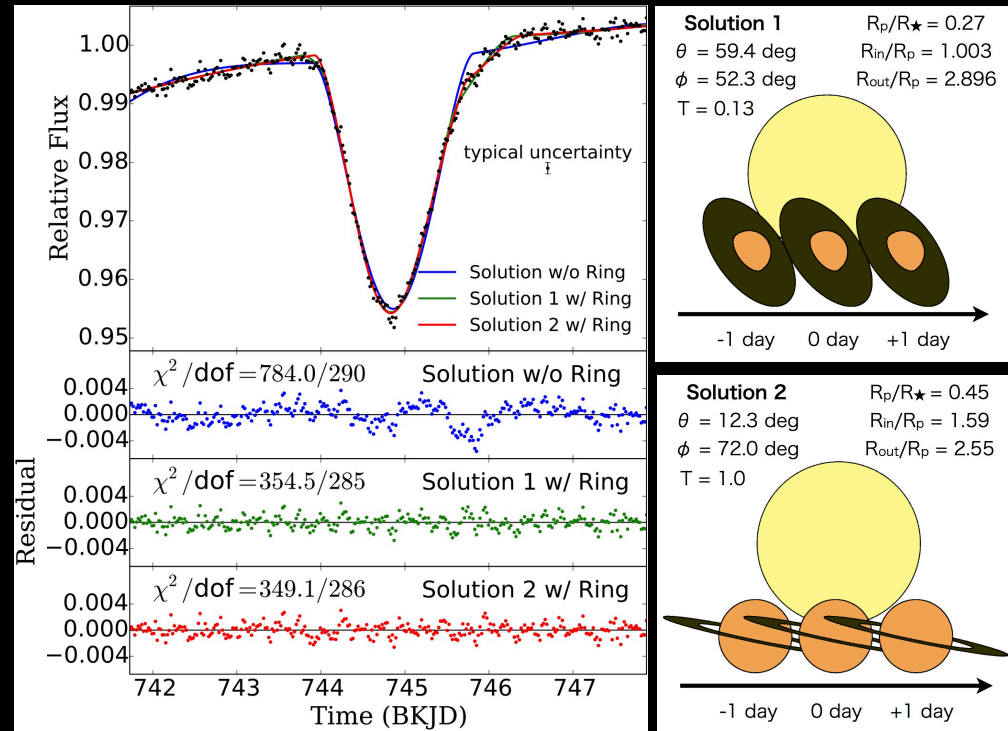
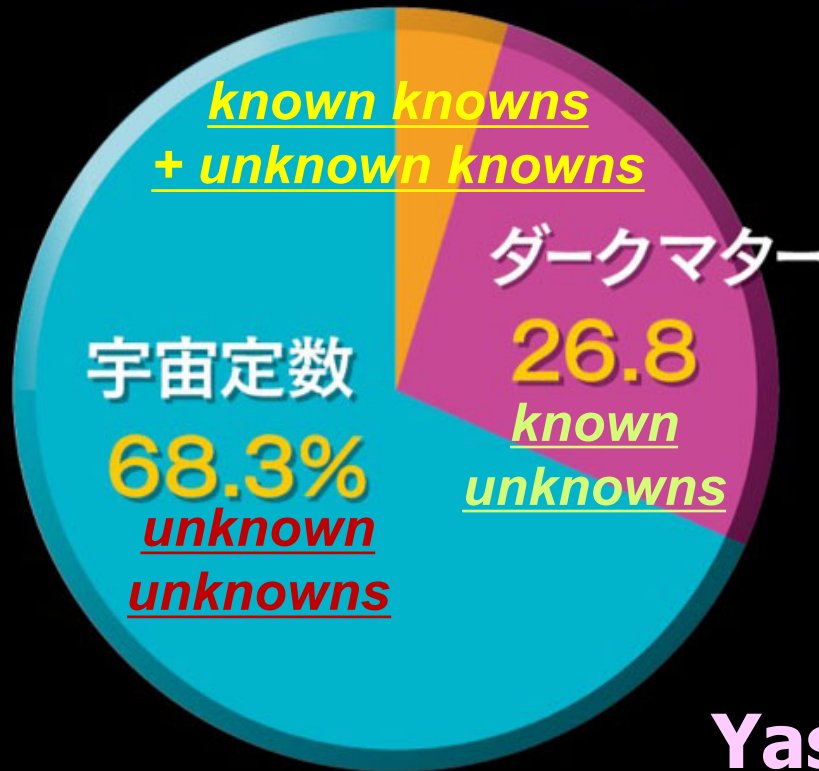


From unknown knowns to known knowns: cases of dark baryon and exo-ring

元素 4.9



Yasushi Suto

Department of Physics and RESCEU, The University of Tokyo

Continuous challenges of X-ray astronomy

11:10-11:30 June 8, 2019 @Tokyo Metropolitan University

a famous American philosopher and poet: D.H.Rumsfeld



The Unknown

As we know,
There are known knowns.
There are things we know we
know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown un-
knowns,
The ones we don't know
We don't know.

—Feb. 12, 2002, Department of
Defense news briefing

Unknowns vs knowns in the universe

- **Dark energy** = unknown unknown(s)
- **Dark matter** = known unknown(s)
- **Baryon** = known knowns ?
 - Stars + hot gas = known knowns
 - Dark baryon = unknown knowns
= **WHIM**
(Warm-Hot Intergalactic Medium) ?

c.f., Fukugita, Hogan & Peebles: ApJ 503 (1998) 518
Cen & Ostriker: ApJ 514 (1999) 1

Diffuse Intergalactic Oxygen Surveyor

A Japanese proposal of a dedicated X-ray mission to search for dark baryons

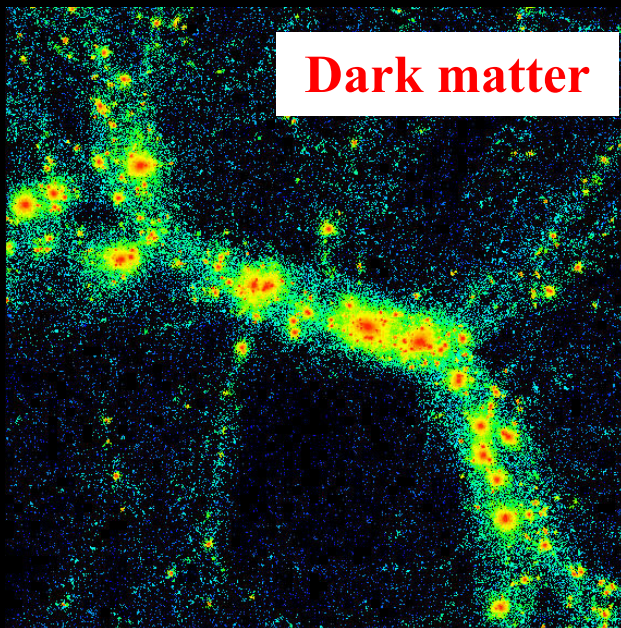


- **PI: Takaya Ohashi** (Tokyo Metropolitan Univ.)
 - + Univ. of Tokyo, JAXA/ISAS, Nagoya Univ., Tokyo Metro. Univ.
- A dedicated small satellite with cost < 40M USD
- Proposed launch in **2010** (not yet approved; looking for international collaboration)
- Unprecedented energy spectral resolution: **$\Delta E = 2\text{eV}$ in soft X-ray band (0.3-1.5keV)**
- Aim at unambiguous detection of WHIM via **Oxygen emission lines**
- Estimate the dark baryon (WHIM) density contribution to the total cosmic baryon budget

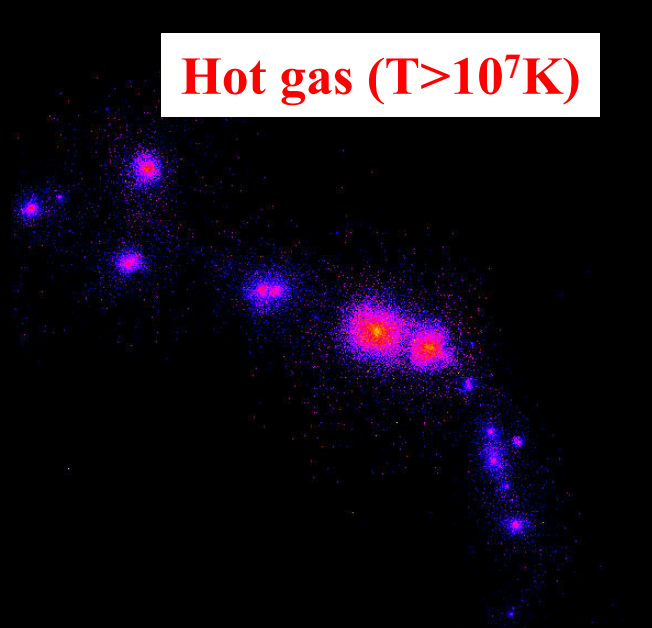
(My presentations at several conferences in 2005)

Simulated distribution of matter in the universe

$(30h^{-1}\text{Mpc})^3$
box around a
massive cluster
at $z=0$
Snapshots
from ΛCDM
SPH simulation



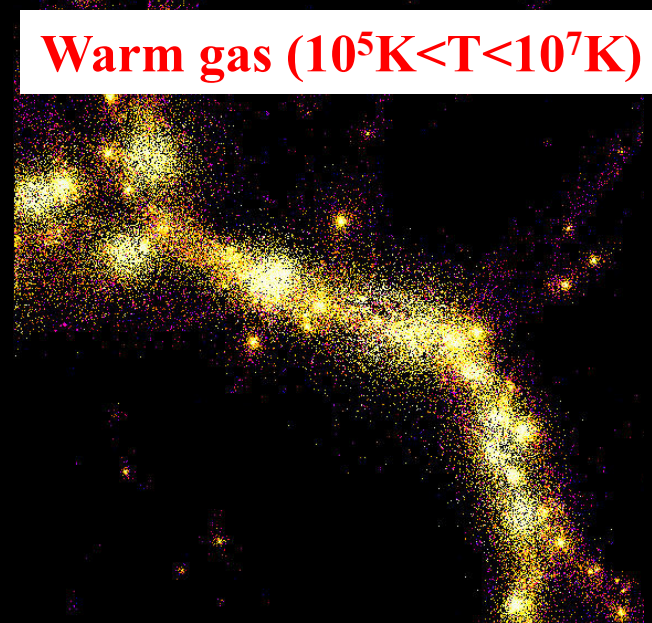
Dark matter



Hot gas ($T > 10^7\text{K}$)



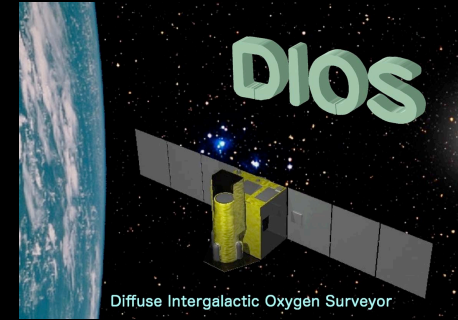
Galaxy (cold clump)



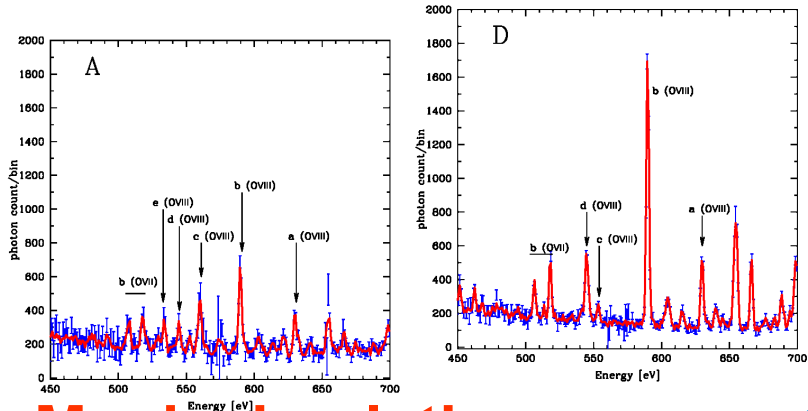
Warm gas ($10^5\text{K} < T < 10^7\text{K}$)

*Yoshikawa,
Taruya, Jing &
Suto ApJ
558(2001)520*

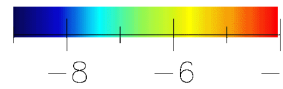
Searching for dark baryons with DIOS (Diffuse Intergalactic Oxygen Surveyor)



PASJ 55 (2003) 879
astro-ph/0303281



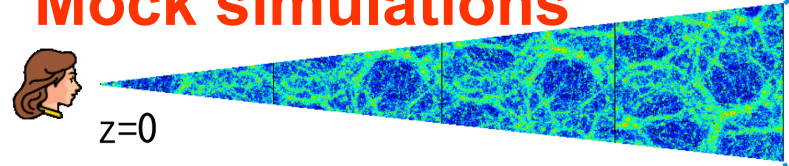
$\text{Log } S_x \text{ [erg/s/cm}^2\text{]}$



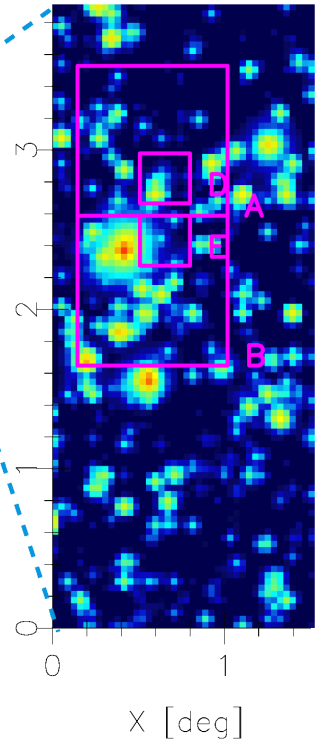
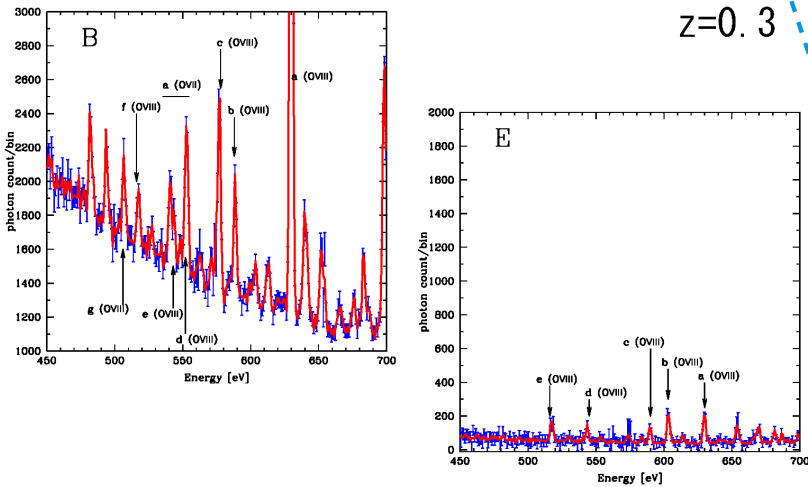
Mock simulations



$z=0$



$z=0.3$



Univ of Tokyo:

K. Yoshikawa

Y.Suto

JAXA/ISAS:

N. Yamasaki

K. Mitsuda

Tokyo Metropolitan Univ.:

T. Ohashi

Nagoya Univ.:

Y. Tawara

A. Furuzawa

DIOS papers

- Detectability of the Warm/Hot Intergalactic Medium through Emission Lines of O VII and O VIII

Yoshikawa, Yamasaki, Suto, **Ohashi**, Mitsuda, Tawara & Furuzawa PASJ 55(2003)879

- Locating the Warm--Hot Intergalactic Medium in the Simulated Local Universe

Yoshikawa, Dolag, Suto, Sasaki, Yamasaki, **Ohashi**, Mitsuda, Tawara, Fujimoto, Furusho, Furuzawa, Ishida, Ishisaki & Takei PASJ 56(2004)939

- Soft X-Ray Transmission Spectroscopy of a Warm/Hot Intergalactic Medium with XEUS

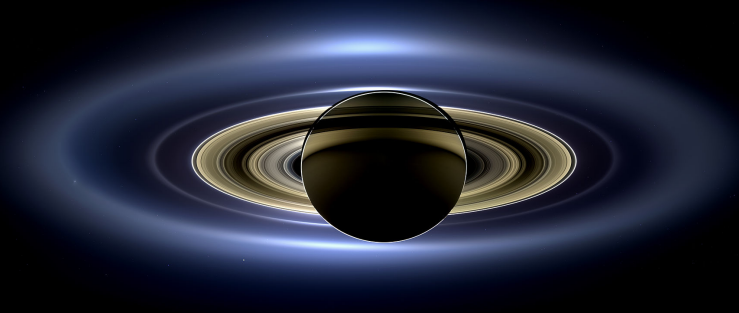
Kawahara, Yoshikawa, Sasaki, Suto, Kawai, Mitsuda, **Ohashi** & Yamasaki PASJ 58(2006)657

Outcomes of DIOS collaboration

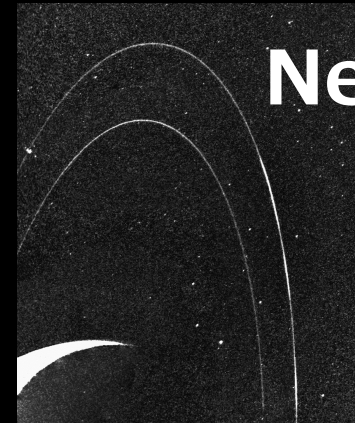
- DIOS has not become reality in Japan, but...
 - Clone idea in China: HUBS (Hot Universe Baryon Surveyor)
 - <http://hubs.phys.tsinghua.edu.cn/en/index.html>
- Kohji Yoshikawa (my post-doc in 2003-2006)
 - WHIM simulation
 - Got tenure (lecturer) and moved to Tsukuba University
- Hajime Kawahara (my student in 2004-2009 and post-doc in 2009-2010)
 - GRB+WHIM simulated spectra (master thesis)
 - Cosmology with X-ray clusters (doctor thesis)
 - Post-doc at Ohashi Lab. in 2010-2013
 - Got tenure (assistant professor) in Department of Earth Science, the University of Tokyo

Yet another unknown known(s): **exo-ring**

Saturn



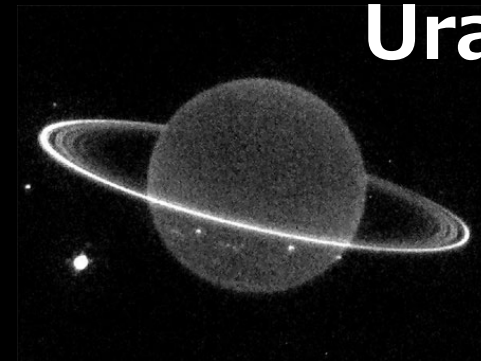
Neptune



Jupiter



Uranus



***Are they common
in exo-planetary systems as well ?***

From Saturnian model to atomic model

- Saturnian architecture inspired the model of atomic structure

- H.Nagaoka: *Phil. Mag.* 7(1904) 445

Ernest Rutherford: *The Scattering of α and β Particles by Matter and the Structure of the Atom*
Phil. Mag. 6(1911) 669



It is of interest to note that Nagaoka* has mathematically considered the properties of a “Saturnian” atom which he supposed to consist of a central attracting mass surrounded by rings of rotating electrons. He showed that such a system was stable if the attractive force was large. From the point of view considered in this paper, the chance of large deflexion would practically be unaltered, whether the atom is considered to be a disk or a sphere.

From atomic model to architecture of exoplanetary systems

Ang. Mom.	Atomic system	Exoplanetary system
L	<p>Quantized energy levels</p> <p>Emission/absorption line transition</p>	<p>Spectroscopic radial velocity</p> <p>Transit photometry, Microlensing</p> <p>Orbital period, semi-major axis, eccentricity, planetary mass</p>
S	<p>Spin of nucleus</p> <p>Hyperfine structure splitting</p>	<p>Rossiter-McLaughlin effect</p> <p>Asteroseismology</p> <p>Stellar spin - planetary orbit angle</p> <p>Stellar spin obliquity</p>
S	<p>Spin of electrons</p> <p>Fine structure splitting</p>	<p>Tidal interaction between star and planet</p> <p>Planetary spin, planetary ring</p>

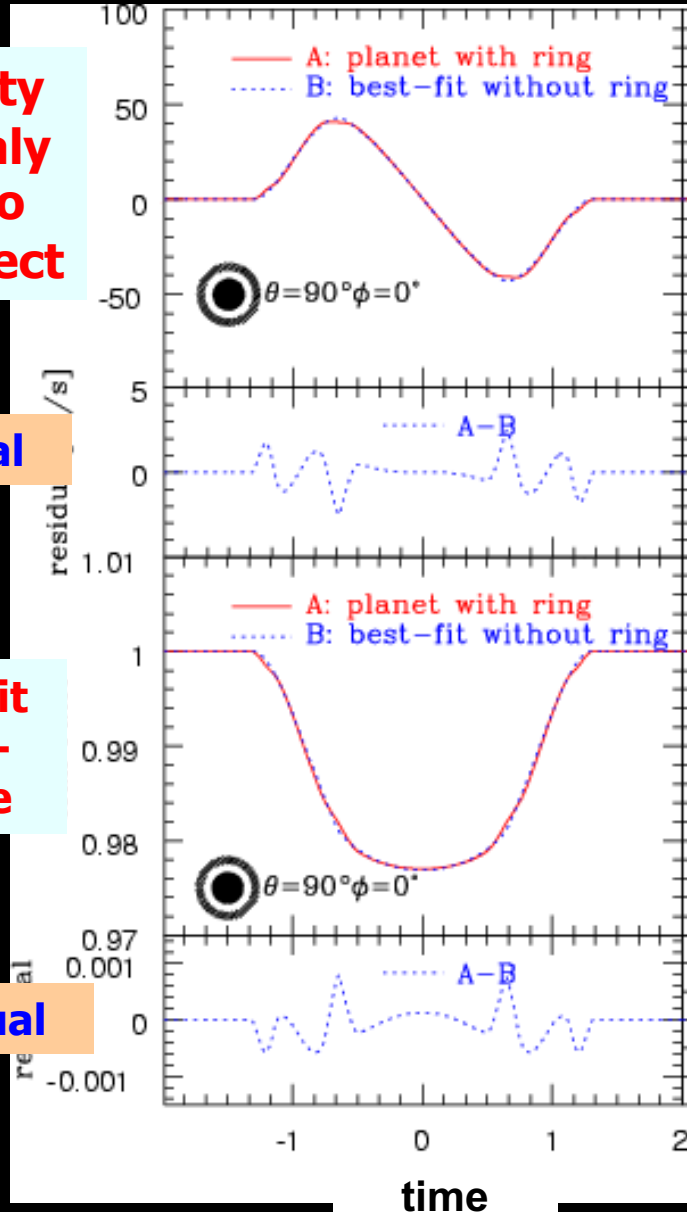
Detectability of an exo-ring

Velocity anomaly due to RM effect

residual

Transit light-curve

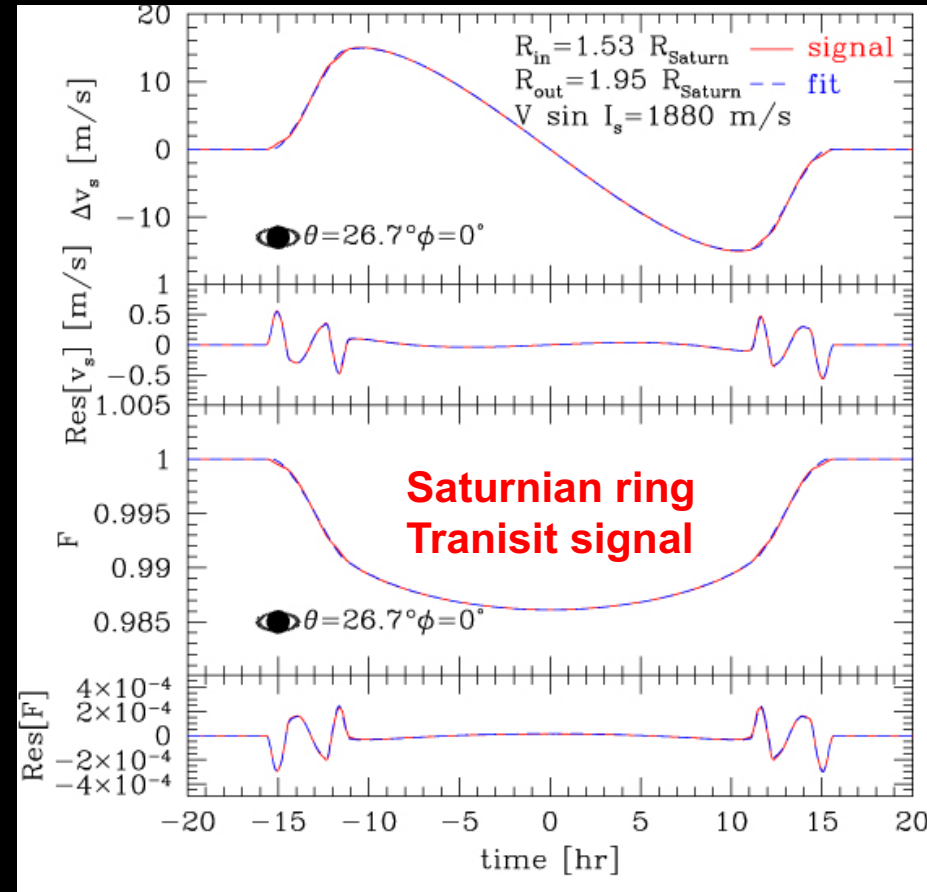
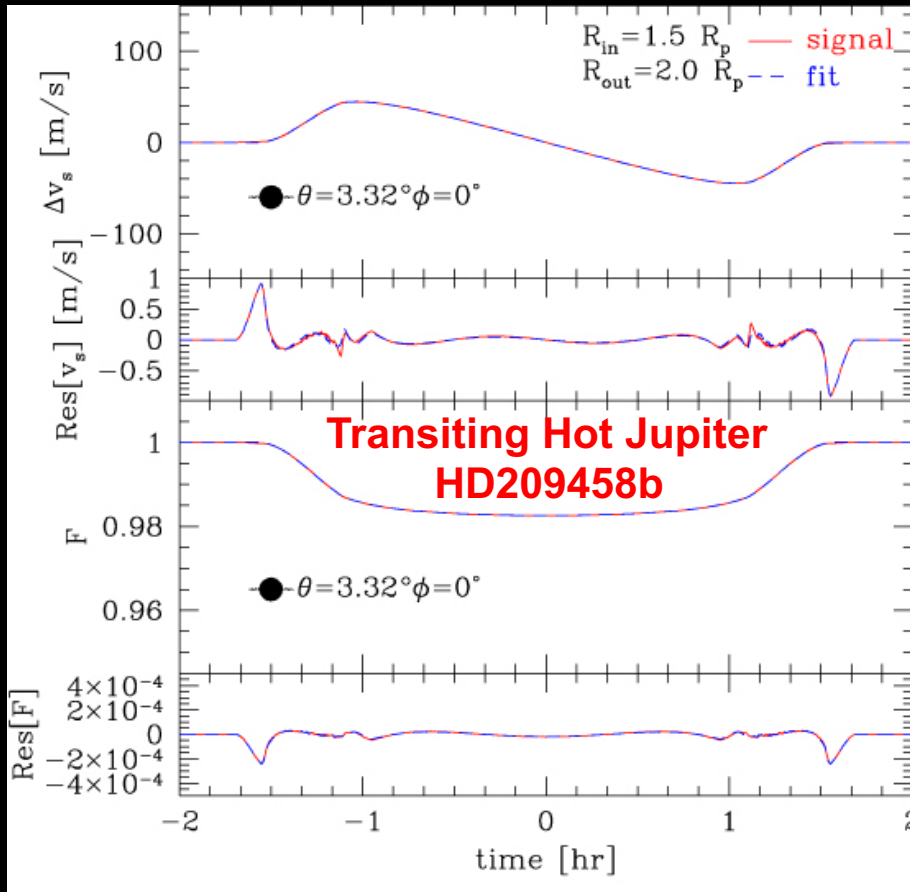
residual



- a hypothetical ring around HD209458
 - $1.5R_{pl} < R_{ring} < 2R_{pl}$
 - deviation from a best-fit single planet
 - $dv \sim 1\text{m/s}$
 - $dF/F \sim 0.1\%$
- Should be easily detectable if any !

Ohta, Taruya +YS
ApJ 690(2009)1

How about hot Jupiter and Saturn rings ?



Ohta, Taruya +YS, ApJ 690(2009)1

- Hot Jupiter: edge-on rotation due to the tidal locking
- Saturn: 30 deg. inclined, but spin of the Sun is small
- **Should be detectable with Kepler if a Saturnian ring exists**

What is the difficulty ?

- Simply limited by the lifetime of researchers
 - Orbital period of Saturn = 29.5 years
 - Robust identification of planets needs more than twice transits > 60 years, i.e., *jobless for the entire life !*
- *Sensible and promising students should not be encouraged to search for exo-rings*
 - Hajime Kawahara found a wonderful student of Ohashi-san, **Sho Uehara !**

Transiting Planet Candidates Beyond the Snow Line Detected by Visual Inspection of 7557 Kepler Objects of Interest

Sho Uehara, H.Kawahara, K.Masuda, S.Yamada & M.Aizawa

ApJ 822(2016) 2

→ ideal target list for exo-ring search !

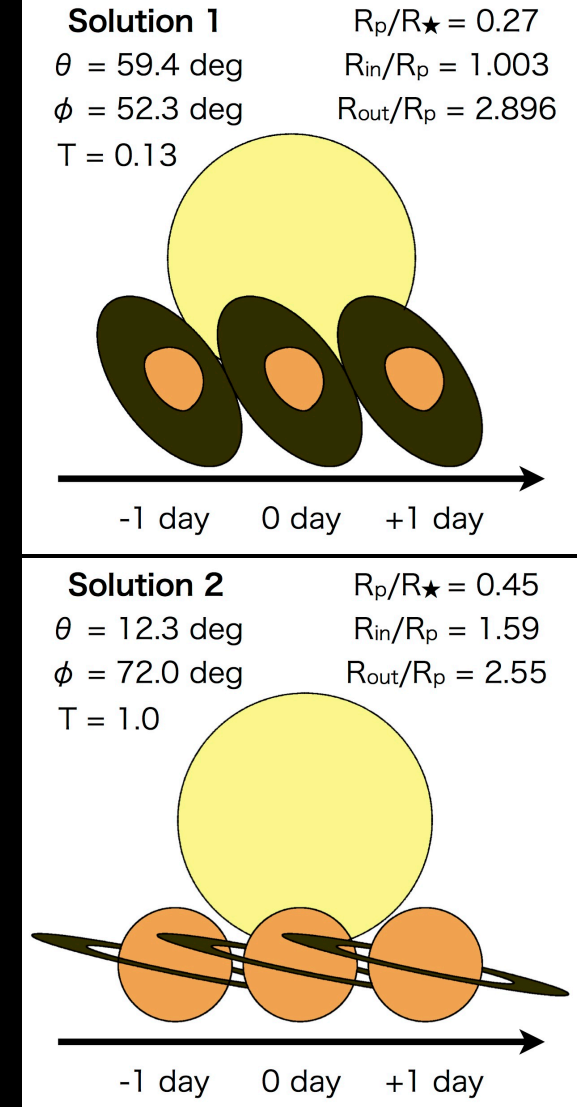
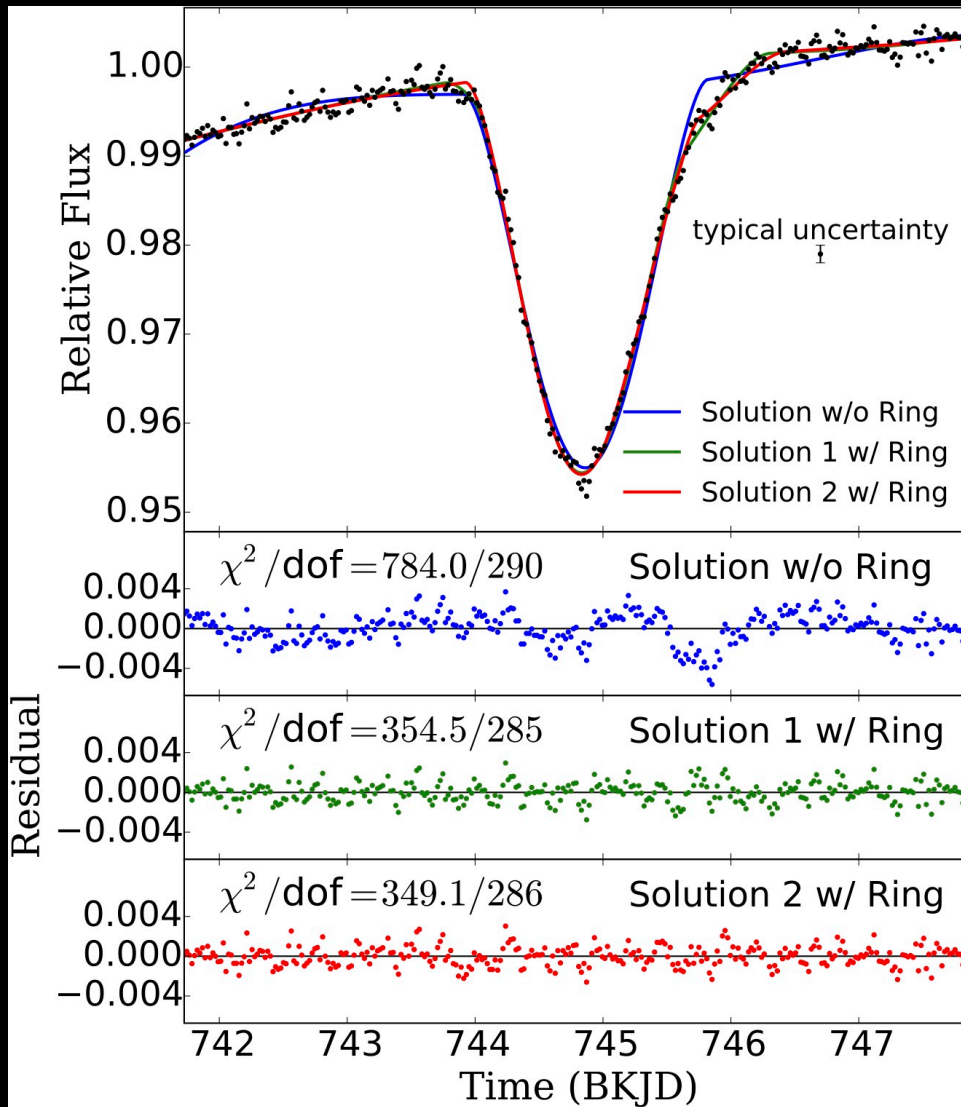
Search for exoplanetary rings via the *Kepler* transit photometry

- 89 targets for our search from KOIs with $T_{\text{eq}} < 200\text{K}$ and other long-period planet candidates (Wang et al. 2015, Uehara et al. 2016)

data	1 transit	2	≥ 3
KOIs with $T_{\text{eq}} < 200\text{K}$	5	2	30
Wang et al. (2015)	17	14	10
Uehara et al. (2016)	21	0	0

Aizawa, Uehara, Masuda, Kawahara + YS
AJ 153(2017)193(23pp)

Two possible solutions of a ringed planet scenario: KIC 10403228



Aizawa et al. (2017)

From unknown knowns to known knowns

- I have to admit that we were not (yet) able to establish the presence of unknown knowns (dark baryons / exo-rings)
 - DIOS may be revised as HUBS in China
 - Exo-rings would be eventually discovered after many generations of astronomers
- Nevertheless, I did enjoy those challenging projects with Ohashi-san and his students
- Therefore I would like to thank Ohashi-san for offering me those wonderful collaboration opportunities, and congratulations to your happy retirement !