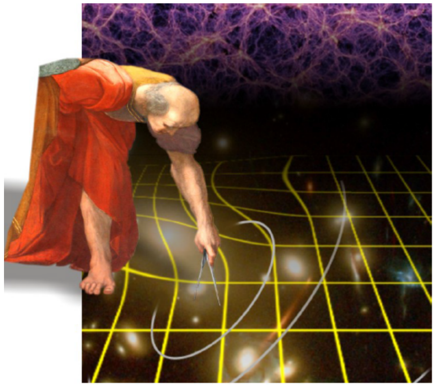
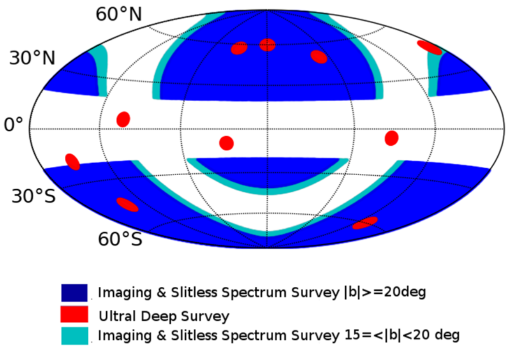
Highlights in cosmology 2019
Sino French collaborations

Charling Tao
CPPM/IN2P3/CNRS
and
THCA, Tsinghua University

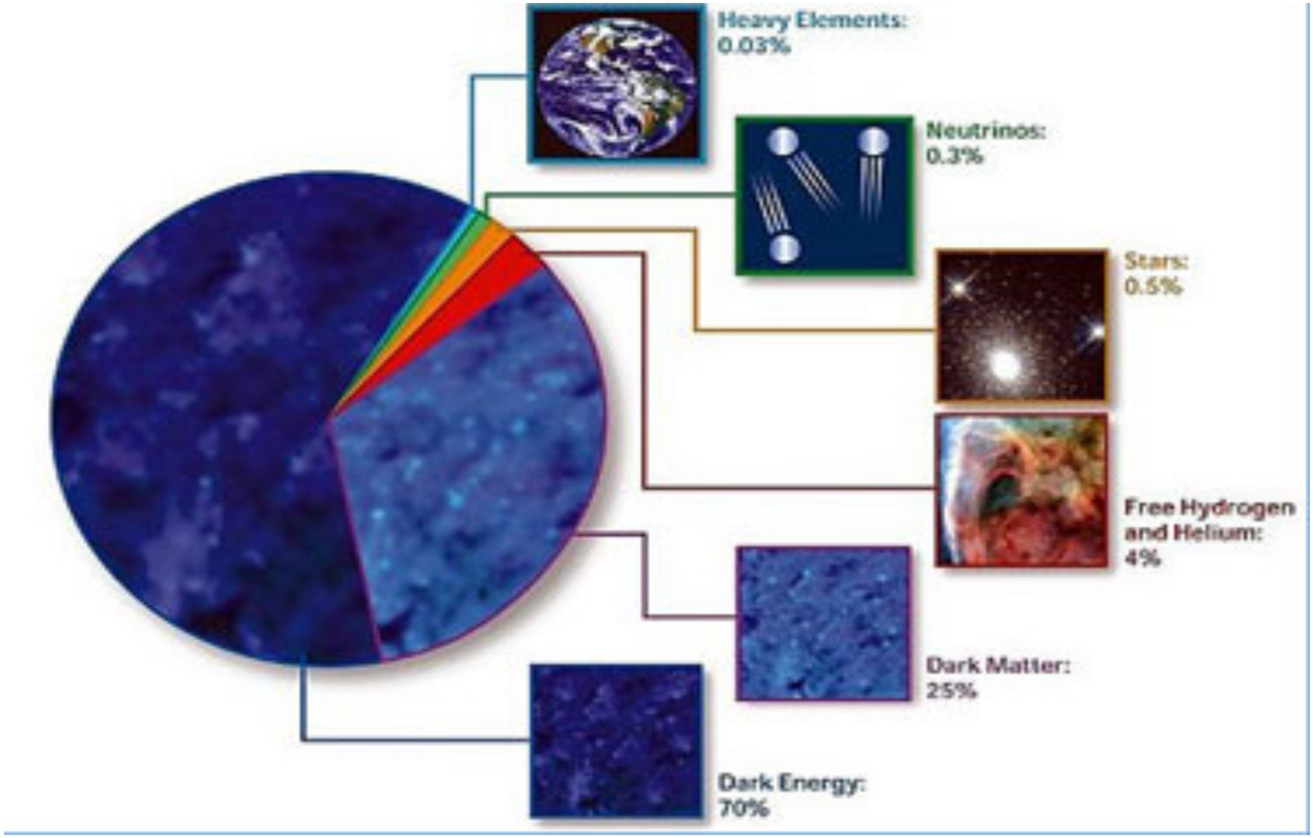


- Euclid/CSS-OS Project office
- Euclid Transient SWG
- Void BAO (cf Zhao Cheng)
- Combinations of probes
- **DM directional detector**



April 2019 – **Shanghai SJTU FCPPL meeting**

Our mysterious Dark Universe !



What we identify today is only 5 +/- O(1) % of the energy density of the Universe

Graph source: Wikipedia

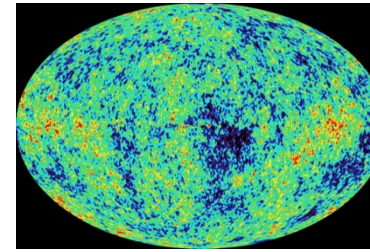
The concordance model stands quite strong!

CMB

Snapshot at ~400,000 yr, viewed from z=0

Angular diameter distance to z~1000

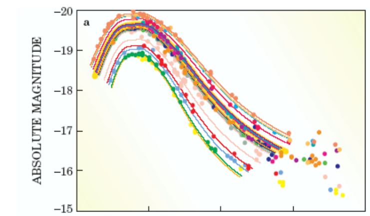
Growth rate of structure (from ISW)



Supernovae

Standard candle

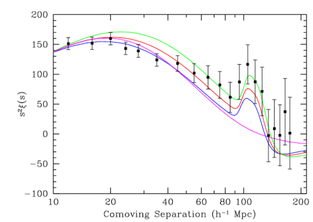
Luminosity distance



Baryon Wiggles

Standard ruler

Angular diameter distance

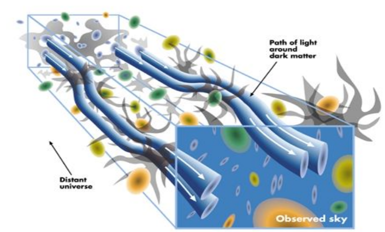


Cosmic Shear

Evolution of dark matter perturbations

Angular diameter distance

Growth rate of structure

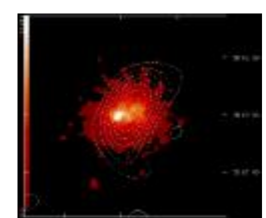


Cluster counts

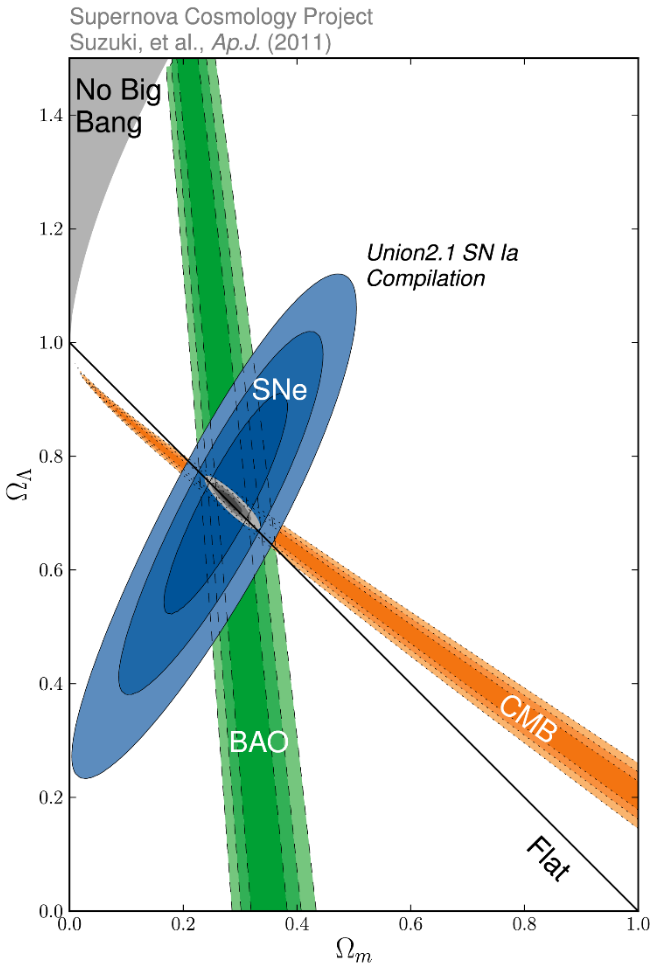
Evolution of dark matter perturbations

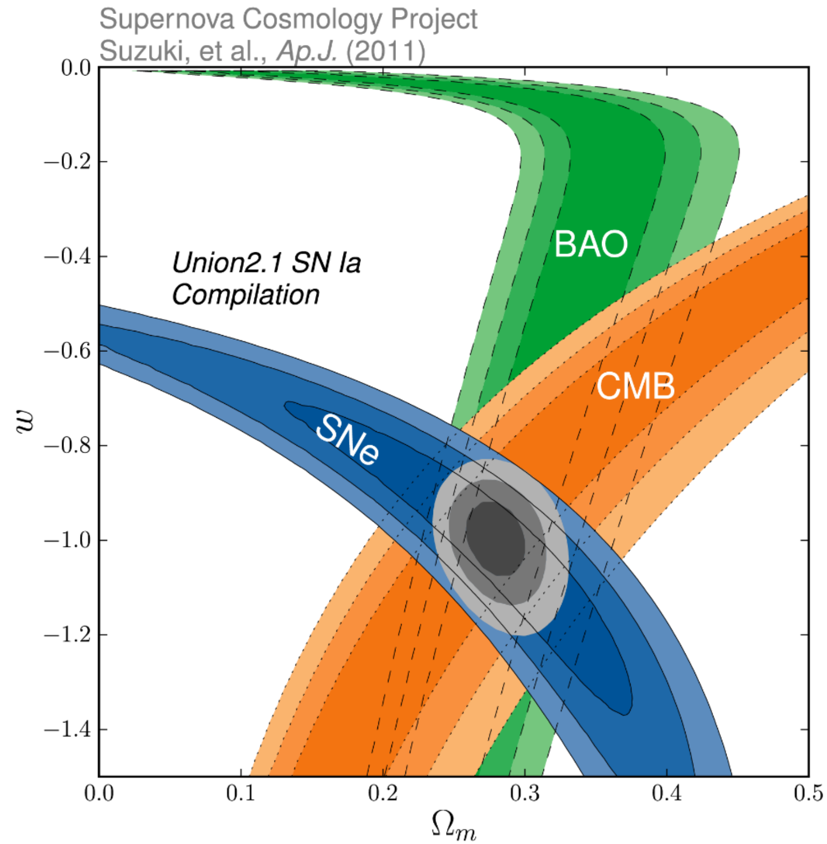
Angular diameter distance

Growth rate of structure



Combination of probes to constrain cosmological parameters





Concordance Λ–CDM model !

Lambda: Cosmological Constant

Eisntein's equations

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

$$R_{\mu\nu} - 1/2\ g_{\mu\nu}(R - \Lambda) = 8\pi\ G\ T_{\mu\nu}$$

Add a constant in Einstein's equations
Or new form of Energy

Introduced by Einstein in 1917 paper NOT to keep the Universe constant,
But to define limiting conditions at infinity!

Cosmological Parameters

- Precise shape of angular spectrum of fluctuations depends on
  - Space curvature
  - Dark energy density
  - Baryonic matter density
  - Dark Matter density
  - Rate of expansion of the Universe H_0
  - initial amplitude of density fluctuations
  - spectral index of power spectrum $P(k)$
  - normalisation and spectral index of eventual tensor perturbations
  - mass and number of neutrino families
  - reionisation moment
  - parameters characterising quintessence, topological defects, etc.

Cosmology Highlights 2018

- DE or Cosmological constant ?

- Is there DM? What DM?

Friedmann Equation with dark energy

w_Λ=-1

$$\frac{H^2}{H_0^2} = \left[\frac{\Omega_{r,0}}{a^4} + \frac{\Omega_{M,0}}{a^3} + \Omega_{\Lambda,0} + \frac{1-\Omega_{T,0}}{a^2}\right]$$

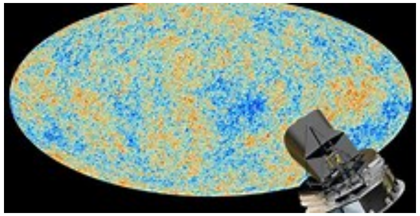
w_{DE} variable

$$\frac{H^2}{H_0^2} = \left[\frac{\Omega_{r,0}}{a^4} + \frac{\Omega_{M,0}}{a^3} + \frac{\rho_X(a)}{\rho_X(0)}\Omega_{X,0} + \frac{1-\Omega_{T,0}}{a^2}\right]$$

$$\frac{\rho_X(a)}{\rho_X(0)} = \exp\left[3\int_{a_0}^{a}(1+w(a'))d\ln a'\right]$$

$$\frac{\dot{\rho}}{\rho} = -3(1+w)\frac{\dot{a}}{a}\,, \qquad d\ln\rho_X(a) = -3(1+w(a))d\ln a$$

Planck 2018



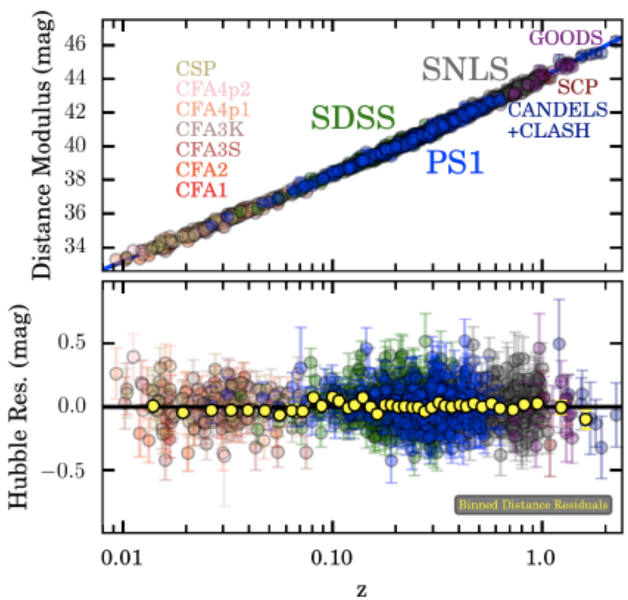
VI. Cosmological parameters

- **stable** compared to previous releases
- Polarization better understood: **0.5 σ** systematics uncertainty
- Planck alone **fits well ΛCDM**, and rather internally consistent
- (Planck + ΛCDM) **consistent with latest results** BAO, SN (Pantheon Scolnic 2018) , RSD, DES lensing 2018
- (Planck + ΛCDM) has **slight tension with DES joint probes**

Pantheon SN IA sample

Scolnic et al, 2018

+ subset of 279 PS1 SN Ia (0. 03 < z < 0.68)
+ SDSS, SNLS, various low-z and HST
total of 1048 SN Ia 0. 01 < z < 2.3,



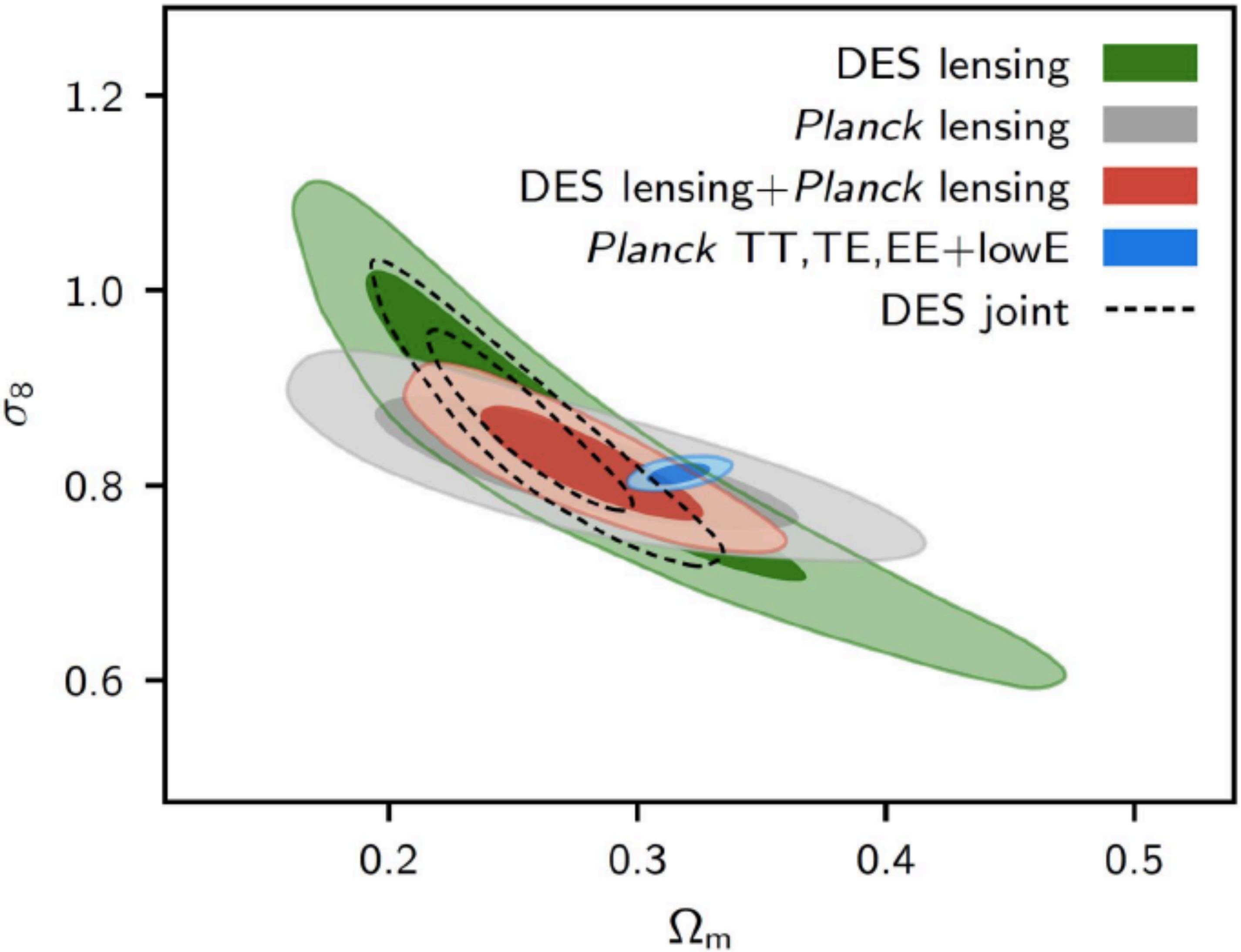
+ Planck 2015 CMB in wCDM model
Ω_m = 0.307 +/-0. 012
w = 1. 026 +/- 0. 041

+ SN and CMB + BAO and local H0,
in $w_0 w_a$ CDM model.

w_0 = 1. 007 +/- 0. 089
w_a = 0. 222 +/- 0. 407

- Tension with previous PS1 and low-z Sne ↘ , thanks to :
- x 2 in PS1 sample, improved calibration and photometry, and stricter light-curve quality cuts.
- Systematic uncertainties - primarily due to modeling the low-z sample.

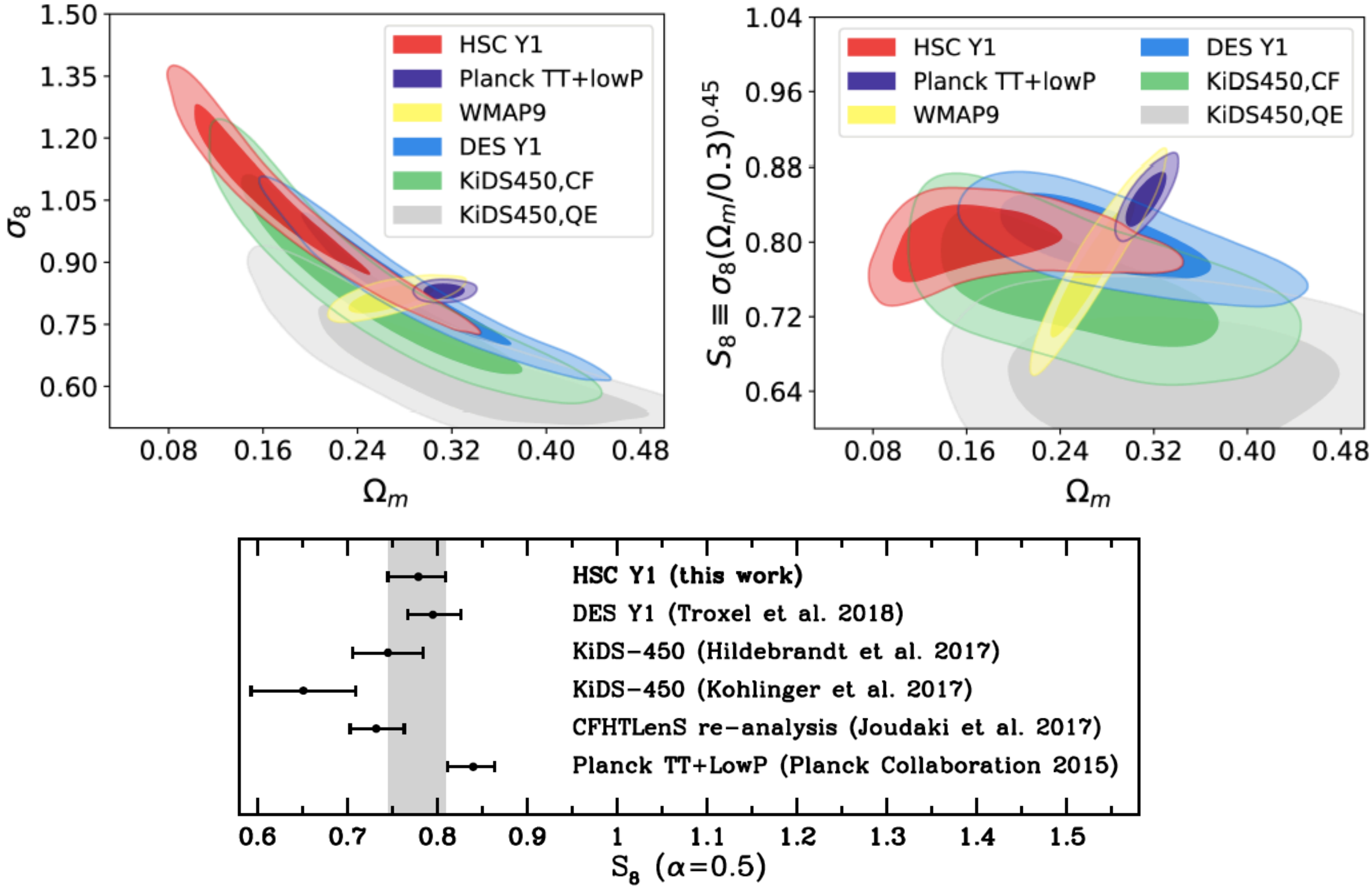
DES 2018



DES lensing
Planck lensing
DES lensing+Planck lensing
Planck TT,TE,EE+lowE
DES joint
1.2
1.0
0.8
0.6
0.2
0.3
0.4
0.5
σ_8
Ω_m

Latest HSC WL data

Hikage et al. 1809.09148

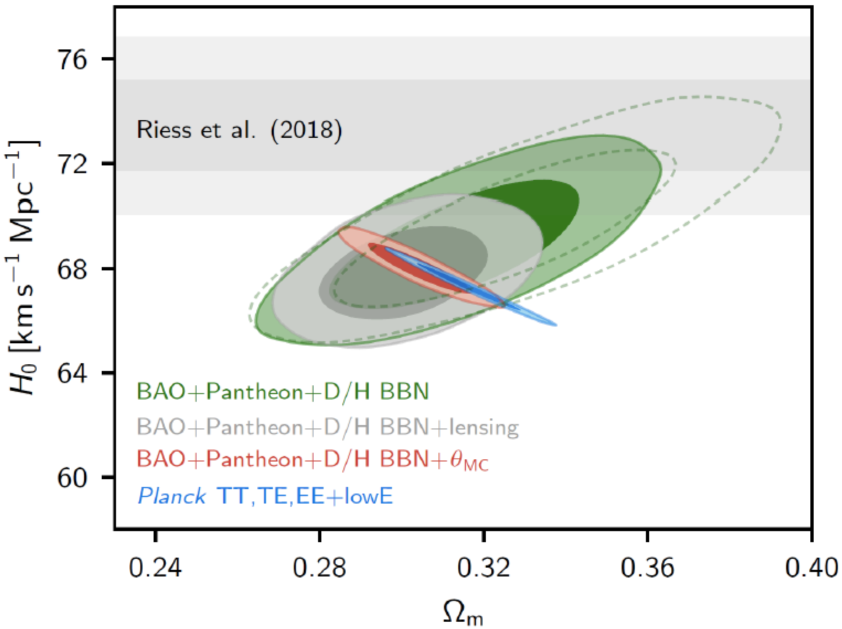


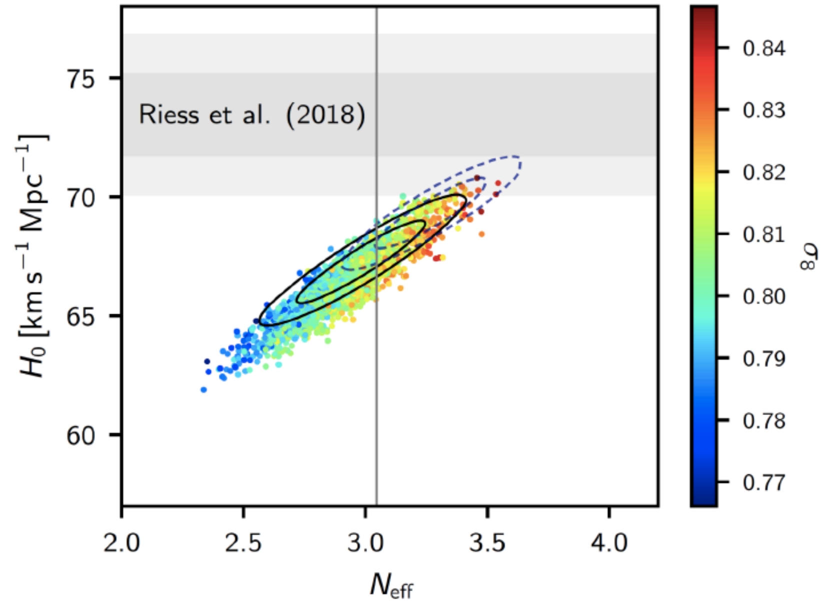
Planck 2018

VI. Cosmological parameters   March 2018

- **stable** compared to previous releases
- Polarization better understood: **0.5 σ** systematics uncertainty
- Planck alone **fits well ΛCDM**, and rather internally consistent
- (Planck + ΛCDM) **consistent with latest results**
  BAO, SN (Pantheon Scolnic 2018) , RSD, DES lensing 2018
- (Planck + ΛCDM) has **slight tension with DES joint probes**
- (Planck + ΛCDM) has **3.6 σ tension with H_0 from SH0ES**

3.6 σ tension between (Planck + ΛCDM) and SH0ES -2018

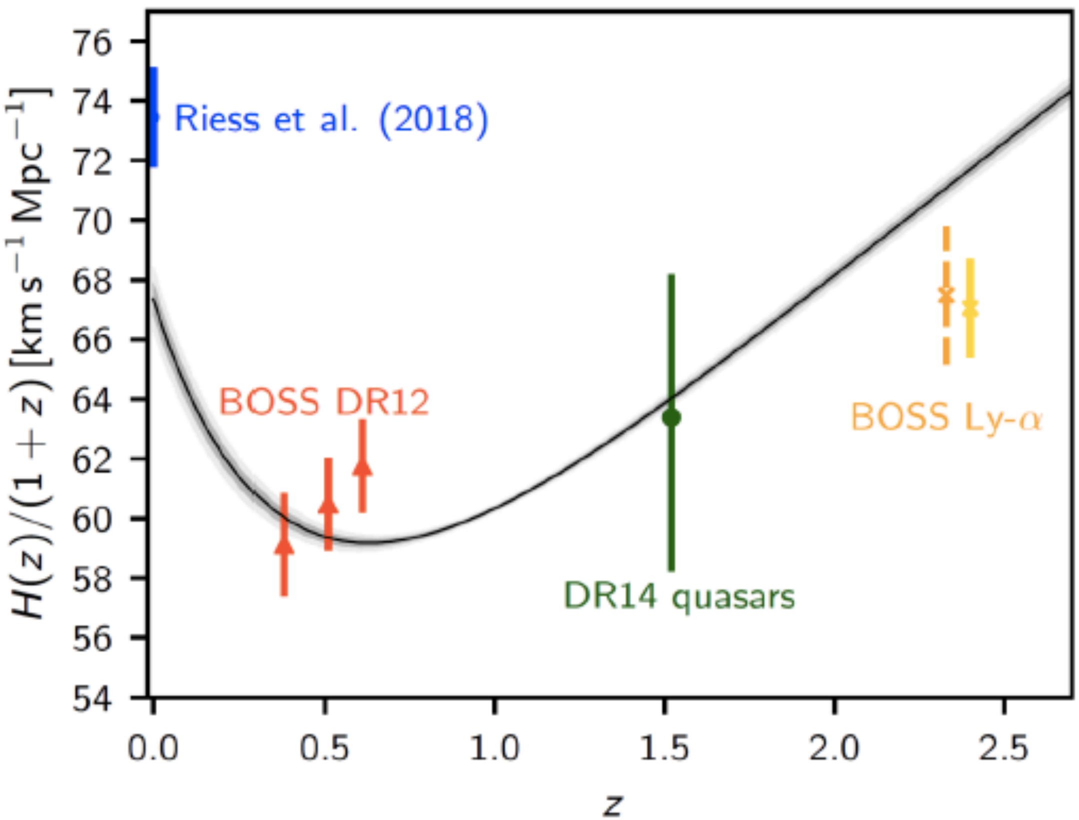




3.6 (now 4.4) σ tension between (Planck + ΛCDM) and SH0ES

Anthony Lewis
2018

Forward ladder measurement (SH0ES, Riess et al.); radial BAO with Planck LCDM $r_{\rm drag}$



Planck LCDM: $H_0 = (67.36 \pm 0.54)$ km/s/Mpc

Riess et al 2018b: $H_0 = (73.52 \pm 1.62)$ km/s/Mpc

Large Magellanic Cloud Cepheid Standards
SH0ES 2019

- An improved determination of the Hubble constant from HST observations of 70 long-period Cepheids in the LMC
- Combining the LMC DEBs, masers in NGC 4258 and Milky Way parallaxes, best estimate:

$H0 = 74.03 \pm 1.42$ km s^{-1} Mpc^{-1}

including systematics, an uncertainty of 1.91%.

- Removing any one of the anchors changes H0 by < 0.7%.

- The difference between H0 measured locally and the value inferred from Planck CMB and CDM

6.6 ± 1.5 km s^{-1} Mpc^{-1} or

$4.4\ \sigma$

(P=99.999% for Gaussian errors)

SH0ES 2019: Riess, Casertano, Yuan, Macri, Scolnic. arxiv 1903.07603

All local geometrical measurements agree!

- **Cepheids and SNIa improvement in stat. and syst.**
- Masers in NGC 4258 (Humphreys et al. 2013),
- Detached eclipsing binaries (DEBs) in the Large Magellanic Cloud (LMC) Pietrzynski et al. 2013,
- Trigonometric parallaxes of Milky Way (MW) Cepheids (Benedict et al.2007; van Leeuwen et al. 2007; Riess et al. 2014; Casertano et al. 2016)
- Tip of the red giant branch (TRGB) to reach SN Ia hosts, ➔ changes < 0.5% for the same sources (Jang & Lee 2017; Jang et al. 2017)
- Dust-insensitive near-infrared SN Ia (NIR, Dhawan et al. 2017)
- Latest time delays from **strong gravitational lensing**.

$H_0 = 72.8 \pm 2.4$ kms^{-1}Mpc^{-1} for realistic values of Ω_M

(Bonvin et al. 2017 **HOliCOW** collaboration)

What about systematics in Planck?

- Result from **Planck is robust** to choice of frequency channels
- **Combination** of BAO, SNIa and CMB data with or without Planck (e.g., WMAP9, Bennett et al. 2013)

  ➔ **low (Planck -like) values of H0**
- ΛCDM model + **BAO data, + light element abundance** (eg baryon-to-photon ratio), without use of any CMB data at all
  ➔ **a Planck-like value of H_0** Addison et al. (2018)

The trouble with H_0 (… or r_s ?)

Bernal, Verde, Riess. arXiv:1607.05617 JCAP 10 (2016) 019

- Measurements are combination $r_d h$,

$H_0 = h \times 100$ km/s/Mpc and r_d is the sound horizon at radiation drag (the standard ruler), constrained by CMB observations.

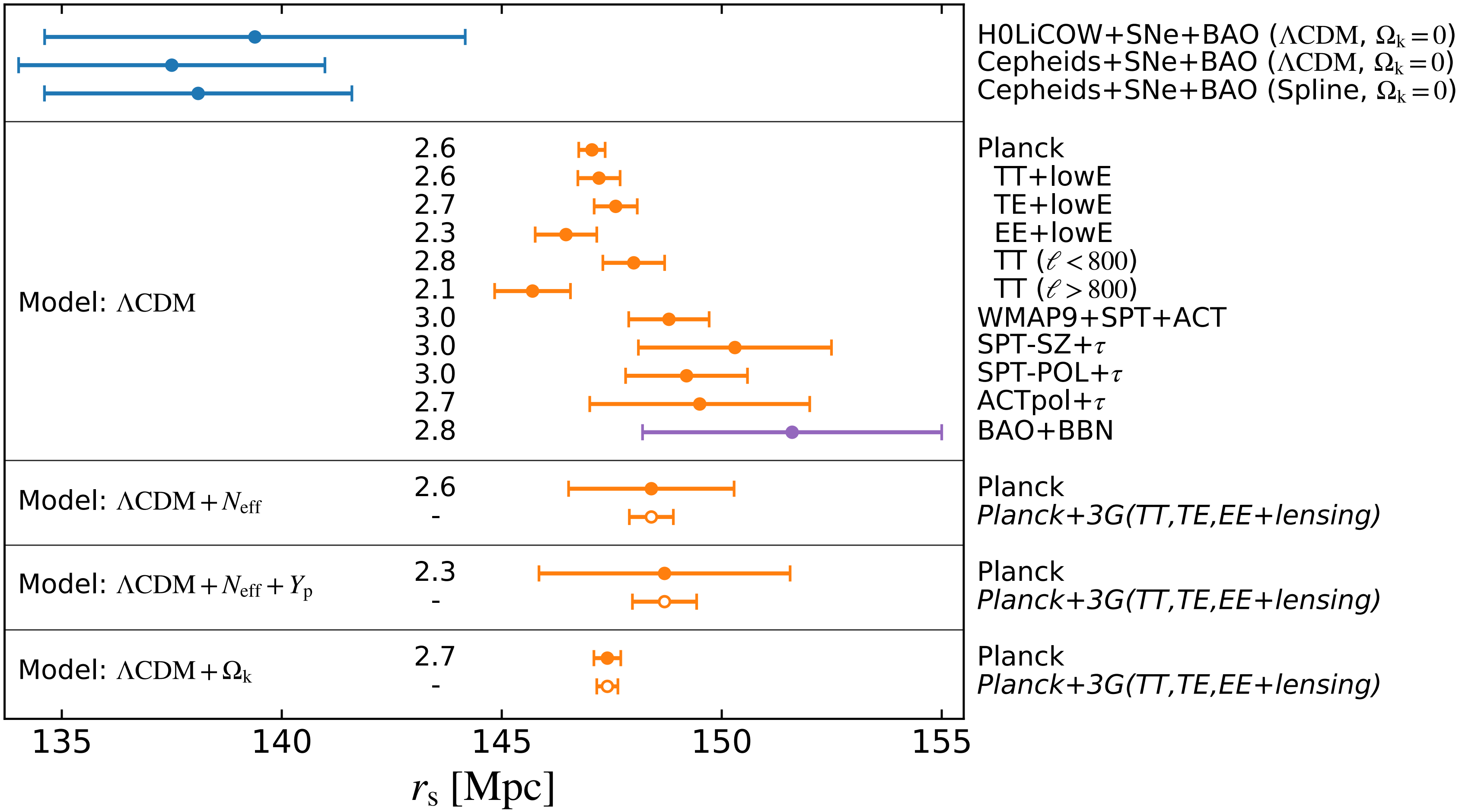
- r_s and H_0 absolute scales for distance measurements (anchors) at opposite ends of the observable Universe

- calibrate the cosmic distance ladder and obtain a model-independent determination of the standard ruler for acoustic scale, r_s.

- **The tension in H_0 reflects a mismatch between the determination of r_s and its standard CMB-inferred value.**

"Sounds Discordant: CLASSICAL DISTANCE LADDER & ΛCDM-BASED DETERMINATIONS OF THE COSMOLOGICAL SOUND HORIZON »

Aylor et al. 1811.00537, Published 2019 March 15 Ap J, 874, Number 1



➔ **Modifications to cosmology are at early times, before recombination, not at late times! ?!**

How to resolve the $H_0 - r_s$ tension?

- **If** it is **early time physics, only CMB** data can give evidence with improved sensitivity on

  acoustic dynamics of the primordial plasma!
- Today's hints of departure from ΛCDM from CMB data are weak
- More results to be expected in the future from CMB in projects like SPT-3G, AdvACT, Simons Observatory, CMB-S4, PICO,…

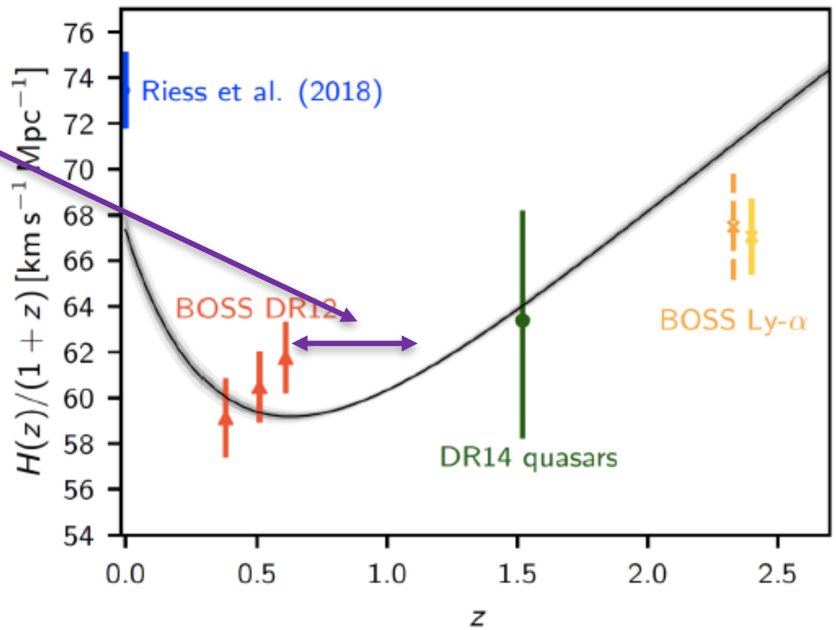
- Cannot exclude today completely **late time physics** and measurement issues!
- improve SN, AGN/quasars, and… Strong Lensing measurements

Where are the Chinese and French?

- Planck
- Some on DES

- Most of us are on eBOSS (June 2019)
- Preparing LSST, Euclid and CSSOS

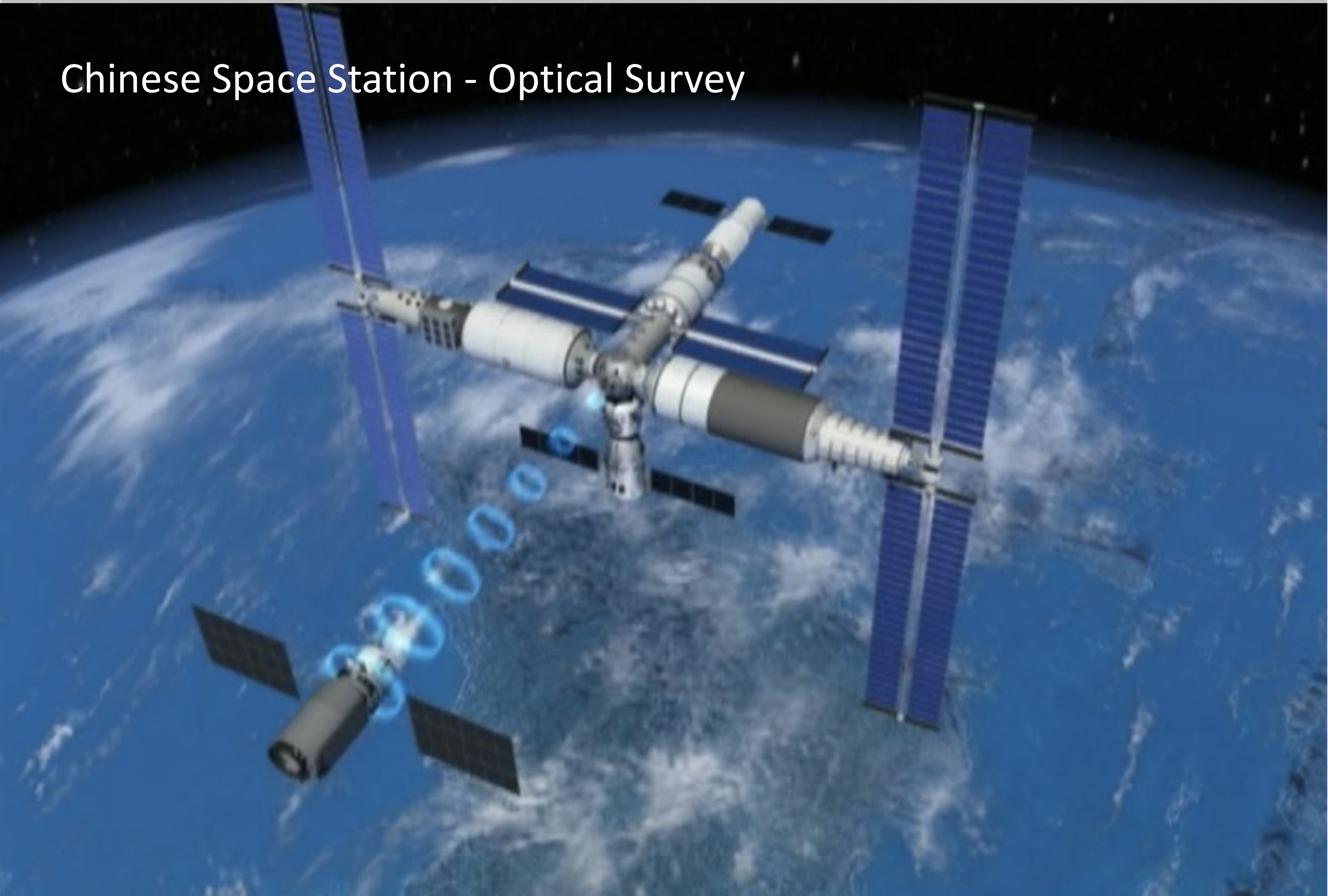
Forward ladder measurement (SH0ES, Riess et al.); radial BAO with Planck LCDM $r_{\rm drag}$



Planck LCDM: $H_0 = (67.36 \pm 0.54)$ km/s/Mpc

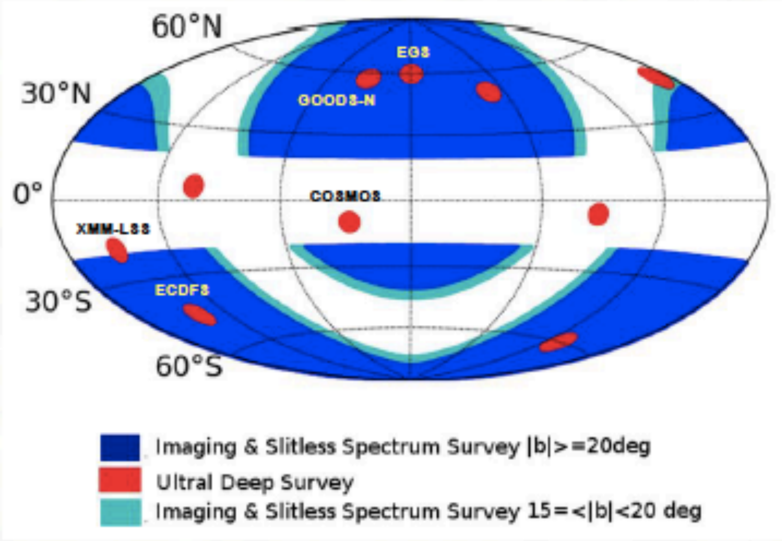
Riess et al 2018b: $H_0 = (73.52 \pm 1.62)$ km/s/Mpc

Chinese Space Station - Optical Survey



Survey Specs

- **17500□° imaging : 255-1000nm, ≥6 filters, avg ≥25.5^m (5σ, point source, AB mag);**
- **17500□° slitless spect: 255-1000nm, R≥200, ≥20-21^m/res;**
- **400□° deep imaging & spect: at least 1^m deeper.**



Ecliptic Coord.
Deep fields will be finalized later; sim results for demo only.

Science

Cosmology: dark energy, dark matter, gravity, large-scale structure, neutrinos, primordial non-Gaussianity…

AGNs: high-z AGNs, clustering, dual AGNs, variability, UV excess, host galaxies…

Galaxies: formation & evolution, mergers, high-zs, dwarfs, LSBs, near field, halos properties…

Milky Way: structure, satellites, dust, extinction…

Stellar science: formation, dwarfs, metal poor…

Solar system (high inclination): TNO、NEA…

Astrometry: reference frame, star clusters…

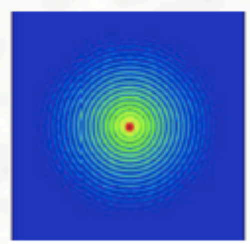
Comparison with Other Surveys

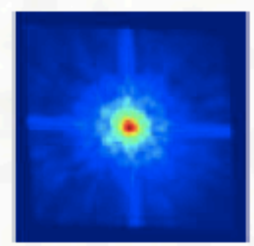
Project	Site/ orbit	Launch /op	FoV	R_{EE80}	Num pixels	Area	Wavelength	Num Filters	Spect
			deg²	"	10^9	deg²	nm		
CSS-OS	LEO	~2024	1.1	0.15 0.074/pix	2.5	17500	255—1000	≥6	yes
Euclid	L2	2022	0.56 0.55	>0.2 pix lmt	0.6 0.07	15000	550—920 1000—2000	1 3	no yes
WFIRST	L2	>2025	0.28	>0.2	0.3	~2000	927—2000	4	yes
LSST	Chile	2022	9.6	~0.5	3.2	18000	320—1050	6	no

R_{EE80}: radius encircling 80% energy

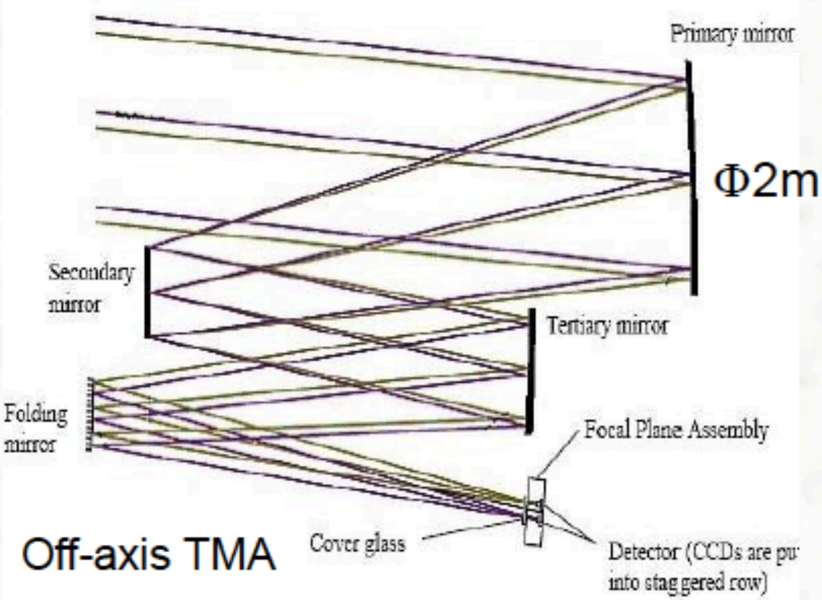
	CSS-OS	HST/ACS WFC	Euclid	WFIRST
R_{EE50}	0.1"	0.06"	0.13"	0.12"
R_{EE80}	0.15"	0.12"	~0.23"	~0.24"

Dynamic sims: R_{EE80} ~0.13"


CSS-OS

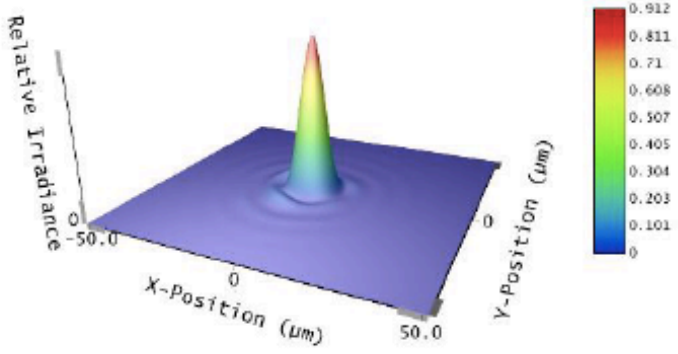

HST

Optical Design & Camera



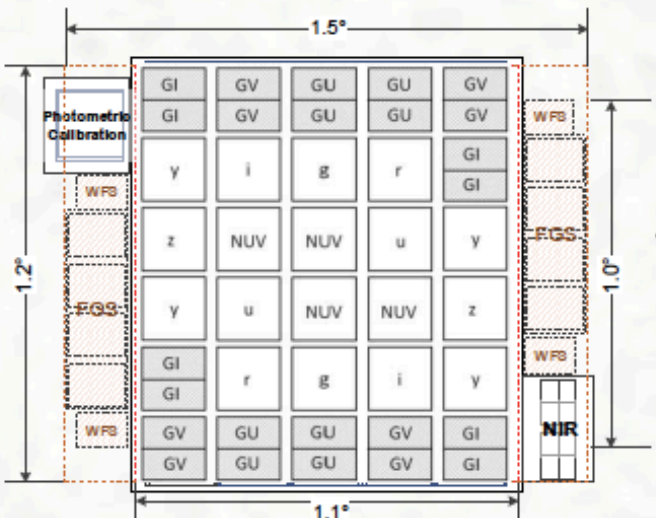
Off-axis TMA

Design PSF @ one corner

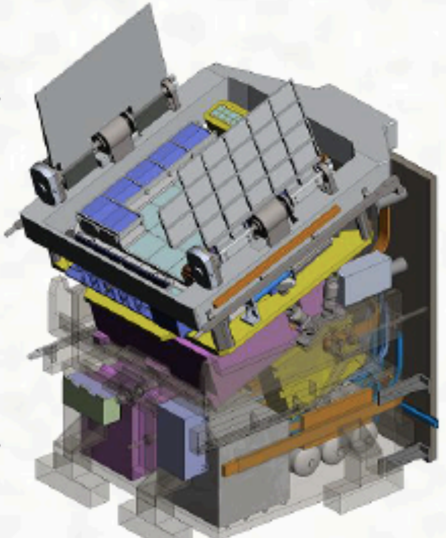


R_{EE80}≤0.15" @ 632.8nm
e_{avg}≤0.05, e_{max}≤0.15

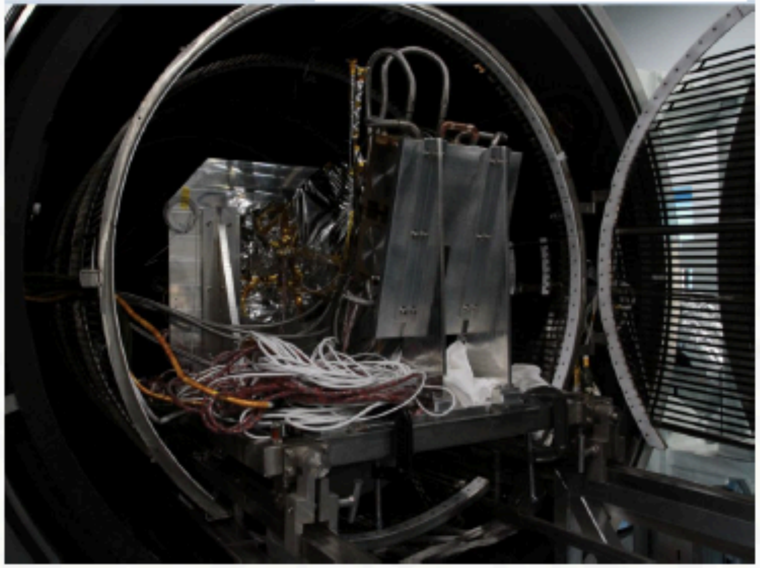
Designed PSF
R_{EE80}<0.11" @ 620nm



Central FoV >1.1 sq deg

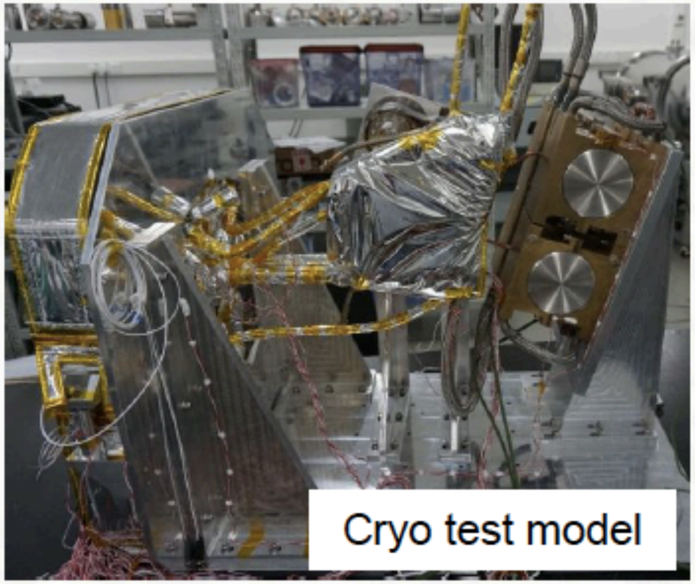


Camera

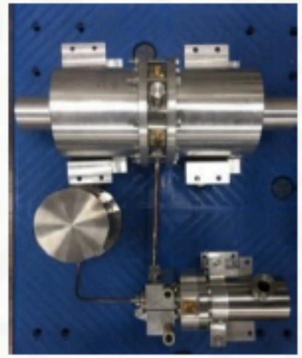


Cryo cooling test

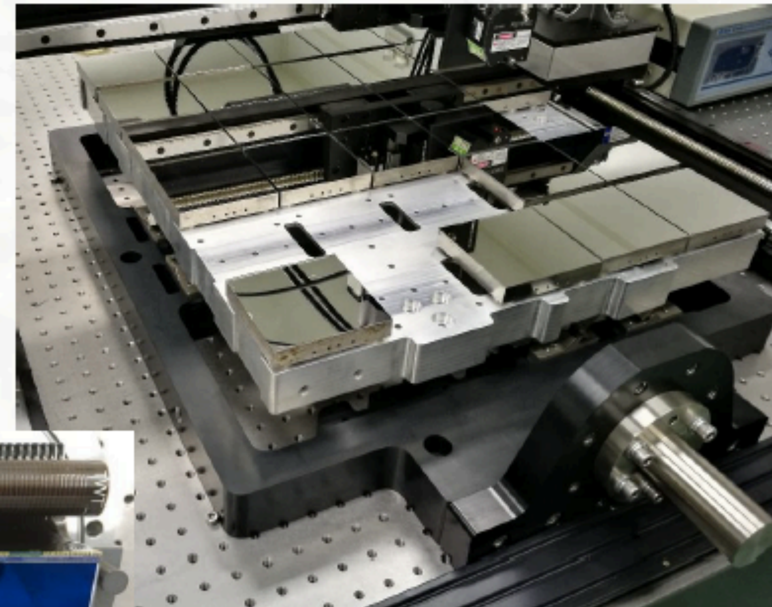
Camera Technology Demonstration



Cryo test model

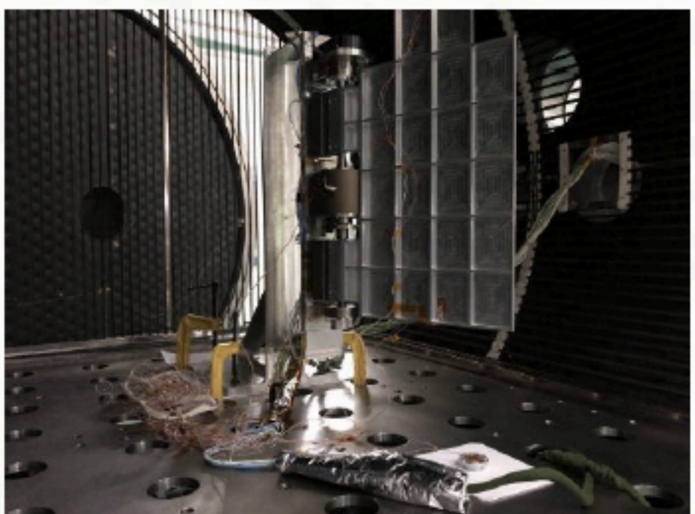


cryocooler

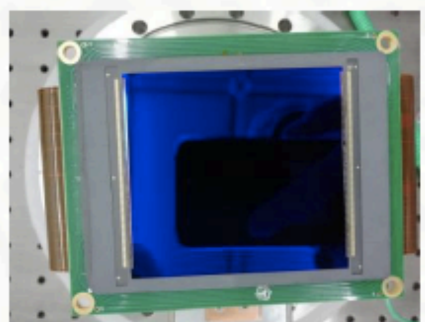


Mock focal plane

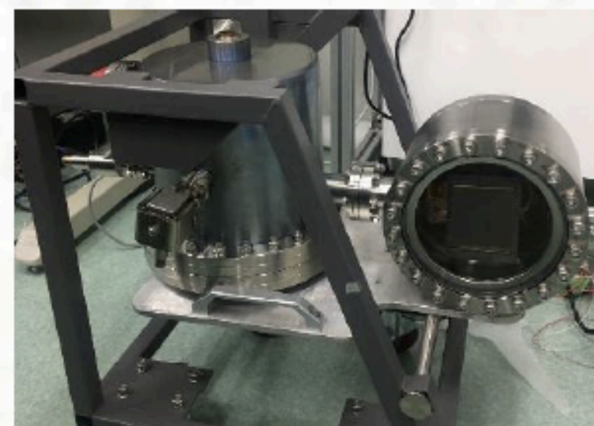
4.6k×11k CCD



Shutter (1.5M+ ops)



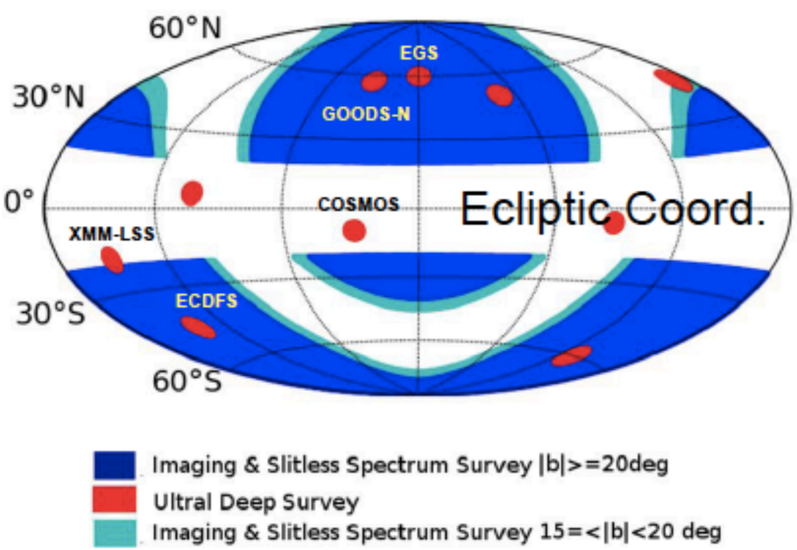
6k×6k CMOS



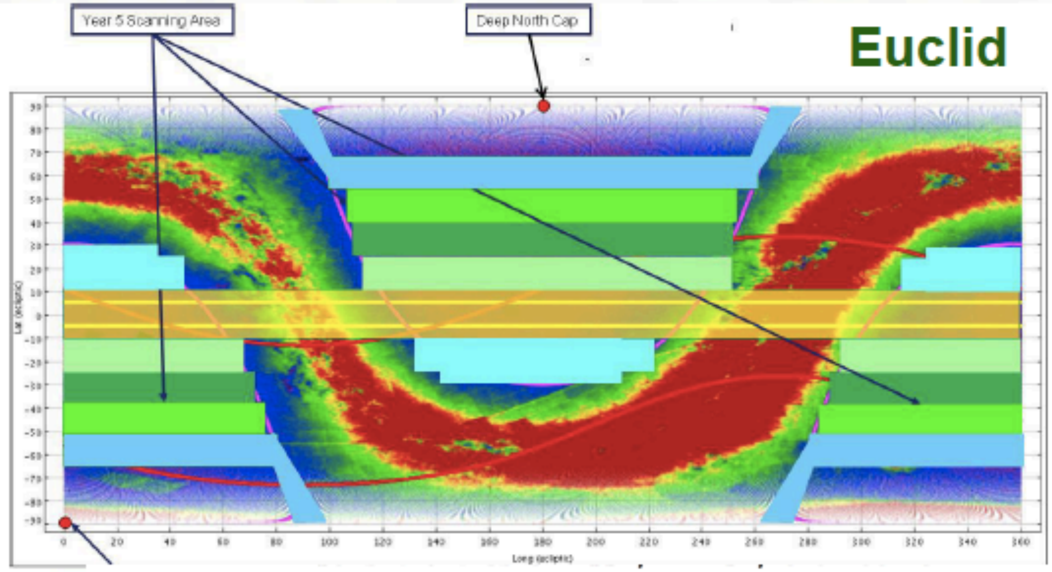
Test Dewar

Complementary Observations

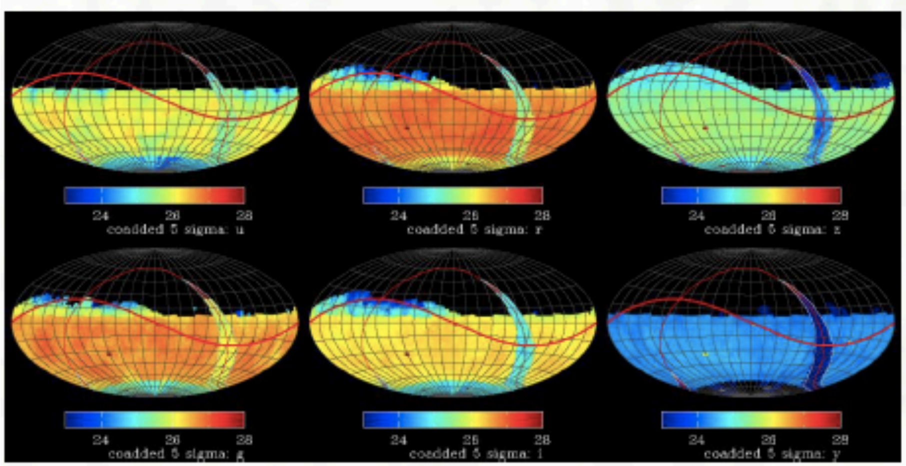
CSS-OS

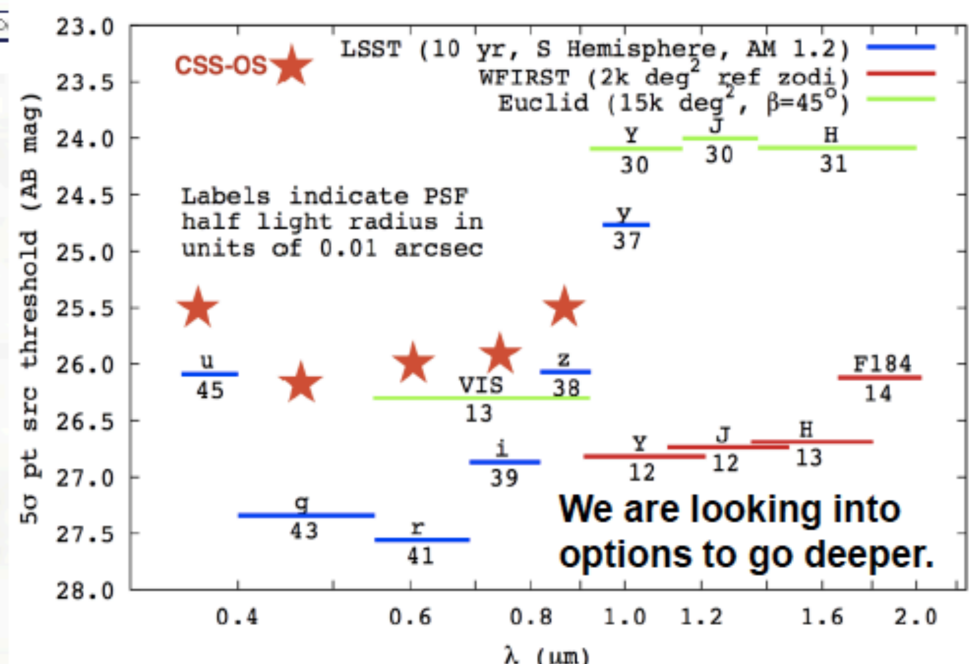


Euclid



LSST

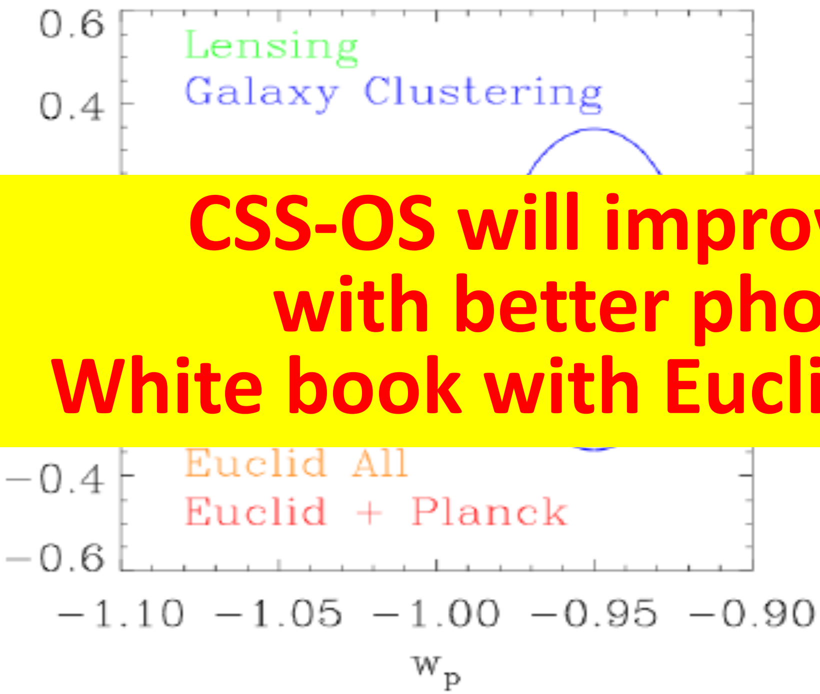




EUCLID

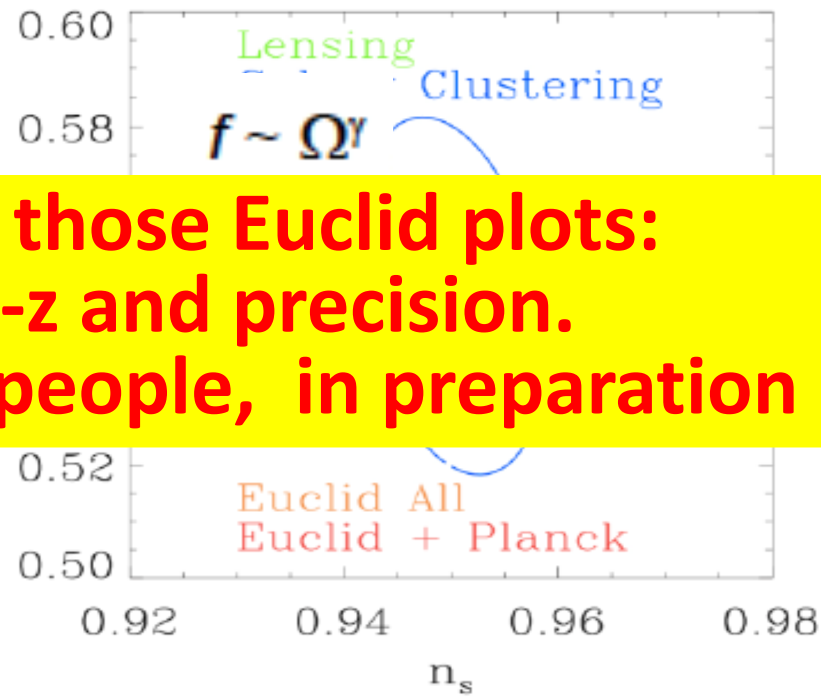
- DE equation of state:

$P/\rho = w$ and $w(a) = w_p + w_a(a_p - a)$



DE constraints from Euclid: 68% confidence contours in the (w_p, w_a).

- Growth rate of structure formation controlled by gravity:



Constraints on the γ and n_s. Errors marginalised over all other parameters.

CSS-OS will improve those Euclid plots: with better photo-z and precision. White book with Euclid people, in preparation

Ref: Euclid RB arXiv:1110.3193

What can CSS-OS/ Euclid do for H_0?

- SNIa   cadence issues
- AGN/Quasar
- Strong Lensing Time delays

not easy – need complementary data

Euclid and Strong Lensing

Three main classes of lenses:

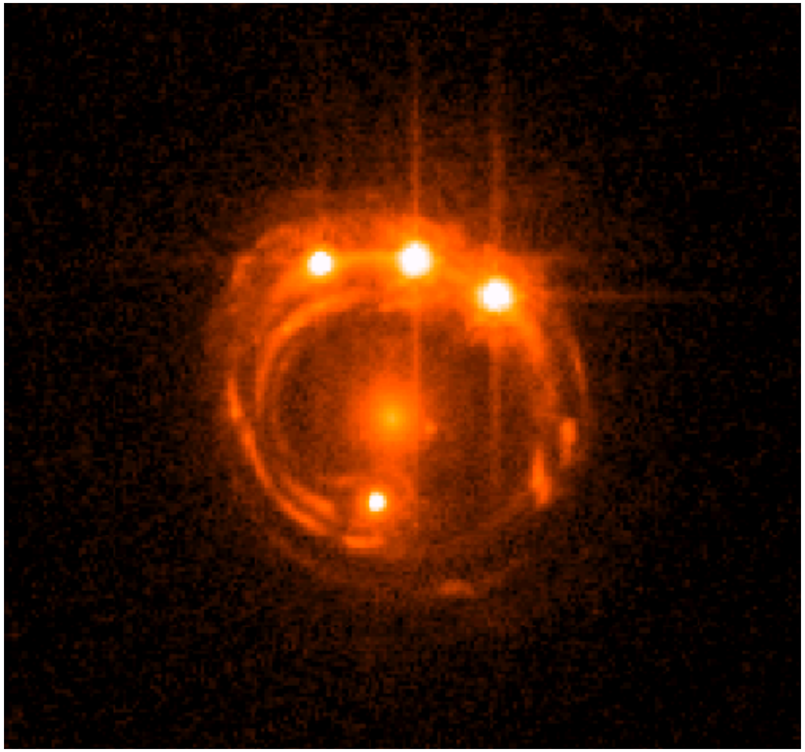
- Individual massive galaxies
- Galaxies in groups/clusters
- Massive galaxy clusters

General expectations:

- Galaxies lensed by galaxies: 10/sq deg or O(10^5) for Euclid 15000 sq deg
- QSO lensed by Galaxies : 10^3
- Clusters/groups with giant arcs:

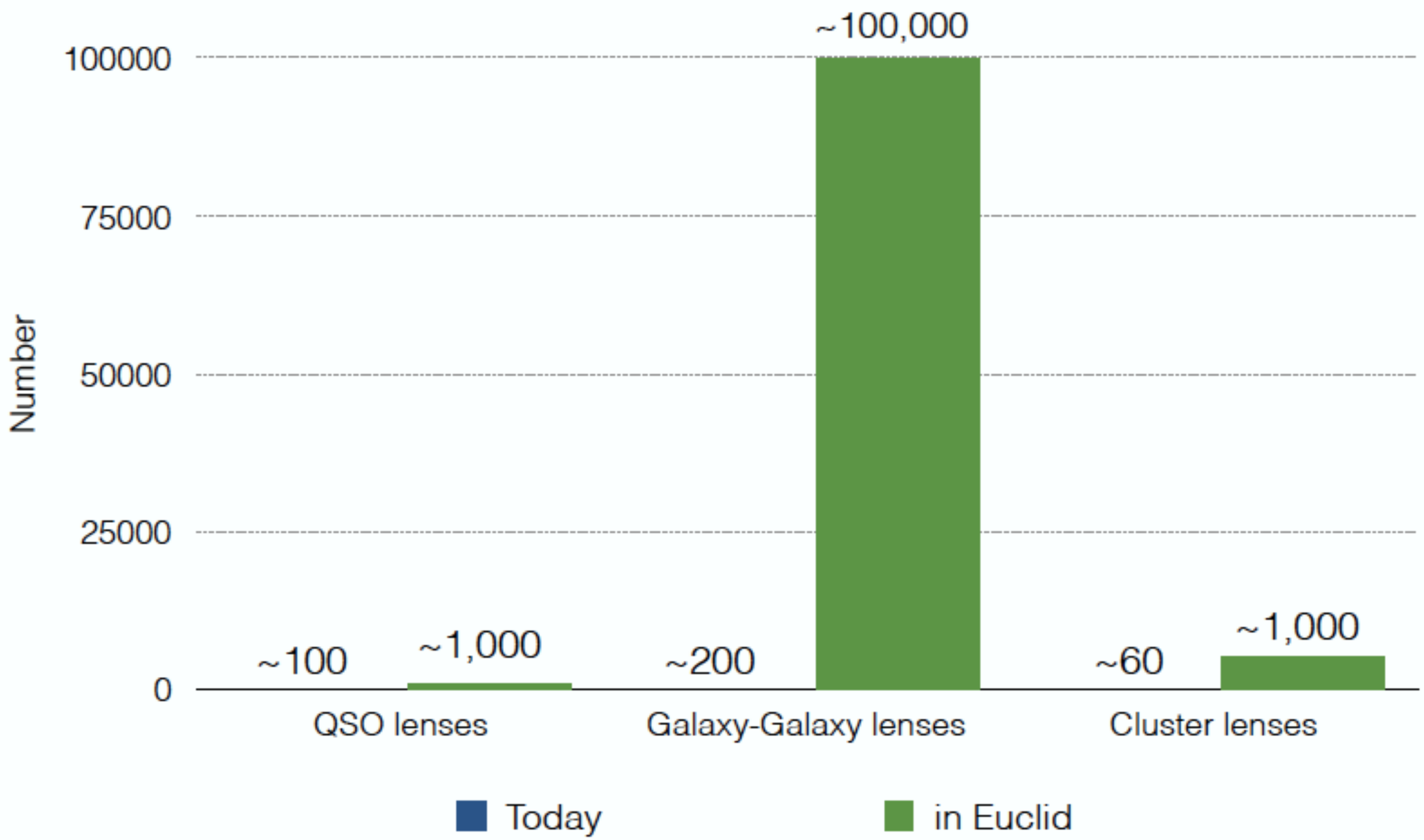
0.5/sq deg or 7500 for Euclid

- Clusters with many multiple images: 100



Example of a strong gravitational lens. quasar RXJ1131-123 is seen quadruple by Hubble Space Telescope,

Numbers of known strong lenses



Future Data Sets : KIDS, DES, Pan-Starrs, LSST, Euclid

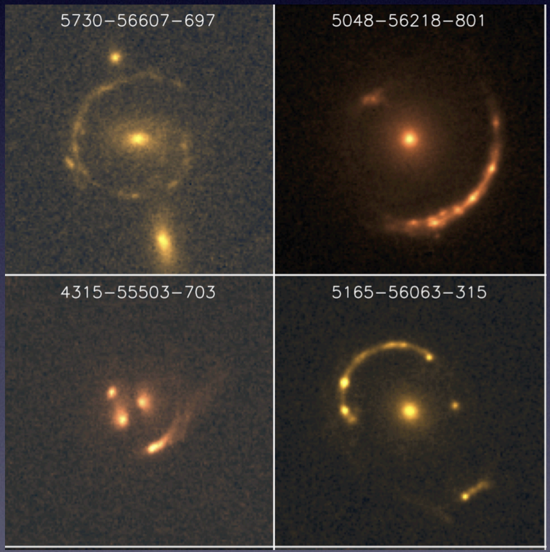
Metcalf, 2015

Expectation for CSS-OS

Li Ran (NAOC)

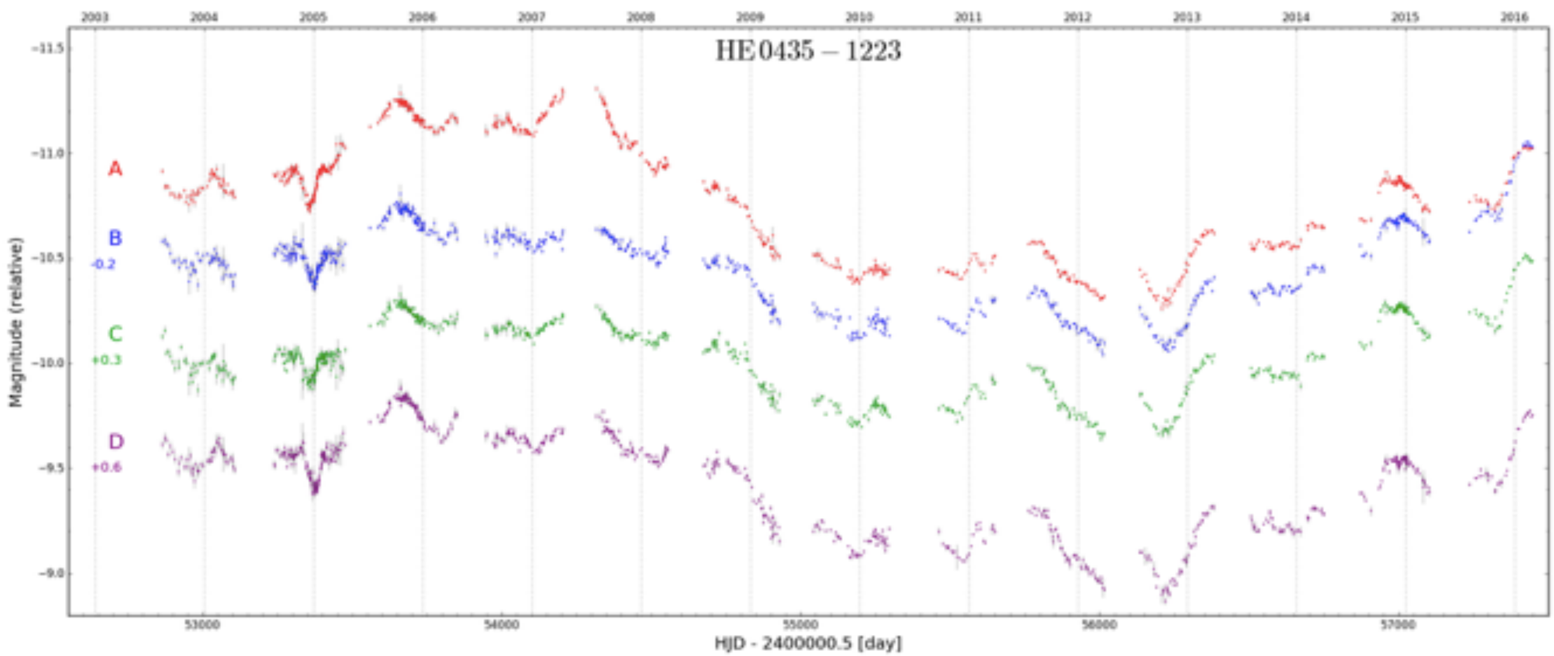
- ~100000 galaxy scale strong lens systems (currently ~400), Including ~1000 double lens system
- Hundreds of massive clusters with many multiple images
- Accurate photo-z for both lens and source.

Provide by Yiping Shu



Challenges for SL determinations of H_0

- Determination of time delays: cadence and time



13-year light curve of HE0435-1223 Time delay with 6.5% uncertainty

- Need to measure/model precisely lens environment
    - Precise imaging
    - Spectroscopy for source and lens redshift
    - Velocity dispersion to mitigate effects of mass sheet degeneracy

Conclusions for SL in Euclid : Metcalf, 2015

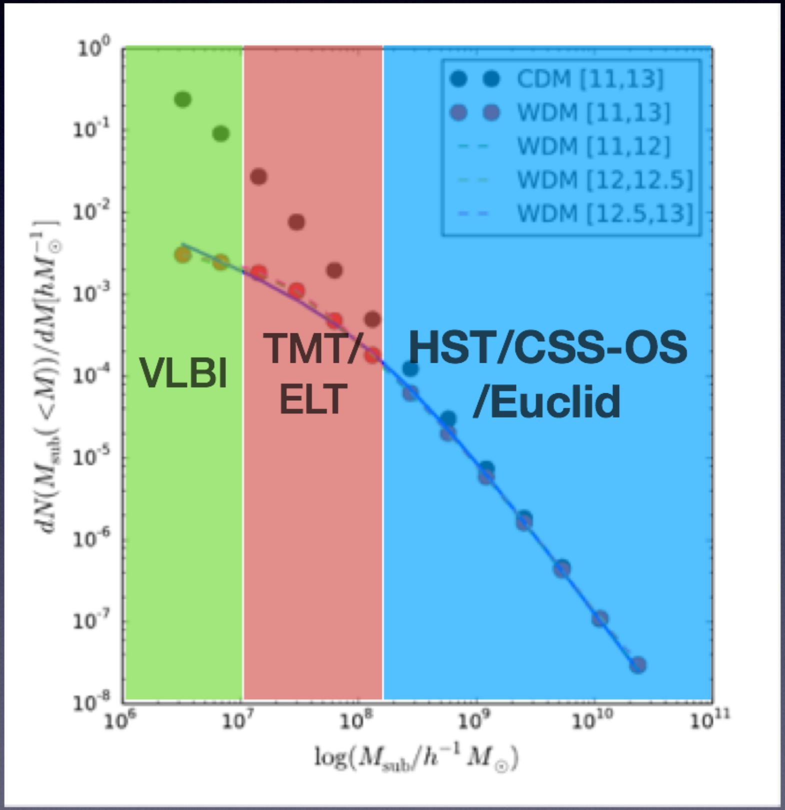
- Future surveys will increase the number of known strong lenses by orders of magnitude.

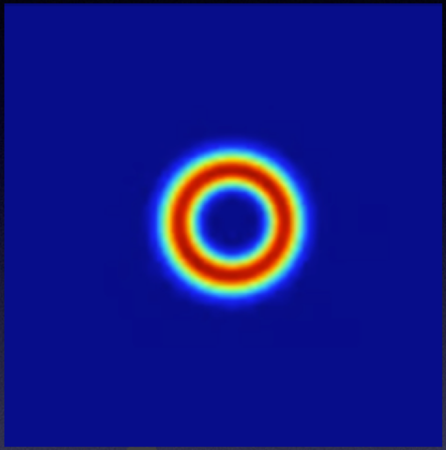
- These lenses will tell us many things about the distribution of matter around galaxies, groups and clusters - small scale structure, separation between dark matter and baryons or possible deviations from GR.

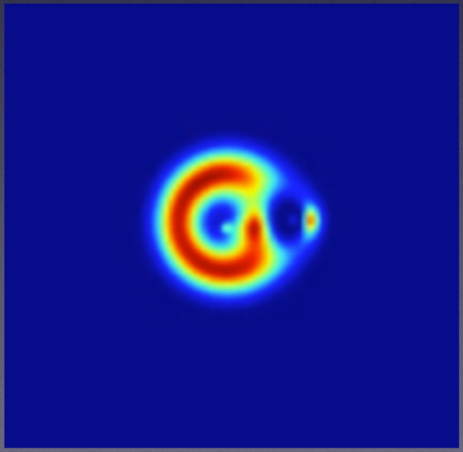
- They will tell us something about cosmology, but it will always be limited by modelling systematics and assumptions about the lenses' mass distribution.

- New tools are being developed to find and analyse strong lenses on a much larger scale.

DM on small scales: Substructure detection



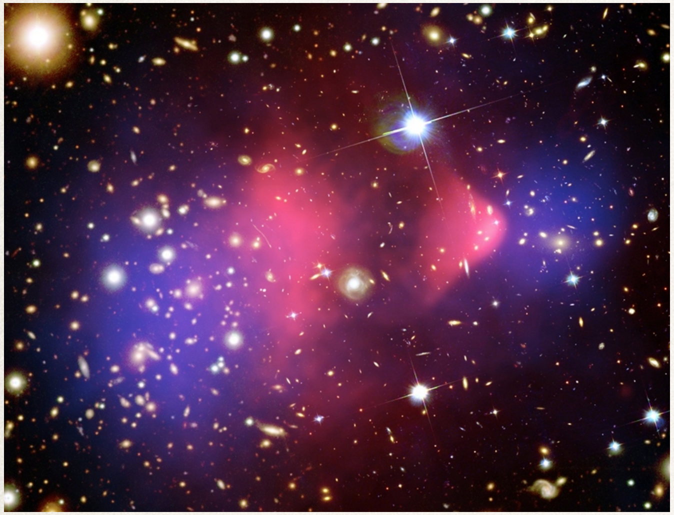


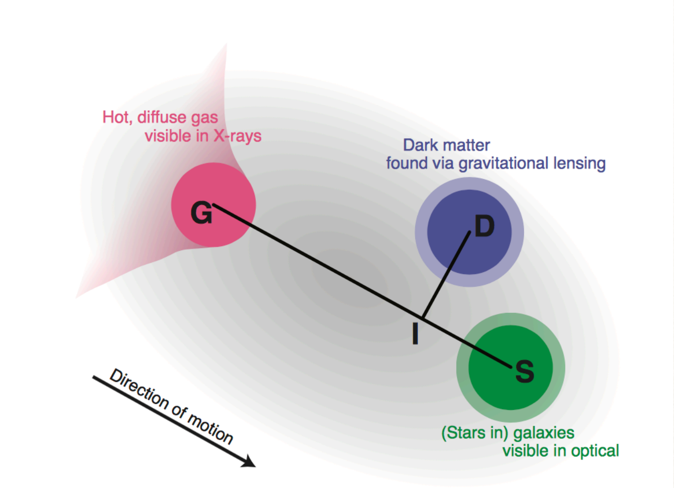


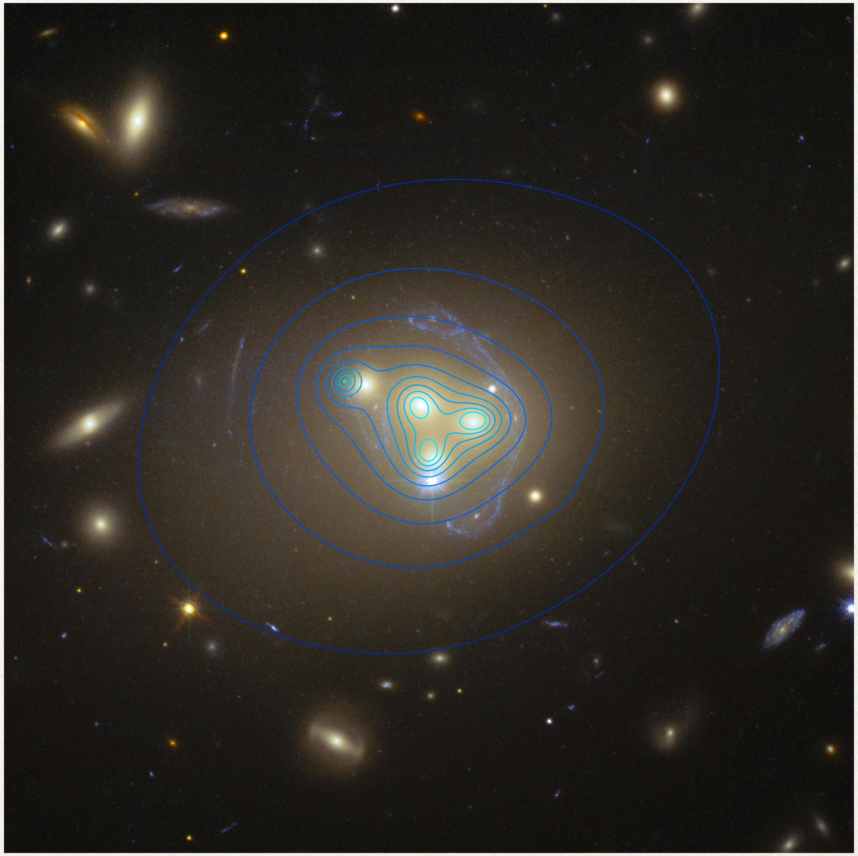
Li et al. 2016 arxiv 1512.06507
CDM vs 3 keV WDM

Li Ran

Self-interacting dark matter?





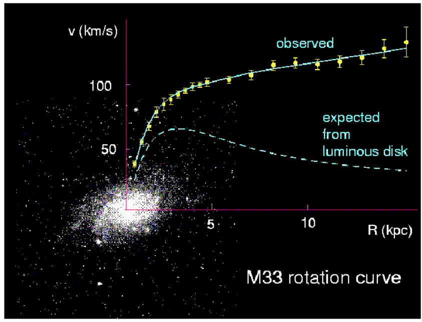


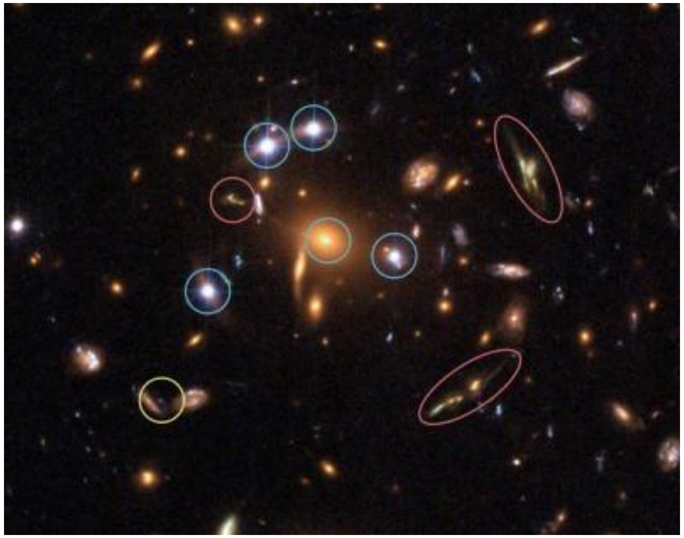
Galaxy cluster Abell 3827
offset is 1.62+0.47 kpc ?

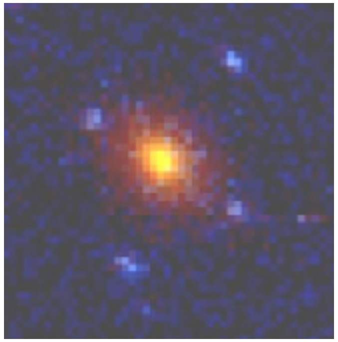
Massey et al. 2015

Wealth of Evidence for DM

- Galaxy rotation curves (V. Rubin)
- Dynamics of galaxy clusters (Zwicky)
- Gravitational lensing mass reconstruction



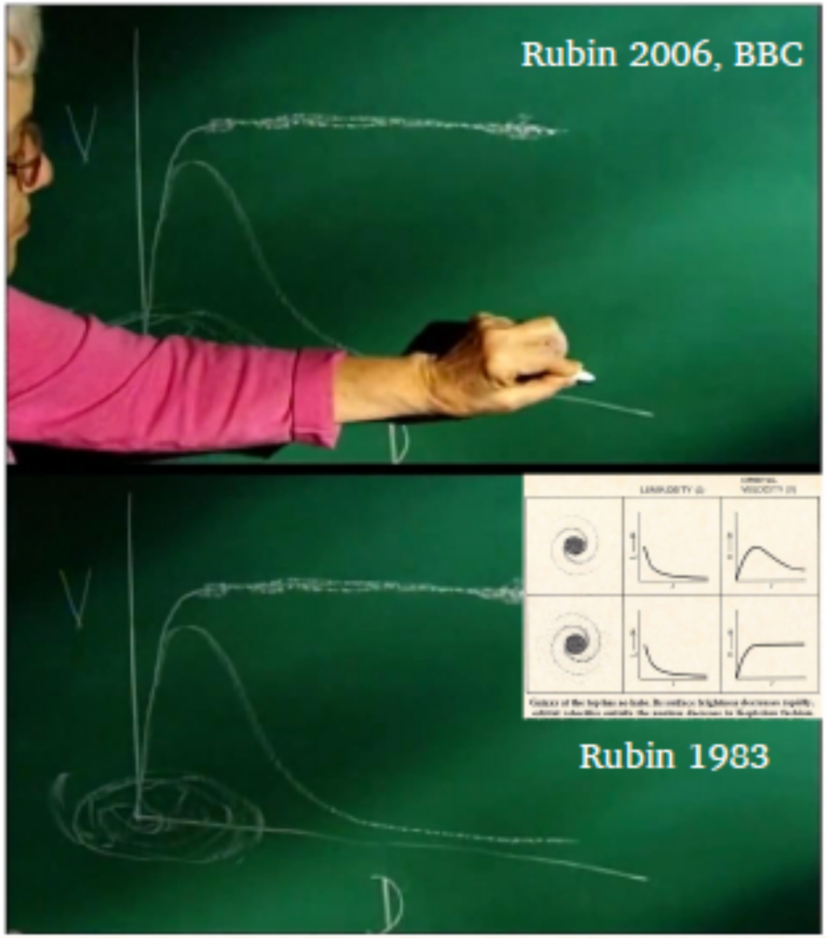




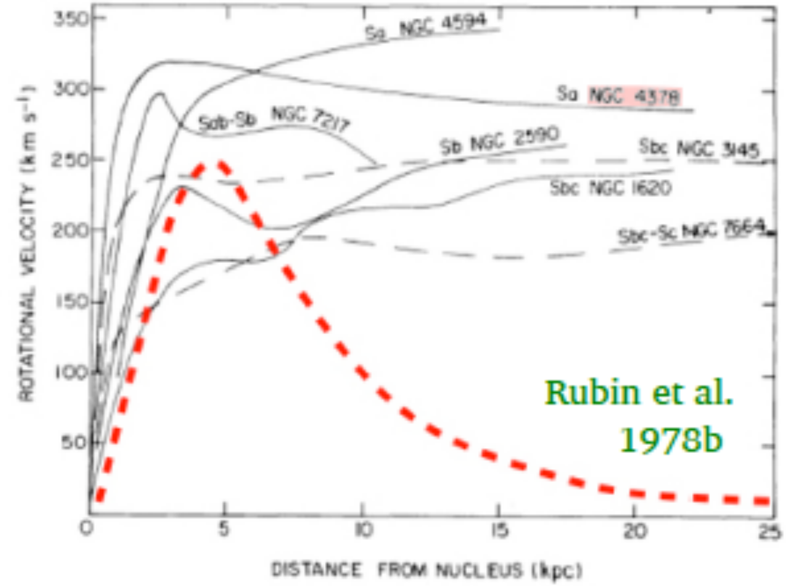
- Bullet cluster (Clowe+,2006)

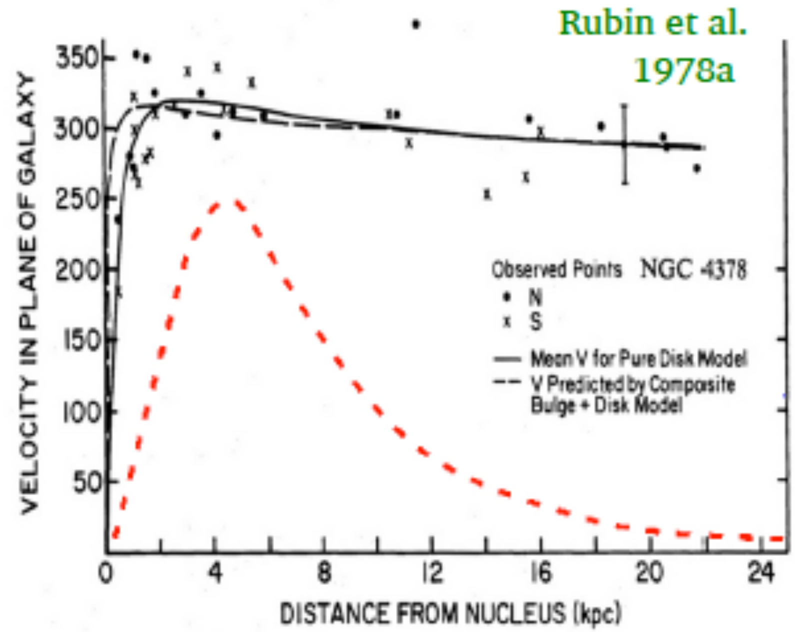
DM: some revisits

Rotation curves : what is often said [incorrectly] to be expected



Galaxy at the top has no halo. Its surface brightness decreases rapidly, orbital velocities outside the nucleus decrease in Keplerian fashion.





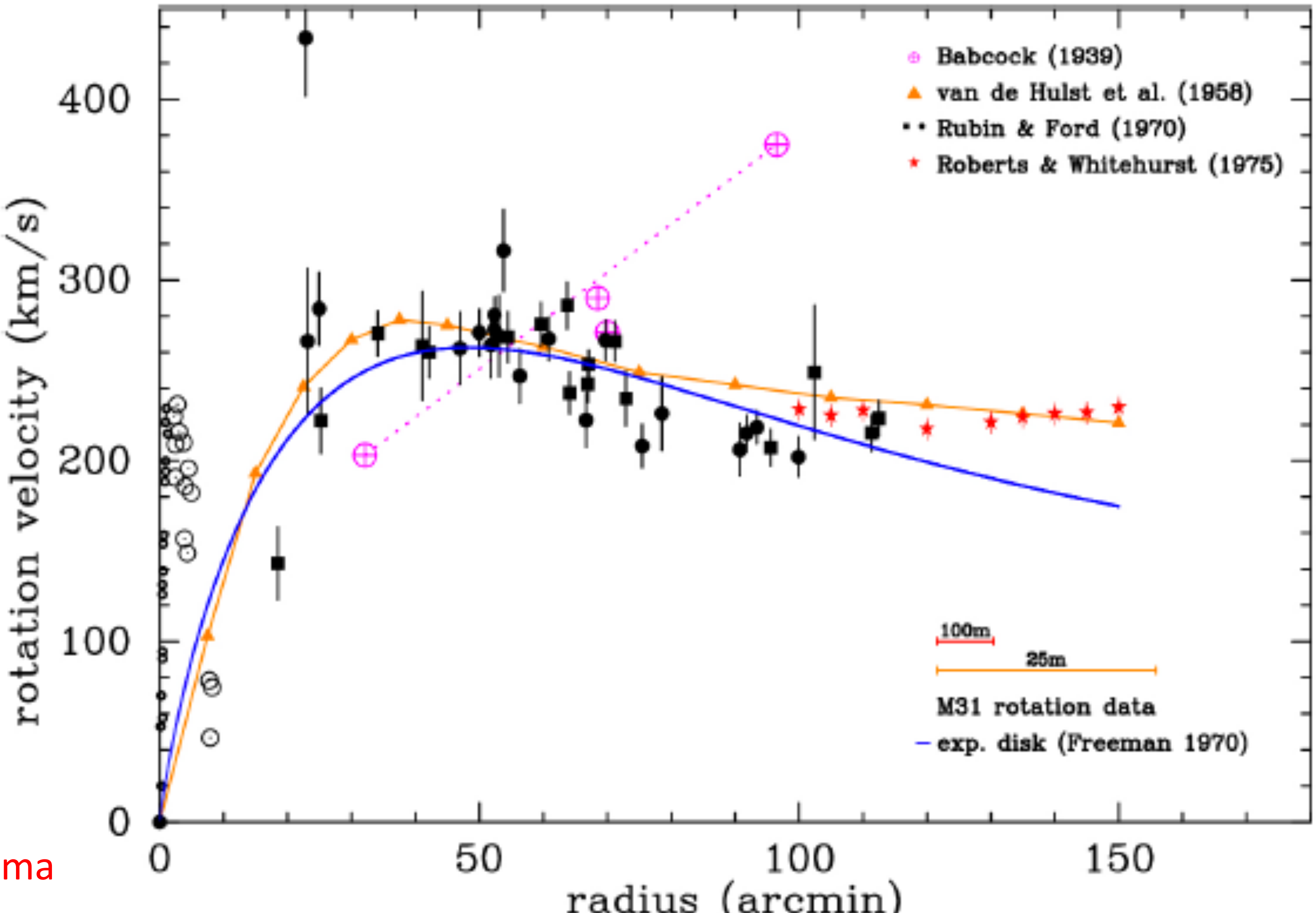
Keplerian behaviour just outside the nucleus can NOT be expected

A. Bosma

Freeman 1970, appendix

For NGC 300 and M33, the 21-cm data give turn-over points near the photometric outer edges of these systems. These data have relatively low spatial resolution; if they are correct, then there must be in these galaxies additional matter which is undetected, either optically or at 21 cm. Its mass must be at least as large as the mass of the detected galaxy, and its distribution must be quite different.

M31 – Need for dark matter based on radio data



A. Bosma

Rotation curve analysis

From data to mass models

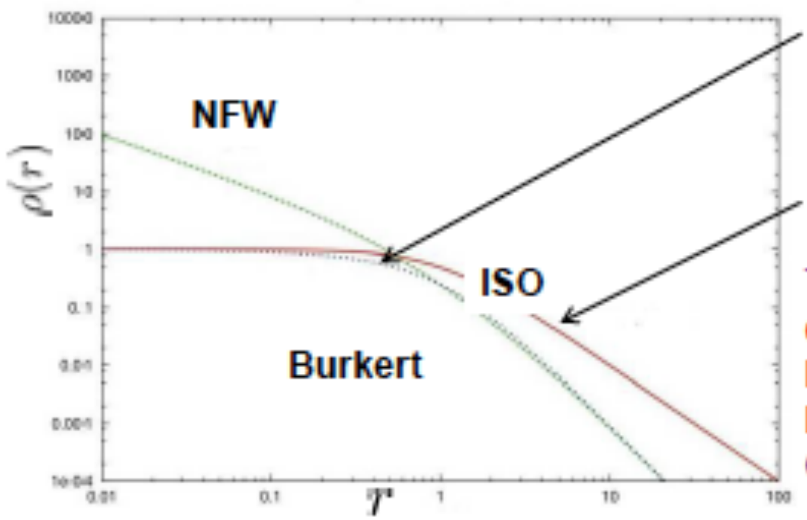
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

observations = model

- V^2_{disk} from I-band photometry
- V^2_{HI} from HI observations
- V^2_{halo} different choices for the DM halo density

Dark halos with central constant density (Burkert, Isothermal)

Dark halos with central cusps (NFW, Einasto)



$$\rho(r) = \frac{\rho_0}{(1 + r/r_0)(1 + (r/r_0)^2)}$$

$$\rho(r) = \frac{\rho_0}{1 + (r/r_0)^2}$$

The mass model has 3 free parameters:

disk mass

halo central density

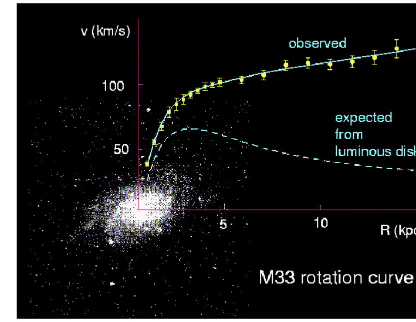
Halo core radius (length-scale)

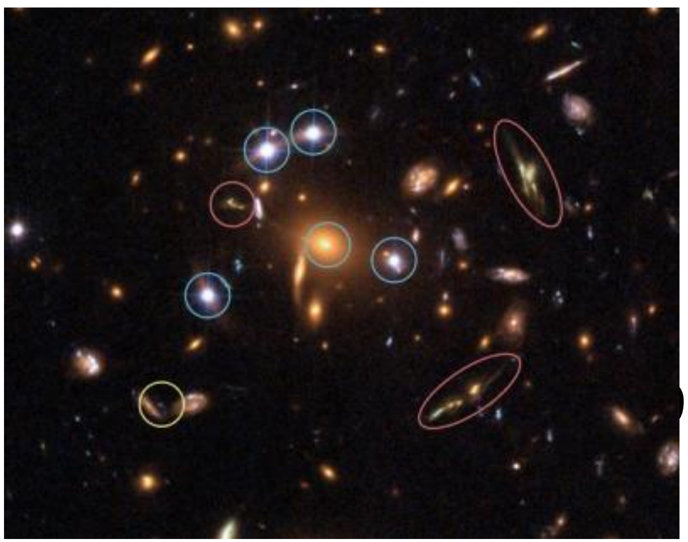
Obtained by best fitting method

P. Salucci, NAOC 2014

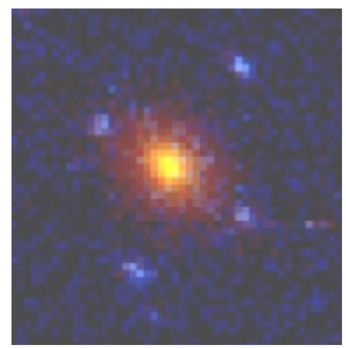
Wealth of Evidence for DM

- Galaxy rotation curves (V. Rubin) Bosma (HI)
- Dynamics of galaxy clusters (Zwicky)
- Gravitational lensing mass reconstruction





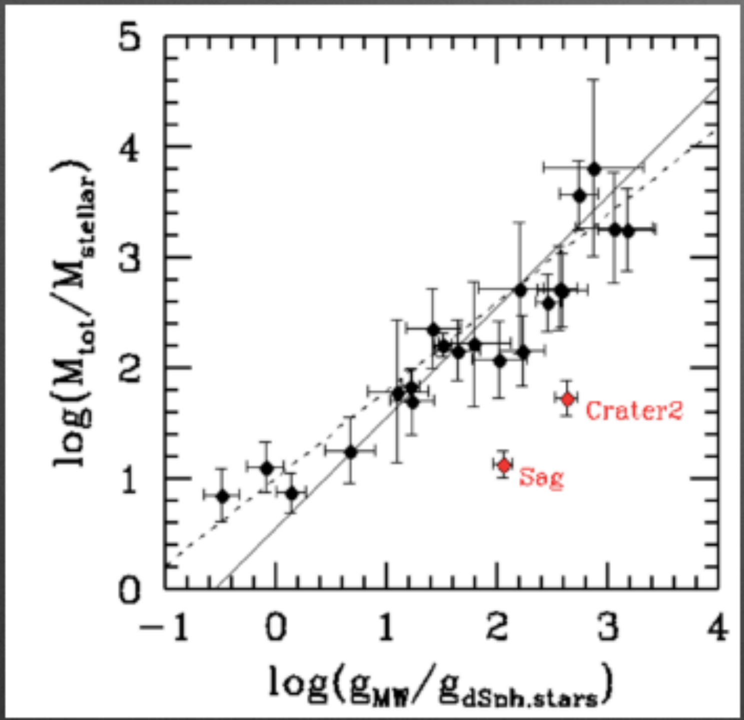
6)

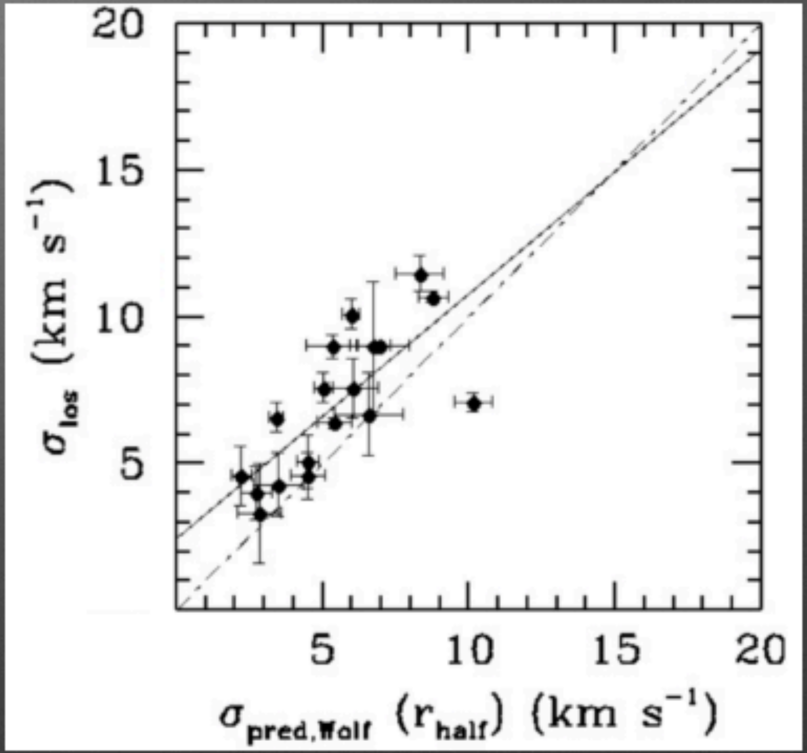


Galactic forces rule dynamics Milky Way dwarf galaxies

Yang Yanbin in Yunnan Sino french meeting Nov 2018

Hammer et al. 2018, ApJ





$$\sigma^2_{los,MW} = \sqrt{2}\, g_{MW}\, r_{half}$$

MW tidal shock predicts

This correlation falsifies the hypothesis of neglecting the MW impact!

NGC1052-DF2 : a Galaxy without DM?

Van Dokkum et al. 2018

➔ **Evidence** for DM! (**against modified gravity**)

Cosmology Highlights 2018

-DE or Cosmological constant ?

- **Planck 2018** : stable
- **SDSS BAO** (Alam et al. 2017), **RSD**
- **SN Pantheon (**Scolnic et al. 2018)
- **DES, KIDS, HSC** (Hikage et al. 2018)

- **H_0 tension** becomes **r_s tension**

- Is there DM? What DM?

- No need for DM in spheroidal dwarves: Hammer et al 2018
- Galaxy without DM van Dokkum et al 2018

➔ Argument for DM

- SL can distinguish between WDM and CDM
- Caveat: Non-linear regions are regions of strong baryonic effects!

Thank you for your attention!

Merci! 谢谢！