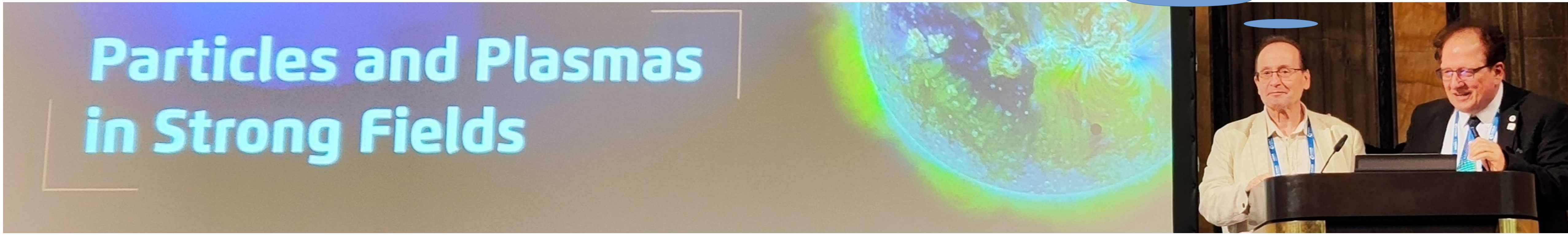
Can rotation solve the Hubble puzzle?



G.G. Barnaföldi, I. Szapudi, I.F. Barna, B. Szigeti

Support: *Hungarian NKFIH 2019-2.1.11-TET-2019-00078, 2019-2.1.11-TET-2019-00050, NEMZ_KI-2022-00033, Wigner Scientific Computing Laboratory, CASUS*

Refs.: *Mathematics 10 (2022) 18, 3220, Universe 9 (2023) 431,*

Mon.Not.Roy.Astron.Soc. 538 (2025) 4, 3038-3041, arXiv:2503.1

PP2025, HZDR/CASUS Dresden/Görlitz,
Germany, 24th June 2024

Outline

The Hubble tension

- General definitions & measurements

The Rotating Universe

- How this can be handled – a historical (re)view

The Model

- Spherical and cylindrical rotating dark matter

Results & Discussion

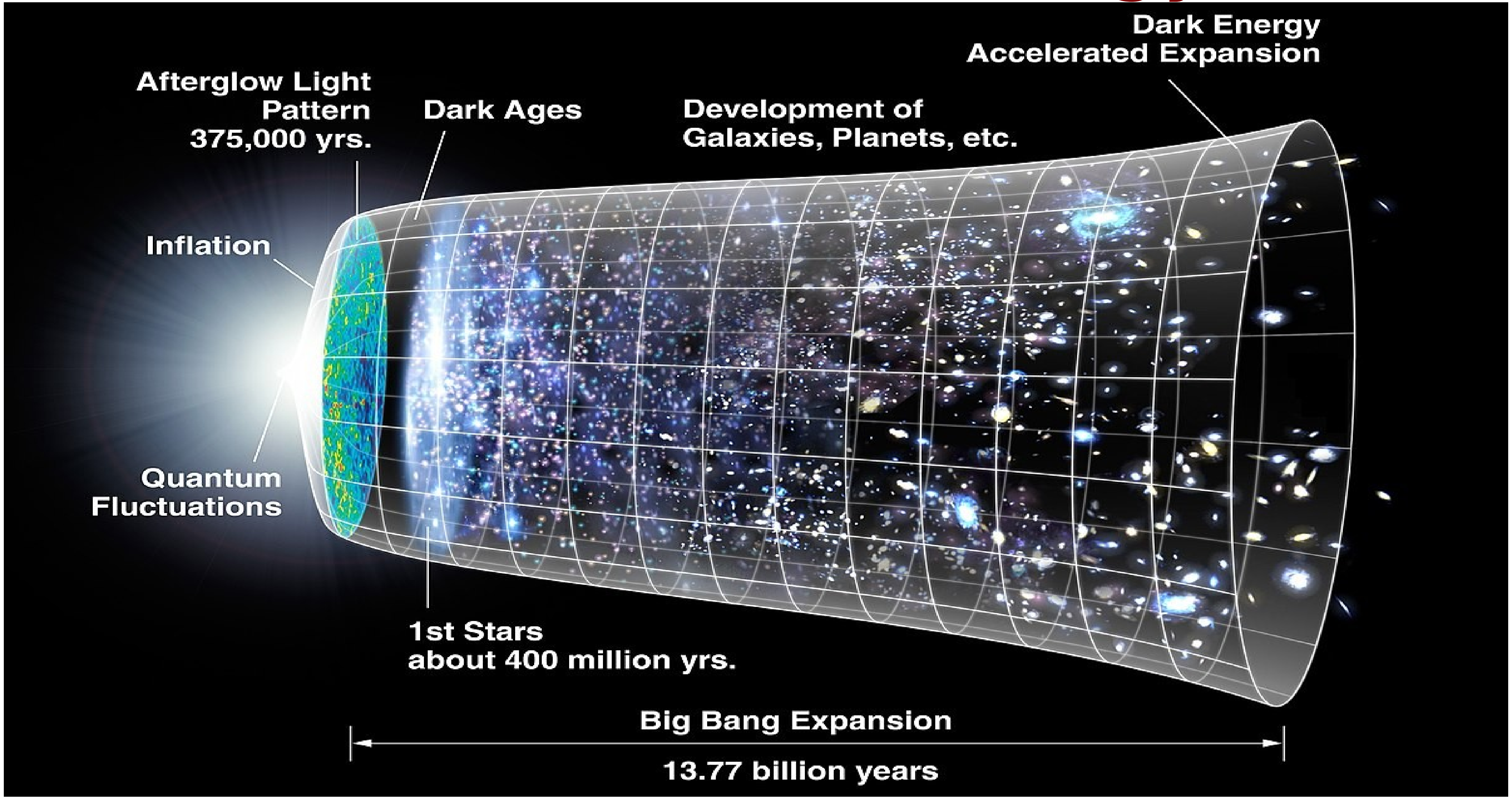
- Comparison to the standard cosmology & other models

Conclusions

→ Yes, and παντα κυκλουται!

The Hubble Tension

Standard cosmology



The Hubble constant(?)

- **Measurement of Hubble–Lemaître:**

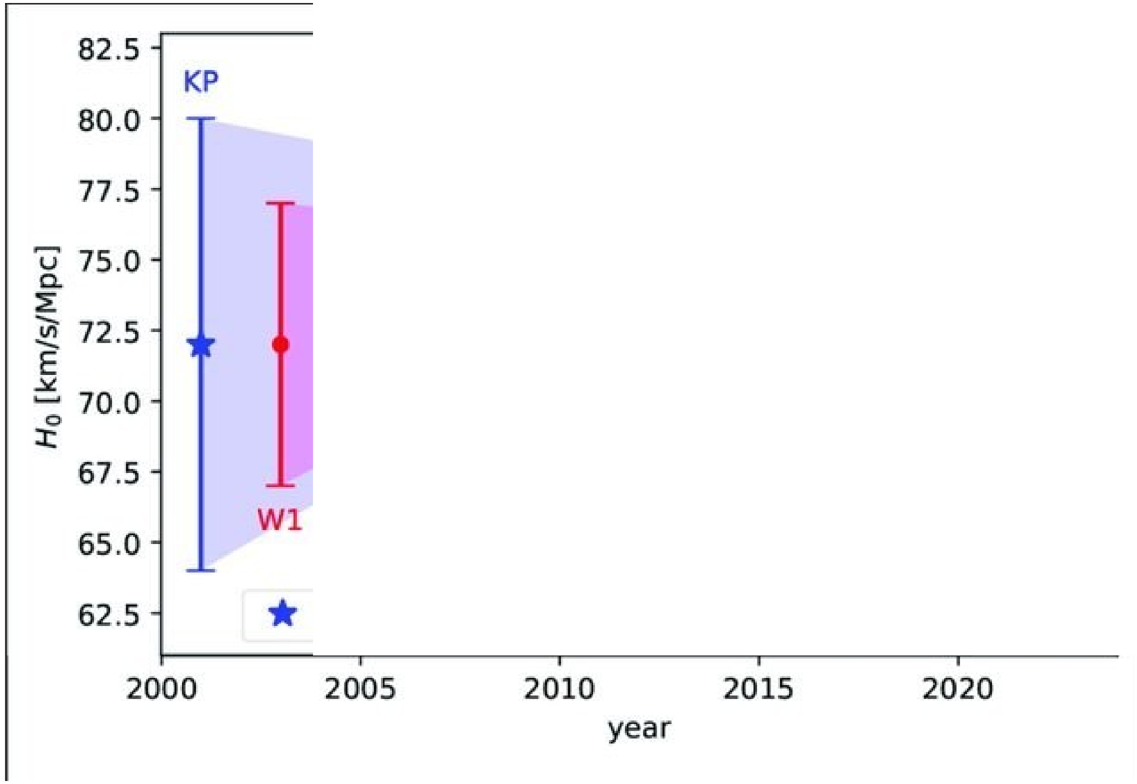
$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

  - **Nearby Object’s (Supernovae)**

    This method relies on observations of Type Ia supernovae and other distance indicators.

  - **Cosmic Microwave Background:**

    The CMB is the afterglow of the Big Bang, which can predict the expansion rate of the early universe and we can extrapolate it to the present day.



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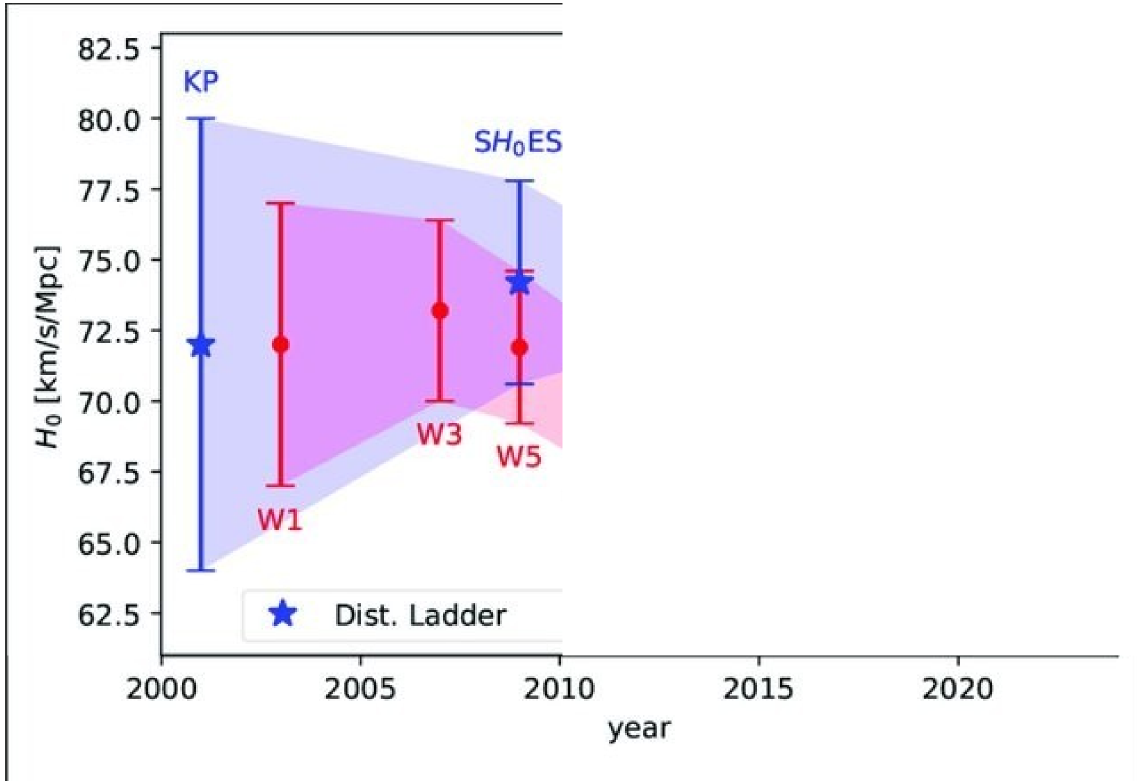

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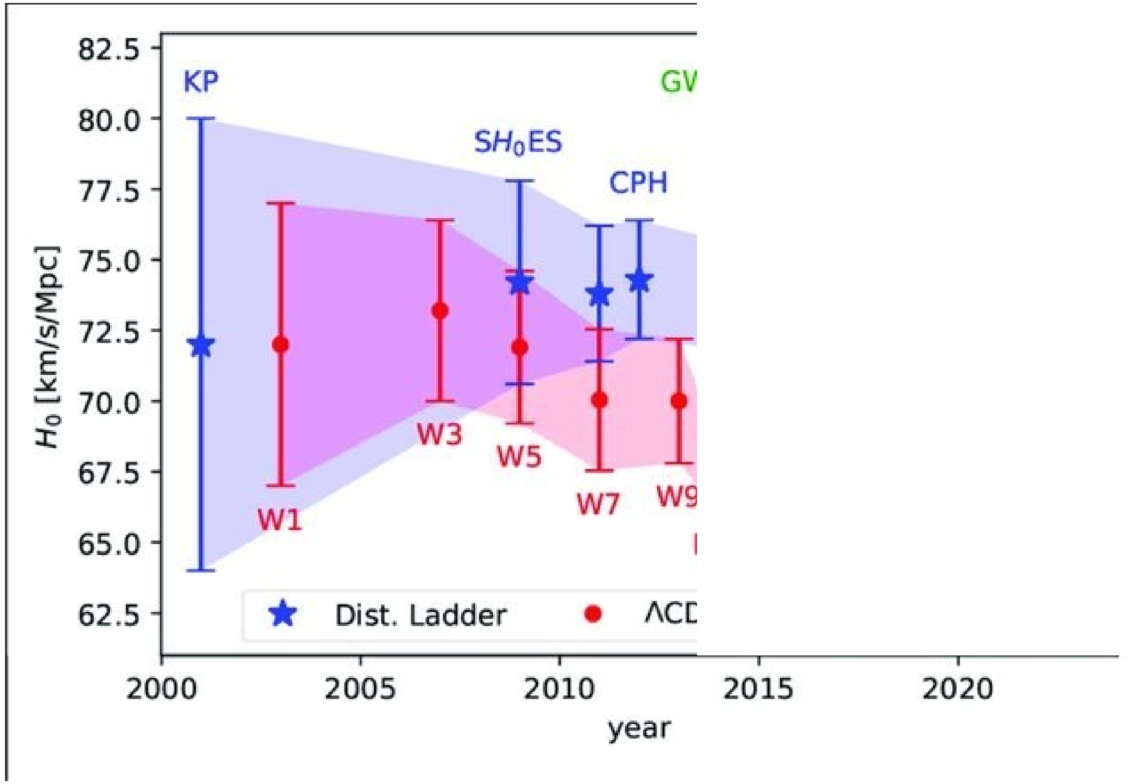

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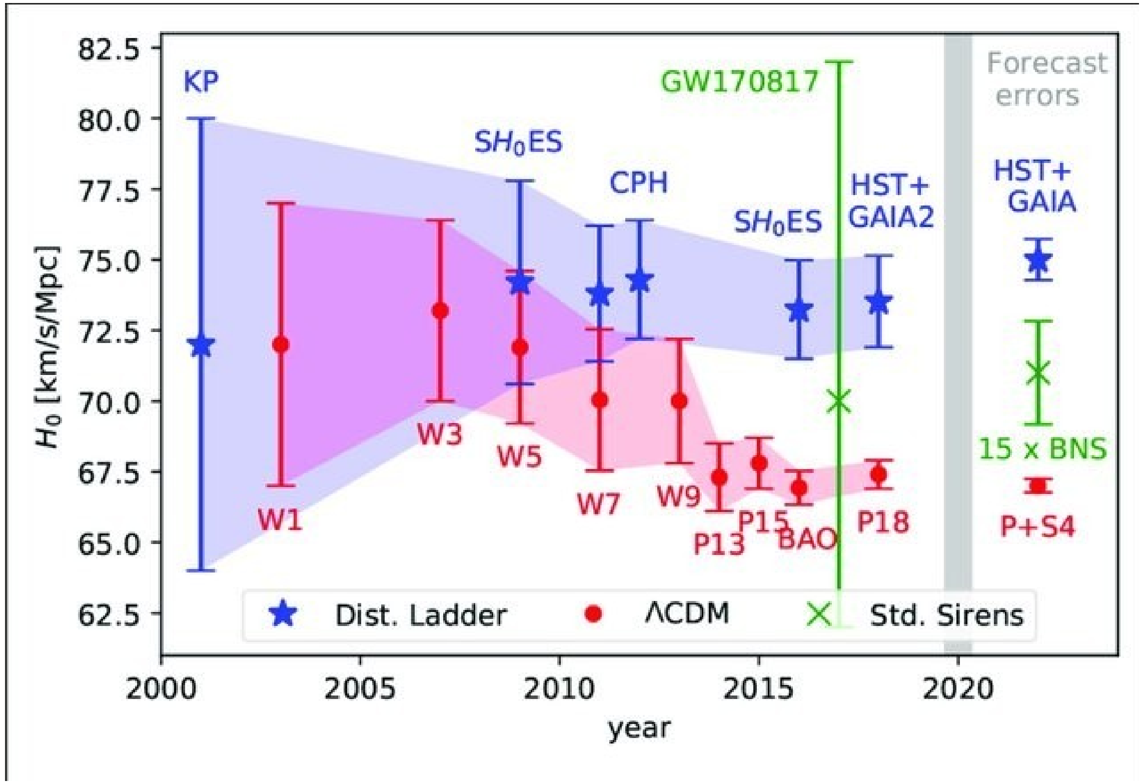
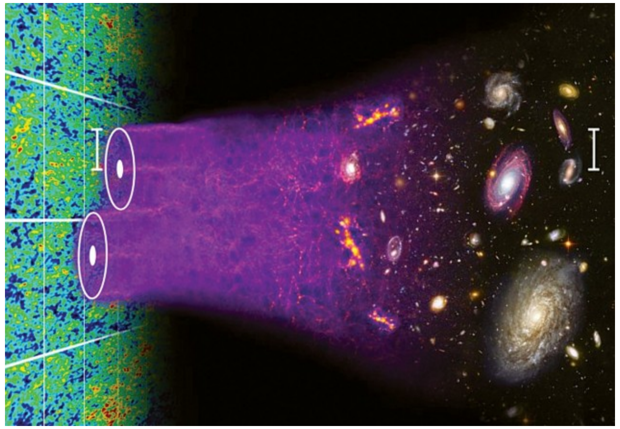
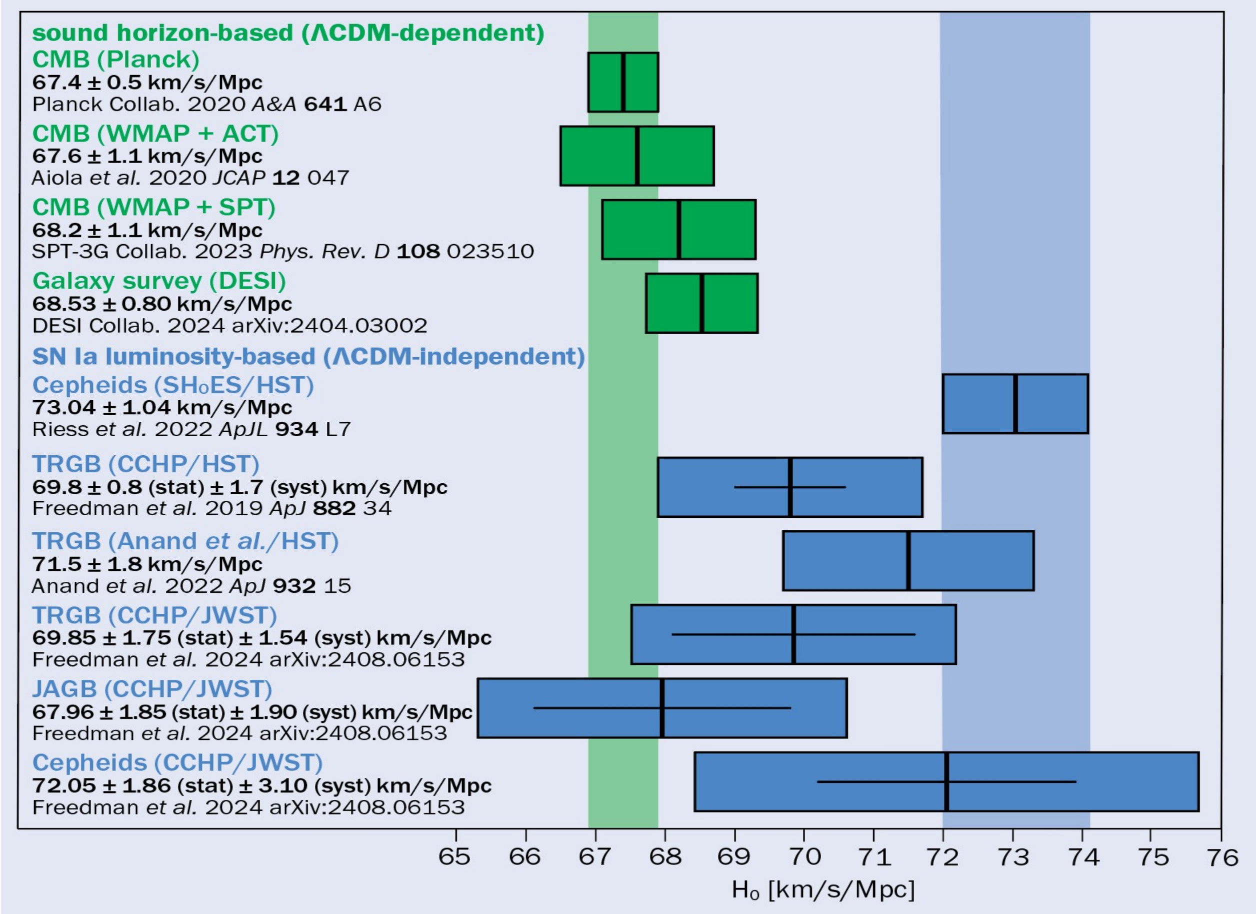
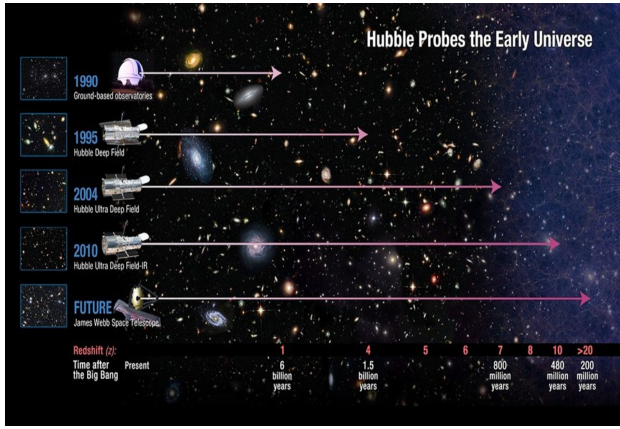


The Hubble tension



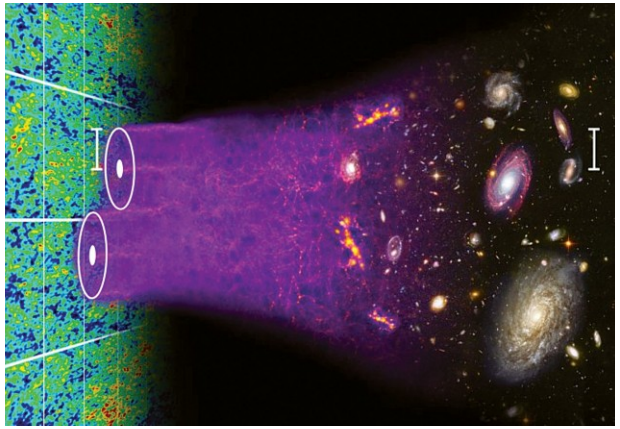


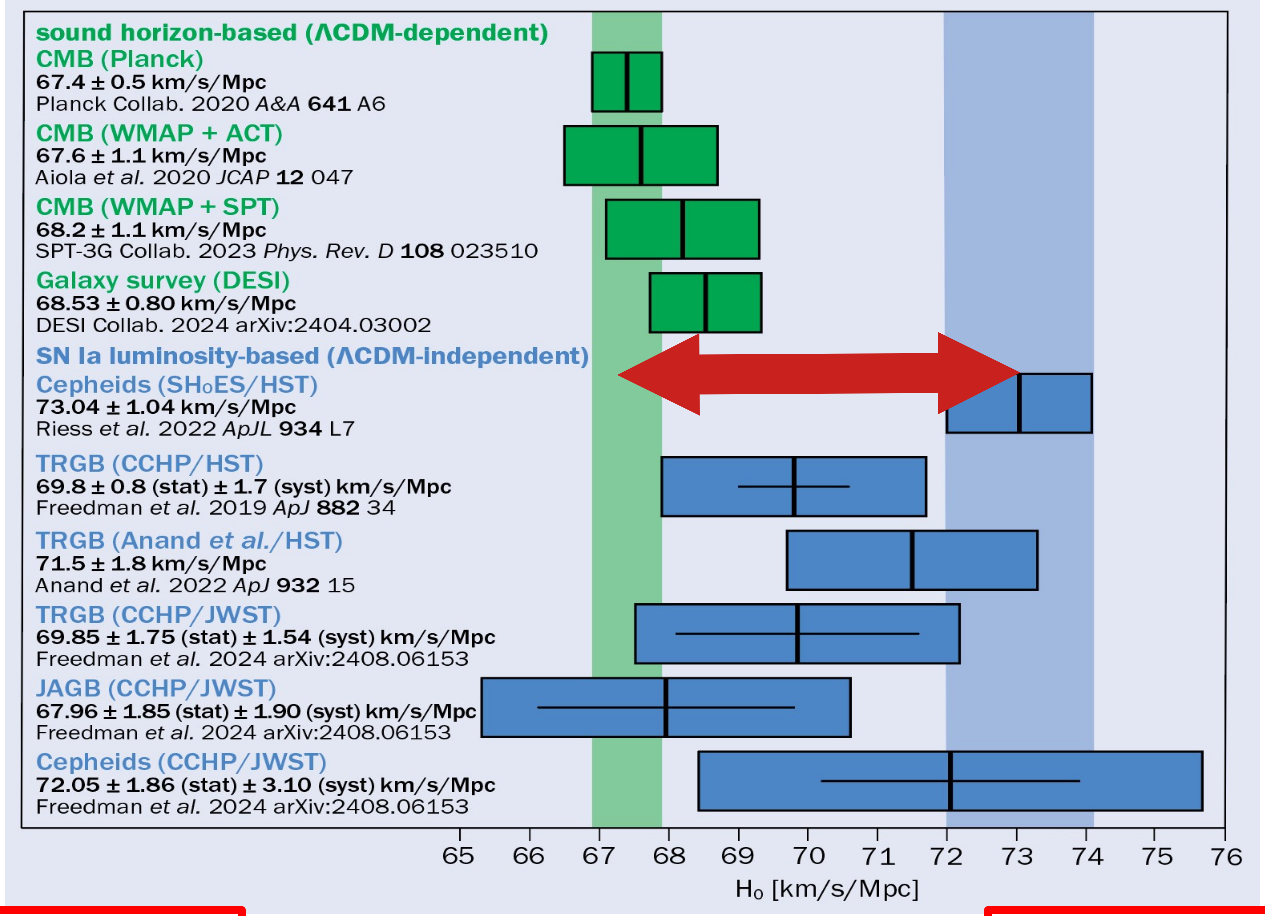


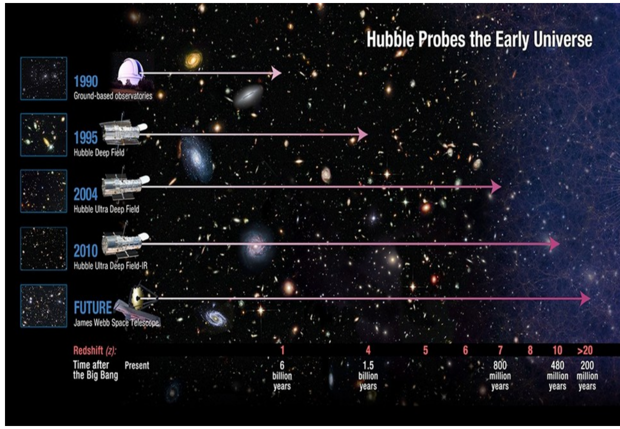
$$H_{\rm CMB} = 67.4 \pm 0.5 \, {\rm kms^{-1} Mpc^{-1}}$$

$$H_{\rm SNe} = 73.04 \pm 1.07 \, {\rm kms^{-1} Mpc^{-1}}$$

The Hubble tension







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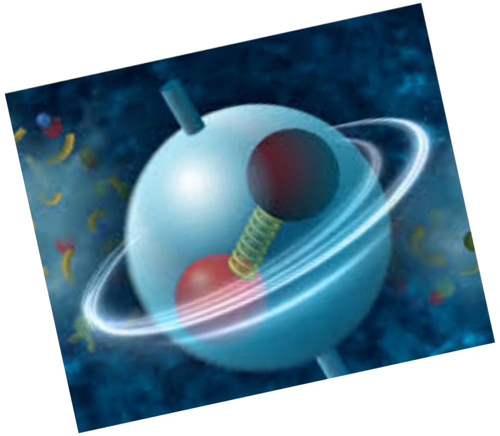
How to resolve Hubble tension?

- **The Hubble tension suggests a potential problem with our understanding of the universe. Some possible explanations include:**
  - **Problems with our cosmological model:** The standard model of cosmology, ΛCDM, may be incomplete or incorrect.
  - **New Physics:** There could be unknown particles or forces influencing the universe's expansion.
  - **Systematic errors in measurements:** It's also possible that there are undetected errors in the measurement techniques.

→ The Hubble tension is an active area of research, and scientists are working to refine measurements and explore potential solutions **→ rotation of the Universe!**

The rotating Universe

Are these rotating?



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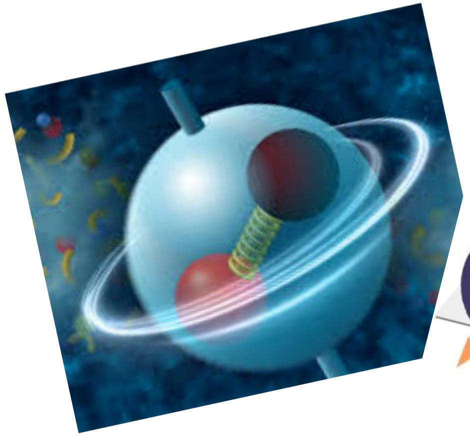

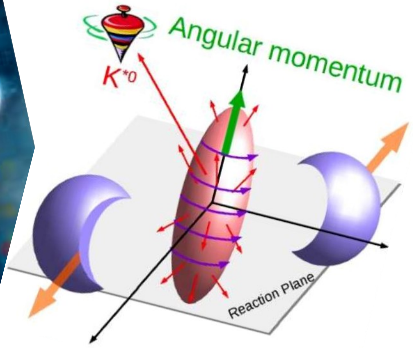

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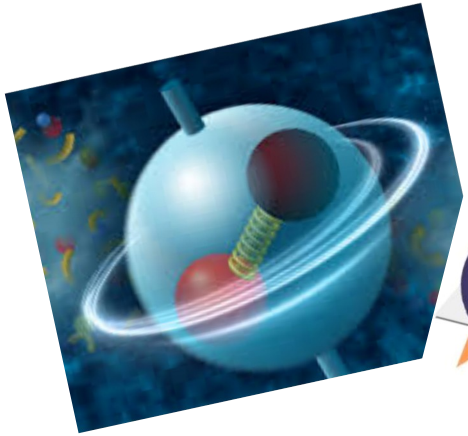

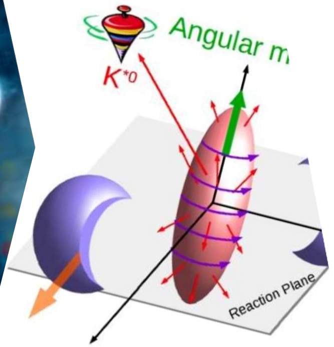

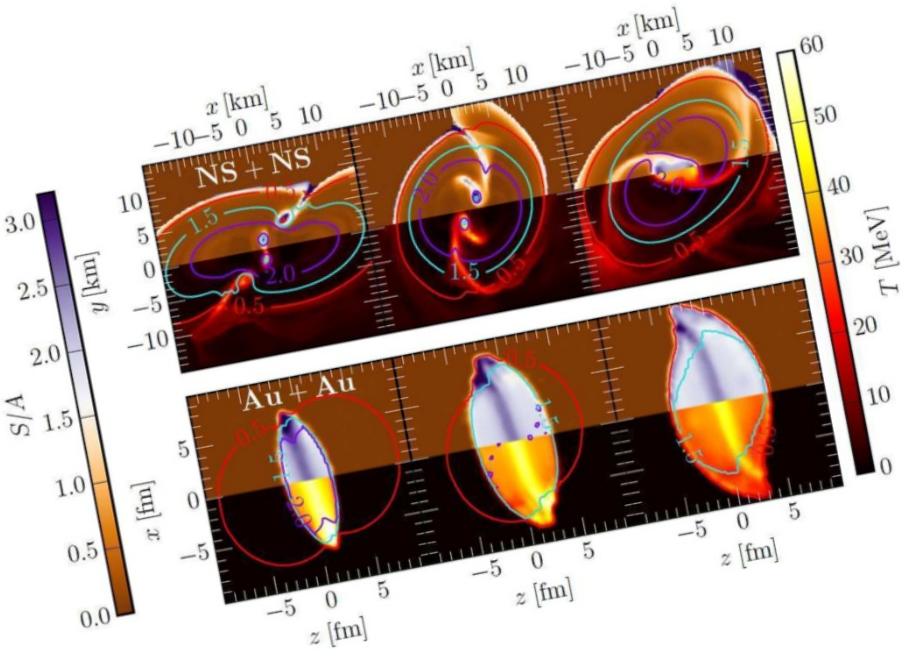

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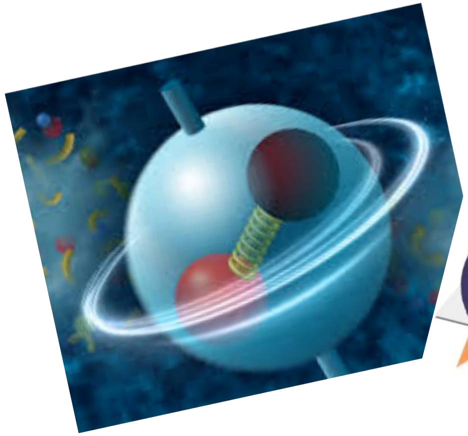

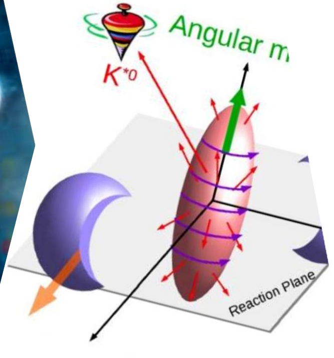

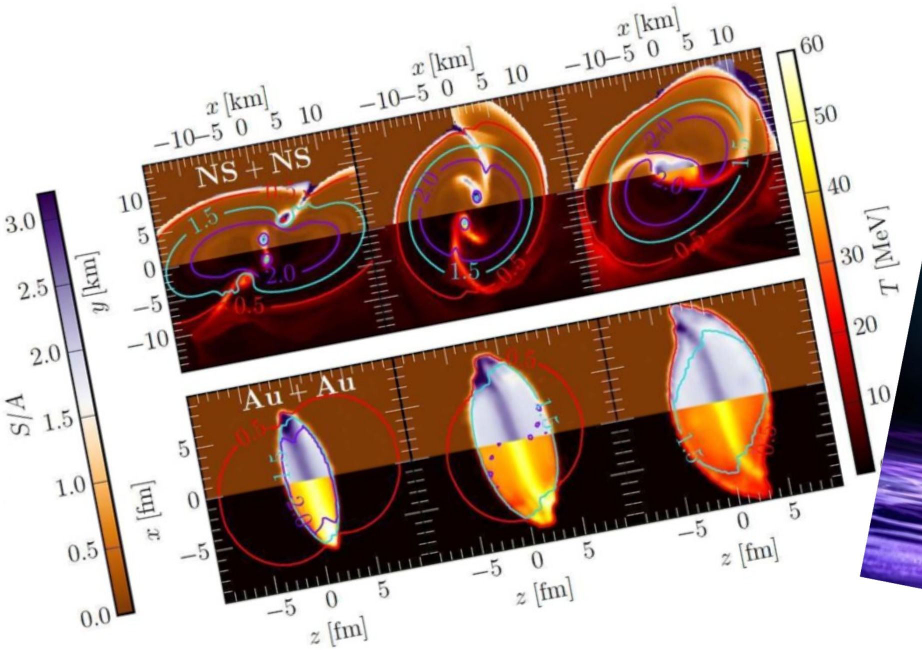

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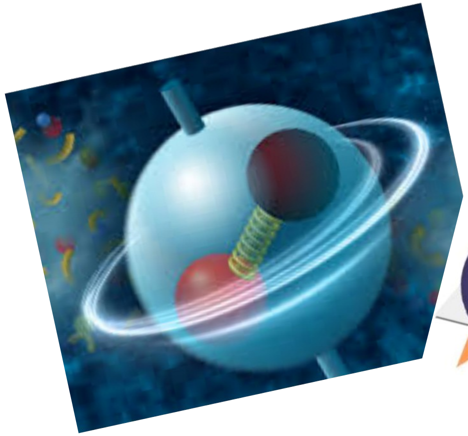

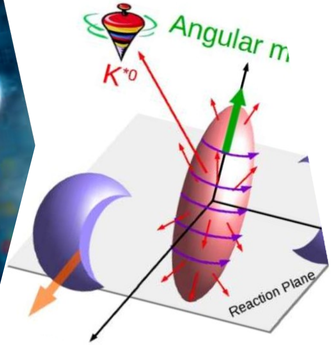

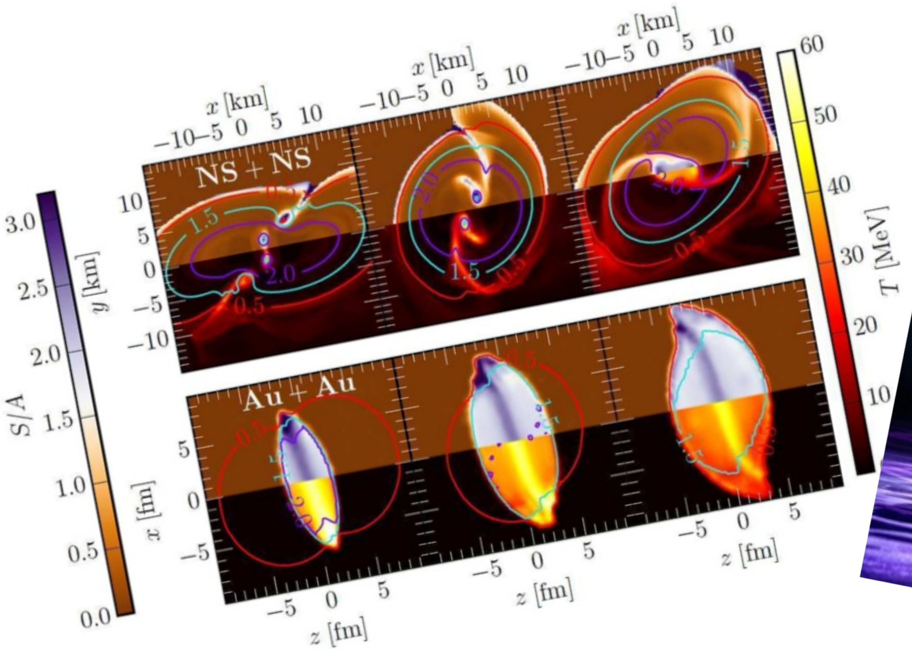

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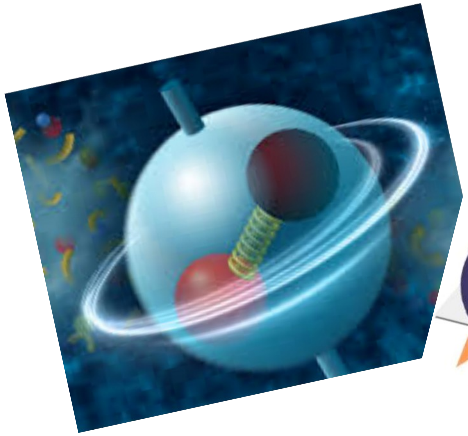

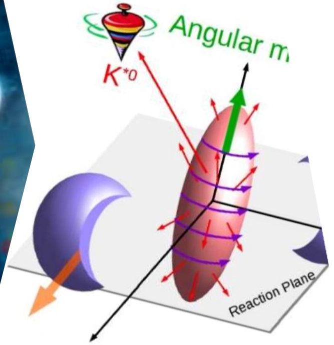

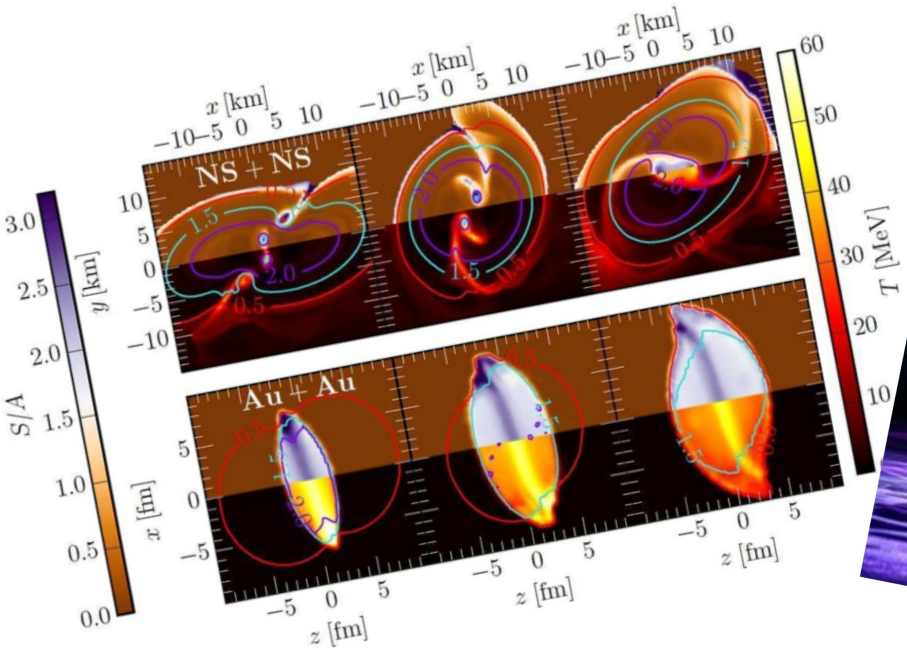

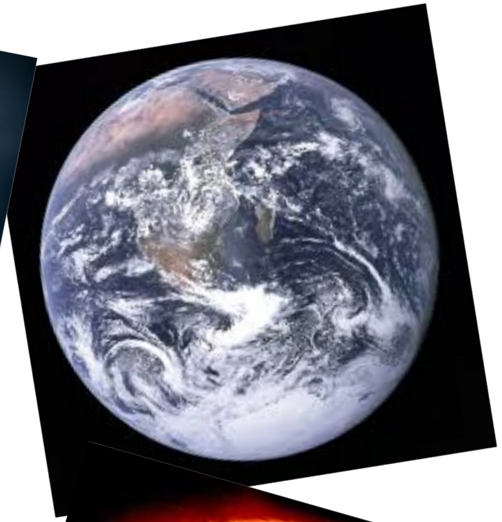

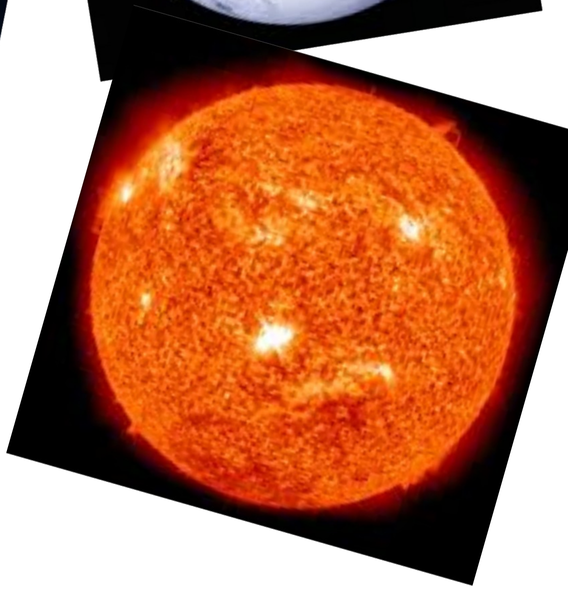

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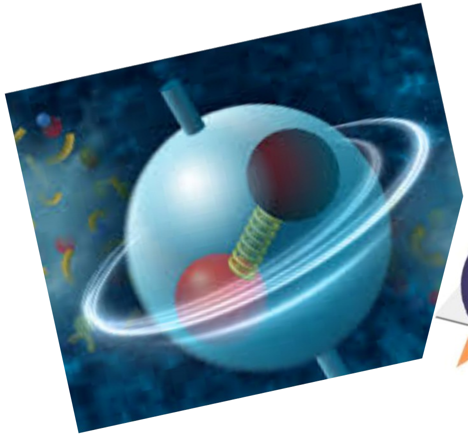

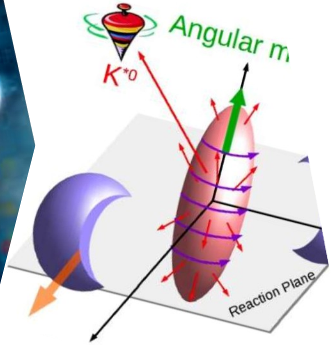

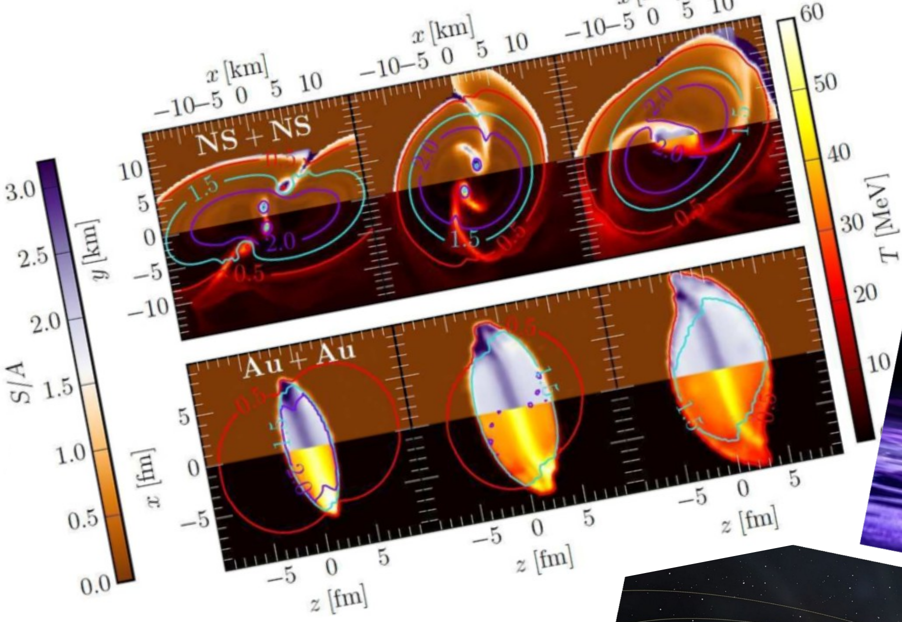

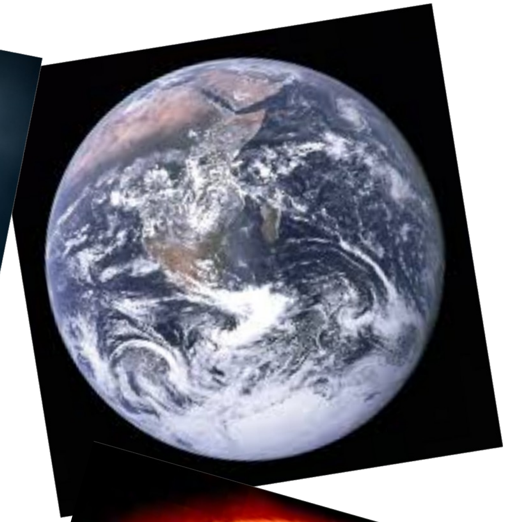

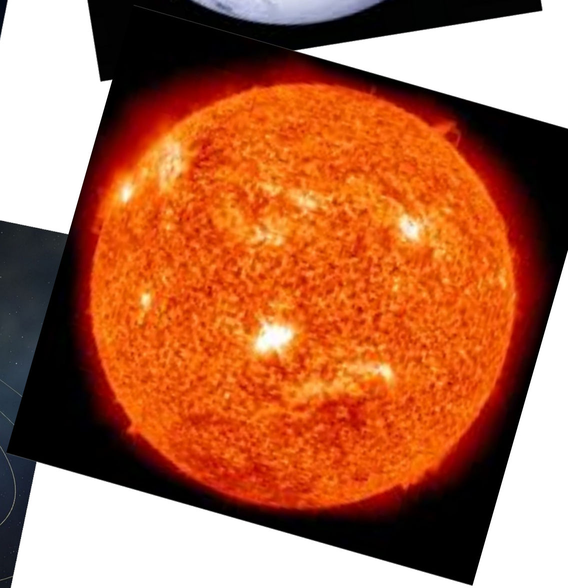

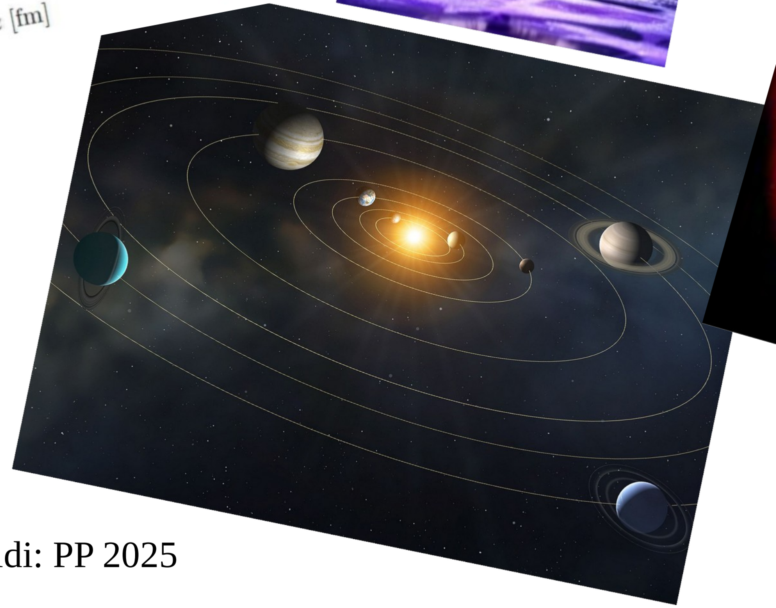

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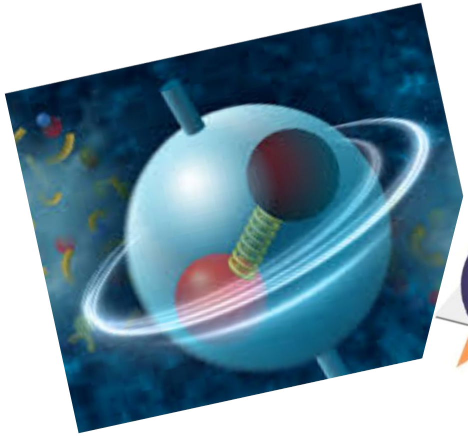

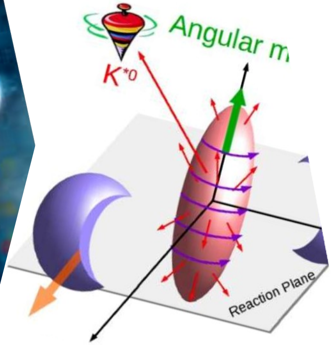

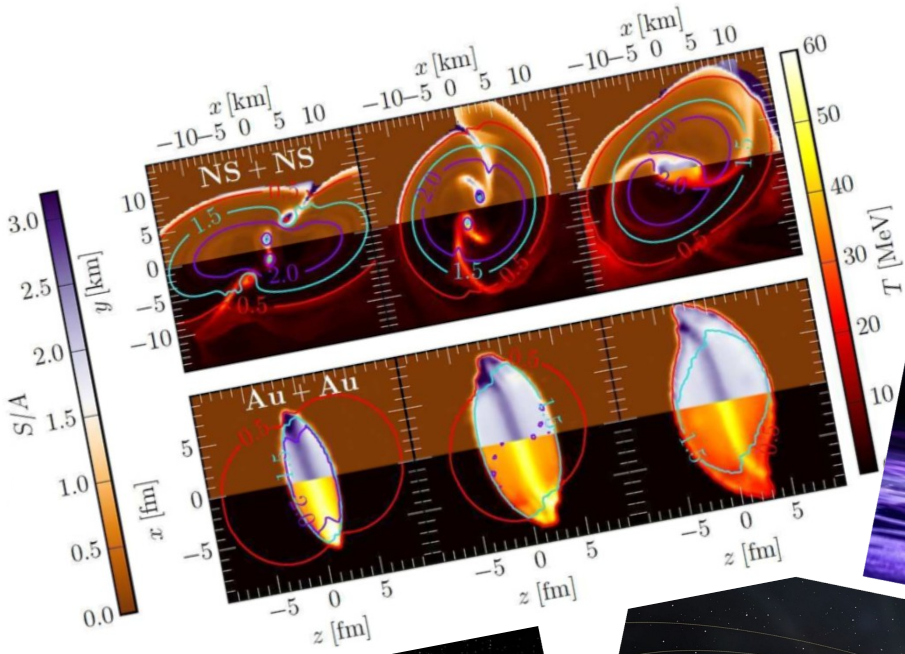

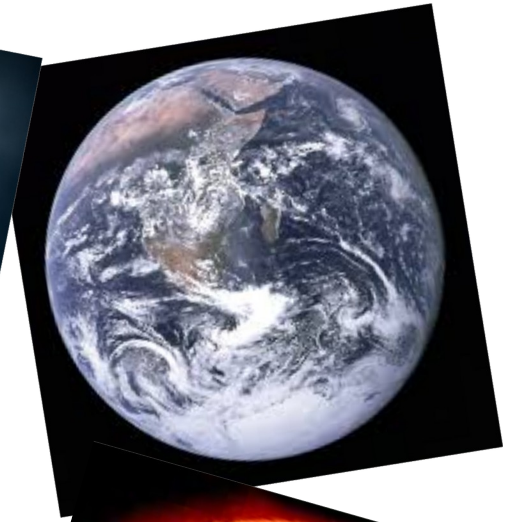

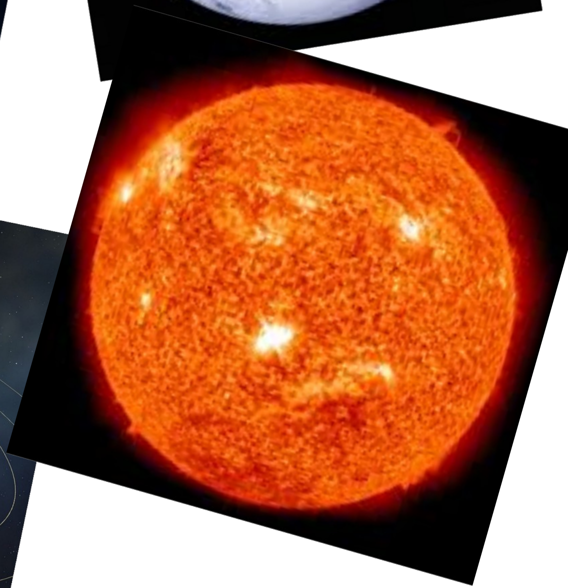

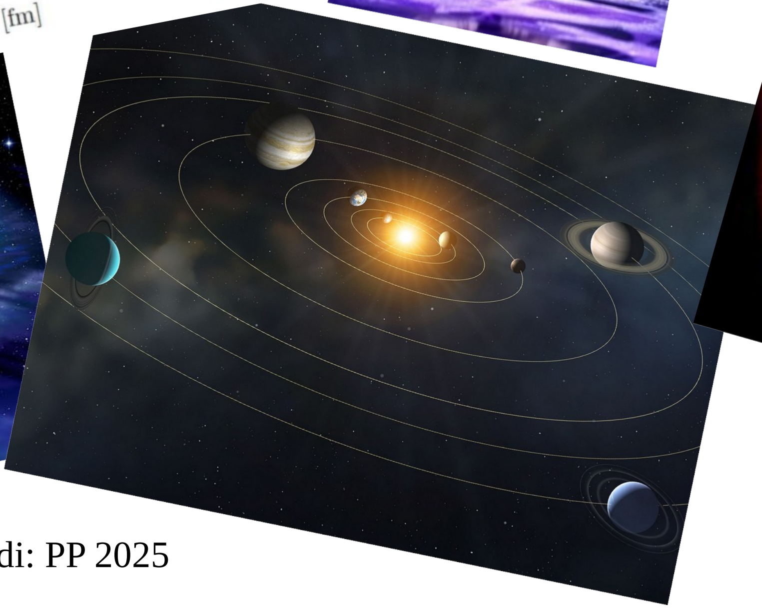

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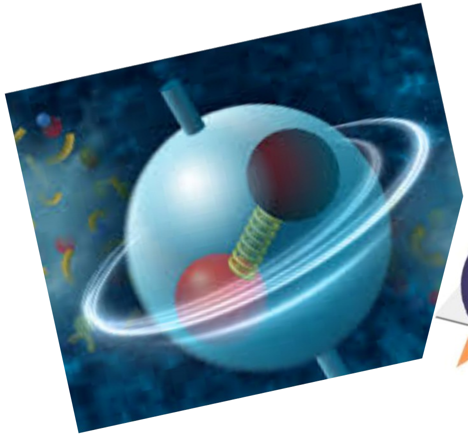

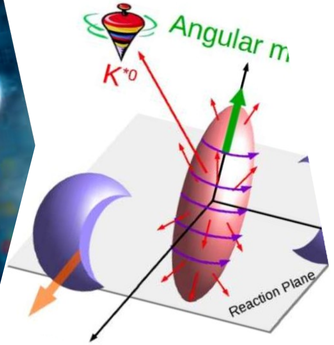

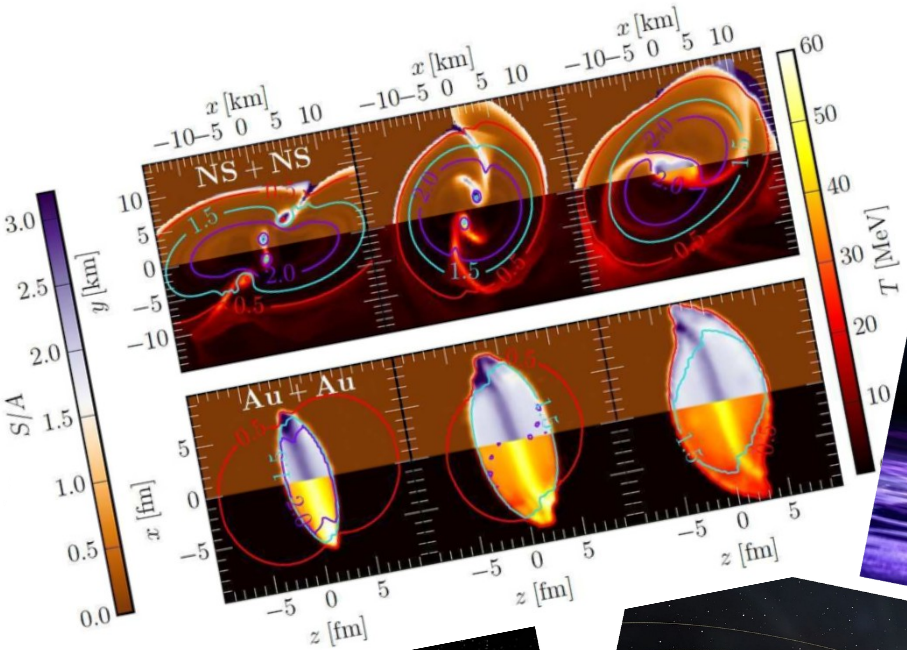

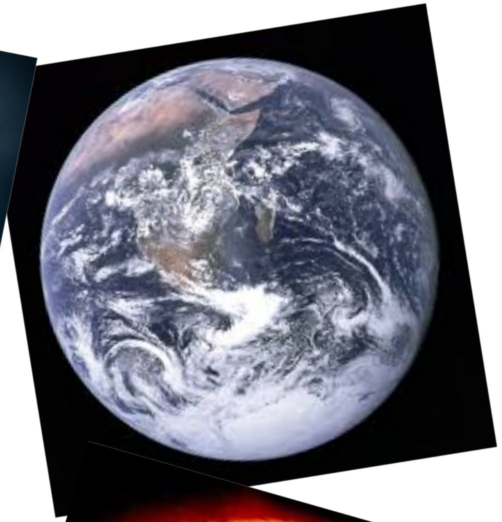

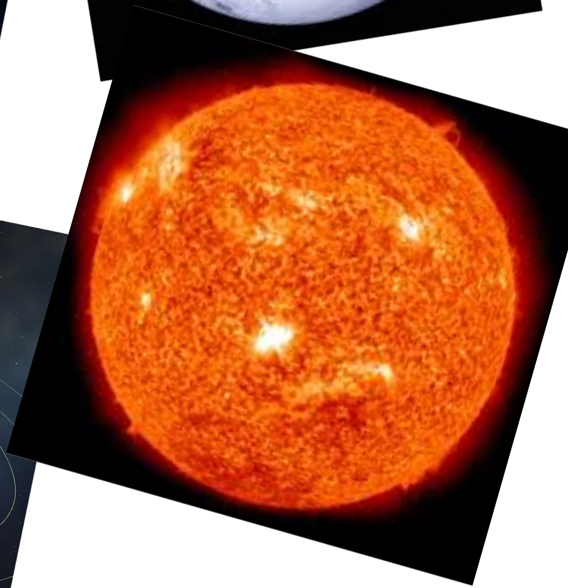

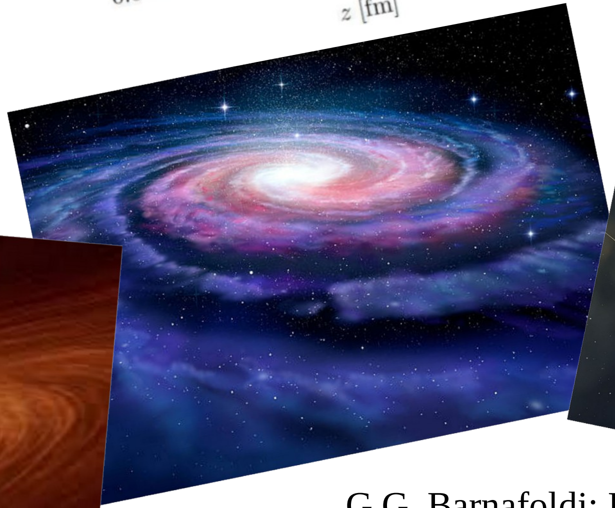

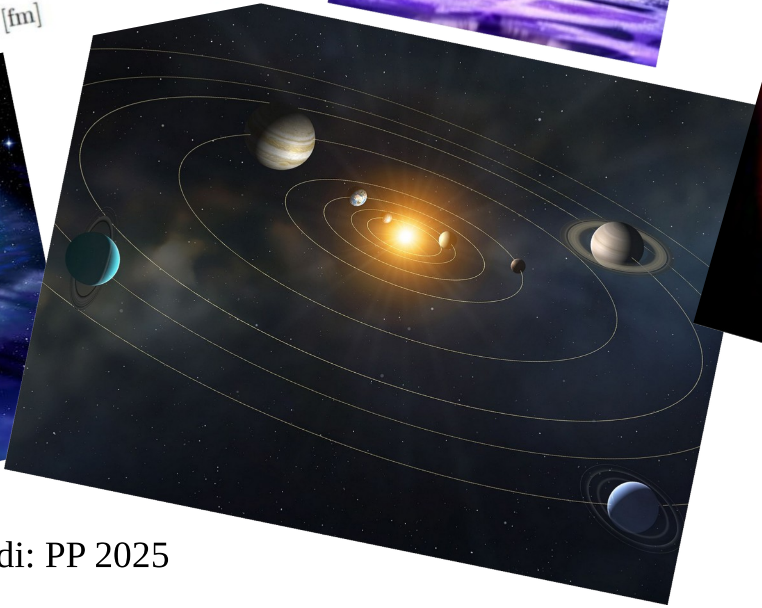

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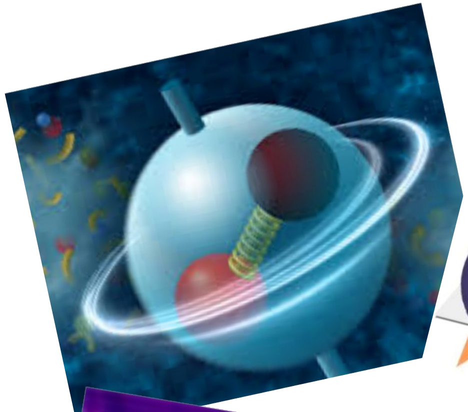
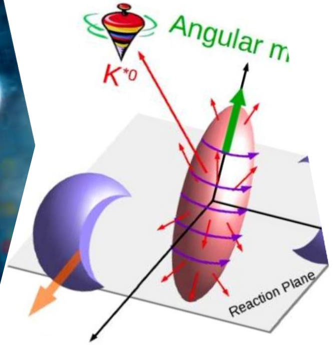
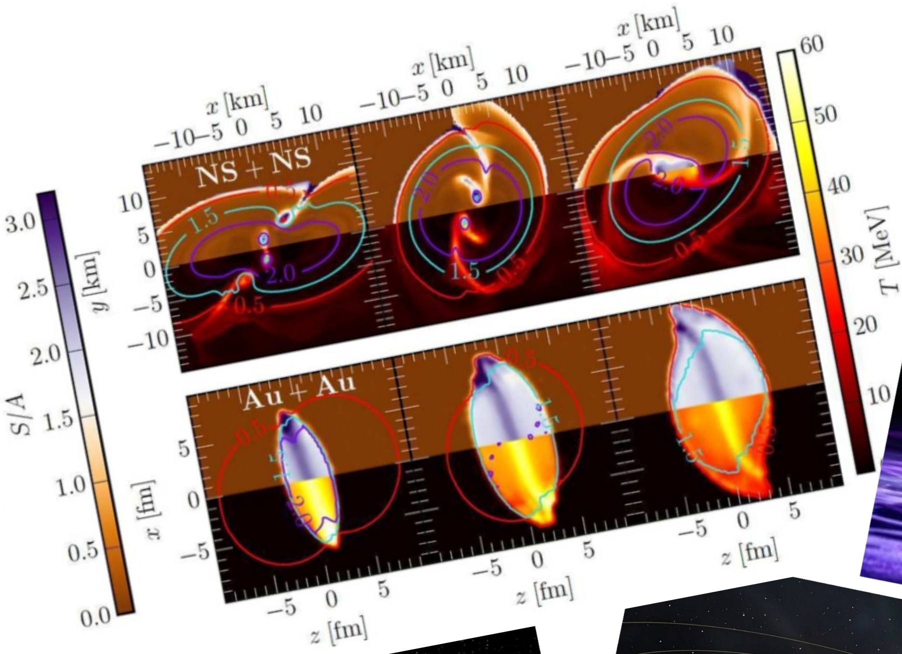
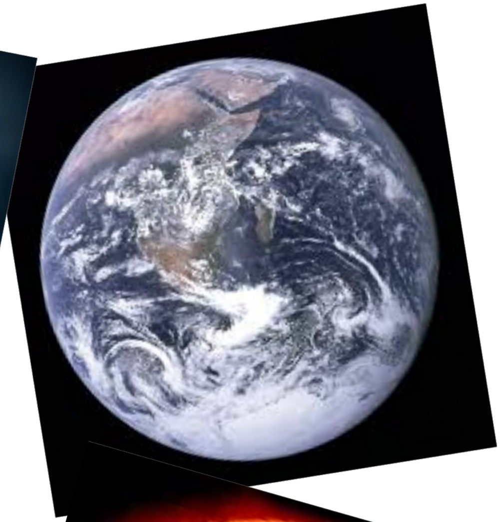
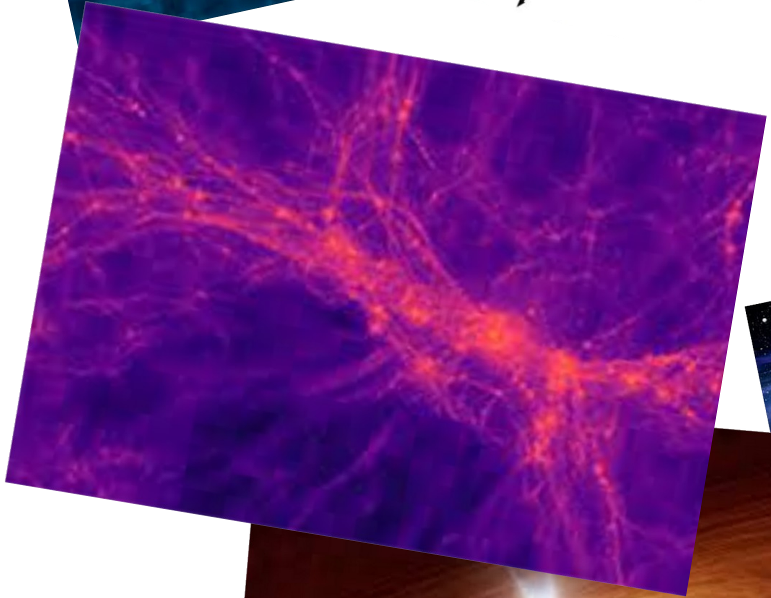
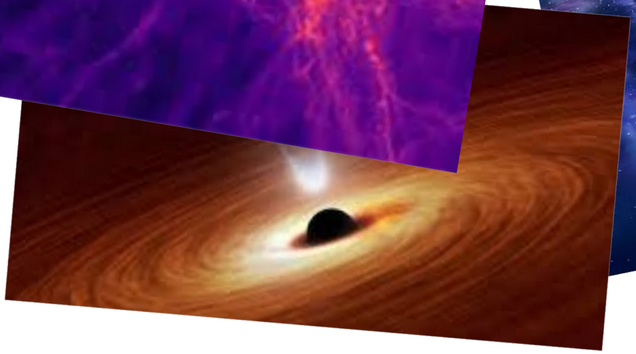


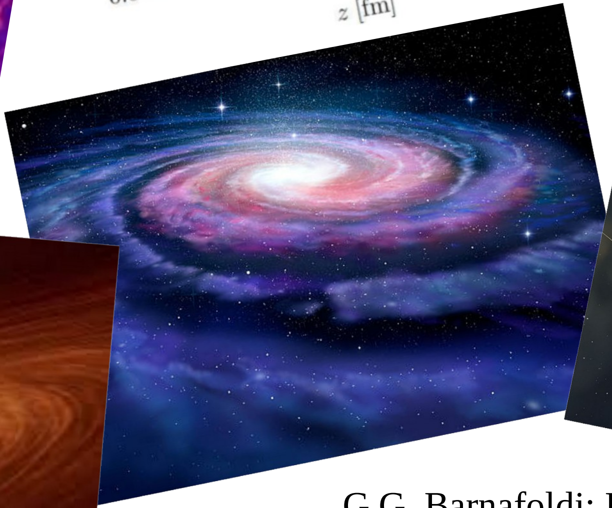


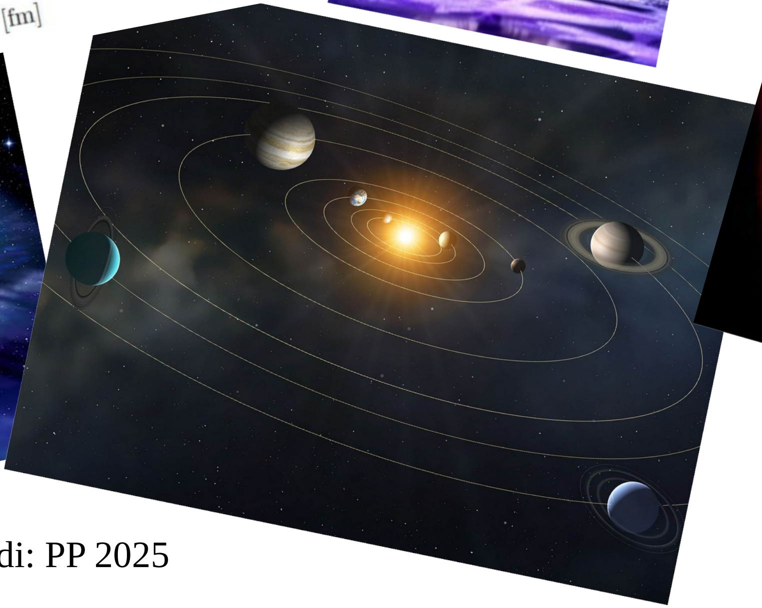


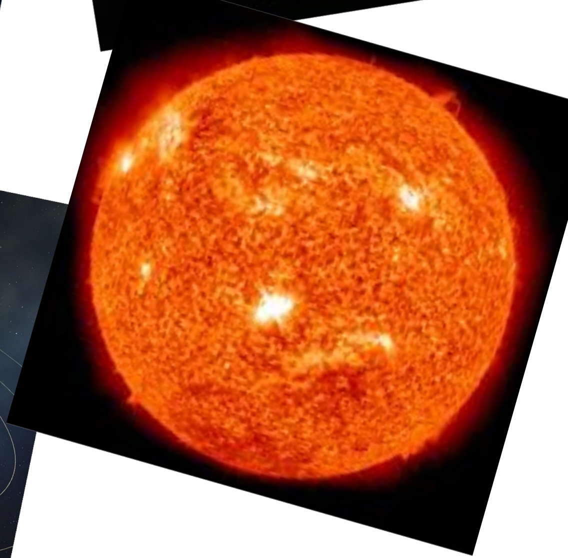




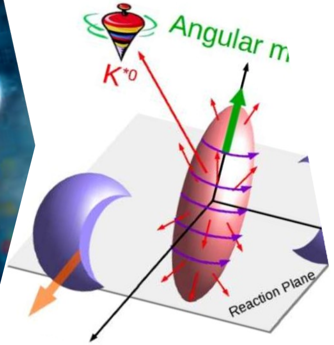


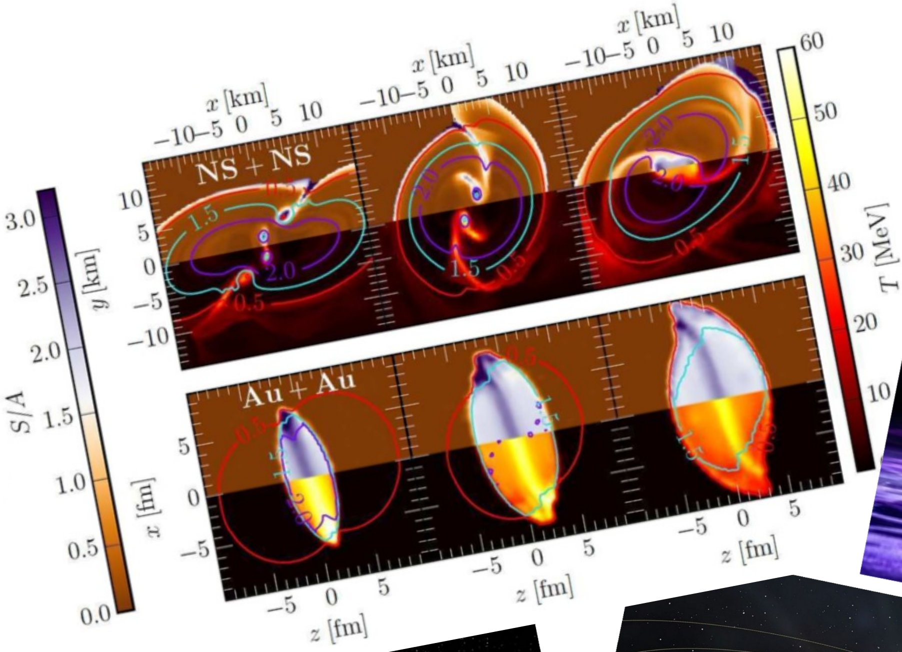


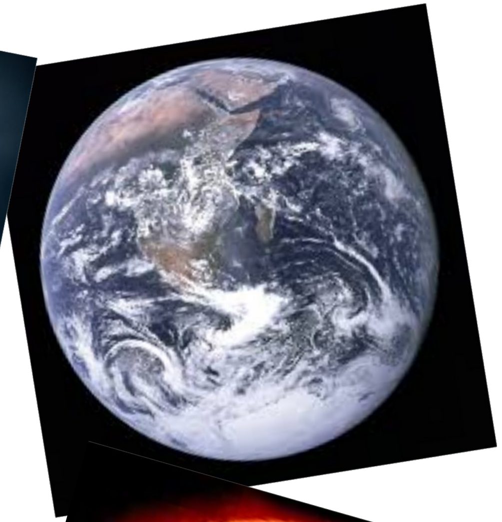


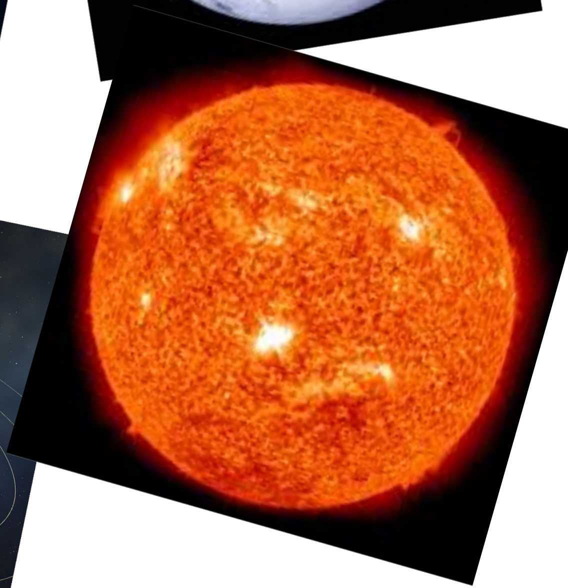


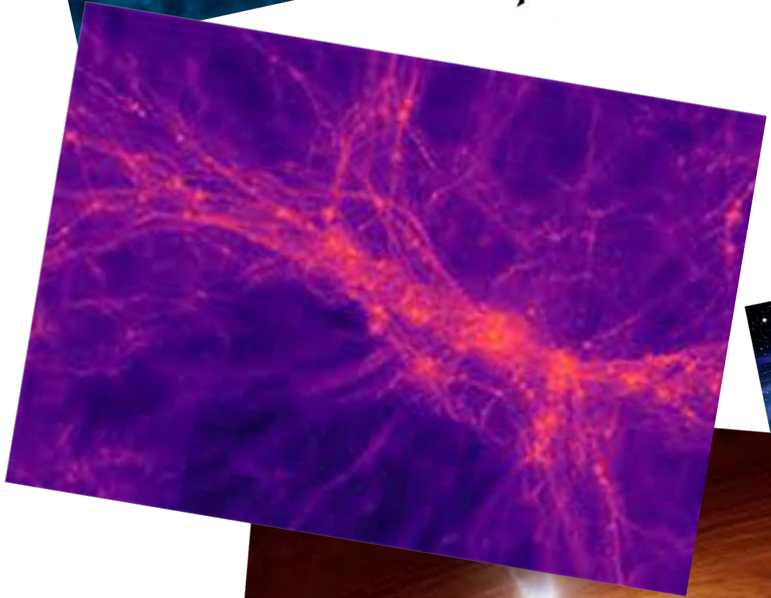
Why should not the Universe rotate?

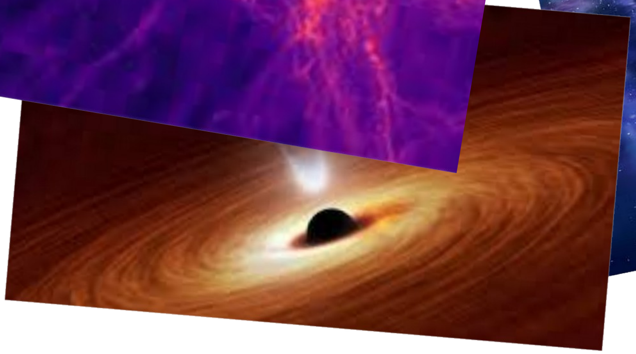


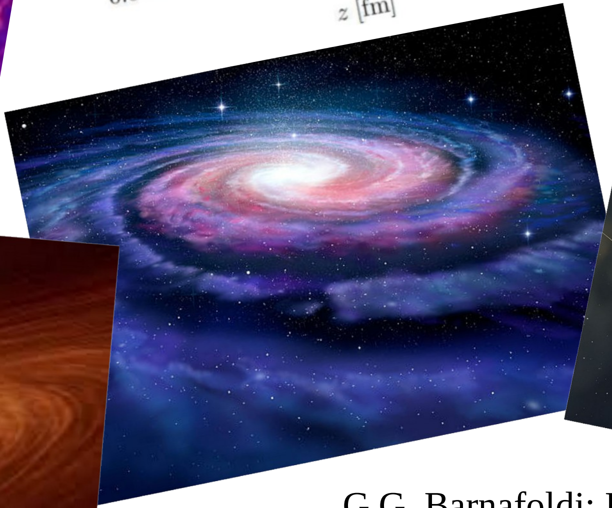


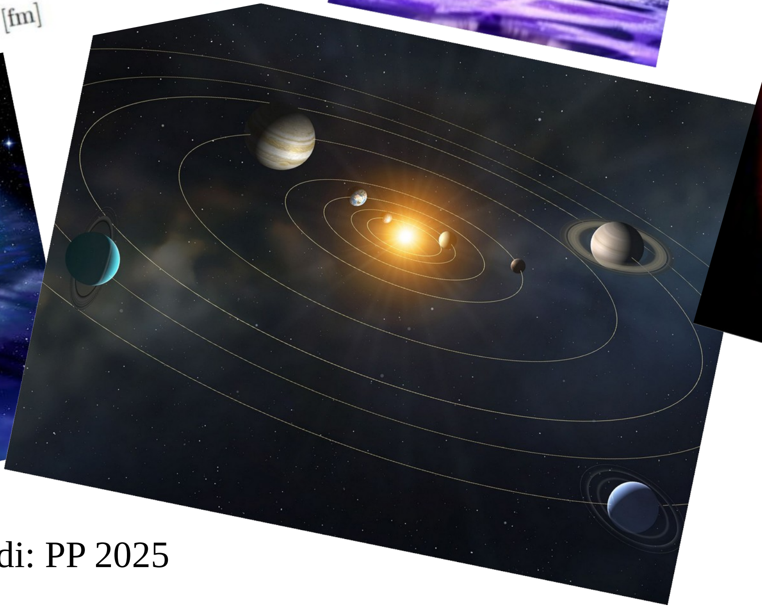








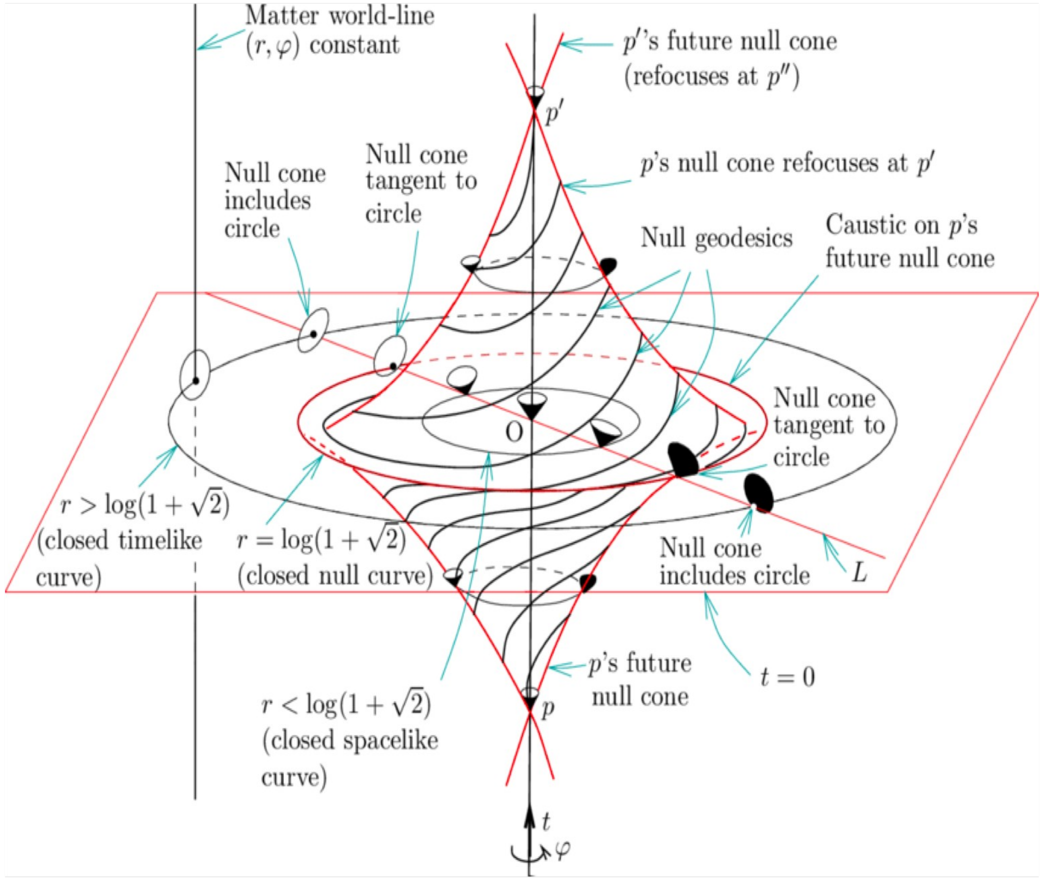




Rotating cosmological models

- **Gödel inspired models** (1947): introduced a rotating universe followed by Heckmann & Schücking (1955-1961), later Silk (1966) and Hawking (1969). Obukhov (2000) made a generalized Gödel solution with global rotation. Buser, Kajari & Schleich (2013) visualized Gödel's universe). Anisotropies in a variety of Bianchi models with large vector perturbations corresponding to rotation are tightly constrained from Planck CMB data by Saadeh et al. (2016).
- **Other motivations for rotation:** Black Holes, spherically symmetric objects with horizons, display near maximal rotation as presented by Daly (2019). Anisotropic Hubble expansion in X-ray observations by Migkas et al. (2021) were suggested. A plausible syllogism is that the Universe has near-maximal rotation, motivated by cosmologies where the universe is the interior of a black hole (Pathria 1972).
- **There are many other proposed solutions** to the Hubble Puzzle (e.g. Di Valentino et al. 2021b) and any modification of the standard model expansion and (e.g. Knox & Millea: 2020). An average rotation effect has similar functional form as dark photons (Fabbrichesi, Gabrielli & Lanfranchi 2021; Aboubrahim et al. 2022), and (Cyr-Racine, Ge & Knox 2022).

→ Rotation affect the Hubble constant strongly….



The Model

The Model

- **Euler – Poisson equations without rotation:**

$$\partial_t \rho + \mathrm{div}(\rho \boldsymbol{u}) = 0 \ ,$$

$$\partial_t(\rho \boldsymbol{u}) + \mathrm{div}(\rho \boldsymbol{u} \otimes \boldsymbol{u}) = -\nabla P(\rho) - \rho \nabla \Phi + \rho \boldsymbol{g}$$

$$\nabla^2 \Phi = 4\pi G \rho,$$

- **Dynamical parameters:** $\rho = \rho(r,t), u = u(r,t),$ and $P = P(r,t)$

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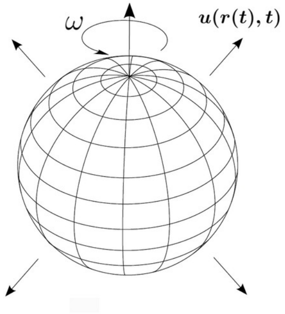
- **Spherical:**

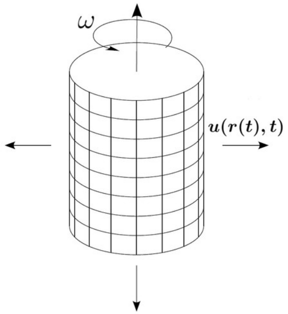
$$\partial_t \rho + (\partial_r \rho)u + (\partial_r u)\rho + \frac{u\rho}{r} = 0\ ,$$



$$\partial_t u + (u\partial_r)u = -\frac{1}{\rho}\partial_r P - \partial_r \Phi(r) + g^*$$
$$\frac{1}{r}\frac{d}{dr}(r\partial_r \Phi) = 4\pi\rho\ .$$

Cylindrical:

$$\partial_t \rho + (\partial_r \rho)u + (\partial_r u)\rho + \frac{2u\rho}{r} = 0\ ,$$



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$$\partial_t(\rho \boldsymbol{u}) + \mathrm{div}(\rho \boldsymbol{u} \otimes \boldsymbol{u}) = -\nabla P(\rho) - \rho \nabla \Phi + \rho \boldsymbol{g}^*$$
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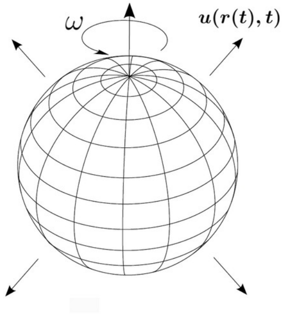

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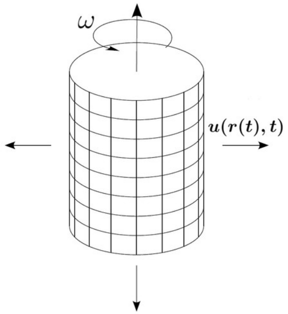

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$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 \partial_r \Phi\right) = 4\pi\rho \,,$$

The EoS

- **A “stiff” dark matter EoS**

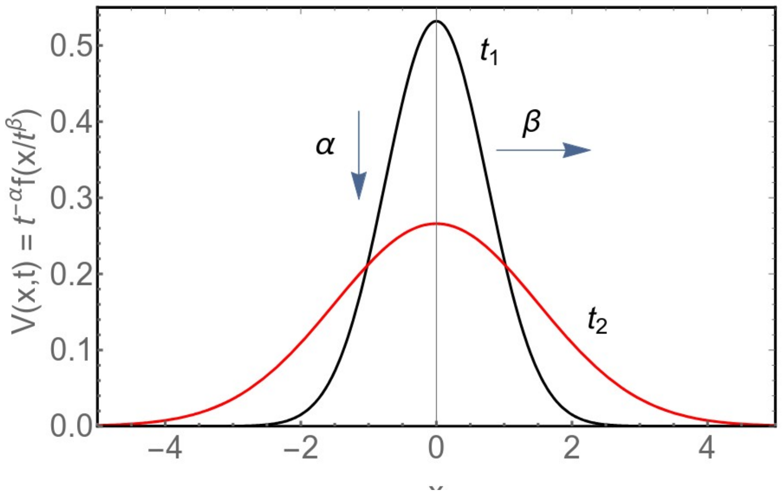
$$p = w\rho^n \qquad \text{for} \qquad n = 1 \quad \longrightarrow \quad \frac{\mathrm{d}p}{\mathrm{d}\rho} = c_s^2 = w$$

- **Speed of sound values – in general [**Mathematics 10 (2022) 18 3220**]**

(i) $w = 0$ means the EoS for ordinary non-relativistic ‘matter’ (e.g., cold dust);
(ii) $w = 1/3$ means ultra-relativistic ‘radiation’ (including neutrinos) and, in the very early universe, other particles that later become non-relativistic;
(iii) $w = -1$ is the simplest case and describes the expanding universe, hypothetical phantom energy $w < -1$ would cause Big Rip;
(iv) $w \neq -1$ means quintessence as hypothetical fluid;
(v) $w = -1/3$ is responsible for the flatness of the Big Bang;
(vi) A scalar field ϕ can be viewed as a sort of perfect fluid with EoS of $w = \dfrac{\frac{1}{2}\phi_t^2 - U(\phi)}{\frac{1}{2}\phi_t^2 + U(\phi)},$

Self-similar solutions

- **A Sedov–von Neumann–Taylor *ansatz*:**
  - $$V(x,t) = t^{-\alpha} f\left(\frac{x}{t^{\beta}}\right) := t^{-\alpha} f(\omega)$$
  - Similarity parameters
  - Gaussian (regular) heat conduction: $\alpha = \beta = 1/2$



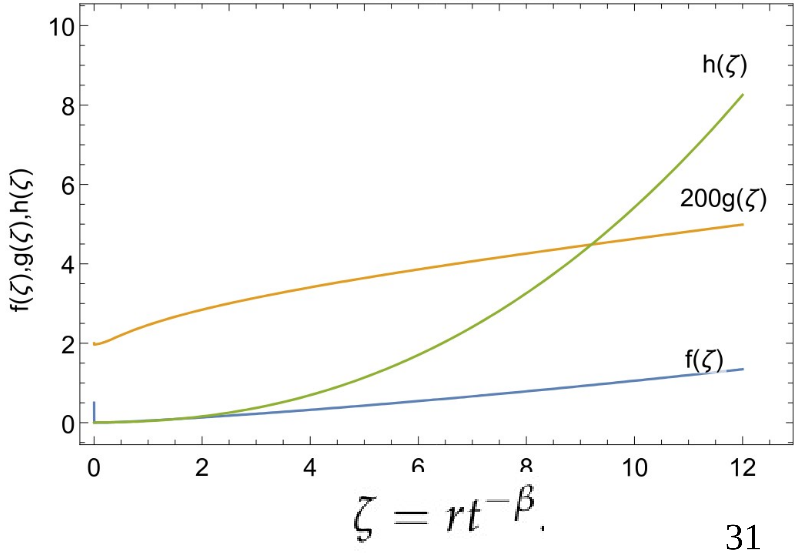
- **Shape functions** (f, g, h)**:**

$$u(r,t) = t^{-\alpha} f\left(\frac{r}{t^{\beta}}\right)$$

$$\rho(r,t) = t^{-\gamma} g\left(\frac{r}{t^{\beta}}\right)$$

$$\Phi(r,t) = t^{-\delta} h\left(\frac{r}{t^{\beta}}\right)$$

$$\zeta = r t^{-\beta}$$



Self-similar solutions

- **Applying the Sedov–von Neumann–Taylor *ansatz*:**
  - Partial Differential Equation (PDE) system becomes Ordinary Differential Equation System (ODE) for the shape functions, of the $\zeta = rt^{-\beta}$.

$$-\zeta g'(\zeta) + f'(\zeta)g(\zeta) + f(\zeta)g'(\zeta) + \frac{2f(\zeta)g(\zeta)}{\zeta} = 0,$$

$$-\zeta^2 f'(\zeta) + \zeta f'(\zeta)f(\zeta) = -\frac{wg'(\zeta)}{g(\zeta)} - h'(\zeta)\zeta + \omega^2 \sin\theta\zeta^2,$$

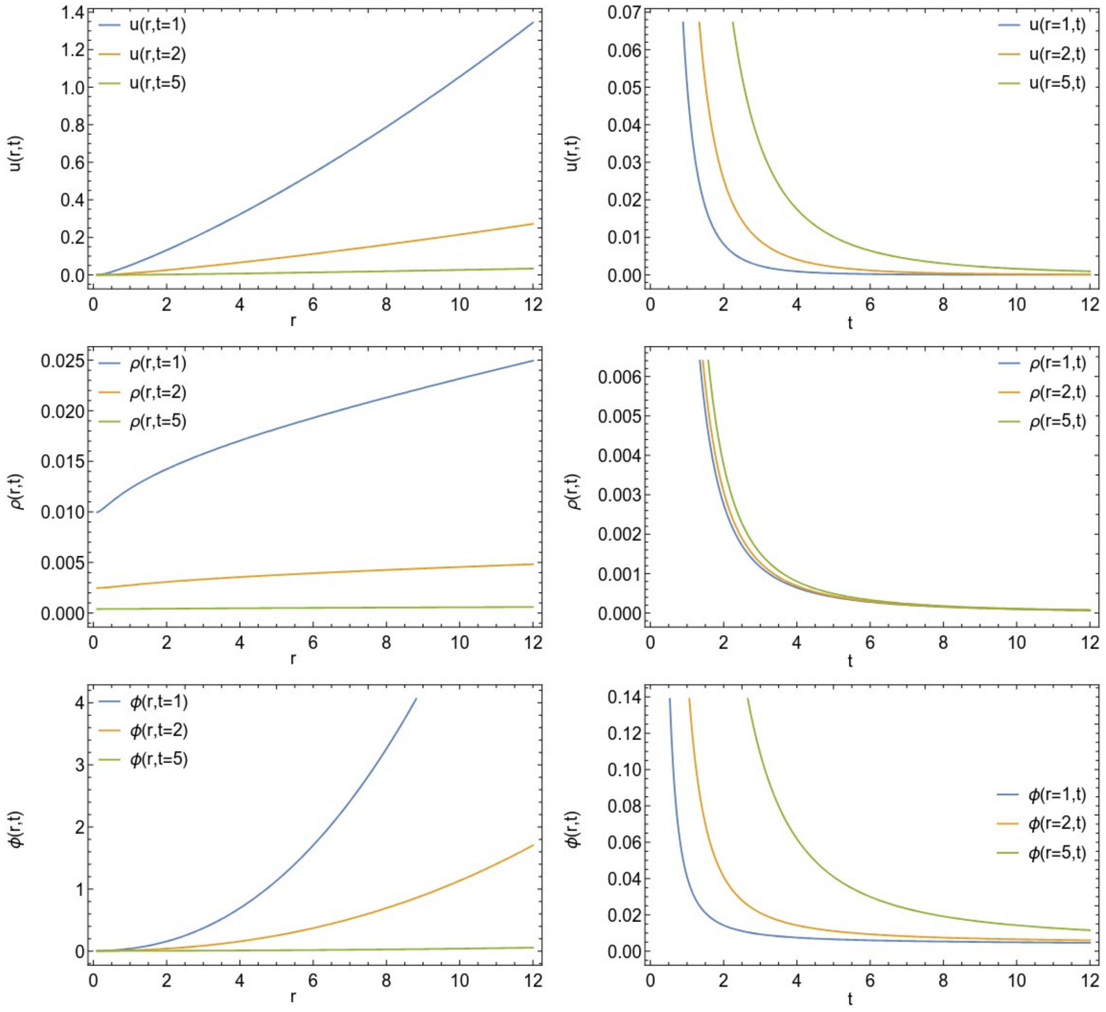
$$h'(\zeta) + h''(\zeta)\zeta = g(\zeta)4\pi G\zeta\ .$$

- **Similarity exponents for these are:** $\alpha = 0, \beta = 1, \gamma = 2$, and $\delta = 0$.

Self-similar solutions

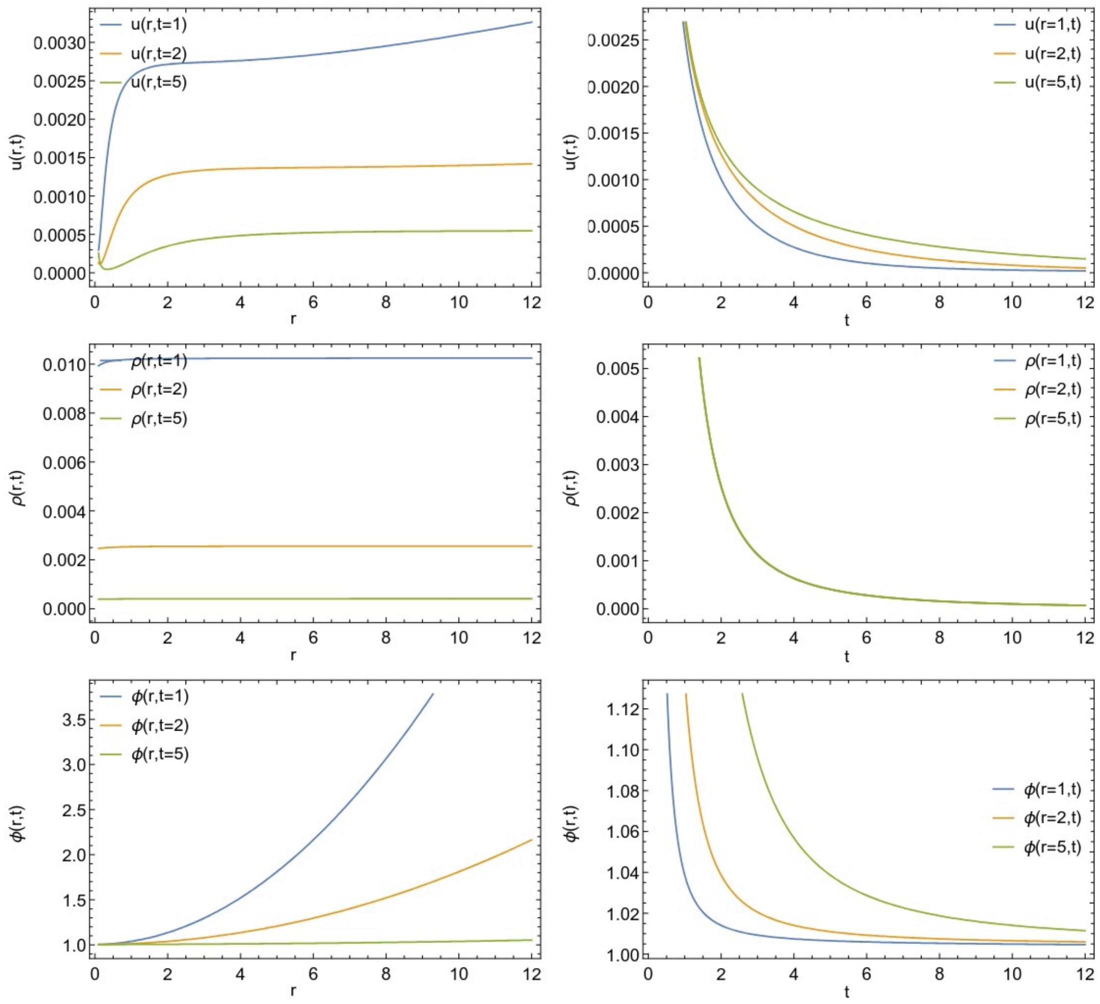
- **Non-rotating case:**
  - Radial velocity and density profile decreases with time
  - Density and velocity profiles are different in radius, but both are increasing.
  - Gravitational potential are decreasing hyperbolically with time, and becomes asymptotically flat.

- **See in** [Universe 9 (2023) 431]



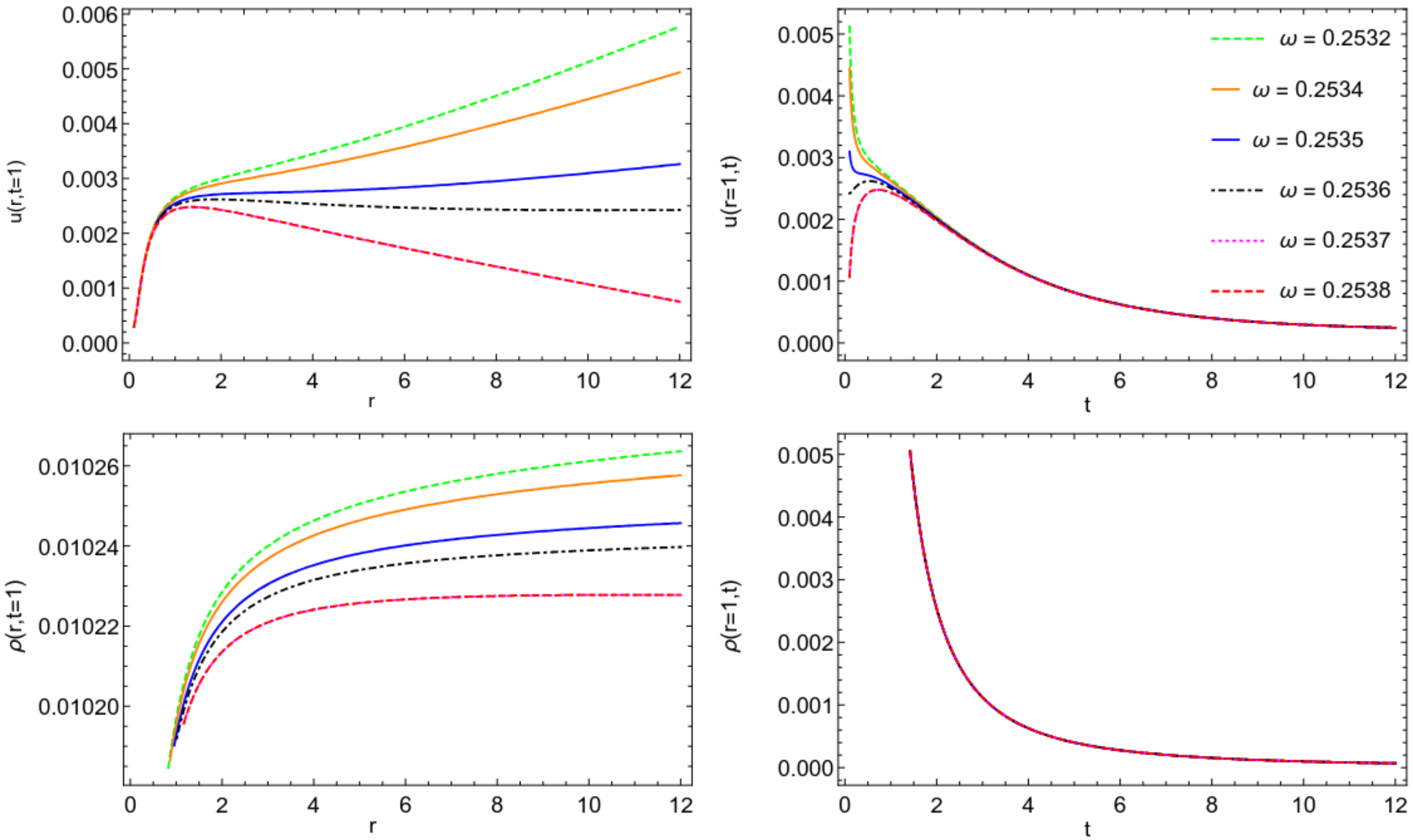
Self-similar solutions

- **Rotating case:**
  - Radial velocity and density profile decreases with time
  - Density and velocity profiles are different in radius: velocity curves have plateau and density become flat.
  - Gravitational potential are decreasing hyperbolically with time, and becomes asymptotically flat.
- **See in** [Universe 9 (2023) 431]



Self-similar solutions

- **Rotating case:**
  - Radial velocity and density as a function of time at different rotation have nice asymptotic limit.
  - Both velocity and density profiles are changing well with rotation.
  - Maximal rotation exists certainly.
- **See in** [Universe 9 (2023) 431]



Resolving the Hubble tension

Connection to Hubble parameter

- **Expansion rate & the Hubble parameter:**
  - Relative distance with the scale: $R(t) = a(t)\, l$
  - Assuming the mass conservation:

$$\frac{\mathrm{d}}{\mathrm{d}t}M(t) = 4\pi\frac{\mathrm{d}}{\mathrm{d}t}\int \rho(a(t)l,t)\, a^3(t)\, l^2\,\mathrm{d}l \stackrel{!}{=} 0 \longrightarrow \rho(a(t)l,t)\frac{\mathrm{d}}{\mathrm{d}t}\left[\rho(a(t)l,t)\right] = -3\frac{\dot{a}(t)}{a(t)}$$

  - Kinematical condition:

$$\frac{\mathrm{d}}{\mathrm{d}t}R(t) = u(R(t),t) \Rightarrow \frac{1}{g(R(t),t)}\frac{\mathrm{d}}{\mathrm{d}t}\left[t^{-\gamma}g(R(t),t)\right] = -3\frac{t^{-\alpha}f(R(t),t)}{R(t)}$$

with the solution:

$$R(t) = u_1 t^{\beta+\frac{\gamma}{\kappa}}\exp\left[-\frac{3u_1t^{\mu}}{\mu\kappa}\right]\times\left[3^{-\frac{\gamma}{\mu\kappa}}u_2t^{\gamma/\kappa}\left(\frac{u_1t^{\mu}}{\nu}\right)^{-\frac{\gamma}{\mu\kappa}}\Gamma\left(1+\frac{\gamma}{\nu},\frac{3u_1t^{\mu}}{\nu}\right)-\mathcal{H}_1u_1\right]^{-1}.$$

Connection to Hubble parameter

- **Expansion rate & the Hubble parameter:**
  - In the solution we assume a Taylor exp:

    $u(r,t) \sim u_1\zeta^1 + u_2\zeta^2$

    then, relative distance can be given:

    $$R(t) = \frac{t}{\mathcal{H}_1 t^{\frac{3u_1-2}{\kappa}} + \frac{3u_2}{2-3u_1}}, \quad \text{where } \kappa = \frac{6}{7}.$$

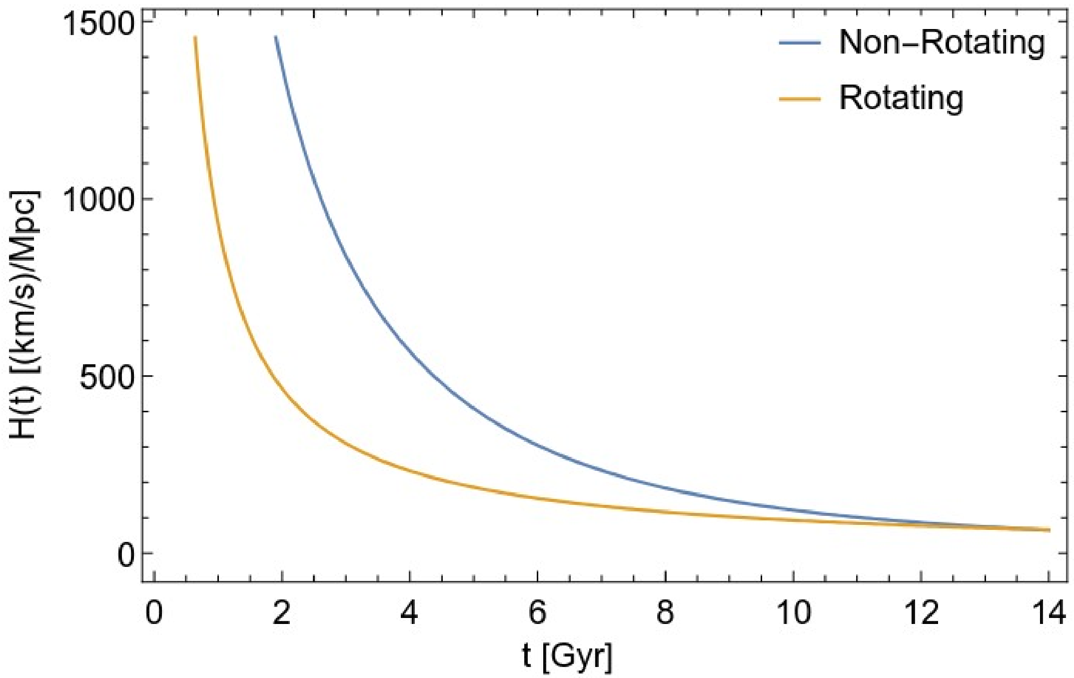
  - From the integration constant:

    $$\left.\frac{\dot{a}(t)}{a(t)}\right|_{t=t_0} = H_0, \text{ if } \quad a(t_0) = 1$$

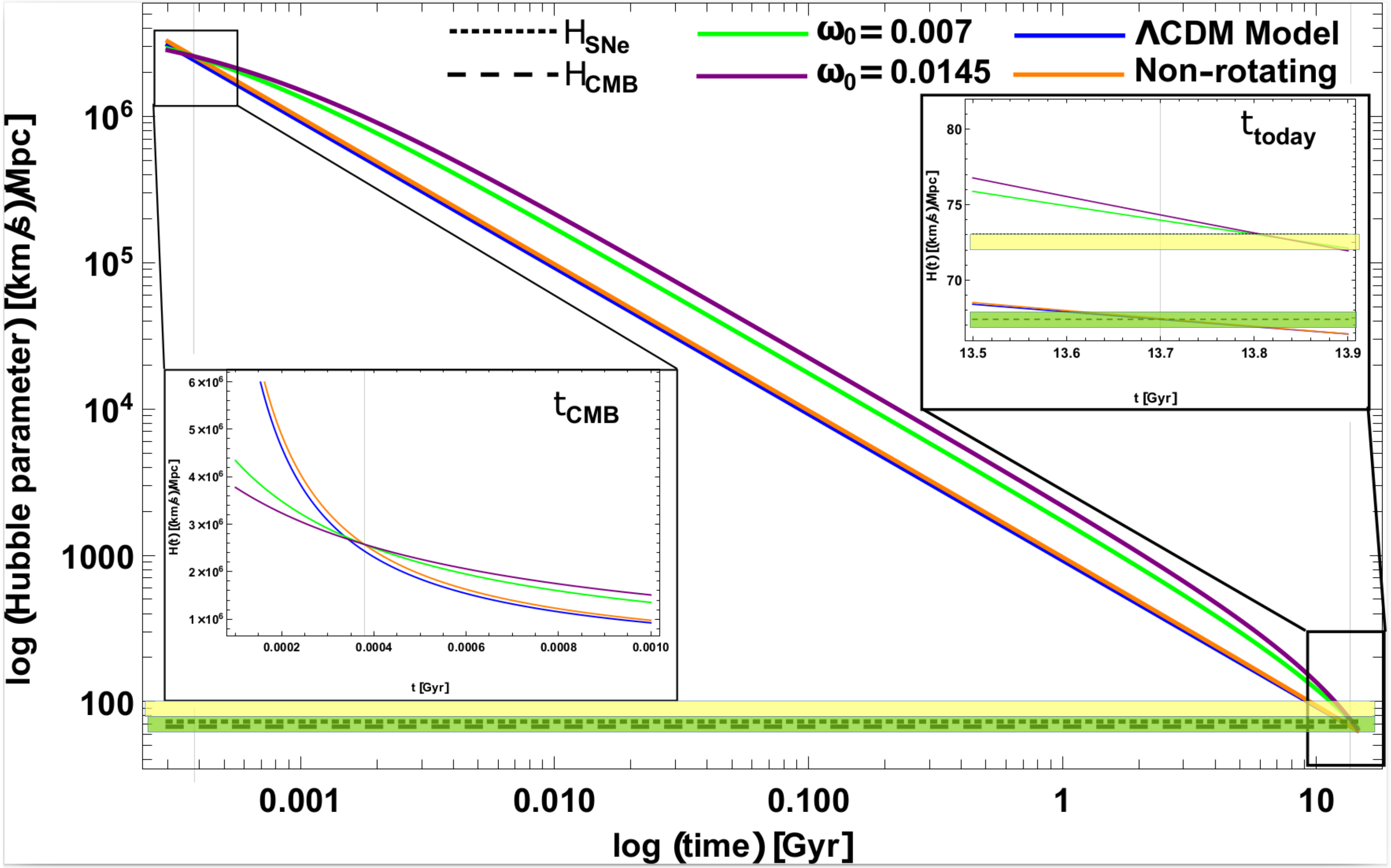
  - For Eucledian (flat) Universe (today):

$$H_0 = 66.6^{+4.1}_{-3.3} \text{ km/s/Mpc}$$

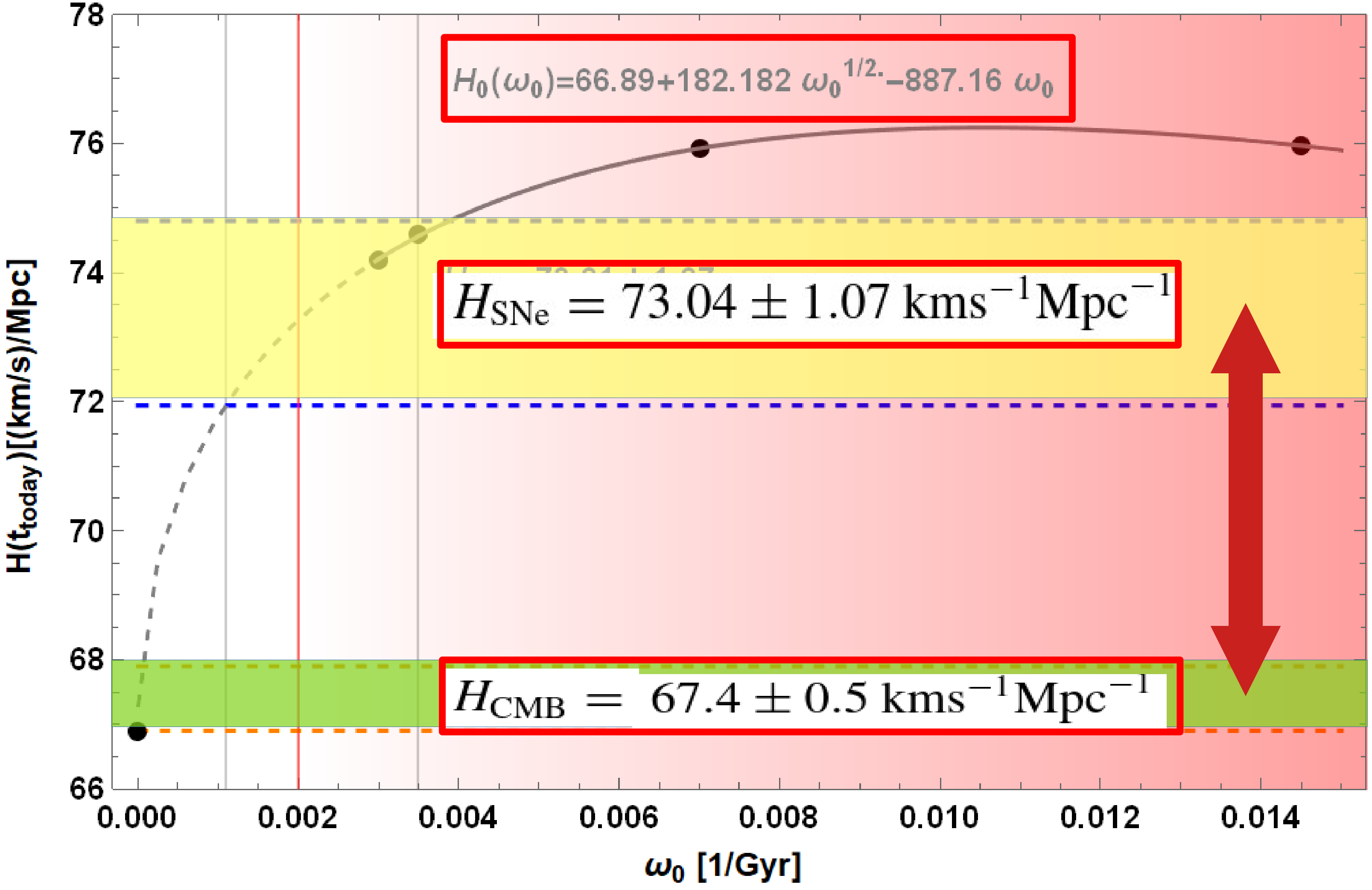
$$\left.\frac{\Omega_M(t)}{\Omega(t)}\right|_{t=t_0} \sim \left.\frac{E_{kin}(R(t),t)}{E_{tot}(R(t),t)}\right|_{t=t_0} = 0.26$$



The calculated Hubble parameter



Hubble parameter in rotating Universe



Discussion of the rotation

- **The rotation of the Universe:**

  - Today, the rotation of the Universe is: $\omega_0 = 0.002^{+0.001}_{-0.0009}\ \mathrm{Gyr}^{-1}$

  - Rotation at the CMB, this value was: $\omega(t_{\mathrm{CMB}}) = 3.54^{+1.3}_{-1.2}\ \mathrm{Myr}^{-1}$

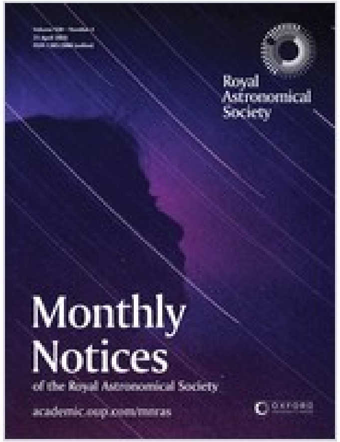
  - Since angular rotation approximately $|\boldsymbol{\omega}(t)| = \omega_0 a^{-2}(t)$ and assuming the speed should be below the speed of light $\omega \lesssim H$, then taking $H(a) \sim a^{-3/2}$, one can estimate the rotation limit today:

    → The result is the maximal rotation, which is below the observational limit, but also compatible with many rotational models:

    $$\omega_0 \lesssim H_0 a^{1/2}(t_{\mathrm{eq}}) \simeq 0.002\ \mathrm{Gyr}^{-1}$$

Summary

- **παντα κυκλουται!**
  - Classical Newtonian model with dark matter with Sedov – von Neumann – Taylor self similarity
  - The Universe is rotating at maximal angular velocity today: 500 billion year/rotation, which resloves the Hubble tension
  - Compatibility with measurements and other theoretical approaches
- **News & youtube videos:**
  - Video1, Video2, Anton Petrov Video, Rakéta, NewsWeek, ScienceAlert, Iflscience, ScienceAlert, Studyfinds, Rakéta - report, Cosmos Magazine, AstroBite, ScienMag, Message to Eagle, The Universe Today, Brian Koberlein, Enholm, EarthSky, Studyfinds, The Debrief, SpaceWeekly



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πάντα κυκλουται!
πάντα ῥεῖ!