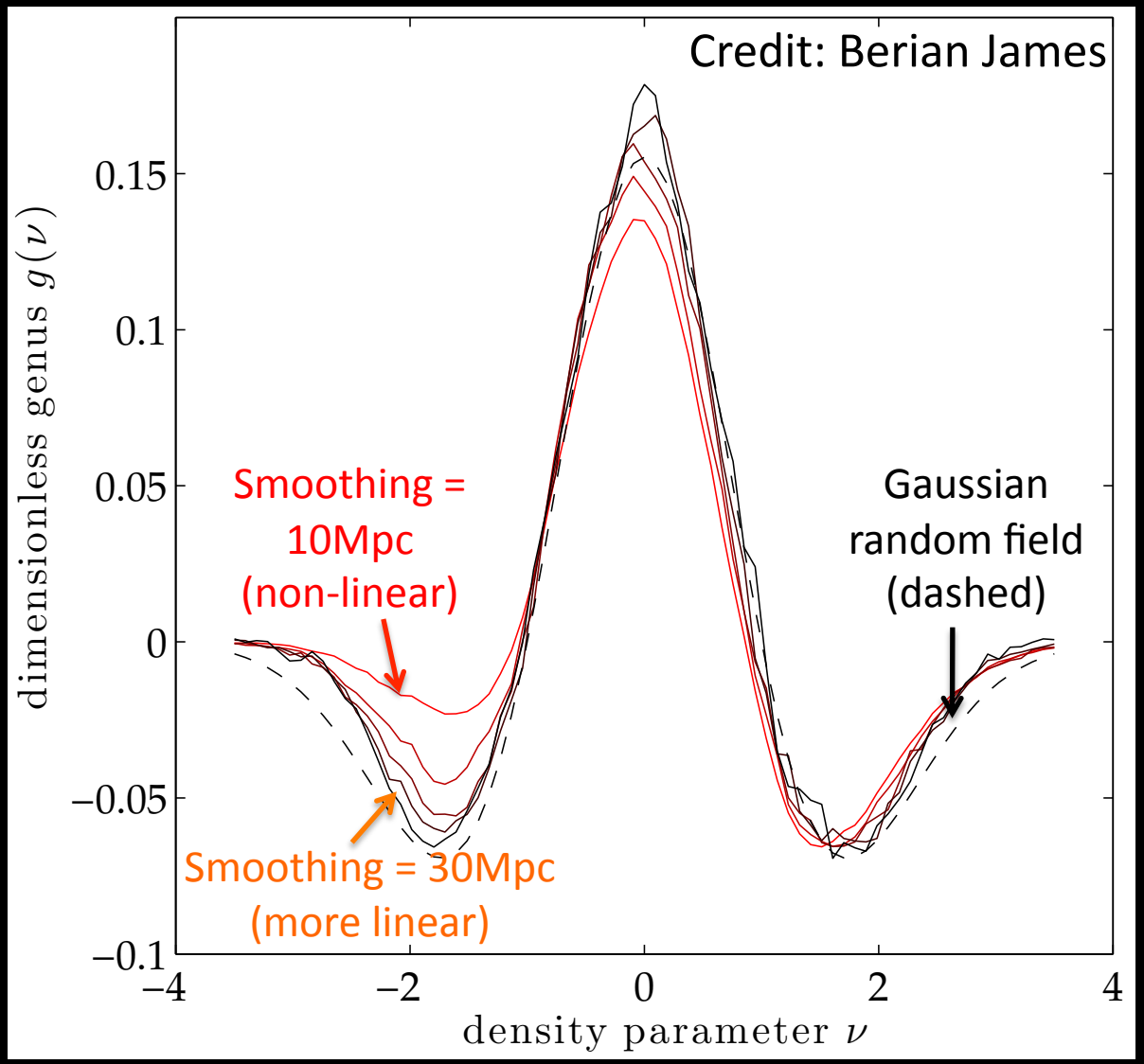
Small scales – non-linear structure



Genus vs smoothing scale

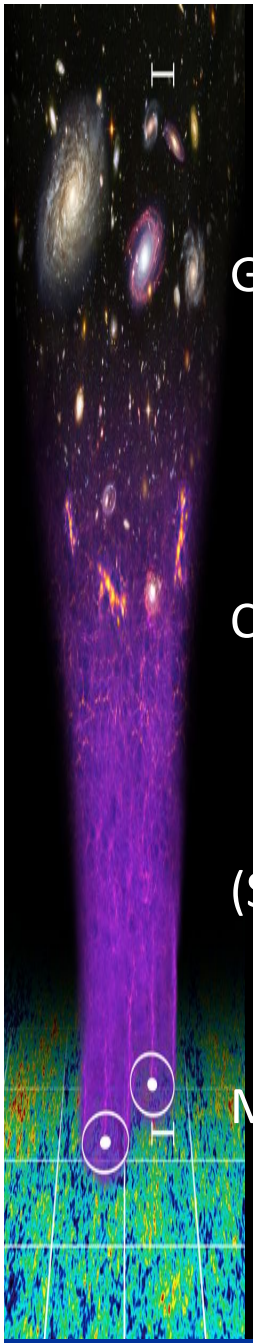


Non-linear structure formation causes deviations from gaussianity



Genus vs redshift

Credit: Berian James

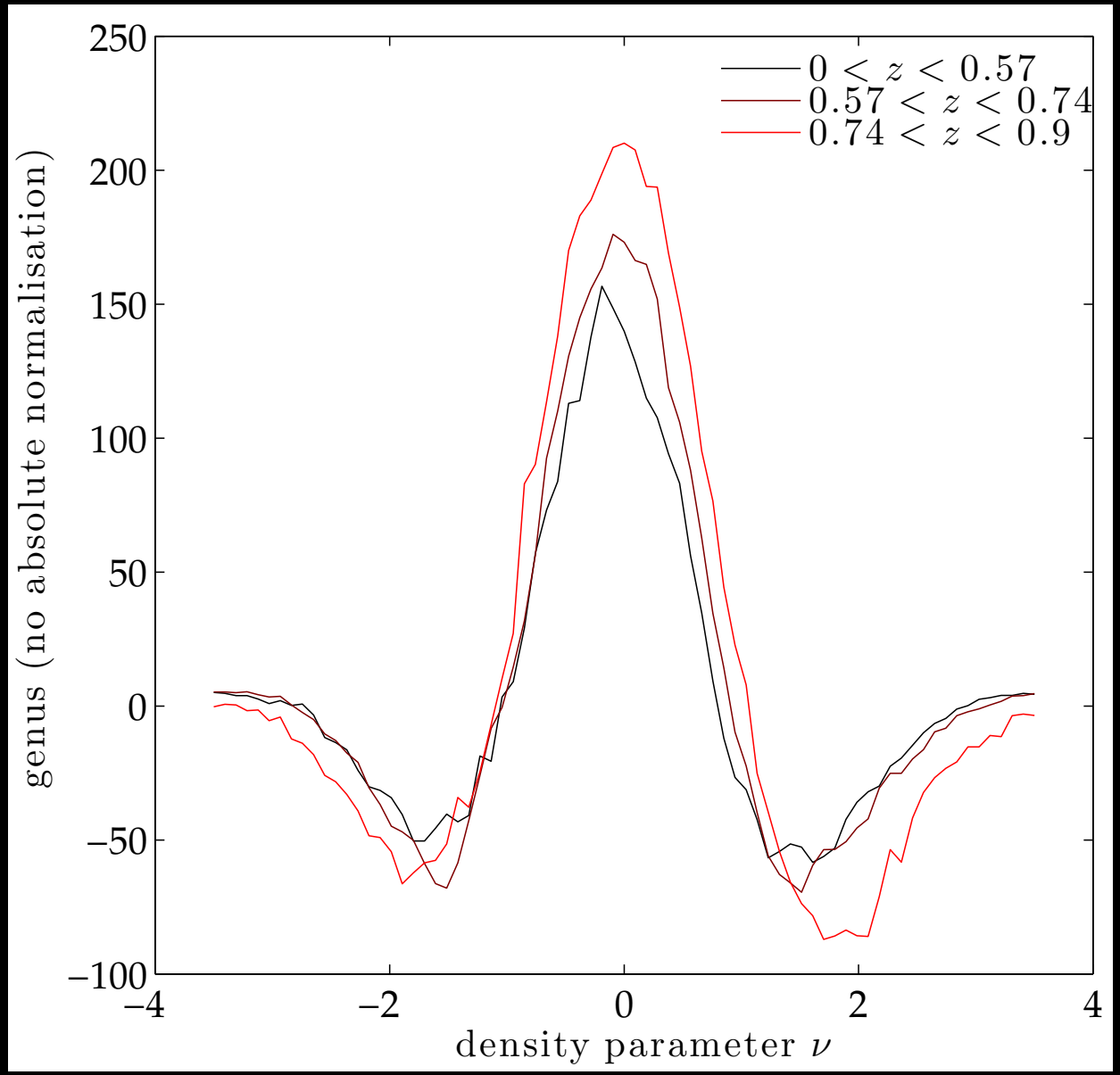


Genus curve is not expected to evolve (in linear theory)

Changes attributed to non-linear evolution

(Scale dependent bias??)

Modelling underway….

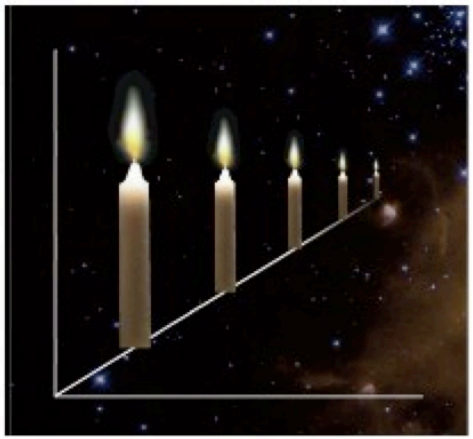


The University Of Queensland AUSTRALIA

Dark Cosmology Centre

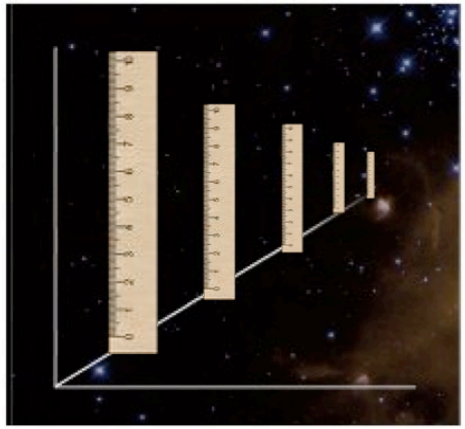
BAO – a standard ruler in 3D

Standard candle



Supernova

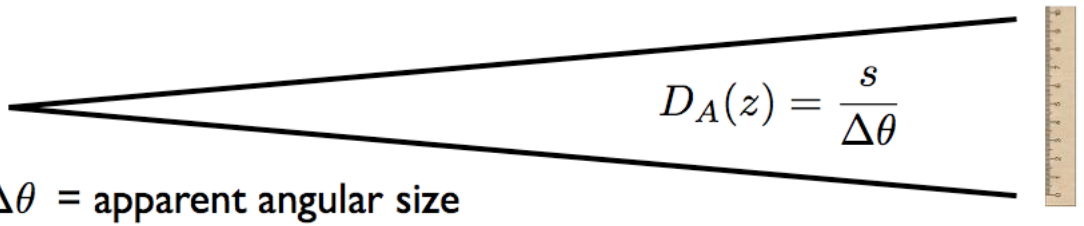
Standard ruler



Cosmic sound wave

- SNe = radial info (line of sight)
- CMB = tangential info (surface of sphere)

- BAO can be applied radially to give H(z) AND tangentially to give $D_A(z)$



$$D_A(z) = \frac{s}{\Delta\theta}$$

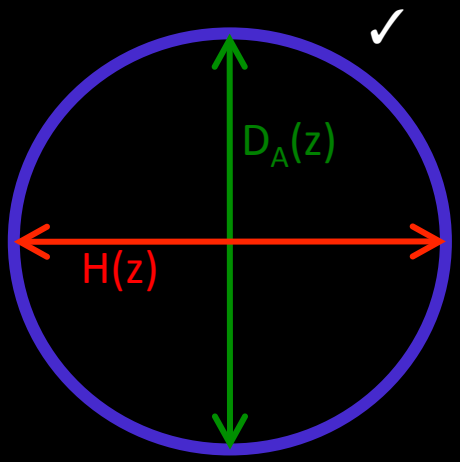
$\Delta\theta$ = apparent angular size
~ 2.6 deg at z=1

Δz = apparent redshift extent
~ 0.06 at z=1

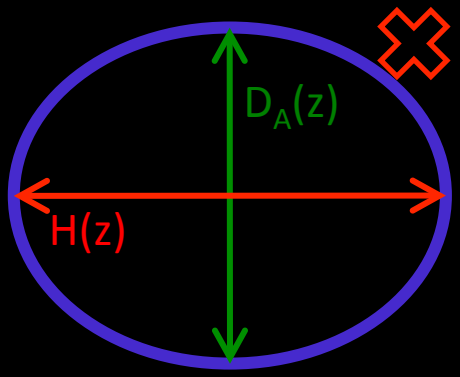
$$H(z) = \frac{c\,\Delta z}{s}$$

The sphericity of spheres

- Alcock-Paczynski test
  - Ratio of observed angular size to radial size varies with cosmology
  - Measure distortions of a sphere and you can measure cosmological parameters.



  - BAO are a standard sphere.



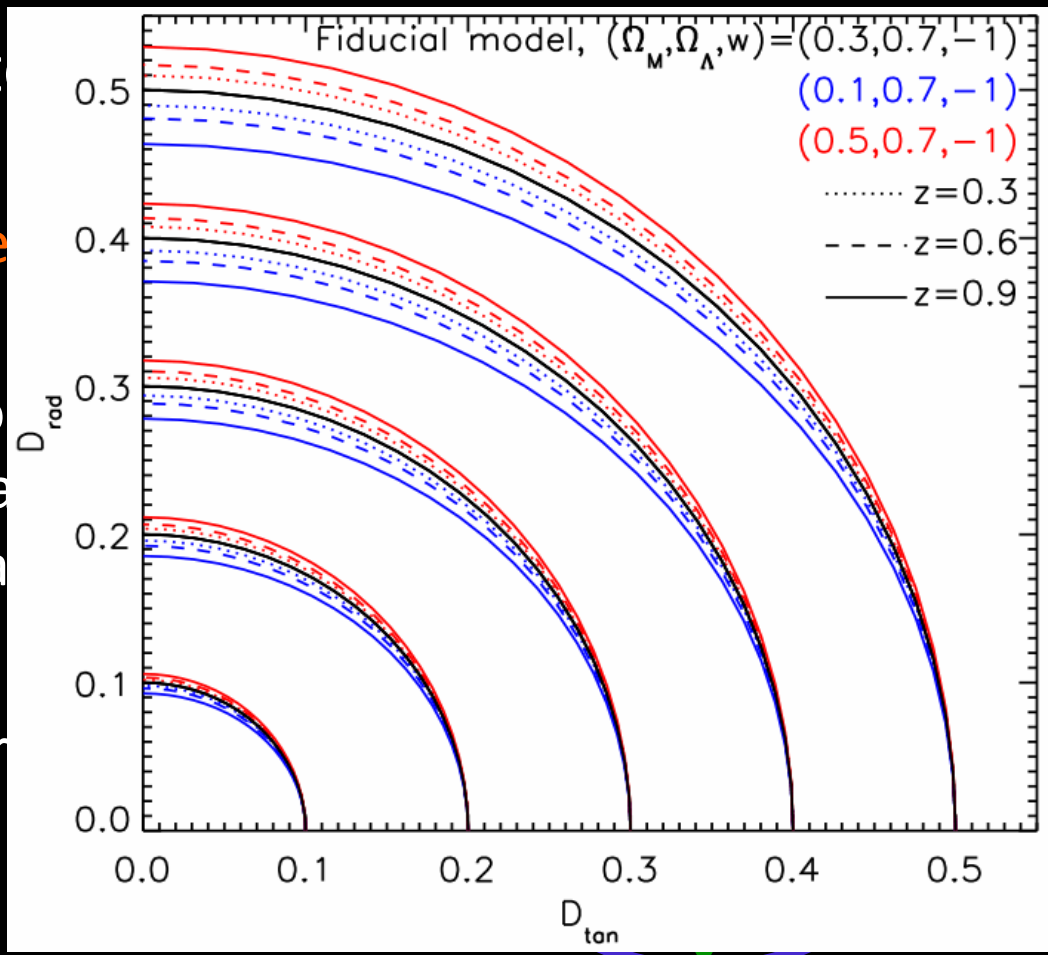
WiggleZ will (hopefully) measure

$D_A(z)$ to ~4%

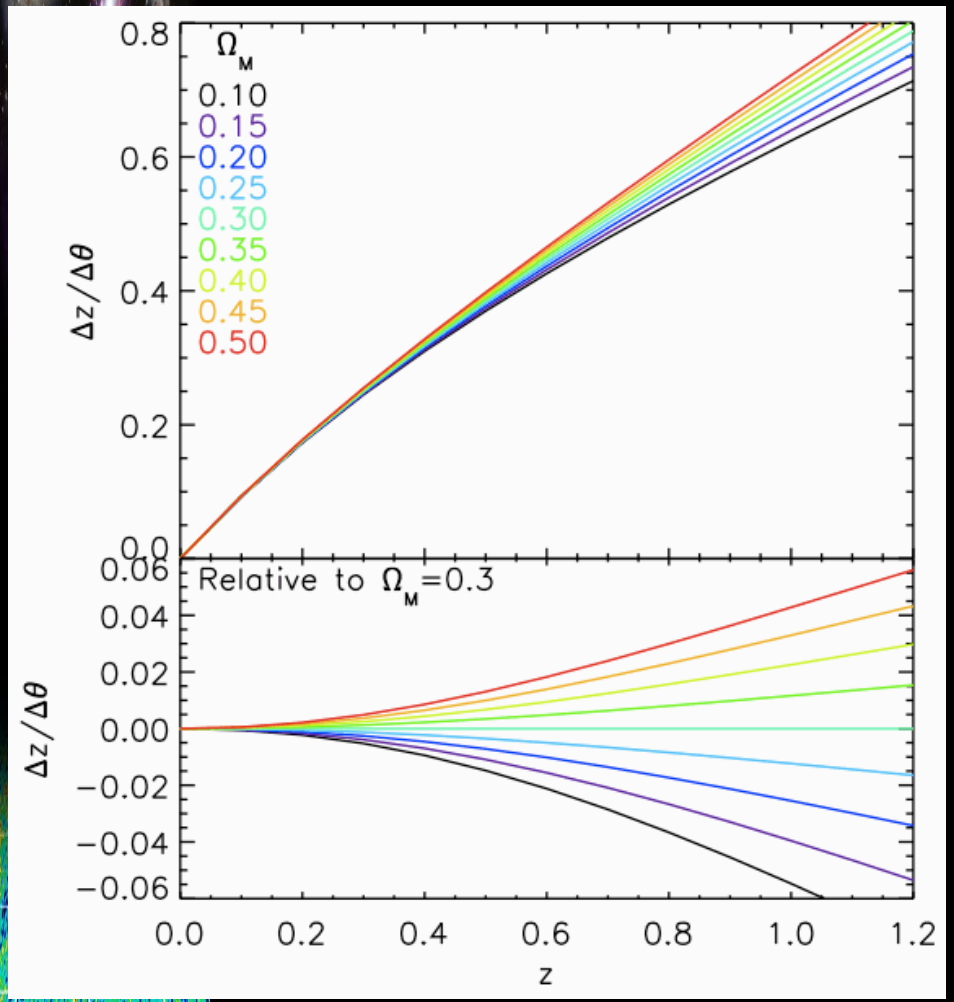
H(z) to ~7%

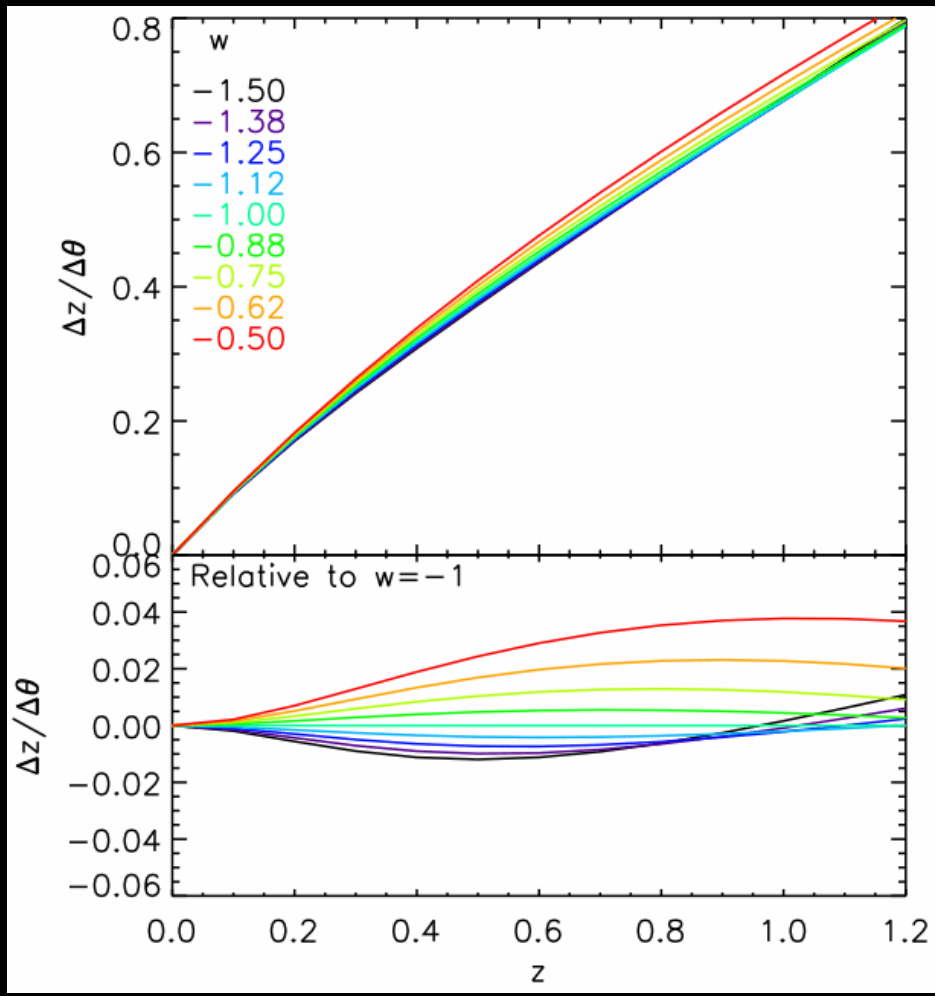
The sphericity of spheres

- Alcock-Paczynski t
  - Ratio of observed
    to radial size varie
    cosmology
  - Measure distortio
    sphere and you ca
    cosmological para
  - BAO are a standar



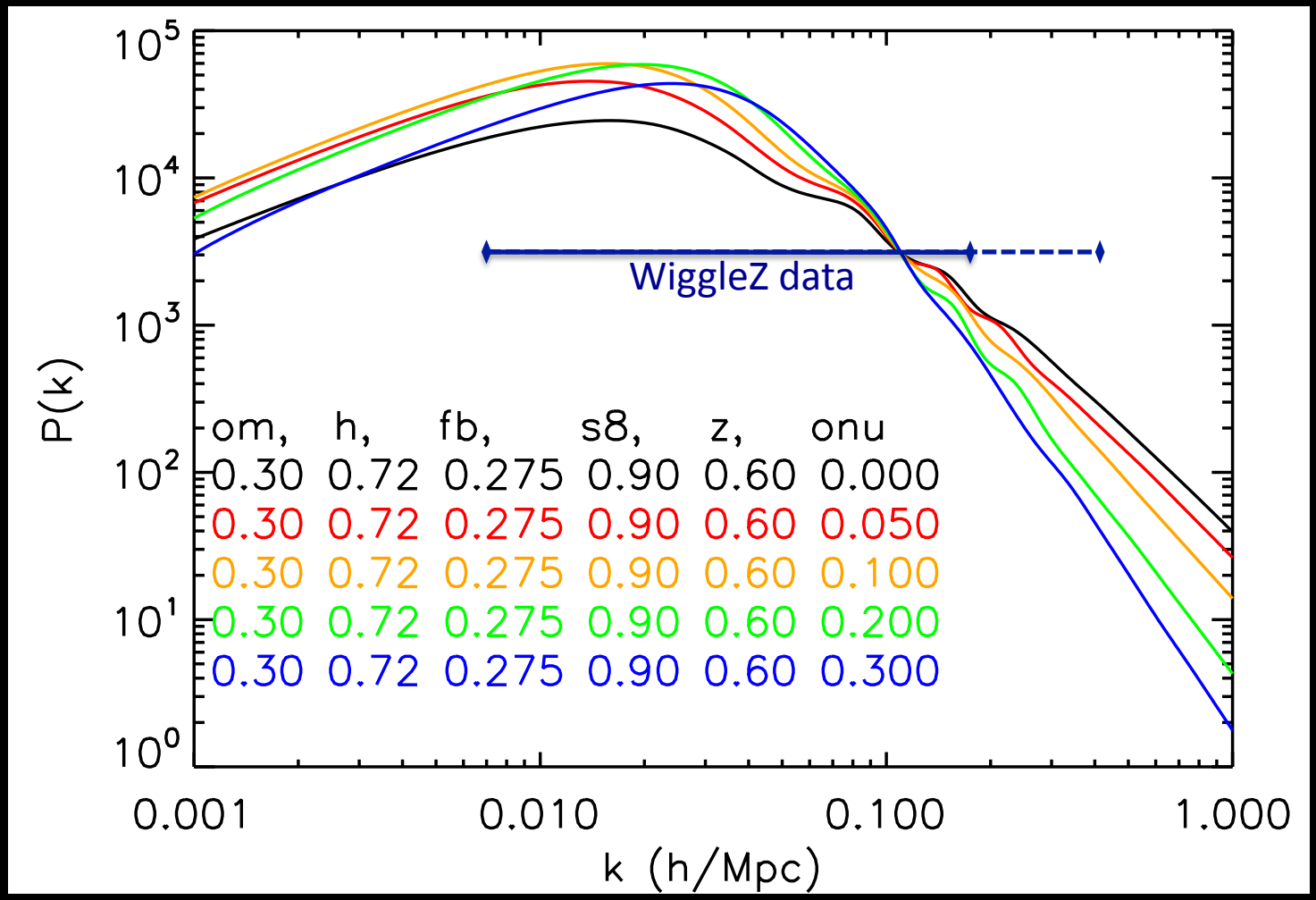
The sphericity of spheres

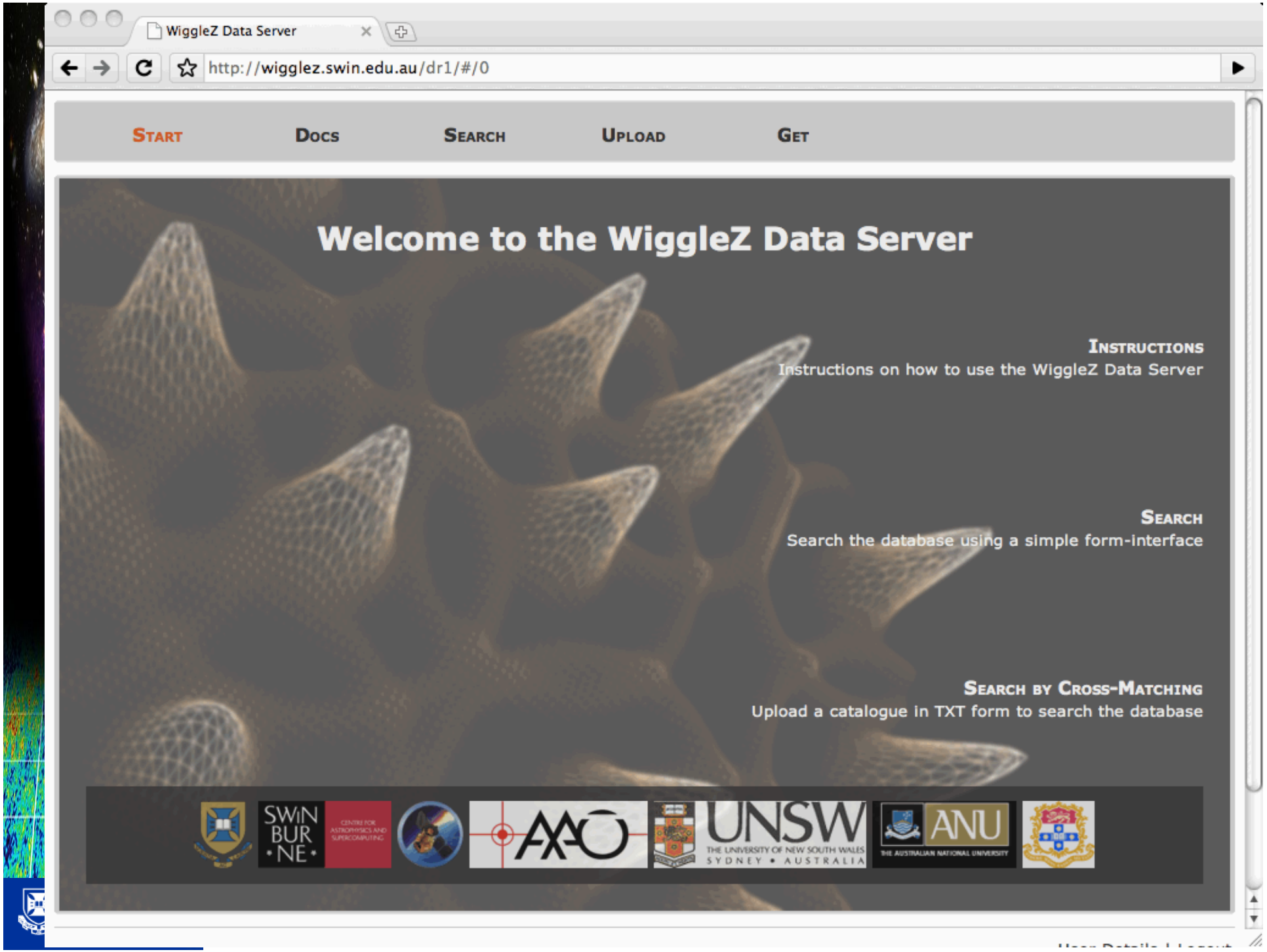


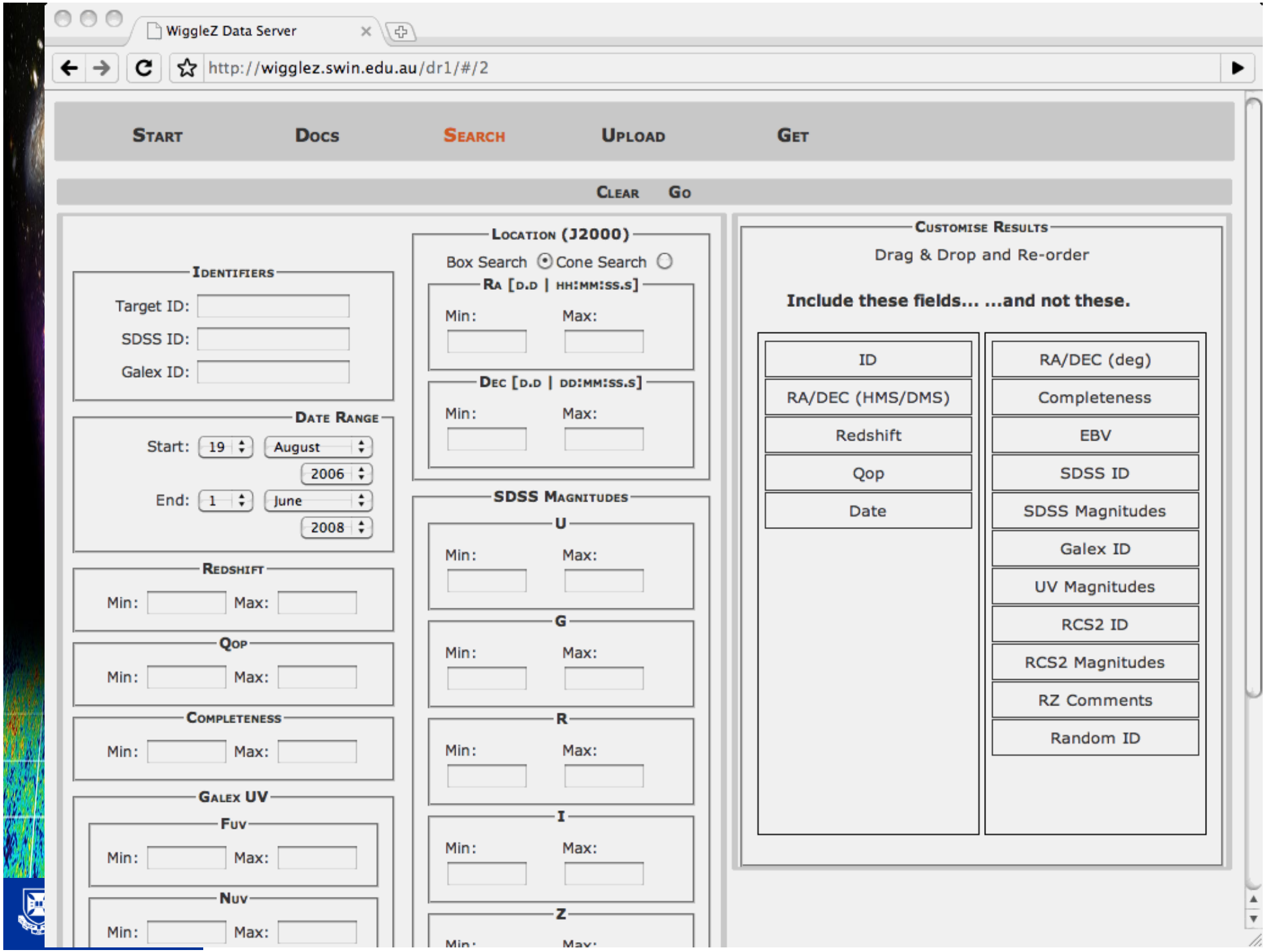


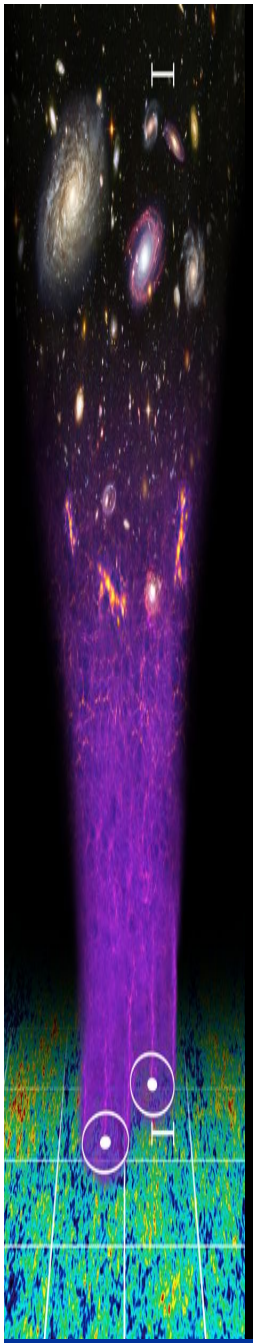
Neutrino mass constraints

- WiggleZ P(k) is linear to higher k than previous surveys




WiggleZ Data Server
http://wigglez.swin.edu.au/dr1/#/0
START
DOCS
SEARCH
UPLOAD
GET
Welcome to the WiggleZ Data Server
INSTRUCTIONS
Instructions on how to use the WiggleZ Data Server
SEARCH
Search the database using a simple form-interface
SEARCH BY CROSS-MATCHING
Upload a catalogue in TXT form to search the database
SWIN BUR NE
AAO
UNSW
THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY • AUSTRALIA
ANU
THE AUSTRALIAN NATIONAL UNIVERSITY


WiggleZ Data Server
http://wigglez.swin.edu.au/dr1/#/2
START
DOCS
SEARCH
UPLOAD
GET
CLEAR
GO
IDENTIFIERS
Target ID:
SDSS ID:
Galex ID:
DATE RANGE
Start: 19 August 2006
End: 1 June 2008
REDSHIFT
Min: Max:
QOP
Min: Max:
COMPLETENESS
Min: Max:
GALEX UV
FUV
Min: Max:
NUV
Min: Max:
LOCATION (J2000)
Box Search Cone Search
RA [D.D | HH:MM:SS.S]
Min: Max:
DEC [D.D | DD:MM:SS.S]
Min: Max:
SDSS MAGNITUDES
U
Min: Max:
G
Min: Max:
R
Min: Max:
I
Min: Max:
Z
Min: Max:
CUSTOMISE RESULTS
Drag & Drop and Re-order
Include these fields... ...and not these.
ID
RA/DEC (HMS/DMS)
Redshift
Qop
Date
RA/DEC (deg)
Completeness
EBV
SDSS ID
SDSS Magnitudes
Galex ID
UV Magnitudes
RCS2 ID
RCS2 Magnitudes
RZ Comments
Random ID



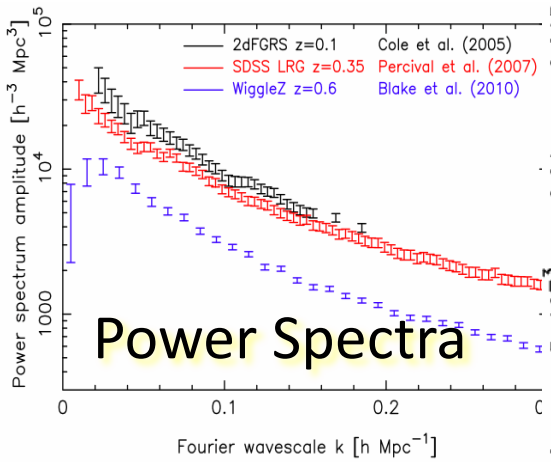
Summary

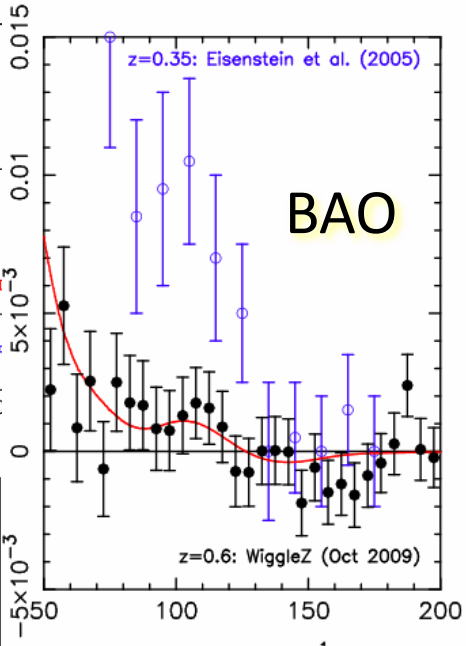
We now have > 200,000 galaxies and have just two semesters of WiggleZ observing remaining

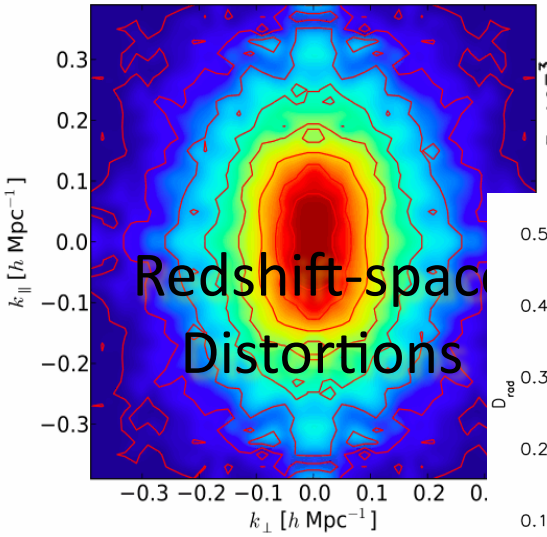
Results using just the first 120,000 are very promising

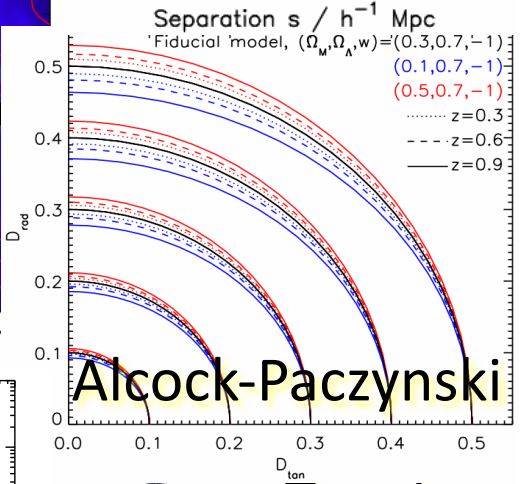
There are a huge number of ways to use this data

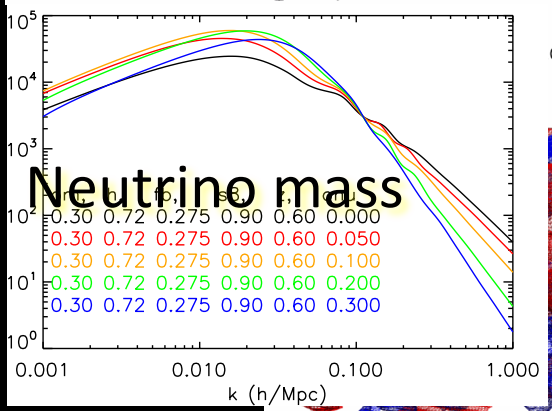
I haven't even mentioned galaxy evolution and formation studies, nor the study of star-forming galaxies at high redshift, etc…

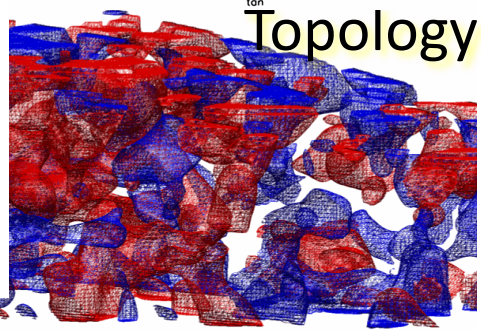












The University Of Queensland AUSTRALIA

Dark Cosmology Centre