ALMA'S VIEW OF THE MID-PLANE IN HERBIG DISCS

UNIVERSITY OF LEEDS

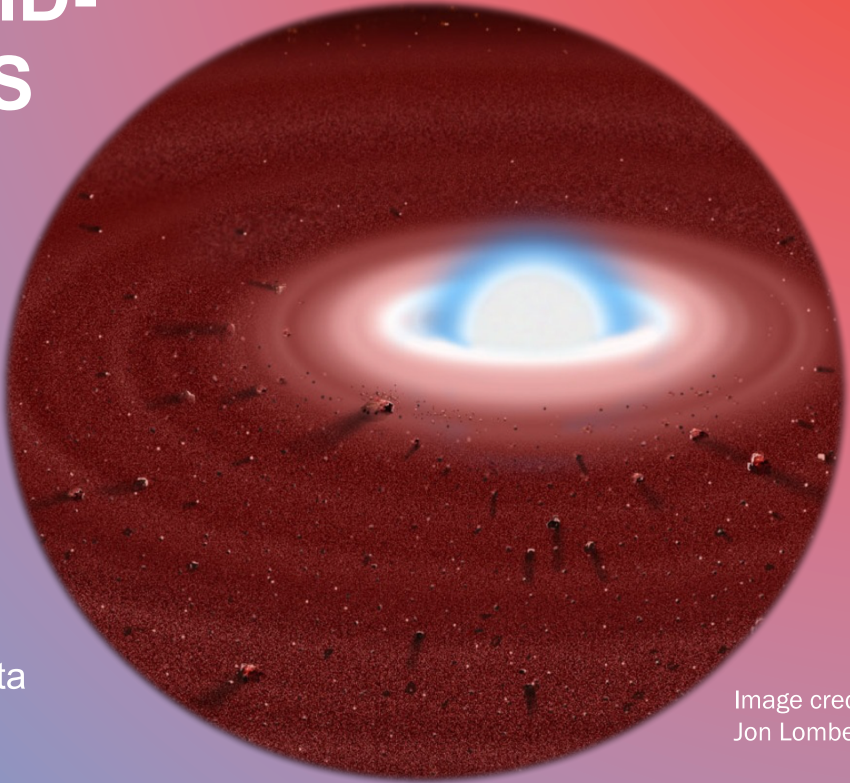


Image credit:
Jon Lomberg

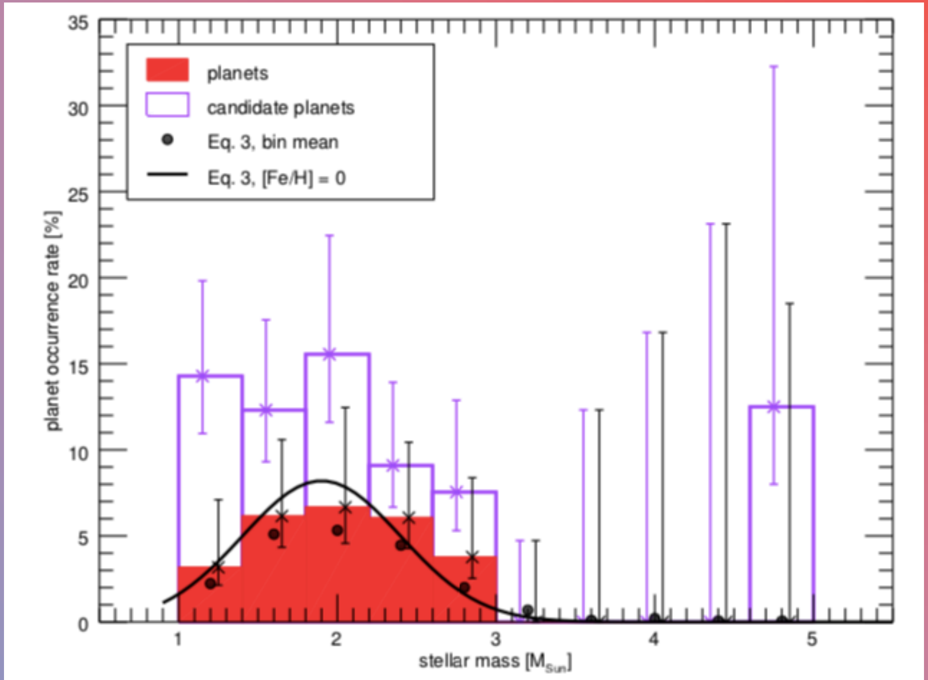
James Miley

Great Barriers in Planet Formation
Palm Cove, 26th July 2019

Olja Panić (Leeds), Mark Wyatt (Cambridge), Grant Kennedy (Warwick), Tom Haworth (Imperial), Ilaria Pascucci (Arizona), Cathie Clarke (Cambridge), Anita Richards (Manchester), Thorsten Ratzka (Graz)

Herbig Stars

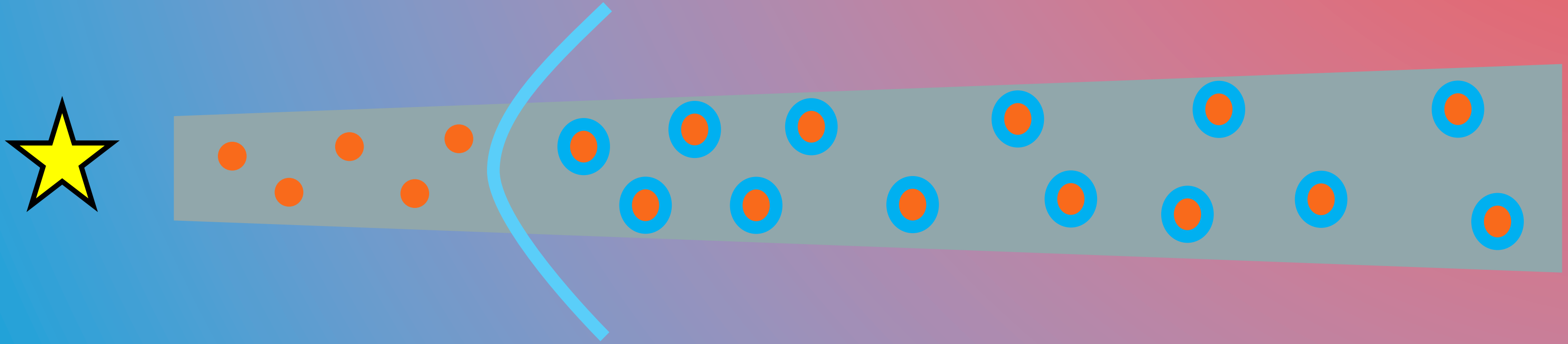
- Intermediate mass
- Spectral Type A/B
- Pre-Main Sequence
- Most likely to host giant planets?



Reffert et al. 2015

Herbig Discs

- Herbig stars host warmer discs than lower mass T Tauri counterparts

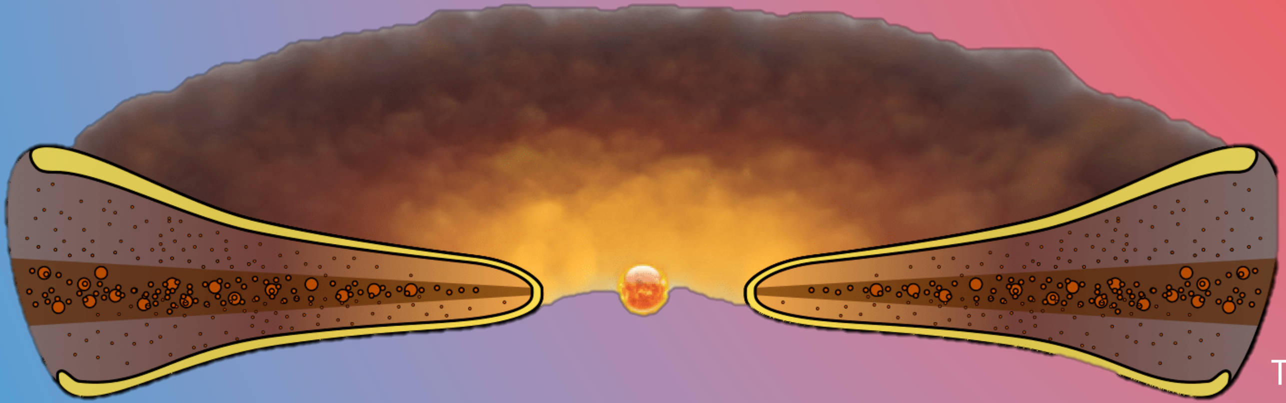


- In a warmer disc, key tracers in the disc remain in the gas phase

ALMA observations

- This work uses data from ALMA survey of Herbig discs (Panic et al. in prep)
- 1.3mm continuum - traces cool material i.e. midplane and outer disc
- $^{13}CO(2\text{-}1)$ and $C^{18}O(2\text{-}1)$ observations in band 6
- ~ 1 arcsecond (~100 au) resolution

Why isotopologues?



Testi at al. 2014

- Isotopologues trace gas towards the midplane
- Emission is more likely to be optically thin, meaning it traces density

Disc mass calculations

We calculate a firm ***lower limit*** to mass in Herbig discs:

- Dust mass

Optically thin emission
k_ν appropriate for mm grains

$$M_{dust} = \frac{F_\nu\, d^2}{k_\nu\, B_\nu(T)}$$

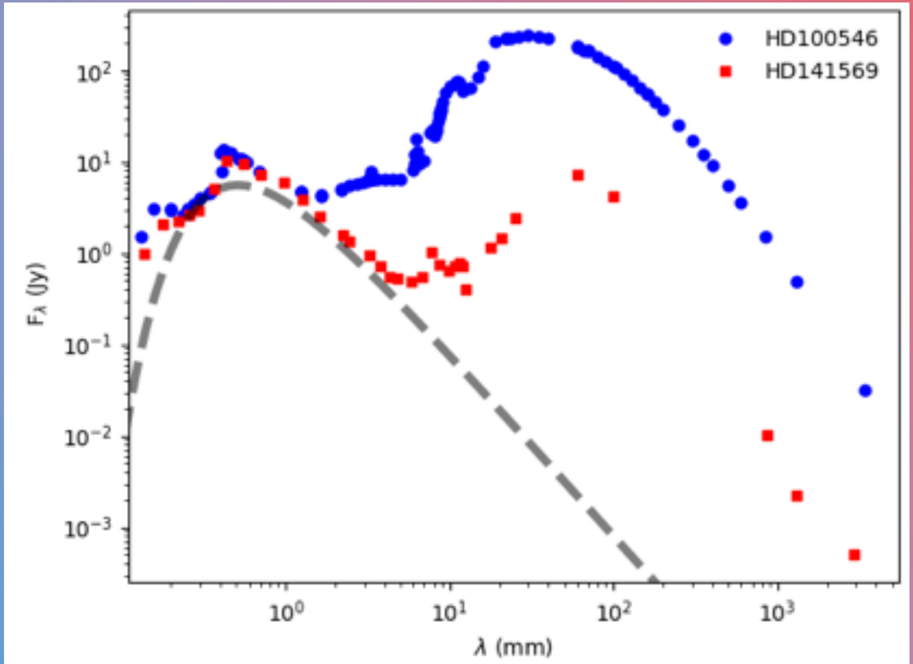
- Gas mass

Optically thin emission
LTE
ISM ratios

$$M_{gas} = \frac{4\pi}{h\nu_{21}} \frac{F_{21} m d^2}{A_{21} x_2}$$

A Tale of Two Discs

HD 100546	*HD 141569*
B9Ve	B9.5Ve
109 pc	111 pc
M≈ 2 M_{Sun}	≈ 2 M_{Sun}
7-10 Myr	5-9 Myr

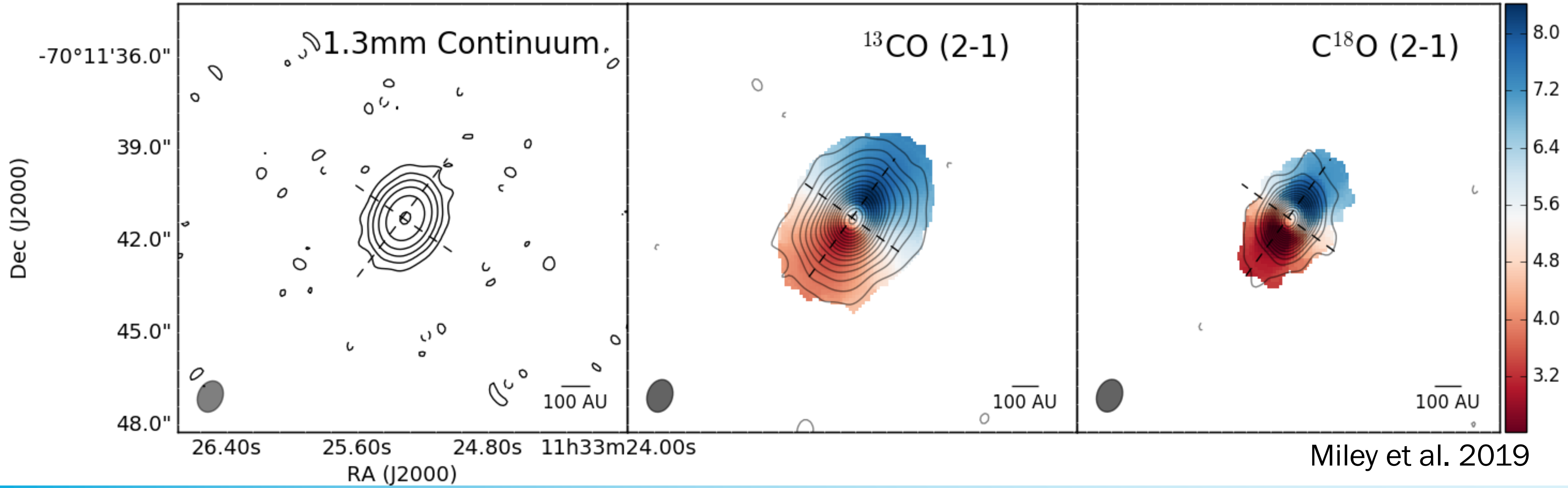


HD 100546

Actively forming protoplanet(s) ?

- Continuum source and distorted ^{12}CO kinematics (Perez+19)
- Direct imaging (Quanz+15, Currie+15)
- Near IR spectroscopy (Brittain+13,14)
- SED Modelling, mid-IR interferometry (Mulders+13, Panic+14)
- ALMA visibility modelling (Walsh+14)

HD 100546



Miley et al. 2019

$R_{outer} \approx 290$ au	$R_{outer} \approx 390$ au	$R_{outer} \approx 300$ au
$F_\nu = 492$ mJy	$F_\nu = 12.9$ Jy km/s	$F_\nu = 2.9$ Jy km/s
$M_{dust} = 1\ M_J$	X Optically thick	$M_{gas} = 18\ M_J$

HD 100546

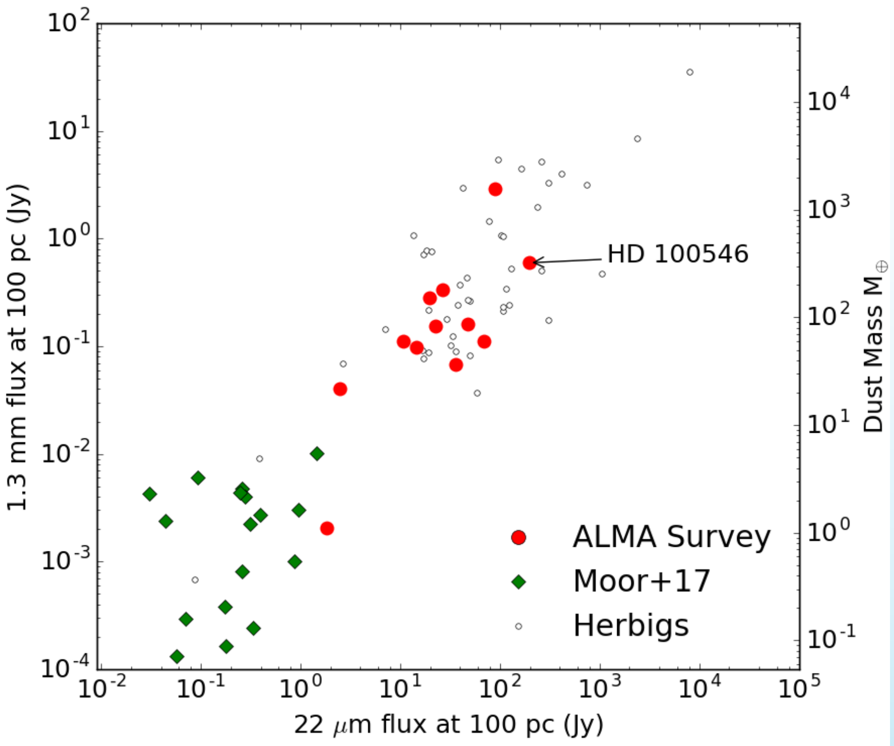
Dust disc:

Dust mass = 1 M_J

Heavier than most other Herbig dust discs

This is more massive than most discs around low-mass stars 10^{-3} – 10^{-1} M_J (Manara+ 2018)

Panić et al, in prep.



HD 100546

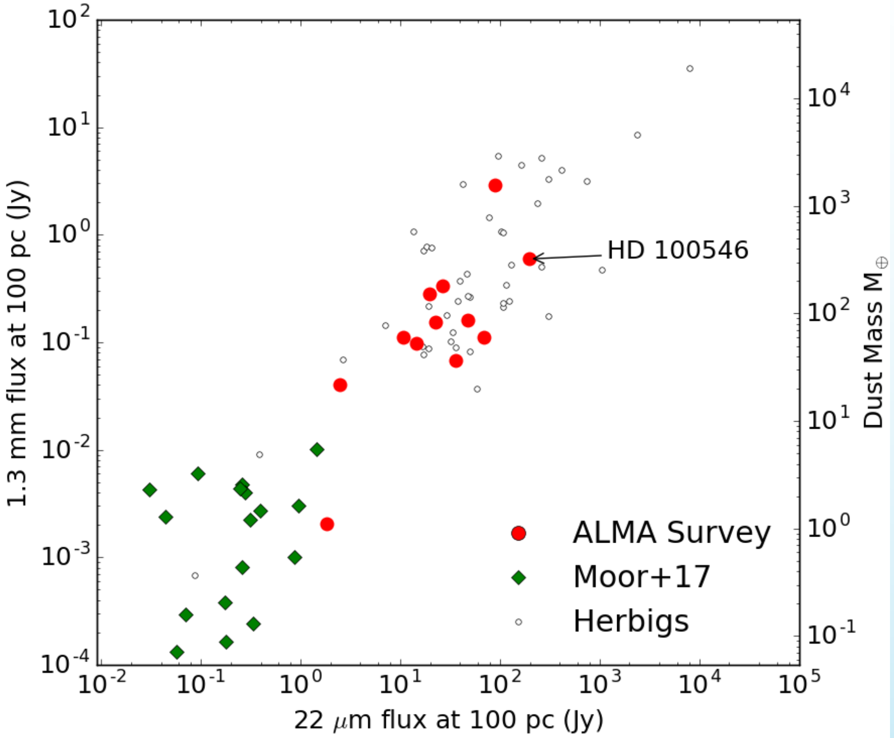
Gas disc:

^{13}CO in the disc is optically thick
Gas mass from $C^{18}O$ = 18 M_J

Heavier than most other Herbig discs: typically 1 – 10 M_J (Panic et al. in prep)

ALMA survey of Lupus, discs have a gas disc mass of < 1M_J (Miotello et al. 2017)

Panić et al, in prep.

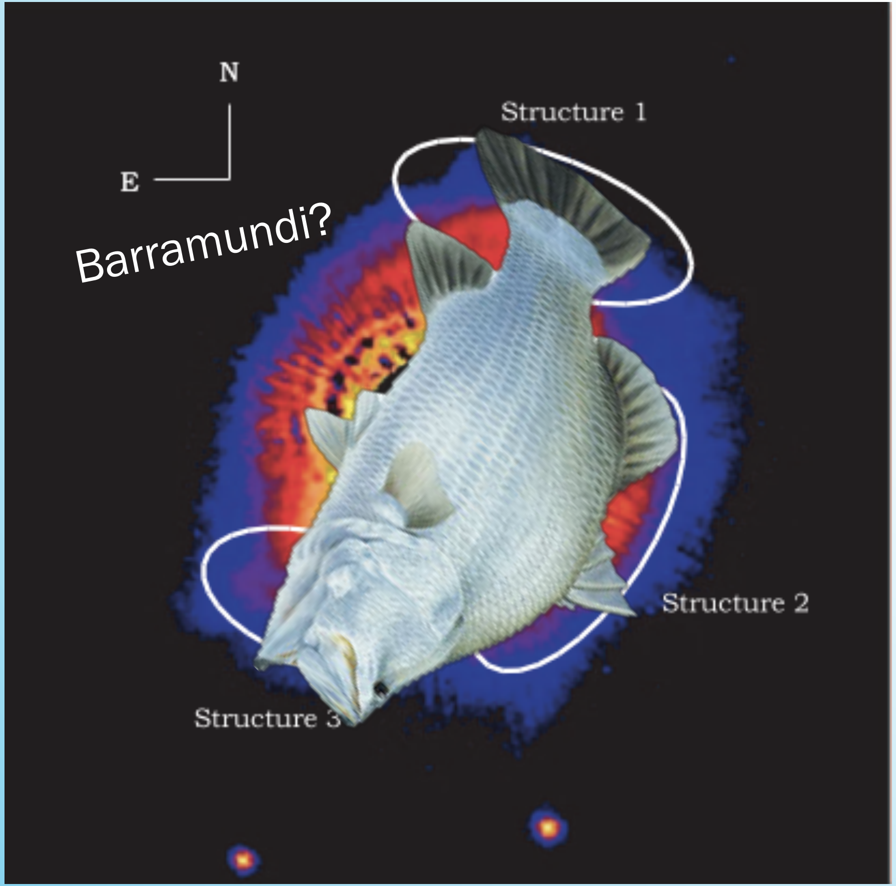


HD 100546

Gas distribution mirroring scattered light structures?

Extended, low-level $C^{18}O$ emission is spatially coincident with features previously identified in scattered light

Midplane density analogue to the spirals on the surface?



HST image: Ardila et al. 2007
Miley et al. 2019

A Tale of Two Discs

HD 100546		*HD 141569*
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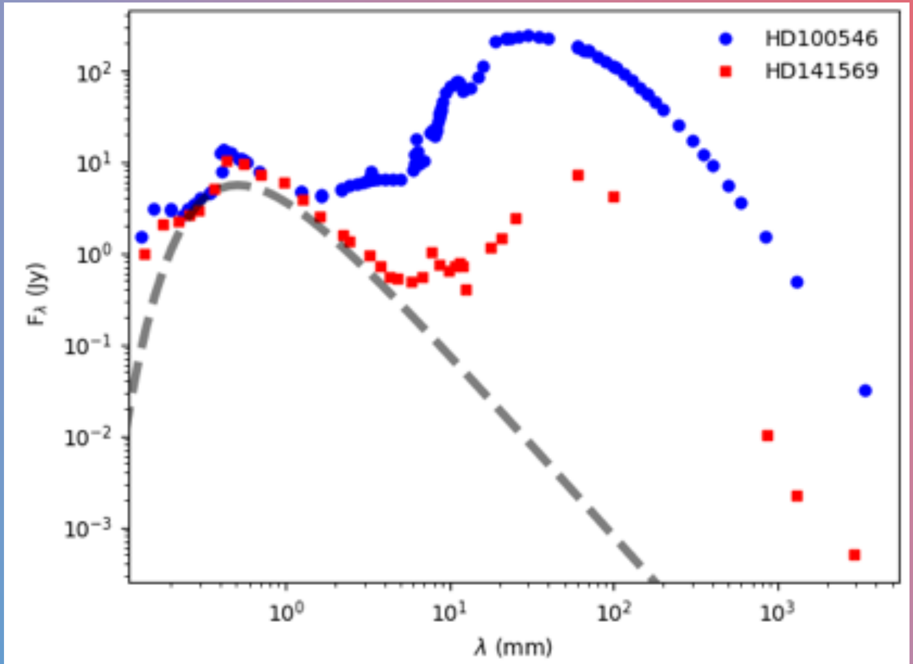
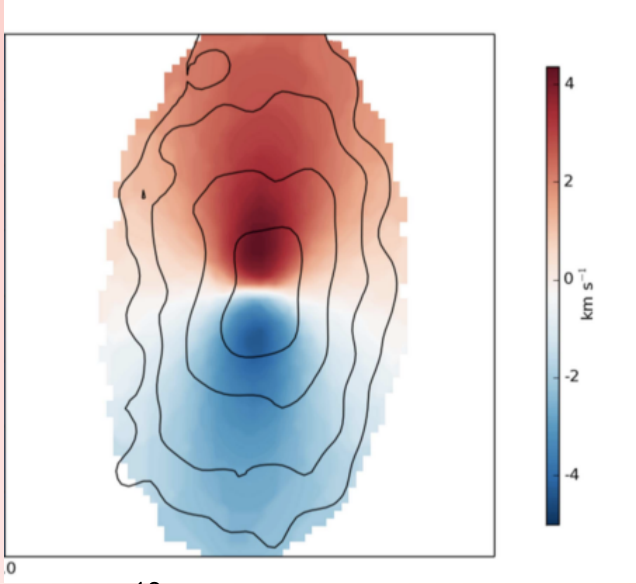
109 pc		111 pc
M≈ 2 M_{Sun}		≈ 2 M_{Sun}
7-10 Myr		5-9 Myr



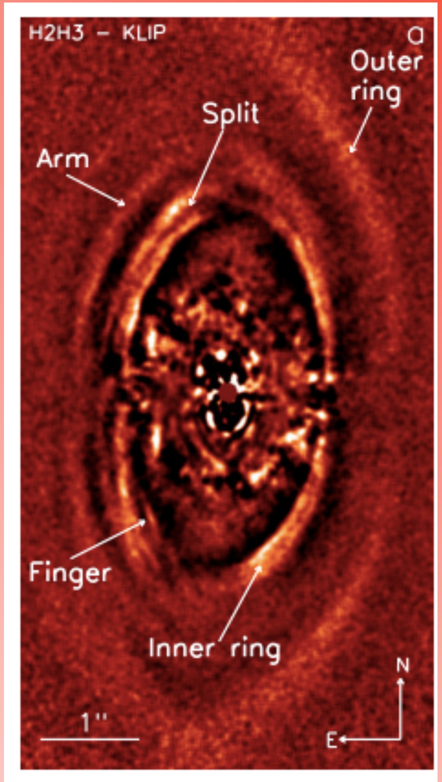
HD 141569

Dust levels of debris disc, but has a significant amount of gas remaining

Is this the youngest `*Hybrid' disc*? (Pericaud et al. 2017)

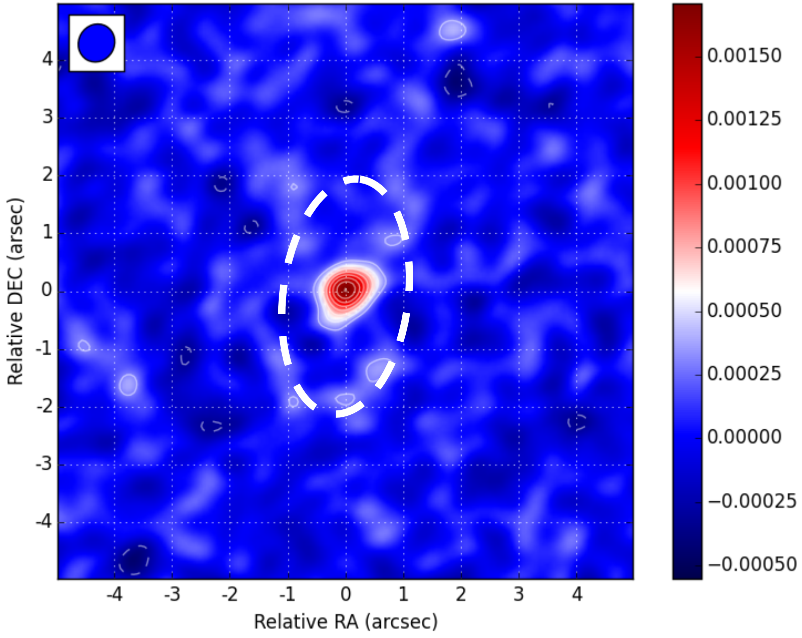


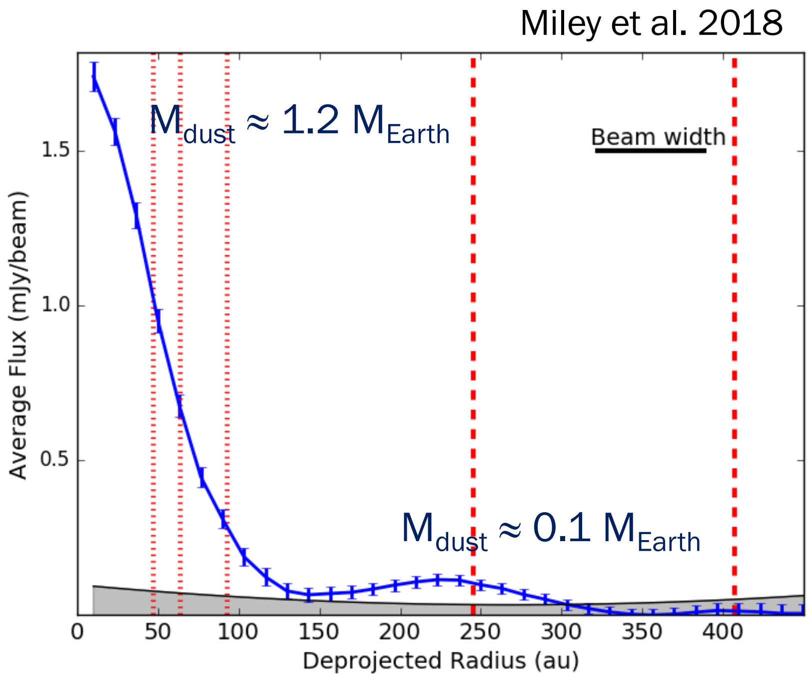
Archival ^{12}CO ALMA - White et al. 2016



VLT/SPHERE
Perrot et al. 2016

HD 141569



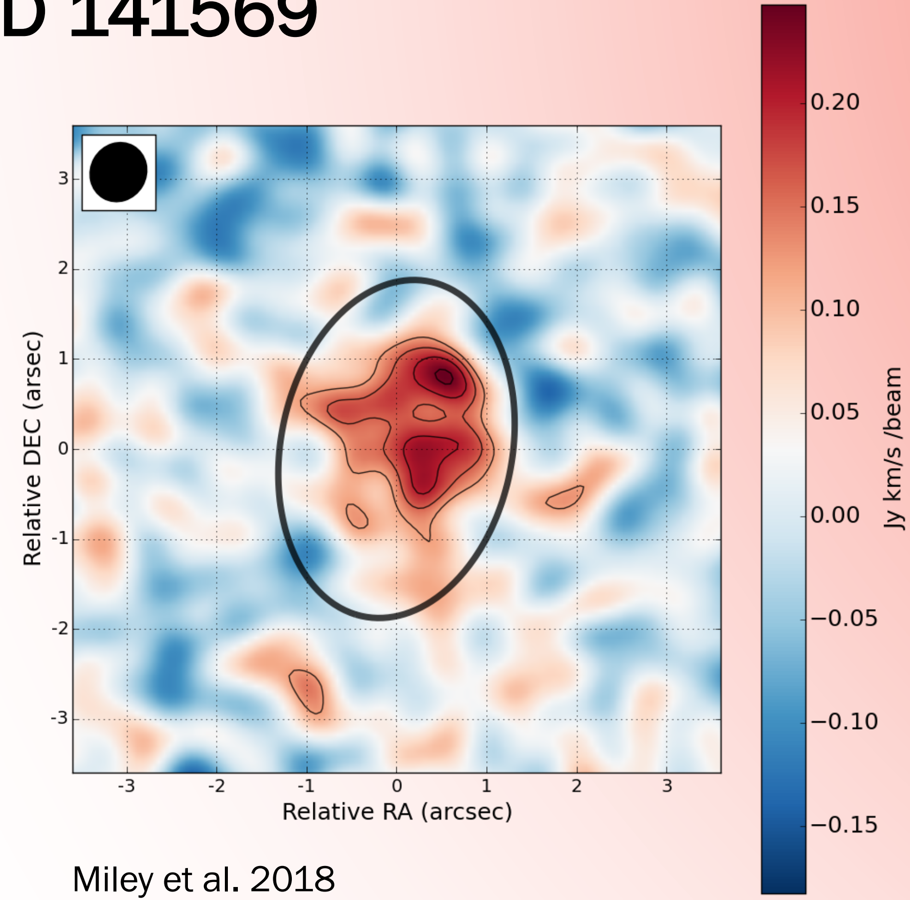


$M_{dust} \approx 1.2\ M_{Earth}$

$(\approx 3.6 \times 10^{-6}\ M_{sun})$

First detection of a mm ring in this disc!

HD 141569



Miley et al. 2018

^{13}CO shows asymmetric distribution

Mass estimate: 0.65M_J

2 orders of magnitude larger than that calculated using ^{12}CO as a mass tracer

All ^{13}CO contained within the scattered light ring at 220au.

HD 141569

Dust mass similar to (gaseous) ***debris*** discs

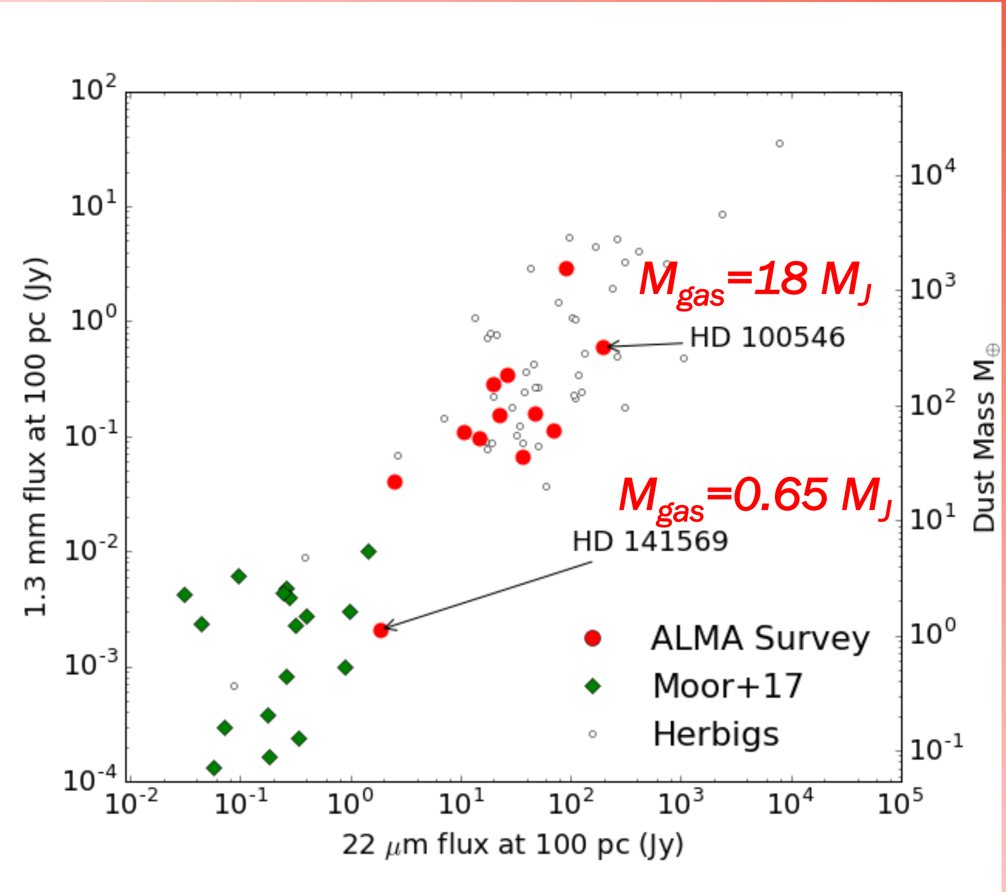
Gas mass similar to (low-mass) ***protoplanetary*** discs $\lesssim 1\ M_J$

The youngest hybrid disc ?

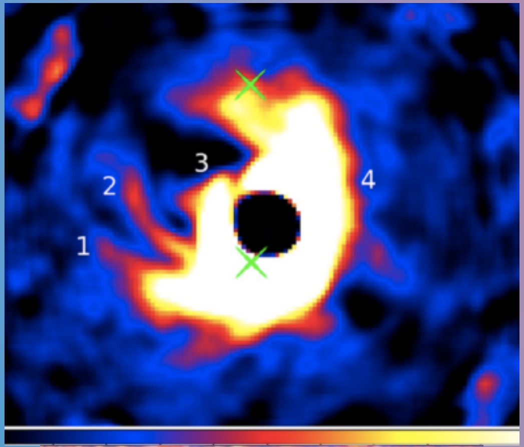
- ➢ Require more optically thin gas line detections to determine the origin of the gas:

  Primordial of secondary ?

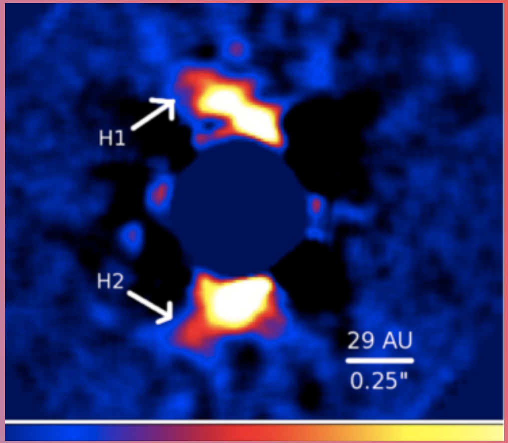
  e.g. β Pic, Matrà+17



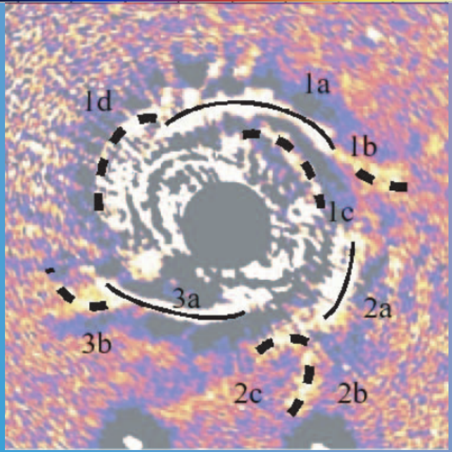
Currie+15
Keck/NIRC2



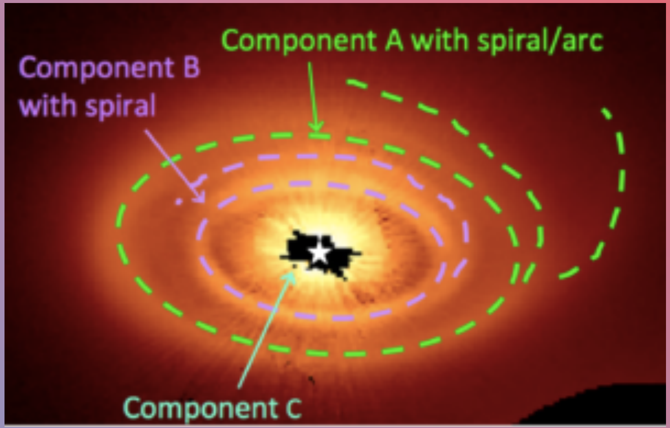
Currie+16
Keck/NIRC2



Ardila+07
HST/ACS



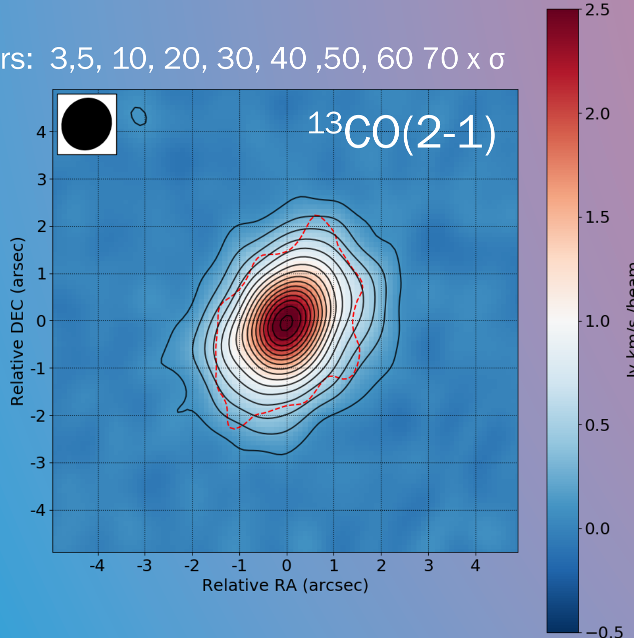
Konishi+16
HST/STIS



- Isotopologues provide a window into the midplane

HD 100546 – a ~~protoplanetary~~ disc ? 'planet-hosting'

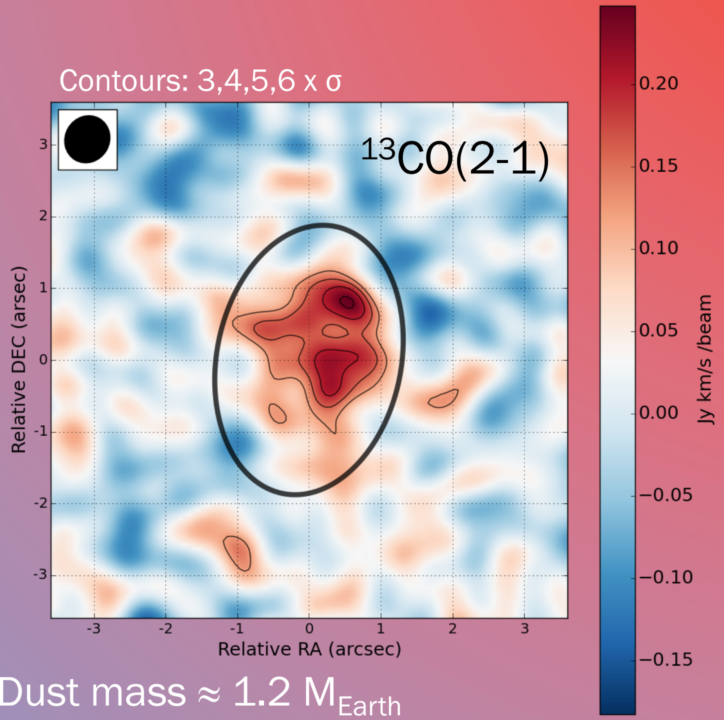
Contours: 3,5, 10, 20, 30, 40 ,50, 60 70 x σ



- Dust mass ≈ 1 M_J
- Gas mass ≈ 18 M_J
- Optically thick, centrally peaked ^{13}CO

HD 141569– a 'hybrid' disc ?

Contours: 3,4,5,6 x σ



- Dust mass ≈ 1.2 M_{Earth}
- Gas mass ≈ 0.65 M_J
- ^{13}CO emission is highly asymmetric and opt. thin

Top take-aways:

- Optically thin continuum and isotopologue observations are powerful tools for characterising the distribution of gas and dust in a disc, particularly warm Herbig discs
- HD100546 has a gas mass of >18M_J – lots of planet building material
- HD141569 shows highly asymmetric ^{13}CO – the youngest hybrid disc ?