

筑波大宇宙理論で育まれた私の BH形成、星形成、惑星形成研究

釣部 通 (茨城大学)

2014年9月27日 筑波大学理論宇宙研究室発足20周年式典

研究室発足20周年、おめでとうございます。

経歴

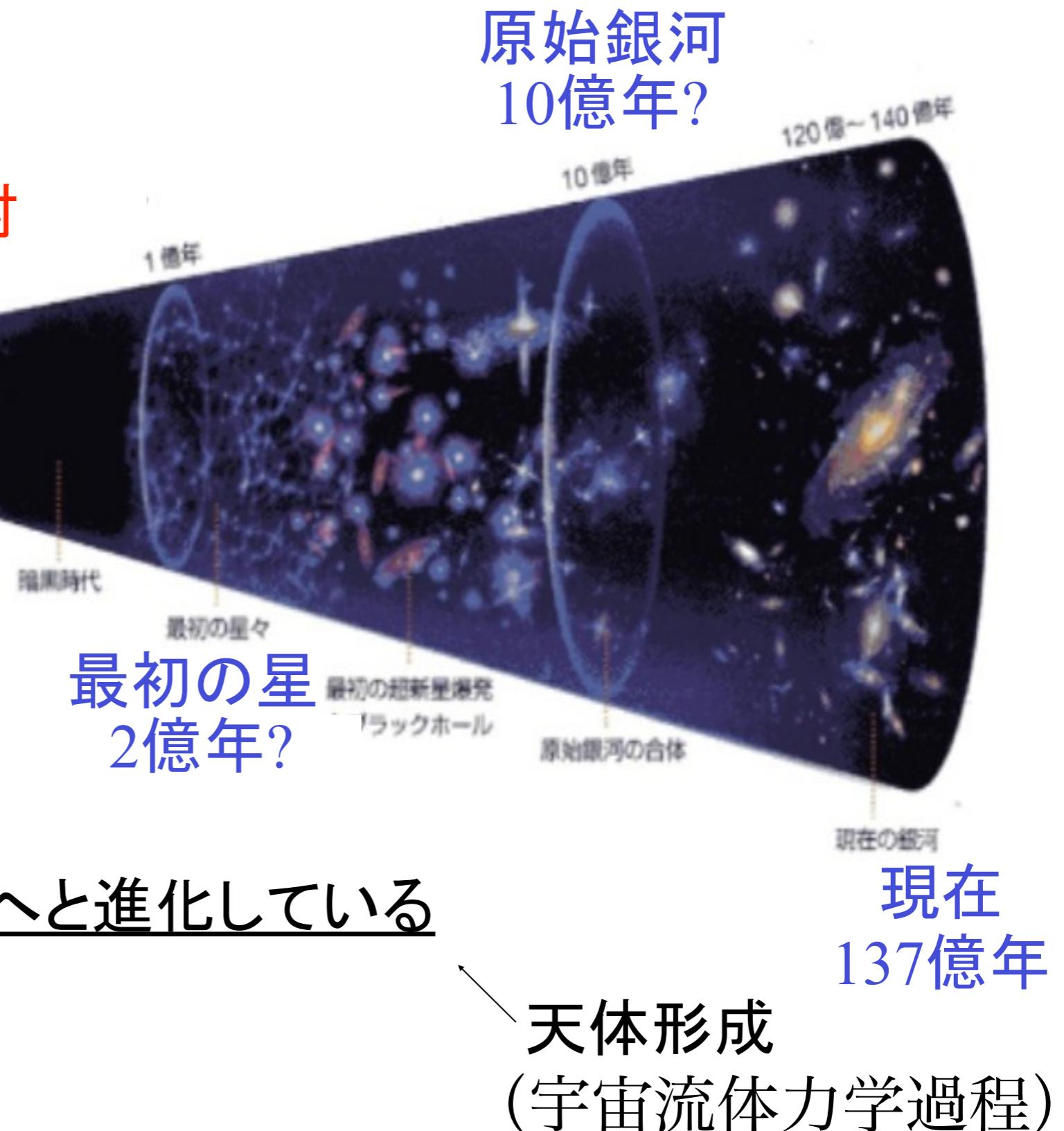
- 1993 国立天文台理論部 (東京大院 天文学専攻)
- 1994-98 筑波大 (委託)
 - 94 物理学系
 - 95- 計算物理学研究センター(RCCP) (新築)
 - 合宿 : 房総、草津, 海外研修 : Princeton
 - 院生 : 萩原、田尻、大越智、大須賀、PD : 中村、須佐
- 1998- 京大物理 天体核研究室 学振PD
- 2000 Yale大 PD (Zepf, Coppi, Larson)
- 2001 大阪大 宇宙進化グループ助教
- 2014 茨城大 理学部 准教授

Introduction

宇宙の進化

宇宙背景放射
38万年

ビッグバン



宇宙は年齢とともに、
単純→複雑、多様な系へと進化している

私のこれまでの研究内容

- 惑星の形成に関する研究
- 原始惑星系円盤など降着円盤に関する研究
- 星間ガス雲の流体力学（衝撃波、乱流、熱不安定性、重力不安定性）の研究
- 宇宙が誕生してから最初に生まれる天体の形成過程の研究
- 星間雲から星が誕生する過程の研究
- ブラックホールに降着する流れの研究

ブラックホール形成

- 筑波大在籍時DC前半まで取り組んでいました
- 宇宙背景放射による輻射抵抗
- TT, Fukue, Umemura (1994)
- TT, Umemura, Fukue (1995)
- TT & Umemura (1997)
- Mineshige, TT, & Umemura (1998)

EARLY COSMIC FORMATION OF MASSIVE BLACK HOLES

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Institute for Advanced Study, Princeton, NJ 08540

AND

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Received 1993 March 9; accepted 1993 June 28

ABSTRACT

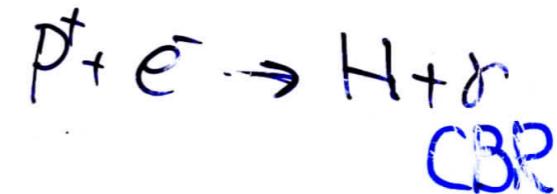
The evolution of nonlinear density fluctuations around the Jeans mass shortly after cosmological recombination is analyzed using a three-dimensional hydrodynamics/dark-matter code. The cosmic background radiation (CBR) exerts Compton friction on free electrons in resistance to their peculiar velocities. The baryonic dynamics therefore depends strongly on the gas ionization history. For a variety of scenarios for the local reionization and in systems with or without non-baryonic components, the baryons lose angular momentum efficiently and collapse to form a compact optically thick object which would probably quickly evolve into a massive black hole. Attention is concentrated on elucidating some of the novel physical effects in early cosmological collapses, but ways in which more realistic calculations might be made and in which the scenario could be incorporated into a more complete cosmogonic model are discussed.

Subject headings: black hole physics — cosmology: theory — early universe — galaxies: formation

当時のOHPより

Introduction

$Z \approx 1000$ Recombination



$Z \gtrsim 5, 10, \dots$ QSO BH Formation

$Z = 0$



現在

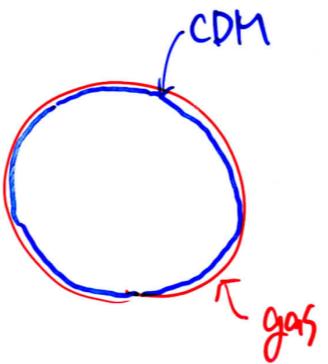


AGN

$$1 > a \equiv t/t_f$$

$z \sim 1000$

Cosmic Expansion



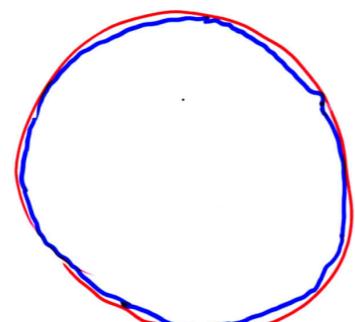
$$\frac{\delta}{\rho} \sim 2$$

$M \approx M_J$

→ Ang. Momentum (tidal)

$z \sim 700 = z_{\max}$

Spherical Collapse



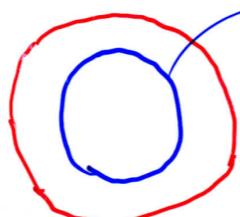
$$R \approx R_{\max}$$

Maximum Expansion.

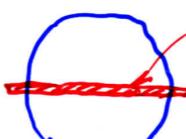
$z \sim 400$

Virialized Halo

$$R_{\text{vir}} = \frac{1}{2} R_{\max}$$



Disk Accretion!



Self Gravitating Disk

- Star Formation
- Ionization

$z \approx 5, 10$



BH Formation

+ Mass Supply

↑ QSO ? AGN?

32. 角運動量損失 \rightarrow Seed BH 形成!

Ang. Mom Problem:

$$J_b \approx R_{\max} V_\phi \approx R_{\max} \Omega r \\ = (2GM_1 R_{\max})^{1/2} \lambda$$

$$R_{\max} = \left(\frac{4\pi G M_b}{3\pi c R_b} \right)^{1/3} (1+z)^{-1}$$

$$\rightarrow R_{\text{rot}} = 3.9 \text{ pc} \left(\frac{M_b}{10^6 M_\odot} \right)^{1/3} \left(\frac{R_b}{0.05} \right)^{-1/3} \left(\frac{\Omega}{0.05} \right)^{2/3} \left(\frac{h}{0.5} \right)^{1/3} \left(\frac{r_{\text{vir}}}{600} \right)$$

Cosmological Collapse

$$R_{\text{rot}} = 10^4 R_s$$

角運動量の抜き取りが速い!

($\lambda \approx 2\pi \text{ T}^{1/3}$)

This work:

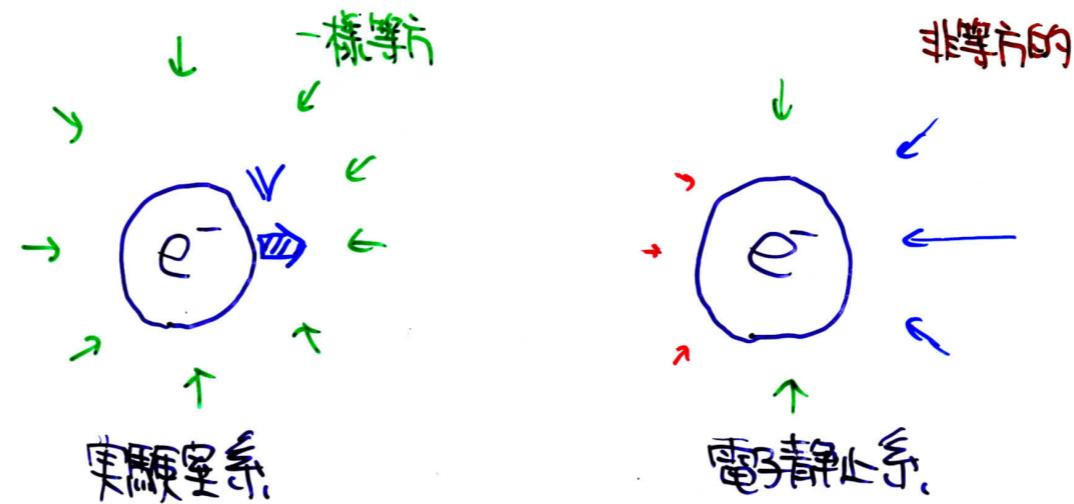
CBRによる radiation drag が 角運動量輸送に
与える影響を考察する

② What is radiation drag?

• 一樣等方輻射場

$$E_{\text{rad}} = 3 \times 10^0 \left(\frac{1+z}{400}\right)^4 a(2.735)^4$$

• Ionized Gas.



$$\frac{dv}{dt} = -\nabla \Phi - \frac{1}{\rho} \nabla P$$

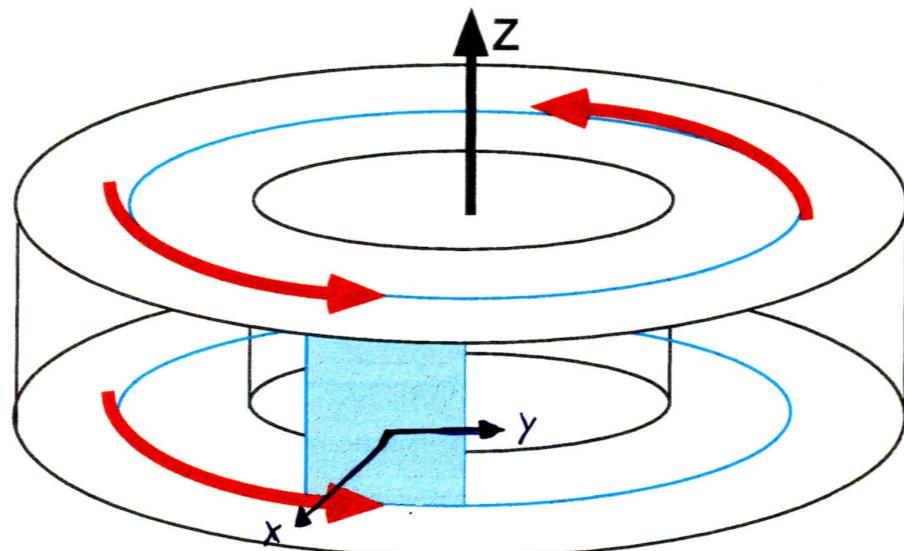
$$\underline{-\beta(z)[v - H(z)r]}$$

Radiation Drag Force

$$\beta(z) = \frac{4}{3} \frac{\sigma \chi_e a T_{\infty}^4}{\mu \text{mpc}} (1+z)^4$$

角運動量 : gas \Rightarrow 輻射場

Numerical Model



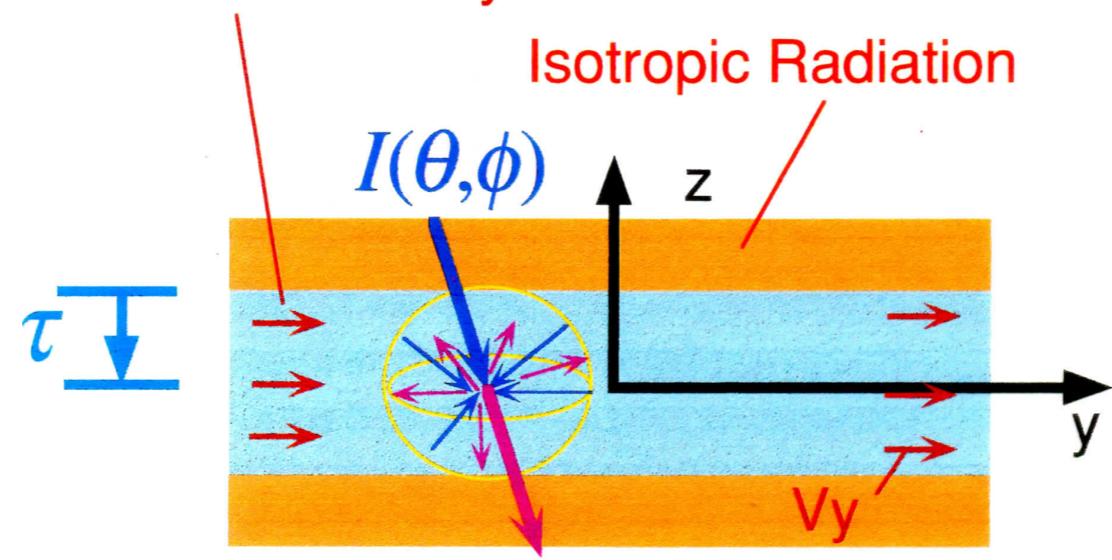
geometrically thin

Slab Geometry

$V_{\text{diff}} \gg V_{\text{flow}}$

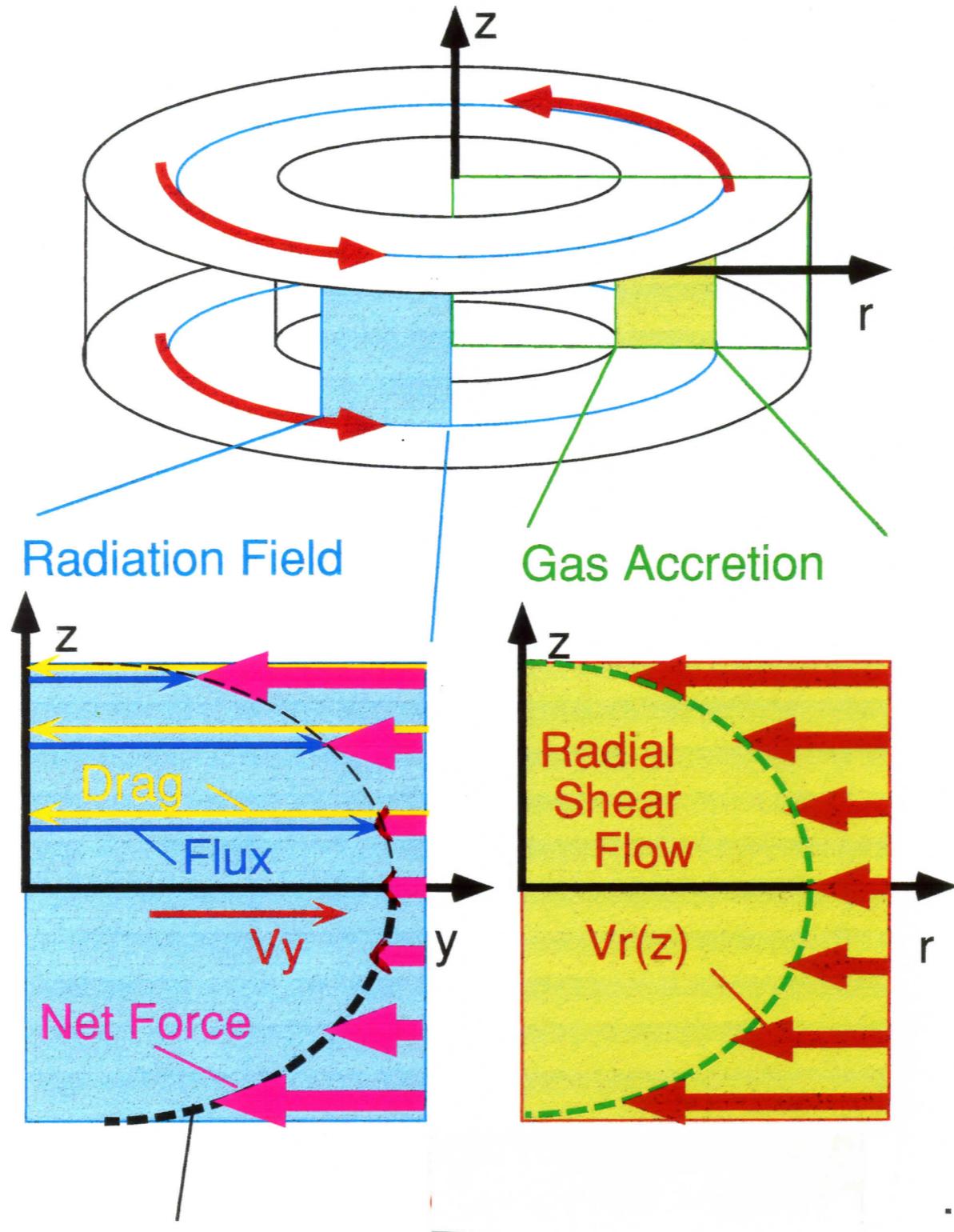
Steady state

Constant Velocity Field



$$I_x(x, z, \phi) \\ F_y - \frac{v_y}{c} (E + P_{yy})$$

Numerical Results

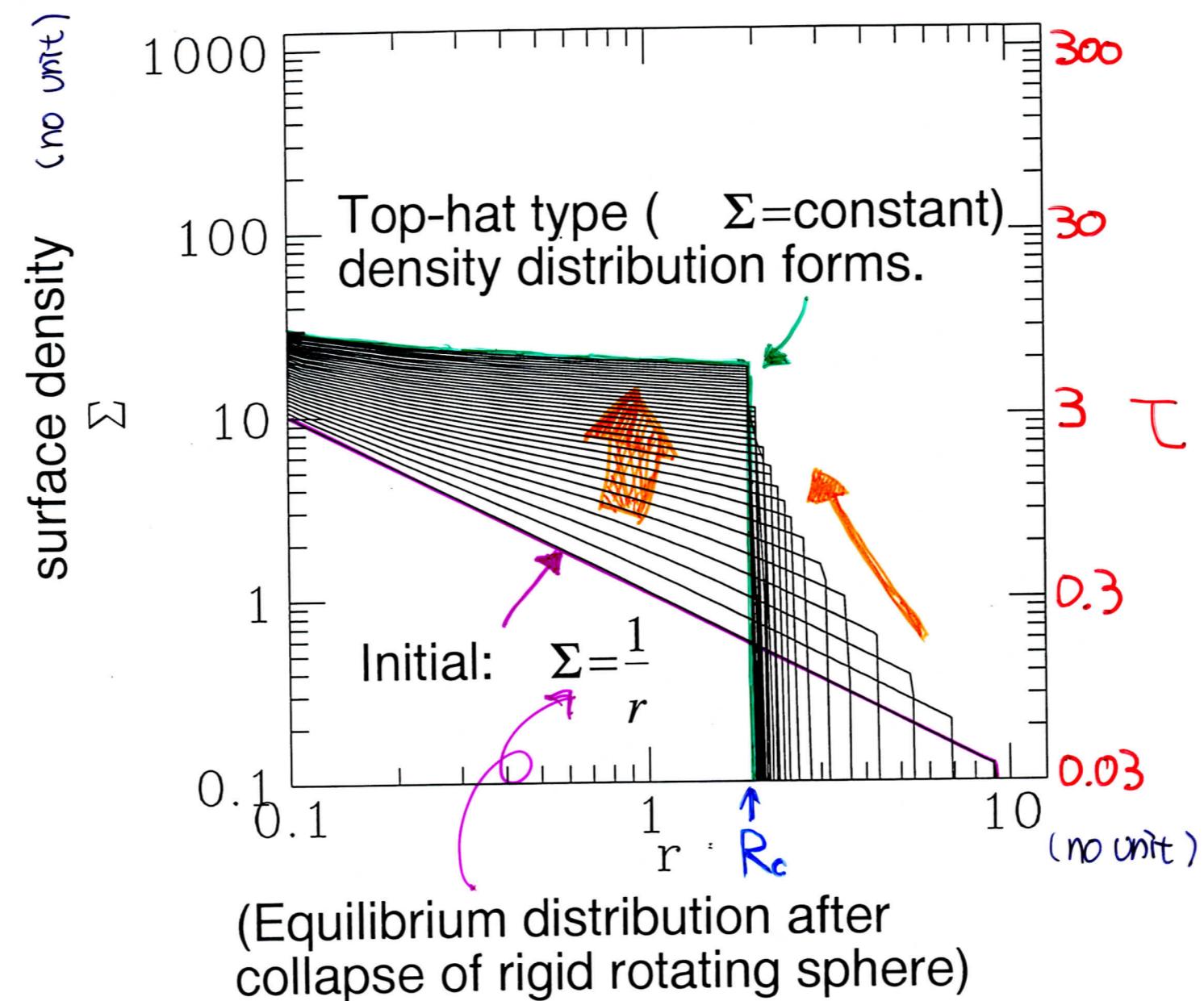


Net Force decreases
exponentially with optical depth
independent of the flow velocity.

↑ $\frac{\text{Flux}}{v}$ does not depend on v .

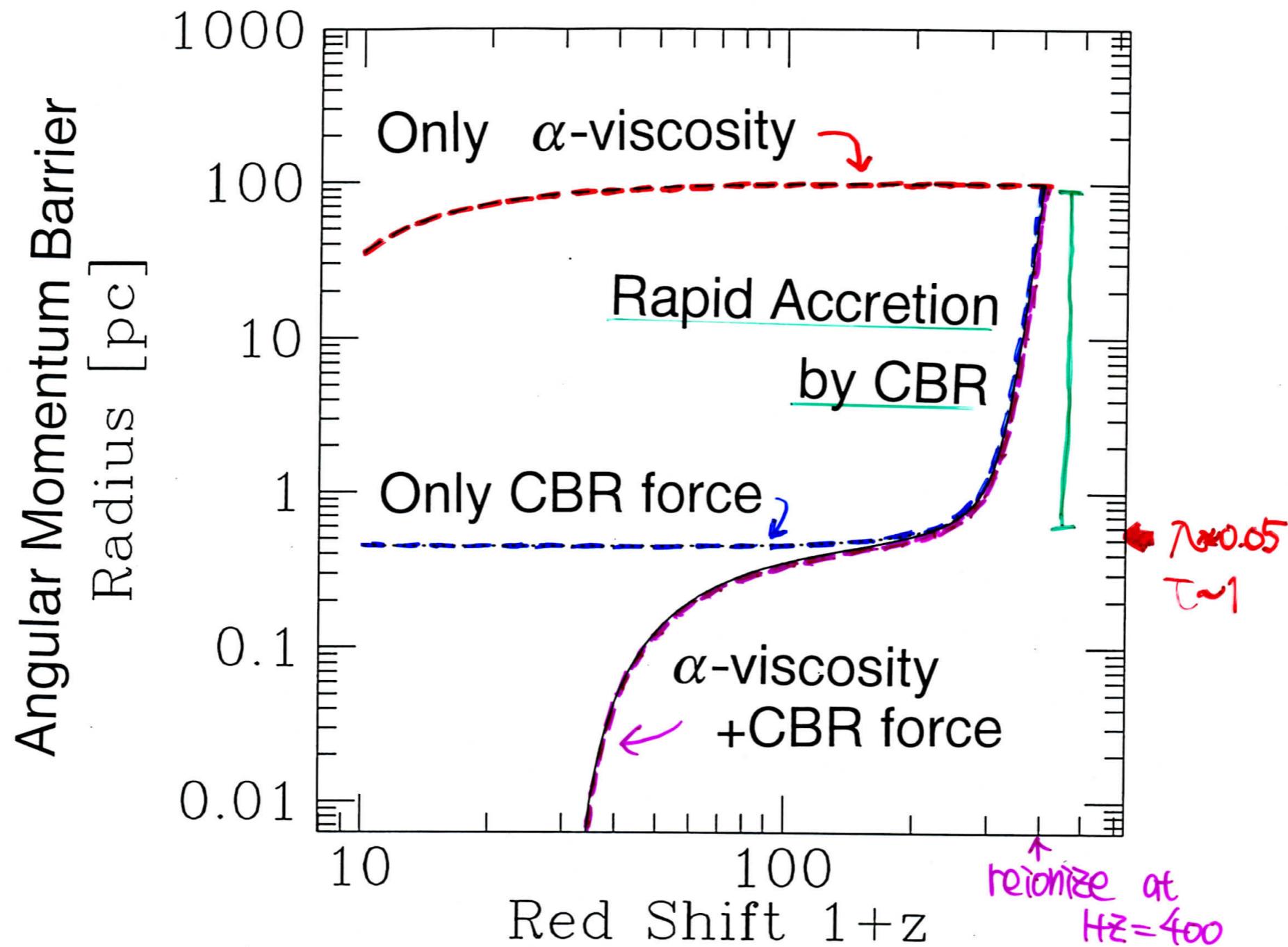
Hydrodynamical Calculation of the disk evolution.

Geometrically thin
axis-symmetric 1D
cold case



★ Accretion stops at critical radius.
at R_c

輻射抵抗と円盤の粘性による円盤の進化



この後、自己重力粘性円盤の進化の研究に進みました
(TT1999->星惑星系形成)

星・惑星の形成

- 自己重力円盤の進化を理解したくてDCの後半以降取り組みました

FORMATION, EARLY EVOLUTION, AND GRAVITATIONAL STABILITY OF PROTOPLANETARY DISKS

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Theoretical Astrophysics Division, National Astronomical Observatory, Mitaka, Tokyo 181, Japan

AND

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Department of Earth and Planetary Physics, Faculty of Science, University of Tokyo, Tokyo 113, Japan;² and
Institute for Theoretical Physics, University of California at Santa Barbara, Santa Barbara, CA 93106-4030

Received 1993 June 17; accepted 1993 August 12

ABSTRACT

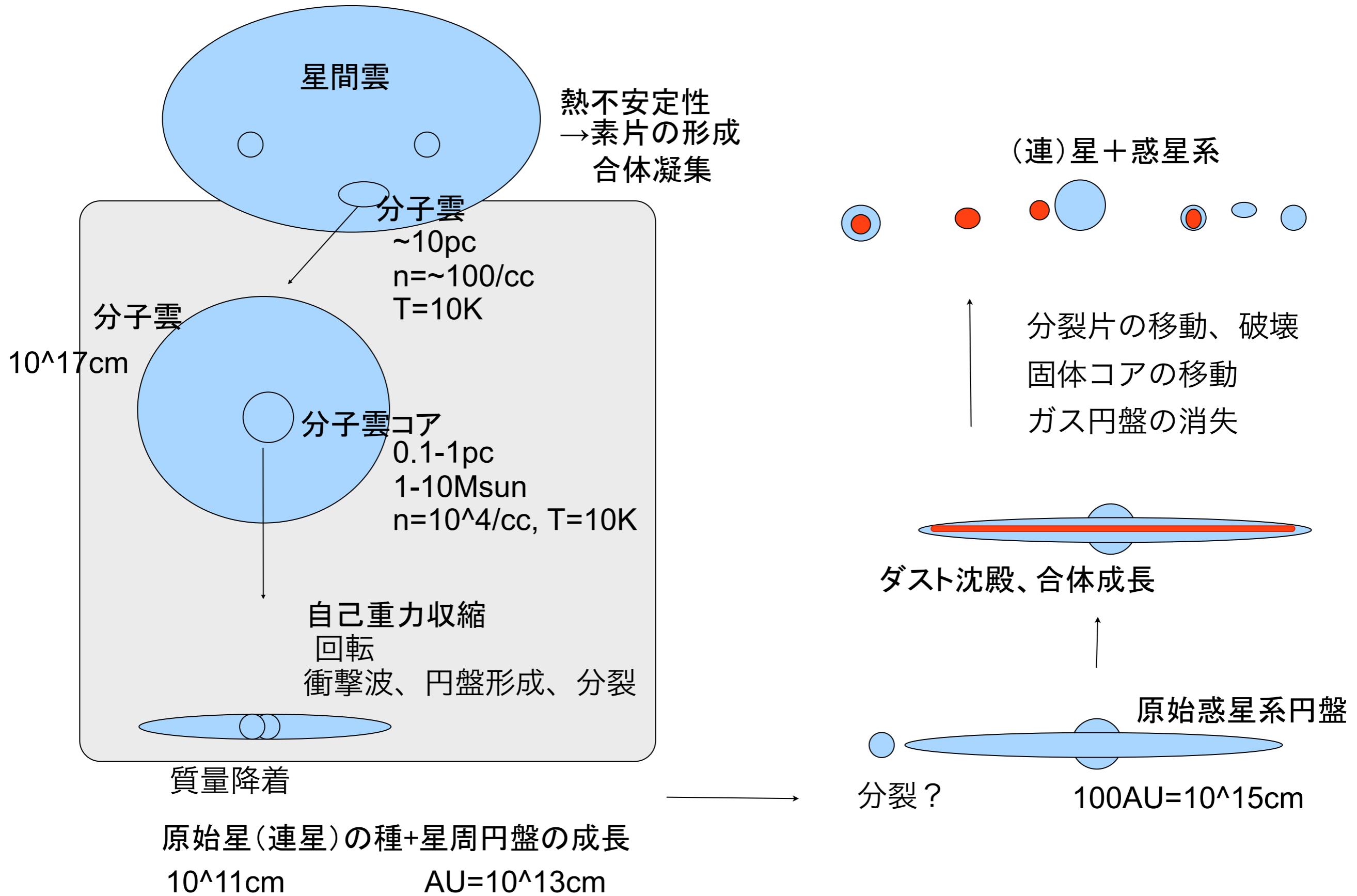
The formation, viscous evolution, and gravitational stability of protoplanetary disks are investigated. The formation process is parameterized by the angular velocity of the molecular cloud core ω , while the viscous evolution is parameterized by the viscosity parameter α in the disk; in this study we consider a range of $(0.4\text{--}6) \times 10^{-14} \text{ s}^{-1}$ for ω and from 10^{-5} to 10^{-1} for α . The axisymmetric gravitational stabilities of the disks are checked using Toomre's criterion.

The resulting disk surface temperature distribution, $(d \log T_s / d \log R) \simeq -0.6$ (R is the cylindrical radius), can be attributed to two heating sources: the viscous heating dominant in the inner disk region, and the accretion shock heating dominant in the outer disk region. This surface temperature distribution matches that observed in many disks around young stellar objects.

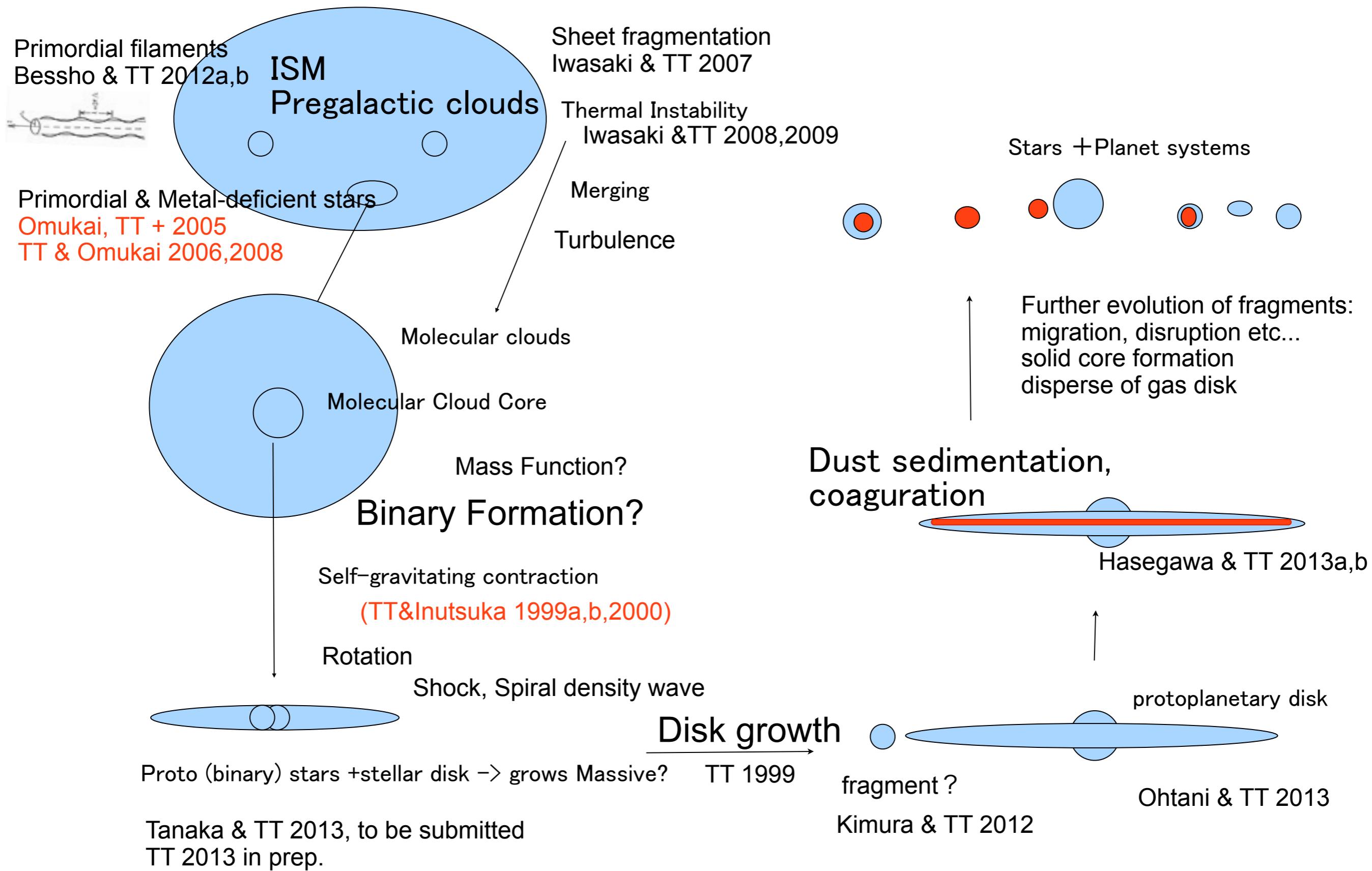
During the infall stage, disks with $\alpha < 10^{-1.5}$ become gravitationally unstable independent of ω . The gravitational instabilities occur at radii ranging from 5 to 40 AU. The ratio of the disk mass to the central star mass ranges from 0.2 to 0.5 at the times of instability, about $4 \times 10^5 \times (\omega/10^{-14} \text{ s}^{-1})^{-0.67}$ yr. Most disks with low α and high ω become gravitationally unstable during their formation phase.

Subject headings: accretion, accretion disks — hydrodynamics — planetary systems — stars: formation

星間雲から星・惑星系への物理過程



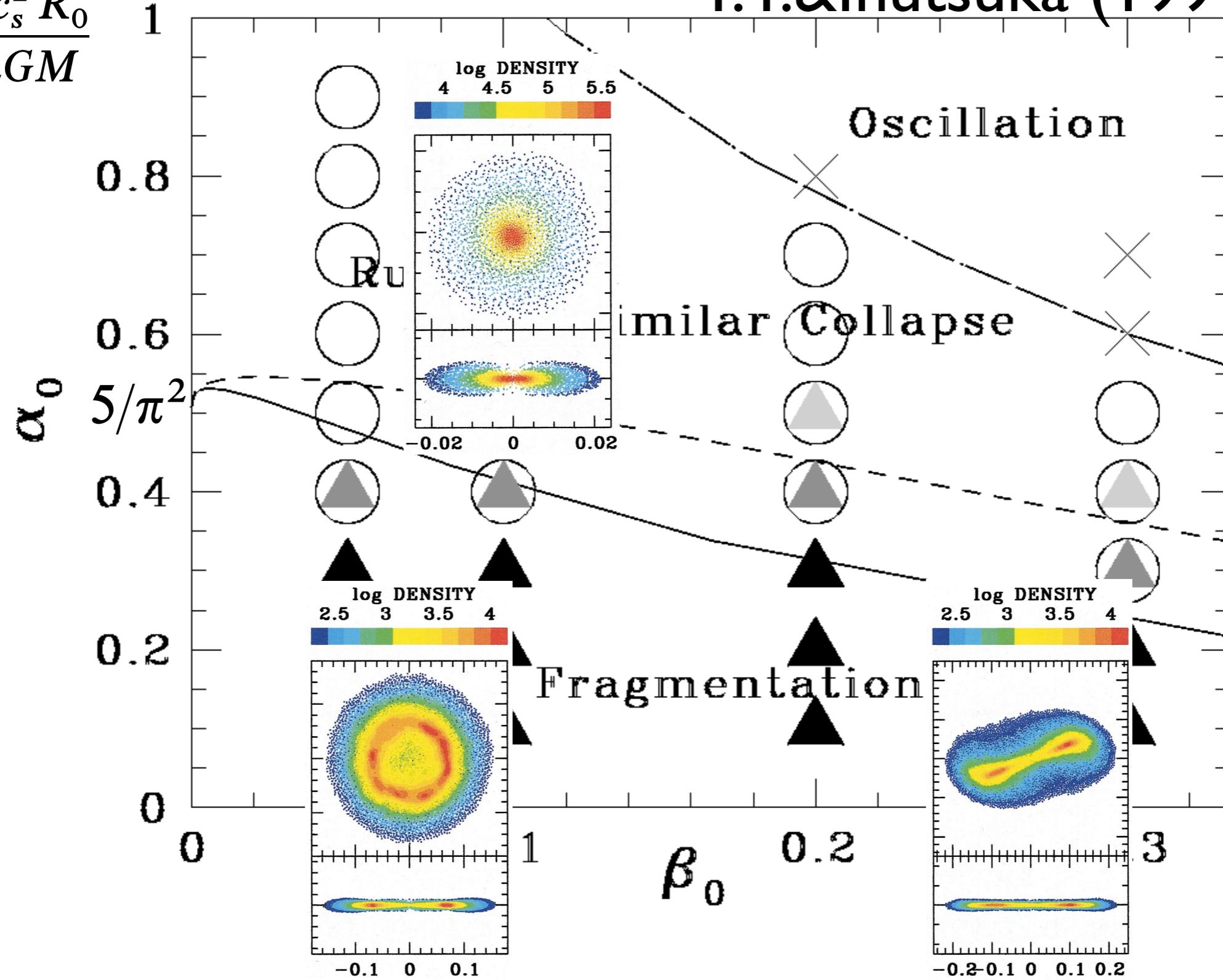
研究成果のまとめ（星・惑星形成関連）



回転収縮雲の分裂条件

T.T.&Inutsuka (1999a,b,2000)

$$\alpha_0 = \frac{5c_s^2 R_0}{2GM}$$

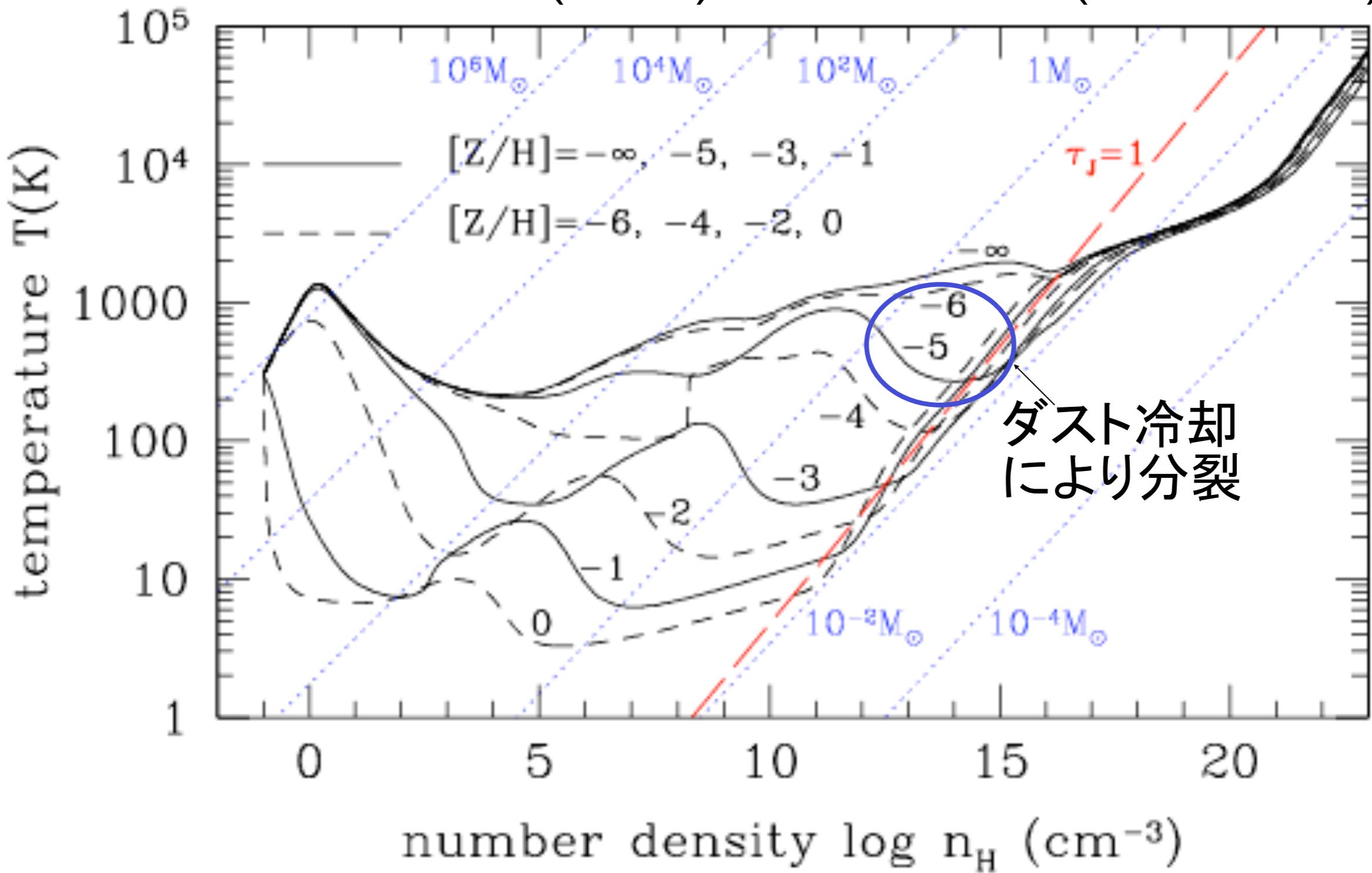


等温

$$\beta_0 = \frac{\Omega_0^2 R_0^3}{3GM}$$

微量重元素雲の分裂

Omukai, TT+ (2005), TT&Omukai (2006, 2008)



近年の研究：

連星や惑星の形成へ

星ができたときに副産物としてできる星周円盤から
連星や惑星が生まれる過程を研究しています。

ガス円盤は、どれくらいの質量になるか？(Ohtani&TT2013)

ガス円盤は、自己重力的に分裂するか？(Kimura&TT 2012)

分裂片はどれくらいまで成長するか？(Tanaka&TT in prep.)

ガス円盤の中でダストは沈殿して微惑星を作るか？

(Hasegawa&TT 2013,2014)

など

まとめ

- ・ 筑波大で取り組んだBH形成における輻射抵抗研究から私の研究はスタートしました。
- ・ それが、自己重力円盤、等温ガス雲、微量重元素ガス雲の収縮と分裂の過程、連星、惑星の形成の研究につながりました。
- ・ 現在の研究教育の土台となっているのが筑波時代に受けた恩恵であり、大変ありがとうございます。
- ・ 今後も研究室がますます発展されることを願います。