Reports on Senior Projects in Experimental Physics I / II

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Contents

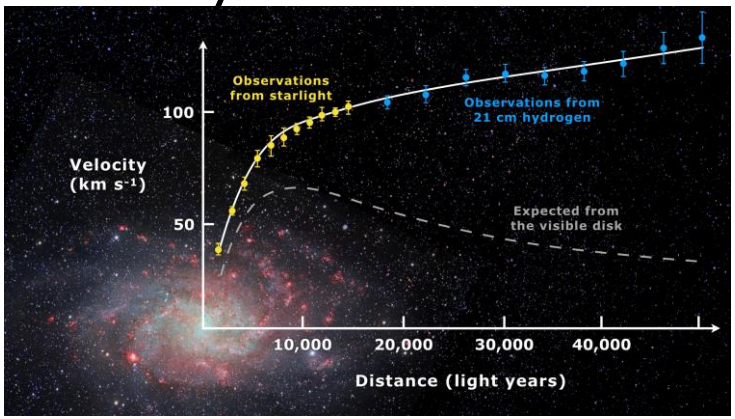
Part 1 :
Ring Cavity Experiment for Dark Matter Axion Search

with Watanabe-kun
in 4S semester @ Ando Lab

Introduction

- The existence of dark matter

Galaxy rotation curve



Wikipedia: Galaxy rotation curve

Bullet cluster

NASA APOD

CMB

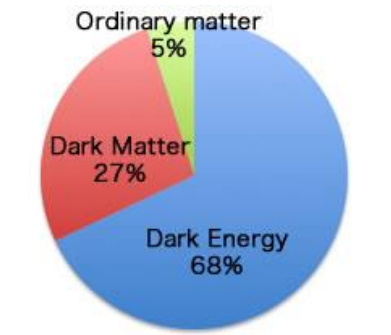


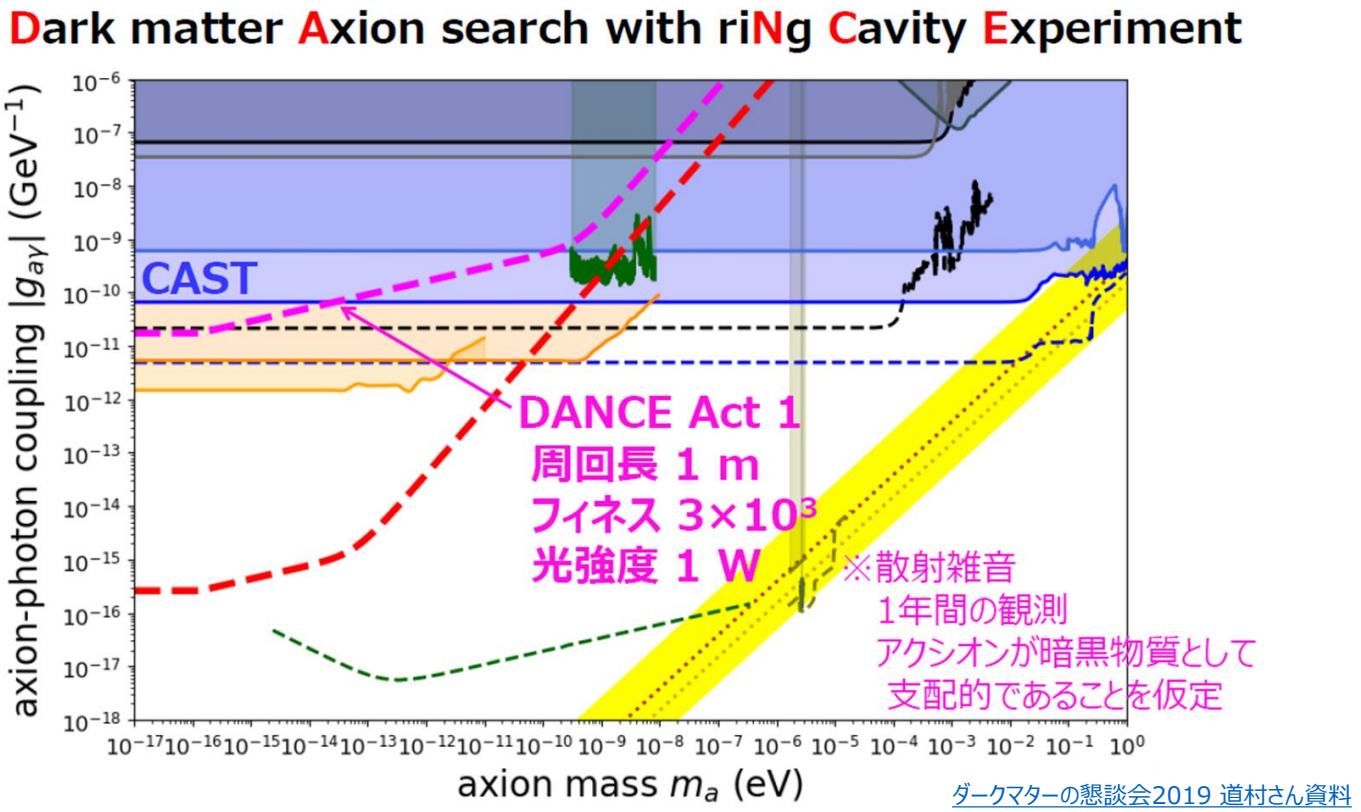
Fig. 1: Components of the Universe

XMASS: Dark Matter

- Candidates of dark matter : WIMPs, axion, PBH

Introduction

- Axion is one of candidates of dark matter
- Previous research placed restrictions in the figure
- If axion exists here, c_R and c_L will be different or linear polarization will rotate
  → observe with ring cavity



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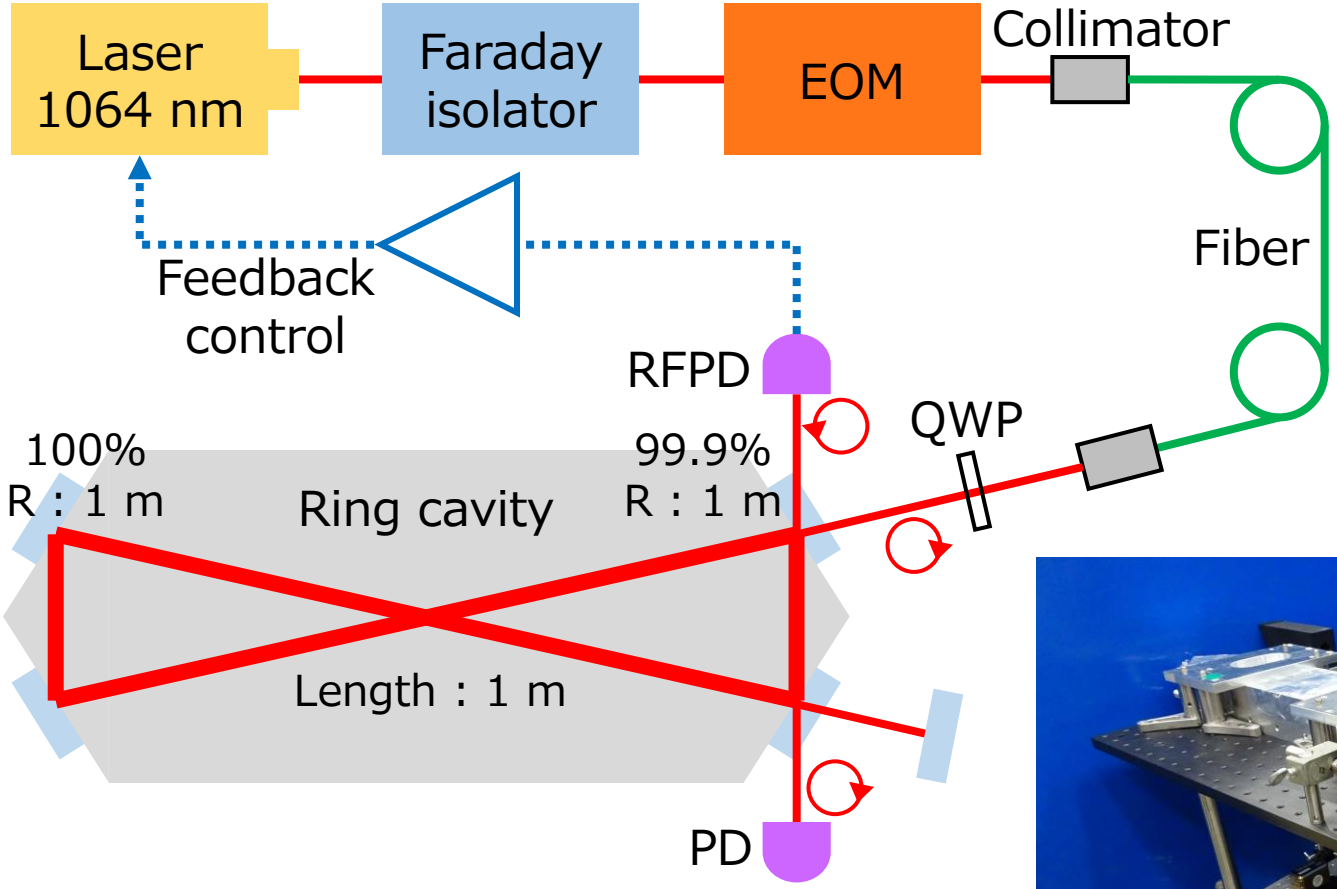
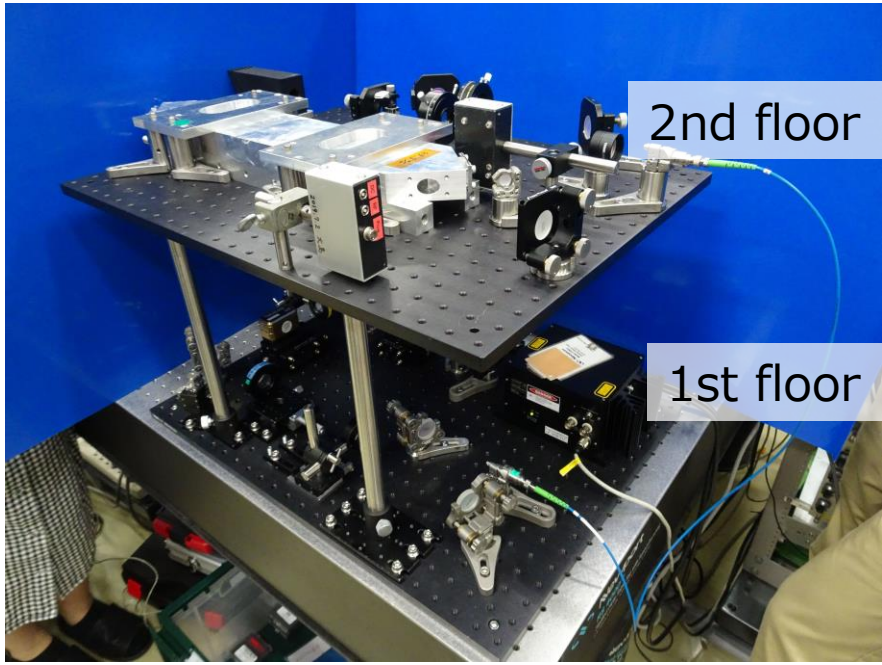
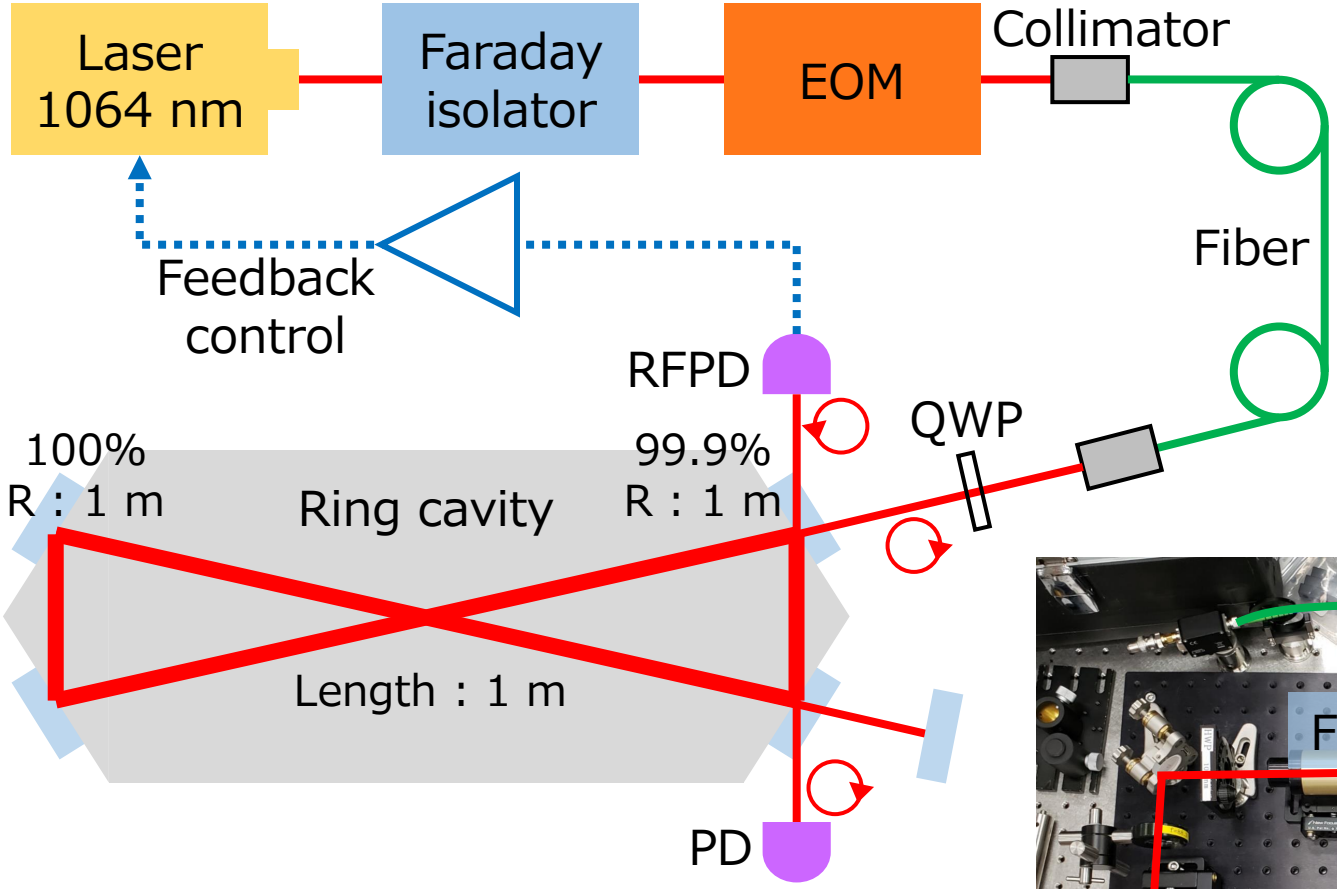
Optical system

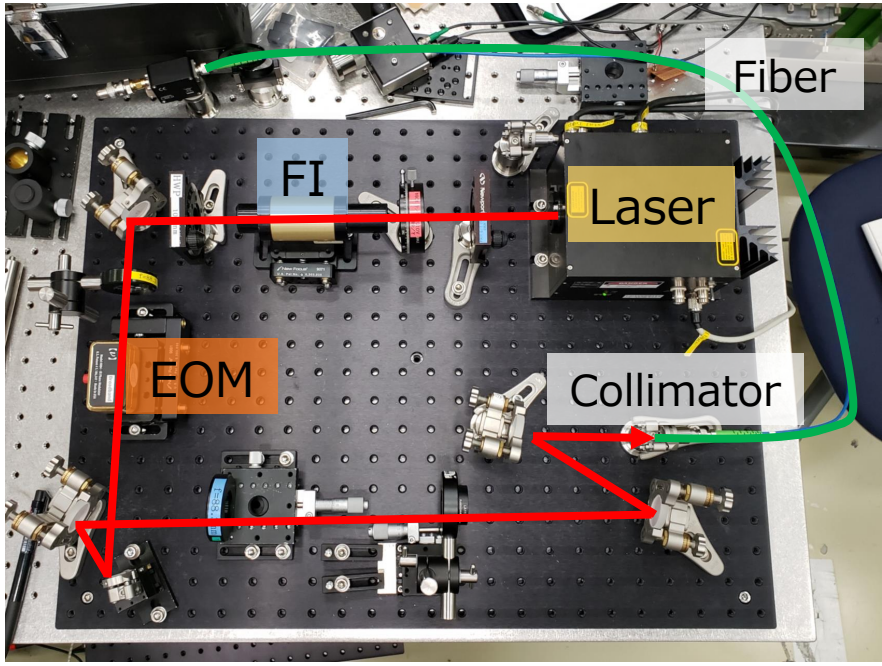




Optical system



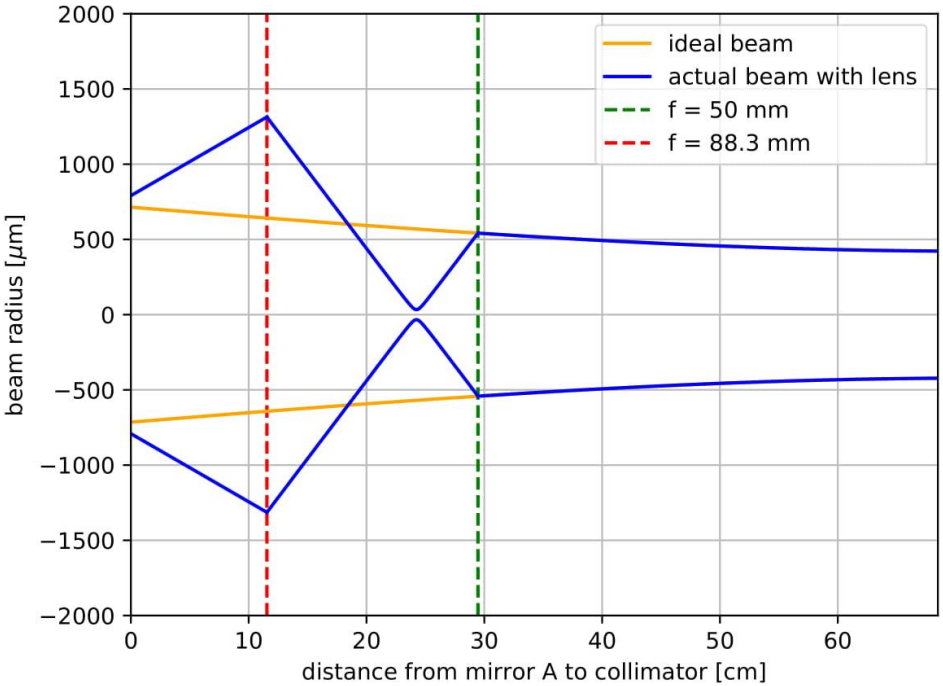
1st floor



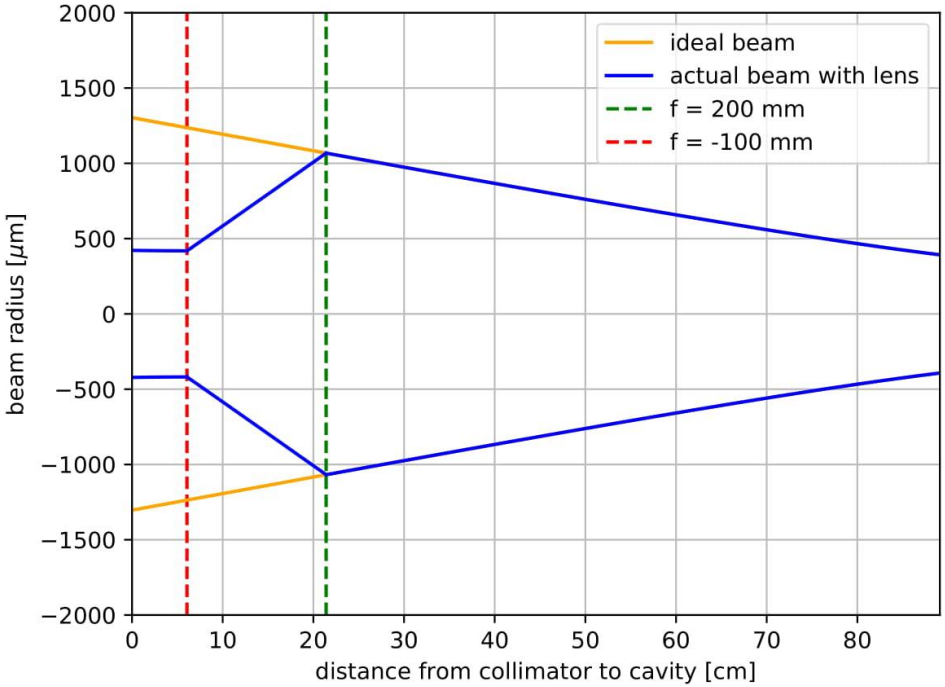
Mode matching

- Mode matching with lenses, beam profiler
- Calculation with Python, JamMt

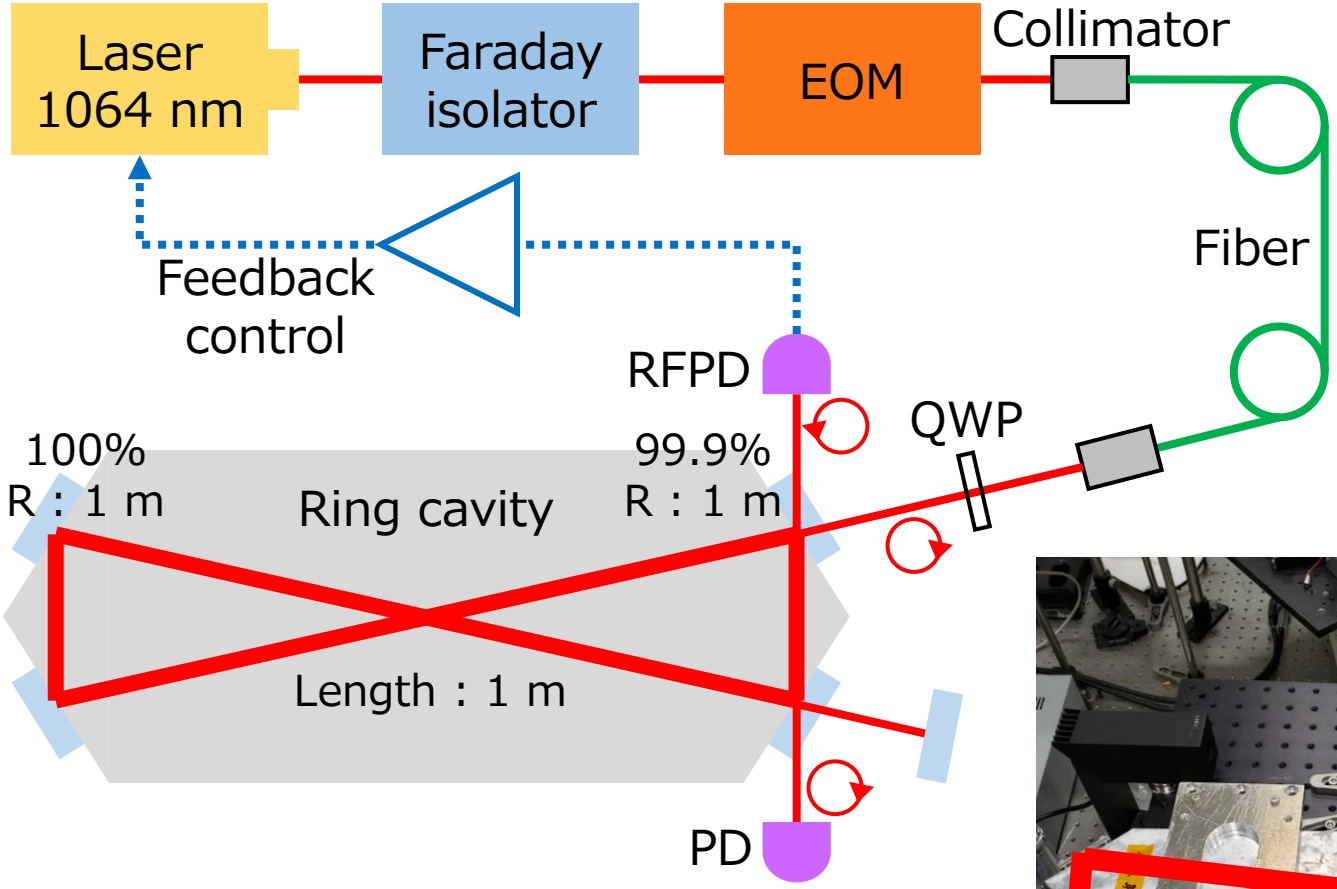
for a fiber



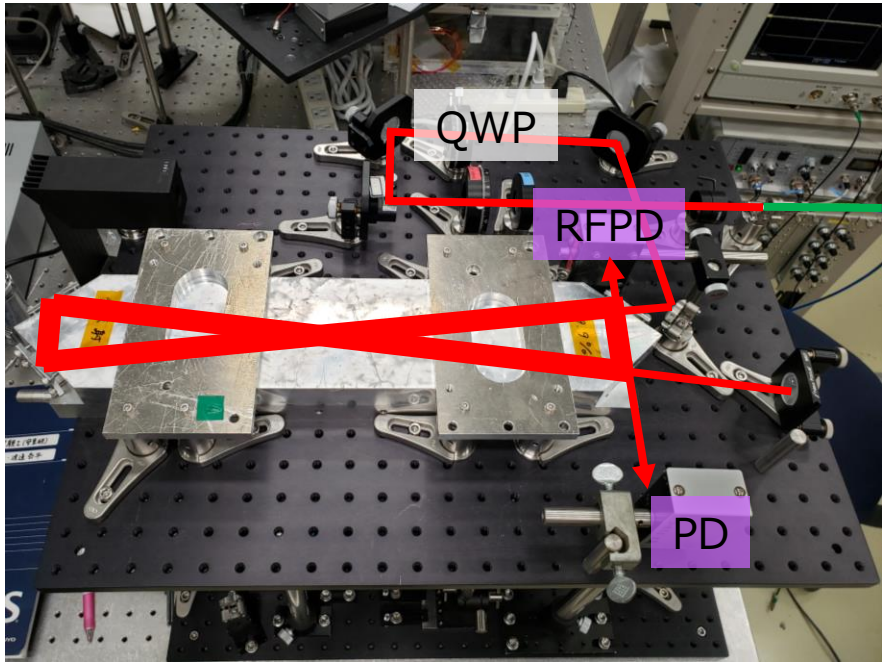
for a ring cavity



Optical system

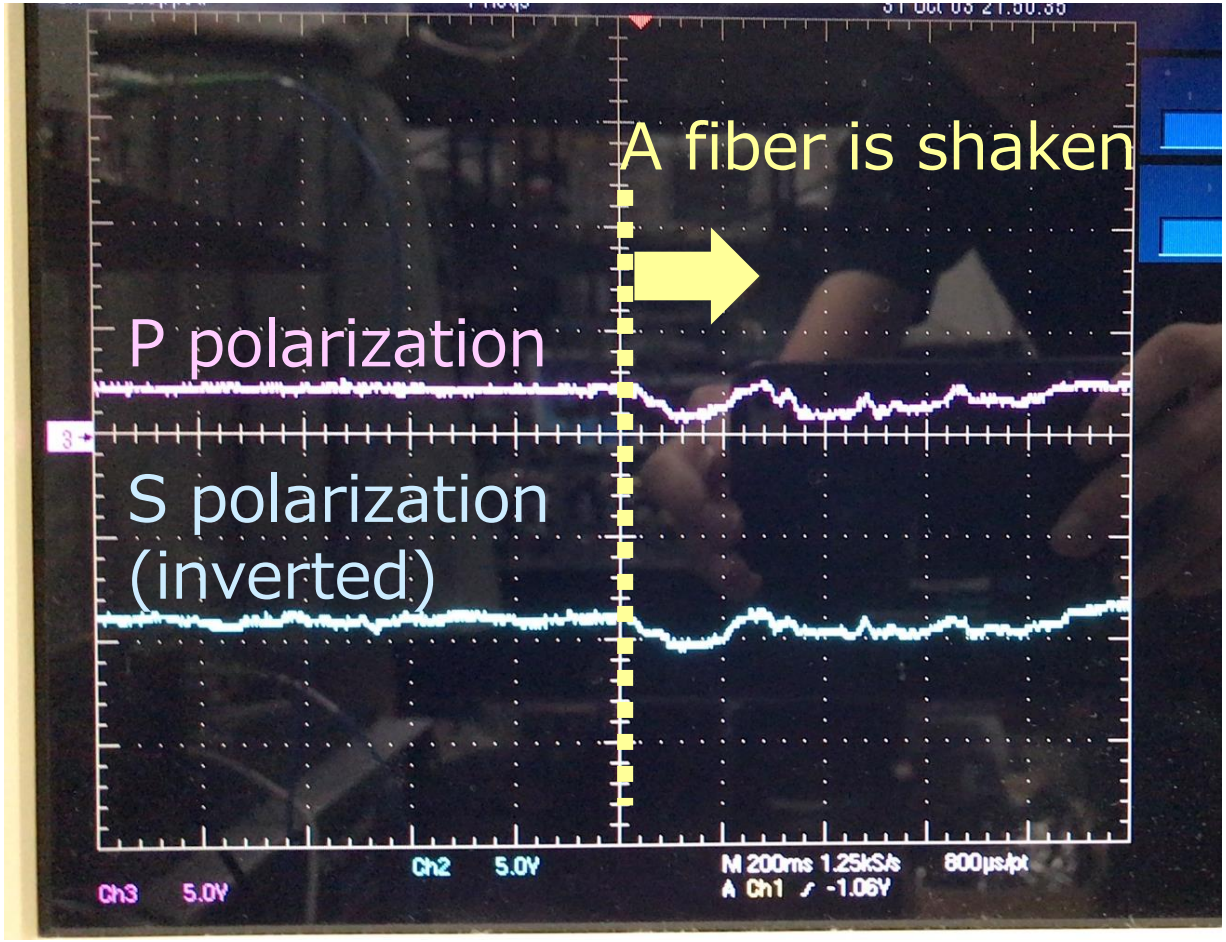


2nd floor

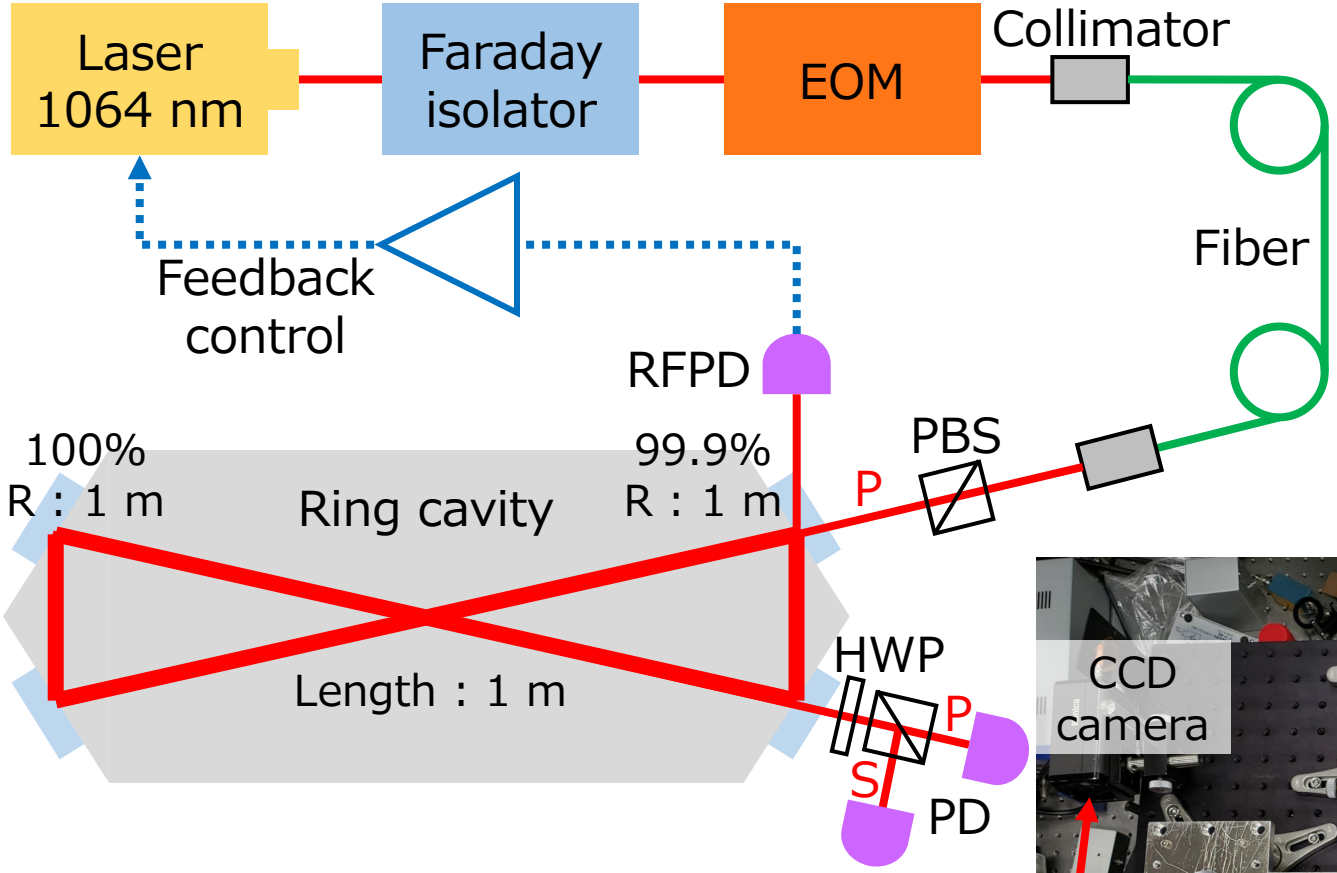


Fiber problem

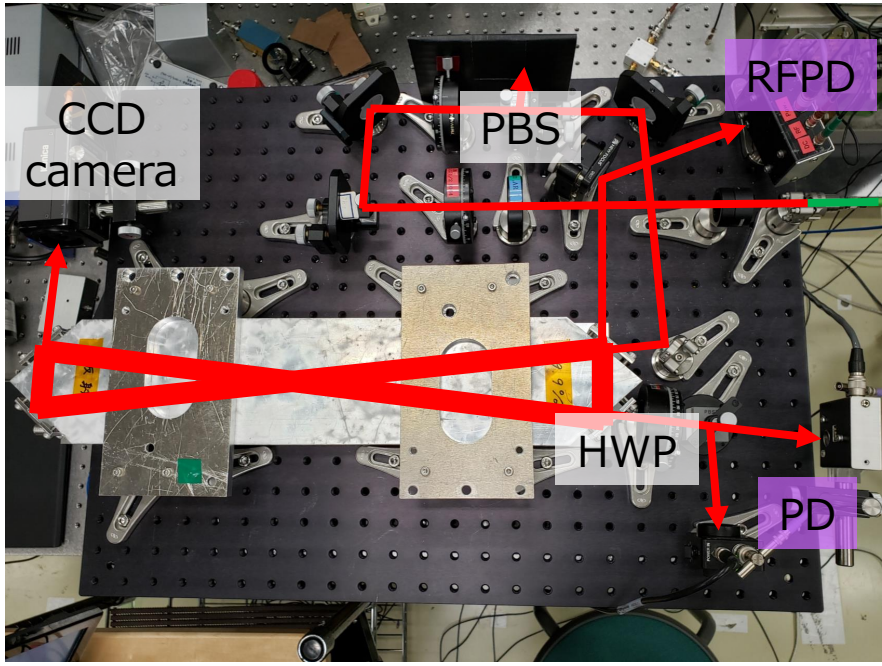
- When a fiber is shaken, polarization rotates
  → difficult to keep circular polarization for a long time
  → change optical system



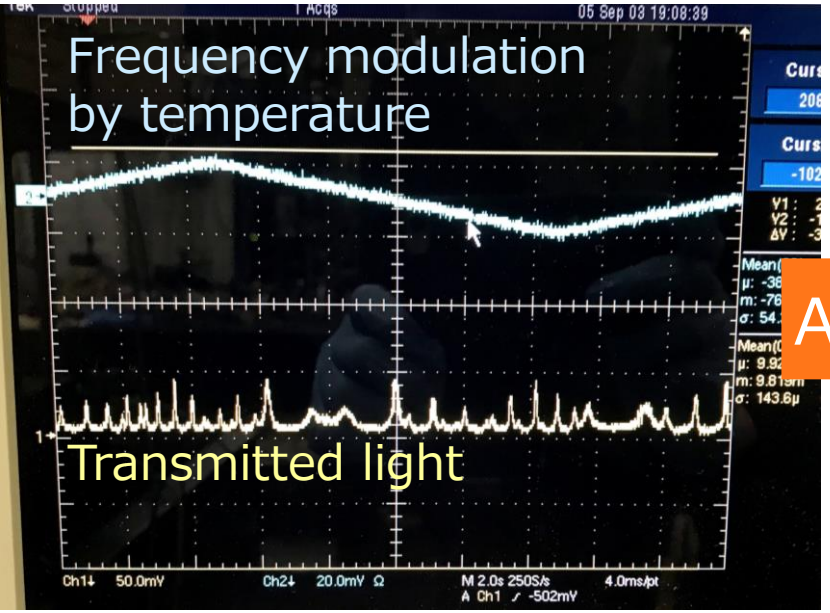
Optical system (ver. 2)



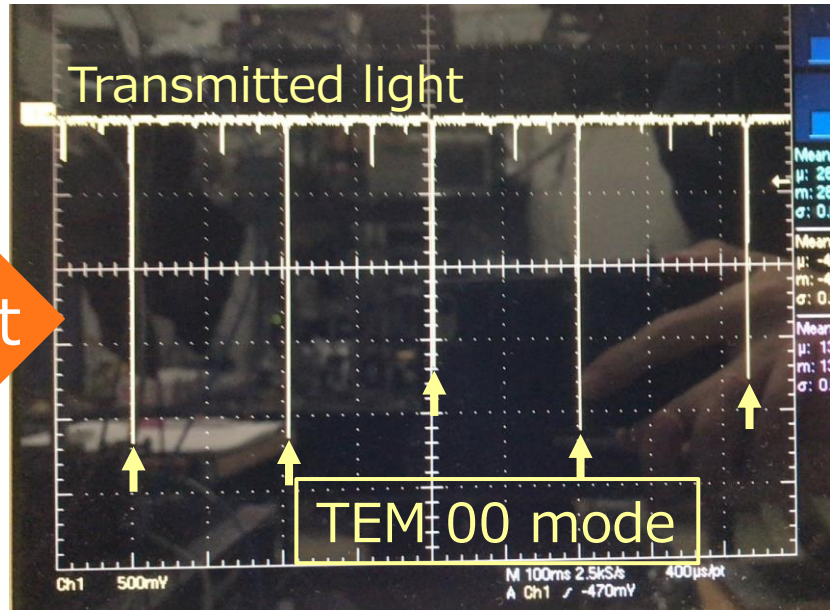
2nd floor



Performance evaluation of cavity

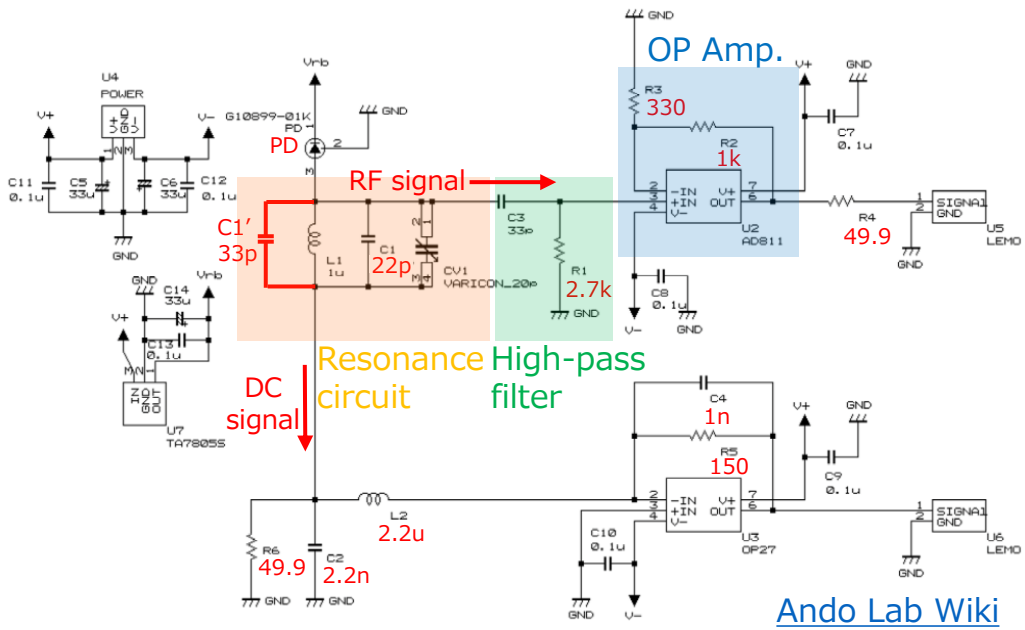


Alignment

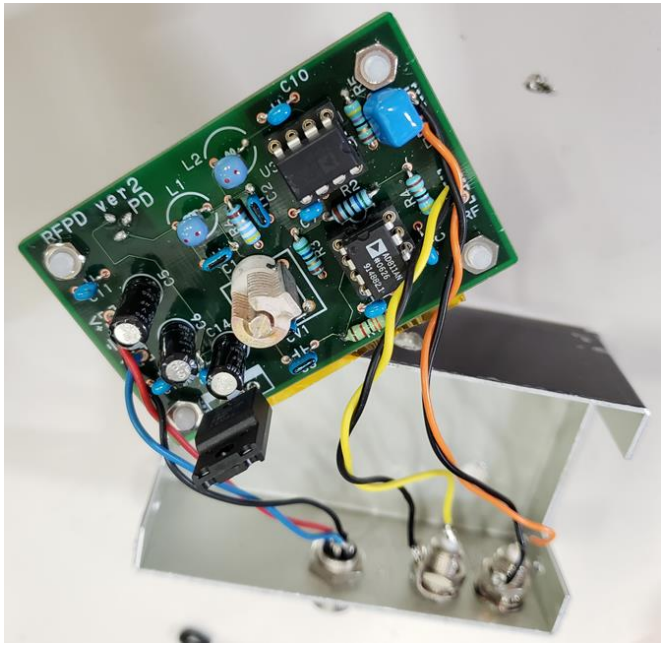


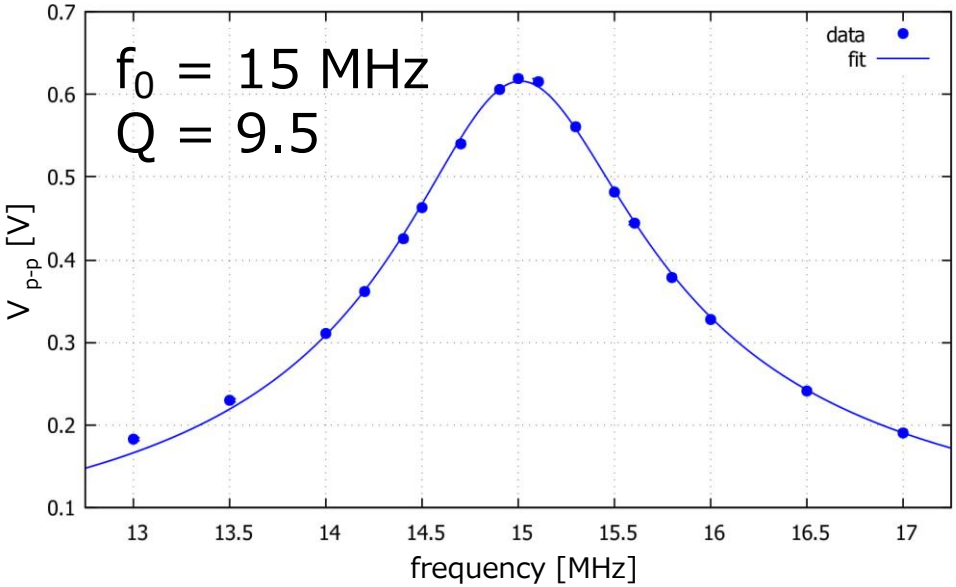
	Measured value (P polarization)	Discussion
Finesse	515 ± 6	Much smaller than design value (3140)
Proportion of mode matching	86 ± 2 %	Big enough

Making RFPD

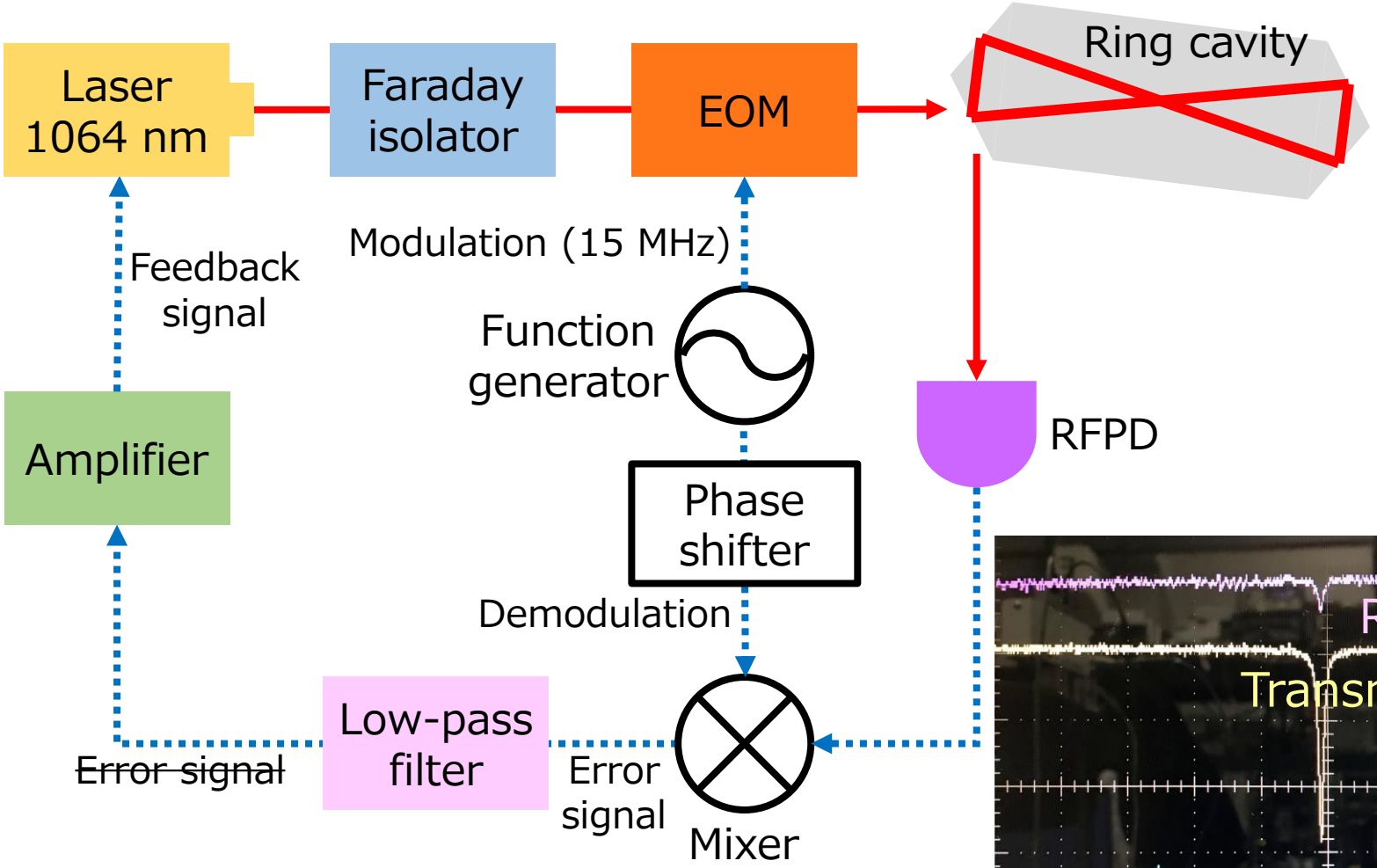


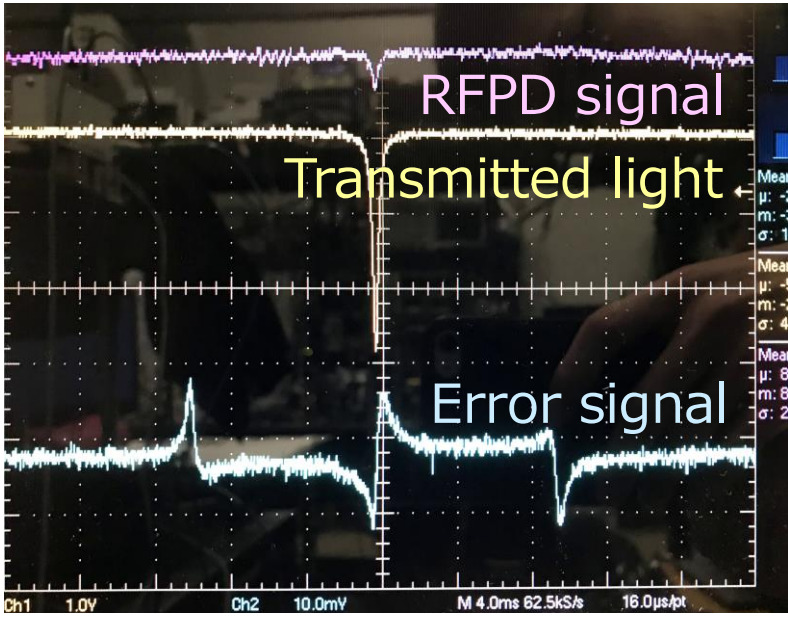
Ando Lab Wiki





Feedback control (PDH technique)

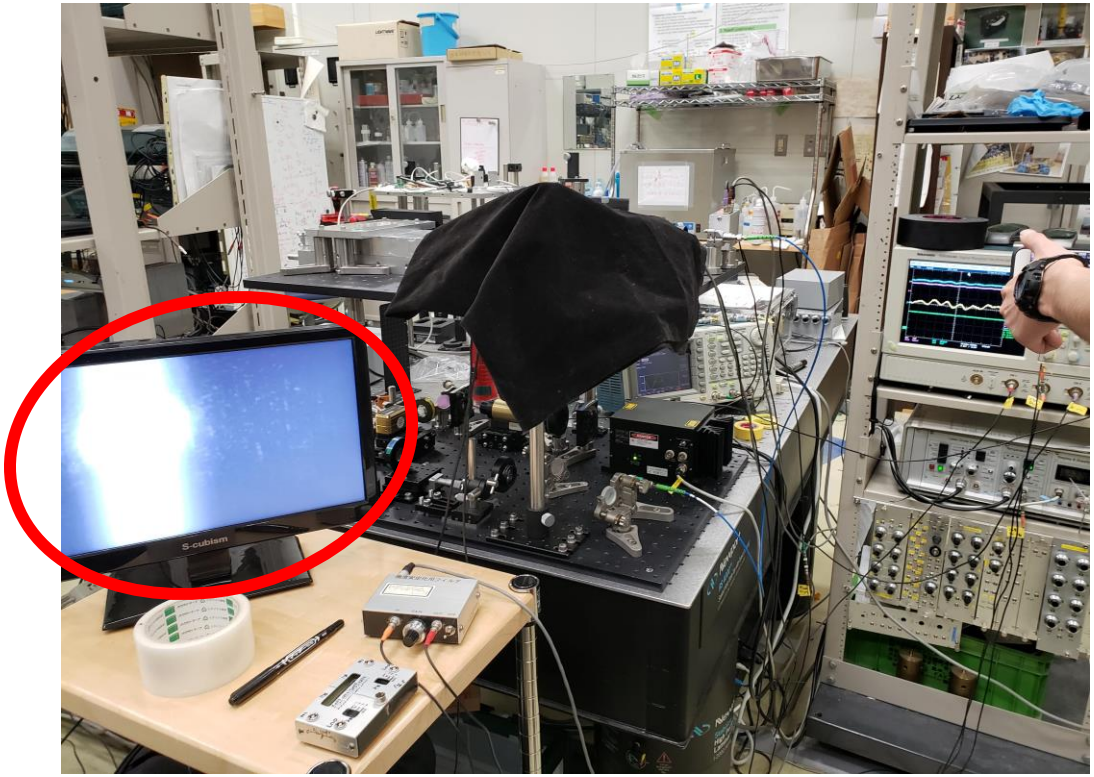




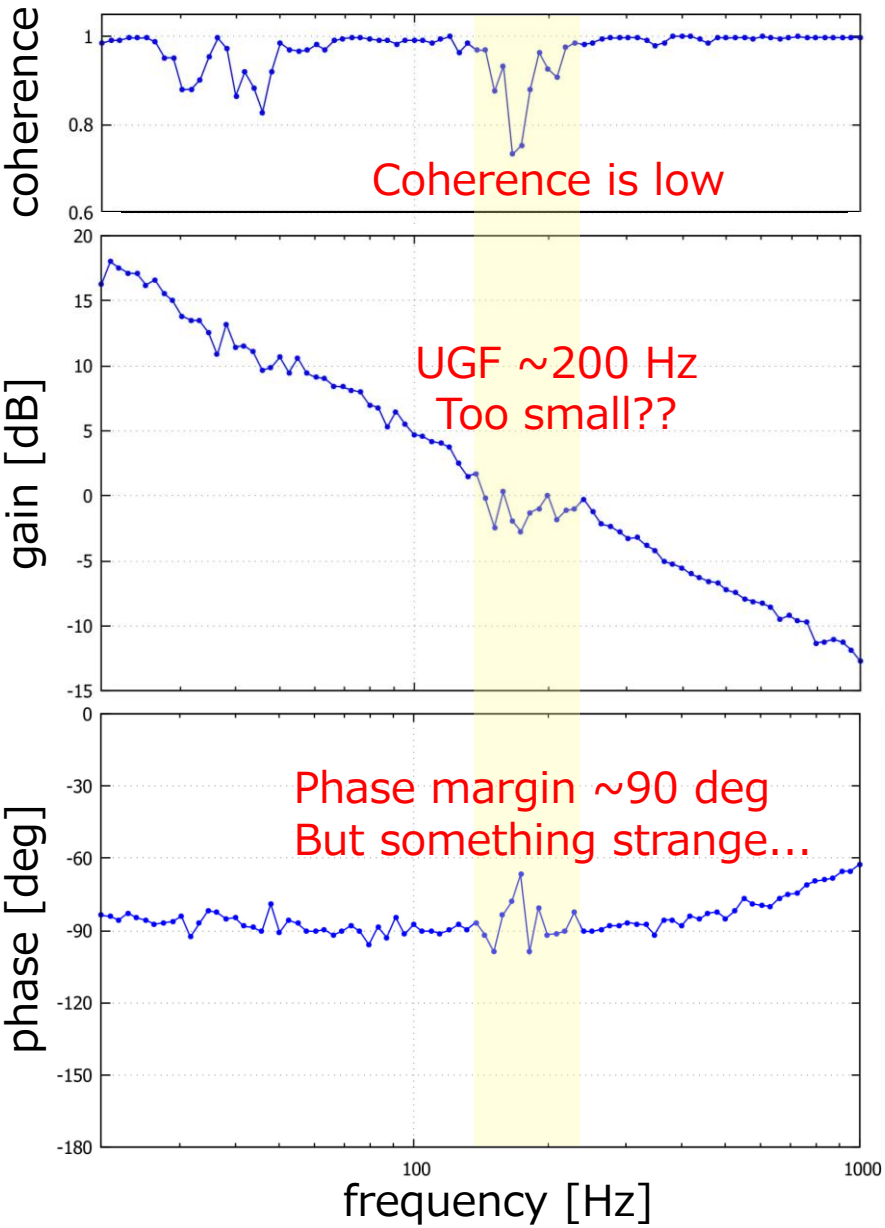
Feedback control

- Succeeded in locking the laser to the cavity
- But ... in only 5 minutes
  Error signal saturated or the light faded away

Monitoring transmitted light
with CCD camera



Open loop transfer function

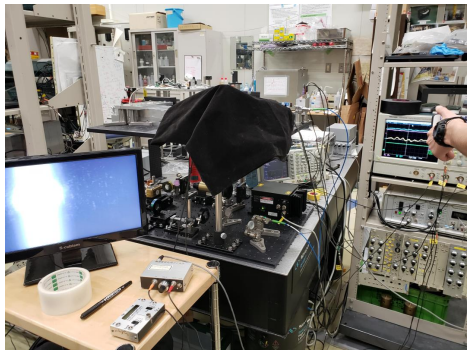


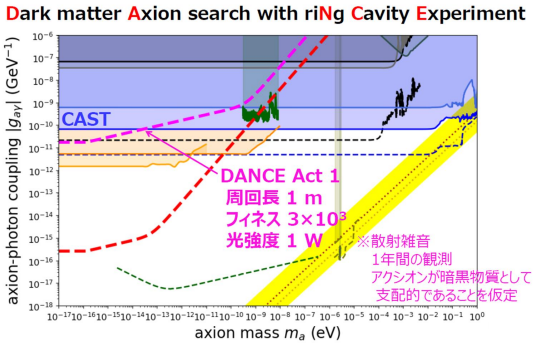
Why feedback control was finished in 5 minutes??

I changed gain and cut-off frequency but failed repeatedly

Future experiments

- Keep feedback control for a long time, get the data and place restrictions in the figure





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- Discover the cause of the small finesse and improve it

	Measured value (P polarization)	Discussion
Finesse	515 ± 6	Much smaller than design value (3140)

Short Break : Self-introduction

Self-introduction

- Timeline about me

1996.11	born in Tokyo
-2015.3	Senior High School, Univ. of Tsukuba
2016.4-	Univ. of Tokyo, Natural Science II
2018.4-	Dept. of Physics
2020.4-	Graduate school, Ando Lab

- My favorites : sports, Disney, Harry Potter, the universe




Educational activities

- Science teacher license of junior & senior high school

Chemical class (教育実習 @ 筑附)

- Teaching assistant of Galaxy School at Kiso Observatory

Everyone @ GS2018

Poster of GS2020
IoA 銀河学校
Science Station

- Staff of NAOJ Mitaka Stargazing

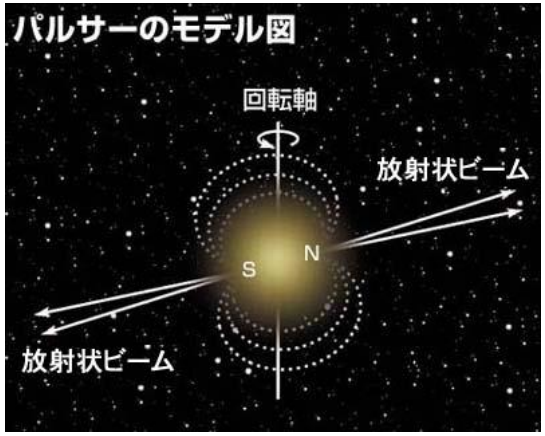
国立天文台 三鷹 観望会

Part 2 :
Measurements of the Jets Motion of PSR B1509–58 by Chandra X-ray Observatory Image Analysis

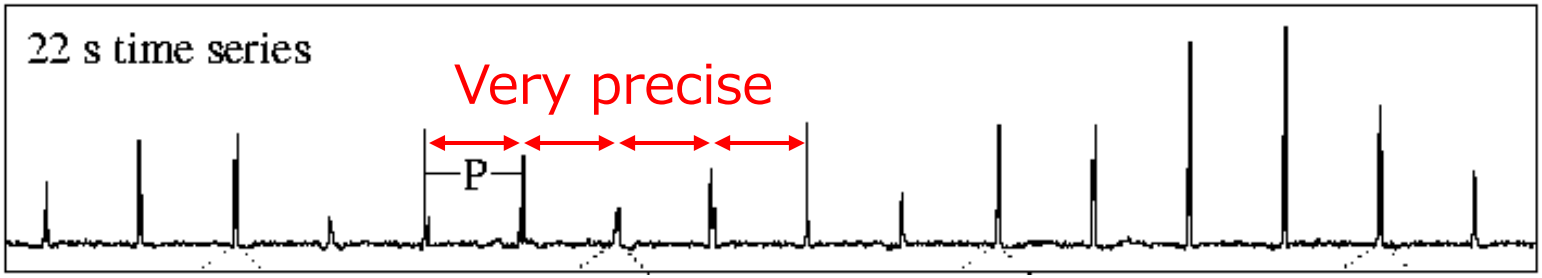
with Tsuji-kun
in 4A semester @ Bamba Lab

Introduction

- A pulsar : a highly magnetized rotating neutron star
- The interval between pulses is basically very precise



JAXA: pulsar



Handbook of Pulsar Astronomy

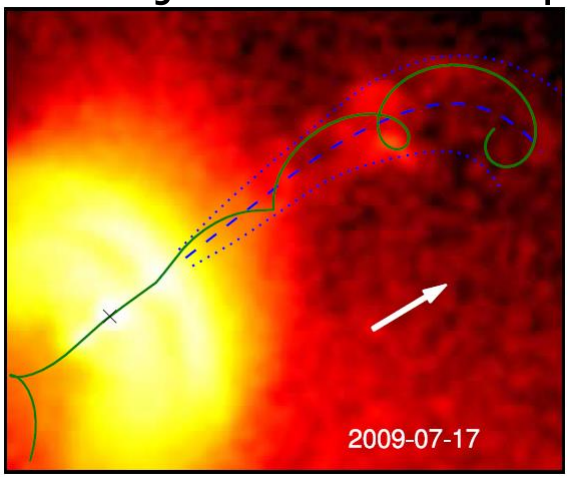
- Glitch : the period changes suddenly in rare cases

Introduction

- Glitch may be better explained by the precession (歳差運動) of a pulsar
- The precession has been observed
  → analyze the image of another pulsar jets to find a new precession

Precession

The helical jet of the Vela pulsar

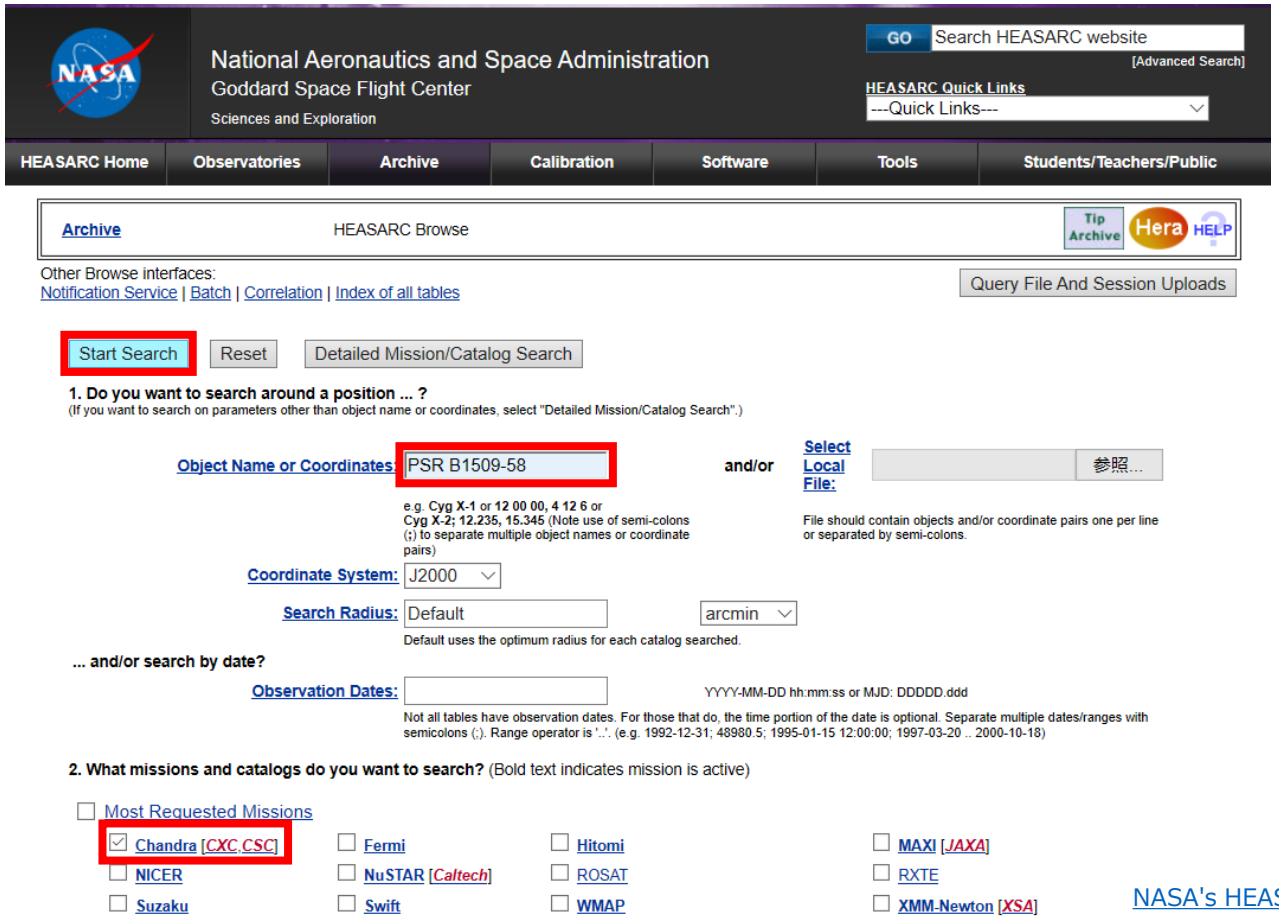


M. Durant+, 2013

Observation

NASA

- Chandra X-ray Observatory archive data
- Object name : PSR B1509−58



NASA's HEASARC: Archive

Observation

- To discover the jets motion of the pulsar
  → chose 3 data observed in different years

Name for simplicity	Obs. ID	Year
A	754	2000
B	5534	2004
C	18023	2017

18 data

Select All	Related Links	Services	obsid	status	name	ra	dec	time	detector	grating	exposure [s]	type	pi	public date	Search Offset ['] from (target)
	ASCA ROSAT RXTE XMM	O R N S D B F	754	archived	G320.4-1.2	15 13 55.60	-59 08 08.9	2000-08-14 13:31:48	ACIS-I	NONE	19280	GO	Kaspi	2001-08-25	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	3833	archived	PSR B1509-58	15 13 55.60	-59 08 09.2	2003-10-18 00:23:07	ACIS-I	NONE	19380	GO	Gaensler	2004-10-24	0.012 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	3834	archived	PSR B1509-58	15 13 55.60	-59 08 09.2	2003-04-21 17:00:25	ACIS-I	NONE	9590	GO	Gaensler	2004-05-01	0.012 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	4384	archived	PSR B1509-58	15 13 55.60	-59 08 09.2	2003-04-28 06:05:29	ACIS-I	NONE	10020	GO	Gaensler	2004-05-01	0.012 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	5515	archived	PSR B1509-58	15 13 55.60	-59 08 09.0	2005-06-13 00:12:14	HRC-I	NONE	45190	GTO	Murray	2006-06-17	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	5534	archived	PSR B1509-58	15 13 55.60	-59 08 08.9	2004-12-28 10:26:36	ACIS-I	NONE	50130	GO	Slane	2006-10-19	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	5535	archived	PSR B1509-58	15 13 55.60	-59 08 08.9	2005-02-07 15:15:07	ACIS-I	NONE	43130	GO	Slane	2006-10-19	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	5562	archived	RCW89	15 13 34.20	-59 01 58.0	2004-12-31 09:12:47	ACIS-S	NONE	29960	GO	Yatsu	2006-01-03	6.759 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	6116	archived	PSR B1509-58	15 13 55.60	-59 08 08.9	2005-04-29 03:40:54	ACIS-I	NONE	47650	GO	Slane	2006-10-19	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	6117	archived	PSR B1509-58	15 13 55.60	-59 08 08.9	2005-10-18 00:11:37	ACIS-I	NONE	46140	GO	Slane	2006-10-19	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D F	9138	archived	RCW 89	15 13 34.20	-59 01 58.0	2008-06-19 18:47:07	ACIS-S	NONE	59740	GO	Yatsu	2009-06-22	6.759 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	14805	archived	PSR B1509-58	15 13 55.60	-59 08 08.9	2013-05-29 14:36:27	ACIS-S	NONE	60100	GO	Ng	2014-05-31	0.011 (PSR B1509-58)
	ASCA ROSAT RXTE XMM	O R N S D B F	18023	archived	PSR B1509-58	15 13 55.50	-59 08 08.8	2017-02-02 23:18:20	ACIS-I	NONE	18560	GO	Xue	2018-02-03	0.002 (PSR B1509-58)
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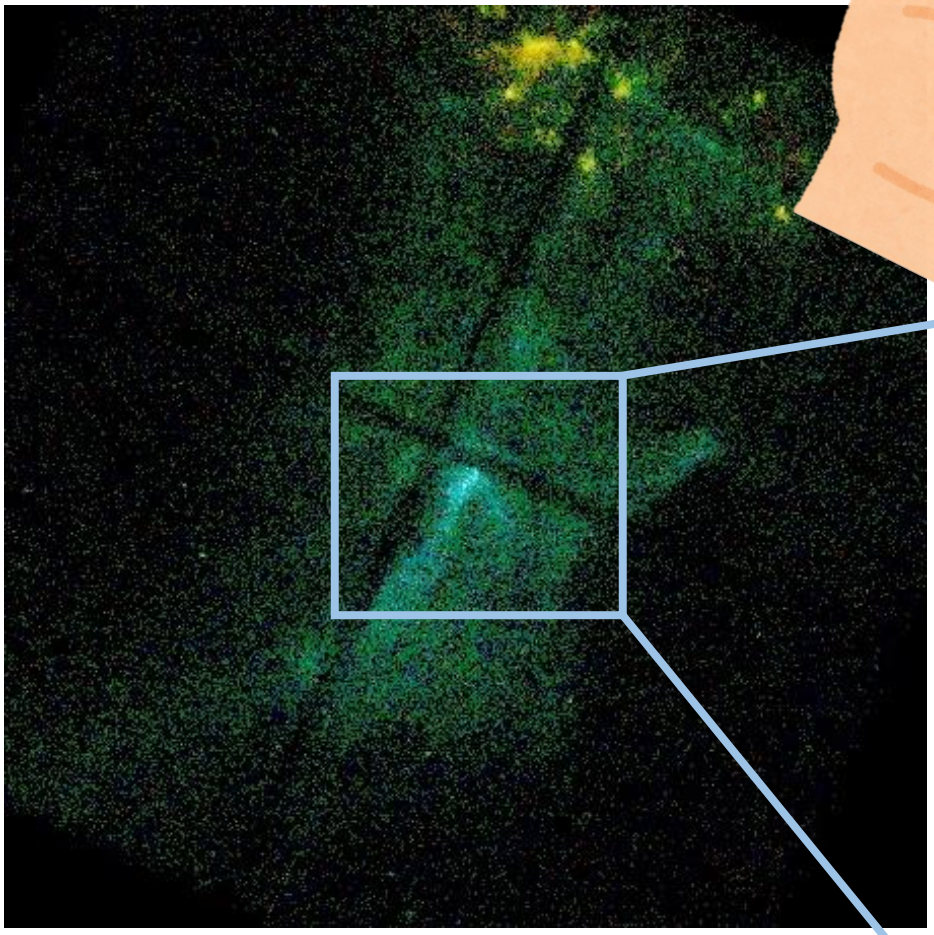
18 rows retrieved from chanmaster

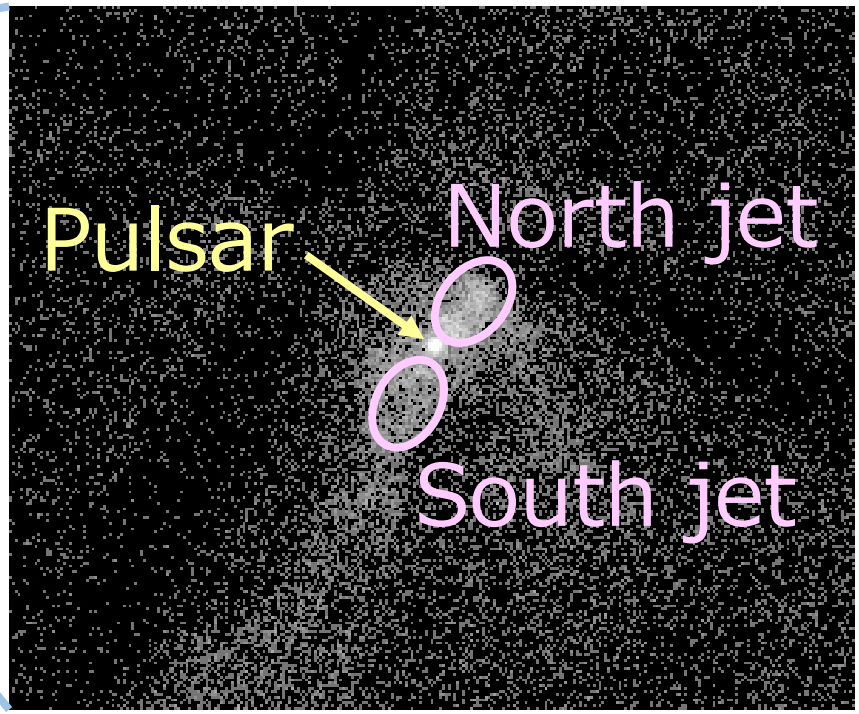
NASA's HEASARC: Archive

Observation

PSR B1509−58



"Hand of God"

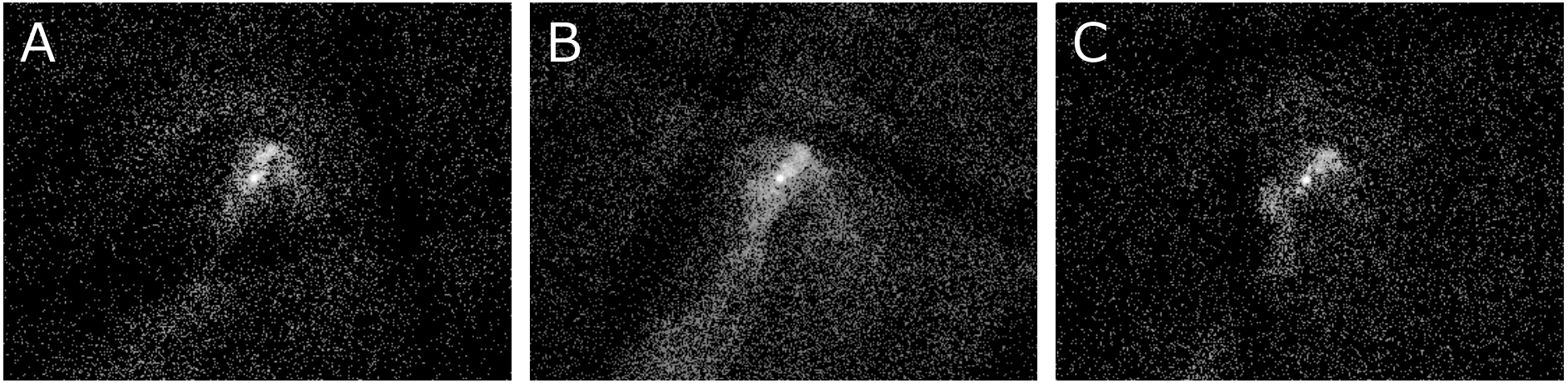


Data : B
energy : 0.3-1 keV, 1-3 keV, 3-8 keV

Analysis

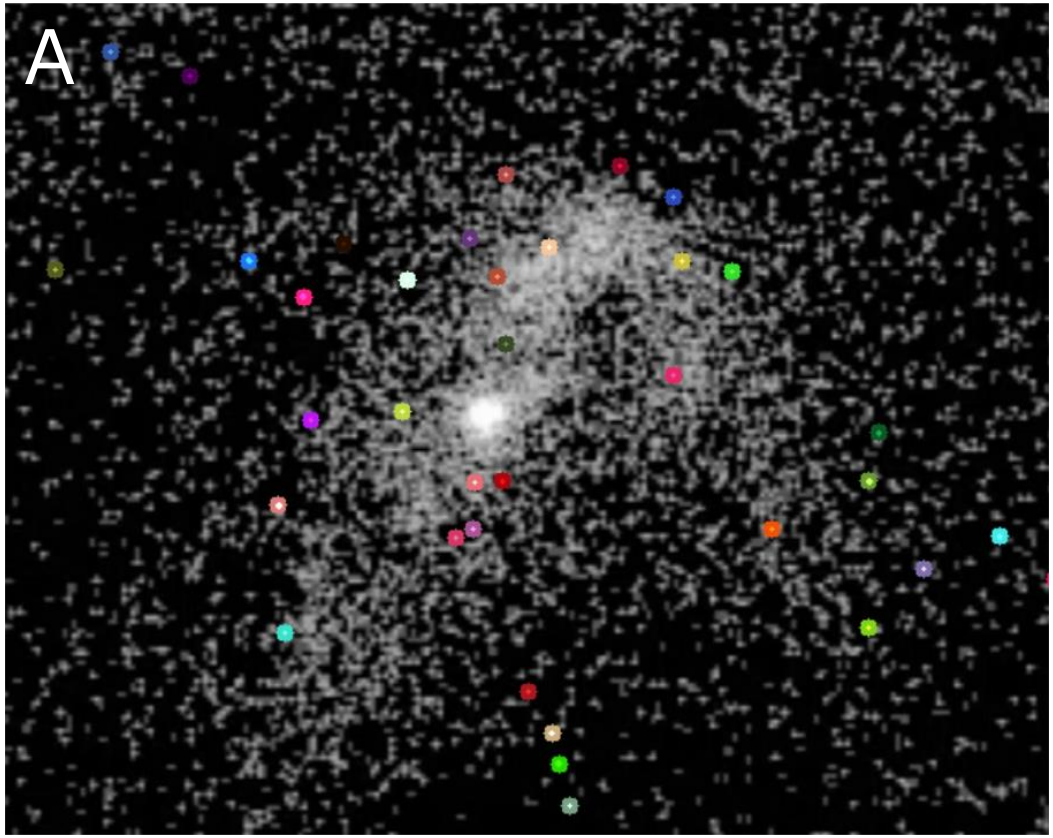
- CIAO : the software for analyzing Chandra data
- Reproject event data for a stack to a common point
- Create image data from event data

energy : 2-8 keV



Analysis

- Optical flow :
  the vector representation of the motion of objects
- Open CV : open source library for dealing with image including optical flow
- The direction of the jet motion is estimated



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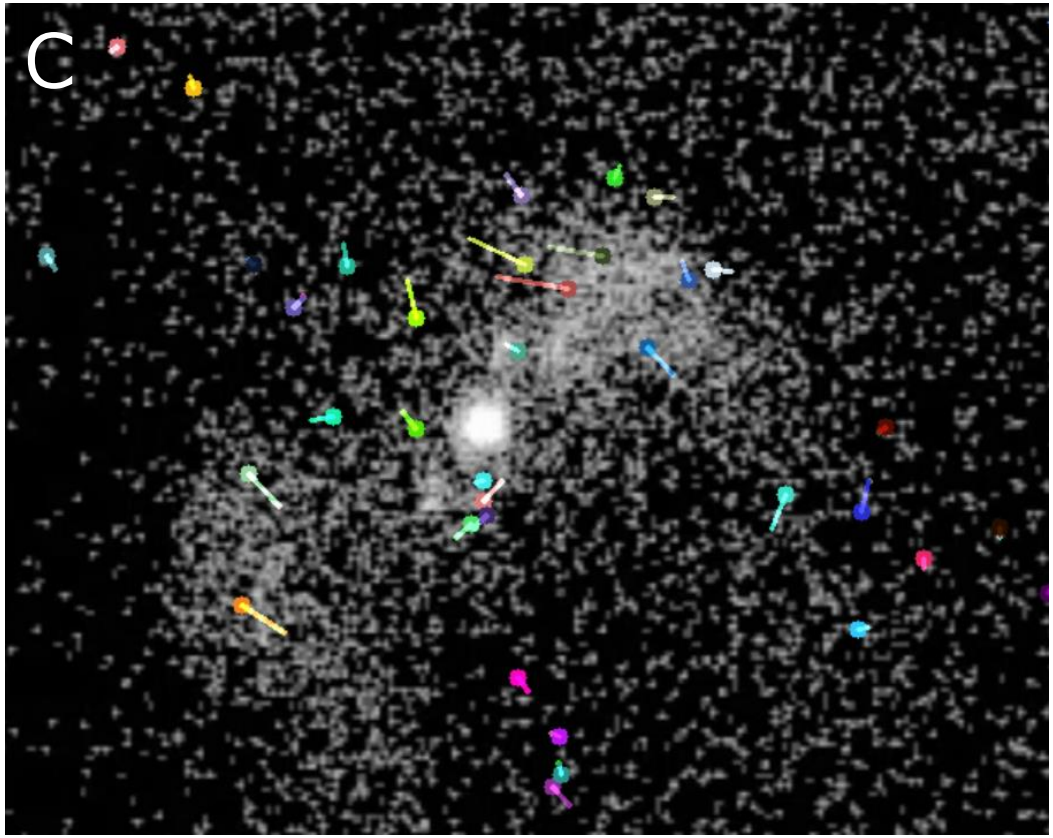

Analysis

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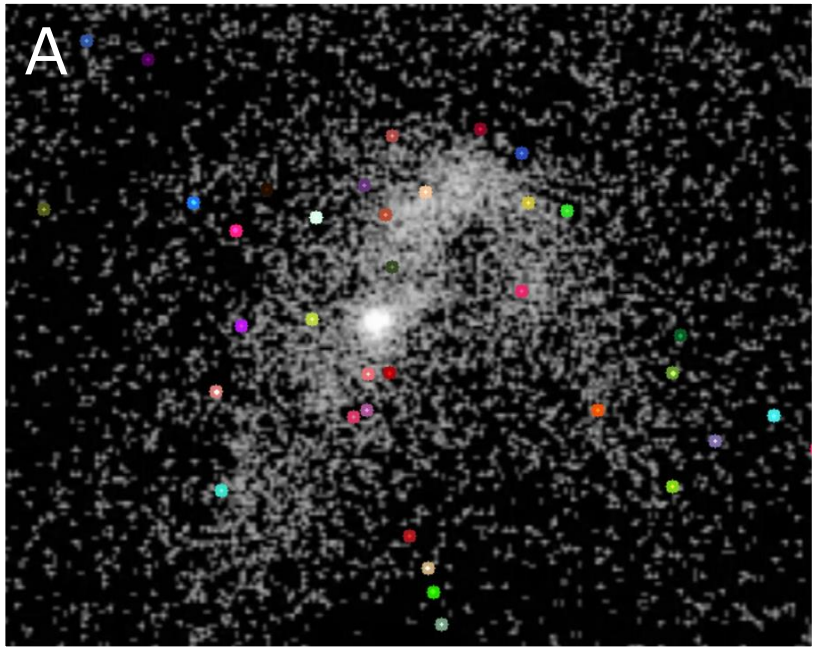
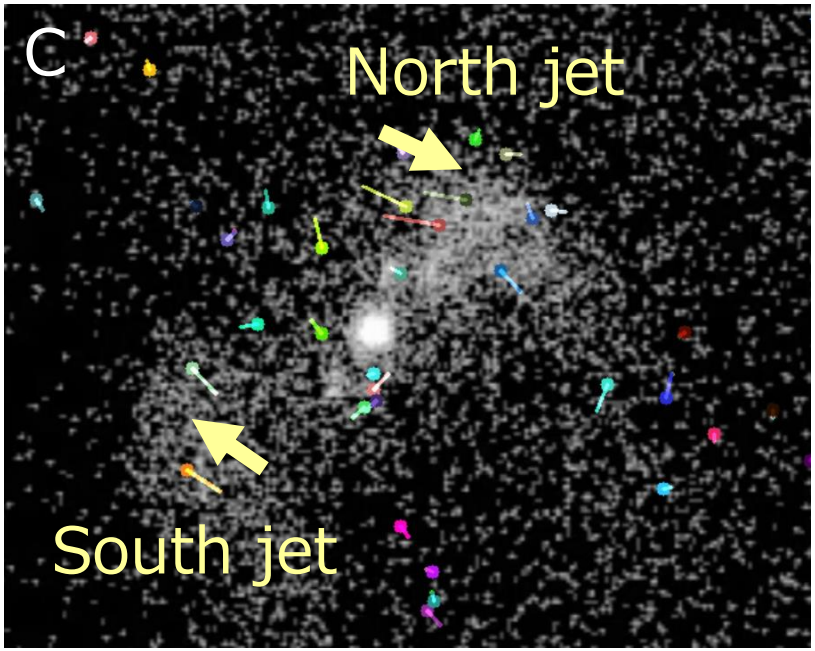


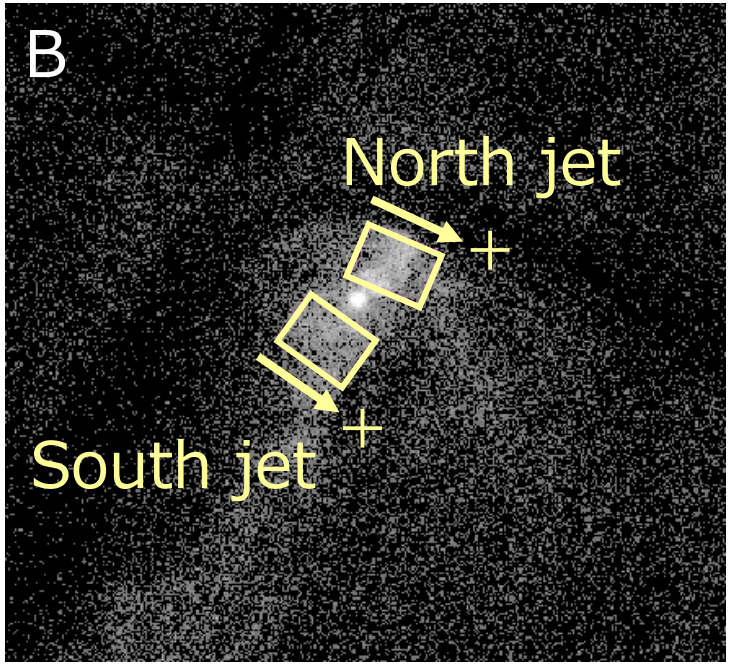


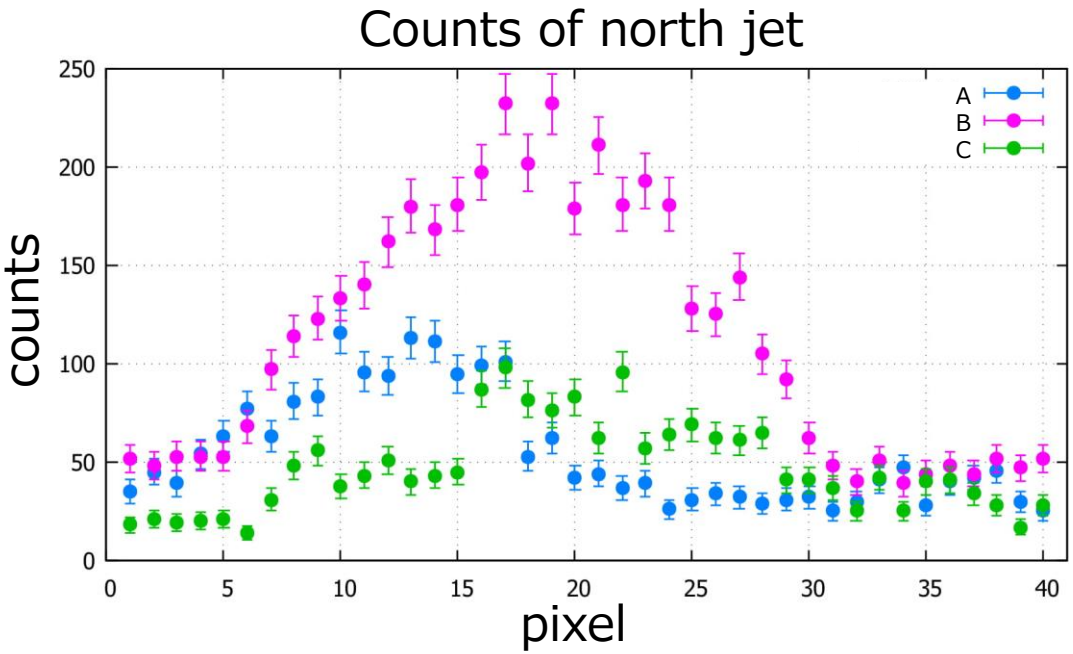
Analysis

Shift & subtraction method

① Measure counts,
then normalize B and C based on A

Example





Data	Exposure time [sec]
A	19280
B	50130
C	18560

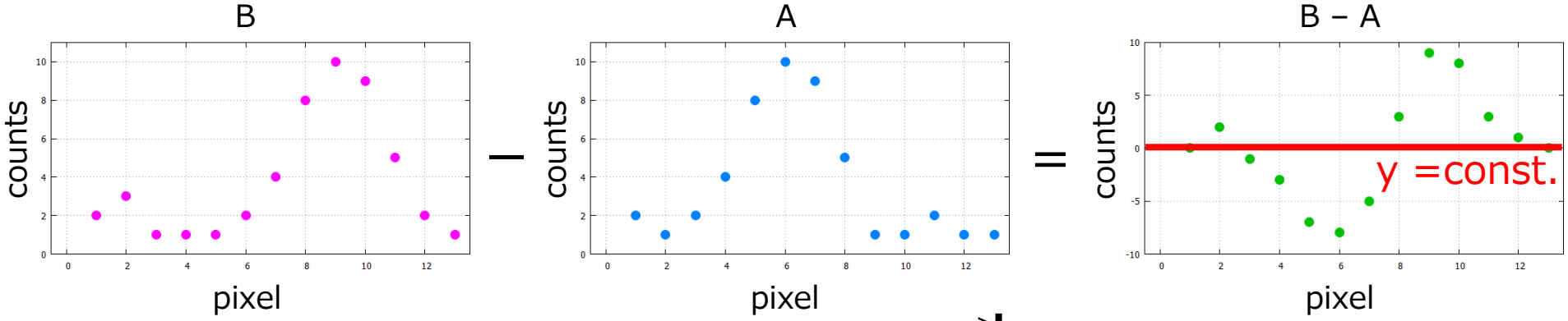
Analysis

Shift & subtraction method

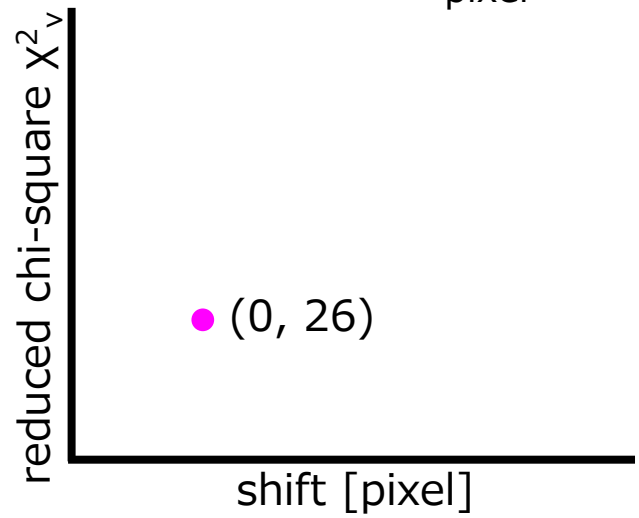
② Shift counts by 1 pixel, subtract each data, then fit by constant function

Example (not shifted)

$\chi^2_v = 26$



③ Plot reduced chi-square vs. shift



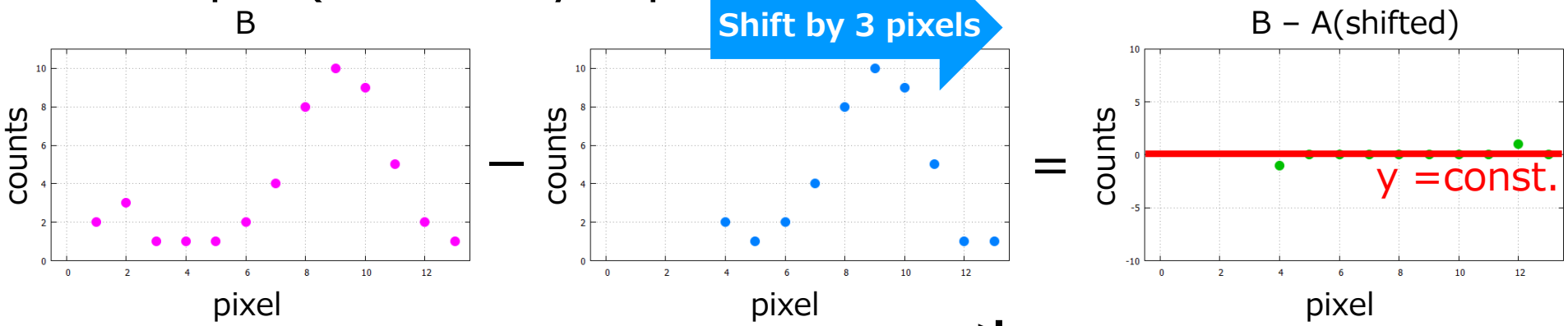
Analysis

Shift & subtraction method

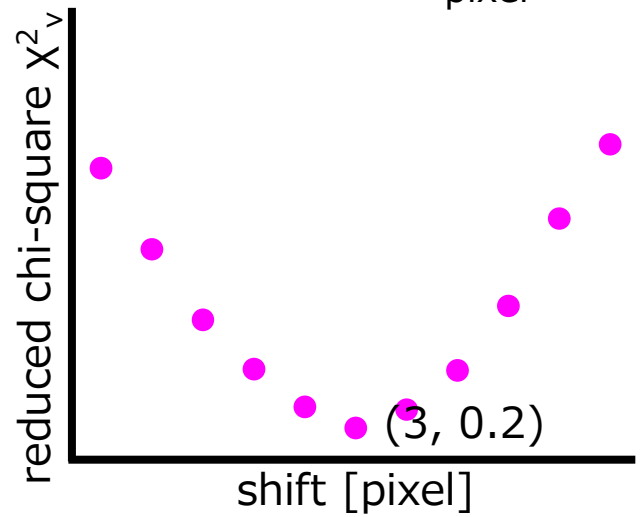
② Shift counts by 1 pixel, subtract each data, then fit by constant function

Example (shifted by 3 pixels)

$\chi^2_v = 0.2$

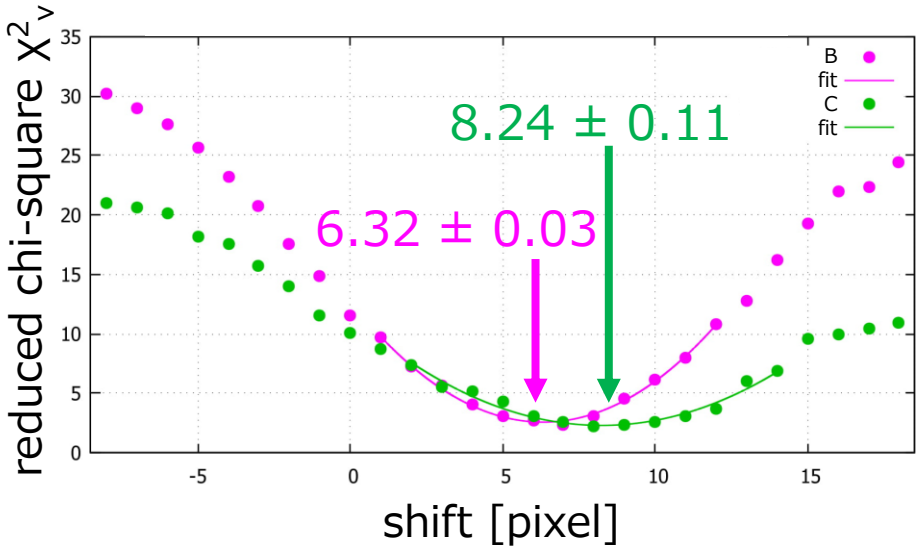


③ Plot reduced chi-square vs. shift



Results

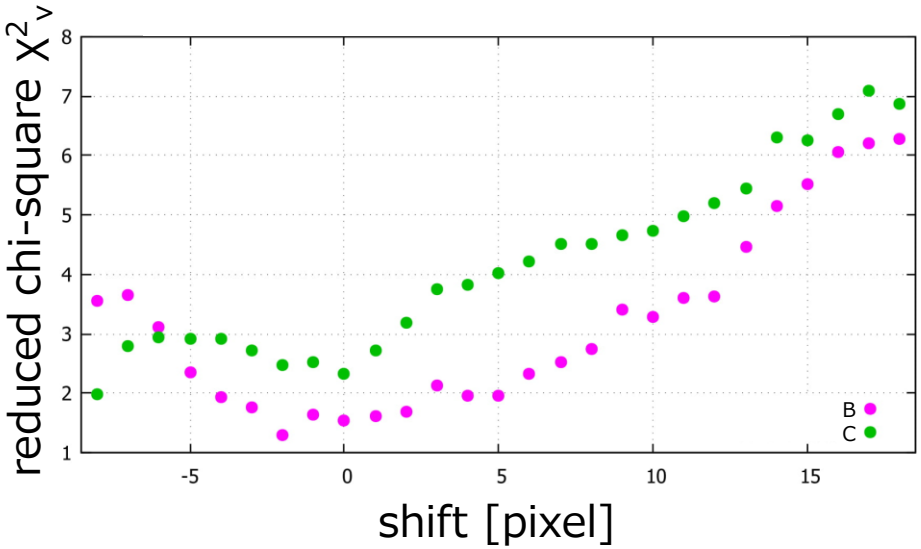
North jet



1 pixel = 0.49 arcsec

Data	Jet shift angle [arcsec]
B	3.10 ± 0.02
C	4.05 ± 0.06

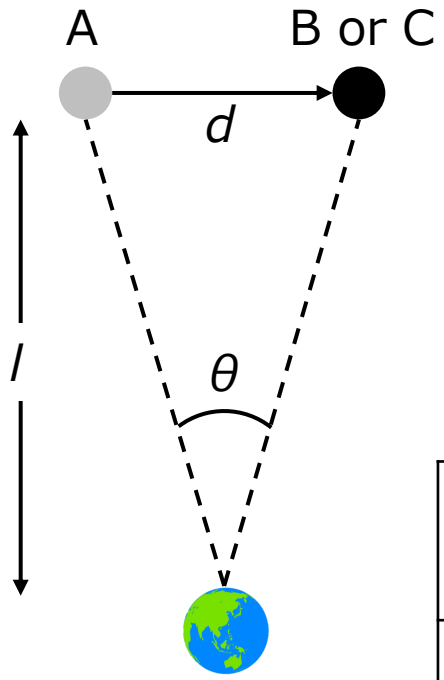
South jet



The shift can't be measured

Discussions

North jet



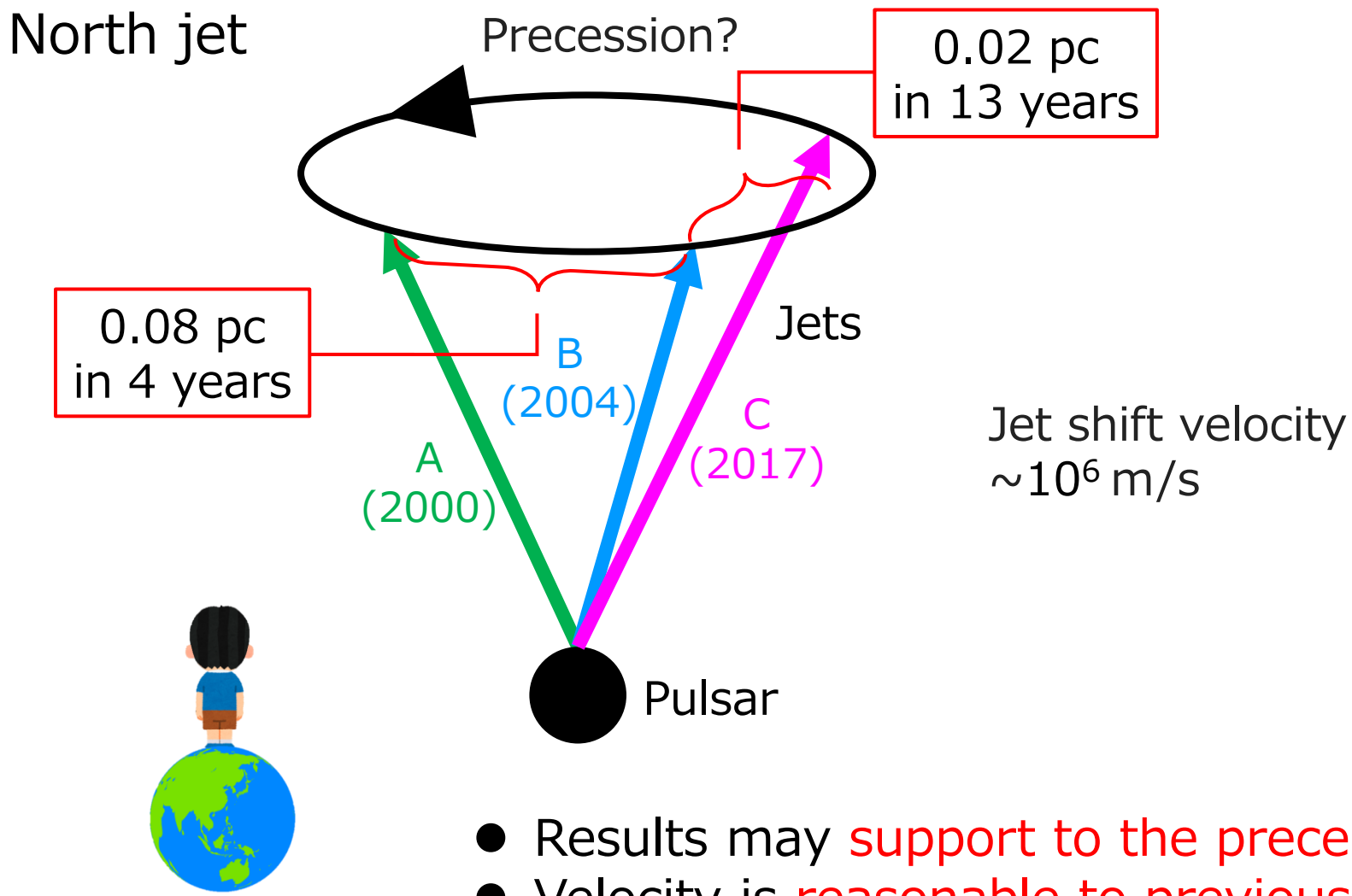
$d = l \tan\theta \approx l\,\theta \quad (\theta \ll 1)$

d : Jet shift distance
θ : Jet shift angle
l : Distance form the pulsar to the earth
5.2 ± 1.4 kpc (from previous research)

Data	Jet shift distance [pc]	Jet shift velocity [m/s]
B	0.078 ± 0.034	$(17.5 \pm 7.5) \times 10^6$
C	0.10 ± 0.03	$(6.1 \pm 1.6) \times 10^6$

÷ 4 years (B)
÷ 17 years (C)

Discussions



Jet shift velocity
$\sim 10^6$ m/s

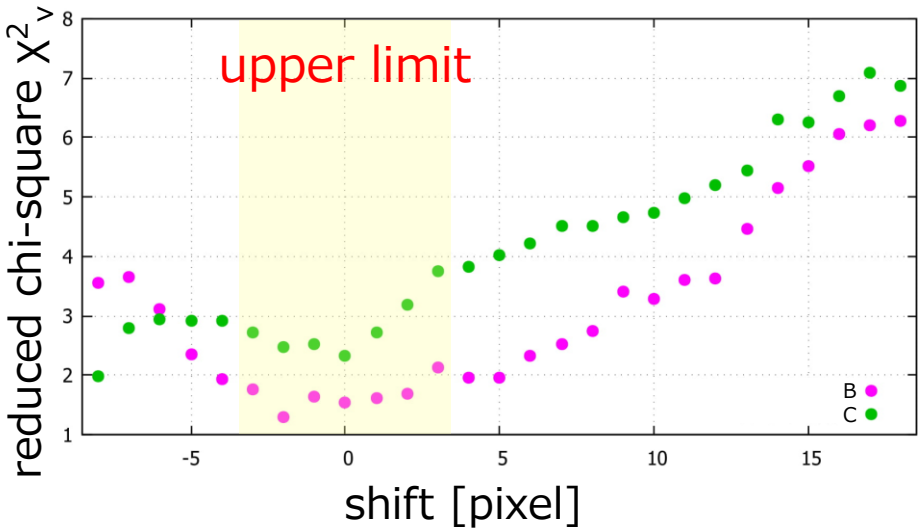
- Results may support to the precession
- Velocity is reasonable to previous research

Discussions & future analysis

South jet

- The shift can't be measured
  South jet is moving slowly?
  South jet is blocked by something?

- Place an upper limit to south jet moving by analyzing more data



Summary

Part 1 :

Ring Cavity Experiment for Dark Matter Axion Search

- Built the ring cavity and evaluated its performance
- Locked the laser to the cavity
  by feedback control in 5 minutes

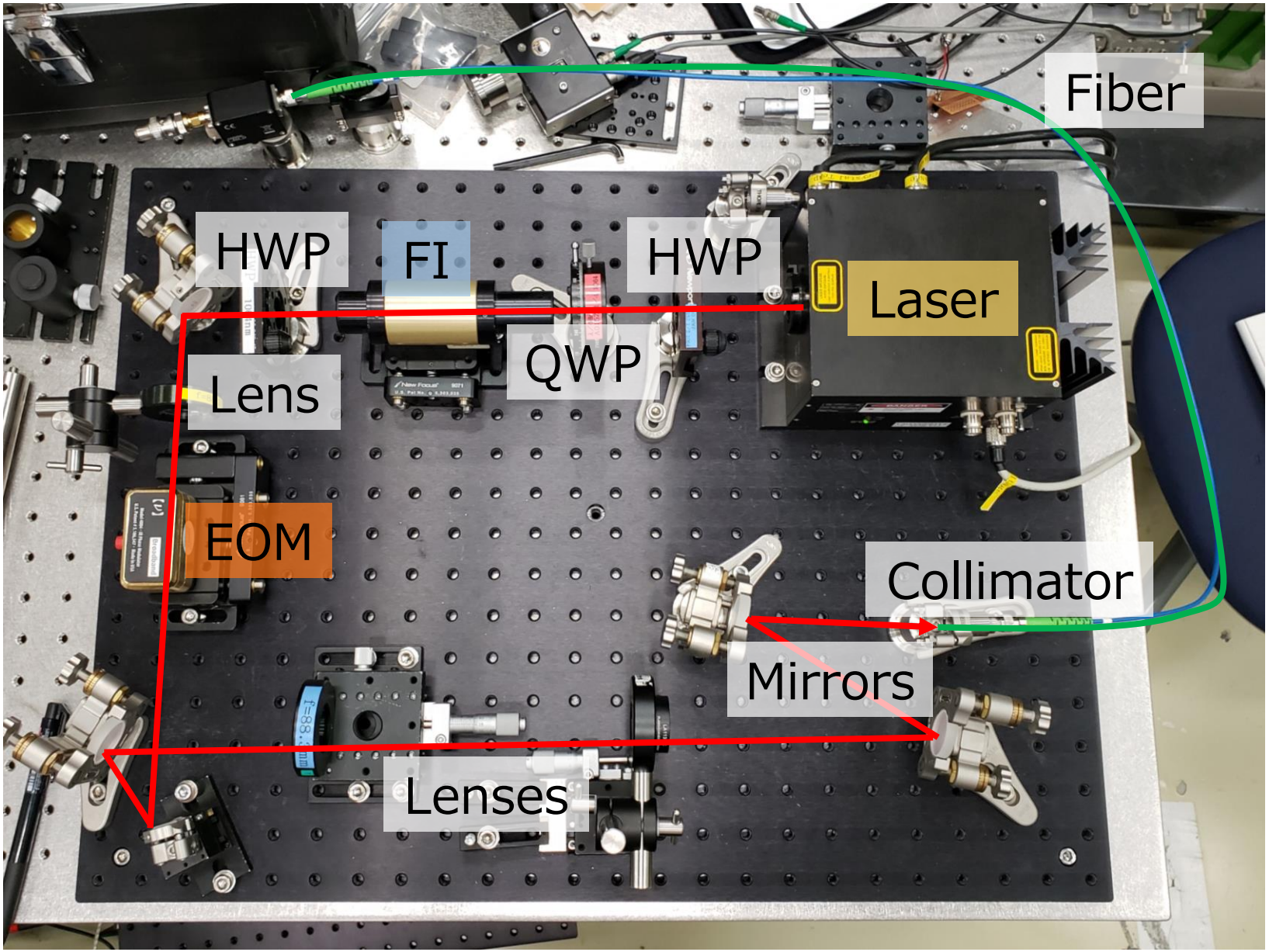
Part 2 :

Measurements of the Jets Motion of PSR B1509–58
by Chandra X-ray Observatory Image Analysis

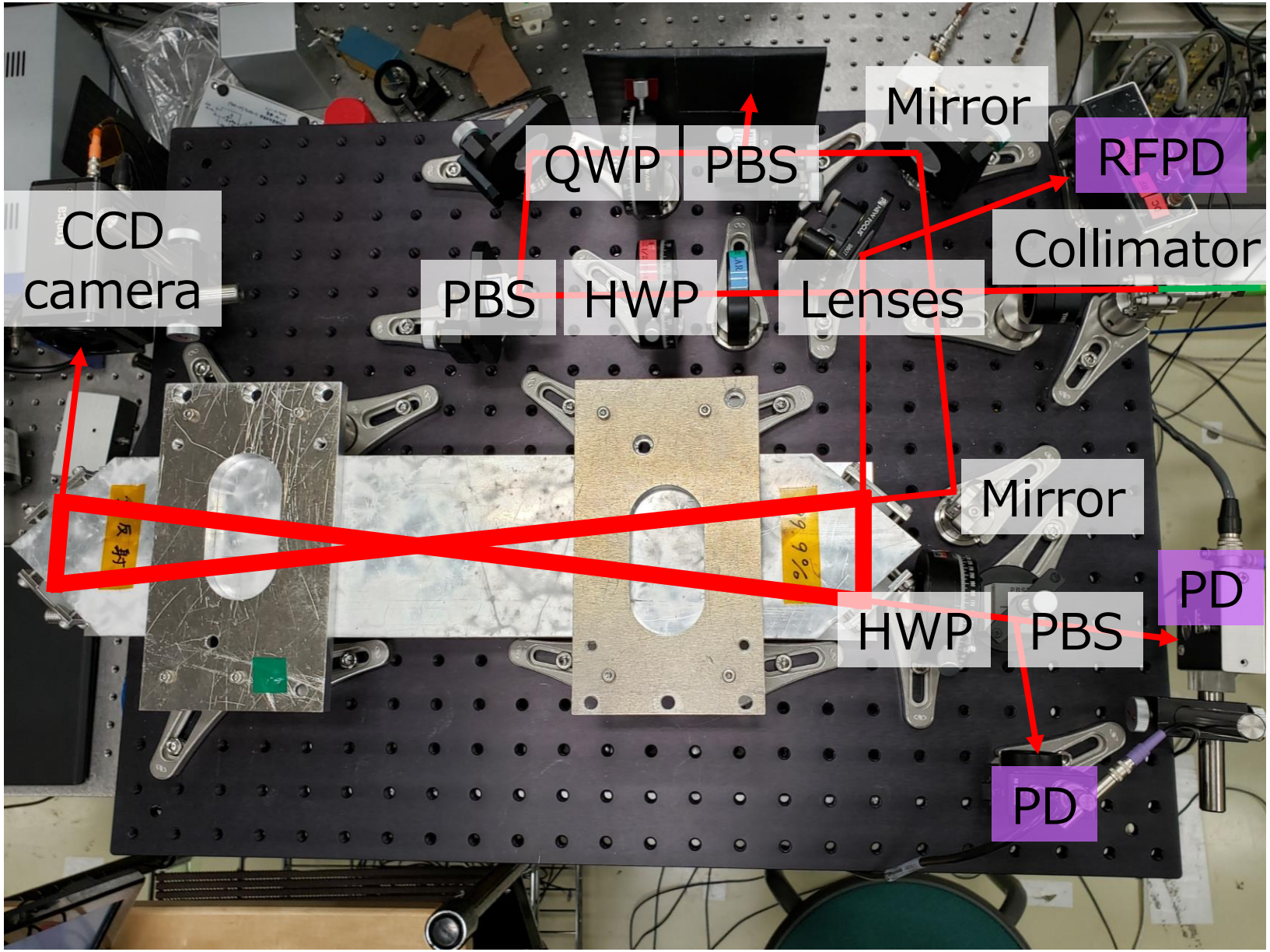
- Discovered the motion of north jet
- Results may support to the precession

Extra Slides

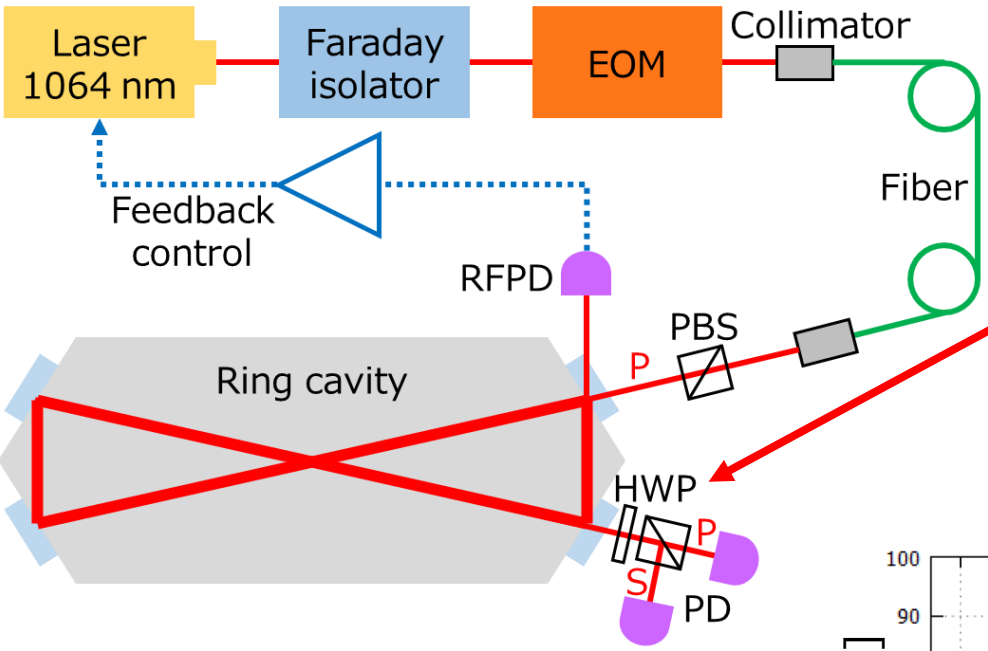
Optical system (1st floor)



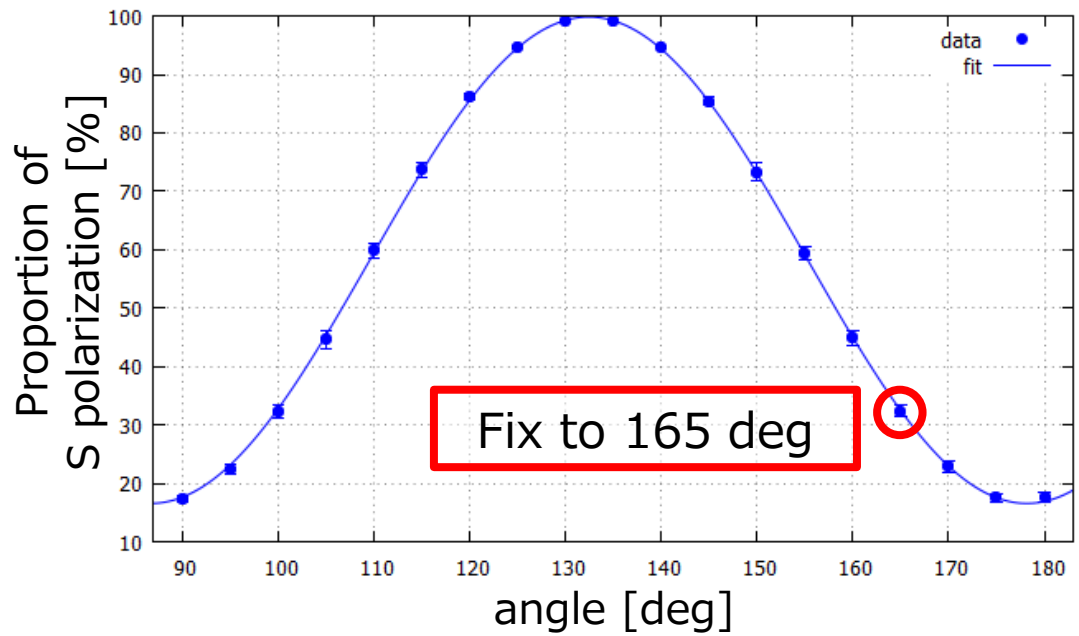
Optical System (2nd floor)



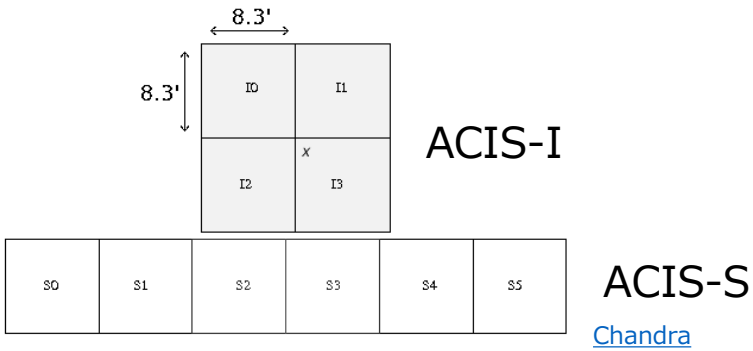
Angle of HWP



Rotate to get
S polarization signal a little



Observation



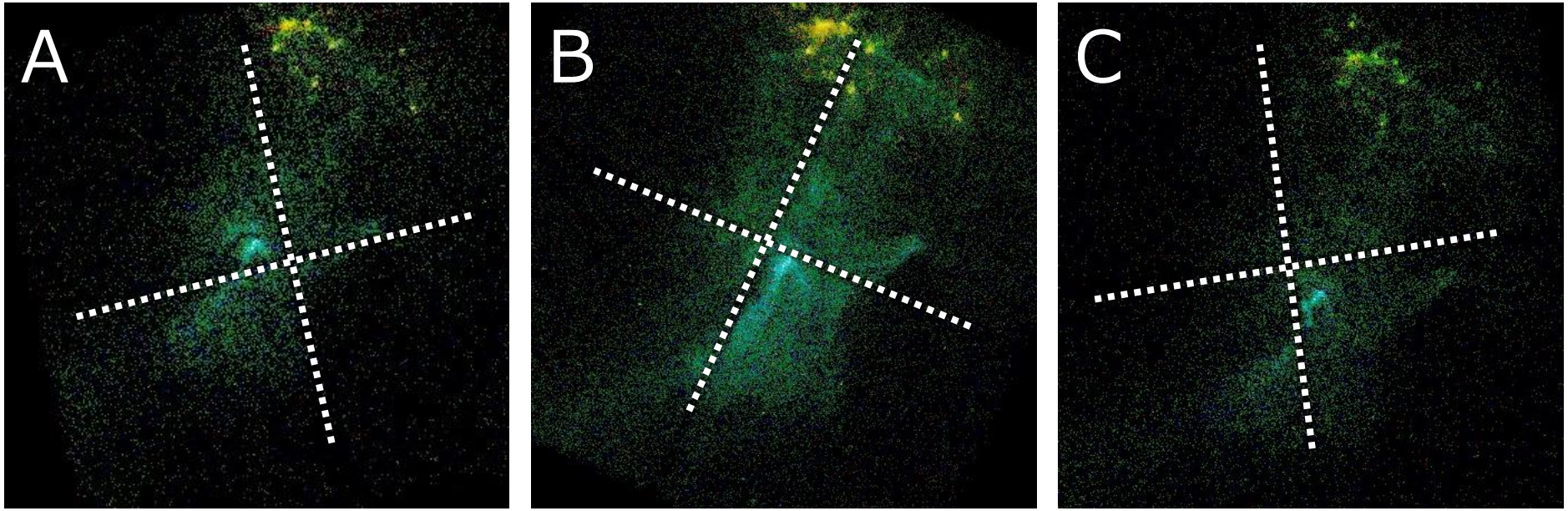
ACIS-I で観測されたデータは表 3.1 の 8 つである。変化が見つけやすいと考えられるため、観測時期が離れた 3 つのデータを選ぶことにした。観測時期が 2003 年から 2005 年の 6 つのデータの中から代表して obsid 5534 を選び、obsid 754, 5534, 18023 の 3 つについて解析を行うことにした。

表 3.1: ACIS-I で観測されたデータ

obsid	name	time	detector	exposure [s]	pi
754	G320.4-1.2	2000-08-14 13:31:48	ACIS-I	19280	Kaspi
3834	PSR B1509-58	2003-04-21 17:00:25	ACIS-I	9590	Gaensler
4384	PSR B1509-58	2003-04-28 06:05:29	ACIS-I	10020	Gaensler
5534	PSR B1509-58	2004-12-28 10:26:36	ACIS-I	50130	Slane
5535	PSR B1509-58	2005-02-07 15:15:07	ACIS-I	43130	Slane
6116	PSR B1509-58	2005-04-29 03:40:54	ACIS-I	47650	Slane
6117	PSR B1509-58	2005-10-18 00:11:37	ACIS-I	46140	Slane
18023	PSR B1509-58	2017-02-02 23:18:20	ACIS-I	18560	Xue

特別実験レポートより抜粋

Reprojection with CIAO



energy : 0.3-1 keV, 1-3 keV, 3-8 keV

Counts of the jets