Missed Debris Disks in the HST archive

An insight of the ALICE project

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The ALICE group at STScI:

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April 7th 2016

Star and Planet Formation:

The process

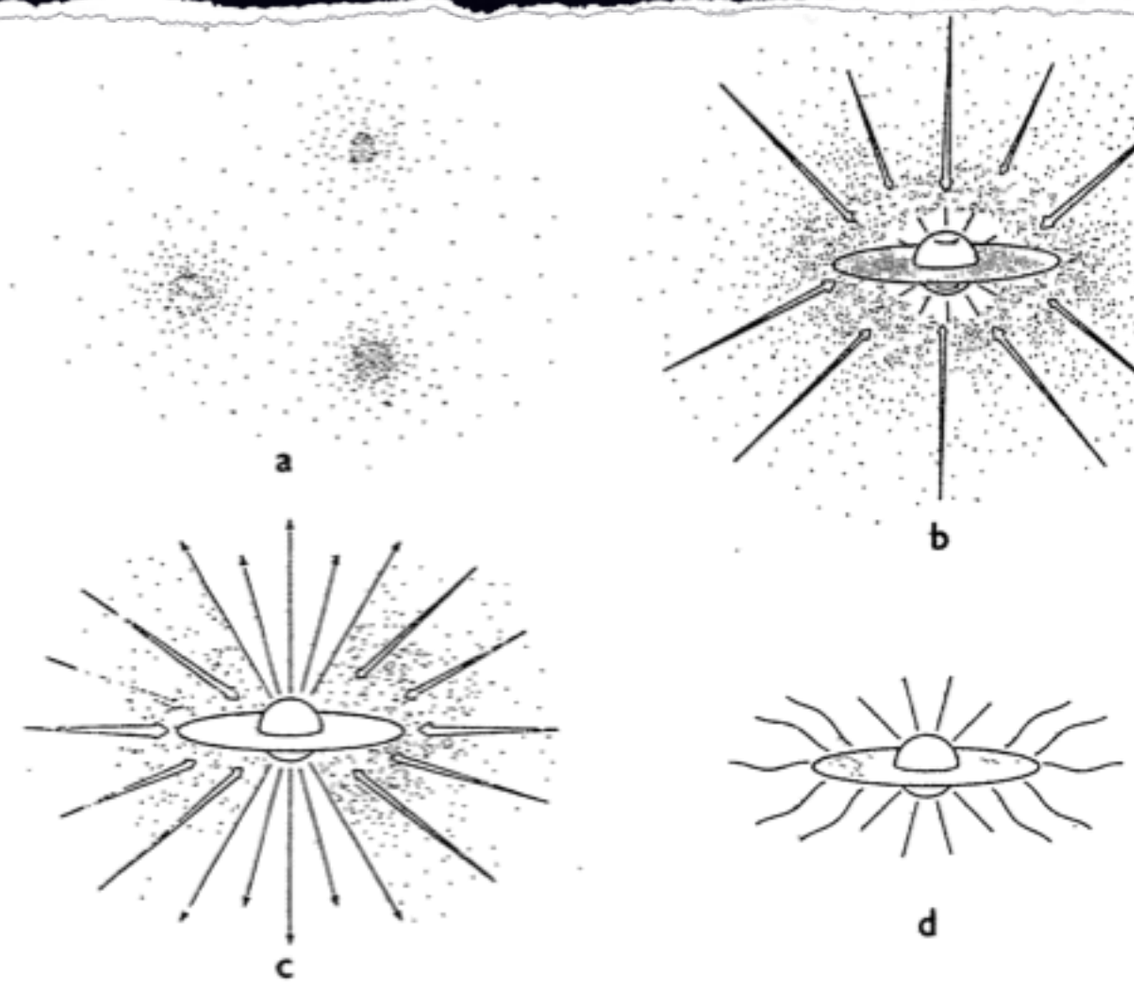


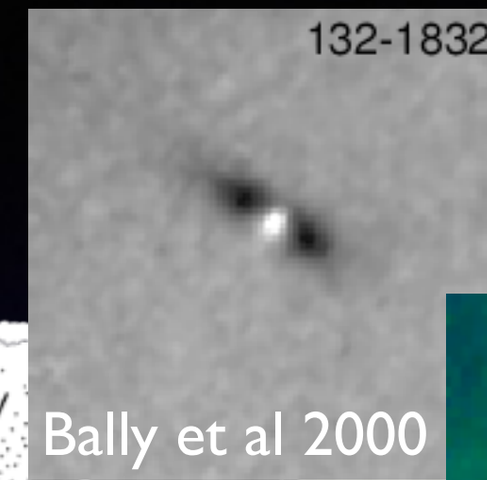
Figure 7 The four stages of star formation. (*a*) Cores form within molecular clouds as magnetic and turbulent support is lost through ambipolar diffusion. (*b*) A protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (*c*) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (*d*) The infall terminates, revealing a newly formed star with a circumstellar disk.

Shu et al. 1987

Star and Planet Formation:

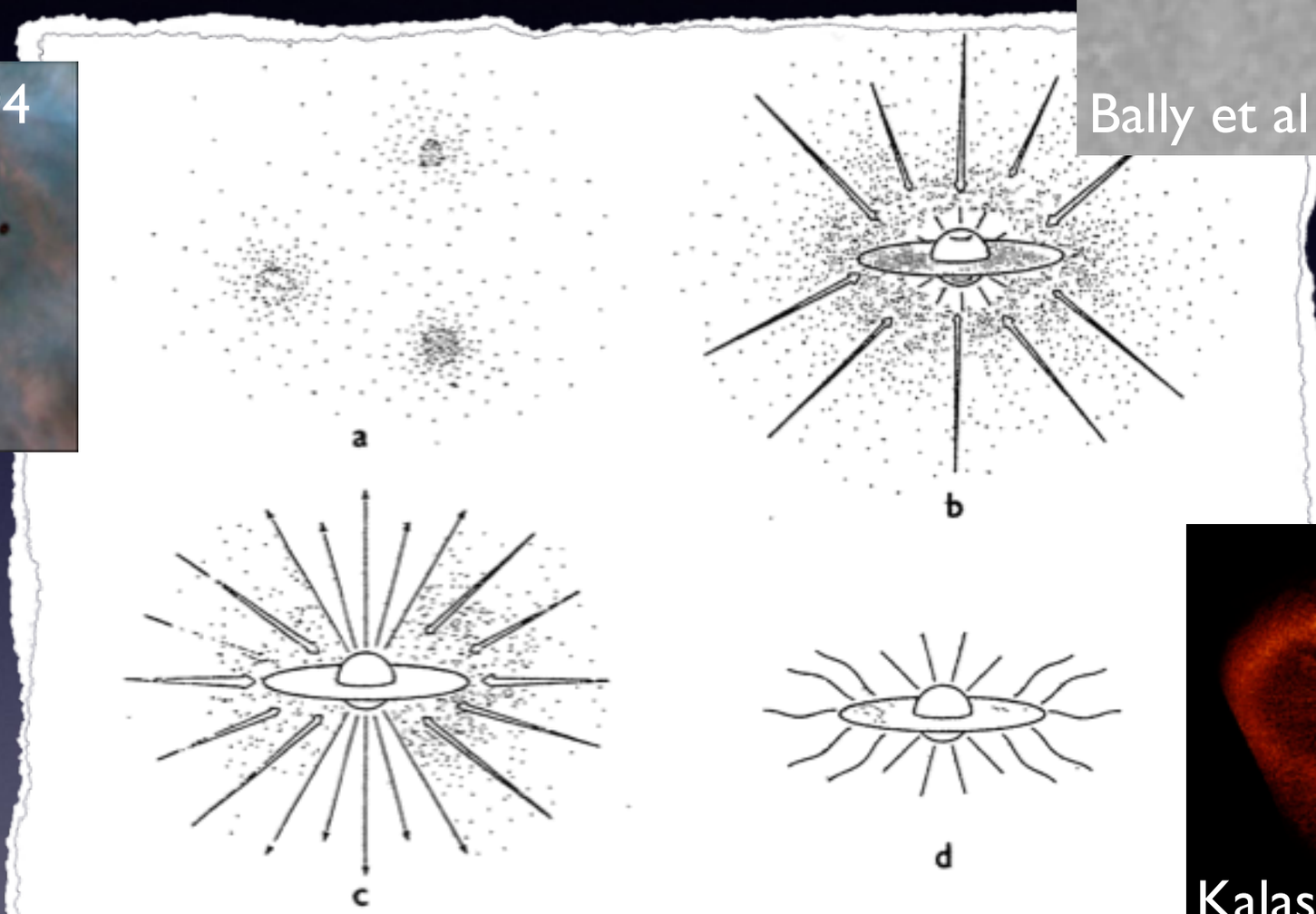
The process

O'Dell & Wen, 1994



Bally et al 2000

Ricci et al. 2008



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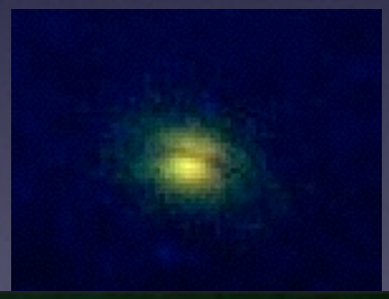
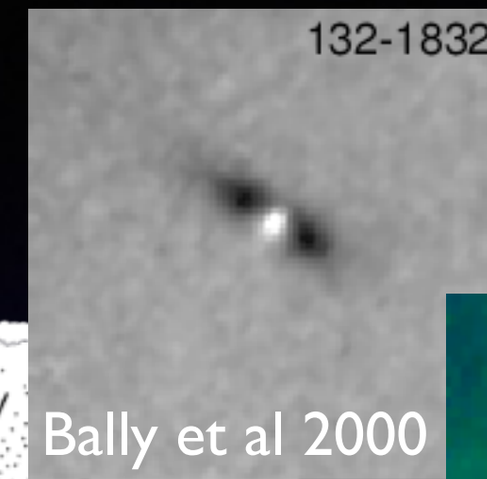


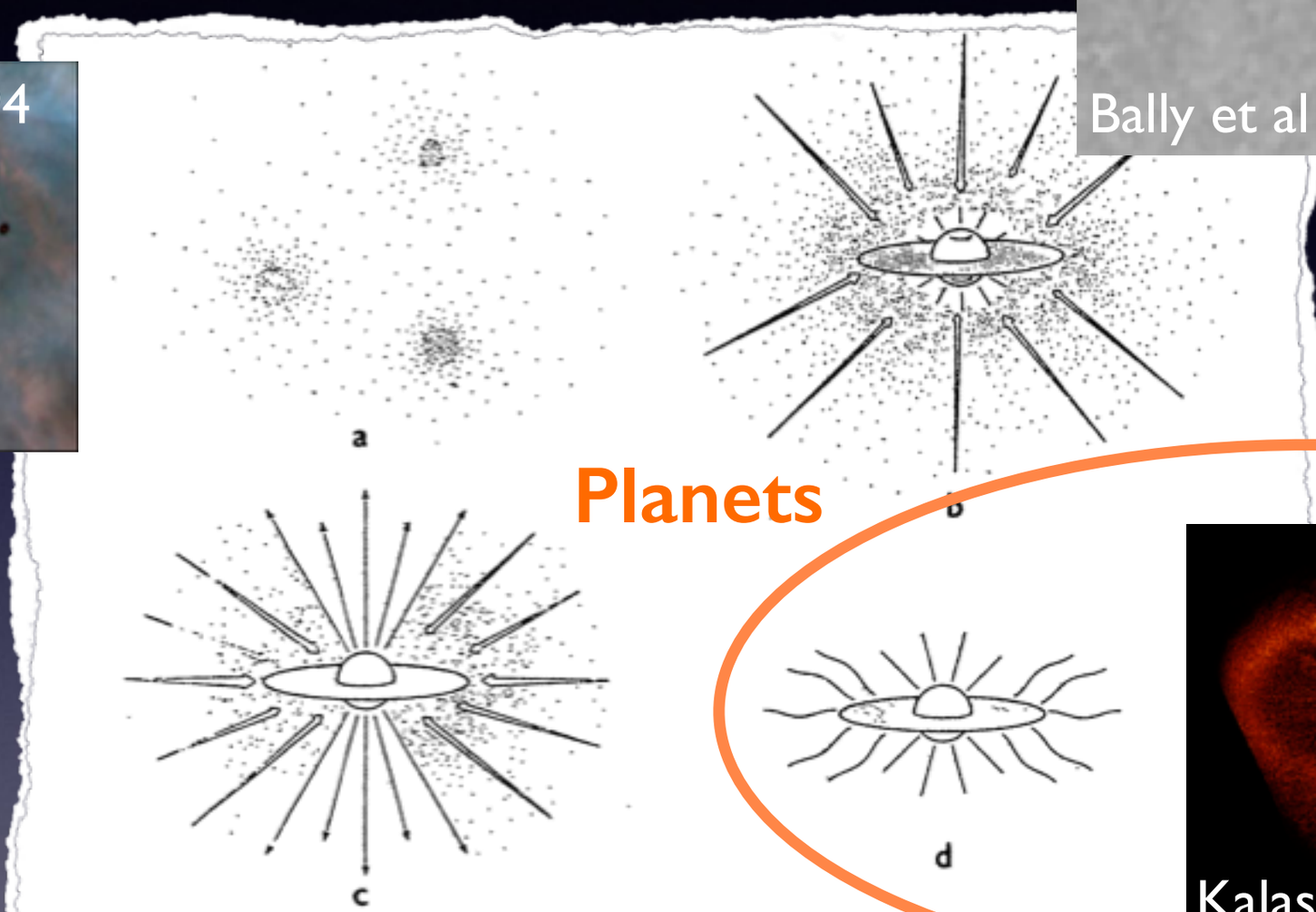
Ricci et al. 2008

Kalas et al 2008

Star and Planet Formation:

The process





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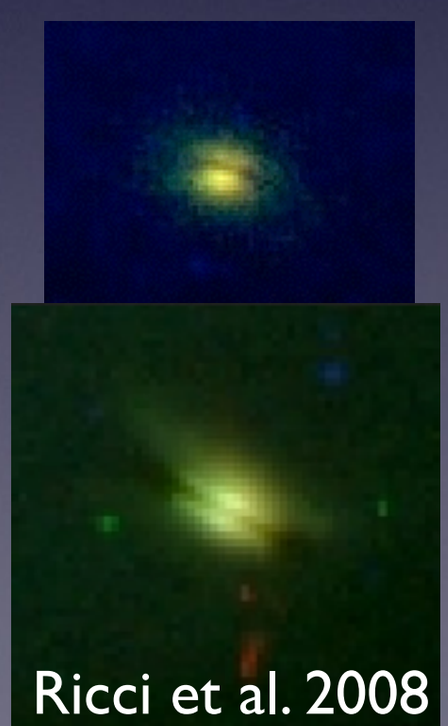
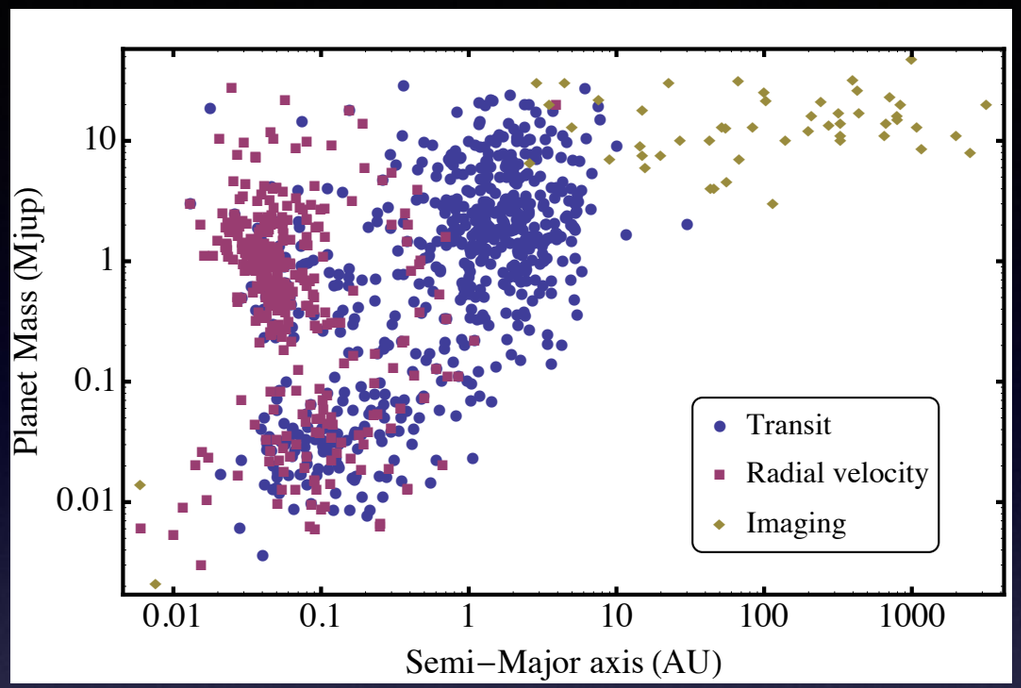
Shu et al. 1987

Planets

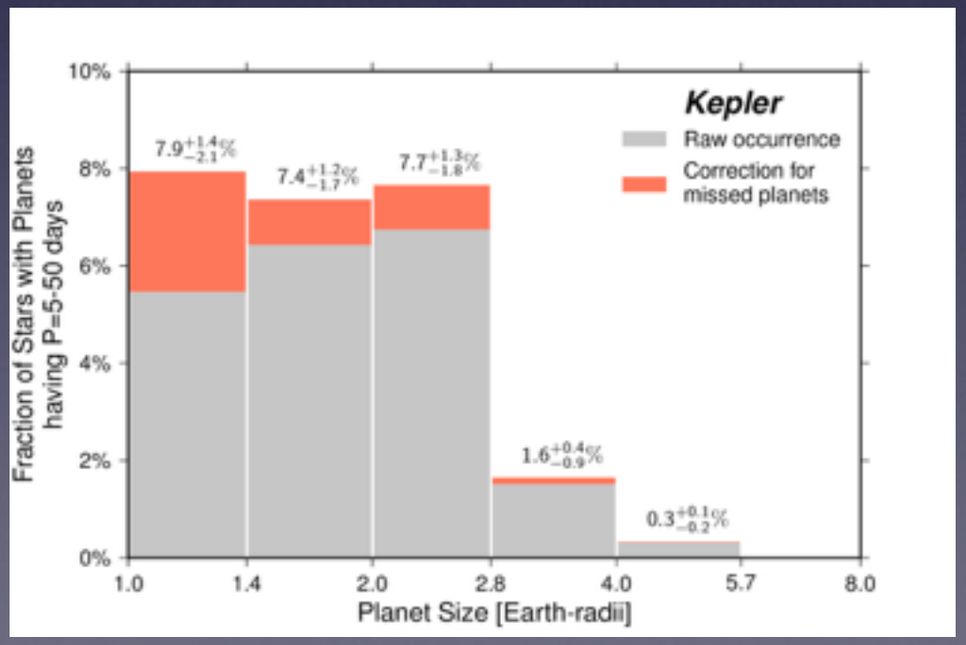


Exoplanet Exploration:
Main questions

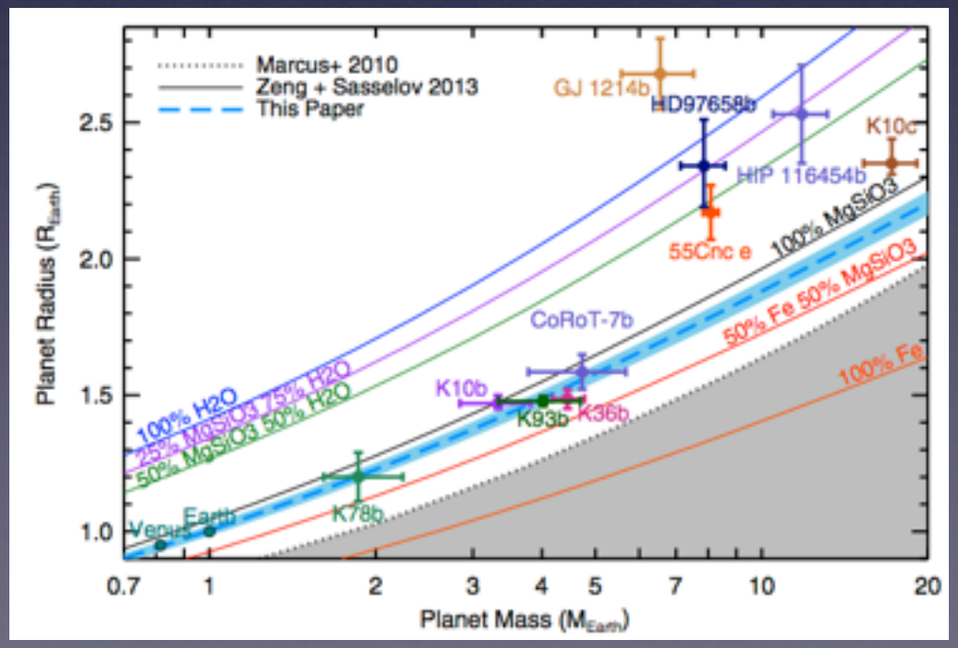
- How frequent are they?
- How diverse are they?
- What are they made of?
- How do they form?



exoplanet.eu



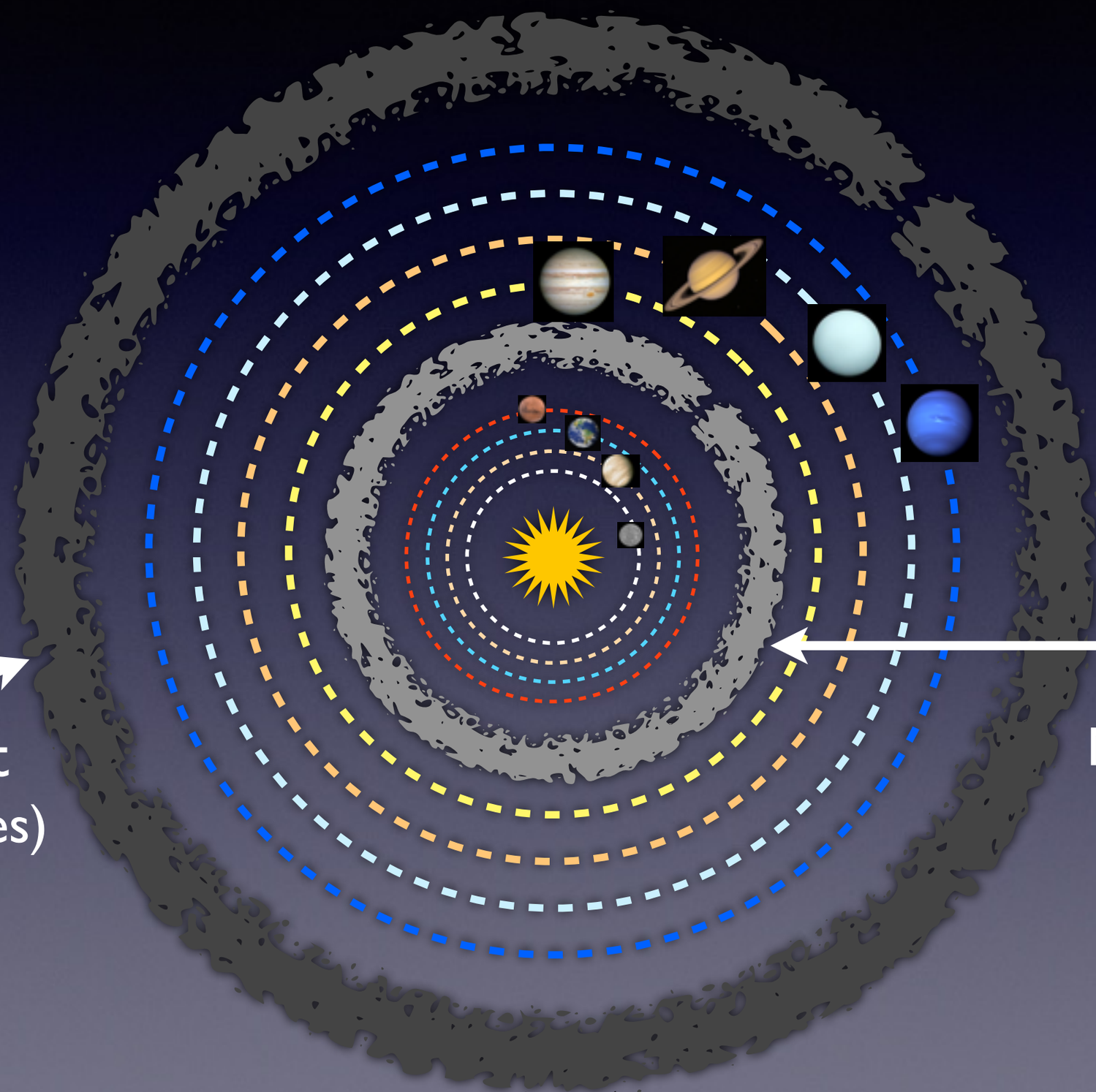
Petigura et al. 2013



Dressing et al. 2015

Debris disks:

Remnants of planet formation

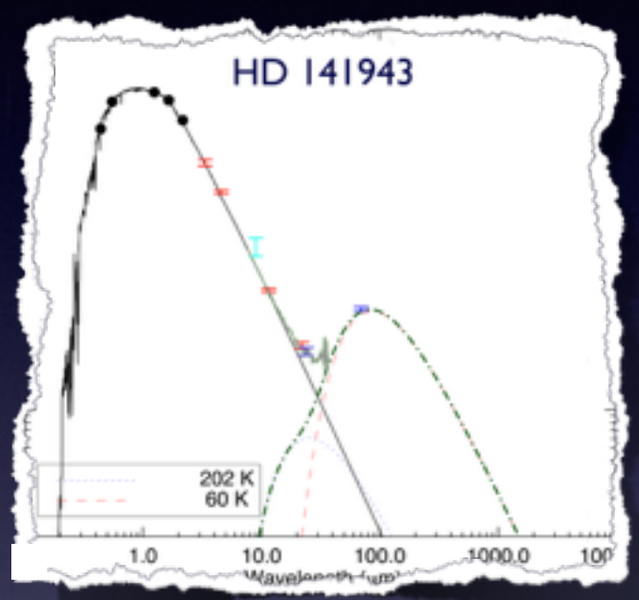


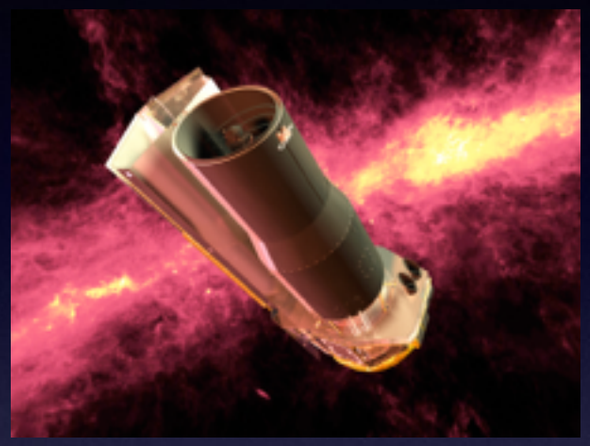
Asteroid belt
(Carbon-rich,
Silicate-rich, and
Metal-rich asteroids)

Kuiper belt
(mixture of ices)

Debris disks:

Remnants of planet formation



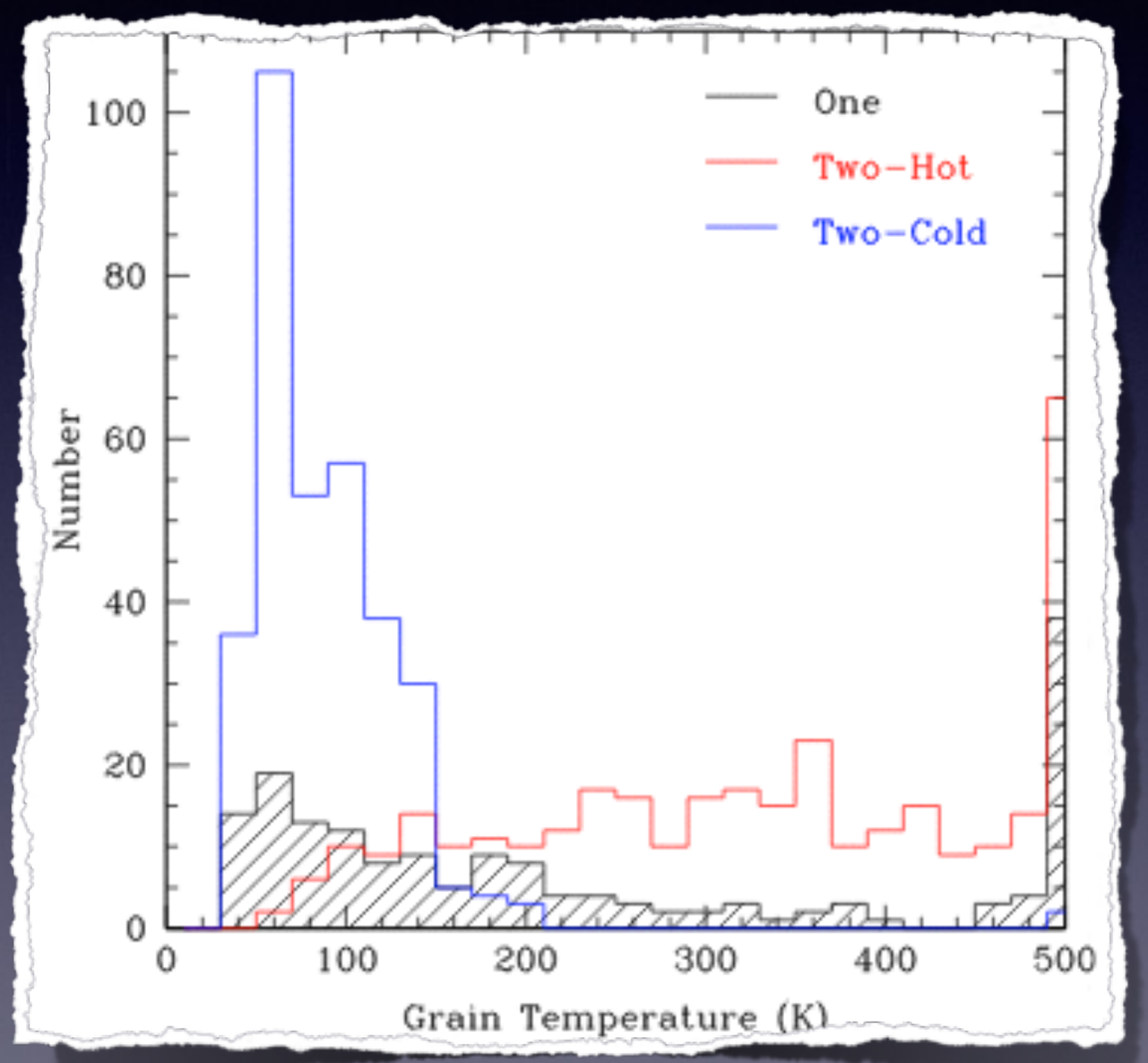


able 15. Overall description of the DUNES sample and summary results.

Sample	F stars	G stars	K stars	Total
Solar-type stars observed by DUNES (the DUNES sample)	27	52	54	133
20 pc DUNES subsample	20	50	54	124
Non-excess stars in the whole DUNES sample	16(59%)	37(71%)	42(78%)	95(71%)
Affected by field contamination	2	3	2	7
Excess stars in the whole DUNES sample	9(2)	12(3)	10(5)	31(10)
Excess stars in the 20 pc subsample	4(20%)	11(22%)	10(18.5%)	25(20.2%)
Resolved debris discs	5(4)	6(4)	5(5)	16 (13)

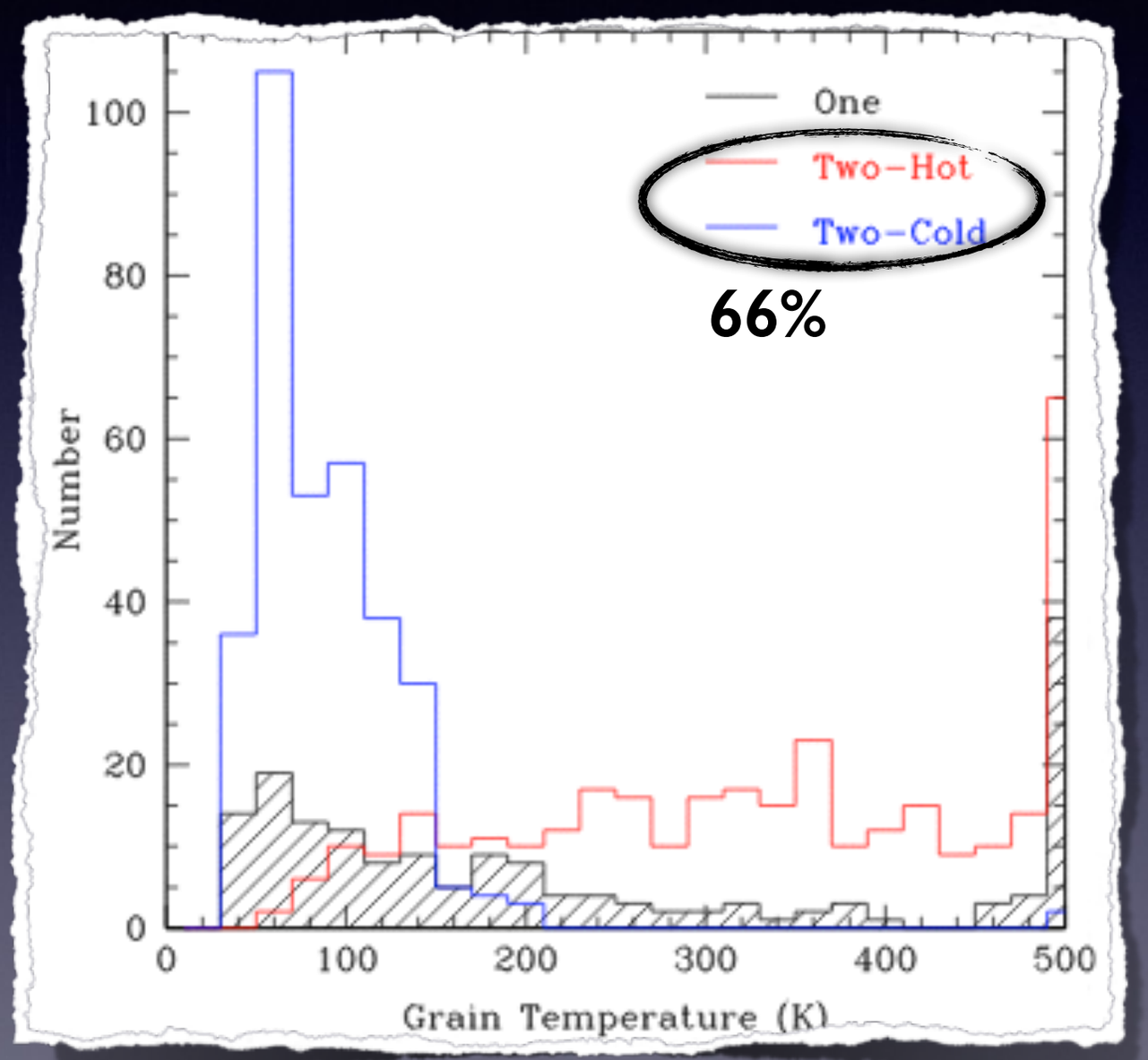
Eiroa et al. 2013

Debris disk - exoplanet relation?



Chen et al. 2014

Debris disk - exoplanet relation?



Chen et al. 2014

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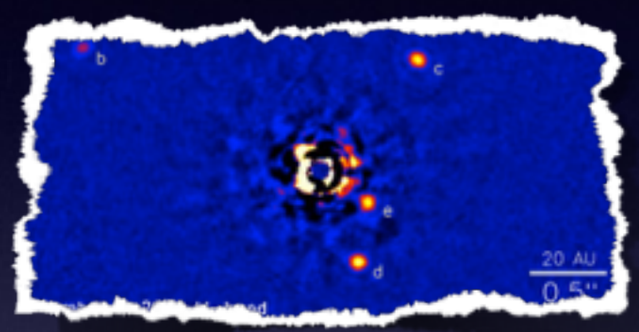
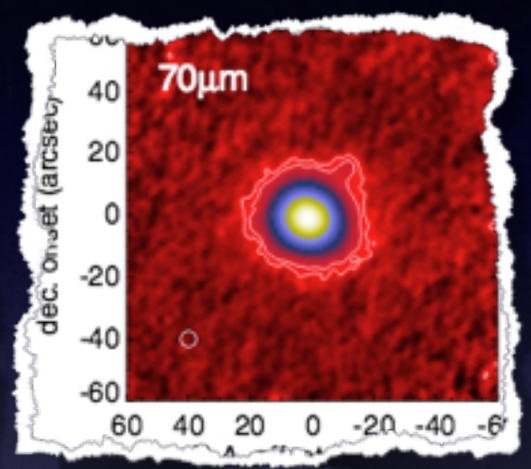
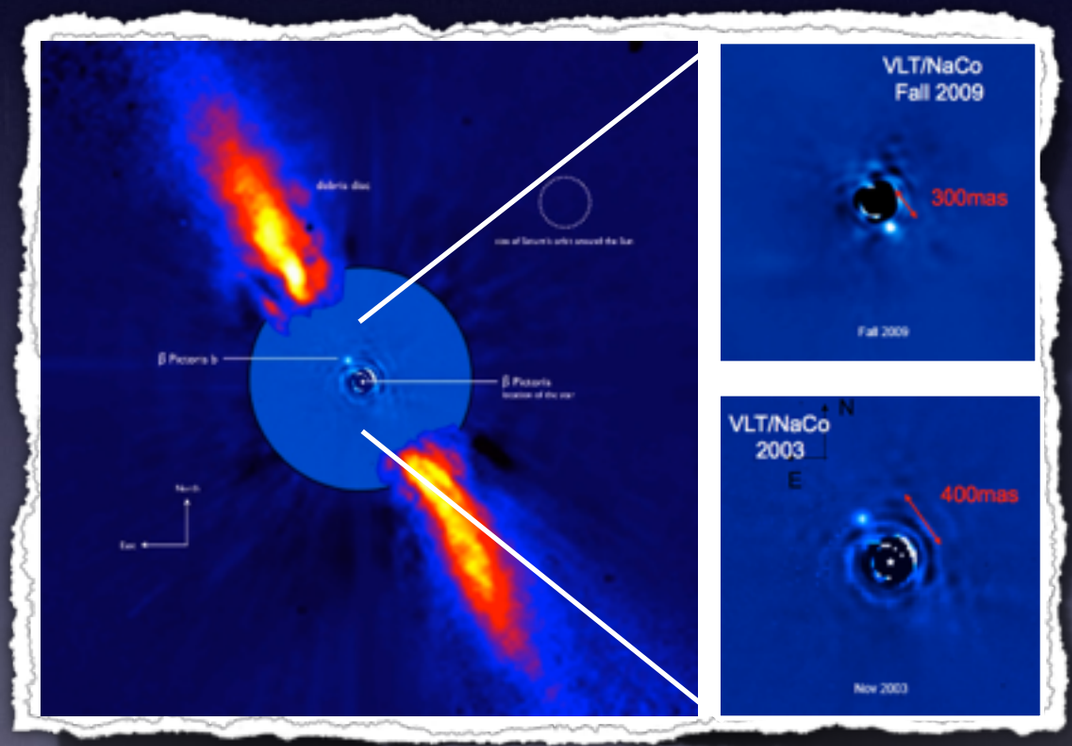
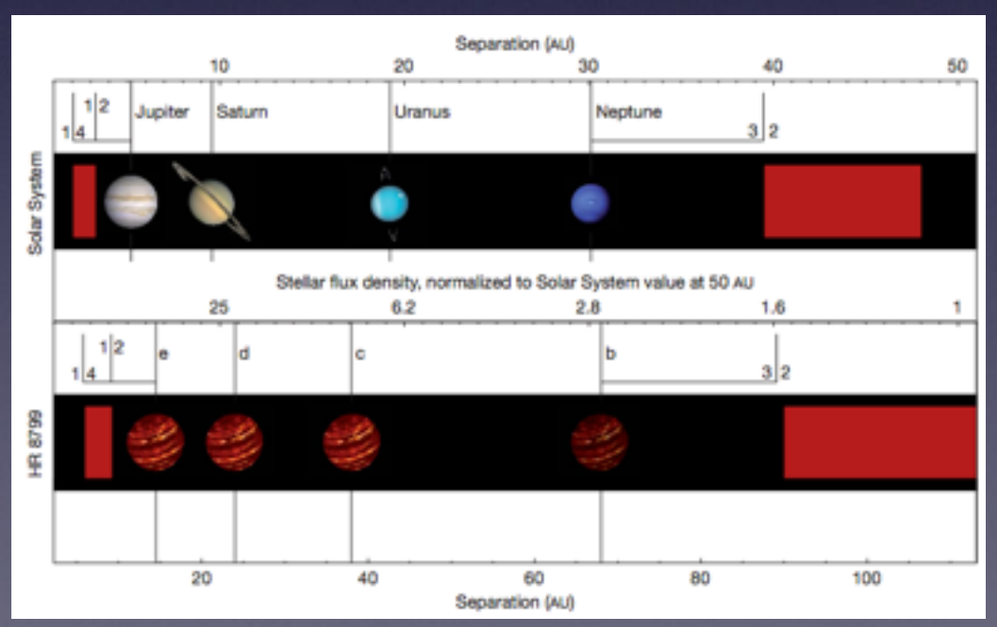




Lagrange et al. 2010, VLT - NACO





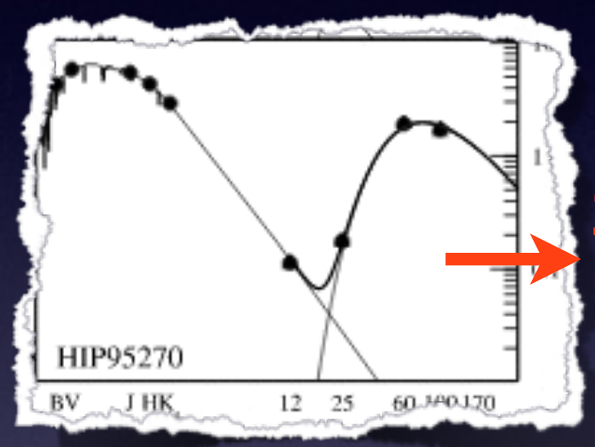
← Solar system

← HR8799

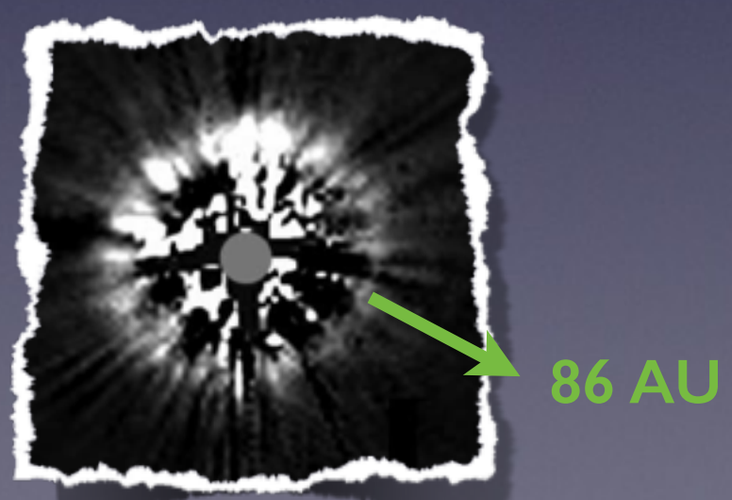
Marois et al. 2010
Matthews et al. 2014

Seing disks, studying planets...

Direct morphologic measurements

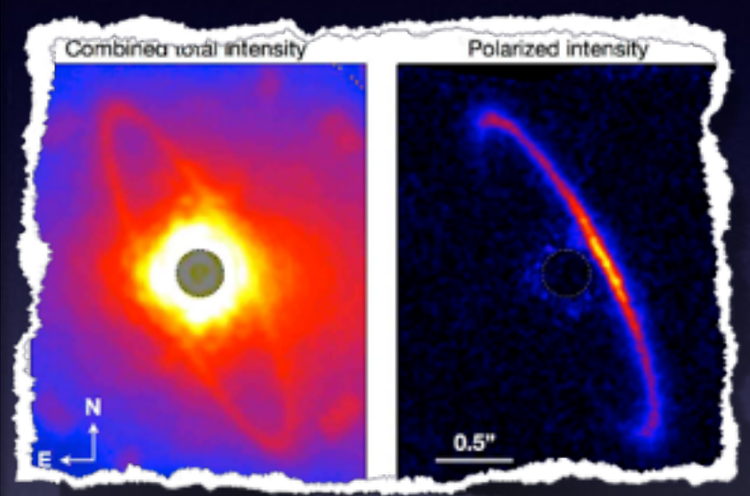


Zuckerman & Song 2004

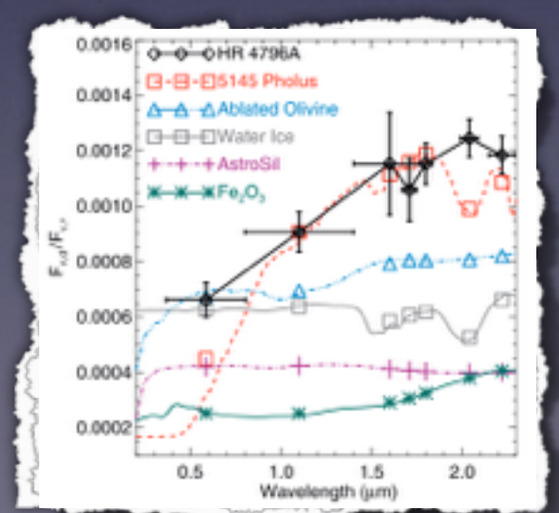


Schneider et al. 2006

Better composition constraints

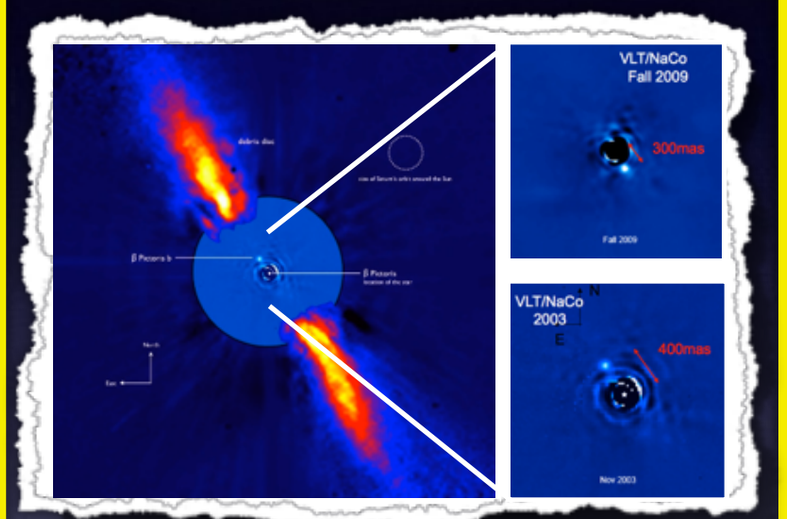


Perrin et al. 2014

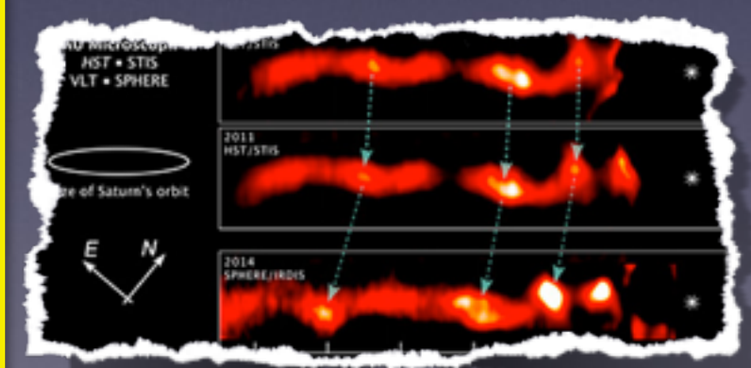


Debes et al. 2008

Signposts of planets



Lagrange et al. 2010



Boccaletti et al. 2015

Outline

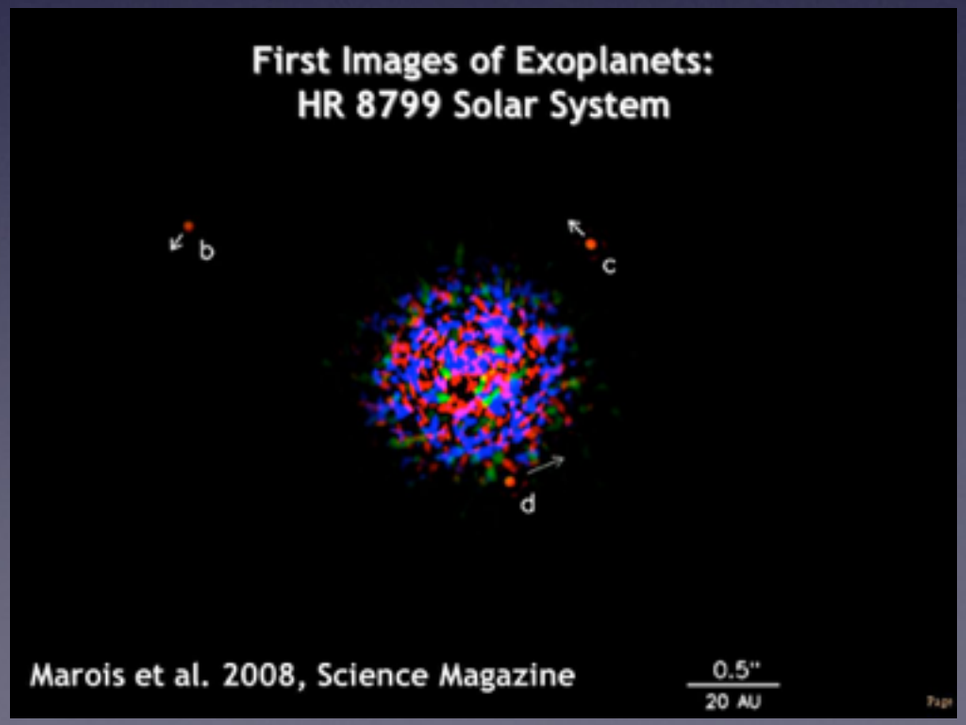
- **The ALICE project**
  - Motivations, Goals, Method
  - The NICMOS archive
  - Status of the project

- **Debris disks imaging**
  - Improvement on known disks
  - New disks
  - Low mass star disks

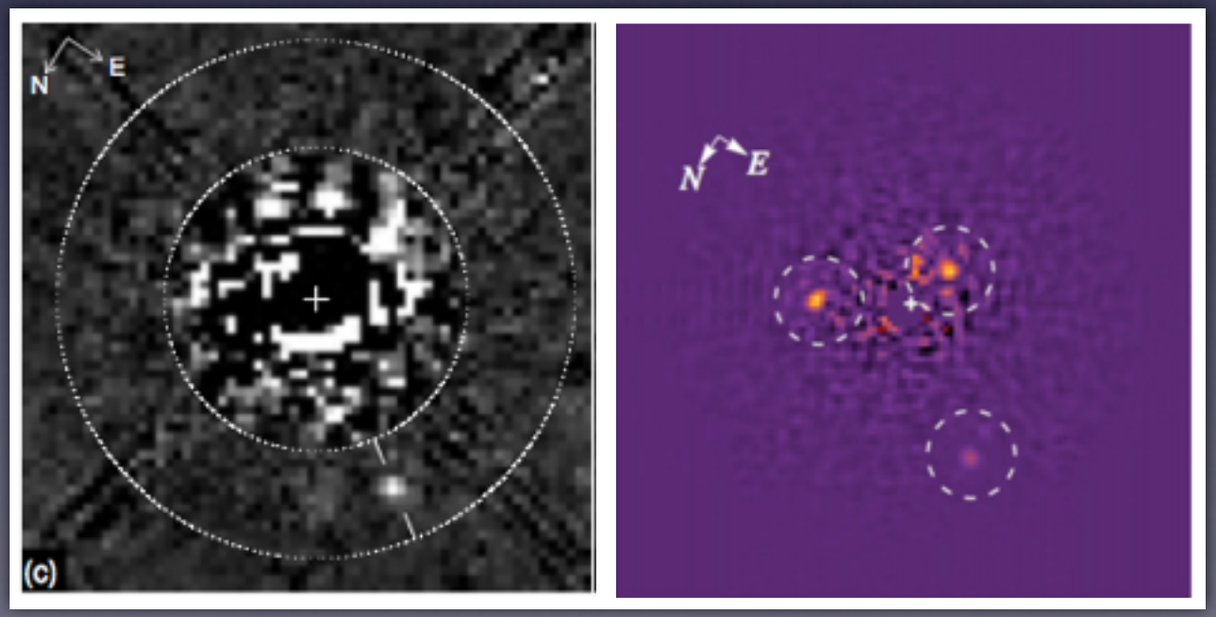
The **ALICE** project

Archival Legacy Investigations of Circumstellar Environments

- **PI:** Remi Soummer
- **Goal:**
  Analyze the NICMOS archive w. new post-processing methods
  Detect circumstellar material missed by older methods



NICMOS data from *1998*



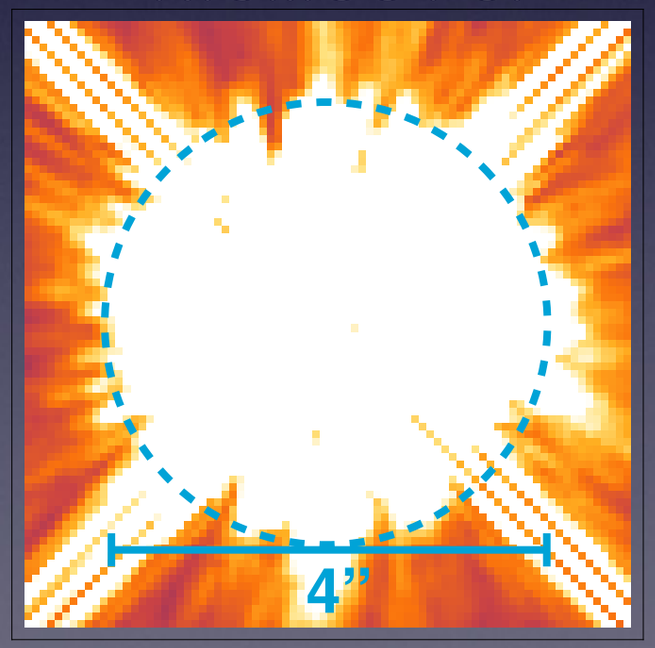
Lafreniere et al. 2009 Soummer et al. 2011

Postprocessing Method

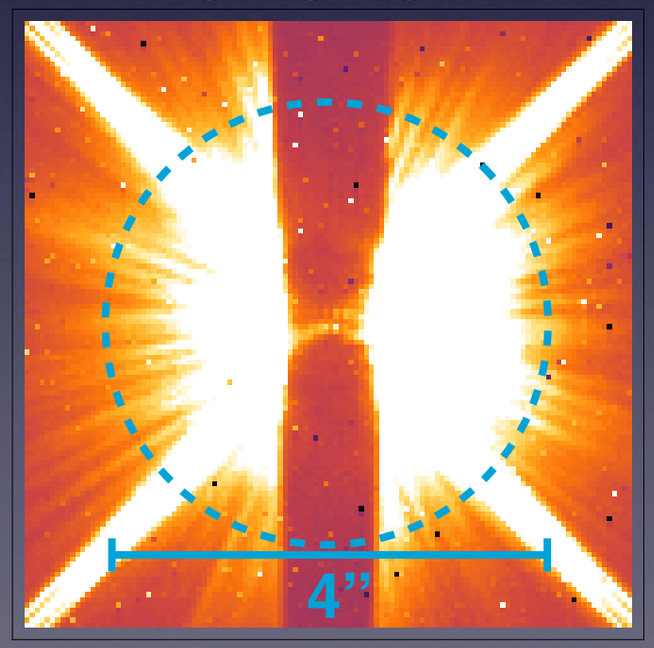
Raw coronagraphic images

- Remaining star light at small angles
- No detection of circumstellar material possible

NICMOS PSF



STIS PSF



Postprocessing Method

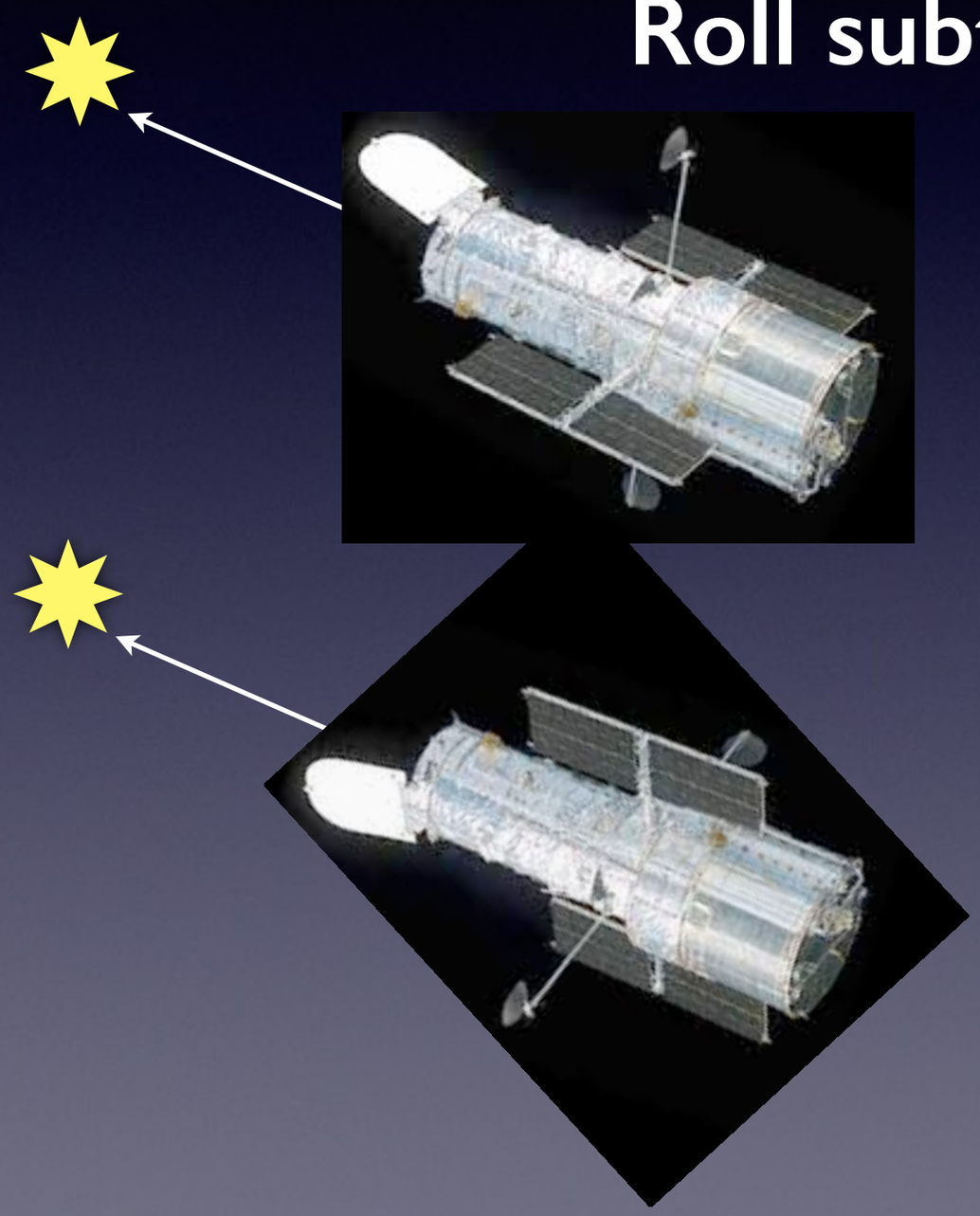
Classical PSF subtraction

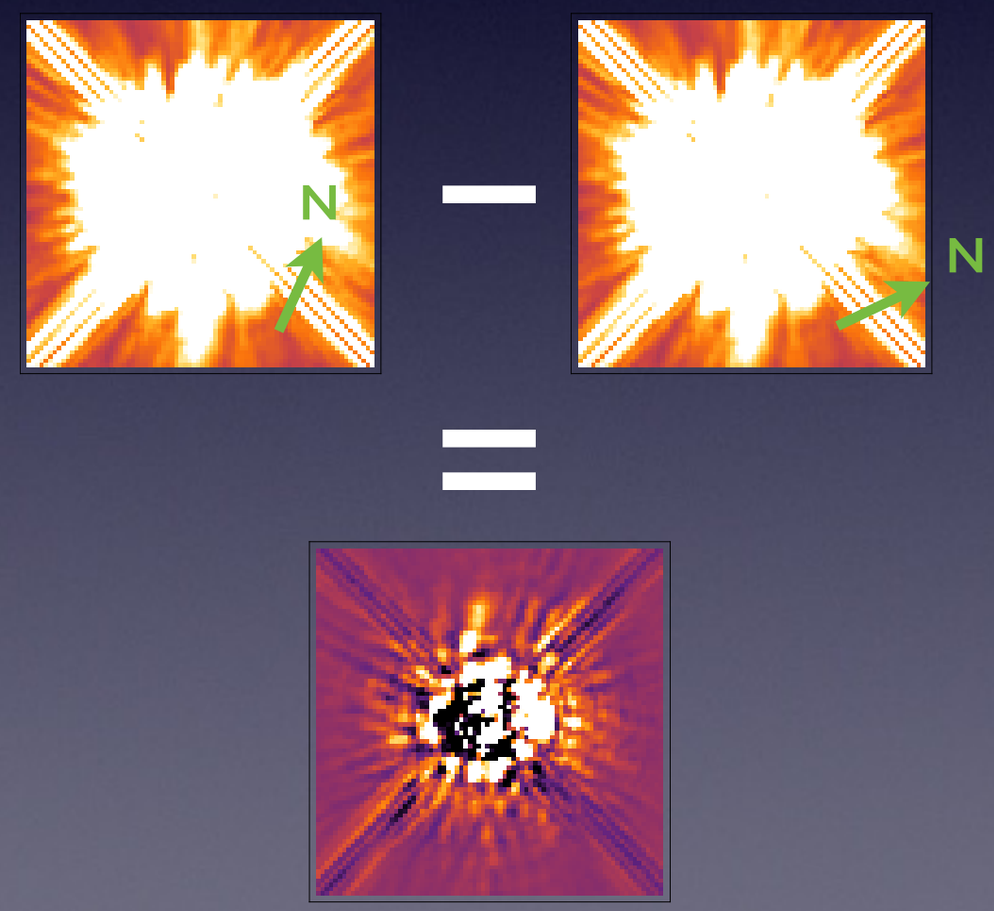
- Subtraction of the PSF of another image
- Gain of a factor 5 - 10 in contrast

Postprocessing Method

Limitation of previous methods

Roll subtraction

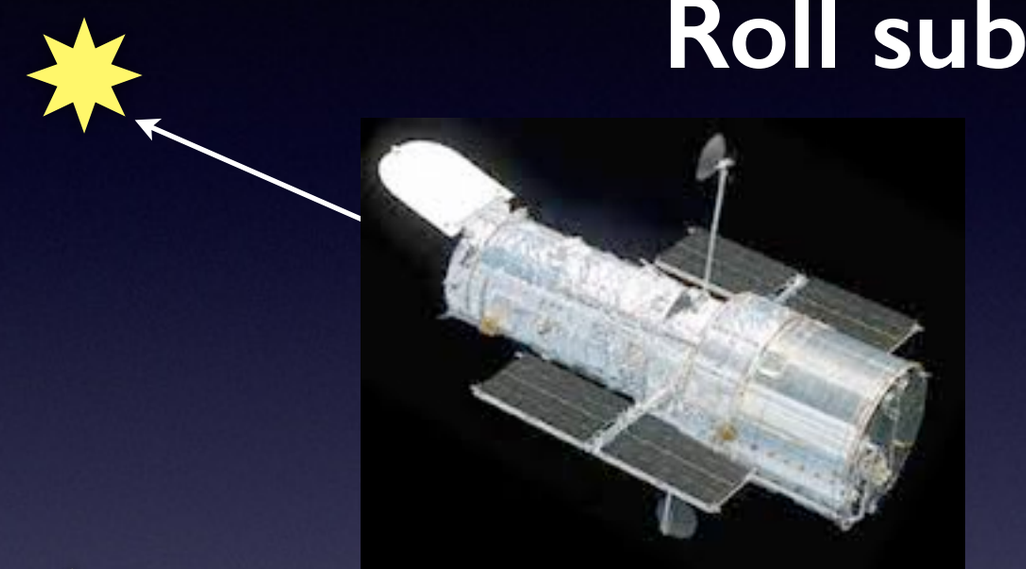


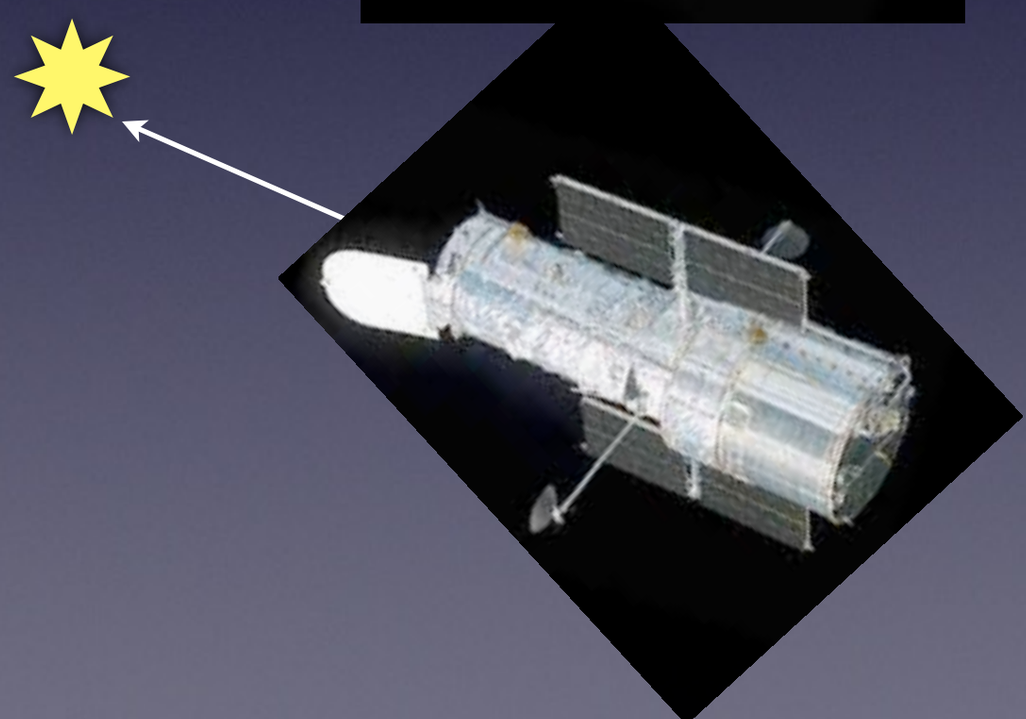


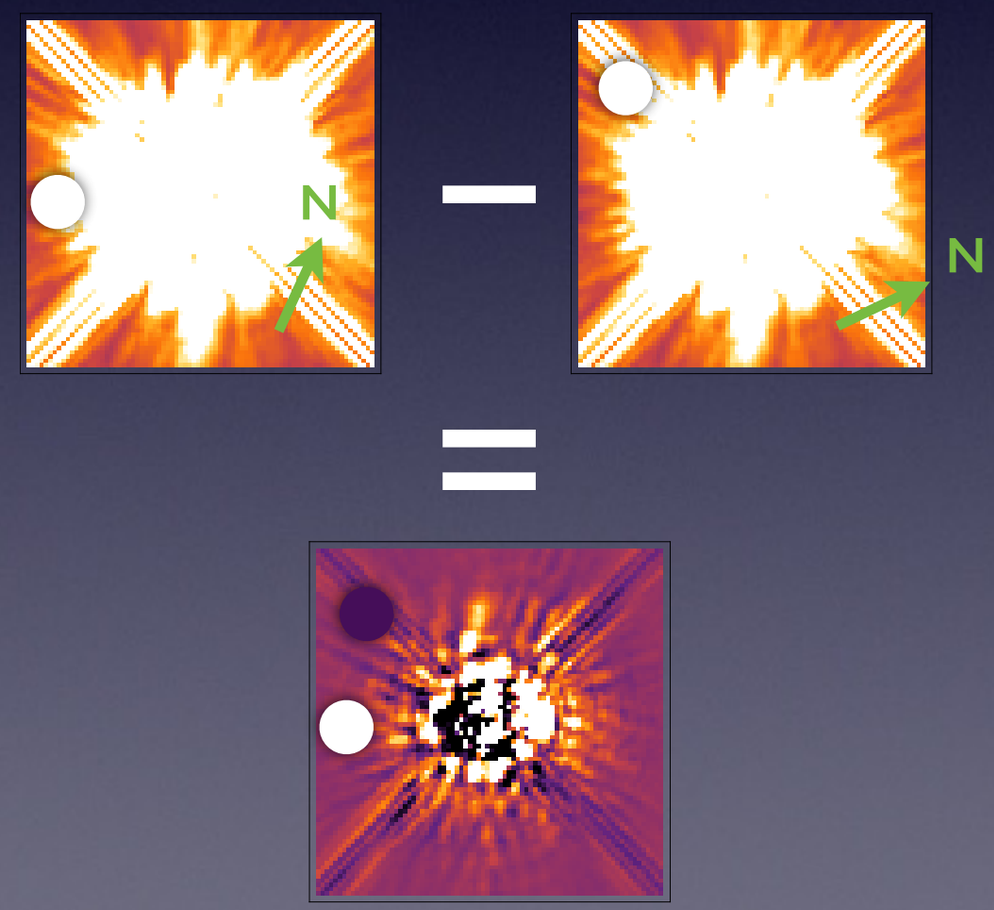
Postprocessing Method

Limitation of previous methods

Roll subtraction



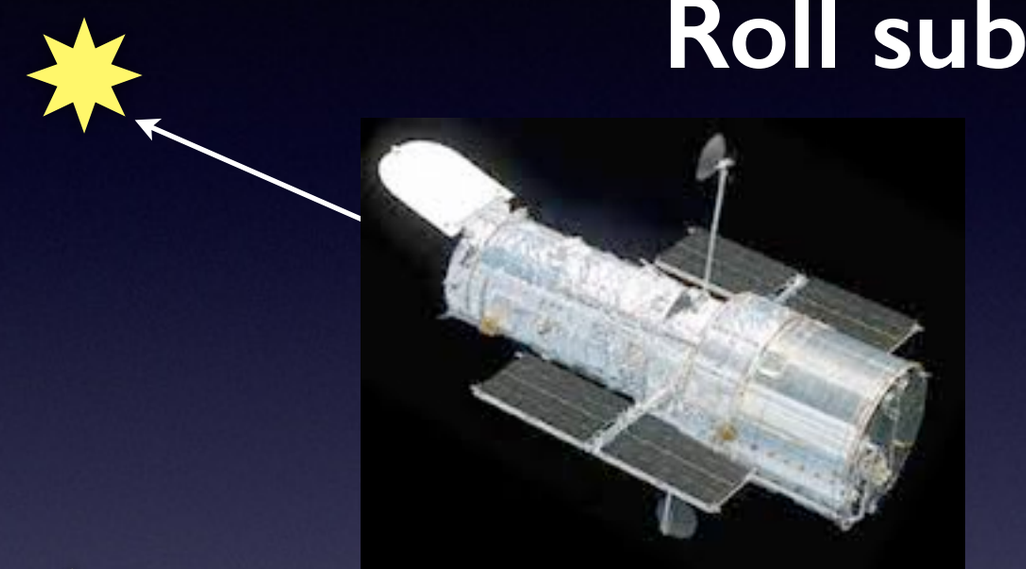


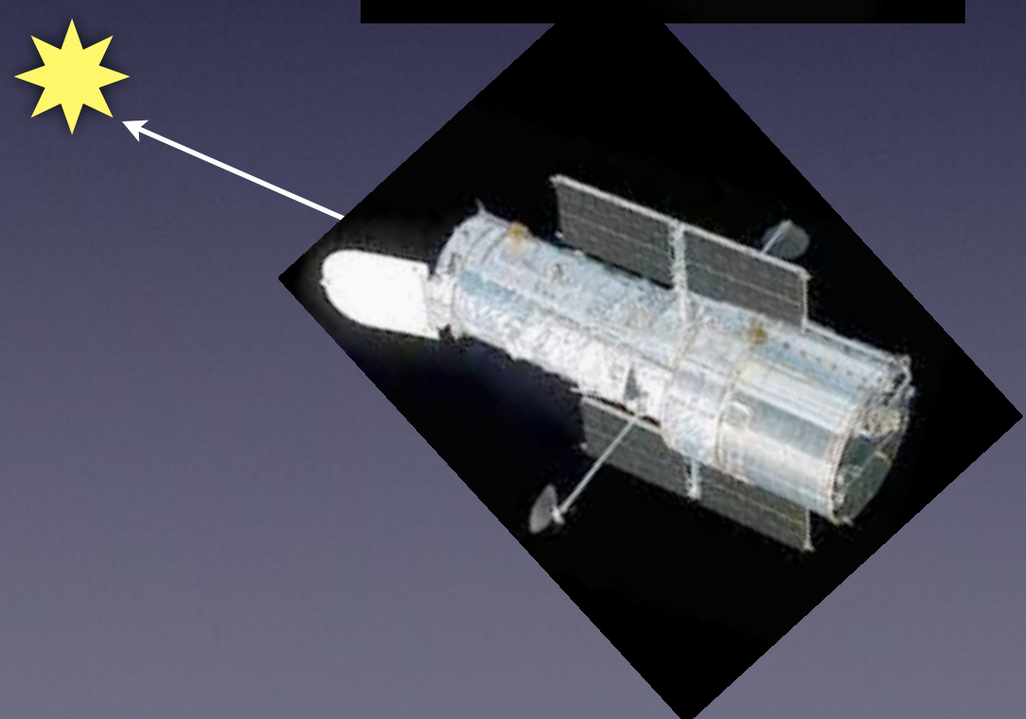


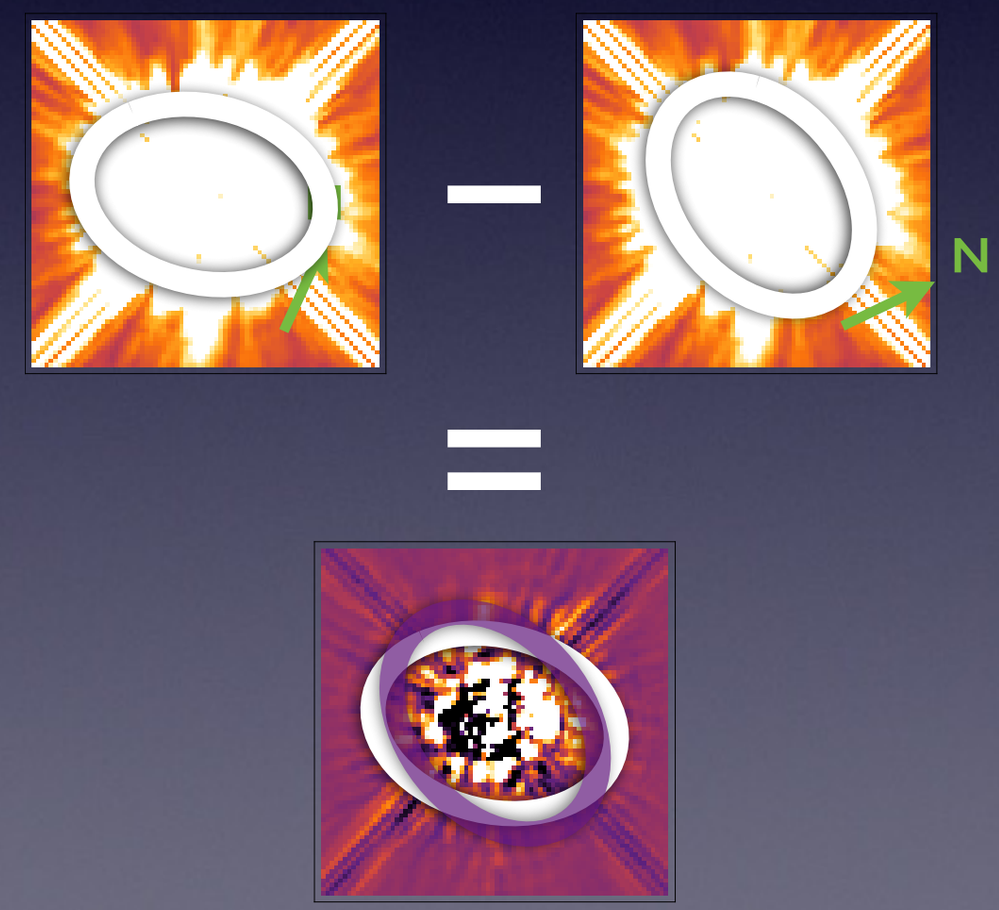
Postprocessing Method

Limitation of previous methods

Roll subtraction



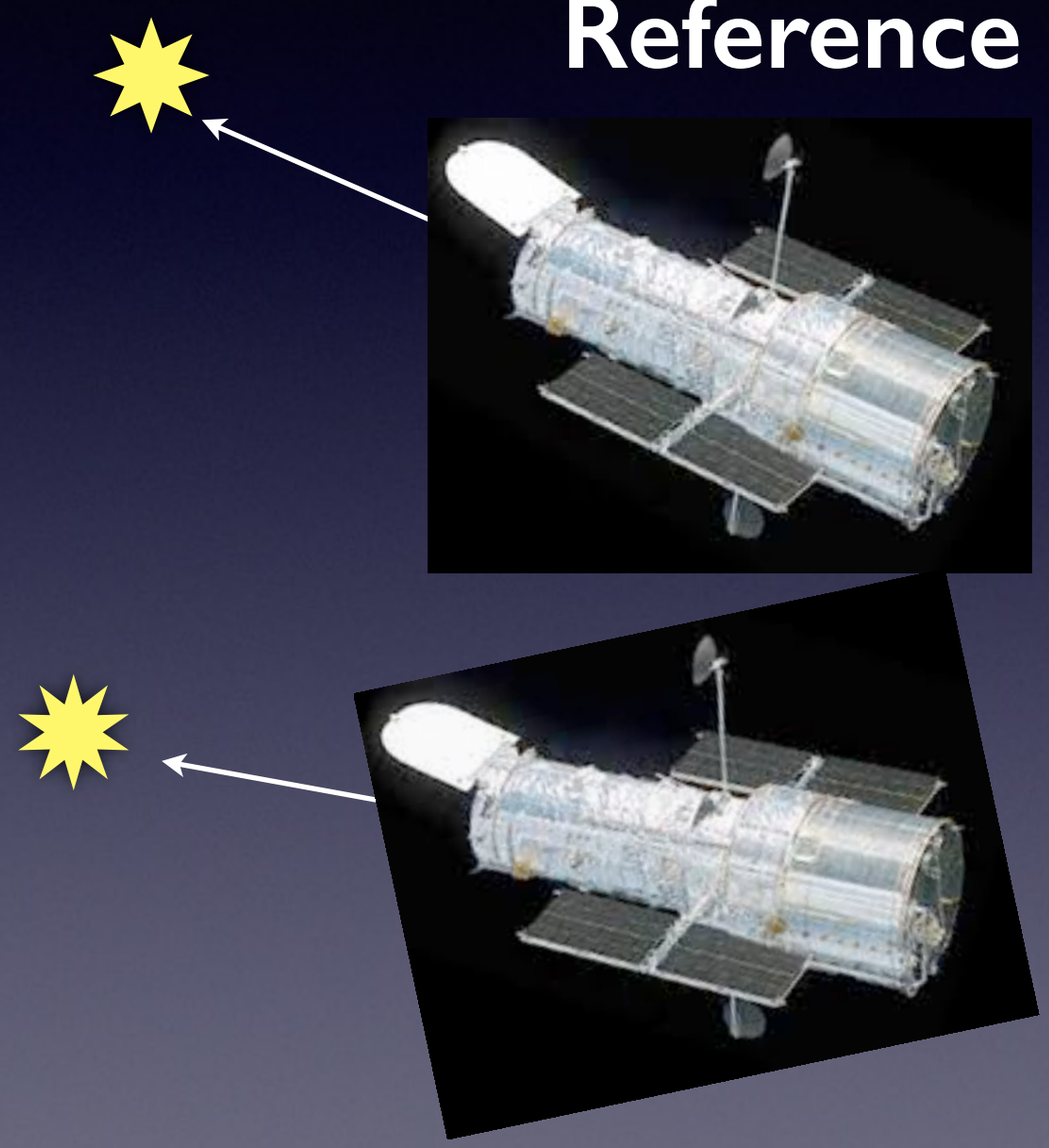


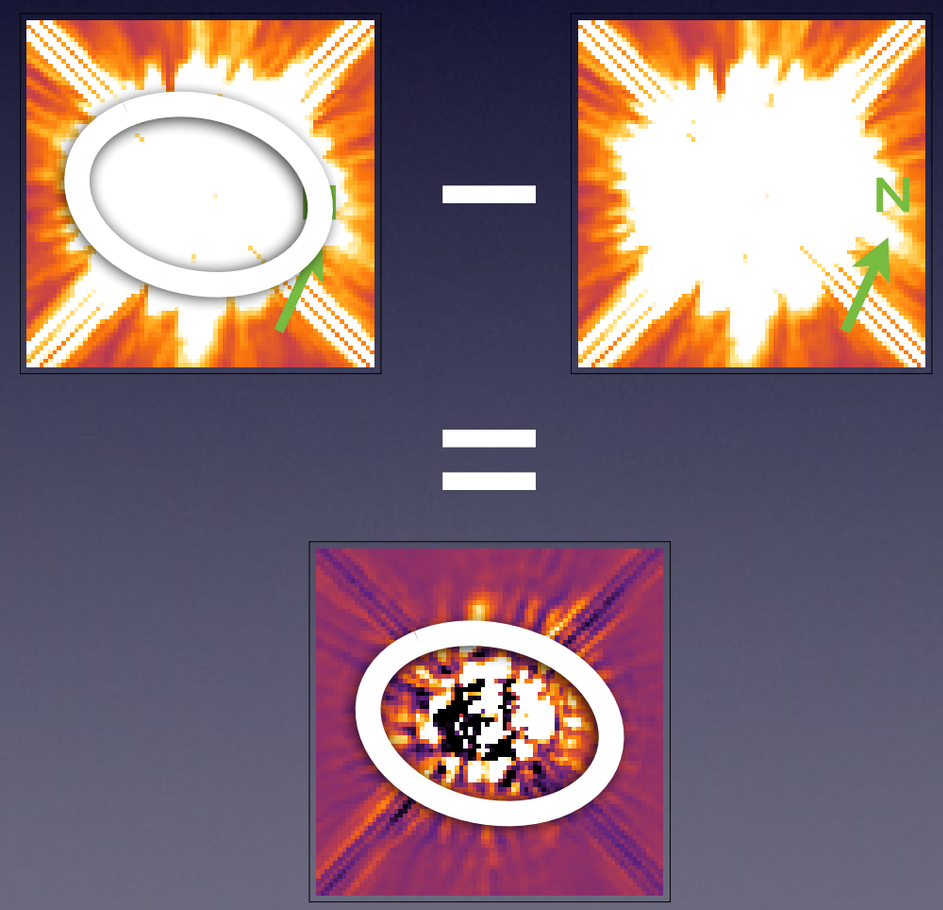


Postprocessing Method

Limitation of previous methods

Reference star subtraction

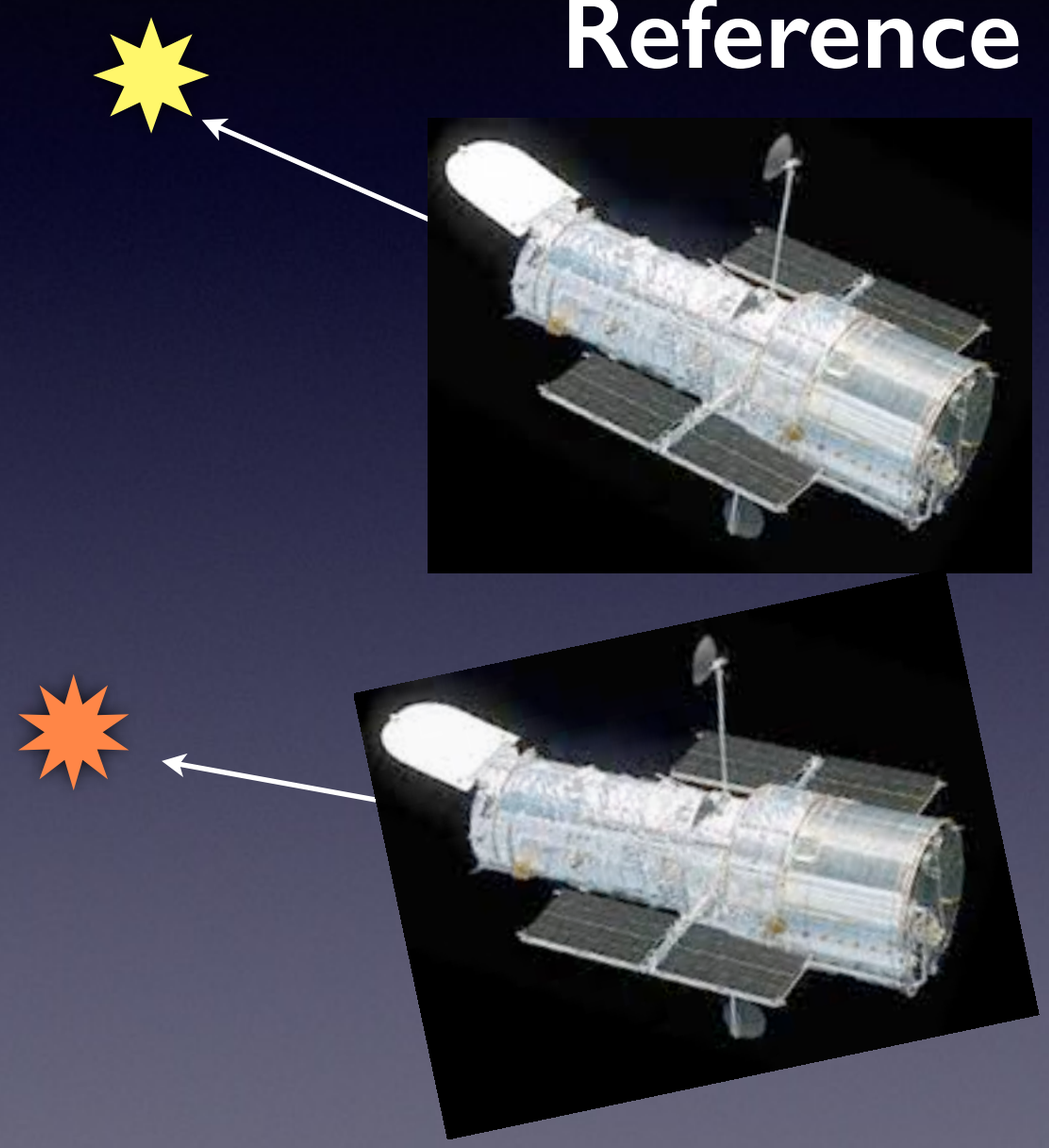


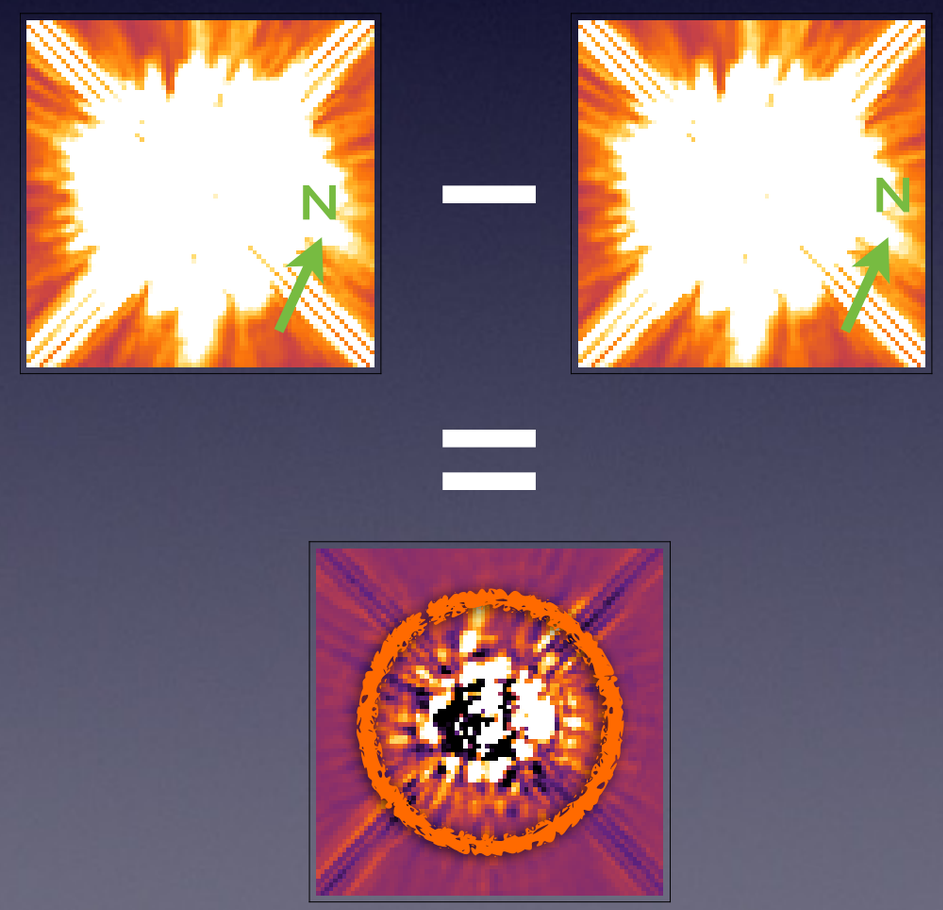


Postprocessing Method

Limitation of previous methods

Reference star subtraction

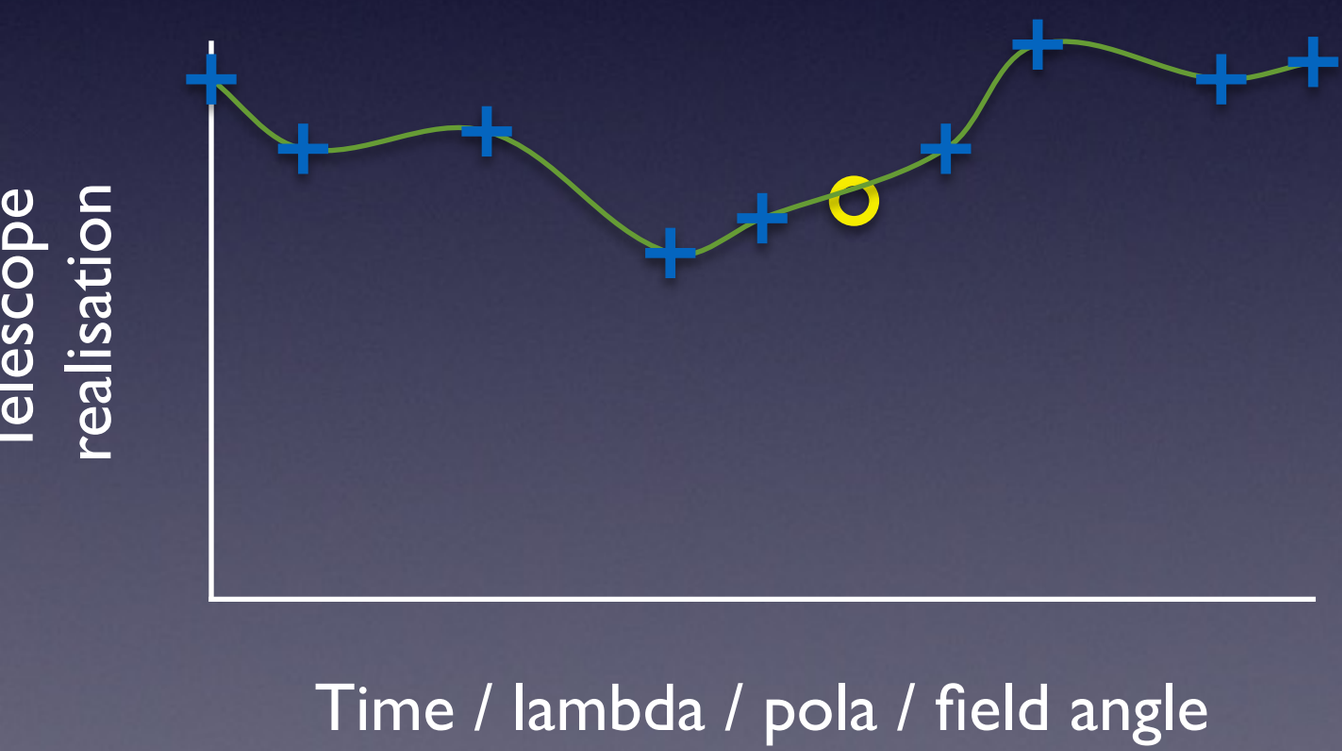


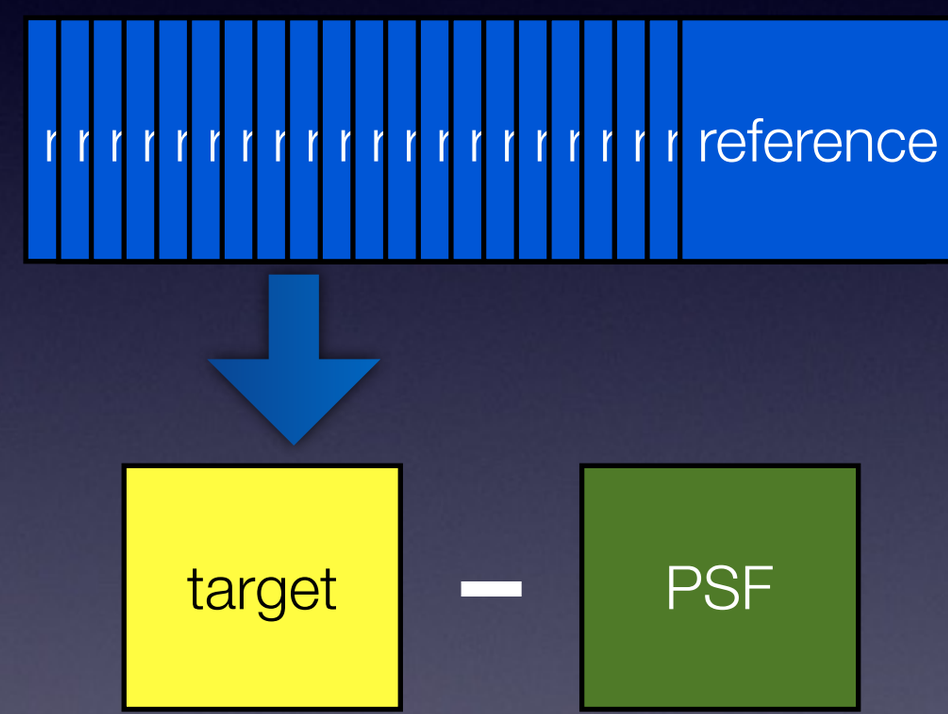


Postprocessing method

Advanced post-processing method

Use PSF libraries to build a synthetic PSF

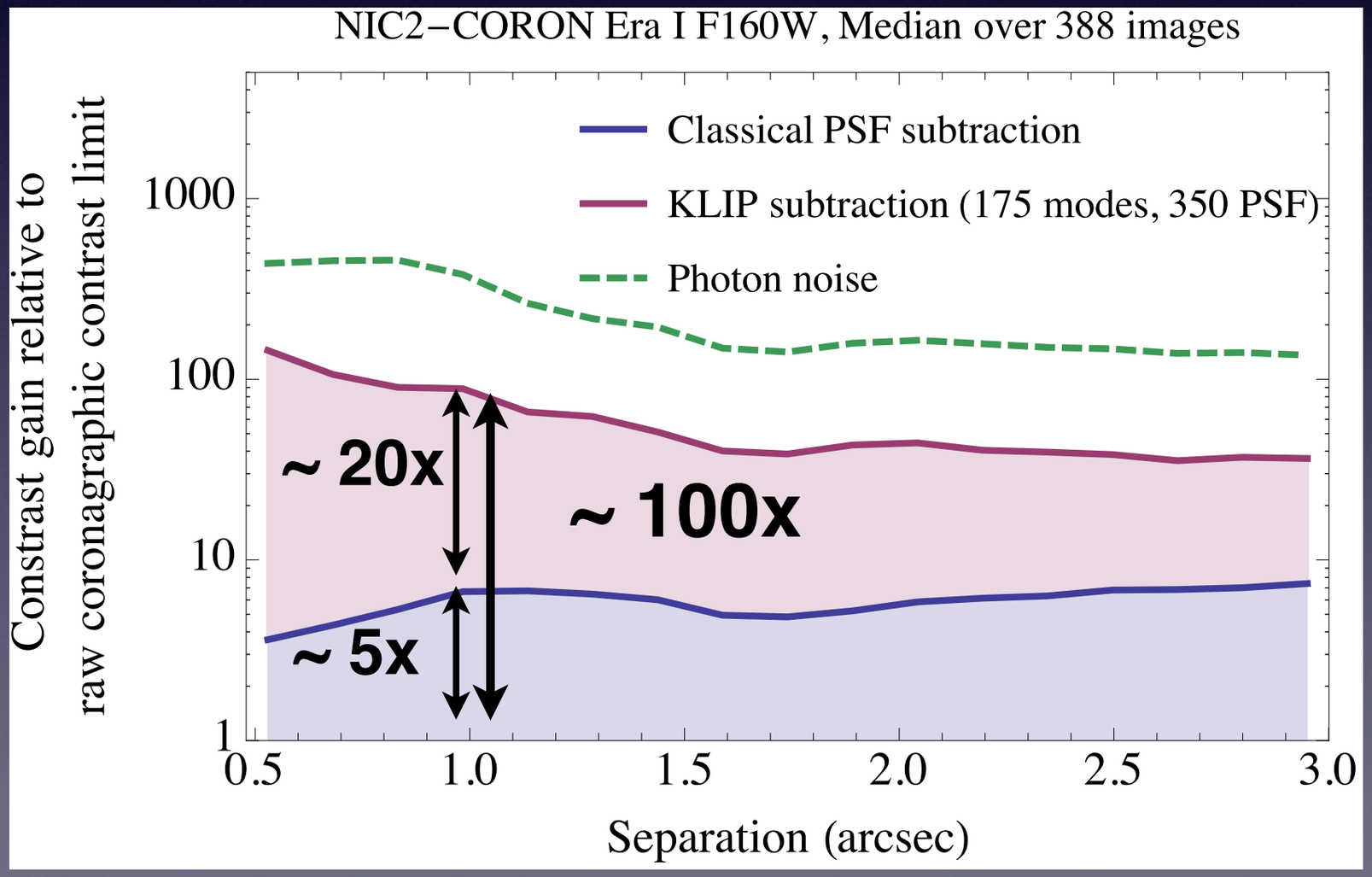




Algorithms:
LOCI (Lafreniere et al. 2007)
KLIP (Soummer et al. 2012)
S4 (Fergus et al. 2014)
TLOCI (Marois et al. 2014)
...

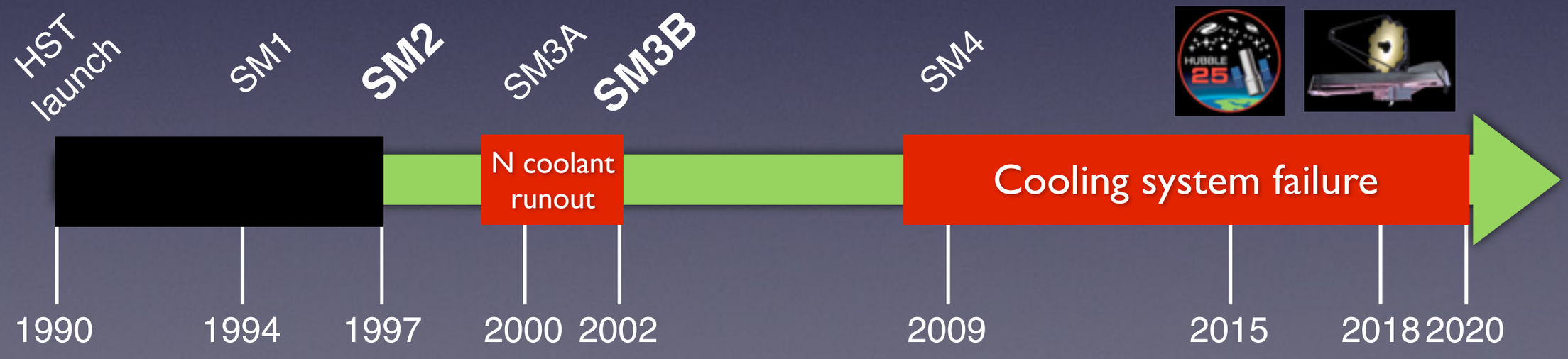
Overall performances

- Mean gain over raw coronagraphic PSF: **~ 100x at 1”**
- Mean gain over classical PSF subtraction: **~ 20x at 1”**



The NICMOS instrument

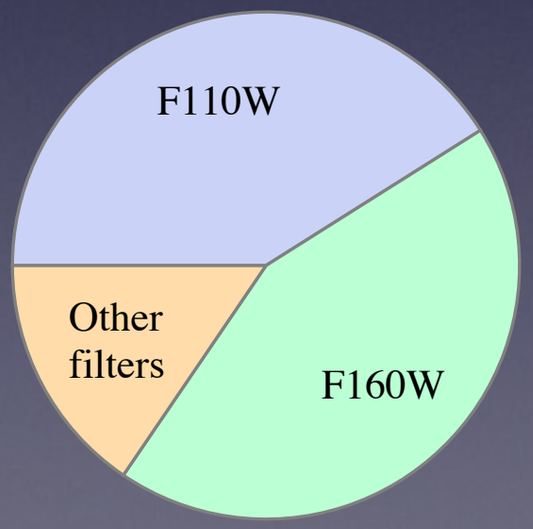
- NICMOS on HST
  - In operation: 1997 - 1999, 2002 - 2008
  - 3 detectors, 0.8 to 2.4 μm
  - 0.3” radius coronagraphic mask in NIC2

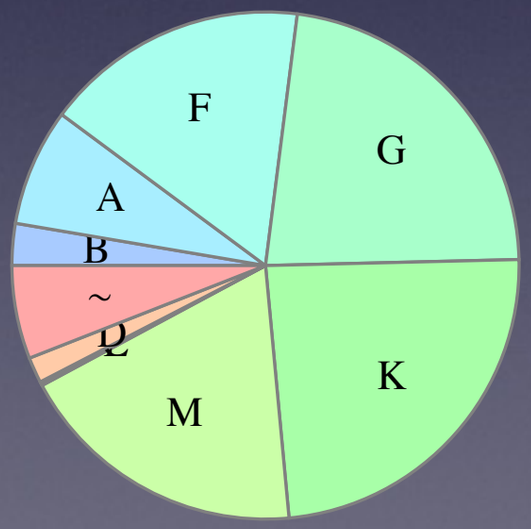


The NICMOS archive

The ideal database PSF library

- ~5600 images — *Very large PSF libraries*
- All spectral types are present — *No chromatic artifacts*
- Stable instrument in space — *Reproducible PSF variations*

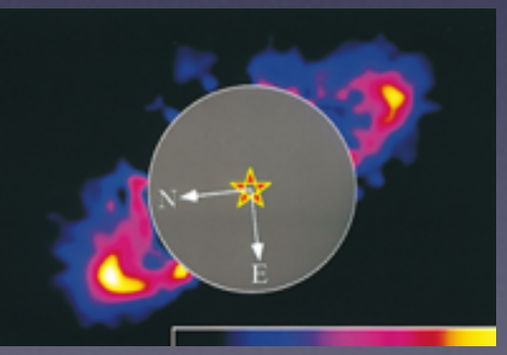




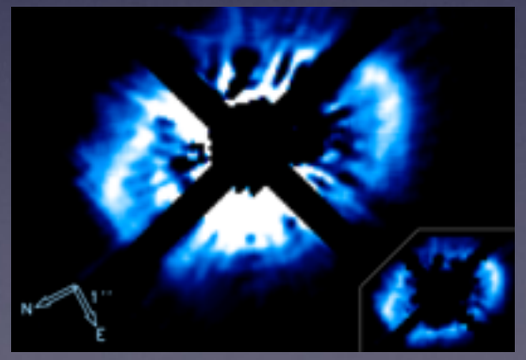
The NICMOS archive

The ideal science content

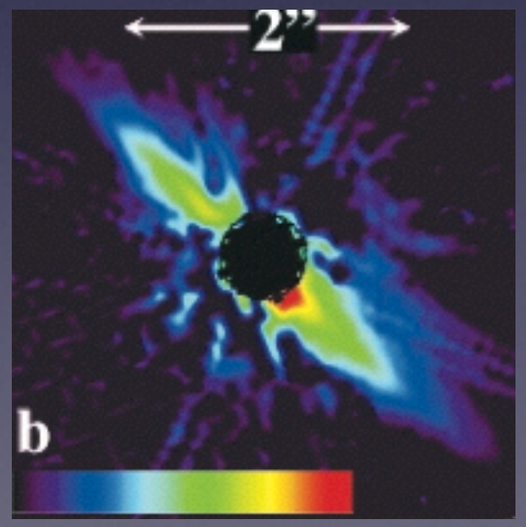
- 405 targets in the archive
- Mainly nearby star surveys for disks and planets
  - 25% looking for debris disks
  - 5 detections + 3 caracterizations



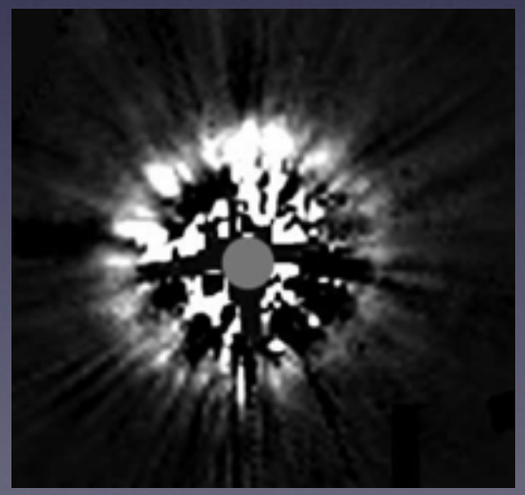
Schneider et al. 1999



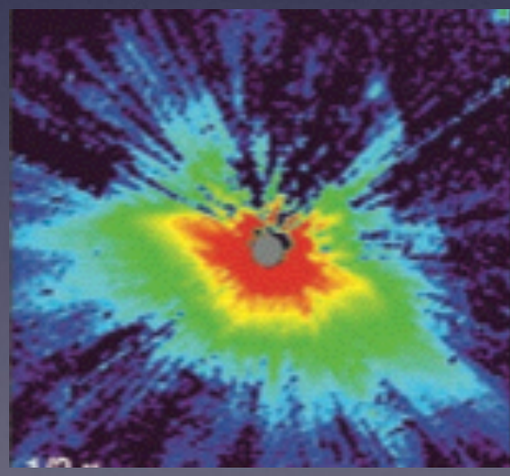
Augereau et al. 1999



Schneider et al. 2005



Schneider et al. 2006



Hines et al. 2007

The ALICE project
A three-year program

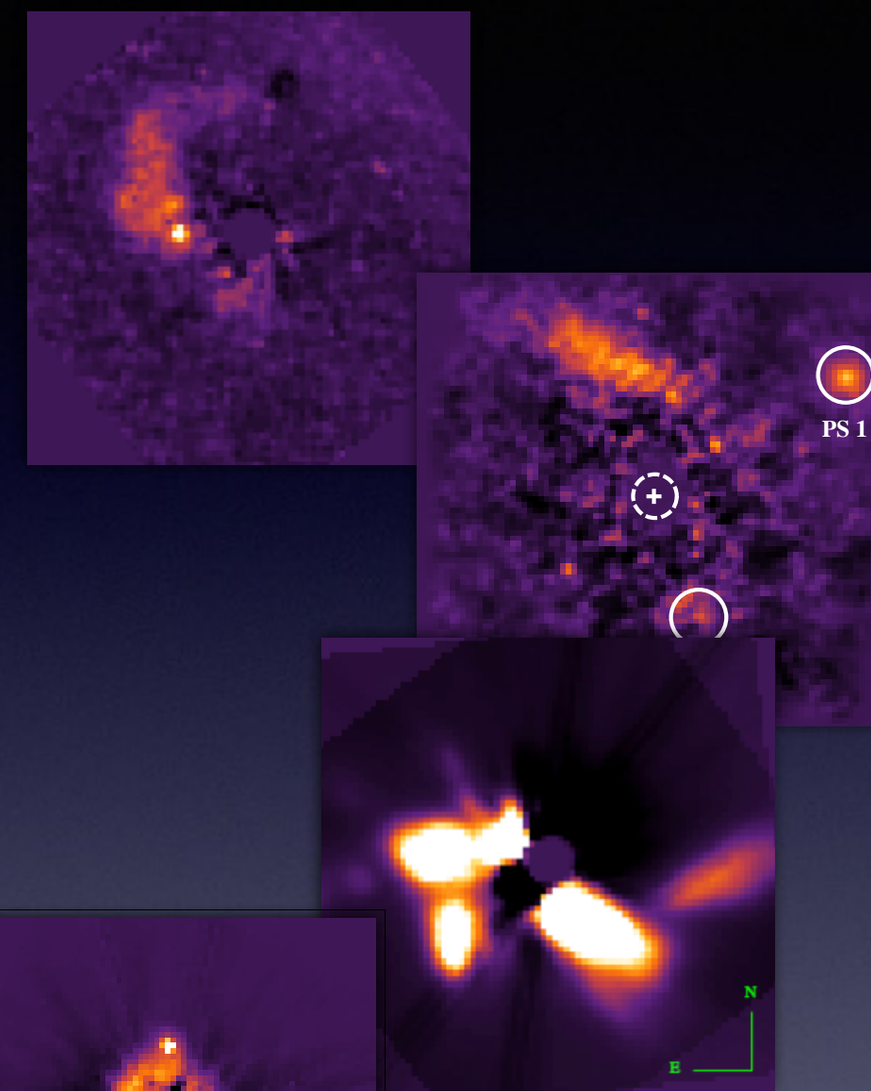
- 2011: rediscovery of HR 8799 b, c and d planet (Soummer et al. 2011)

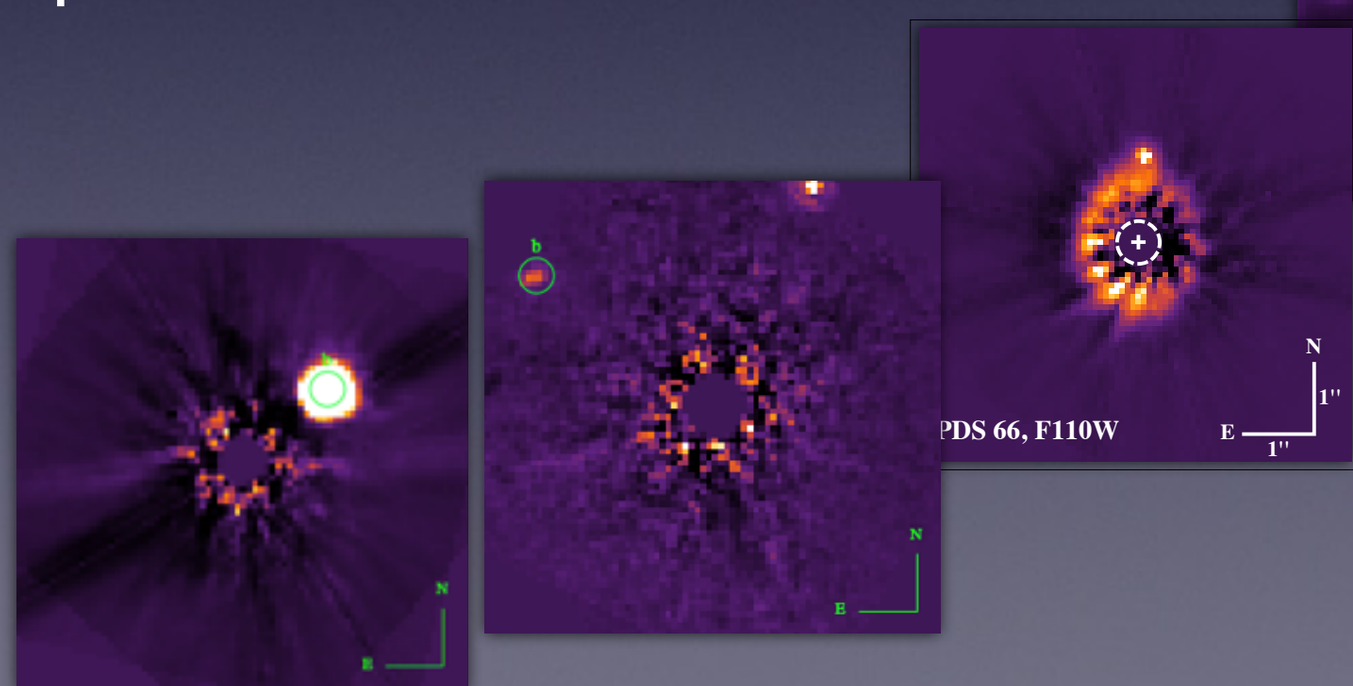
- **2012: HST AR legacy grant on the ALICE project**
  - 2012 - mid 2013: Preliminary pipeline based on 2011 code
  - 2014: Final stand-alone pipeline (Choquet et al. 2014)
  - 2015: Consistent reprocessing of the archive
  - **Early 2016: Delivery of high-level science products to MAST**

- 2016: Exploitation of the results
  - Follow-up campaigns
  - Completeness analysis

The one-slide summary
(including already known objects)

- Quasars / galaxies: 3
- Young stellar objects: 2
- Protoplanetary disks : 25
- Debris disks: 18
- Solid point sources: ~100





Outline

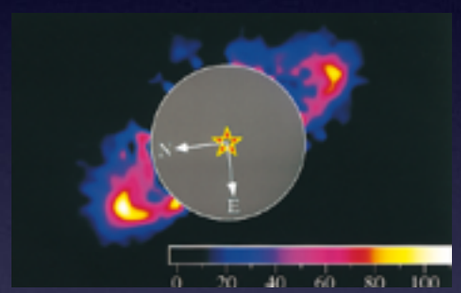
- **The ALICE project**
  - Motivations, Goals, Method
  - The NICMOS archive
  - Status of the project

- **Debris disks imaging**
  - Improvement on known disks
  - New disks
  - Low mass star disks

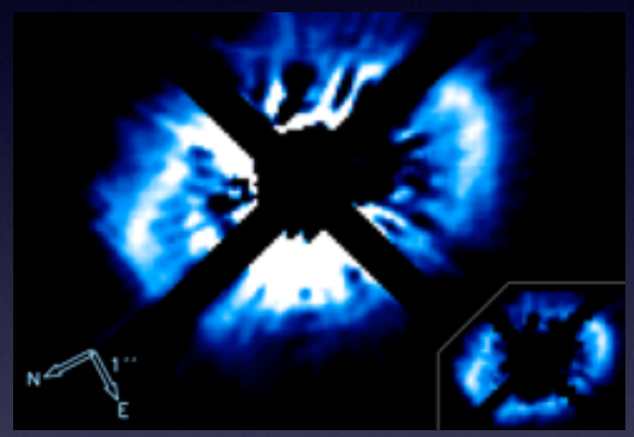
ALICE results

Improved reduction of known disks

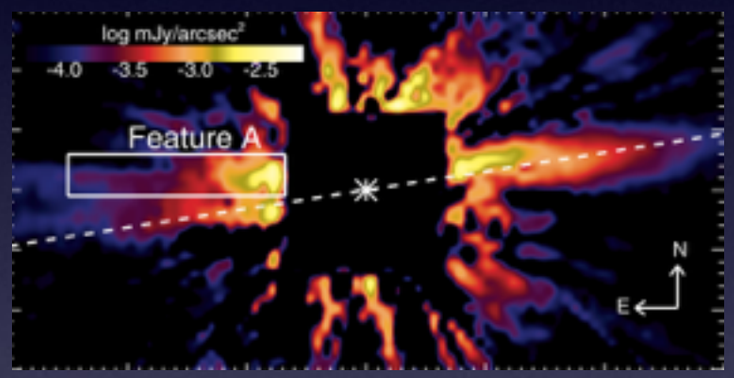
Schneider et al. 1999



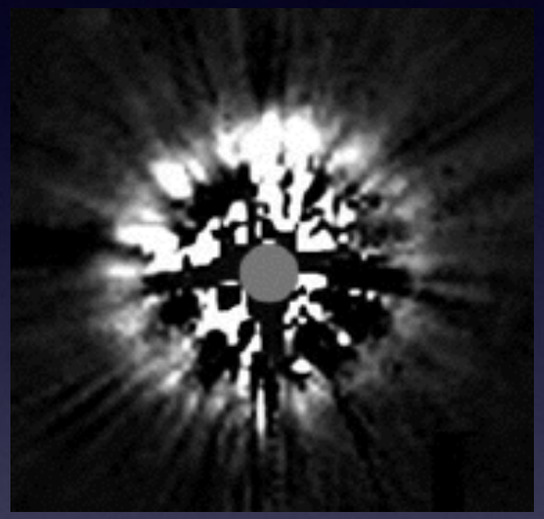
Augereau et al. 1999

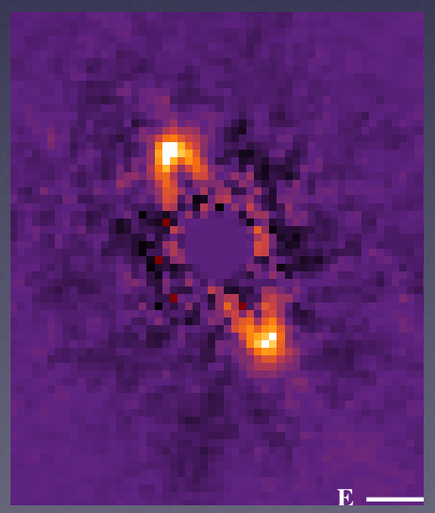


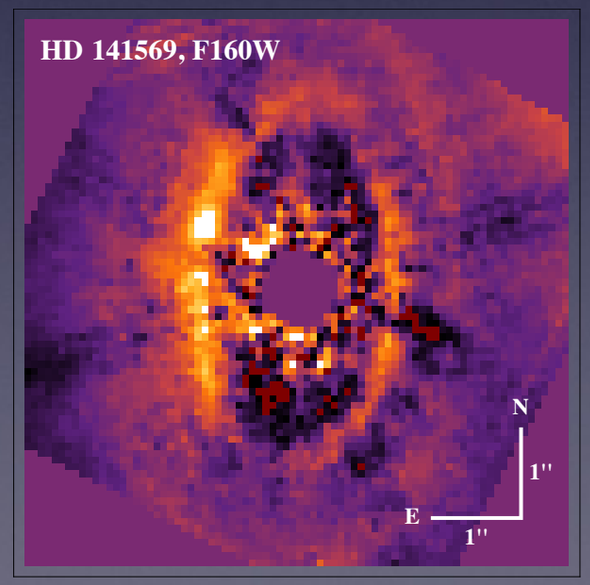
Debes et al. 2008

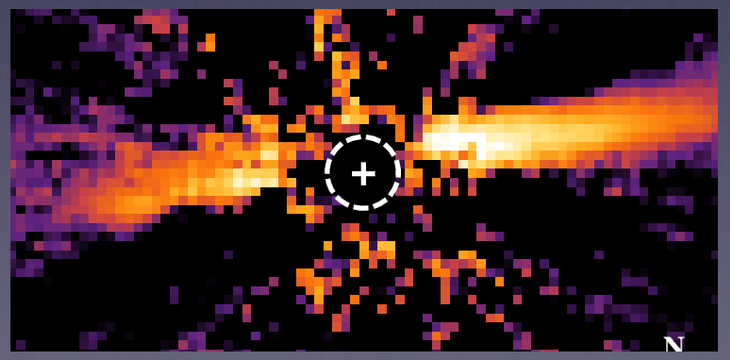


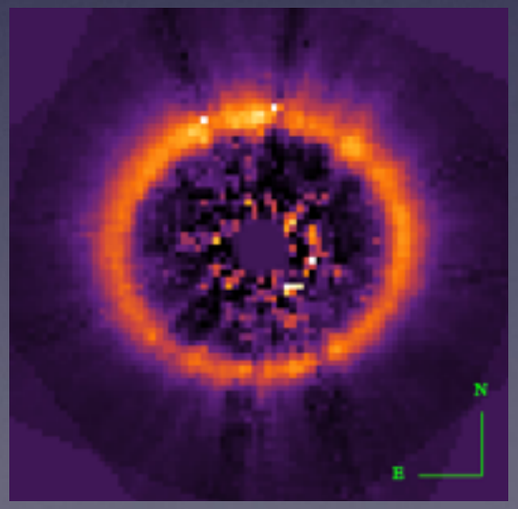
Schneider et al. 2006





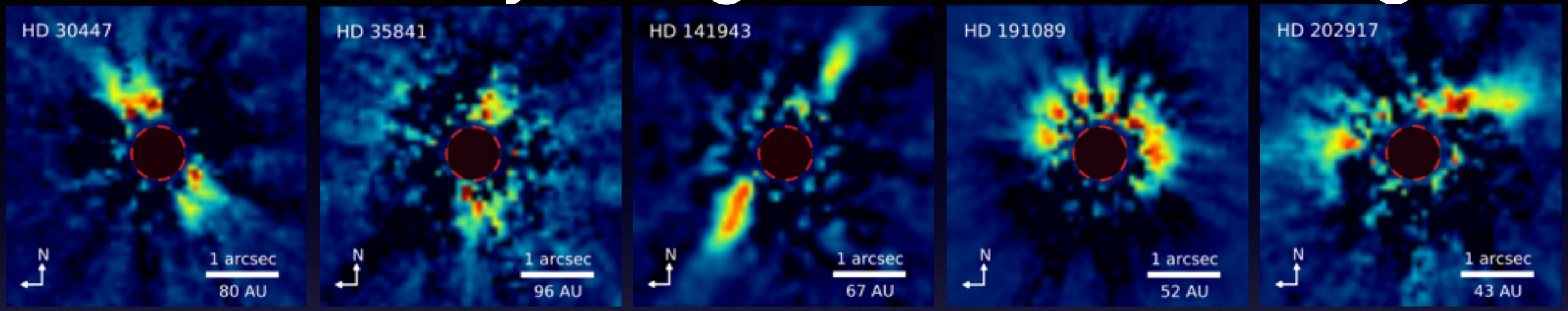


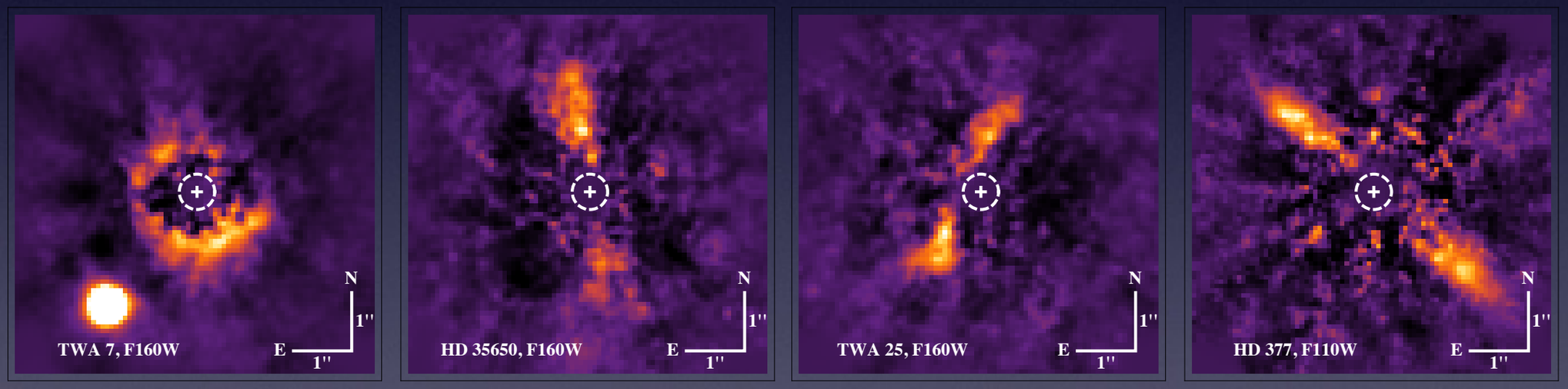




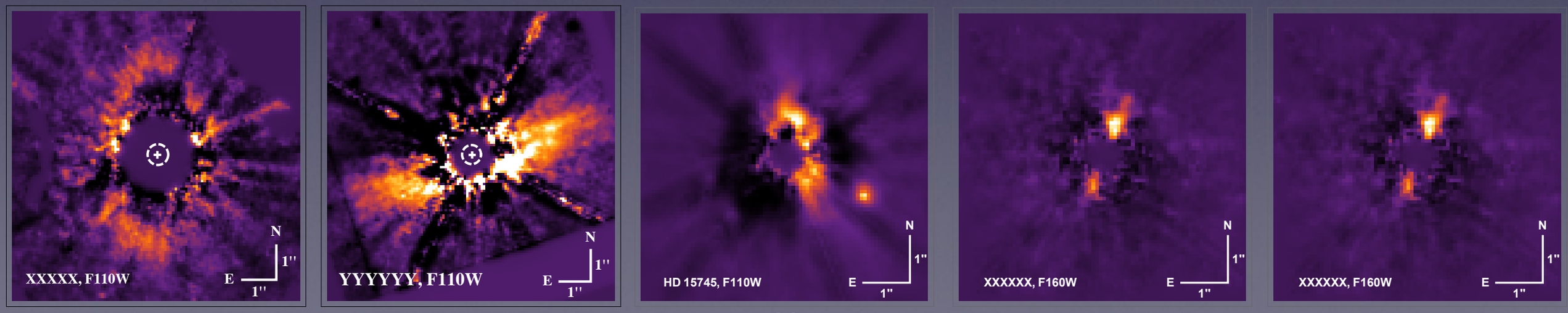
ALICE results

Disks newly imaged in scattered light



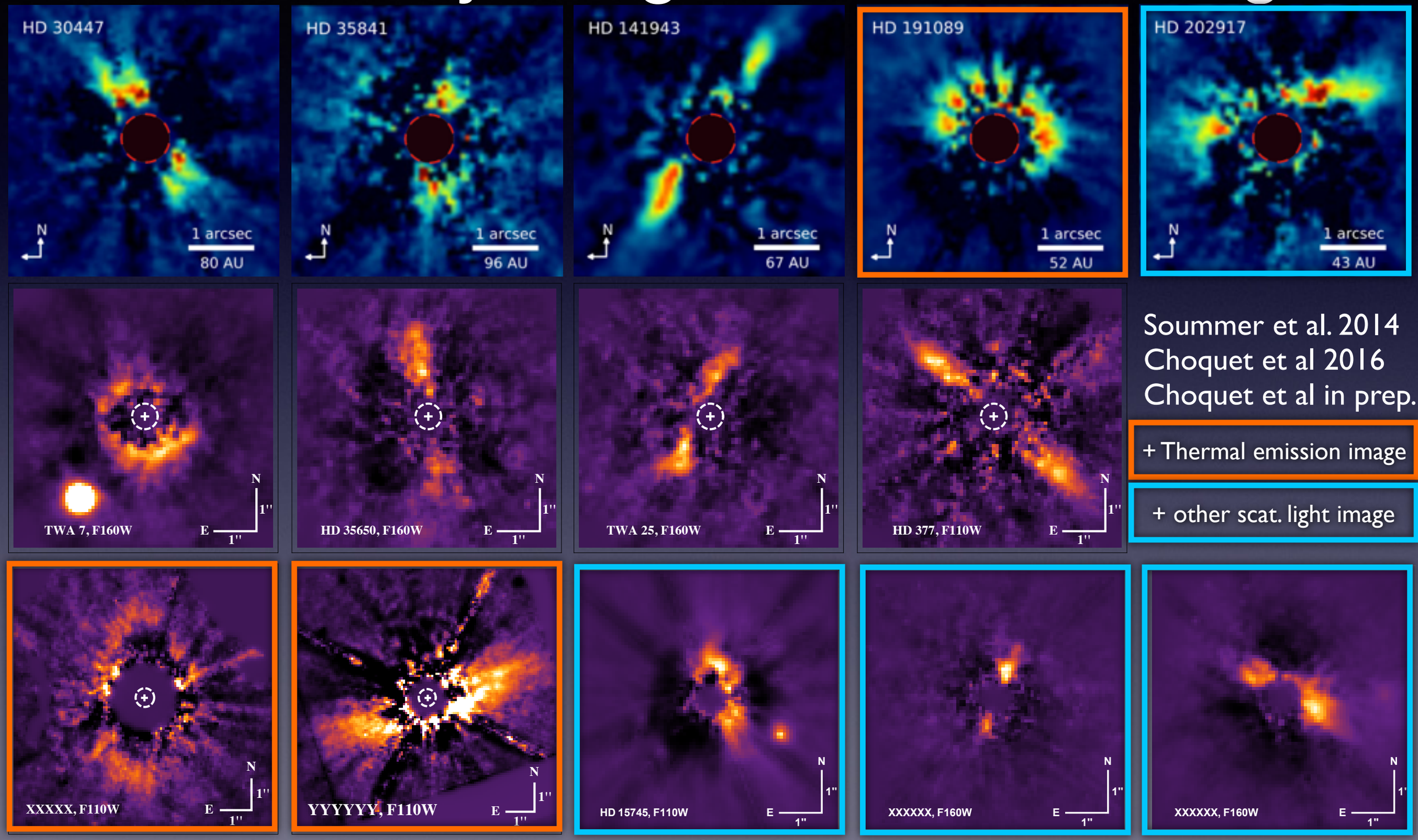


Soummer et al. 2014
Choquet et al 2016
Choquet et al in prep.



ALICE results

Disks newly imaged in scattered light



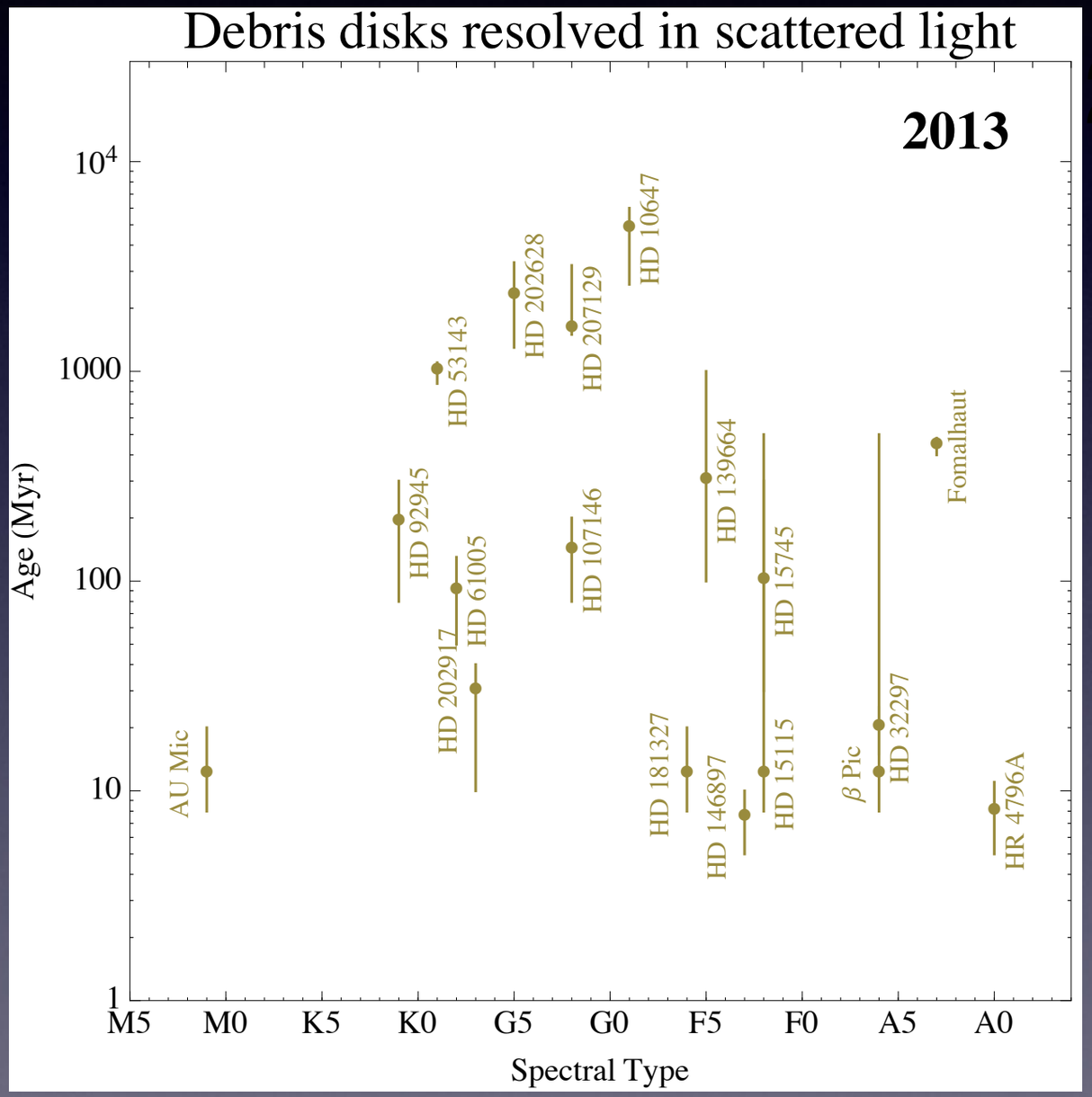
Soummer et al. 2014
Choquet et al 2016
Choquet et al in prep.

+ Thermal emission image

+ other scat. light image

ALICE results

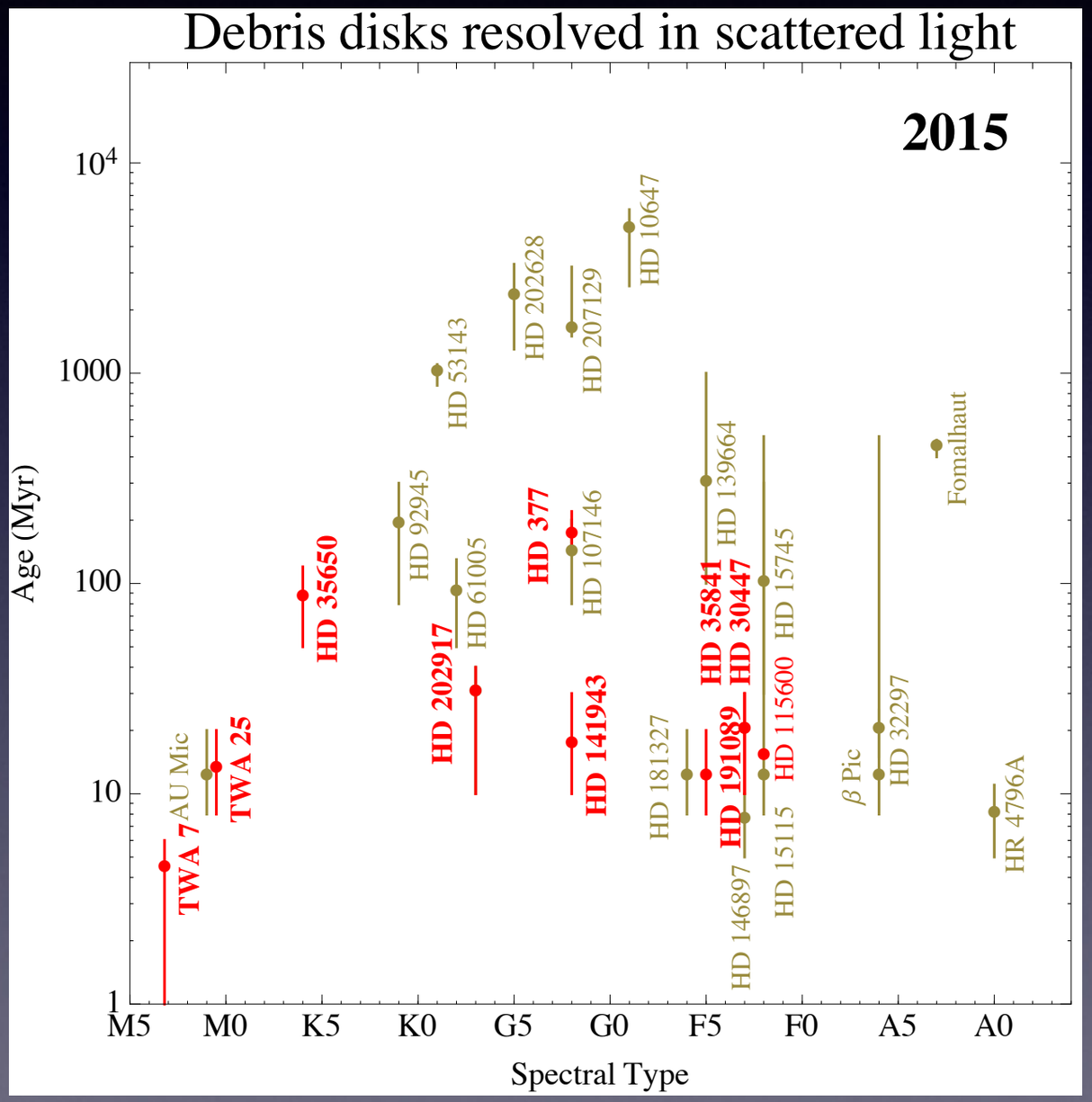
Resolved debris disks overview



2013:
18 disks resolved in scattered light

ALICE results

Resolved debris disks overview



2013:

18 disks resolved in scattered light

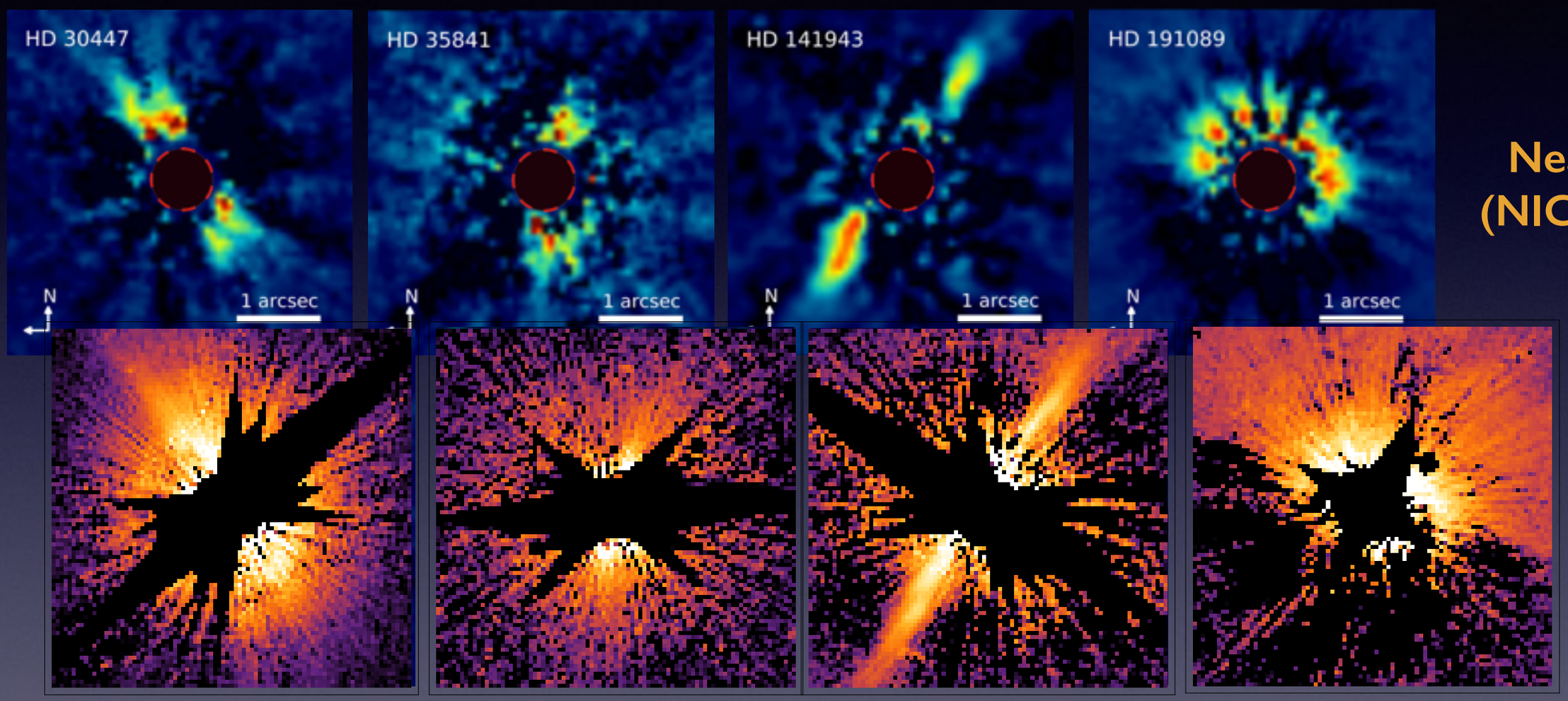
2015:

- 10 new ALICE disks
- 4 new SPHERE/GPI disks

32 disks resolved in scattered light **(30% ALICE disks)**

ALICE results

Disks newly imaged in scattered light



Near-IR (NICMOS)

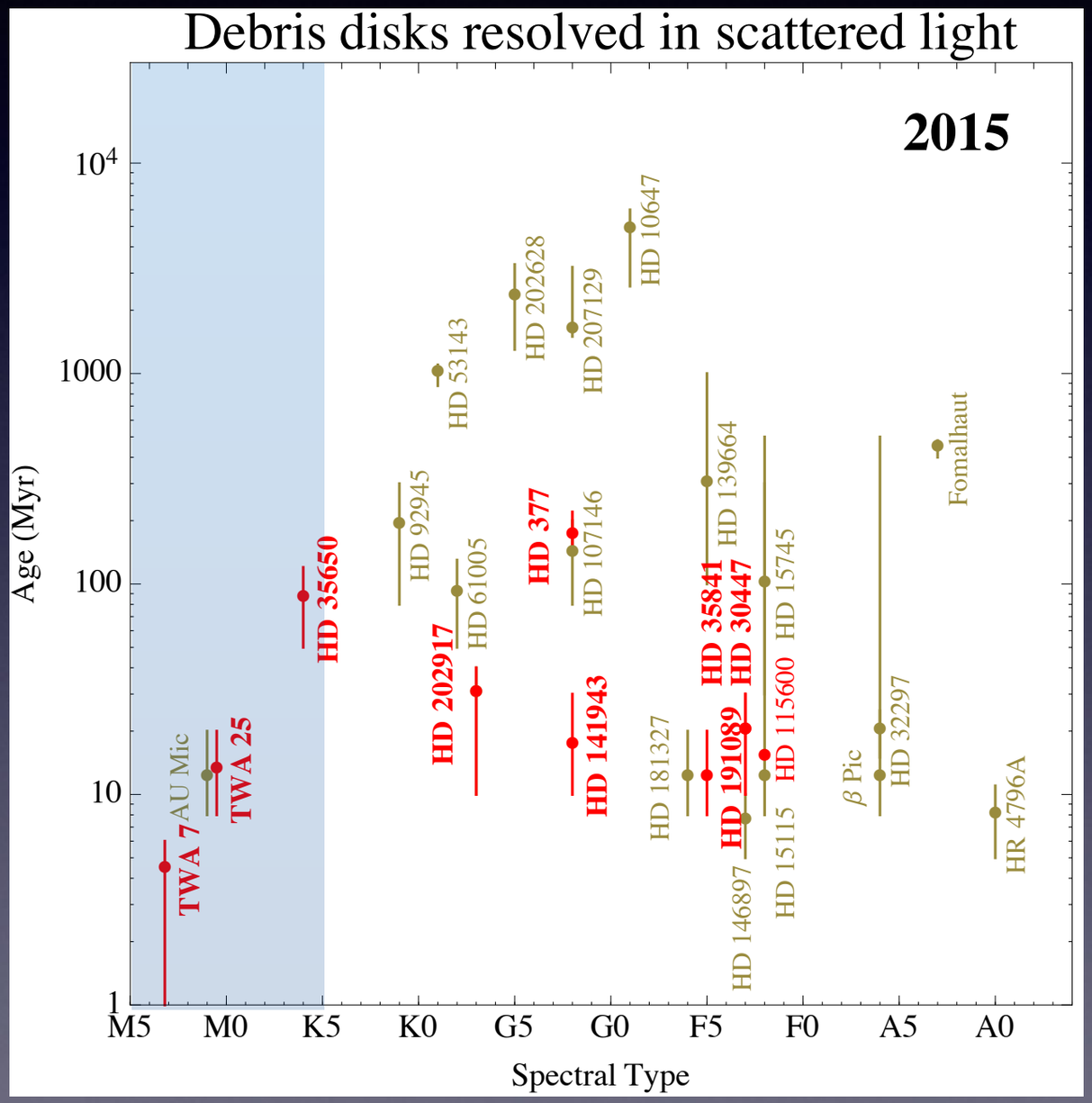
Visible (STIS)

- STIS follow-up observations
  - Visible images (color of the grains)
  - Better angular resolution

Perrin et al. in prep

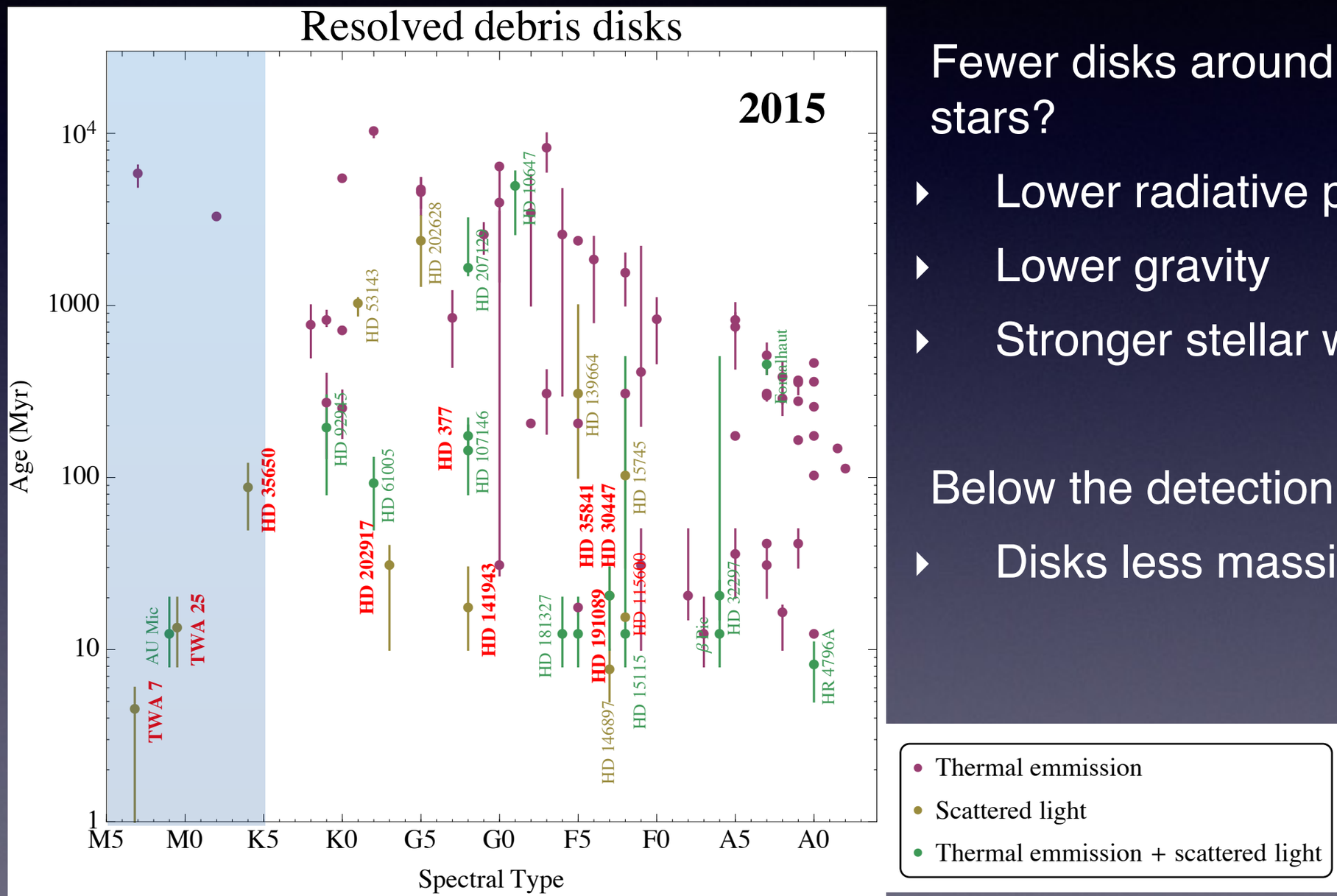
ALICE results

Where are the M dwarf disks?



ALICE results

Where are the M dwarf disks?



Fewer disks around low-mass stars?

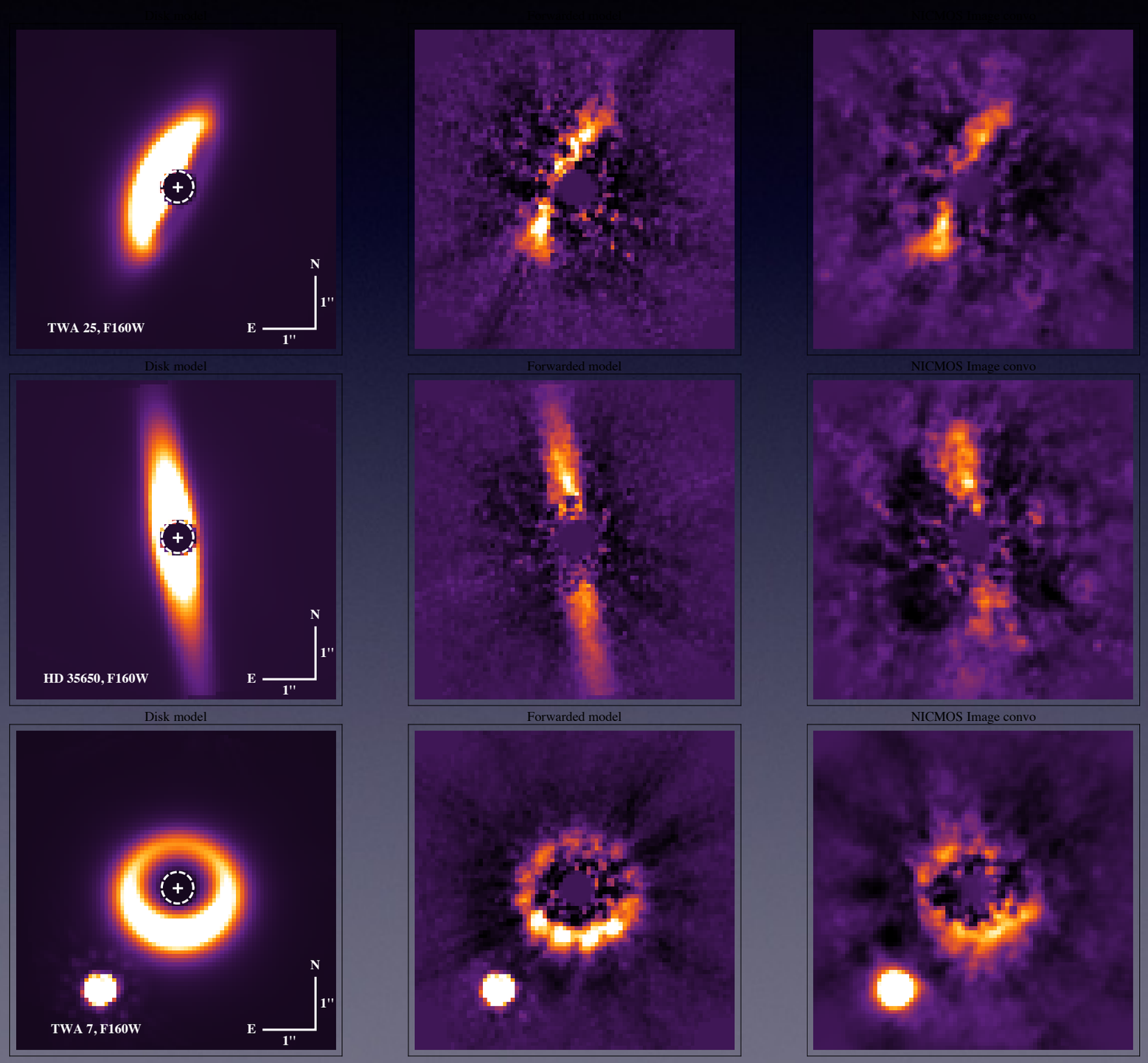
- Lower radiative pressure
- Lower gravity
- Stronger stellar winds

Below the detection limits?

- Disks less massive

ALICE results

Disks photometry



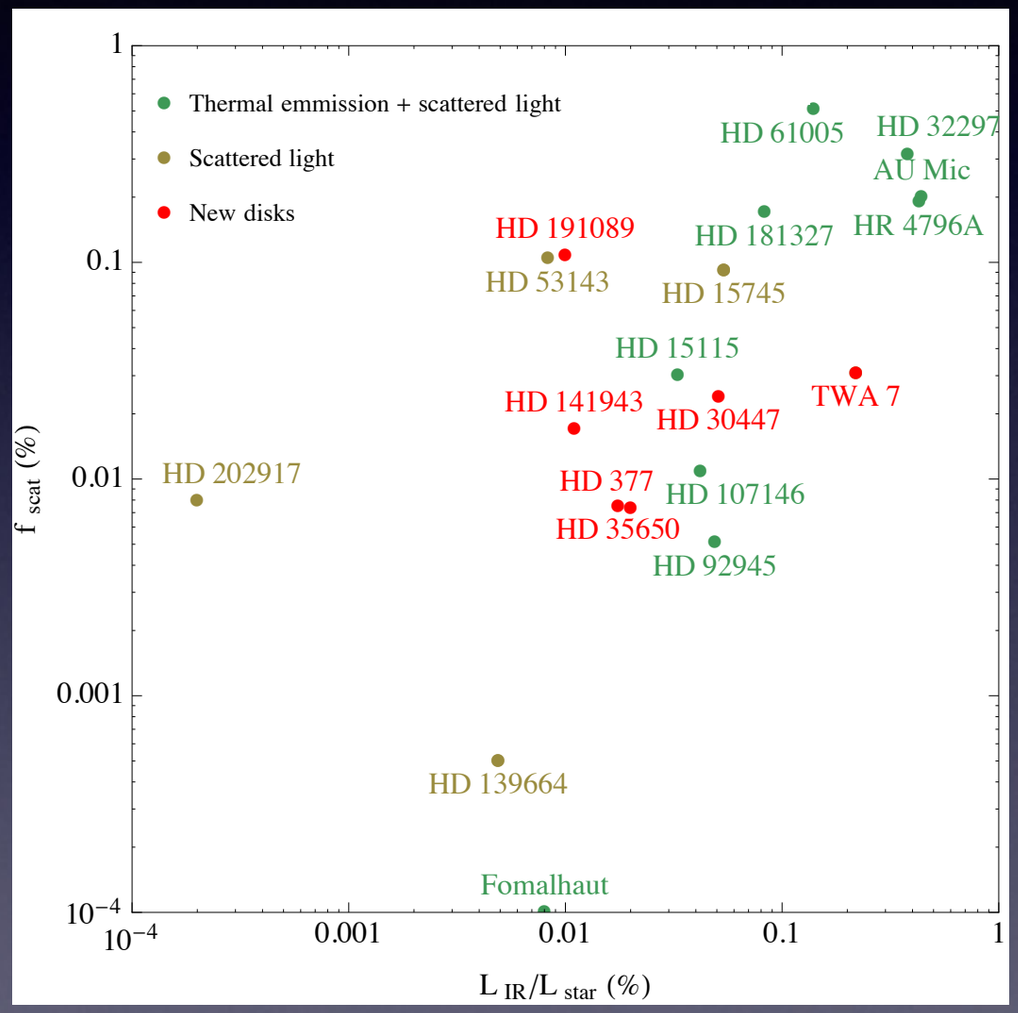
TWA 25	*f_scat:*
Spectral type:	M0.5
Distance:	54 pc
Age:	13 Myr
Association:	TWA
SB:	28 μJy/as^2

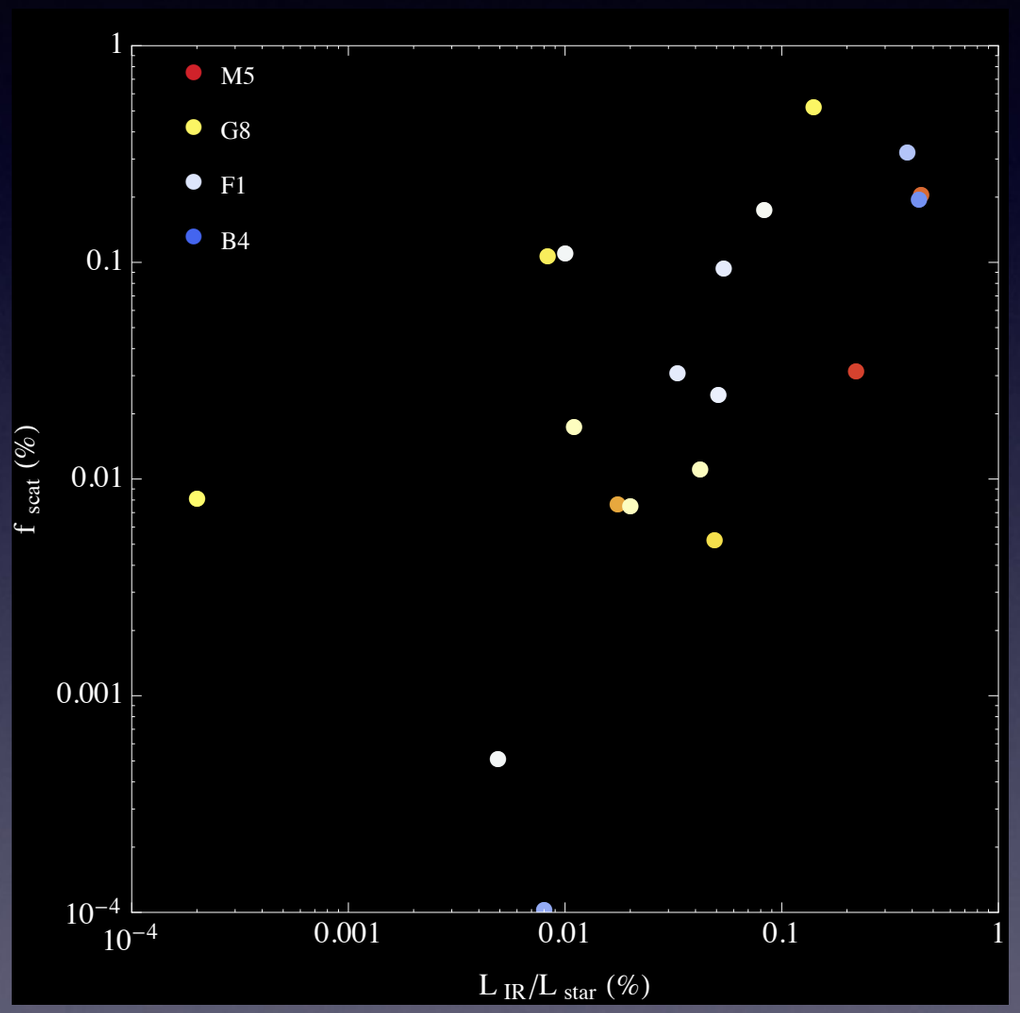
HD 35650	*f_scat:*
Spectral type:	K6
Distance:	18 pc
Age:	~80 Myr
Association:	AB Dor
SB:	56 μJy/as^2

TWA 7	*f_scat:*
Spectral type:	M3.2
Distance:	34 pc
Age:	4.4 Myr
Association:	TWA
SB:	78 μJy/as^2

ALICE results

Disks comparative study

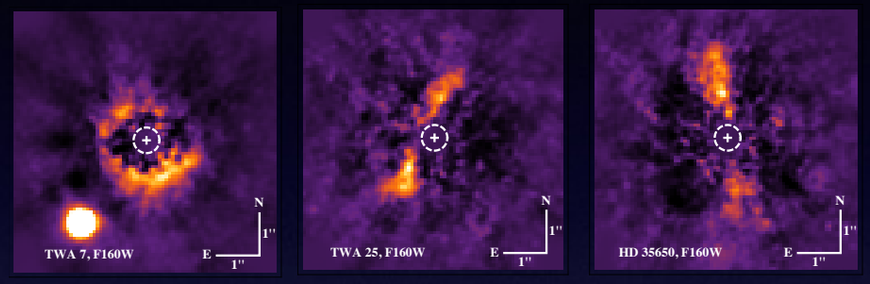




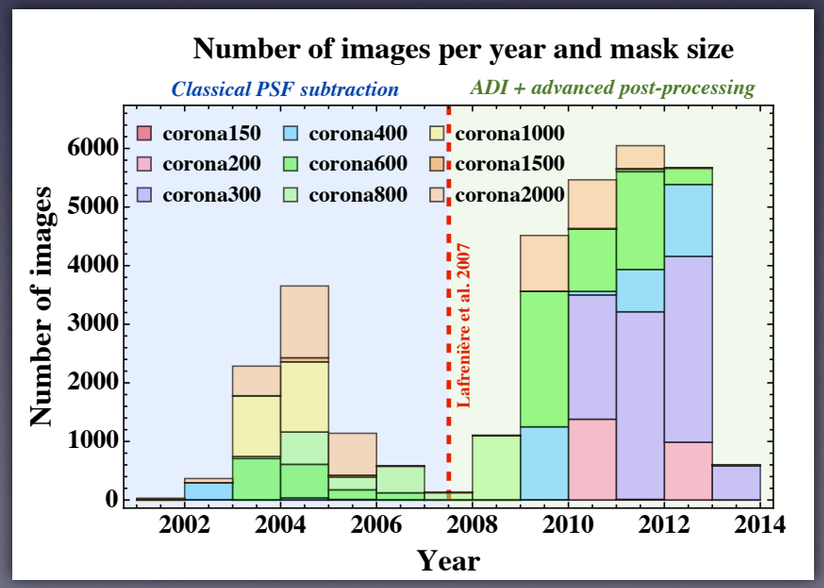
- Caveat: inconsistent dataset (different filters, different metrics)

Take-home messages & Prospects

- **ALICE status**
  - Archive reprocessing complete
  - 11 debris disks newly imaged
  - Detection of 3 disks around low-mass stars



Keck NIRC2 archive



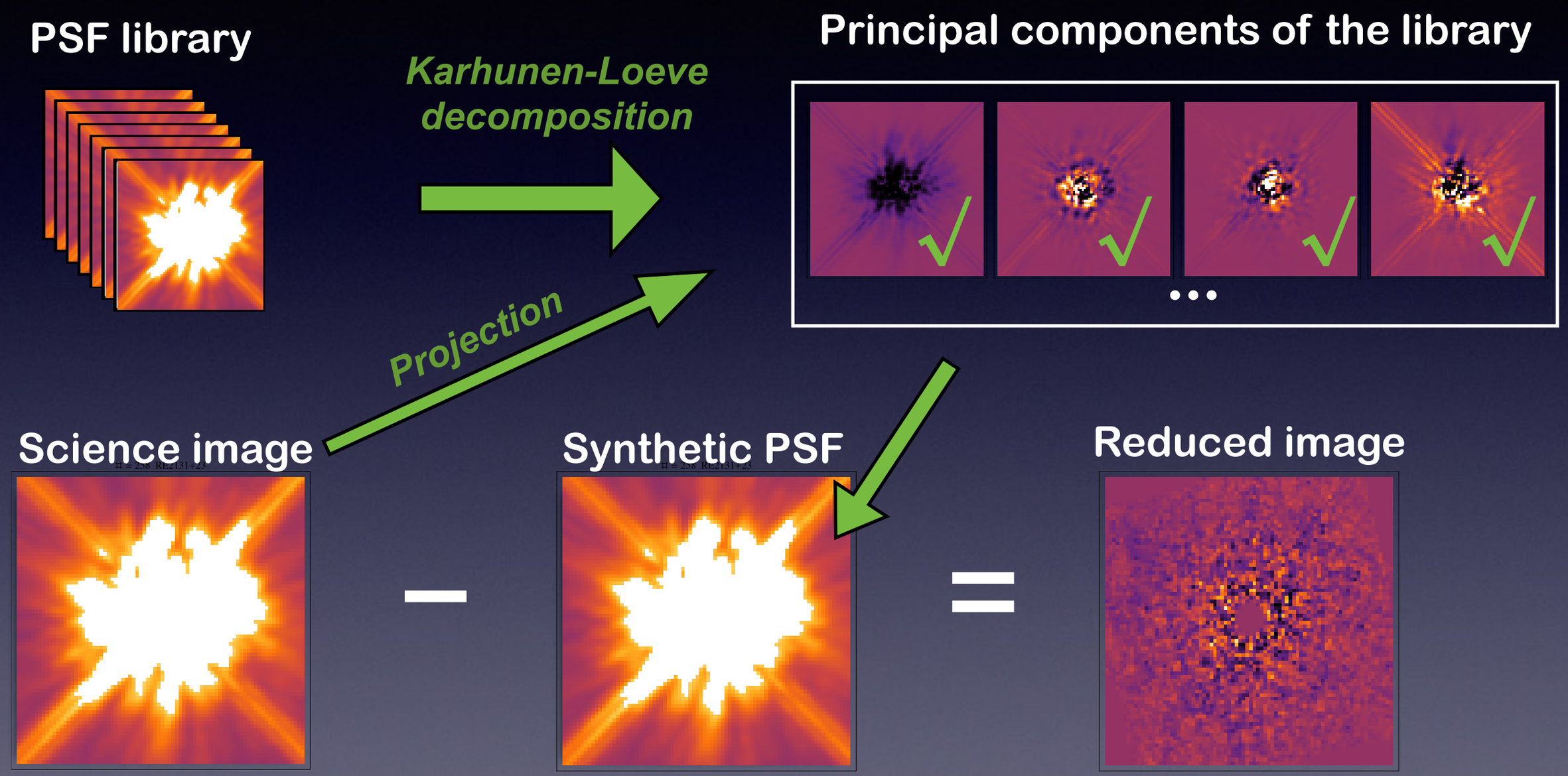
- **Prospects**
  - Follow up and modeling of the disks
  - Comparative study of debris disks
  - Analysis of the Keck archive

That’s it!

That’s it!

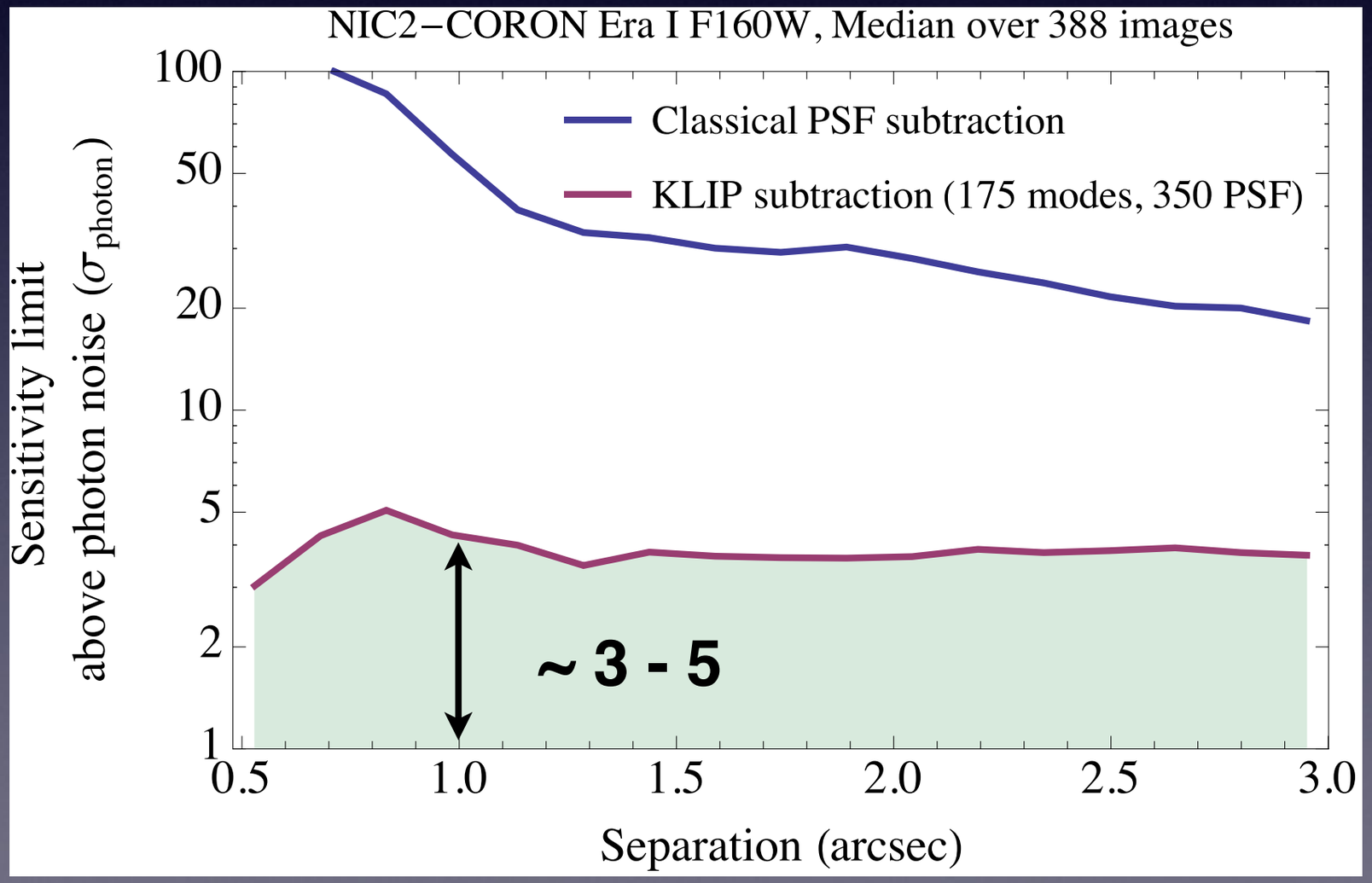
ALICE results

Algorithm calibration



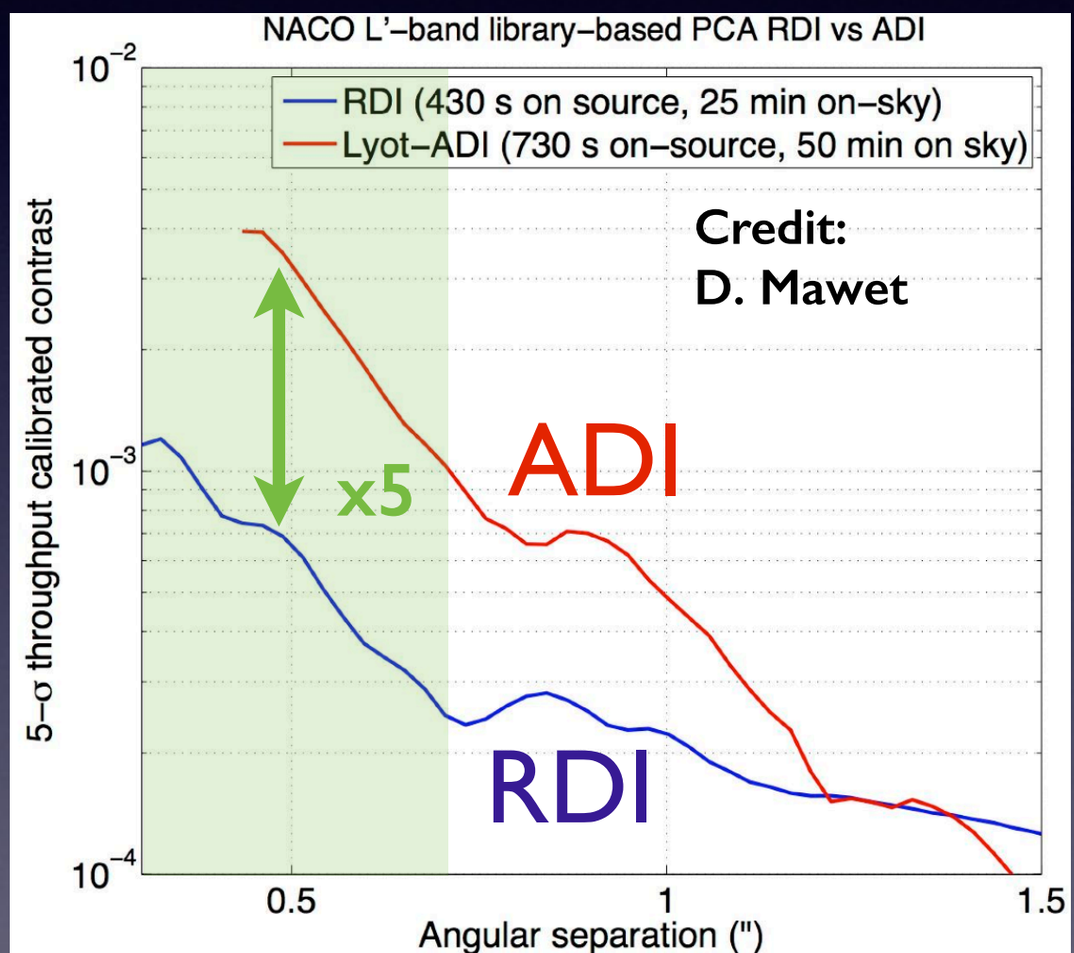
Experience from the program
Contrast gain

- Contrast limit after KLIP: **a few times the photon noise floor**

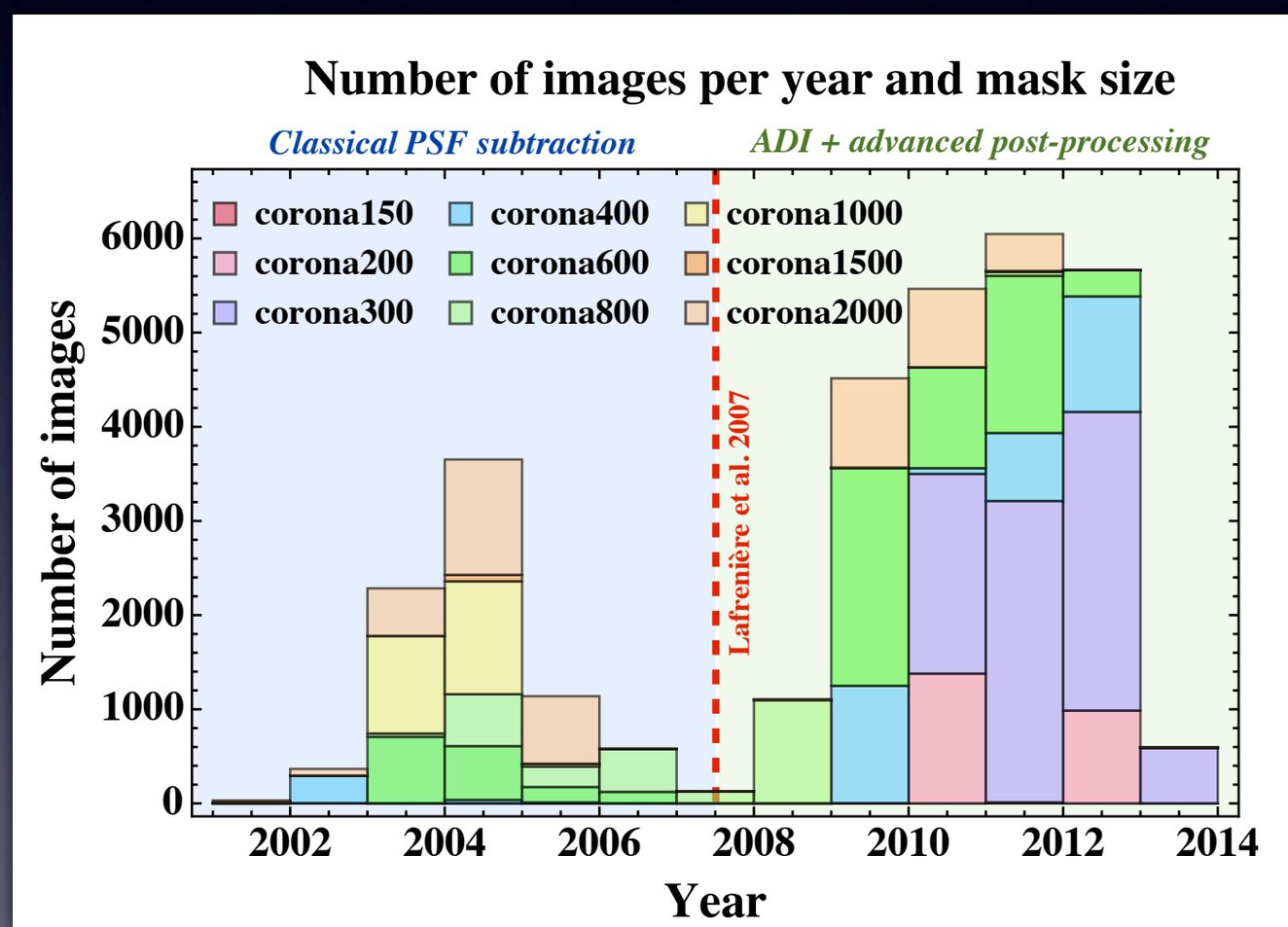


Prospects

Ground-base telescope archives



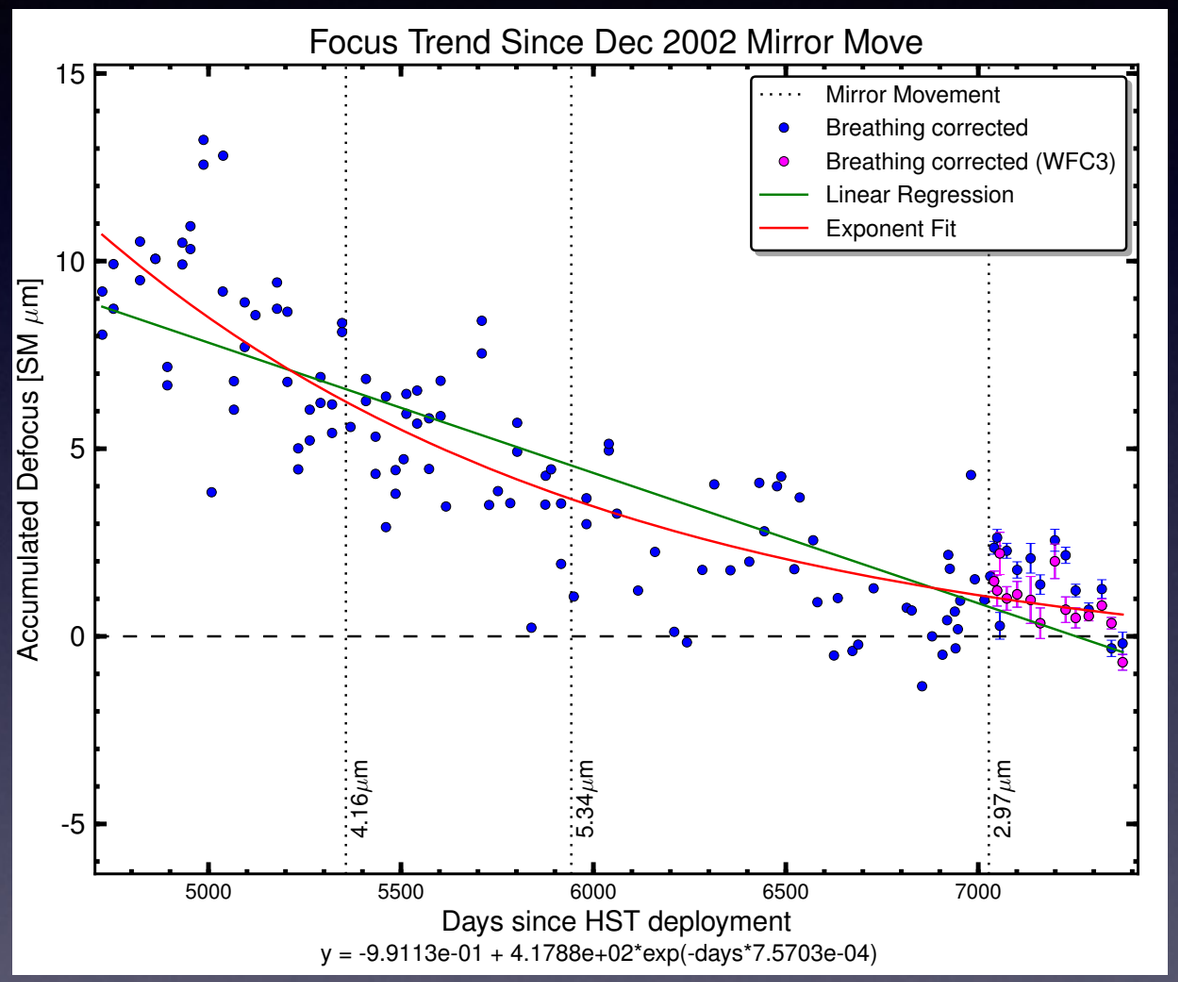
Keck NIRC2 archive

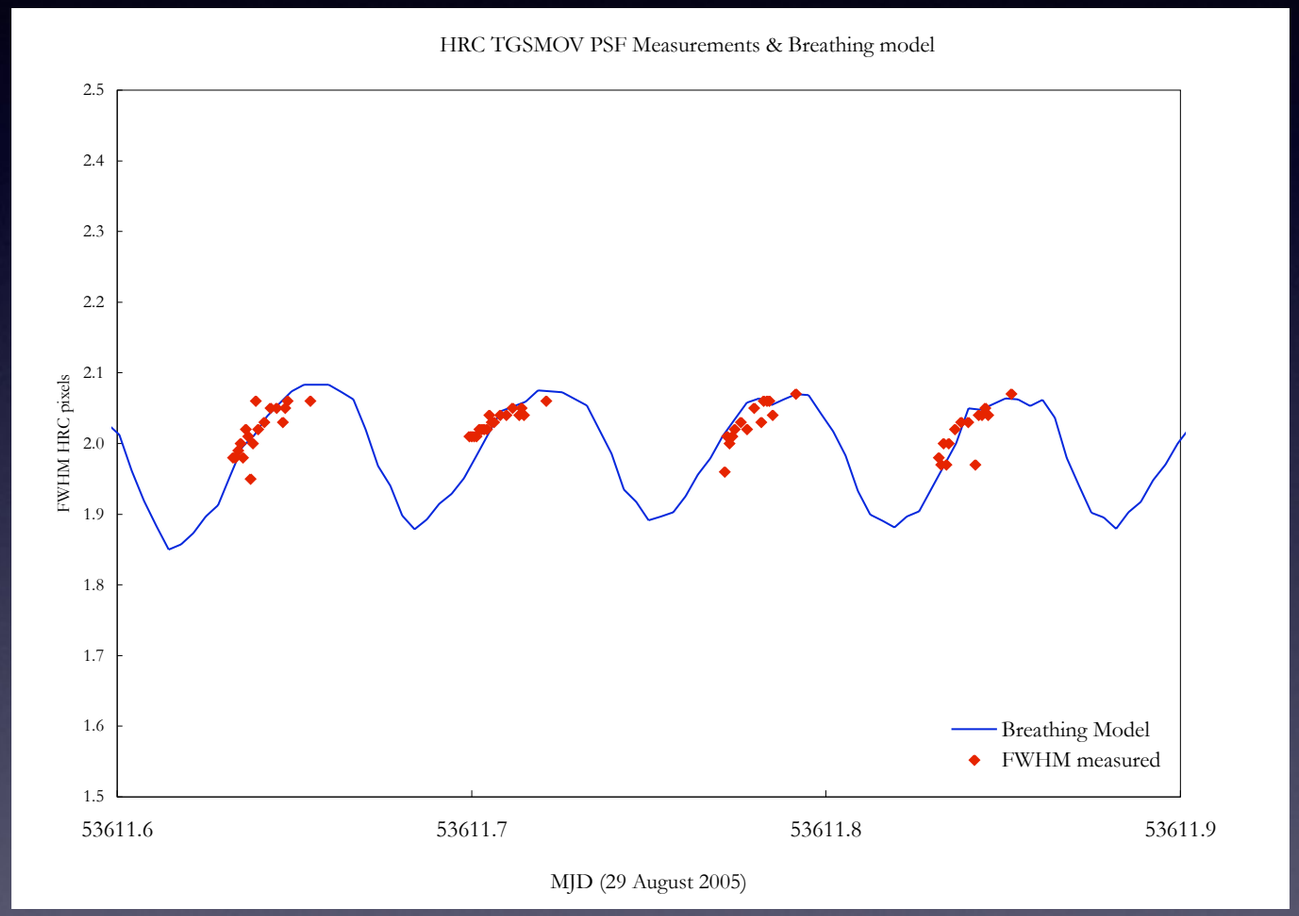


~ x10

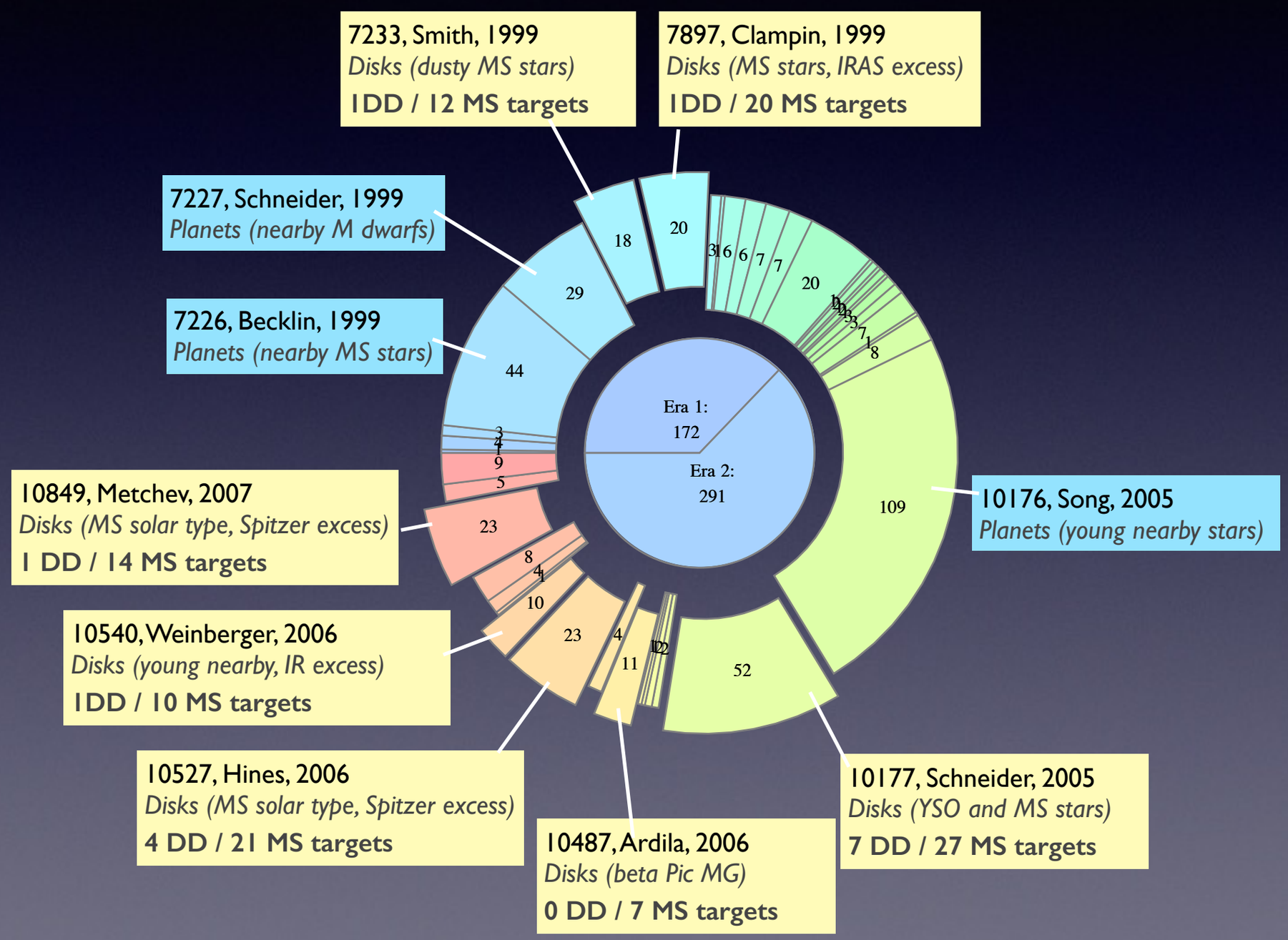
~ x5

Backup slides





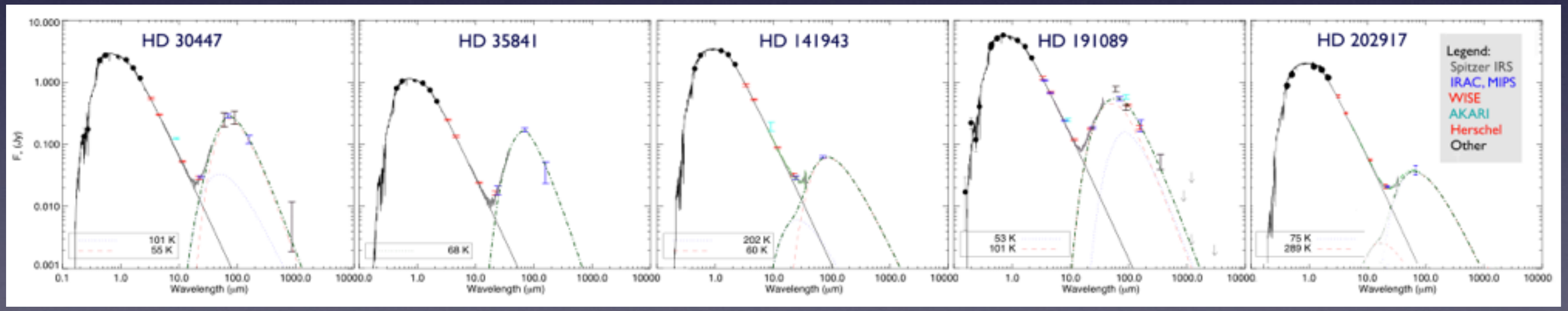
Lallo et al. 2006


7233, Smith, 1999
Disks (dusty MS stars)
1DD / 12 MS targets
7897, Clampin, 1999
Disks (MS stars, IRAS excess)
1DD / 20 MS targets
7227, Schneider, 1999
Planets (nearby M dwarfs)
7226, Becklin, 1999
Planets (nearby MS stars)
10849, Metchev, 2007
Disks (MS solar type, Spitzer excess)
1 DD / 14 MS targets
10540, Weinberger, 2006
Disks (young nearby, IR excess)
1DD / 10 MS targets
10527, Hines, 2006
Disks (MS solar type, Spitzer excess)
4 DD / 21 MS targets
10487, Ardila, 2006
Disks (beta Pic MG)
0 DD / 7 MS targets
10177, Schneider, 2005
Disks (YSO and MS stars)
7 DD / 27 MS targets
10176, Song, 2005
Planets (young nearby stars)
Era 1:
172
Era 2:
291
18
20
29
44
23
10
23
4
11
52
109
20

Backup slides

Table 1
System Properties and *HST* Program Information

Name	SpT	V	B–V	$L_{IR}/L_{\star}$[a] ($\times 10^{-4}$)	Dist. (pc)	Ref.	Association	Age (Myr)	Ref.	*HST* Program	Filter	Observation Date
HD 30447	F3V	7.86	0.39	7.9	80 ± 5	1	Columba	10–40	5, 6	10177	F110W	2005
HD 35841	F3V	8.90	0.41	13	96	2	Columba	10–40	5, 6	10177	F110W	2005
HD 141943	G2V	7.85	0.63	1.2	67 ± 7	3, 4	···	17–32	4, 8, 9	10176, 10527	F160W, F110W	2006, 2007
HD 191089	F5V	7.18	0.44	13	52 ± 1	1	β Pic	8–20	7	10527	F110W	2007
HD 202917	G7V	8.67	0.65	2.5	43 ± 2	1	Tuc–Hor	10–40	5, 6	7226, 10849	F160W, F110W	1999, 2007

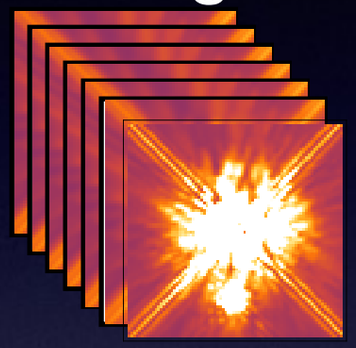


Soummer et al. 2014

ALICE results

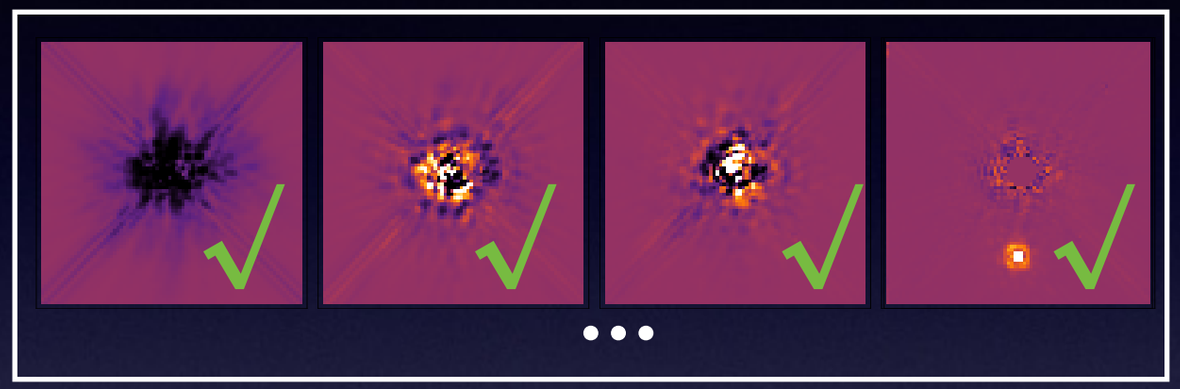
Algorithm calibration

PSF library with signal



Karhunen-Loeve decomposition

Principal components of the library



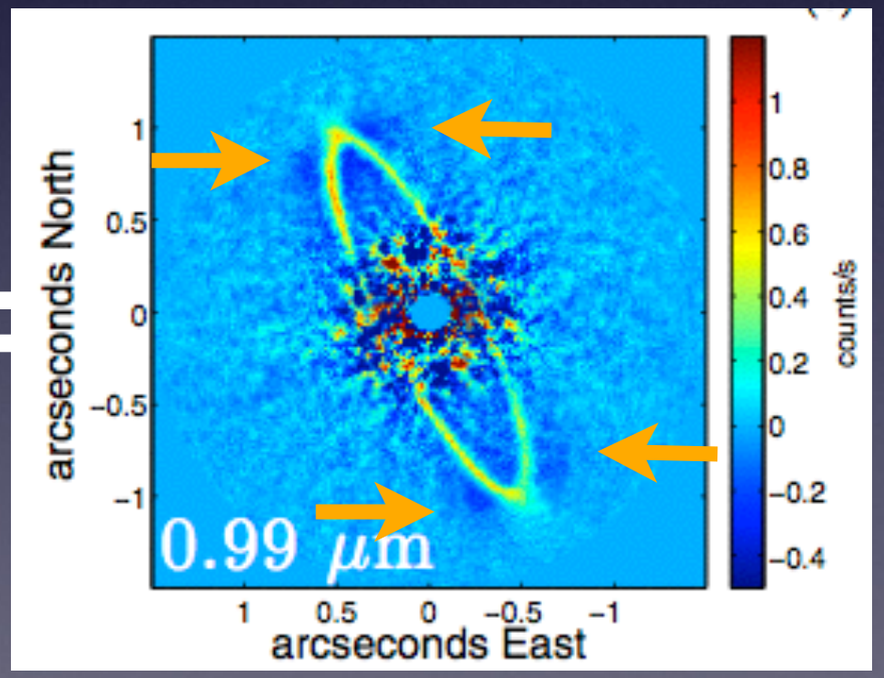
Projection

Science image

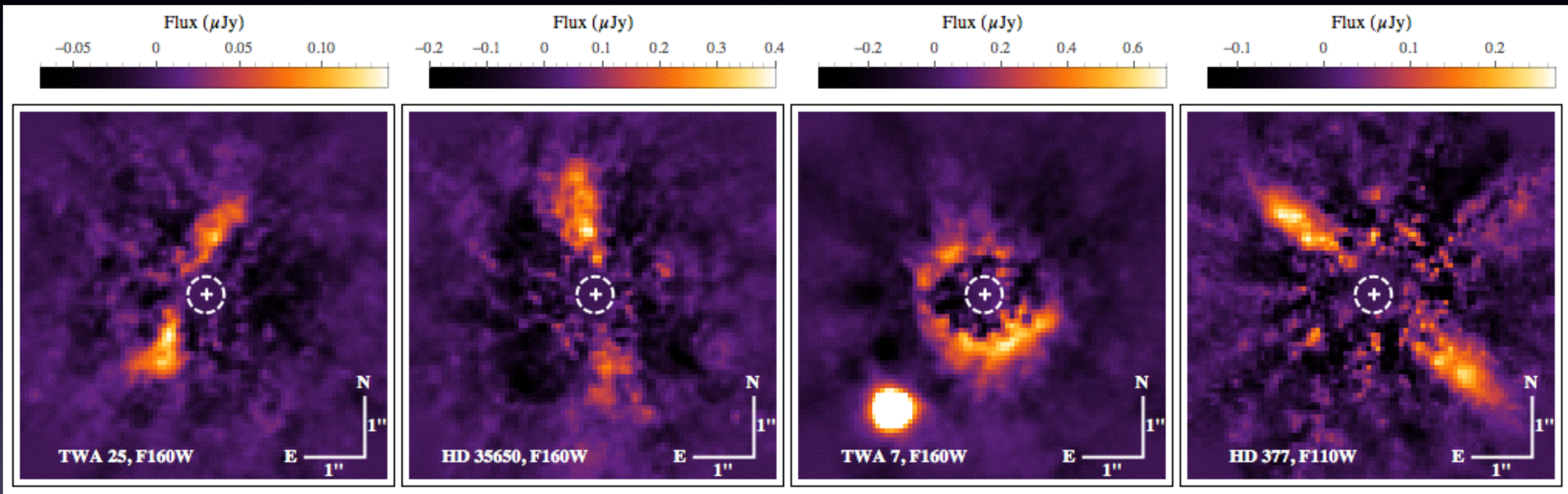
−

Synthetic PSF

=



Rodigas et al. 2015

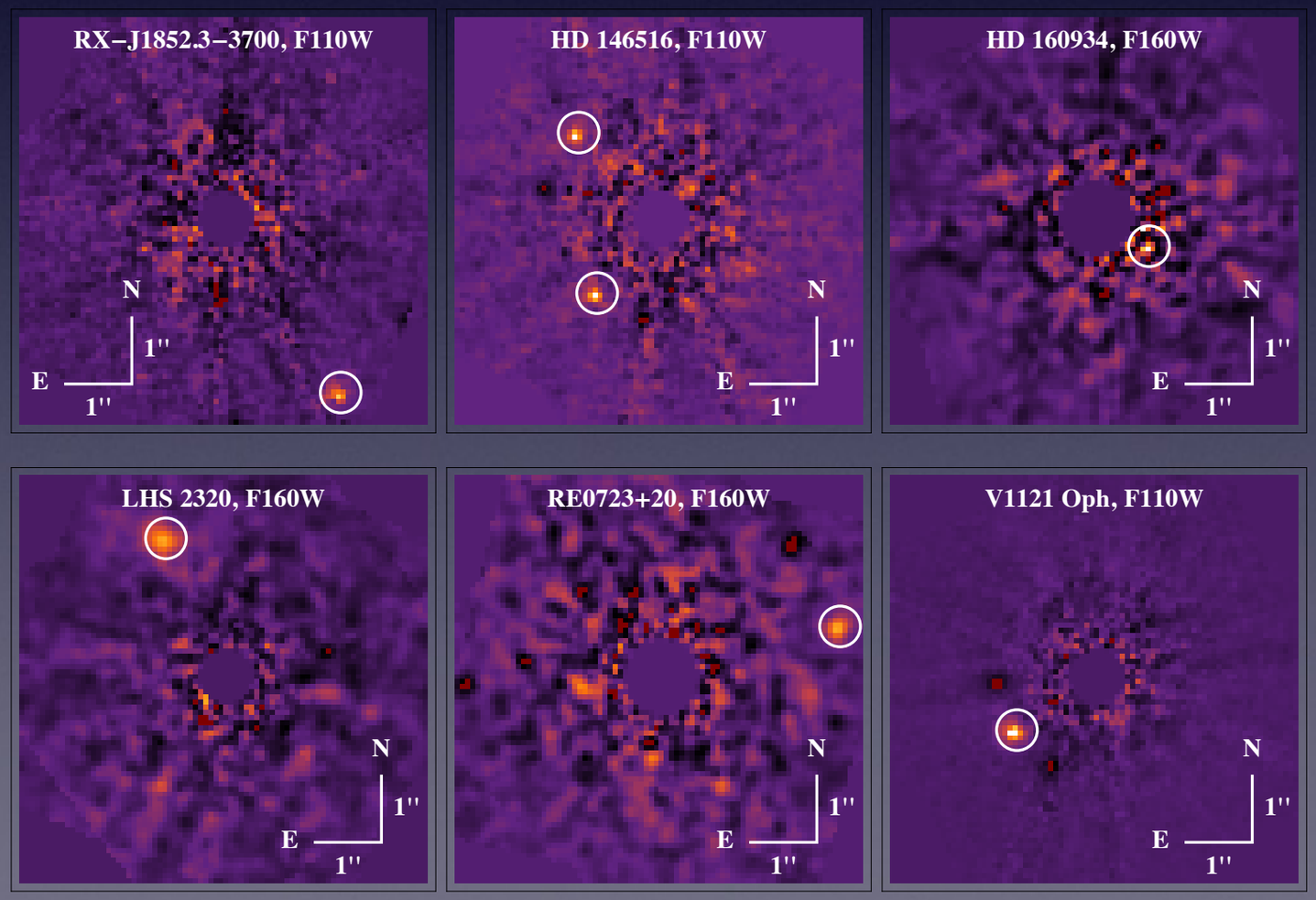


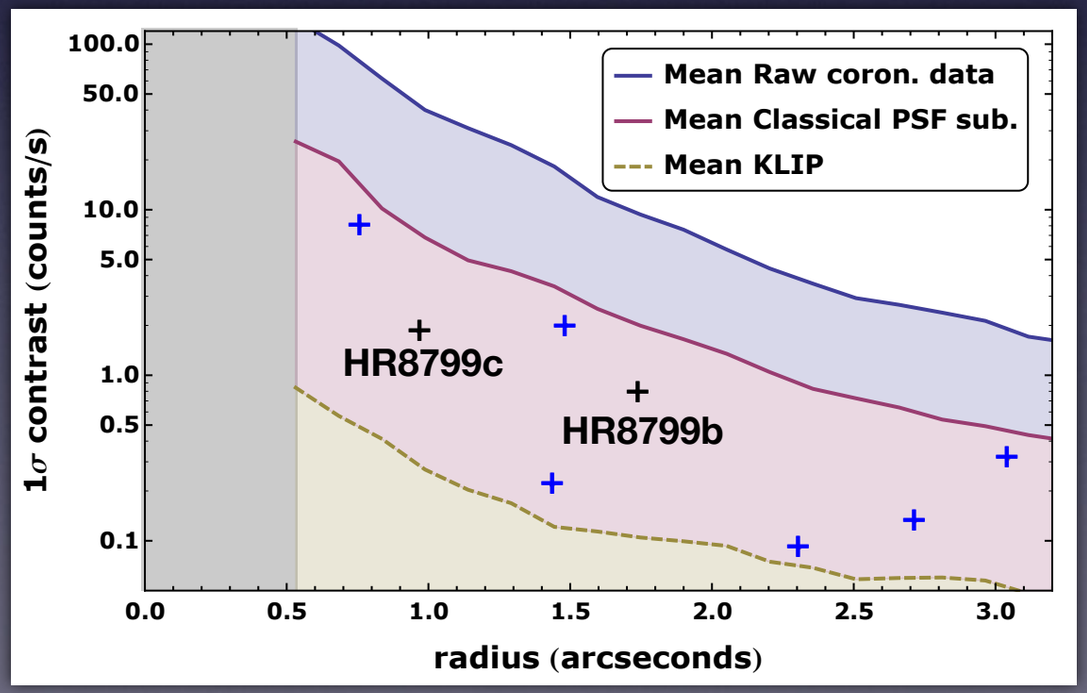
TWA 25		**HD 35650**		**TWA 7**		**HD 377**	*J:*
Spectral type:	M0.5	*Spectral type:*	K6	*Spectral type:*	M3.2	*Spectral type:*	G2
Distance:	54 pc	*Distance:*	18 pc	*Distance:*	34 pc	*Distance:*	39 pc
Age:	13	*Age:*	80 Myr	*Age:*	4.4	*Age:*	220
Association:	Myr	*Association:*	AB	*Association:*	Myr	*Association:*	Myr
V:	TWA	*V:*	Dor	*V:*	TWA	*V:*	-
H:	11.41	*H:*	9.054	*H:*	10.91		

ALICE results

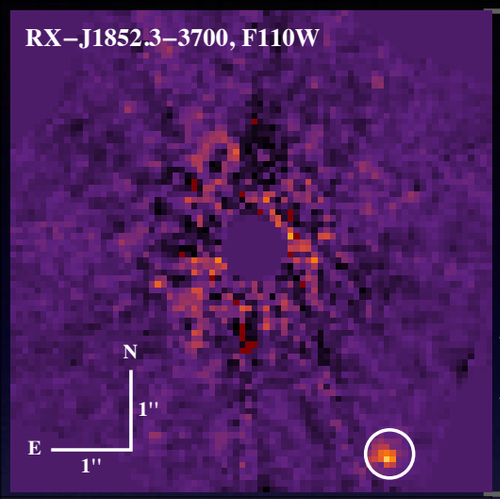
New substellar companion candidates

- Upcoming follow-up observations:
  - HST cycle 21: WFC3 program, PI L. Pueyo
  - VLT period 92: SINFONI program, PI L. Pueyo



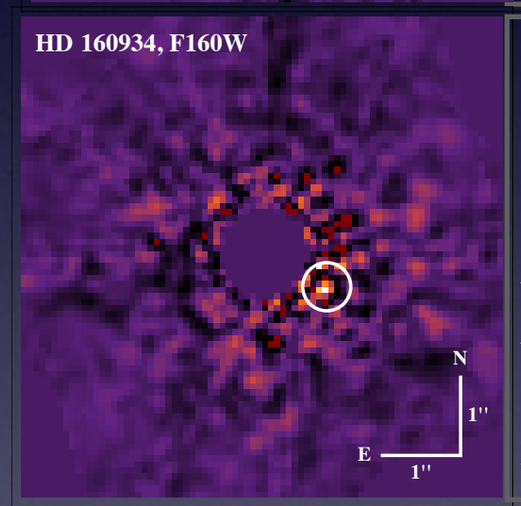


Backup slides



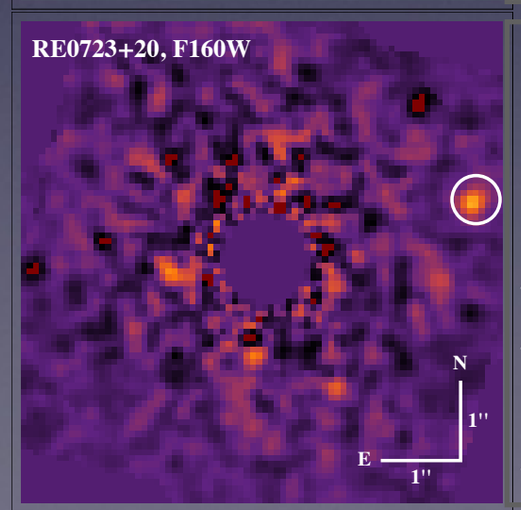
RX J1852.3-3700 ΔJ_{cand}:

Spectral type:	K3
Distance:	130 pc
Age:	3 Myr
Association:	Cha
J_{star}:	9.77



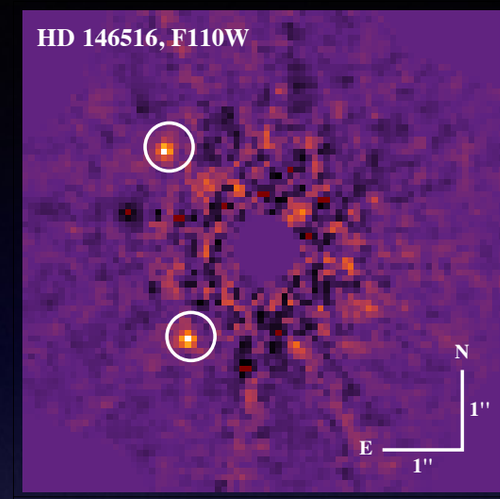
HD 160934

Spectral type:	K7Ve
Distance:	33 pc
Age:	100
Association:	Myr
H_{star}:	AB Dor
ΔH_{cand}:	7.00



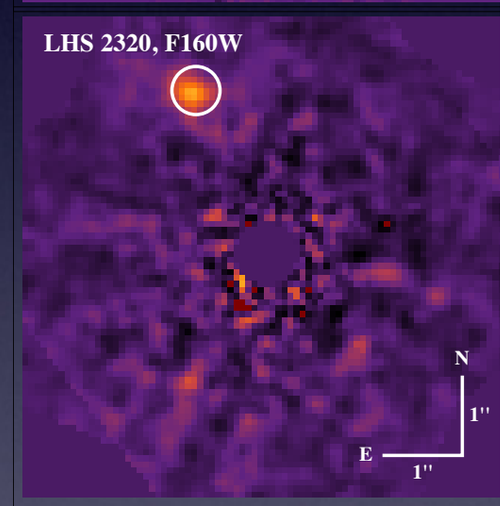
RE0723+20

Spectral type:	K5Ve
Distance:	25 pc
Age:	100
Association:	Myr
H_{star}:	AB Dor
ΔH_{cand}:	7.03



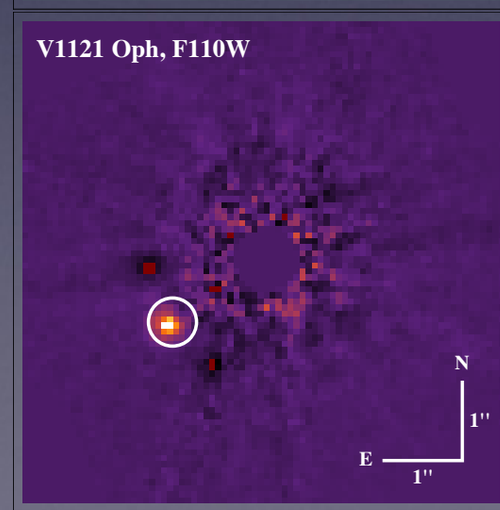
HD 146516

Spectral type:	G7V
Distance:	120 pc
Age:	10 Myr
Association:	Up
J_{star}:	Sco
ΔJ_{cand}:	8.51



LHS 2320

Spectral type:	M5.0V
Distance:	22 pc
Age:	100
Association:	Myr
H_{star}:	-
ΔH_{cand}:	9.28



V1121 Oph

Spectral type:	K4Ve
Distance:	125 pc
Age:	1 Myr
Association:	ρ Oph
J_{star}:	8.30
ΔJ_{cand}:	8.6

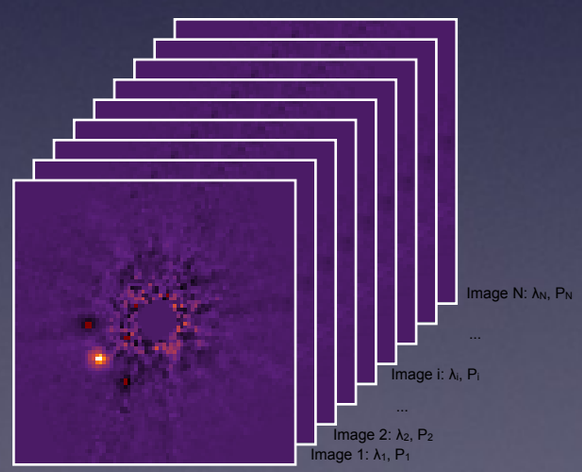
The ALICE project

High level science products

- Effort to standardize the science products of HC instruments
- Collaboration with JWST coronagraph WG, GPI, SPHERE, P1640 teams

Multi-extension FITS file

3 image extensions (images, noise map, SNR map)



1 table extension (λ, polarization, field orientation)

	EFFWAVE (μm)	EFFWAVEERR (μm)	EFFBAND (μm)	EFFBANDERR (μm)
Image 1	1.65	0.001	0.35	0.001
Image 2	1.492	0.001	0.035	0.001
...	...	...	...	...
Image i	1.65	0.001	0.035	0.001
...	...	...	...	...
Image N	1.807	0.001	0.035	0.001

1 optional extension (point source detection)

	SNR (-)	SEP (arcsec)	PA (°)	Flux (mag)
Image 1	12	1.1	231	18.7
Image 2	9	1.09	231	18.2
...	...	...	...	...
Image i	10	1.1	232	18
...	...	...	...	...
Image N	12	0.9	231	18.9

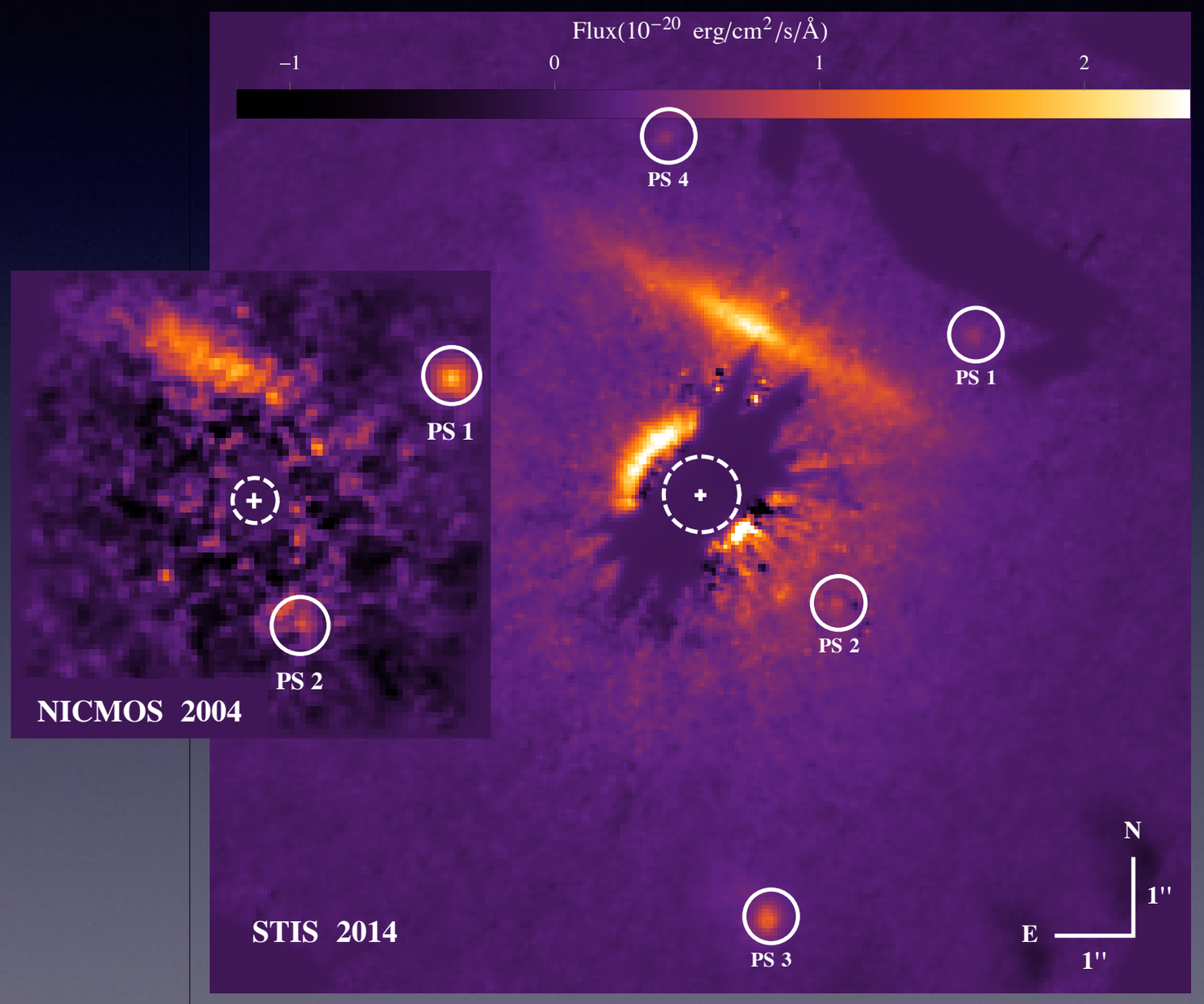
Choquet et al. 2014

- Compatible with IFU data, PDI data and imagers

ALICE results

~~Disks newly imag~~ttered light

Background objects



- Background galaxy probability:
  ~ 6 in the 400 NICMOS archive
- Lower probability with ground based instruments
  (because of smaller pixels)

Choquet et al. 2015, submitted