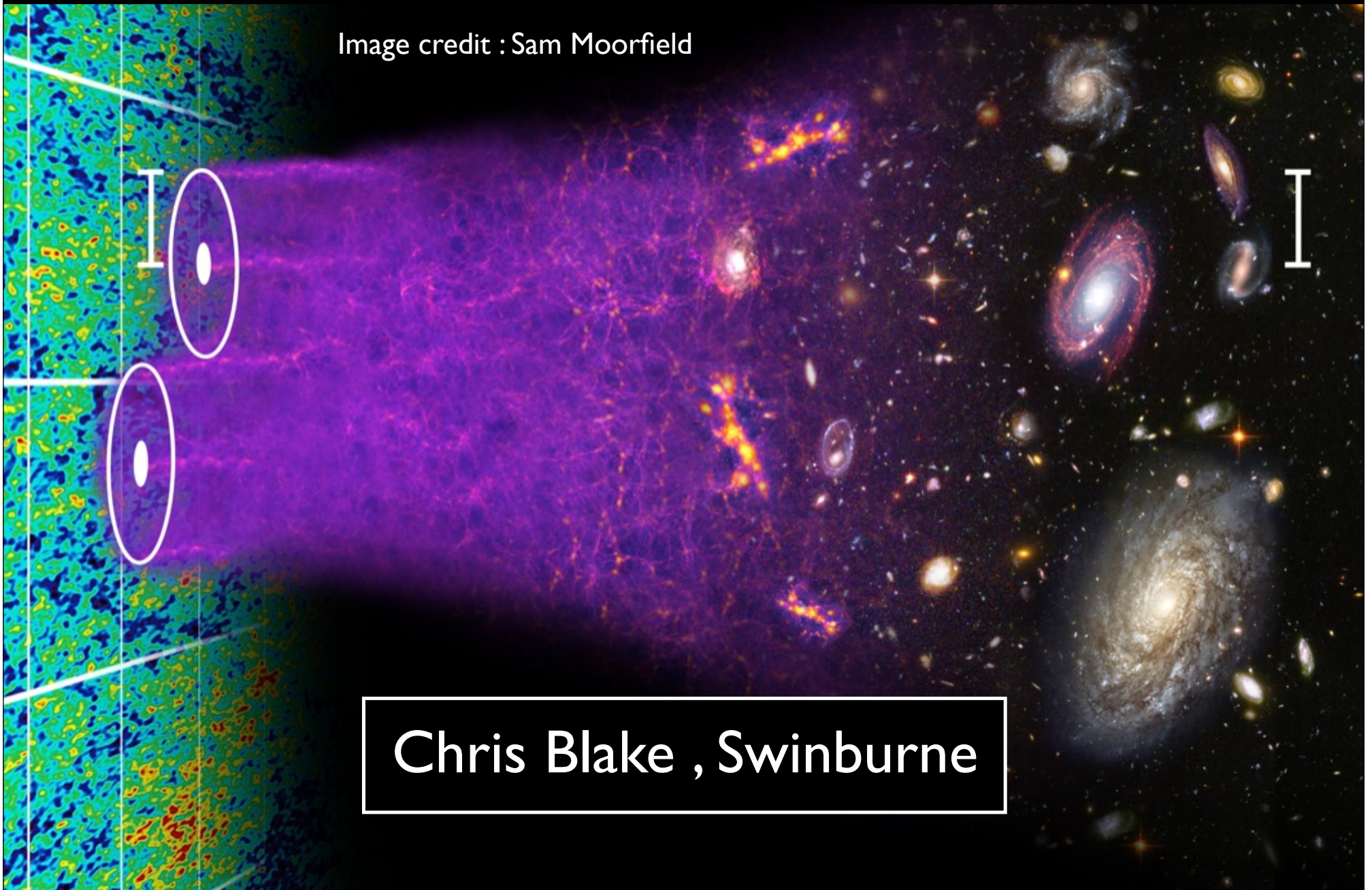


# Cosmology with the WiggleZ Survey

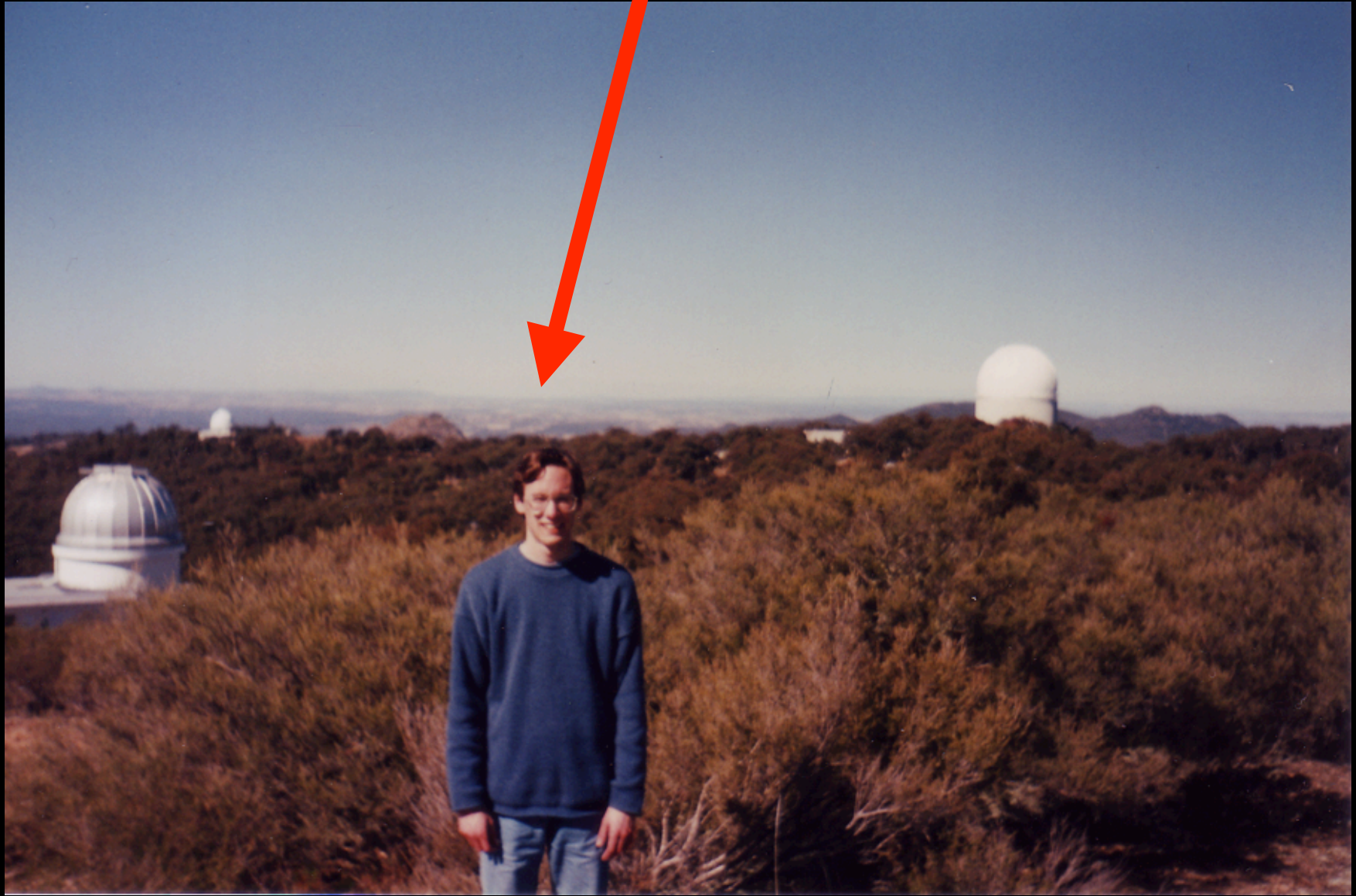
Image credit : Sam Moorfield



Chris Blake , Swinburne



Me (1997)



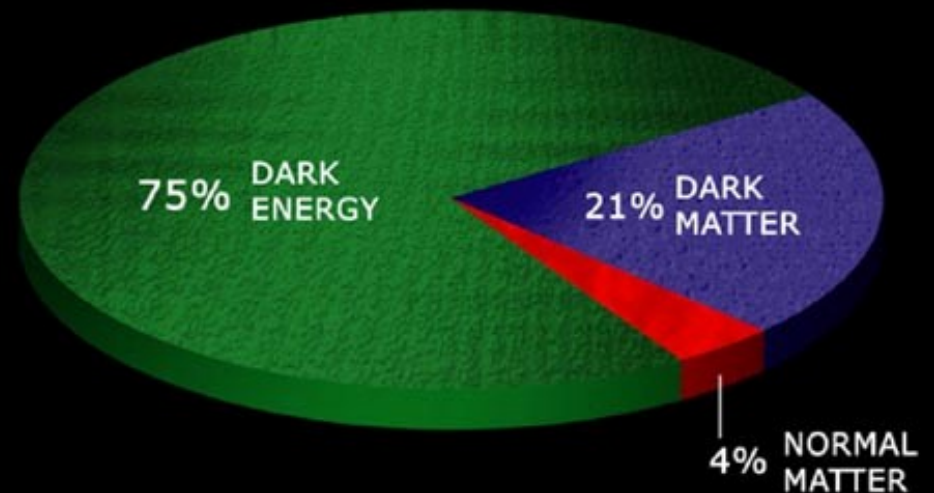
Me (2010)



# What does a cosmologist do?



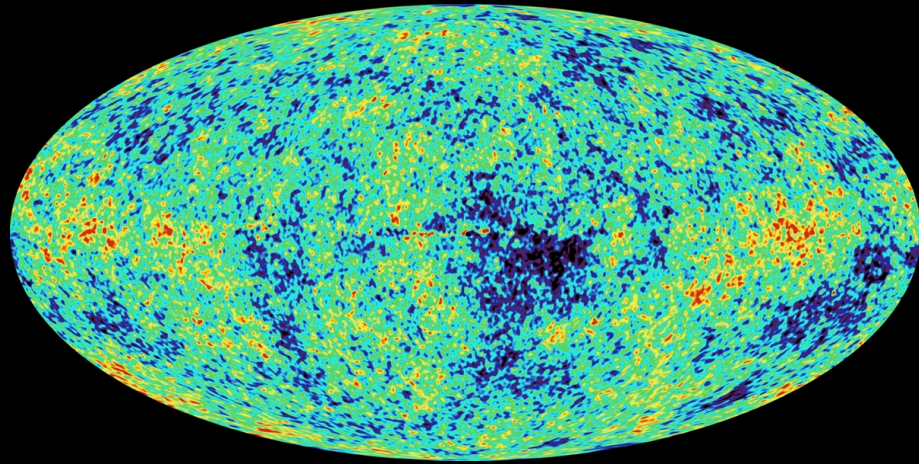
COSMOLOGY MARCHES ON



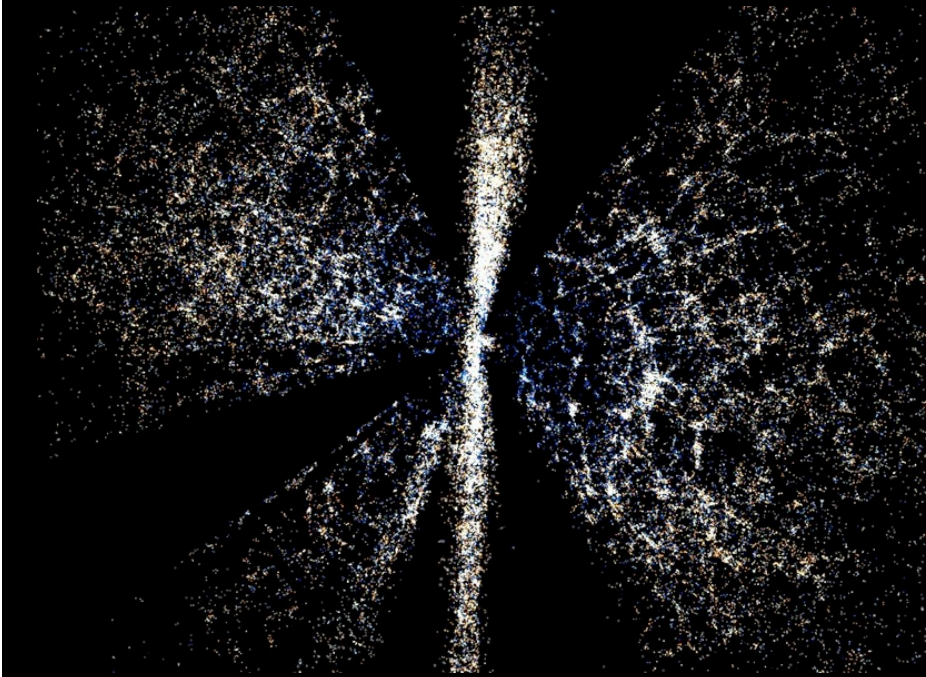


# Cosmologist's tools

Cosmic microwave background



Galaxy surveys

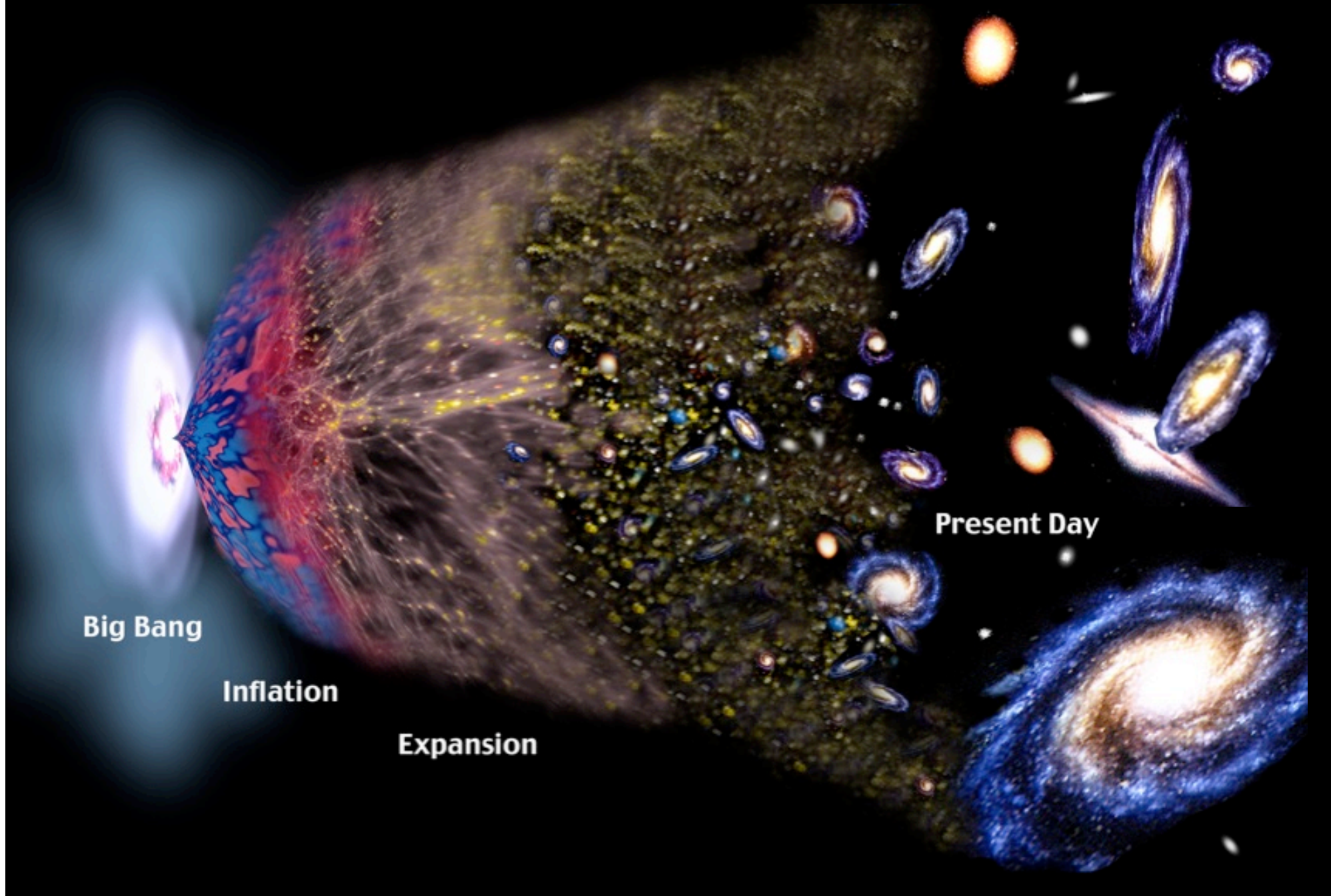


Supernovae



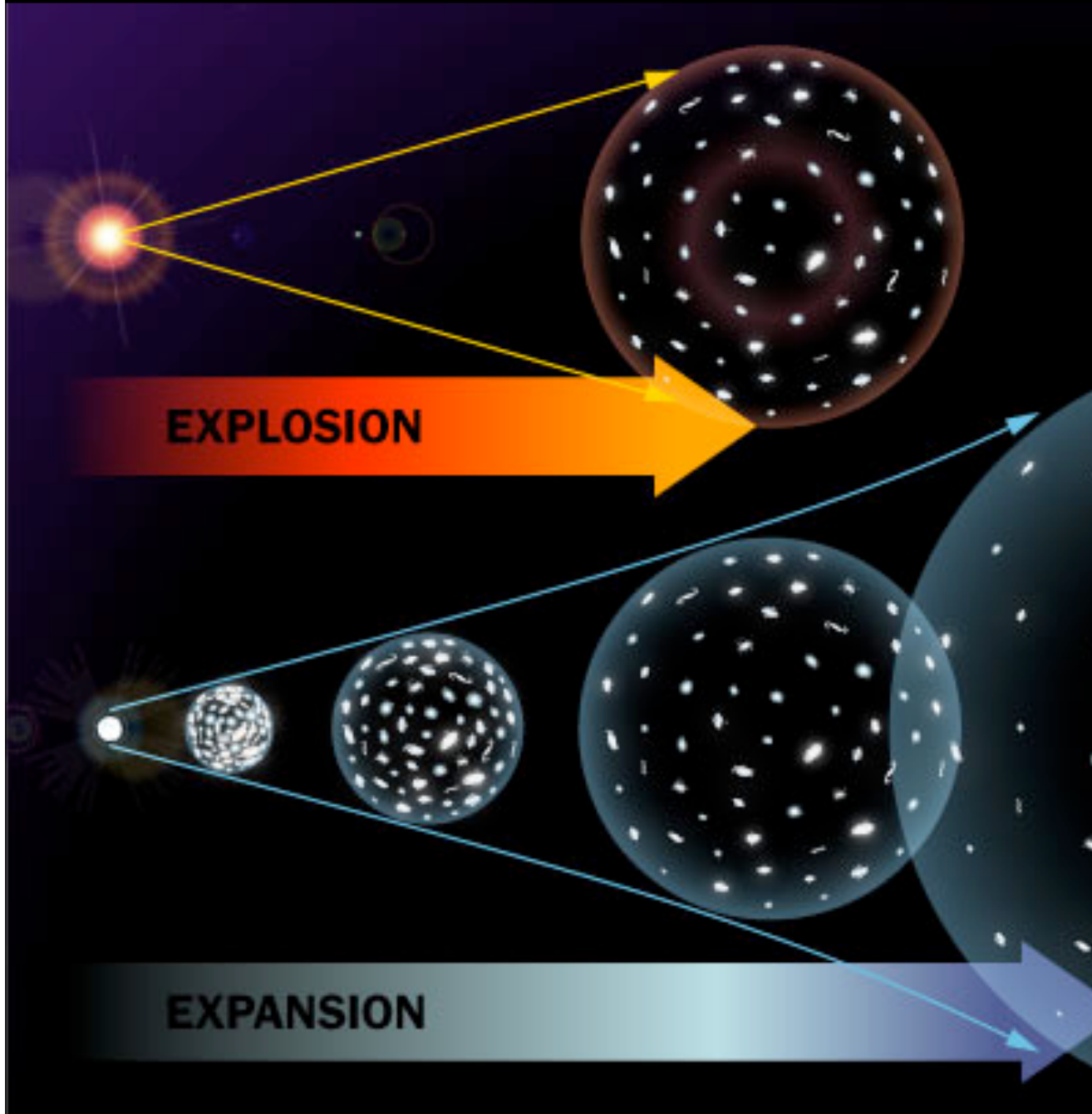


# Our current picture of the Universe

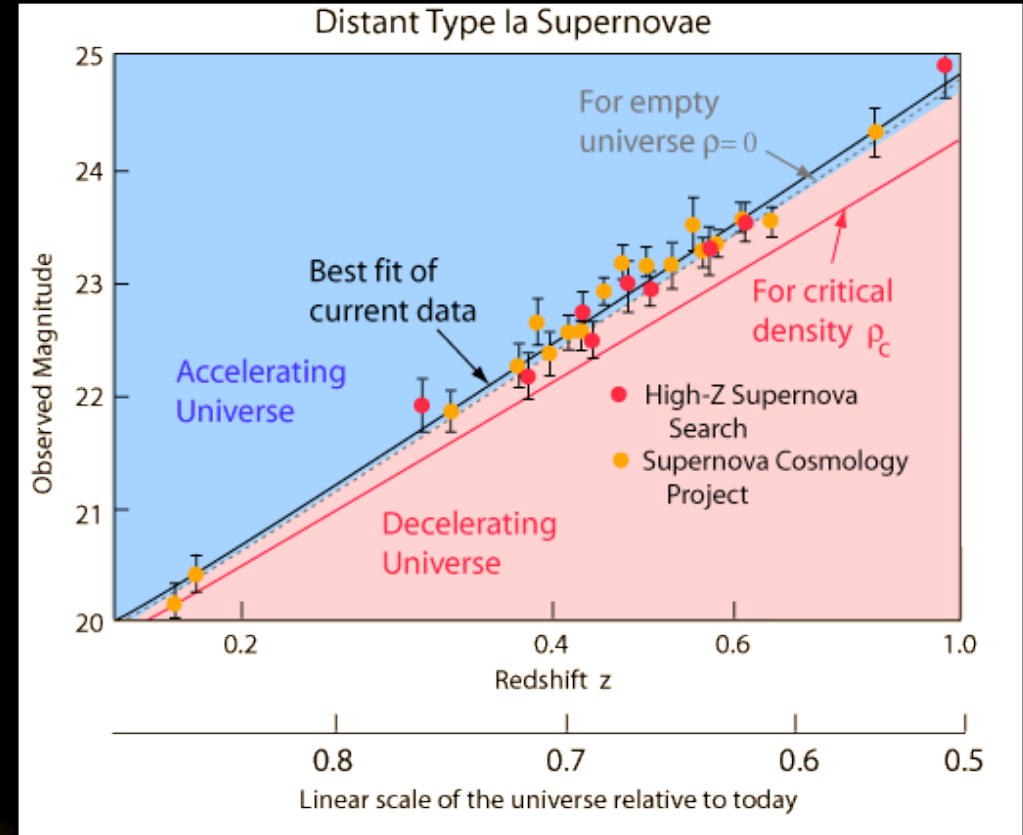
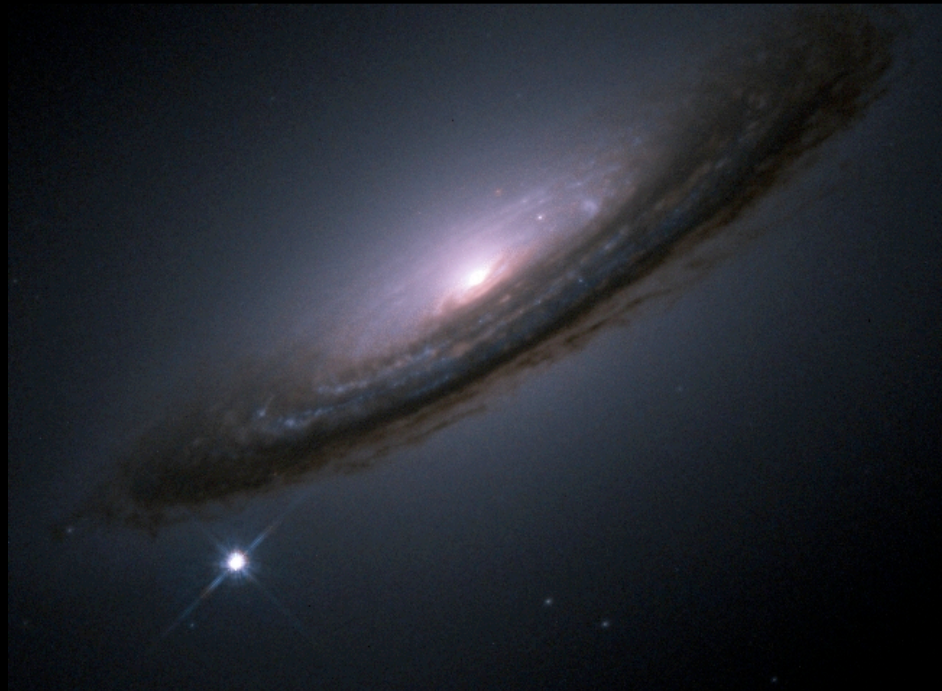




# The Universe is expanding ...

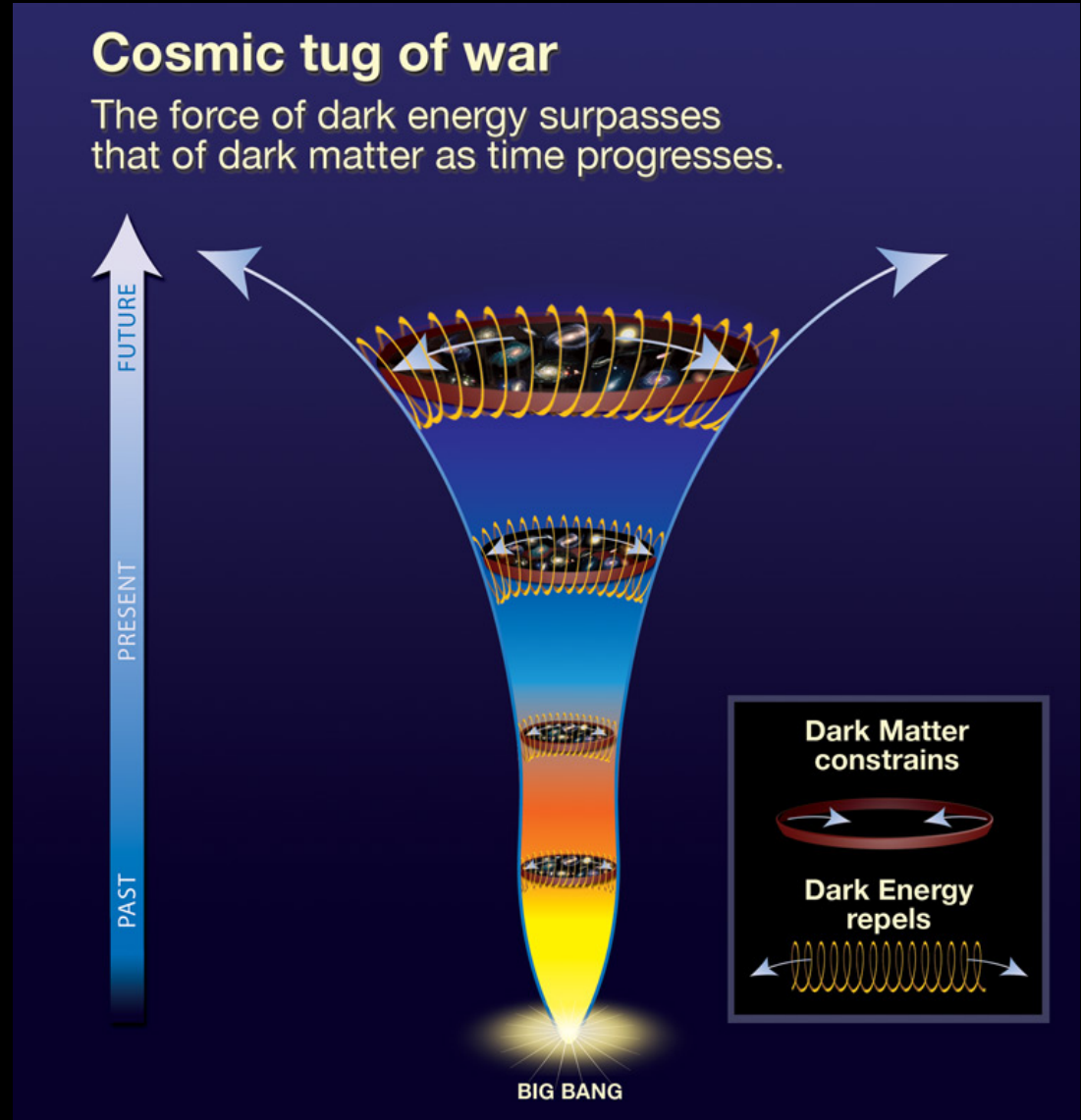
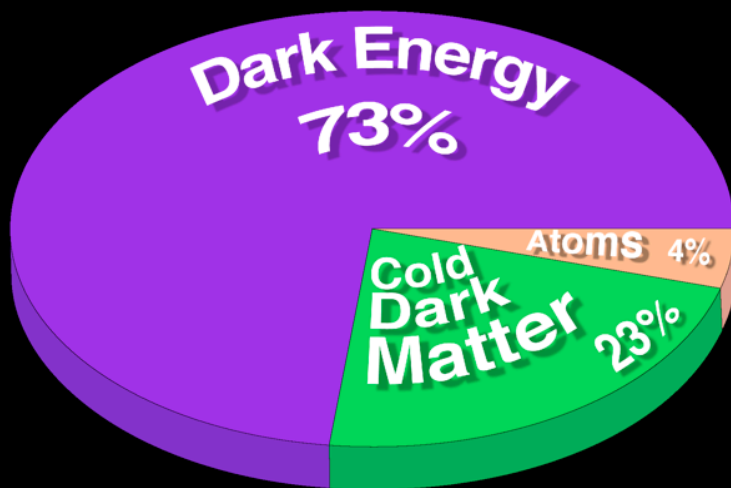
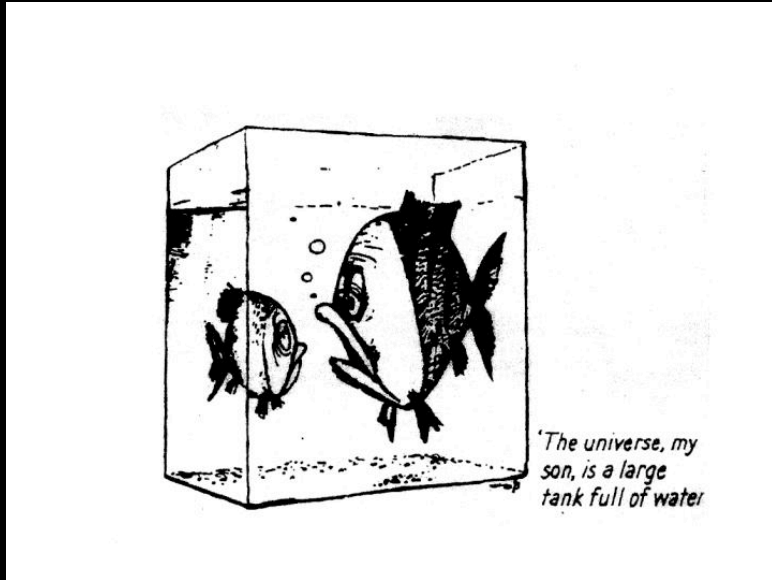


# ... and the expansion is speeding up ! ...



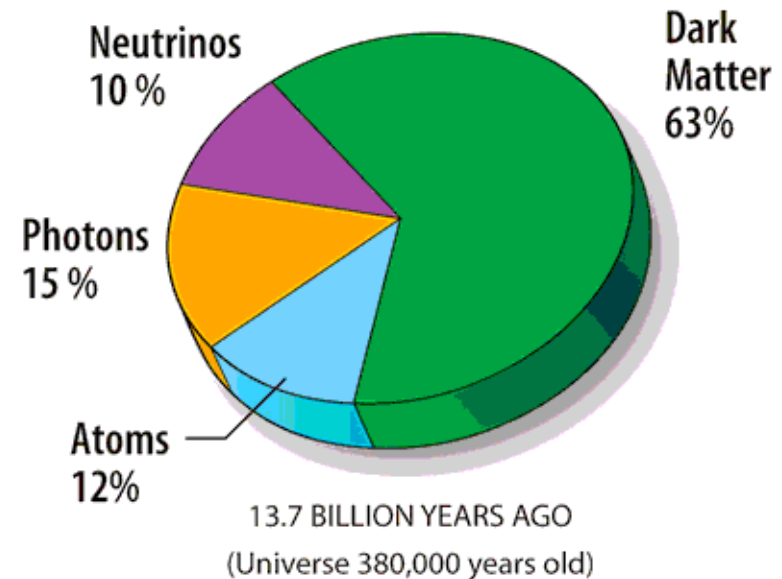
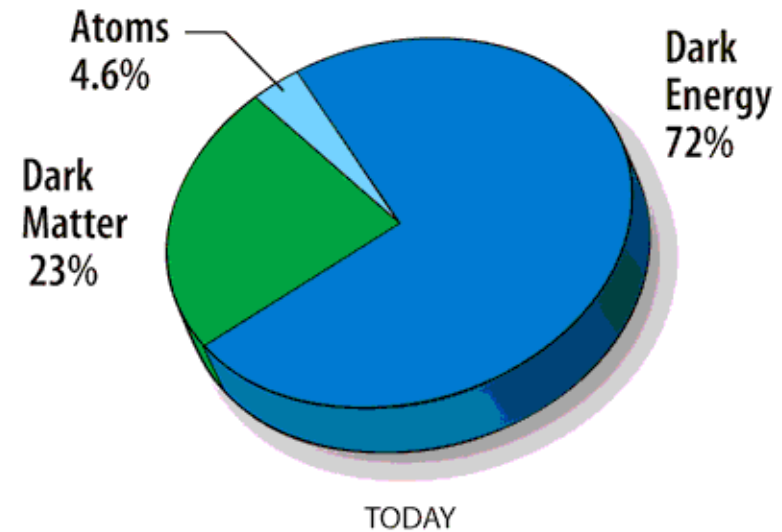


# Our current model of cosmology



# Dark energy : what do we know?

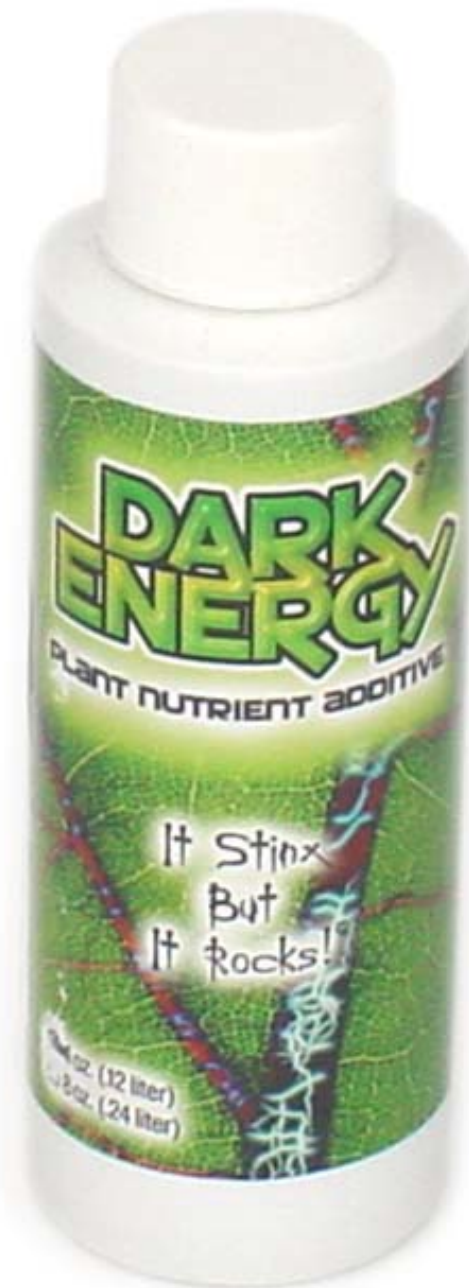
- Dark energy **smoothly fills space** with a roughly constant energy density
- Dark energy **dominates the Universe today** but is insignificant at high redshift
- Dark energy propels the cosmos into a phase of **accelerating expansion**





# Dark energy : what don't we know?

- Physically, is it a manifestation of **gravity** or **matter-energy**?
- **Why now?** - why does dark energy become important billions of years after the Big Bang?
- If dark energy is **vacuum energy**, how can we explain its magnitude?
- How are our observations of dark energy affected by **inhomogeneity**?



# A powerful tool : galaxy redshift surveys

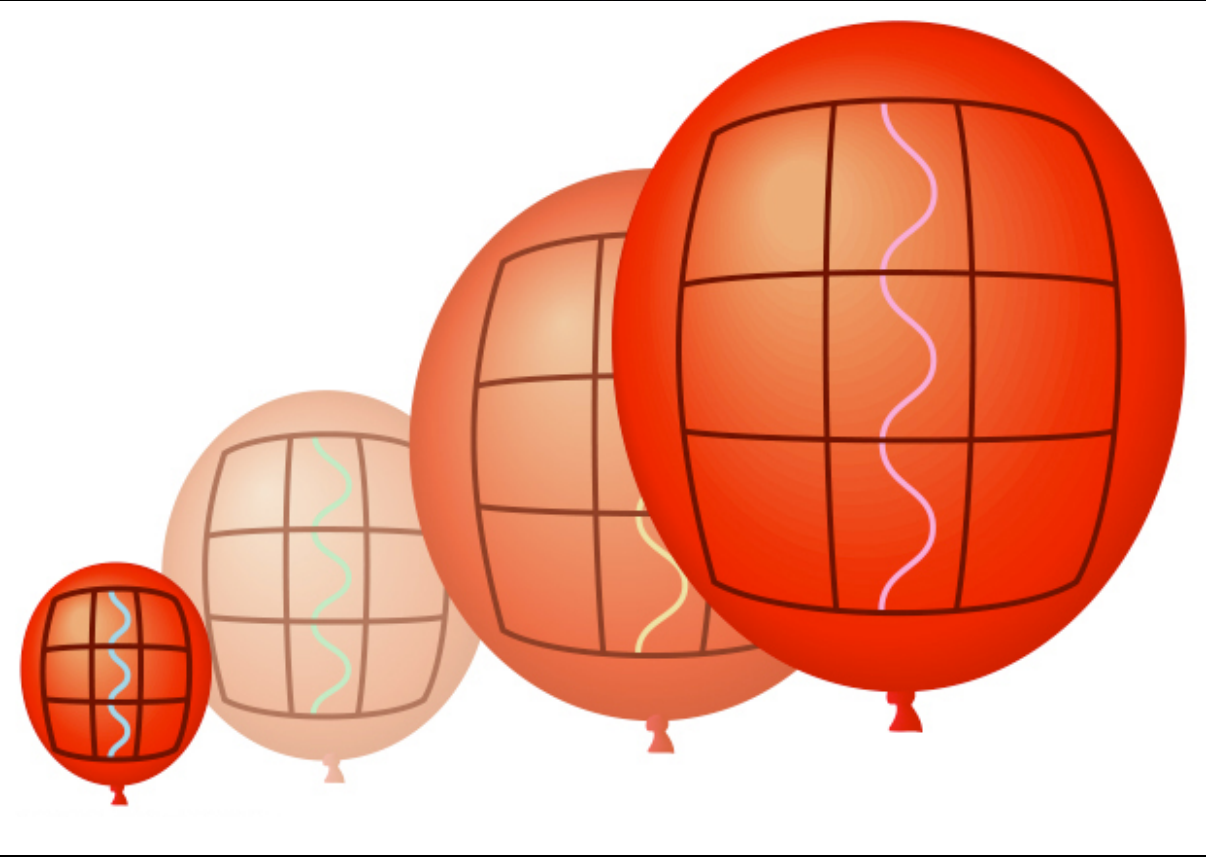
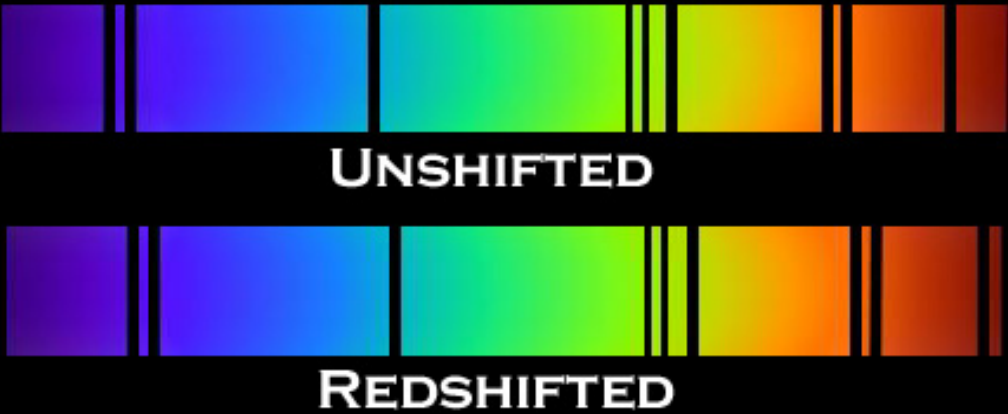
Measure both the expansion of the Universe and the laws of gravity

2-degree Field Galaxy  
Redshift Survey

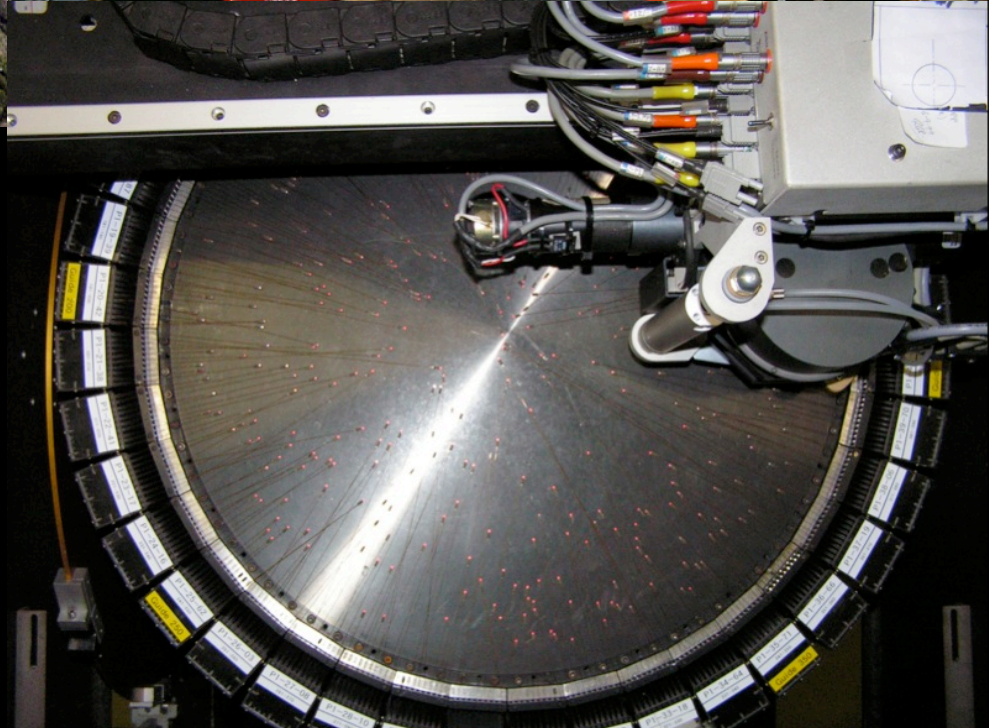
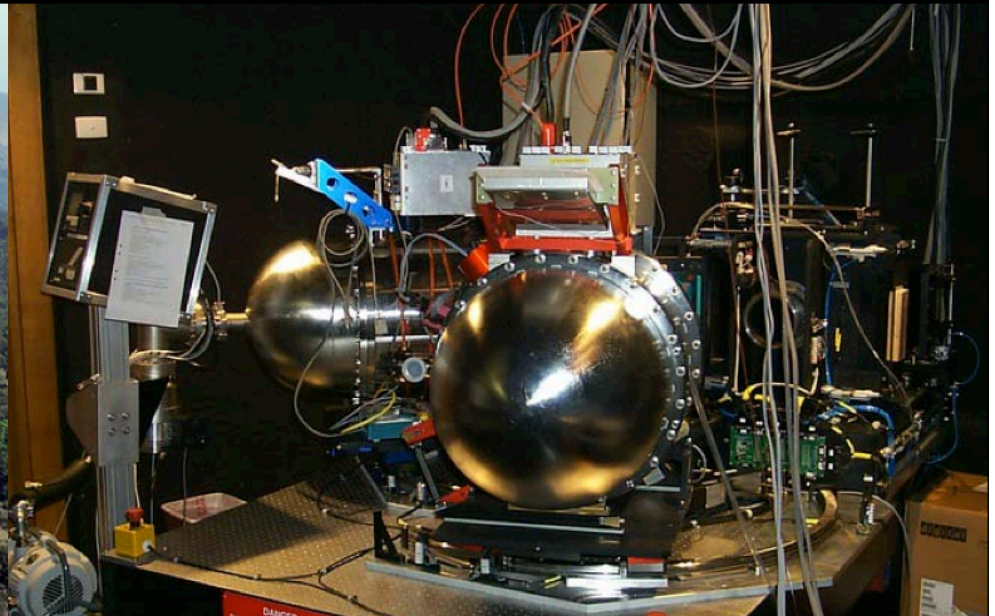




# Cosmological redshift



# The WiggleZ Dark Energy Survey



- 1000 sq deg ,  $0.2 < z < 1.0$
- 200,000 redshifts
- blue star-forming galaxies
- Aug 2006 - Jan 2011



# The WiggleZ Survey (observational) Team

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

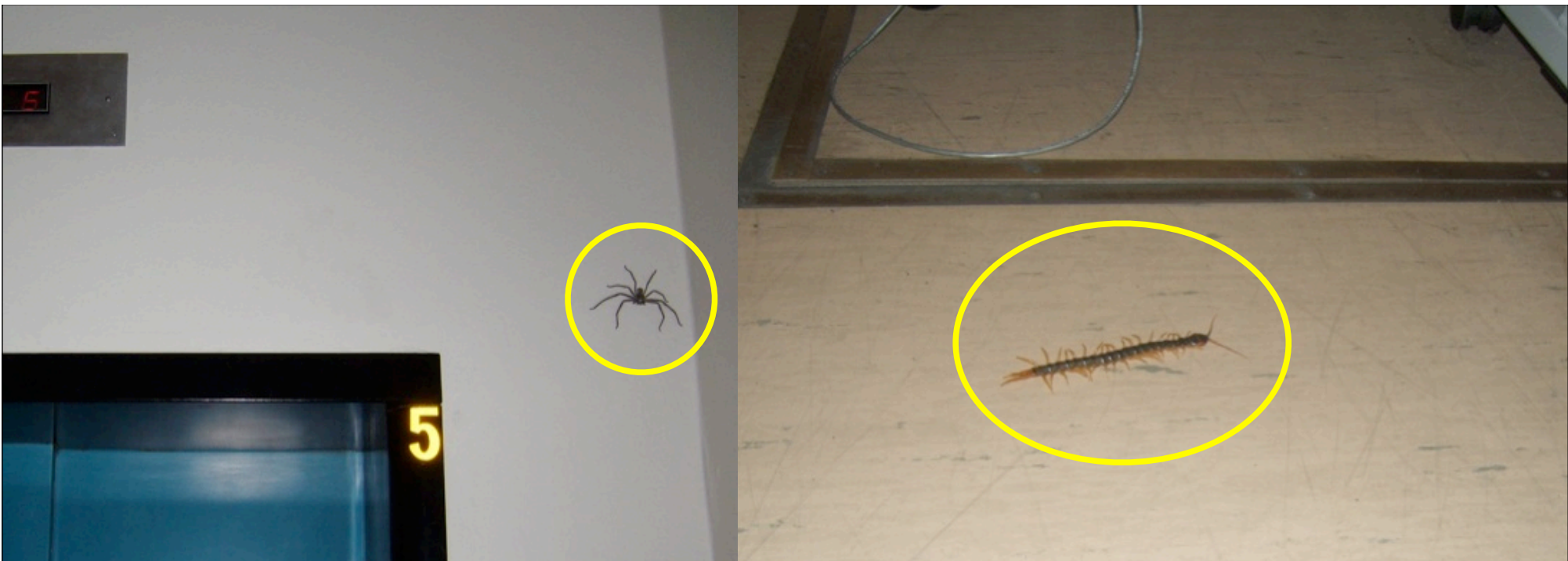
**University of Queensland** : Tamara Davis , Michael Drinkwater

Sarah Brough (AAO) , Matthew Colless (ANU) , Scott Croom (U.Syd.) , Ben Jelliffe (U.Syd.) , Russell Jurek (ATNF) , Kevin Pimbblet (Monash) , Mike Pracy (U.Syd) , Rob Sharp (ANU) , David Woods (UBC)

**GALEX team** : Karl Forster , Barry Madore , Chris Martin , Ted Wyder

**RCS2 team** : David Gilbank , Mike Gladders , Howard Yee





CCD Control

```
AAAT Instrument Account - Linux.aatlx.aao.gov.au:/instsoft/instusers/aatinst
File Edit View Terminal Go Help
Starting DRAMA version 11oct07
Selected version file is /instsoft/drama/11oct07.ver
Drama version 1.5.2 enabled.
Starting new shell, Use exit to return
Setting up for logging in from aat(lxa,lxb,xdb)
Using existing VNC server.
To restart VNC, first do "8bitdisplay2df -kill ?"
access control disabled, clients can connect from any host
2df software setup
[1] 30115
Setting up AAO 2 CCD software for machine aatlx.aao.gov.au
aatinst@aatlx.aao.gov.au:/instsoft/instusers/aatinst
> Failed to initialise server
SYSGO_SERVER:Error binding port to socket, Address already in use

[1] Exit 1
6/syago_server -f ... /instsoft/drama/local/obs2df/r3_6g/linux_x8
aatinst@aatlx.aao.gov.au:/instsoft/instusers/aatinst
>
aatinst@aatlx.aao.gov.au:/instsoft/instusers/aatinst
>
aatinst@aatlx.aao.gov.au:/instsoft/instusers/aatinst
>
aad -out fuck
```

Control Task Status: CONFIGURING  
Time: 13-Oct-07 09:10:45 Telescope Time: 13-Oct-07 19:10:45

Telescope Control (Ctrl-T)  
Tracking Object

Status:	Tracking
Mean RA:	21:31:21.42
Mean DEC:	04:10:09.9
HA:	-00:58
ZD:	38.06
Air Mass:	1.27

Positioner: Failed

Messages

```
15:20:18 message from task TDFPT
15:20:18 "TDFPT", completed with status = %DITS-F-TASKDISC
15:20:18 message from task FPICAM
15:20:18 "FPICAM", completed with status = %DITS-F-TASKDISC, Task disconnected
15:20:55 Unexpected disconnect message from task ADC
15:20:55 Action "MONITOR" to task "FPICAM", completed with status = %DITS-F-TASKDISC, Task disconnected
15:20:55 Too many error dialogs - please see scrolling area for remaining messages
```

Task ADC has died

Task FPICAM has died

Unexpected disconnect message from task ADC

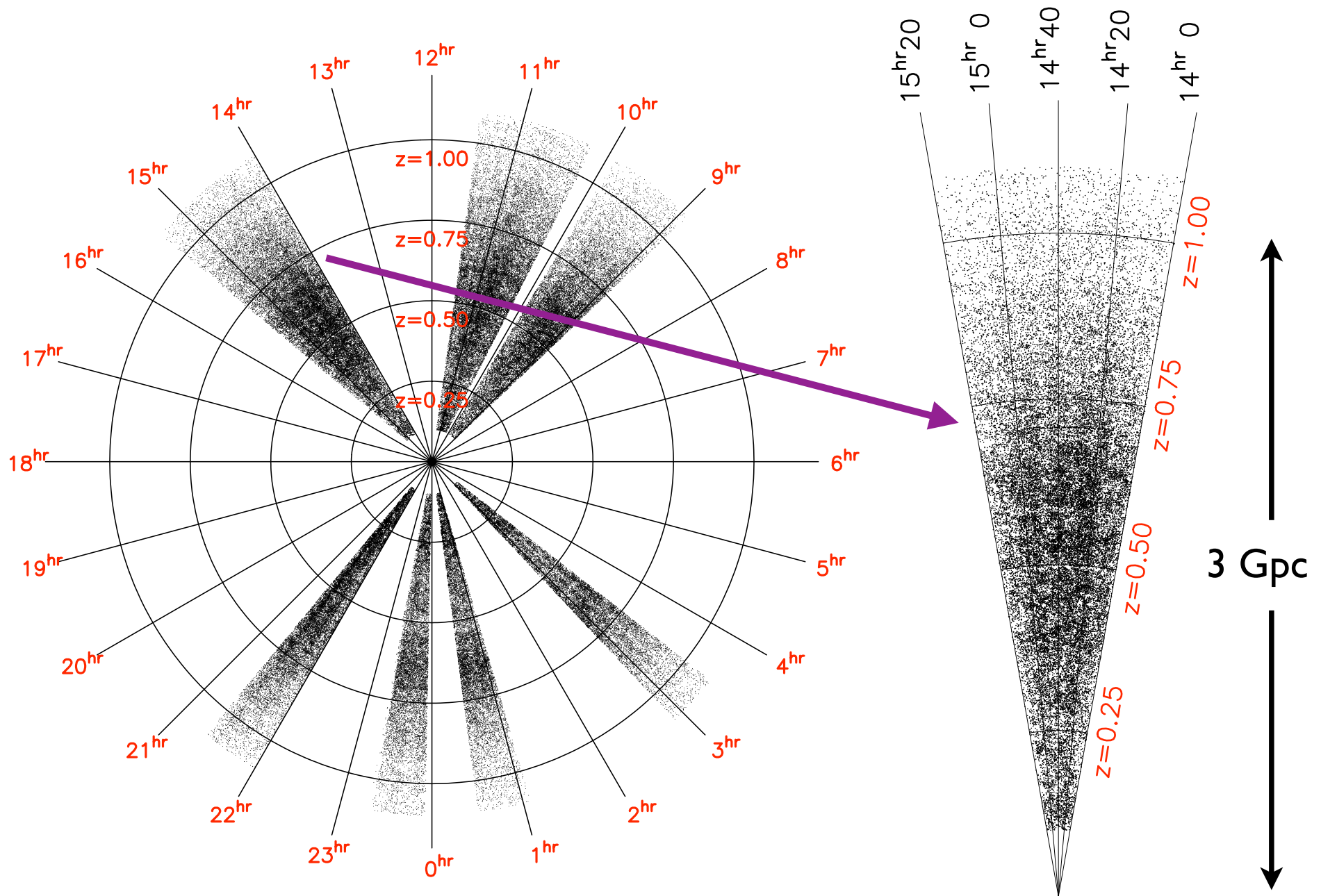
Too many error dialogs - please see scrolling area for remaining messages

Parameters from task TDFGRIP

Parameter	Type	Value
BACKLIT	ALWAYS	CCD SHUTTER
CCD	SHUTTER	



# The WiggleZ Dark Energy Survey

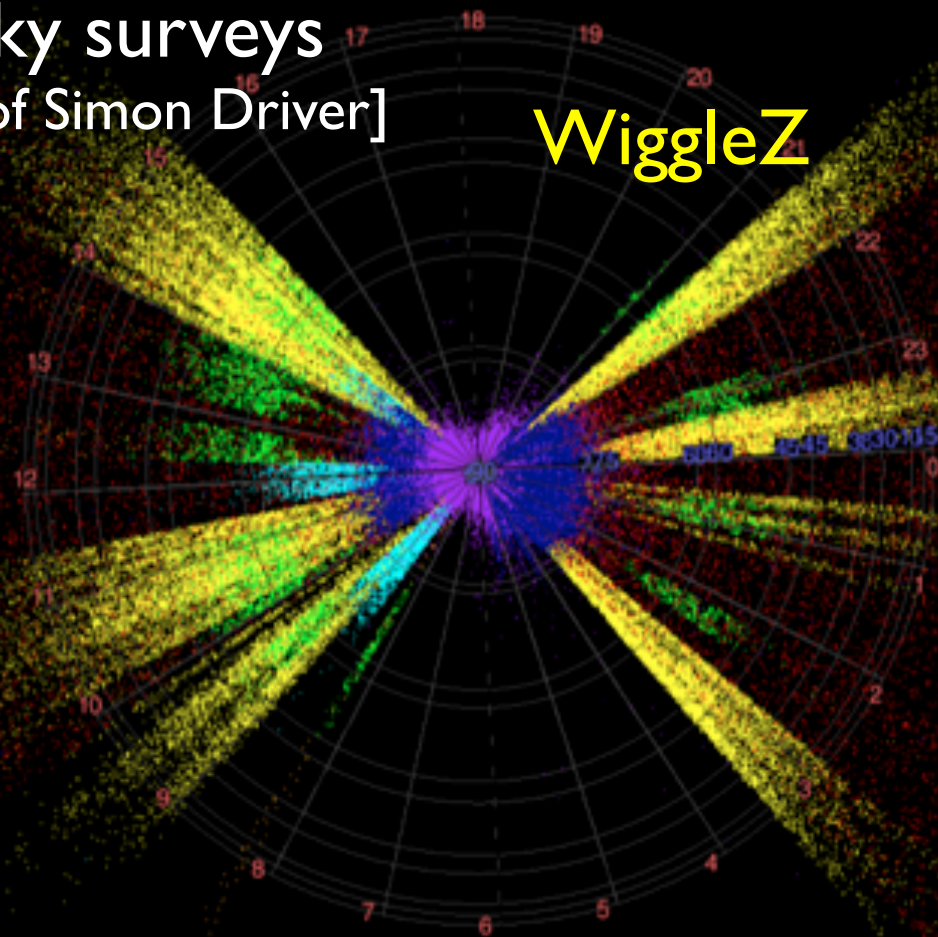


# The WiggleZ Dark Energy Survey

Southern sky surveys

[image courtesy of Simon Driver]

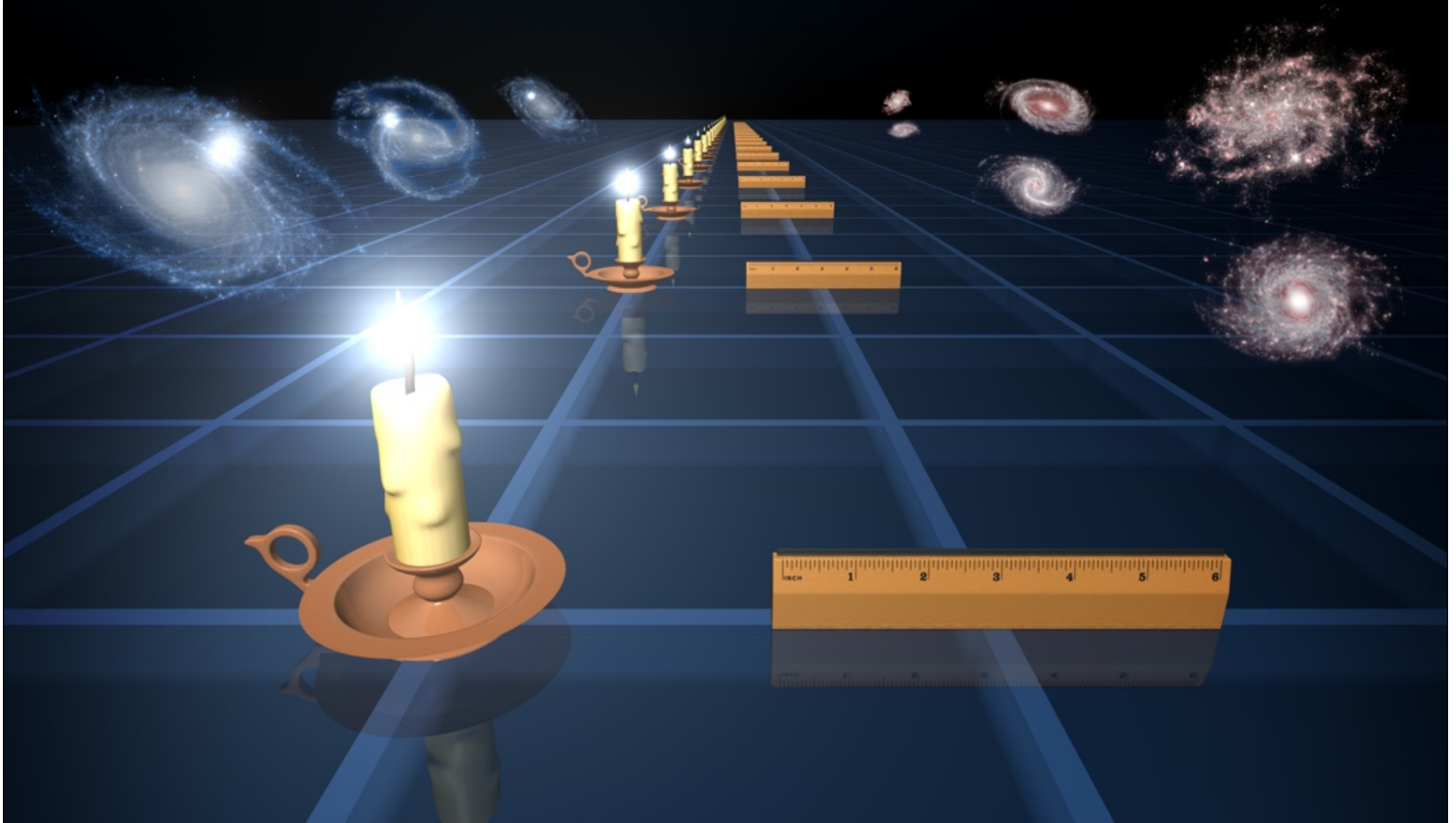
WiggleZ



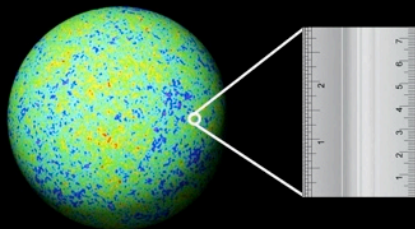
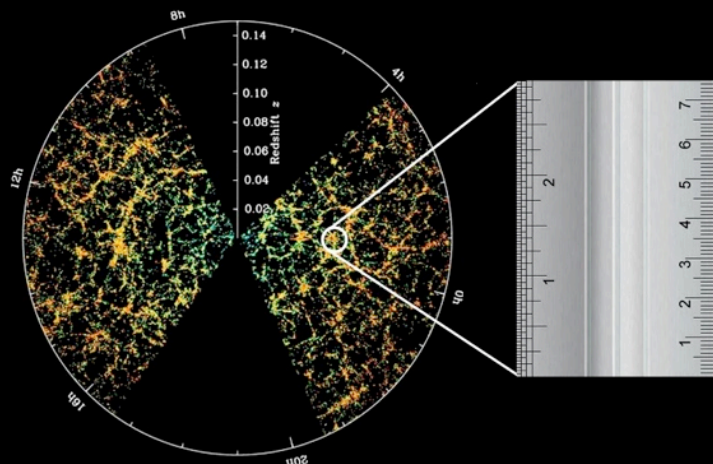
6dFGS (purple), 2dFGRS (blue), MGC (navy), GAMA (cyan), 2SLAQ-LRG (green),  
WiggleZ (yellow), 2SLAQ-QSO (orange), 2QZ (red); the celestial sphere is at  $z=1$ .



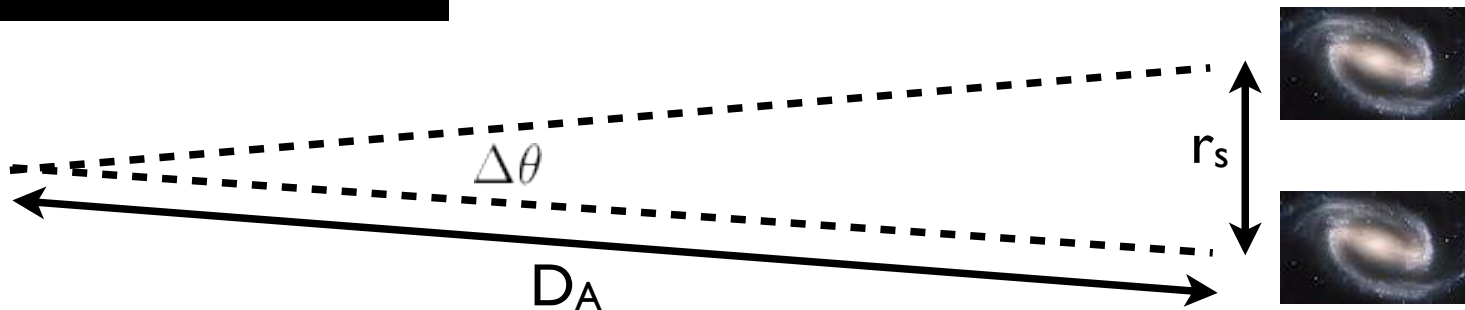
# Standard candles and rulers



# Standard ruler : baryon acoustic peak

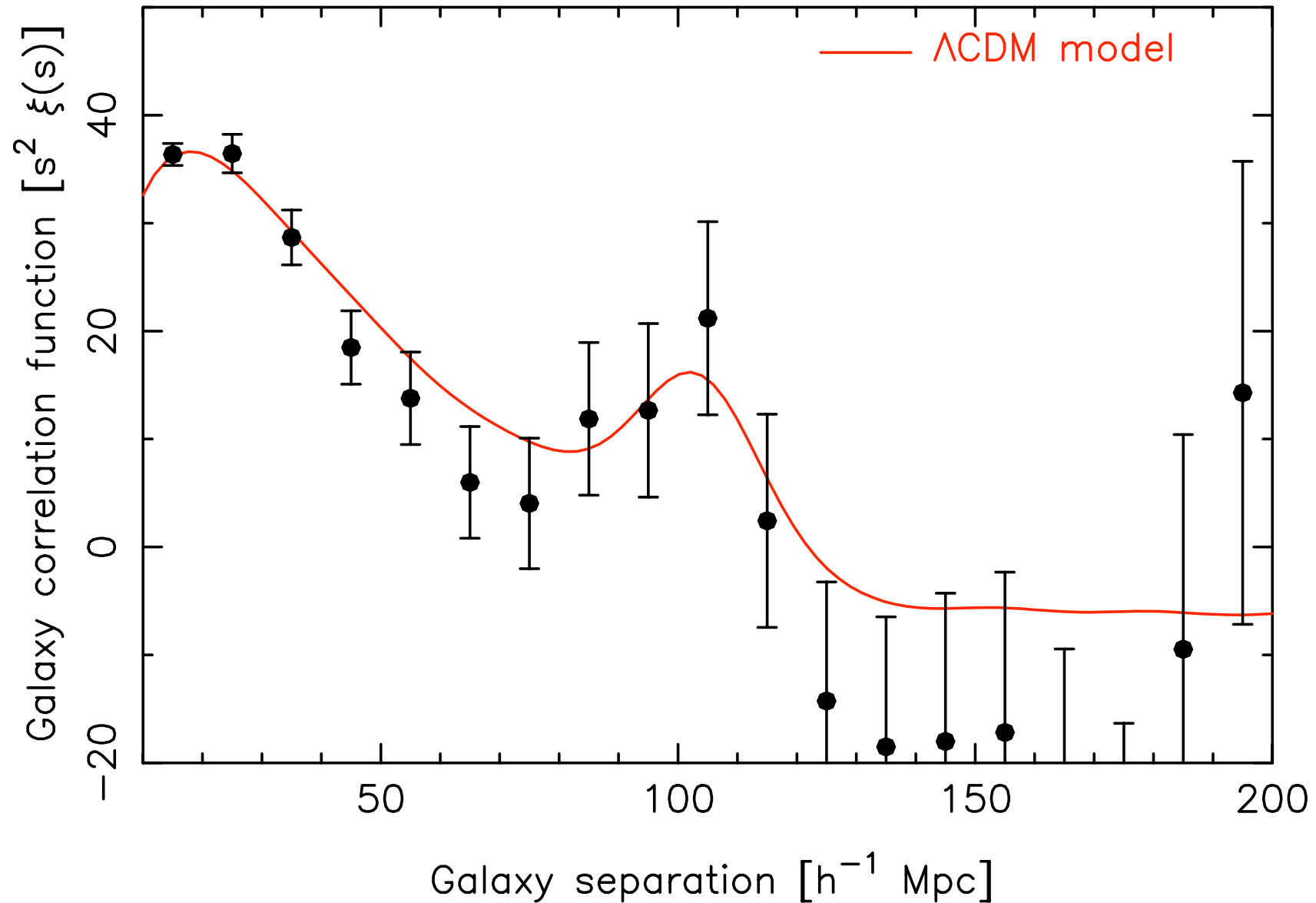


- Preferred co-moving separation of  $105 h^{-1} \text{ Mpc}$  between clumps imprinted at recombination
- We observe a preferred angular separation between galaxies at some redshift
- Allows distance determination by simple geometry

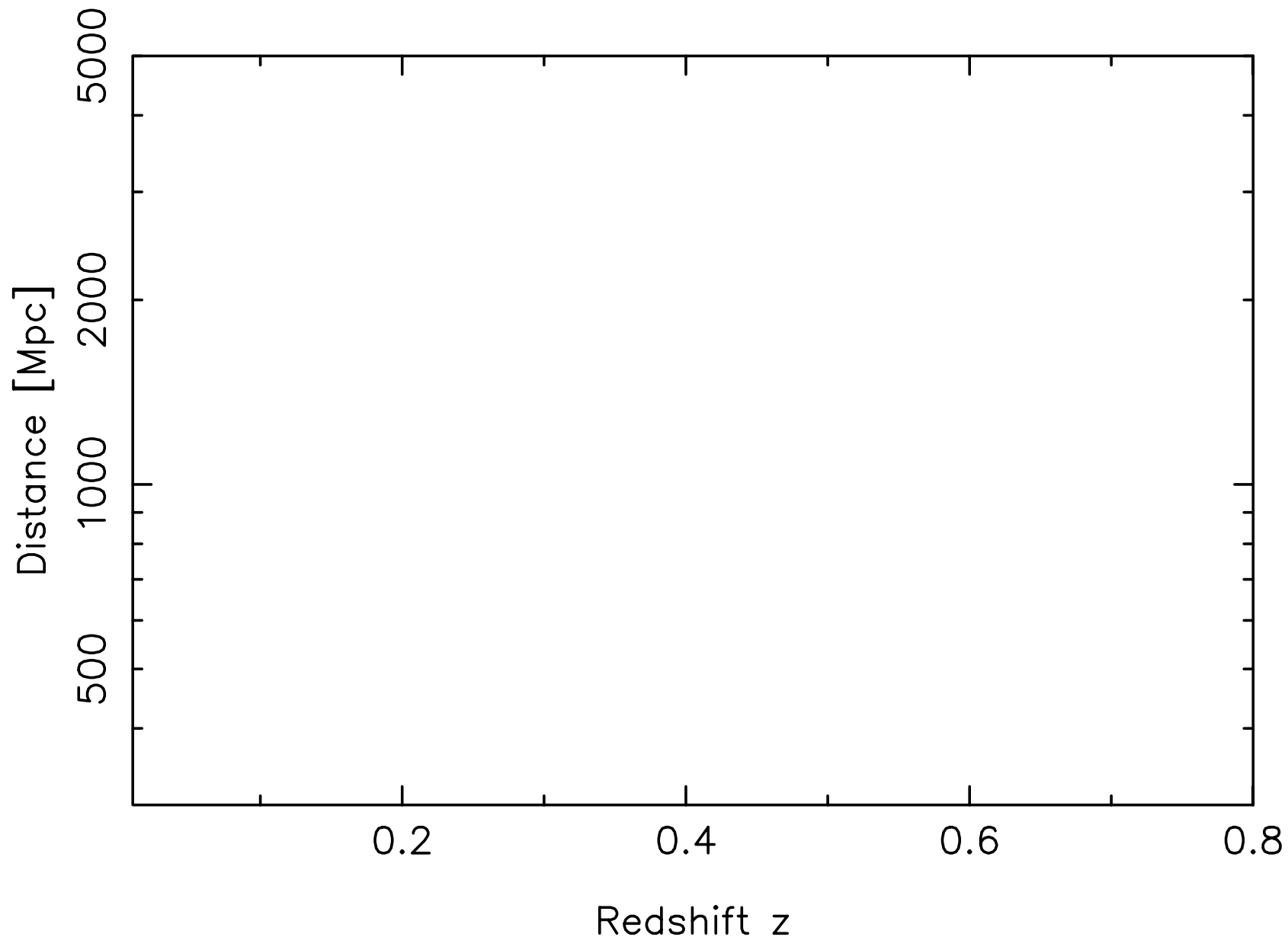




# The baryon acoustic peak in WiggleZ

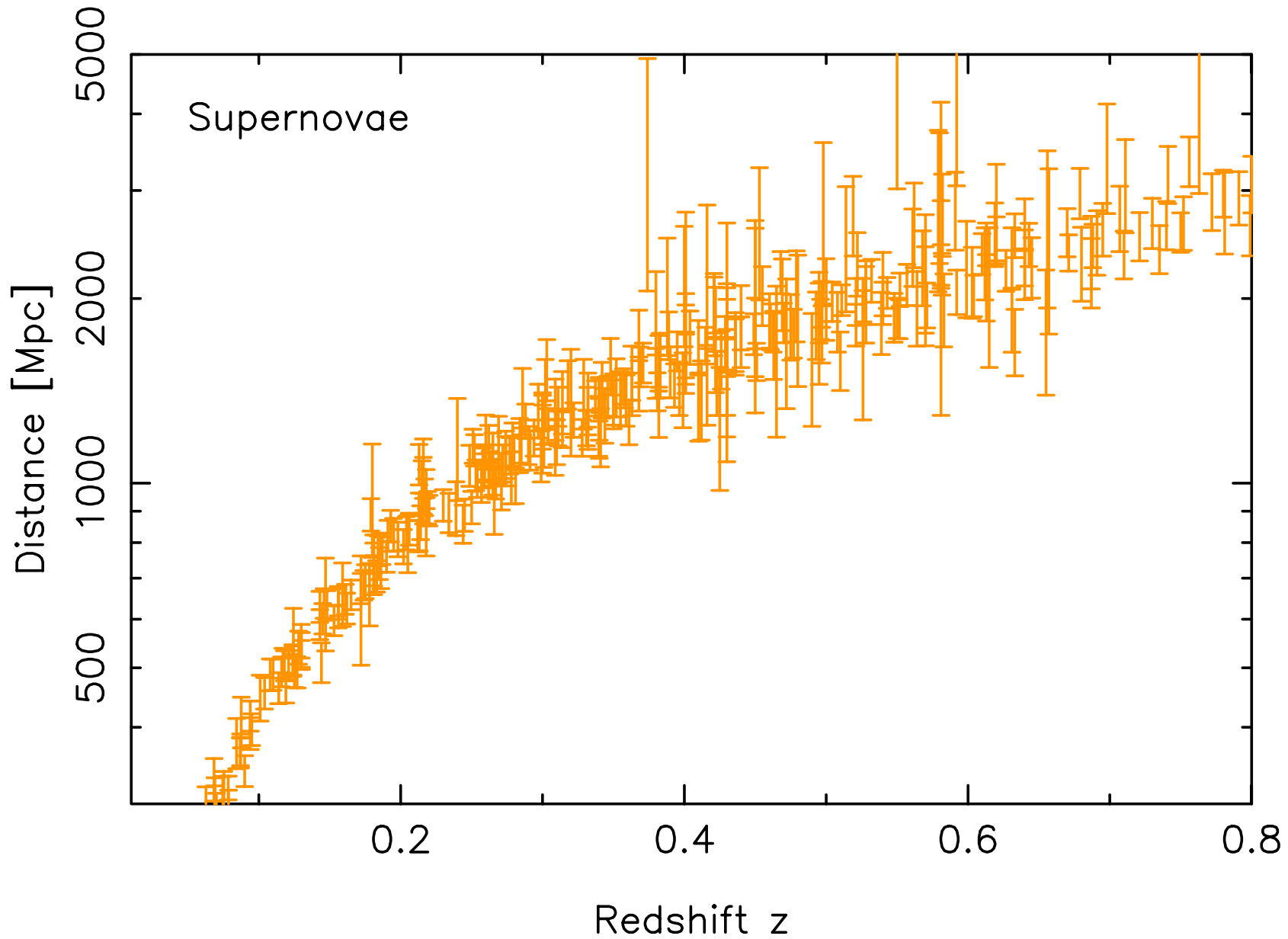


# Distance-redshift relation

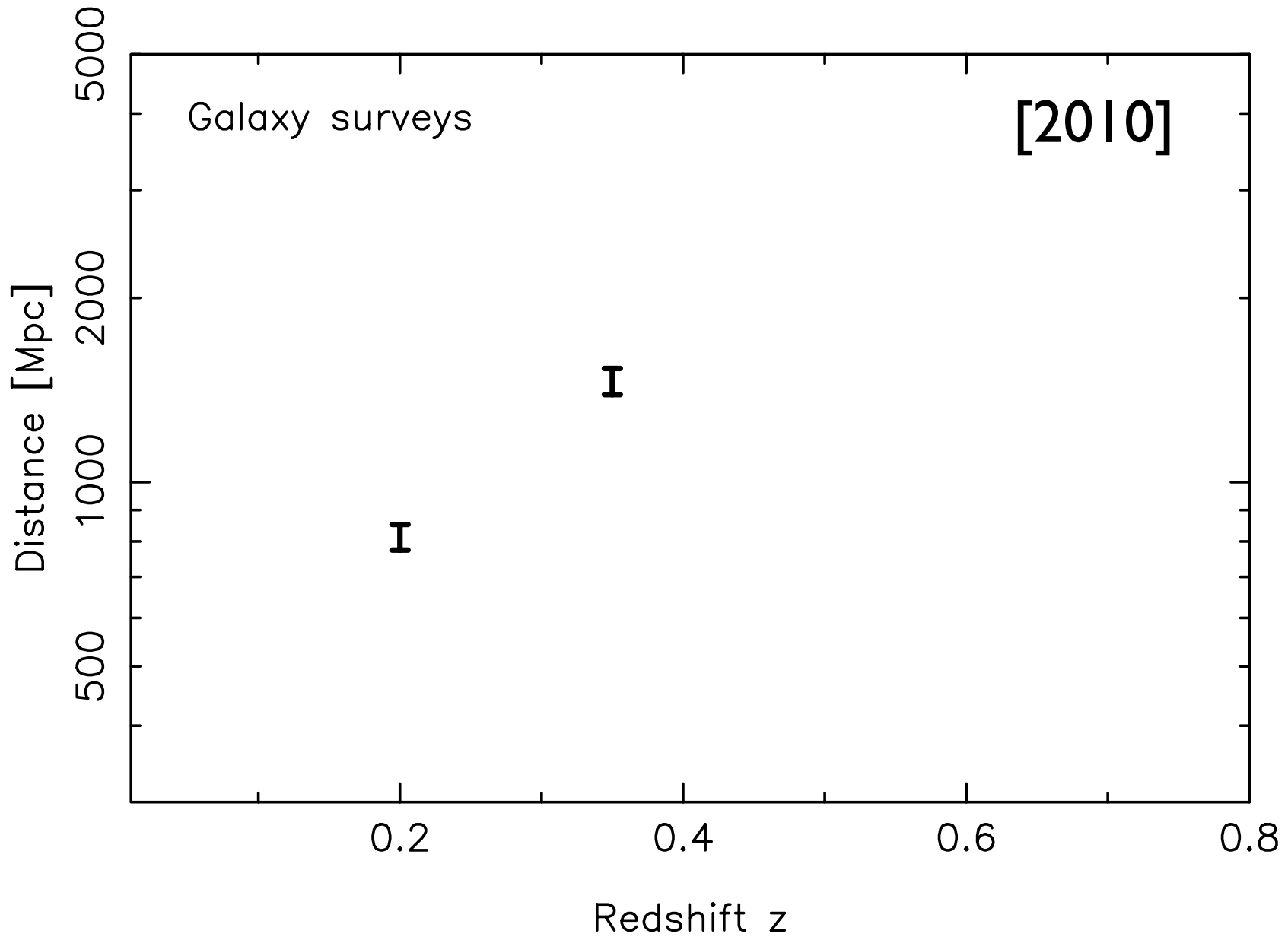




# Distance-redshift relation

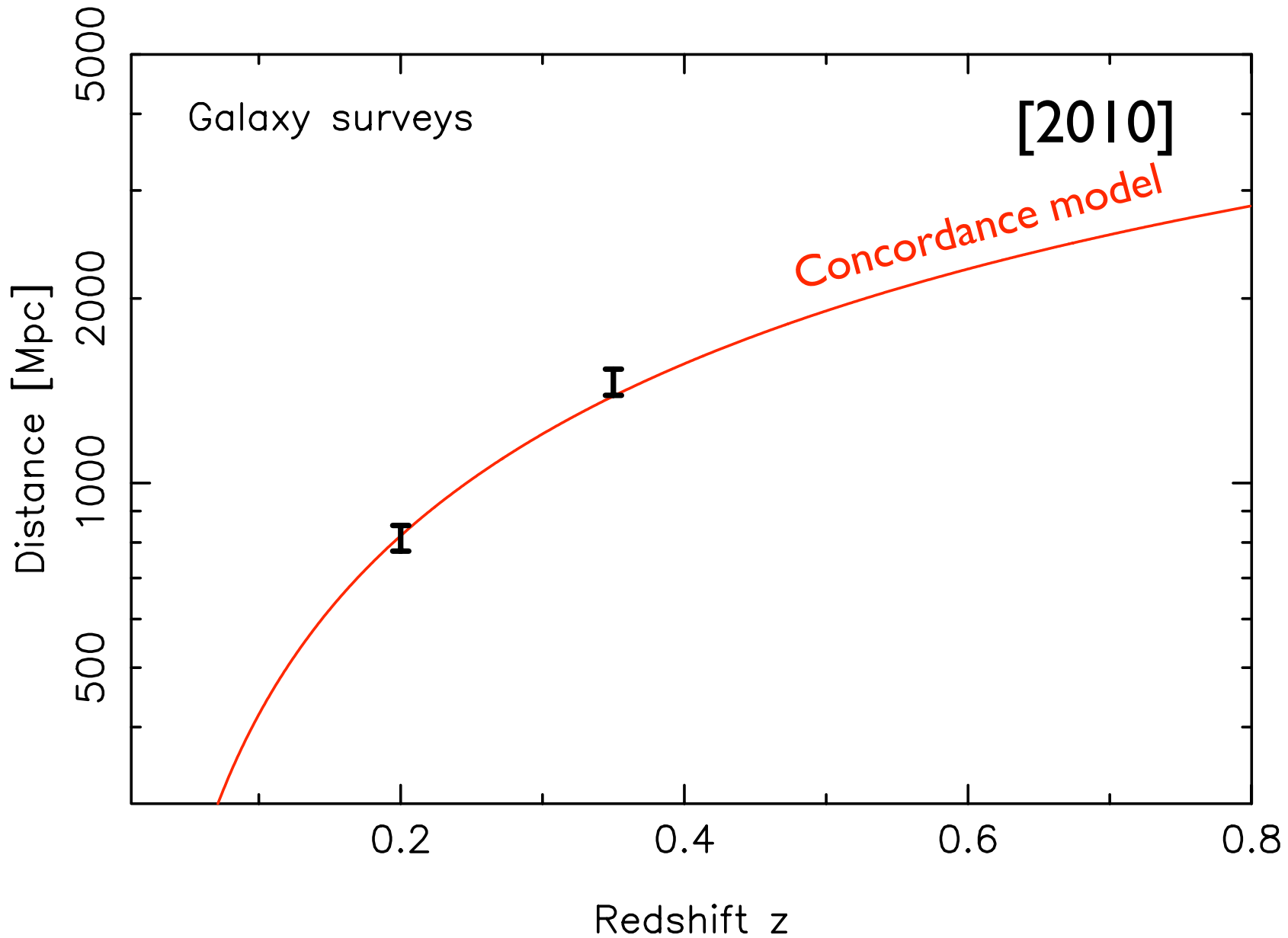


# Distance-redshift relation

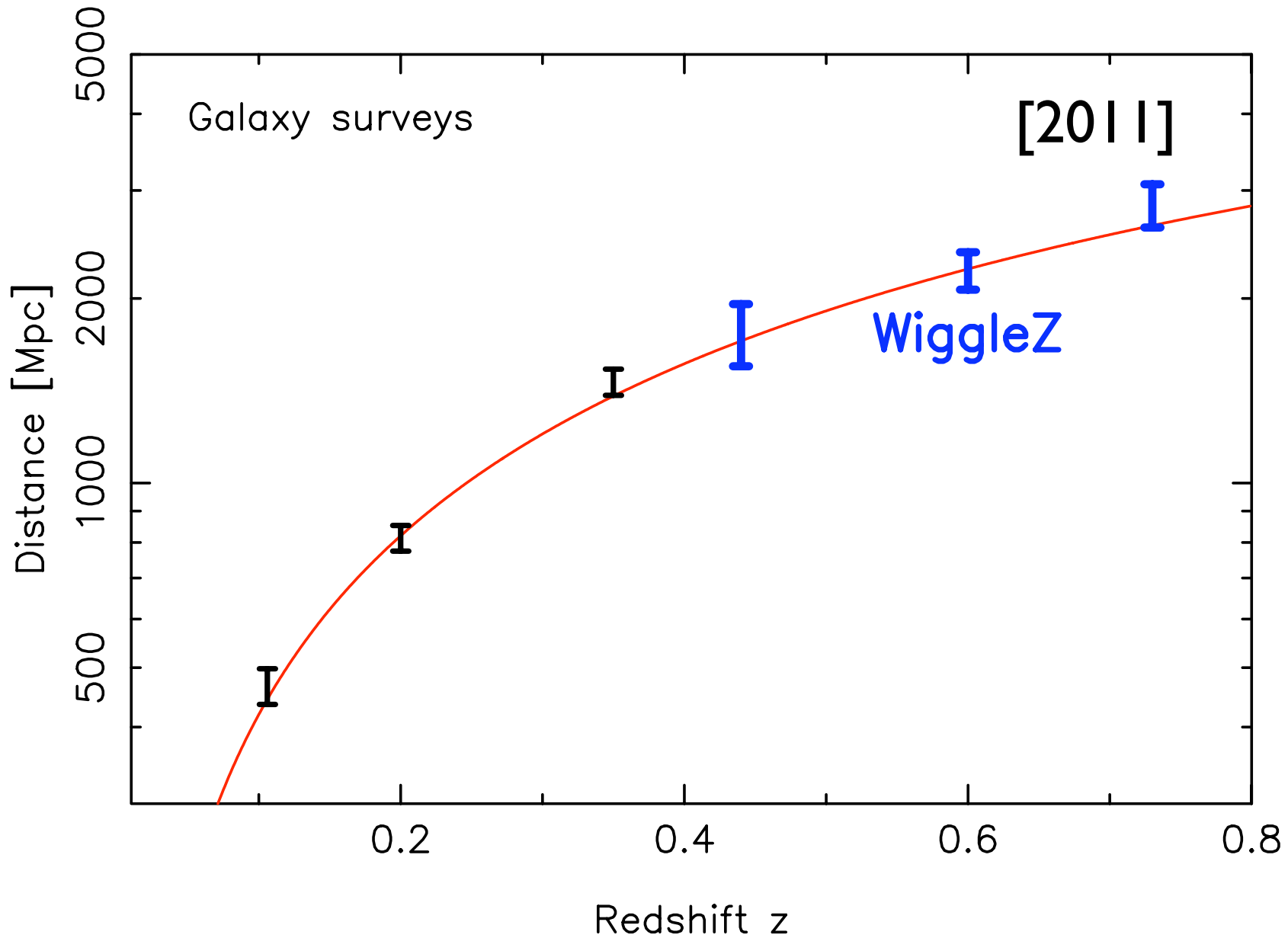




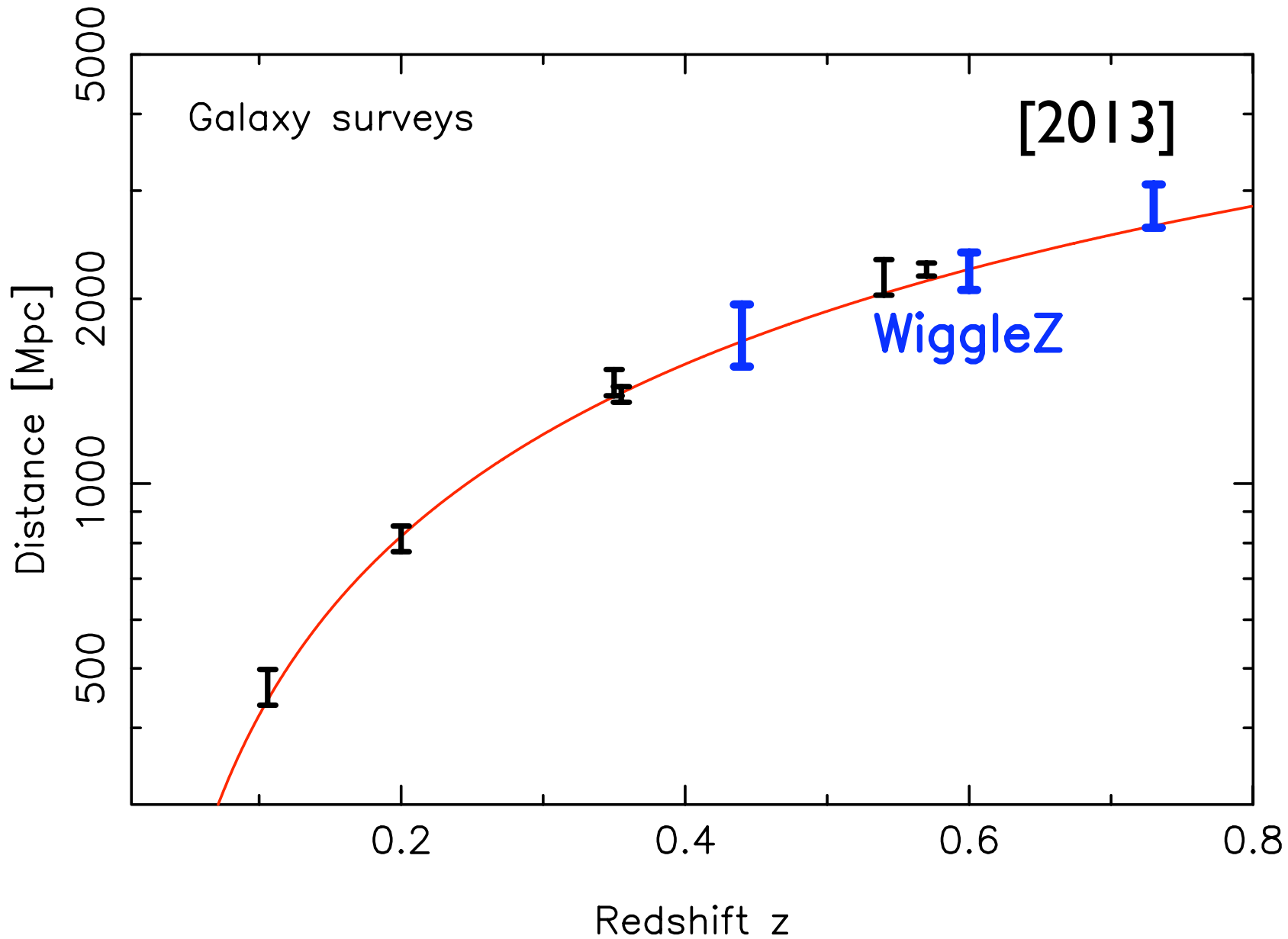
# Distance-redshift relation



# Distance-redshift relation

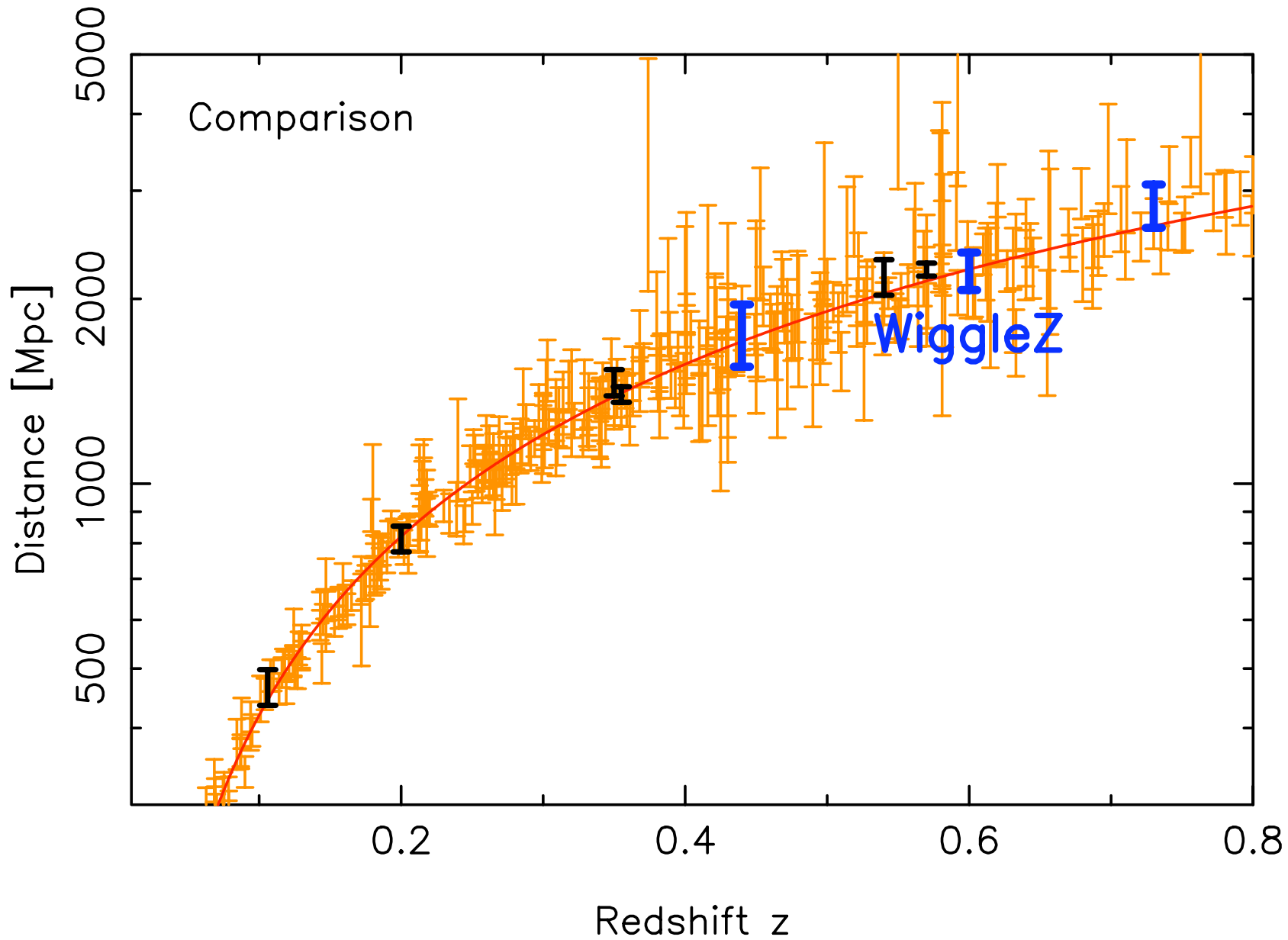


# Distance-redshift relation

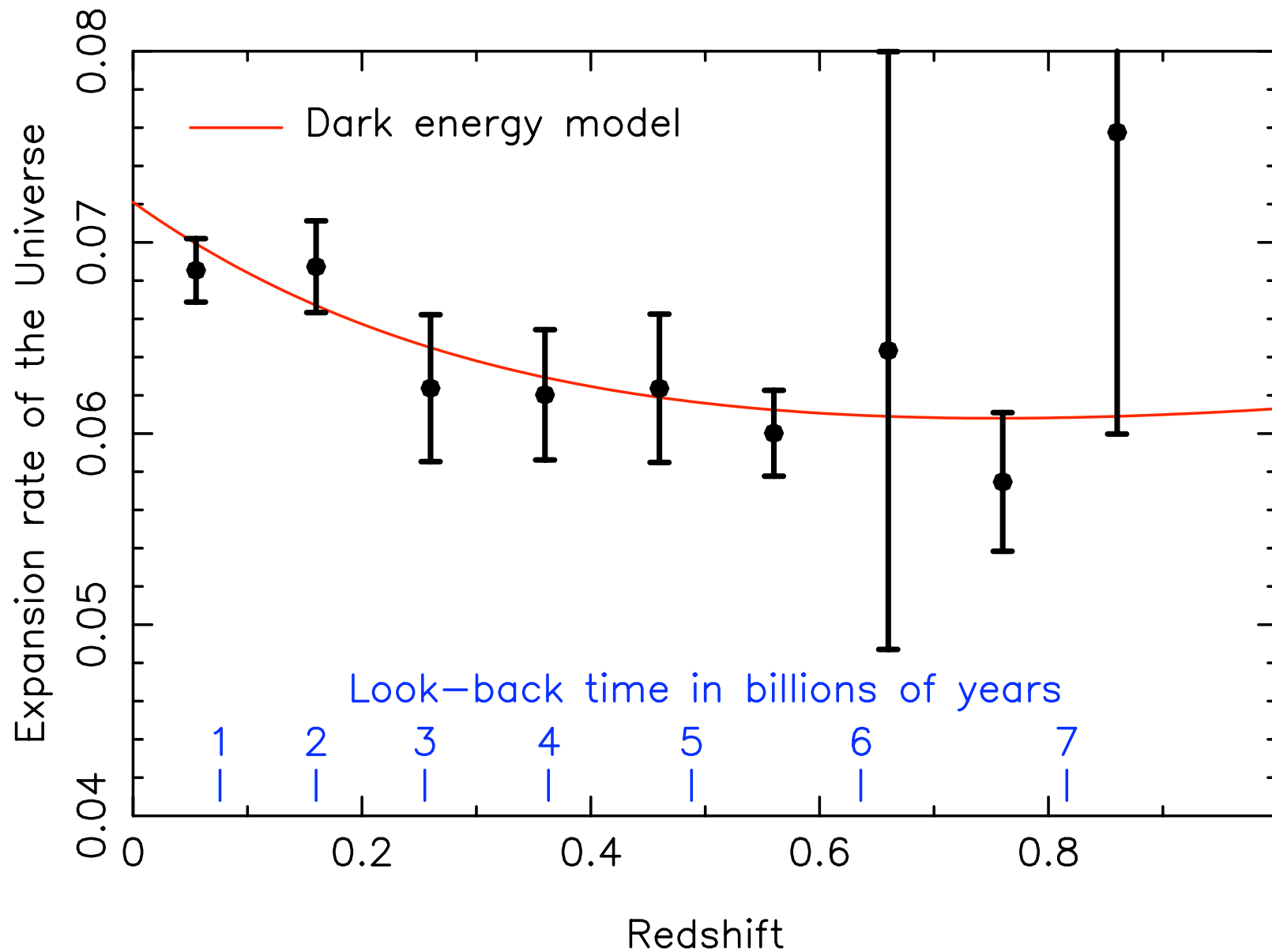




# Distance-redshift relation



# Our result : new evidence for dark energy



# Dark energy : the “w” parameter

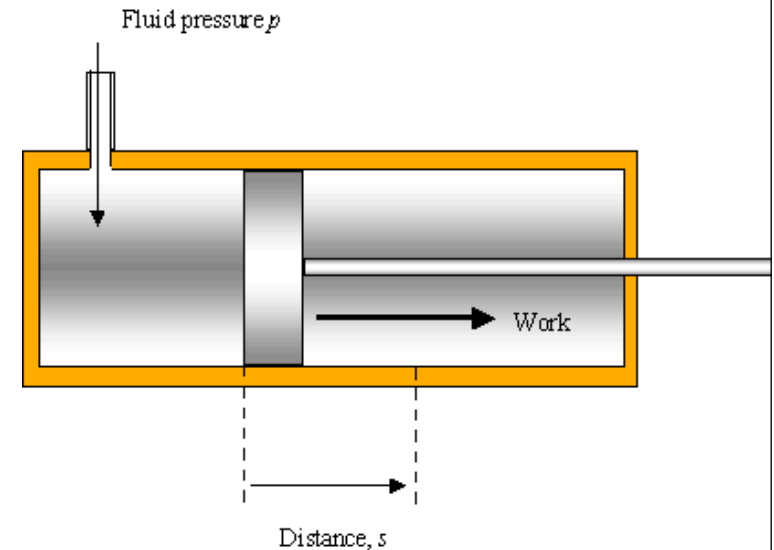
## Key values ...

Matter :  $w = 0$

Radiation :  $w = 1/3$

Cosmological constant :  $w = -1$

Accelerating fluid :  $w < -1/3$



## Physics of dark energy ...

Equation of state :  $P = w \rho$

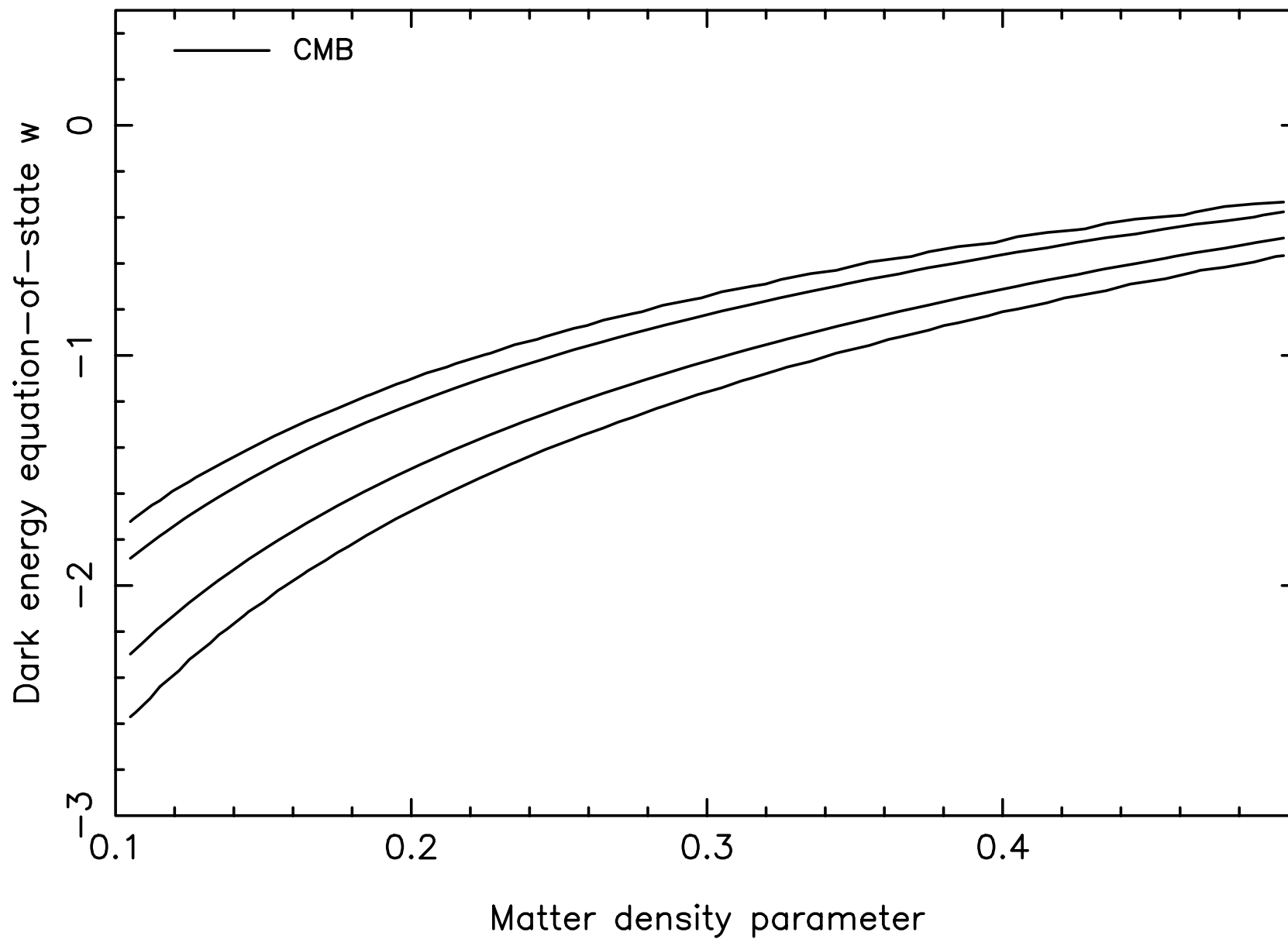
Conservation of energy :  $dE = d(\rho a^3) = -p d(a^3)$

Re-arranging :  $\rho \propto a^{-3(1+w)}$

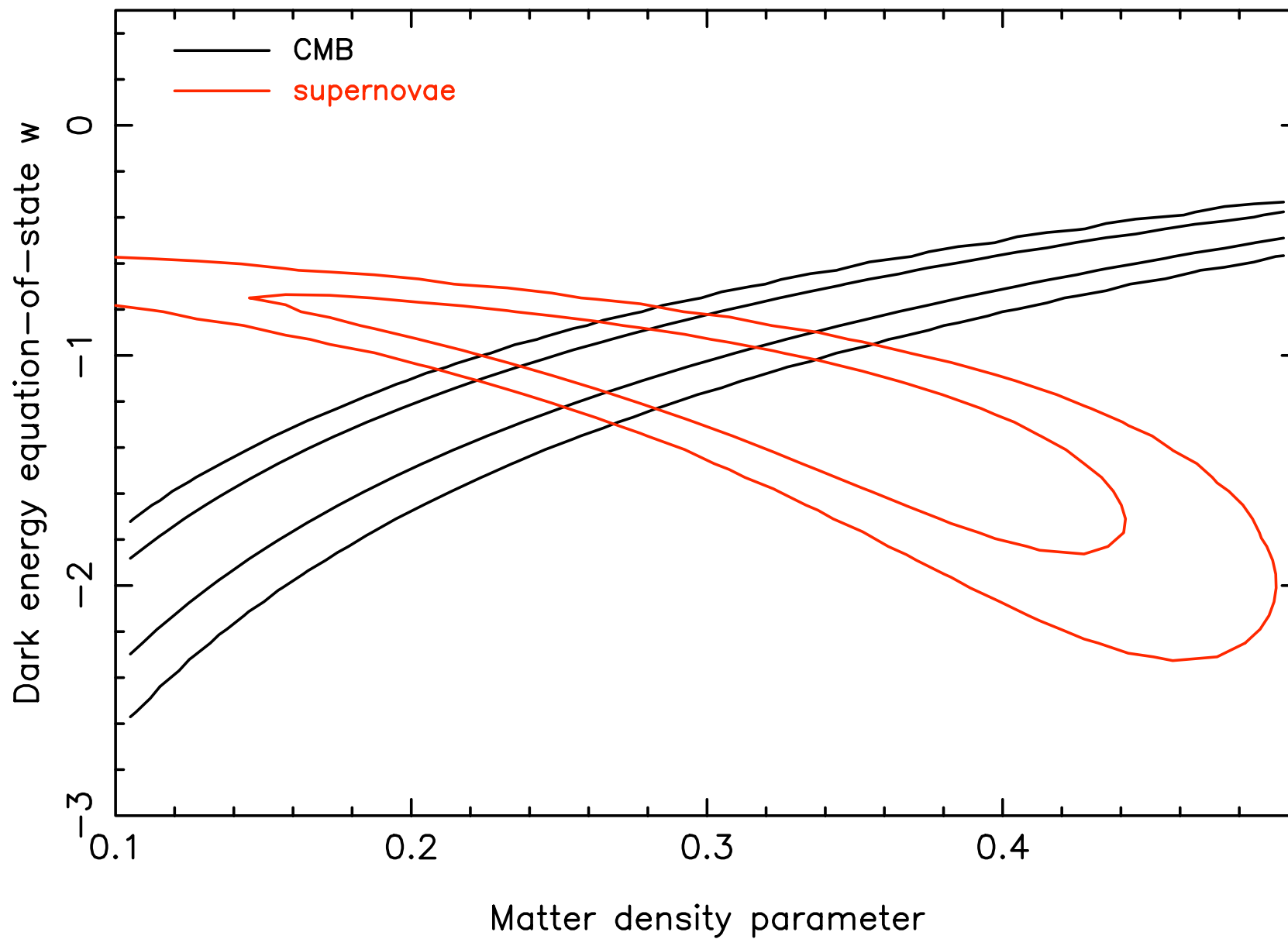
Friedmann equation :  $da/dt \propto a^{-(1+3w)/2}$



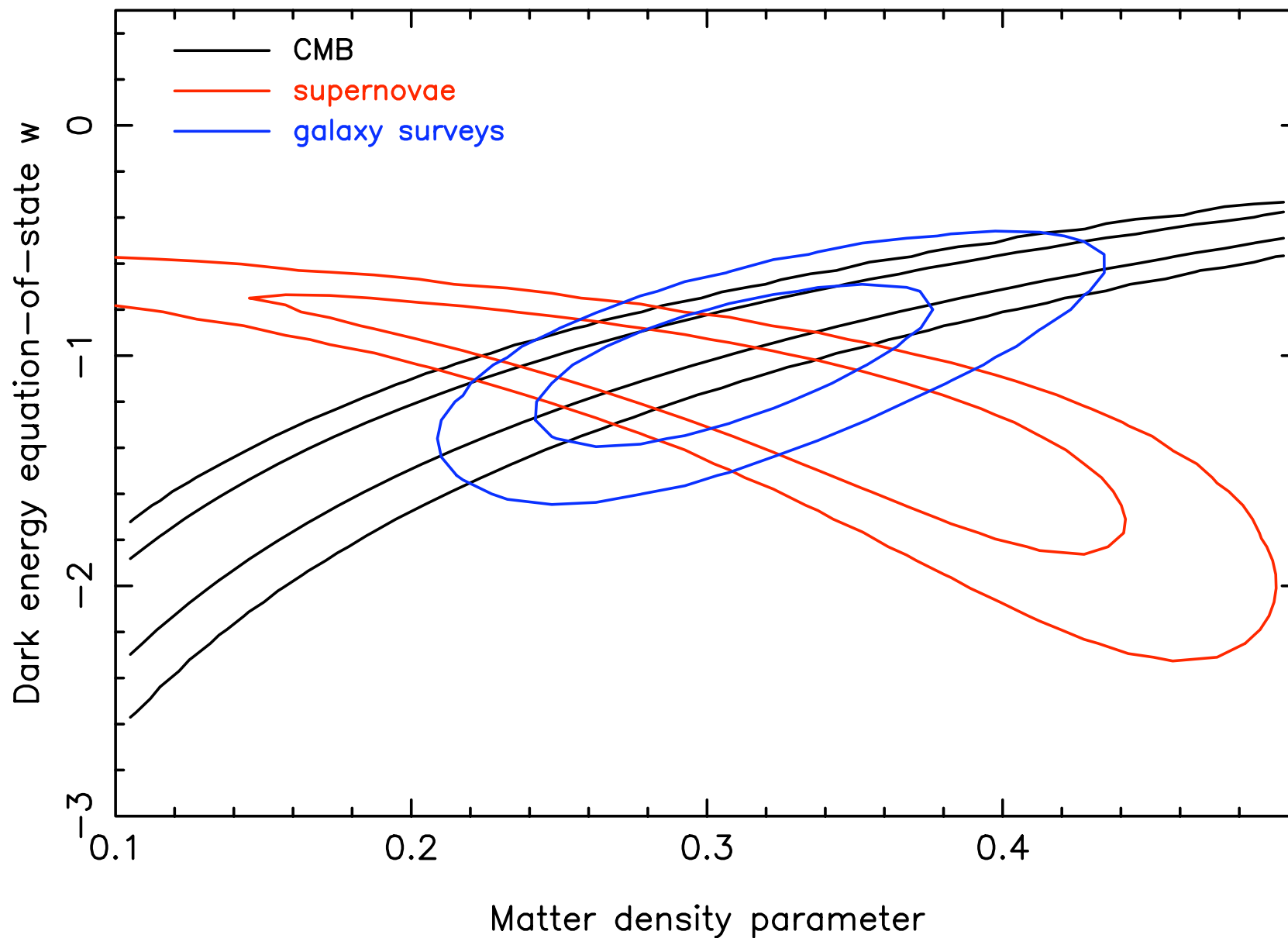
# Cosmological data working together



# Cosmological data working together

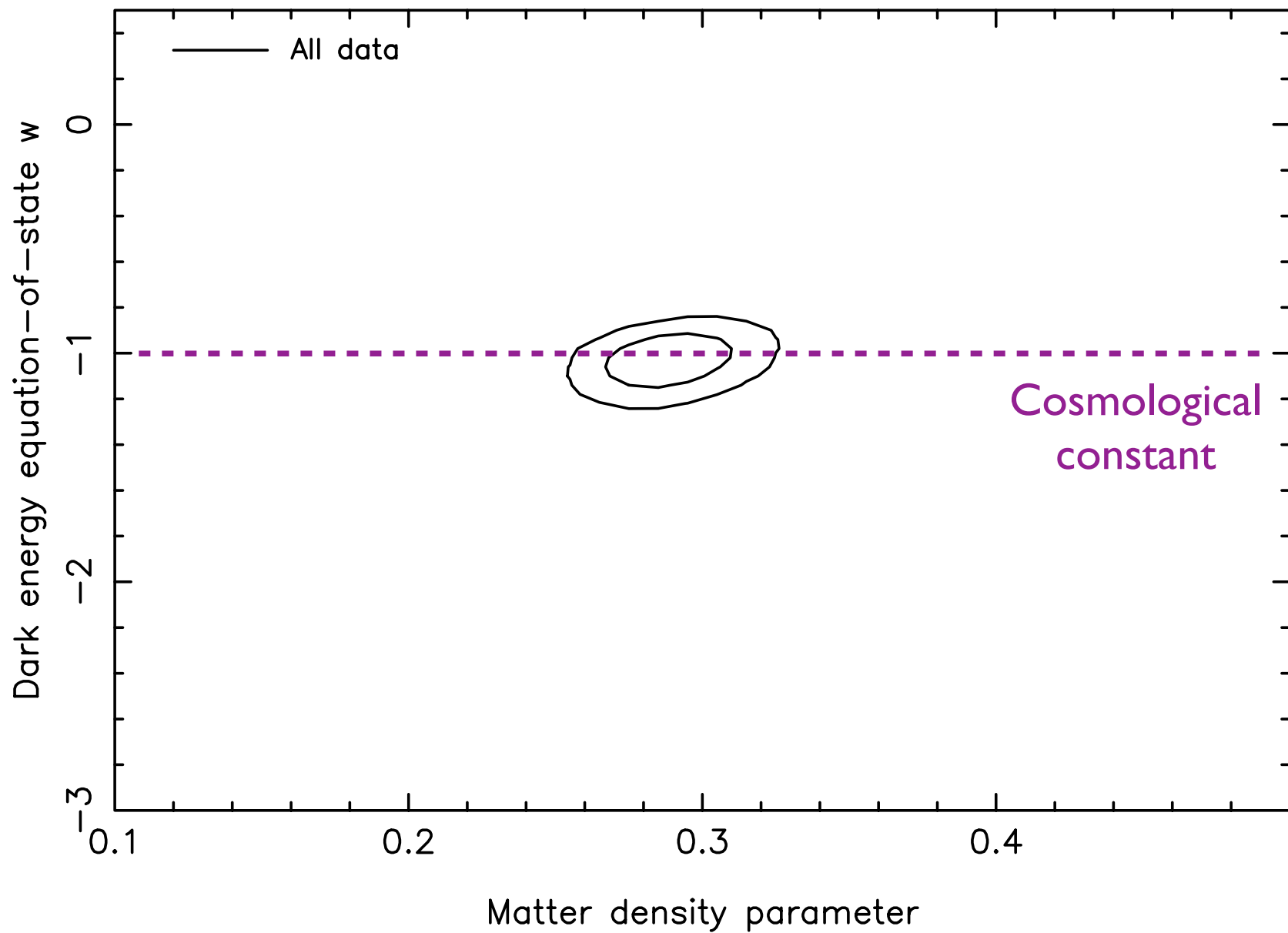


# Cosmological data working together

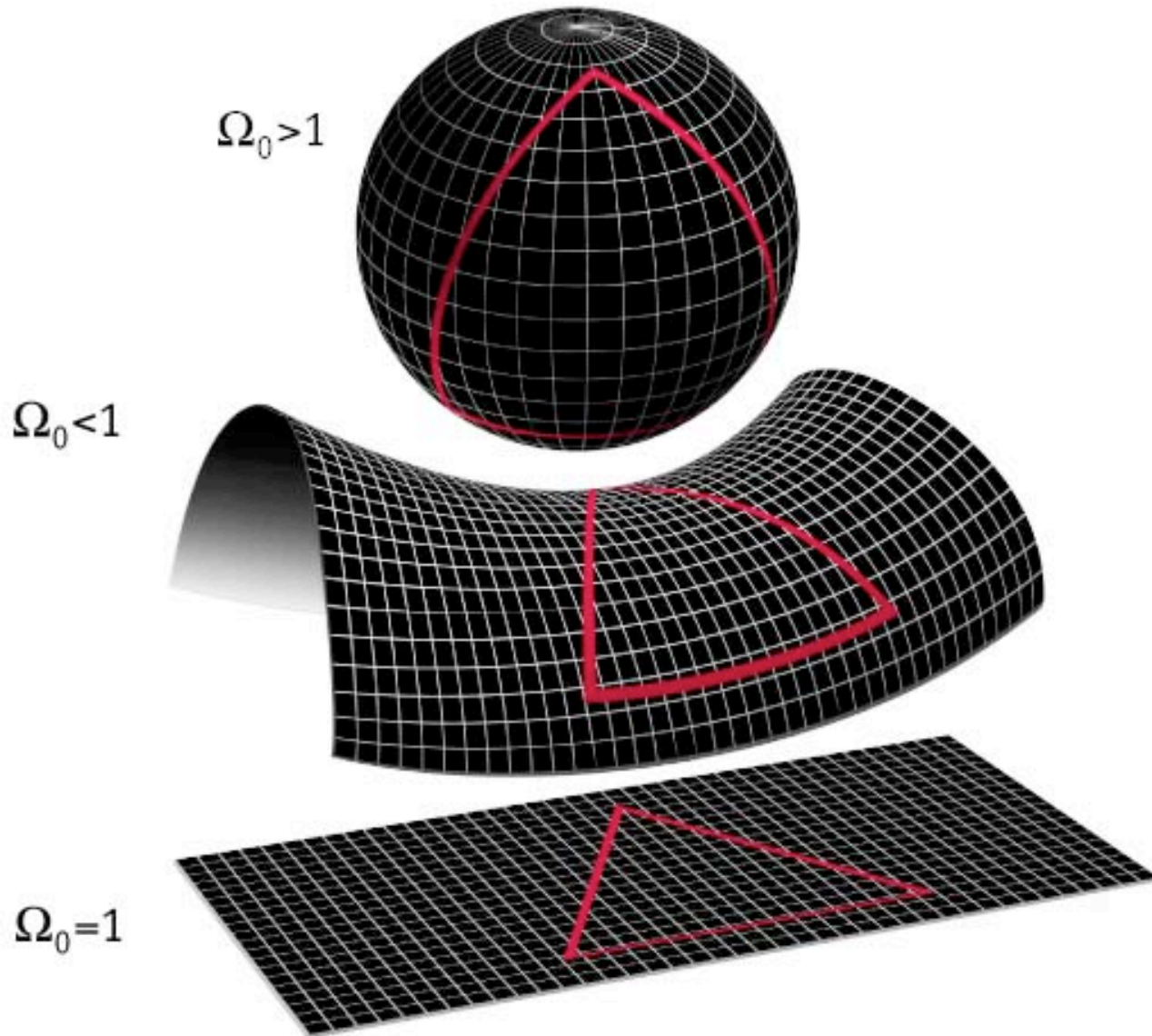




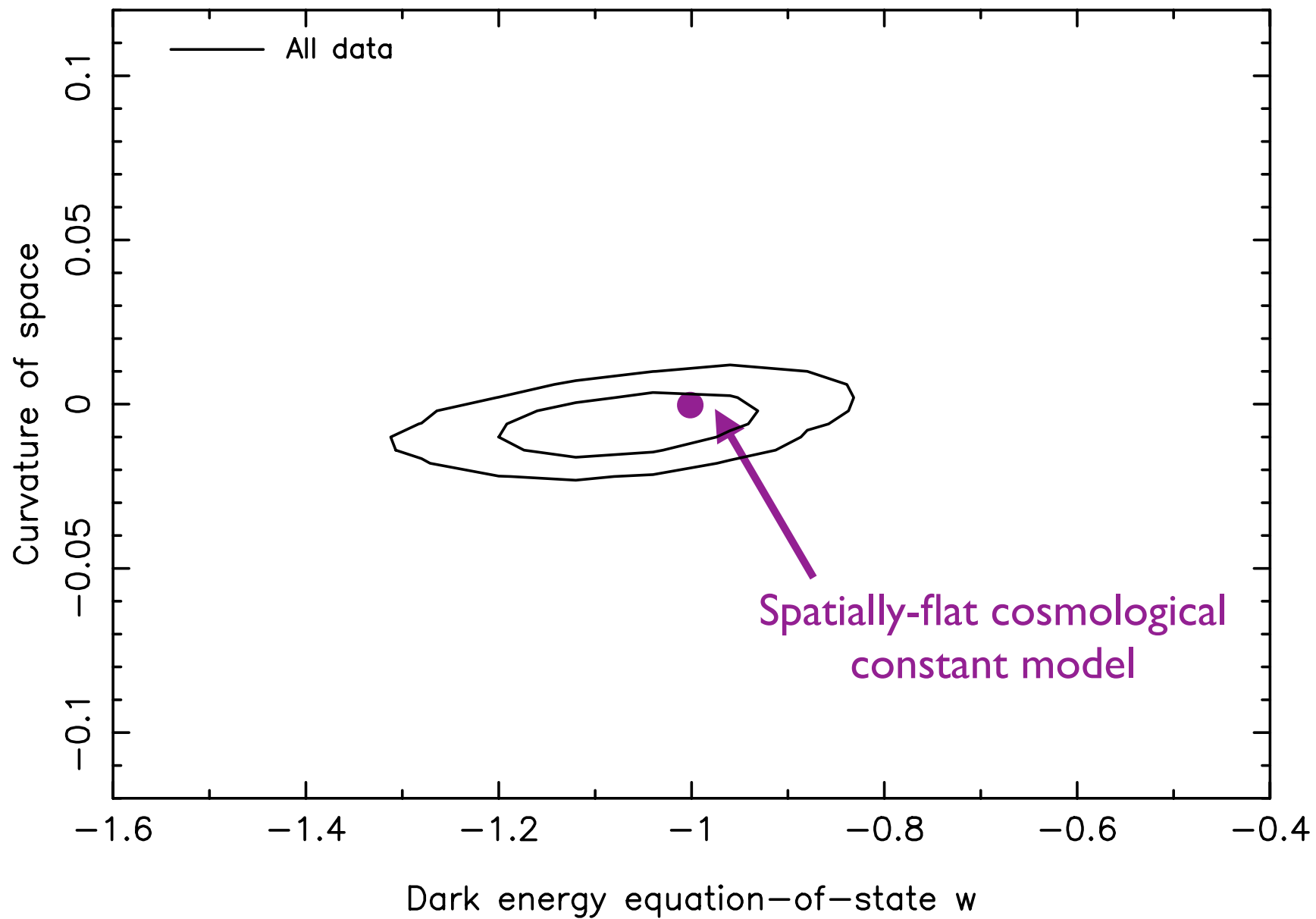
# Cosmological data working together



# Curvature of space



# Curvature of space



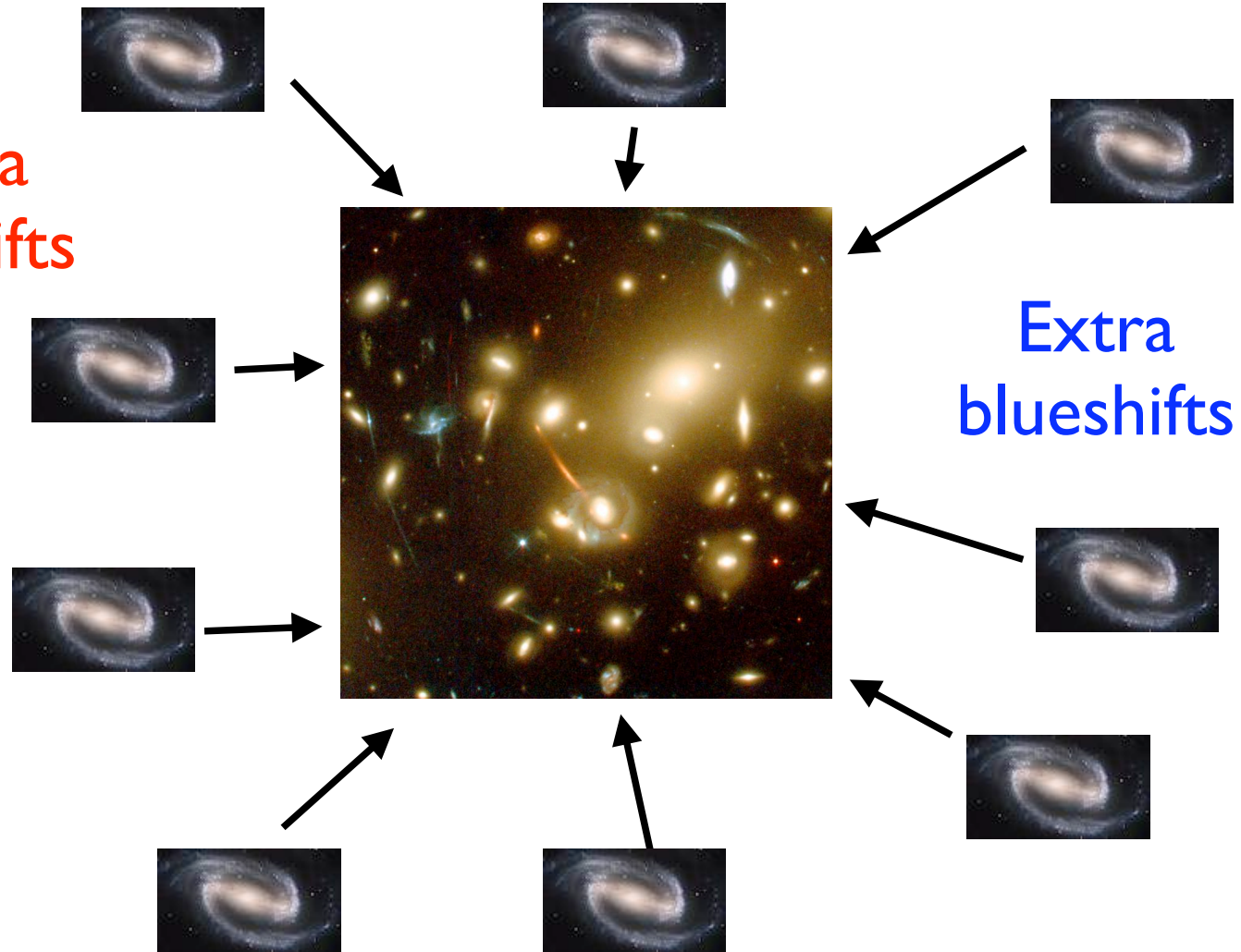
# Galaxy flows



observer

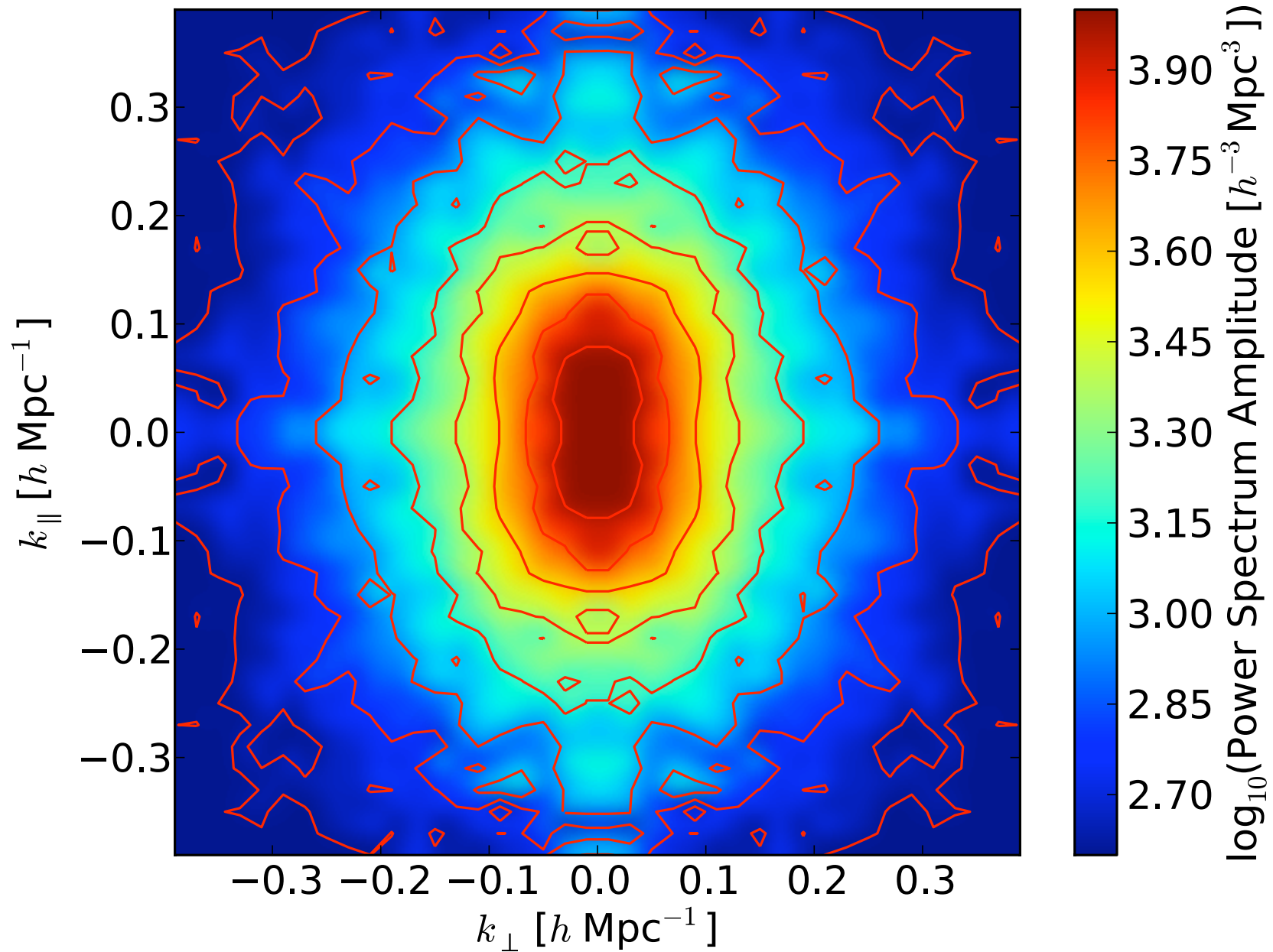
Extra  
redshifts

Extra  
blueshifts

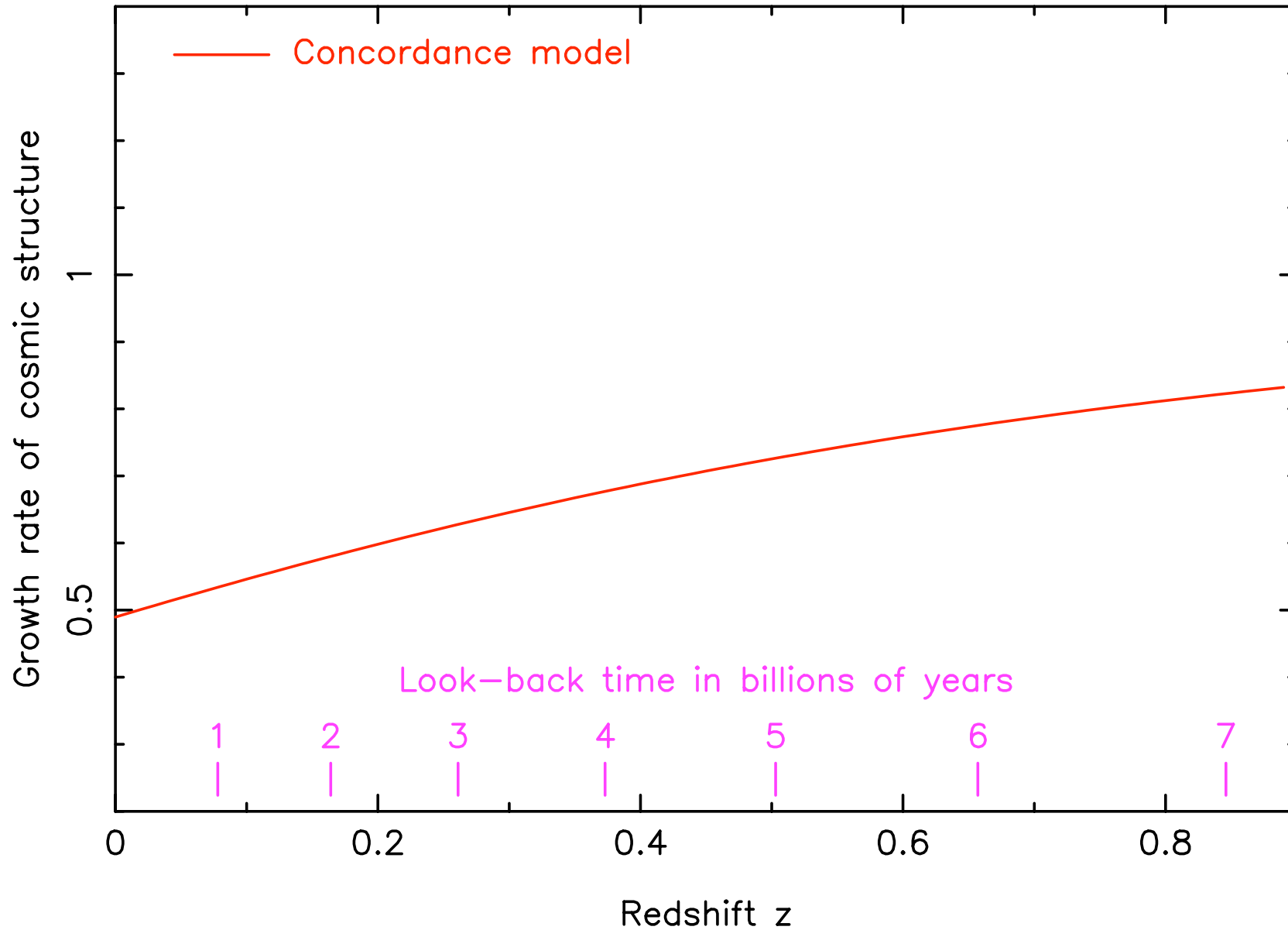




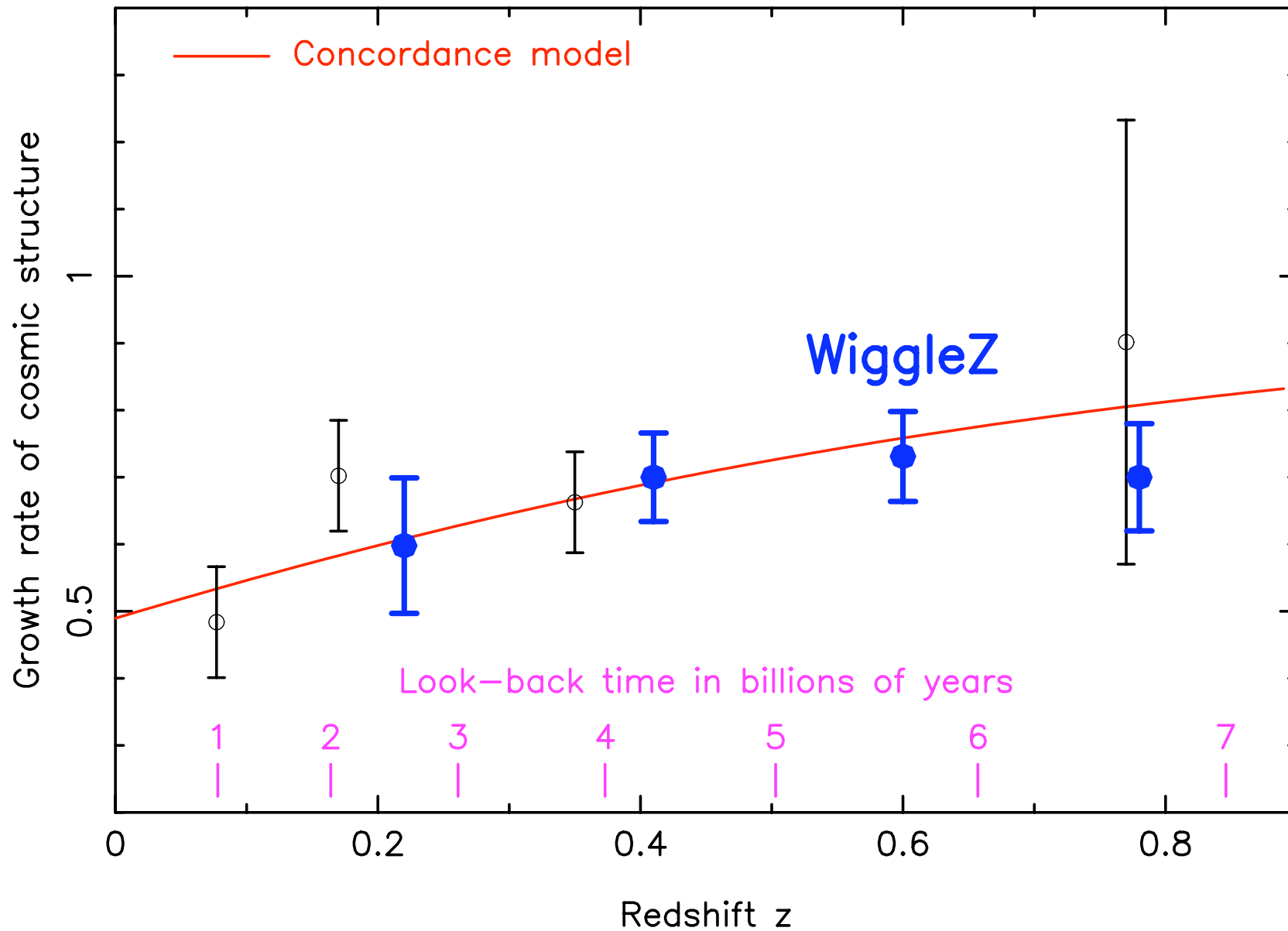
# Galaxy flows in WiggleZ



# Galaxy flows in WiggleZ



# Galaxy flows in WiggleZ



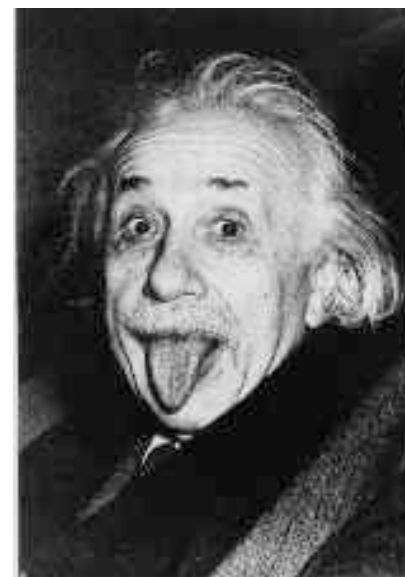
# Summary of results from WiggleZ

- **Large galaxy surveys** offer a powerful means to test the cosmological model
- **Baryon acoustic oscillations** measure cosmic distances to  $z=0.8$  and provide cross-check with supernovae
- **Galaxy flows** provide accurate measurement of growth of structure to high redshift
- **General Relativity + cosmological constant** models have been tested in a new way and remain a good fit
- **If dark energy behaves as Lambda, what is its physics?**

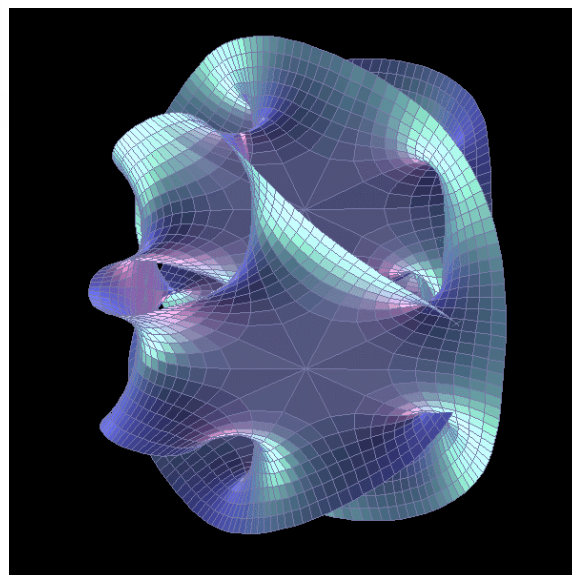


# In that case , what is dark energy?

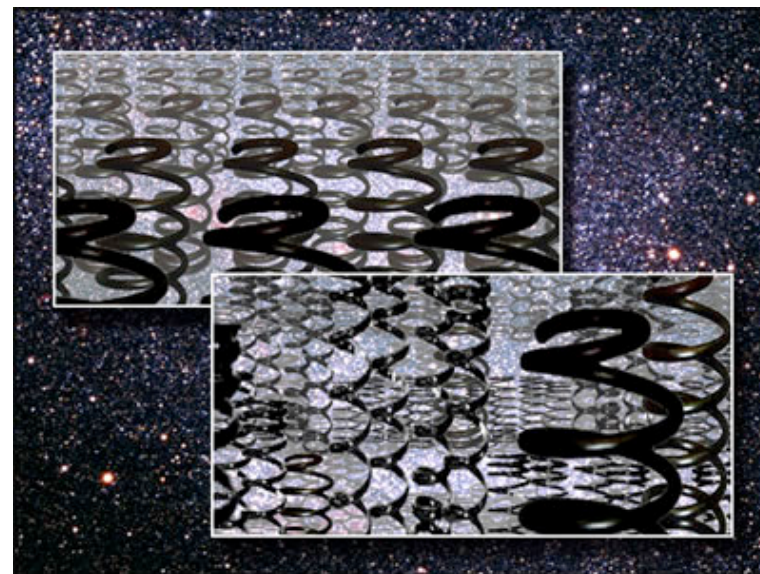
New laws of gravity?



Extra dimensions?



New cosmic materials?





Thank you!

