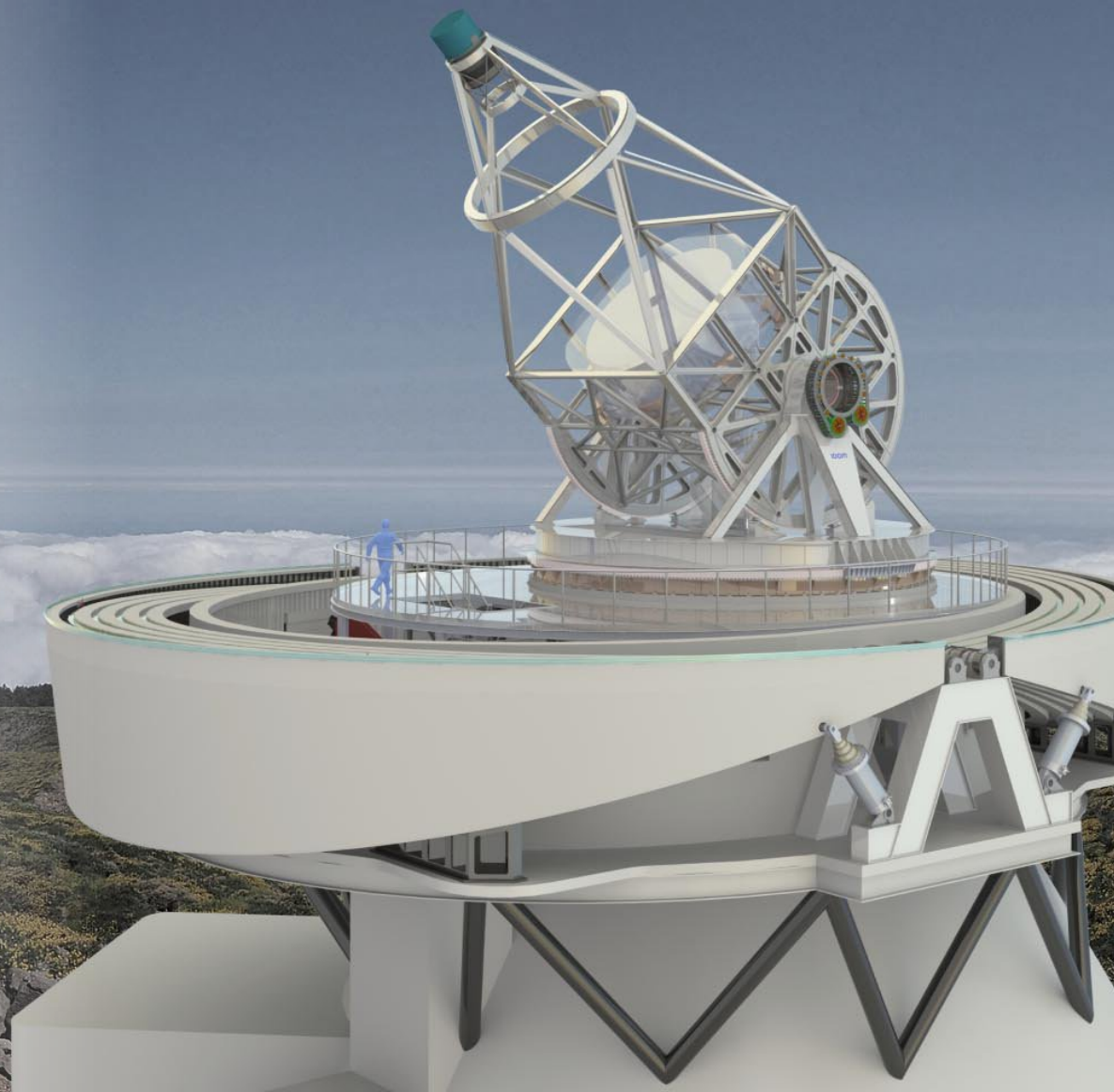
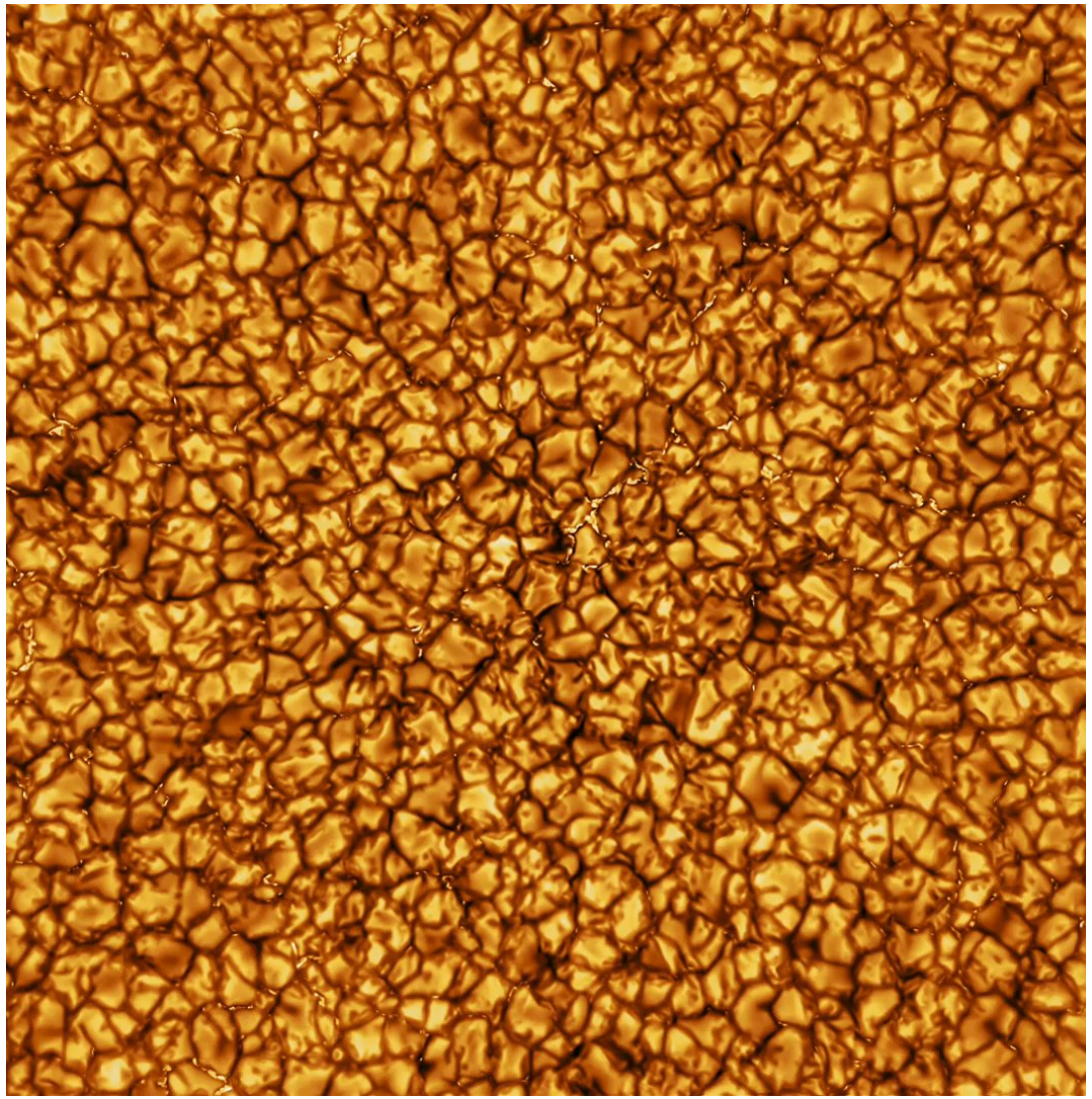
Deep learning image burst stacking to reconstruct high resolution ground-based solar observations



Christoph Schirninger

Motivation

- 4 m solar telescopes:
  - Daniel K. Inouye Solar Telescope (DKIST)
  - European Solar Telescope (EST)
- Impact on Earth
- Solar variability
  - Sun varies on a wide range of spatial and temporal scales
- Connection to other stars



DKIST observation, Dec. 10, 2019, at 705 nm

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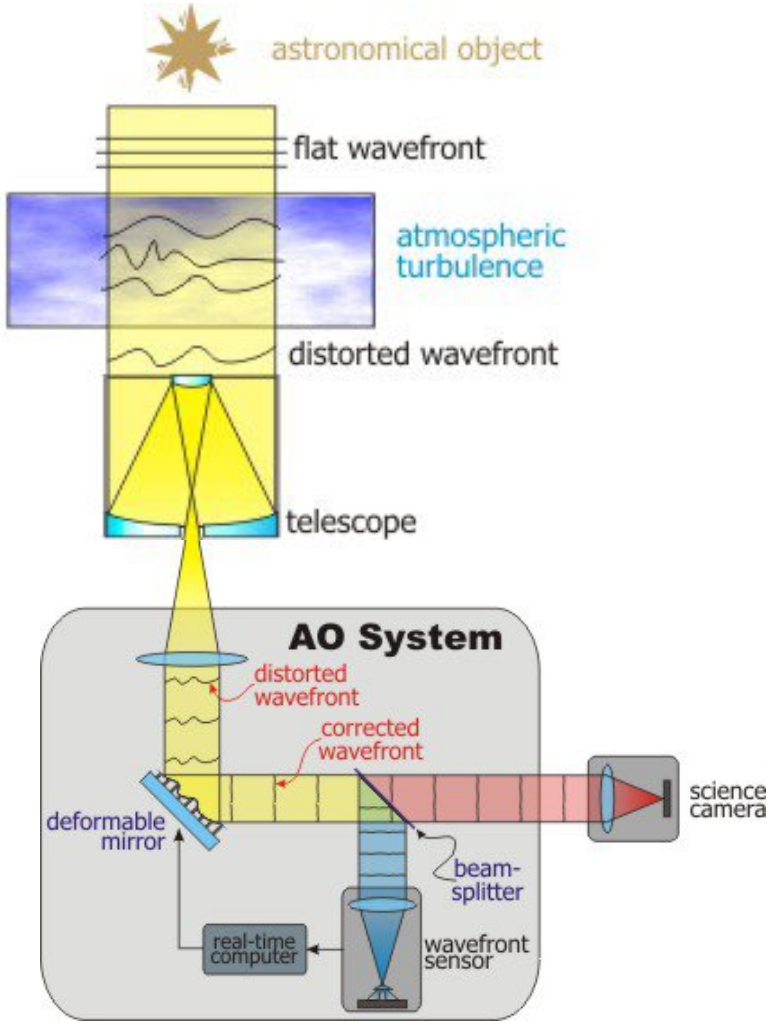
Not diffraction limited but seeing limited!

DKIST observation, Dec. 10, 2019, at 705 nm

Astronomical seeing



Credit: *Vik Dhillon,* astronomical techniques

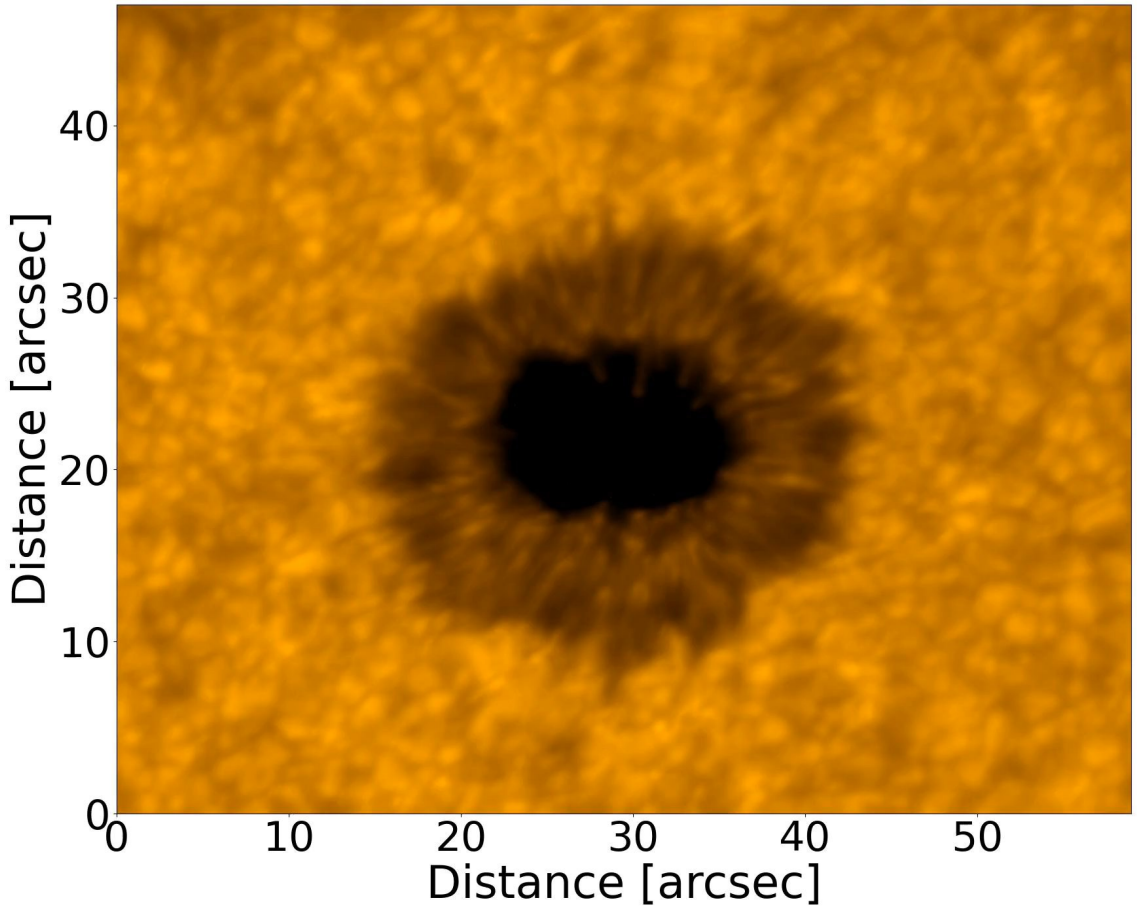
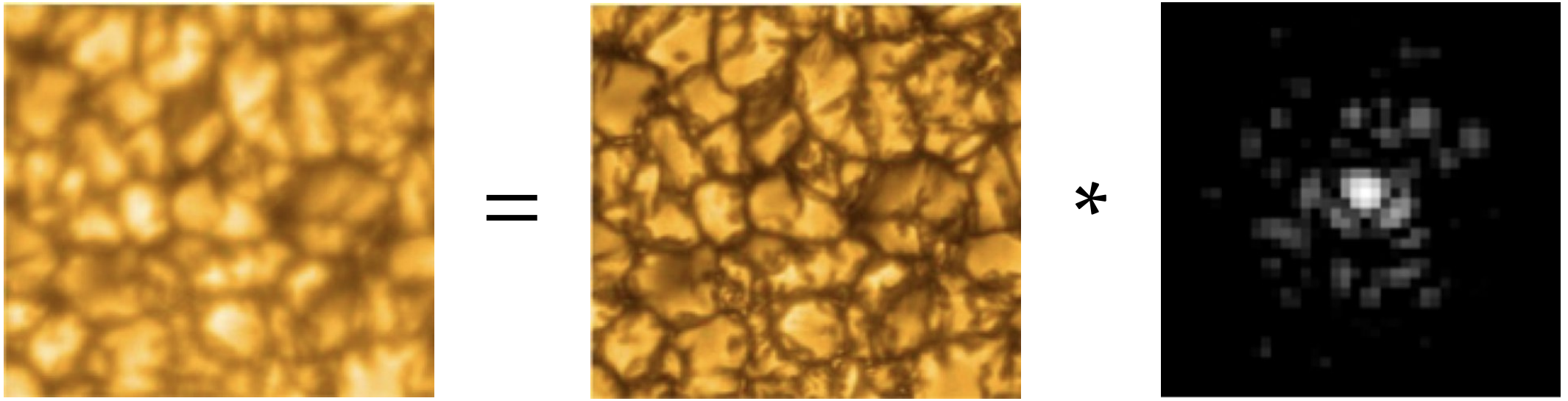


Image burst from the 1.5 m GREGOR telescope

Problem setting

$I_n(x)$ $O(x)$ $P_n(x)$



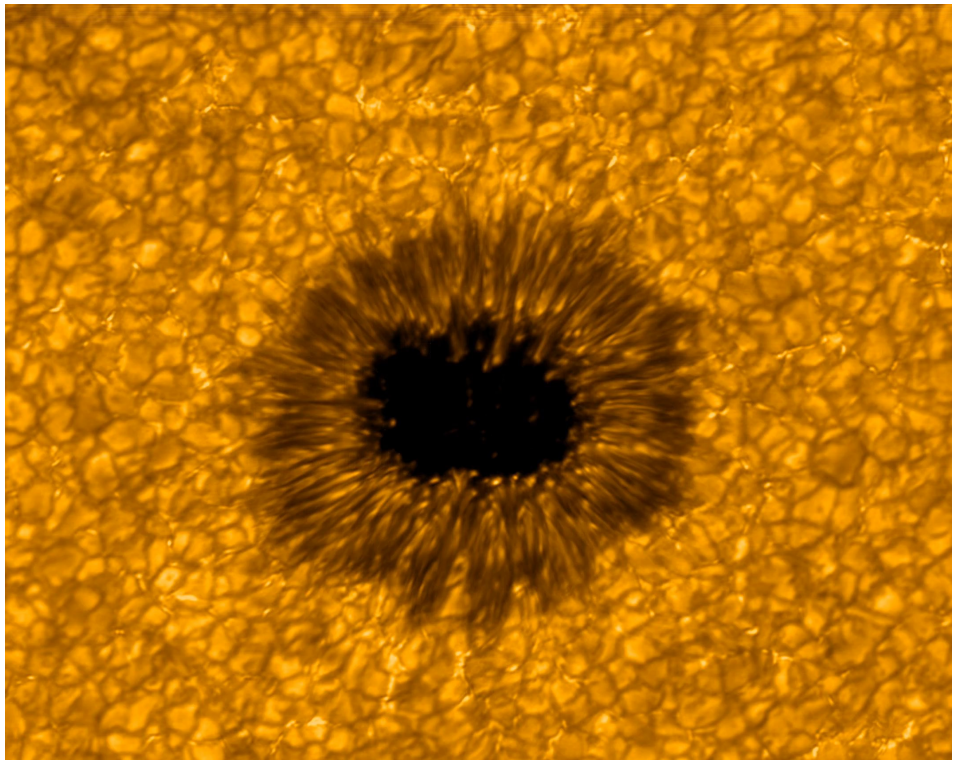
$I_n(x)$ ...original frame n
$O(x)$ ... real object
$P_n(x)$ ...point spread function

Image reconstruction methods

- Multi Frame Blind Deconvolution (MFBD)
- Multi Object Multi Frame Blind Deconvolution (MOMFBD)
- Speckle reconstruction

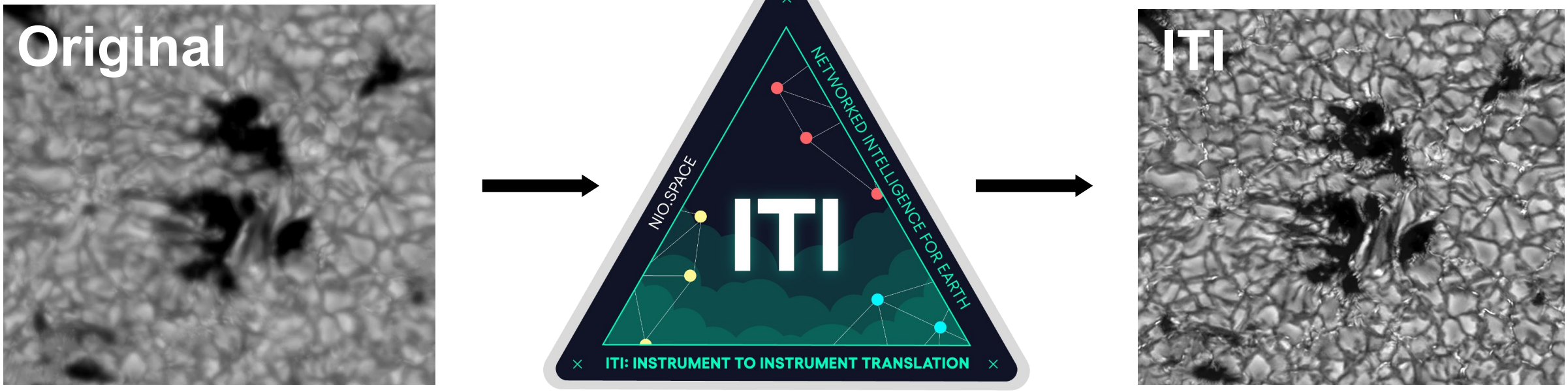
Shortcomings:

- Computational expensive
- Limited in its success

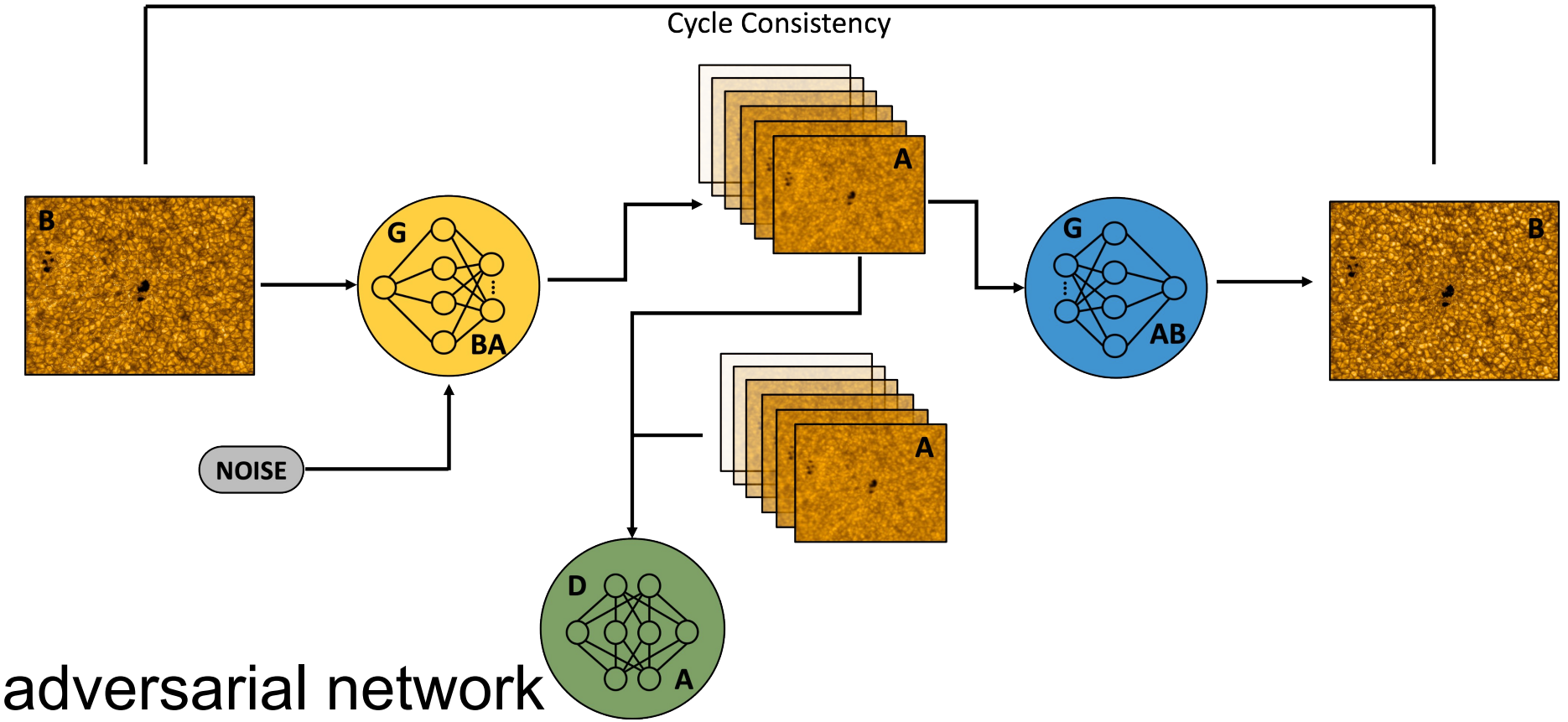


Speckle reconstruction from the 1.5 m GREGOR telescope

Image-to-Image (ITI) translation



ITI training cycle



- Generative adversarial network
- Unpaired image-to-image
- Loss: Reconstruction Loss + Adversarial Loss

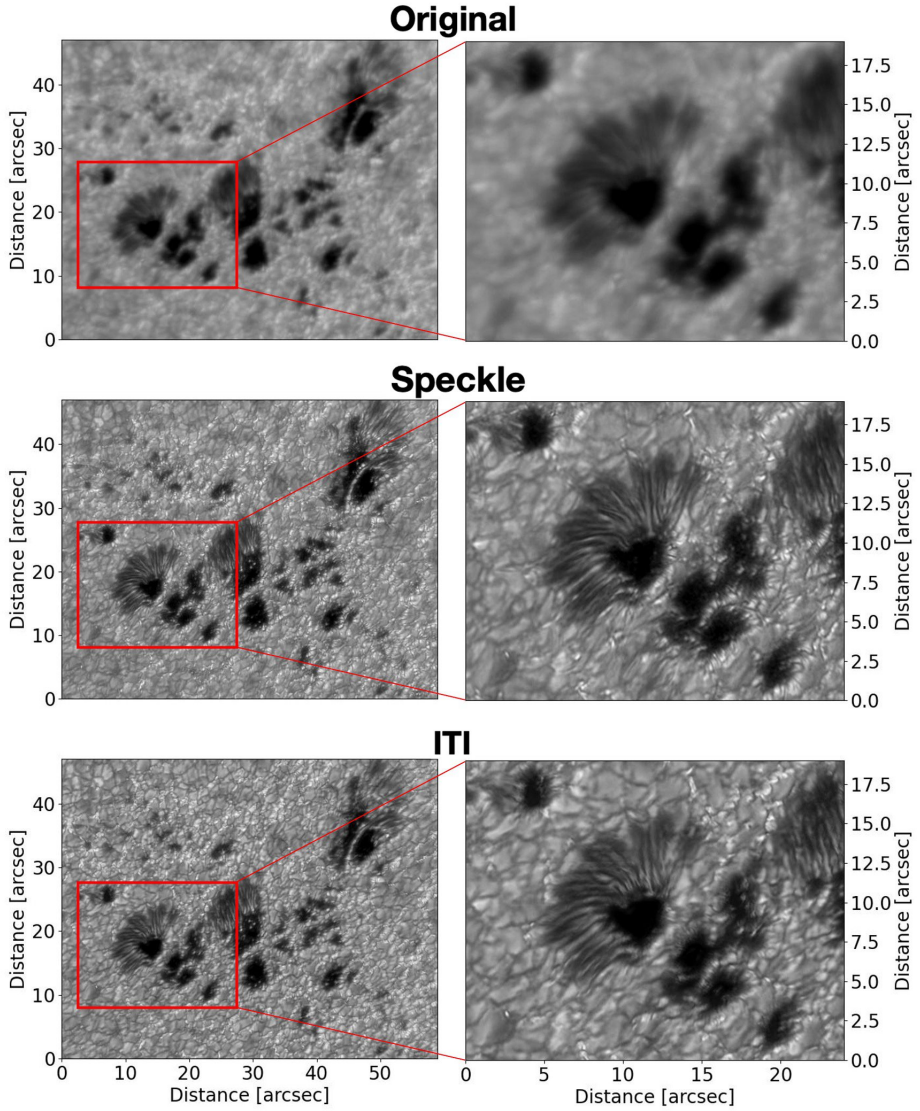
Dataset

	# Original image bursts	# Speckle reconstructions
G-Band	1078	745
Blue Continuum	960	392

- 1.5 m GREGOR telescope
- Unpaired image-to-image translation

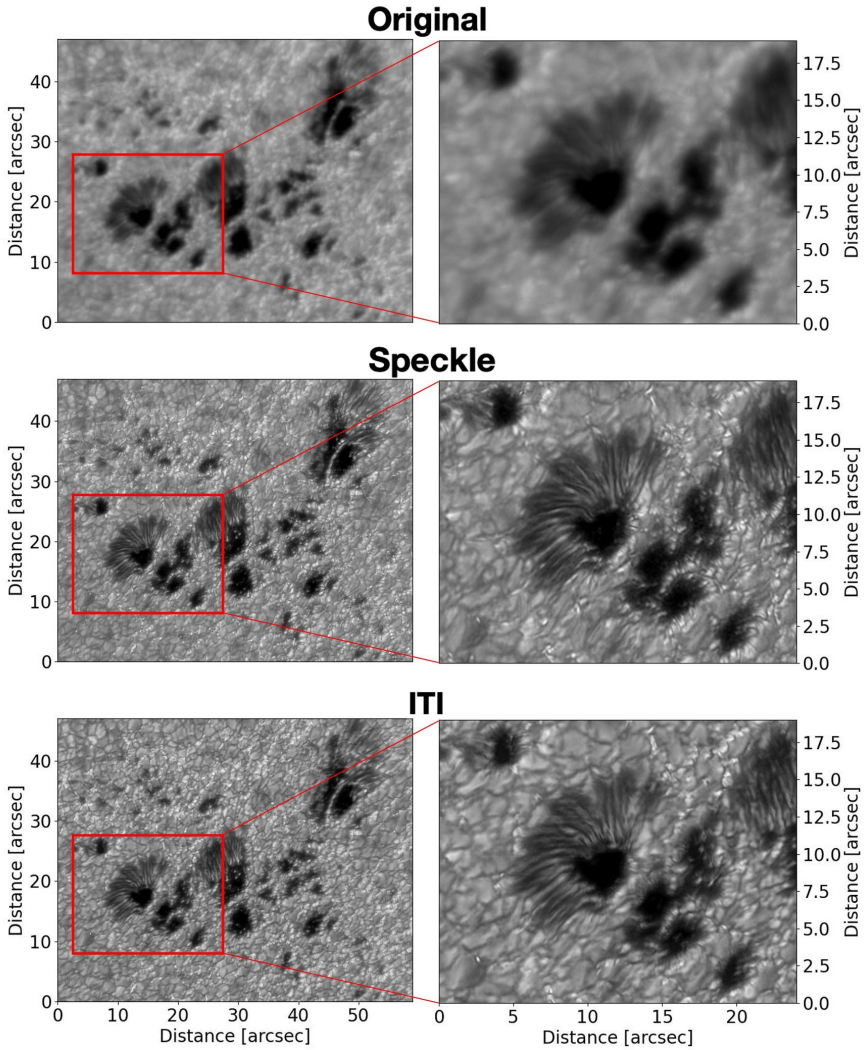
  Enlarges dataset by: ~ 44 % for G-Band
  ~145 % for Blue continuum

Results: G-Band (430.7 nm)



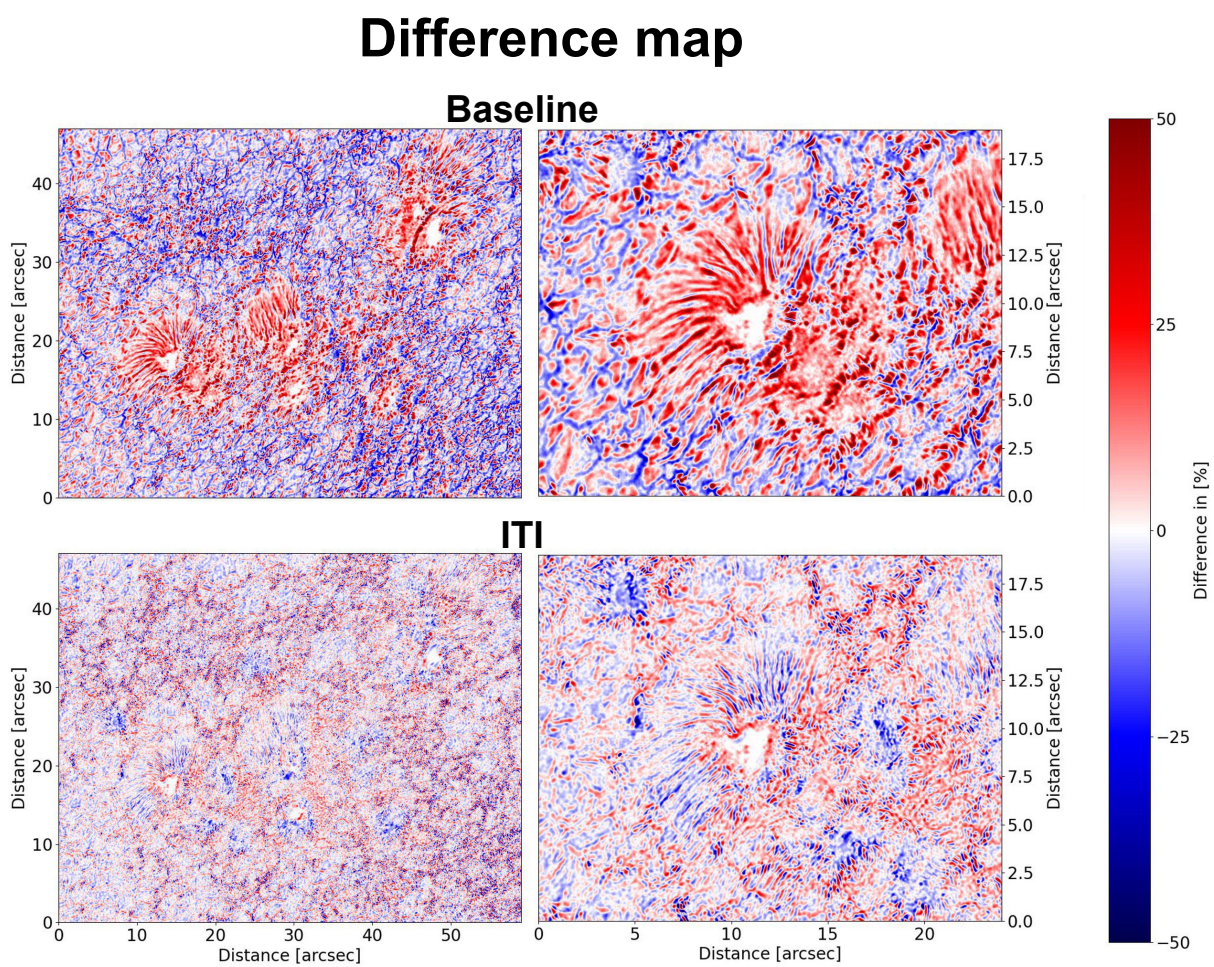
- Single frame of original burst
- Speckle reconstruction
- ITI reconstruction

Results: G-Band (430.7 nm)

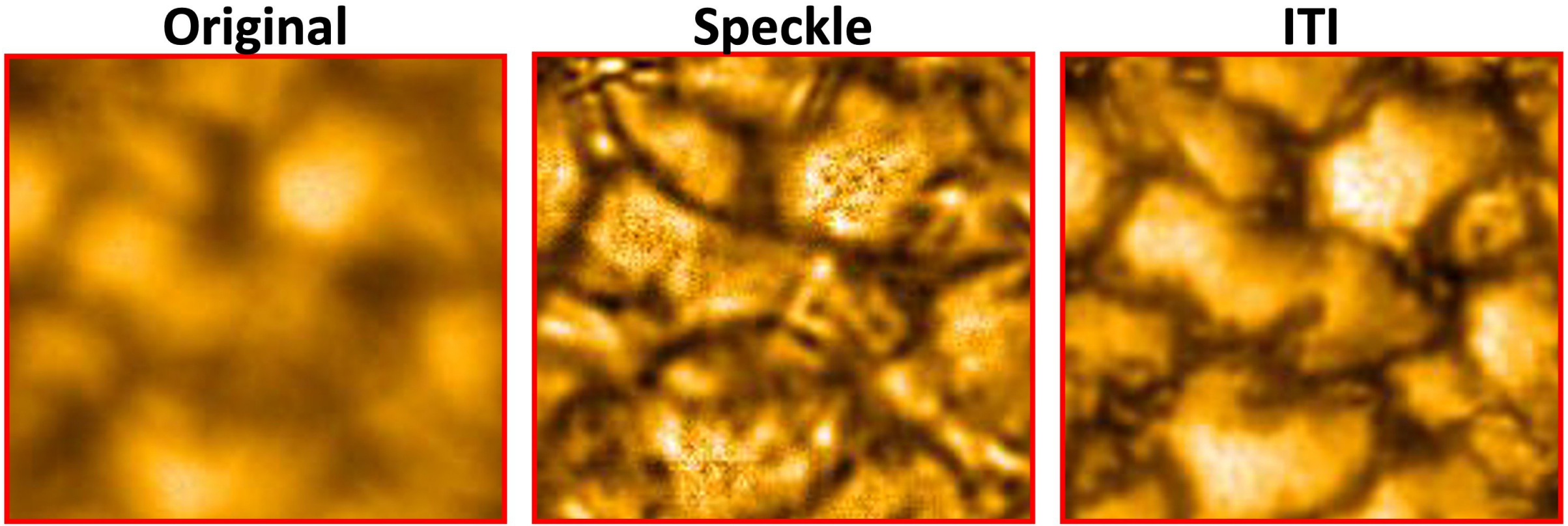


Original - Speckle

ITI - Speckle



Handling speckle artifacts



Left: Single frame of original burst. Center: Speckle reconstruction showing artifacts. Right: ITI reconstruction

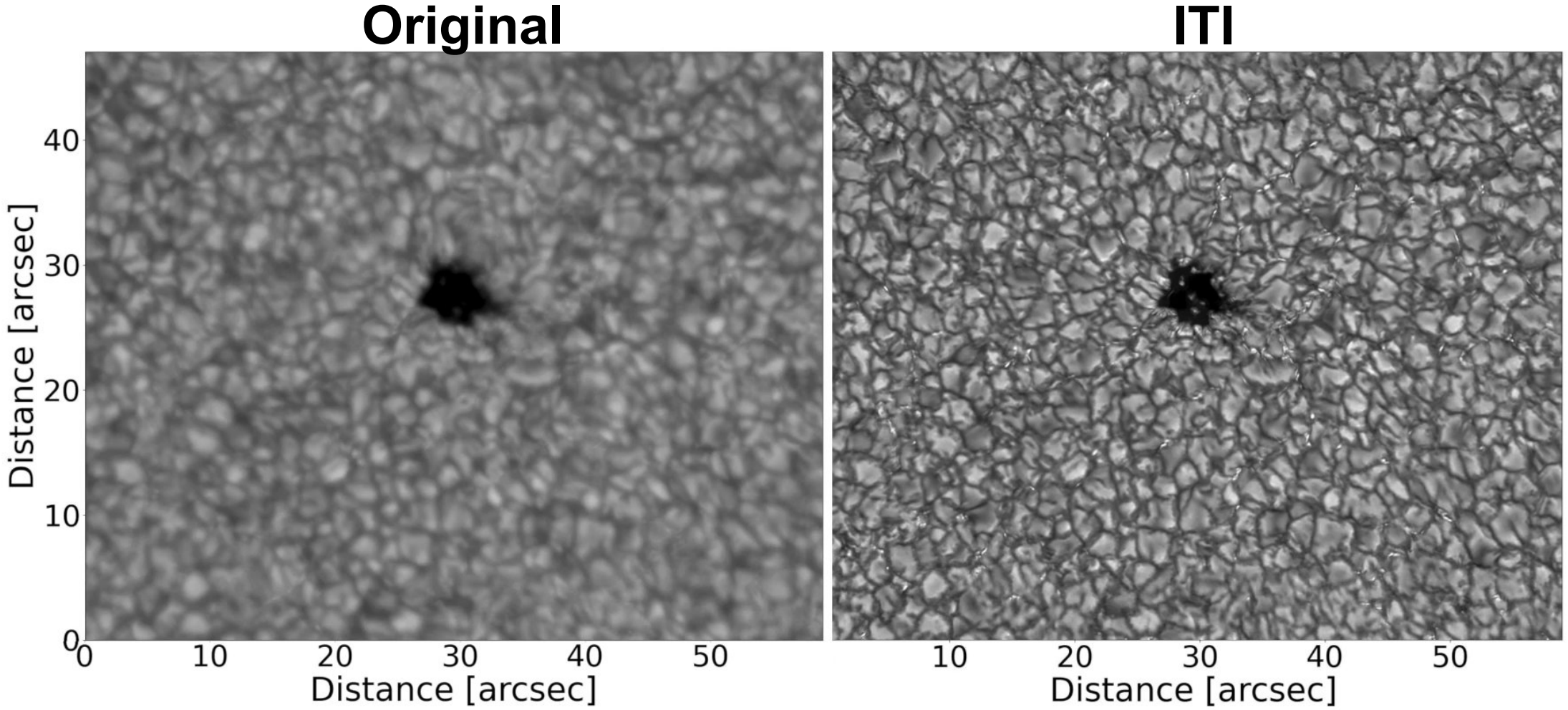
Quality metrics

	PSNR ↑		SSIM ↑		MAE ↓		FID ↓	
	Baseline	ITI	Baseline	ITI	Baseline	ITI	Baseline	ITI
GBand	15.27	**19.49**	0.35	**0.63**	0.14	**0.07**	38.08	**14.16**
Blue Continuum	13.58	**16.74**	0.27	**0.47**	0.18	**0.12**	55.79	**11.83**

- PSNR: Peak signal to noise ratio
- SSIM: Structural similarity index measure
- MAE: Mean absolute error
- FID: Fréchet inception distance

Baseline:
Single frame of original burst – speckle reconstruction

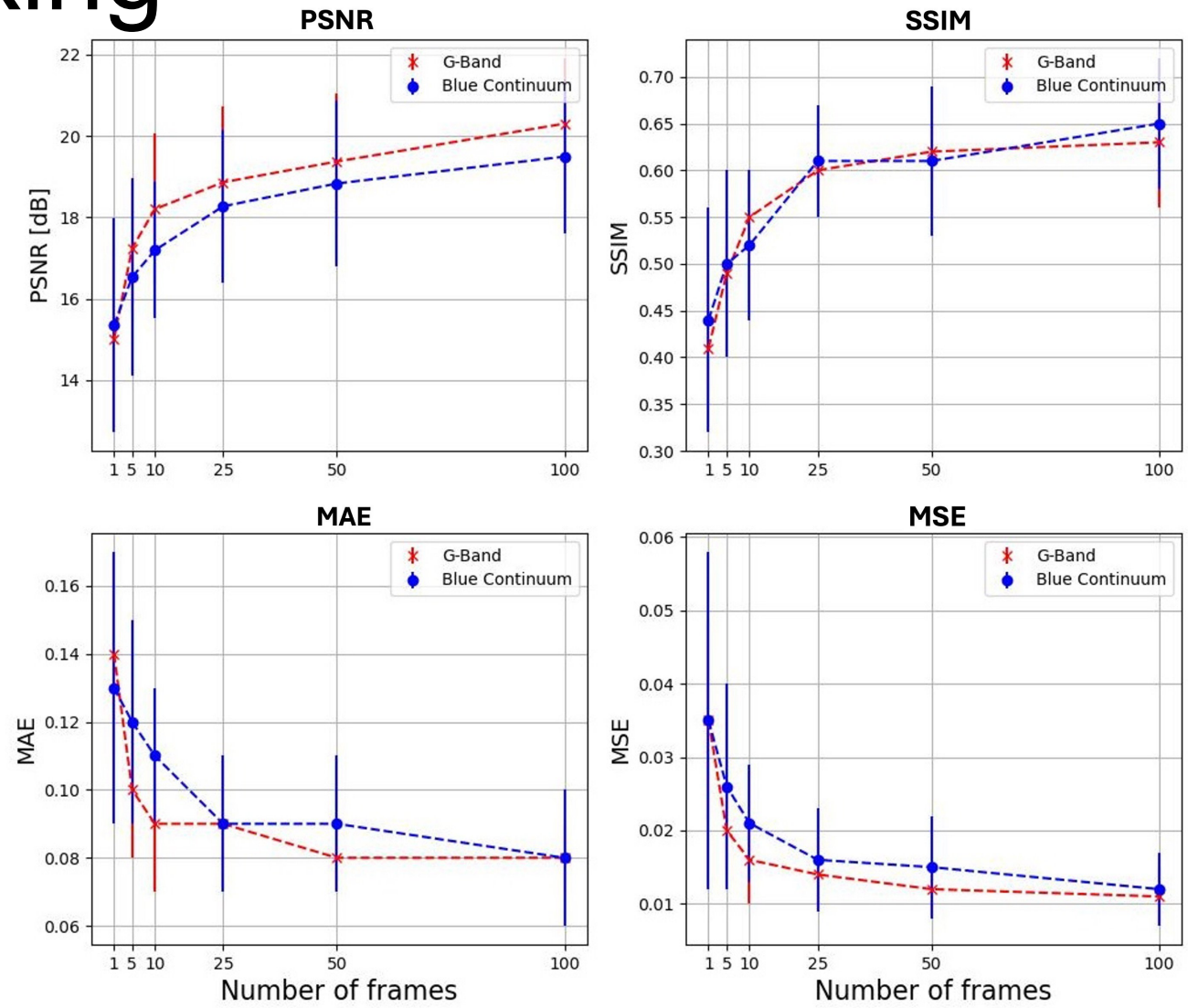
Time series reconstruction



G-Band observation series from 2023-04-24 08:00:31 to 08:19:56

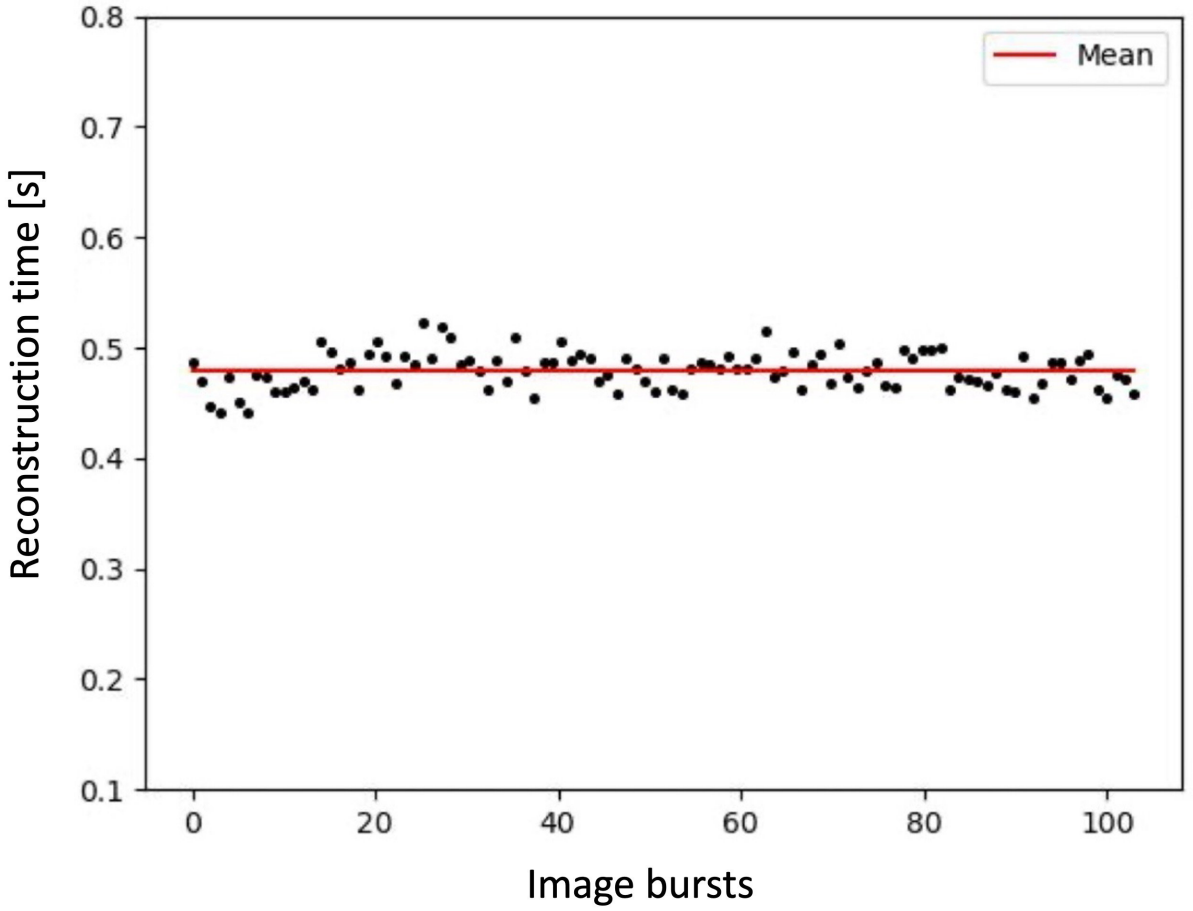
Image burst stacking

- **Where is the additional spatial information coming from?**
- Quality increase with increasing number of frames
- Best quality using the entire image burst of 100 frames



Translation time

- Real time image reconstructions
  - < 0.5 s on a NVIDIA A100 GPU
  - ~ 3.5 s on an AMD CPU



Reconstruction time on a NVIDIA A100 GPU

Conclusion

- ITI reconstructions in **real-time**
- Information stacking for realistic reconstructions
- Mores robust reconstructions

- Apply to DKIST and EST