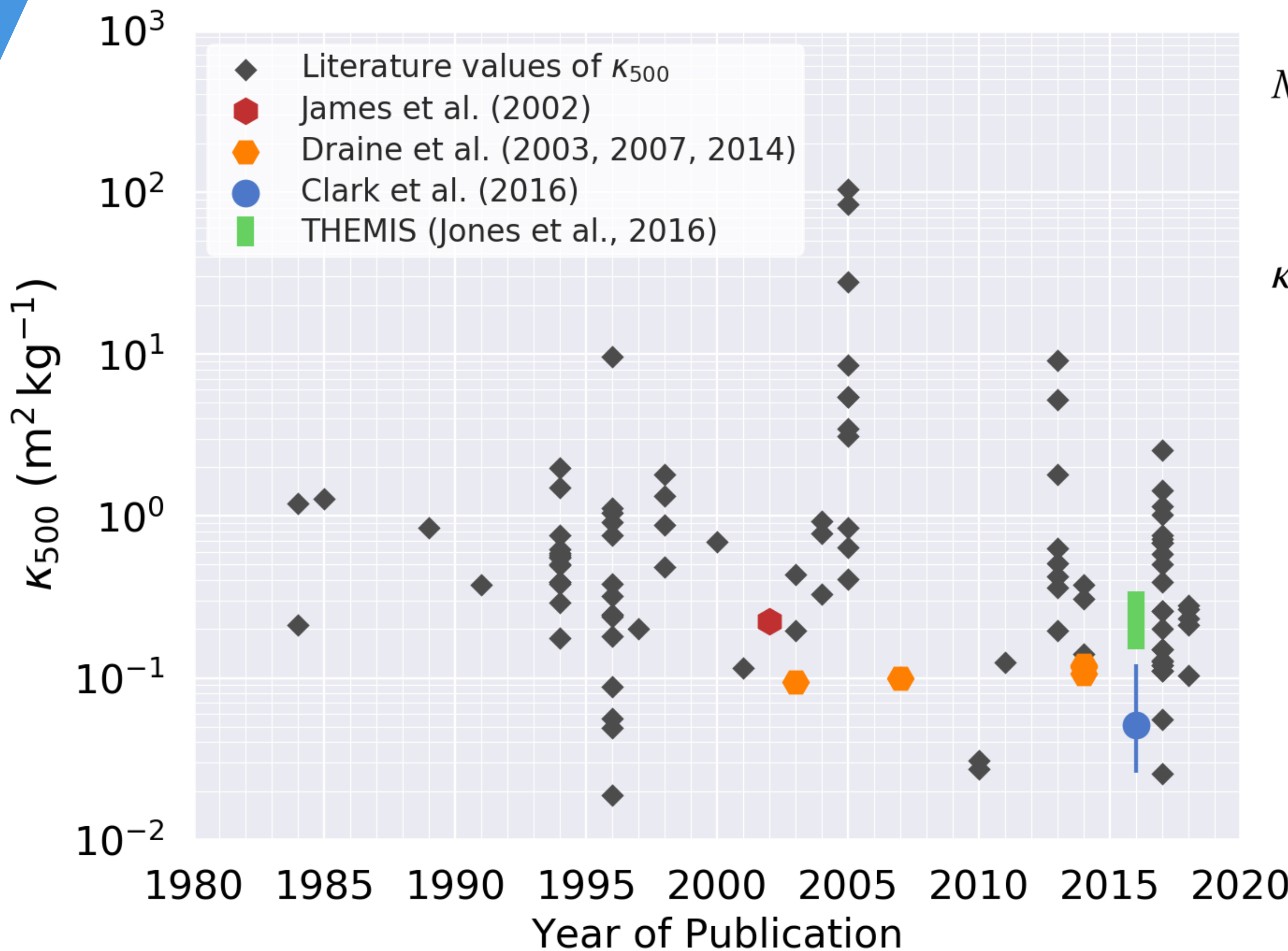
Mapping κ_d in Nearby Galaxies

Chris Clark

Pieter De Vis
Simone Bianchi
& the DustPedia team

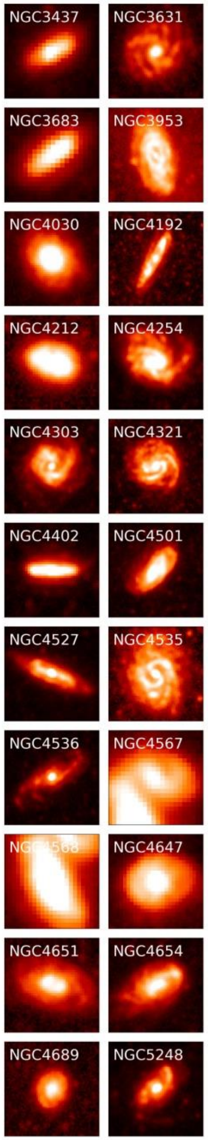
Literature Values for κ_d

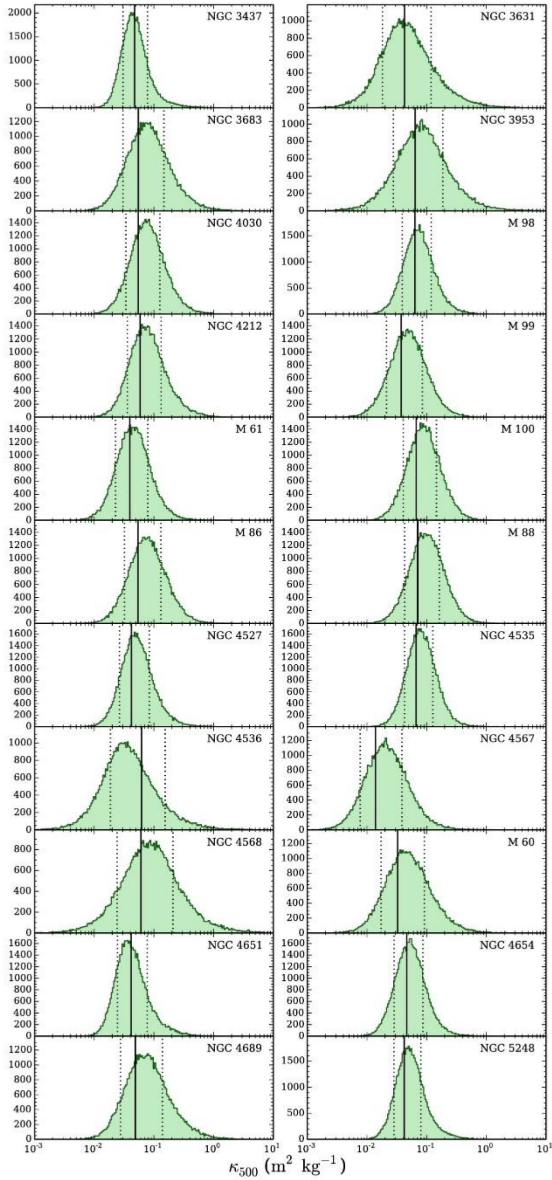


$$M_d = \frac{S_\nu D^2}{\kappa_\nu B_\nu(T)}$$

$$\kappa_\lambda = \kappa_0 \left(\frac{\lambda_0}{\lambda}\right)^\beta$$

Estimating κ_d with the HRS

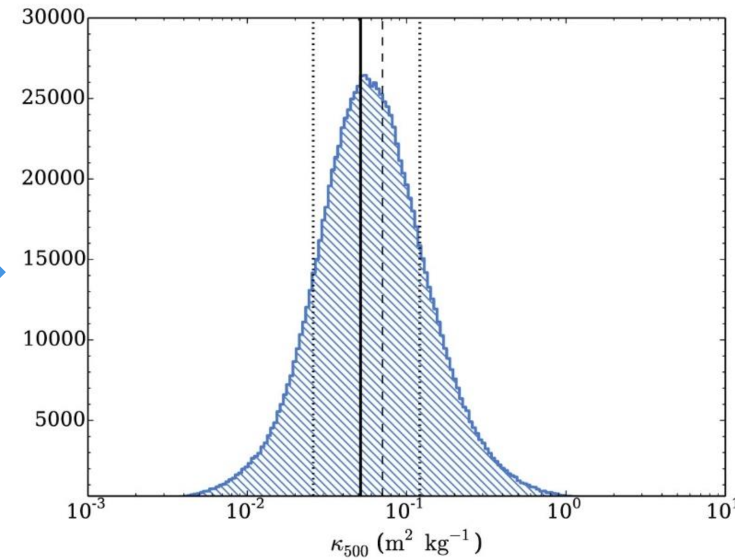




$$\kappa_\lambda = \frac{D^2}{\xi\,(M_{HI} + M_{H_2})\,\varepsilon_d\, f_Z} \sum_i^n \left(\frac{S_{\lambda_i}}{B_\lambda(T_i)} \right)_i$$

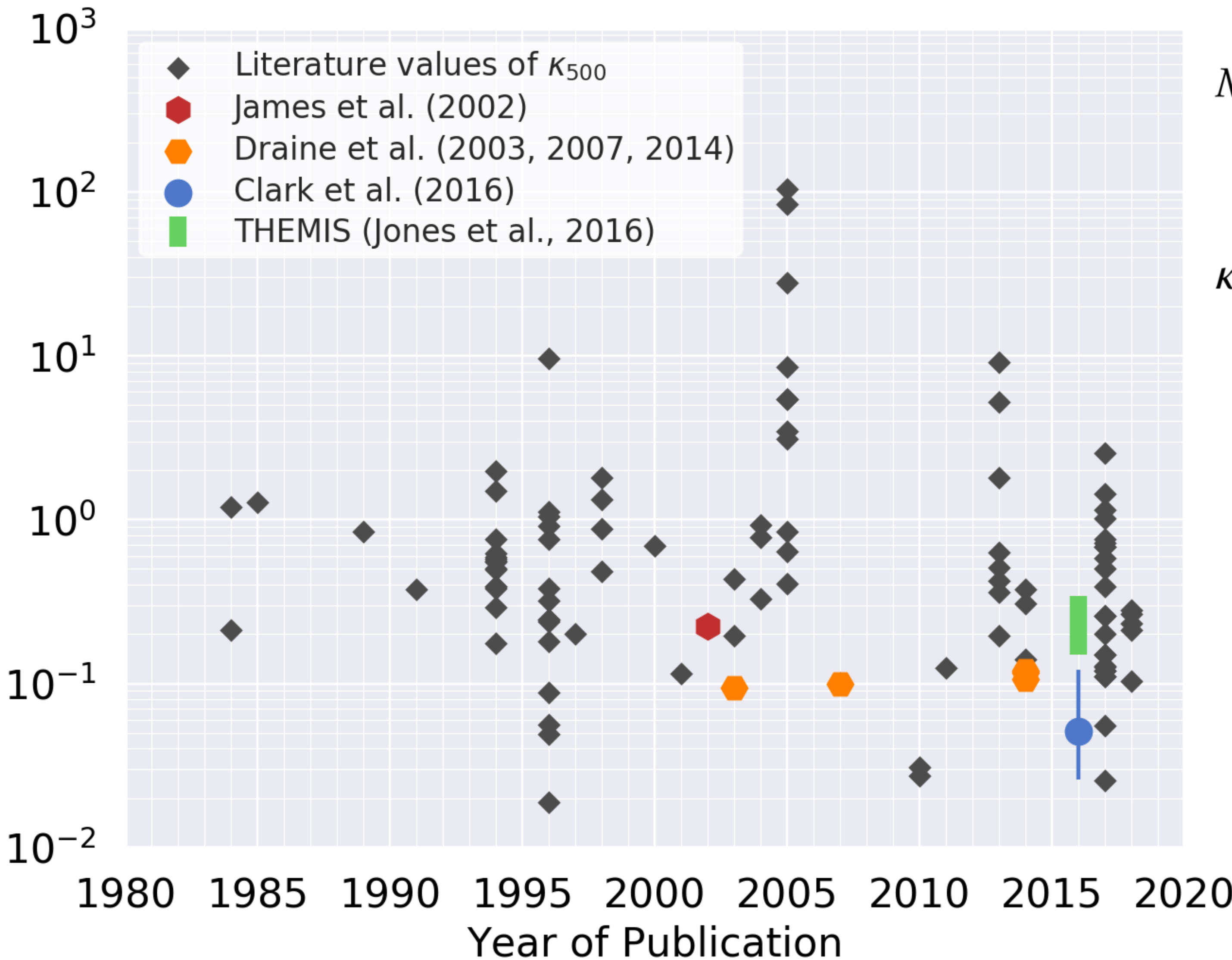
κ_{500} = 0.051 m^2 kg^{-1}

(± 0.24 dex)



James+ (2002); Ciesla+ (2012); Clark+ (2016)

Literature Values for κ_d

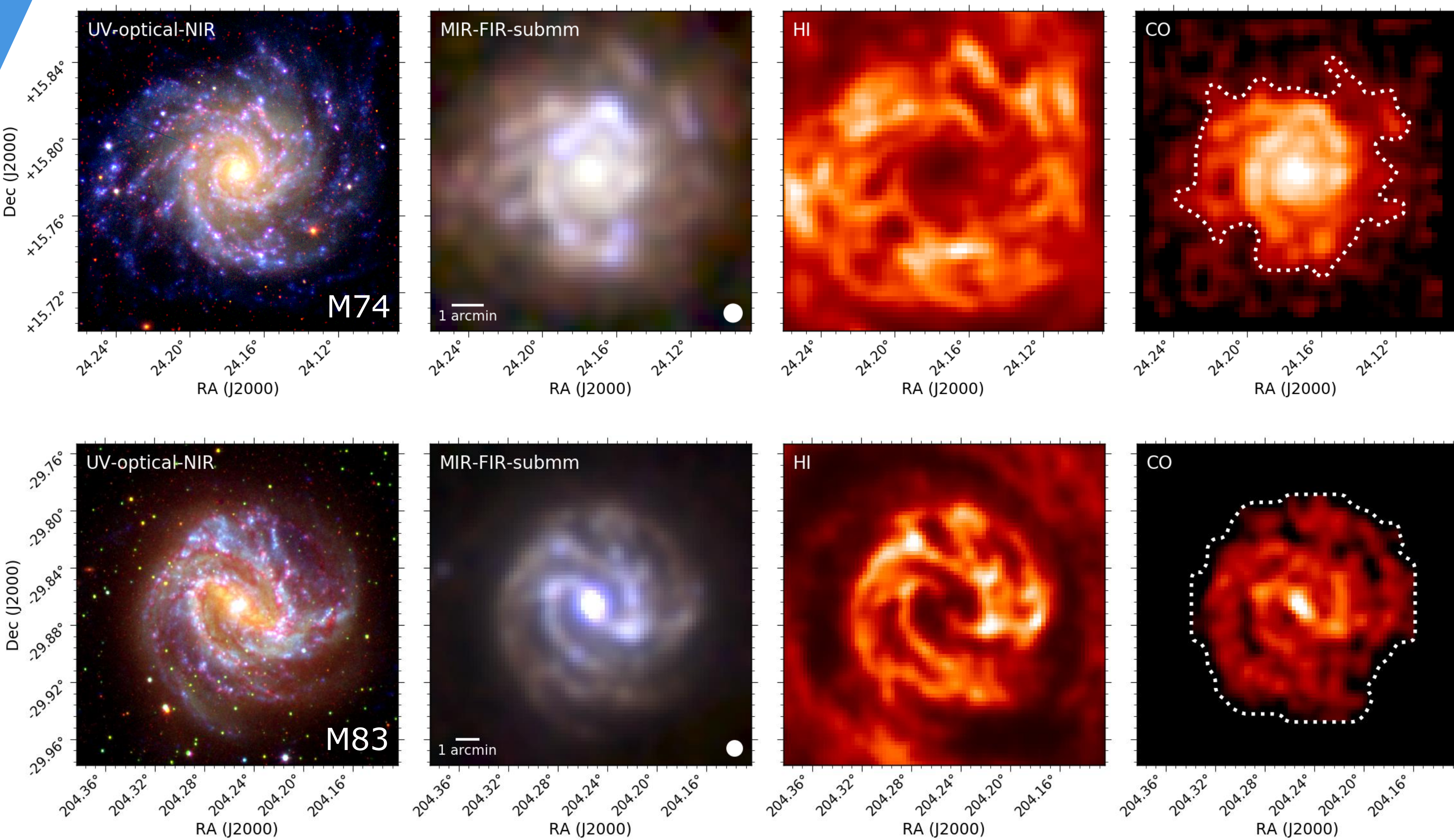


$$M_d = \frac{S_\nu D^2}{\kappa_\nu B_\nu(T)}$$

$$\kappa_\lambda = \kappa_0 \left(\frac{\lambda_0}{\lambda}\right)^\beta$$

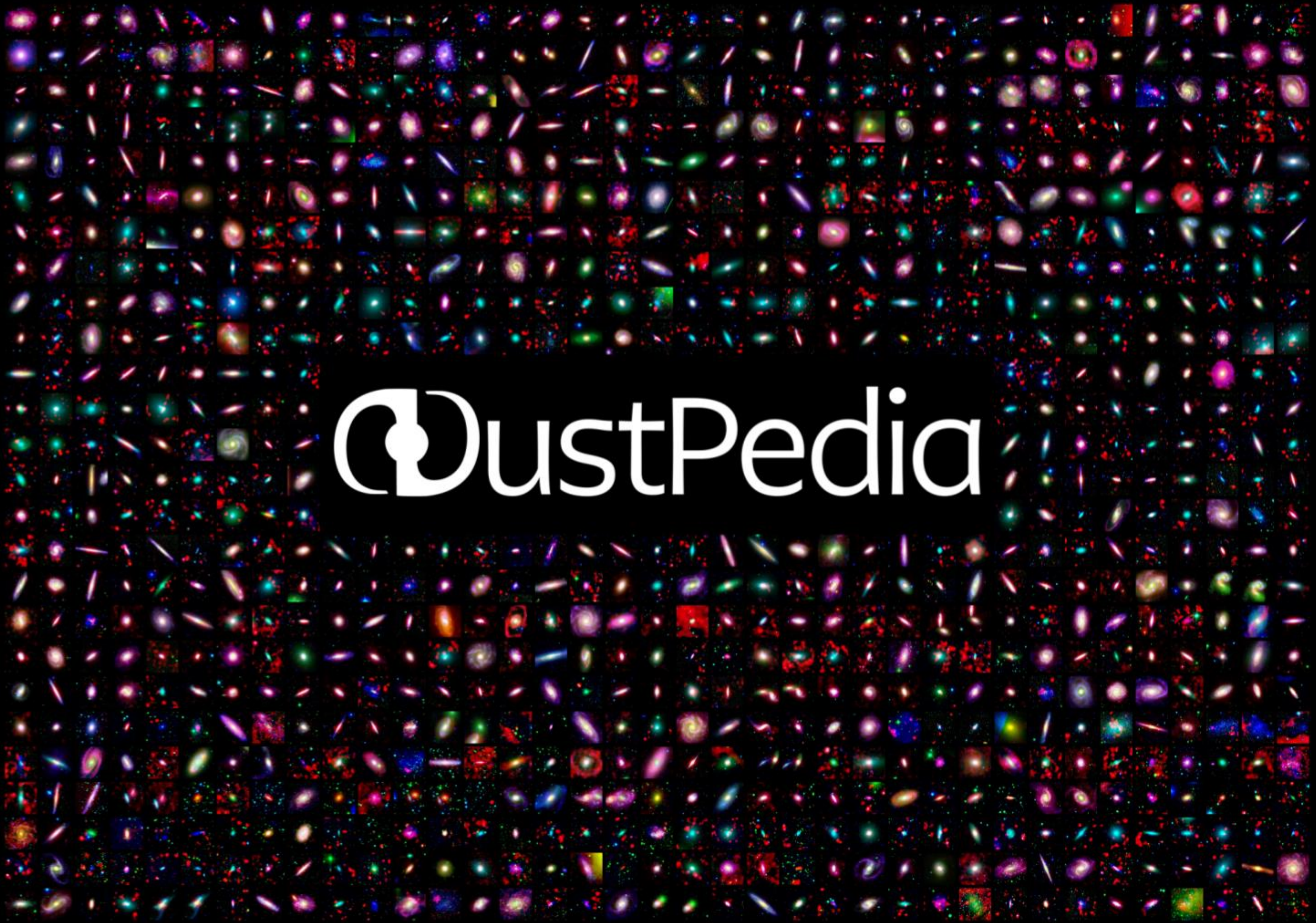
Alton+ (2004); Demyk+ (2013); Köhler+ (2015); Clark+ (2016); Jones+ (2017); Clark+ (2019) **Chris Clark**

Mapping κ_d Within Galaxies

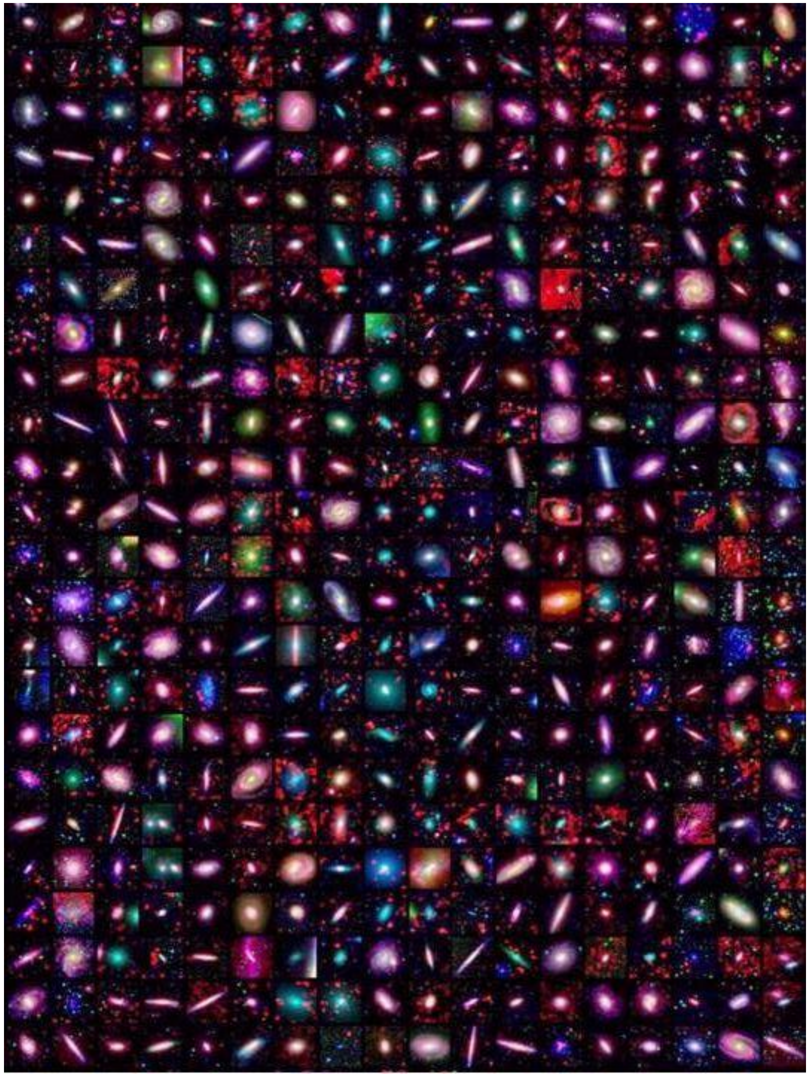


Casasola+ (2017); Clark+ (2018); Casasola+ (in prep.) Clark+ (2019)

Chris Clark


DustPedia

The DustPedia Database

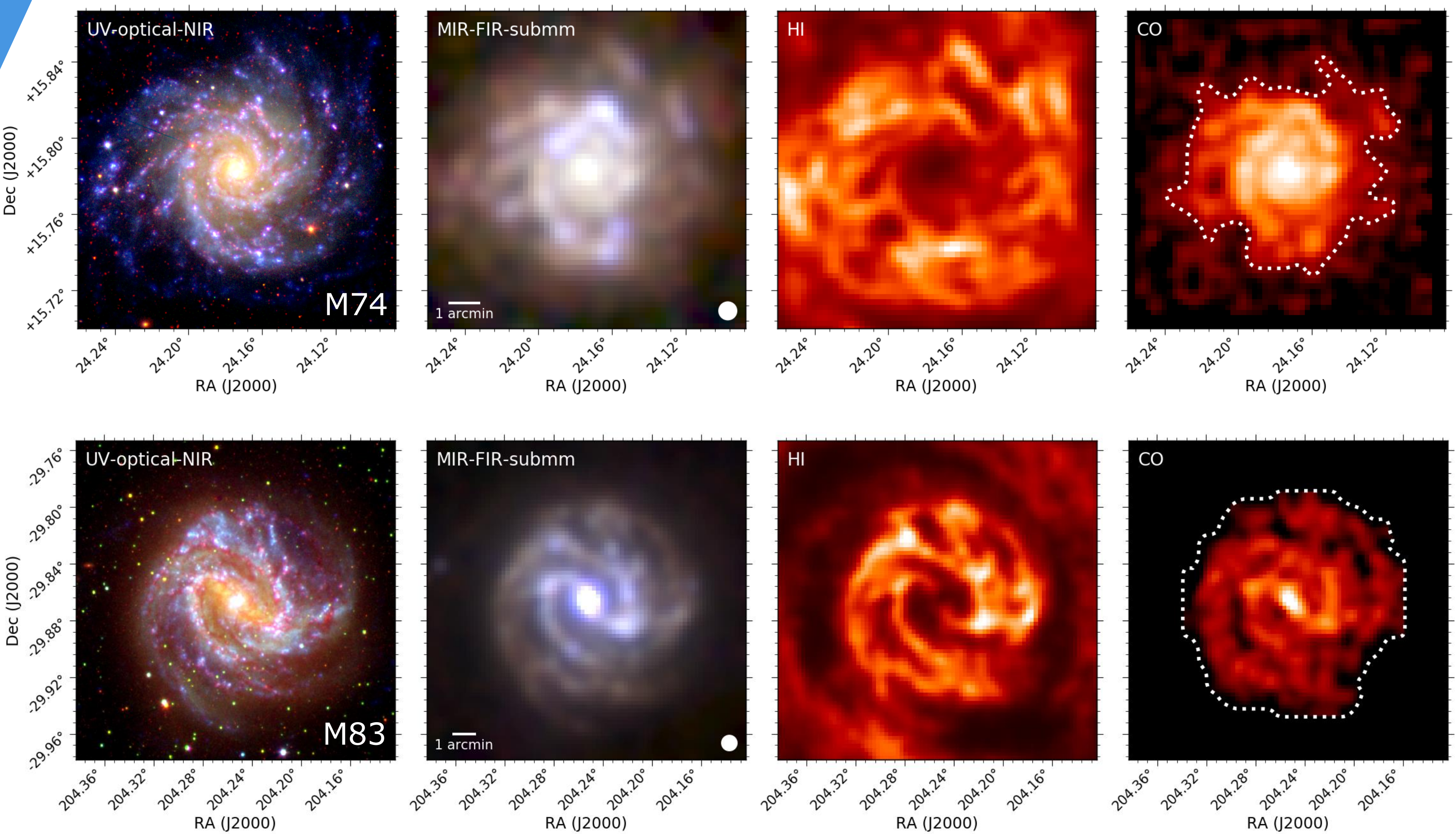


UV-NIR-FIR montage of some of the galaxies in the DustPedia database

- The DustPedia (Davies+, 2017) covers all 875 nearby (D<40 Mpc) extended (1’ < D25 < 1°) galaxies observed by *Herschel*.
- Standardised imagery & photometry spanning 42 UV–microwave bands (Clark+, 2018).
- Homogenised atomic & molecular gas values for 764 & 255 DustPedia galaxies respectively (Casasola+, *in prep.*; De Vis+, 2019).
- 10000 consistently-determined gas-phase metallicity datapoints (from IFU, slit, and fibre spectra) for 492 DustPedia galaxies (De Vis+ 2019).

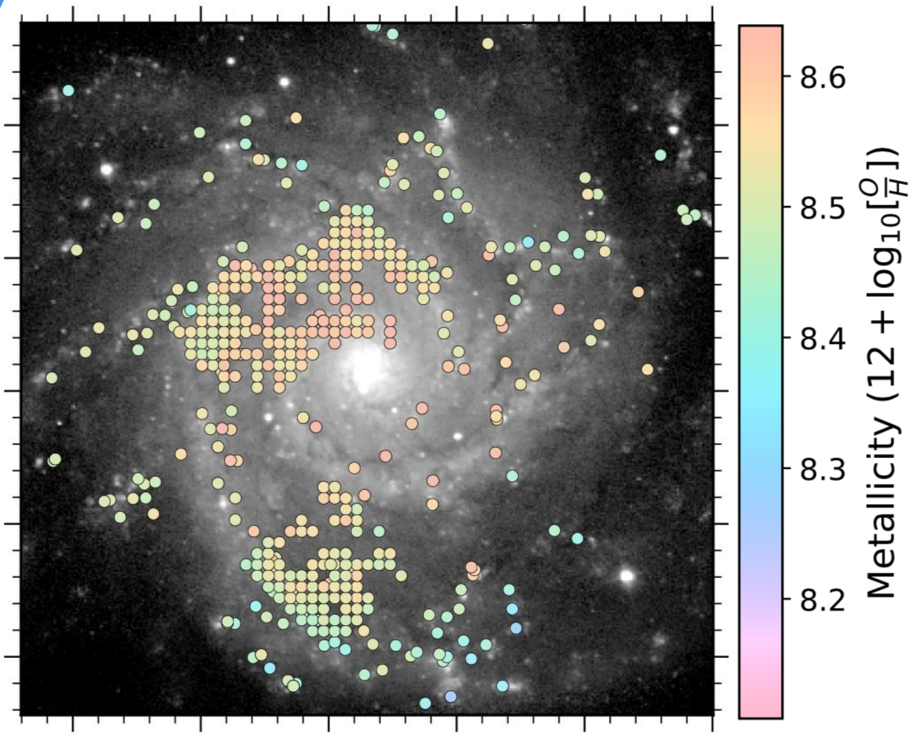
DustPedia.com

Mapping κ_d Within Galaxies

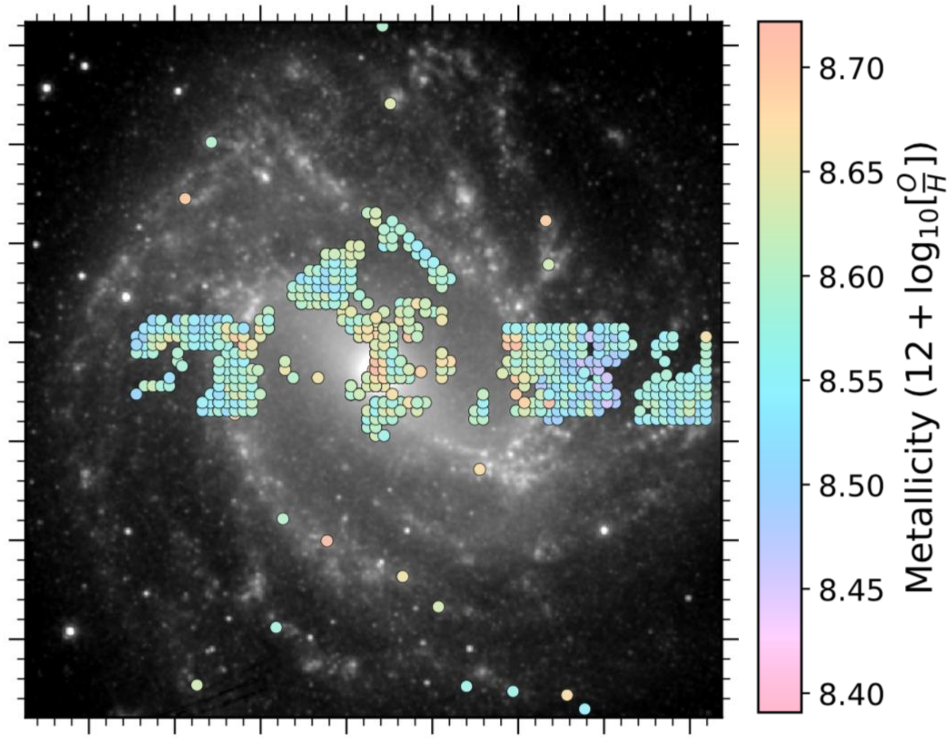


Casasola+ (2017); Clark+ (2018); Casasola+ (in prep.) Clark+ (2019)

Metallicity Data in M74 & M83



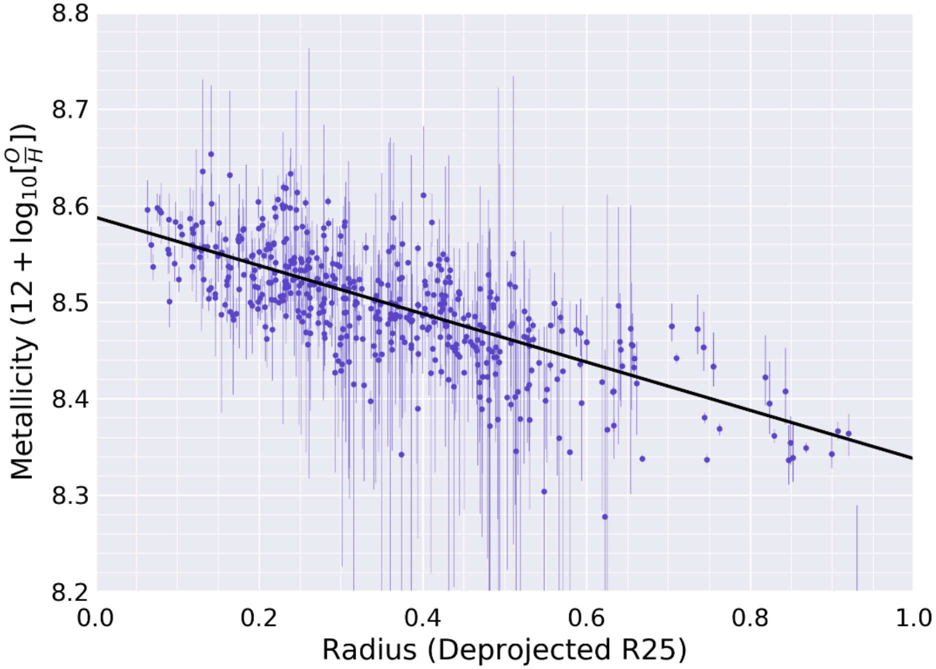
M74

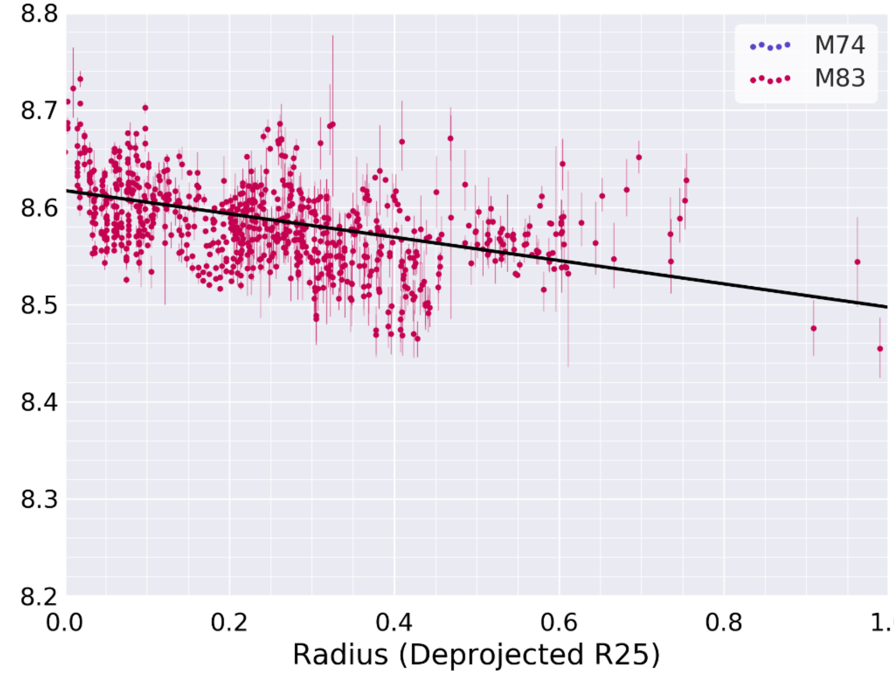


M83

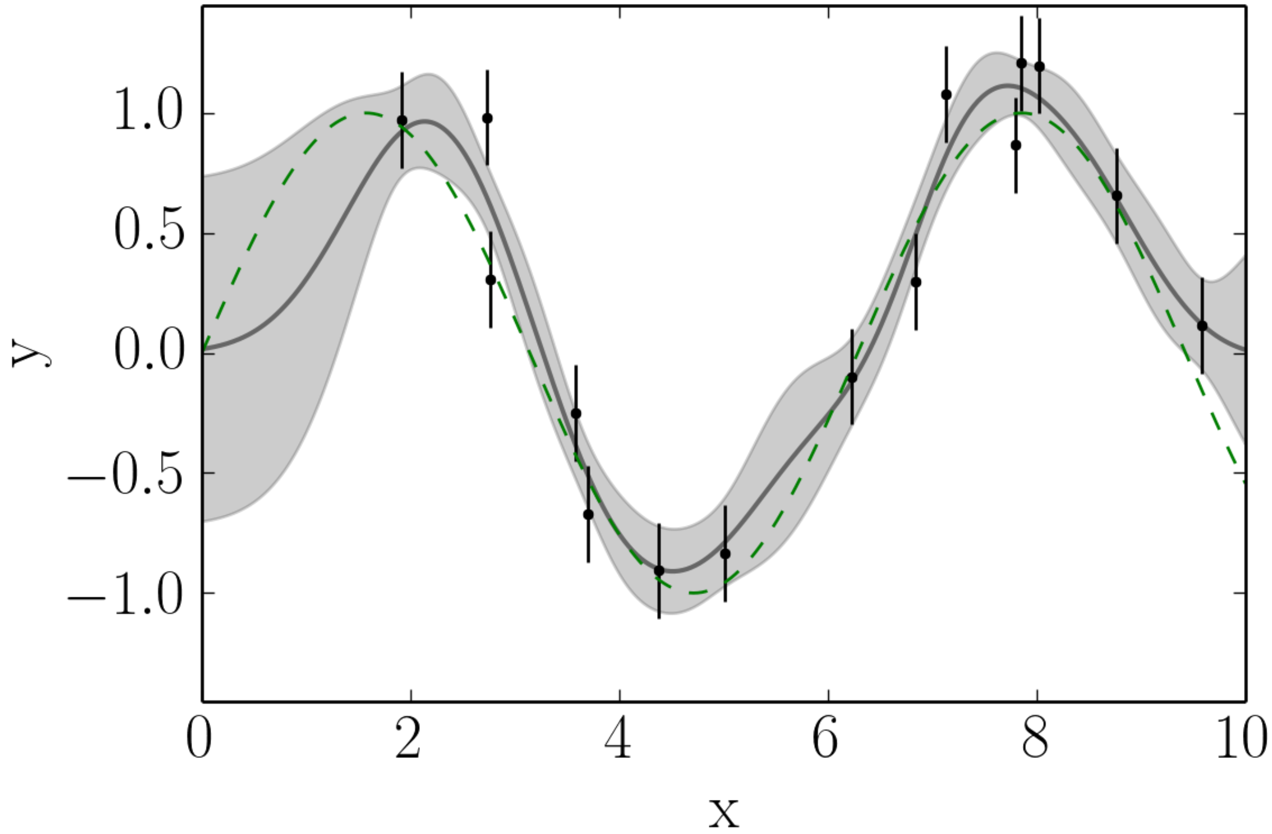
De Vis+ (2019); Clark+ (2019)

Metallicity Gradients

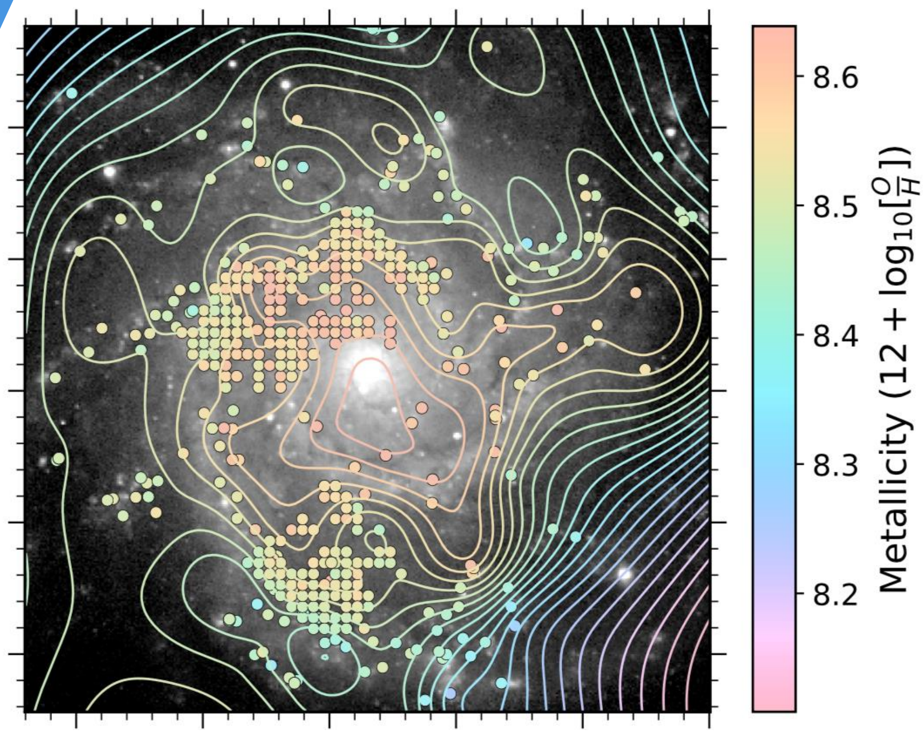




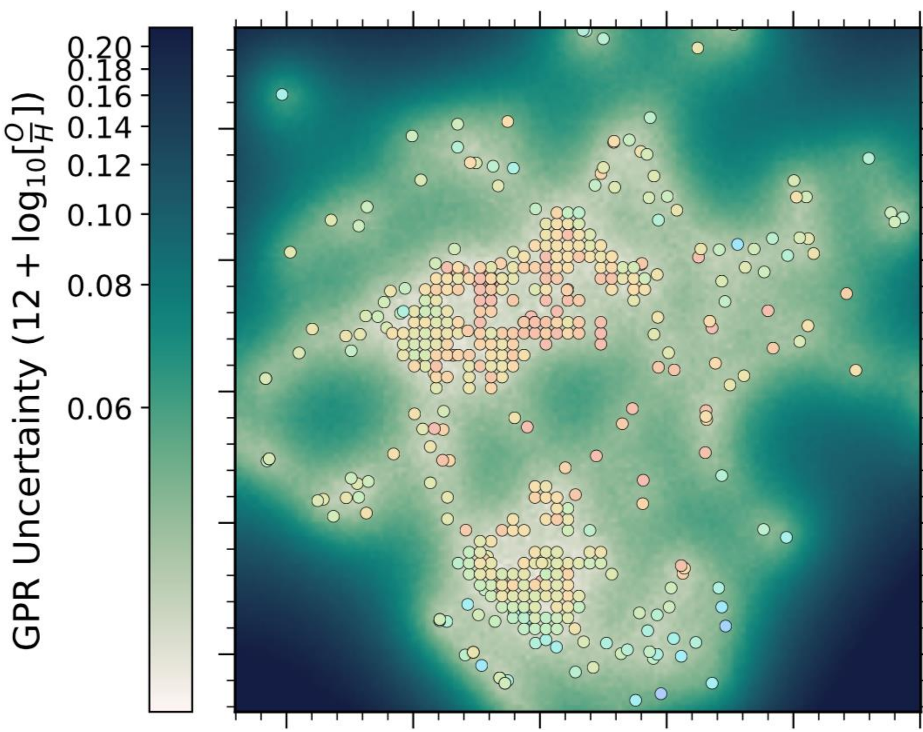
Gaussian Process Regression



Gaussian Process Regression

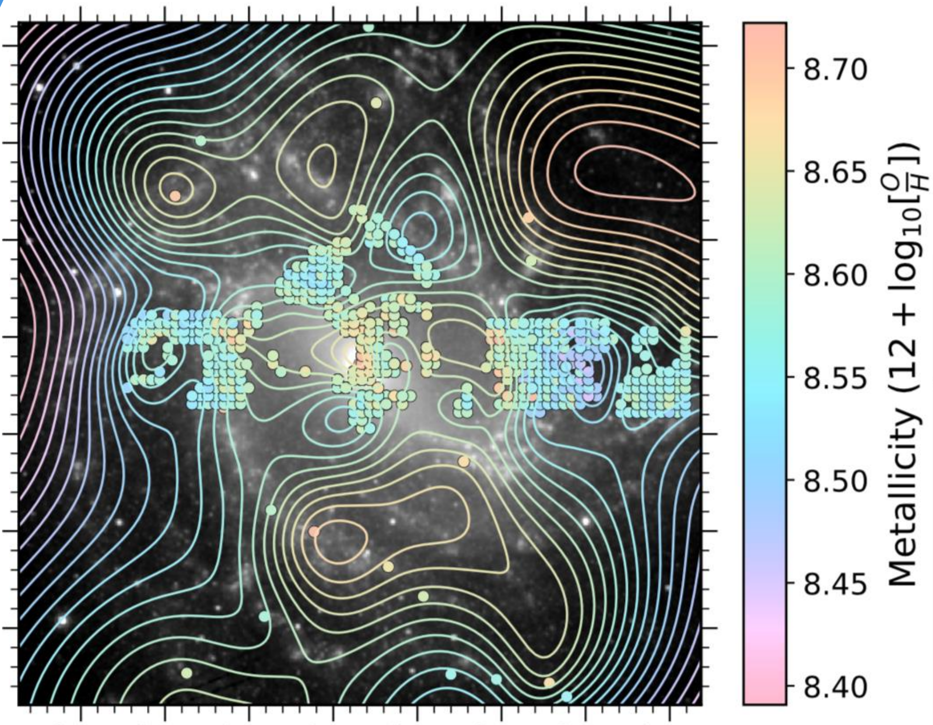


M74 Metallicity Map

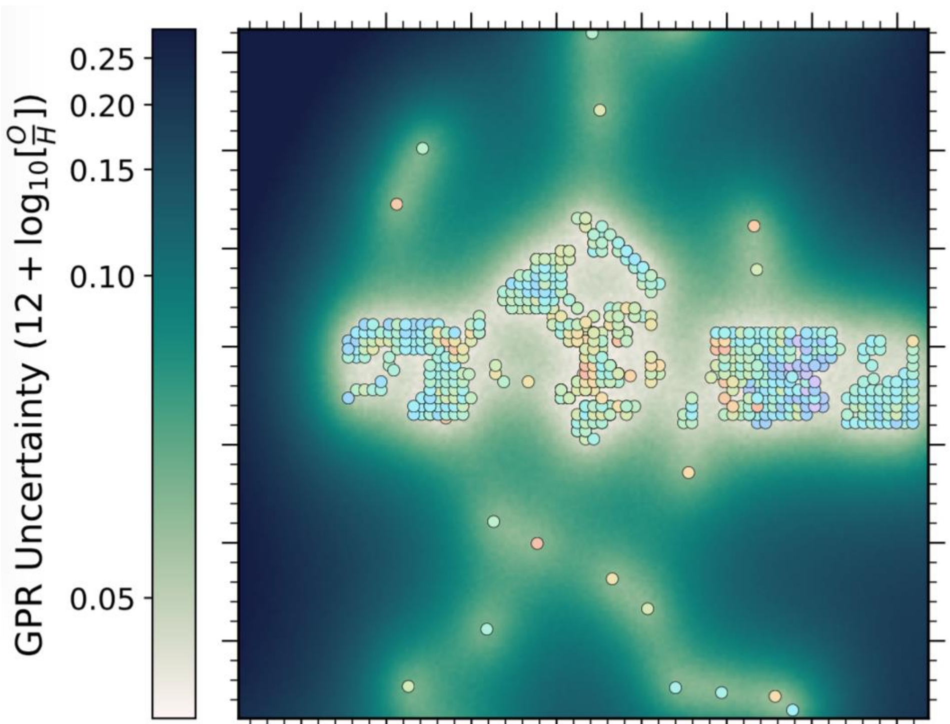


M74 Metallicity Uncertainty

Gaussian Process Regression

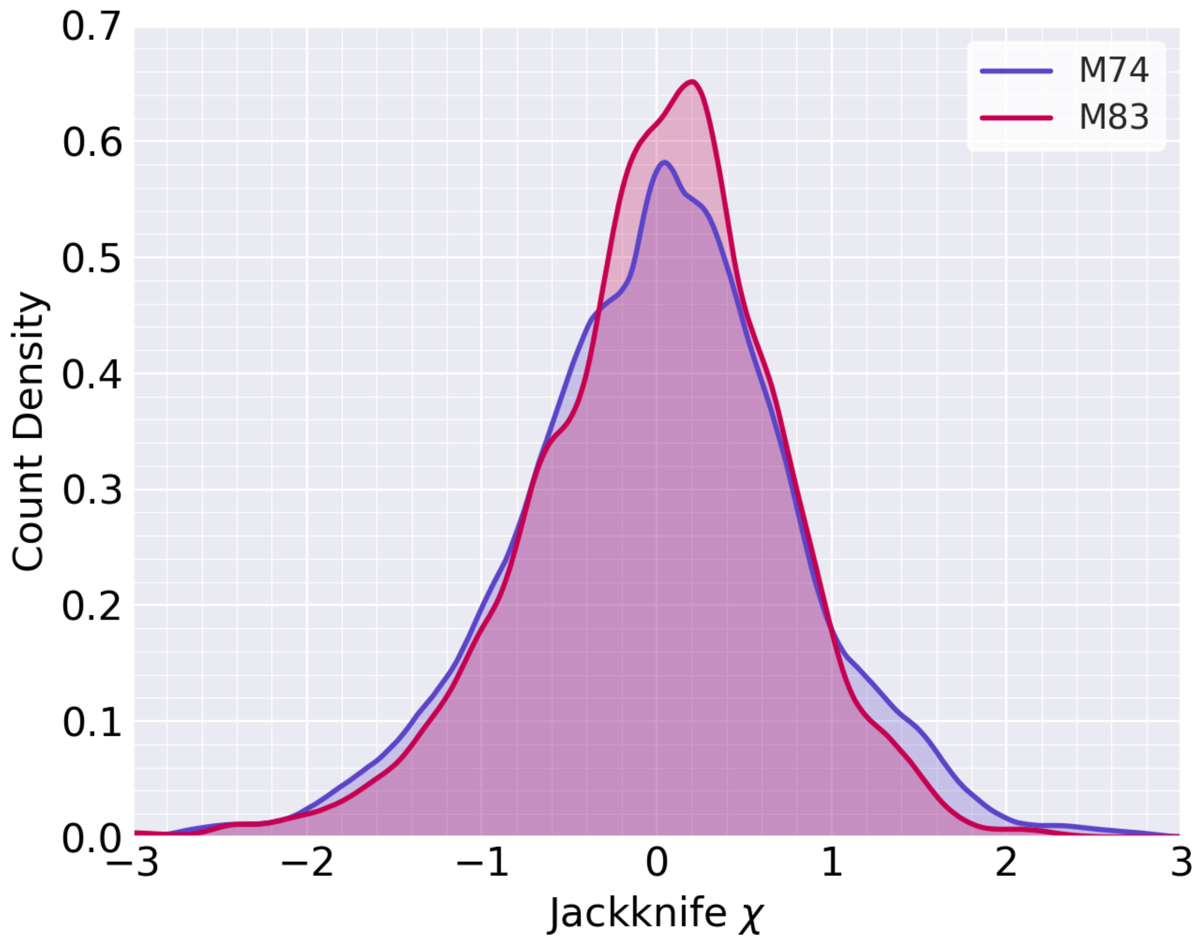


M83 Metallicity Map

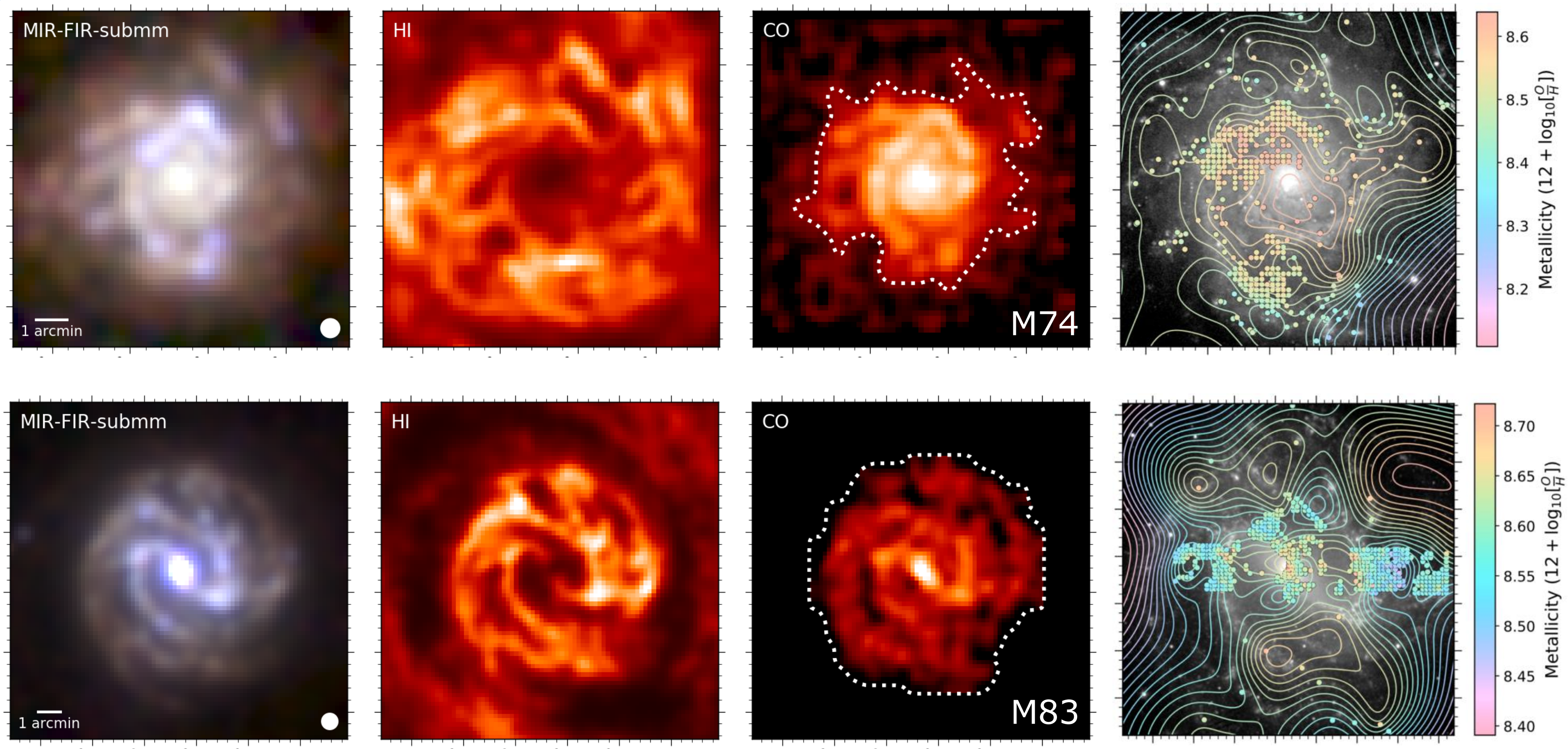


M83 Metallicity Uncertainty

GPR – Works Reliably!



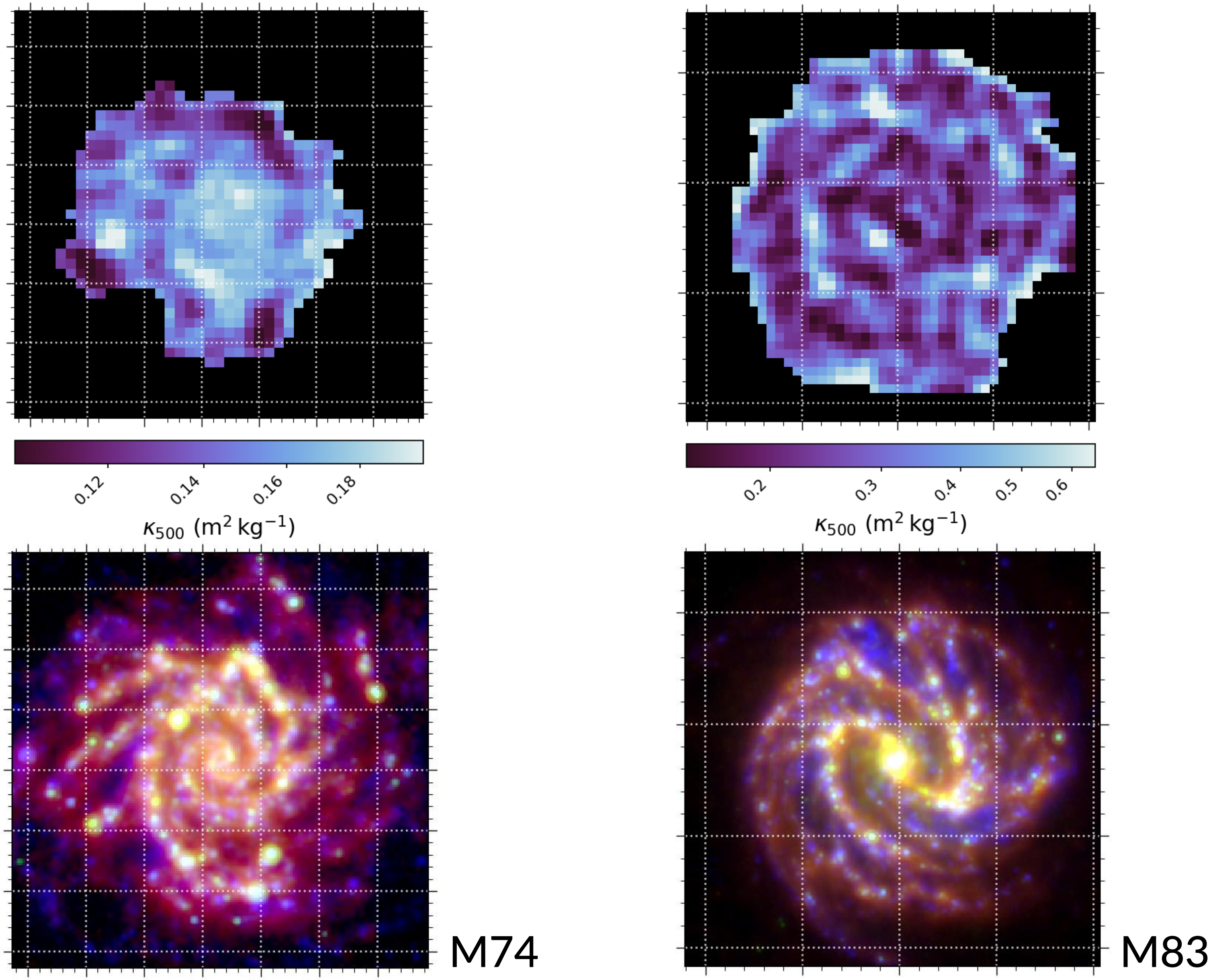
All the Necessary Data



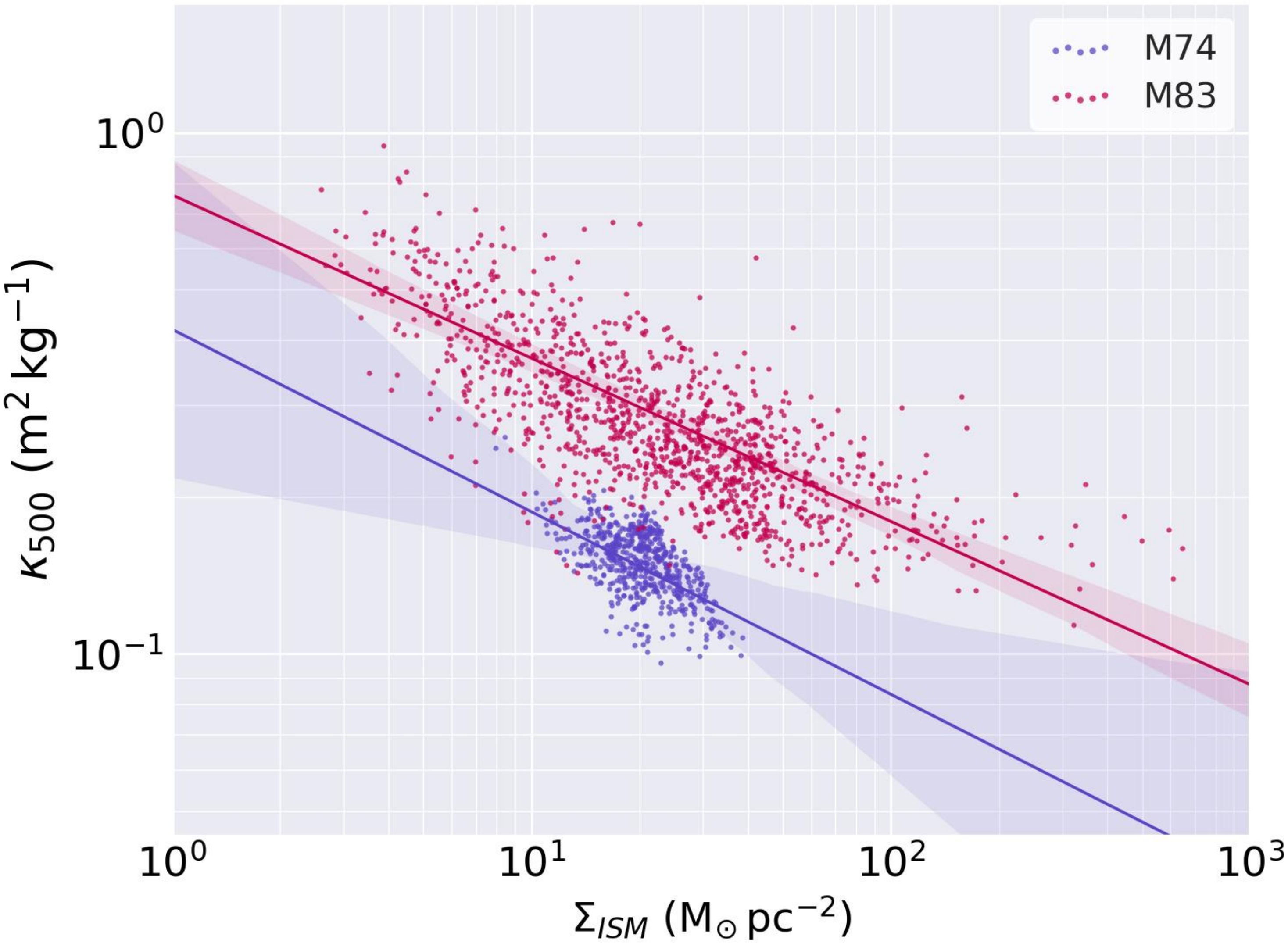
Casasola+ (2017); Clark+ (2018); De Vis+ (2010); Casasola+ (in prep.) Clark+ (2019)

Chris Clark

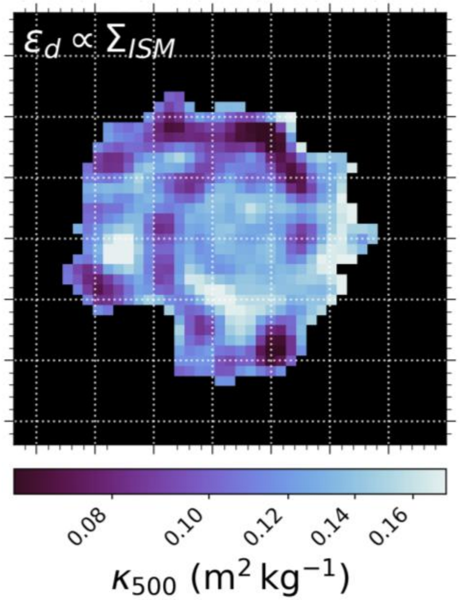
Maps of κ_d within M73 & M83



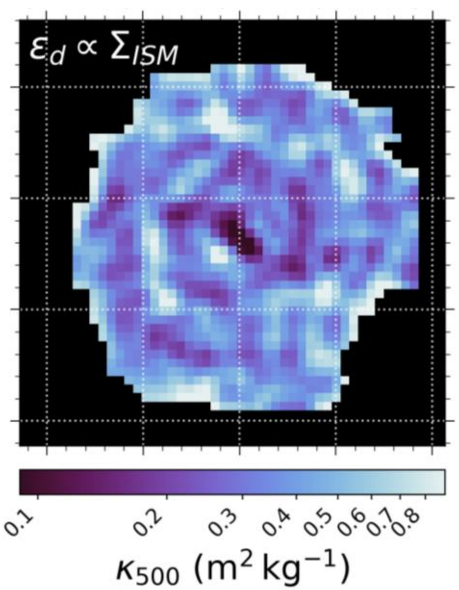
κ_d vs ISM Surface Density



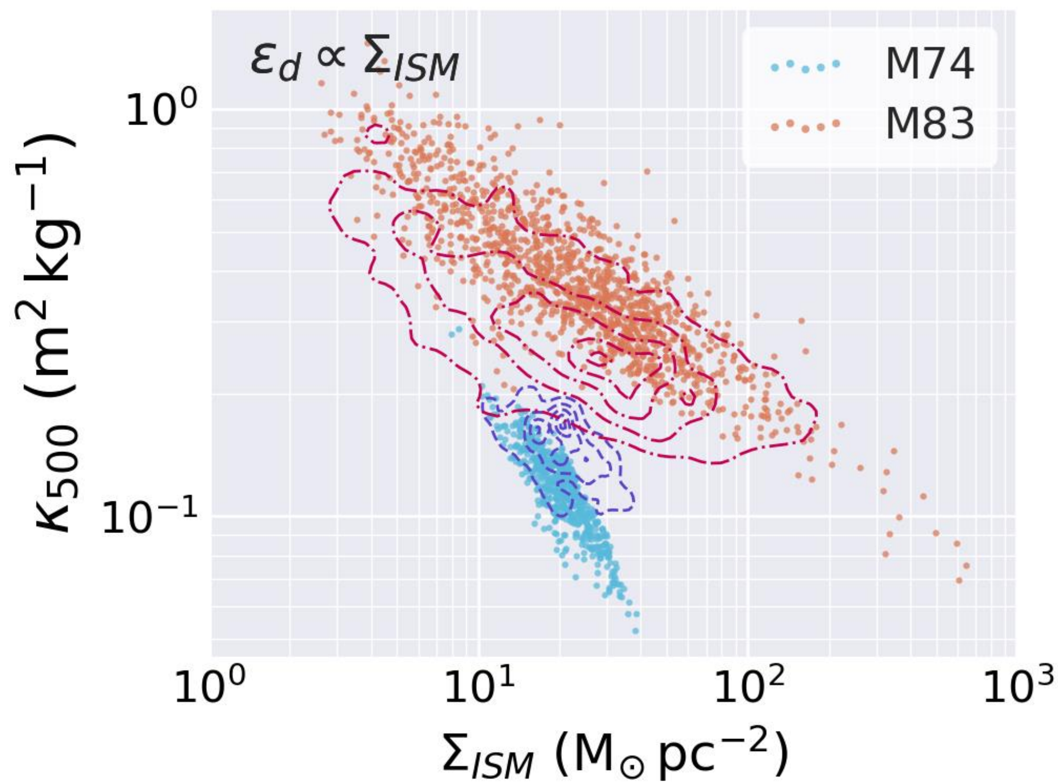
Alternate Model: DTM ∝ Density



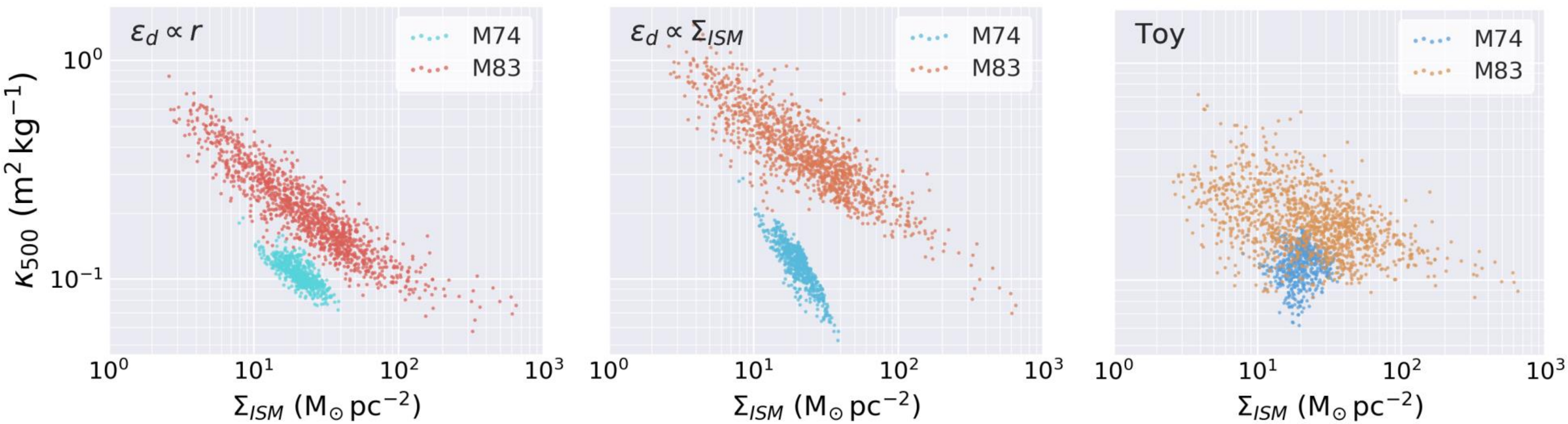
M74



M83



Alternate Models

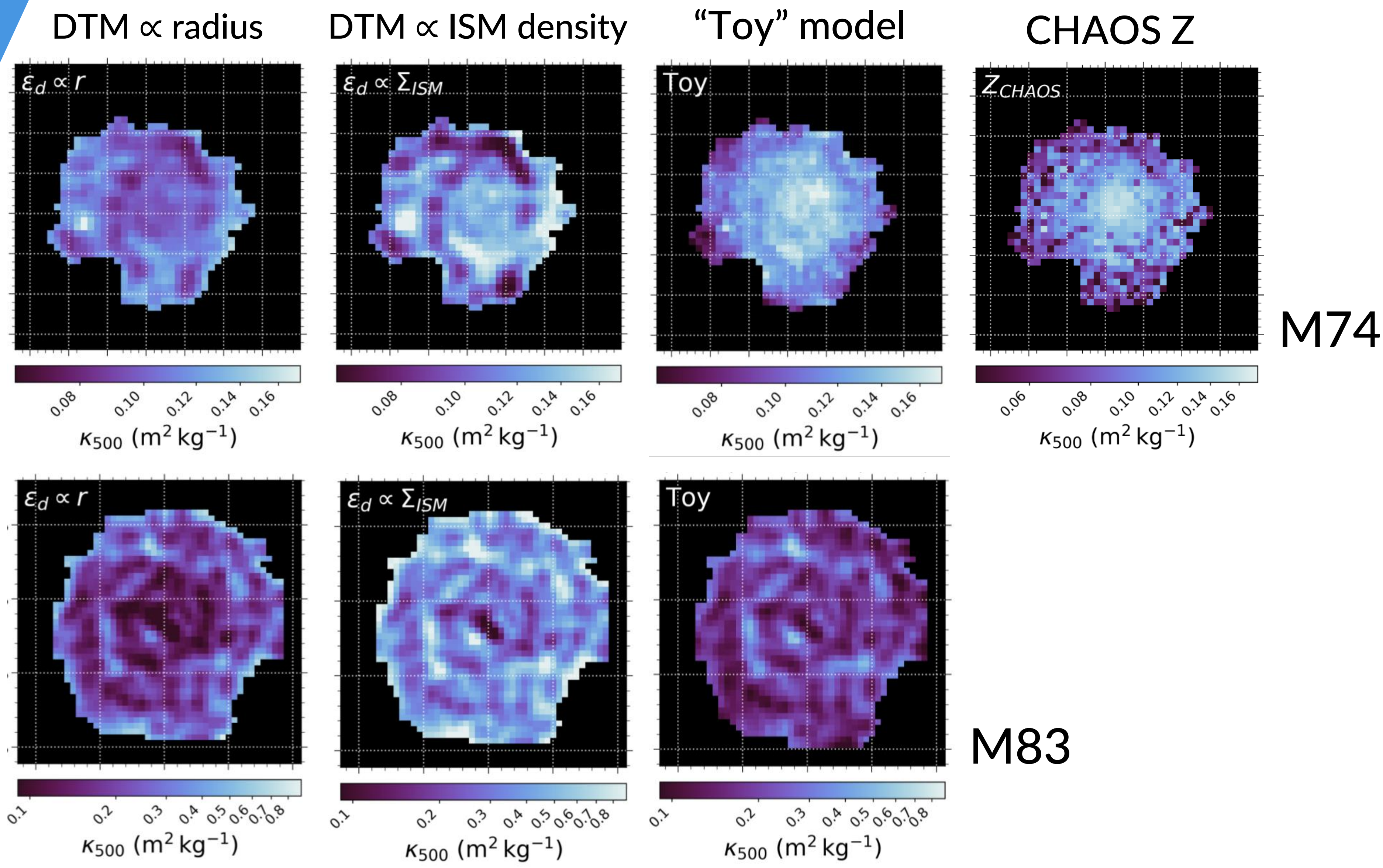


DTM ∝ radius

DTM ∝ ISM density

“Toy” model

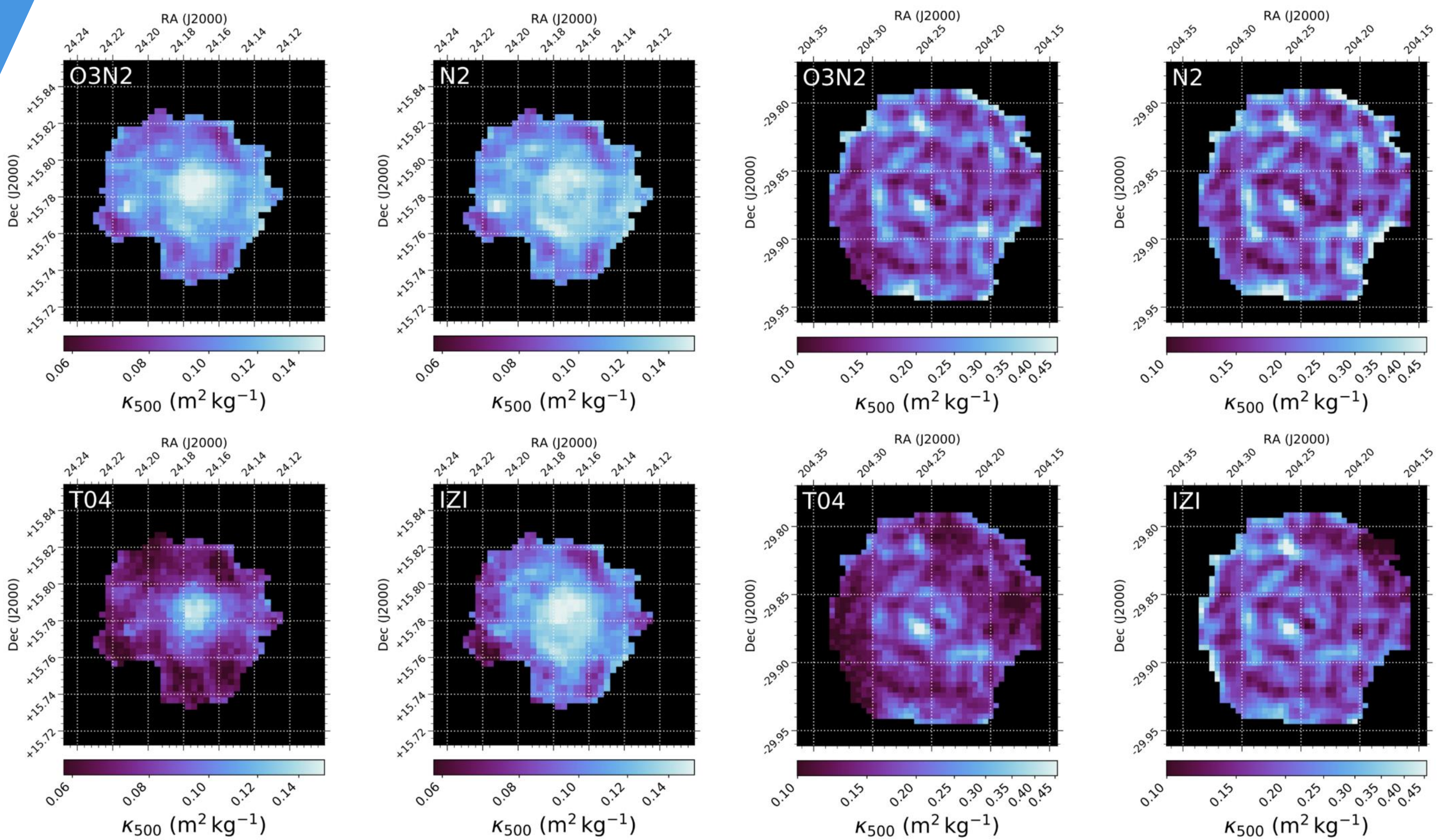
Alternate Models



Clark+ (2019)

Chris Clark

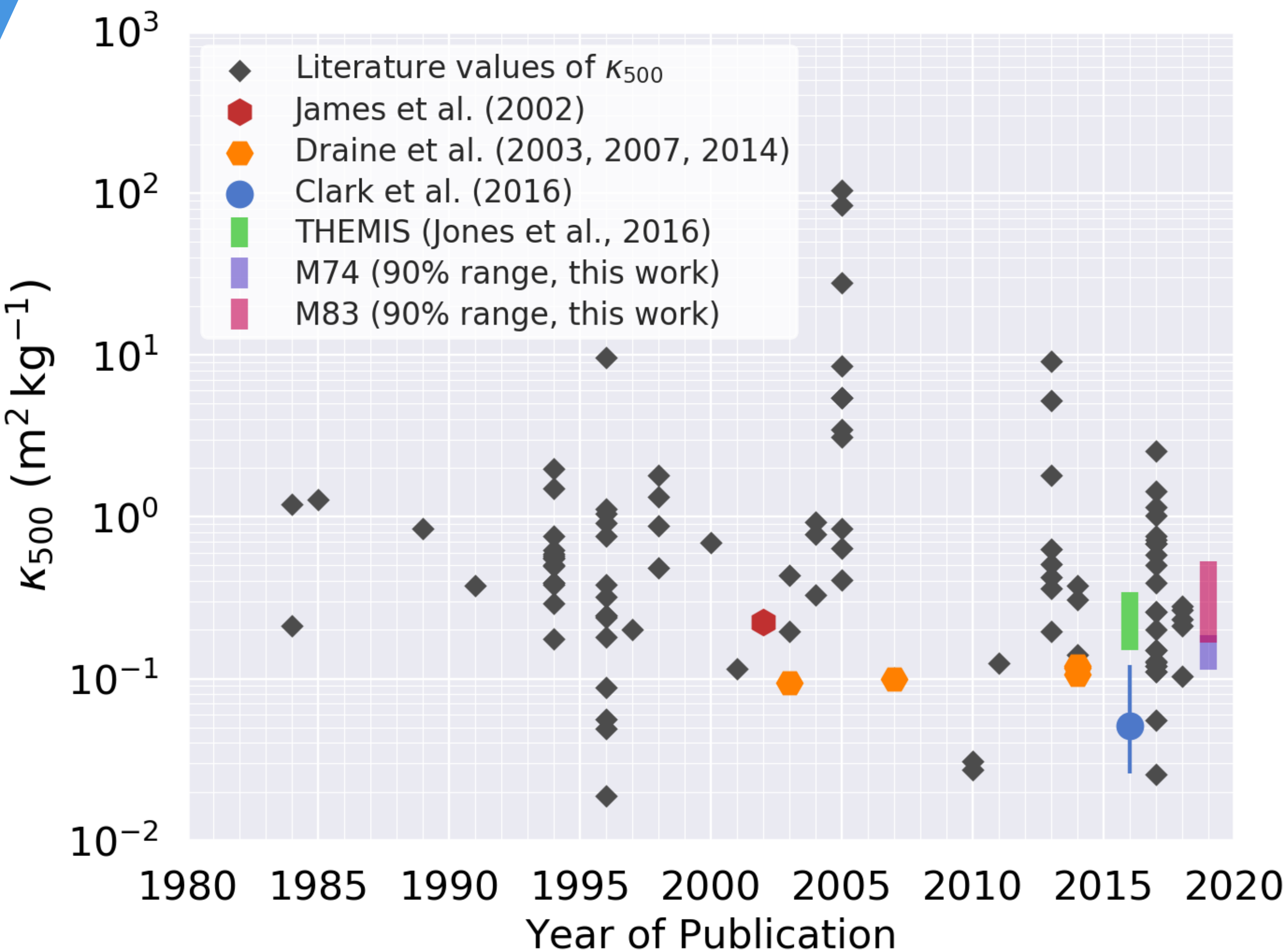
Other Metallicity Prescriptions

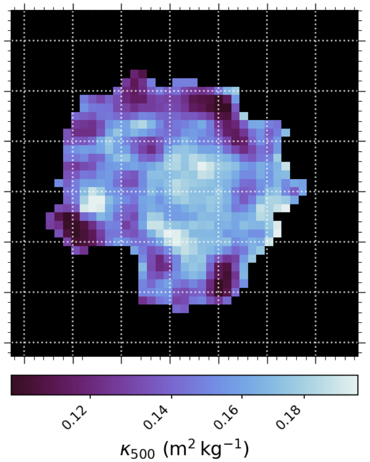


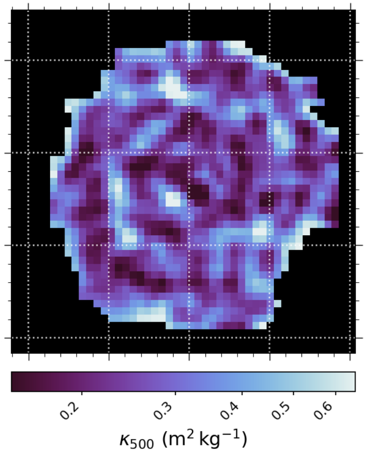
M74

M83

Results Summary



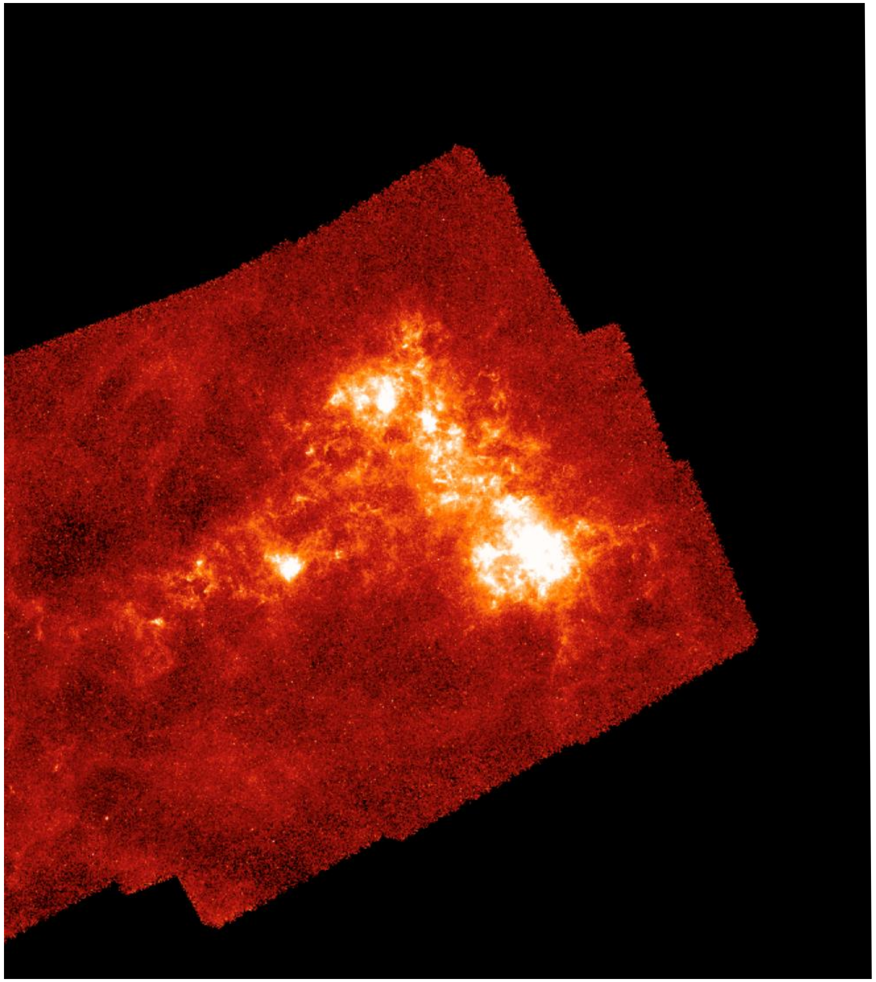




Alton+ (2004); Demyk+ (2013); Köhler+ (2015); Clark+ (2016); Jones+ (2017); Clark+ (2019)

Chris Clark

Next: the SMC, at All Scales

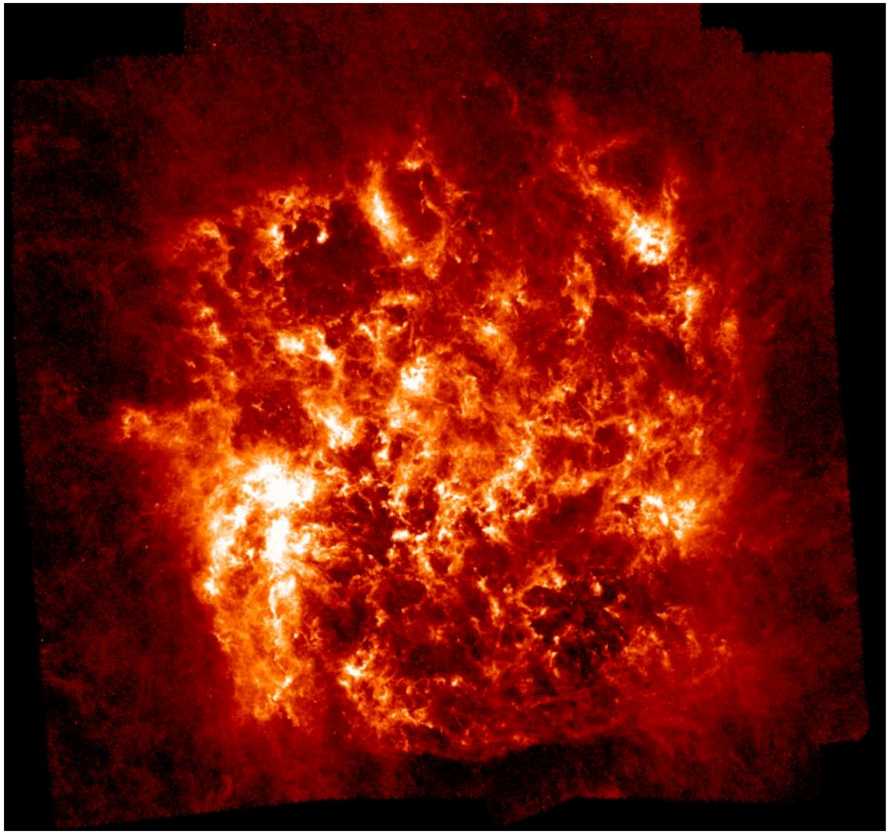


Herschel only; no faint+large scales

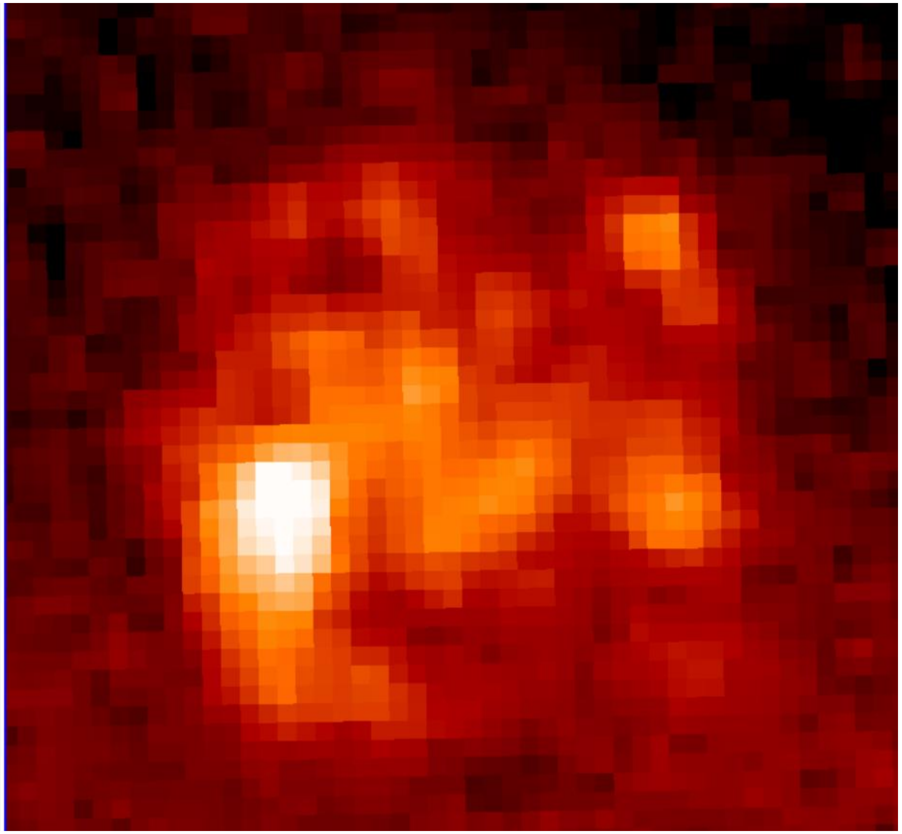
So, You Want To Study Dust in the MCs?

- Herschel!
  - *...Except faint and large-scale emission all got filtered out.*
- Okay, Planck then!
  - *...Planck is great! But its resolution is poor, and it observed at >350um, so can't constrain dust temperature (and therefore mass).*
- How about Spitzer?
  - *...Which has similar background-level problems to Herschel. Plus, severe non-linearity issues at high surface brightness for 160 um.*
- But there's always IRAS, right?
  - *...Unless you want to observe something that is extended and has very high surface brightness. Like the Magellanic Clouds.*
- Urm, I suppose I could try using Akari?
  - ...
- Good point. How about JCMT? Or ISO?
  - *...Never observed more than tiny parts of the Clouds.*
- I suppose that leaves...

The Only Solid Data is COBE!



Herschel-SPIRE



COBE-DIRBE

Combine All The Data

COBE
Far-infrared data,
large angular scales

IRAS
Far-infrared data,
medium angular scales

COBE + IRAS
FIR data, large and
medium angular scales

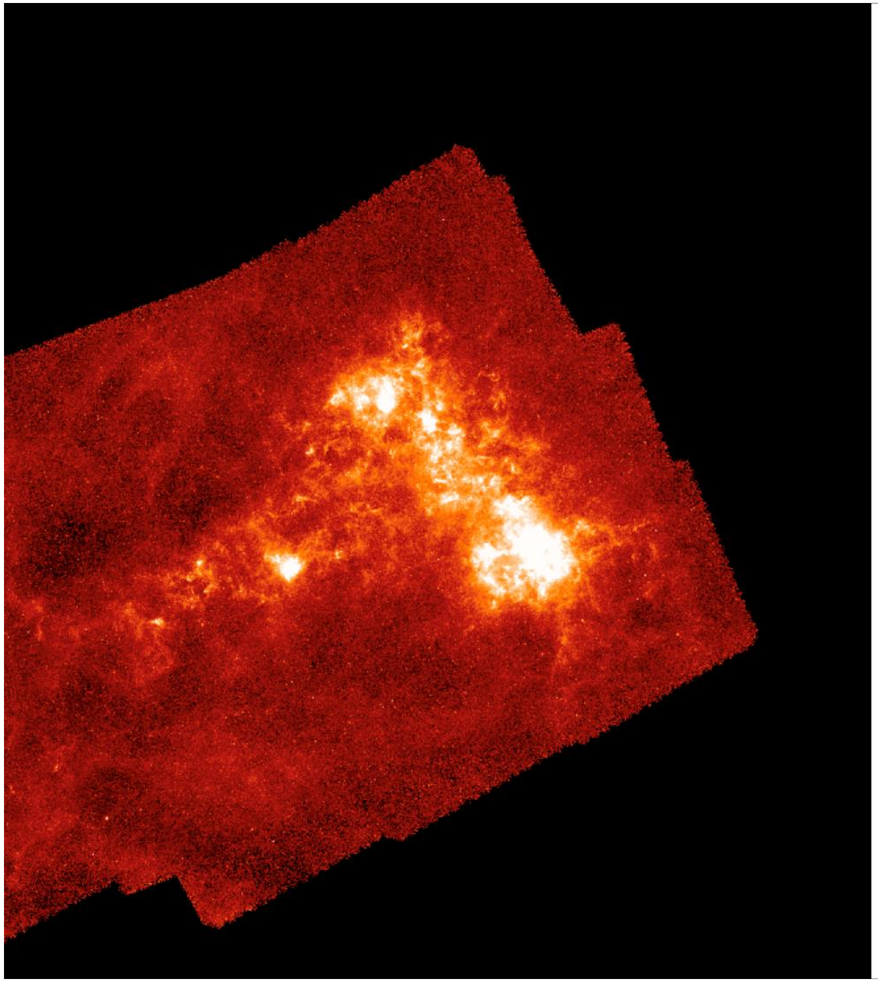
Planck
Submm data, large &
medium angular scales

COBE + IRAS + Planck
FIR-submm data, large &
medium angular scales

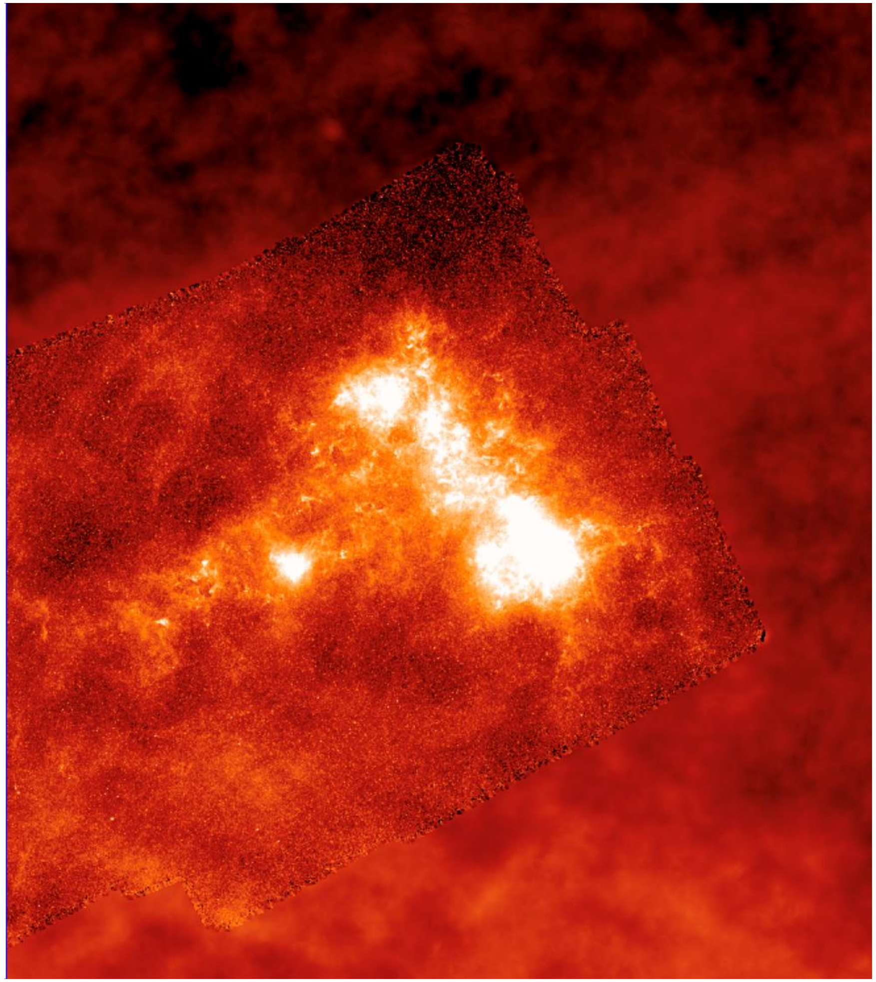
Herschel
FIR-submm data,
small angular scales

COBE + IRAS + Planck + Herschel
*FIR-submm data, large &
medium & small angular scales*

Next: the SMC, at All Scales

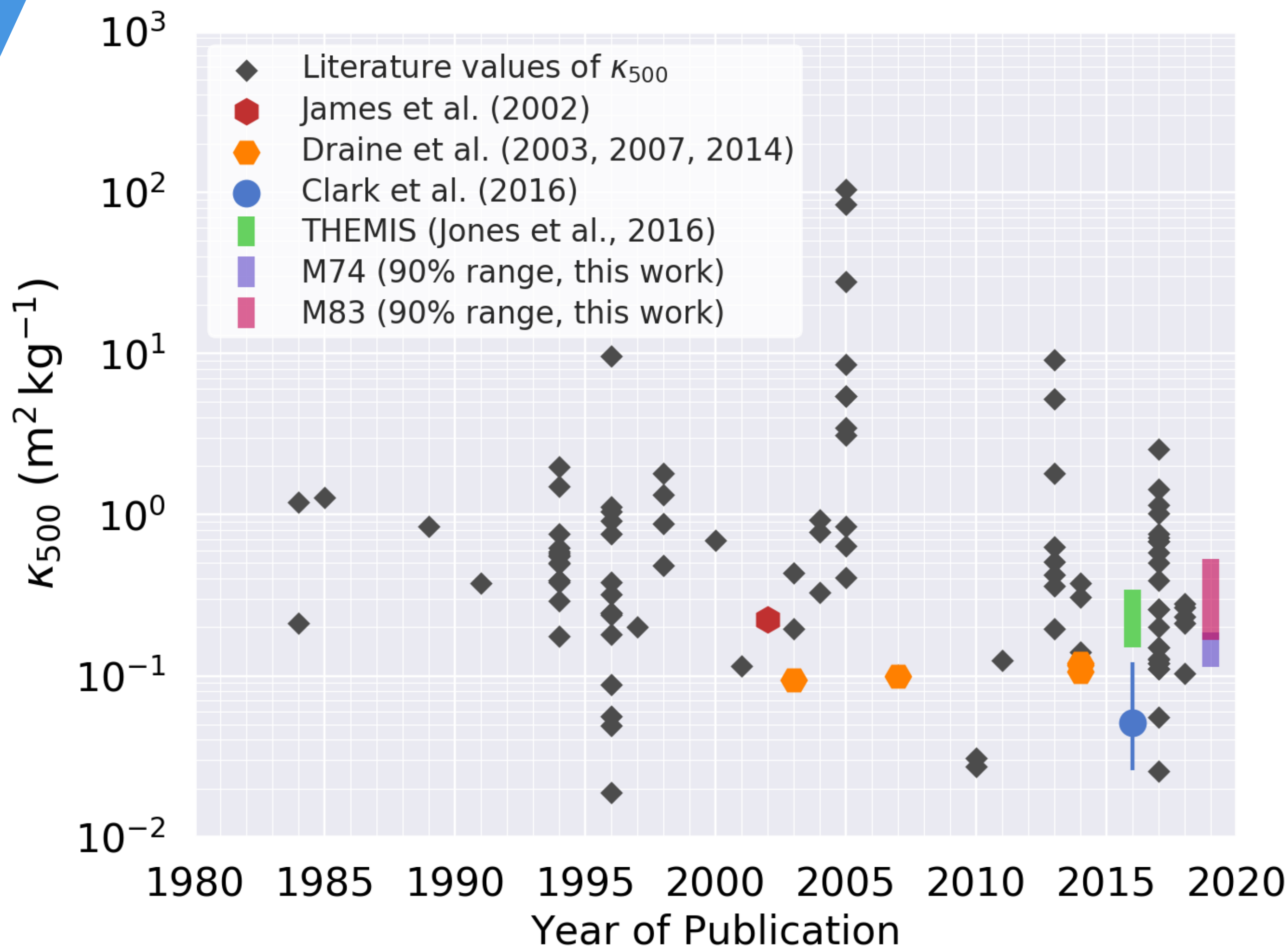


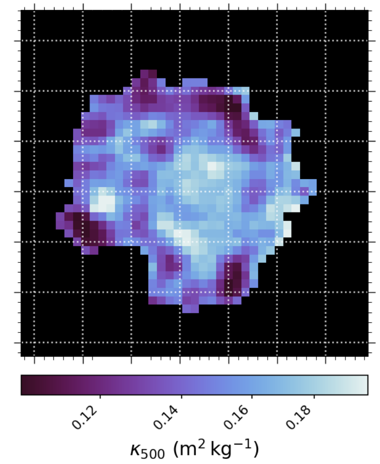
Herschel only; no faint & large scales

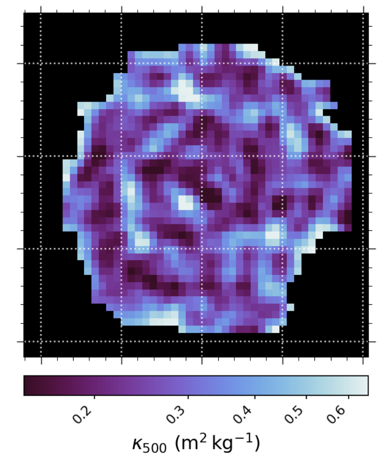


Herschel et al; Fourier-combined

Results Summary





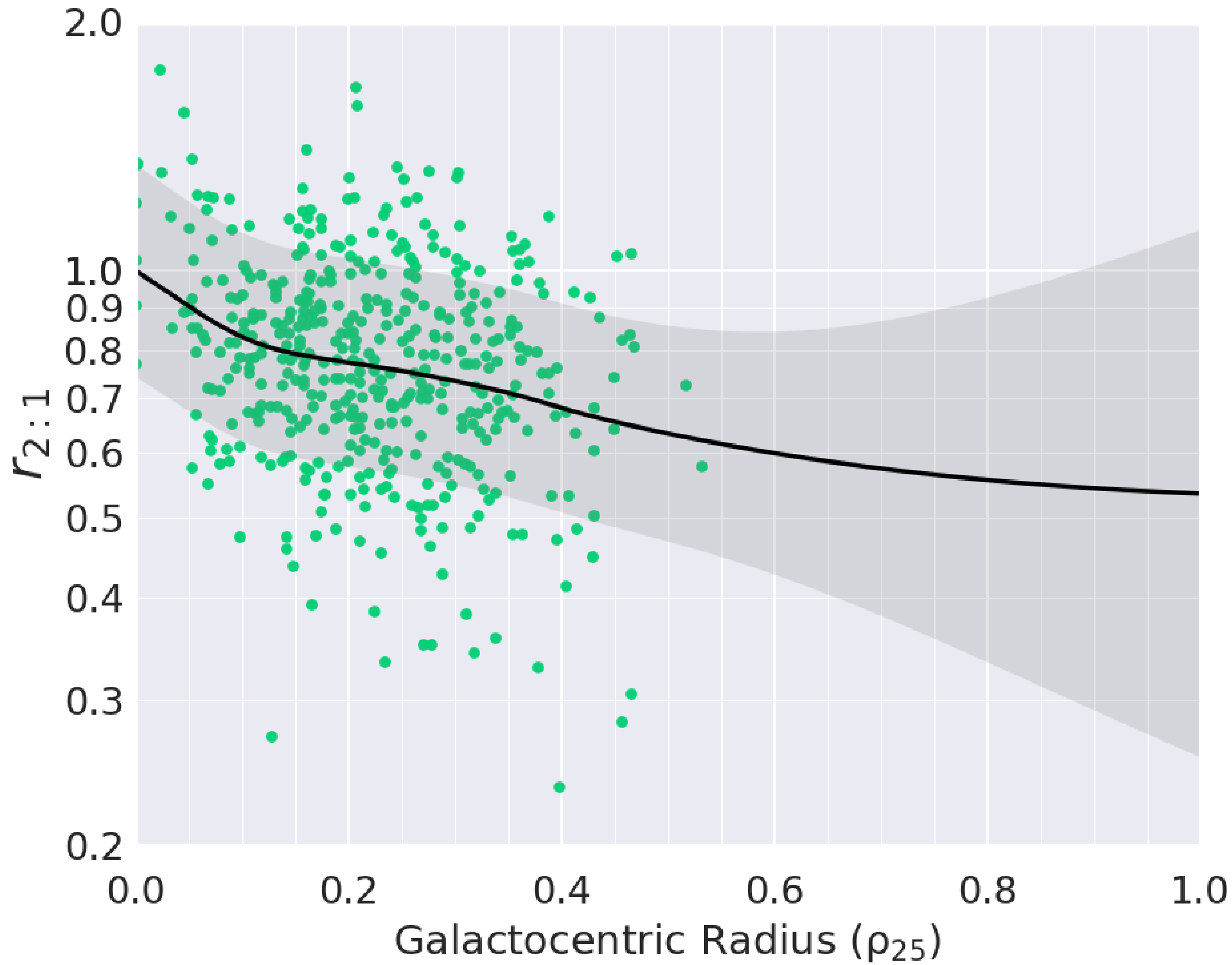


DustPedia

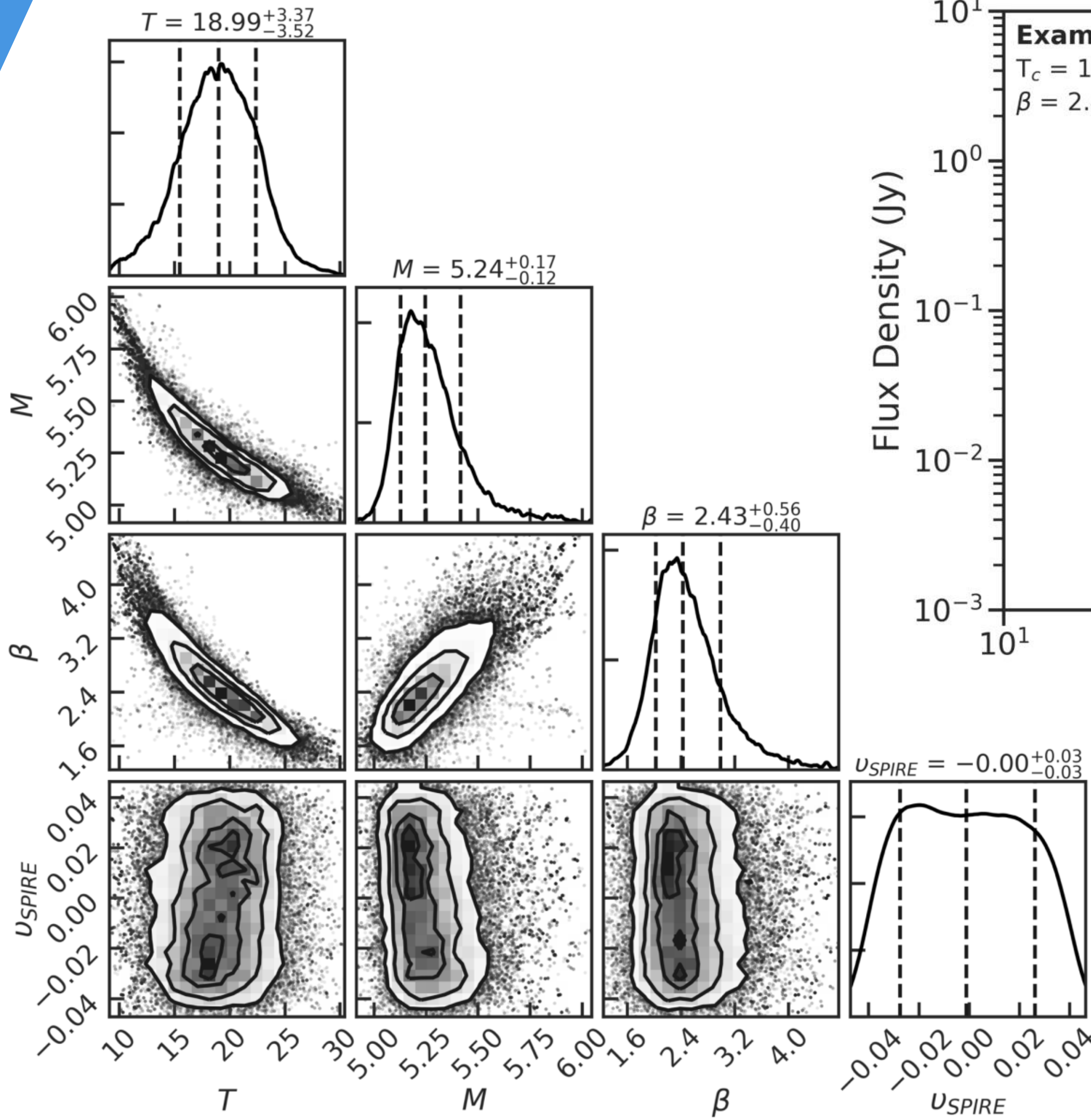
SEVENTH FRAMEWORK PROGRAMME

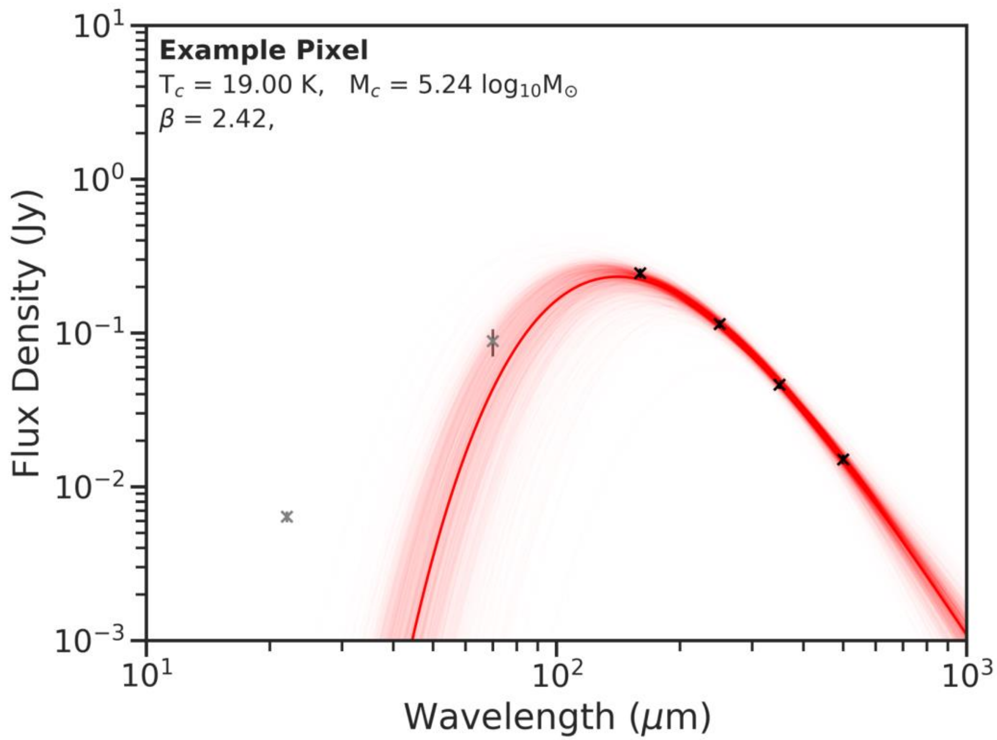
Alton+ (2004); Demyk+ (2013); Köhler+ (2015); Clark+ (2016); Jones+ (2017); Clark+ (2019) **Chris Clark**

CO $r_{2:1}$ Regression



SED-Fitting Example





Dust-to-Metals via Depletions

- Wiseman+ (2016) and De Cia+ (2016) find DTM varies with metallicity, from DLA depletions; but for metallicities of >0.1 $Z_\odot$ this variation is less than factor of ***≤2***.
- Jenkins+ (2009) find Milky Way variation of factor ***≤2.7***.

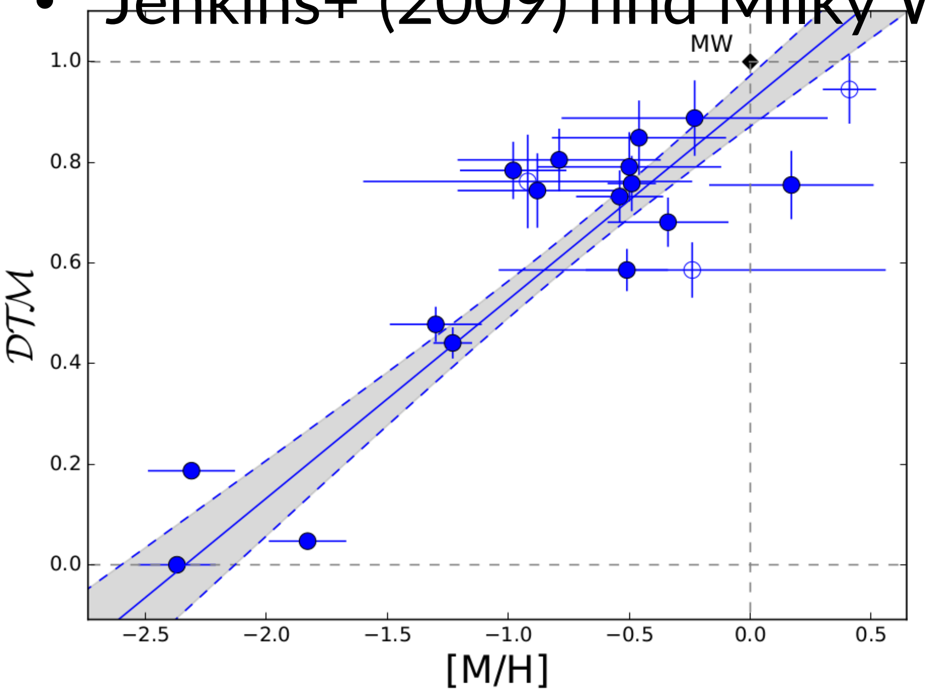


Figure 7 from Wiseman+ (2016)

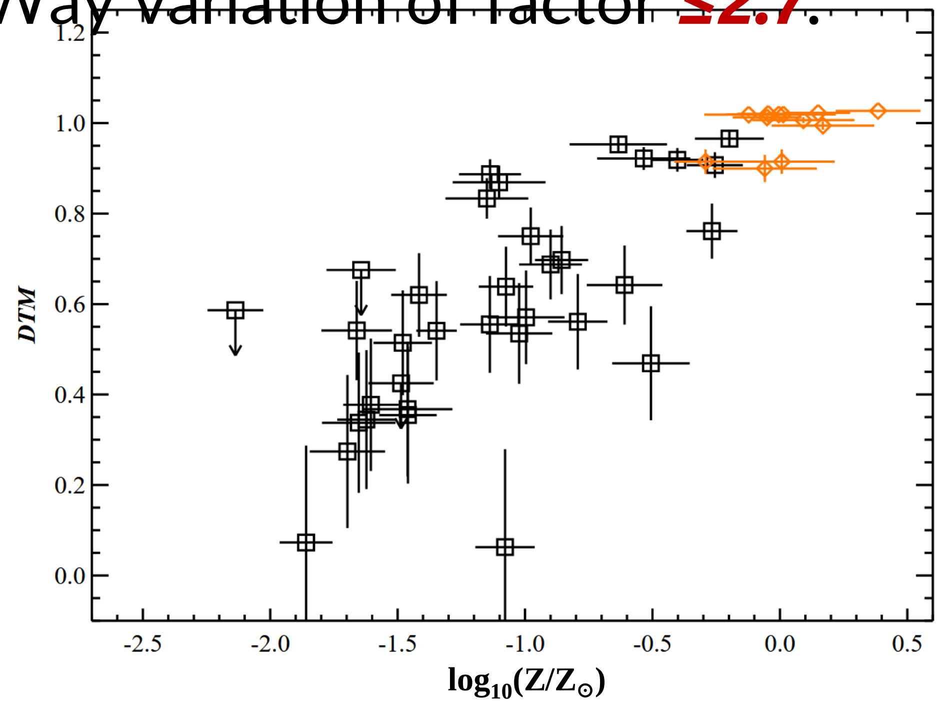


Figure 15 from De Cia+ (2016)

Dust-to-Metals in Simulations

- Popping+ (2017) find DTM varies by factor of ***<4*** at metallicities >0.1 $Z_\odot$ in semi-analytic models.
- McKinnon+ (2016) find DTM varies by factor of ***≤3.5*** at z<0.5 in hydrodynamical zoom-in simulations.

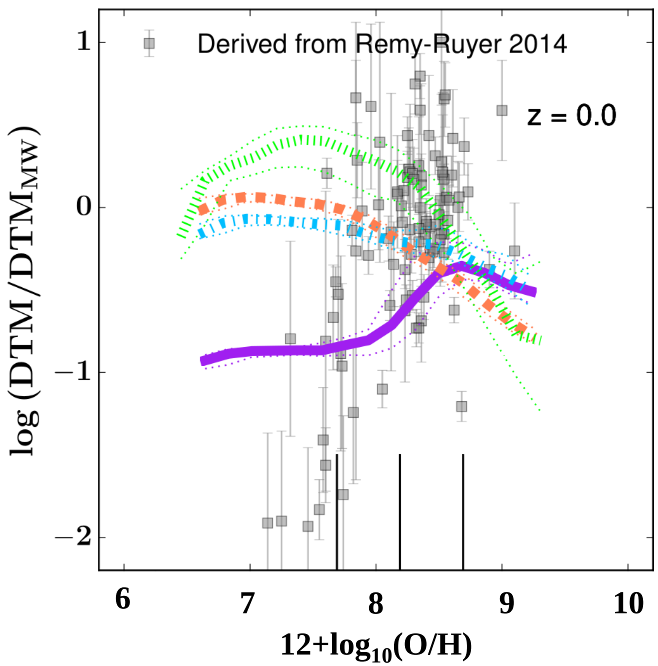


Figure 5 from Popping+ (2017)

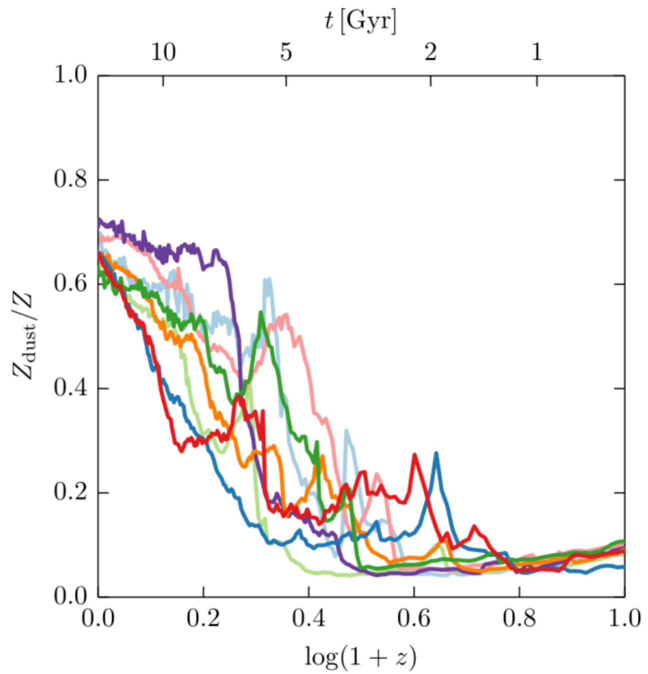


Figure 15 from McKinnon+ (2016)

Dust-to-Metals in THEMIS

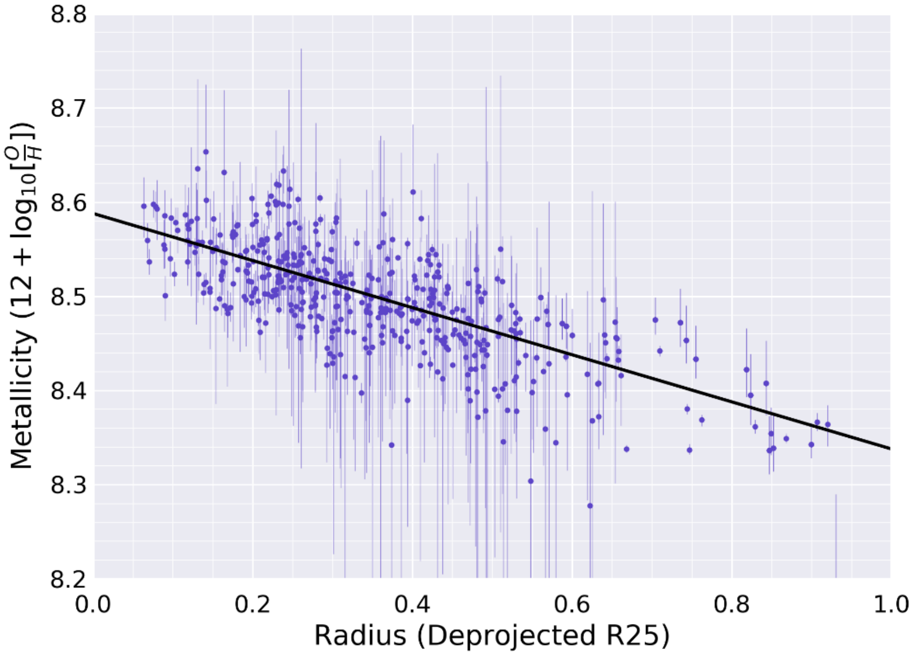
- Dust-to-metals expected to vary by factor of ***~3.6*** in THEMIS dust model (Jones+ 2017;2018).

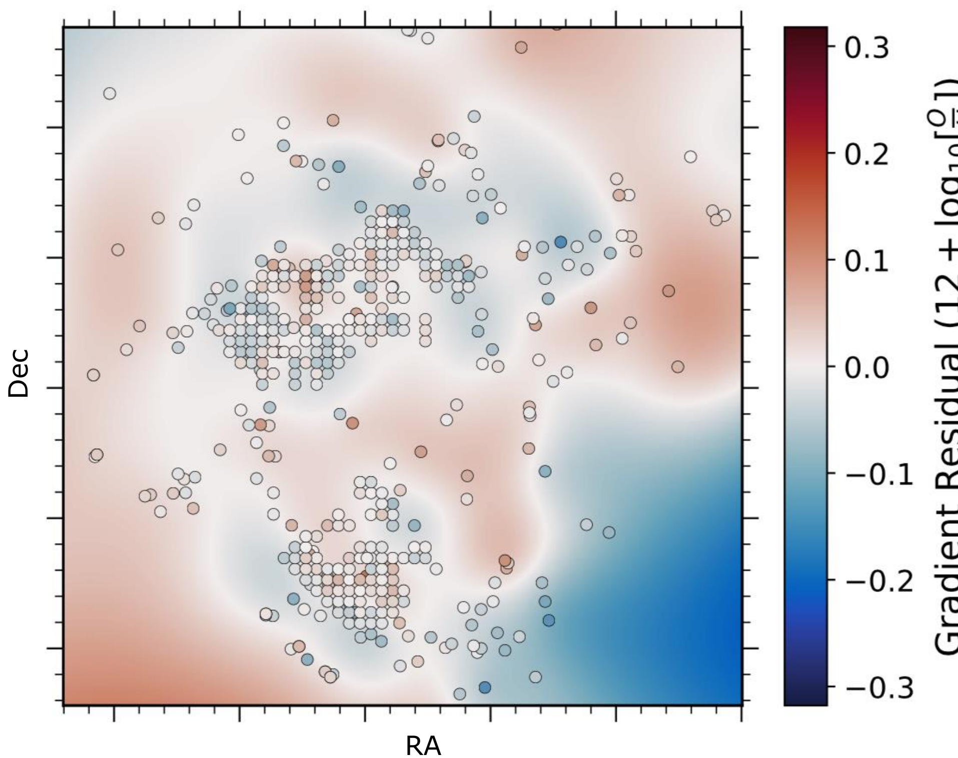
Table 3. The gas-to-dust mass ratios (G/D), dust mass relative to hydrogen, dust mass relative to the available metals, carbon and oxygen abundances, [C] and [O], in dust (in parts per million, ppm) and the percentage by volume of carbonaceous matter in dust, $V_{f,\mathrm{C}}$. This is shown as a function of the ISM environment and the corresponding dust model, where: DISM indicates the standard diffuse ISM dust model, C (O) carbon (oxygen) atom accretion from the gas and ice the presence of ice mantles. Fractional variations from the standard diffuse ISM abundances of carbonaceous nano-particles (big grains) $\frac{1}{n}\mathrm{C_{np}}$ ($\frac{1}{n}\mathrm{C_{bg}}$) or no contribution at all (0×). Low Z indicates sub-solar, low metallicity environments.

Environment	$\approx n_\mathrm{H}$ (cm^{-3})	$\approx T_\mathrm{gas}$ (K)	Dust type	G/D	$\frac{M_\mathrm{dust}}{m_\mathrm{H}}$	$\frac{\mathrm{dust}}{\mathrm{metal}}$	[C] (ppm)	[O] (ppm)	$V_{f,\mathrm{C}}$ (%)
dense	10^4	15	DISM+C+O+ice	55	0.0184	0.88	406	566	41
translucent	1500	20	DISM+C+O	81	0.0124	0.60	406	270	74
translucent	1500	20	DISM+C	102	0.0098	0.47	406	110	65
diffuse	50	100	standard DISM	135	0.0074	0.36	206	110	47
diffuse	50	100	$\frac{1}{2}\mathrm{C_{np}}$	153	0.0066	0.32	135	110	36
diffuse	50	100	$\frac{1}{10}\mathrm{C_{np}}$	170	0.0059	0.28	77	110	23
diffuse	50	100	$\frac{1}{10}\mathrm{C_{np}}, \frac{1}{2}\mathrm{C_{bg}}$	180	0.0056	0.27	52	110	17
energetic	0.25	10^4	$0\times\mathrm{C_{np}}, \frac{1}{2}\mathrm{C_{bg}}$	185	0.0054	0.26	38	110	13
energetic	0.25	10^4	$0\times\mathrm{C_{np}}, 0\times\mathrm{C_{bg}}$	196	0.0051	0.25	13	110	5
energetic	0.25	10^4	bare a-Sil	202	0.0049	0.24	0	110	0
low Z/x-ray	0.01	10^6	$\frac{1}{3}$ a-Sil	613	0.0016	0.08	0	36	0
low Z/x-ray	0.01	10^6	$\frac{1}{30}$ a-Sil	6742	0.0002	0.01	0	4	0

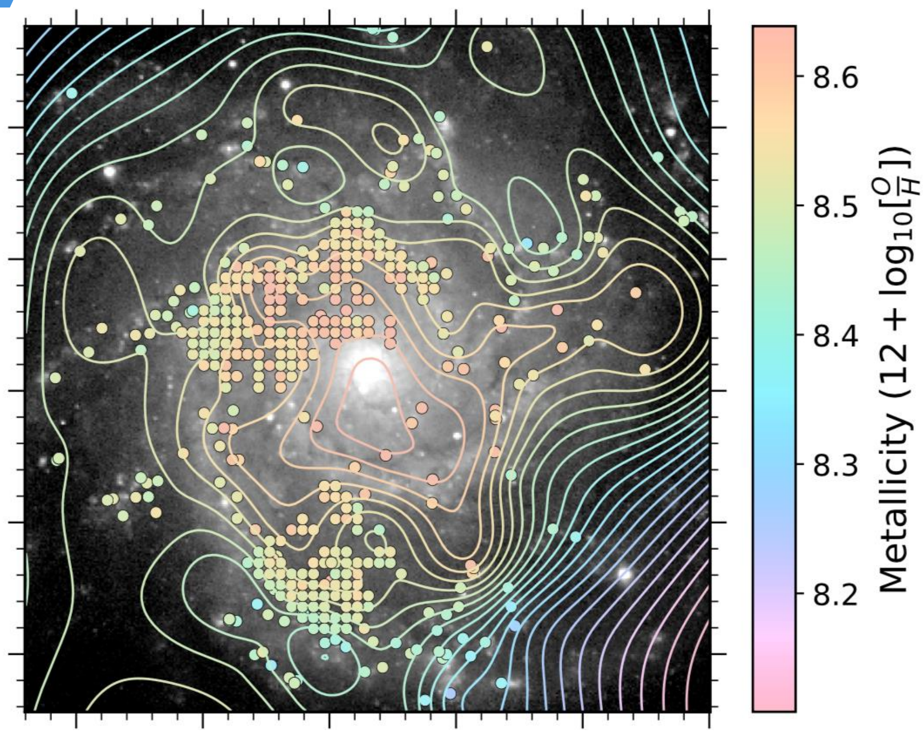
Table 3 from Jones+ (2018)

GPR - Metallicity Residuals

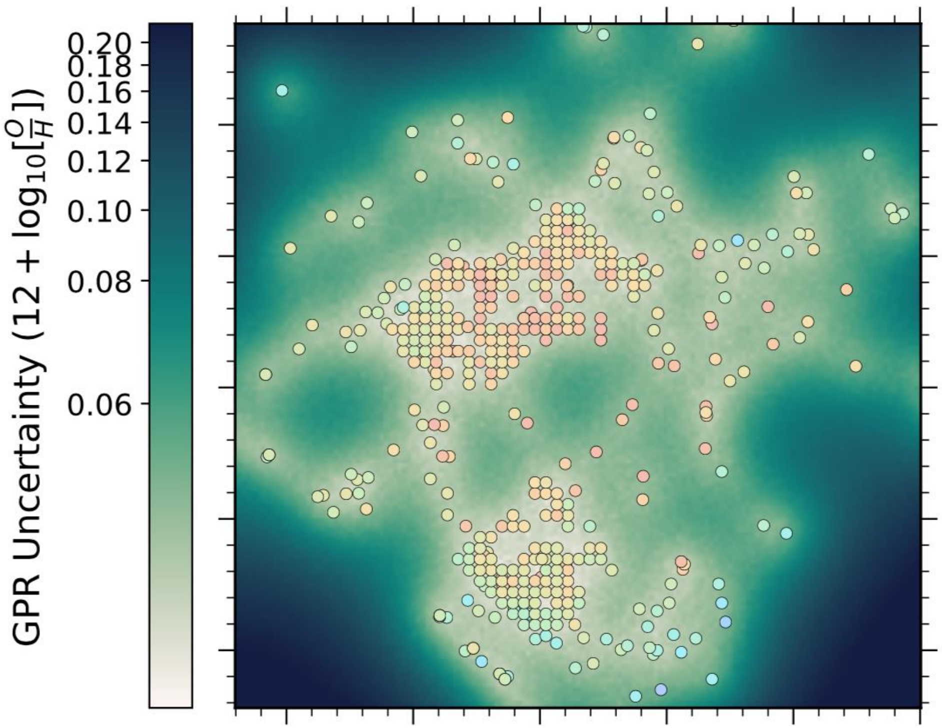




GPR - Metallicity Map for M74



M74 Metallicity Map



M74 Metallicity Uncertainty

GPR - Metallicity Map for M83