Multiplicity study of massive stars with High-contrast imaging

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What are massive stars?

What are massive stars?
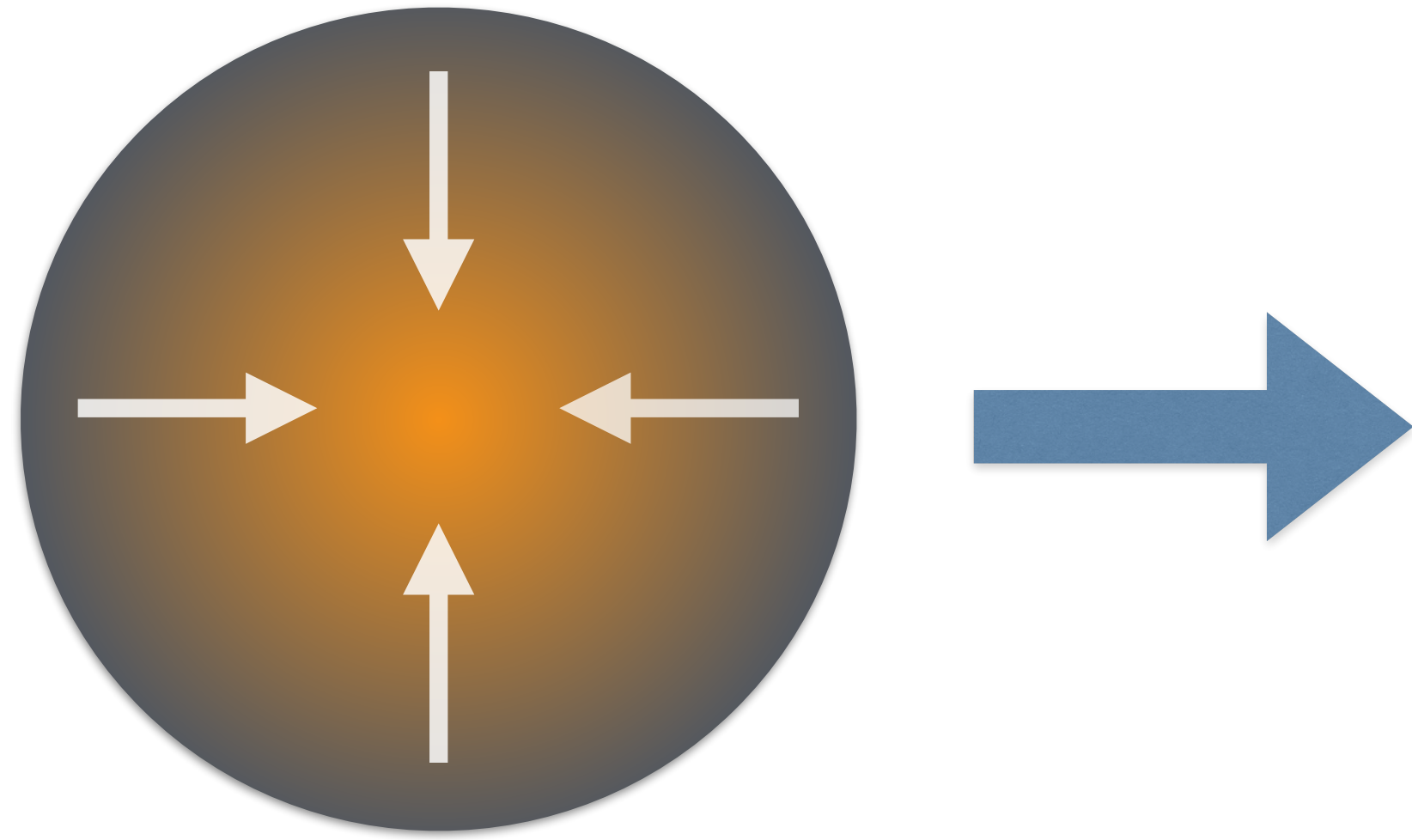
Progenitors of gravitational waves

$M>8M_\odot$

$\tau_{form}\sim10^5$ years

>80% binaries

Massive Star Formation
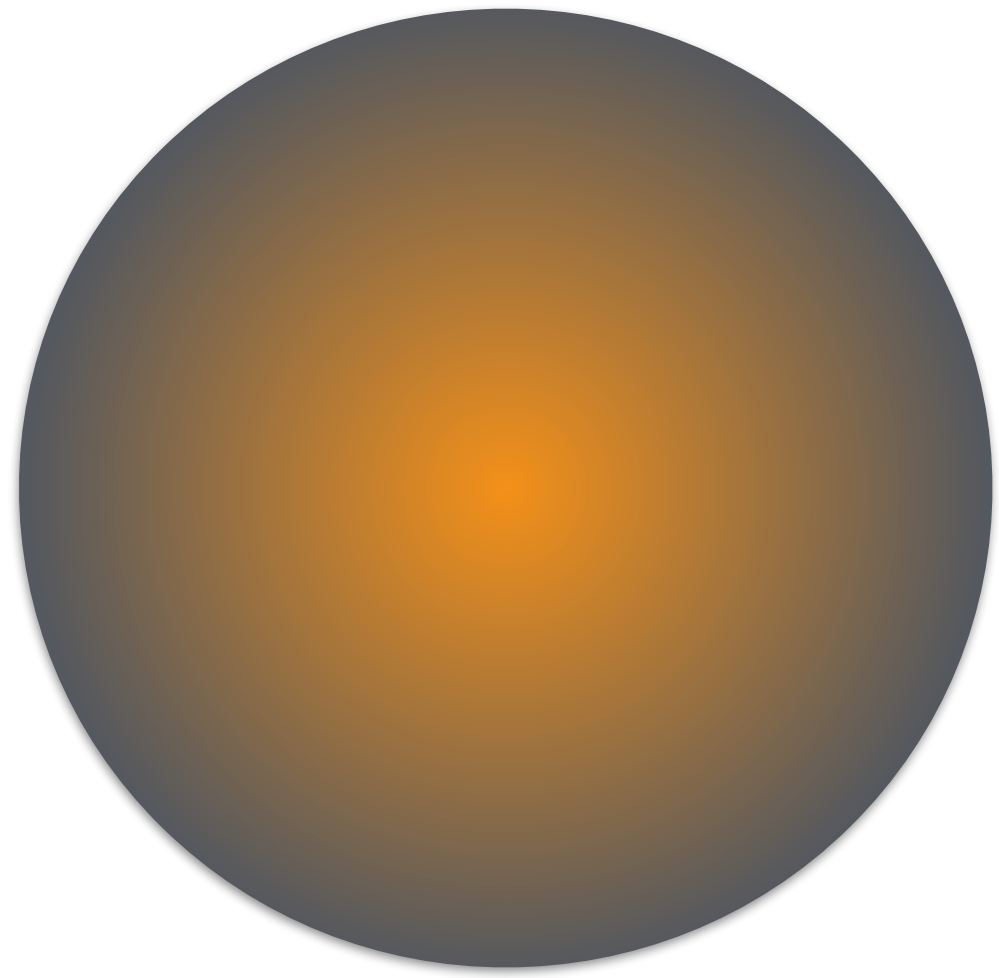
Massive Star Formation

Massive Star Formation
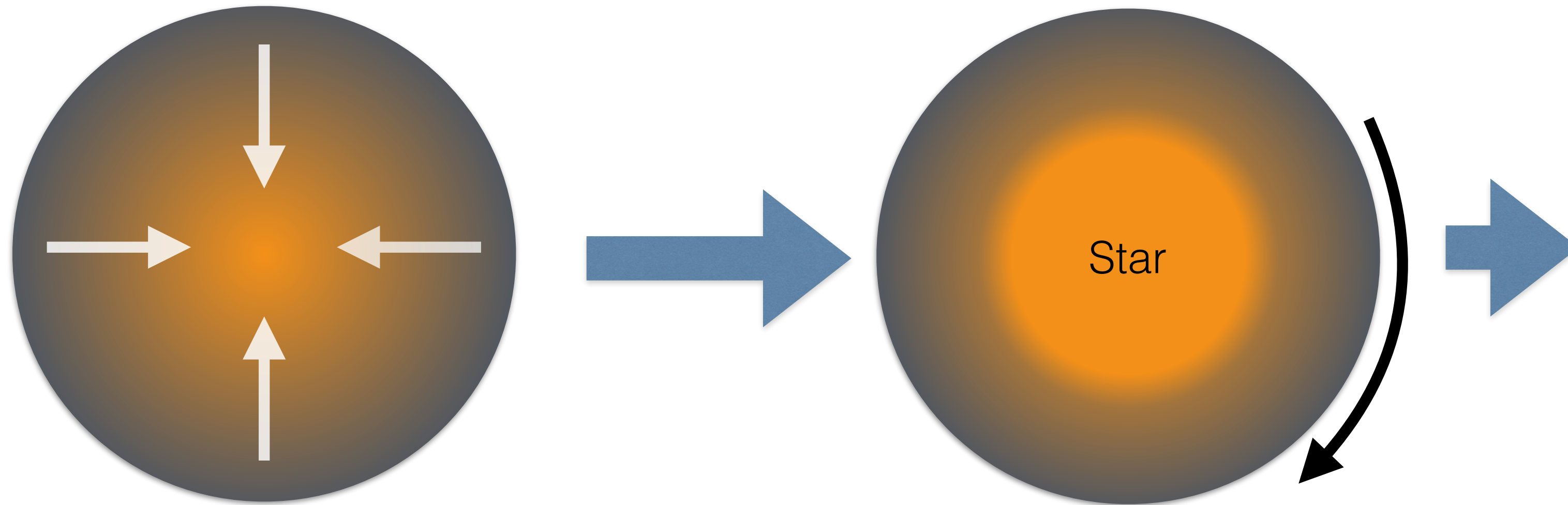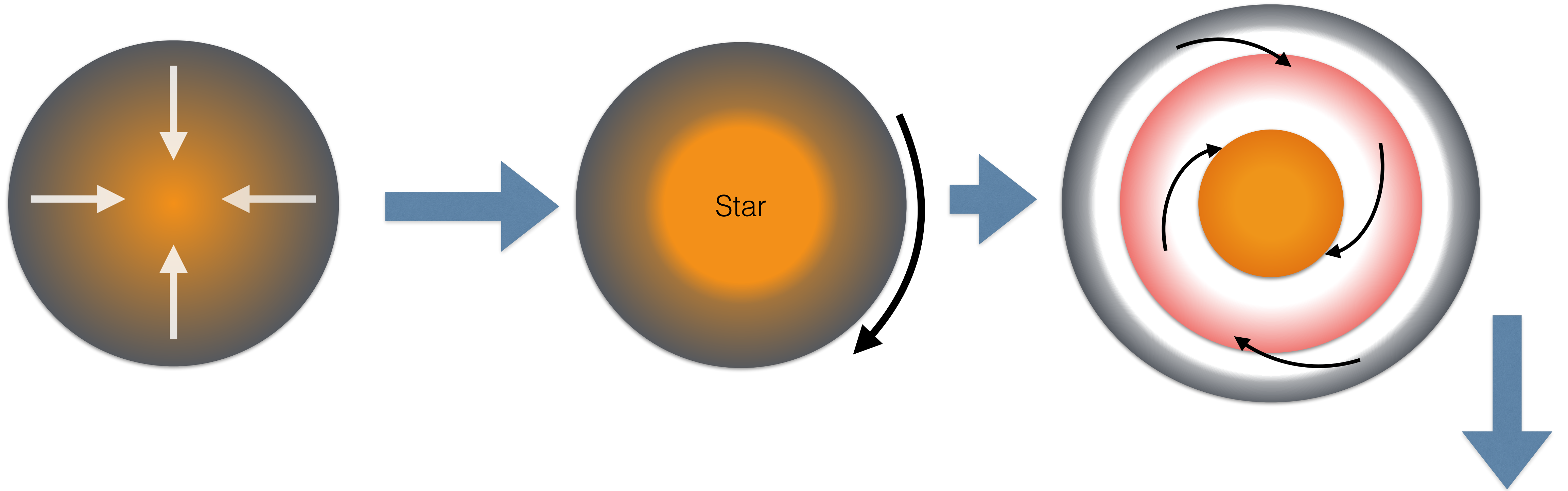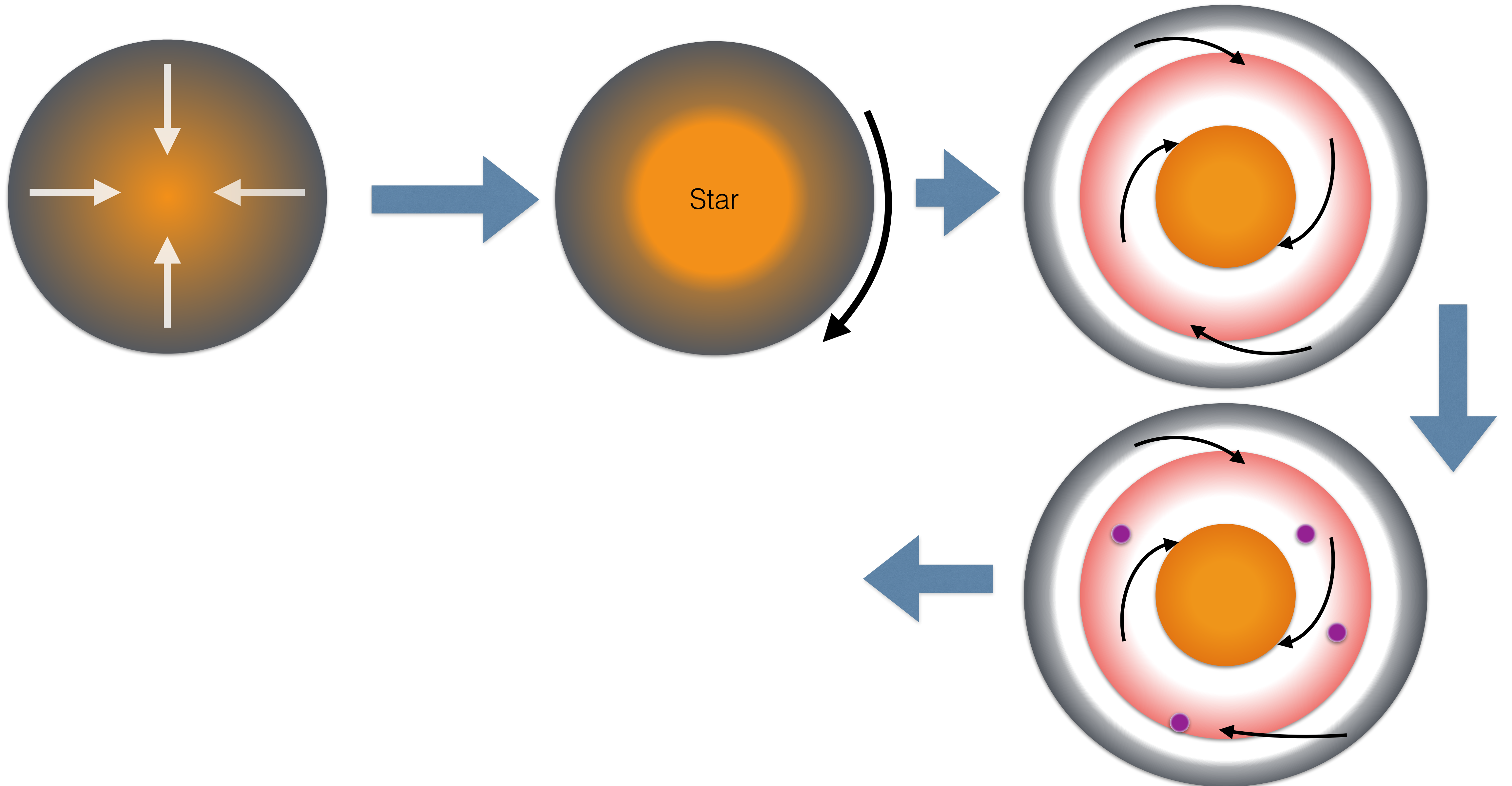
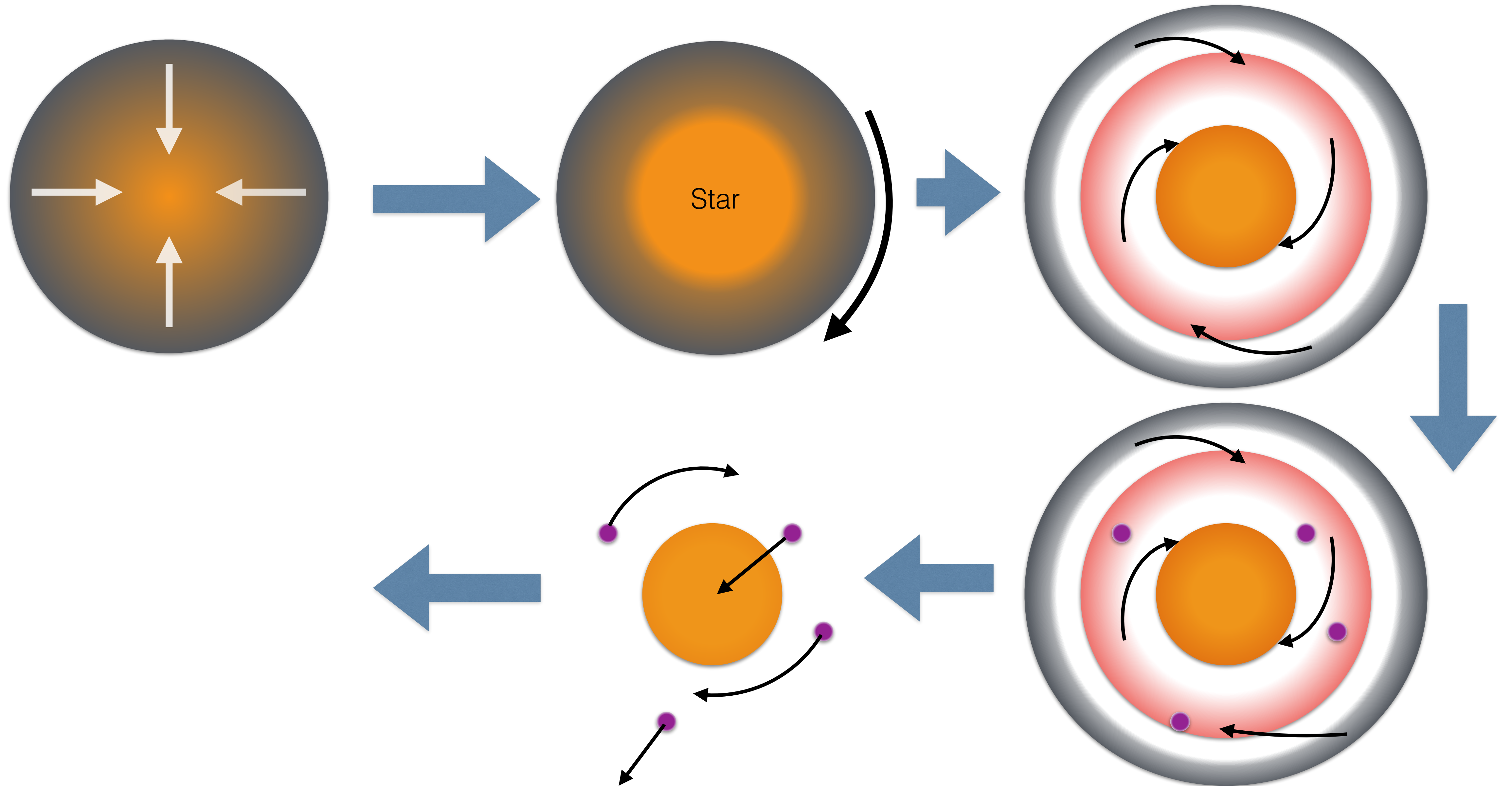

Star

Massive Star Formation

Star

Massive Star Formation

Massive Star Formation

Massive Star Formation
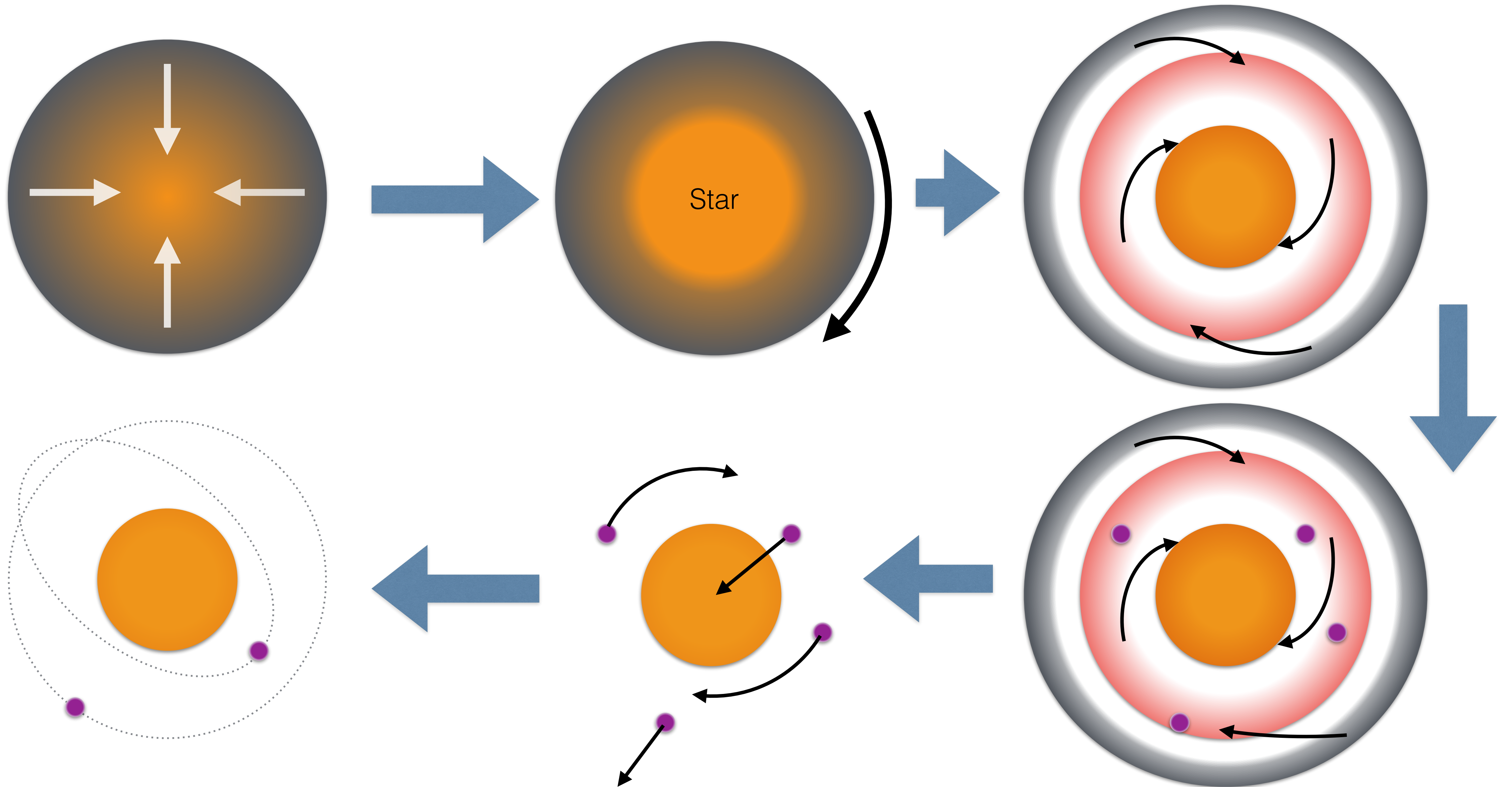
Massive Star Formation Problems

Massive Star Formation Problems

Short formation timescale

Rareness and large distances

Obscured environment

Observational difficulties

Direct observation of star formation

Study the properties of the outcome of star formation
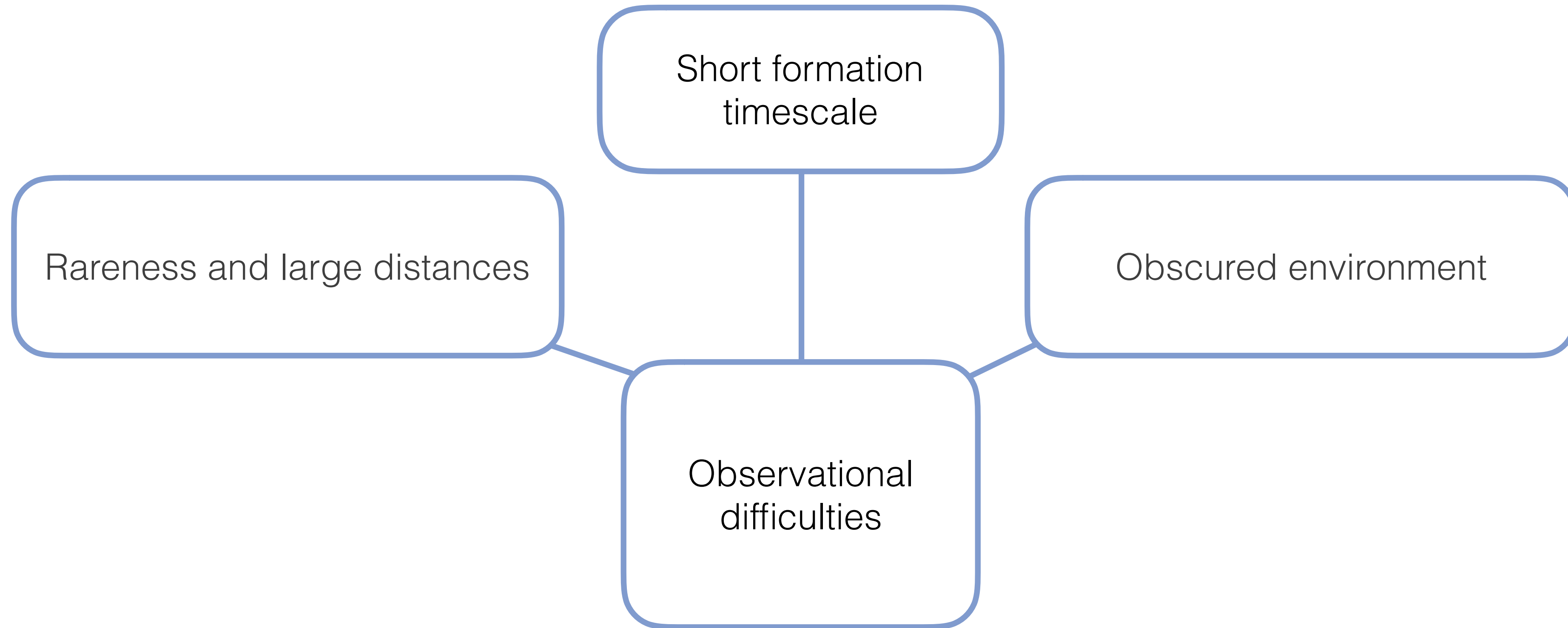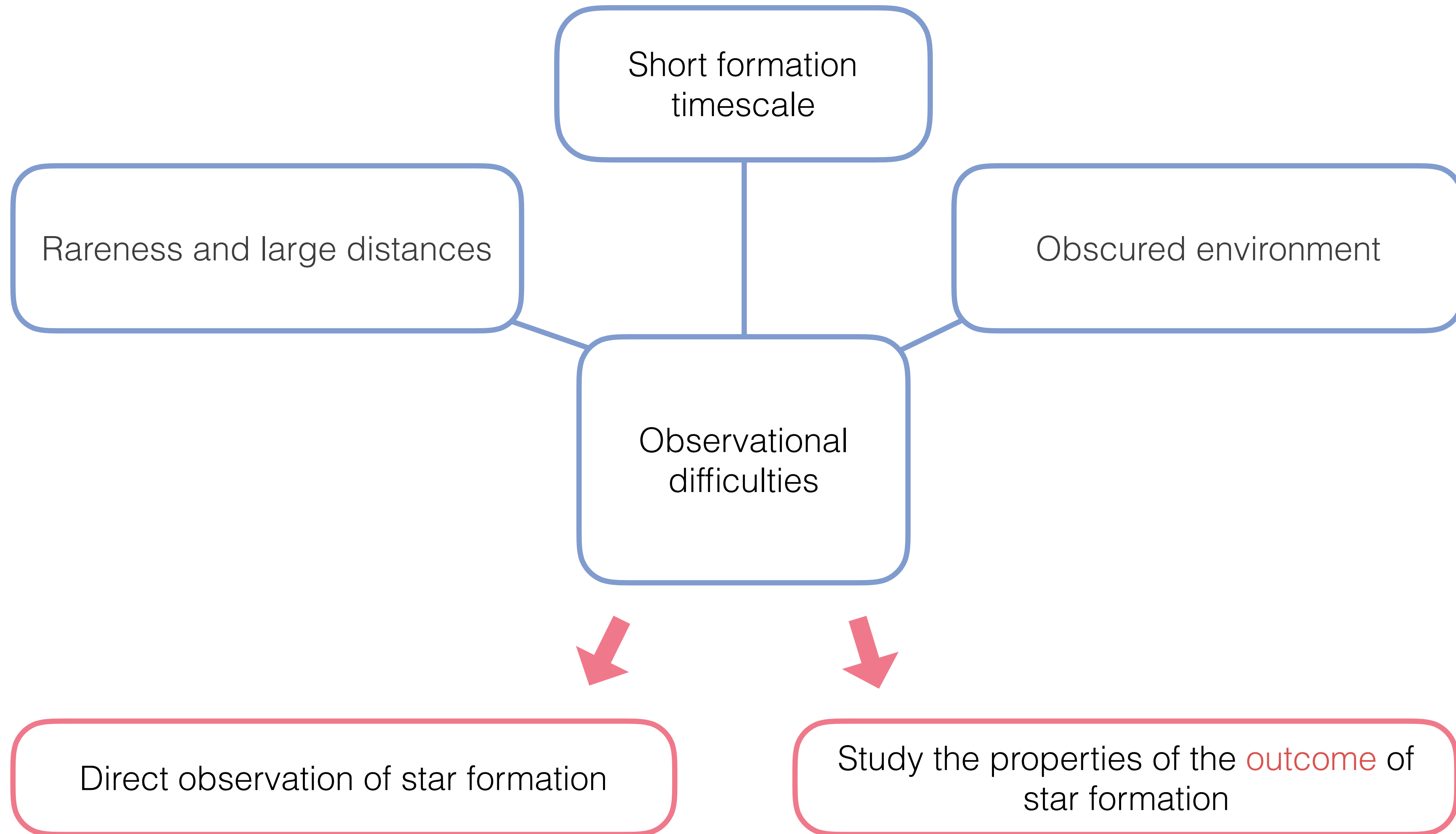
CHIPS

CHIPS

Carina **H**igh-contrast **I**maging **P**roject of massive **S**tars

©ESO/T.Preibisch

C H S

Carina — close massive star region

C H I P S

High-contrast **I**maging ——— VLT/SPHERE in IRDIFS mode

©ESO/J.Girard
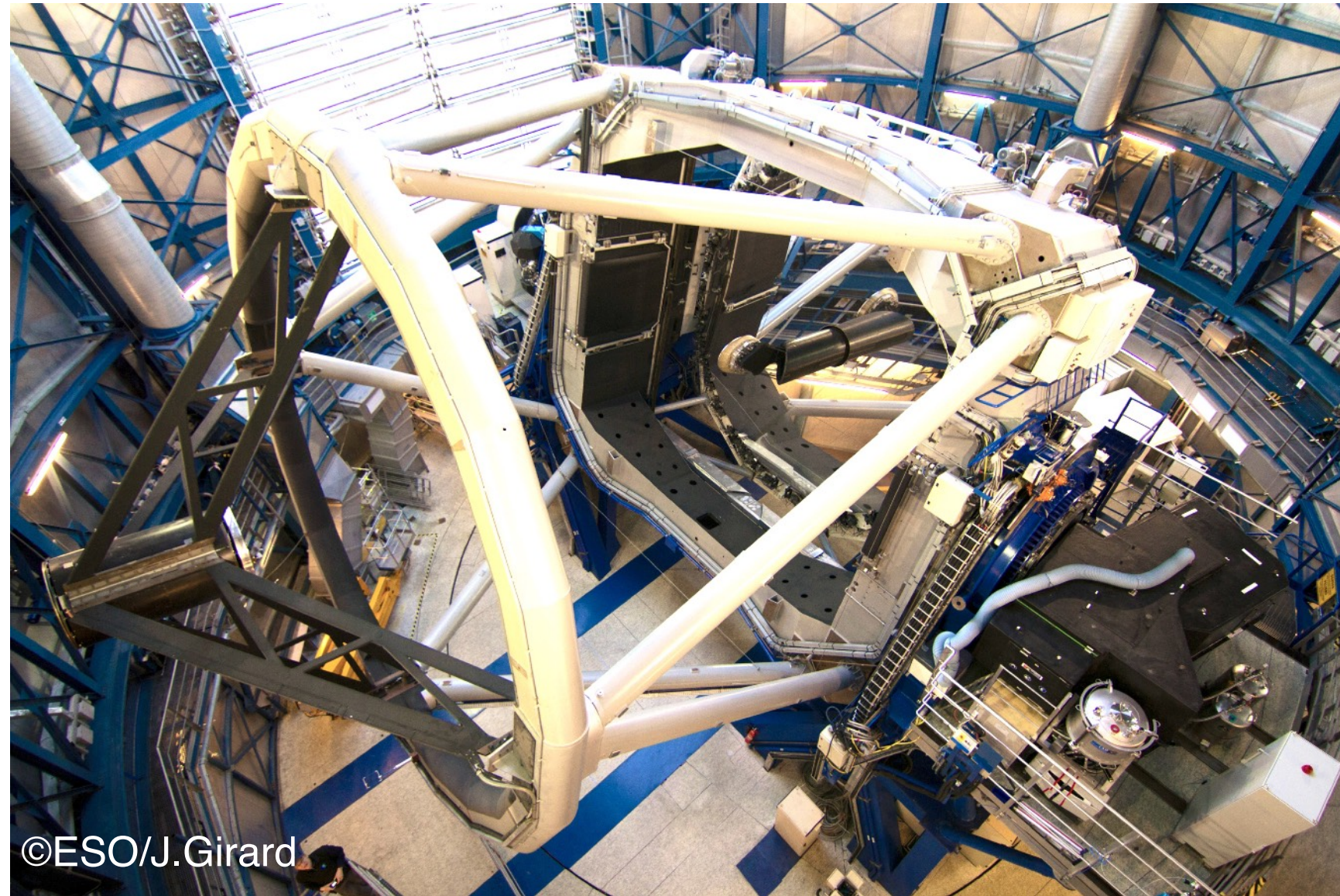
SPHERE	IFS	IRDIS
Spectral Range (μm)	0.95-1.75	0.95-2.32
FOV (arcsec²)	1.73	11
Pixel Scale (marcsec)	7.4	12.25
Bands	Y-J-H	K (1&2)

High-contrast **I**maging

VLT/SPHERE in IRDIFS mode

C H I P S

Project of massive **S**tars

Multiplicity properties of 93 massive O and WR

faint and low-mass companions

C H I P S

Project of massive **S**tars

40 stars already reduced

53 stars in P104

4D data cubes

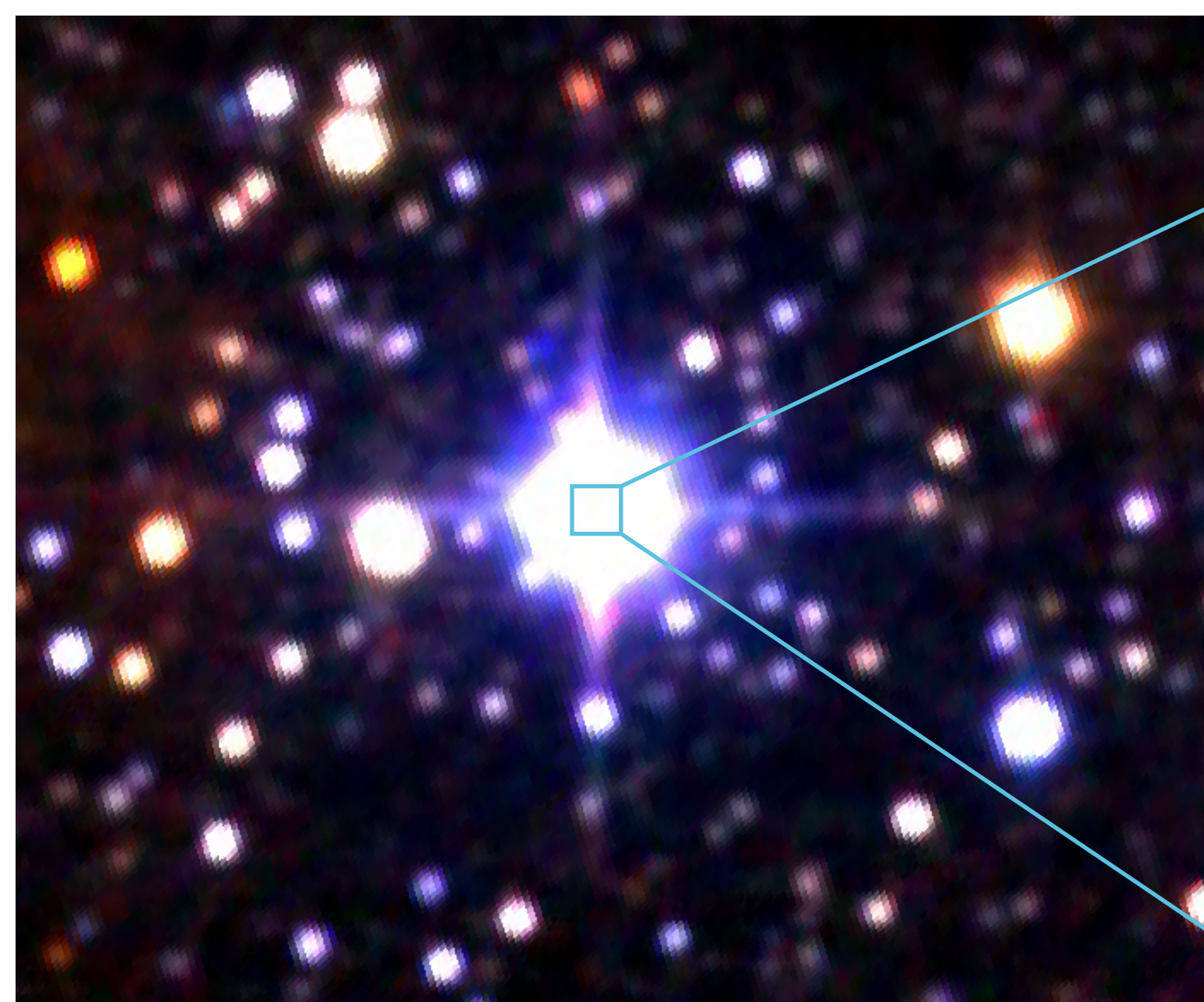Multiplicity properties of 93 massive O and WR

faint and low-mass companions

Some example data

QZ Car (HD 93206)

FOV = 5', 2MASS

FOV = 5', 2MASS
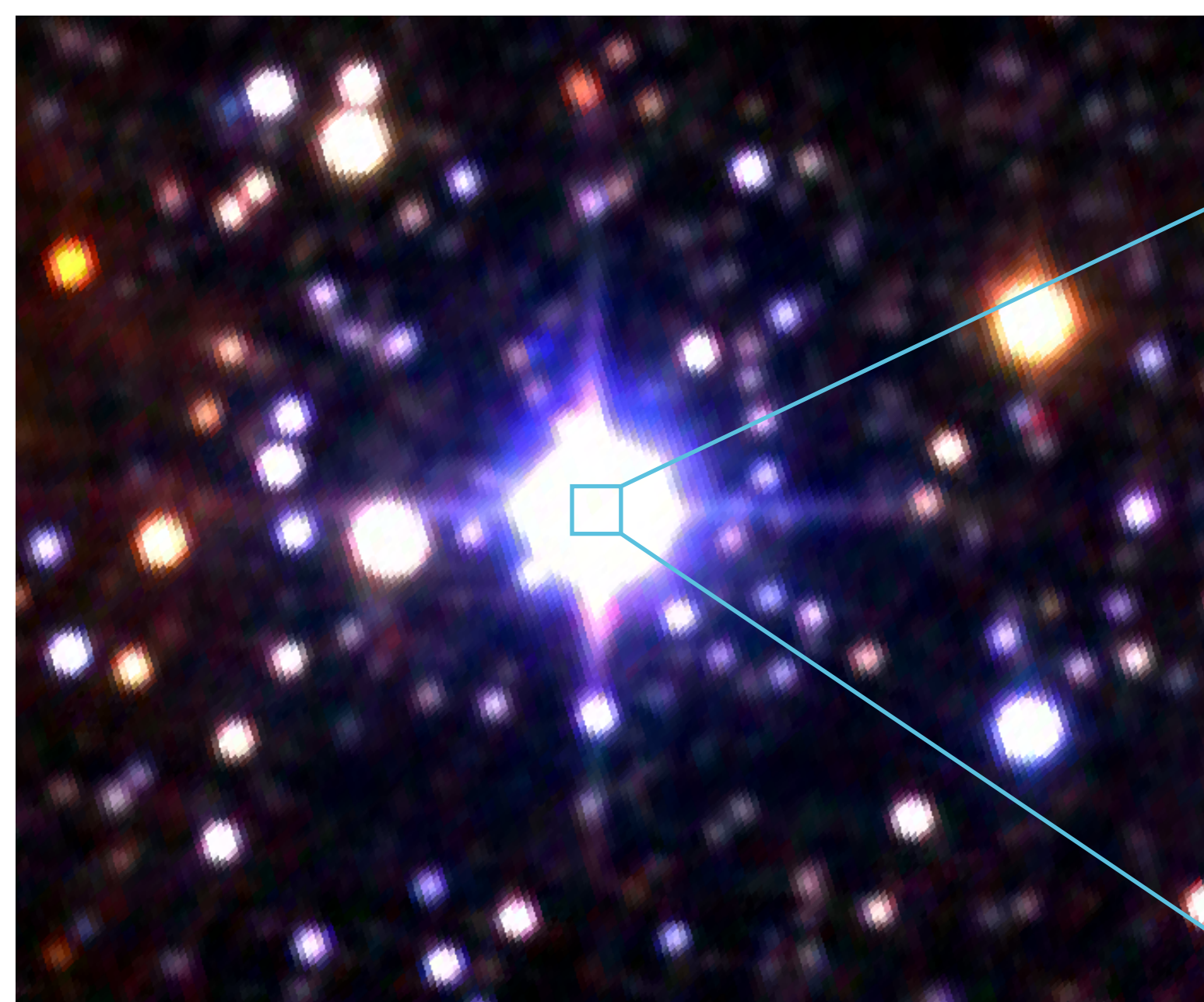
HD93206

16"x16"

Ab
E
B
Aa

2"

N
E
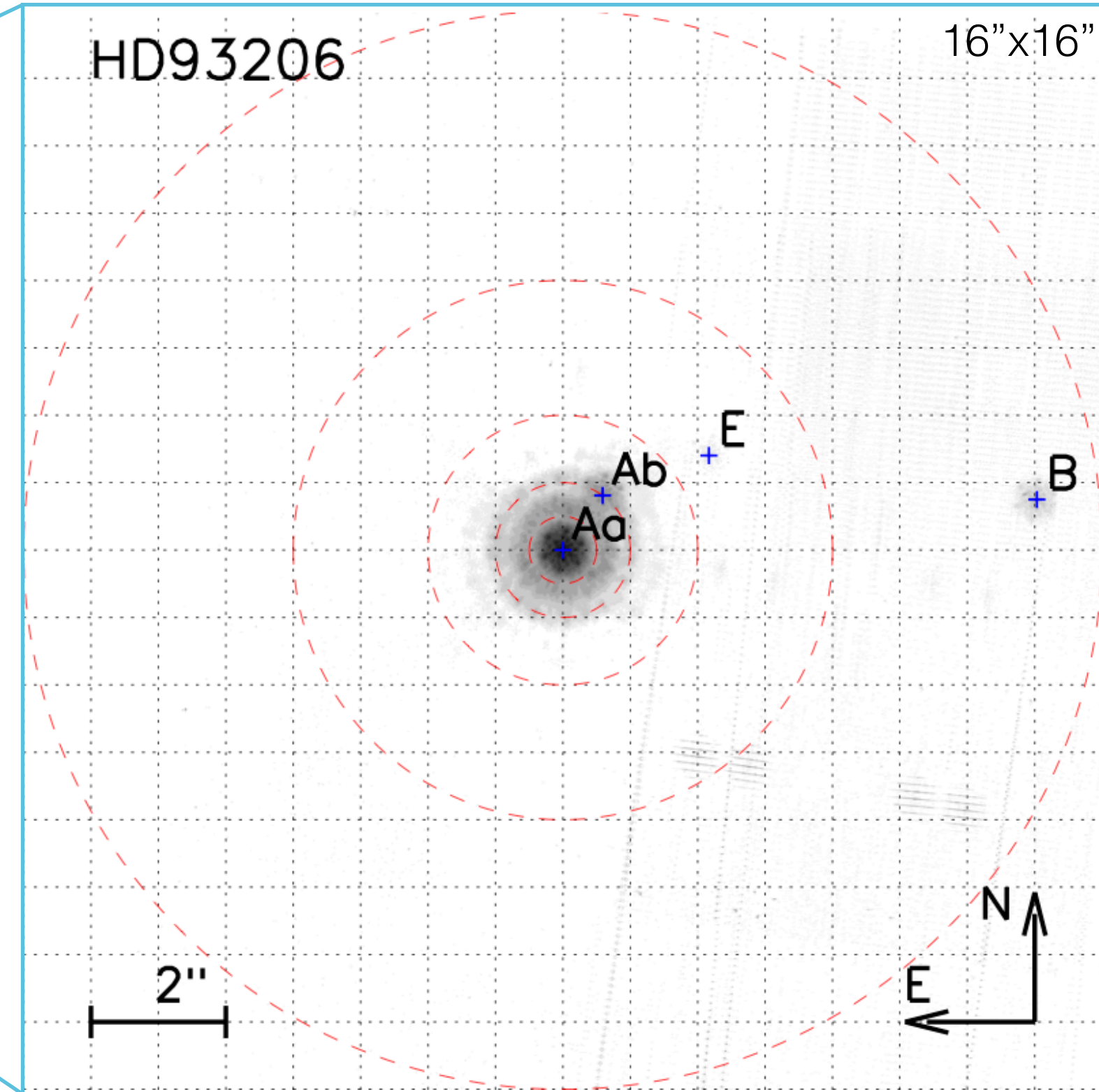
SMaSH+ Image
Sana et al, 2014

FOV = 5', 2MASS
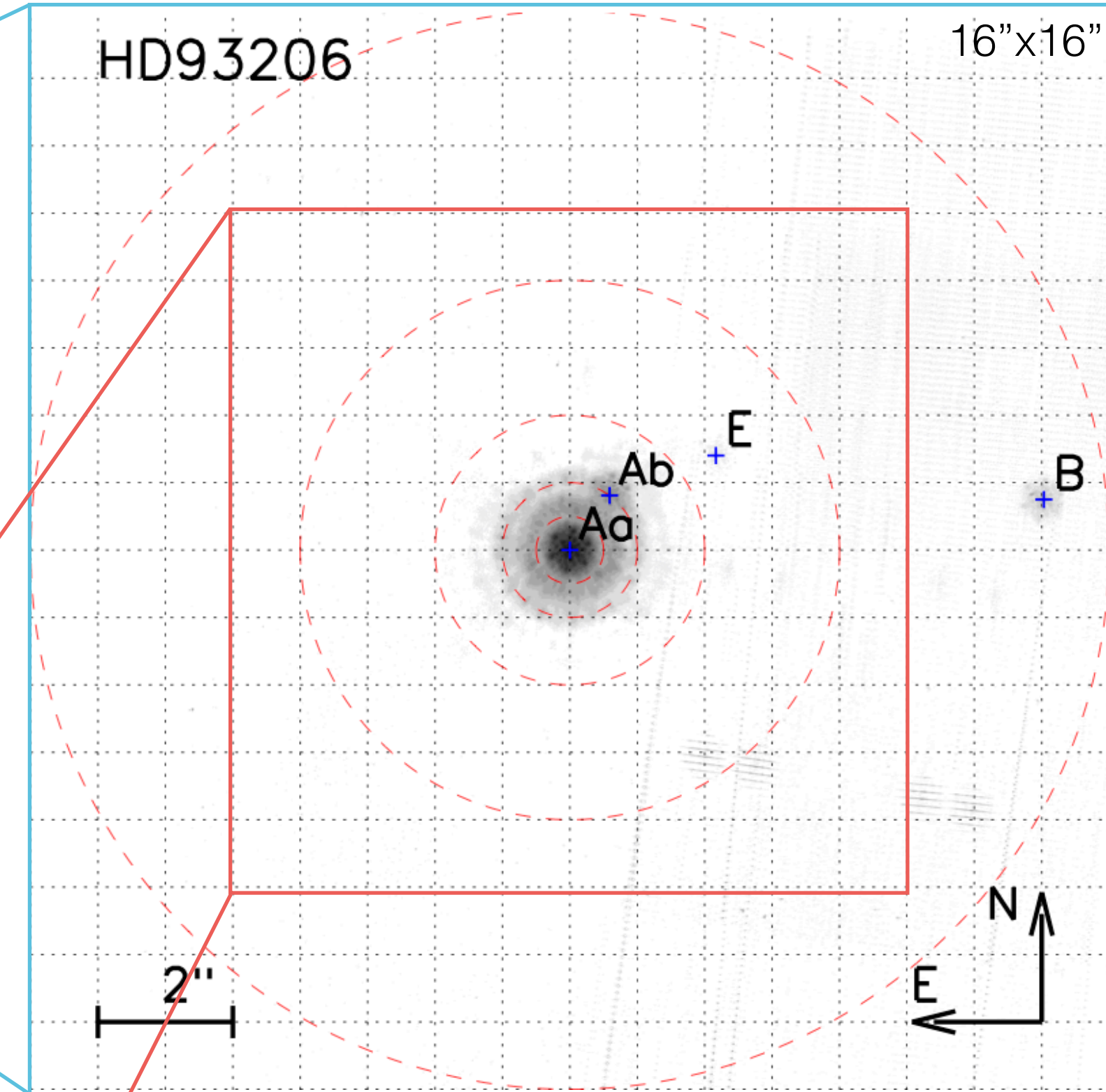
HD93206   16"x16"

E

Ab

Aa   B

SMaSH+ Image
Sana et al, 2014

2"

N

E

IRDIS

d (AU)
10000   5000   0   5000   10000

S8

S1 S5

S7   E
         Ab

S11   S9 S10

S2
S4   Ad

S14   S3

S6

S12

N

E   S13

S16   S15

FOV = 5', 2MASS

HD93206

16"x16"

Aa

Ab

E

B

N

IRDIS

IFS

d (AU)

10000 5000 0 5000 10000

6

4

2

0

2

4

6

d (arcsec)

S8

S1 S5

Ab E

S7

S11

S2

S9 S10

S4

Ad

S3

S14

S6

S12

N

E

S13

S16 S15

10000

5000

0

5000

10000

d (AU)

d (AU)

2000 1500 1000 500 0 500 1000 1500 2000

1.0

0.8

0.6

0.4

0.2

0.0

0.2

0.4

0.6

0.8

1.0

d (arcsec)

Ab

Ad

N

E

2000

1500

1000

500

0

500

1000

1500

2000

d (AU)

1.0 0.8 0.6 0.4 0.2 0.0 0.2 0.4 0.6 0.8 1.0

d (arcsec)
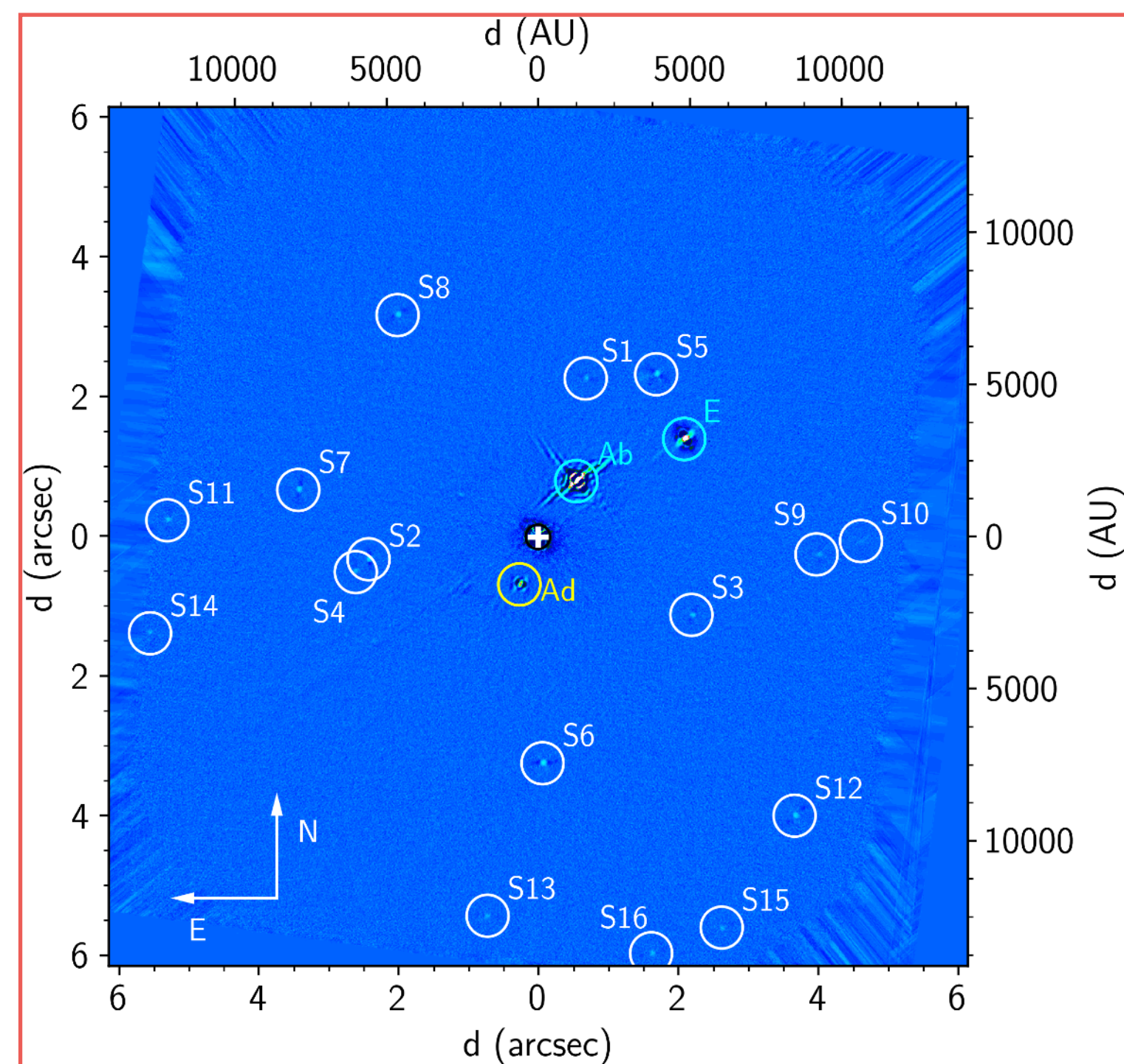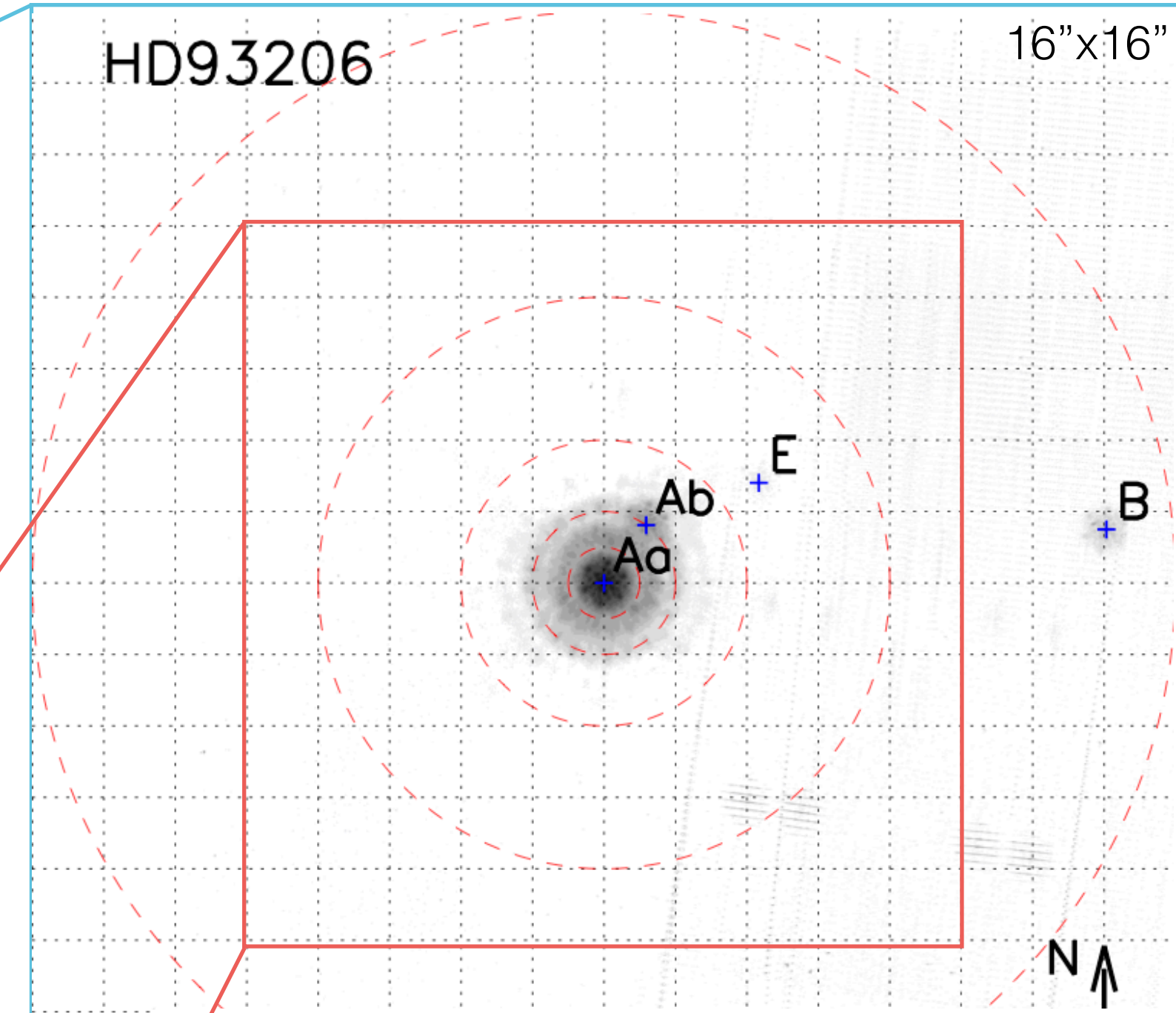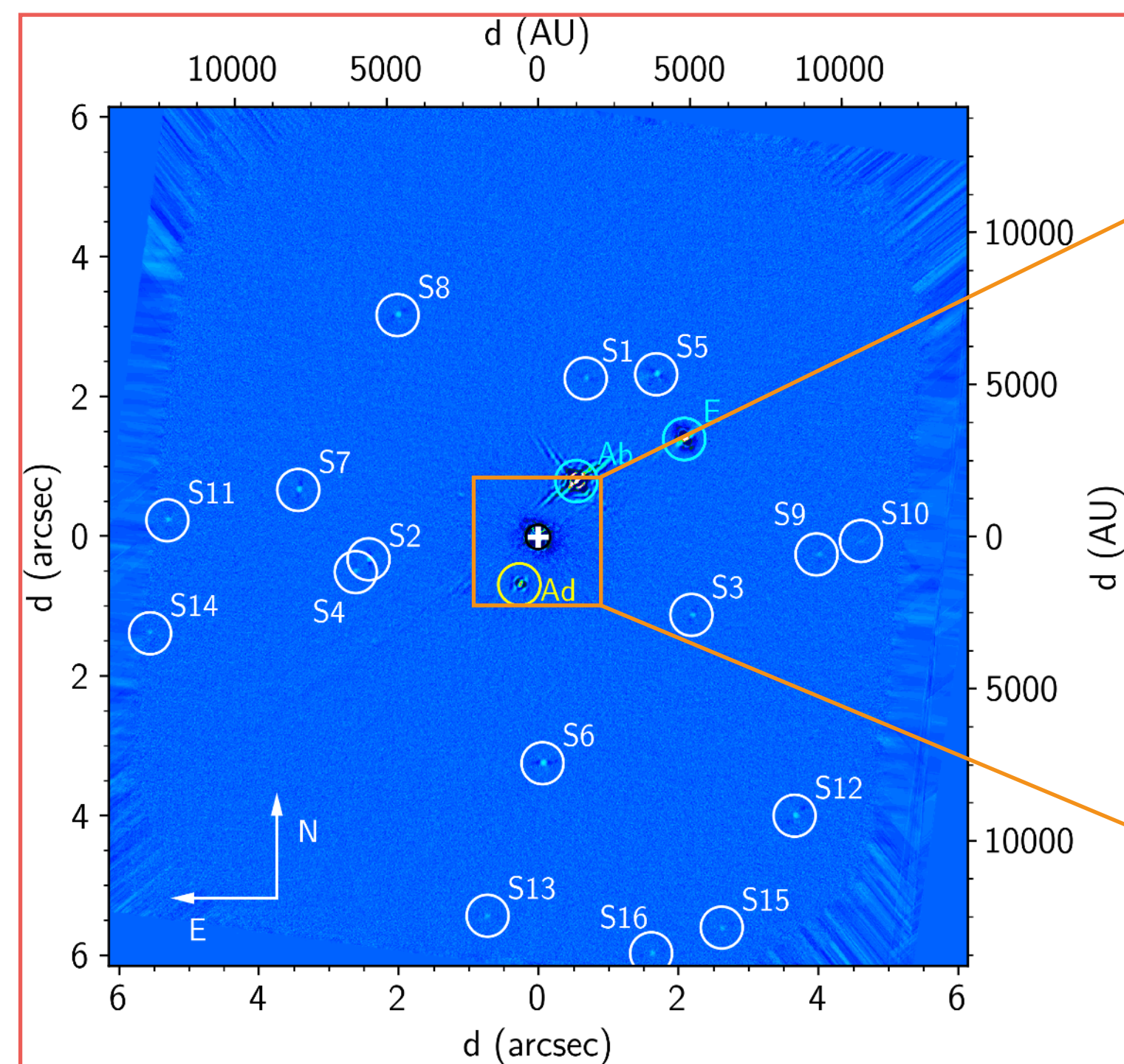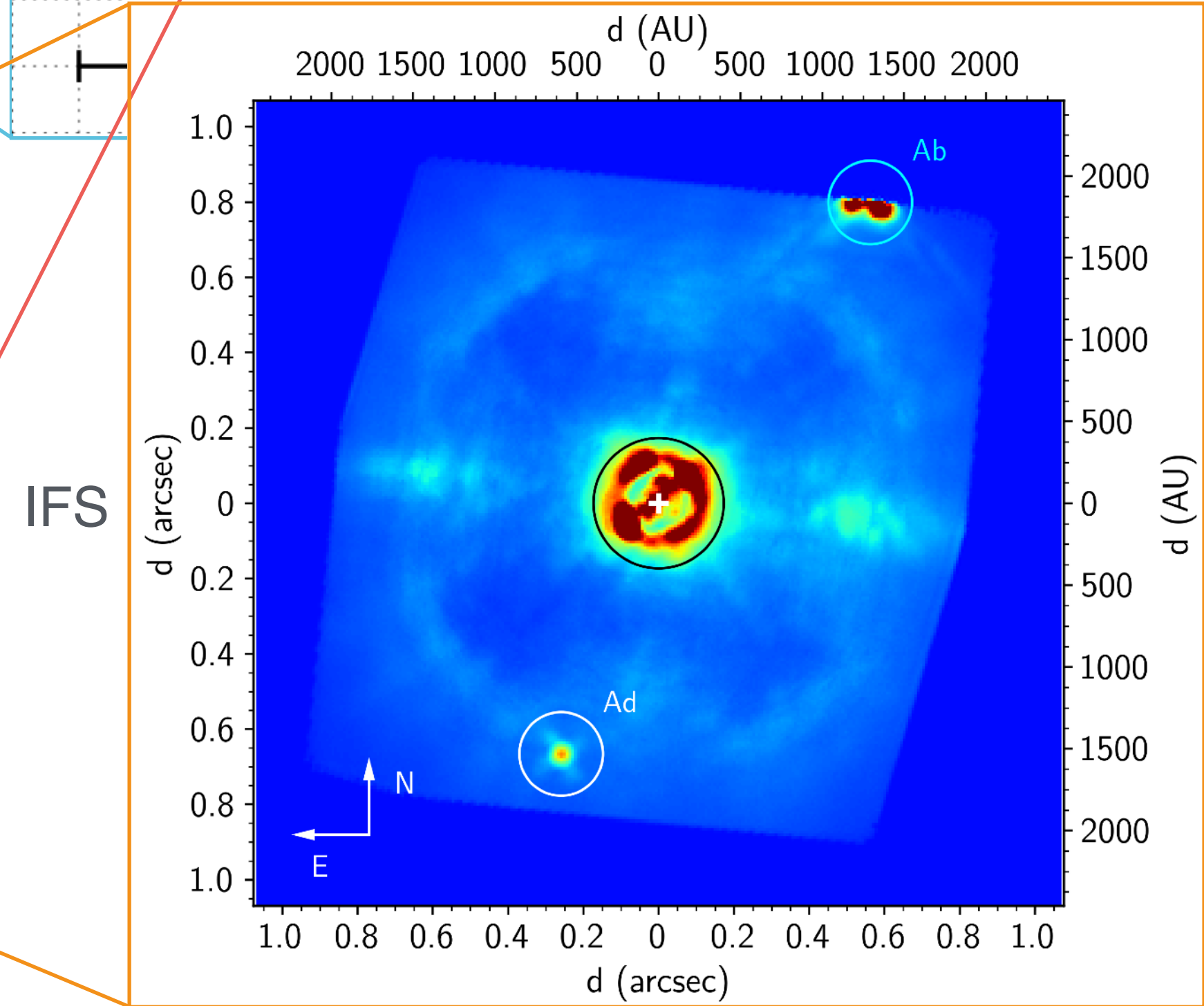
Detection method
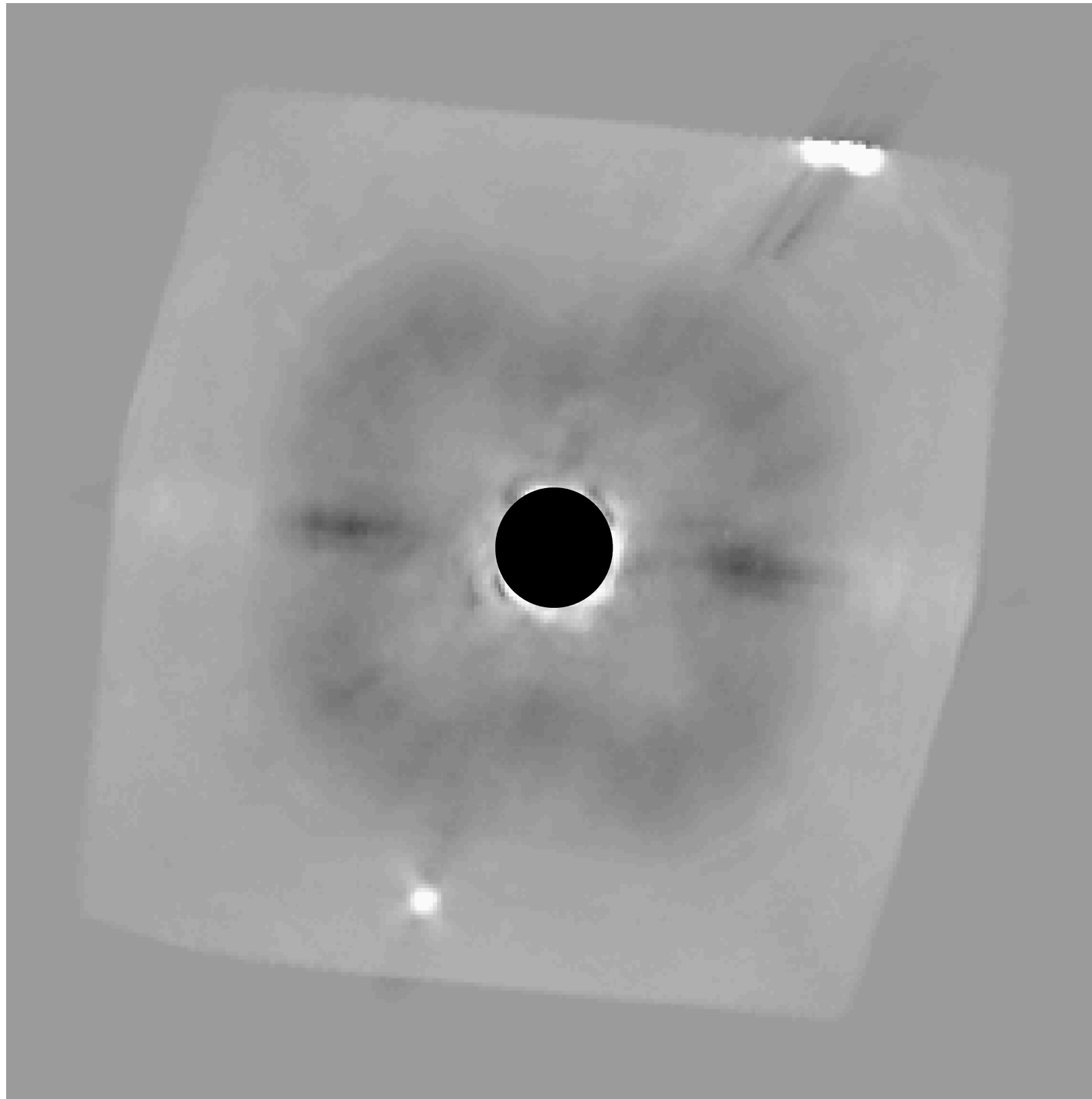
Bright red: SNR ≥ 5

Derotated and wavelength collapsed image
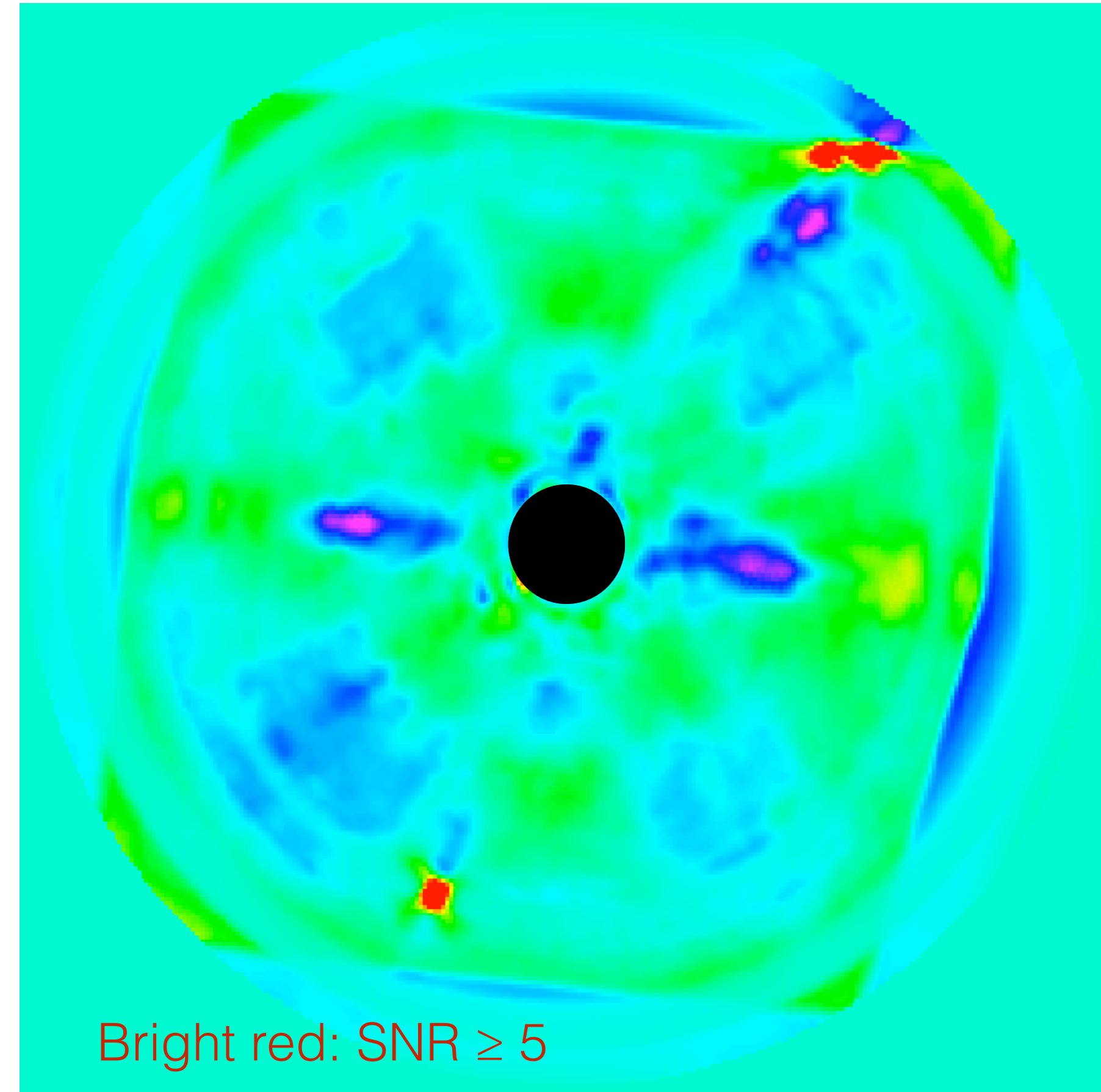
SNR map

SMaSH+ (Sana+,2014) & HST-FGS (Aldoretta+,2015)

Δ mag

Angular separation (mas)

PIONIER
NACO-SAM
HST-FGS
NACO-FOV
SPHERE

□ H band
⊡ K band

Ab
Ad
E

Rainot+(in prep.)
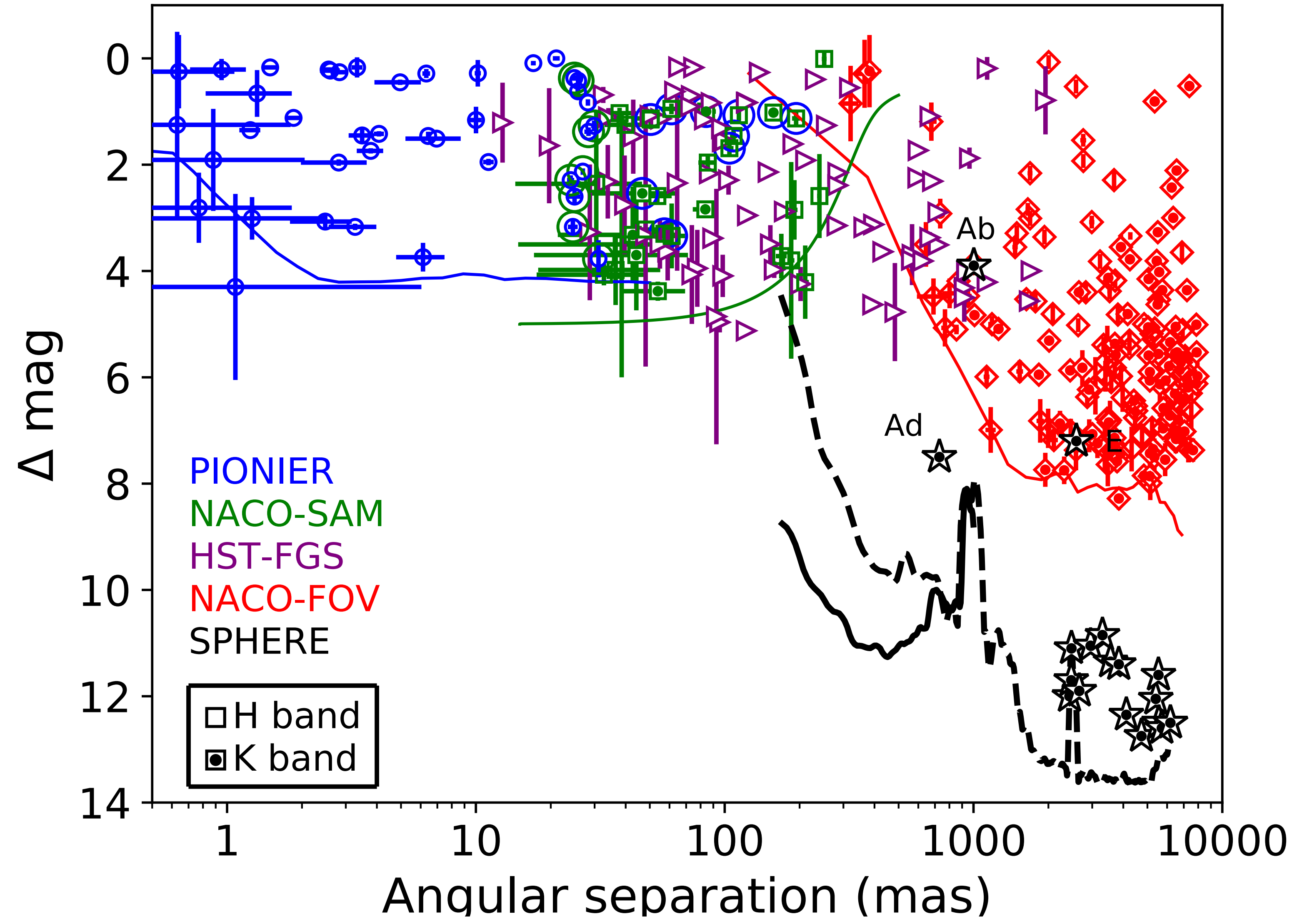
Spectrum Extraction

QZ Car (HD 93206)

(Sanchez-Bermudez et al. 2017)
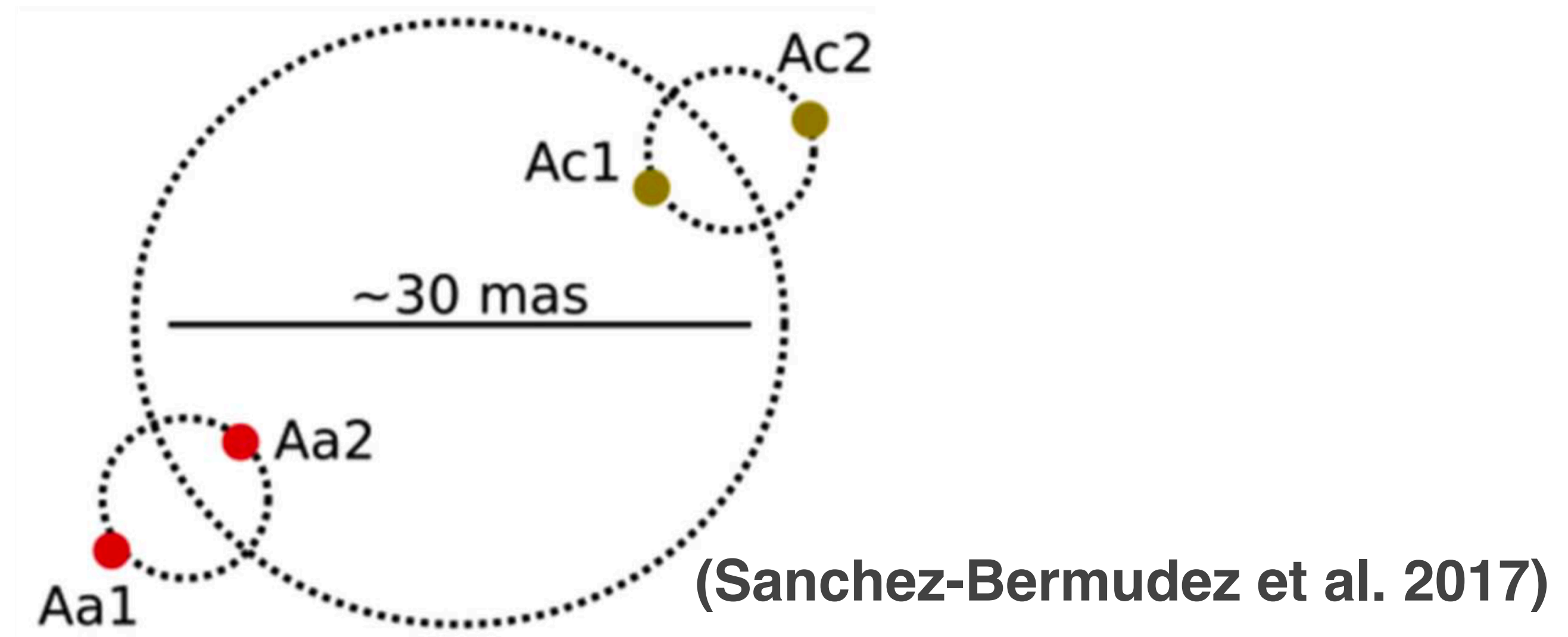
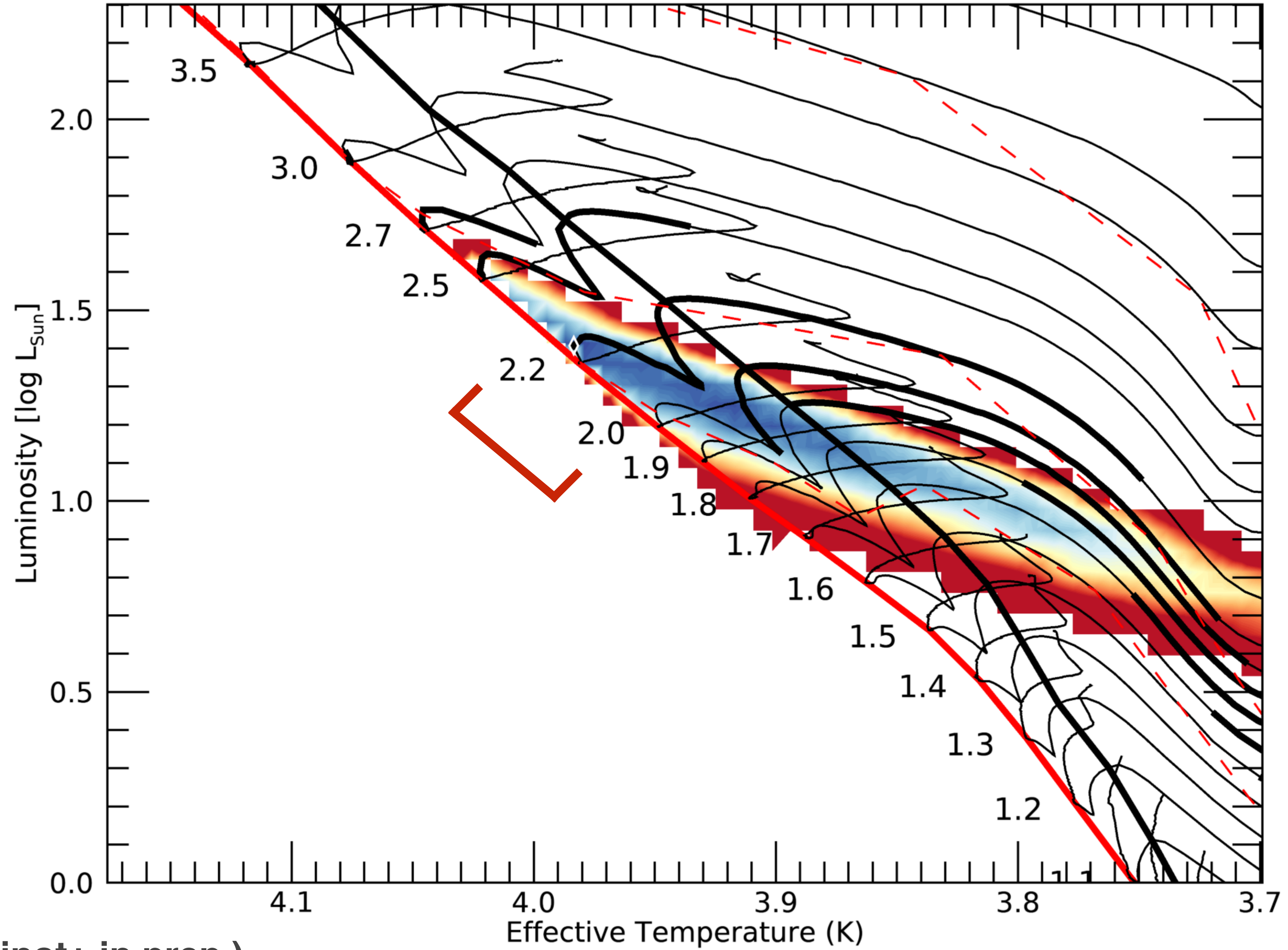| Component	Spectral Type	T_{eff} (K)	R_* ($R_\odot$)	M_* ($M_\odot$)	L_* ($\log[L_*/L_\odot]$)	$\dot{M}$ ($M_\odot.yr^{-1}$)	$\log(g)$	v_∞ ($km.s^{-1}$)
Aa1	O9.7 I	32000	22.5	40	5.7	8.21×10^{-6}	3.19	1794.3
Aa2	b2 v	20000	6.0	10	3.7	2.39×10^{-14}	4.3	1186.4
Ac1	O8 III	32573	26.9	14.1	5.3	3.32×10^{-6}	3.57	2191.2
Ac2	o9 v	32463	8.9	28	4.9	3.16×10^{-9}	3.92	2427.1

(Rainot+ in prep.)

Calibrated spectrum
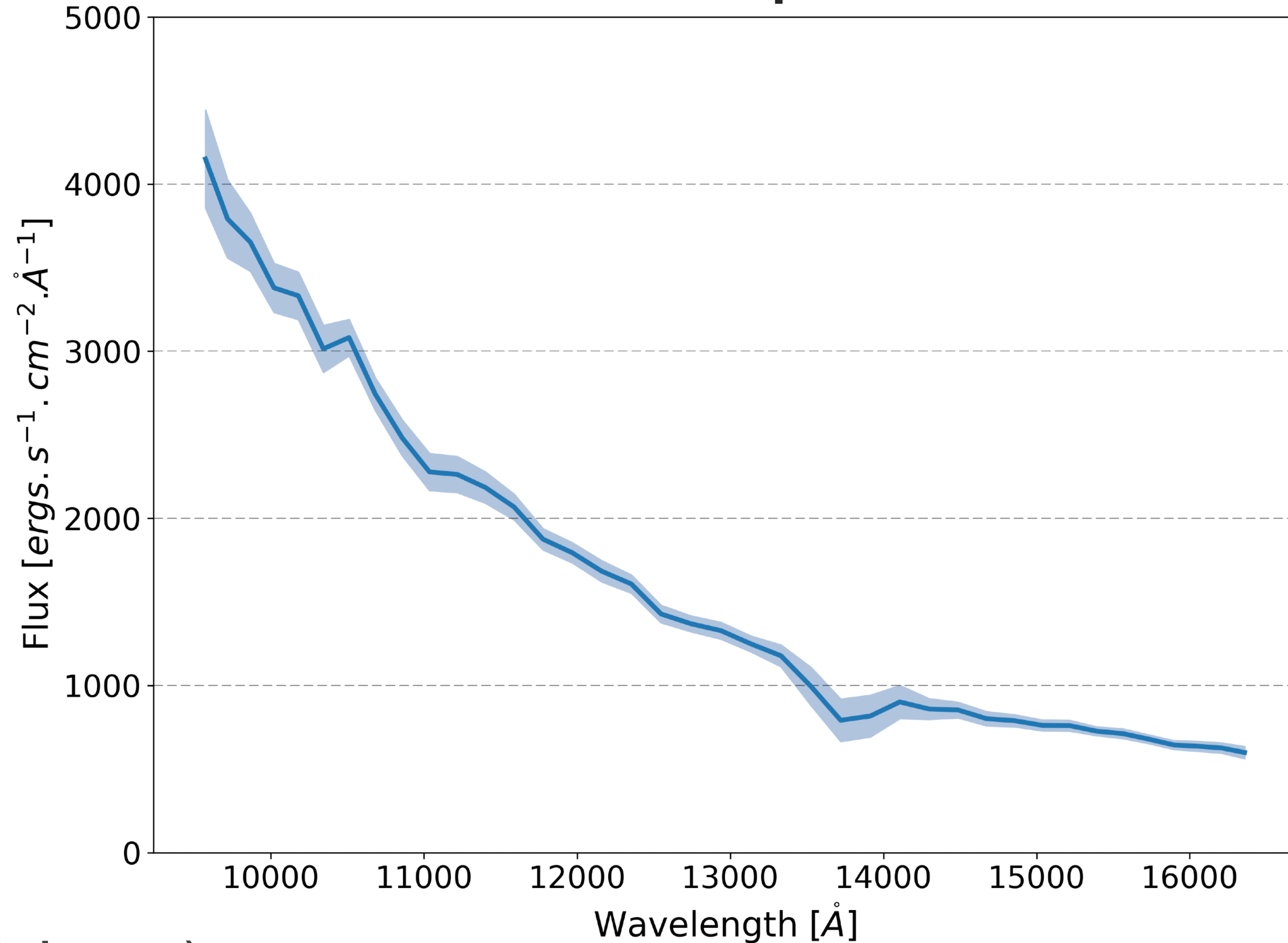
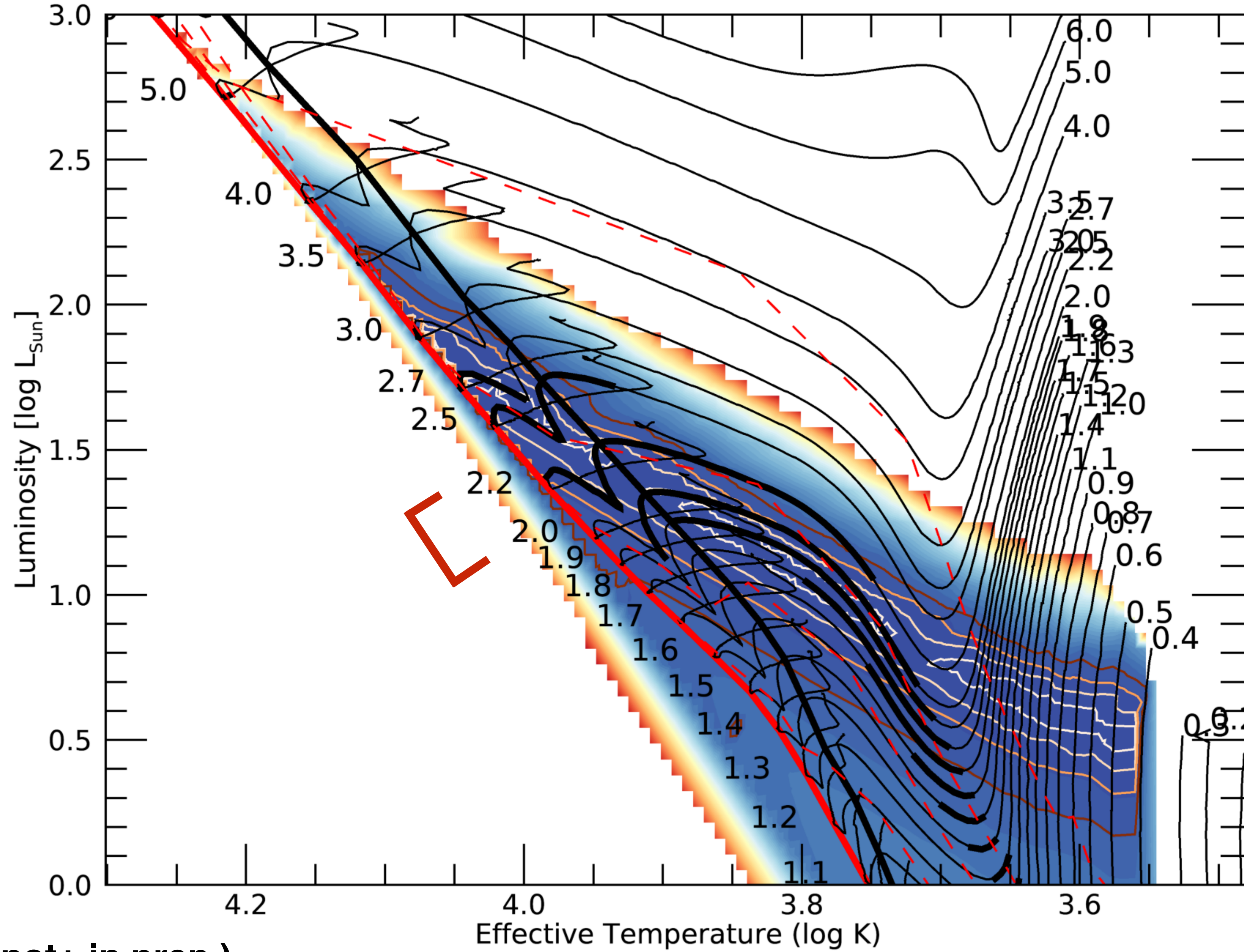**(Rainot+ in prep.)**

QZ Car - Ad (IFS)

(Rainot+ in prep.)

QZ Car - Ad (IRDIS)

(Rainot+ in prep.)
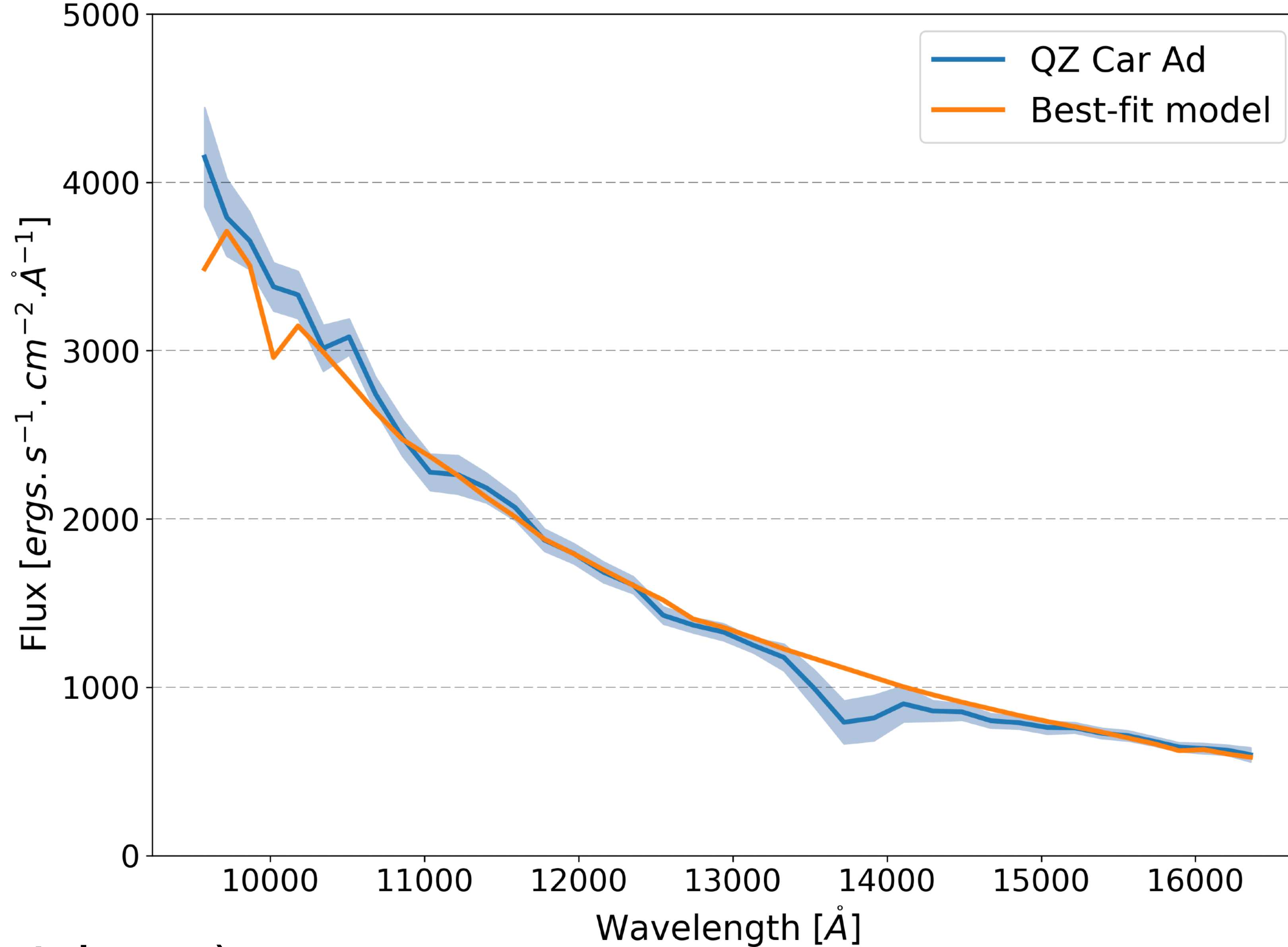
IFS - QZ Car Ad

(Rainot+ in prep.)

IFS - QZ Car Ad

$T_{eff} = 9600K$

$\log(g) = 4.28$

$R = 1.77R_\odot$

$M = 2.2M_\odot$

Legend: QZ Car Ad; Best-fit model

Flux [$ergs.s^{-1}.cm^{-2}.Å^{-1}$] vs Wavelength [$Å$]
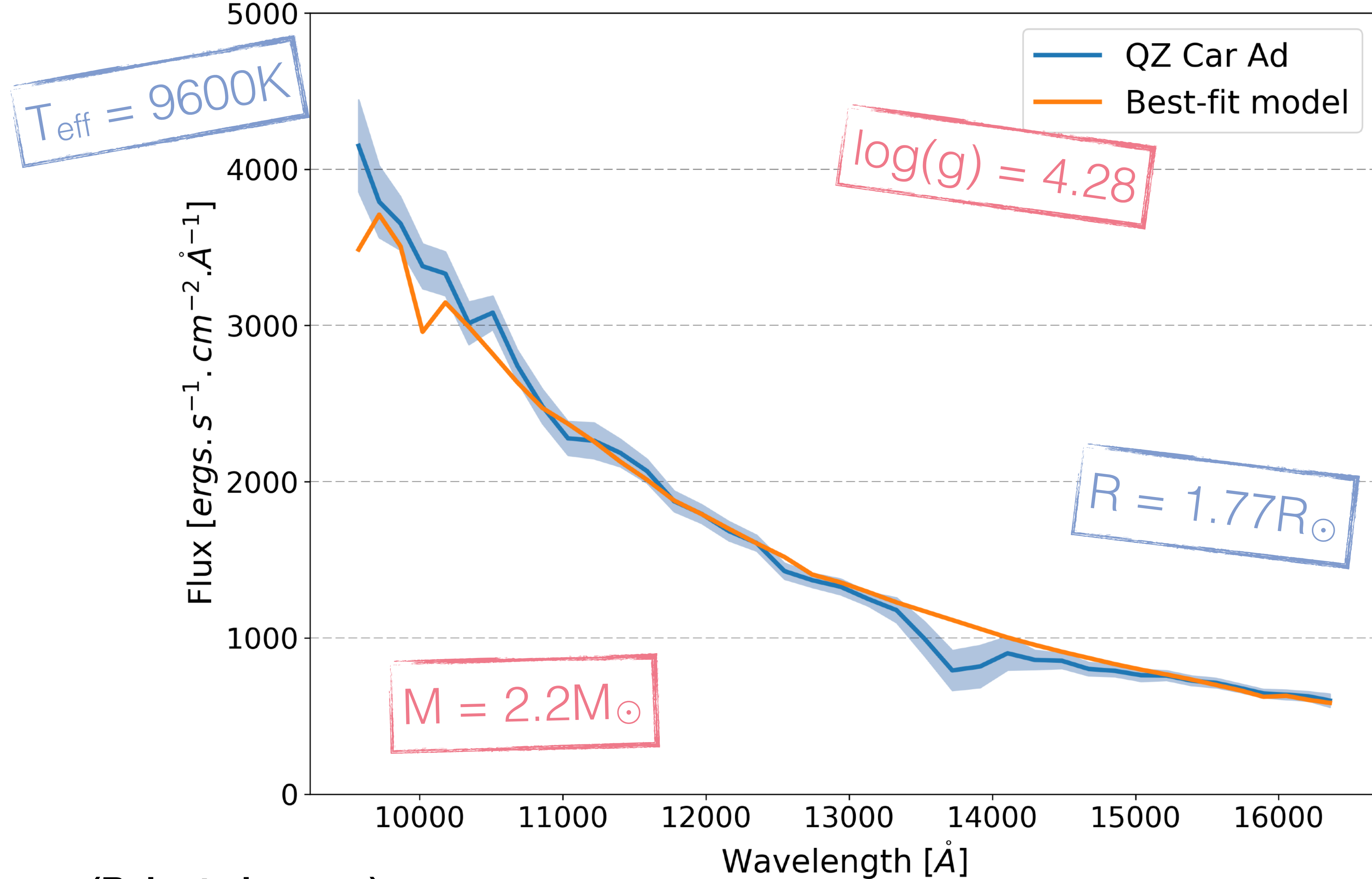
(Rainot+ in prep.)

With better spectroscopy
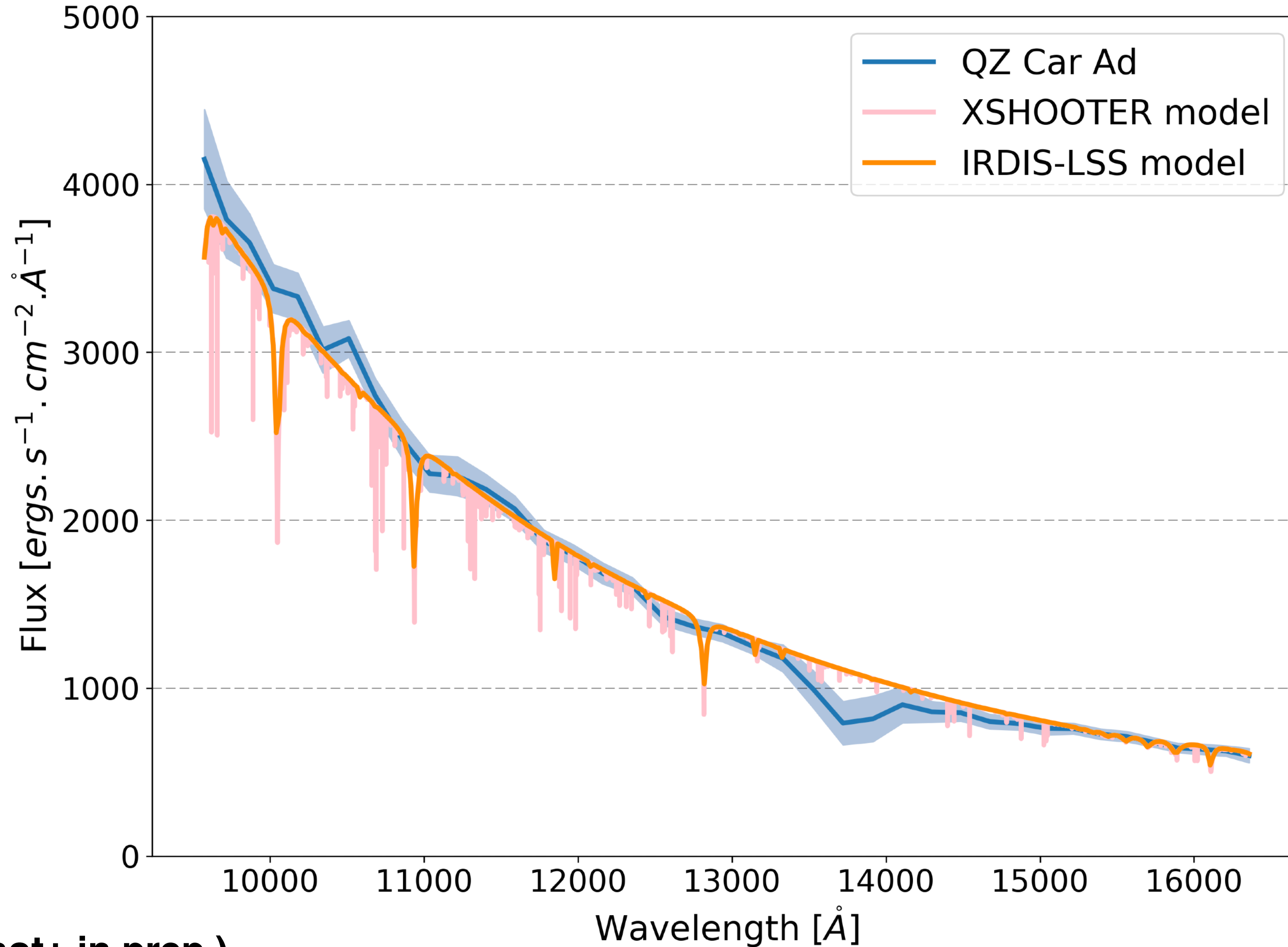
(Rainot+ in prep.)

Multiplicity Results - IFS

Images	Visible companions (SNR > 5σ)	Candidates (5σ > SNR > 3σ)
40	12	17

‣ Detection ratio ≃ 0.42 companions/star

‣ Expected ≃ 40 companions / 93 images

Conclusion

‣ Discovery of a new companion: QZ Car Ad at 2.3kpc

‣ Might be an A0-A1 star with: T= 9600K, M = 2.2M$_\odot$, R = 1.77R$_\odot$ and log(g) = 4.28

‣ High-detectability rate with high-contrast imaging

‣ 53 stars remain to be observed with SPHERE (P104)

‣ First paper to be submitted soon!

Thank you!

Extra Slides

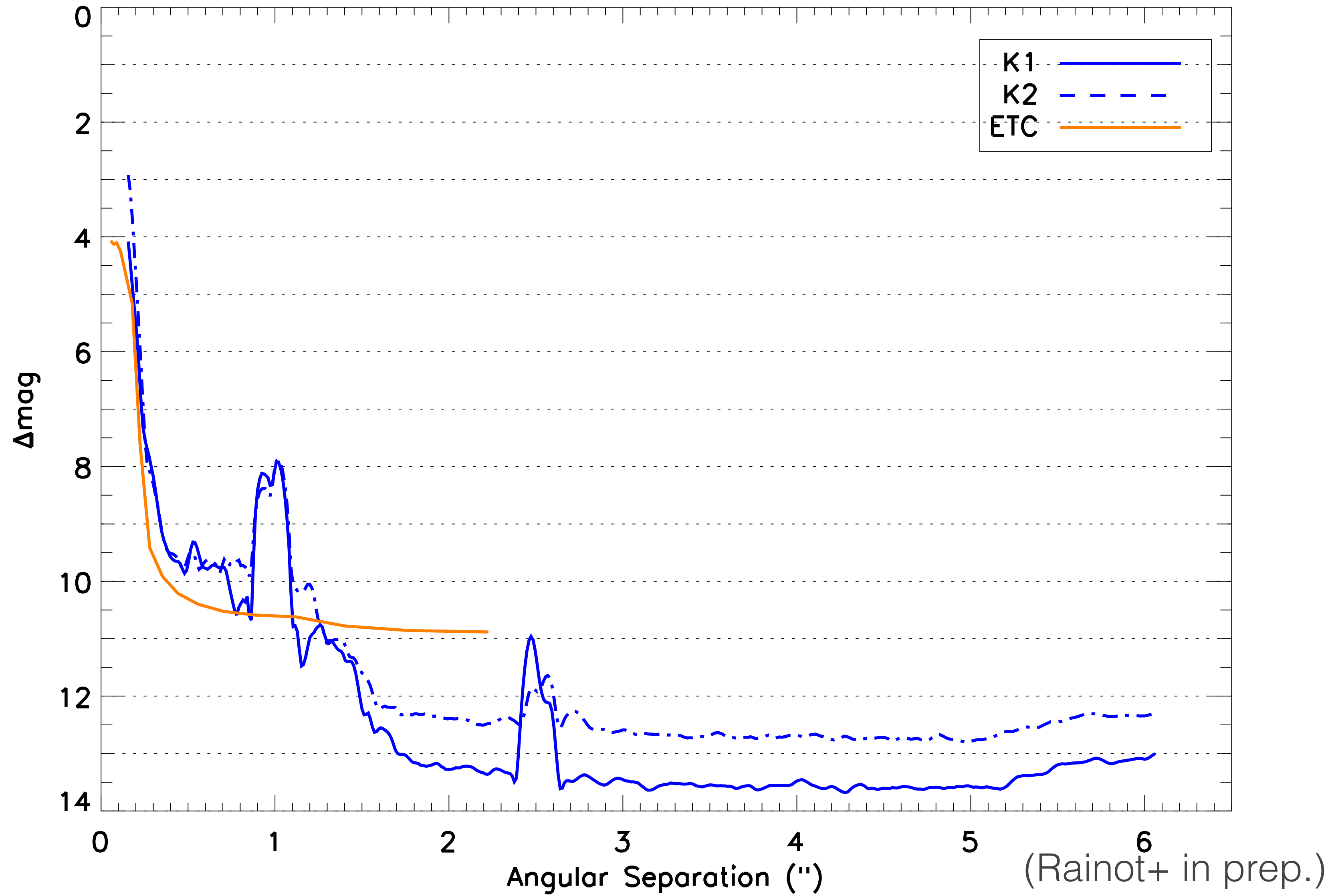# IFS Contrast Curves

IFS
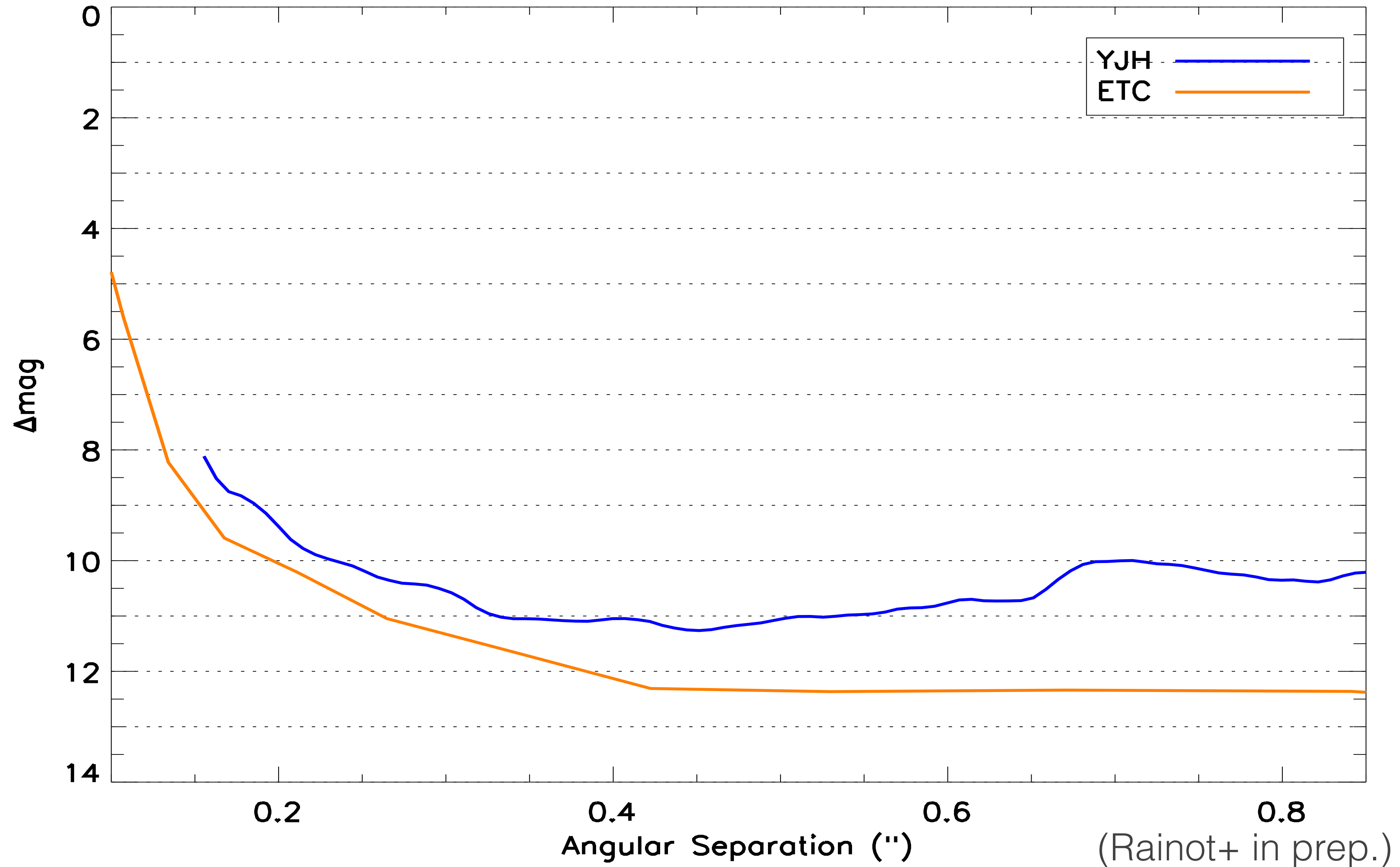
(Rainot+ in prep.)

IRDIS Contrast Curves

IRDIS

(Rainot+ in prep.)

QZ Car Sources

(Rainot+ in prep.)

Source	Ad	Ab	E	S1	S2
ρ (mas)	729.1±1.3	1002.9±1.7	2590.4±4.3	2429.4	2475.8±5.9
d (10^3 a.u.)	1.7 ± 0.1	2.3 ± 0.1	6.0 ± 0.1	5.6 ± 0.1	5.7 ± 0.1
PA (°)	169.9±0.1	335.6±0.1	314.3±0.1	343.1	197.8±0.1
ΔK_1	7.5±0.2	3.9±*0.01*	7.3±0.04	11.9	11.1±0.18
ΔK_2	7.5±0.18	3.9±0.01	7.1±0.15	12.1	11.1±0.17
P_{spur}^{2MASS} (%)	0.16± 0.02	0.04± 0.02	1.77± 0.29	*>11*	*>11*
P_{spur}^{gaia} (%)	0.06± 0.01	0.05± 0.02	0.56± 0.16	19.8± 0.9	6.81± 0.54

Source	S3	S4	S5	S6	S7
ρ (mas)	2470.8±	2661.4±	2955.7±5.0	3298.6±5.5	3553.9±5.9
d (10^3 a.u.)	5.7 ± 0.1	6.1 ± 0.1	6.8 ± 0.1	7.6 ± 0.1	8.2 ± 0.1
PA (°)	205.9±	221.8±	334.3±0.1	191.8±0.1	89.1±0.1
ΔK_1	11.9±	12.0±	11.1±0.16	10.8±0.06	11.4±0.10
ΔK_2	11.5	11.8	11.02±0.15	10.9±0.10	11.3±0.11
P_{spur}^{2MASS} (%)	*>11*	*>13*	*>16*	*>20*	*>23*
P_{spur}^{gaia} (%)	13.7± 0.8	21.1± 1.0	8.92± 0.74	8.31± 0.79	18.8±1.3

Source	S8	S9	S10	S11	12
ρ (mas)	3836.2±6.5	4113.9	4730.9	5401.2	5537.3
d (10^3 a.u.)	8.8 ± 0.1	9.5 ± 0.1	10.9 ± 0.1	12.4 ± 0.1	12.7 ± 0.1
PA (°)	42.5±0.1	266.5	269.6	87.3	222.8
ΔK_1	11.5±0.10	12.5	13.0	11.9	11.5
ΔK_2	11.3±0.13	12.2	12.5	12.2	11.7
P_{spur}^{2MASS} (%)	*>27*	*>31*	*>41*	*>54*	*>57*
P_{spur}^{gaia} (%)	23.3± 1.5	91.8± 3.3	137± 5	103± 5	61.1±3.6

Source	S13	S14	S15	S16	
ρ (mas)	5581.9	5712.1±	6184.5	6184.8	
d (10^3 a.u.)	12.8 ± 0.1	13.1 ± 0.1	14.2 ± 0.1	14.2 ± 0.1	
PA (°)	172.4	103.9	295.0	285.1	
ΔK_1	12.8	12.7	*12.8*	*12.8*	
ΔK_2	12.2	12.5	*12.2*	*12.2*	
P_{spur}^{2MASS} (%)	*>57*	*>60*	*>71*	*>71*	
P_{spur}^{gaia} (%)	187± 6	200± 7	232± 8	232± 8	

Analysis Techniques
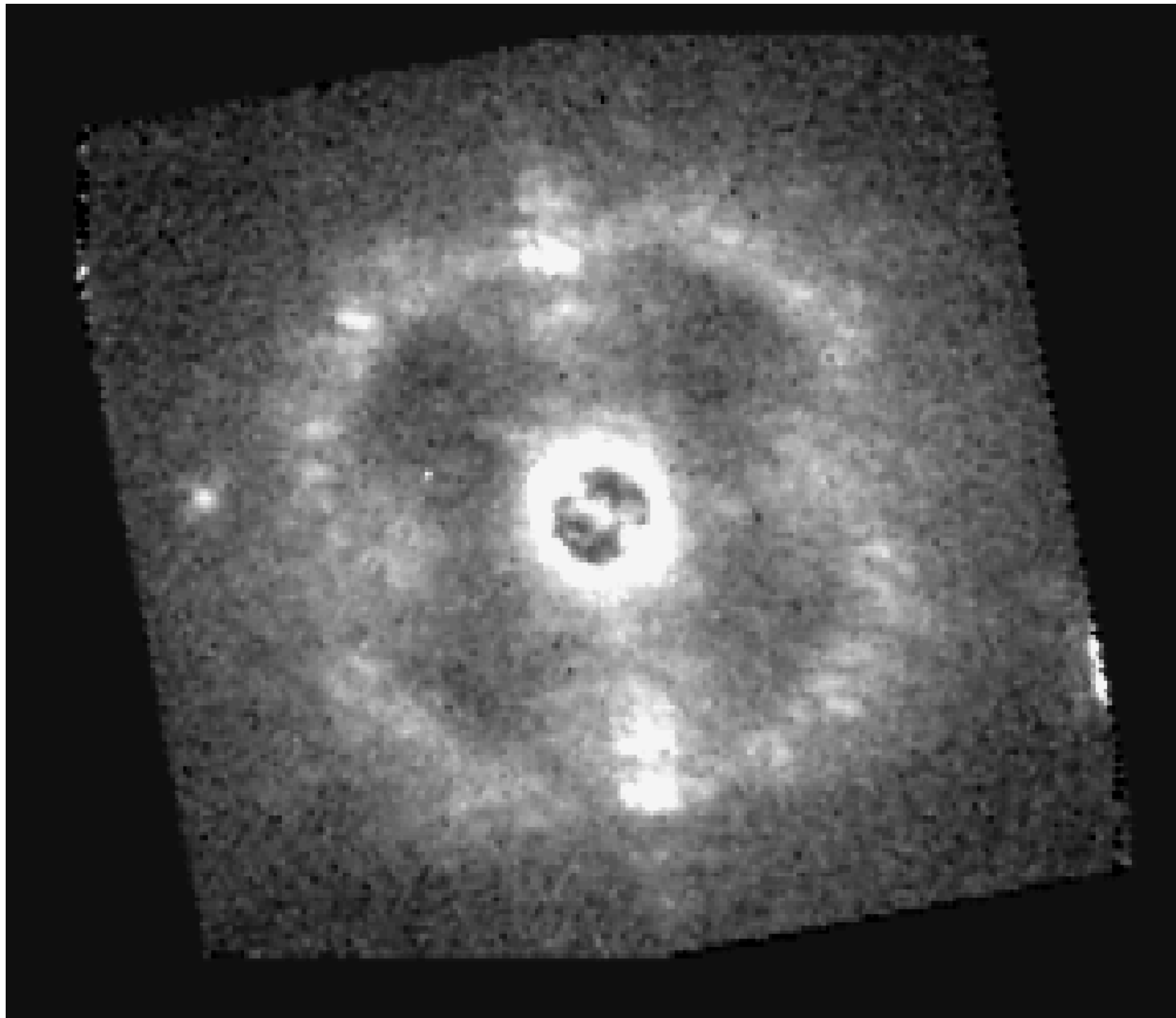
Original image

Post-processed cube