Oxford St-Anne's college

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Small « c »-cosmology

(can help to do some « C » cosmology)

Jean-Philippe UZAN

Cosmological models and ΛCDM

Its construction relies on 4 hypothesis

1. Theory of gravity [General relativity]
2. Matter [Standard model fields + CDM + Λ]
3. Symmetry hypothesis [Copernican Principle]
4. Global structure [Topology of space is trivial]

→ New physics with simple cosmological solution

→ Standard physics with more involved solution

In agreement with all the data.

Testing the model

Once the model is specified, it exhibits rigidities, i.e. quantities that are related by some relations in this theoretical framework but are not if some hypothesis of the model are not satisfied.

They are included in the interpretation of the observation and experiment

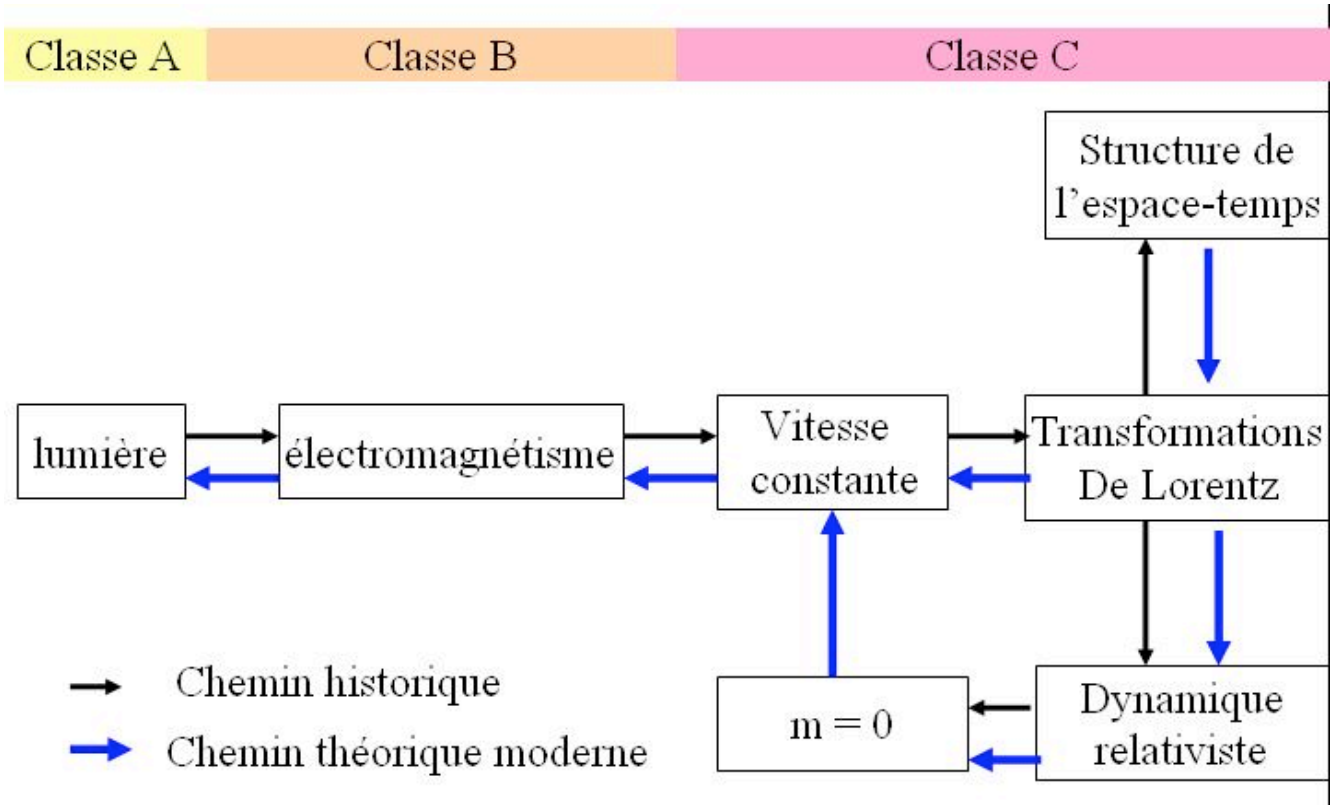
Observable universe is the largest physical system we know (today)

- compare model to data -> parameters…
- test alternative models
- use data to construct « model-independent » tests of the hypothesis

Example: speed of light

Universal speed
Electromagnetic wave
Gravity waves

Reduce to the same *c* but need not to



General relativity

Metric theories of gravity relativity rely on the *weak equivalence Principle*

1- Universality of free fall
2- Local position invariance
3- Local Lorentz invariance

$$S_{matter}(\psi, g_{\mu\nu}) \qquad S_{grav} = \frac{c^3}{16\pi G}\int\sqrt{-g_*}\,R_*\,d^4x$$

$$\boxed{g_{\mu\nu} = g^*_{\mu\nu}}$$

Different regims (for tests/allowed modification)

distinguish *weak-strong field* regimes / *large-small distances*

Corrective terms in the action have to be compared to *R*

Parameter space

Tests of general relativity on astrophysical scales are needed

- galaxy rotation curves: low acceleration o
- acceleration: low curvature

Solar system:

$$\frac{R}{\phi^3} = \frac{c^4}{G^2 M_\odot^2}$$

Cosmology:

$$R = 3H_0^2\{\Omega_m(1+z)^3 + 4\Omega_\Lambda\}$$

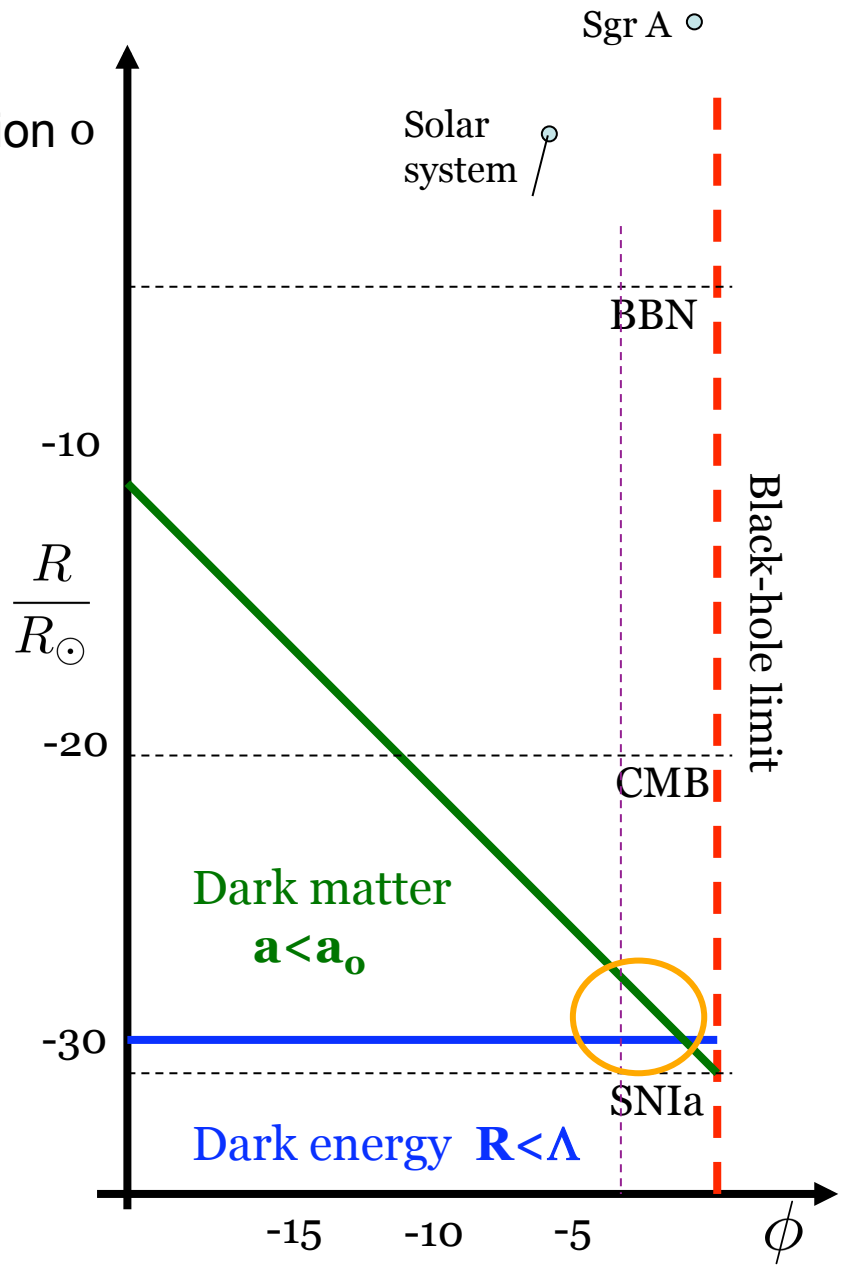
Dark energy:

$$R < R_\Lambda = 12H_0^2\Omega_\Lambda$$

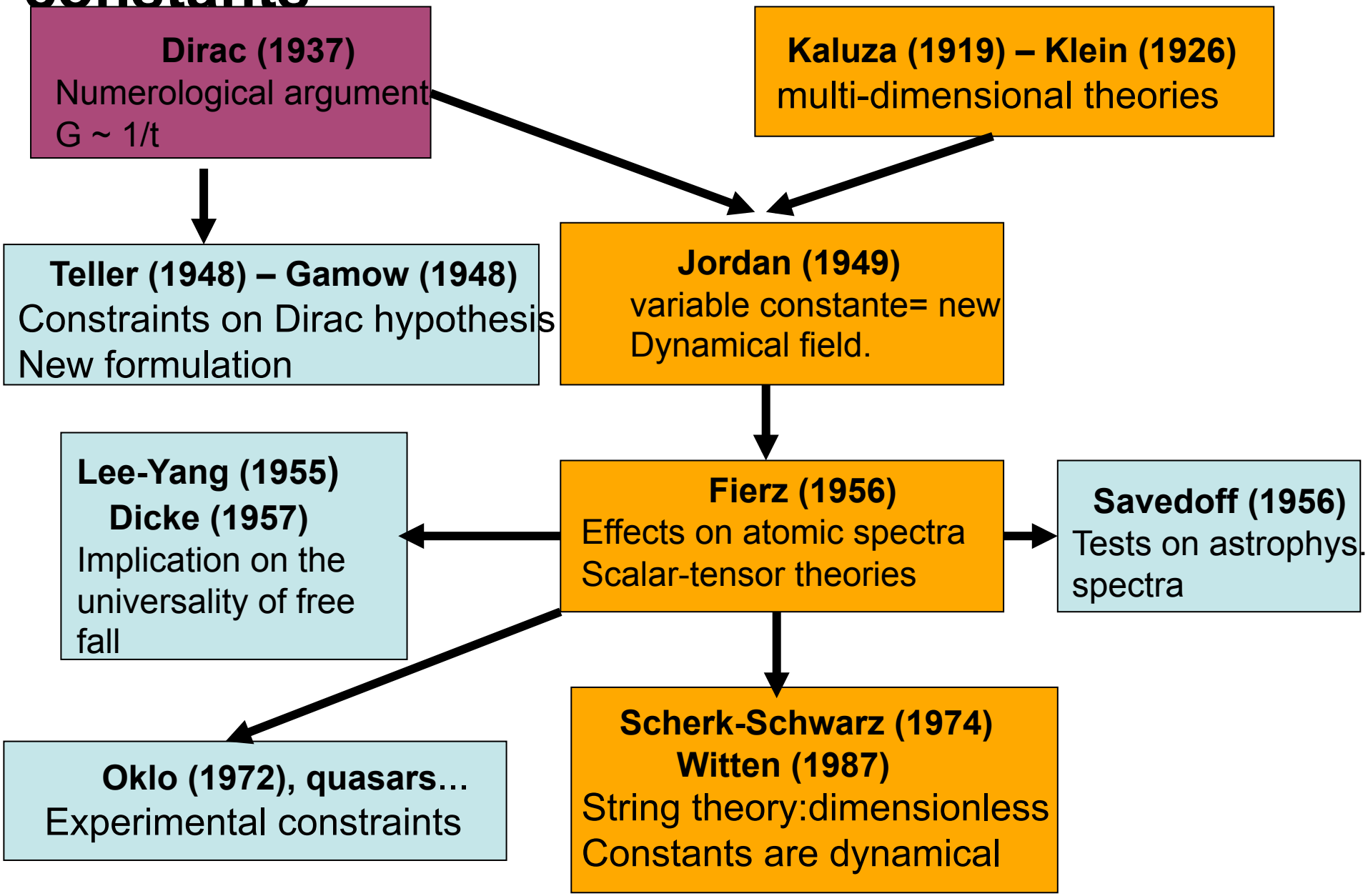
Dark matter:

$$a < a_0 \sim 10^{-8}\mathrm{cm.s}^{-2}$$

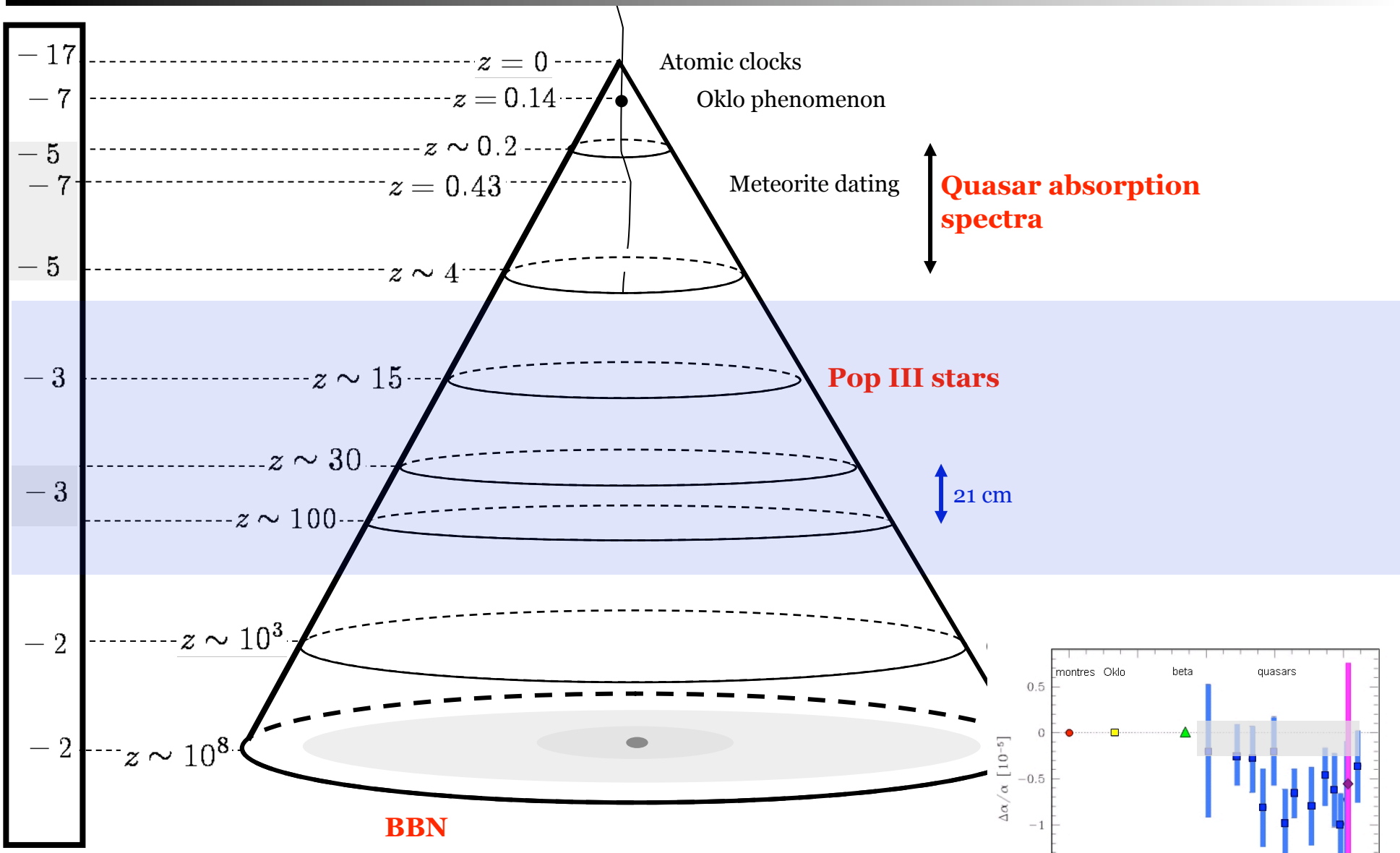
$$a^2 = \phi R < a_0^2$$

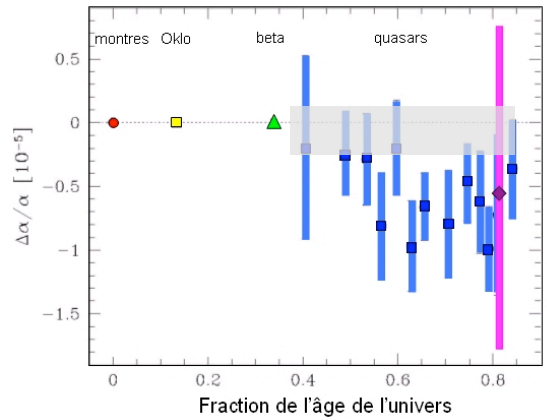


Equivalence principle and fundamental constants



Systems to test fundamental constant





[JPU, RMP **75** (2003) 425; astro-ph/0409424] arXiv:0907.3081

Data and tests

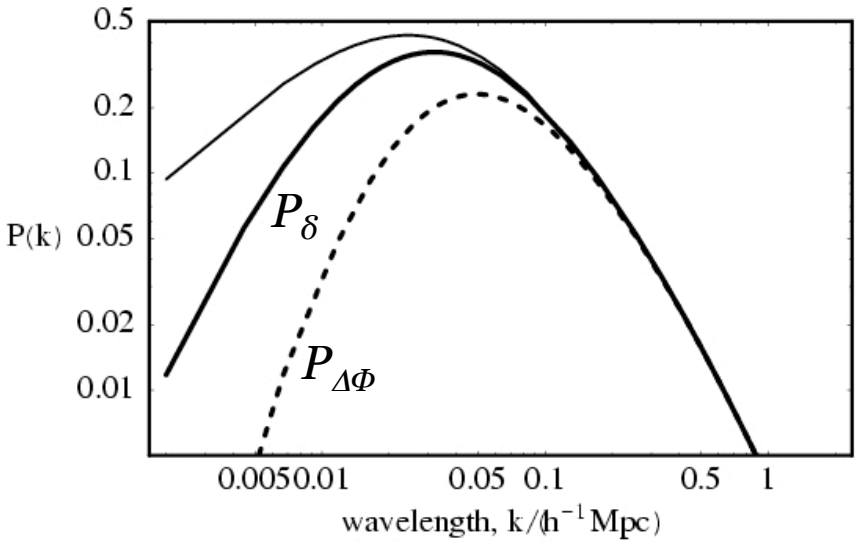
DATA	OBSERVABLE
Weak lensing	$\kappa \propto \Delta(\Phi + \Psi)$
Galaxy map	$\delta_g = b\,\delta$
Velocity field	$\theta = \beta\,\delta$
Integrated Sachs-Wolfe	$\Theta_{SW} \propto \dot{\Phi} + \dot{\Psi}$

Various combinations of these variables have been considered

Example:

JPU and Bernardeau, Phys. Rev. D **64** (2001)

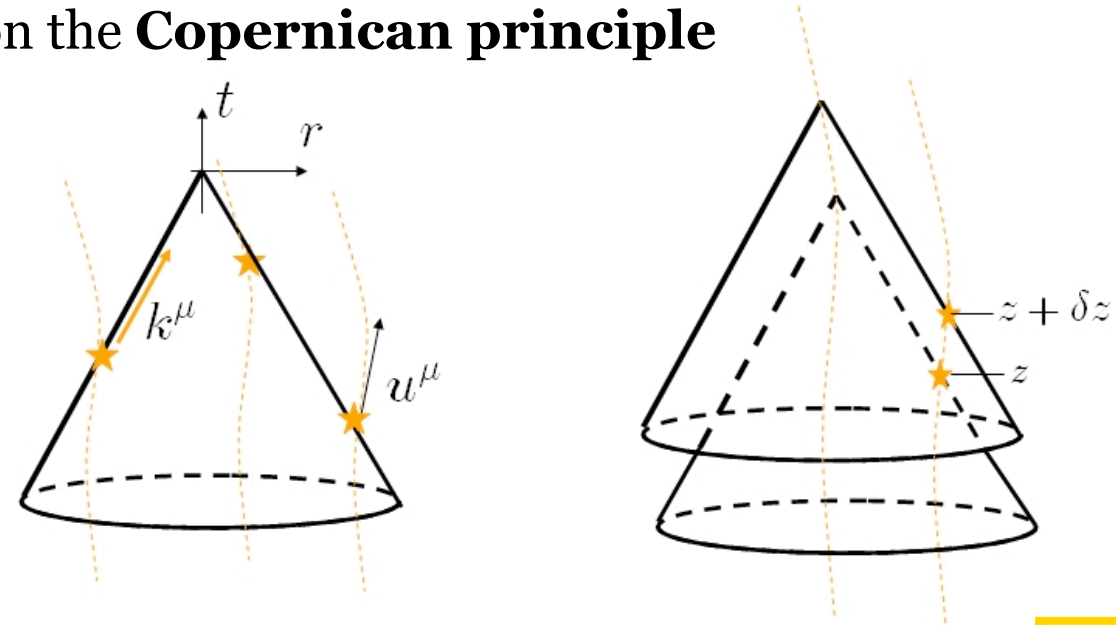
arXiv:0908.2243



..... ESA/EUCLID

Copernican principle

Based on the **Copernican principle**



LTB $$\dot{z} = H_0(1+z) - H(z) + \boxed{\frac{1}{\sqrt{3}}\sigma(z)}$$

JPU, Clarkson, Ellis, PRL 2008

Typical order of magnitude (z~4)

$$\delta z \sim -5 \times 10^{-10} \qquad \text{on} \qquad \delta t \sim 10\,\text{yr}$$

CODEX project for ELT

JPU, Bernardeau, Mellier, arXiv:0711.1950

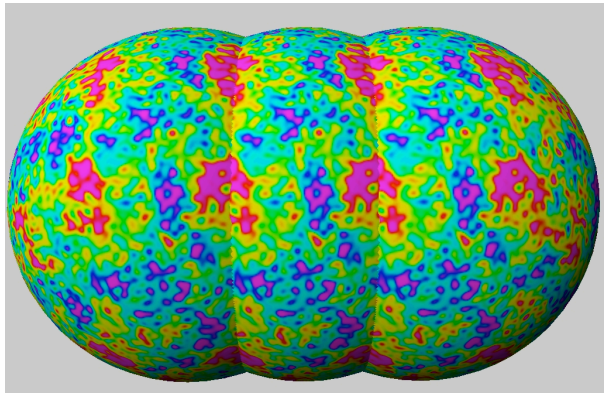
Other possibilities: CMB-Planck sprctrum [Stebbins, Caldwell], Curvature parameter [Clarckson,Lu,Bassett], SNIa [Ferreira, Clifton,Land]

Topology

Local geometry compatible with different topology

Spatially finite universe

- level I
- economical way to simulate « infinite universe »
- hyperbolic, spherical space: curvature scale sets « size » of space



Riazuelo, JPU, Weeks, Riazuelo, 2002]

$L/2R_{LSS}>0.91$

Cornish, spergel, starkman, 2004,...]

Auguste Blanqui (1825-1881)

« L'éternité par les astres »

L'univers tout entier est composé de systèmes stellaires. Pour les créer, la nature n'a que cent *corps simples à sa disposition. Malgré le parti prodigieux* qu'elle sait tirer de ces ressources et le chiffre incalculable de combinaisons qu'elles permettent à sa fécondité, le résultat est nécessairement un nombre *fini, comme celui des éléments eux-mêmes, et pour remplir l'étendue, la* nature doit répéter à l'infini chacune de ses combinaisons *originales ou types*.

Voici néanmoins un grand défaut : il n'y a pas progrès. Hélas ! non, ce sont des rééditions vulgaires, des redites