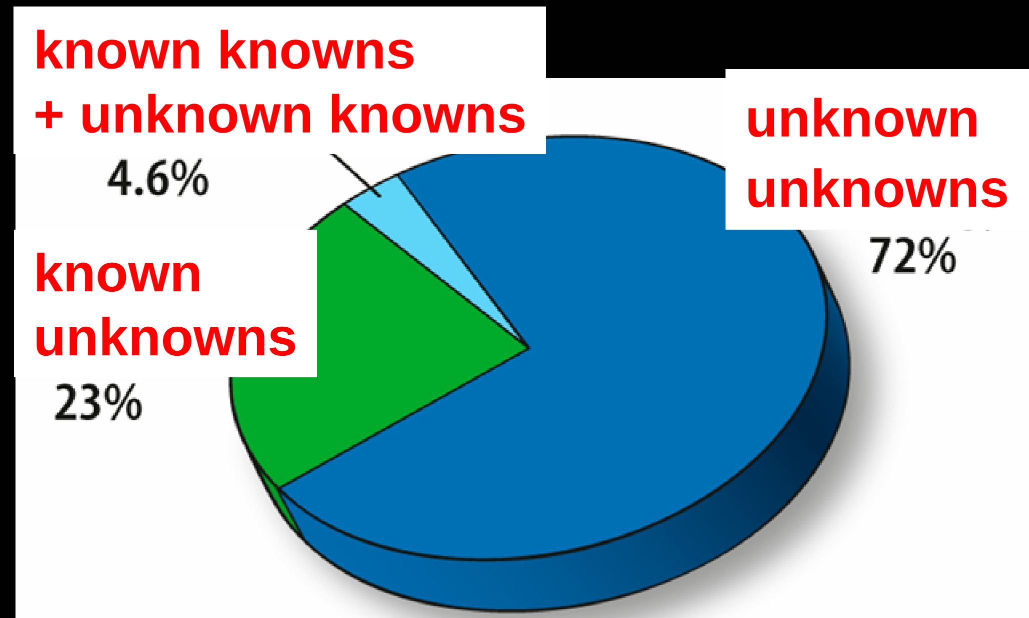
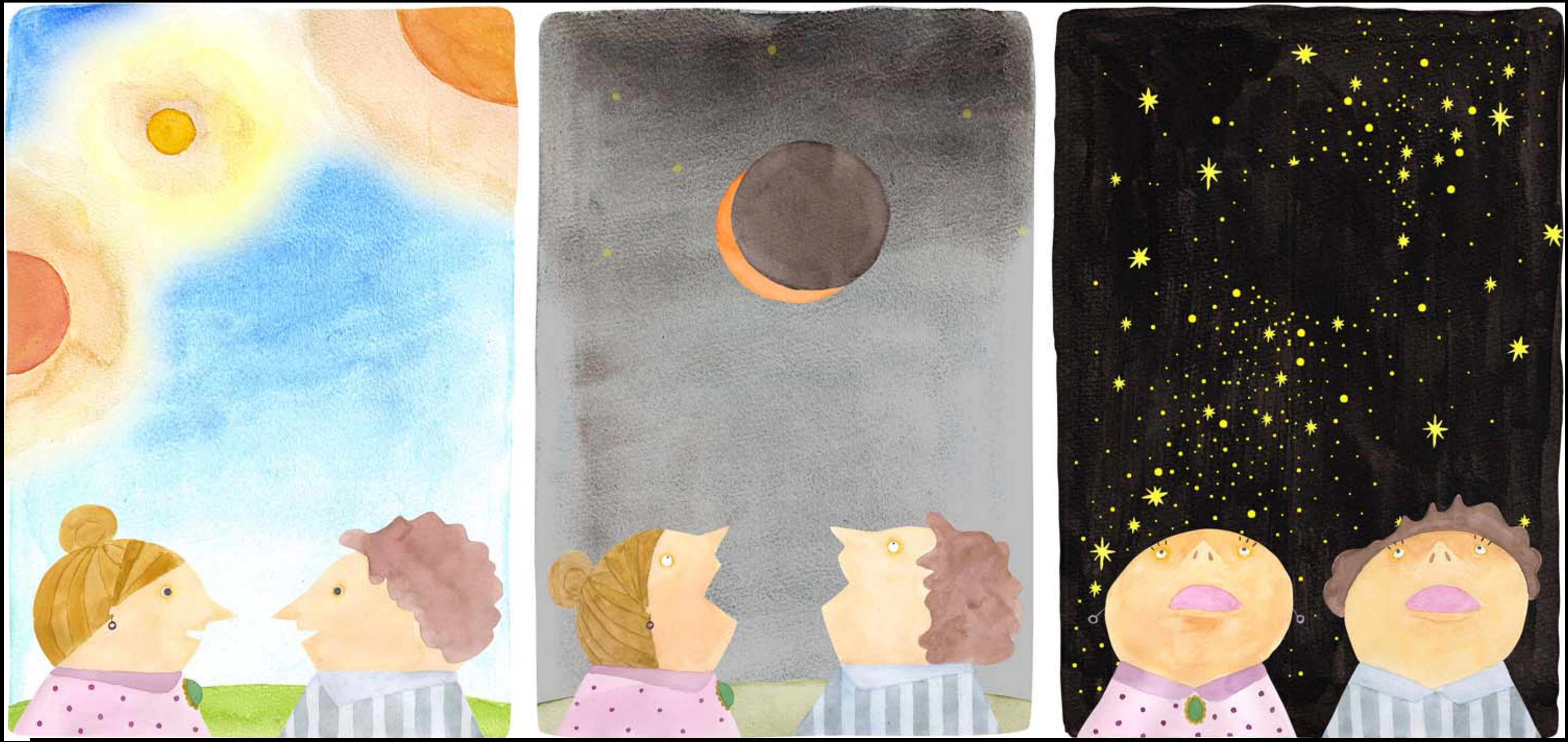
# Unknown knowns and unknown unknowns in the universe


**Yasushi Suto** *Dept. of Phys., The University of Tokyo*
*& Global Scholar, Dept. of Astrophys. Sci., Princeton University*

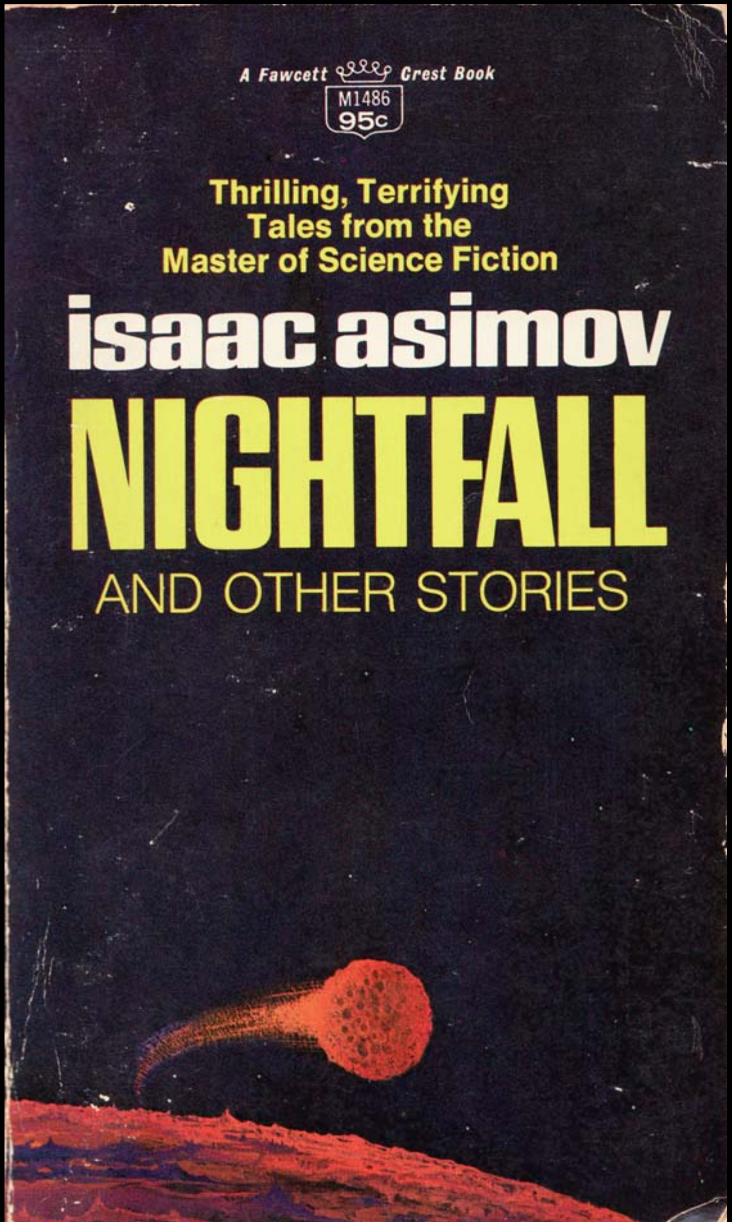
*Workshop on Chemical Evolution of the Universe*
*10:10-10:40, October 31, 2011 @Tokyo Metropolitan University*

# Nightfall: We didn’t know anything




- no “night” on “Lagash” except the total eclipse due to another inner planet every 2049 years
- People realized the true world for the first time through the darkness full of “stars”

# Issac Asimov: Nightfall




- “Light !” he screamed. Aton, somewhere, was crying, whimpering horribly like a terribly frightened child. *“Stars -- all the Stars -- we didn't know at all. We didn't know anything.”*

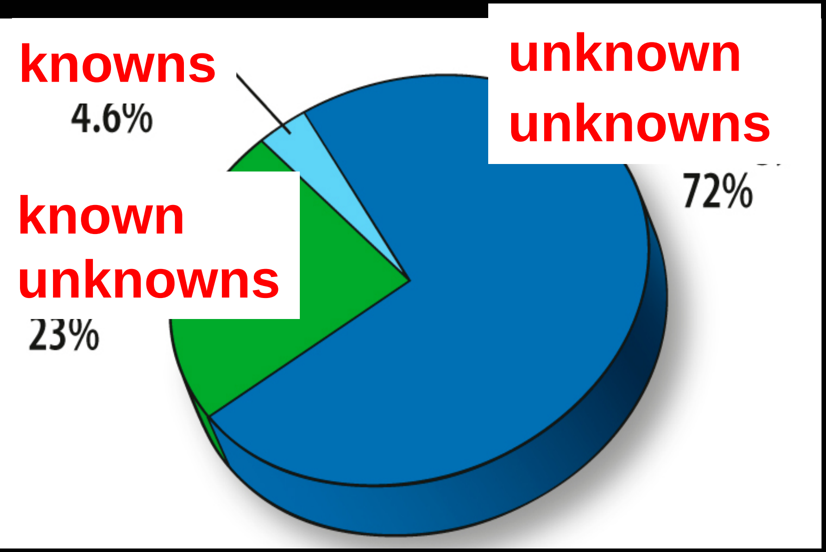
# a famous American philosopher and poet: D.H.Rumsfeld

**The Unknown**

As we know,
There are known knowns.
There are things we know we
know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown un-
knowns,
The ones we don't know
We don't know.

*—Feb. 12, 2002, Department of Defense news briefing*

# Composition of the universe




atom
(baryons)

- ordinary matter makes up merely 5 percent

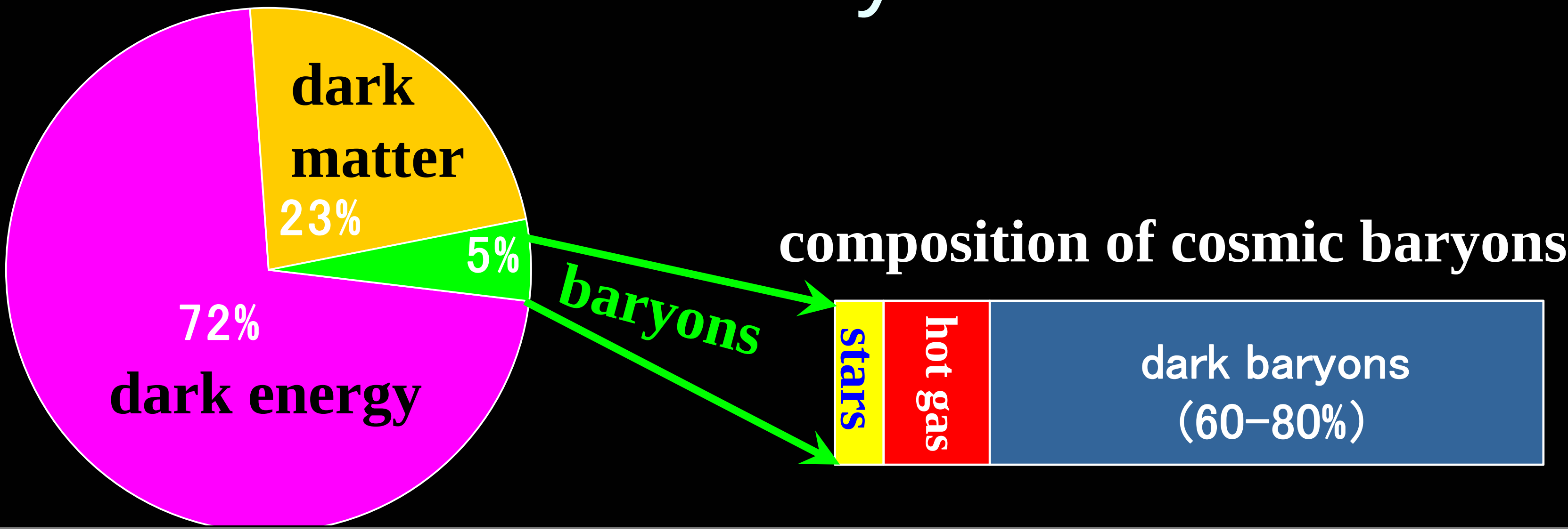
dark matter

- galaxies and clusters are surrounded by invisible mass an order-of-magnitude more massive than their visible part

dark energy

- even more exotic component !
- homogeneously fills the universe (unclustered component)
- repulsive force (negative pressure; $P = -\rho$ ?)
- Einstein's cosmological constant ?
- or just an illusion ...

# Most of the cosmic baryon is “dark” as well



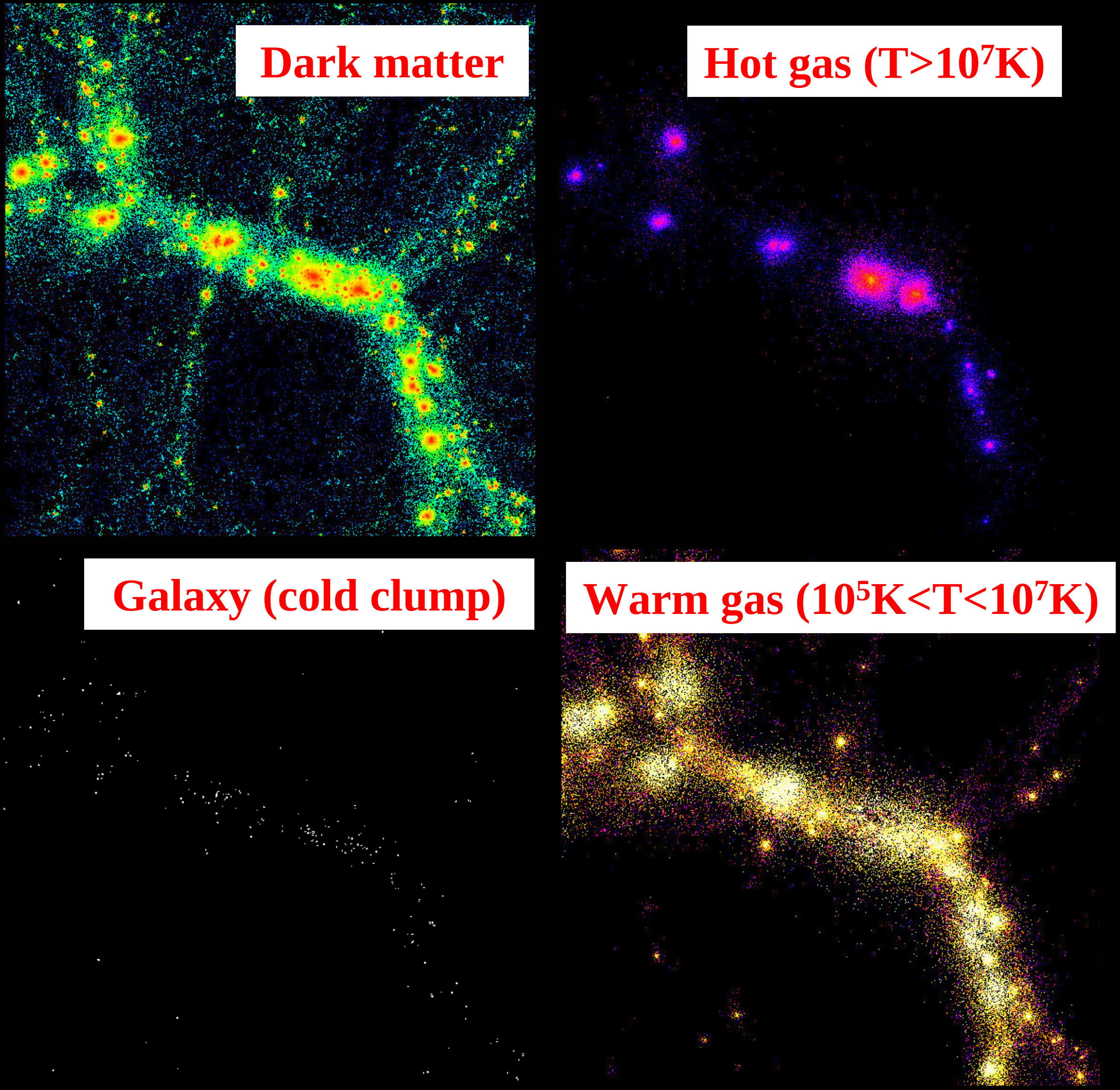

**Cosmic Baryon Budget: Fukugita, Hogan & Peebles: ApJ 503 (1998) 518**

| Component | Central | Maximum | Minimum | Grade[a] |
|---|---|---|---|---|
| 1. Stars in spheroids ............... | $0.0026\ h_{70}^{-1}$ | $0.0043\ h_{70}^{-1}$ | $0.0014\ h_{70}^{-1}$ | A |
| 2. Stars in disks ..................... | $0.00086\ h_{70}^{-1}$ | $0.00129\ h_{70}^{-1}$ | $0.00051\ h_{70}^{-1}$ | A − |
| 3. Stars in irregulars ............... | $0.000069\ h_{70}^{-1}$ | $0.000116\ h_{70}^{-1}$ | $0.000033\ h_{70}^{-1}$ | B |
| 4. Neutral atomic gas .............. | $0.00033\ h_{70}^{-1}$ | $0.00041\ h_{70}^{-1}$ | $0.00025\ h_{70}^{-1}$ | A |
| 5. Molecular gas ..................... | $0.00030\ h_{70}^{-1}$ | $0.00037\ h_{70}^{-1}$ | $0.00023\ h_{70}^{-1}$ | A − |
| 6. Plasma in clusters ............... | $0.0026\ h_{70}^{-1.5}$ | $0.0044\ h_{70}^{-1.5}$ | $0.0014\ h_{70}^{-1.5}$ | A |
| 7a. Warm plasma in groups ...... | $0.0056\ h_{70}^{-1.5}$ | $0.0115\ h_{70}^{-1.5}$ | $0.0029\ h_{70}^{-1.5}$ | B |
| 7b. Cool plasma .................... | $0.002\ h_{70}^{-1}$ | $0.003\ h_{70}^{-1}$ | $0.0007\ h_{70}^{-1}$ | C |
| 7′. Plasma in groups ............... | $0.014\ h_{70}^{-1}$ | $0.030\ h_{70}^{-1}$ | $0.0072\ h_{70}^{-1}$ | B |
| 8. Sum (at $h = 70$ and $z \simeq 0$)...... | 0.021 | 0.041 | 0.007 | ... |

# Simulated distribution of matter in the universe

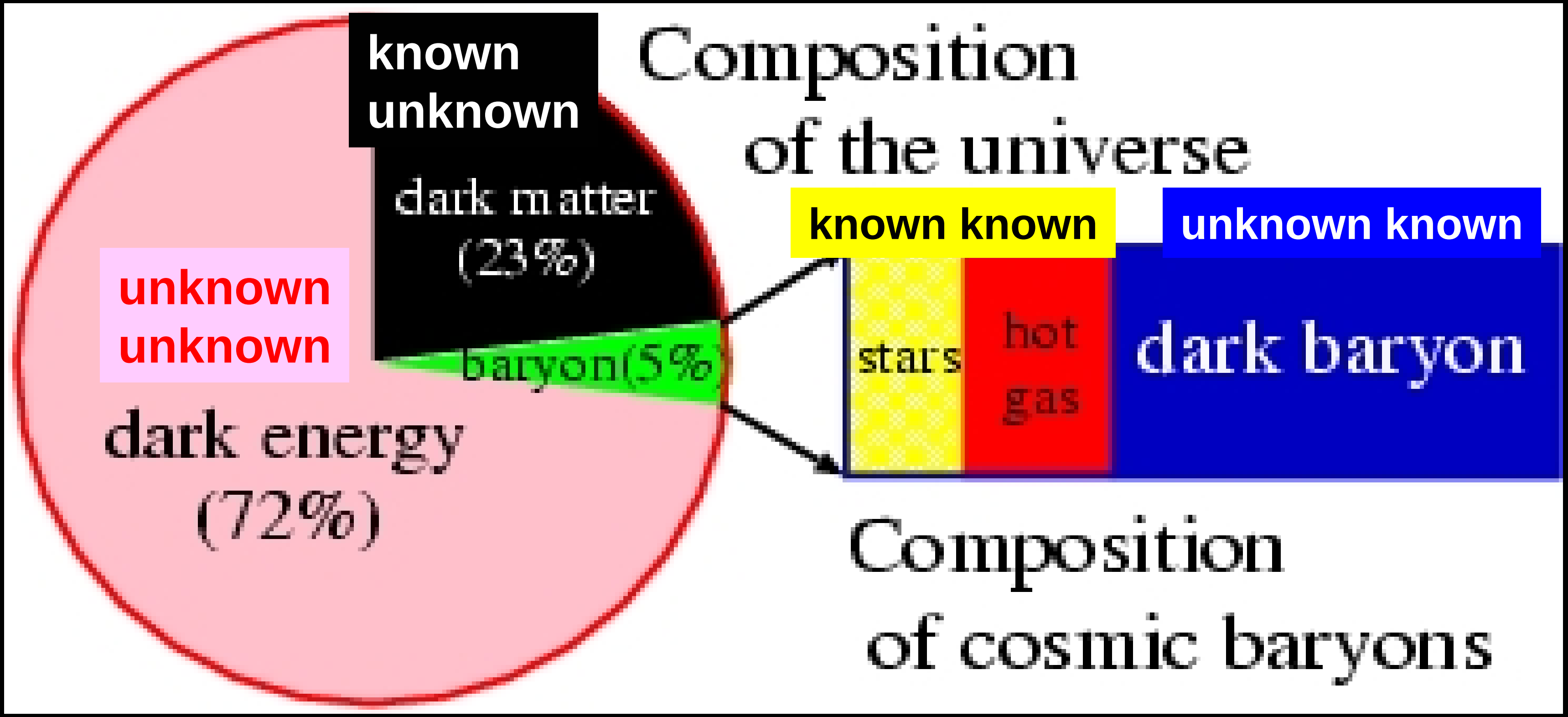
**$(30h^{-1}\mathrm{Mpc})^3$ box around a massive cluster at z=0**

**ΛCDM SPH simulation (Yoshikawa, Taruya, Jing & Suto 2001)**



# Unknowns

- Search for the unknowns in the universe
  - Dark baryons: unknown knowns
  - Dark matter: known unknowns
  - Dark energy: unknown unknowns



# Can we unveil the dark sides of the universe soon ?

- **Dark matter**
  - Breakthrough results from on-going accelerators and/or underground experiments in 5-10 years ?
- **Dark baryons**
  - only astronomical observations can make a scientific new contribution
- **Dark energy**
  - unlikely to have any breakthroughs from experiments and/or theories in high energy in this century
  - Astronomy is believed to be the most powerful

# Why is dark energy *observable* ?

- **Objects are usually identified only through differential measurements**
  - **Visible matter**: contrast between dark and bright regions
  - **Dark matter**: spatial clustering dynamically and gravitationally traced by visible stars, galaxies and quasars
- **Dark energy, if distributed completely homogeneously, can be detected ?**
  - **differential measurements in time domain (cosmic acceleration, structure growth)**

# ***Expanding*** **the expanding universe**

- *Expand* the "size" of the universe

$$a(t) = a(t_0) + \left.\frac{da}{dt}\right|_{t_0}(t-t_0) + \frac{1}{2}\left.\frac{d^2a}{dt^2}\right|_{t_0}(t-t_0)^2 + \cdots$$

  - current size:

    $a(t_0)$ ⇔ the value itself has no physical meaning

  - current expansion rate: the Hubble constant

    $$H_0 \equiv \left.\frac{da/dt}{a}\right|_{t_0}$$

    ⇔ unpredictable: basically determined by the initial condition (can be either negative or positive)

  - current acceleration rate: the deceleration parameter

    $$q_0 \equiv -\left.\frac{a\,d^2a/dt^2}{(da/dt)^2}\right|_{t_0}$$

    ⇔ related to the cosmic energy density via the Einstein eq. (should be positive)

# Universe should not be accelerated !

- **Newton's inverse square law**

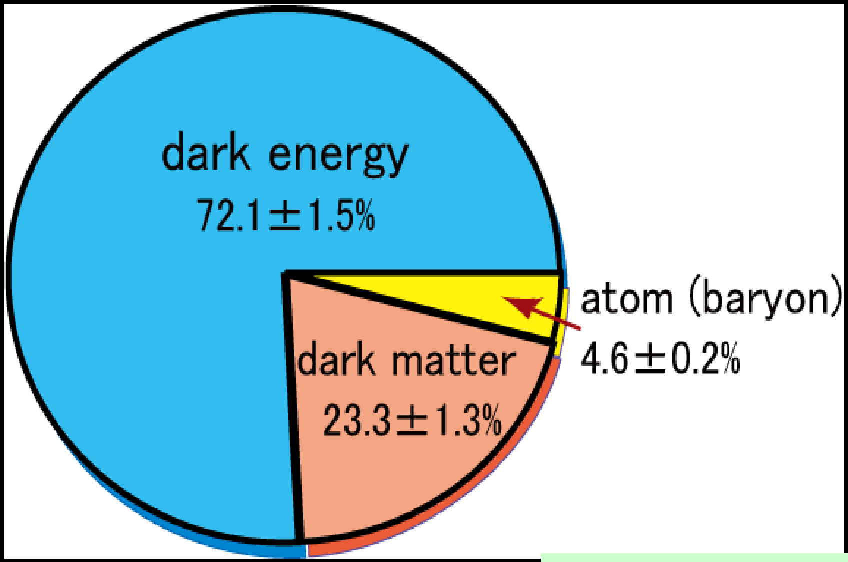
$$\frac{d^2a}{dt^2} = -\frac{GM(<a)}{a^2} = -\frac{G}{a^2}\left(\frac{4\pi}{3}\rho a^3\right) = -\frac{4\pi G}{3}\rho a < 0$$

- **Einstein's general relativity**

$$\frac{d^2a}{dt^2} = -\frac{4\pi G}{3}(\rho + \boxed{3p + \rho_{DE} + 3p_{DE}})a$$

  - Pressure contributes to gravity
  - Negative pressure required for acceleration
    - Cosmological constant: $p_{DE}=-\rho_{DE}$
    - More generally, dark energy: $p_{DE}=w\rho_{DE}$ with $w<-1/3$
- **General relativity is wrong at cosmological scales ? (modified gravity)**

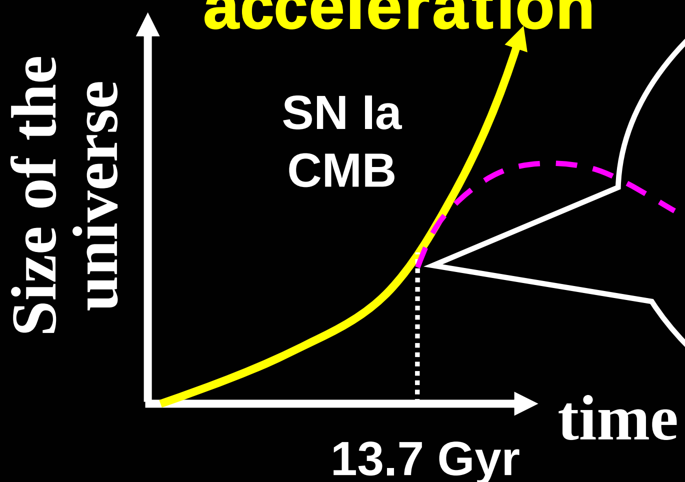
# Cosmic acceleration vs. dark energy





Implies something unknown !

cosmic acceleration




Universal repulsion?

Cosmological constant?

Dark energy?

Modified gravity?

# 2011 Nobel prize in Physics

- **Saul Perlmutter, Brian P. Schmidt and Adam G. Riess**
  - for the discovery of the accelerating expansion of the Universe through observations of distant supernovae

# Dark energy and the equation of state of the universe

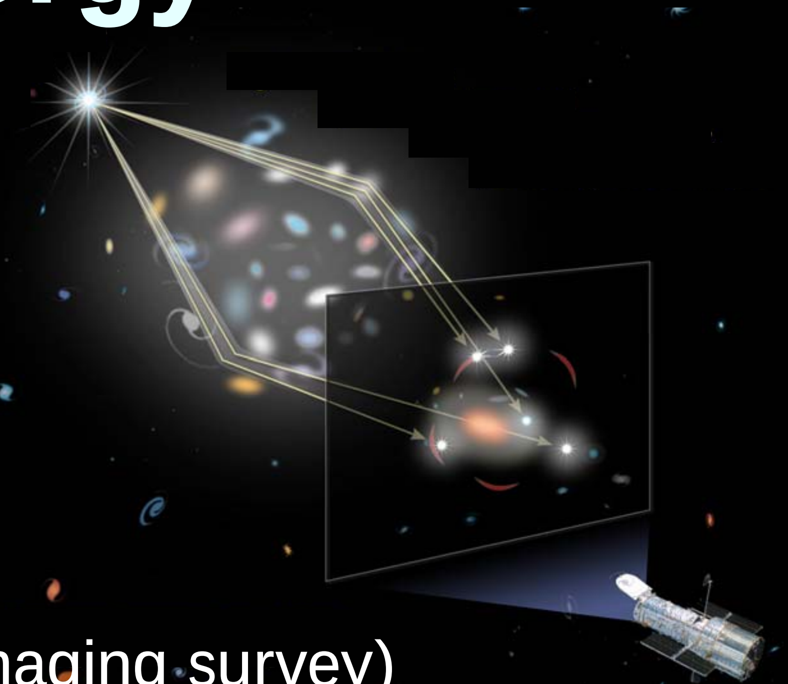
- **Parameterized equation of state**
  - (pressure) = **w** x (density)
    - w=0: dark matter, baryons
    - w=1/3: photons
    - **w=-1: cosmological constant**
  - Poisson eq. in GR :

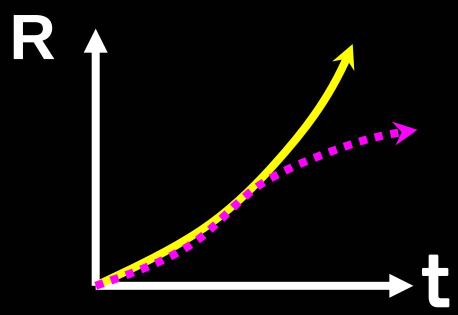
$$\Delta \phi = 4\pi G(\rho + 3p) = 4\pi G\rho(1+3w)$$

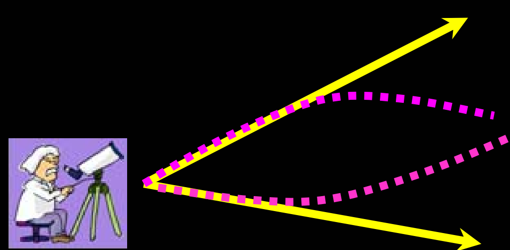
**w<-1/3 ⇒ repulsion force**

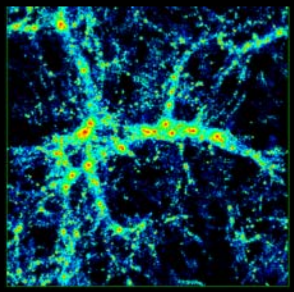
# Observational signatures of dark energy

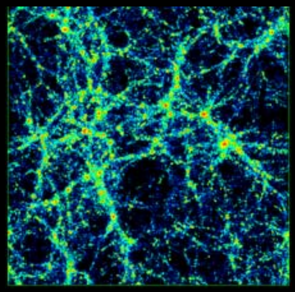
- **cosmic acceleration**
- **geometry of the universe**
- **evolution of structure**
- **4 major probes**
  - Supernova Hubble diagram
  - Cosmic Microwave Background
  - Gravitational lensing (galaxy imaging survey)
  - *Baryon Acoustic Oscillation (galaxy redshift survey)*



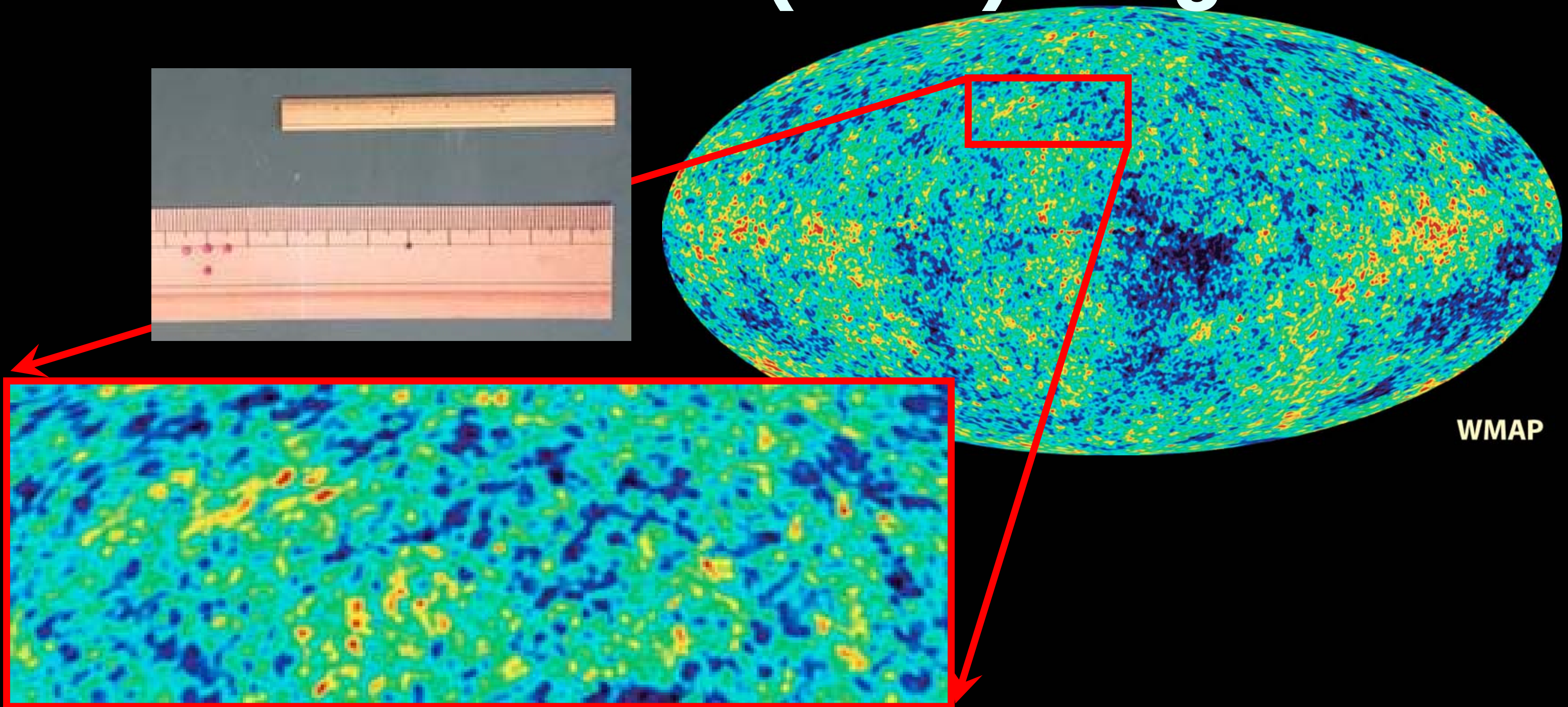






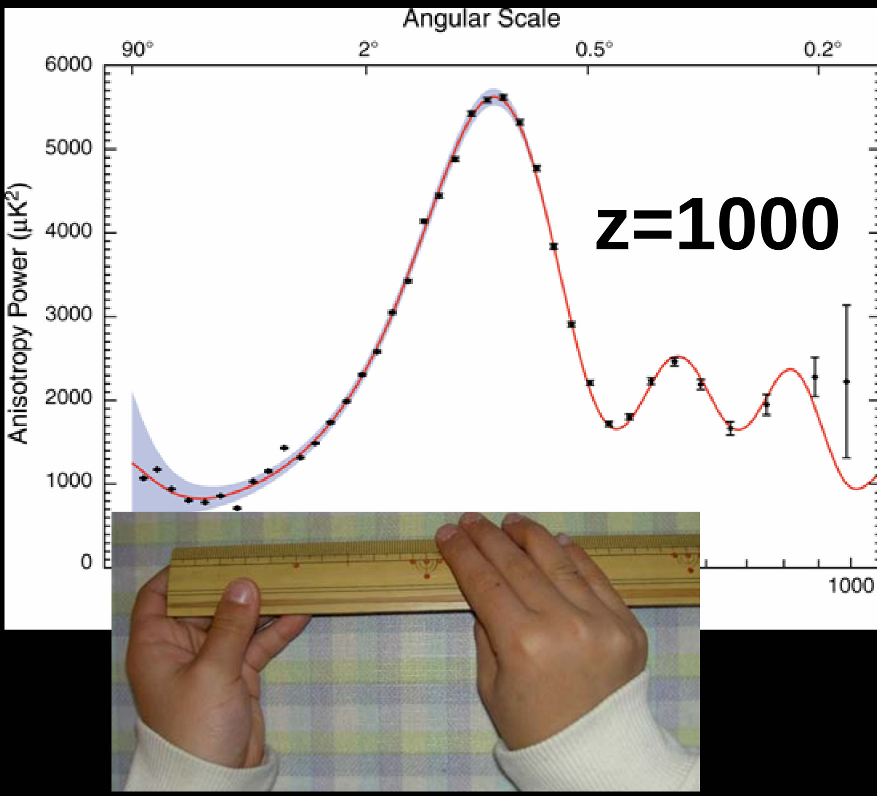
# Standard ruler: baryon acoustic oscillation (BAO) length

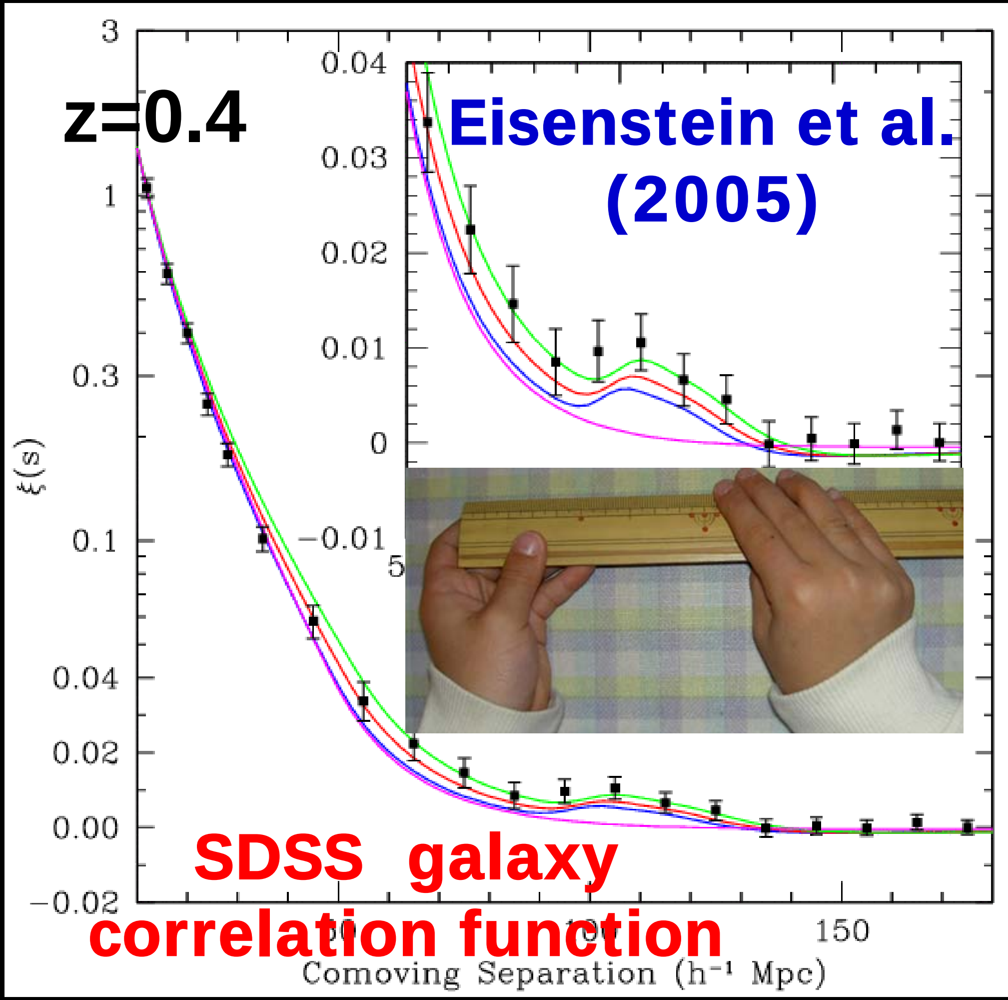



- Sound horizon length at recombination（$\fallingdotseq c_s \times 0.37$Myr）
  - $r_s = 147\ (\Omega_m h^2 / 0.13)^{-0.25}\ (\Omega_b h^2 / 0.024)^{-0.08}$ Mpc
- Estimate the distance to the CMB last-scattering surface using the above as a standard ruler

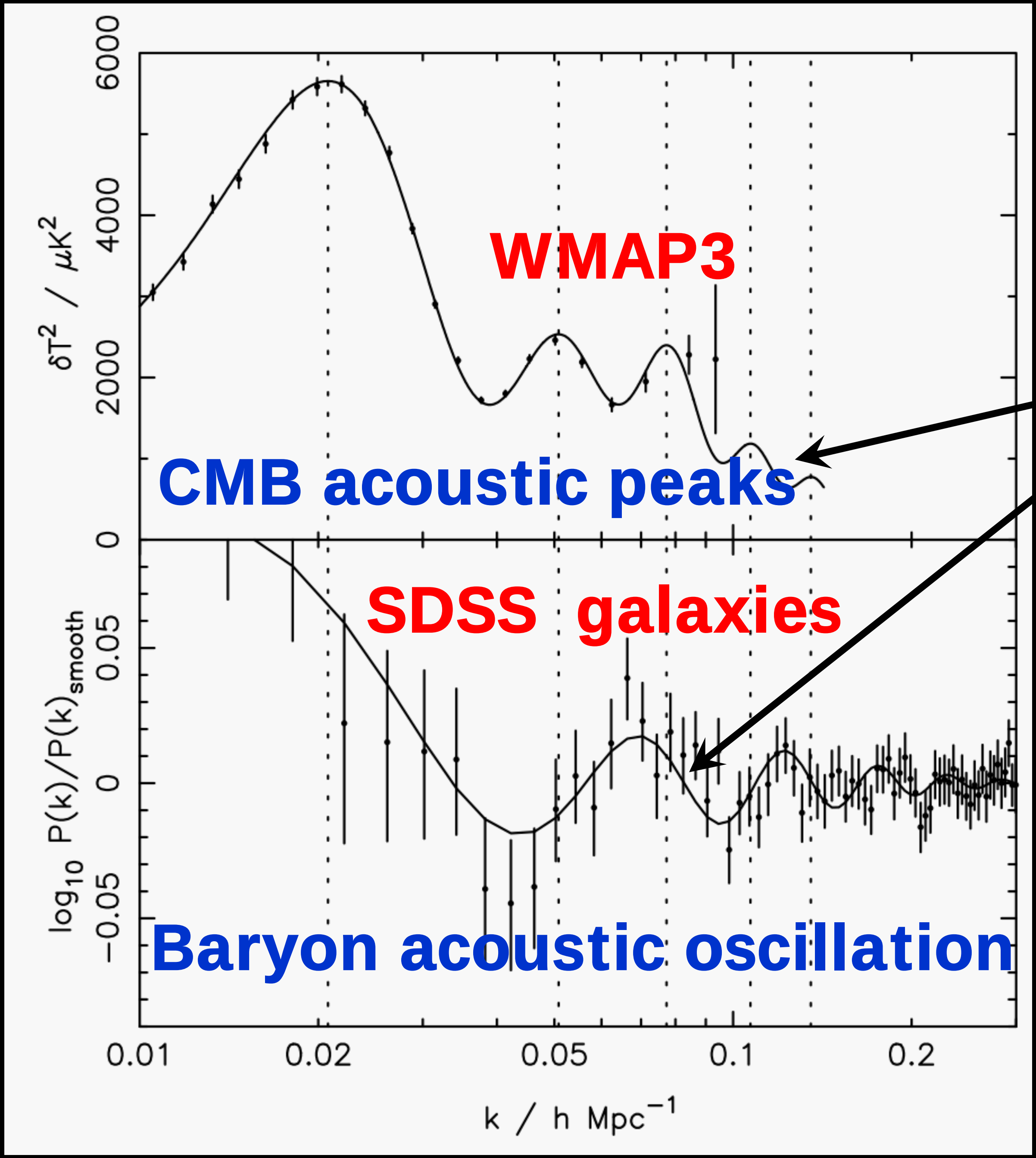
# Acoustic oscillations detected

CMB photons
WMAP 3yr
(Spergel et al. 2007)




$$r_s = 147(0.13/\Omega_m h^2)^{0.25}(0.024/\Omega_b h^2)^{0.08}\ \mathrm{Mpc}$$



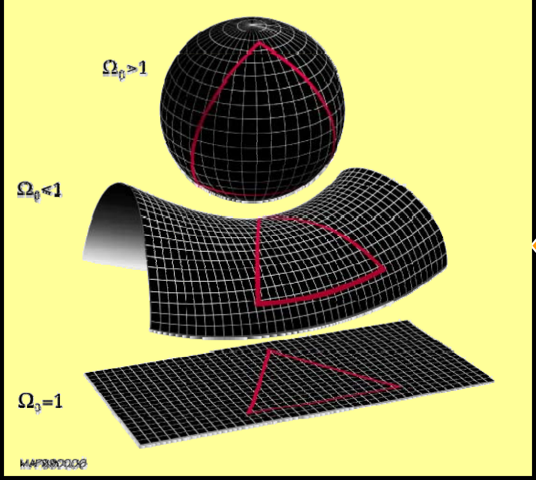

$\Omega_m = 0.24$ best-fit WMAP model

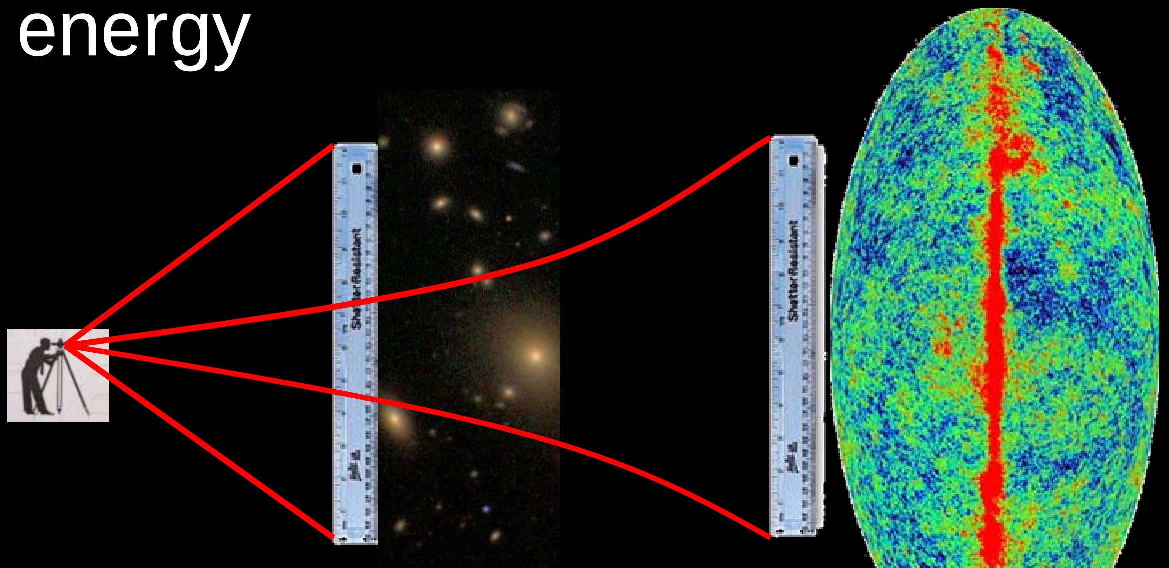
Percival et al. (2007)

# Baryon acoustic oscillation (BAO) as a standard ruler

$$r_s = 147(0.13/\Omega_m h^2)^{0.25}(0.024/\Omega_b h^2)^{0.08}\ \mathrm{Mpc}$$

- Distance measurement at different epochs
- Promising methodology to observationally constrain dark energy

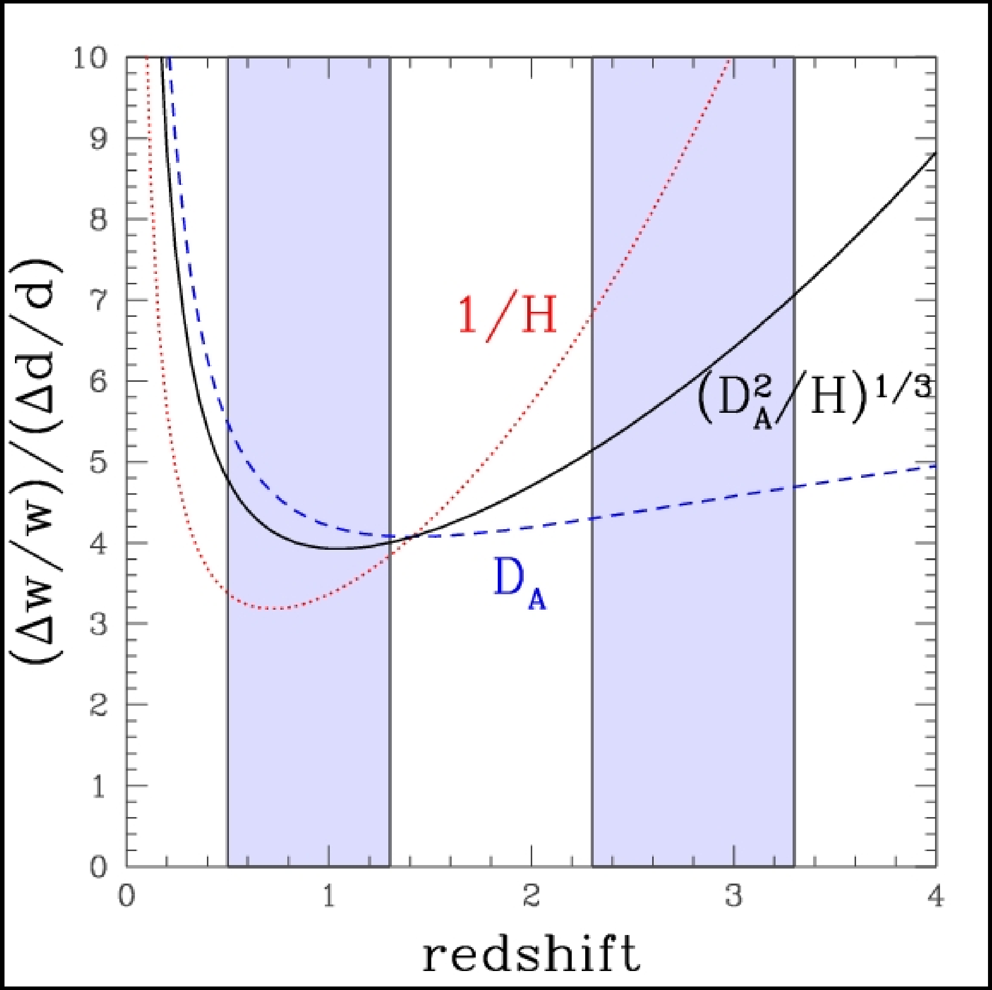


**Difference in time domain**

Picture credit: Bob Nichol

# Required accuracy of the BAO scale measurement to constrain w




- 3% accuracy of w requires to determine BAO scale at z=1 within <1%
- ***⇒ Needs bigger surveys of galaxies***

**Nishimichi et al. (2007)**

# International Research Network for Dark Energy (JSPS, core-to-core program 2007-2012）

## DENET

**Princeton U.**
**Dept. of Astrophys. Sci.**
**coordinator**
**Edwin Turner**

CMB
Gravitational lens
Baryon oscillation

**Univ. of Tokyo**
**Res. Center for the Early Universe**
**coordinator**
**Yasushi Suto**

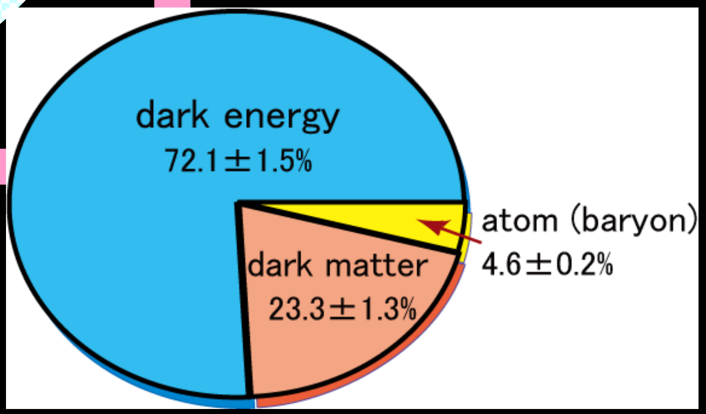
Tohoku Univ.
NAOJ
Hiroshima Univ.
Kyoto Univ.
Nagoya Univ.

**Institut d'Astrophysique de Paris**
**coordinator**
**Jerome Martin**

Modified gravity
Extra-dimension
backreaction

**Edinburgh U.**
**Royal Obs.**
**coordinator**
**John Peacock**

Theoretical model
Baryon oscillation
Weak lens mapping



# Future dark energy surveys

- DES: Dark Energy Survey (Fermi Lab+, 2011-?)
  - Imaging galaxy survey
  - 5000 $deg^2$@Chile 4m telescope
- LSST: Large Synoptic Survey Telescope (SLAC+, 2016-?)
  - Imaging galaxy survey
  - 20000 $deg^2$@Chile 8.4m dedicated telescope
- SuMIRe HSC: Hyper Suprime-Cam (Subaru+Princeton+Taiwan, 2012-)
  - Imaging galaxy survey (1.5deg FOV)
  - 1500 $deg^2$@Subaru 8m telescope
- SuMIRe PFS: Prime Focus Spectrograph

  (Subaru+US,France,Taiwan,Brazil,,, 2016-???)
  - Spectroscopic galaxy survey (1.3deg FOV)
  - 2500 fibers, 10000 galaxy redshifts a night

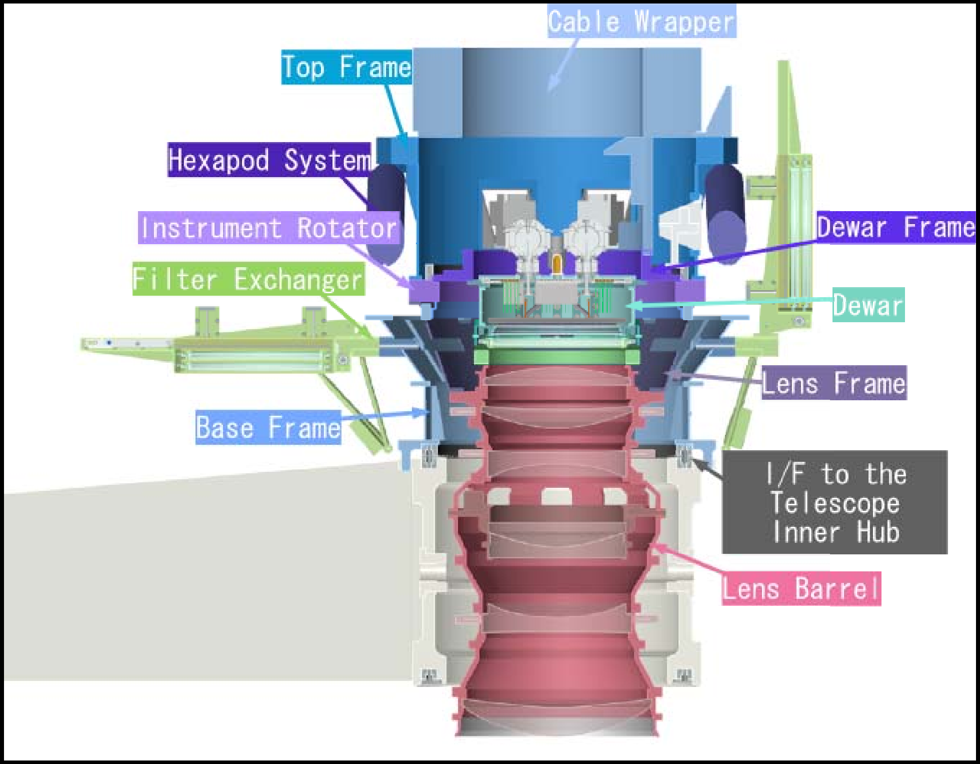
# Galaxy survey project: SuMIRe

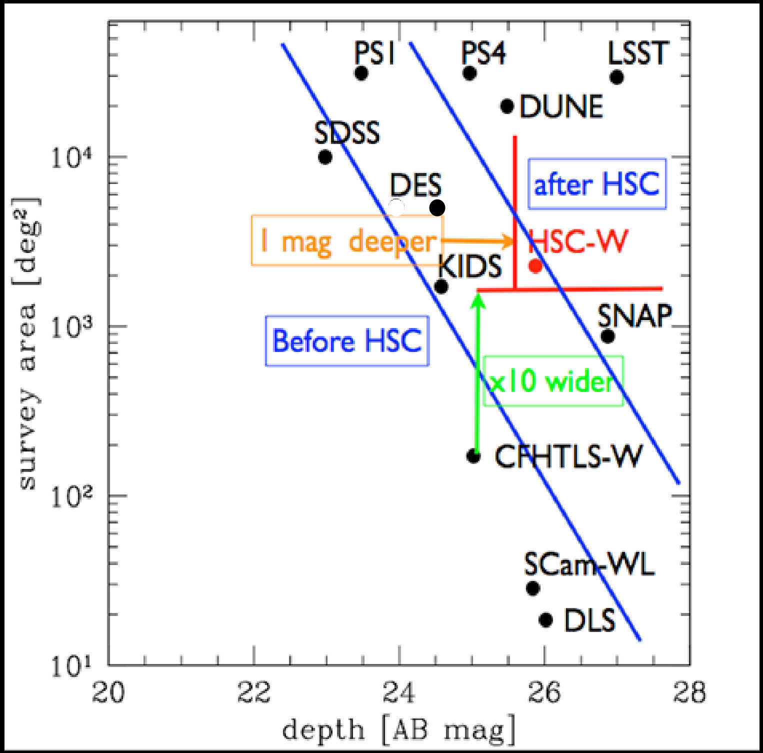
***Su*****baru *M*easurement of *I*maging and *Re*dshift of the universe**

- PI: Hitoshi Murayama (director of IPMU, U. of Tokyo)
  - Japanese Institutes in charge: IPMU, The University of Tokyo, NAOJ,,,
- **Imaging survey with HSC** (Hyper-Suprime Cam)
  - Japan + Princeton + ASIAA (Taiwan)
- **Spectroscopic survey with PFS** (Prime Focus Spectrograph)
  - Japan + US, Taiwan, France, Brazil,,,

# HSC: Hyper-Suprime Cam

- **Japan+Princeton+ASIAA (2012-2016)**
  - Imaging galaxy survey (1.5deg FOV) g,r,i,z,Y
  - 200 nights for 1500 deg$^2$ wide survey for weak lensing
  - 100 nights for deep surveys of galaxies

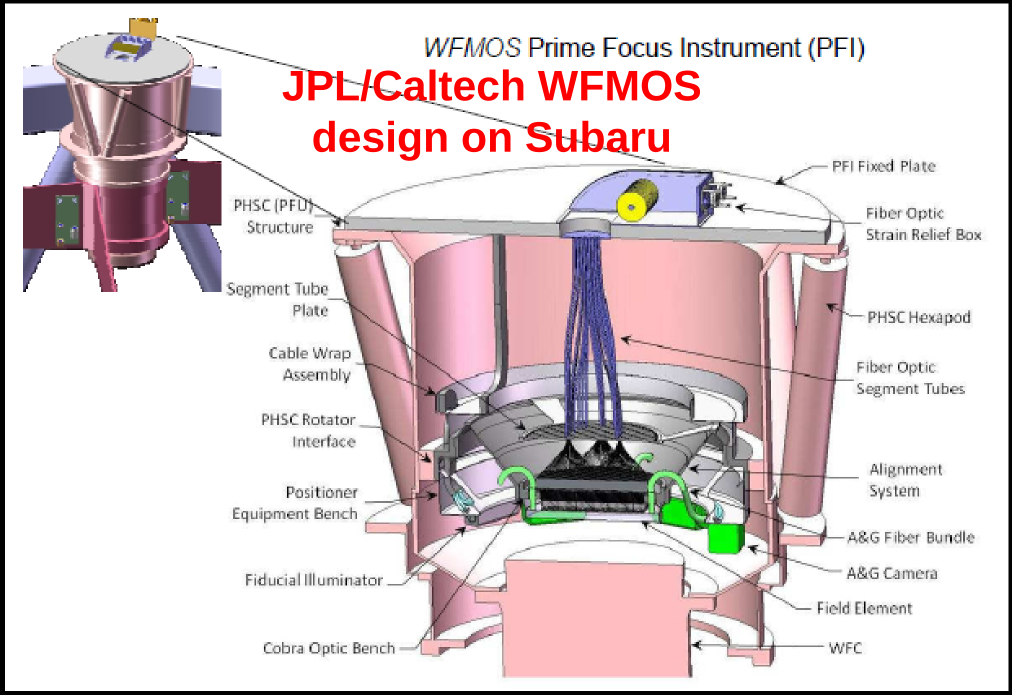


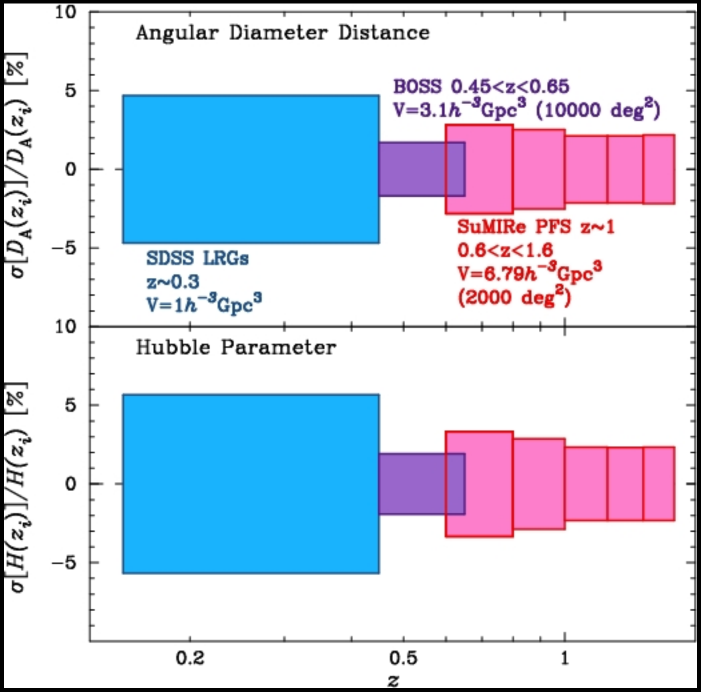




Presented at DENET-Princeton conference (2009) by Satoshi Miyazaki (NAOJ)

# PFS: Prime Focus Spectrograph

- **Japan+ (2016-2020 ???)**
  - Spectroscopic galaxy survey (1.3deg FOV)
  - 2500 fibers, 10000 galaxy redshifts a night
  - BAO, galactic evolution, Galactic archaeology

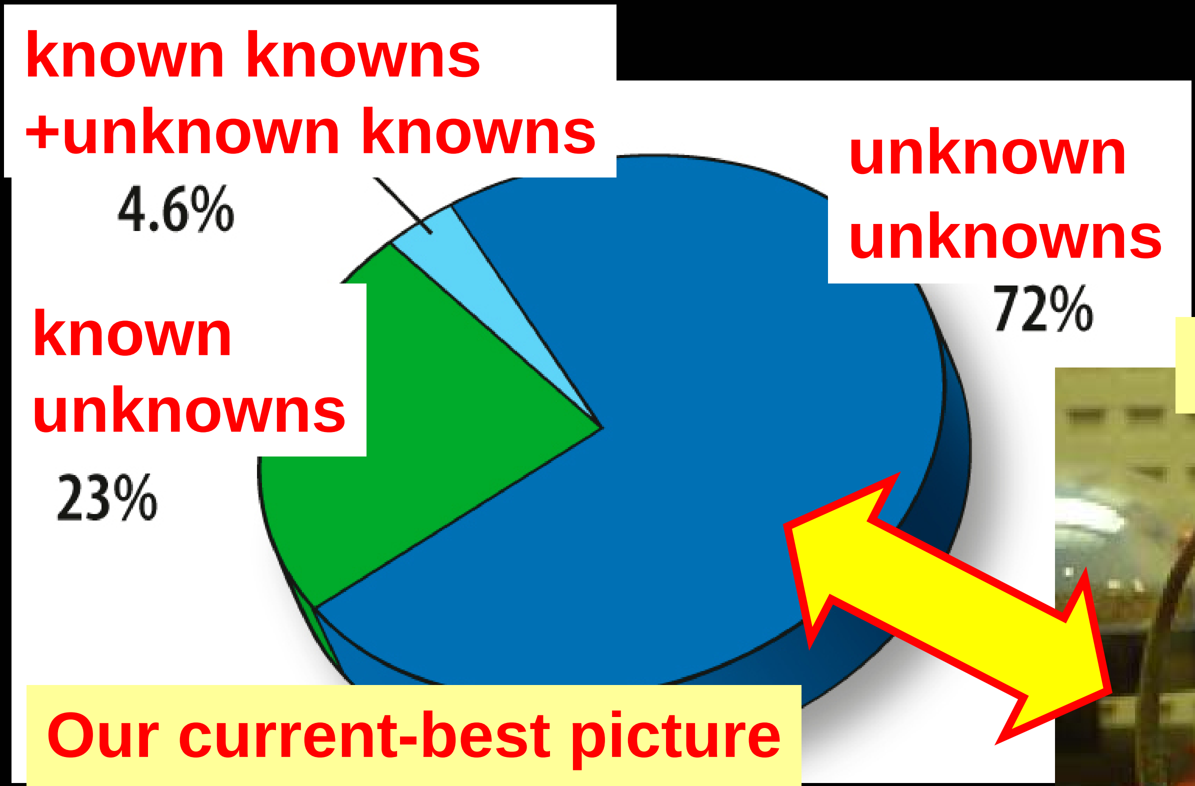



presented at DENET summer school (2009)
by Mike Seiffert (JPL/Caltech)

Courtesy of
Masahiro Takada (IPMU)

# Hopefully soon, we will recognize that we didn't know anything!




Our current-best picture of the universe

Ancient Indian picture


Have we made progress at all ?