Unveiling the traits of massive young stellar objects (MYSOs) through a multi-scale analysis

Abigail Frost

René Oudmaijer, Stuart Lumsden, Willem-Jan de Wit

Science & Technology Facilities Council

UNIVERSITY OF LEEDS

Overview

1. Motivation
2. Methodology
3. Results
4. Future Work

Motivation

- Massive young stellar objects are difficult to observe due to their embedded nature and rarity
- Previous studies have mostly:
  - Performed a detailed analysis of one source
  - Performed simpler analysis of a sample of objects
- Ideally want both - a combined analysis using high resolution observations for a number of objects

Methodology

Observations

Interferometry

- 7-13um
- MIDI (VLTI)
- Data from Boley et al. 2013
- 10mas scales

Imaging

- ~20um imaging
- VISIR & COMICS
- Data from de Wit et al. 2009 and P97 proposal (PI: Frost)
- 100mas scales

SEDs

Multi-wavelength

data from

the RMS Survey,

previous work and the literature

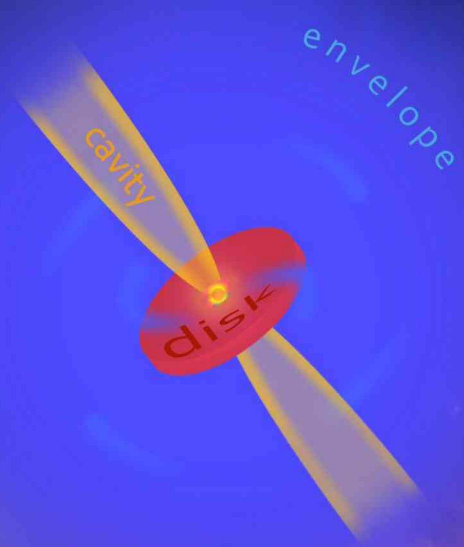
Multi-scale characteristics of the MYSOs

Advanced Research Computing

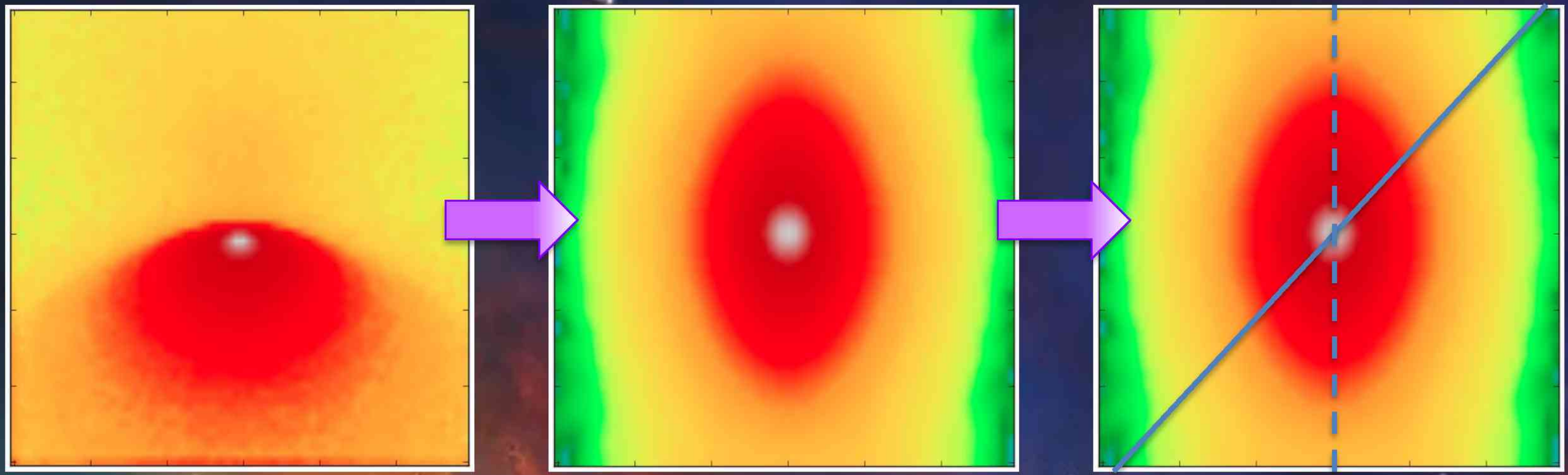
RT modelling

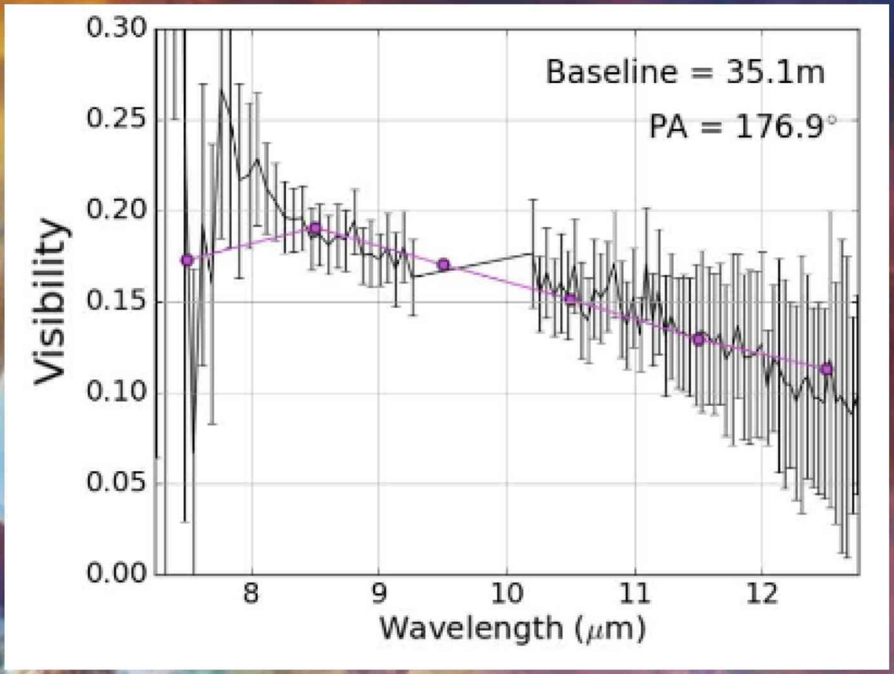
Modelling

- Monte Carlo style radiative transfer
- HO-CHUNK 3D (Whitney, 2013)
- 'Highmass embedded' base model used for this work:
    - Envelope:
        - Ulrich (rotating and infalling)
        - Power law
    - Outflow cavities:
        - Streamlined
        - Polynomial
        - Variety of density distributions
    - Disk:
        - Two components definable with different grain size distributions
        - Substructures possible

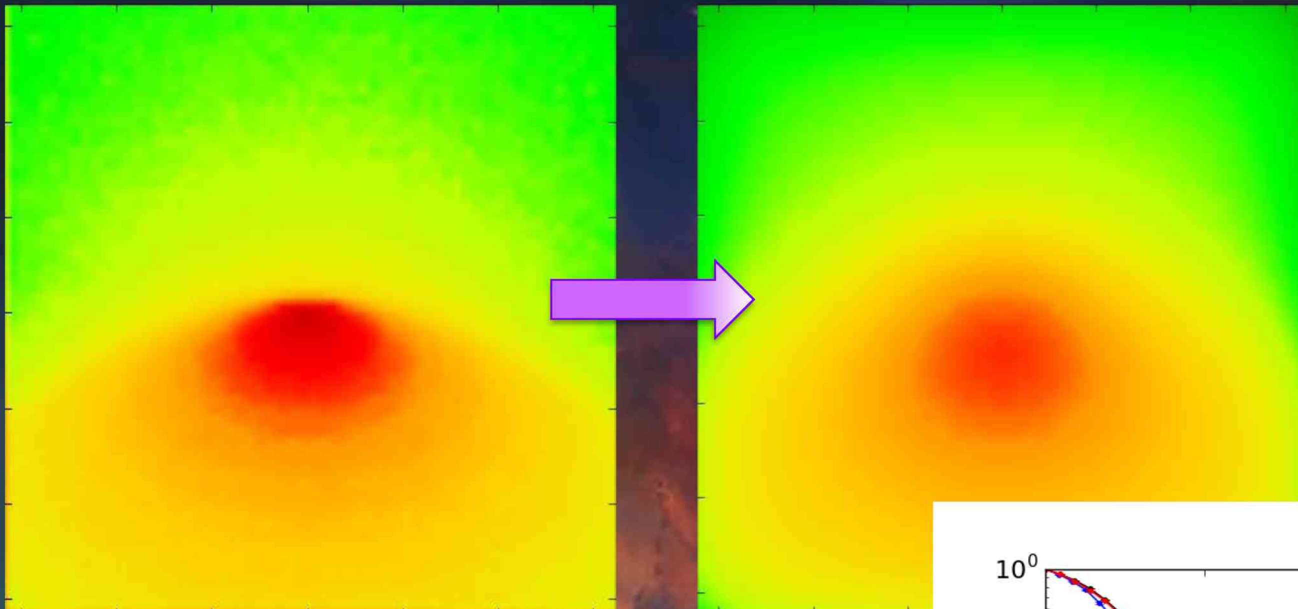


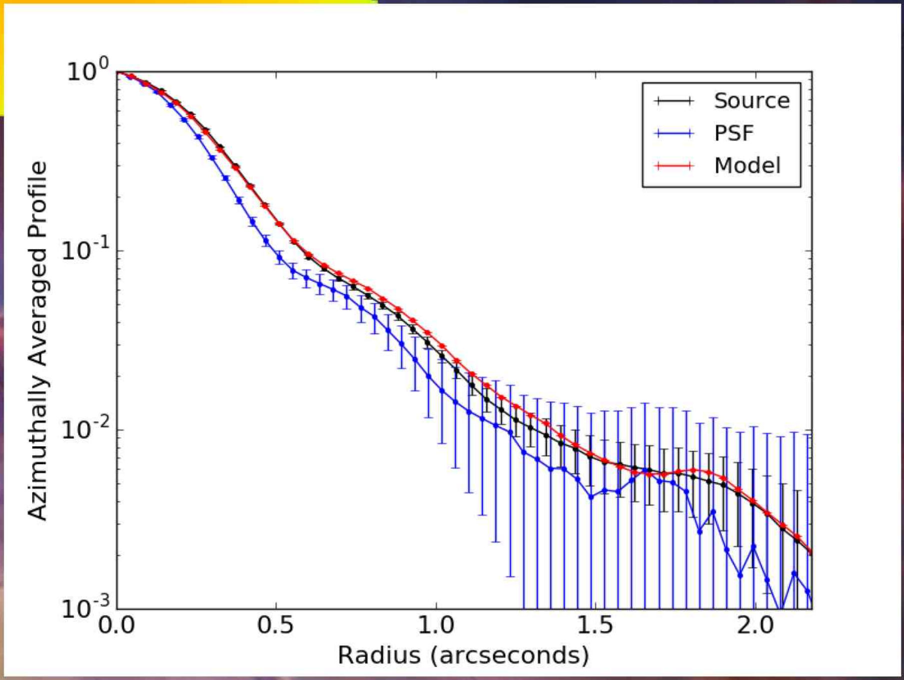
Simulating interferometric observations





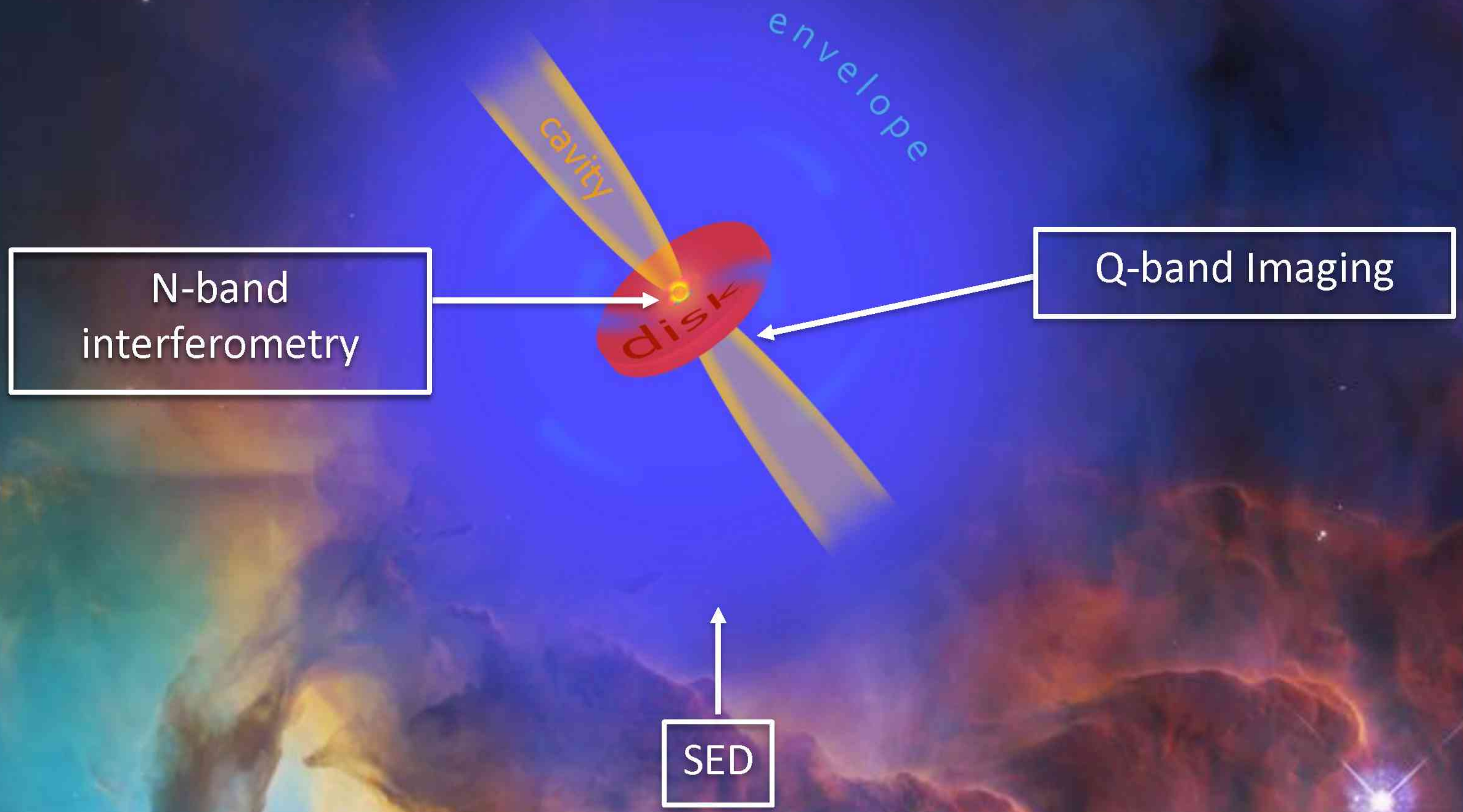
Simulating imaging observations





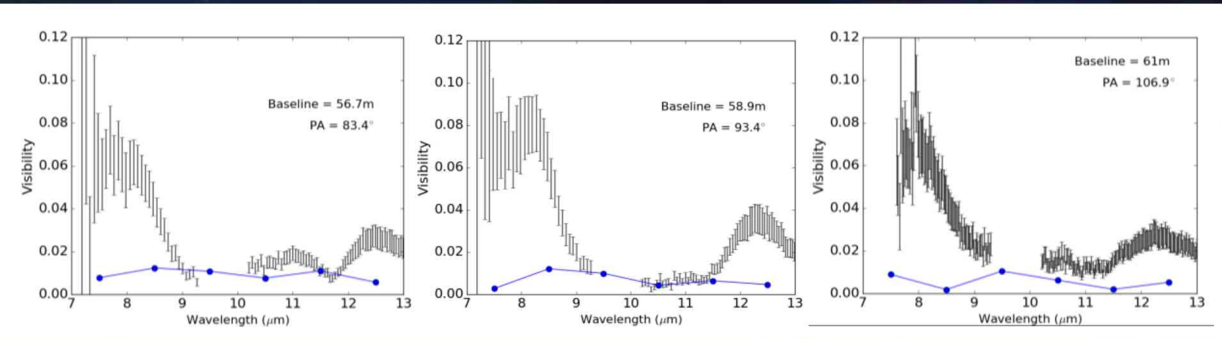
Results

What is each observable tracing?

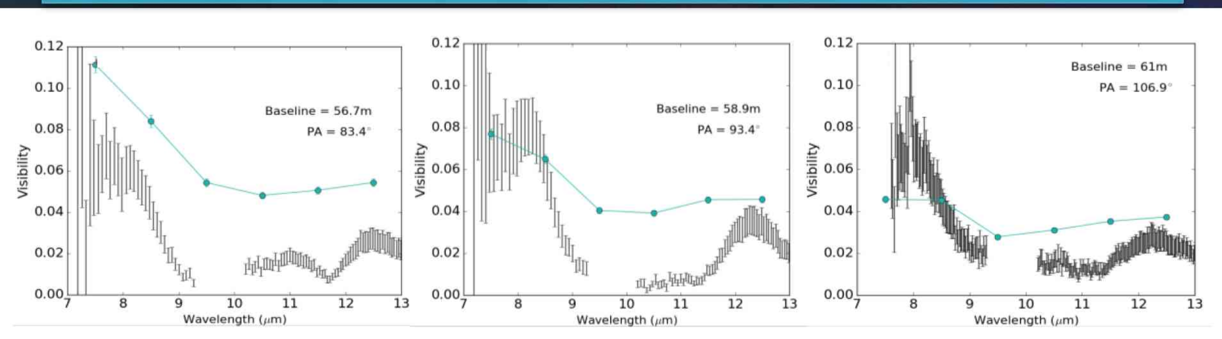


N.B. It is possible to fit just one of the higher resolution observations with the SED alone without the remaining observable being successfully fit - combination is key!

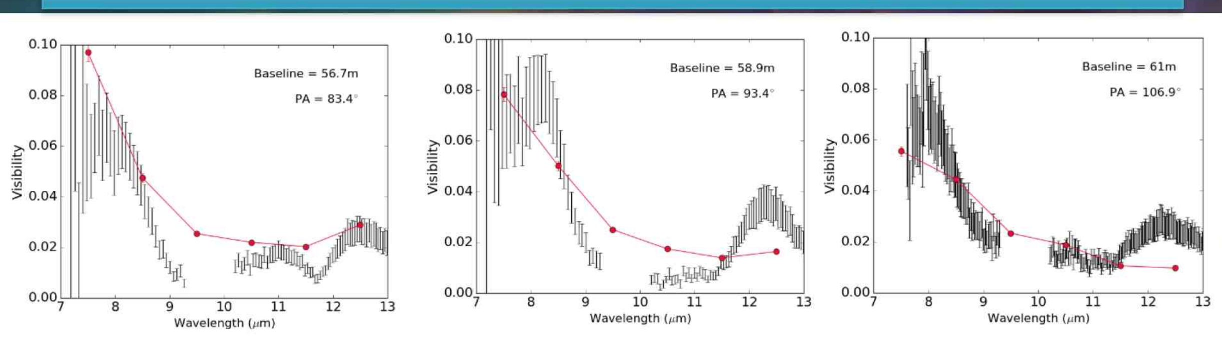
No disk (minimum dust radius sublimation radius)

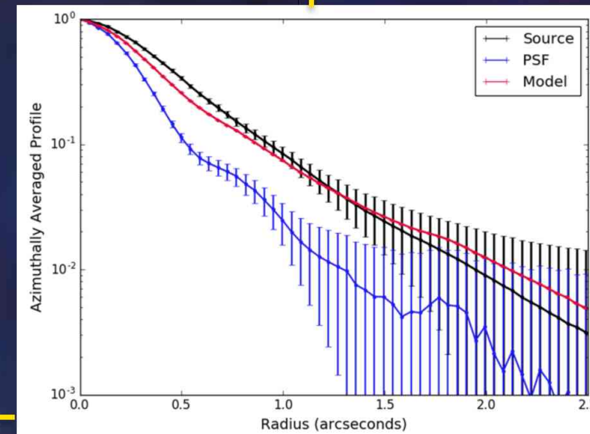


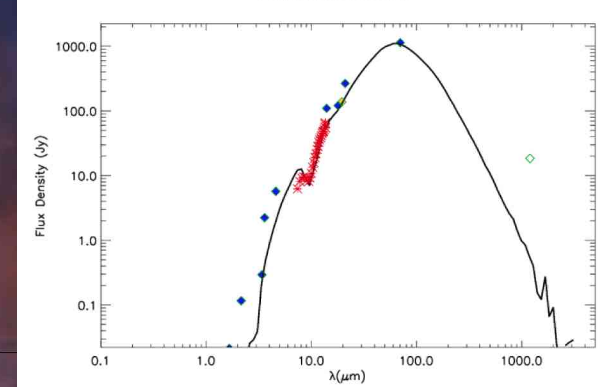
Disk (minimum dust radius sublimation radius)



Disk with inner clearing







VISIR and SED fits comparable for all - need the high-resolution data!

Sample

- Applied methodology to sample of ~10 sources (largest in the literature) and obtained detailed parameter space for all sources including:

Source	$M_\star$ ($M_\odot$)	$L_\star$ ($L_\odot$)	i (°)	d (kpc)	$R_{\rm env}^{\rm min}$ (au)	$R_{\rm env}^{\rm max}$ (au)	R_c (au)	$\dot{M}_{infall}$ ($M_\odot yr^{-1}$)	θ_{cav} (°)	n_{cav} (gcm^{-3})	Cav exp	M_{disk} ($M_\odot$)	$R_{\rm disk}^{\rm min}$ (au)	$R_{\rm disk}^{\rm max}$ (au)
W33A	25	49270	60	2.4	18 (R_{sub})	5×10^5	500	7.4×10^{-4}	20	1×10^{-19}	0	1	18 (R_{sub})	500
G305.20+0.21	25	48500	35	4	60	5×10^5	2000	7.5×10^{-4}	12	8×10^{-21}	0	1	60	2000
NGC 2264 IRS1	8	4200	15	0.74	4 (R_{sub})	5×10^5	500	9×10^{-4}	25	8×10^{-21}	0.25	0.1	4 (R_{sub})	500
S255 IRS3	20	21550	120	1.8	12 (R_{sub})	5×10^4	500	7.5×10^{-8}	30	6×10^{-19}	0	1	12 (R_{sub})	500
IRAS 17216-3801	38	172000	15	3.08	1	5×10^5	1000	1×10^{-3}	30	9×10^{-21}	1	1	100	1000
Mon R2 IRS2	15	5500	130	0.84	20	5×10^5	1000	9.5×10^{-4}	30	3×10^{-21}	0	0.1	20	1000
M8EIR	13.5	12100	25	1.325	30	5×10^5	2000	4×10^{-3}	25	8×10^{-21}	0.25	0.1	30	2000
AFGL 2136	20	141000	60	2.2	125	5×10^5	2000	1×10^{-3}	22.5	3×10^{-19}	0	20	125	2000

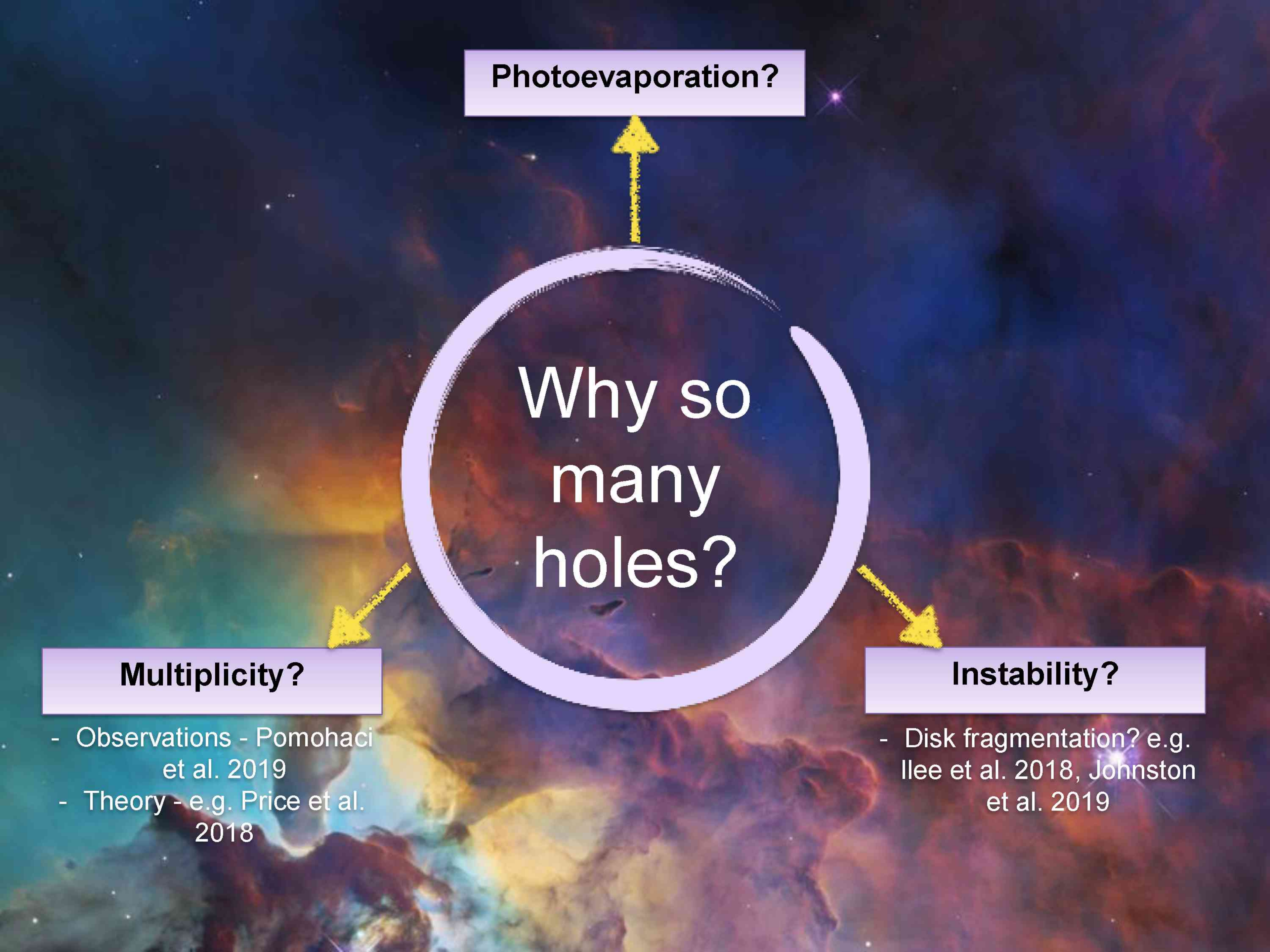
Trends

Same overall geometry

Ulrich-type envelope
- Typical infall rates 1e-3 Mdot/yr
- All similar size

Polynomial shaped outflow cavities
- Variety of densities and opening angles

Disk
- 25% flat, 75% flared
- Large amount of substructure detected
- Most inner holes
- One gap


Photoevaporation?
Why so many holes?
Multiplicity?
- Observations - Pomohaci et al. 2019
- Theory - e.g. Price et al. 2018
Instability?
- Disk fragmentation? e.g. Ilee et al. 2018, Johnston et al. 2019

Evolutionary classification of Cooper et al. 2013

	H_2	Br γ	Br 10	Fluor. Fe II
Type I	Strong	Absent	Absent	Absent
Type II	Present	Present	Weak or Absent	Absent
Type III	Weak or Absent	Strong	Present	Present

- NIR spectra available for nearly all sources allowing comparison with this classification
- A few notable comparisons:
  - Type III sources all had wide cavity opening angles
    - Using the models of Offner et al. 2010 this corresponds to ages of 105yrs
  - All disks with substructure were Type III objects
    - Supports the idea of photo evaporation being the cause of the inner holes as Type III sources are suspected to be driving UV winds which generates HI and fl-FeII

Follow-up work

- Integrating high-resolution sub-mm/mm data into the methodology
- Expansion to more sources
- Follow-up studies of suspected substructure
  - ALMA
    - Kinematics and stability checks
    - Investigation of disk structure at larger radii
  - MATISSE
    - Two successful proposals for follow-up to reconstruct images of detected disks (PI: Frost)
- Investigate multiplicity
  - GRAVITY/PIONIER e.g. Koumpia et al. 2019
  - Sparse aperture masking -> closure phases can reveal presence of binary

Summary

- Summary:
  - We fit one radiative transfer model to three kinds of observation simultaneously in order to determine the physical characteristics of a group of MYSOs
- All the model MYSOs studied have disks and most of those disks show substructure
  - Follow-up studies with MATISSE can unambiguously confirm these
- Classification of Cooper et al. 2013 combined with this work shows certain parameters are common to certain suspected ages

See Frost et al. (2019) (A&A) for more information and an example study