Pierre Binétruy (1955-2017)

A multi-dimensional scientist

- Particle physics (phenomenology & fundamentals)

  PhD (1980): "Theoretical and Phenomenological Aspects of Gauge Theories" (Supervisor: Mary K. Gaillard)

- Cosmology (inflation, dark energy)

- Gravitation (gravitational waves, black holes)

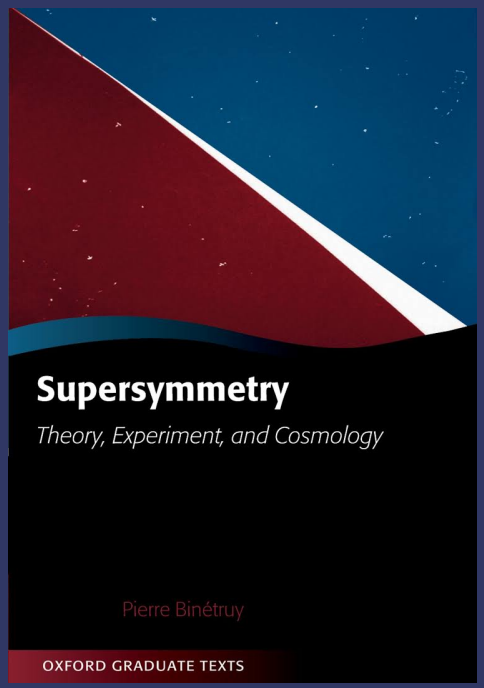
Particle physics

Strong involvement in supersymmetric theories

- Phenomenology (link with experiments)
- Fundamental aspects (e.g. supersymmetry breaking, mass hierarchy, anomalous U(1), etc…)
- Cosmological aspects

Physics report: « Supergravity couplings: a geometric formulation »
(with G. Girardi & R. Grimm, 2001)

Textbook: « Supersymmetry: Theory, Experiment and Cosmology »
(Oxford Univ Press, 2006 & 2012)



Cosmology & supersymmetry

Exploring the interface between high energy physics & cosmology

- Inflation: « Candidates for the inflaton field in superstring models » (1986), with M.K. Gaillard

- Quintessence (1999)

  Potential of the form $V(\phi) = \frac{\mu^{4+\alpha}}{\phi^{\alpha}}$ (Ratra-Peebles)

  constructed in supersymmetric models.

D-term inflation (1996)

with G. Dvali

- Supergravity models
  - Starting from $K(\phi^i, \bar{\phi}^j)$ and $W(\phi^i)$, one gets

$$\mathcal{L} = K_{i\bar{j}} \partial_\mu \phi^i \partial^\mu \bar{\phi}^j - V_F$$

with the potential

$$V_F = e^{K/M_P^2} \left[K^{i\bar{j}} \left(W_i + \frac{1}{M_P^2} K_i W \right) \left(W_j + \frac{1}{M_P^2} K_j W \right)^* - 3\,|W|^2 \right]$$

  - Global susy limit: $V_F = K^{i\bar{j}} W_i W_j^*$

  - Eta problem: $\eta \equiv M_P^2 V''/V$

$$\mathcal{L} \approx -\partial_\mu \phi \partial^\mu \bar{\phi} - V(0) \left(1 + \frac{\phi \bar{\phi}}{M_P^2} + \dots \right)$$

$$m_\phi^2 = \frac{V(0)}{M_P^2} + \dots \approx 3H^2 + \dots$$

D-term inflation (1996)

with G. Dvali

- With a U(1) symmetry, one can add a Fayet Iliopoulos term
  - Lagrangian $\mathcal{L} = K_{i\bar{j}} \partial_\mu \phi^i \partial^\mu \bar{\phi}^j - V_F - V_D$
  - Simple example: ϕ_0, ϕ_+, ϕ_- $\quad W = \lambda \phi_0 \, \phi_+ \, \phi_-$

$$V_F = \lambda^2 |\phi_0|^2 (|\phi_+|^2 + |\phi_-|^2) + \lambda^2 |\phi_+ \phi_-|^2$$

$$V_D = \frac{g^2}{2} \left(|\phi_+|^2 - |\phi_-|^2 + \xi \right)^2$$

Global susy

For $|\phi_0| > \frac{g}{\lambda} \sqrt{\xi}$, the minimum is $V_{\min} = \frac{1}{2} g^2 \xi^2$

D-term inflation (1996)

with G. Dvali

- Including 1-loop corrections

$$V_{\rm eff}(\phi_0) = \frac{g^2}{2}\xi^2\left(1 + \frac{g^2}{16\pi^2}\ln\frac{\lambda^2|\phi_0|^2}{\Lambda^2}\right)$$

- The slow-roll conditions are not spoilt by the exponential term of the F-potential, since the latter vanishes.

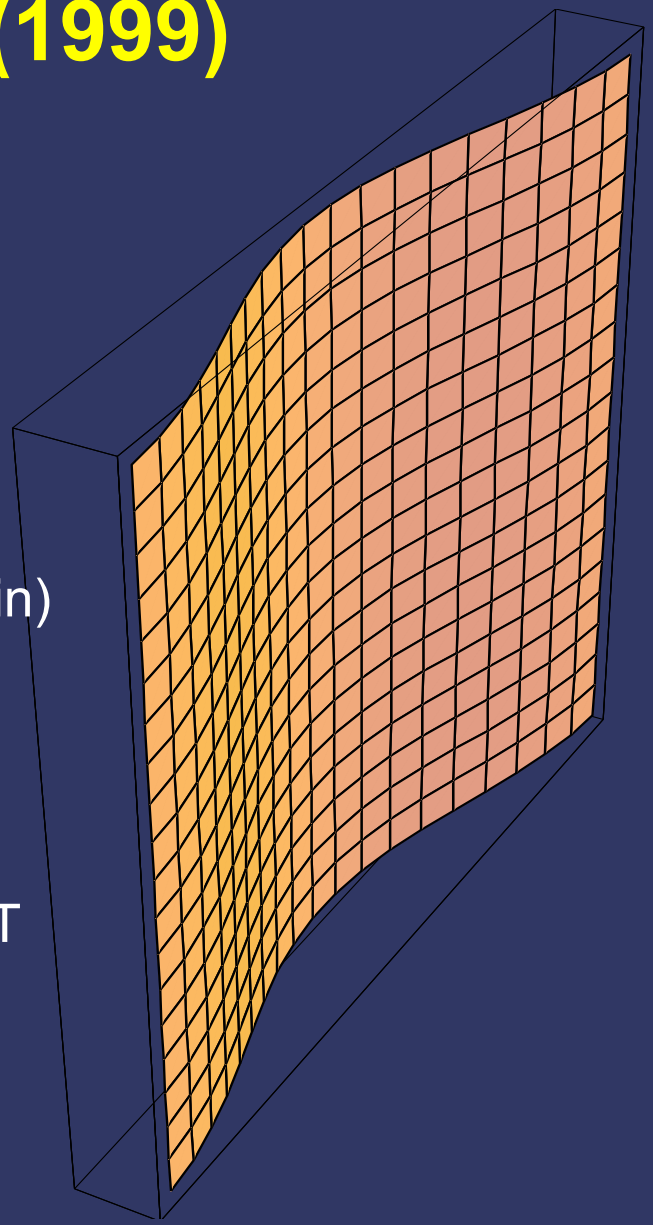
- Further refinements discussed in Binétruy, Dvali, Kallosh & van Proeyen (2004).

Brane cosmology (1999)

- Braneworlds
  - Extra dimensions

    Higher dim spacetime: the "bulk"
  - Confinement of matter

  in the "brane" (in contrast with Kaluza-Klein)



- Motivations
  - Strings: D-branes, Horava-Witten; AdS/CFT
  - Particle physics: hierarchy problem
  - **Gravity**: new compactification scheme

Brane cosmology (1999)

- 5D metric

Binétruy, Deffayet & DL (May 99)

$$ds^2 = -n^2(t,y)dt^2 + a^2(t,y)\, d\vec{x}^2 + dy^2$$

- 5D Einstein equations $G_{AB} = \kappa_5^{-2} T_{AB}$

- Brane in y=0 $T^A_B = S^A_B \delta(y) = \mathrm{Diag}[-\rho_b(t), P_b(t), 0]\delta(y)$

  Junction conditions $[K^\mu_\nu - K\delta^\mu_\nu] = -\kappa_5^2\, S^\mu_\nu$

- Modified Friedmann equation $H^2 = \frac{\kappa_5^4}{36}\rho_b^2$

$H^2 \propto \rho^2_{\mathrm{cosm}}$ incompatible with standard cosmology.

Brane cosmology (1999)

- Randall-Sundrum (June 99)
  - Anti-de Sitter bulk $\Lambda_5 < 0$
  - Brane tension: σ_b such that $\kappa_5^2 \sigma_b^2 + 6\Lambda_5 = 0$
  - One recovers standard gravity on scales $r > \ell \equiv (-6/\Lambda_5)^{1/2}$

- Cosmology [Binétruy, Deffayet, DL & Ellwanger (Oct 99)]

$$\rho_b = \sigma_b + \rho_{\rm cosm}$$

$$H^2 = \frac{\Lambda_5}{6} + \frac{\kappa_5^4}{36}\rho_b^2 \quad \Longrightarrow \quad H^2 = \frac{\kappa_5^4}{18}\rho_{\rm cosm} + \frac{\kappa_5^4}{36}\rho_{\rm cosm}^2$$

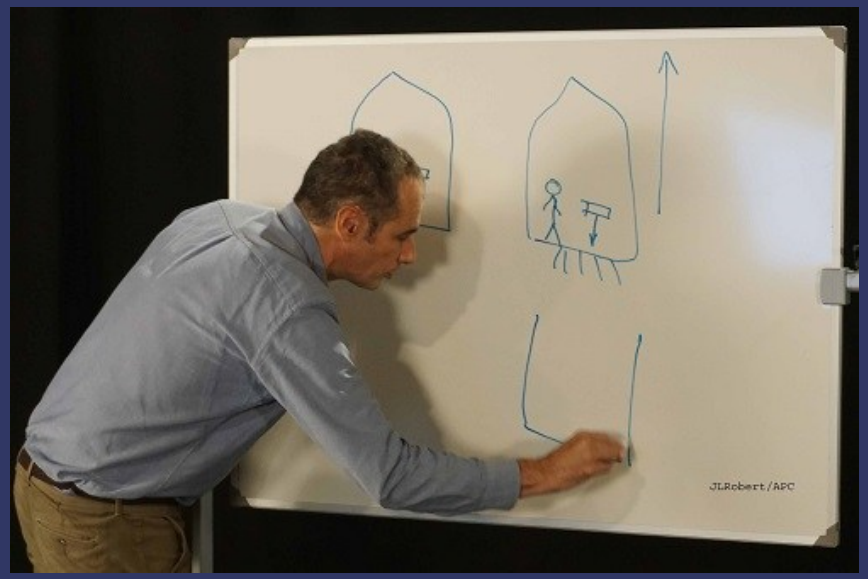
Gravitational waves (2005…)

- GW science with LISA (LISA collaboration)
- Production of GW from cosmic strings (with Bohé, Hertog & Steer, 2009-10)
- GW cosmological backgrounds and LISA (with Bohé, Caprini & Dufaux, 2012)
- Primordial GW from inflation (with Domcke, Pieroni, 2016)
- LISA Pathfinder [Armano et al. PRL 116, 231101 (2016)]

Teaching « Gravitation »

- MOOC (Massive Open Online Course) on gravitation for the general public
  - French version: « Gravité ! Du Big Bang aux Trous Noirs »
  - English version: « Gravity ! The Big Bang, Black Holes and Gravitational Waves »

90 000 registered participants !



Teaching « Gravitation »

- Popular book on gravitational waves

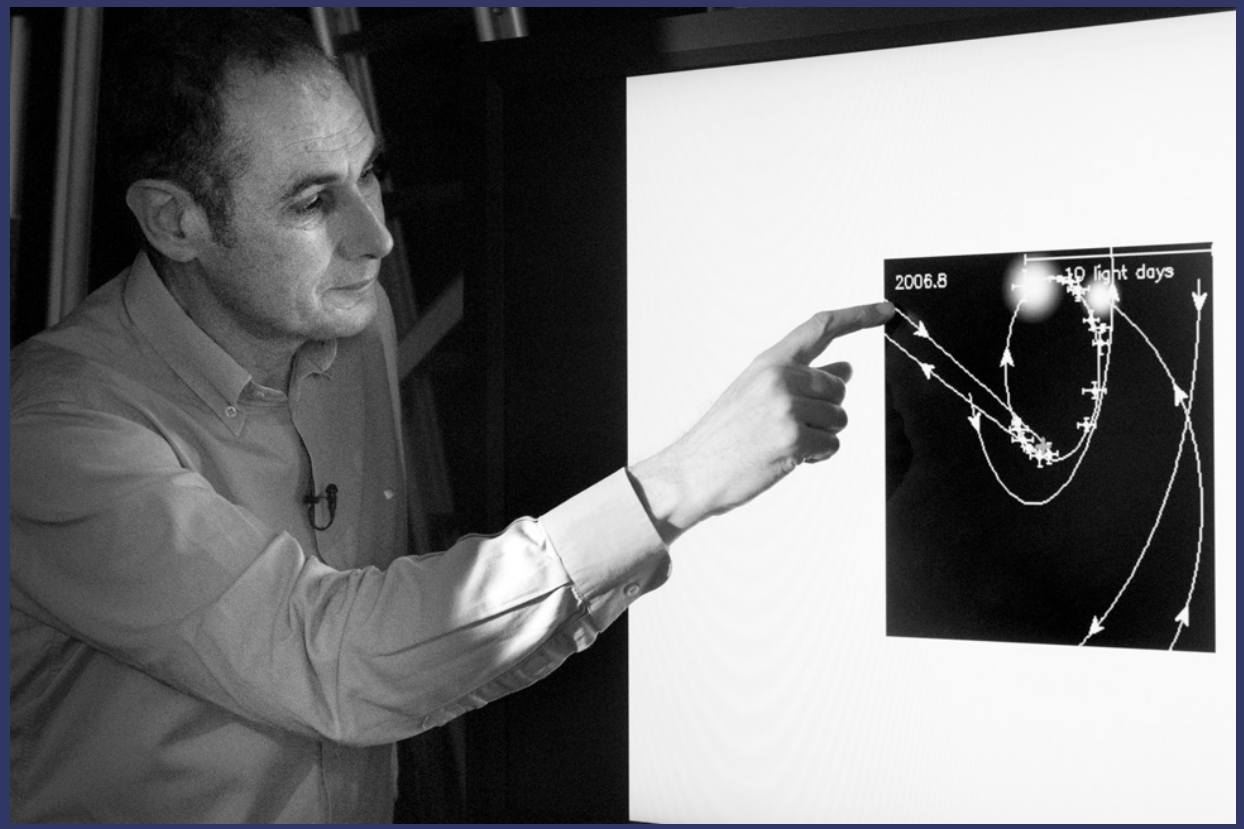
English version to appear soon

Structuring role in the French research

- Working group « GDR-SUSY » (1997-2004): theorists & experimentalists
- Foundation of a new lab: APC (AstroParticle & Cosmology). Director until 2013
- Foundation, with George Smoot, of the PCCP (Paris Center for Cosmological Physics). Adm: Marie Verleure
- Member of many committees in France & in Europe
- Expert on the « intrincacies of the French system »

Structuring role in the French research

- GW research:
  - Involvement of APC in LISA, LisaPathfinder, LIGO-Virgo (from 2005)
  - LISA-France Consortium (9 laboratories)
  - Foundation of the Working group GDR-« Gravitational waves » (2016-…)



Pierre Binétruy (1955-2017)