# The influence of diffuse scattered light in observations of faint haloes





Paudel et al. (2013), ApJ, 767, 133

#### **Christer Sandin** Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

June 24 2015, European Week of Astronomy and Space Science, Univ. La Laguna, Tenerife, SP16

### For me, it all began with a paper on the **ubiquity** of haloes around planetary nebulæ...

ALP



# Exploring the origin of excess light around various types of galaxies







Face-on disc galaxies





Ellipticals and BCGs





#### Very few studies seriously consider scattered light as a possible explanation to their results

 $\mu_g \ [{\rm mag} \ {\rm arcsec}^{-2}]$ 



ΔΤΡ



z [pixel] z [pixel] z [pixel]

## **3**<sup>rd</sup> review of radially extended PSFs: claims temporal changes to the PSF are unpredictable



TABLE 1 PSF Measurements

					PSF		
Reference	OBSERVATORY	Telescope	Altitude (m)	BANDPASS	$\mu^{a}$ (mag arcsec <sup>-2)</sup>		α
King (1971) <sup>b</sup>	Palomar	48 inch Schmidt	1713	В	12.7 at 10", 15.0 at 30"		-2 at 10"-30'
Kormandy (1973)	Palomar	48 inch Schmidt	1713	В	$1 \times \text{King at } 30''$		-2 at $r < 3', -1.7$ at $r > 3'$
Shectman (1974)	Palomar	48 inch Schmidt	1713	RG-1	1.25 × King at 100"	/	-2.6
Capaccioli & de Vaucouleurs (1983)	McDonald	0.9 m	2100	В	$0.6 \times \text{King at } 10''$		(-1.6, -1.8) at $r > 10''$
Middlemass et al. (1989)	La Palma	2.5 m	2325	6563 Å	$2 \times \text{King at } 10''$		-3.5 at $10'' - 25''$
Surma et al. (1990) <sup>c</sup>	Calar Alto	1.23 m	2190	R	$4.8 \times \text{King}$ at 10", $1.4 \times 3$	t 30″	-1.6 at 30"-100", -2.0 at 100"-300"
Uson et al. (1991)	KPNO	No. 1 0.9 m	2160	R	$1.6 \times \text{King at } 30''$		-2 at 30"-800"
Mackie (1992)	KPNO	Burrel 0.6 m	2160	g	$1.7 \times \text{King} \text{ at } 20''$		-2 at 20"-100"
Gonzalez et al. (2005)	LCO	Swope 40 inch	2282	i	d		-1.6 at $10''-40''$ , $-2.2$ at $40''-400''$
This work	LCO	du Pont 2.5 m	2282	r	$1.2 \times \text{King}$		(-2.5, -3) at $10''-400''$

<sup>a</sup> Surface brightness for a star normalized to 0 mag and based on the fit to the measured profile.

<sup>b</sup> The measured surface brightness shows scatter of roughly 1 mag arcsec<sup>-2</sup> around the fit.

<sup>c</sup> This measurement was made using a reimager, which means that the PSF includes the scattering and ghosting properties of a multielement optical system in addition to the telescope and atmosphere. It is included here for completeness but is not comparable with direct imaging through a reflective telescope.

<sup>d</sup> The value of  $\mu$  is not given.

#### Bernstein (2007), ApJ, 666, 663

"There is no general conclusion regarding the slope of the PSF at large radii"

### **3**<sup>rd</sup> review of radially extended PSFs: claims temporal changes to the PSF are unpredictable



AIP

#### 4<sup>th</sup> review of rad. extended PSFs





Sandin (2014), A&A, 567, A97

#### 4<sup>th</sup> review of rad. extended PSFs





Sandin (2014), A&A, 567, A97

#### The outer parts of the PSF contribute significantly to the encircled energy!



Sandin (2014), A&A, 567, A97



### Example models of edge-on galaxies illustrate the necessity of using fully extended PSFs





AIP

#### Example models of edge-on galaxies illustrate the necessity of using fully extended PSFs



AIP

## A halo was discovered in photometry observations of the edge-on galaxy NGC 5907





Sackett et al. (1994), Nature, 370, 441



(Zheng et al. (1999), AJ, 117, 2757;) Martínez-Delgado et al. (2008), ApJ, 689, 184

z (kpc) Surface-brightness 2.0 4.0 6.0 8.0 and color profiles  $PSF_{V.0m} * \mu_B$ of NGC 5907 agree  $\mathsf{PSF}_{V,3m} * \mu_{\mathsf{R}}$  $PSF_{K71} * \mu_B$ with scattered-light  $\mathsf{PSF}_{\mathsf{MBH}} * \mu_{\mathsf{B}}$  $\mathsf{PSF}_{\mathsf{MBH}}^{\mathsf{new}} * \mu_{\mathsf{BH}}$ ι<sub>R,i</sub>(r)–μ<sub>R</sub>(r=0) (mag arcsec<sup>-2</sup> profiles  $\mathsf{PSF}_{\mathsf{I.0m}} * \mu_{\mathsf{i}}$  $PSF_{I3m} * \mu_i$  .  $\infty$ Sackett et al. (1994), Nature, 370, 441 10 (Morrison et al. 1994, AJ, 108, 1191): • a Lequeux et al. (1996), A&A, 312, L1: \* b) **Zheng et al. (1999)**, AJ, **117**, **2757**: 0 2.0 Sandin (2014), A&A, 767, A97 R–i (mag arcsec<sup>-2</sup>) 0. 20 40 60 100 120 140 80

z (arcsec)

### A very careful analysis of data of NGC 5907 reveals a halo; there is only one issue





*R* band – Sackett et al. (1994), Nature, 370, 441; Morrison et al. (1994), AJ, 108, 1191; Sandin (2014), A&A, 767, A97

### The influence of scattered light was never checked for measurements of thick discs

FGC 310



*R* band, tick marks 5", 1 mag/arcsec<sup>2</sup> contours, 26 mag/arcsec<sup>2</sup> thick line Dalcanton & Bernstein (2000), AJ, 120, 203; fig. 3



Bizyaev et al. (2014), ApJ, 787, 24 present another 6000 objects...



#### The influence of scattered light was never checked for measurements of thick discs



##

Yoachim & Dalcanton (2006), AJ, 131, 226; Sandin (2015), A&A, 577, A106

#### One study falsifies the finding of de Jong (2008) that scattered-light effects are general





## Very few studies seriously consider scattered light as a possible explanation to their results



MNRAS, submitted (poster SP16.5)

### Face-on disc galaxies that show a type III-s structure fit a scattered-light explanation well



AIP





Sandin (2015), A&A, 577, A106

#### The observations of the BCG ESO 400-G043 are fitted well with a scattered-light halo





#### The ellipticity depends on the PSF!

### This review is about redone analysis in works of others – after adding a neglected component





A theory in the empirical sciences can never be proven, but it can be falsified, meaning that it can and should be scrutinised by decisive experiments. If the outcome of an experiment contradicts the theory, one should refrain from ad hoc manoeuvres that evade the contradiction merely by making it less falsifiable.

#### NGC 5023: contours of the low-resolution HI overlaid on an H $\alpha$ image of NGC 5023



Kamphuis et al. (2013), MNRAS, 434, 2069

### Conclusions: scattered light is a ubiquitous component that needs to be correctly removed





Haloes? Thick Discs? Galaxy hosts? Red excess?



Conclusions: scattered light is a ubiquitous component that needs to be correctly removed



#### The accuracy needs to be determined for each image individually

...the temporal variations of the PSF are unknown ...the sky background level may differ

The PSF needs to be accurately determined out to at least 1.5× the considered radius

The PSF varies spatially, with  $\lambda$ , and with the time Faint sources are difficult to use for the PSF

Colour gradients are extremely sensitive to the PSF

Higher accuracy is required if the measurements and the scattered light model are similar

#### Supplementary information is found on-line – if you need more details...





http://www.aip.de/Members/csandin

#### A very careful analysis of data of NGC 5907 reveals a halo; there is only one issue





Sandin (2014), A&A, 767, A97

...and the same can be said about profiles of other edge-on galaxies, such as IC 5249

> ..and NGC 4565, NGC 3957, **NGC 4244**





**NGC 4565** 



AIP





Jablonka et al. (2010), A&A, 513, A78: ●, ○ Pohlen et al. (2004), A&A, 422, 465: \_\_,

Sandin (2015), A&A, 577, A106







Fry et al. (1999), AJ, 118, 1209: ◊, ● Tikhonov & Galazutdinova (2005), Astrophys., 48, 221: □ Streich et al. (submitted): \*

Sandin (2015), A&A, 577, A106



## Example models of face-on and Sérsic galaxies show the necessity of using fully extended PSFs

• ##+ ++



### Face-on disc galaxies that show a type III-s structure fit a scattered-light explanation well



Erwin et al. (2008), AJ, 135, 20; Sandin (2015), A&A, 577, A106



#### A scattered-light halo appears at some radius and magnitude for all Sérsic profiles



$$I(r) = I_e \exp(-b_n [(\frac{r}{r_e})^1 - 1])$$
  
$$b_n \simeq 2(n - 0.327$$

Sérsic (1968); Capaccioli (1989); Caon et al. (1993)

The observations of the BCG ESO 400-G043 are fitted well with a scatteredlight halo

#### The intensity scale emphasizes the center









An exponential disc appears sufficient to explain the host galaxy of Mrk 5; instead of *n*=2.83

Cairós et al. (2001), ApJS, 133, 321: Caon et al. (2005), ApJS, 157, 218: Amorín et al. (2009), A&A, 501, 75: \_...

Sandin (2015), A&A, 577, A106











The host galaxy of Mrk 297 fits the scattered light description well

> Values differ in the host

Papaderos et al. (1996), A&AS, 120, 207 – ◊ Cairós et al. (2001), ApJS, 133, 321 – ◊

Sandin (2015), A&A, 577, A106







#### Micheva et al. (2013a) measure a PSF with the NOT in 2004





#### The accuracy of the sky determines what can actually be observed





Sandin (2015), A&A, 577, A106