New Horizons Science Team Meeting
2024 May 15

CHIMERA Occultation Constraints
on the Abundance of km-Scale KBOs

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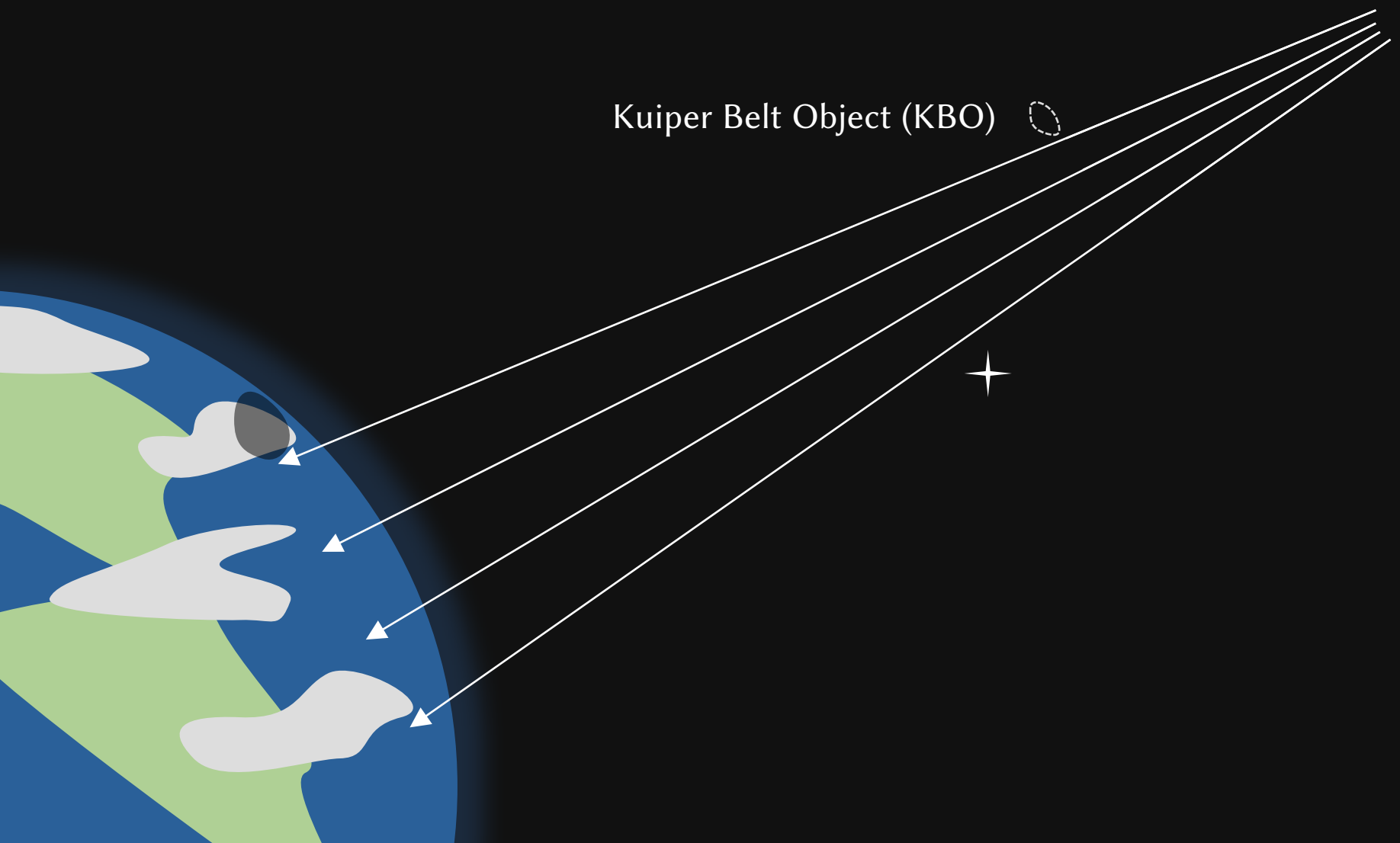
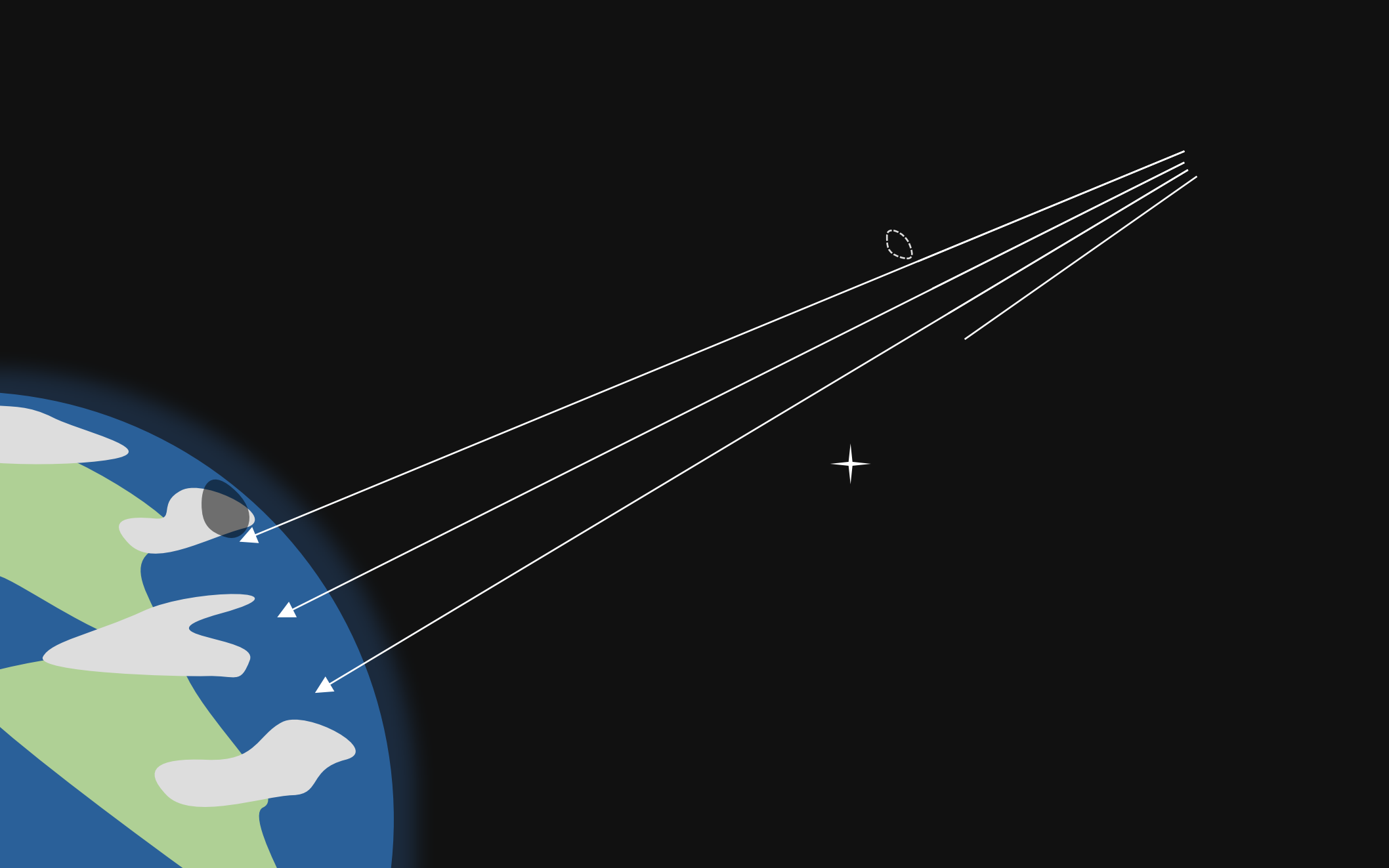
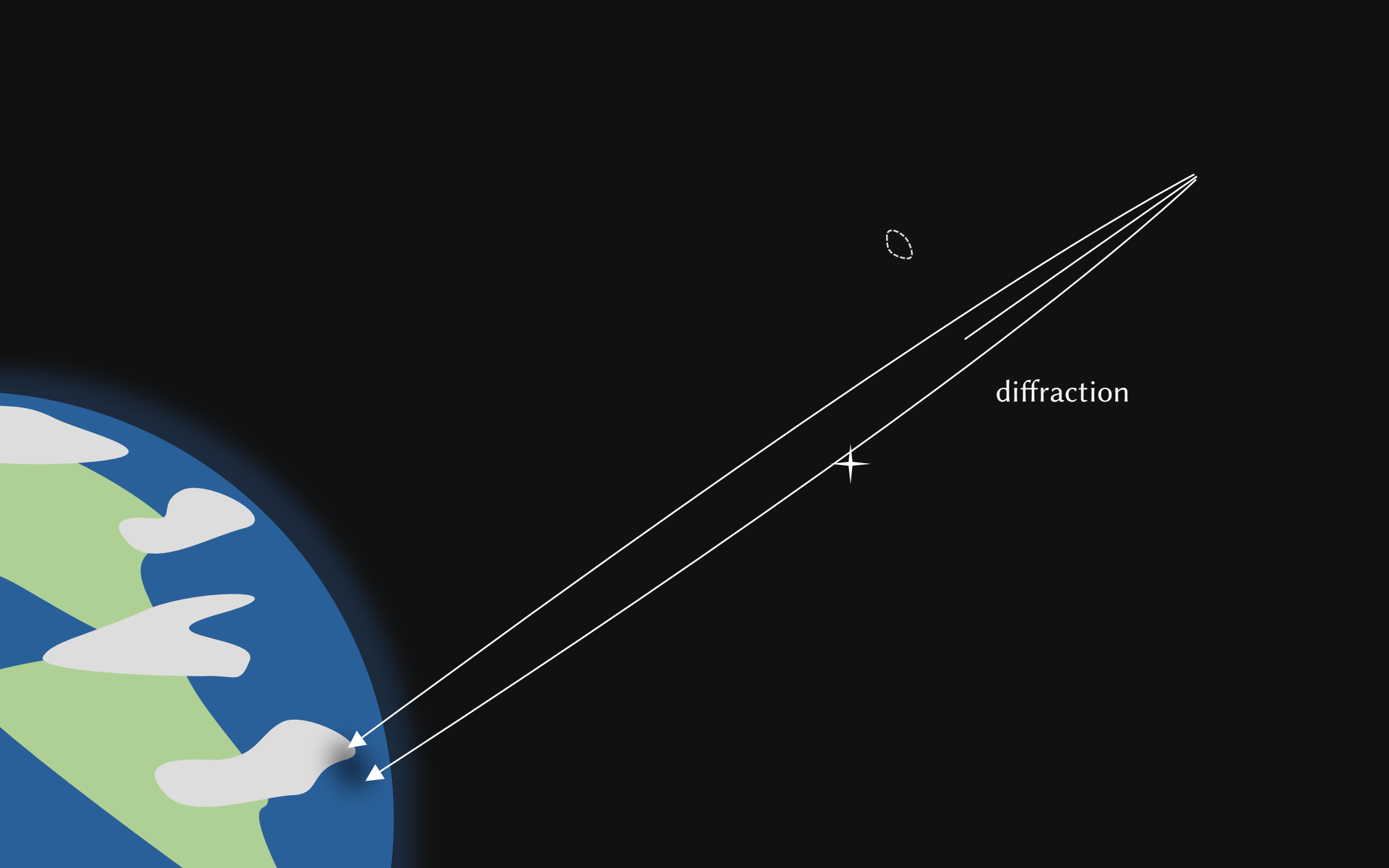
Lowell Observatory

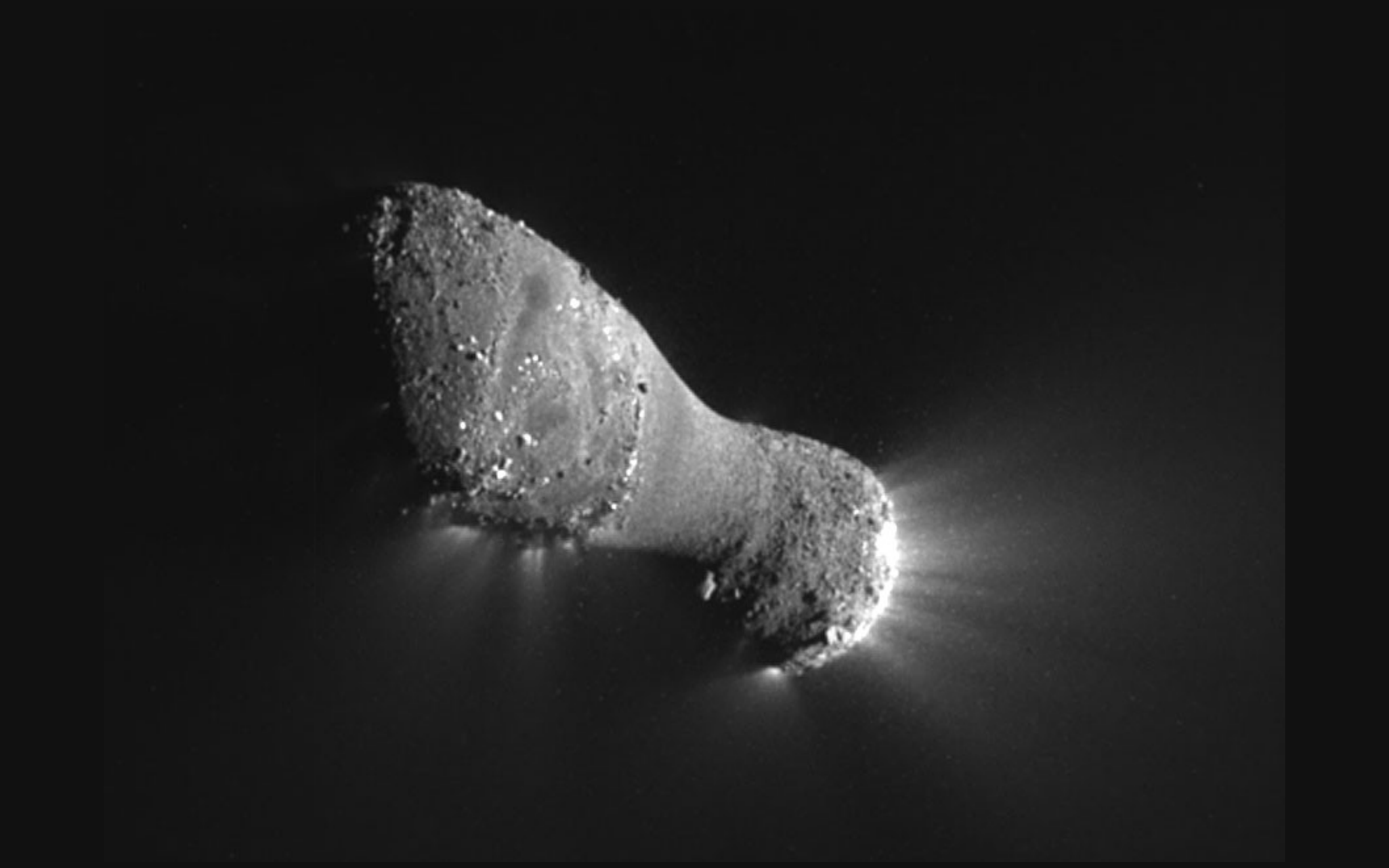
(based on work done at Caltech)

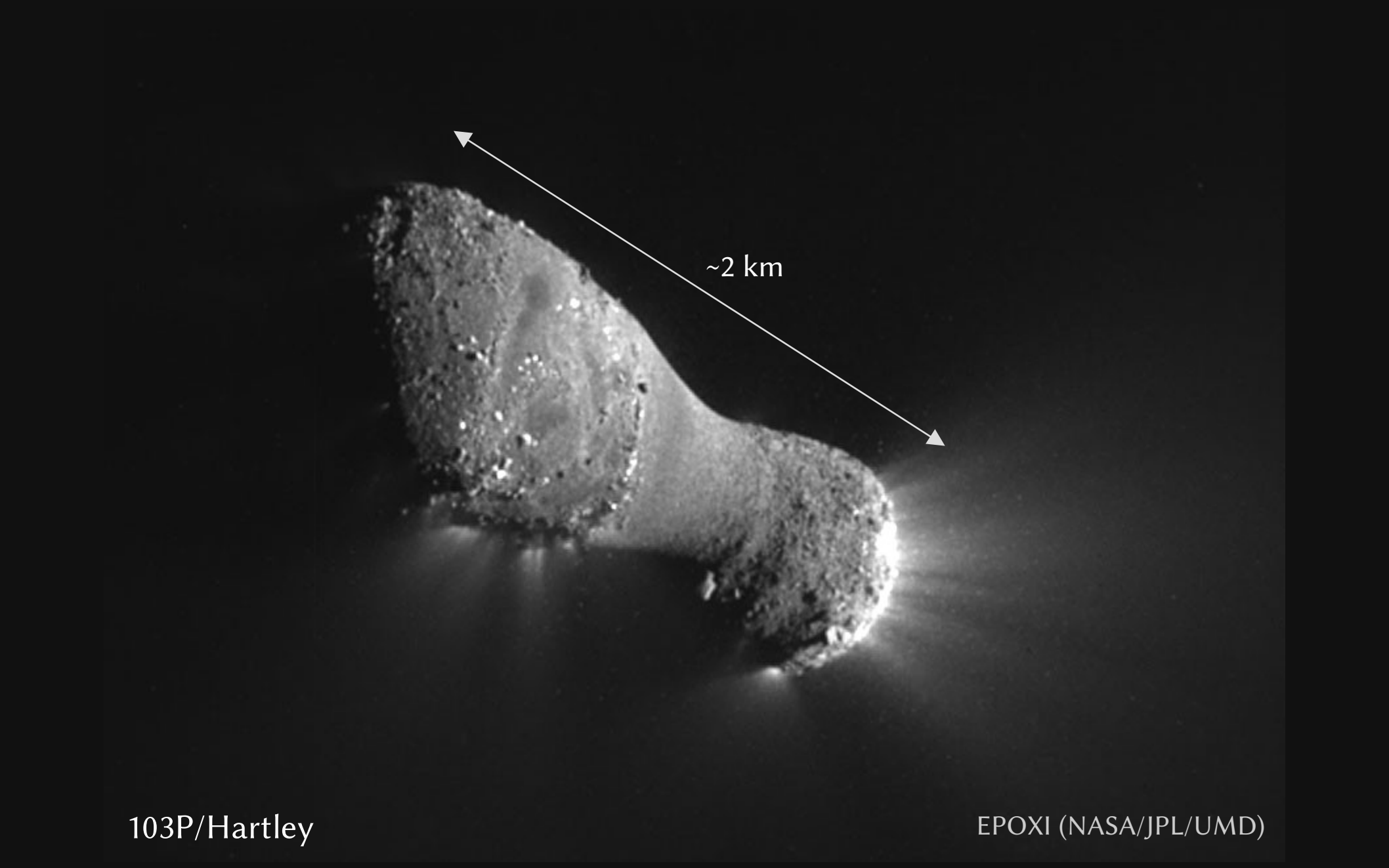
Collaborators: Gregg W. Hallinan, Navtej S. Saini, Hilke E. Schlichting, Leon K. Harding, Jennifer W. Milburn


Kuiper Belt Object (KBO)



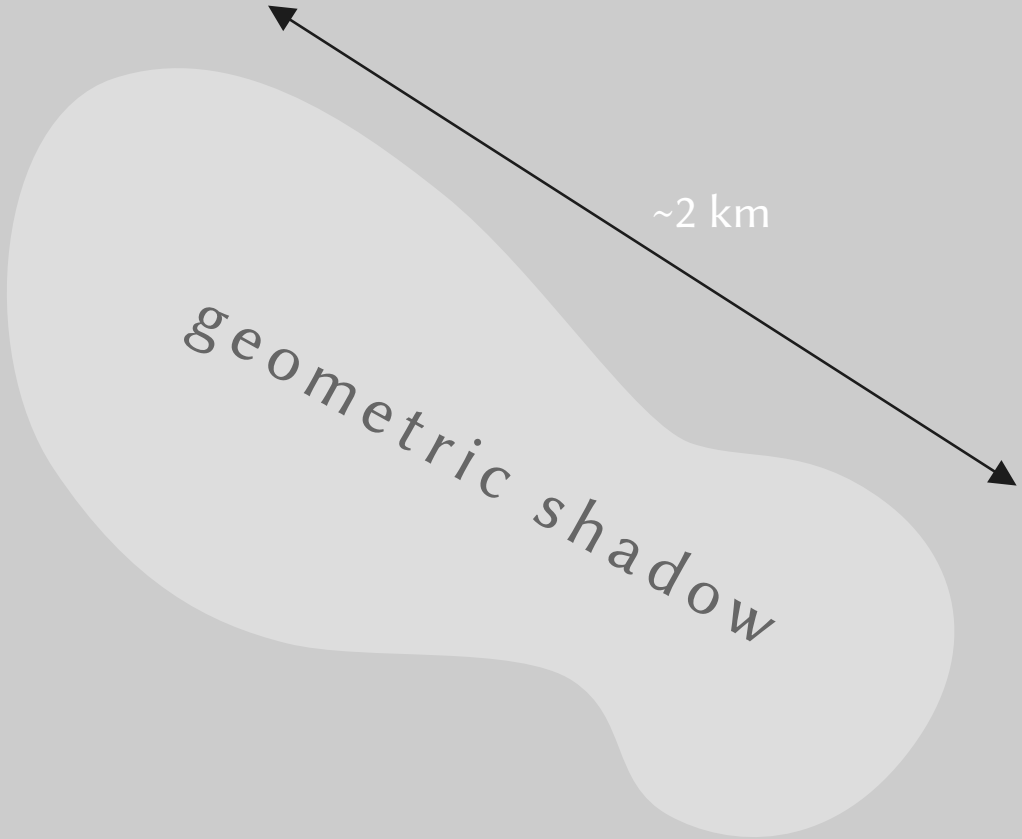

diffraction

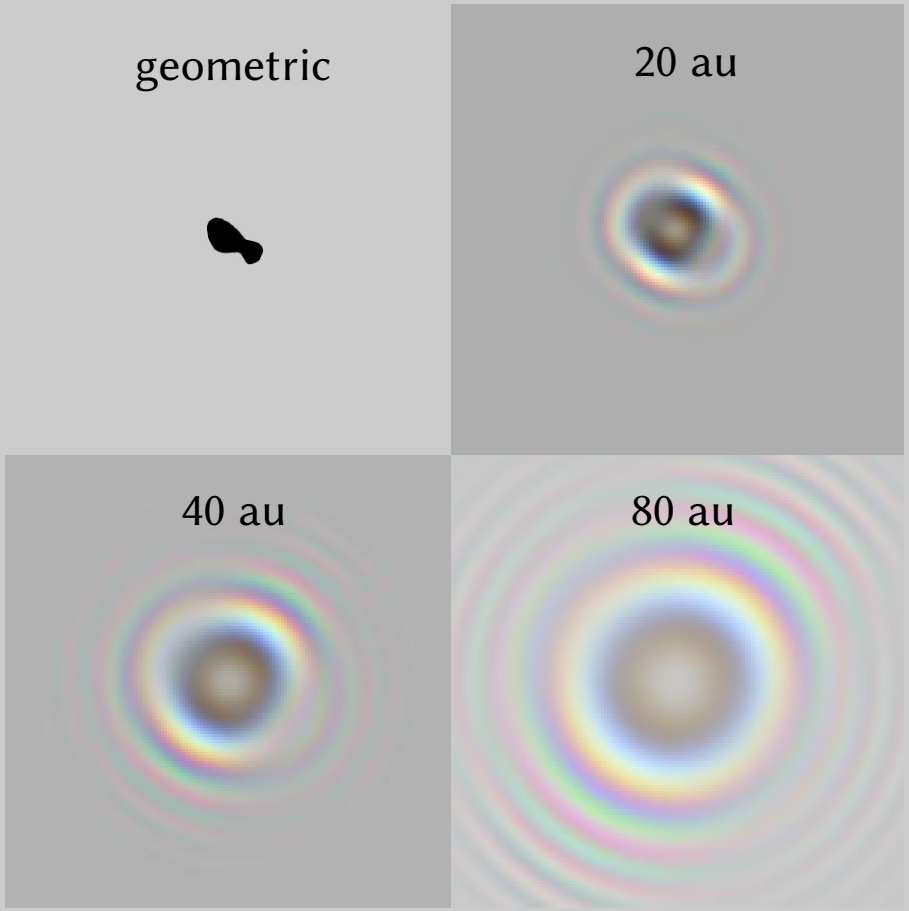


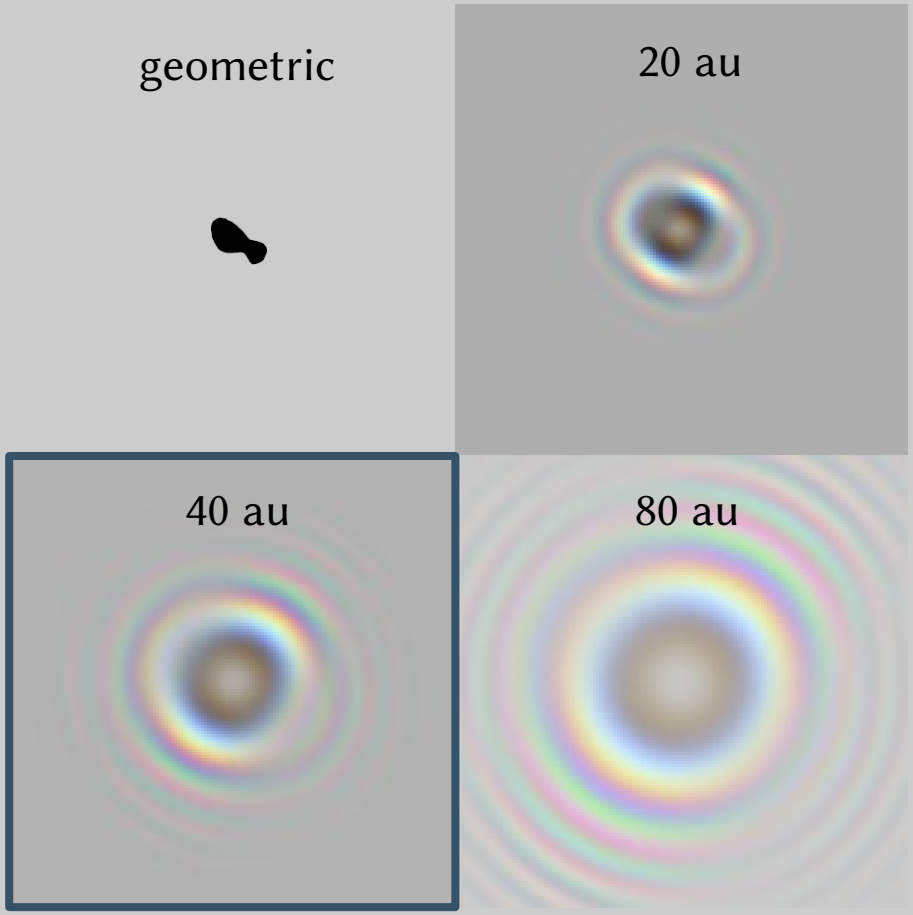


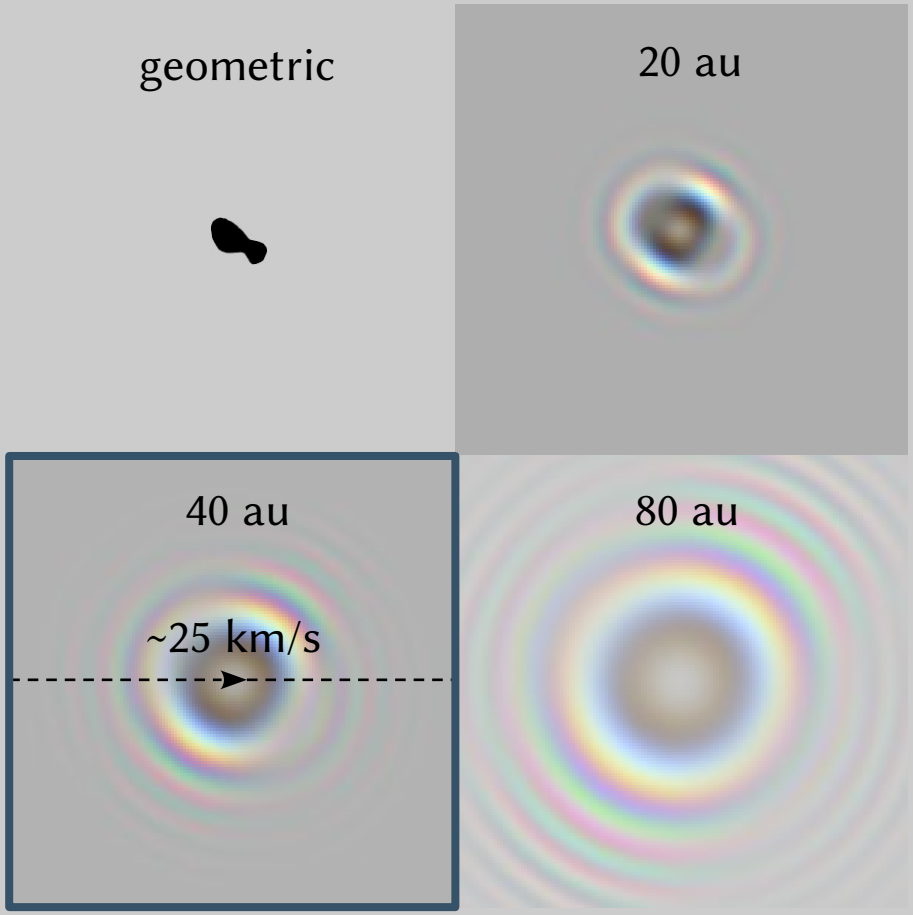
103P/Hartley

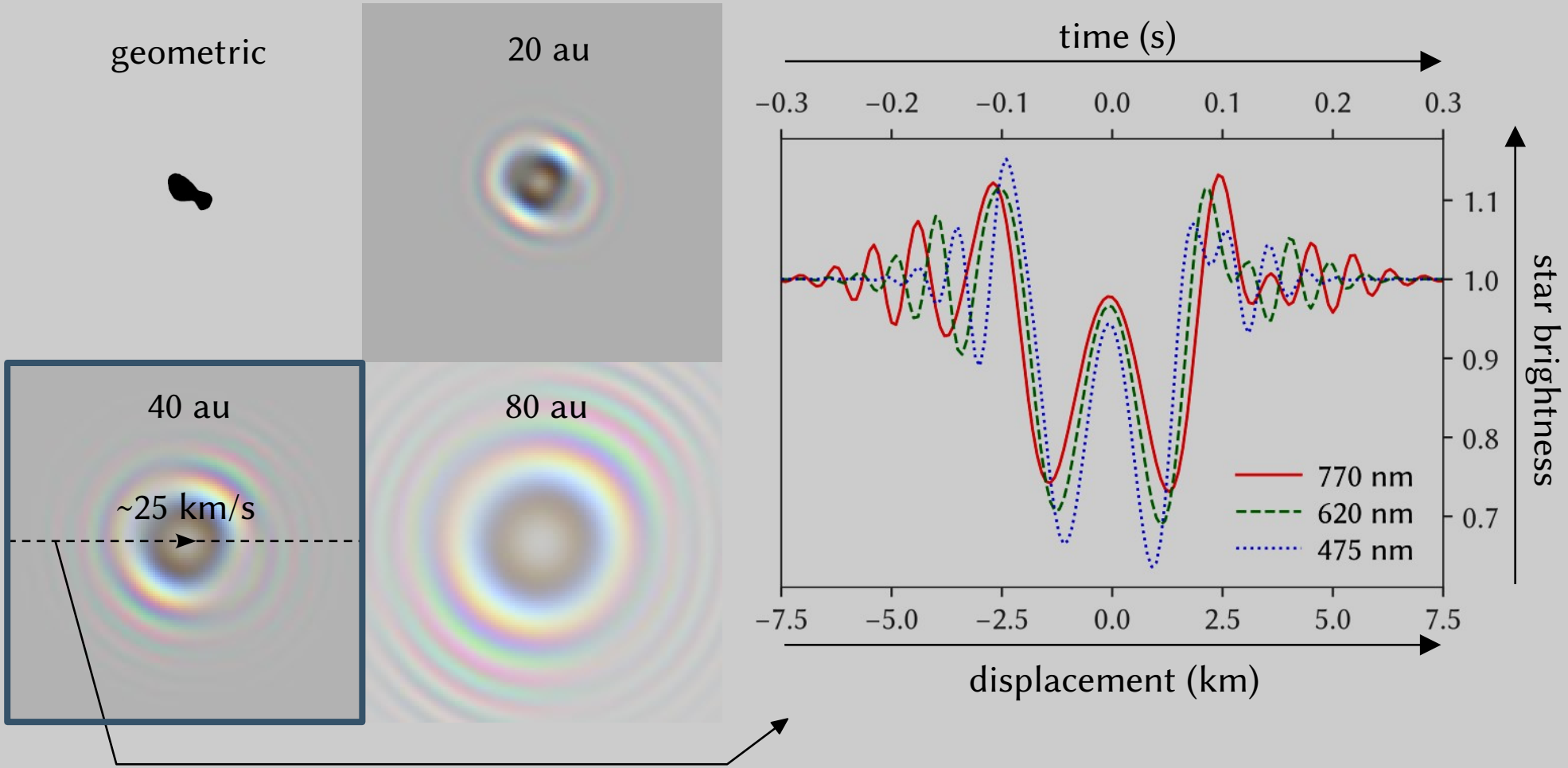
EPOXI (NASA/JPL/UMD)

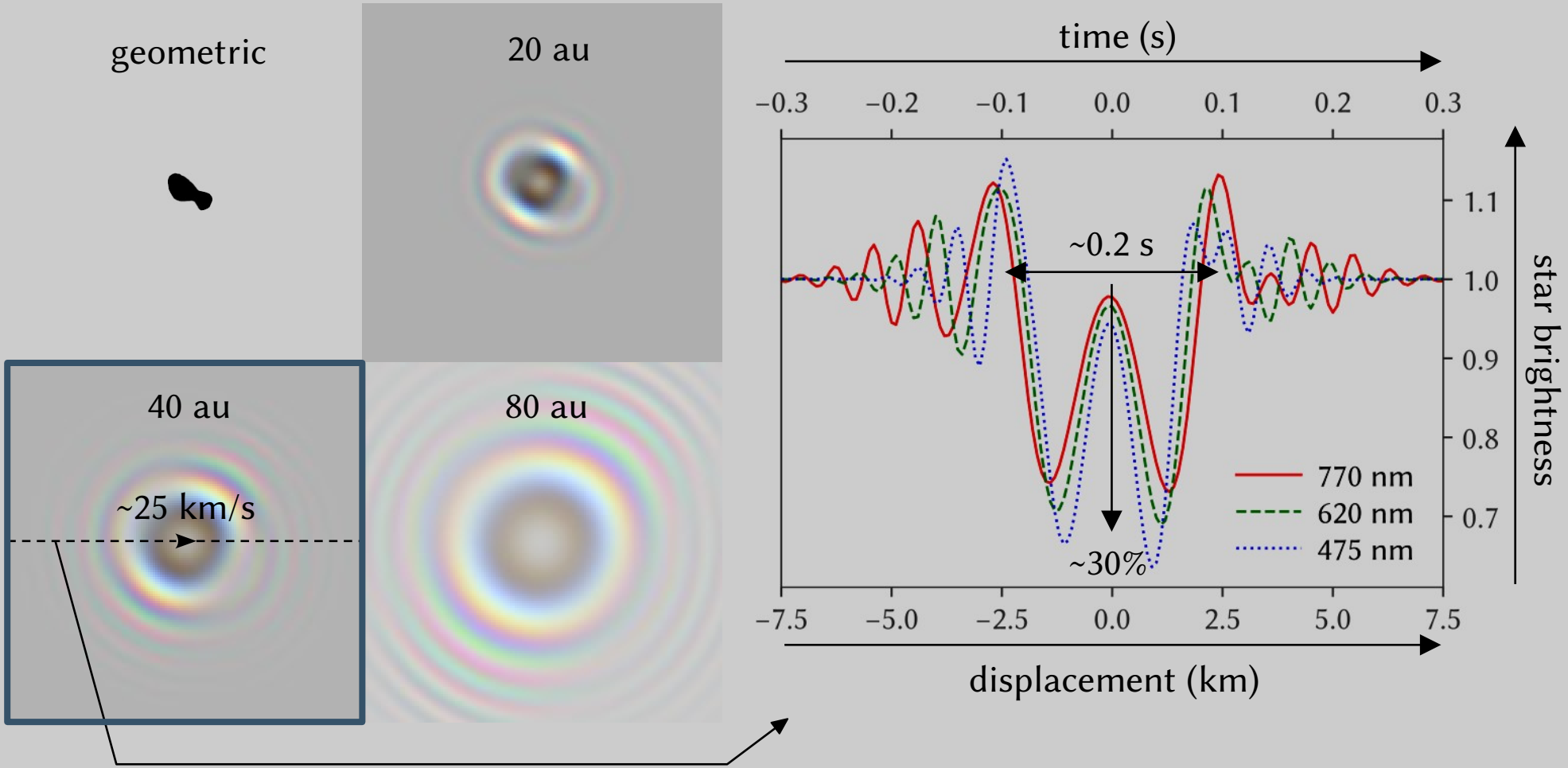

~2 km
geometric shadow

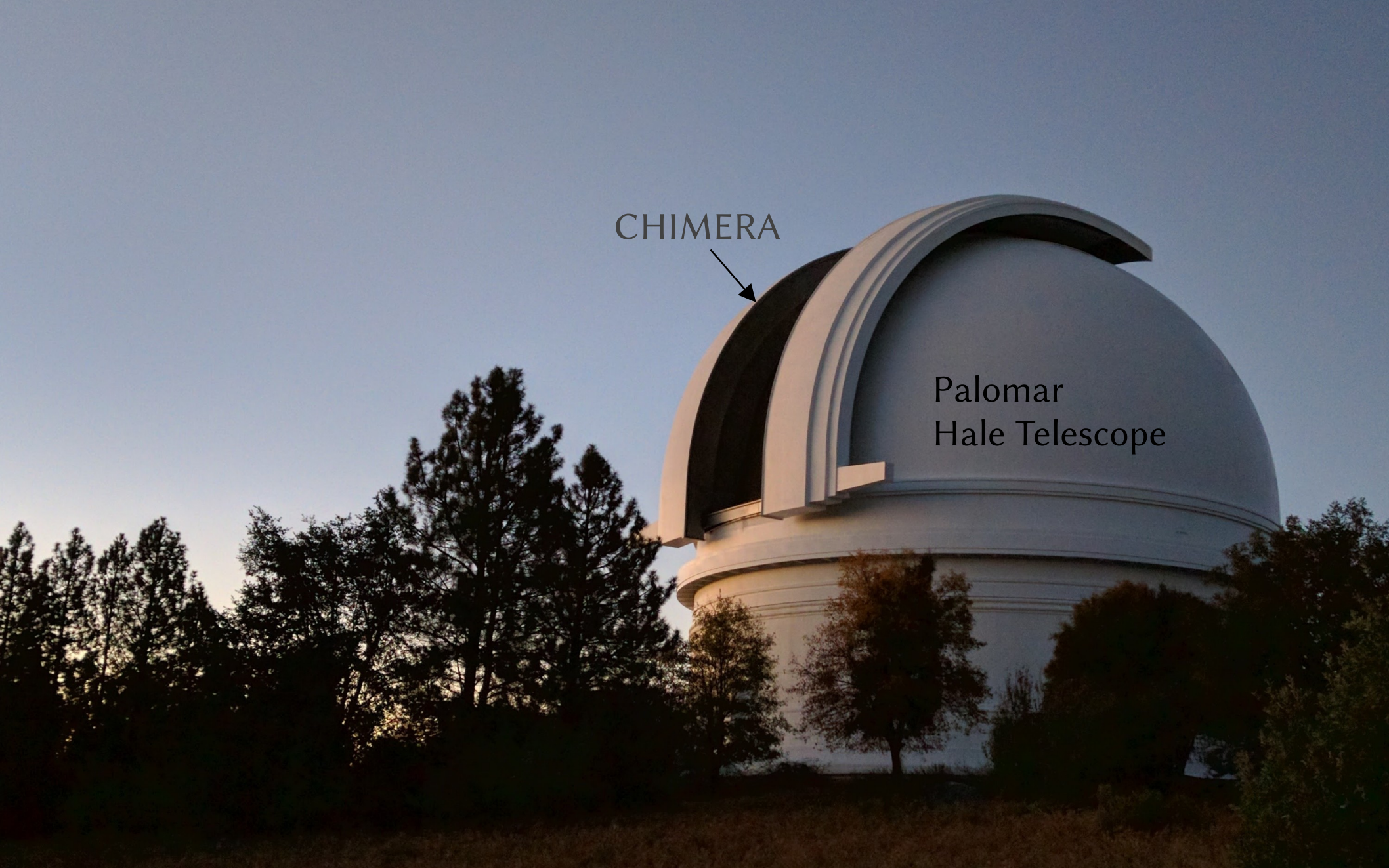

geometric
20 au
40 au
80 au


geometric
20 au
40 au
80 au


geometric
20 au
40 au
~25 km/s
80 au

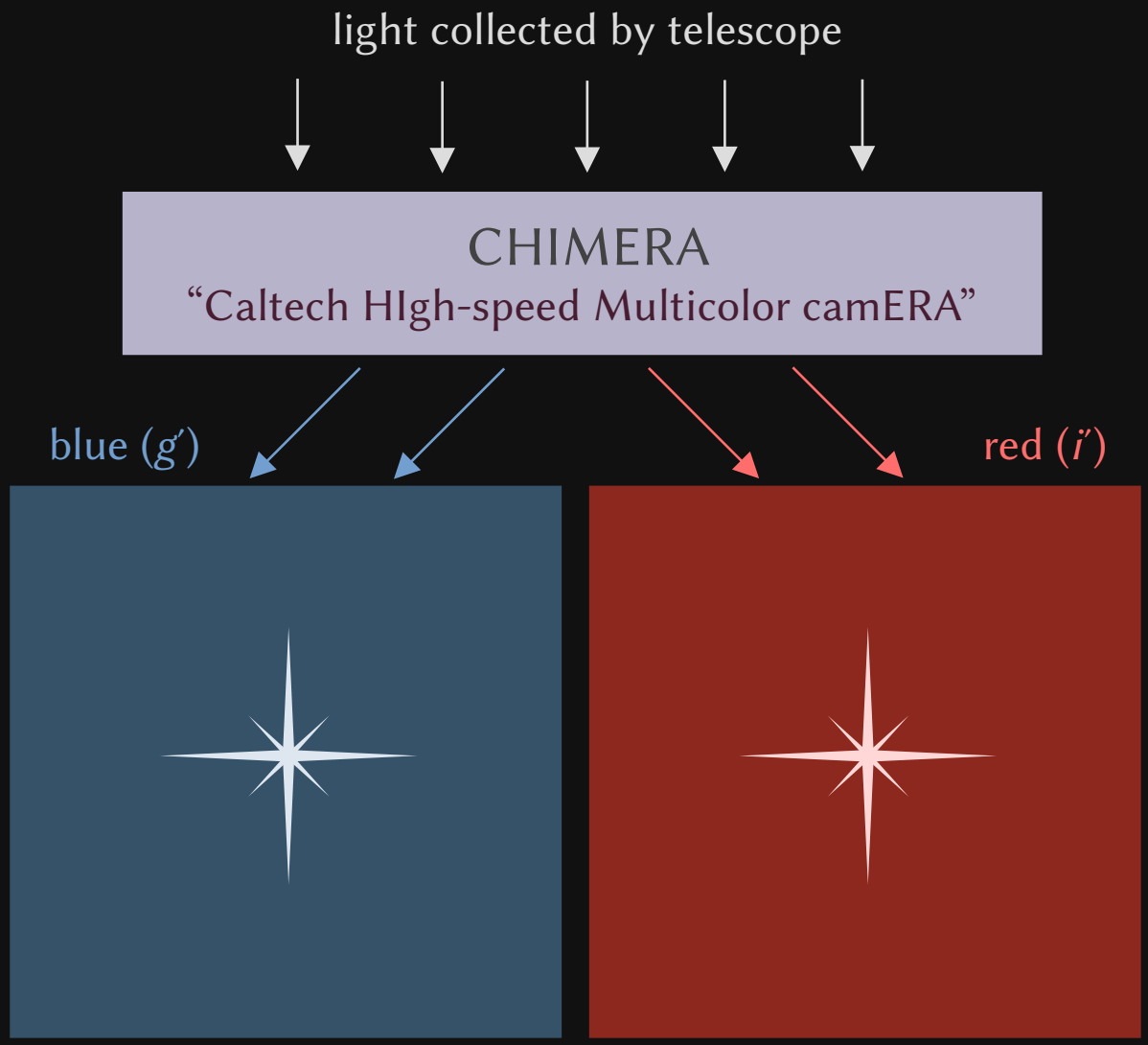

geometric
20 au
40 au
80 au
~25 km/s
time (s)
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
1.1
1.0
0.9
0.8
0.7
star brightness
770 nm
620 nm
475 nm
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
displacement (km)

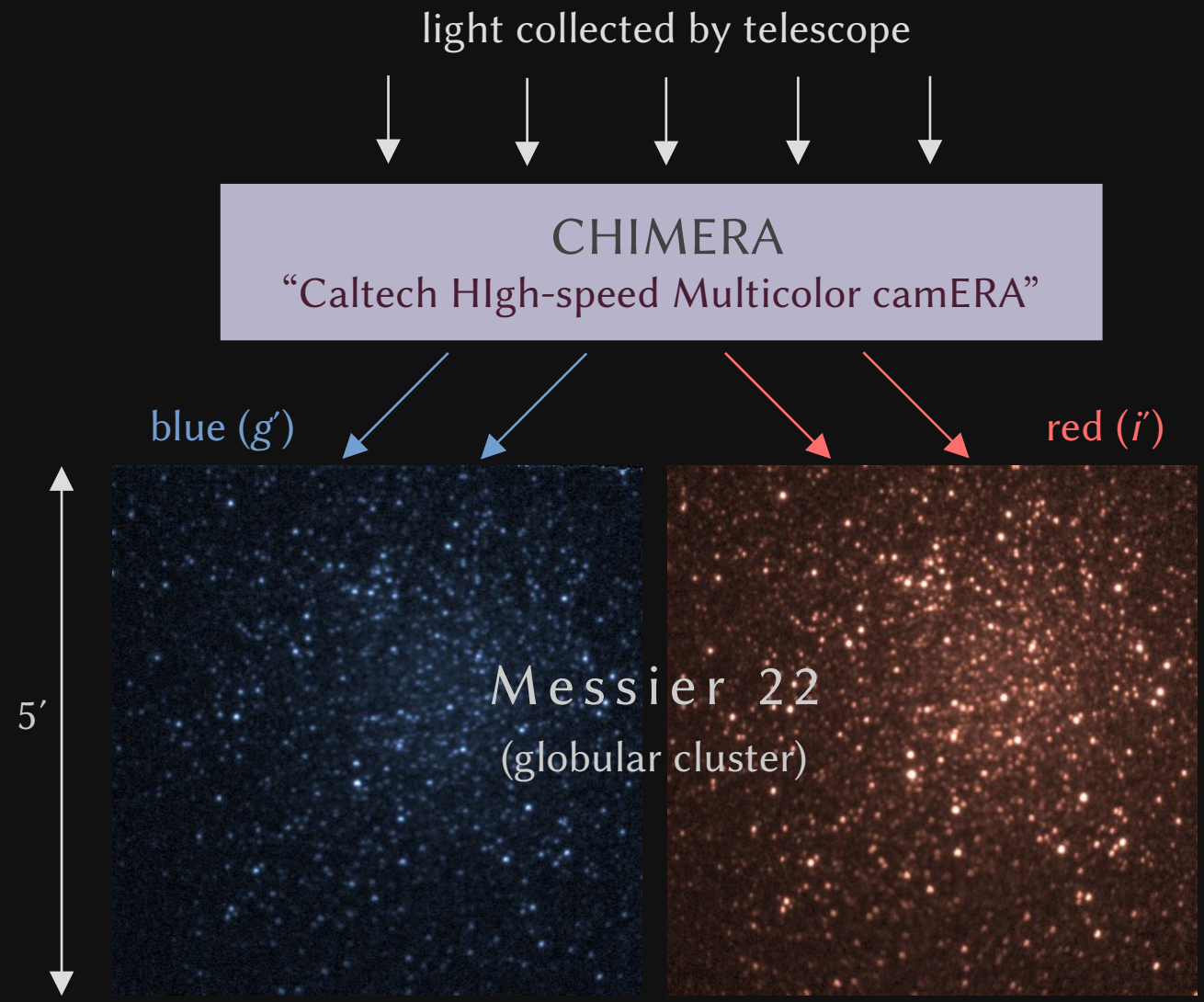

geometric
20 au
40 au
80 au
~25 km/s
time (s)
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
~0.2 s
~30%
770 nm
620 nm
475 nm
1.1
1.0
0.9
0.8
0.7
star brightness
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5
displacement (km)

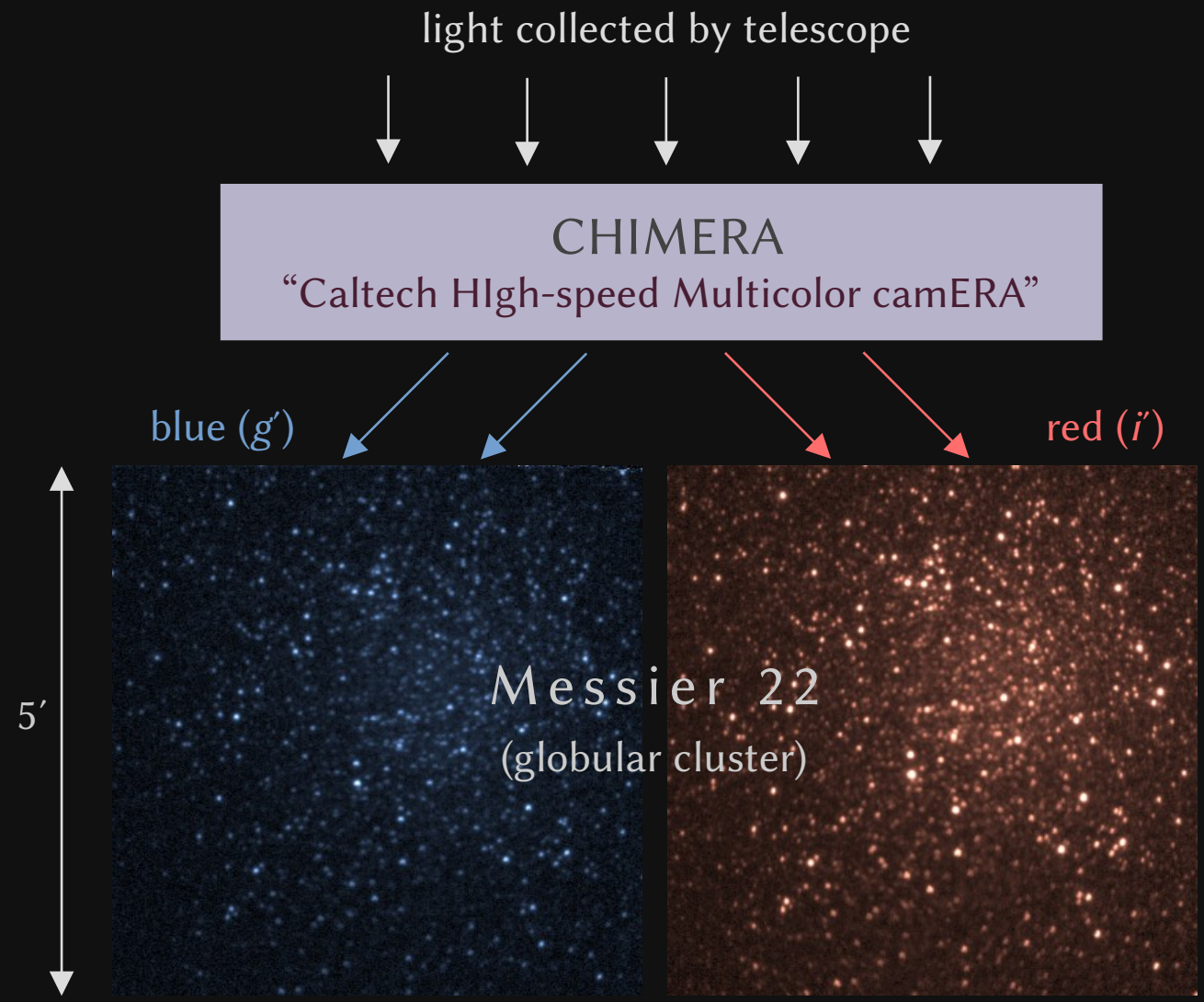

CHIMERA
Palomar
Hale Telescope

CHIMERA

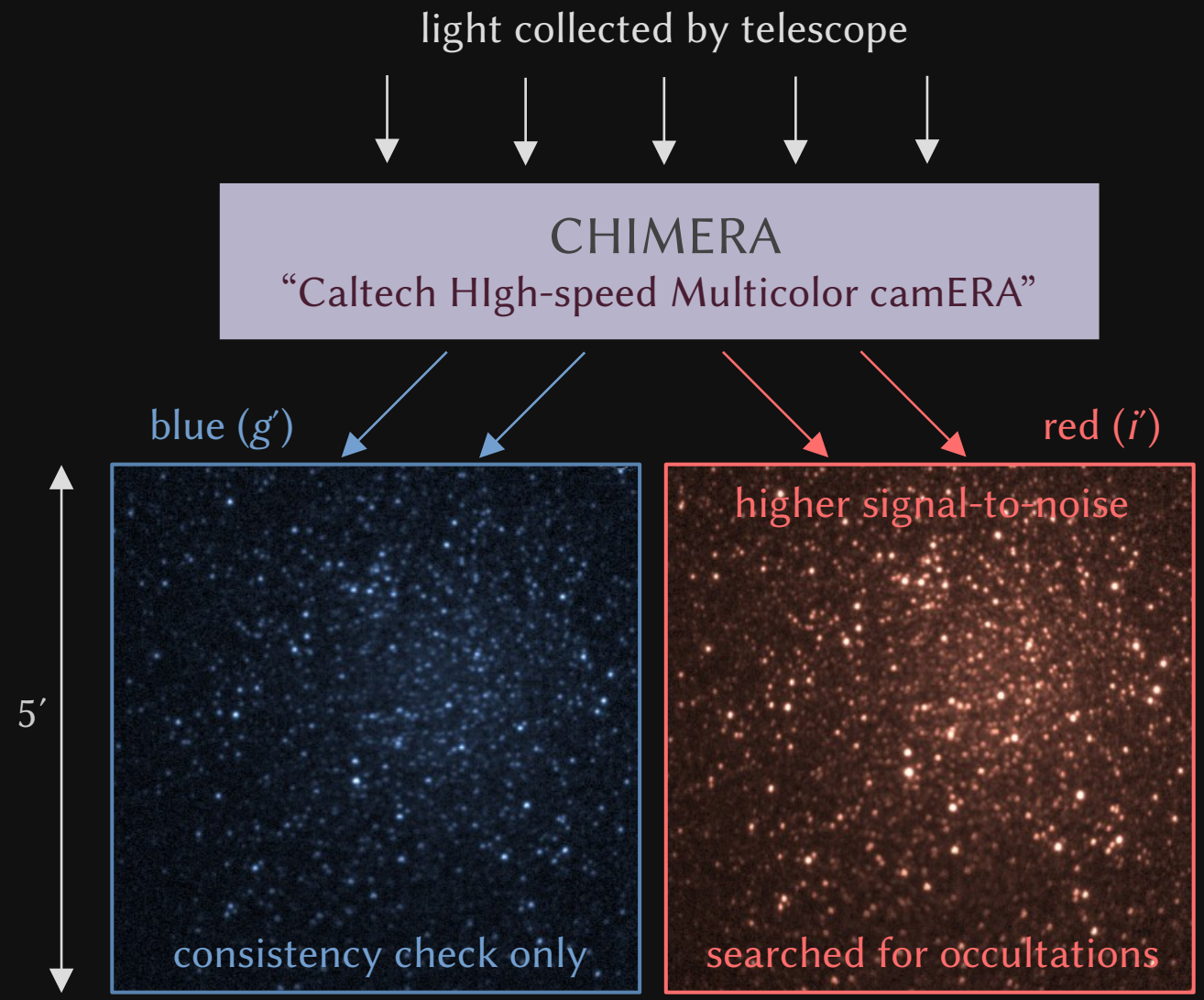
"Caltech HIgh-speed Multicolor camERA"


light collected by telescope
CHIMERA
“Caltech HIgh-speed Multicolor camERA”
blue (g′)
red (i′)

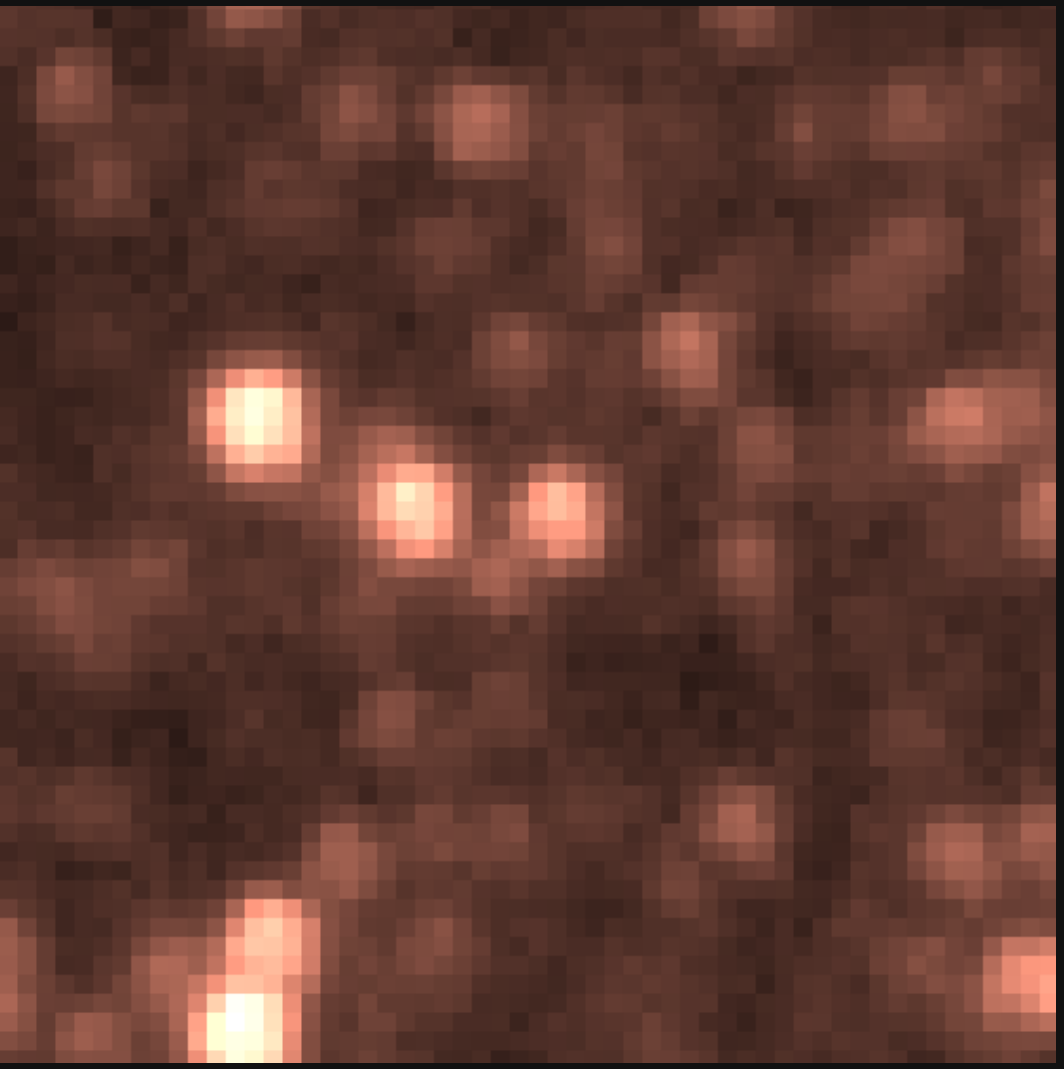

light collected by telescope
CHIMERA
"Caltech HIgh-speed Multicolor camERA"
blue (g′)
red (i′)
5′
Messier 22
(globular cluster)

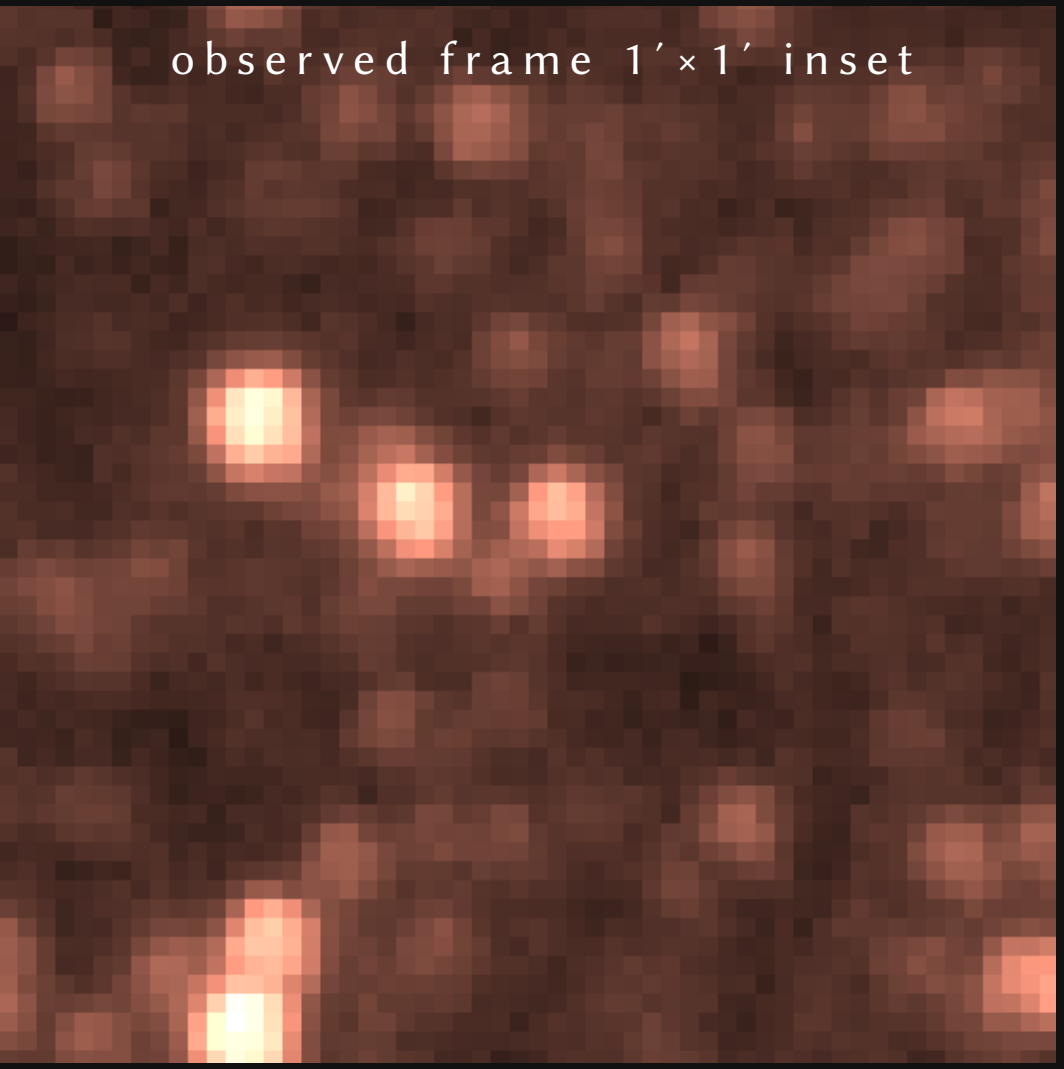


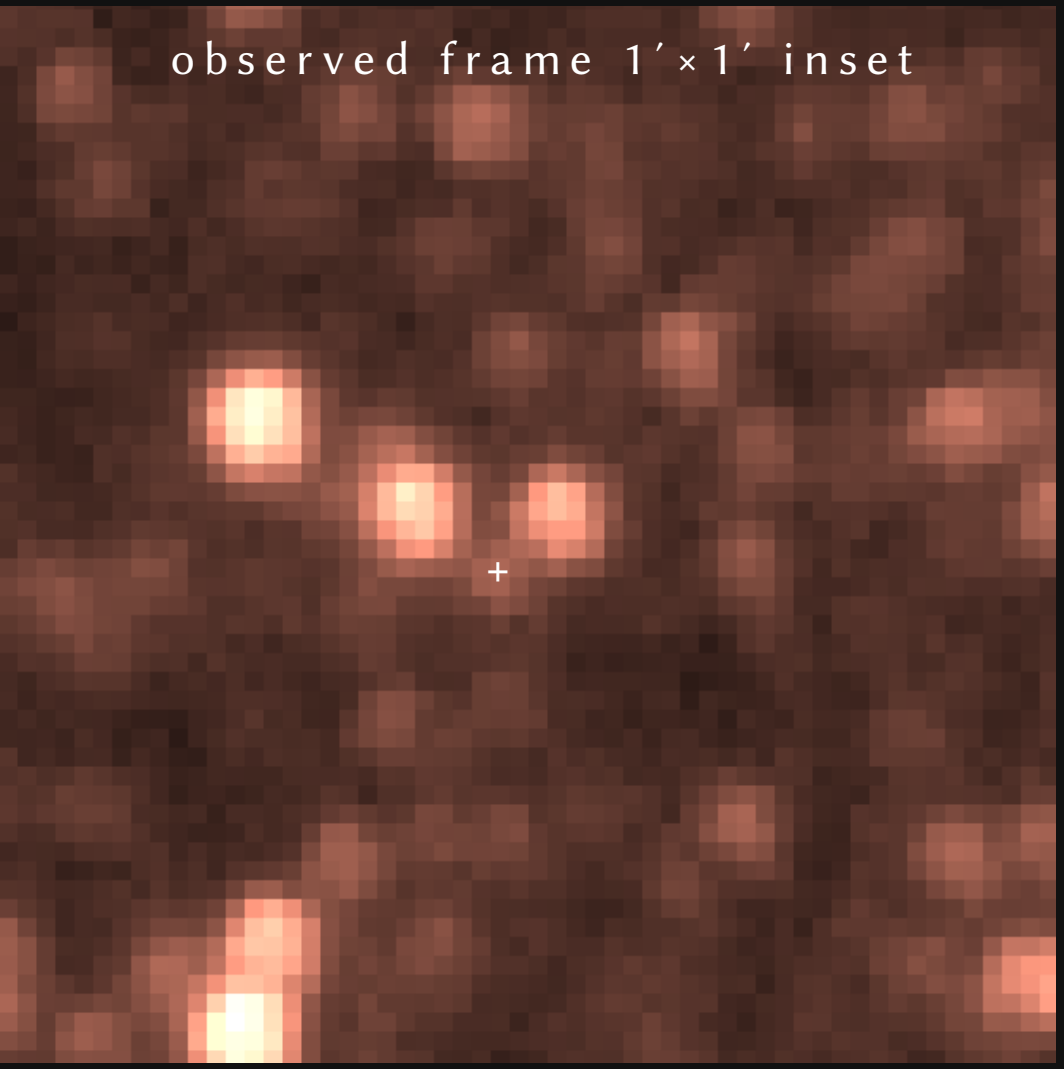
~63 hr @ ~33 frames/s over 24 nights in 2015–2017

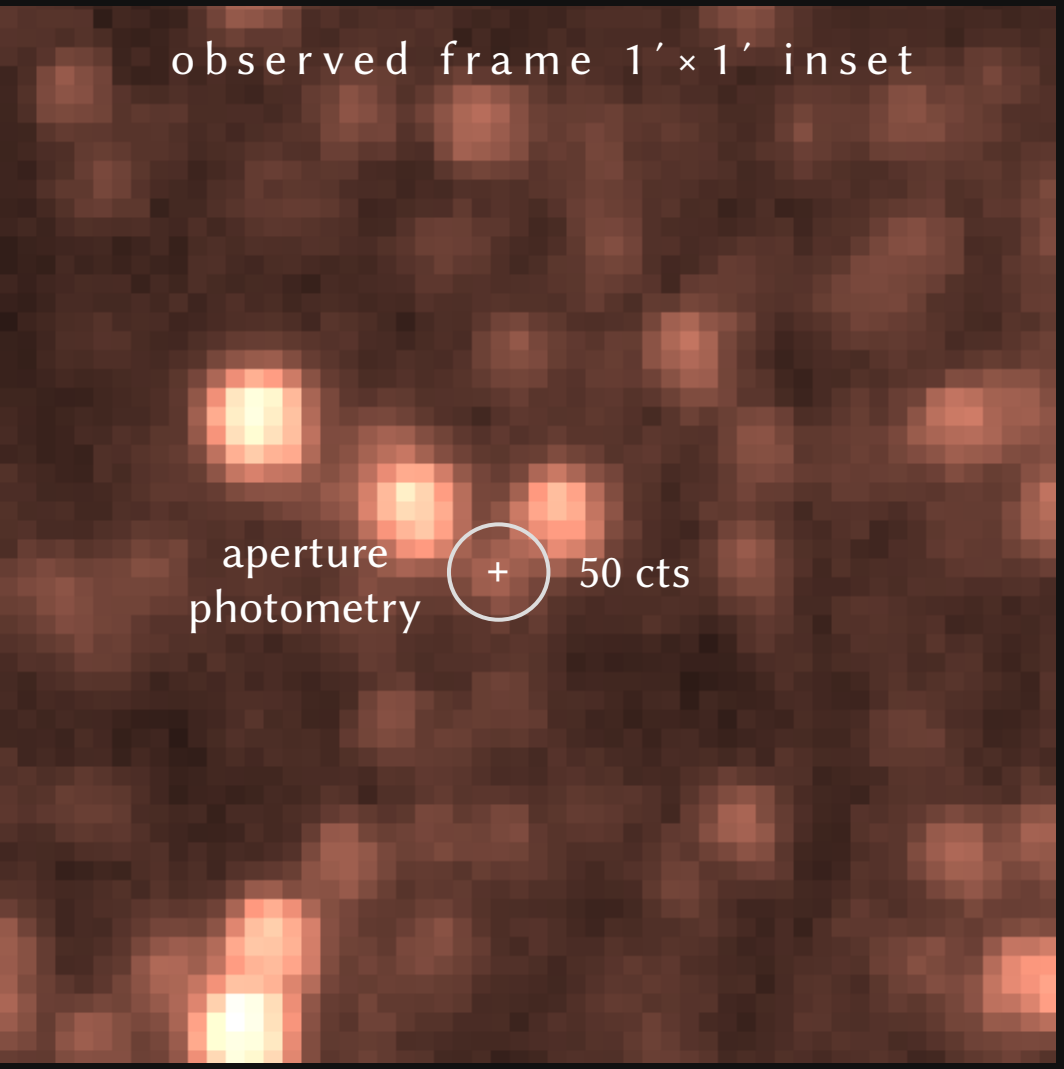


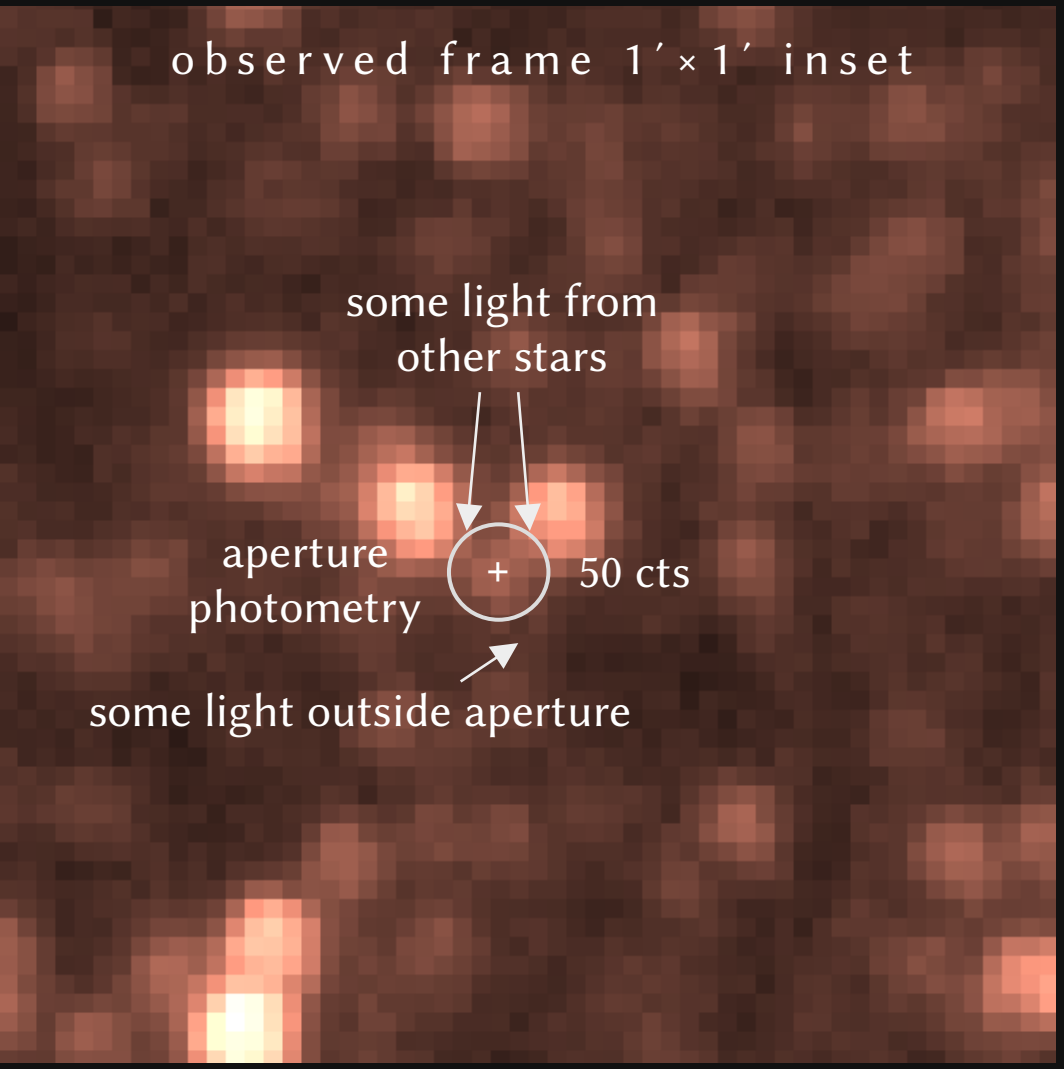
~63 hr @ ~33 frames/s over 24 nights in 2015–2017

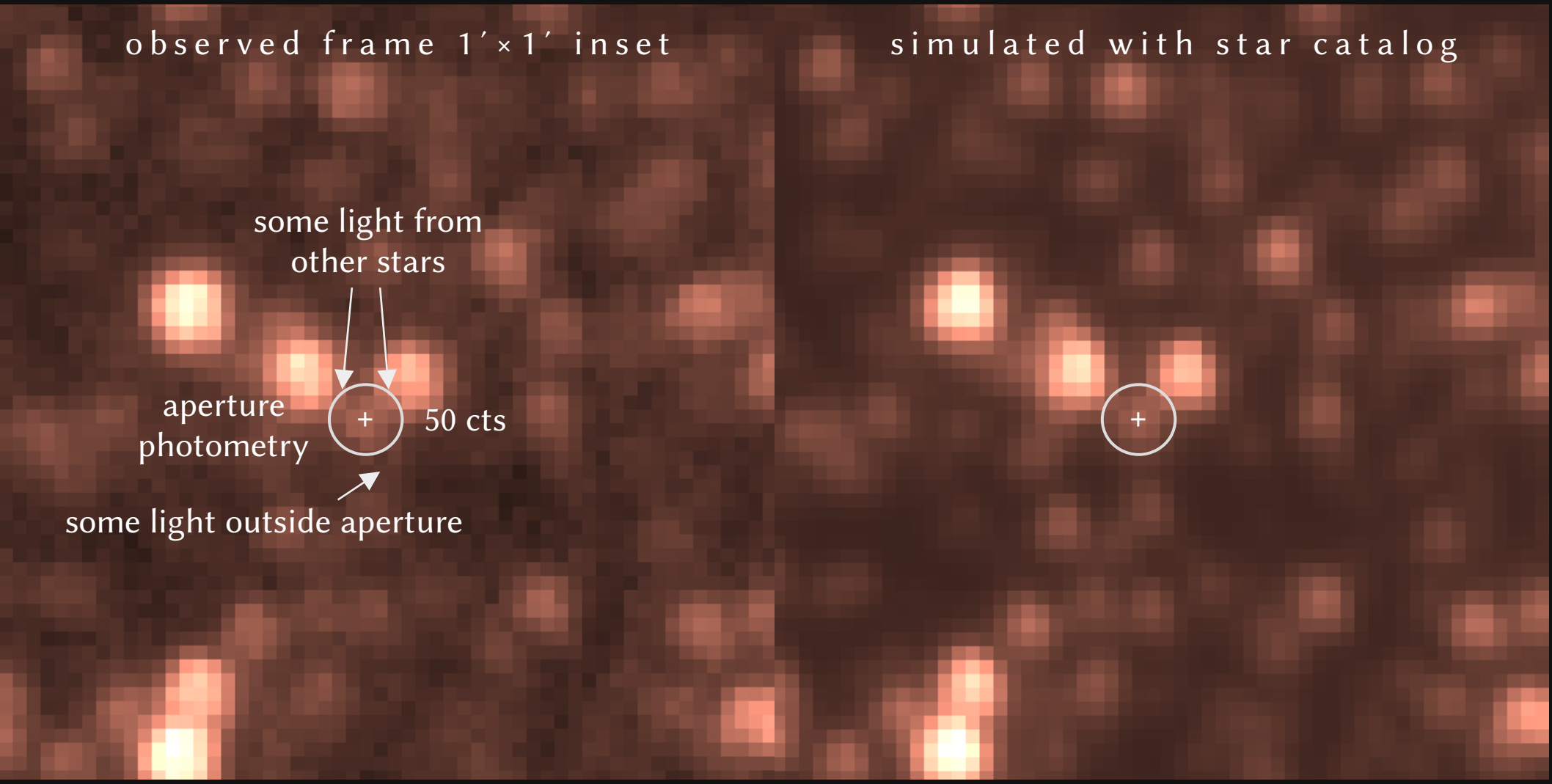


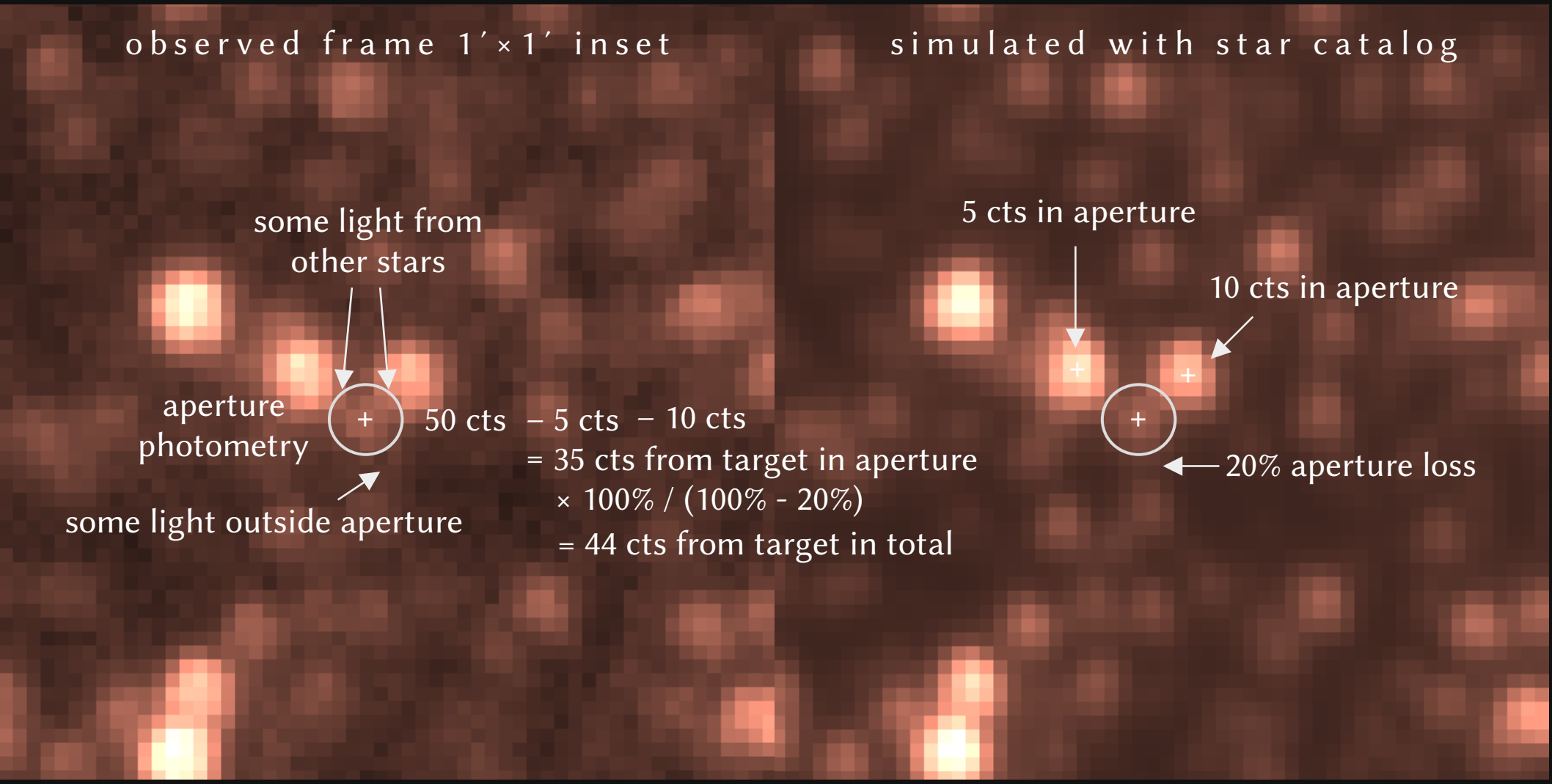

observed frame 1′×1′ inset

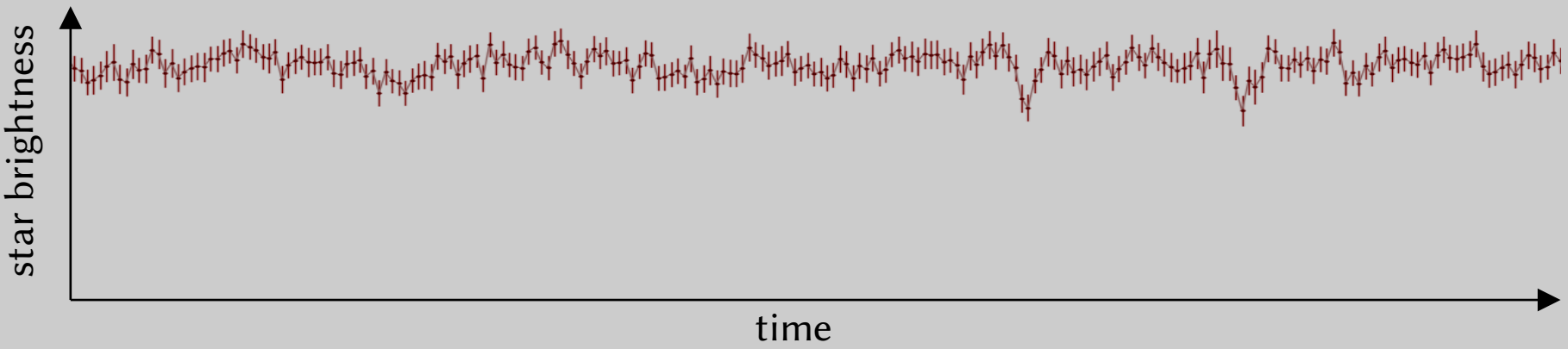

observed frame 1′×1′ inset

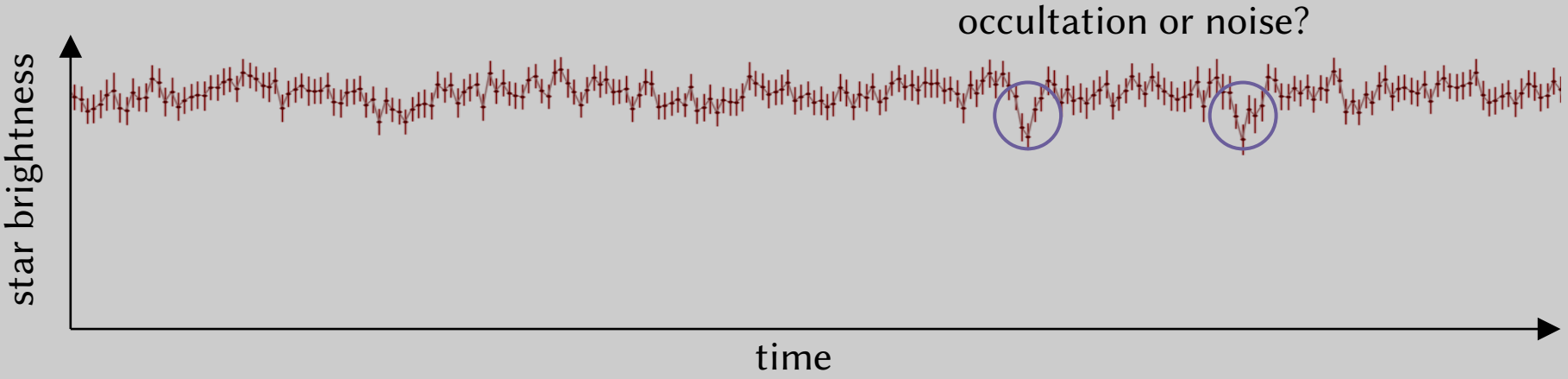

observed frame 1′×1′ inset
aperture
photometry
50 cts

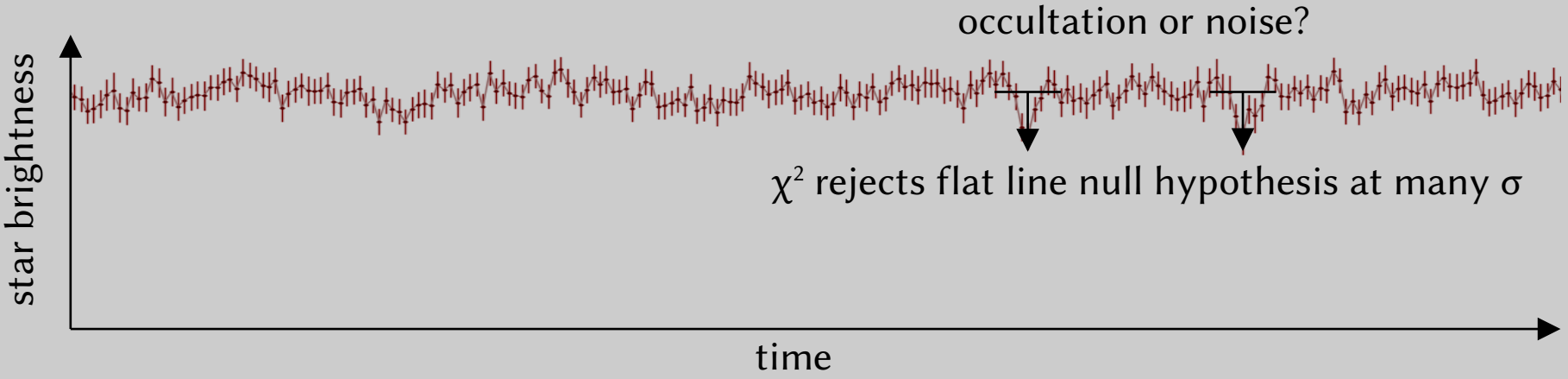

observed frame 1′×1′ inset
some light from
other stars
aperture
photometry
50 cts
some light outside aperture

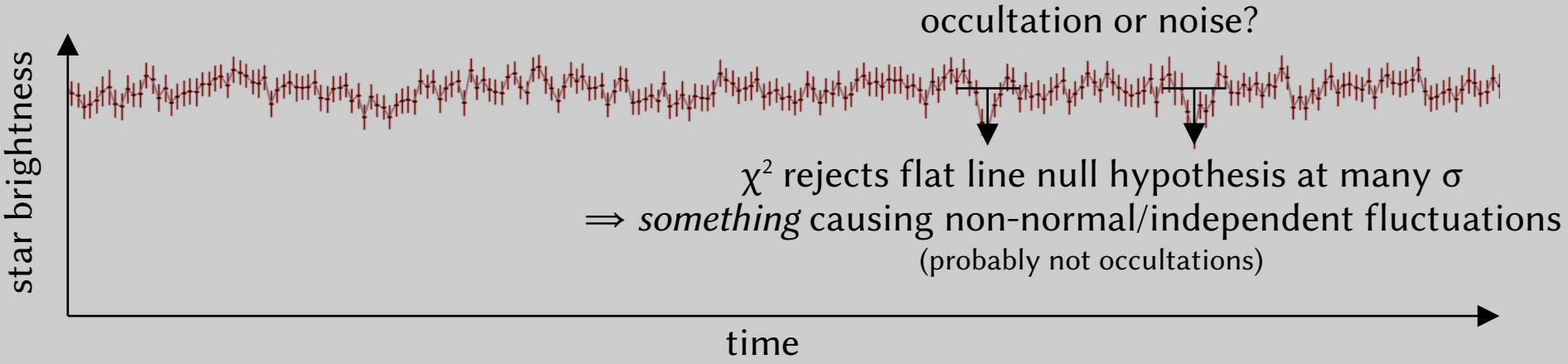

observed frame 1′×1′ inset
some light from other stars
aperture photometry
50 cts
some light outside aperture
simulated with star catalog

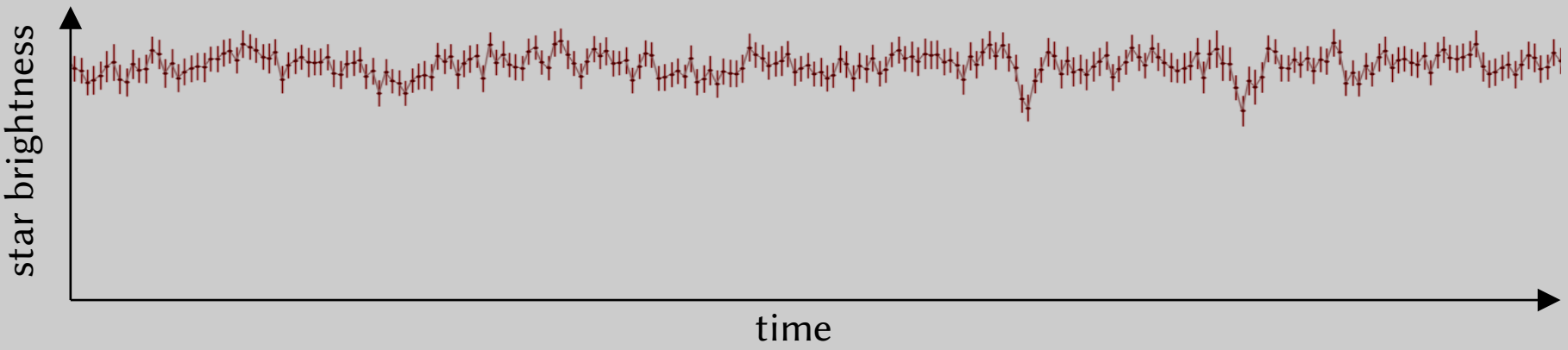

observed frame 1′×1′ inset
some light from other stars
aperture photometry
some light outside aperture
50 cts – 5 cts – 10 cts
= 35 cts from target in aperture
× 100% / (100% - 20%)
= 44 cts from target in total
simulated with star catalog
5 cts in aperture
10 cts in aperture
20% aperture loss

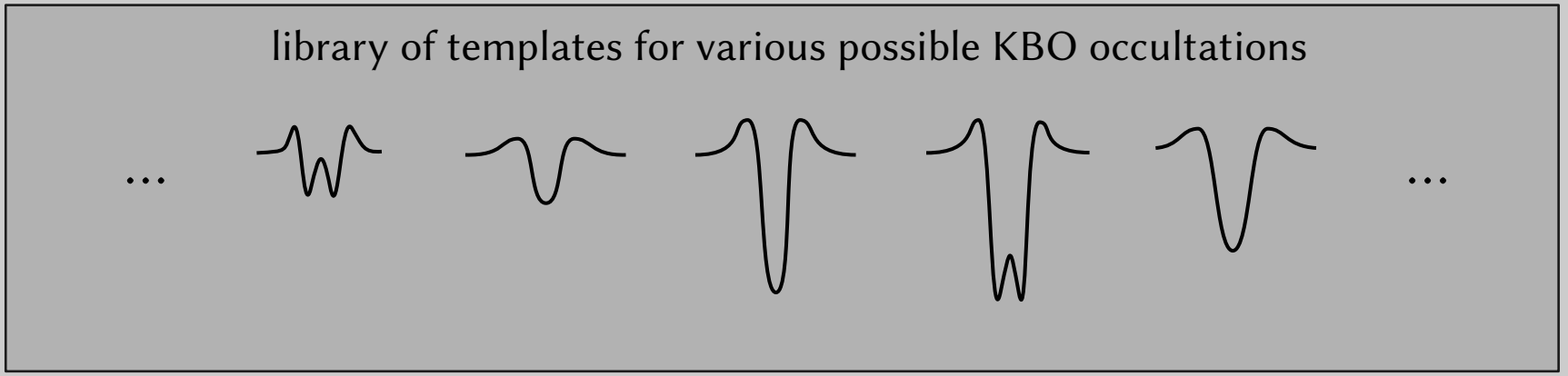

star brightness
time


occultation or noise?
star brightness
time

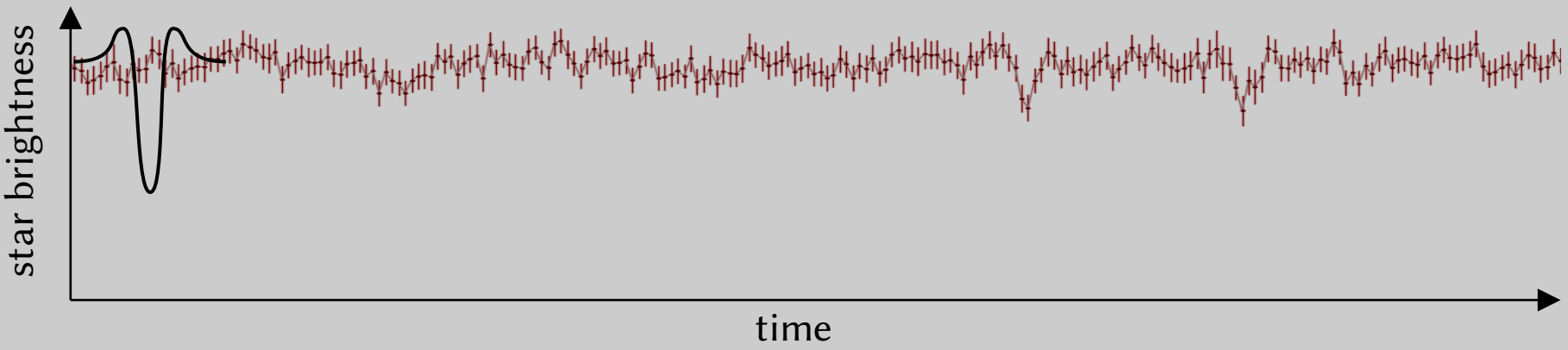

occultation or noise?
star brightness
χ^2 rejects flat line null hypothesis at many σ
time

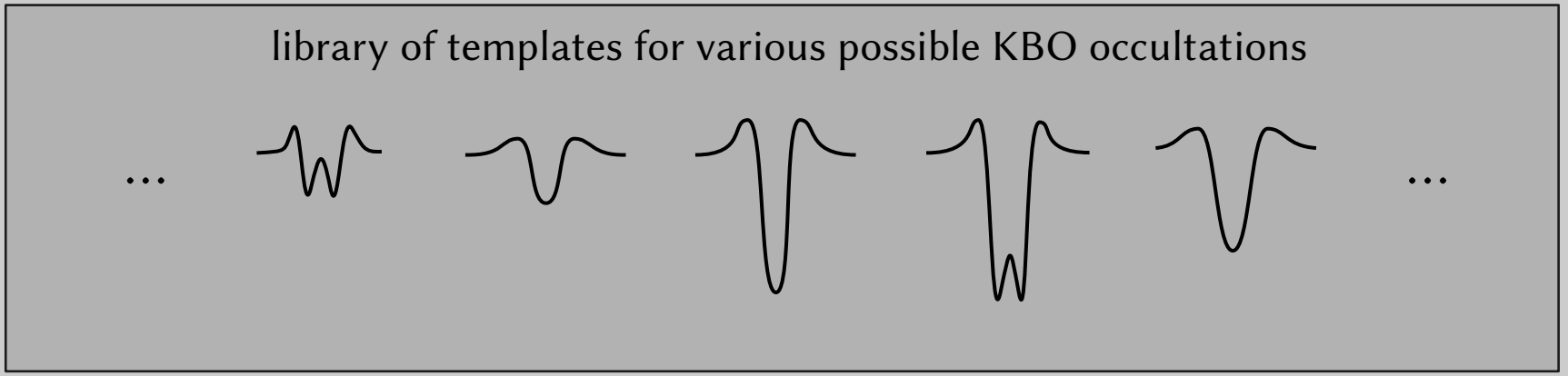

occultation or noise?
star brightness
time
χ^2 rejects flat line null hypothesis at many σ
$\Longrightarrow$ *something* causing non-normal/independent fluctuations
(probably not occultations)


star brightness
time


library of templates for various possible KBO occultations
...
...

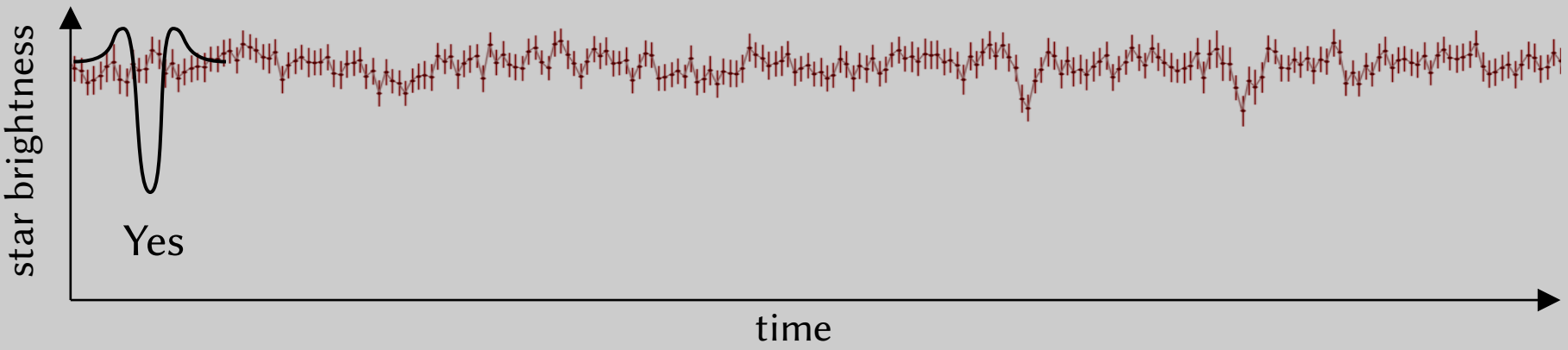
Can we rule out this occultation?

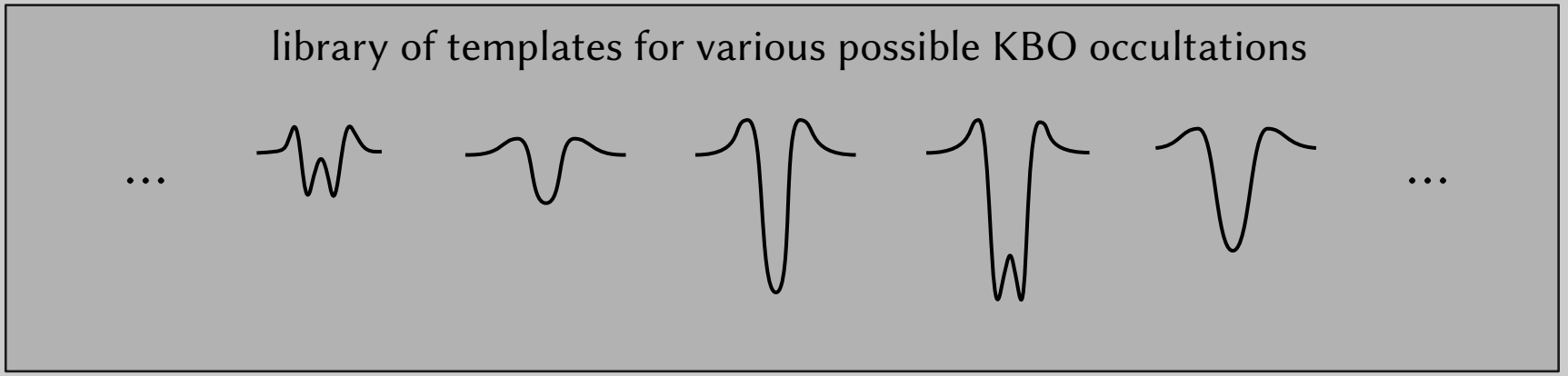




Can we rule out this occultation?

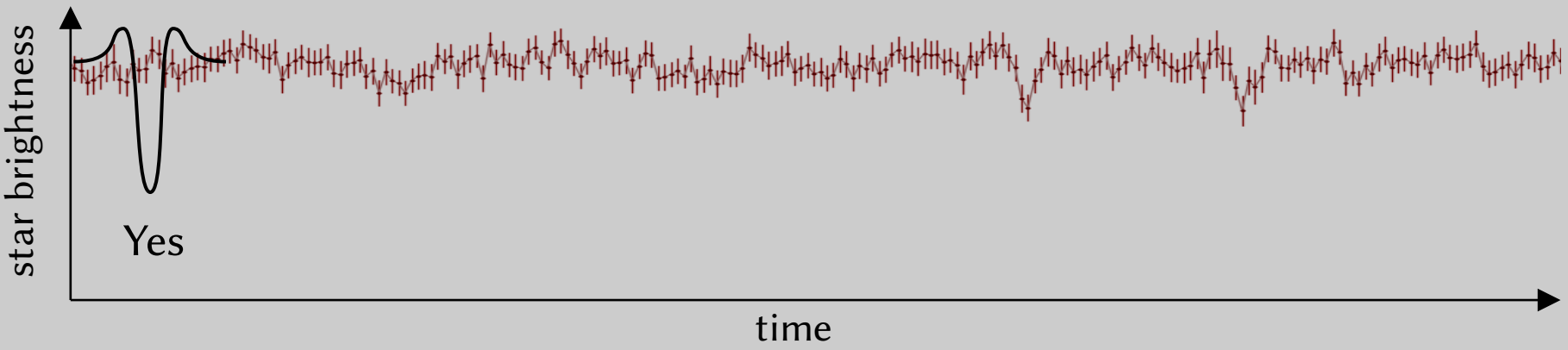
(allow for 16% loss, i.e., <+1σ from typical difference)

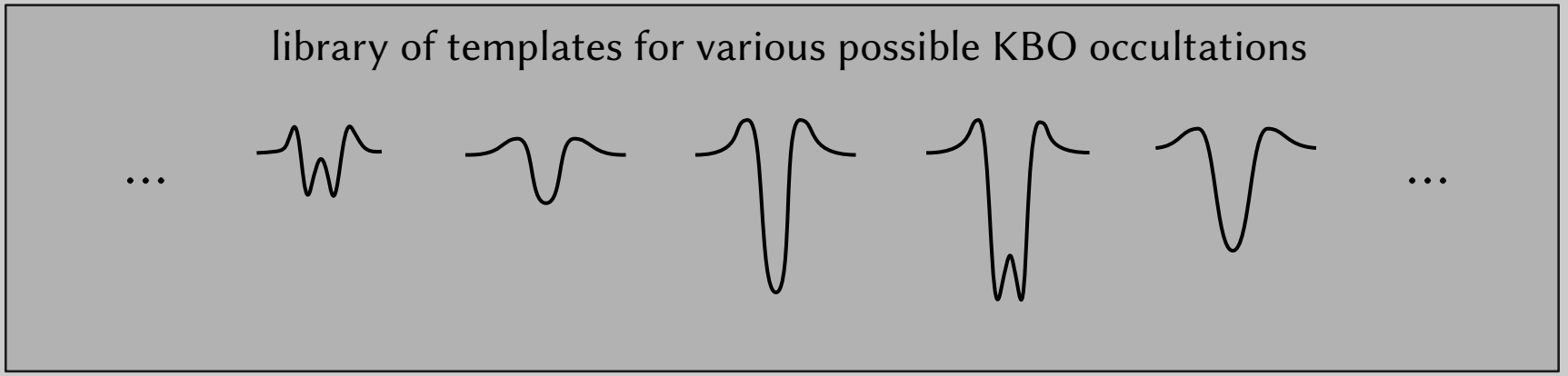




Can we rule out this occultation?

(allow for 16% loss, i.e., <+1σ from typical difference)





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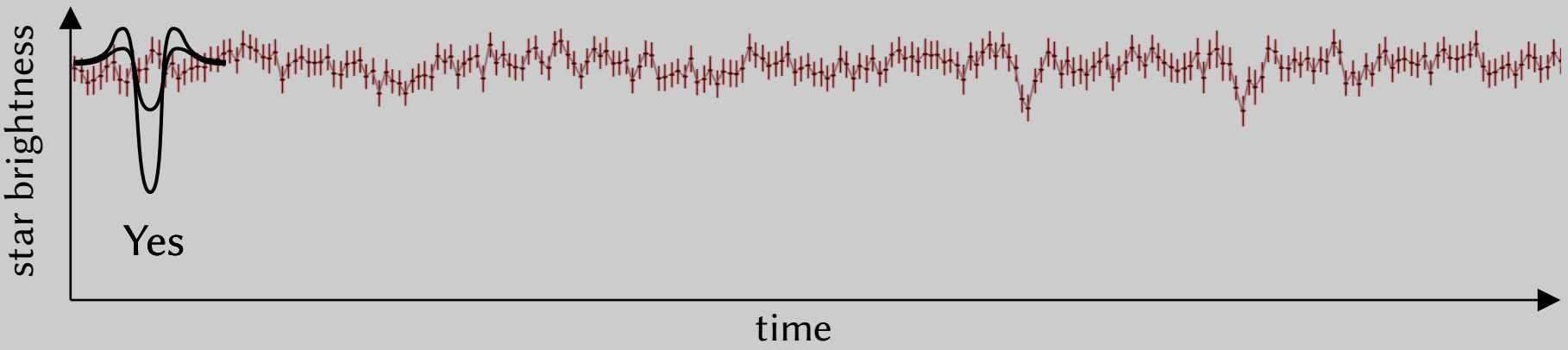

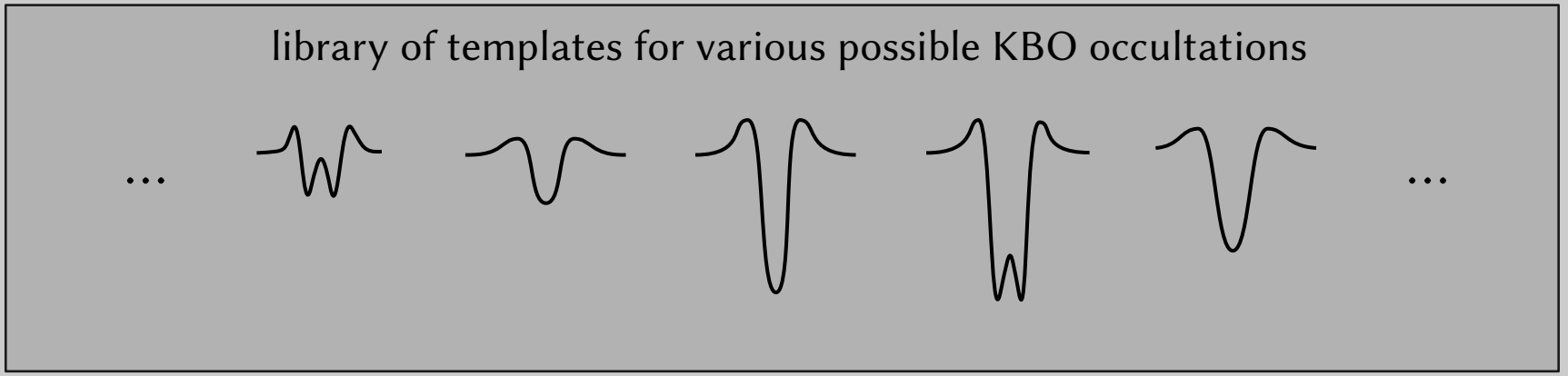

Can we rule out this occultation?

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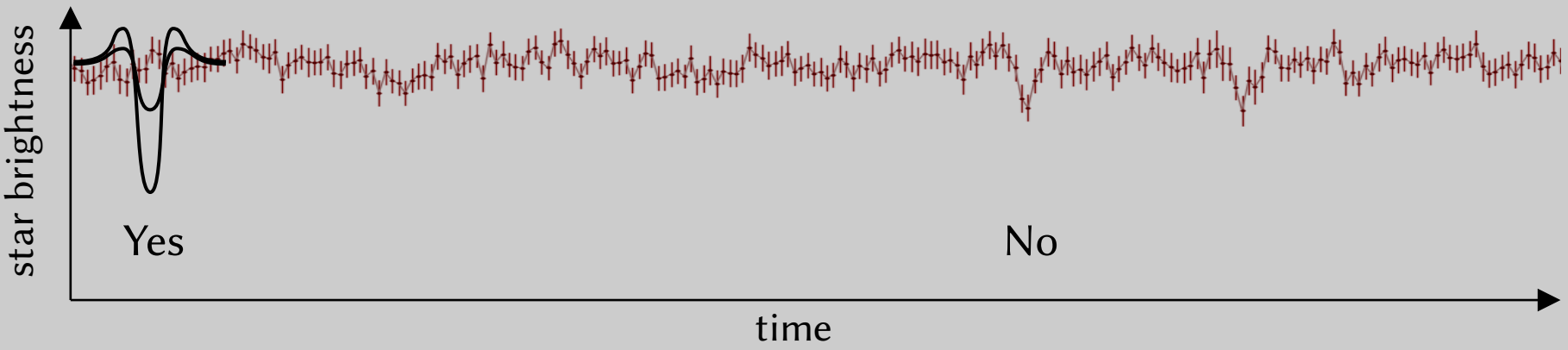

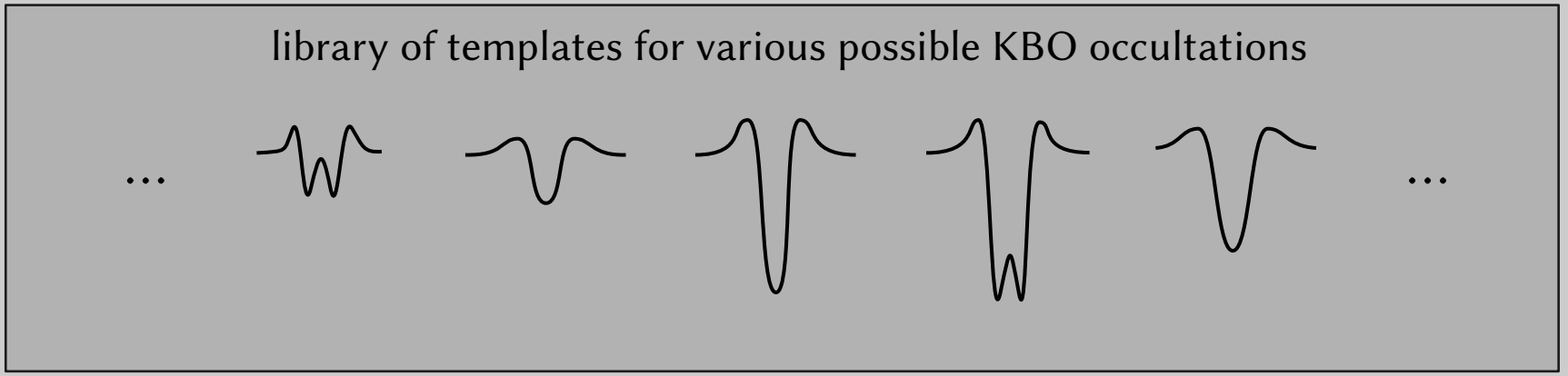

Can we rule out this occultation?

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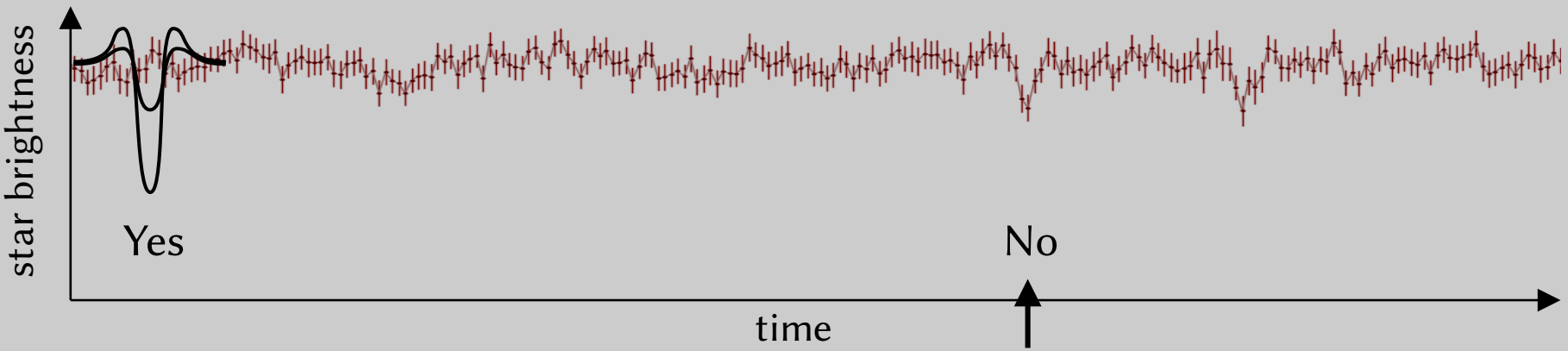
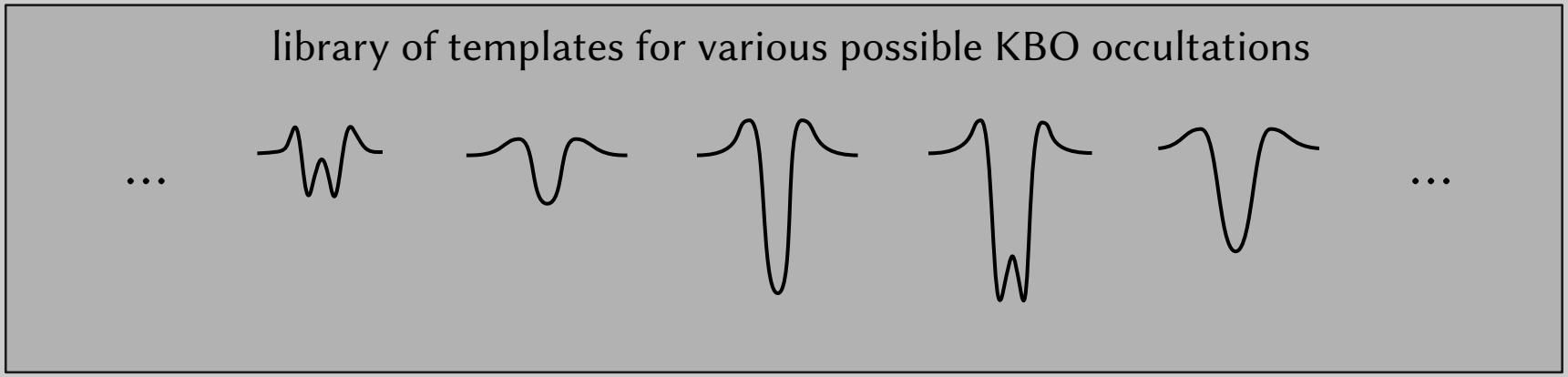
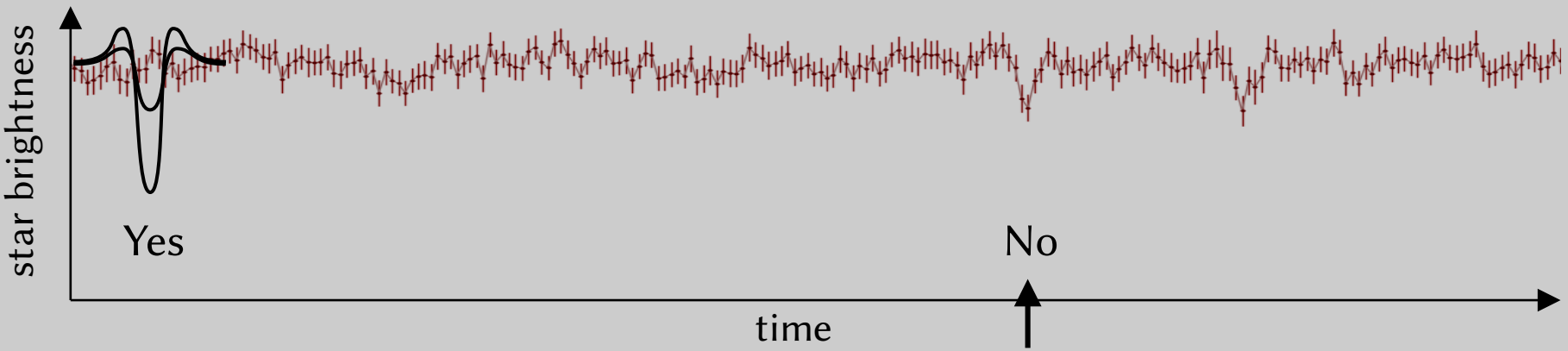


failed to reject ≠ 16%+ chance of being an occultation



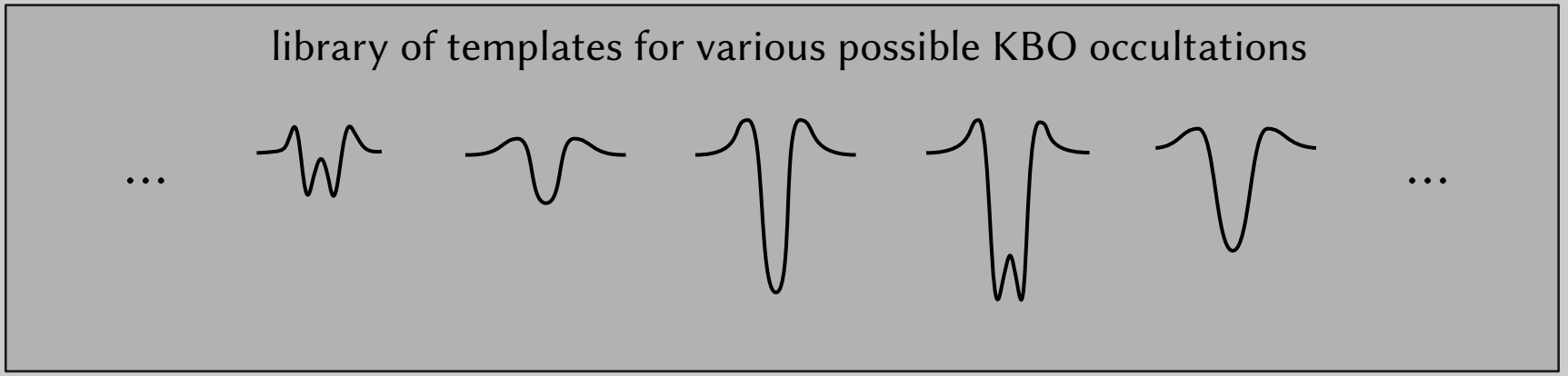
Can we rule out this occultation?

(allow for 16% loss, i.e., <+1σ from typical difference)



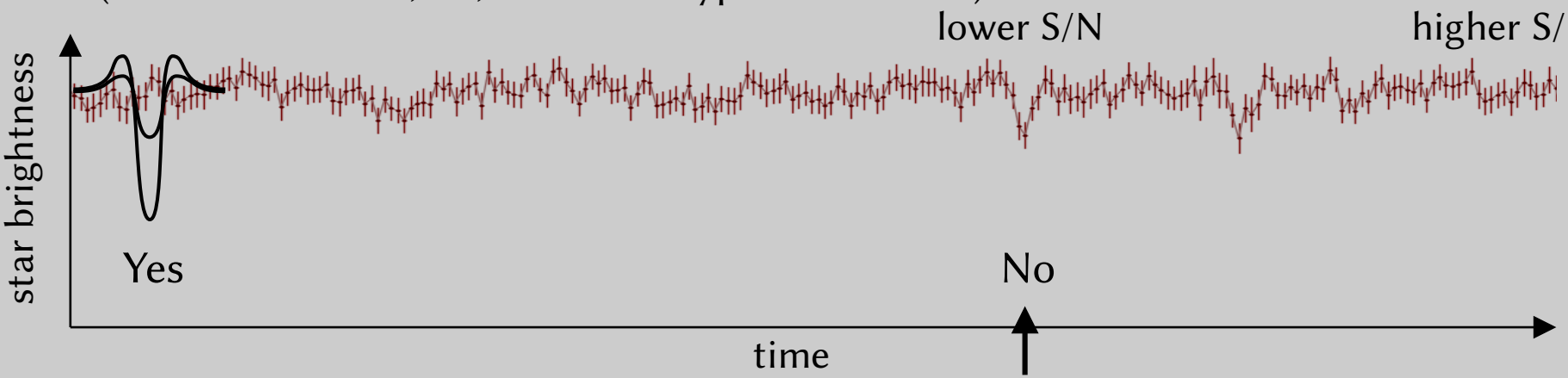
failed to reject ≠ 16%+ chance of being an occultation

better interpretation: “cleared” sections contain ~16% of real occultations (if any)



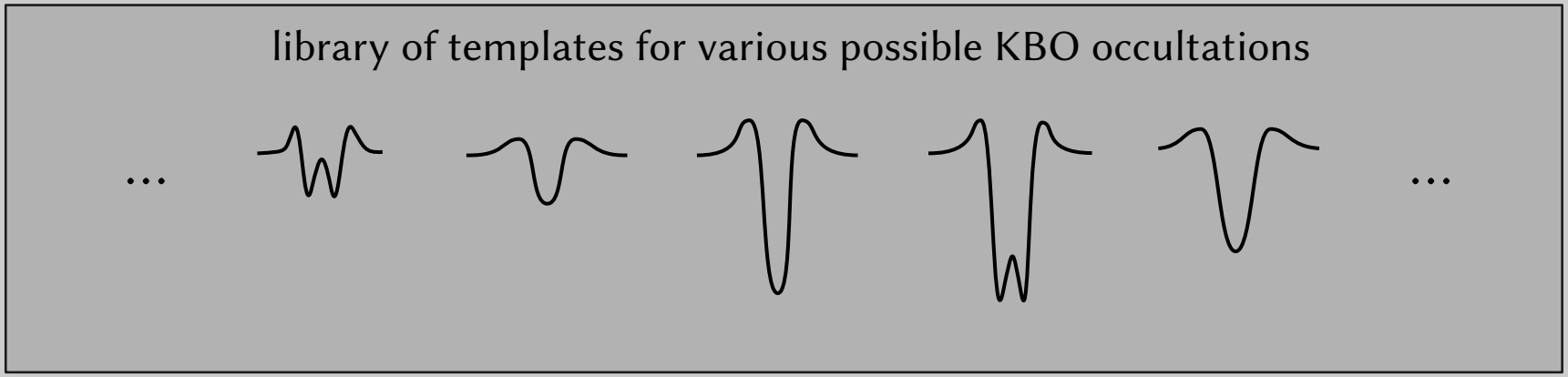
Can we rule out this occultation?

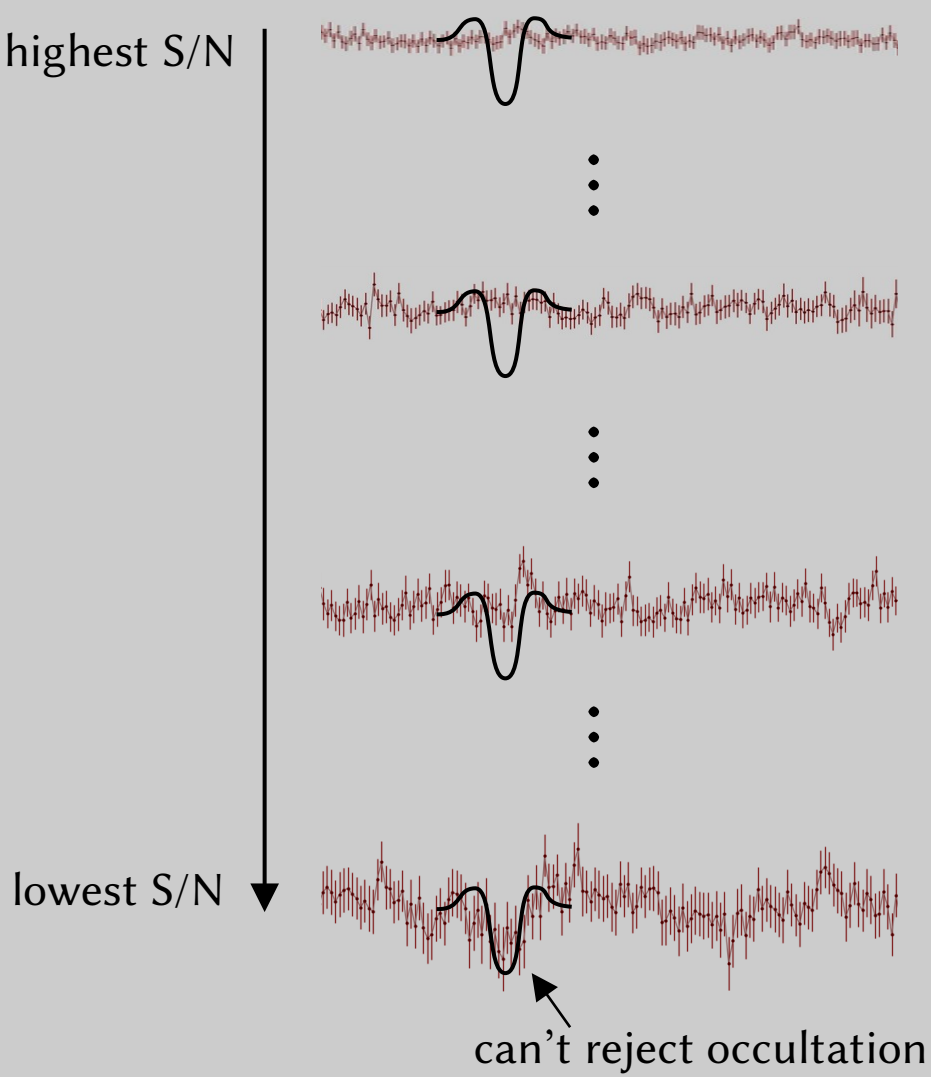
(allow for 16% loss, i.e., <+1σ from typical difference)

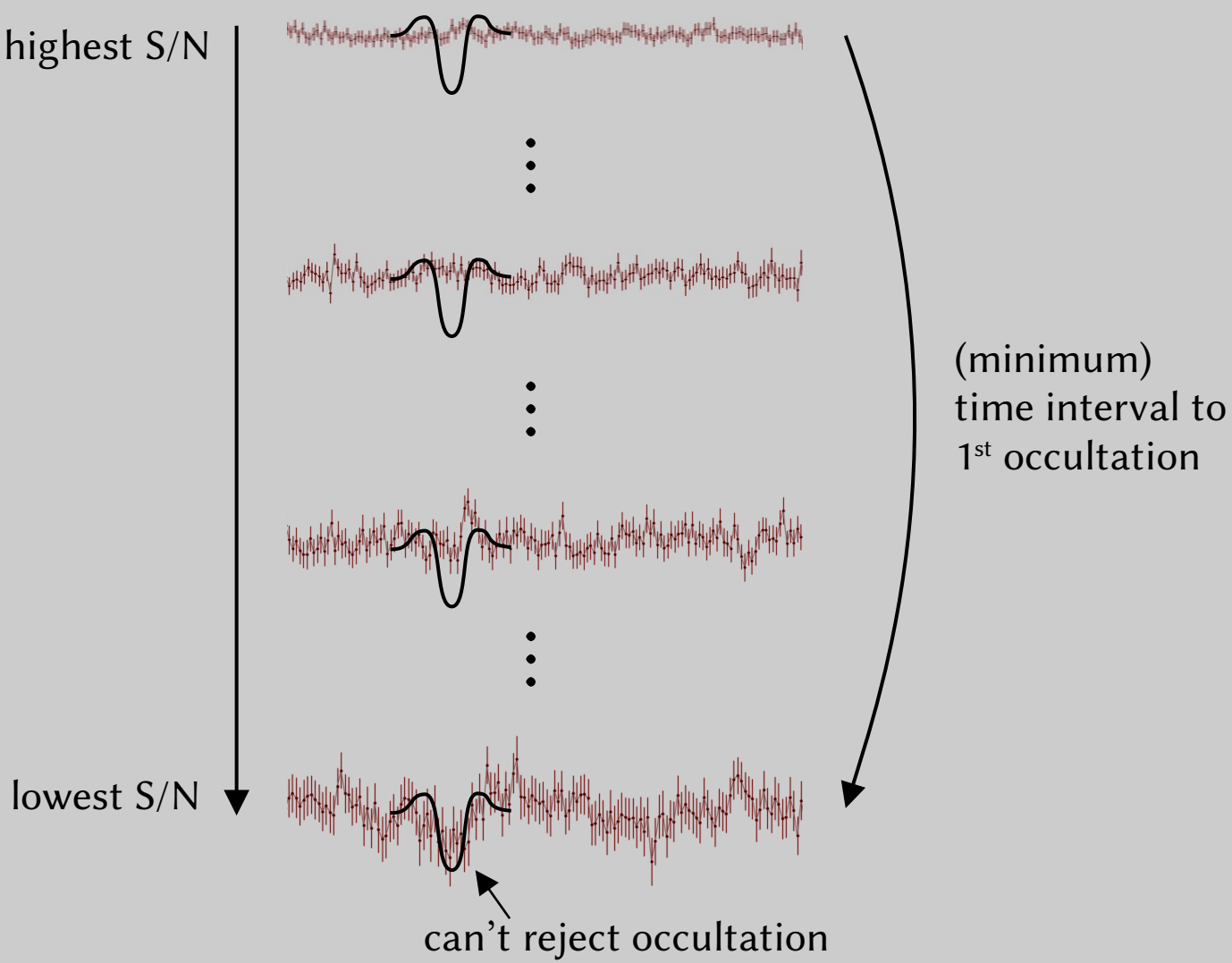


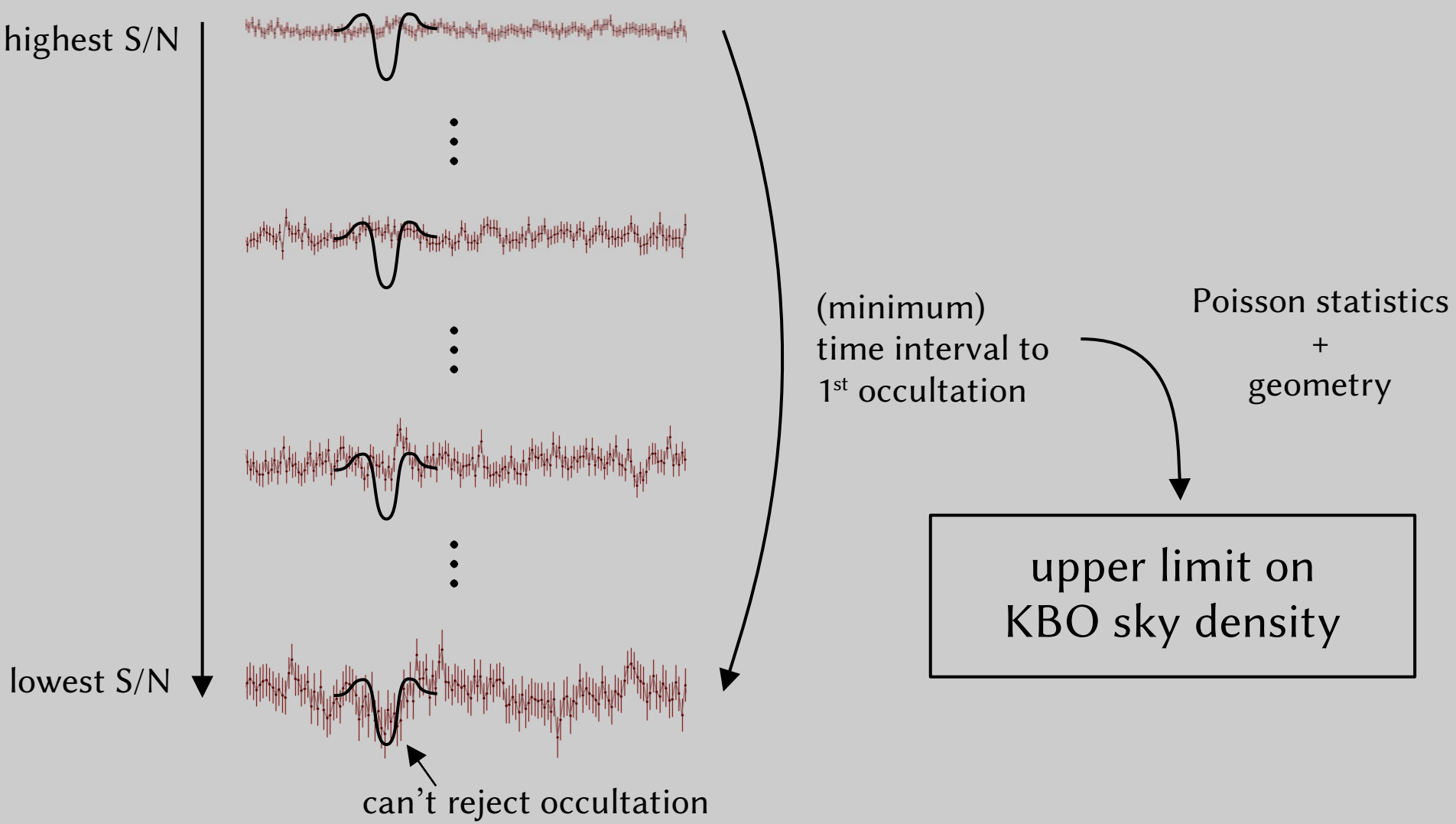
failed to reject ≠ 16%+ chance of being an occultation

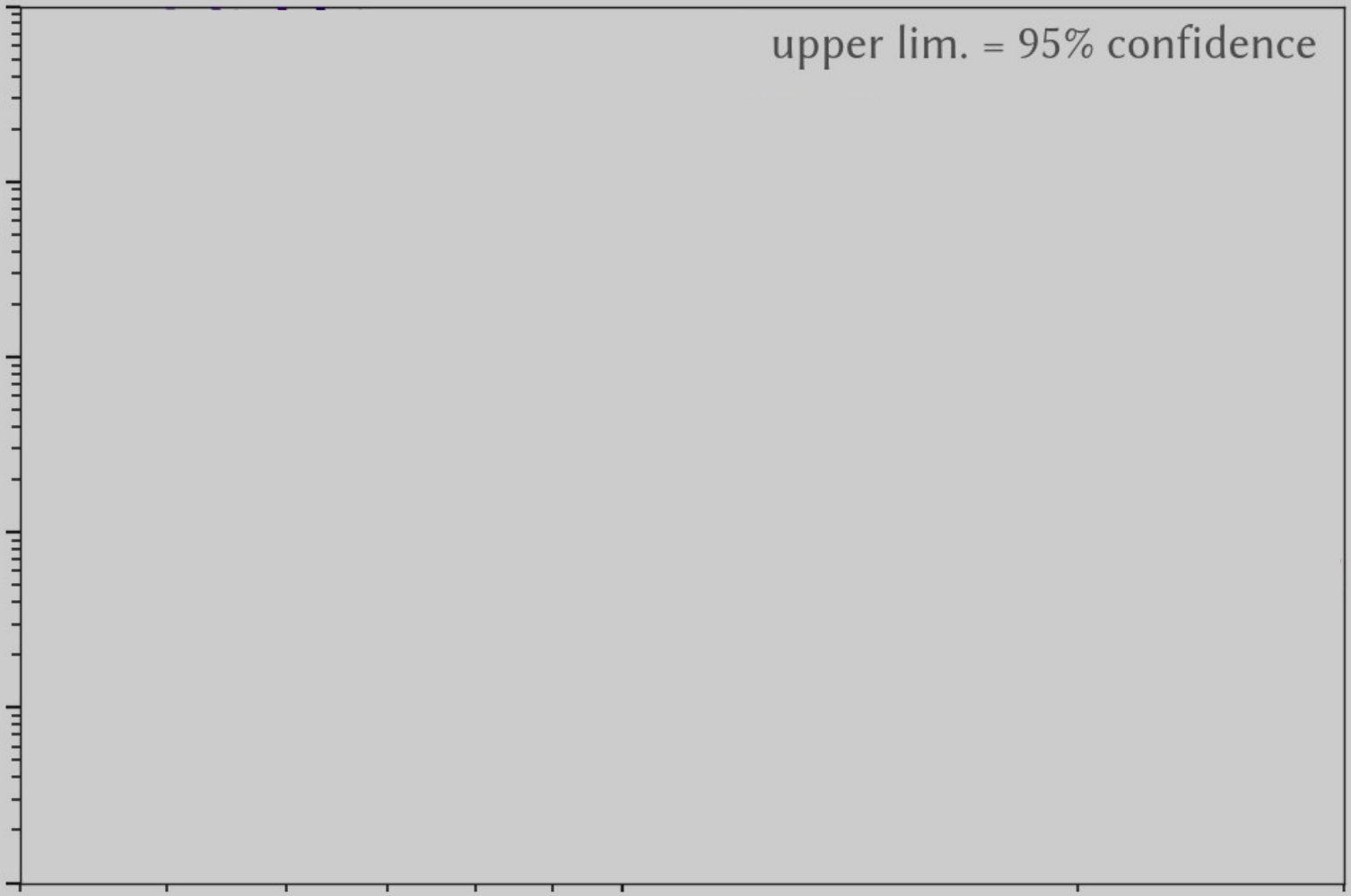
better interpretation: “cleared” sections contain ~16% of real occultations (if any)

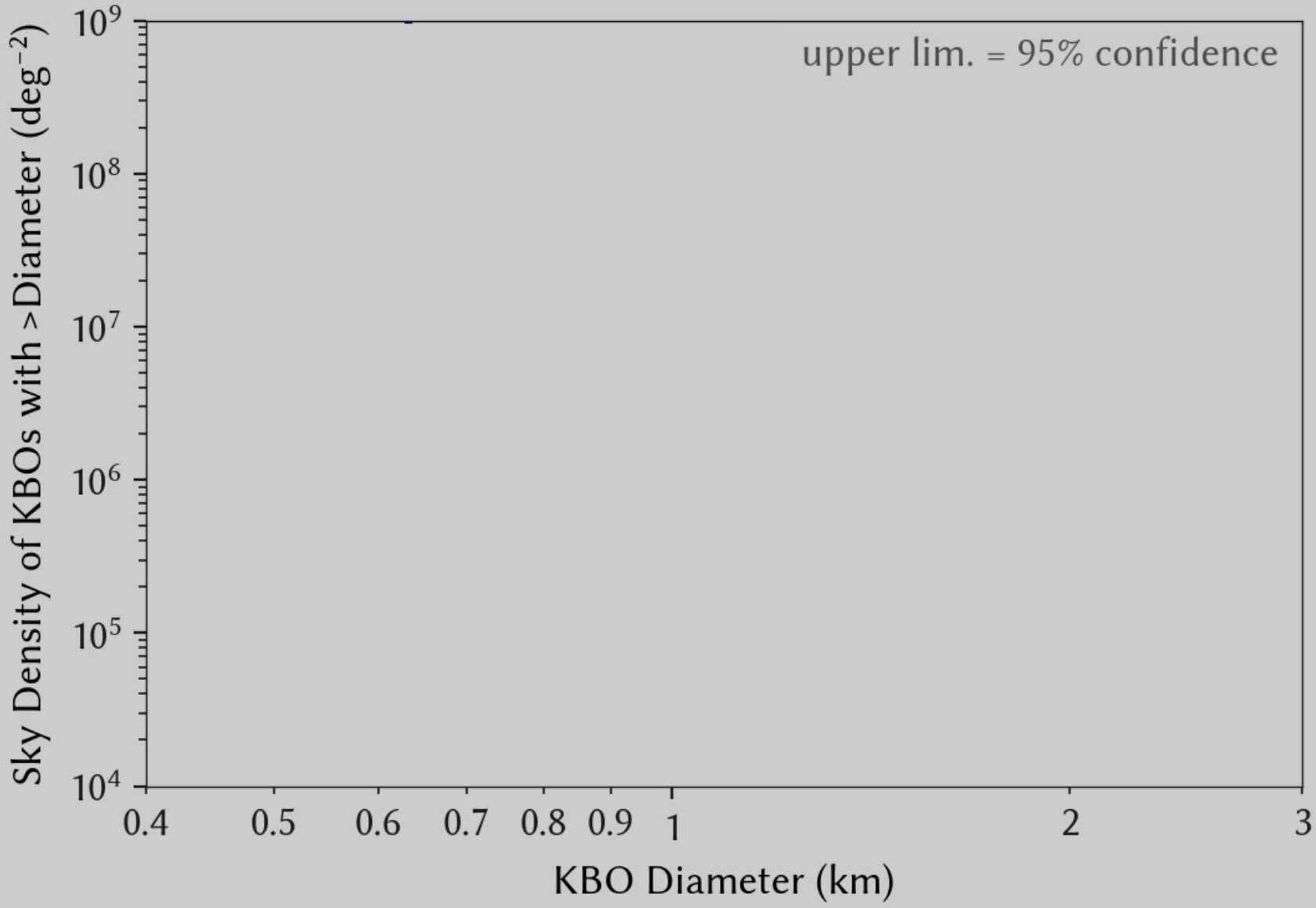


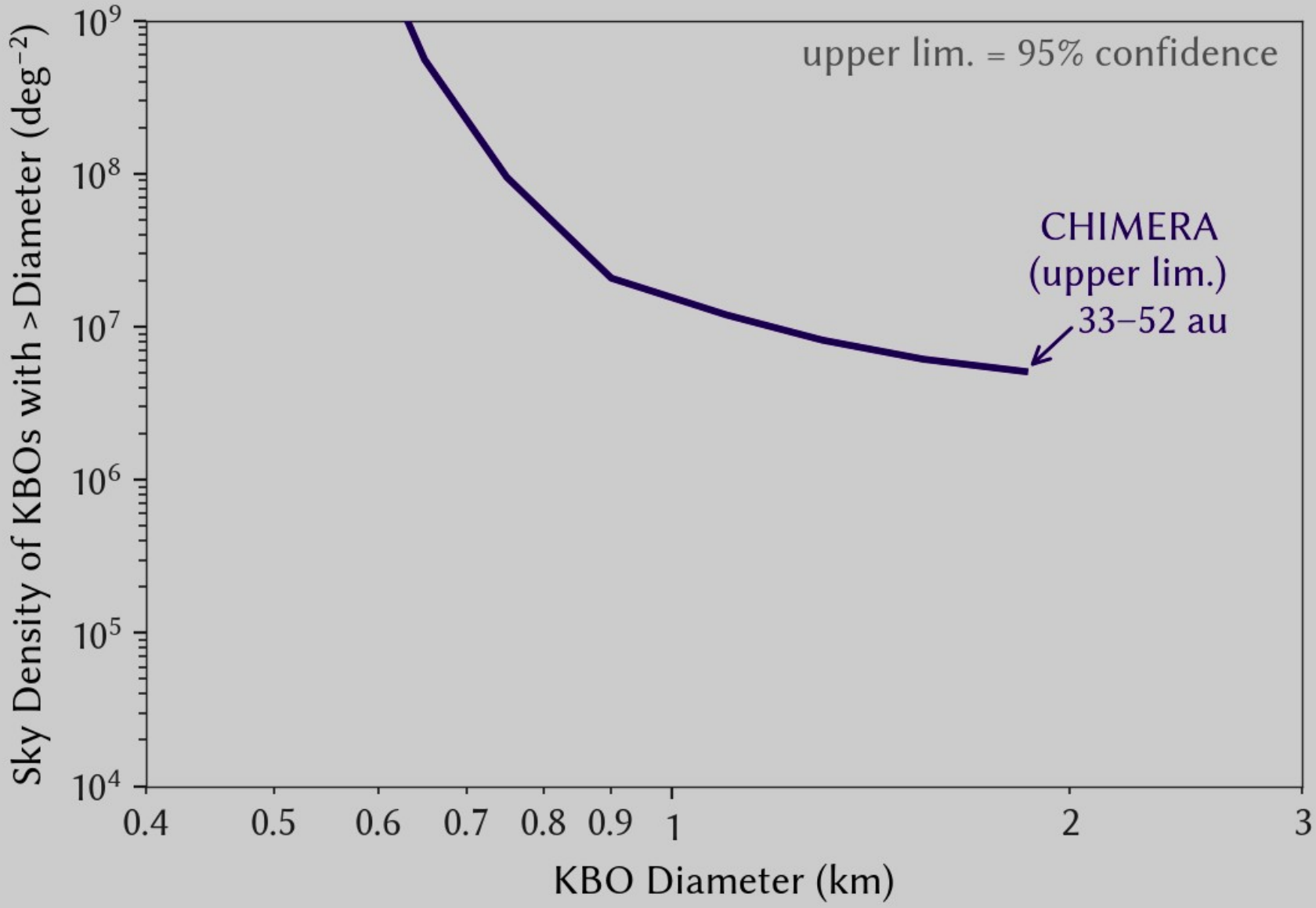

highest S/N
lowest S/N
can’t reject occultation

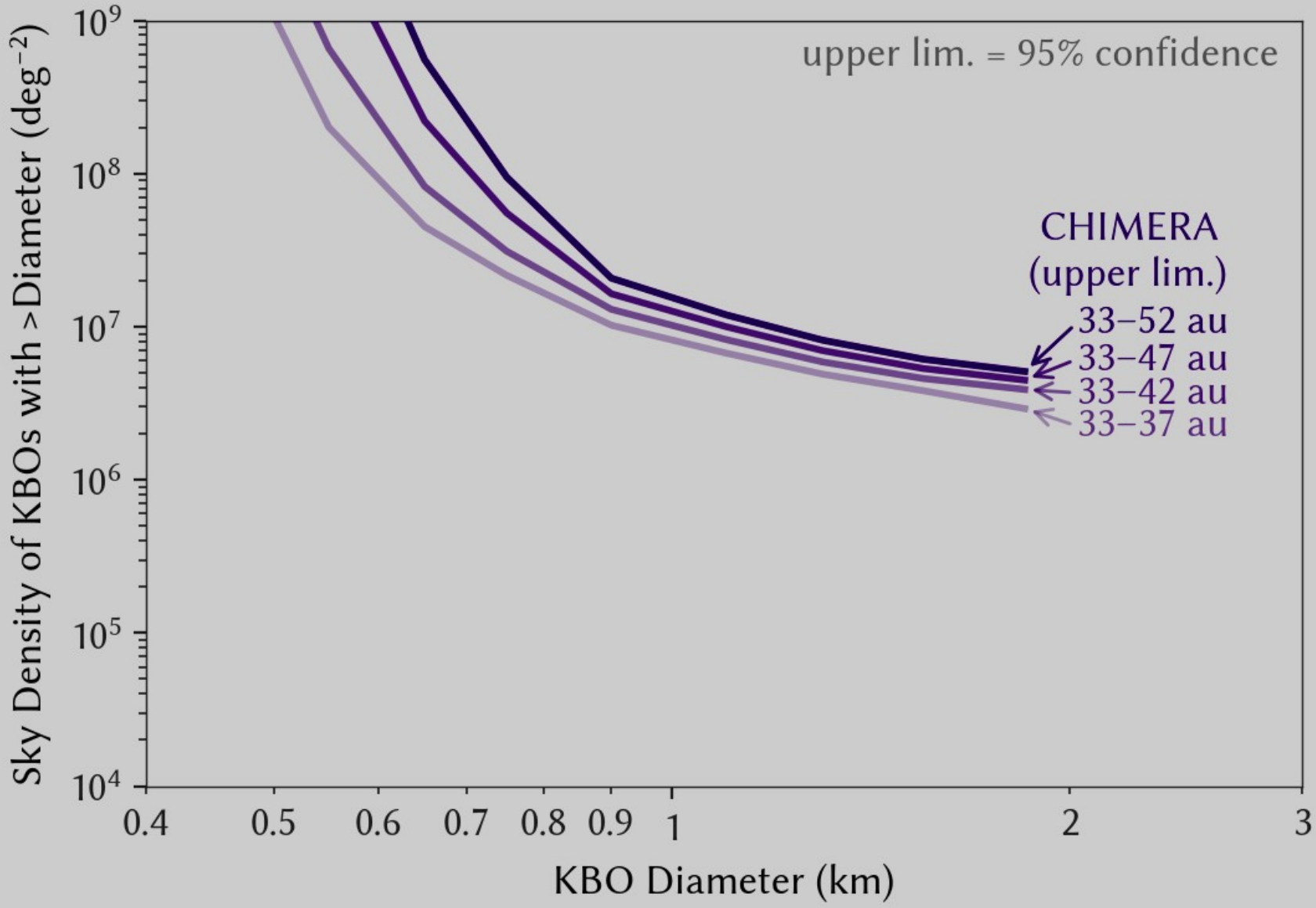

highest S/N
lowest S/N
(minimum)
time interval to
1st occultation
can't reject occultation

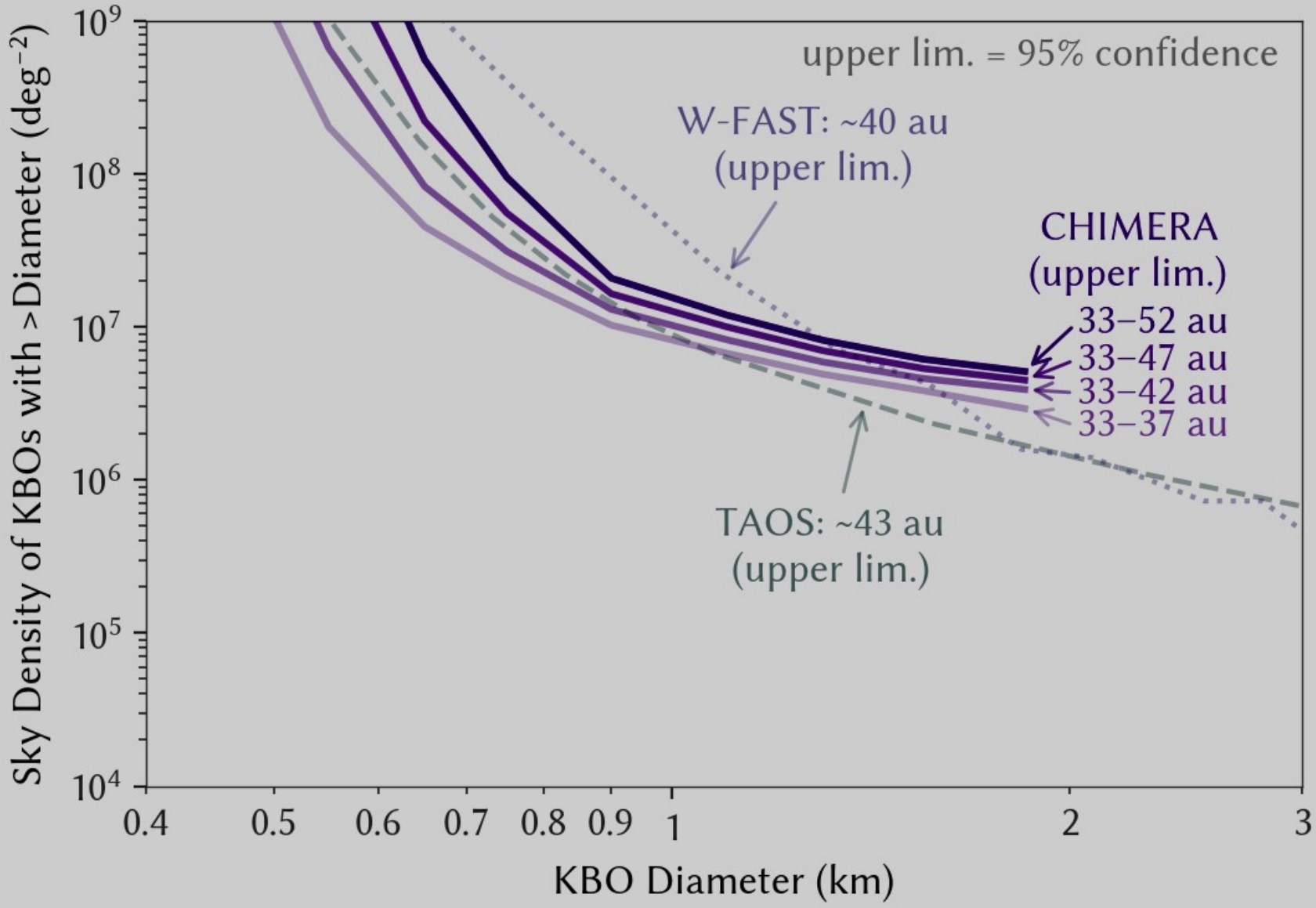

highest S/N
lowest S/N
can’t reject occultation
(minimum)
time interval to
1st occultation
Poisson statistics
+
geometry
upper limit on
KBO sky density


upper lim. = 95% confidence


upper lim. = 95% confidence
Sky Density of KBOs with >Diameter (deg^{-2})
10^9
10^8
10^7
10^6
10^5
10^4
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
KBO Diameter (km)


upper lim. = 95% confidence
CHIMERA
(upper lim.)
33–52 au
Sky Density of KBOs with >Diameter (deg^{-2})
10^9
10^8
10^7
10^6
10^5
10^4
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
KBO Diameter (km)


upper lim. = 95% confidence
CHIMERA
(upper lim.)
33–52 au
33–47 au
33–42 au
33–37 au
Sky Density of KBOs with >Diameter (deg⁻²)
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
KBO Diameter (km)


upper lim. = 95% confidence
W-FAST: ~40 au
(upper lim.)
CHIMERA
(upper lim.)
33–52 au
33–47 au
33–42 au
33–37 au
TAOS: ~43 au
(upper lim.)
Sky Density of KBOs with >Diameter (deg⁻²)
10⁹
10⁸
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0.4
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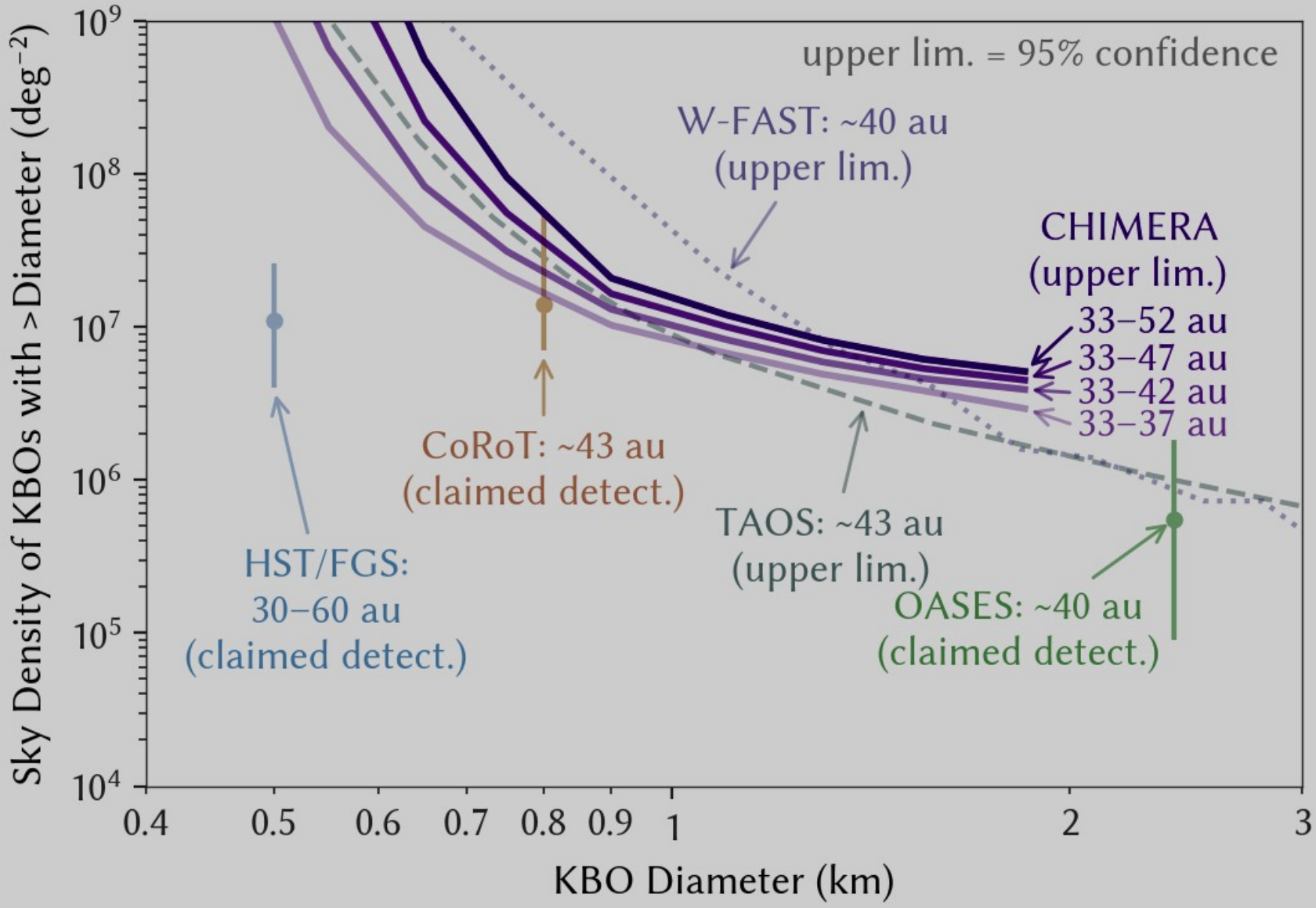
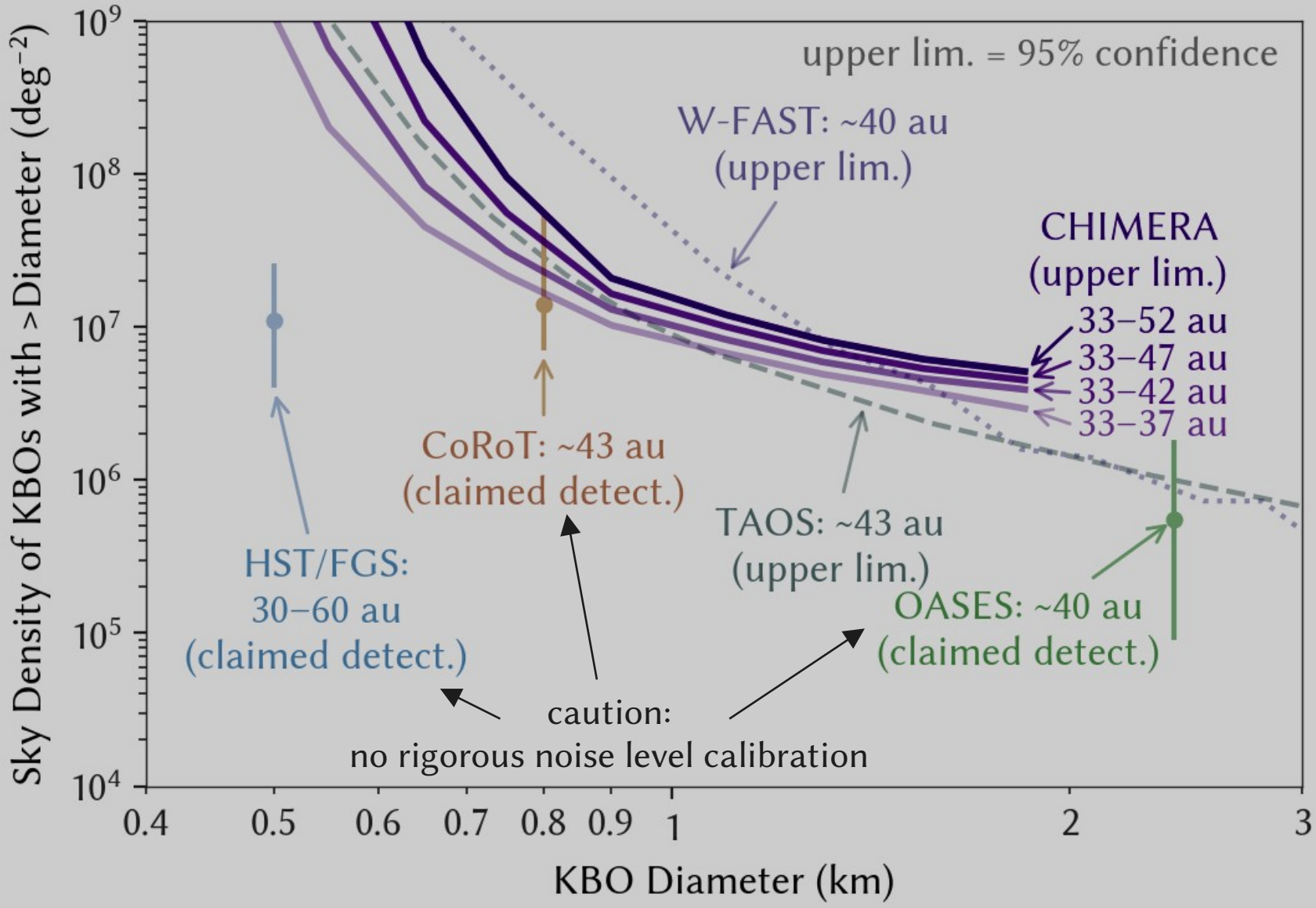
KBO Diameter (km)


upper lim. = 95% confidence
W-FAST: ~40 au
(upper lim.)
CHIMERA
(upper lim.)
33–52 au
33–47 au
33–42 au
33–37 au
CoRoT: ~43 au
(claimed detect.)
HST/FGS:
30–60 au
(claimed detect.)
TAOS: ~43 au
(upper lim.)
OASES: ~40 au
(claimed detect.)
Sky Density of KBOs with >Diameter (deg^{-2})
10^9
10^8
10^7
10^6
10^5
10^4
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
KBO Diameter (km)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TAOS: ~43 au
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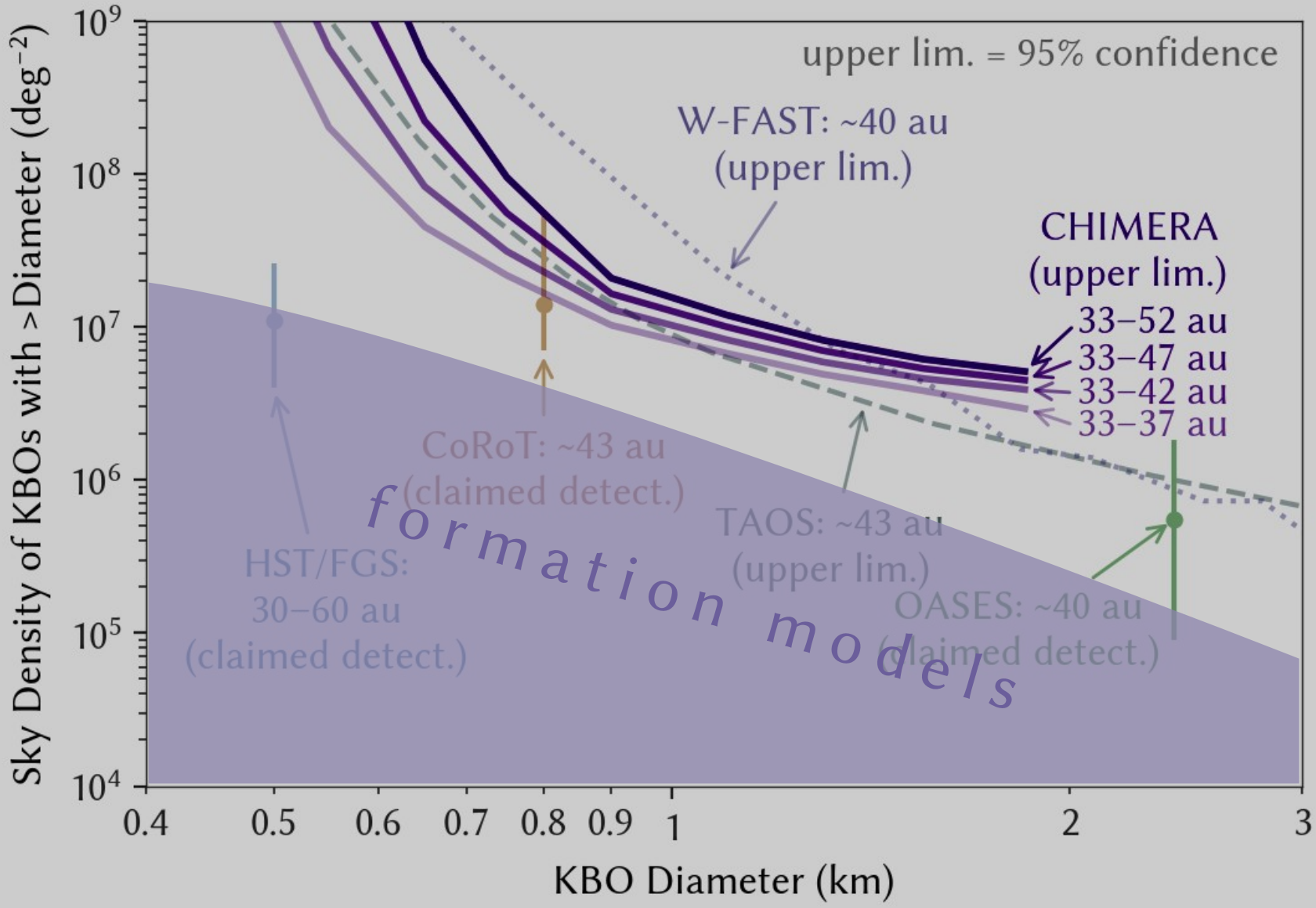
HST/FGS:
30–60 au
(claimed detect.)
OASES: ~40 au
(claimed detect.)
caution:
no rigorous noise level calibration
Sky Density of KBOs with >Diameter (deg^{-2})
10^9
10^8
10^7
10^6
10^5
10^4
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
KBO Diameter (km)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CHIMERA
(upper lim.)
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formation models
Sky Density of KBOs with >Diameter (deg⁻²)
KBO Diameter (km)
10⁹
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0.5
0.6
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0.8
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1
2
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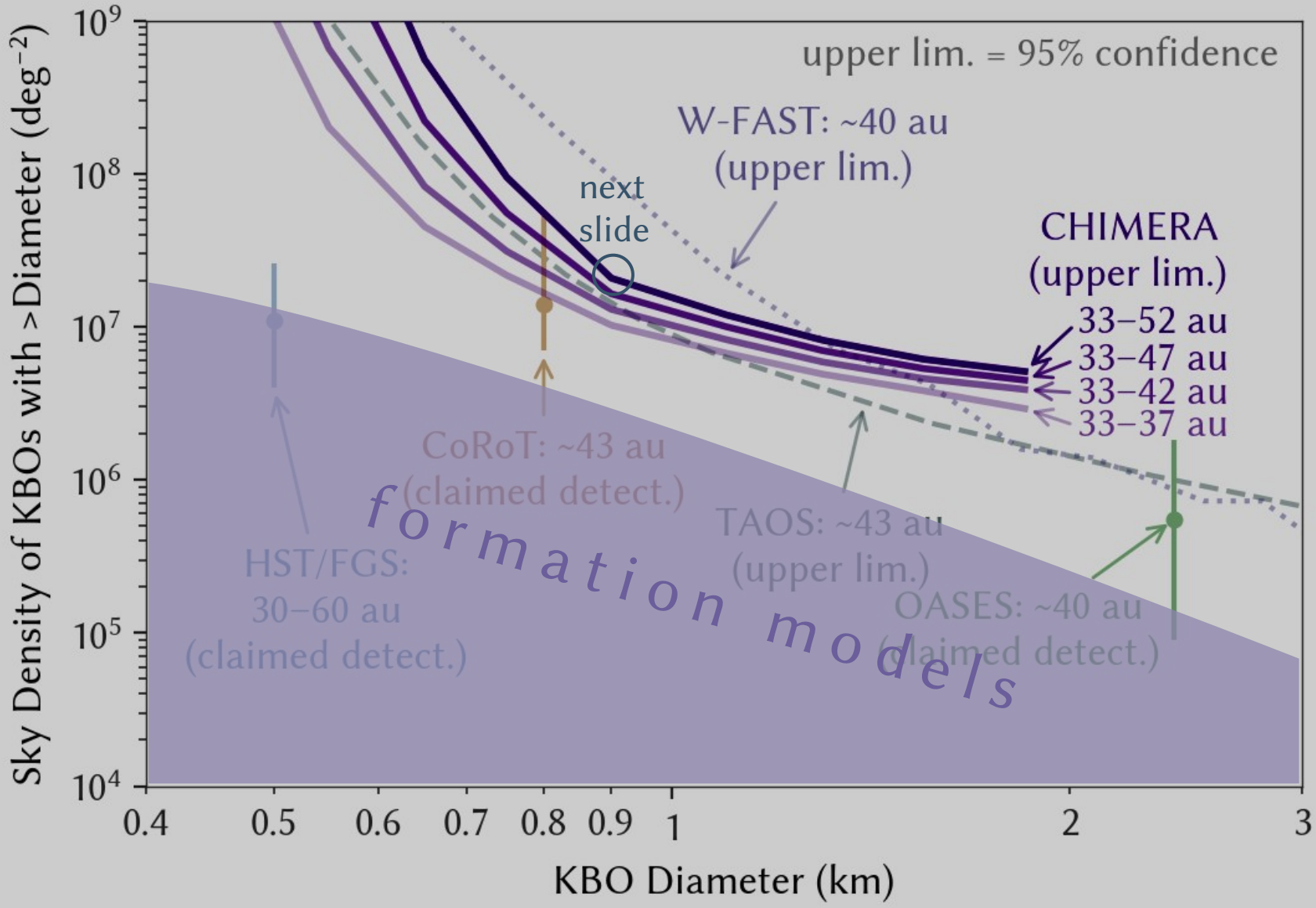
upper lim. = 95% confidence
W-FAST: ~40 au
(upper lim.)
next
slide
CHIMERA
(upper lim.)
33–52 au
33–47 au
33–42 au
33–37 au
CoRoT: ~43 au
(claimed detect.)
TAOS: ~43 au
(upper lim.)
HST/FGS:
30–60 au
(claimed detect.)
OASES: ~40 au
(claimed detect.)
formation models
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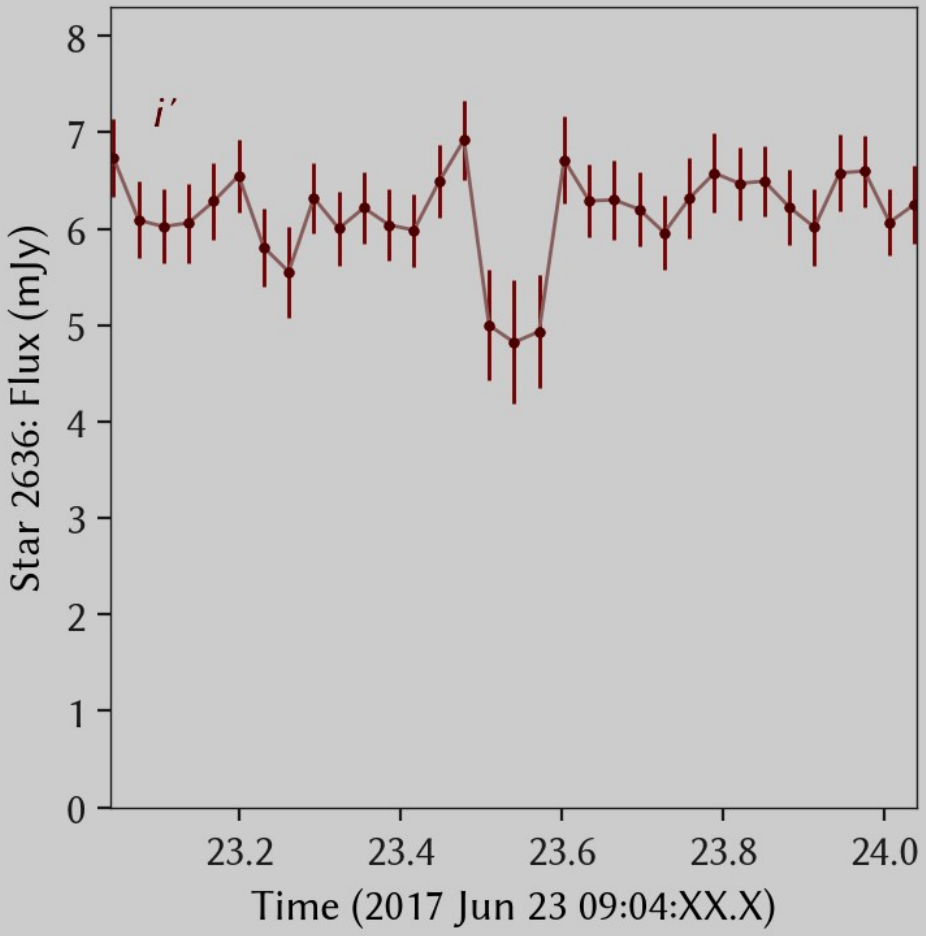
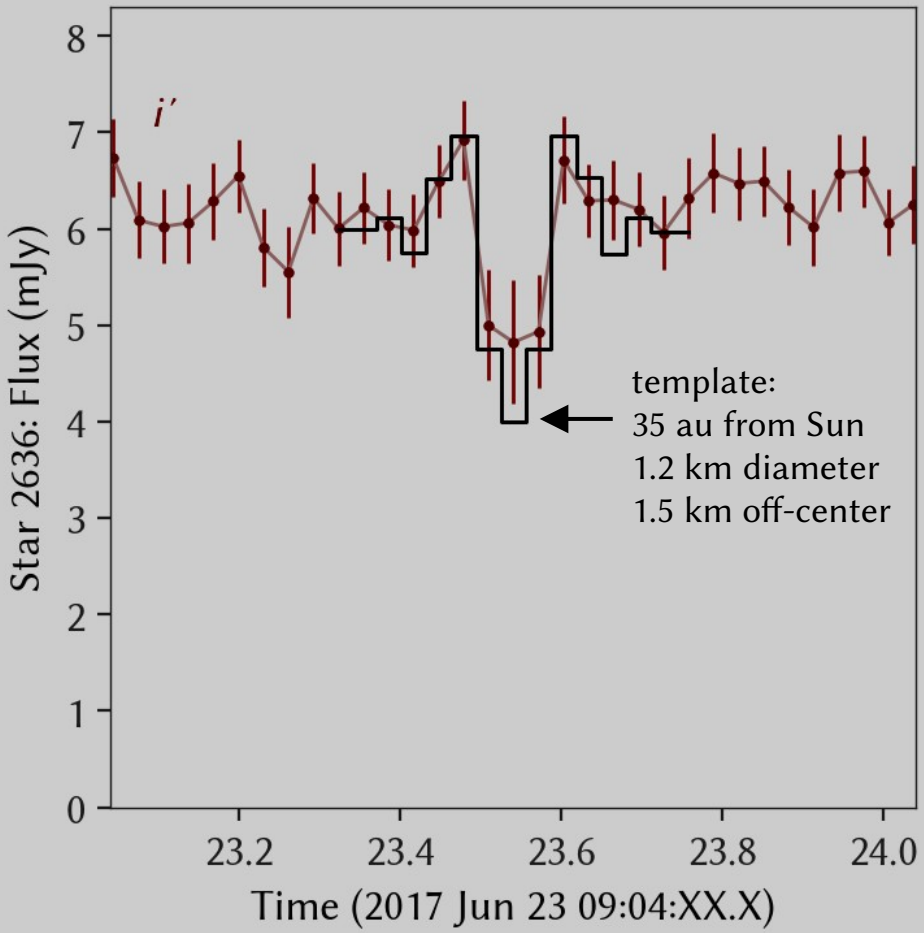
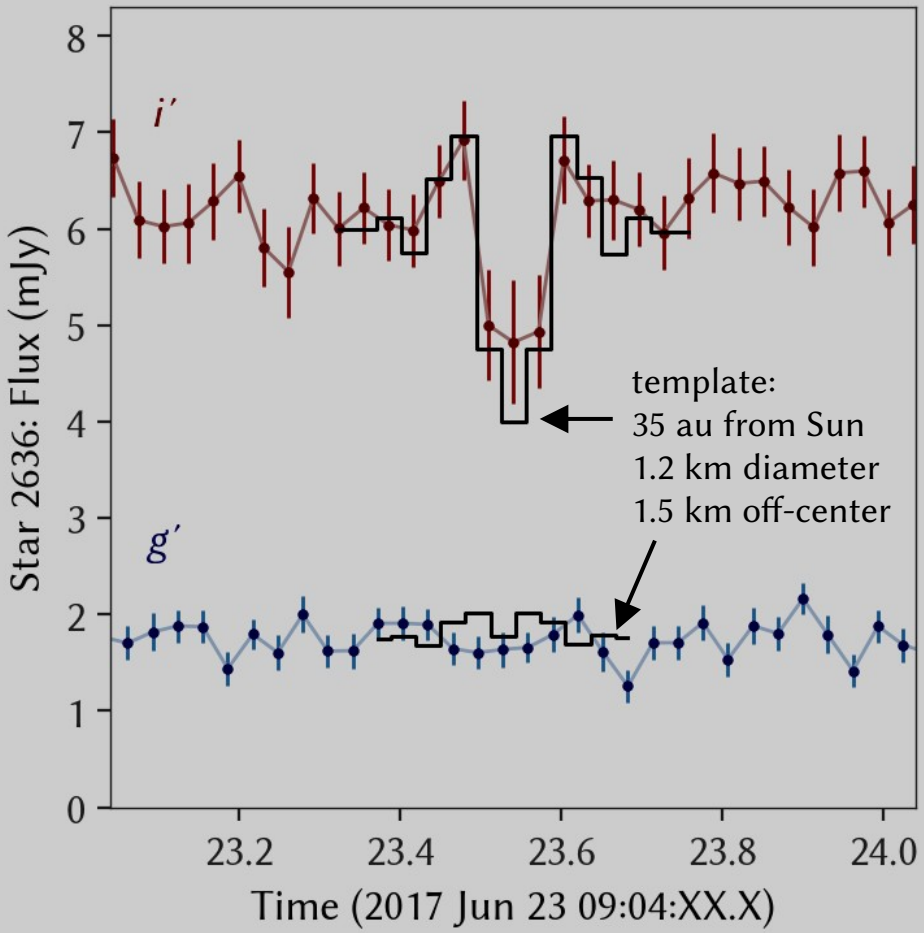
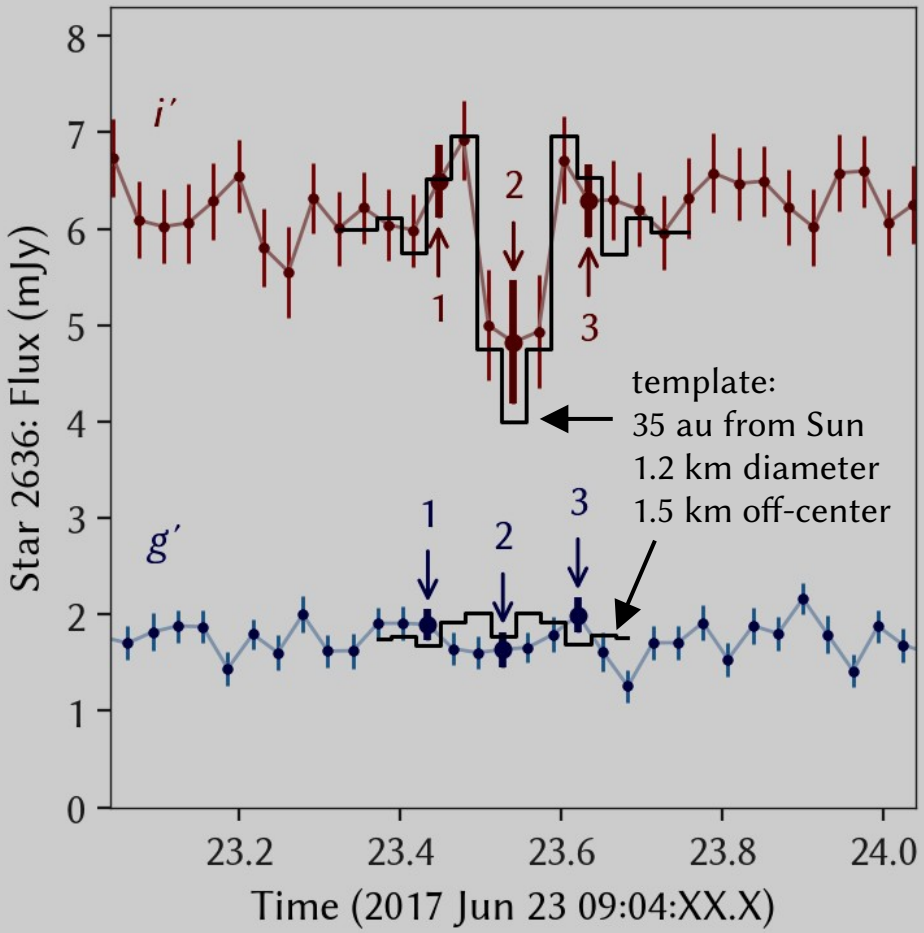
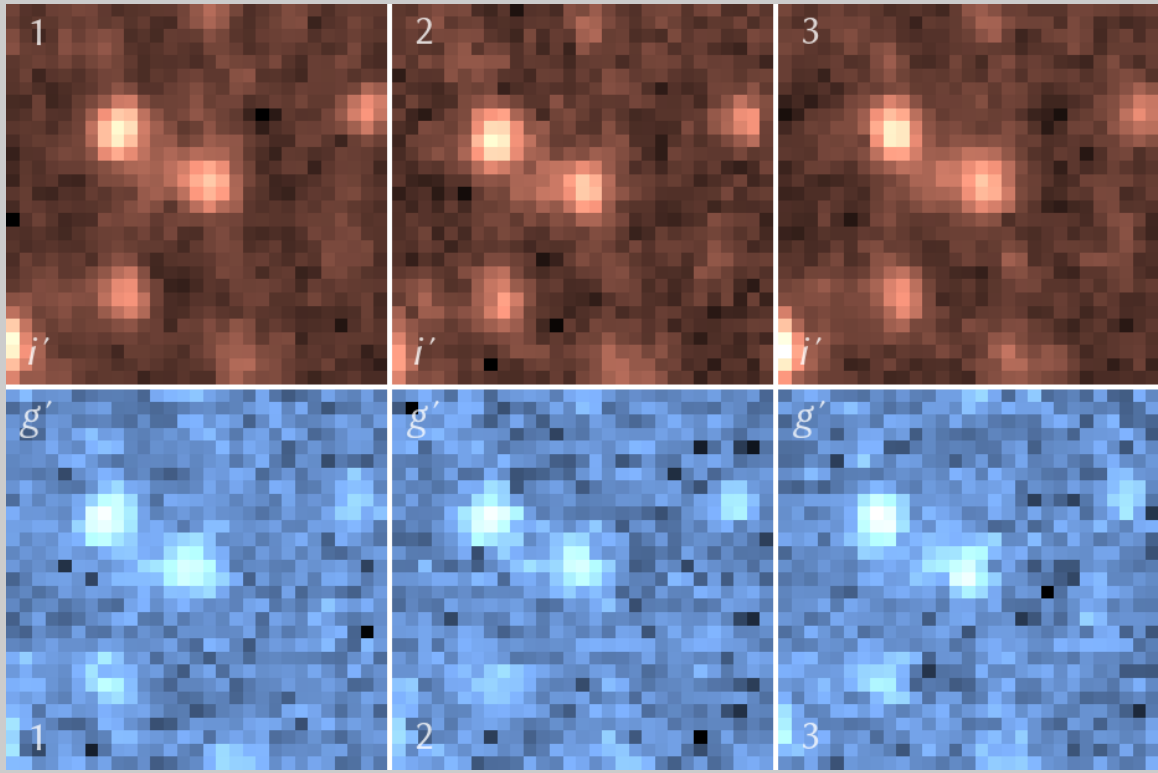
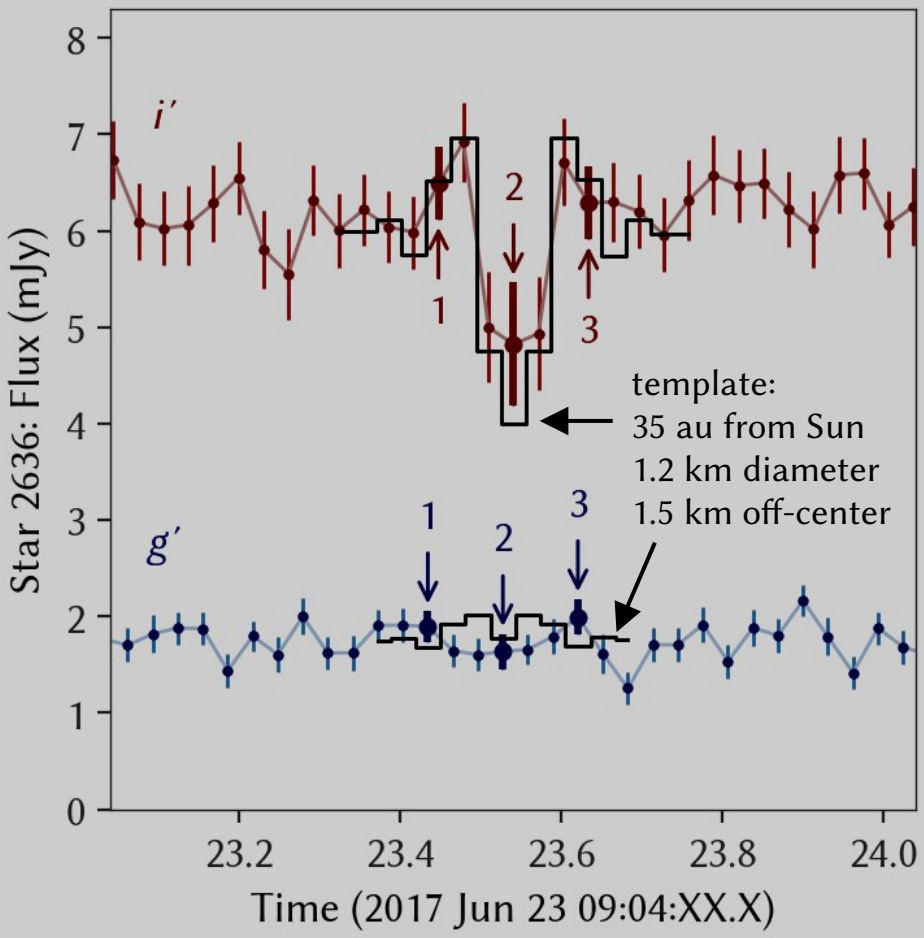

i′
Star 2636: Flux (mJy)
0
1
2
3
4
5
6
7
8
23.2
23.4
23.6
23.8
24.0
Time (2017 Jun 23 09:04:XX.X)

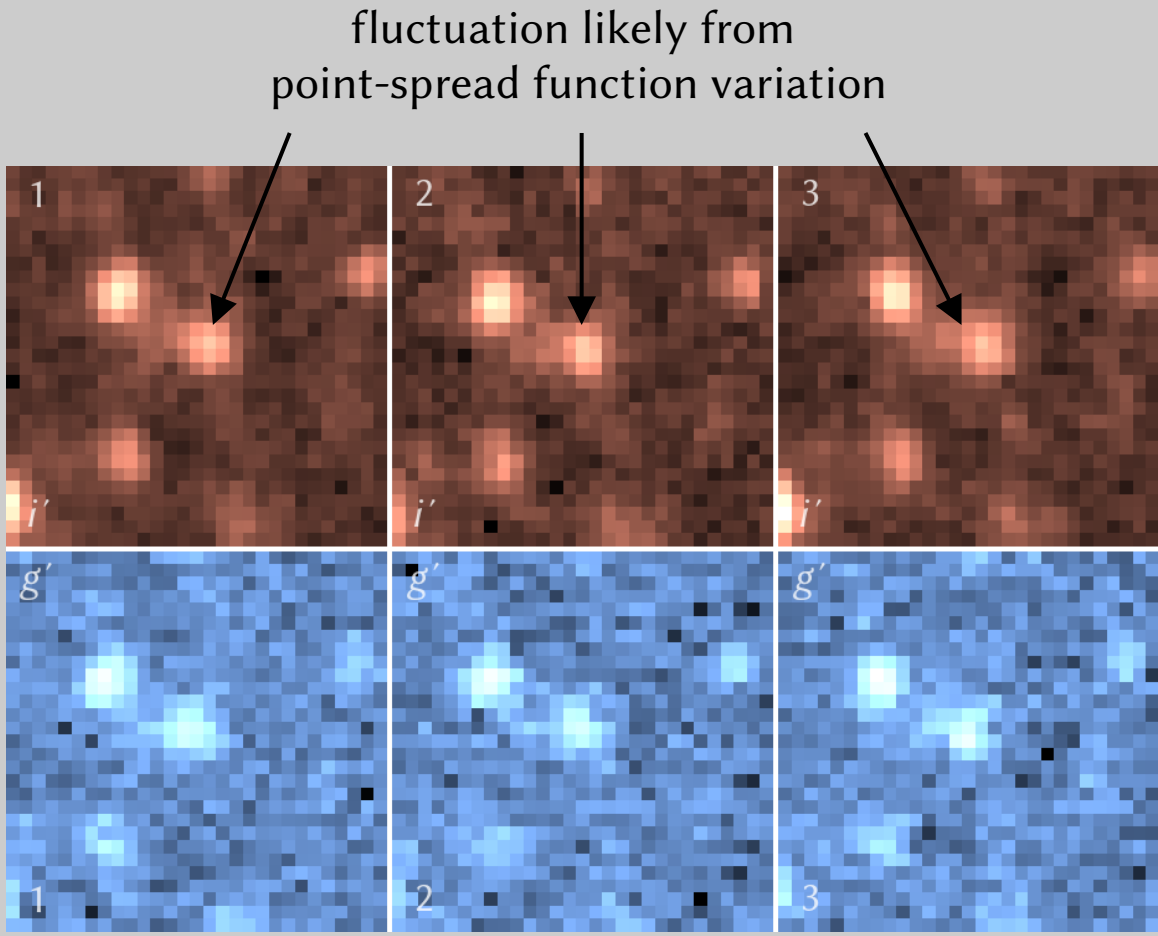

i′
template:
35 au from Sun
1.2 km diameter
1.5 km off-center
Star 2636: Flux (mJy)
0
1
2
3
4
5
6
7
8
23.2
23.4
23.6
23.8
24.0
Time (2017 Jun 23 09:04:XX.X)


i′
g′
template:
35 au from Sun
1.2 km diameter
1.5 km off-center
Star 2636: Flux (mJy)
Time (2017 Jun 23 09:04:XX.X)
0
1
2
3
4
5
6
7
8
23.2
23.4
23.6
23.8
24.0


Star 2636: Flux (mJy)
Time (2017 Jun 23 09:04:XX.X)
i′
g′
1
2
3
template:
35 au from Sun
1.2 km diameter
1.5 km off-center


1
2
3
i′
g′


Star 2636: Flux (mJy)
Time (2017 Jun 23 09:04:XX.X)
i′
g′
1
2
3
template:
35 au from Sun
1.2 km diameter
1.5 km off-center


fluctuation likely from
point-spread function variation
1
2
3
i′
g′

Conclusions

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Zhang et al. 2023. "CHIMERA Occultation Constraints on the Abundance of Kilometer-scale Kuiper Belt Objects," *AJ*, 166, 242.