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25 Oct. 2017

Exploring exotic matter and energy by gravitational lensing

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Kitamura, Nakajima, Izumi, Hagiwara,
R.Takahashi,
Tsukamoto, ...

イントロ

エキゾチックな時空の現象論模型

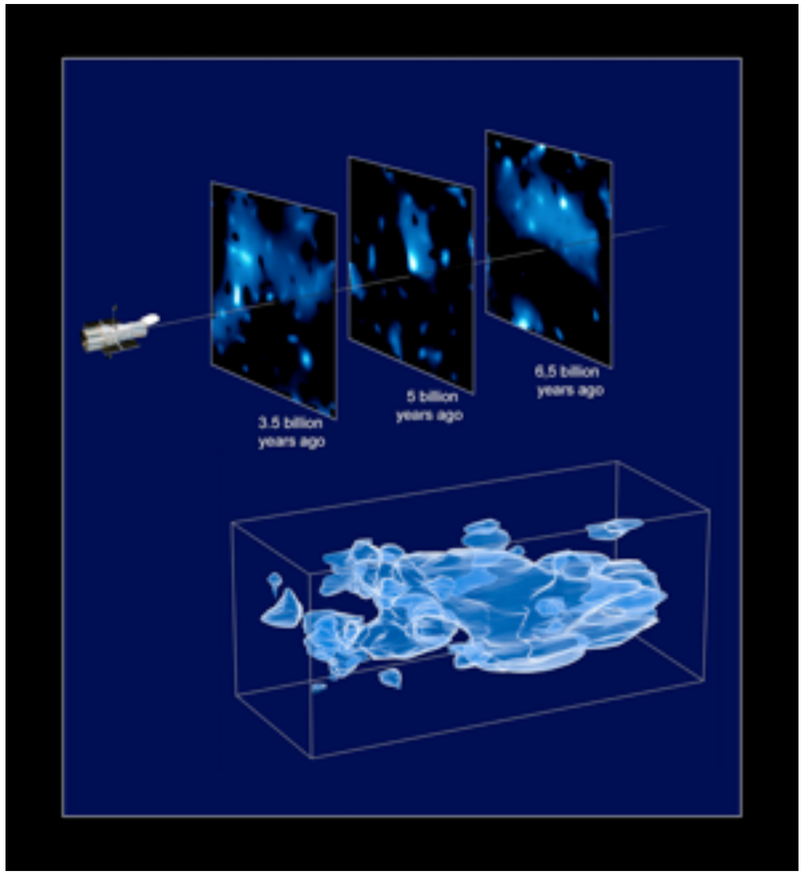
まとめ

(通常の)物質＋DM＋DE＝100%

他に新しいモノ（コト）？

(%）BHもNSも100年前は空想の話、
しかし、いまホットな天体観測現象

“Gravitational Lens” (GL) as a powerful tool



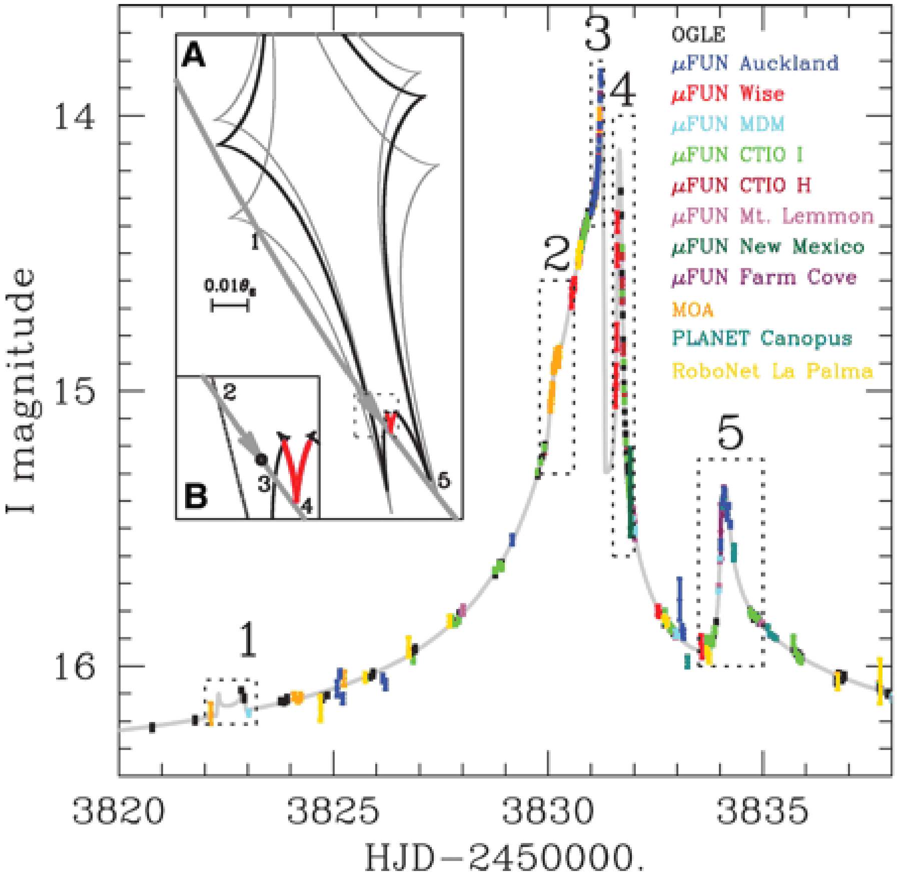
NASA/HST

Gravitational Lens HST • WFPC2

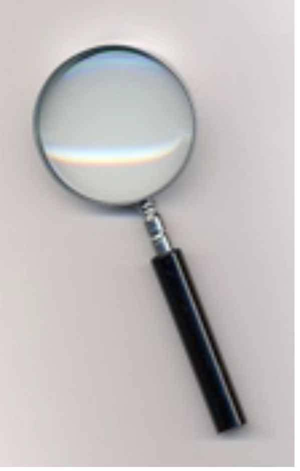
Galaxy Cluster 0024+1654

PRC96-10 • ST ScI OPO • April 24, 1996

W.N. Colley (Princeton University), E. Turner (Princeton University), J.A. Tyson (AT&T Bell Labs) and NASA

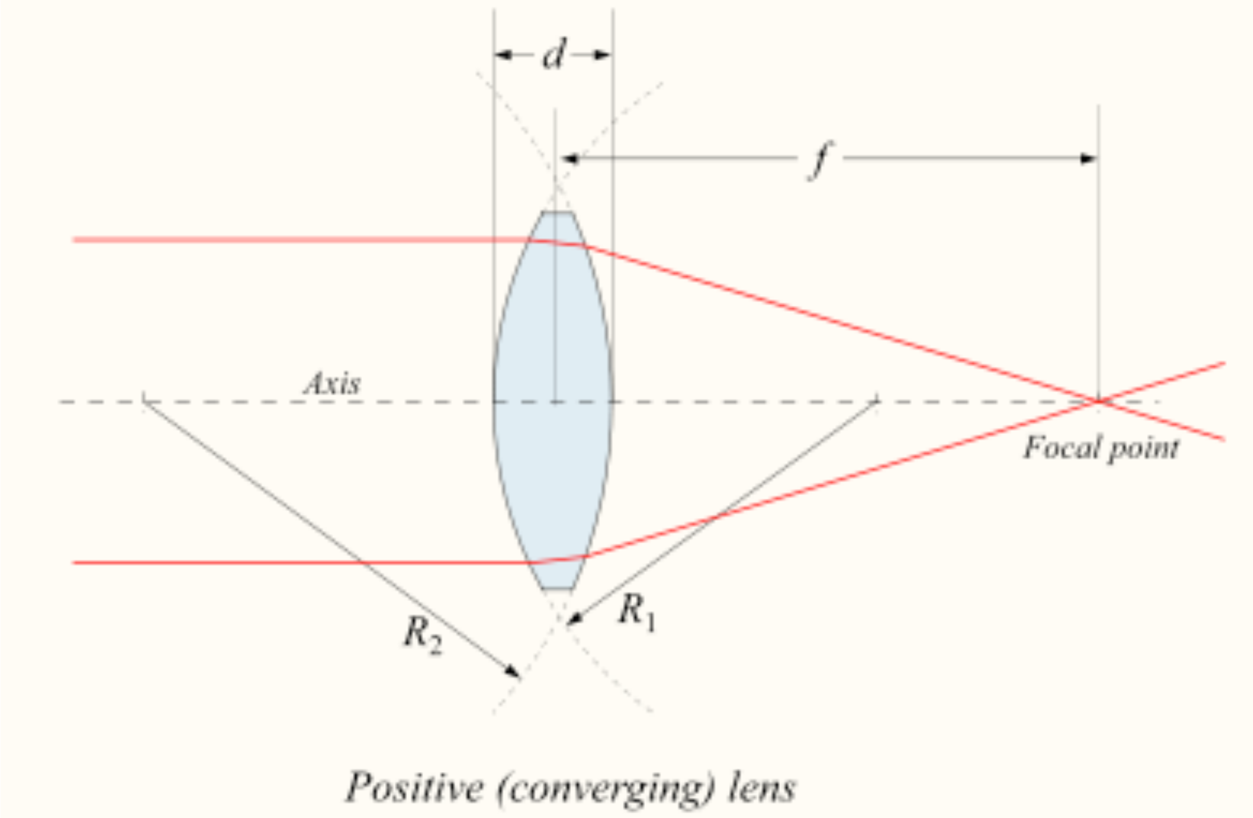


Gaudi et al. Science (08)



「光学レンズ」との類似　---

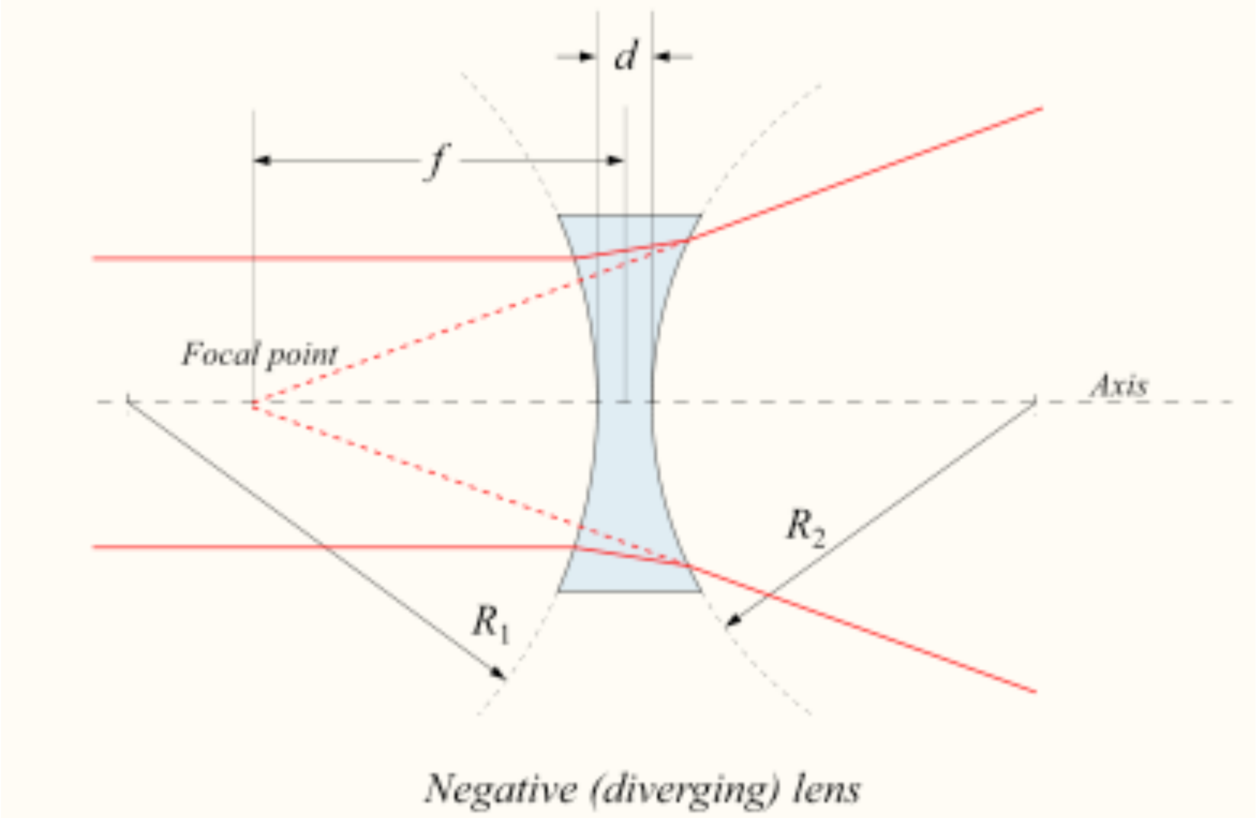
凸レンズ



$$\kappa > 0$$

通常の「重力レンズ」

凹レンズ



$$\kappa < 0$$

負の場合

『凹型重力レンズ』を探索すれば、
何か新しい物質・エネルギーを
伴う時空構造（天体とよべる？？）
が発見できるか？

The Astrophysical Journal, 725:787–793, 2010 December 10 doi:10.1088/0004-637X/725/1/787

GRAVITATIONAL MICROLENSING BY THE ELLIS WORMHOLE

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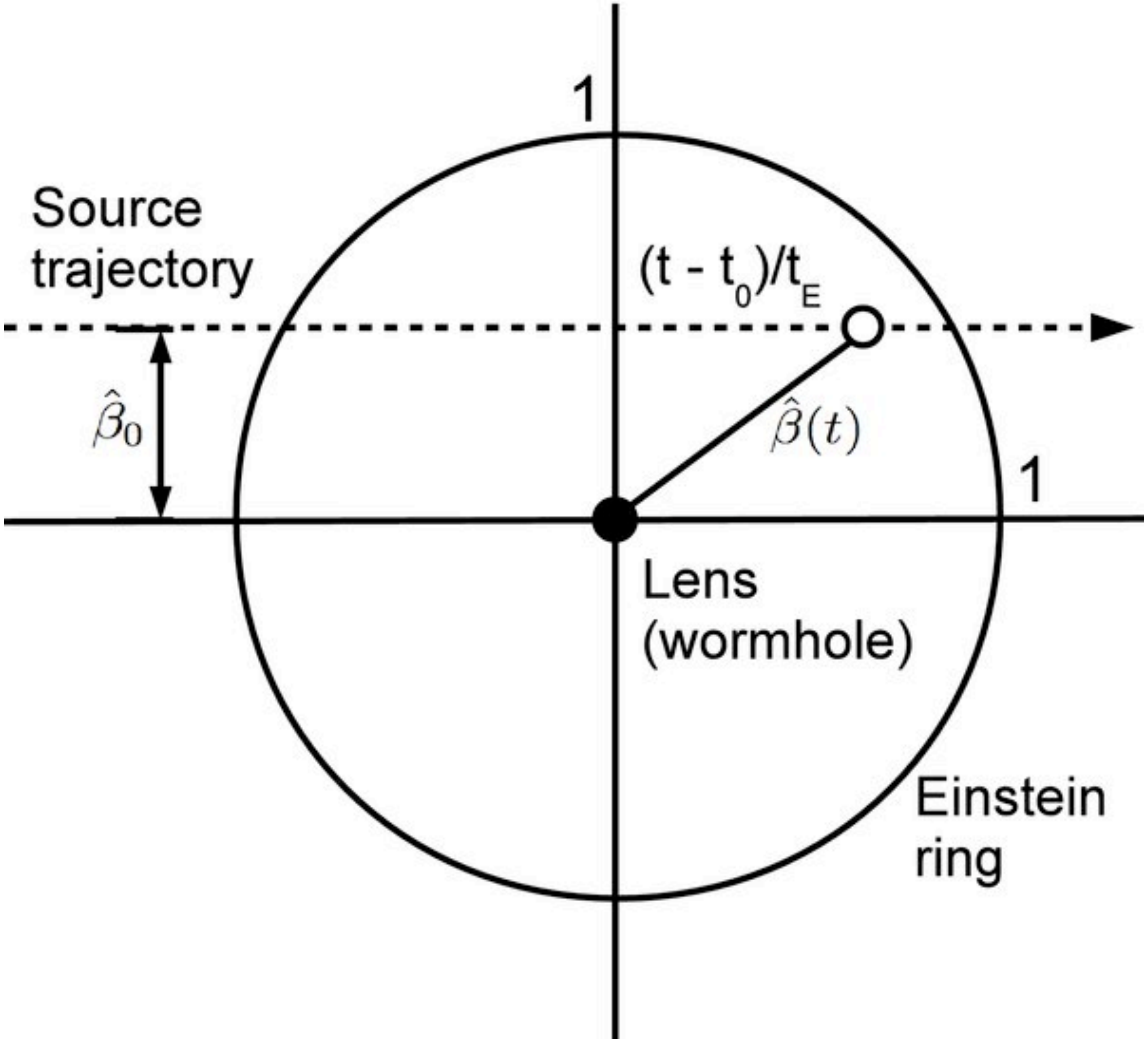
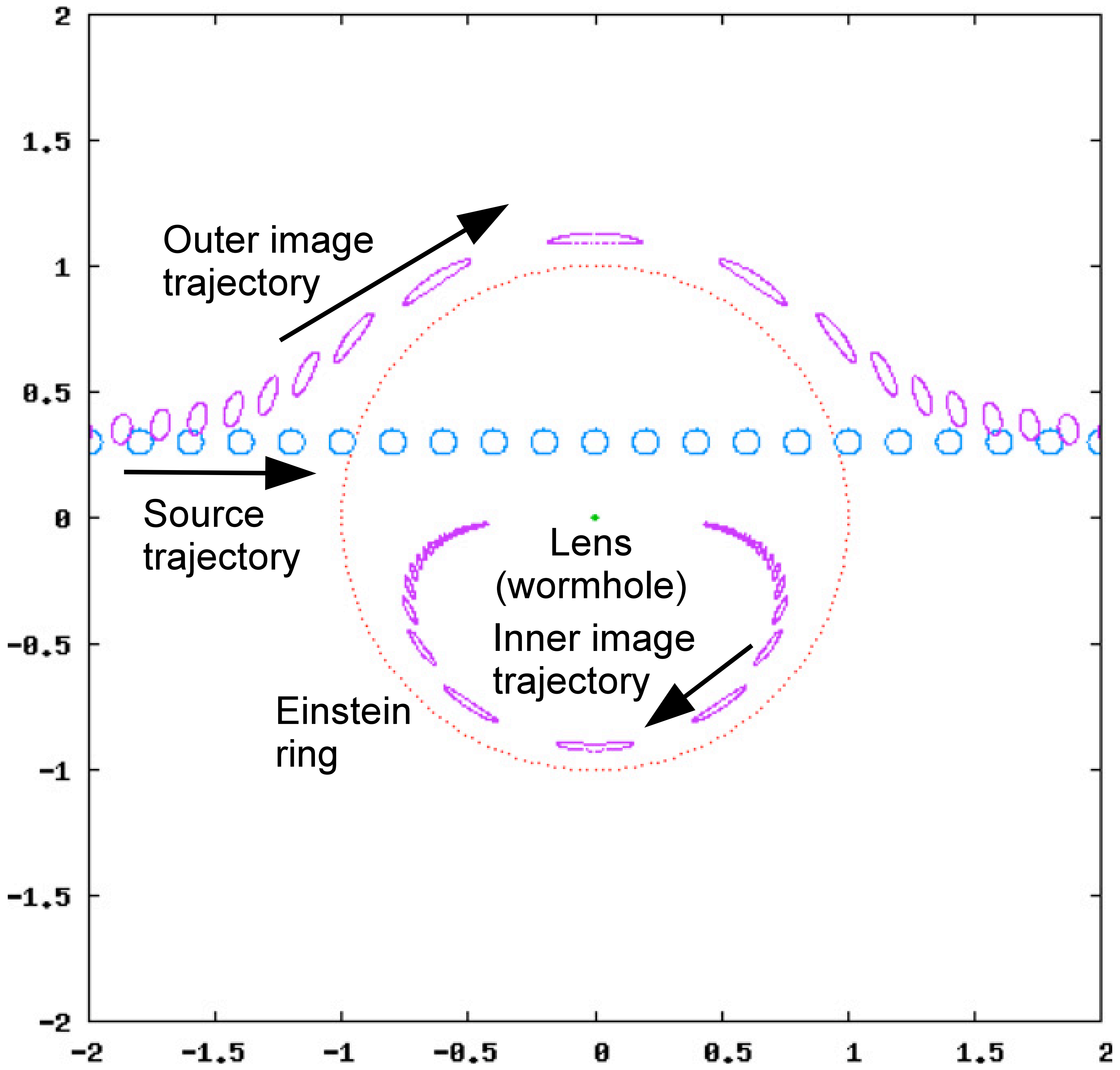
Received 2010 February 21; accepted 2010 October 7; published 2010 November 19

ABSTRACT

A method to calculate light curves of the gravitational microlensing of the Ellis wormhole is derived in the weak-field limit. In this limit, lensing by the wormhole produces one image outside the Einstein ring and another image inside. The weak-field hypothesis is a good approximation in Galactic lensing if the throat radius is less than 10^{11} km. The light curves calculated have gutters of approximately 4% immediately outside the Einstein ring crossing times. The magnification of the Ellis wormhole lensing is generally less than that of Schwarzschild lensing. The optical depths and event rates are calculated for the Galactic bulge and Large Magellanic Cloud fields according to bound and unbound hypotheses. If the wormholes have throat radii between 100 and 10^7 km, are bound to the galaxy, and have a number density that is approximately that of ordinary stars, detection can be achieved by reanalyzing past data. If the wormholes are unbound, detection using past data is impossible.


1
Source trajectory
$(t - t_0)/t_E$
$\hat{\beta}_0$
$\hat{\beta}(t)$
1
Lens (wormhole)
Einstein ring


Outer image trajectory
Source trajectory
Lens (wormhole)
Inner image trajectory
Einstein ring
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

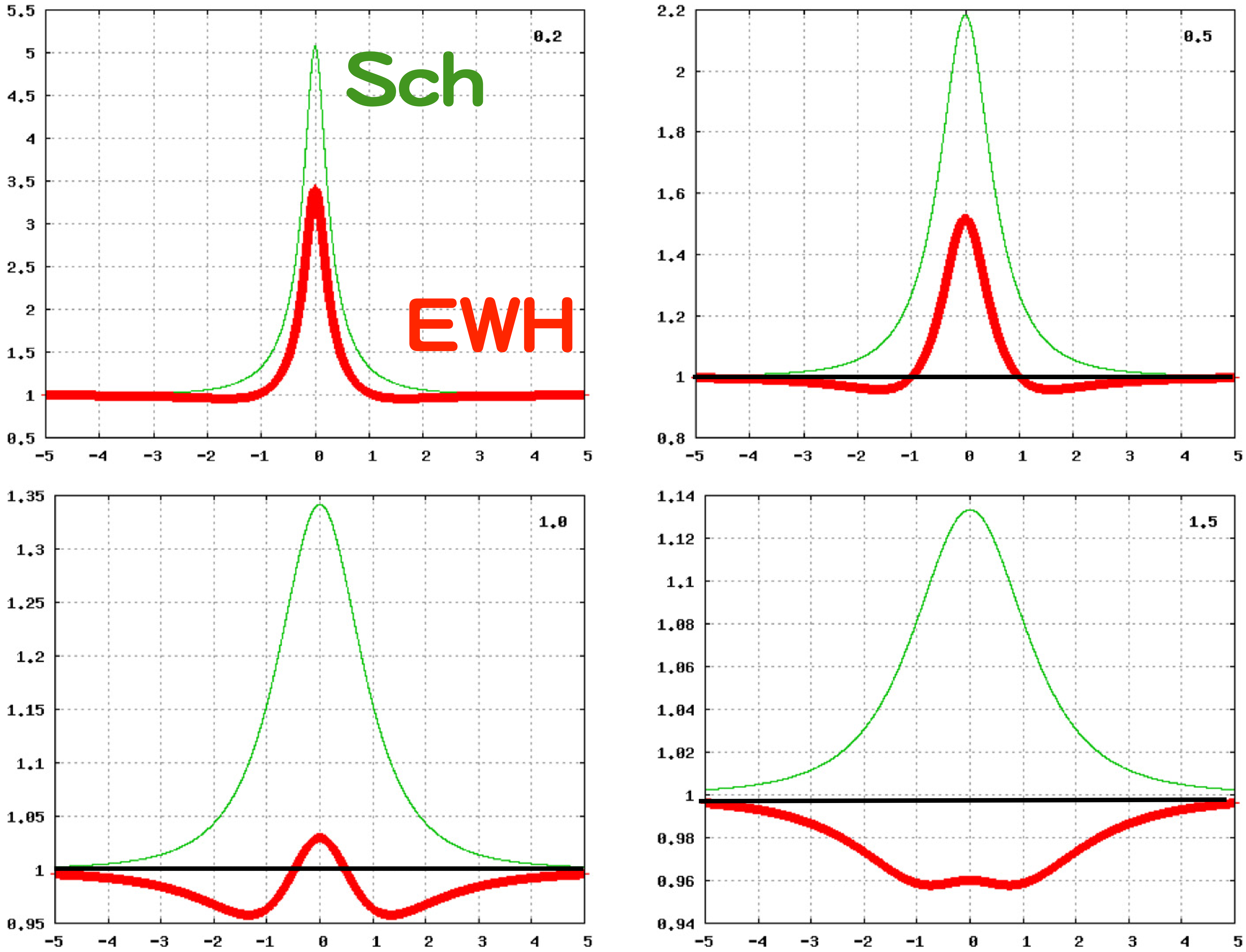


Figure 4. Light curves for $\hat{\beta}_0 = 0.2$ (top left), $\hat{\beta}_0 = 0.5$ (top right), $\hat{\beta}_0 = 1.0$ (bottom left), and $\hat{\beta}_0 = 1.5$ (bottom right). Thick red lines are the light curves for wormholes. Thin green lines are corresponding light curves for Schwarzschild lenses.

(A color version of this figure is available in the online journal.)

凹レンズによる減光！

Exotic Object捜しにおいて

ワームホールに限定する必要はない

とはいえ、何か理論模型があると便利

イントロ

エキゾチックな時空の現象論模型

まとめ

時空構造の新しい理論模型を提唱した
(逆べキ則、３パラメタの数式)

Kitamura, Nakajima, HA(2013)

$$ds^2 = -\left(1 - \frac{\varepsilon_1}{r^n}\right)dt^2 + \left(1 + \frac{\varepsilon_2}{r^n}\right)dr^2$$
$$+ r^2(d\theta^2 + \sin^2\theta d\phi^2) + O(\varepsilon_1^2, \varepsilon_2^2, \varepsilon_1\varepsilon_2),$$

(1)　遠方で平坦、かつ静止

(2)　弱い場の近似

(3) n=１：通常の天体
n=2：ワームホール
(時空のトンネル)

連星への拡張：Bozza+ (2016)

光の曲がり角 $$\alpha(b) = \frac{\bar{\varepsilon}}{b^n}$$

n=0 : Singular Isothermal Sphere (SIS)

n=1 : Schwarzschild

n=2 : Ellis Worm Hole (EWH)

同じ曲がり角が独立に提唱

Tsukamoto and Harada (2013)

高次元時空模型との関連

Tsukamoto, Kitamura, Nakajima, HA (2014)

物理的な解釈

質量面密度

$$\kappa(b) = \frac{\bar{\varepsilon}(1-n)}{2}\frac{1}{b^{n+1}}$$

ε>0 かつ n>1ならば,
負の質量(エネルギー)面密度を表す

$\kappa > 0$ Non-vac. Ricci-focusing	$\varepsilon > 0 \,\&\, n < 1$	SIS
	$\varepsilon < 0 \,\&\, n > 1$	
Vac. $\kappa = 0$ Weyl-focusing	$n = 1$	Sch
$\kappa < 0$ Non-vac. Ricci-defocusing	$\varepsilon > 0 \,\&\, n > 1$	EWH
	$\varepsilon < 0 \,\&\, n < 1$	

For $\varepsilon > 0$,

Einstein ring for $\beta = 0$

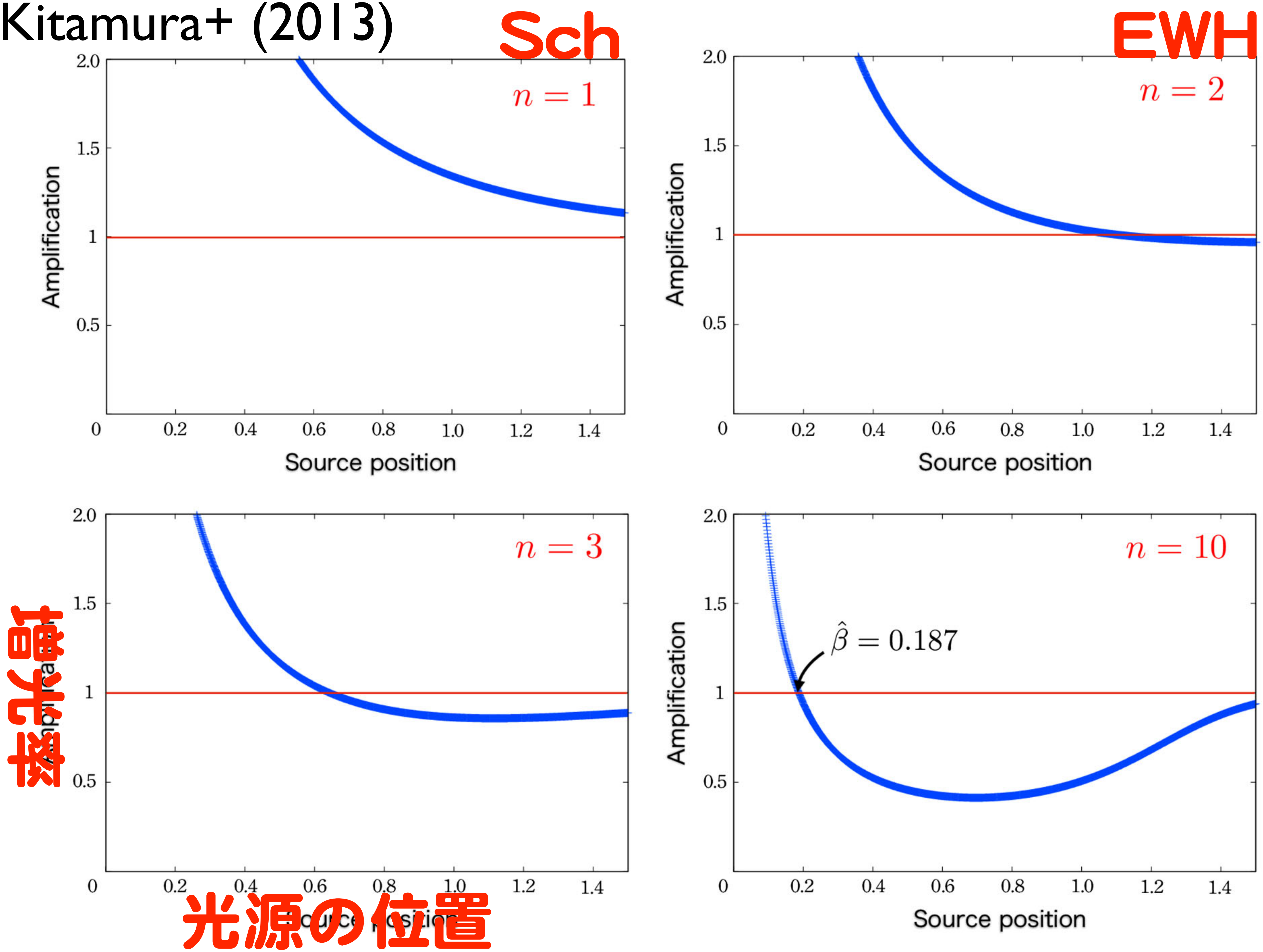
$$\theta_{\mathrm{E}} \equiv \left(\frac{\bar{\varepsilon} D_{LS}}{D_S D_L^n}\right)^{\frac{1}{n+1}}.$$

If $\varepsilon < 0$,

(tentative) Einstein ring radius

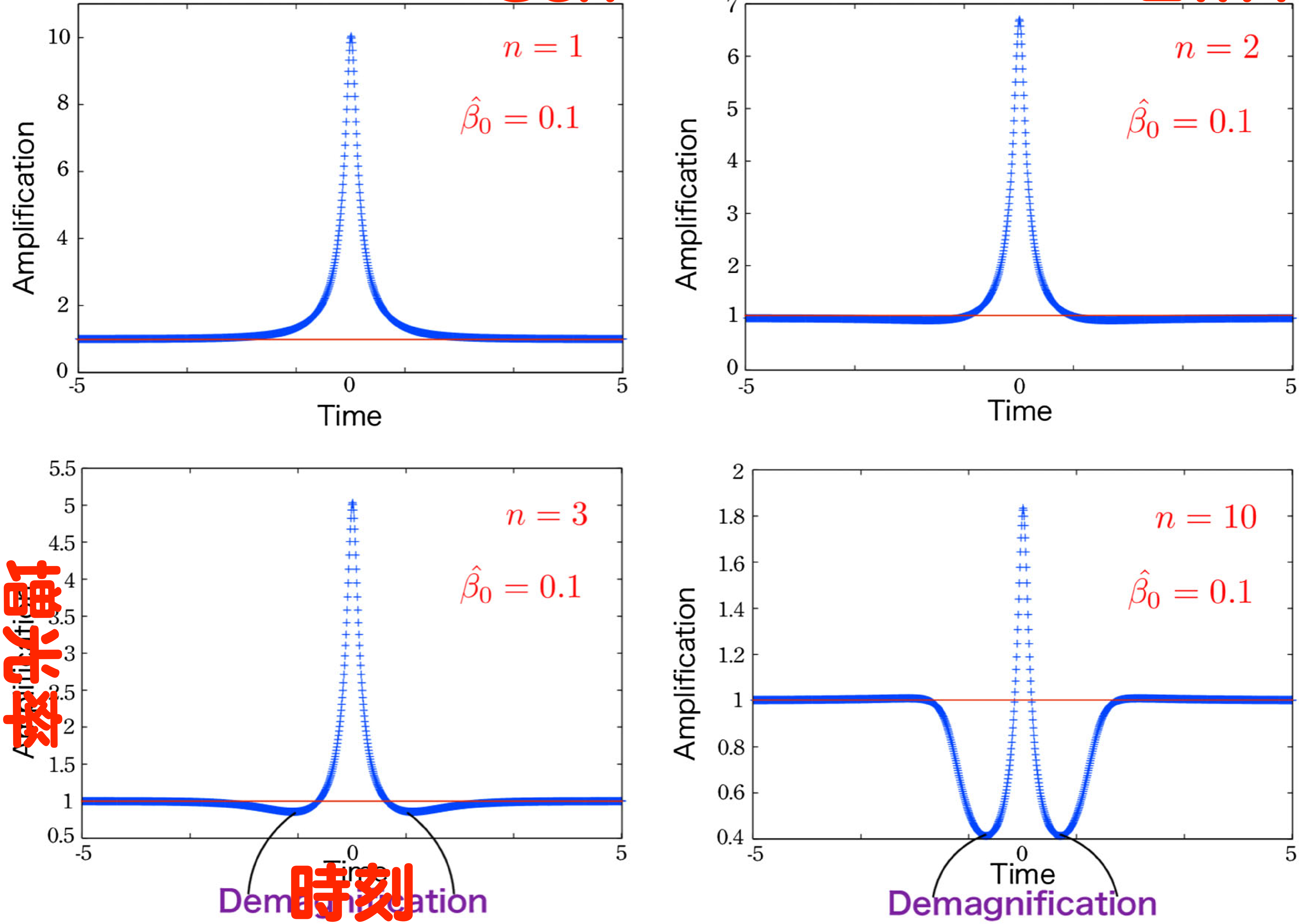
$$\theta_{\mathrm{E}} \equiv \left(\frac{|\bar{\varepsilon}| D_{LS}}{D_S D_L^n}\right)^{\frac{1}{n+1}},$$

Kitamura+ (2013)



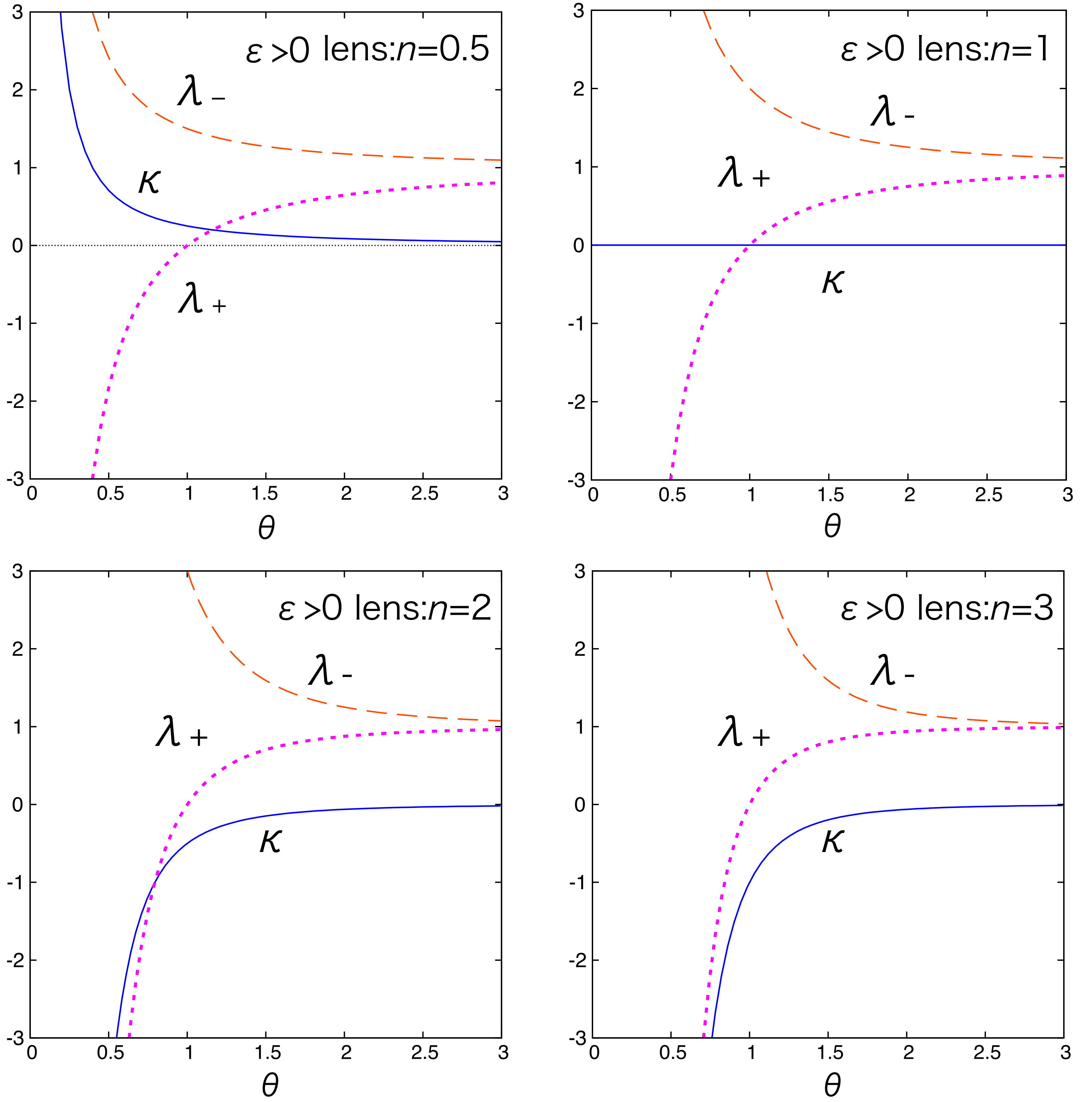
Kitamura+ (2013)

Sch **EWH**



減光はワームホール以外でも可能

PHYSICAL REVIEW D **88,** 024049 (2013)



$\lambda_- > \lambda_+$

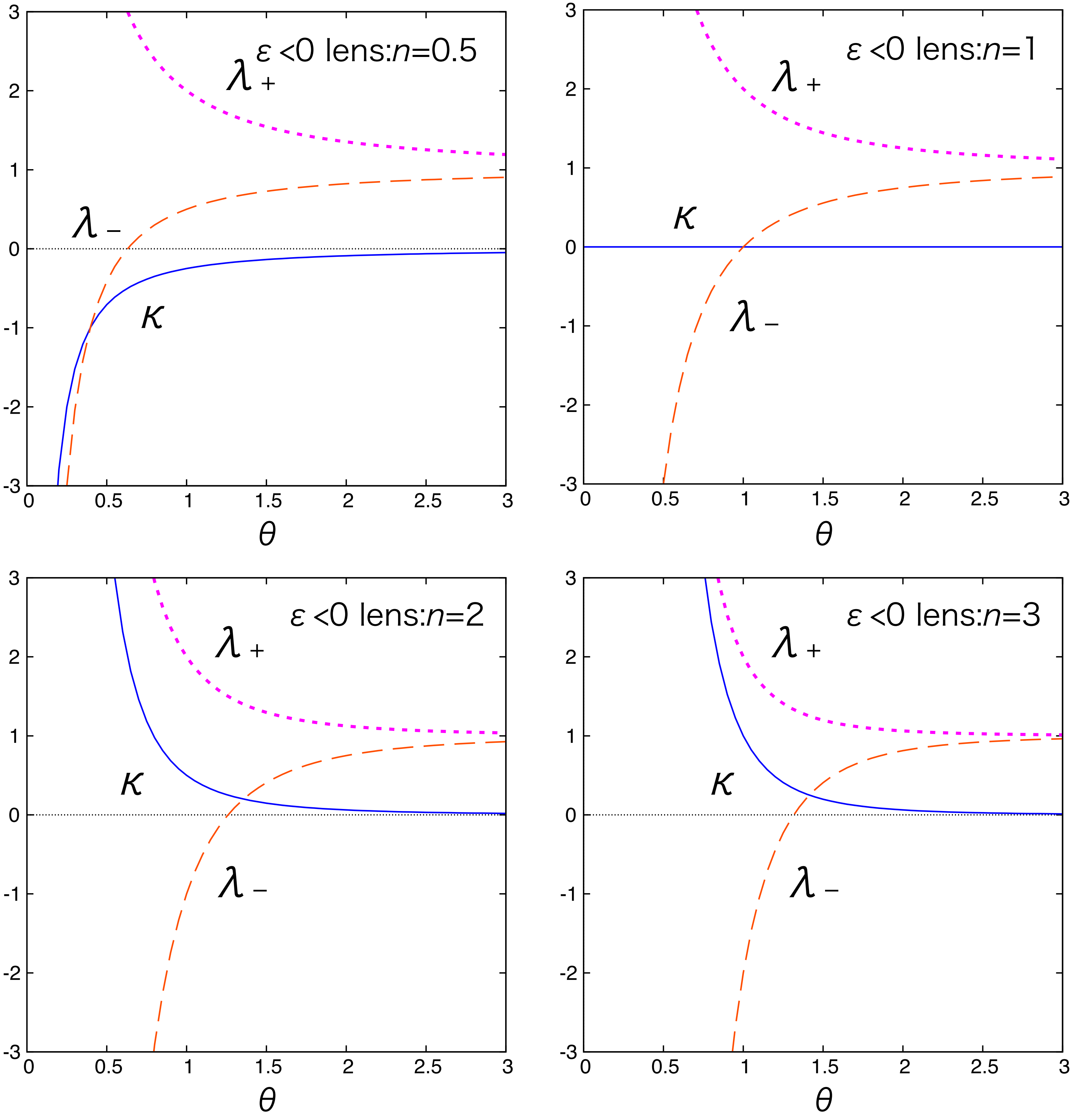
tangentially elongated

By axisymmetry along l.o.s. the magnification matrix is

$$(A_{ij}) = \begin{pmatrix} 1-\kappa-\gamma & 0 \\ 0 & 1-\kappa+\gamma \end{pmatrix} \equiv \begin{pmatrix} \lambda_- & 0 \\ 0 & \lambda_+ \end{pmatrix},$$

$$\lambda_+ = \frac{\hat{\beta}}{\hat{\theta}} = 1 - \frac{1}{\hat{\theta}^{n+1}},$$

$$\lambda_- = \frac{d\hat{\beta}}{d\hat{\theta}} = 1 + \frac{n}{\hat{\theta}^{n+1}}.$$



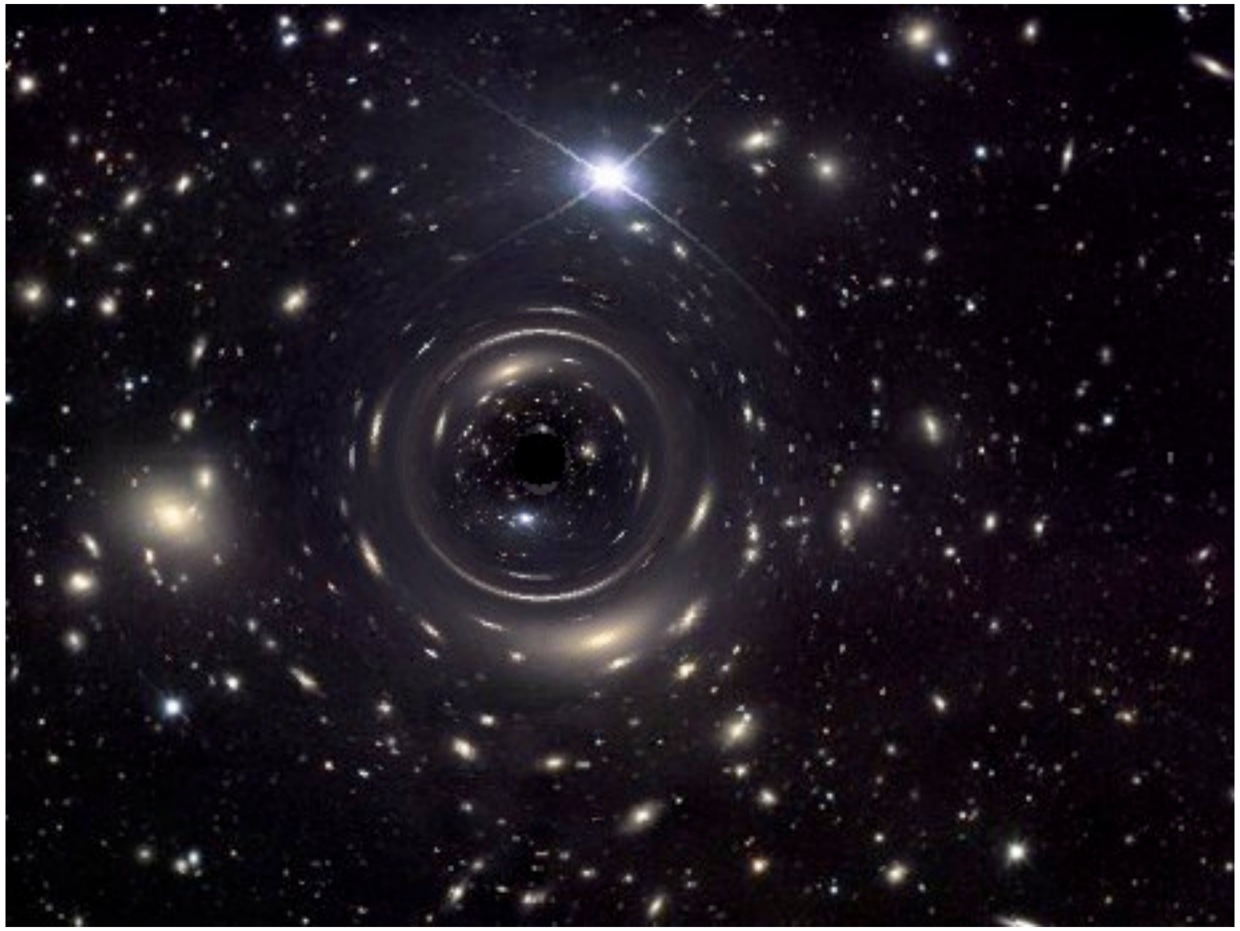
$$\lambda_- < \lambda_+$$

radially elongated

No lens

あくまで
イメージ図

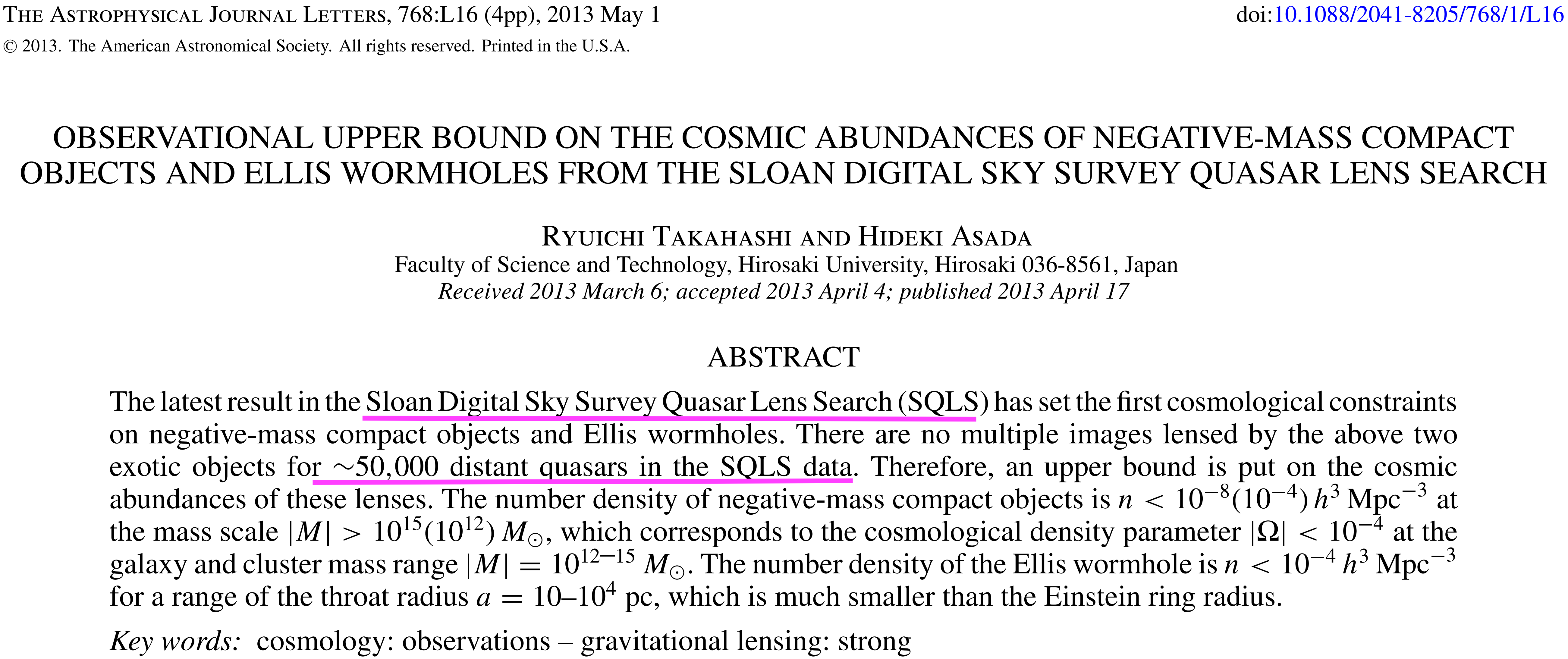
$M > 0$



$M < 0$

courtesy of Koji Izumi

First cosmological upper bound



The Astrophysical Journal Letters, 768:L16 (4pp), 2013 May 1 doi:10.1088/2041-8205/768/1/L16

OBSERVATIONAL UPPER BOUND ON THE COSMIC ABUNDANCES OF NEGATIVE-MASS COMPACT OBJECTS AND ELLIS WORMHOLES FROM THE SLOAN DIGITAL SKY SURVEY QUASAR LENS SEARCH

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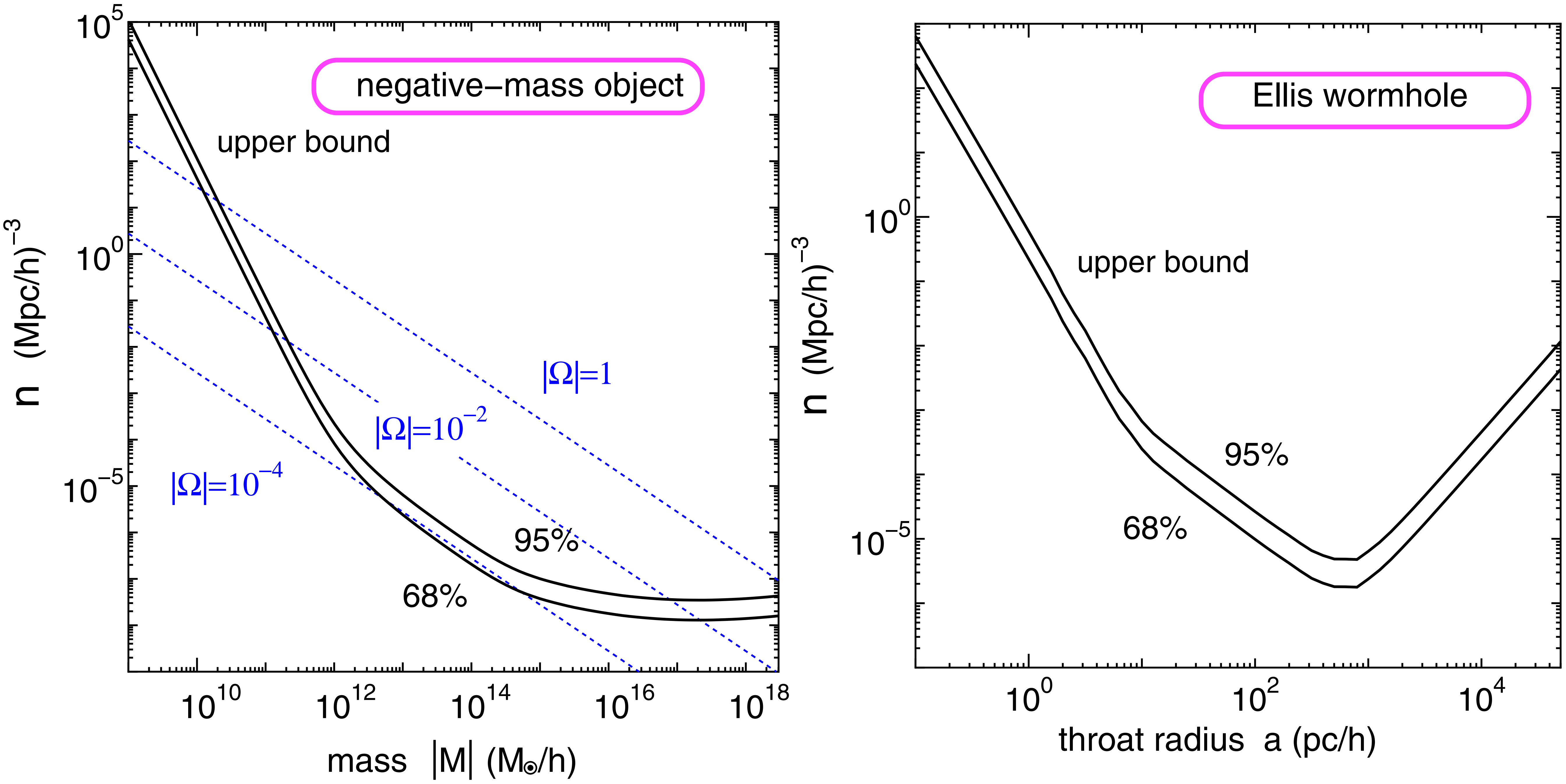
Received 2013 March 6; accepted 2013 April 4; published 2013 April 17

ABSTRACT

The latest result in the Sloan Digital Sky Survey Quasar Lens Search (SQLS) has set the first cosmological constraints on negative-mass compact objects and Ellis wormholes. There are no multiple images lensed by the above two exotic objects for ~50,000 distant quasars in the SQLS data. Therefore, an upper bound is put on the cosmic abundances of these lenses. The number density of negative-mass compact objects is $n < 10^{-8}(10^{-4})\, h^3\ \mathrm{Mpc}^{-3}$ at the mass scale $|M| > 10^{15}(10^{12})\, M_\odot$, which corresponds to the cosmological density parameter $|\Omega| < 10^{-4}$ at the galaxy and cluster mass range $|M| = 10^{12-15}\, M_\odot$. The number density of the Ellis wormhole is $n < 10^{-4}\, h^3\ \mathrm{Mpc}^{-3}$ for a range of the throat radius $a = 10$–10^4 pc, which is much smaller than the Einstein ring radius.

Key words: cosmology: observations – gravitational lensing: strong


negative−mass object
upper bound
|Ω|=1
|Ω|=10^{-2}
|Ω|=10^{-4}
95%
68%
n (Mpc/h)$^{-3}$
10^5
10^0
10^{-5}
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
mass |M| (M$_\odot$/h)
Ellis wormhole
upper bound
95%
68%
n (Mpc/h)$^{-3}$
10^0
10^{-5}
10^0
10^2
10^4
throat radius a (pc/h)

イントロ

エキゾチックな時空の現象論模型

まとめ

1) Exotic matter/energyを伴う
重力レンズ現象の基礎論を展開した

2) 実際の天文観測につなぐ部分は今後の課題

e.g.『(通常の)凸型重力レンズ』における
有限距離の光源と観測者の効果

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