EXCELENCIA SEVERO OCHOA

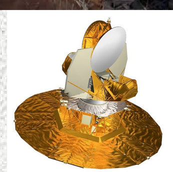
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

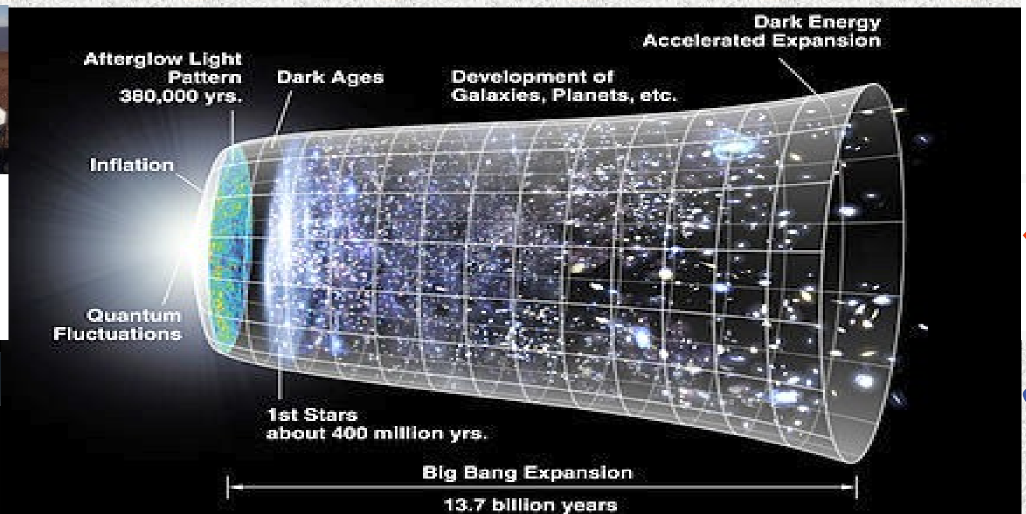
Funded by the European Union

Universidad de La Laguna

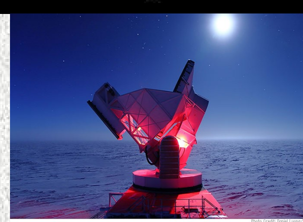
PID-2021-126616NB-I00

CMB meets LSS



DARK ENERGY SURVEY



Quijote

LiteBIRD

J-PAS Javalambre Physics of the Accelerating Universe Astrophysical Survey

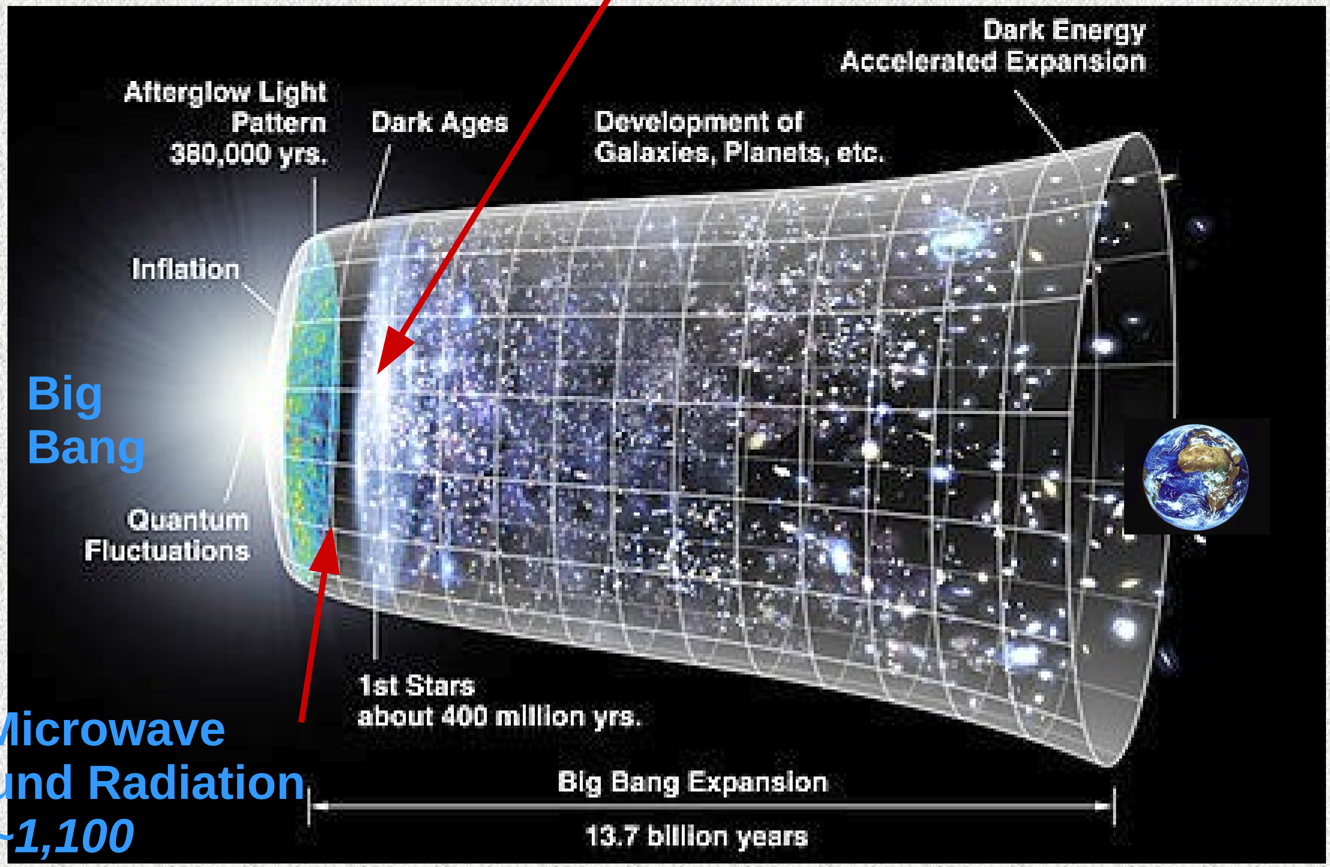
Carlos Hernández-Monteagudo

Instituto de Astrofísica de Canarias / Universidad de La Laguna

Our current understanding of the Universe ...

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

First stars and cosmological reionization



Big Bang

Cosmic Microwave Background Radiation (CMB), *z~1,100*

Cosmological time →

Outline

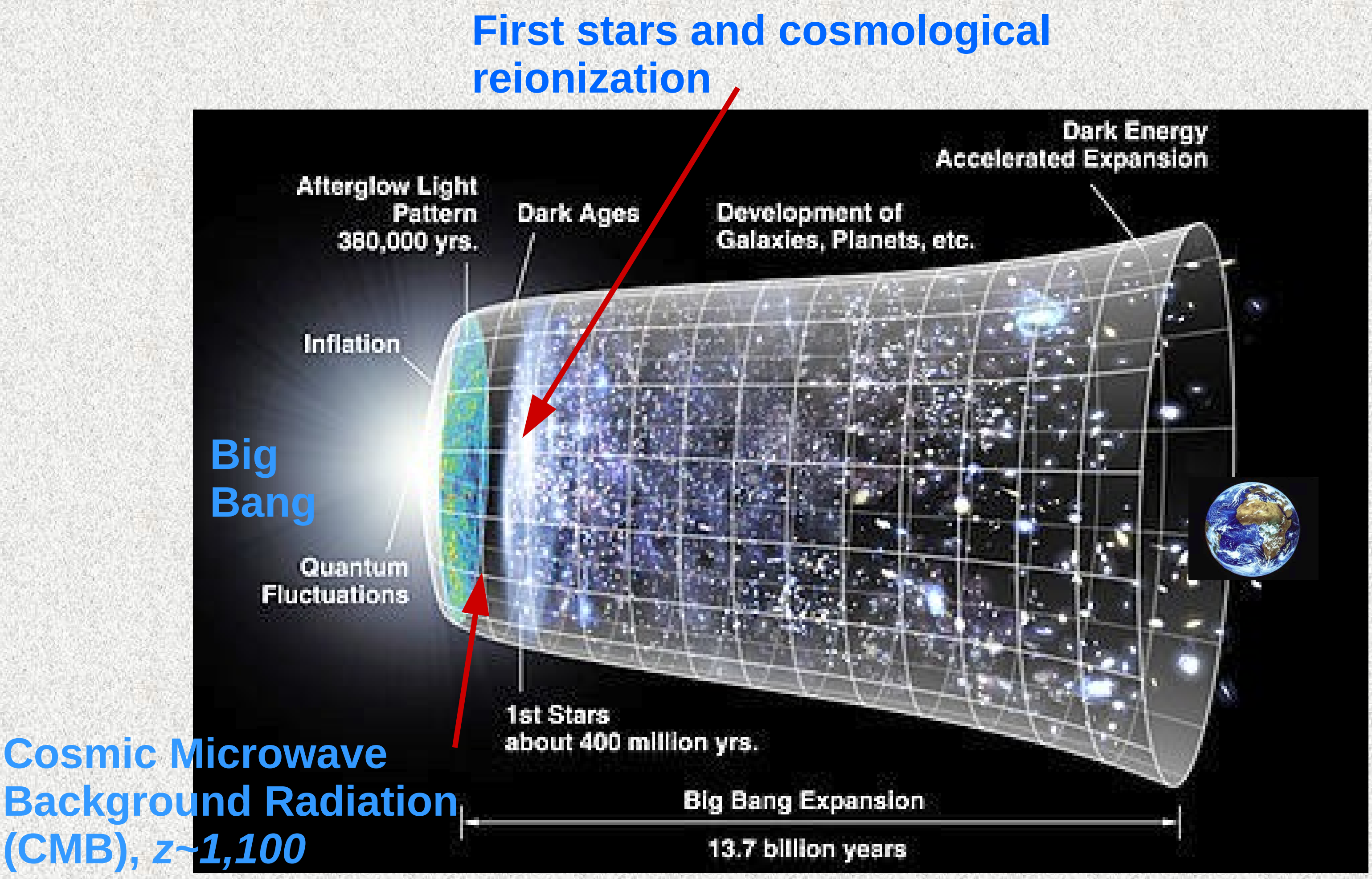
- **CMB x LSS:** Interaction of **CMB photons** with **metals** and **ions** from **reionization**

- **CMB x LSS:** Interaction of **CMB photons** with (*varying*) **gravitational potentials** (integrated **Sachs-Wolfe** and **Rees-Sciama** effects)

- **CMB x LSS:** Interaction of **CMB photons** with **free electrons**: **Thomson** scattering **(kinetic Sunyaev-Zeldovich effect** [kSZ]) and **Compton** scattering (**thermal SZ**, [tSZ])

- **LSS x LSS/CMB:** Involvement in **spectro-photometric redshifts** (J-PLUS, J-PAS). **Angular redshift fluctuations** (ARF)

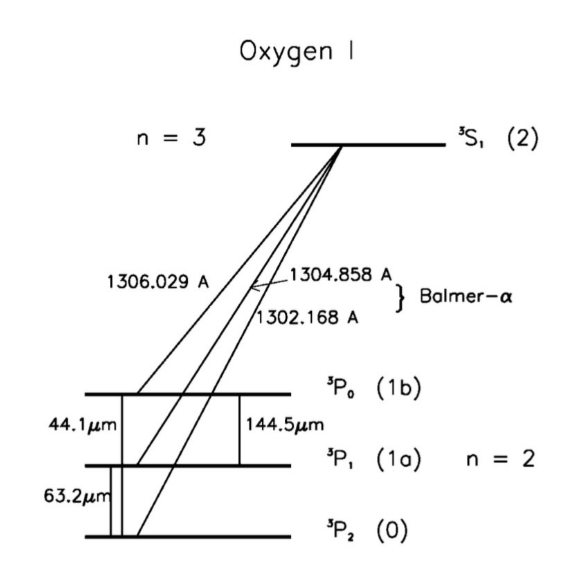
Our current understanding of the Universe ...



Cosmological time →

CMB photons scattering off the first molecules, atoms and ions in the universe

CHM et al., ApJLetters, 2006c



CMB radiation should **scatter off** neutral and ionized species (like **OI, OIII, CO**), thus **modifying** the **CMB intensity** and **polarization** pattern in a **frequency dependent** way ...

CHM, Rubiño-Martín, & Sunyaev, MNRAS, 2006

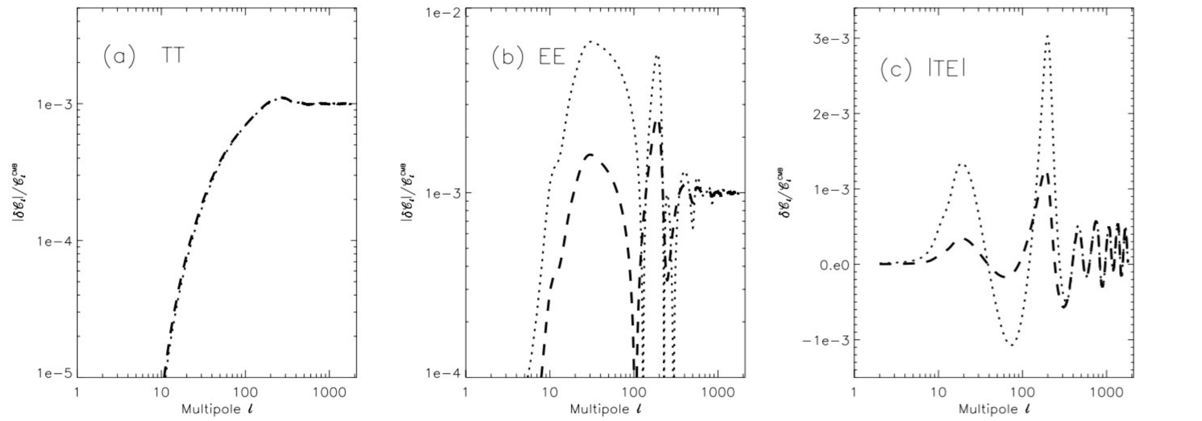


Figure 3. Relative increment of TT, EE and TE angular power spectra with respect to the standard ΛCDM scenario due to the presence of a resonant line placed at $z_X \simeq 500$ with $(\tau_X, E_1) = (5 \times 10^{-4}, 1/3)$ (dashed line) and $(\tau_X, E_1) = (5 \times 10^{-4}, 1)$ (dotted line). Note that for panels (a) and (b) we are plotting absolute values. Since the blurring of original anisotropies is independent of E_1, both lines converge to $2\tau_X$ in the high-l range for the EE plot as well. Note that due to the change of sign of C_l^{TE}, in panel (c) we prefer to normalize by $\sqrt{C_l^{TT} C_l^{EE}}$.

CMB photons scattering off the first molecules, atoms and ions in the universe

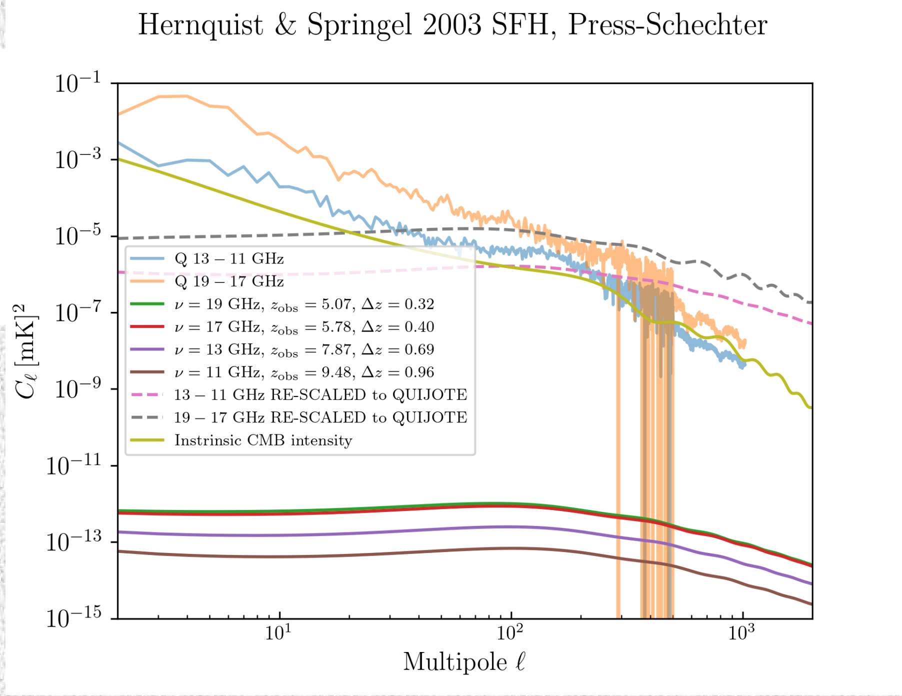
CMB radiation should **scatter off** neutral and ionized species (like **OI, OIII, CO**), thus **modifying** the **CMB intensity** and **polarization** pattern in a **frequency dependent** way ...

MNRAS 000, 1–3 (2022) Preprint 4 September 2024 Compiled using MNRAS LaTeX style file v3.0

The extra-galactic signal in QUIJOTE MFI intensity maps. Evidence for correlation with surveys of the Large Scale Structure and constraints on CO $J\,1 \rightarrow 0$ emission at high redshifts.

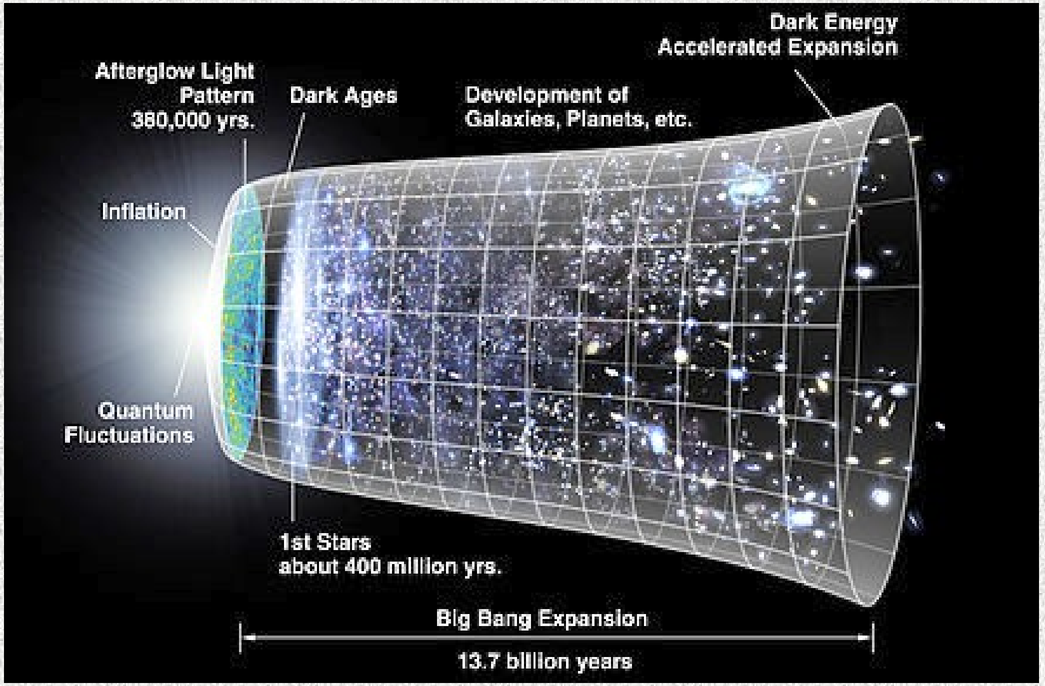
Carlos Hernández-Monteagudo[1,2] ⋆, and the rest of us[3].
[1] Instituto de Astrofísica de Canarias, La Laguna, E-38205, Tenerife, Spain
[2] Departamento de Astrofísica, Universidad de La Laguna, E-38206, Tenerife, Spain
[3] Another Department, Different Institution, Street Address, City Postal Code, Country

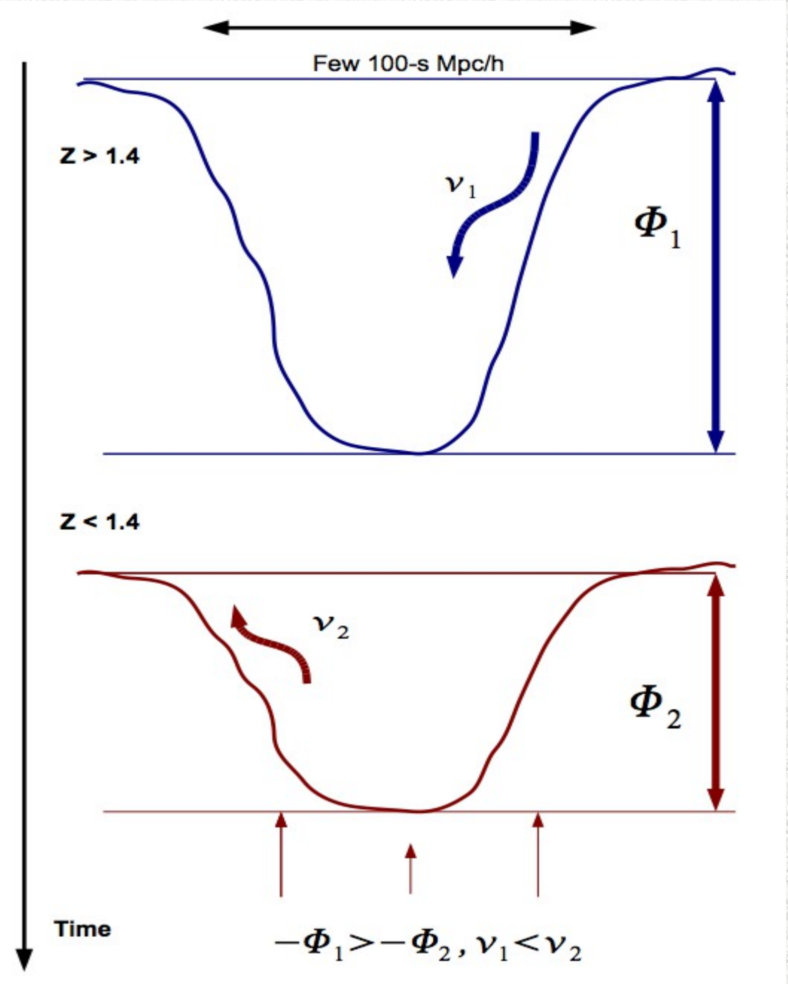
CHM+, 2024, en prep.



Constraints on **CO** emission at high *z (z~5 – 10)* using different **intensity maps** from **QUIJOTE** experiment

CMB photons crossing time dependent gravitational potentials (iSW & RS effects)

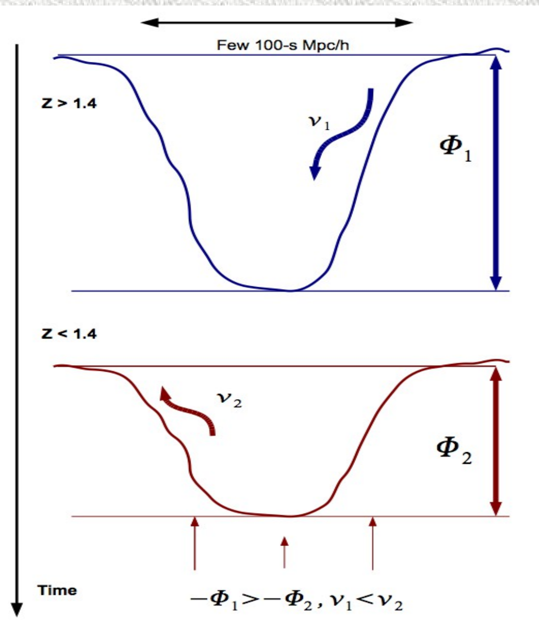


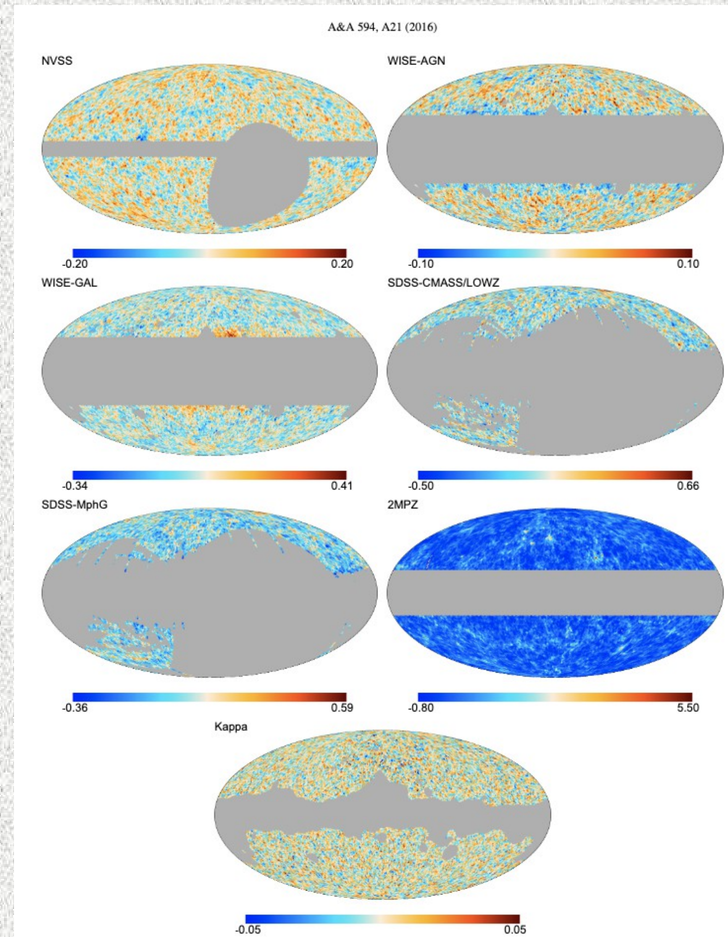


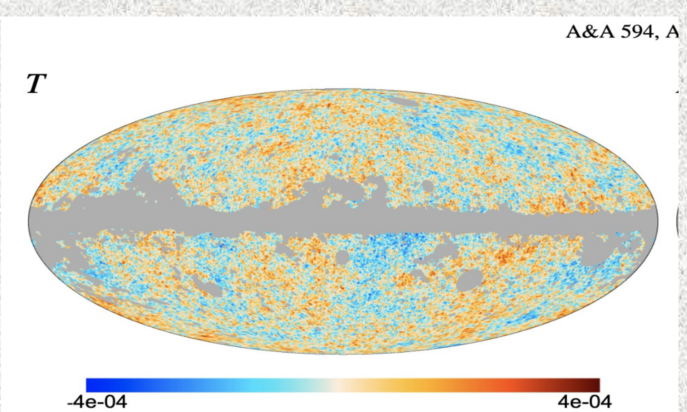
In a LCDM scenario, the iSW is seeded by ***Dark Energy***

CMB photons crossing time dependent gravitational potentials (iSW & RS effects)

Planck
Telescope
(ESA)

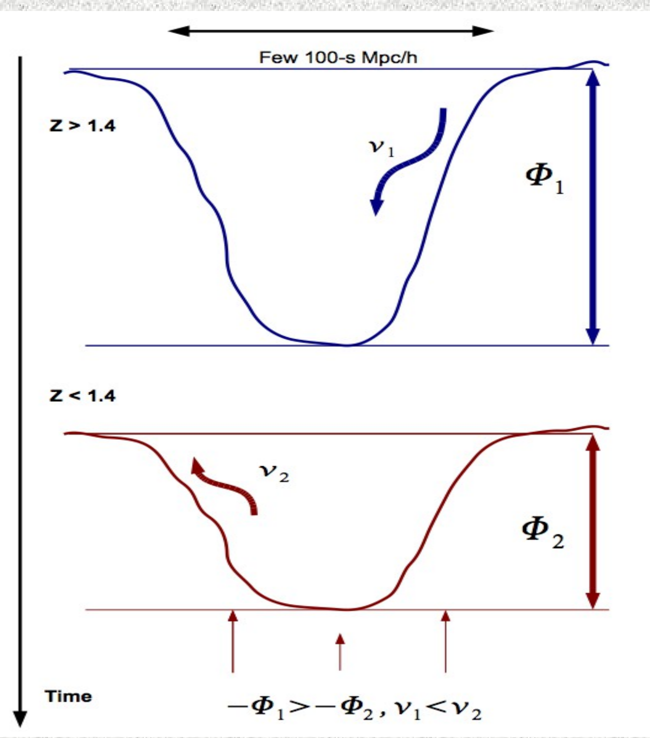






X

CMB photons crossing time dependent gravitational potentials (iSW & RS effects)



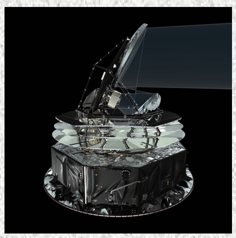
A&A 594, A21 (2016)

Table 2. ISW amplitudes A, errors σ_A, and significance levels $S/N = A/\sigma_A$ of the CMB-LSS cross-correlation (survey-by-survey and for different combinations).

LSS data	COMMANDER		NILC		SEVEM		SMICA		Expected
	$A \pm \sigma_A$	S/N	$A \pm \sigma_A$	S/N	$A \pm \sigma_A$	S/N	$A \pm \sigma_A$	S/N	S/N
NVSS	0.95 ± 0.36	2.61	0.94 ± 0.36	2.59	0.95 ± 0.36	2.62	0.95 ± 0.36	2.61	2.78
WISE-AGN ($\ell_{\min} \geq 9$)	0.95 ± 0.60	1.58	0.96 ± 0.60	1.59	0.95 ± 0.60	1.58	1.00 ± 0.60	1.66	1.67
WISE-GAL ($\ell_{\min} \geq 9$)	0.73 ± 0.53	1.37	0.72 ± 0.53	1.35	0.74 ± 0.53	1.38	0.77 ± 0.53	1.44	1.89
SDSS-CMASS/LOWZ	1.37 ± 0.56	2.42	1.36 ± 0.56	2.40	1.37 ± 0.56	2.43	1.37 ± 0.56	2.44	1.79
SDSS-MphG	1.60 ± 0.68	2.34	1.59 ± 0.68	2.34	1.61 ± 0.68	2.36	1.62 ± 0.68	2.38	1.47
Kappa ($\ell_{\min} \geq 8$)	1.04 ± 0.33	3.15	1.04 ± 0.33	3.16	1.05 ± 0.33	3.17	1.06 ± 0.33	3.20	3.03
NVSS and Kappa	1.04 ± 0.28	3.79	1.04 ± 0.28	3.78	1.05 ± 0.28	3.81	1.05 ± 0.28	3.81	3.57
WISE	0.84 ± 0.45	1.88	0.84 ± 0.45	1.88	0.84 ± 0.45	1.88	0.88 ± 0.45	1.97	2.22
SDSS	1.49 ± 0.55	2.73	1.48 ± 0.55	2.70	1.50 ± 0.55	2.74	1.50 ± 0.55	2.74	1.82
NVSS and WISE and SDSS	0.89 ± 0.31	2.87	0.89 ± 0.31	2.87	0.89 ± 0.31	2.87	0.90 ± 0.31	2.90	3.22
All	1.00 ± 0.25	4.00	0.99 ± 0.25	3.96	1.00 ± 0.25	4.00	1.00 ± 0.25	4.00	4.00

Notes. These values are reported for the four *Planck* CMB maps: COMMANDER; NILC; SEVEM; and SMICA. The last column gives the expected S/N within the fiducial ΛCDM model.

Planck Telescope (ESA)



Limited S/N due to relatively high cosmic variance on large scales!

CMB photons Thomson [kSZ] and Compton [tSZ] scattering off free electrons

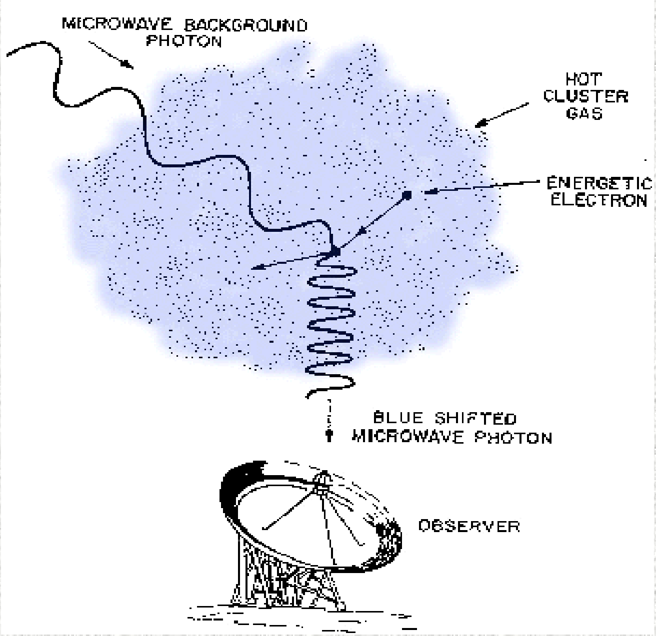
[kSZ]

$$\frac{\Delta T_{kSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e \frac{\mathbf{v}\cdot\hat{\mathbf{n}}}{c} \times L_{cloud}$$

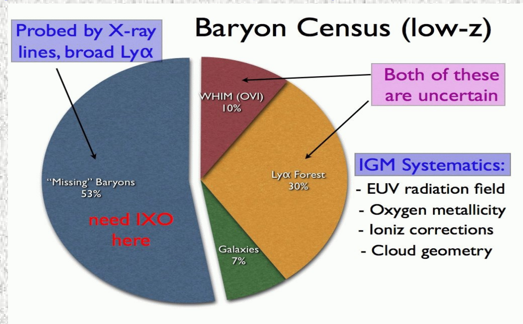
[tSZ]

$$\frac{\Delta T_{tSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e T_e \times L_{cloud} \sim p_e \times L_{cloud}$$

$$E(\hat{\mathbf{n}}) \sim n_e Q_2^{CMB}$$



Mike Shull (2015) on the *missing baryons*

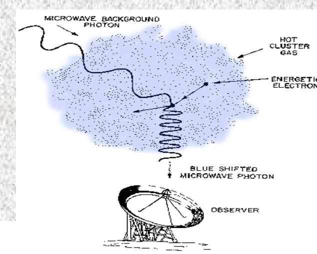


CMB photons Thomson [kSZ] and Compton [tSZ] scattering off free electrons

$$\frac{\Delta T_{kSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e \frac{\mathbf{v}\cdot\hat{\mathbf{n}}}{c} \times L_{cloud}$$

$$\frac{\Delta T_{tSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e\, T_e \times L_{cloud} \sim p_e \times L_{cloud}$$

$$E(\hat{\mathbf{n}}) \sim n_e\, Q_2^{CMB}$$



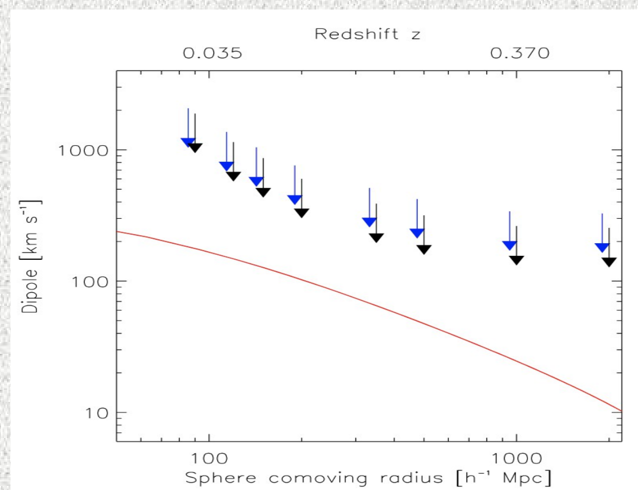
A&A 561, A97 (2014)
DOI: 10.1051/0004-6361/201321299

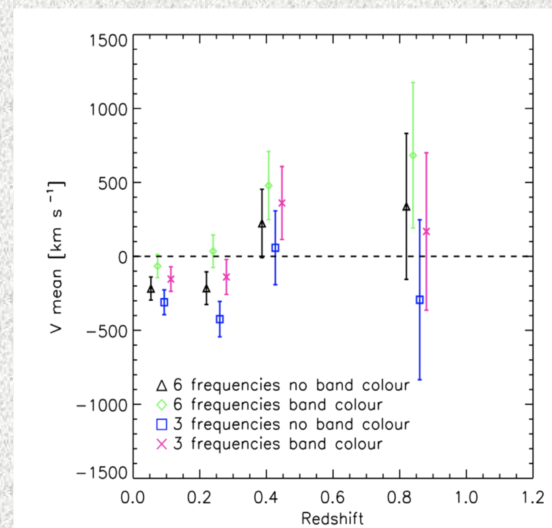
Astronomy & Astrophysics

***Planck* intermediate results**

XIII. Constraints on peculiar velocities

Constraints on the **Cosmological Principle** (*Dark Flow* ruled out)





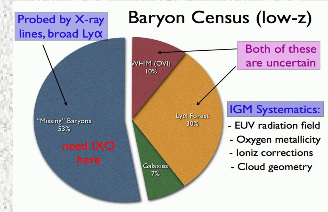
Galaxy clusters at ***z~0.18*** show average velocities **< 62 km/s** wrt their CMB frame

CMB photons Thomson [kSZ] and Compton [tSZ] scattering off free electrons

$$\frac{\Delta T_{kSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e \frac{\mathbf{v}\cdot\hat{\mathbf{n}}}{c} \times L_{cloud}$$

$$\frac{\Delta T_{tSZ}(\hat{\mathbf{n}})}{T_0} \sim n_e T_e \times L_{cloud} \sim p_e \times L_{cloud}$$

$$E(\hat{\mathbf{n}}) \sim n_e Q_2^{CMB}$$



Solving the *missing baryon* problem (PRL)

Gravitation and Astrophysics –

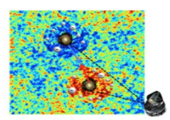
Editors' Suggestion

PDF HTML

Evidence of the Missing Baryons from the Kinematic Sunyaev-Zeldovich Effect in Planck Data

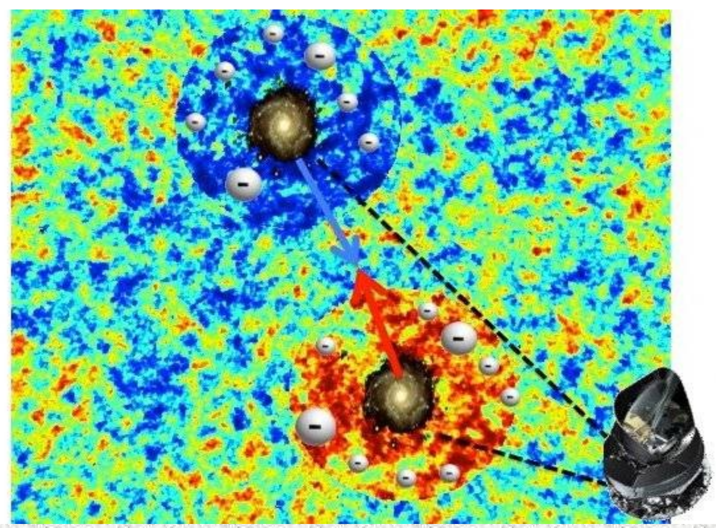
Carlos Hernández-Monteagudo, Yin-Zhe Ma, Francisco S. Kitaura, Wenting Wang, Ricardo Génova-Santos, Juan Macías-Pérez, and Diego Herranz

Phys. Rev. Lett. **115**, 191301 (2015) – Published 3 November 2015

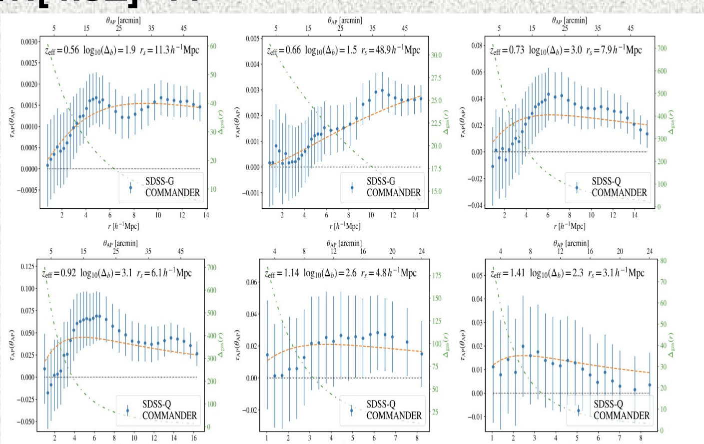


Analysis of Planck measurements of the cosmic microwave background provides evidence that many of the baryons expected to exist in the Universe, but not detected in stars, are in the gas around the Central Galaxies identified in the Sloan galaxy survey.

Show Abstract



Chaves-Montero, CHM+,2021, MNRAS, Unbound gas profiles in halos up to *z*~5 obtained by **ARFxkSZ** cross-correlations, **S/N[kSZ]=11**



Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)

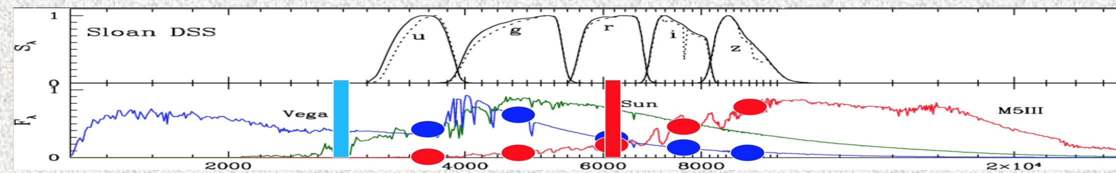
Observatorio Astrofísico de Javalambre (OAJ)

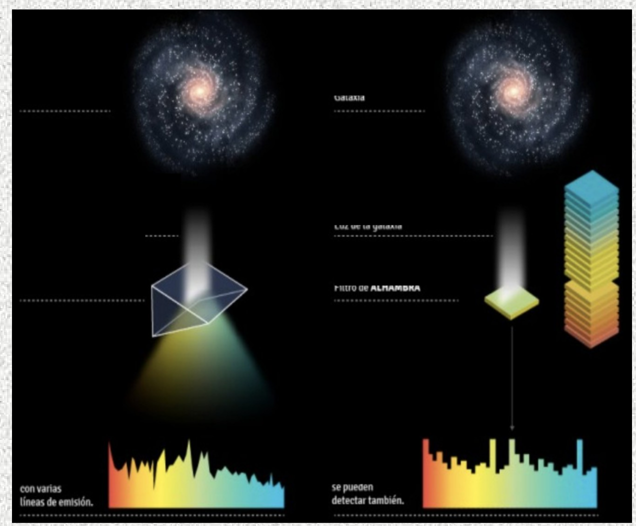
S-PLUS

J-PAS

Javalambre Physics of the Accelerating Universe Astrophysical Survey

Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)





Spectroscopic surveys

- Require a photometric *pre-selection* of targets
- Require typically longer integration times
- Require positioning ***each*** fiber on top of ***each*** target, something complex if this is to be done for tens of ***millions*** of objetcs
- Provide very precise z-measurements

Photometric surveys

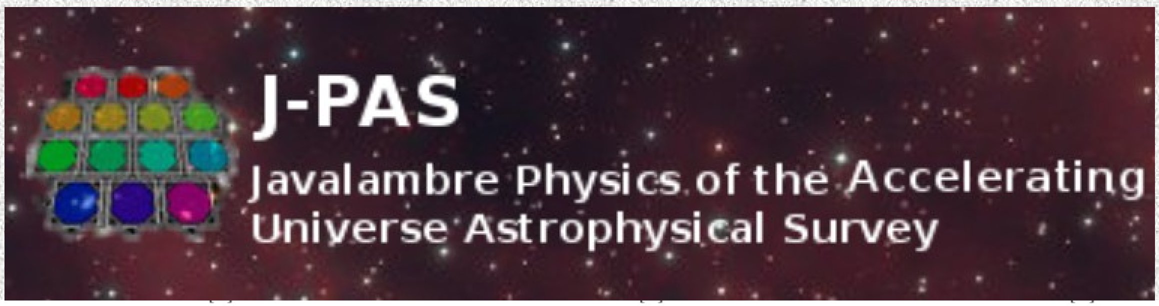
- Indiscriminate (no pre-selection biases)
- Typically much deeper
- Require demanding calibration of ***each*** the optical bands
- Provide less precise photo-z-s (depending upon the number of optical bands)

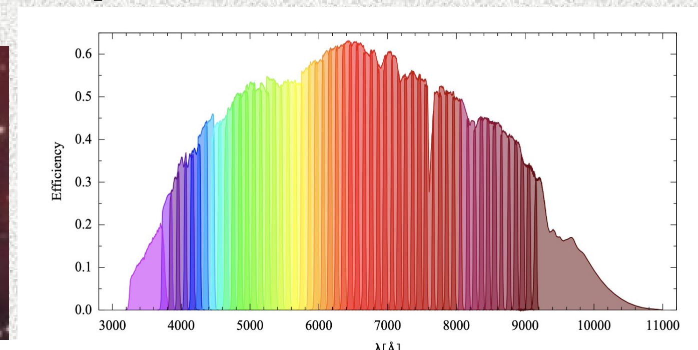
Spectro-photometric surveys

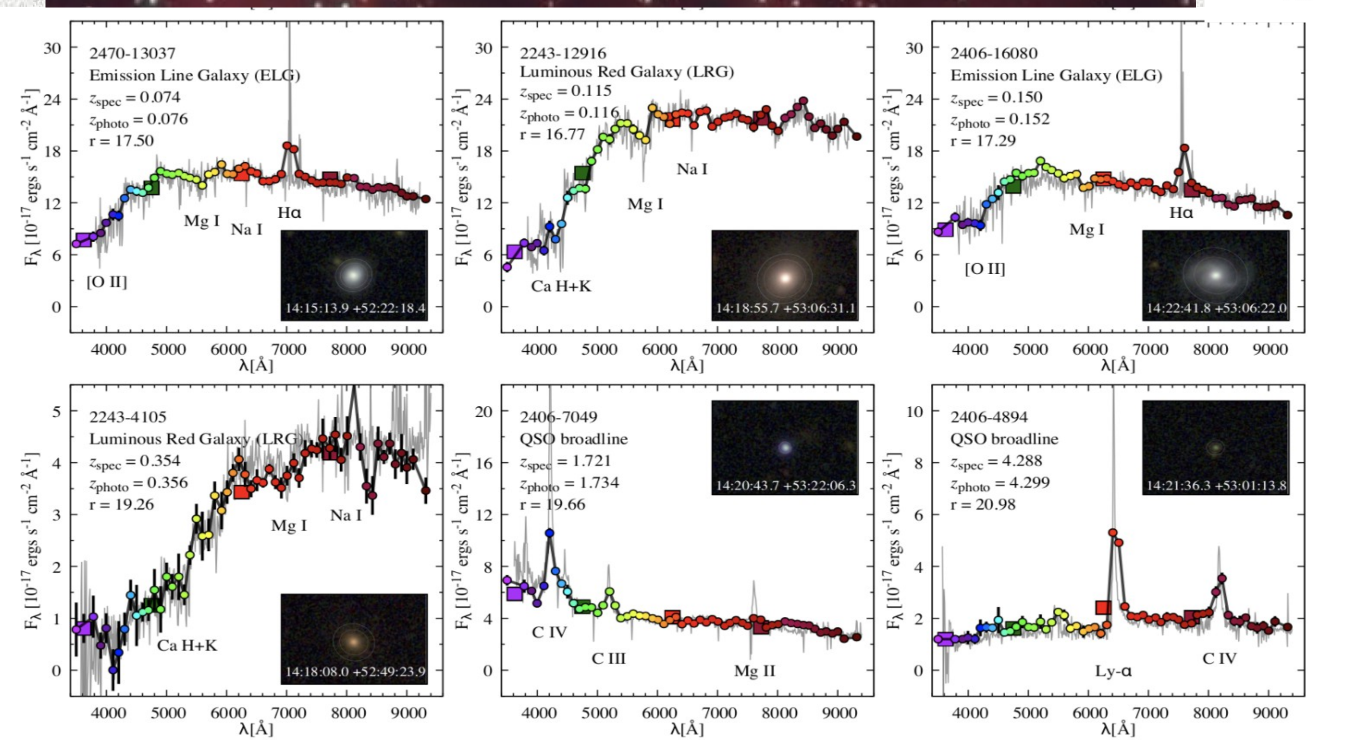
- Present same advantages to photometric survey (**no target pre-selection,**, **higher depth**), with the added value of having ***(1+z) measurements*** with precision **better** than ~0.3% for ~30% of sources if the number ofnarrow bands >40—50 .

- Accurate calibration required for **many more** optical filters

Using spectro-photometric surveys as *redshift machines: a*ngular redshift fluctuations (ARF)







Very accurate photo-zs for **tens** of **millions** of sources – Spectro-photometric surveys are ***(photo-)redshift machines***

Bonoli et al. 2021

Using spectro-photometric surveys as *redshift machines: a*ngular redshift fluctuations (ARF)

After choosing a central redshift and an associated redshift Gaussian shell width

$$W_j = W(z_j;\sigma_z) \equiv \exp -\{(z_{\rm obs} - z_j)^2/(2\sigma_z^2)\}$$

$$1 + \delta_g(\hat{\mathbf{n}}) = \frac{\sum_{j\in p} W_j}{\langle \sum_{j\in p} W_j \rangle_{\hat{\mathbf{n}}}}$$

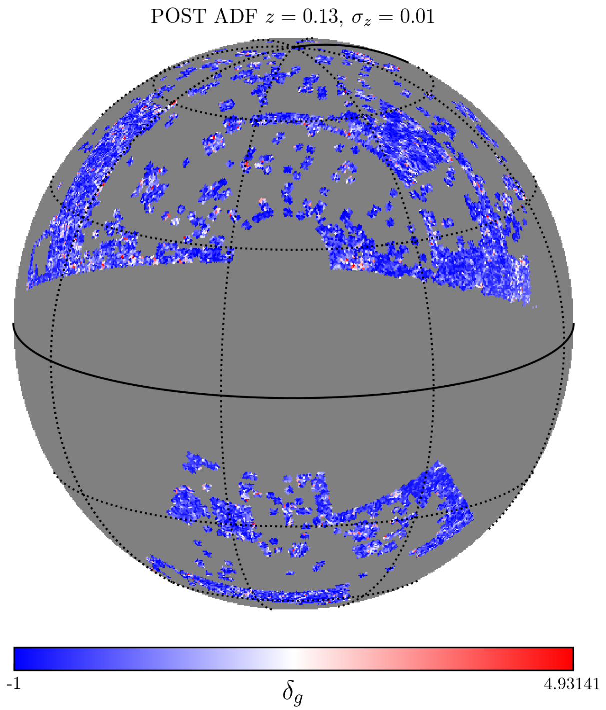
… one can count galaxies (***angular density fluctuations*** – ***ADF*** – *or* ***standard clustering****)*

$$\delta z(\hat{\mathbf{n}}) = \frac{\sum_{j\in p} W_j (z_j - \bar{z})}{\langle \sum_{j\in p} W_j \rangle_{\hat{\mathbf{n}}}}, \qquad \bar{z} = \frac{\langle \sum_{j\in p} W_j z_j \rangle_{\hat{\mathbf{n}}}}{\langle \sum_{j\in p} W_j \rangle_{\hat{\mathbf{n}}}}$$

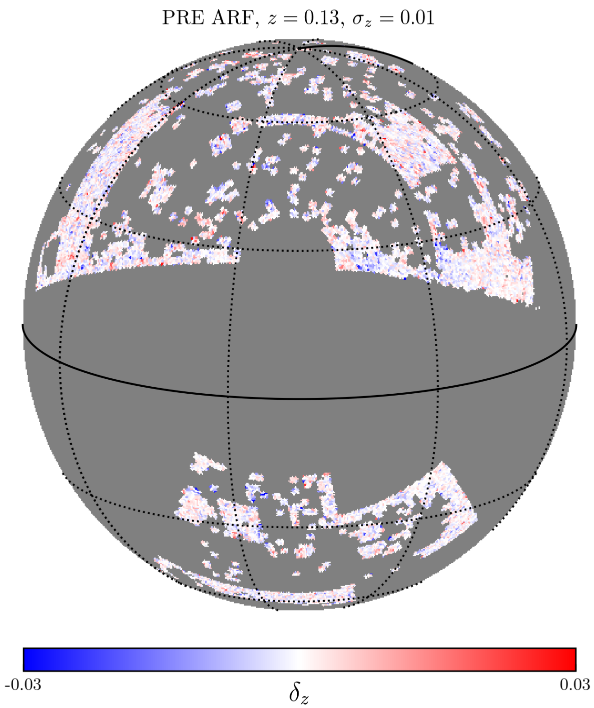
… or one study the **fluctuacions** of ***redshift*** with respect an angular average: ***angular redshift fluctuations*** *or* ***ARF***

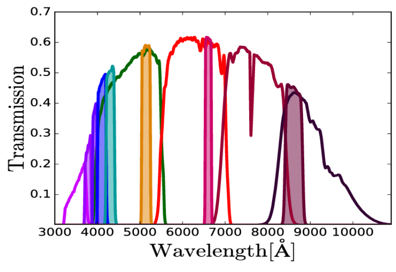
Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)

ADF



ARF

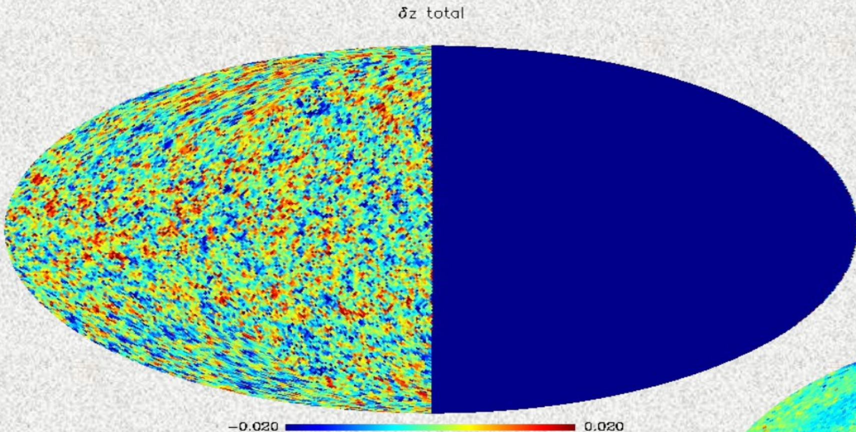




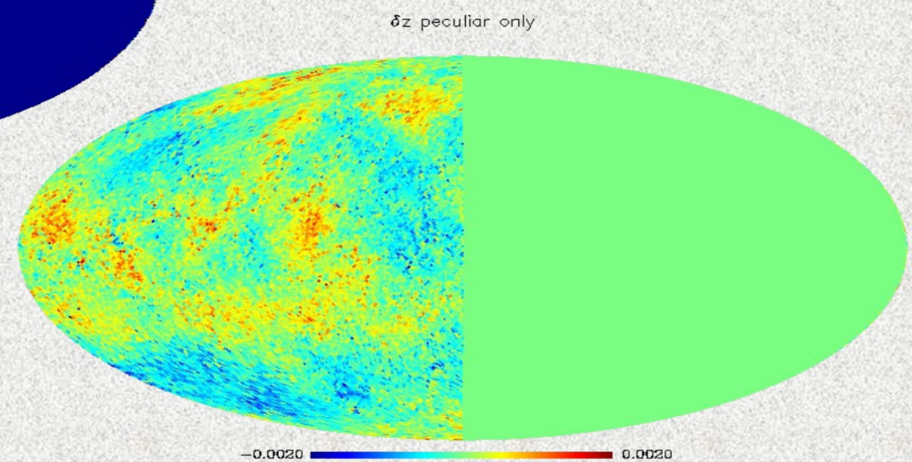
Using spectro-photometric surveys as *redshift machines: a*ngular redshift fluctuations (ARF)

$$z_j(\mathbf{n}) = \frac{\sum_g z_g(\mathbf{n}) \cdot W[(z_g(\mathbf{n}) - z_{c,j})/\sigma_z]}{\sum_g W[(z_g(\mathbf{n}) - z_{c,j})/\sigma_z]}$$

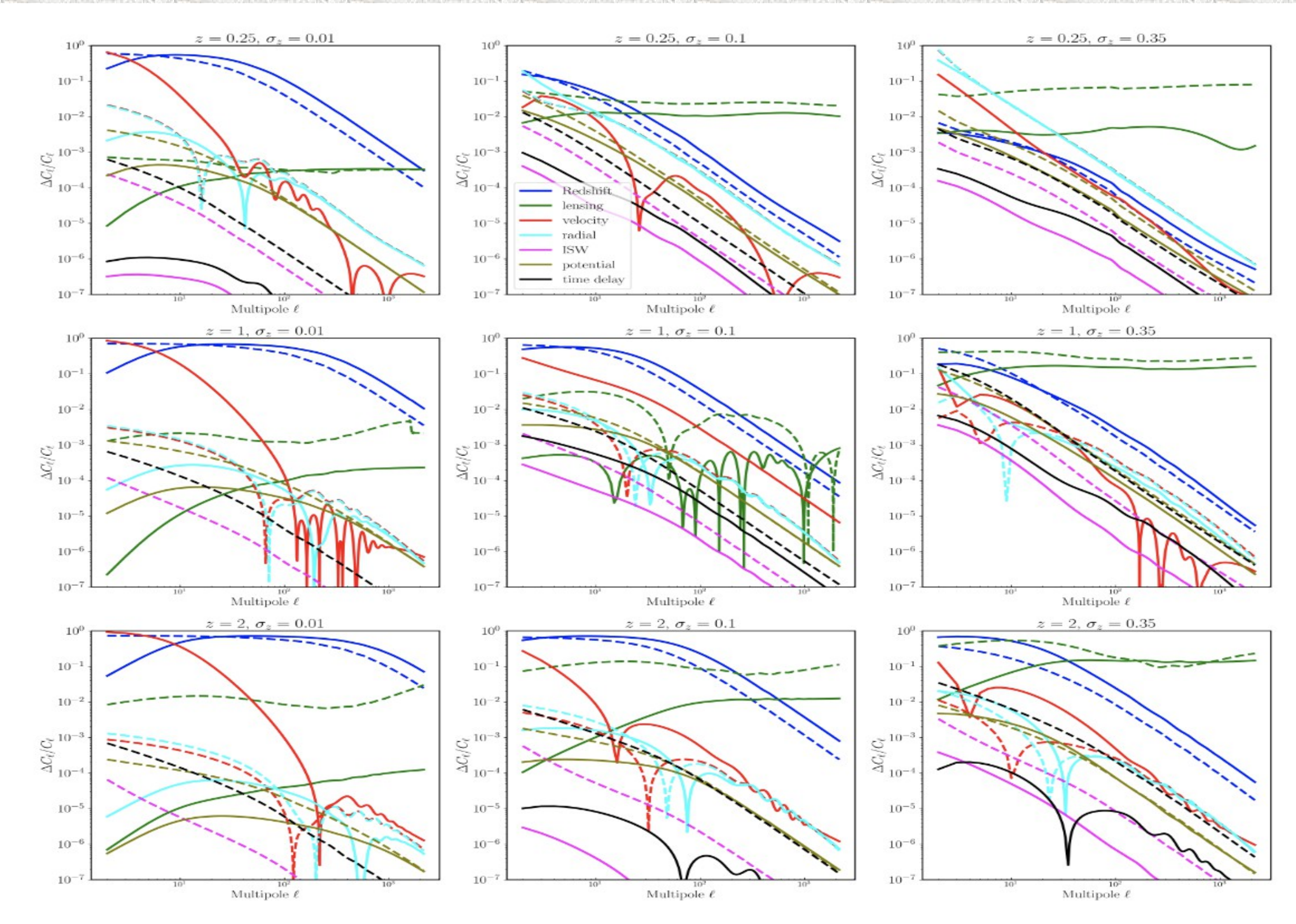
z = zHubble + zpec



z = zpec



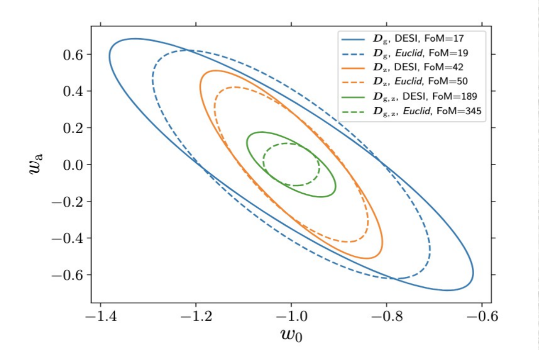
Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)



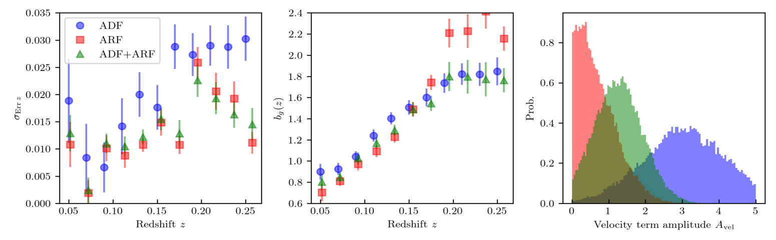
Relativistic corrections for **ARF** in modified **Boltzmann** code: **ARFCAMB** (*linear* order of perturbation theory)**.**

Lima-Hernández, CHM, Chaves-Montero, JCAP, 2022

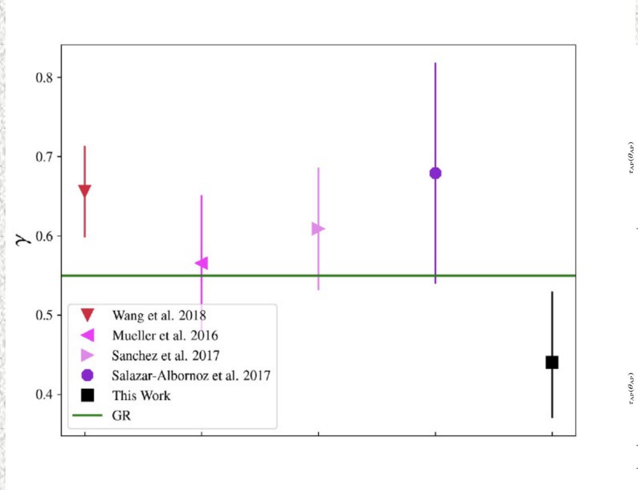
Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)

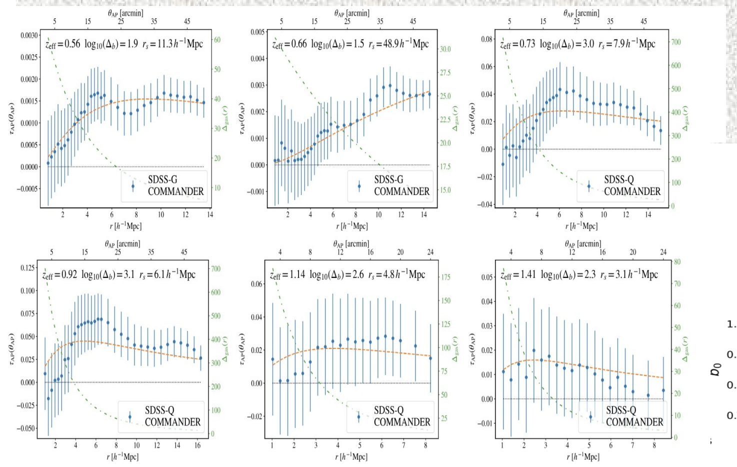


In Legrand, CHM+,2021, A&A we showed that **ARF improve by 10x the sensitivity of ADF** on **Dark Energy**

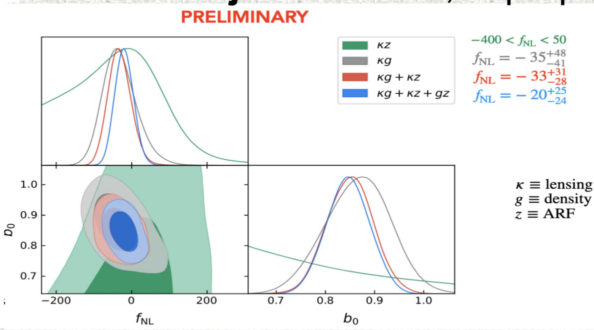


In CHM+,2024, (submitted) we use **ARF** to measure **galaxy bias** and constrain **peculiar velocities** in **J-PLUS DR3**





Competitive upper limits to $\mathbf{f_{NL}}$ via **ARF** using Quaia x *Planck* CMB lensing, **Bermejo-Climent** +, in prep.



CHM+,2021, MNRAS *letters,* Contraints on **modified gravity** using de **ARF** in BOSS DR13

Chaves-Montero, CHM+,2021, MNRAS, Unbound gas profiles in halos up to *z~5* obtained by **ARFxkSZ** cross-correlations, **S/N[kSZ]=11**

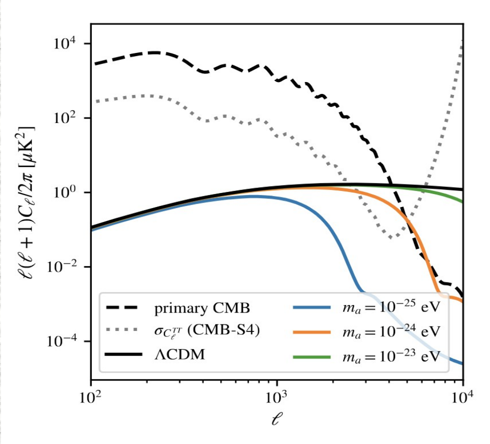
Using spectro-photometric surveys as *redshift machines:* angular redshift fluctuations (ARF)

Ongoing projects ...

- Exploring ARF in the **non-linear regime** with **EFT** (Alba **Crespo (PhD)**, Jorge Martín **Camalich**)
- Exploring ARF in **cosmic voids** and their sensitivity to **Omega_m**, **f\sigma_8 (Mar Pérez Sar, PhD**)
- Exploring ARF and their sensitivity to **parity violations** (**Angulo+** [DIPC])
- Exploring ARF with **cosmic reconstructions** (with **Francisco Shu Kitaura**)

In the 2-do list ...

- ARF sensitivity to **homogeneity** and the **Cosmological Principle**
- ARF **bi-spectrum** and its sensitivity to f_NL
- ARF sensitivity to **axions** as **DM** candidate (as done for the kSZ by Farren et al)
- ...



Farren et al. 2023

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Thank you!