How to detect directly the black hole parameters

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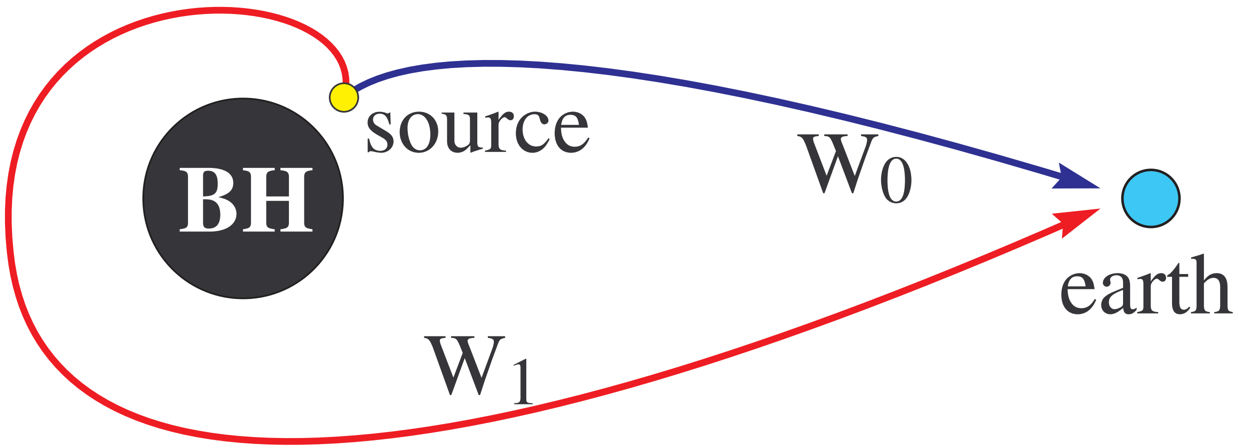
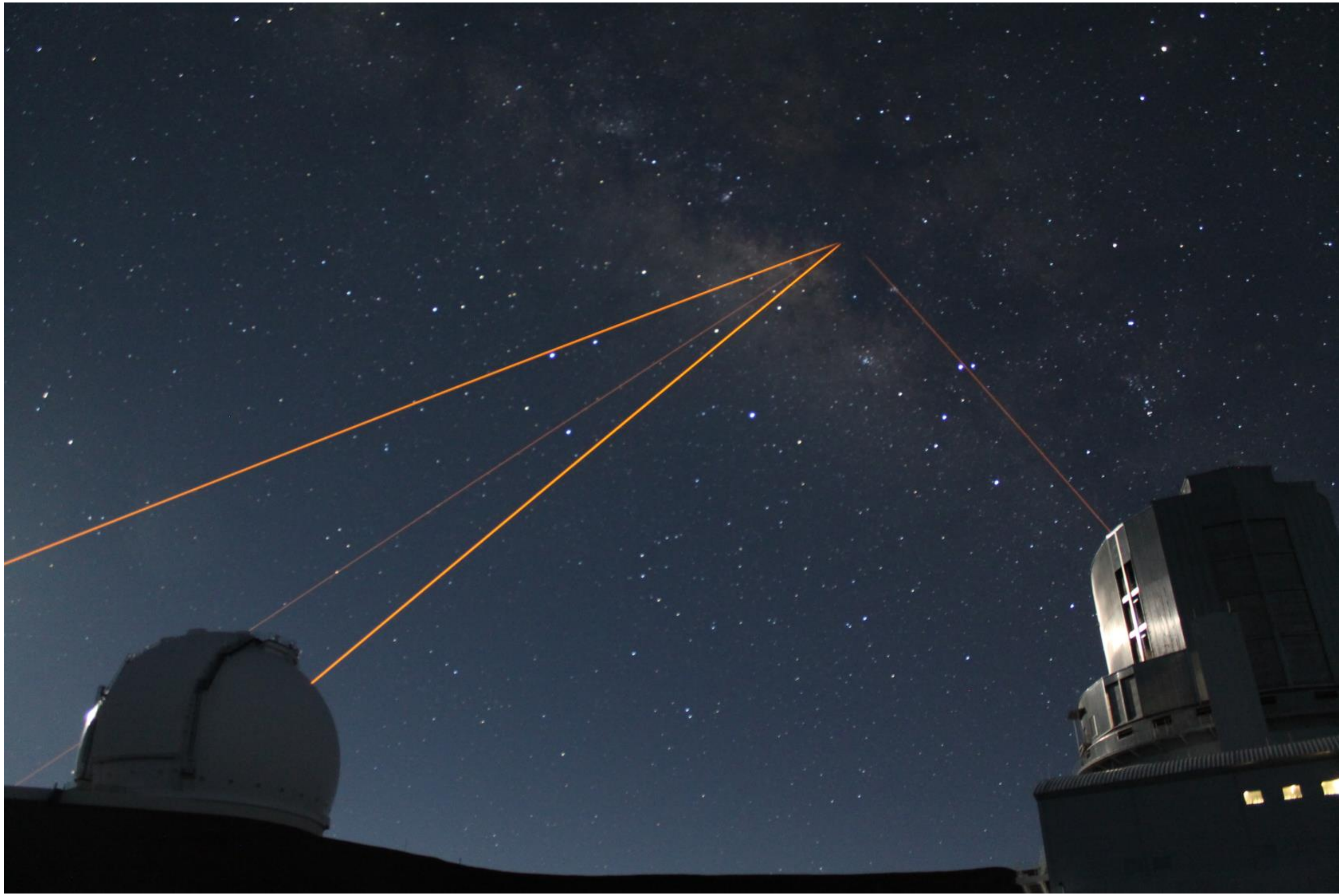


Subaru seminar, 2014.5.23



Subaru, Keck 1 and 2, Gemini, 4 beams to Galactic center
Photo by Dan Birchall, 19 May 2014

Subaru, Keck 1 and 2, Gemini, 4 beams to Galactic center
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Plan of Talk

1. Introduction : Basic idea for direct BH detection

2. Proposal : A principle of direct BH detection
method for one telescope

3. Under calculation : Short review of the aim of
my current calculation

4. Summary

(17 slides except for this slide)

1. Introduction : basic idea

1.1 From candidate to itself

- Best observational knowledge of BH at present
  $\rightarrow$ BH candidates by Newtonian gravity

  $\Updownarrow$ Large Gap in Physics !!

- BH is **a general relativistic (GR) object**
  $\rightarrow$ The only way to find "BH itself" is
  a direct detection of GR effect caused by BH.

What is it? How can we do it?

1.2 BH detection in GR context

- Theoretical (mathematical) fact in GR

Uniqueness (or No Hair) Theorem

BH is uniquely specified by 3 parameters
(under physically suitable conditions in math. cal.):

M : mass
J : spin angular momentum
Q : electric charge

(No other parameter (hair) is assigned to BH.)

- BH detection in GR context is as follows:

  Qualitative meaning is ($\because$ BH is a GR object)

  to recognize the existence of BH

  by detecting GR effect.

$\Downarrow$ $\because$ Uniqueness Thm

Quantitative meaning of BH detection

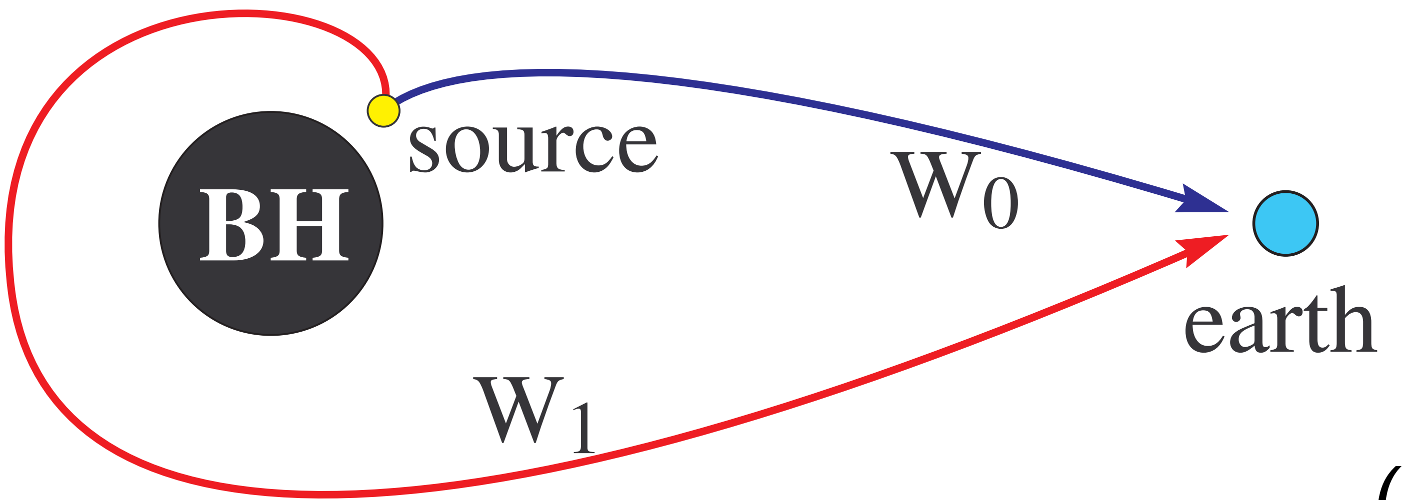
To measure the parameters M and J

by detecting GR effect.

Note: $Q = 0$ is expected in real situations.

1.3 GR effect of BH as our target

- Target : **Strong Gravitational Lensing effect**
- An ideal situation we want to observe:
  - ◇ Clear environment around BH except the source
  - ◇ Burst-like and spherical emission
    seen from the source



W_0 : "0th ray"
(direct ray)

W_1 : "1st ray"
(secondary ray)

$\Downarrow$ our basic idea is simple!

- Basic idea of a direct BH detection:

  From two observational quantities

$$\left\{ \begin{array}{ll} \Delta t_{\rm obs} & : \text{ Time delay} \\ \mathcal{E}_{\rm obs} = \dfrac{E_1}{E_0} & : \text{ Amp. ratio} \end{array} \right. \text{ of } \mathrm{W}_0 \text{ and } \mathrm{W}_1 \ ,$$

  Obtaine two BH parameters M and J .

- Method to observe $(\Delta t_{\rm obs} \, , \, \mathcal{E}_{\rm obs})$ should be **realizable by one telescope.**

2. Principle of direct BH obs.

- Making use of time series data of one telescope

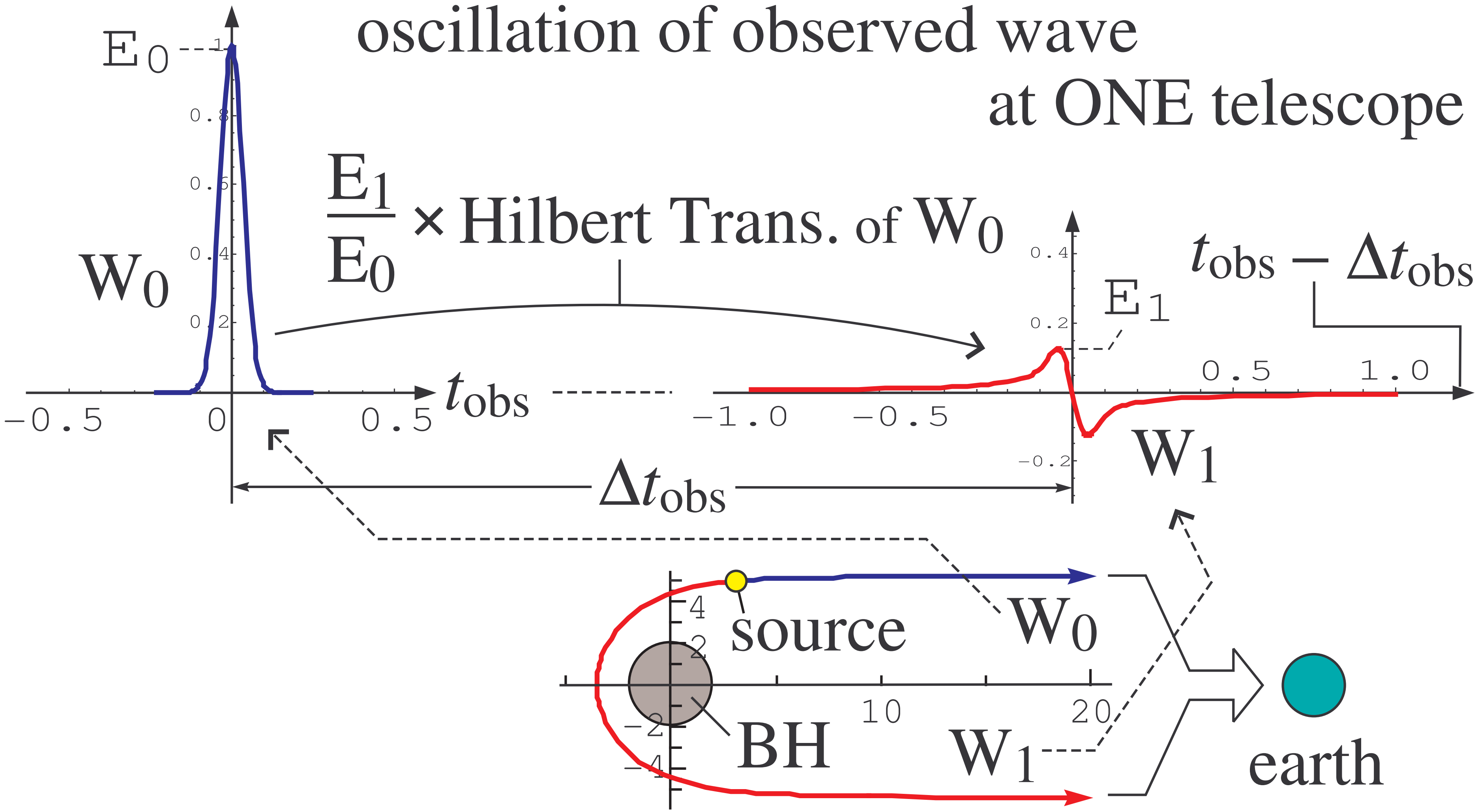
2.1 Ex. of time series data on one ideal tele.

- Suppose:
  The emission of source is Gaussian in time.

- Suppose:
  The telescope detects the time-variation of
  electric field (or its intensity) at all wave length.

$\Downarrow$ Then $\cdots$

- Gaussian emission → **waveform changes !**



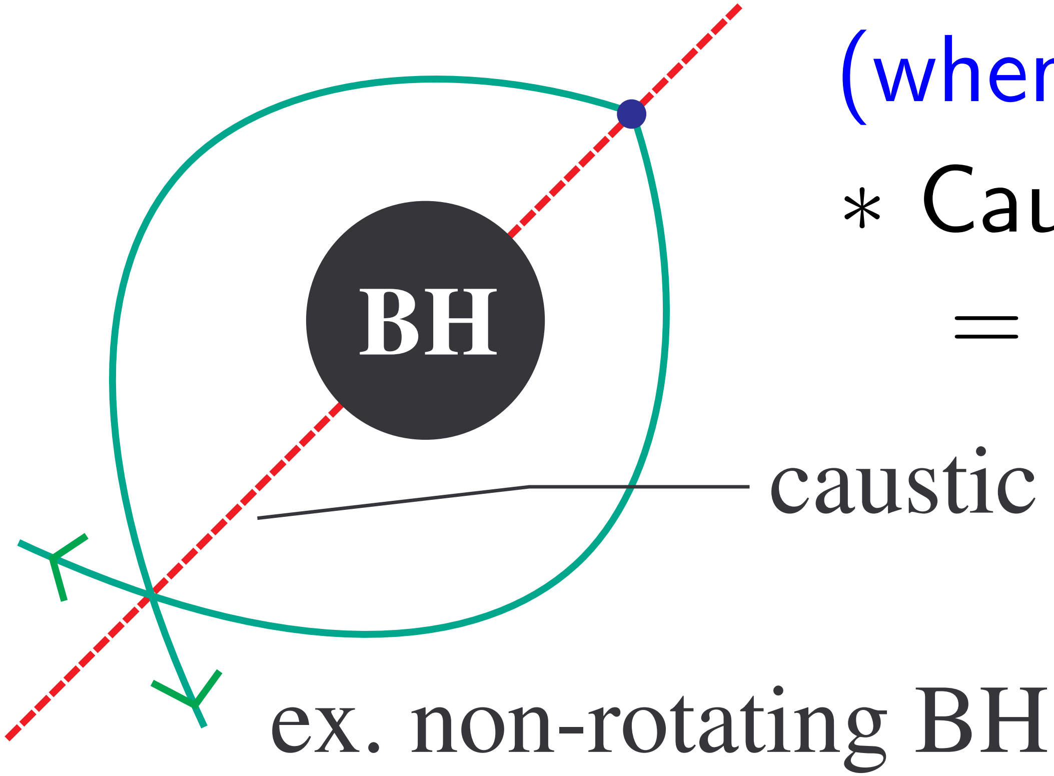
Ref: Zenginoglu &Galley PRD86(2012)064030 , YouTube

- **Gouy Phase Shift** : General phenomenon of wave

  The phase of oscillation shifts unexpectedly,

  when the wave passes a caustic.

  (when some rays cross there.)

  $*$ Caustic

  $=$ Crossing points of rays

Math.: Wave opt. approx. breaks down.

Higher order approx. reveals this effect.

$\rightarrow$ When some rays of wave cross at a caustic,

$$\begin{cases} \text{Positive freq. Fourier component:} \\ \qquad \text{Phase shifts by } -\dfrac{\pi}{2} \text{ [rad]} \\ \text{Negative freq. Fourier component:} \\ \qquad \text{Phase shifts by } +\dfrac{\pi}{2} \text{ [rad]} \end{cases}$$

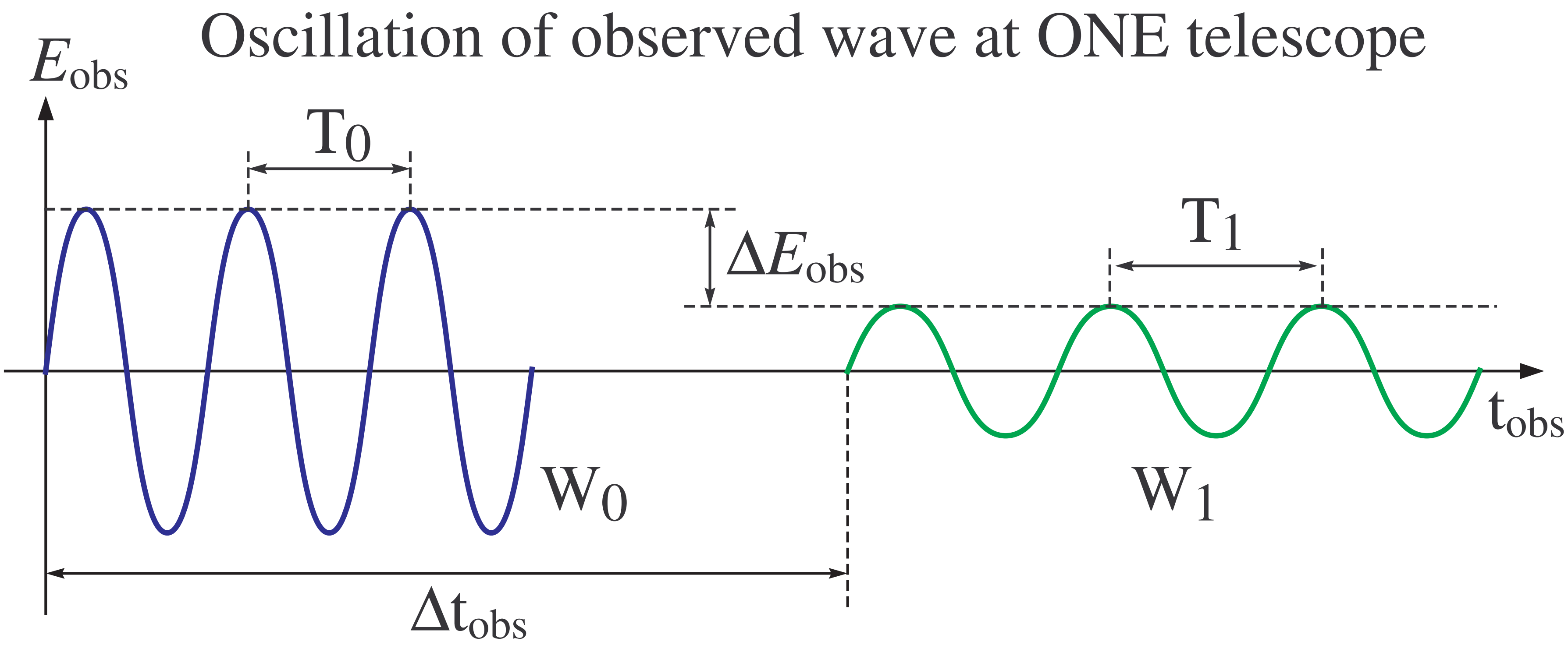
Note: Spectrum remains unchanged.

Math.: This is expressed by Hilbert trans.

a wave $f(t) \xrightarrow{\text{Hilbert}} H[f](t) \; \propto \; \mathrm{Re} \int_{-\infty}^{\infty} \mathrm{d}z \, \dfrac{f(z)}{t-z}$

2.2 Ex. of time series data with line emission

- Suppose: An exact line emission by the source

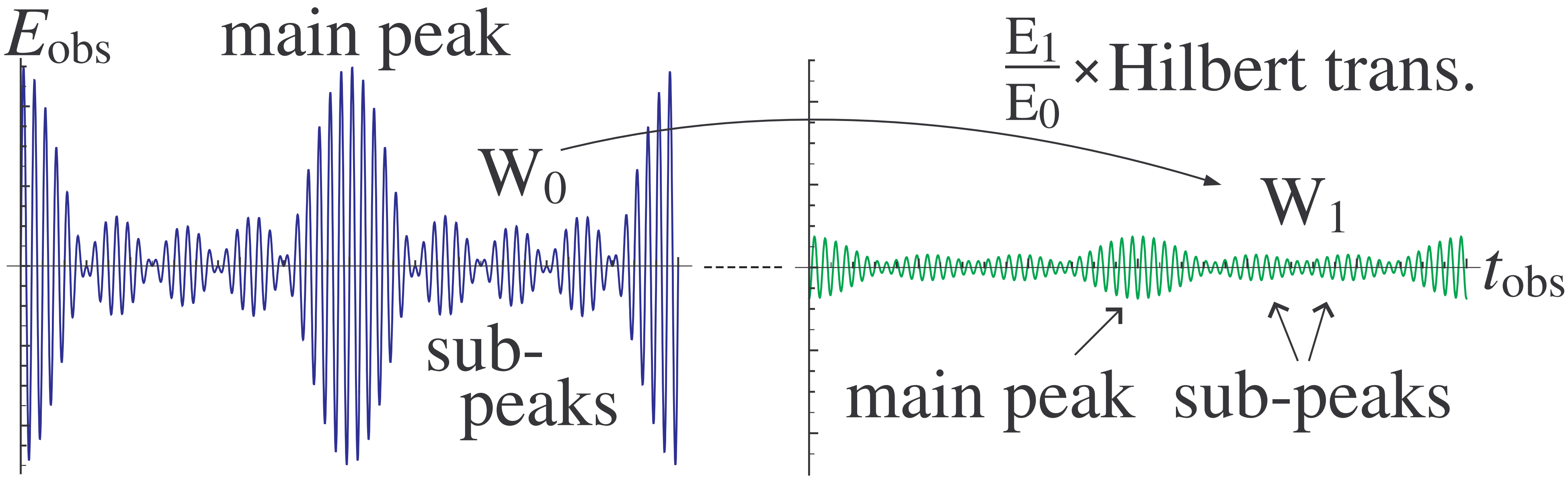


$$\rightarrow \begin{cases} T_0 \neq T_1 \text{ due to kinematic Doppler effect.} \\ \text{Gouy phase shift } H[\sin](\omega t) = \cos(\omega t) \end{cases}$$

2.3 Ex. of an observation with a band width

- Waveform in time series data is a **Beat**

$$\text{Ex.}\ \ W_0 = \sum_{n=0,\pm1,\pm2} \sin[\,(\omega + n\,\delta\omega)\,t\,]\ , \quad \begin{cases} \omega = 2\pi \\ \delta\omega = \dfrac{2\pi}{30} \end{cases}$$



→ Waveform-change may be apparent in beating wave.

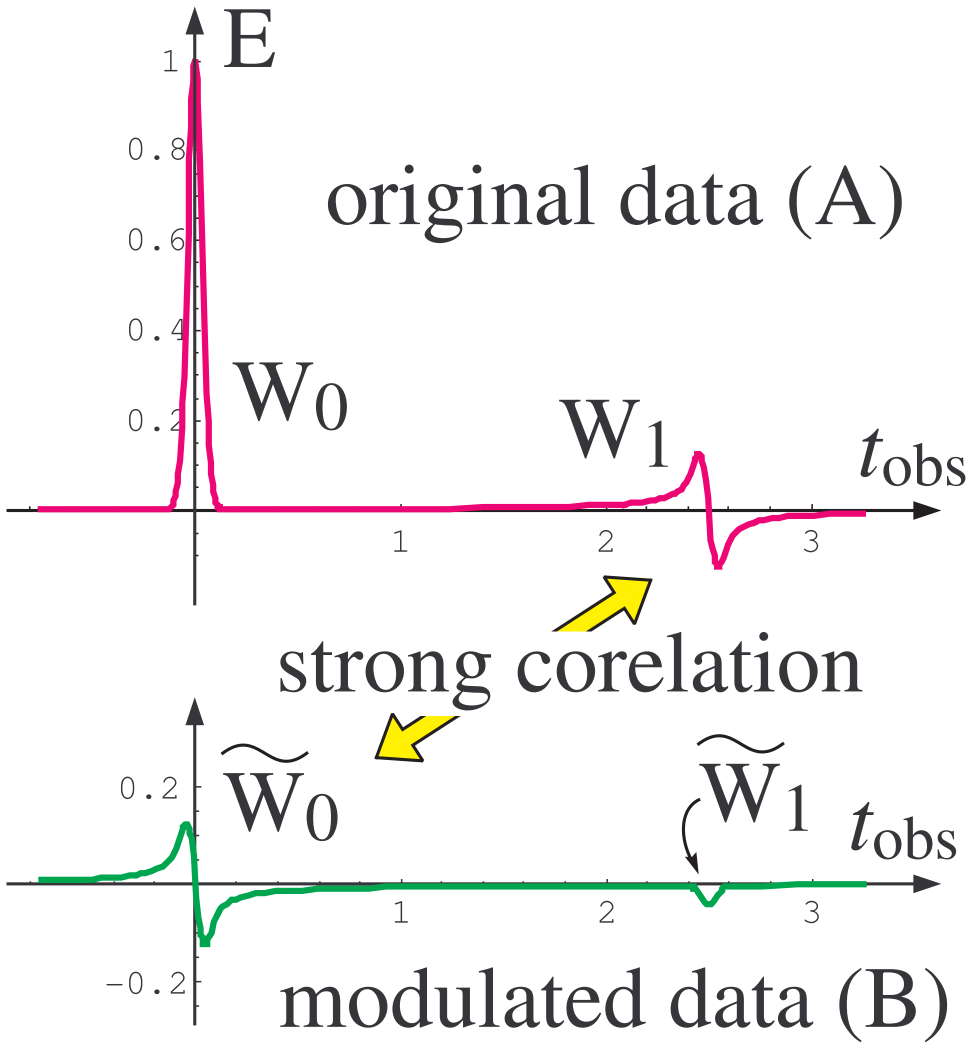
2.4 Time Delay Self-correlation (TDS) method

Step1: Data copy (A, B)

Step2: Modulation of B

- ∘ Hilbert trans. of B
- ∘ B $\times$ Constant ($\mathcal{E}_{\rm obs}$)
- ∘ Doppler correction on B

Step 3: Correlation search between A and B



$\rightarrow$ W_0 and W_1 are found,

and $\Delta t_{\rm obs}$, $\mathcal{E}_{\rm obs}$, T_1/T_0 are obtained.

- An actual case:
  - W_0 and W_1 are covered with background noise.
  - The background noise is a random oscillation.

$\rightarrow$ Background noise vanishes in Correlation Integral.

$$\int d\tau \, N(t)N(t+\tau) = 0 \text{ for a random noise } N(t)$$

$\rightarrow$ Non-random signals, W_0 and W_1, are to be obtained by Step 3.

3. Under calculation (theory)

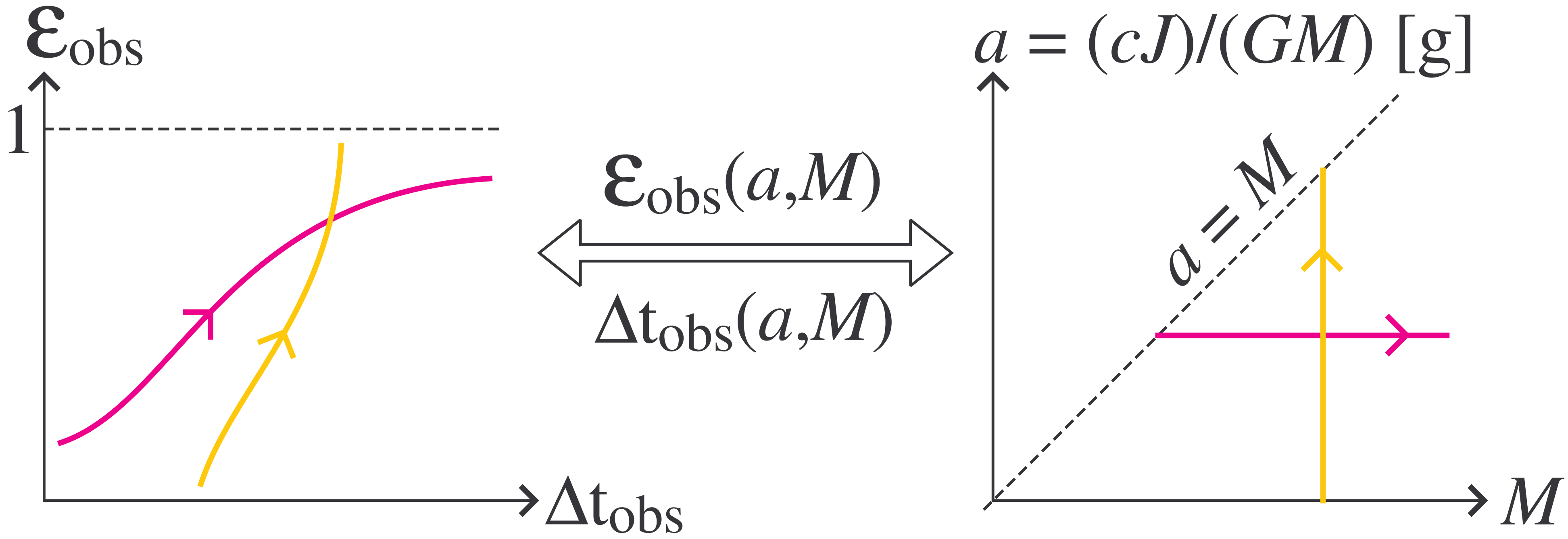
3.1 Correspondence $(\Delta_{\rm obs}, \mathcal{E}_{\rm obs}) \leftrightarrow (M, J)$

- Suppose the values:

$$\left\{\begin{array}{l}
\text{source position : } (\, t_{\rm s} \,,\, r_{\rm s} \,,\, \theta_{\rm s} \,,\, \varphi_{\rm s} \,) \text{ at emission} \\
\text{source velocity : } (\, u^t_{\rm s} \,,\, u^r_{\rm s} \,,\, u^\theta_{\rm s} \,,\, u^\varphi_{\rm s} \,) \text{ at emission} \\
\text{emission spectrum : } I_{\rm s}(\nu_{\rm s}) \text{ seen from the source} \\
\text{inclination angle : } \theta_{\rm obs} \\
\text{observation frequency : } \nu_{\rm obs}
\end{array}\right.$$

$$\Downarrow$$

under calculation with General Relativity



by definition : $\mathcal{E}_{\rm obs} < 1$, $0 < \Delta t_{\rm obs}$, $a < M$

This diagram enables us to read (M, J)

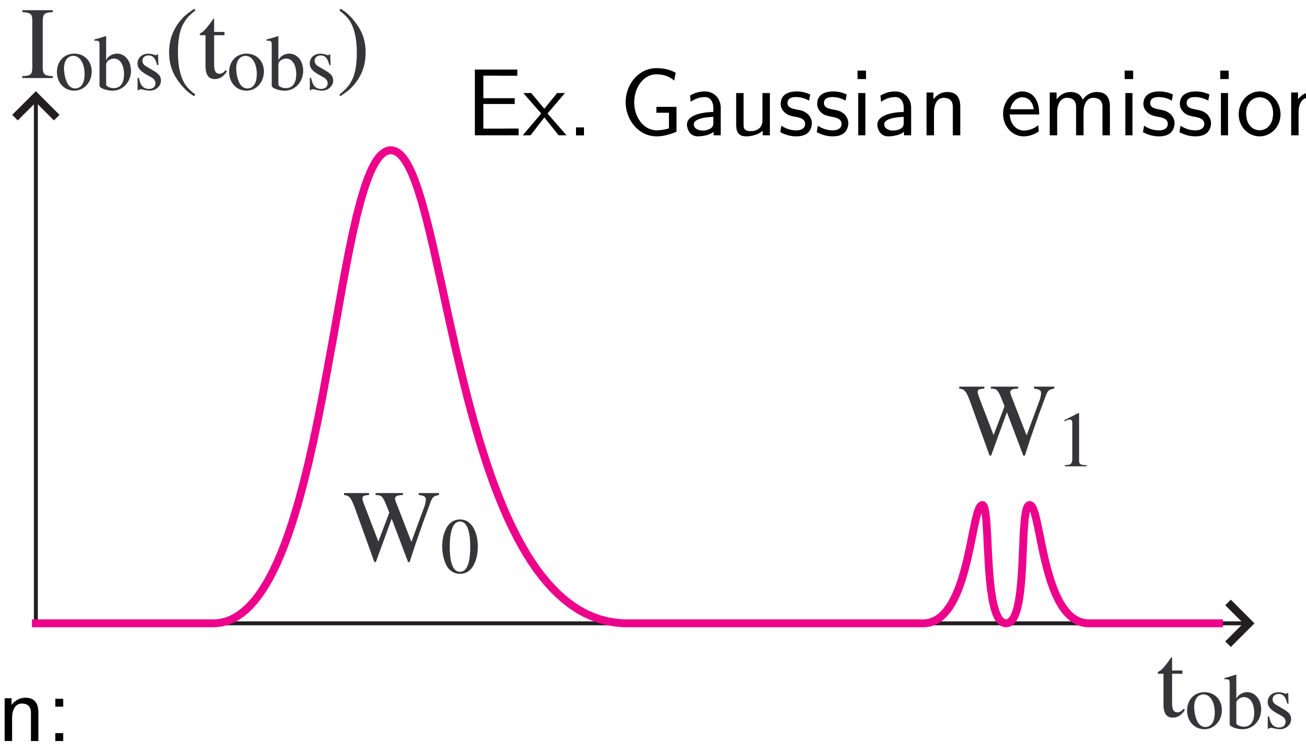
from observational data $(\Delta t_{\rm obs}, \mathcal{E}_{\rm obs})$

3.2 TDS with Light Curve ?

$I_{\rm obs} \propto E^2 \rightarrow$

(E : Amplitude)

$\Downarrow$



Under consideration:

Mathematical transformation

between W_0's curve and W_1's curve.

$\rightarrow$ With this, the "step 2" is extended to light curve.

4. Summary

- Direct BH detection is to measure M and J via a direct observation of GR effect.
- For Strong Gravitational Lensing by BH, TDS method may realize the direct BH detection by one telescope.
- Correspondence diagram $(M, J) \leftrightarrow (\Delta t_{\rm obs}, \mathcal{E}_{\rm obs})$ is under construction with GR.
- Extension of TDS to light curve, a construction of light curve trans. is also under consideration.