Resolved optical-IR SEDs of Galaxies: Universal relations and their break-down on local scales

SZ & Groves, arXiv:1106.2165, MNRAS in press

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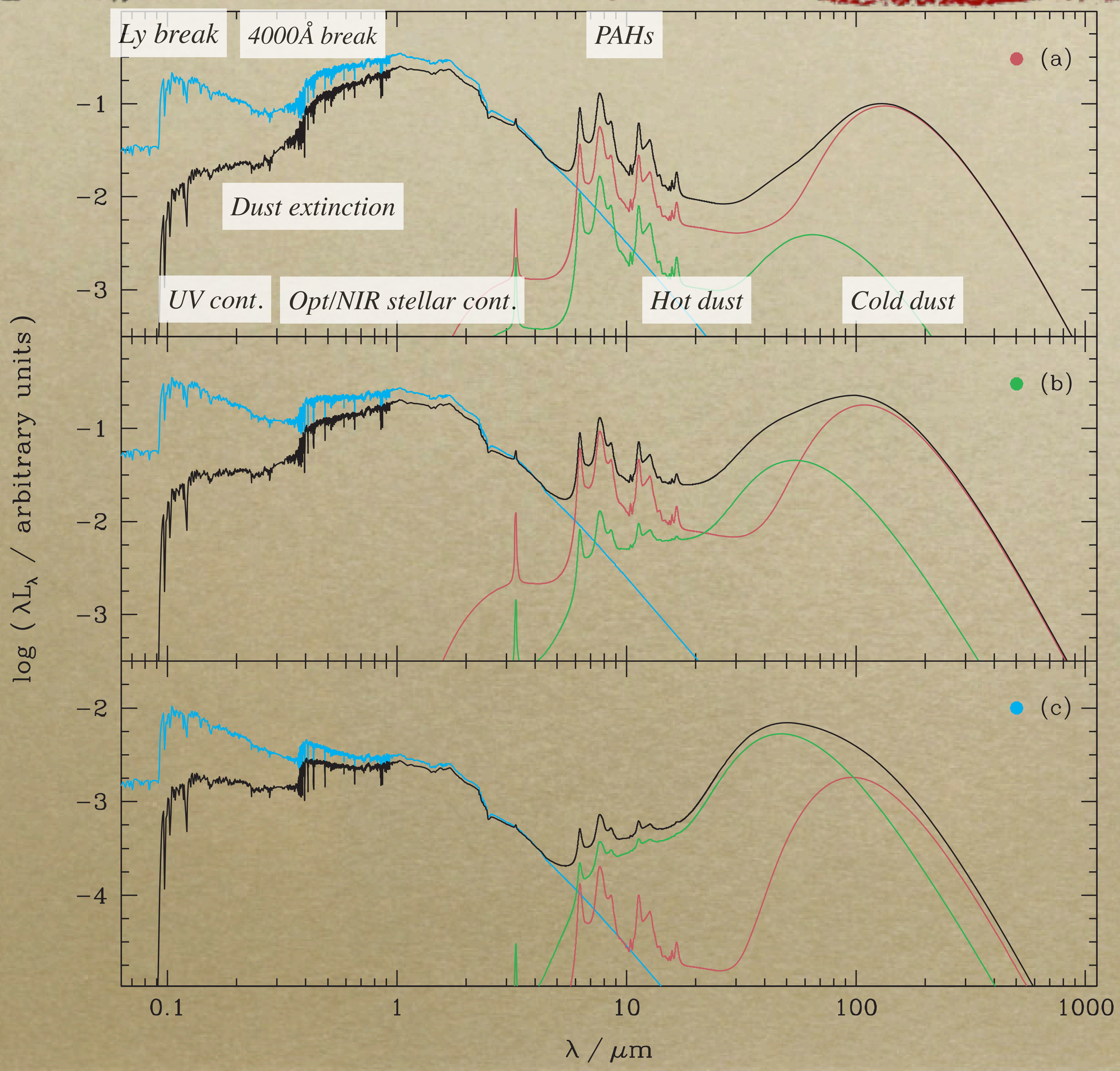
*In collaboration with **Brent Groves** (MPIA)*

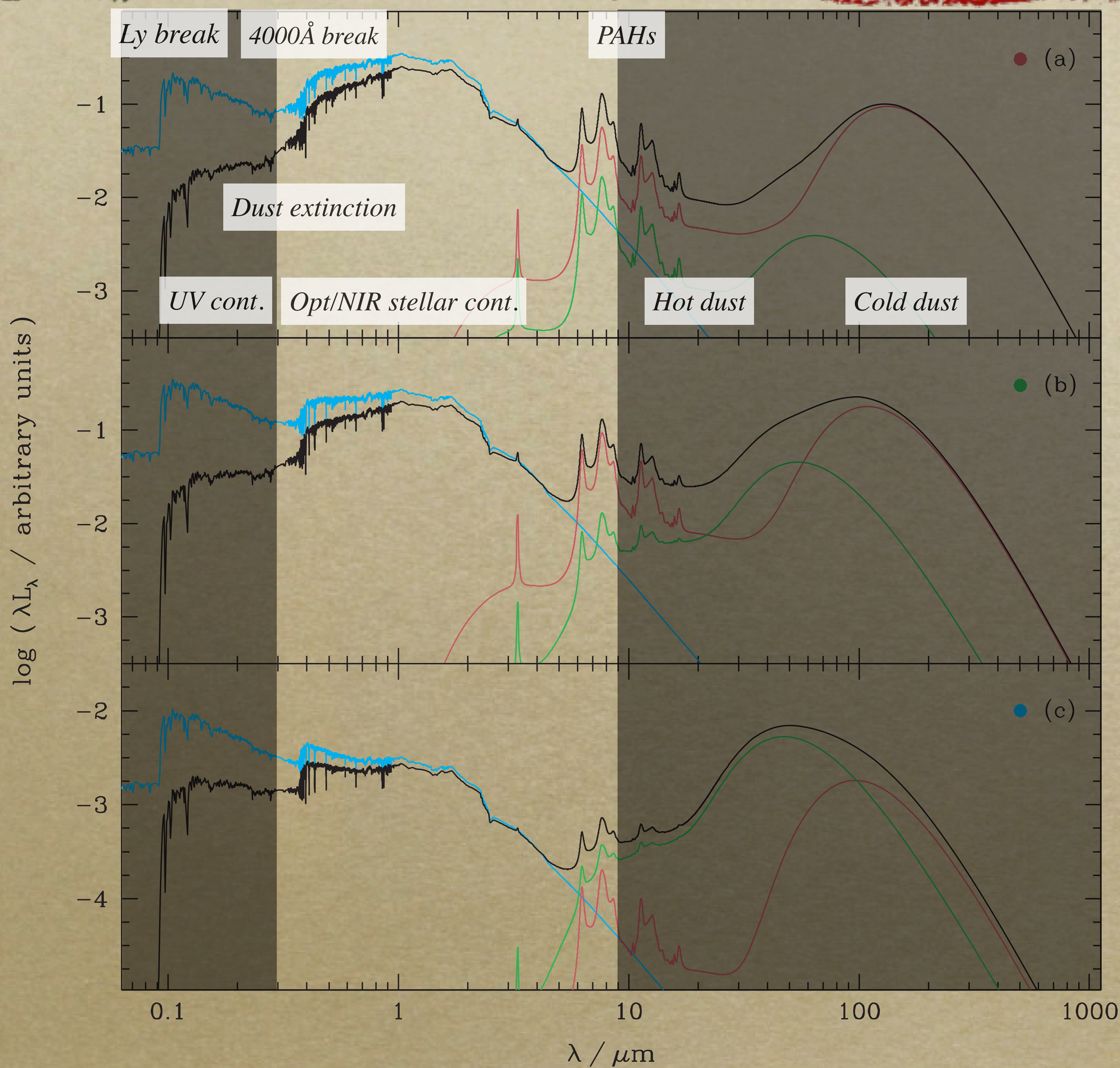
30.6.2011 - From dust to Galaxies - IAP

Galaxy SEDs: the link between stars and dust



DaCunha+08

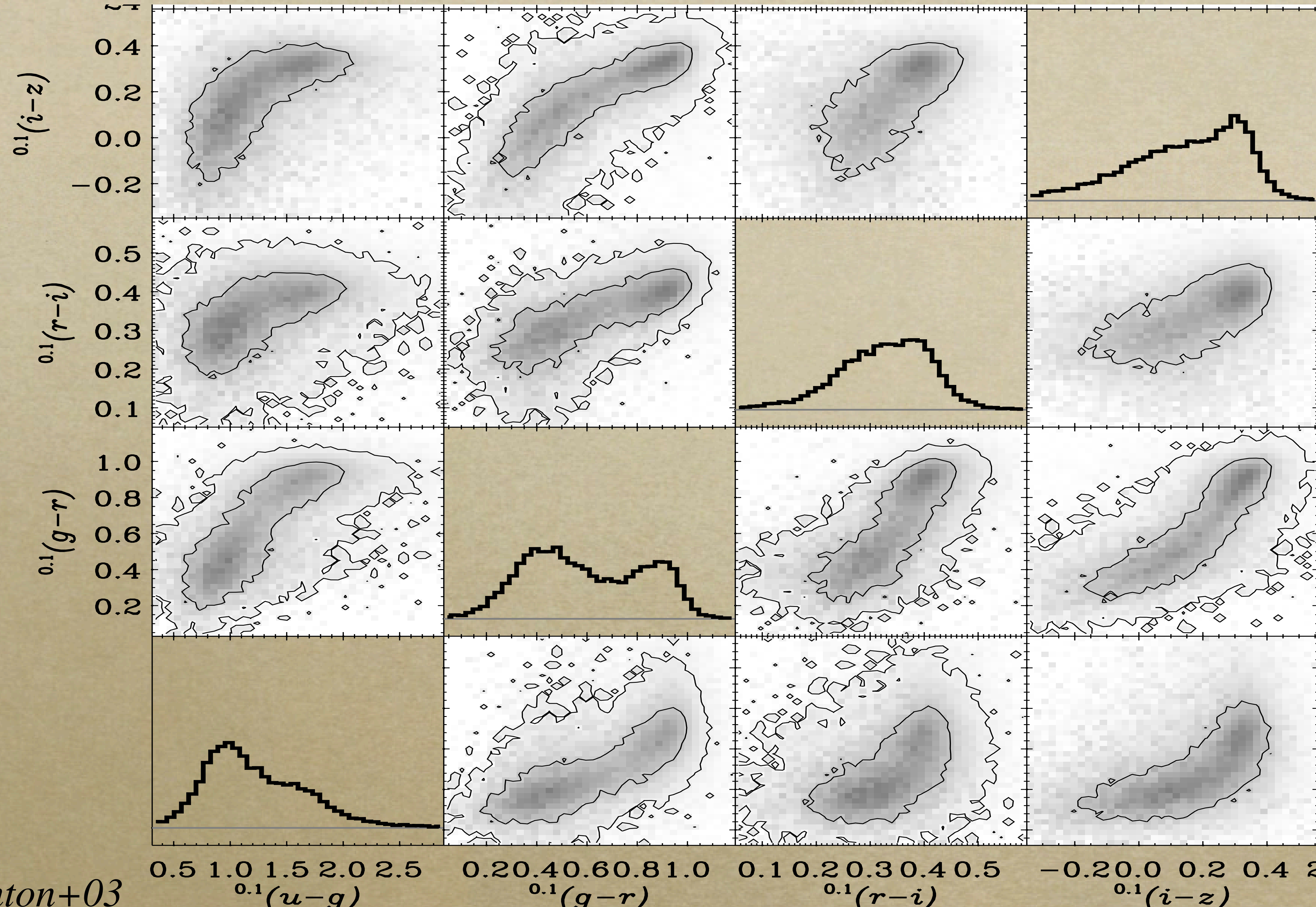
Galaxy SEDs: the link between stars and dust



DaCunha+08

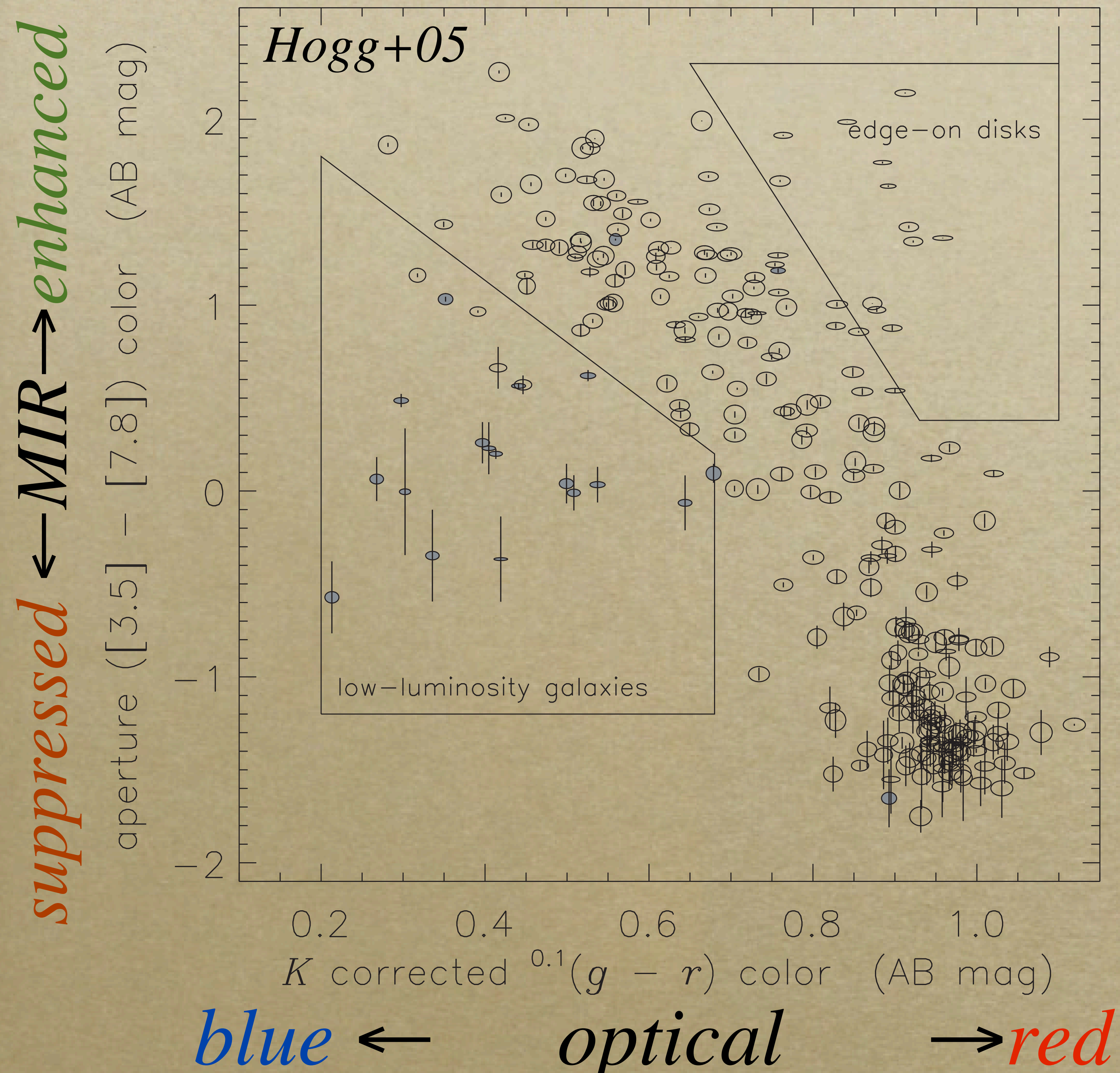
“Obvious” ***global*** optical-(mid)IR correlations

- ***Global*** *correlations between optical-optical, optical-IR and IR-IR colors are now well established*



Blanton+03

Optical colors, correlated → shape of stellar cont., sensitive to age (plus Z and dust)



- *MIR vs opt/NIR colors ↔dust vs stellar emission*
- *High sSFR ⇒ blue optical colors due to young stars, abundant UV radiation absorbed and re-emitted produces enhanced IR*
- *Low sSFR ⇒ red optical colors, less IR*

Galaxies are more than a “point”

- ***Strong SED variations within galaxies**: different physical conditions, stellar populations, SF, dust*
- *Color **correlations** hold on “**local**” scales?*
  - *Physical mechanisms affecting optical and IR are concurrent and contrary: dust emission is powered by UV-blue luminous stars, which in turn are reddened by the dust!*
  - *once stars and dust clumps are resolved (**tens of pc**) relations **must break down***
  - *What about scales of approx. **0.1 to 1 kpc**?*
  - *Will this teach us anything about how **homogeneous** are galaxies and “**mixing**” timescales?*

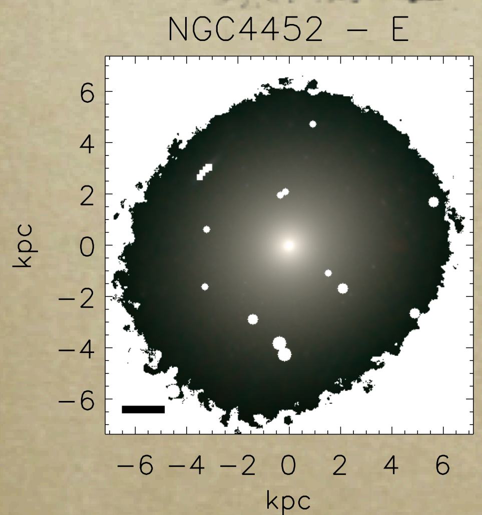
Setting up the experiment...

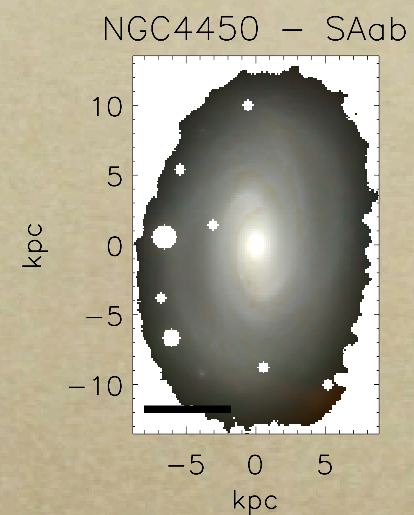
- *7 galaxies covering the full range of morphologies, D<20 Mpc, observed in*
  - *optical (ugriz SDSS)*
  - *H-band (1.65μm, CAHA/GOLDMine, UKIDSS)*
  - *3.6-4.5-5.7-8μm (Spitzer-IRAC, in SINGS)*
  - *Hα (SINGS ancillary)*
- *Bands matched in resolution, approx. 200 pc, and*
- *enhanced S/N (**adaptsmooth**-ed, SZ09)*

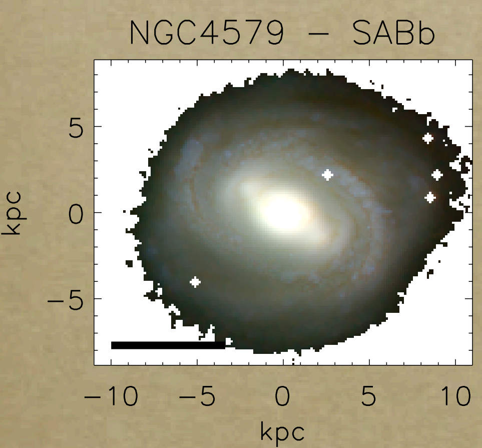
The sample in full color

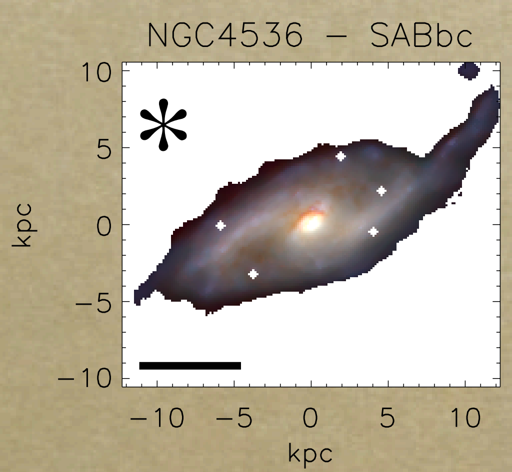
Table 2. Physical properties of the sample galaxies.

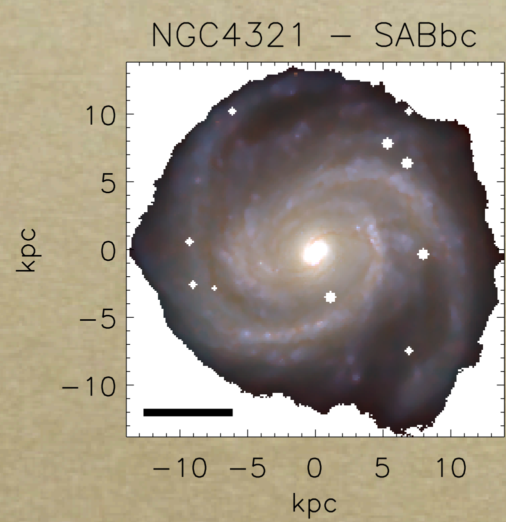
Denomination (1)	Morph. type (2)	Inclination degrees (3)	M^* log $M_\odot$ (4)	SFR log $M_\odot$ yr^{-1} (5)	sSFR log yr^{-1} (6)	Z(gas) 12 + log (O/H) (7)	Nuclear classification (8)
NGC 3521	SAB(rs)bc	64	10.52	0.33	−10.19	9.01	LINER
NGC 4254	SA(s)c	30	9.71	0.82	−8.89	9.17	LINER
NGC 4321	SAB(s)bc	32	10.46	0.55	−9.91	9.11	LINER
NGC 4450	SA(s)ab	43	10.80	0.03	−10.77	9.13	LINER
NGC 4536	SAB(rs)bc	67	9.59	0.49	−9.10	9.00	None[a]
NGC 4552	E0-1	...	10.97	...	...	9.12	LINER
NGC 4579	SAB(rs)b	38	10.06	−0.06	−10.12	9.22	LINER

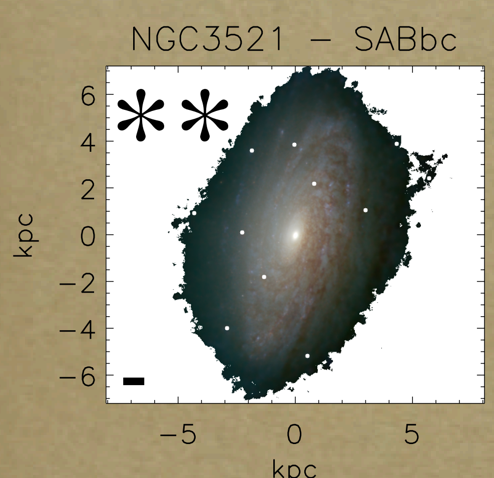


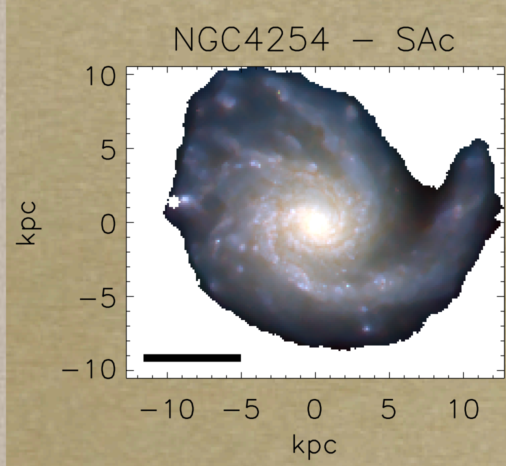






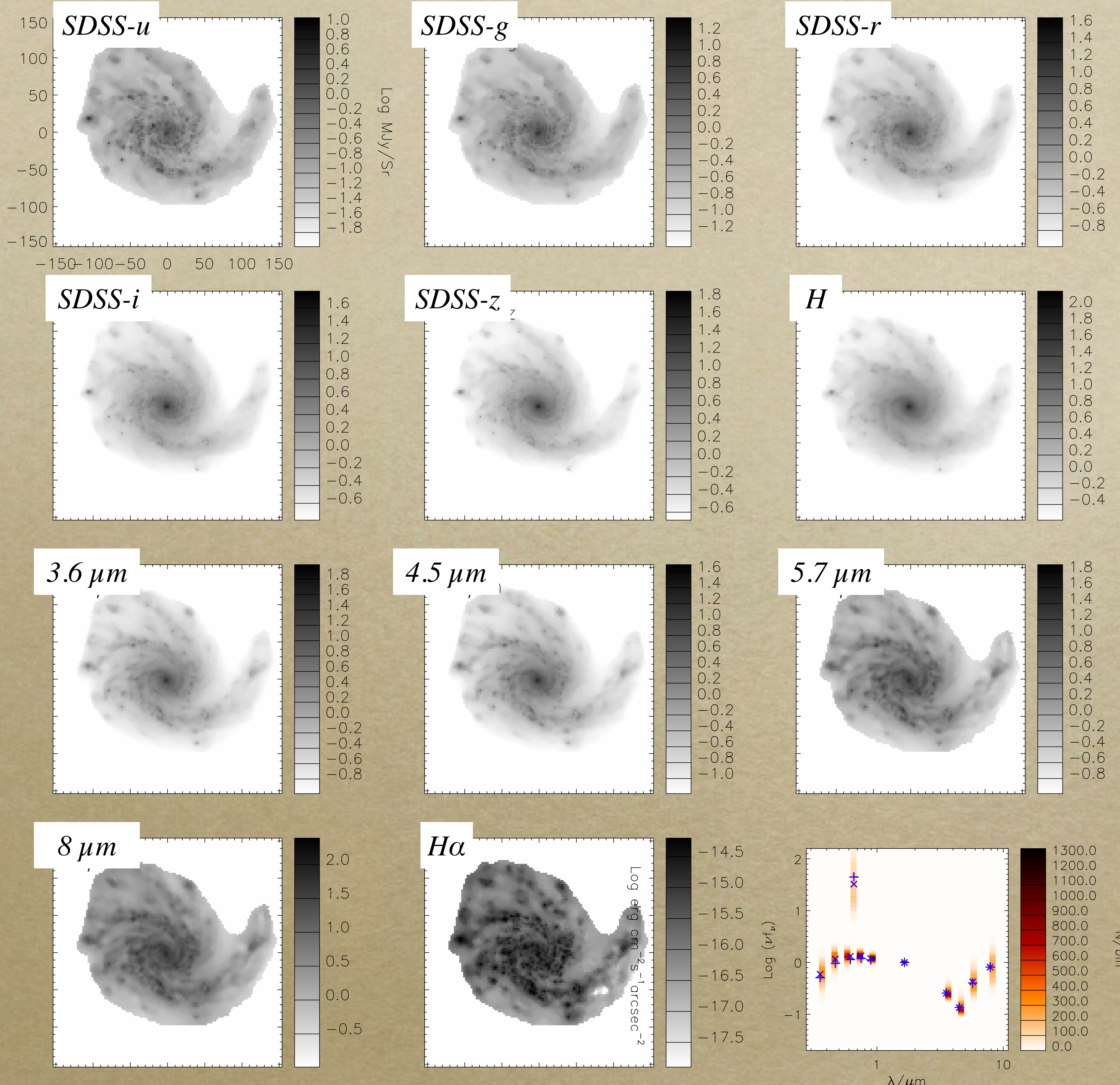




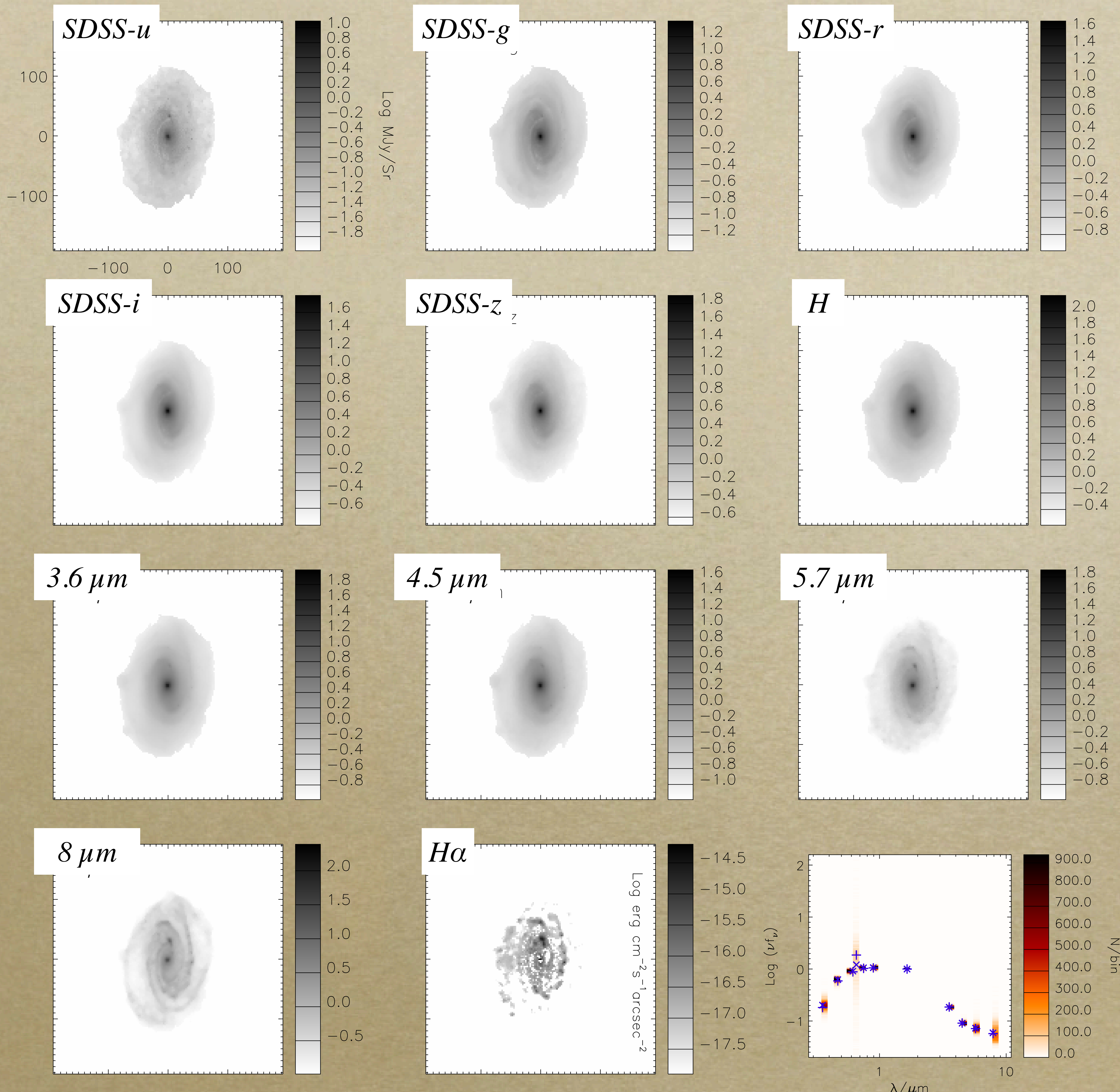


SZ, Charlot & Rix (2009, MNRAS)

NGC 4254

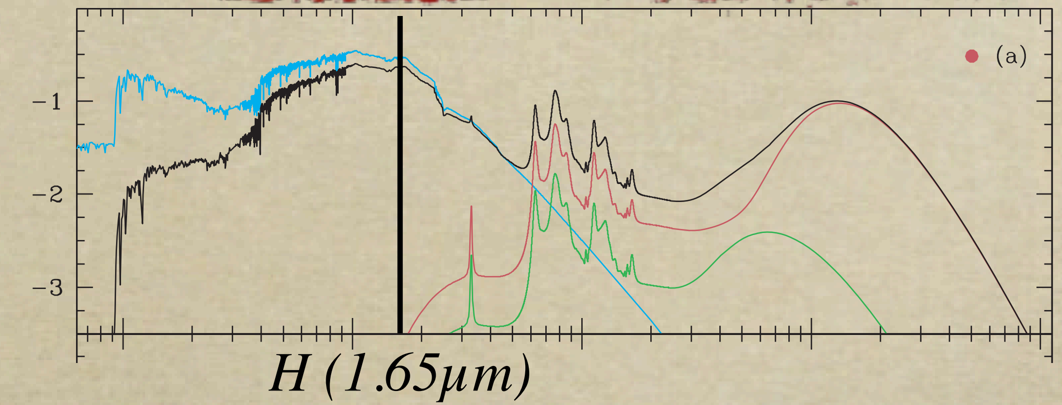

SDSS-u
SDSS-g
SDSS-r
SDSS-i
SDSS-z
H
3.6 μm
4.5 μm
5.7 μm
8 μm
Hα
Log MJy/Sr
Log erg cm^-2 s^-1 arcsec^-2
Log (νf_ν)
λ/μm
N/bin

NGC 4450



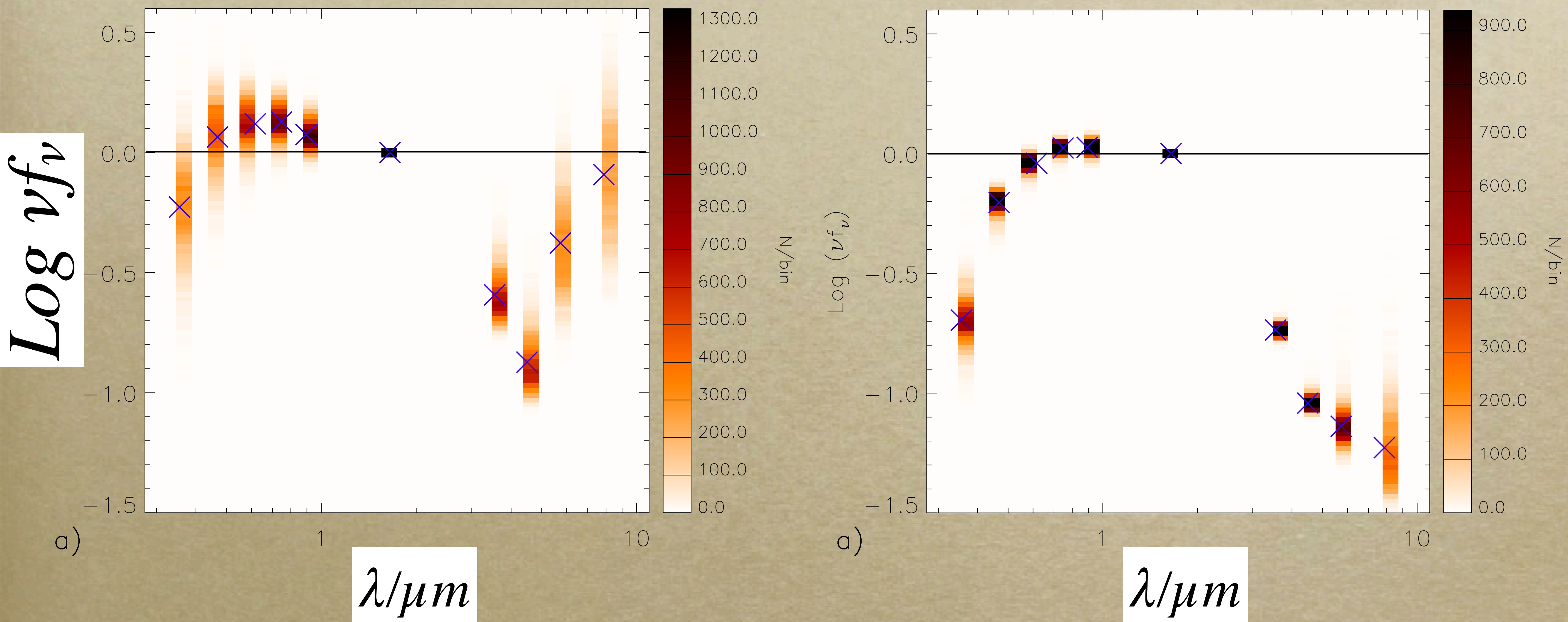
SDSS-u
SDSS-g
SDSS-r
SDSS-i
SDSS-z
H
3.6 μm
4.5 μm
5.7 μm
8 μm
Hα
Log MJy/Sr
Log erg cm^{-2}s^{-1}arcsec^{-2}
Log (νf_ν)
λ/μm
N/bin

H band-normalized SEDs



- *Normalize SEDs to H-band*
  - *describe SED* ***shape*** *independent of brightness*
  - *H-band (1.65μm) is a convenient boundary between stellar-light and dust-emission dominated wavelengths*
  - *Mostly sensitive to stellar mass, minimum contamination by dust either in emission or absorption*
- *Definition of "color":*
  - *color [X]=Log $\nu f_\nu(X)$ - Log $\nu f_\nu(H)$*

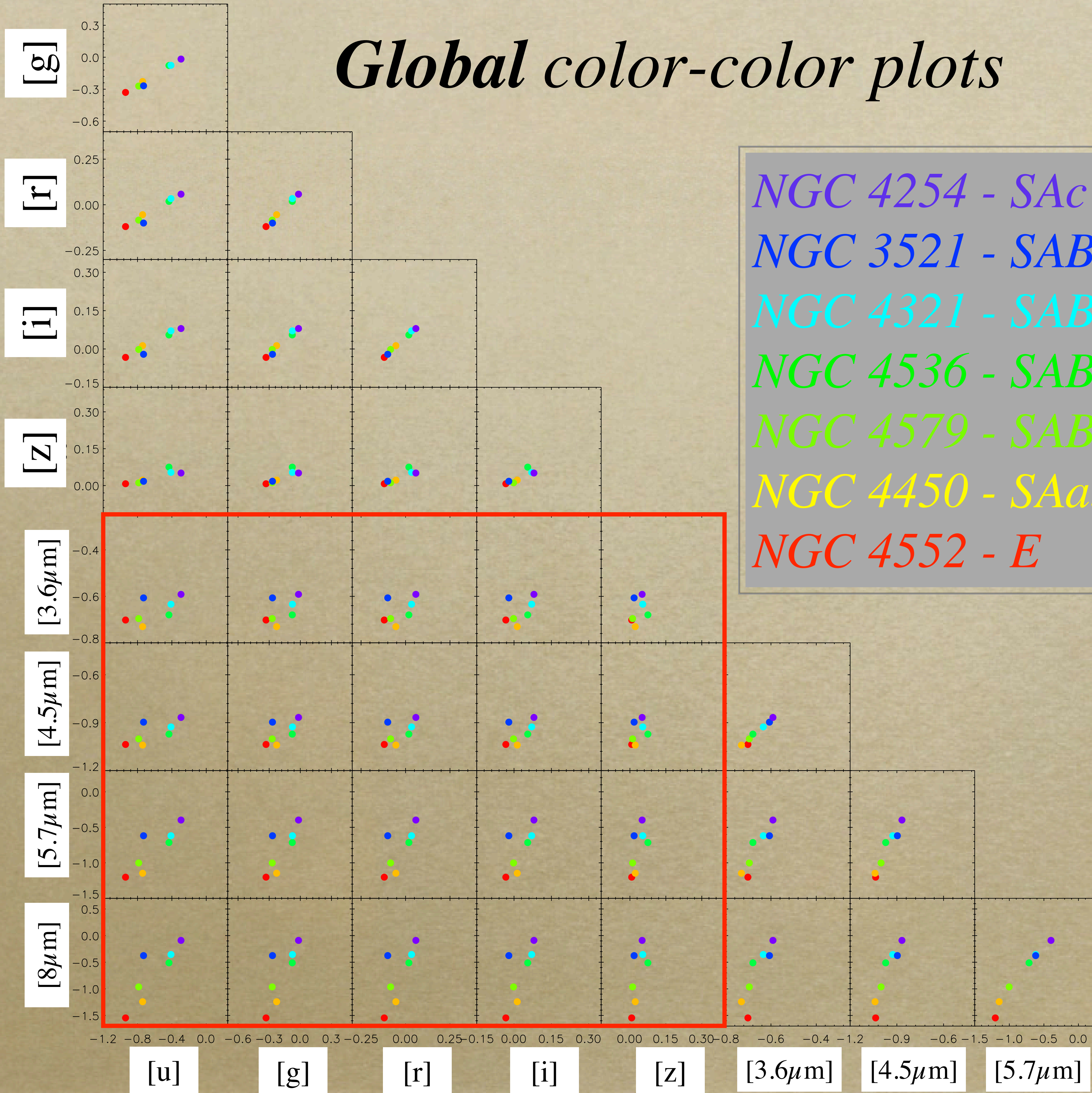
Recovery of known global correlations



NGC 4254:
blue optical,
enhanced MIR
large scatter

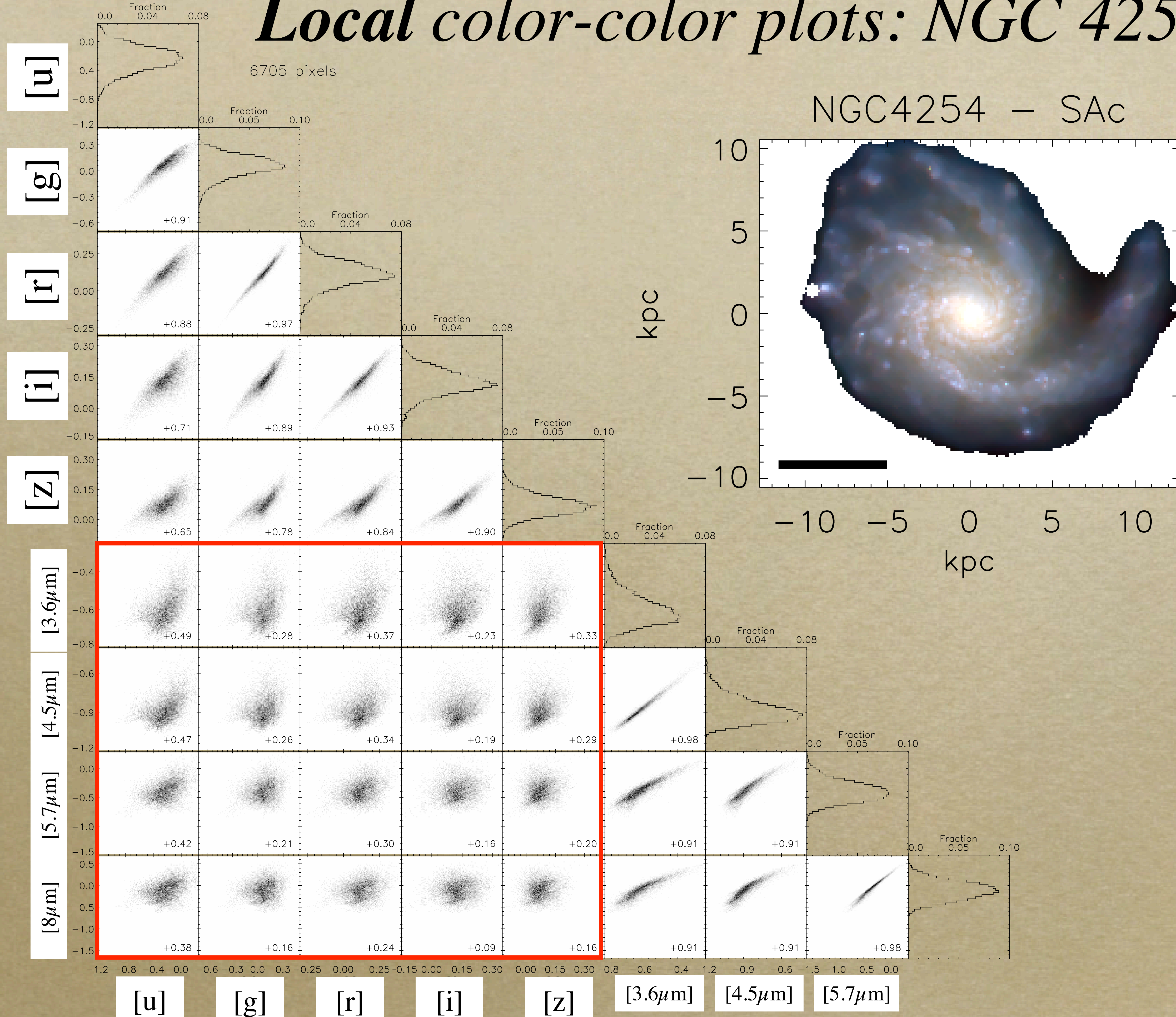
NGC 4450:
red optical,
low MIR
small scatter

Global *color-color plots*

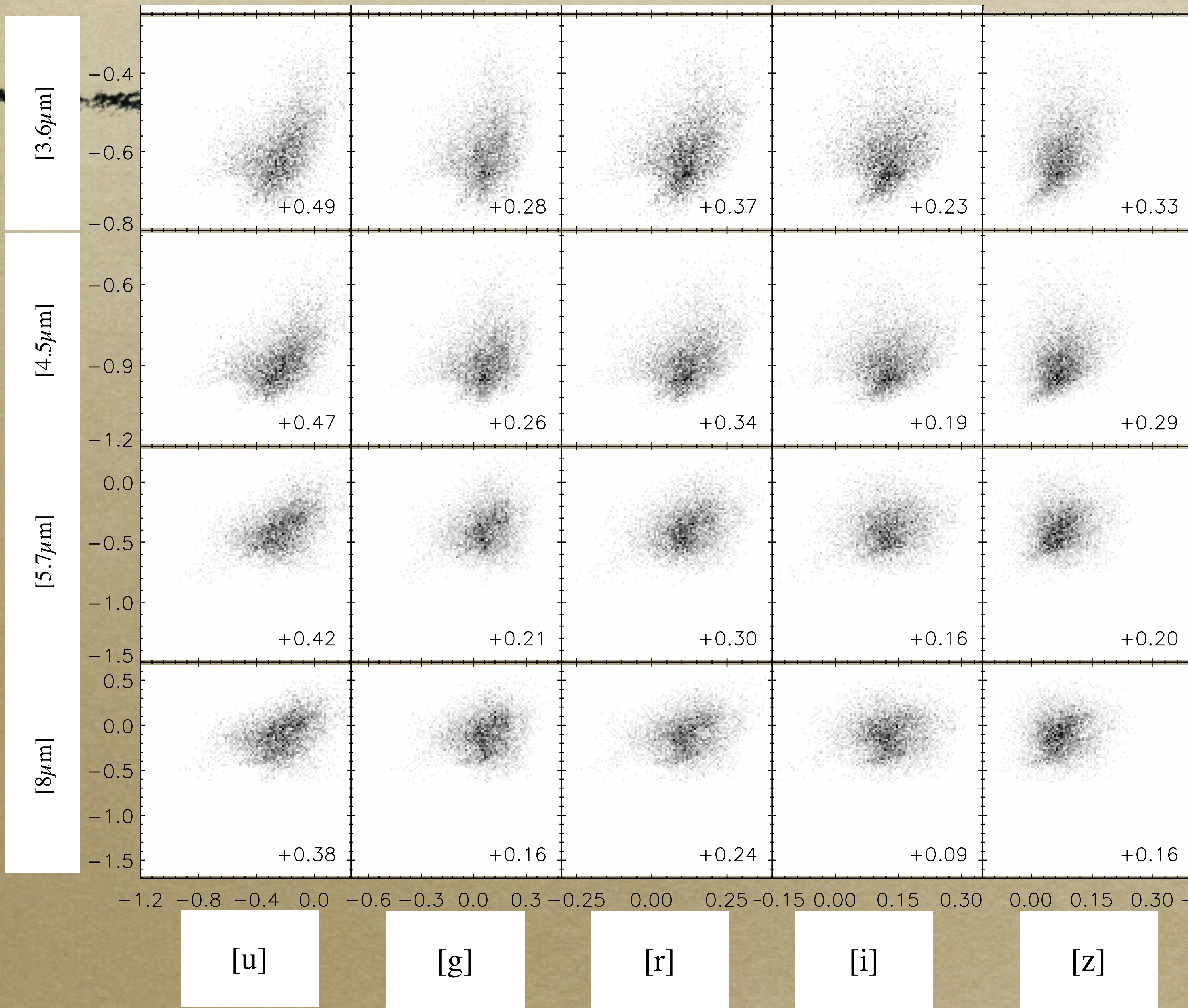


NGC 4254 - SAc
*NGC 3521 - SABbc***
NGC 4321 - SABbc
*NGC 4536 - SABbc**
NGC 4579 - SABb
NGC 4450 - SAab
NGC 4552 - E

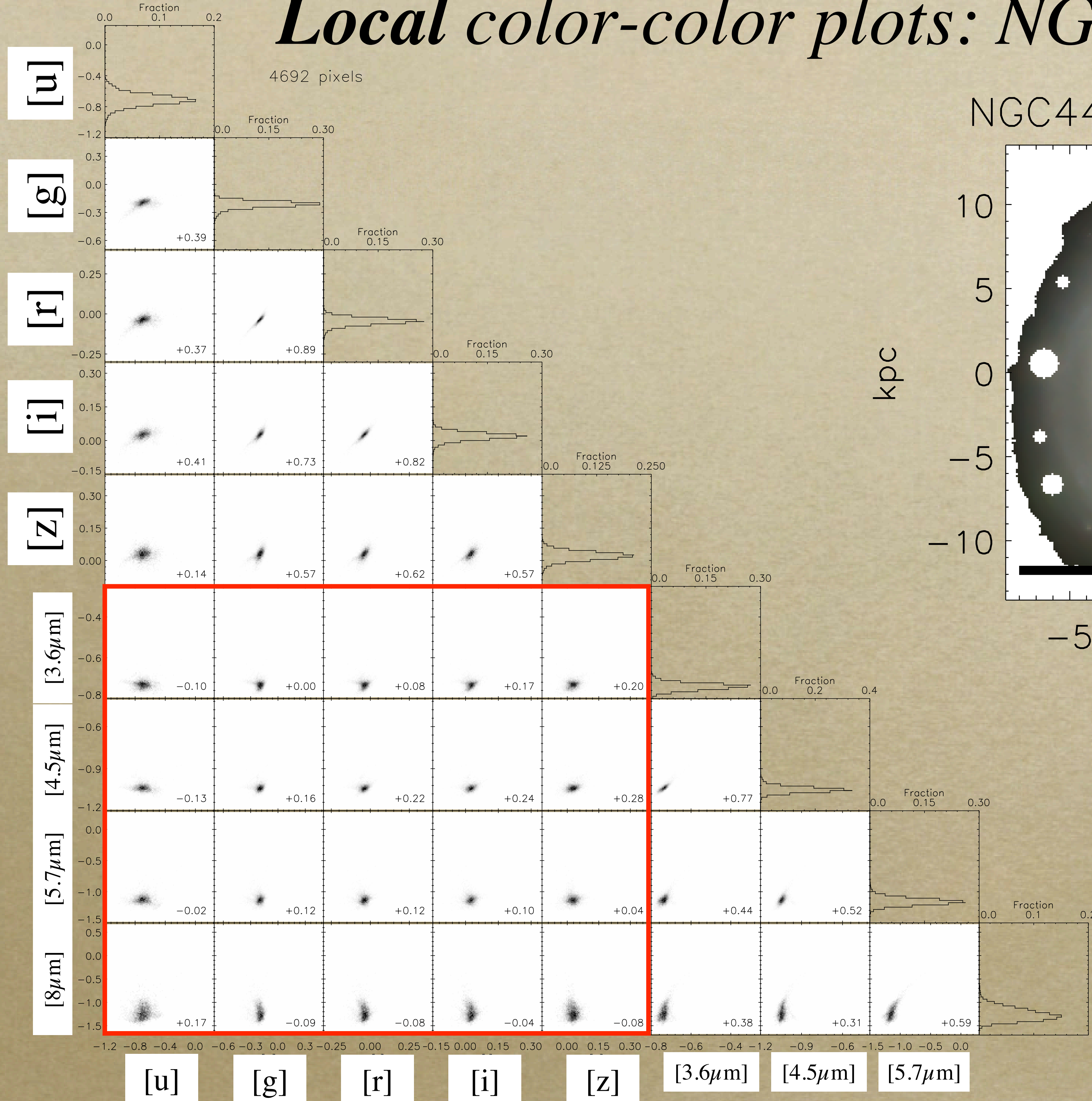
Local *color-color plots: NGC 4254*

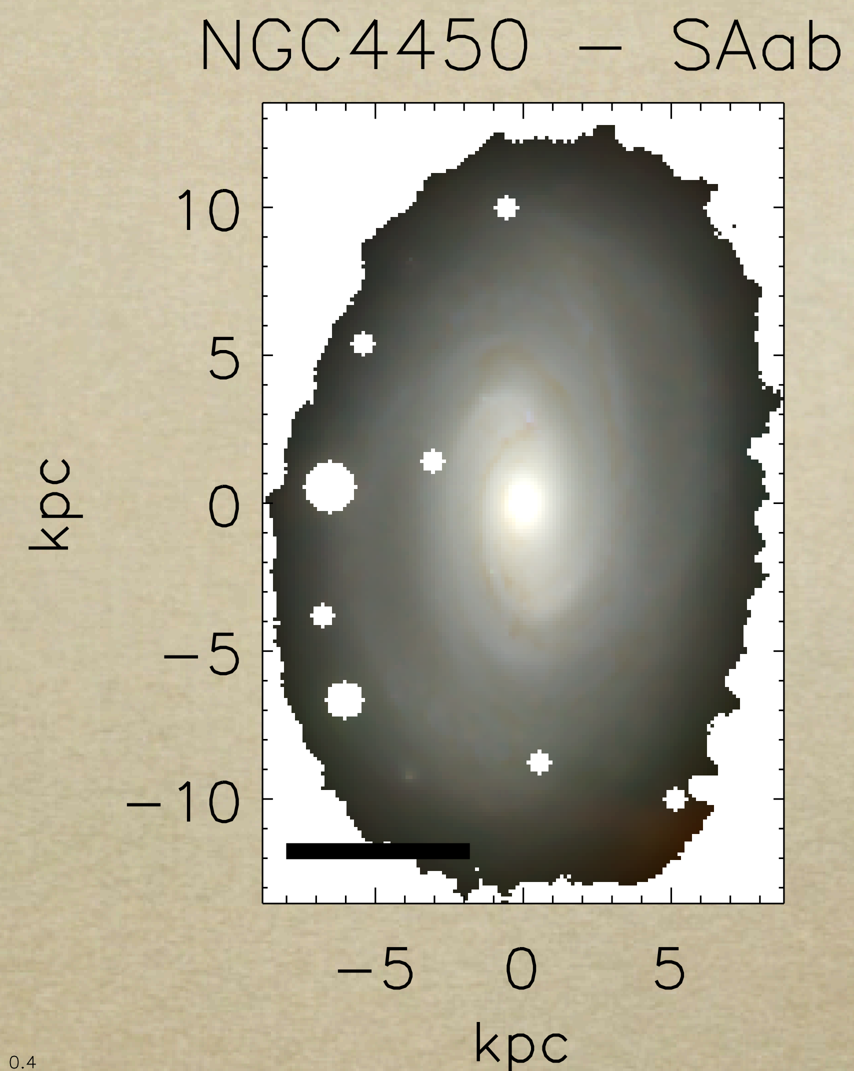


Break down of opt-IR correlations on scales of ≈0.2 kpc



Local *color-color plots: NGC 4450*





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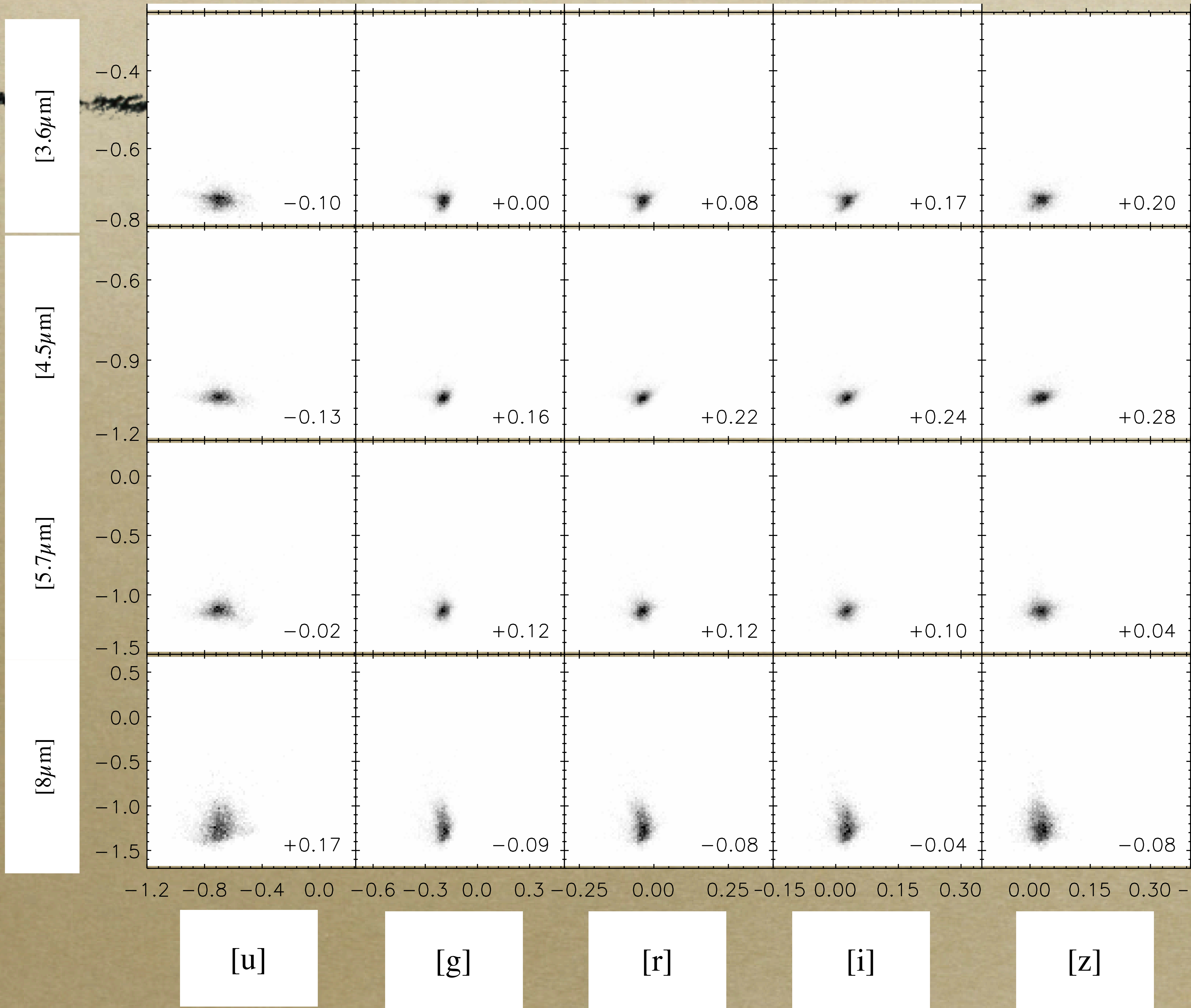
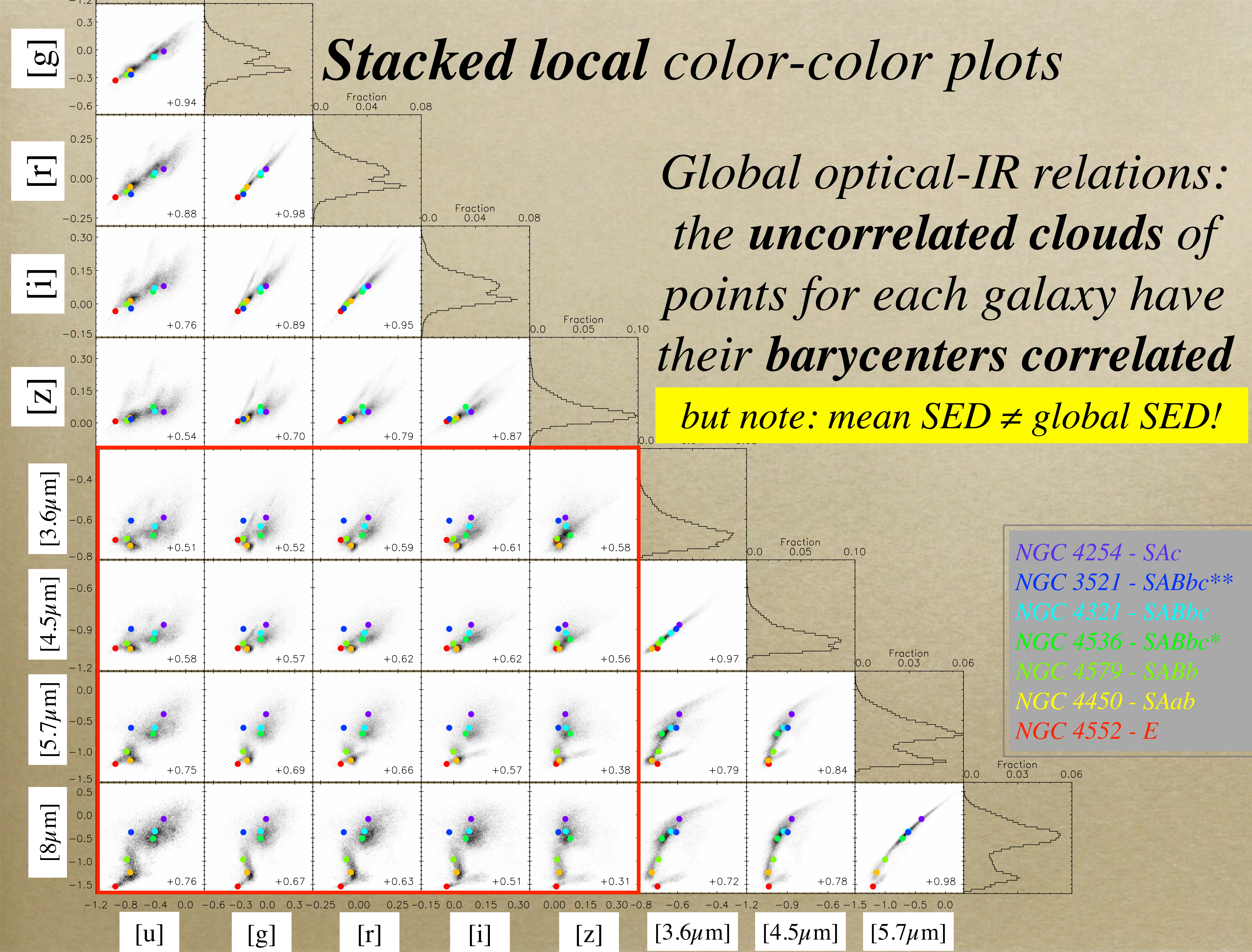


Stacked local *color-color plots*

Global optical-IR relations: the ***uncorrelated clouds*** *of points for each galaxy have their* ***barycenters correlated***

but note: mean SED ≠ global SED!



- *On local (~0.2 kpc) scales:*
  - *optical and IR largely independent*
  - *optical-optical and IR-IR well correlated*

- *On local (~0.2 kpc) scales:*
  - *optical and IR largely independent*
  - *optical-optical and IR-IR well correlated*
- *Are local SEDs a 2-parameter family?*

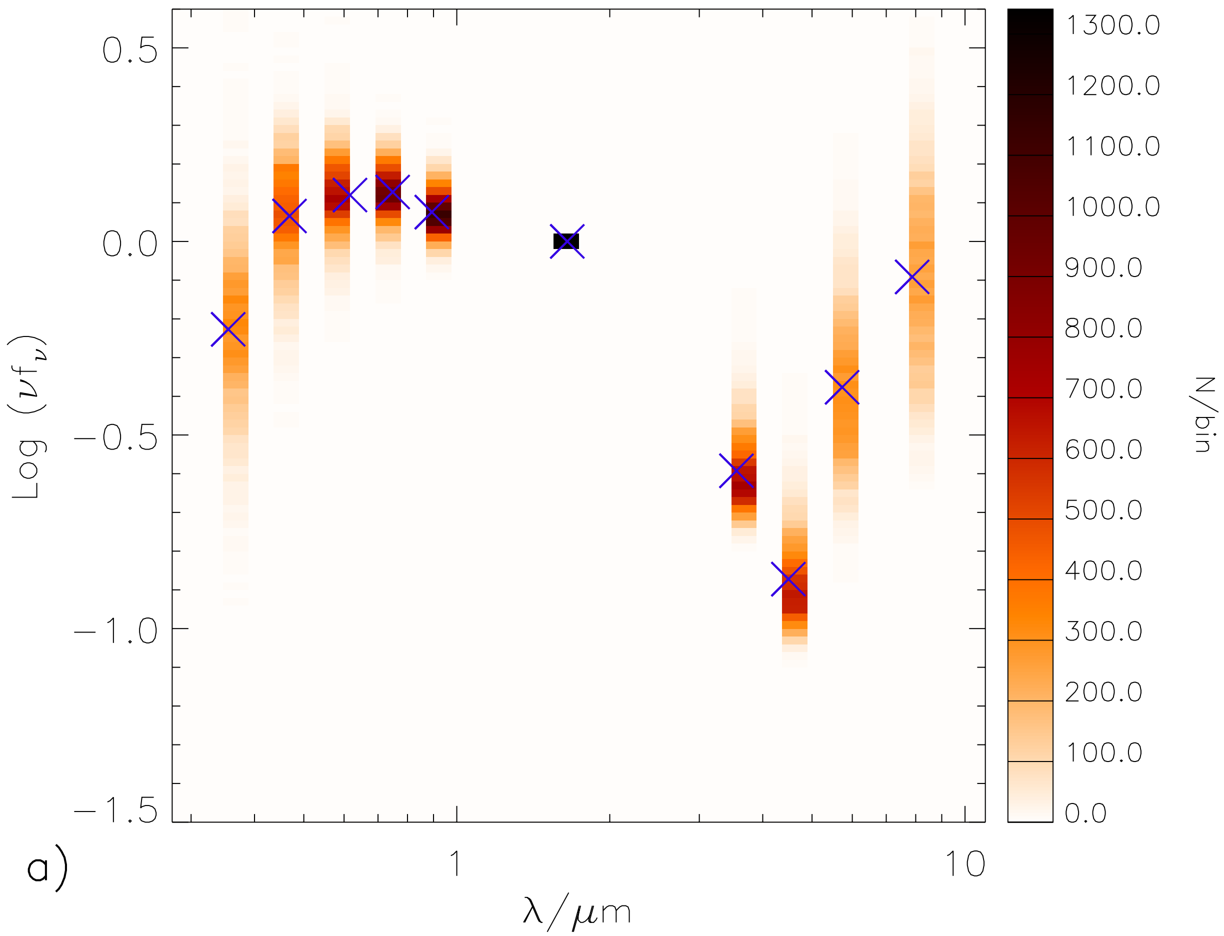
Principal component analysis (PCA)

$$\mathrm{SED}_i = \{\log \nu_X f_{\nu_X,i} - \log \nu_H f_{\nu_H,i}\}_{X=u,g,r,i,z,3.6,4.5,5.7,8\mu\mathrm{m}}$$

$$\mathrm{SED}_i = \mathrm{SED}_{\mathrm{mean}} + \sum_{j=1,9} a_{i,j} \mathrm{PC}j$$

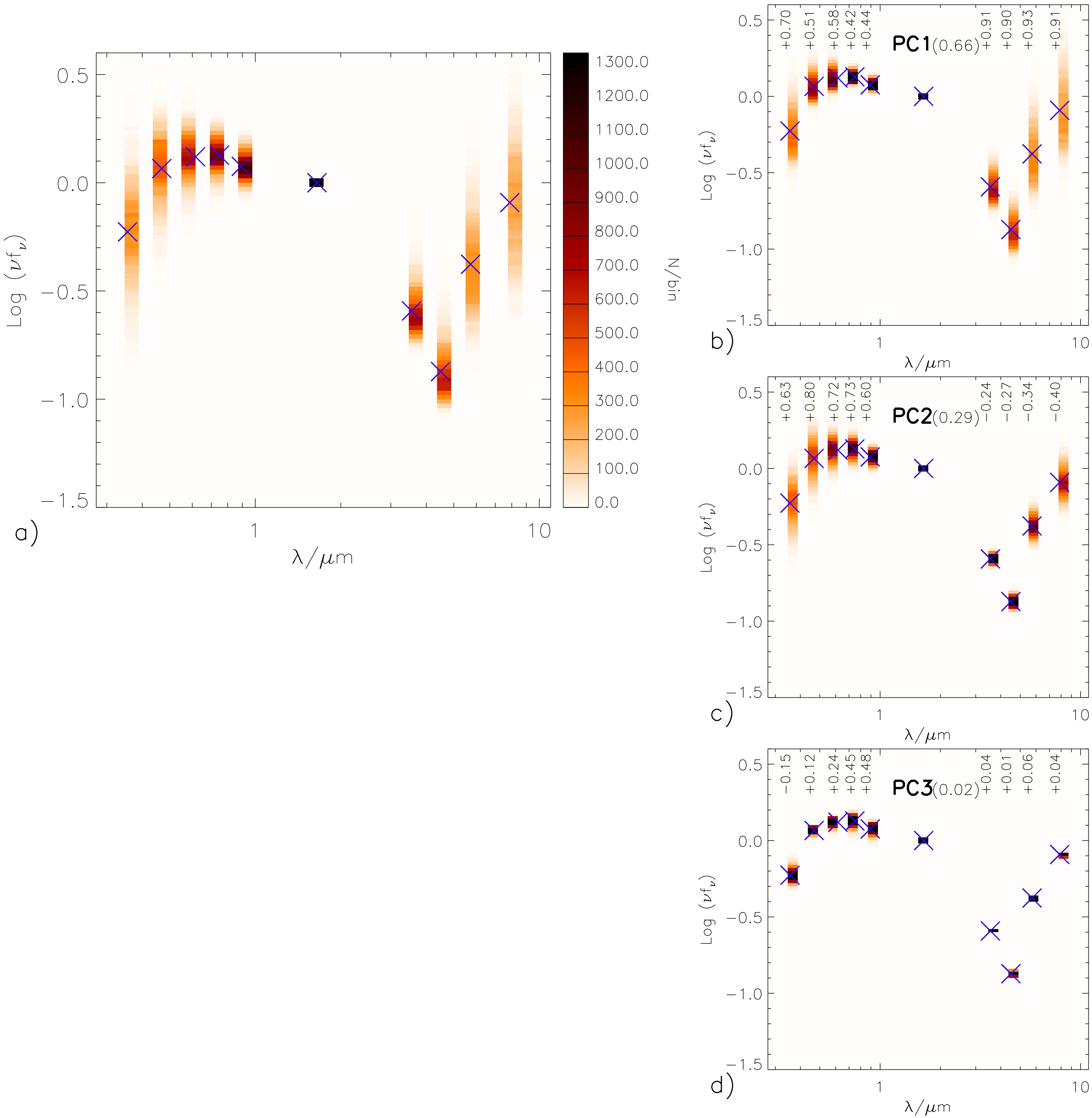
- *PC_j are **uncorrelated** and*
- *ordered such that the **first** PCs retain **most of the variation***
- *SED_i vectors well represented by the linear combination of the first few PCs*

NGC 4254



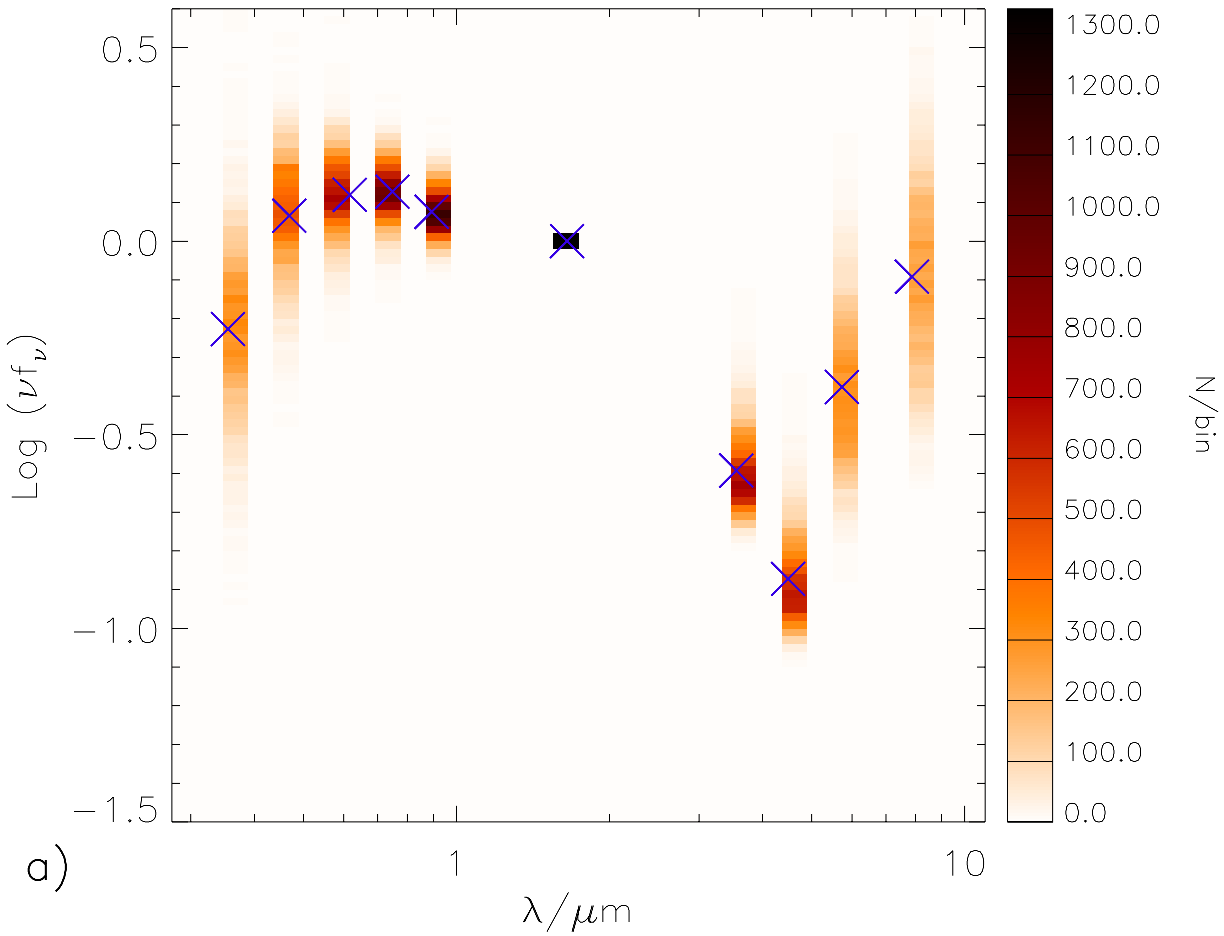
Log (νf_ν)
0.5
0.0
−0.5
−1.0
−1.5
1
10
λ/μm
a)
N/bin
1300.0
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0

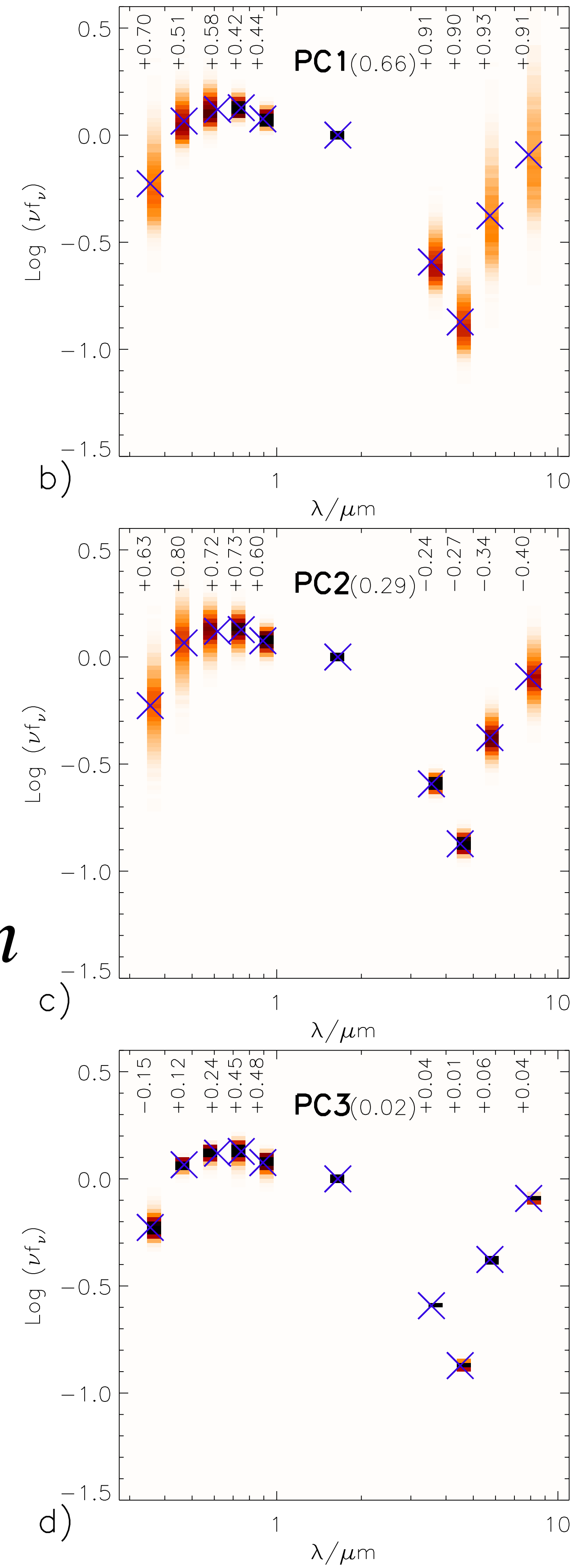
NGC 4254



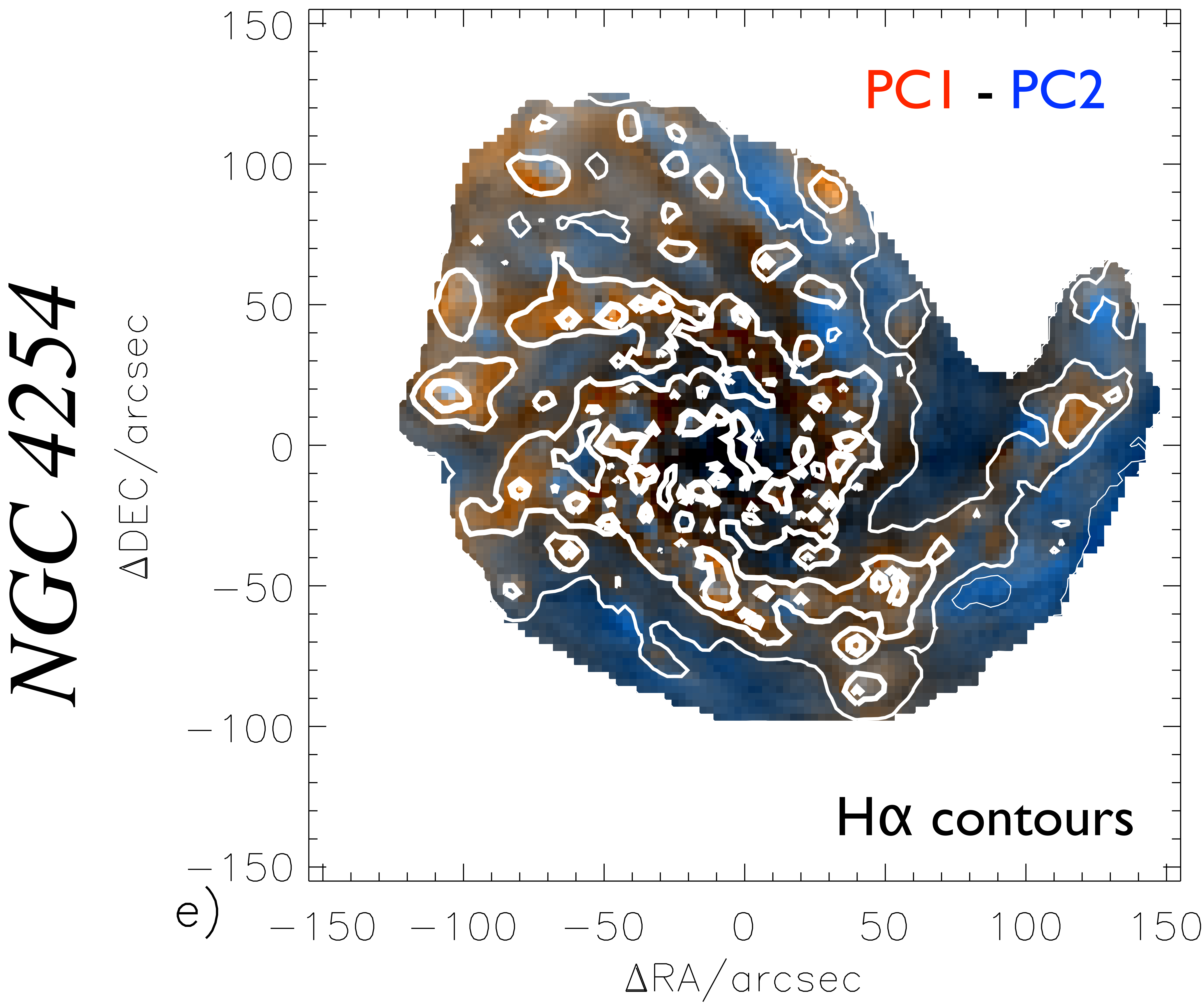
a)
b)
c)
d)
Log (νf_ν)
λ/μm
N/bin
PC1(0.66)
PC2(0.29)
PC3(0.02)
+0.70 +0.51 +0.58 +0.42 +0.44 +0.91 +0.90 +0.93 +0.91
+0.63 +0.80 +0.72 +0.73 +0.60 −0.24 −0.27 −0.34 −0.40
−0.15 +0.12 +0.24 +0.45 +0.48 +0.04 +0.01 +0.06 +0.04

NGC 4254

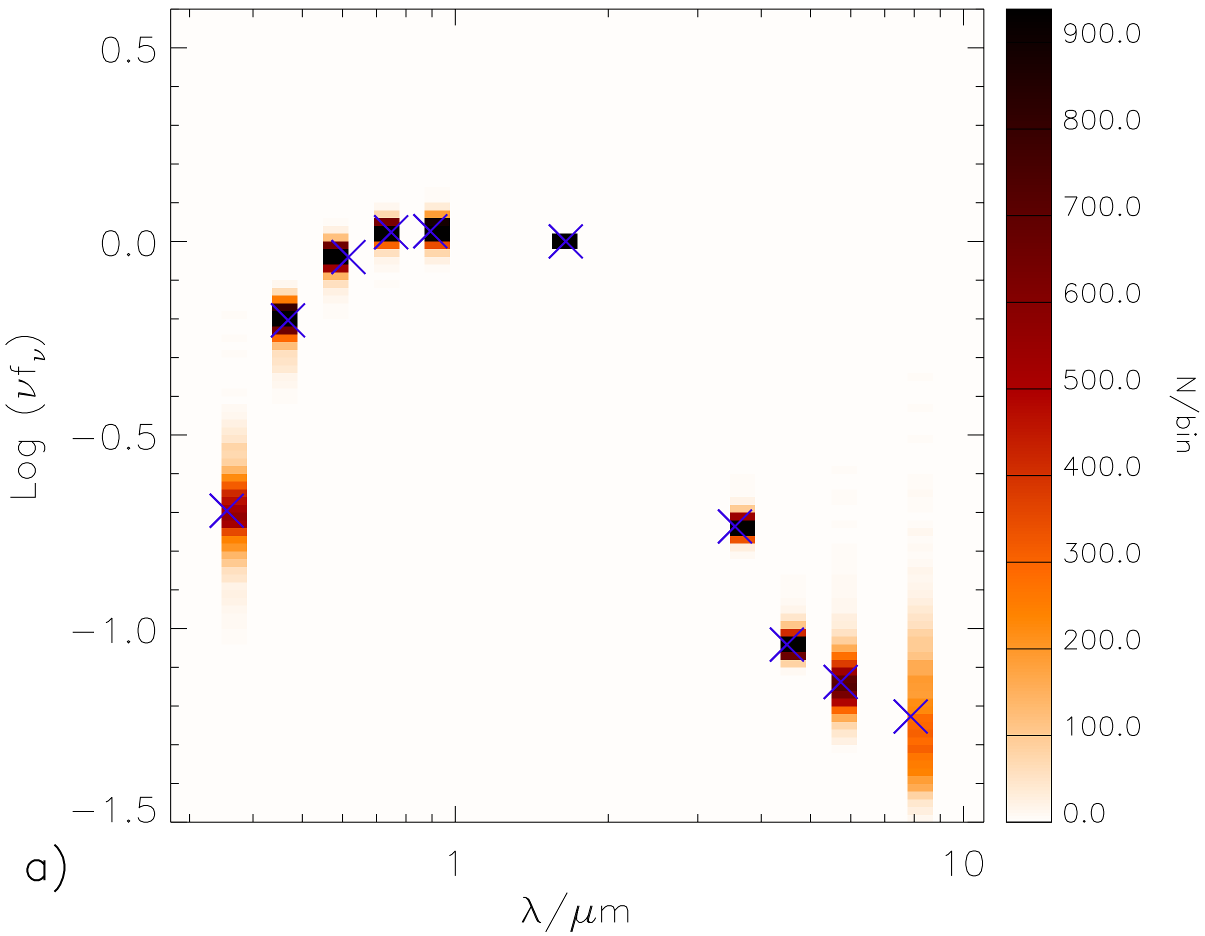




- *PC1 is driven by variations in IR (i.e. PAHs and hot dust)*
- *PC2 dominates variations in optical, driven by age, dust absorption [and Z]*


NGC 4254
PC1 - PC2
Hα contours
ΔDEC/arcsec
ΔRA/arcsec
e)
150
100
50
0
−50
−100
−150

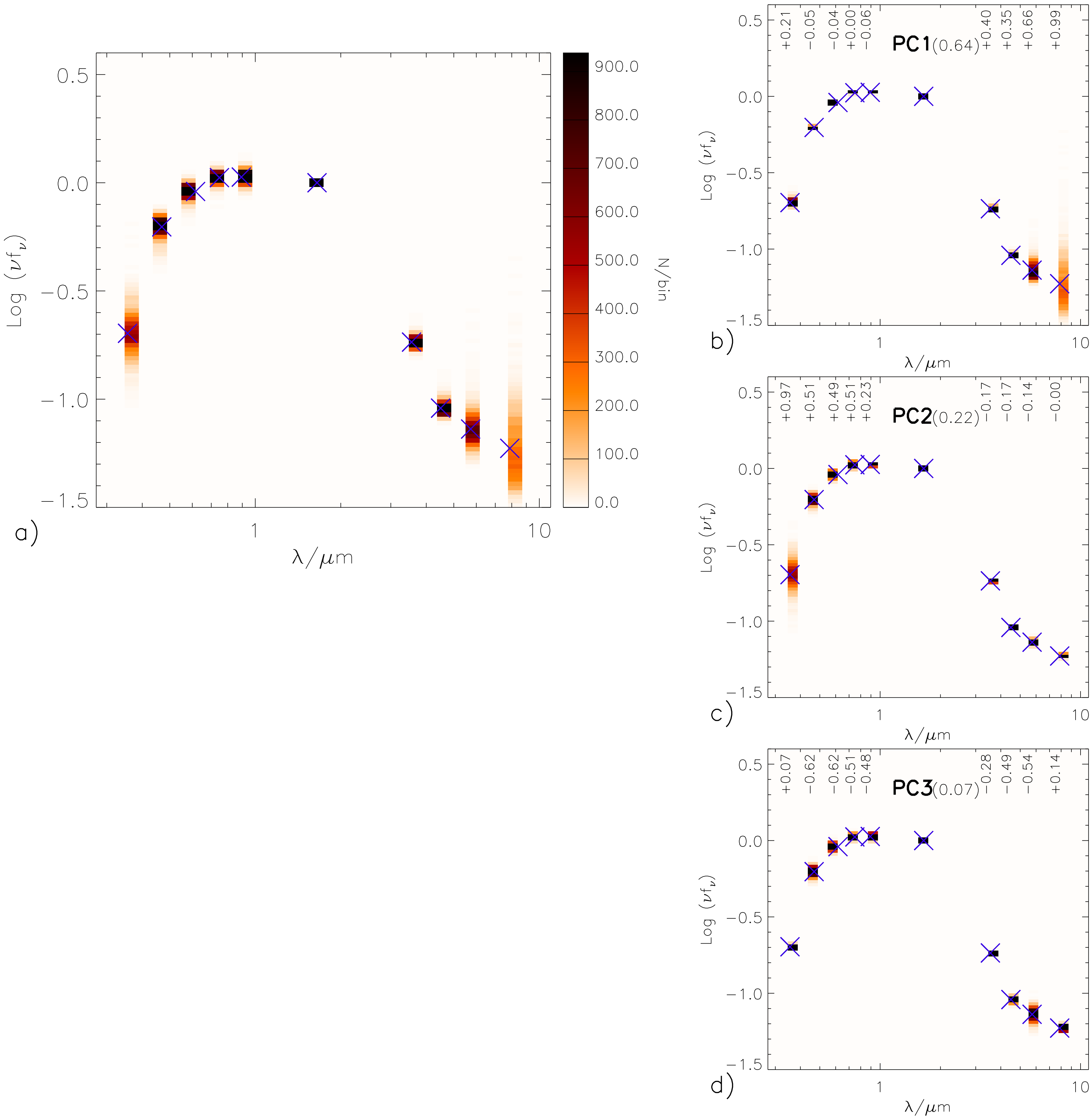
NGC 4450



0.5
0.0
−0.5
−1.0
−1.5
Log (νf_ν)
1
10
λ/μm
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
N/bin

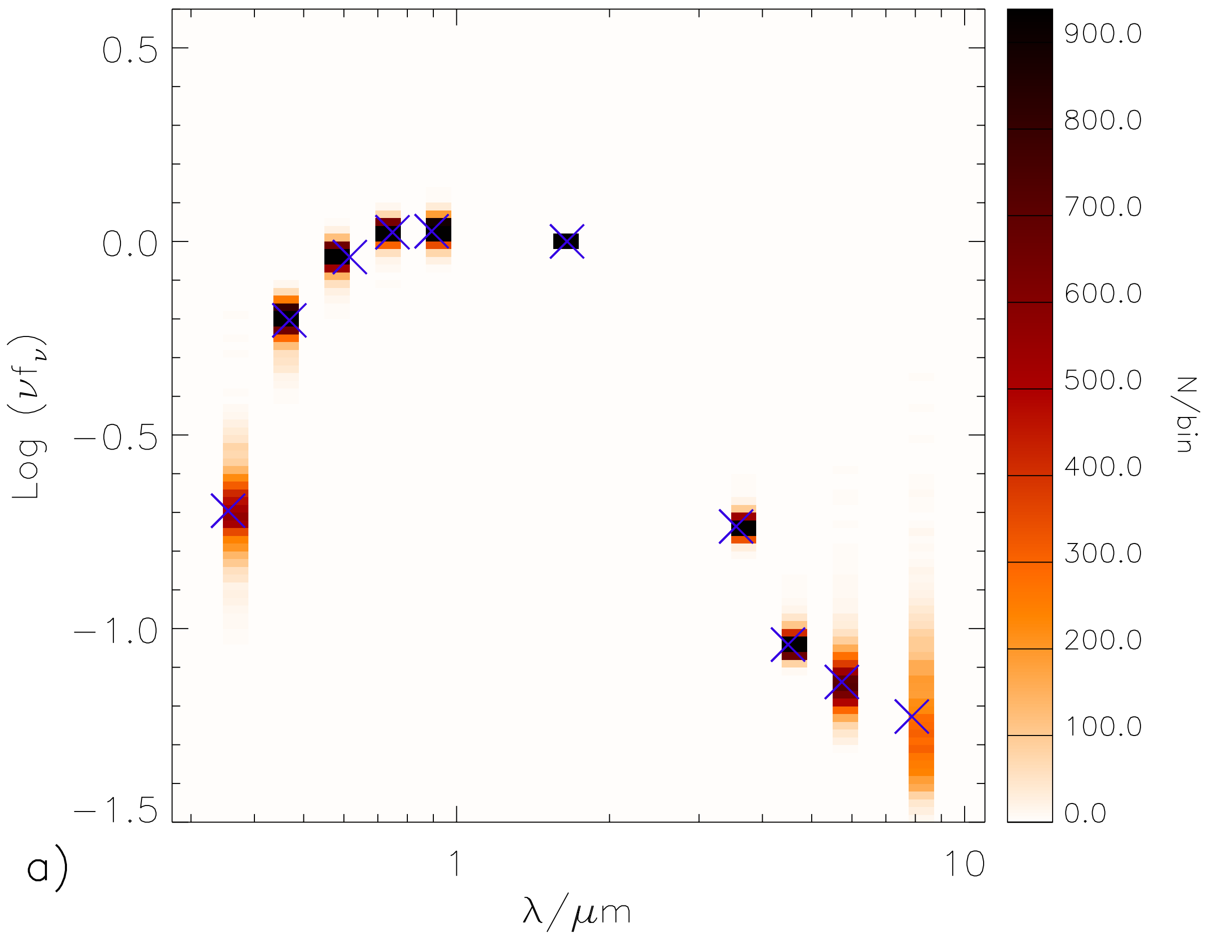
a)

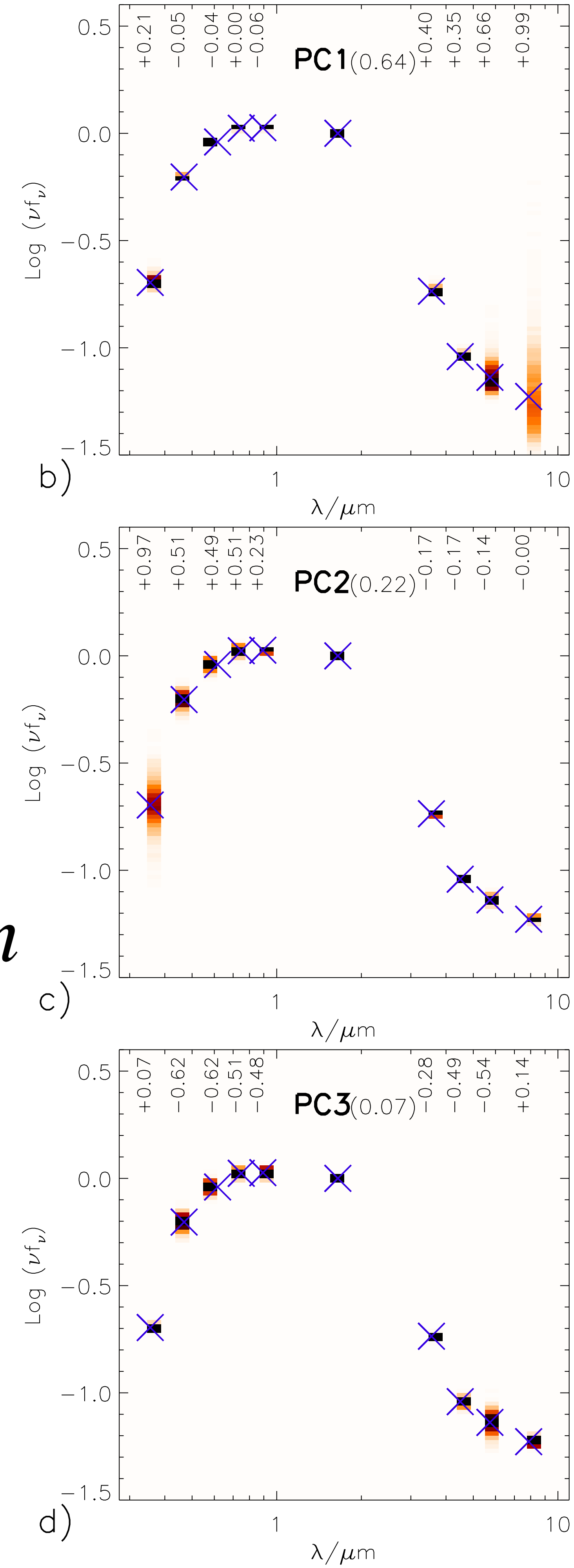
NGC 4450



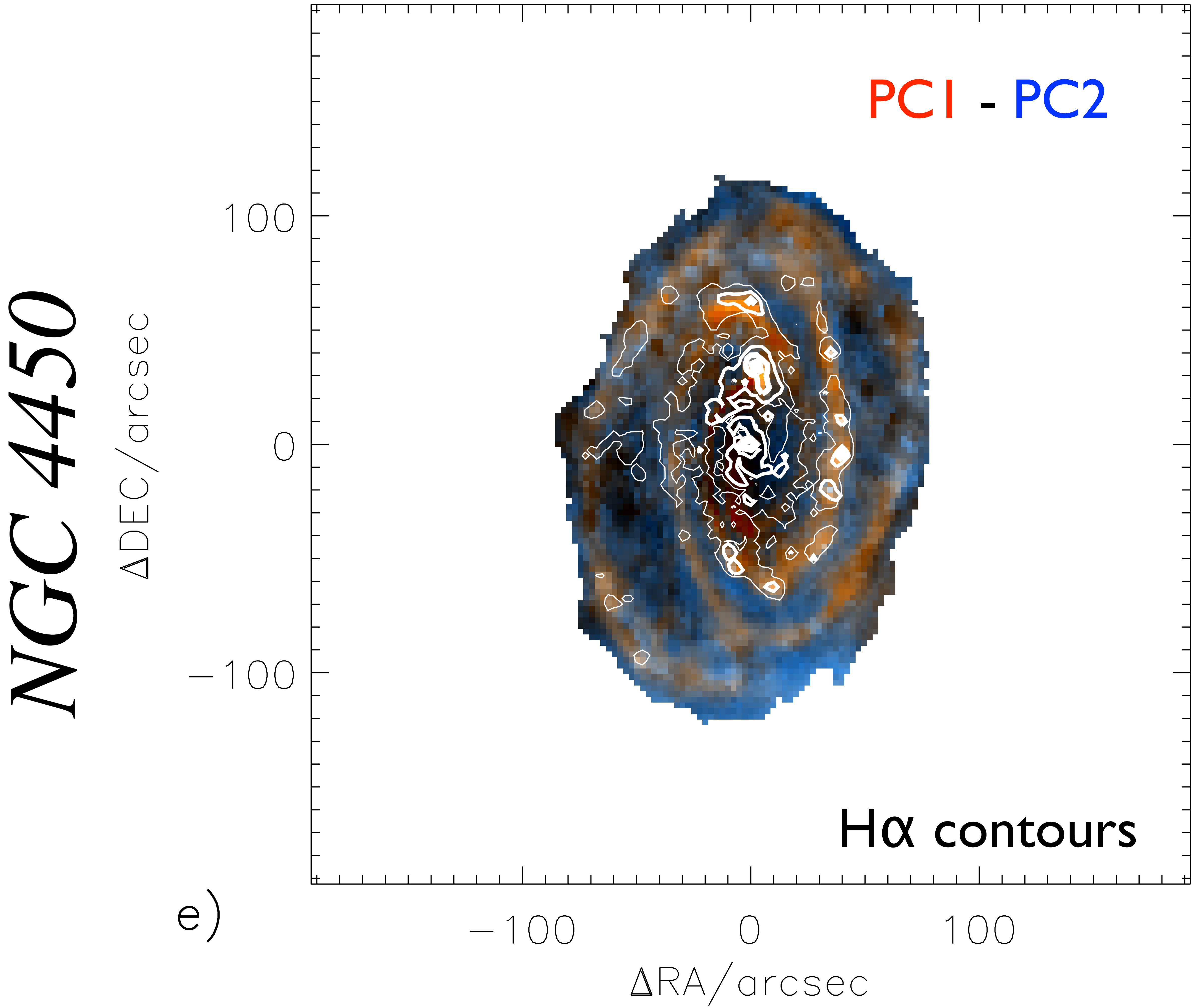
a)
b)
c)
d)
Log (νf_ν)
λ/μm
N/bin
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
PC1(0.64)
+0.21 −0.05 −0.04 +0.00 −0.06 +0.40 +0.35 +0.66 +0.99
PC2(0.22)
+0.97 +0.51 +0.49 +0.51 +0.23 −0.17 −0.17 −0.14 −0.00
PC3(0.07)
+0.07 −0.62 −0.62 −0.51 −0.48 −0.28 −0.49 −0.54 +0.14

NGC 4450



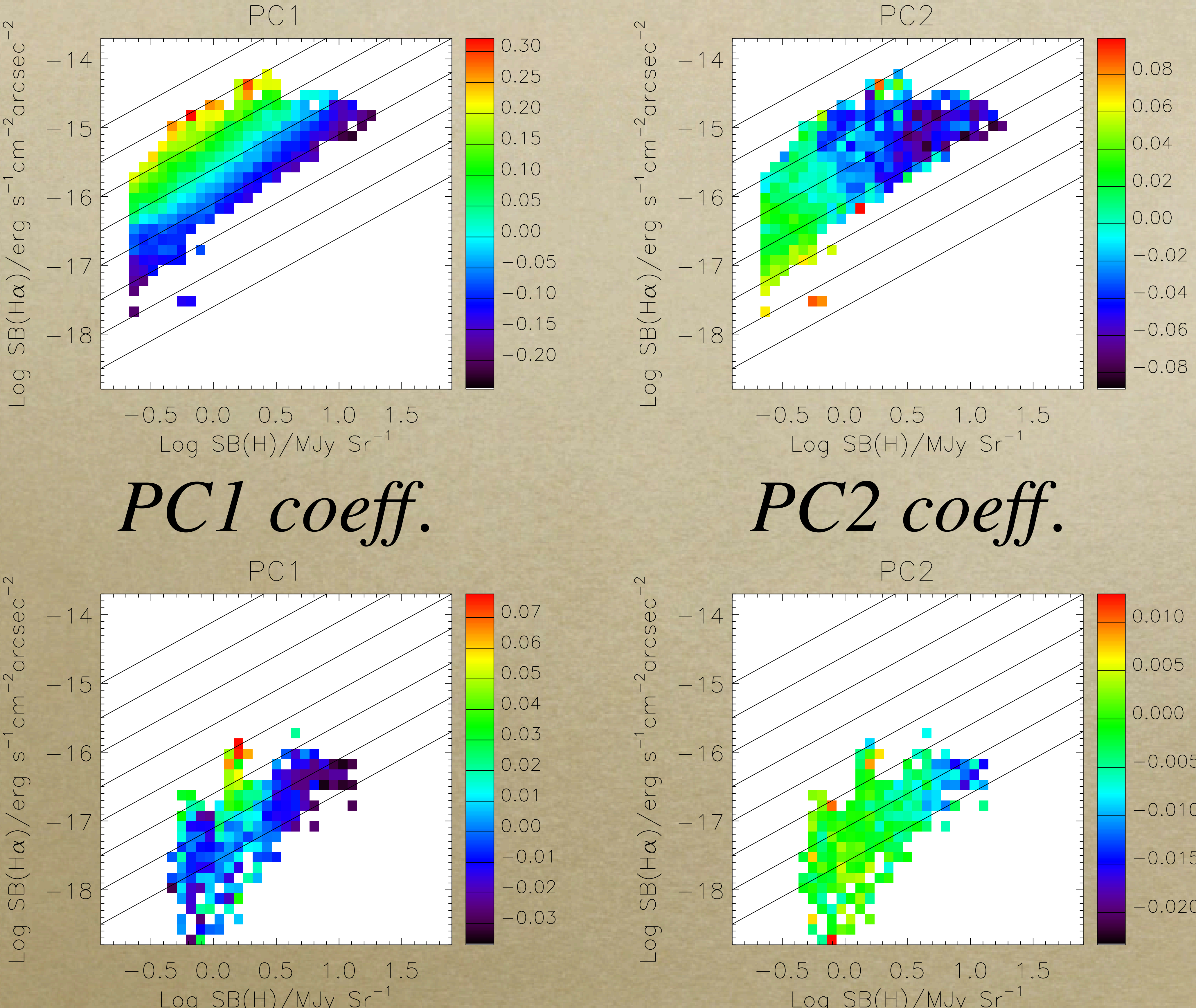


- *PC1 is driven by variations in IR (i.e. PAHs and hot dust)*
- *PC2 dominates variations in optical, driven by age, dust absorption [and Z]*


NGC 4450
PC1 - PC2
Hα contours
ΔDEC/arcsec
100
0
−100
ΔRA/arcsec
−100
0
100
e)

Surf. brightness Hα ~ SFR →

NGC 4254



NGC 4450

Surf. brightness H-band ~ M→*

- ***PC1*** *is driven variations in IR (i.e. PAHs and hot dust):* ***~ sSFR***
  - ***timescale ~10^7yr***
- ***PC2*** *dominates variations in optical, driven by* ***stellar age****, dust absorption [and Z] (anti-correlation with stellar mass density)*
  - ***timescale ~$10^{8\text{-}9}$yr***

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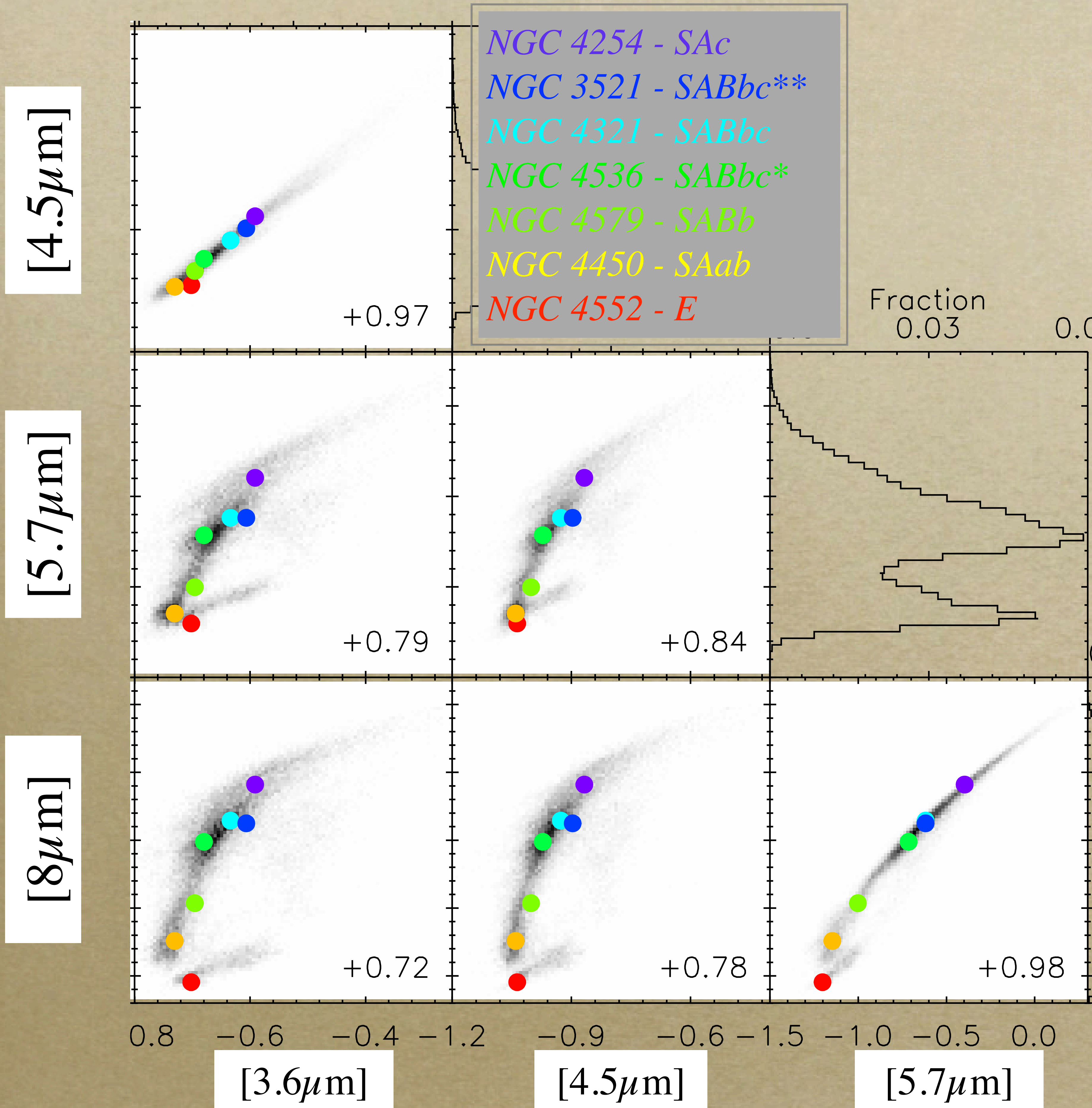
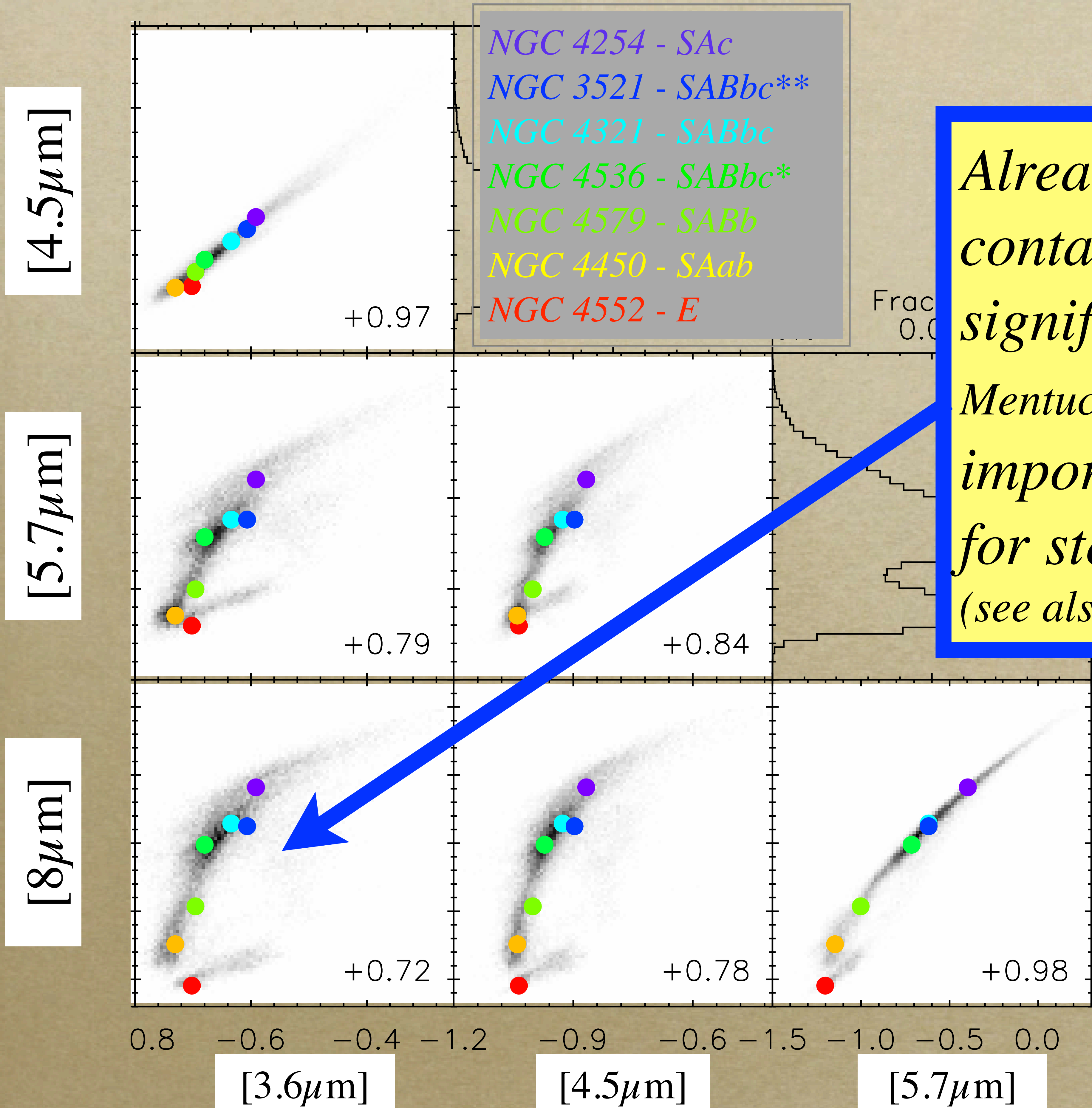
  - ***timescale ~10^7yr***
- ***PC2*** *dominates variations in optical, driven by* ***stellar age****, dust absorption [and Z] (anti-correlation with stellar mass density)*
  - ***timescale ~10^{8-9}yr***

- *Picturing a galaxy with different "exposure times" while it evolves: origin of the small scale break-down*
- *Global correlations result from smooth global SFH*

Stacked local *MIR color-color plots*

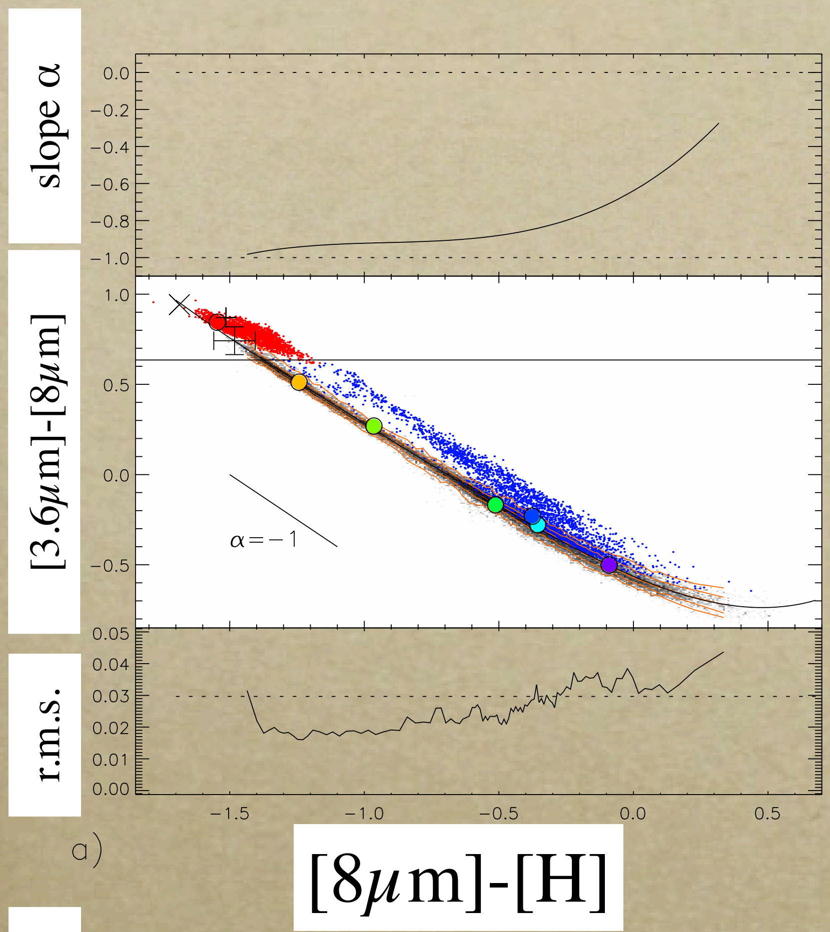


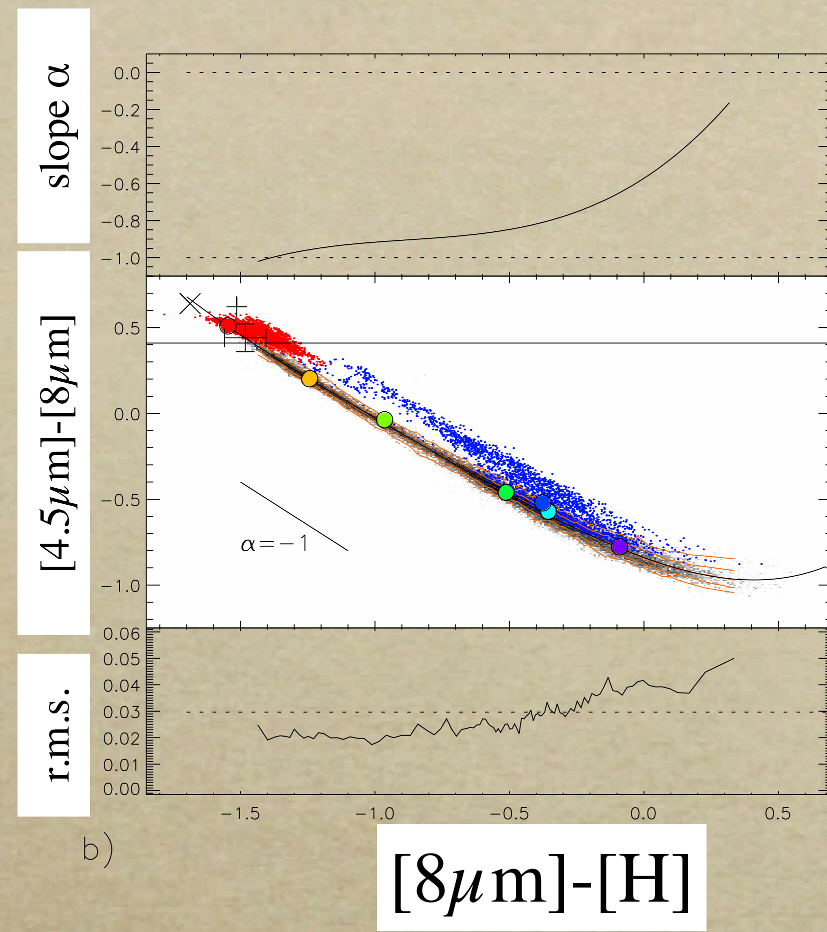
Stacked local *MIR color-color plots*



Already at 3.6μm dust contamination is significant (see also Mentuch, Abraham & SZ '10) - important implications for stellar mass maps (see also SZ, Charlot & Rix '09)

Universal IR scaling relations





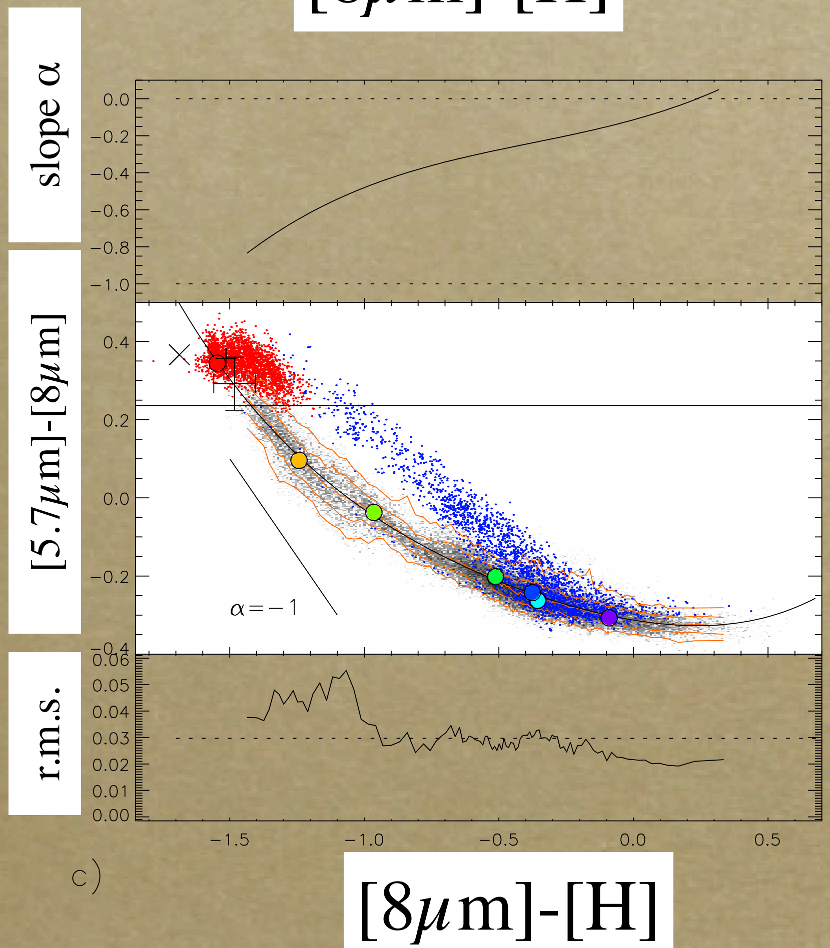
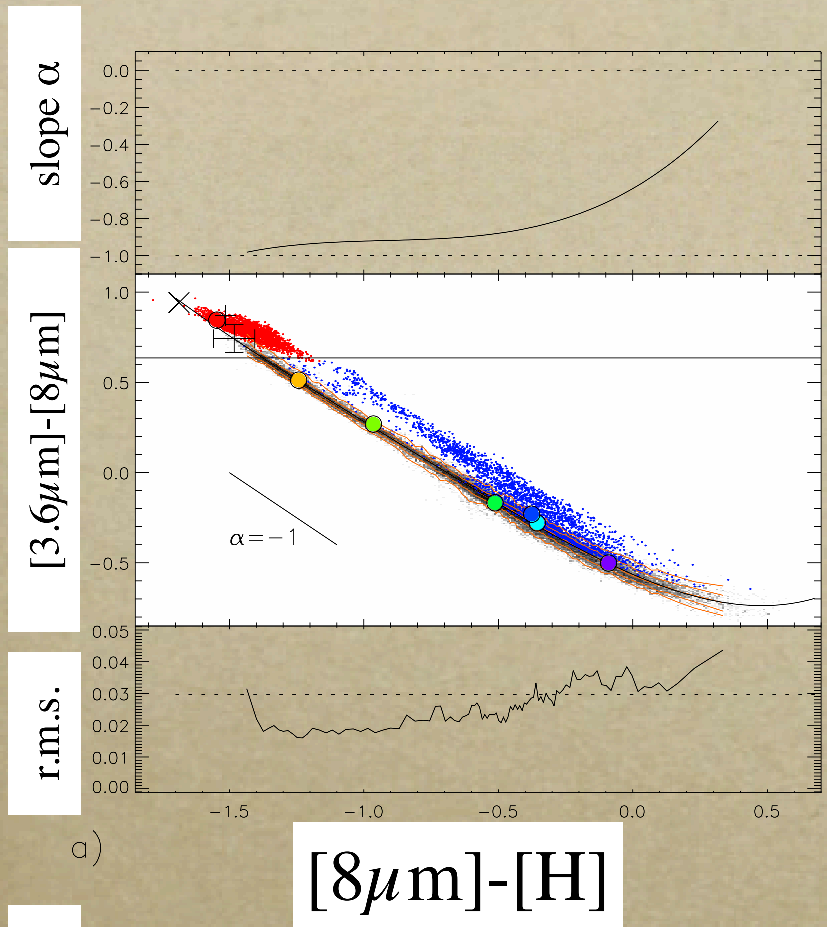


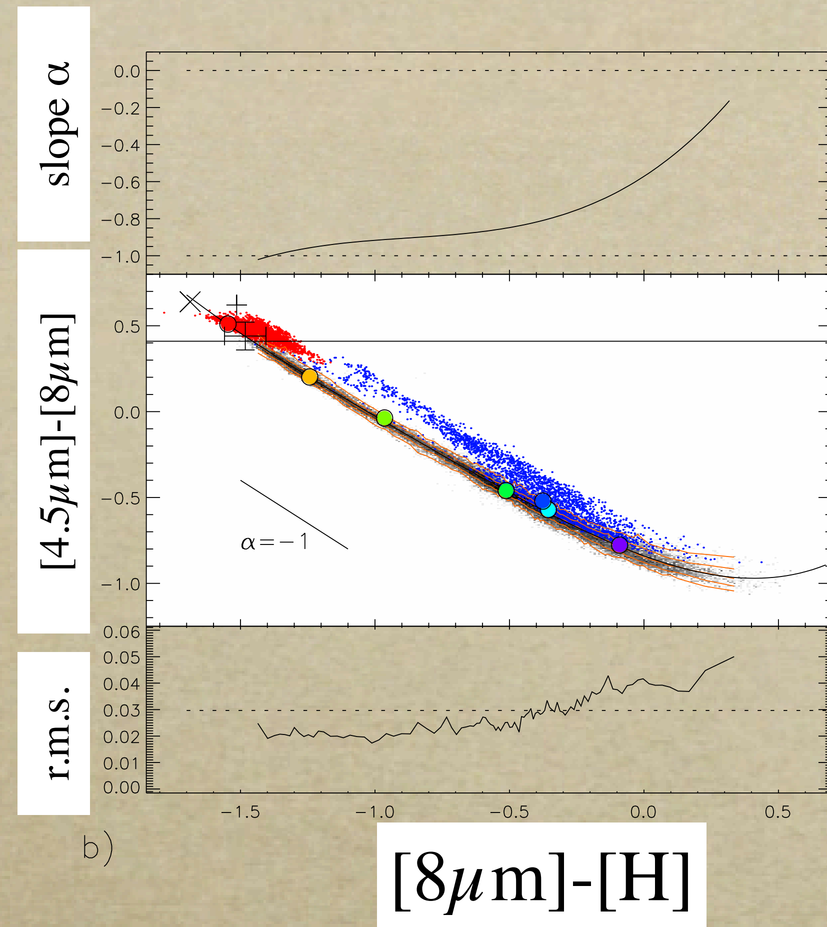
Table 2. Polynomial fit coefficients to the IR colour-colour relations presented in Fig. 8. The y color named in column 1 can be obtained from $[8\mu m]-[H]=x$ as $y=c_0+c_1x+c_2x^2+c_3x^3+c_4x^4$

Colour (1)	c_0 (2)	c_1 (3)	c_2 (4)	c_3 (5)	c_4 (6)
$[3.6\mu m]-[8\mu m]$	-0.564	-0.639	0.420	0.291	0.079
$[4.5\mu m]-[8\mu m]$	-0.840	-0.572	0.471	0.321	0.091
$[5.7\mu m]-[8\mu m]$	-0.312	-0.114	0.201	0.092	0.060

Universal IR scaling relations

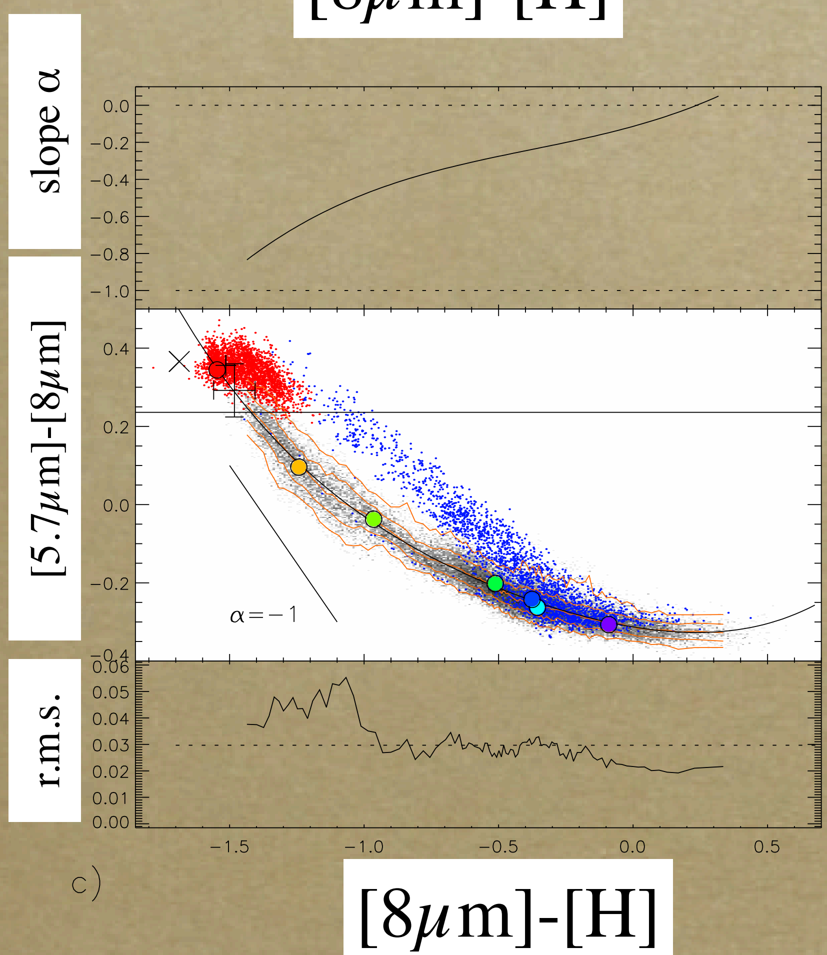


a)



b)

High predictive power of 8μm/H ratio



c)

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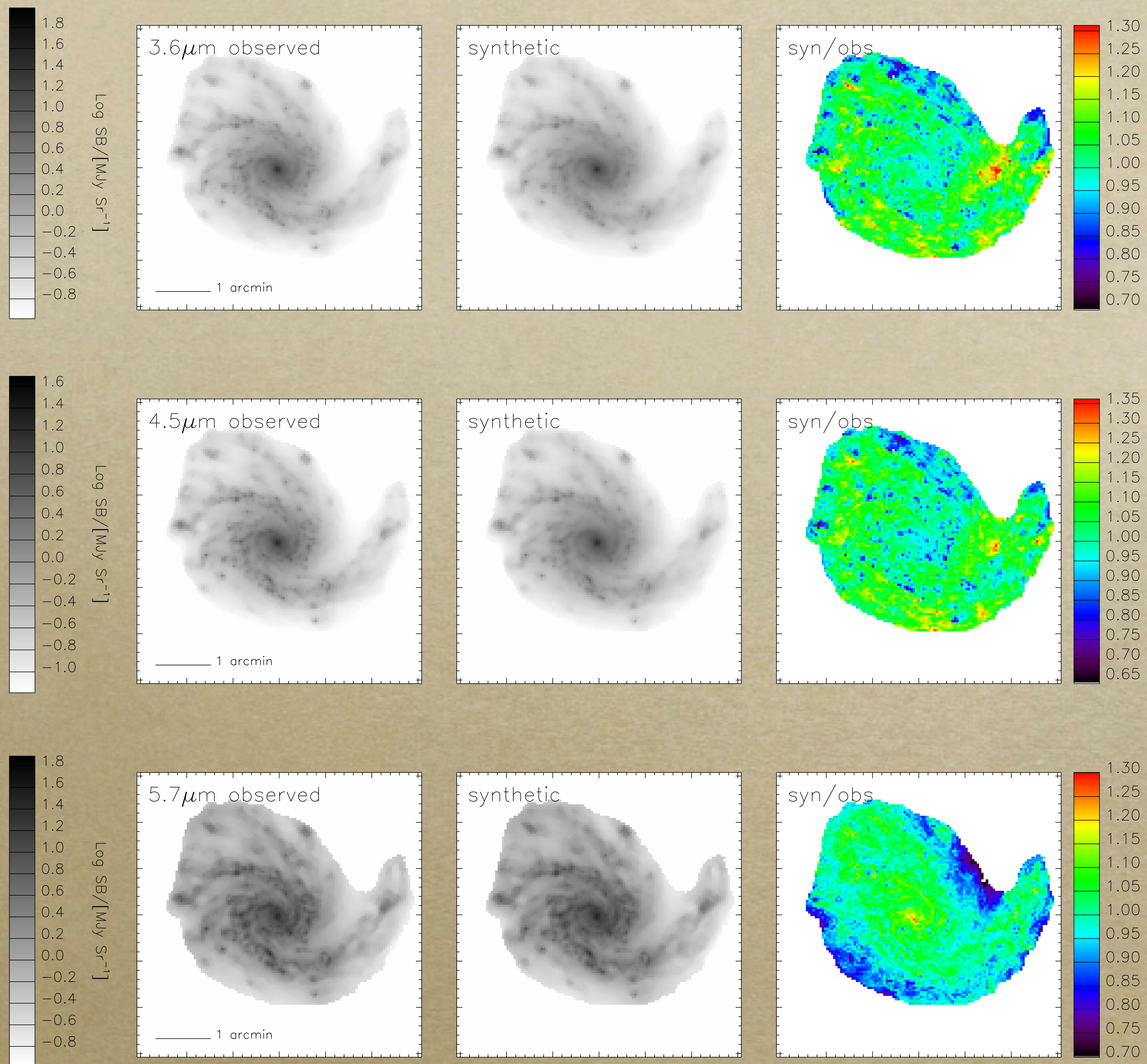
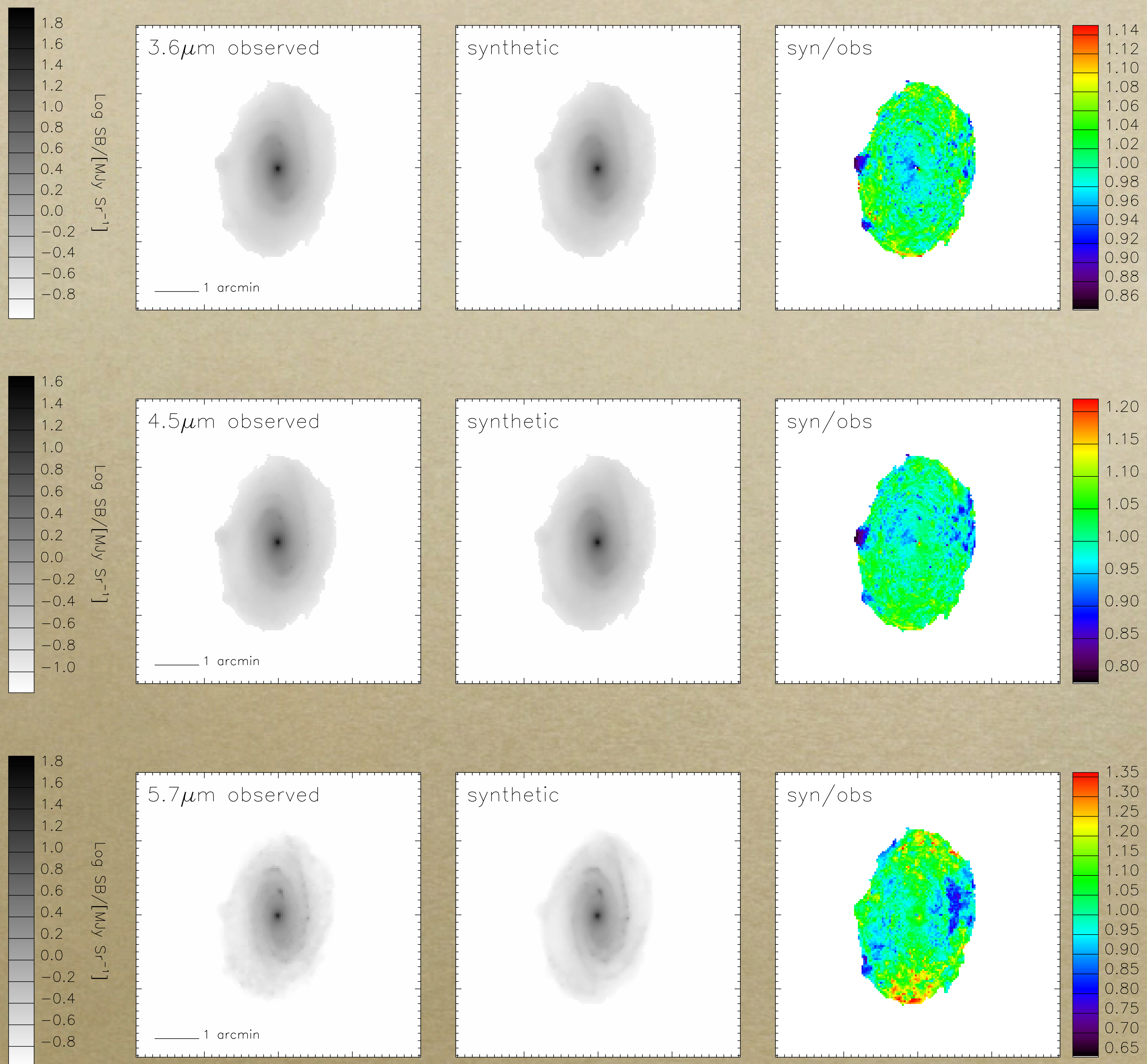

3.6μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]
4.5μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]
5.7μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]

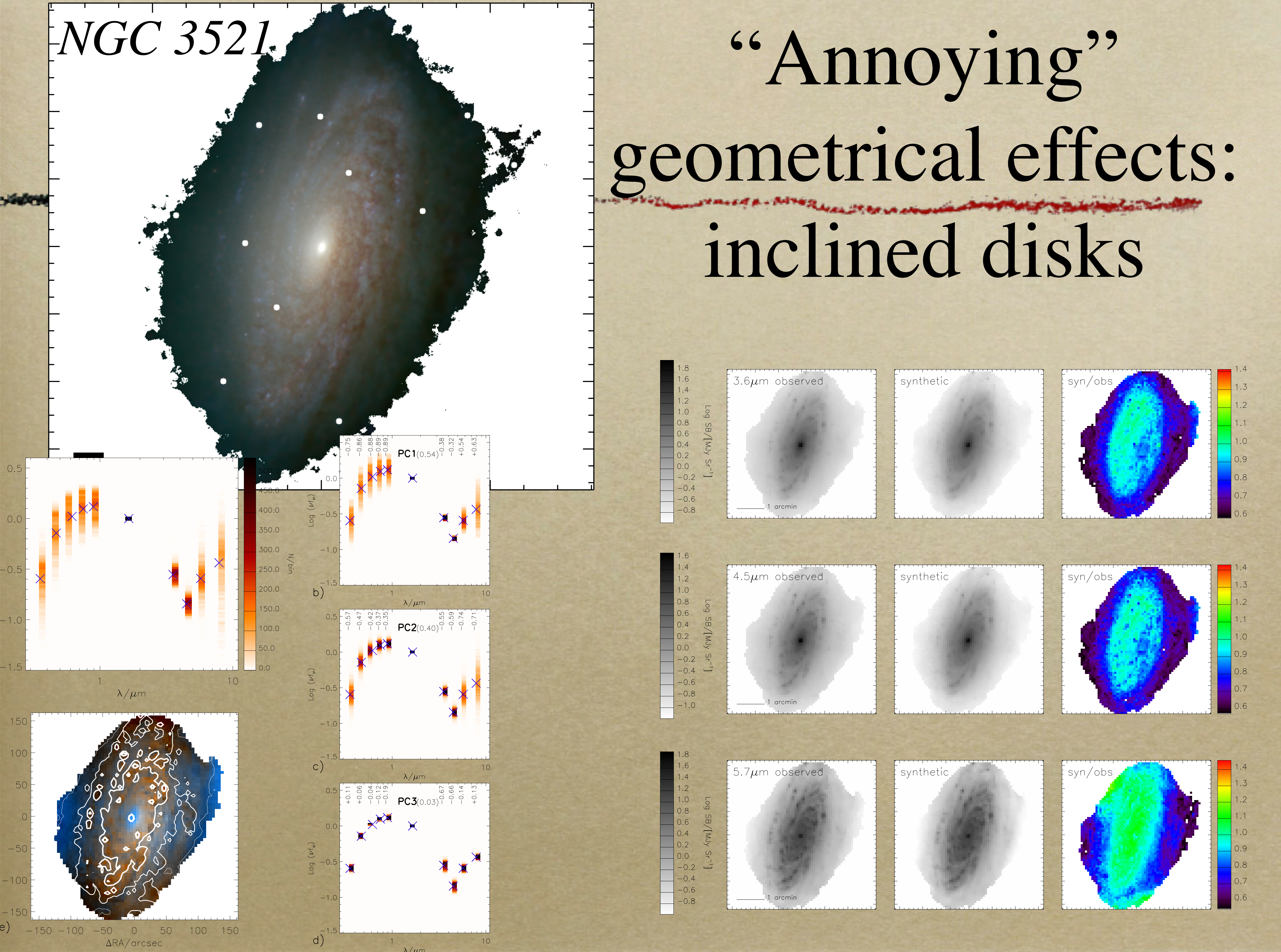

3.6μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
4.5μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
5.7μm observed
synthetic
syn/obs
1 arcmin
Log SB/[MJy Sr⁻¹]
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65

- *Very tight universal correlations between (M)IR colors*
  - *reconcile with PAH variations?*
- *Knowledge of brightness at 1.65μm (purely stellar) and 8μm (max dust+stars) allows to derive intermediate wavelengths with few % accuracy*
- *Provide purely stellar emission ratios by asymptotic extrapolation*

Table 3. Pure stellar emission flux ratios derived from IR colour-colour relations presented in Fig. 8. A comparison to the predictions from stellar population synthesis models is given in the three bottom rows (see text for details).

Slope from relation (1)	$[3.6]-[H]$ (2)	$[4.5]-[H]$ (3)	$[5.7]-[H]$ (4)	$[8]-[H]$ (5)	$[4.5]-[3.6]$ (6)	$[5.7]-[3.6]$ (7)	$[8]-[3.6]$ (8)
$[3.6\mu m]-[8\mu m]$	−0.742	−1.044	−1.194	−1.491	−0.301	−0.453	−0.749
$[4.5\mu m]-[8\mu m]$	−0.740	−1.046	−1.178	−1.384	−0.306	−0.437	−0.644
$[5.7\mu m]-[8\mu m]$	−0.741	−1.038	−1.199	−1.572	−0.297	−0.458	−0.832
mean	-0.741 ± 0.001	-1.043 ± 0.003	-1.190 ± 0.009	-1.482 ± 0.077	-0.301 ± 0.004	-0.449 ± 0.009	-0.742 ± 0.077
Helou et al. (2004)	...	...	...	...	−0.225	−0.399	−0.635
CB07 (> 2Gyr)	−0.745	−1.047	−1.321	−1.687	−0.302	−0.576	−0.942
CB07 (≈ 1Gyr)	−0.644	−0.893	−1.158	−1.514	−0.249	−0.514	−0.870

"Annoying" geometrical effects: inclined disks



Conclusions

see SZ & Groves, arXiv:1106.2165, MNRAS in press

- ***Optical-IR relations*** *contain informations on physics of galaxy evolution, in particular how SF, heating of dust, aging of stellar populations relate to each other*
- ***Global relations break down on small (few 100 pc) scales****, probably because* locally *the* ***evolution*** *of the* ***distinct physical parameters (having different time scales)*** *which govern the emission in the optical and IR regimes is not as* ***smooth*** *as it is* globally
- ***MIR relations*** *are almost* ***universal*** *even for local scales: but why?*