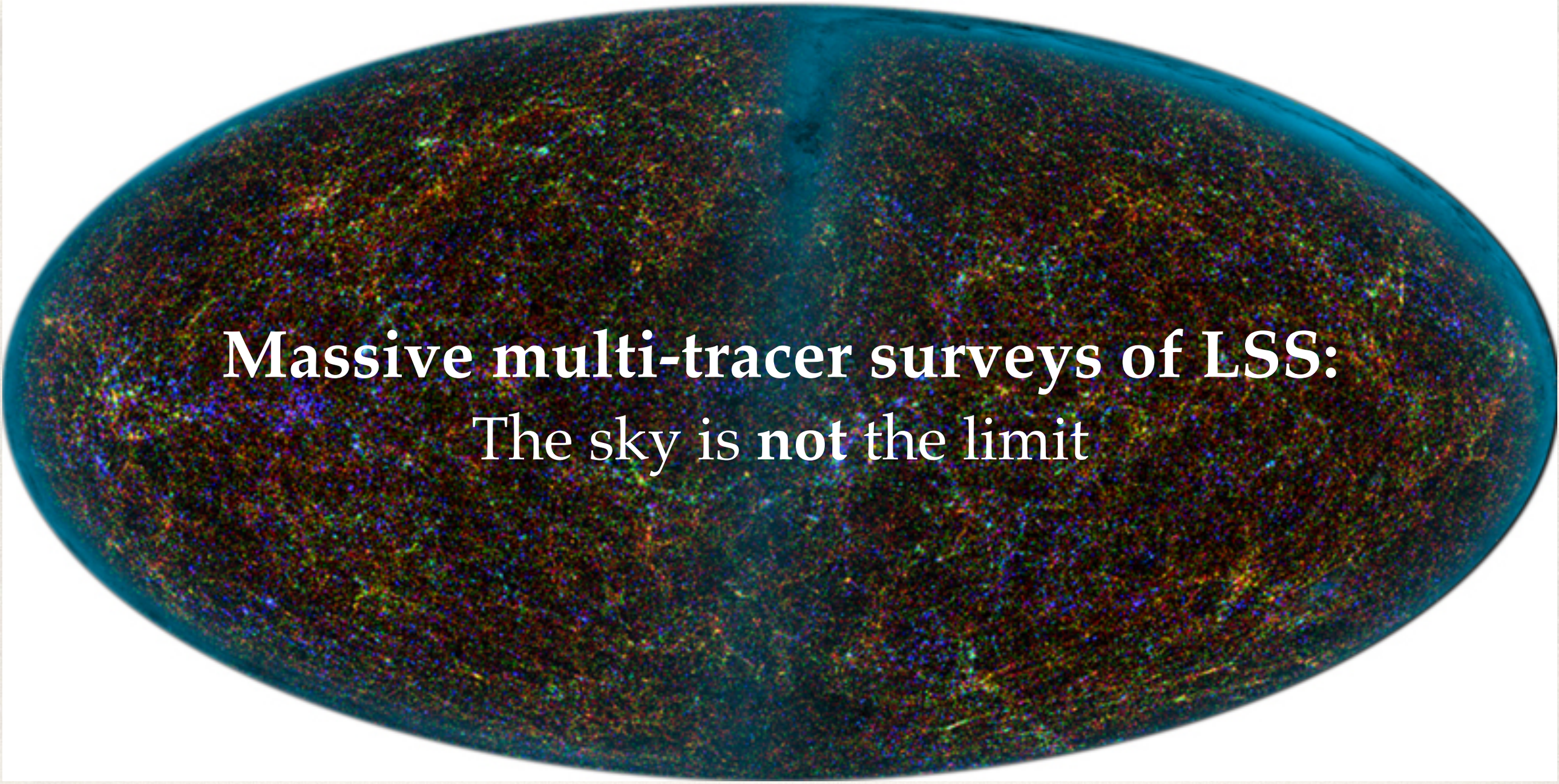


Massive multi-tracer surveys of LSS:

The sky is **not** the limit

L. Raul Abramo

Physics Institute & LabCosmos

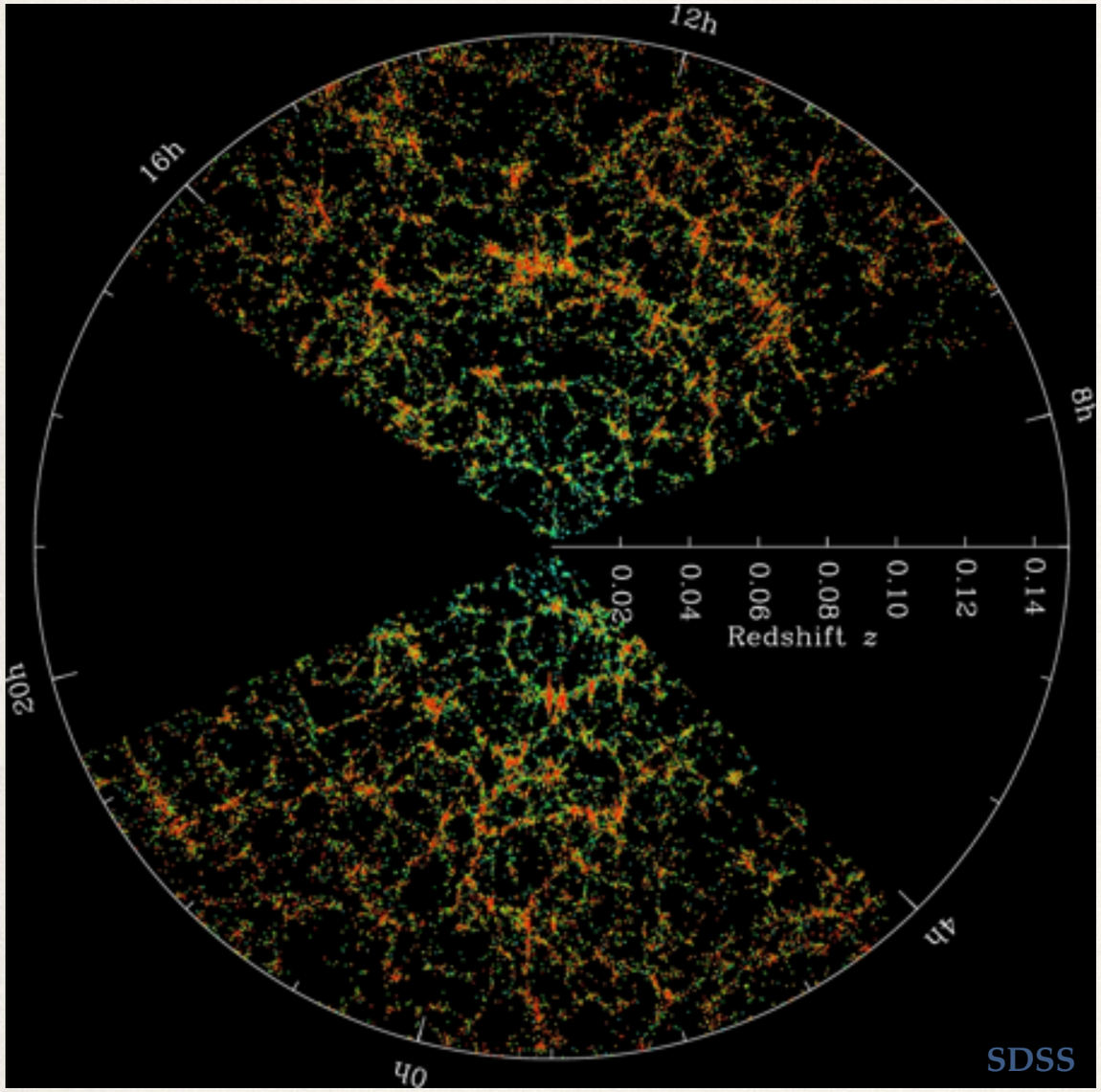
University Of Sao Paulo

LABCOSMOS

http://www.iag.usp.br/labcosmos/en/

Galaxy surveys are evolving

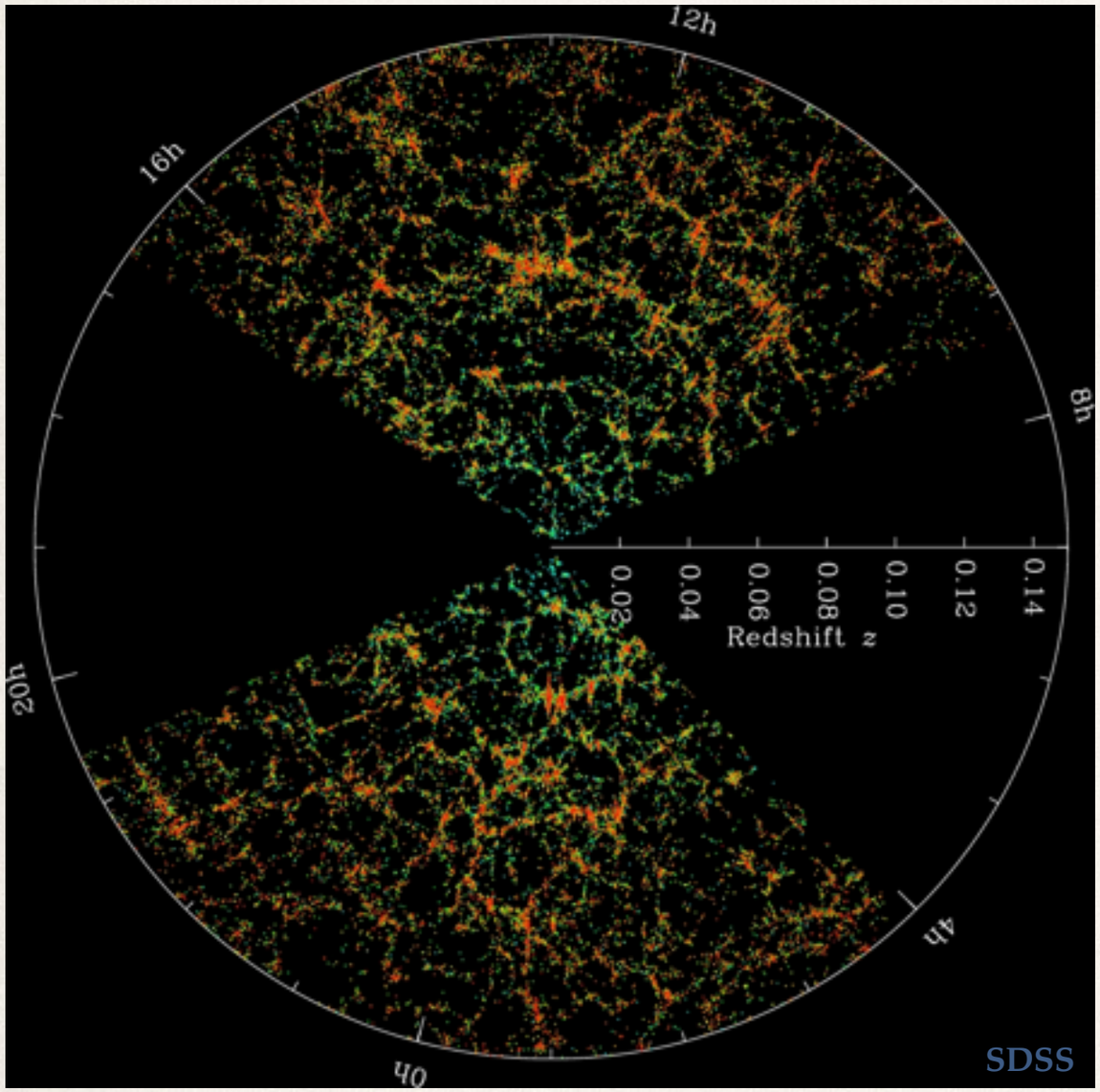
We used to live in an
era of shot ("counts") noise



[**Finding galaxies** was the limiting factor]

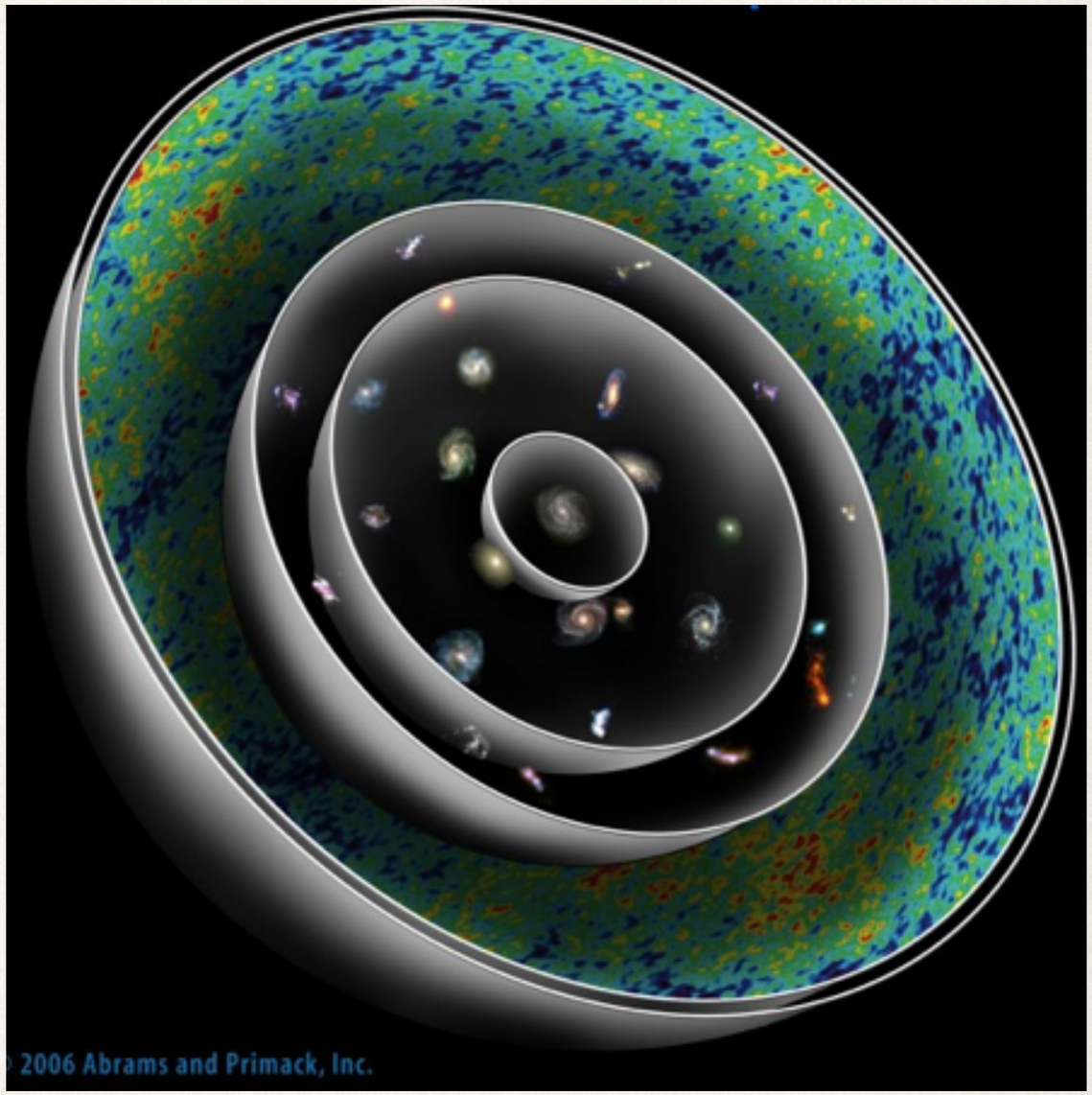
Galaxy surveys are evolving

We used to live in an
era of shot ("counts") noise



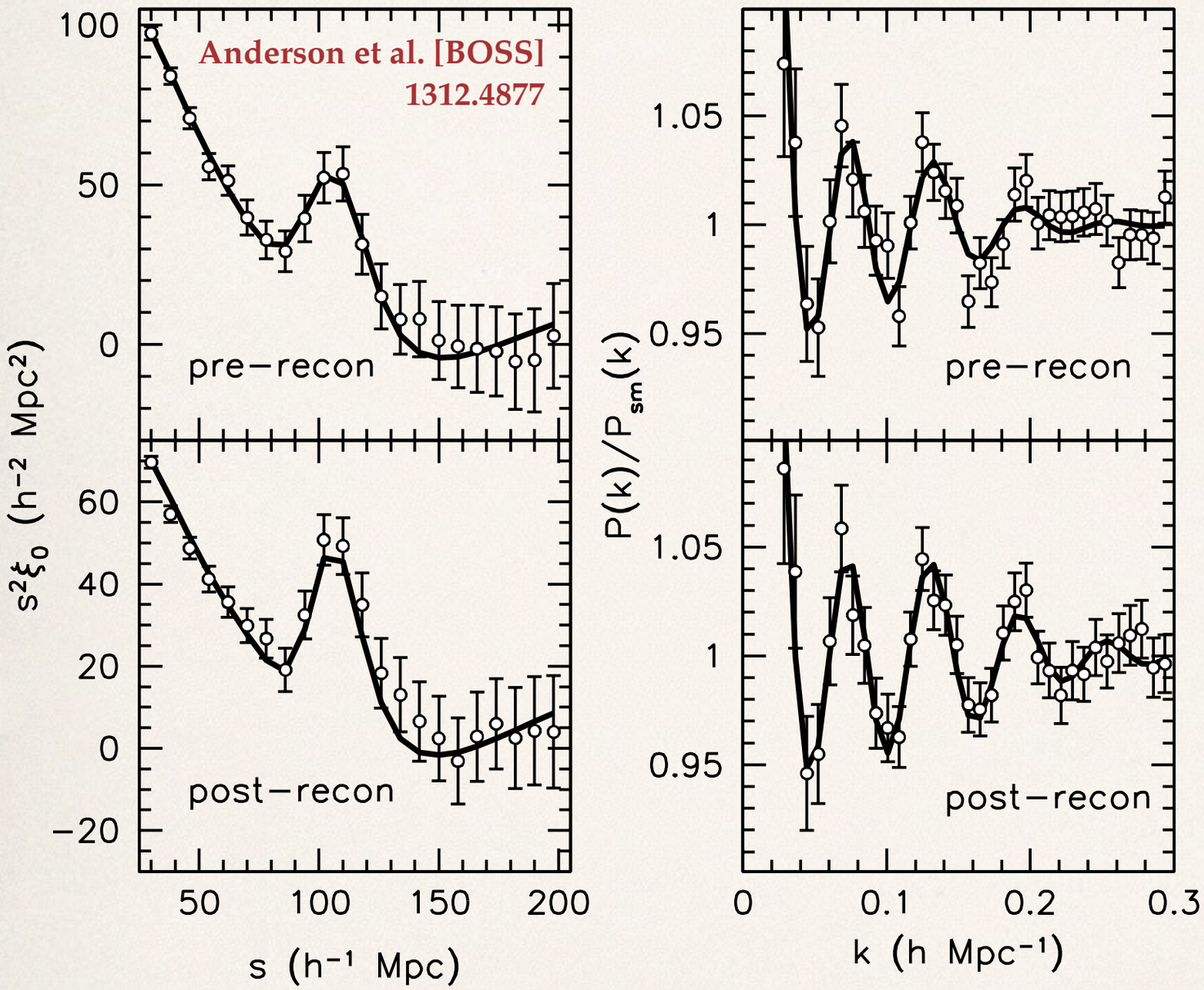
[**Finding galaxies** was the limiting factor]

We are now entering the
age of cosmic variance



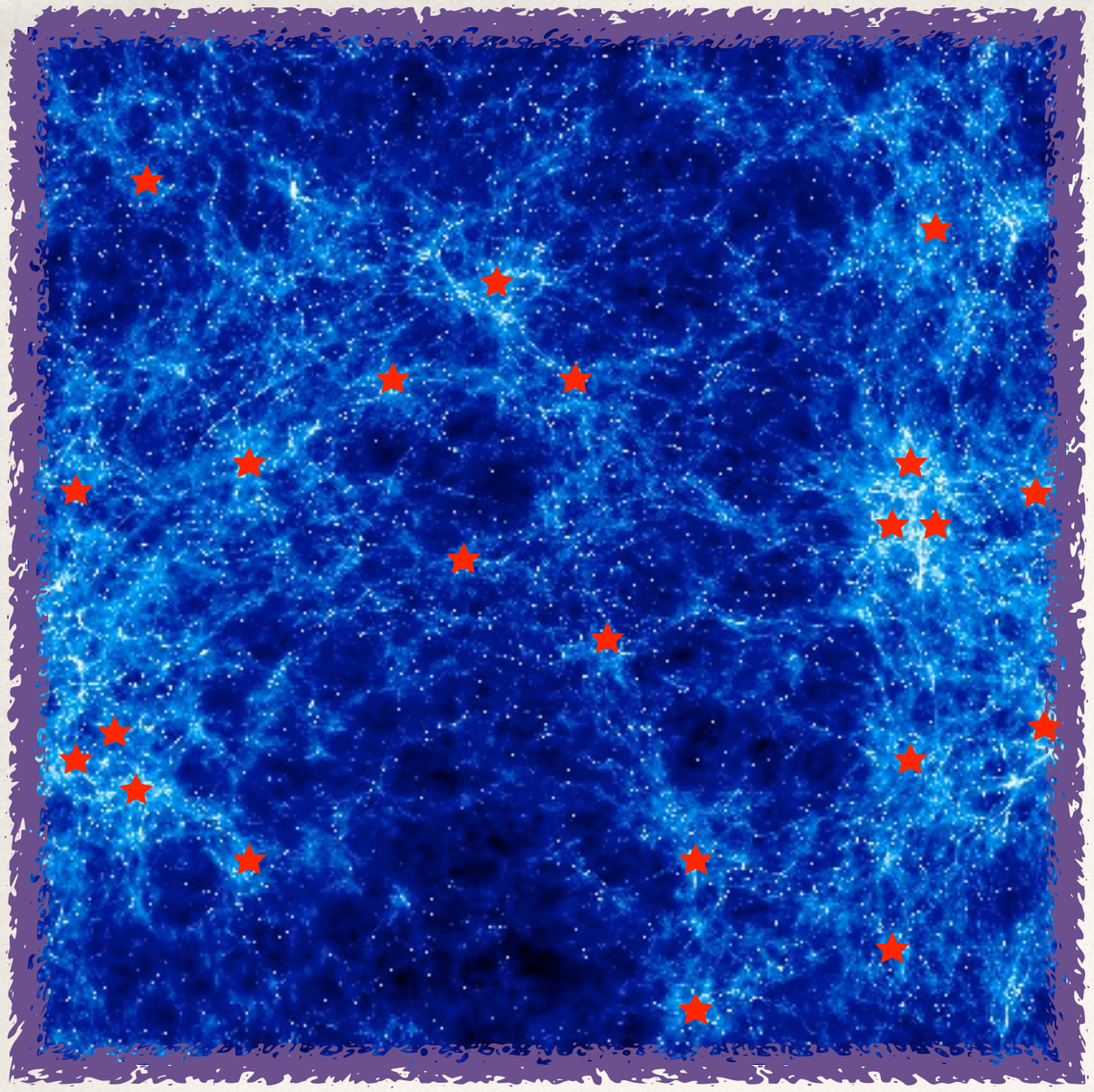
[**Gaining volume** is the limiting factor]

Cosmological surveys are now severely limited by **cosmic variance** (and systematics)



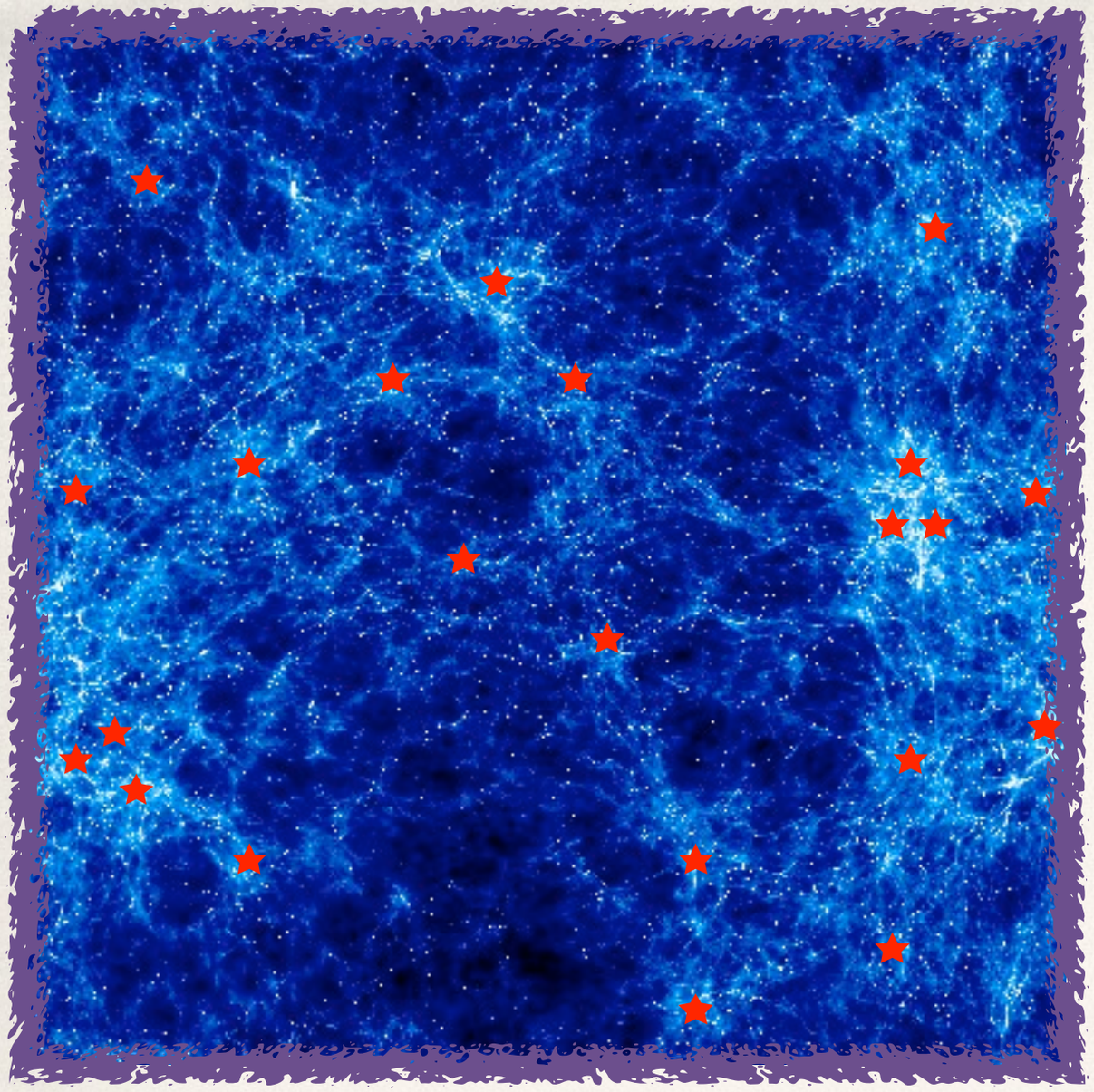
These **error bars** have a large contribution from **cosmic variance**: in order to improve, we must increase the **volume** of our surveys

However, up to any given redshift there is only a finite volume to survey. Moreover, we are reaching closer to the limits of the observable Universe!



Shot noise:
finite number of **counts** of the tracers of the underlying density field

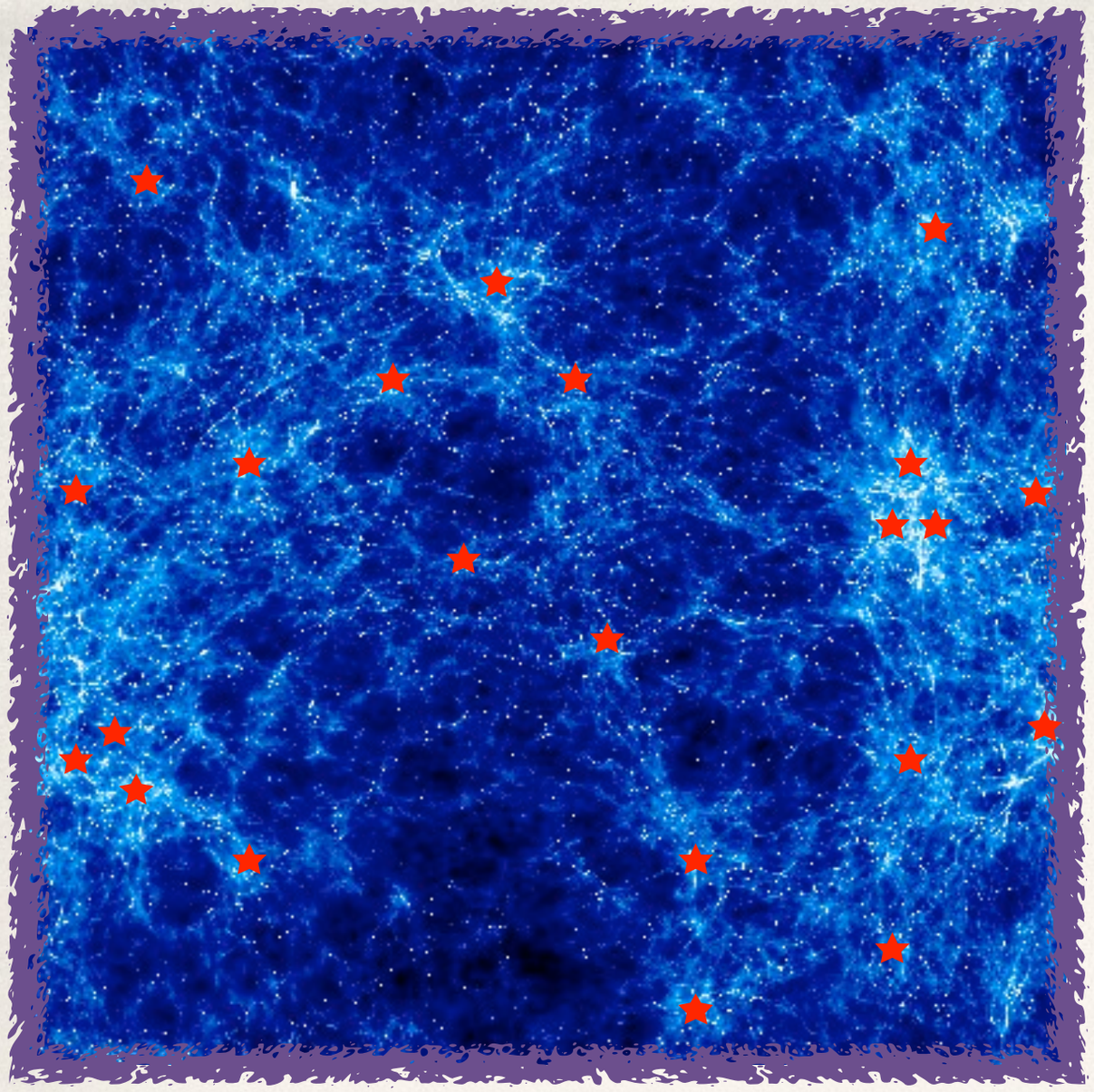
Cosmic variance:
finite **volume** inside which we can estimate the **amplitudes and phases** of the (Gaussian) random **modes** of the density field



Shot noise:
finite number of **counts** of the tracers of the underlying density field

Cosmic variance:
finite **volume** inside which we can estimate the **amplitudes and phases** of the (Gaussian) random **modes** of the density field

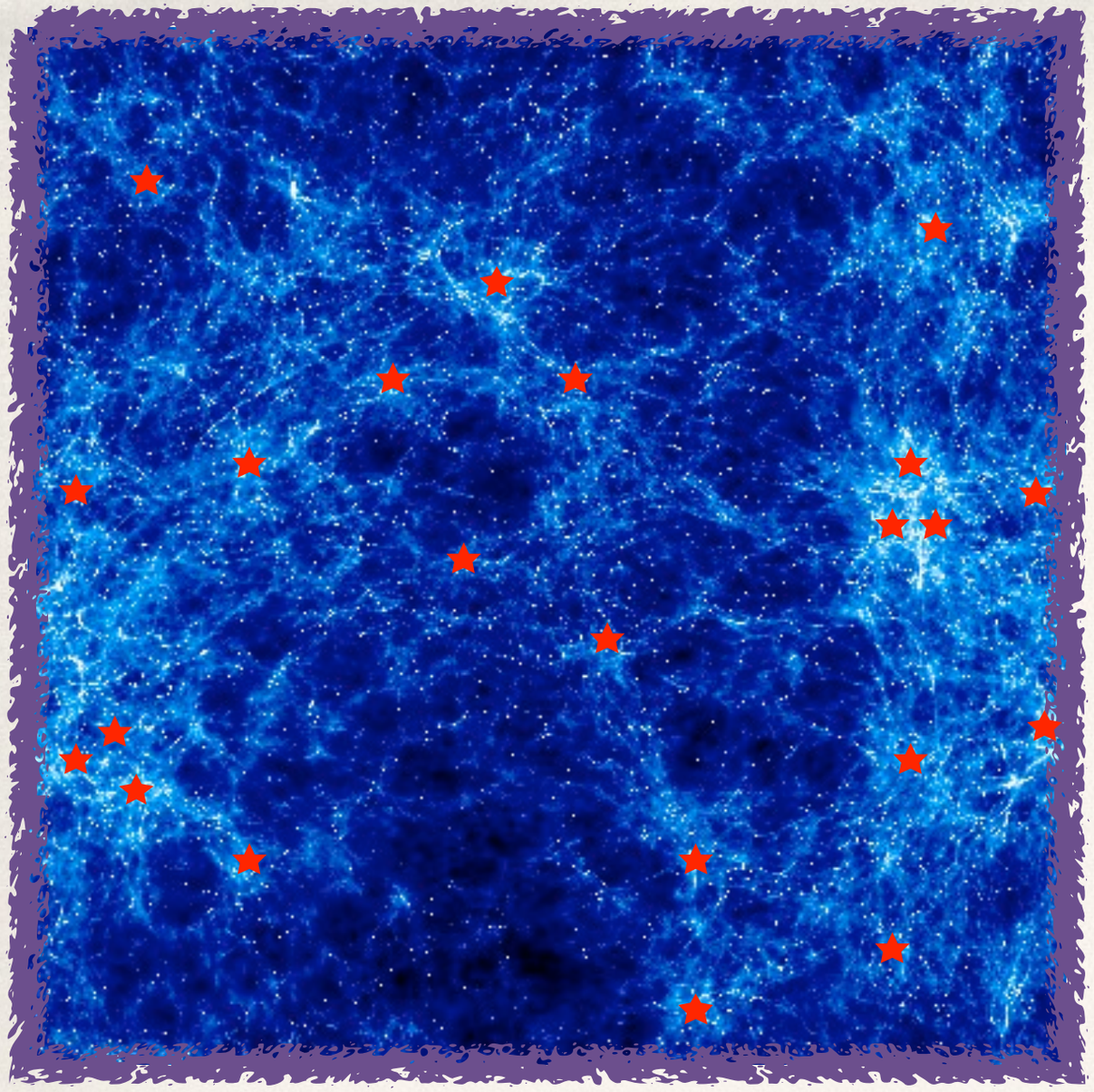
$$\langle \frac{\delta n_g(\vec{x})}{\bar{n}_g} \frac{\delta n_g(\vec{y})}{\bar{n}_g} \rangle_V \simeq b_g^2 \langle \delta_m(\vec{x}) \delta_m(\vec{y}) \rangle_V + \frac{1}{\bar{n}_g} \delta_D(\vec{x} - \vec{y})$$



Shot noise:
finite number of **counts** of the tracers of the underlying density field

Cosmic variance:
finite **volume** inside which we can estimate the **amplitudes and phases** of the (Gaussian) random **modes** of the density field

$$\langle \frac{\delta n_g(\vec{x})}{\bar{n}_g} \frac{\delta n_g(\vec{y})}{\bar{n}_g} \rangle_V \simeq b_g^2 \, \langle \delta_m(\vec{x}) \delta_m(\vec{y}) \rangle_V + \frac{1}{\bar{n}_g} \delta_D(\vec{x} - \vec{y}) \quad \longleftrightarrow \quad P_g(\vec{k}) \simeq b_g^2 \, P_m(\vec{k}) + \frac{1}{\bar{n}_g}$$



Shot noise:
finite number of **counts** of the tracers of the underlying density field

Cosmic variance:
finite **volume** inside which we can estimate the **amplitudes and phases** of the (Gaussian) random **modes** of the density field

$$\langle \frac{\delta n_g(\vec{x})}{\bar{n}_g} \frac{\delta n_g(\vec{y})}{\bar{n}_g} \rangle_V \simeq b_g^2 \, \langle \delta_m(\vec{x}) \delta_m(\vec{y}) \rangle_V + \frac{1}{\bar{n}_g} \delta_D(\vec{x} - \vec{y}) \quad \longleftrightarrow \quad P_g(\vec{k}) \simeq b_g^2 \, P_m(\vec{k}) + \frac{1}{\bar{n}_g}$$

Clustering in units of shot noise

$$\bar{n}_g \, P_g(\vec{k}) \simeq \bar{n}_g \, b_g^2 \, P_m(\vec{k}) + 1$$

Fisher information of galaxy surveys (single type of galaxy)

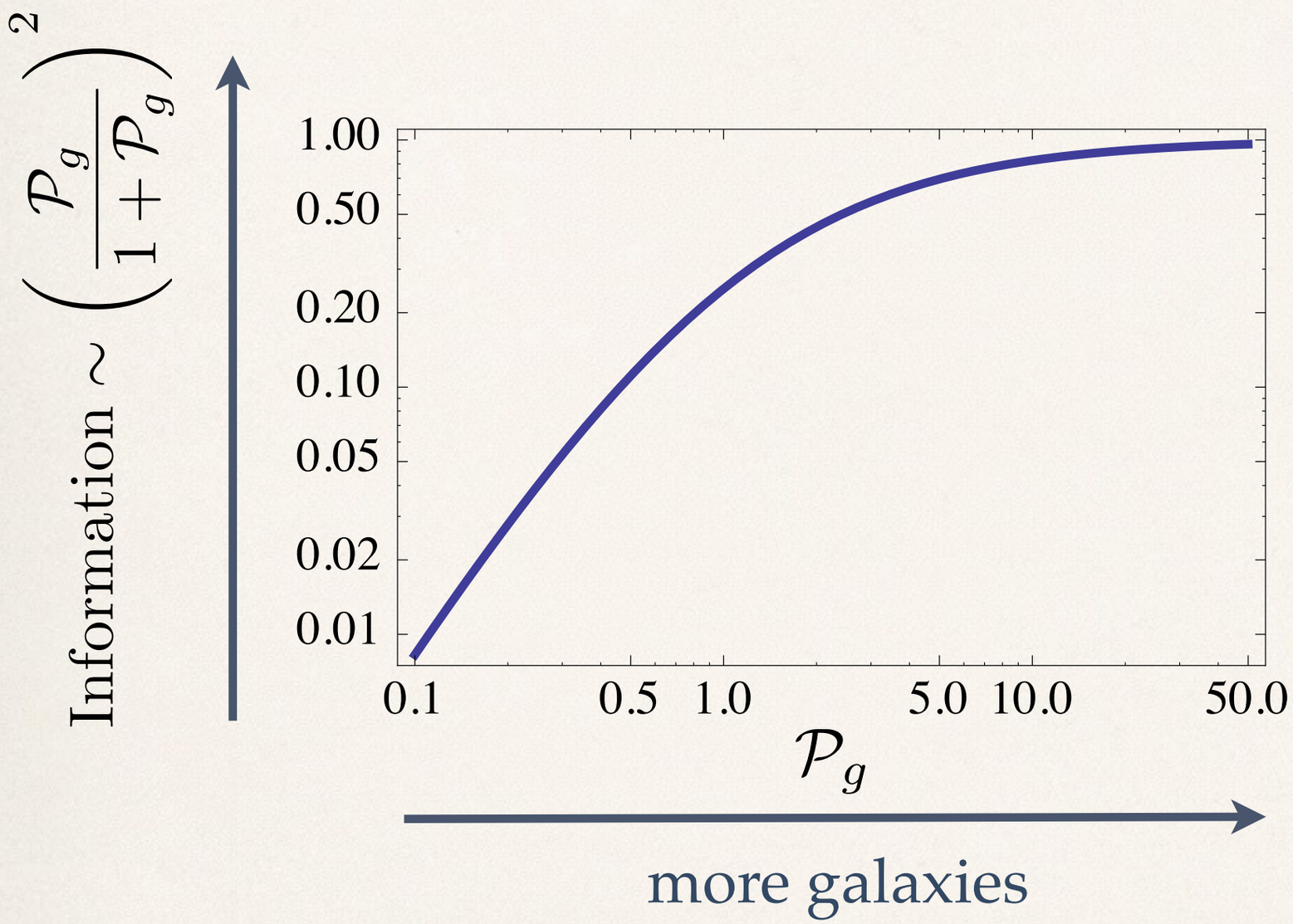
Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x}) \left[b_g(z,k) + f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (single type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

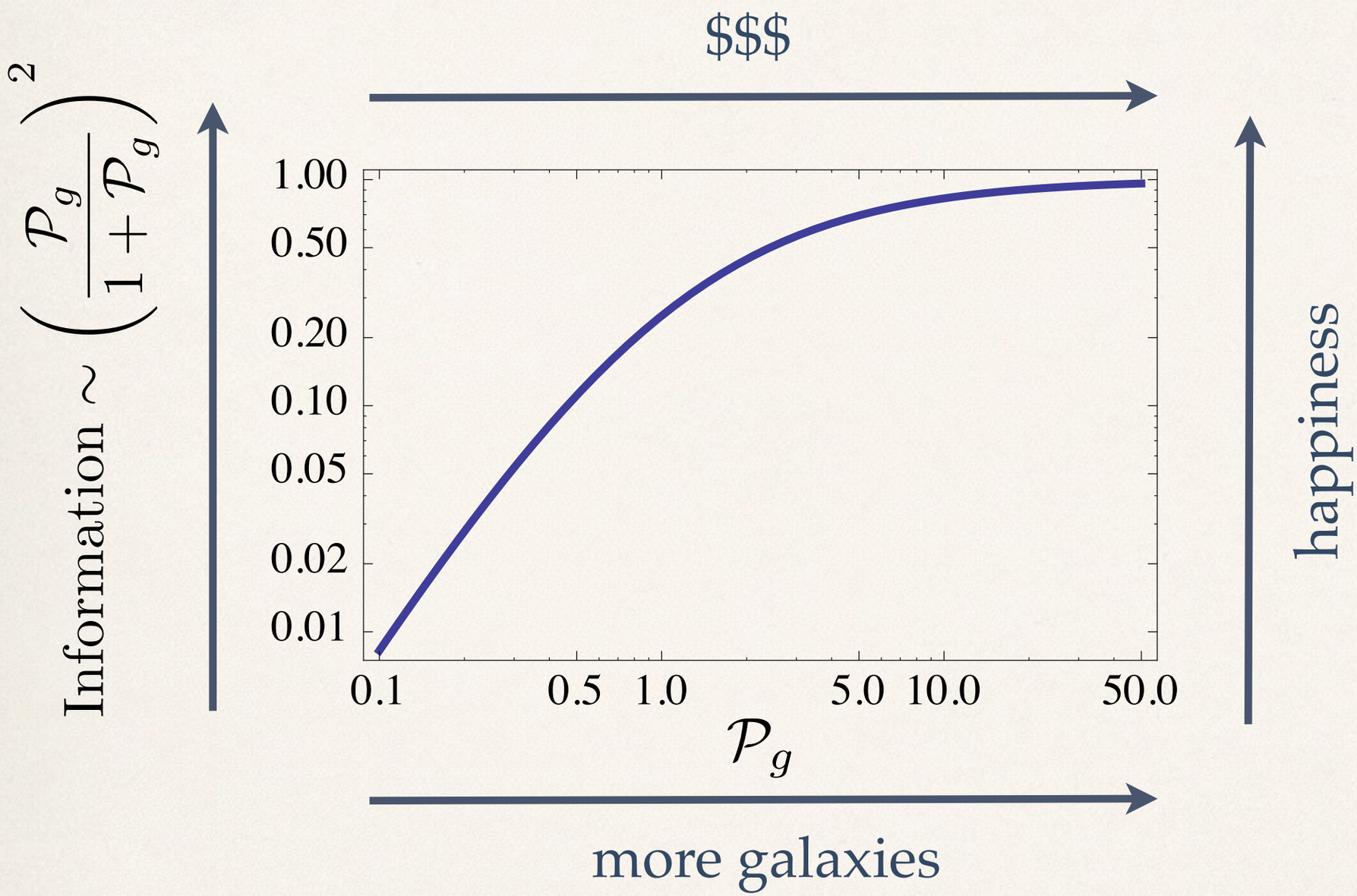


Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x})\,\left[b_g(z,k)+f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (**single** type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

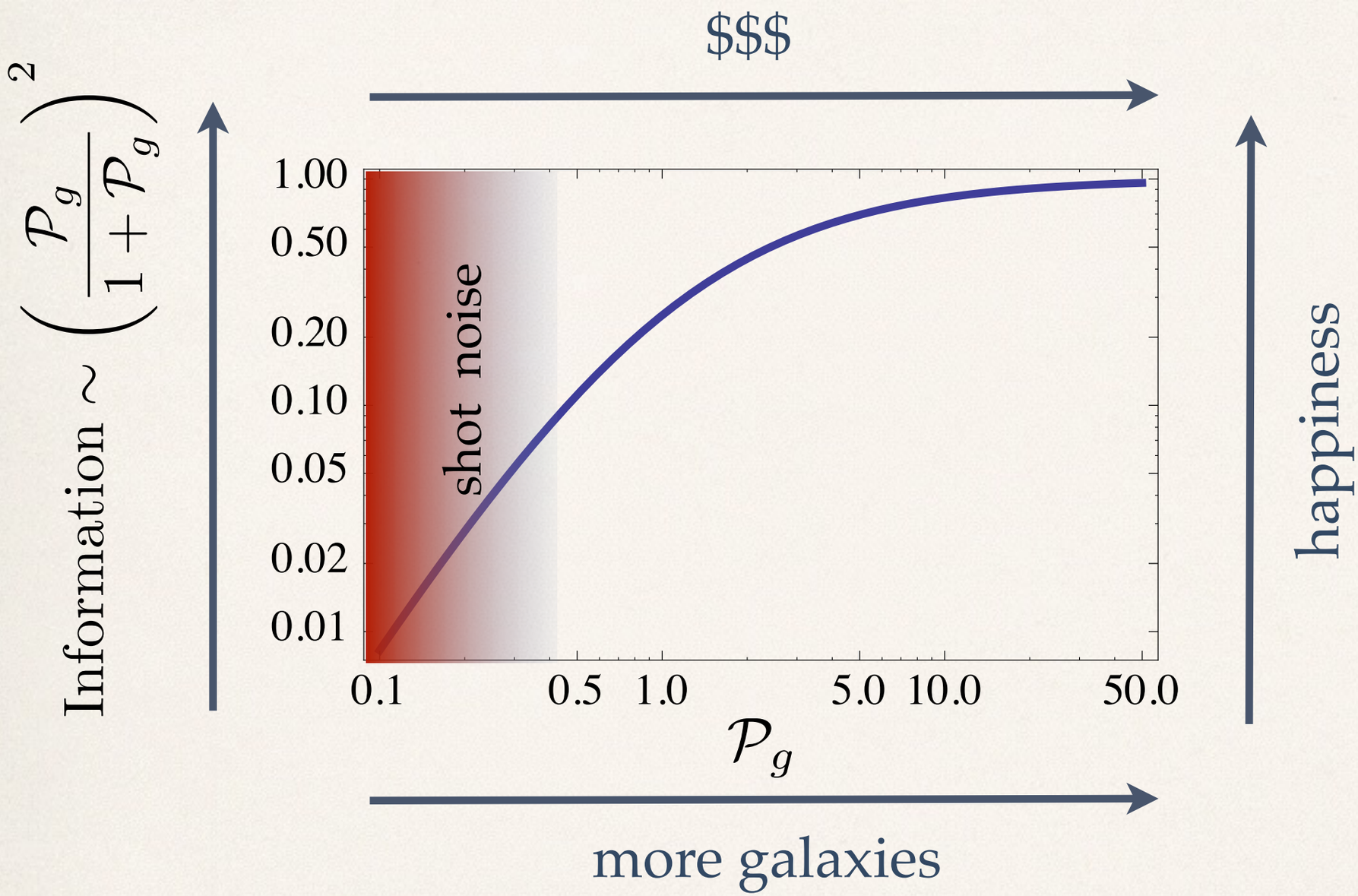


Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x})\,\left[b_g(z,k)+f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (**single** type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

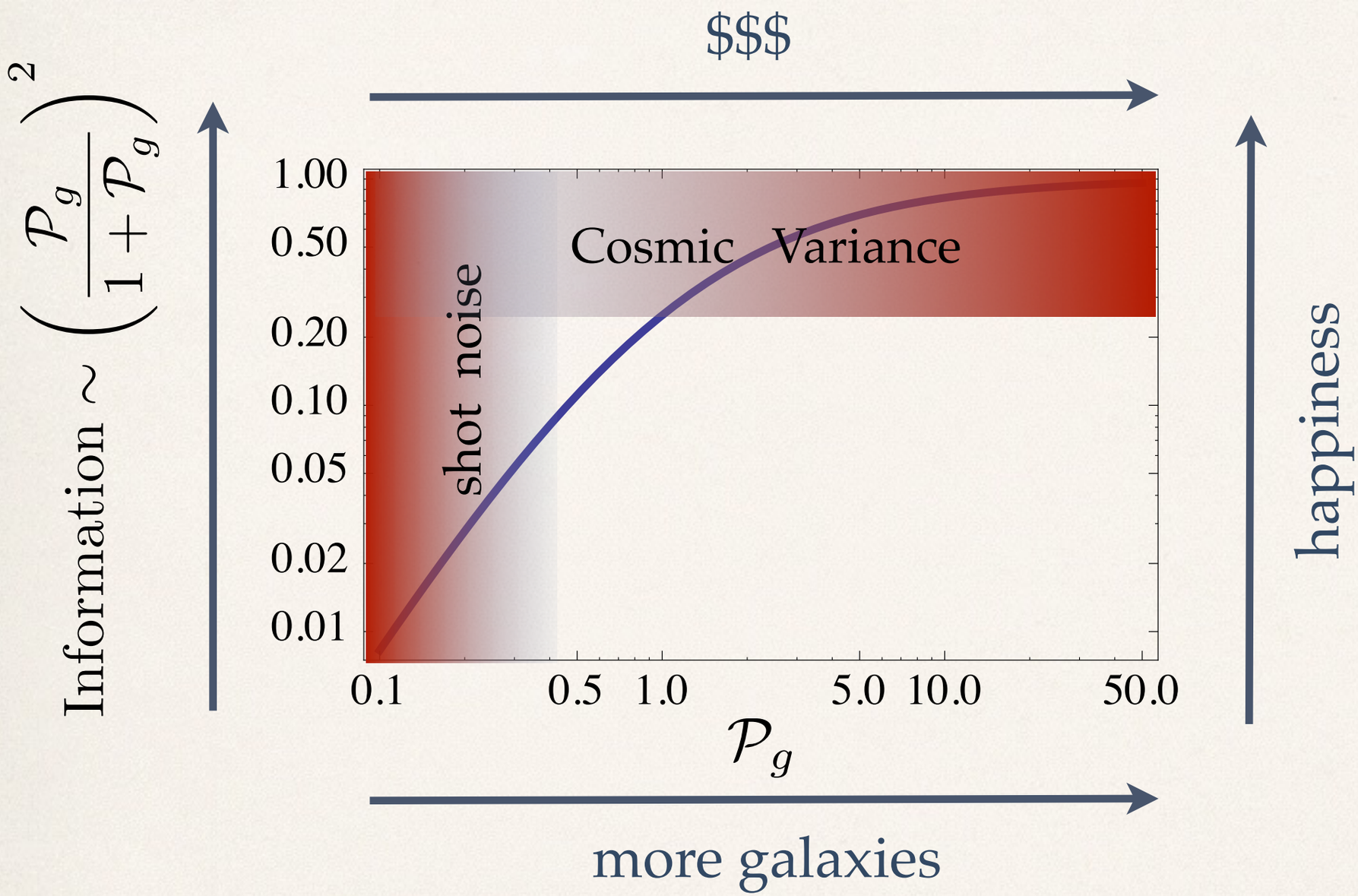


Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x})\,\left[b_g(z,k)+f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (**single** type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

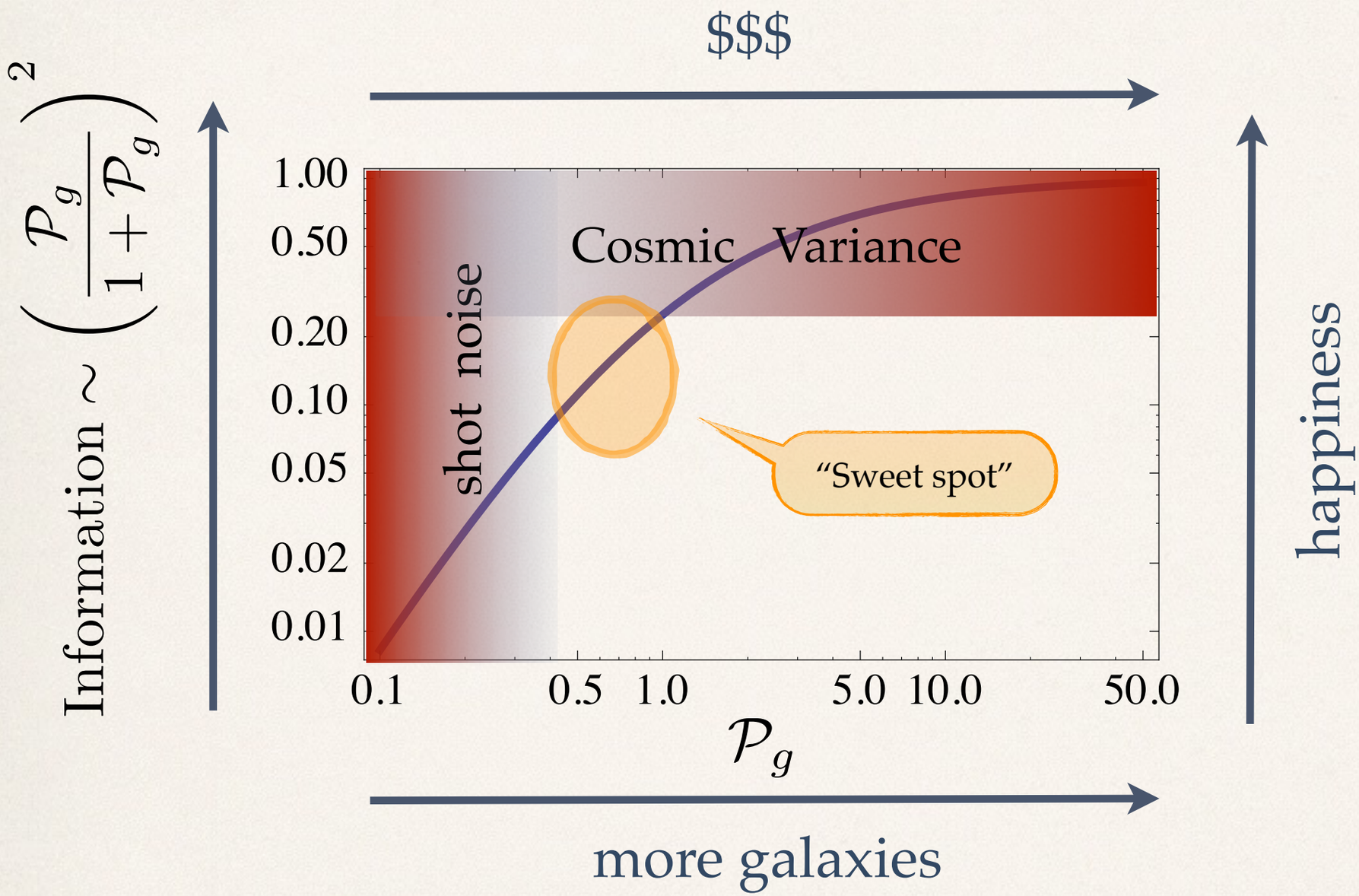


Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x}) \left[b_g(z,k) + f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (**single** type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)

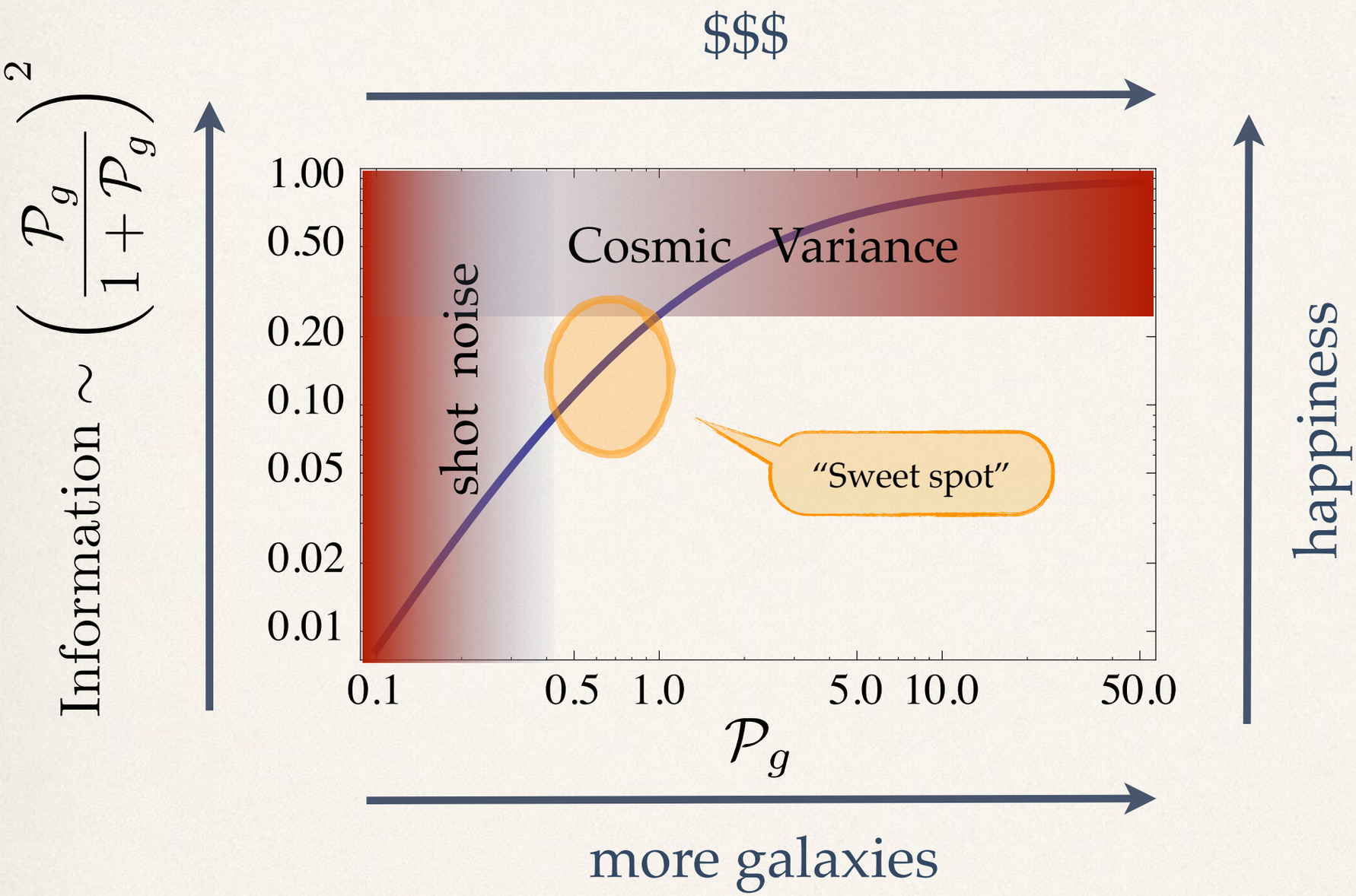


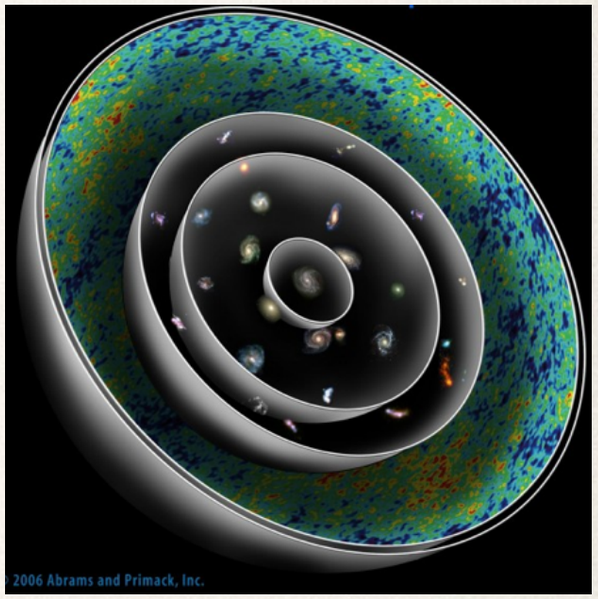
Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x})\,\left[b_g(z,k)+f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

Fisher information of galaxy surveys (**single** type of galaxy)

Feldman, Kaiser & Peacock (1994)
Tegmark et al. (1997)





Are we about to hit a cosmic variance "wall"?

Clustering strength of galaxy type "*g*" in redshift space

$$\mathcal{P}_g(\vec{x},\vec{k}) \equiv \bar{n}_g(\vec{x})\,\left[b_g(z,k)+f(z)\,\mu_k^2\right]^2 G^2(z)\,P_m(k)$$

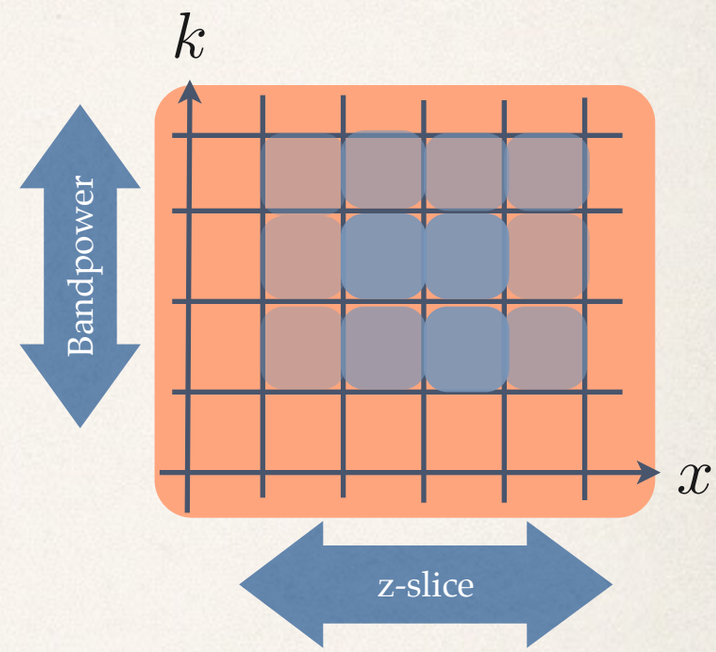
Fisher information in phase space

FKP '94
R.A., MNRAS (2013)

On each **cell of phase space volume** there is a certain **amount of information** about the spectrum (and other quantities), given by:

$$F[\log \mathcal{P}_g] \times \frac{\Delta V_x \, \Delta V_k}{(2\pi)^3} = \frac{1}{2}\left(\frac{\mathcal{P}_g}{1+\mathcal{P}_g}\right)^2 \times \frac{\Delta V_x \, \Delta V_k}{(2\pi)^3}$$

phase space
volume = $\Delta\mathcal{V}$**.**



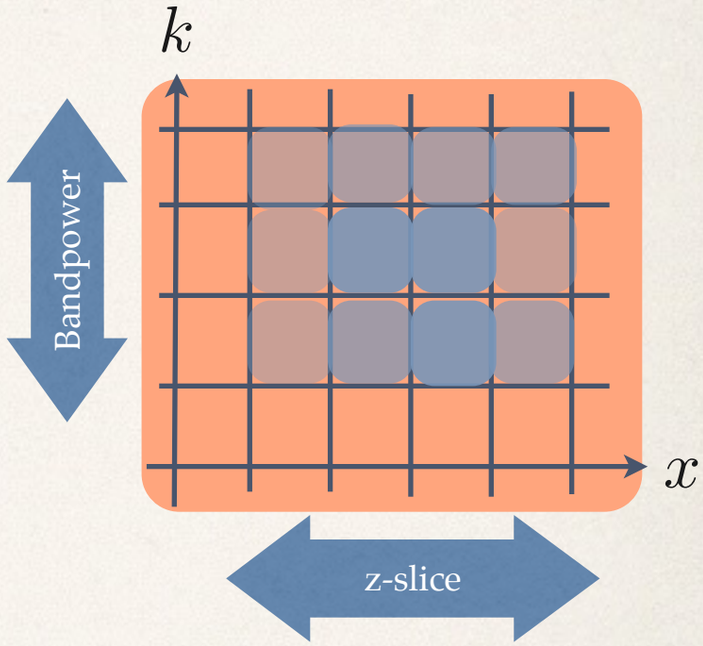
Fisher information in phase space

FKP '94
R.A., MNRAS (2013)

On each **cell of phase space volume** there is a certain **amount of information** about the spectrum (and other quantities), given by:

$$F[\log \mathcal{P}_g] \times \frac{\Delta V_x \, \Delta V_k}{(2\pi)^3} = \frac{1}{2}\left(\frac{\mathcal{P}_g}{1+\mathcal{P}_g}\right)^2 \times \frac{\Delta V_x \, \Delta V_k}{(2\pi)^3}$$

phase space **volume =** $\Delta\mathcal{V}$.



The **precision** (SNR) with which we can **estimate the clustering strength** is:

$$\frac{\mathcal{P}_g^2}{\sigma^2(\mathcal{P}_g)} = F[\log \mathcal{P}_g] \times \Delta\mathcal{V} = \frac{1}{2}\left(\frac{\mathcal{P}_g}{1+\mathcal{P}_g}\right)^2 \Delta\mathcal{V}$$

Limited, < 1/2

Multi-tracer Fisher information matrix

Seljak 2008
McDonald & Seljak 2008
Gil-Marín et al. 2011
Hamaus, Seljak & Desjacques 2011,2012
Cai & Bernstein 2011

Fisher matrix:
R.A. 2013
R.A. & Katie Leonard 2013

Data:
Blake et al. [GAMA] 2013
…

$$F[\log \mathcal{P}_\alpha, \log \mathcal{P}_\beta] = \frac{1}{4}\left[\frac{\mathcal{P}_\alpha \mathcal{P}_\beta (1-\mathcal{P})}{(1+\mathcal{P})^2} + \delta_{\alpha\beta}\frac{\mathcal{P}_\alpha \mathcal{P}}{1+\mathcal{P}}\right]$$

Clustering strengths of **each** galaxy **type**: $\mathcal{P}_\alpha$

Total clustering strength of a survey: $\mathcal{P} \equiv \sum_\alpha \mathcal{P}_\alpha$

Multi-tracer Fisher information matrix

Seljak 2008
McDonald & Seljak 2008
Gil-Marín et al. 2011
Hamaus, Seljak & Desjacques 2011,2012
Cai & Bernstein 2011

Fisher matrix:
R.A. 2013
R.A. & Katie Leonard 2013

Data:
Blake et al. [GAMA] 2013
…

$$F[\log \mathcal{P}_\alpha, \log \mathcal{P}_\beta] = \frac{1}{4}\left[\frac{\mathcal{P}_\alpha \mathcal{P}_\beta (1-\mathcal{P})}{(1+\mathcal{P})^2} + \delta_{\alpha\beta}\frac{\mathcal{P}_\alpha \mathcal{P}}{1+\mathcal{P}}\right]$$

Clustering strengths of **each** galaxy **type**: $\mathcal{P}_\alpha$

Total clustering strength of a survey: $\mathcal{P} \equiv \sum_\alpha \mathcal{P}_\alpha$

$$F = \frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2$$

1 tracer

Multi-tracer Fisher information matrix

Seljak 2008
McDonald & Seljak 2008
Gil-Marín et al. 2011
Hamaus, Seljak & Desjacques 2011,2012
Cai & Bernstein 2011

Fisher matrix:
R.A. 2013
R.A. & Katie Leonard 2013

Data:
Blake et al. [GAMA] 2013
…

$$F[\log \mathcal{P}_\alpha, \log \mathcal{P}_\beta] = \frac{1}{4}\left[\frac{\mathcal{P}_\alpha \mathcal{P}_\beta (1-\mathcal{P})}{(1+\mathcal{P})^2} + \delta_{\alpha\beta}\frac{\mathcal{P}_\alpha \mathcal{P}}{1+\mathcal{P}}\right]$$

Clustering strengths of **each** galaxy **type**: $\mathcal{P}_\alpha$

Total clustering strength of a survey: $\mathcal{P} \equiv \sum_\alpha \mathcal{P}_\alpha$

$$F = \frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2 \Longrightarrow \frac{1}{4}\begin{pmatrix} \frac{\mathcal{P}_1^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_1\mathcal{P}}{1+\mathcal{P}} & \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} \\ \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_2^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_2\mathcal{P}}{1+\mathcal{P}} \end{pmatrix}$$

1 tracer **2 tracers**

Multi-tracer Fisher information matrix

Seljak 2008
McDonald & Seljak 2008
Gil-Marín et al. 2011
Hamaus, Seljak & Desjacques 2011,2012
Cai & Bernstein 2011

Fisher matrix:
R.A. 2013
R.A. & Katie Leonard 2013

Data:
Blake et al. [GAMA] 2013
…

$$F[\log \mathcal{P}_\alpha, \log \mathcal{P}_\beta] = \frac{1}{4}\left[\frac{\mathcal{P}_\alpha \mathcal{P}_\beta (1-\mathcal{P})}{(1+\mathcal{P})^2} + \delta_{\alpha\beta}\frac{\mathcal{P}_\alpha \mathcal{P}}{1+\mathcal{P}}\right]$$

Clustering strengths of **each** galaxy **type**: $\mathcal{P}_\alpha$

Total clustering strength of a survey: $\mathcal{P} \equiv \sum_\alpha \mathcal{P}_\alpha$

$$F = \frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2 \Longrightarrow \frac{1}{4}\begin{pmatrix} \frac{\mathcal{P}_1^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_1\mathcal{P}}{1+\mathcal{P}} & \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} \\ \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_2^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_2\mathcal{P}}{1+\mathcal{P}} \end{pmatrix} \Longrightarrow \frac{1}{4}\begin{pmatrix} \frac{\mathcal{P}_1^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_1\mathcal{P}}{1+\mathcal{P}} & \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_1\mathcal{P}_3(1-\mathcal{P})}{(1+\mathcal{P})^2} \\ \frac{\mathcal{P}_1\mathcal{P}_2(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_2^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_2\mathcal{P}}{1+\mathcal{P}} & \frac{\mathcal{P}_2\mathcal{P}_3(1-\mathcal{P})}{(1+\mathcal{P})^2} \\ \frac{\mathcal{P}_1\mathcal{P}_3(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_2\mathcal{P}_3(1-\mathcal{P})}{(1+\mathcal{P})^2} & \frac{\mathcal{P}_3^2(1-\mathcal{P})}{(1+\mathcal{P})^2} + \frac{\mathcal{P}_3\mathcal{P}}{1+\mathcal{P}} \end{pmatrix}$$

1 tracer **2 tracers** **3 tracers**

So… are we in fact **gaining** any information by **splitting galaxies** into **sub-types**, or are we just "shuffling it around"**?**

Multi-tracer Fisher information matrix

Yes, we **gain** information.

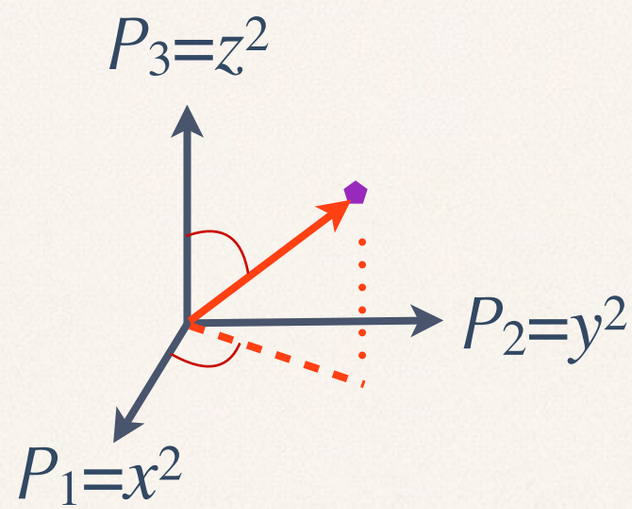
In fact, with **multiple tracers** the Fisher matrix is **unbounded**!

Multi-tracer Fisher information matrix

Yes, we **gain** information.
In fact, with **multiple tracers** the Fisher matrix is **unbounded**!

We can **diagonalize** the multi-tracer Fisher matrix by changing variables:

⇒**Hyper-spherical coordinates!**



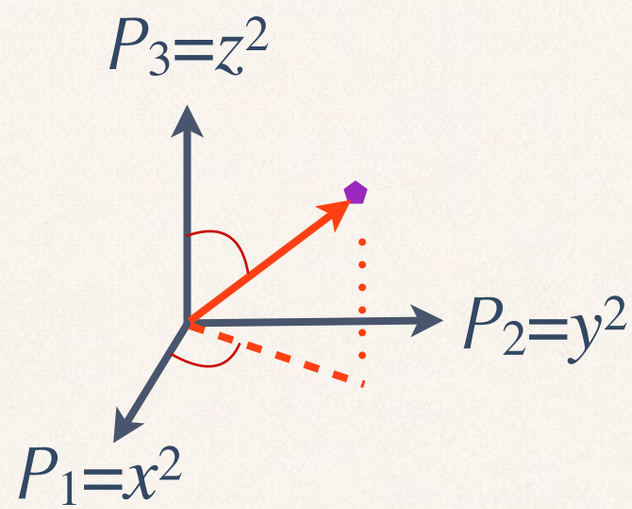
$$\left\{\begin{array}{c}\mathcal{P}_1\\ \mathcal{P}_2\\ \mathcal{P}_3\end{array}\right\}=\left\{\begin{array}{c}x^2\\ y^2\\ z^2\end{array}\right\}\quad\Longleftrightarrow\quad\left\{\begin{array}{c}r^2\\ \tan^2\theta\\ \tan^2\phi\end{array}\right\}=\left\{\begin{array}{c}\mathcal{P}\\ \frac{\mathcal{P}_3}{\mathcal{P}_1+\mathcal{P}_2}\\ \frac{\mathcal{P}_2}{\mathcal{P}_1}\end{array}\right\}$$

Multi-tracer Fisher information matrix

Yes, we **gain** information.
In fact, with **multiple tracers** the Fisher matrix is **unbounded**!

We can **diagonalize** the multi-tracer Fisher matrix by changing variables:

⇒**Hyper-spherical coordinates!**



$$\left\{\begin{array}{c}\mathcal{P}_1\\ \mathcal{P}_2\\ \mathcal{P}_3\end{array}\right\}=\left\{\begin{array}{c}x^2\\ y^2\\ z^2\end{array}\right\} \iff \left\{\begin{array}{c}r^2\\ \tan^2\theta\\ \tan^2\phi\end{array}\right\}=\left\{\begin{array}{c}\mathcal{P}\\ \frac{\mathcal{P}_3}{\mathcal{P}_1+\mathcal{P}_2}\\ \frac{\mathcal{P}_2}{\mathcal{P}_1}\end{array}\right\}$$

Total clustering strength

Relative clustering strengths

Multi-tracer Fisher information matrix

In “spherical" coordinates (i.e., using the total clustering strength and the relative clustering strengths) the **Fisher matrix becomes diagonal**!

E.g.: three species of tracers

$$F_{Sph} = \begin{Bmatrix} \frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2 & 0 & 0 \\ 0 & \frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\cos^2\theta & 0 \\ 0 & 0 & \frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\sin^2\phi\cos^2\phi \end{Bmatrix}$$

Multi-tracer Fisher information matrix

In “spherical" coordinates (i.e., using the total clustering strength and the relative clustering strengths) the **Fisher matrix becomes diagonal**!

E.g.: three species of tracers

Total clustering: < 1/2

$$F_{Sph} = \begin{Bmatrix} \boxed{\frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2} & 0 & 0 \\ 0 & \frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\cos^2\theta & 0 \\ 0 & 0 & \frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\sin^2\phi\cos^2\phi \end{Bmatrix}$$

Multi-tracer Fisher information matrix

In “spherical" coordinates (i.e., using the total clustering strength and the relative clustering strengths) the **Fisher matrix becomes diagonal**!

E.g.: three species of tracers

Total clustering: < 1/2

$$F_{Sph} = \begin{Bmatrix} \boxed{\frac{1}{2}\left(\frac{\mathcal{P}}{1+\mathcal{P}}\right)^2} & 0 & 0 \\ 0 & \boxed{\frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\cos^2\theta} & 0 \\ 0 & 0 & \boxed{\frac{1}{4}\frac{\mathcal{P}^2}{1+\mathcal{P}}\sin^2\theta\sin^2\phi\cos^2\phi} \end{Bmatrix}$$

Relative clusterings: information ~ $\mathcal{P} = \sum_\alpha \bar{n}_\alpha b_\alpha^2 P_m$

☛ **unbounded**

☛ **extra information!**

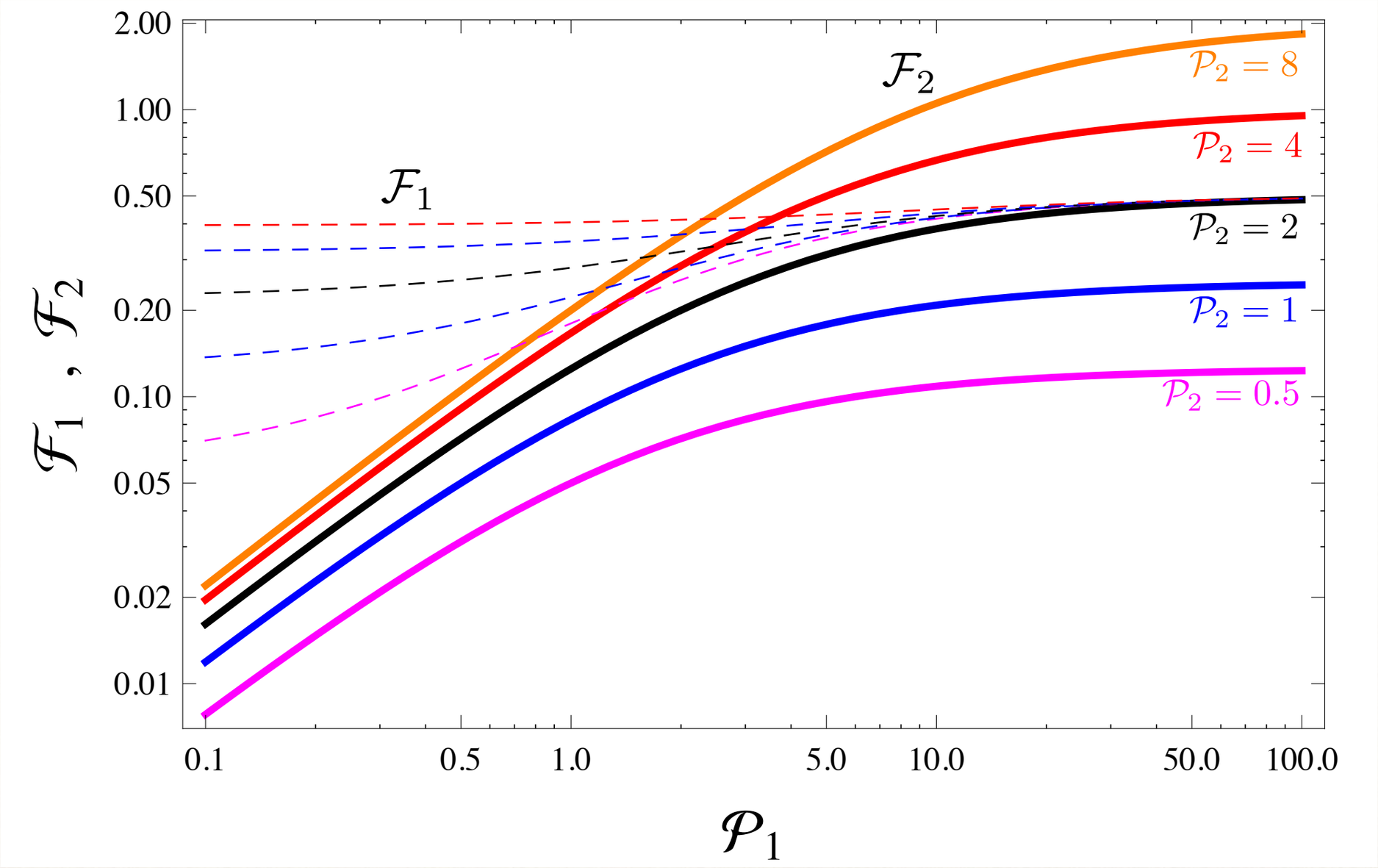
Very simple example:
<u>two</u> types of tracers of large-scale structure

Total clustering

$$\mathcal{F}_1 = \frac{1}{2}\left(\frac{\mathcal{P}_1 + \mathcal{P}_2}{1 + \mathcal{P}_1 + \mathcal{P}_2}\right)^2$$

Relative clustering

$$\mathcal{F}_2 = \frac{1}{4}\frac{\mathcal{P}_1\,\mathcal{P}_2}{1 + \mathcal{P}_1 + \mathcal{P}_2}$$



Seljak 2008
McDonald & Seljak 2008

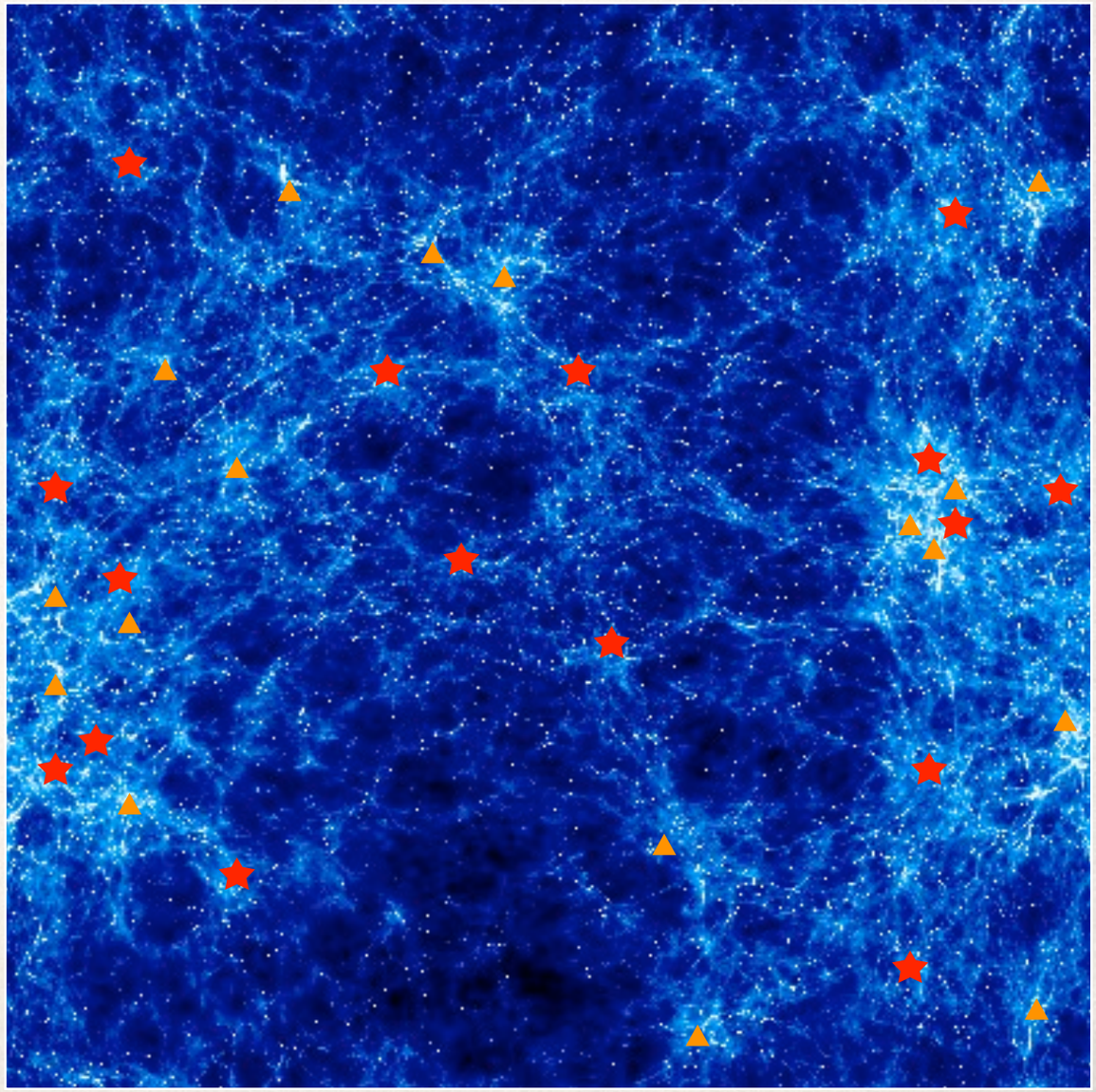
Very simple argument:

cosmic variance is only inherited through the spectrum

By **comparing** the clustering **between different tracers** of large-scale structure (e.g.: LRGs, ELGs, etc.), we can **measure with arbitrary accuracy*** the physical parameters that determine the different **clustering strengths**:

$$\mathcal{P}_1 = n_1\,(b_1 + f\,\mu_k^2)^2\,P(k;z)$$

$$\mathcal{P}_2 = n_2\,(b_2 + f\,\mu_k^2)^2\,P(k;z)$$



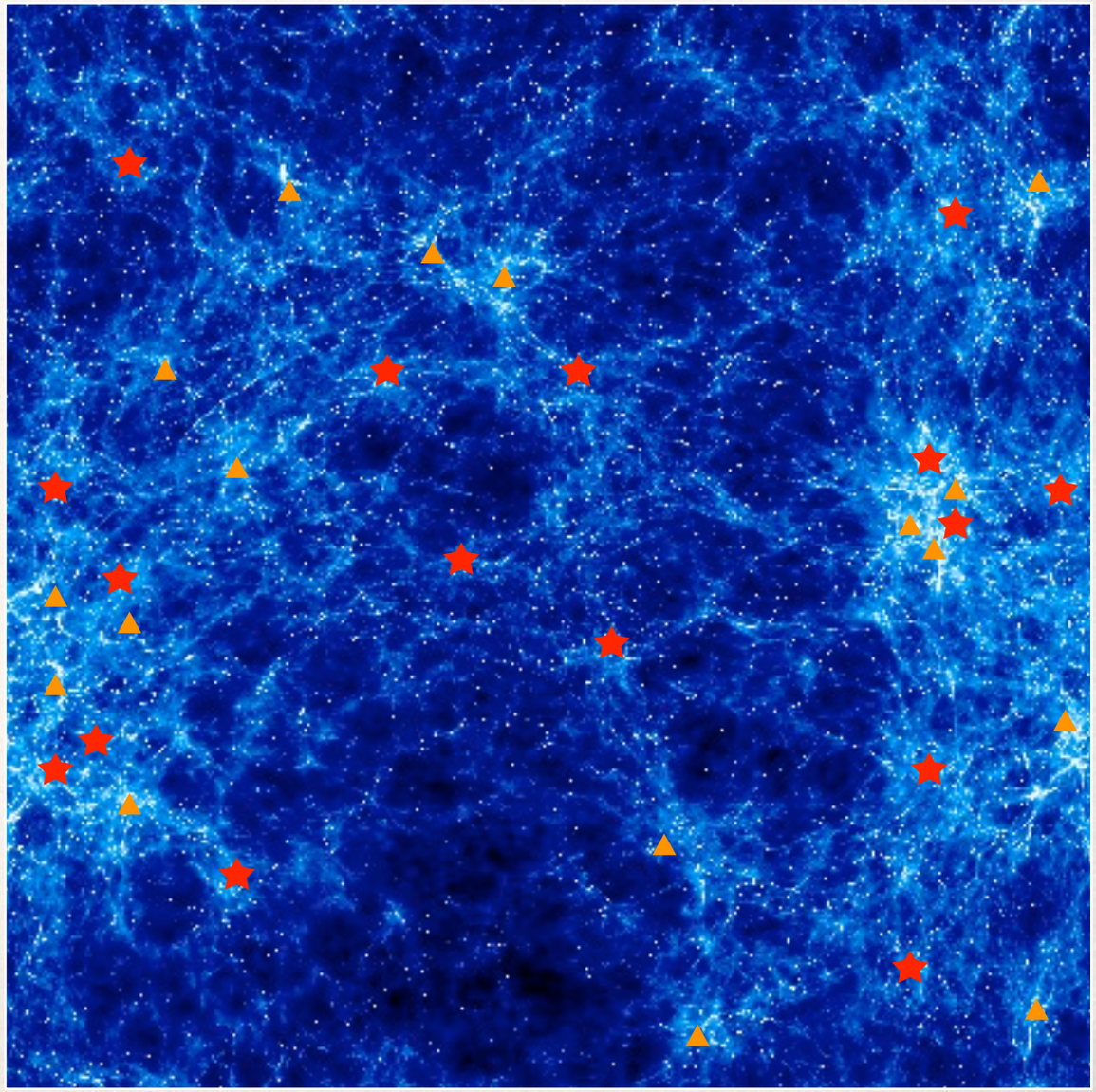
Seljak 2008
McDonald & Seljak 2008

Very simple argument:

cosmic variance is only inherited through the spectrum

By **comparing** the clustering **between different tracers** of large-scale structure (e.g.: LRGs, ELGs, etc.), we can **measure with arbitrary accuracy*** the physical parameters that determine the different **clustering strengths**:

$$\frac{\mathcal{P}_1 = n_1\,(b_1 + f\,\mu_k^2)^2\,P(k;z)}{\mathcal{P}_2 = n_2\,(b_2 + f\,\mu_k^2)^2\,P(k;z)}$$



Seljak 2008
McDonald & Seljak 2008

Very simple argument:

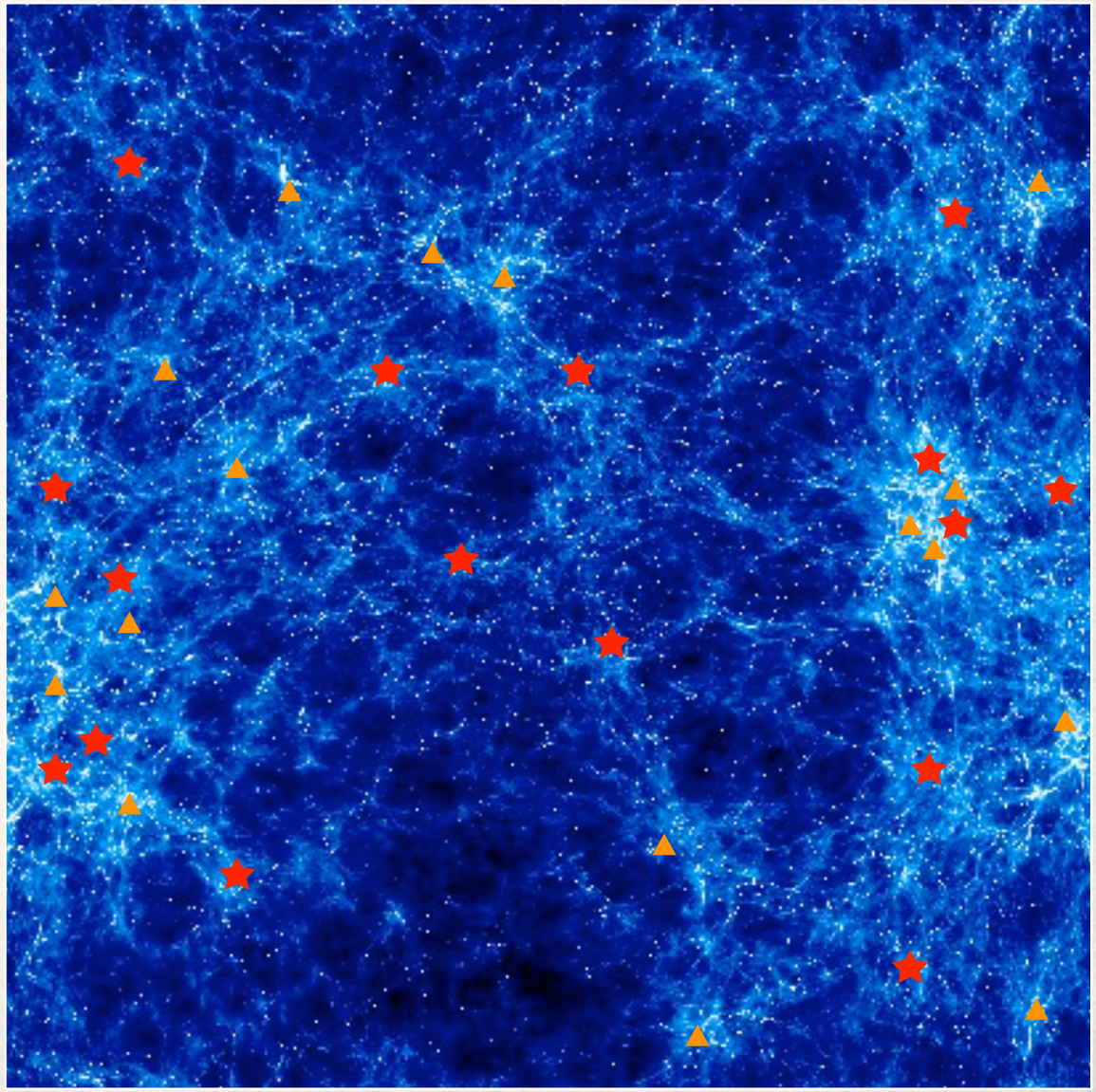
cosmic variance is only inherited through the spectrum

By **comparing** the clustering **between different tracers** of large-scale structure (e.g.: LRGs, ELGs, etc.), we can **measure with arbitrary accuracy*** the physical parameters that determine the different **clustering strengths**:

$$\frac{\mathcal{P}_1 = n_1\,(b_1 + f\,\mu_k^2)^2\,P(k;z)}{\mathcal{P}_2 = n_2\,(b_2 + f\,\mu_k^2)^2\,P(k;z)}$$

$$\frac{\mathcal{P}_1}{\mathcal{P}_2} = \frac{n_1\,(b_1 + f\,\mu_k^2)^2}{n_2\,(b_2 + f\,\mu_k^2)^2}$$

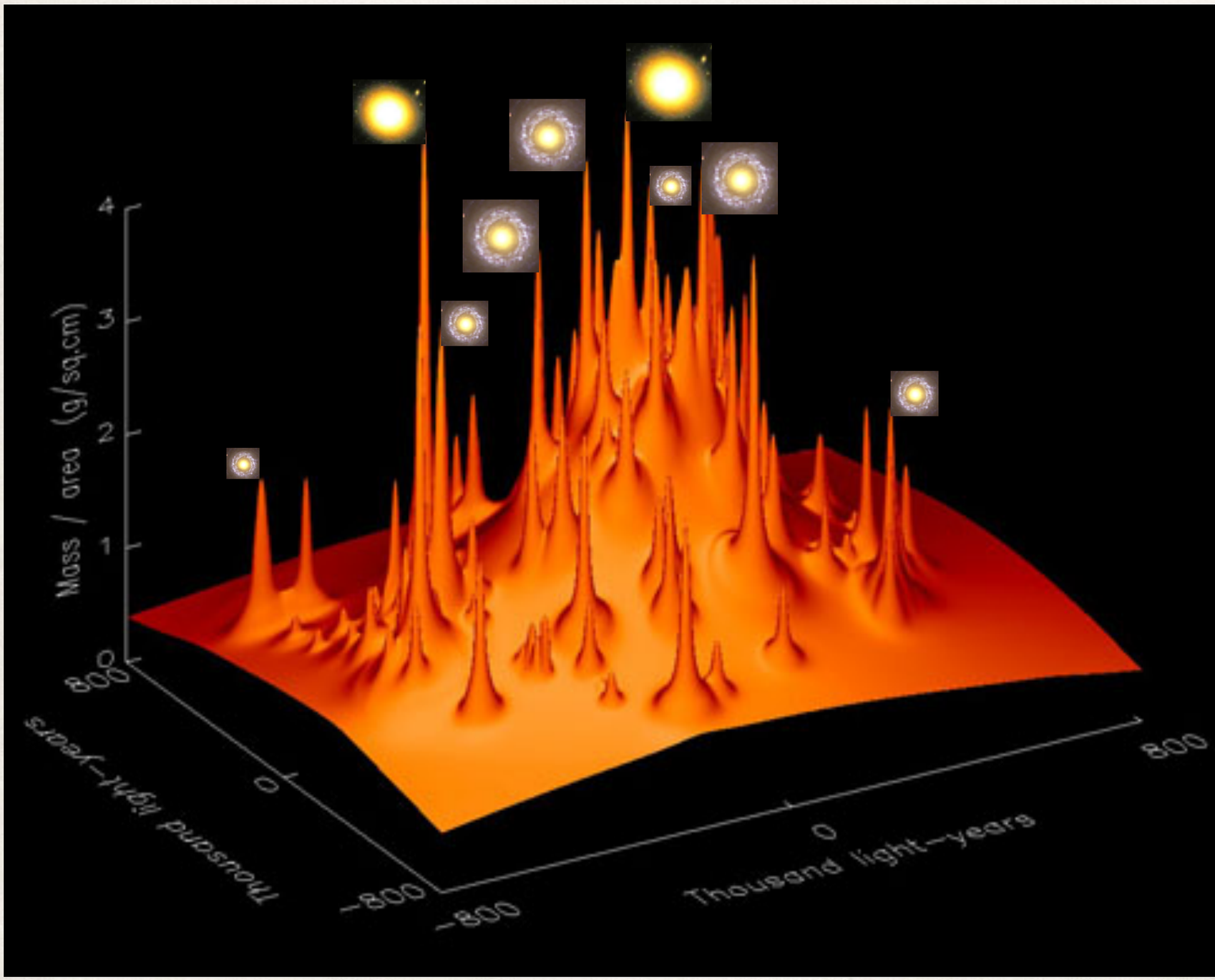
Cosmic variance does **not** apply:
- * **bias** * **RSDs**
- * **PNG**

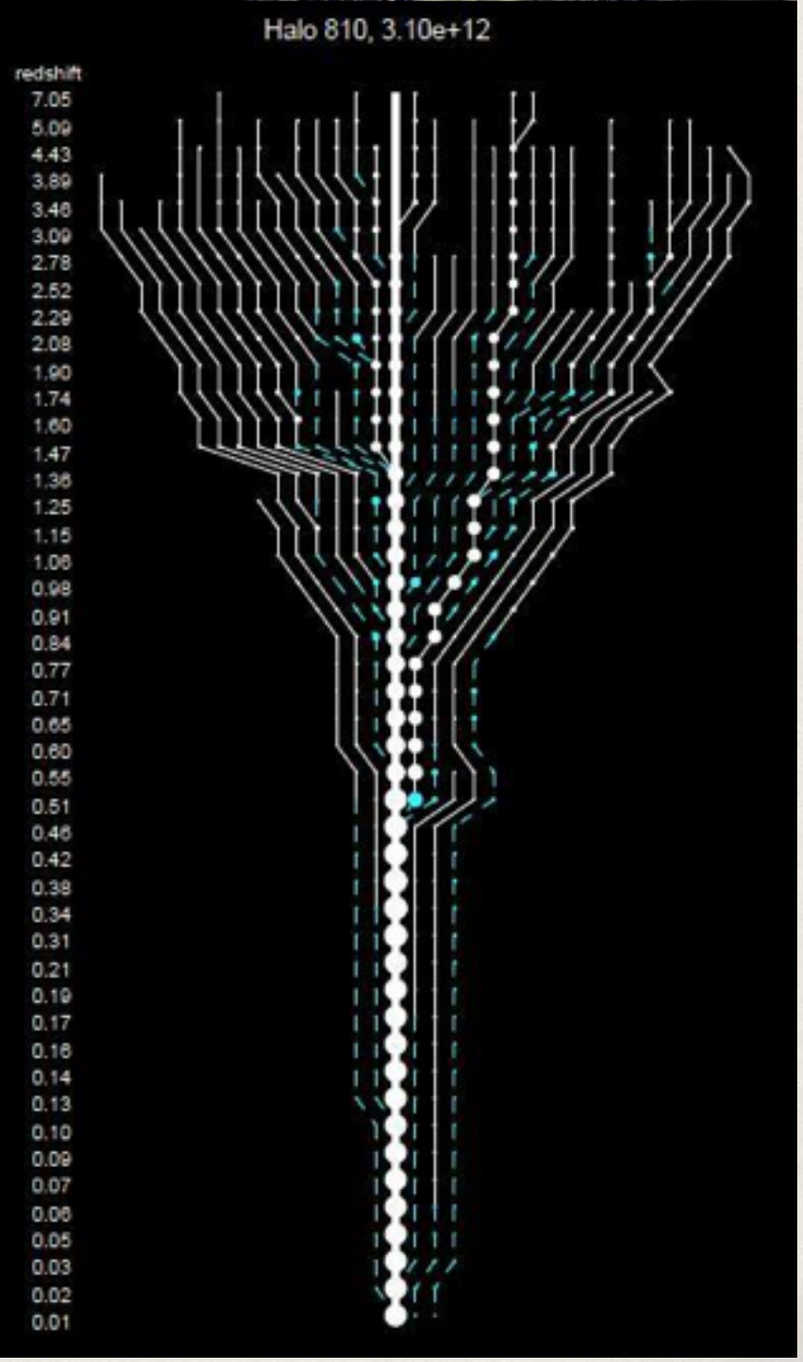


The key: very **high numbers** of distinct types of tracers (red galaxies, blue galaxies, emission-line galaxies, quasars, etc.)

Just give me the goddman z already!

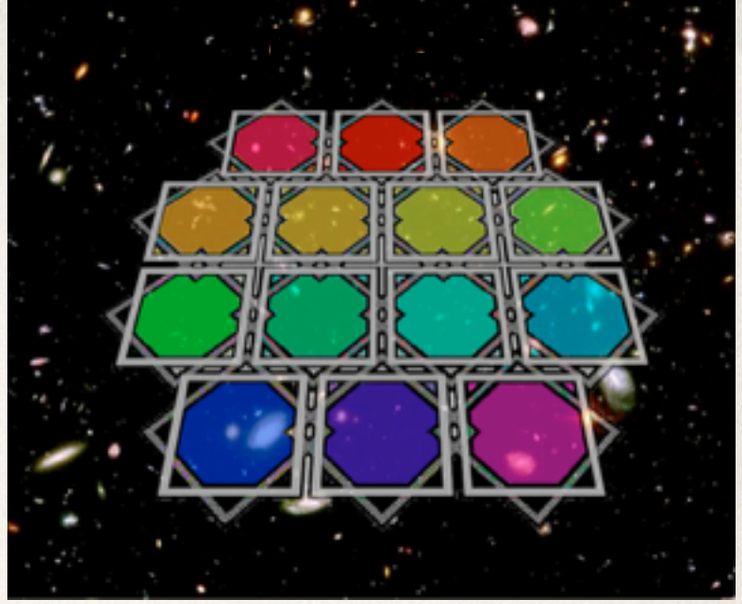
Galaxies are more than just a nice redshift!





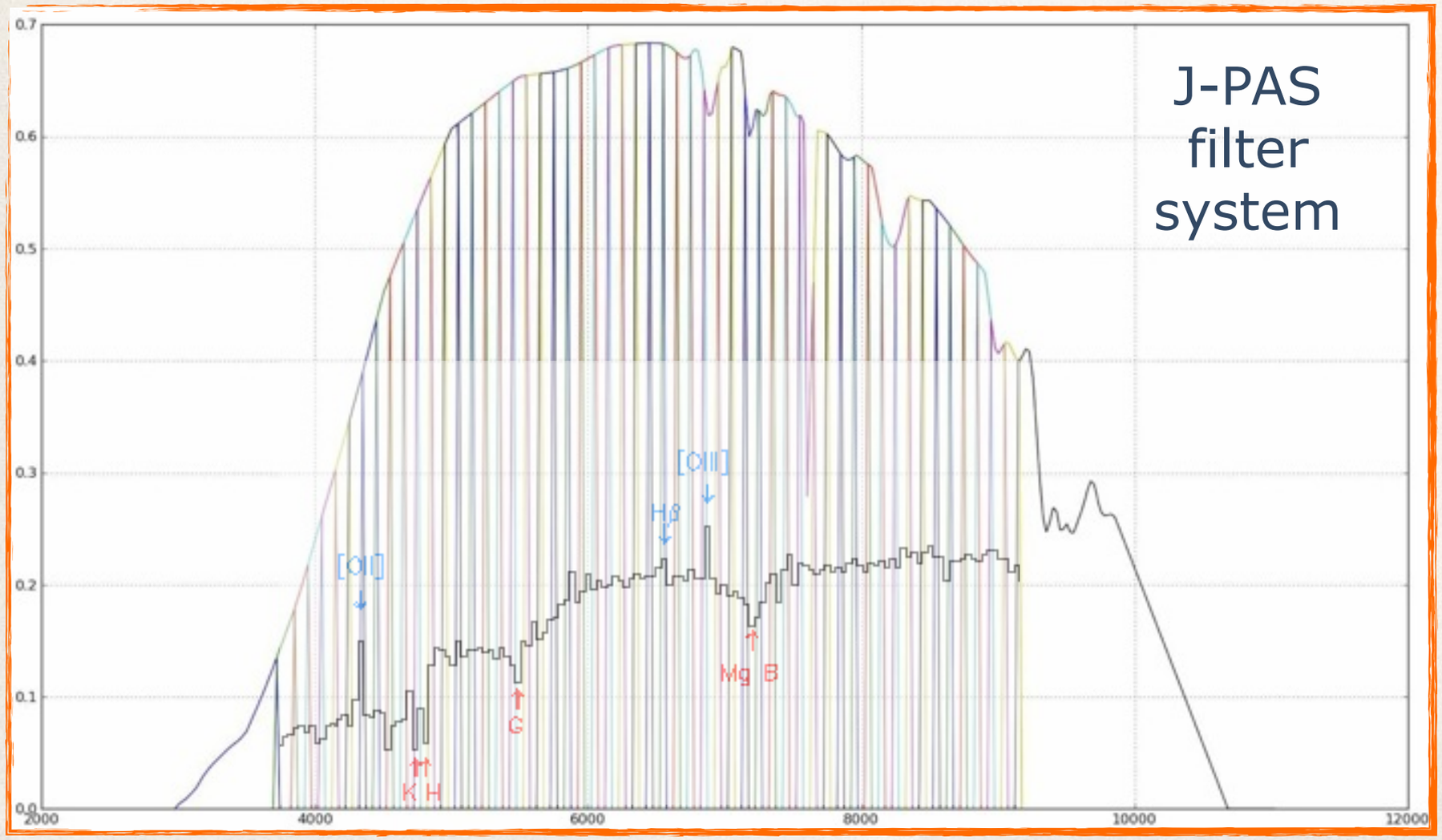
J-PAS

Javalambre **P**hysics of the Accelerated Universe **A**strophysical **S**urvey



- New site - OAJ, mainland Spain
- Two new telescopes (2.5m & .8m) dedicated to surveys
- An innovative strategy: imaging in 54 **narrow-band filters**
- Benitez et al., 1403.5237 — **http: // j-pas.org**

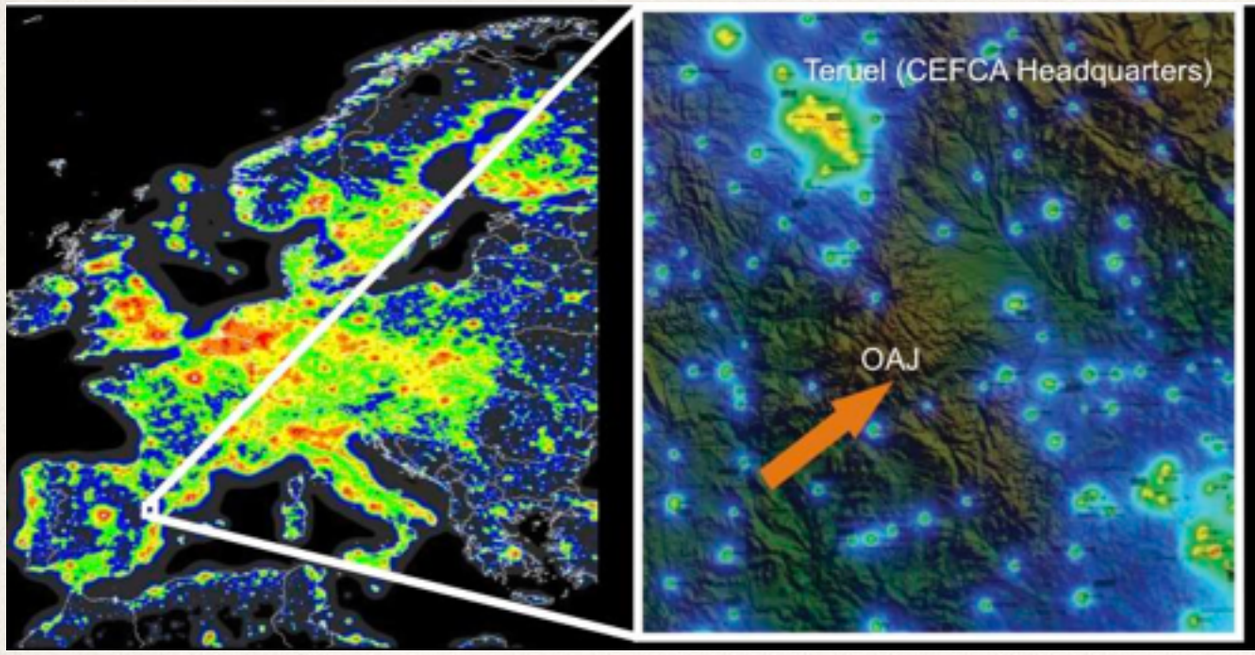
⇨ Images & low-resolution (R~60) spectra of **everything** (i<~22.5)

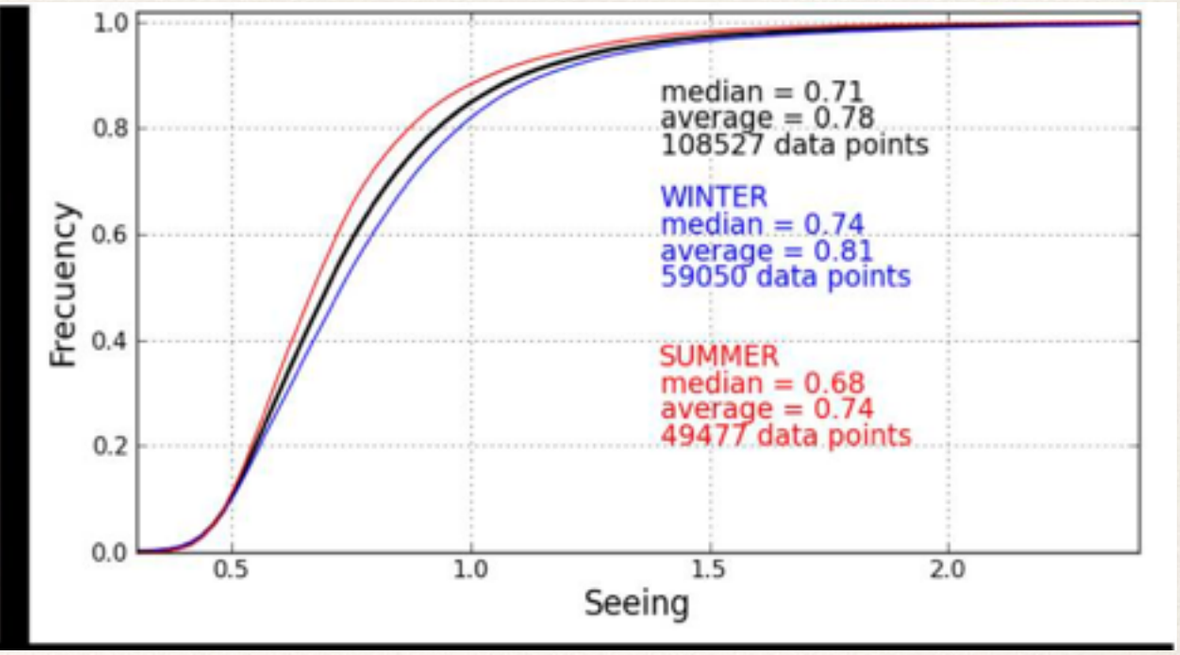


> 8500 deg^2 !

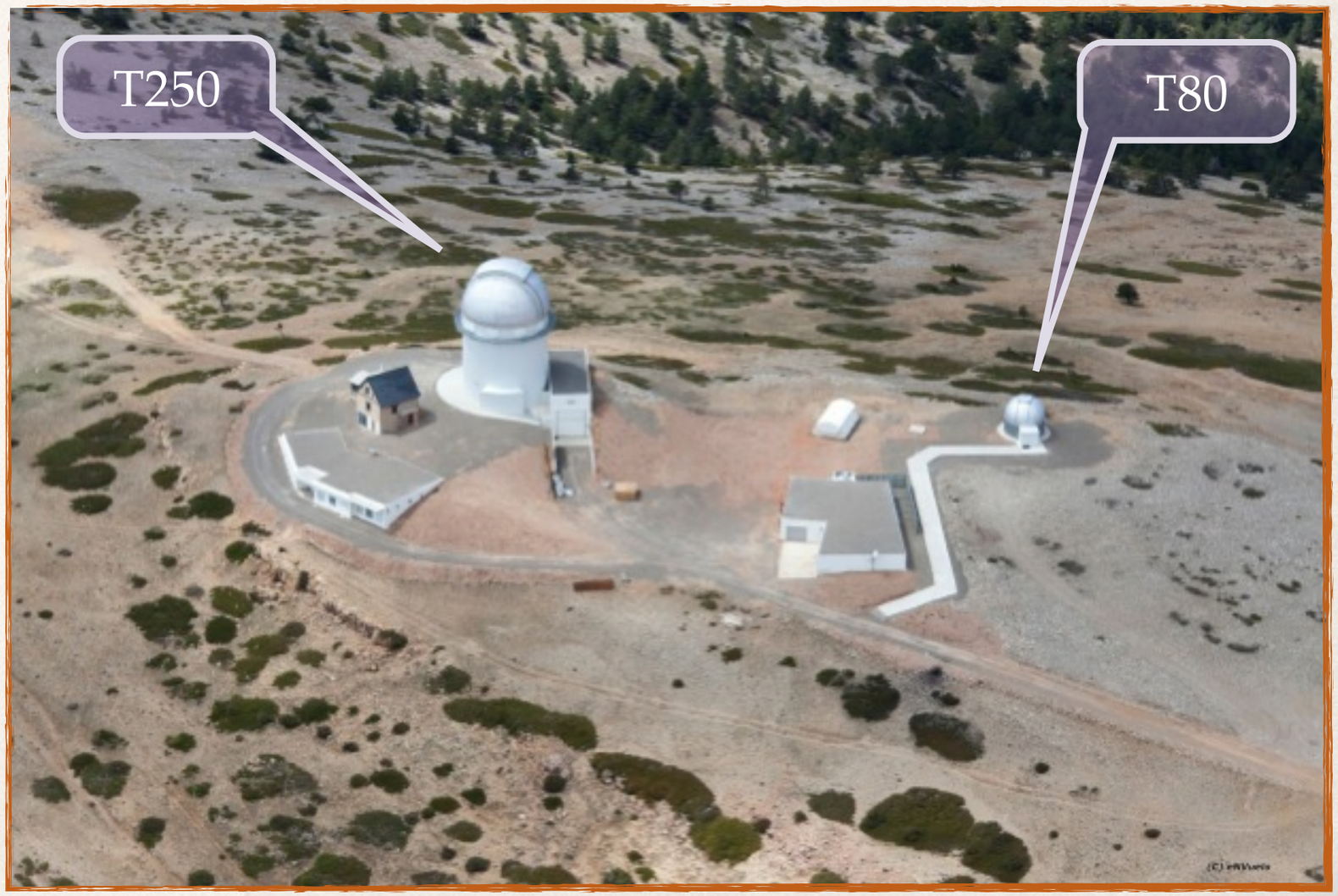
- ⇨ Dark energy
- ⇨ Galaxy evolution
- ⇨ LSS & BAOs
- ⇨ Supernovas
- ⇨ Clusters
- ⇨ QSOs

➪ Joint Spain + Brazil project; total cost ~ € 45 million





- ➪ Two telescopes: 2,5 m and 0,8 m
- ➪ 1,2 Gpixel camera, FoV 3°
- ➪ Science **data** beginning in 2015 (running 'til 2020/21)



Main telescope - T250 (2.5m)

M1 = 2.5m

FoV = 3 deg = 476 mm at FP

Effective coll. area = 3.89 m^2

Etendue = 27.5 m^2 deg^2

Plate scale = 22.67"/mm = 0.22"/pix

Focal length = 9098 mm (F#3.5)

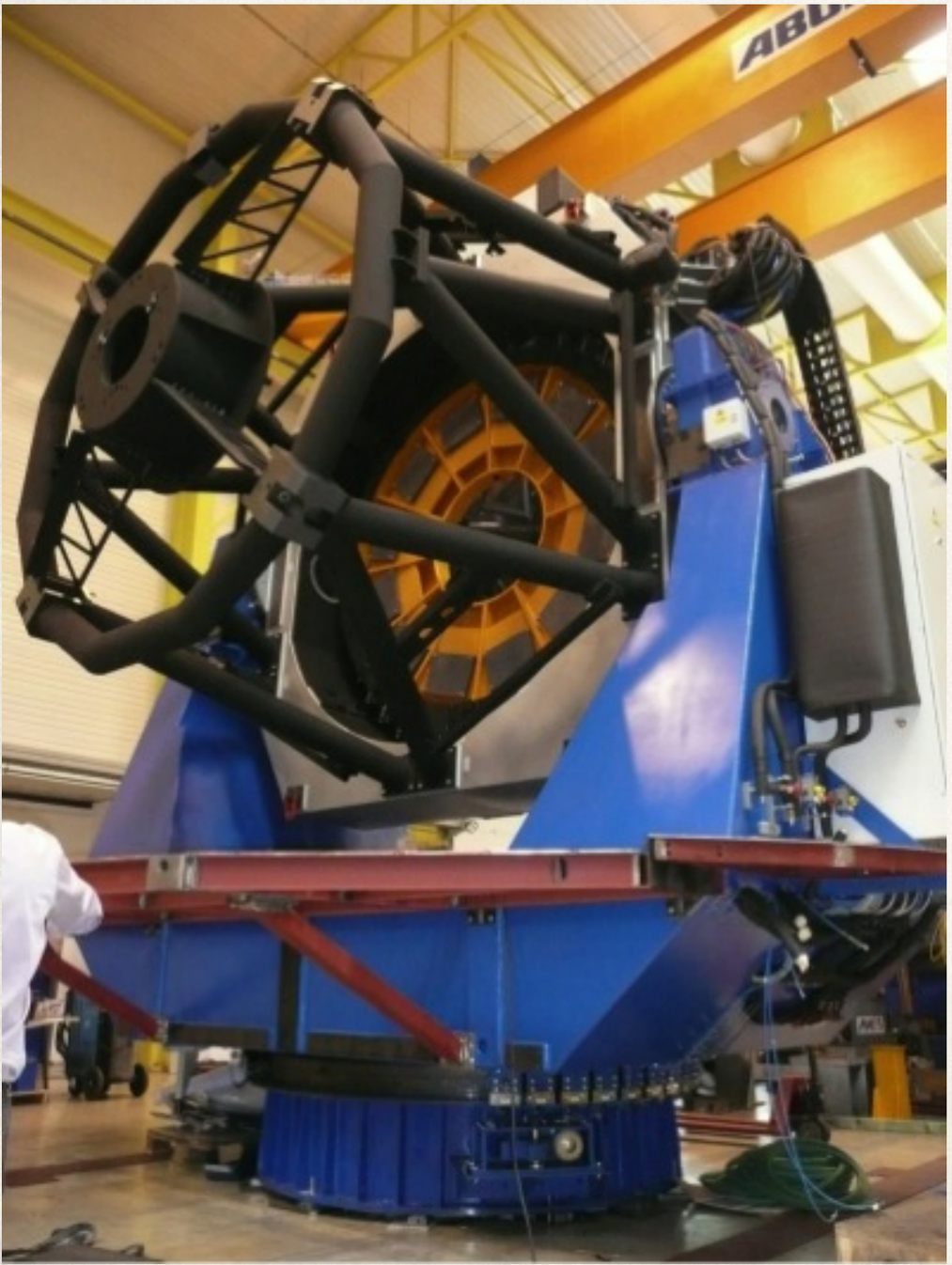
Type = Ritchey Chrétien-like

Mount = Alt-azimuthal

Focus = Cassegrain

Field corrector = 3 lenses

Mass = 45.000 Kg

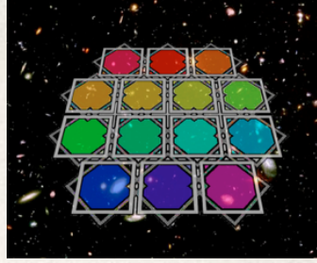


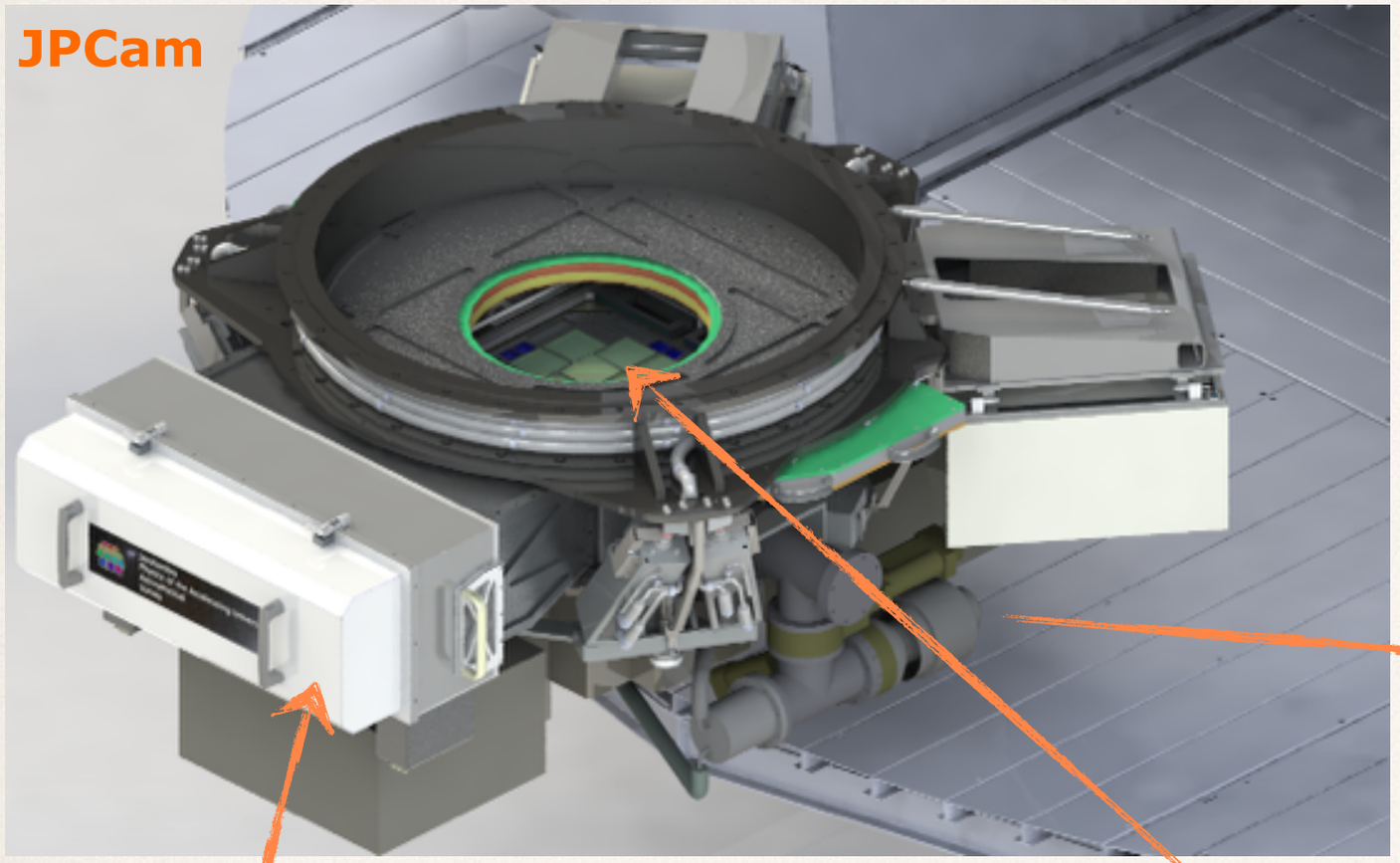
On lab (AMOS)
c. 2012

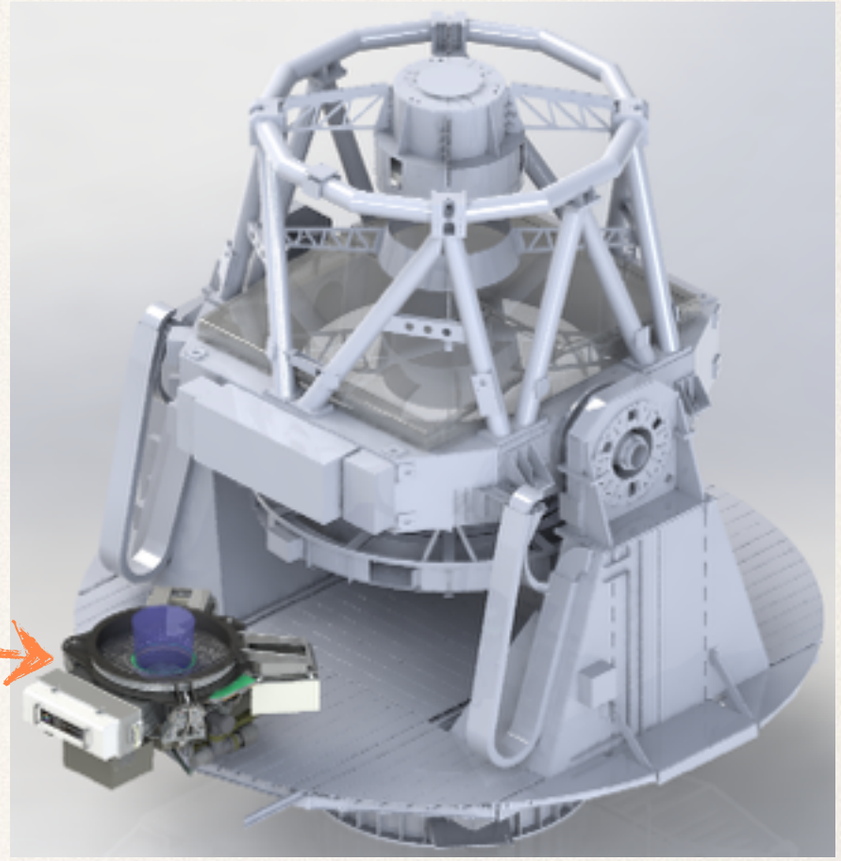
On site
March 2014

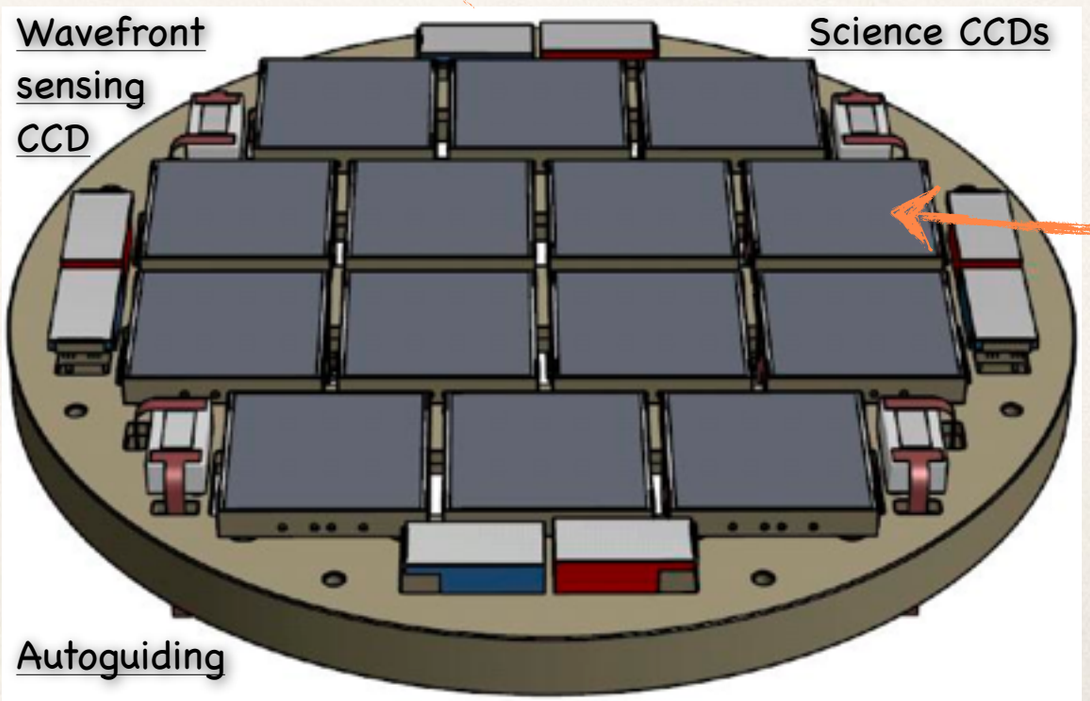
Camera - JPCam

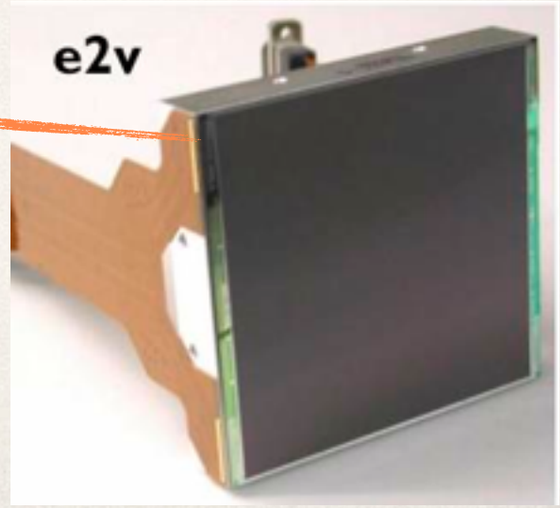
* Array of 14 large-format CCDs from E2V
* 9.216 x 9.216 pixels (**1.2 Gpix camera!**)
* QE > 80% (400-900 nm)



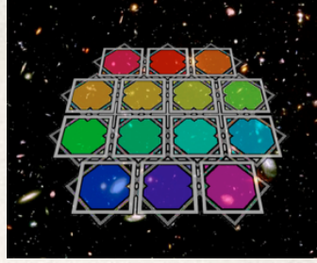


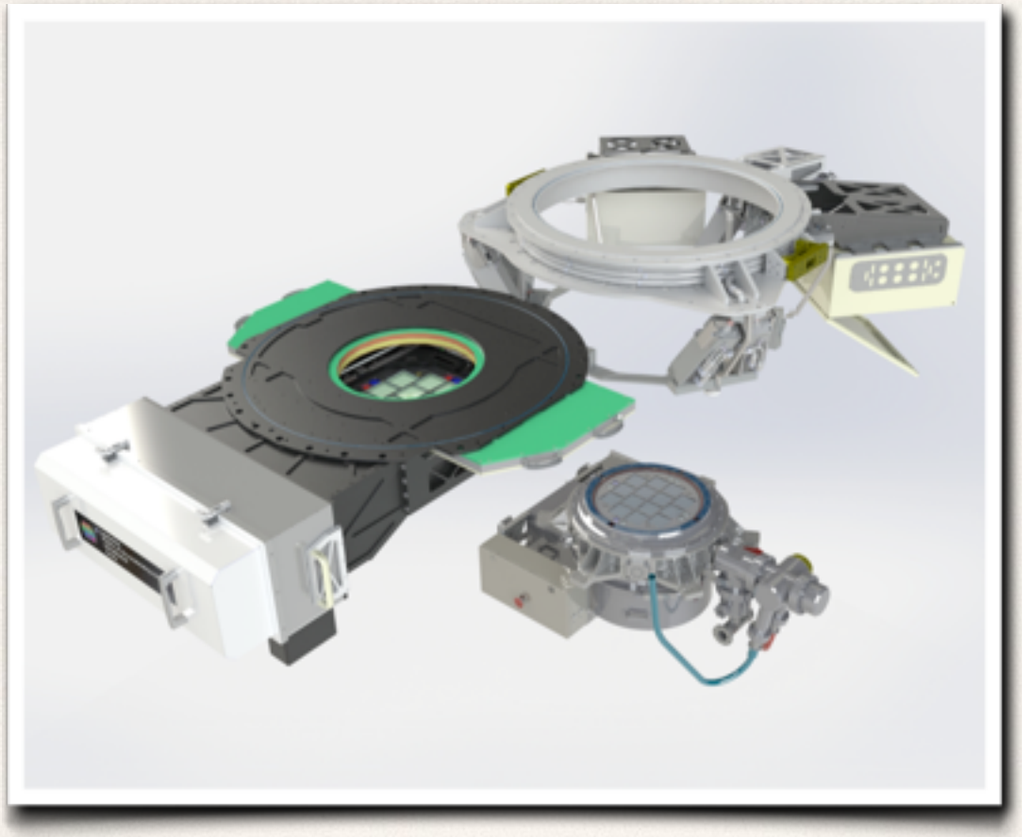


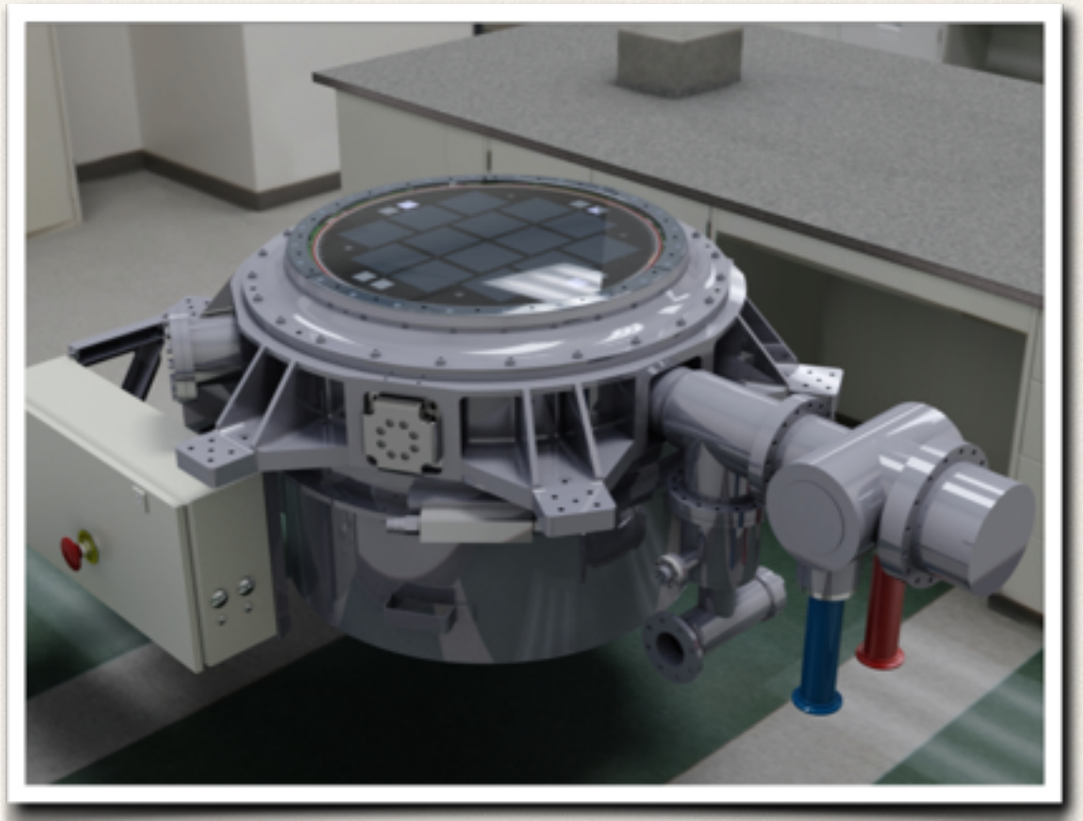


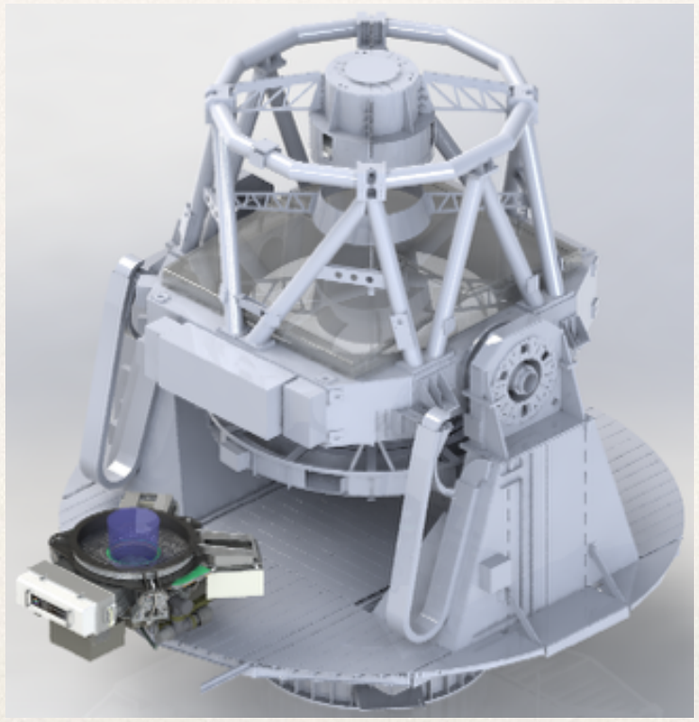


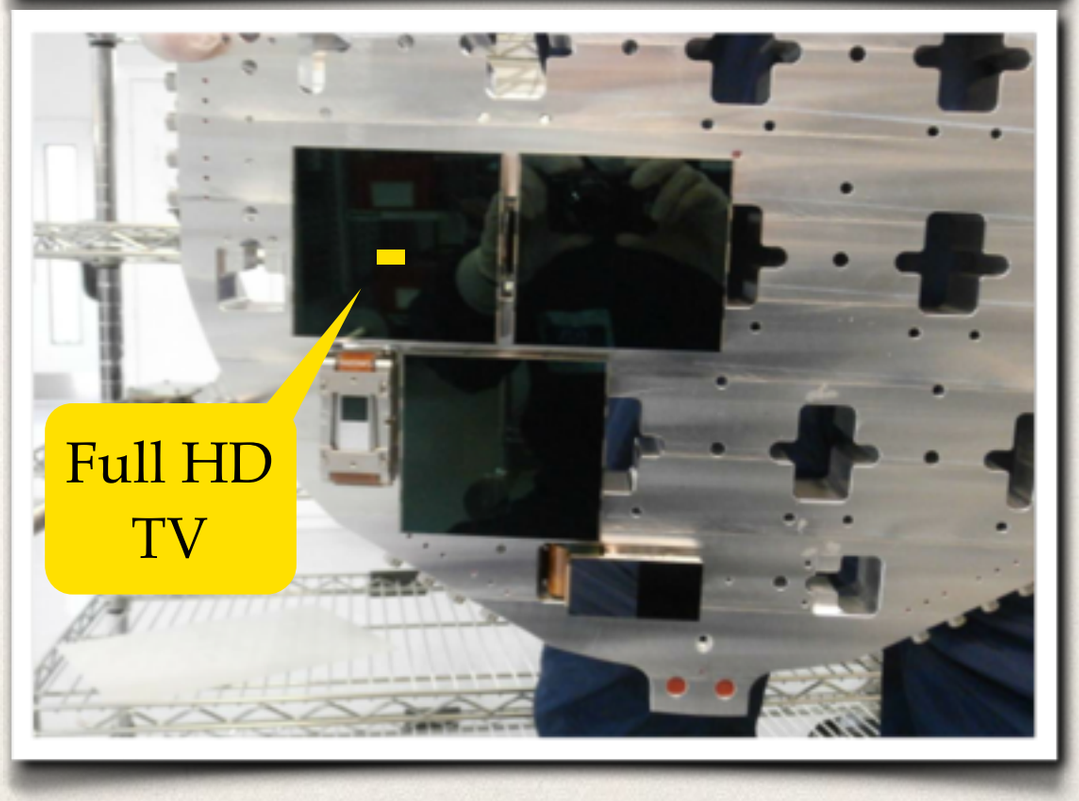
Camera JPCam - completed by Q4/2014-Q1/2015



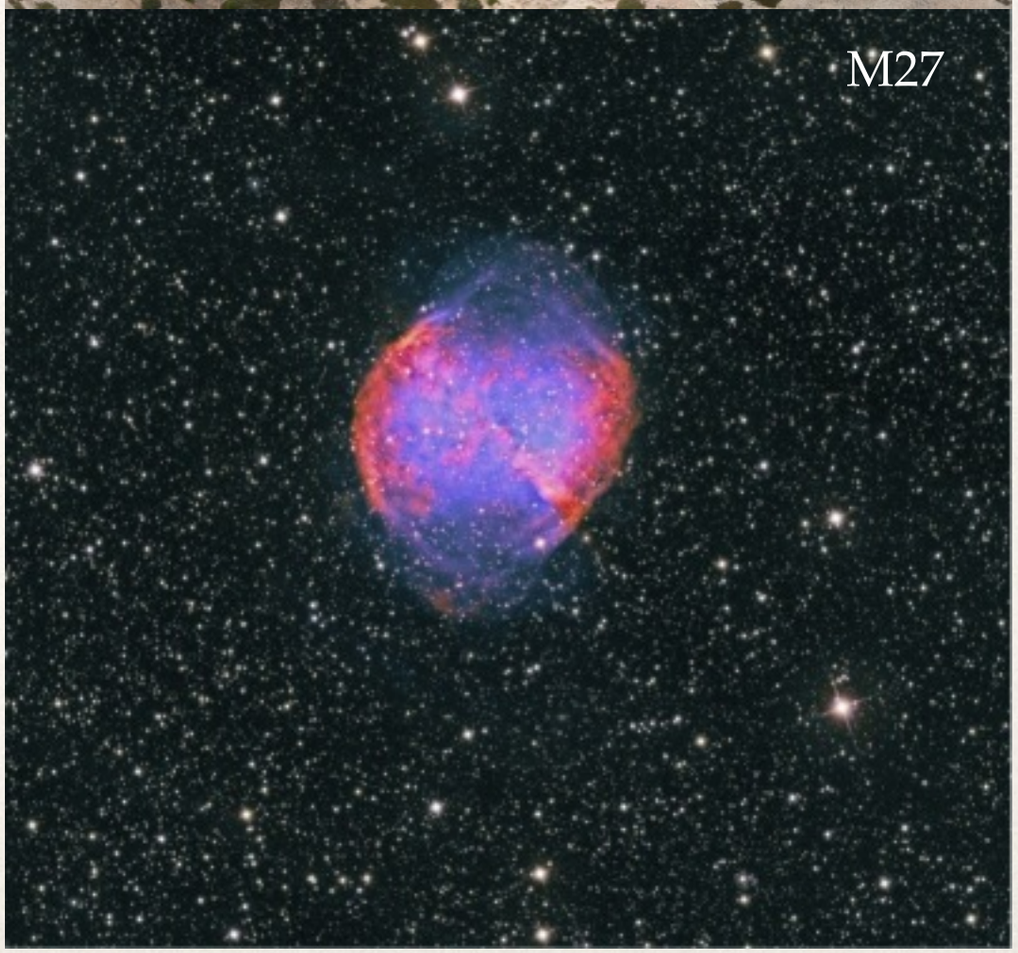




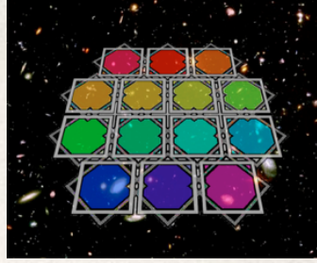




Some pics

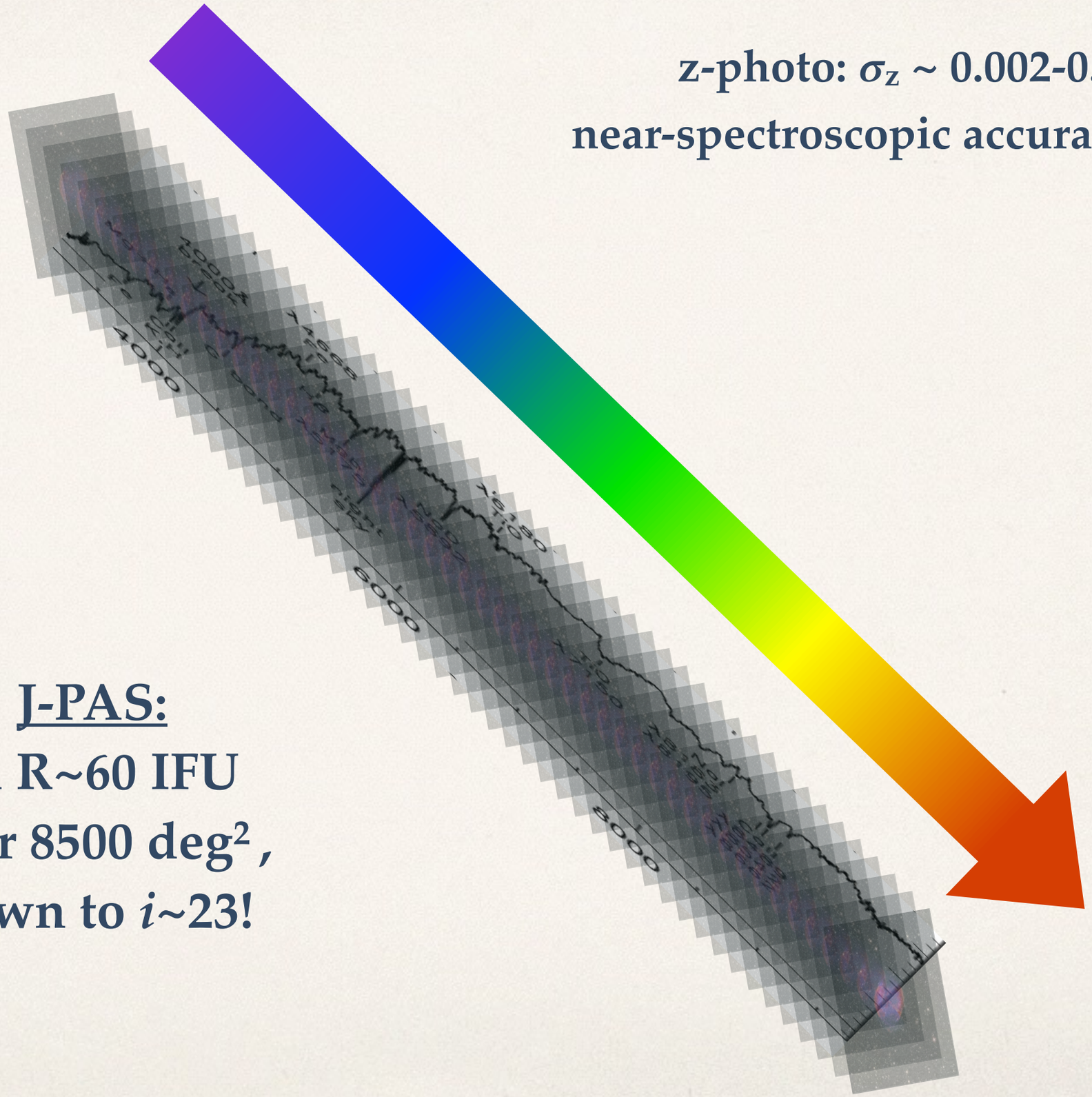


Datacube: 54 narrow-band + 7 broad-band filters



z-photo: $\sigma_z \sim 0.002\text{-}0.003\ (1+z)$

near-spectroscopic accuracy & precision



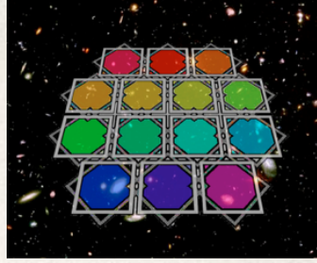
J-PAS:

an R~60 IFU

over 8500 deg^2 ,

down to *i*~23!

J-PAS: an 8500 deg^2 IFU



- ~ 1.3 x 10^7 **LRGs** up to **z<1.1** - $\sigma_z \sim 0.003(1+z)$
- ~ 10^8 **ELGs** up to **z<1.3** - $\sigma_z \sim 0.0025(1+z)$
- > 2 x 10^8 **galaxies** (generic) to **z<1.3** - $\sigma_z \sim 0.01(1+z)$

Benitez et al. 2014

- ~ 2 x 10^6 **QSOs** up to **z<4** - $\sigma_z \sim 0.0015(1+z)$

R.A., Strauss , Lima et al. 2012

- > 10^5 **clusters & groups**

Zandivarez et al. 2014

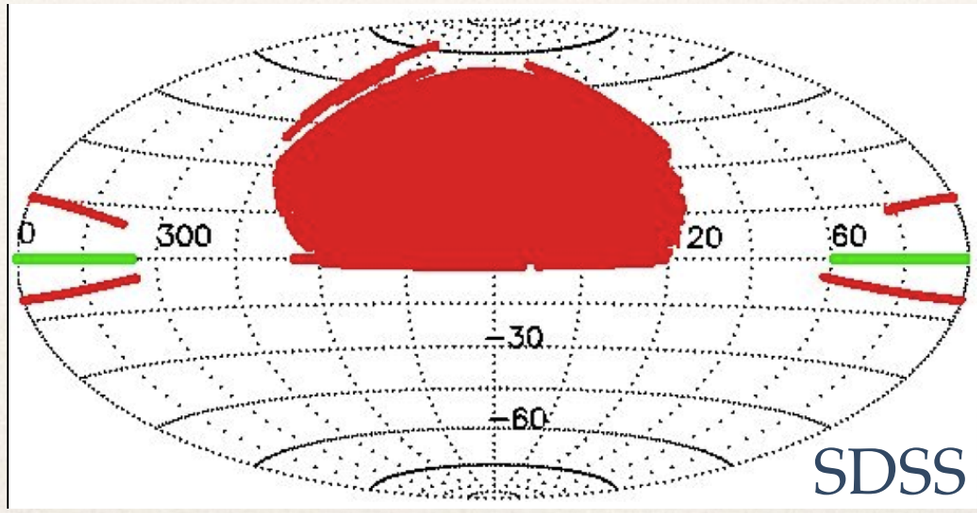
- ~10^4 **supernovas** (no need of spectroscopic follow-up!)

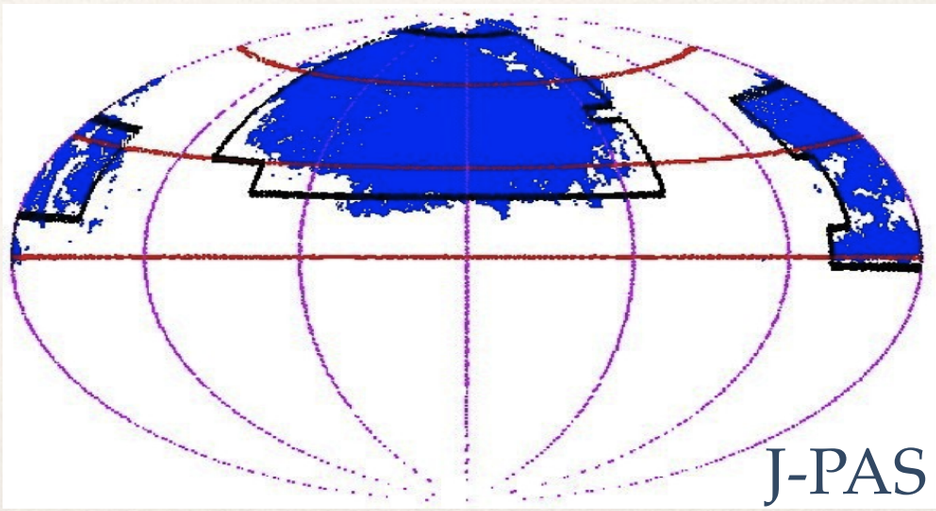
Xavier, R.A., Sako et al. 2014

- Serendipitous discoveries & more
- 54 narrow-band images of **everything down to r~22.5**

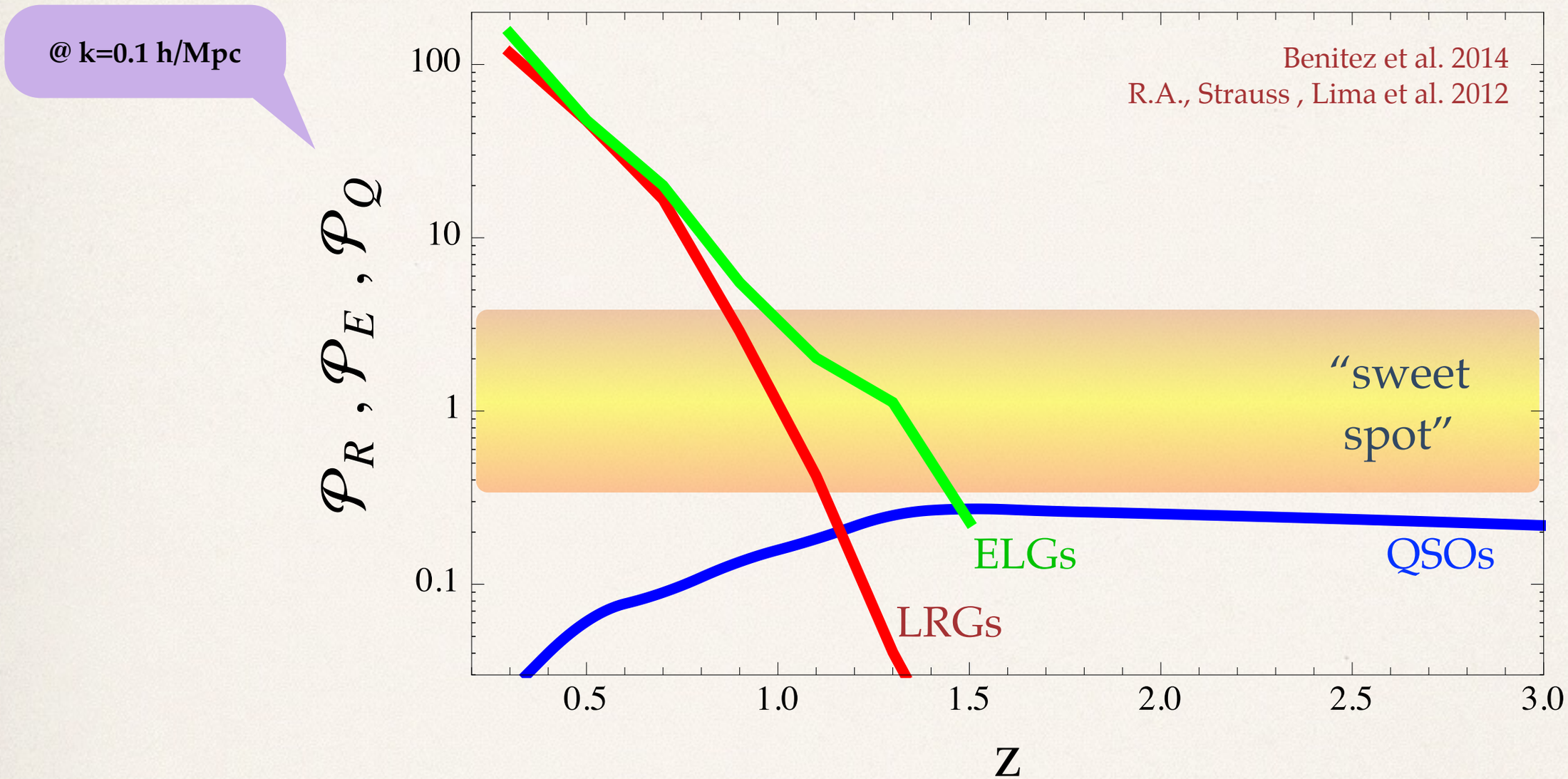
Footprint:

~SDSS





Massive & deep multi-tracer survey with J-PAS



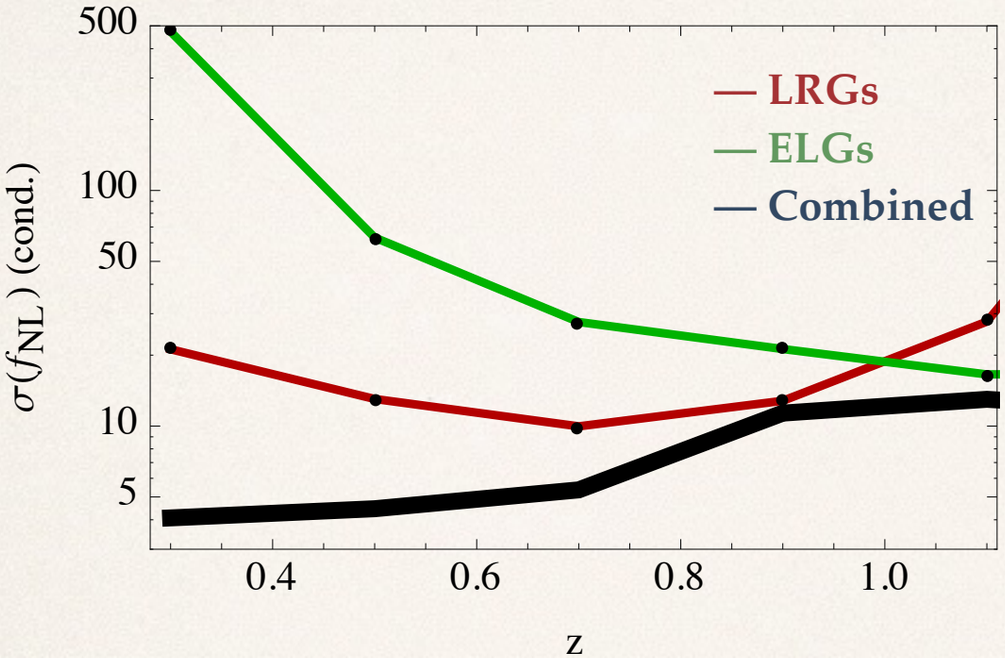
See also:

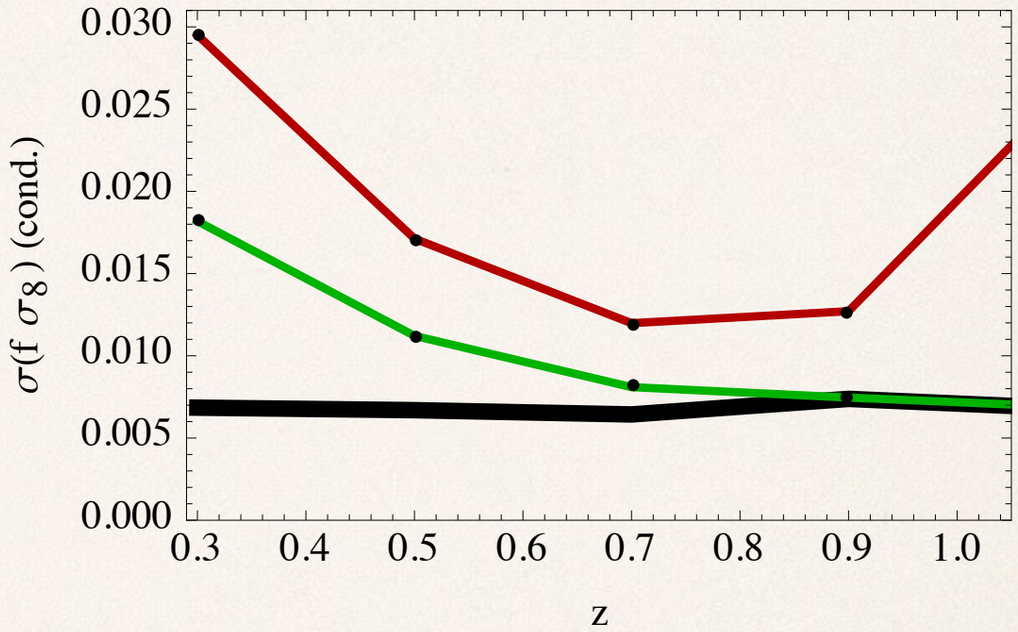
* GAMA - Blake et al., MNRAS 2013 : $\mathcal{P}_\alpha$ >10 for z<0.25
* Radio galaxies & SKA - Ferramacho et al., MNRAS 2014
* 21cm intensity mapping - Bull et al., arXiv:1405.1452

R.A. & Leonard 2013

1. Conditional errors

PNG (f_{NL} local) and matter growth rate ($f\sigma_8$) benefit from multi-tracer analysis

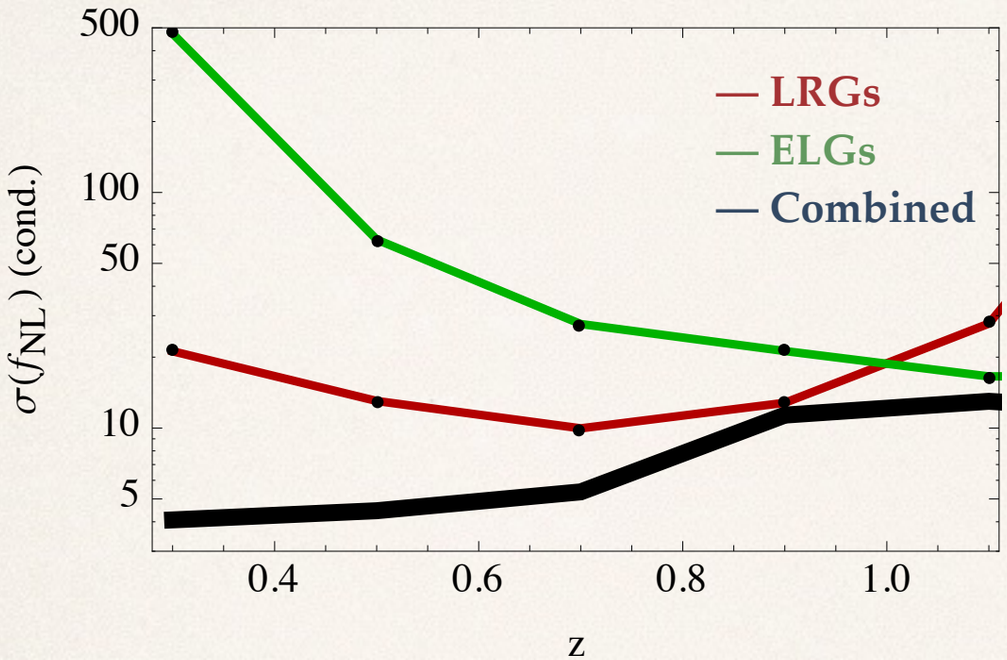


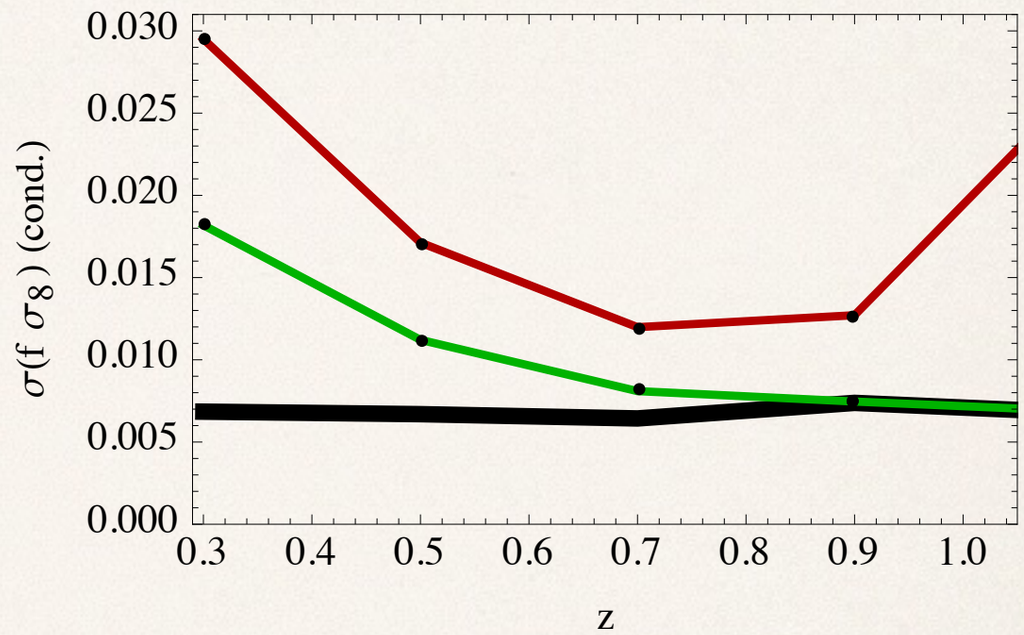


R.A. & Leonard 2013

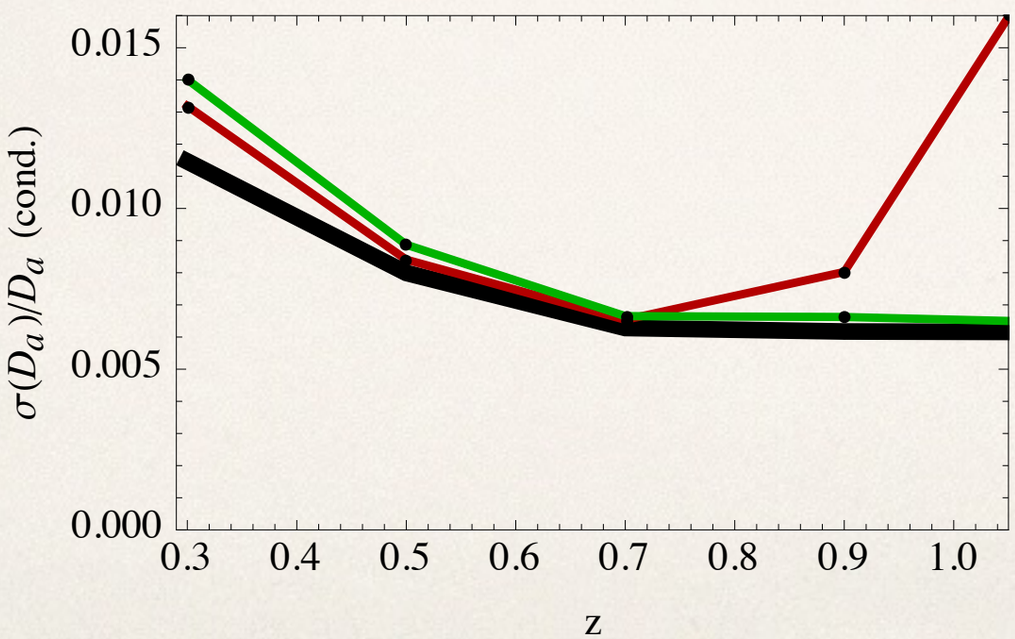
1. Conditional errors

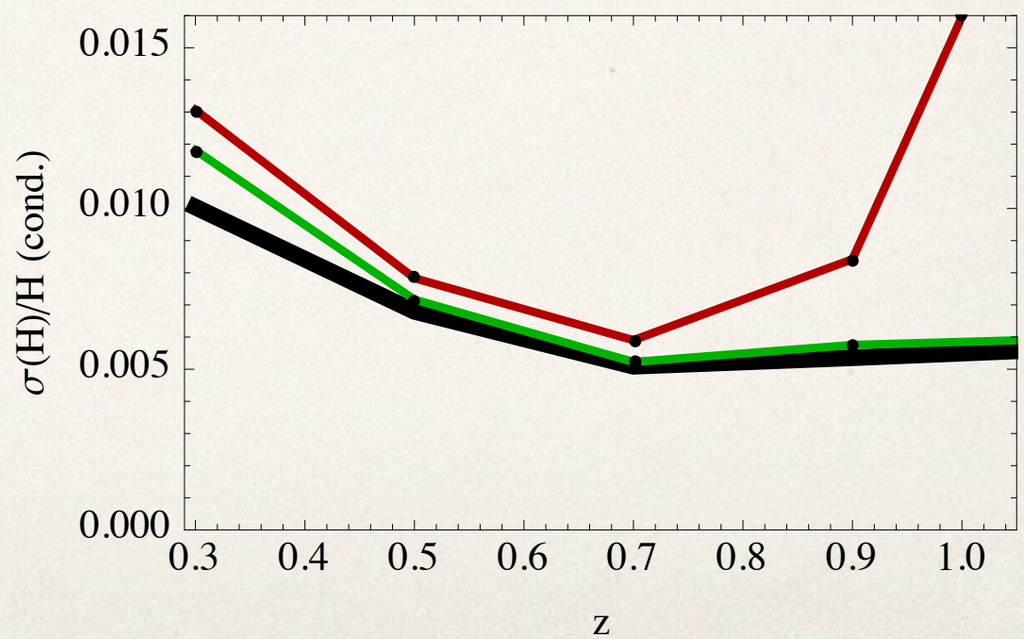
PNG (f_{NL} local) and matter growth rate ($f\sigma_8$) benefit from multi-tracer analysis





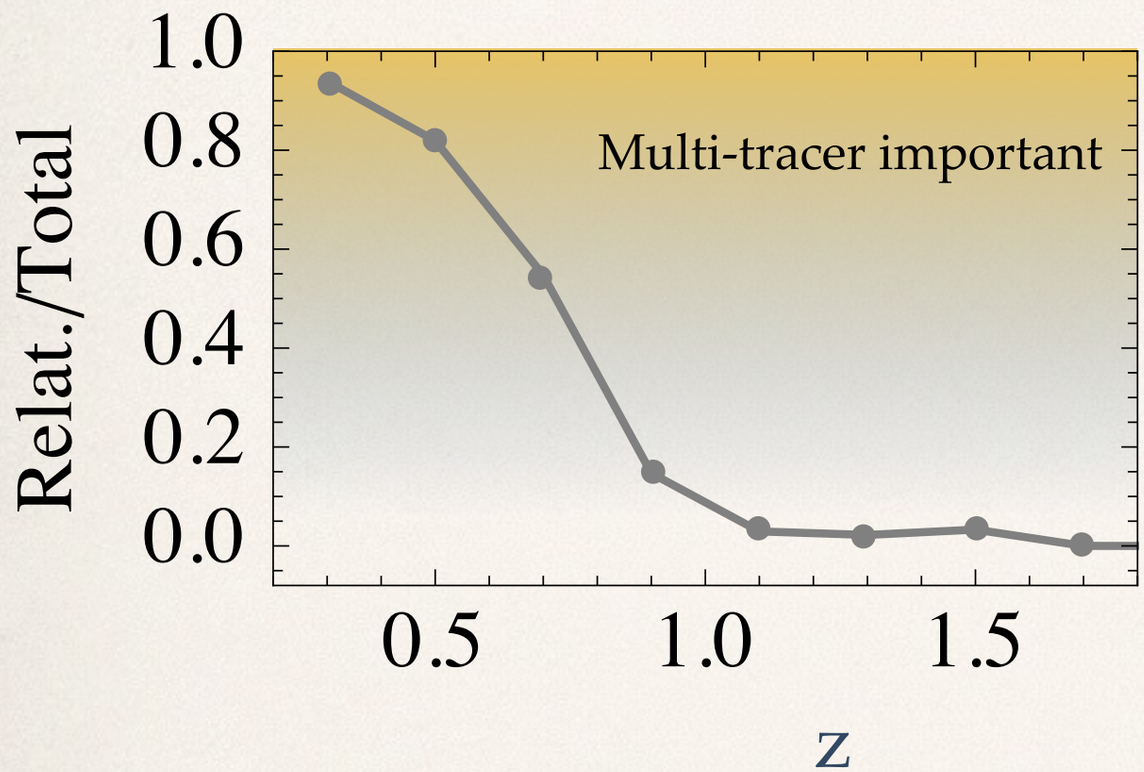
The BAO distance scales, not so much…



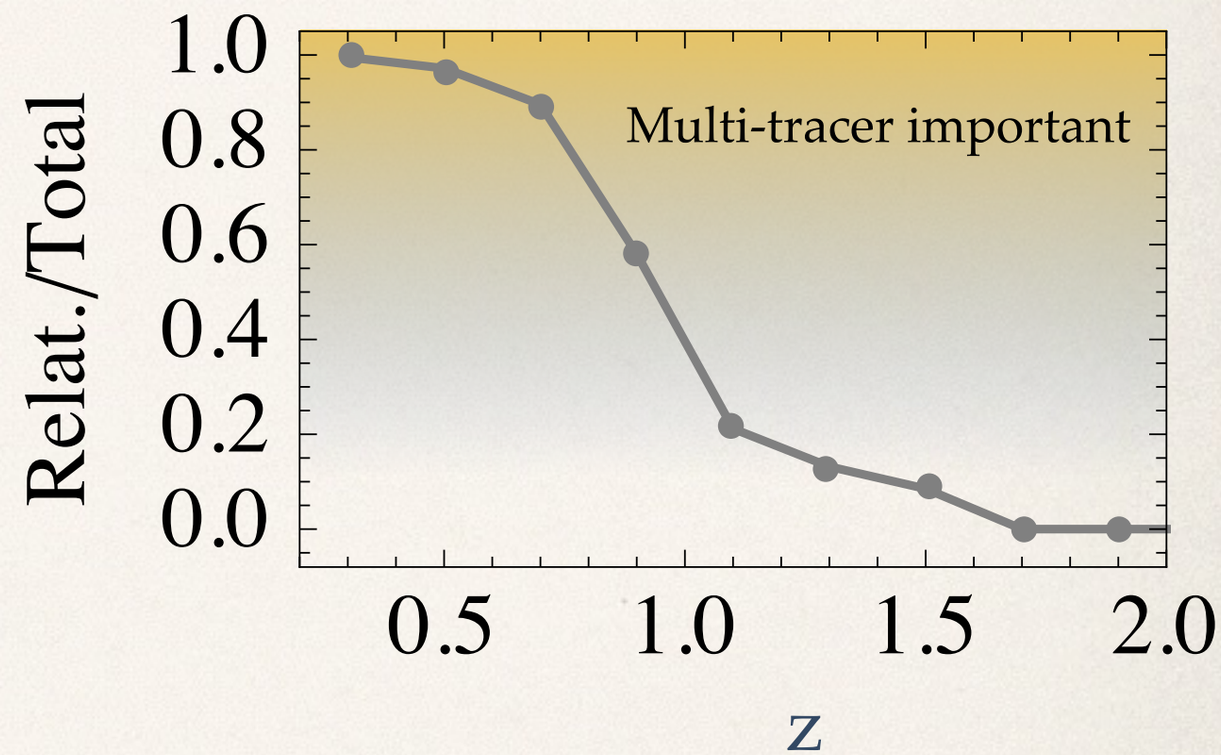


For **high number densities** (~low redshifts), the contribution from the **relative clustering strengths** dominates the (Fisher) information of **bias-related quantities**

matter growth rate $f\sigma_8$



f_{NL}

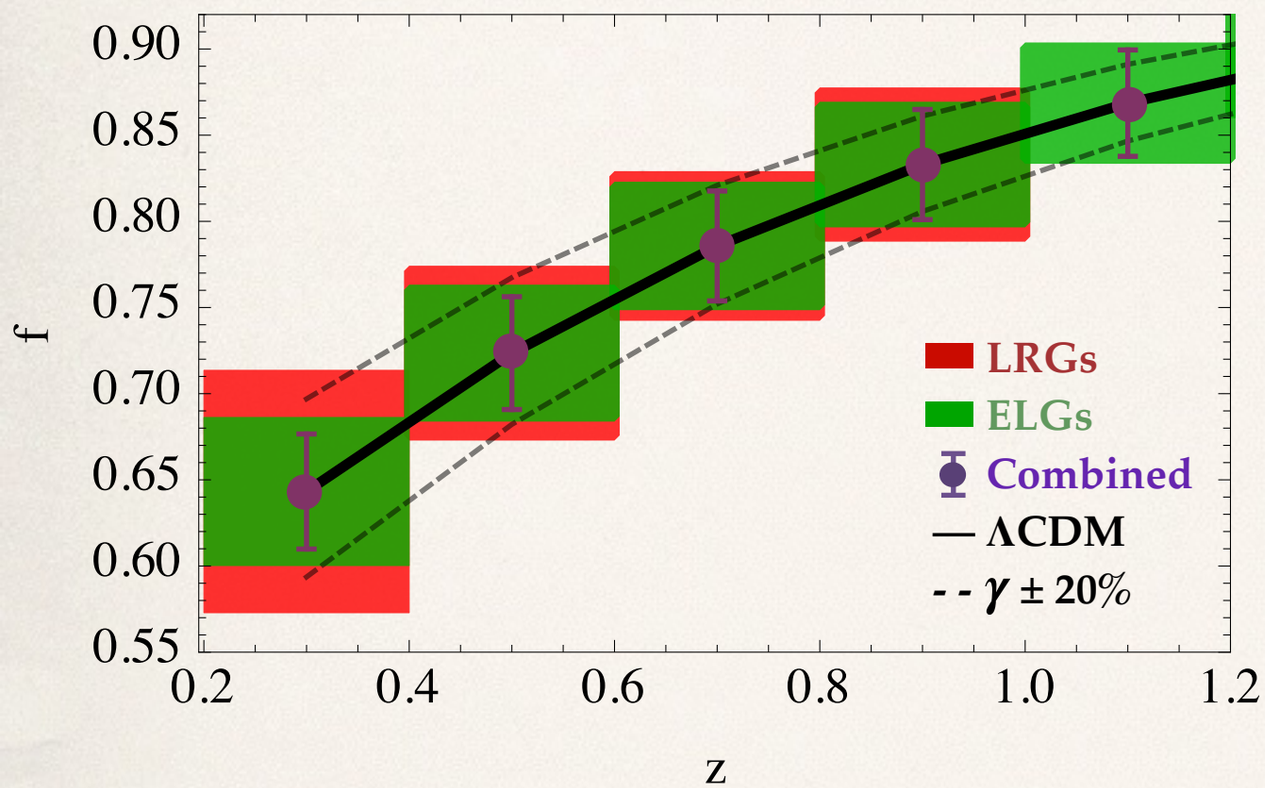


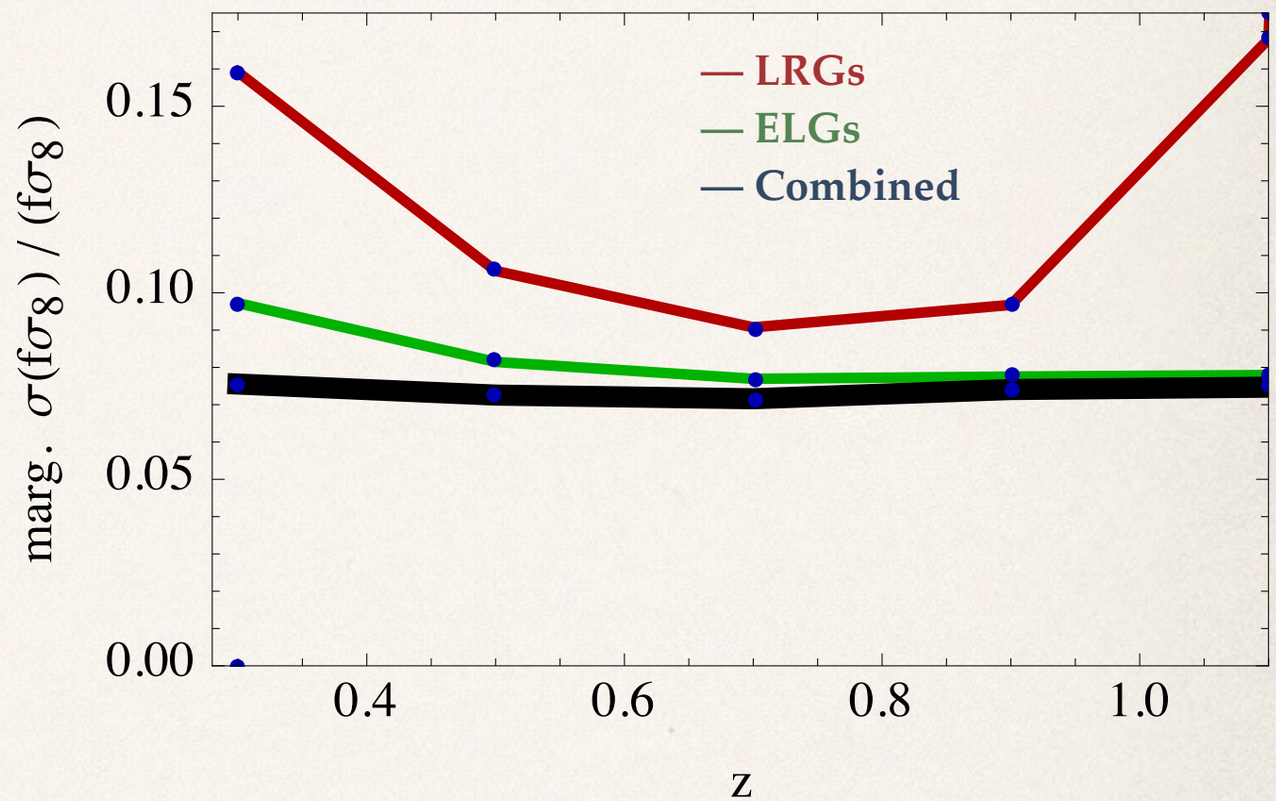
Relat. = Fisher information from relative clustering strengths

Total = Total fisher information (absolute + relative)

2. Marginalized errors

Prior knowledge of the bias of the tracers (from, e.g., lensing) suppresses the degradation due to marginalization *wrt* bias

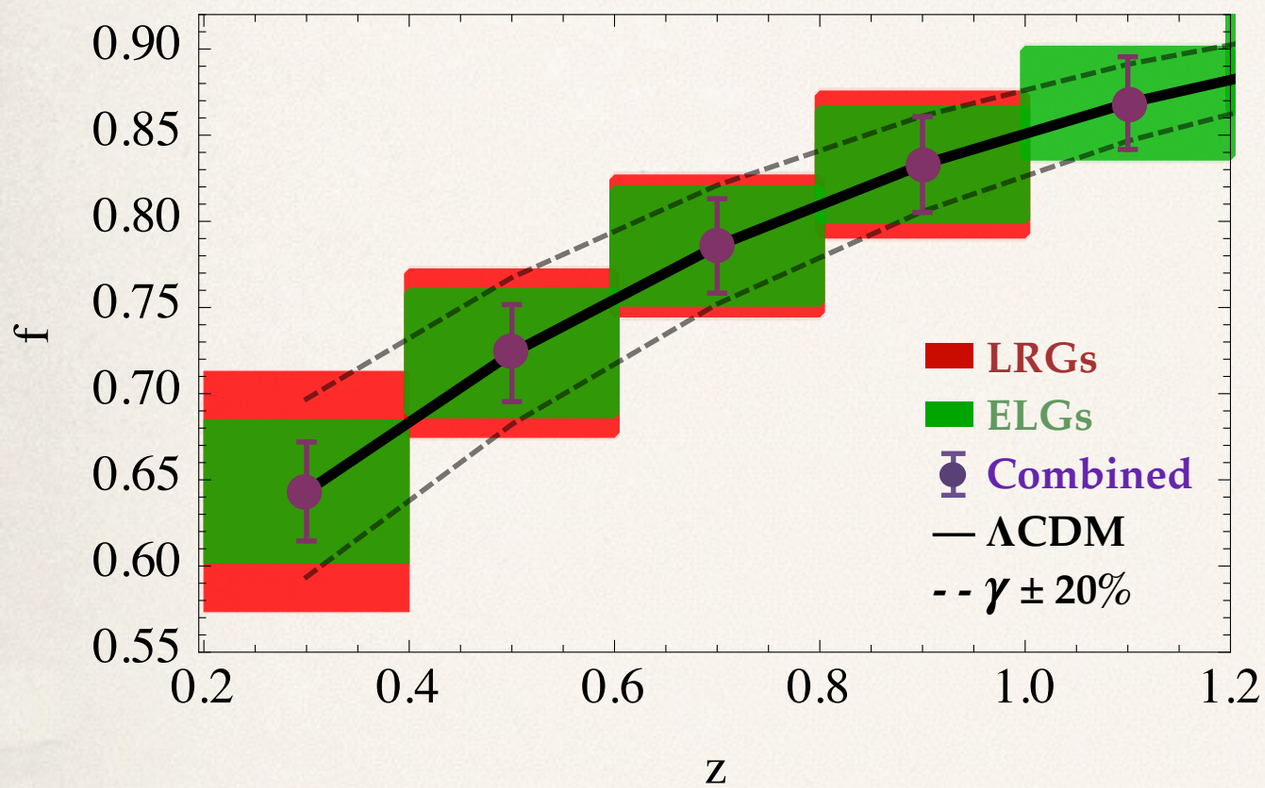


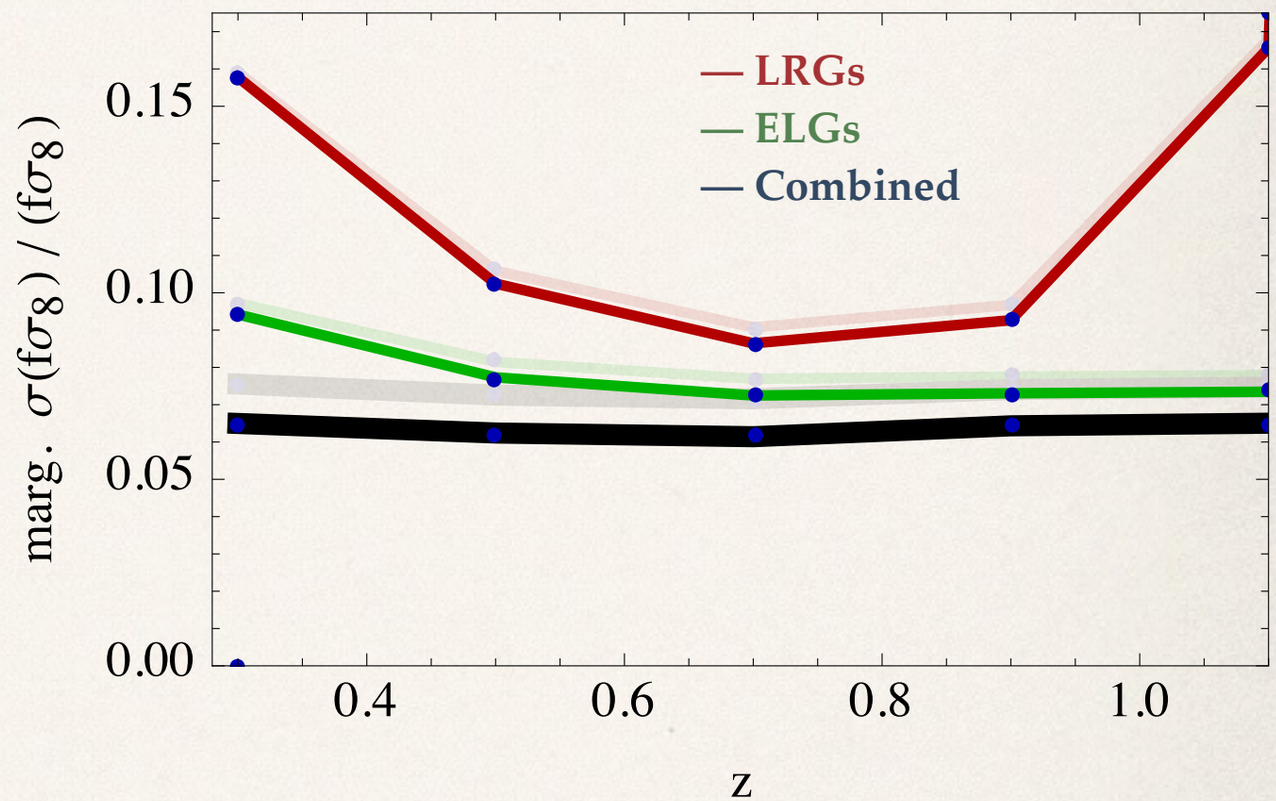


No prior on bias

2. Marginalized errors

Prior knowledge of the bias of the tracers (from, e.g., lensing) suppresses the degradation due to marginalization *wrt* bias



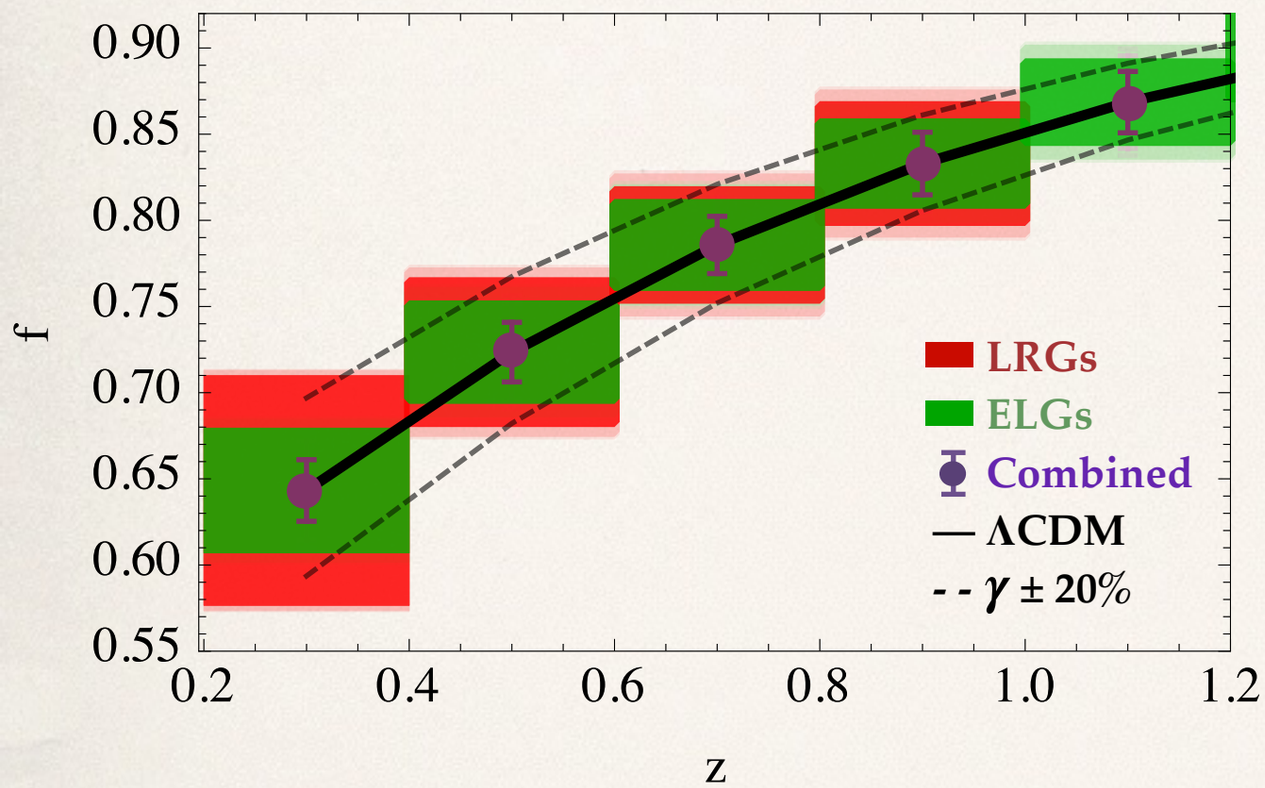


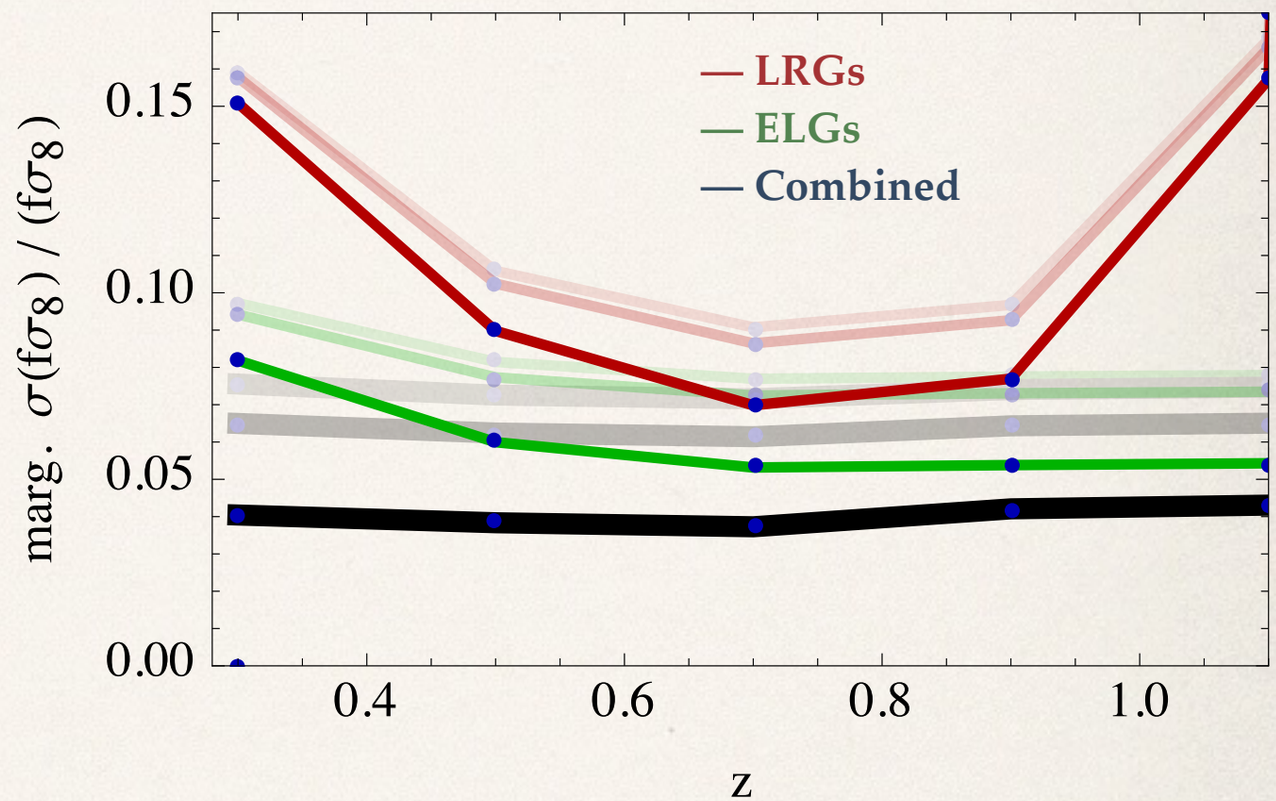
No prior on bias

Weak (~20%) prior on bias

2. Marginalized errors

Prior knowledge of the bias of the tracers (from, e.g., lensing) suppresses the degradation due to marginalization *wrt* bias





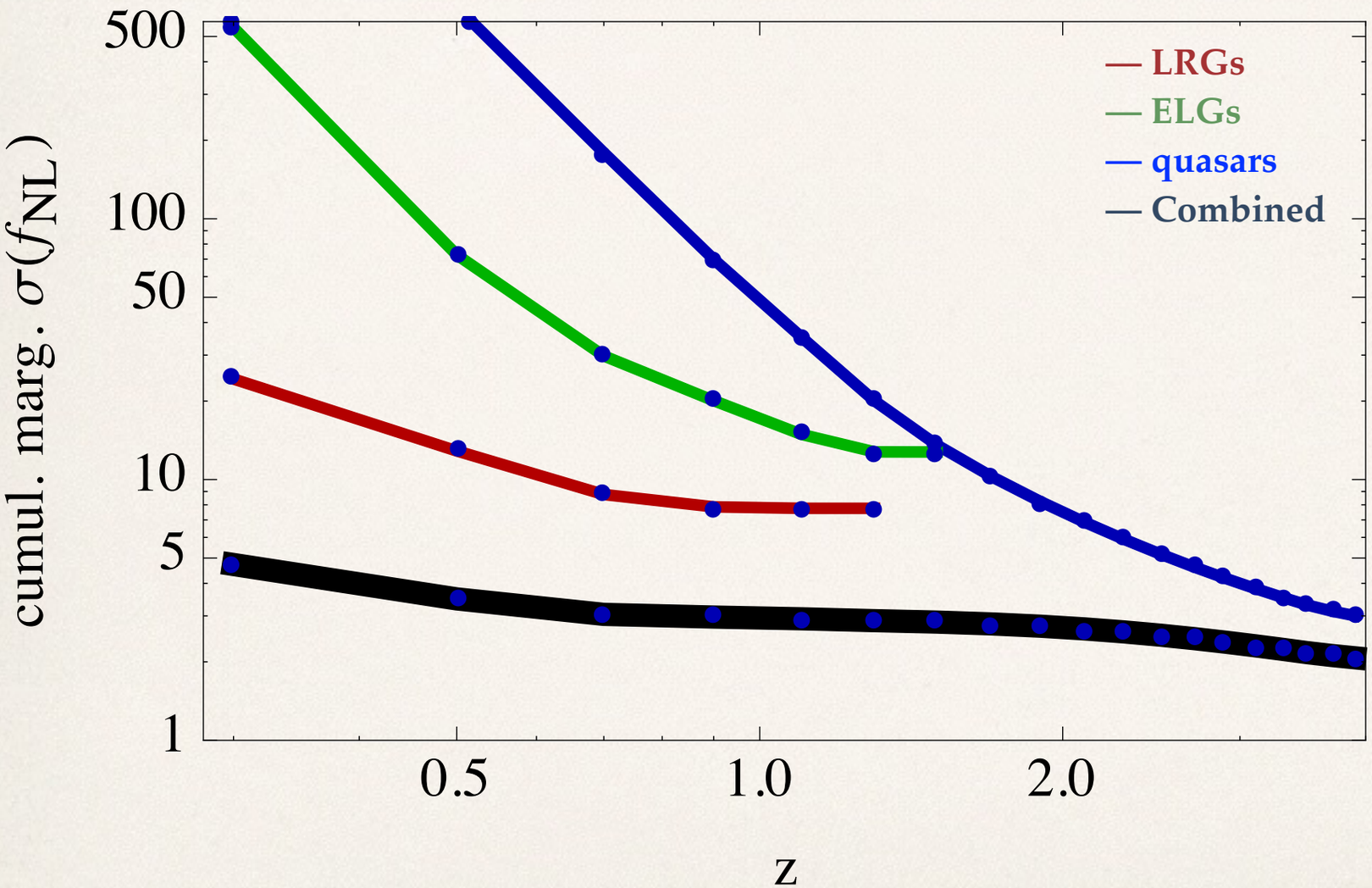
No prior on bias

Weak (~20%) prior on bias

Strong (~5%) prior on bias

f_{NL} is almost unaffected:
the k-dependence of $\Delta b_{NL} \sim f_{NL} \times k^{-2}$ helps break the degeneracy with bias

Cumulative uncertainty on f_{NL} when the redshift slices are combined

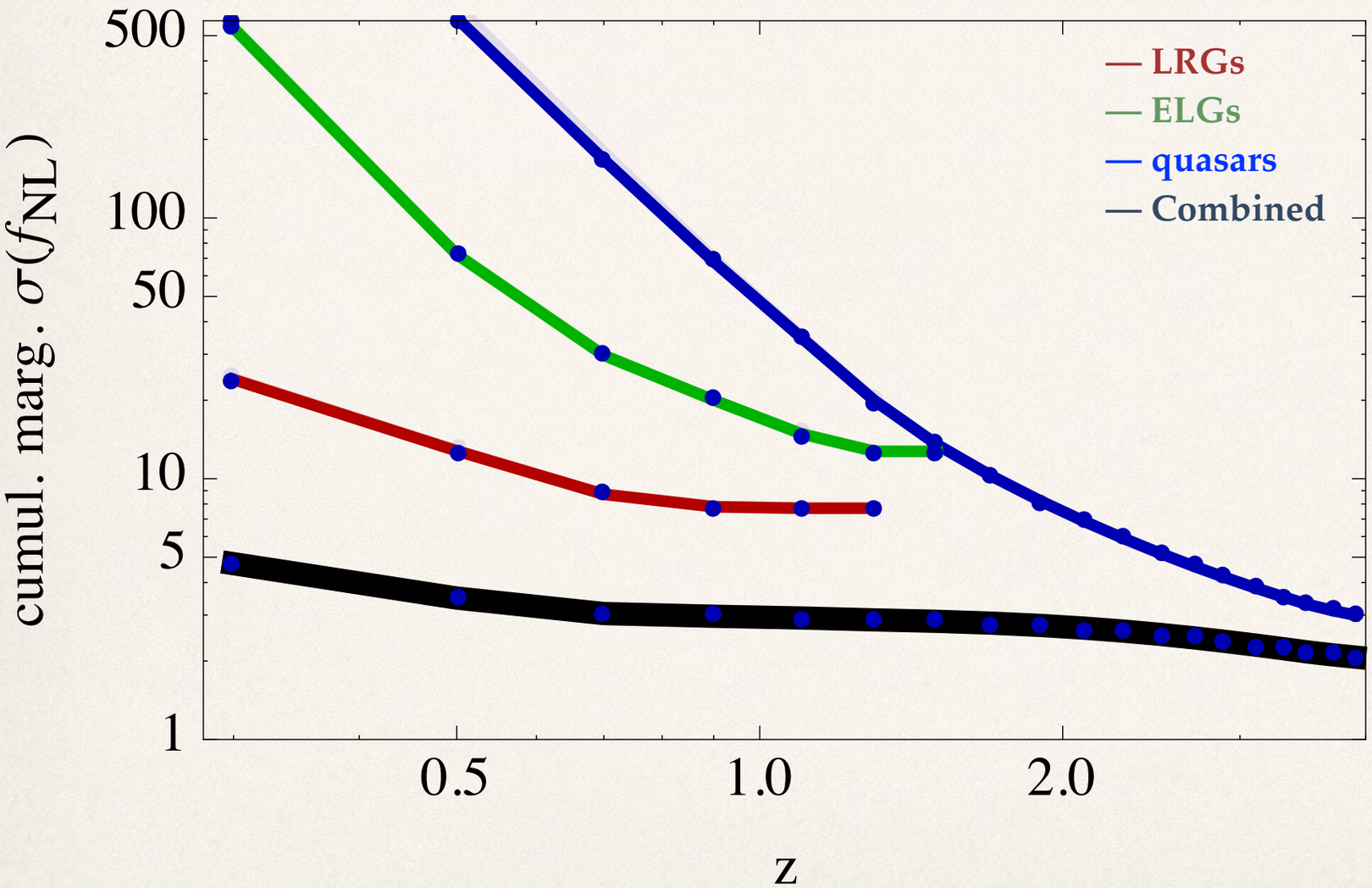


No prior on bias

1σ error: ~2

f_{NL} is almost unaffected:
the k-dependence of $\Delta b_{NL} \sim f_{NL} \times k^{-2}$ helps break the degeneracy with bias

Cumulative uncertainty on f_{NL} when the redshift slices are combined



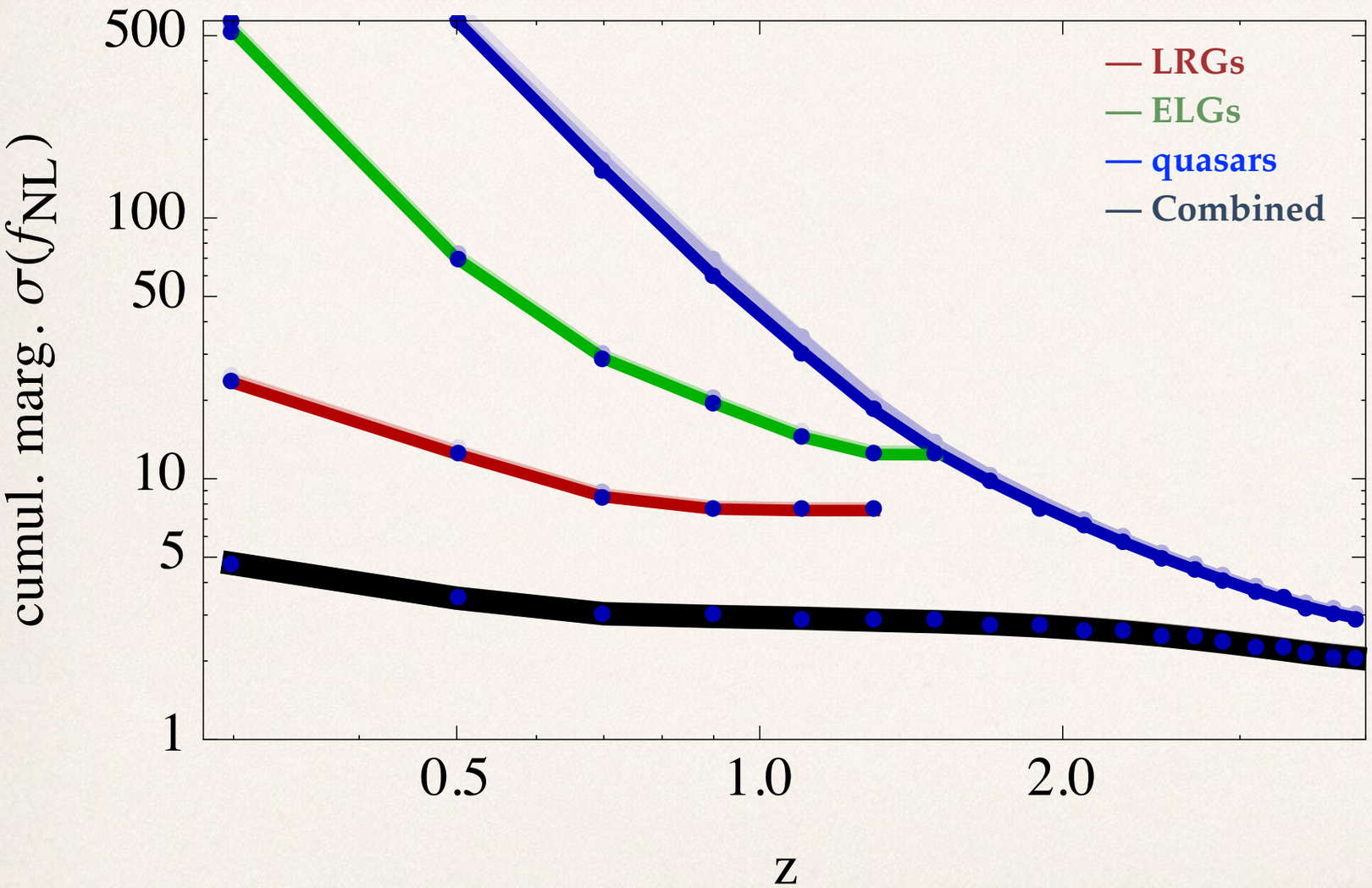
No

Weak (~20%) prior on bias

1σ error: ~2

f_{NL} is almost unaffected:
the k-dependence of $\Delta b_{NL} \sim f_{NL} \times k^{-2}$ helps break the degeneracy with bias

Cumulative uncertainty on f_{NL} when the redshift slices are combined



No

Weak (~20%)

Strong (~5%) prior on bias

1σ error: ~2

Conclusions

- In the new *age of cosmic variance*, multi-tracer surveys (e.g., J-PAS) will be far superior to single-tracer surveys of large-scale structure

- These tracers of LSS can be different types of galaxies, galaxies of different luminosities, QSOs, or even the DM halos themselves

- Boost from multi-tracer analysis kicks in for very large number densities of the tracers (total $\gtrsim 10^{-2}\ h^3\ \mathrm{Mpc}^{-3}$)

- New horizons for constraining modified gravity & inflation

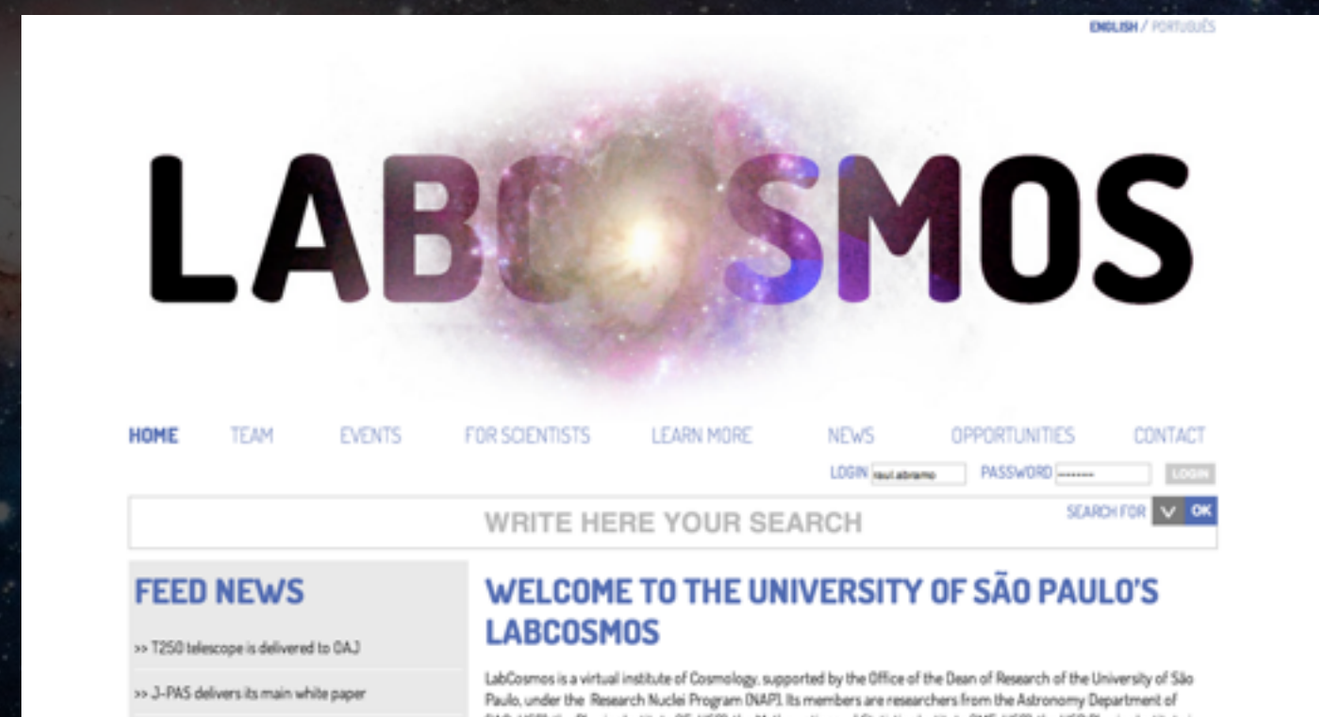
- Actual data is right around the corner (next ~5-7 years)

- Difficulties: covariance of the biases; non-linearities and modelling or RSDs; assembly bias; cross-covariances…

- What multi-tracer analysis can tell us about the bispectrum?

END

http://j-pas.org



http://www.iag.usp.br/labcosmos