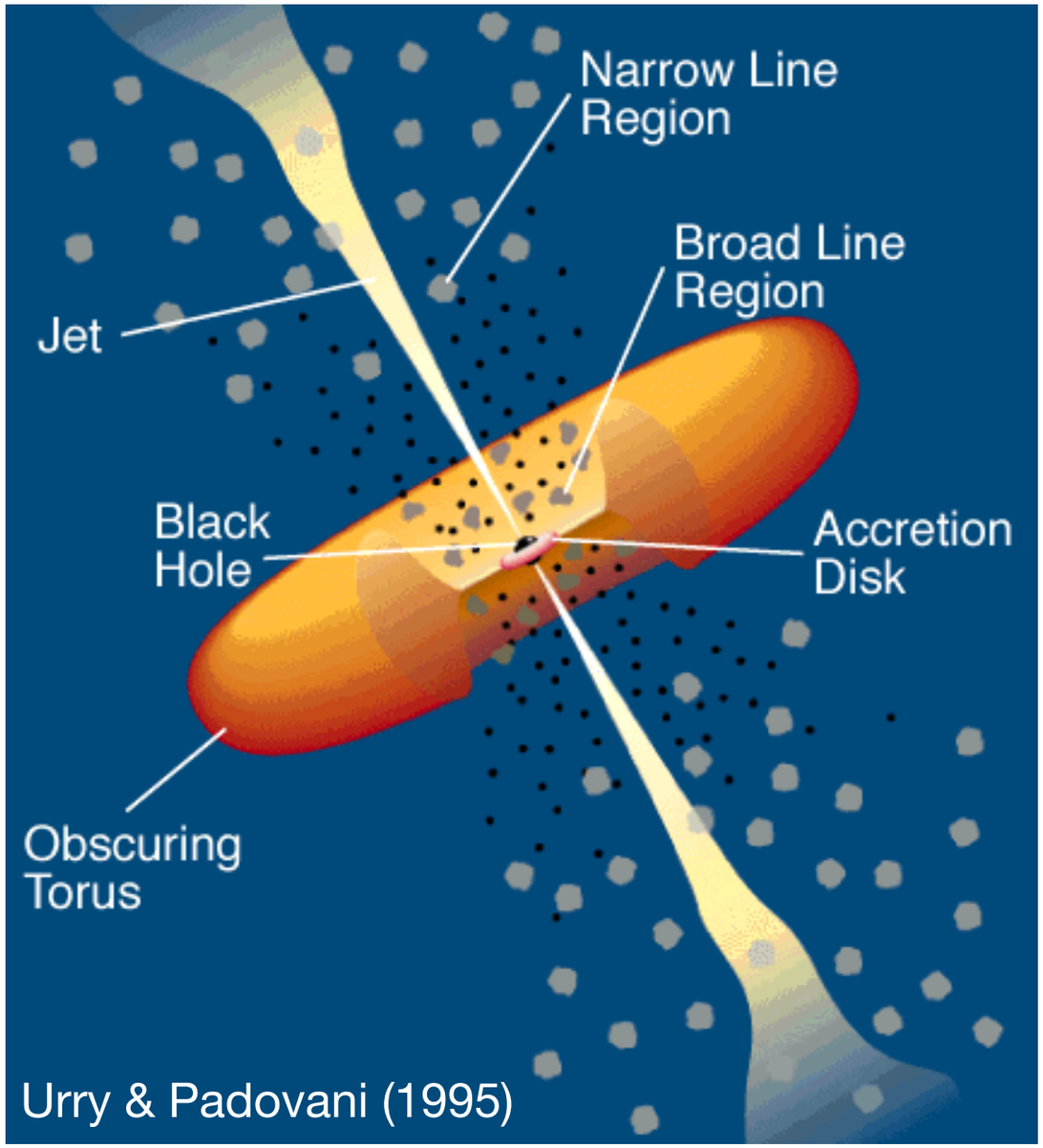
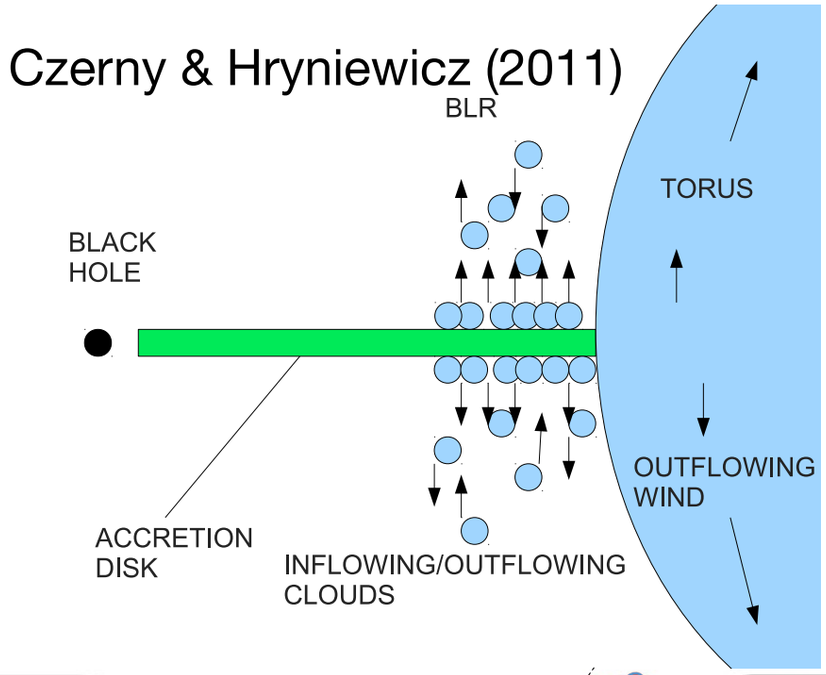
BLR Modeling from Near-IR Interferometry, and the Hot Dust Size – AGN Luminosity Relation

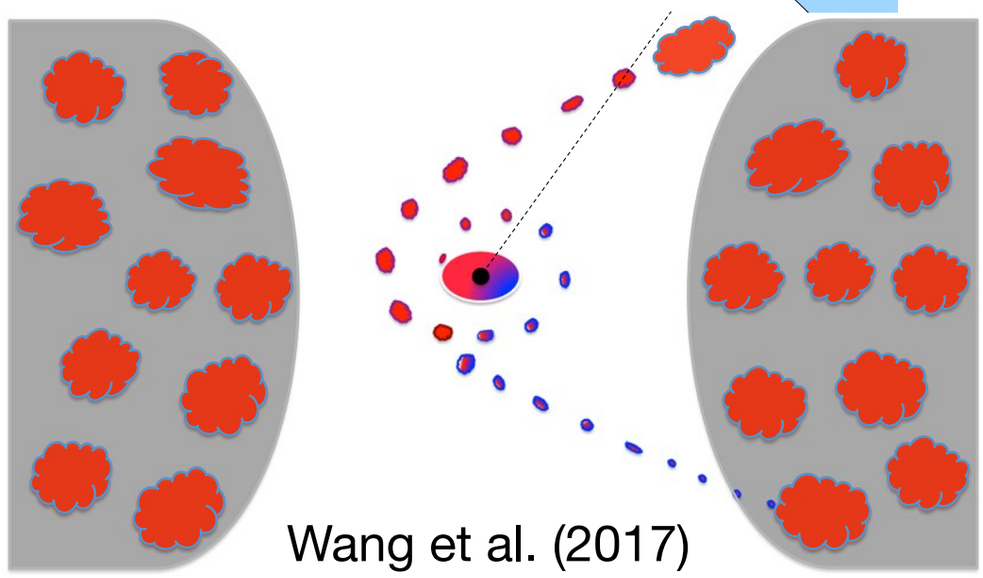
Jinyi Shangguan
on behalf of the GRAVITY Collaboration

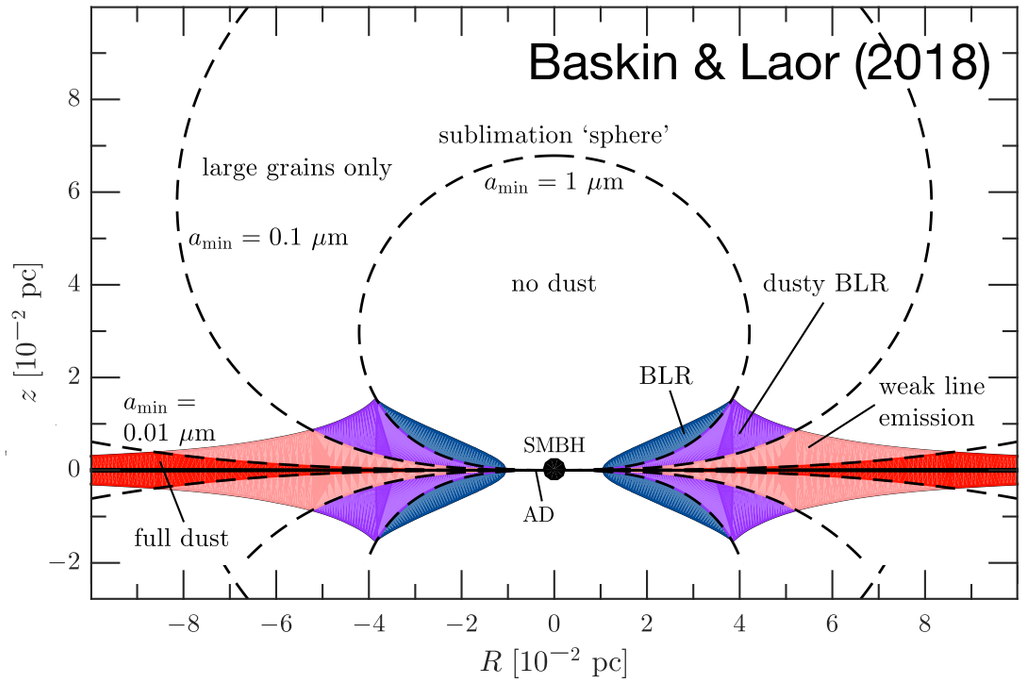
Max-Planck Institute for Extraterrestrial Physics

AGN Broad Line Region

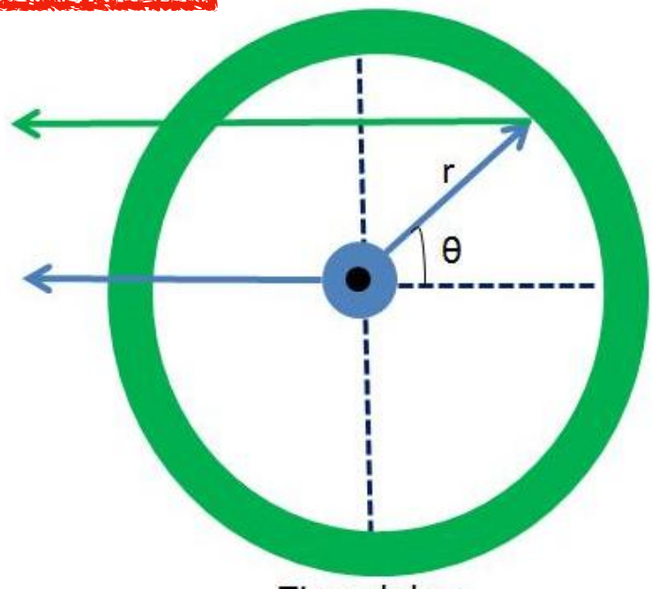




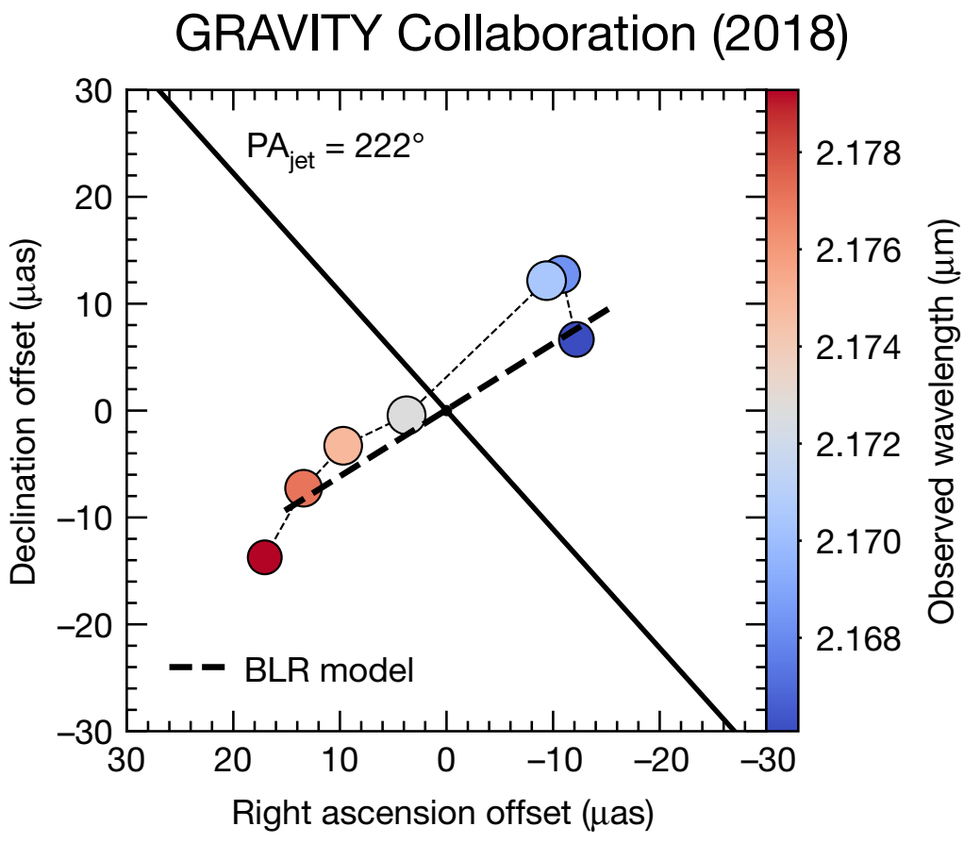




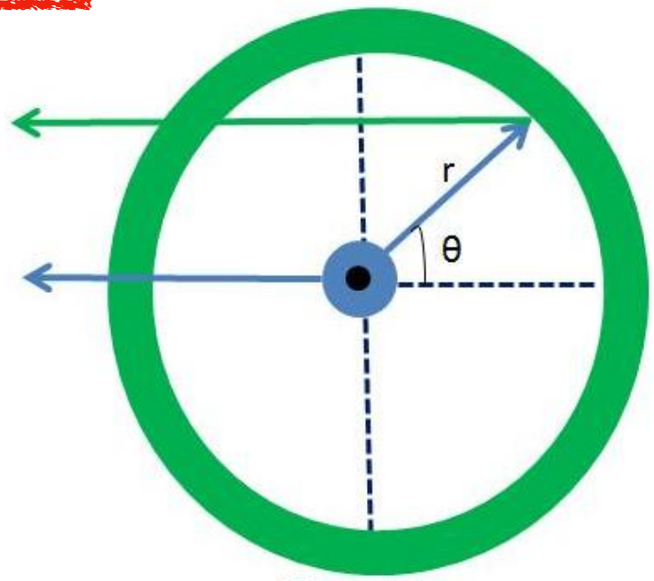
Measure BH mass



Time delay:
$\tau = (1+ \cos\theta) r/c$

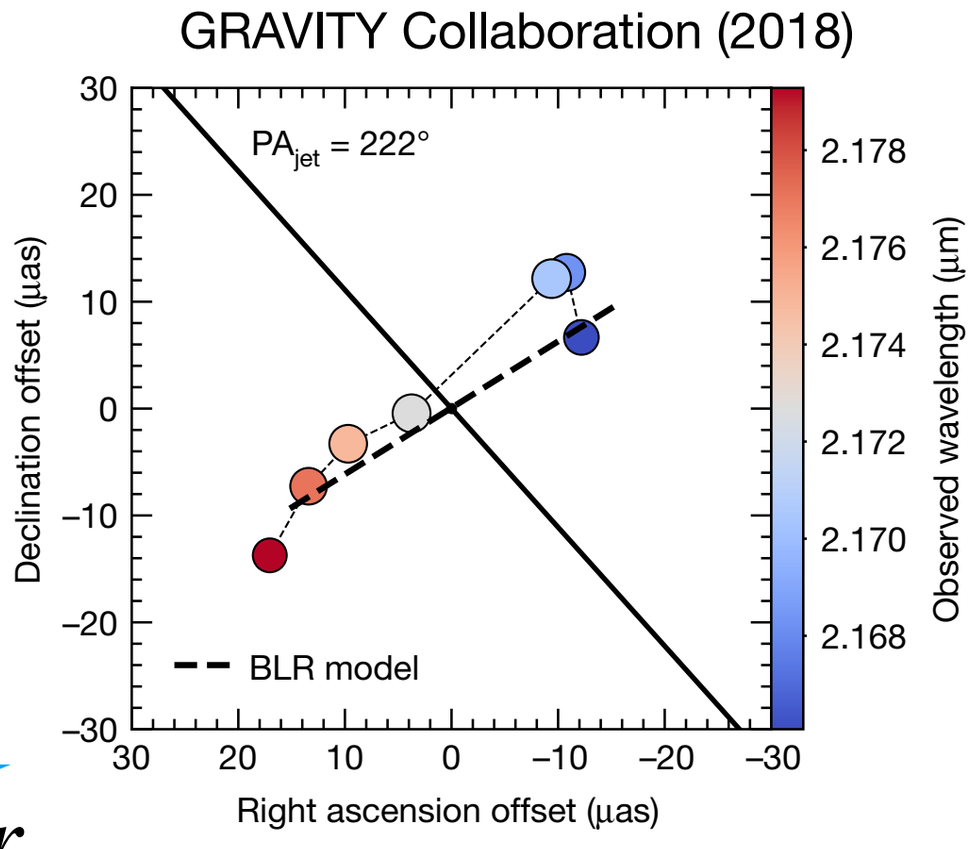


GRAVITY + RM

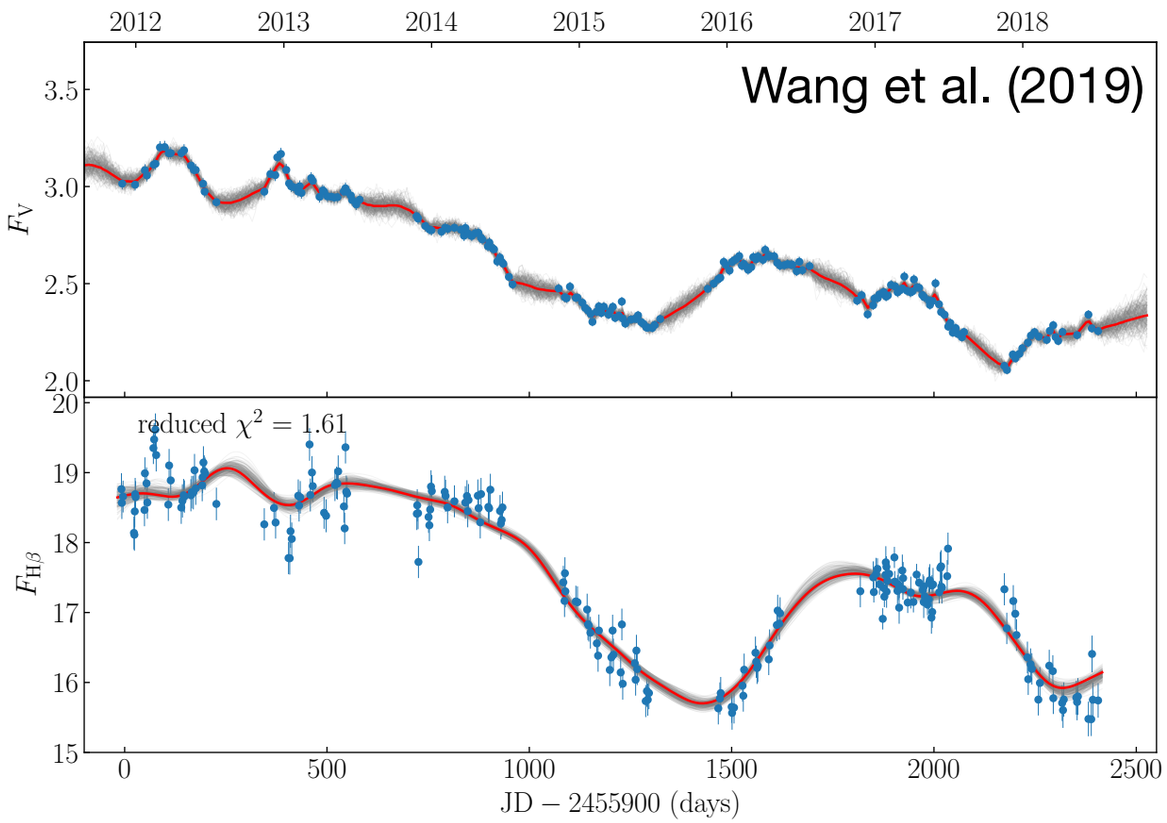


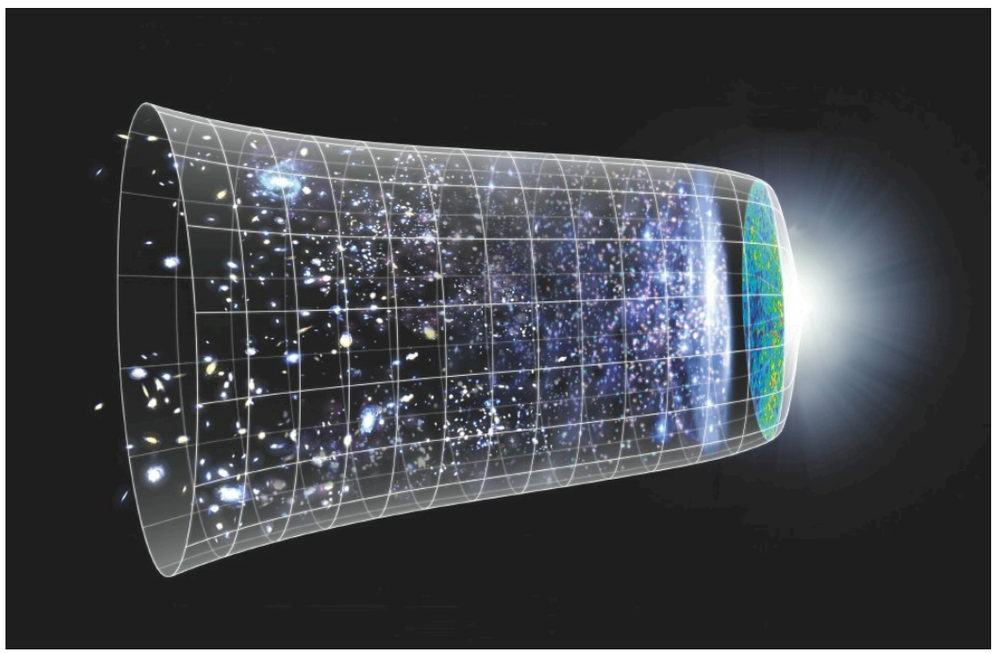
Time delay:
$\tau = (1+ \cos\theta) r/c$

+



$$D_{\mathrm{A}} = \frac{r}{\theta}$$





Phase reference
Object
Wavefront reference
2” FoV
Telescope #1
Metrology fringes
Metrology sensor
Telescope #2
Metrology
Starlight
Star separator
2” FoV
Delay line
Deformable mirror
Laser
Laser Guiding
Acquisition camera
IR wavefront sensor
Beam combiner instrument
Tiptilt Pupil
dOPD control
IO beam combiner
Spectrometer
A
B
C
D
Fiber coupler
Phase shifter
Metrology laser
Polarization control
OPD control

Use the AGN as the phase reference

Phase reference

Object

Wavefront reference

2” FoV

Telescope #1

Metrology fringes

Metrology sensor

Metrology

Starlight

Telescope #2

Star separator

2” FoV

Delay line

Deformable mirror

Laser

Laser Guiding

Acquisition camera

IR wavefront sensor

Beam combiner instrument

Tiptilt Pupil

dOPD control

IO beam combiner

Spectrometer

A

B

C

D

Fiber coupler

Phase shifter

Metrology laser

Polarization control

OPD control

Use the AGN as the phase reference

Phase reference

Object

Wavefront reference

2” FoV

Telescope #1

Metrology fringes

Metrology sensor

Telescope #2

Metrology

Starlight

Star separator

2” FoV

Delay line

Deformable mirror

Laser

Laser Guiding

Acquisition camera

Low and medium resolution spectra are measured

IR wavefront sensor

Tiptilt Pupil

Beam combiner instrum

dOPD control

IO beam combiner

Spectrometer

A

B

C

D

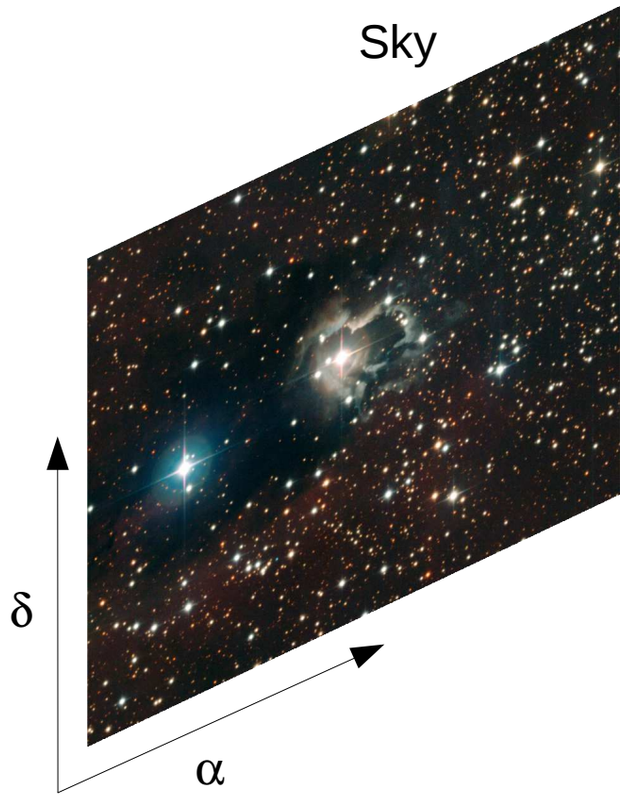
Fiber coupler

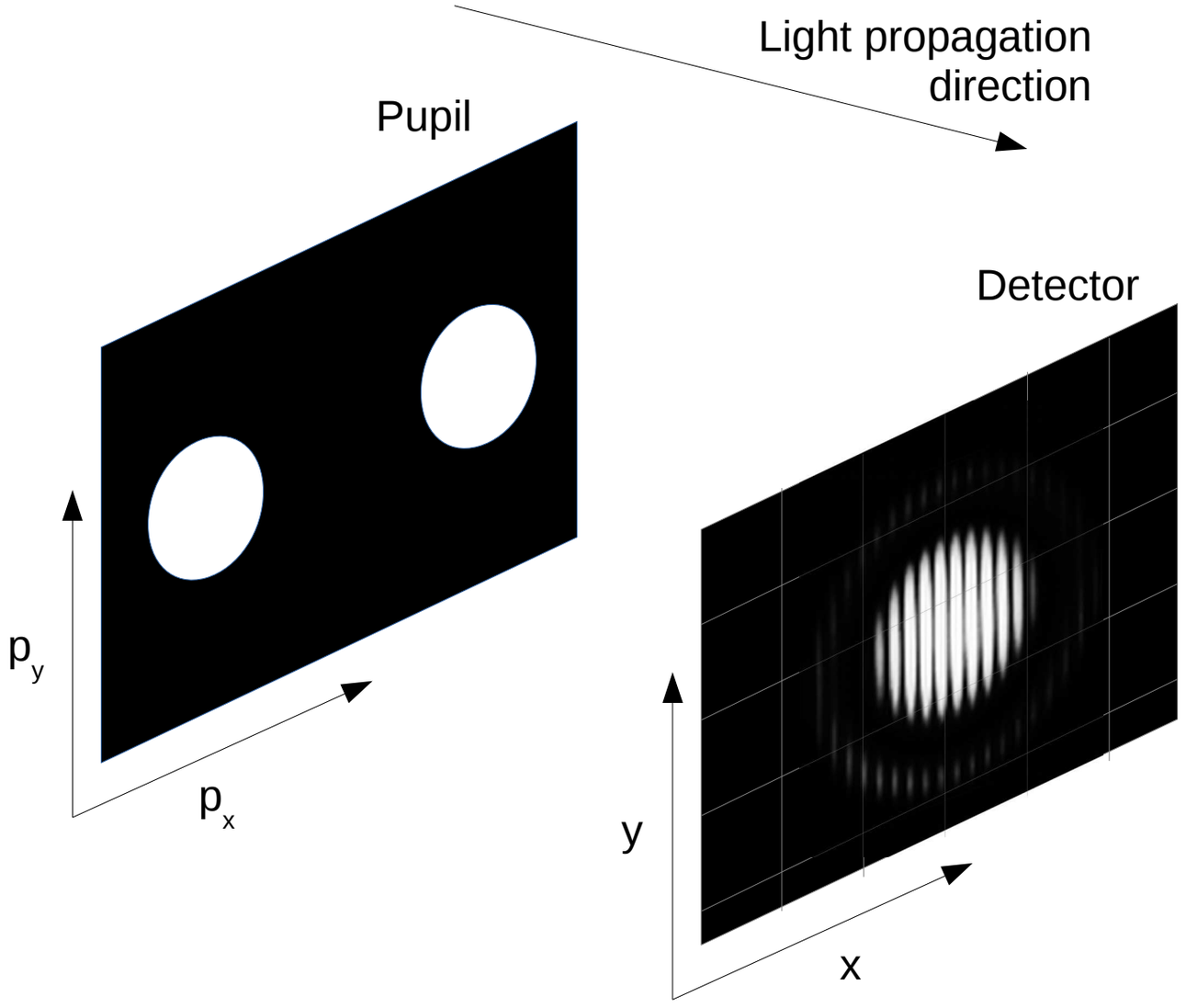
Phase shifter

Metrology laser

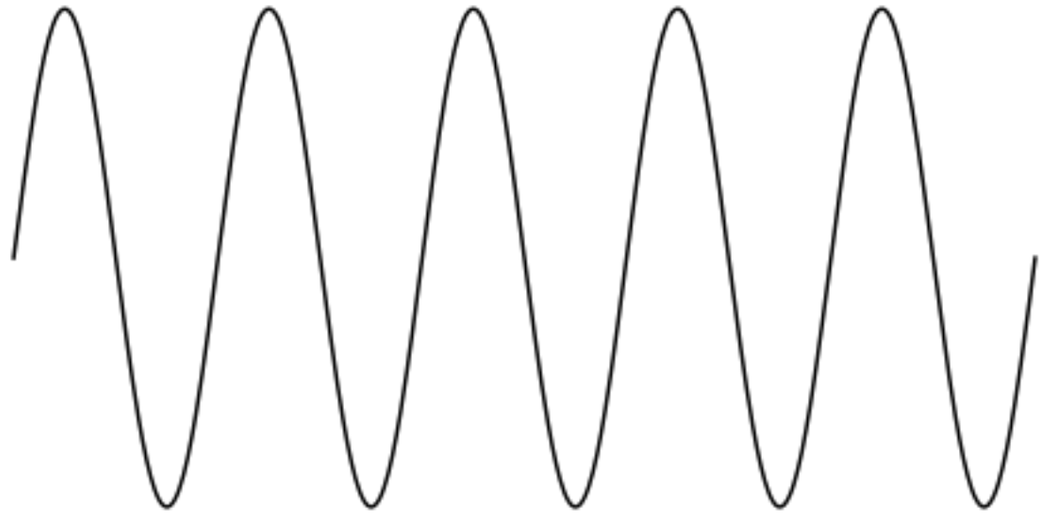
Polarization control

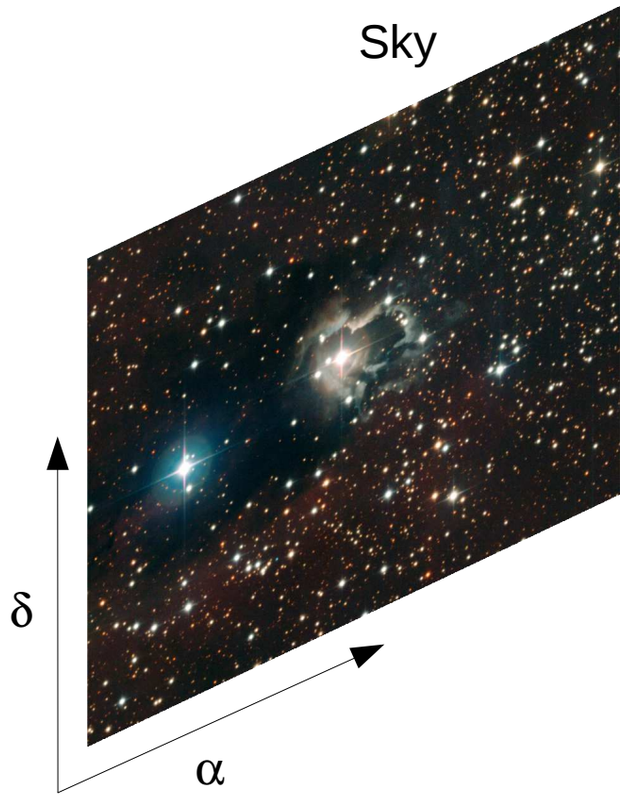
OPD control

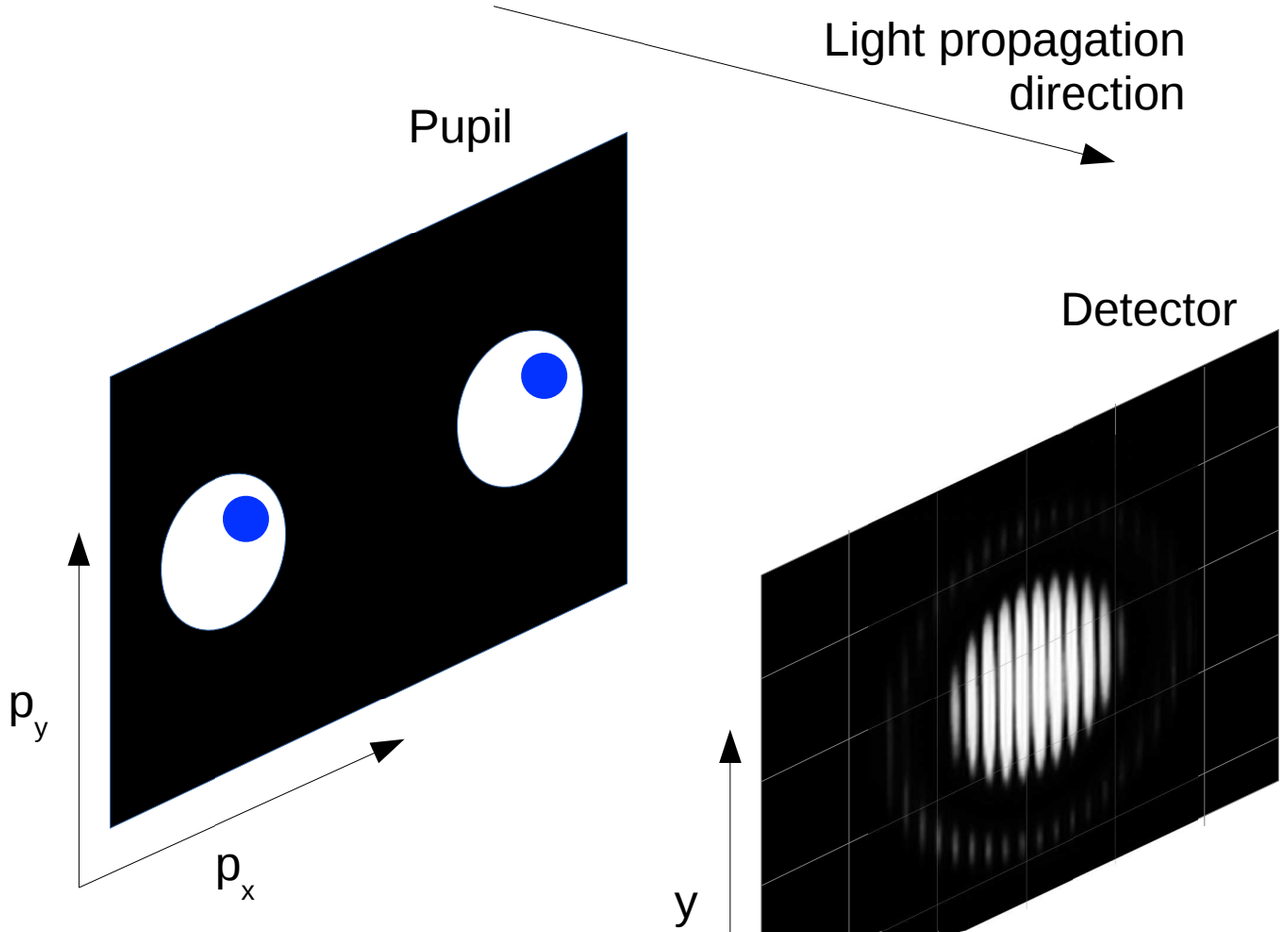




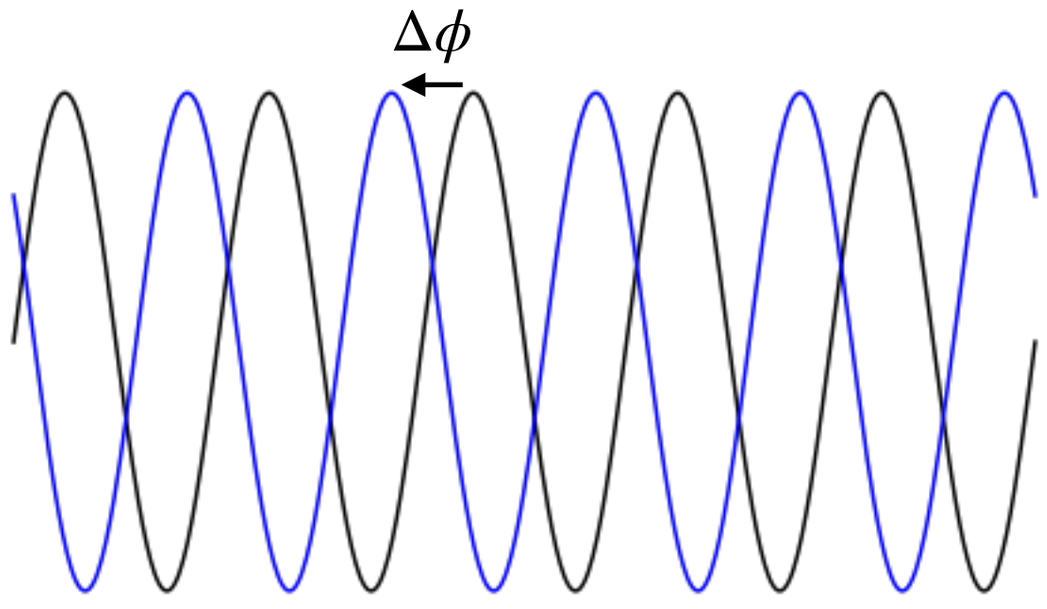
differential phase







differential phase



Sky

δ

α

Light propagation direction

Pupil

p_y

p_x

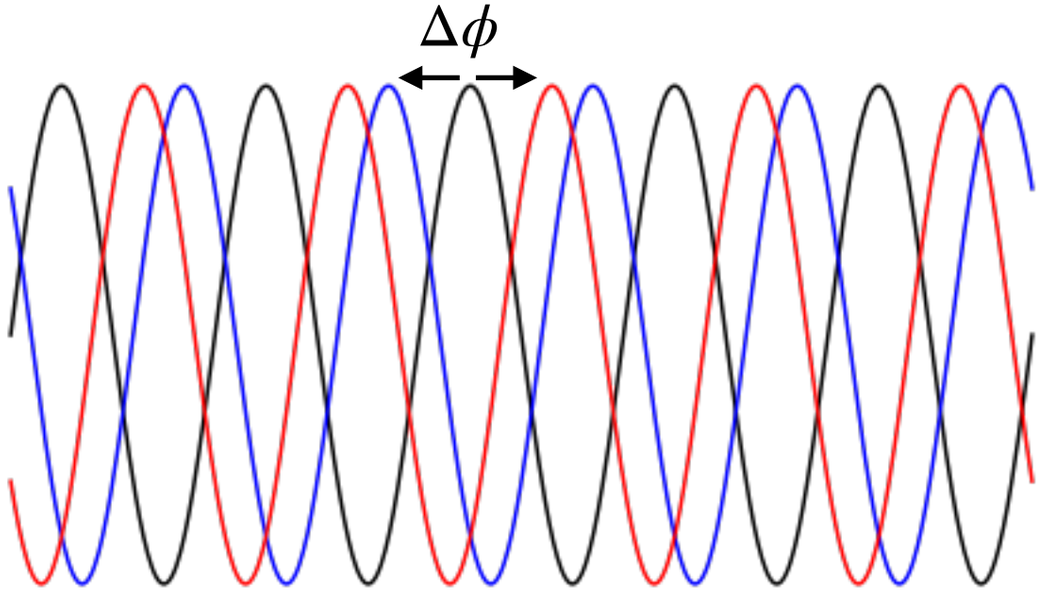
Detector

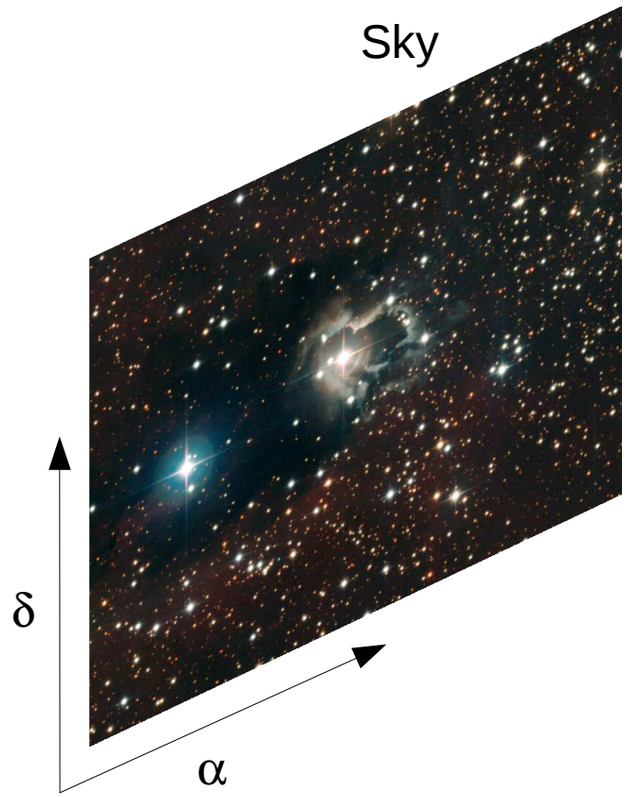
y

x

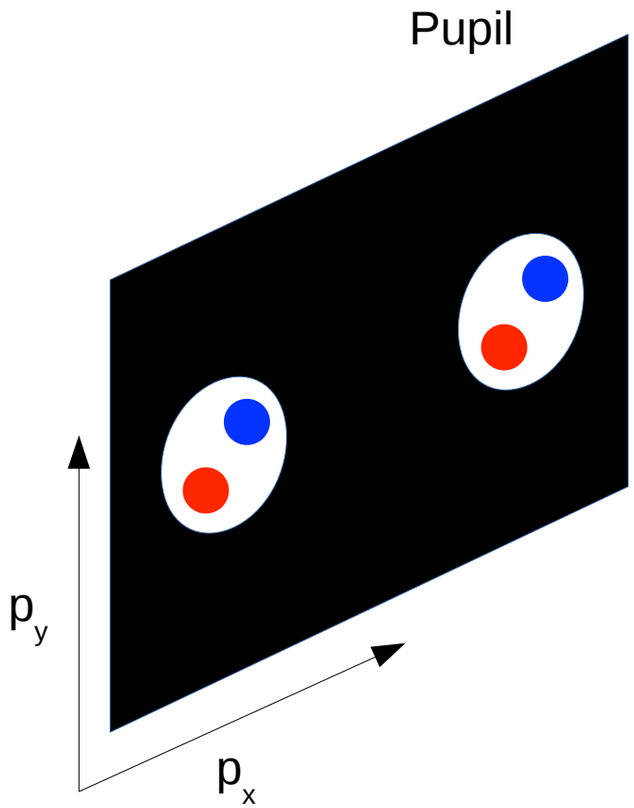
differential phase

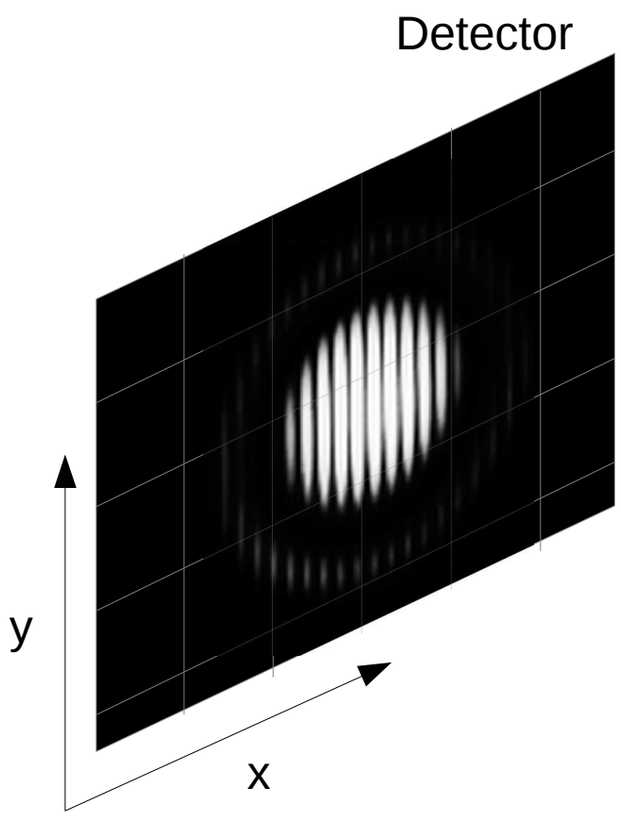
$\Delta\phi$





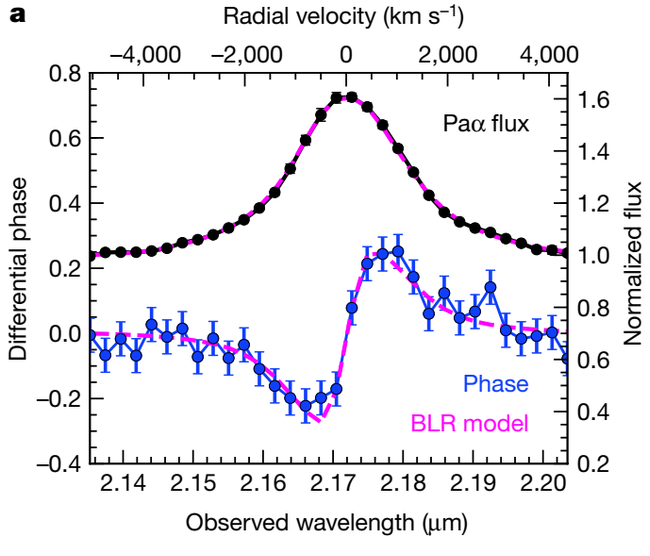
Light propagation direction

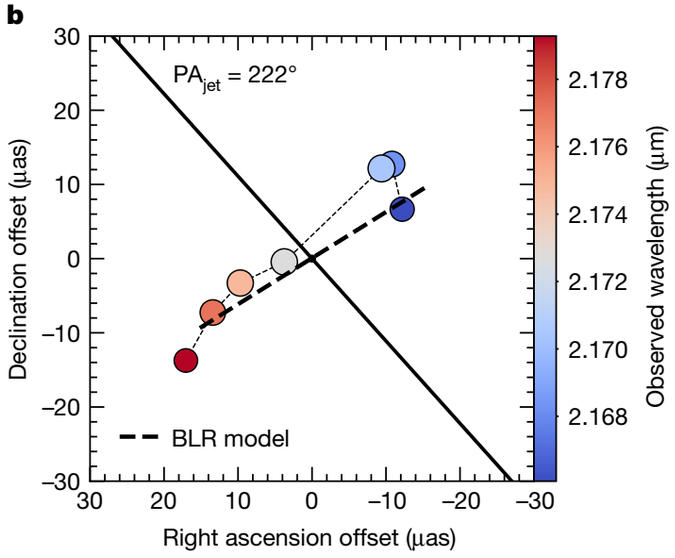


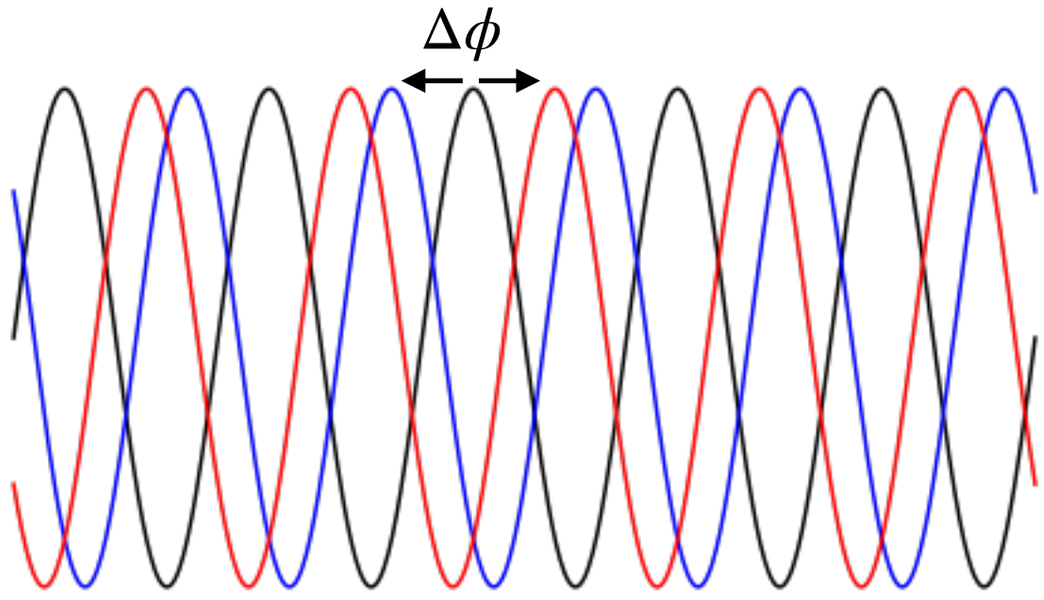


differential phase **line strength** **baseline** **photocenter**

$$\Delta\phi = -2\pi \frac{r(\lambda)}{1+r(\lambda)} [\vec{u}(\lambda) \cdot \vec{\epsilon}(\lambda)]$$







BLR modeling from 3C273 GRAVITY data

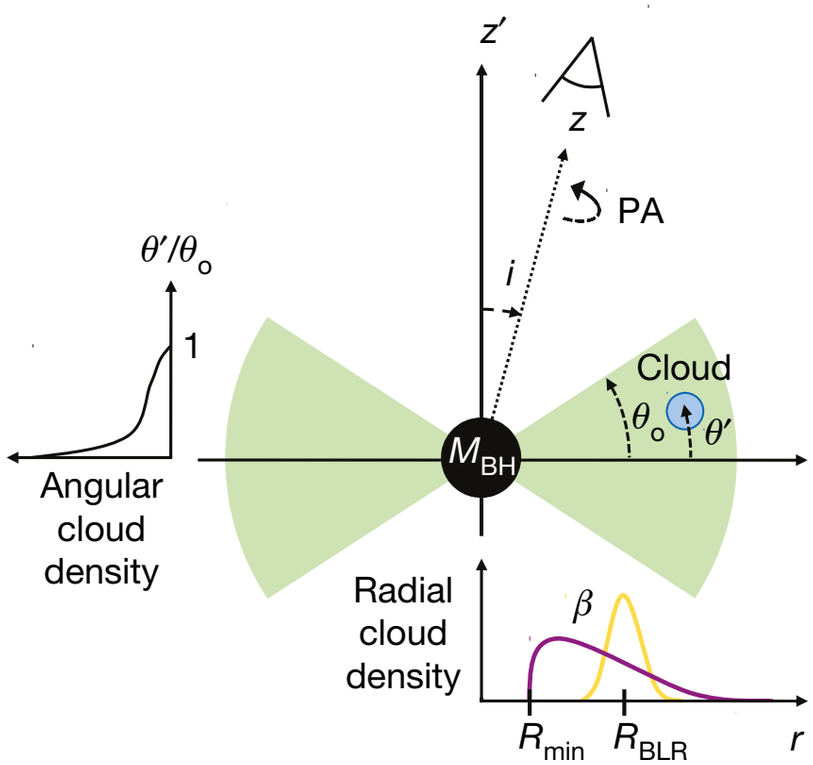
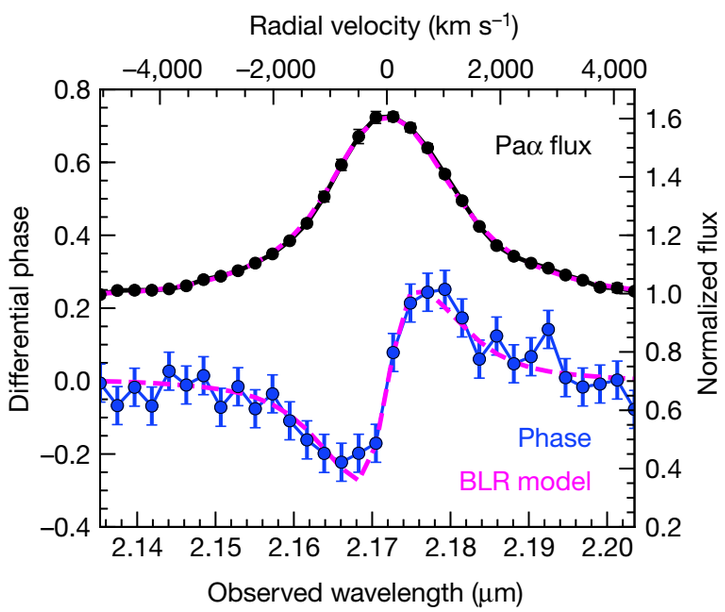
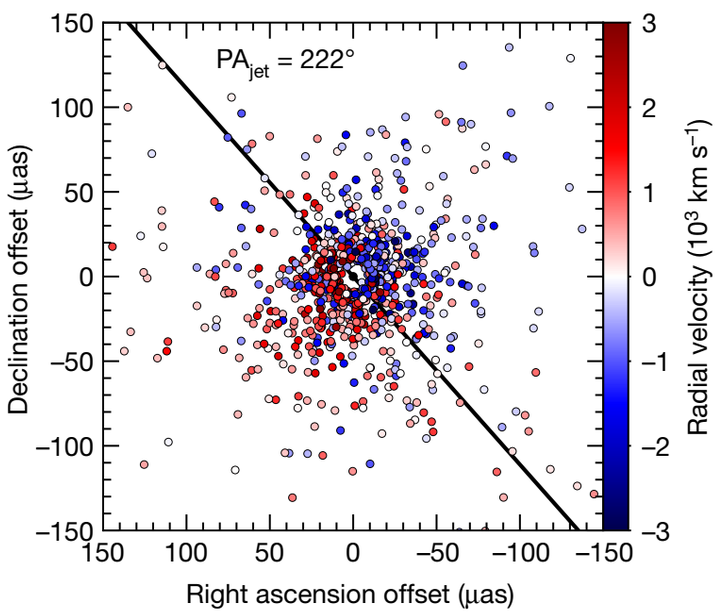


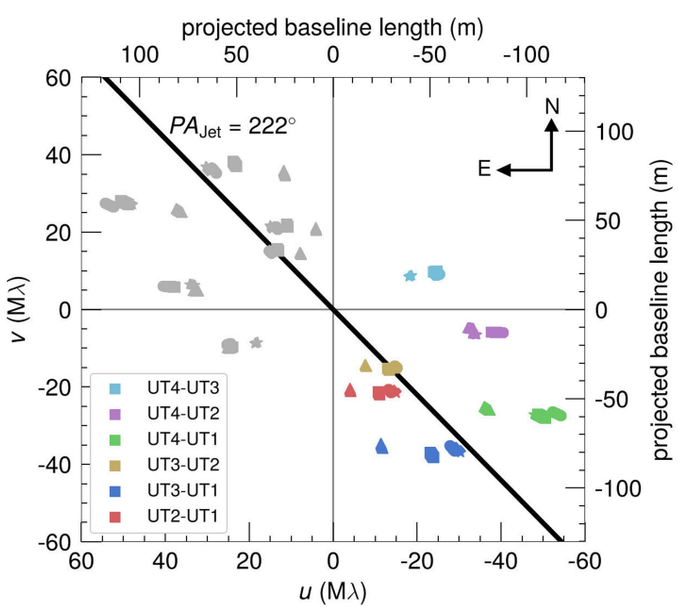
Table 1 | Estimates of the kinematic BLR model parameters

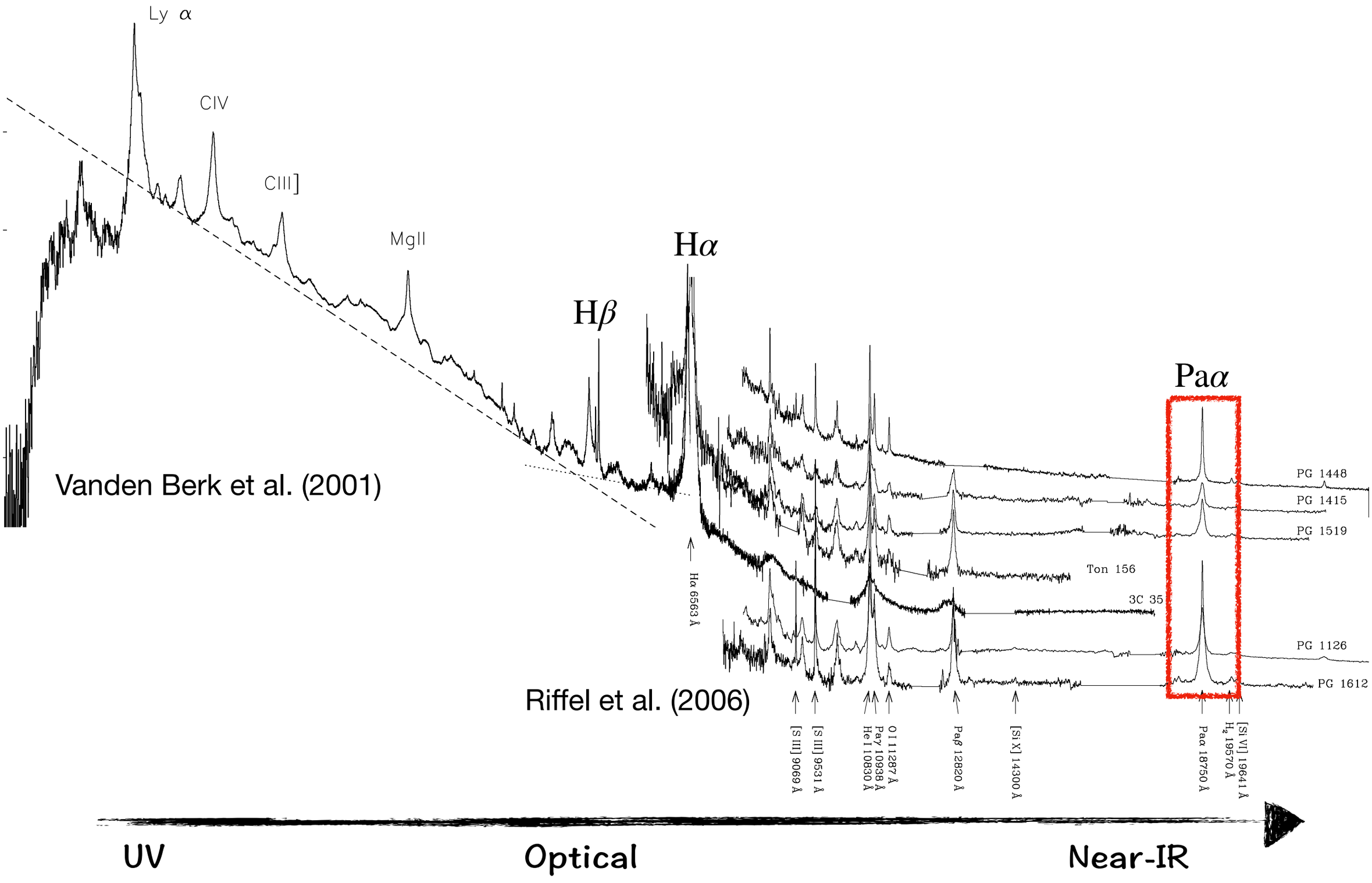
Parameter	Value	Description
R_{BLR} (μas)	46 ± 10	Mean angular distance of the cloud from the black hole
R_{min} (μas)	11 ± 3	Minimum angular distance of the cloud from the black hole
β	1.4 ± 0.2	Radial distribution shape parameter
θ_o (°)	45^{+9}_{-6}	Half-opening angle of the disk
i (°)	12 ± 2	Inclination angle of the observer
PA (° E of N)	210^{+6}_{-9}	Position angle on the sky
M_{BH} ($10^8 M_\odot$)	2.6 ± 1.1	Black-hole mass

GRAVITY Collaboration (2018)



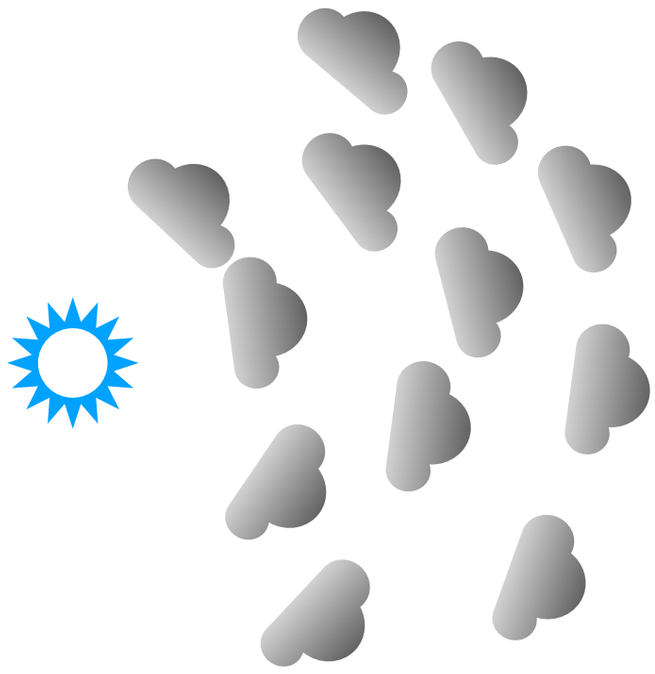


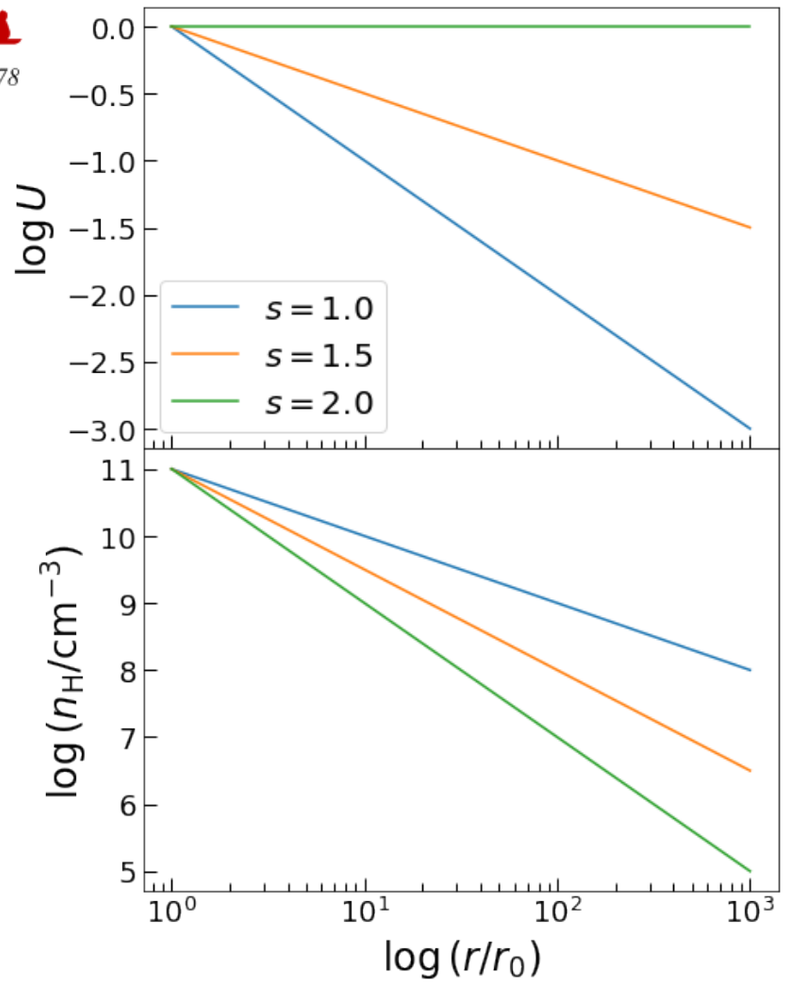


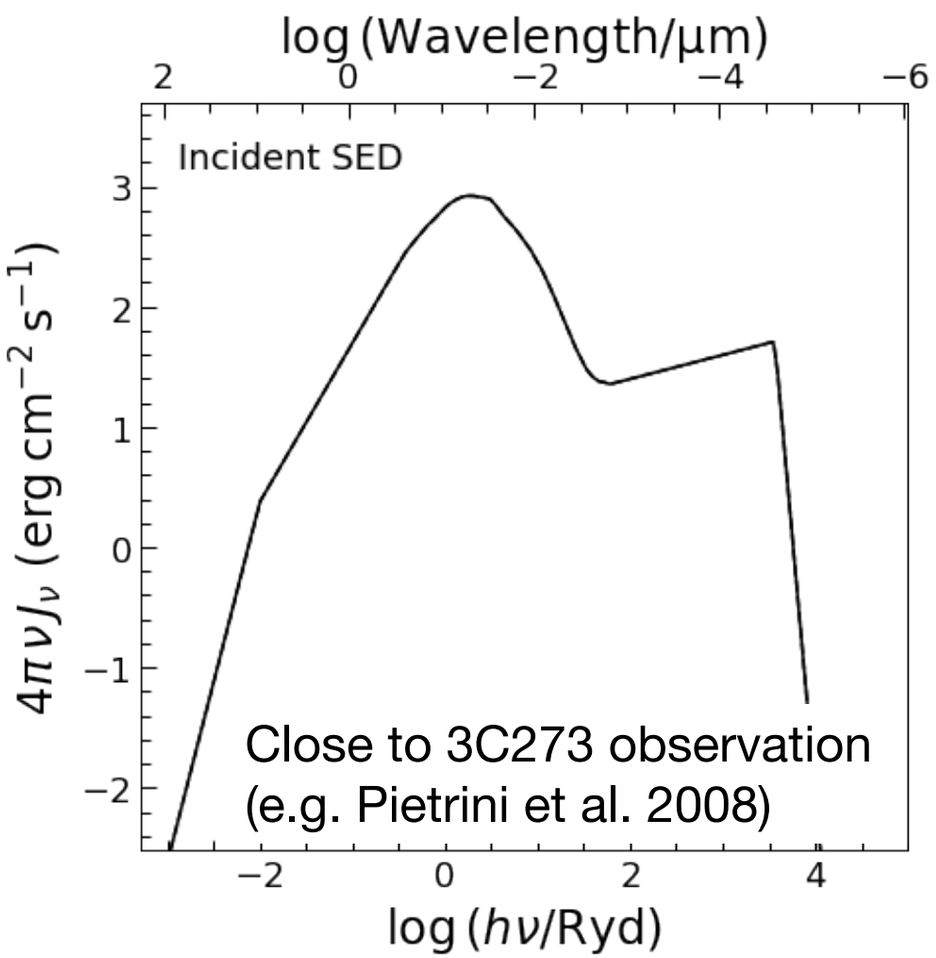

Ly α
CIV
CIII]
MgII
Hβ
Hα
Paα
Vanden Berk et al. (2001)
Riffel et al. (2006)
PG 1448
PG 1415
PG 1519
Ton 156
3C 35
PG 1126
PG 1612
Hα 6563 Å
[S III] 9069 Å
[S III] 9531 Å
O I 11287 Å
Paγ 10938 Å
He I 10830 Å
Paβ 12820 Å
[Si X] 14300 Å
Paα 18750 Å
H2 19570 Å
[Si VI] 19641 Å
UV
Optical
Near-IR

Cloudy & Associates

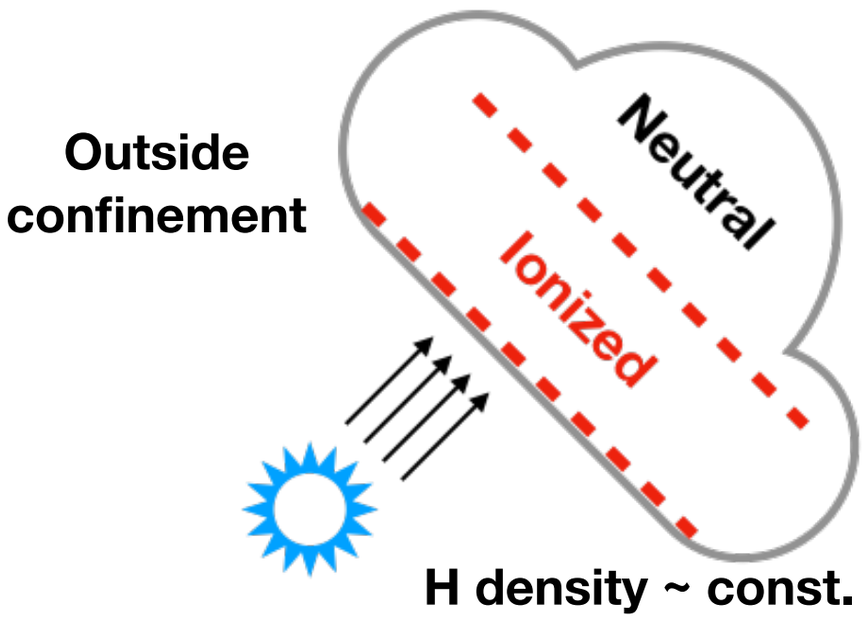
Photoionization Simulations for the Discriminating Astrophysicist Since 1978



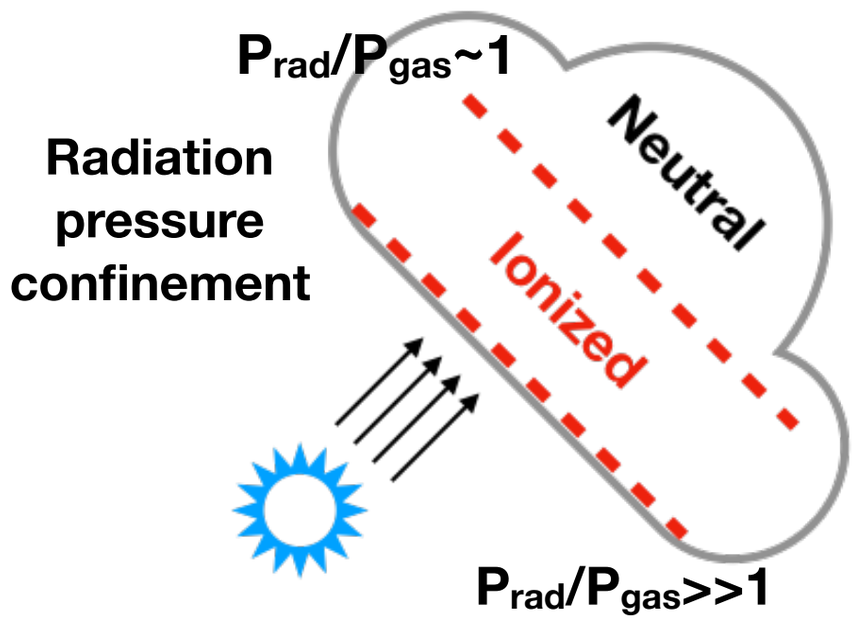




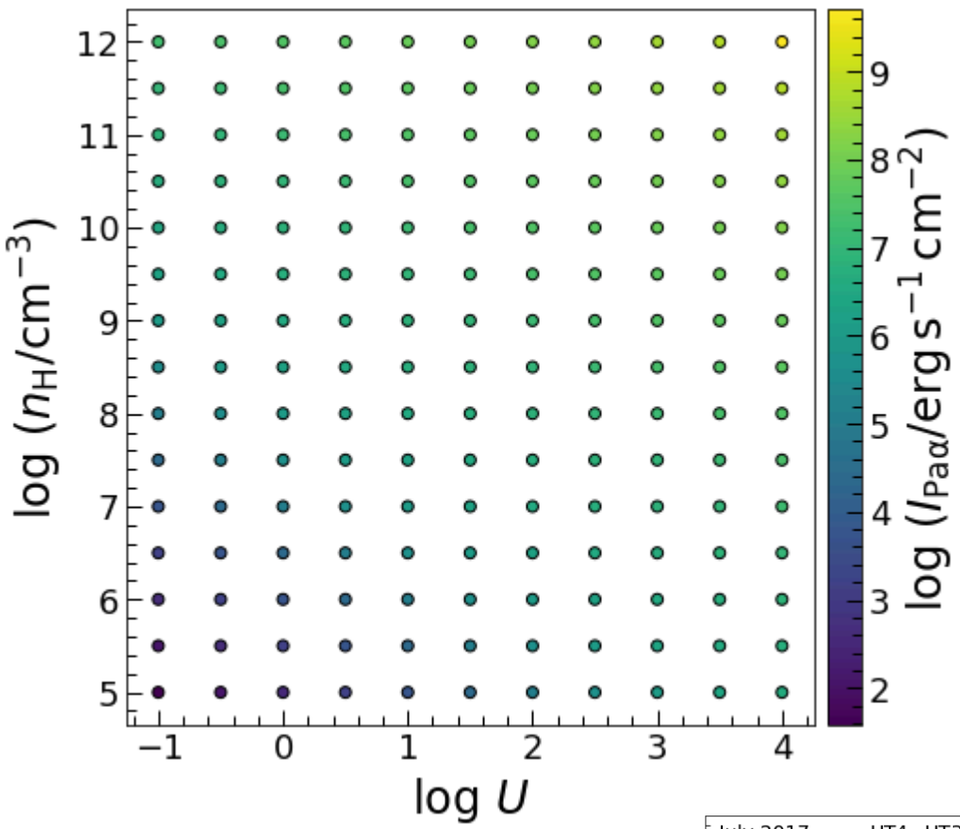
Constant density
(Kaspi & Netzer 1999)

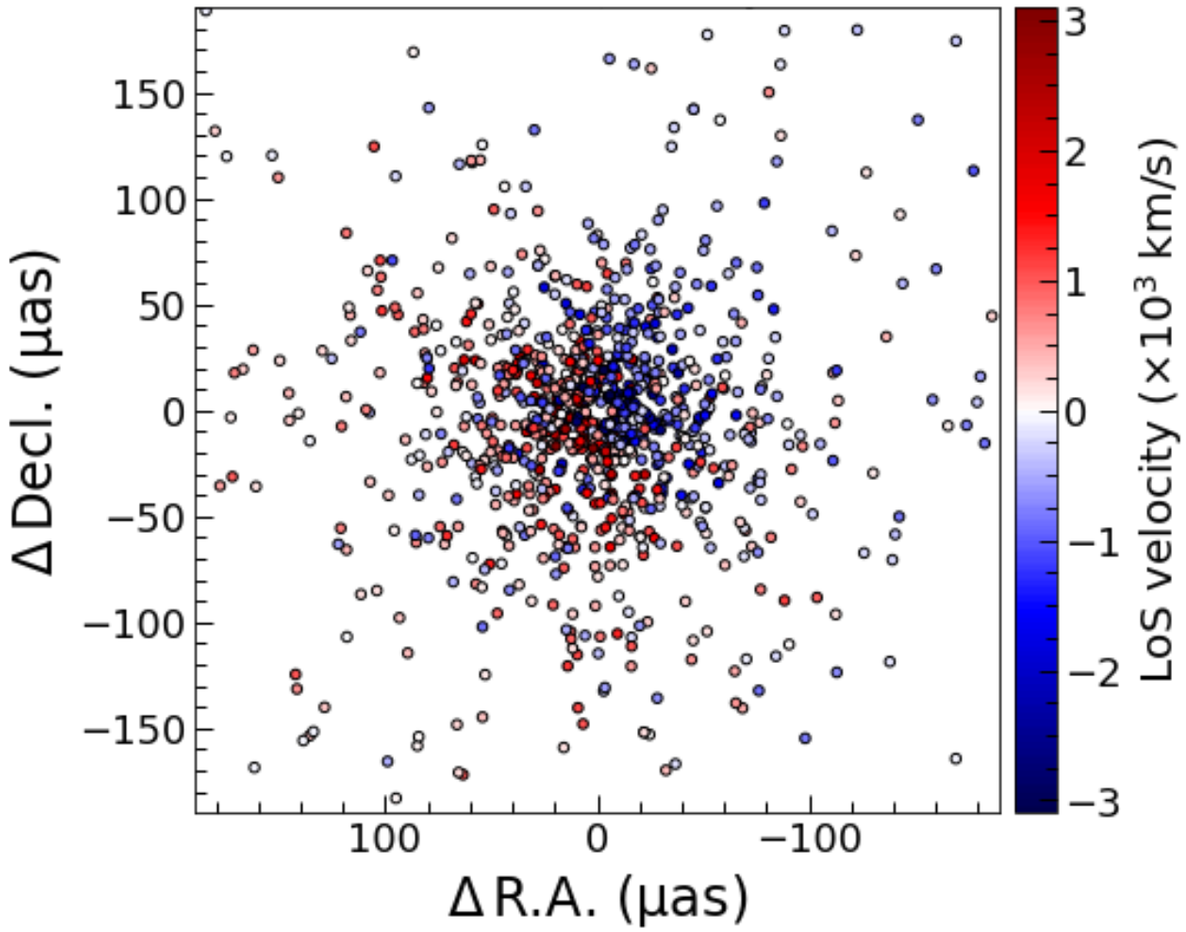


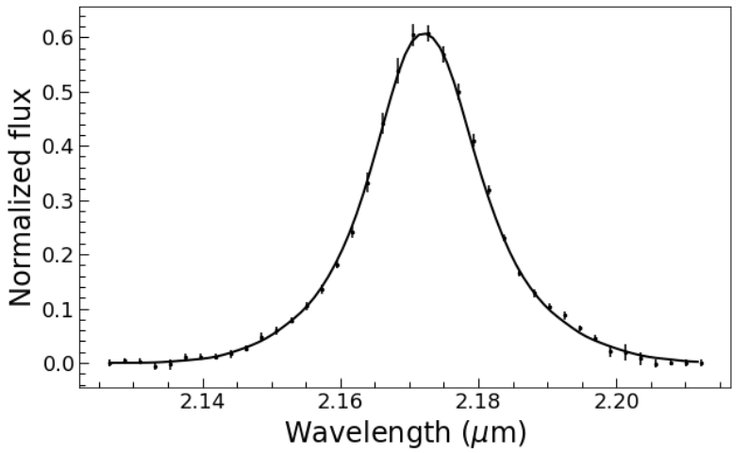
Constant total pressure
(e.g., Baskin et al. 2014)

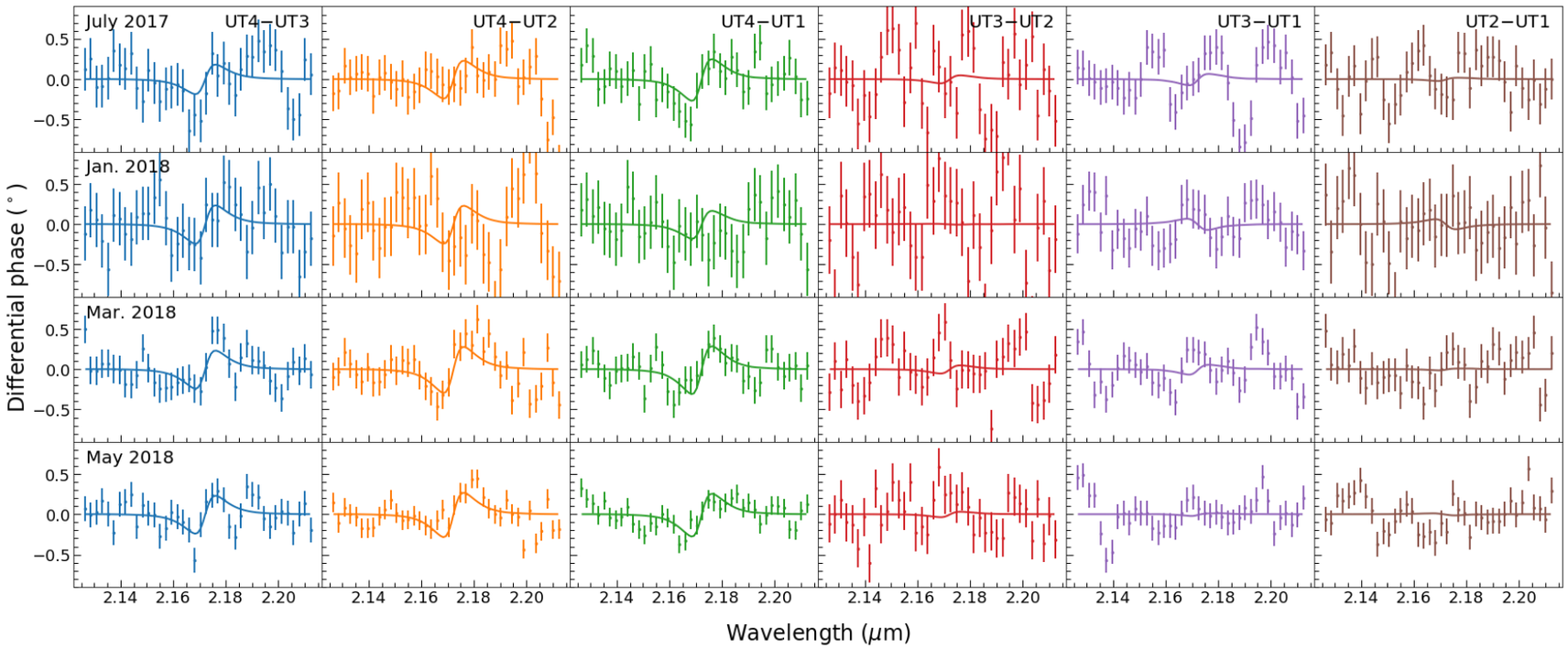


Fitting results

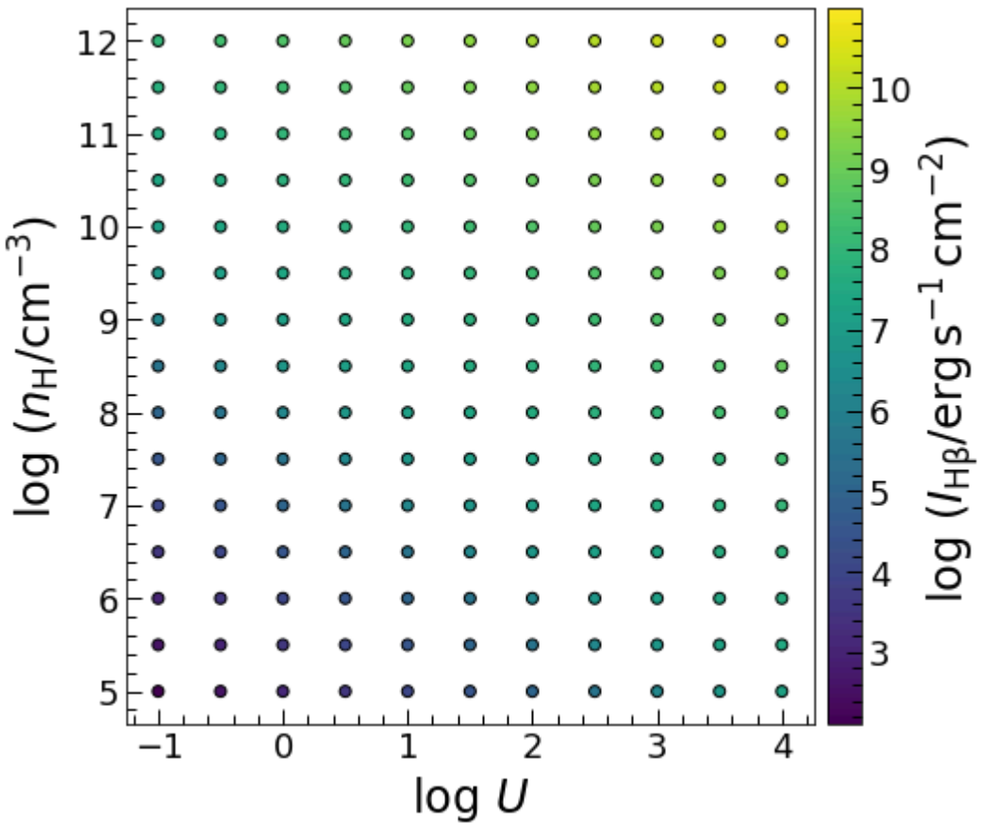


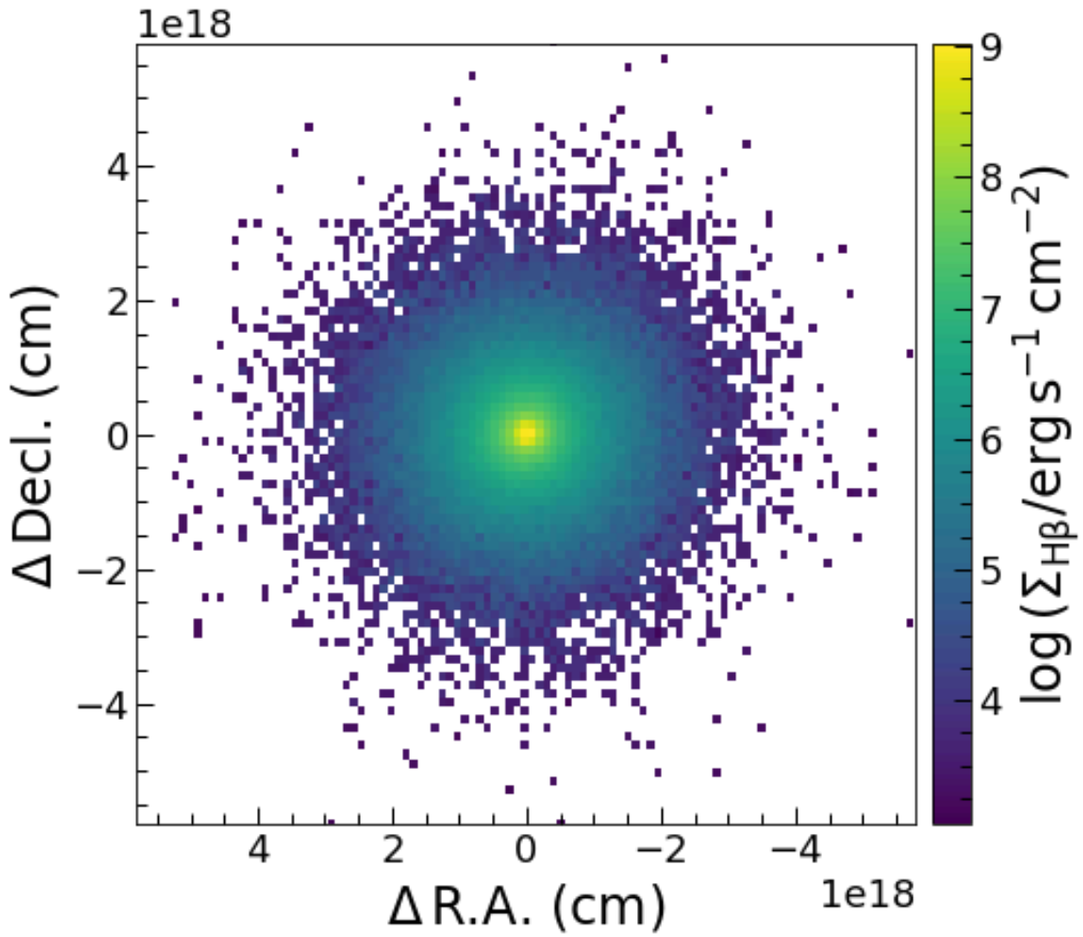


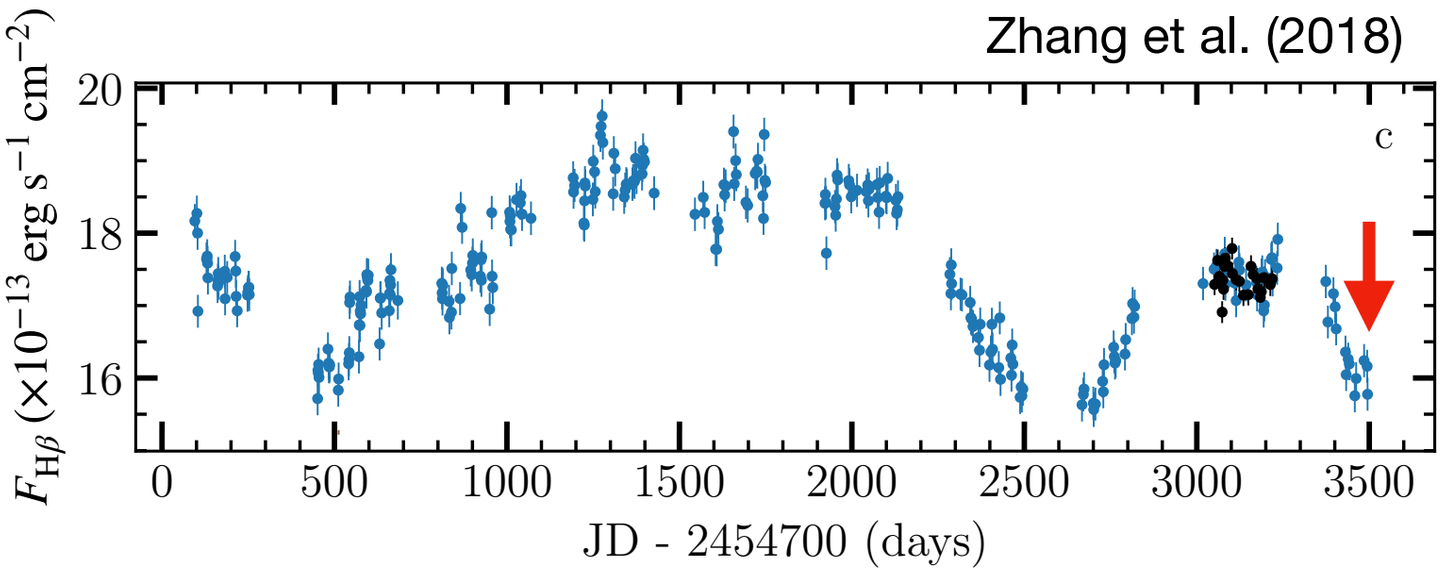


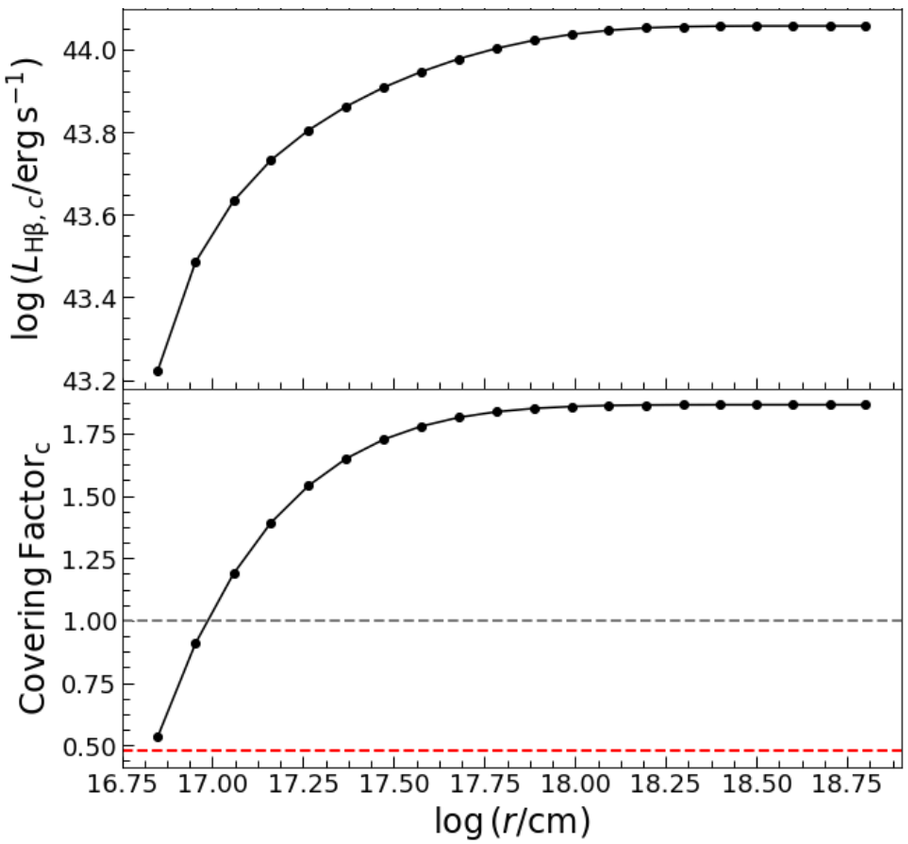


Fitting results









Resolving the hot dust emission with GRAVITY

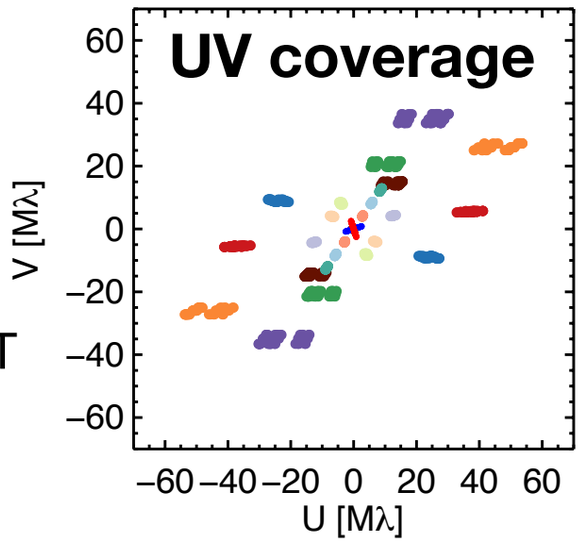
Oliver Pfuhl
@ESO

NGC 1068 visibility

Speckle interferometry
(Weigelt et al. 2004)

GRAVITY@AT

GRAVITY@UT



V^2

1.0000
0.1000
0.0100
0.0010
0.0001

GRAVITY Collaboration
2019 (submitted)

0 10 20 30 40 50 60

UV distance [Mλ]

$$\sim \frac{Baseline}{\lambda}$$

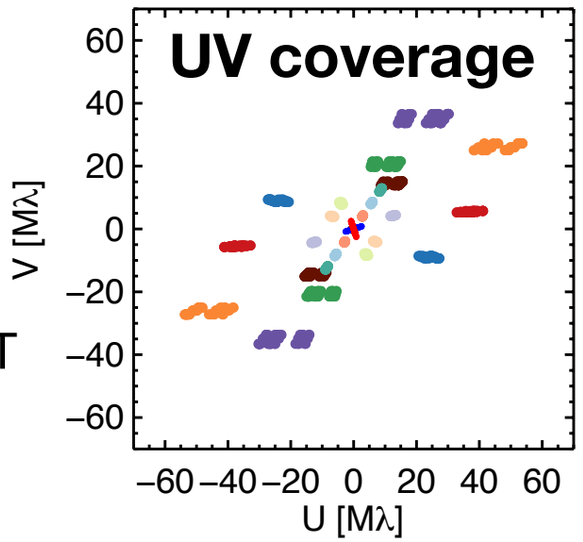
Oliver Pfuhl
@ESO

NGC 1068 visibility

Speckle interferometry
(Weigelt et al. 2004)

GRAVITY@AT

GRAVITY@UT



V^2

1.0000
0.1000
0.0100
0.0010
0.0001

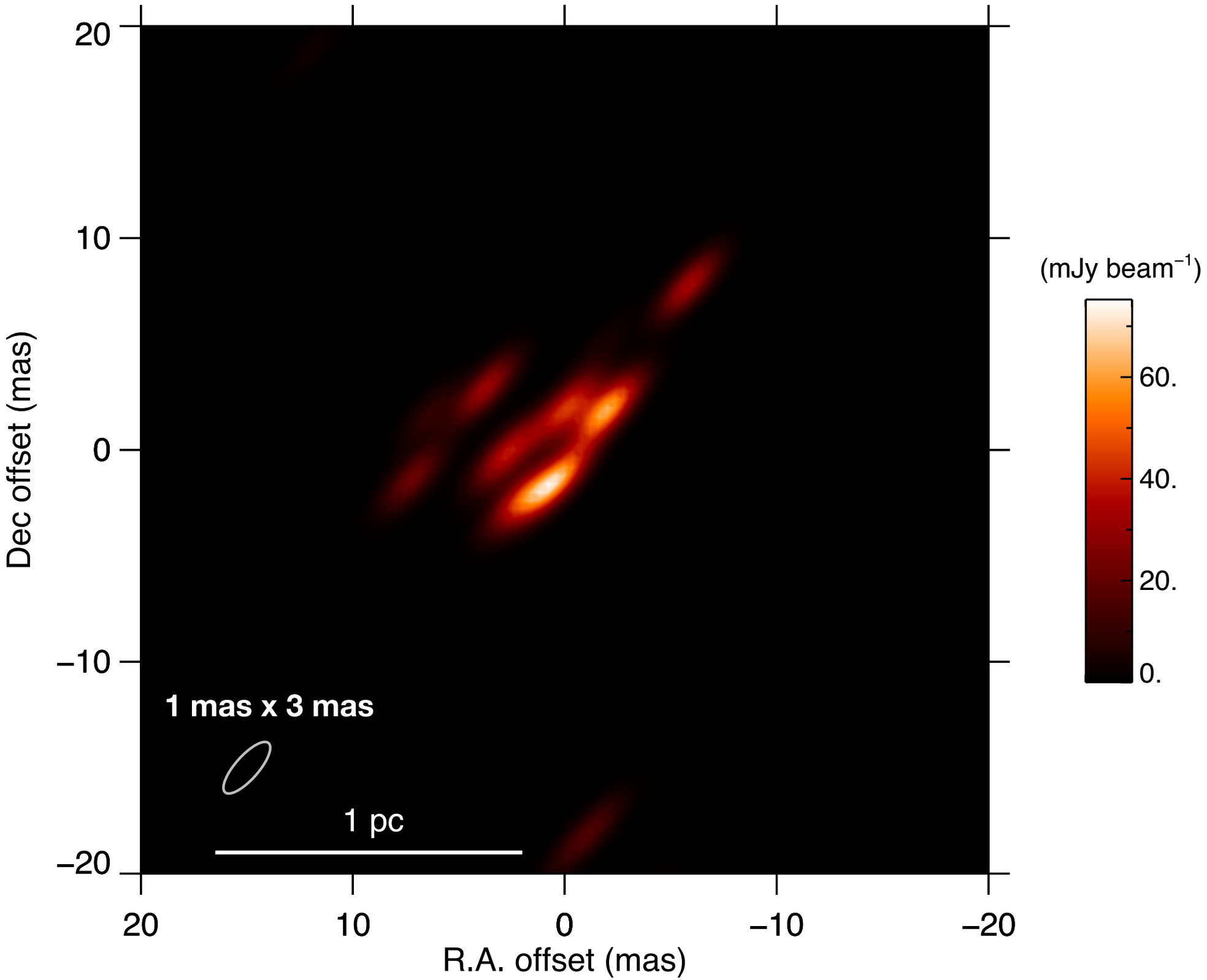
GRAVITY Collaboration
2019 (submitted)

0 10 20 30 40 50 60

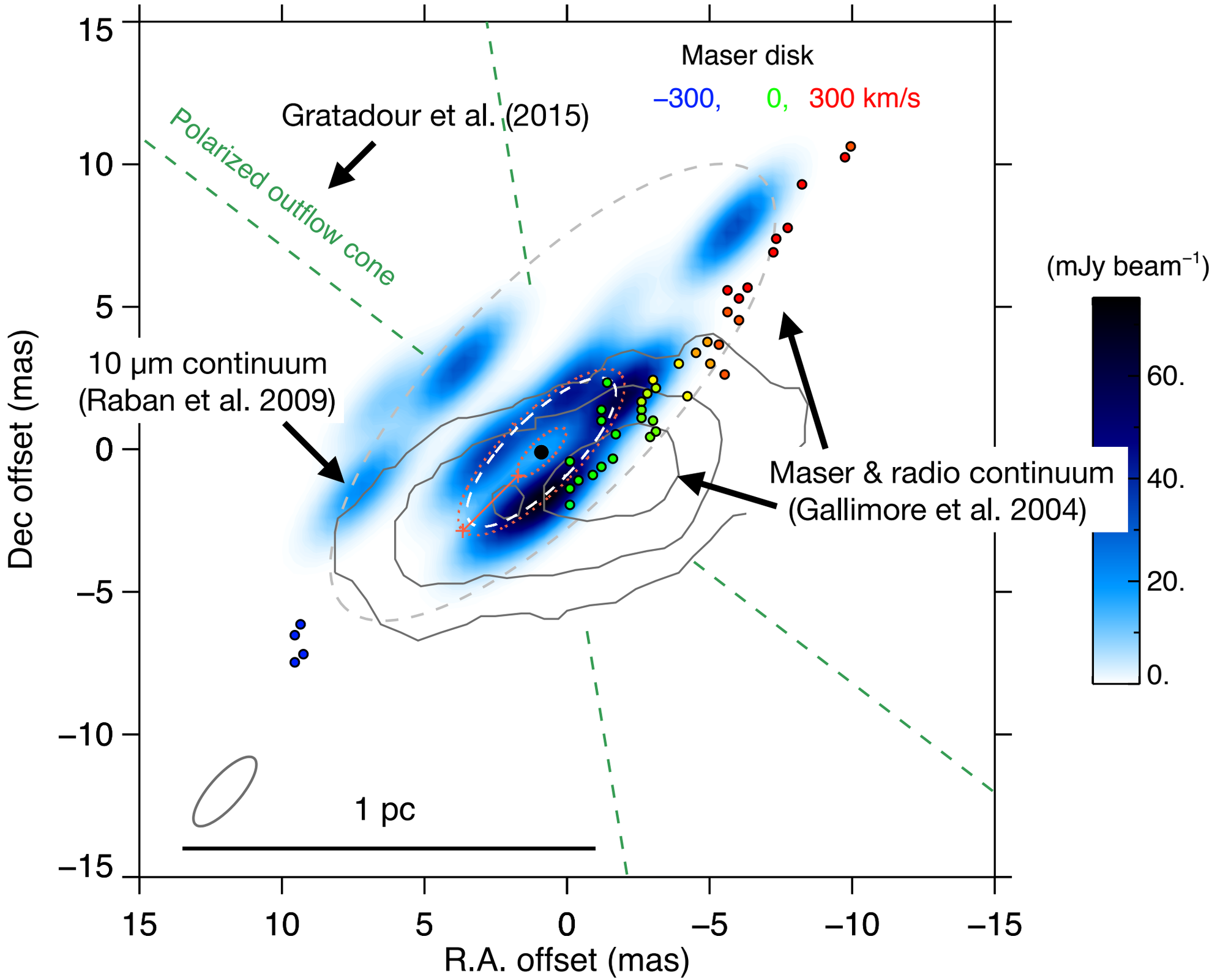
UV distance [Mλ]

$$\sim \frac{Baseline}{\lambda}$$

NGC 1068 imaging

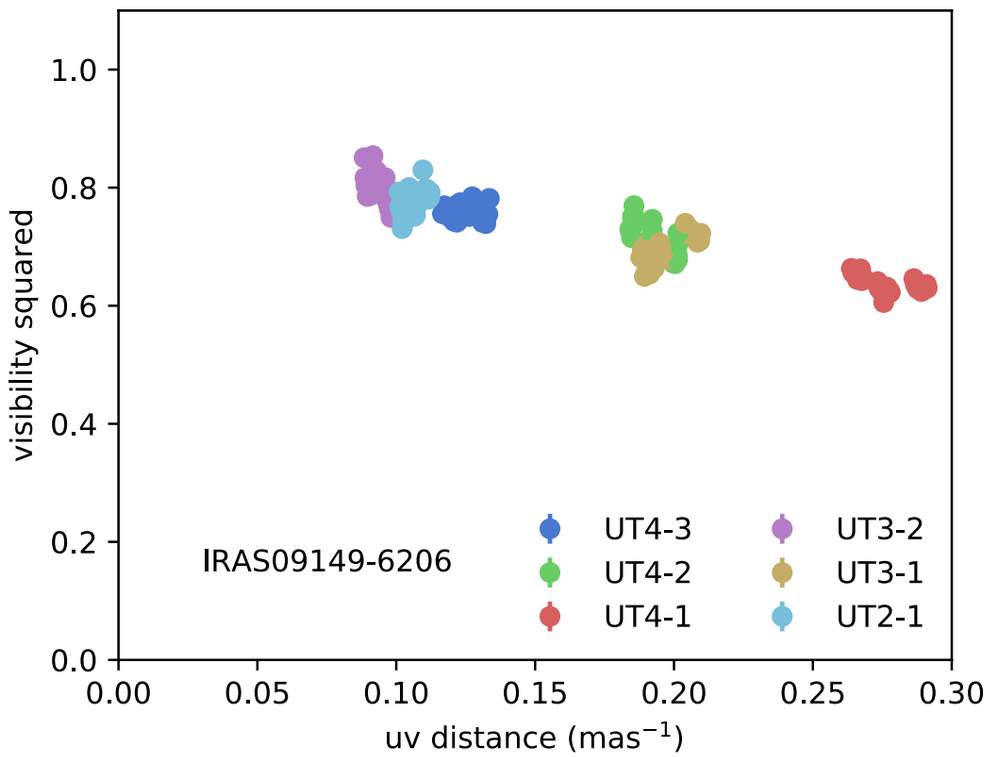


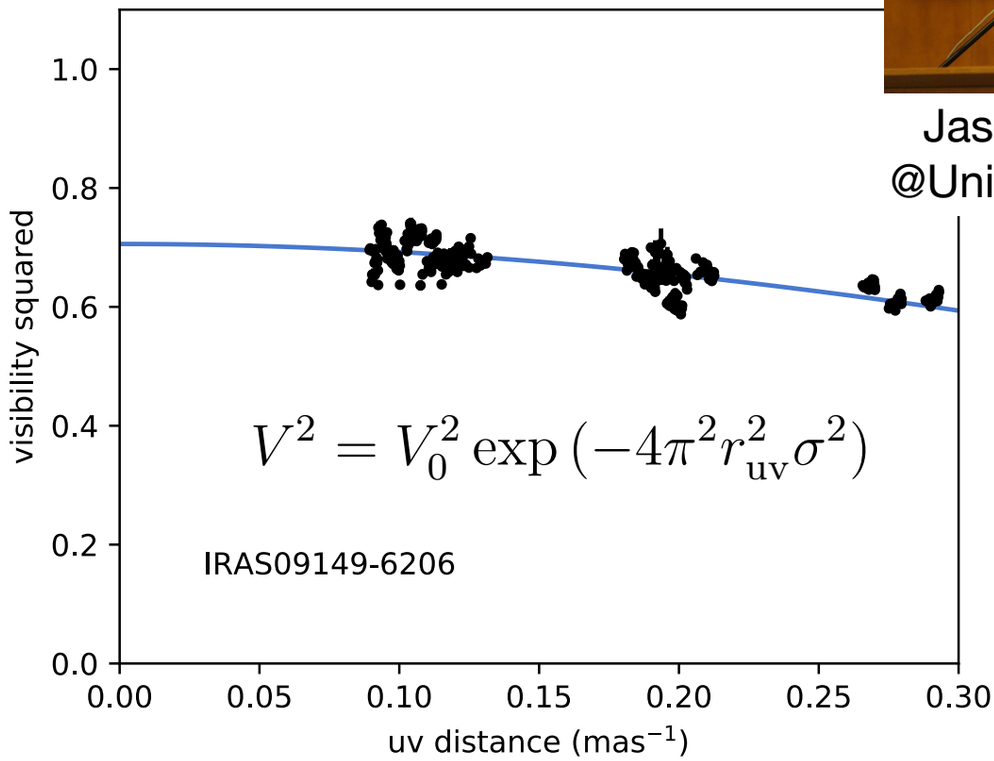
NGC 1068 imaging: A ring structure

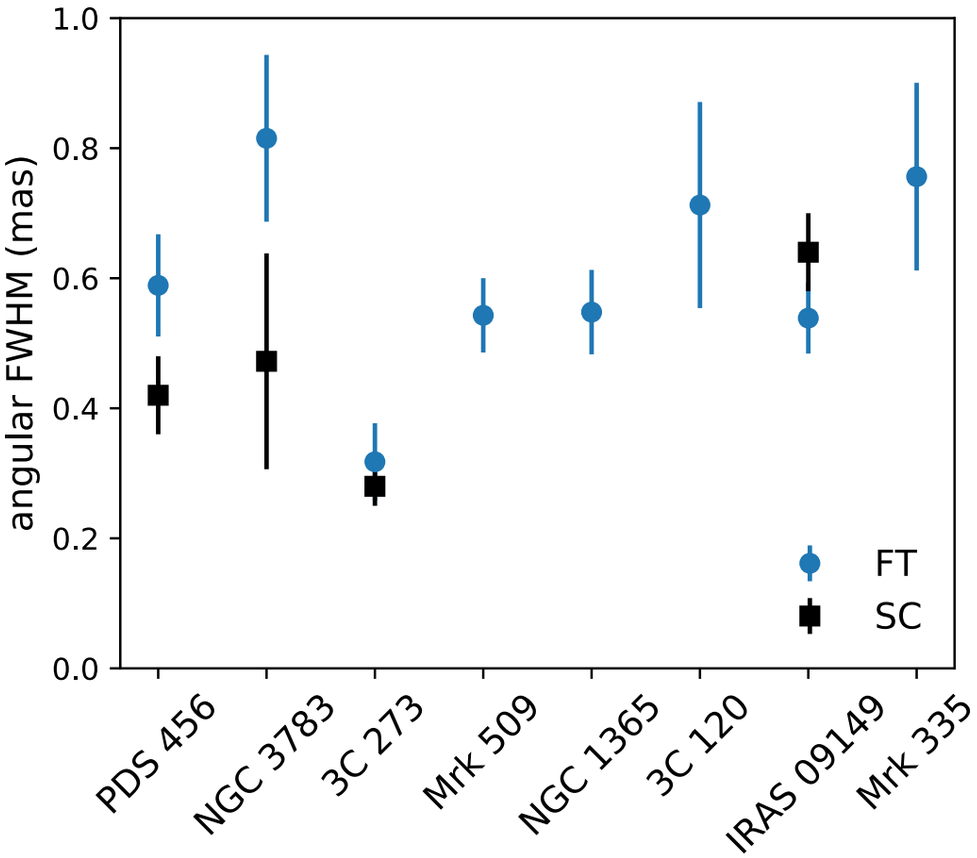


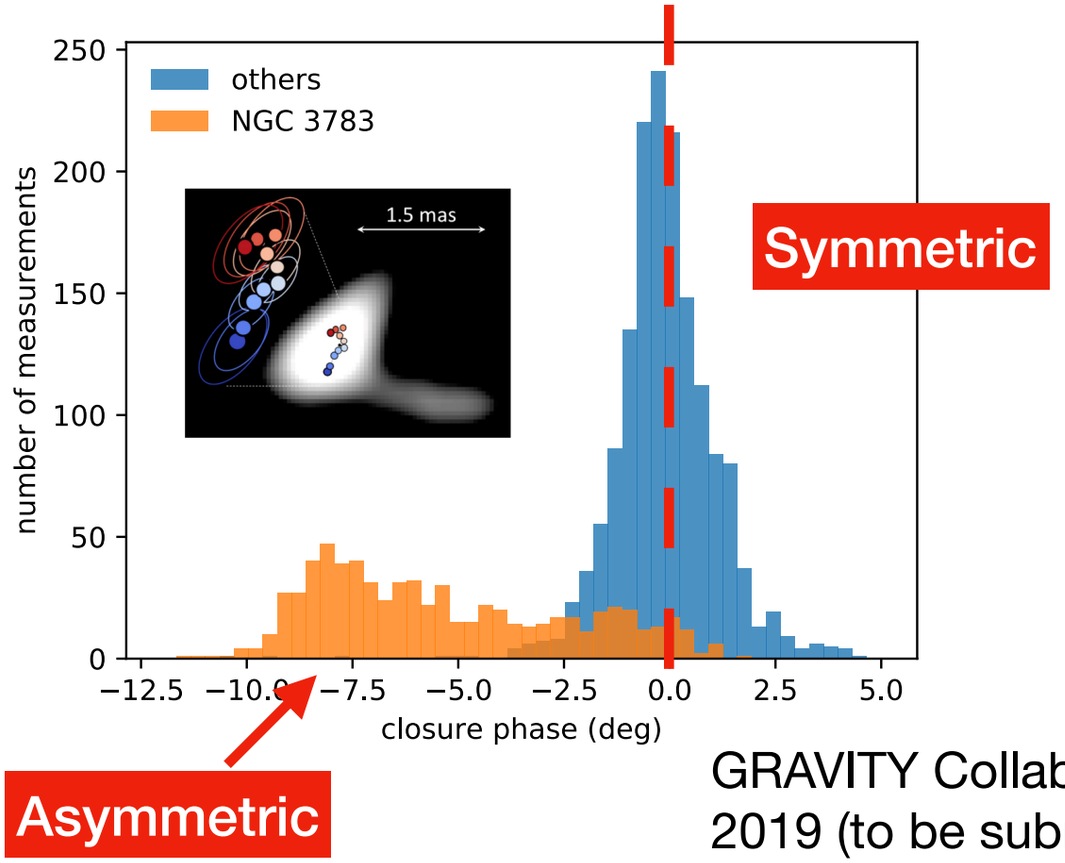
Hot dust size of Type 1 AGNs

Jason Dexter
@Univ. Colorado









GRAVITY Collaboration
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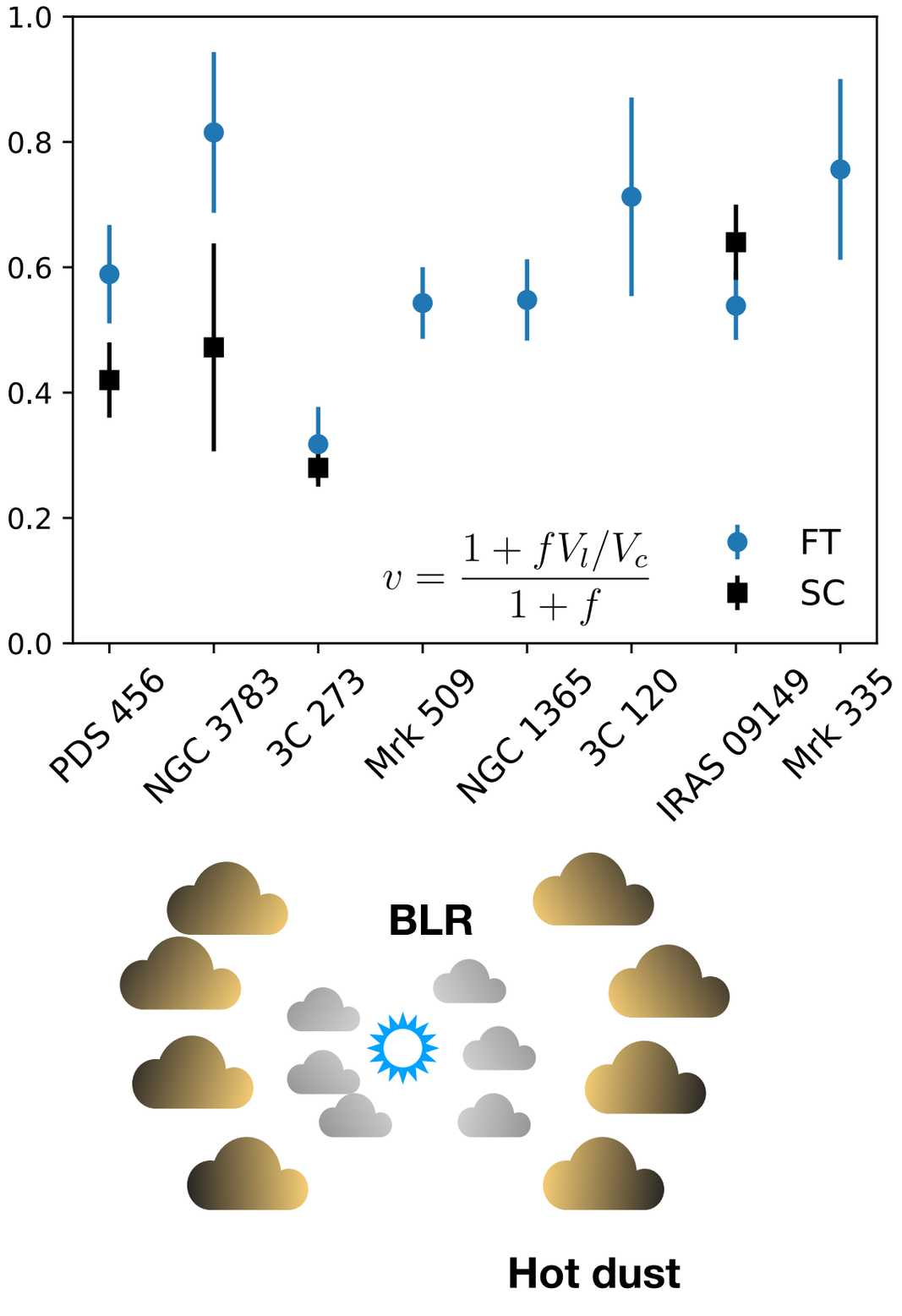
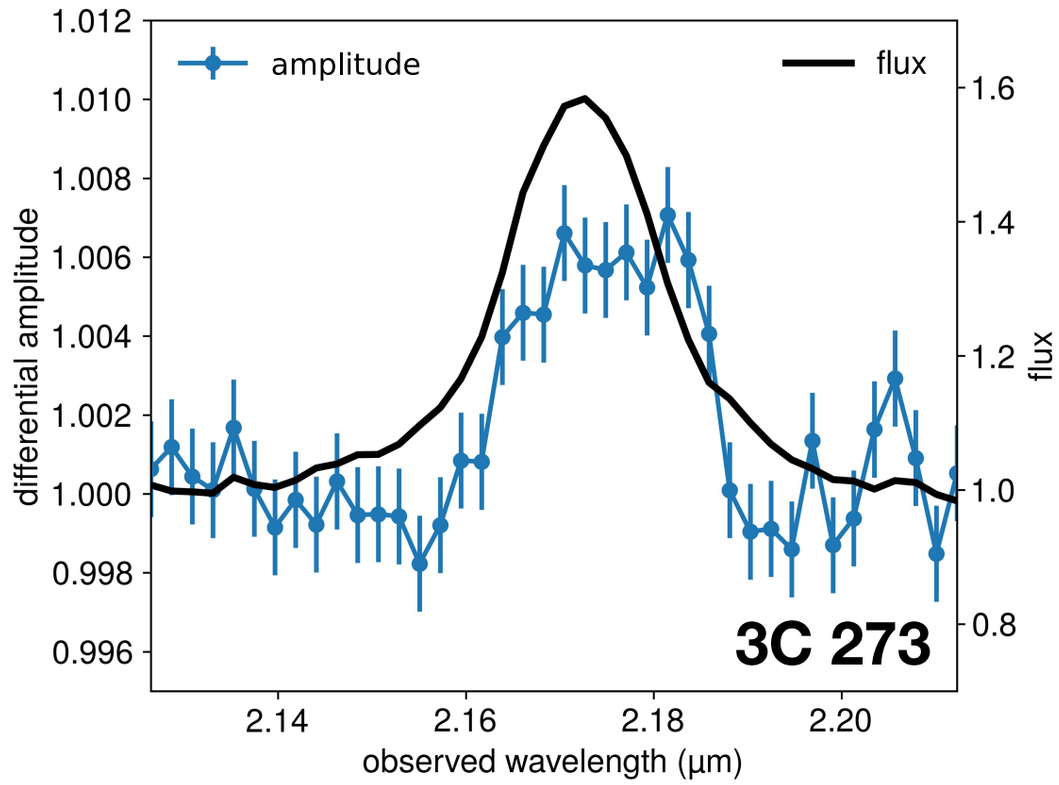
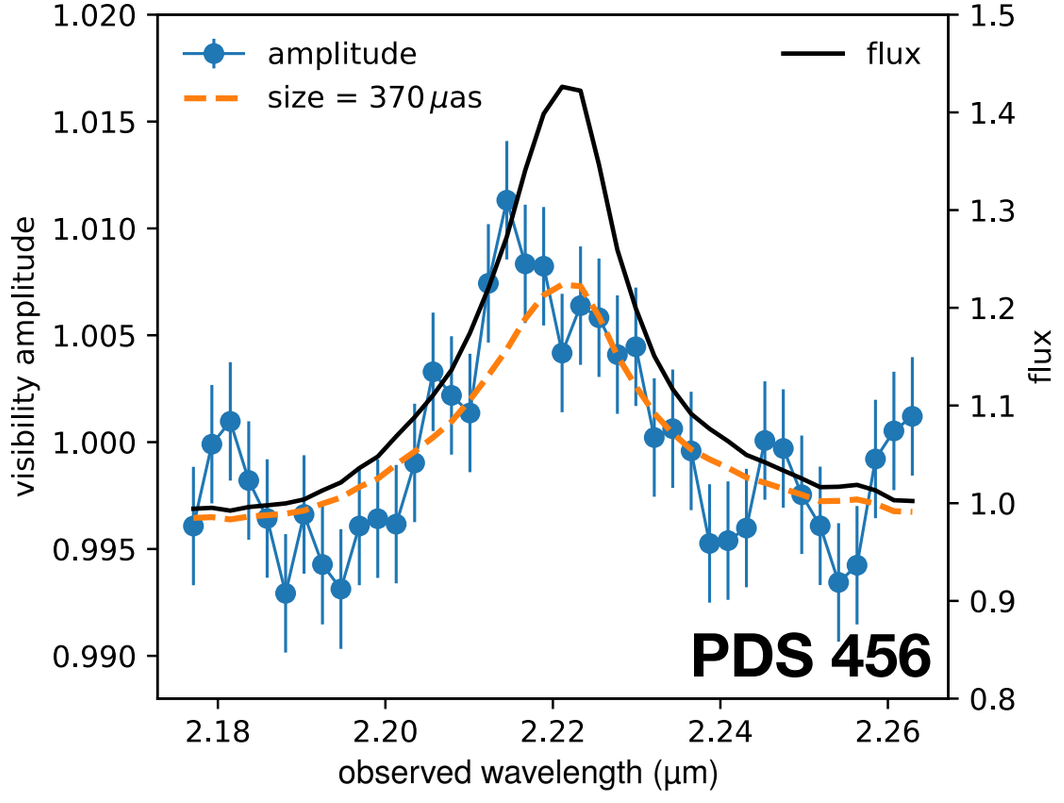
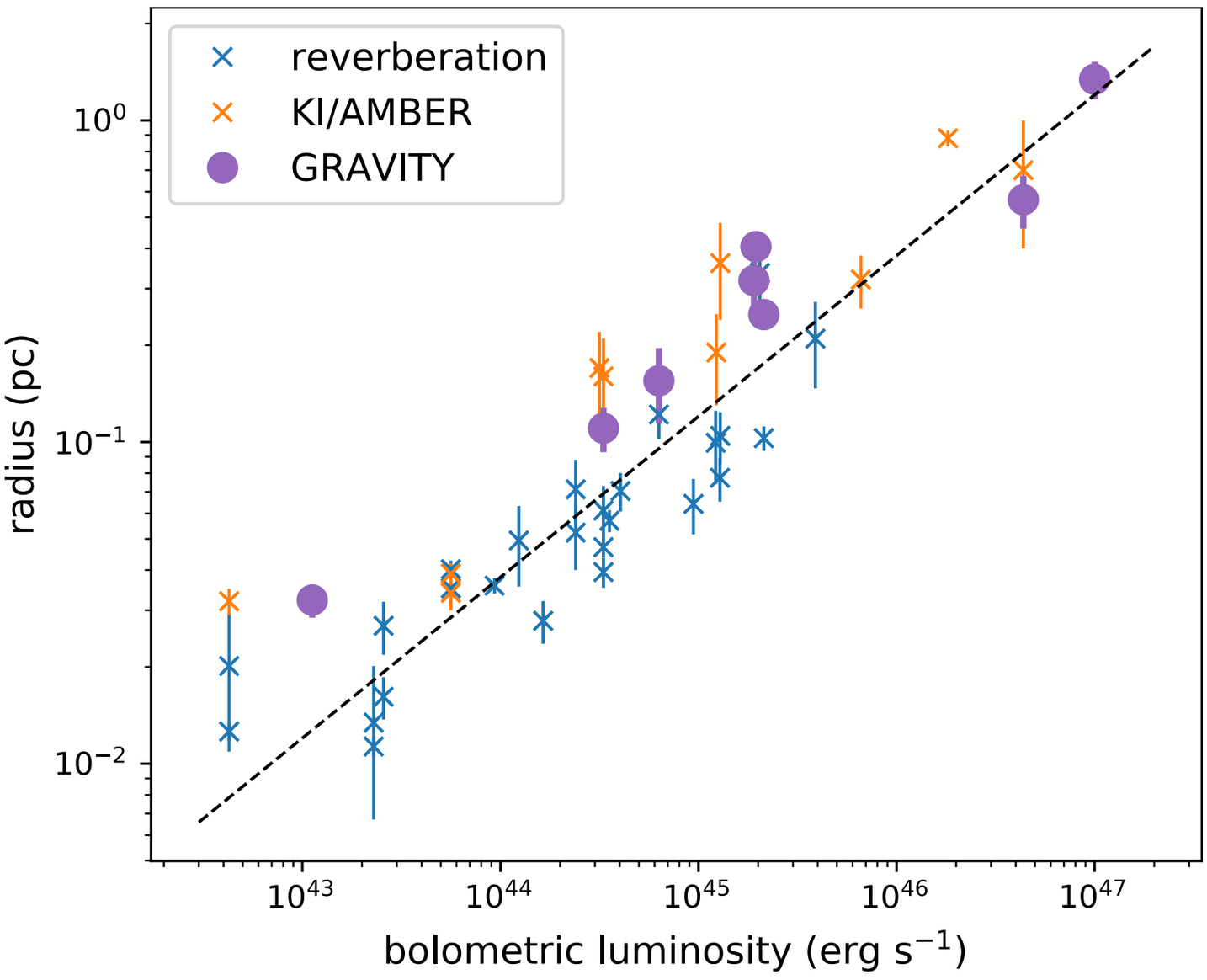
BLR is smaller than the torus

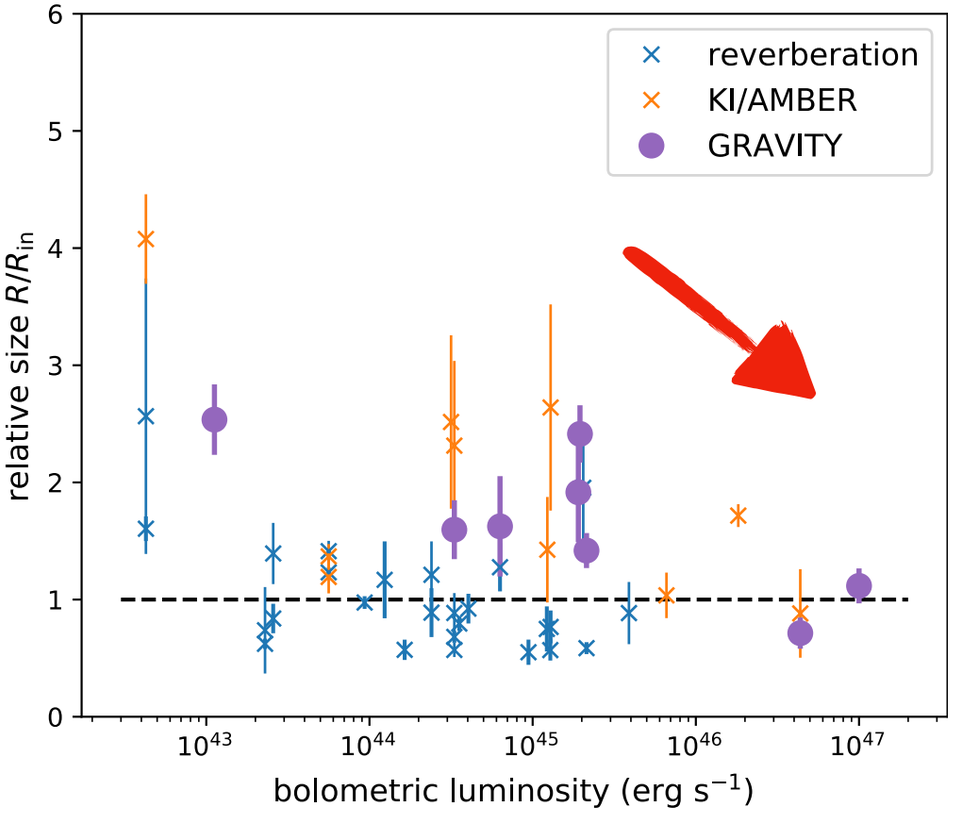


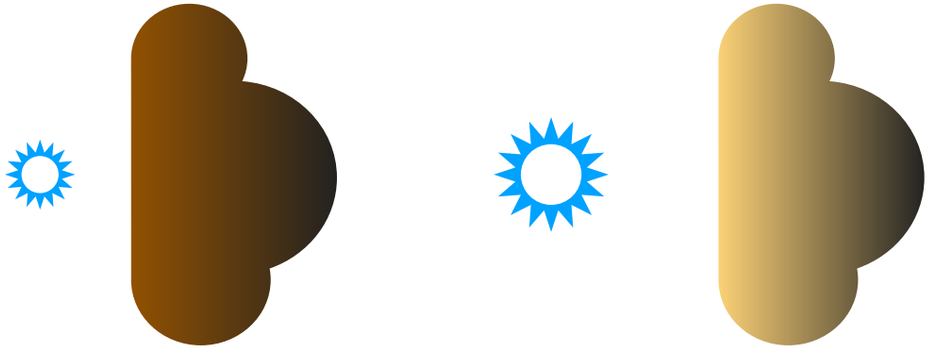




Luminosity-size relation of hot dust emission





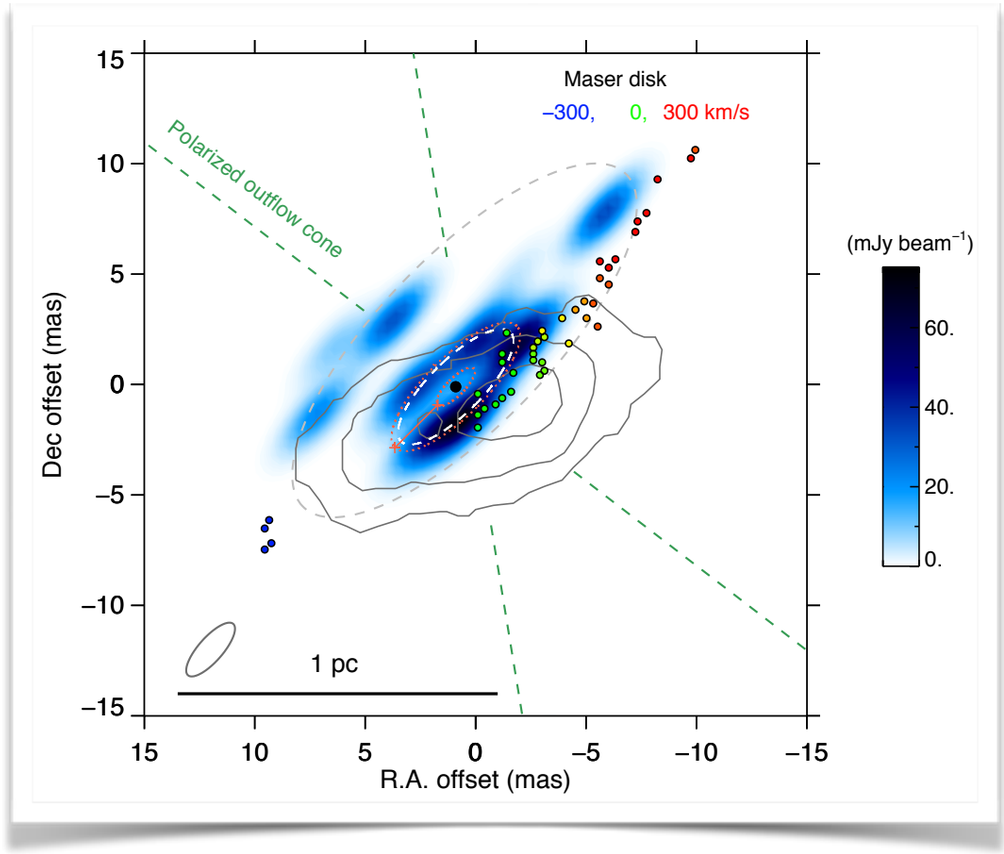


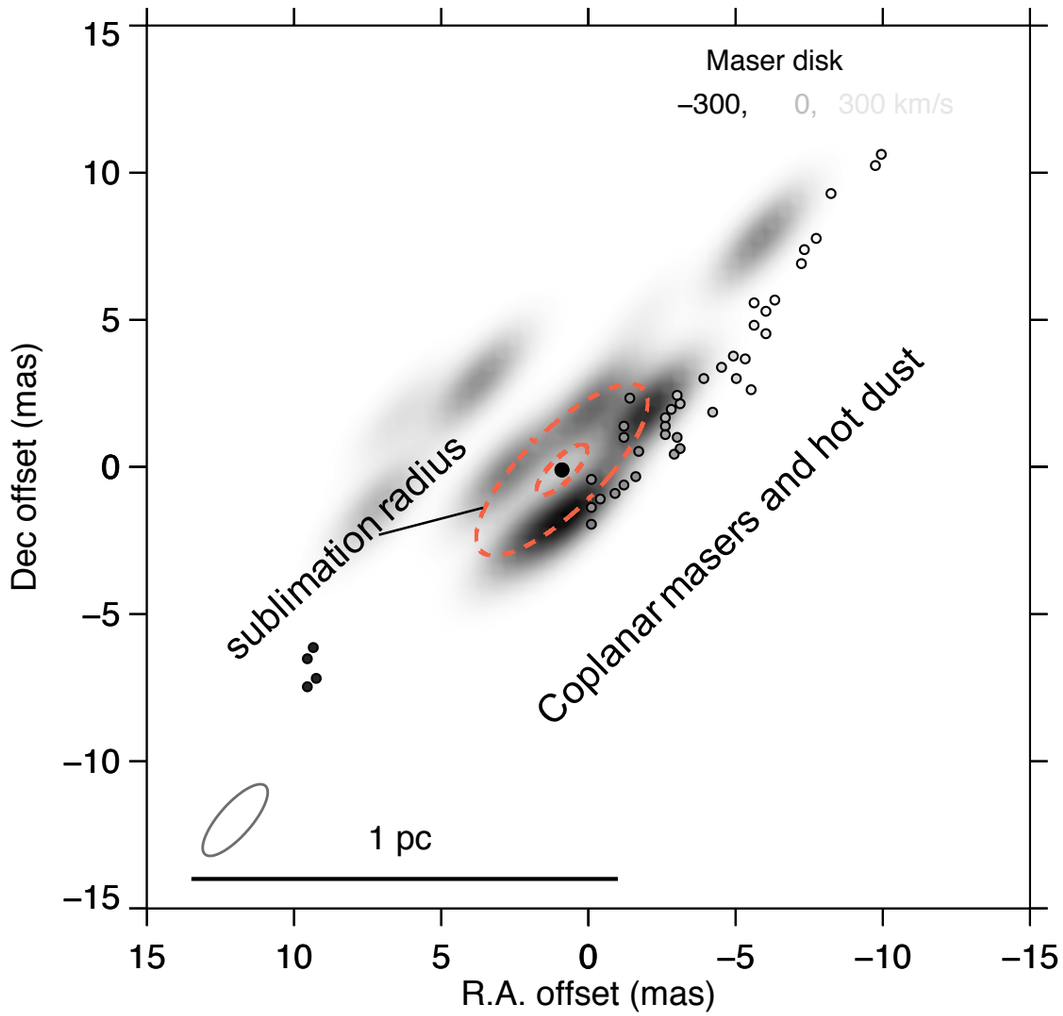
Summary

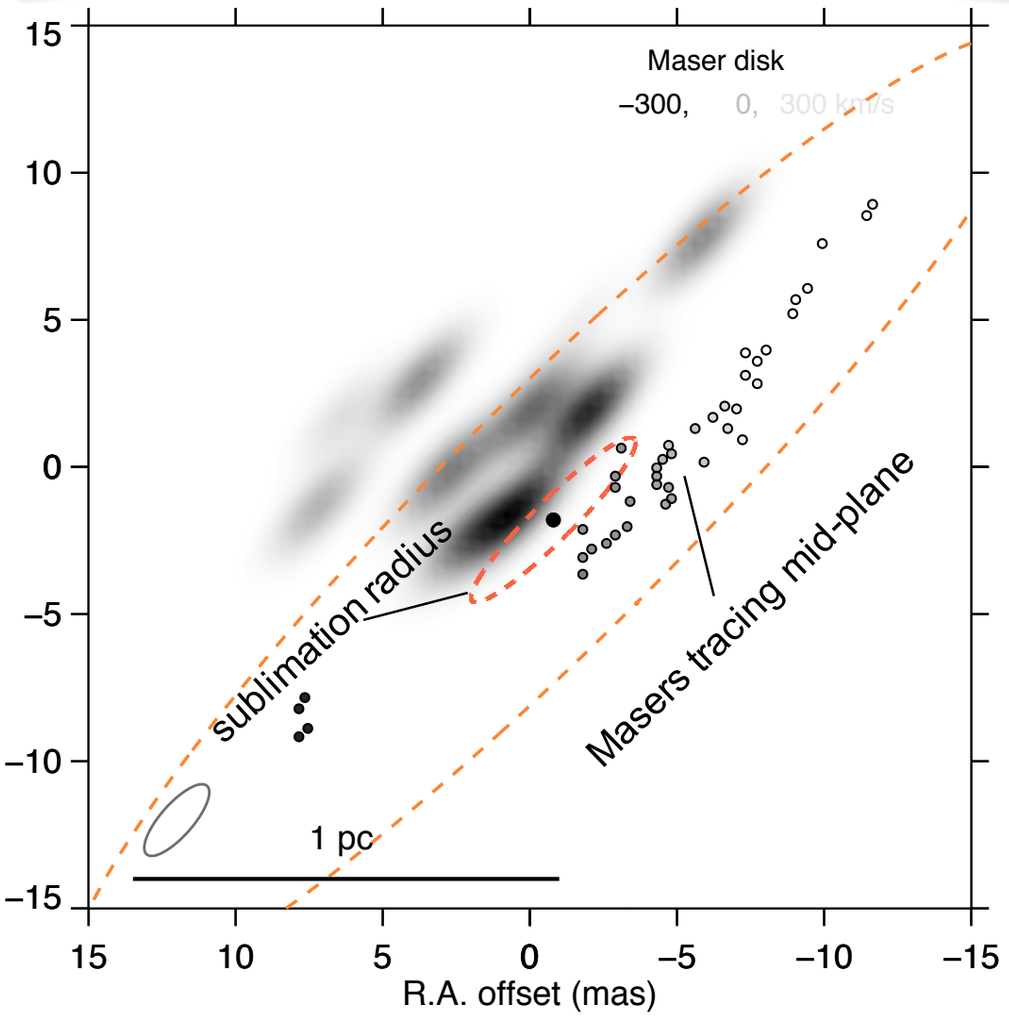
Thanks!

- Near-IR interferometry is powerful to measure the BH mass and to use quasars as probes of the cosmology
- Implement a BLR model and include the photoionization physics
  - Covering factor is larger than expected
- Direct imaging of NGC 1068 *K*-band emission reveals a ring structure aligned with the maser disk
- 8 new GRAVITY hot dust sizes: strong R-L relation as found in previous works
- Continuum emission is always more extended than BLR
- Hot dust size drops relatively towards bright AGNs

Appendix: NGC 1068
Alternative scenario







Appendix: Visibility loss