A03 group updates

Investigation of Primordial Black Holes and Macroscopic Dark Matter（原始ブラックホール・巨視的ダークマターの探求）

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Primordial Black Hole

◎Remnants of primordial non-linear inhomogeneity

◎BHs not produced by late time stellar collapse

◎Reliable formation scenario:

collapse of rarely dense regions generated by quantum fluctuation during inflation

It's rare, but has a finite probability!!

◎If you accept inflation, you should be able to accept the **PBH formation**

◎**PBH** is a plausible and appealing **DM** candidate

- ➢ BHs "exist" in our universe
- ➢ BHs behave as **DM** in a cosmological scale
- ➢ Reliable scenario of **PBH** formation

How many PBHs in our universe?

◎They could provide a substantial part of DM

◎How large fraction of DM PBHs can account for?

To answer this, we need

- ➢ precise theoretical estimation of abundance
- ➢ realistic and attractive models
- ➢ tests through observational constraints

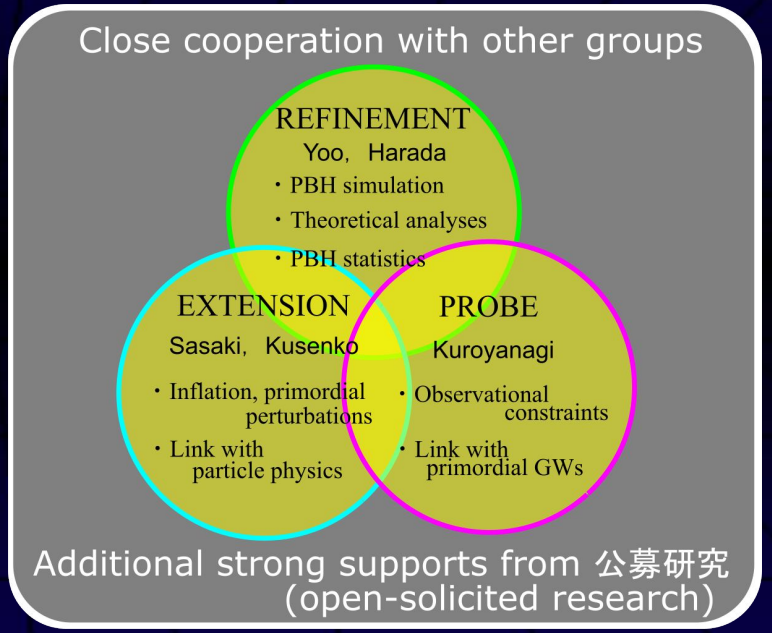
◎What are distinct characters of PBH DM?

For the prediction, we need

- ➢ deeper understanding of formation process
- ➢ finding model dependent features
- ➢ proposal of specific observables to probe it

◎Possible other macroscopic DM?

- ➢ Exotic stars (gravastar, soliton star, Q-balls...)



Activities of A03 in the fiscal year 2023

- Regular meetings (https://sites.google.com/view/pbhmacrodm/)
  - 5th meeting 2022/06/09 online — 10 mins short talks by Sasaki-san, Kusenko-san, Koga-san
  - 6th meeting 2022/08/09 in-person — Brainstorming, 12 participants
  - 7th meeting 2022/11/21 in-person — Brainstorming, with C01, about 20 participants
- Workshop: Dynamics of primordial black hole formation (3/9,10)

- 2302.14080 *Primordial-tensor-induced stochastic gravitational waves*
  Mohammad Ali Gorji, **Misao Sasaki**
- 2303.05178 *New shape of parity-violating graviton non-Gaussianity*
  Jinn-Ouk Gong, Maria Mylova, **Misao Sasaki**
- 2303.07661 *Gravitational wave hints black hole remnants as dark matte*
  Guillem Domènech, **Misao Sasaki**
- 2304.13053 *Halo Formation from Yukawa Forces in the Very Early Universe*
  Guillem Domènech, Derek Inman, **Alexander Kusenko**, **Misao Sasaki**
- 2304.02267 *Hairy black holes in AdS with Robin boundary conditions*
  Tomohiro Harada, Takaaki Ishii, Takuya Katagiri, Norihiro Tanahashi
- 2304.06350 *Stochastic gravitational wave background constraints from Gaia DR3 astrometry*
  Santiago Jaraba, Juan García-Bellido, **Sachiko Kuroyanagi**, Sarah Ferraiuolo, Matteo Braglia
- 2304.13284 *Revisiting compaction functions for primordial black hole formatio*
  Tomohiro Harada, **Chul-Moon Yoo**, **Yasutaka Koga**
- 2305.12812 *Non-Linearity-Free prediction of the growth-rate $f\sigma_8$ using Convolutional Neural Networks*
  Koya Murakami, Indira Ocampo, Savvas Nesseris, Atsushi J. Nishizawa, **Sachiko Kuroyanagi**

Activities of A03 in the fiscal year 2023

- 2305.13429 *Constraints on late-forming exploding black holes*
  Zachary S.C. Picker, **Alexander Kusenko**
- 2305.13434 *Explaining the GeV excess with exploding black holes*
  Zachary S.C. Picker, **Alexander Kusenko**
- 2305.13830 *Spins of primordial black holes formed with a soft equation of state*
  Daiki Saito, **Tomohiro Harada**, **Yasutaka Koga**, **Chul-Moon Yoo**
- 2305.18140 *Highly asymmetric probability distribution from a finite-width upward step during inflation*
  Ryodai Kawaguchi, Tomohiro Fujita, **Misao Sasaki**
- 2306.04056 *Defrosting and Blast Freezing Dark Matter*
  Marcos M. Flores, Chris Kouvaris, **Alexander Kusenko**
- 2307.00915 *The effects of orbital precession on hyperbolic encounters*
  Marienza Caldarola, **Sachiko Kuroyanagi**, Savvas Nesseris, Juan Garcia-Bellido
- 2307.13109 *Extra-tensor-induced origin for the PTA signal: No primordial black hole production*
  Mohammad Ali Gorji, **Misao Sasaki**, Teruaki Suyama
- 2308.05904 *Log-periodic gravitational-wave background beyond Einstein gravity*
  Gianluca Calcagni, **Sachiko Kuroyanagi**
- 2308.08623 *G objects and primordial black holes*
  Marcos M. Flores, **Alexander Kusenko**, Andrea M. Ghez, Smadar Naoz
- 2308.09094 *Structure formation after reheating: Supermassive primordial black holes and Fermi ball dark matter*
  Marcos M. Flores, Yifan Lu, **Alexander Kusenko**
- 2309.14193 *Universal gravitational waves from interacting and clustered solitons*
  Kaloian D. Lozanov, **Misao Sasaki**, Volodymyr Takhistov
- 2309.15510 *Gravitational Waves in the Circular Restricted Three Body Problem*
  Mikel Martin, **Sachiko Kuroyanagi**, Savvas Nesseris

Activities of A03 in the fiscal year 2023

- 2310.07439 *Next-to-leading order corrections to gravitational wave emission from close hyperbolic encounters*
  Alex Roskill, Marienza Caldarola, **Sachiko Kuroyanagi**, Savvas Nesseris
- 2310.16482 *Primordial Black Hole formation from overlapping cosmological fluctuations*
  Albert Escrivà, **Chul-Moon Yoo**
- 2310.19317 *Turbulence on open string worldsheets under non-integrable boundary conditions*
  Takaaki Ishii, Ryo Kitaku, Keiju Murata, **Chul-Moon Yoo**
- 2310.19857 *Primordial black holes and their gravitational-wave signatures*
  LISA Cosmology Working Group • Eleni Bagui et al. (**Sachiko Kuroyanagi**)
- 2311.05423 *Constraints on Non-Gaussian primordial curvature perturbation from the LIGO-Virgo-KAGRA third observing run*
  Ryoto Inui, Santiago Jaraba, **Sachiko Kuroyanagi**, Shuichiro Yokoyama
- 2311.17760 *Primordial Black Holes and induced gravitational waves from a smooth crossover beyond Standard Mode*
  Albert Escrivà, Yuichiro Tada, **Chul-Moon Yoo**
- 2312.07058 *Axion Cloud Decay due to the Axion-photon Conversion with Multi-pole Background Magnetic Fields*
  Yusuke Sakurai, **Chul-Moon Yoo**, Atsushi Naruko, Daisuke Yamauchi
- 2312.15062 *Feeding plankton to whales: high-redshift supermassive black holes from tiny black hole explosions*
  Yifan Lu, Zachary S.C. Picker, **Alexander Kusenko**
- 2401.02314 *Applying the Viterbi Algorithm to Planetary-Mass Black Hole Searches*
  George Alestas, Gonzalo Morras, Takahiro S. Yamamoto, Juan Garcia-Bellido, **Sachiko Kuroyanagi** et al.
- 2401.06329 *Numerical simulation of type II primordial black hole formation*
  Koichiro Uehara, **Albert Escrivà**, **Tomohiro Harada**, Daiki Saito, **Chul-Moon Yoo**
- 2402.13341 *Revisiting formation of primordial black holes in a supercooled first-order phase transition*
  Marcos M. Flores, **Alexander Kusenko**, **Misao Sasaki**

A03 talks in this symposium

7th Mar. 16:45 - 17:10 **Sachiko Kuroyanagi**

Primordial Black Hole and stochastic gravitational wave background

8th Mar. 09:10 - 09:25 **Koichiro Uehara**

2401.06329 *Numerical simulation of type II primordial black hole formation*

Koichiro Uehara, Albert Escrivà, **Tomohiro Harada**, Daiki Saito, **Chul-Moon Yoo**

8th Mar. 09:25 - 09:40 **Yasutaka Koga**

2305.13830 *Spins of primordial black holes formed with a soft equation of state*

Daiki Saito, **Tomohiro Harada**, **Yasutaka Koga**, **Chul-Moon Yoo**

8th Mar. 09:40 - 09:55 **Albert Escrivà**

2311.17760 *Primordial Black Holes and induced gravitational waves from a smooth crossover beyond Standard Model*

Albert Escrivà, Yuichiro Tada, **Chul-Moon Yoo**

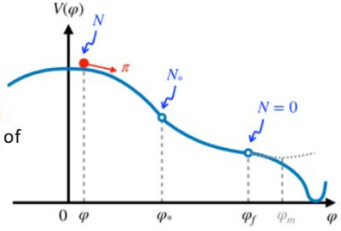
Activity in Kavli IPMU

Logarithmic Duality of the Curvature Perturbation

S. Pi and M. Sasaki, PRL 131 (2023), 011002

General expressions for the curvature perturbation R for models with potential approximated by a piecewise quadratic potential V(ϕ) are derived. We find a general formula for R(δϕ,δπ), consisting of a sum of logarithmic functions of the field perturbation δϕ and the velocity perturbation δπ. Each logarithmic expression has an equivalent dual expression.

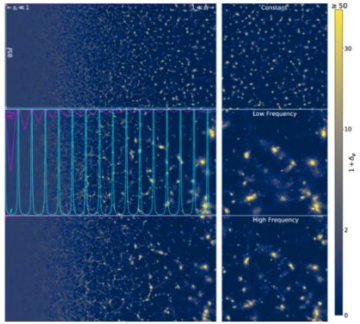
$$\mathcal{R} = \frac{1}{\lambda_\pm}\ln\left[1+\frac{\lambda_\mp\delta\varphi}{\pi+\lambda_\mp\varphi}\right] - \frac{1}{\lambda_\pm}\ln\left[1+\frac{\delta\pi_*}{\pi_*+\lambda_\mp\varphi_*}\right] + \frac{1}{\tilde{\lambda}_\pm}\ln\left[1+\frac{\delta\pi_*}{\pi_*+\tilde{\lambda}_\mp\tilde{\varphi}_*}\right].$$



Halo formation from Yukawa forces in the very early Universe

G. Domènech, D. Inman, A. Kusenko, and M. Sasaki

Phys. Rev. D 108 (2023), 103543



If long-range attractive forces exist, cosmic halo formation can begin in the radiation-dominated era. We study a simple realization of this effect in a system where dark matter fermions have Yukawa interactions mediated by scalar particles. We develop a precise modeling of the fermion density fluctuations, and perform N-body simulations. We find that halo formation occurs exponentially fast and on scales substantially larger than simple estimates predict.

The 20th Sakata-Hayakawa Memorial Lectureship

Feb 3, 2014

PBH formation from a nonspherical density profile with a misaligned deformation tensor

CY in prep.

Conclusion:
The dimensionless PBH spin s is typically so small that $s \ll 0.1$ for $w=p/\rho \gtrsim 1/5$

3+1 dimensional simulation of PBH formation

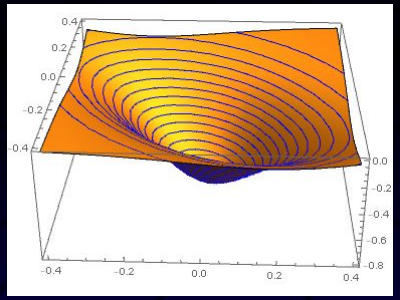
◎Initial curvature perturbation

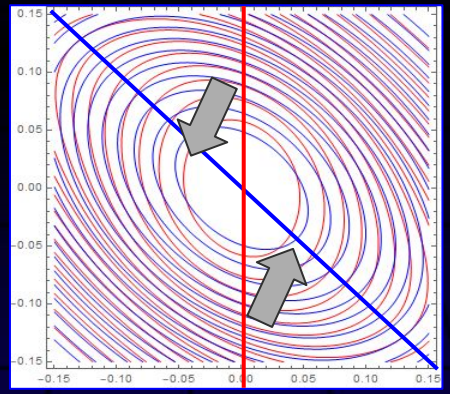
$$ds^2 \simeq -dt^2 + a(t)^2 e^{-2\zeta(x)} d\vec{x} \cdot d\vec{x}$$

$$\frac{\zeta}{\mu} \simeq -1 + \frac{1}{2}\left(k_1^2 (x+y)^2/2 + k_2^2 (x-y)^2/2 + k_3^2 z^2\right) + \mathcal{O}(r^4)$$

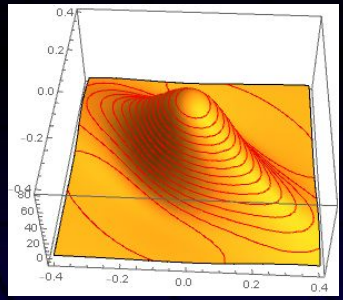
$$\frac{\triangle\zeta}{\mu k^2} \simeq 1 - \frac{1}{2}\left(\kappa_1^2 x^2 + \kappa_2^2 y^2 + \kappa_3^2 z^2\right) + \mathcal{O}(r^4)$$

ζ～gravitational potential on (x,y) plane





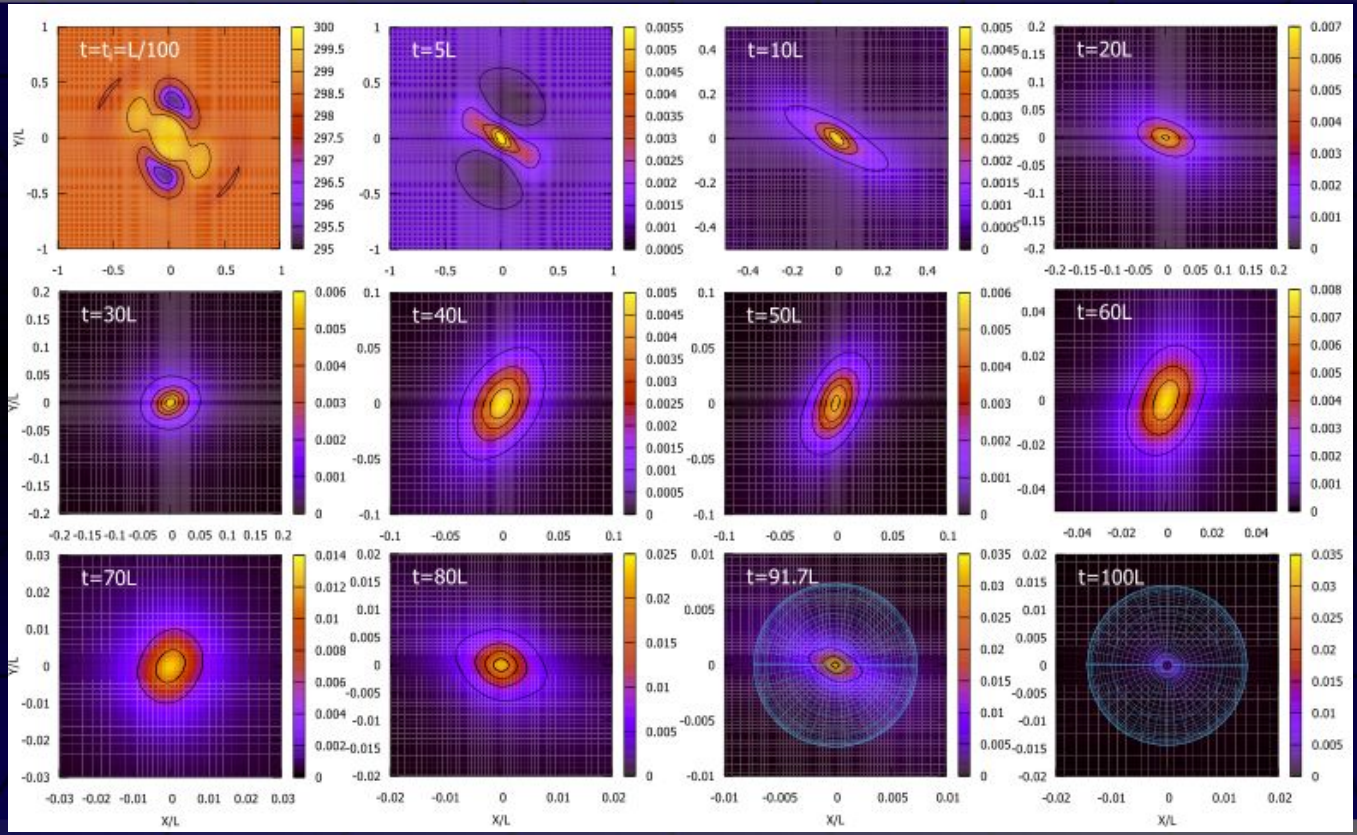
Δζ～energy density on (x,y) plane



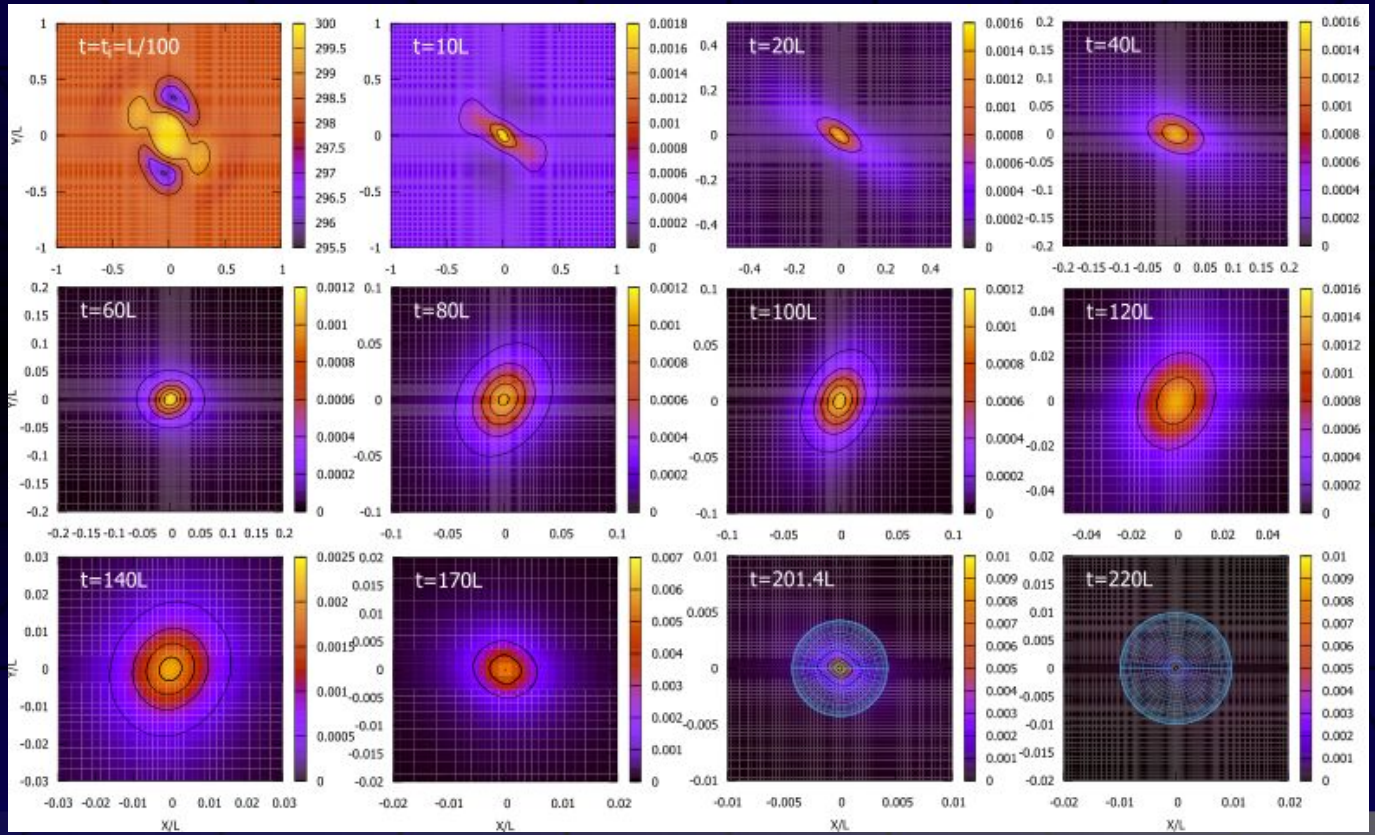
tidal torque ⇒ angular momentum transfer ⇒ spinning **PBH**

◎3+1 dimensional full GR numerical simulation with BSSN formalism

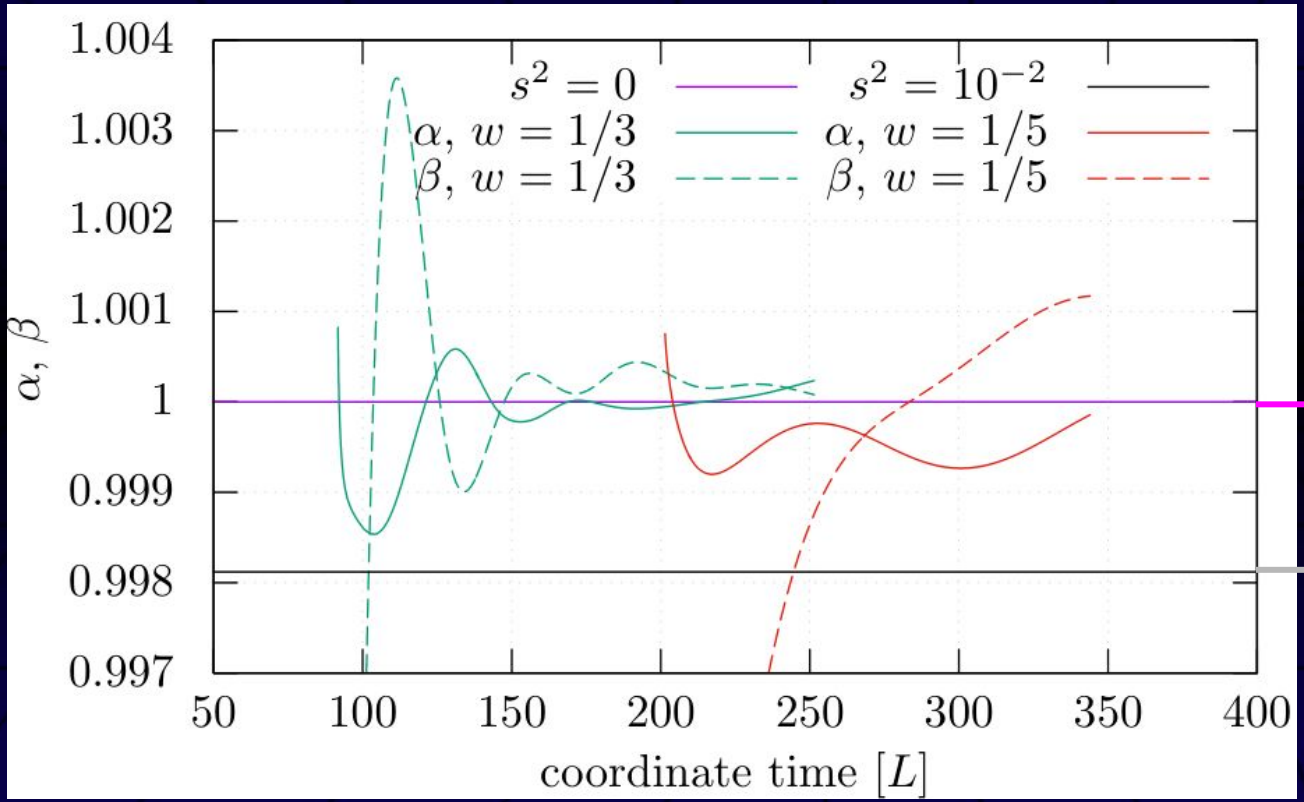
Snapshots for w=p/ρ=1/3



Snapshots for w=p/ρ=1/5



Shape of the horizon

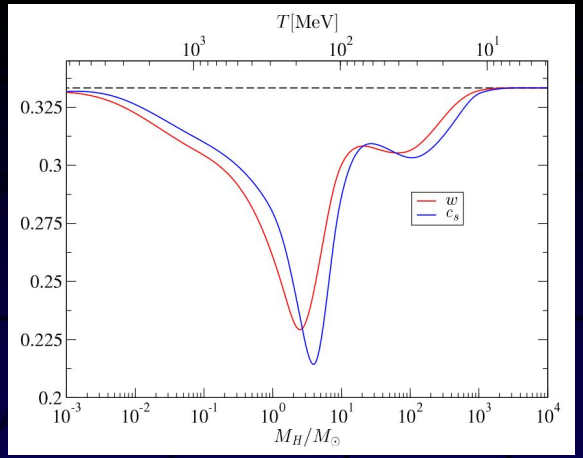


spherical

Kerr BH with a/M=0.1

PBH formation from a nonspherical density profile with a misaligned deformation tensor

CY in prep.



Conclusion:
The dimensionless PBH spin *s* is typically so small that *s* ≪0.1 for w=p/ρ≳1/5
⇒no significant spin-up from QCD cross-over

3 talks

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It's time to study Primordial Black Hole!

◎We aim to develop the **PBH** study further and clarify the possibility of **PBH DM**

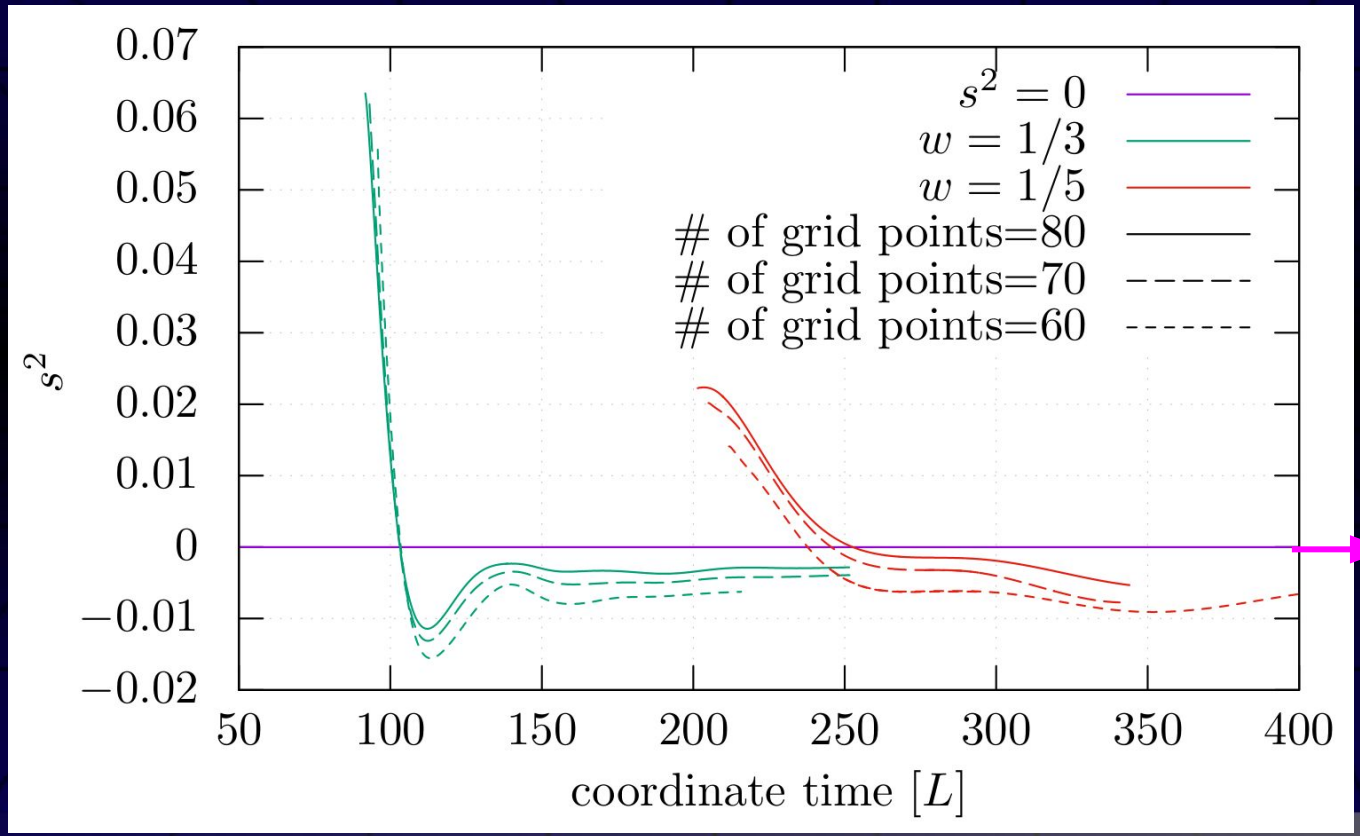
◎The field is broad and still many possibilities to extend and think of

◎Anybody is welcome to join us. Please contact me if you are interested in our activity.

Let's enjoy PBH research with us!
Thank you for your attention.

End

Effective spin of the horizon



spherical

Time evolution of the area of the horizon