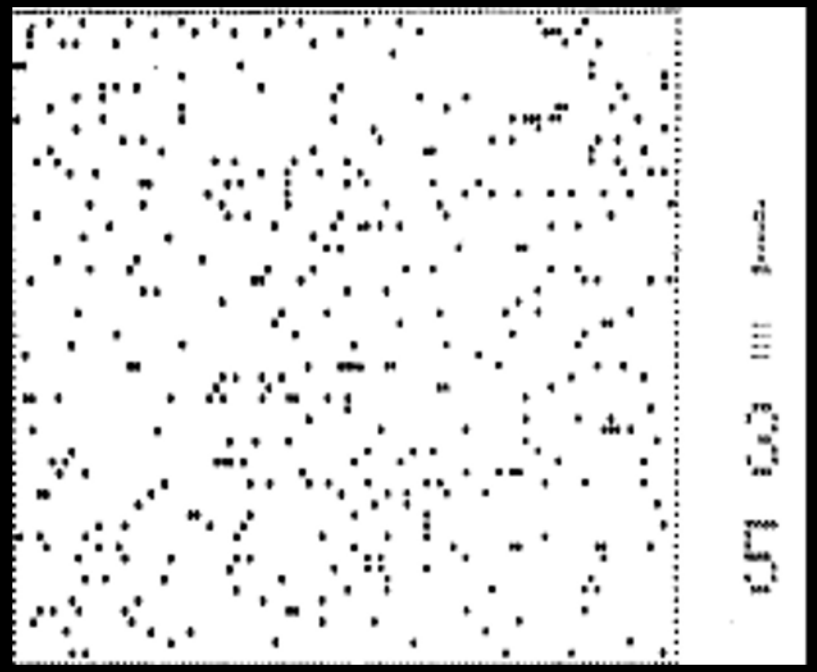
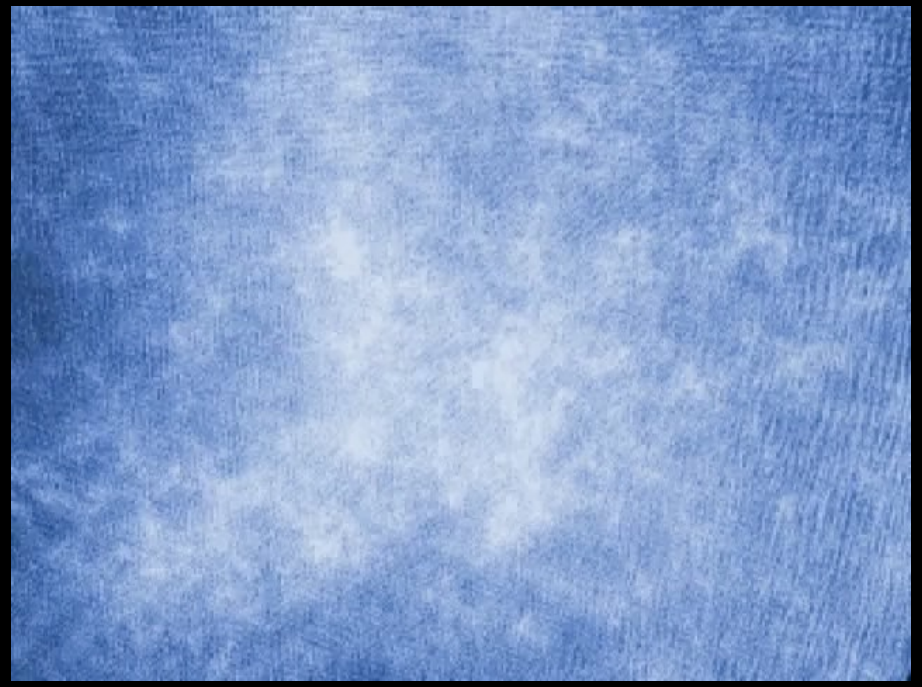
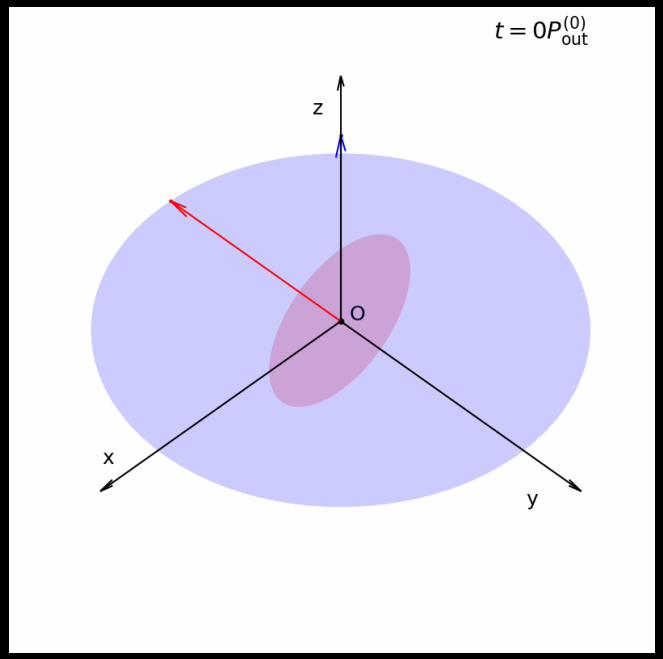
From N to 3



Miyoshi & Kihara (1975)



Yoshikawa, Taruya, Jing+YS (2001)



Hayashi+YS (2020)

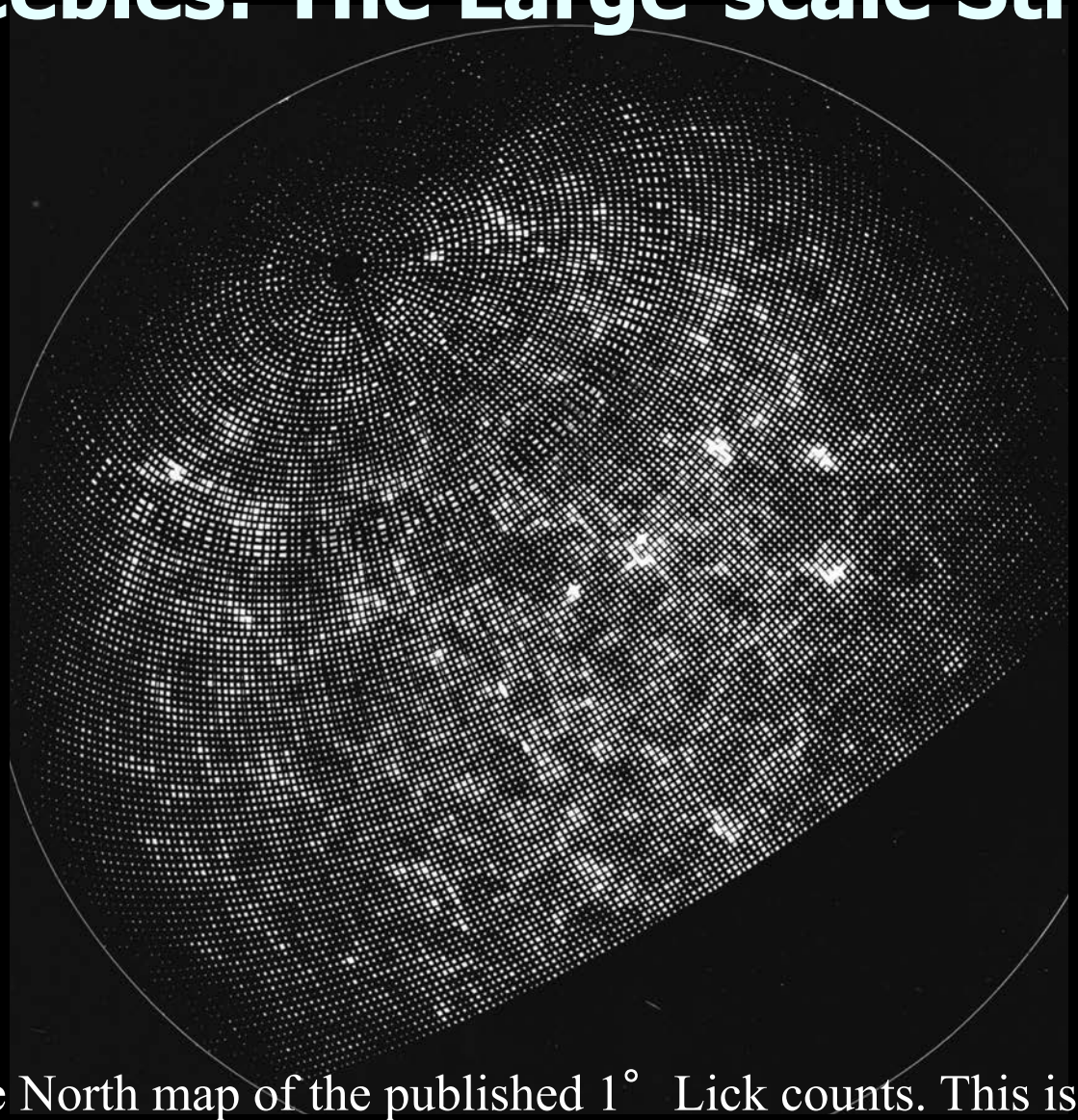
Yasushi Suto: Department of Physics, the University of Tokyo

The 14th RESCEU symposium: From Large to Small Structures in the Universe

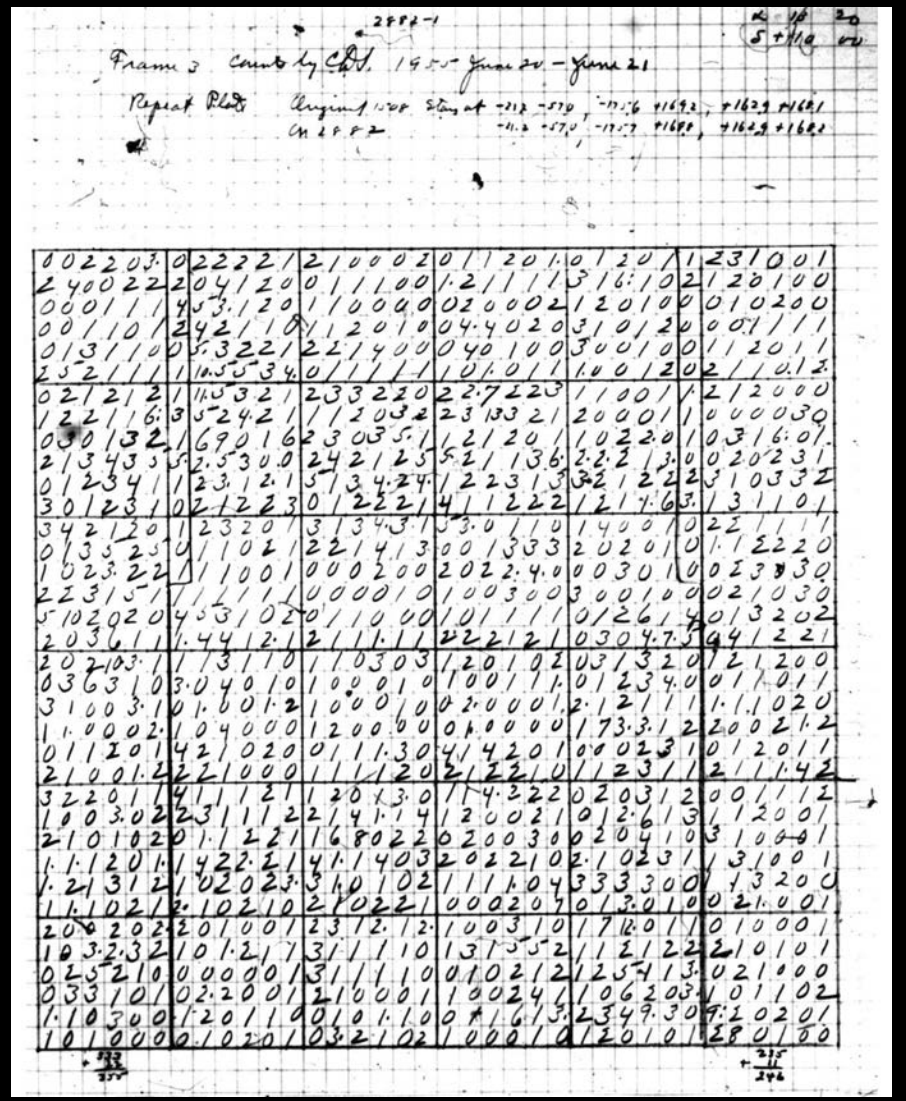
@ Koshiba Hall, the University of Tokyo: November 1, 2023

1. N in simulations

Peebles: The Large-scale Structure of the Universe (1980)



The North map of the published 1° Lick counts. This is a negative image of the figure we made using a computer to draw the squares and blacking the squares by hand.



Peebles: Annu. Rev. Astron. Astrophys 50 (2012) 1-28

Pioneering work on cosmological N-body simulations

- Miyoshi & Kihara: PASJ 27 (1975) 333
  - First N-body simulations of large-scale structure in a comoving, periodic cube, N=400
- Aarseth, Gott, & Turner : ApJ 228 (1979) 664
  - in expanding spheres, N=980, 1000, 4000
- Davis, Efstathiou, Frenk & White: ApJ 292 (1985) 371
  - P^3M simulations, N=32768,
  - Established the CDM paradigm, galaxy biasing, non-zero cosmological constant, 2pt & 3pt correlation functions
- Navarro, Frenk & White: ApJ 462 (1996) 563
  - Universal density profile of dark matter halos

Courtesy of Ed Turner:
digitized from his old 16mm movie film based on Aarseth, Gott, & Turner ApJ 228 (1979) 664

The first cosmological N-body simulations of galaxy clustering by Miyoshi and Kihara (1975)

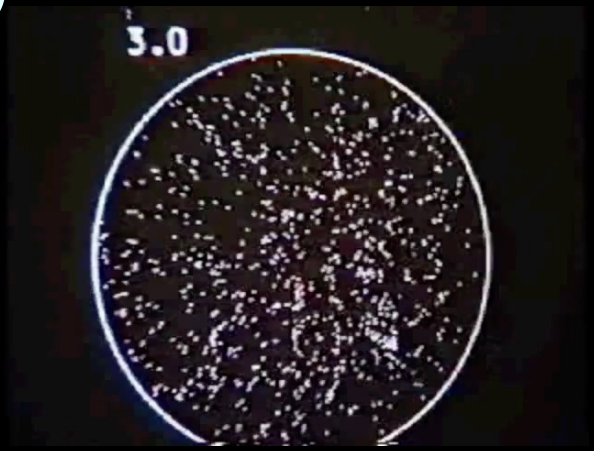
Development of the Correlation of Galaxies in an Expanding Universe

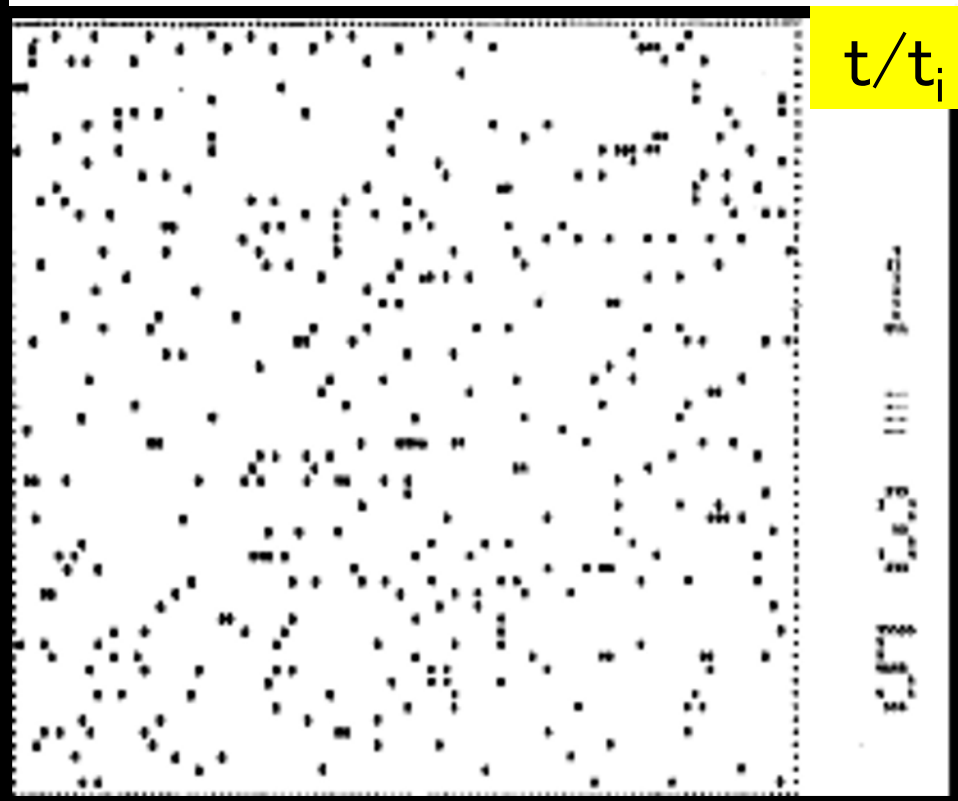
Miyoshi & Kihara Publ.Astron.Soc.Japan 27 (1975) 333

Kazunori MIYOSHI* and Taro KIHARA

Department of Physics, Faculty of Science, University of Tokyo, Tokyo

(Received 1974 December 4)





N-BODY SIMULATIONS OF GALAXY CLUSTERING. I. INITIAL CONDITIONS AND GALAXY COLLAPSE TIMES

SVERRE J. AARSETH
Institute of Astronomy, Cambridge University
J. RICHARD GOTT III*
Department of Astrophysical Sciences, Princeton University
AND
EDWIN L. TURNER
Harvard-Smithsonian Center for Astrophysics

ApJ 228(1979)664

Received 1978 June 29; accepted 1978 September 8

ABSTRACT

N-body simulations are used to model galaxy clustering in an expanding universe. The starting point of an *N*-body simulation corresponds to the epoch of protogalaxy formation when the protogalaxies become density enhancements of order unity and begin to behave like point masses. This typically occurs at a redshift of 10–30. As the models expand, the galaxies cluster; the result is remarkably similar to the observed clustering. In addition to having reasonable covariance

My question to Kazunori Miyoshi (2008)

須藤：当時のラインプリンターで粒子分布を描いた際には、印刷面積が最大となるフォントを印字したのではないかと想像するのですが、一体何をお使いなのでしょう? 8, M, Wあたりかなと推察しているのですが

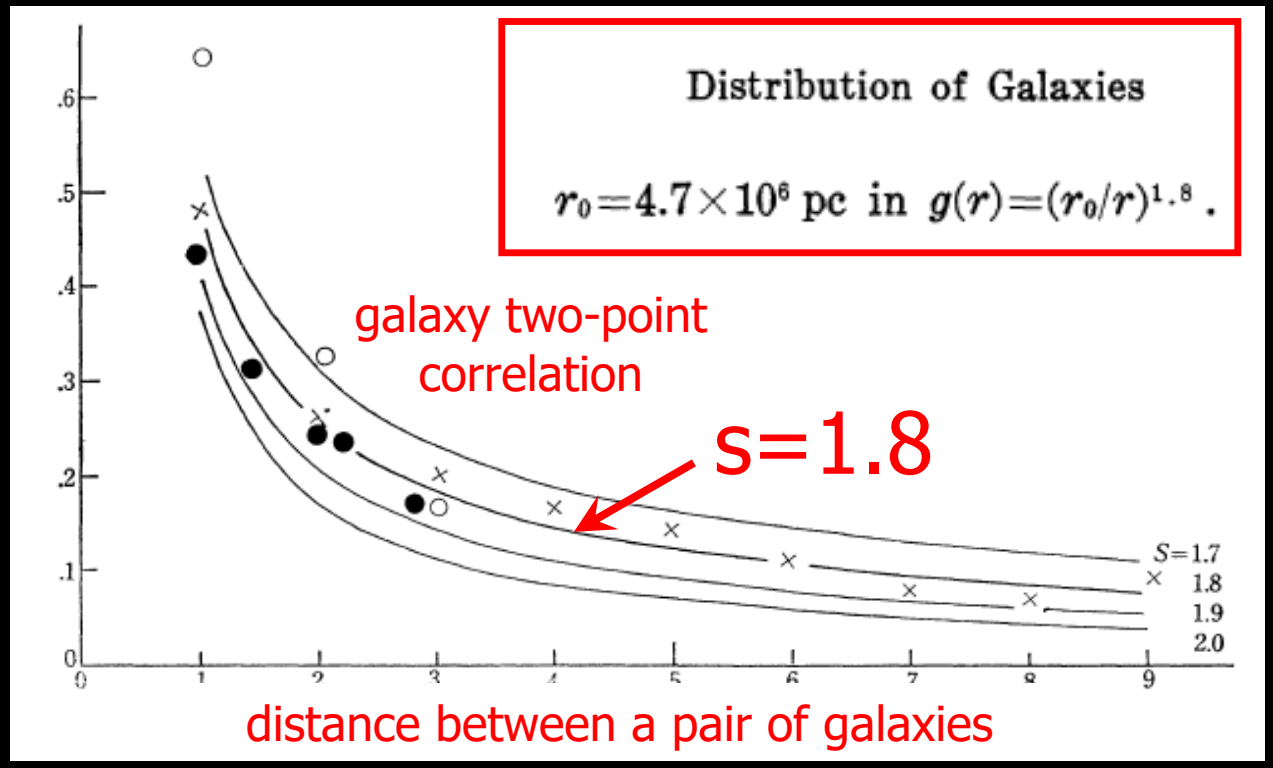
三好：確認しましたところ、"O" と"*" の重ね打ちでした。当時の物理教室は図書室、実験講座（理論講座の内、原子核の有馬先生だけは実験扱い）に積算校費を重点配分し、理論研は大型計算機センターの利用負担金も苦しい状況でしたから、名大のプラズマ研究所（当時）のHITAC8500（課題申請が認められると負担金なし）を夜間オペレーションで使わせて貰いました。プラズマ研究所で使っていたラインプリンタ用紙は、数字の列の対応を見易くするために１インチごとに鶯色の帯が入っており、夜間に紙を裏向きにセットして実行しました

Discovery of a power-law of galaxy two-point correlation functions by Totsuji and Kihara (1969)

Totsuji & Kihara
Publ.Astron.Soc.Japan
21 (1969) 221

The Correlation Function for the Distribution of Galaxies

Hiroo TOTSUJI and Taro KIHARA
Department of Physics, Faculty of Science, University of Tokyo
(Received May 15, 1969; revised June 26, 1969)



Groth & Peebles ApJ 217(1977)385

STATISTICAL ANALYSIS OF CATALOGS OF EXTRAGALACTIC OBJECTS. VII. TWO- AND THREE-POINT CORRELATION FUNCTIONS FOR THE HIGH-RESOLUTION SHANE-WIRTANEN CATALOG OF GALAXIES*

EDWARD J. GROTH AND P. J. E. PEEBLES
Joseph Henry Laboratories, Physics Department, Princeton University
Received 1977 March 4; accepted 1977 April 7

$$\xi(r) = (r_0/r)^{1.77} ,$$

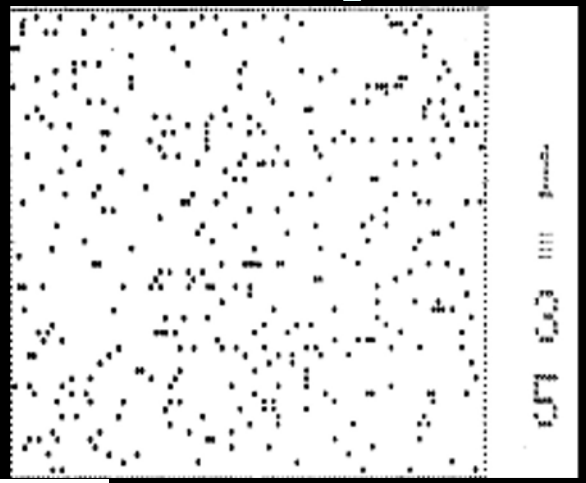
$$hr_0 = 4.7 \text{ Mpc} ,$$

$$0.05 \text{ Mpc} \lesssim hr \lesssim 9 \text{ Mpc} .$$

Pioneering perspective of physicists in the University of Tokyo (Miyoshi & Kihara 1975)

Another notion used to describe a deviation from uniformity is the "correlation function," which is obtained by a statistical process. While this quantity is not intuitive, it is above all ambiguity. The definition of a correlation function $g(\boldsymbol{r})$ is (LANDAU and LIFSHITZ 1968, §118)

$$g(\boldsymbol{r}_1-\boldsymbol{r}_2)=\langle\{n(\boldsymbol{r}_1)-\langle n\rangle\}\{n(\boldsymbol{r}_2)-\langle n\rangle\}\rangle/\langle n\rangle^2-\delta(\boldsymbol{r}_1-\boldsymbol{r}_2)/\langle n\rangle\,, \qquad (1.1)$$



As regards the correlation function of the galaxy distribution, main points of interest are the following.

(i) Is the correlation function an inverse power function of the distance? If so, what value do the power index and the characteristic length take?

(ii) How does the correlation function depend on time?

The first problem was analyzed by TOTSUJI and KIHARA (1969). Their results obtained by processing the data of galaxy counts (SHANE and WIRTANEN 1967) are $g(r)=(r_0/r)^s$ with $s=1.75\pm0.05$ and $r_0=(4.4\pm0.6)$ Mpc. PEEBLES (1974) also obtained the index $s=1.77$, mainly working with the same data. The second problem cannot be solved with the observational data, and the purpose of the present paper is to obtain some information by computer simulations.

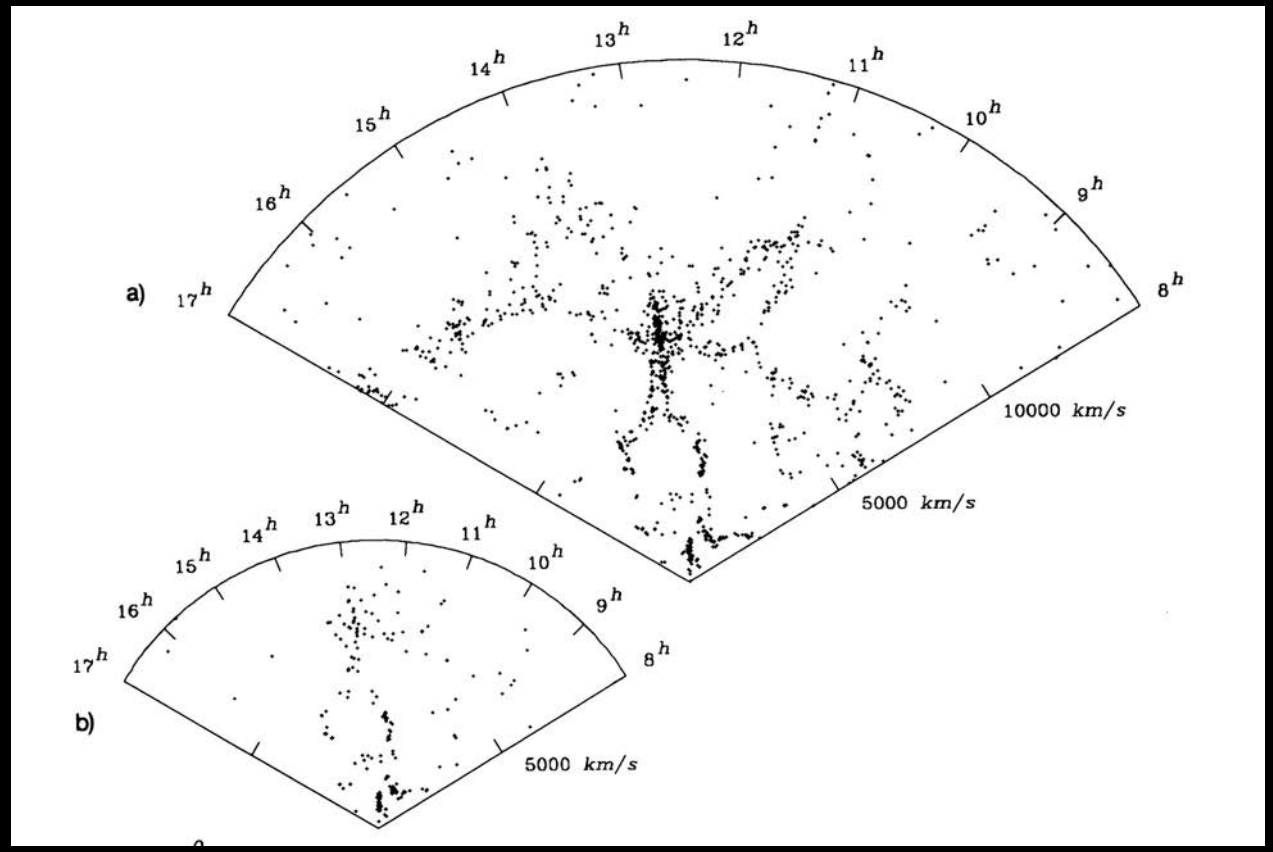
Miyoshi & Kihara (1975) had predicted the slice of the universe (1986)

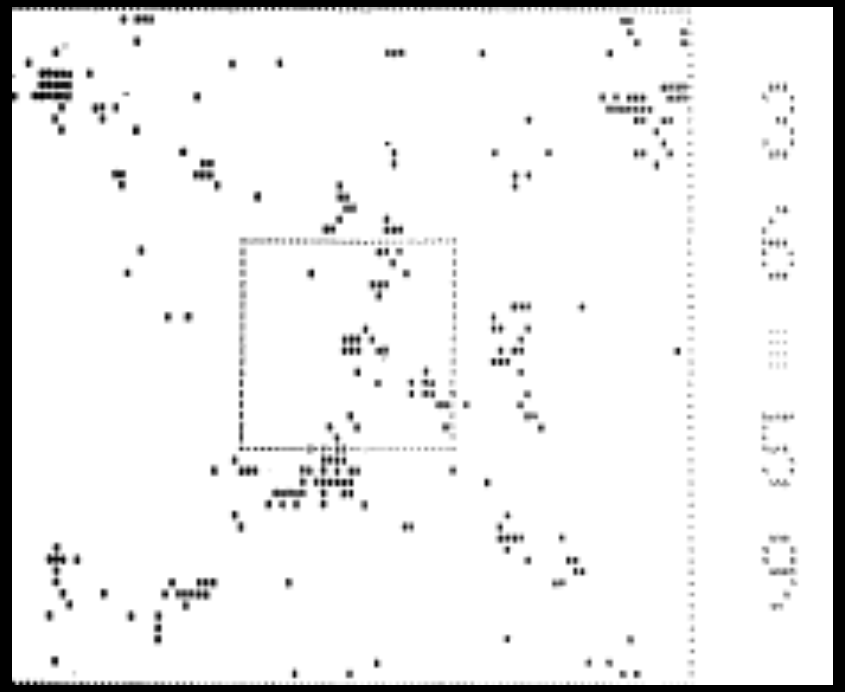
A SLICE OF THE UNIVERSE[1]

VALÉRIE DE LAPPARENT,[2,3] MARGARET J. GELLER,[2] AND JOHN P. HUCHRA[2]

Received 1985 November 12; accepted 1985 December 5

CfA redshift survey
de Lapparent, Geller & Huchra
ApJ 302 (1986)L1





Miyoshi & Kihara (1975)
N=400 simulation

Increasing the value of N

APPLICATION OF THE EWALD METHOD TO COSMOLOGICAL *N*-BODY SIMULATIONS

LARS HERNQUIST,[1,5] FRANÇOIS R. BOUCHET,[2] AND YASUSHI SUTO[1,3,4]

Received 1990 February 28; accepted 1990 June 11

ApJS 75(1991)231

ABSTRACT

Fully periodic boundary conditions are incorporated into a gridless cosmological *N*-body code using the Ewald method. It is shown that the linear evolution of density fluctuations agrees well with analytic calculations, contrary to the case of quasi-periodic boundary conditions where the fundamental mode grows too rapidly. The implementation of fully periodic boundaries is of particular importance to relative comparisons of methods based on hierarchical tree algorithms and more traditional schemes using Fourier techniques such as PM and P^3M codes.

COSMOLOGICAL *N*-BODY SIMULATIONS WITH A TREE CODE: FLUCTUATIONS IN THE LINEAR AND NONLINEAR REGIMES

TATSUSHI SUGINOHARA
Department of Physics, The University of Tokyo
YASUSHI SUTO
Department of Physics, Ibaraki University; and Research Institute for Theoretical Physics, Hiroshima University
FRANÇOIS R. BOUCHET
Institut d'Astrophysique de Paris, CNRS
AND
LARS HERNQUIST
Department of Astrophysical Sciences, Princeton University

Received 1990 February 27; accepted 1990 August 22

ApJS 75(1991)631

REDSHIFT-SPACE CORRELATION FUNCTIONS IN THE COLD DARK MATTER SCENARIO

YASUSHI SUTO
Uji Research Center, Yukawa Institute for Theoretical Physics, Kyoto University, Uji 611, Japan
AND
TATSUSHI SUGINOHARA
Department of Physics, The University of Tokyo, Tokyo 113, Japan

Received 1990 September 21; accepted 1990 December 17

ABSTRACT

ApJL 370(1991)L15

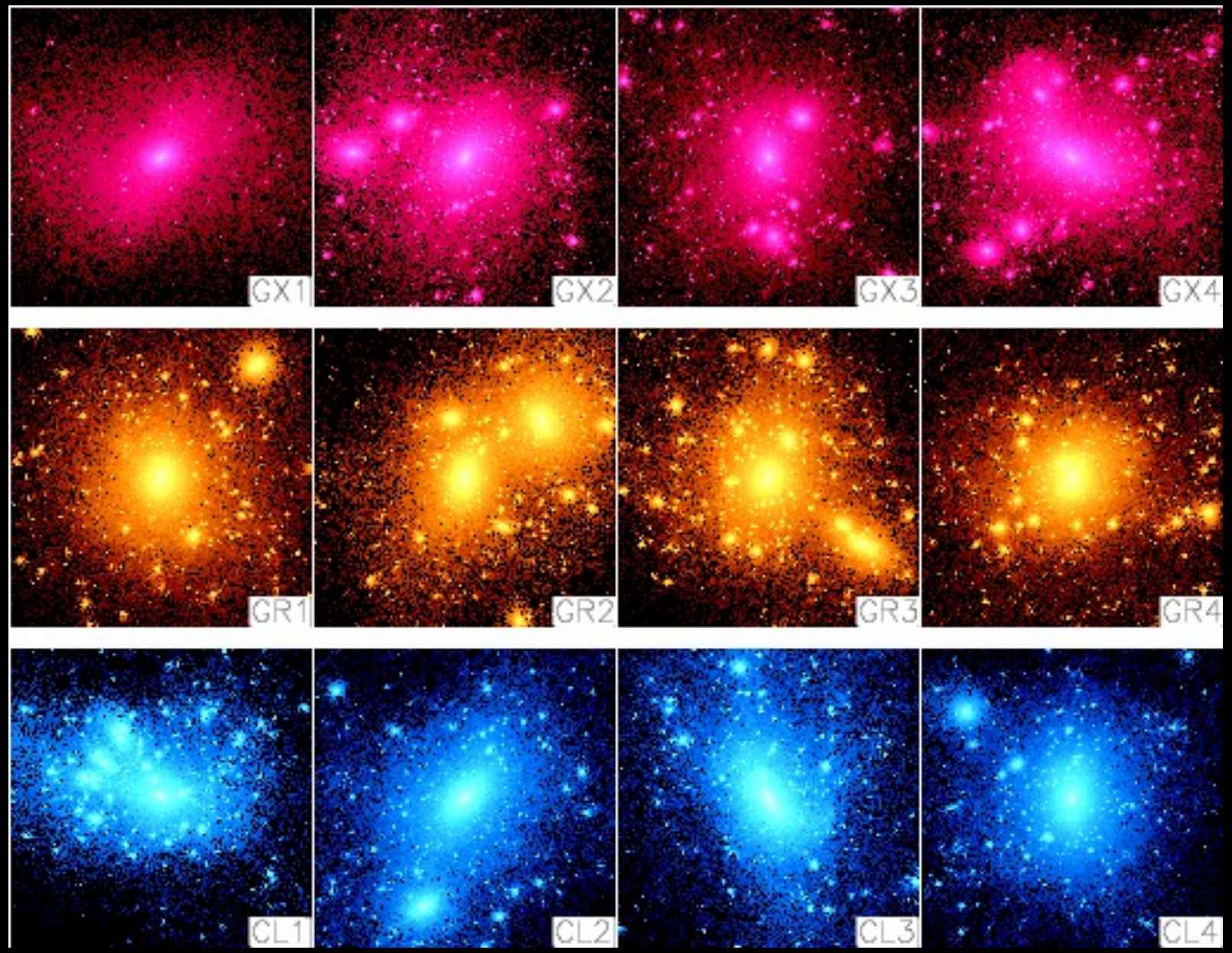
Universality and diversity of dak matter halos

galaxies~ $5x10^{12}M_{sun}$

groups~ $5x10^{13}M_{sun}$

clusters~ $3x10^{14}M_{sun}$

Jing & YS, ApJ 529(2000)69

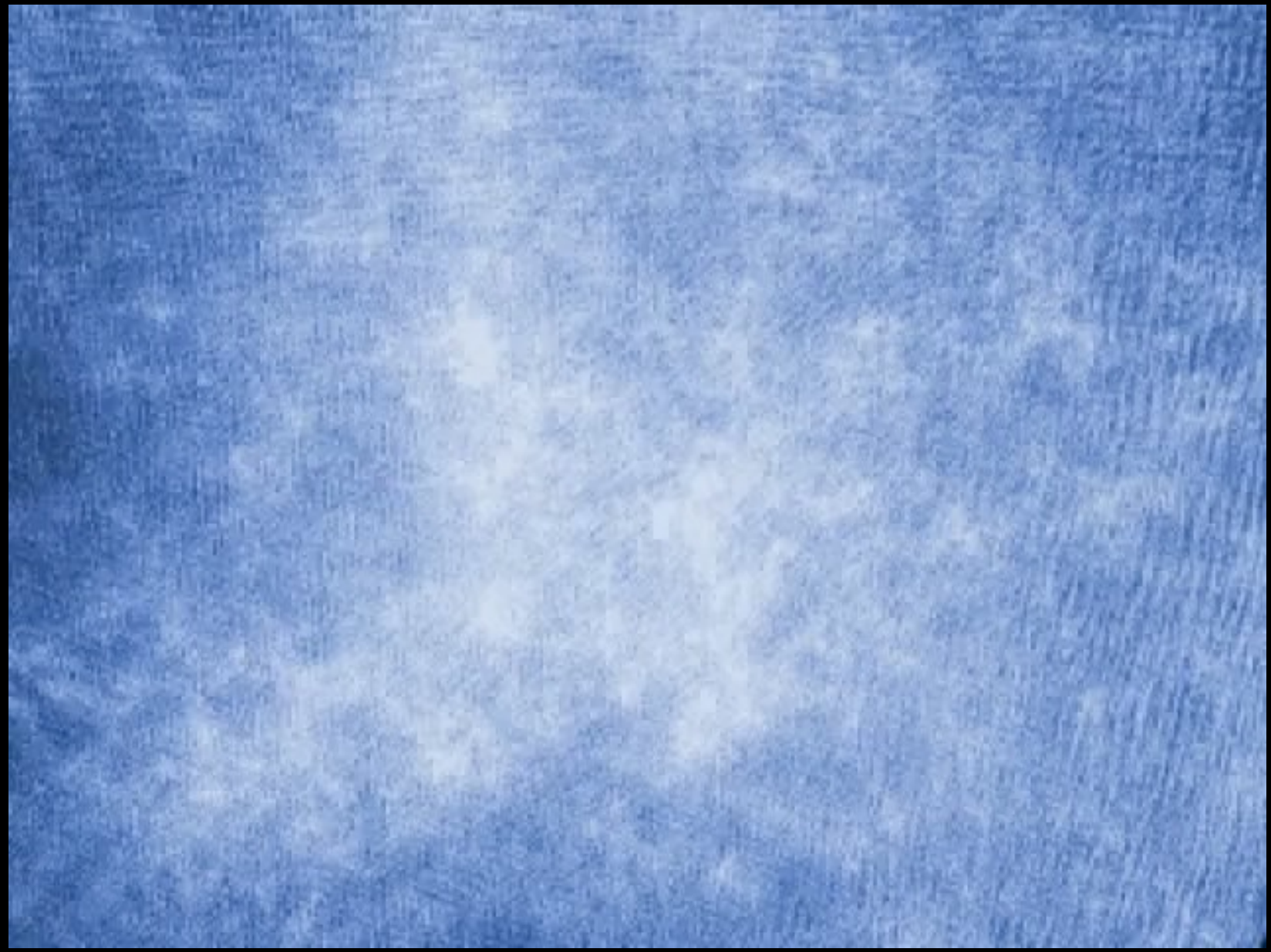


Cosmological hydrodynamical simulations

dark matter halos
⇒ X-ray gas
⇒ galaxies

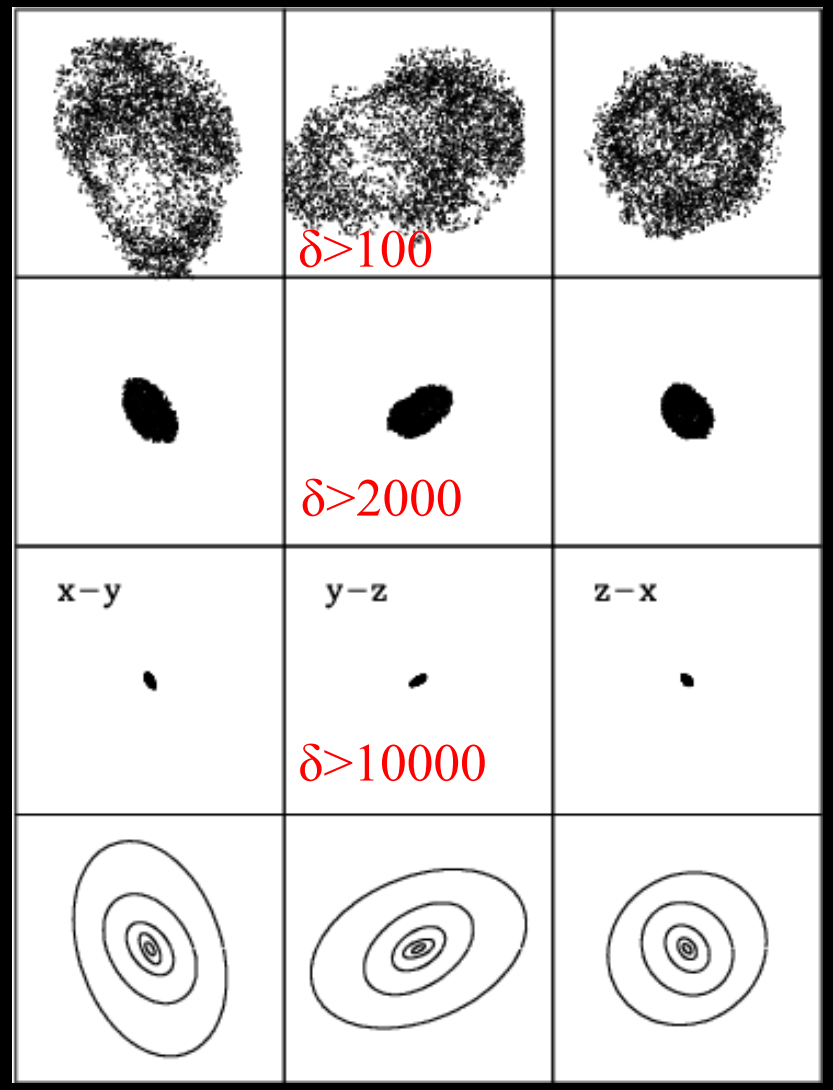
evolution in a box
of $(75h^{-1}\ \mathrm{Mpc})^3$

Yoshikawa, Taruya,
Jing & YS
ApJ 558(2001)520



Triaxial model of dark matter halos

Isodensity of dark matter halos



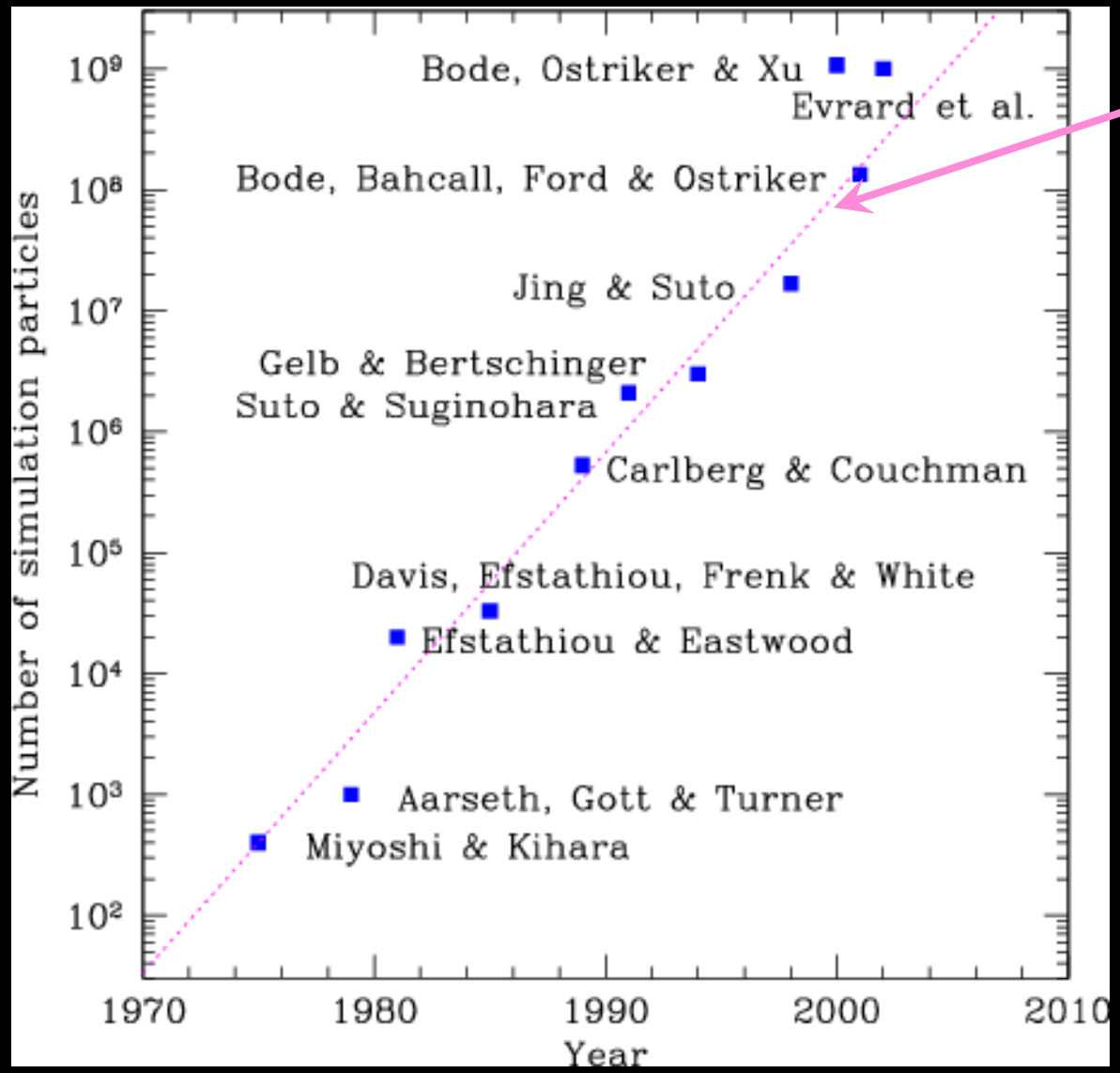
$$\rho(R) = \frac{\delta_c \rho_{crit}}{(R/R_s)^{\alpha}(1+R/R_s)^{3-\alpha}}$$

$$R^2(\rho) \equiv \frac{X^2}{a^2(\rho)} + \frac{Y^2}{b^2(\rho)} + \frac{Z^2}{c^2(\rho)}$$

Jing & YS ApJ 574 (2002) 538

- widely applied for a variety of cosmological problems, even if it is fairly simplified
  - concentric, self-similar (axis ratio is independent of radius)

Exponential evolution of "N" in cosmological N-body simulations



$N=400\times10^{0.215(\mathrm{Year}-1975)}$

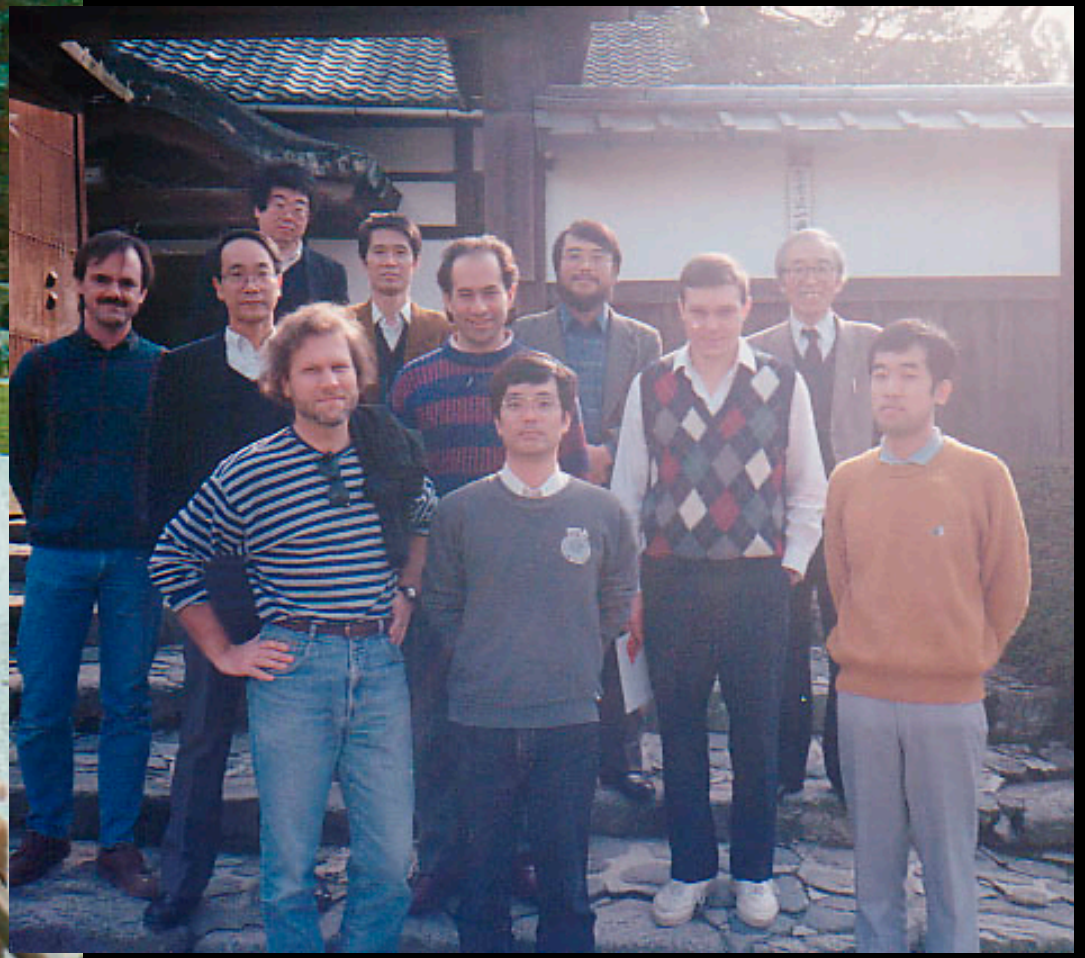
(Suto 2003)

- N in a $(1h^{-1}\mathrm{Gpc})^3$ comoving box will exceed the real number of DM particles in the box:
  - $N=10^{76}$ in 2319 (if DM is WIMP with m=10GeV)
  - $N=10^{108}$ in 2468 (if DM is fuzzy DM with $m=10^{-22}$eV)
- So, I decided to stop larger simulations!

⇒ cosmological survey with Subaru

2. N in Subaru

JSPS-NSF exchange program (PI: Humitaka Sato)
1992 December workshop in Kyoto



30 years later…
(2023 February 18@Torun, Poland)

SDSS map of galaxies

The 2019 Kyoto Prize Workshop

"*Wide-Field Sky Survey of the Universe: From the Past to the Future of Astronomy*"

@November 13, 2019, the University of Tokyo

HSC (Hyper-Supreme Cam) in the making (1)

- From: aihara <aihara@phys.s.u-tokyo.ac.jp>
  - *Date: Tue, 16 Mar 2004 14:32:54 +0900*
  - Large Synoptic Survey Telescope (LSST) project というのをご存知ですか？SNAP もそうですが、LSST のカメラは高エネルギー屋さんがやっています。きょう、Steve Kahn （ご存じかどうかしりませんが）と話して、もし、私が入る気ならば、日本のastronomerにも声をかけたらどうかと言われました
- From: Yasushi Suto <suto@phys.s.u-tokyo.ac.jp>
  - *Date: Tue, 16 Mar 2004 15:04:03 +0900 (JST)*
  - 重力レンズ関係で、日本でもっとも興味をもちそうなのは、宮崎さん（釜江研出身！）@すばる観測所ですね。

HSC in the making (2)

- From: Satoshi Miyazaki <satoshi@anela.mtk.nao.ac.jp>
  - *Date: Sun, 21 Mar 2004 18:31:27 -1000*
  - 相原様　　ご無沙汰しております、釜江研でお世話になっていた宮崎です。今、天文学会に出るために名古屋大学に来ていますが、そこで東大の須藤さんとお会いして、相原さんがLSSTに興味をお持ちだと聞きました。これまでに、私たちのグループではすばる用のSuprime-Camというカメラを作り実際にWeak Lensing Surveyをはじめています。より広い視野のカメラを求めて、技術検討を始めました。これはすばる用のカメラのため実はLSSTは我々のライバルとなります。相原さんが広視野の望遠鏡に興味をお持ちと聞き、何か一緒に仕事をさせていただけないかと、メールさせていただきました。いつかお時間のある時にお話を聞いていただけないでしょうか？

HSC in the making (3)

- From: Satoshi Miyazaki <satoshi@anela.mtk.nao.ac.jp>
  - *Date: Wed, 31 Mar 2004 14:16:36 -1000*
  - 須藤様　3/25に相原さんと釜江さんに会って話を聞いてきました。釜江さんはLSSTに関しては今から入って行っても、ただの下働きになってしまうからやめたほうがよいという意見を言っていました。そのふたりの話が一段落した後に、「私はHyperSuprimeというLSSTを打ち負かすことができる計画を持っています」と、我々のSuprime-Camアップグレード計画を紹介したところ、釜江さんや相原さんは非常に興味を持ってくれました。**相原さんは「15億円の科研費を出すのだ」と言い始めました。**この先どうなるか分かりませんが、須藤さんから教えていただいた情報により、いろいろ可能性が開けてきました。

HSC in the making (4)

- From Ed Turner elt@astro.princeton.edu
  - Fri, 28 Jul 2006 23:07:03 -0400 (EDT)
  - *Dear Yasushi,*

    It is of much more direct interest to me than it was when we talked in June. The reason is that in Princeton we have recently had some discussions about the possibility of approaching you (Subaru) re the possibility of some type of collaboration or joint project or perhaps a pair of projects. I should emphasize that at this point the whole situation is very uncertain, and this idea is a rather vague one, but it seems to David Spergel (copied on this message) and me that it might be a good time to see if it is totally unrealistic or if it seems to you worth looking into the possibility a bit more. What do you think?

HSC in the making (5)

- Mon, 31 Jul 2006 07:43:52 +0900 (JST)
- *Dear Ed,* · · · I believe that a possible joint project between Subaru and Princeton is definitely welcome by the Subaru community.
- In case you are interested in proceeding a bit further, I am happy to approach several people very informally at this point to see their personal feeling.
- I understand that the possibility would involve many uncertainties in both sides and thus be fairly unpredictable, but I believe it is really worthwhile to explore more.

SDSS collaboration meeting organized by Changbom Park@ Seoul, Nov. 2006

I convinced Michael Strauss (Princeton) to work with Subaru

Cosmology with wide-field photometric and spectroscopic galaxy surveys

November 9-10, 2006 @ University of Tokyo

In Japan, all important things are agreed upon over dinner with drinks

Discussion on NAOJ-Princeton collaboration over *Shabu-shabu*
December 19, 2006@Kisoji, Mitaka

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

DENET

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

Institut d'Astrophysique de Paris
coordinator
Jerome Martin

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

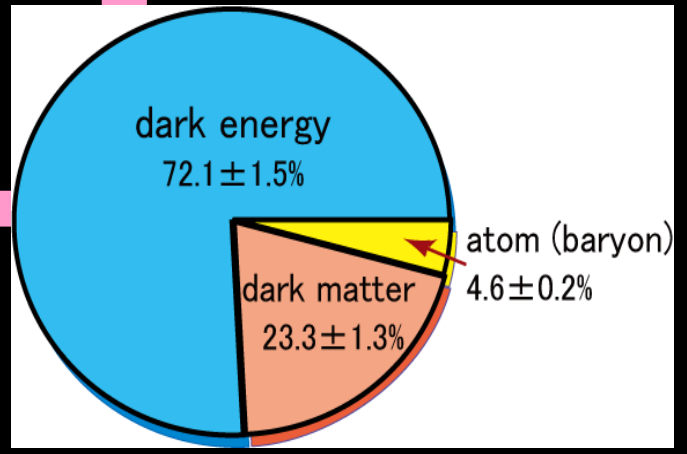
Tohoku Univ.
NAOJ
Hiroshima Univ.
Kyoto Univ.
Nagoya Univ.

CMB
Gravitational lens
Baryon oscillation

Modified gravity
Extra-dimension
backreaction

Edinburgh U. Royal Obs.
coordinator
John Peacock

Theoretical model
Baryon oscillation
Weak lens mapping



RESEARCH CENTER FOR THE EARLY UNIVERSE
THE UNIVERSITY OF TOKYO
RESCEU

東京大学 大学院
理学系研究科・理学部
SCHOOL OF SCIENCE, THE UNIVERSITY OF TOKYO

JSPS 日本学術振興会
Core-to-Core Program
DENET
International Research
Network for Dark Energy

JSPS core-to-core program workshop

Cosmology with wide-field imaging surveys of galaxies

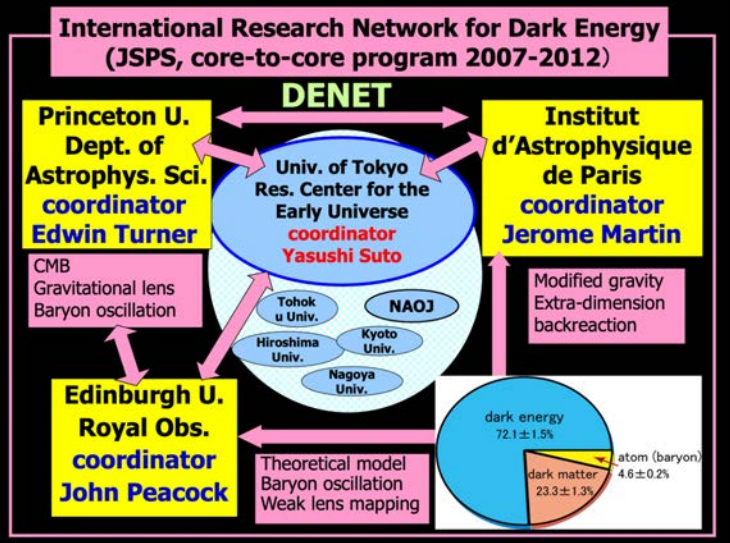
June 7 - 8, 2007, Koshiba Hall
The University of Tokyo

Invited Speakers
Hiroaki Aihara (Tokyo)
Jim Gunn (Princeton)
Takashi Hamana (NAOJ)
Robert Lupton (Princeton)
Takahiko Matsubara (Nagoya)
Satoshi Miyazaki (NAOJ)
David Spergel (Princeton)
Michael Strauss (Princeton)
Masahiro Takada (Tohoku)
Tomonori Totani (Kyoto)
Edwin Turner (Princeton)
Toru Yamada (Tohoku)
Kazuhiro Yamamoto (Hiroshima)

Scientific organizing committee
Hiroaki Aihara (Tokyo)
Hiroshi Karoji (NAOJ)
Satoshi Miyazaki (NAOJ)
David Spergel (Princeton)
Yasushi Suto (Tokyo)
Edwin Turner (Princeton, chair)

Local organizing committee
Takashi Hiramatsu (Tokyo)
Erik Reese (Tokyo)
Yasushi Suto (Tokyo, chair)
Atsushi Taruya (Tokyo)
Jun'ichi Yokoyama (Tokyo)

DENET (Dark Energy Network) from HSC to PFS



Decrypting the Universe

Large Surveys for Cosmology

Invited Speakers
D. Spergel
S. Cole
E. Copeland
M. Doi
A. Helmi
O. Lahav
R. Maartens
Y. Mellier
S. Miyazaki
A. Murphy
M. Takada

24th-26th October 2007
Edinburgh, Scotland

Joint Royal Observatory Edinburgh / JSPS
Core-to-Core Program Workshop
www.roe.ac.uk/roe/workshop/2007

Local Organising Committee
A. Heavens
R. Ivison
A. Nicol
P. Norberg (Chair)
P. Simon
F. Simpson
A. Taylor

Cosmology Near & Far: Science With WFMOS

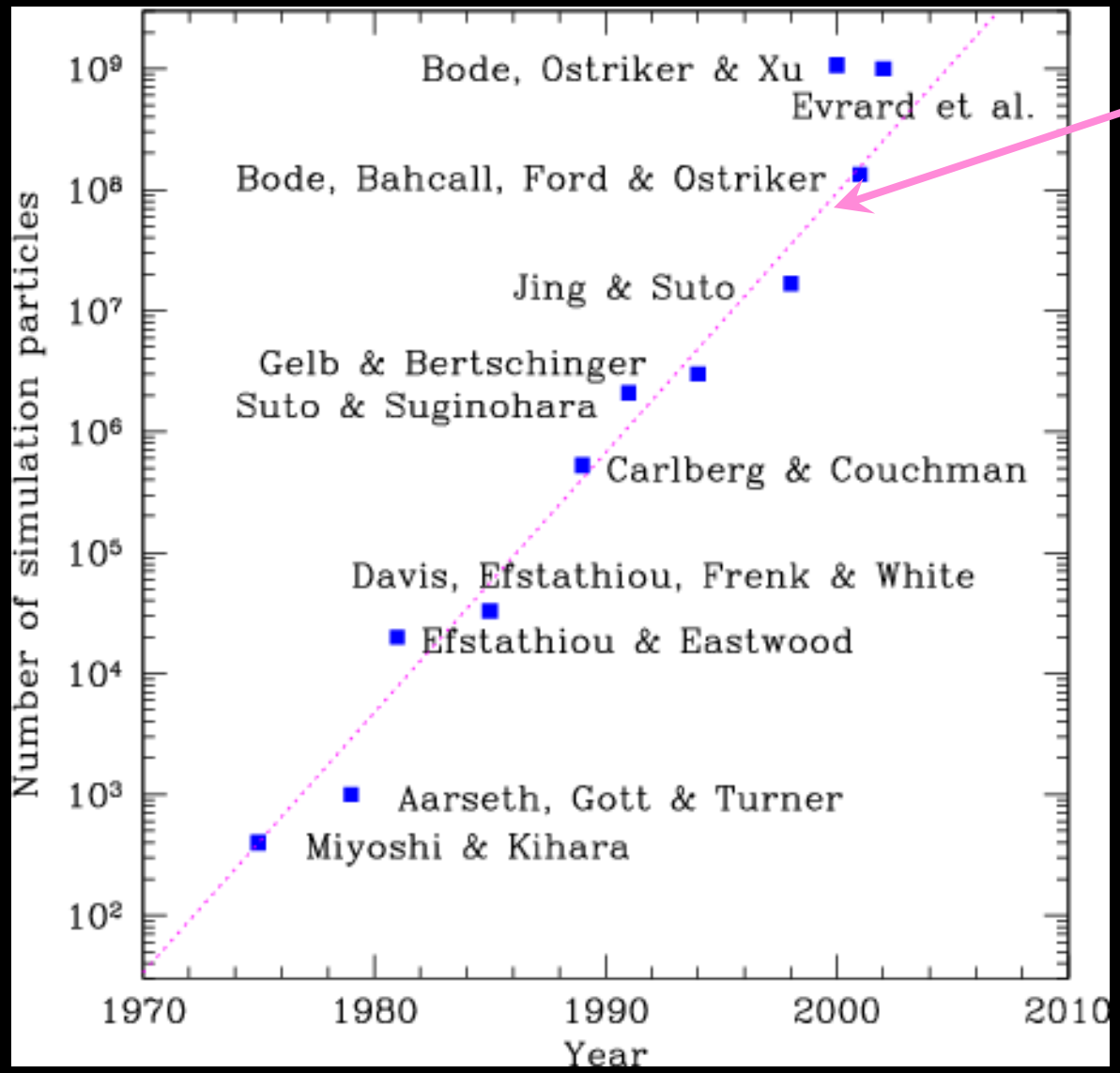
May 19-23, 2008@Kona, Hawaii

A Joint Conference by Subaru • Gemini • JSPS • NOAO • UK STFC • AAL

DENET and Princeton joint conference:
Science Opportunities with Wide-Field Imaging and Spectroscopy of the Distant Universe
November 9-11, 2009@Princeton Univ.

3. N=3

Exponential evolution of "N" in cosmological N-body simulations



$N=400\times10^{0.215(\mathrm{Year}-1975)}$

(Suto 2003)

- N in a $(1h^{-1}\mathrm{Gpc})^3$ comoving box will exceed the real number of DM particles in the box:
  - $N=10^{76}$ in 2319 (if DM is WIMP with m=10GeV)
  - $N=10^{108}$ in 2468 (if DM is fuzzy DM with $m=10^{-22}$eV)
- So, I decided to stop larger simulations!

⇒ N=3 (Hayashi, Wang & YS 2019)

Physics Department Colloquium at University of Tokyo on November 10, 2000

THE DETECTION AND CHARACTERIZATION OF EXTRASOLAR PLANETS

Ed Turner Princeton University Observatory

Our planet observations at Subaru

(HD209458b with High Dispersion Spectrograph in September 2002, and photometric blind search of transiting planets with Suprime-Cam in October 2002)

Josh Winn's (and also my) first paper on exoplanets

A Search for Hα Absorption in the Exosphere of the Transiting Extrasolar Planet HD 209458b

Joshua N. WINN,[1*] Yasushi SUTO,[2] Edwin L. TURNER,[3] Norio NARITA,[2]
Brenda L. FRYE,[3*] Wako AOKI,[4] Bun'ei SATO,[4,5] and Toru YAMADA[4]
[1]*Harvard-Smithsonian Center for Astrophysics, 60 Garden St. MS-51, Cambridge, MA 02138, USA*
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(Received 2004 April 16; accepted 2004 May 6)

Abstract

There is evidence that the transiting planet HD 209458b has a large exosphere of neutral hydrogen, based on a 15% decrement in Lyman-α flux that was observed by Vidal-Madjar et al. during transits. Here we report upper limits on Hα absorption by the exosphere. The results are based on optical spectra of the parent star obtained with the Subaru High Dispersion Spectrograph. Comparison of the spectra taken inside and outside of transit reveals no exospheric Hα signal greater than 0.1% within a 5.1 Å band (chosen to have the same $\Delta\lambda/\lambda$ as the 15% Lyα absorption). The corresponding limit on the column density of $n = 2$ neutral hydrogen is $N_2 \lesssim 10^9\,\mathrm{cm}^{-2}$. This limit constrains proposed models involving a hot ($\sim 10^4$ K) and hydrodynamically escaping exosphere.

Back to N=2!

Winn et al.
PASJ 56
(2004) 655

I am very proud of this methodologically pioneering paper

2006PASJ...58..869U

An Extrasolar Planet Transit Search with Subaru Suprime-Cam*

Urakawa, Seitaro; Yamada, Toru; Suto, Yasushi and 5 more

2006/10

cited: 1

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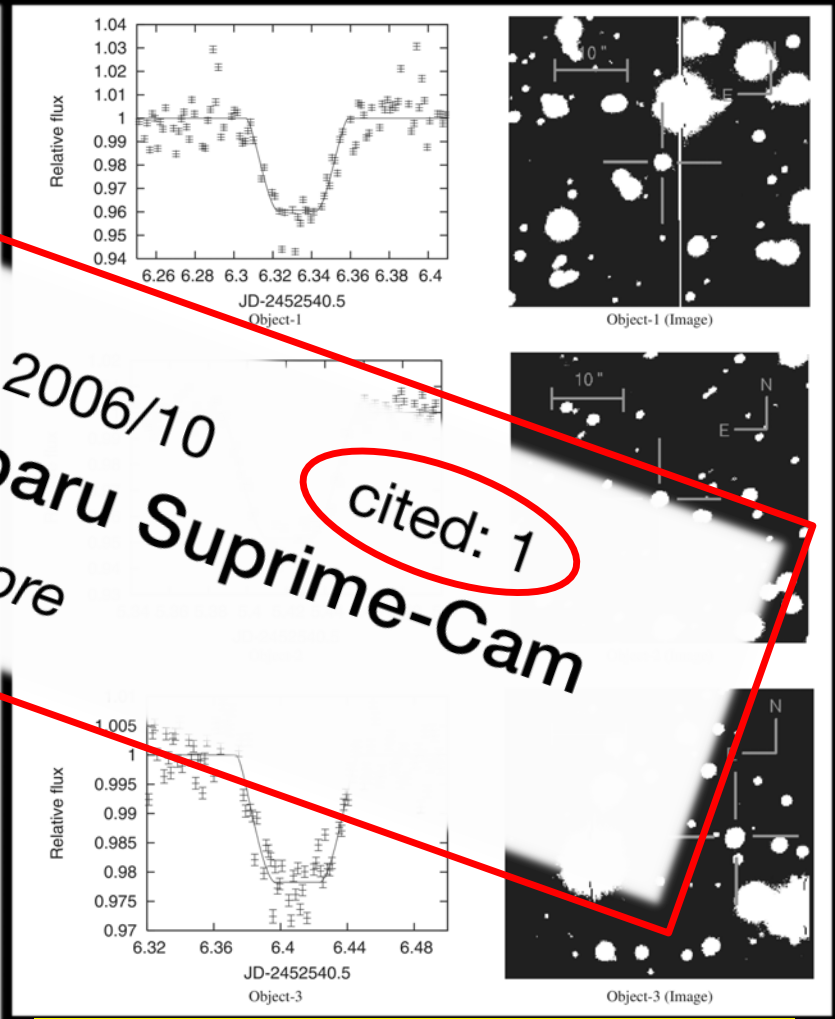
Urakawa et al. PASJ 58 (2006)869

We report the results of a prototype photometric search for transiting extrasolar planets using Subaru Suprime-Cam. Out of about 100000 stars monitored around the Galactic plane ($l = 90°$, $b = 0°$), we find that 7700 show photometric precision better than 1% for 60 s exposures, which is required to detect extrasolar planets by the transit method. Thus, Suprime-Cam has the photometric stability and accuracy necessary for a transiting planet survey. During this observing run, we detected three objects (around 18.5 mag for i'-band) that exhibit a single full transit-



N=3 transit candidates

THE ROSSITER-McLAUGHLIN EFFECT AND ANALYTIC RADIAL VELOCITY CURVES FOR TRANSITING EXTRASOLAR PLANETARY SYSTEMS

YASUHIRO OHTA, ATSUSHI TARUYA,[1] AND YASUSHI SUTO[1]

N=2 Ohta, Taruya +YS: ApJ 622(2005)1118

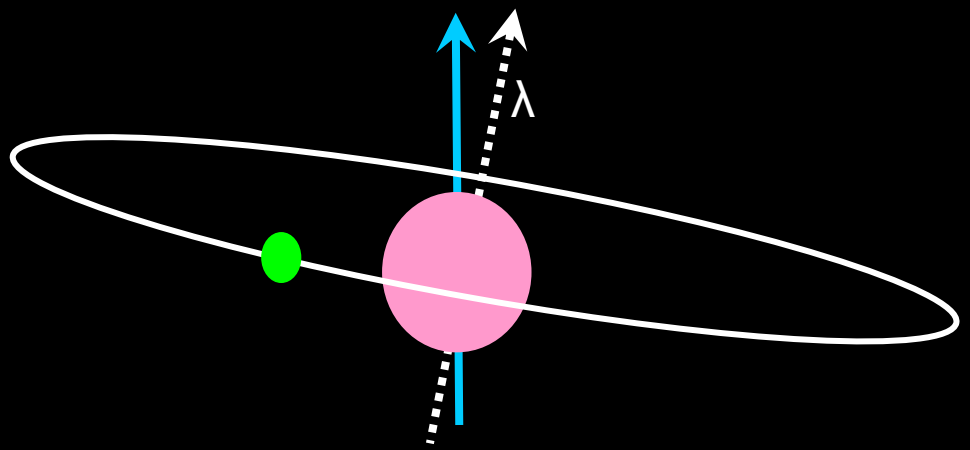
effect; if its planetary orbit and the stellar rotation share the same direction as discovered for the HD 209458 system, it would be an important confirmation of the current view of planet formation out of the protoplanetary disk surrounding the protostar. If not, the result would be more exciting and even challenge the standard view, depending on the value of the misalignment angle λ.

First perturbative analytic formula for the Rossiter-McLaughlin effect
We introduced the symbol λ to denote the projected spin-orbit angle
⇒ Hirano et al. (2010,2011)

Measurement of spin-orbit alignment in an extrasolar planetary system

- Joshua N. Winn, R.W. Noyes, M.J. Holman, D.B. Charbonneau, Y. Ohta, A. Taruya, Y. Suto, N. Narita, E.L. Turner, J.A. Johnson, G.W. Marcy, R.P. Butler, & S.S. Vogt
  - ApJ 631(2005)1215

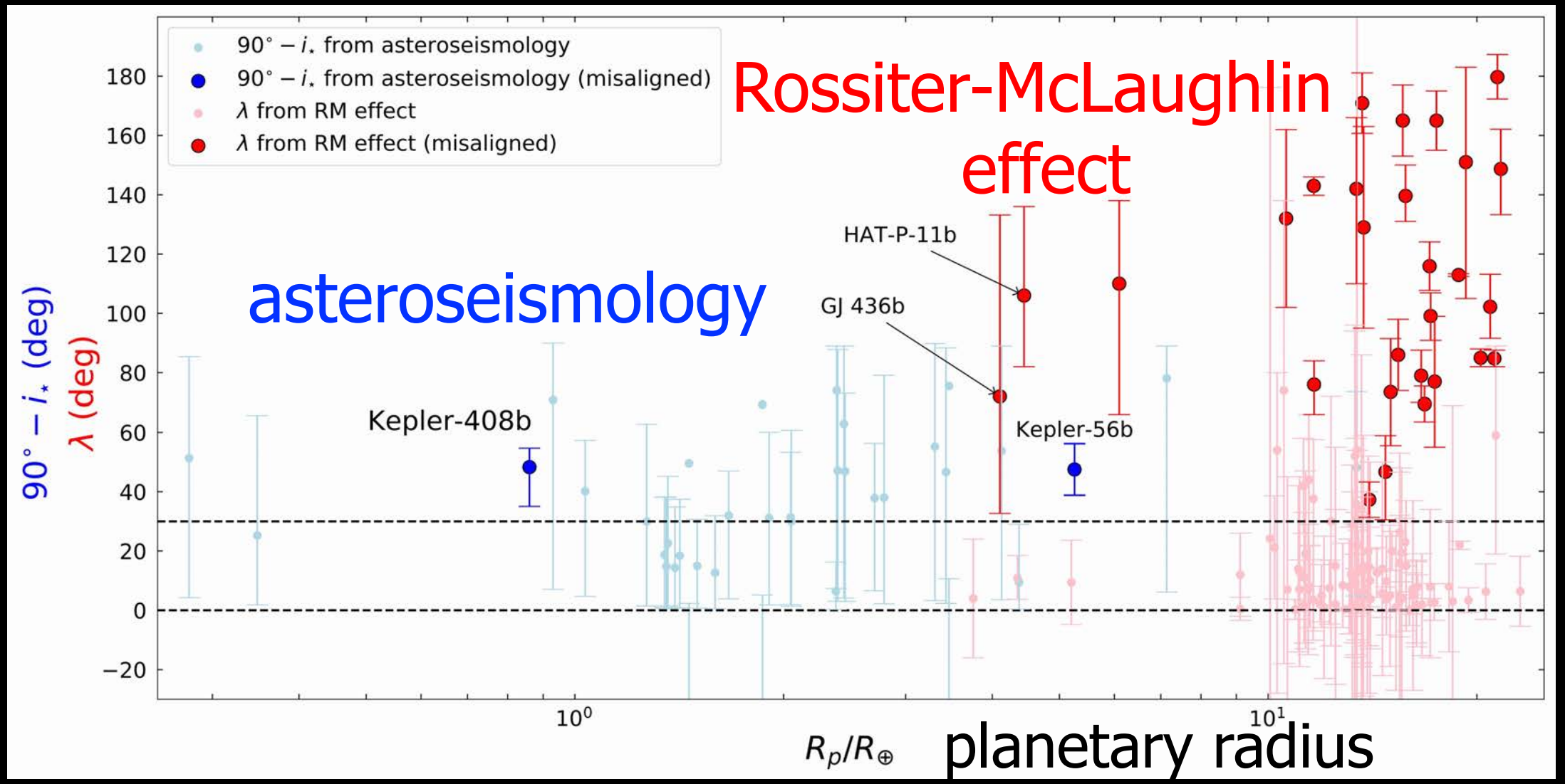
$\lambda = -4.4° \pm 1.4°$



HD209458: Keck data + RM effect perturbation formula by Ohta, Taruya & YS (2005)

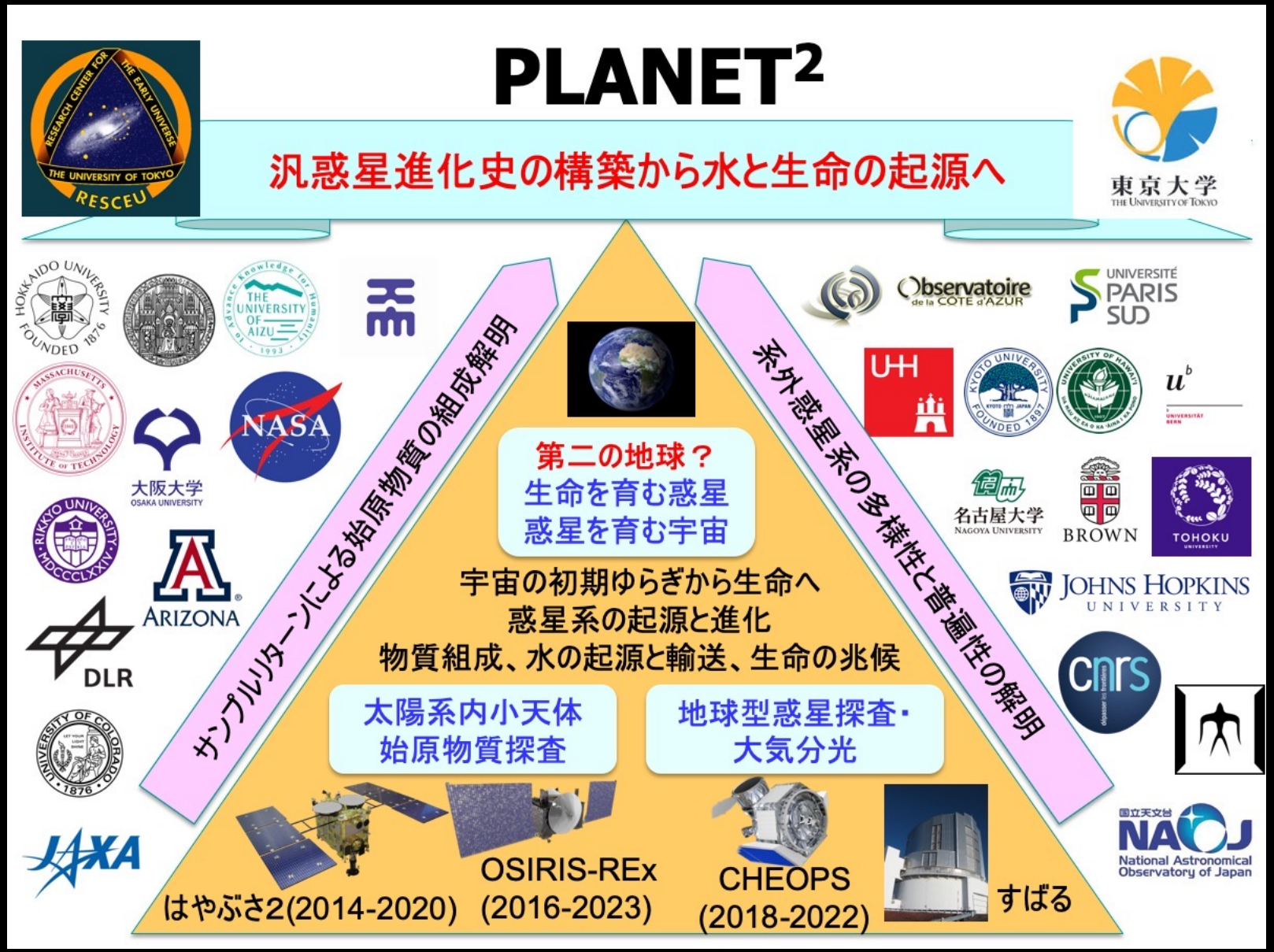
⇒ Most importantly, this paper led Josh to be a world expert on the spin-orbit (mis)alignment of exoplanets

Spin-orbit angles against the planetary radius



Kamiaka, Benomar, YS, Dai, Masuda, & Winn, AJ 157(2019)137

JSPS core-to-core program (2016-2021)



- PI: Seiji Sugita (Dept. of Earth and Planet Sciences, Univ. of Tokyo)
- co-PIs: Masahiro Ikoma, Yasushi Suto

The 18th RESCEU summer school in 2018 @Hakodate, Hokkaido

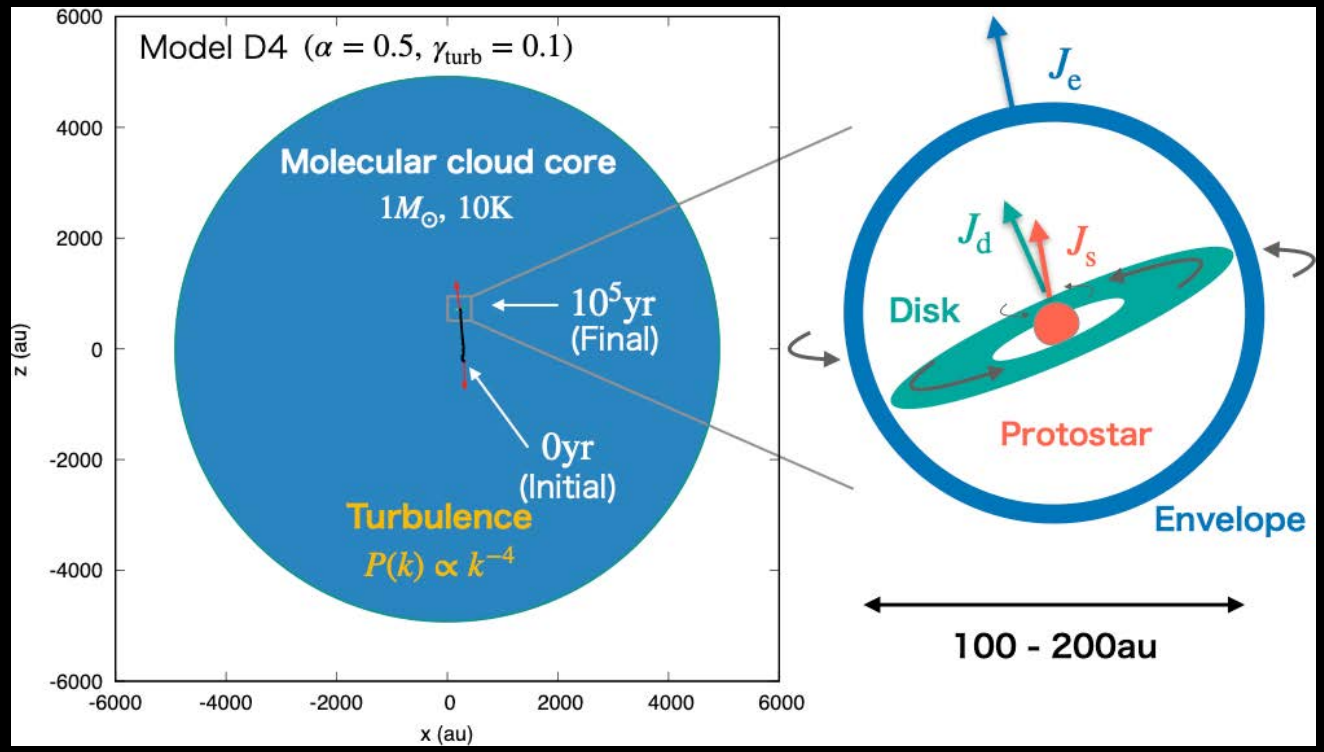
- **Re'em Sari (Hebrew Univ.)** , Haibo Yu (UC Riverside), Kohta Murase (Penn State Univ.)

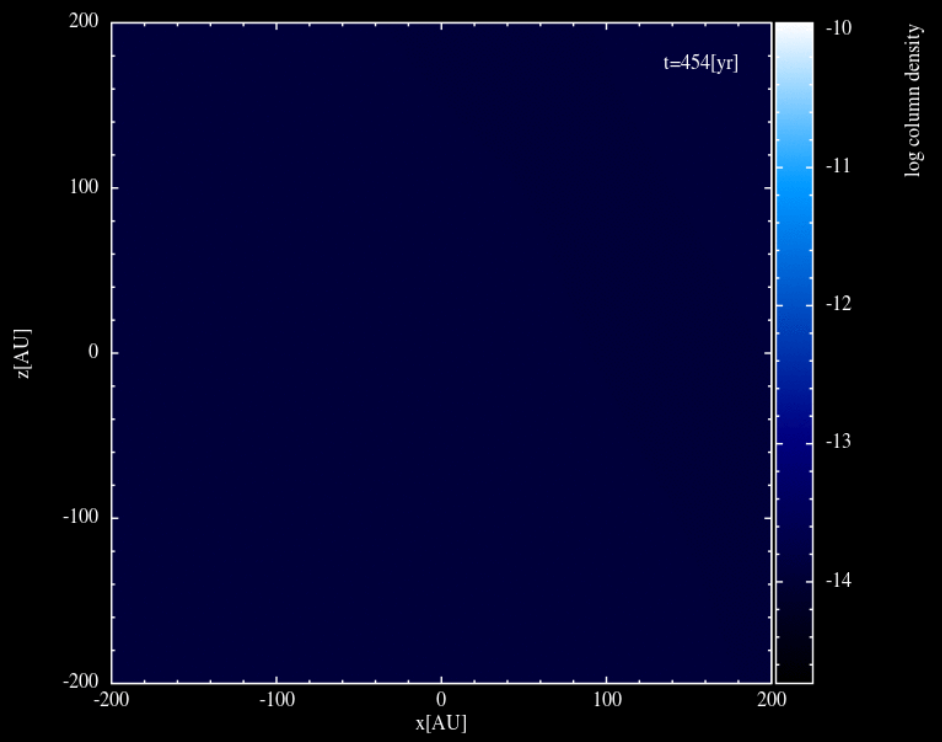
The 19th RESCEU summer school in 2019 @Akita

- **Konstantin Batygin (Caltech),** Patrick Brady (Univ. of Wisconsin-Milwaukee), Tanmay Vachaspati (Arizona State Univ.)

Primordial star-disk alignment in turbulent molecular cloud cores

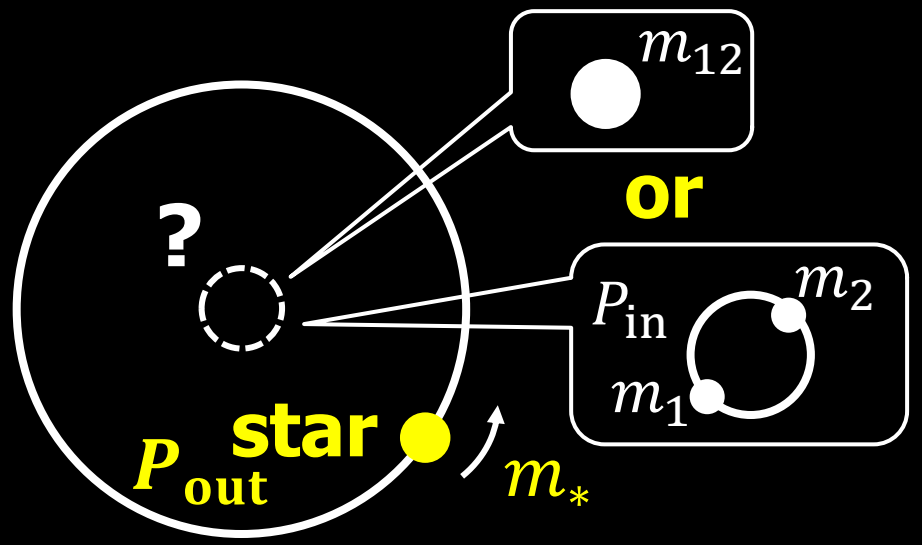
- **SPH simulation**
  - 1million SPH particles + sink particle
  - isothermal turbulent cloud cores of $1M_{sun}$
  - neglect magnetic field





Takaishi, Tsukamoto + YS (2020)
MNRAS 492, 5641

RV (radial velocity) modulations of a tertiary star



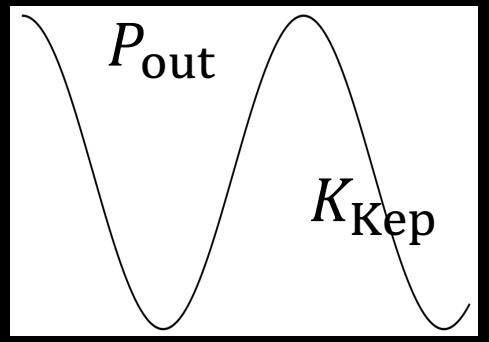
Keplerian motion RV
+ RV modulations of a tertiary star due to a hidden inner binary

Hayashi, Wang + YS: ApJ 890(2020)112
Hayashi + YS: ApJ 897(2020)29
Hayashi, YS + Trani (2023): arXiv:2307.01793

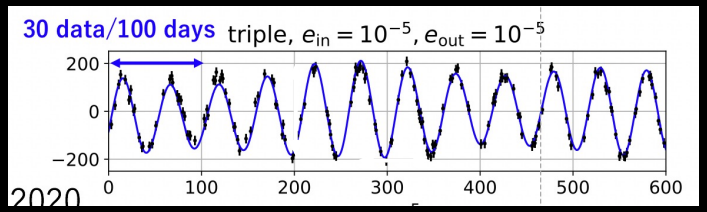
Morais & Correia (2008, 2012)

(i) short-term

$$\mathrm{Amp} \sim K_{\rm Kep}\left(\frac{P_{\rm in}}{P_{\rm out}}\right)^{\frac{7}{3}}$$



+



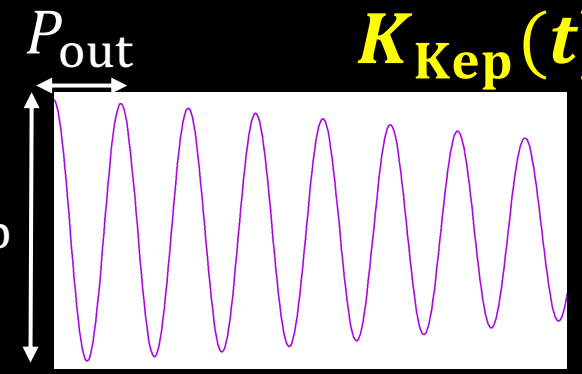
$$\mathrm{period} \sim P_{\rm in}/2$$

Kepler motion **+ Short-term RV variations (inner-binary perturbation)**

(ii) long-term for non-coplanar triples

Inclination $I_{\rm out}(t)$ modulated in the ZKL timescale

$$K_{\rm Kep}(t) = K_0 \sin I_{\rm out}(t)$$



semi-amplitude of Kepler RV varies over longer timescales

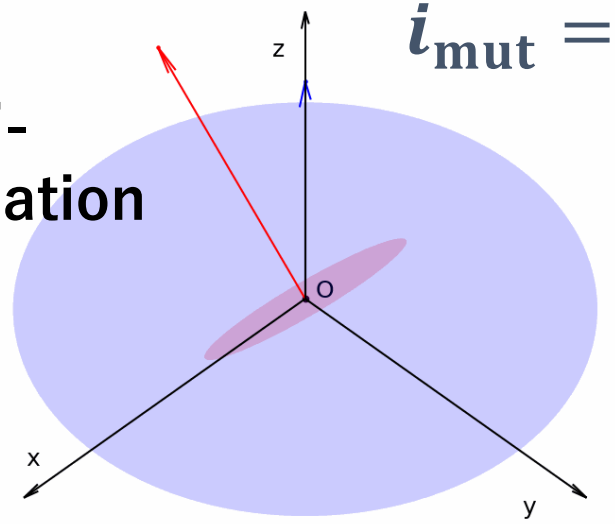
Evolution of inclination for non-coplanar triples

$t = 0 P_{\rm out}^{(0)}$

$i_{\rm mut} = 45°$

weak Kozai-Lidov oscillation

⇒ small-amplitude nodal precession



Hayashi + YS: ApJ 897(2020)29

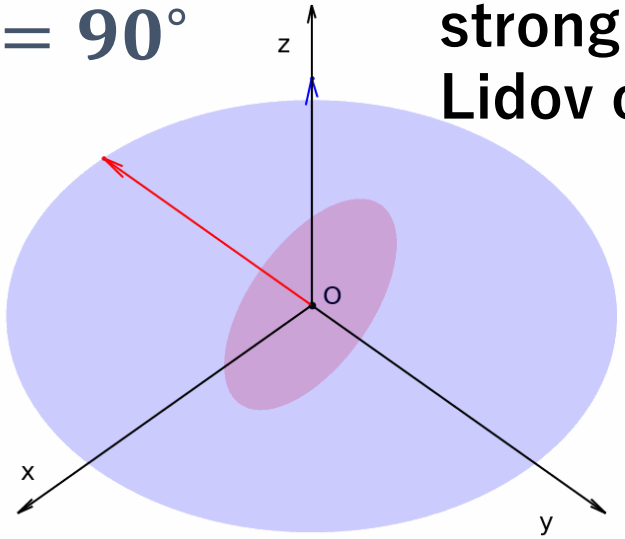
$K_{\rm Kep} = K_0 \sin I_{\rm out}(t)$

$t = 0 P_{\rm out}^{(0)}$

$i_{\rm mut} = 90°$

strong Kozai-Lidov oscillation

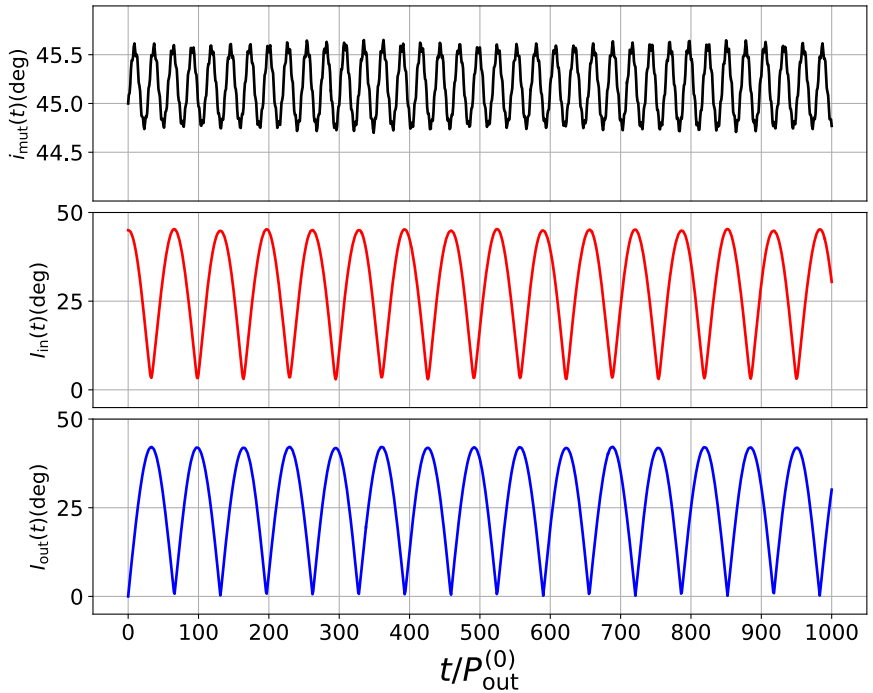
⇒ large-amplitude sporadic precession



$i_{\rm mut}(t)$

$I_{\rm in}(t)$

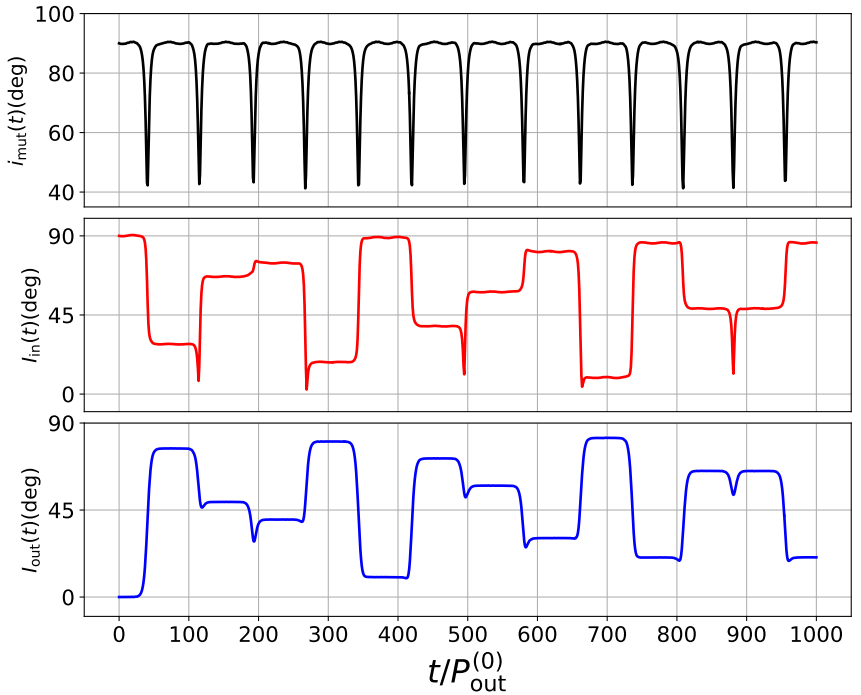
$I_{\rm out}(t)$



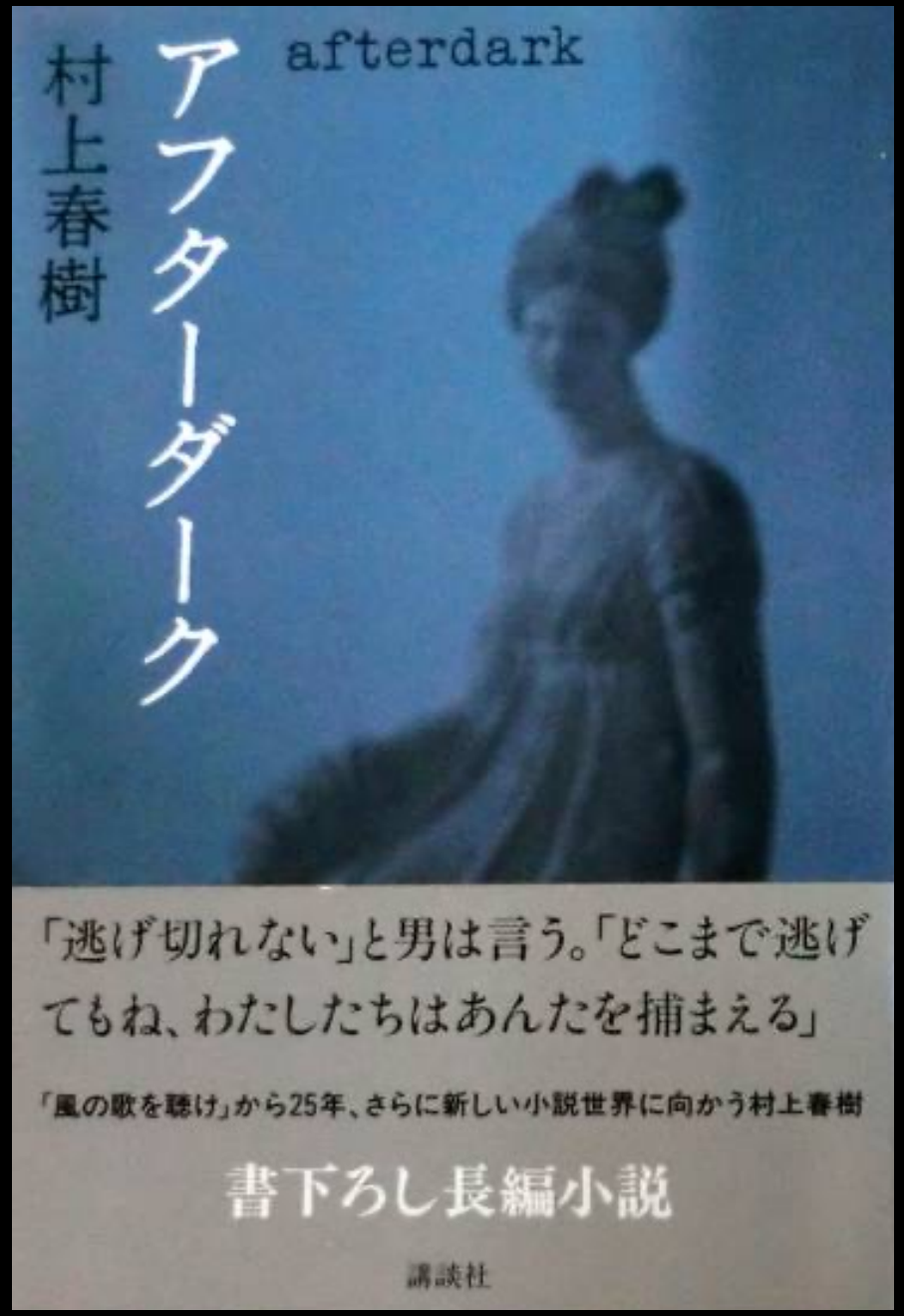
$i_{\rm mut}(t)$

$I_{\rm in}(t)$

$I_{\rm out}(t)$



4. Summary (?)



From After Dark to Beyond Dark

(Haruki Murakami "After Dark", English translation by Jay Rubin)

I once read a story about three brothers who washed up on an island in Hawaii

- Three brothers went out fishing and got caught in a storm. They drifted on the ocean for a long time until they washed up on the shore of an uninhabited island. It was a beautiful island with coconuts growing there and tons of fruit on the trees, and a big, high mountain in the middle.

The night they got there, a god appeared in their dreams and said

- A little farther down the shore, you will find three big, round boulders. I want each of you to push his boulder as far as he likes. The place you stop pushing your boulder is where you will live. The higher you go, the more of the world you will be able to see from your home. It's entirely up to you how far you want to push your boulder.

The youngest brother quit first. He said

- Brothers, this place is good enough for me. It’s close to the shore, and I can catch fish. It has everything I need to go on living. I don‘t mind if I can't see that much of the world from here.

His two elder brothers pressed on, but when they were midway up the mountain, the second brother quit. He said

- Brother, this place is good enough for me. There is plenty of fruit here. It has everything I need to go on living. I don't mind if I can’t see that much of the world from here.

The eldest brother continued walking up the mountain. There he stopped and surveyed the world. Now he could see more of the world than anyone

- This was the place he would live — where no grass grew, where no birds flew. For water, he could only lick the ice and frost. For food, he could only gnaw on moss. But he had no regrets, because now he could look out over the whole world.

Mari offers her opinion:
"To me, the lives chosen by the two younger brothers make the most sense."

- "True," he concedes. "Nobody wants to go all the way to Hawaii to stay alive licking frost and eating moss. That's for sure. But the eldest brother was curious to see as much of the world as possible, and he couldn't suppress that curiosity, no matter how big the price was he had to pay"
- ***"Intellectual curiosity."***
- "Exactly."

English translation by Jay Rubin

Intellectual curiosity

- "True," he concedes. "***Nobody wants to go all the way to Hawaii to stay alive licking frost and eating moss.*** That's for sure. But the eldest brother was curious to see as much of the world as possible, and he couldn't suppress that curiosity, no matter how big the price was he had to pay"

Nobody wants to go all the way to Hawaii to stay alive licking frost and eating moss.

Nobody

Indeed, we are *the Nobody* (≠ *Nbody*)

Three big "Boulders"
@summit of Mauna Kea, Hawaii

Subaru telescope

Youngest brother @sea shore, Hilo, Hawaii

Second Brother @2800m above sea level

Eldest brother @4200m above sea level

But he saw more of the world...

Lesson learned: science is endless exploration of unknowns beyond the current horizon

My conclusion : The value of N does not matter!

@Aki City
Kochi Prefecture
Japan

Thank you very much for coming all the way to this intellectual and curious symposium

N=17

N=8 (not 9)