UX ORI OBJECTS

FROM AN INTERFEROMETRIC PERSPECTIVE

ALEXANDER KREPLIN, 30.09.2019

„THE UX ORI TYPE STARS AND RELATED TOPICS“, ST. PETERSBURG

UNIVERSITY OF EXETER

OUTLINE

- INTRODUCTION
  - STAR FORMATION AND THE UX ORI PHENOMENON
  - INTERFEROMETRY
- OBSERVATIONS
  - THE UX ORI TYPE STAR KK OPH
  - THE PROTOTYPE UX ORI
  - V1026 SCO AND CO ORI
- SUMMARY AND FUTURE WORK
  - ALMA + OPTICAL INTERFEROMETRY

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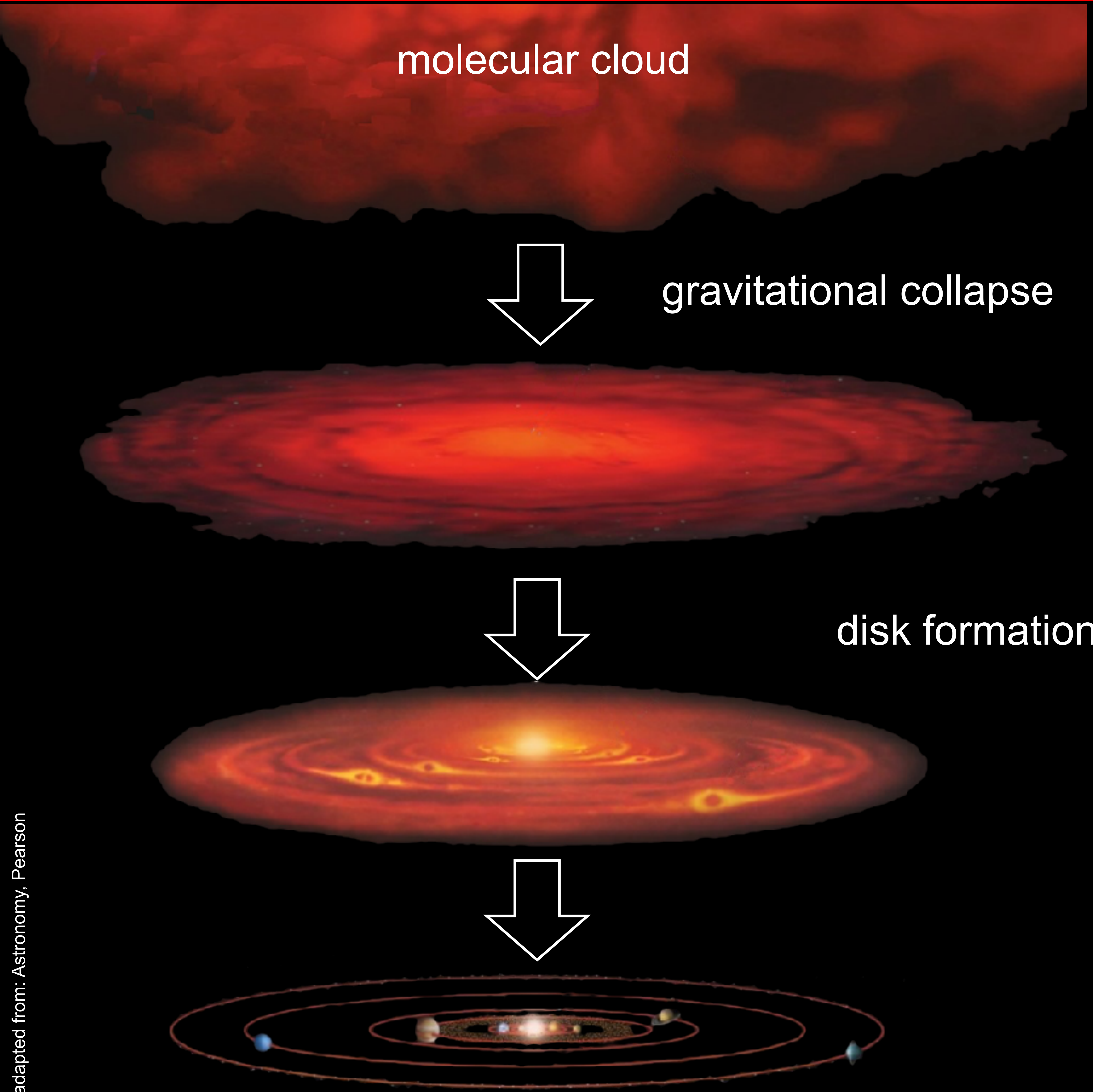
STAR FORMATION



adapted from: Astronomy, Pearson

evolutionary sequence

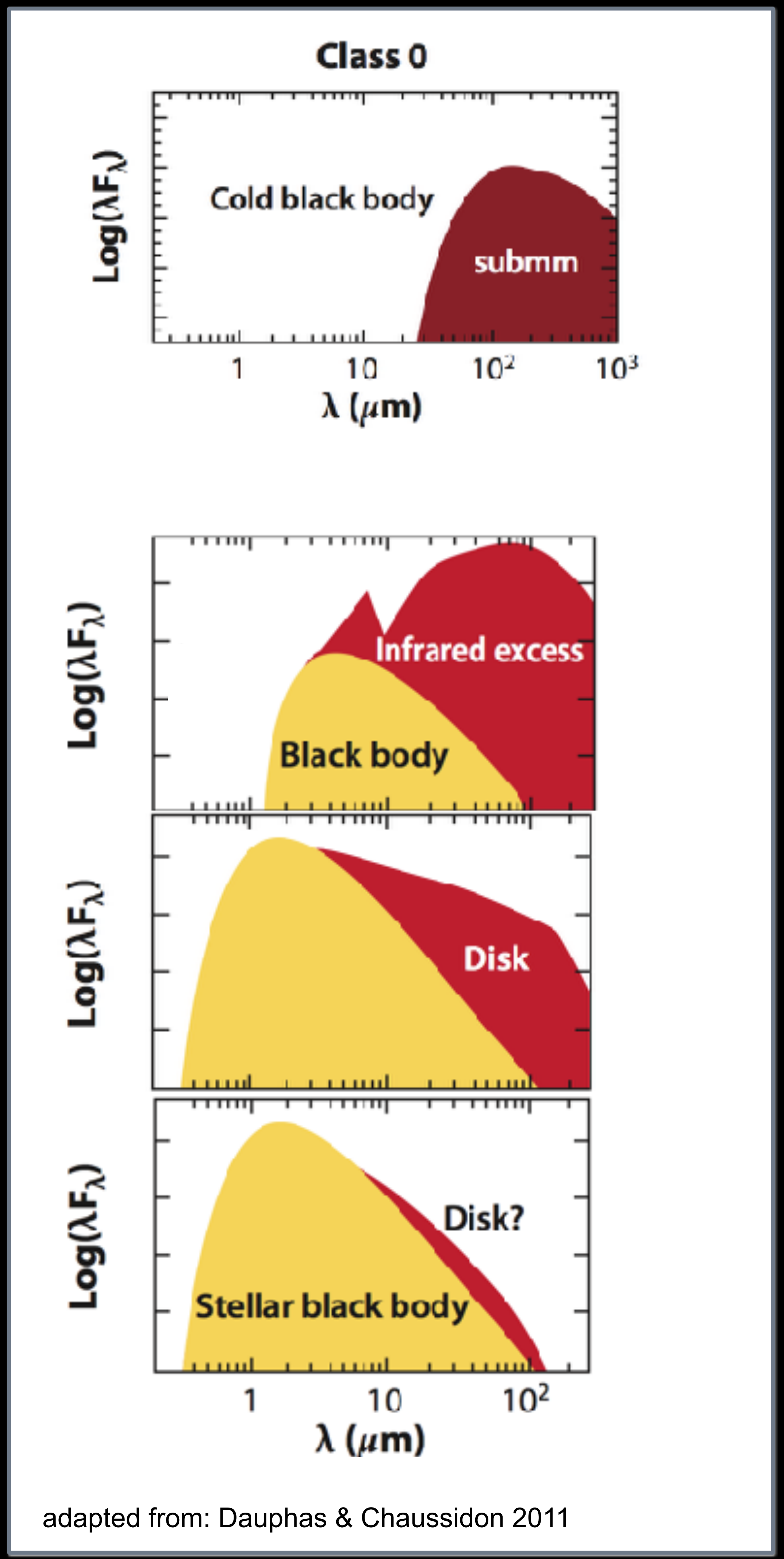
0.03 Myr — Class 0

0.2 Myr — Class I

1.0 Myr — Class II

10 Myr — Class III

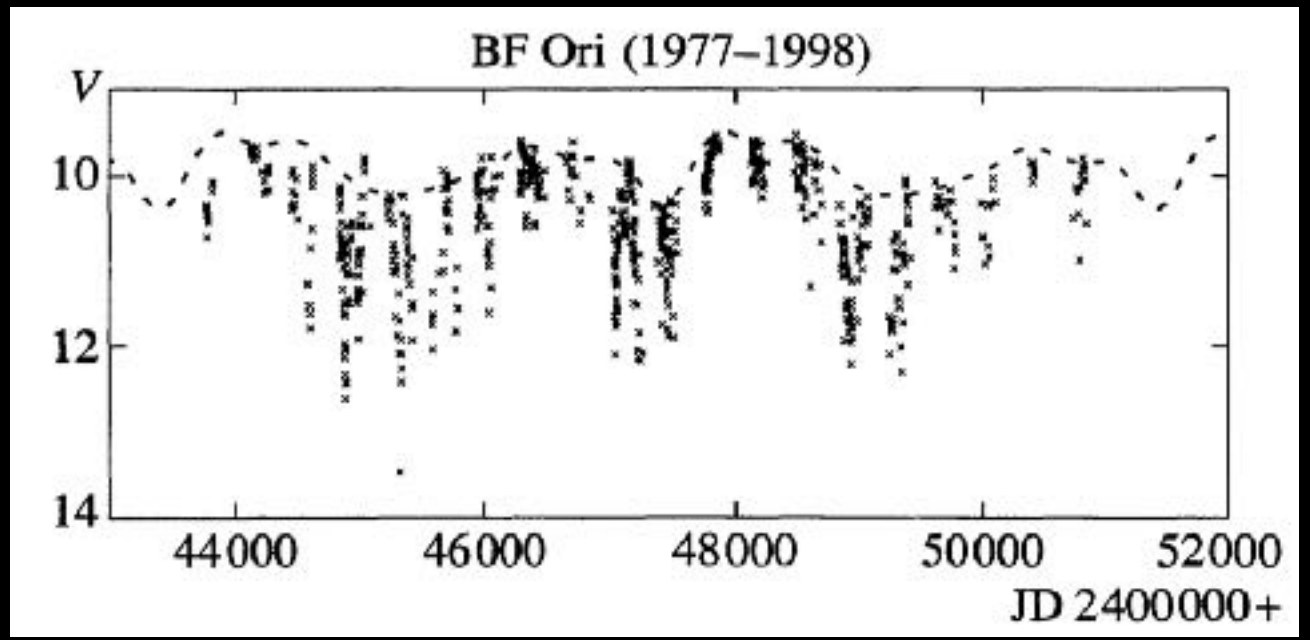
Spectral Energy distribution (SED)



UX ORI PHENOMENON

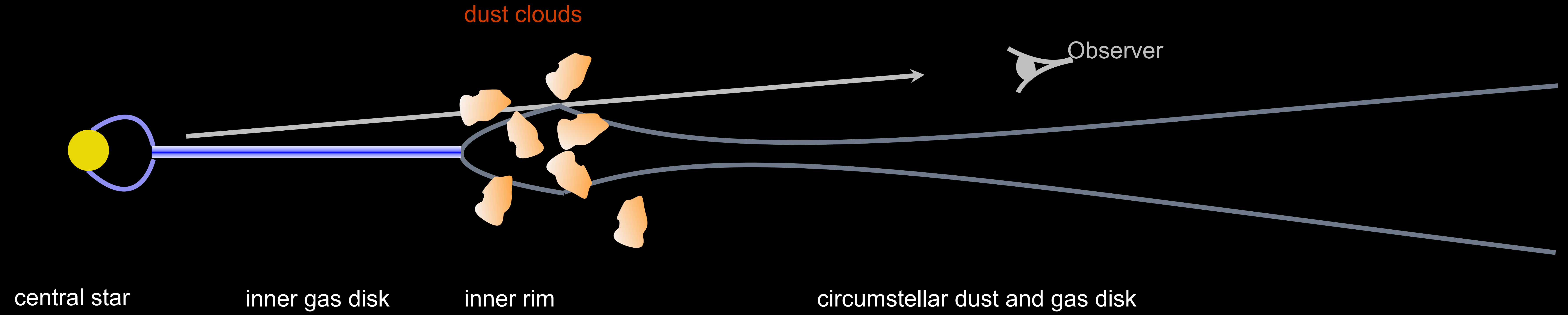
Irregular brightness variations from 2-3 magnitudes in the visual band.

Observed light gets bluer in the deep minima, and the fraction of polarized light increases.



GRININ ET AL. 1998, ASTL, 24, 802

Interpretation



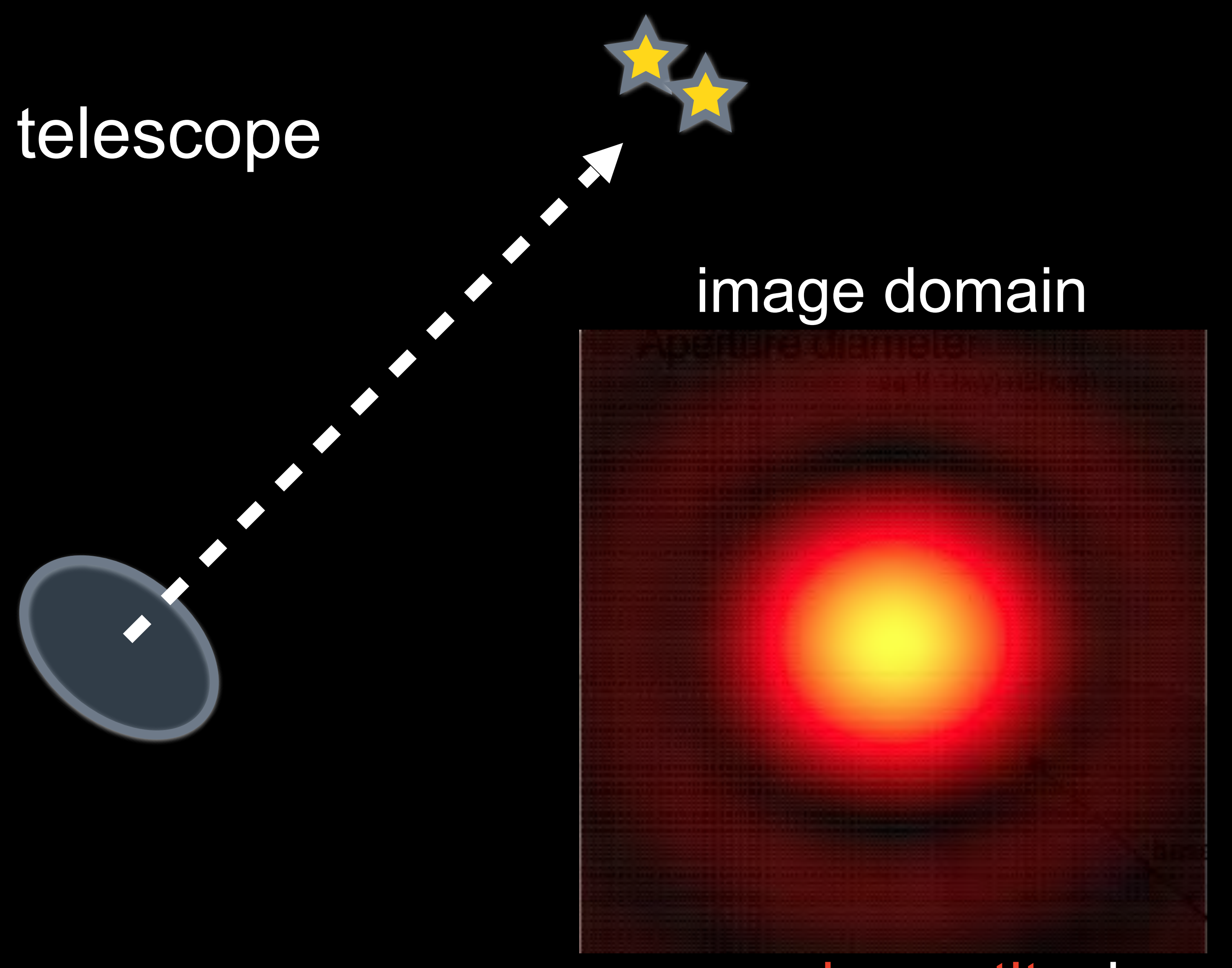
Dust orbiting in the disk or disk atmosphere can pass through the line of sight and obscure the central star.

High angular resolution is required to observe the innermost scales of circumstellar disks.
Even for the closest star forming regions (~140pc away) this becomes a challenge (1AU ~ 7mas).

INTERFEROMETRY

What happens during an observation of a scientific target (e.g., a binary)?

Angular resolution $\sim \frac{\lambda}{D}$



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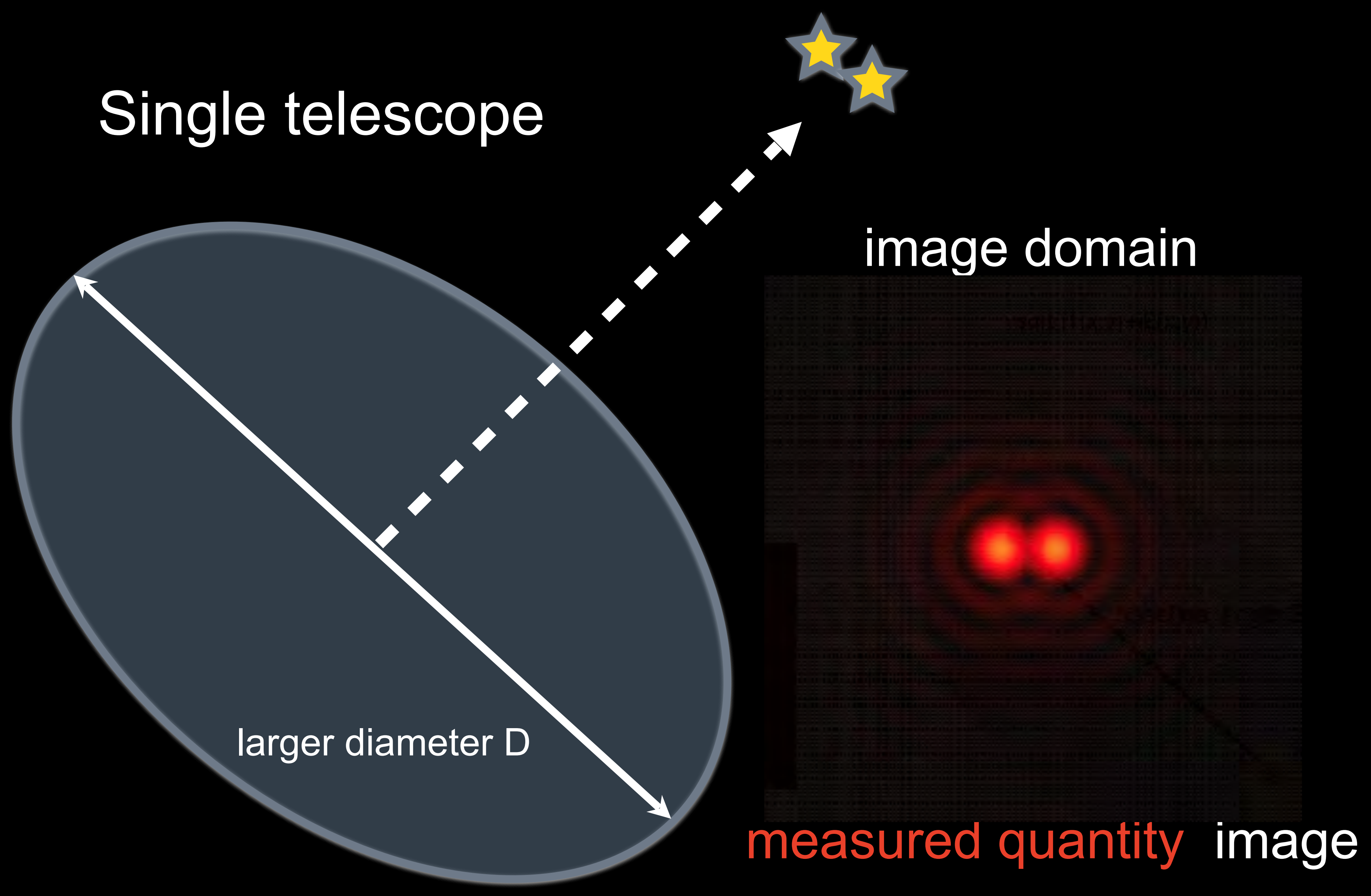

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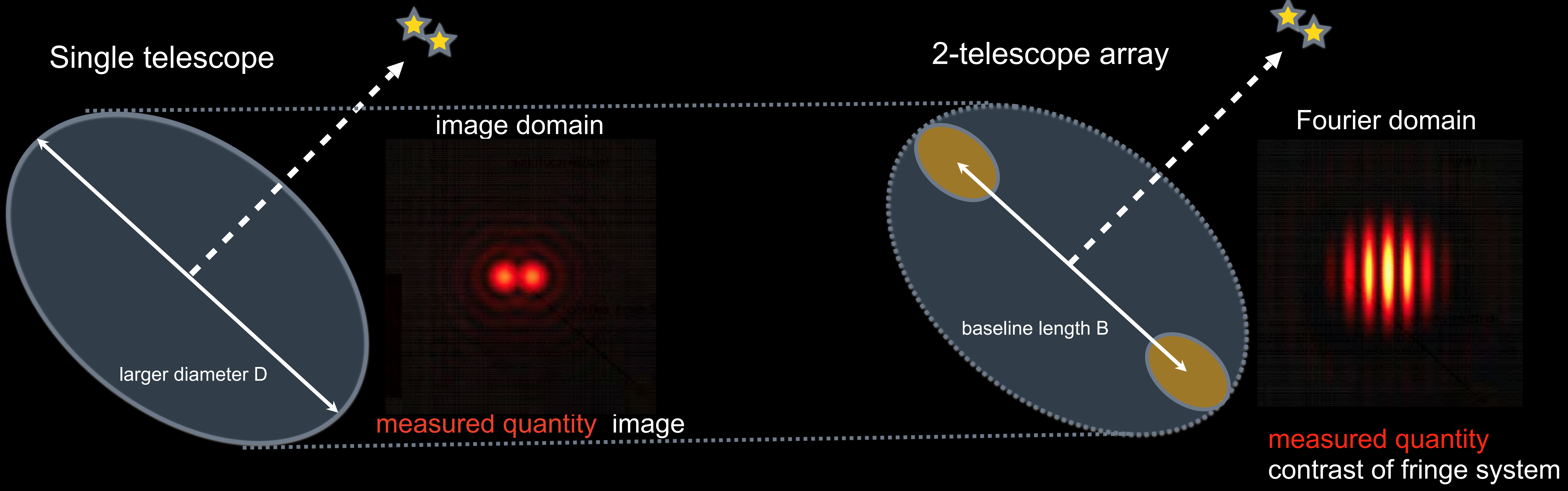

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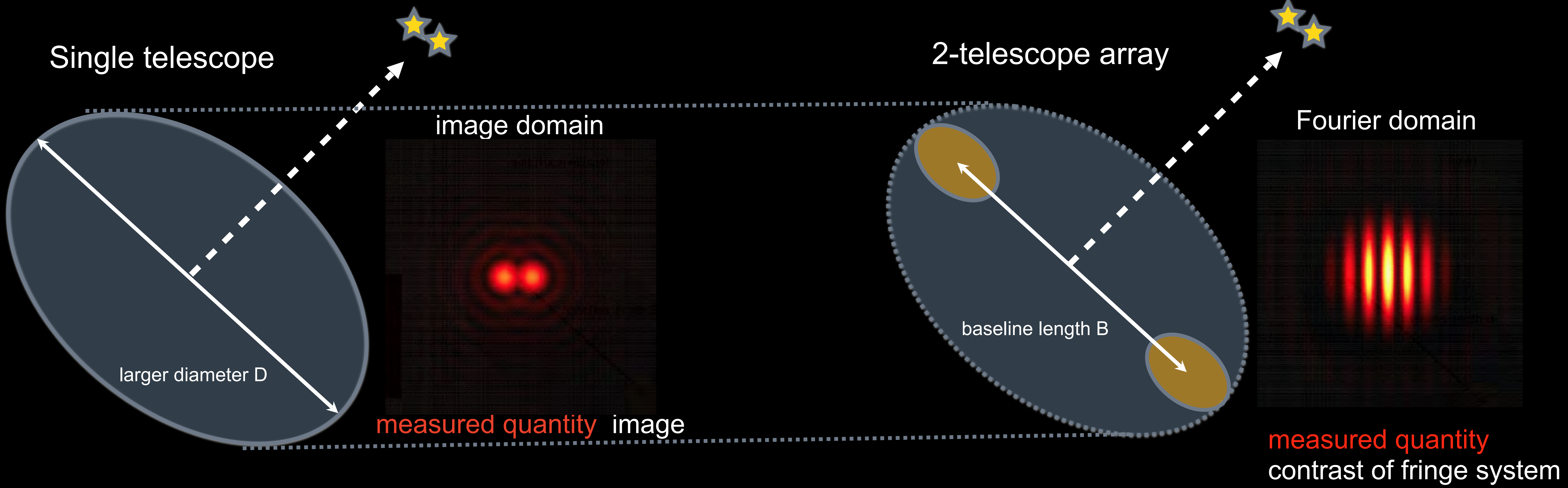
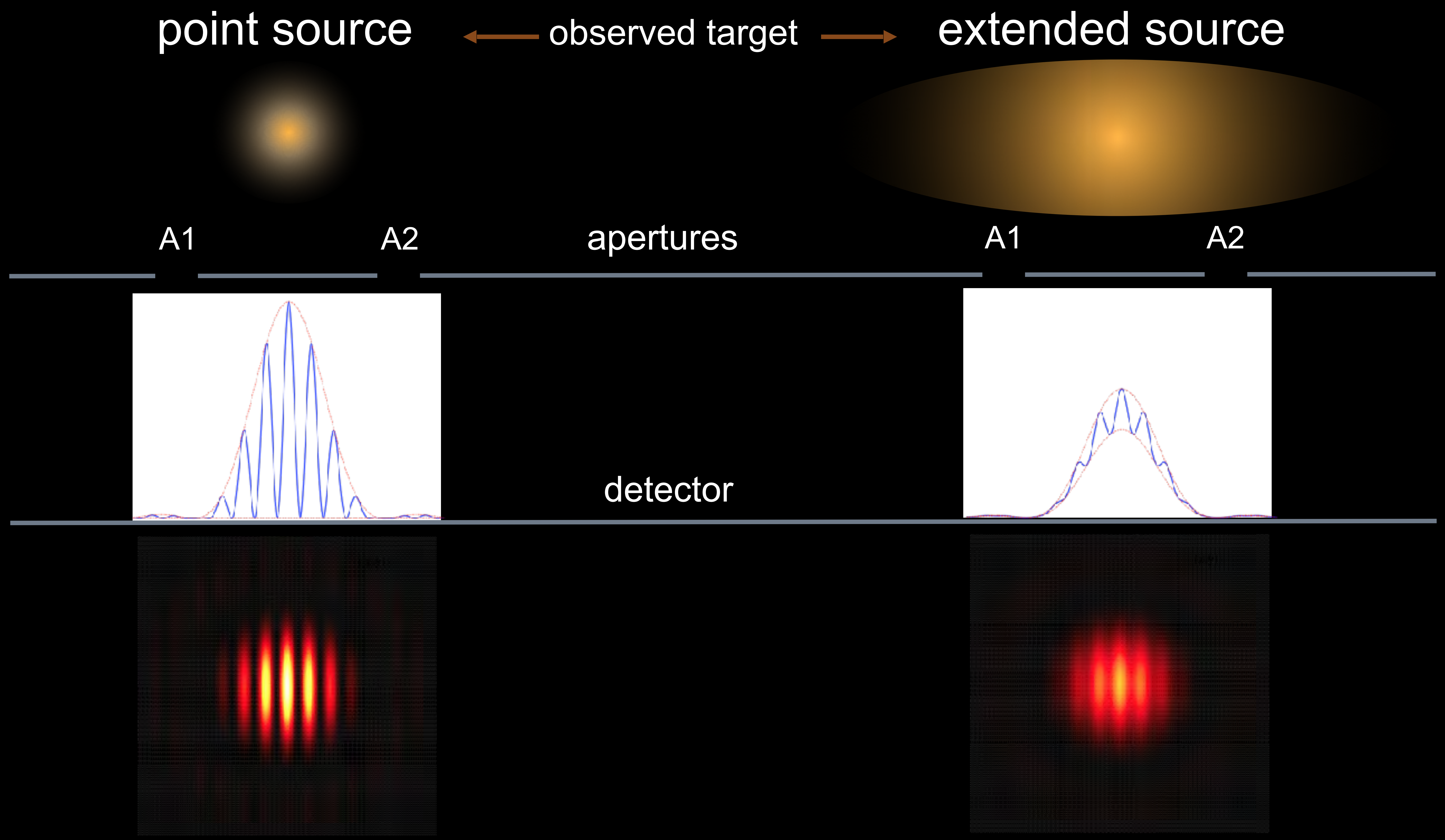


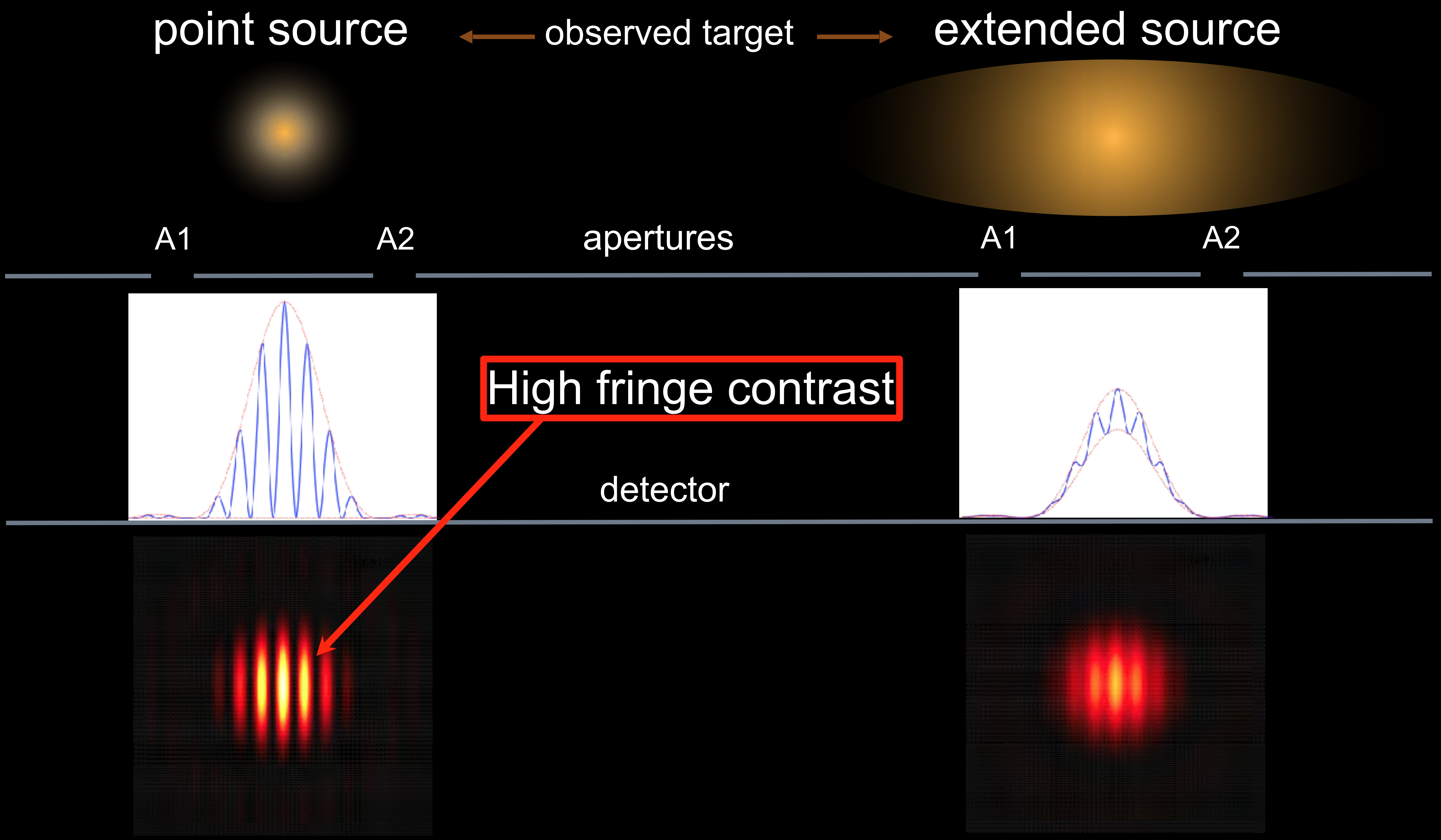
Instead of building larger telescope mirrors (which is very expensive), one can combine the light of several smaller telescopes that are separated at large distances, called baseline lengths.

⇒ high angular resolution BUT no real image…

INTERFEROMETRY



INTERFEROMETRY



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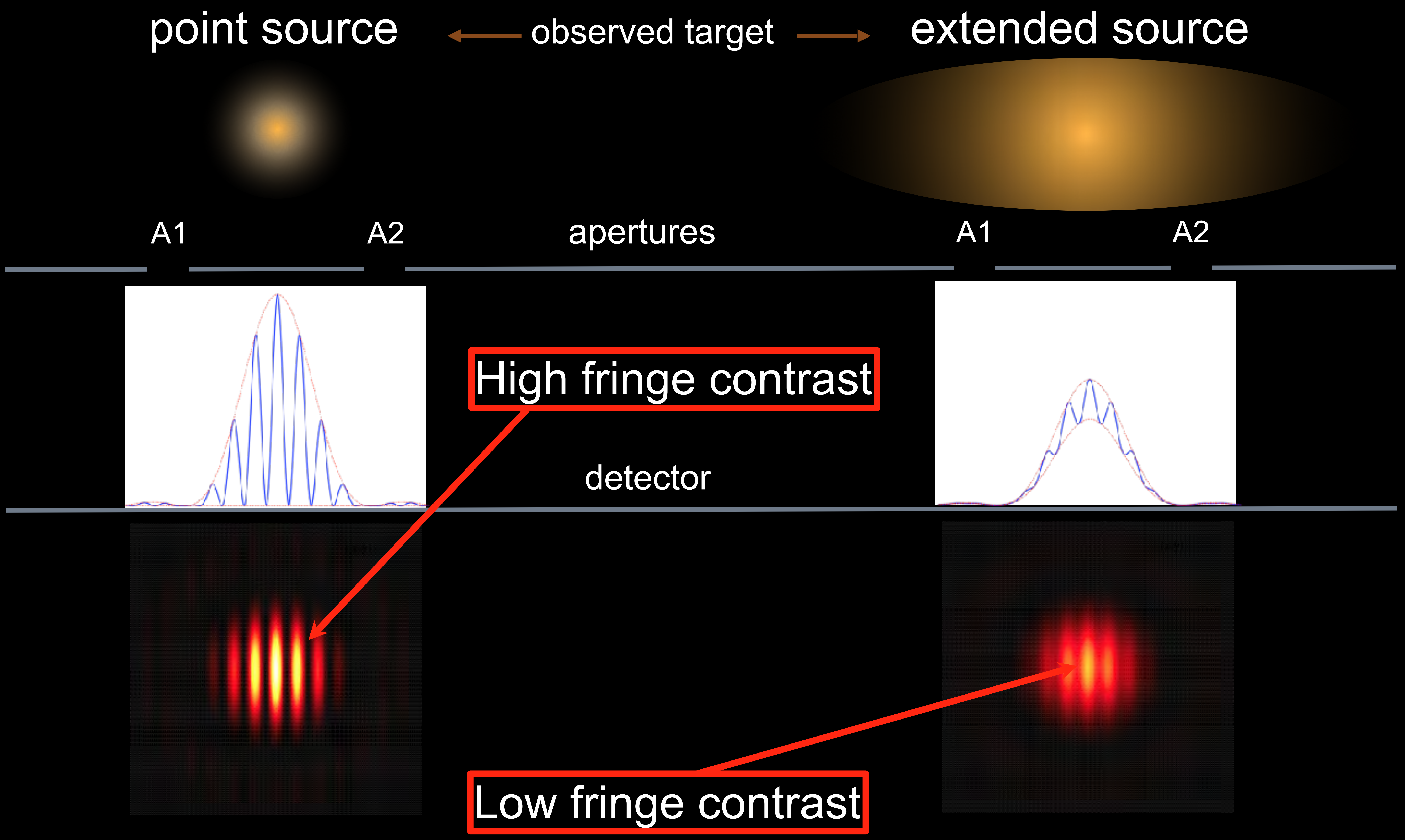
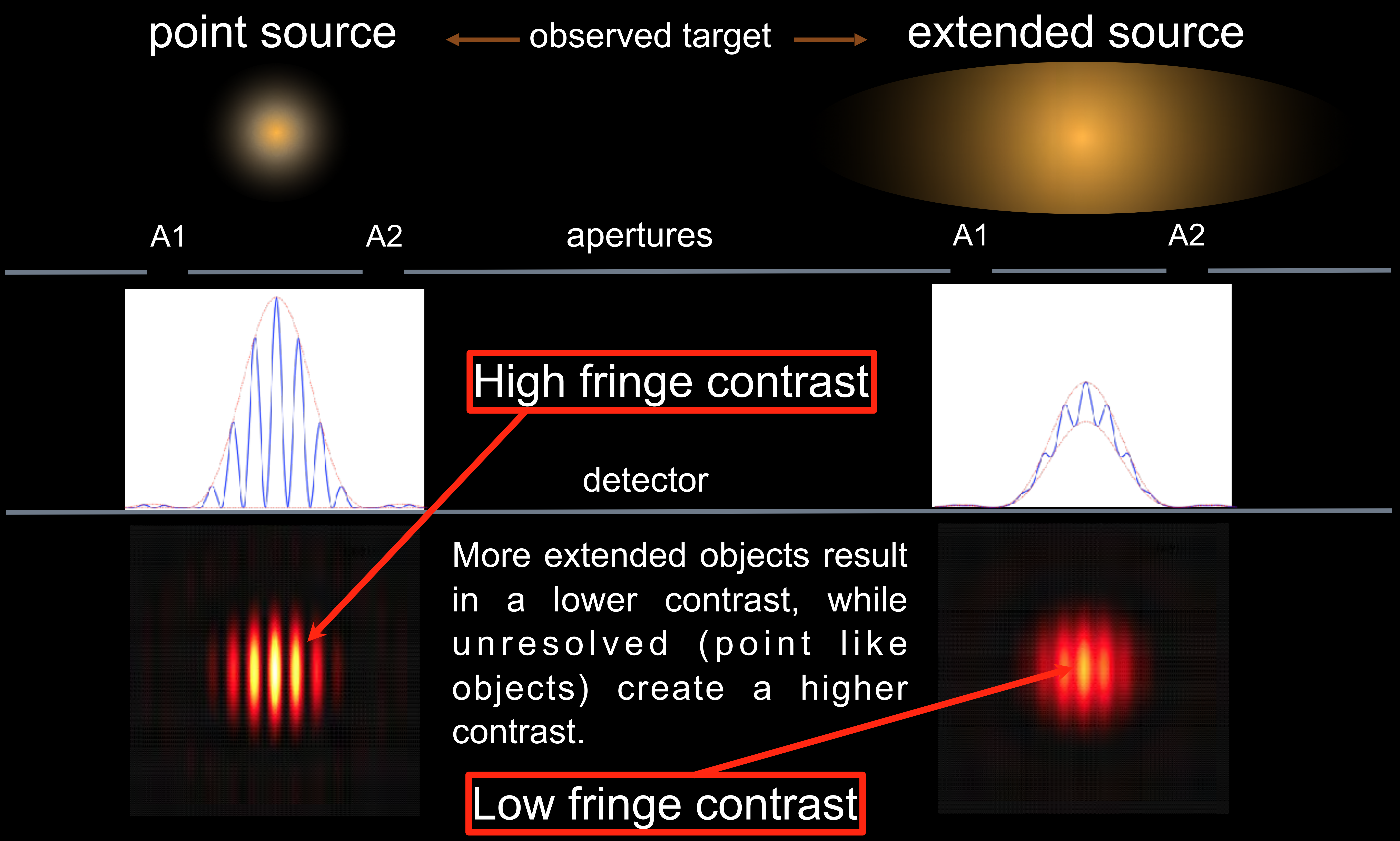


INTERFEROMETRY



More extended objects result in a lower contrast, while unresolved (point like objects) create a higher contrast.

INTERFEROMETRY

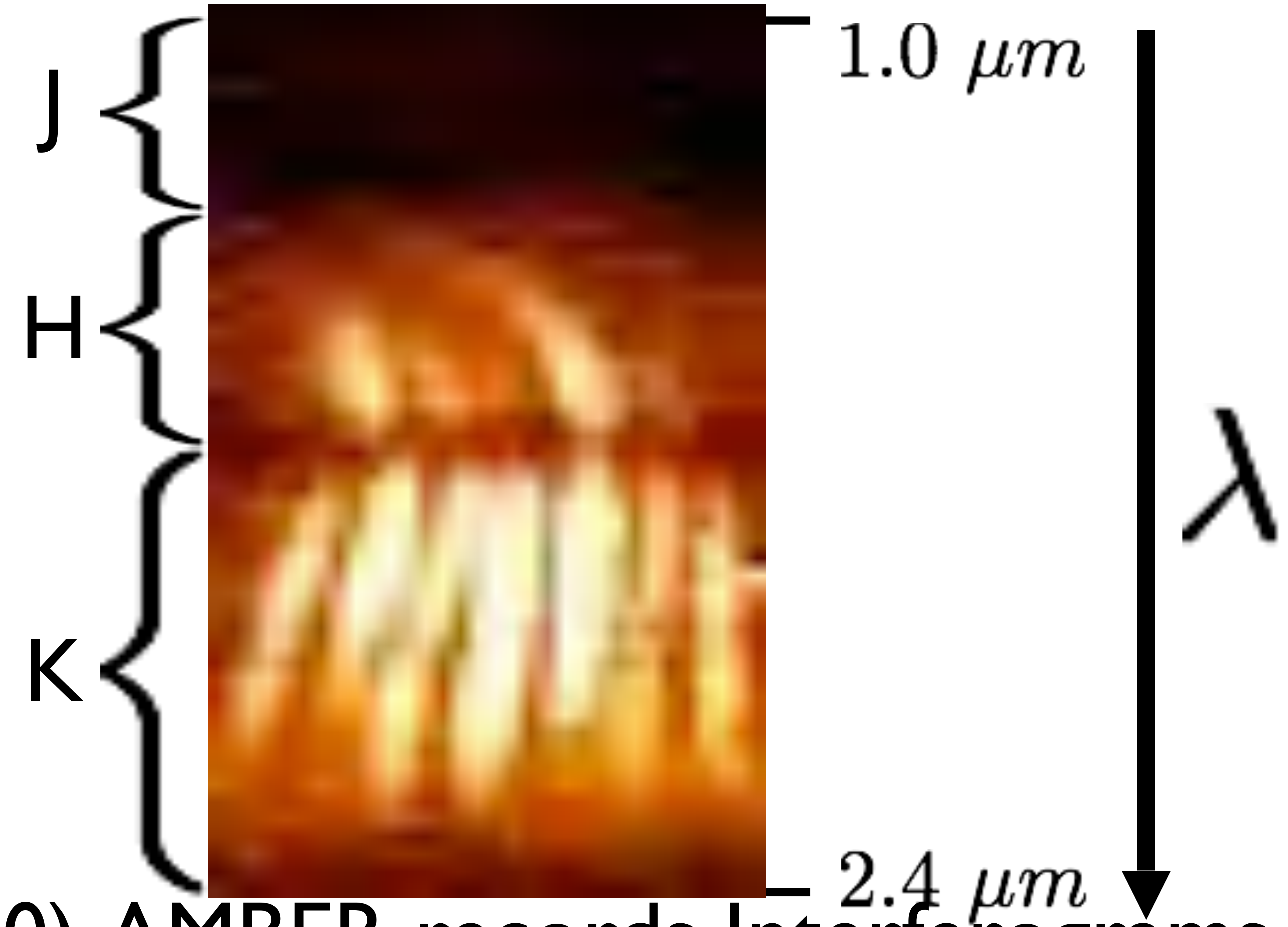
photometric beam 1 | photometric beam 2 | interferometric beam | photometric beam 3

INTERFEROMETRY

HIGH (R = 12000)

MEDIUM (R= 1500)

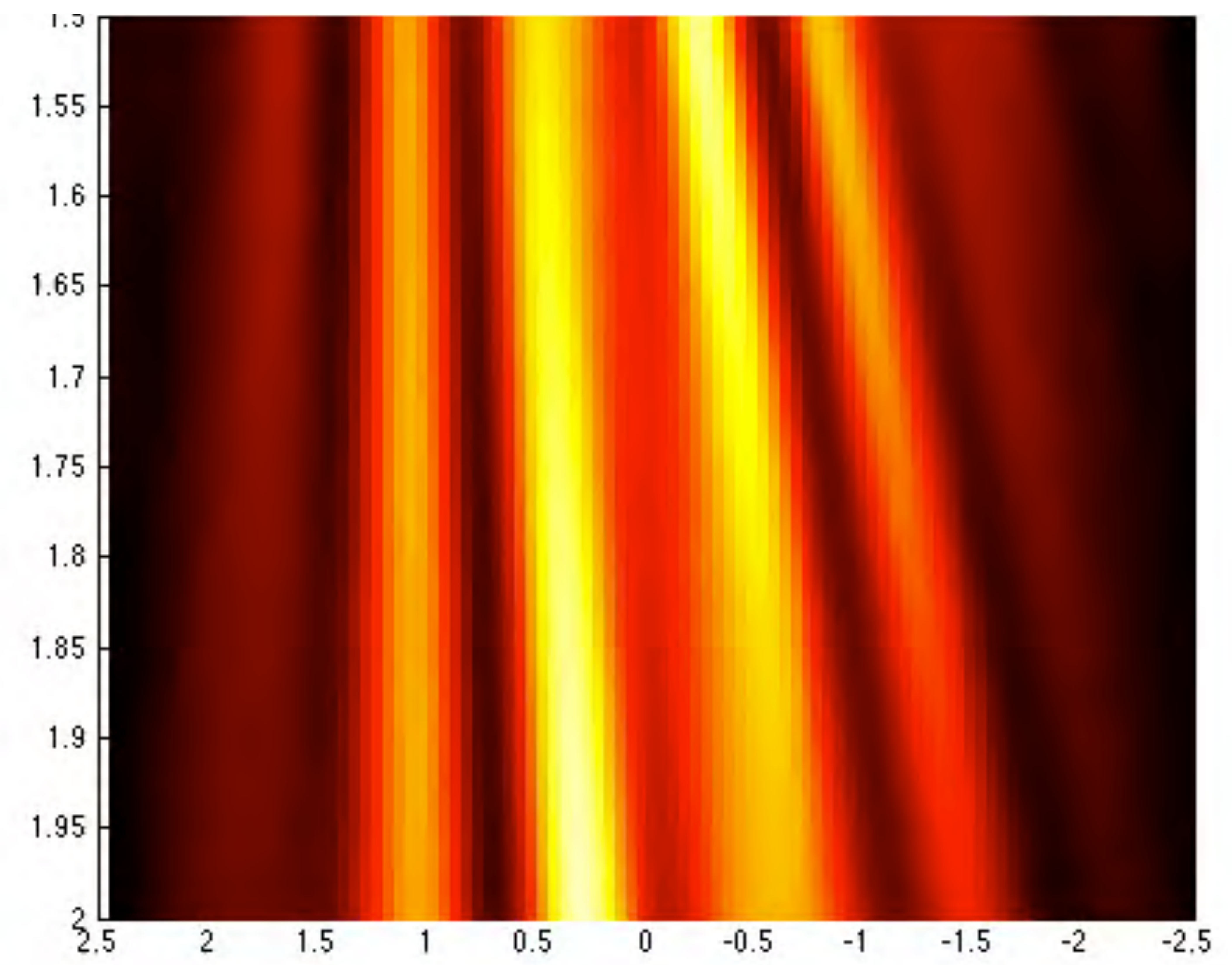
LOW (R = 30)



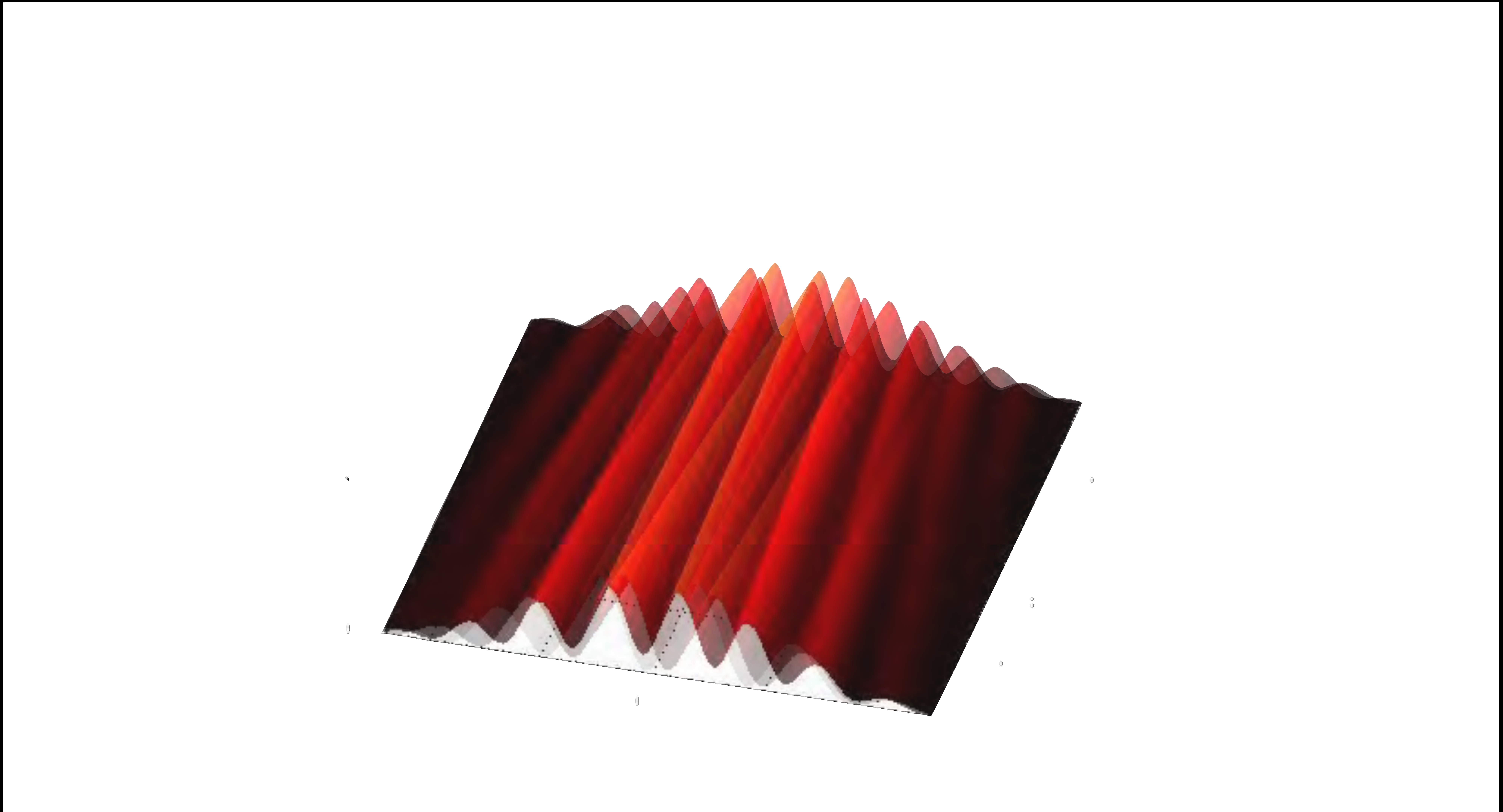
In low resolution (R = 30), AMBER records Interferograms in the J-, H- and K-Band simultaneously

INTERFEROMETRY

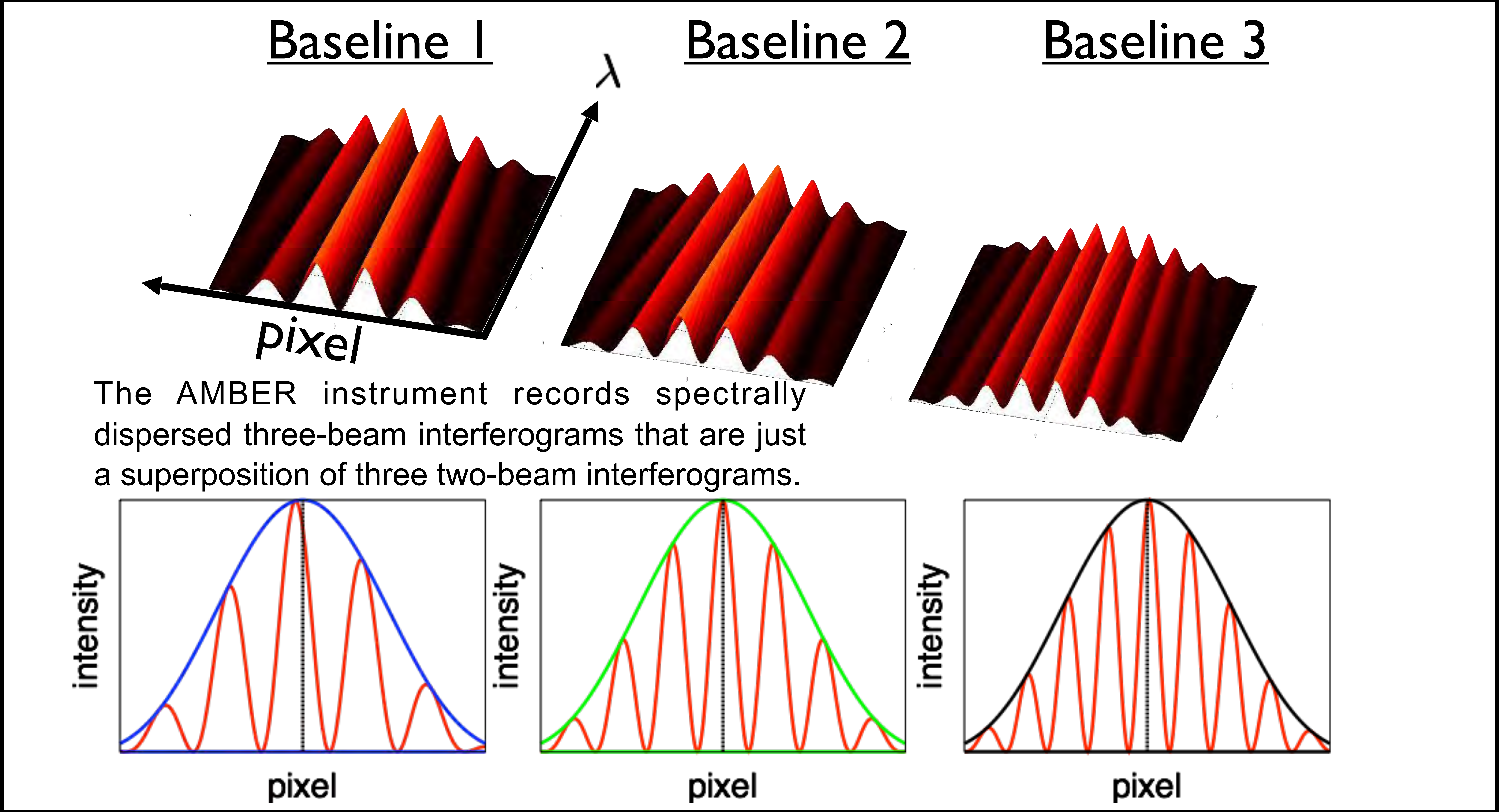
INTERFEROMETRY



INTERFEROMETRY

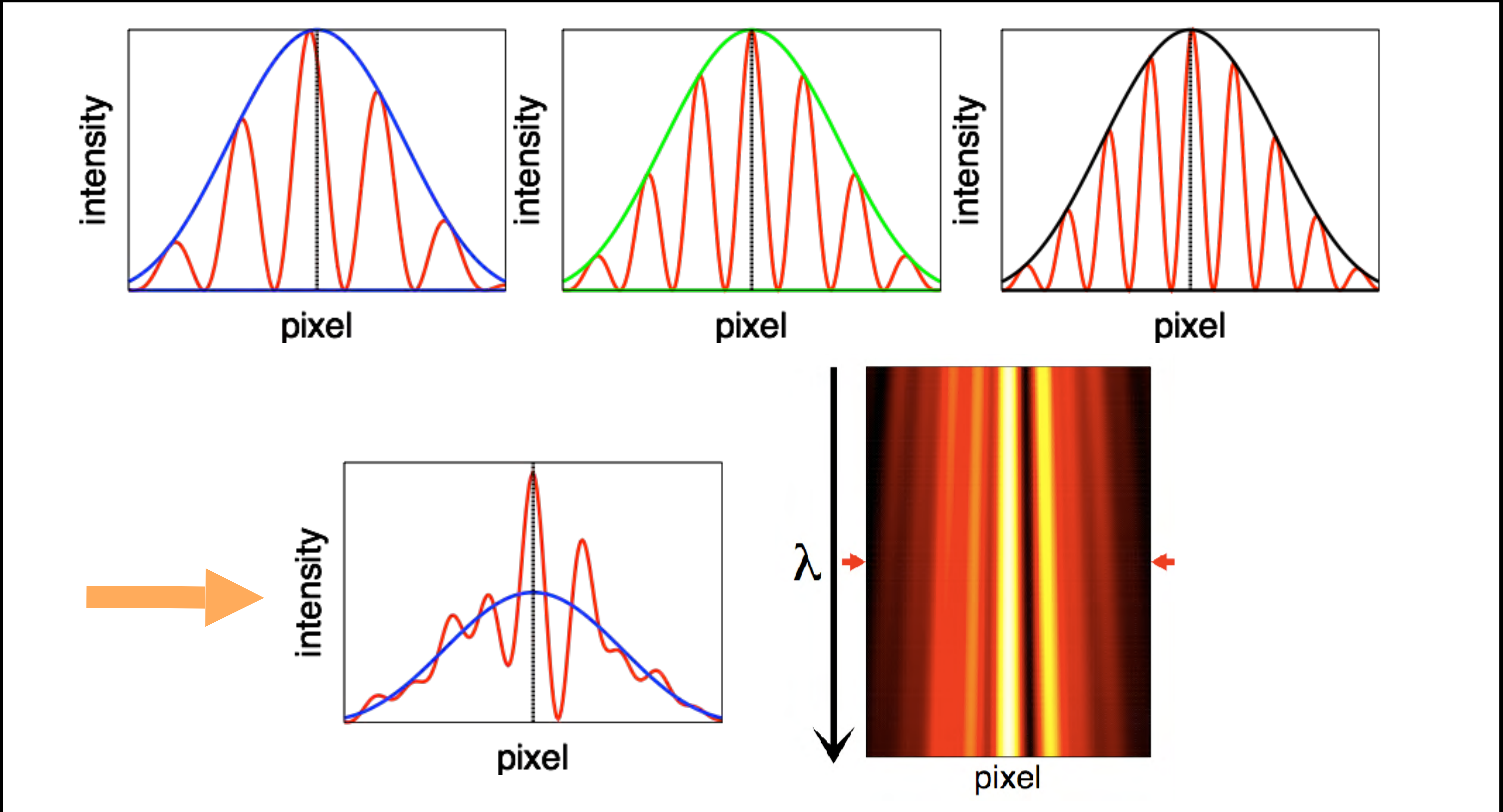


INTERFEROMETRY

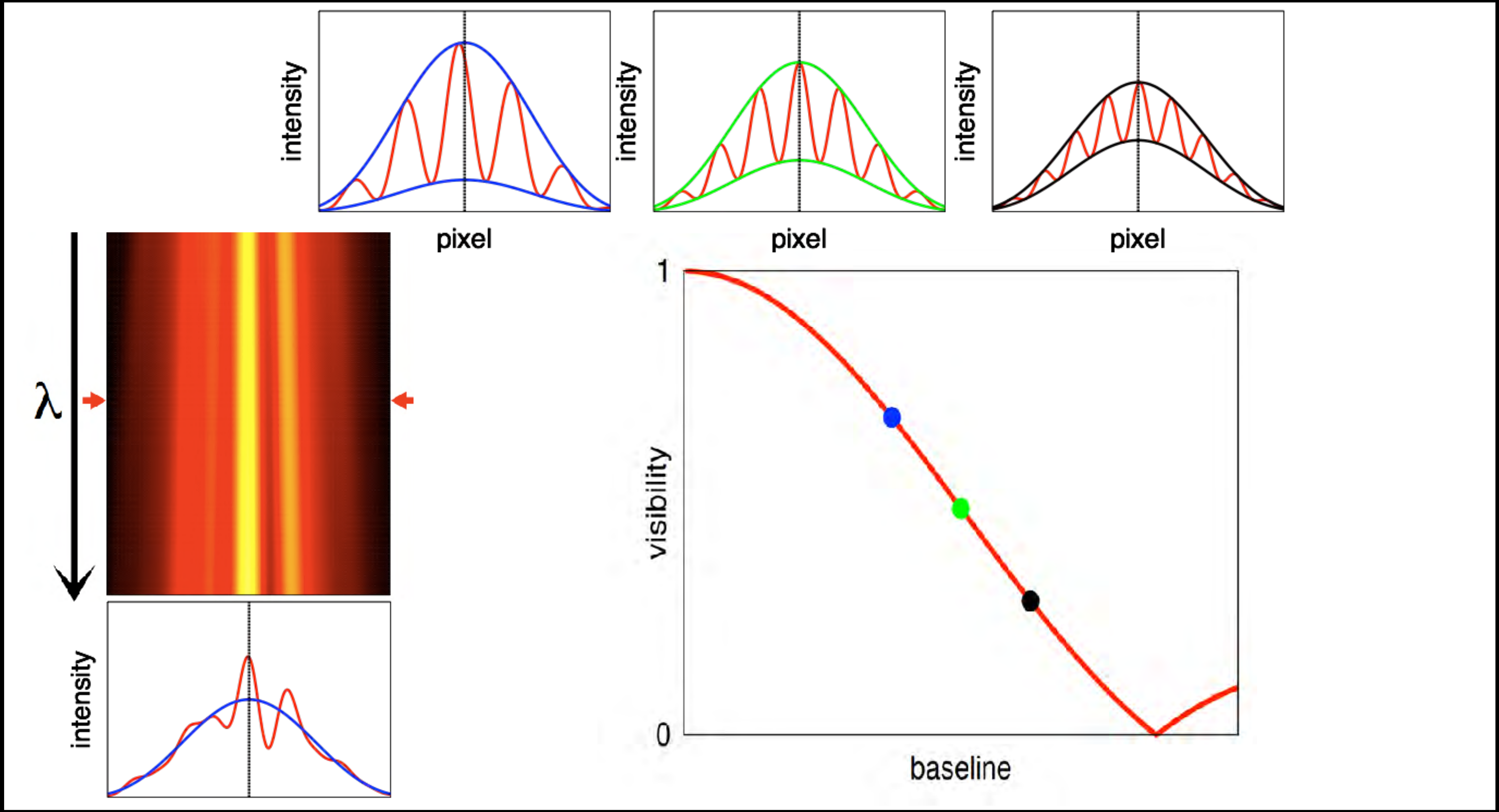


The AMBER instrument records spectrally dispersed three-beam interferograms that are just a superposition of three two-beam interferograms.

INTERFEROMETRY



INTERFEROMETRY



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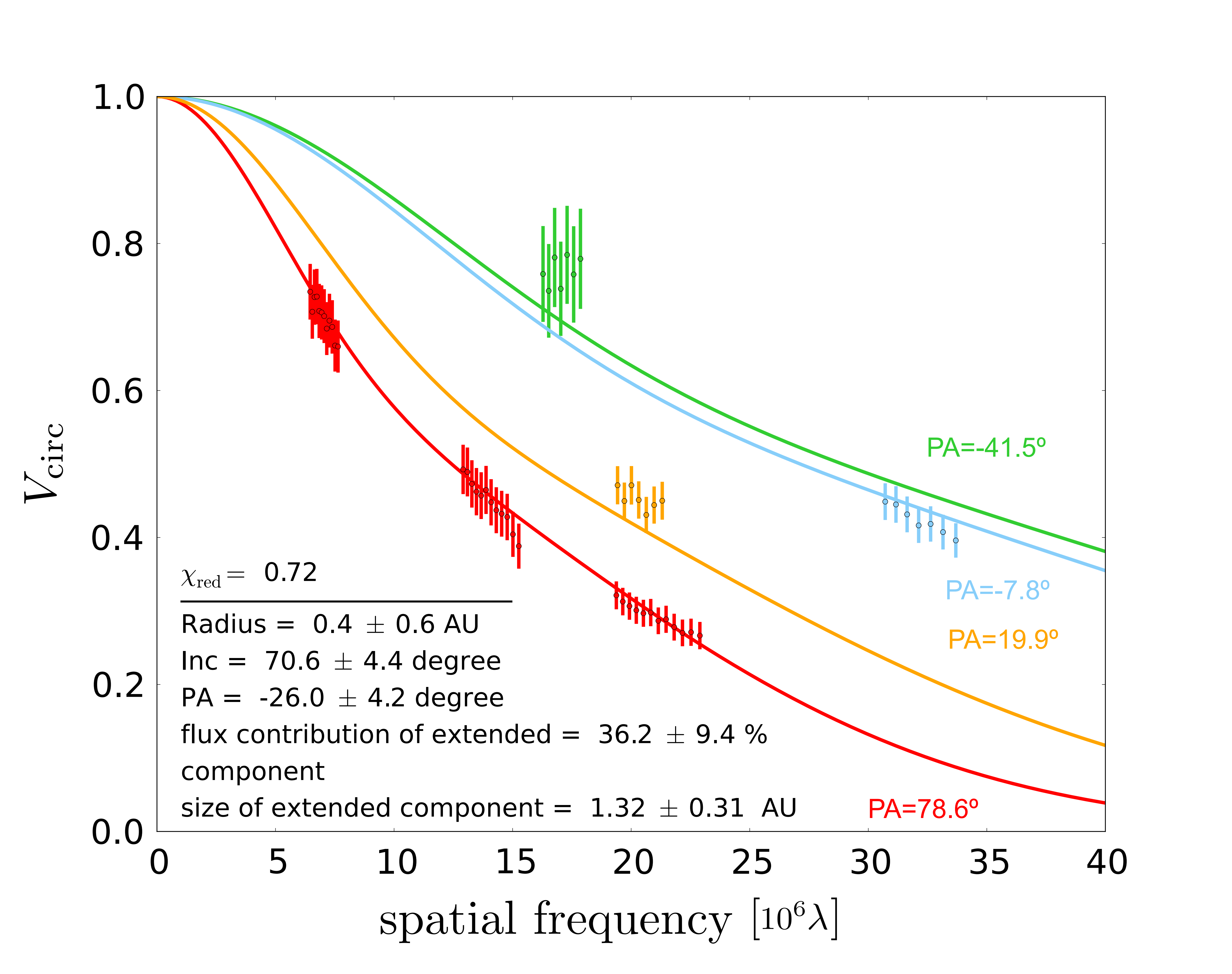
DISK AT NEARLY EDGE-ON INCLINATION

- VLTI/AMBER observations reveal an elongated brightness distribution
- Stellar properties:
  Teff = 8500 K, $R_{\star}$=2.0 $R_{\odot}$, d=160 pc

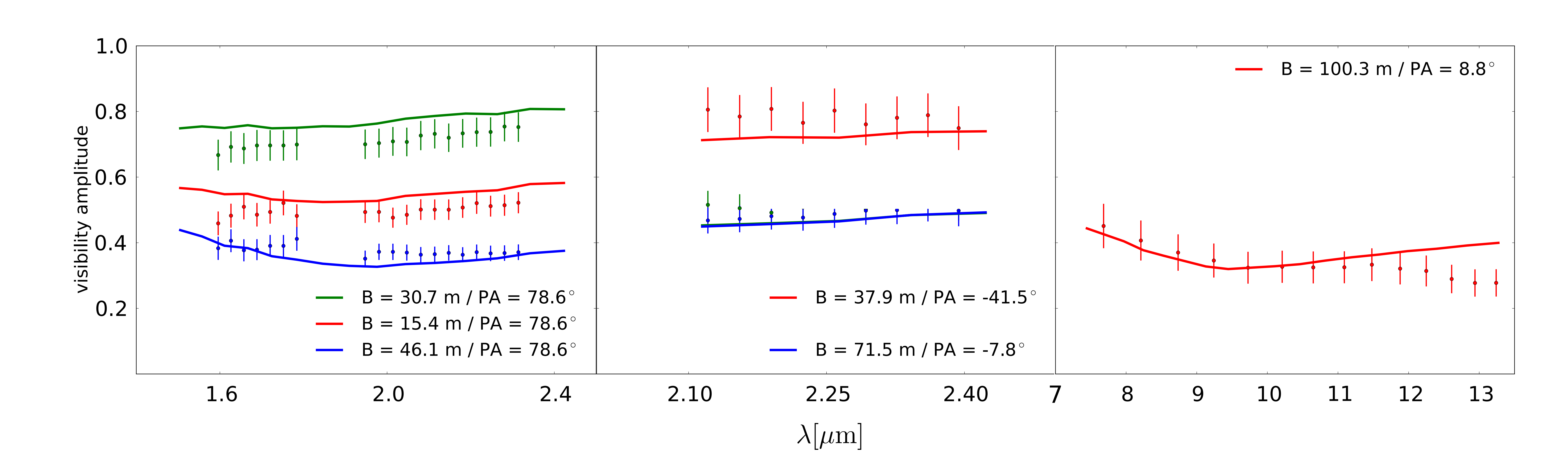


KREPLIN ET AL. 2013, A&A, 551, 21

KK OPH

DISK AT NEARLY EDGE-ON INCLINATION

- RADMC model (Dullemond & Dominik 2004, A&A, 417, 159)
- Simultaneous modeling of the SED and the NIR and MIR visibilities

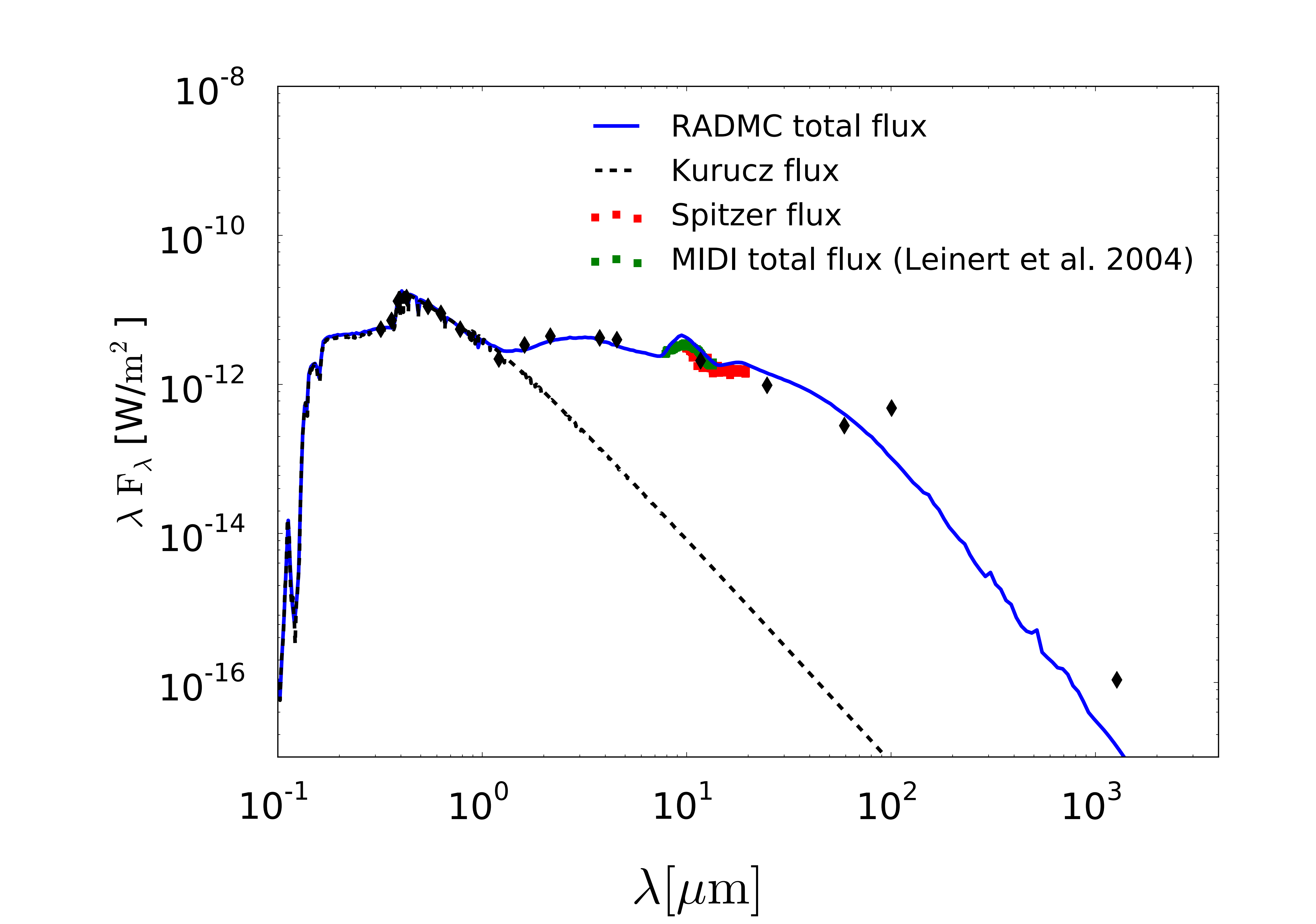


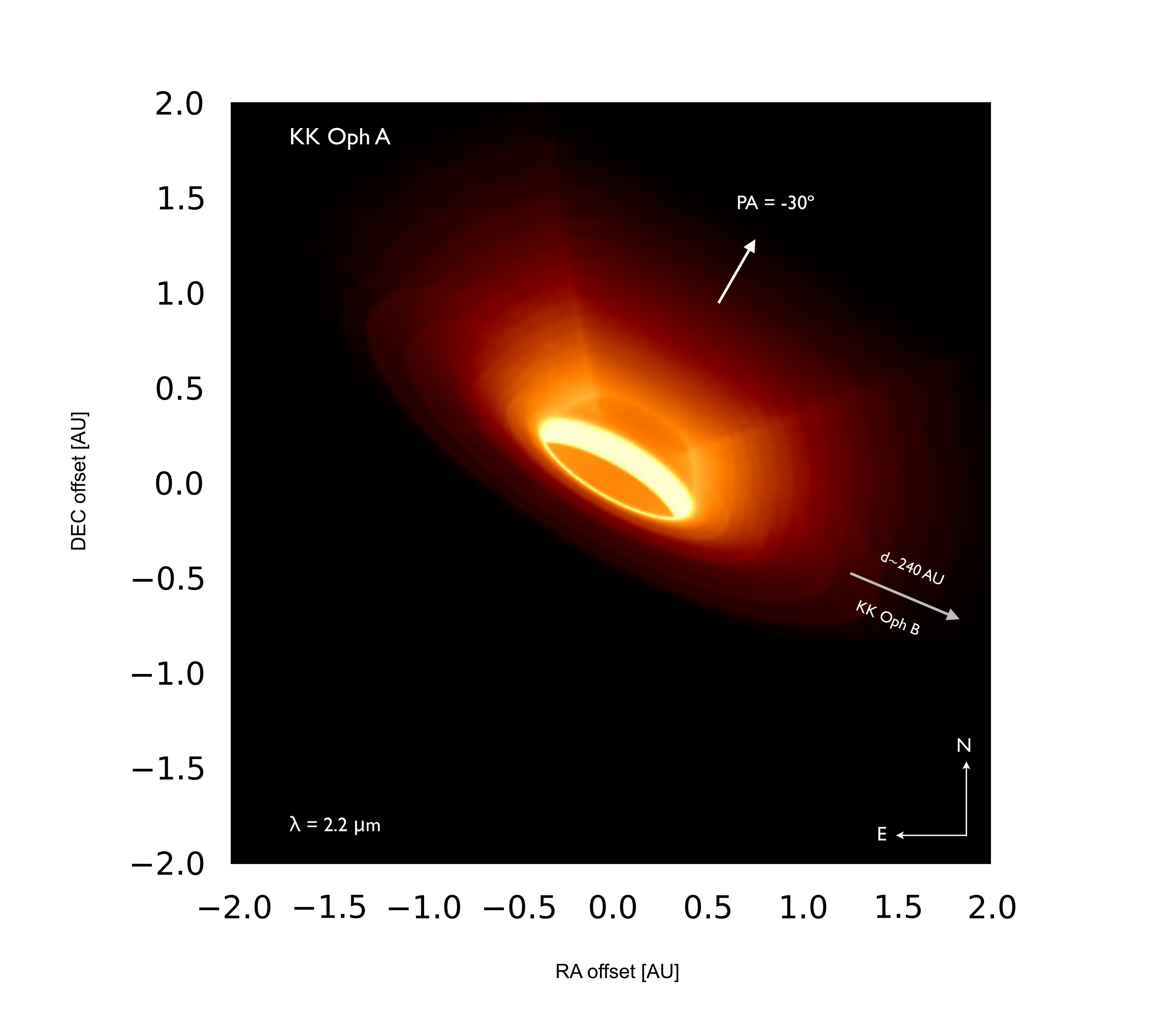
KREPLIN ET AL. 2013, A&A, 551, 21

KK OPH

DISK AT NEARLY EDGE-ON INCLINATION

- Rin = 0.56 au, INC = 70°, PA = -30°
- System PA supports binary formation models leading to coplanarity

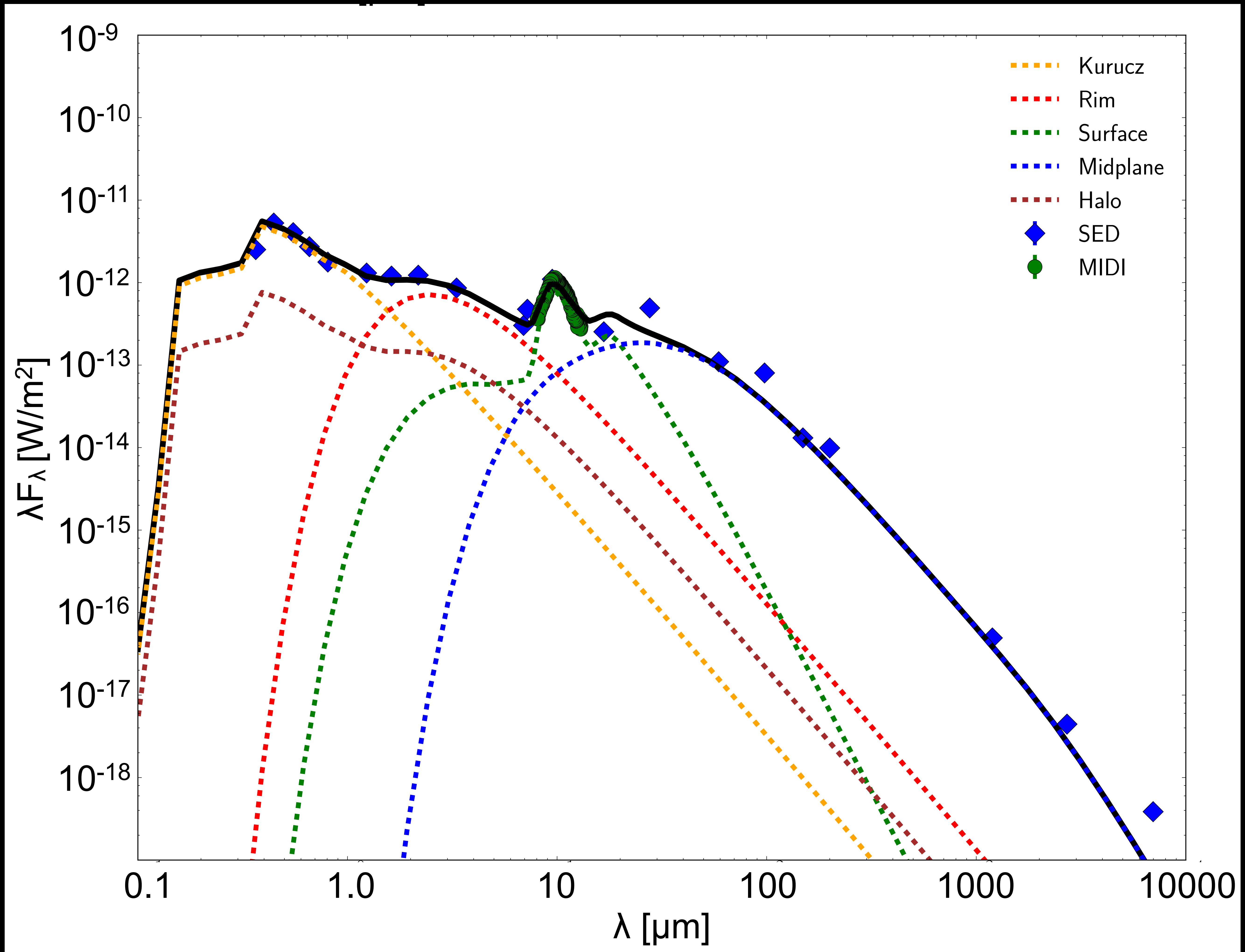




KREPLIN ET AL. 2013, A&A, 551, 21

DISK AT NEARLY EDGE-ON INCLINATION

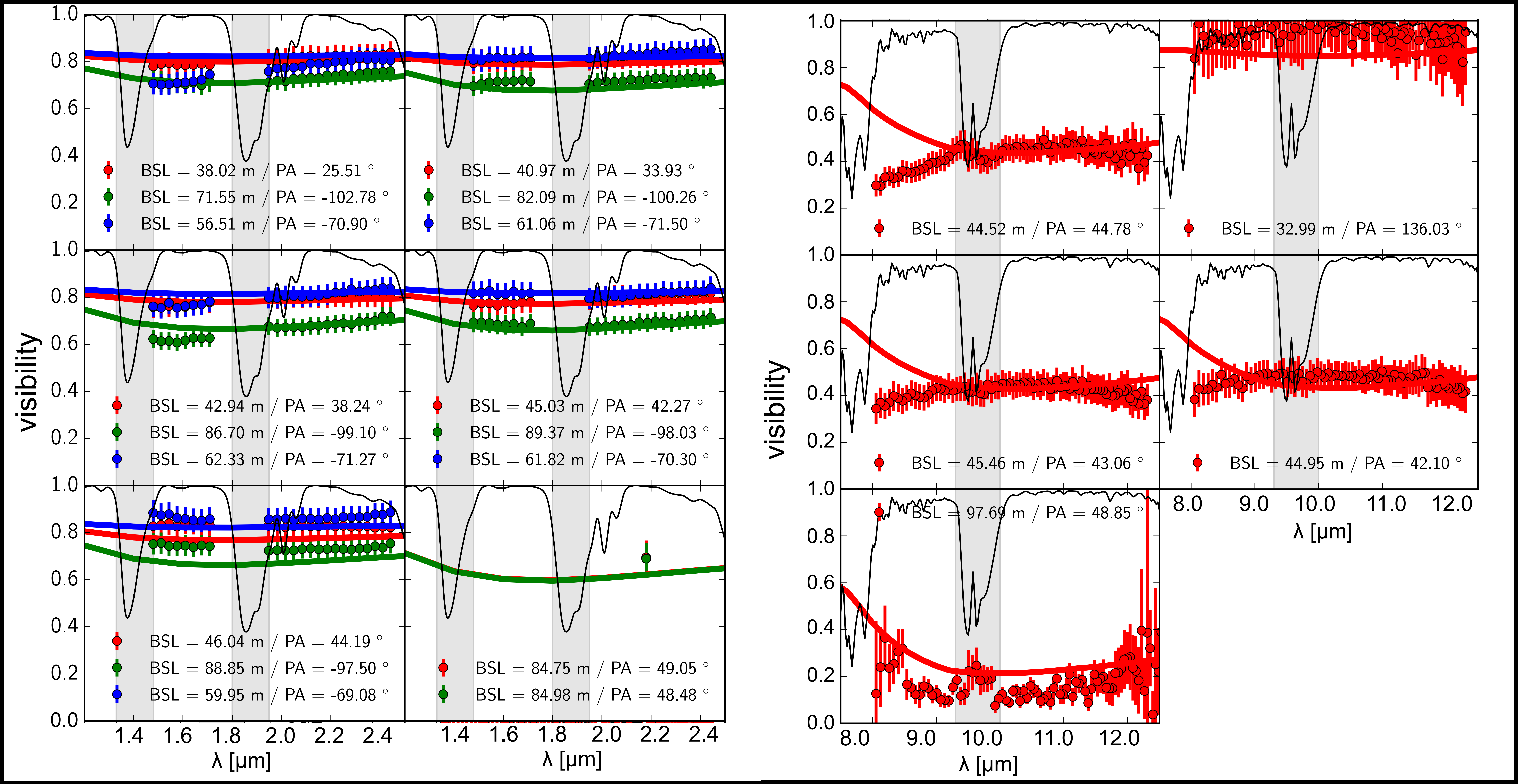
- Stellar properties:
  Teff = 8600 K, R☆=2.7 R☼, d=460 pc
- The intrinsic V-band polarization angle in deep minima might be used as an indicator for the approximate orientation of the symmetry axis of the circumstellar disk (Grinin et al. 1991, Ap&SS, 186, 283).
- Polarimetric mesurements of UX Ori show a linear V-band polarization angle of 125.5-128.7° (Voshchinnikov et al. 1988, Astrophys., 28, 182).



KREPLIN ET AL. 2016, A&A, 590, 96

DISK AT NEARLY EDGE-ON INCLINATION

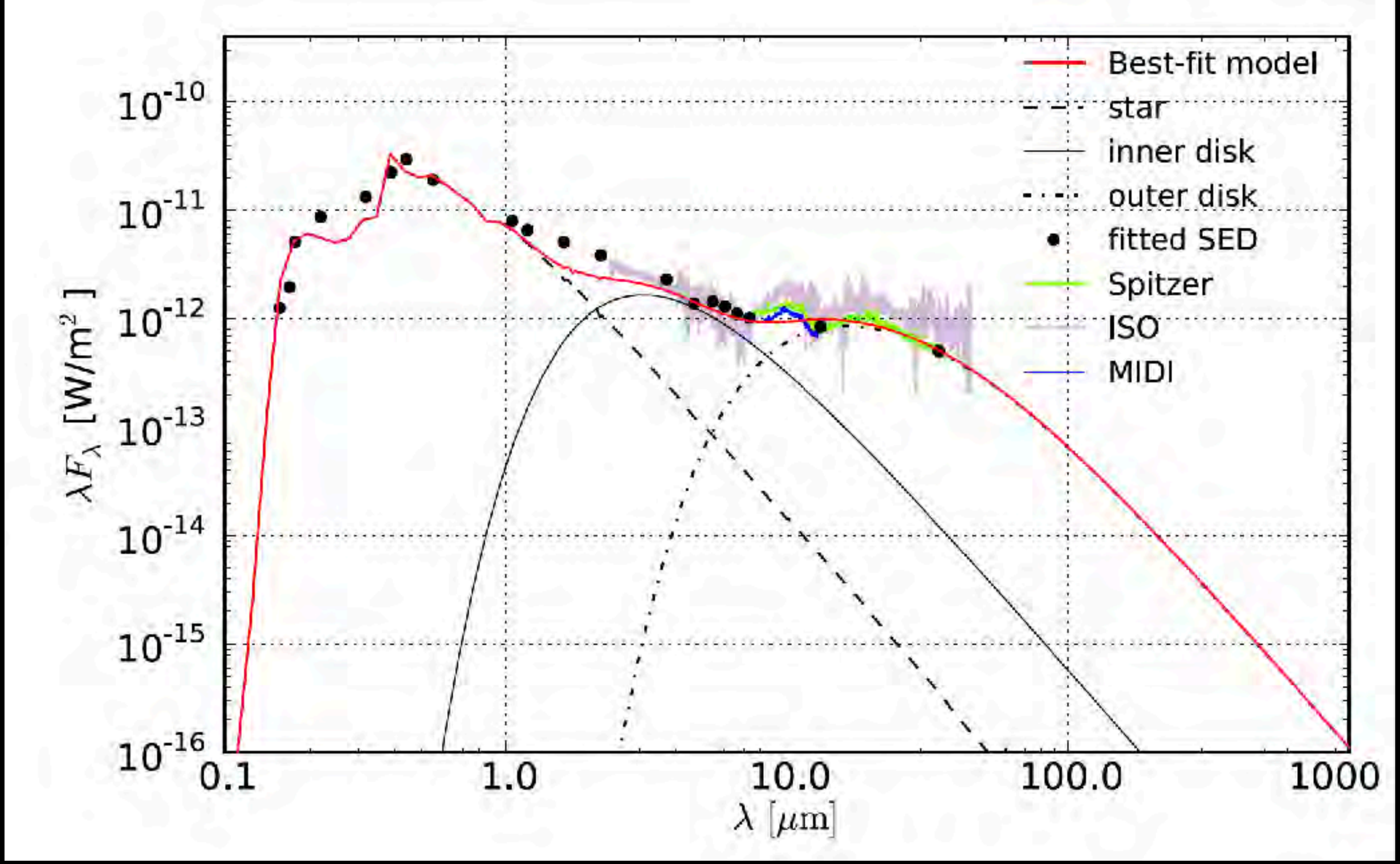
- Chiang-Goldreich model
- Tin = 1498 K (0.46 au)
  Rout = 25 AU
  Mdisk = 0.6 M☼
  INC = 70°
  PA = 133°



KREPLIN ET AL. 2016, A&A, 590, 96

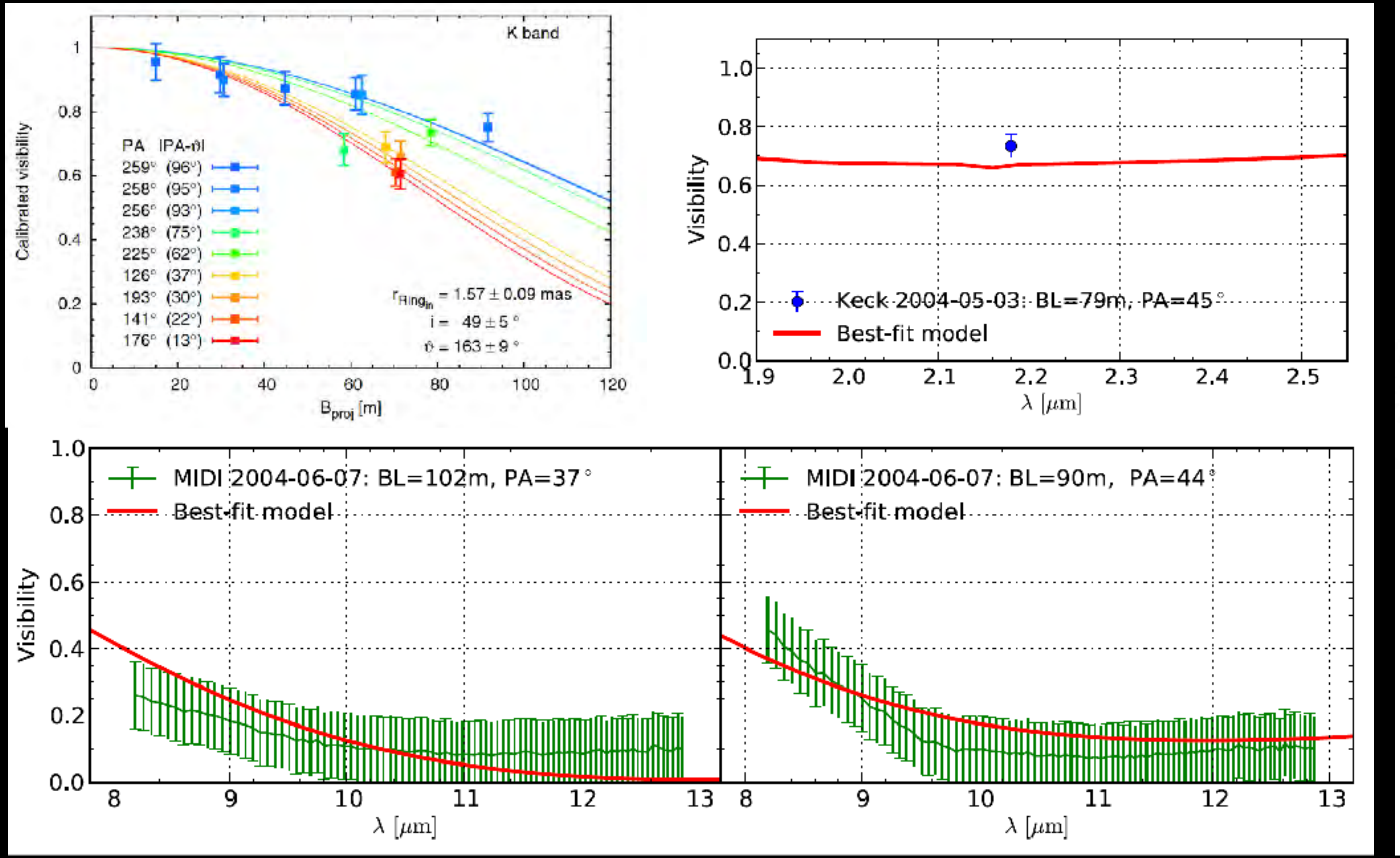
DISK AT INTERMEDIATE INCLINATION

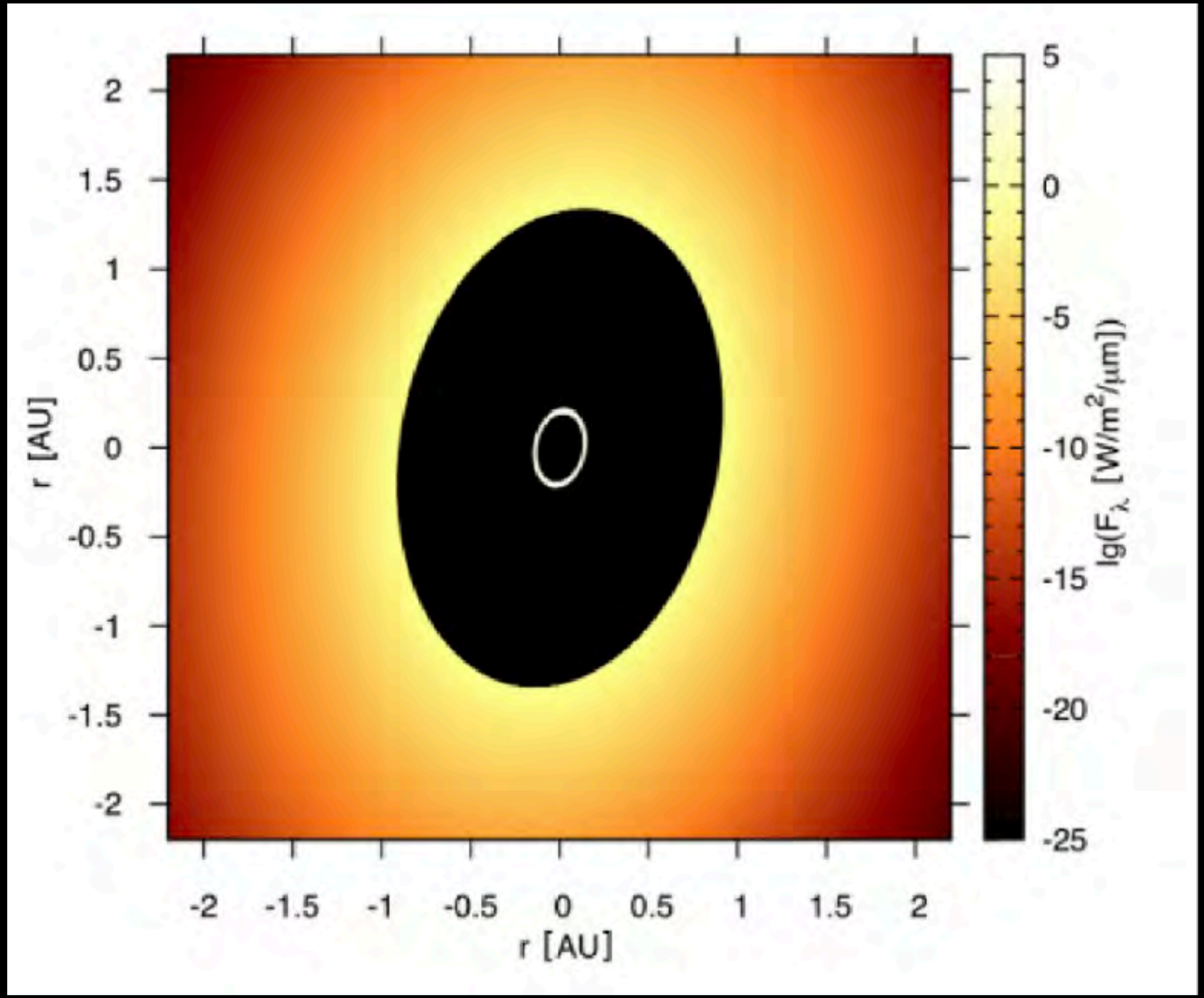
- Stellar propoerties:
  Teff = 8500 K, R☆=2.7 R☼, d=116 pc
- Simultaneous fit of SED and NIR + MIR visibilities suggests a two-component model.



VURAL ET AL. 2014, A&A, 569, 25

DISK AT INTERMEDIATE INCLINATION



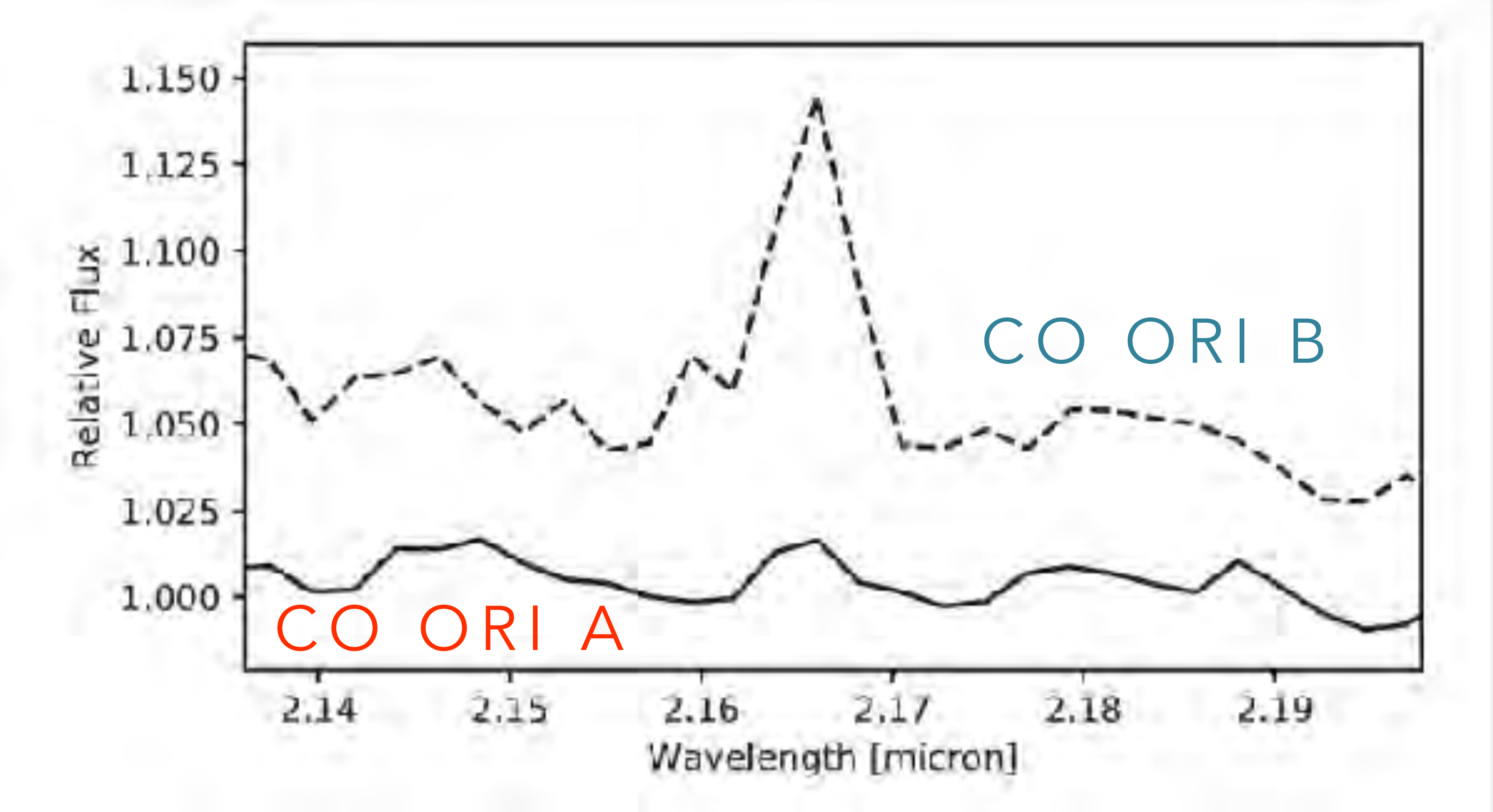


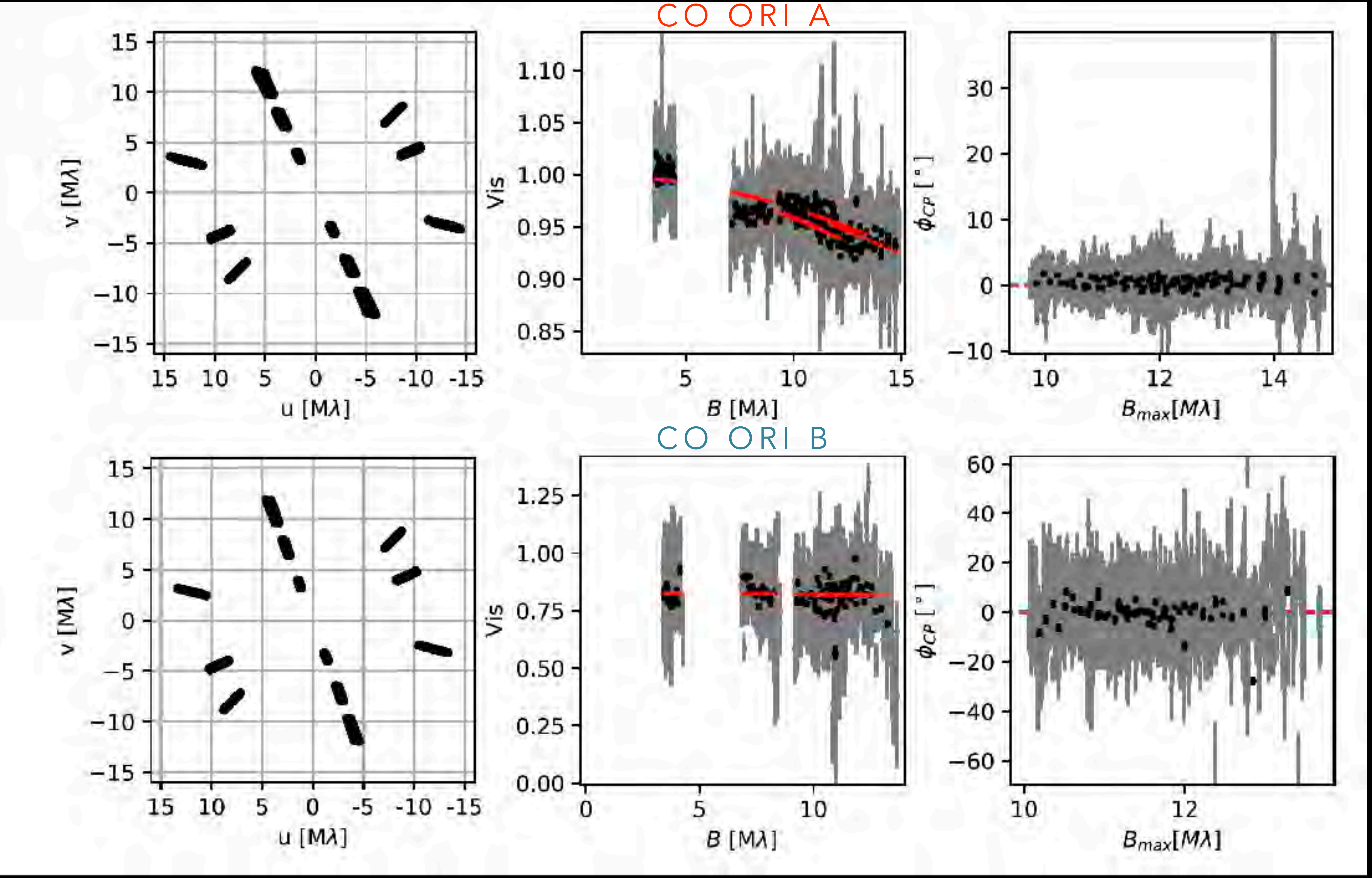
VURAL ET AL. 2014, A&A, 569, 25

- Temperature-gradient model:
  Tin1 = 1257 K, Rin1 = 0.19 au, Tin2 = 334 K, Rin2 = 1.35 au, INC = 50°, PA = 169°

DISK AT INTERMEDIATE INCLINATION

- Stellar properties:
  CO Ori A
  Teff = 6030 K, d=430 pc
  CO Ori B
  Teff = 4500 K, d=430 pc
- Geometric modeling: INC = 30°





DAVIES ET AL. 2018, MNRAS, 474, 5406

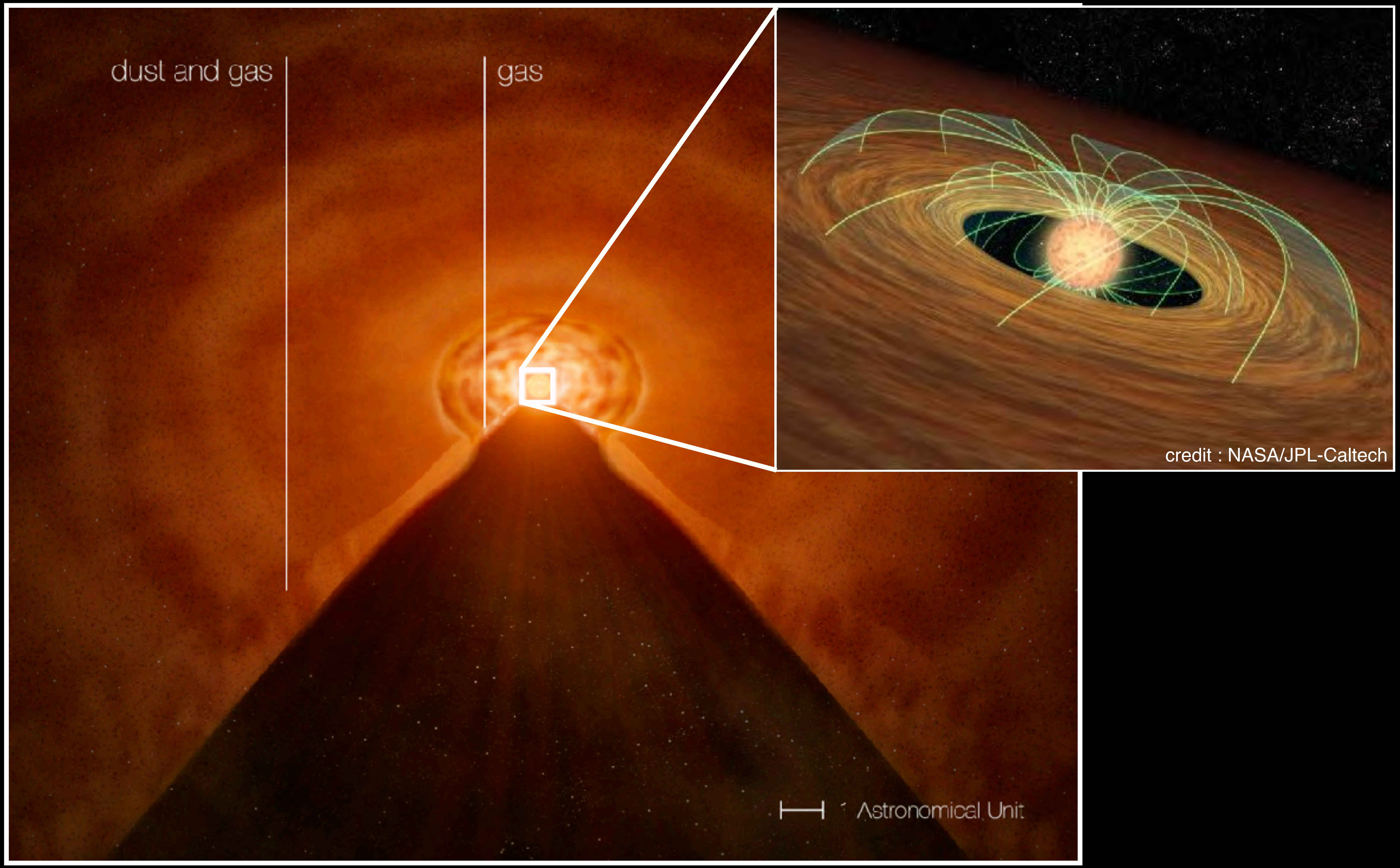
OUTLINE

SUMMARY

- Interferometrically studied UX Ori stars show intermediate to high inclination angles ~30° (CO Ori; Davies et al. 2018), ~30°-50° (CQ Tau; Eisner et al. 2004, Chapillion et al. 2008), ~50° (V1026 Sco, Vural et al. 2014), and ~70° (VV Ser, KK Oph, UX Ori; Pontoppidan et al. 2007, Kreplin et al. 2013, 2016)

➡
- Dusty outflow (e.g. Vinkovic & Jurkic 2007, Tambovtseva & Grinin 2008)
- Centrifugal driven disk wind (e.g. Bans & Königl 2012)
- External pertubations by a low-mass companion (e.g. Rostopchina et al. 2007, Demidova et al. 2010, Artemenko et al. 2010)

ONGOING AND FUTURE WORK



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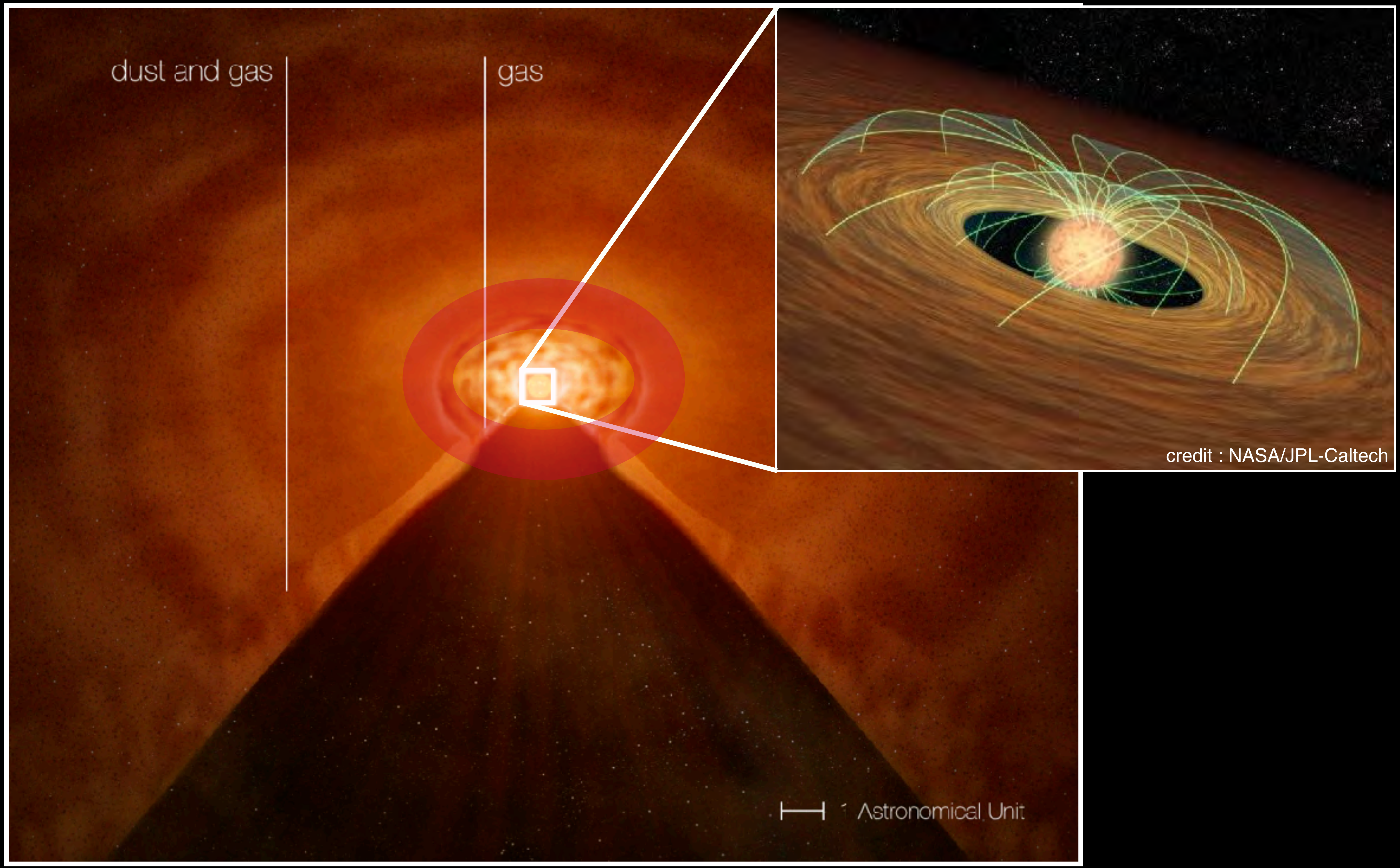
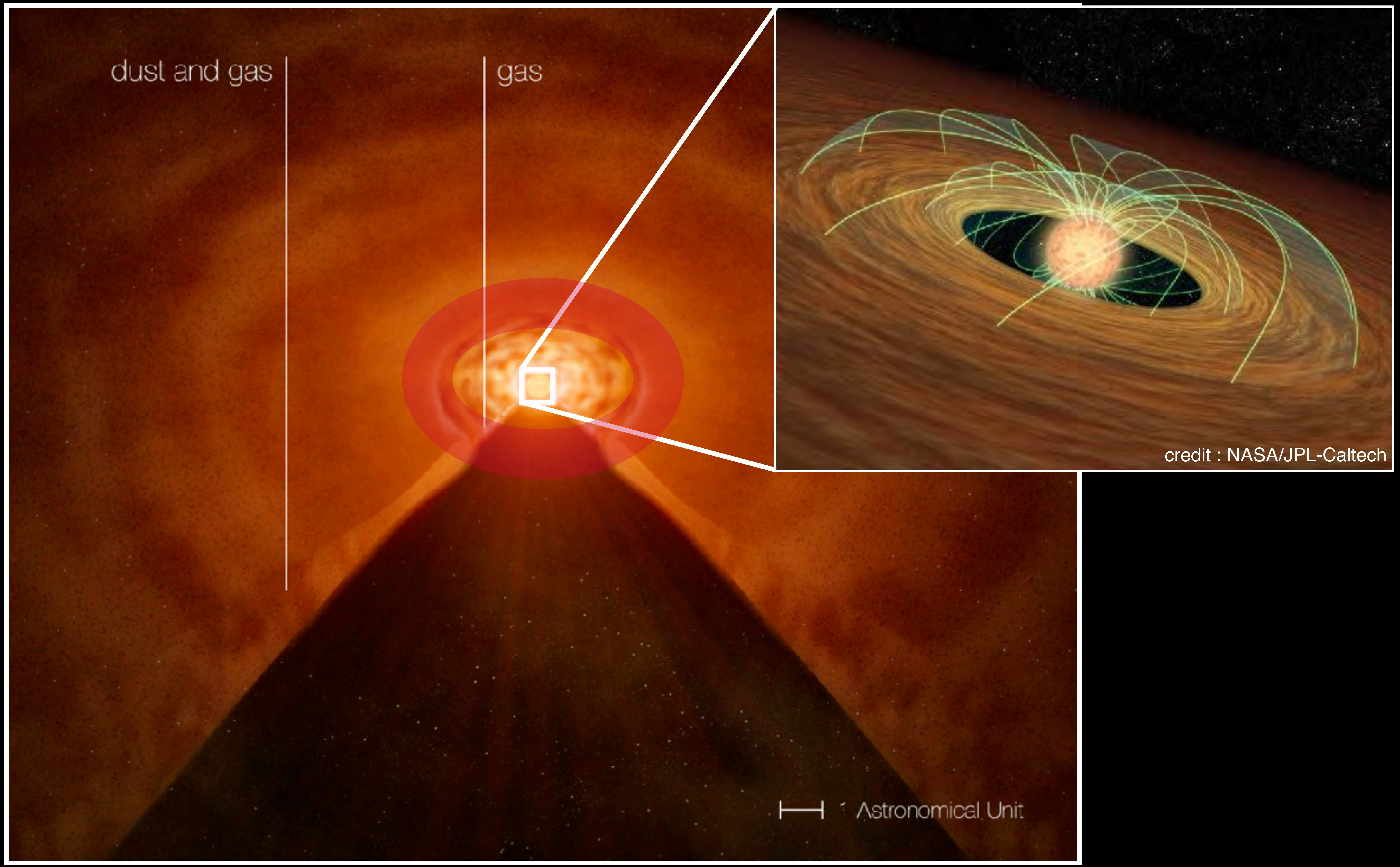


Hot dust can be traced by K-band continuum observations

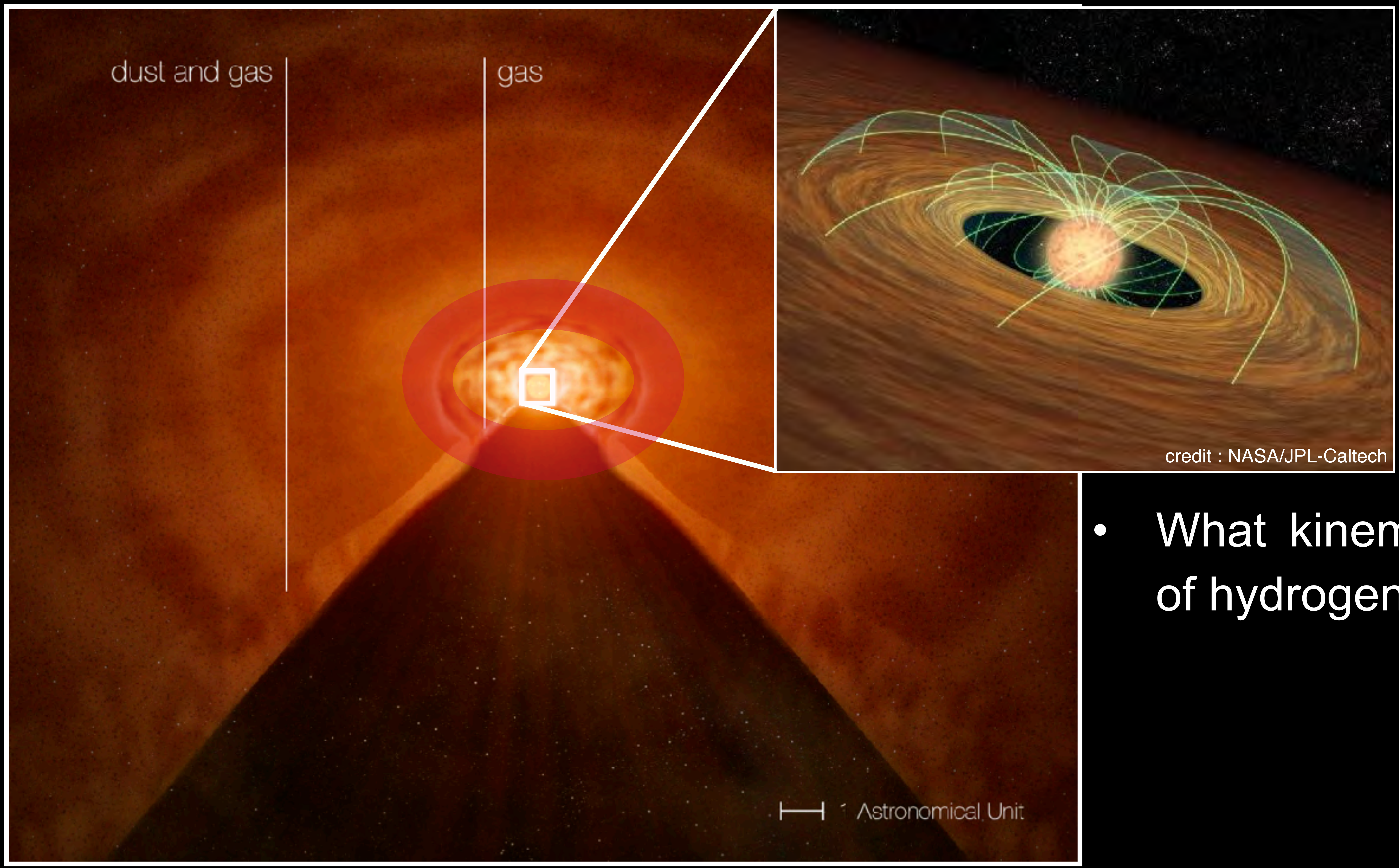
ONGOING AND FUTURE WORK



Hot dust can be traced by K-band continuum observations

- The circumstellar hydrogen gas can be traced by spectral lines

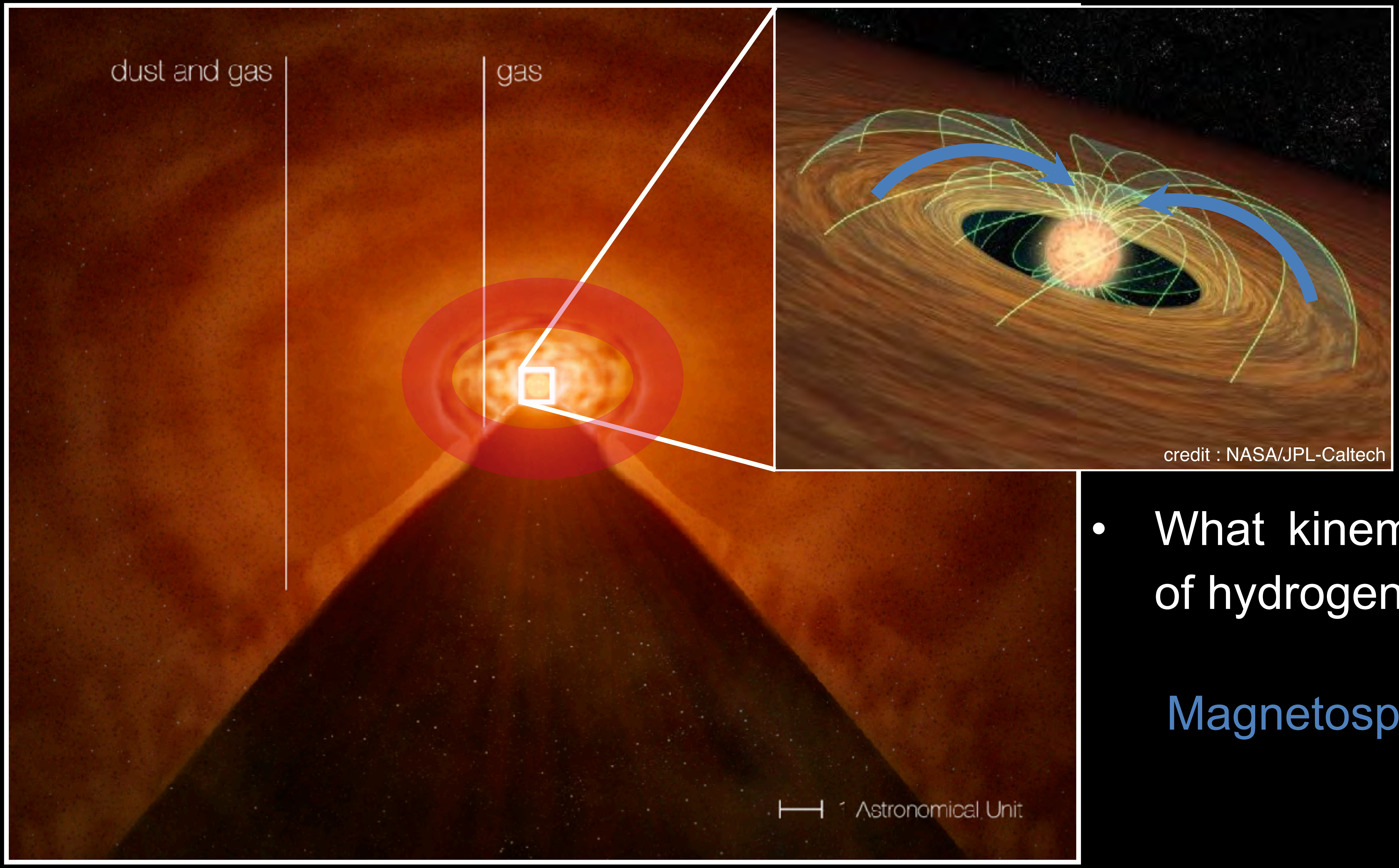
ONGOING AND FUTURE WORK



Hot dust can be traced by K-band continuum observations

- The circumstellar hydrogen gas can be traced by spectral lines
- What kinematic processes dominate the creation of hydrogen lines?

ONGOING AND FUTURE WORK



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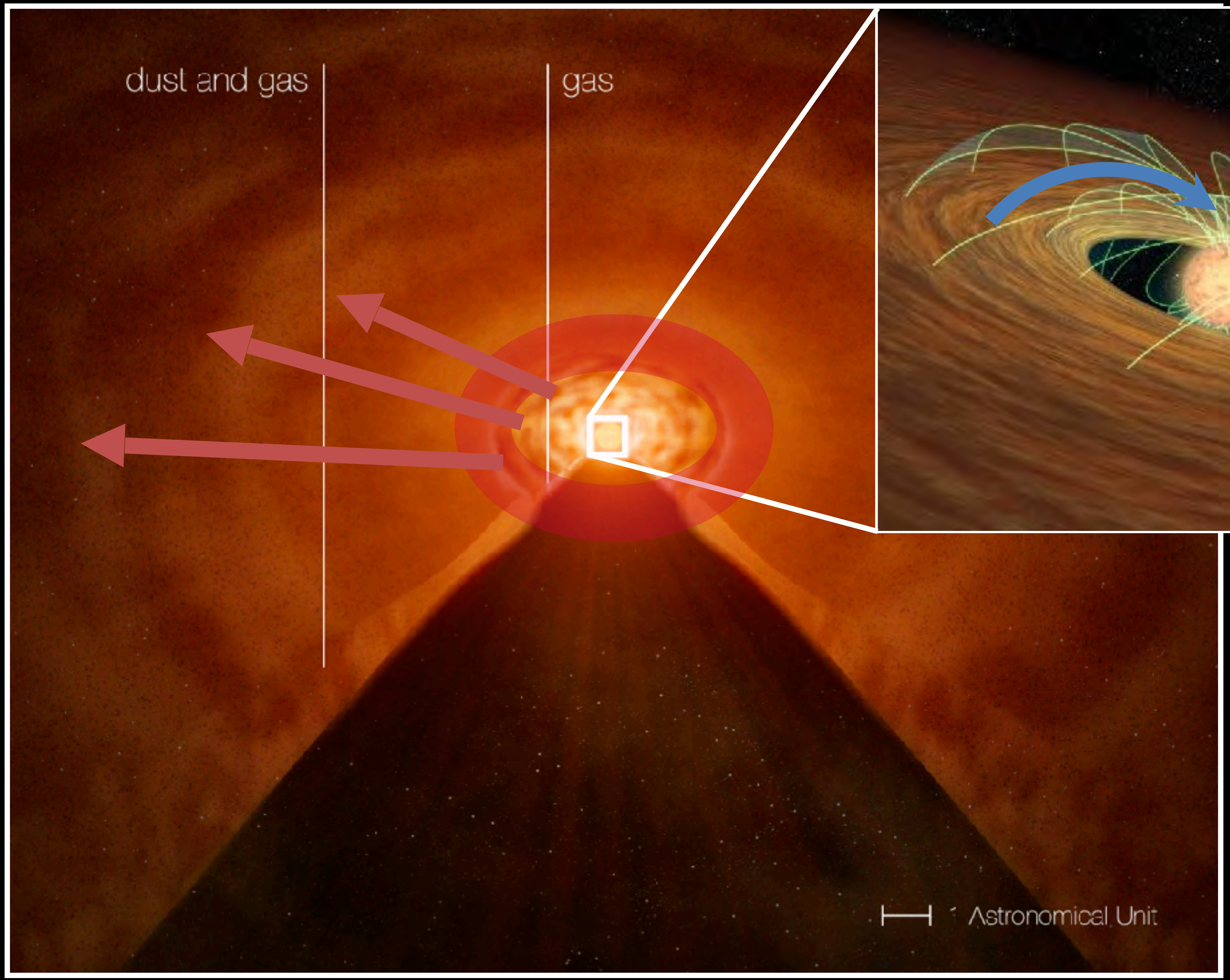
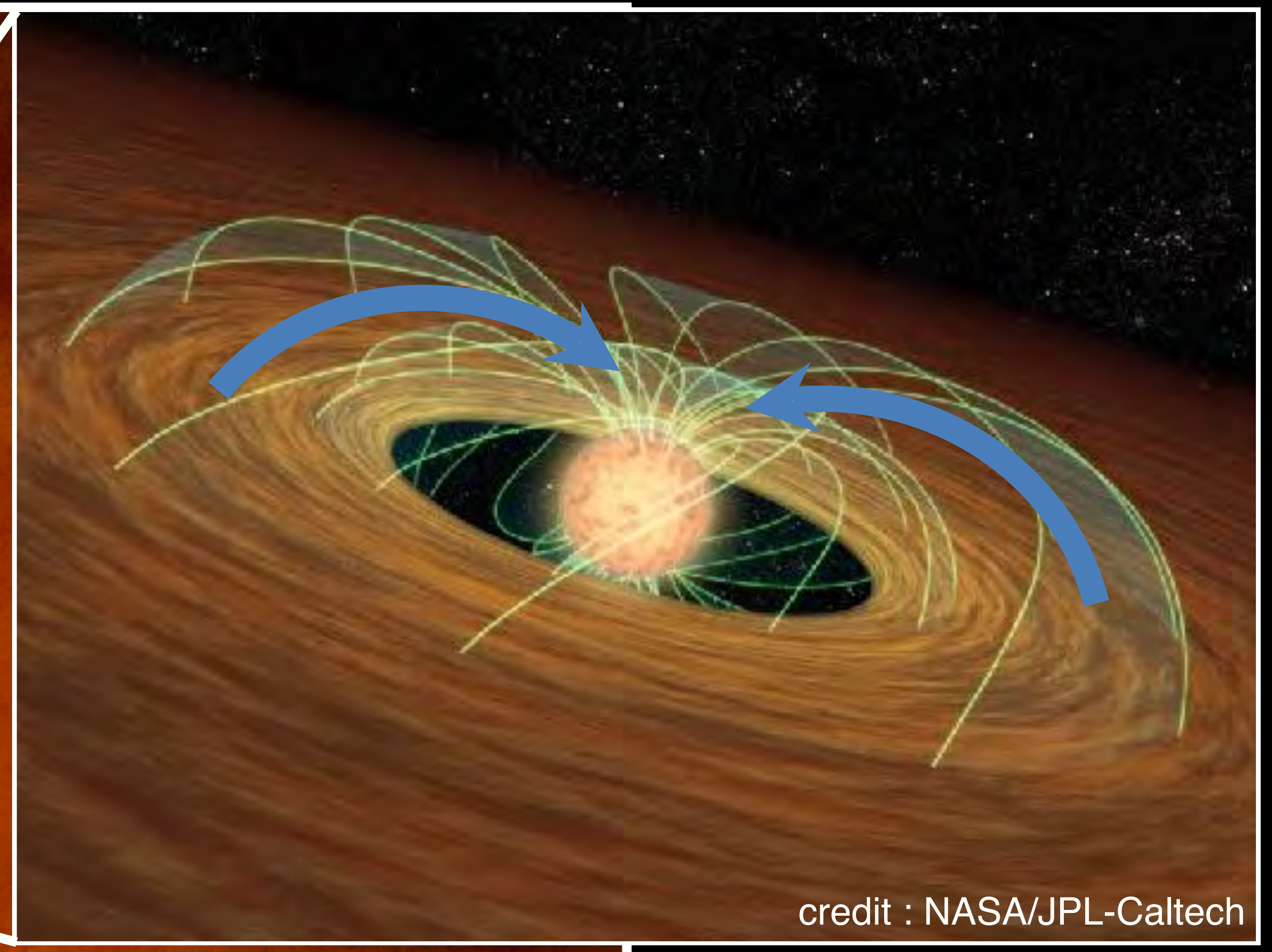
Magnetospheric accretion close to the star

ONGOING AND FUTURE WORK





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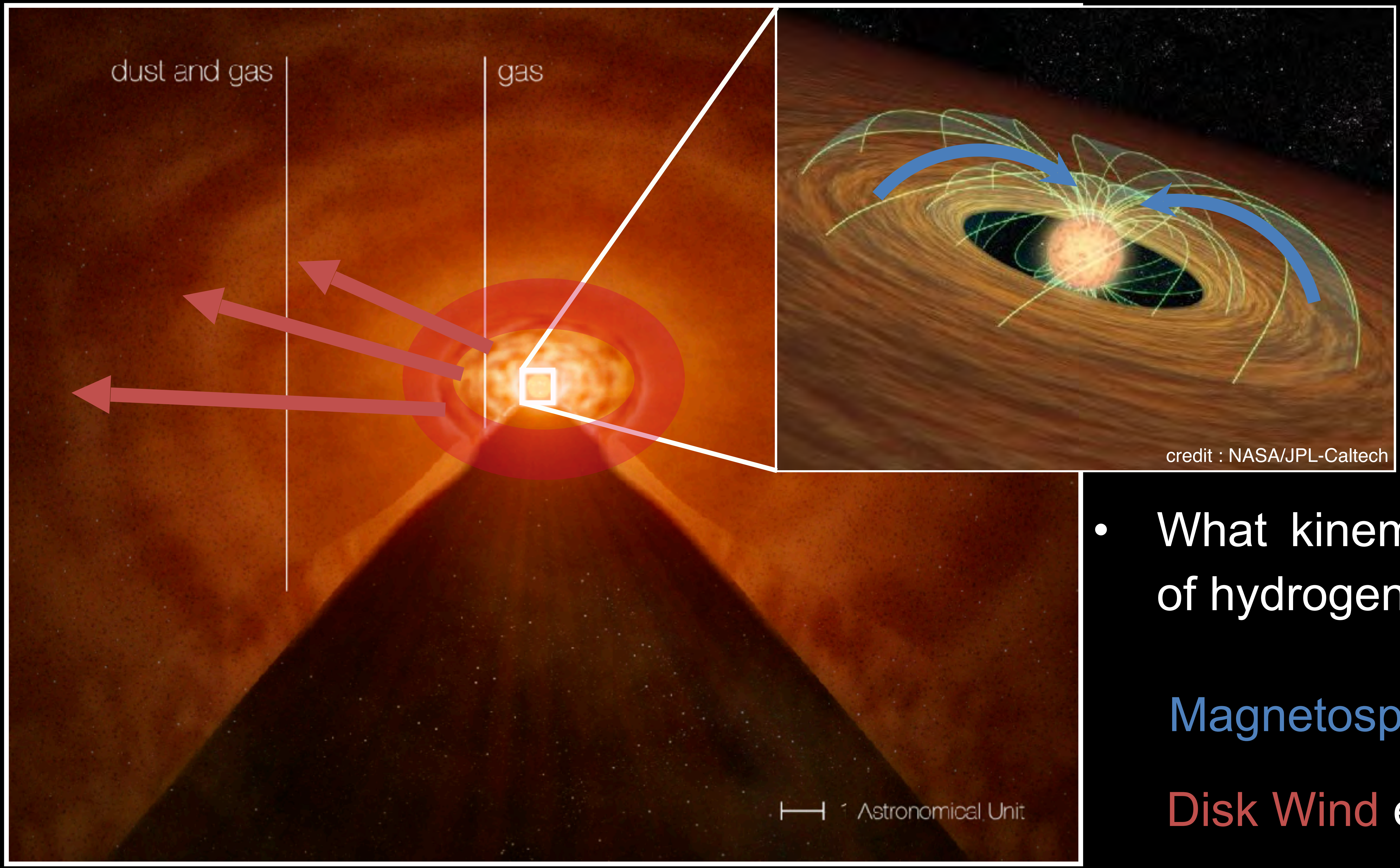
Magnetospheric accretion close to the star

Disk Wind extending on a broader scale

ONGOING AND FUTURE WORK



Hot dust can be traced by K-band continuum observations

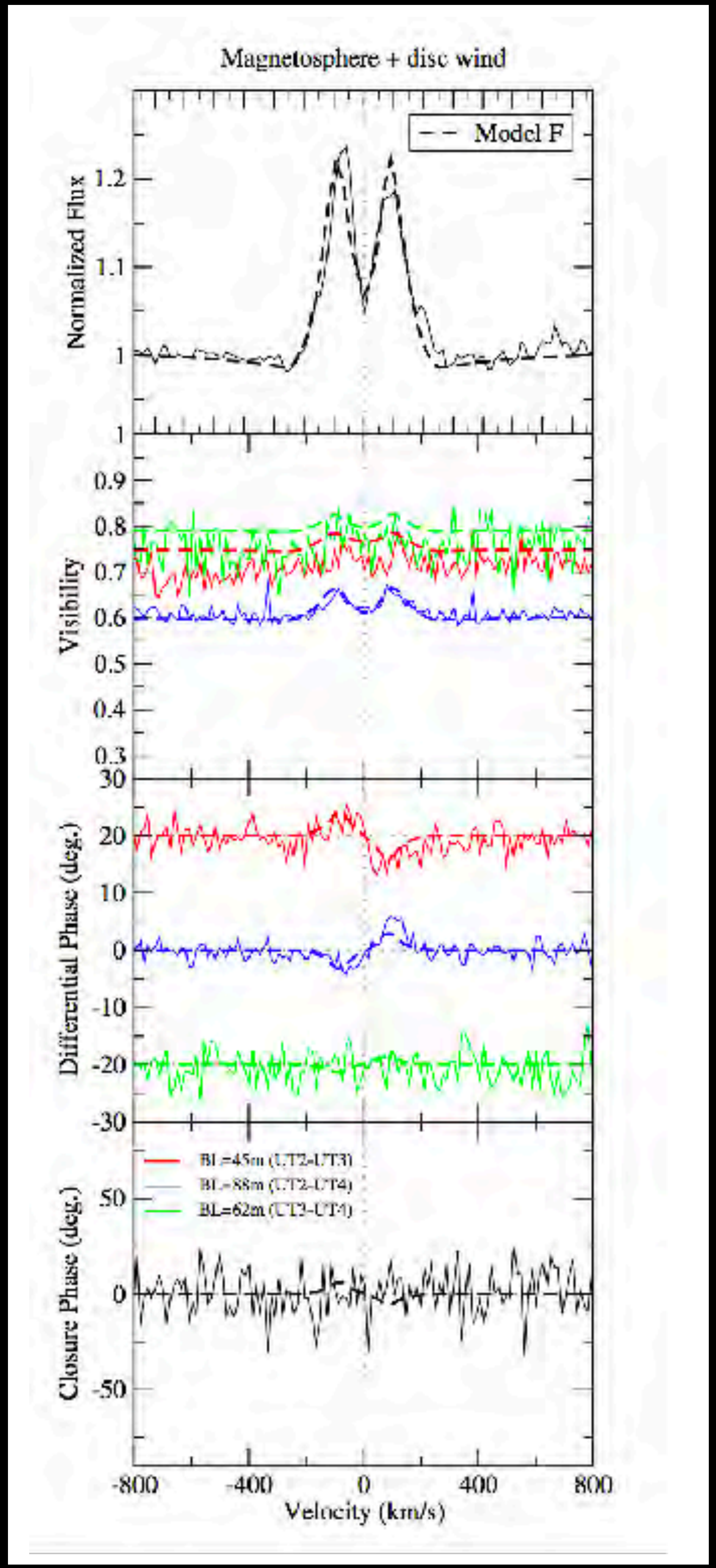
- The circumstellar hydrogen gas can be traced by spectral lines
- What kinematic processes dominate the creation of hydrogen lines?

Magnetospheric accretion close to the star

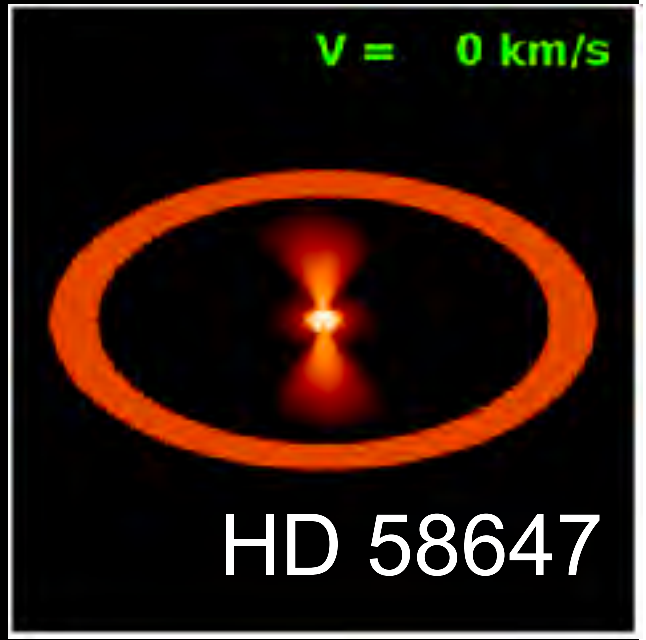
Disk Wind extending on a broader scale

→ High spatial and high spectral interferometric observations can distinguish between the scenarios

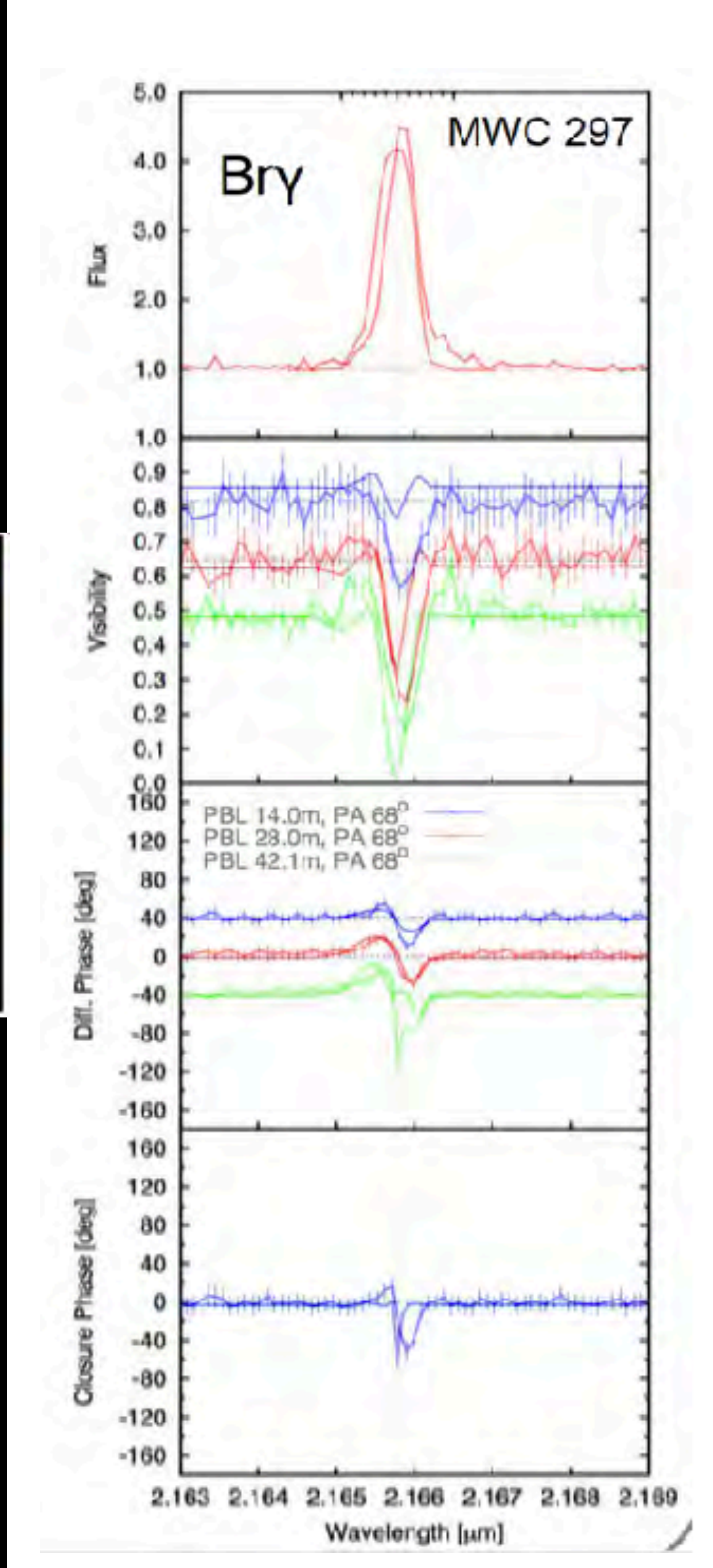
ONGOING AND FUTURE WORK



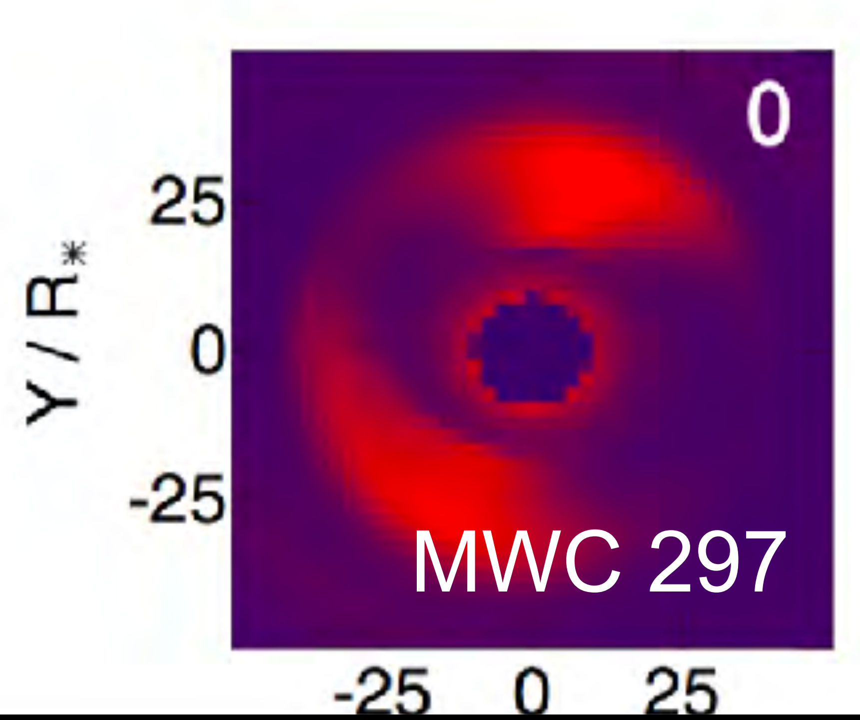
Disk emission
+
Magnetospheric Accretion



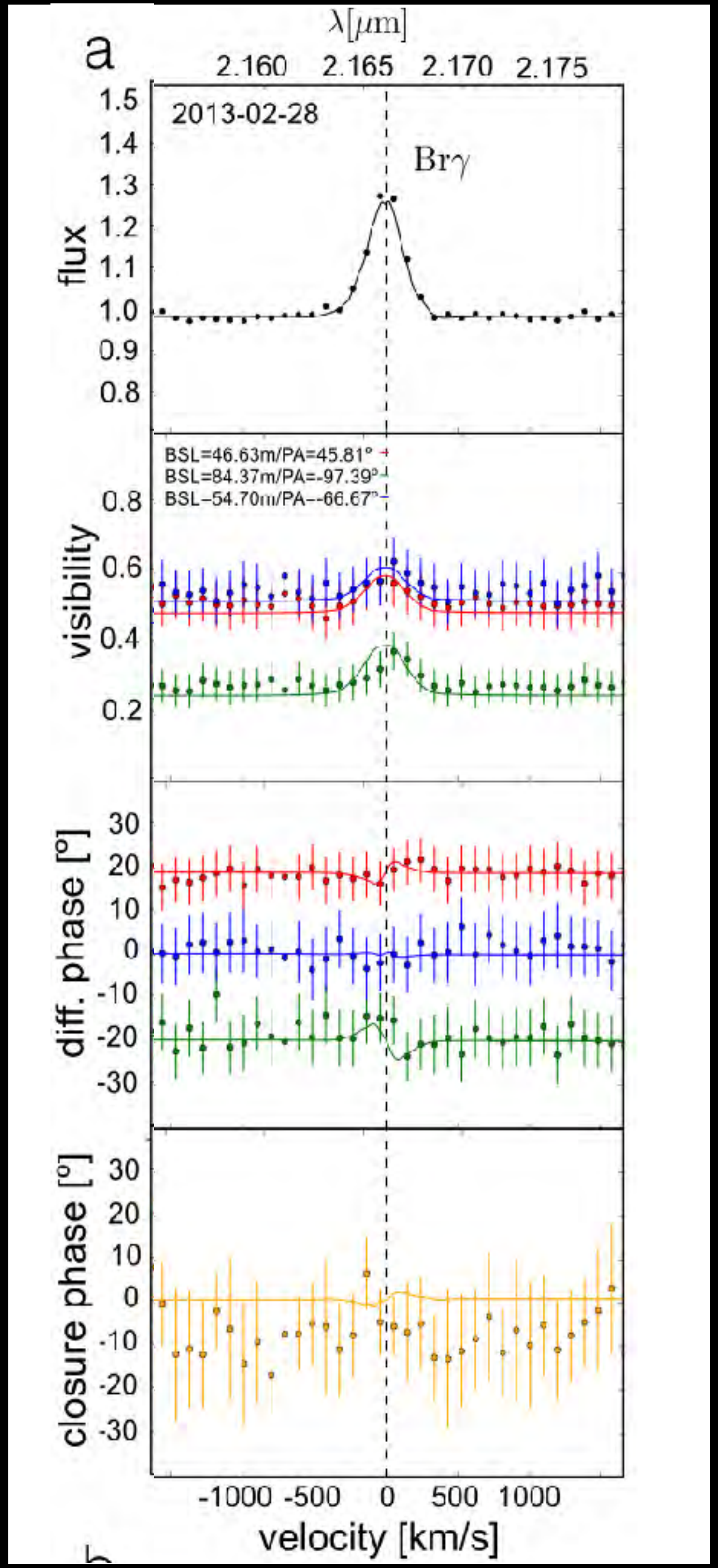
KUROSAWA ET AL. 2015
MNRAS, 457, 2236



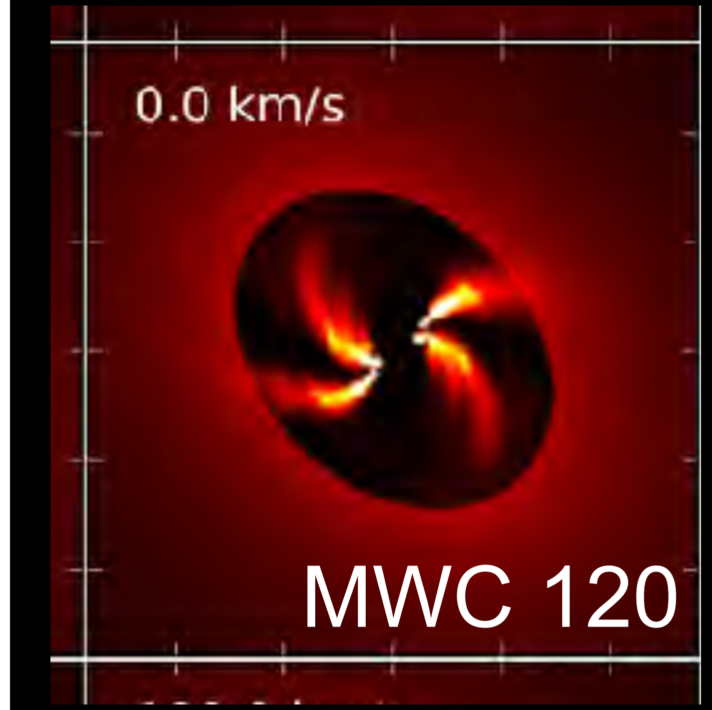
Disk emission
+
Extended Disk Wind



WEIGELT ET AL. 2011
A&A, 527, A103

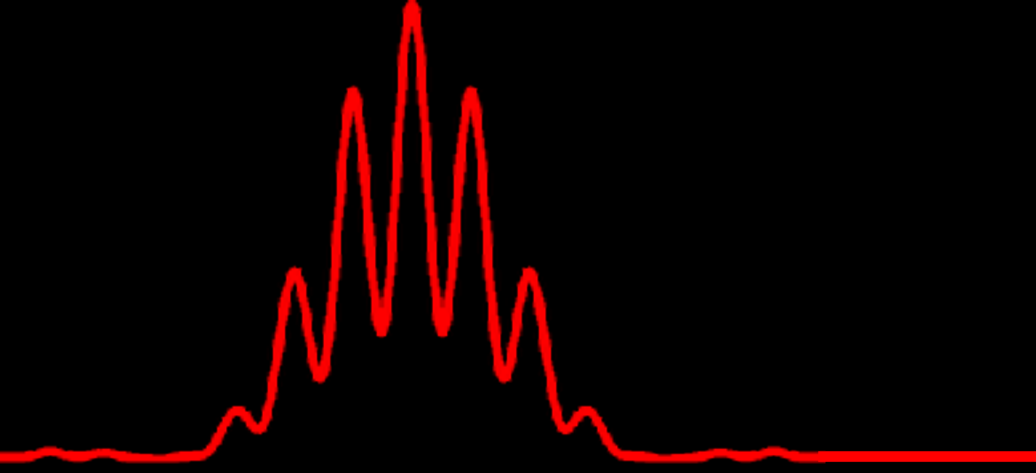


Disk emission
+
Disk Wind

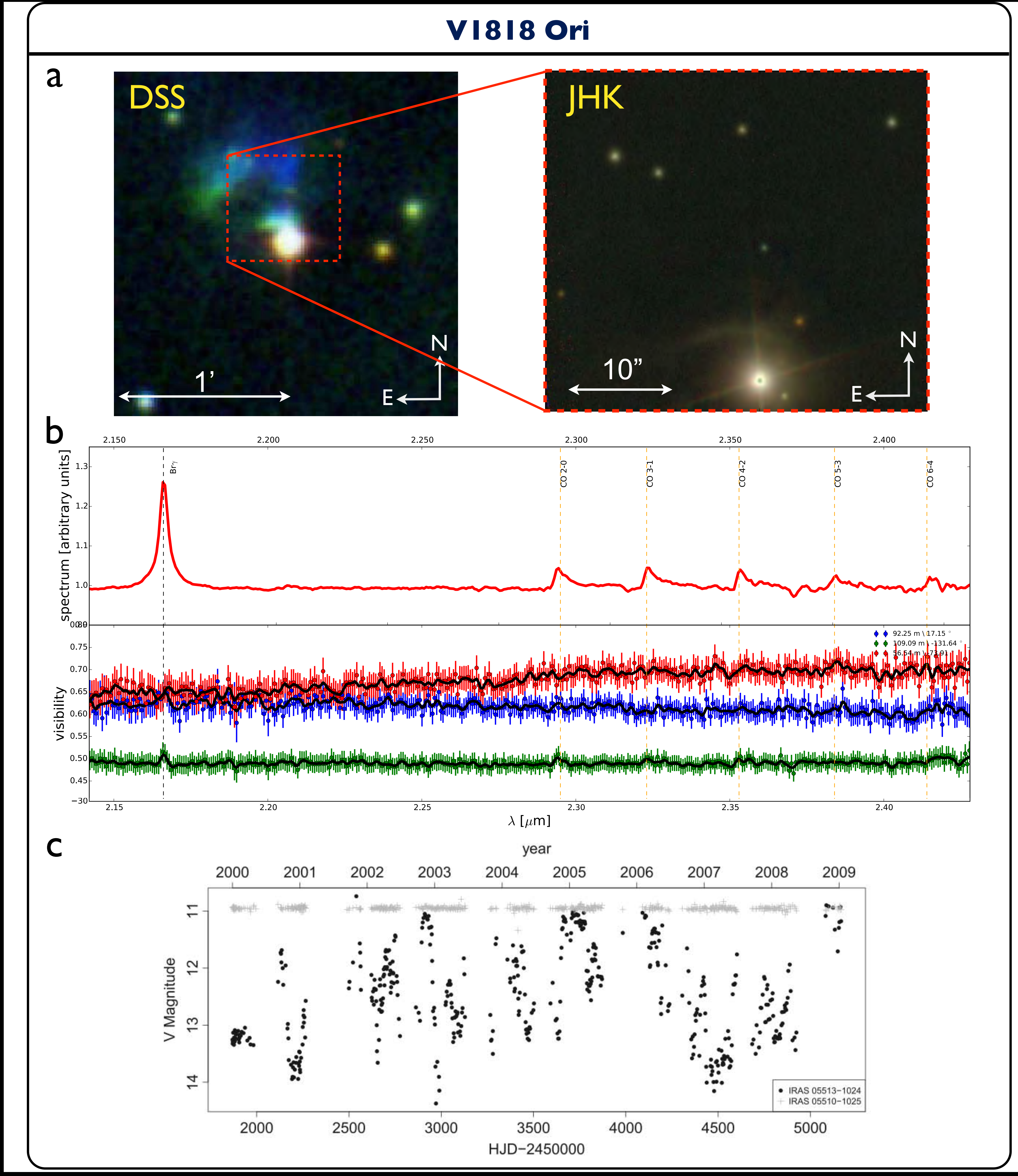


KREPLIN ET AL. 2018
MNRAS, 47, 4520

ONGOING AND FUTURE WORK: V1818 ORI

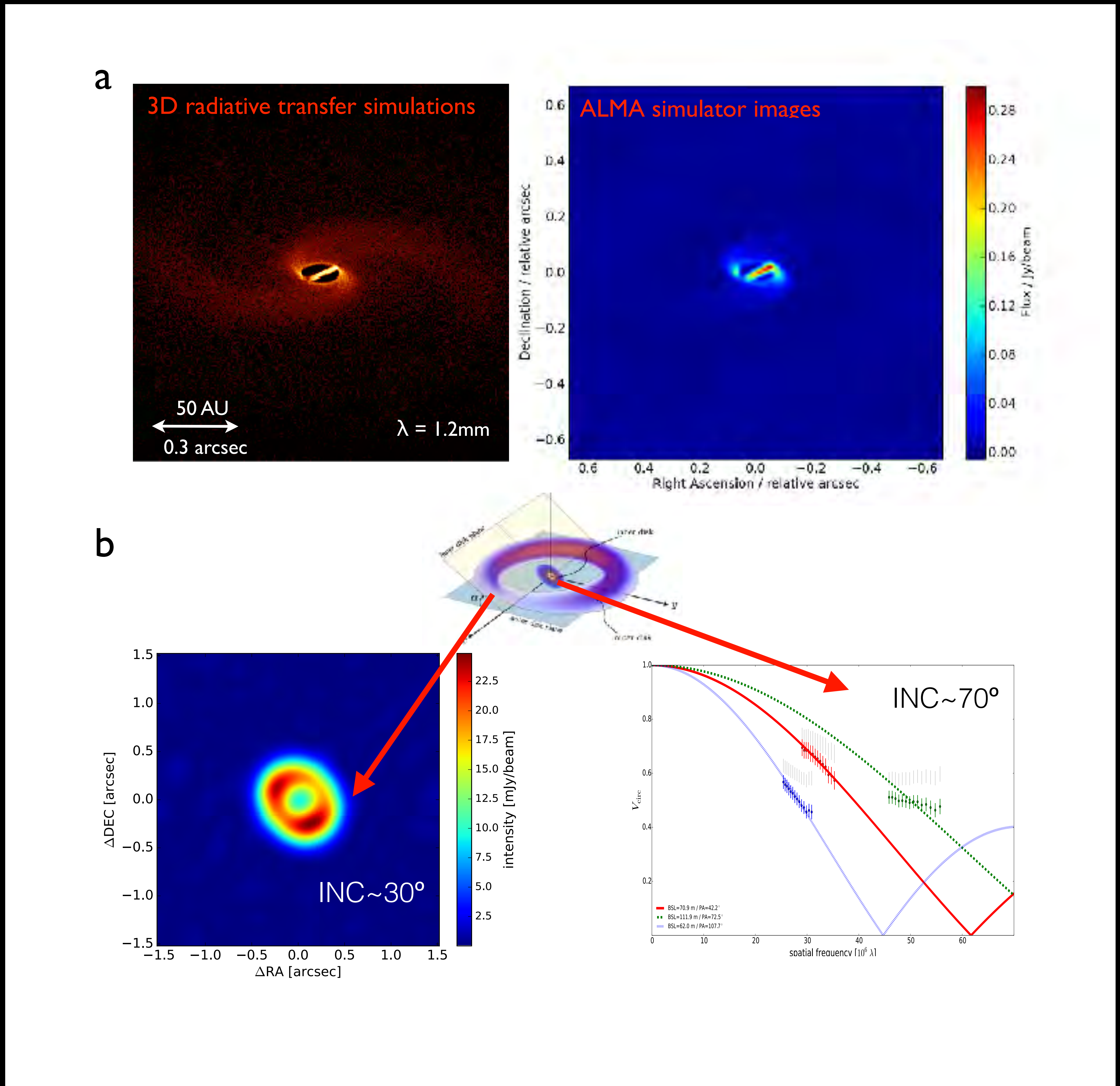


- The Herbig Be candidate star V1818 Ori (Vieira et al. 2003, AJ, 126, 2971) is one of the few Herbig stars that displays CO bandhead emission in addition to the Brγ line (Connelley et al. 2010, AJ, 140, 1214). It is surrounded by a nearby reflection nebula and an arc-shaped nebula ~8″ in north-east direction.
- The light curve shows irregular brightness variations similar to UX Ori stars that might be explained by obscurations of the central star by orbiting dust clouds in an almost edge-on disk (Grinin et al. 1991; Natta et al. 1997)



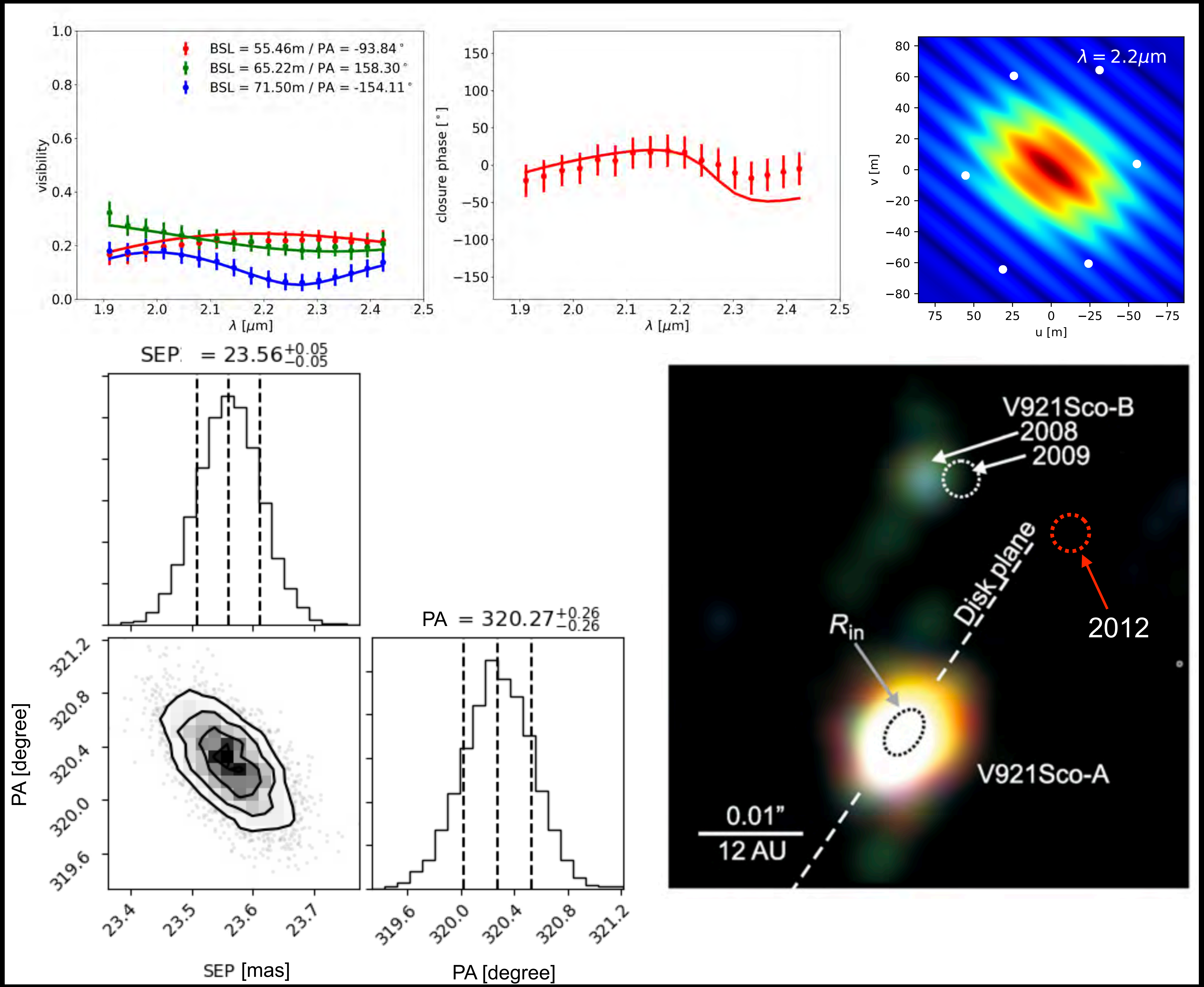
ONGOING AND FUTURE WORK: ALMA STUDY

- Detailed hydrodynamic simulations have been carried out to explain the light curve variations in UX Ori objects caused by disk material brought into the line of sight by asymmetries in the cirumstellar disk. These asymmetric structures can be created, for example, by a close stellar (Ruge et al. 2015, A&A, 579, A110), close sub-stellar (Demidova et al. 2014, AstL, 40, 334), a wide companion (Dogan et al. 2015, MNRAS, 449, 1251), or by instabilities in magnetized disks (Flock et al. 2015, A&A, 574A, 68F). All these models lead to significant warps and disk misalignments. Such an asymmetric disk structure would lead to different apparent disk inclination and position angle measurements that changes with separation from the star.



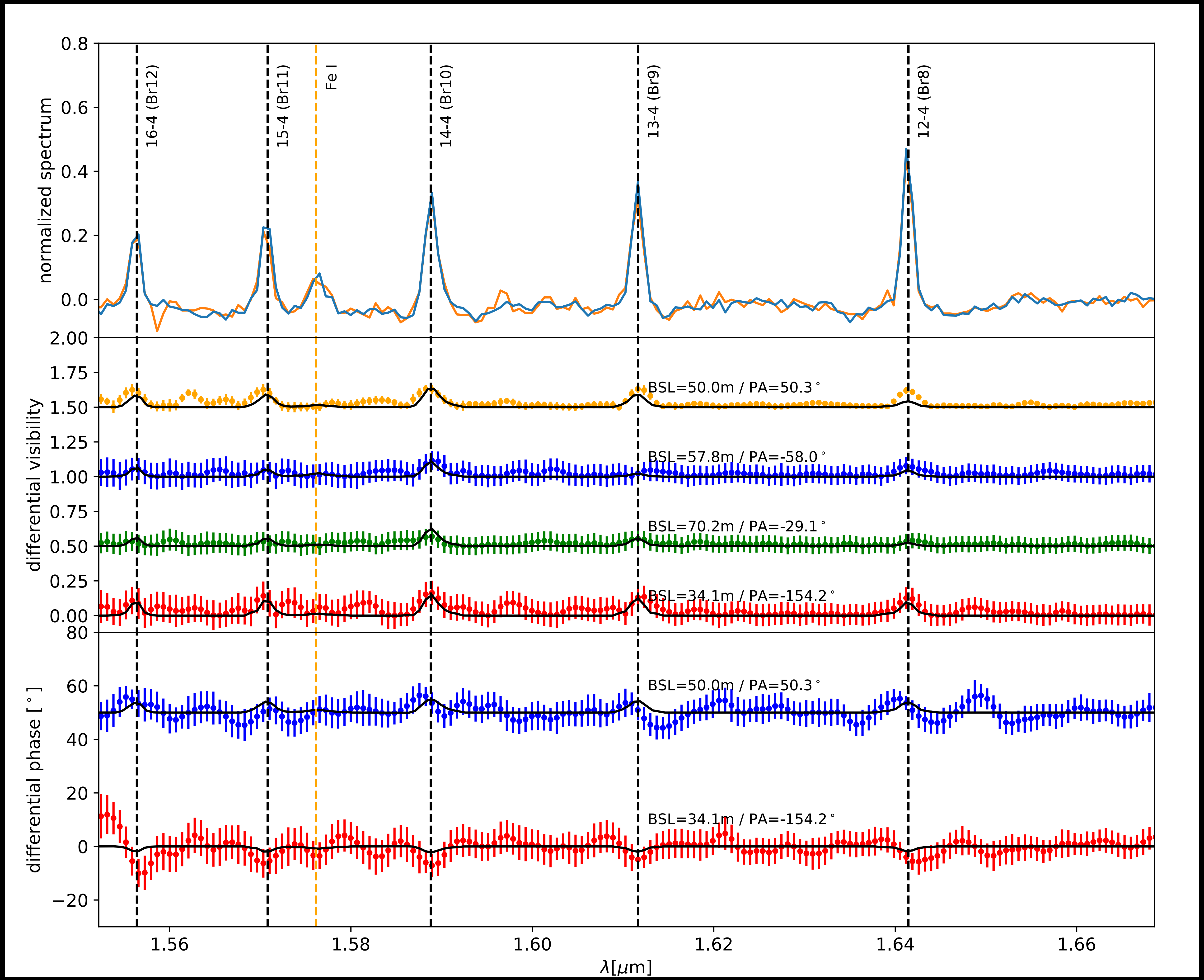
ONGOING AND FUTURE WORK: V921 SCO

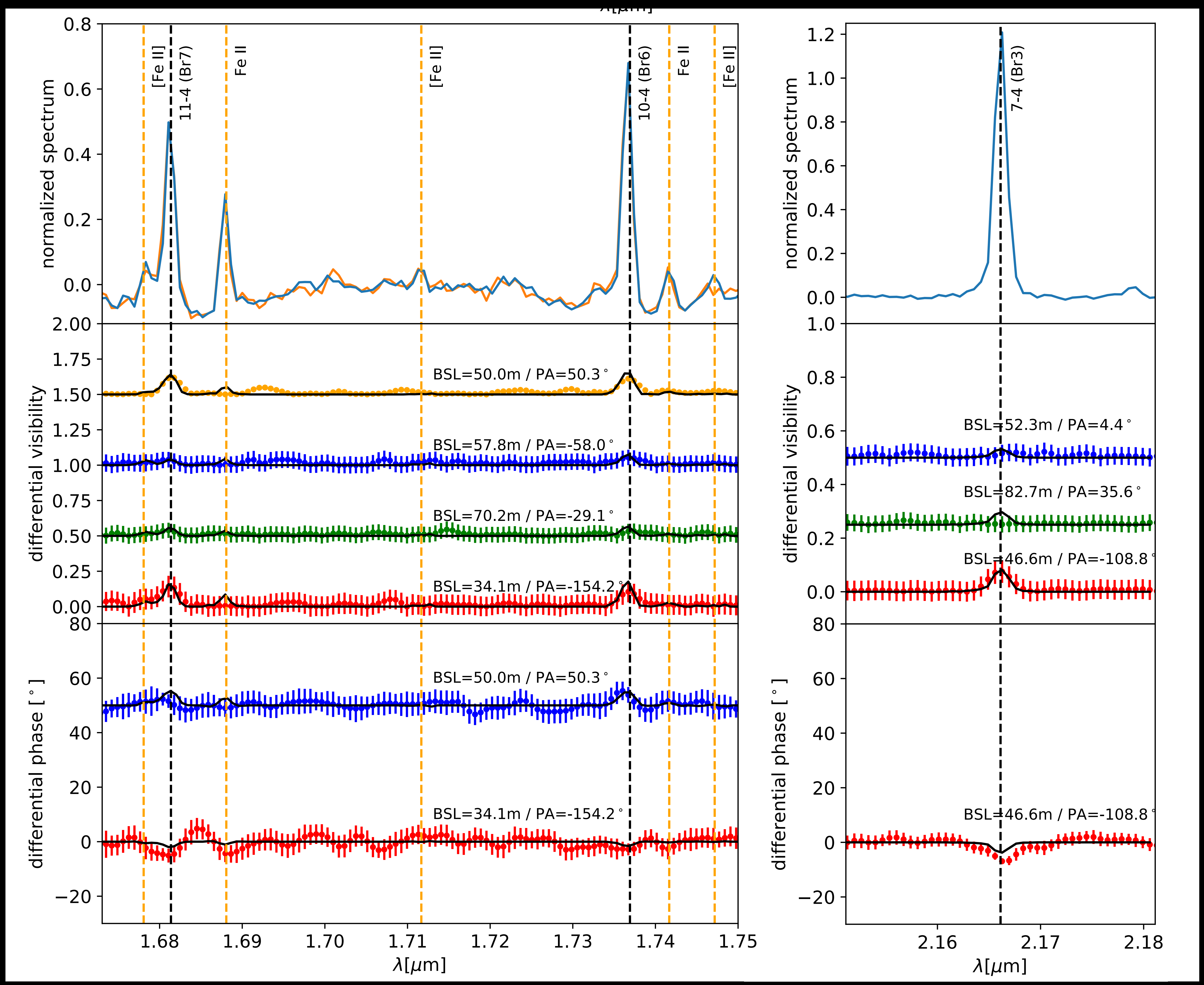
- Low spectral resolution AMBER data were used to estimate the position of the companion V921 Sco B and confirmed a clockwise movement on sky with respect to the primary of 33° between 2008 and 2012



KREPLIN ET AL. IN PREPARATION

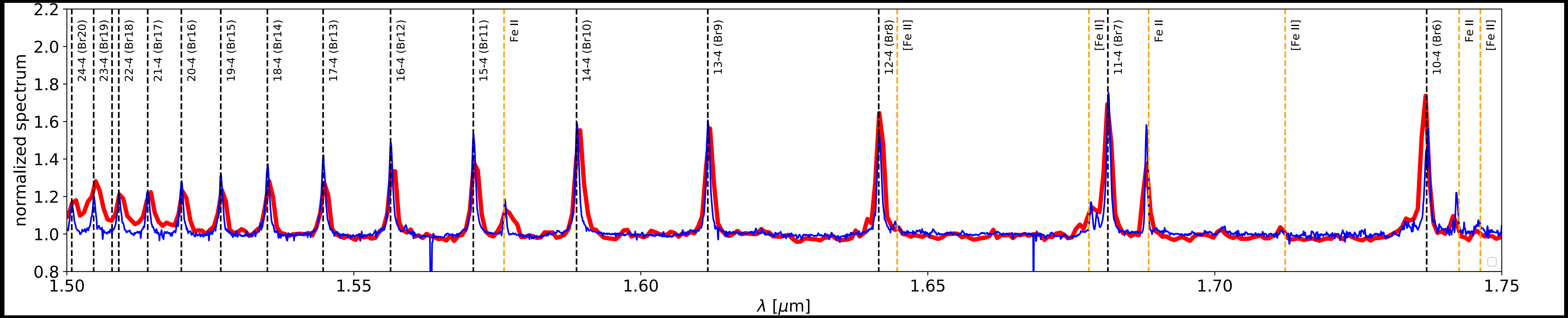
ONGOING AND FUTURE WORK: V921 SCO

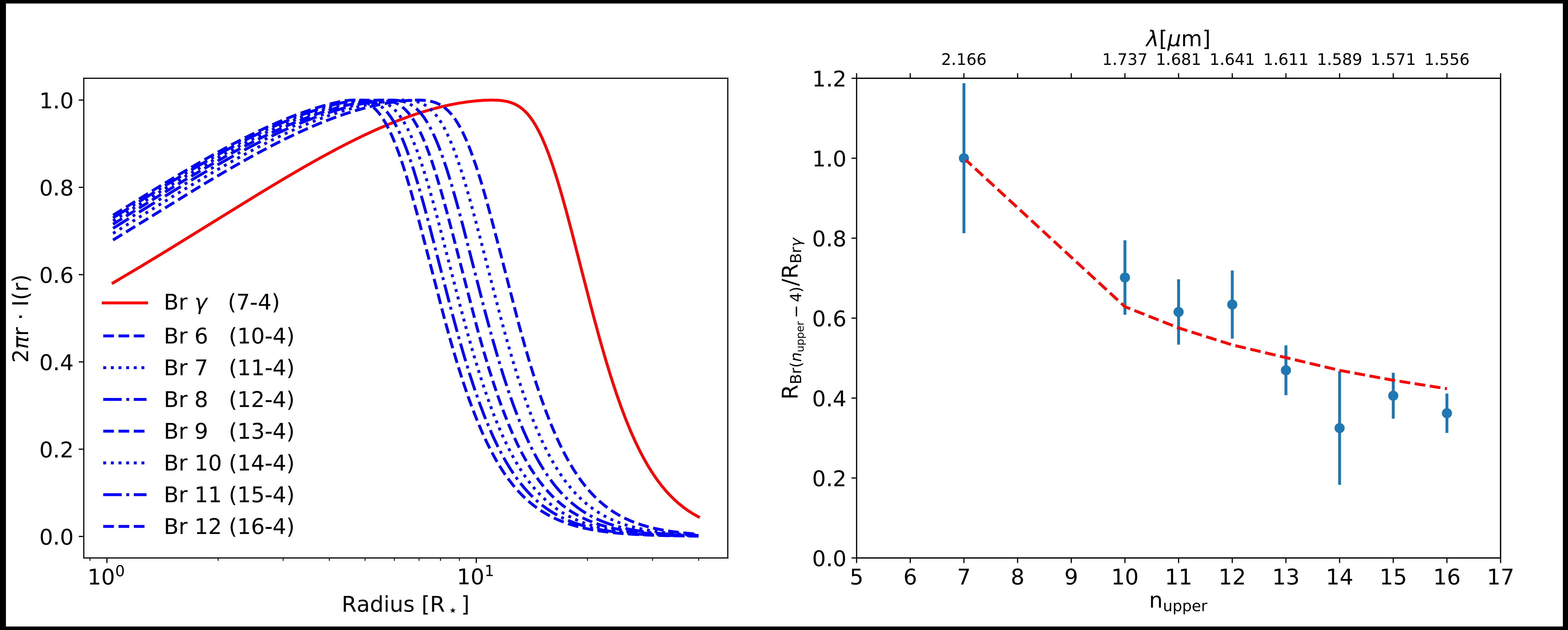


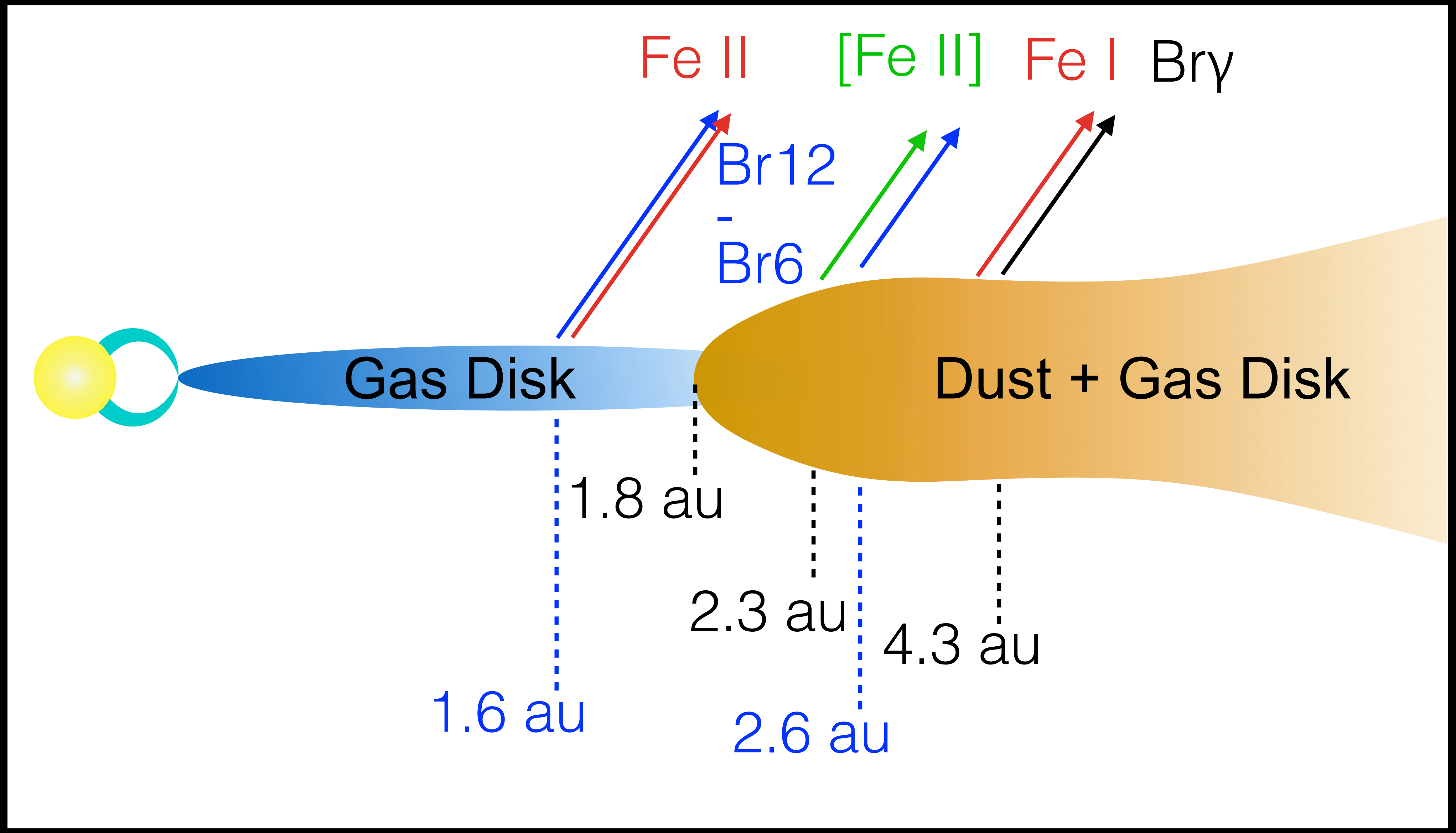


KREPLIN ET AL. IN PREPARATION

ONGOING AND FUTURE WORK: V921 SCO



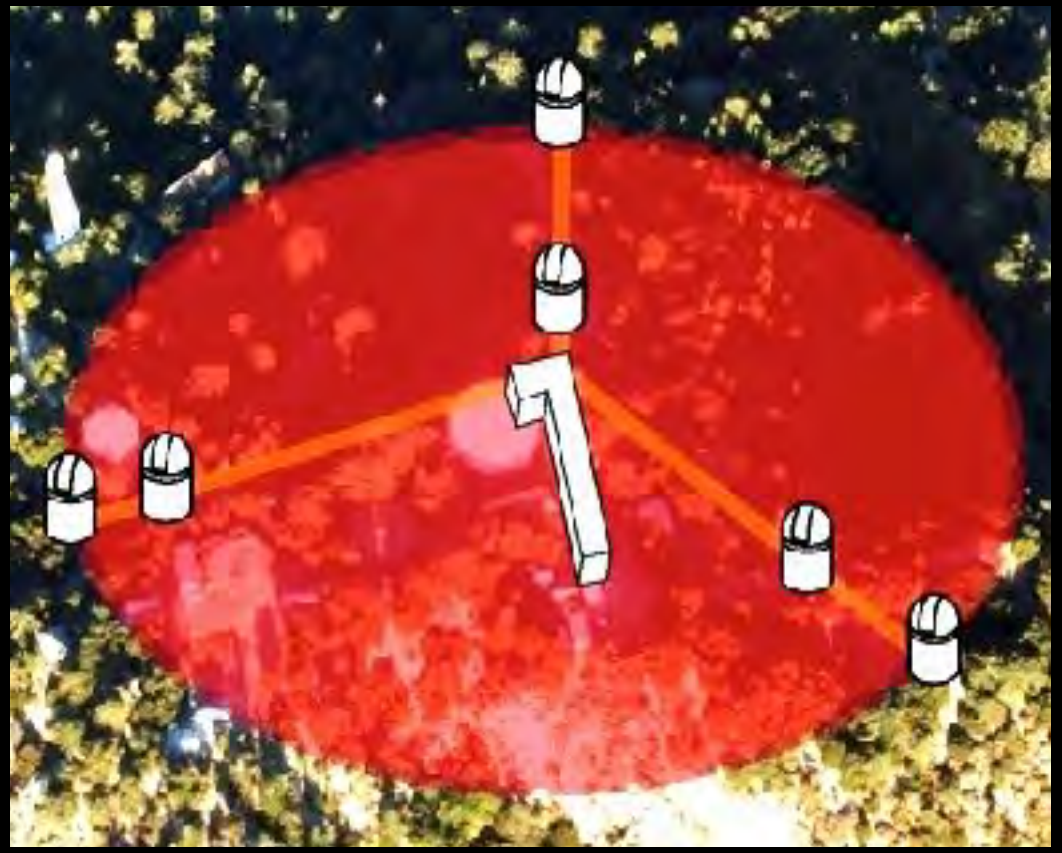




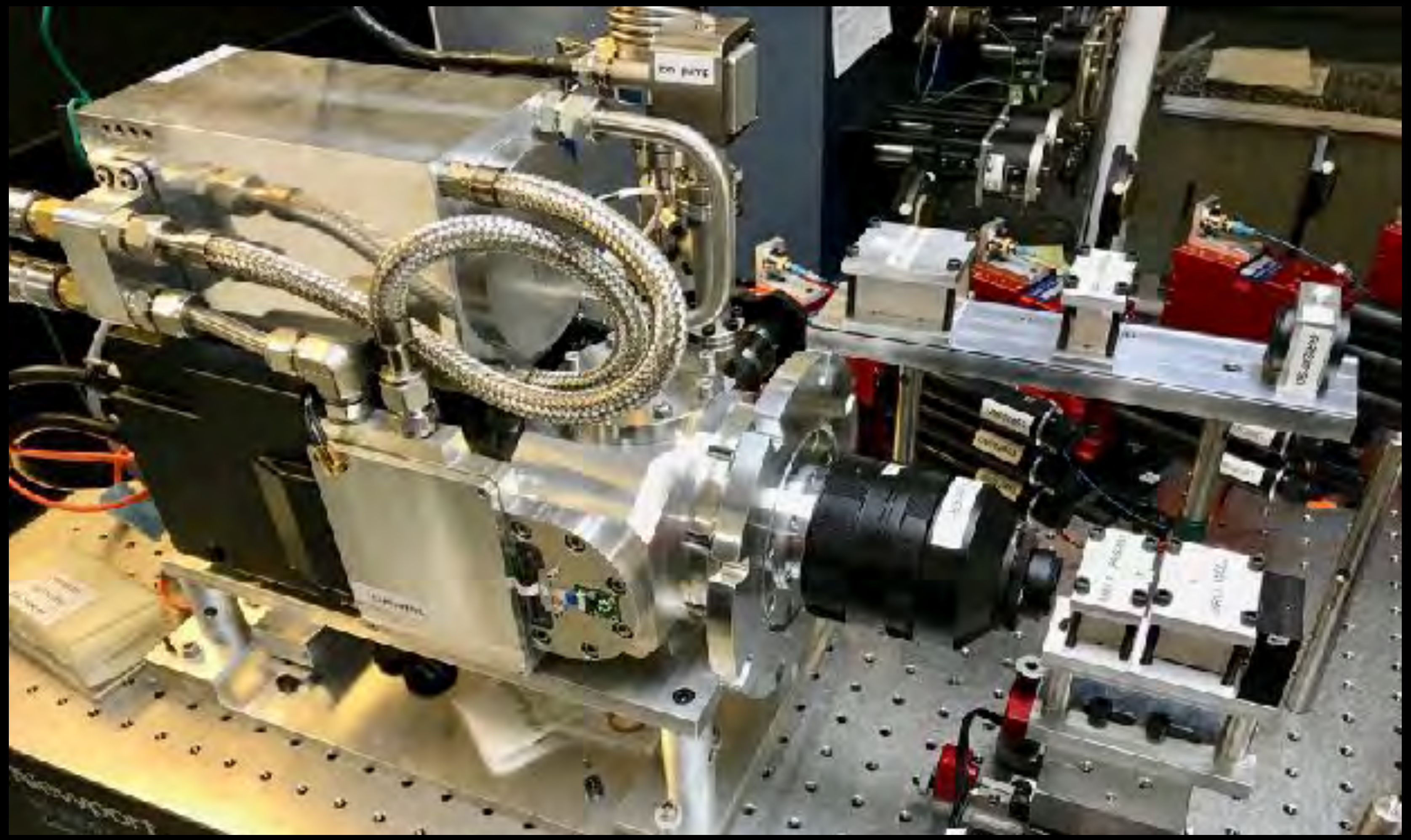
KREPLIN ET AL. IN PREPARATION

MIRC-X CHARA 6-TELESCOPE IMAGING

MIRC-X: ERC-funded project to build 6 telescope interferometric beam combiner for imaging planet-forming discs (University of Exeter / Michigan)



Installed at GSU's CHARA array (California): 6 one-meter telescopes spread over 330m

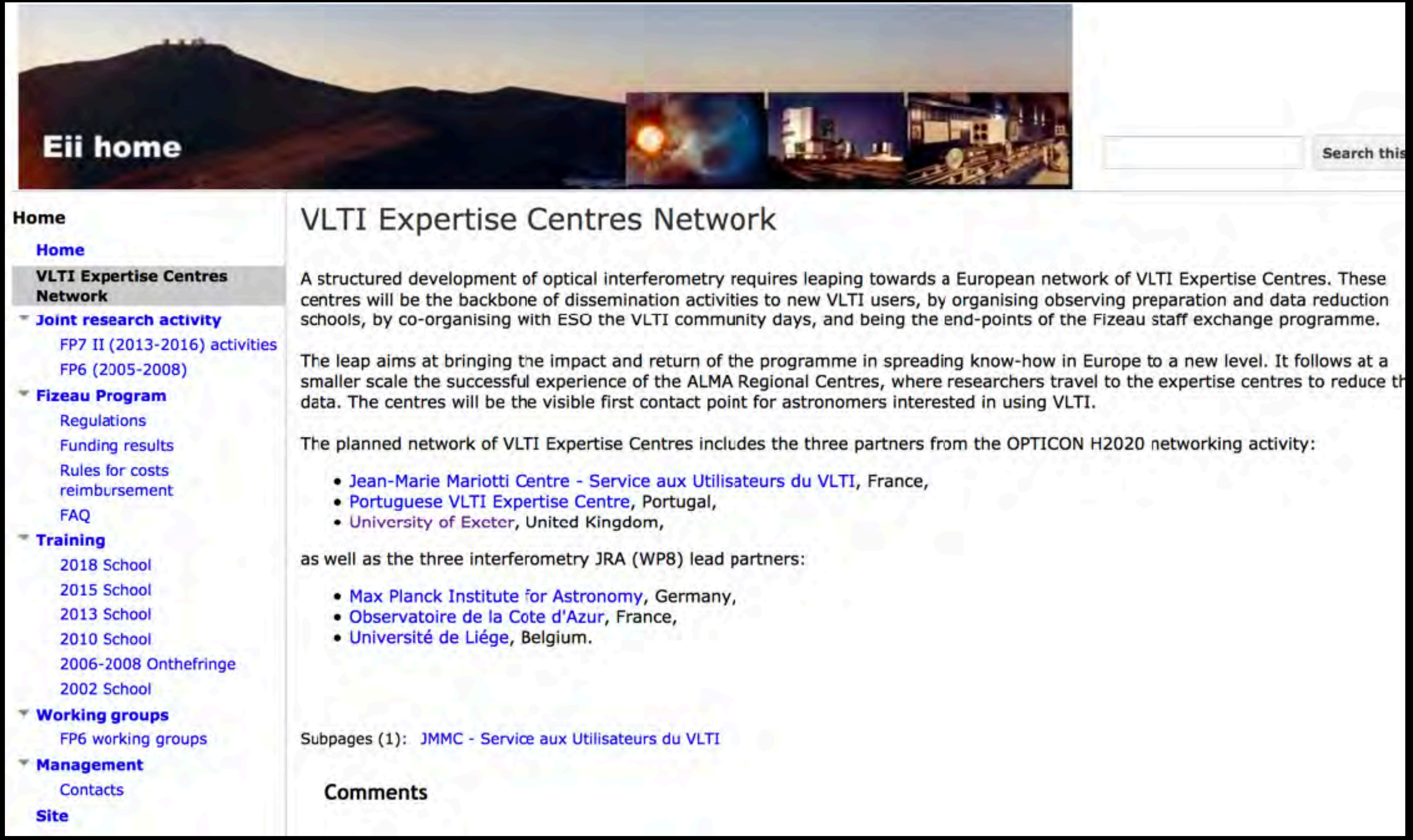


Enables imaging at highest resolution ever achieved in infrared: λ/D=0.001" (λ=1.6µm)

(120x sharper than Hubble, 40x VLT, 25x ALMA)

VLTI EXPERTISE CENTRES

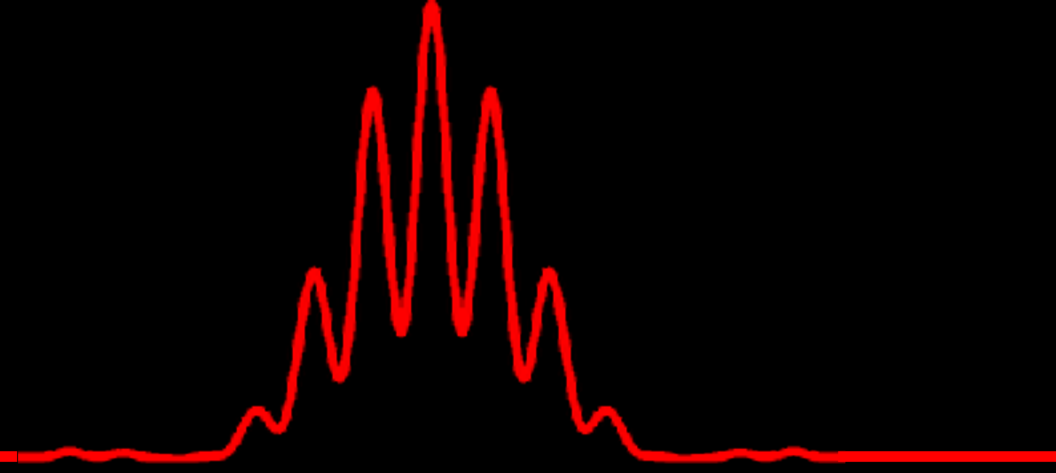
- JMMC, Porto, Exeter, Heidelberg, Nice, Liege
- Provide support on:
  - ➢ Proposal preparation
  - ➢ Observation preparation
  - ➢ Data reduction
- Contact address for all “future” VLTI users
- Travel funds to visit VLTI expertise centres (Fizeau exchange programme)
- Organisation of schools, trainings and workshops, VLTI community days



➡ http://www.european-interferometry.eu/

СПАСИБО ЗА ВНИМАНИЕ

THANKS FOR YOUR ATTENTION



DUSTY WIND ?

INNER RIM ?

EXTERNAL PERTUBATIONS ?

MISALIGNED/WARPED DISKS?