

SMBHを周回する星の 視線速度モニター計画

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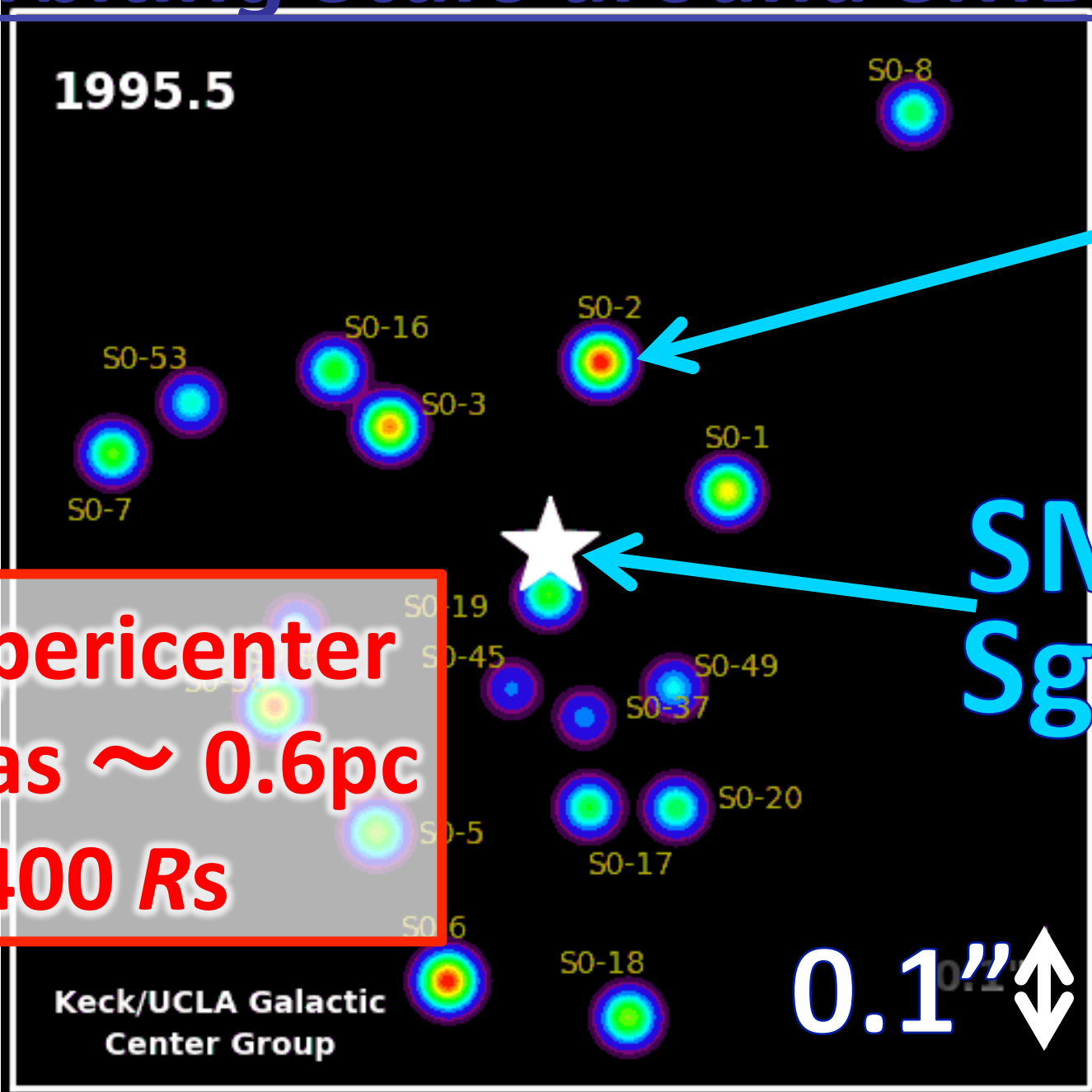
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Orbiting Stars around SMBH 2/24



S2

SMBH
Sgr A*

S2's pericenter
15mas \sim 0.6pc
 \sim 1400 R_s

Orbiting Stars around SMBH 3/24

Nishiyama: “There is a supermassive BH at the center of ...”

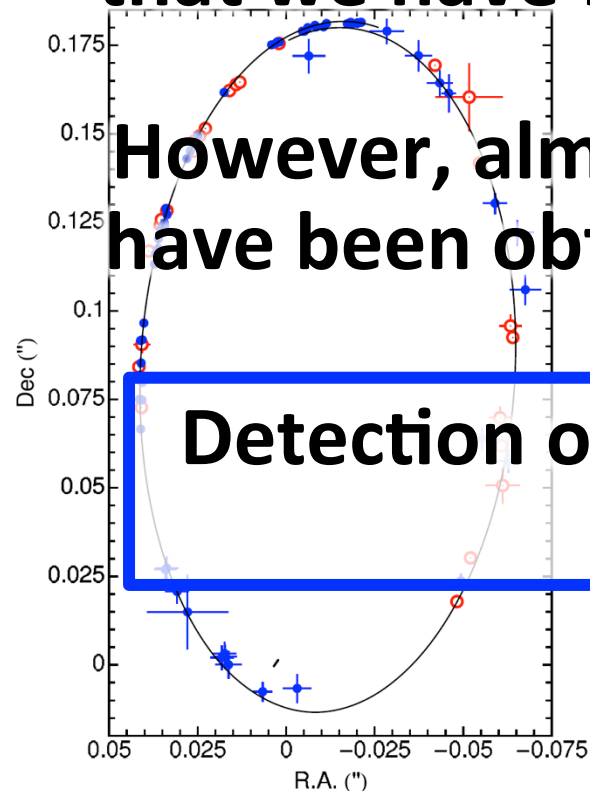
Theoretical physicists: “No, it is still a BH *candidate*.”

No *direct* evidence for the existence of BH.”

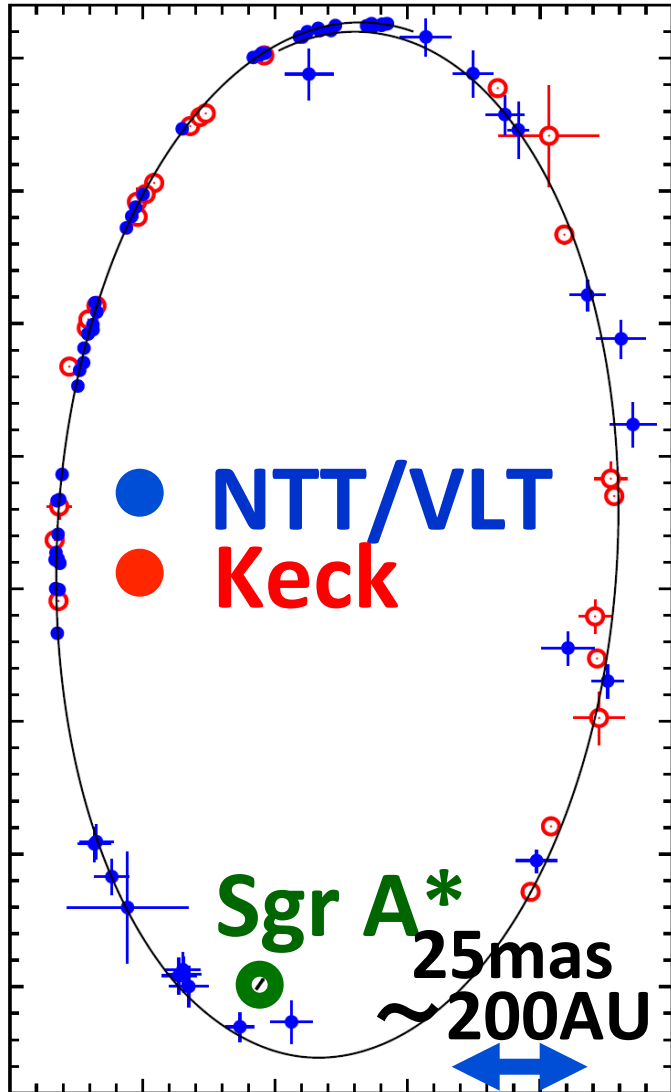
“we now have sufficient (*indirect*) evidence to claim that we have found astrophysical BHs” (Zhang 10)

However, almost all of the “sufficient evidence” have been obtained through *Newtonian gravity*.

Detection of General Relativistic (GR) effects around BHs



S2 Orbit



S2 (S0-2)

- Spectral Type : O8-B0V
- Orbital Period : 15.5 yr
- Next pericenter : 2018
- Pericenter dist. : 120AU

Strength of Relativistic Effects (Gravitational Potential):

$$\Upsilon(\text{S2}) = [GM_{\text{SgrA}^*}/c^2]/r_{\text{peri}} \sim 10^{-3}$$

cf. Hulse-Taylor pulsar

$$\Upsilon \sim 5 \times 10^{-6}$$

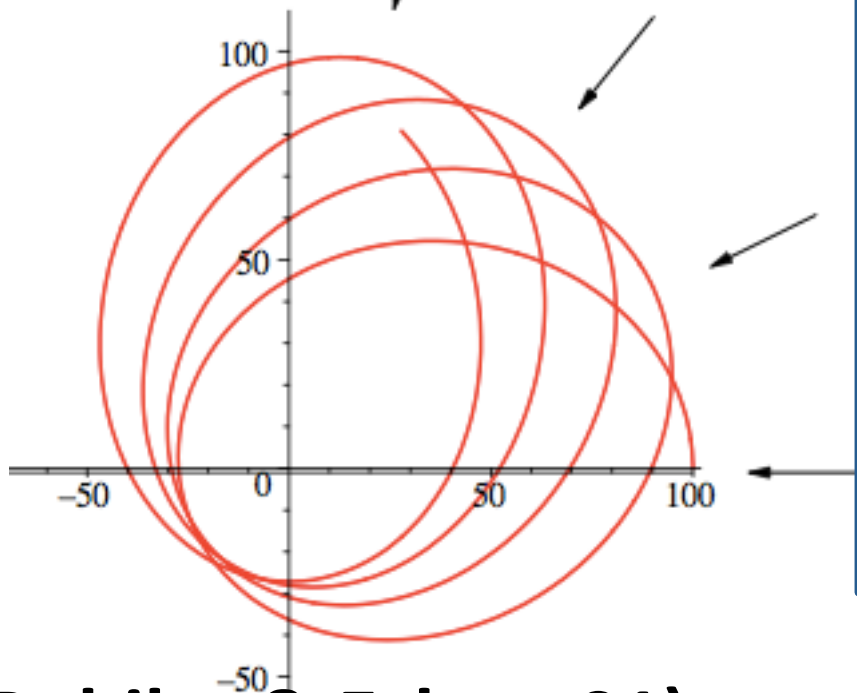
GR Effects on Stellar Orbits

5/24

Observations of General Relativistic effects

1. Astrometry

Periapse Shift
(Prograde Precession)



(Rubilar & Eckart 01)

S2

Shift ~ **1 mas/orbit**
@apocenter
cf. current accuracy
~ 0.1 mas
(Yelda+11)

GR Effects on Stellar Orbits

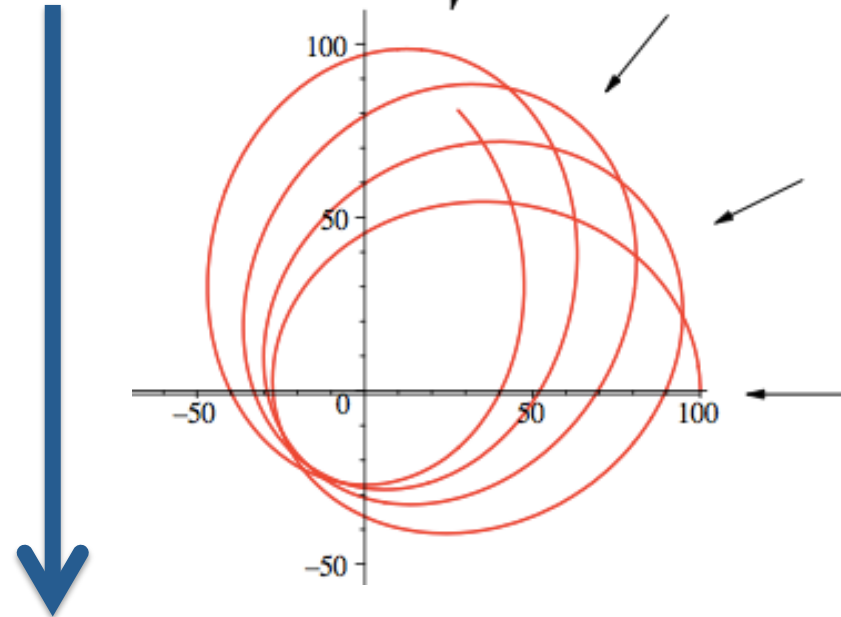
6/24

2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028

S2 pericenter

S2 apocenter

TMT/IRIS



GR Effects on S2 RV

7/24

Observations of General Relativistic effects

2. Radial Velocity (RV)

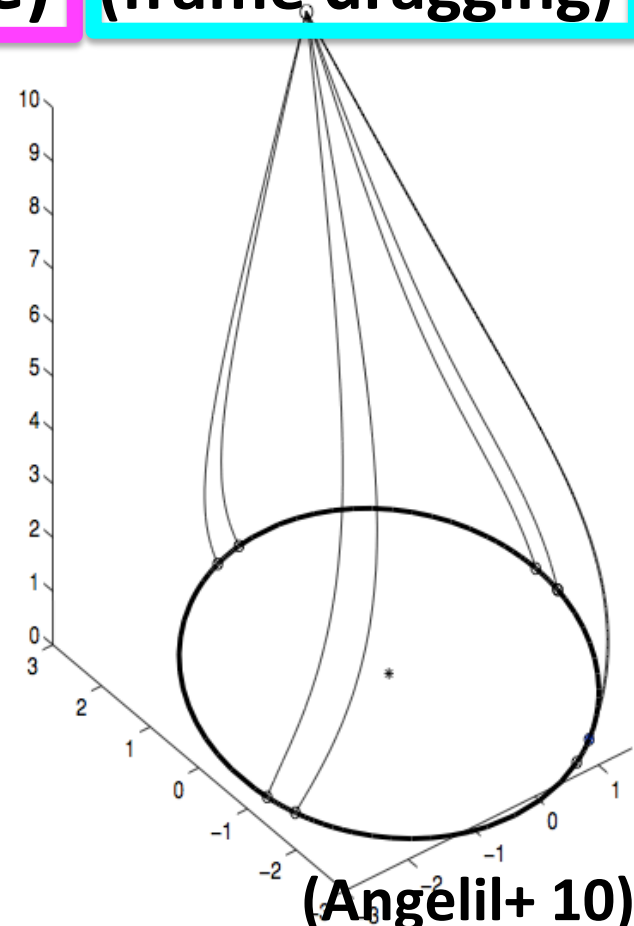
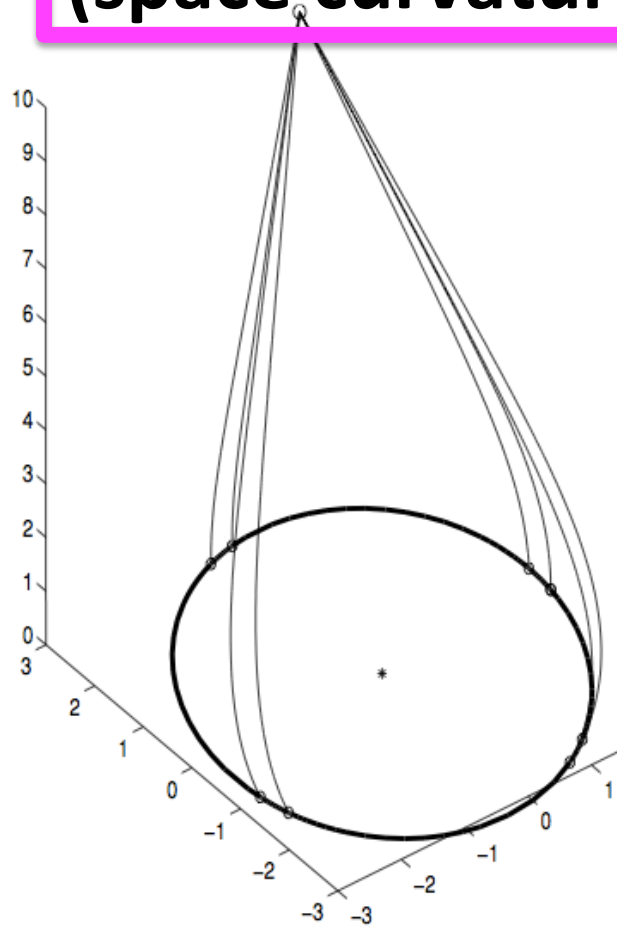
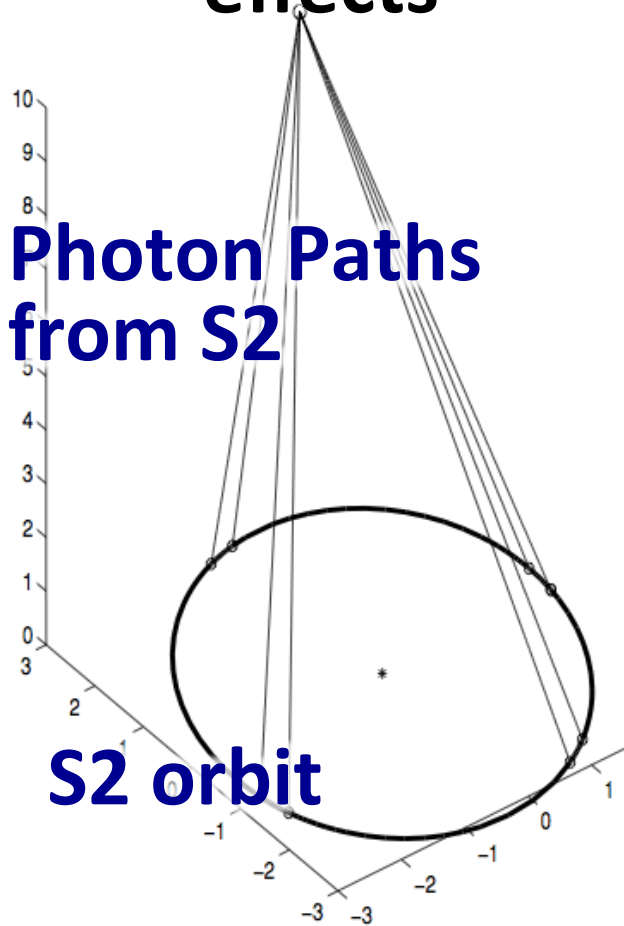
No Relativistic effects

Schwarzschild BH
(space curvature)

Kerr BH
(frame dragging)

Photon Paths
from S2

S2 orbit

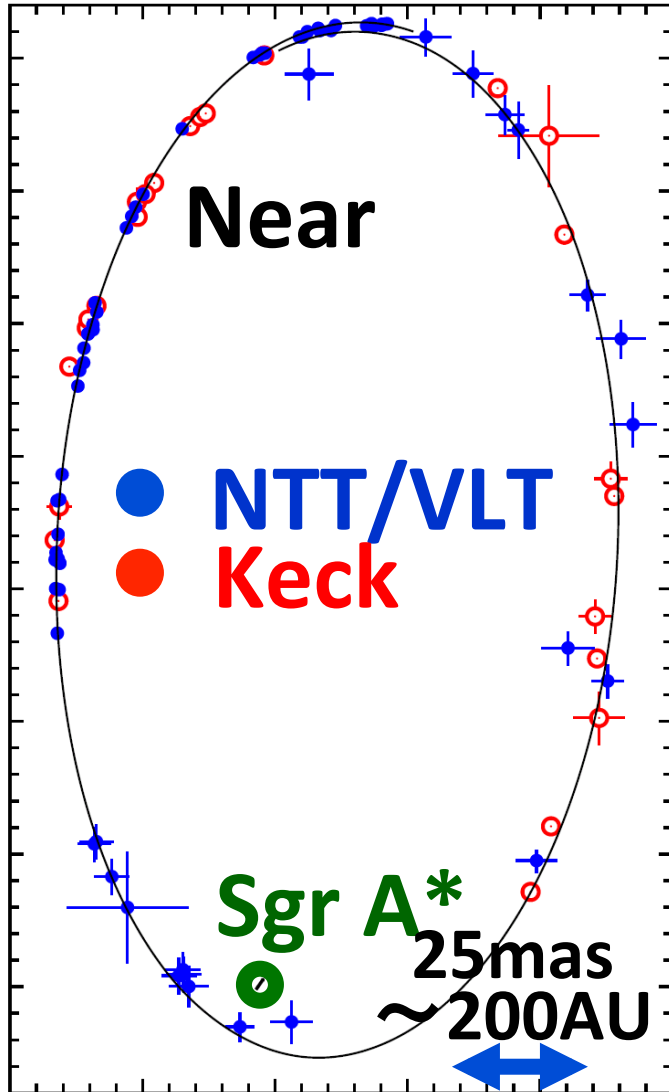


(Angelil+ 10)

GR Effects on S2 RV

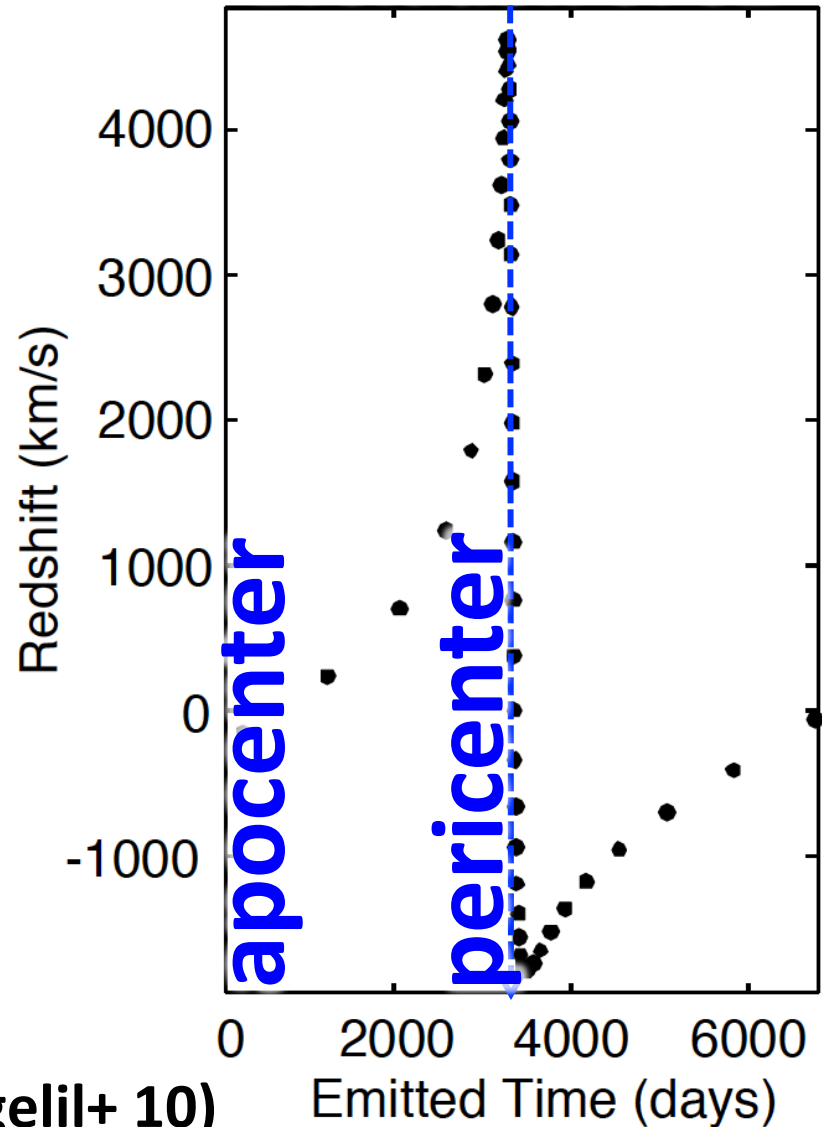
8/24

S2 Orbit



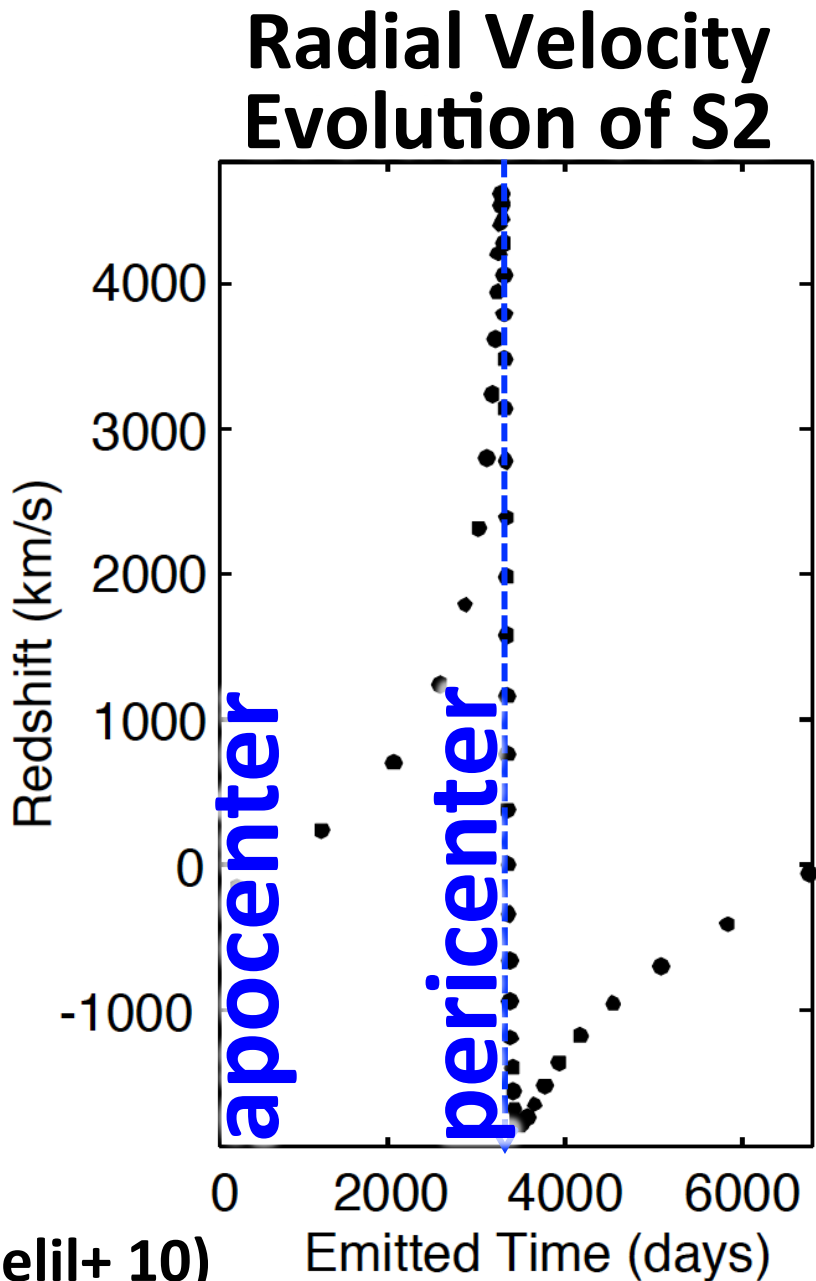
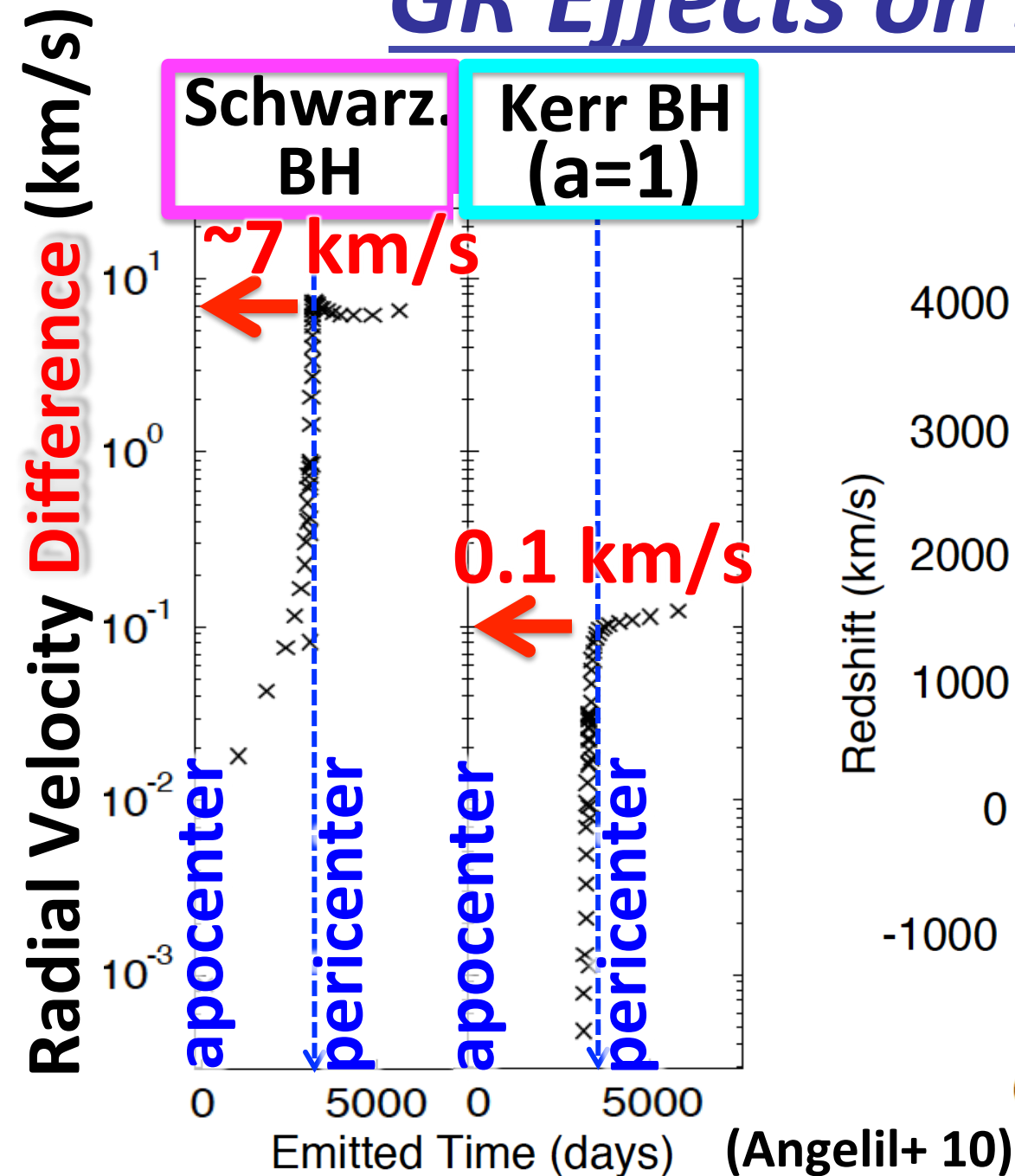
Gillessen+09

Radial Velocity Evolution of S2

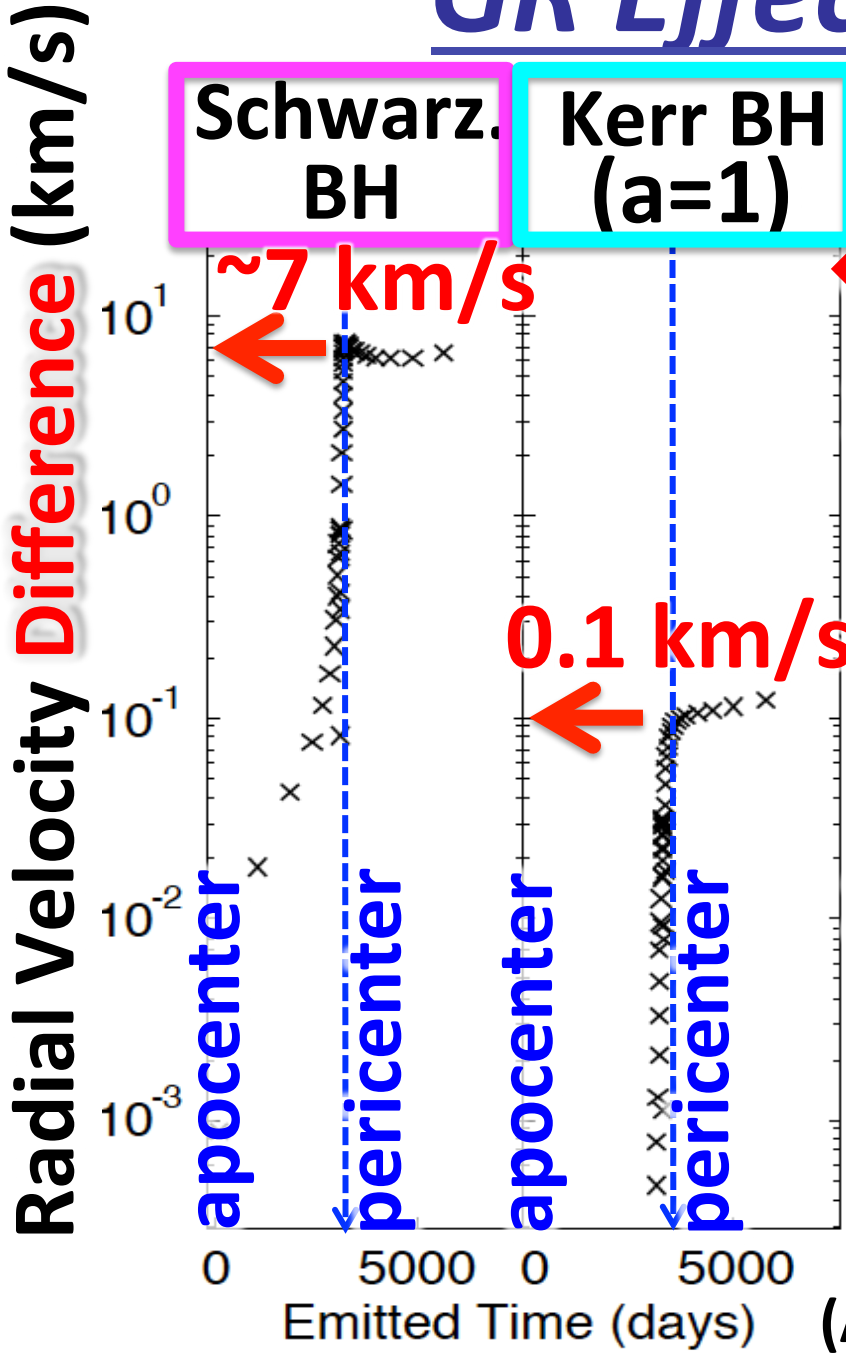


(Angelil+ 10)

GR Effects on S2 RV



GR Effects on S2 RV



- ◆ Orbital Shift of S2 due to
- 1. Schwarz. BH
→ Difference from a pure Kepler orbit:
~7 km/s
- 2. Kerr BH (frame dragging)
→ **< 0.1 km/s**

S2 Spectroscopy with TMT

11/24

Detection of Space-curvature around SMBH Sgr A*

Target: S2 (O8-B0V)

Period: 2018 & ~2034, but monitoring necessary

Observations: Near-infrared Spectroscopy

**Instrument: NIR(>1.6 μ m), high-dispersion,
AO with Laser guide system**

→ long term monitoring of RV

Accuracy: 1. ~2.5 km/s (Schwarz. effect, 3σ)

2. ~0.03 km/s (frame-dragging, 3σ)

S2 Spectroscopy with TMT

12/24

Expected RV accuracy for S2

~2.5 km/s

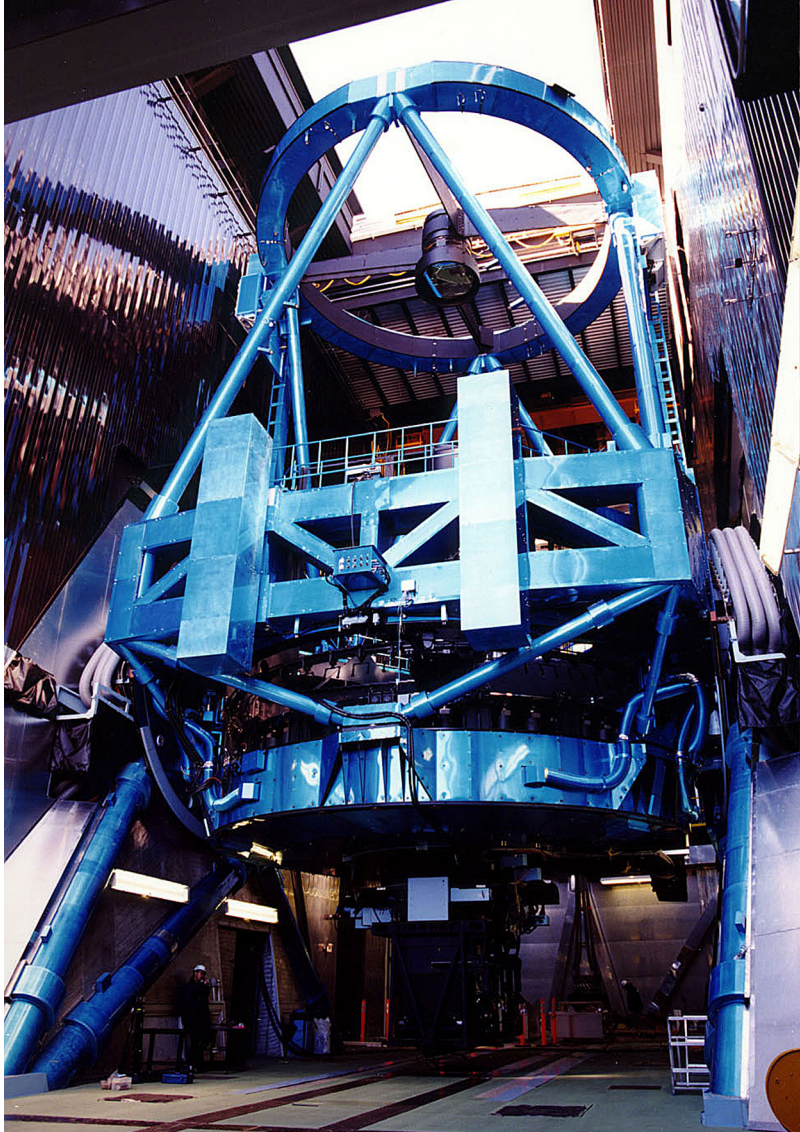
~0.03 km/s

	Keck	Subaru	Subaru
	OSIRIS	IRCS	IRD
Band	<i>K</i>	<i>K</i>	<i>H</i>
R	3,600	~20,000	70,000
Calibration	OH	OH	Laser COM
SN	20	10	10
$\delta RV \propto (1/R) (1/SN) (1/\text{num. line})^{1/2}$			
δRV [km/s]	20	~4.0	~2.0
δRV w/ COM	-		~0.2

H=15.4, K=14.0, exposure=2h

Observation

Subaru telescope



Adaptive optics system
AO188

+

Laser guide star system

+

NIR camera IRCS

H (1.49 - 1.83 μm)

K (1.90 - 2.49 μm)

$R = \lambda/\Delta\lambda \sim 20,000$

Total exposure: 150min

Observation

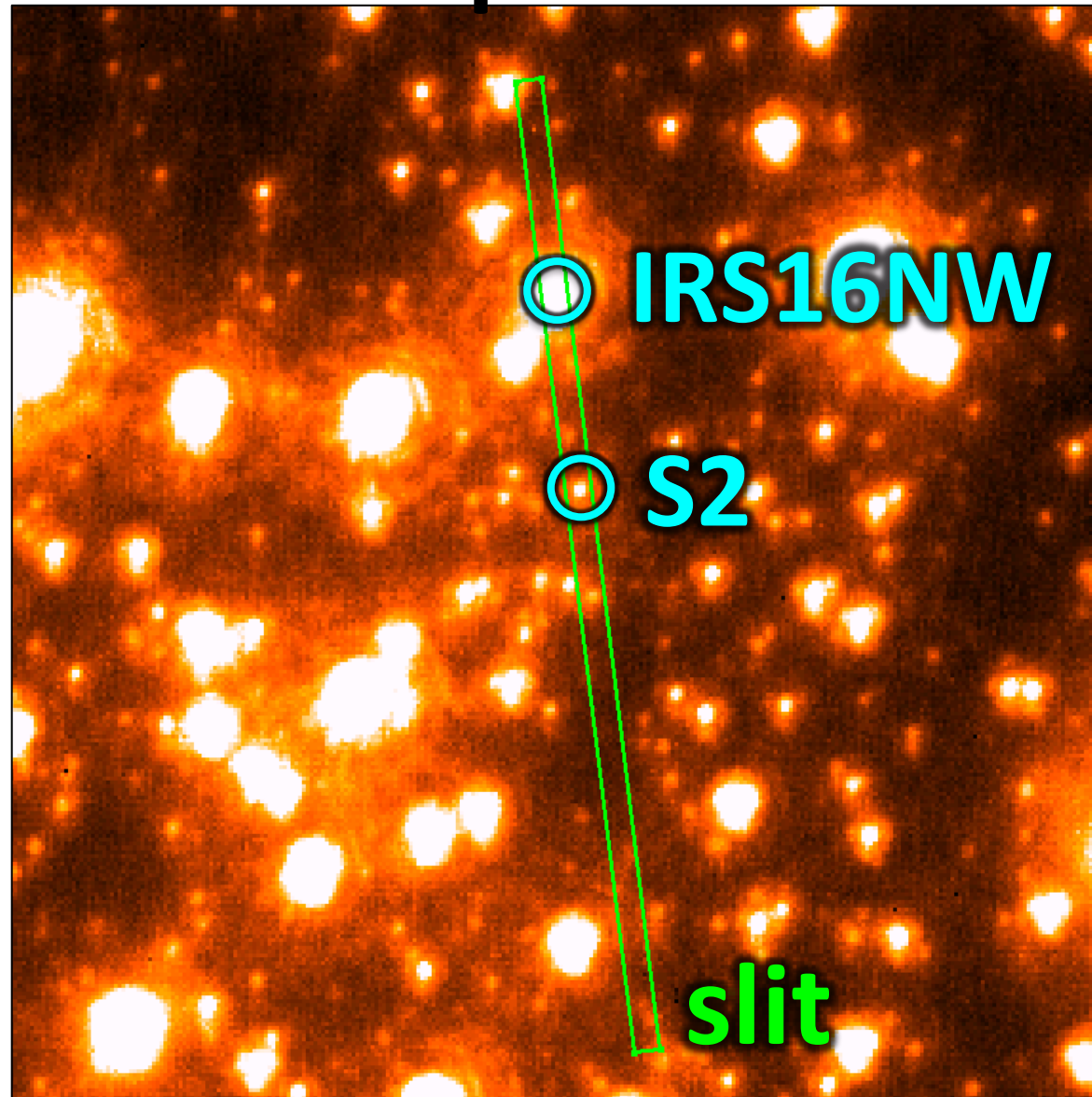
14/24

2014/5/20



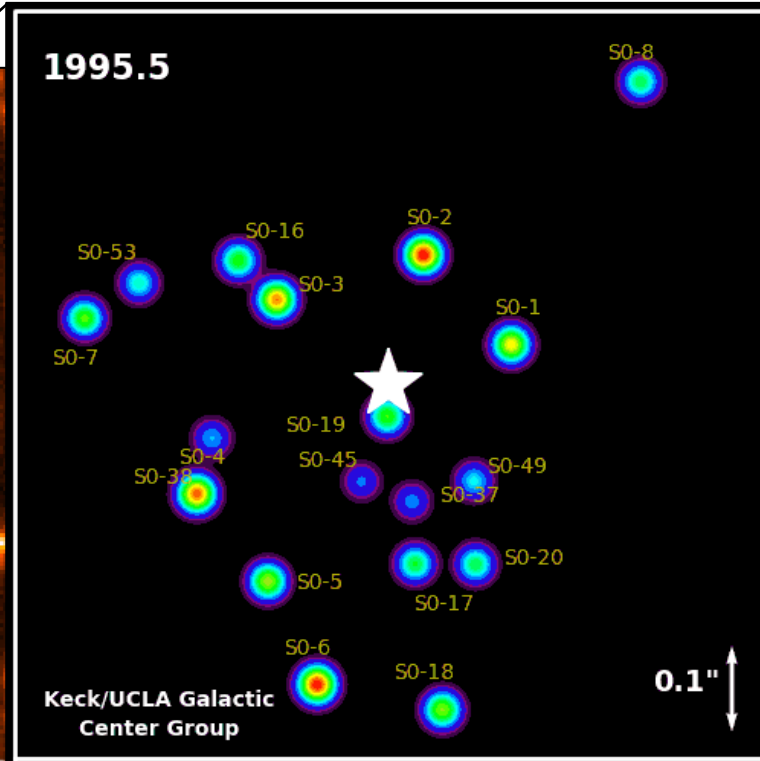
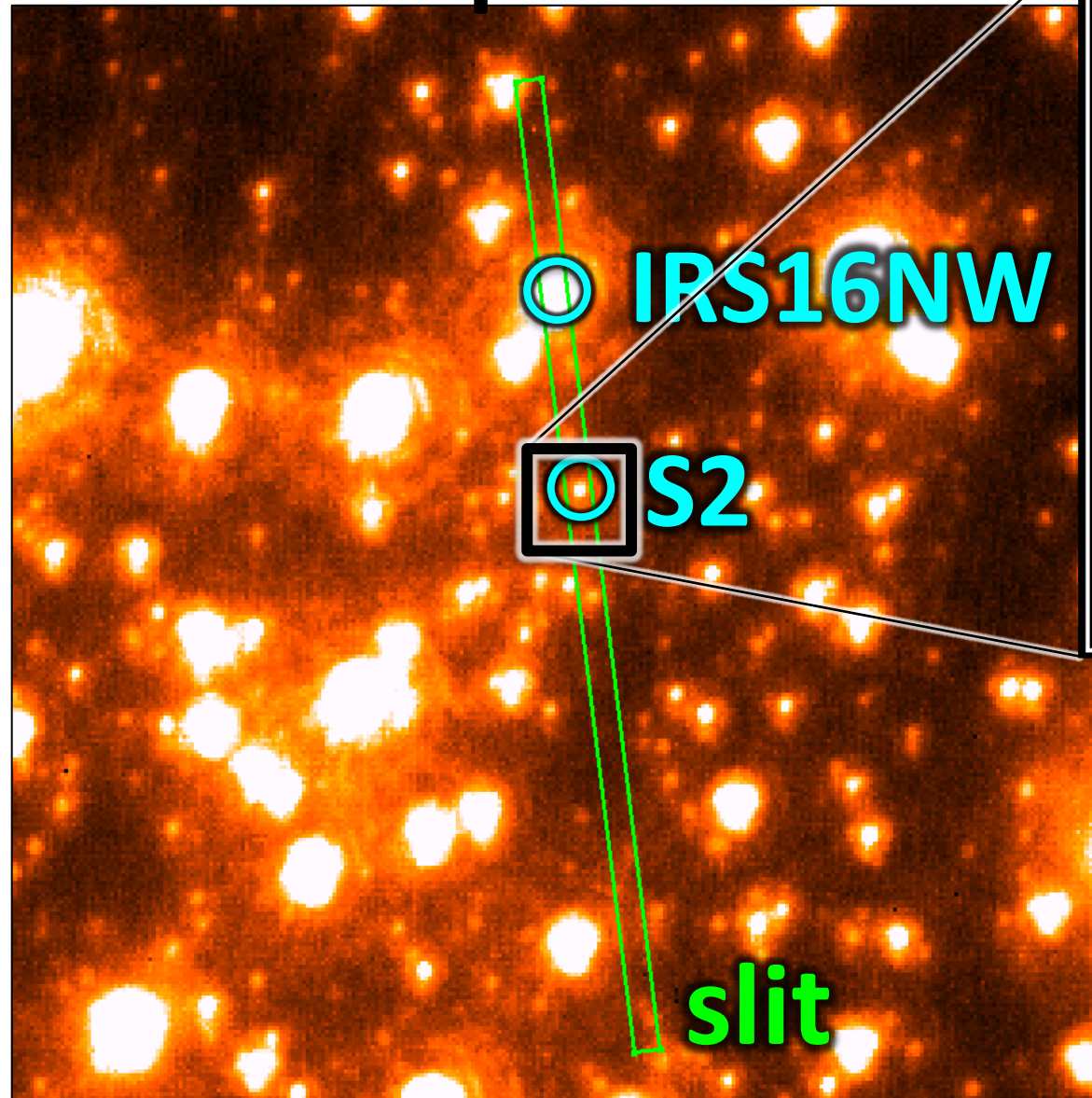
Observation

Slit position

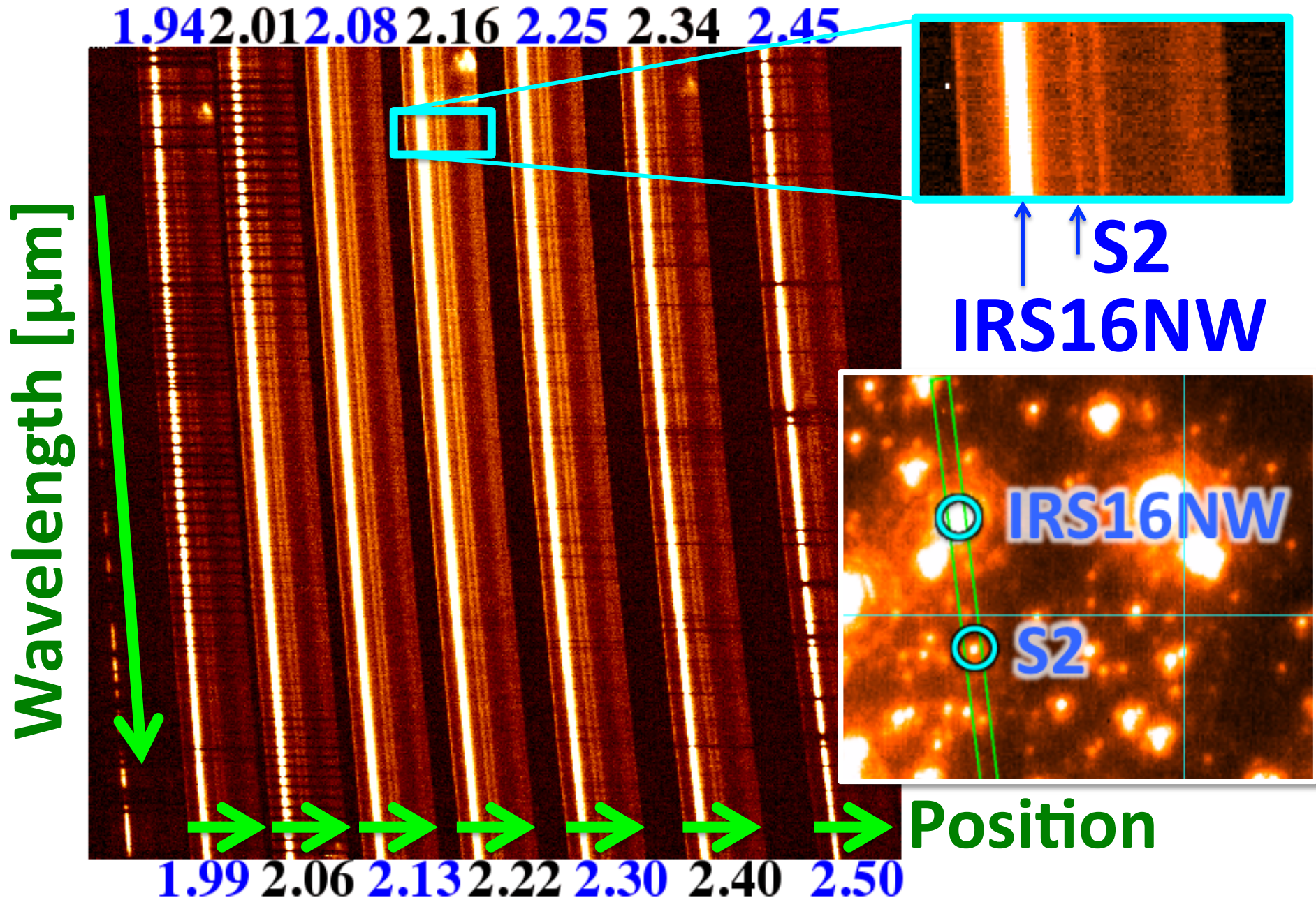


Observation

Slit position

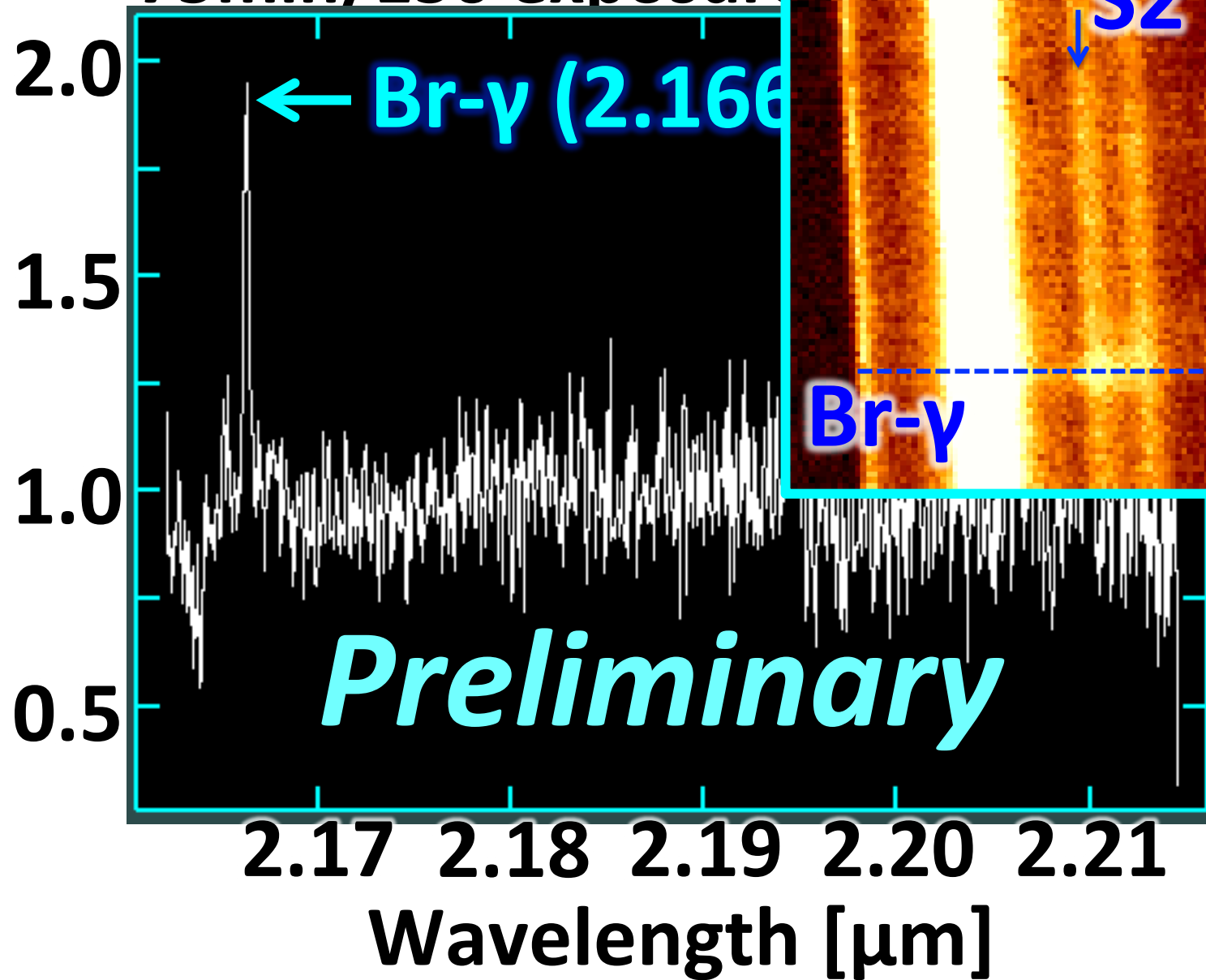


Raw Data



S2 Spectrum

75min/150 exposures



Future Works

- **Further combine in K (75min/150)**
- **More lines required**
- ***H*-band spectrum**
- **λ Calibration (OH? Ar? atmos. abs.?)**
- **Sky subtraction**
- **Background subtraction**
- **Continuum determination**
- **...**

S2 Spectroscopy with TMT 23/24

Expected RV accuracy for S2

~2.5 km/s	Keck	Subaru	Subaru	TMT
~0.03 km/s	SIRIS	IRCS	IRD	NIRES
Band	<i>K</i>	<i>K</i>	<i>H</i>	<i>K</i>
R	3,600	~20,000	70,000	20,000
Calibration	OH	OH	Laser COM	OH?
SN	20	10	10	~400
$\delta RV \propto (1/R) (1/SN) (1/\text{num. line})^{1/2}$				
δRV [km/s]	20	~4.0	~2.0	<~0.2
δRV w/ COM	-		~0.2	<~0.02

H=15.4, K=14.0, exposure=2h

GC Studies in the Future

2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028

S0-102 apocenter

S2 pericenter

S0-102 pericenter

S2 apocenter

S0-102 apocenter

**Periapse shift
Subaru/IRCS/IRD**

TMT/IRIS

**Spin parameter
TMT/NIRES**

2034

