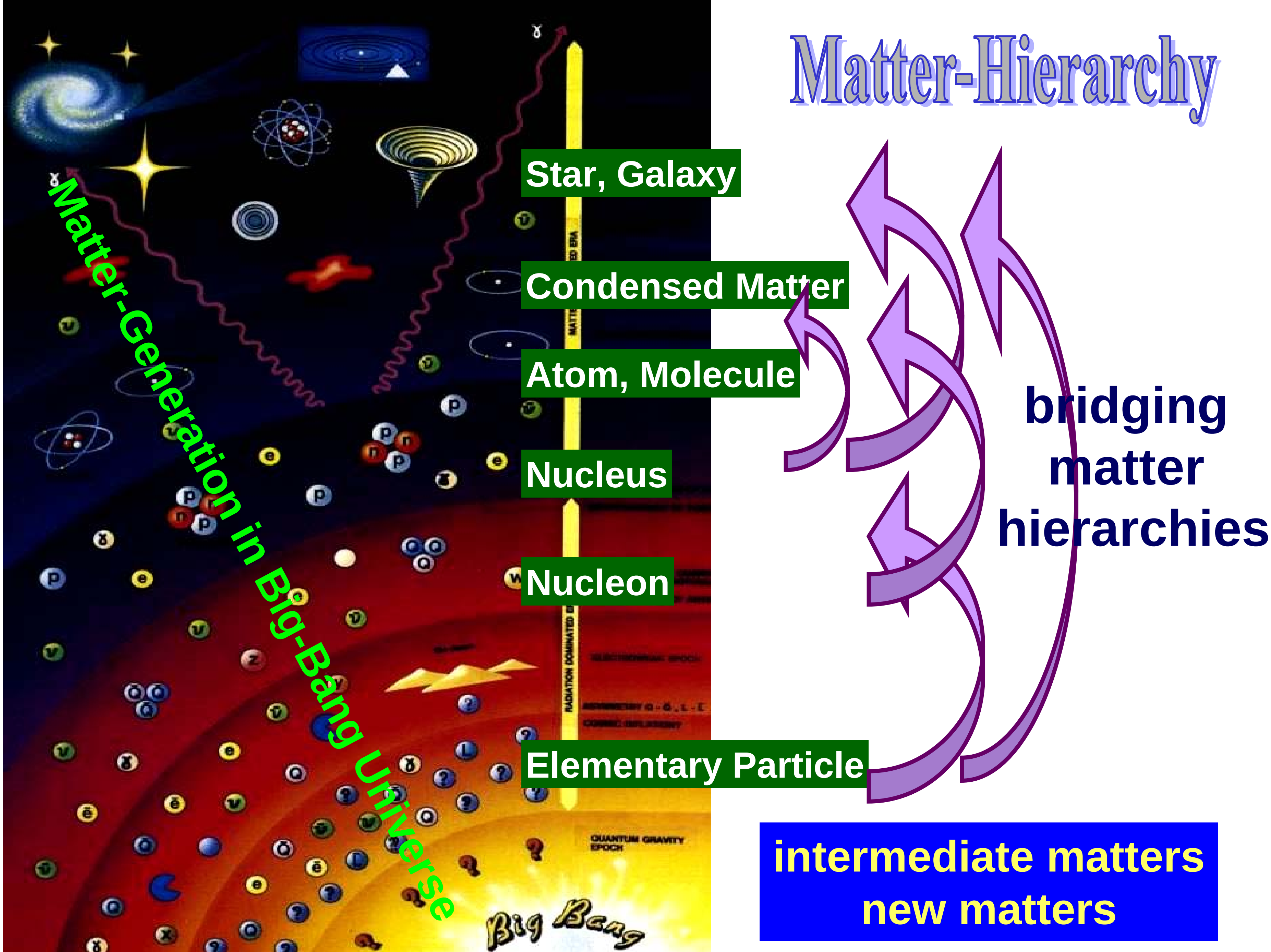
Exploring New Science by Bridging Particle-Matter Hierarchy

21st Century COE Program
:
for 5 years from 2003

Matter-Hierarchy



intermediate matters
new matters

Project Strategy

- encourage current activities on individual matter hierarchy

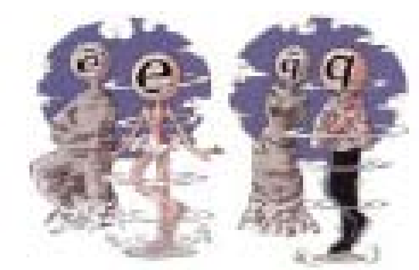
- create new activities bridging matter hierarchies

- Current Activities
- Proposed New Activities

Current Activities

Elementary Particle : Theory

Exploring Physics Beyond the Standard Model of Particle Physics



Candidates for Beyond Standard Model

- **SUPERSYMMETRY**
  - **Grand Unification? Physics at Ultimate Short Distance**
- **Hidden Dimensions**
  - **Radical Change to Law of Gravity: String Theory at Hand ?**
- **Alternatives:** Strong Dynamics? Higgsless theory?
  - **?????**

Elementary Particle : Experiment 1

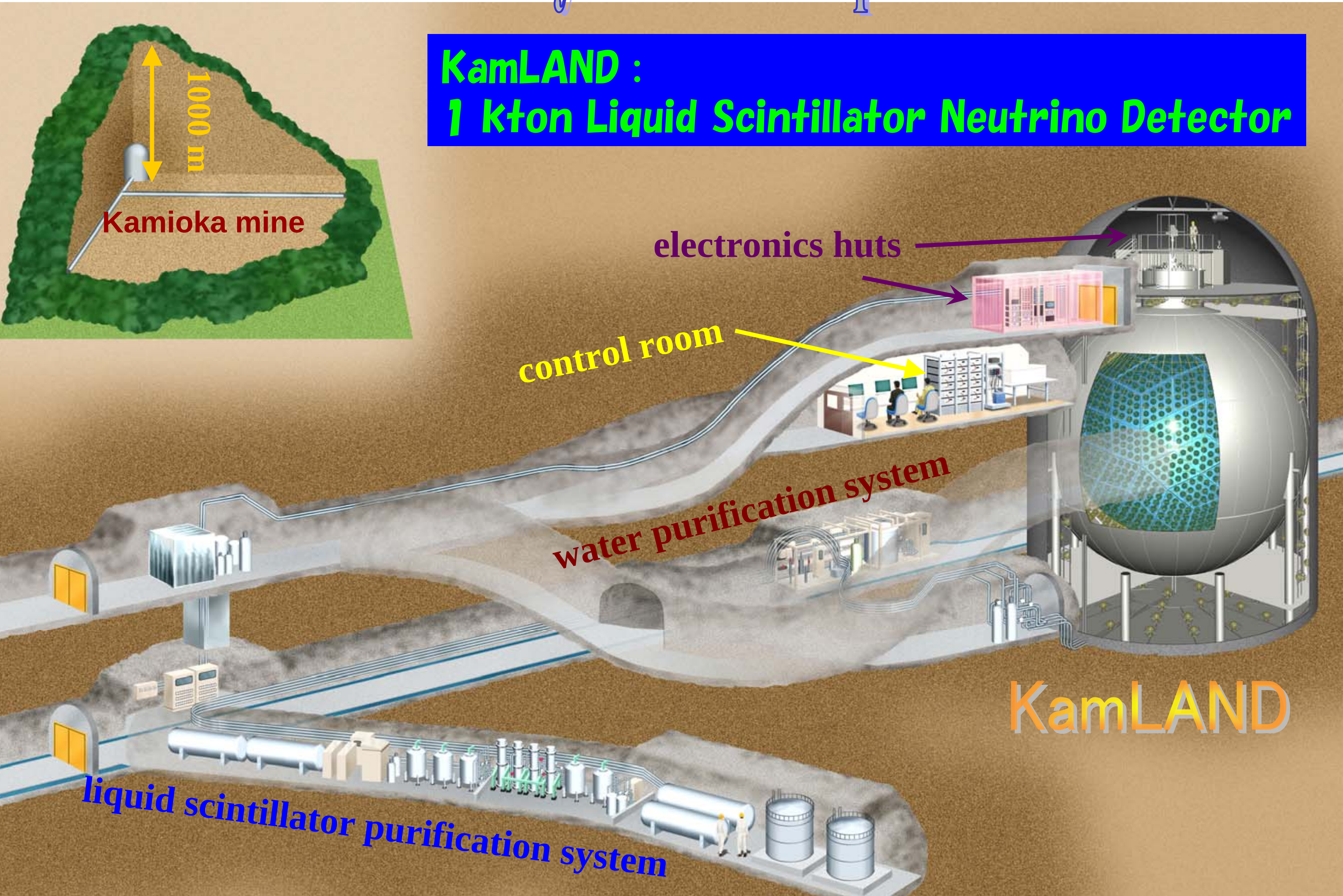
KEK $e^- e^+$ Collider
B-Factory

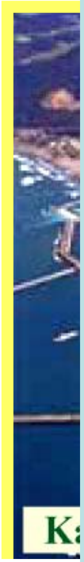
Tohoku Team

Observation of Large CP Violation and Evidence for Direct CP Violation in B0->pi+pi- Decays (Jan. 19, 2004)

Why did the anti-matter disappear in the universe ?

Elementary Particle : Experiment 2





indication :

neutrino oscillation based on finite neutrino masses

solve :

solar neutrino deficit (solar neutrino problem → a long-standing puzzle for ~ 30 years)

Phys. Rev. Lett. 90, 021802 (2003)

First Results from KamLAND: Evidence for Reactor Anti-Neutrino Disappearance

citation no = 269 in 2003

K. Eguchi,[1] S. Enomoto,[1] K. Furuno,[1] J. Goldman,[1] H. Hanada,[1] H. Ikeda,[1] K. Ikeda,[1] K. Inoue,[1] K. Ishihara,[1]
W. Itoh,[1] T. Iwamoto,[1] T. ... ,[1] M. Koga,[1] Y. Koseki,[1]
T. Maeda,[1] T. Mitsui,[1] M. M... wa,[1] K. Owada,[1] T. Sakabe,[1]
I. Shimizu,[1] J. Shirai,[1] F. S... K. Tamae,[1] H. Watanabe,[1]
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M.P. Decowski,[3] D.A. Dwyer,[3] S.J. Freedman,[3] Y. Fu,[3] B.K. Fujikawa,[3] K.M. Heeger,[3] K.T. Lesko,[3] K.-B. Luk,[3]
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R.D. McKeown,[4] J. Ritter,[4] B. Tipton,[4] P. Vogel,[4] C.E. Lane,[5] T. Miletic,[5] P.W. Gorham,[6] G. Guillian,[6] J.G. Learned,[6]
J. Maricic,[6] S. Matsuno,[6] S. Pakvasa,[6] S. Dazeley,[7] S. Hatakeyama,[7] M. Murakami,[7] R.C. Svoboda,[7] B.D. Dieterle,[8]
M. DiMauro,[8] J. Detwiler,[9] ... [10] W. Bugg,[10] H. Cohn,[10]
Y. Efremenko,[10] Y. Kamyshkov, ... Gould,[11] H.J. Karwowski,[11]
D.M. Markoff,[11] J.A. Messimore,[11] K. Nakamura,[11] R.M. Rohm,[11] W. Tornow,[11] A.R. Young,[11] and Y.-F. Wang[12]
(KamLAND Collaboration)
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Japan – US – China Collaboration

VOL. 15, NO. 1 JANUARY/FEBRUARY 2004

SCIENCEWATCH®

TRACKING TRENDS AND PERFORMANCE IN BASIC RESEARCH

WHAT'S HOT IN PHYSICS... 2003

Rank	Paper	Citations This Period (Jul-Aug 03)	Rank Last Period (May-Jun 03)
1	M. Greiner, *et al.*, **"Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms,"** *Nature*, 415(6867): 39-44, 3 January 2002. [U. Munich, Germany; Max Planck Inst. Quantum Optics, Garching, Germany; ETH Zurich, Switzerland] *507KZ	38	4
2	Q.R. Ahmad, *et al.*, **"Measurement of the rate of $NU_e + d \rightarrow p + p + e^-$ interactions produced by ^8B solar neutrinos at the Sudbury Neutrino Observatory,"** *Phys. Rev. Lett.*, 87(7): 1301, 13 August 2001. [15 institutions worldwide] *463LU	37	1
3	Q.R. Ahmad, *et al.*, **"Direct evidence for neutrino flavor transformation from neutral-current interactions in the Sudbury Neutrino Observatory,"** *Phys. Rev. Lett.*, 89(1): 1301, 1 July 2002. [17 institutions worldwide] *563YN	36	2
4	K. Eguchi, *et al.*, **"First results from KamLAND: Evidence for reactor antineutrino disappearance,"** *Phys. Rev. Lett.*, 90(2): 1802, 17 January 2003. [12 institutions worldwide] *636FP	30	†
5	D. Vion, *et al.*, **"Manipulating the quantum state of an electrical circuit,"** *Science*, 296(5569): 886-9, 3 May 2002. [CEA Saclay, Gif-sur-Yvette, France] *549KF	28	†
6	R.R. Metsaev, **"Type IIB Green-Schwartz superstring in plane wave Ramond-Ramond background,"** *Nucl. Phys. B*, 625:70-96, 18 March 2002. [Lebedev Phys. Inst., Moscow, Russia] *531CY	25	†
7	Q.R. Ahmad, *et al.*, **"Measurement of day and night neutrino energy spectra at SNO and constraints on neutrino mixing parameters,"** *Phys. Rev. Lett.*, 89(1):1302, 1 July 2002. [17 institutions worldwide] *563YN	23	3
8	C.B. Netterfield, *et al.*, **"A measurement by BOOMERANG of multiple peaks in the angular power spectrum of the cosmic microwave background,"** *Astrophys. J.*, 571(2): 604-14, 1 June 2002. [14 institutions worldwide] *556CB	23	8
9	N.W. Halverson, *et al.*, **"Degree Angular Scale Interferometer first results: A measurement of the cosmic microwave background angular power spectrum,"** *Astrophys. J.*, 568(1): 38-45, 20 March 2002. [U. Chicago, IL; U. Calif., Berkeley; JPL, Pasadena; CA; Caltech, Pasadena] *531VN	22	9
10	Y.A. Vlasov, *et al.*, **"On-chip natural assembly of silicon photonic bandgap crystals,"** *Nature*, 414(6861): 289-93, 15 November 2001. [NEC Res. Inst., Princeton, NJ; A.F. Ioffe Phys.-Tech. Inst., St. Petersburg, Russia; Princeton U., NJ] *492CM	20	†

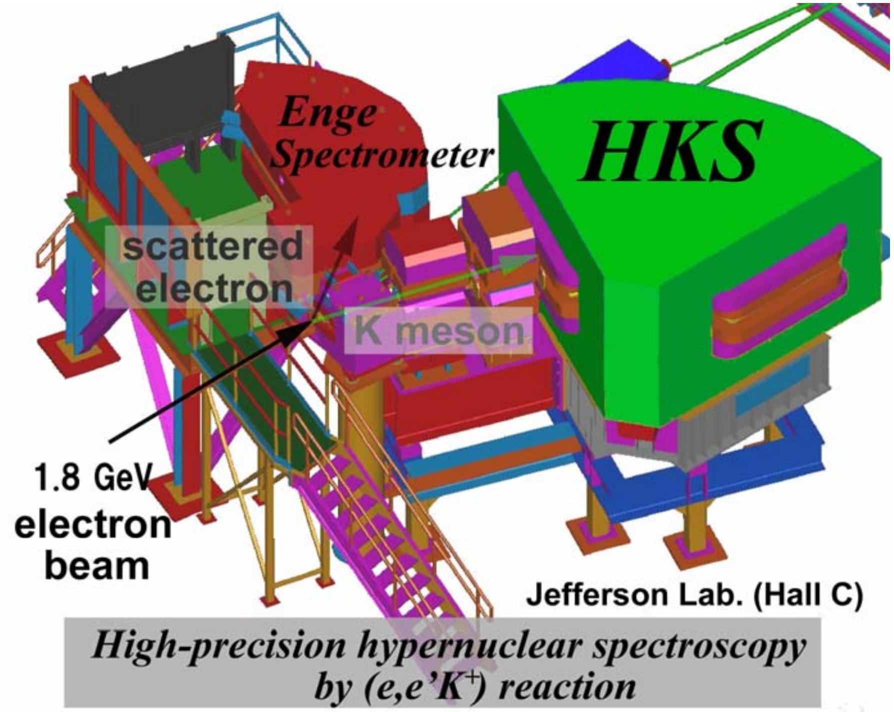
SOURCE: ISI's Hot Papers Database

*, †—See legend in the table on page 5

Nucleus : Experiment

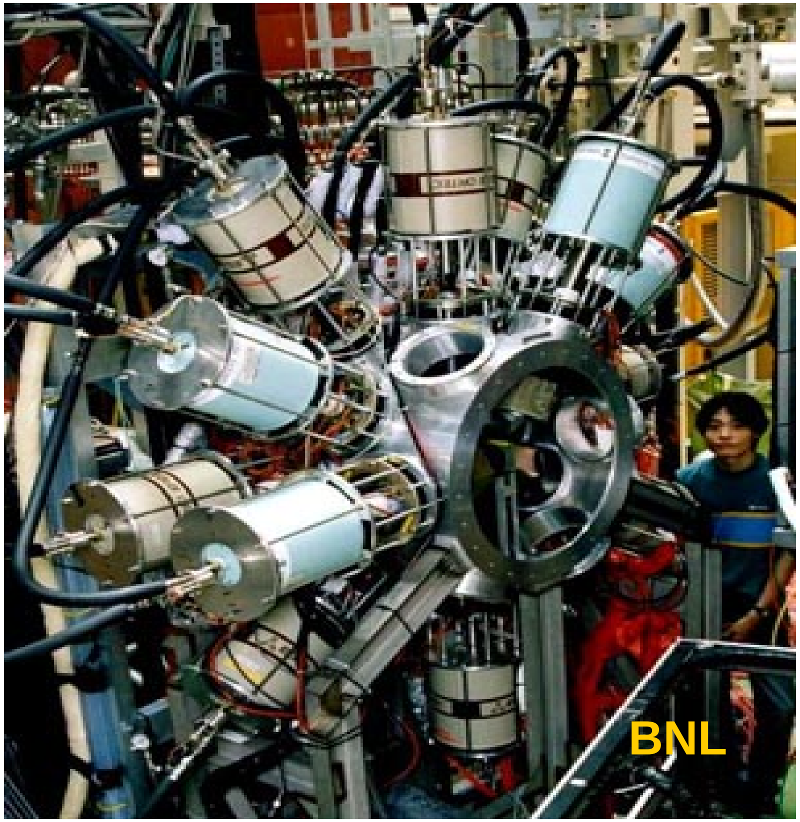
High-Precision Spectroscopy of Hyper-Nuclei

High-Resolution Kaon Spectrometer (HKS)



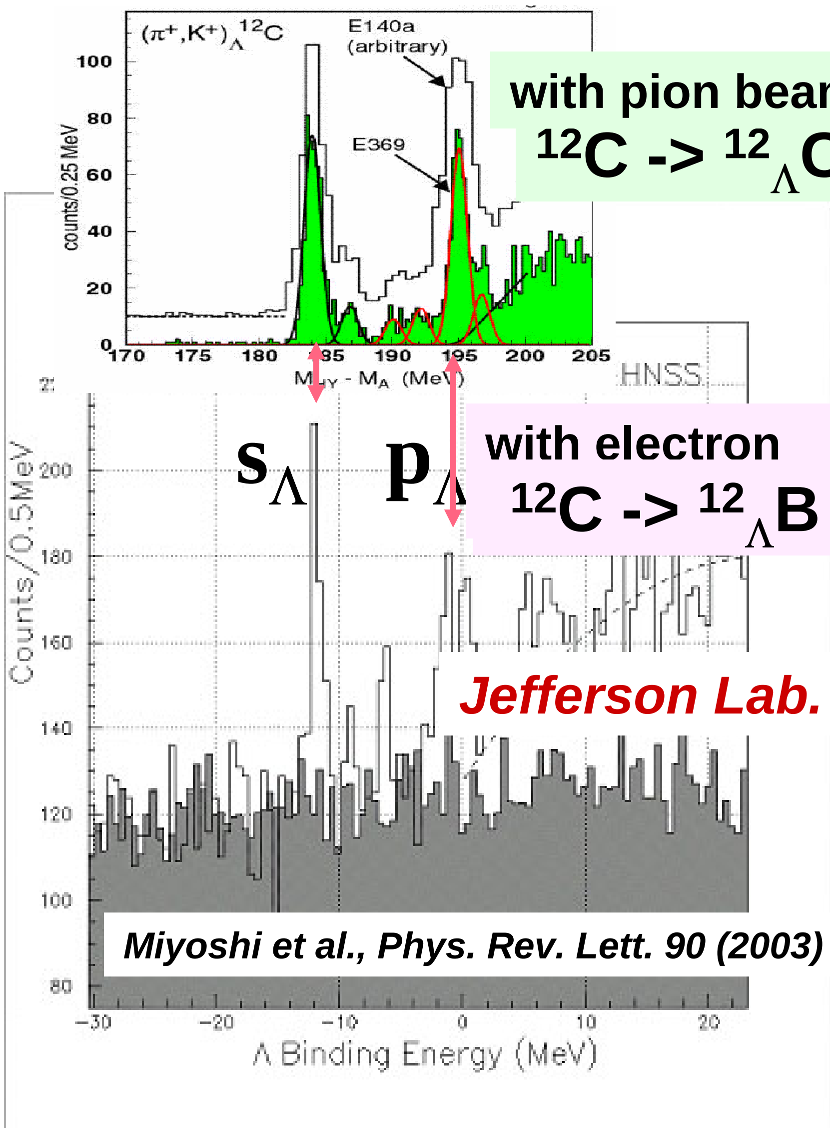
-Constructed by Tohoku U.
-Under installation at Jefferson Lab.

High-Precision γ-Ray Spectrometer (Hyperball)



HKS

Hyperball

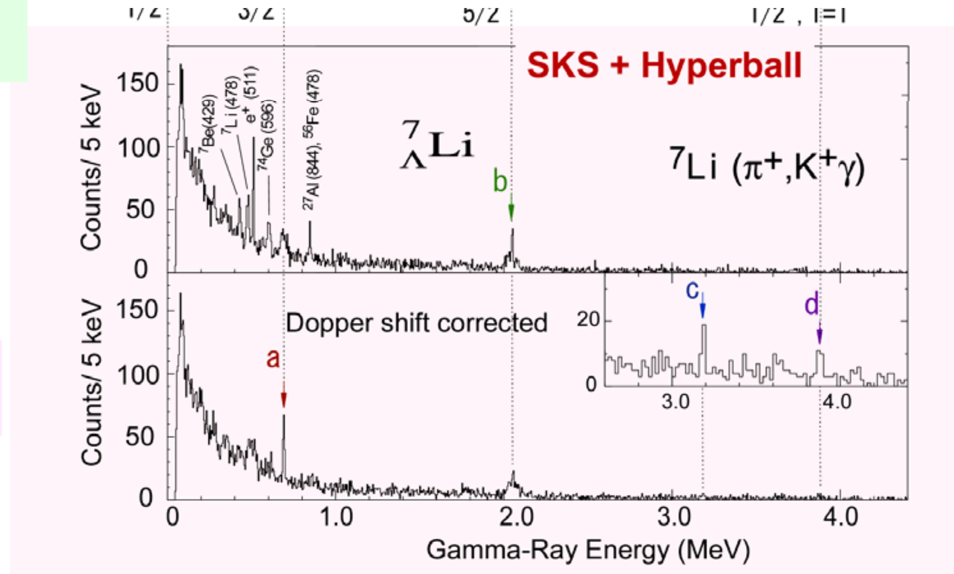


with pion beam
$^{12}C \rightarrow {}^{12}_{\Lambda}C$

with electron
$^{12}C \rightarrow {}^{12}_{\Lambda}B$

Jefferson Lab.

Miyoshi et al., Phys. Rev. Lett. 90 (2003) 232502.



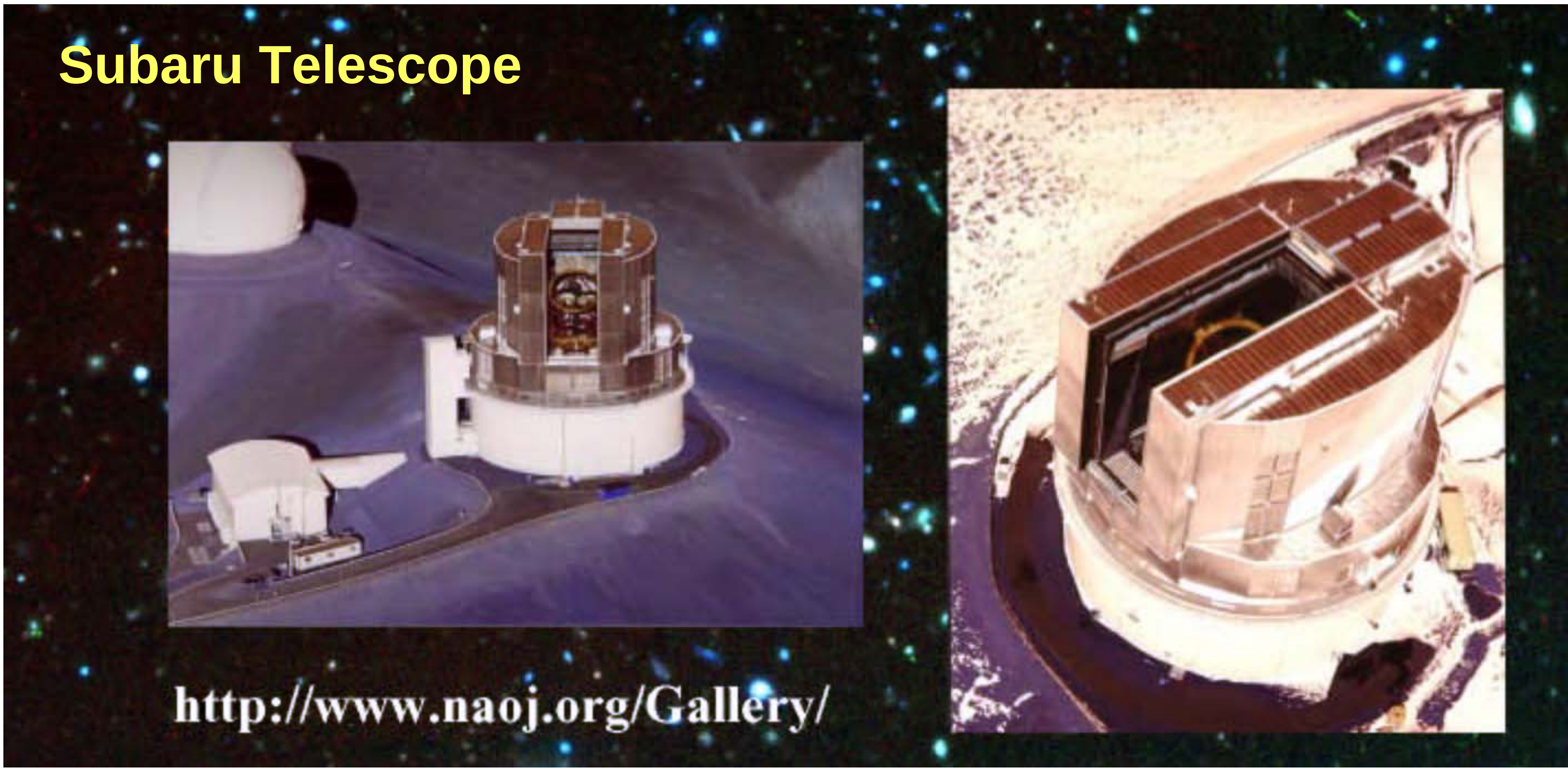
H. Tamura et al., Phys. Rev. Lett. 84 (2000) 5963

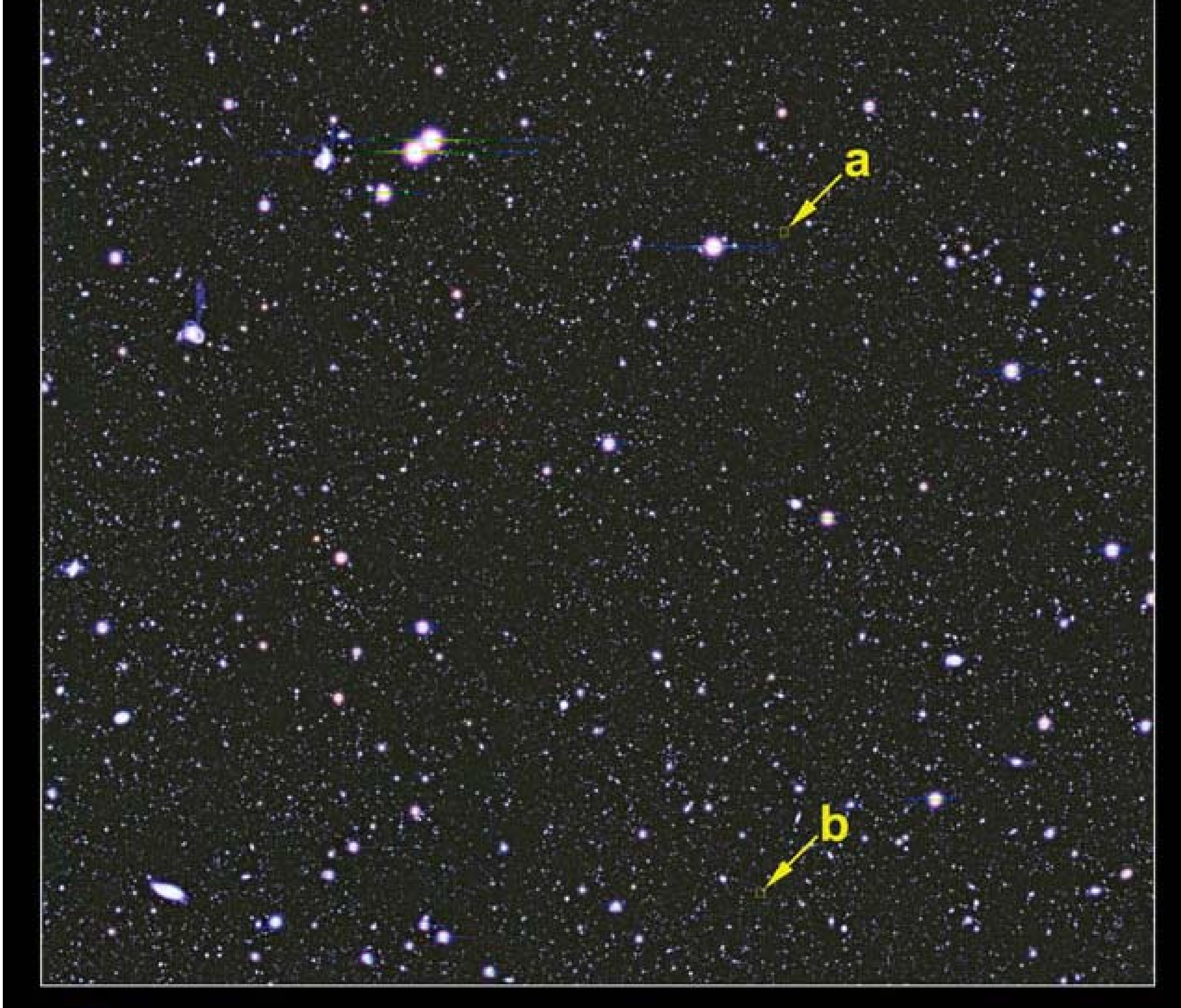
K. Tanida et al., Phys. Rev. Lett. 86 (2001) 1982

H. Akikawa et al., Phys. Rev. Lett. 88 (2002) 082501

3 orders of magnitude improvement in energy resolution

Astronomy



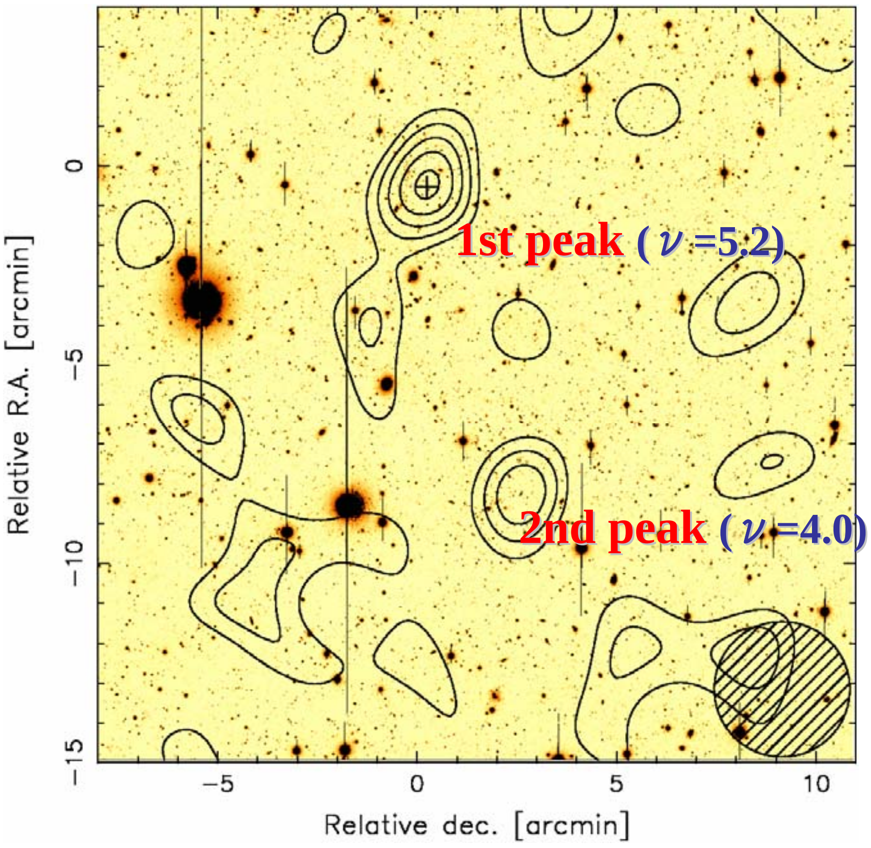


58)

ct)

Investigation : distribution of dark matter
Determination : nature of dark energy

Gravitational Lens



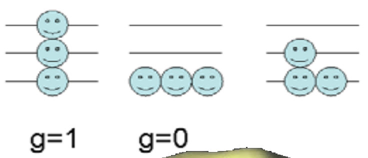
contour plot :
dark matter distribution
(Subaru telescope)

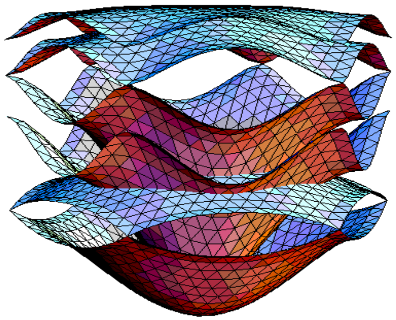
Condensed Matter : Theory

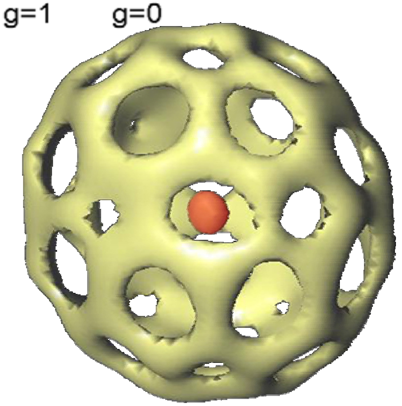
$$\Delta D = -g\Delta N$$

- elementary excitations in solids with fractional statistics.

g=1: fermions
g=0: bosons
g=1/2: semions or parafermions

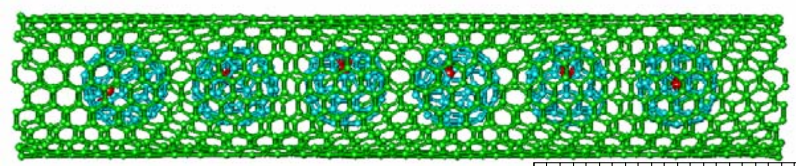




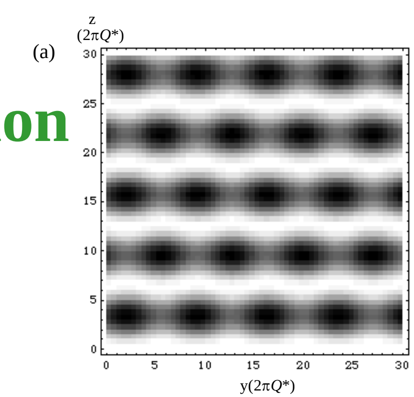


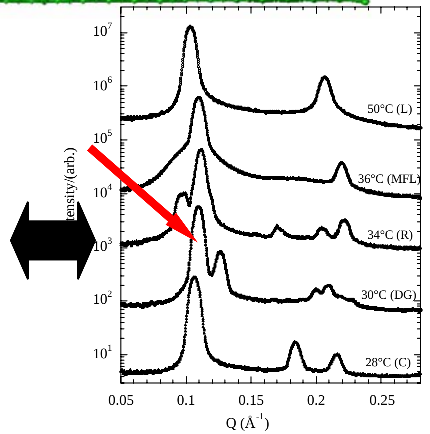
- Carbon nanotube

- fullerene: new materials



- Ginzburg-Landau model for structural phase-transition of block copolymers





Condensed Matter : Experiment 1

Synchrotron Radiation X-Ray and Neutron Scattering

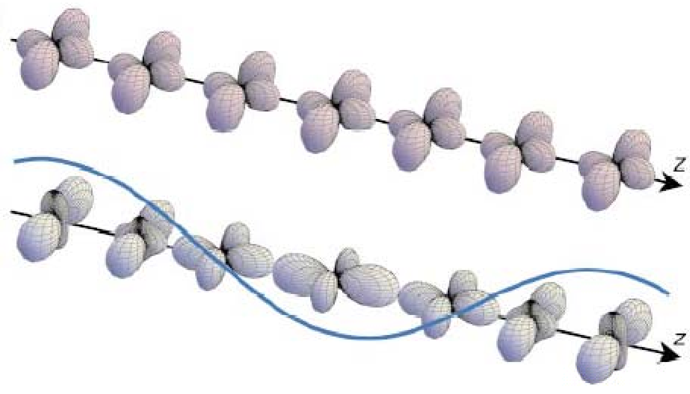
excitation mechanisms
of
phonon & magnon

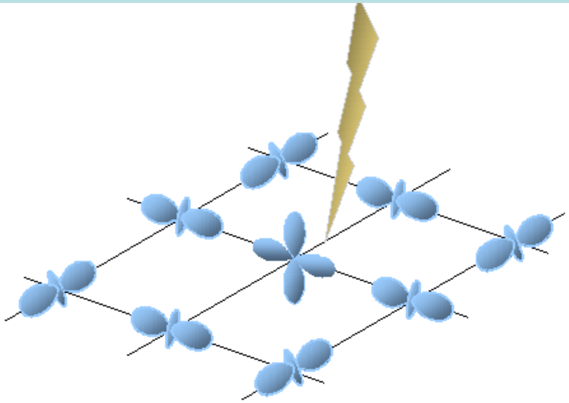
3 degrees of freedom of electrons
(Charge, Spin and Orbital)
:
in strongly correlated electron systems

resonant x-ray inelastic scatterings

Orbital degree of freedom and the excitations

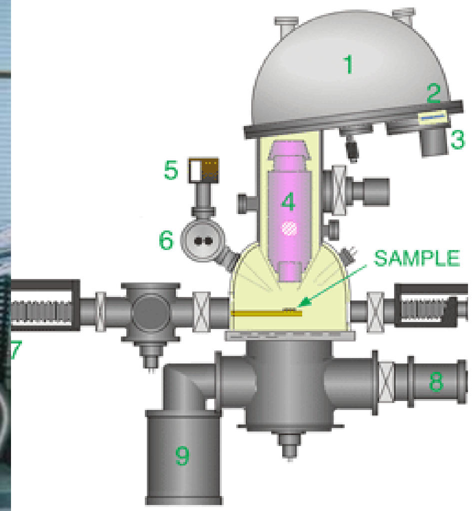
Collective Orbital Excitation	Individual Orbital Excitation

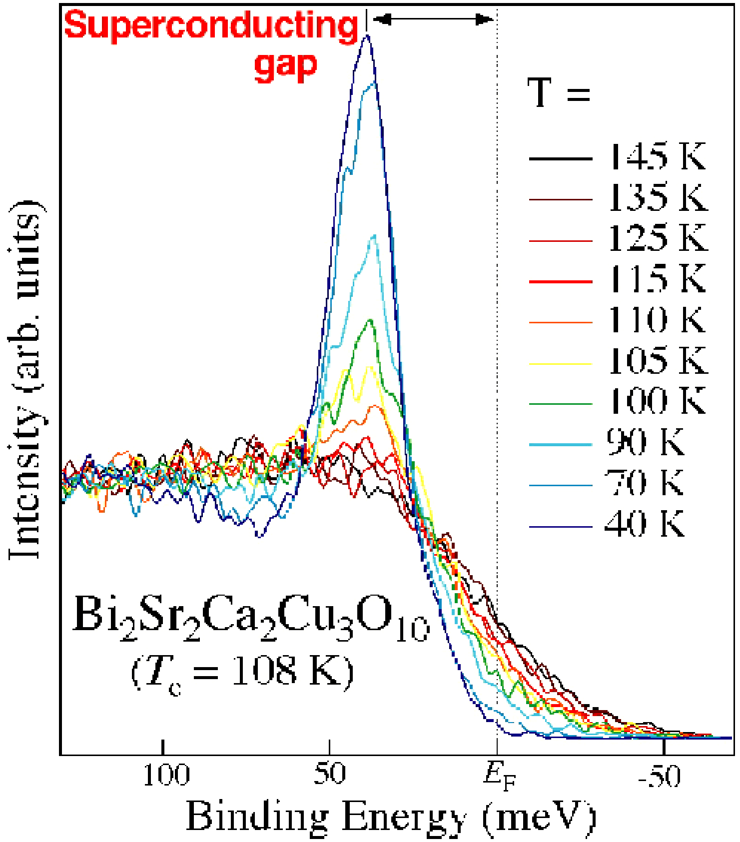




Condensed Matter : Experiment 2

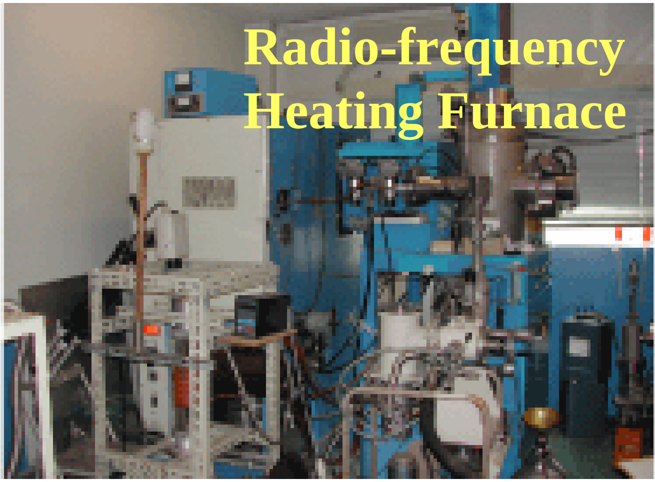
High Resolution Photoelectron Spectroscopy

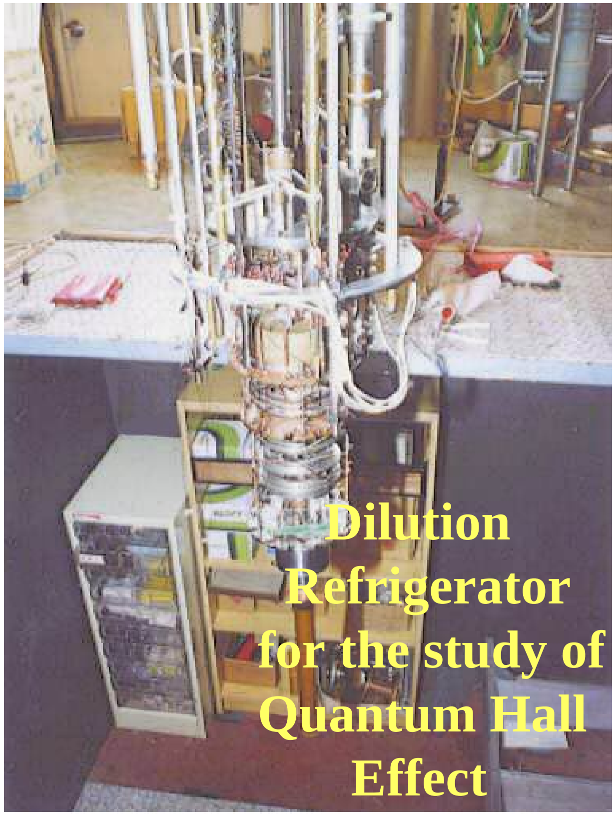


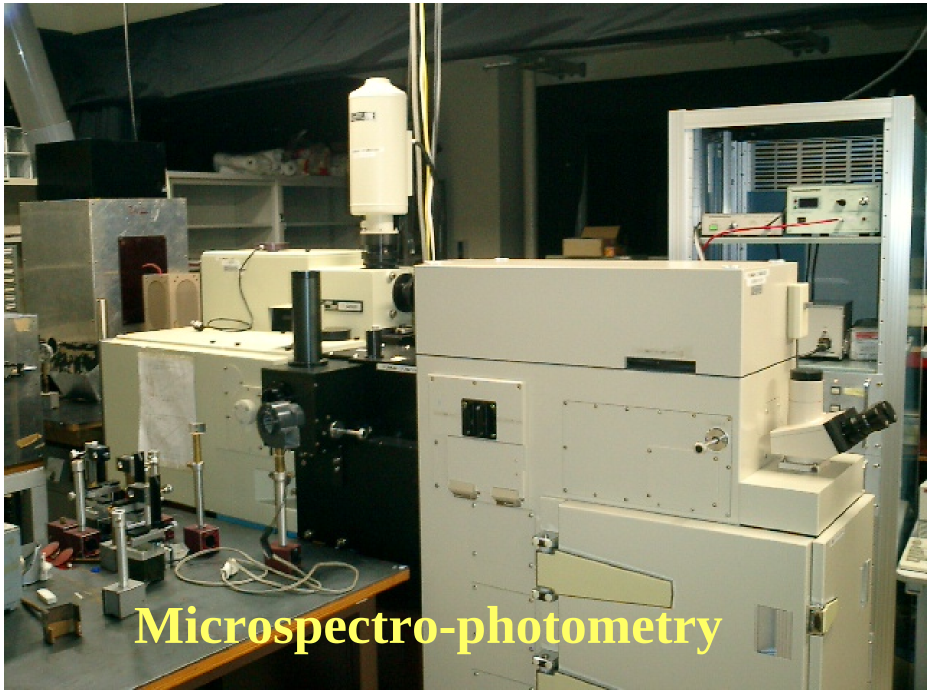


first and direct evidence of superconducting energy gap in high Tc superconductor

Condensed Matter : Experiment 3





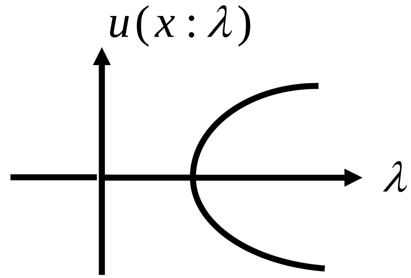


Mathematical Science

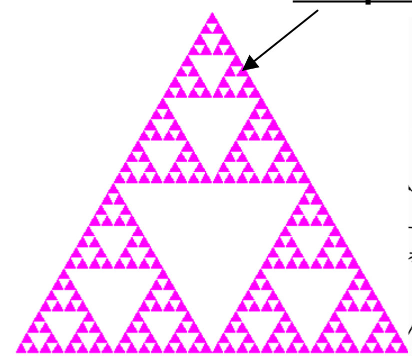
✻ Nonlinear Analysis

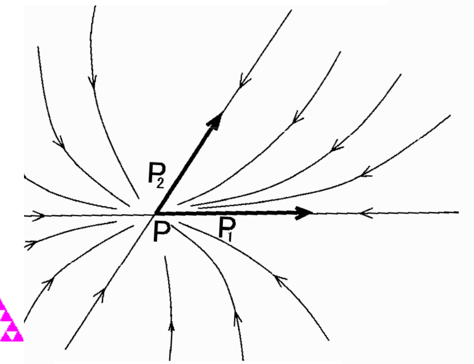
- Dynamical System
- Bifurcation Theory
- Pattern Formation
- Fourier Analysis

Bifurcation Diagram



Sierpinski Gusket





Dynamical Orbit

✻ PDE Theory

- Yang-Mills Equation
- Navier-Stokes Equation
- Reaction Diffusion Equation

:

$$\partial_\alpha F^{\alpha\beta} + [A_\alpha, F^{\alpha\beta}] = 0$$

$$\frac{Du}{Dt} = \nu \Delta u - \frac{1}{\rho} \nabla P$$

$$\frac{\partial u}{\partial t} = \Delta u + f(u)$$

Millennium Prize Problems

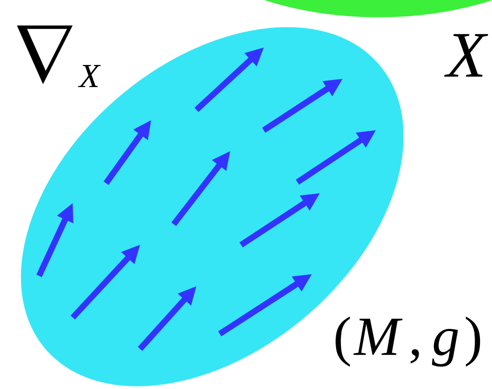
（Clay Math. Institute）

$1,000,000

✻ Differential Geometry

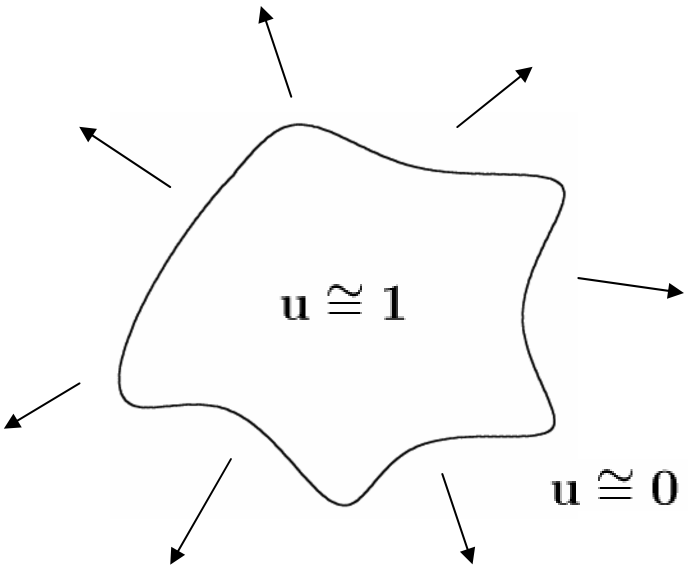
- 4-Dimensional Manifold
- Topology of Fibrebandle
- Conformal Field Theory

:



* **Fisher's Equations (Monostable reaction – diffusion Equations)**

$$\frac{\partial u}{\partial t} = \Delta u + u(1-u) \quad \text{in } \mathbb{R}^N$$



spreading pattern by the transition from an unstable state (u=0) to a stable state (u=1)

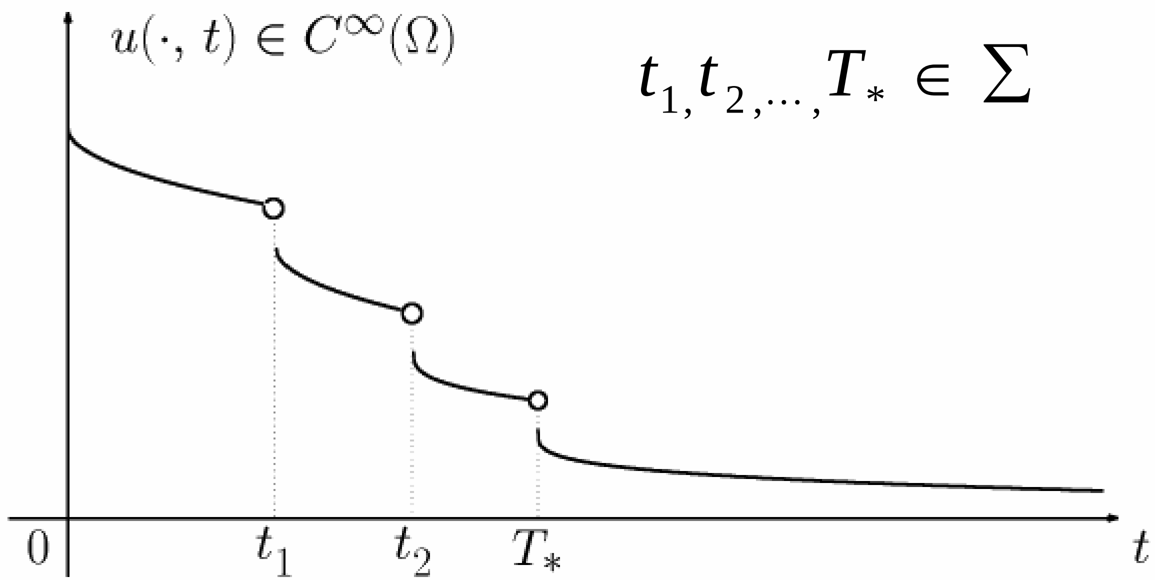
Fisher's eq. : mathematical model of biological population growth process and phase transition

* **Navier-Stokes Equations :** $\frac{\mathbf{Du}}{\mathbf{Dt}} = \nu \boldsymbol{\Delta} - \frac{1}{\rho}\nabla \mathbf{p},\ \nabla \cdot \mathbf{u} = 0,\ \mathbf{x} \in \Omega,\ \mathbf{t} > 0$

Ω **: arbitrary 3 - Dimensional domain**

Claim $\sum = \{t \in (0,\infty) \mid u(\cdot,t) \notin C^{\infty}(\Omega)\}$ **: singular times**

$\Rightarrow$ $H^{1/2}(\sum) = 0$ **(1/2 Hausdorff dimension of $\sum$ is zero)**

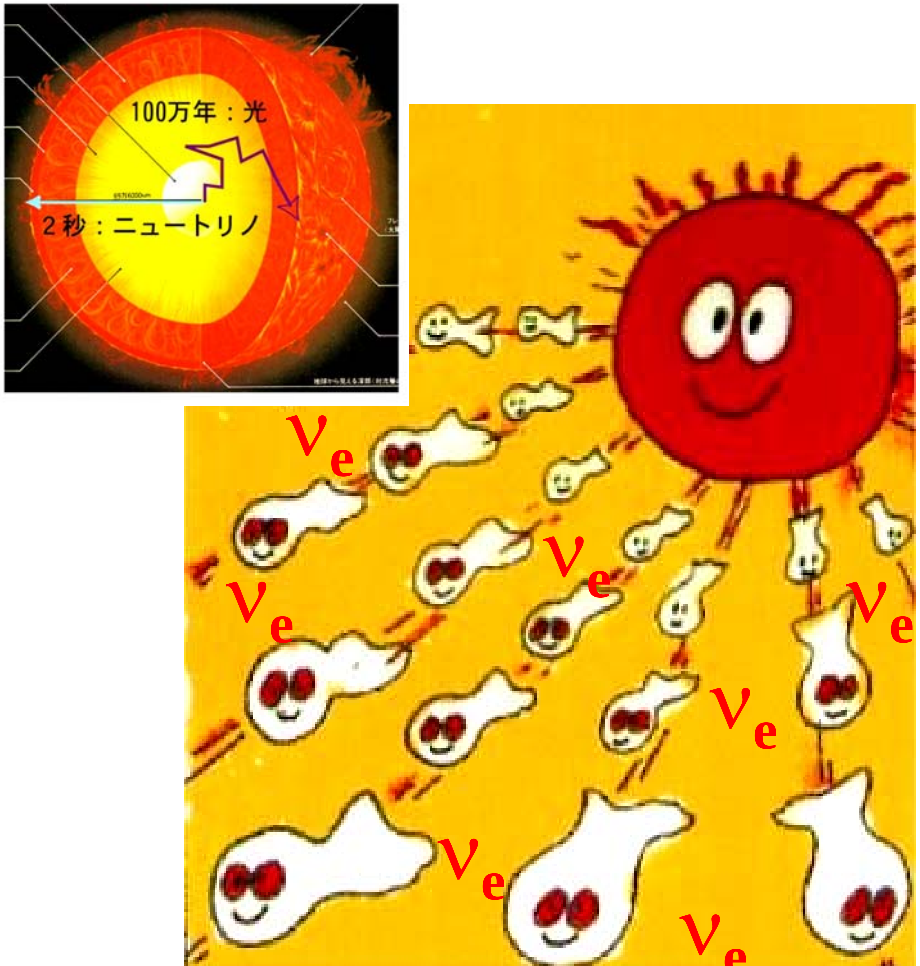


Activities Proposed in

Exploring New Science by Bridging Particle-Matter Hierarchy

Diagnosis of the Sun through Solar Neutrinos

Elementary Particle + Nucleus + Star & Galaxy



- detecting ^{7}Be solar neutrinos in KamLAND
- refining solar evolution model
- polishing up calculations of fusion cross sections

$p+p \mapsto {}^2H + e^+ + \nu_e$

$p + e^- + p \mapsto {}^2H + \nu_e$

$^2H + p \mapsto {}^3He + \gamma$

85 %

$^3He + {}^3He \mapsto {}^4He + 2p$

15 %

$^3He + {}^4He \mapsto {}^7Be + \gamma$

0.02 %

$^7Be + p \mapsto {}^8B + \gamma$

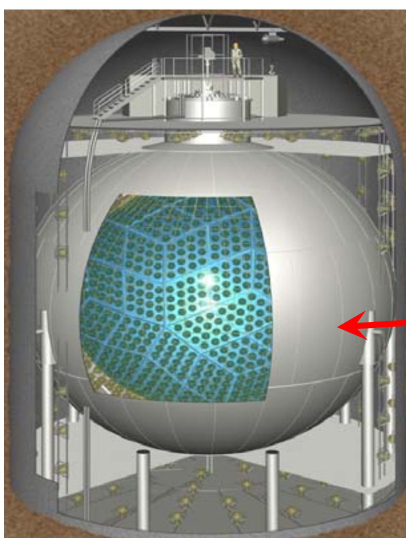
$^8B \mapsto {}^8Be^* + e^+ + \nu_e$

$^8Be^* \mapsto {}^4He + {}^4He$

$^7Be + e^- \mapsto {}^7Li + \nu_e$

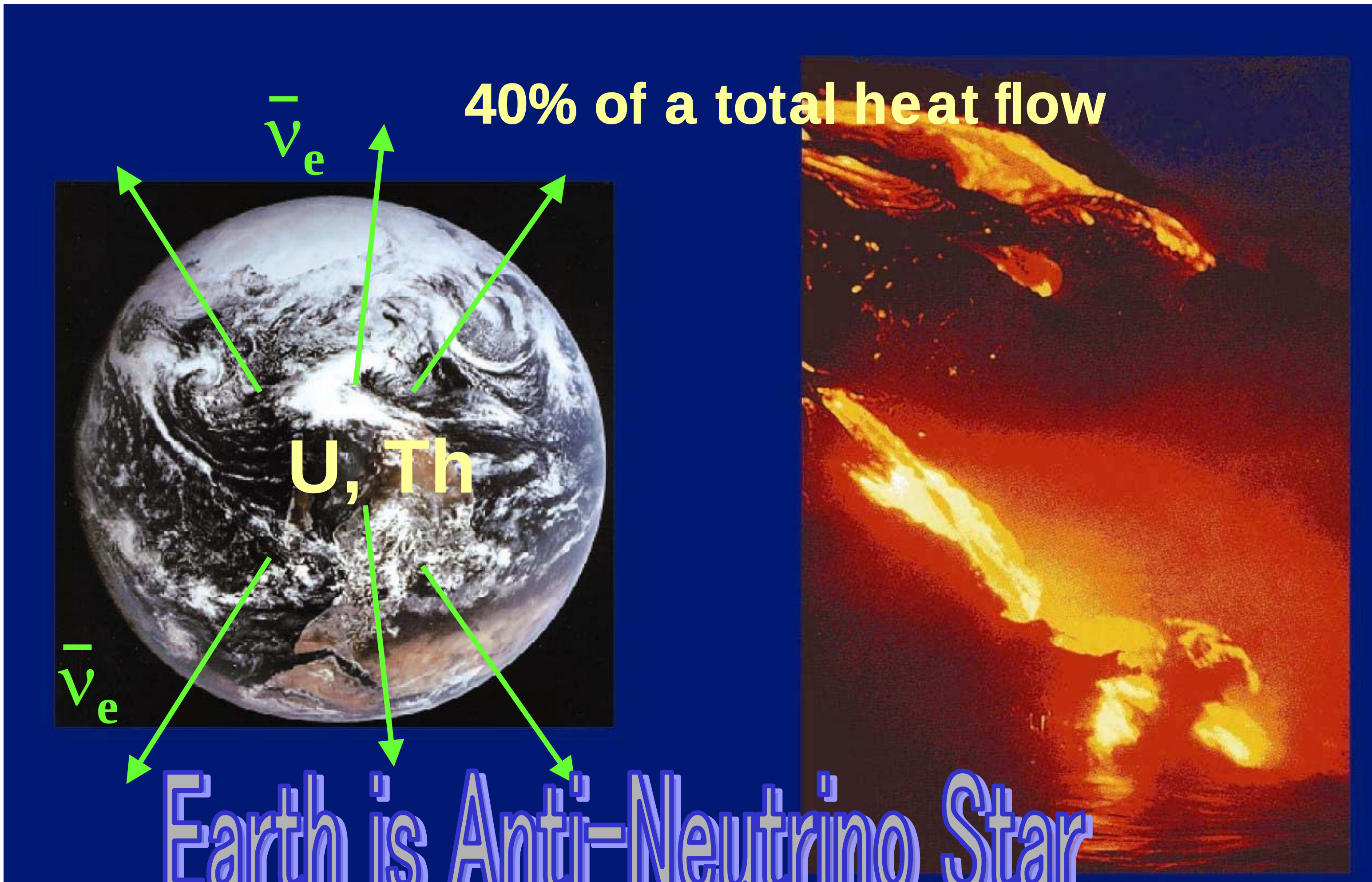
$^7Li + p \mapsto {}^4He + {}^4He$

$^3He + p \mapsto {}^4He + e^+ + \nu_e$



Diagnosis of the Earth through GeoNeutrinos

Elementary Particle + Nucleus + Earth



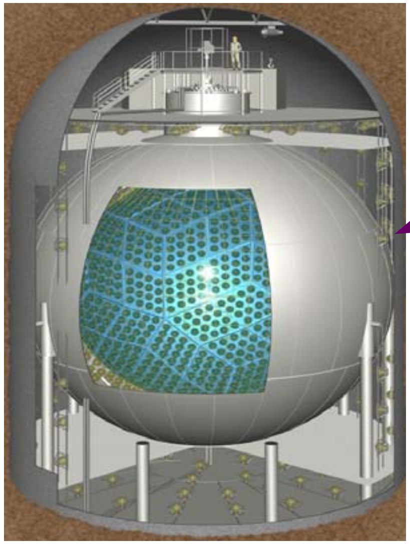
Earth is Anti-Neutrino Star

- **Heat Generation inside the Earth**
  - **-- total heat flow ~ 40 TW ?**
  - **-- U/Th contribution ~ 16 TW ???**

$$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\ {}^{4}\mathrm{He} + 6\ e^{-} + 6\ \bar{\nu}_e + 51.7\ \mathrm{MeV}$$

$$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\ {}^{4}\mathrm{He} + 4\ e^{-} + 4\ \bar{\nu}_e + 42.7\ \mathrm{MeV}$$

geoneutrinos

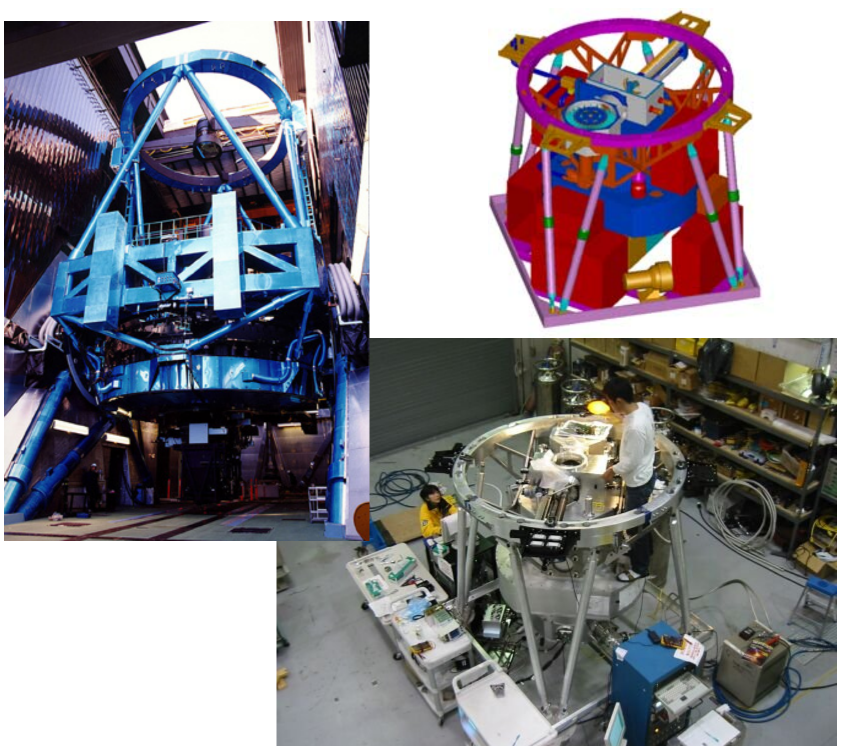


KamLAND :
first chance to search for geoneutrinos

Exploring Dark Matter Haloes

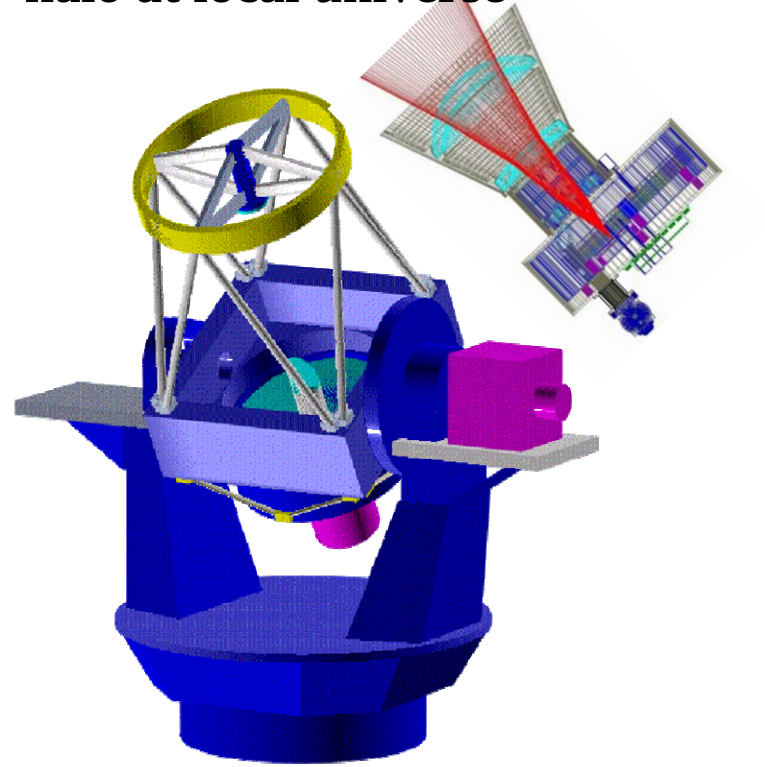
Star & Galaxy + Elementary Particle

Galaxy evolution in dark matter halo at early universe



Near-Infrared Imager and Spectrograph with 8.2 m SUBARU Telescope

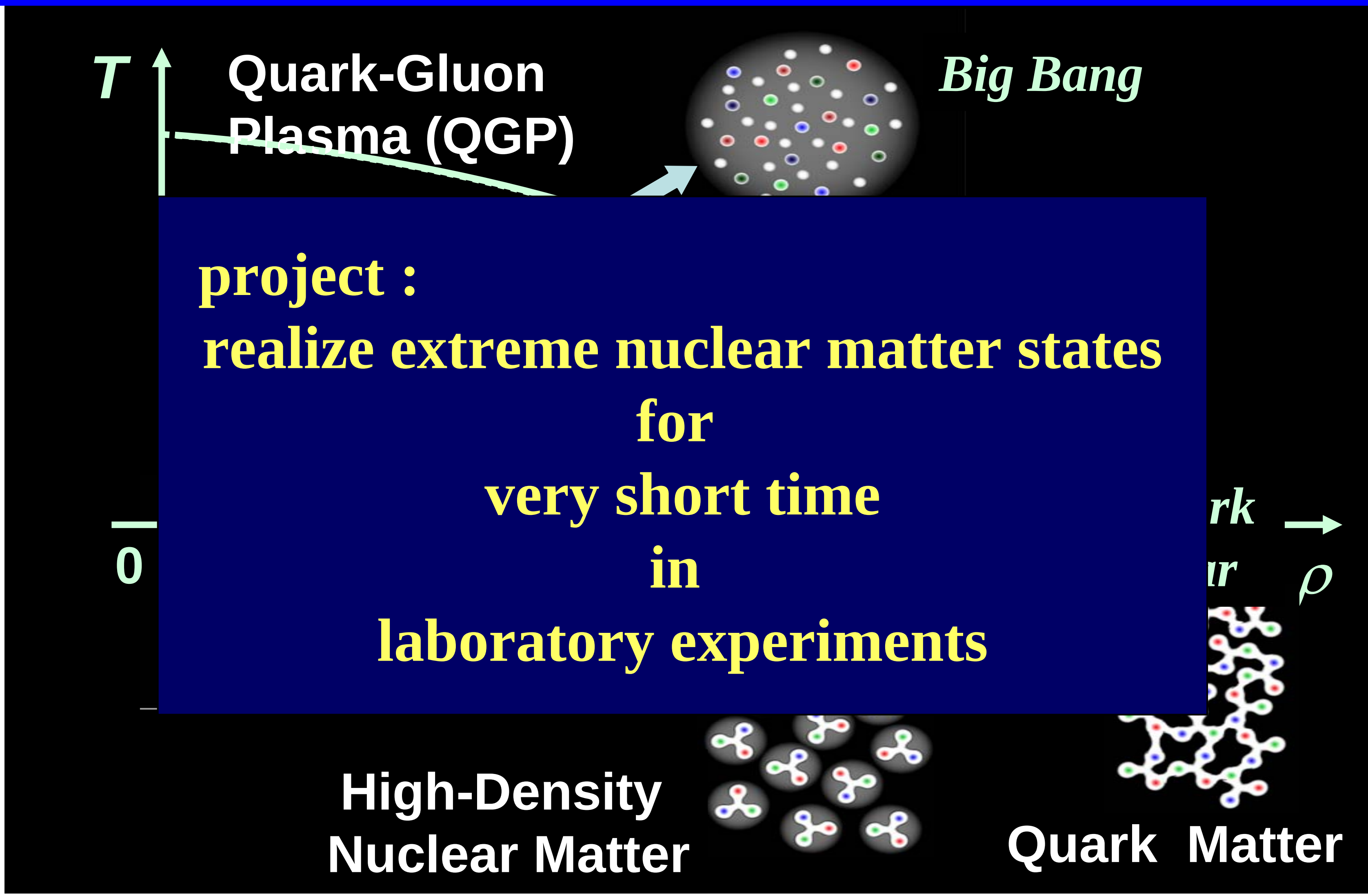
Galaxy distribution in dark matter halo at local universe



2m Near-Infrared Telescope & Wide-Field Imager

Exploring Extreme Nuclear Matter

Nucleus + Elementary Particle + Condensed Matter + Star & Galaxy



project :

realize extreme nuclear matter states

for

very short time

in

laboratory experiments

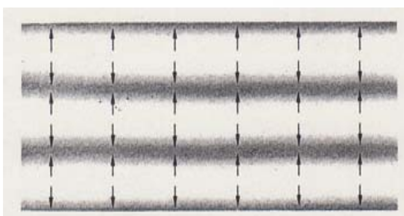
Elementary Excitations in Condensed Matter

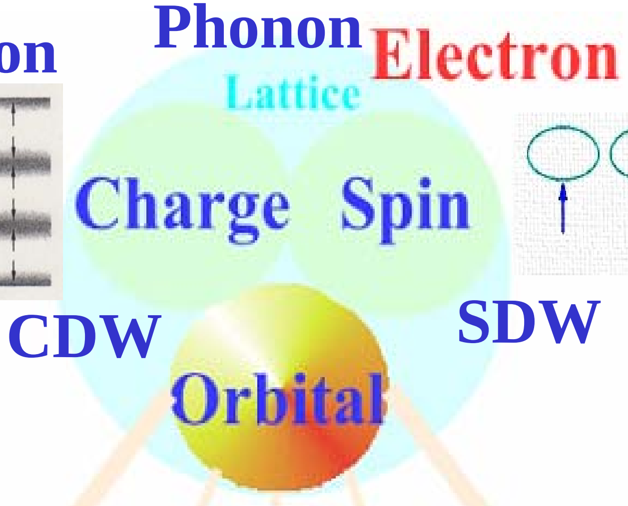
Condensed Mater + Nucleus + Elementary Particle + Star & Galaxy + Mathematics

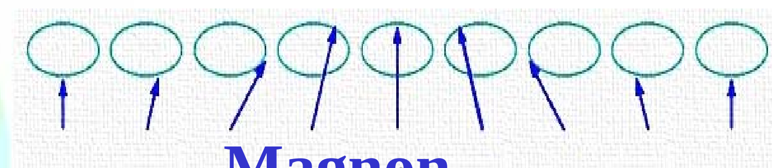
Polaron

Phonon

Exciton







Magnon

Plasmon

CDW

SDW

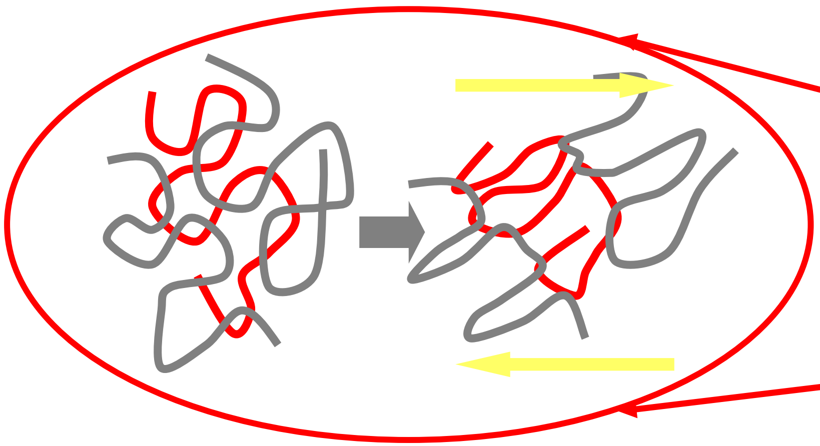
Orbiton

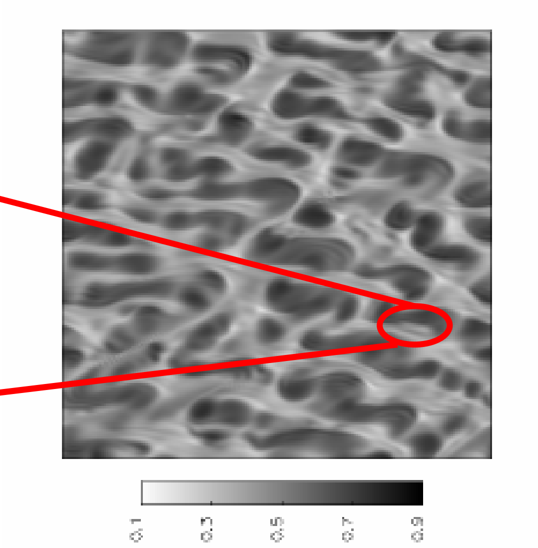
Collective Excitations in Condensed Matter

Mathematical Physics Group

path-integral formalism

strongly-deformed polymer chains





Path integral representation of polymers

$$\frac{\partial}{\partial n} Q\left(n, \boldsymbol{r}; n', \boldsymbol{r}'\right) = \left[\frac{b^2}{6}\nabla^2 - \beta V\left(\boldsymbol{r}\right)\right] Q\left(n, \boldsymbol{r}; n', \boldsymbol{r}'\right)$$

Time evolution of polymer density

$$\frac{\partial \phi\left(\boldsymbol{r}, t\right)}{\partial t} + \nabla \cdot \left\{\phi\left(\boldsymbol{r}, t\right)\boldsymbol{v}\left(\boldsymbol{r}, t\right)\right\} = L\nabla^2 \frac{\delta F}{\delta \phi\left(\boldsymbol{r}, t\right)}$$

Conclusions

illustrate
our present situation
and
future status

present situation : stellar gas

5 years : brilliant results

Exploring New Science
by Bridging
Particle-Matter Hierarchy