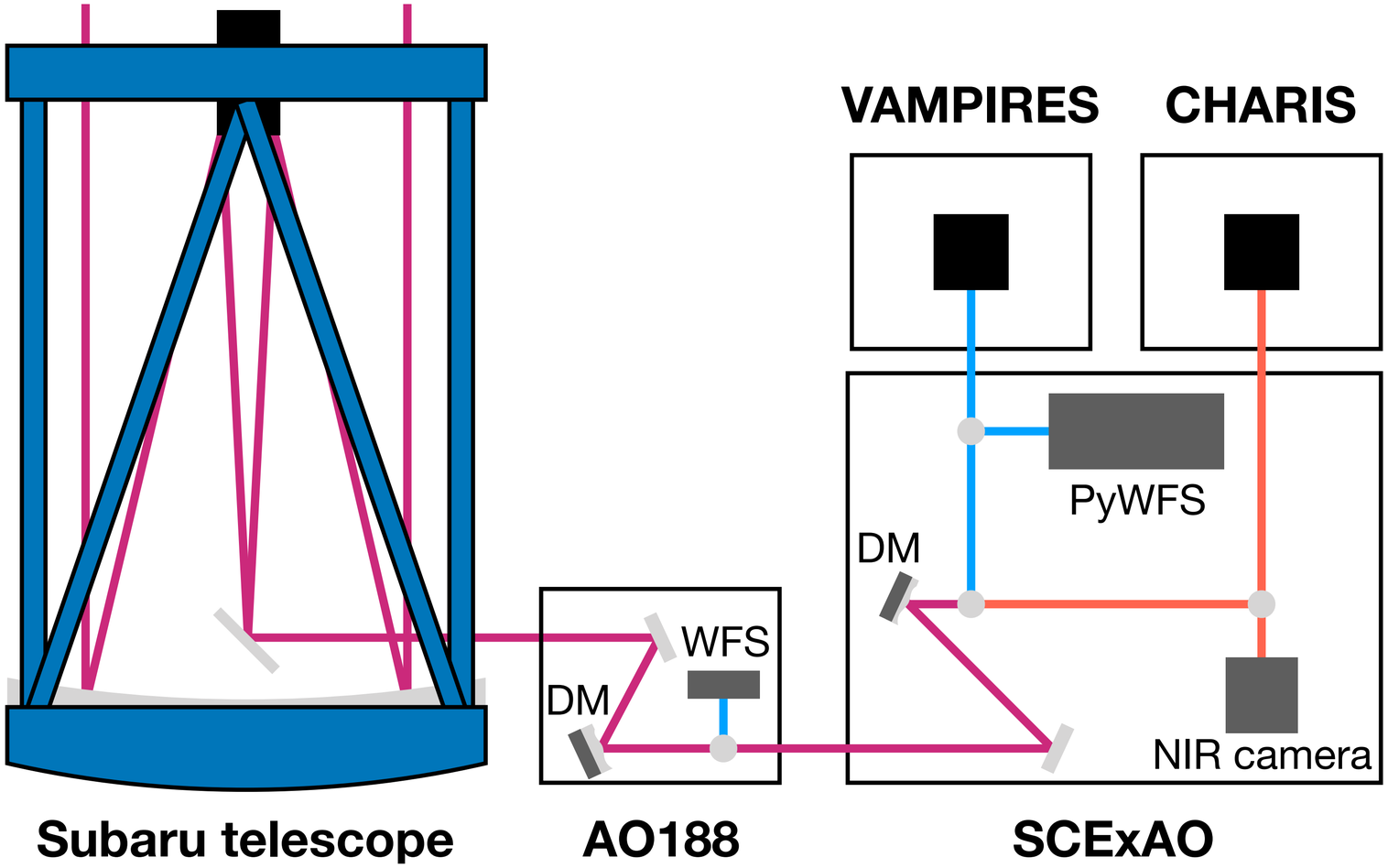
FAST & FURIOUS

Controlling the low-wind effect at Subaru/SCExAO

Steven Bos, Sebastien Vievard, Michael Wilby, Frans Snik, Julien Lozi, Olivier Guyon, Barnaby Norris, Nemanja Jovanovic, Frantz Martinache, Jean-Francois Sauvage, Christoph Keller

The low-wind effect and island effect



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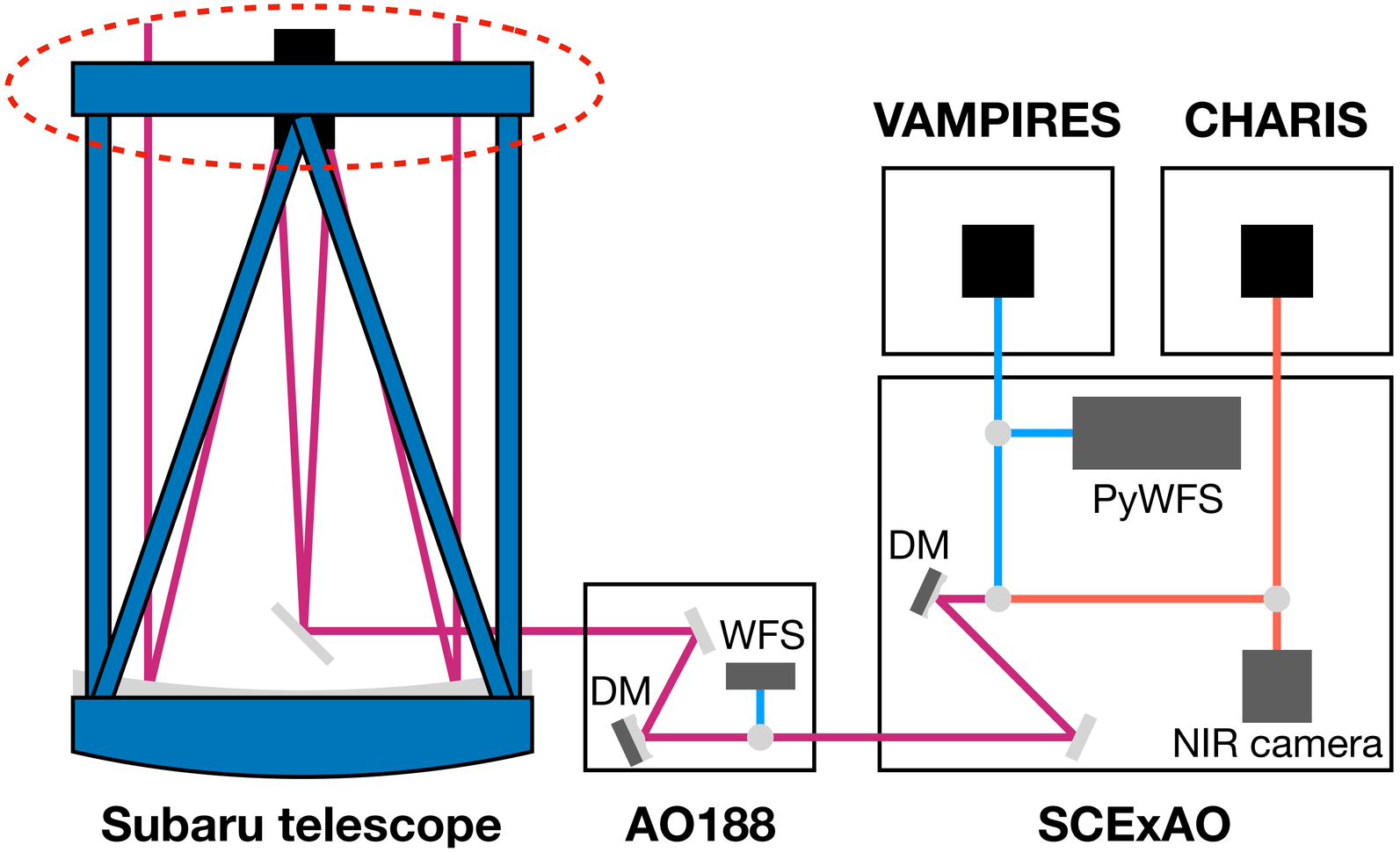

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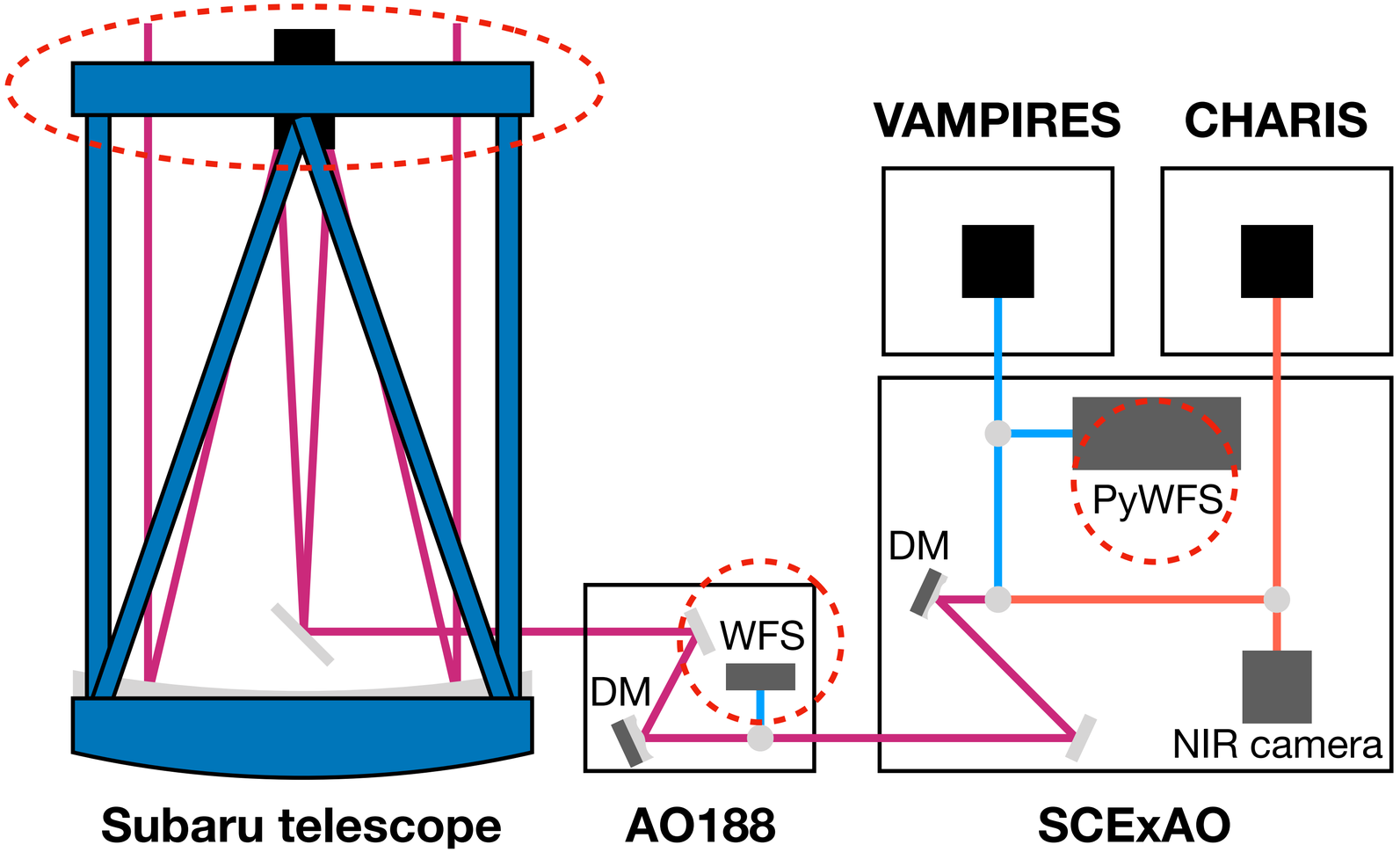
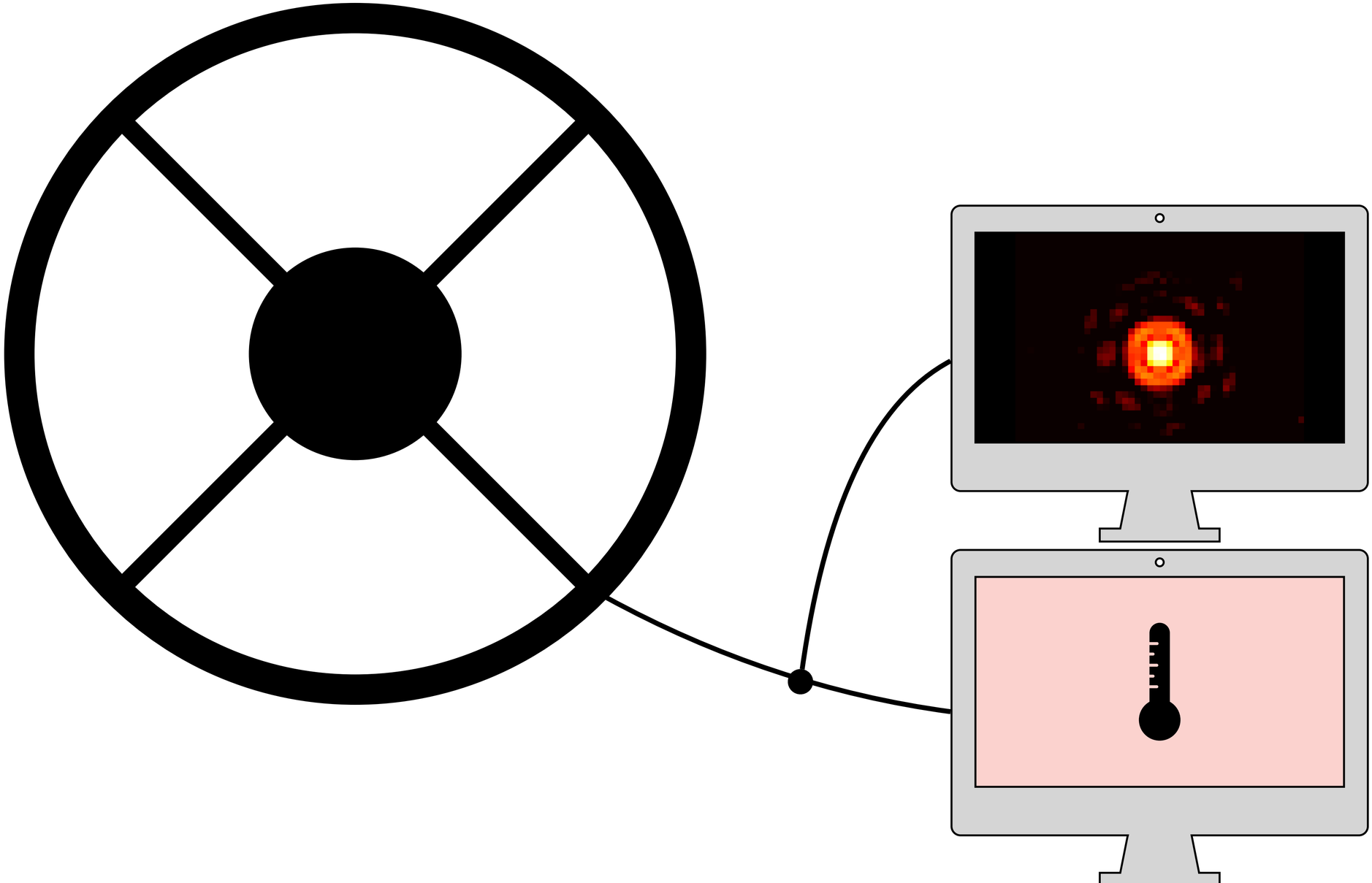


The low-wind effect (LWE)



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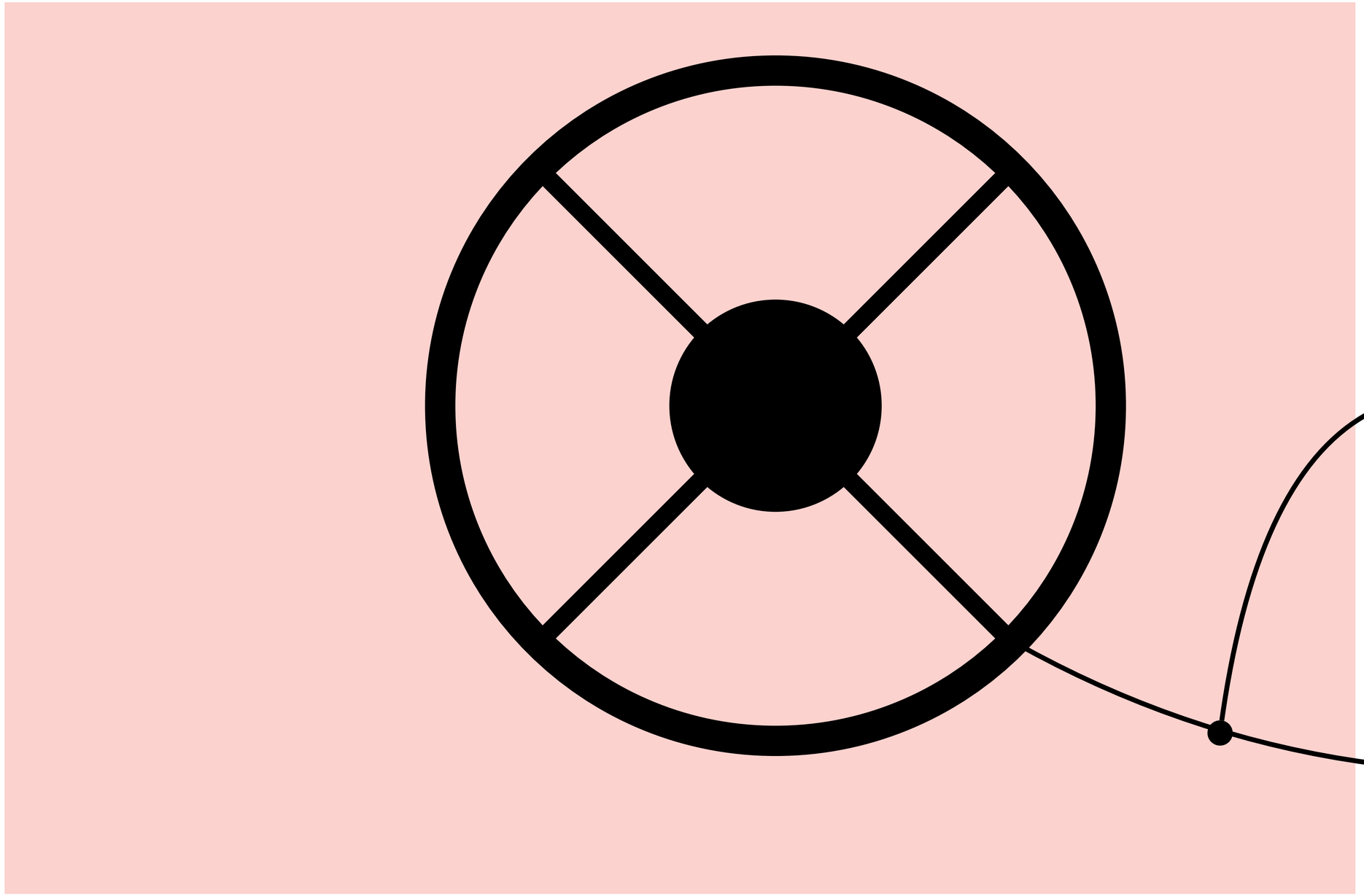

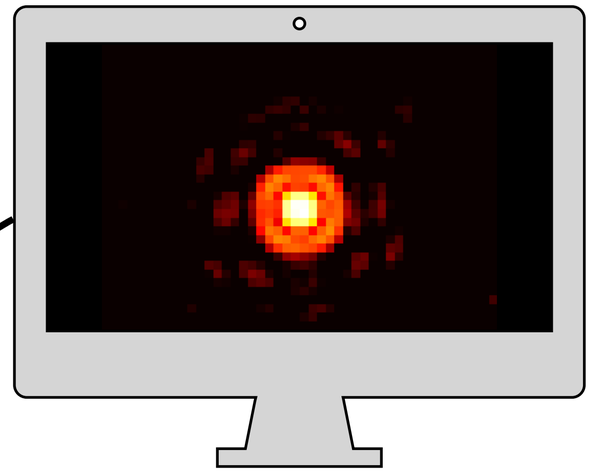

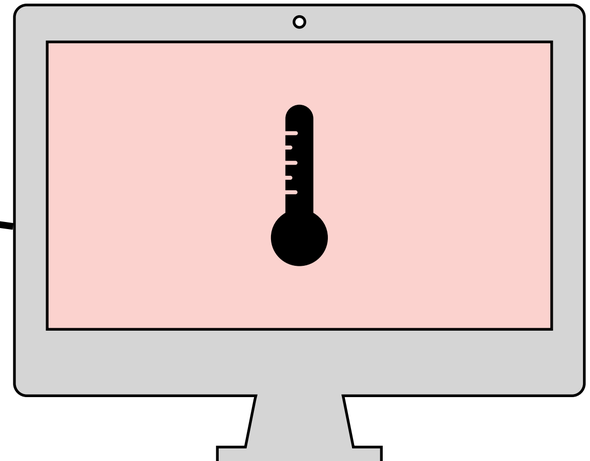

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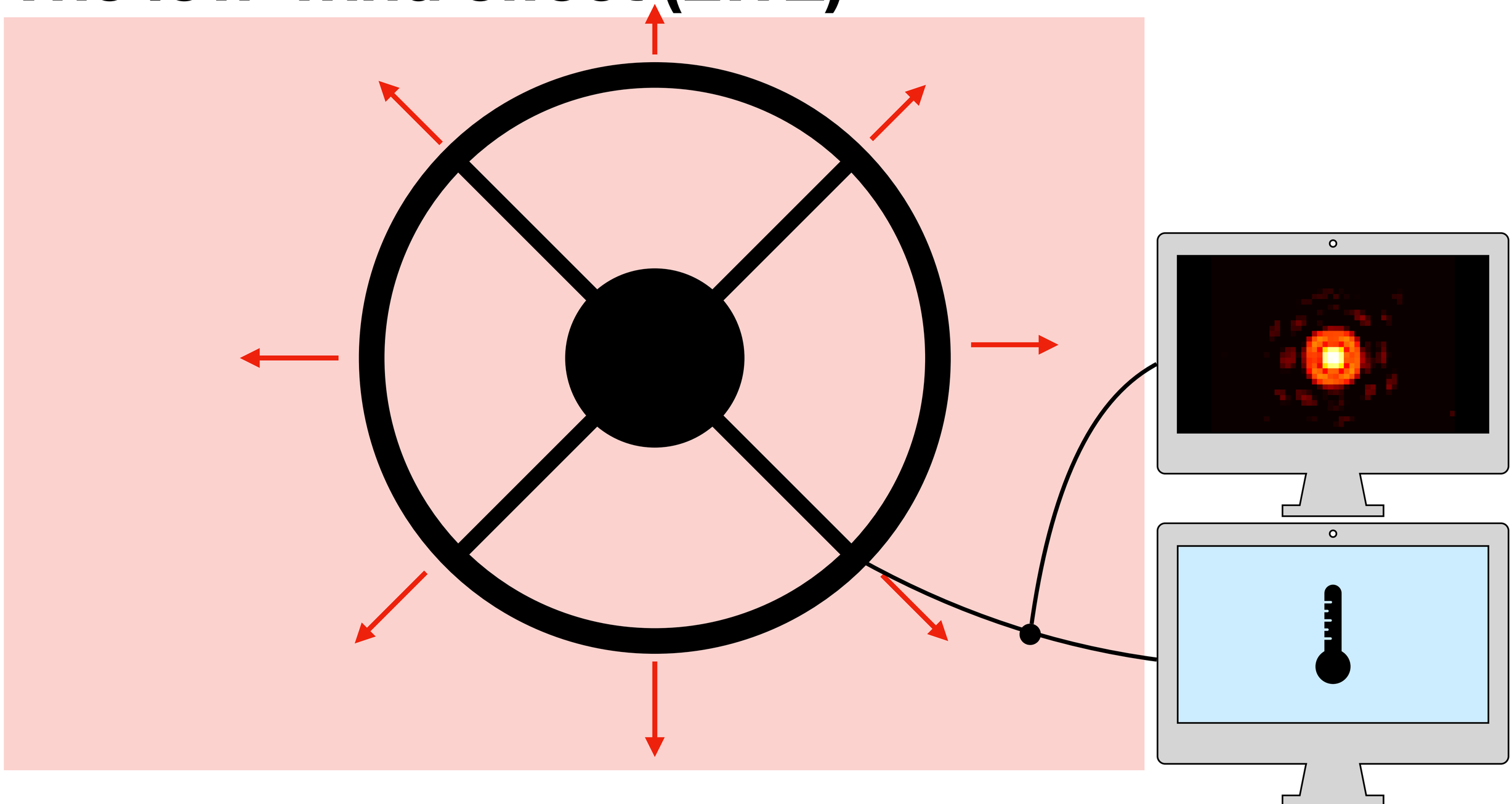

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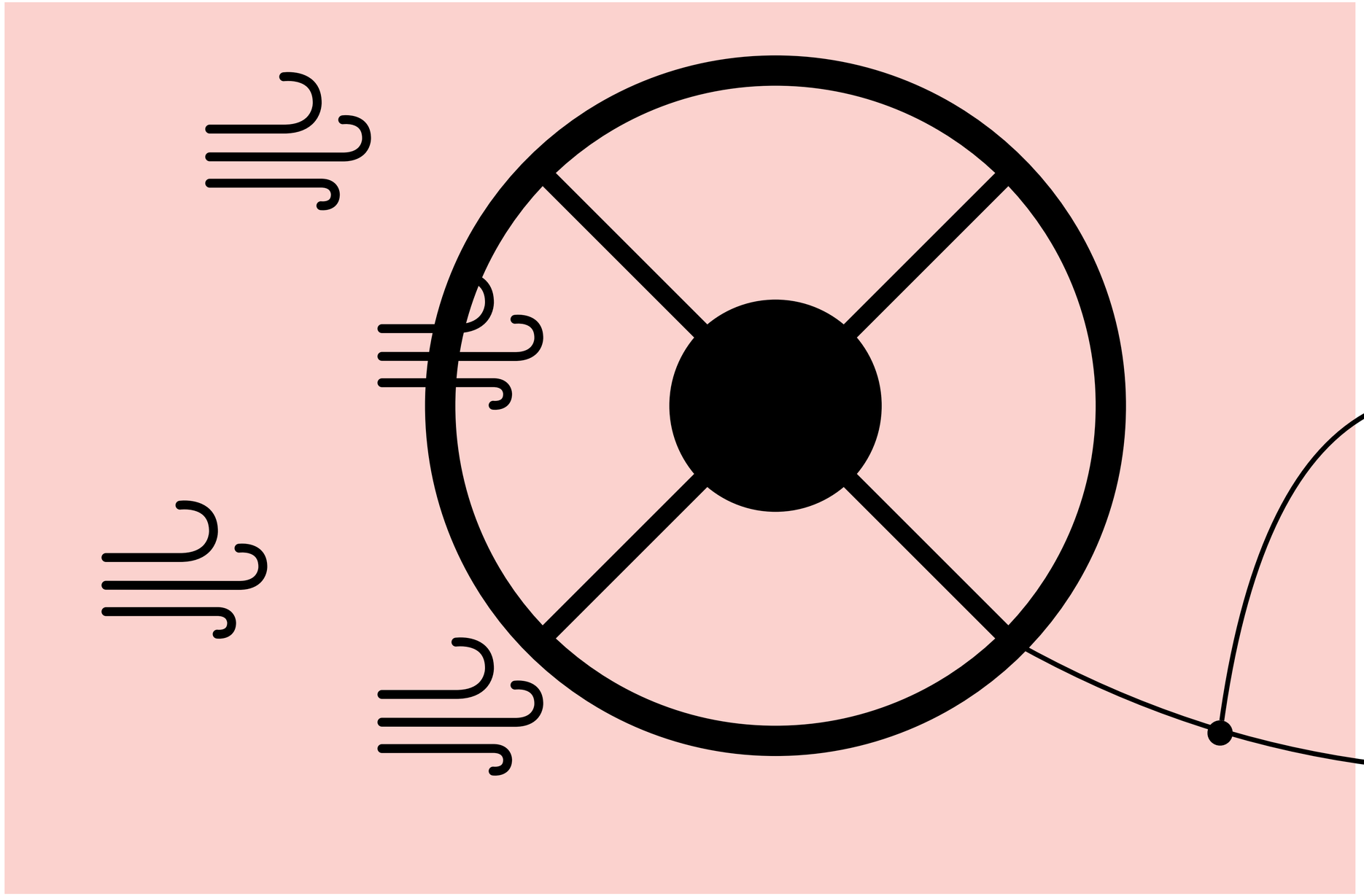

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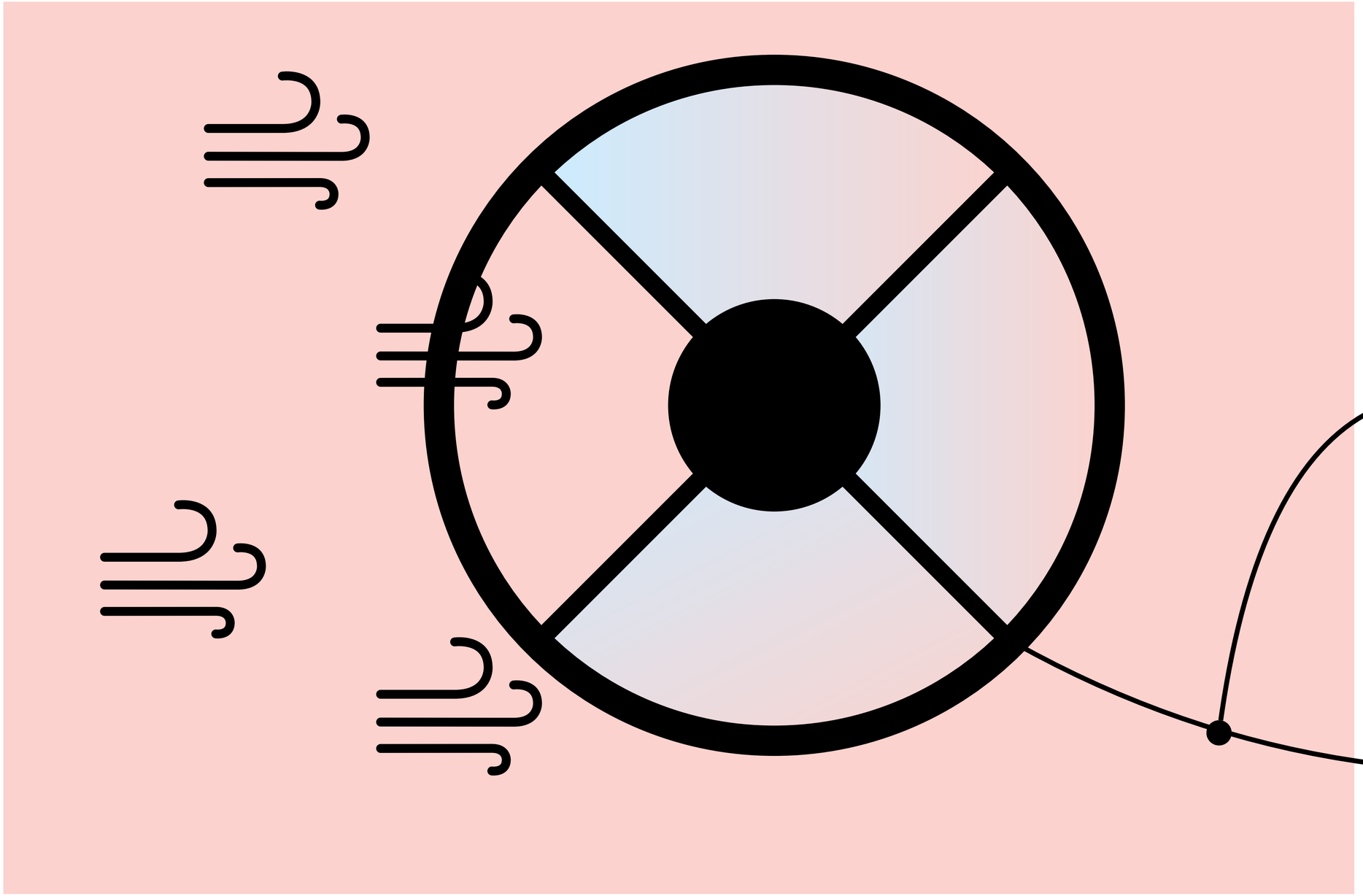

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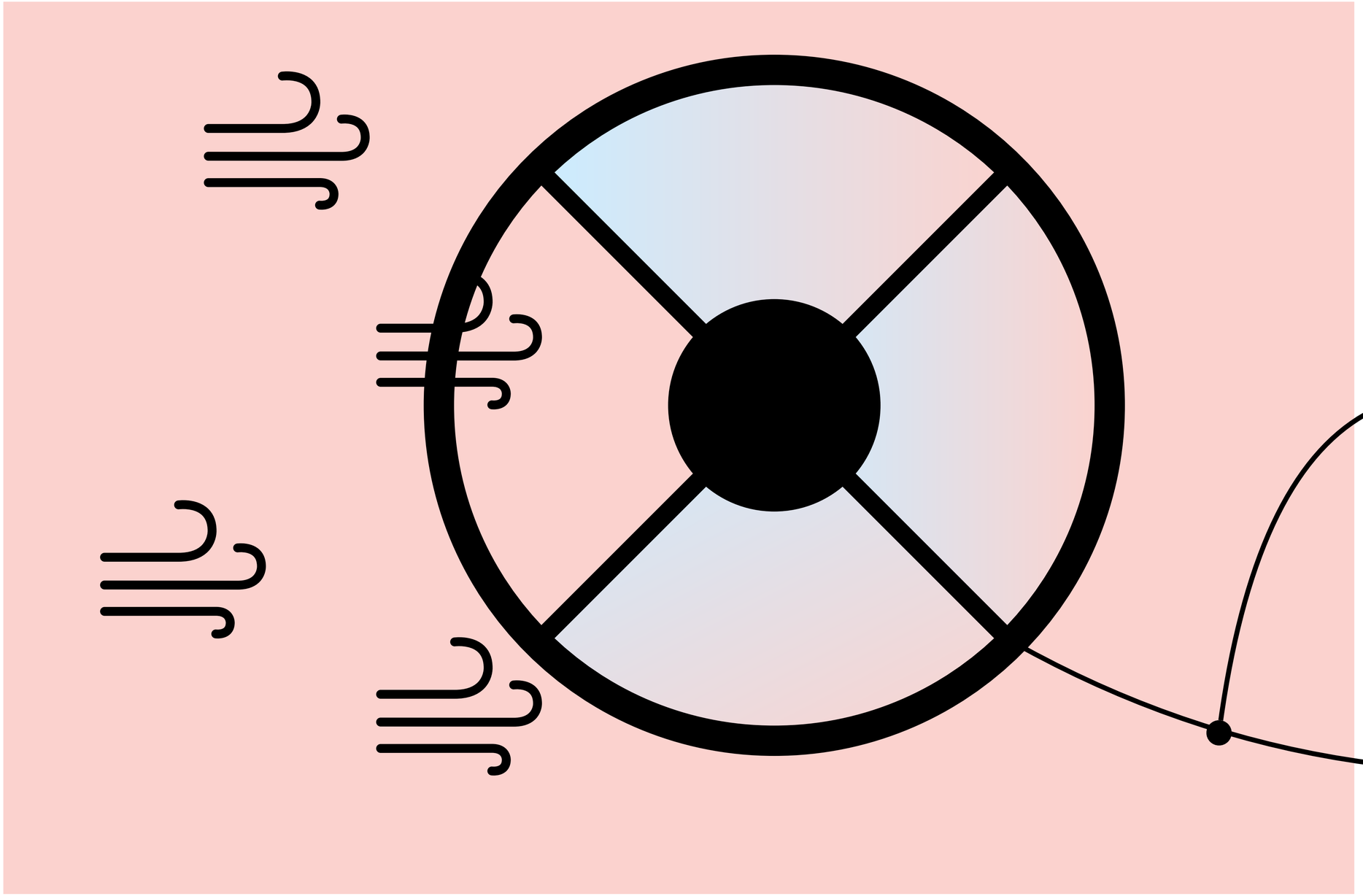
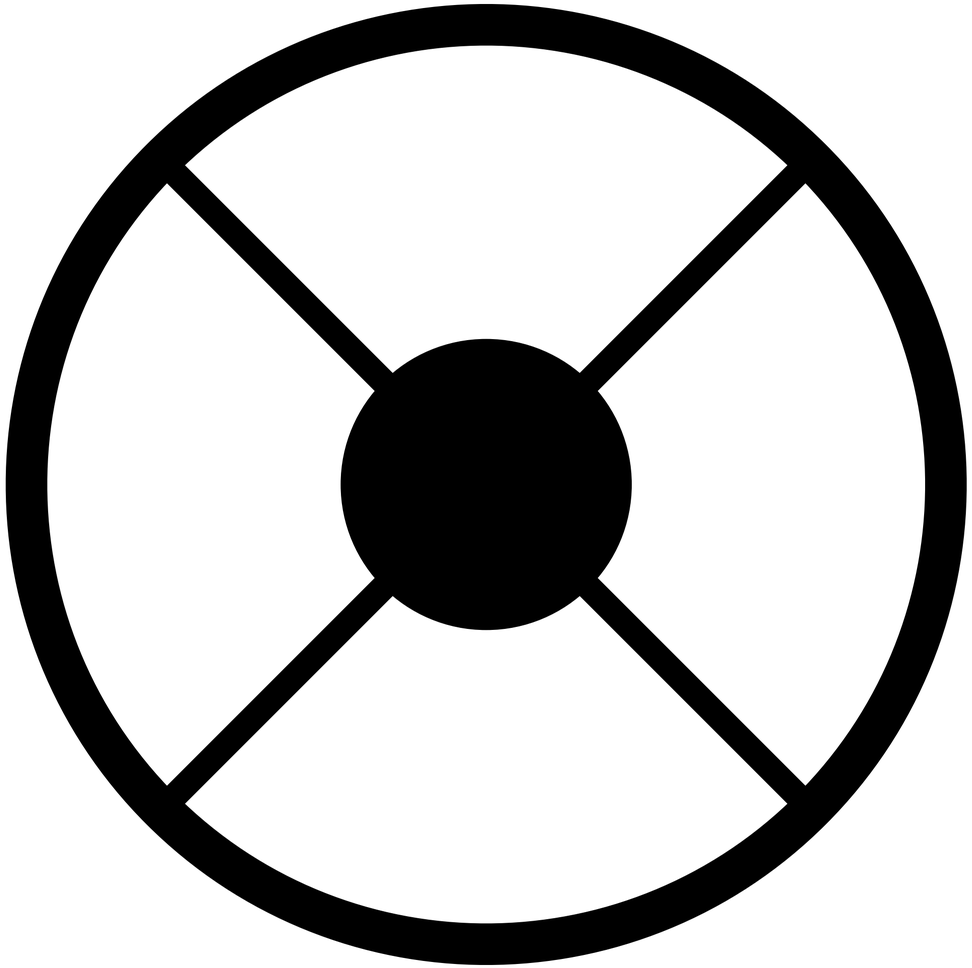


The island effect (IE)



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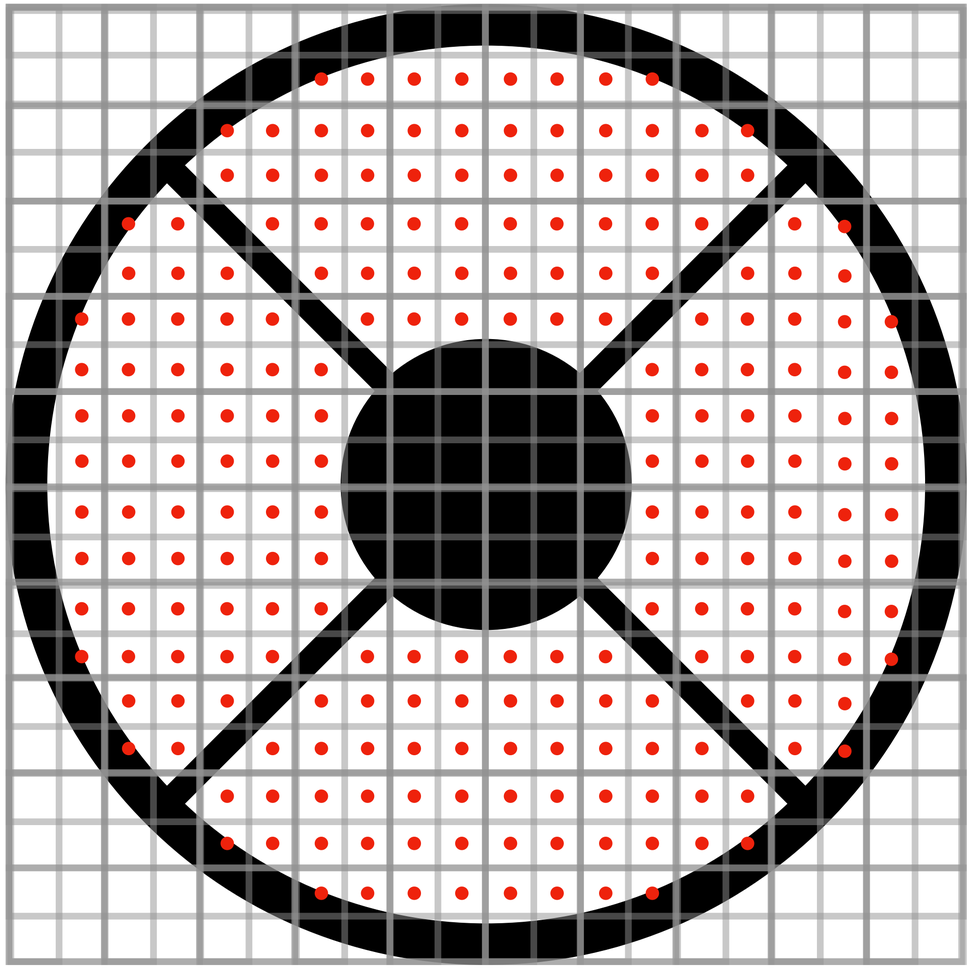

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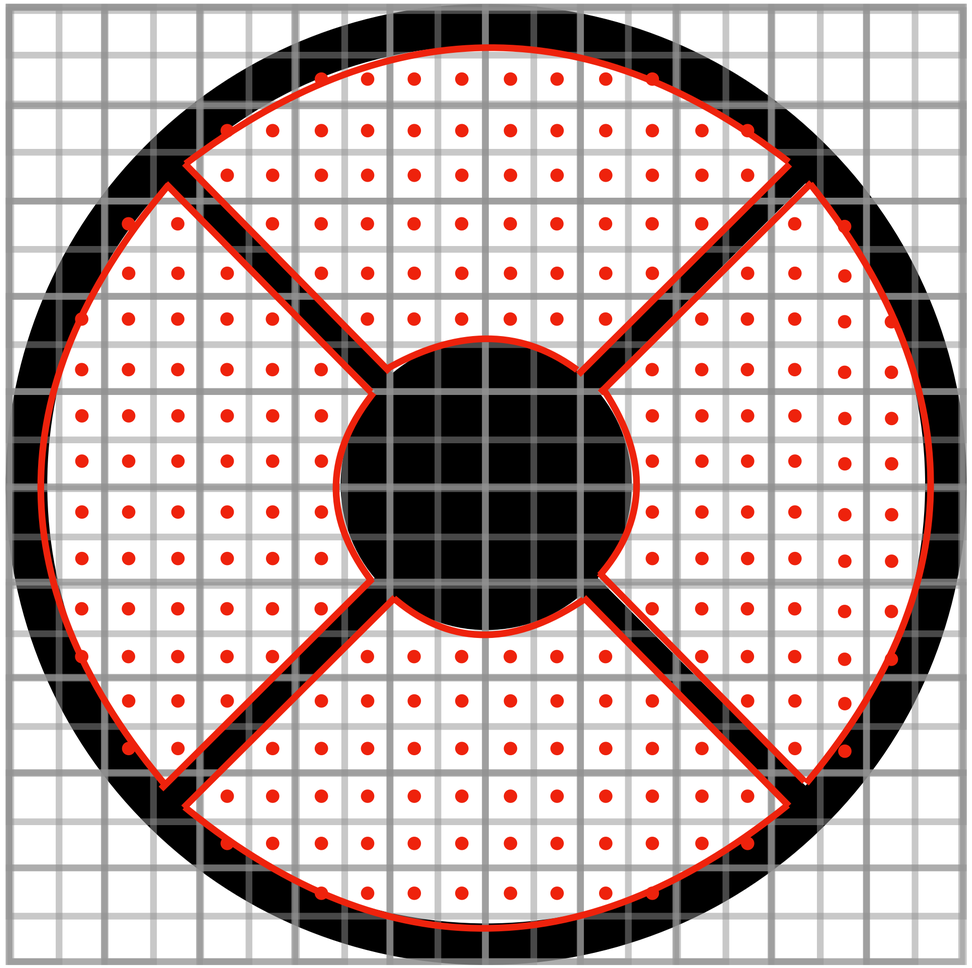

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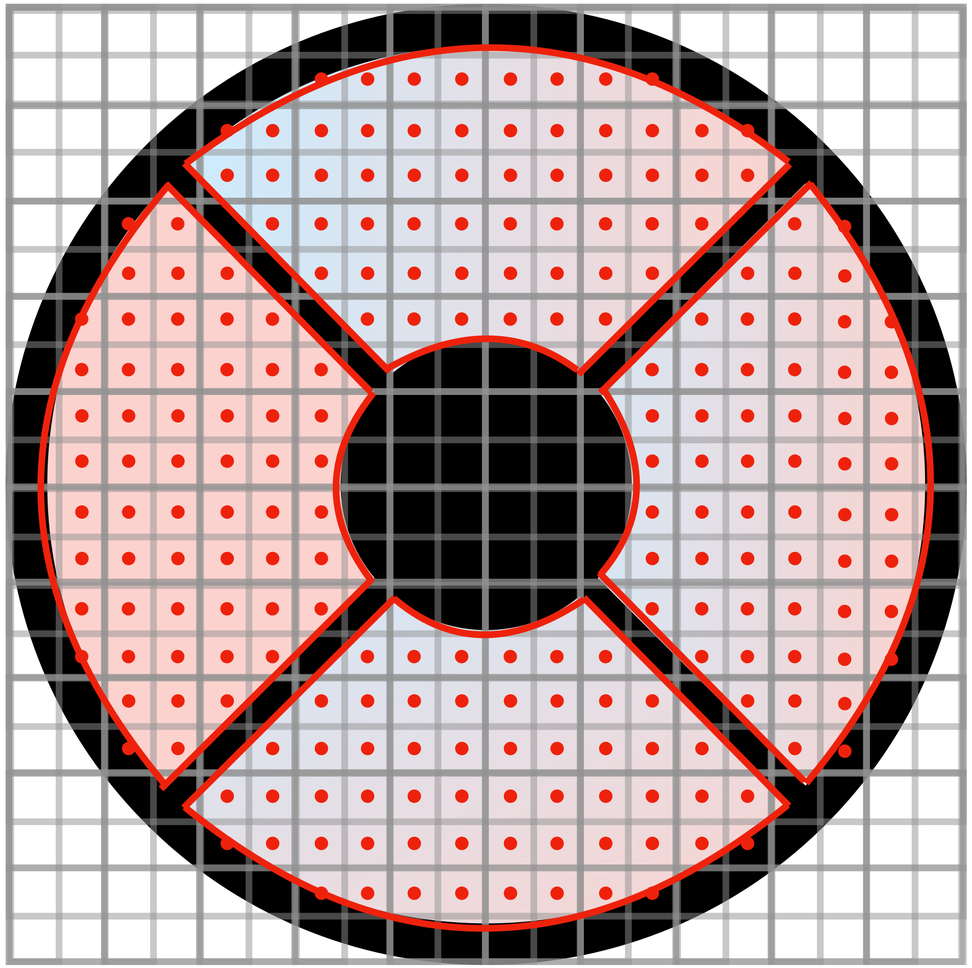

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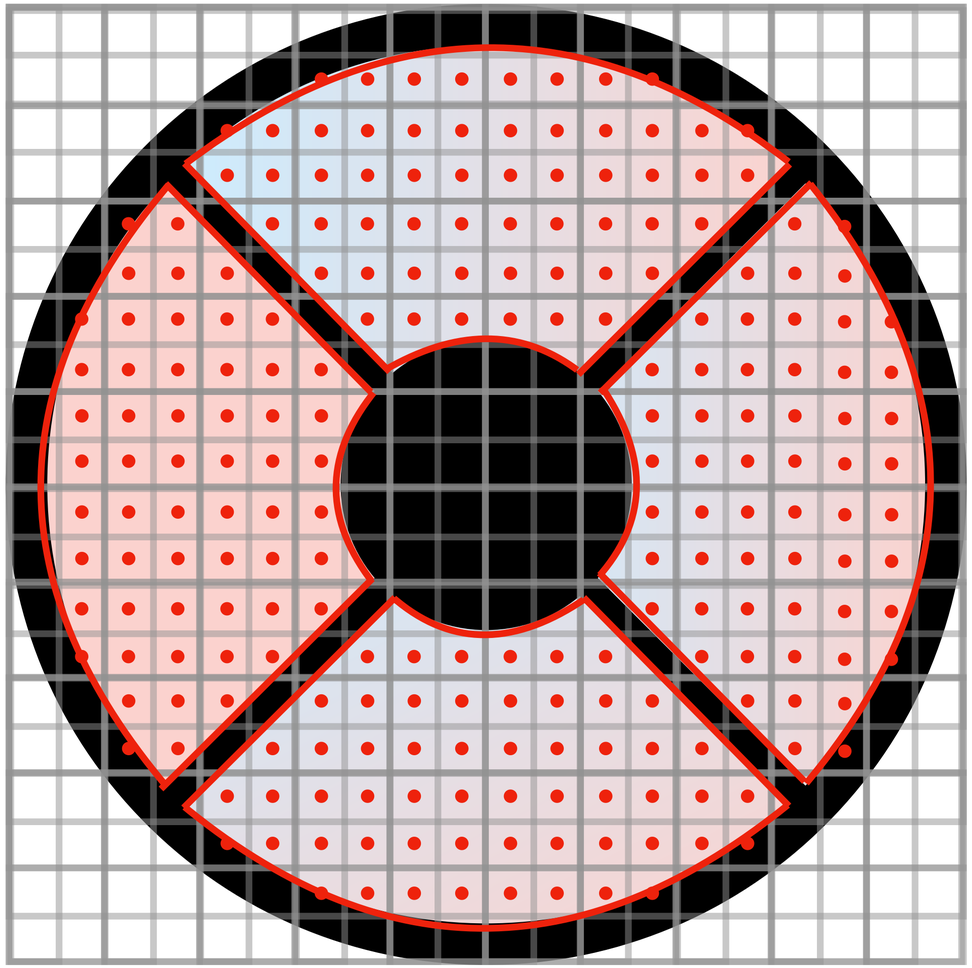
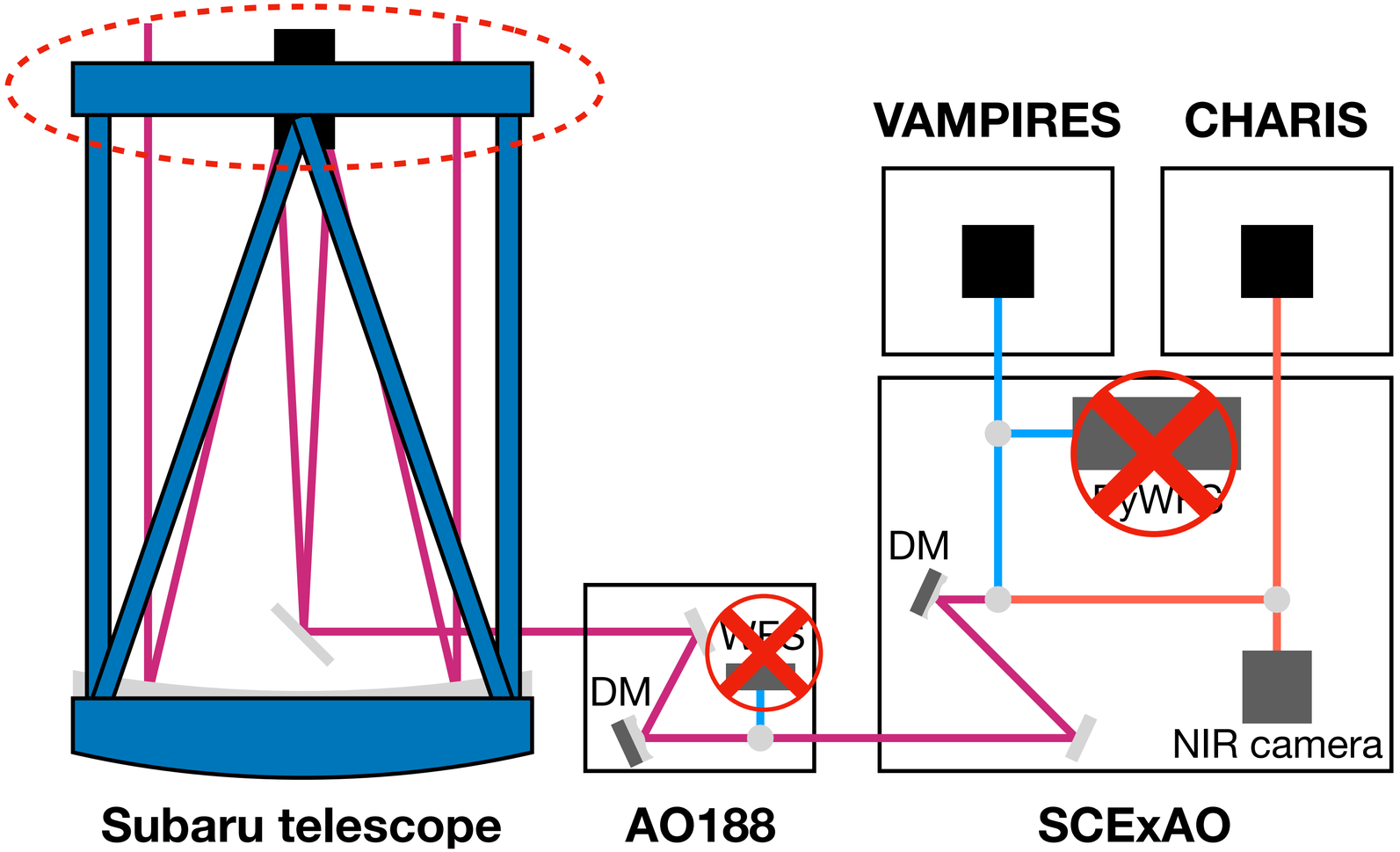


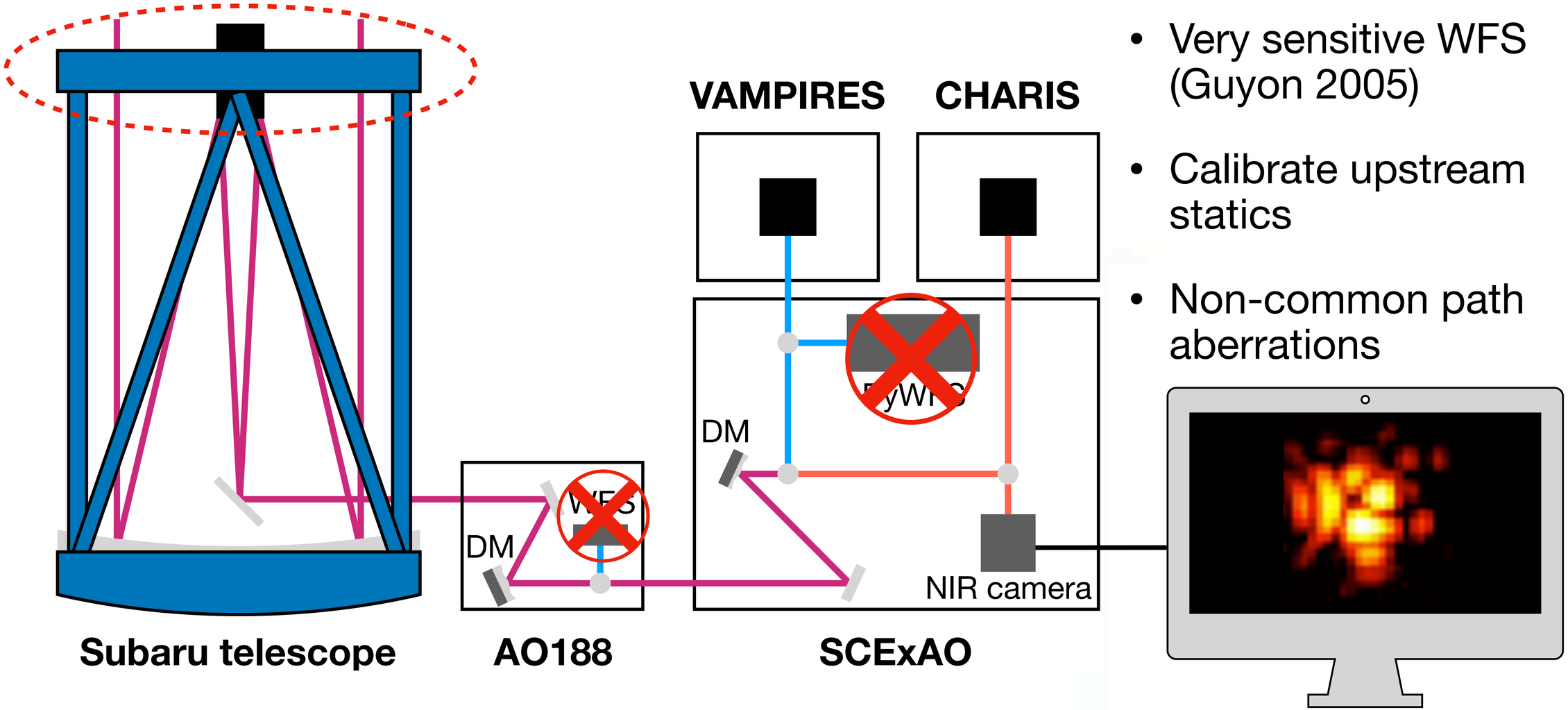
Pyramid wavefront sensor also has reduced sensitivity

Why focal-plane wavefront sensing?



Why focal-plane wavefront sensing?

- Strong LWE signal
- Very sensitive WFS (Guyon 2005)
- Calibrate upstream statics
- Non-common path aberrations



The Fast&Furious algorithm

- Sequential phase diversity algorithm (Gonsalves 2002)
  - Can only run in closed loop

Keller et al. (2012)
Korkiakoski et al. (2014)
Wilby et al. (2018)
Bos et al. (2020)

The Fast&Furious algorithm

- Sequential phase diversity algorithm (Gonsalves 2002)
  - Can only run in closed loop

- Software only solution to FPWFS
  - Focal-plane images of (non-coronagraphic) PSFs
  - Control of the DM

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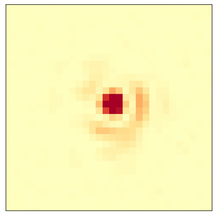
The Fast&Furious algorithm

I_i



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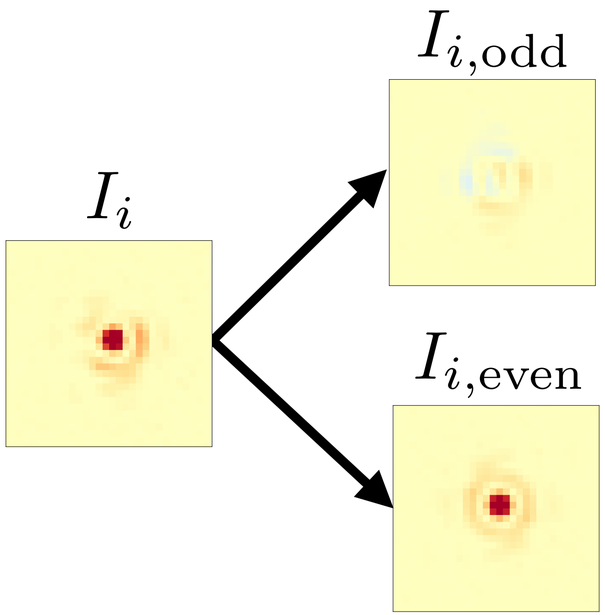

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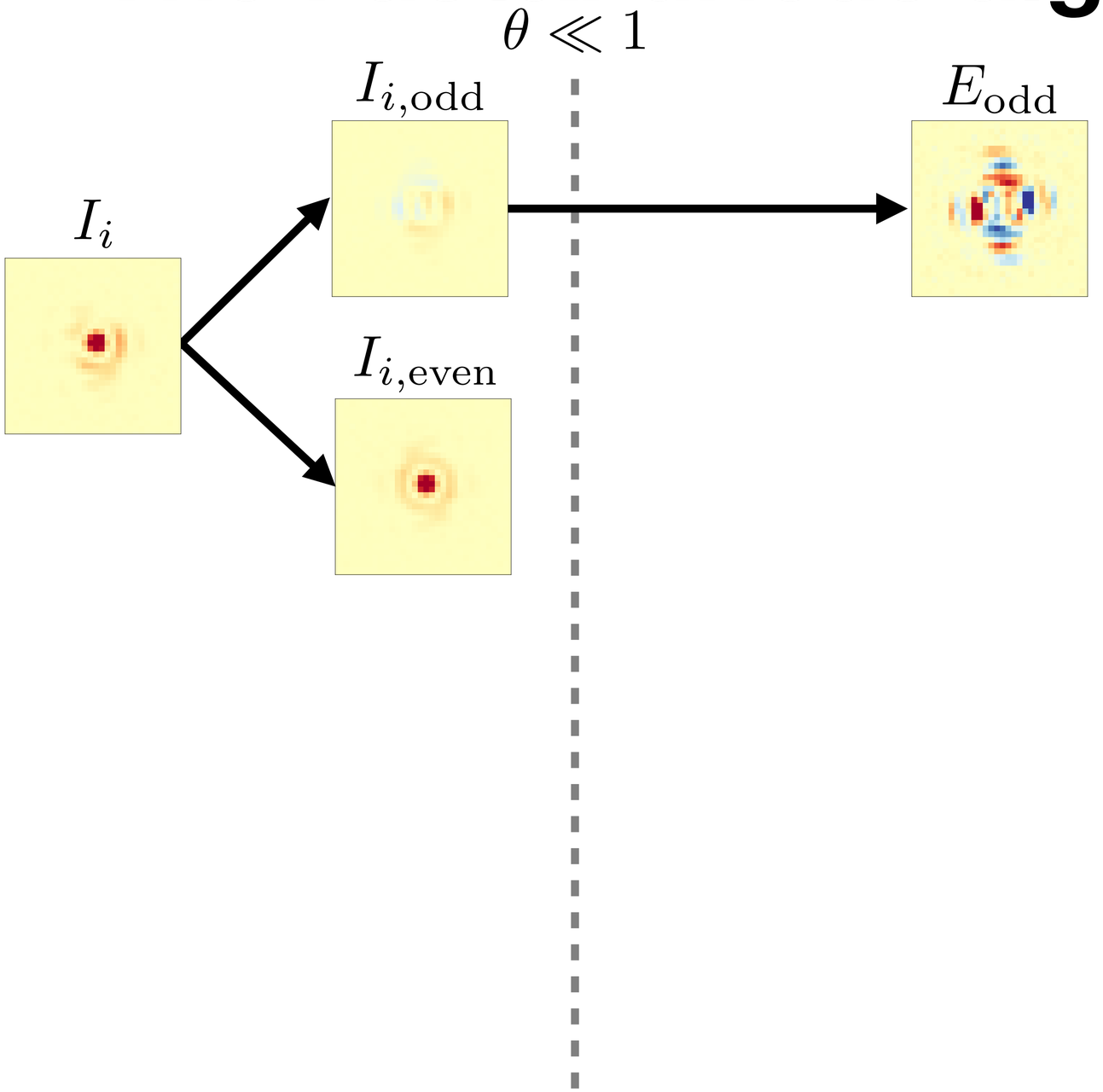

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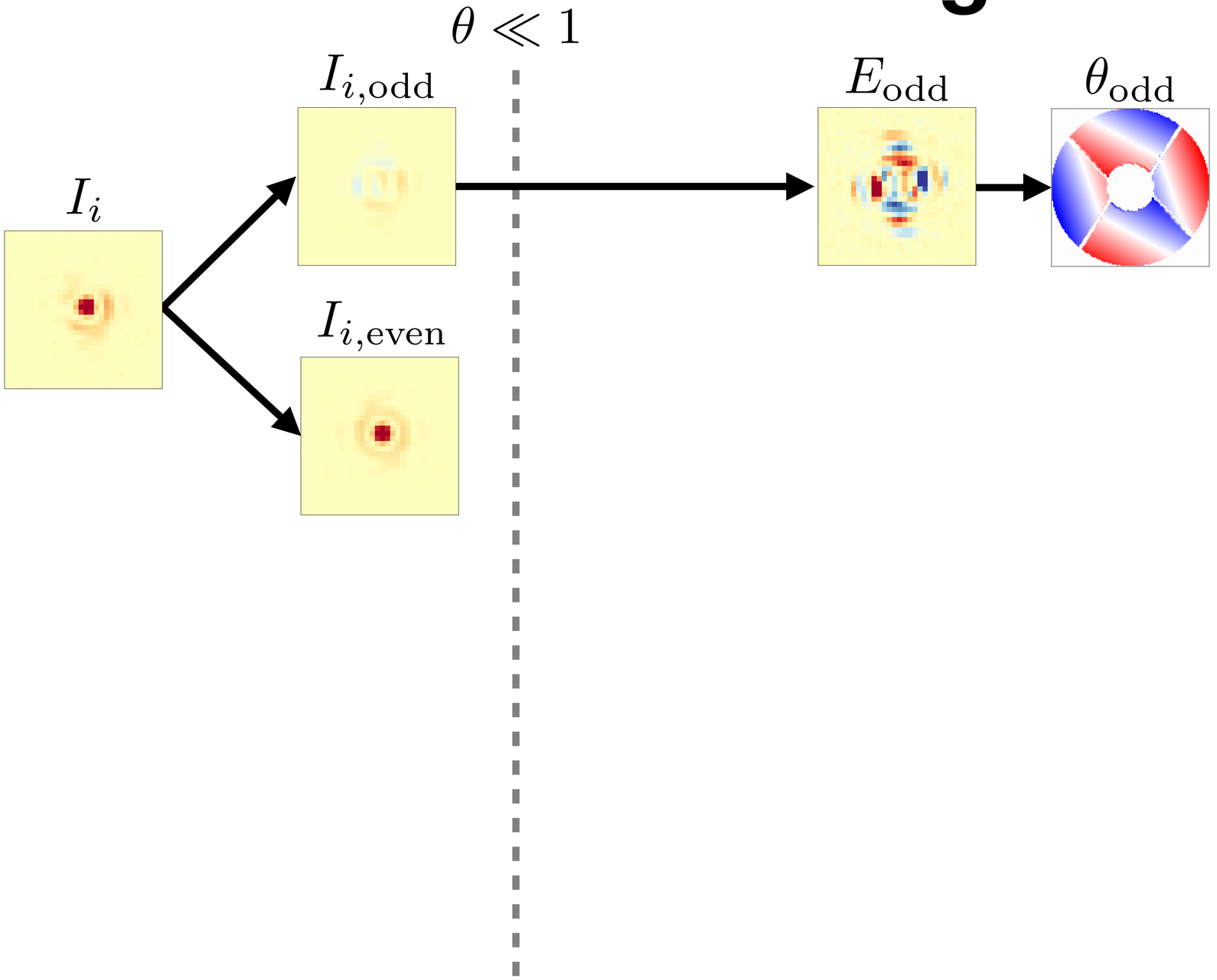

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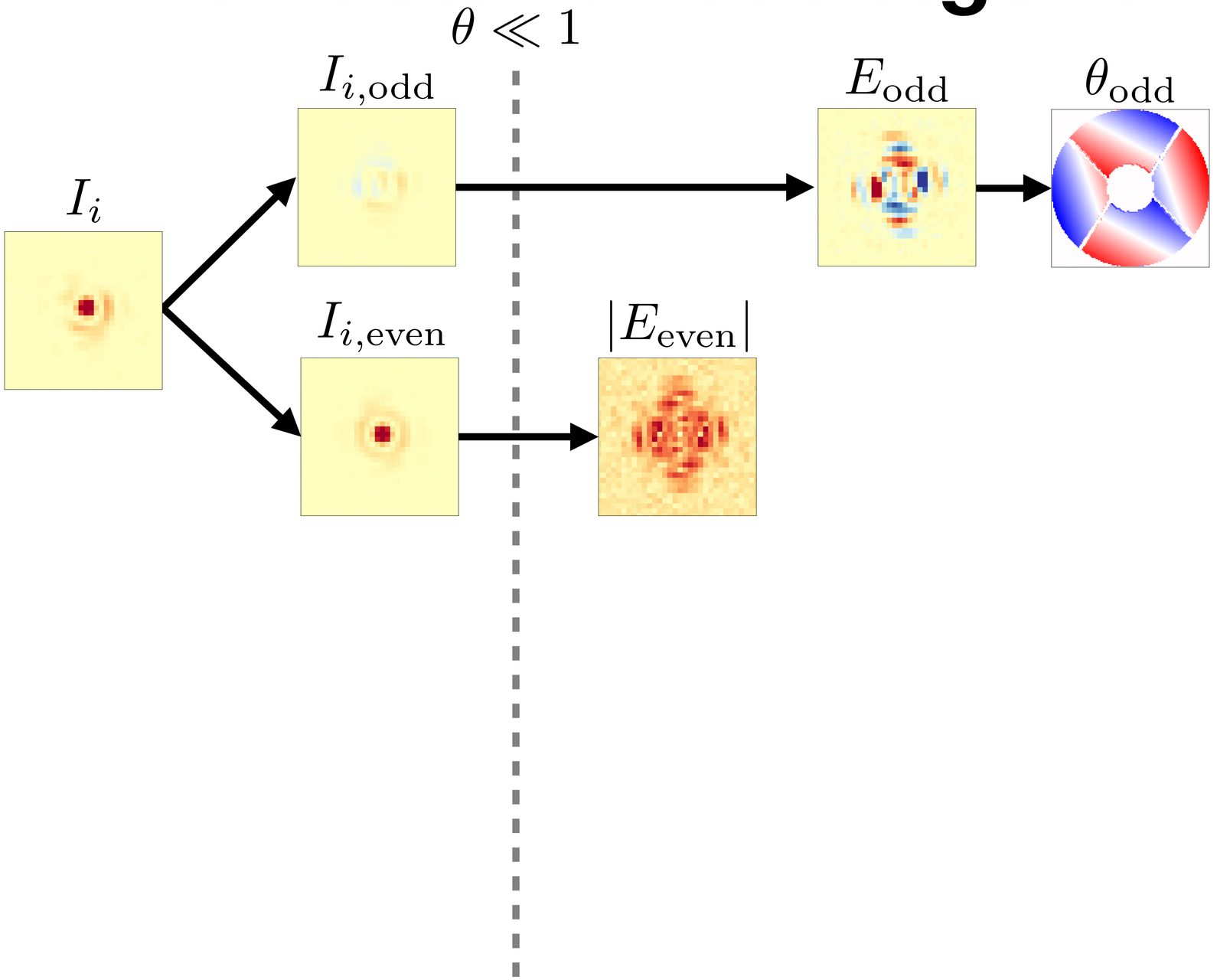

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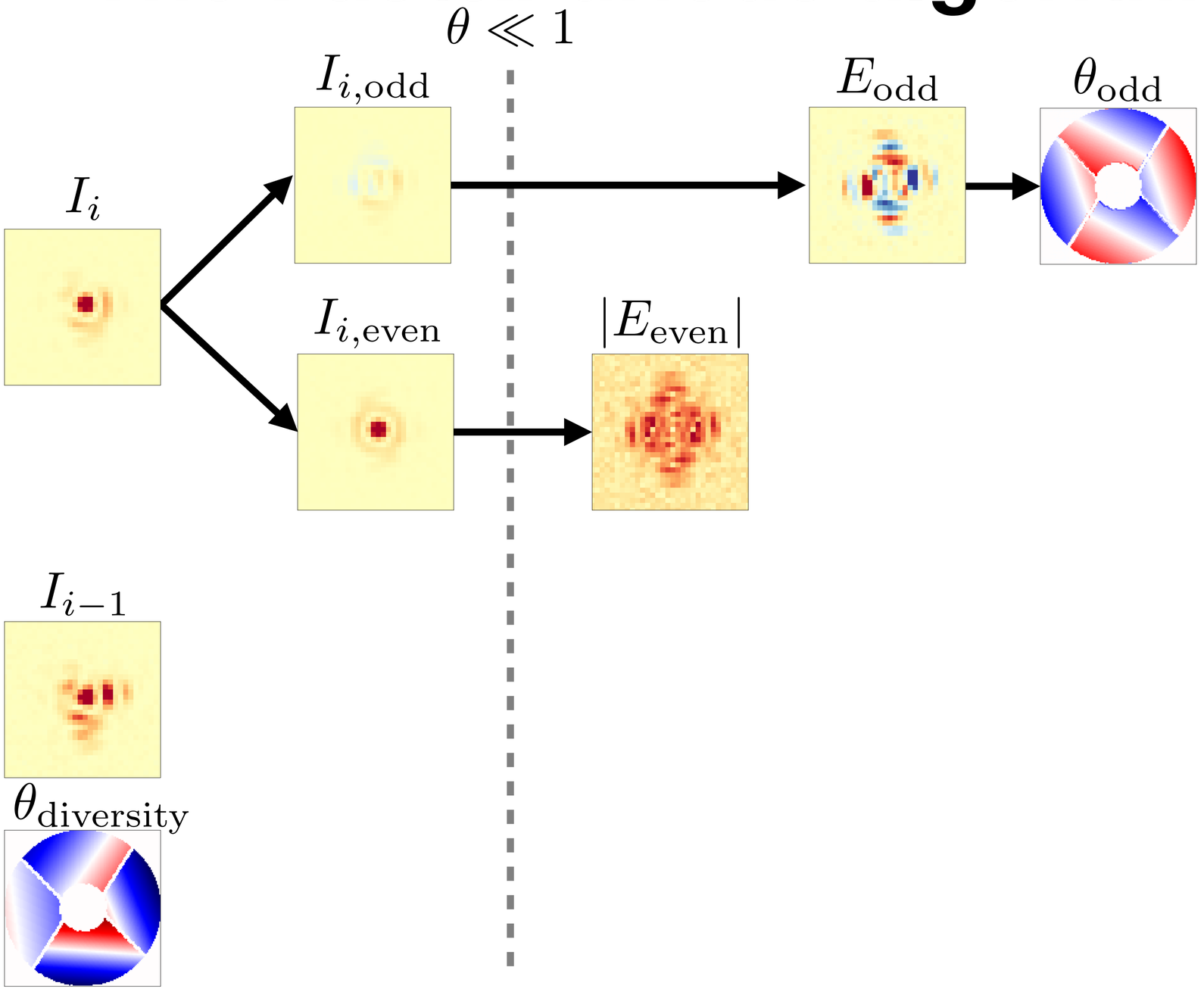

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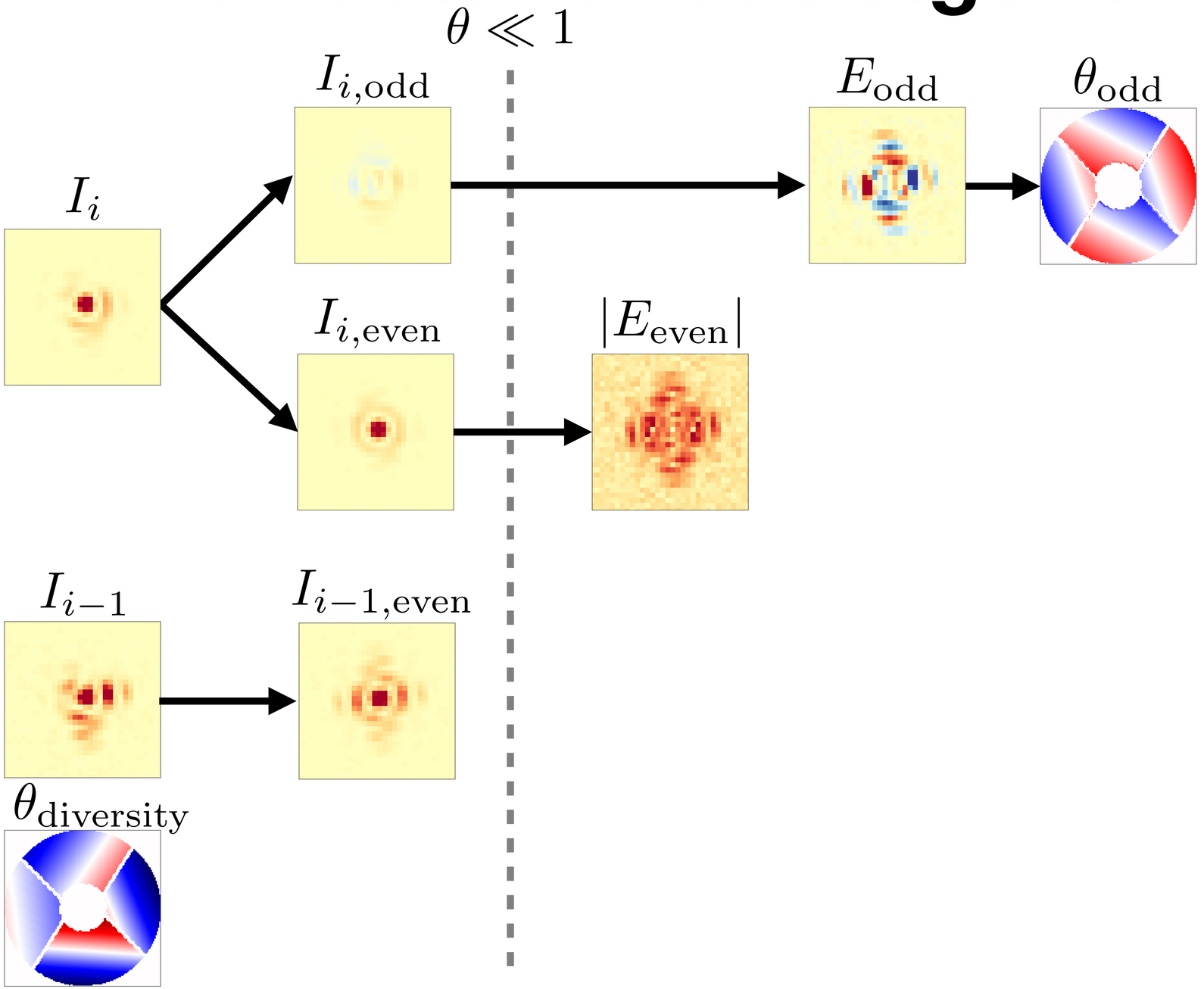

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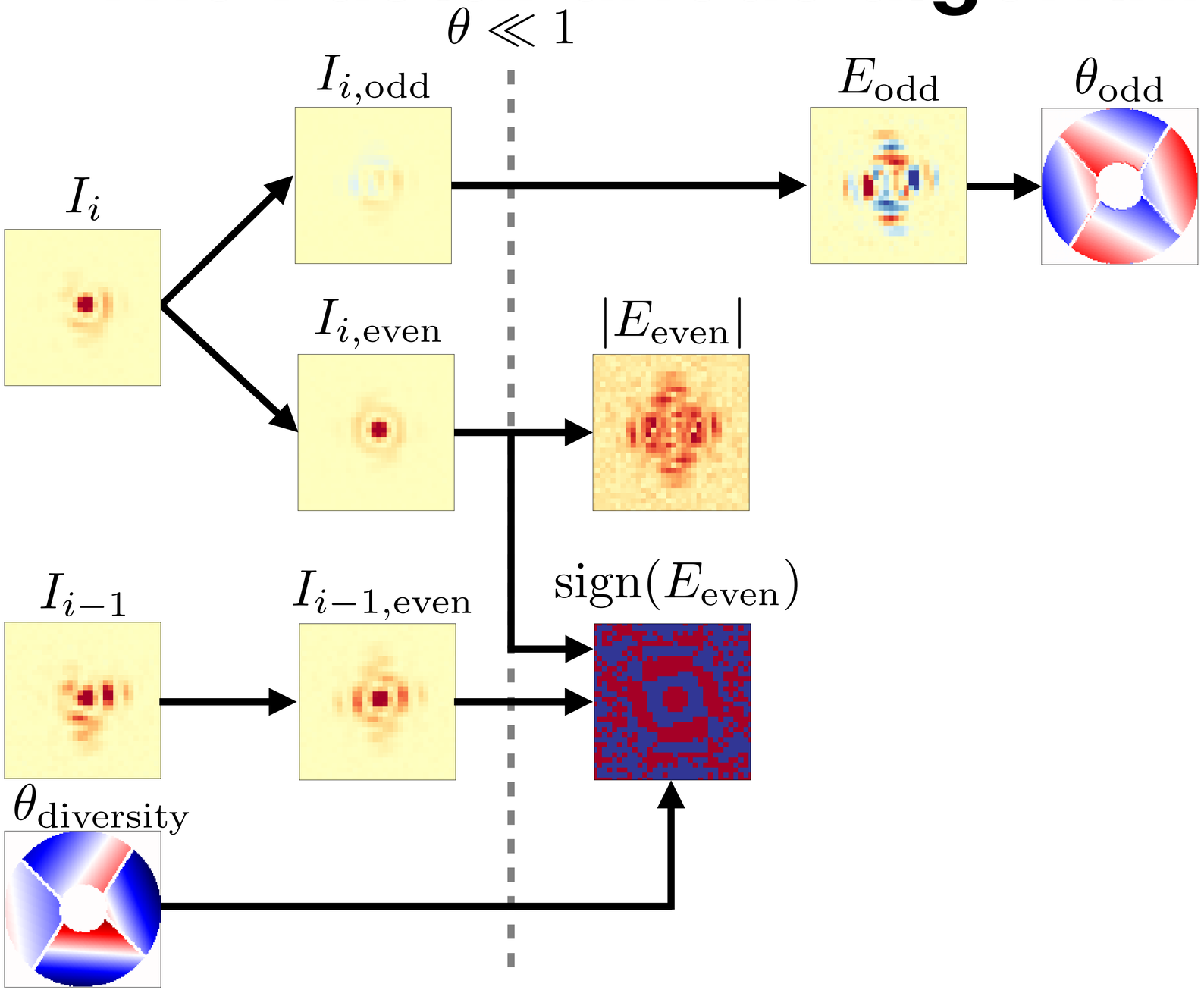

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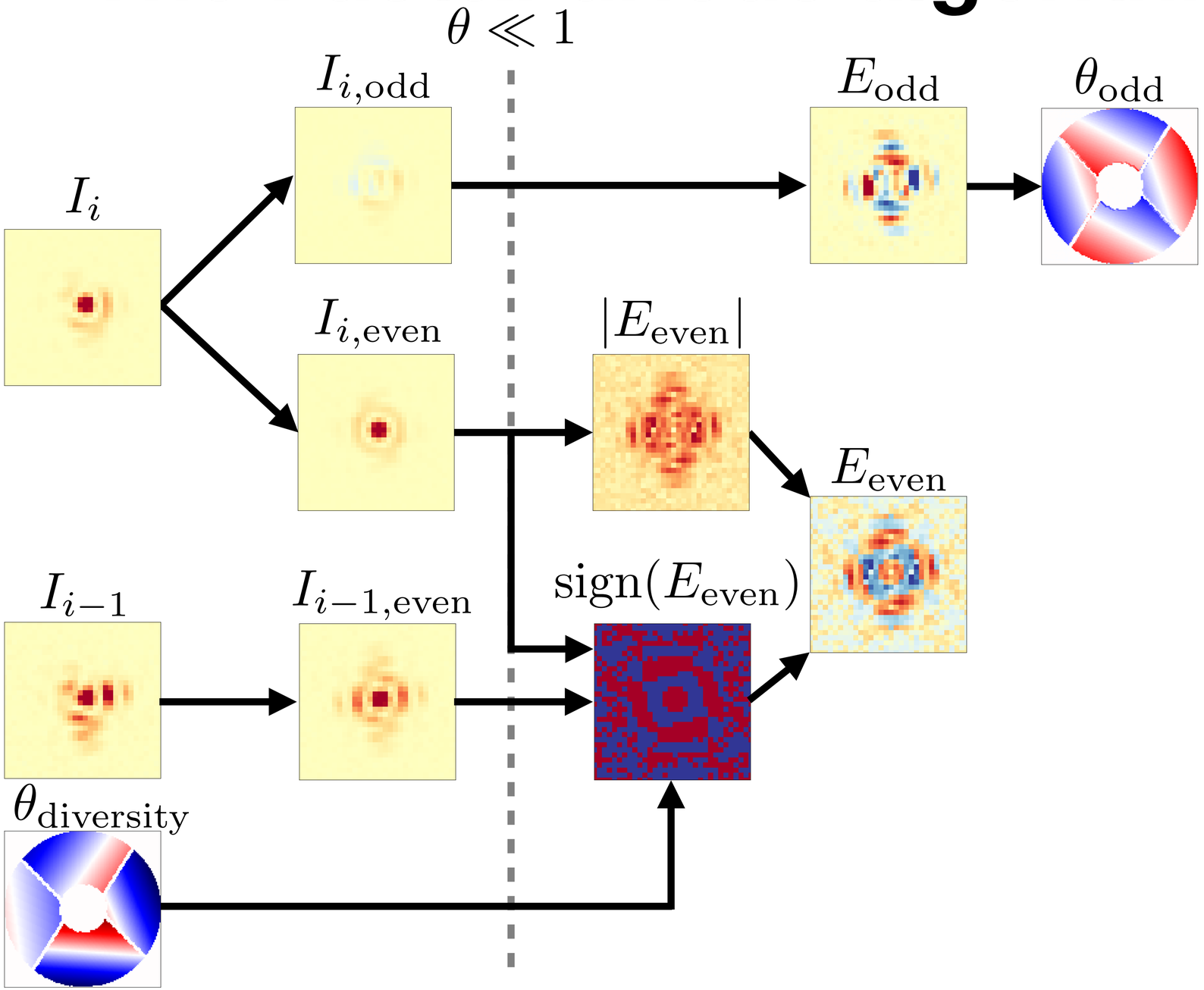

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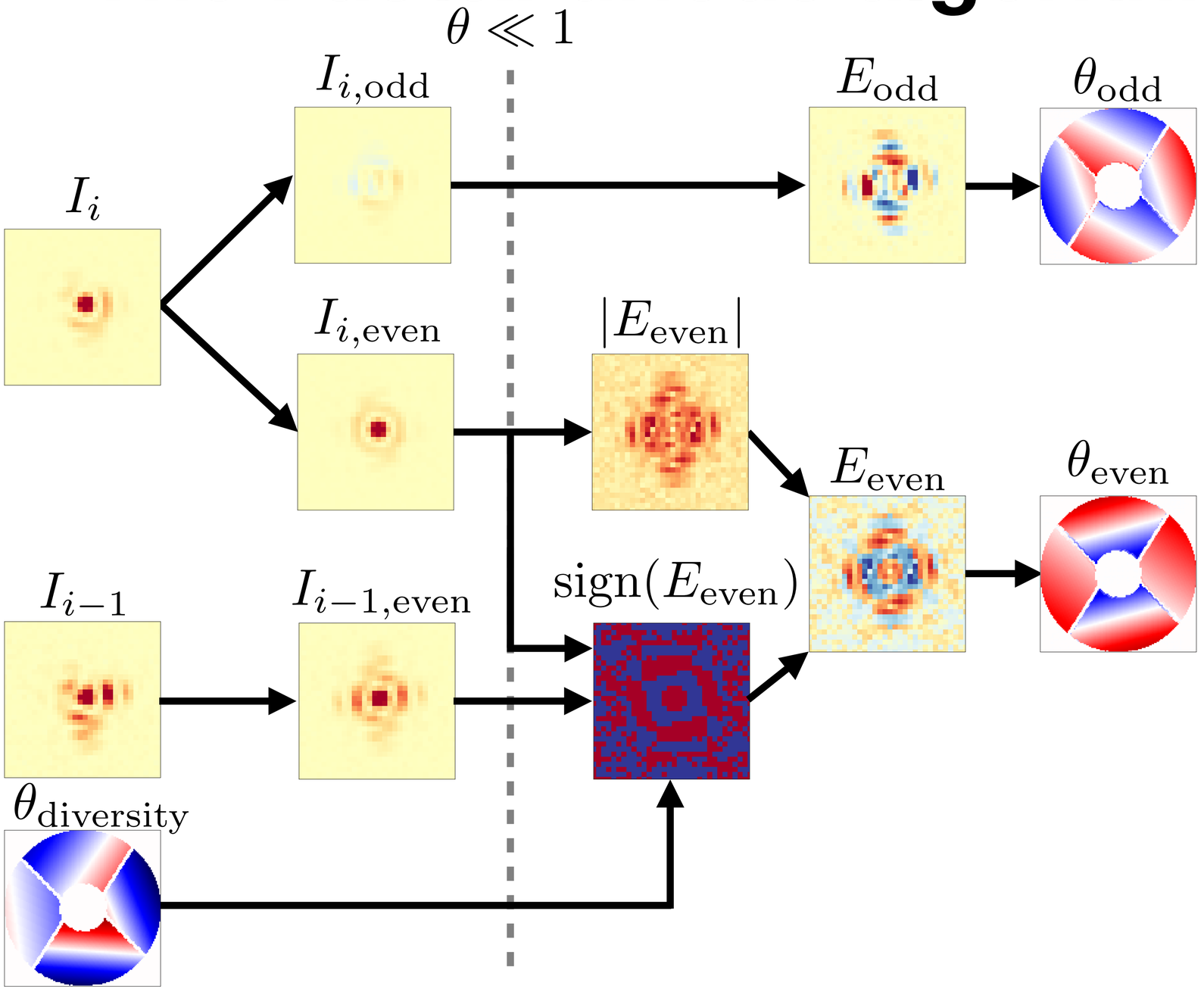

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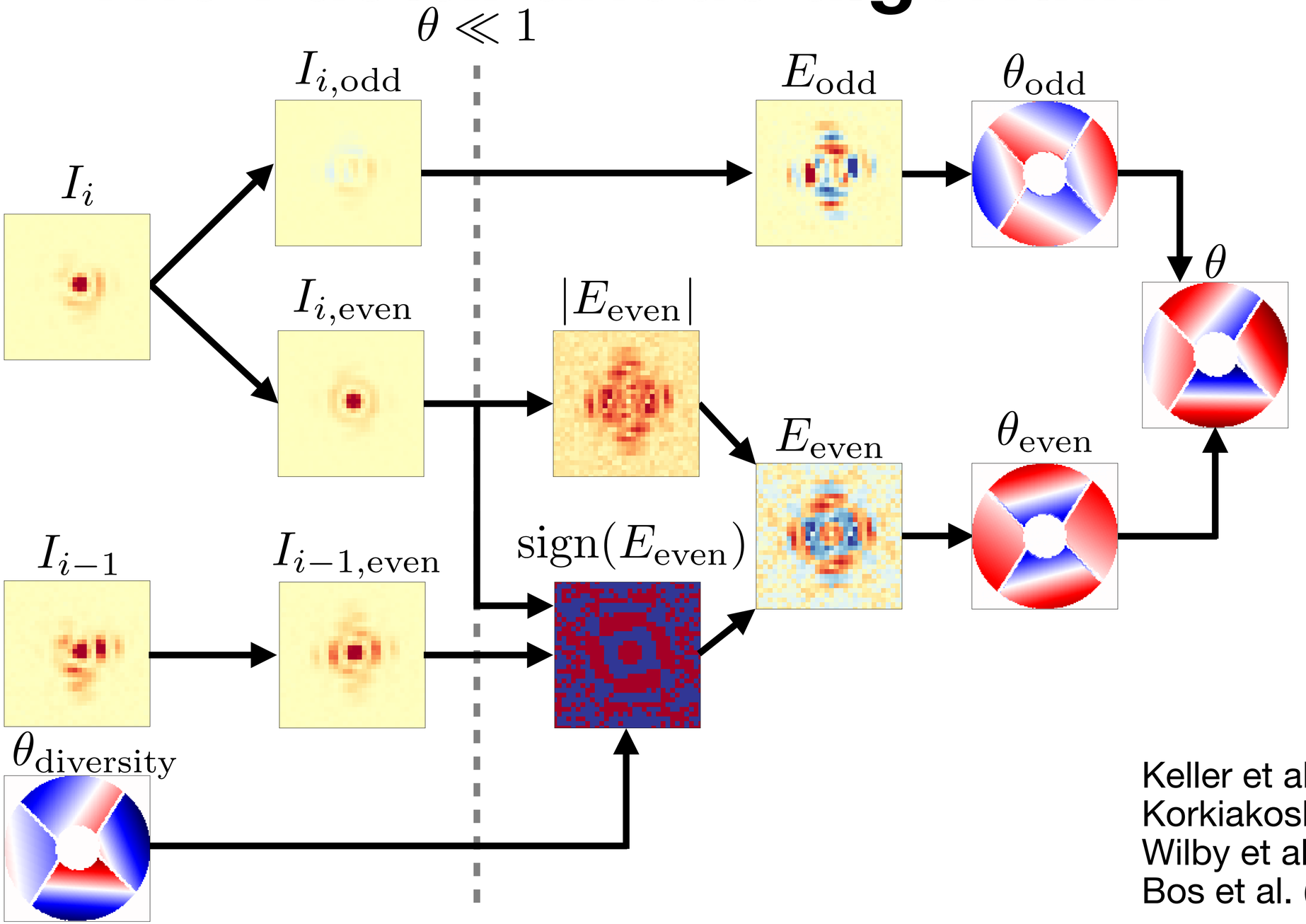

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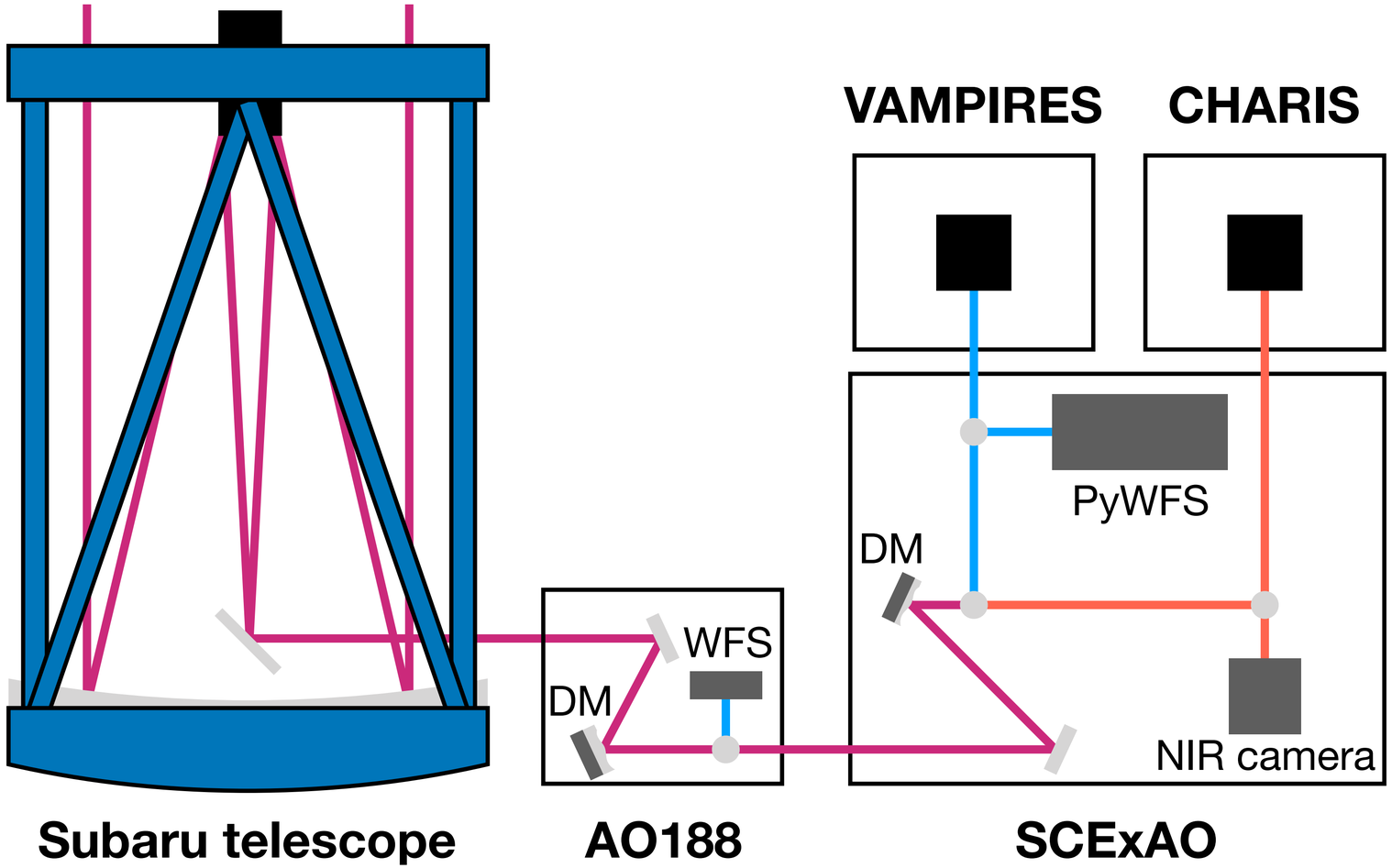
Fast & Furious at Subaru/SCExAO



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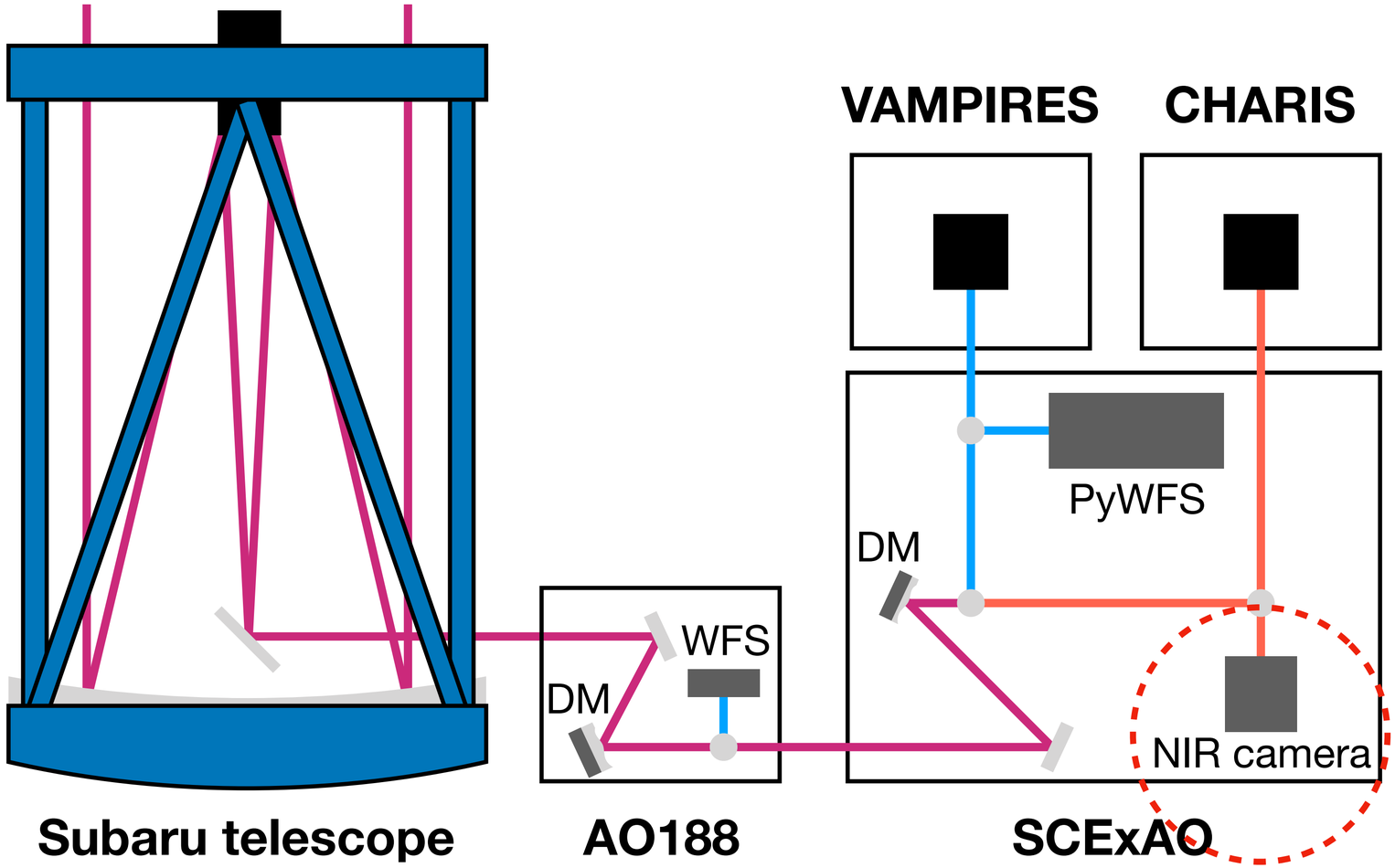

- NIR camera
  - C-RED2

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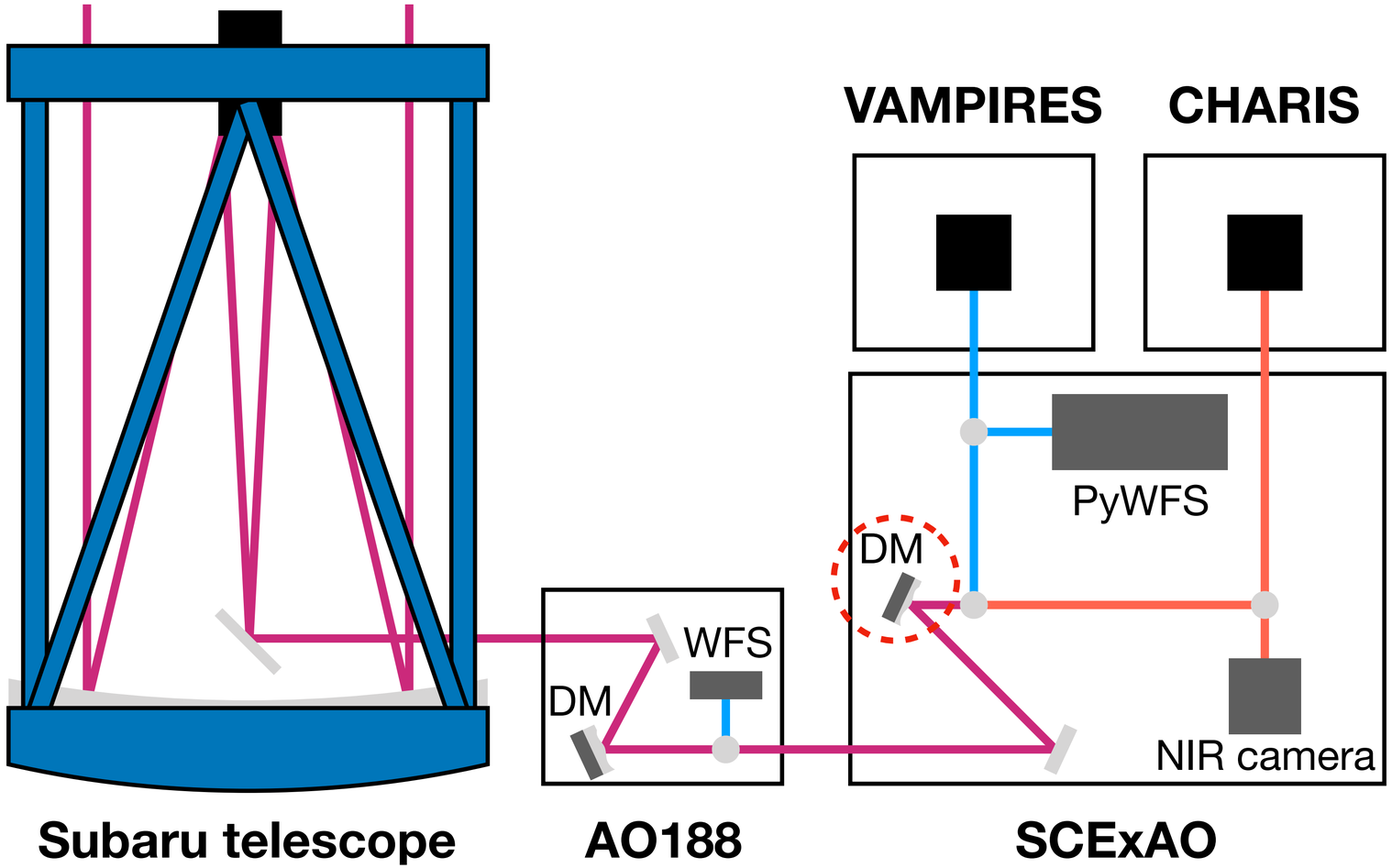
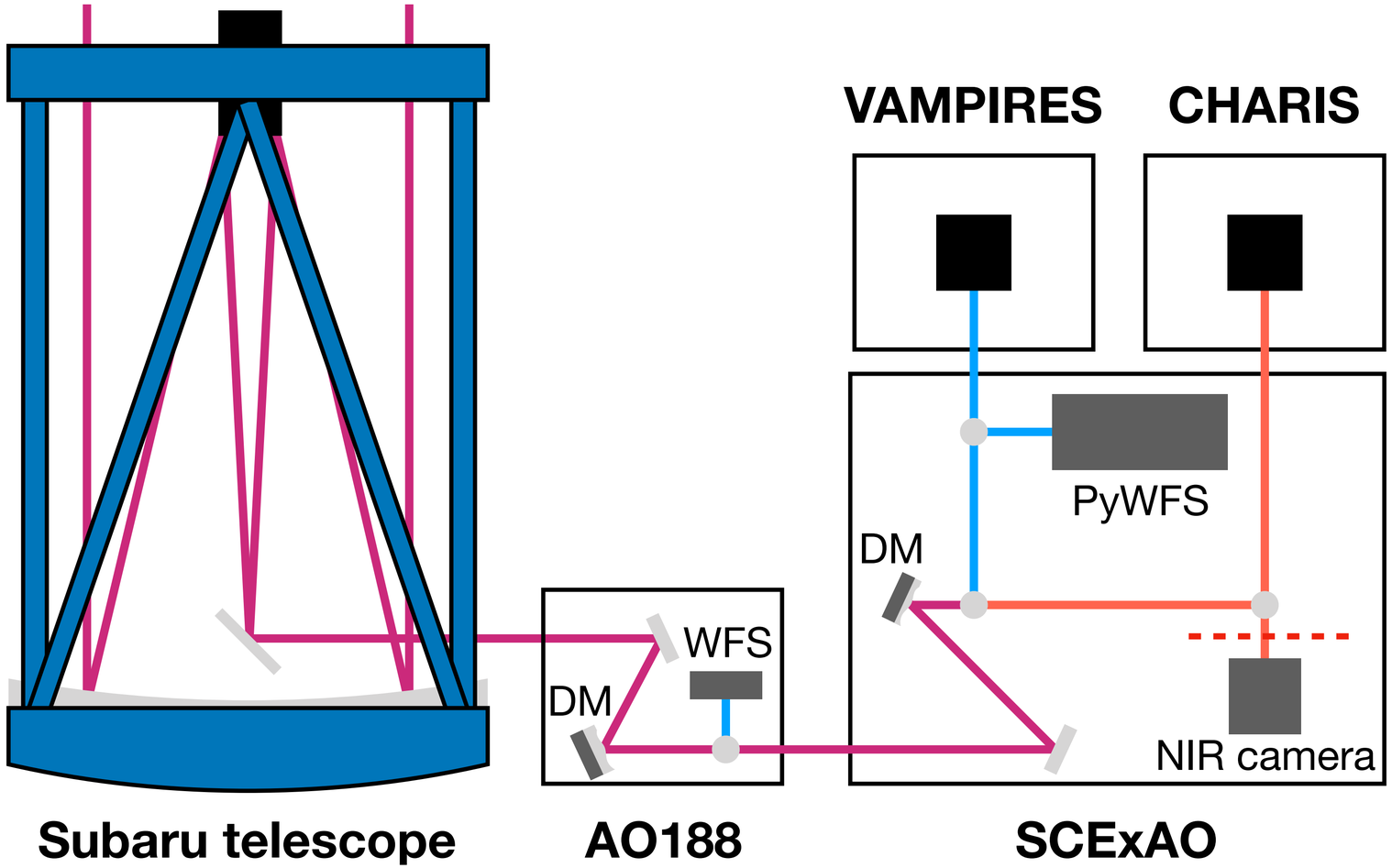


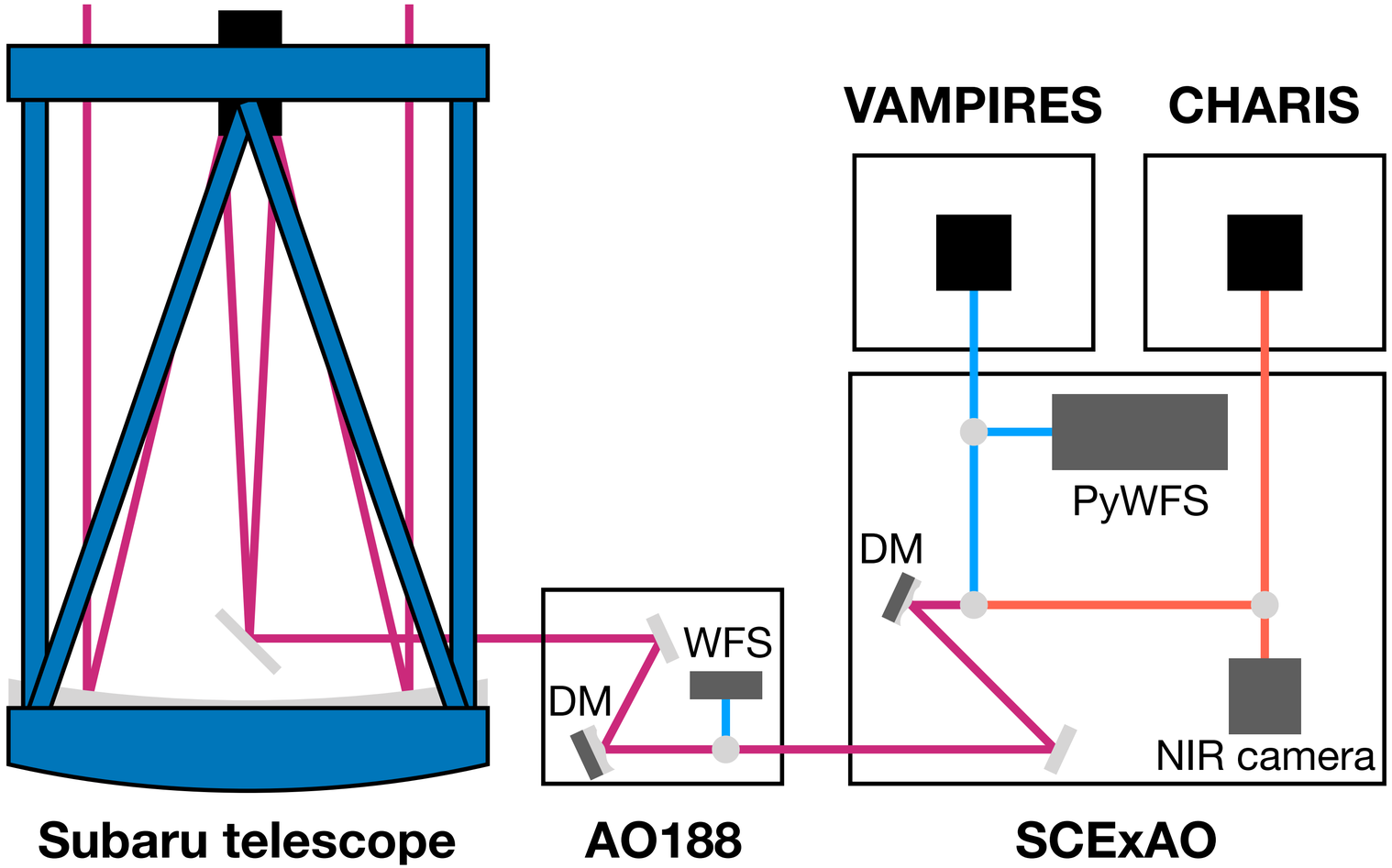
- NIR camera
  - C-RED2
- DM
  - 45 actuators over pupil

Fast & Furious at Subaru/SCExAO



- NIR camera
  - C-RED2
- DM
  - 45 actuators over pupil
- Filters
  - H-band
  - 25nm at 1550 nm

Fast & Furious at Subaru/SCExAO



- NIR camera
  - C-RED2
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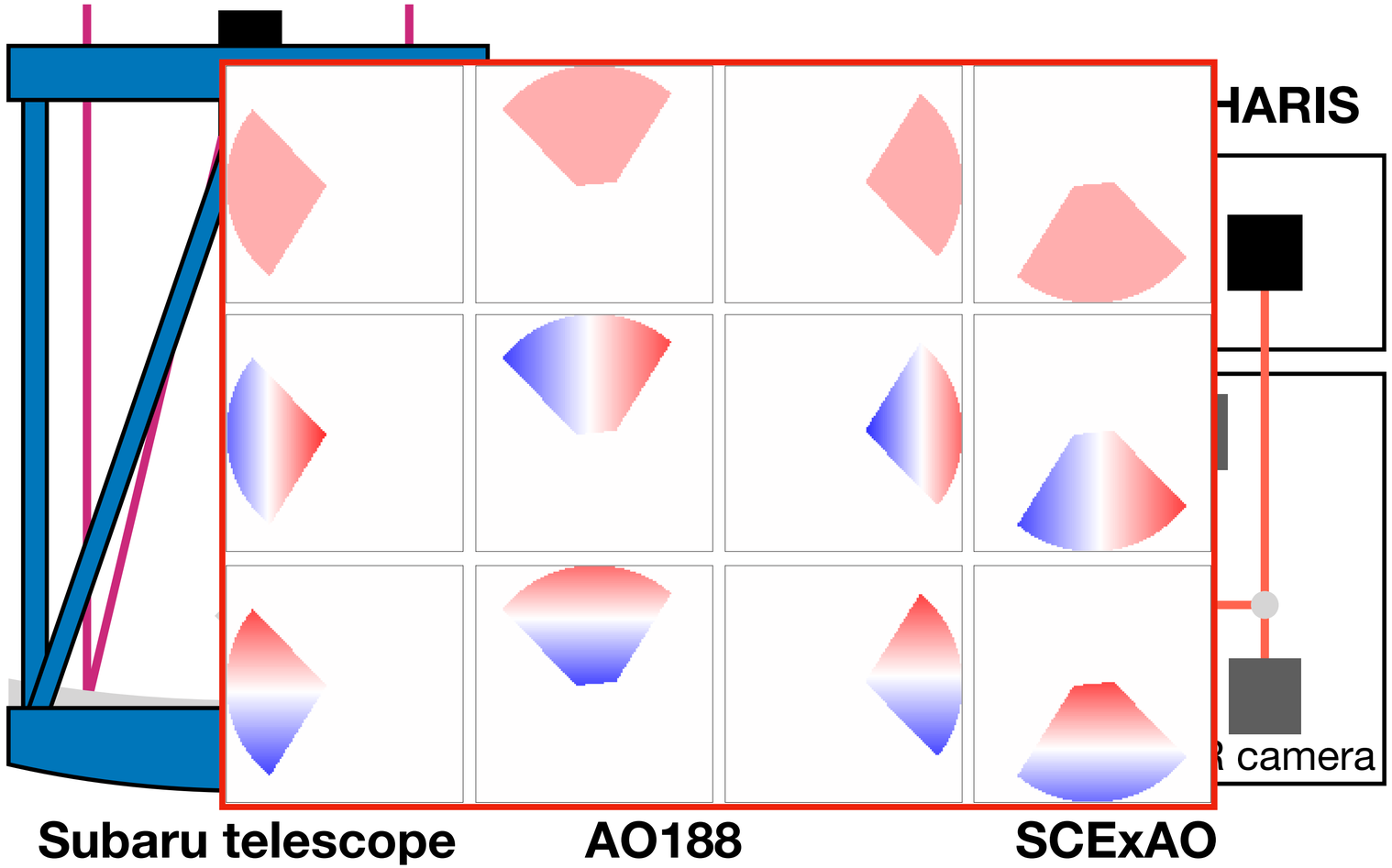
- Loop speed: 10 - 20 Hz

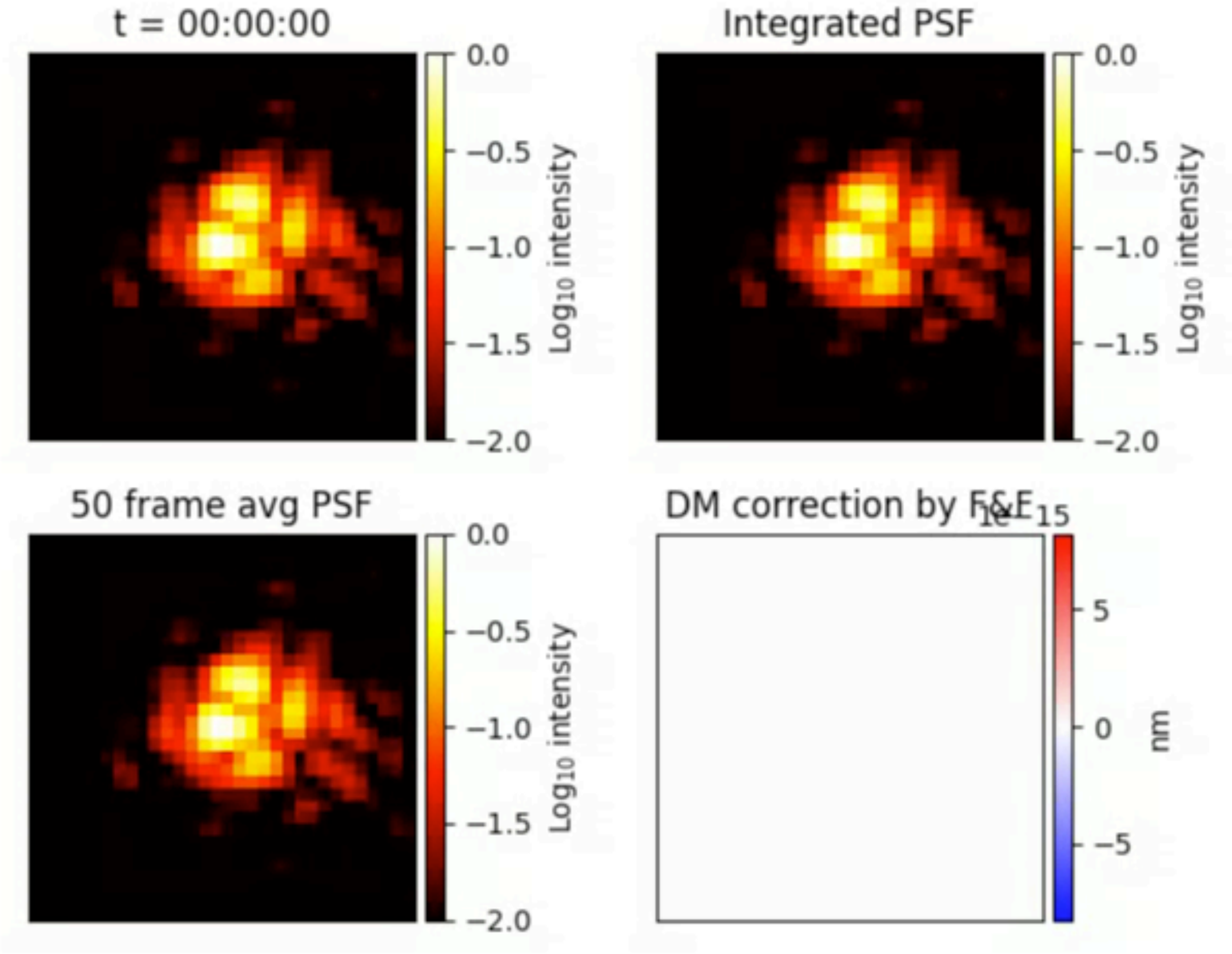
Fast & Furious at Subaru/SCExAO



- NIR camera
  - C-RED2
- DM
  - 45 actuators over pupil
- Filters
  - H-band
  - 25nm at 1550 nm
- Loop speed: 10 - 20 Hz
- Controlled modes:
  LWE modes + 50 Zernike modes

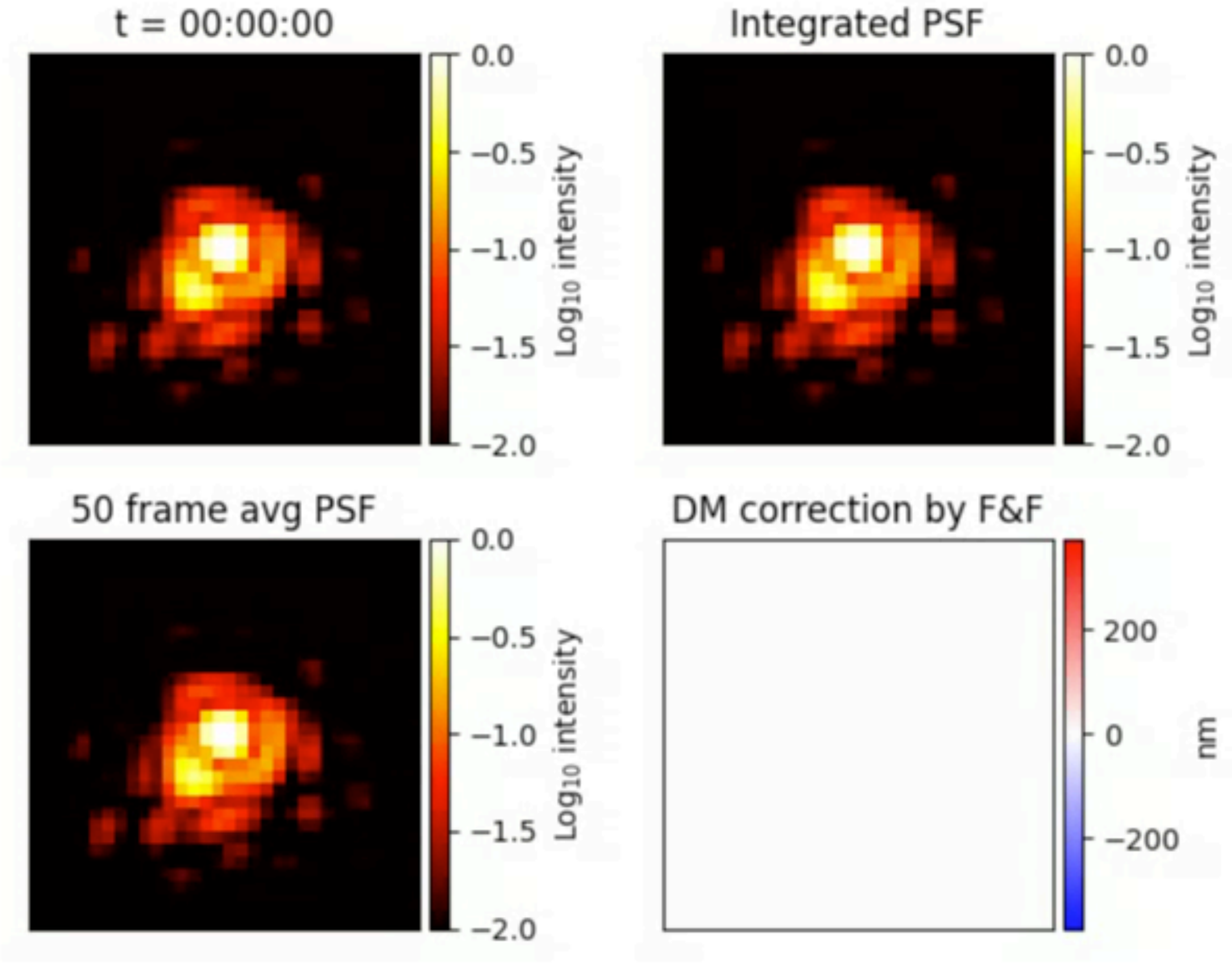
On-sky results

F&F loop open



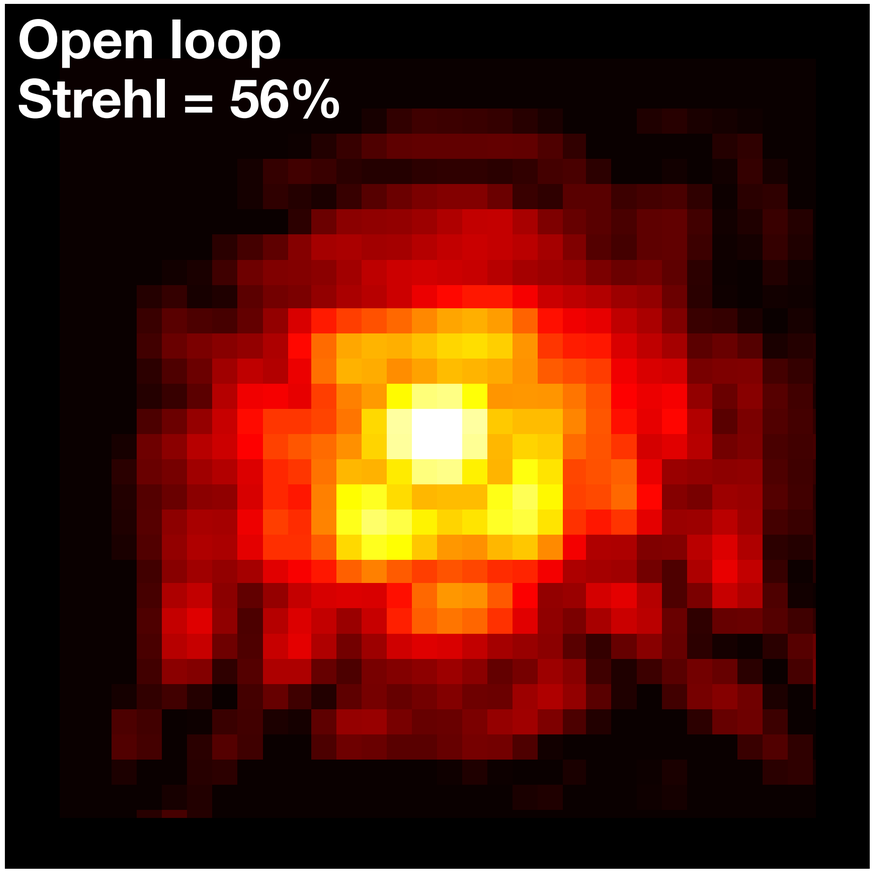
On-sky results

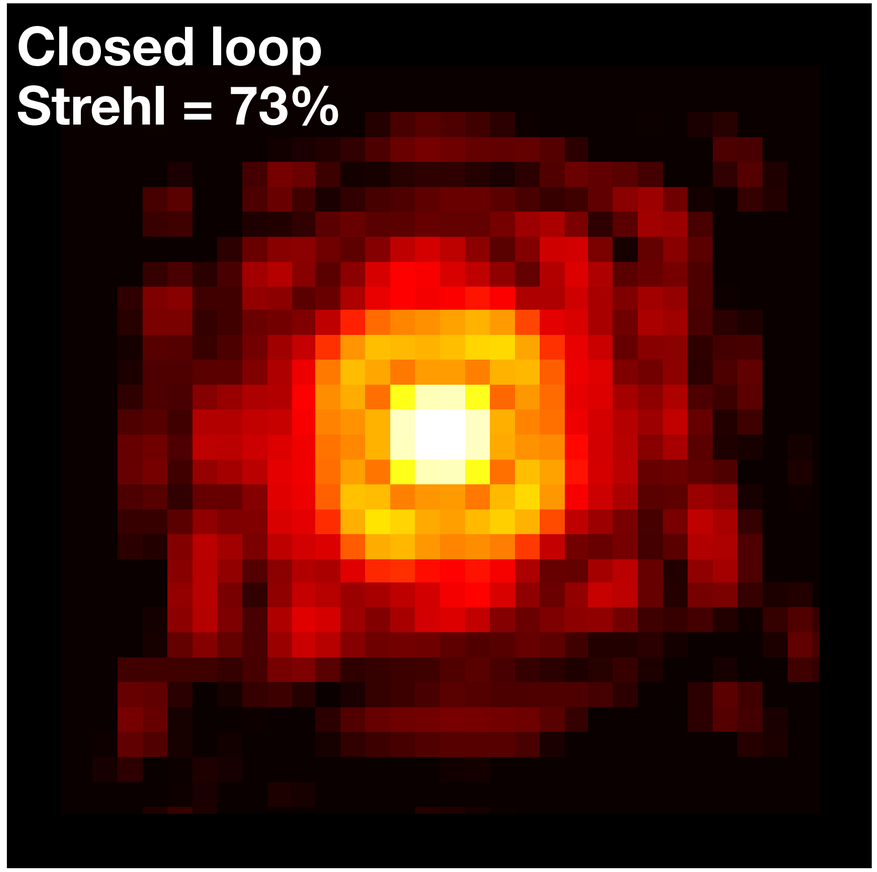
F&F loop closed



On-sky results

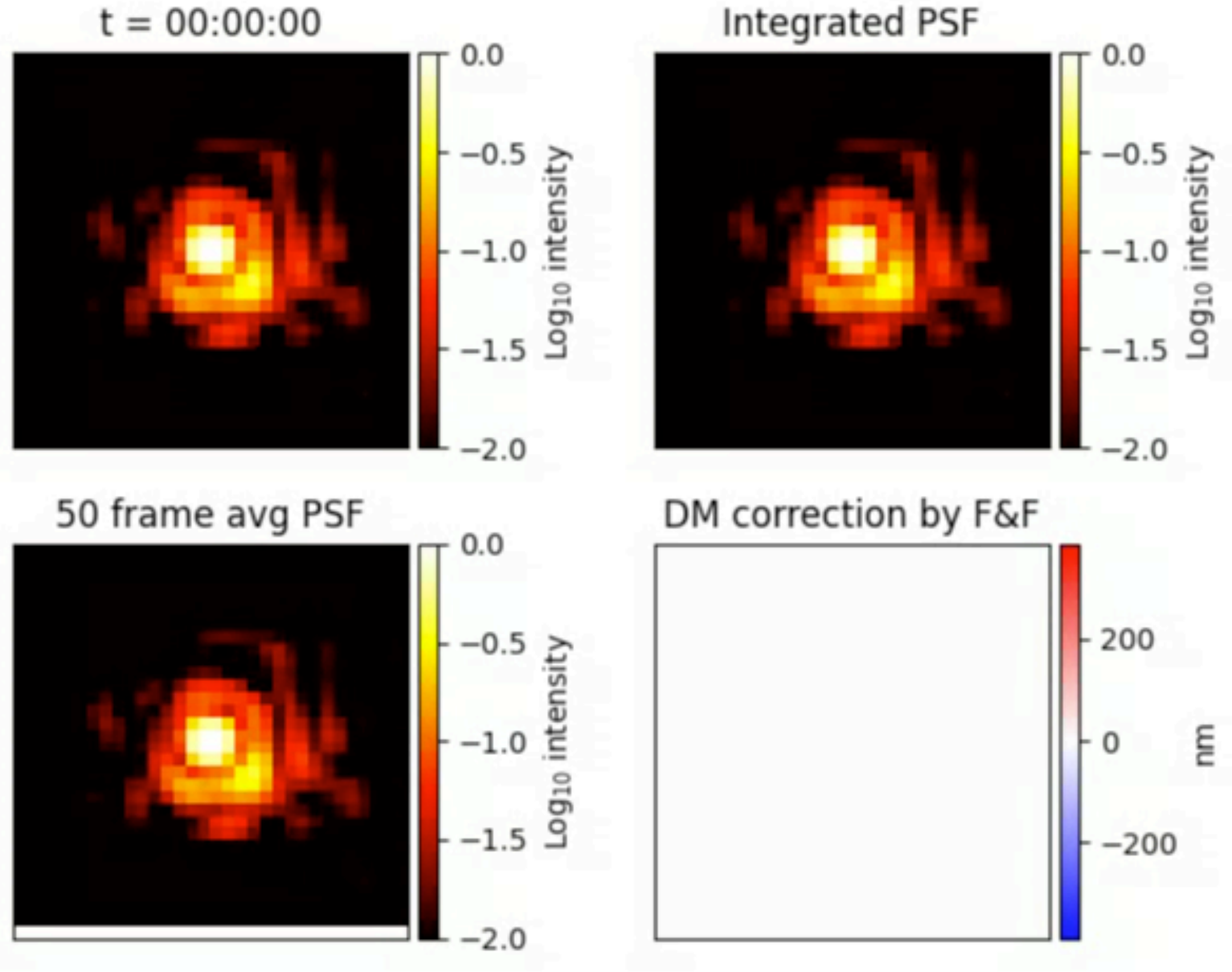
Performance quantification





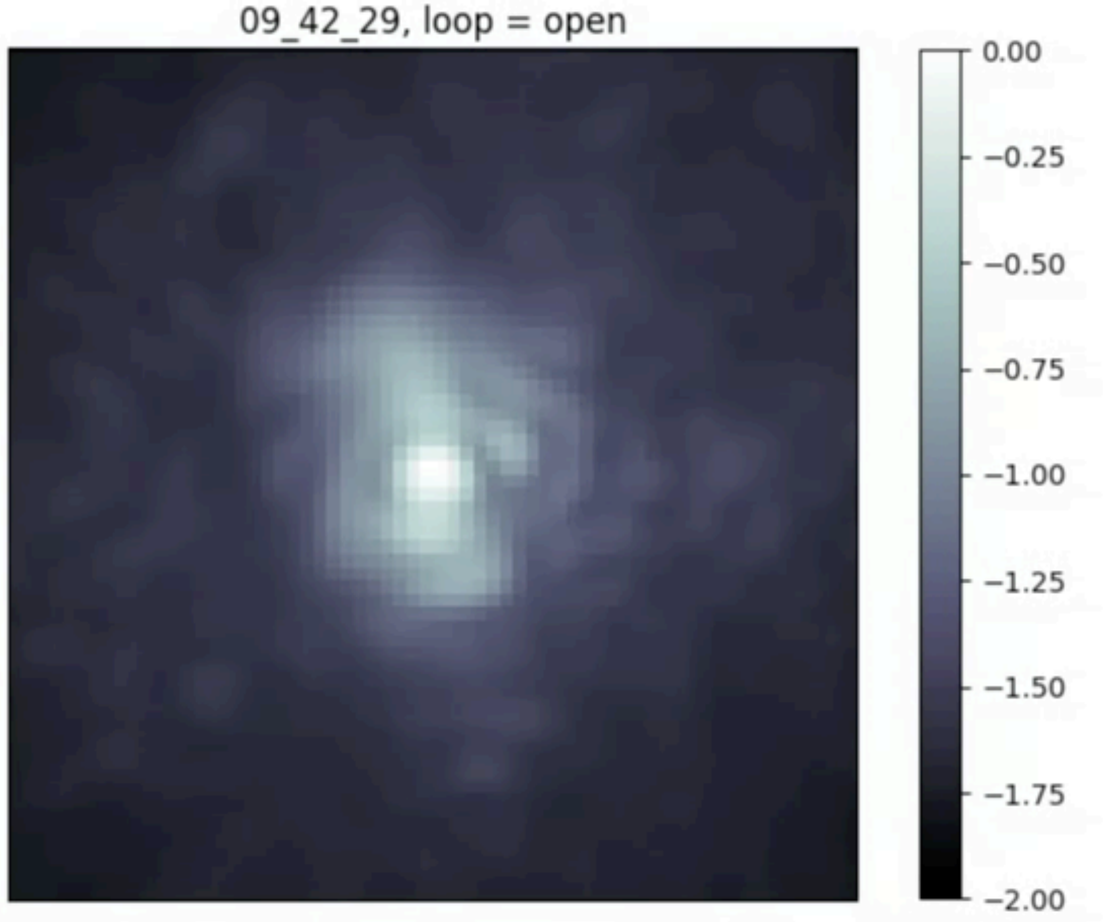
On-sky results

Temporal stability



On-sky results

Optical PSF



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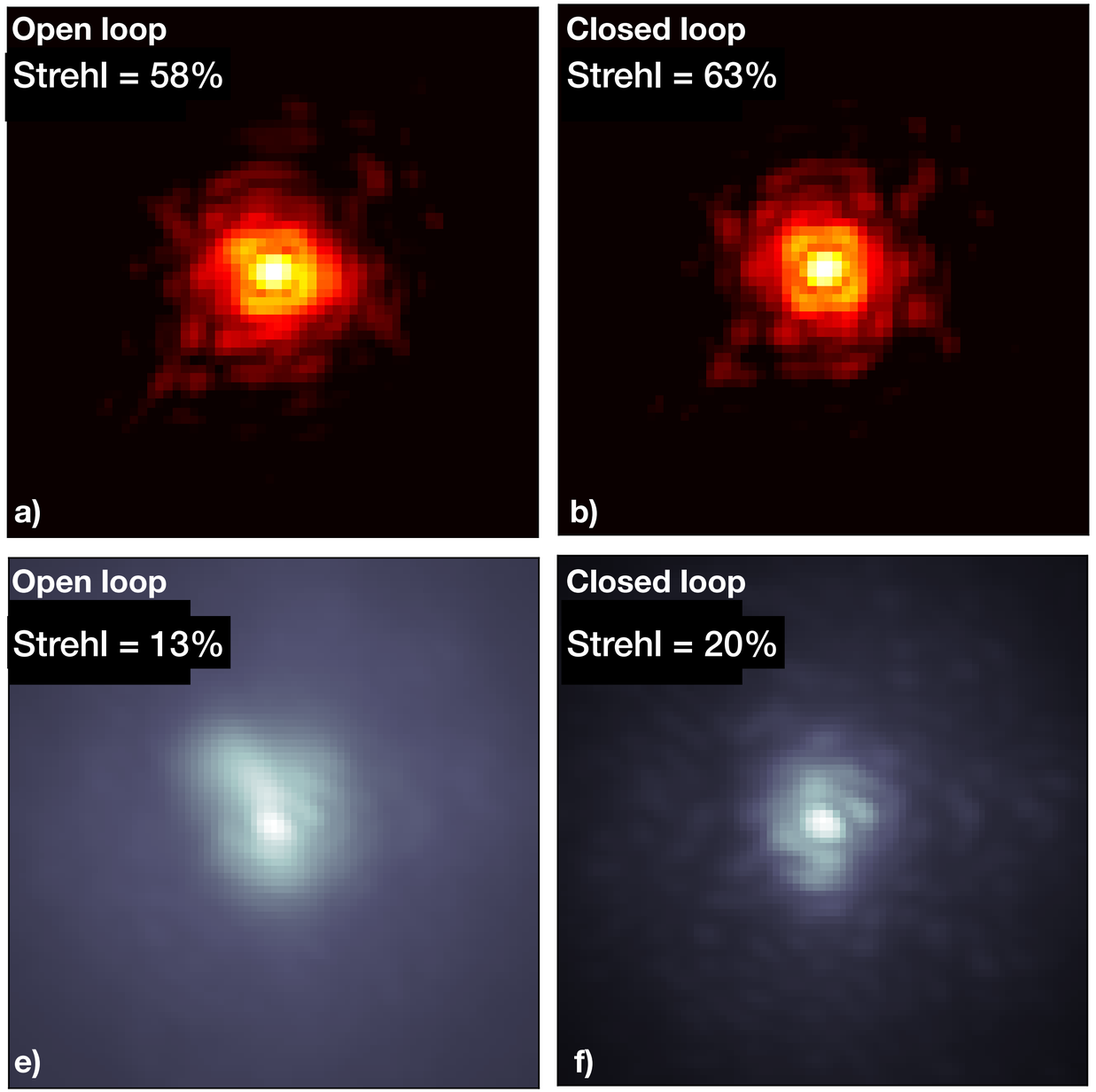
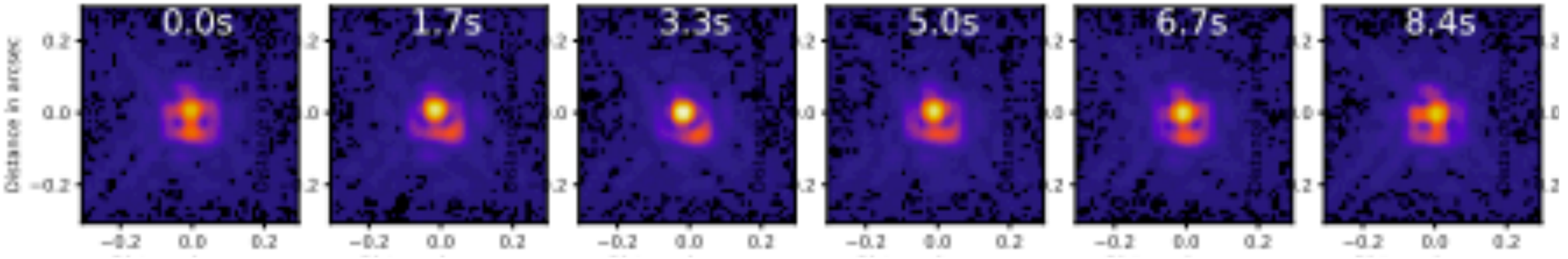


LWE at Subaru

- **Timescales**
  VLT: t ~ 1-2 sec (Milli et al. 2018)



Milli et al. (2018)

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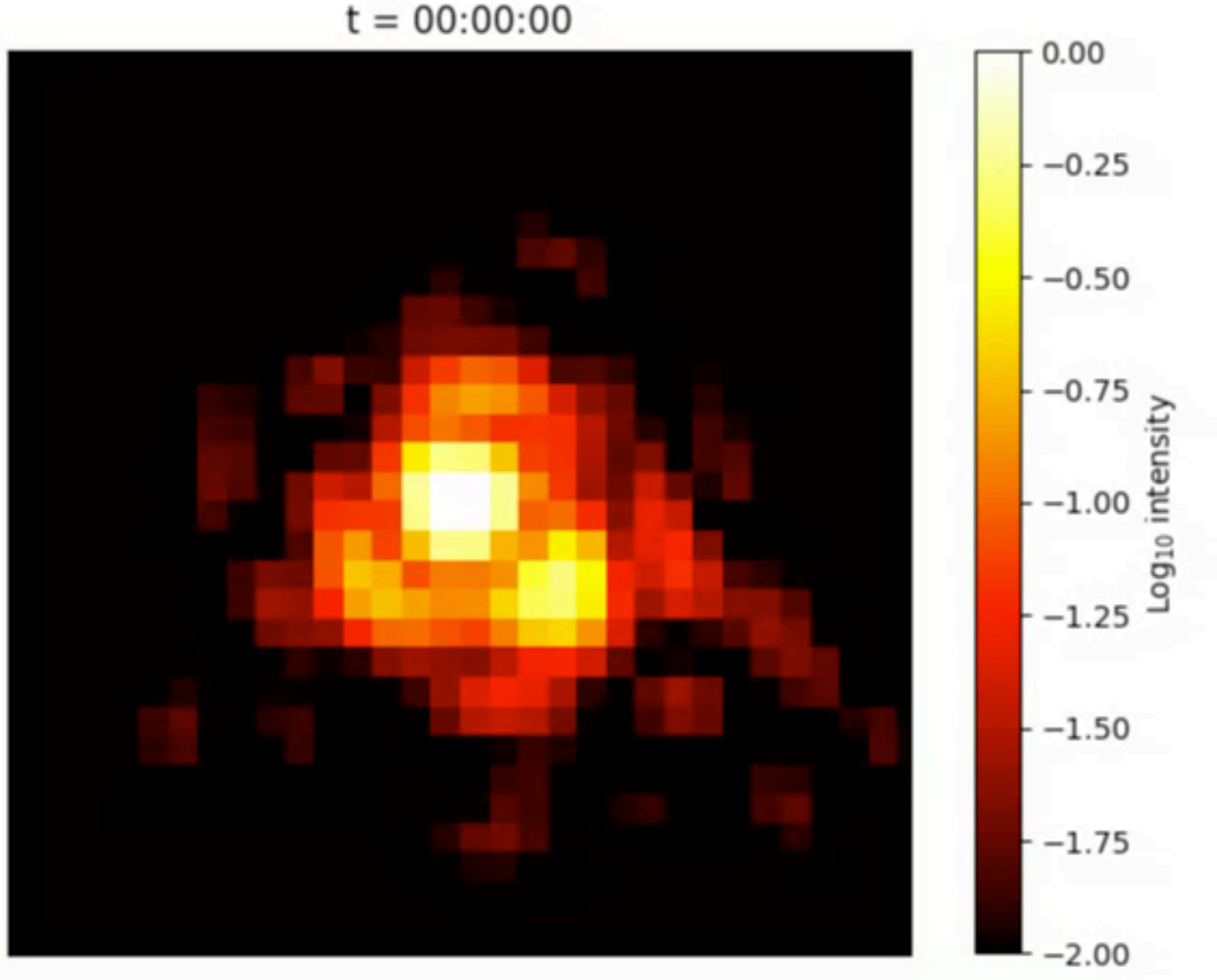

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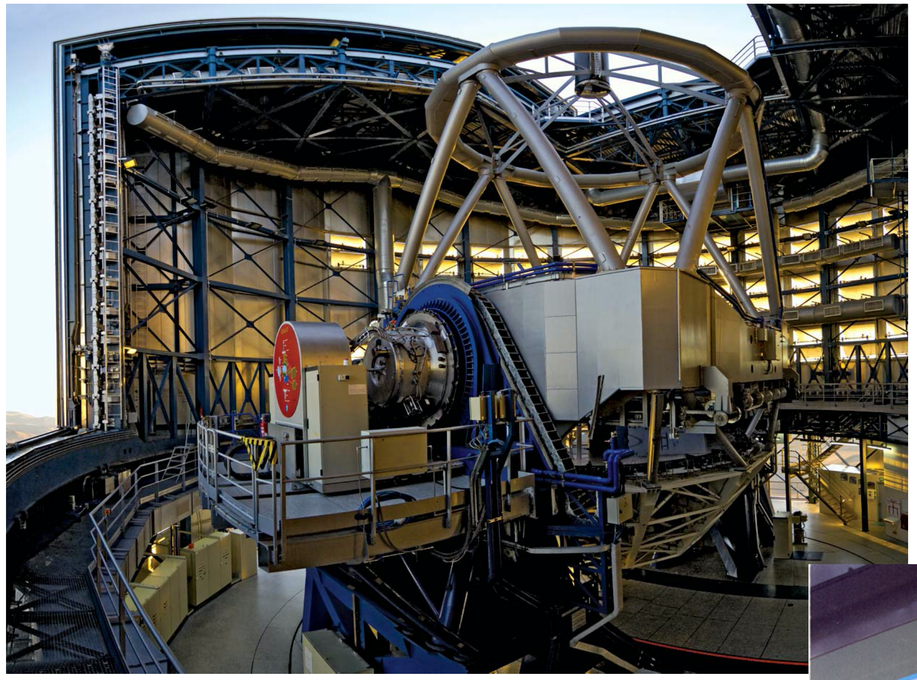

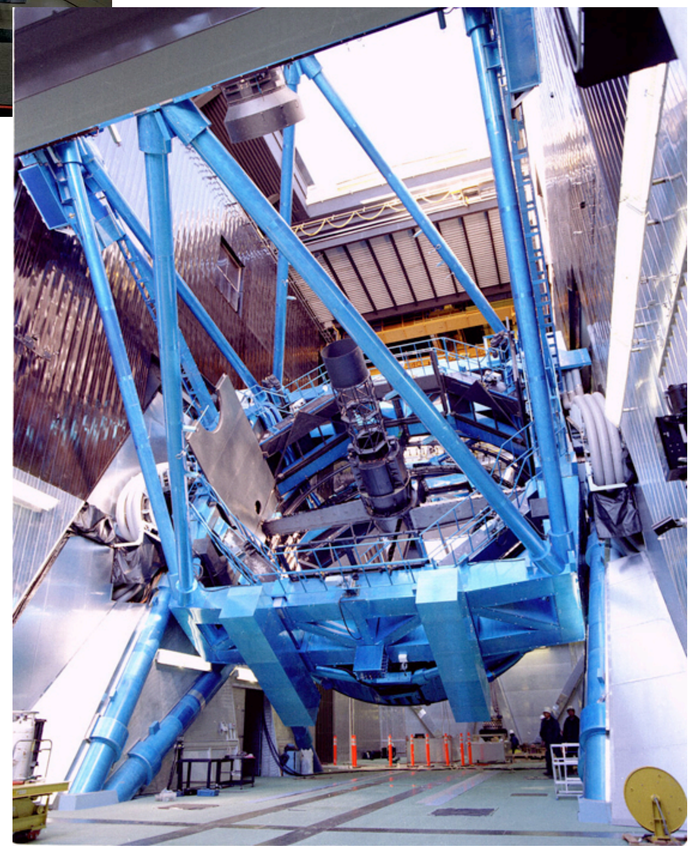

LWE at Subaru

- **Timescales**
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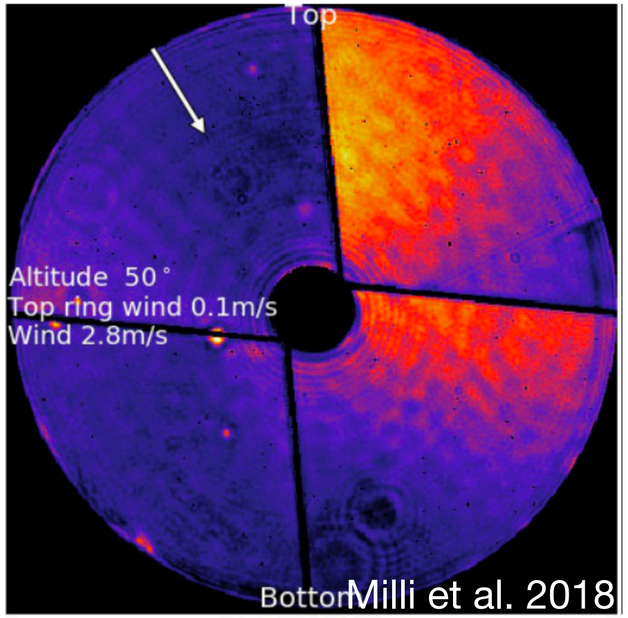
  Causes: Dome structure?

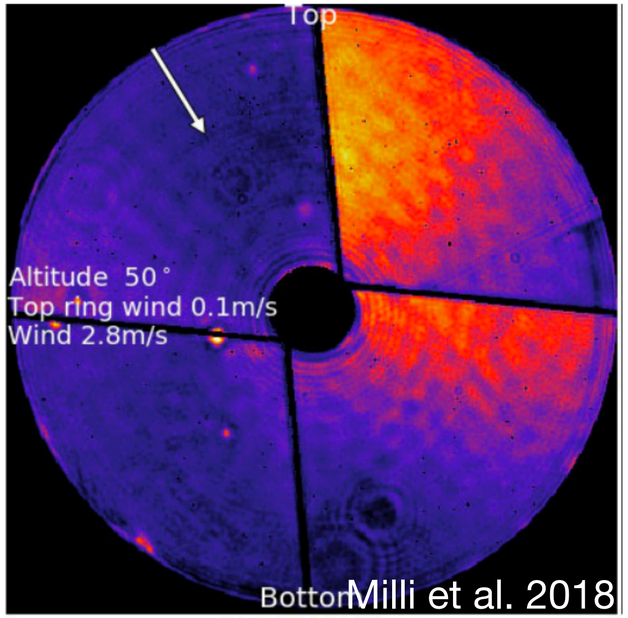
- **Pupil-plane morphology**
  VLT: LWE by spiders

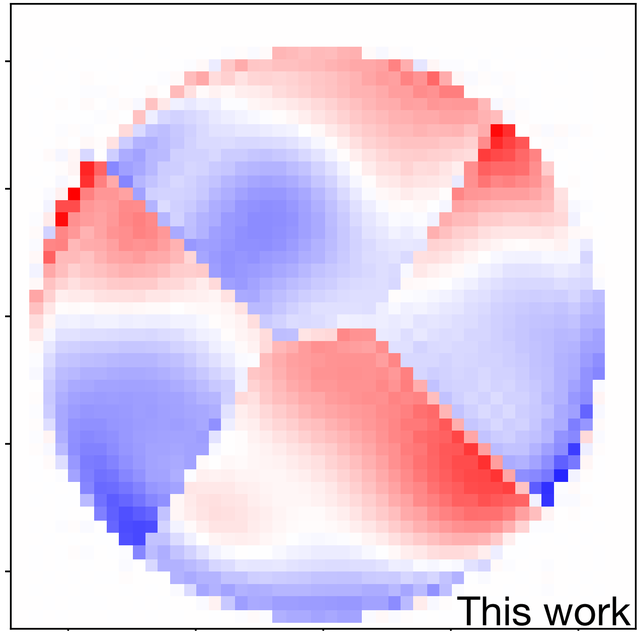


LWE at Subaru

- **Timescales**
  VLT: t ~ 1-2 sec (Milli et al. 2018)
  Subaru: t >= 4 sec (this work)
  Causes: Dome structure?

- **Pupil-plane morphology**
  VLT: LWE by spiders
  Subaru: LWE by spiders **and** top ring



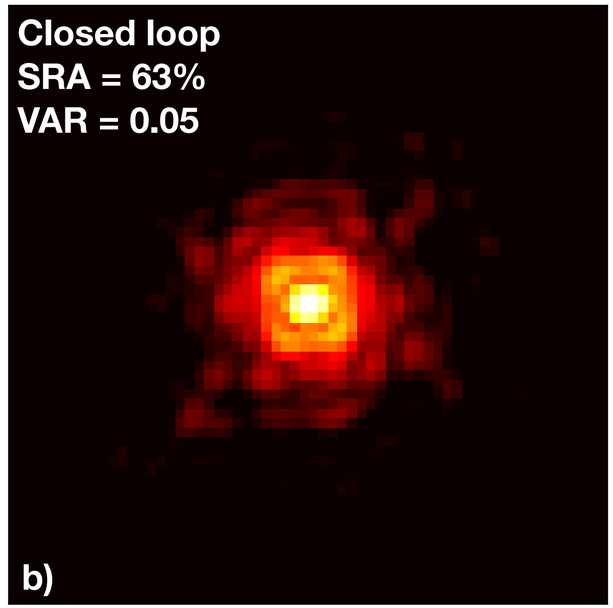


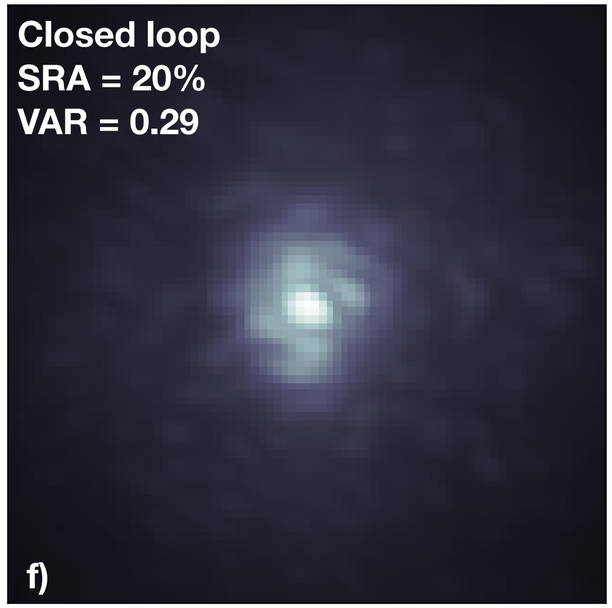
Future work

Future work

SCExAO:

- Run F&F in the optical, NIR does coronagraphy

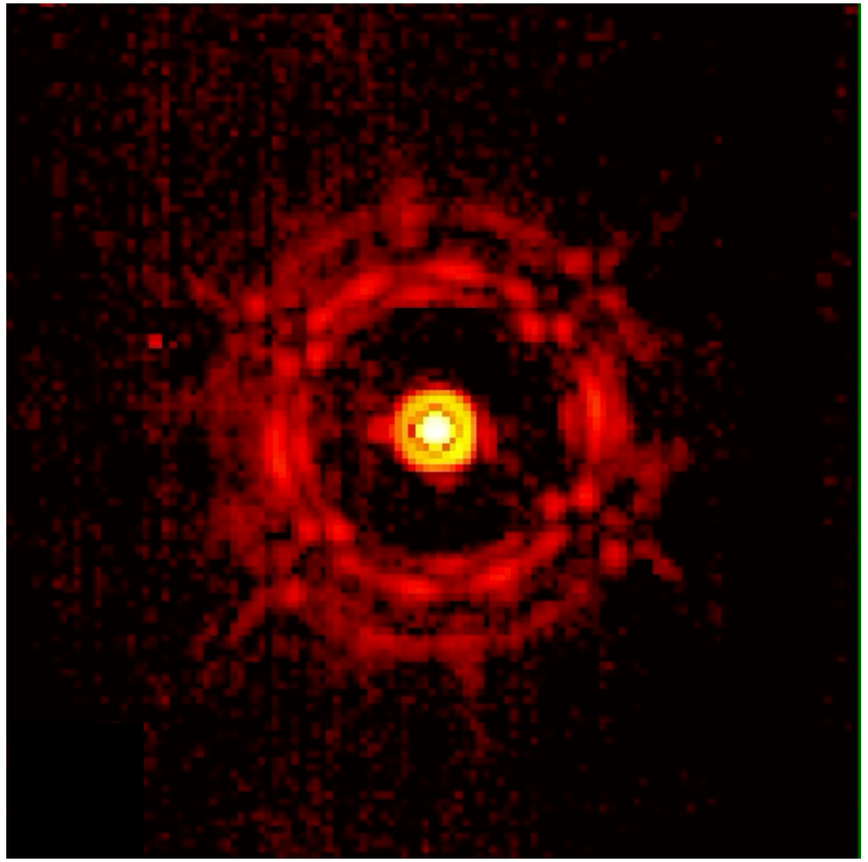




Future work

SCExAO:

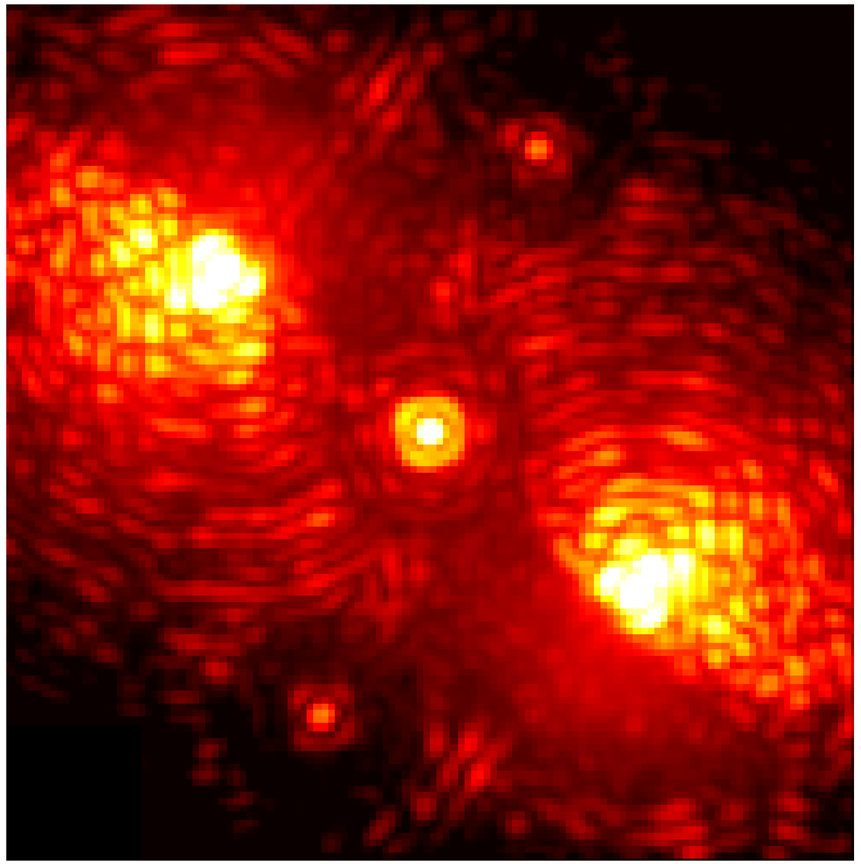
- Run F&F in the optical, NIR does coronagraphy
- Combine with kernel phase measurements
  Collaborator: Romain Laugier



Future work

SCExAO:

- Run F&F in the optical, NIR does coronagraphy
- Combine with kernel phase measurements
  Collaborator: Romain Laugier
- Run on central PSF vAPP coronagraph.



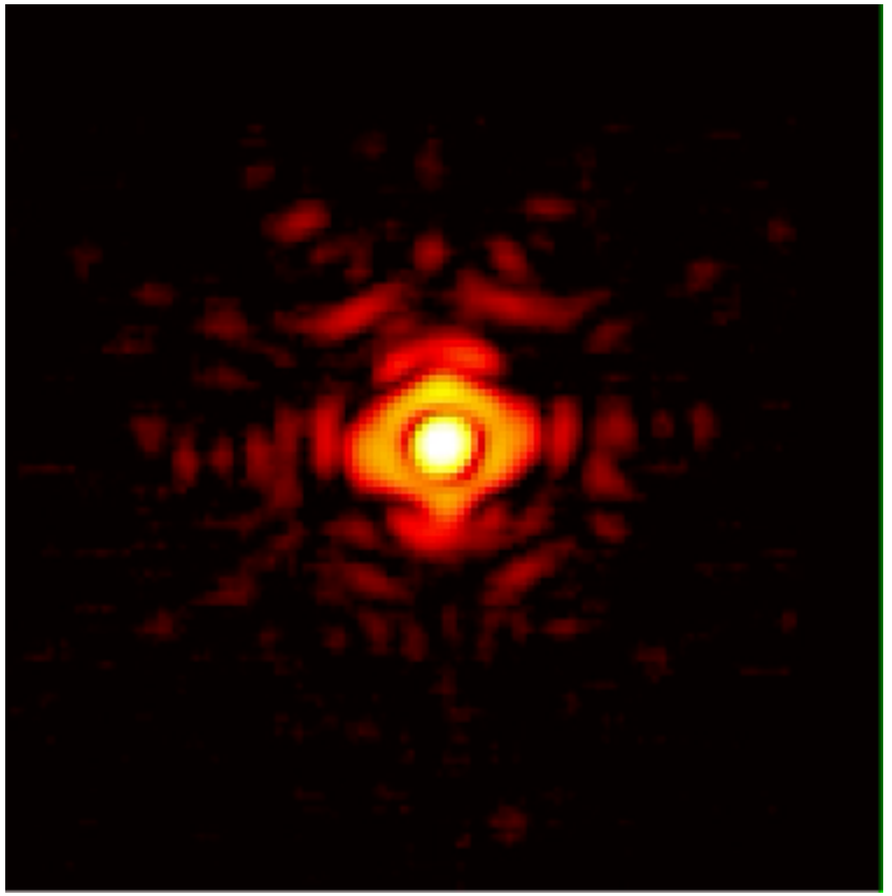
Future work

SCExAO:

- Run F&F in the optical, NIR does coronagraphy
- Combine with kernel phase measurements Collaborator: Romain Laugier
- Run on central PSF vAPP coronagraph.

Keck:

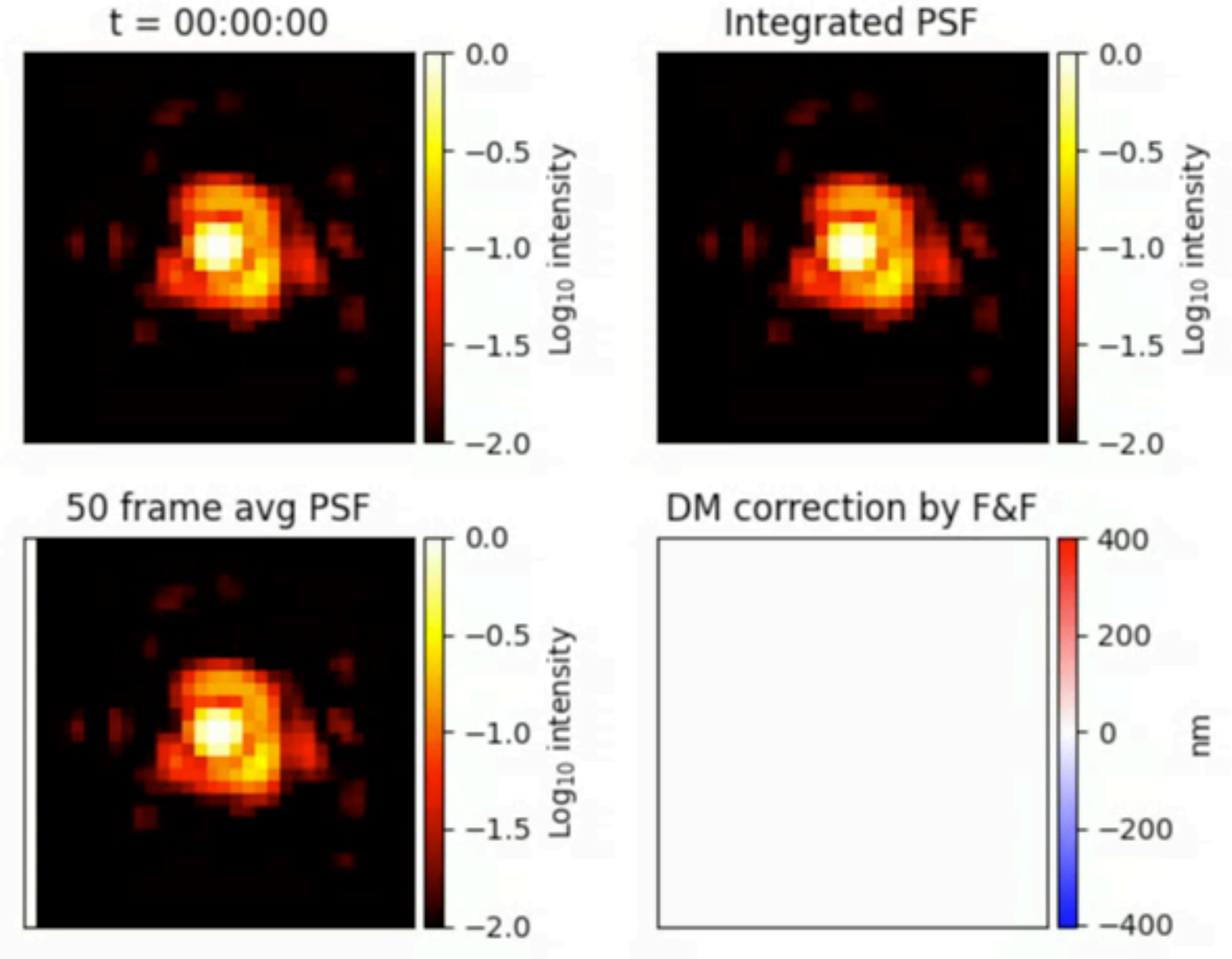
- Calibrate low order statics / NCPA Collaborators: Michael Bottom, Jacques Delorme, Sam Ragland, Sylvain Cetre, Laurent Pueyo



Conclusion

- Fast & Furious is a powerful focal-plane wavefront sensing algorithm
- Successful on-sky deployment and correction of LWE.
- LWE at Subaru Telescope:
  - Longer timescales compared to VLT
  - Different pupil-plane phase morphology (also LWE from top ring)

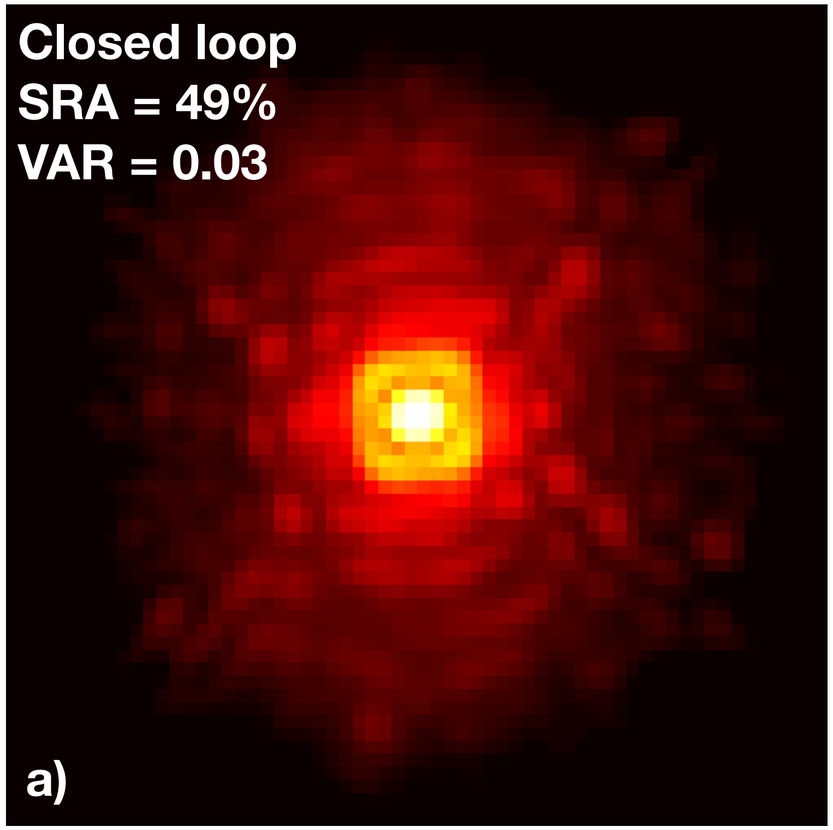
Thank you!

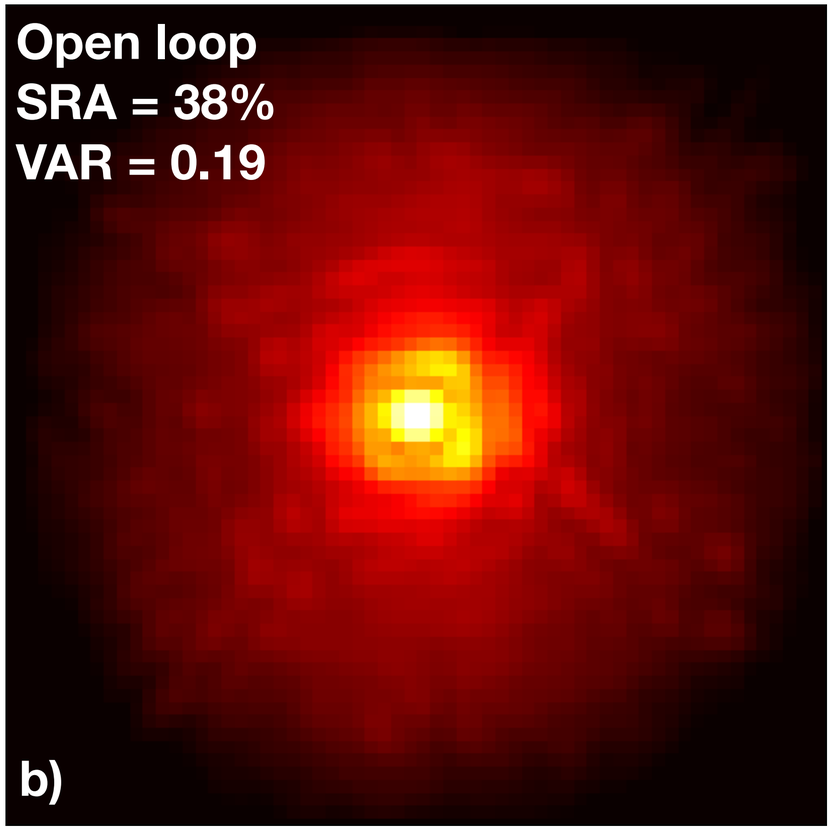


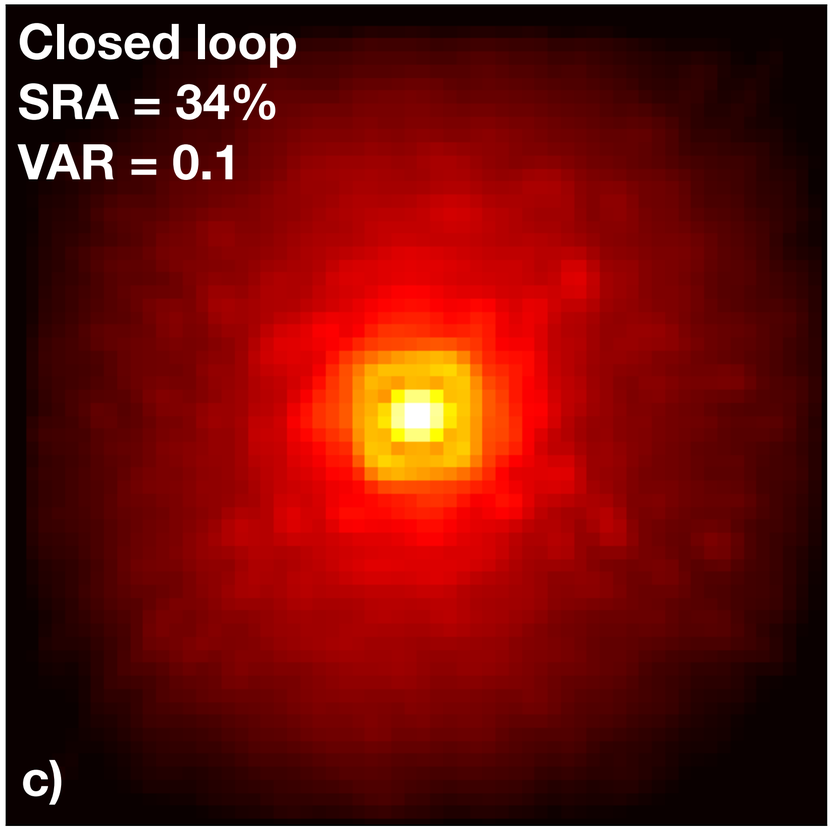
- Contact: stevenbos@strw.leidenuniv.nl
- For more information see:
  Bos, S. P., Vievard, S., Wilby, M. J., et al. 2020, A&A, 639, A52

On-sky results: Poor conditions

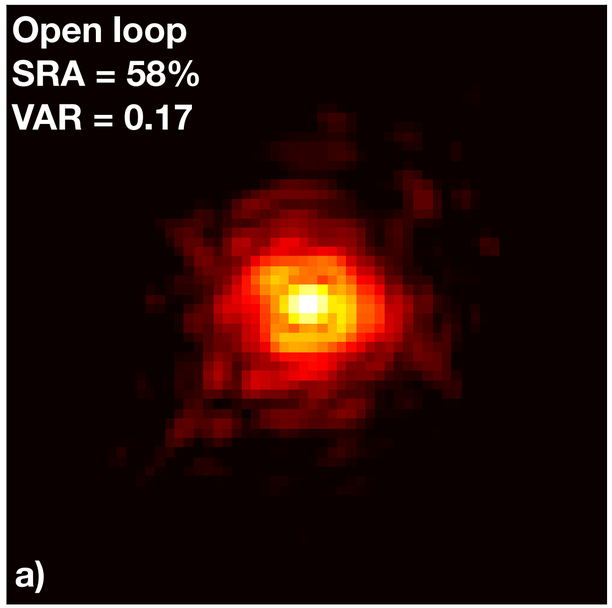
12-12-2019

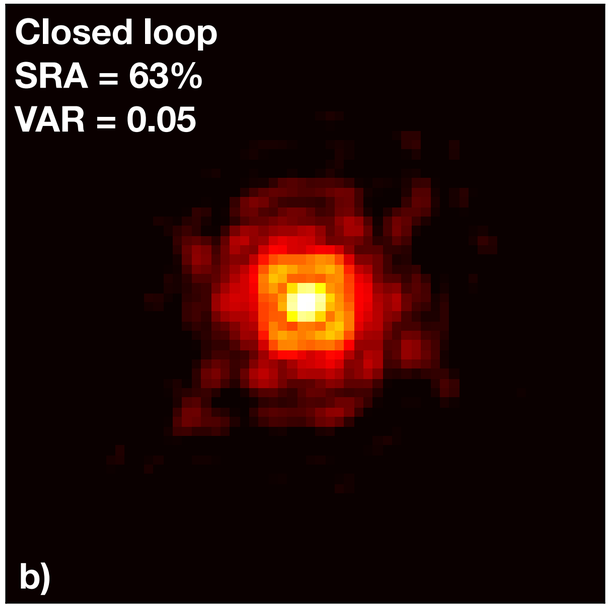


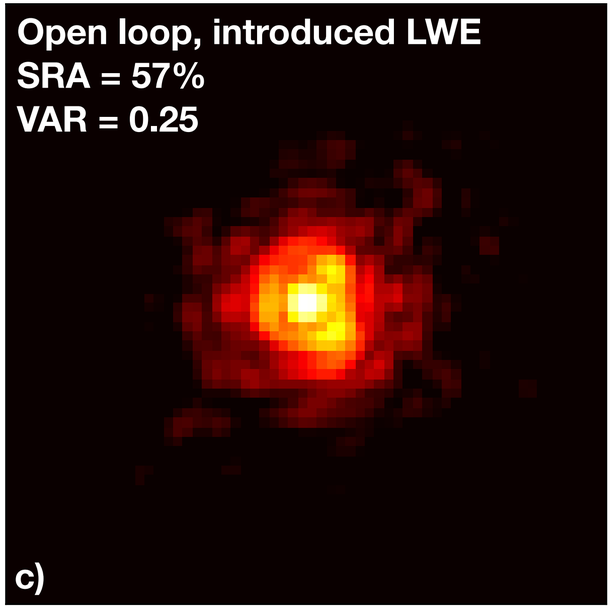


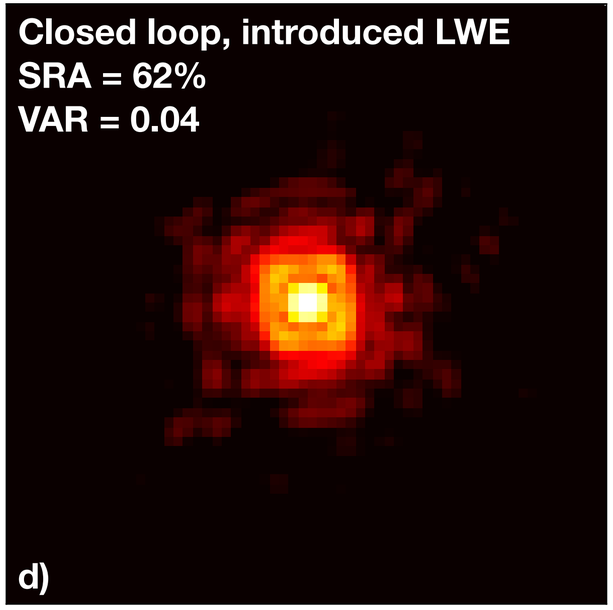


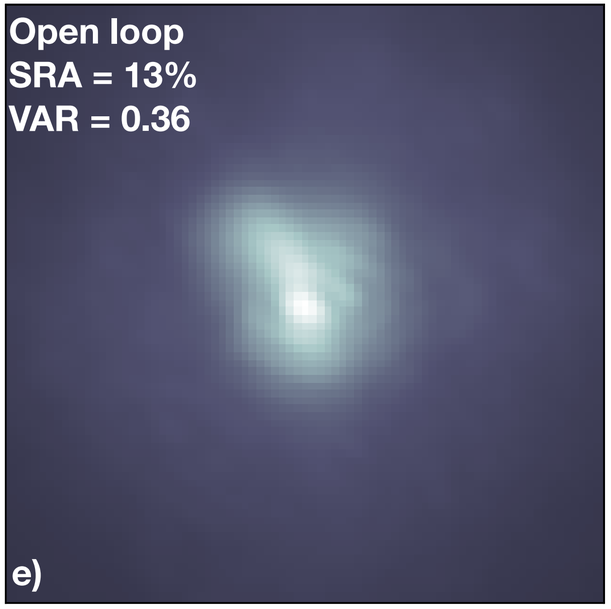
On-sky results: Medium conditions

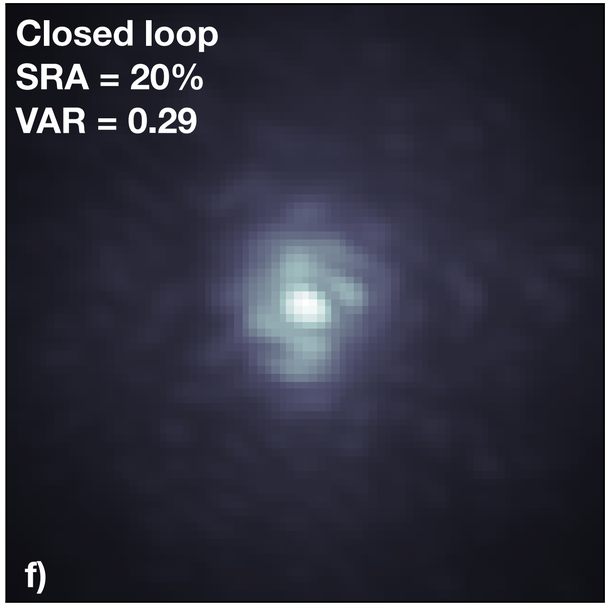


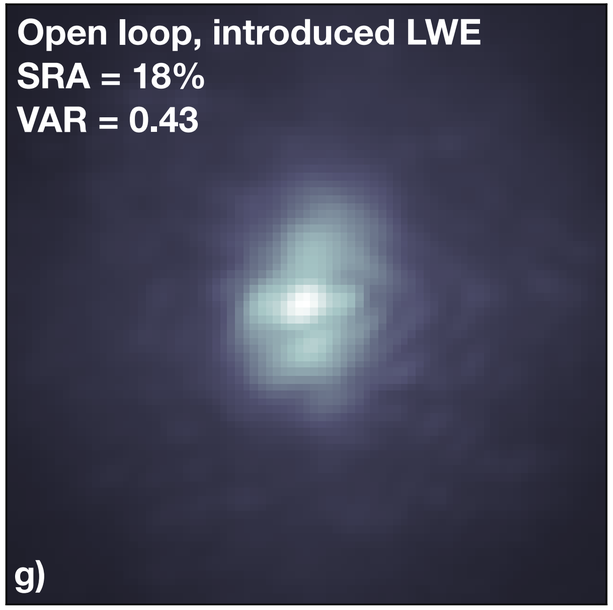


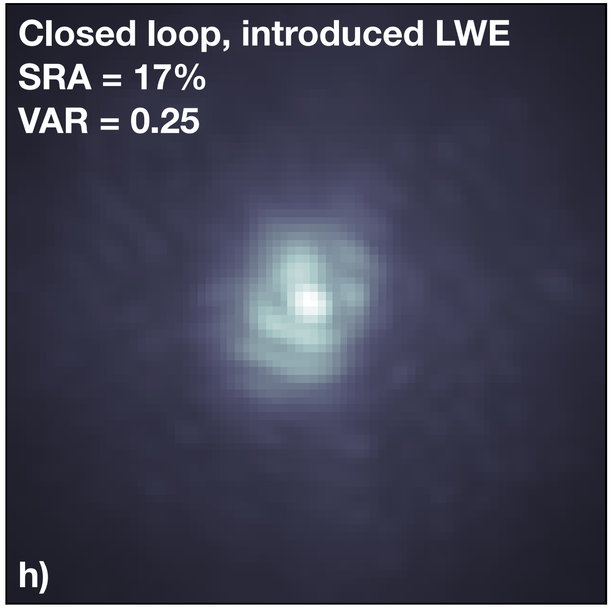




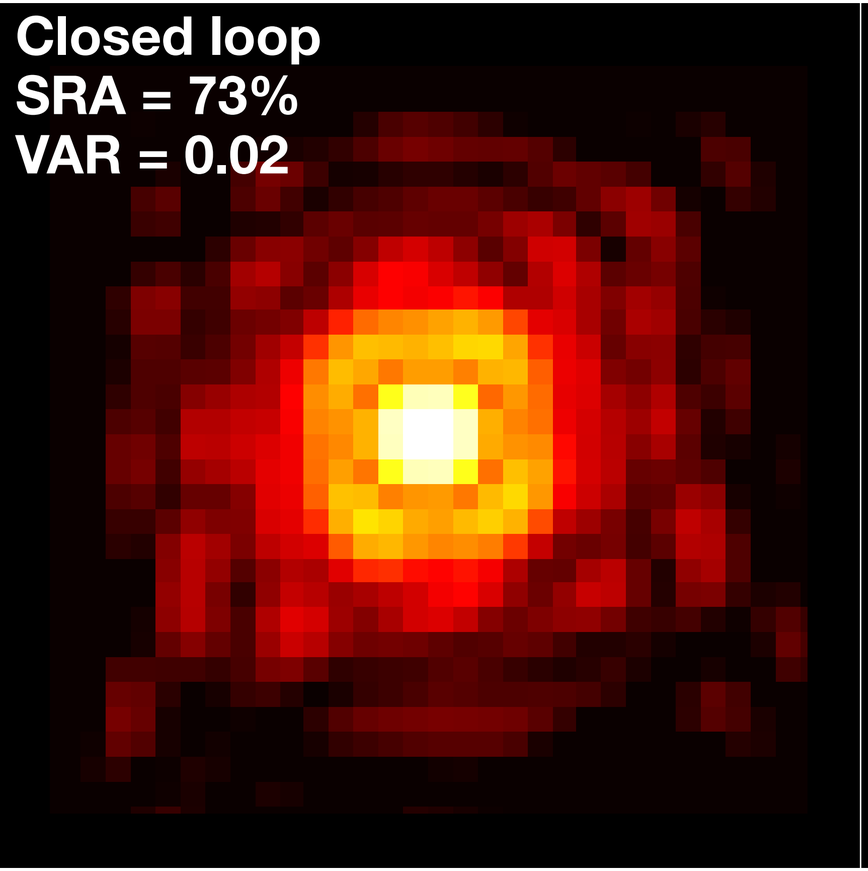


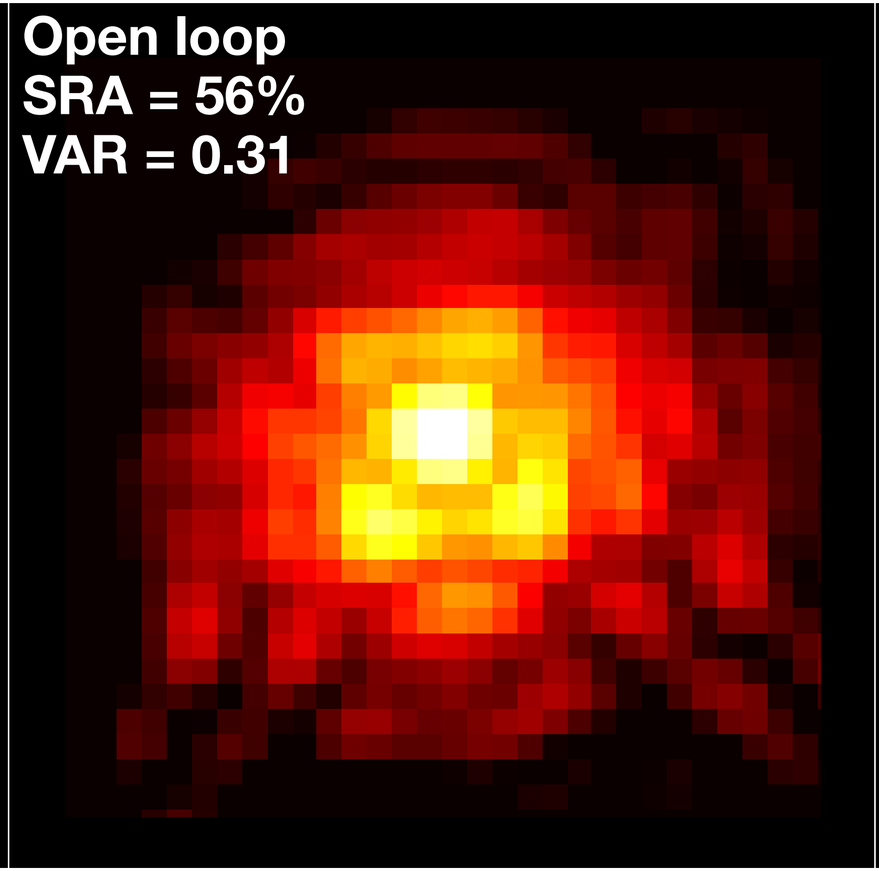


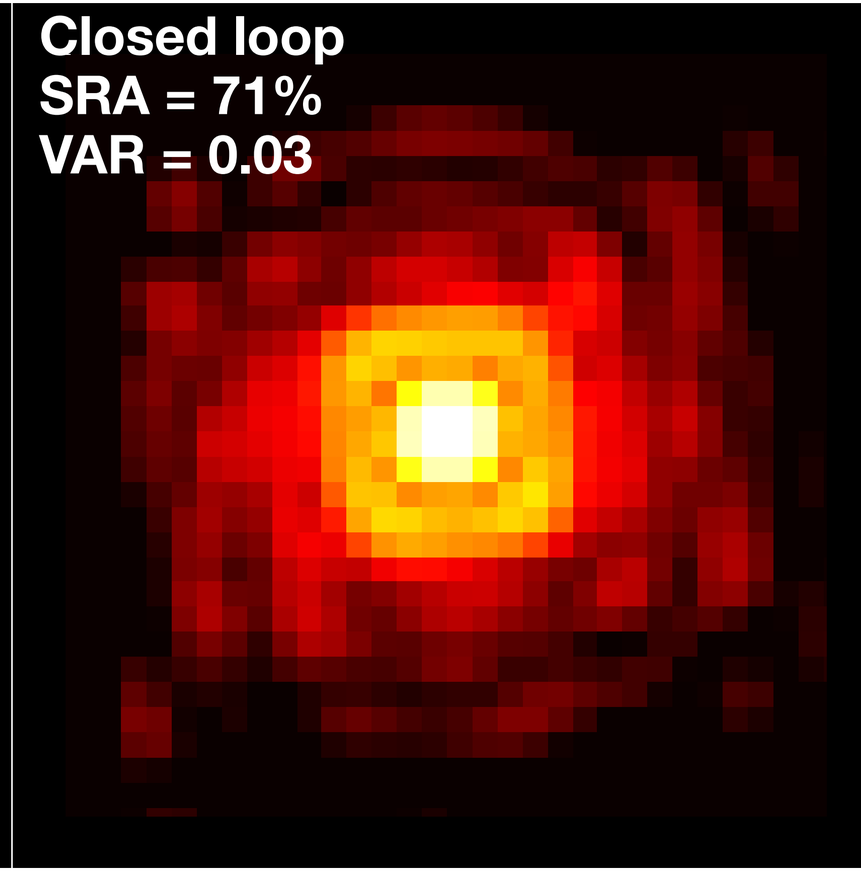




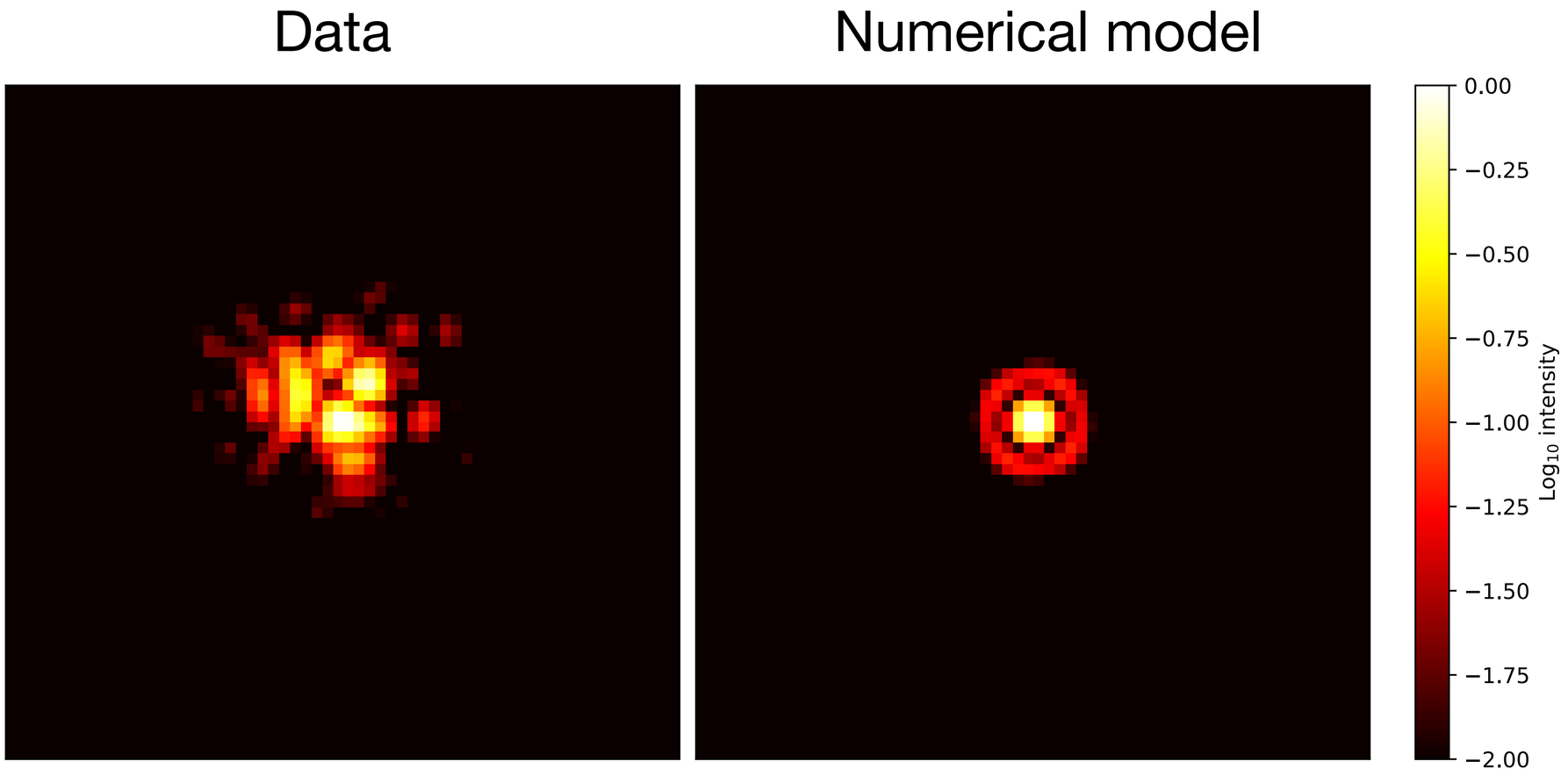
On-sky results: Good conditions



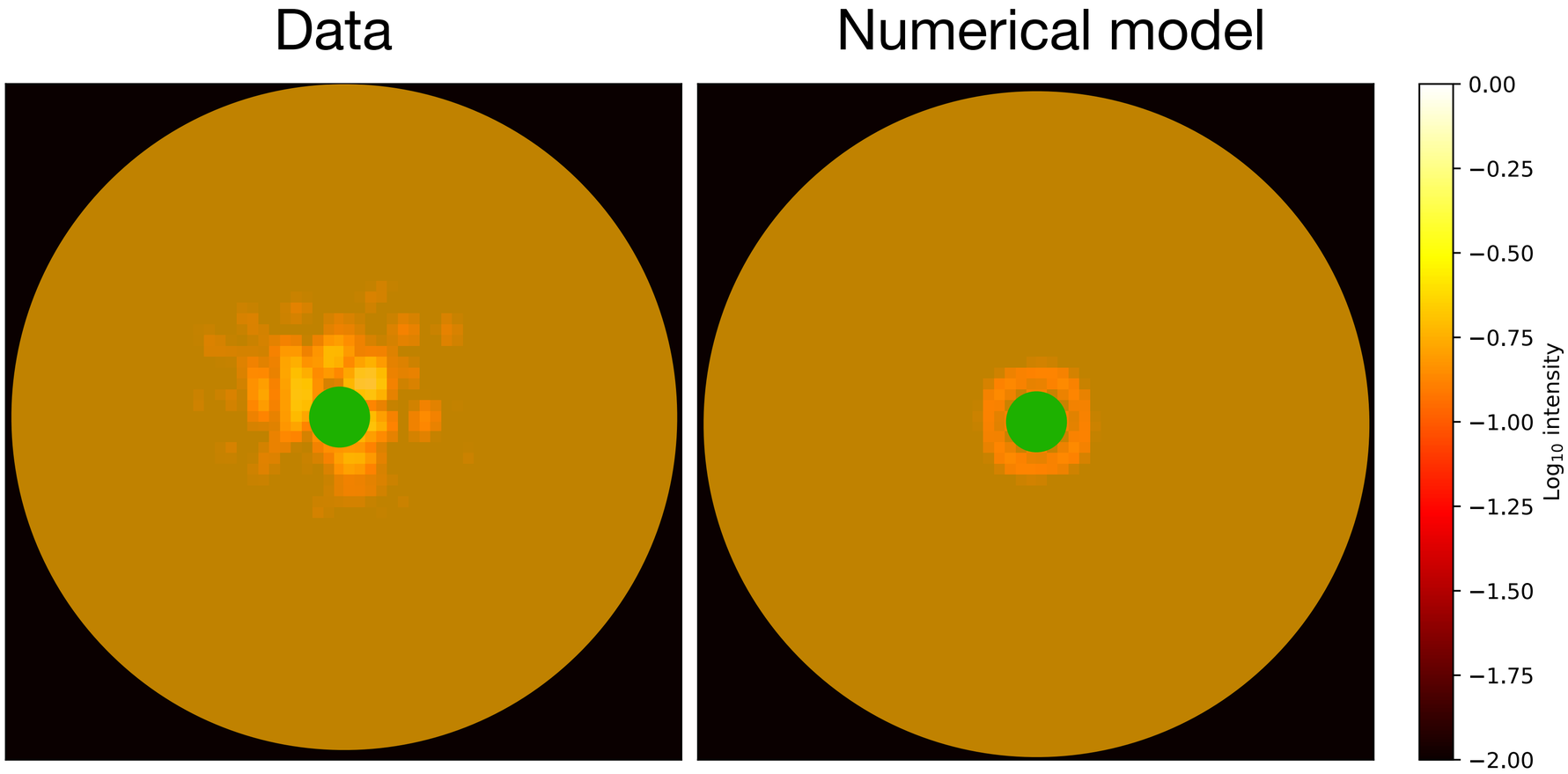




Performance metrics



Performance metrics

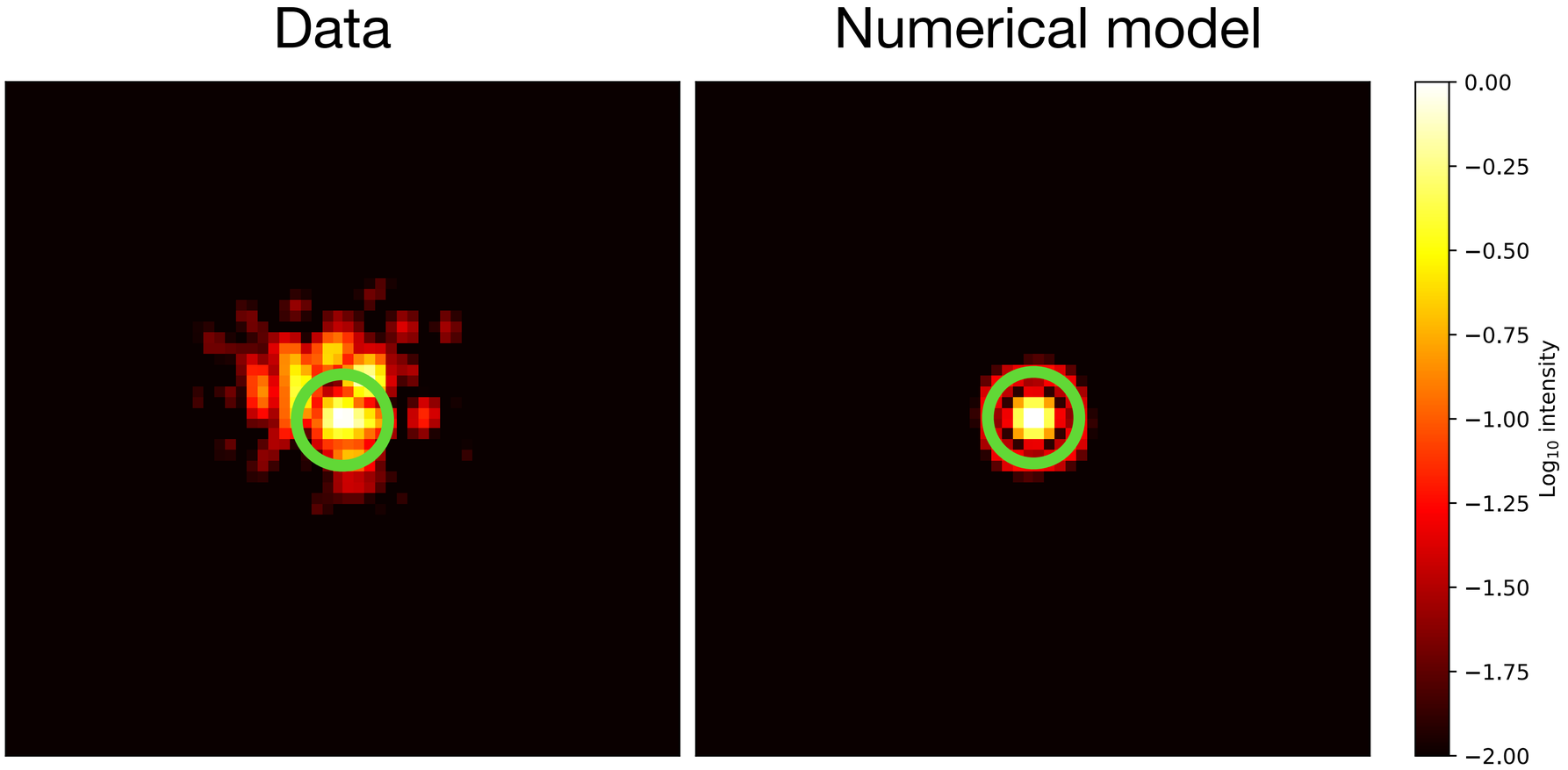


- Strehl Ratio Approximation **(SRA)**

$$\mathrm{SRA} = \frac{\sum \mathrm{Data}(\bullet) / \sum \mathrm{Data}(\bullet)}{\sum \mathrm{Model}(\bullet) / \sum \mathrm{Model}(\bullet)}$$

Typical internal source: SRA ~ 0.94

Performance metrics

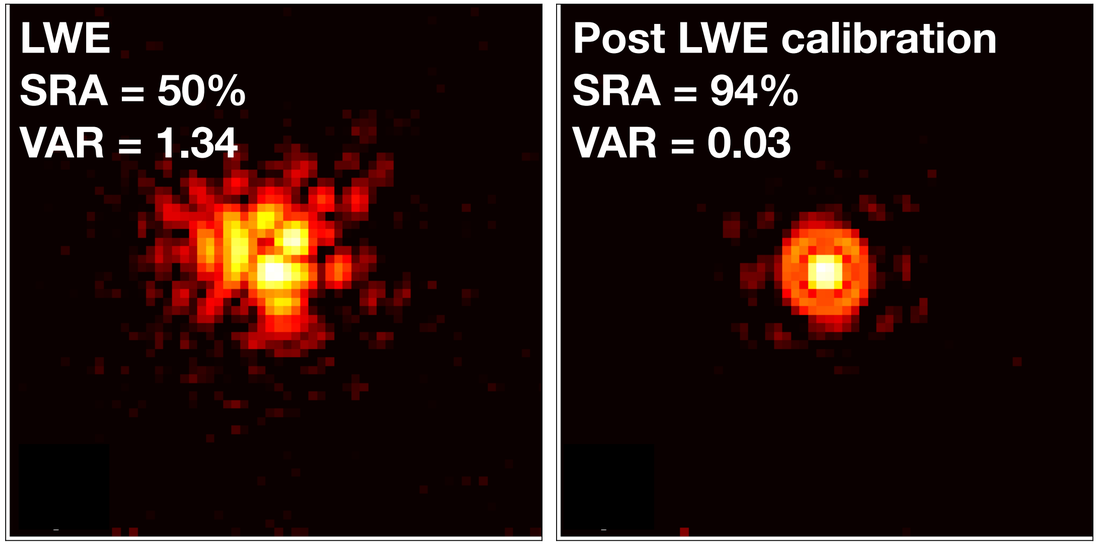


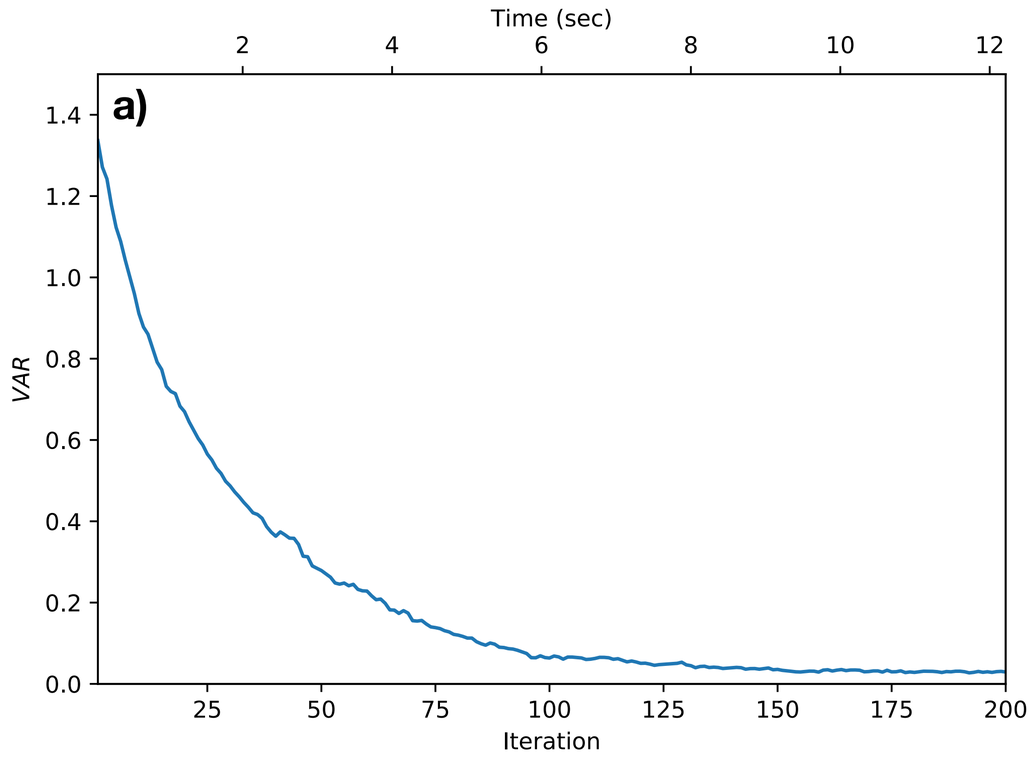
- Strehl Ratio Approximation **(SRA)**
- Variance of the normalized first Airy Ring **(VAR)**

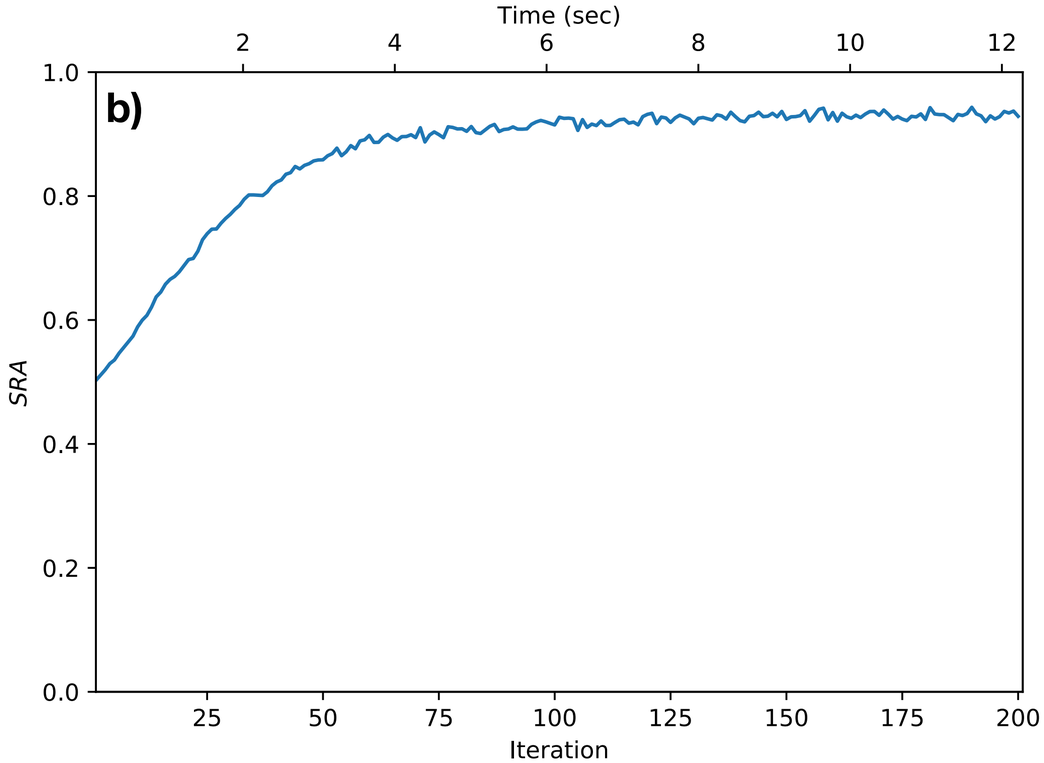
$$\mathrm{Var} = \mathrm{Variance}\left\{ \frac{\mathrm{Data}(\bigcirc)/\langle \mathrm{Data}(\bigcirc)\rangle}{\mathrm{Model}(\bigcirc)/\langle \mathrm{Model}(\bigcirc)\rangle} \right\}$$

Typical internal source: VAR ~ 0.03

F&F convergence speed

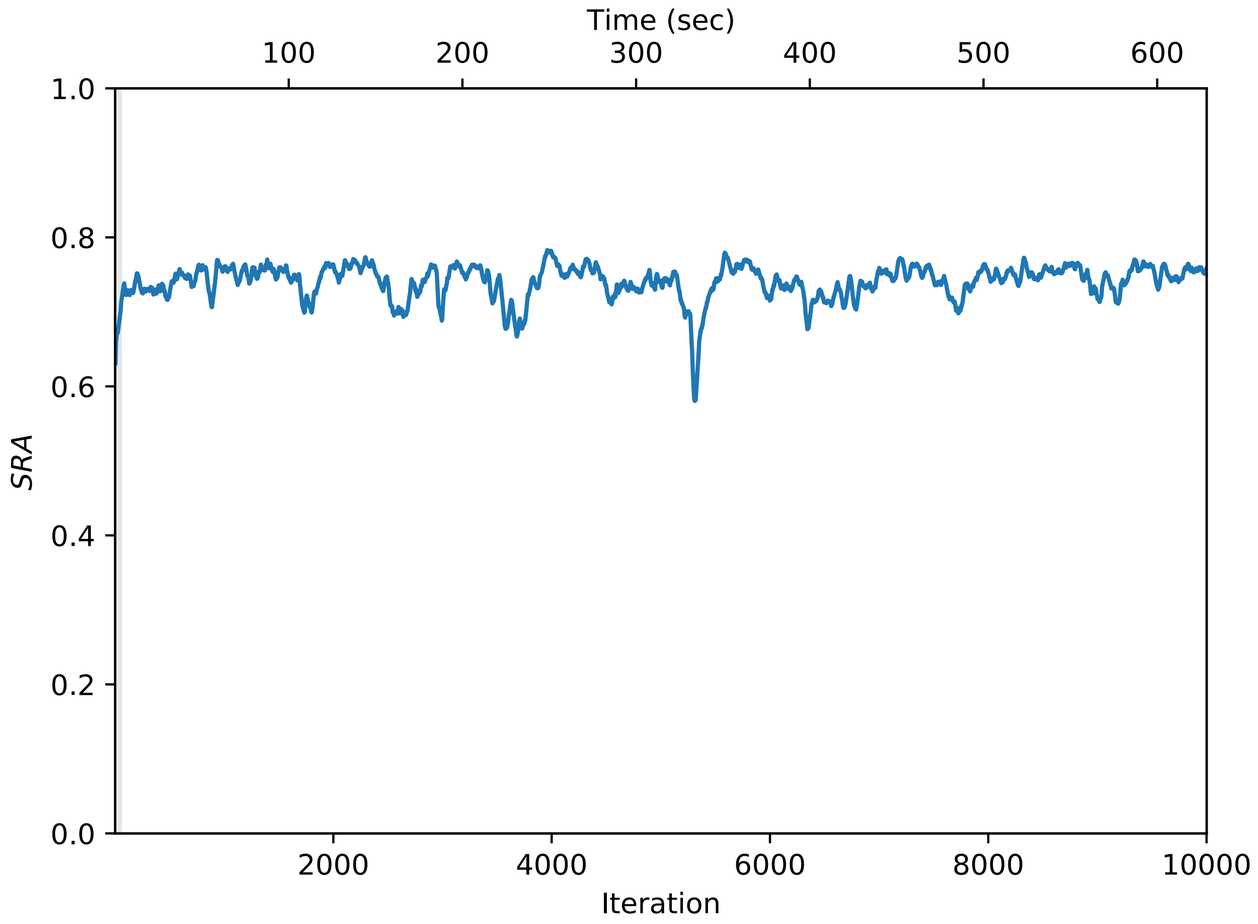


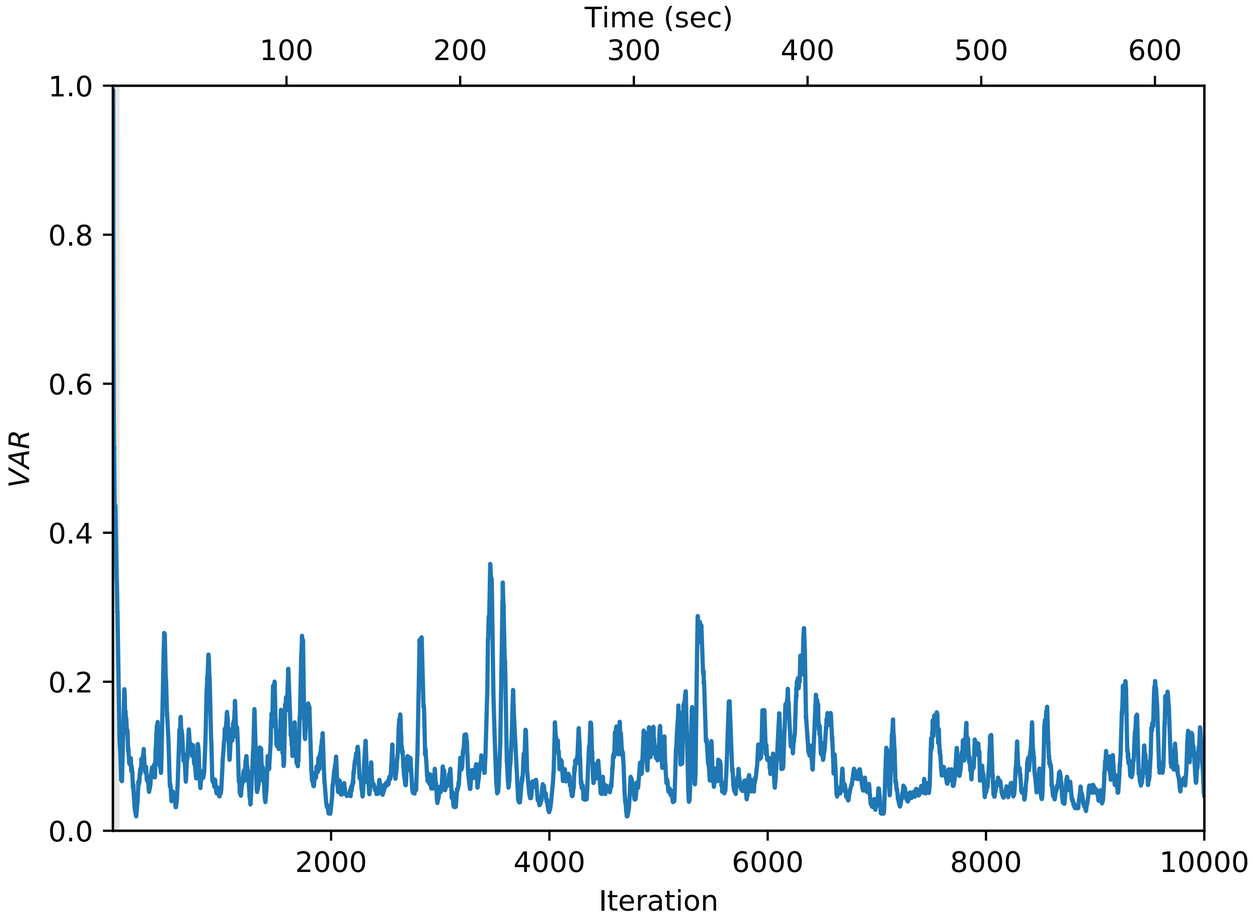




Temporal stability

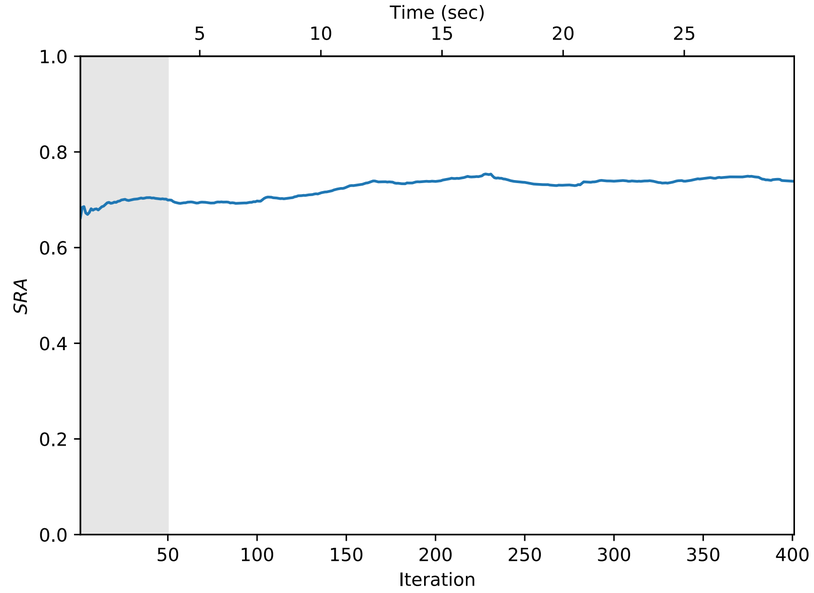
F&F 10 minutes run

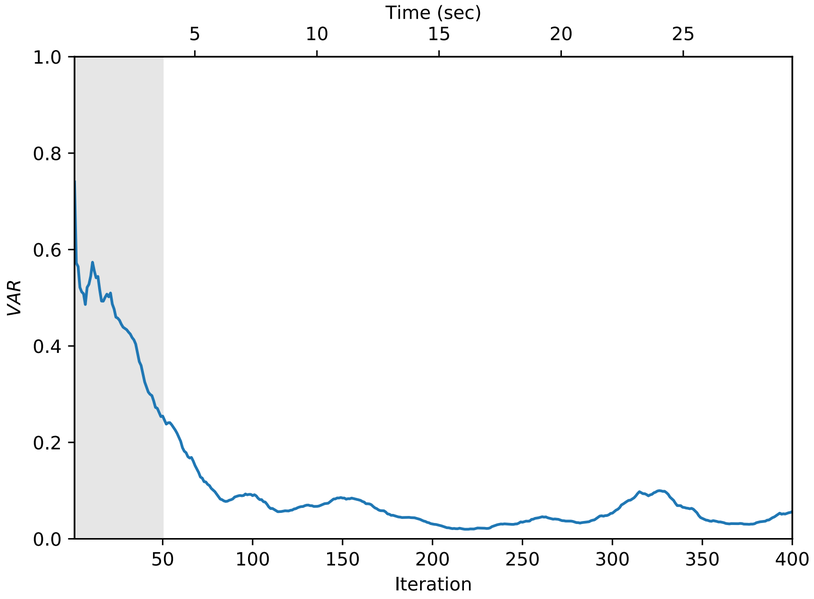




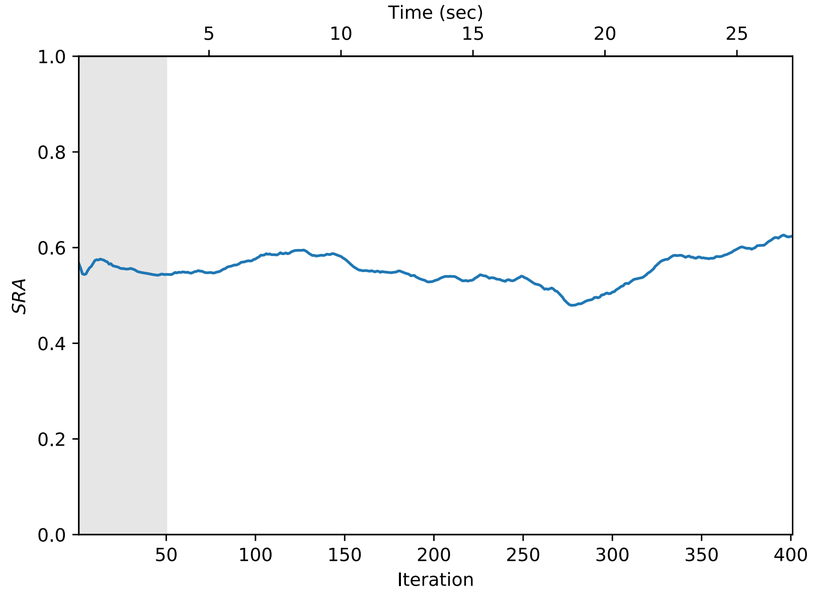
Temporal stability - Good conditions

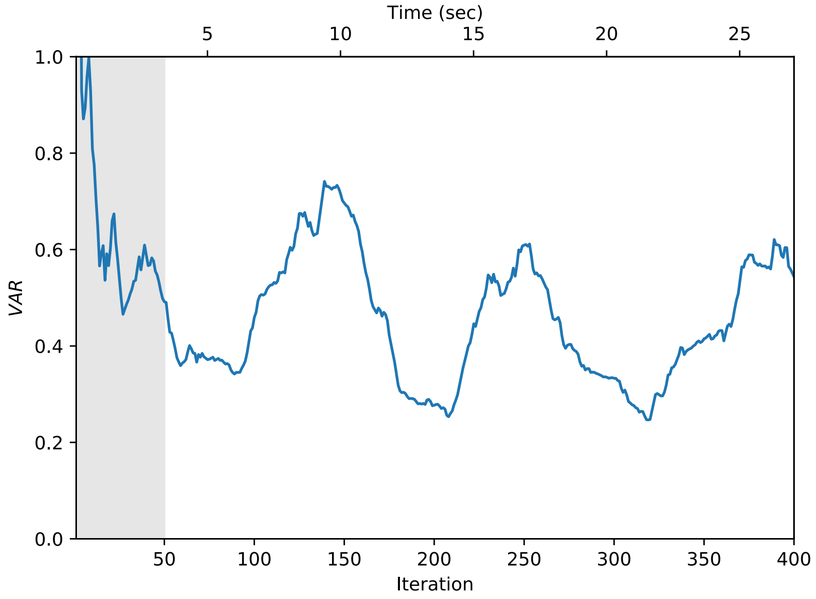
Closed loop



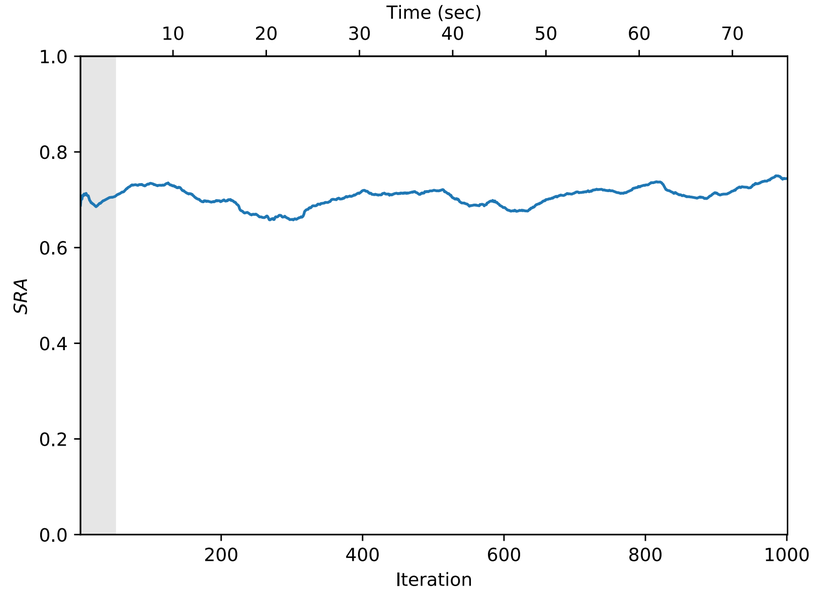


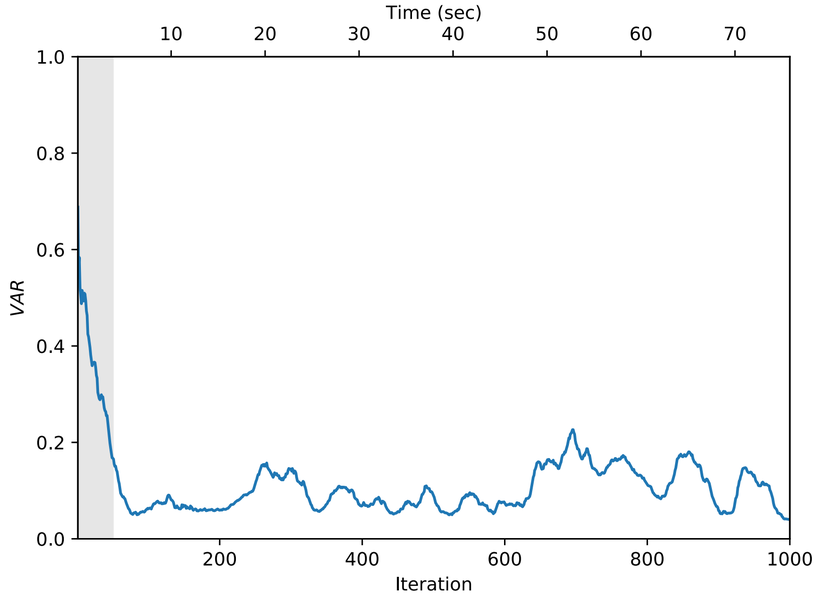
Open loop

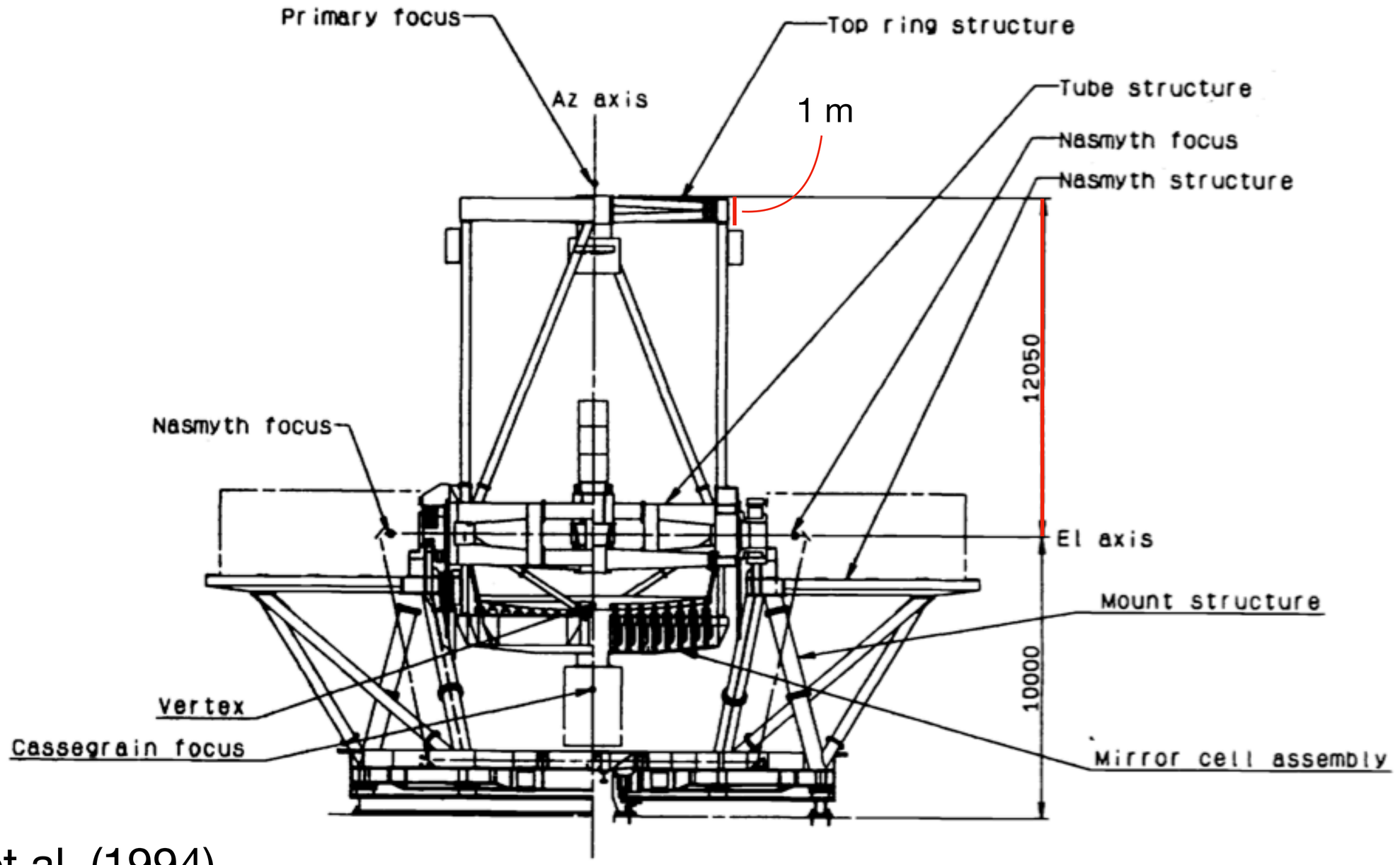




Closed loop







Miyawaki et al. (1994)