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# Testing Dipole Radiation with NSs

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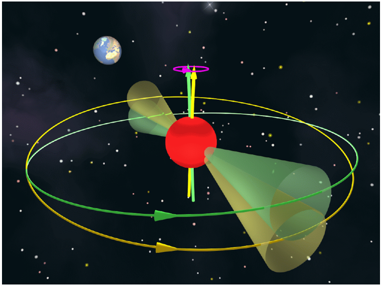
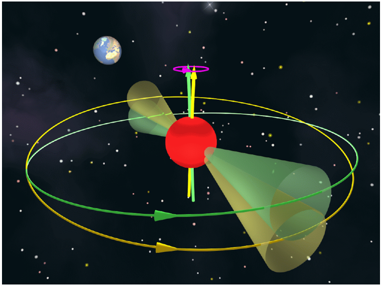
# Pulsars

- Pulsars are rotating magnetized neutron stars



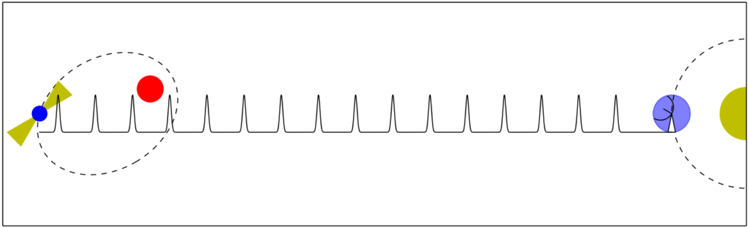
# Pulsars

- Pulsars are rotating magnetized neutron stars
- Due to their large moment of inertia and small external torque, their rotation is extremely stable $\Rightarrow$ lighthouse



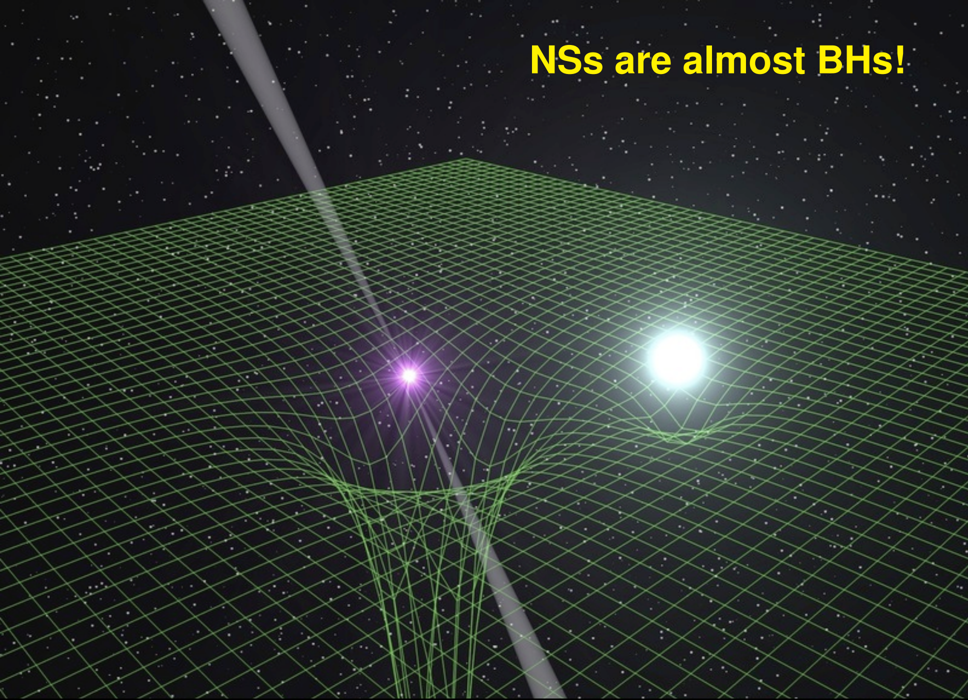
# Pulsar Timing

- Large radio telescopes are used to record the times of arrival of pulses, which are affected by
  - Solar dynamics
  - **Binary motion**
  - Interstellar medium



# Fundamental clocks in curved spacetime

# Monster of Spacetime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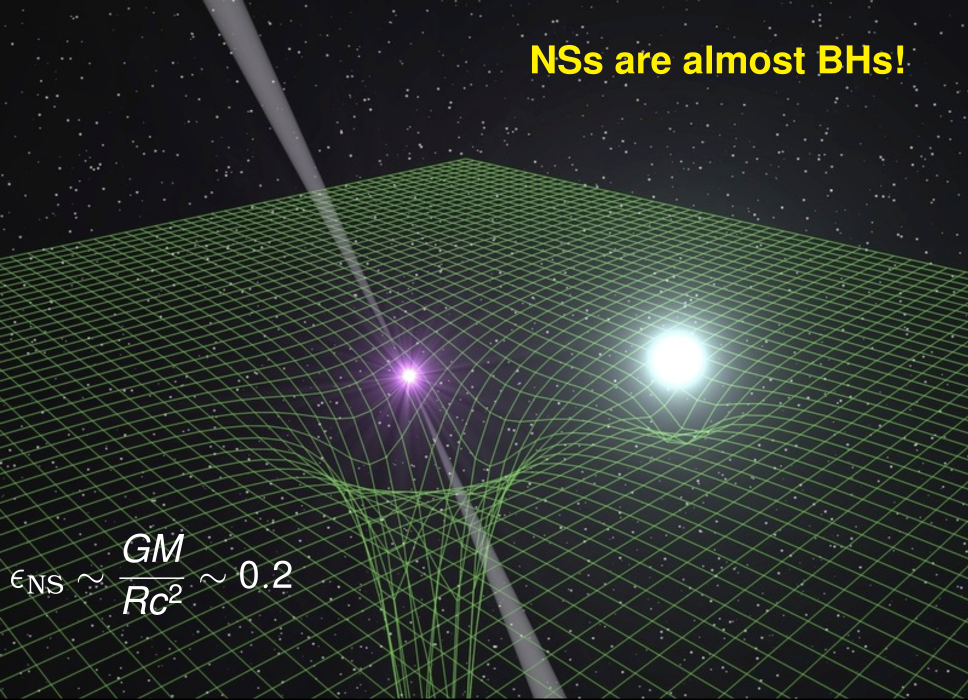
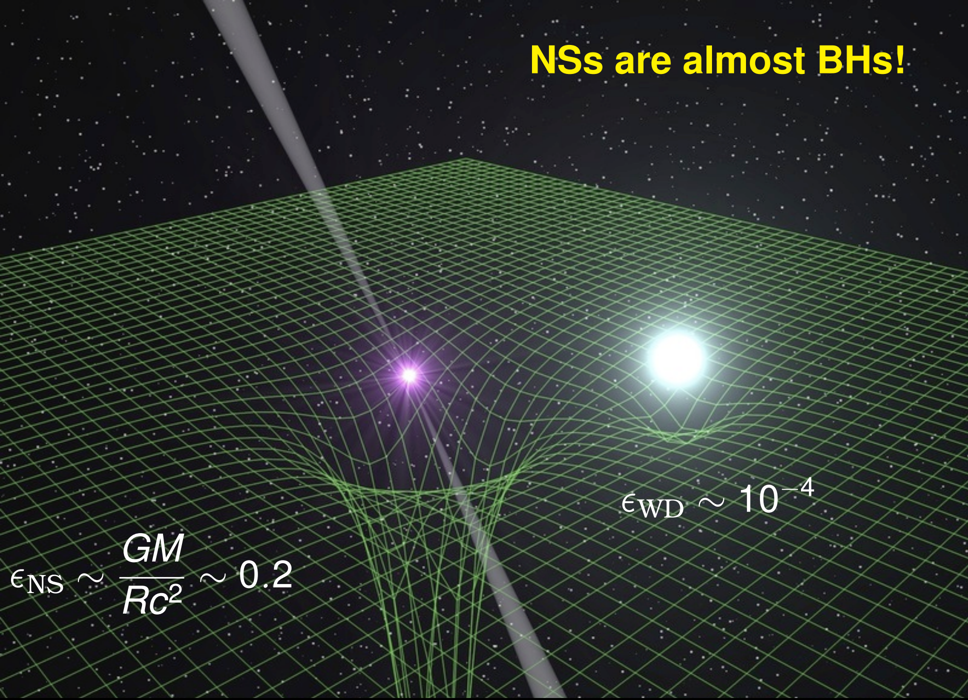
# NSs are almost BHs!



$$\epsilon_{\rm NS} \sim \frac{GM}{Rc^2} \sim 0.2$$



# NSs are almost BHs!

$$\epsilon_{\rm NS} \sim \frac{GM}{Rc^2} \sim 0.2$$

$$\epsilon_{\rm WD} \sim 10^{-4}$$

# Scalar-Tensor Gravity

$$S = \frac{c^4}{16\pi G_*} \int \frac{\mathrm{d}^4 x}{c} \sqrt{-g_*} \left[ R_* - 2g_*^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V(\varphi) \right] + S_m \left[ \psi_m ; A^2(\varphi) g^*_{\mu\nu} \right]$$

Damour & Esposito-Farèse 1992; 1993; 1996

# Scalar-Tensor Gravity

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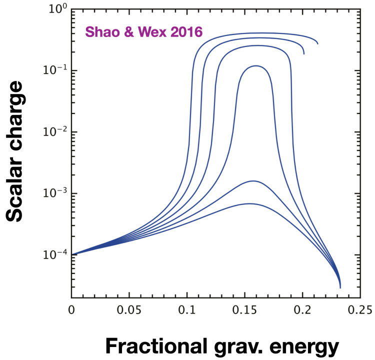
- A class of cosmologically well-motivated scalar-tensor theories, that are solely described by two theory parameters: $\alpha_0$ & $\beta_0$

$$V(\varphi) = 0$$

$$A(\varphi) = \exp\left(\beta_0 \varphi^2 / 2\right) , \quad \alpha_0 = \beta_0 \varphi_0$$

Damour & Esposito-Farèse 1992; 1993; 1996

# Scalar-Tensor Gravity

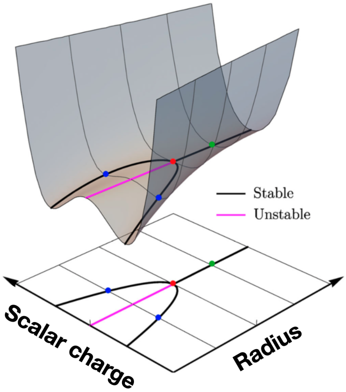



*Nonperturbative* **spontaneous scalarization**

could happen for isolated neutron stars

Damour & Esposito-Farèse 1992; 1993; 1996

# Scalar-Tensor Gravity

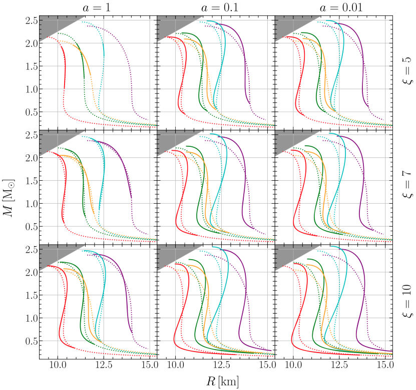



**Strong-field** behavior is analogous to **Landau's phase transition** after a critical point

Damour & Esposito-Farèse 1996; Esposito-Farèse 2004; Sennett, Shao, Steinhoff 2017

# Massive Scalar-Tensor Gravity

- When a mass term is included, say $V(\varphi) \sim m^2\varphi^2$, a Yukawa-type suppression happens for the deviation

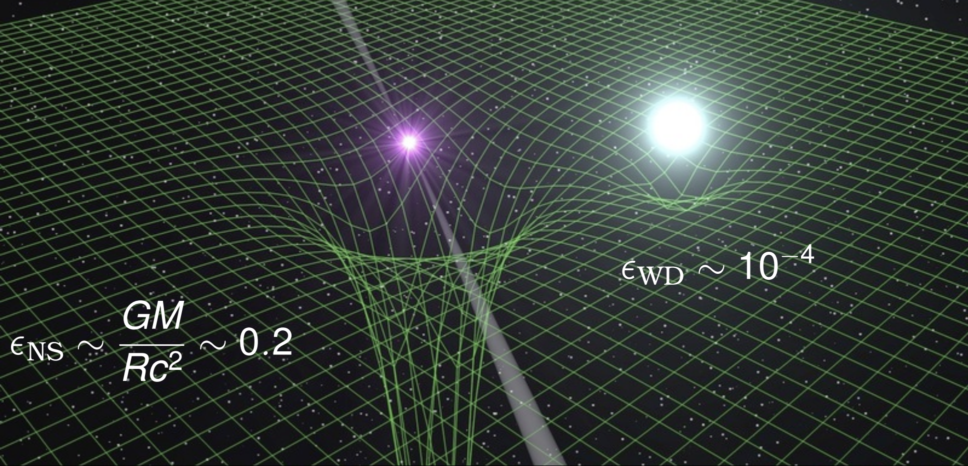



Ramazanoğlu & Pretorius 2016; Xu, Gao, Shao 2020; Hu, Gao, Xu, Shao, in prep

**Strong-field gravity can be VERY different from weak-field gravity**

# Scalar-Tensor Gravity

Due to their **asymmetry**, neutron-star white-dwarf systems provide stringent limits on dipole radiation $\dot{P}_b^{\rm dipole} \propto (\alpha_{\rm NS} - \alpha_0)^2$

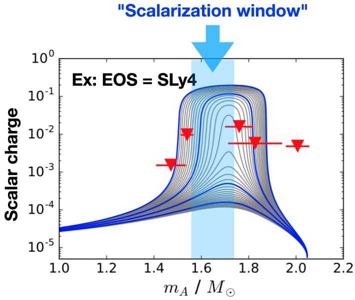


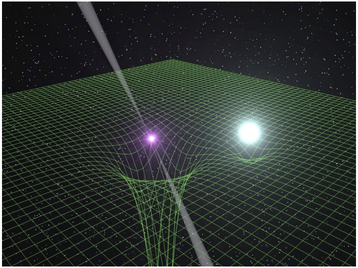
$$\epsilon_{\rm WD} \sim 10^{-4}$$

$$\epsilon_{\rm NS} \sim \frac{GM}{Rc^2} \sim 0.2$$

# Combination of Multiple NS-WD Binaries

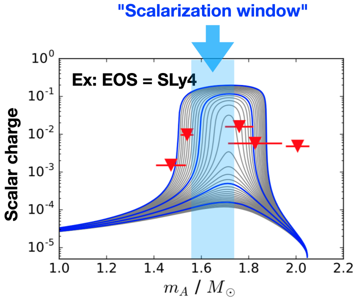
- Strong-field effects could happen at different NS masses for different EOSs [Shibata et al. 2014, PRD 89:084005]

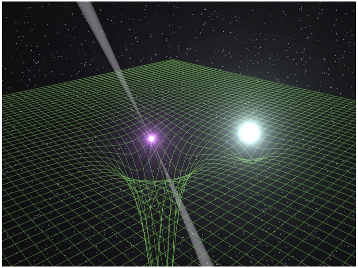


# Combination of Multiple NS-WD Binaries

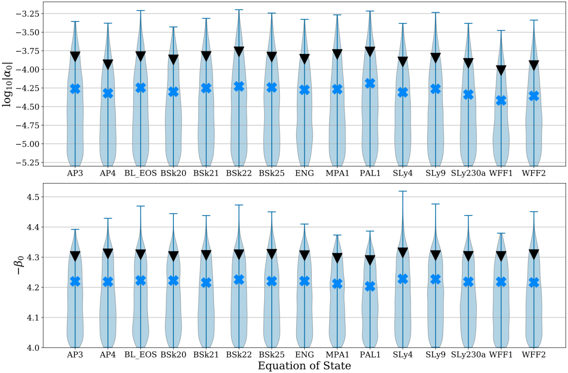
- Strong-field effects could happen at different NS masses for different EOSs [Shibata et al. 2014, PRD 89:084005]
- Combining NS-WDs put the best limits on a class of scalar tensor theories for different EOSs [Shao et al. 2017, PRX 7:041025]



# Combination of Multiple NS-WD Binaries

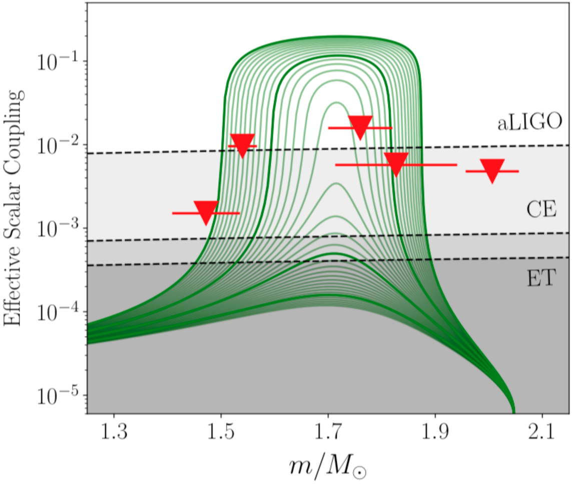
- Reduced-order surrogate models to speed up Markov-chain Monte Carlo runs: **pySTGROM**,[1] & **pySTGROMX**[2]




[1] https://github.com/BenjaminDbb/pySTGROM
[2] https://github.com/mh-guo/pySTGROMX

Zhao, Shao, et al. 2019
Guo, Zhao, Shao, arXiv:2106.01622

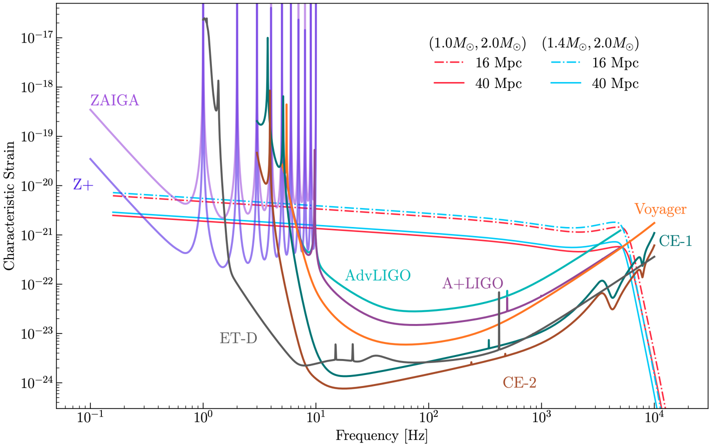
# Gravitational Waves




Will 1994; Damour & Esposito-Farèse 1998; Shao et al. 2017, PRX

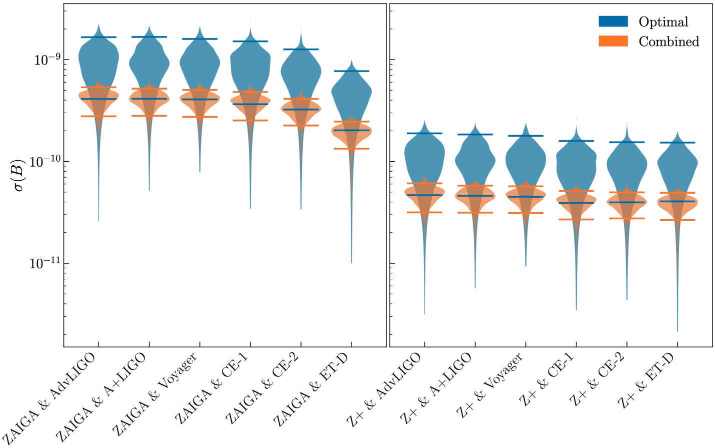
# Gravitational Waves

**laser interferometers & atom interferometers**




Esposito-Farèse 1998; Zhao, Shao, et al., arXiv:2106.04883

# Gravitational Waves

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# Summary

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- Radio telescopes, ground-based laser/atom interferometers, as well as space-based GW detectors [Liu, Shao, Zhao, Gao 2020] can be utilized to achieve high-precision tests of dipole radiation

# Summary

- Testing dipole radiation is an important part for validating the strong equivalence principle, thus GR
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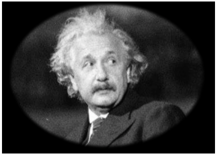
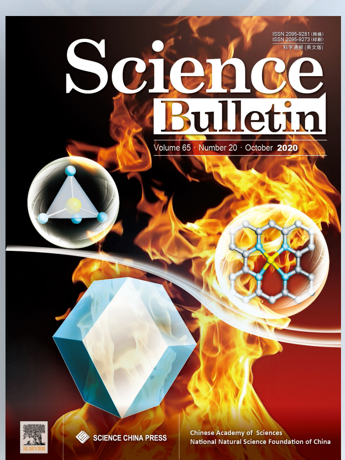
**We will see ;-)**



# An Oriental Express of Science to the World

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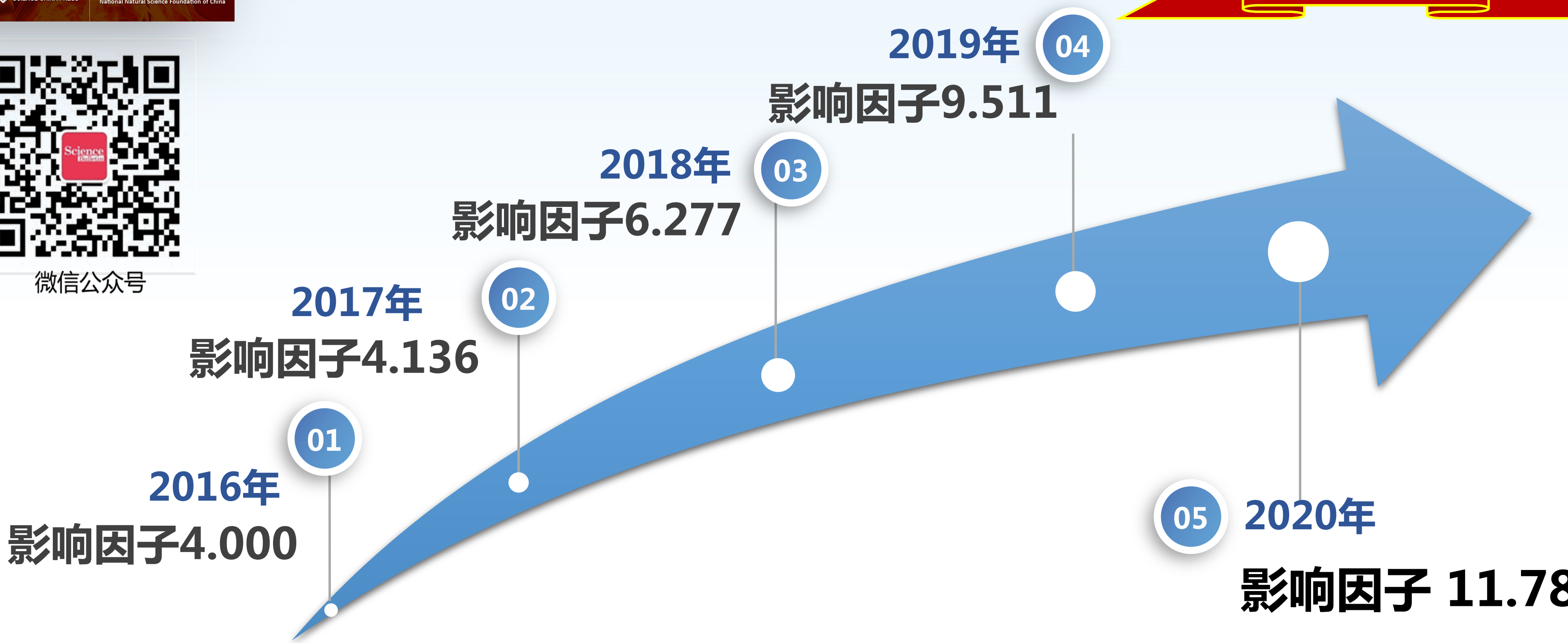


Thank you!