The quest for exoplanet direct imaging with ELT apertures:

A hunt for companions with the Large Binocular Telescope

ExoExplorer Science Series
March 18, 2022

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UNIVERSITY OF NOTRE DAME

Image: U Arizona

This is what a directly imaged planet looks like

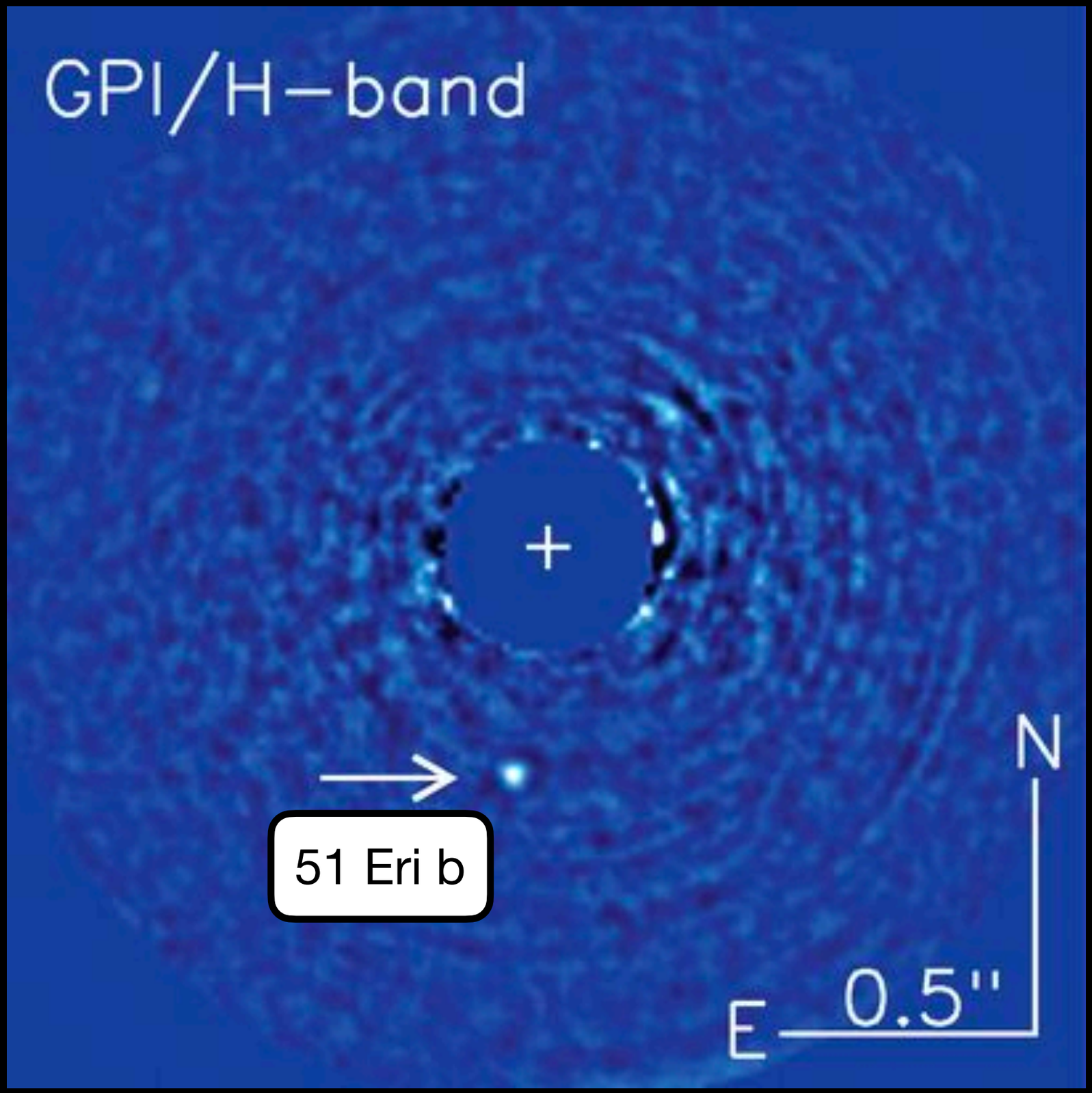
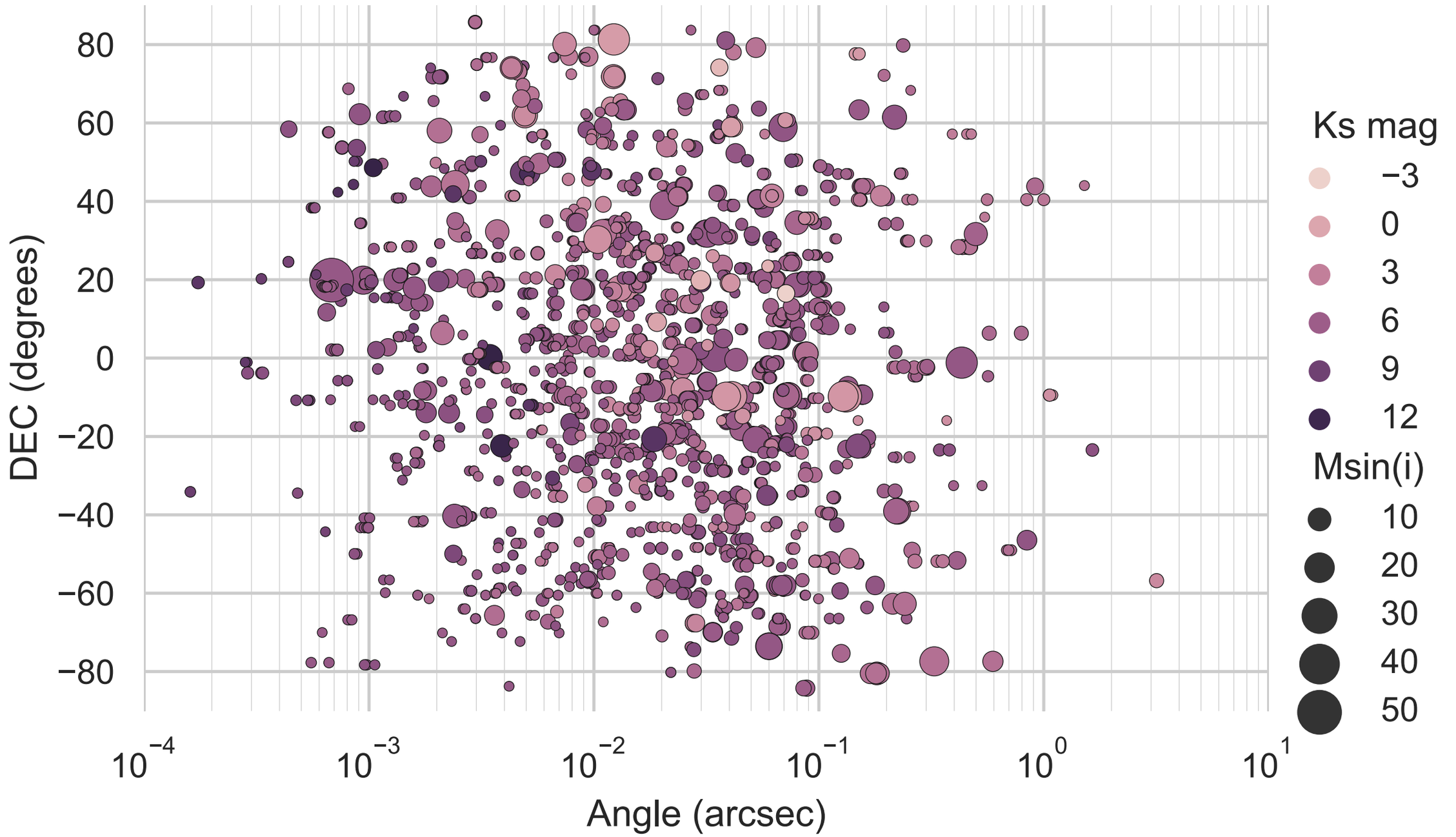


Fig. 1 in Macintosh+ 2014 Science

Current RV planets



How do we break the mass/msin(i) degeneracy?

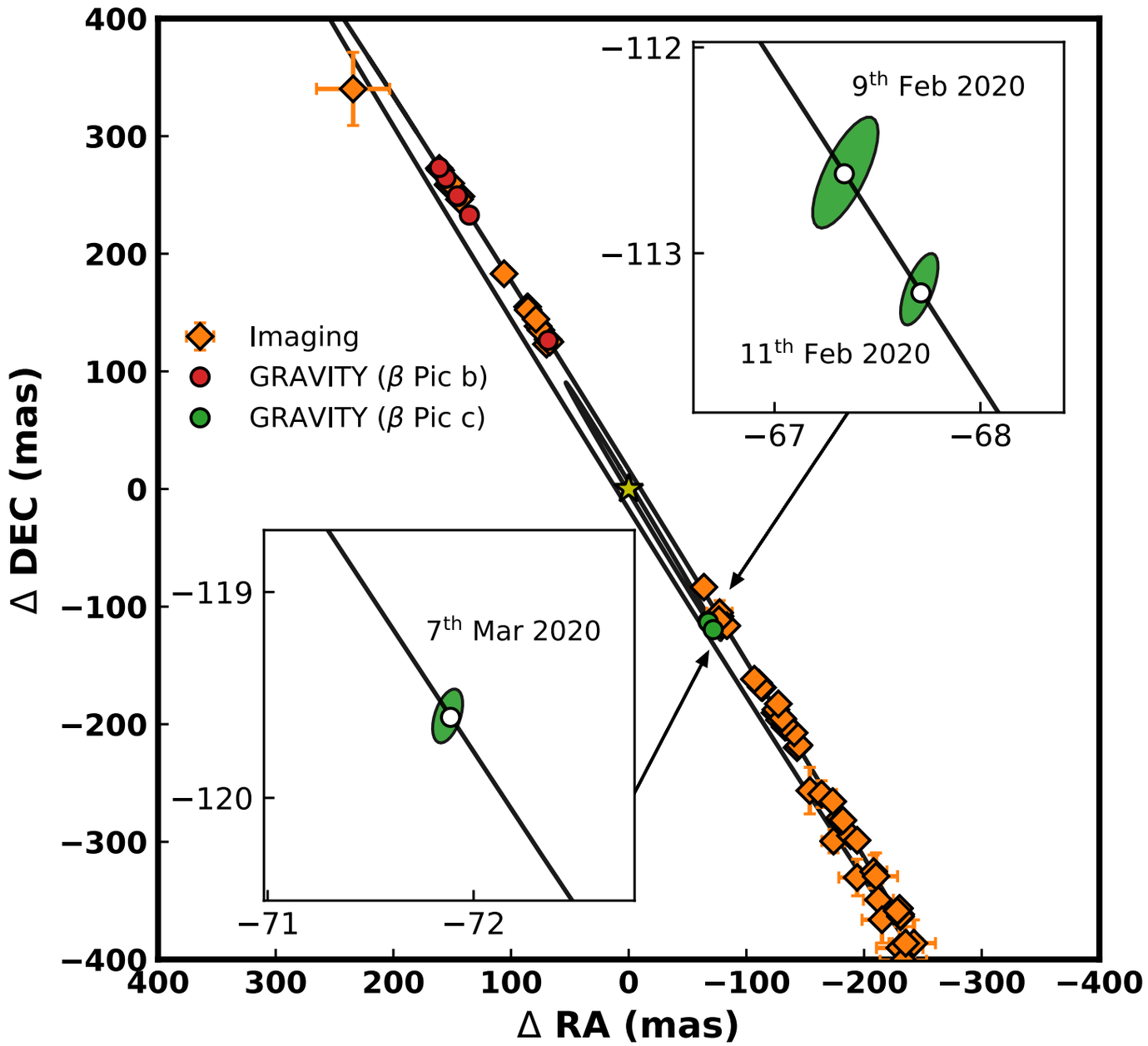
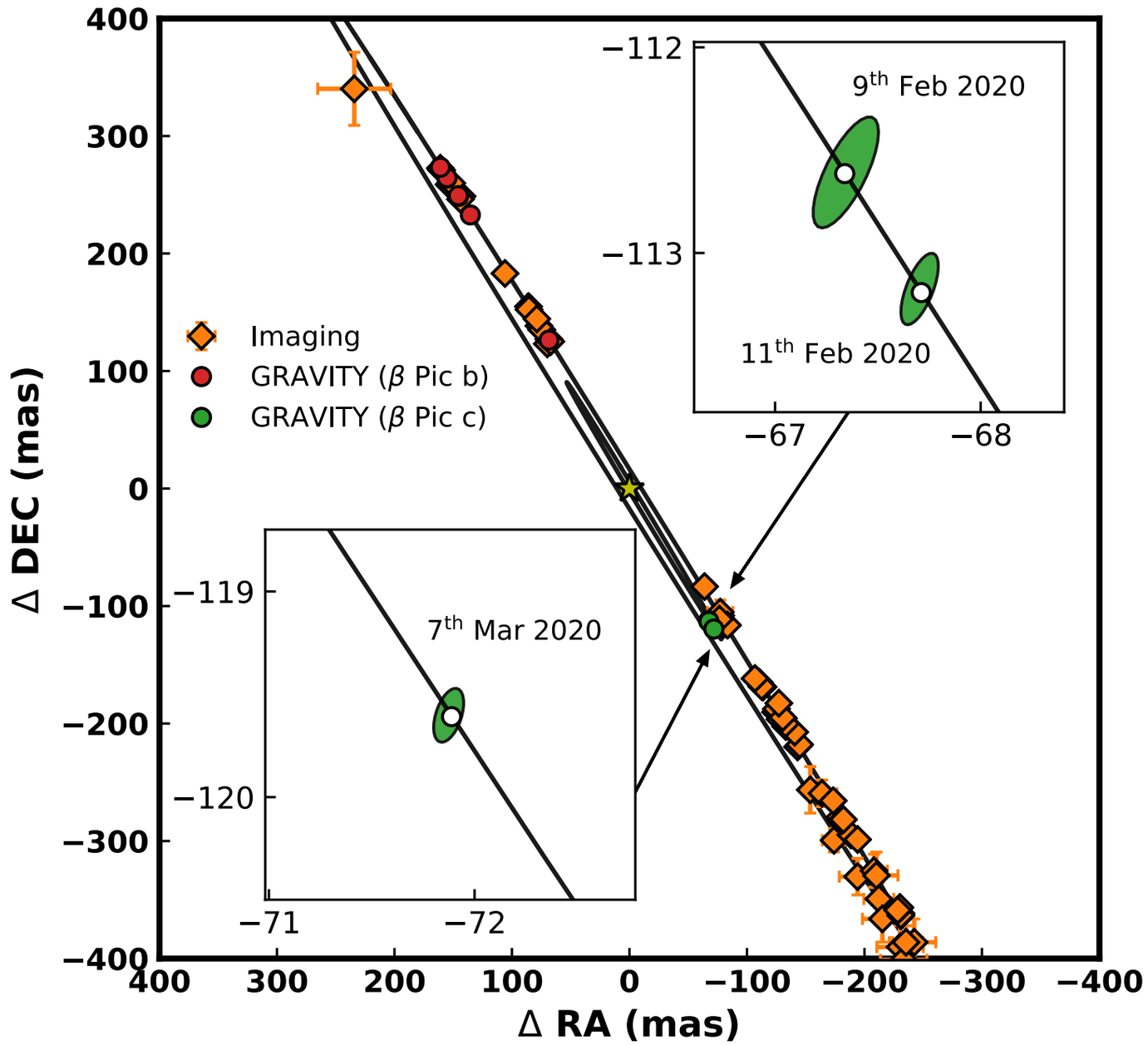


Fig. 3 in Nowak+ 2020 A&A

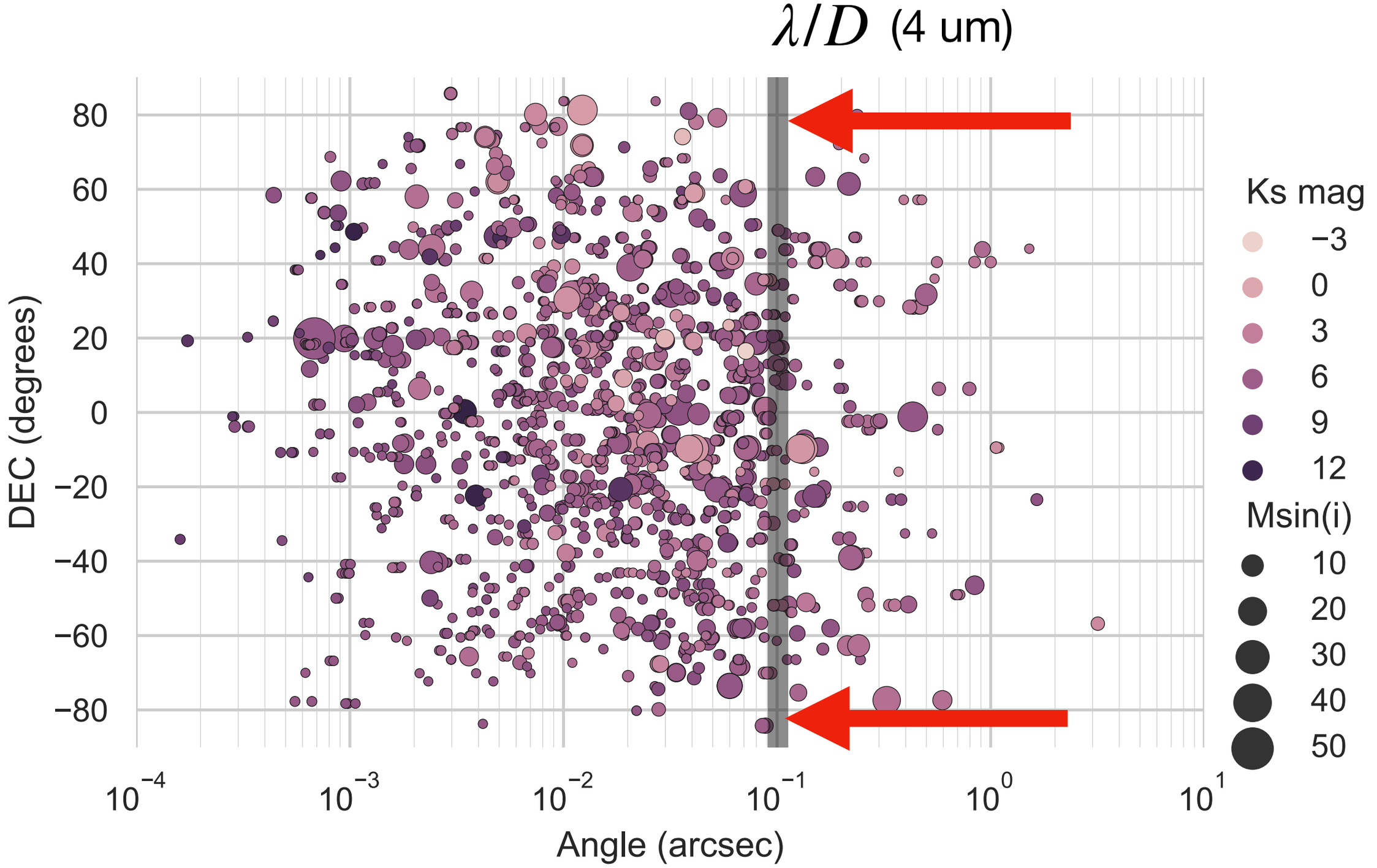
How do we break the mass/msin(i) degeneracy?



RV & DI → m_P , formation scenarios

Fig. 3 in Nowak+ 2020 A&A

Resolution to probe the RV planet population



Giant Magellan Telescope – GMTO Corporation

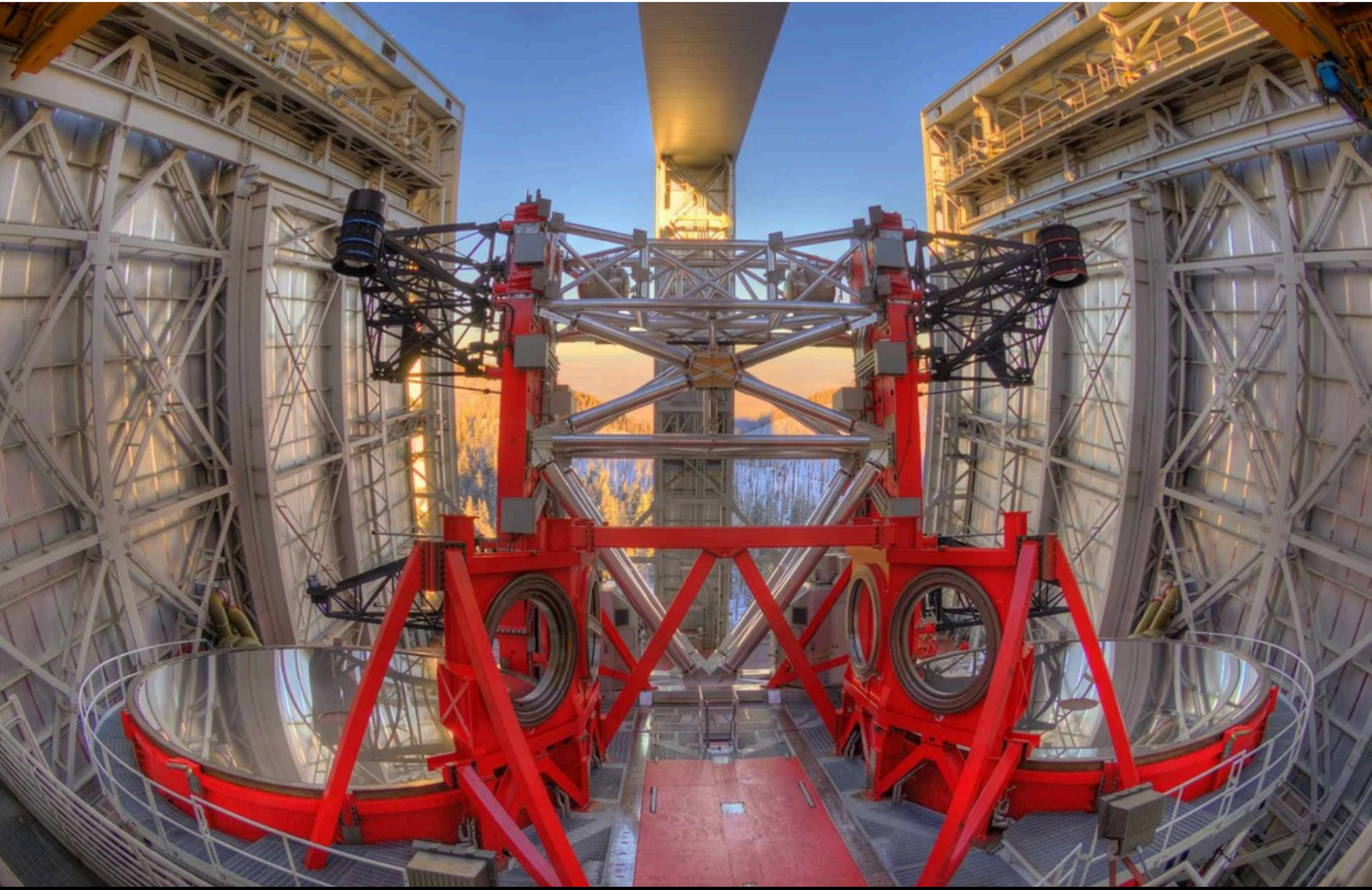
How do we do push the frontiers of exoplanet direct imaging with ELTs?

Giant Magellan Telescope – GMTO Corporation

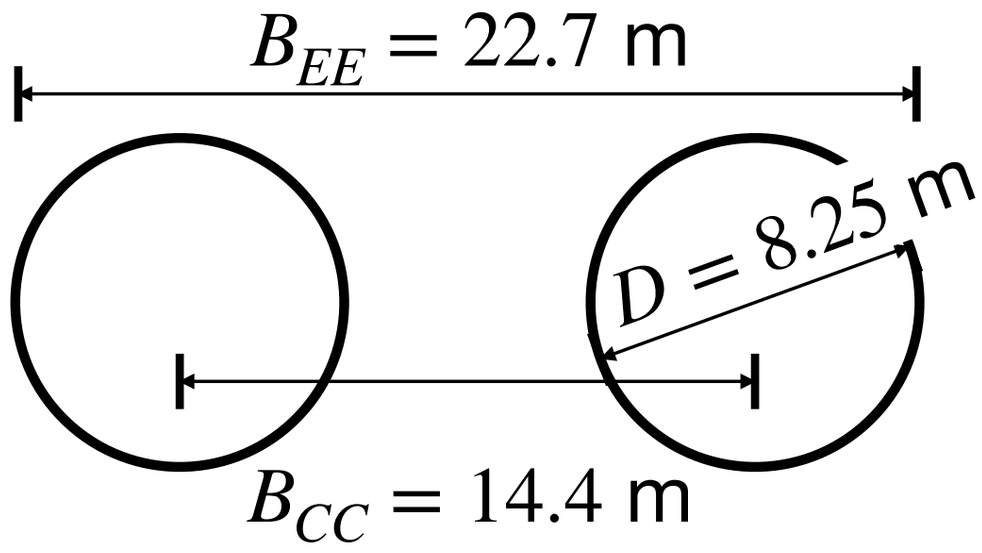
The Large Binocular Telescope (Mt. Graham, AZ)

John Hill

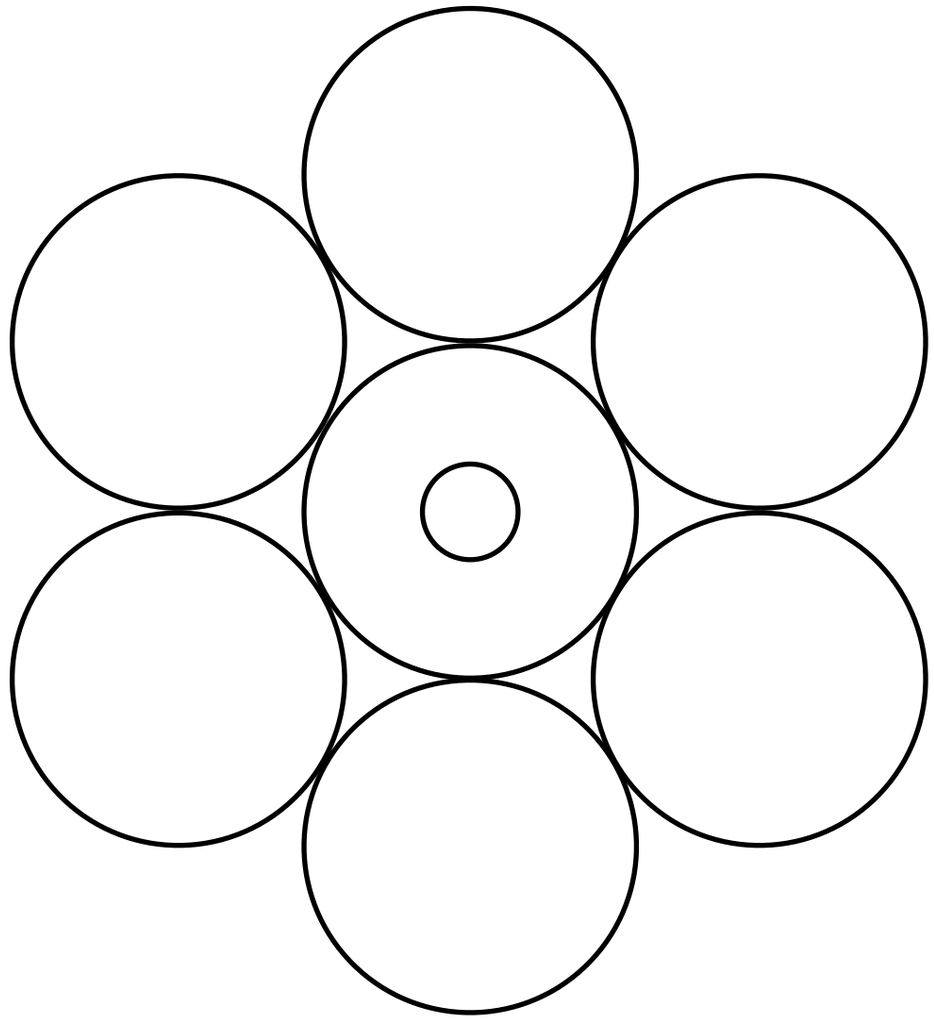
The Large Binocular Telescope (Mt. Graham, AZ)



Largest apertures are from the ground

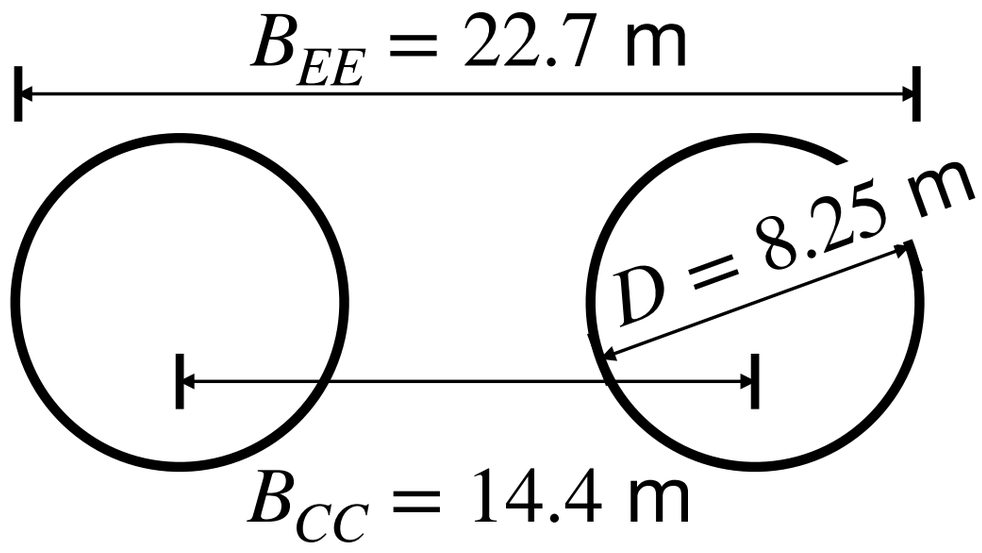


LBT

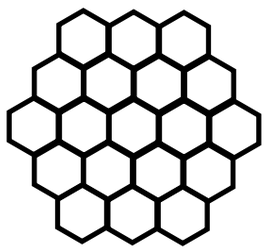


GMT

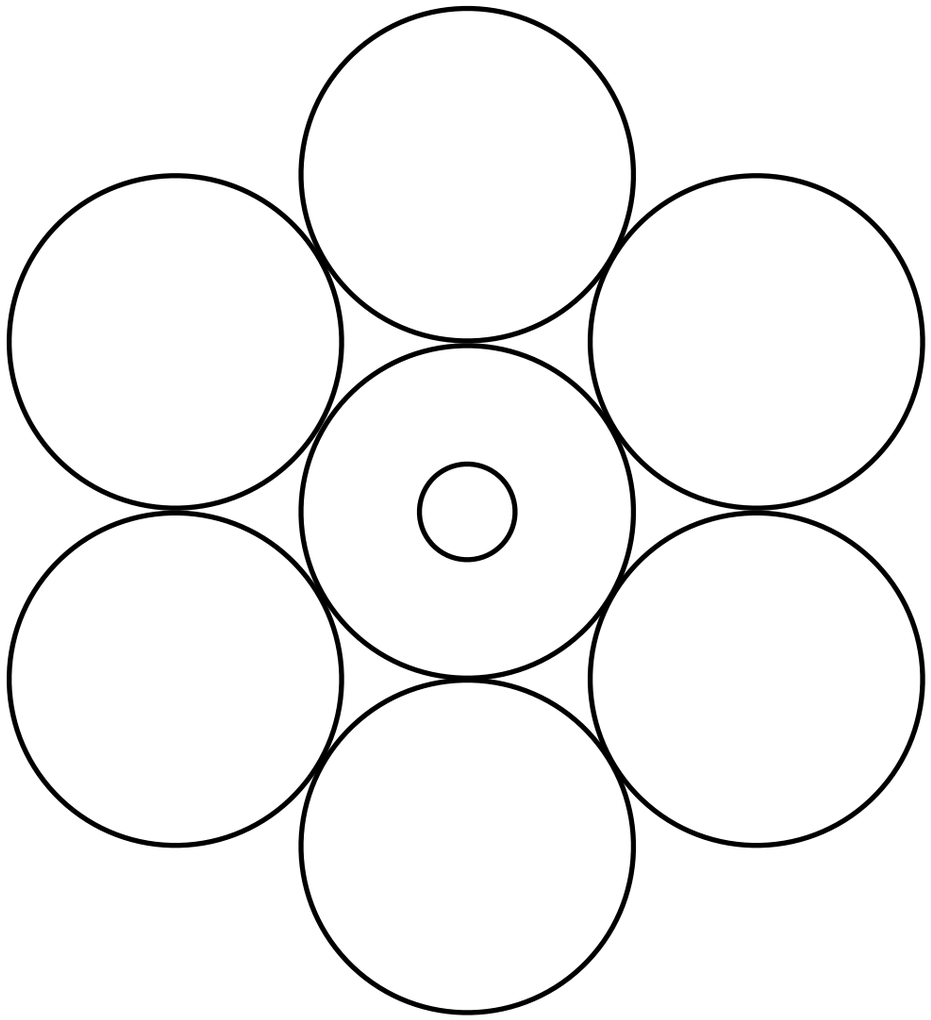
Largest apertures are from the ground



LBT

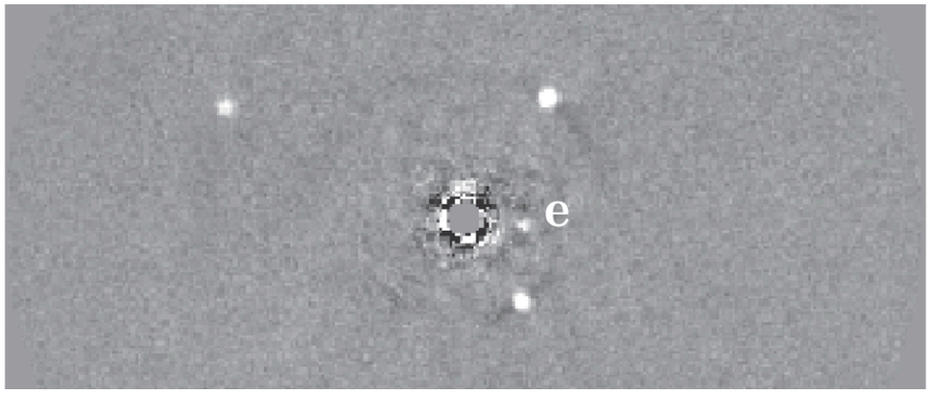


JWST



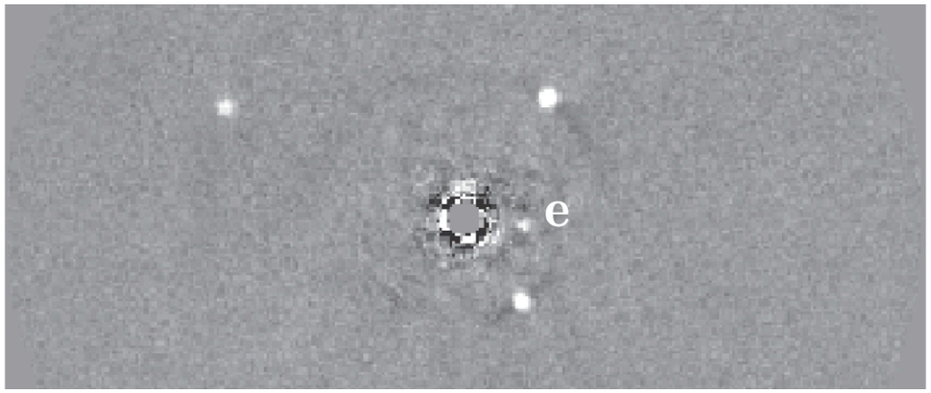
GMT

John Hill



Direct imaging

Stone+ 2018 AJ



Direct imaging

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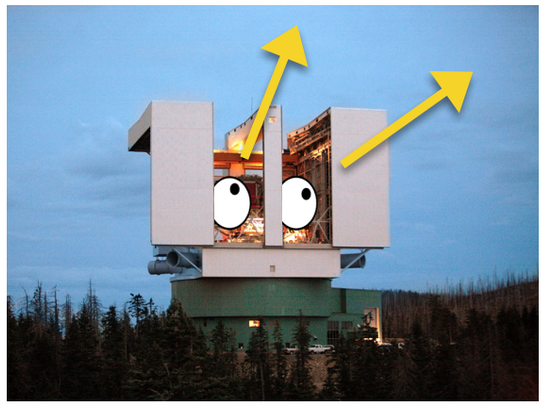
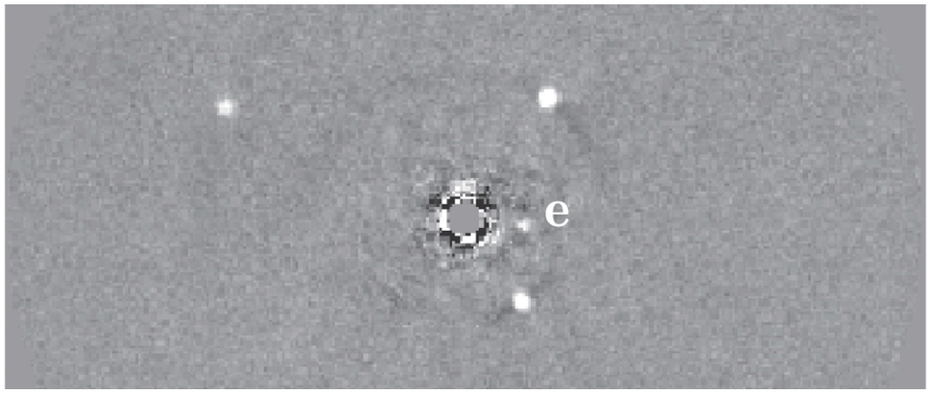


Wall-eyed pointing

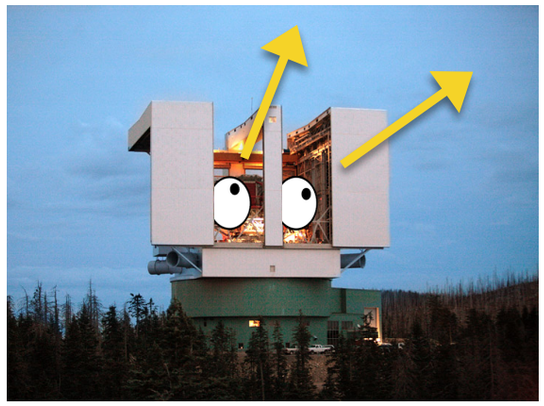
Spalding+ 2017 PASP

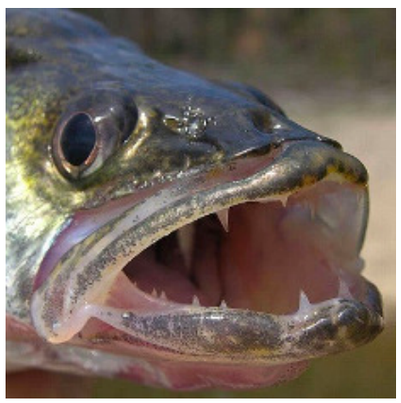
John Hill



Direct imaging

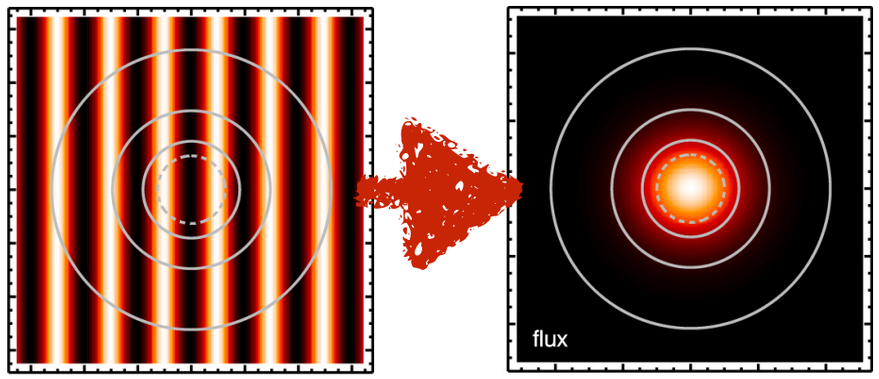
Stone+ 2018 AJ





Wall-eyed pointing

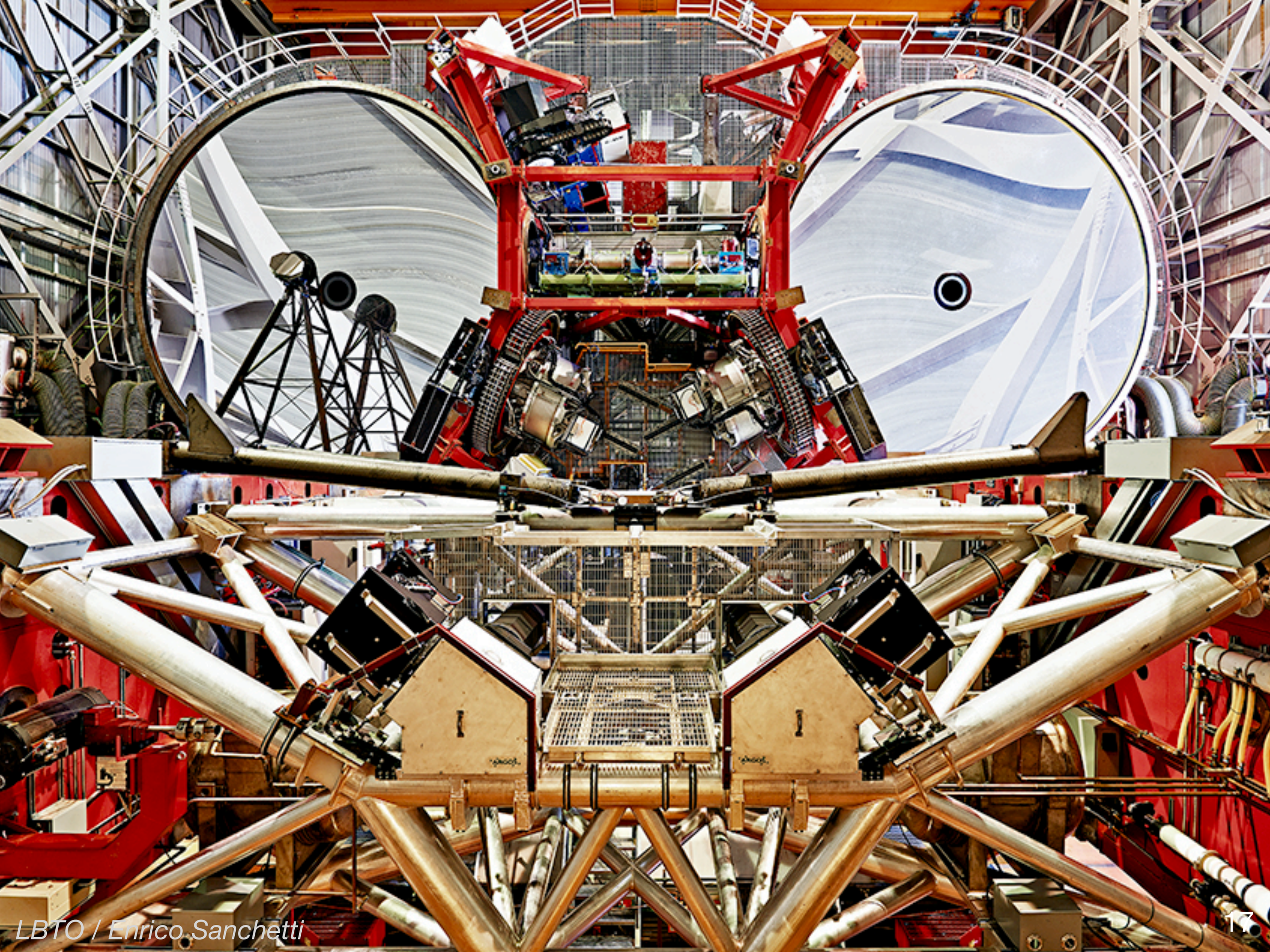
Spalding+ 2017 PASP



Nulling interferometry

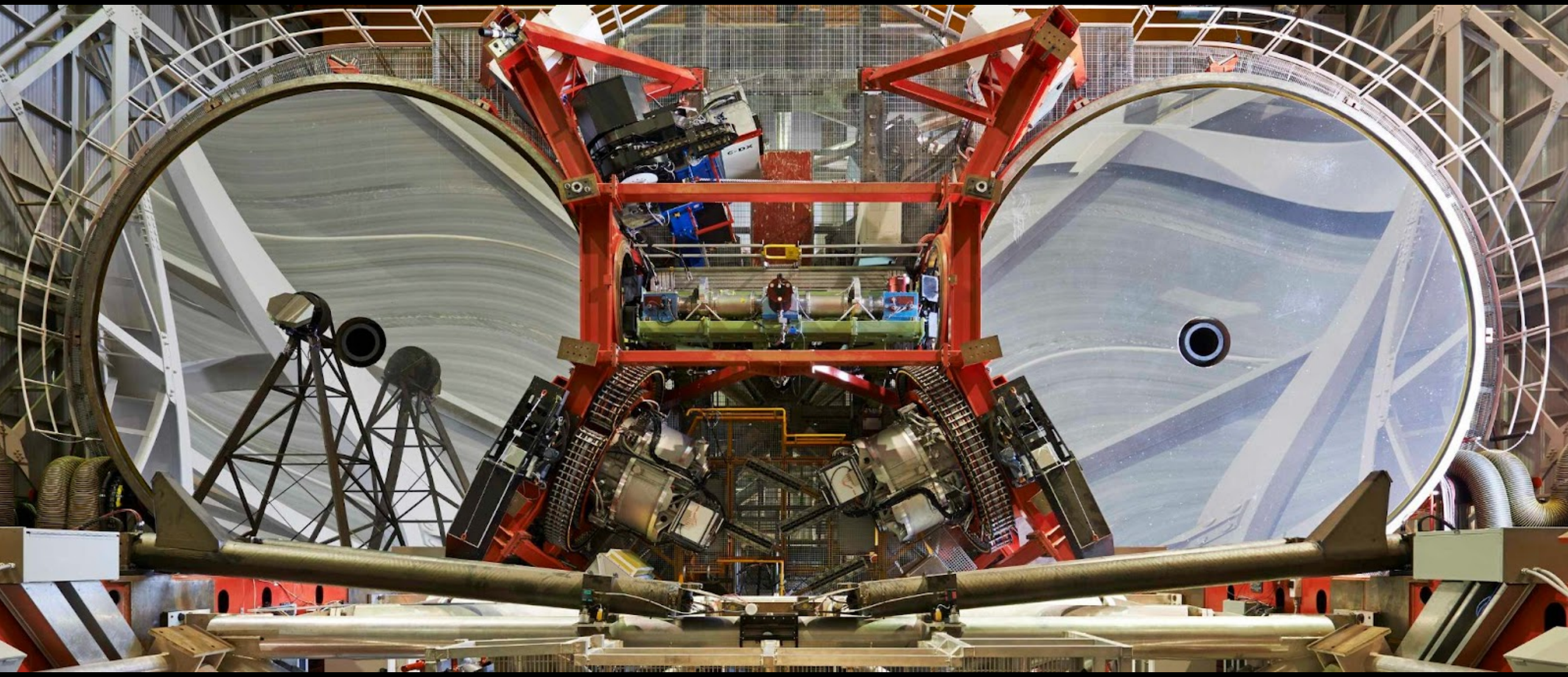
Ertel+ 2020 AJ & *Physics Today* (April 2022)

John Hill



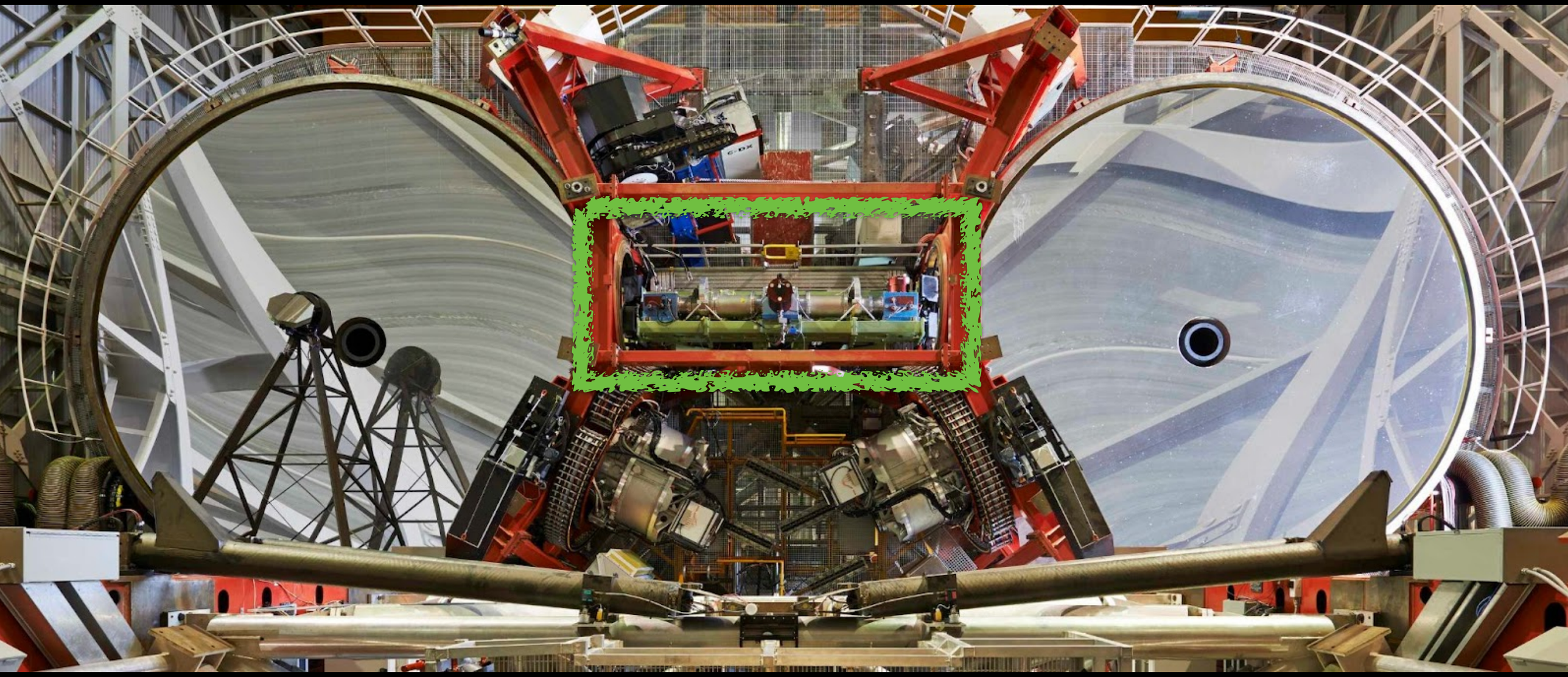
LBTO / Enrico Sanchetti

The LBT Interferometer



LBTO / Enrico Sanchetti

The LBT Interferometer



LBTO / Enrico Sanchetti

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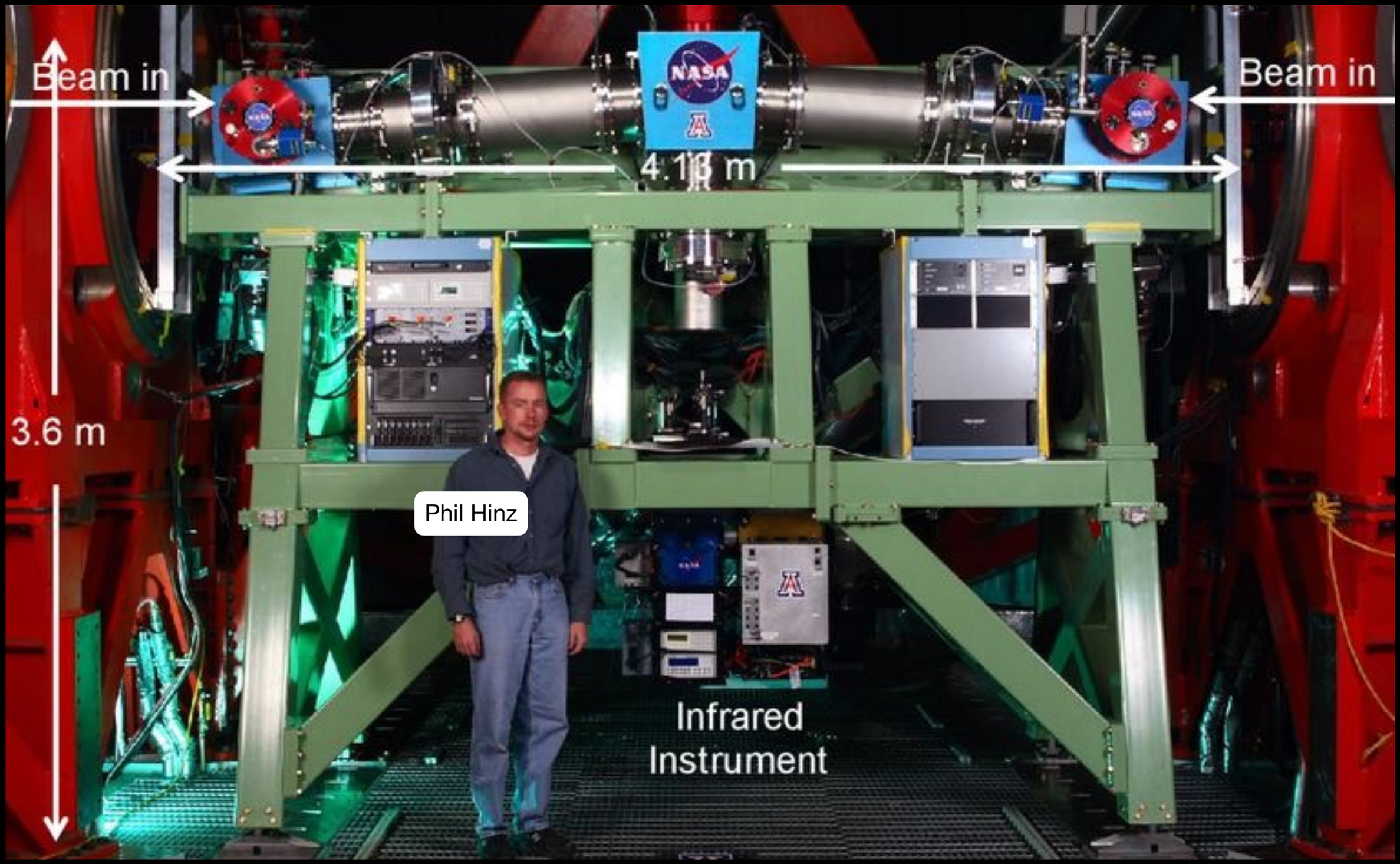
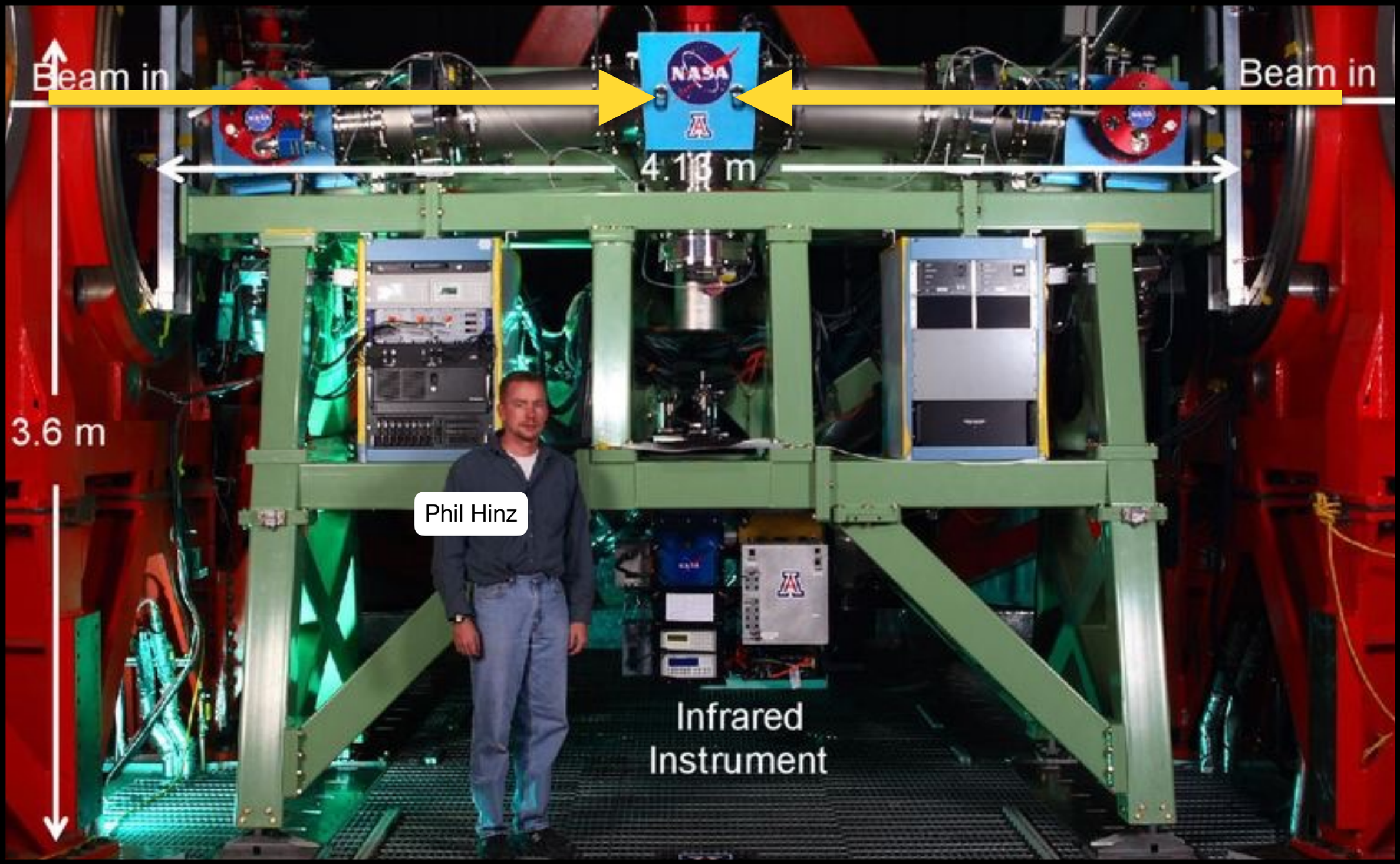
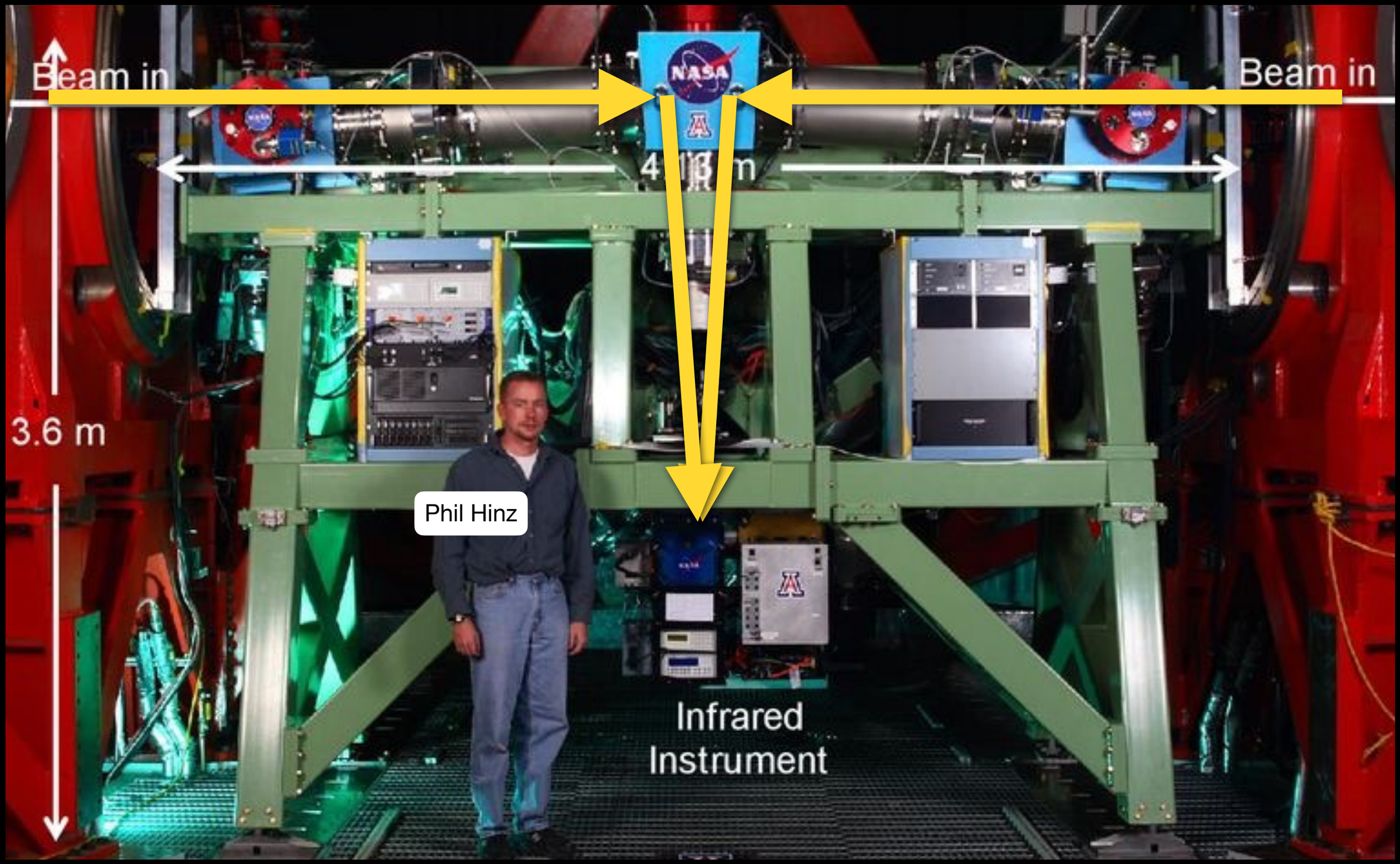


The LBT Interferometer



The LBT Interferometer



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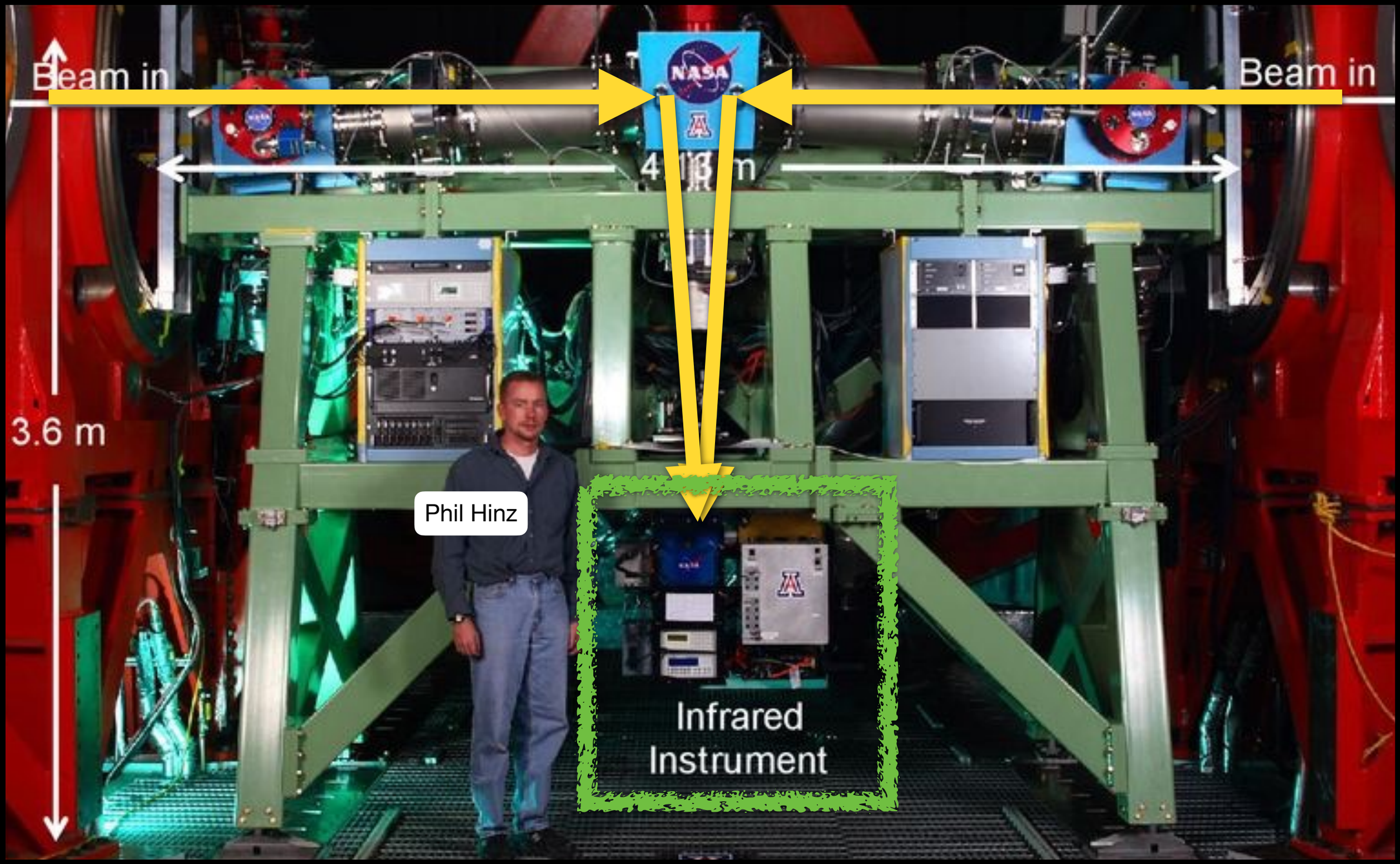
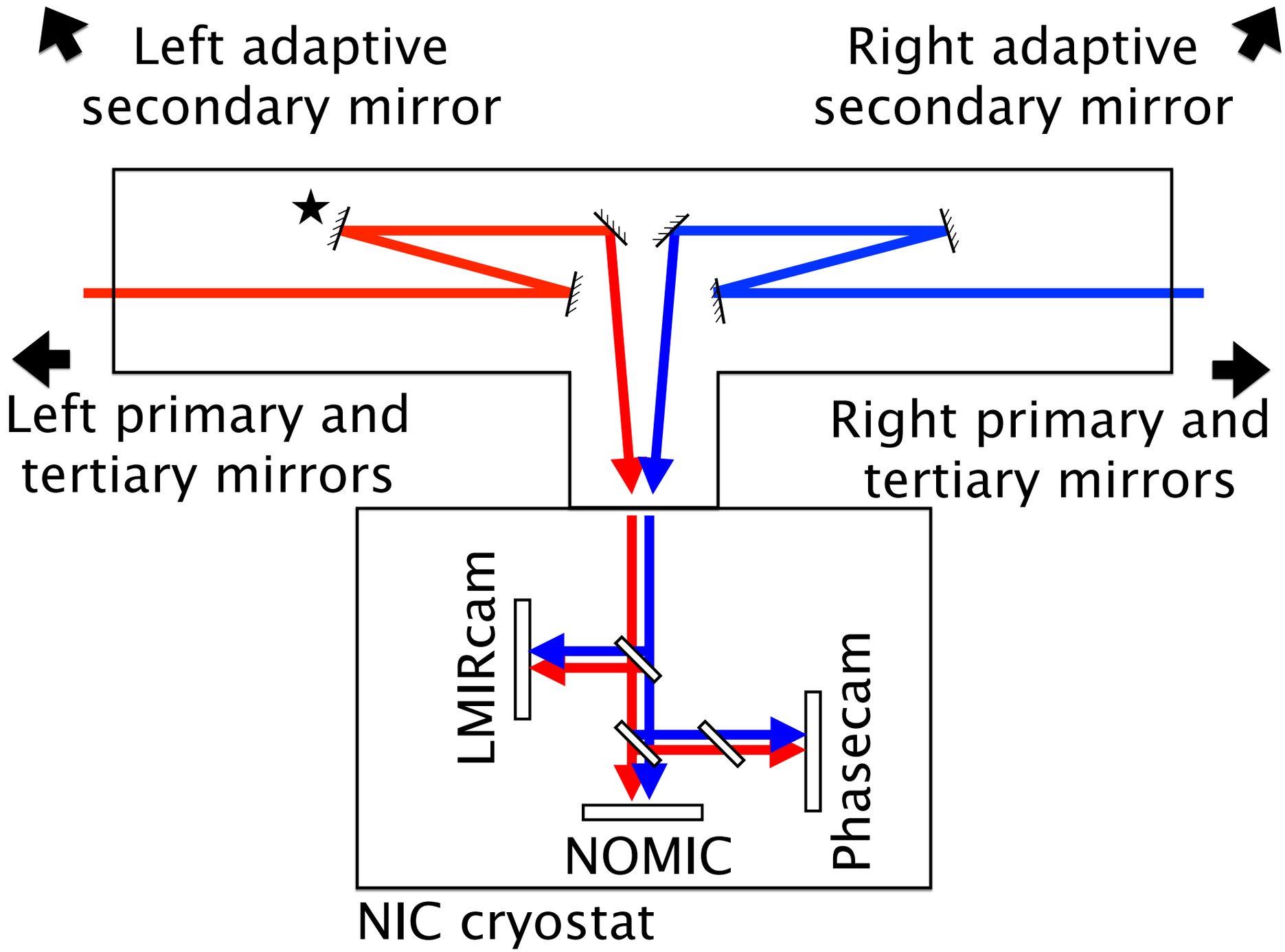


The LBT Interferometer



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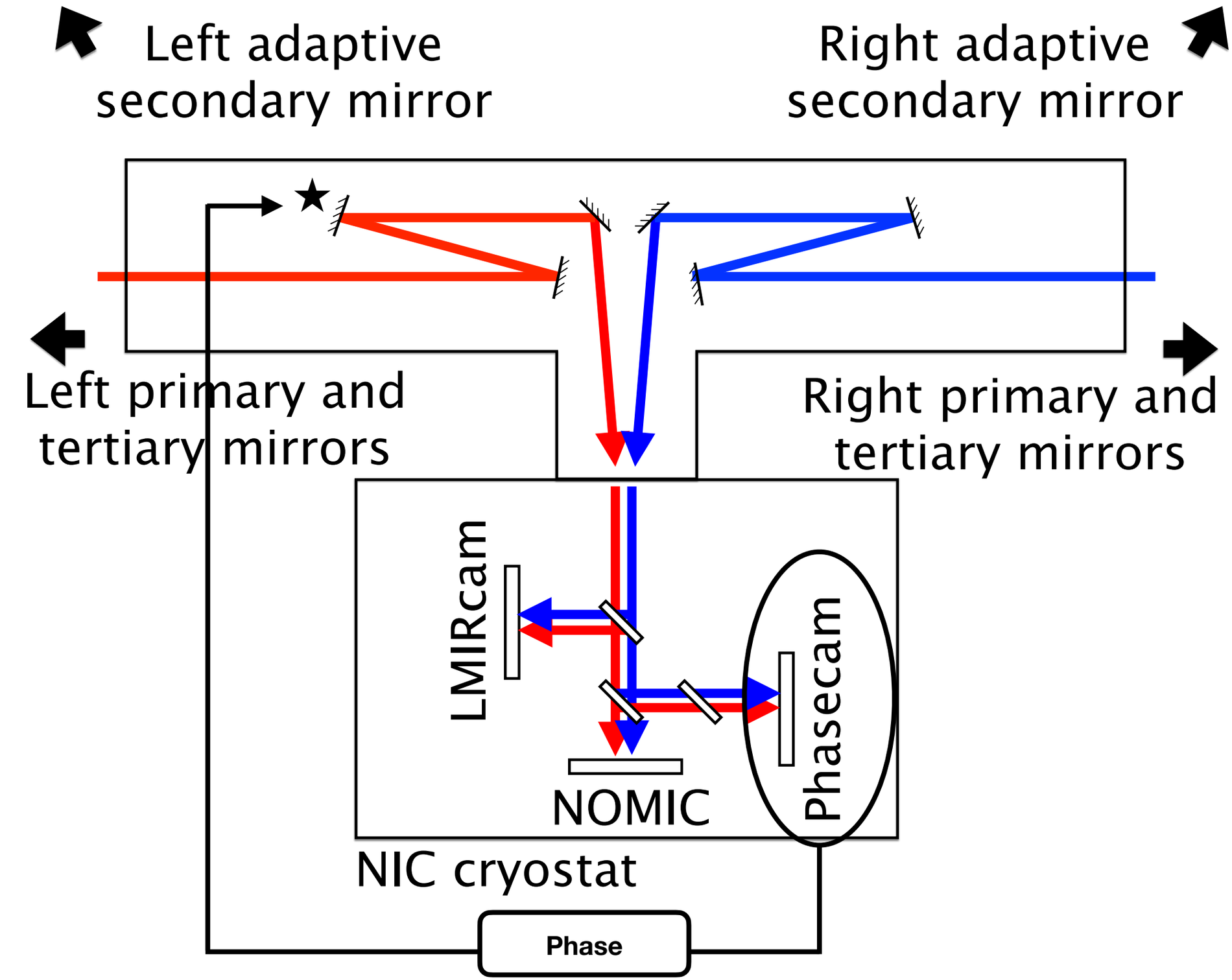
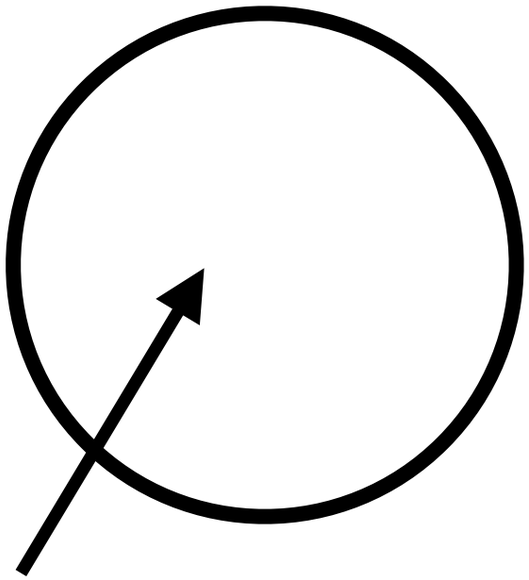
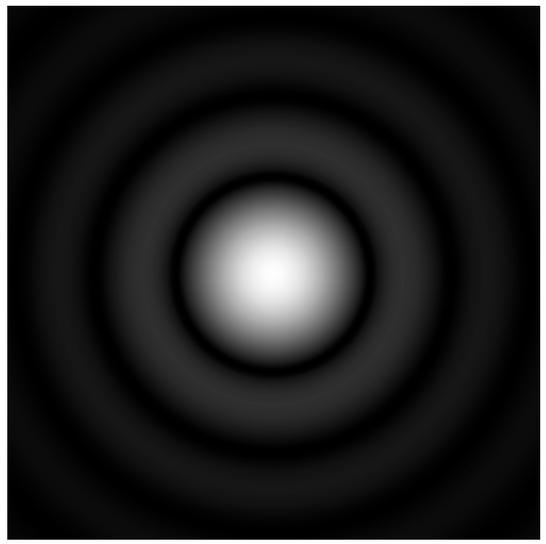


LBT: the first ELT aperture

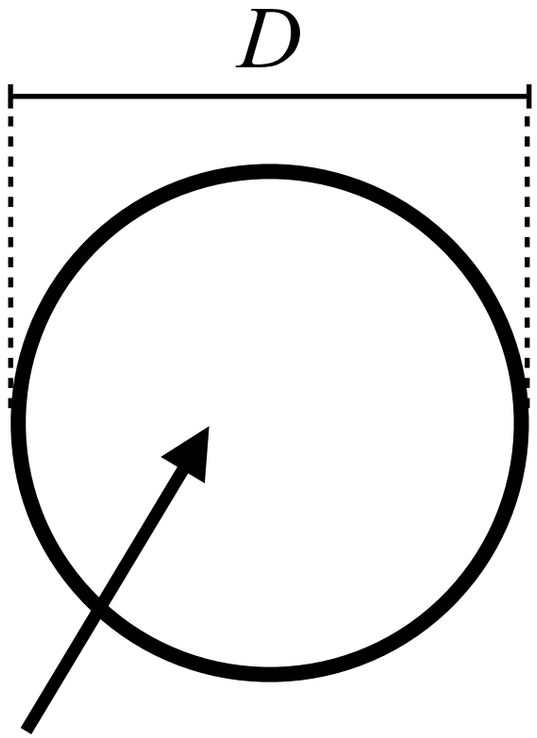


8-m telescope



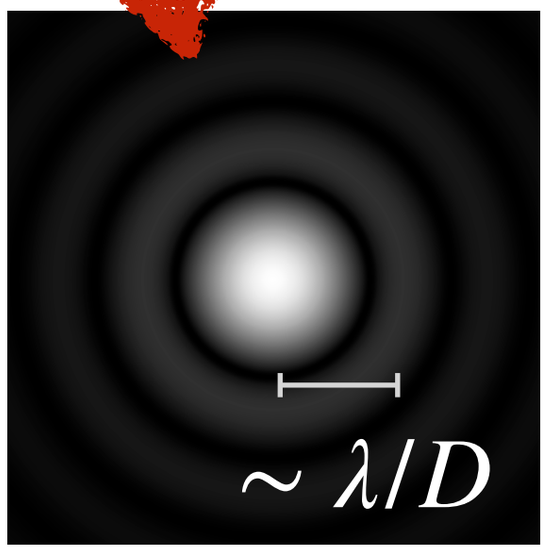
light pattern

LBT: the first ELT aperture



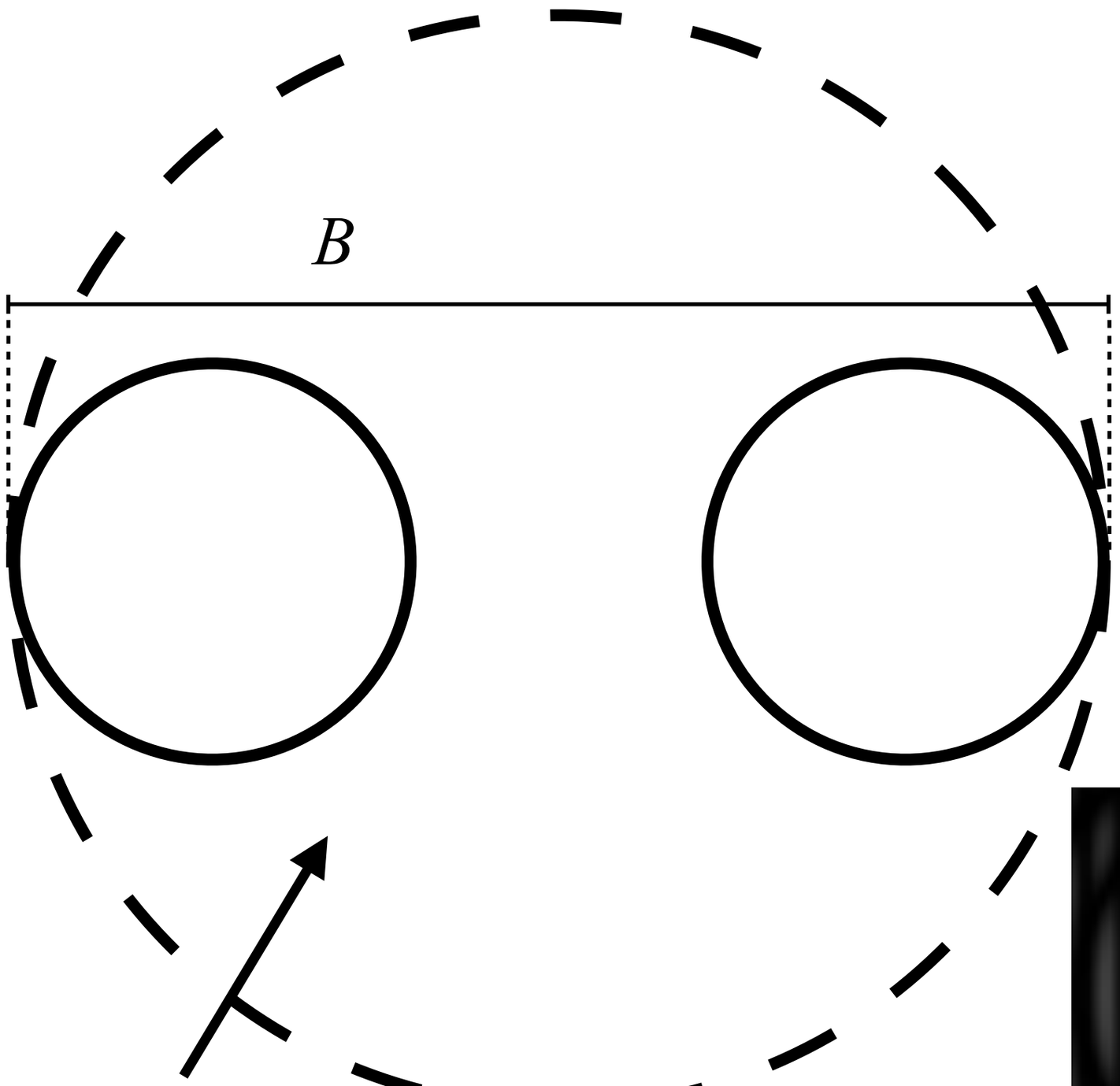
8-m telescope

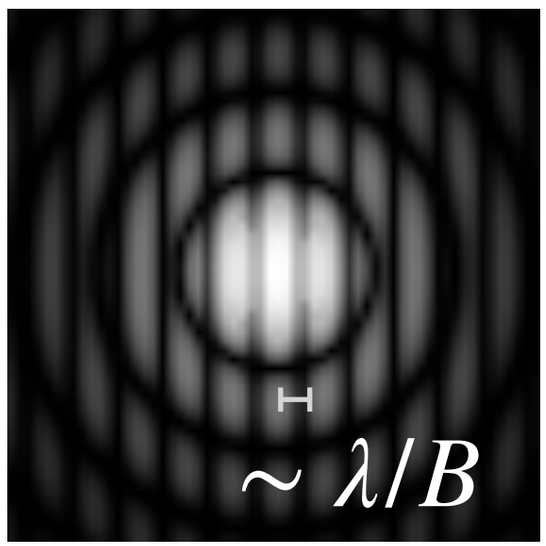
point spread function, "PSF"



light pattern

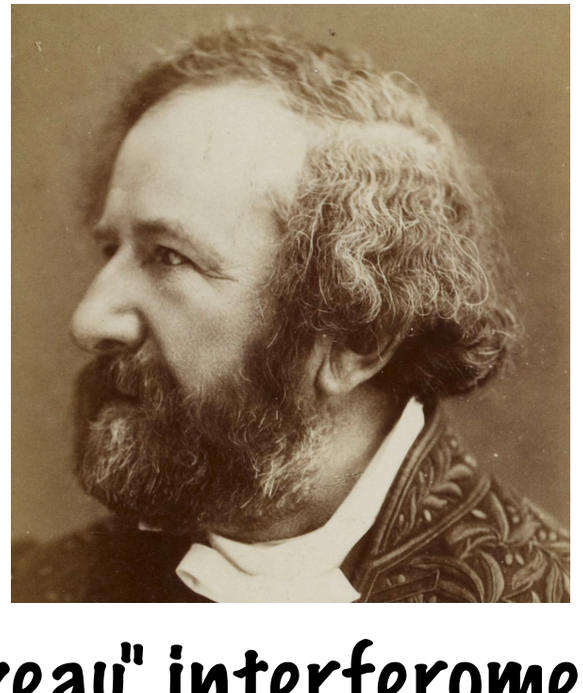
LBT: the first ELT aperture



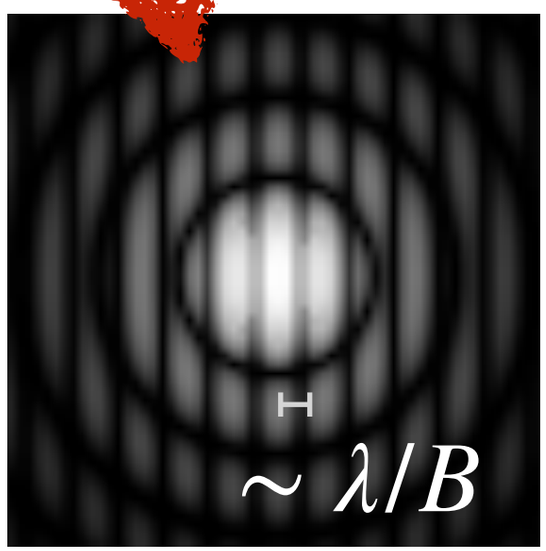


light pattern

LBT: the first ELT aperture



"Fizeau" interferometry

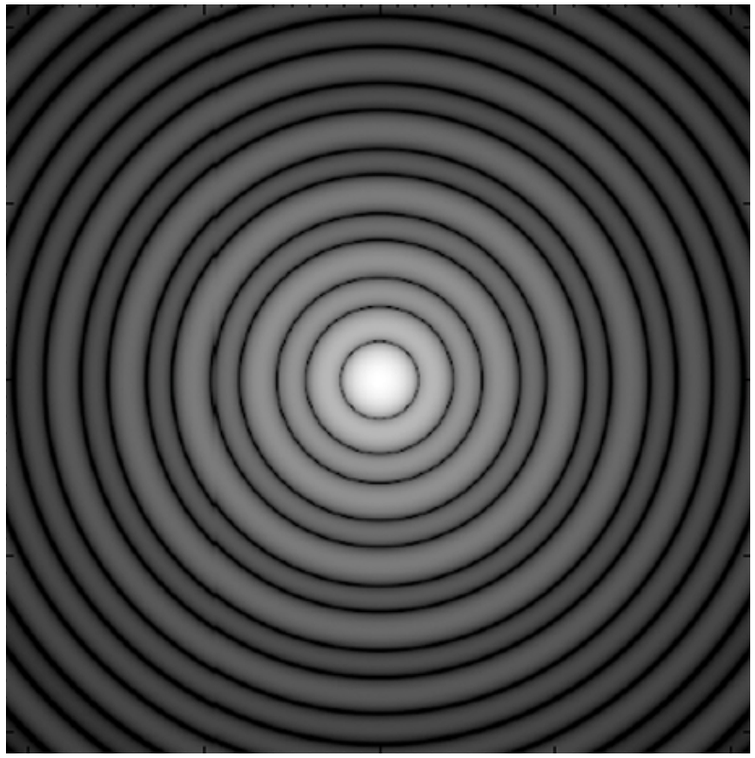


light pattern

22.7 m telescope

LBT: the first ELT aperture

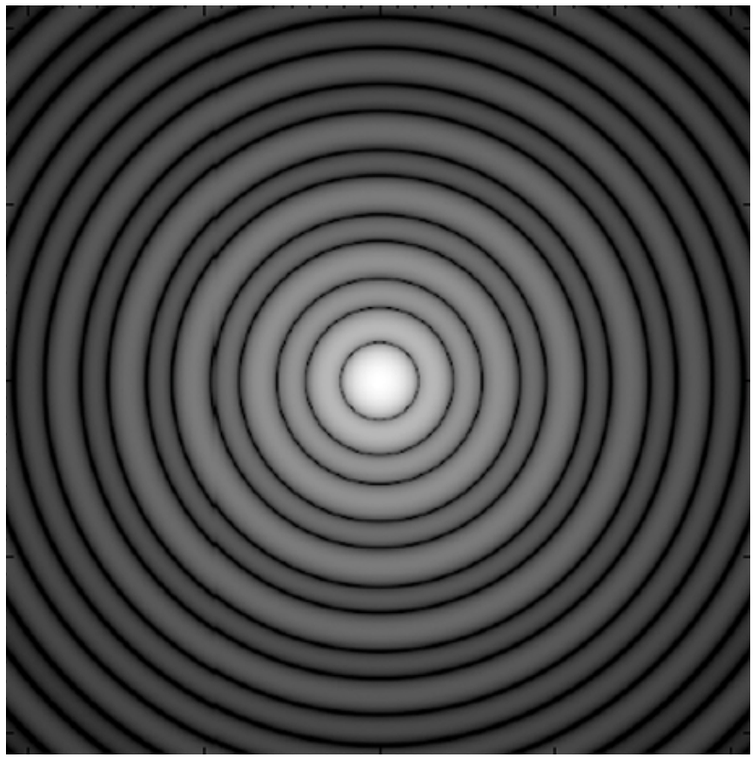
8.4 m telescope



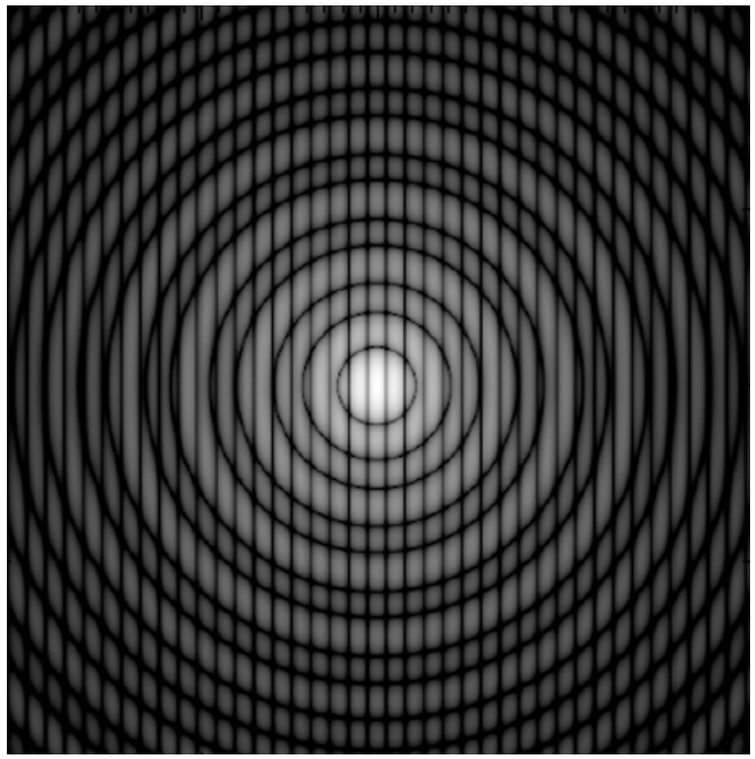
Adapt. from Fig. 4 in Patru+ 2017 MNRAS

LBT: the first ELT aperture

8.4 m telescope

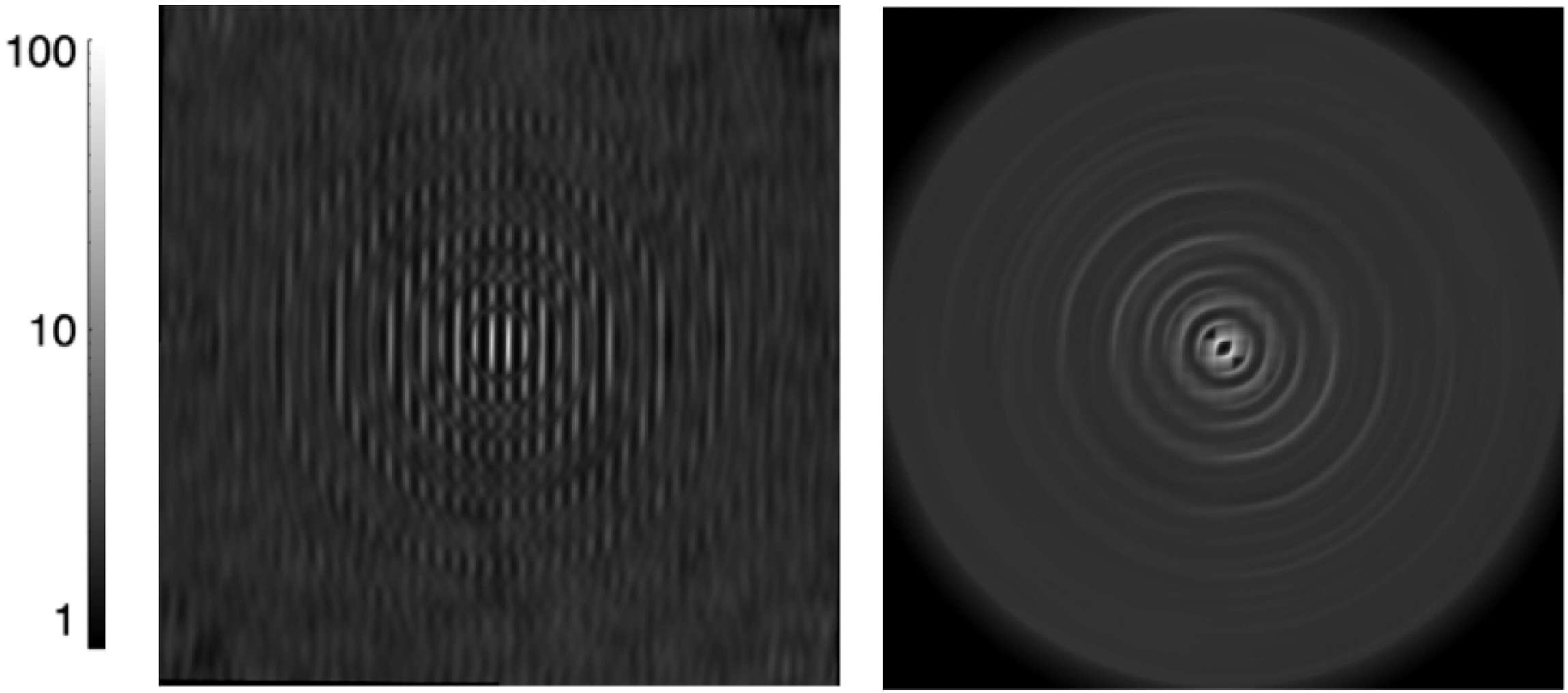


22.7 m telescope



Adapt. from Fig. 4 in Patru+ 2017 MNRAS

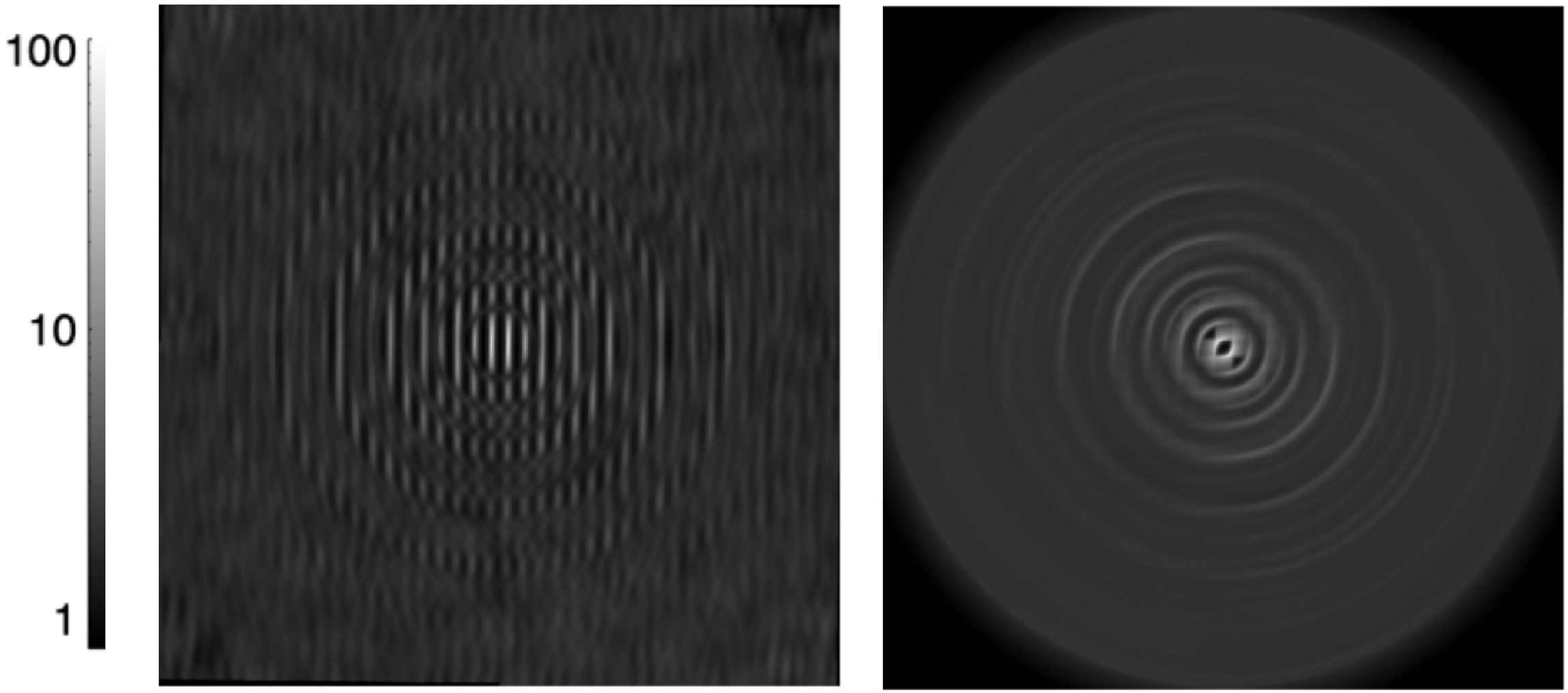
Gain in high-contrast imaging with Fizeau



Adapt. from Fig. 8 in Patru+ 2017 MNRAS

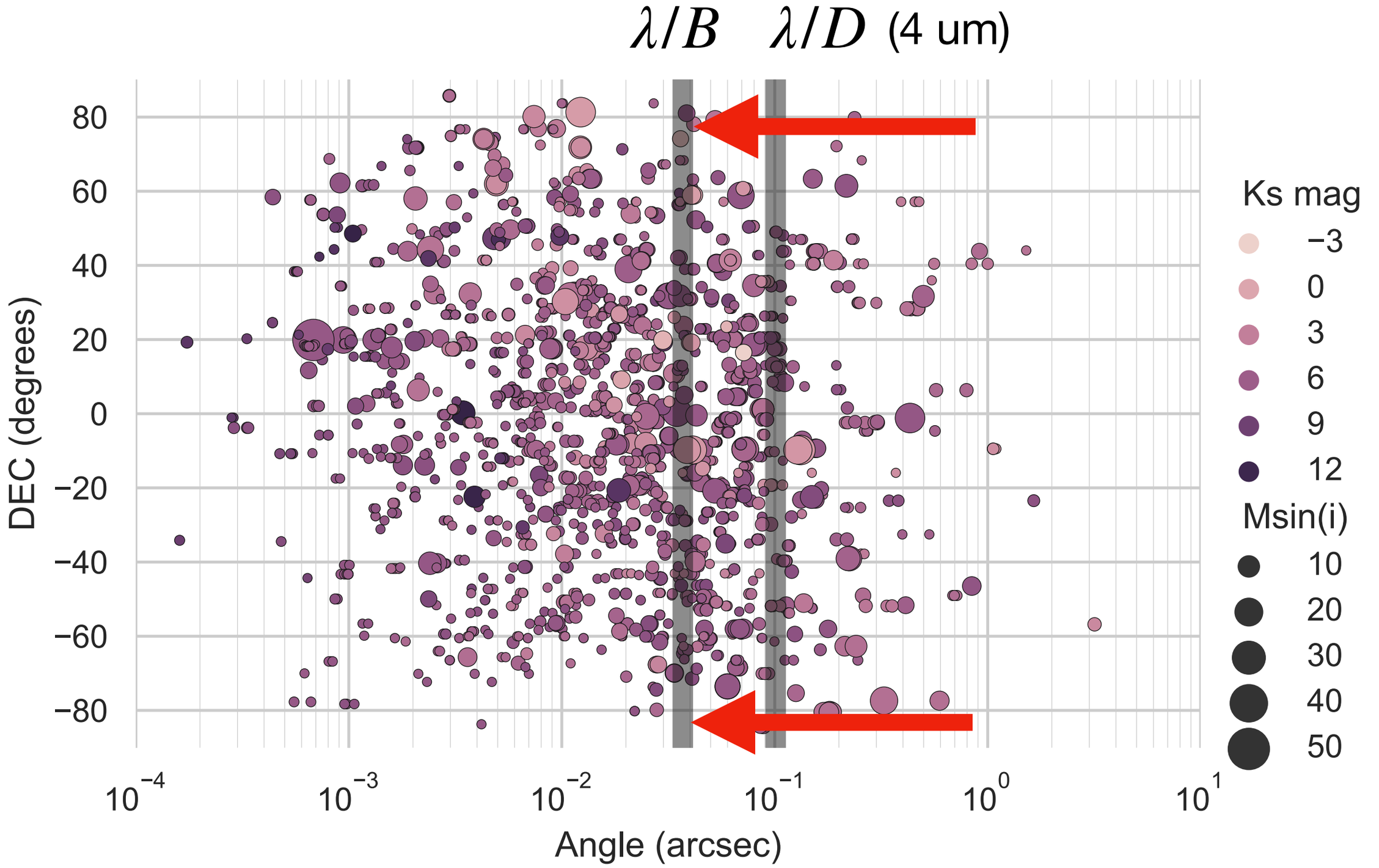
Gain in high-contrast imaging with Fizeau

$$G(x, y) \propto \frac{\mathrm{PSF}_{\mathrm{One}}}{\mathrm{PSF}_{\mathrm{Fizeau}}}$$

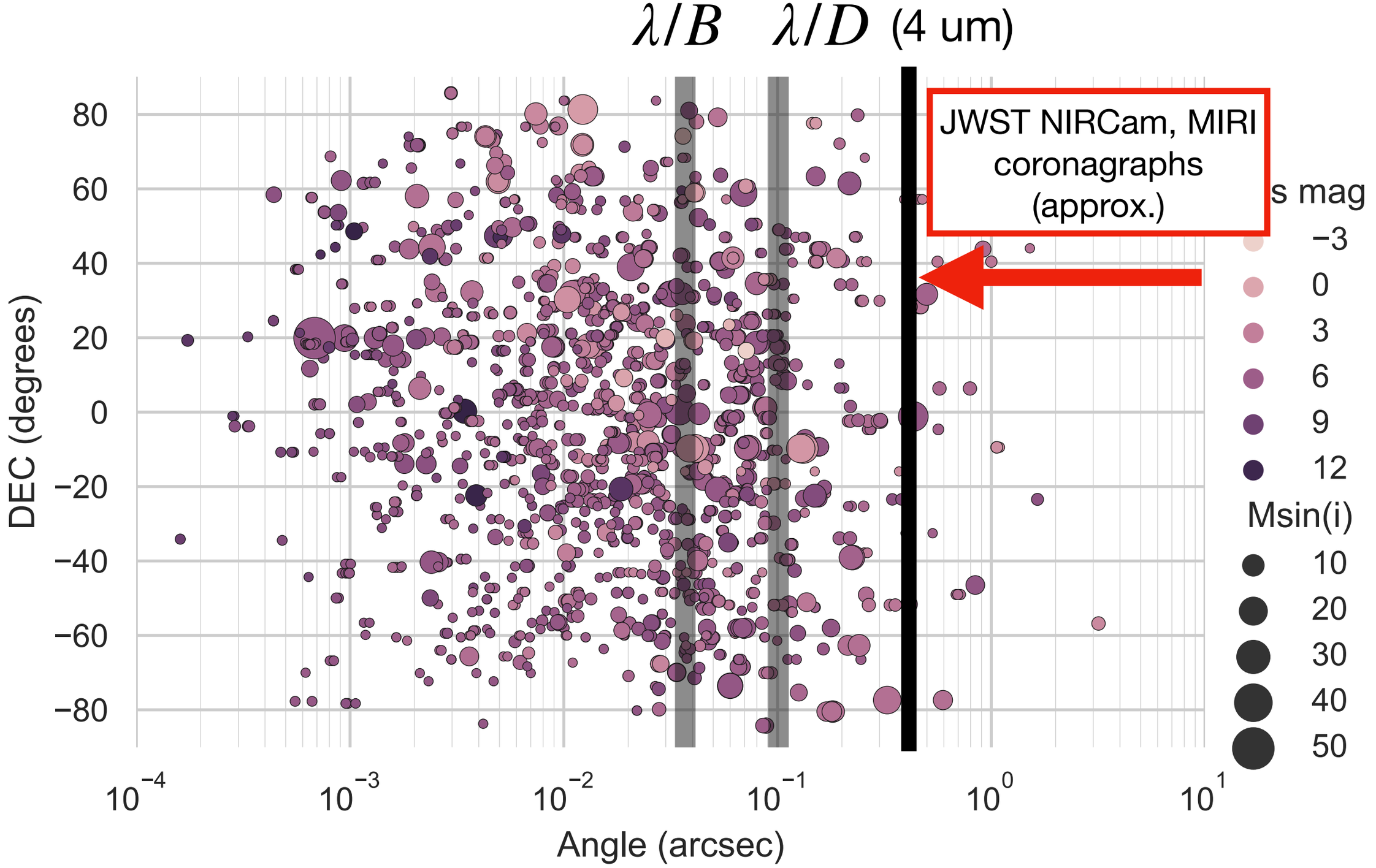


Adapt. from Fig. 8 in Patru+ 2017 MNRAS

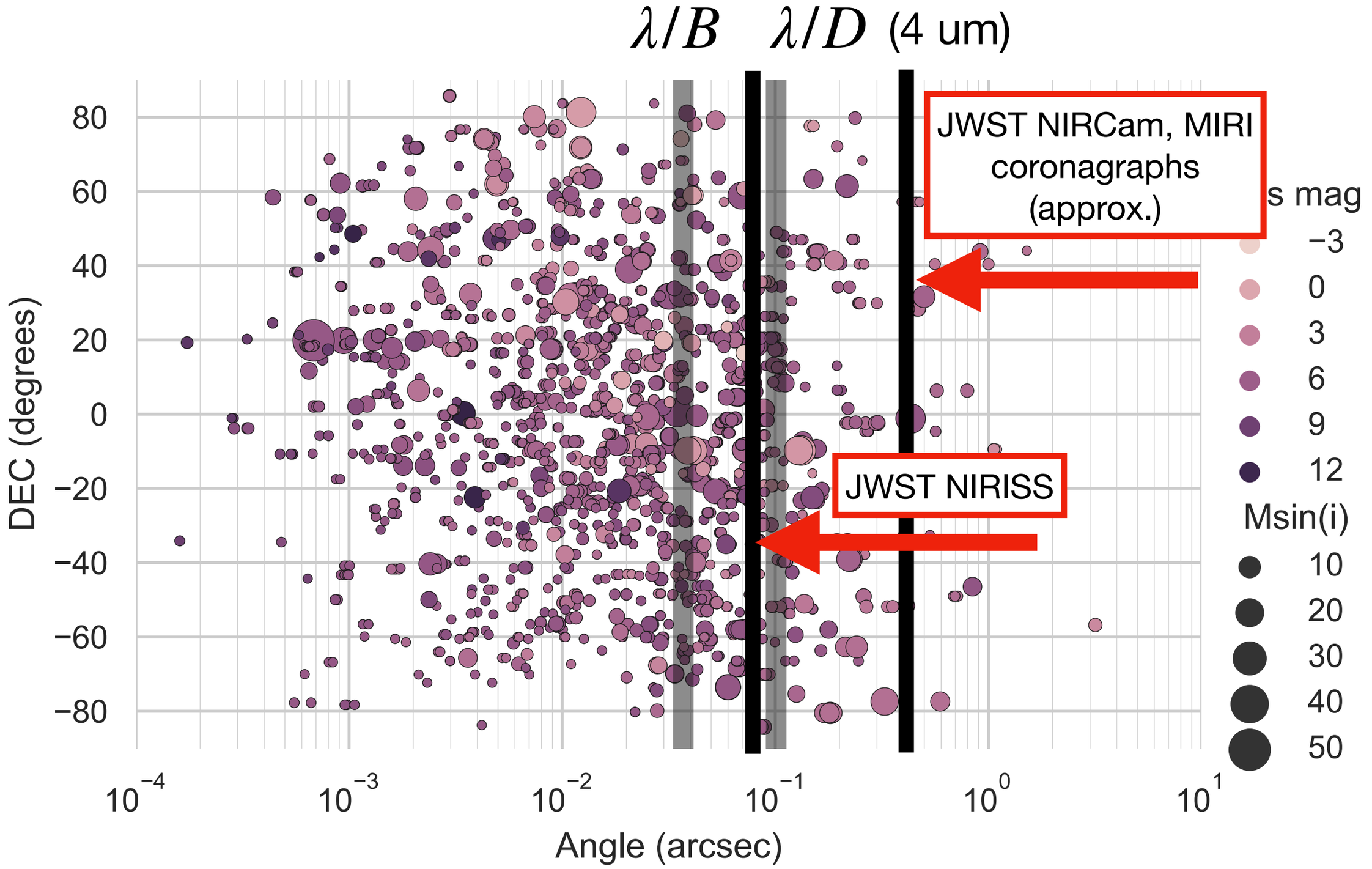
Current RV planets



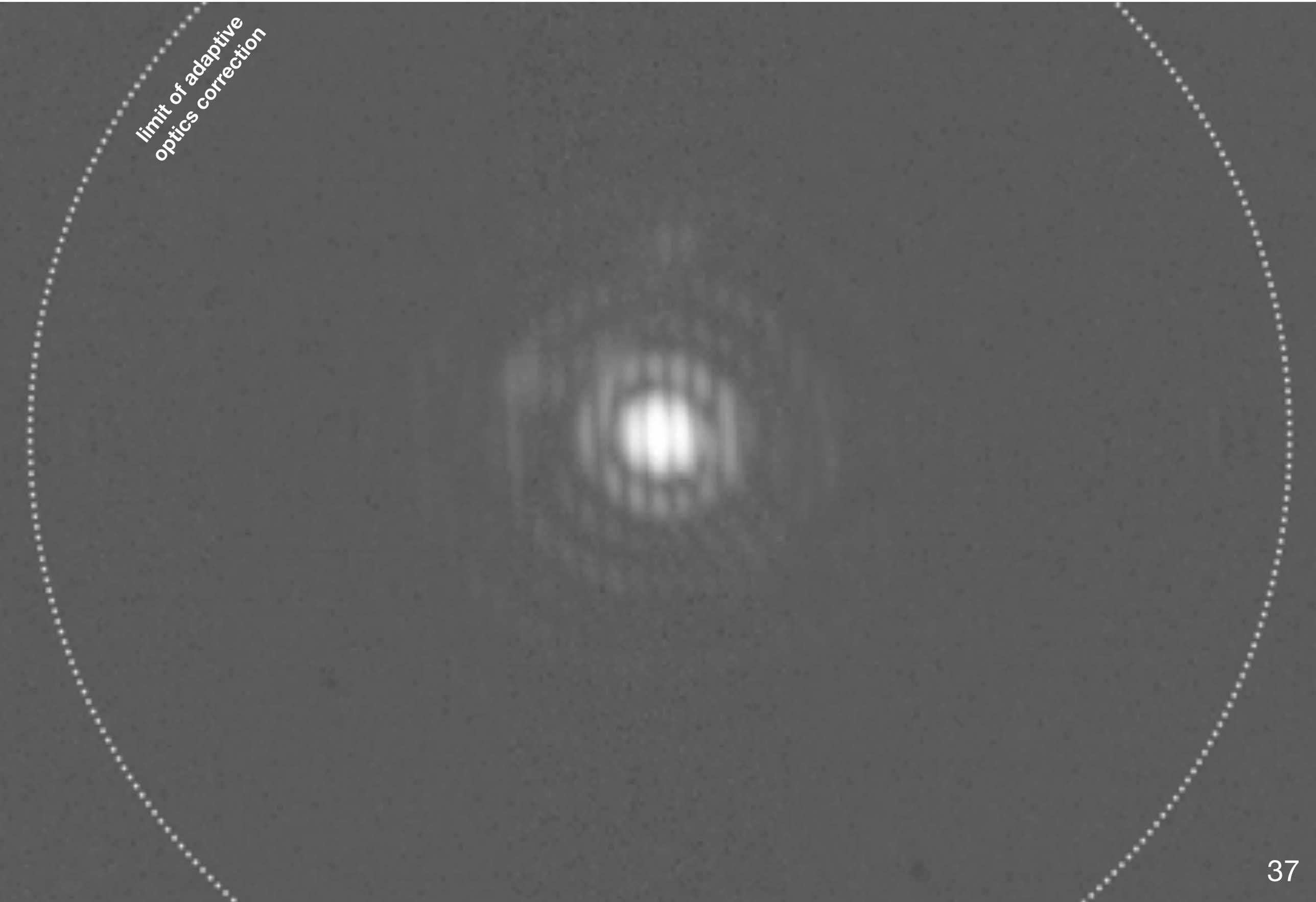
Current RV planets



Current RV planets

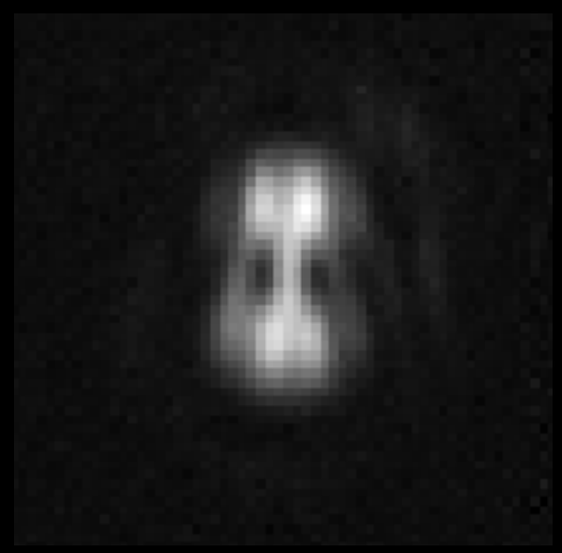


Altair: the first high-contrast Fizeau target



A PSF with additional degrees of freedom

IDEAL



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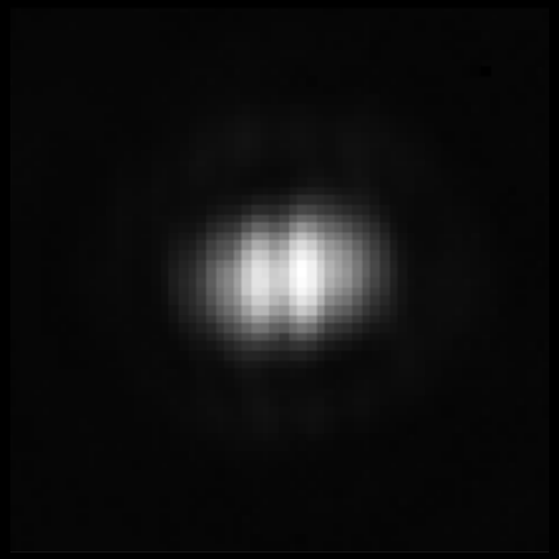

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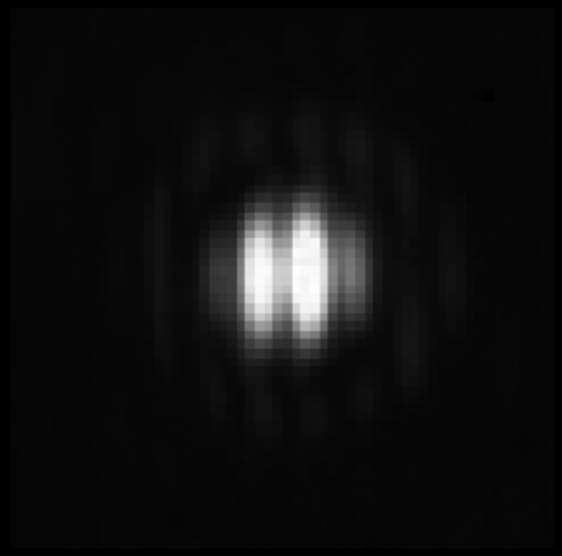

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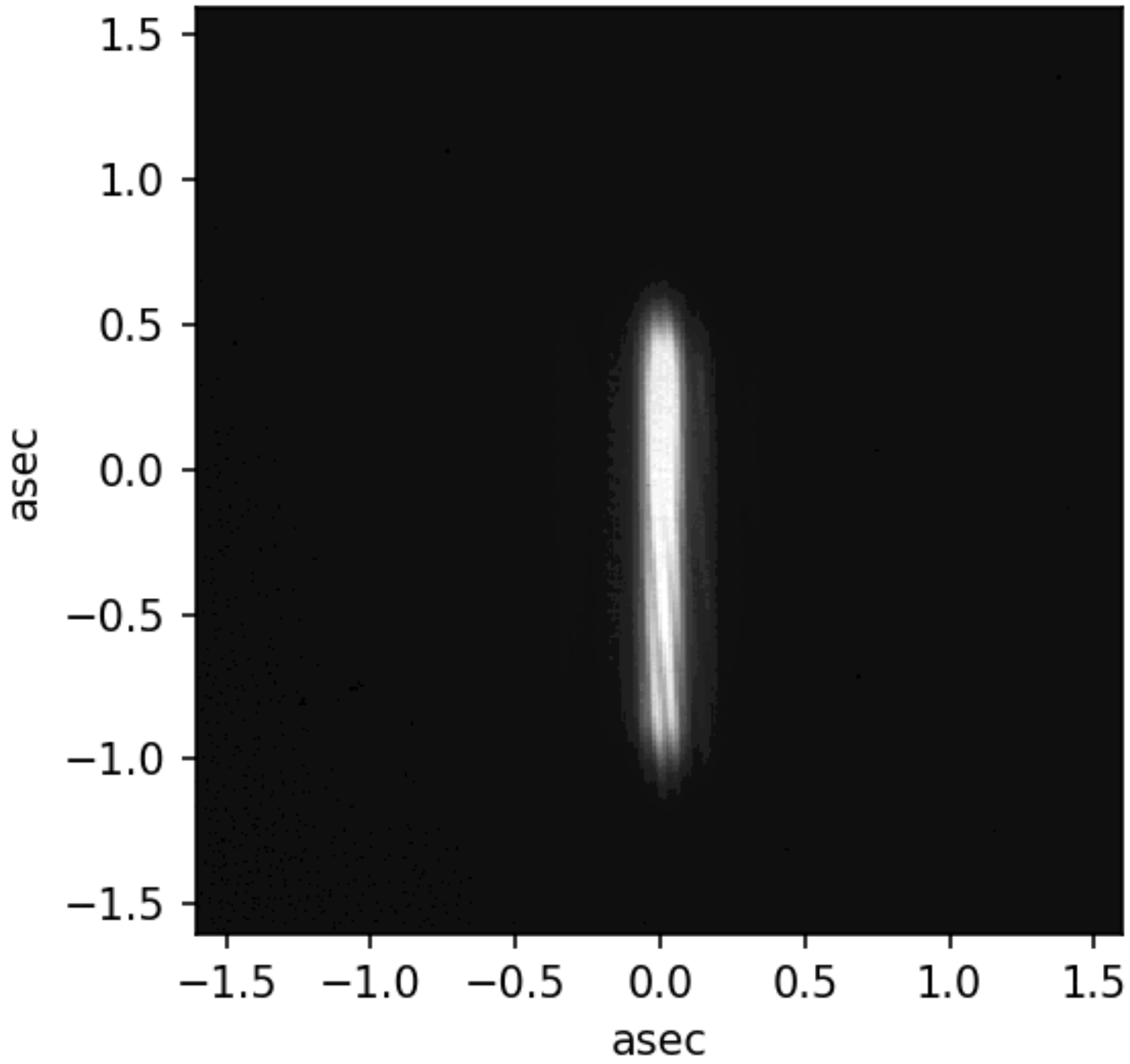
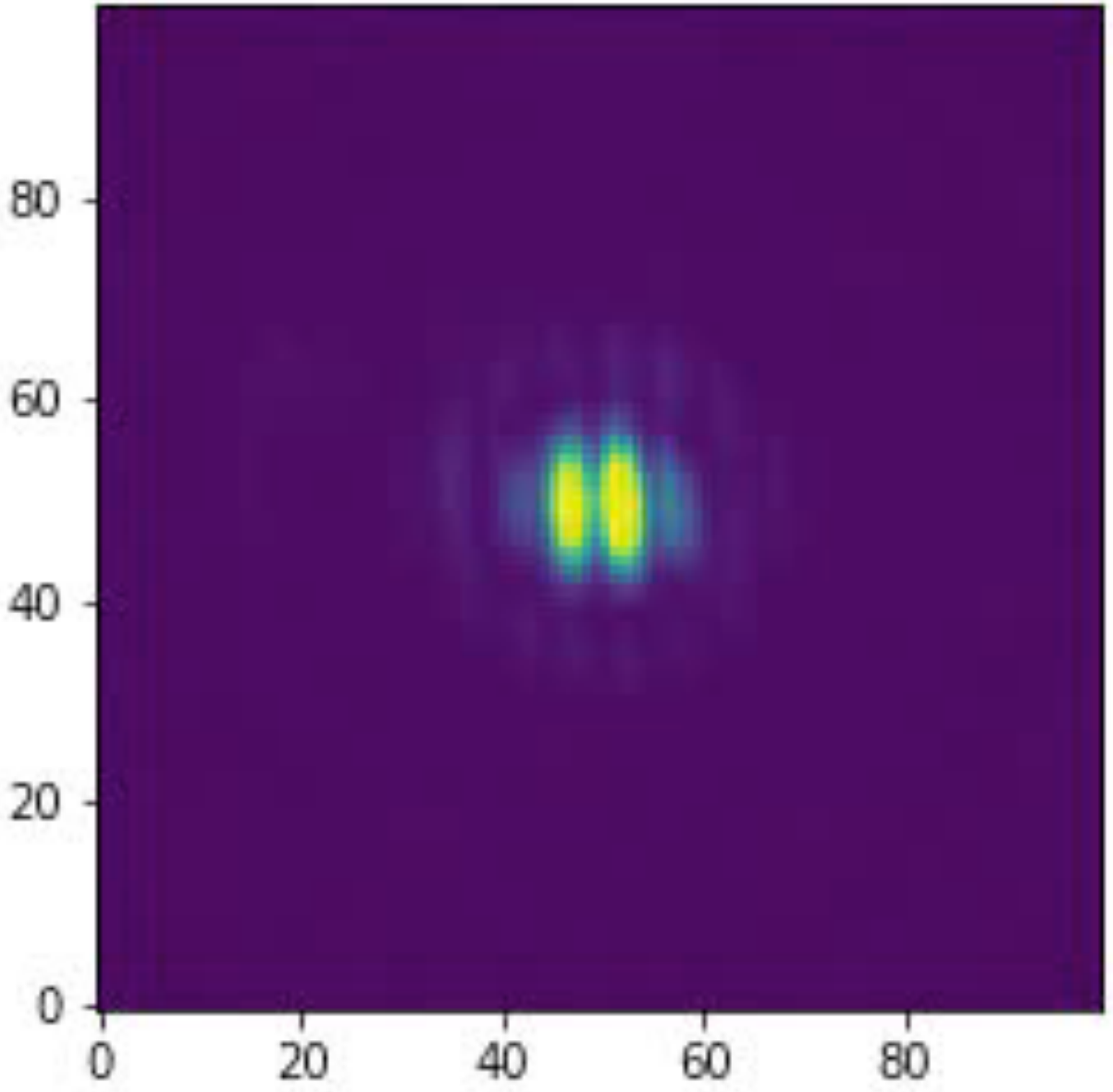
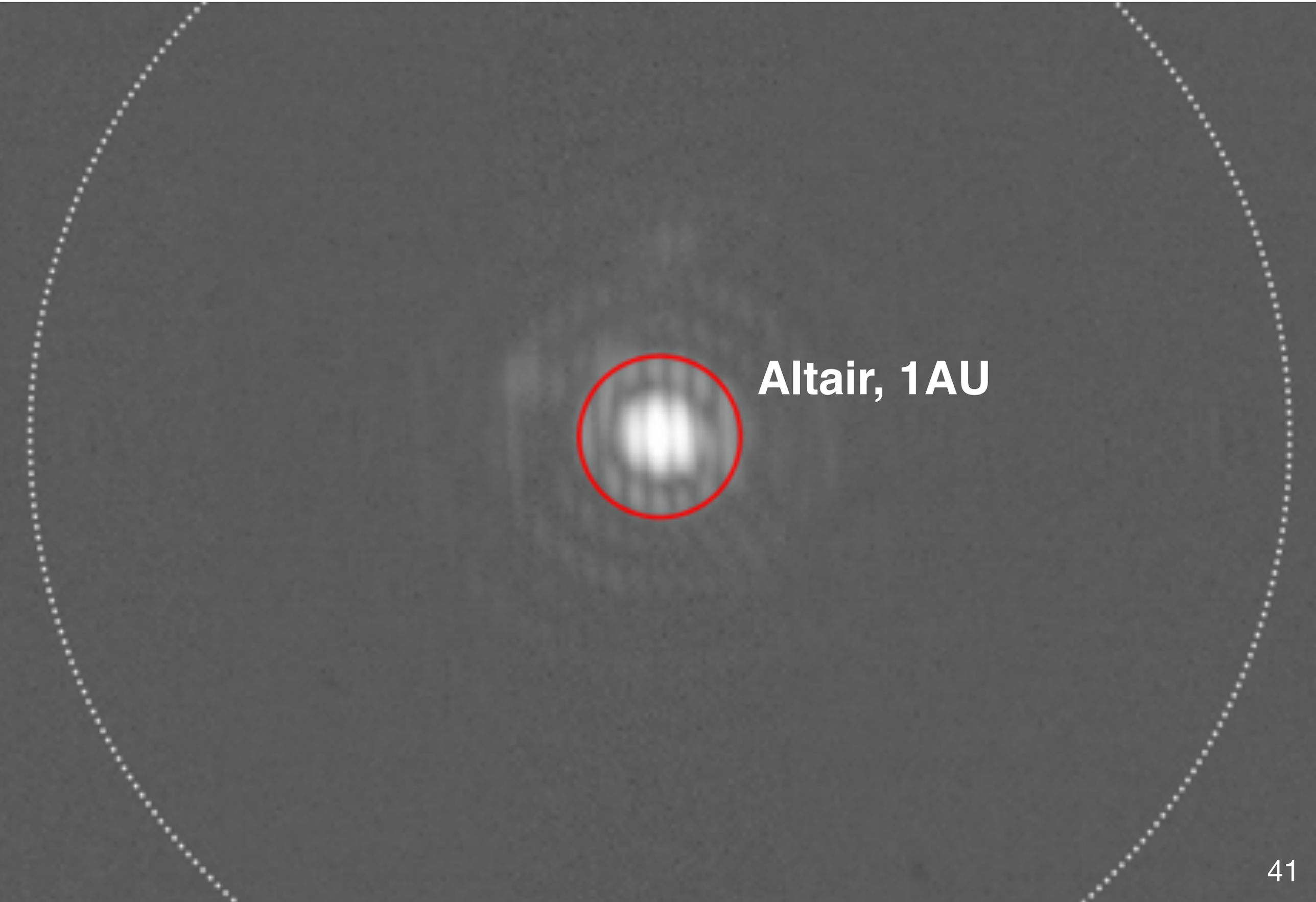
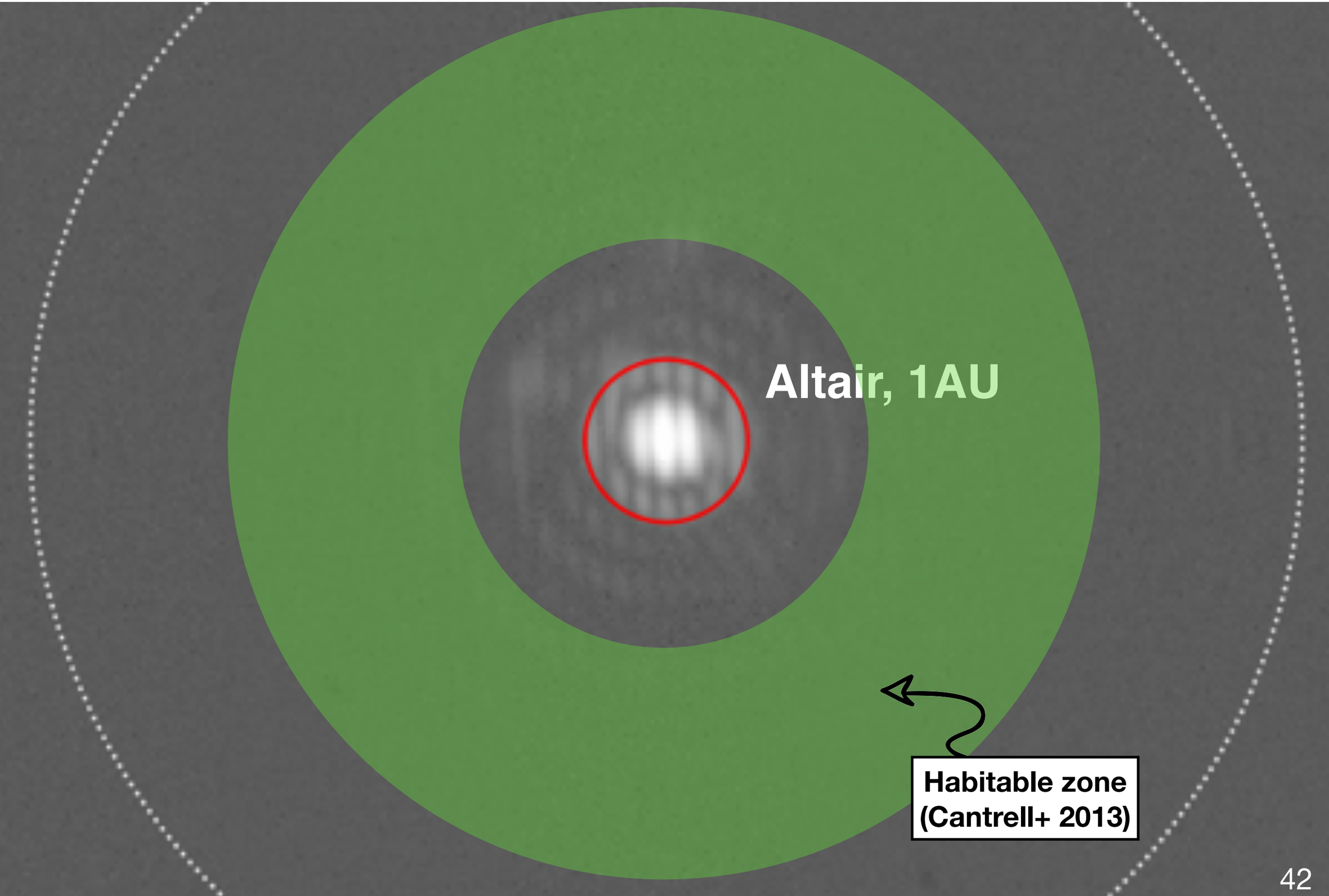

1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
asec
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
asec


80
60
40
20
0
0
20
40
60
80

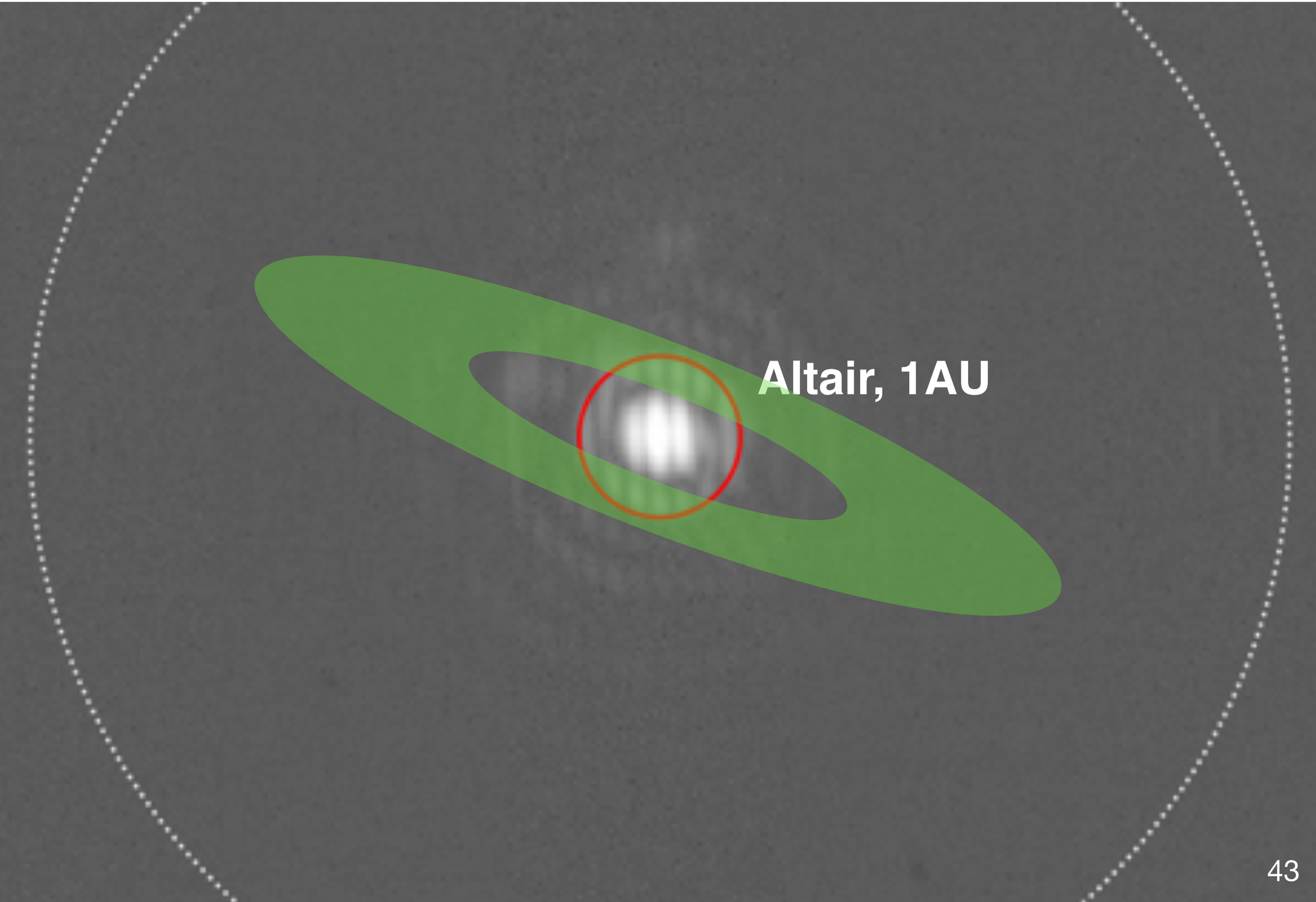
The scale of the Altair system



The scale of the Altair system

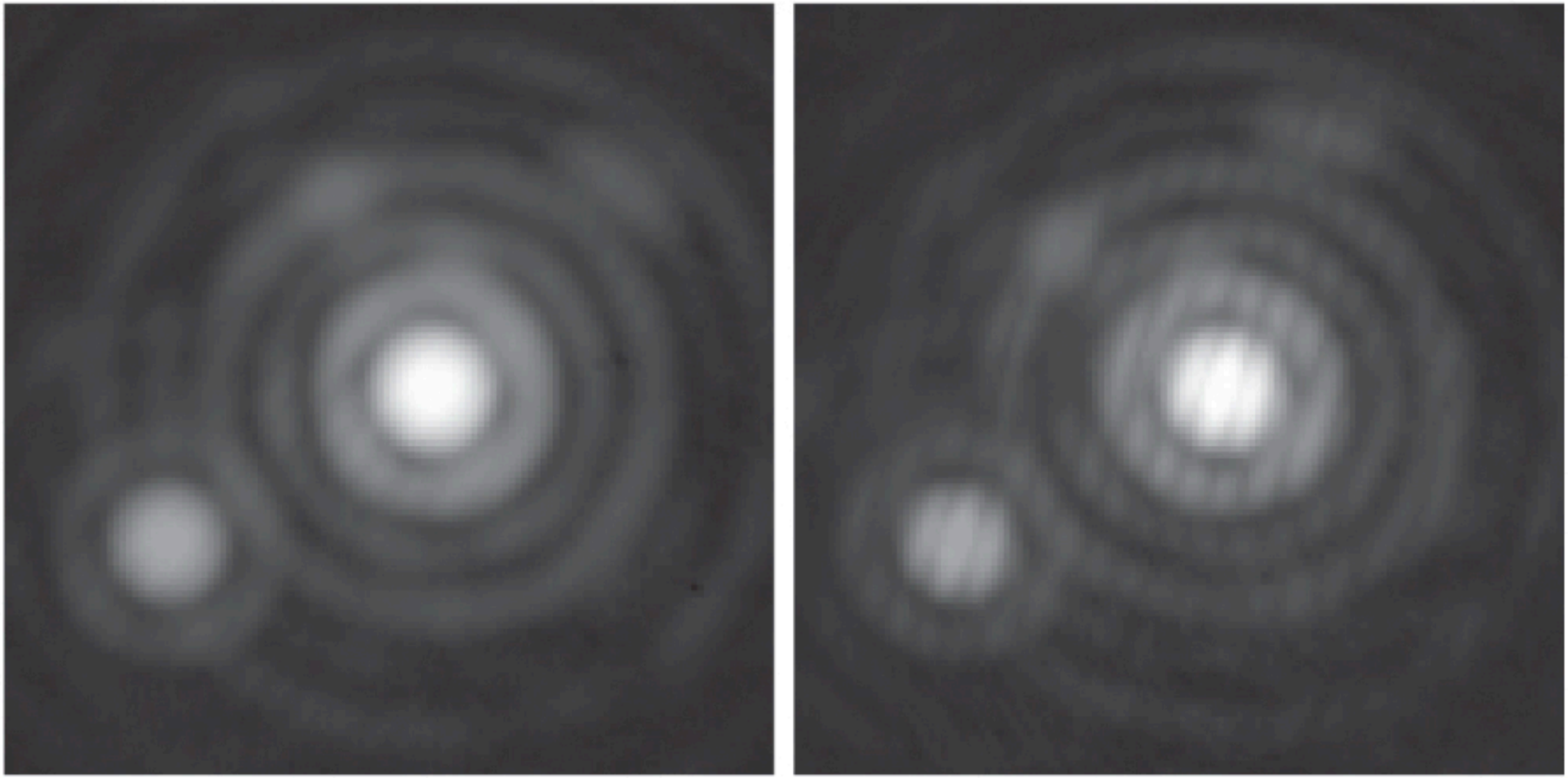


The scale of the Altair system

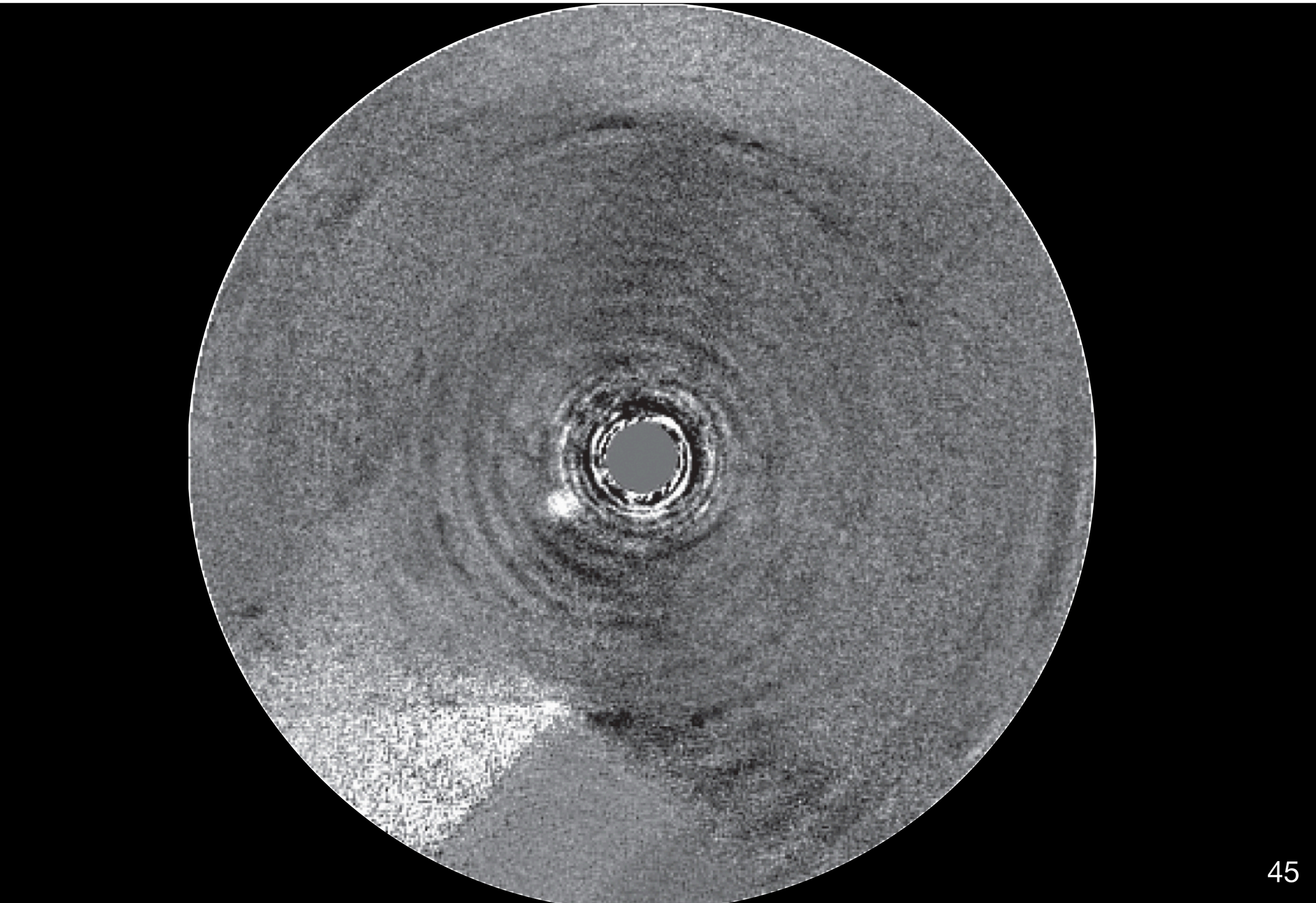


Post-processing with Fizeau: the classical regime

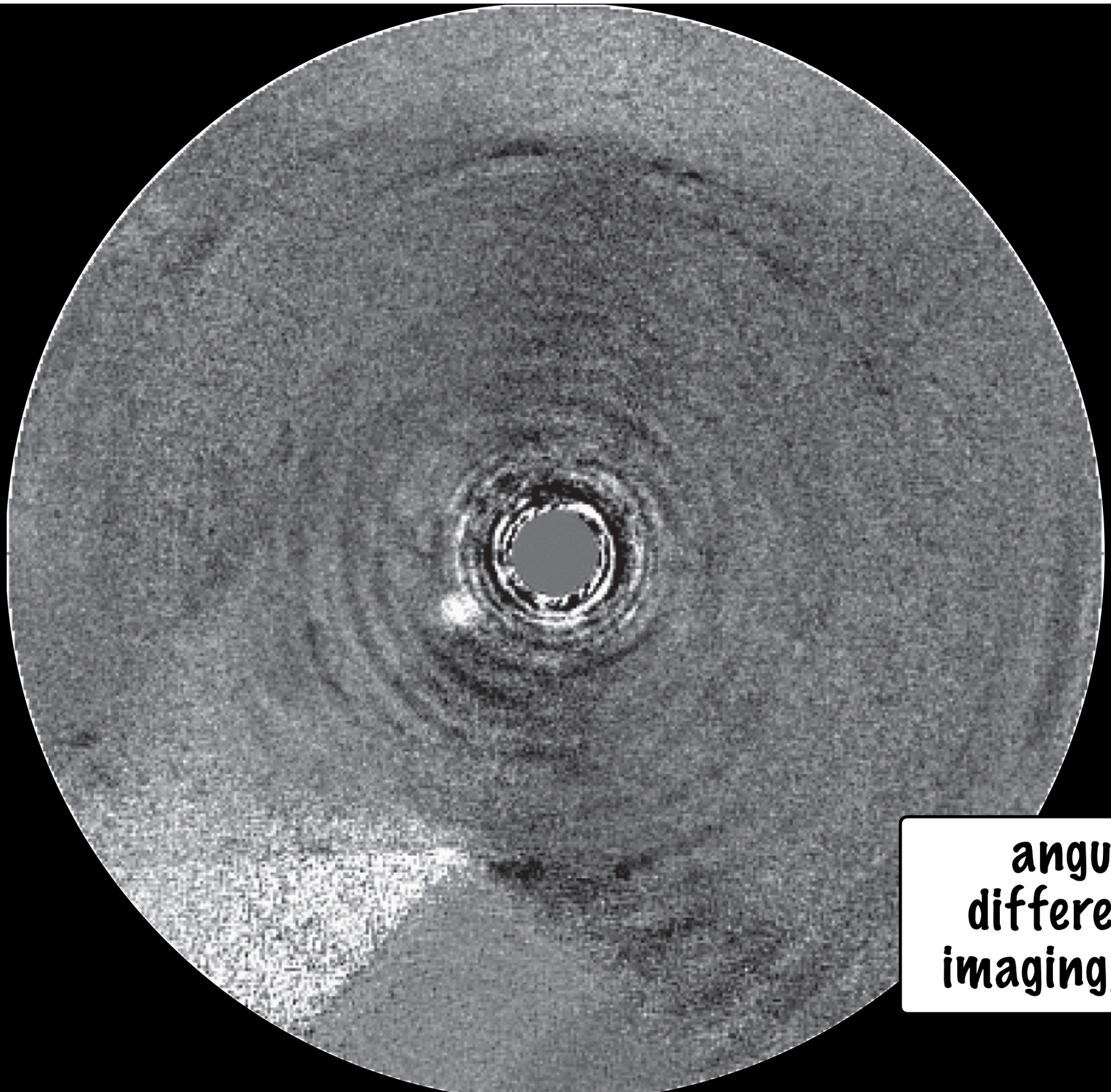
$$\rho > \lambda/D$$



Post-processing with Fizeau: the classical regime



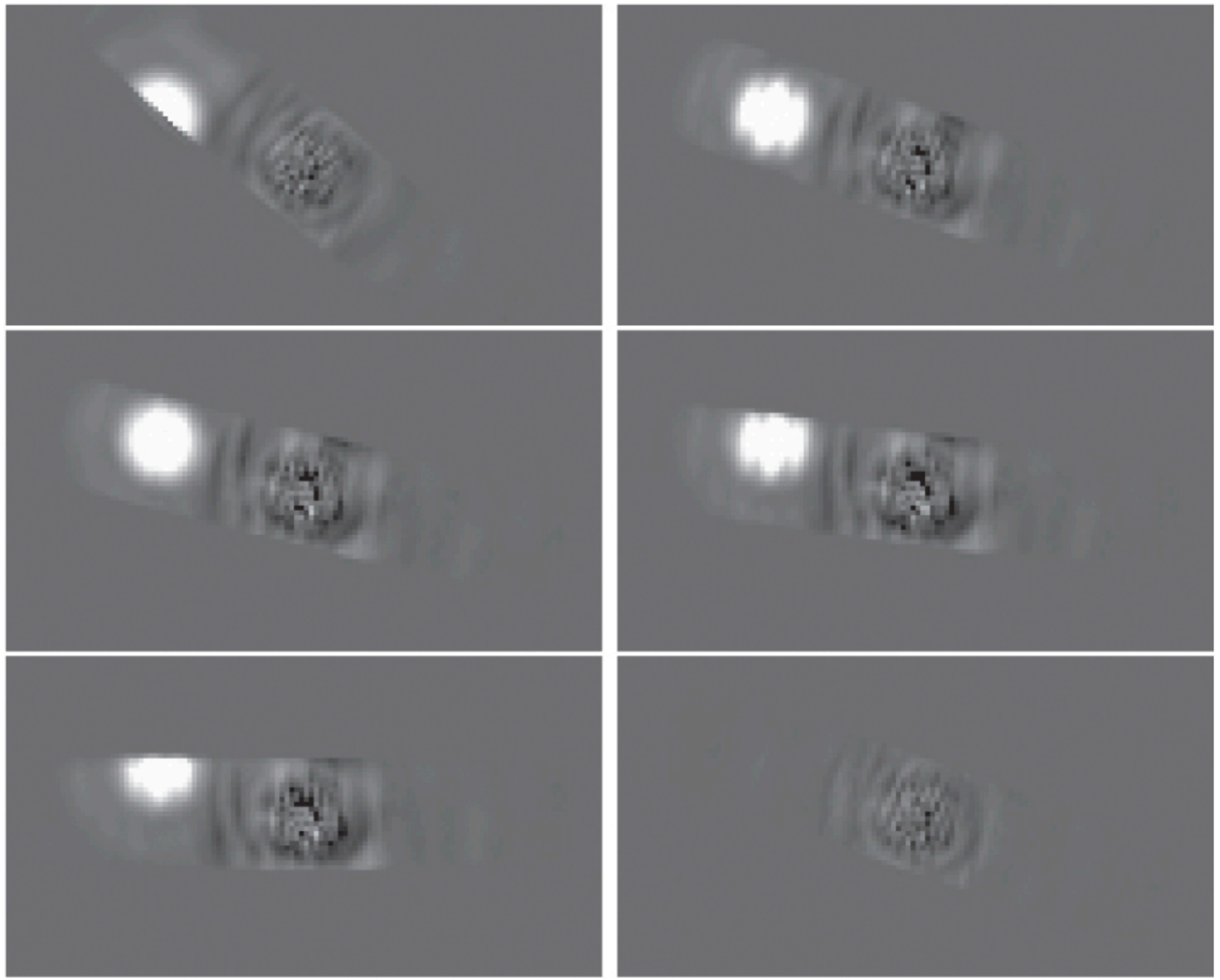
Post-processing with Fizeau: the classical regime



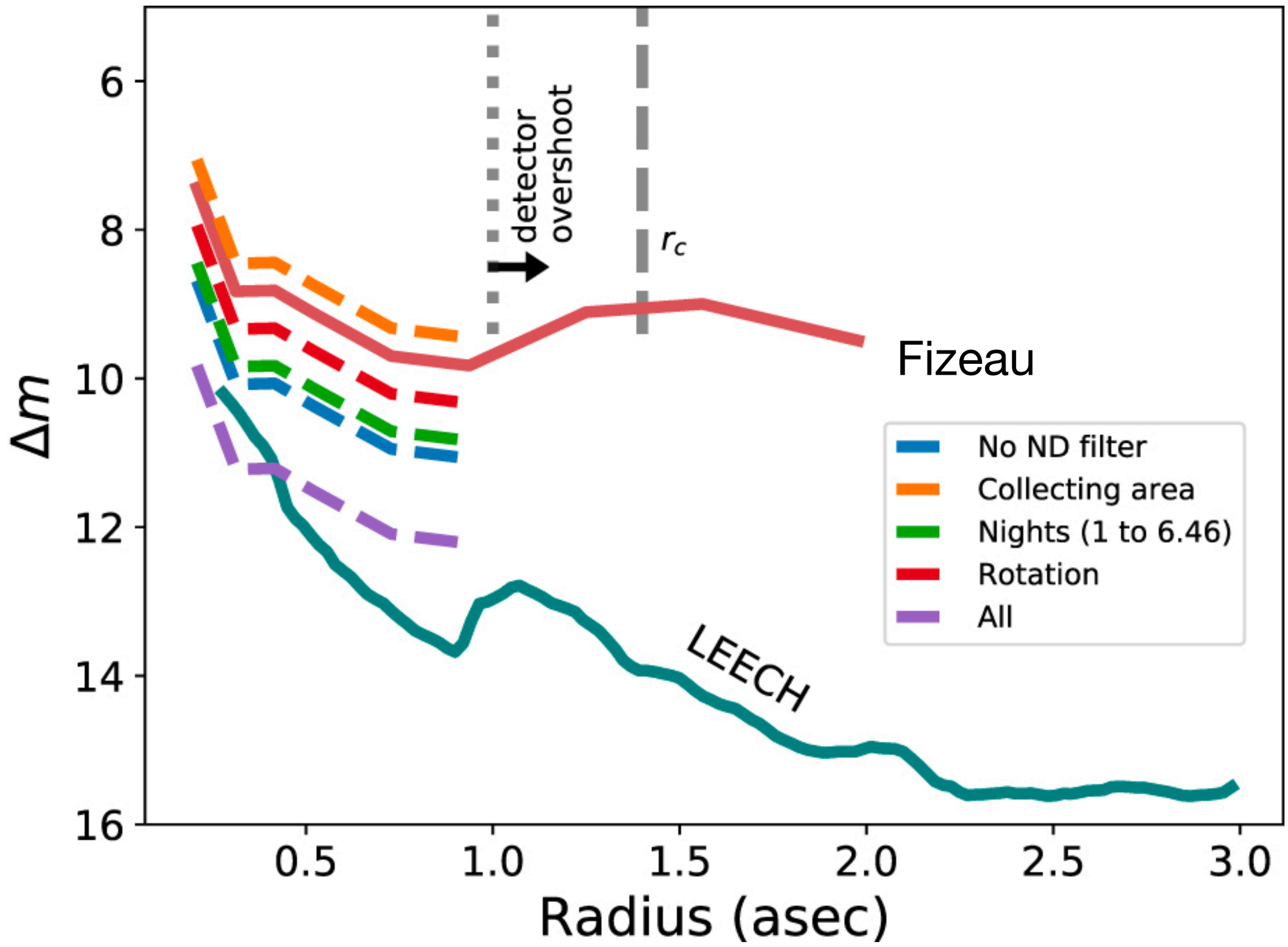
angular differential imaging, "ADI"

Post-processing with Fizeau: the Fizeau regime

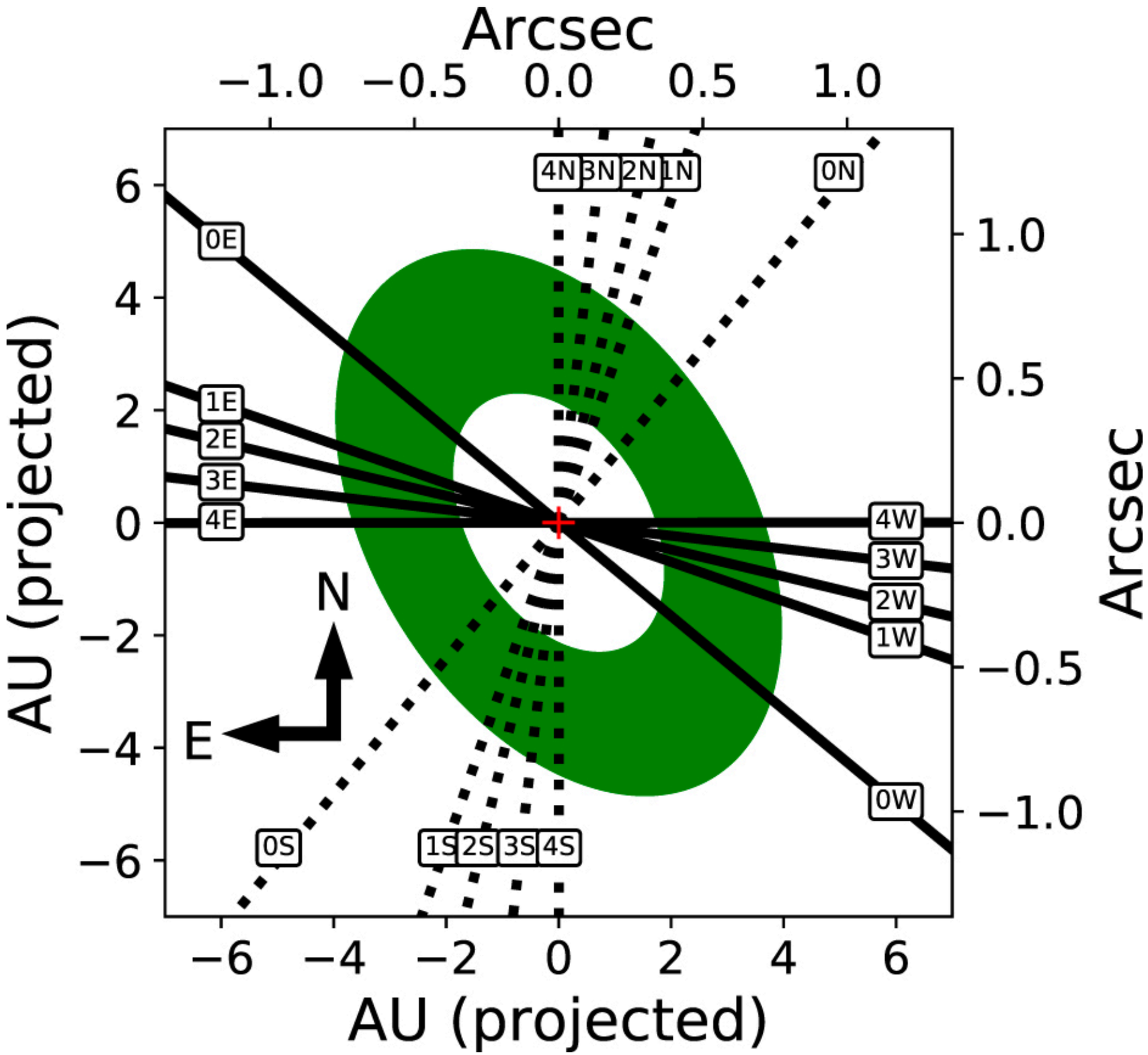
$$\lambda/D \gtrsim \rho \gtrsim \lambda/B$$



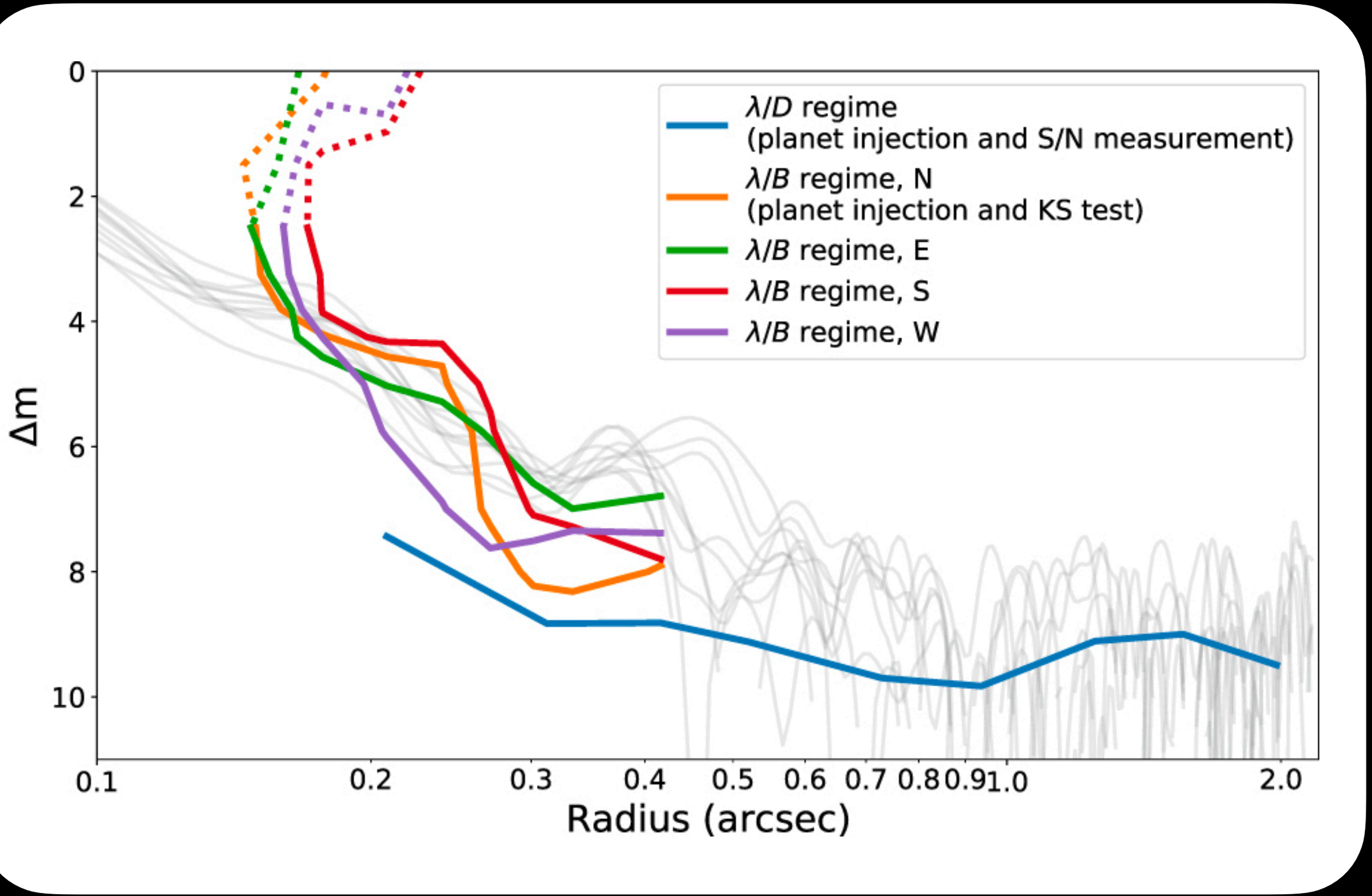
Contrast curves in the classical angular regime



Fizeau baselines through the Altair HZ



Contrast curves: all together now



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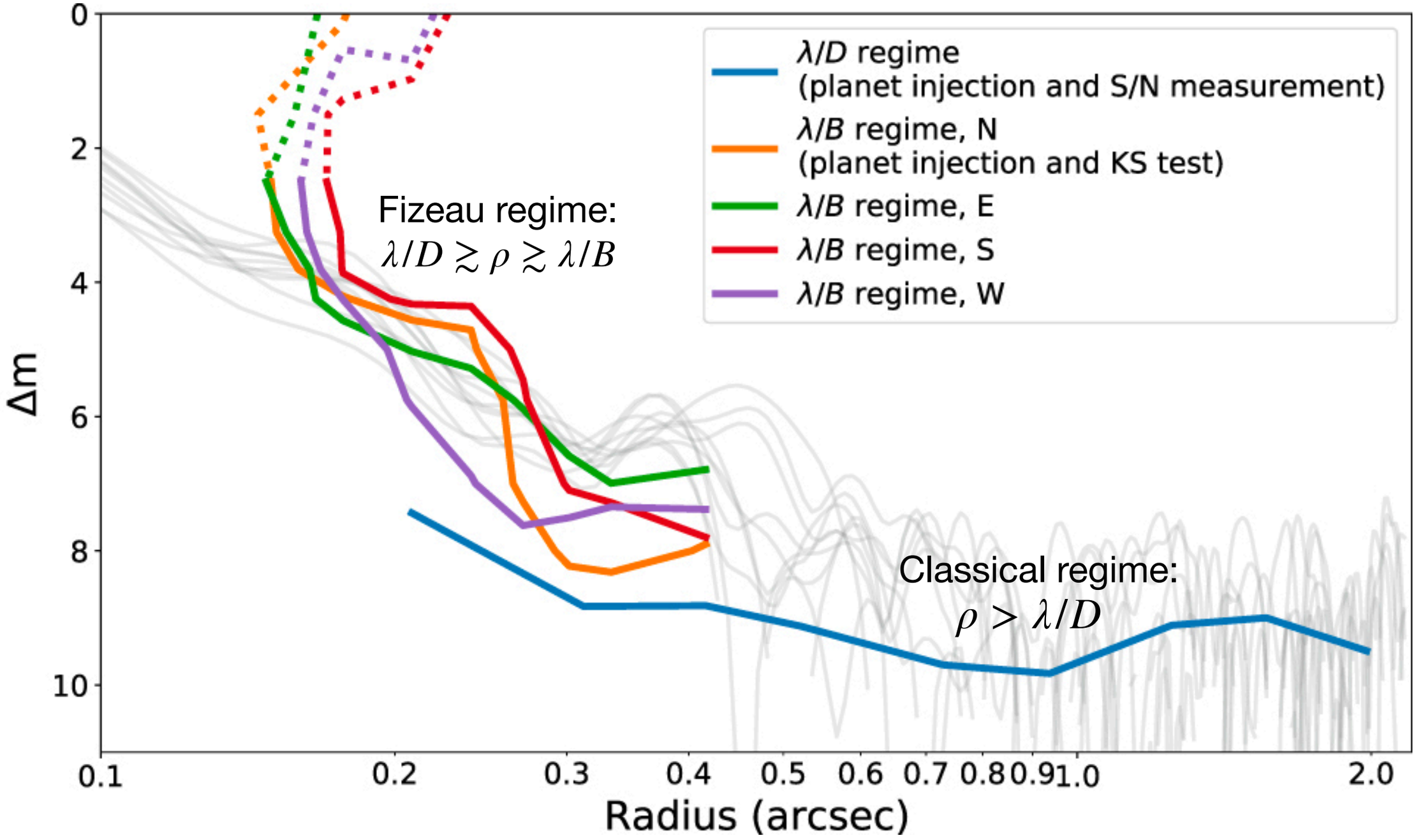
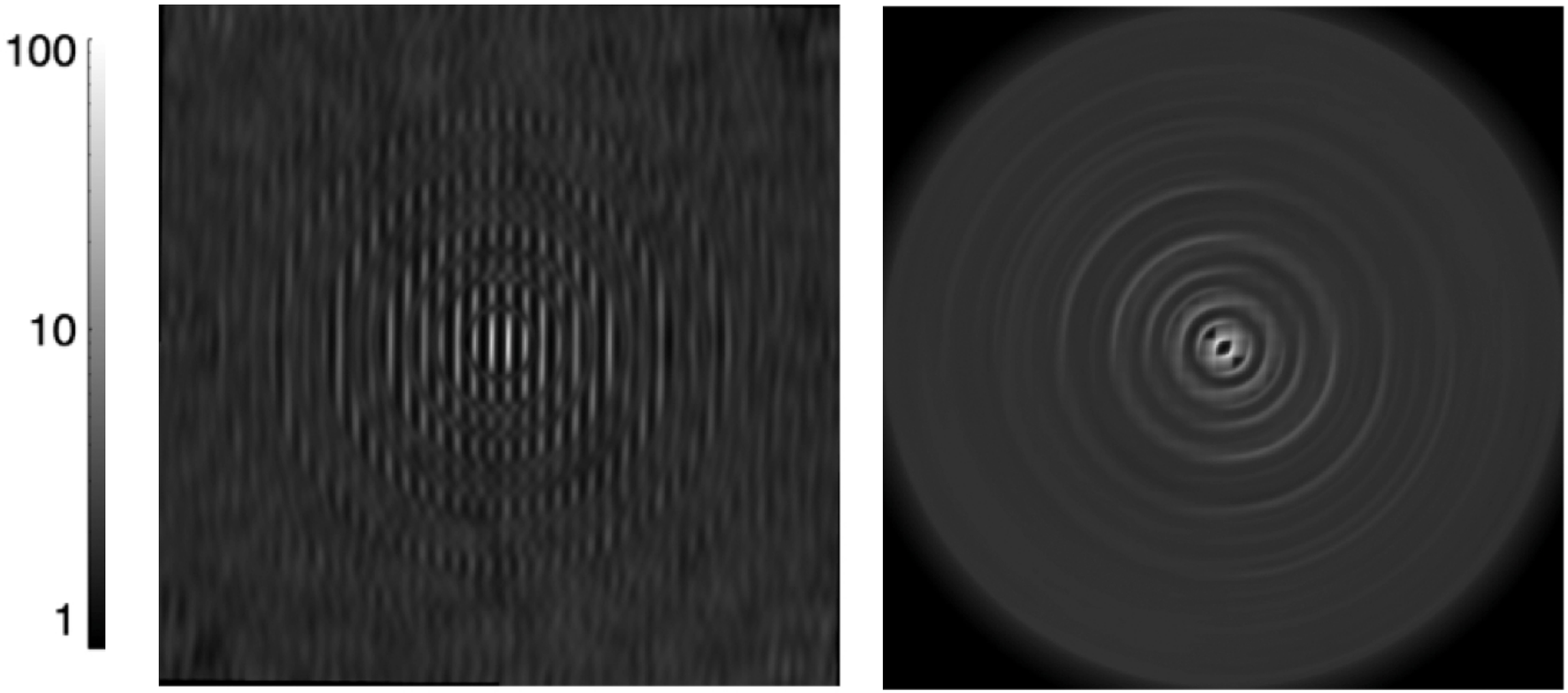


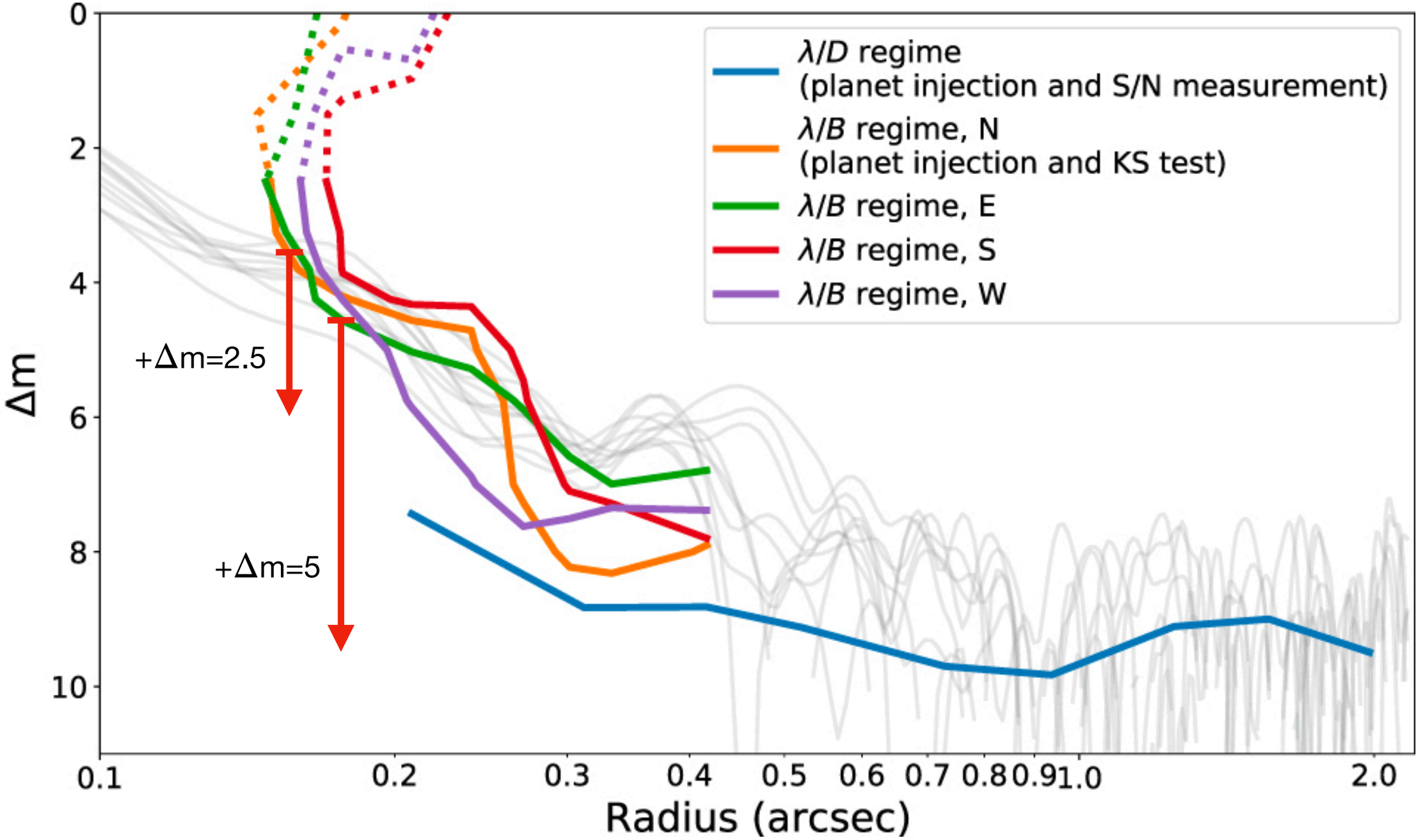
Gain in high-contrast imaging with Fizeau

$$G(x, y) \propto \frac{\mathrm{PSF}_{\mathrm{One}}}{\mathrm{PSF}_{\mathrm{Fizeau}}}$$



Adapt. from Fig. 8 in Patru+ 2017 MNRAS

What improvement does the gain suggest?



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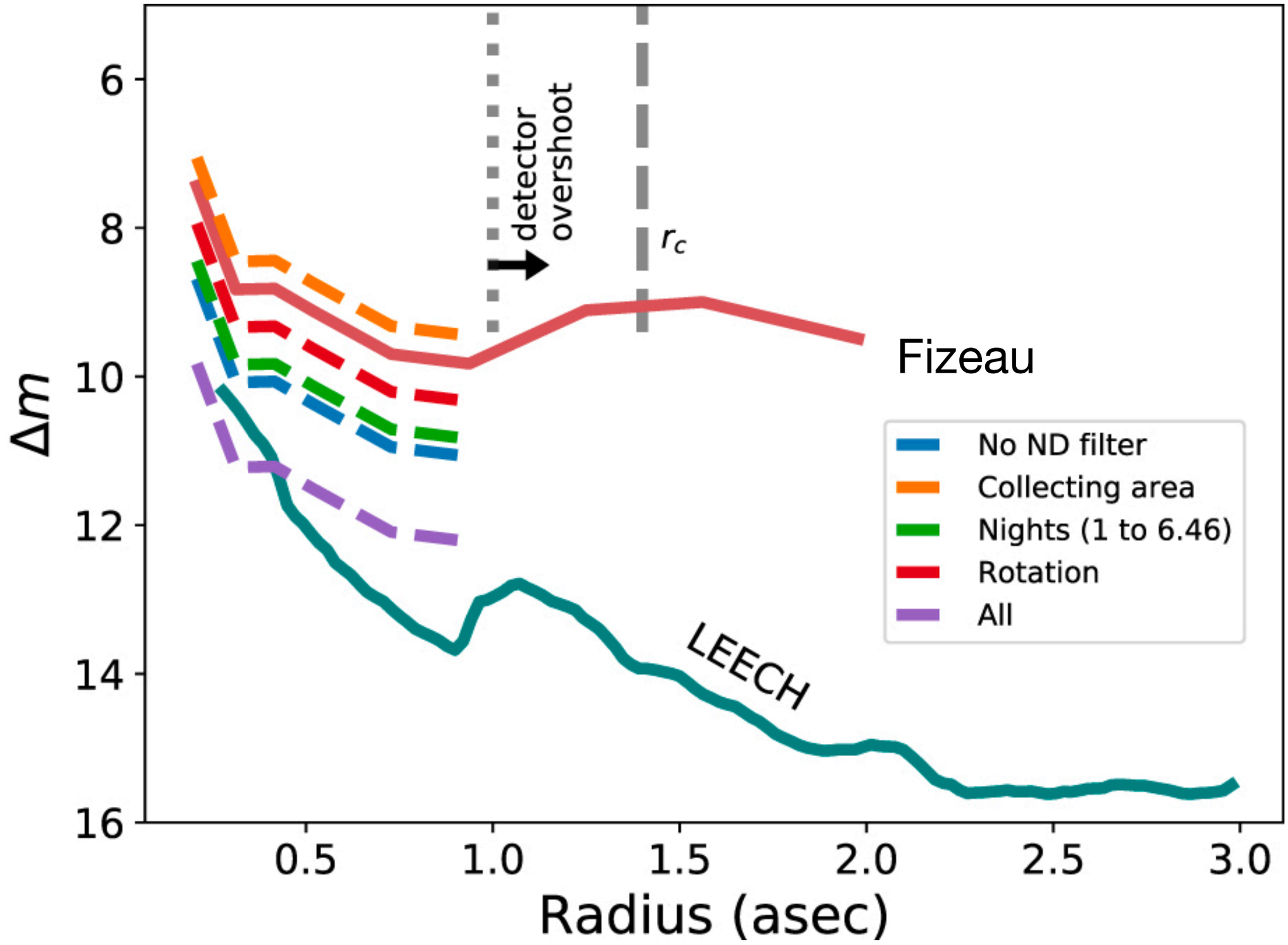

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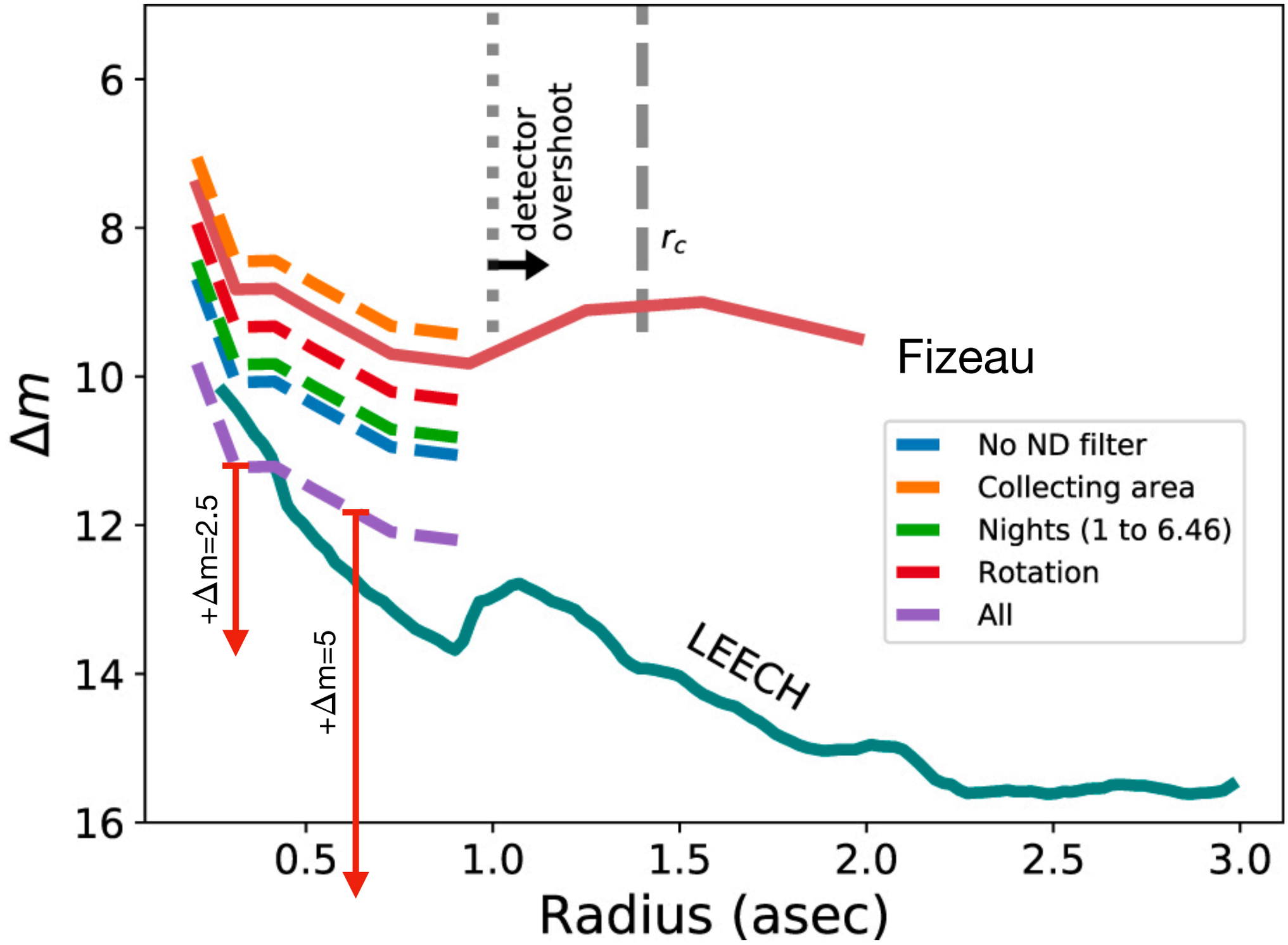

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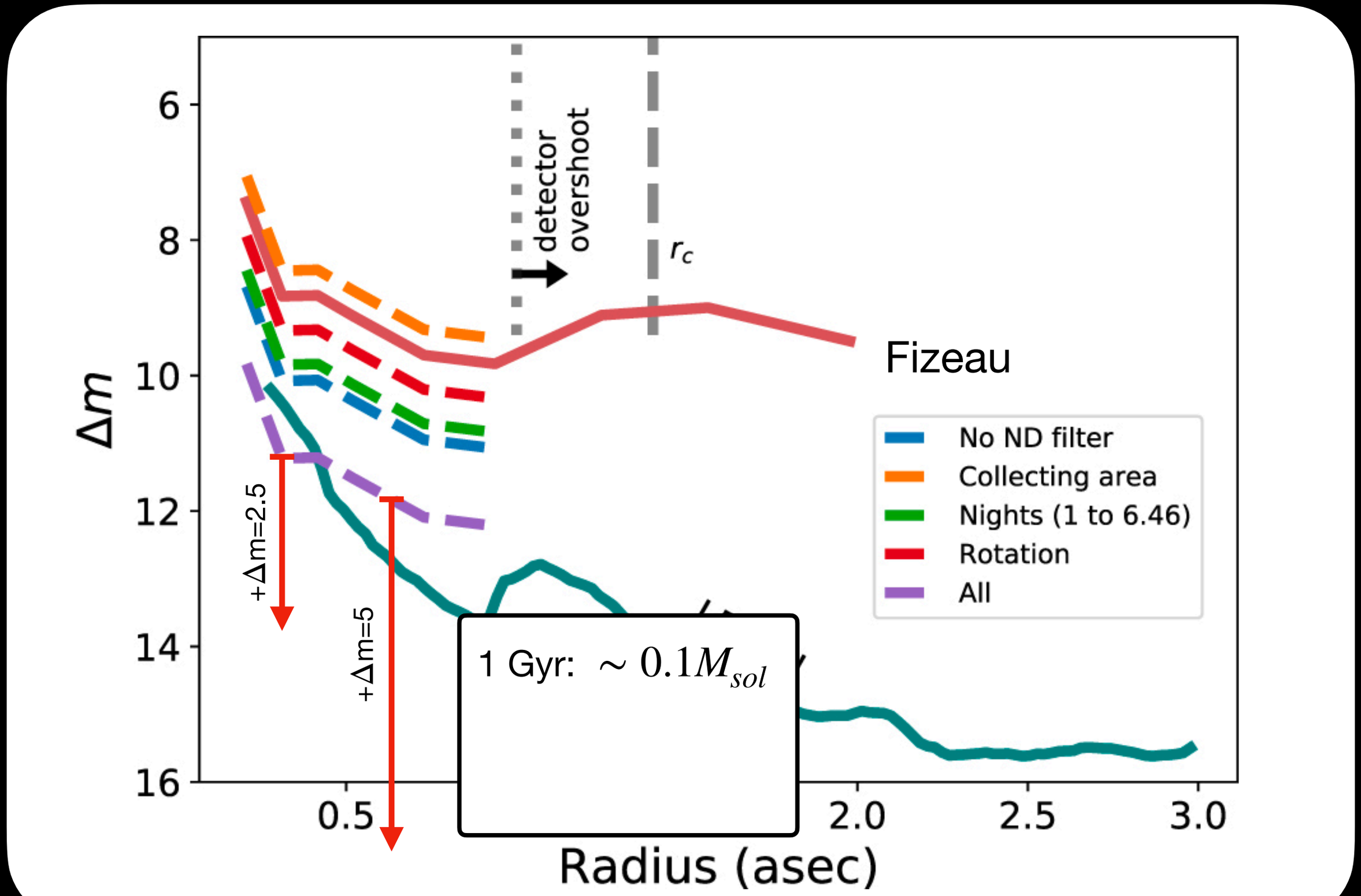

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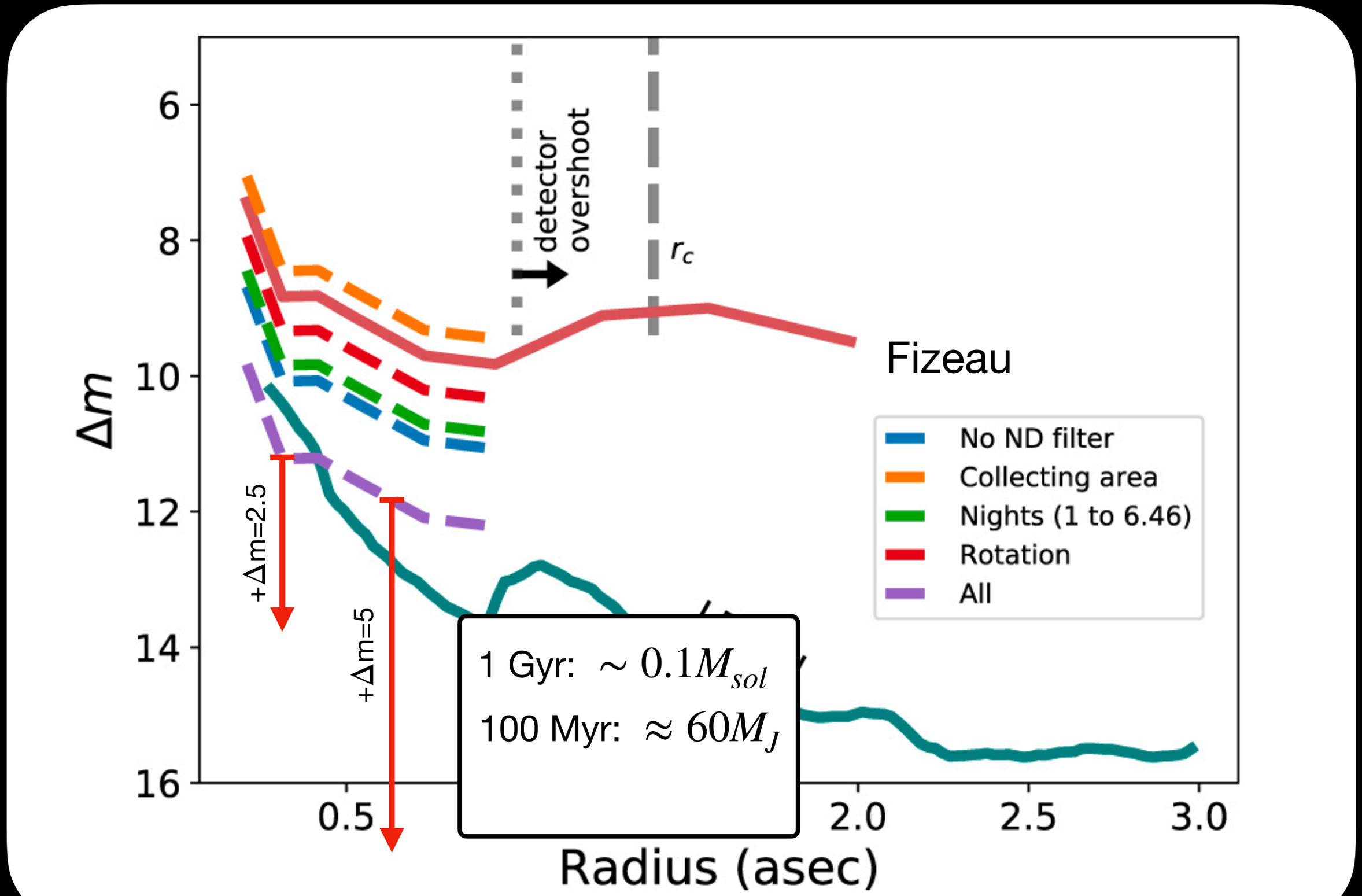

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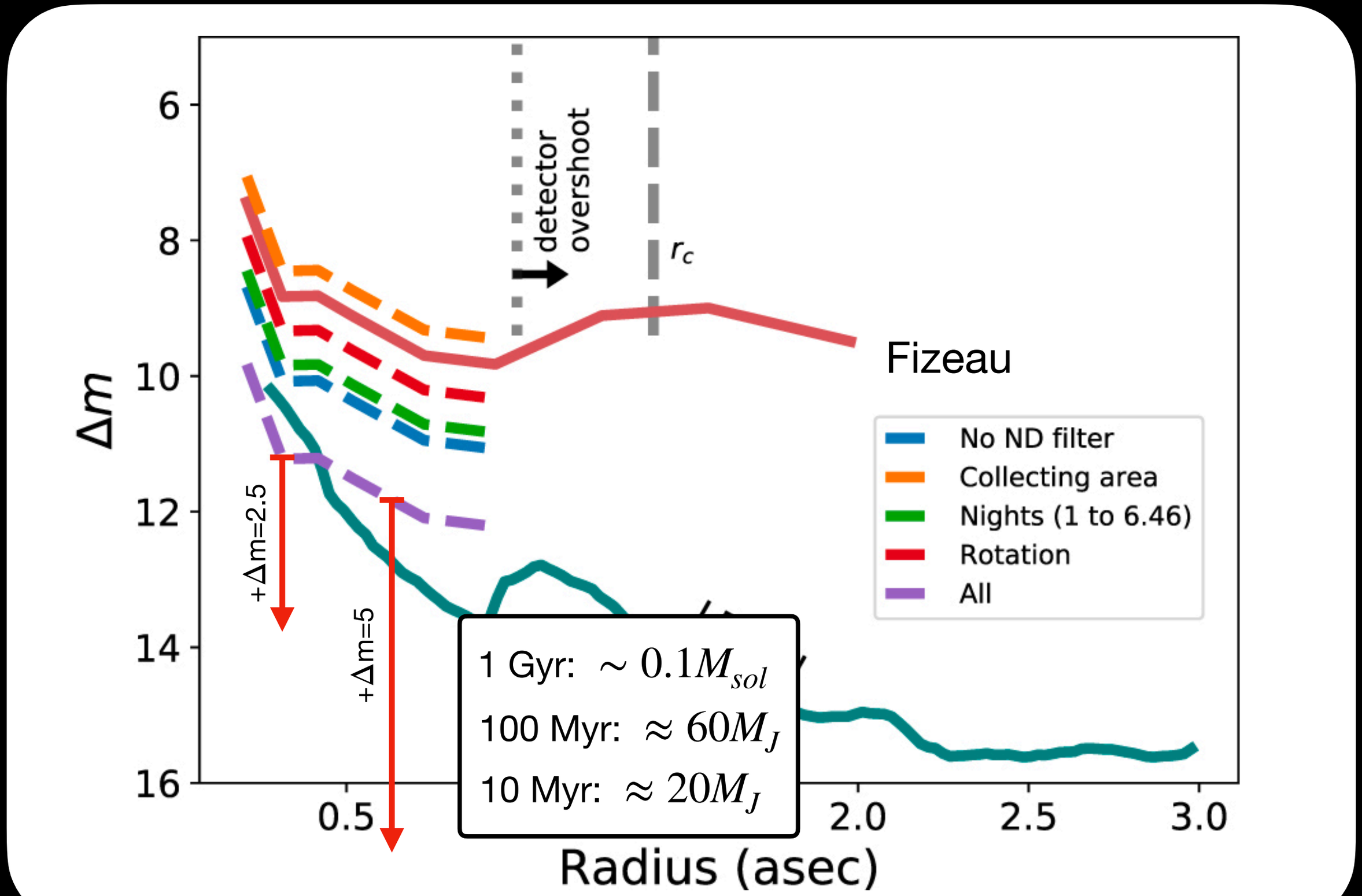

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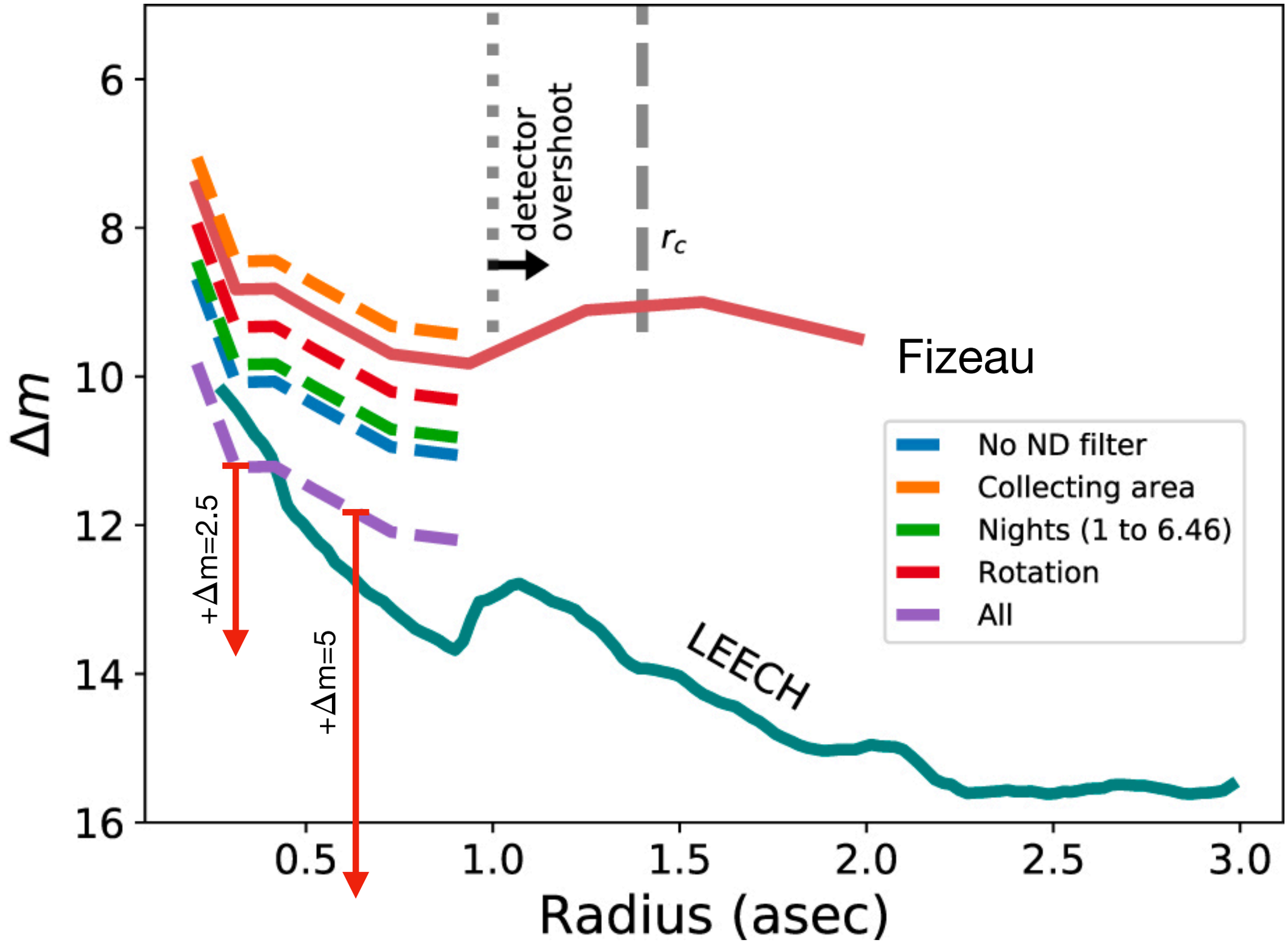

Areas for improvement (examples)

Image: U Arizona

Areas for improvement (examples)

DONE

Upgrade of detector readout electronics: ~10% -> ~80% integration time efficiency

Image: U Arizona

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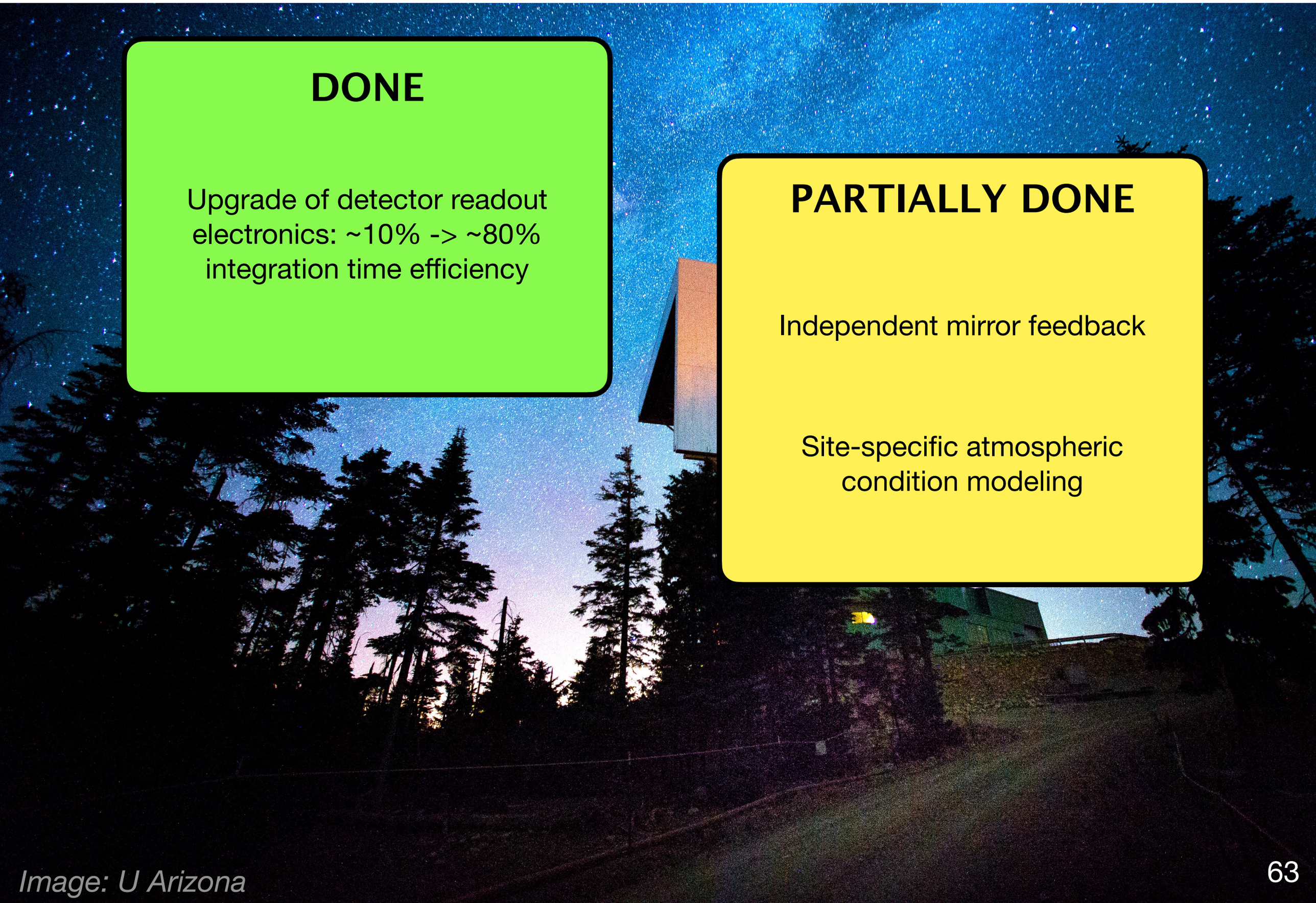
Upgrade of detector readout electronics: ~10% -> ~80% integration time efficiency

PARTIALLY DONE

Independent mirror feedback

Image: U Arizona

Areas for improvement (examples)



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Upgrade of detector readout electronics: ~10% -> ~80% integration time efficiency

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Independent mirror feedback

Site-specific atmospheric condition modeling

Image: U Arizona

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PLANNED

Lower-noise wavefront sensor detector

Image: U Arizona

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PLANNED

Lower-noise wavefront sensor detector

Future directions for LBTI in Fizeau mode:
Spalding+ 2022 *AJ* 163:62

Image: U Arizona

Take-away points

Image: U Arizona

Take-away points

Image: U Arizona

Take-away points

Binocular observing can accommodate unique parts of search space

Fizeau variant of ADI can be used to look for companions

Image: U Arizona

Take-away points

Binocular observing can accommodate unique parts of search space

Fizeau variant of ADI can be used to look for companions

Bottlenecks to sensitivity include integration time and phase noise, but upgrades on the way

Image: U Arizona

Steward Observatory

Large Binocular Telescope Observatory

Eckhart Spalding
espaldin@nd.edu
mwanakijiji.github.io/

UNIVERSITY OF NOTRE DAME

Image: U Arizona