Observing GR Effcts and Mass of the Massive BH at the Center of our Galaxy

– GR and BH by Subaru Telescope –

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+ Members of our Plan
  using Subaru Telescope

- Test.Grav.2017, 2017.01.26–28 (talk on 26)
- JGRG26, 2016.10.24–28 (talk on 28)

Direction of our plan

- We will to measure GR effects of
  an extreme-mass-ratio BH-star system
  by ele-mag waves (IR).
- Future expectation: Compare to LISA's results!?

List of members :

observaion & data analysis	theory & data fitting
Shogo Nishiyama	Hiromi Saida — talk here
Yoshifusa Ita	Yosuke Takamori
Masashi Omiya	Masaaki Takahashi
Satoshi Hamano	

1. Introduction

1.1 "Direct" BH Observation

- By BH Uniqueness Thm, we define ...

Direct BH Obs.

It is to measure the mass and spin of BH through observing directly GR effects of a BH.

◇ 1st example is the aLIGO's GW detection.

◇ No example by Ele-Mag Wave (EMW) obs.

→ Our interest: **"Direct" BH obs. by EMW**

1.2 Our Target

- Sagittarius A* (**Sgr A***)

$\rightarrow$ Massive BH candidate at the center of our galaxy with present estimations (Boehle et al 2016):

Mass :	$M_{\mathrm{SgrA}} \simeq 4.02 \times 10^6 \, M_\odot$ (4% error)
Spin :	$a_{\mathrm{SgrA}} \cdots$ no consensus
Distance :	$D_{\mathrm{SgrA}} \simeq 7.86$ kpc (2% error)

$\rightarrow$ Present estimations are obtained by

Newtonian fitting of stars orbiting Sgr A*.

$\because$ mag. of GR effects $<$ present error bars

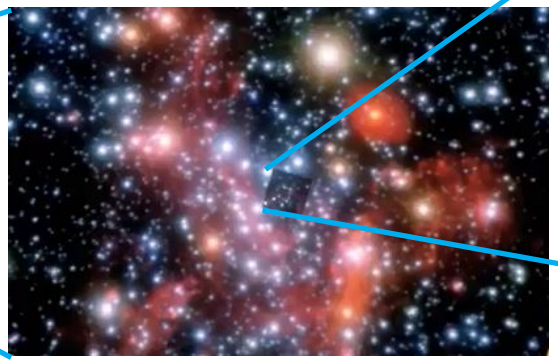
2. Our Current Plan

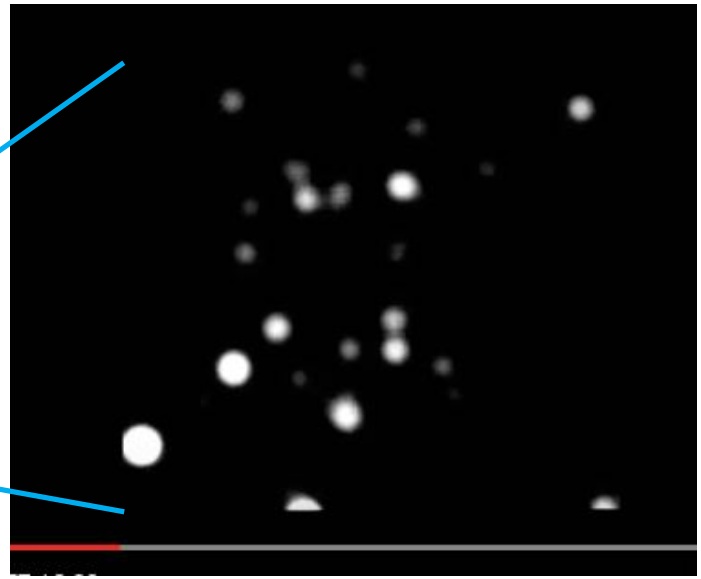
2.1 S-stars: S0-2 (S2) as the probe

- Some stars orbiting Sgr A* (S-stars) are resolved.

Towards the Galactic Center
Stars Orbiting Sgr A*
by ESO, Gillessen & Genzel

near-Infrared observations





- **Newtonian 2-body cal. of each star agrees with 15 years data within present error-bars.**

→ The "S2" orbits Sgr A* with the shortest period (16-year-period) in known S-stars.

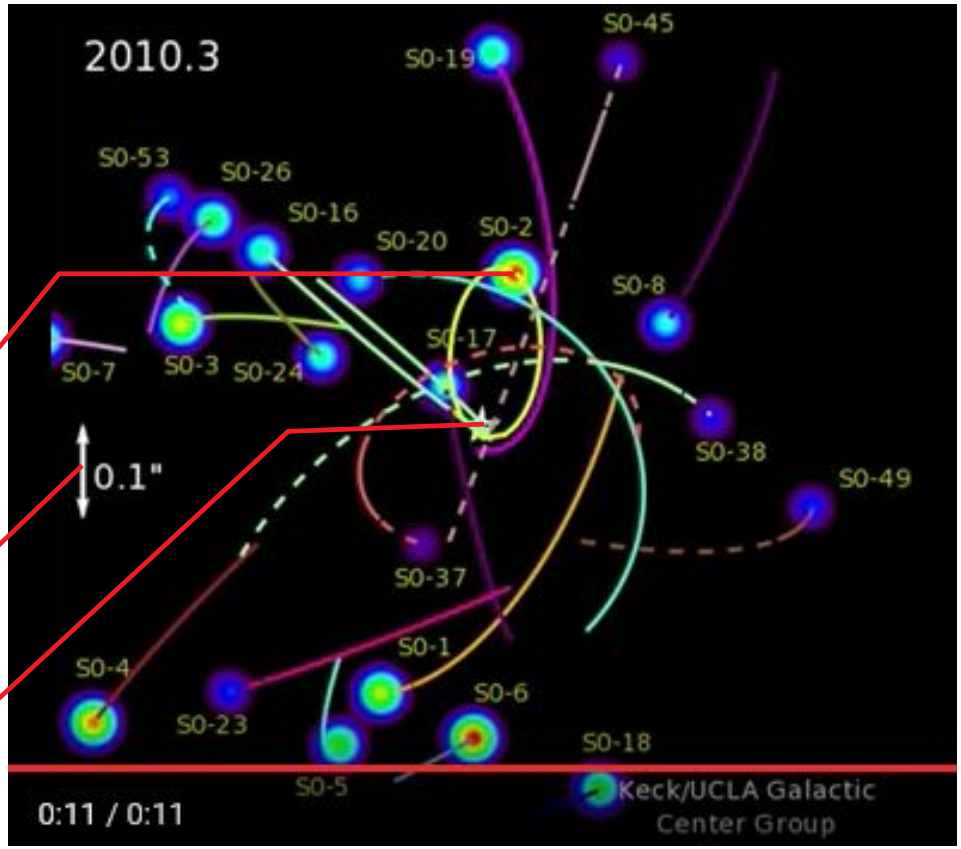
S-stars

Newtonian fitting with IR obs. data by Keck/UCLA

S0-2 (S2)

length $\sim 10^3$AU

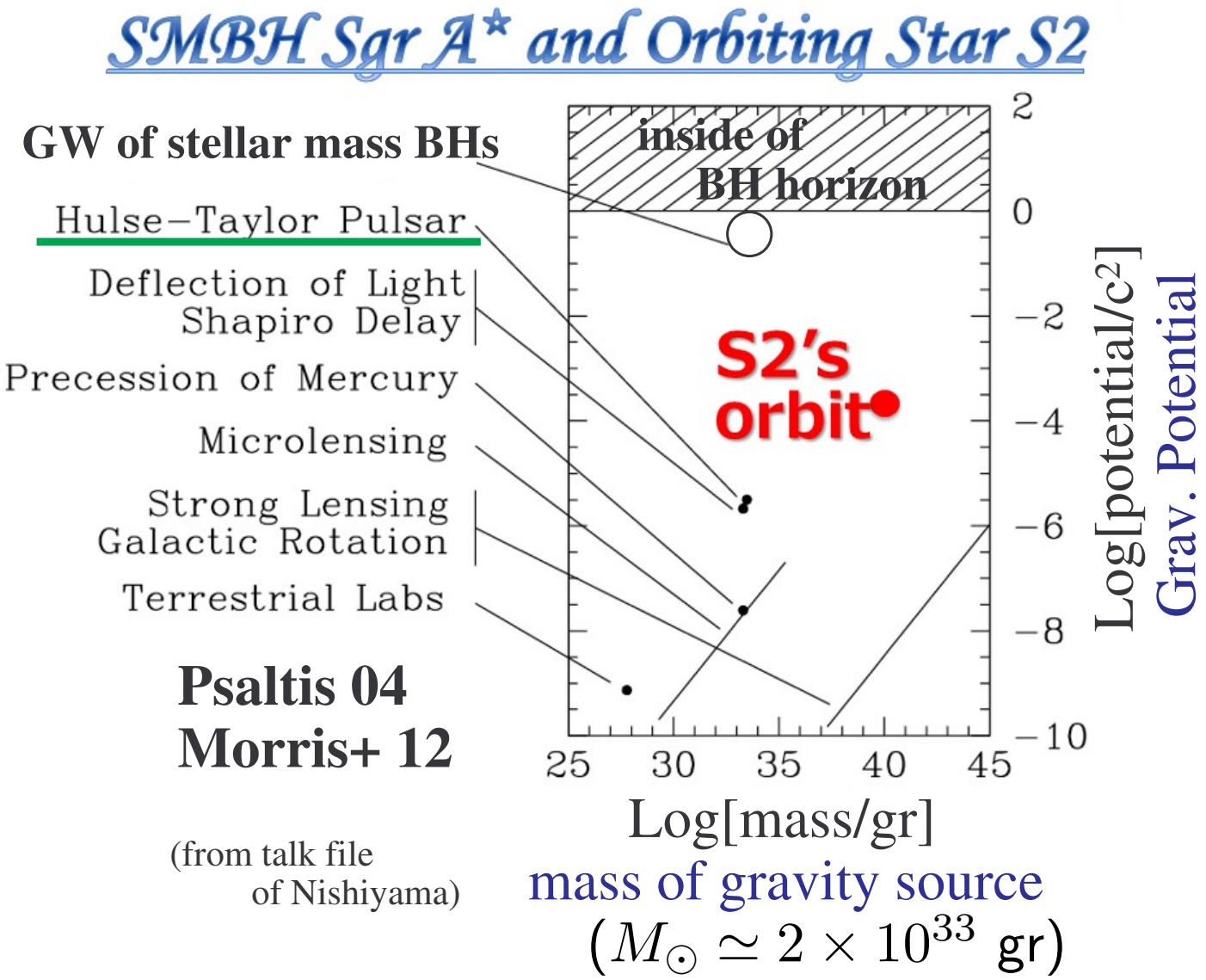
Sgr A*



- S2 has a short pericenter distance

$$\simeq 100 \text{ AU} \simeq 10^3 \frac{GM_{\rm SgrA}}{c^2}$$

S2 at pericenter (in 2018 !!) will experiene the strongest grav. potential ever observed by EM waves.



(from talk file of Nishiyama)

$\Downarrow$

Sgr A* + S2 can be a good laboratory for testing BH and GR by EM obs.

- 2-body system with Sgr A*

  $\rightarrow$ **S2 is the simple probe of BH's gravity.**

- The strongest gravity in EM wave obs.

  $\rightarrow$ **S2 is the "deep" probe for BH's gravity by EM wave observations.**

$\rightarrow$ We are observing S2 from 2014

by Subaru telescope (at Mt. Maunakea, Hawaii island)

2.2 Our Idea

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- Our obs. quantity:
  Redshift z of Infra-Red photon from S2

$$z := \frac{\lambda_{\rm obs}}{\lambda_{\rm S2}} - 1$$

◇ **Subaru telescope** is good for high precision obs. of z.

↔ US and Europe (Germany) groups seem to focus on high precision obs. of S2's position.

my photo

- GR effect observed by Subaru telescope:

$$\underline{\Delta z := z_{\text{Einstein}} - z_{\text{Newton}}}$$

$$\text{where} \begin{cases} z_{\text{Einstein}} & = z \text{ calculated in GR} \\ z_{\text{Newton}} & = z \text{ cal. in Newtonian grav.} \end{cases}$$

◇ GR-redshift z_{Einstein} is composed of

  ○ Timelike geodesic of S2 orbiting Sgr A*

  ○ Null geodesics of light rays from S2 to us

in Kerr spacetime.

◇ Current status of my calculation:

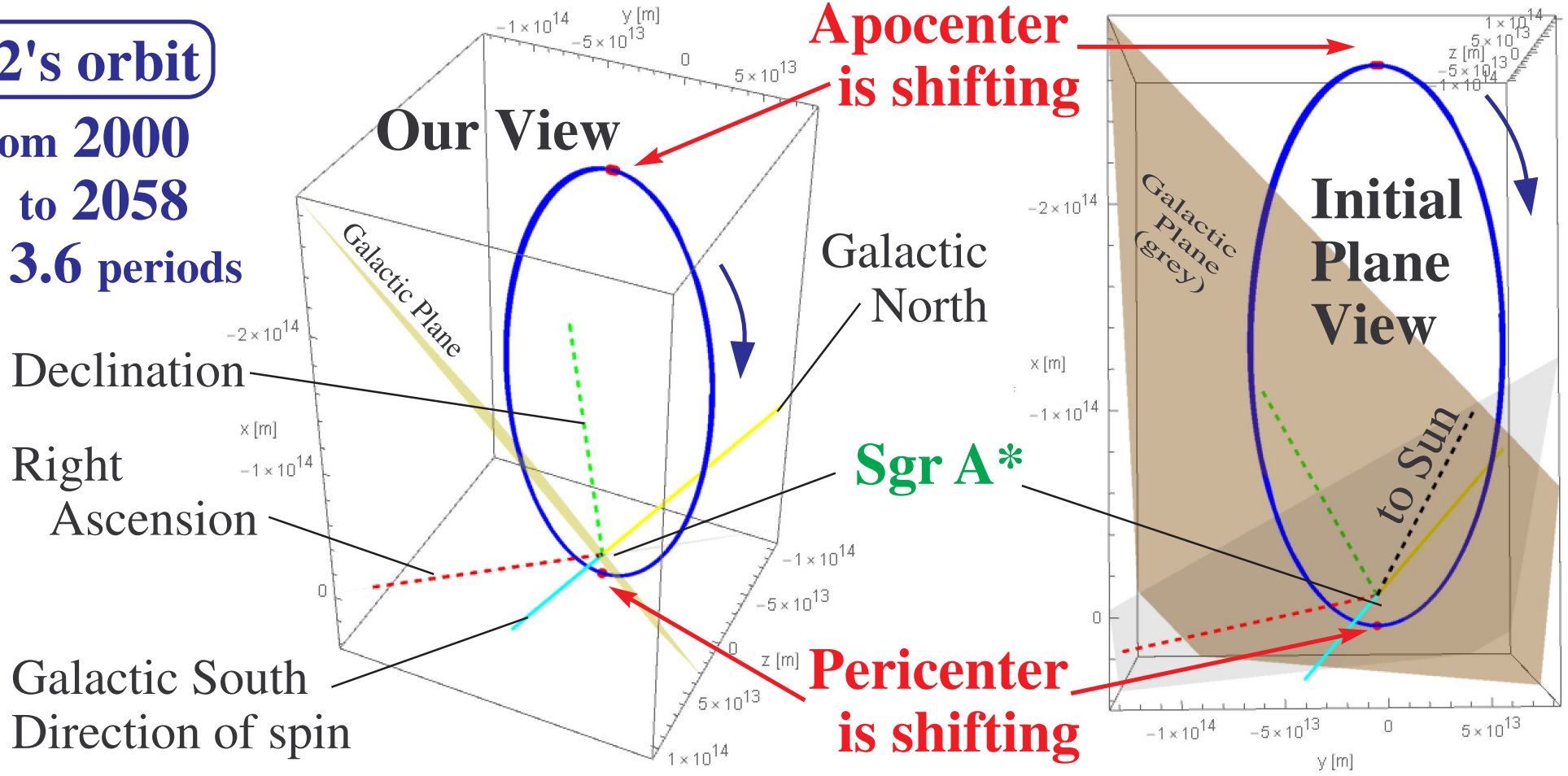
S2's motion by GR, but $\underline{\text{Light rays by SR}}$

(grav. redshift $<$ Subaru's resolution)

- Estimations assuming I.C. from Newtonian results,

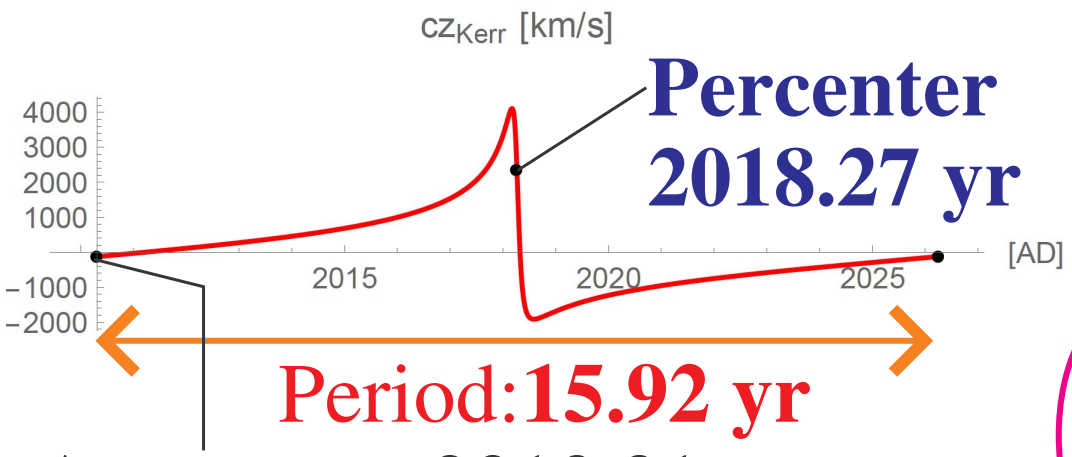
$$\begin{cases} M_{\mathrm{SgrA}} = 4.02 \times 10^6 M_\odot \text{ (from Boehle et al 2016)} \\ a_{\mathrm{SgrA}} = 0.98\, M_{\mathrm{SgrA}} \text{ (test value)} \end{cases}$$

S2's orbit
from 2000
to 2058
= 3.6 periods



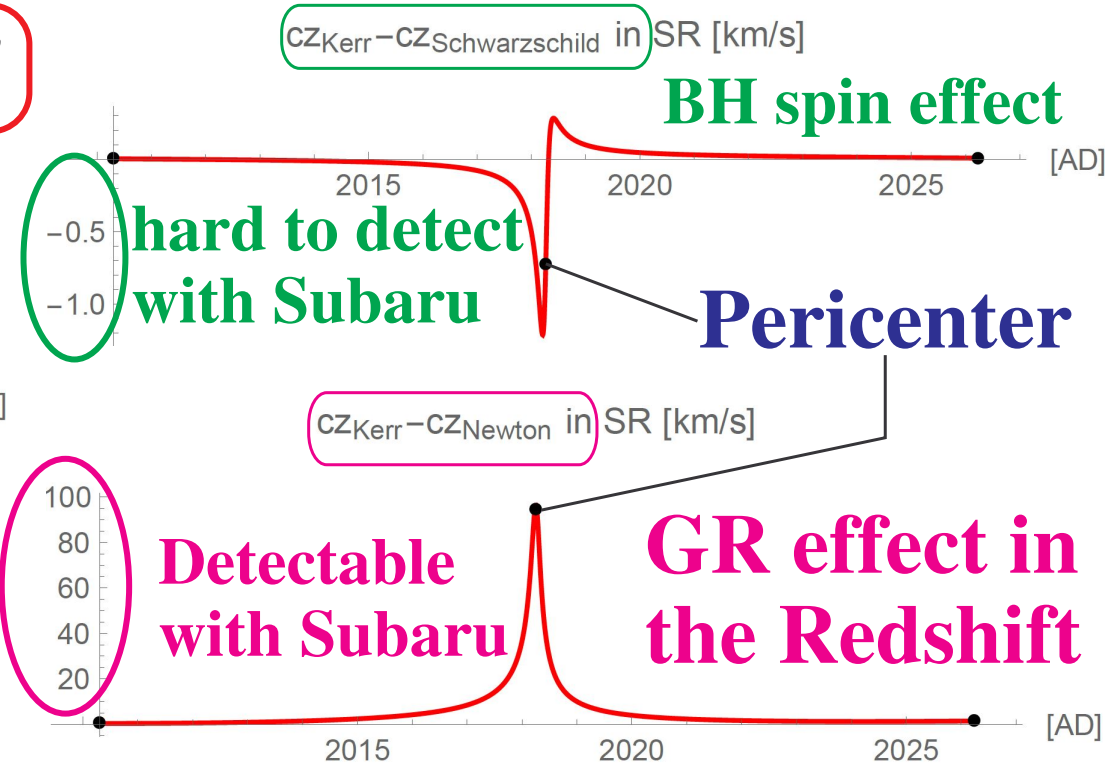
◇ Expected $cz_{\rm Einstein}$ and GR effects for 1 period

cz [km/s]: "Radial Velocity"



Apocenter: 2010.31 yr

I.C. from Boehle et al 2016

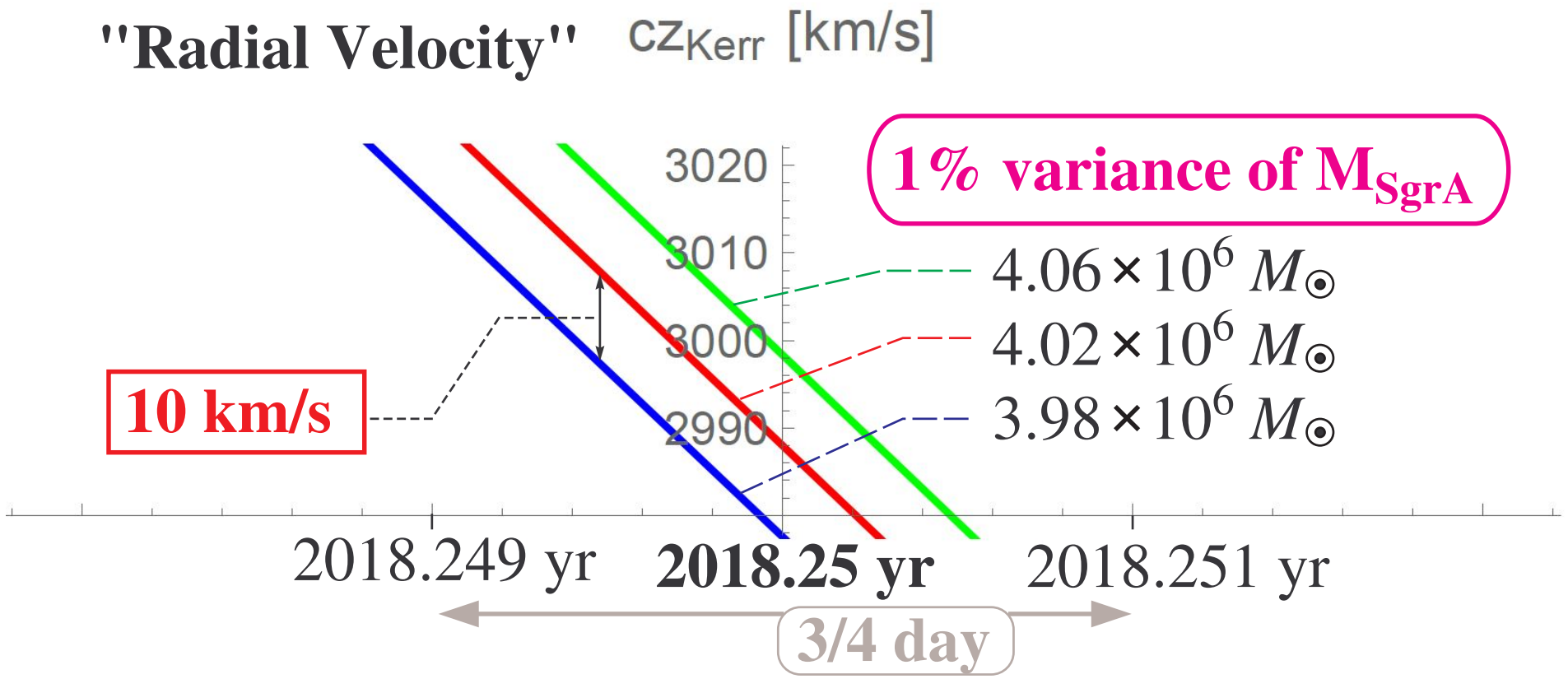


→ Max. of GR effect:

$$c\,\Delta z_{\rm max} \simeq \textbf{100 km/s} \text{ at } 2018.25 \text{ yr}$$

→ **We can measure with Subaru telescope.**

◇ Expected variance of M_{SgrA} near 2018.25



→ Accuracy of mass measurement:

1% var. of M_{SgrA} ⇔ **10 km/s** var. of cz

→ **We can measure with Subaru telescope.**

- Estimation by our Subaru observations
  - ◇ Our error (preliminary)

May.2014	Aug.2015	May.2016	Jul.2016
○	×	○	×
fair	mech. trouble	fine	bad seeing

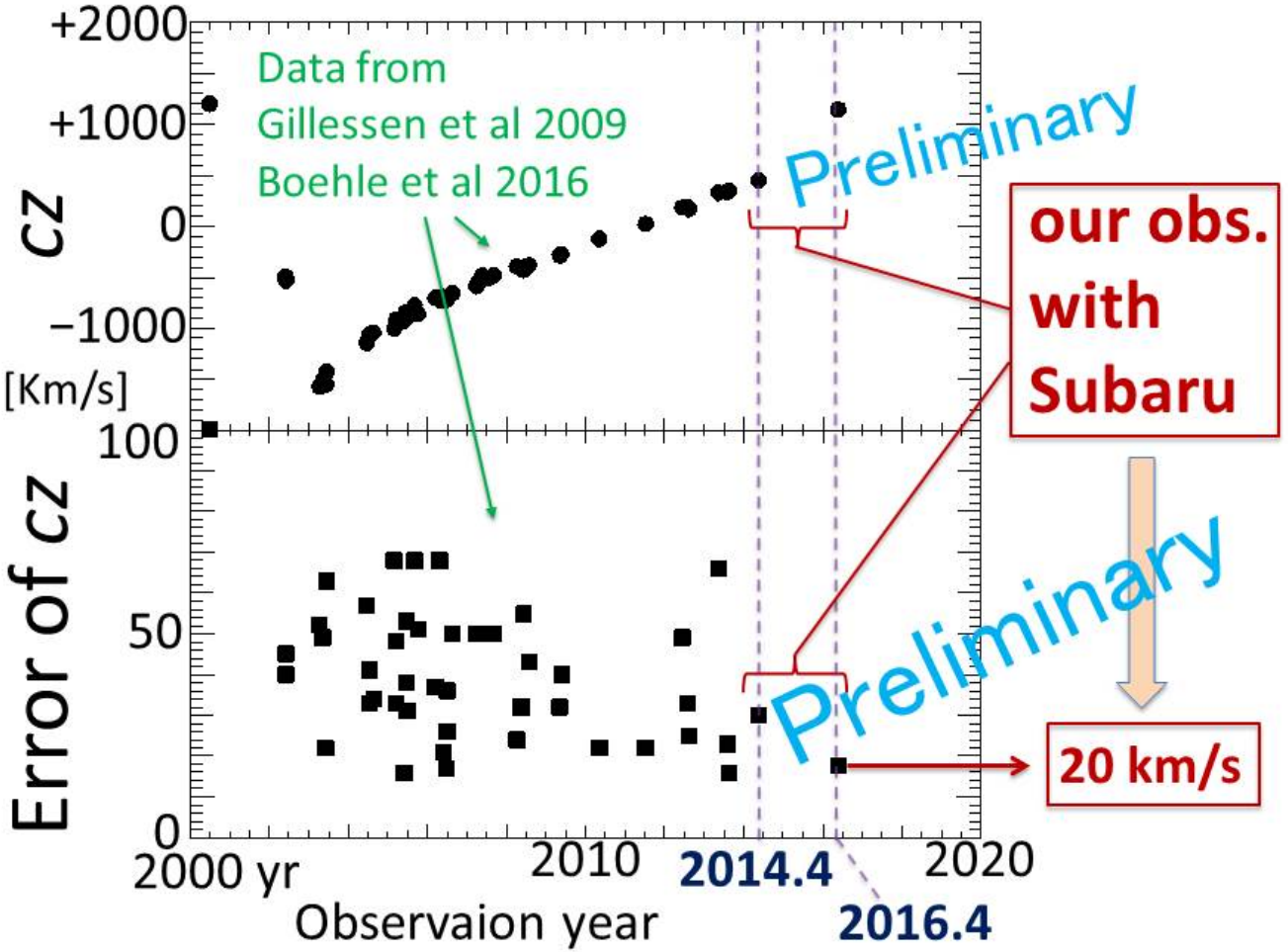
$\delta(cz) \sim 20$ km/s

Subaru's high resolution observation of cz

⇓

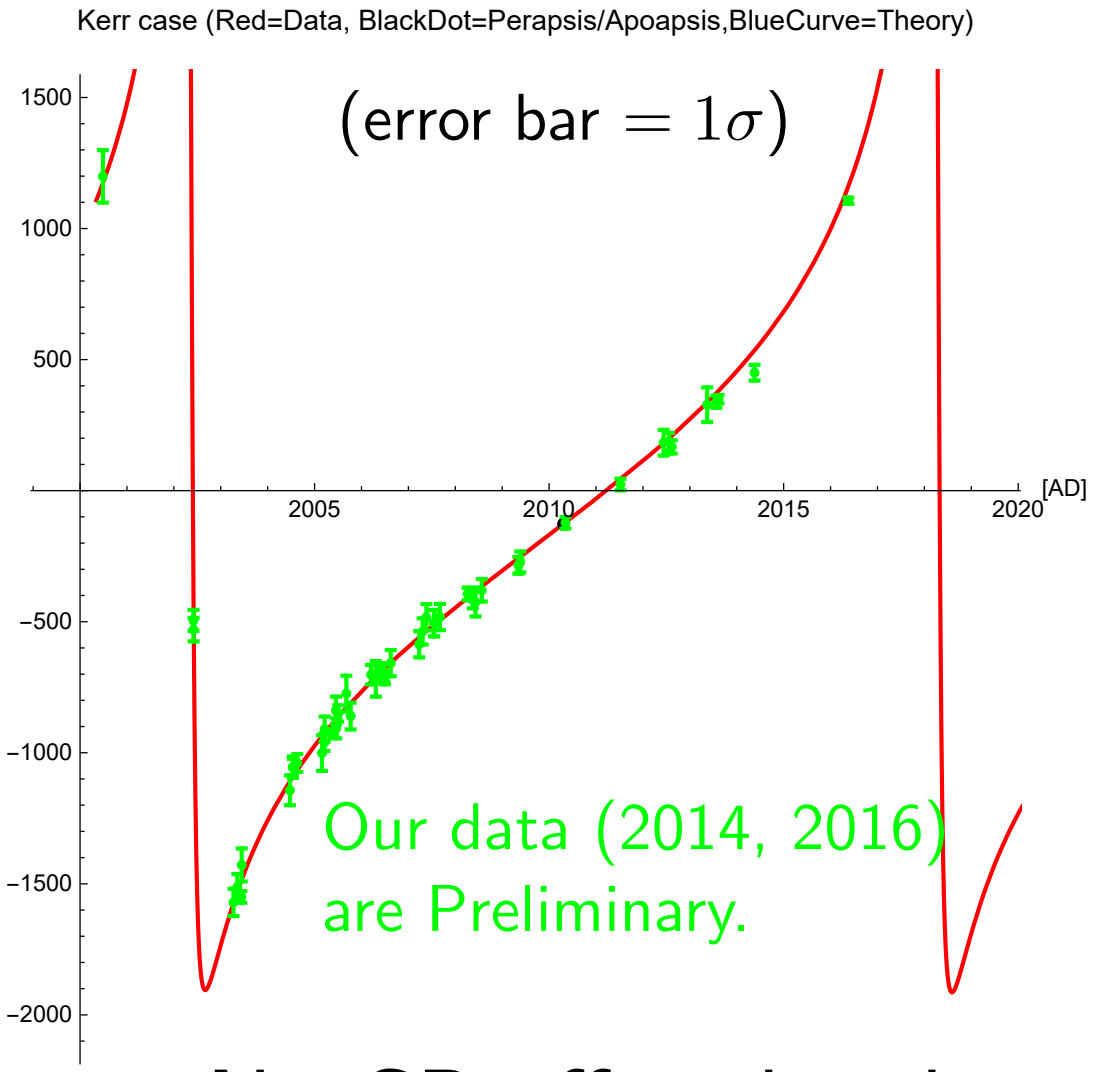
Taking more data until 2021, we aim to reduce

$\delta(cz) \rightarrow$ **10 km/s**

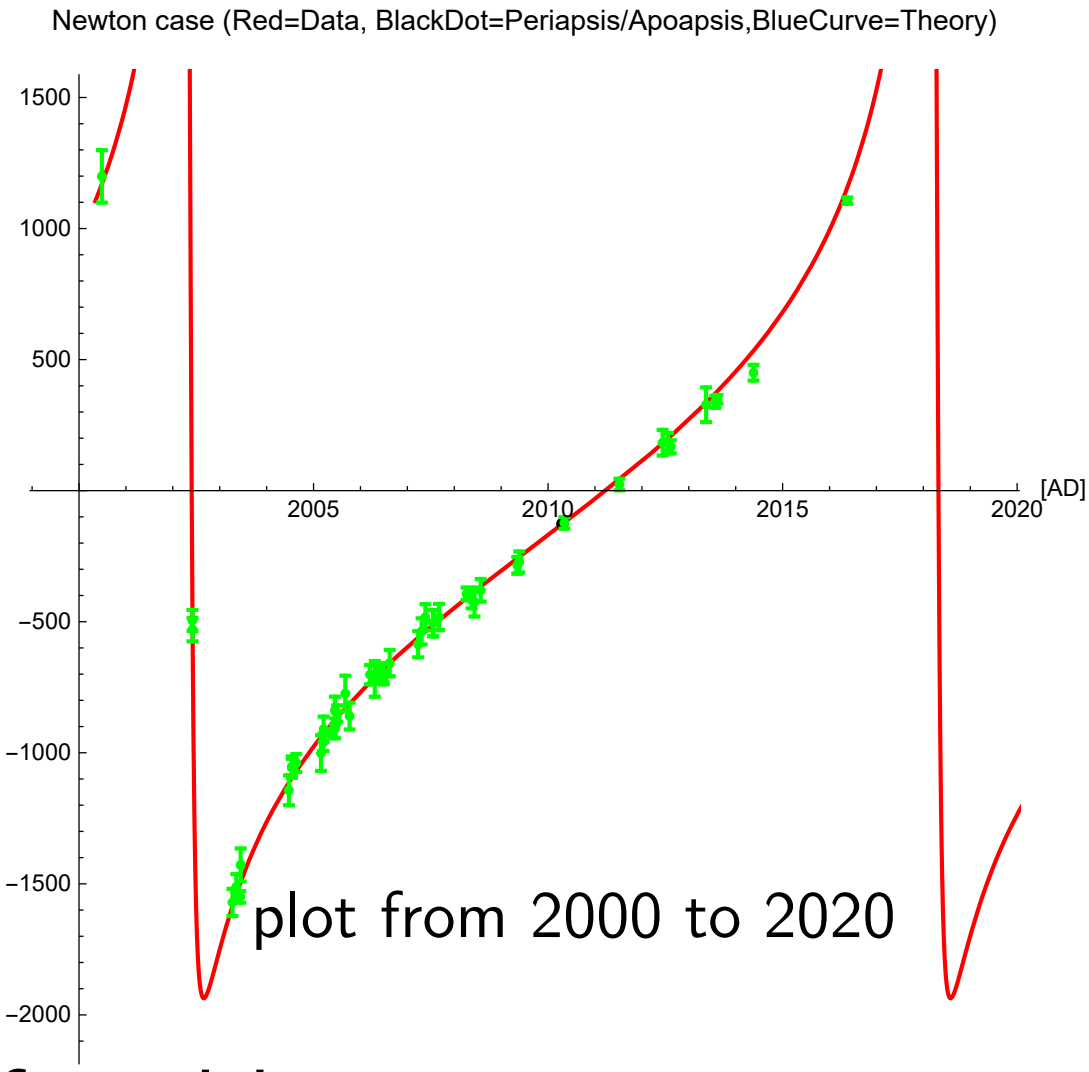


- Data and Current GR estimasion of cz

left: Kerr case



right: Newton case



$\longrightarrow$ No GR effect has been found by now.

3. Summary and Tasks

Our Aim, towards BH "direct" obs. by EMW

By performing

- Subaru observation of GR effect of Sgr A*
- GR fitting of those observational data

we aim to

- Detect GR effect of Sgr A* with 10σ precision
- Measure M_{SgrA} with 1% accuracy

and our current tasks are...

- Tasks for theoretical prediction

◇ Current I.C. of S2 motion is taken from
Newtonian fitting result at apocenter.

→ Under construction of numerical code for
full GR fitting of observational data.

◇ Current ray calculation is done with Special Rel.

∵ Grav. redshift effect $\sim$ a few km/s $<$ 10 km/s
Hard to detect by Subaru telescope.

→ Improve our calculation to solve null geodesics
for near future telescope. (ex. 30m telescope)

- Tasks for observation and data analysis

◇ Intense observation around 2018

→ Proposal to Subaru telescope

◇ Correction of observed spectrum

→ Making use of atmospheric absorption lines

◇ Elimination of errors

→ systematic, seasonal, etc...

I see Sgr A* as the laboratory of BH and GR.

— END —

—— Supplements ——

- S2's important evidences

◇ 2-body (S2+Sgr A*) Newtonian fitting goes well within the error-bars of present observational data.

◇ The strongest grav. potential ever observed by EMW is expected at S2's pricenter, 2018.

$$\Downarrow$$

S2 as a good probe of strong grav.

S2 will provide us with GR effects of Sgr A* (at least PN) by simple GR calculations.

(PN, 2PN or more $\cdots$ depend on telescope's capability.)

- Current estimation: — **Preliminary** —
  Monitoring observation of S2 until 2021 such as

year	2017	2018	2019	2020	2021
obs.	~~3~~ , 1 or 2 obs.	6 obs.	3 obs.	2 obs.	2 obs.

(1 obs. $=$ 0.5 night $\times$ 4)

  may produce the precision and accuracy:

  - Max. GR effect 100 km/s with Error 10 km/s

    $\rightarrow$ GR effect detection with precision $\sim 10\sigma$

  - 1% var. of M_{SgrA} by 10 km/s var. of cz

    $\rightarrow$ M_{SgrA} measurement with accuracy $\sim 1\%$