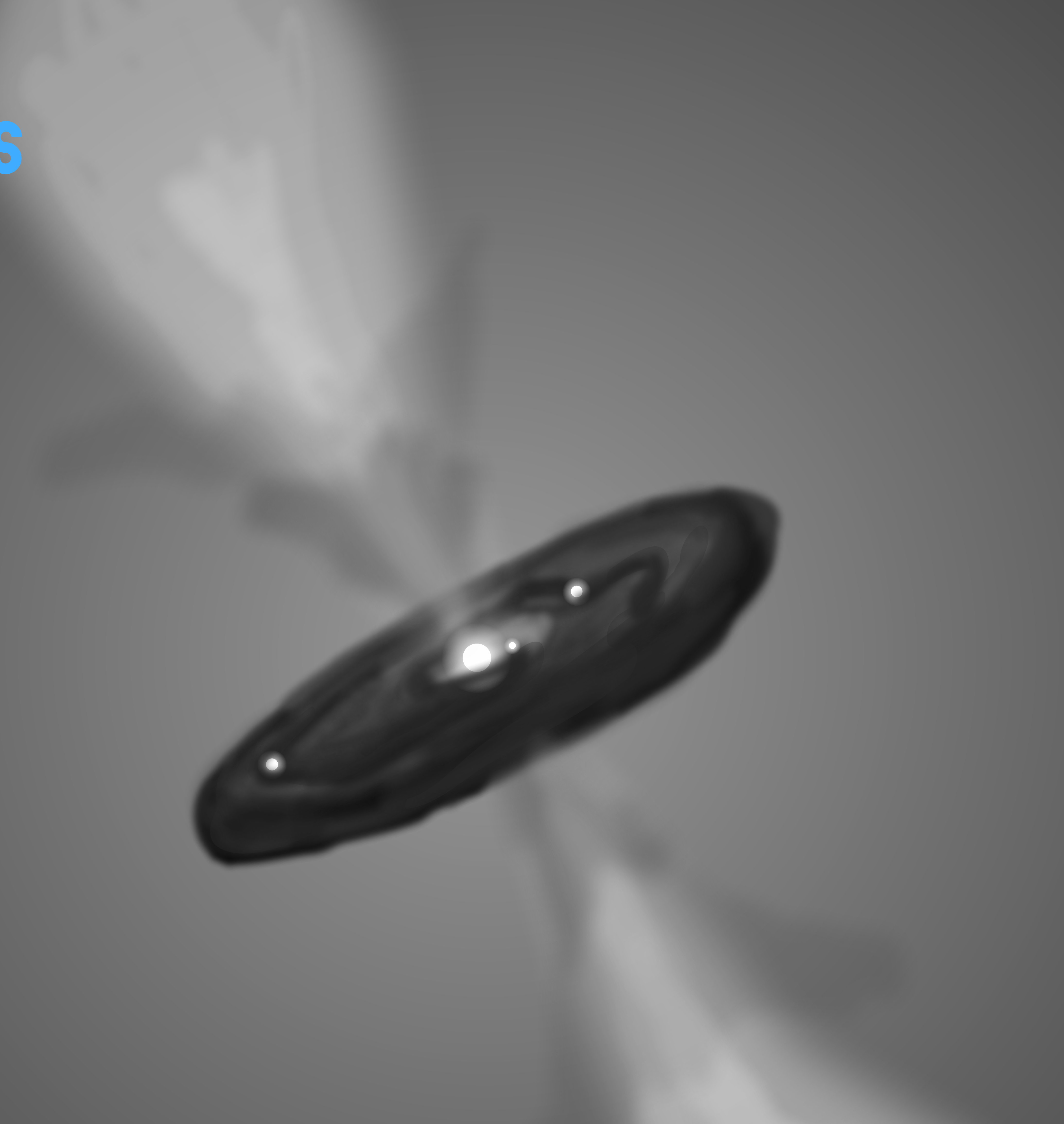
# Revealing the physics of high-mass disks in observations and simulations

Peter Schilke
Alvaro Sanchez-Monge | I. Physikalisches Institut
Universität zu Köln

André Oliva | Institut für Astronomie und Astrophysik
Eberhard Karls Universität Tübingen



Background illustration:
André Oliva

Ringberg Meeting: *Puzzles of Star Formation* | MPIA | July 2021

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

DAAD

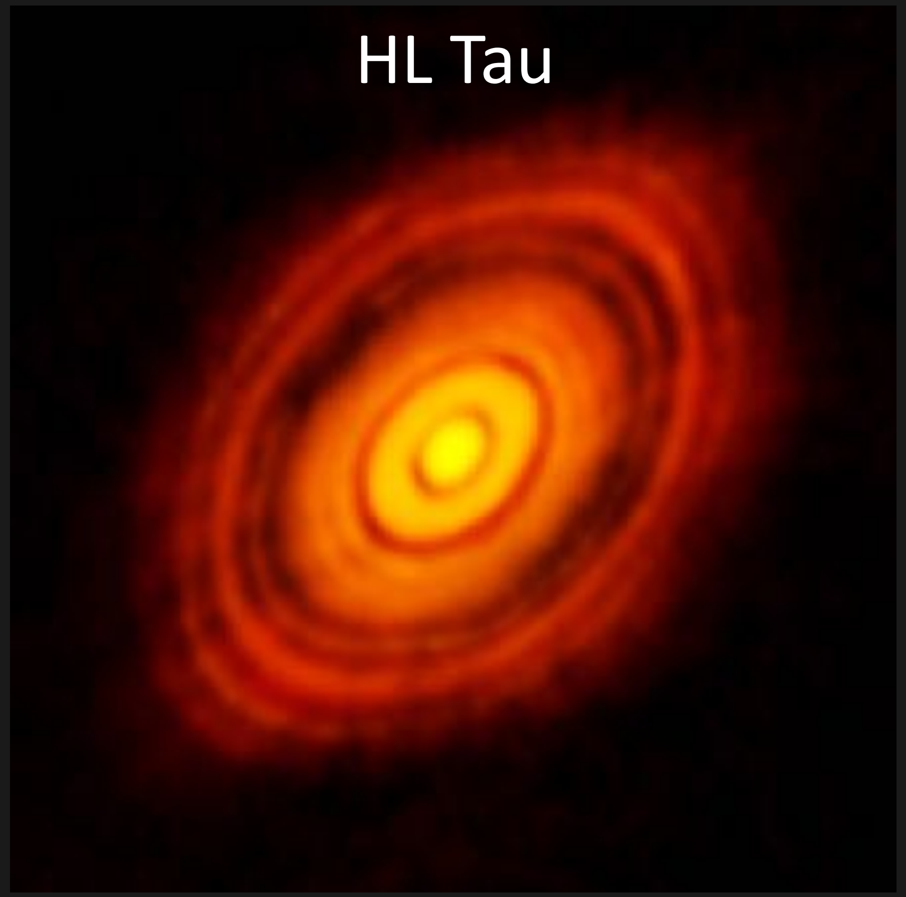
UNIVERSIDAD DE COSTA RICA

# Observations of disks around massive stars

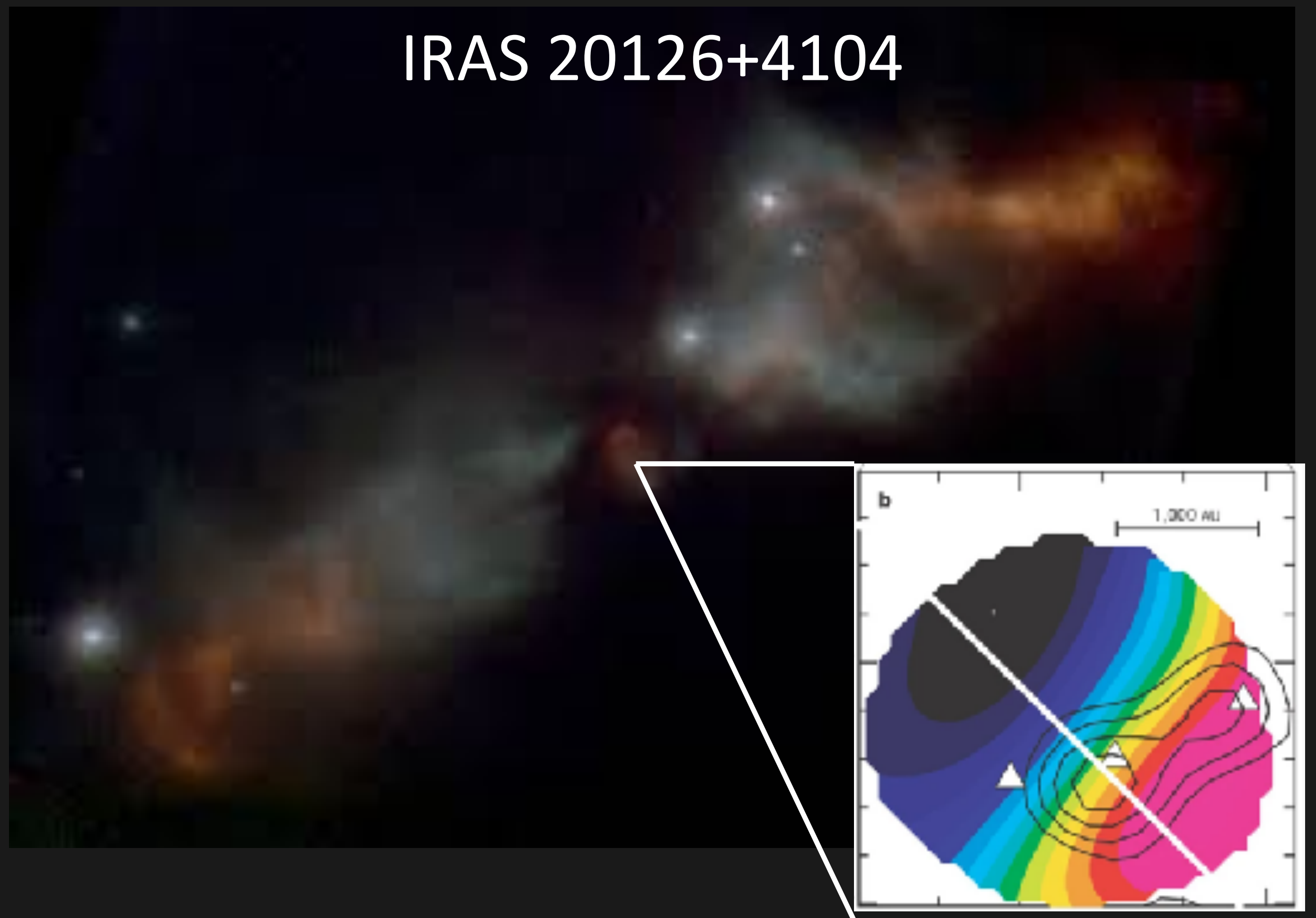
low-mass

**high-mass**

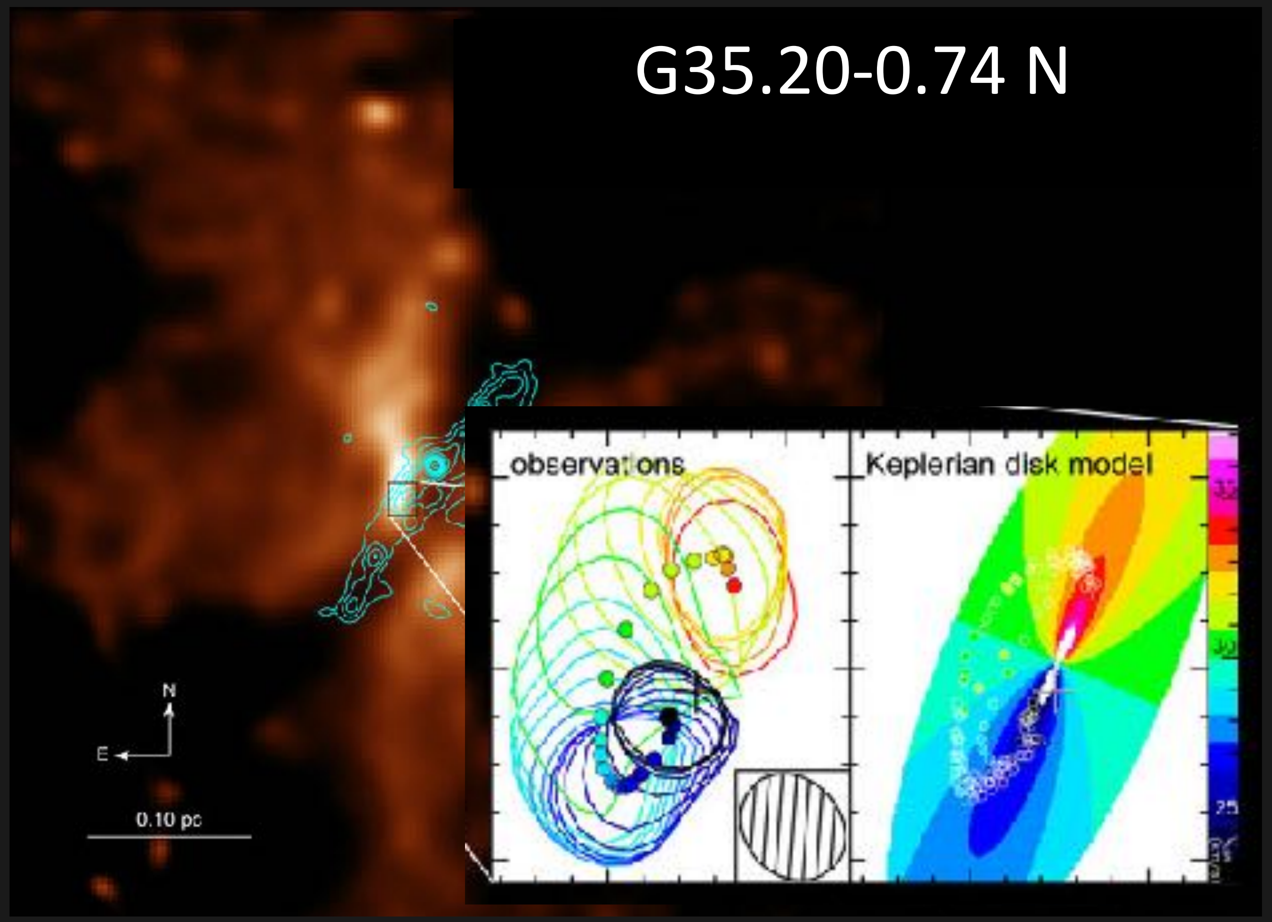
1 M⊙ 7 M⊙ 16 M⊙ 40 M⊙



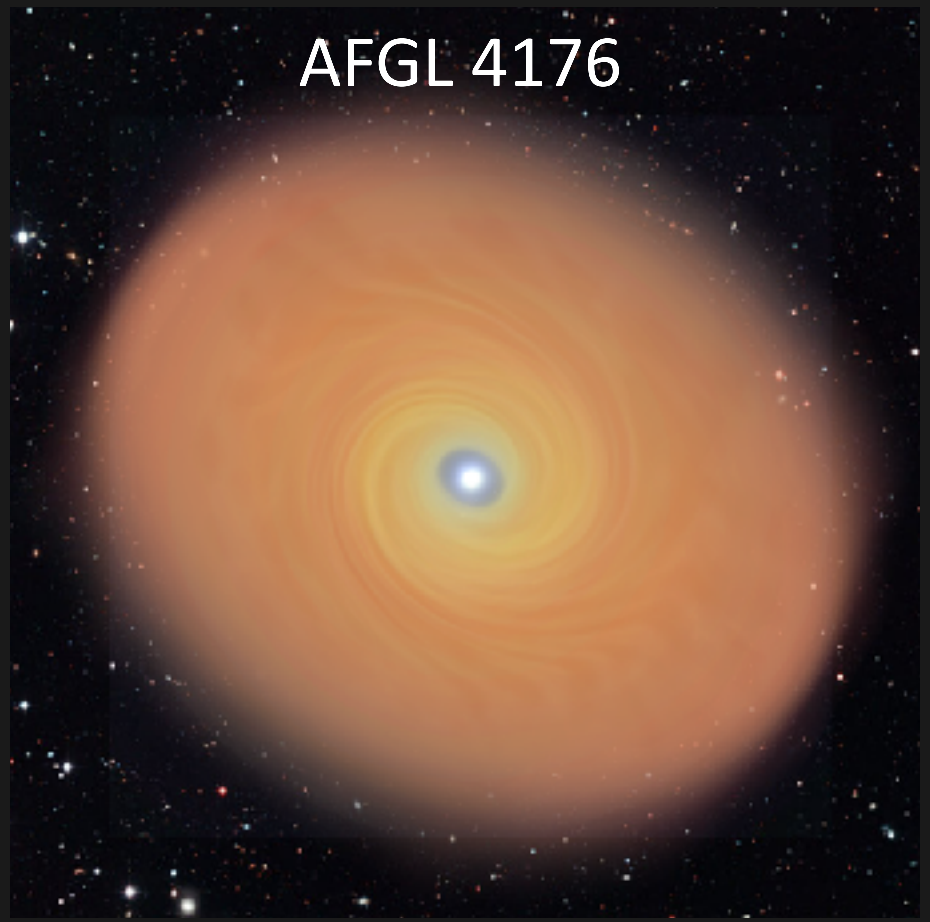

ALMA et al (2015)




Cesaroni et al (2014)




Sánchez-Monge et al (2013)

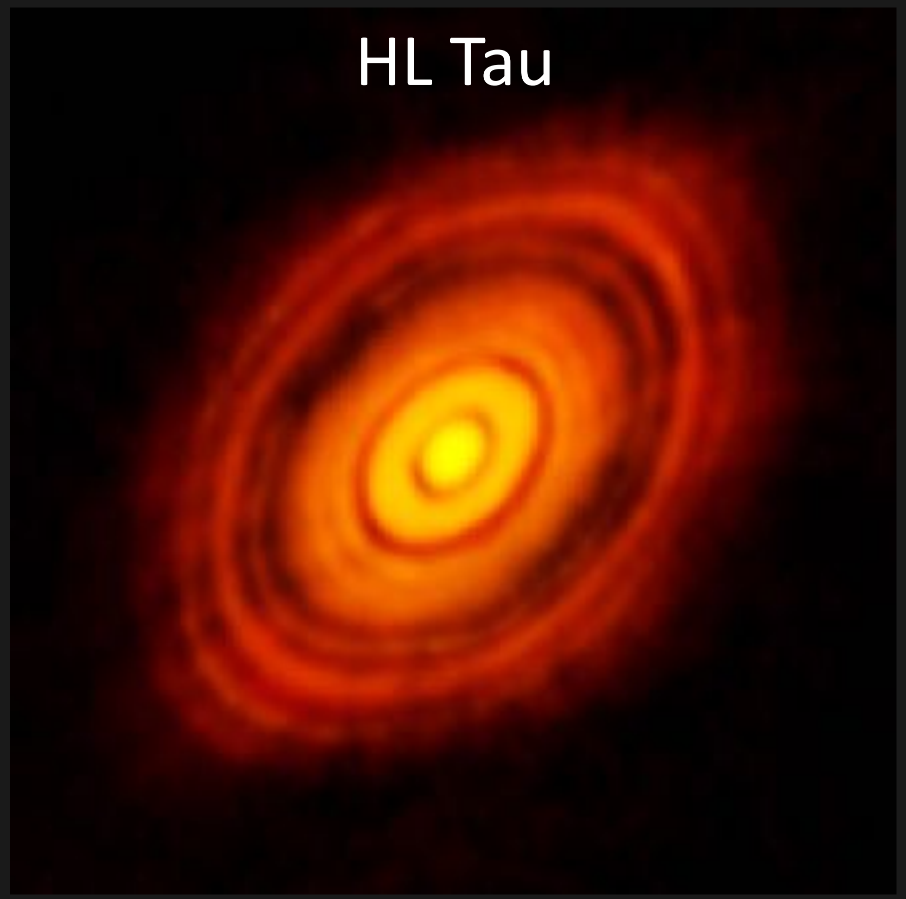



Johnston et al (2015)

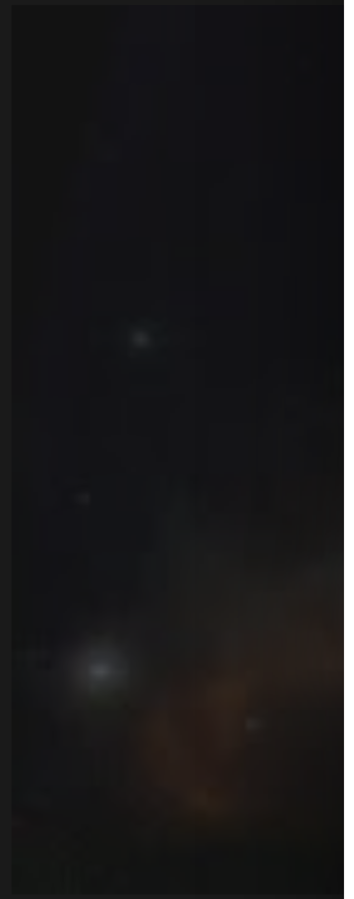
# Observations of disks around massive stars

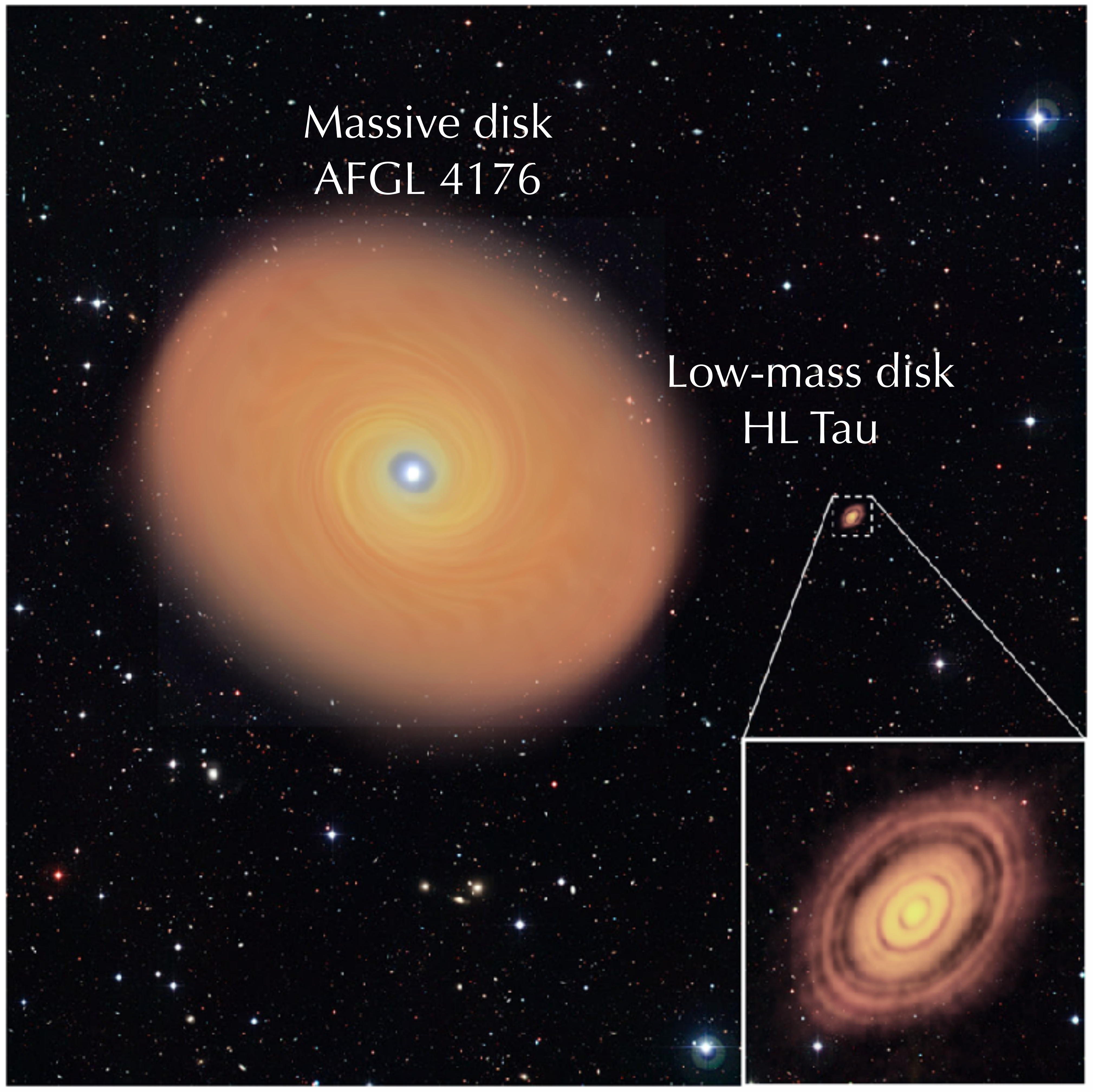
low-mass ⟷ high-mass

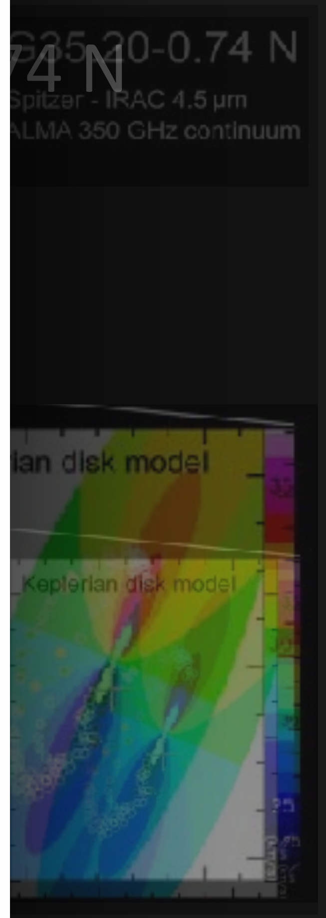
$1\ M_\odot$ — $40\ M_\odot$

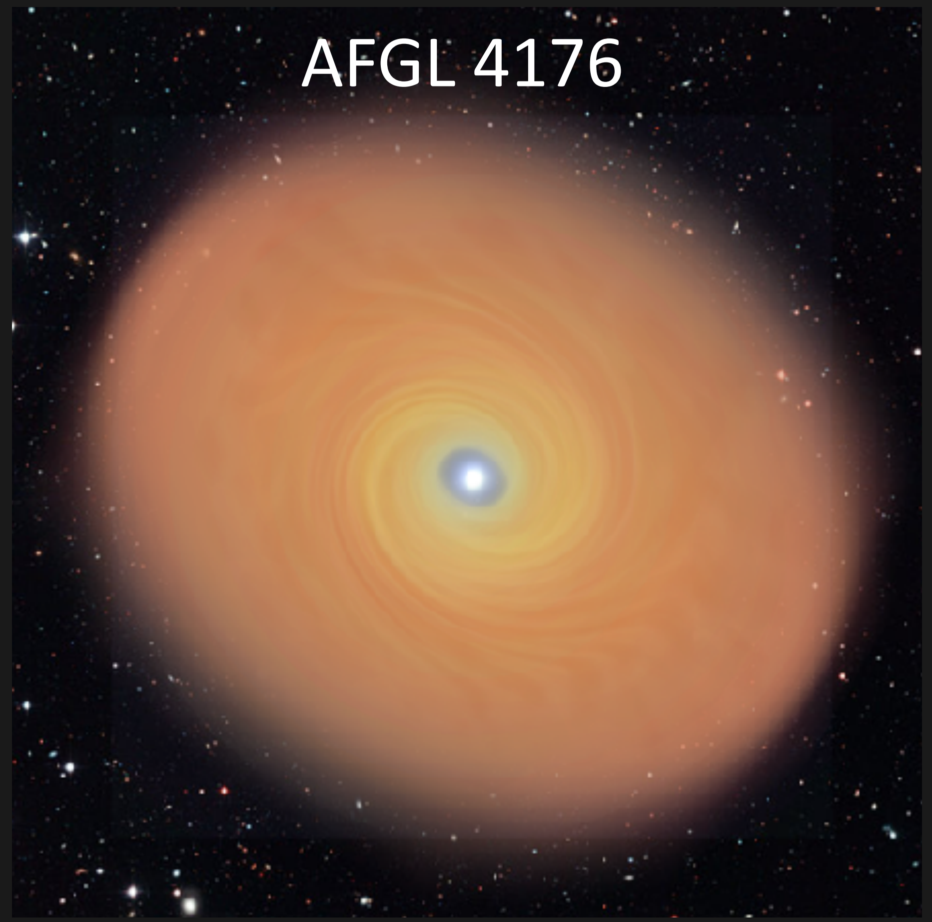



ALMA et al (2015)








Johnston et al (2015)

# Observations: Disks (sub-)structure

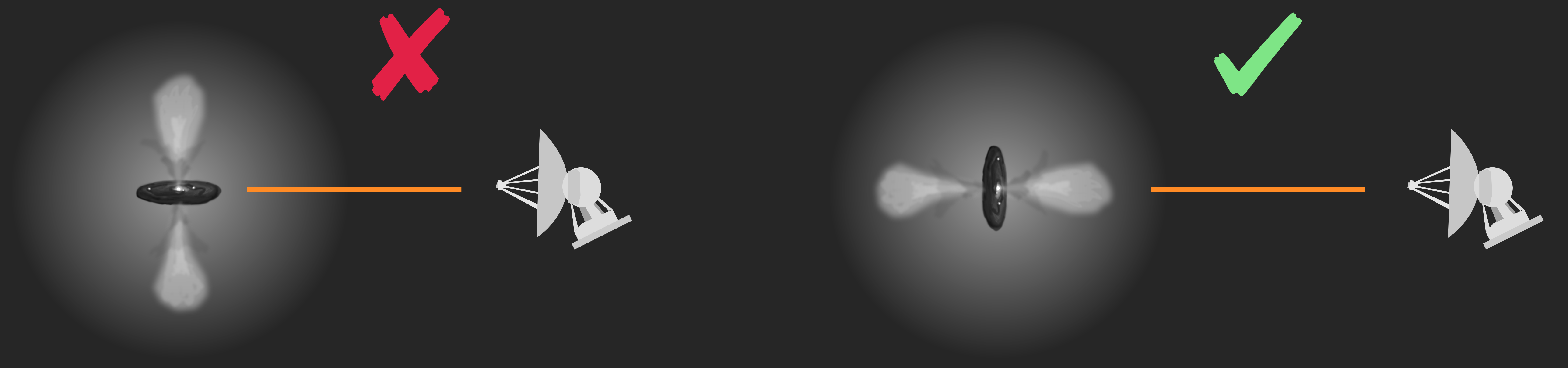
**High-resolution observations are now possible!**

ALMA : 20-50 mas (or 40 au at 2 kpc / or 100 au at 5 kpc)

VLT-I (or ELT) : about mas (or a few au)

**Possible difficulties in the infrared (?):**

- Disks can be highly embedded (i.e., obscured by dust)
- We can take advantage of geometrical configurations (e.g., disks seen “almost” face-on)



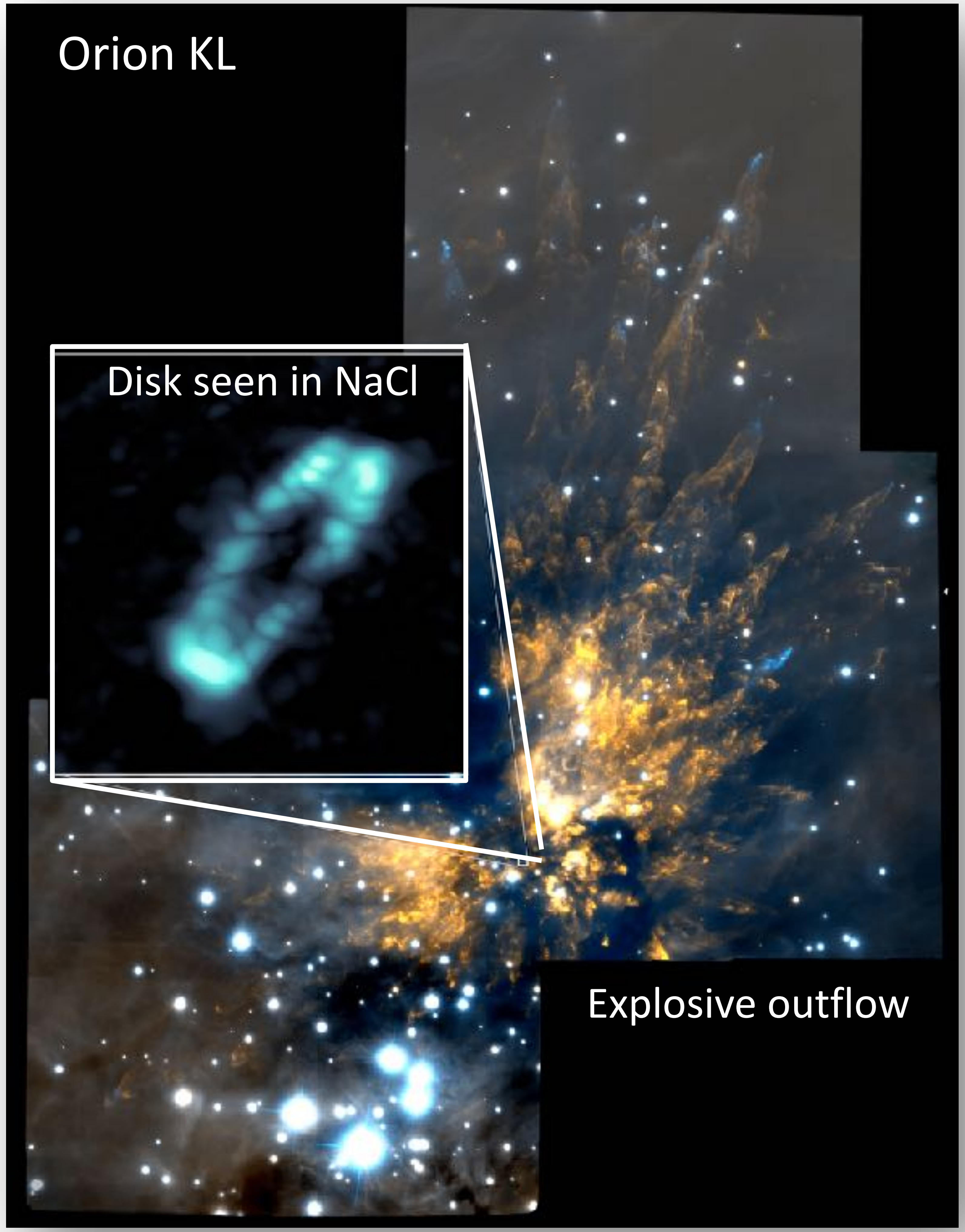
Infrared emission obscured by dust

Infrared emission observable through the outflow cavity

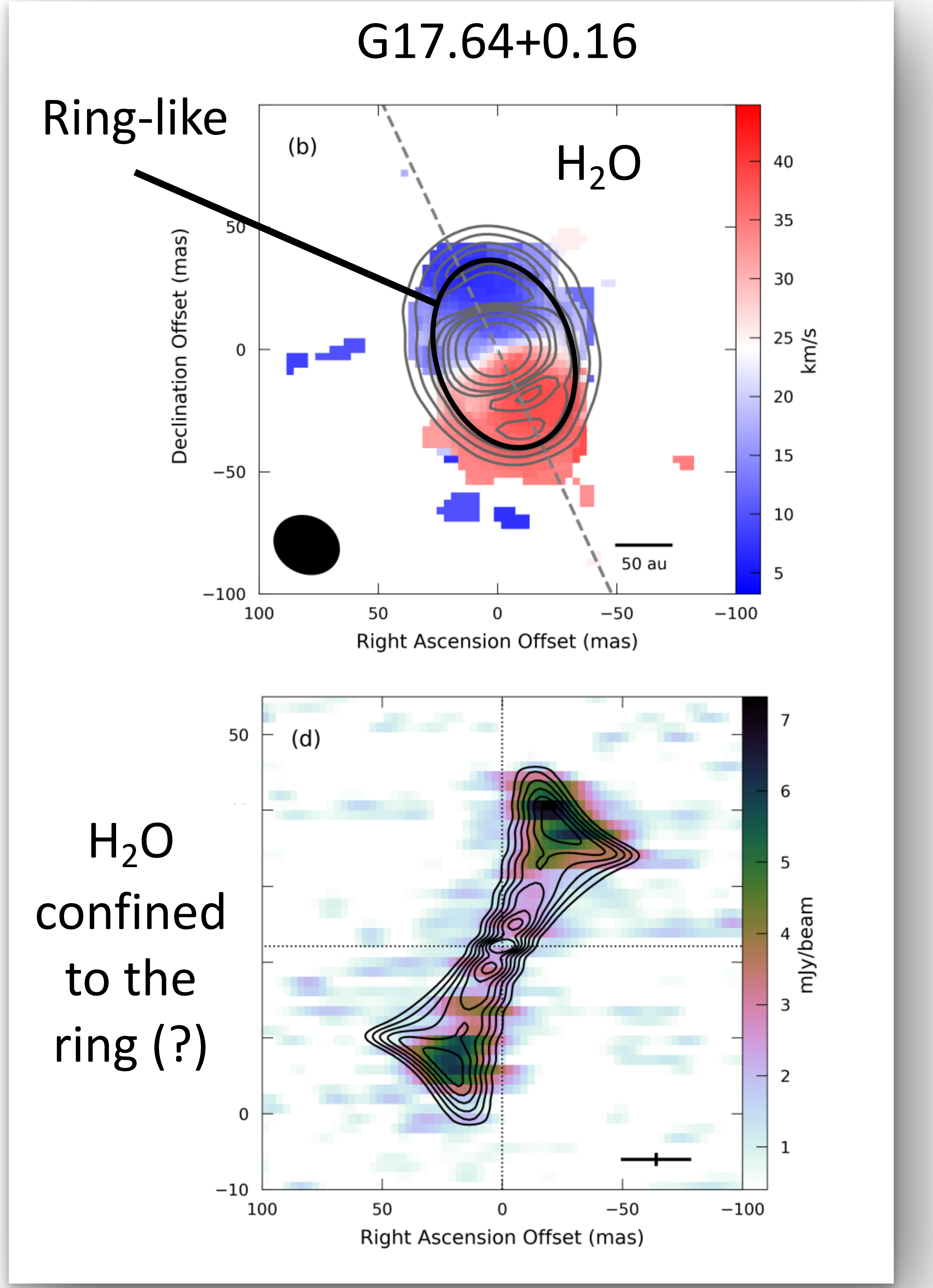
# Observations: Disks (sub-)structure

**High-resolution observations are now possible!**

ALMA : 20-50 mas (or 40 au at 2 kpc / or 100 au at 5 kpc)




Ginsburg et al 2019, ApJ, 872, 54

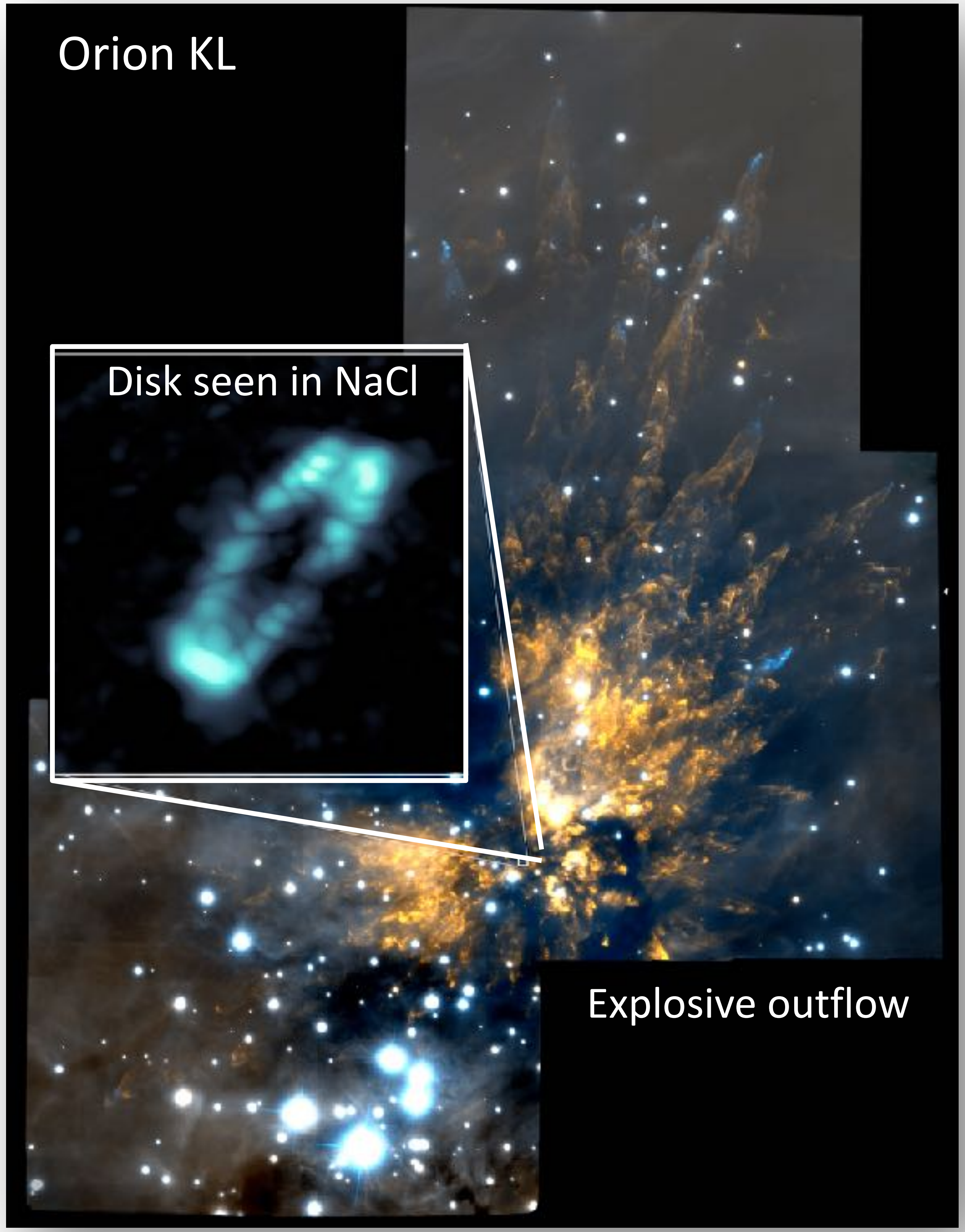



Maud et al 2019, A&A, 627, L6

# Observations: Disks (sub-)structure

**High-resolution observations are now possible!**

ALMA : 20-50 mas (or 40 au at 2 kpc / or 100 au at 5 kpc)




Ginsburg et al 2019, ApJ, 872, 54

**What are the best tracers ?**

- 'normal' COMs may trace mainly envelope around the disk ?
- vibrational excited states ?
- salts (NaCl, KCl, …)? , water ?

**Which sub-structures ?**

- spiral arms ?
- rings ? ( are similar to low-mass ? )
- large cavities due to binary disk truncation ?

# High-resolution numerical simulations

Oliva & Kuiper 2020 A&A 644 A41

(gas) hydrodynamics

self-gravity

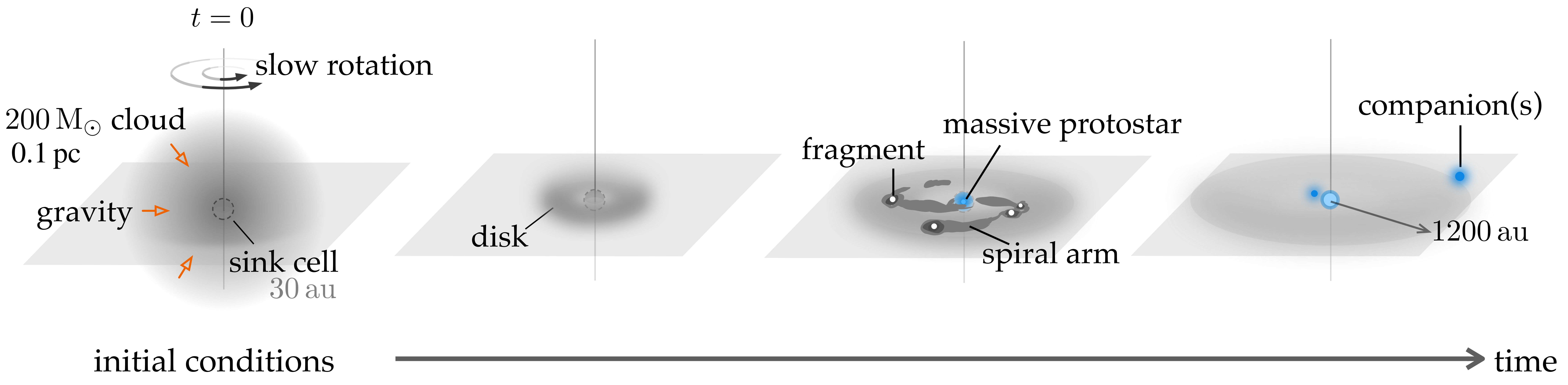
stellar irradiation

thermal re-emission

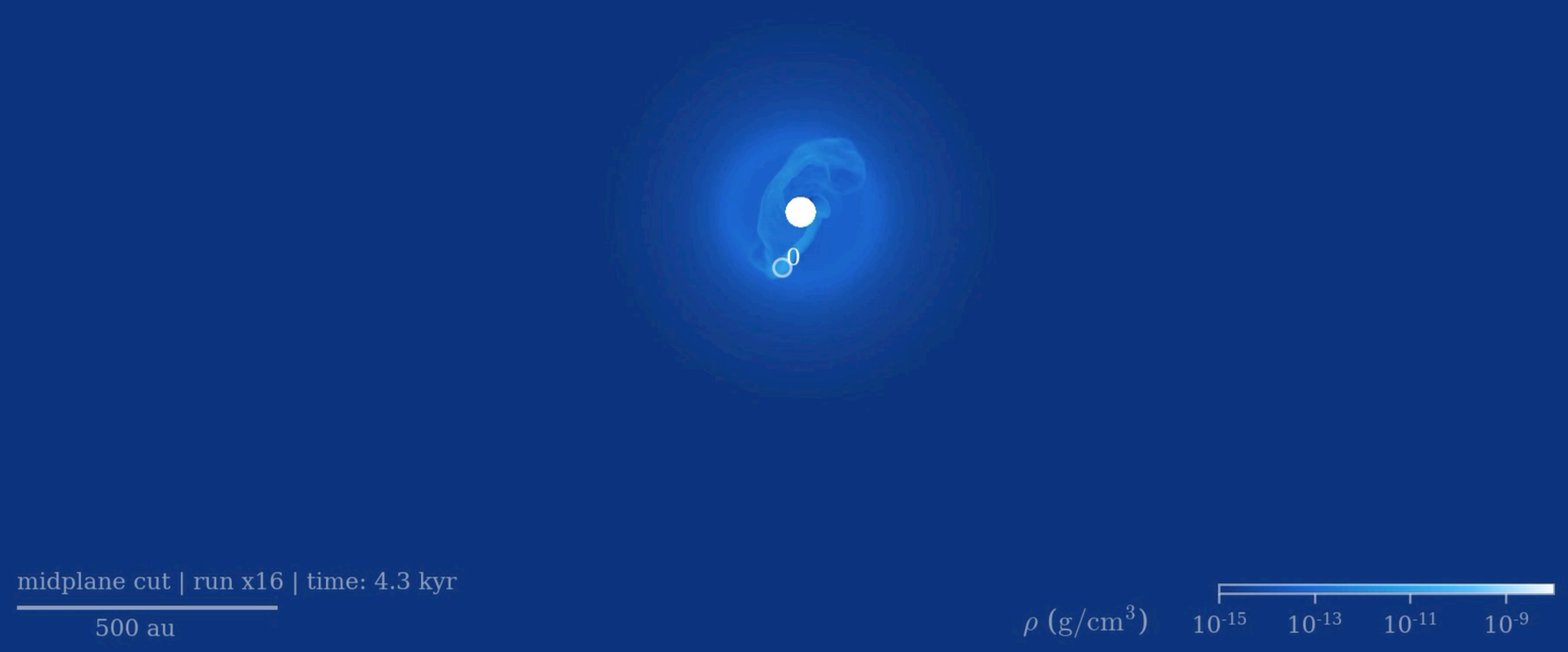
stellar evolution

dust sublimation and evaporation

sub-au max. resolution



# From fragments to companions

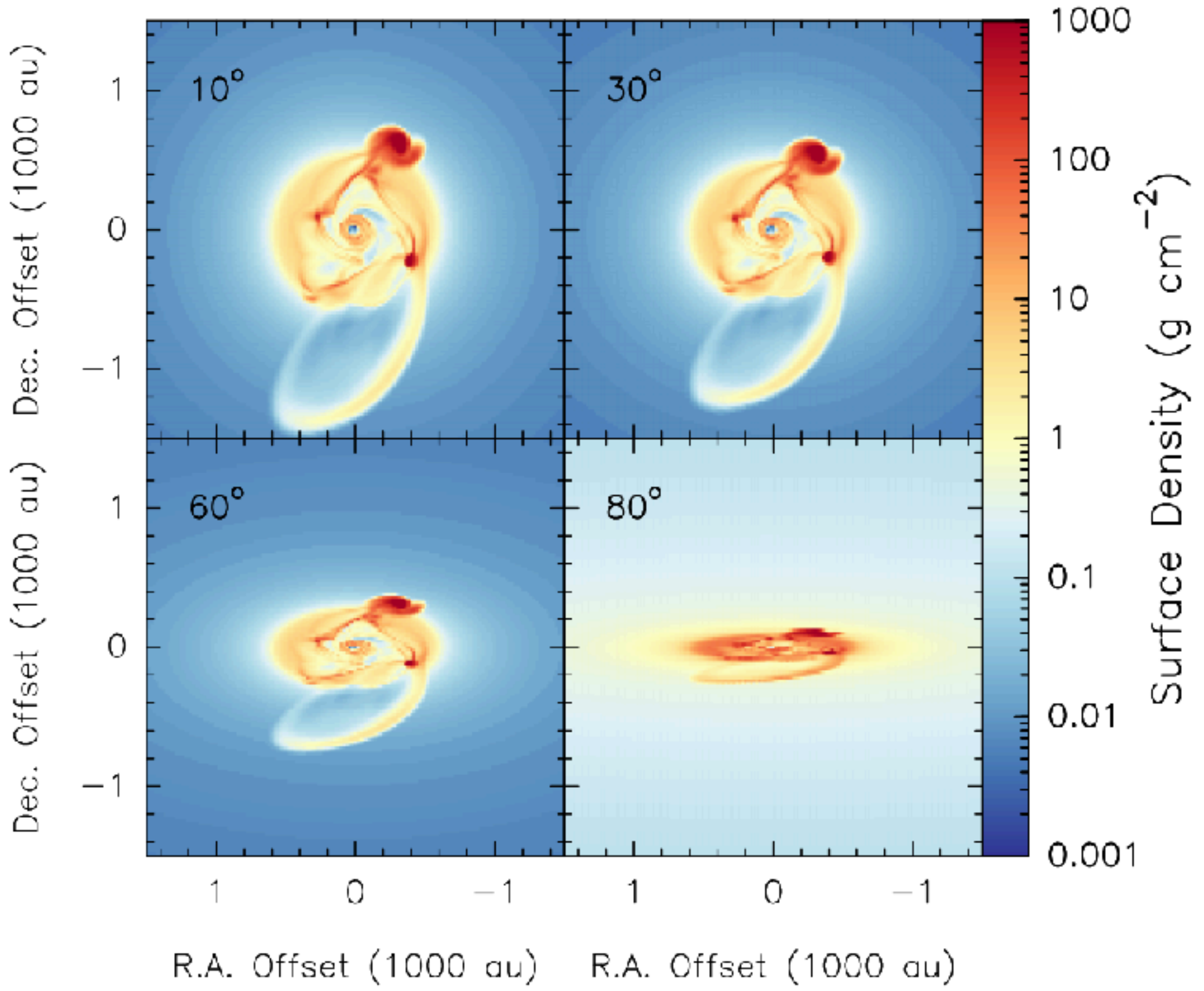


# From fragments to companions

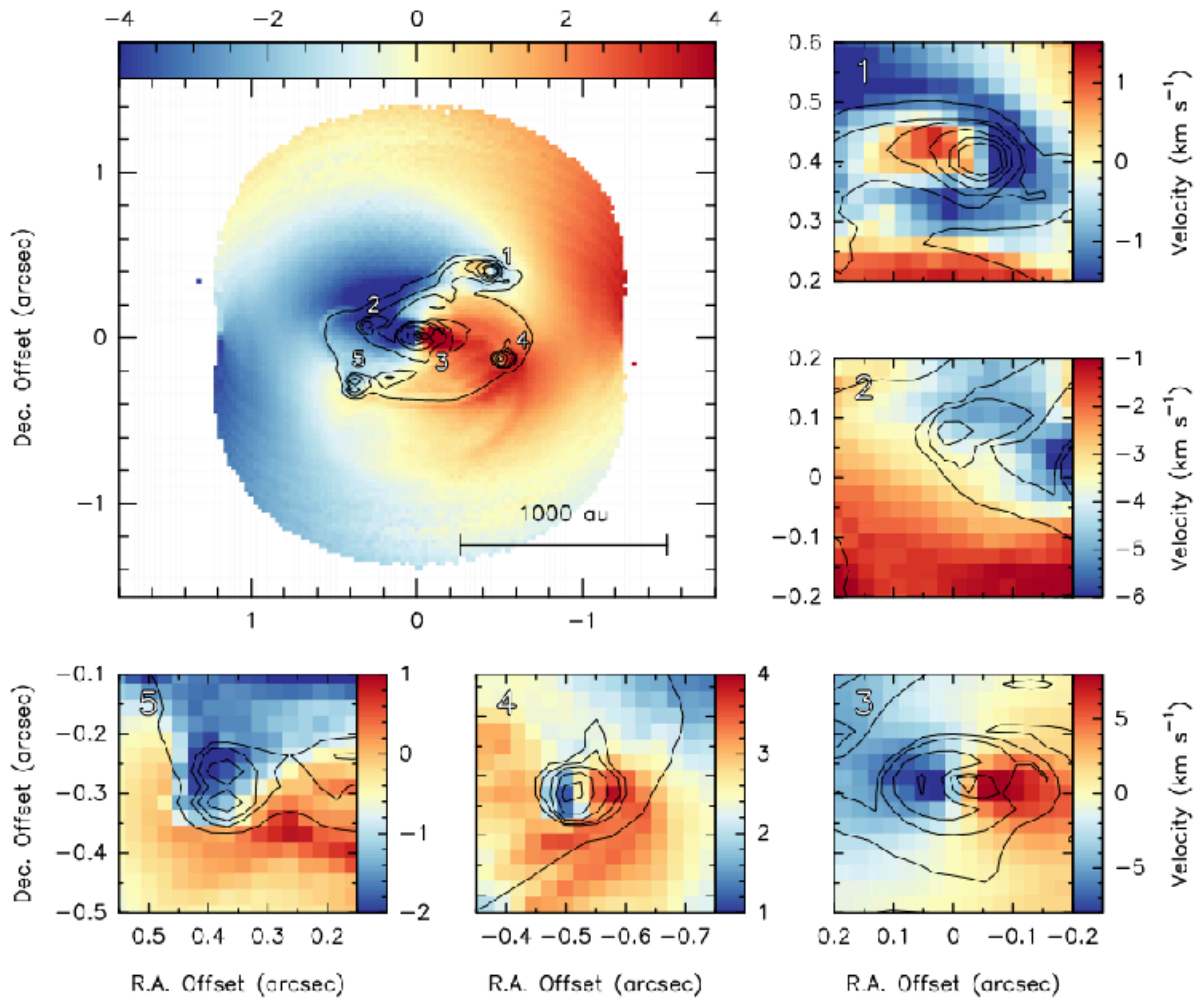
# From fragments to companions

# But... could we observe this?

**ALMA:** 20-50 mas (or 40 au at 2 kpc / or 100 au at 5 kpc)

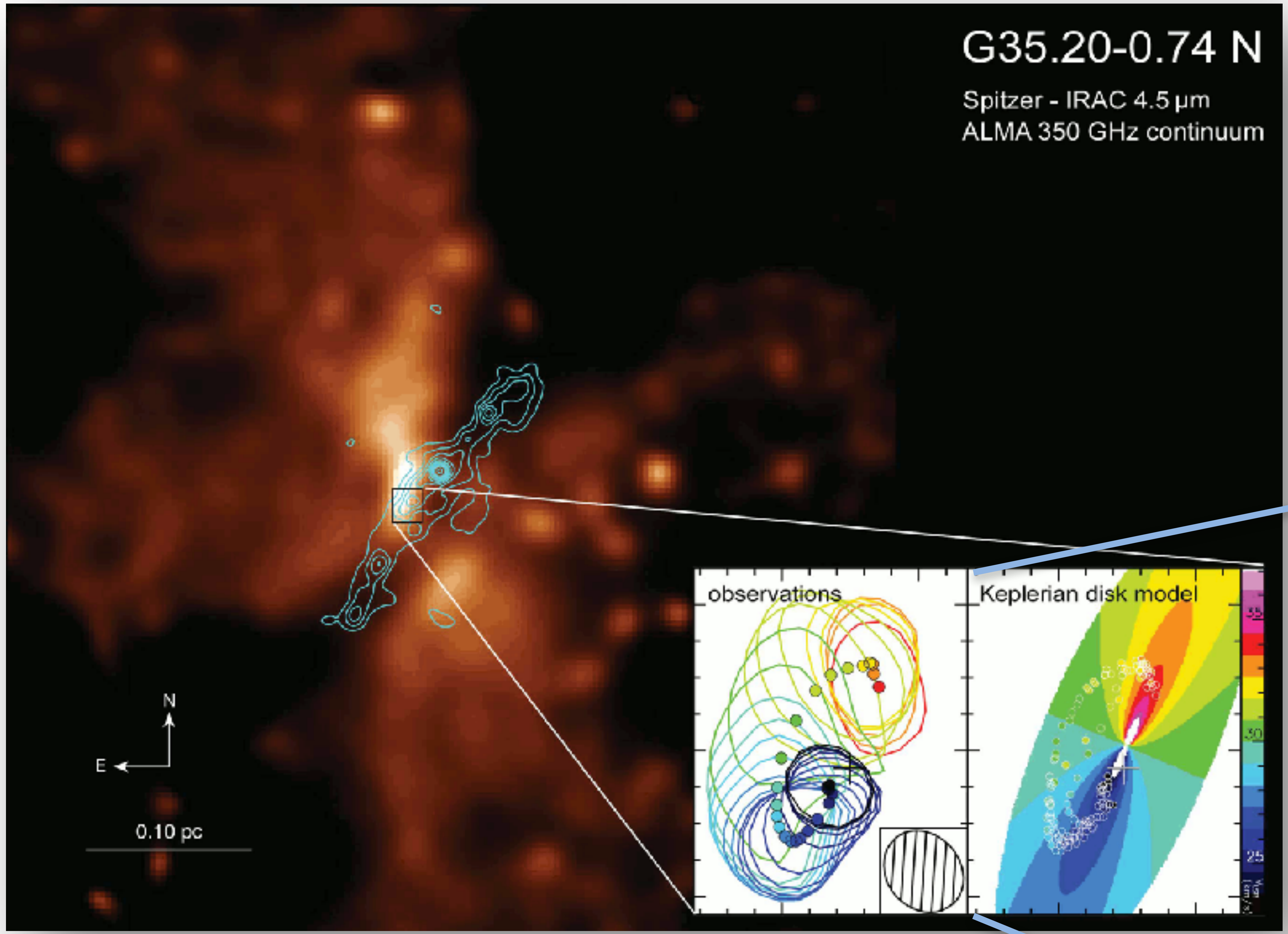



Oliva & Kuiper 2020, A&A,644, A41

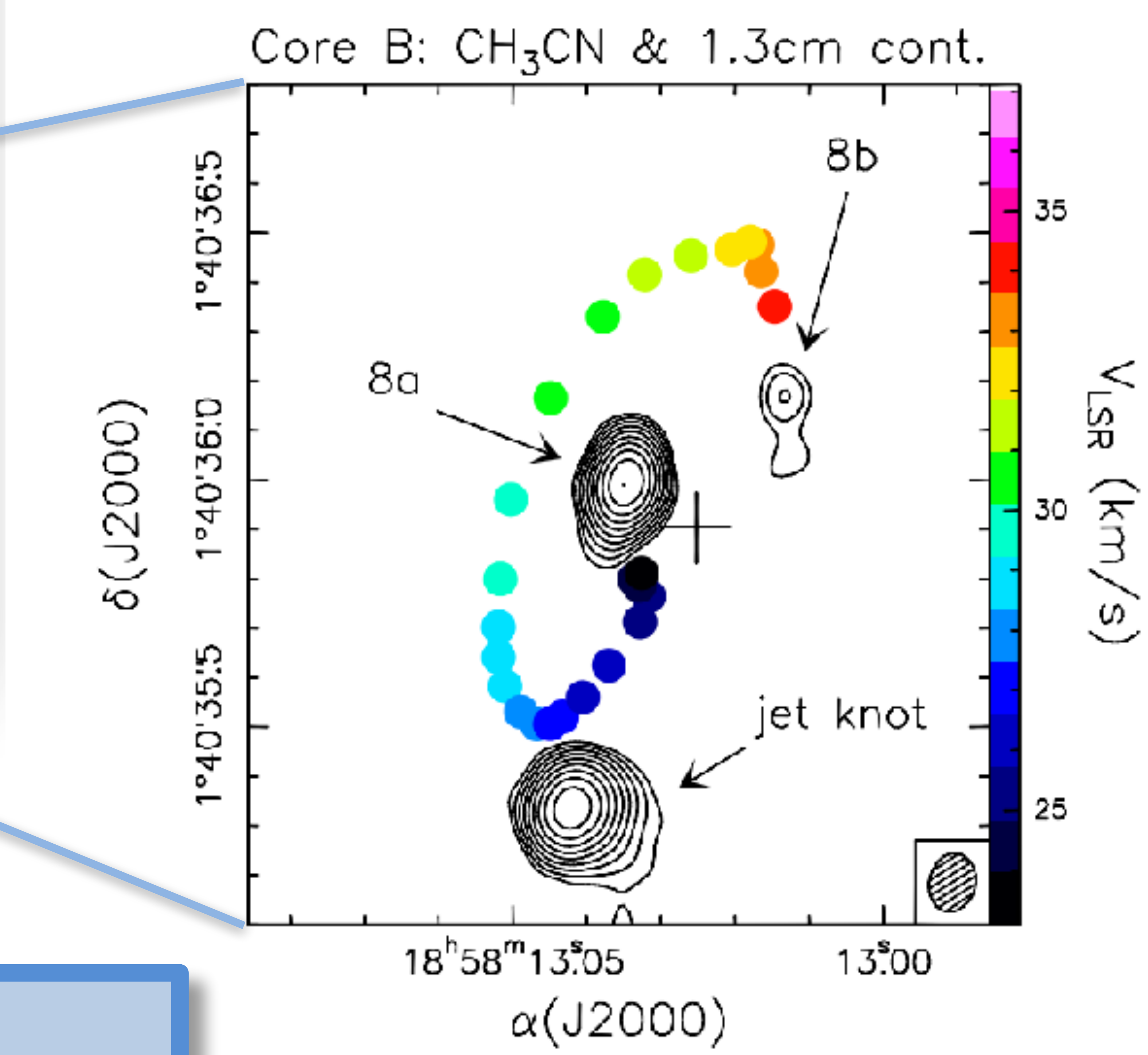



Ahmadi et al 2019, A&A, 632, A50

# Observations: Disks (sub-)structure




**Keplerian circumbinary disk**
around a 800-au binary system




Sánchez-Monge et al 2013, A&A, 552, L10
Beltrán et al 2016, A&A, 593, A49

**Binarity / disk fragmentation**

- disk velocity structure if fragments or binary systems ?
- smaller disks around fragments ?

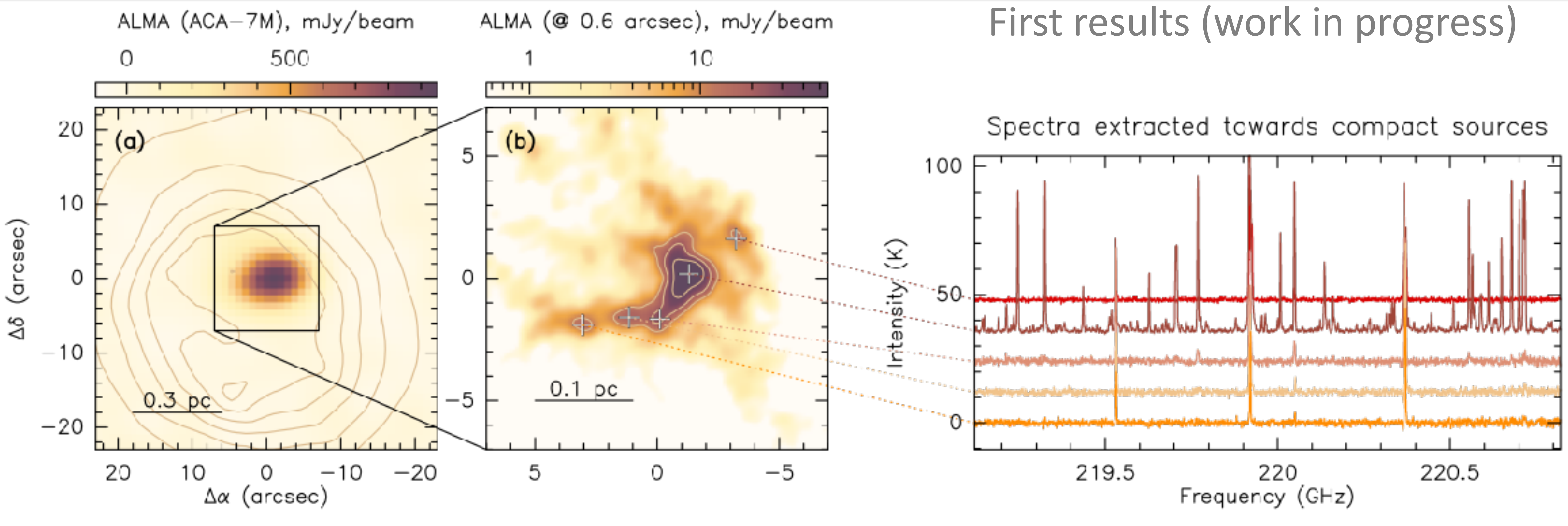
# Observations: Statistics are necessary

**Large surveys will be possible!**

Properties of disks as a function of
stellar mass, luminosity, evolutionary stage, …
and even more general environmental properties (see later)

**ALMAGAL**: 1000+ high-mass star forming sources across the Galaxy
spatial resolution about 1000 au **(disk candidates)**

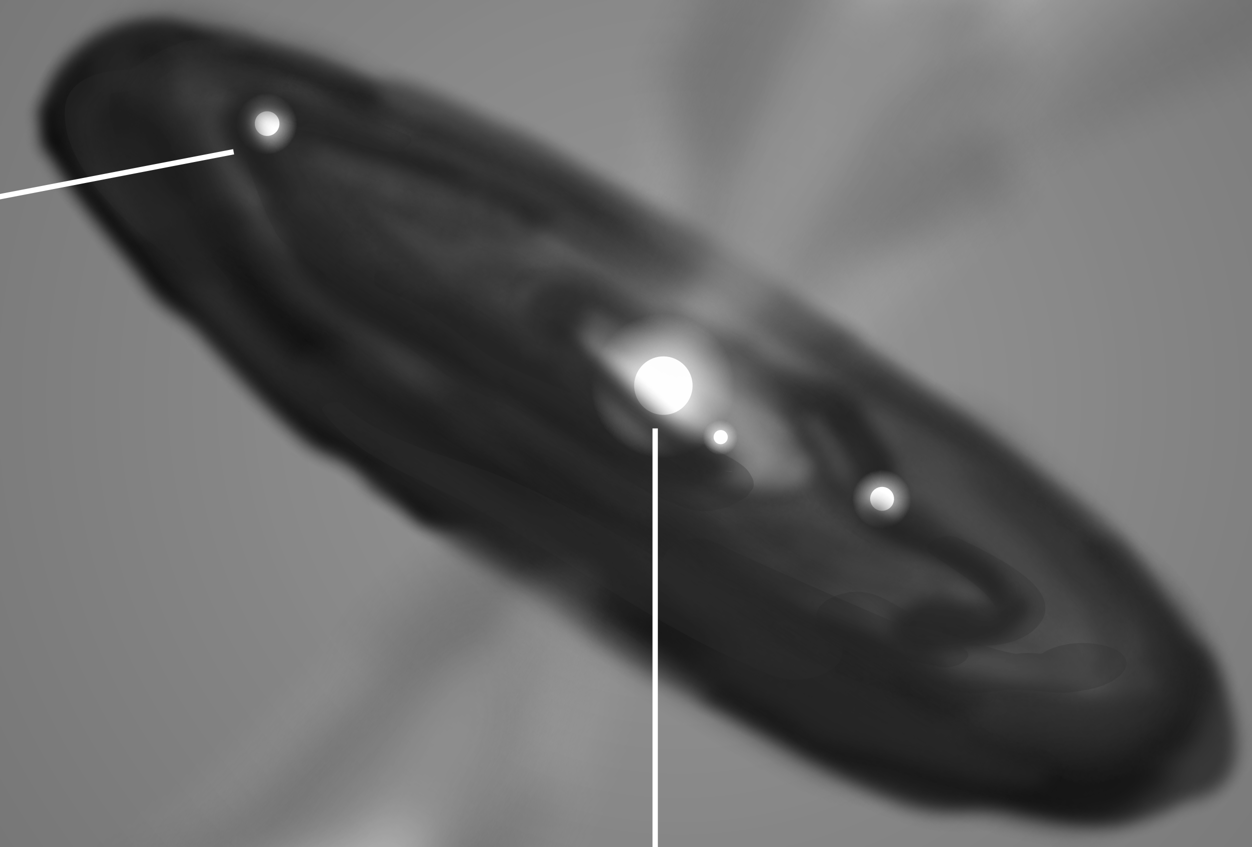
First results (work in progress)



# Open questions

What is the role of magnetic fields on fragmentation?

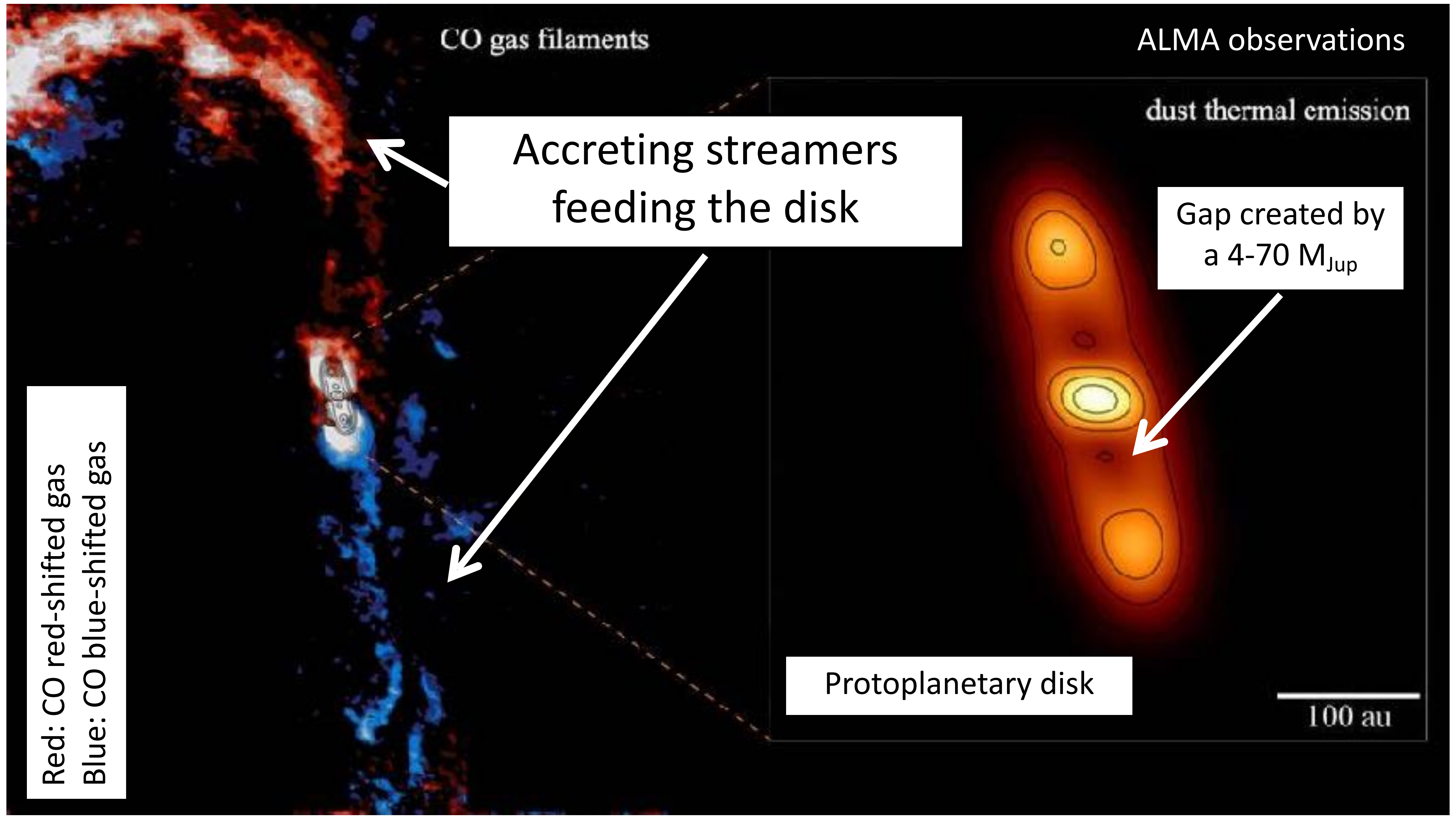
How massive will the companions formed by disk fragmentation be?



Post-processing chemistry and dust evolution

How does the picture change in the case of a binary in the center?

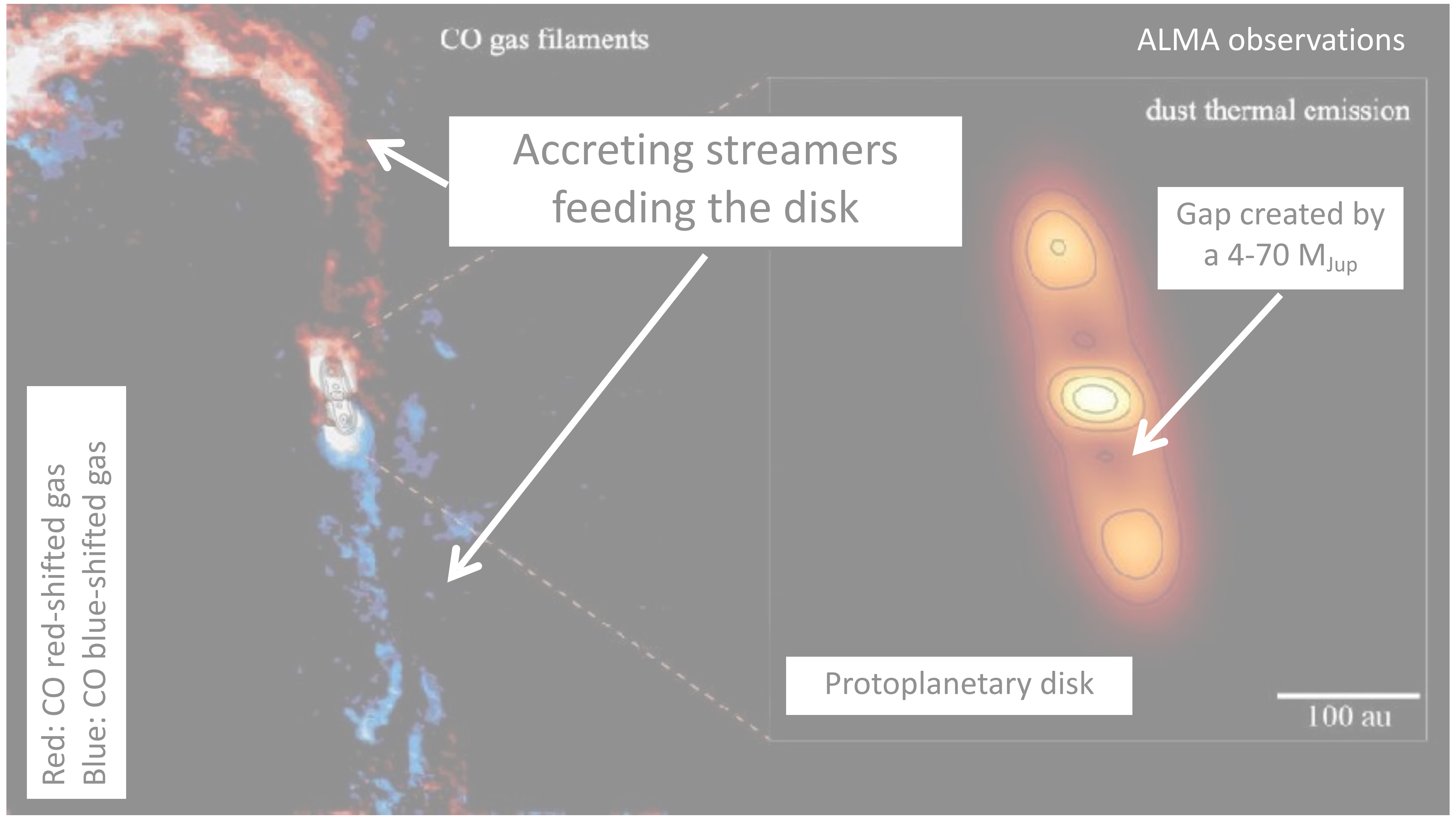
# Observations: Connecting to larger scales




BHB2007 low-mass star : Alves et al 2020, ApJ, 904, L6

**Accretion streamers** in low-mass disks (see Pineda/Segura-Cox discussion)

# Observations: Connecting to larger scales

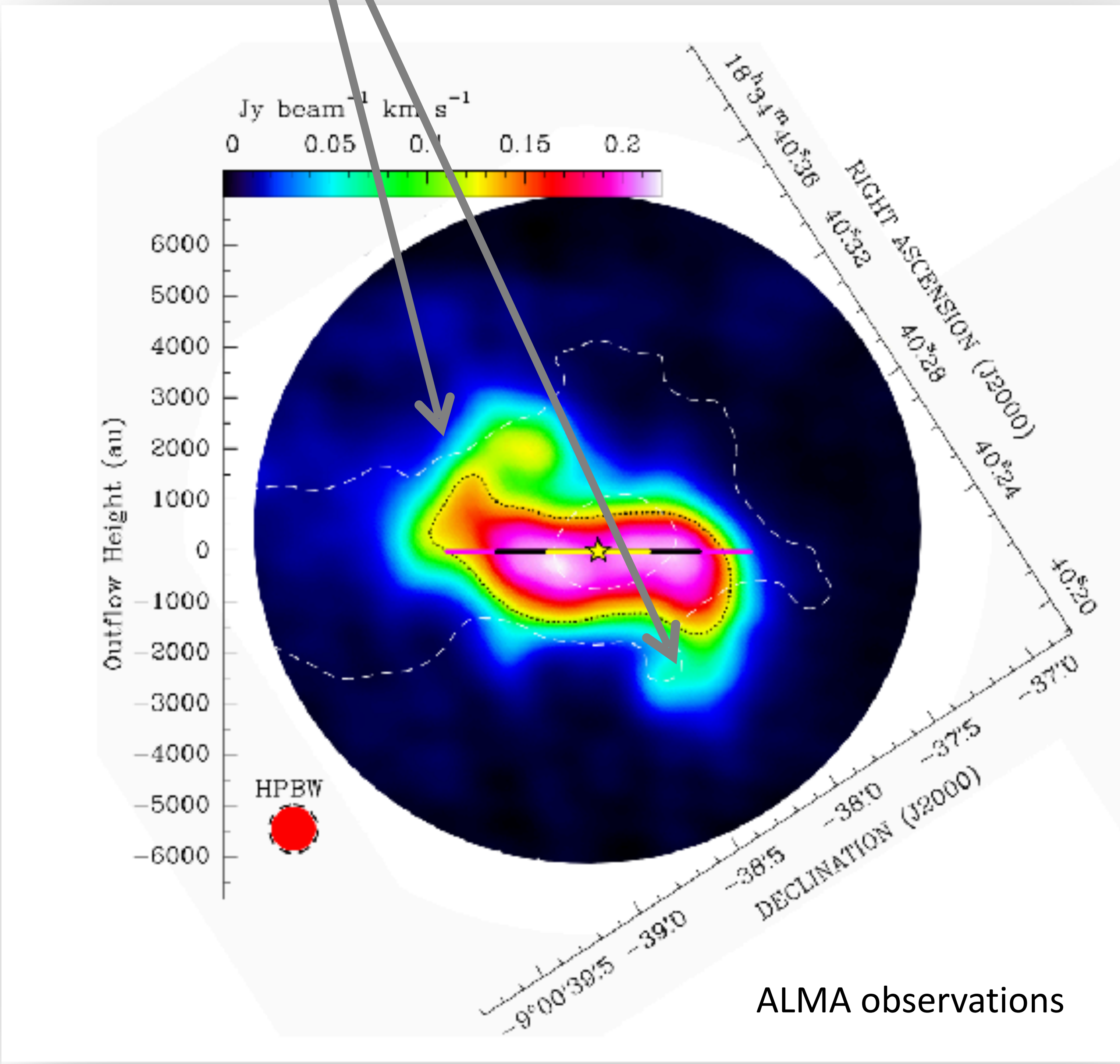



BHB2007 low-mass star : Alves et al 2020, ApJ, 904, L6

**Accretion streamers** in low-mass disks (see Pineda/Segura-Cox discussion)

Possible accretion streamers in a high-mass disk

G023.01-00.41 high-mass star
Sanna et al 2019, A&A, 623, A77

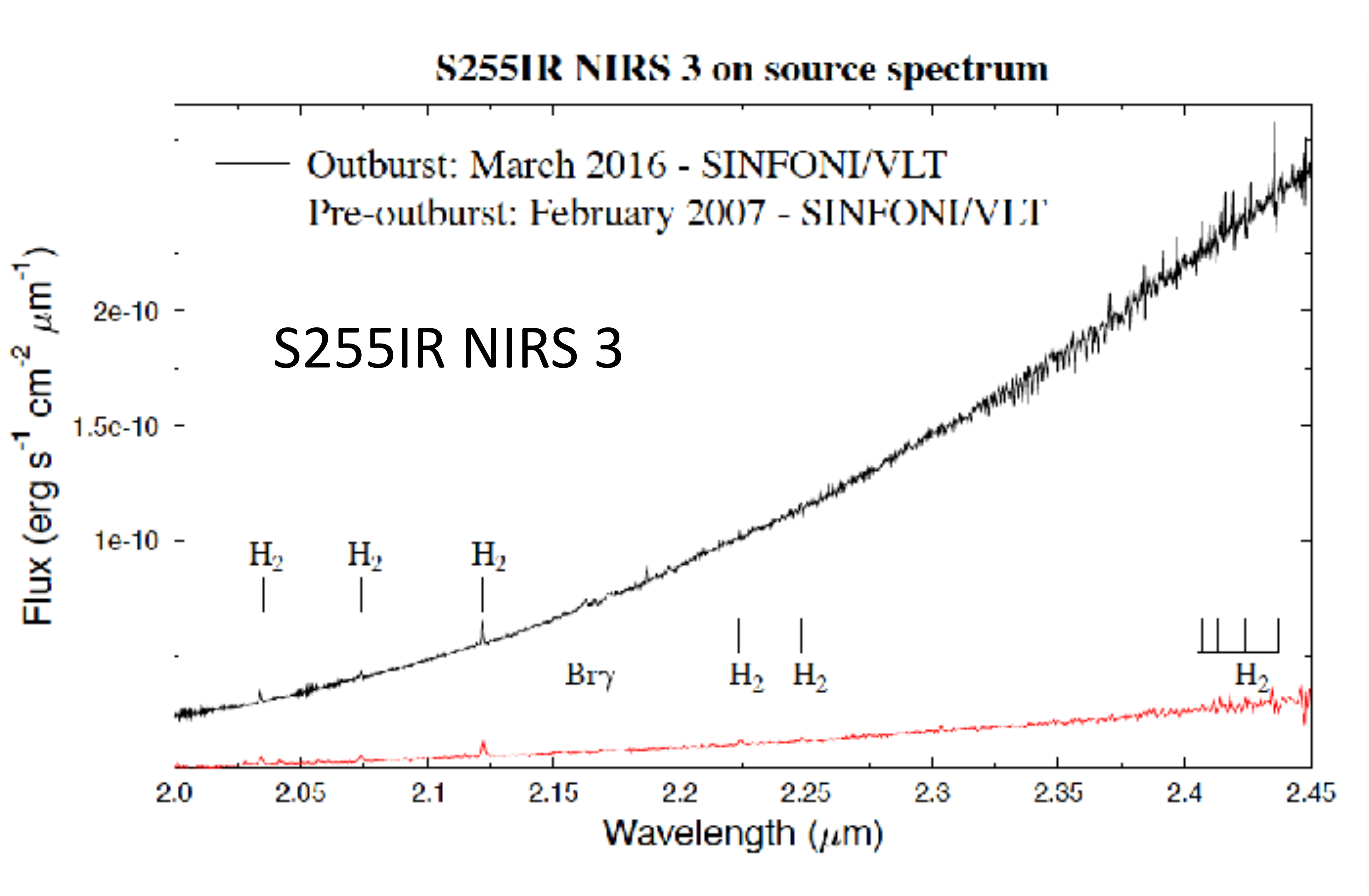



## Accretion process… observationally ?

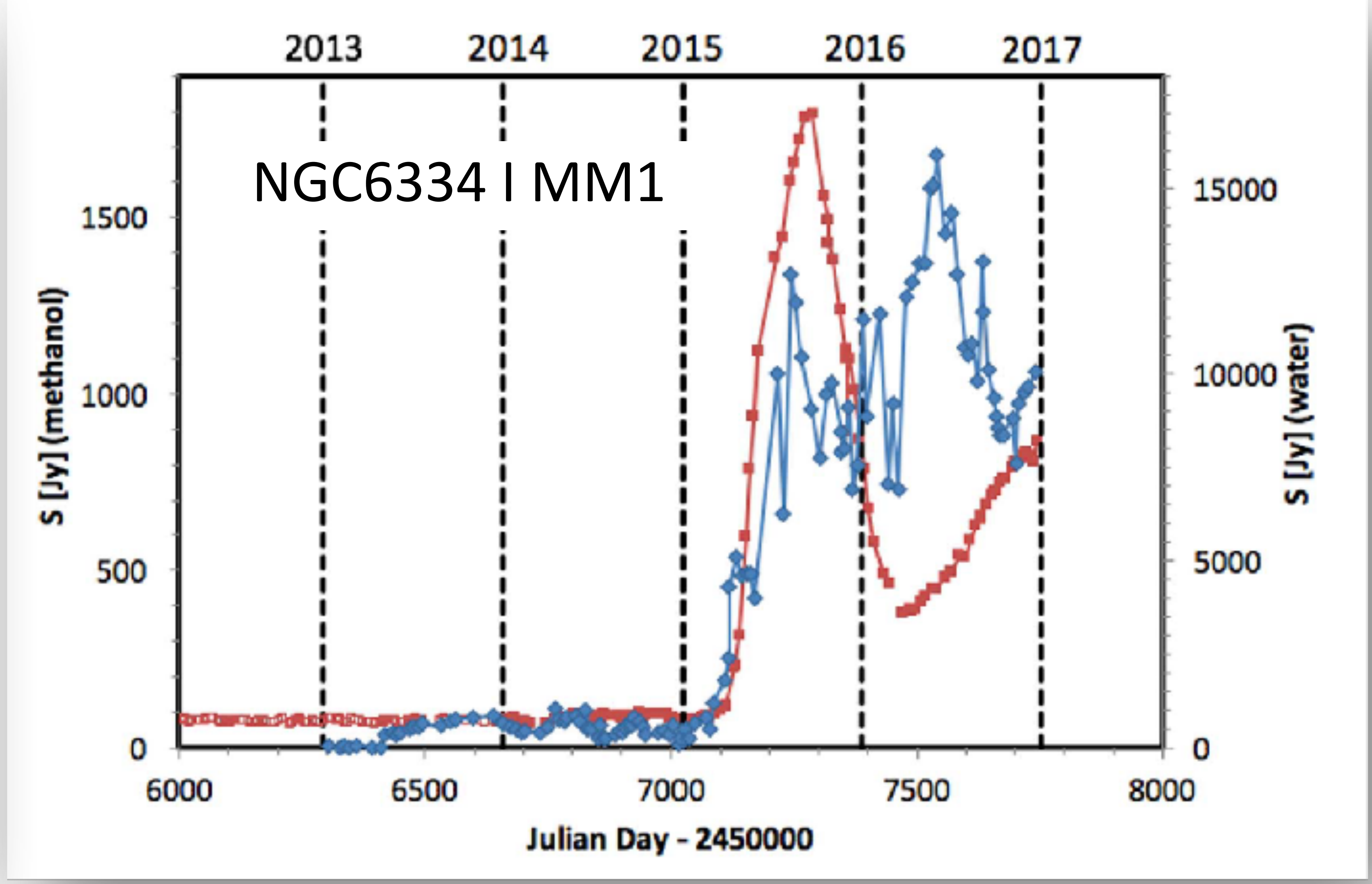
- How does accretion proceed ? (envelope to disk to star)
- Can we measure e.g. spectrum of accretion luminosity at different regions ?
- Do stellar accretion rates scale with large-scale infall rates ?

# Observations: "Time-domain" astronomy

Caratti o Garatti et al 2017, Nature Physics, 13, 276



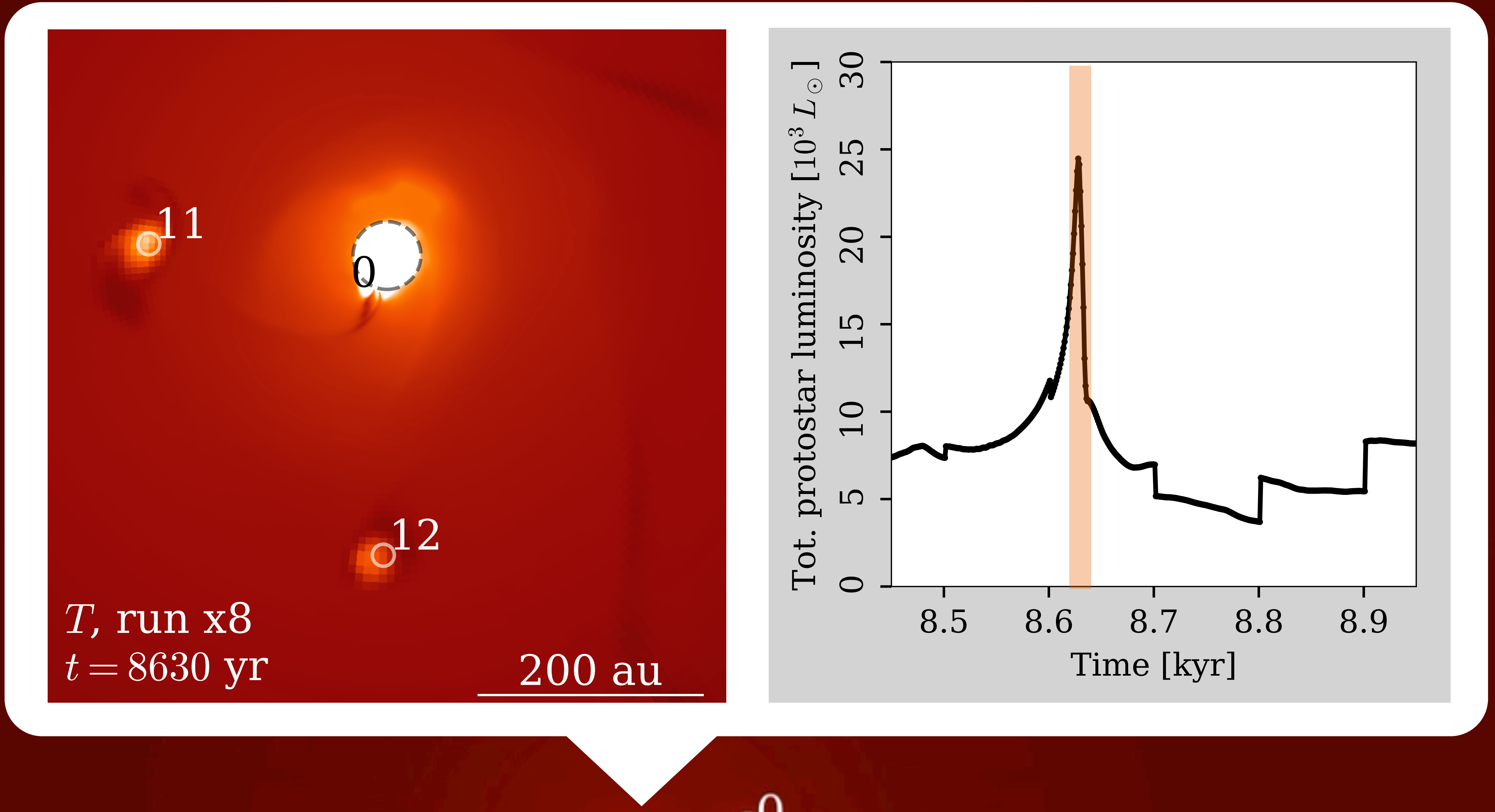

Hunter et al 2017, ApJ, 837, L29

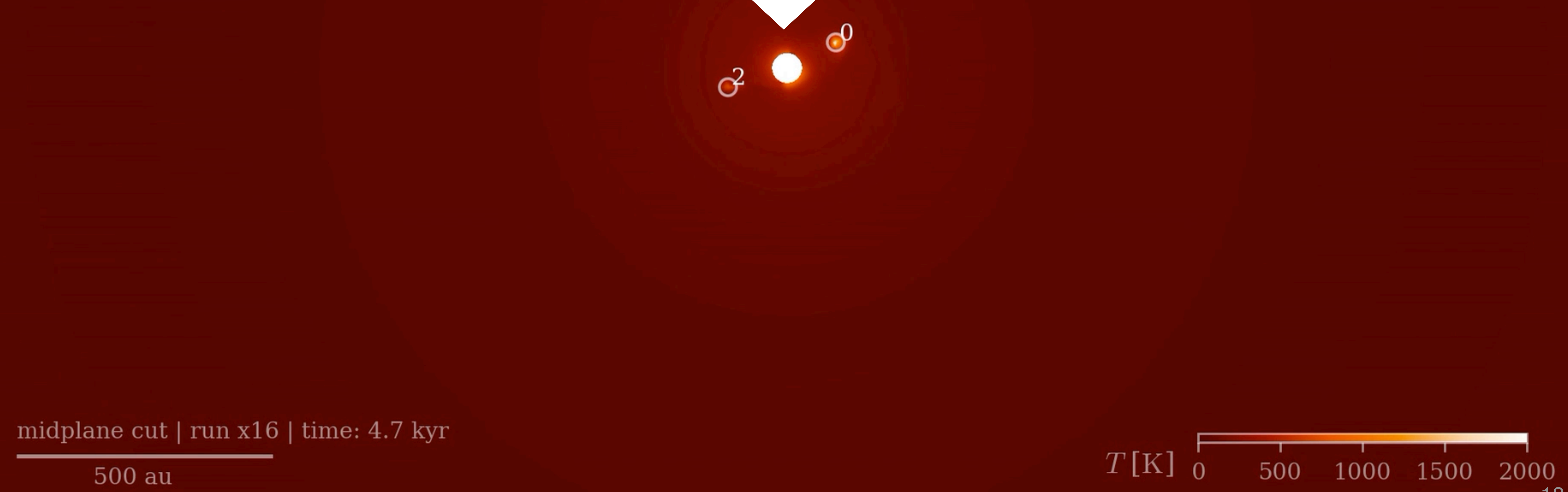



**Episodic accretion in high-mass stars**

- Seen as outburst in IR, mm, masers and multiple eject in outflows
- It could explain the excess of radio emission observed in about 30% of HII regions ?
- Can we identify objects that will undergo an outburst event ?
- Large surveys (e.g., ALMAGAL-like) can provide useful pre-burst data for the future

# Accretion bursts



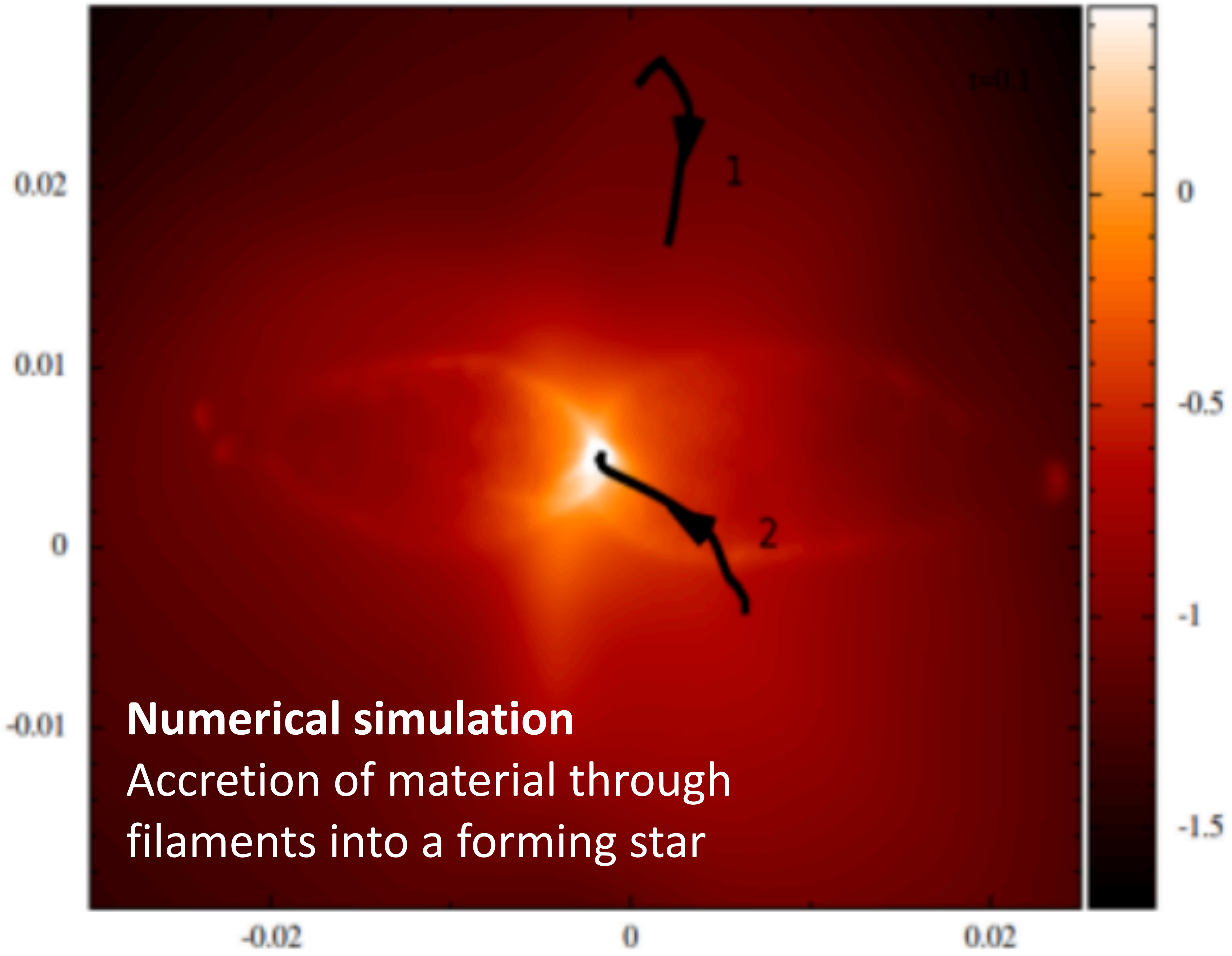



# Observations: "Time-domain" astronomy

**Chemistry of episodic accretion**

MHD + chemical simulations predict observable chemical changes in outbursts

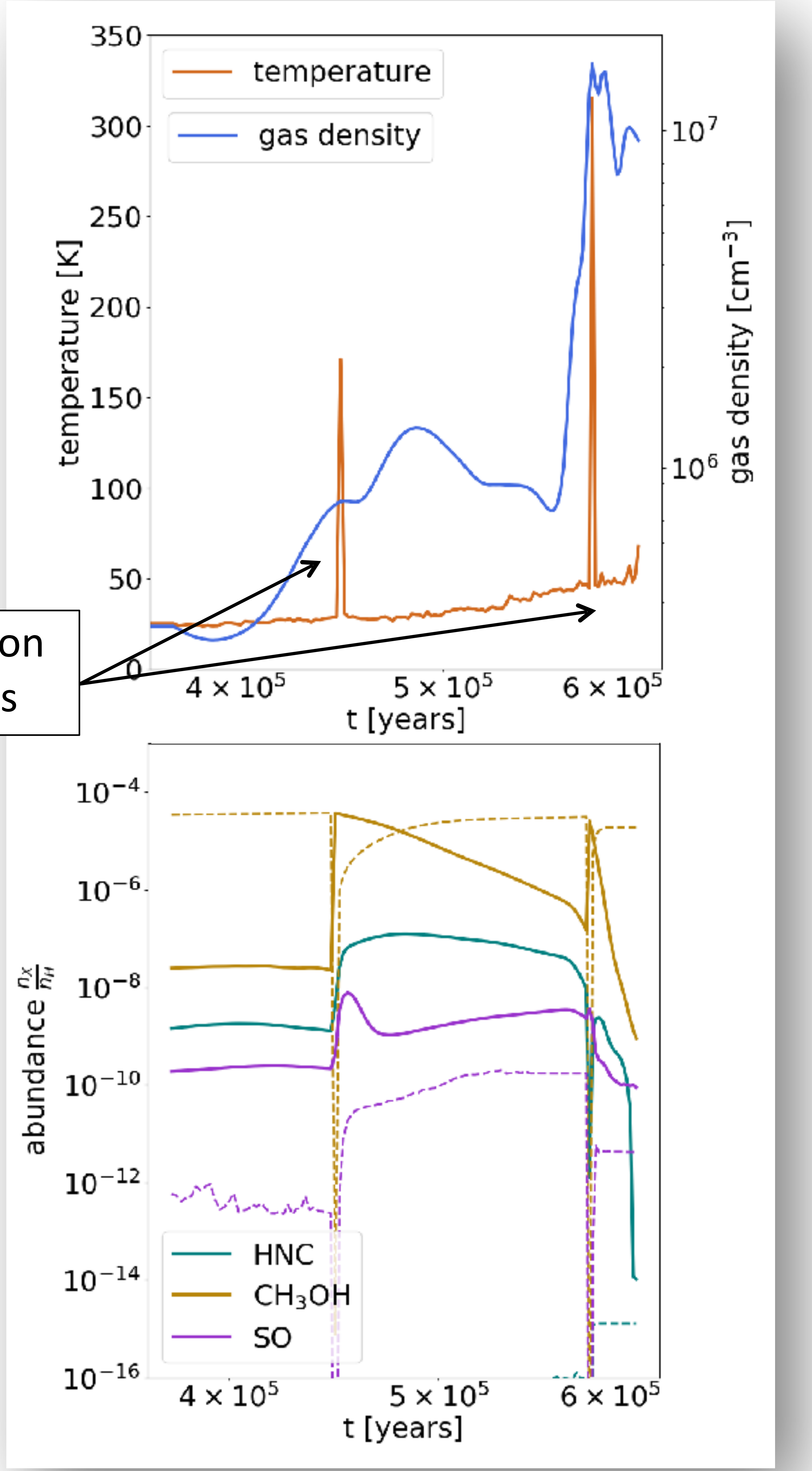
**Can we observe them ?**




**Numerical simulation**
Accretion of material through filaments into a forming star

Nassim Tanha (PhD Thesis)

Accretion events

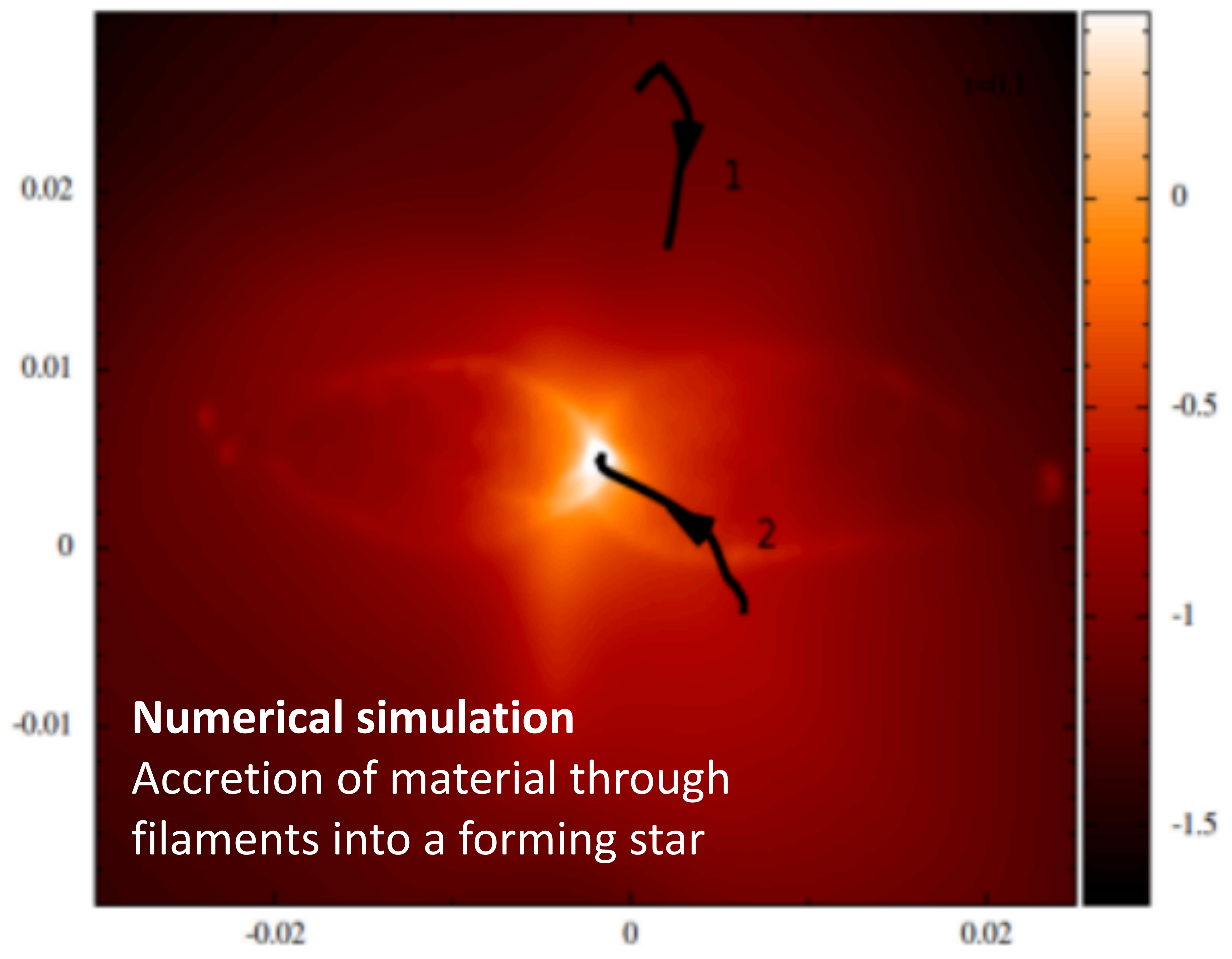


# Observations: "Time-domain" astronomy

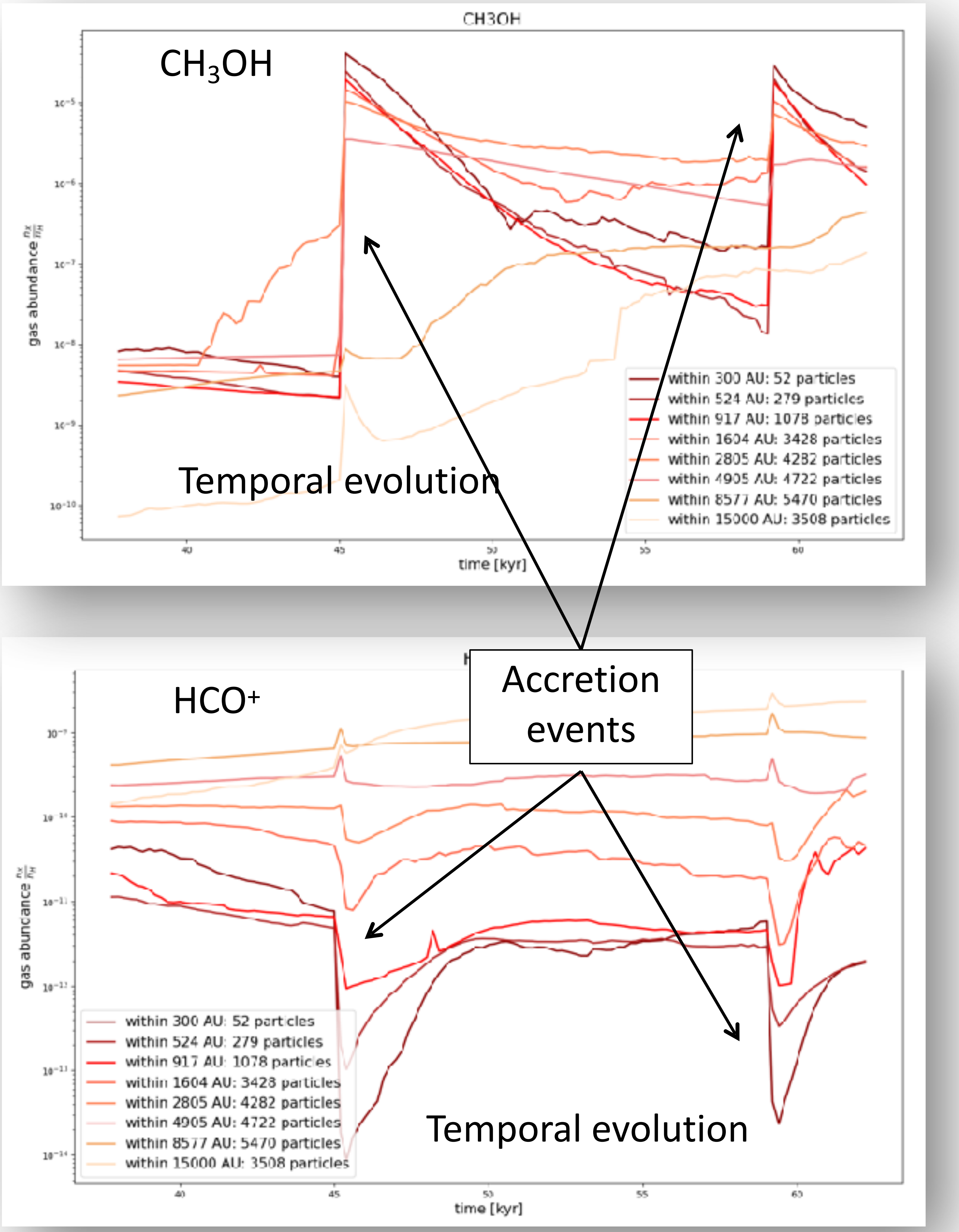
**Chemistry of episodic accretion**

MHD + chemical simulations predict observable chemical changes in outbursts

**Can we observe them ?**




Nassim Tanha (PhD Thesis)



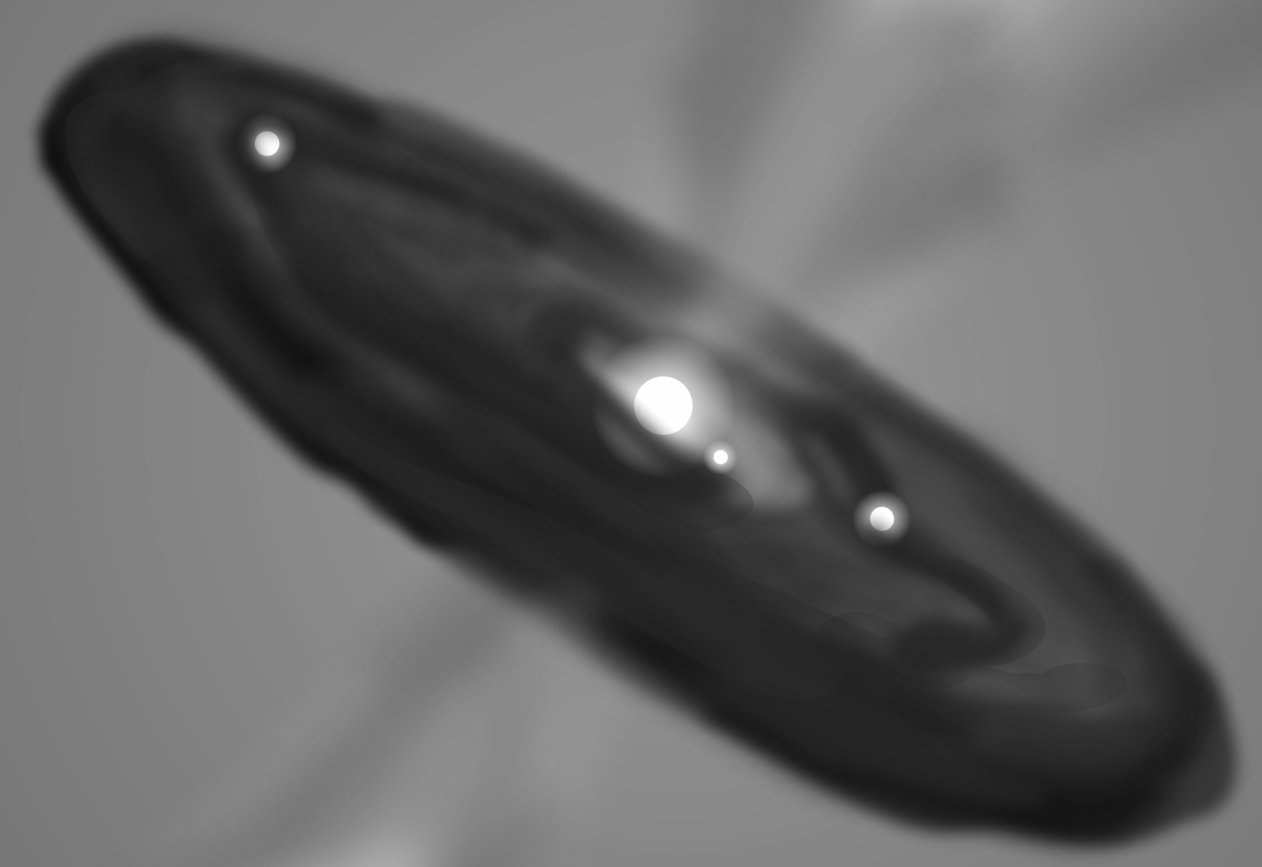
# Open questions

What is the light curve of an accretion burst?

How often do they happen?

What are the effects of the environment on accretion?

Gravitational interactions from neighboring stars?



# Observations: Missing pieces of the puzzle

## What are the best tracers ?

- 'normal' COMs may trace mainly envelope around the disk ?
- vibrational ?, salts ? , water ?

## Which sub-structures ?

- spiral arms ?
- rings ? ( are similar to low-mass ? )
- large cavities due to binary disk truncation ?

## Binarity / disk fragmentation

- disk velocity structure if binary / fragments ?
- smaller disks around fragments ?

## Accretion … observationally ?

- Envelope to disk to star
- Do stellar accretion rates scale with large-scale infall rates ?

## Episodic accretion in high-mass stars

- Outburst in IR, mm, masers and outflows
- Excess of radio emission in HII regions ?
- Objects that will undergo an outburst event ?

## Chemistry of accretion

MHD + chemical simulations predict observable chemical changes

## Large surveys will be possible!

Properties of disks as a function of stellar mass, luminosity, evolutionary stage, …
Large surveys (e.g., ALMAGAL-like) can provide useful pre-burst data for time variability

# Embracing Diversity

- People tend to look for THE solution for astrophysical problems

  > (in)famous example:
  >
  > monolithic collapse vs. competitive accretion

- Most people accept now that none of these captures reality entirely, but have we gone consistently from aiming to find *THE solution* to looking for the parameter space of solutions?

# Why not?

- **Theory**
  - Very expensive to do models
  - Prohibitively expensive to explore large parameter space
  - Easier to pretend one silver bullet solution can be found
- **Observations**
  - Low statistics of observations (this is slowly changing)
  - Looking for commonalities rather than differences

# Caveats

- **Confirmation bias**
  - Tendency to look for confirmation of anticipated properties
  - Both in planning observations and in interpreting results
    - If you fit a Keplerian rotation curve to a disk, you will get some kind of result, but you will never probe if the disk is not Keplerian
    - Effect gets amplified if using Maching Learning: ML can only find what it has been taught to find: challenge of designing and creating realistic and complete training sets
- **1-event statistics**
  - From a recent paper on high-mass disks reporting the detection of one disk:
  - *These results suggest that accretion disks around massive stars are more massive and hotter than their low-mass siblings, but they still are quite stable.*

# Questions/Path forward

- **Pushing the borders, both in observations and theory**
  - What is the range of parameters that can realize e.g. high-mass disks in Nature?
  - (angular momentum, turbulence, magnetic field strength, magnetic field orientation, initial mass, connection to a larger mass reservoir, metallicities…)
  - ...and what do the results look like?
  - (size, fragmentation, spiral arms, properties of resulting binary or multiple systems)

# Revealing the physics of high-mass disks in observations and simulations


Peter Schilke
Alvaro Sanchez-Monge | I. Physikalisches Institut, Universität zu Köln

André Oliva | Institut für Astronomie und Astrophysik, Eberhard Karls Universität Tübingen



Ringberg Meeting: *Puzzles of Star Formation* | MPIA | July 2021


Background illustration:
André Oliva

Reserve slides

# Resolution uncovers phenomena

x1 — disk scale height

x2 — spiral arms

x4 — fragments

x8 — disks around fragments

x16 — hydrostatic cores

# Further evolution of disk fragments into companions

# 2.5D Rad.-n.id.-MHD simulations

Oliva & Kuiper *in prep.*