CosPA Theory: An Overview

- CosPA: Taiwan CosPA Project
- Homogeneous and Isotropic Universe
- Present Status of CosPA-3
- Prospects

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November 15, 2001 at EAMA5

CosPA: Taiwan CosPA Project

The Project in Search of Academic Excellence on Cosmology and Particle Astrophysics

funded by Ministry of Education

January 2000 – March 2004

- P.I.: W-Y. Pauchy Hwang （黃偉彥）
- Co-P.I.: K. Y. Lo （魯國鏞）

- Sub-Project No.1:
  Array for Microwave Background Radiation (AMIBA): From Construction and Operation to Data Acquisition and Analysis
  P.I.: K. Y. Lo （**魯國鏞**）
- Sub-Project No. 2:
  Experimental Particle Physics Studies on Issues related to “Early Universe, Dark Matter, and Inflation”
  P.I.: W. S. Hou （**侯維恕**）
- Sub-Project No.3:
  Theoretical Studies of Cosmology and Particle Astrophysics
  P.I.: W-Y. Pauchy Hwang （**黃偉彥**）

- Sub-Project No.4:
  Frontier Observation in Optical and Infrared Astronomy
  P.I.: Typhoon Lee （李太楓）
- Sub-Project No.5:
  National Infrastructure
  P.I.: Wing Ip （葉永烜）
- Total budget of about 15 million US dollars, over 4 years.

What do we attempt to accomplish through these projects?

Subproject No. 1 on Radio Astronomy

- Build the AMiBA telescope.
- Attempt to observe the CMB polarizations.
- Conduct SZ survey of high-z clusters.

Subproject No. 4 on OIR Astronomy

- Participate the WIRCAM Project of the CFHT.
- Use CFHT/OIR to conduct the LSS survey to complement the SZ survey of the AMiBA.

Subproject No. 2 on Particle Astrophysics

- B & CP
- Feasibility studies of DM searches
- Build a neutrino telescope (EUSINO) to detect high energy cosmic neutrinos.

Subproject No. 5 on National Infrastructure

- Making the link between education and research
- TAOS and other small-telescope research projects.

Subproject No. 3 on Theoretical Studies of Cosmology and Particle Astrophysics (CosPA - 3)

To make significant progresses, hopefully some breakthroughs, in the prime area of cosmology, i.e. the physics of the early universe.

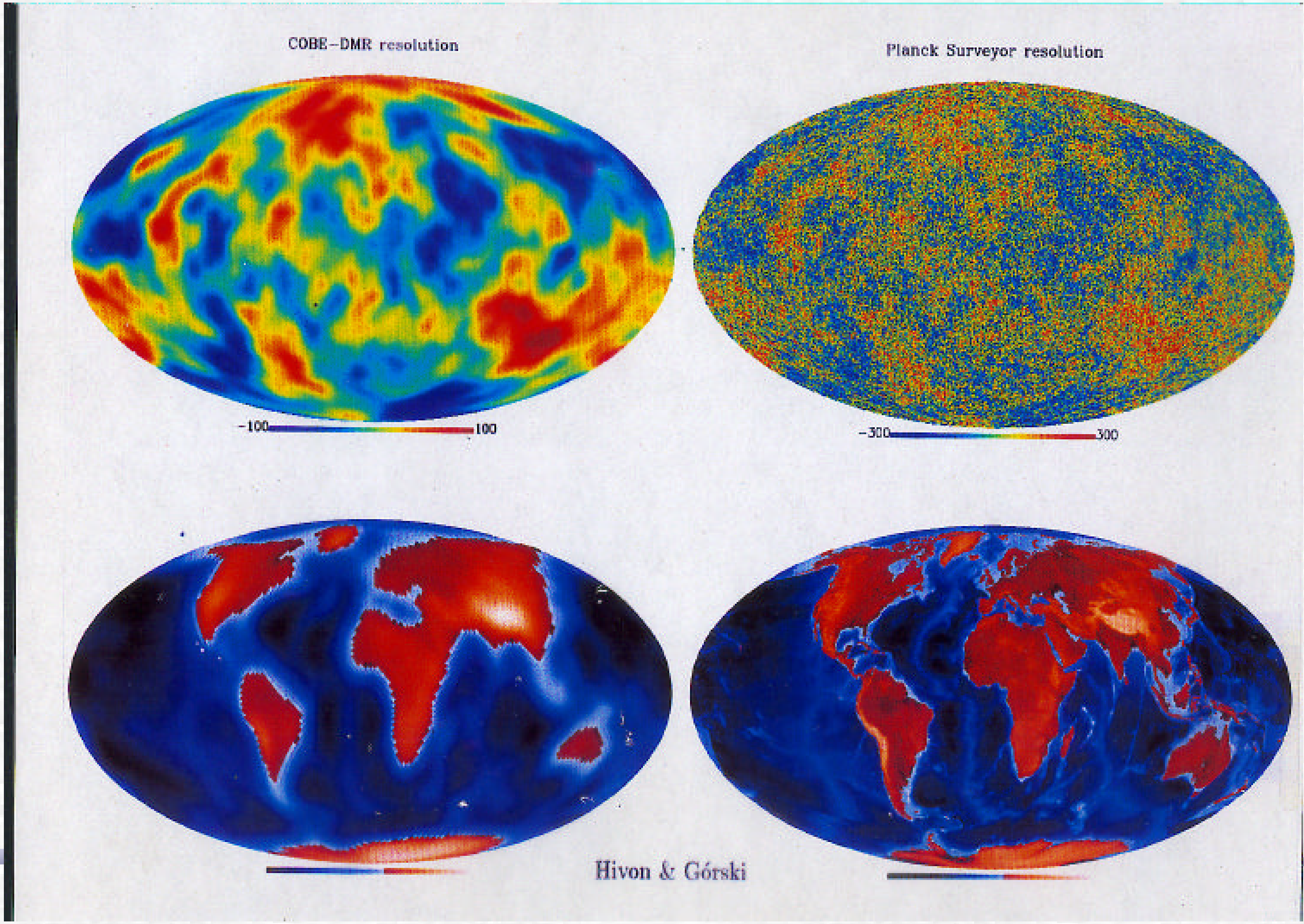
Although emphasis should be placed more on the CMB physics (a subject directly related to the AMIBA), theoretical physics must not be too limited in its scope – it would be short-lived otherwise.

P.I.: W-Y. Pauchy Hwang

Co-P.I.: Tzihong Chiueh, Xiao-Gang He, Kin-Wang Ng,
Yuan Chi, Ue-Li Pen, Pei-Ming Ho, Miao Li;
G. L. Lin, W. F. Kao, Darwin Chang, Proty Wu

Homogeneous and Isotropic Universe

Cosmology: Physics of the Early Universe



1992 **COBE/DMR** $\Delta T / T \sim 10^{-5}$

"at least as much impact as the original Penzias-Wilson discovery."

NASA	**MAP (2001)**
Princeton	**Q/DMAP**
Berkeley	**MAXIMA**
Chicago	**DASI**
Caltech	**Boomerang, CBI**
CMU	**Viper**
NRAO	**VLA**
Cambridge	**VSA**
Manchester	**Jodrell Bank**
ESA	**Planck (2008)**
U. B. C.	**BAM, White Dish**
ATNF	**ATCA**
Taiwan	**AMIBA (2004)**

Cosmological Principle

宇 宙 學 原 理

Robertson-Walker metric

$$ds^2 \;?\; dt^2 \;?\; R^2(t) ? \frac{dr^2}{1 ? kr^2} ? r^2 d?^2 ? r^2 \sin^2 ? d?^2 ?$$

k = +1, positive spatial curvature (closed)

-1, negative (open)

0, flat (critical)

$${}^3R \;?\; \frac{6k}{R^2(t)}$$

Einstein Equation

$$G_{??} \quad ? \quad 8?G?_{??} \quad ? \quad ?\, g_{??}$$

幾何結構　　物質分佈

Perfect fluid:

$$?^{?}{}_{?} \quad ? \quad \begin{pmatrix} ?? & 0 & 0 & 0 \\ 0 & ?\,p & 0 & 0 \\ 0 & 0 & ?\,p & 0 \\ 0 & 0 & 0 & ?\,p \end{pmatrix}$$

?：能量密度

P：壓力

(00):

$$\frac{\dot{R}^2}{R^2} ? \frac{k}{R^2} ? \frac{8?G}{3} ? ? \frac{?}{3} \qquad (1)$$

(ii):

$$2\frac{\ddot{R}}{R} ? \left(\frac{\dot{R}}{R}\right)^2 ? \frac{k}{R} ? ? 8?Gp ? ? \qquad (2)$$

$$\frac{\ddot{R}}{R} ? ? \frac{4?G}{3} ?? ? 3p ?? \frac{?}{3} \qquad (3)$$

Supernovae Cosmology Project (1999): $\frac{\ddot{R}}{R} ? 0$

愛因斯坦方程式與宇宙學原理可以推出的幾個結論

$$2\frac{\ddot{R}}{R} ? (1 ? 3w)\left(\frac{\dot{R}^2}{R^2} ? \frac{k}{R^2}\right) ? (1 ? w)? ? 0 \qquad \left(w ? \frac{p}{?}\right)$$

Assume $p ? ? ?$ & $k ? 0$:

$$\ddot{R} ? \frac{\dot{R}^2}{R} ? 0 \qquad ✍ \qquad R ? e^{?t}$$

A baby universe growing exponentially: Inflation !!

第一項重要結論：大暴漲！！

Let us assume there is only a scalar field, say, a "real" one:

$$? \quad ? \quad \frac{1}{2} ?\square^{2} \quad ? \quad V(?)$$

$$p \quad ? \quad \frac{1}{2} ?\square^{2} \quad ? \quad V(?)$$

Slow rollover: a period of time with $?\square^{2} ?? V$

Then $p \; ? \; ? \; ?$

✍ Inflation !!

第二項結論

Radiation dominated: $p ? \frac{?}{3}$

$$d(?R^3) ? pd(R^3) ? 0$$

✍ $? ? R^{?4}$

Matter dominated: $p ? 0$

(nonrelativistic particles)

✍ $? ? R^{?3}$

$$2 ? 10^{?31}\, g/cm^3 \;\; ? \;\; ?_B^0 \;\; ? \;\; ?_{NR}^0 \;\; ? \;\; 2 ? 10^{?29}\, g/cm^3$$

$$?_?^0 \;\; ? \;\; ? \; \frac{T_0^4}{c^2} \;\; ? \;\; 5 ? 10^{?35}\, g/cm^3$$

a **= Stefan-Boltzmann constant**

$$t ? \;\; 0^? \;\; : \; R ? \;\; 0$$

- **radiation-dominated universe**

$k ? 0, ? \;\; ? \; 0,$ & $? \; ? \; \dfrac{?_0}{R^4}$ (Radiation dominated)

$$? \quad \dot{R}^2 \; ? \; \frac{8?G?_0}{3R^2} \qquad ? \quad R \; ? \; ?\frac{16?G?_0}{3}?^{1/2} t^{1/2}$$

$$? \quad ? \; ? \; ?\frac{3}{16?G?_0}?^2 \frac{?_0}{t^2} \; ? \; a\frac{T^4}{c^2}$$

第三項結論：大霹靂（宇宙之膨脹與冷卻）

$$? \; ? \; \frac{3}{32?G} t^{?2}, T \; ? \left(\frac{3c^2}{32?Ga}\right)^{1/4} t^{?1/2}$$

$$? \; 10^{10} t^{?1/2} ({}^0K)$$

Important Times	Temperature
$t \; ? \; 10^{?10}$ sec	$T \; ? \; 10^{15\,?} K(? \; 100 GeV)$
$10^{?5}$ sec	$3 ? 10^{12\,?} K(? \; 300 MeV)$
$10^{?4}$ sec	$10^{12\,?} K(? \; 100 MeV)$
1 sec	$10^{10\,?} K(? \; 1 MeV)$ (neutrinos decouple.)
10 sec	$3 ? 10^{9\,?} K(? \; 300 KeV)$ (photons decouple.)

4 Stages of Life of Our Universe
宇宙之四個生命

- The very Early Universe – the Inflation Era
  time $t < t = 0^+$
- The Early Universe — the Hot Big Bang Era
  $t = 0^+$ up to $t \sim 1$ sec
- The Baby Universe — the Post Big Bang Era
  $t \sim 1$ sec up to $t \sim 300{,}000$ years
- The Present Universe —
  Structure Formation / Evolution Era
  $t \sim 300{,}000$ years onwards

What do we expect to learn in the near future ?

- CMB anisotropies over the entire sky, in much better angular and temperature resolutions.
- CMB polarizations.
- Surveys of high-z clusters, through SZ, OIR, supernovae, gravitational lensing, etc.

The Very Early Universe

$t < t = 0^{+}$ sec

Inflation

Consistent

Evolution?

The Early Universe

$T = 0^{+}$ up to t ~ 1 sec

Hot Big Bang

Natural

Initial

Conditions?

The Baby Universe

t ~ 1 sec up to 300,000 years

CMB Anistropy and Polarization

The Present Universe

Large-Scale Structures

The Present Status of CosPA-3

- **Research Faculty:**
  Tzihong Chiueh (闕志鴻), Prof.
  Xiao-Gang He (何小剛), Prof.
  Pei-Ming Ho (賀培銘), Associate Prof.
  W-Y. Pauchy Hwang (黃偉彥), Prof.
  Miao Li (李淼), Visiting Prof.
  Kin-Wang Ng (吳建宏), Co-P.I.
  Ue-Li Pen (彭威禮), Co-P.I.
  Jiun-Huei Proty Wu (吳俊輝), Assistant Prof.
  Chi Yuan (袁旂), Joint Prof.

- **Research Faculty: (Signed up recently)**
  Darwin Chang (張達文), NTHU
  Win-Fun Kao (高文芳), NCTU
  Guey-Lin Lin (林貴林), NCTU
- **Postdoctoral Fellows:**
  Kaiti Wang (汪愷悌), Research Assistant Prof.
  Chiang-Mei Chen (陳江梅)
  Dilip Kumar Ghosh, from India
  Je-An Gu (顧哲安)
  Yao-Huan Tseng (曾耀寰)
  Hyun Seok Yang, from Korea
- **Currently 16 Ph.D students**
- **About the same number of M.S. students**

- We are also inviting a number of senior scientists in order to stimulate interactions at a deeper level, or for collaborations.
- Visitors over the last half a year:
  Andrew Liddle
  David Gross
  Bruce McKellar
  Robert Brandenberger
  Misao Sasaki
  Stephan Narison
  Asoke N. Mitra
  etc.

Important Research Topics as of Today

- CMB Anisotropies and Polarizations:
  Primary & Secondary.
- Simulations of Large-Scale Structures
  tied to Survey of High-z Clusters.
- Noncommutative Spacetime & Inflation.
- Accelerating Universe & Quintessence.
- Phase Transitions in the Early Universe.

The role of Phase Transitions in the Early Universe has become one of the leading problems in cosmology.

Produce inhomogeneities and amplify existing inhomogeneities.

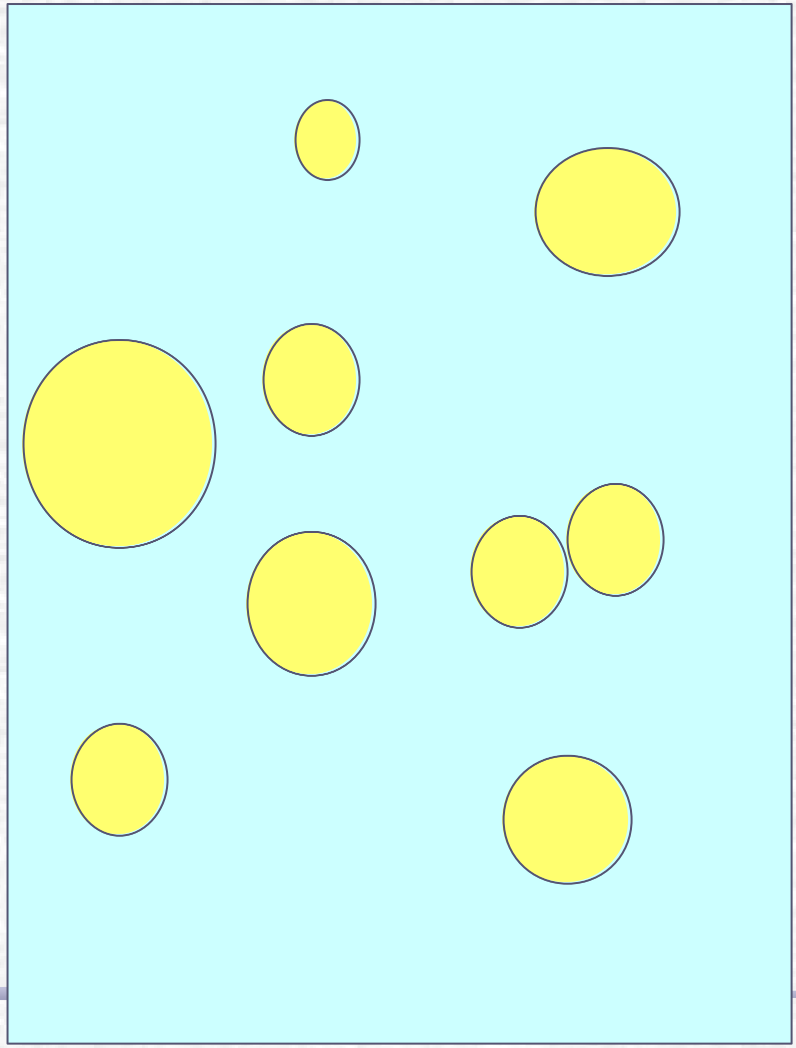
Account for the origin of the detailed structure of CMB.

Also in collaboration with:
Ernest M. Henley (U. of Washington),
L. S. Kisslinger (CMU),
Mikkle B. Johnson (Los Alamos),
Sandip Pakvasa (Hawaii).

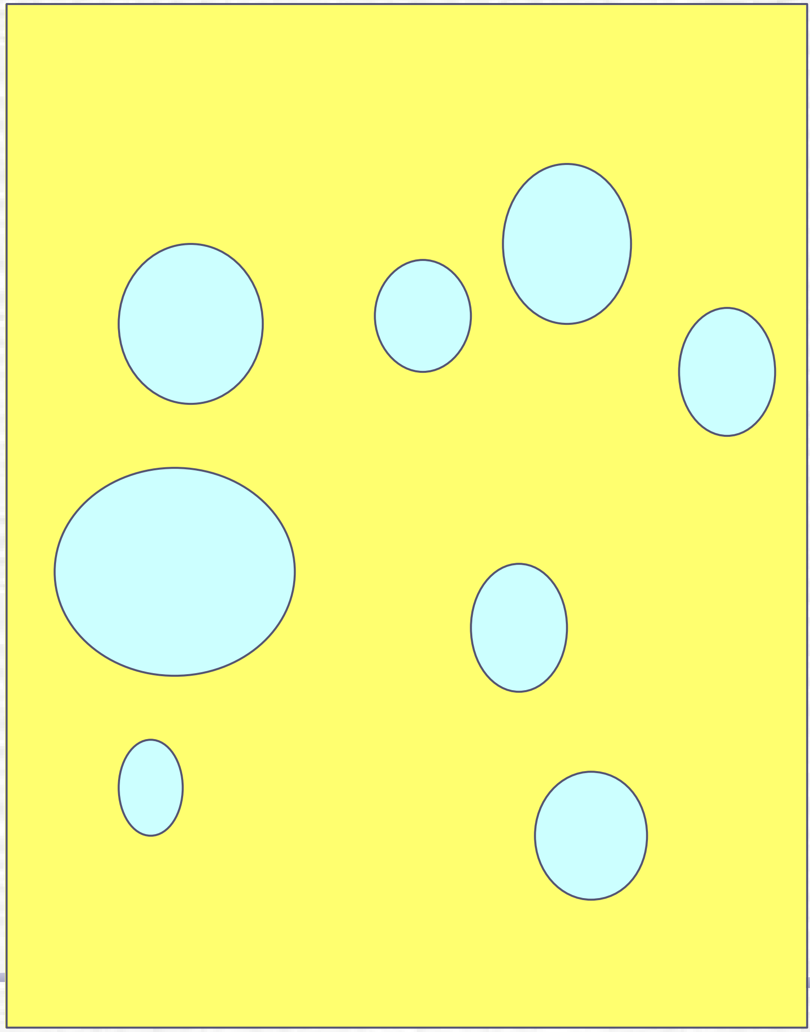
- Electro-weak (EW) phase transition (which endows masses to the various particles) and QCD phase transition (which gives rise to confinement of quarks and gluons to within hadrons in the true QCD vacuum) are two well-established phenomena in the standard model of particle physics.
- Formulation of EW and QCD phase transitions has become one of the most challenging problems in the physics of the early universe.

Phase Transitions in the Early Universe

$T > T_c$

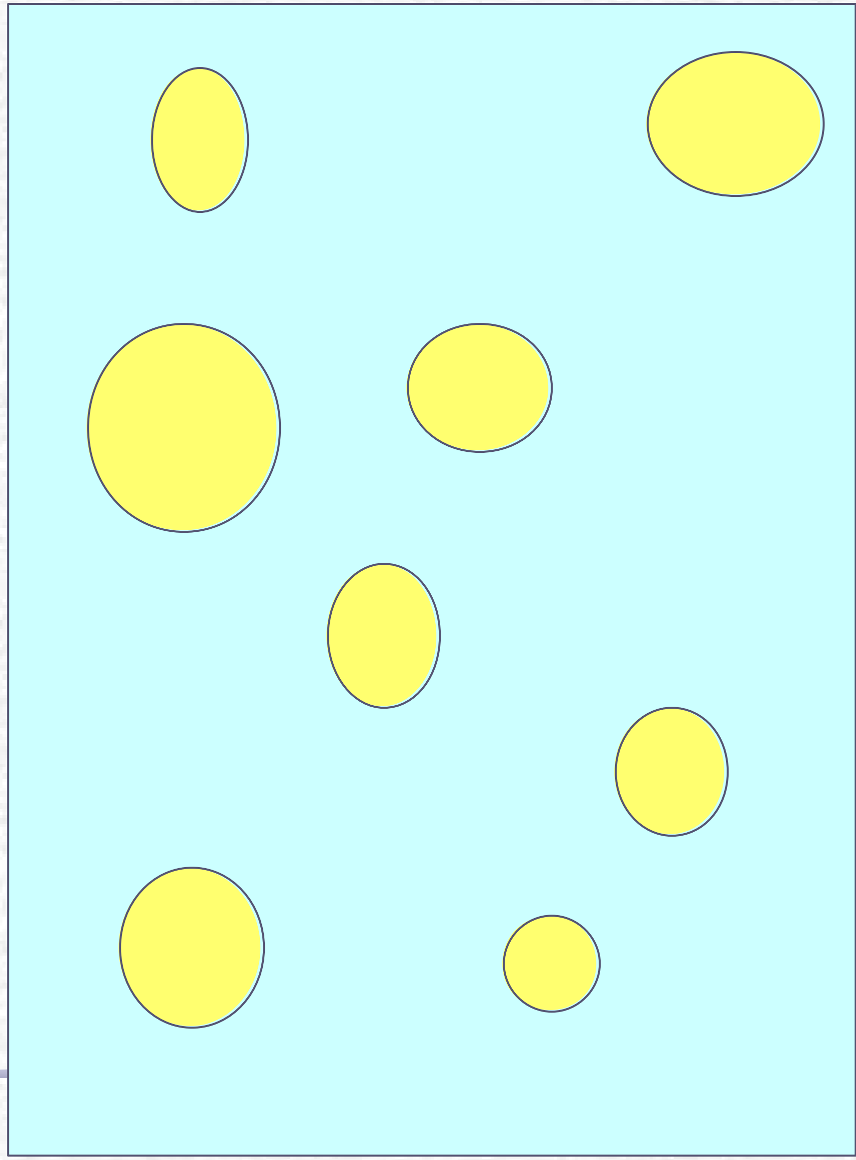


$T < T_c$



Anatomy of the Problem

- How does an individual bubble grow or explode ?
- How do two bubbles merge into a single one or explode into each other ?
- What is the chance of squeezing enough matter into a sufficiently small volume in order to form black holes ?
- Statistical ensemble of “bubbles” of various sizes.



Prospects

- At the turn of the century, cosmology is transforming itself into an experimental science. It has become the main-stream research in astronomy, as well as in particle astrophysics. It may take 20 to 30 years before the competition is over.
- Taiwan is joining this red-hot race through the Taiwan CosPA Project. The project, if successful, should help us to build a world-class, research-based, respectable astronomy in Taiwan.