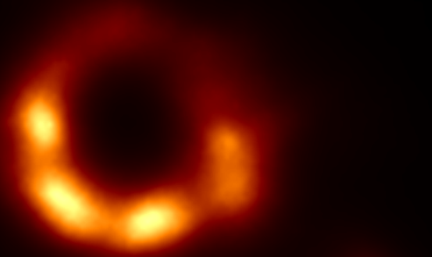
4D Radio Imaging

M87* resolved in space, time, and frequency

Philipp Arras, Philipp Frank, Philipp Haim, Jakob Knollmüller, Reimar Leike,
Martin Reinecke, Torsten A. Enßlin (2020), arXiv:2002.05218
MPI for Astrophysics, Garching, Germany



Event Horizon
Telescope
Collaboration
(2019)

Arras, Frank, Haim,
Knollmüller, Leike,
Reinecke, Enßlin
(2020)

Arras, Frank, Haim,
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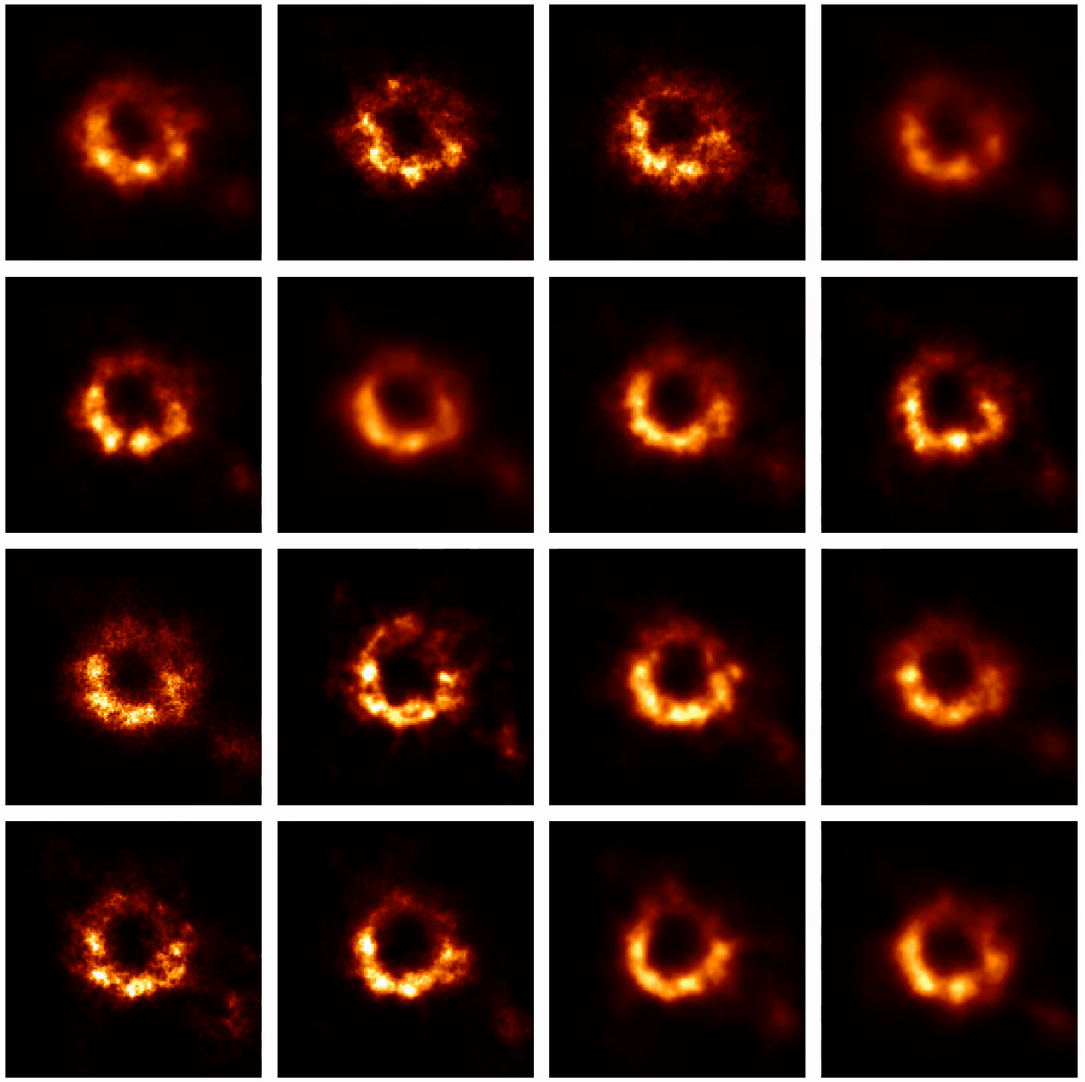
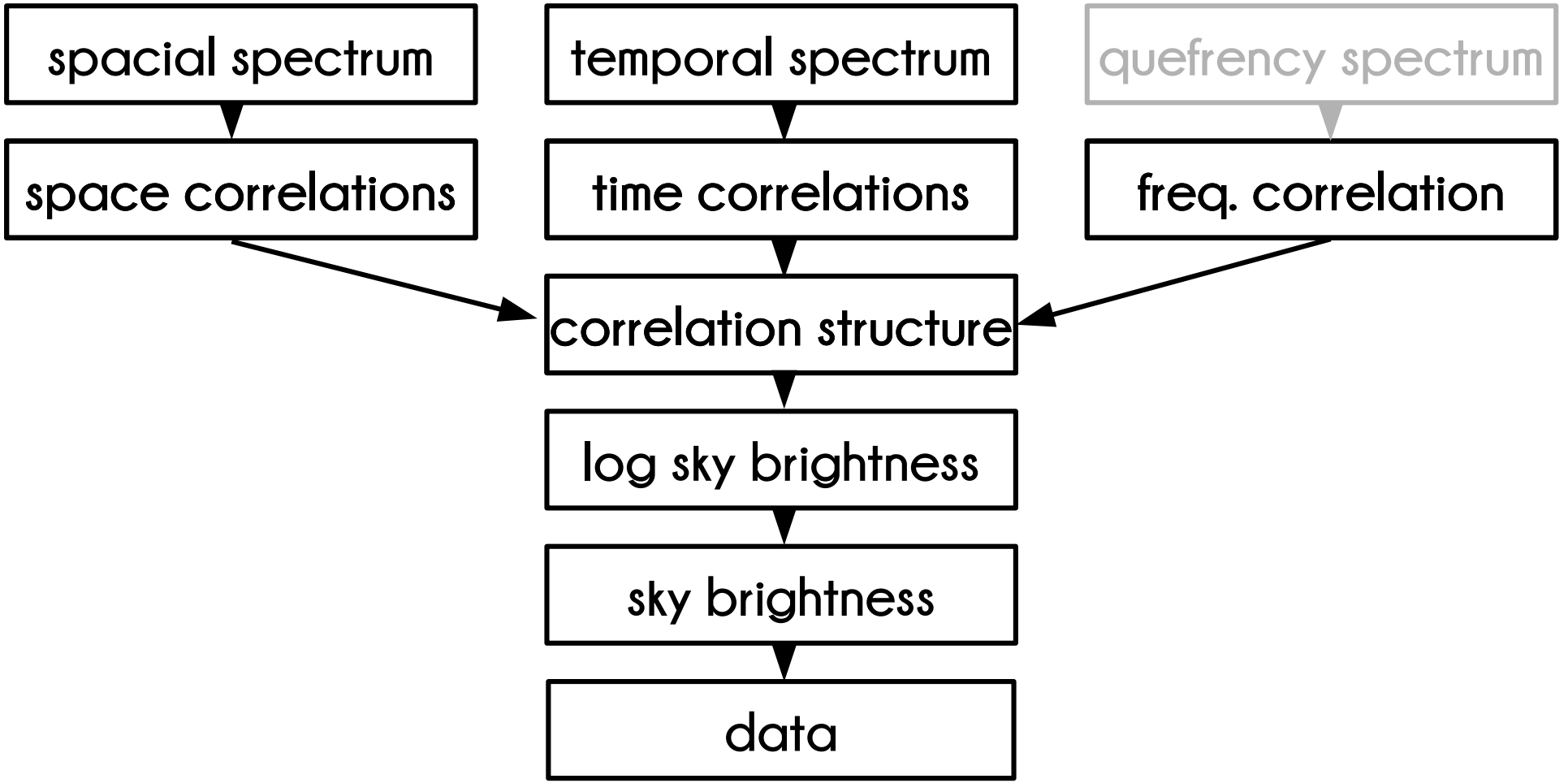
(2020)

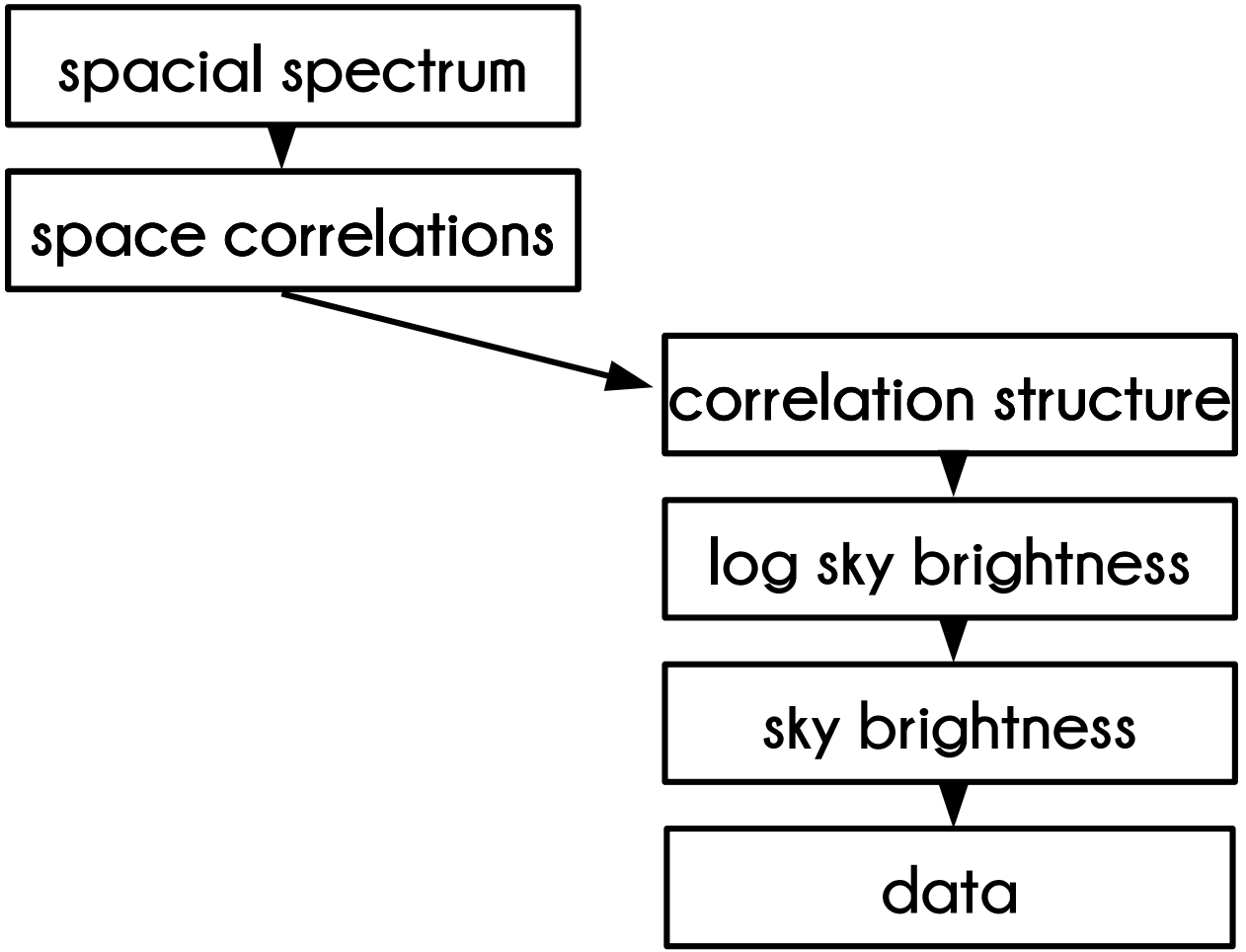


Arras, Frank, Haim, Knollmüller, Leike, Reinecke, Enßlin (2020)

Model


spacial spectrum
temporal spectrum
quefrency spectrum
space correlations
time correlations
freq. correlation
correlation structure
log sky brightness
sky brightness
data

Model


spacial spectrum
space correlations
correlation structure
log sky brightness
sky brightness
data

Model

spacial spectrum

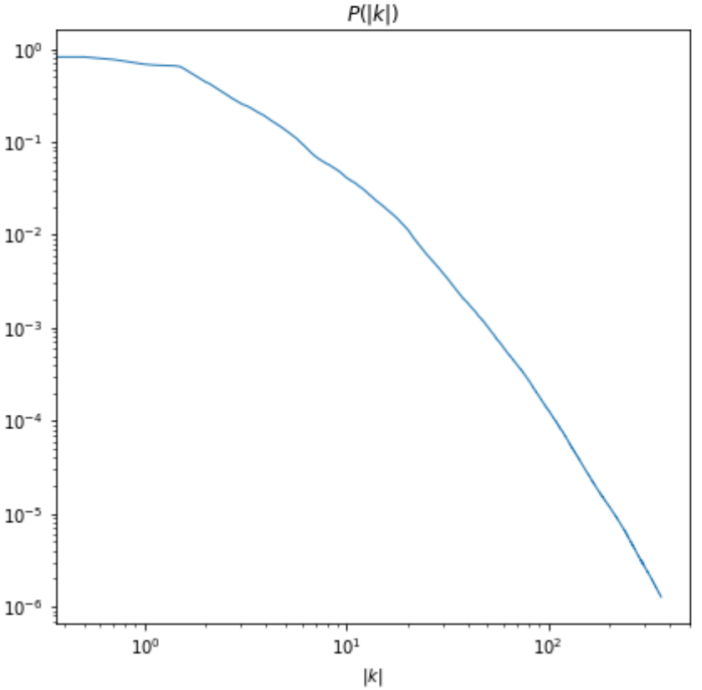
space correlations

correlation structure

log sky brightness

sky brightness

data



Model

spacial spectrum

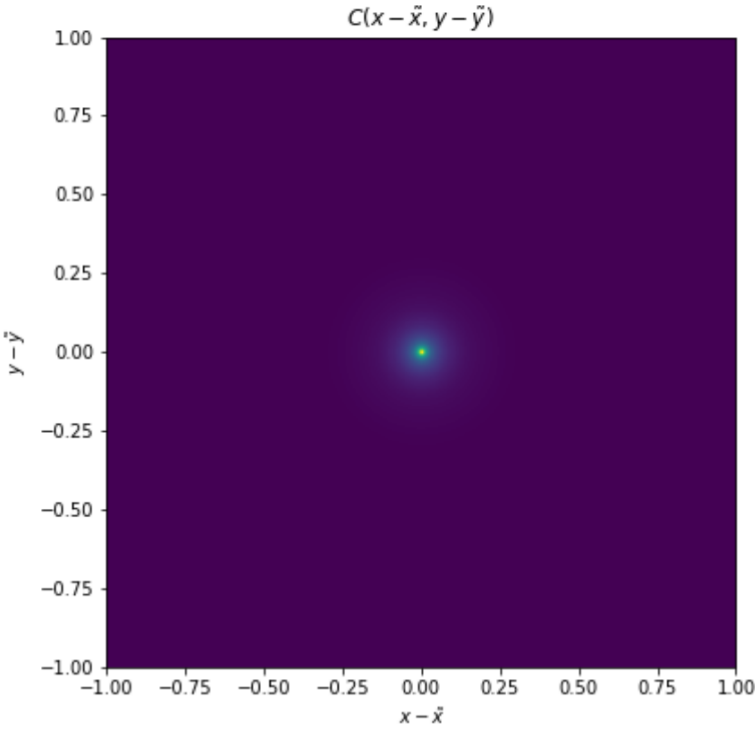
space correlations

correlation structure

log sky brightness

sky brightness

data



Model

spacial spectrum

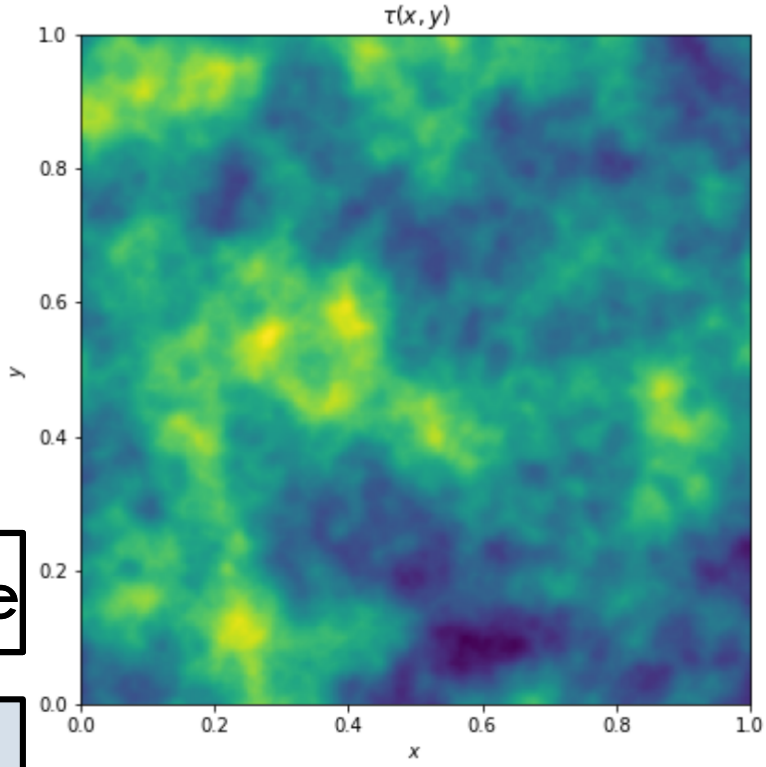
space correlations

correlation structure

log sky brightness

sky brightness

data



Model

spacial spectrum

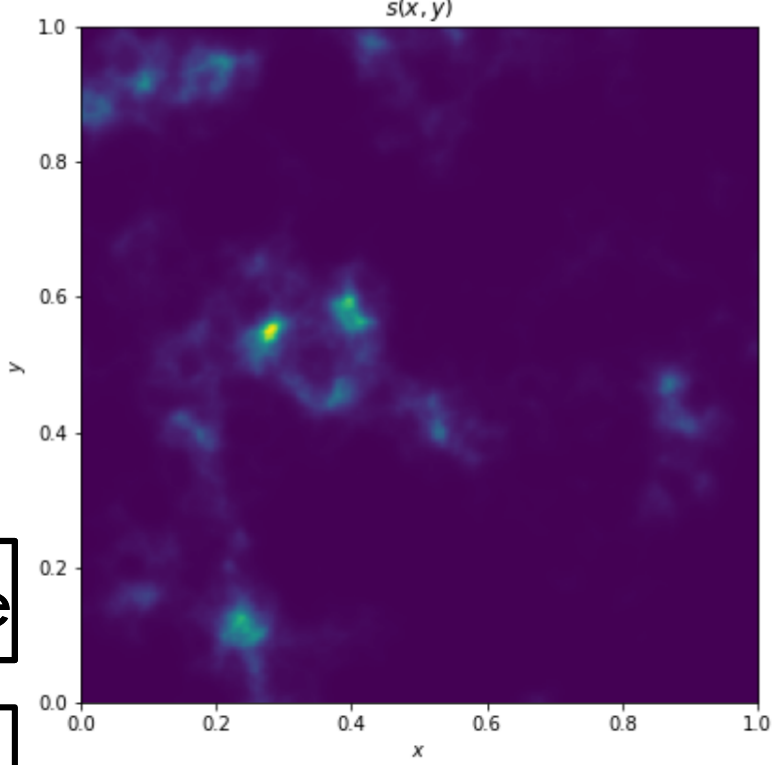
space correlations

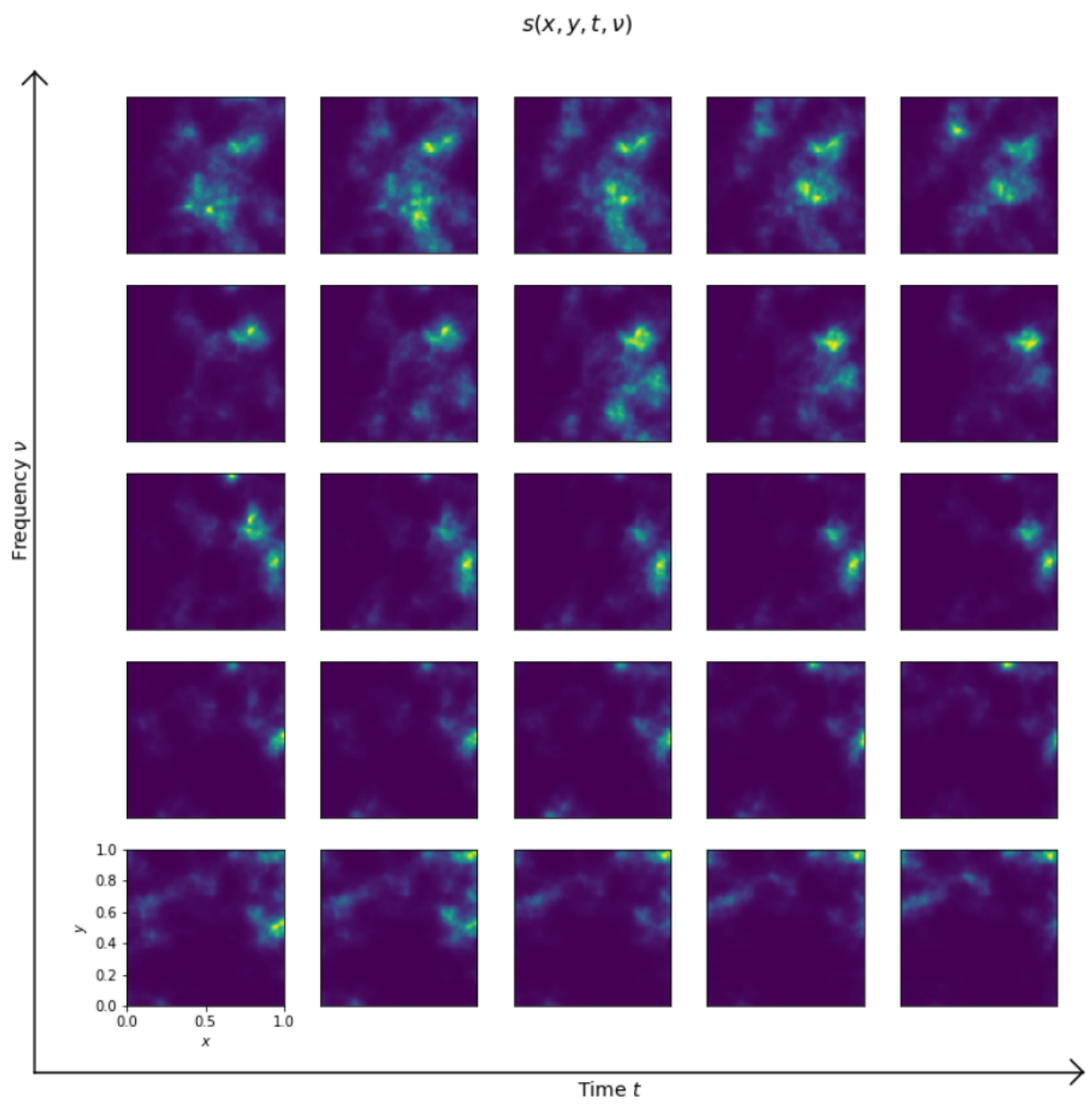
correlation structure

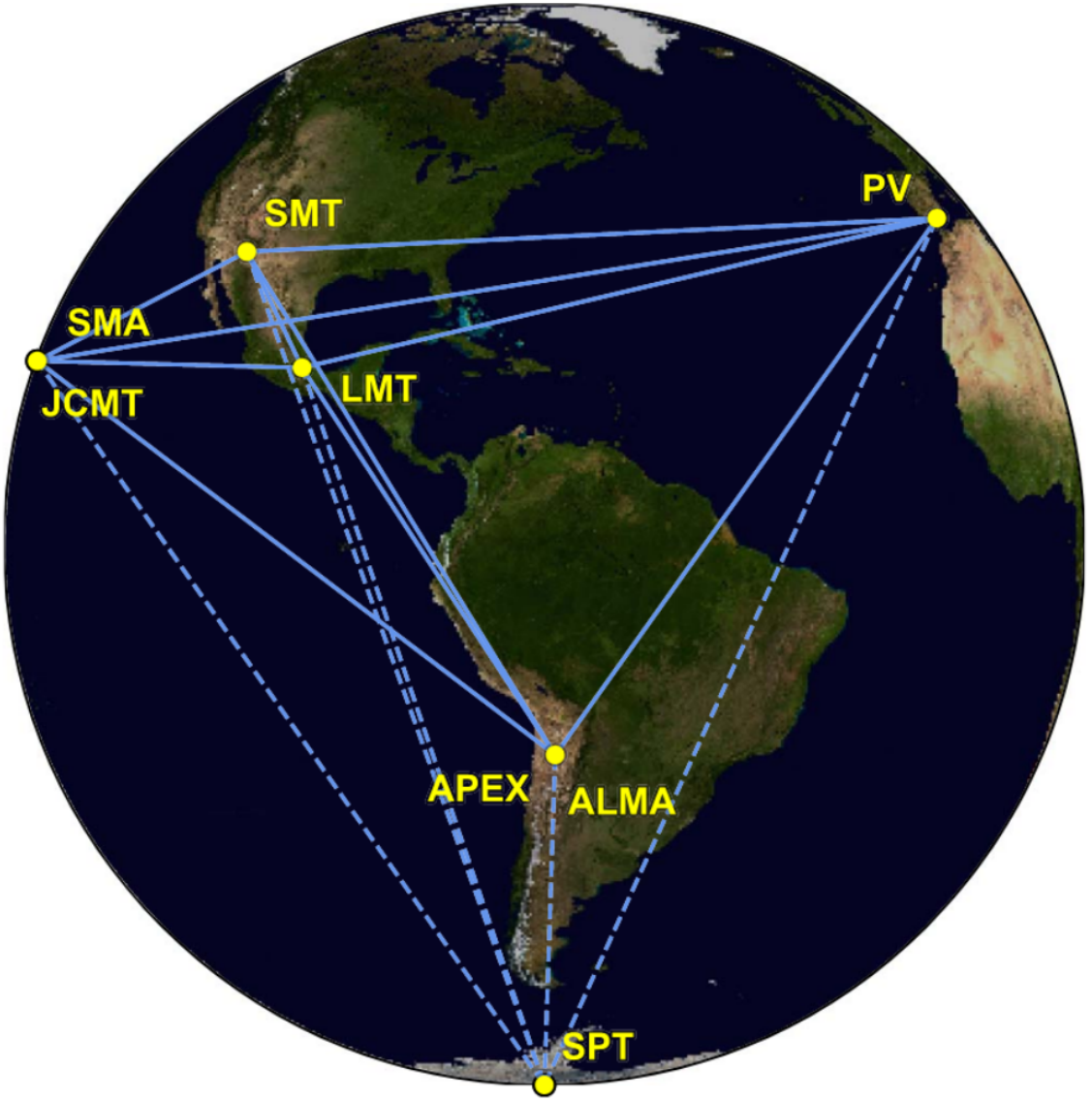
log sky brightness

sky brightness

data

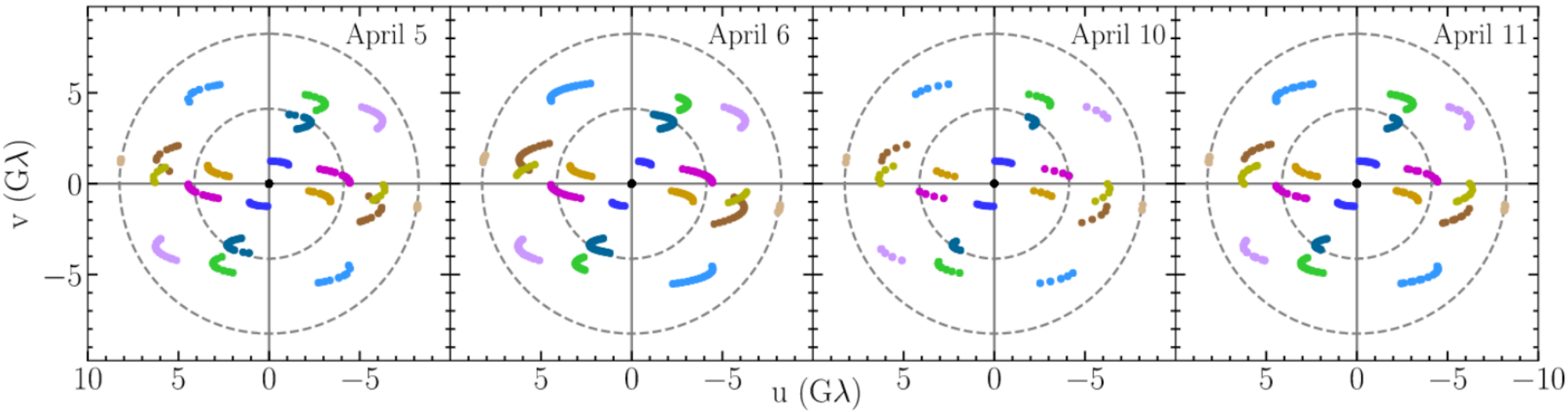



$s(x, y, t, \nu)$
Frequency ν
Time t
y
x
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0

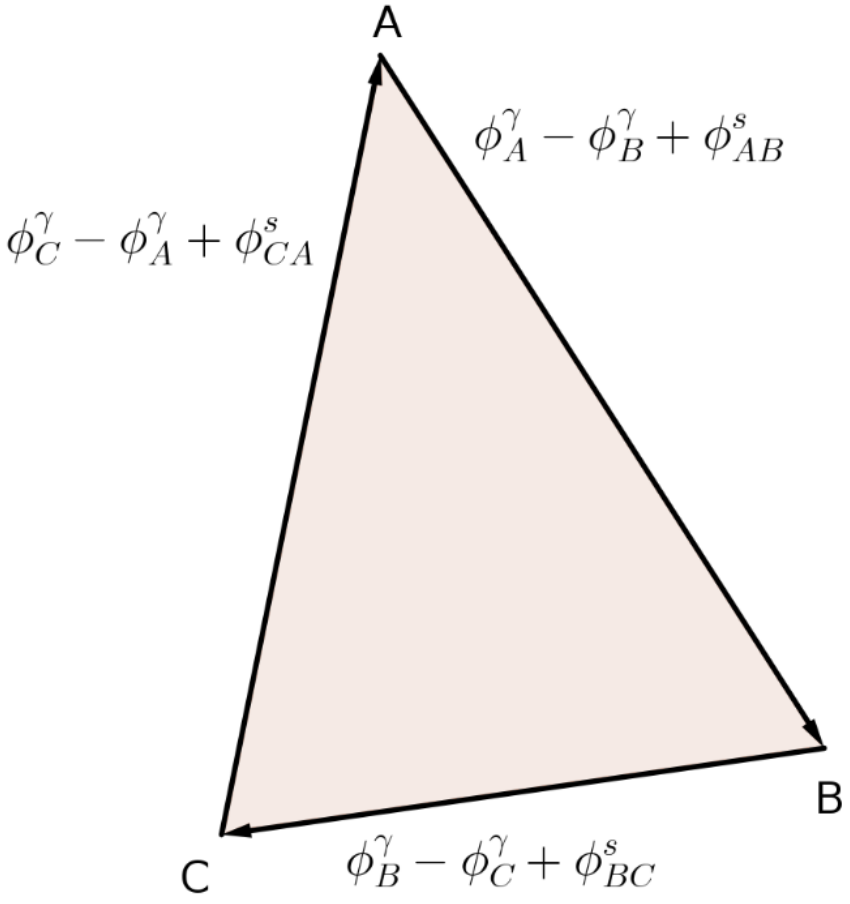

PV
SMT
SMA
LMT
JCMT
APEX
ALMA
SPT

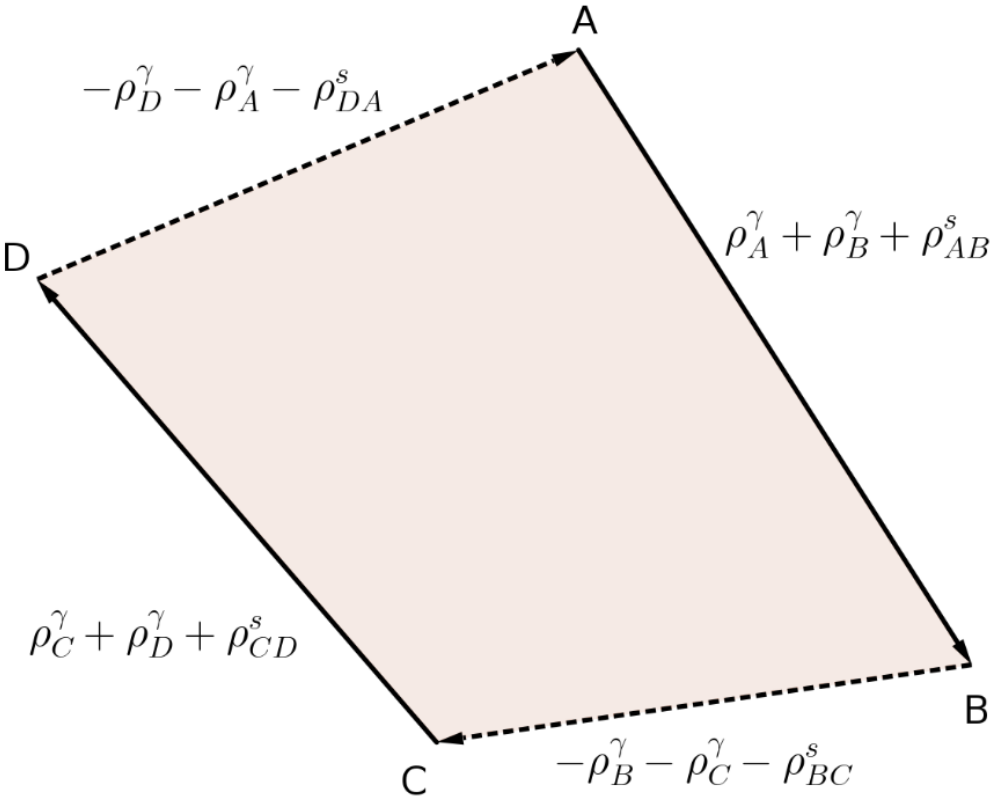
Data

- Data provided by the Event Horizon Telescope (EHT)
- Extremely sparse measurements (~ 4100 Visibilities in total)
- Significant temporal variability on observational scales
- Averaaed down to two freauency bands at 227 and 229 GHz

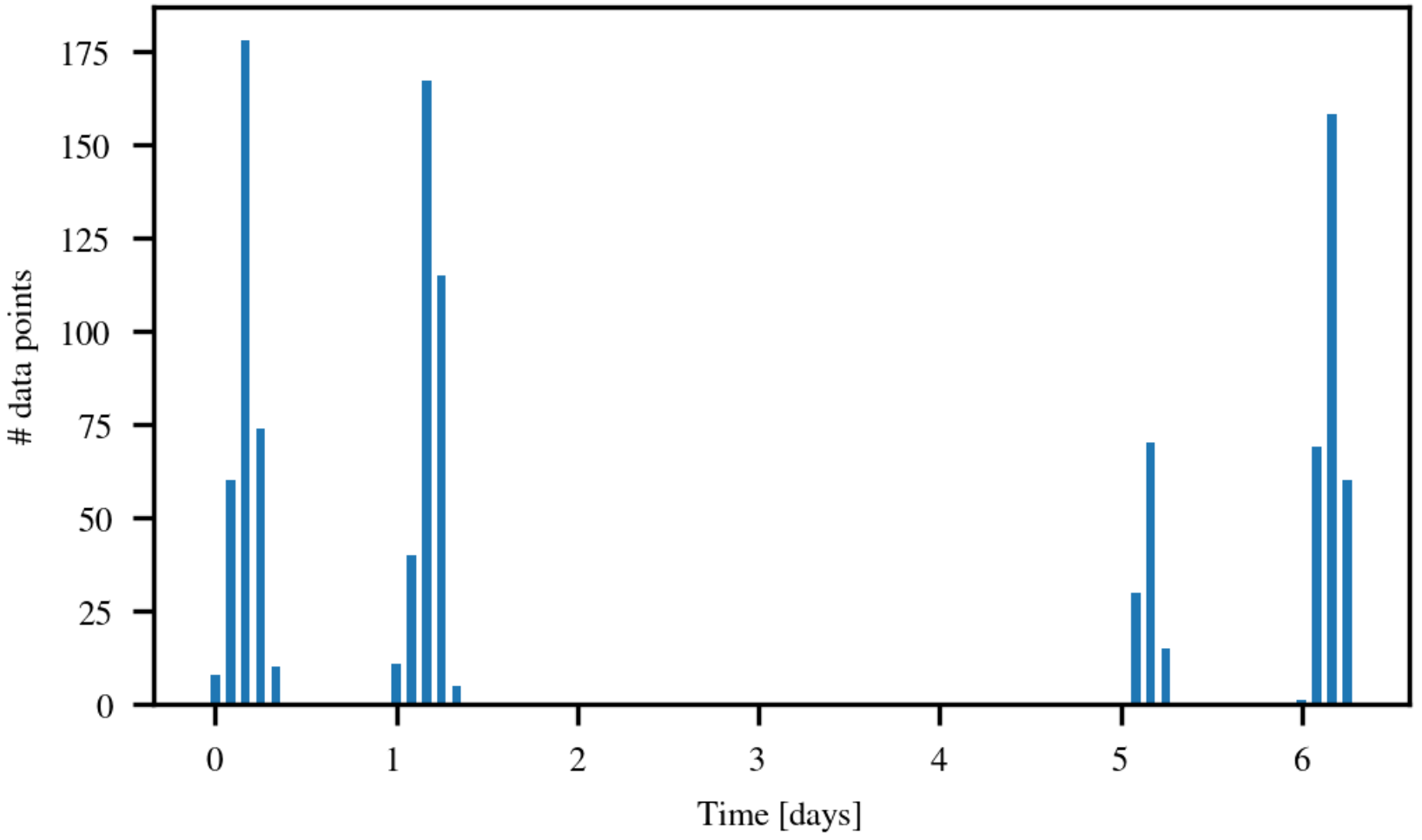


Data

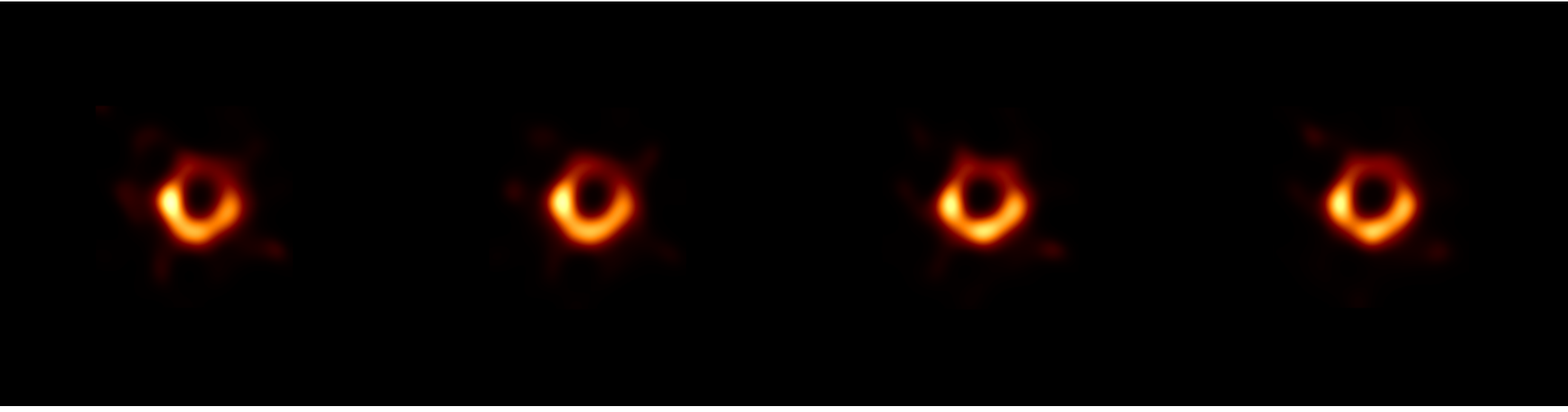

A
$\phi^{\gamma}_{A} - \phi^{\gamma}_{B} + \phi^{s}_{AB}$
$\phi^{\gamma}_{C} - \phi^{\gamma}_{A} + \phi^{s}_{CA}$
B
C
$\phi^{\gamma}_{B} - \phi^{\gamma}_{C} + \phi^{s}_{BC}$


A
$-\rho^{\gamma}_{D} - \rho^{\gamma}_{A} - \rho^{s}_{DA}$
$\rho^{\gamma}_{A} + \rho^{\gamma}_{B} + \rho^{s}_{AB}$
D
$\rho^{\gamma}_{C} + \rho^{\gamma}_{D} + \rho^{s}_{CD}$
B
C
$-\rho^{\gamma}_{B} - \rho^{\gamma}_{C} - \rho^{s}_{BC}$

Data



Data



Event Horizon Telescope Collaboration (2019)

Event Horizon
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Collaboration
(2019)

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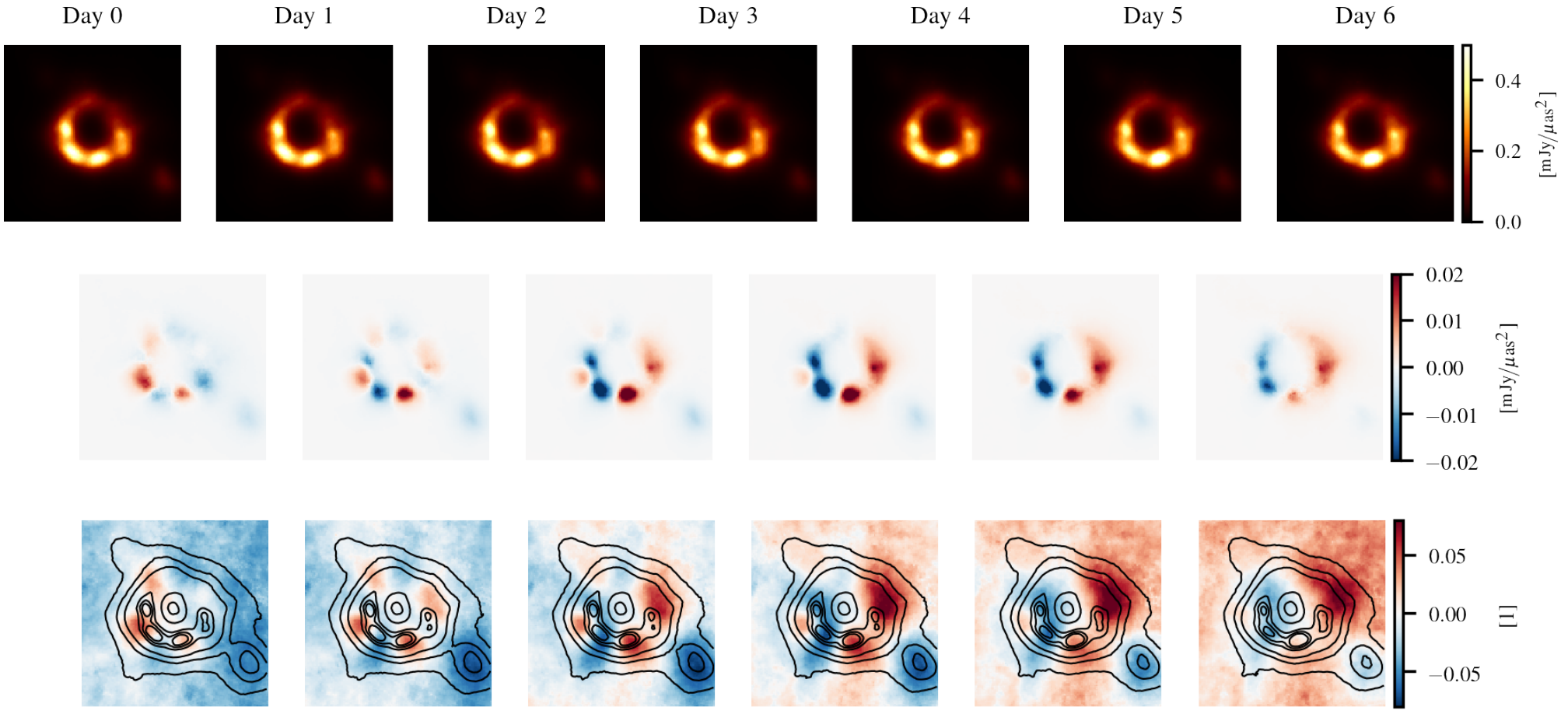
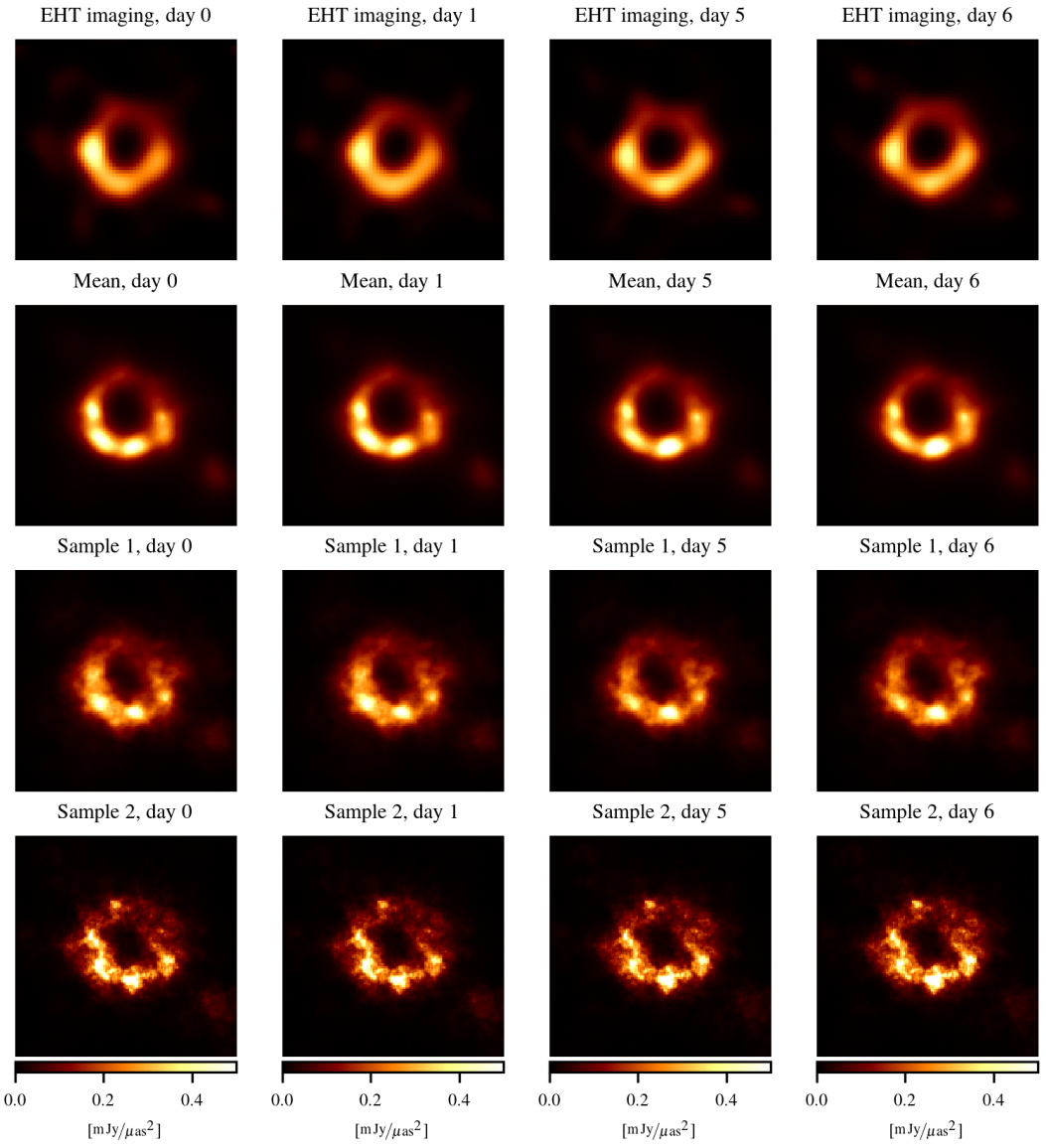
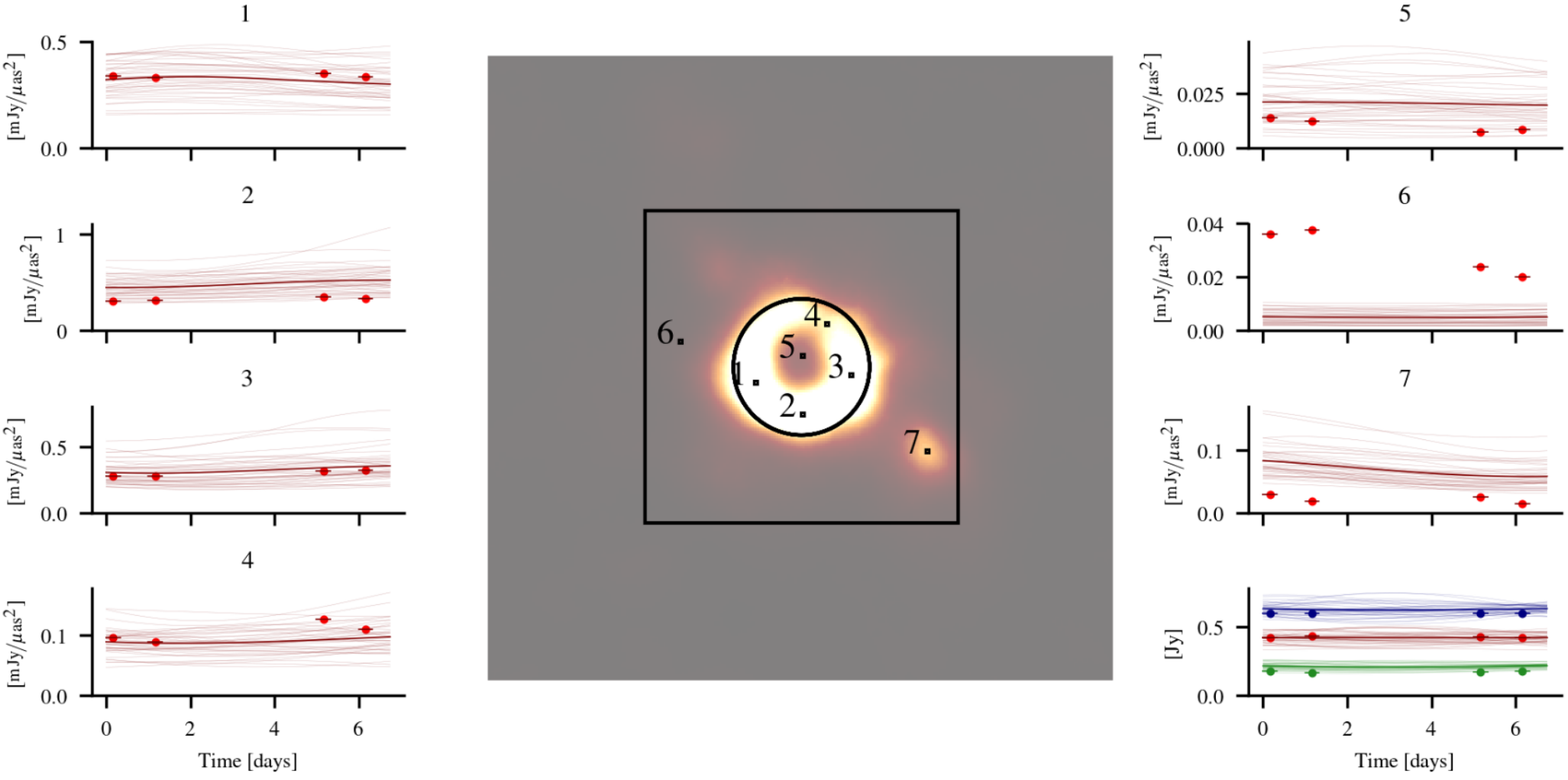
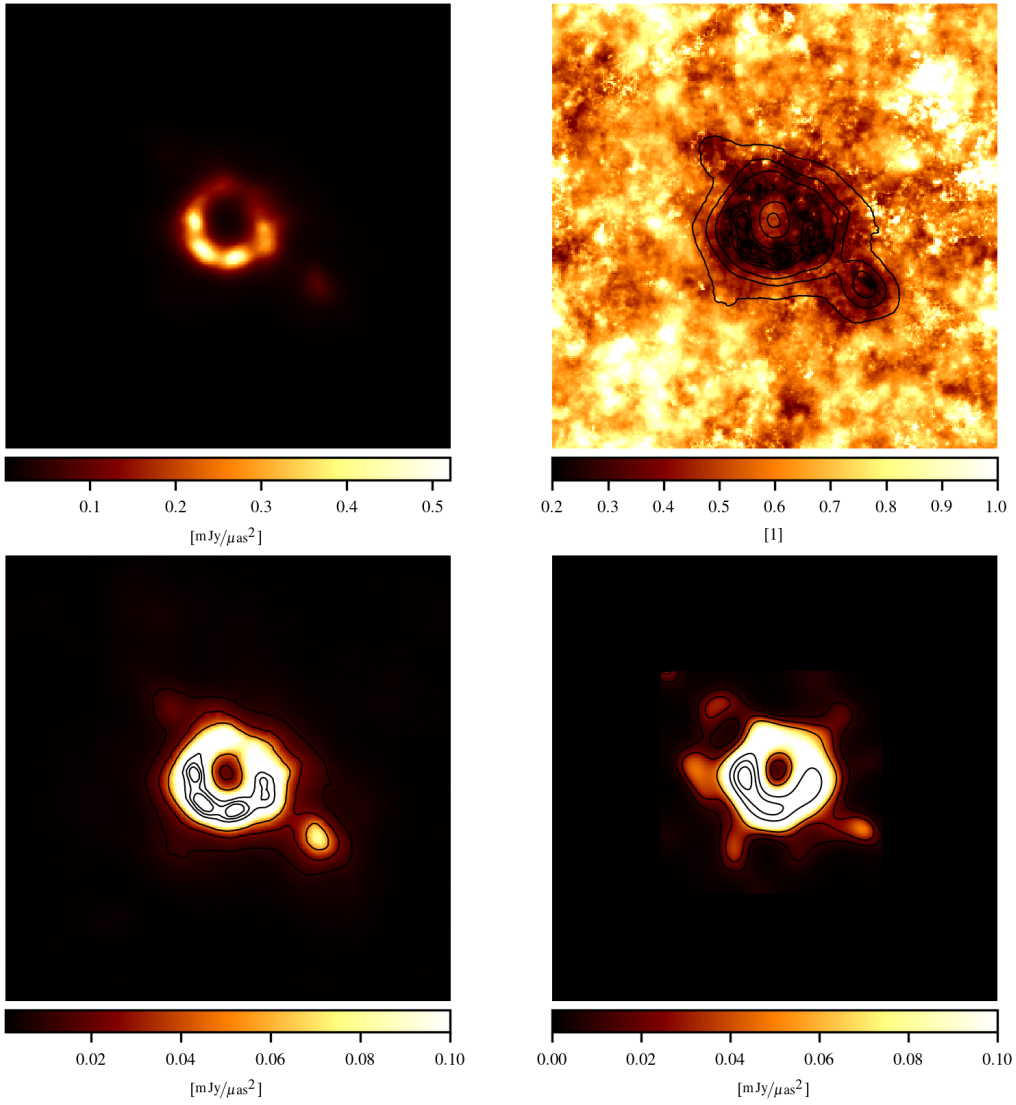
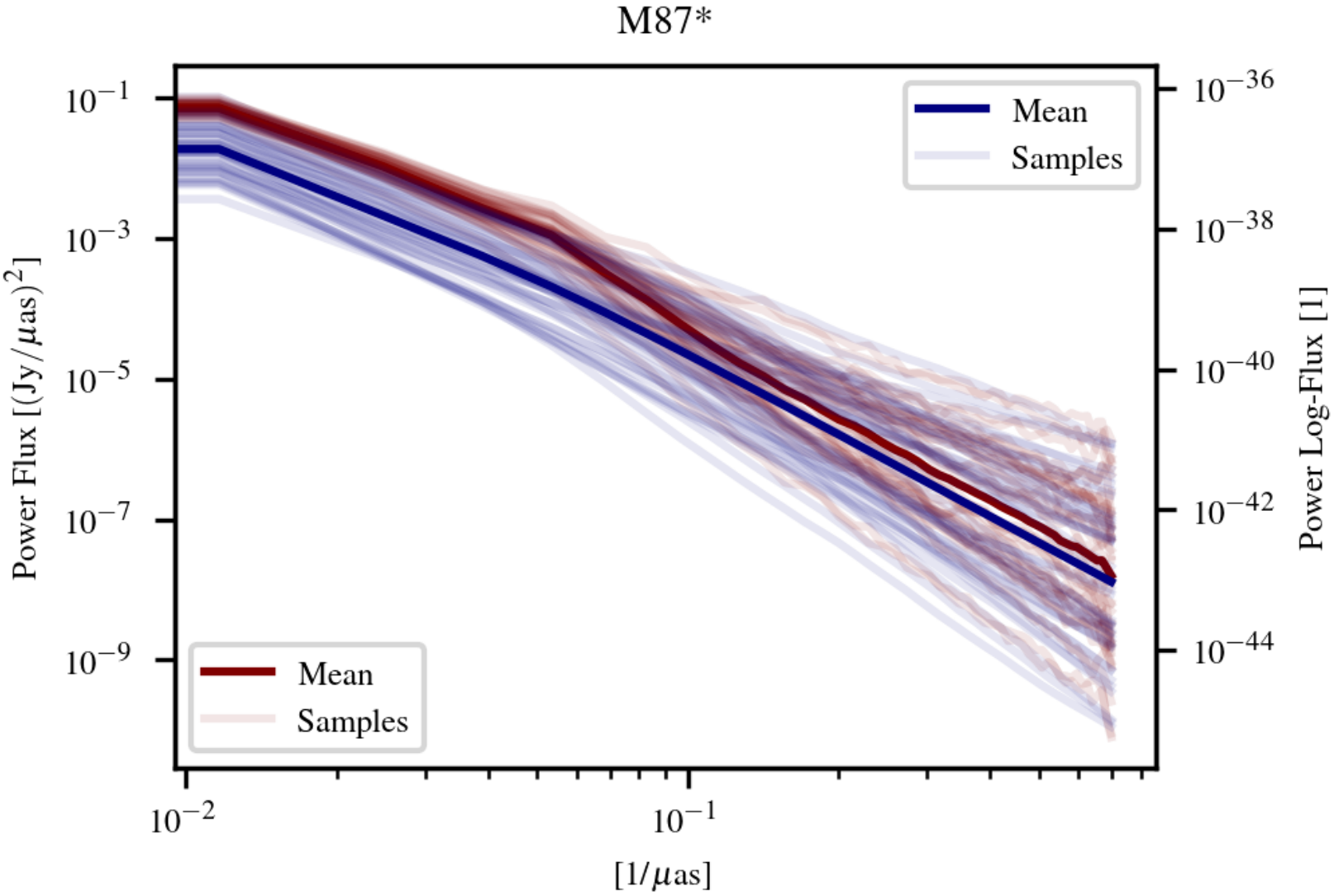

Day 0
Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
0.4
0.2
0.0
[mJy/μas²]
0.02
0.01
0.00
−0.01
−0.02
[mJy/μas²]
0.05
0.00
−0.05
[1]


EHT imaging, day 0
EHT imaging, day 1
EHT imaging, day 5
EHT imaging, day 6
Mean, day 0
Mean, day 1
Mean, day 5
Mean, day 6
Sample 1, day 0
Sample 1, day 1
Sample 1, day 5
Sample 1, day 6
Sample 2, day 0
Sample 2, day 1
Sample 2, day 5
Sample 2, day 6
0.0
0.2
0.4
[mJy/μas²]

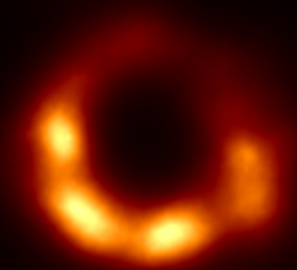

1
2
3
4
5
6
7
[mJy/μas²]
[Jy]
Time [days]
Time [days]


0.1
0.2
0.3
0.4
0.5
[mJy/μas²]
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
[1]
0.02
0.04
0.06
0.08
0.10
[mJy/μas²]
0.00
0.02
0.04
0.06
0.08
0.10
[mJy/μas²]


M87*
Mean
Samples
Mean
Samples
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
Power Flux [(Jy/μas)^2]
10^{-36}
10^{-38}
10^{-40}
10^{-42}
10^{-44}
Power Log-Flux [1]
10^{-2}
10^{-1}
[1/μas]

4D Radio Imaging

M87* resolved in space, time, and frequency



- Spatio-temporal-spectral-imaging + uncertainty
- Detailed statistical information as byproducts
- VLBI-RESOLVE publicly available
- Method development continues …