

Searching for Substellar Companions with Keck and Gemini Adaptive Optics

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Introduction

Objective:

Obtain useful constraints on the frequency of wide brown dwarf and planetary companions.

Instruments and Telescopes:

Near-infrared adaptive optics imaging on Gemini and Keck

Keck AO+KCAM

256x256, 17.43 mas/pixel, 4.46"x4.46"

Gemini Hokupa'a AO+QUIRC

1024x1024, 19.74 mas/pixel, 20.2"x20.2"

Target Selection:

Require natural guide stars <30" from target and $R < 14$ for Keck and $R < 14-18$ for Gemini

Sample:

extrasolar planetary systems and young stars

Observing Strategy

Saturation and Dynamic Range:

Short exposures in which target is not saturated

-> photometric calibration, detection of close companions

Long exposures that are background-limited far from primary

-> detection of faint wide companions

Keck targets = H=2-7

-> short exposures w/ N3, N2, N1, open, long exp+open

Gemini targets = H=8-11

-> exposures of 1 and 75 sec

Example: H=5

2.5 sec + N2 = not saturated

2.5 sec + N1 = saturated

2.5 sec + open = saturated

25 sec + open = saturated at $r < 30$ pix ($< 0.5''$)

Observing Strategy

Latent Images and Flat Fielding:

Keck:

- twilight sky flats
- no latent images

Gemini:

- probing separations of $<4''$ -> use 2x2 5" dithers and use diagonal frame as flat field
- prefer to obtain all short exposures before long exposures to avoid latent images, but wasn't possible because of need to minimize filter changes

Photometric Calibration:

- Calibrate photometry with short exposures of the target
- For Gemini queue observations, can check against default calibration

Observing Strategy

Frequency of observations of PSF stars:

Keck:

Typical time lapse is ~10-20 min.

Gemini:

In reasonable observing strategy and given official overheads, the minimum time between images of target and PSF is ~30 min.

Choice of PSF stars:

- Prefer a PSF star that has is similar to target in magnitude, color, and position on sky.
- For both Keck and Gemini, most of our targets are grouped into pairs that are close together on the sky and the stars in a pair are used as PSF stars for each other.

Observing Strategy

Astrometry:

- Accurate positions of candidate companions relative to primary stars are needed for proper motion measurements.
 - > Without moving telescope, obtain short unsaturated exposure of primary followed by the long exposures.
- Presence of multiple companions in field of view is helpful.

Registration of individual exposures:

- Registration is easily performed if unsaturated objects are detected in individual frames, which is more likely the larger field of view of Gemini data.
- Registration is more difficult when the only detected sources is the highly saturated primary.
 - > For Keck data, obtain first half of exposures at 1 position and second half at a second position offset by 5, 5 pixels; sufficient for bad pixel rejection while making registration easier.

Observing Strategy

Choice of filters:

Use JHK expect multiple candidate companions or companions that are cool enough to show methane absorption.

Keck:

-> Most efficient to use only H and follow up candidates with more band, proper motion data, or spectroscopy.

Gemini:

-> Because of high official overhead per target, the additional time to use 3 filters rather than 1 is small.

Observing Sequence

Keck:

- 1) center target #1 in upper left quadrant
- 2) 10 x longest exp/least opaque filter that doesn't saturate
- 3) repeat filters N2, N1, open
- 4) repeat 1-3 at target #2
- 5) return to #1, open+shortest exposure, offset to dead quadrant, 3 long exposures/dither/3 long exposures
- 6) repeat 4 at 2 more PA's (+120, +240)
- 7) repeat 5-6 at #2

Gemini:

- 1) 1 sec exposure in 2x2 dither
- 2) 2x75 sec exposures in 2x2 dither
- 3) repeat 1-2 at 2 more filters
- 4) repeat 1-3 at next target

Reduction and Analysis

Basic image reduction:

Dark subtraction, flat fielding

Registration:

Use faint sources or outer PSF of saturated target (but tricky because of rotating PSF)

Keck image properties:

- point-like artifacts within seeing disk
- elongated artifacts outside of seeing disk
- rotating PSF
- waffle
- ghosts

Gemini image properties:

smoother PSF, fewer point-like artifacts

Reduction and Analysis

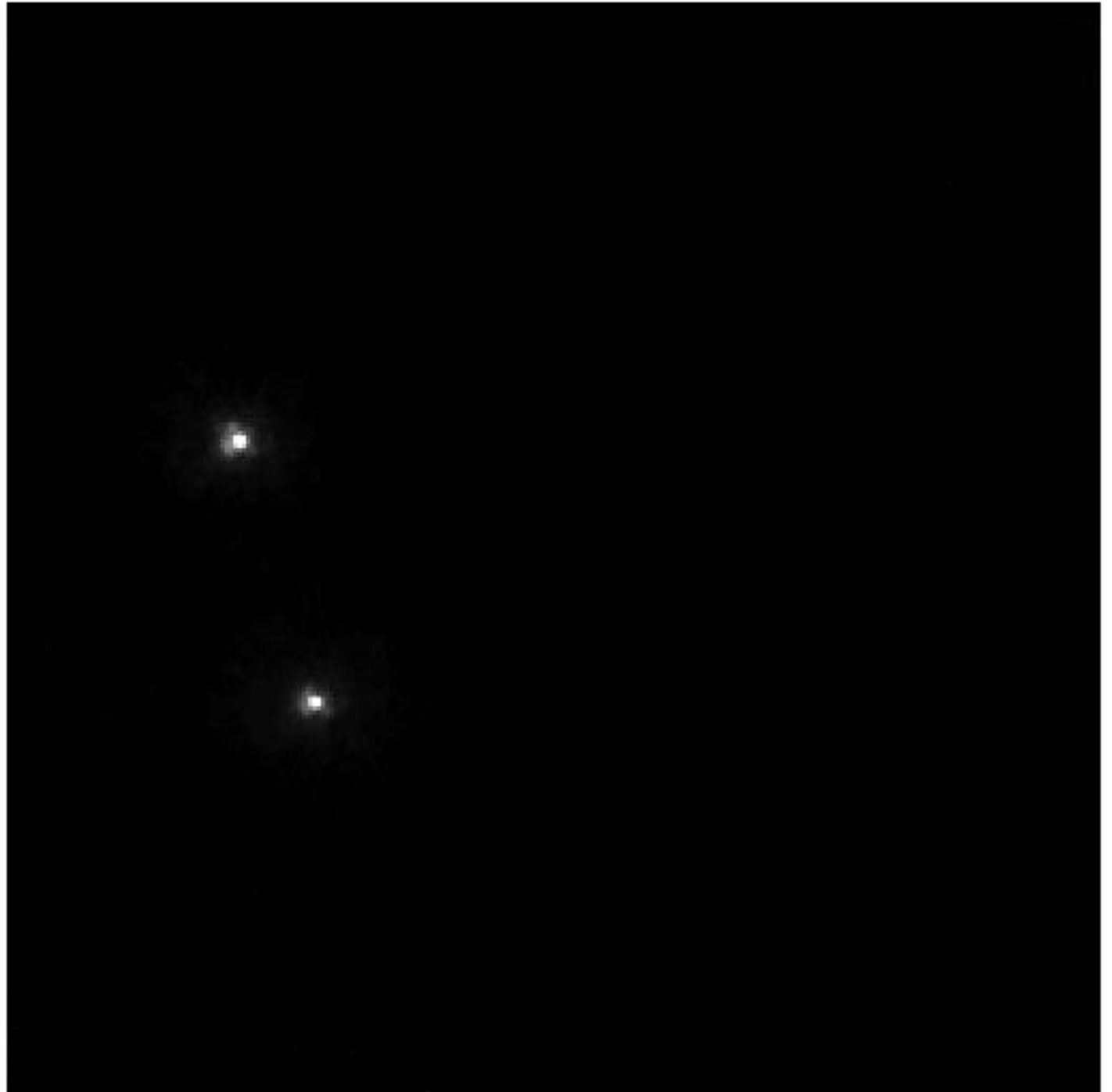
Close companions ($<0.5''$):

- Deconvolution is not useful because of rotation of PSF with time and the frequent saturation of the primary.
- Close companions must be identified by visually comparing to PSF star.

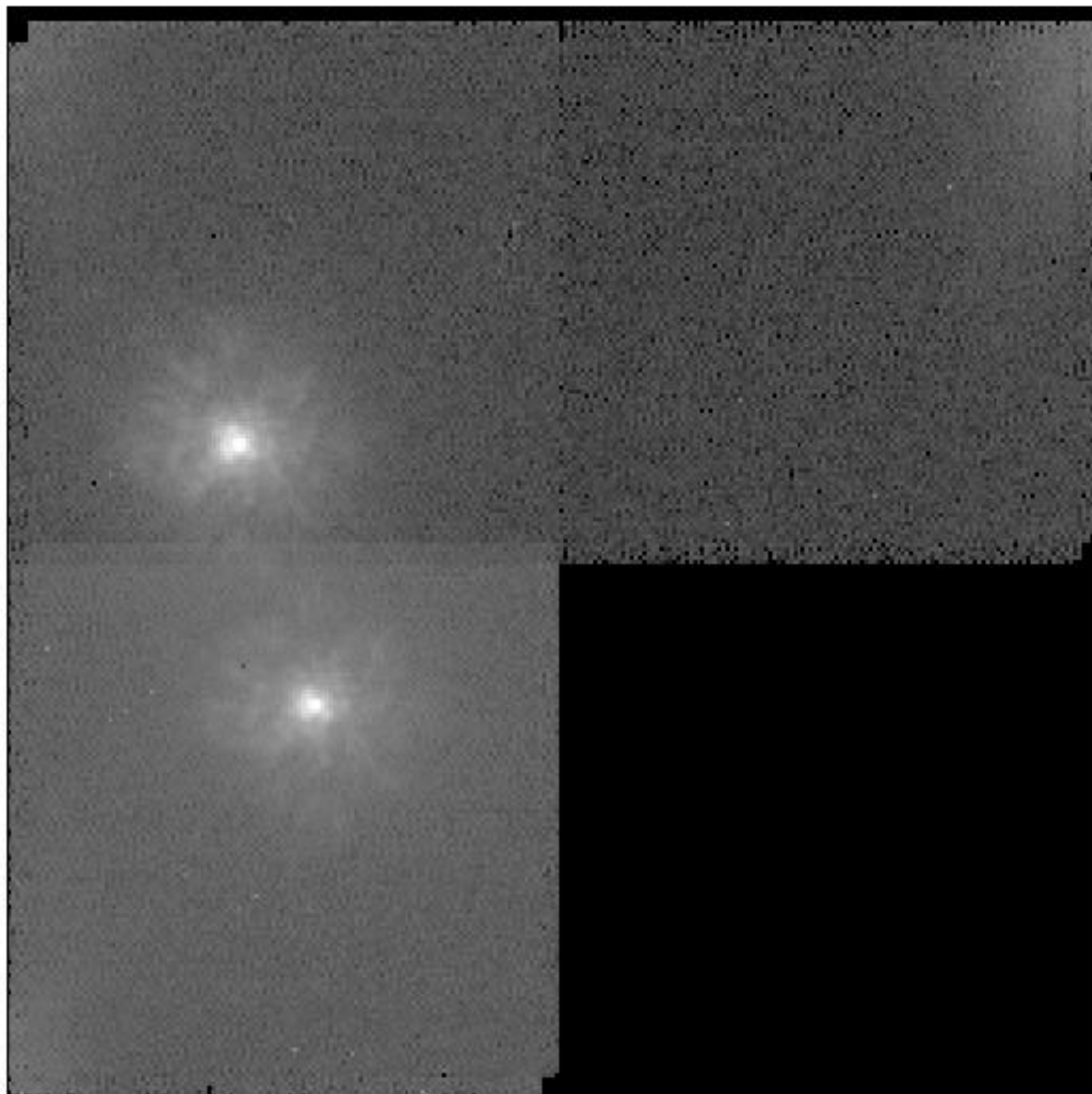
Wide companions ($>0.5''$):

PSF star is unnecessary; companions are easily identified visually

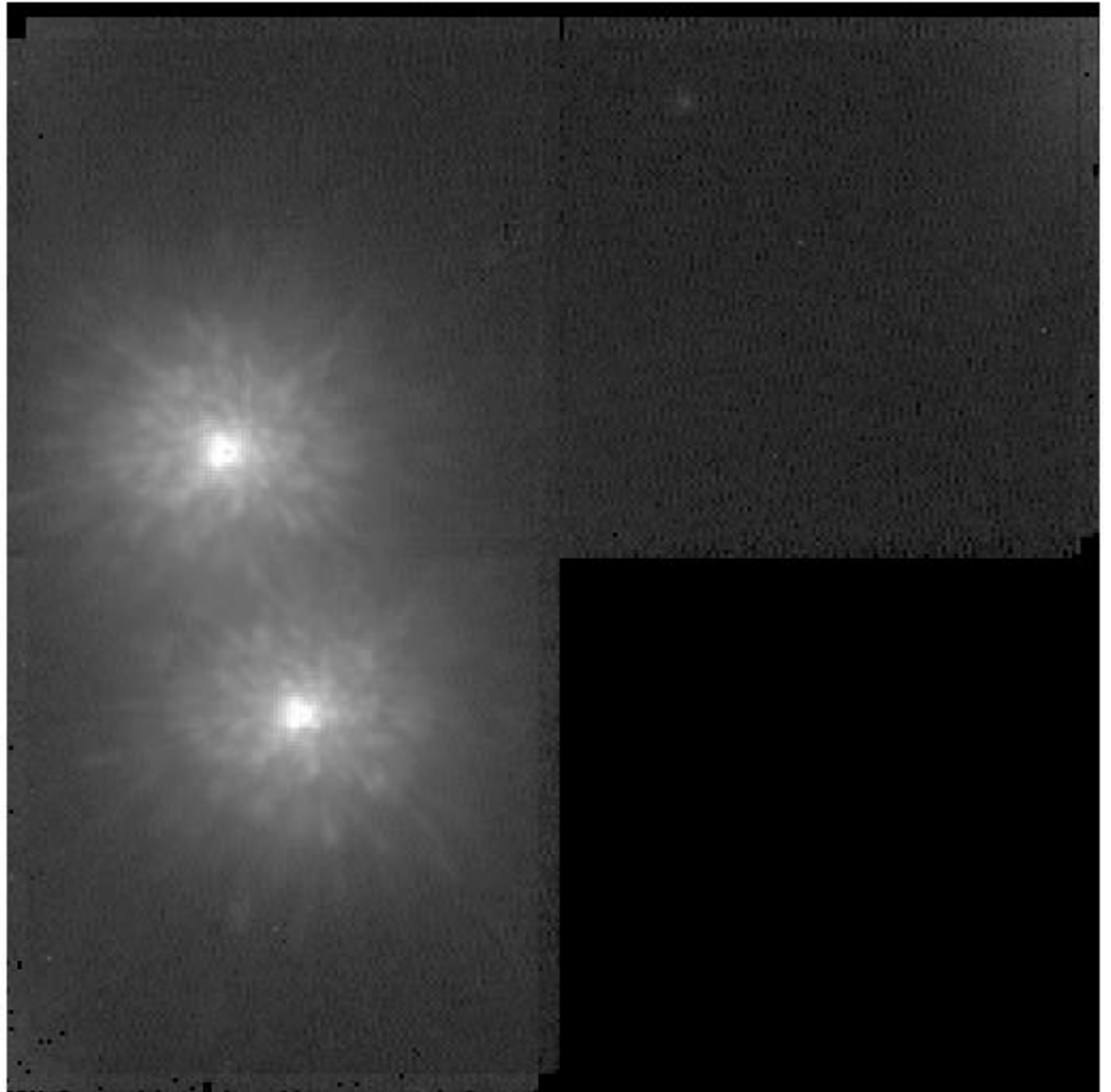
Keck
N1+7 x 2s
linear scale
4.46"x4.46"



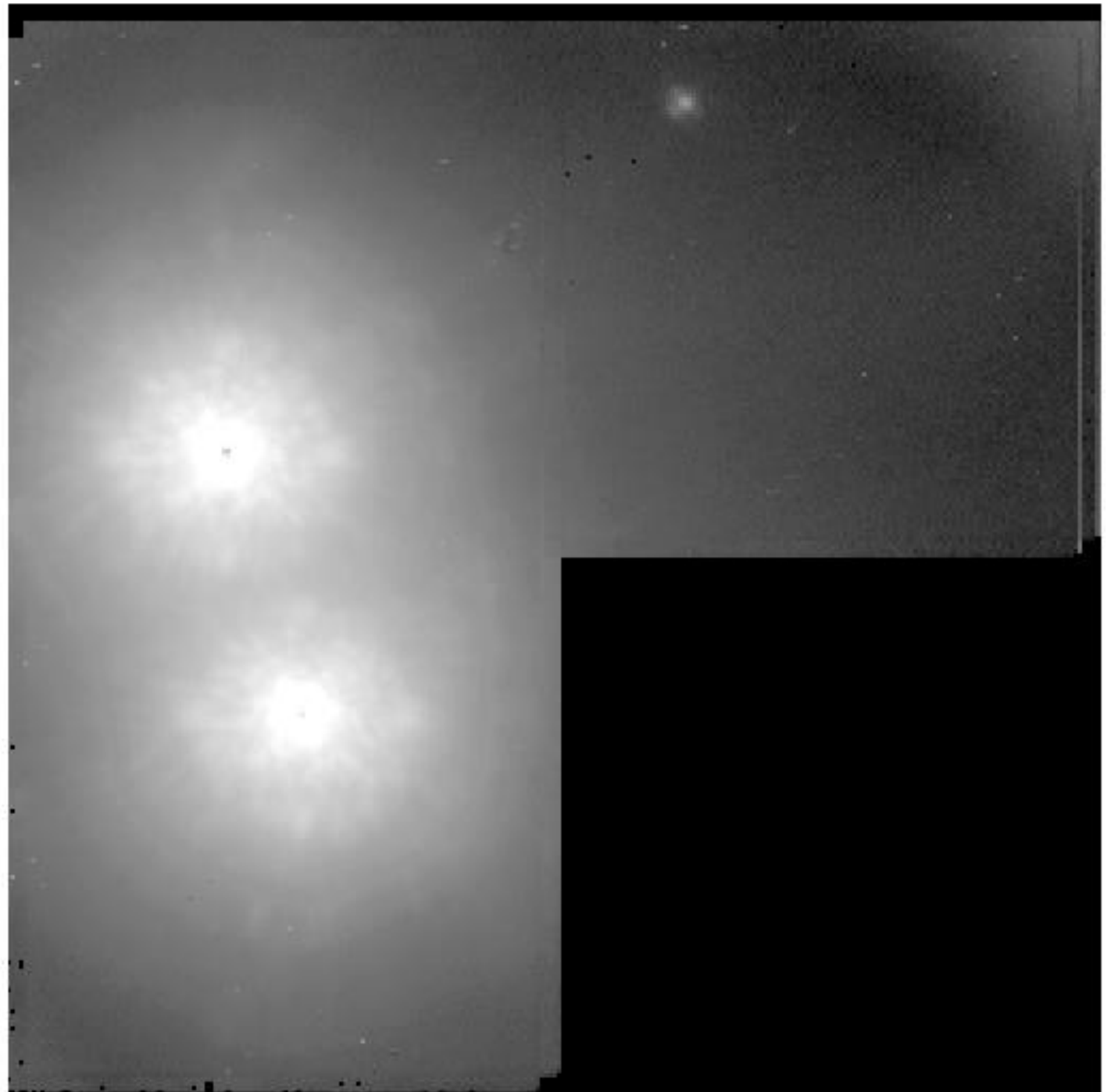
Keck
N1+7 x 2s
log scale
4.46"x4.46"



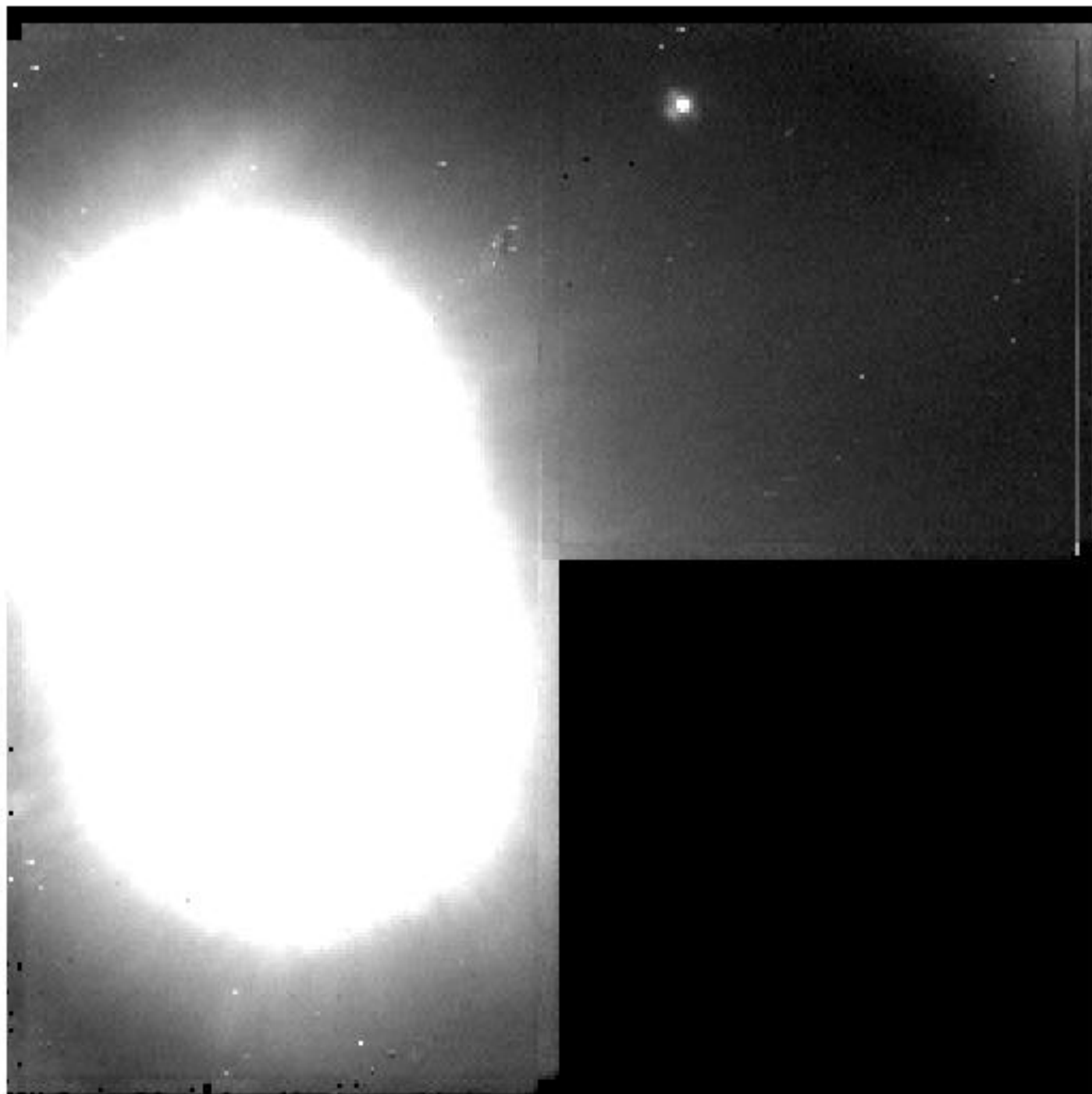
Keck
8 x 2s
log scale
4.46"x4.46"



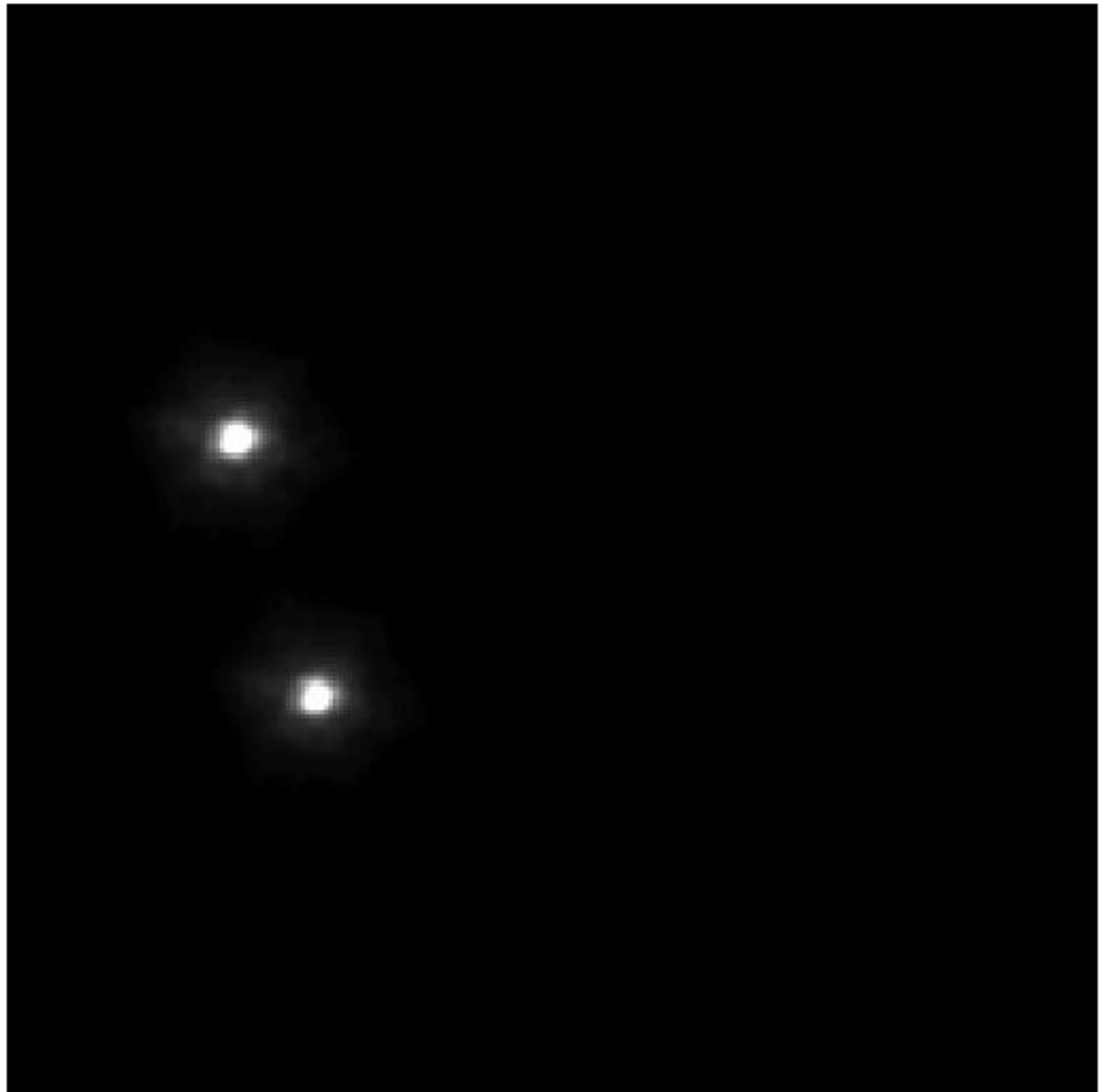
Keck
12 x 30s
log scale
4.46"x4.46"



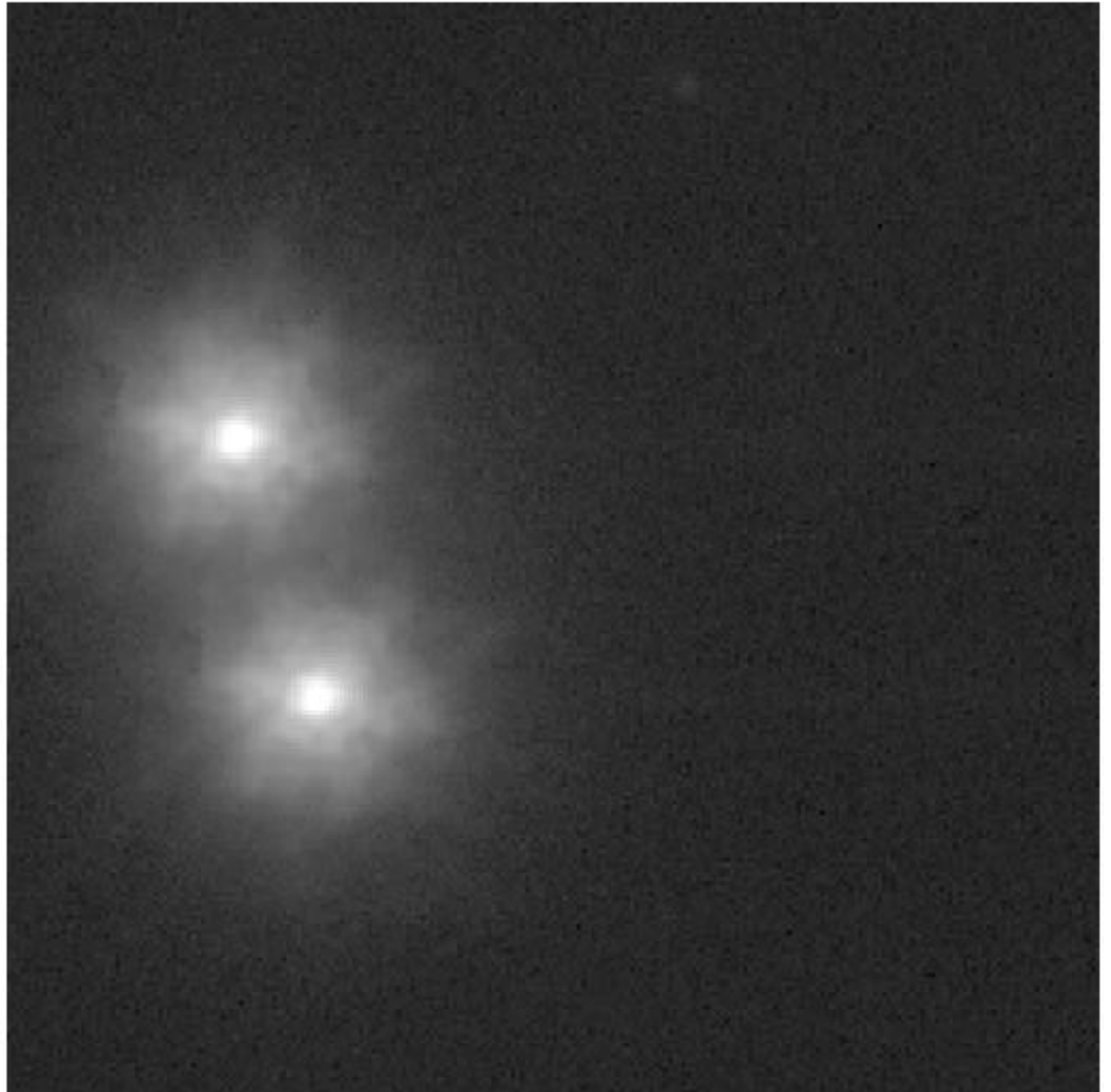
Keck
12 x 30s
linear scale
4.46"x4.46"



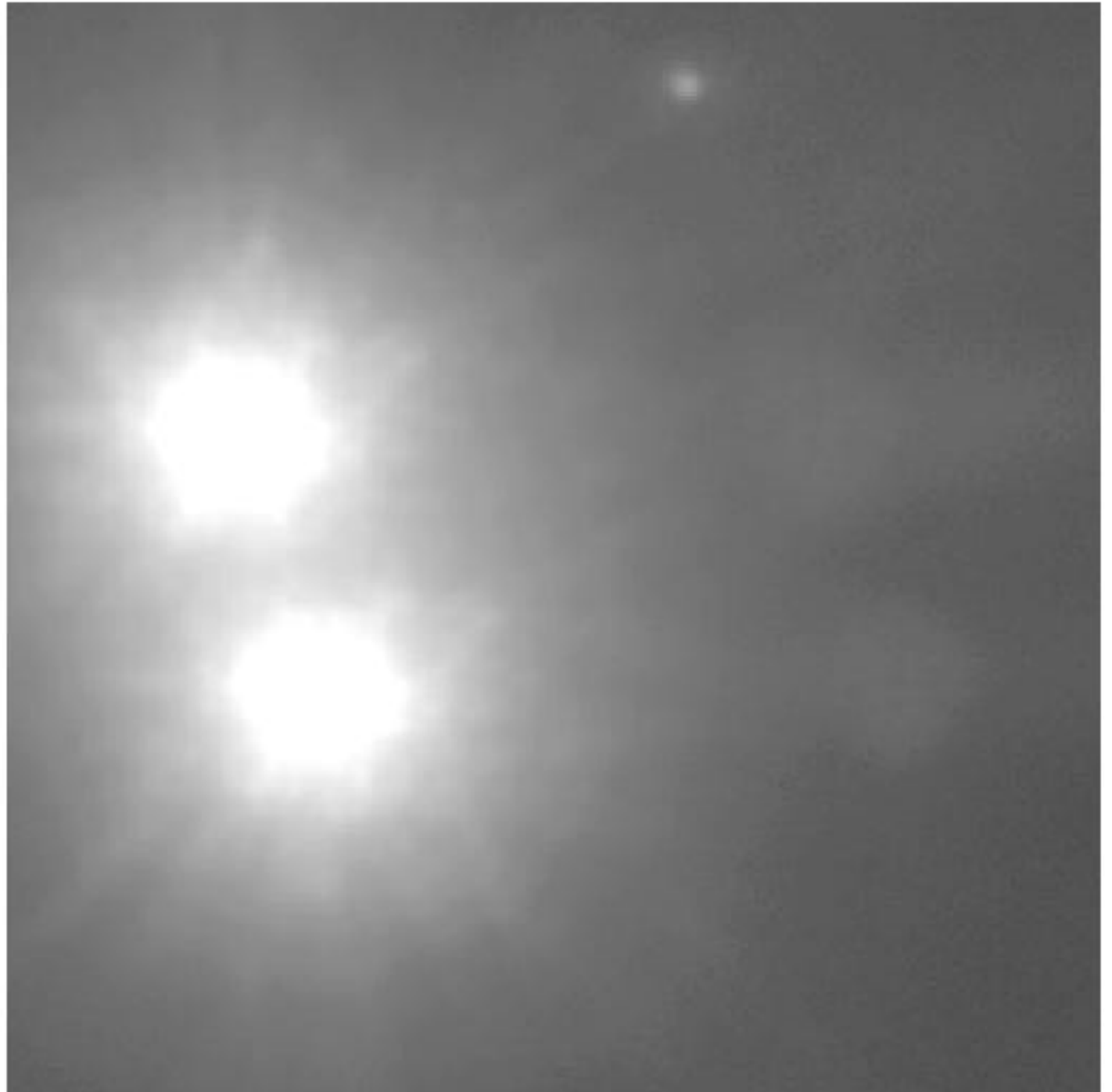
Gemini
4 x 1s
linear scale
4.46"x4.46"



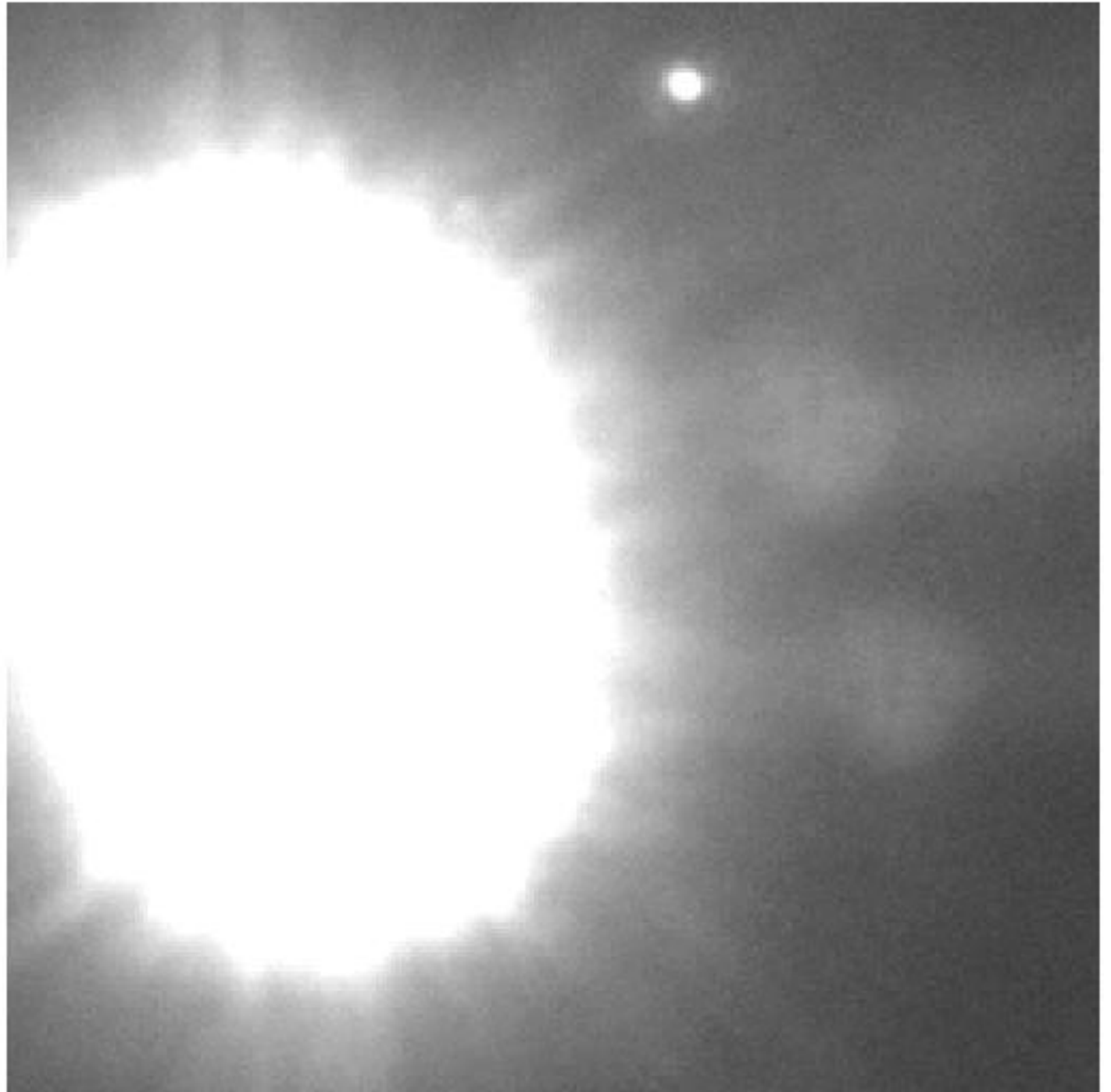
Gemini
4 x 1s
log scale
4.46"x4.46"



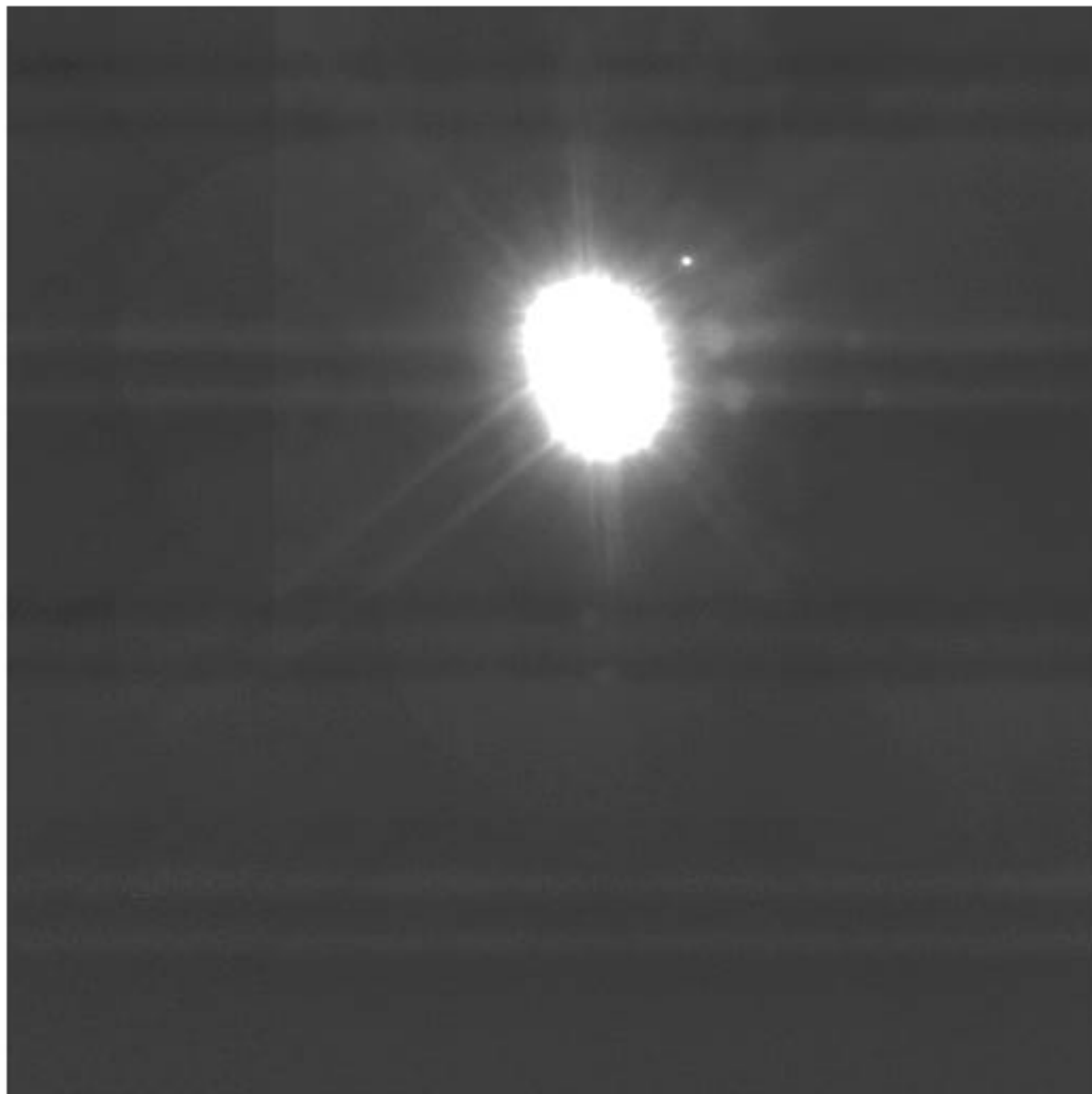
Gemini
8 x 75s
log scale
4.46"x4.46"



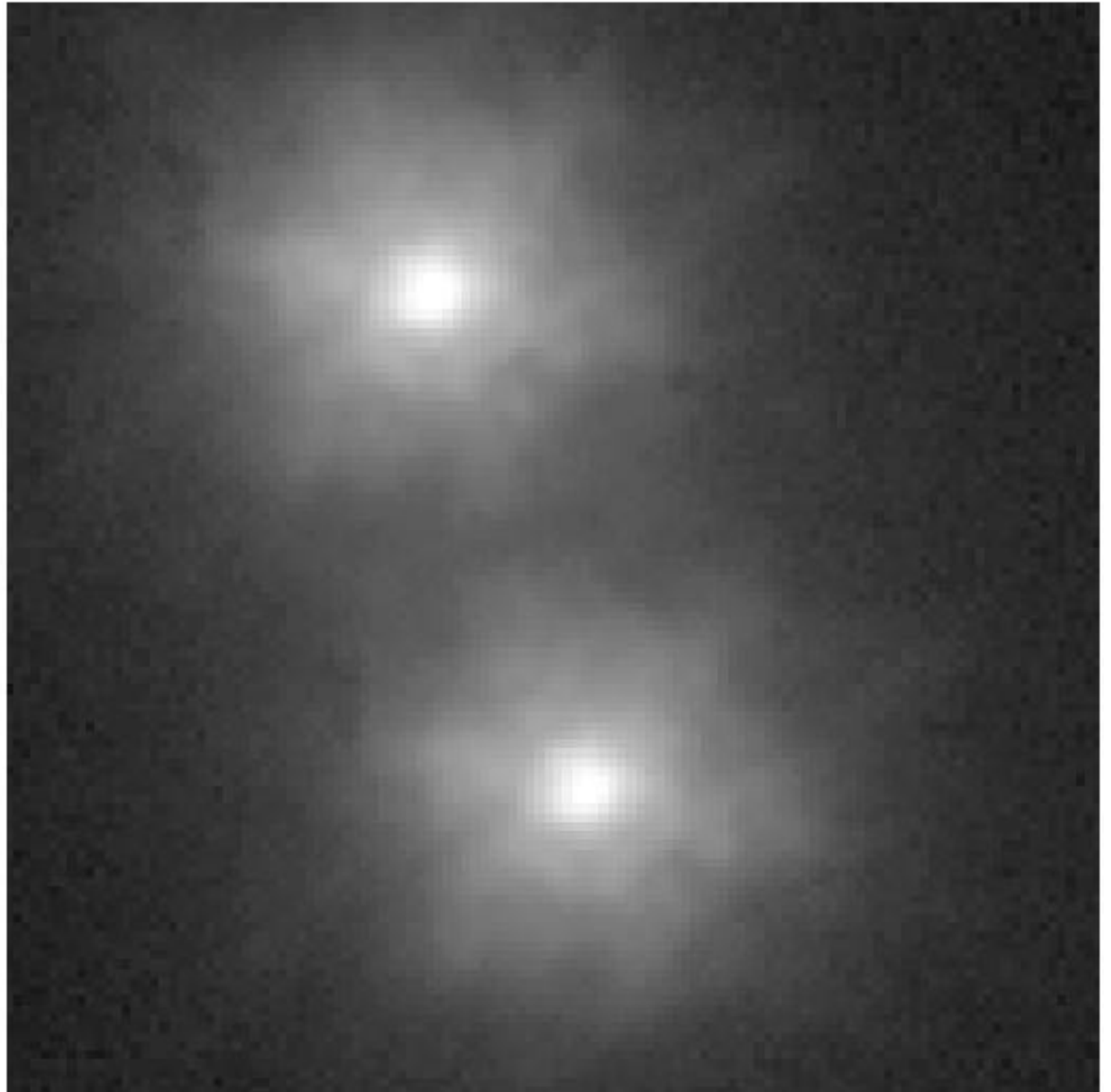
Gemini
8 x 75s
linear scale
4.46"x4.46"



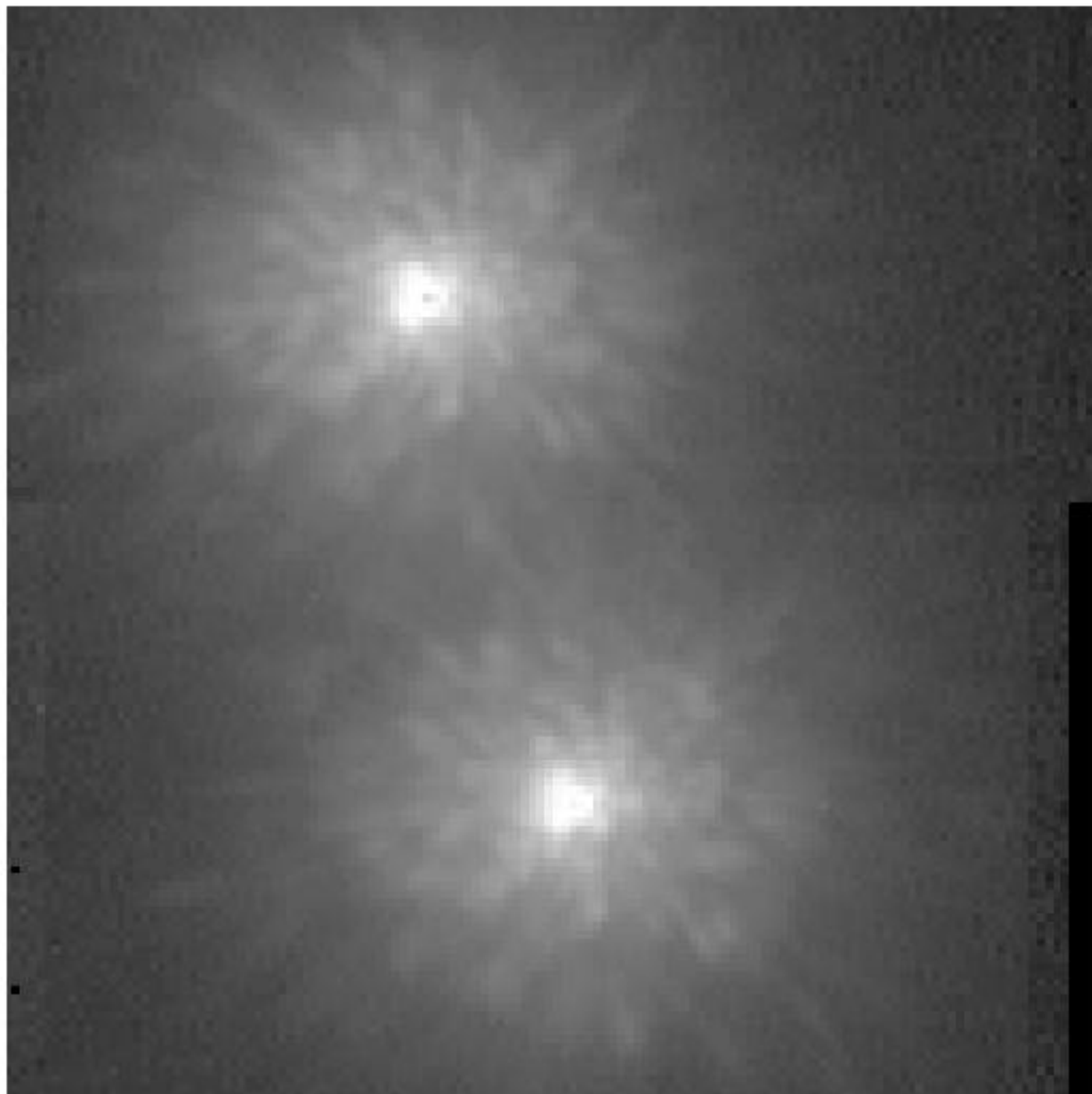
Gemini
8 x 75s
linear scale
20"x20"



Gemini
4 x 1s
log scale
2.37"x2.37"

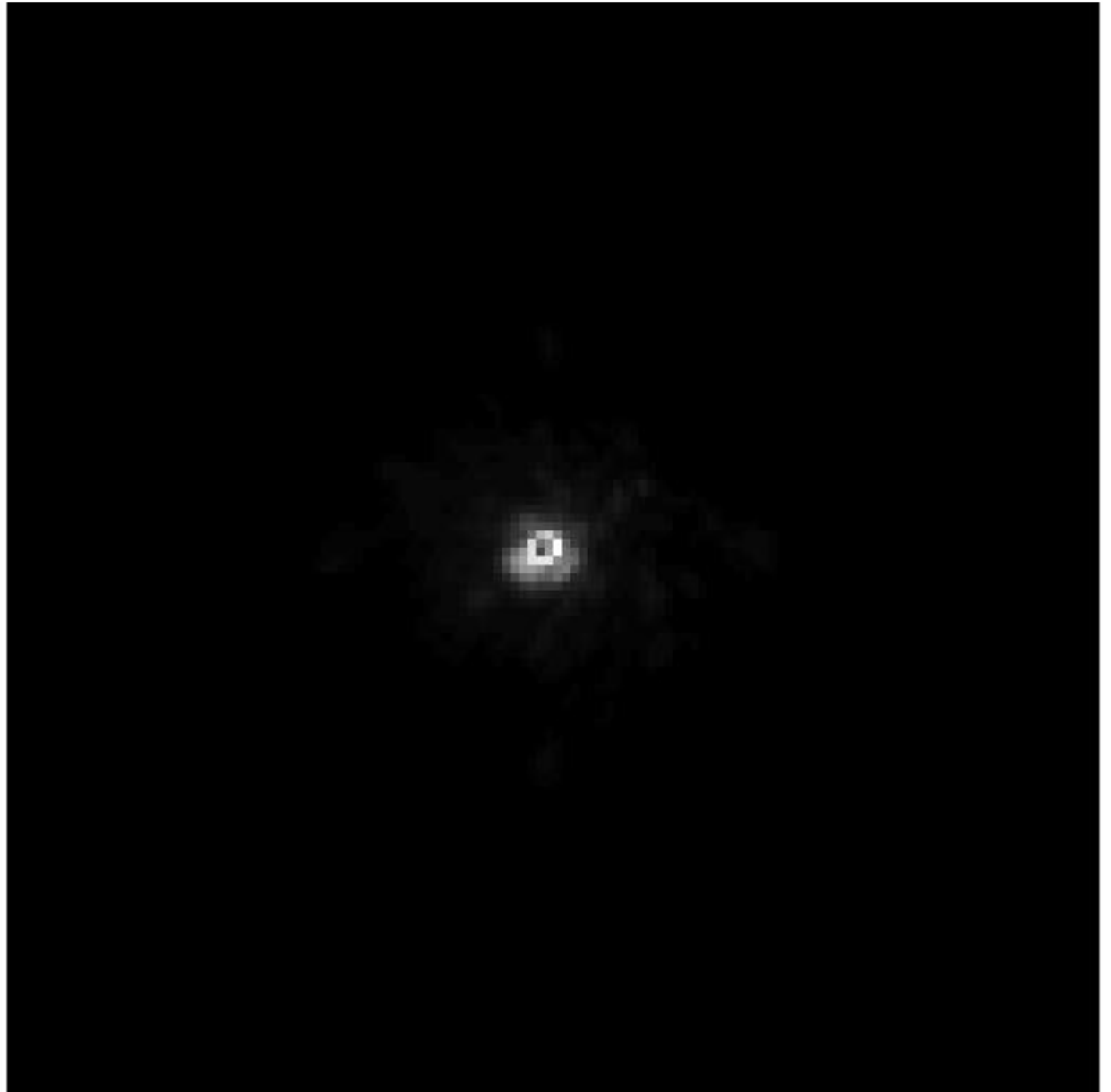


Keck
8 x 2s
log scale
2.37"x2.37"



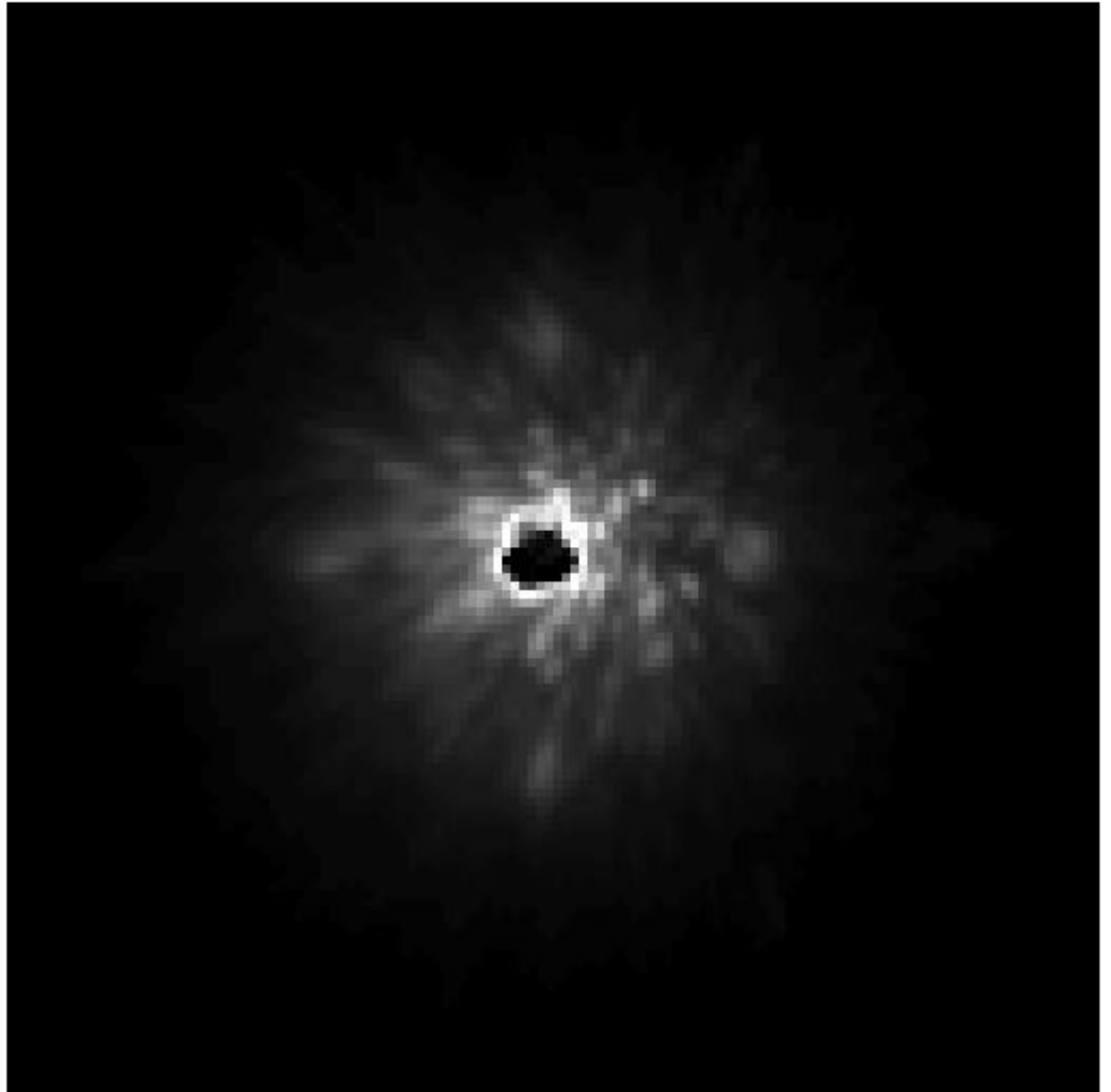
Keck

– Eri: $H=1.6$
N3+10 x 1.1s
linear scale
2.23"x2.23"



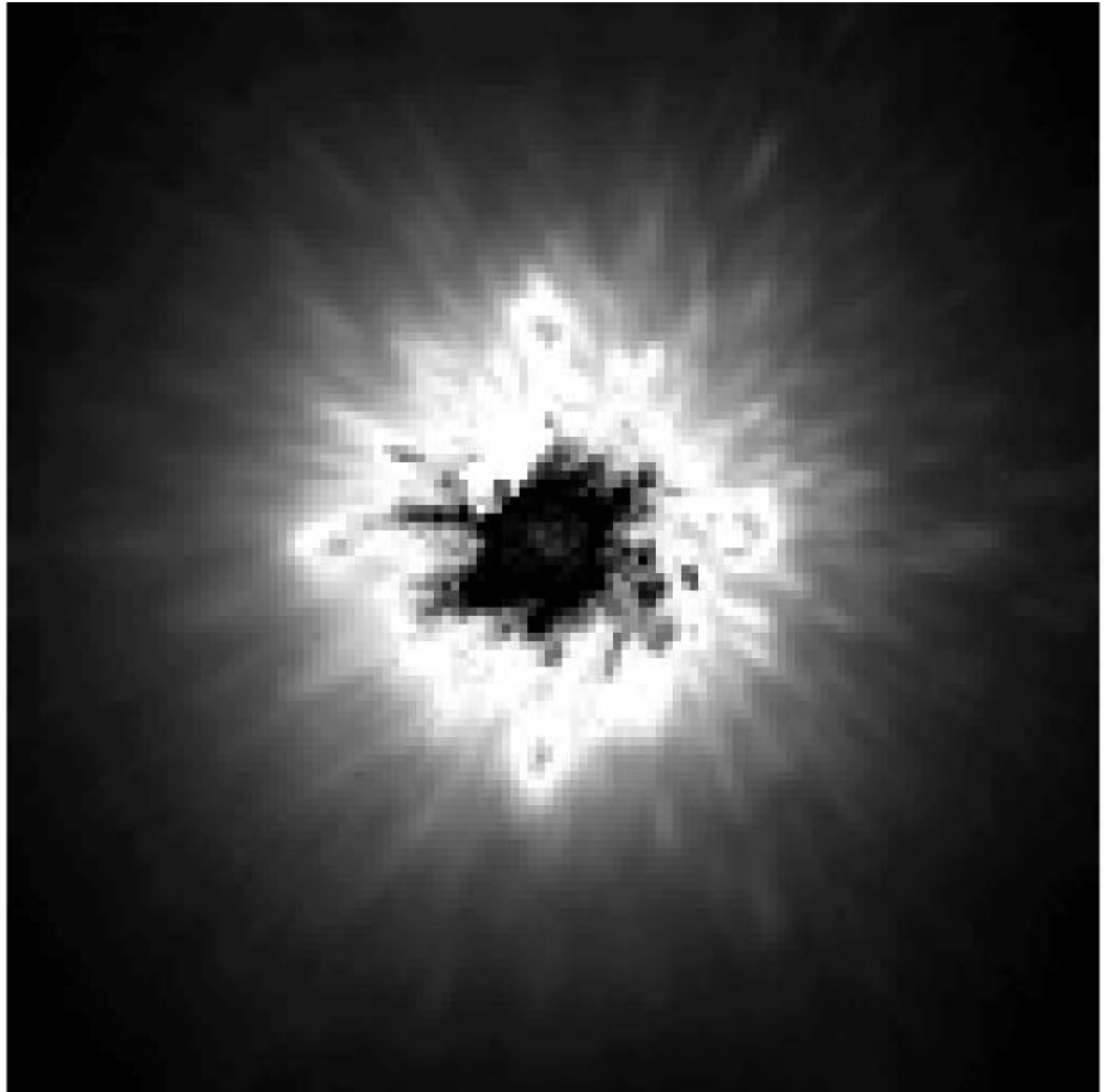
Keck

- Eri: H=1.6
N2+10 x 1.1s
linear scale
2.23"x2.23"



Keck

– Eri: $H=1.6$
N1+10 x 1.1s
linear scale
2.23"x2.23"



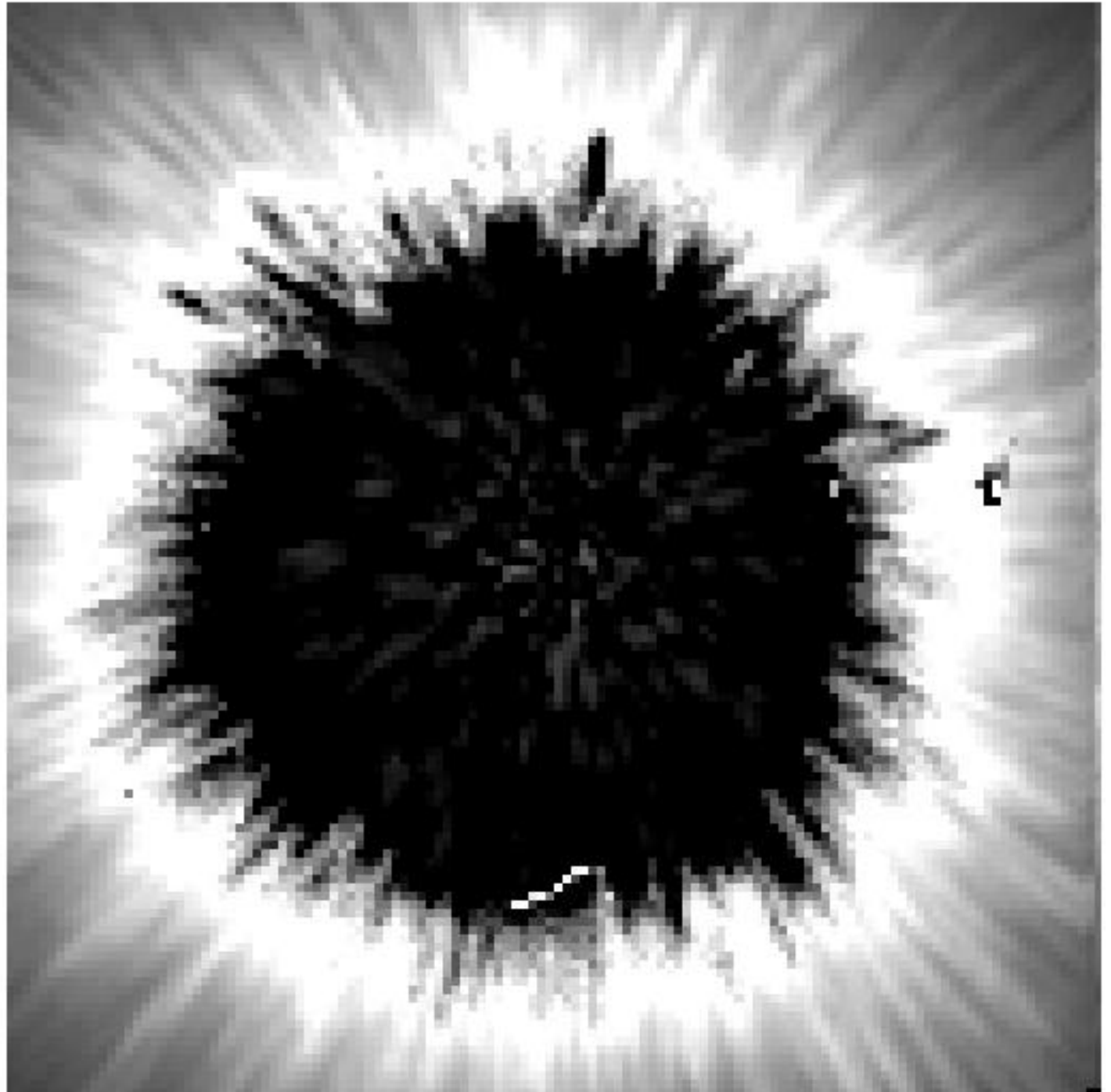
Keck

– Eri: $H=1.6$

1 x 1.1s

linear scale

2.23"x2.23"



Keck
– Eri: $H=1.6$
66 x 5s
linear scale
4.46"x4.46"

