Stellar populations of quasar host galaxies

Knud Jahnke
AIP Galaxies division

Hauskolloquium
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Overview

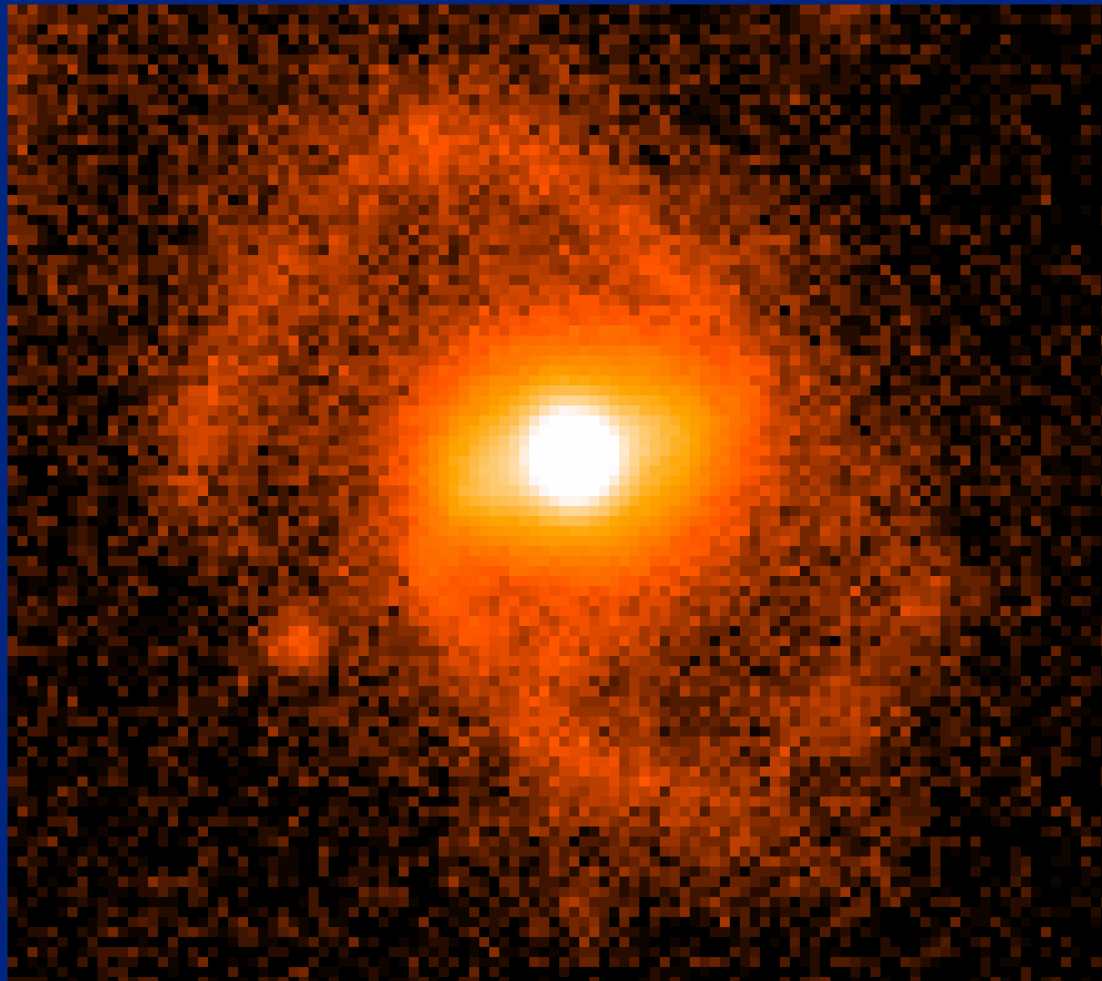
- Introduction/motivation
- Multicolour imaging
- On-nucleus spectroscopy
- What does this teach us?
- Outlook

Introduction

HE 1043–1346

z=0.068

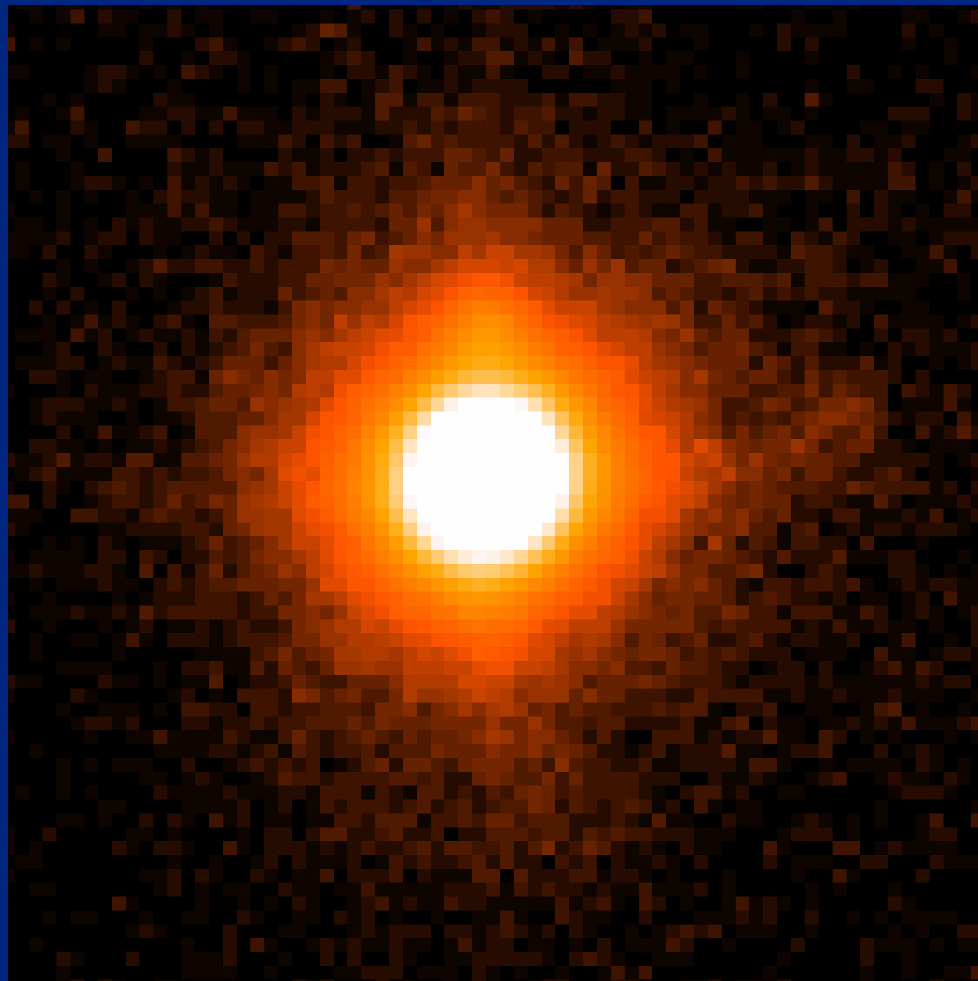
Sb-Sc spiral



HE 1029–1401

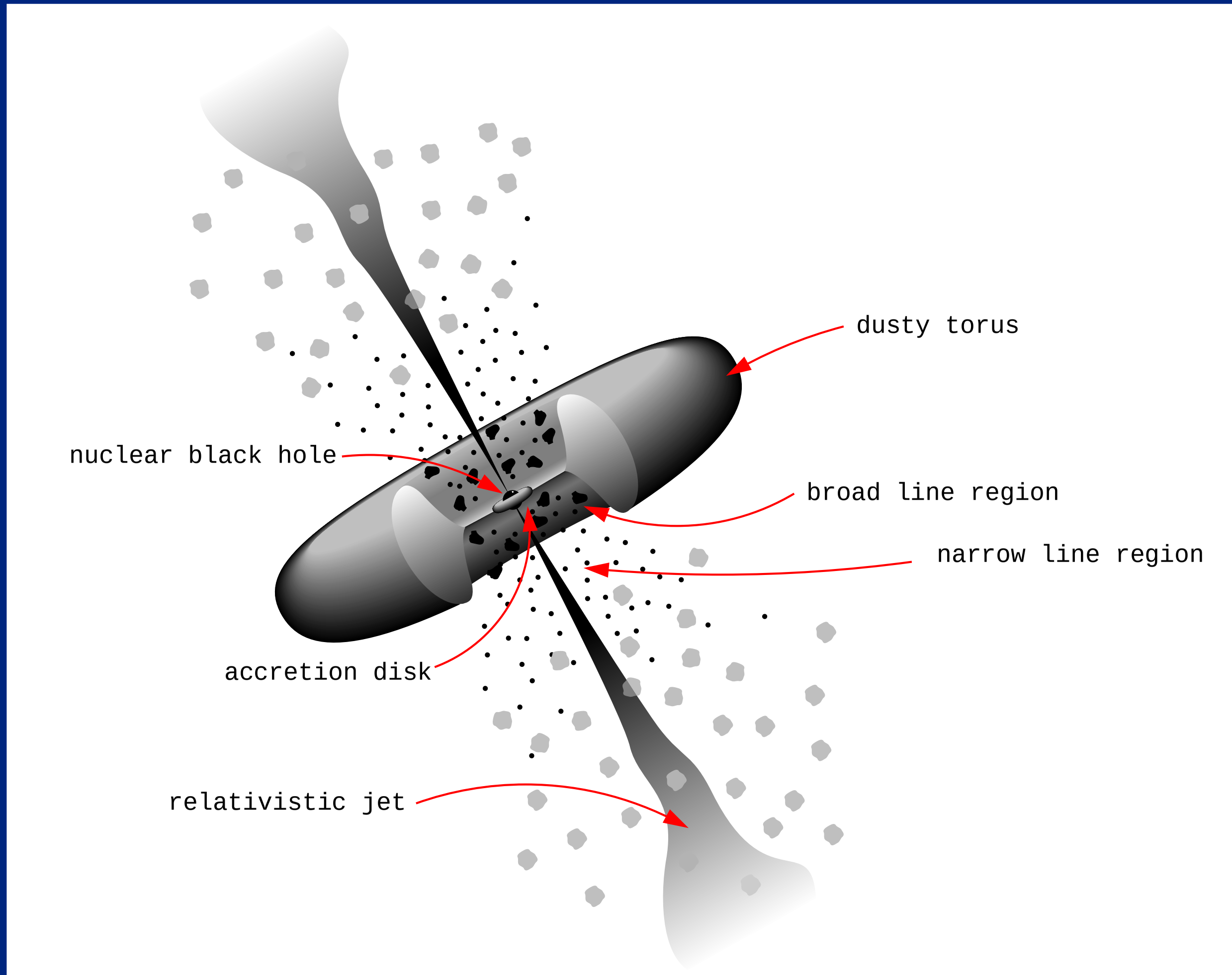
z=0.085

E0 elliptical



Nuclear model

(Urry & Padovani 1995)



Knowledge

- quasars are rare: 10^{-4} compared to field galaxies of equal L
  (Wisotzki, Kuhlbrodt, Jahnke 2001)

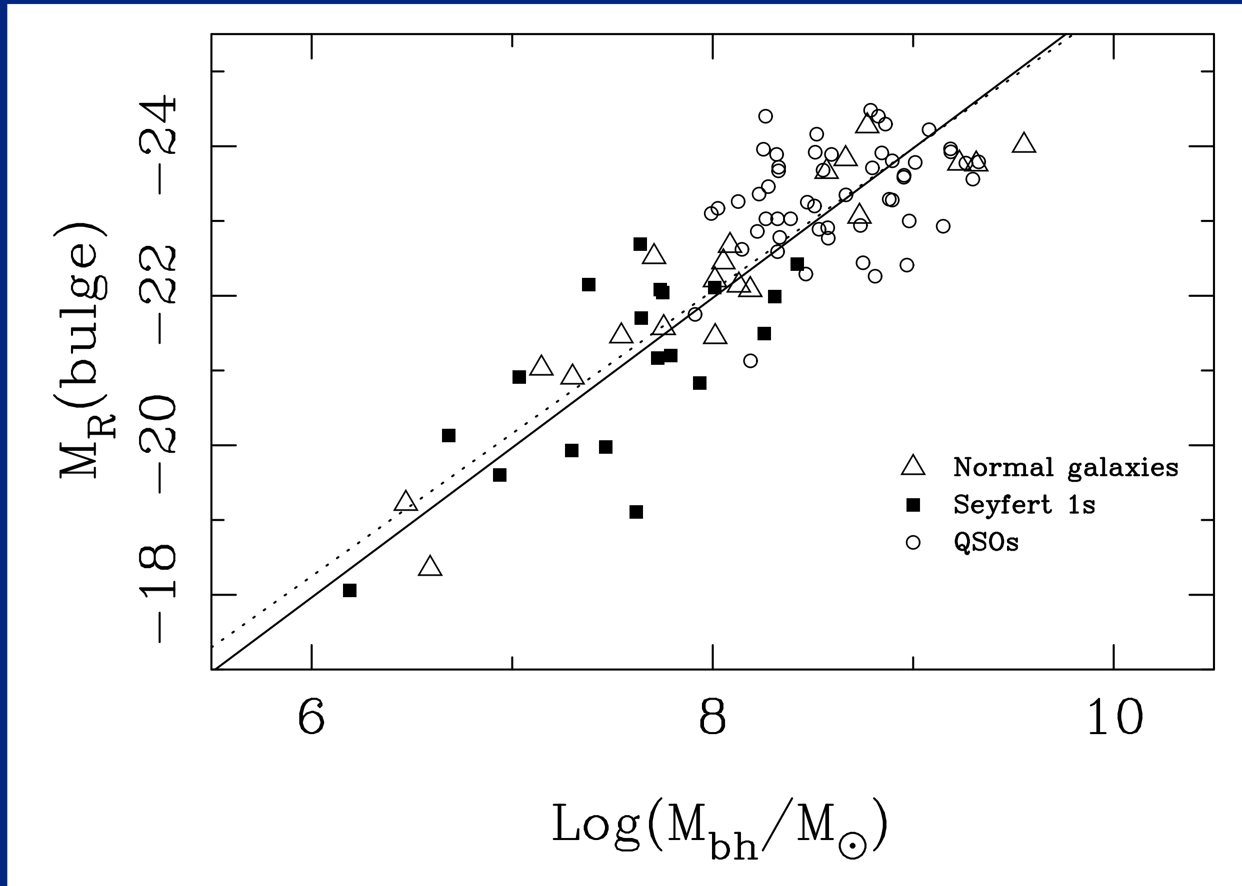
- massive black holes (BH) likely in all galaxies

- masses of BH connected to mass of surrounding galaxy
  (Magorrian et al. 1998)
  $\longrightarrow$ coupled evolution of BH and host galaxy!

- short “duty cycle” of quasars

$\longrightarrow$ not an isolated phenomenon!
$\longrightarrow$ quasar phase snapshot of galaxy evolution?

(McLure & Dunlop 2002)



- morphology
  - E to Sc/SBc, no Irr
  - symmetric to disturbed

  $\longrightarrow$ for higher L: more E, less interaction and companions (e.g. Dunlop et al. 2001, Kuhlbrodt et al. 2003)

- luminosities
  - correlation: bulge L to nuclear L (McLeod et al. 1999, McLure et al. 2001, 2002)
  - luminosity function (LF) compatible to early type field galaxies (Wisotzki, Kuhlbrodt, Jahnke 2001)

$\longrightarrow$ interaction trigger for activity?/!
$\longrightarrow$ supporting hierarchical clustering

Spectral information: a new dimension

- compare morphology vs. stellar content vs. gas content
- search for spectroscopic signs of past tidal interaction

$\longrightarrow$ spectral information very valuable

Colour and spectroscopic studies

- (multi-)colour studies
  - expensive $\longrightarrow$ few studies
  - contradictory results (normal vs. blue)
- spectroscopic studies
  - expensive and difficult data treatment
  - larger studies: Boroson et al. 1982–1985, Nolan et al. 2001

Two ’spectroscopic’ approaches

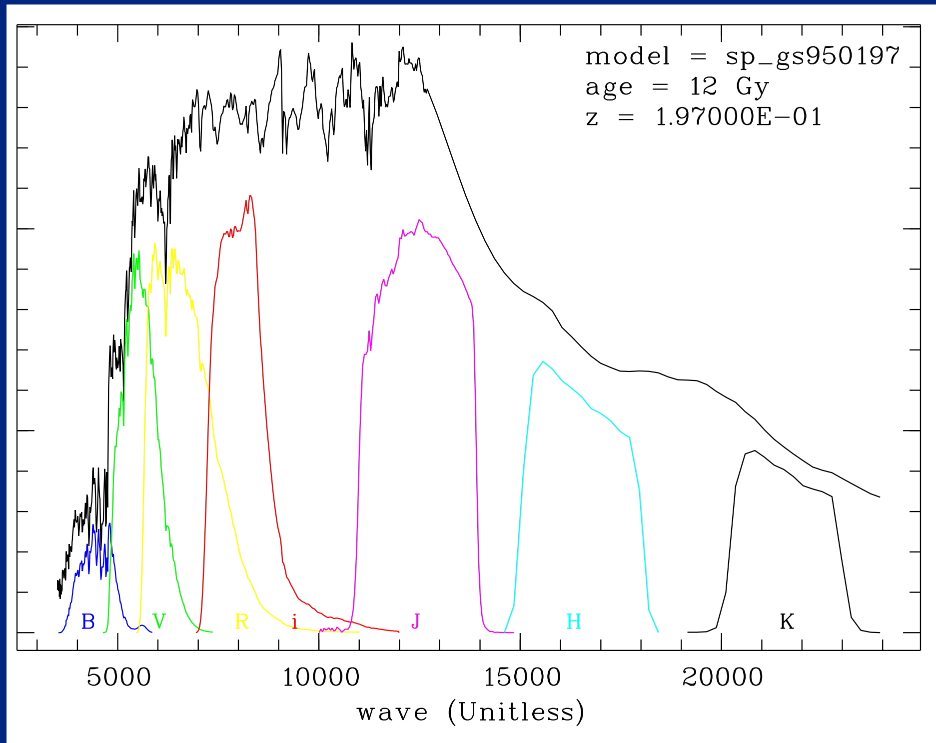
- optical/NIR multicolour broad band imaging
  $\longrightarrow$ long spectral baseline, coarse data

- on-nucleus spectroscopy
  $\longrightarrow$ high resolution, shorter baseline, expensive, difficult separation

Problem in both cases: extraction of the host galaxy flux
Solution in both cases: spatial modelling of host and nucleus

Multicolour imaging

Multicolour imaging



- observe complete low-z quasar sample in B,V,R,I,J,H,K_s
- remove nuclear light contribution
- investigate
  - morphologies (light distribution, ellipticities, arms, asymmetries,...)
  - colours (optical, optical–NIR)
  - stellar populations (evolution synthesis model fits)
- compare to inactive galaxies

Sample selection

- 19 objects, $z < 0.2$, selected from HES, complete from 611 deg^2, subsample of Köhler et al. 1997
- $13.7 \leq V_{\mathrm{total}} \leq 16.8$
- $-21.7 \leq M_V \leq -24.9$

($H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$, $\Lambda = 0$)

Observations

Mostly ESO telescopes:

Band	Instrument	Objects	$t_{\rm int}$ [s]	Scale
B	ESO 3.6m/EFOSC2	12	30	$0''.61$/pixel
B	ESO 3.6m/EFOSC1	3	30	$0''.34$/pixel
B	ESO 1.54m/DFOSC	2	380/730	$0''.39$/pixel
B	NOT/ALFOSC	2	1000/1200	$0''.19$/pixel
V,*R*,*I*	ESO 1.54m/DFOSC	19	300–1200	$0''.39$/pixel
J,*H*,K_s	ESO NTT/Sofi	19	160–900	$0''.29$/pixel

Two-dimensional spatial modelling

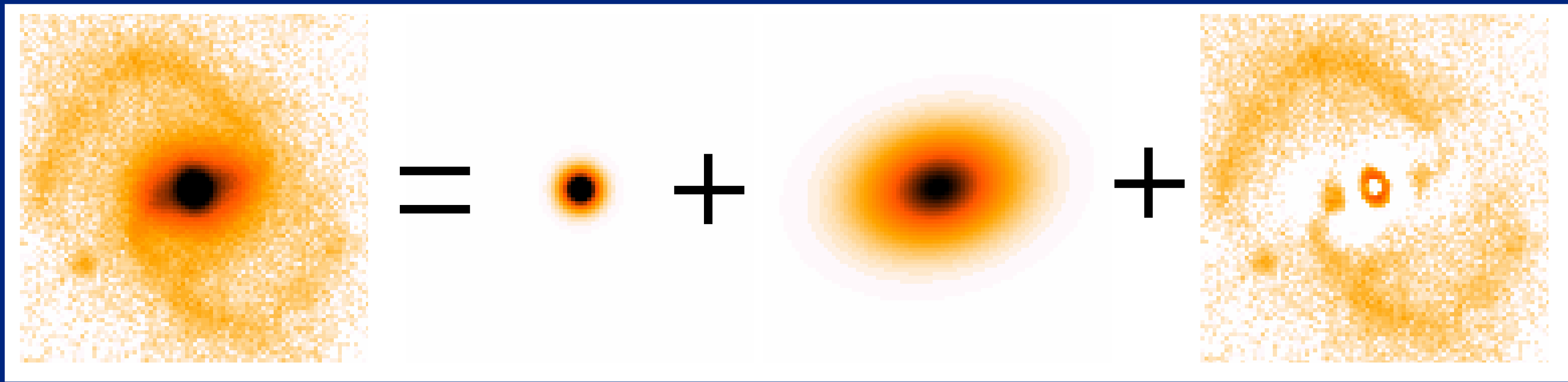
- nuclear shape and flux unknown
- $\longrightarrow$ Two-dimensional spatial modelling (PAMDAI, developed and tested by B. Kuhlbrodt (Kuhlbrodt, Wisotzki, Jahnke 2003))
- properties of PAMDAI:
  - all stars in the field used for point spread function (PSF) shape estimate
  - modelling of spatial PSF variations $\longrightarrow$ precise estimate
  - two-dimensional host galaxy model, one/two components
  - two-dimensional convolution of host model with PSF
  - adaptive subpixel grid for high efficiency
  - best parameters via downhill-simplex χ^2 minimisation

Host galaxy models

- exponential disk:
  $F_{\mathrm{disk}}(r) = F_{\mathrm{disk},0} \exp\left[-1.68 \frac{r}{r_{1/2}}\right]$ (Freeman 1970)

- de Vaucouleurs spheroidal:
  $F_{\mathrm{sph}}(r) = F_{\mathrm{sph},0} \exp\left[-7.67 \left(\frac{r}{r_{1/2}}\right)^{1/4}\right]$ (de Vaucouleurs & Capaccioli 1979)

- fully elliptical: $r = r(\varepsilon, \phi)$

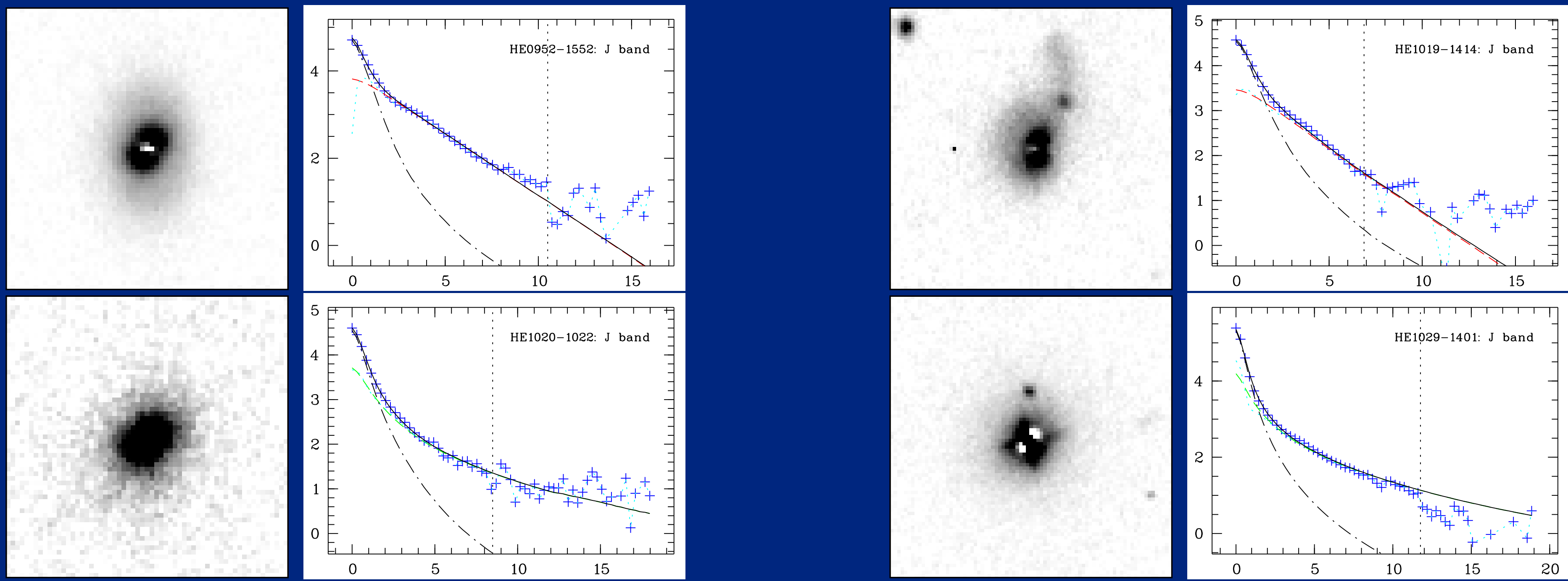


Modelling and photometry

- homogeneous treatment of all bands
  - identical fit areas
  - identical masking
  - identical final geometry
  - identical photometry
- only in few cases variable scale lengths

$\longrightarrow$ no bias in colours

Modelling results



Results

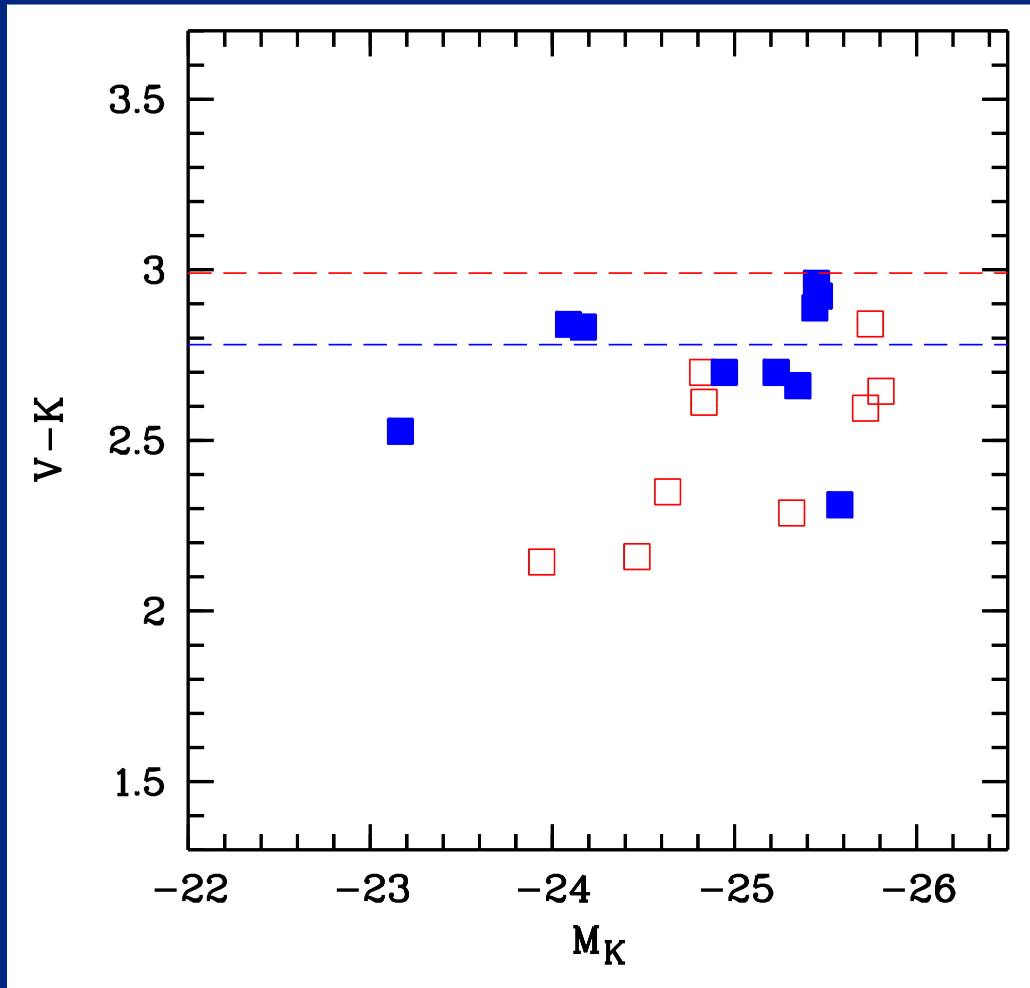
- successful for all but 7 objects in B
- 9 disks, 9 spheroidals, 1 disk + bulge
- disks
  - high inclinations missing $\longrightarrow$ unified model
  - 3.5 kpc $\leq r_{1/2} \leq$ 13.7 kpc
- spheroidals
  - $\overline{q} = b/a = 0.82 \longrightarrow$ like luminous inactive ellipticals
  - 1.5 kpc $\leq r_{1/2} \leq$ 10.4 kpc

Colours

	$B–V$	$V–R$	$R–I$	$I–J$	$J–H$	$H–K$	$V–K$
Ellipticals							
Inactive	0.96	0.61	0.70	0.77	0.71	0.20	2.99 (0.12)
QSO host sample	0.52	0.44	0.48	0.67	0.59	0.31	2.48 (0.25)
Δ	0.44	0.17	0.22	0.10	0.12	–0.11	0.50
Disks (Sb)							
Inactive	0.68	0.54	0.63	0.67	0.78	0.25	2.87 (0.36)
QSO host sample	0.55	0.53	0.53	0.87	0.57	0.24	2.73 (0.20)
Δ	0.13	0.01	0.10	–0.20	0.21	0.01	0.14

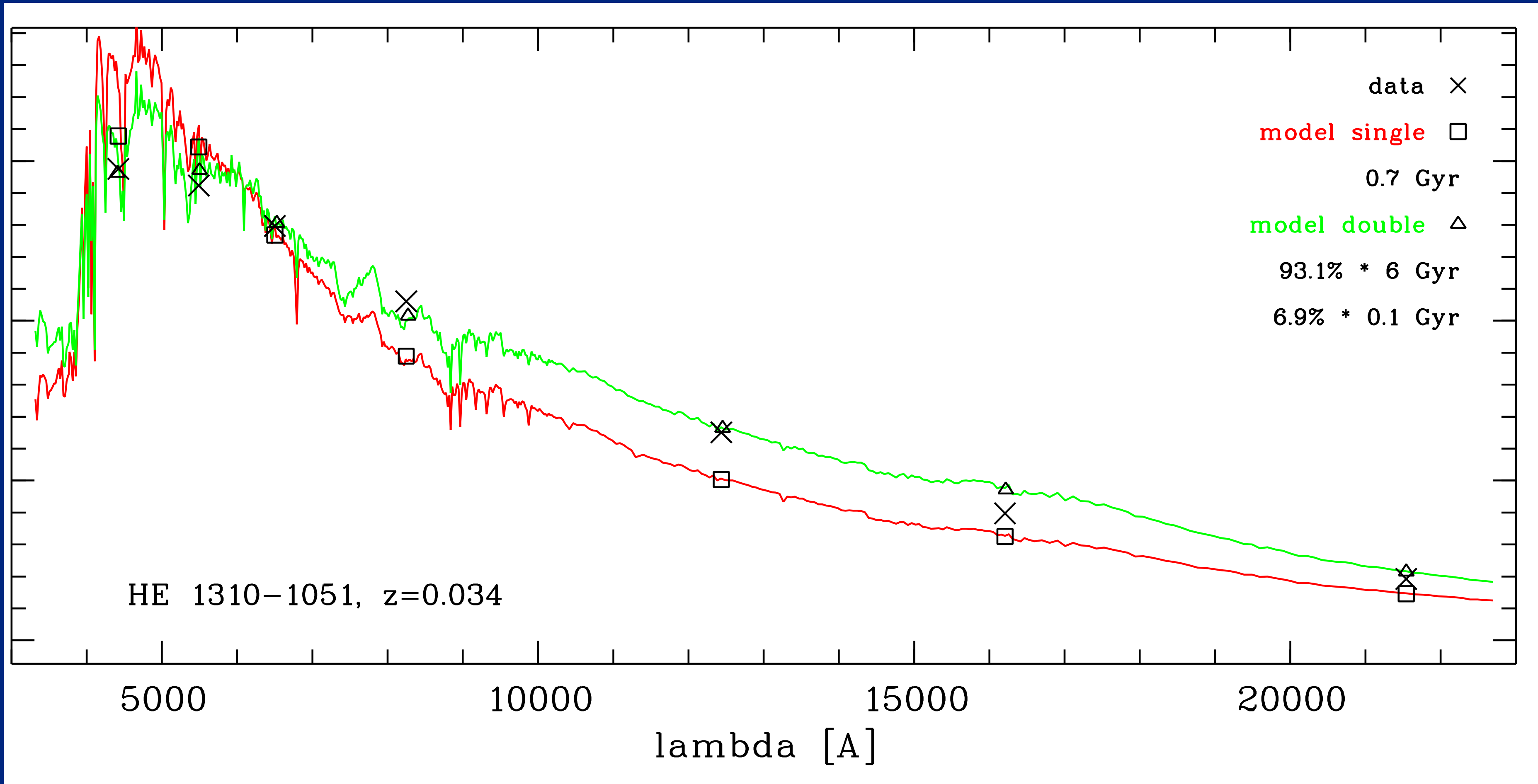
K-corrections: Fukugita et al. 1995 (optical), Mannucci et al. 2001 (NIR)

inactive colours: Fukugita et al. 1995 (optical), Fioc & Rocca-Volmerange 1999 (optical-NIR, NIR-NIR)


3.5
3
2.5
2
1.5
V−K
−22
−23
−24
−25
−26
M_K

Stellar population models

- SSP model family by Bruzual & Charlot 1996
  - Scalo IMF
  - solar metallicity
  - but: general results not depending on choice of model!
  - 0.1, 0.7, 2, 6, 14 Gyr + continuous star formation model (CSF)
- 1 SSP fit: age free
- 2 SSP fit: 0.1 Gyr fixed, second age free, relative mixing free
- χ^2 minimisation fitting to 6/7 data points


data
model single
0.7 Gyr
model double
93.1% * 6 Gyr
6.9% * 0.1 Gyr
HE 1310−1051, z=0.034
5000
10000
15000
20000
lambda [A]

Model fitting results

- objects with B missing not reliable
- 1 SSP:
  - very similar for disks and ellipticals
  - only 1 object each preferring 6 Gyr, none 14 Gyr
- 0.1 Gyr + 1 SSP:
  - all consistent with 2 Gyr and CSF
  - $> 2\%$ of 0.1 Gyr required by only 2 disks
- intermediately young populations, also for E; evolved populations ruled out
- consistent with $V - K$ colours alone

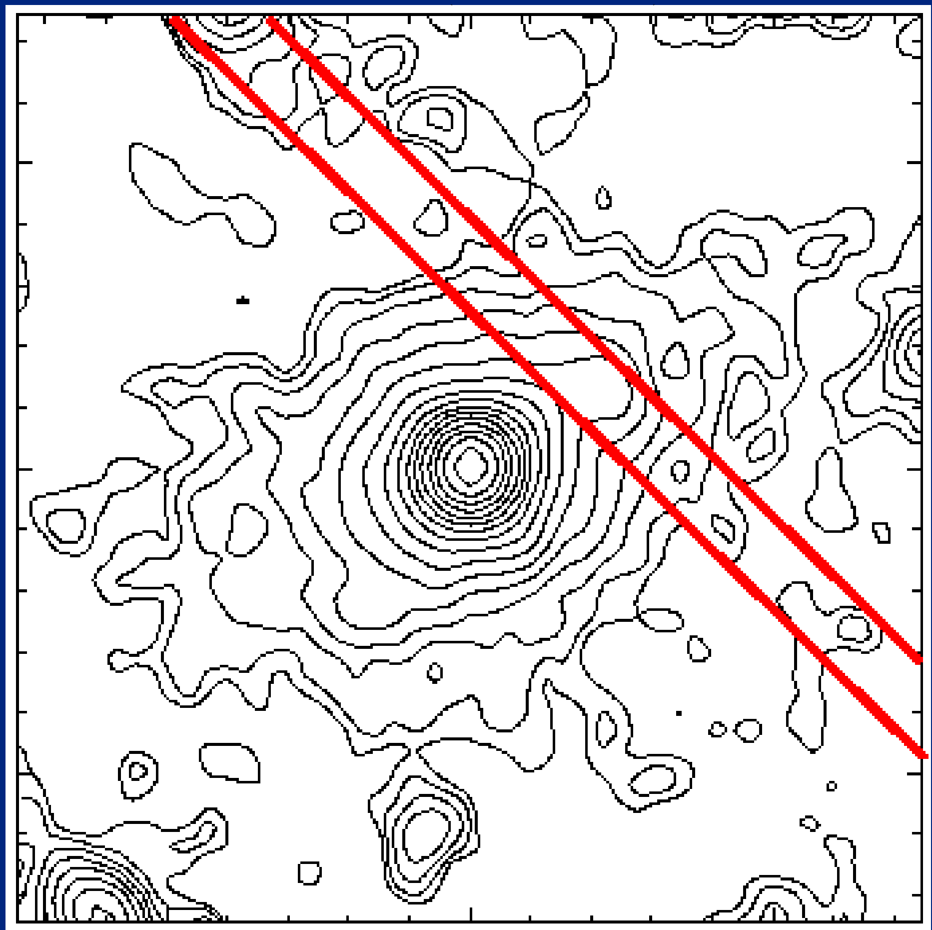
Multicolour imaging: summary

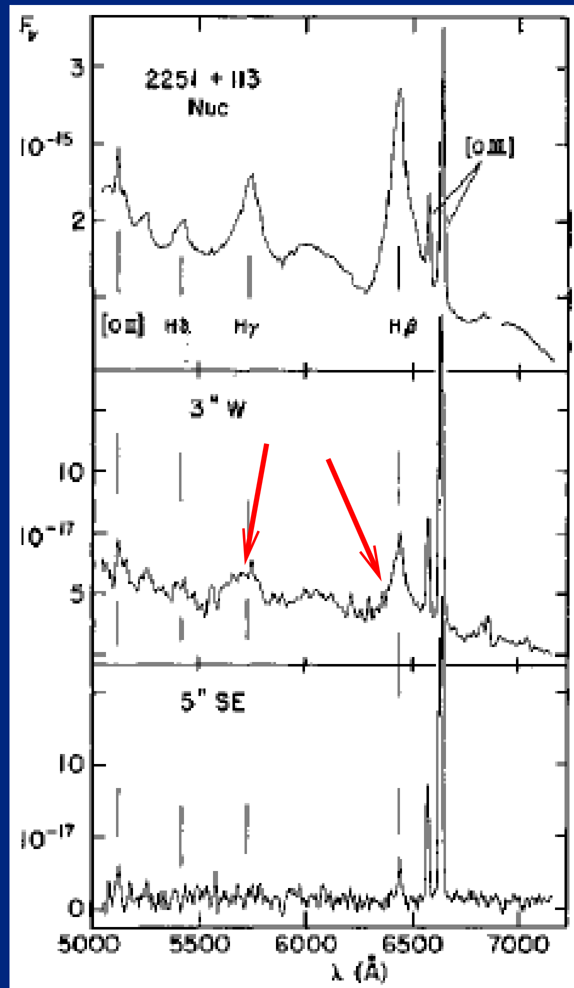
- disks and ellipticals found
- wide range of morphologies and asymmetries
- $M_{\rm nuc} - M_{\rm host}$ correlation confirmed
- disks: largely normal, slightly bluer than inactive Sb
- ellipticals:
  - as blue as late type disks
  - SSP model fitting consistent with CSF or 2 Gyr population

On-nucleus spectroscopy

On-nucleus spectroscopy

- technique so far:
  - off-nucleus spectroscopy, $r \geq 3''$ $\longrightarrow$ avoiding nucleus plus removal of nuclear residuals
- drawbacks:
  - control of nuclear residuals difficult
  - sampling far outside nuclear region $\longrightarrow$ potentially boring
- wanted: on-nucleus spectroscopy
  - problem: very high contrast nucleus–host
  - solution: *spatial* modelling, similar to imaging





(Hughes et al. 2000, Hutchings & Crampton 1990)

On-nucleus spectroscopy

- technique so far:
  - off-nucleus spectroscopy, $r \geq 3''$ $\longrightarrow$ avoiding nucleus plus removal of nuclear residuals
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  - control of nuclear residuals difficult
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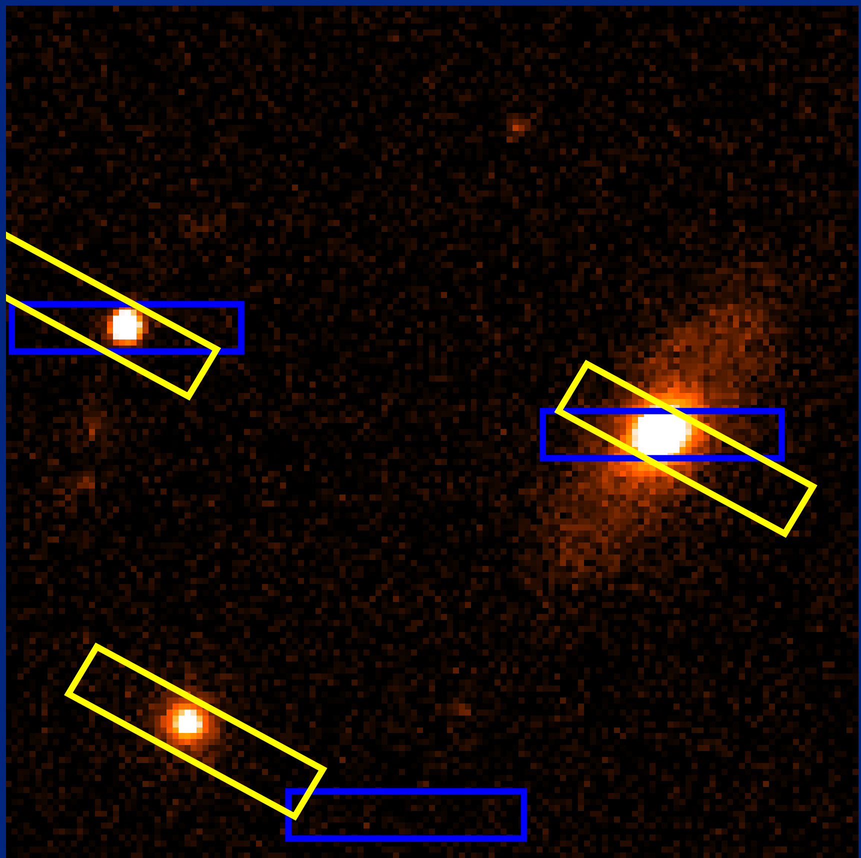
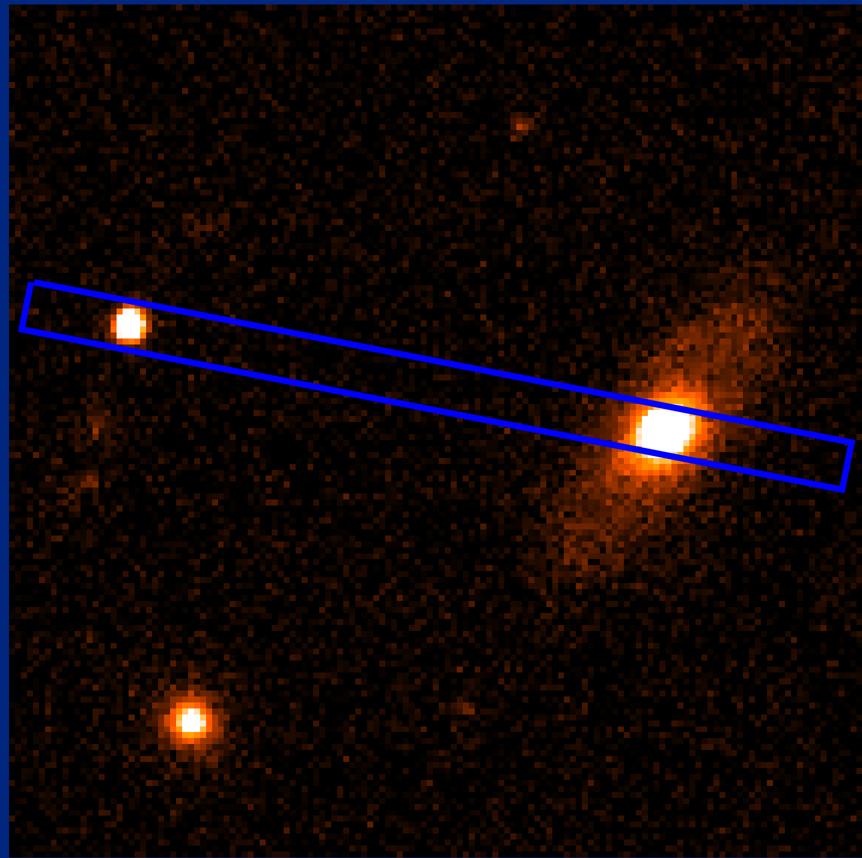
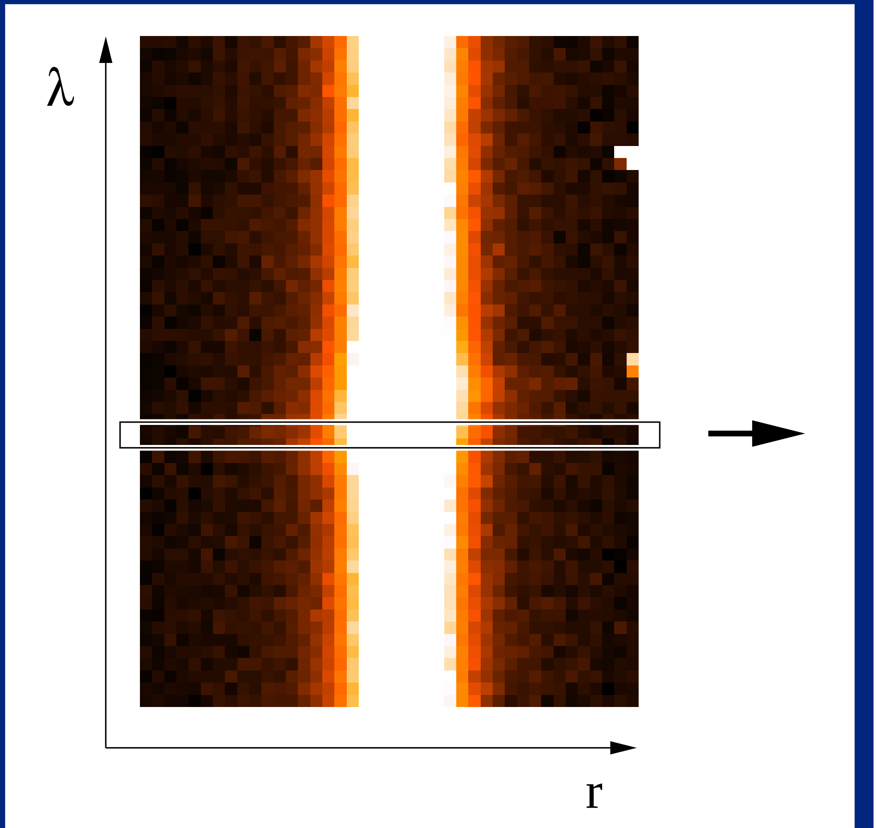
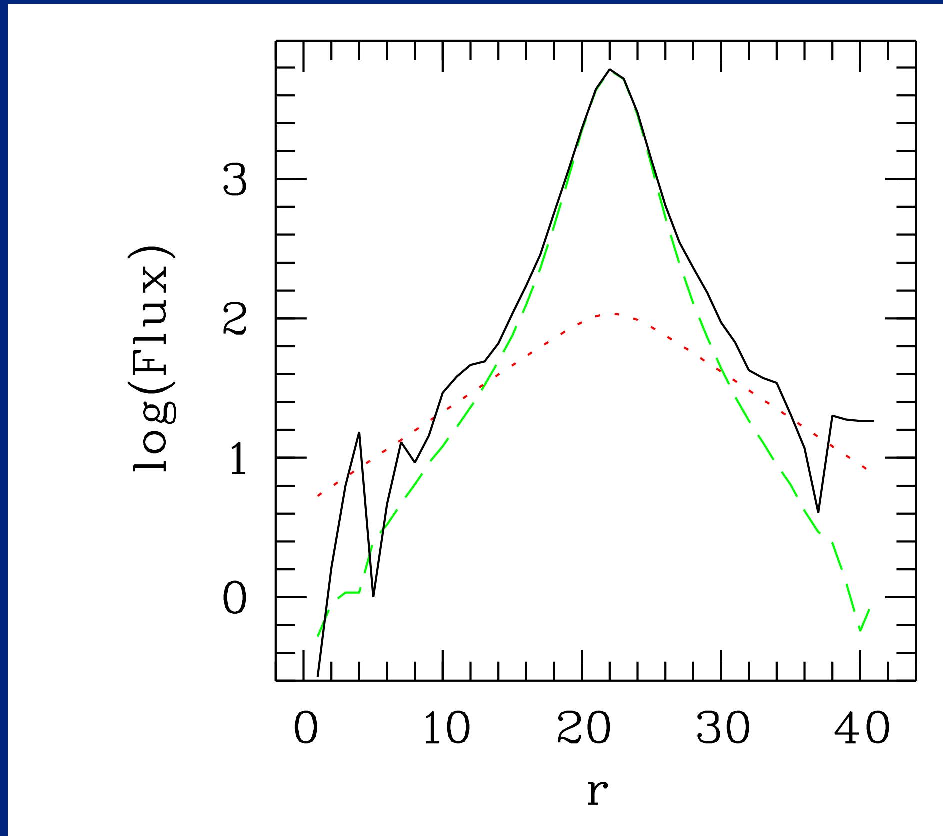




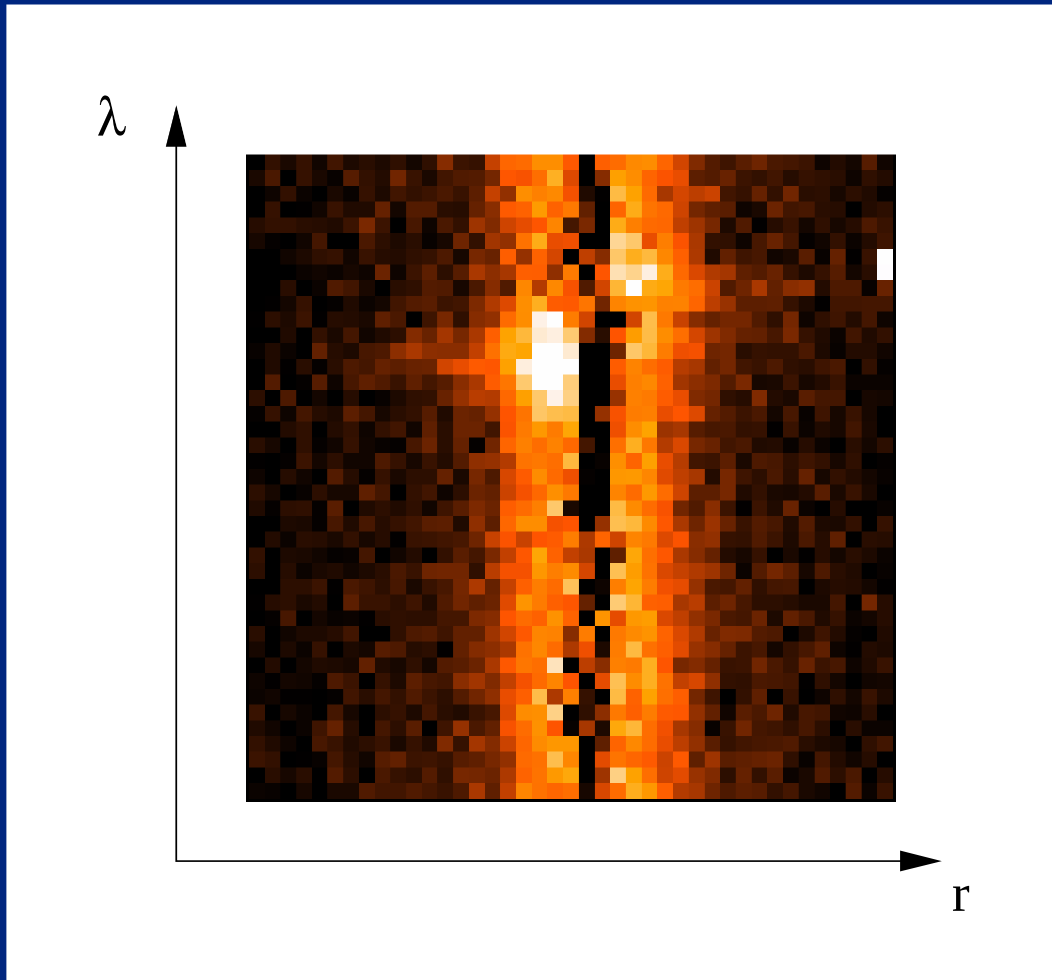
Multi-object-spectroscopy vs. long slit spectroscopy


λ
r


log(Flux)
0
1
2
3
0
10
20
30
40
r

- very important: use all information available
  - morphological parameter input from imaging
  - slow wavelength dependence of parameters
- PSF: analytical model plus empirical correction
- host: exponential disk or de Vaucouleurs spheroidal
- reduction of parameters in successive steps
- final step: nuclear and host flux only free parameters

$\longrightarrow$ 2d nuclear spectrum model $\longrightarrow$ 2d host galaxy spectrum


λ
r

Quality of fit diagnostics

- resulting spectra should be positive
- no forbidden lines in absorption
- broad emission lines not in absorption
- shape of residual (=quasar–nucleus–host)
- broad band colours need to be reconstructable
- comparing different PSF stars
- comparing different images

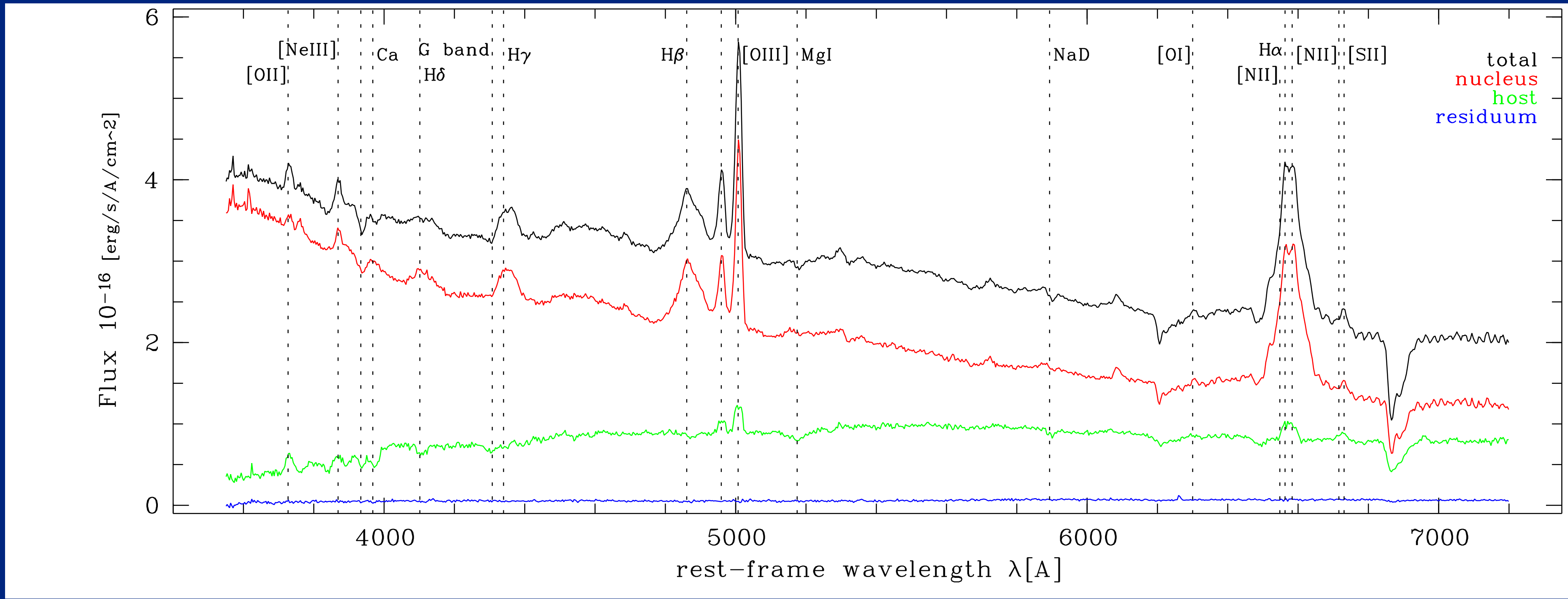
The “EFOSC sample”

- 8 object subsample of multicolour sample
- ESO 3.6m with EFOSC:
  - wavelength range: 3800–8000 Å
  - resolution: $\sim$250
  - 0.314″/pixel
  - integration time: 1200–4800 s
- morphological parameters existing

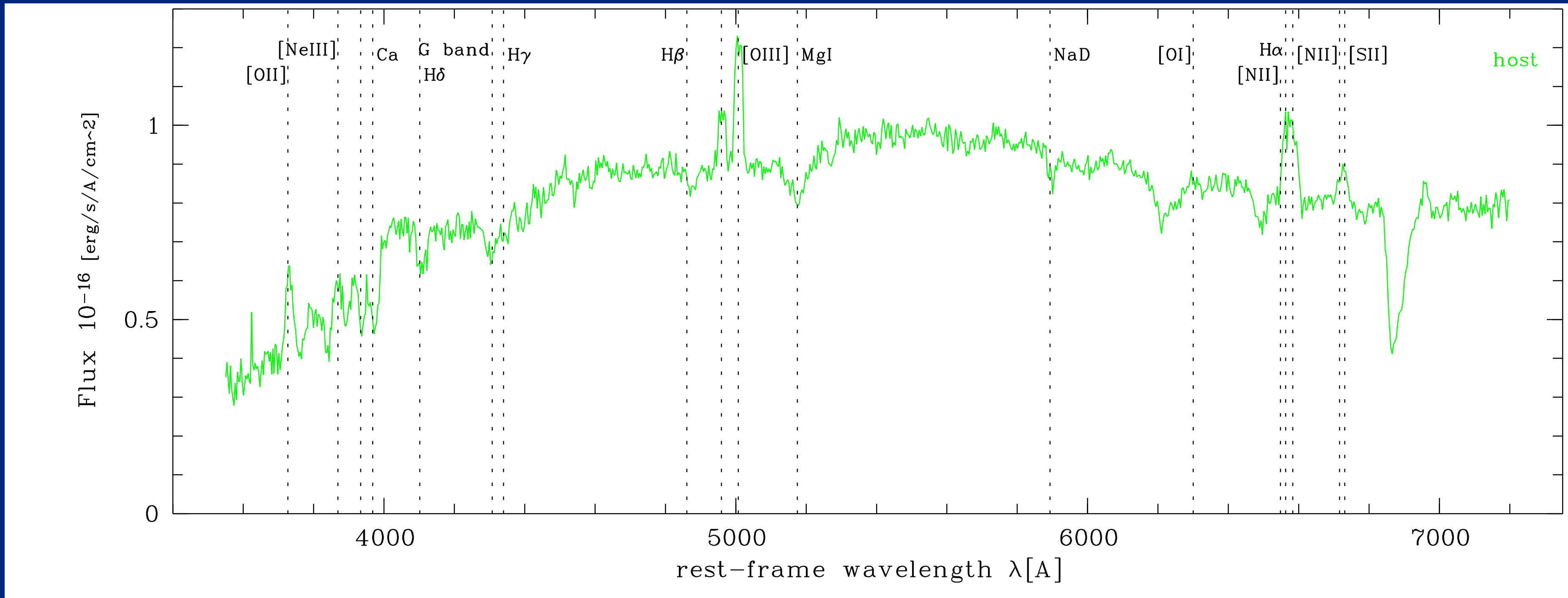
The "FORS sample"

- 10 (total 20) objects from HES, $z < 0.33$, $M_B < -24$
- Collaboration with F. Courbin et al. (Liége)
- VLT Antu with FORS1, MOS:
  - wavelength range: 3800–9000 Å (3 grisms)
  - resolution: $\sim$700
  - 0.2″/pixel
  - integration time: 1200–2400 s
- morphological parameter: B. Kuhlbrodt, L. Wisotzki

Modelling results EFOSC

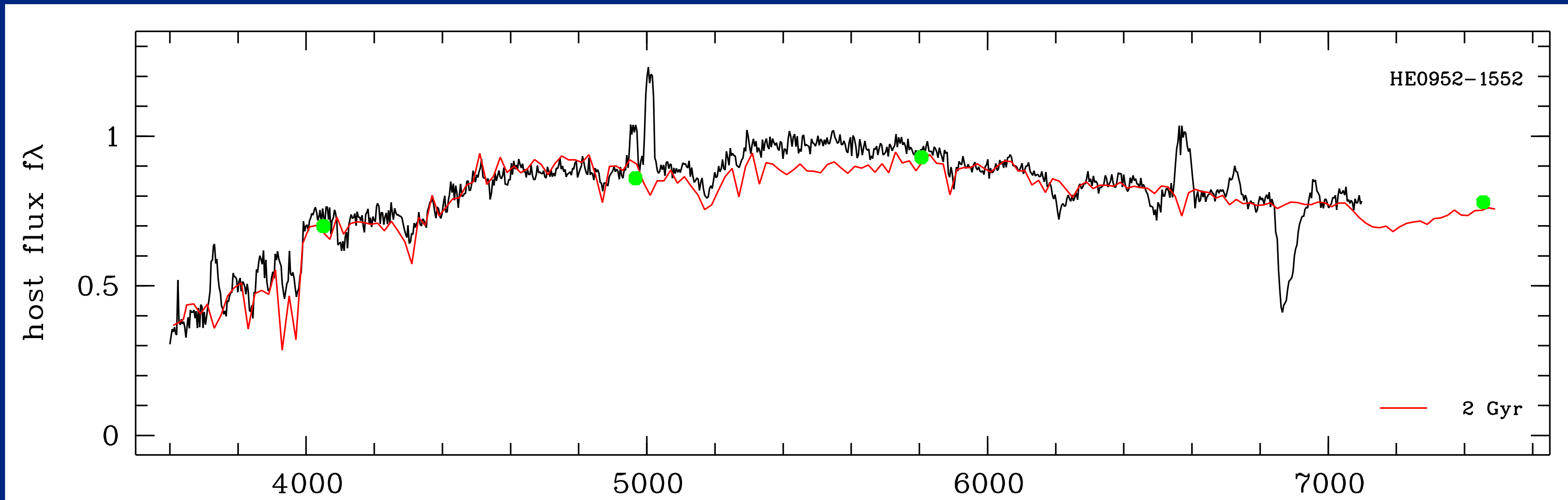


EFOSC: HE 0952–1552, extracted spectra: total, nucleus, host, residual

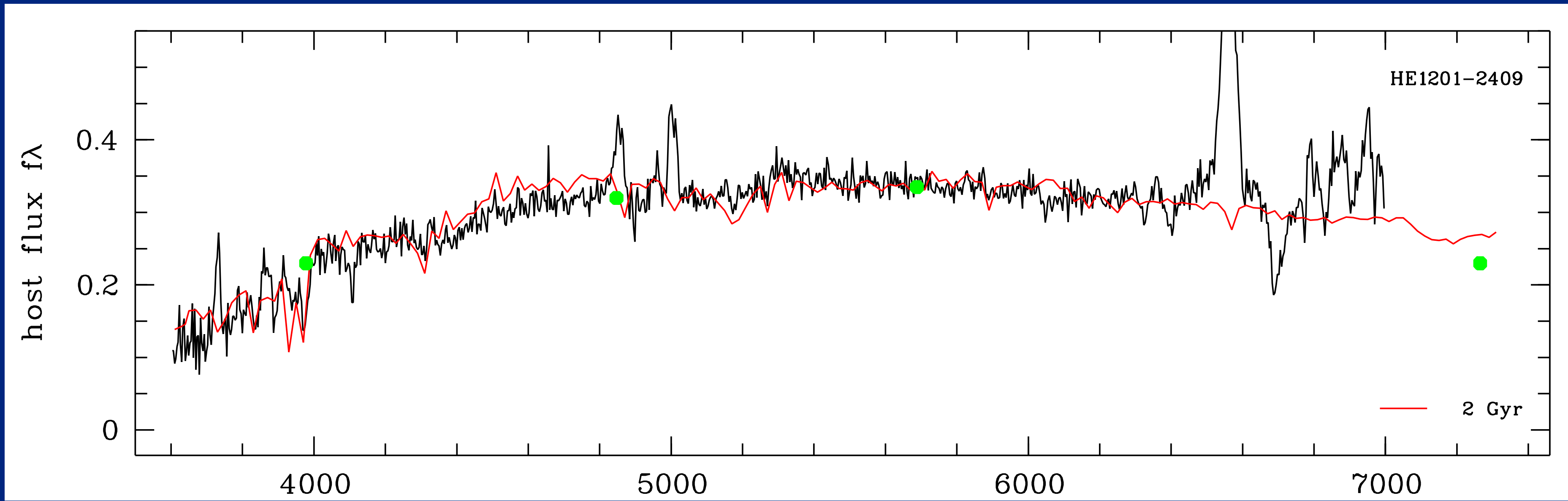


EFOSC: HE 0952–1552, extracted spectrum: host galaxy

Comparison to broad band colours and models

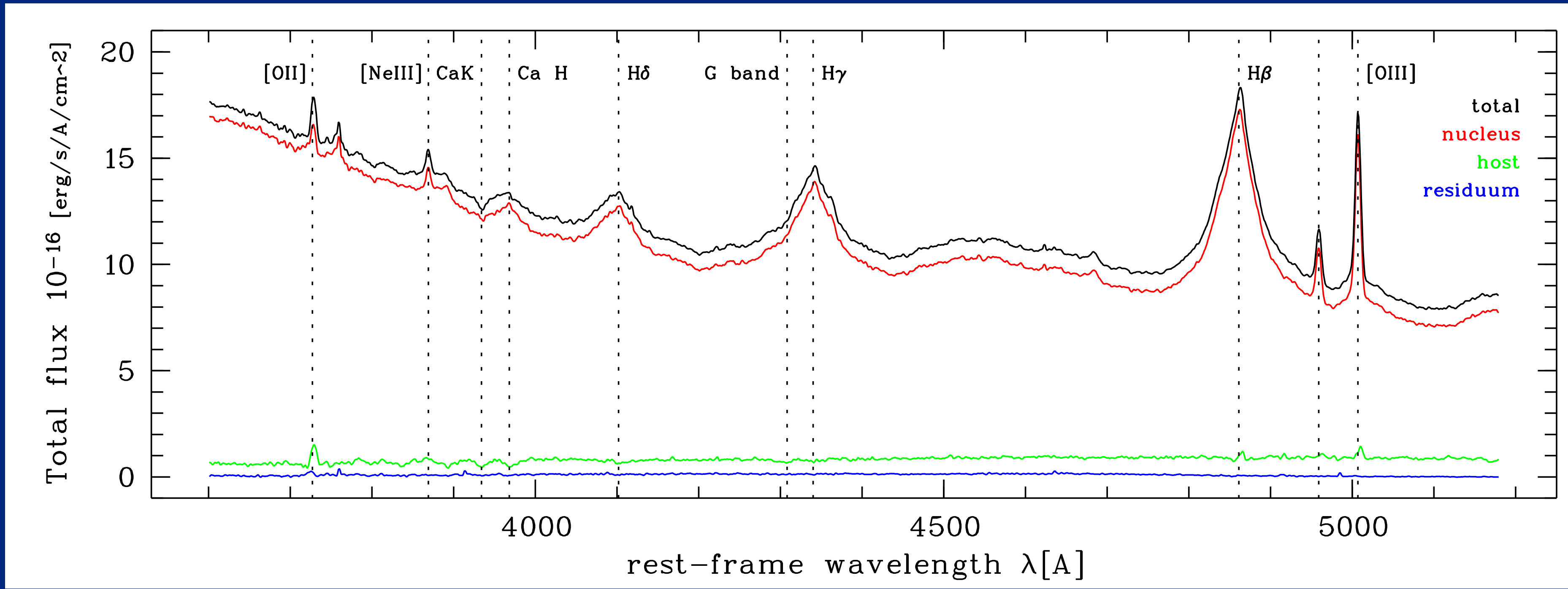


HE 0952–1552: 100% 2 Gyr (disk)

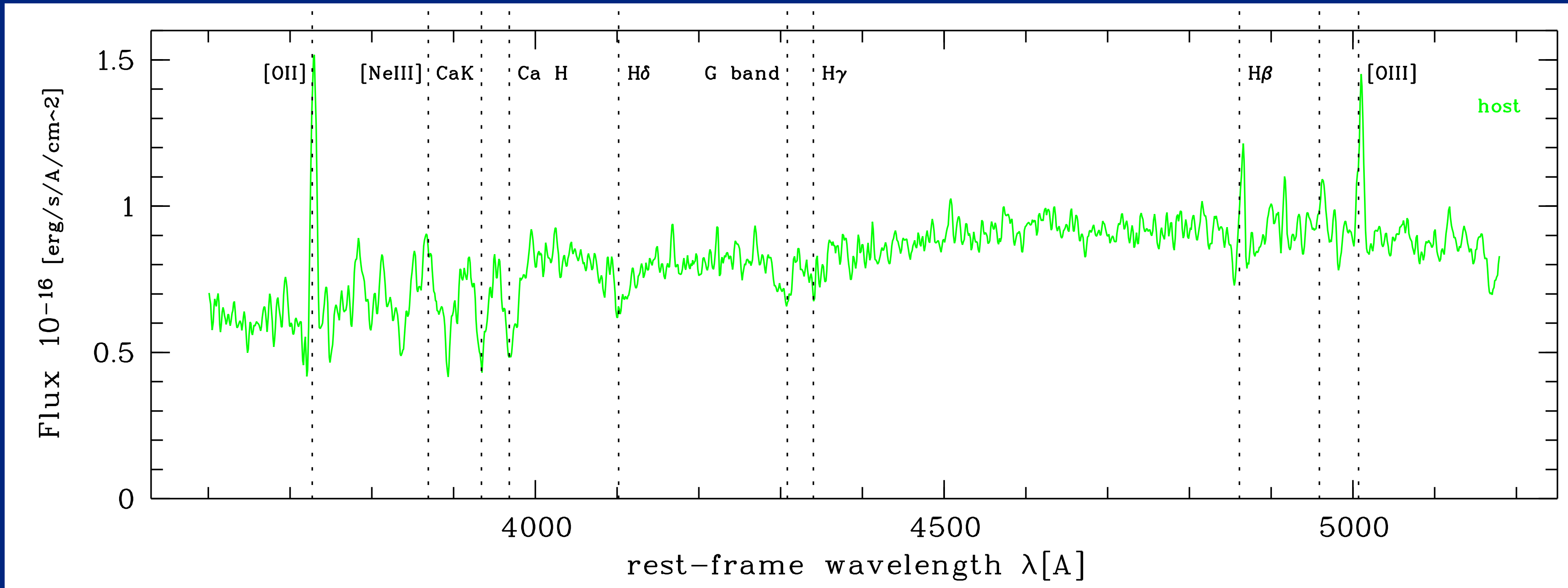


HE 1201–2409: 100% 2 Gyr (elliptical)

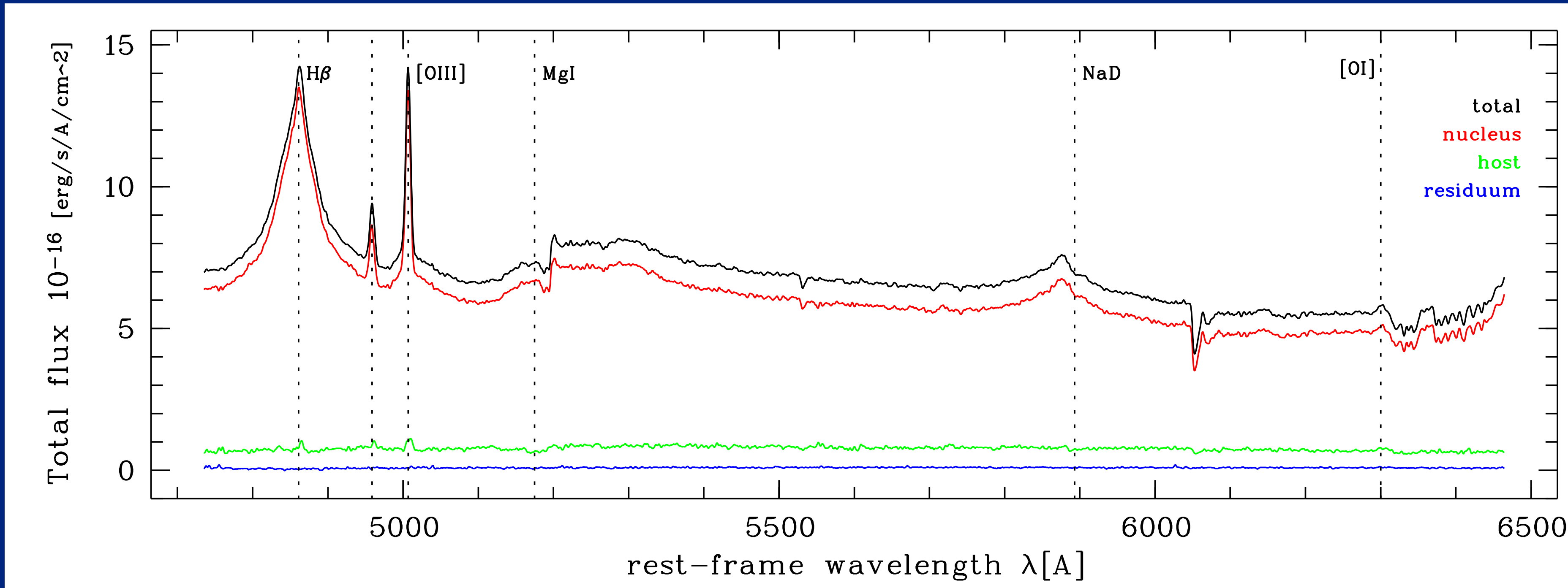
Modelling results FORS



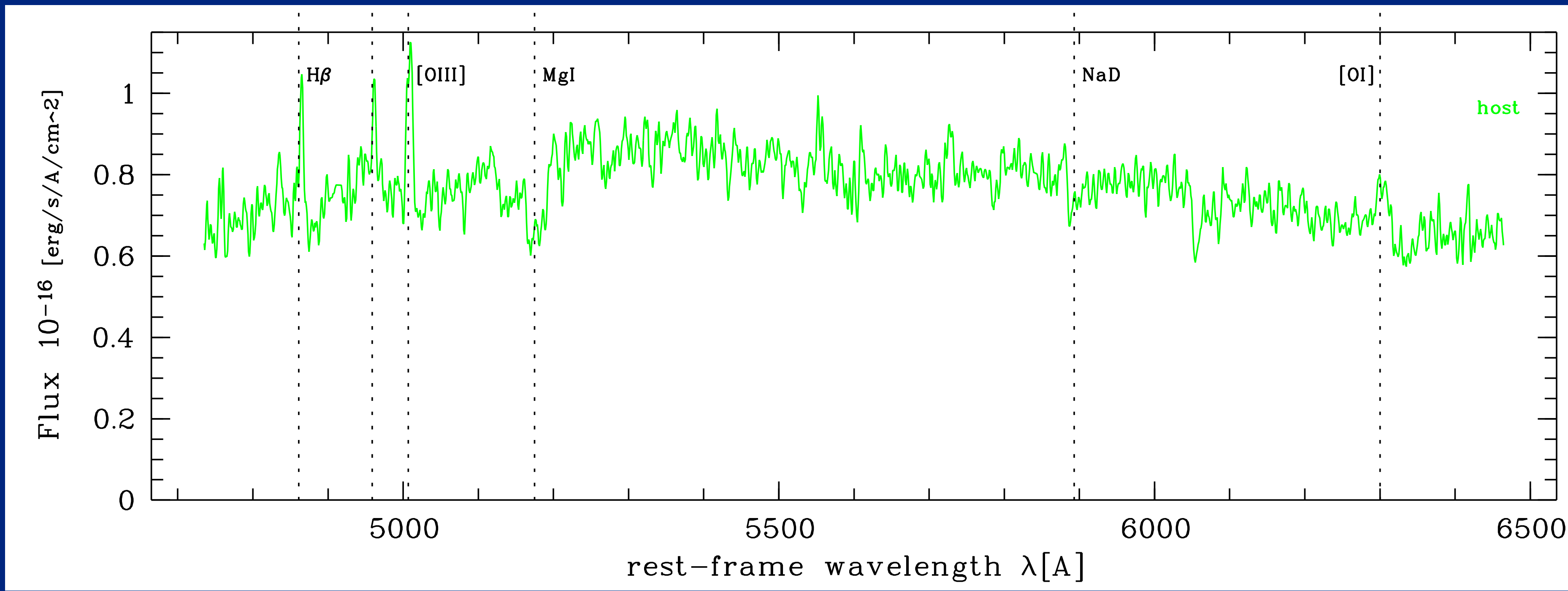
FORS: HE 1503+0228, B grism: total, nucleus, host, residual



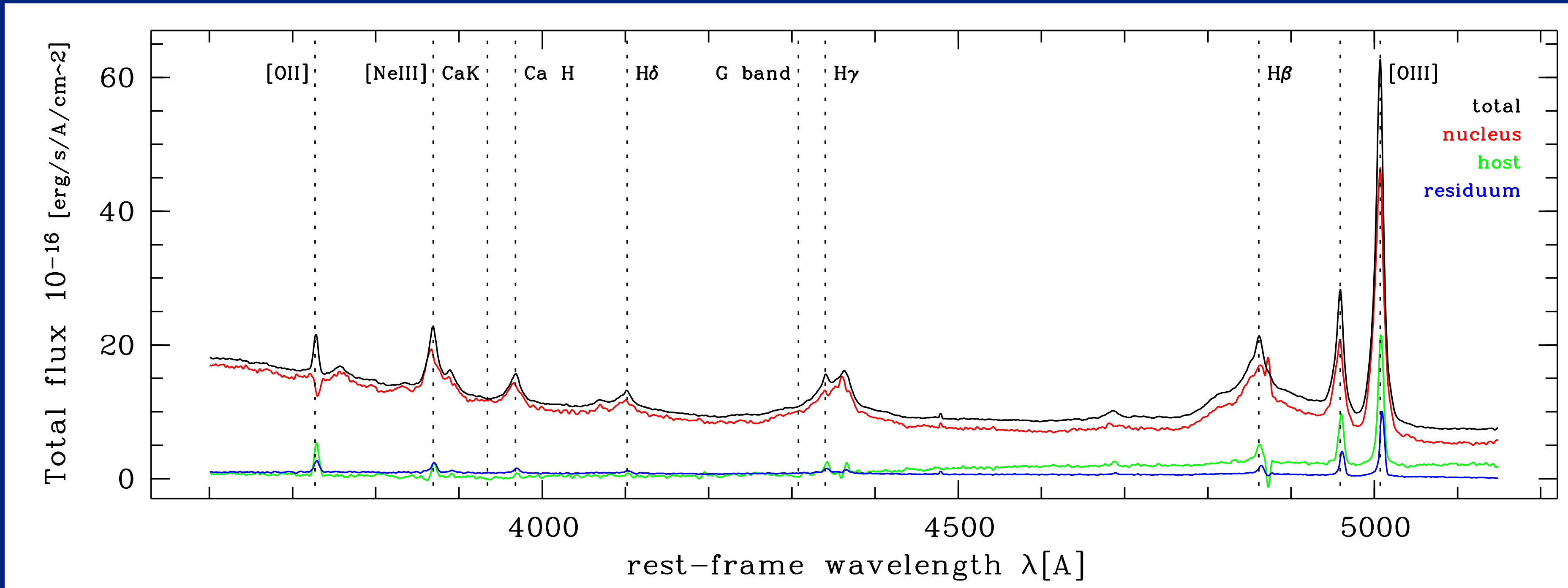
FORS: HE 1503+0228, B grism: host galaxy



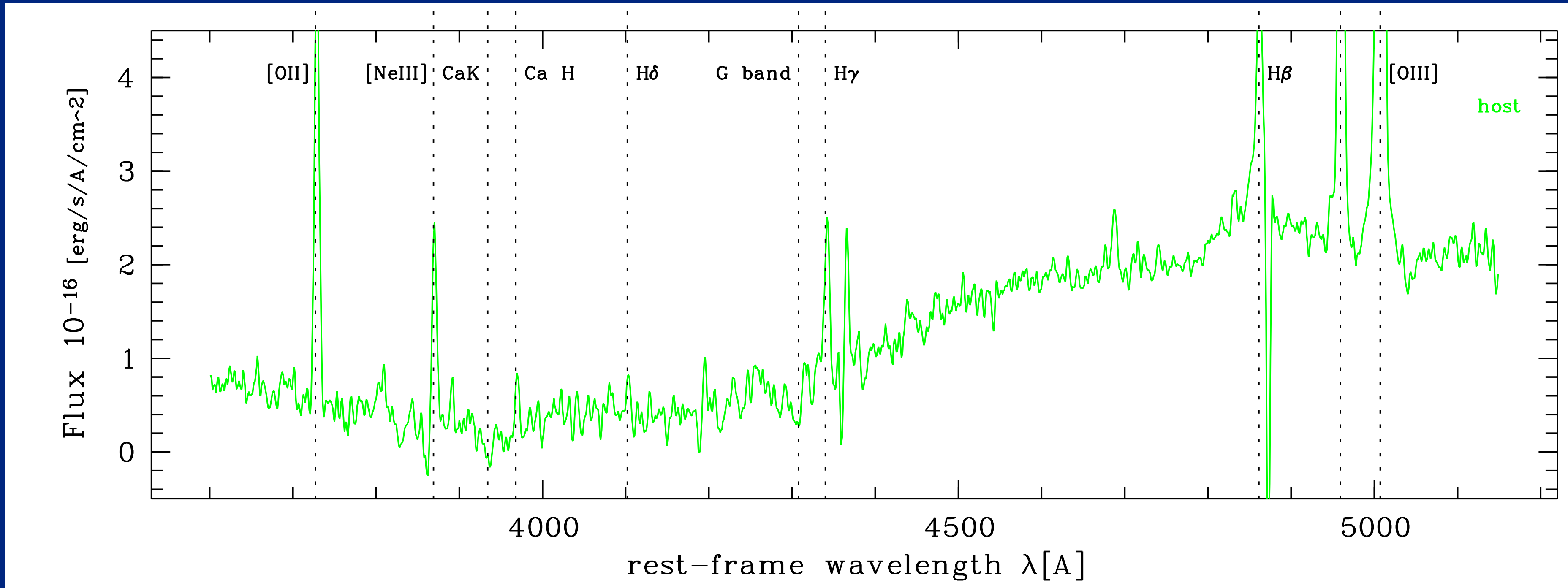
FORS: HE 1503+0228, R grism: total, nucleus, host, residual



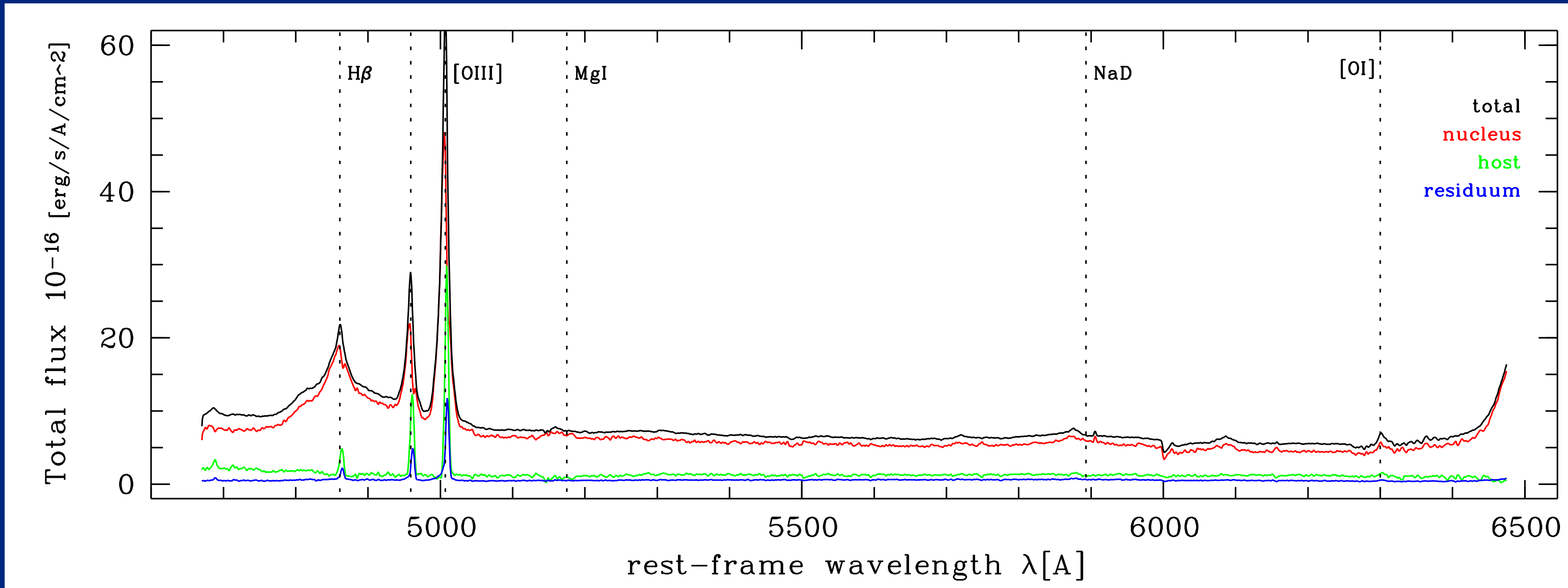
FORS: HE 1503+0228, R grism: host galaxy



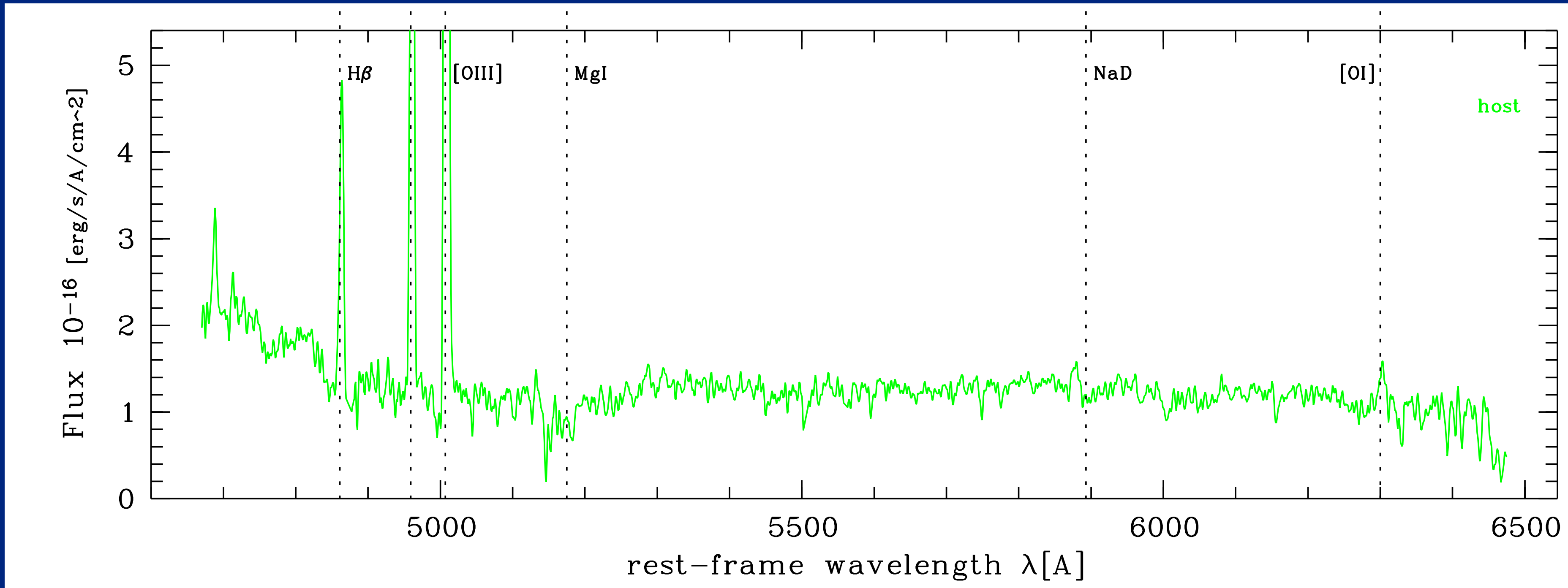
FORS: HE 1434–1600, B grism: total, nucleus, host, residual



FORS: HE 1434–1600, B grism: host galaxy

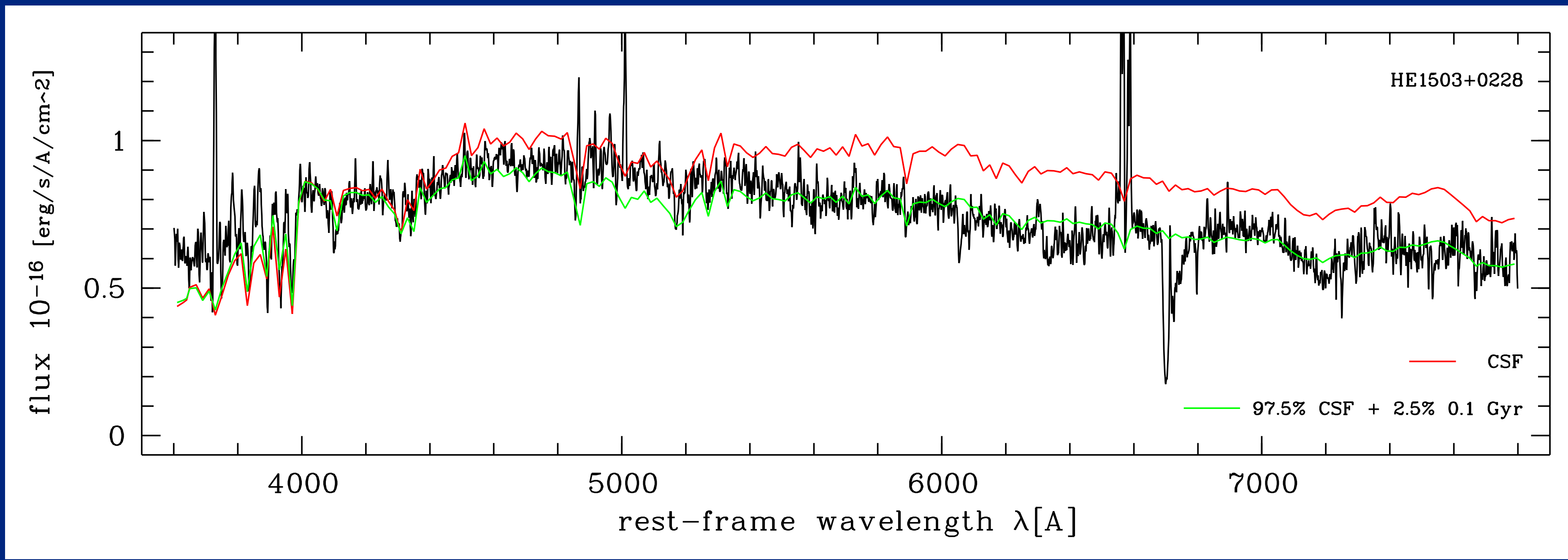


FORS: HE 1434–1600, R grism: total, nucleus, host, residual

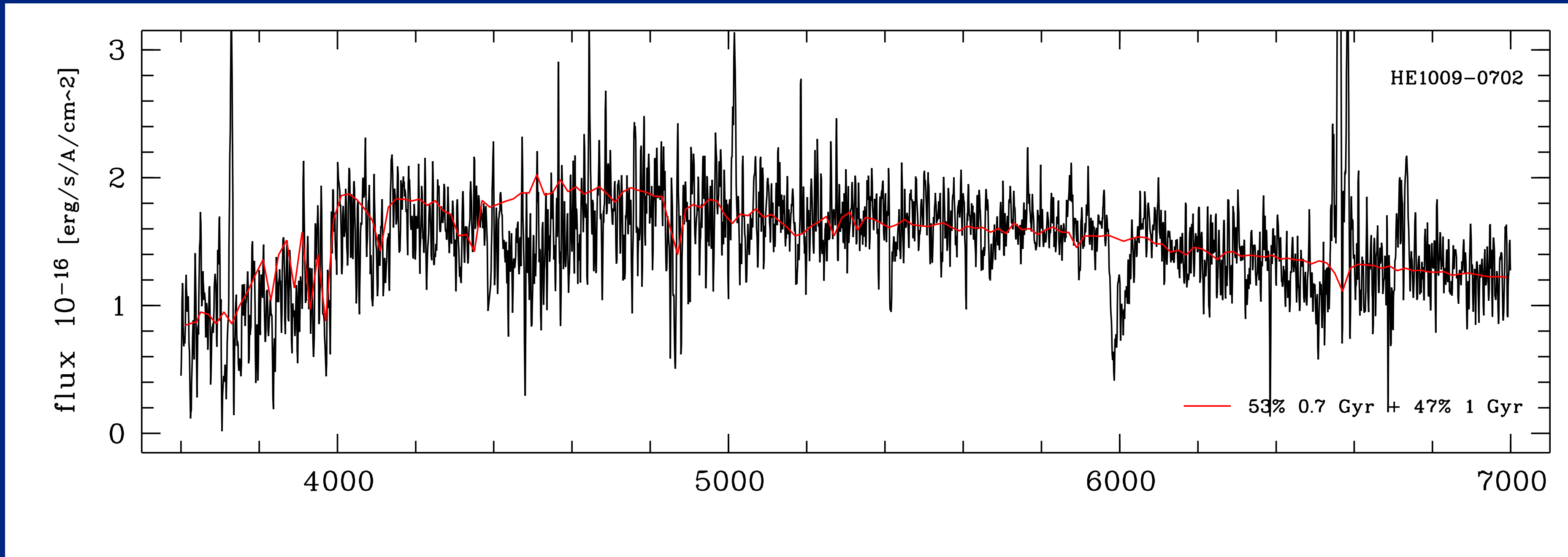


FORS: HE 1434–1600, R grism: host galaxy

Comparison to models



HE 1503+0228: 100% CSF vs. 97.5% CSF + 2.5% 0.1 Gyr

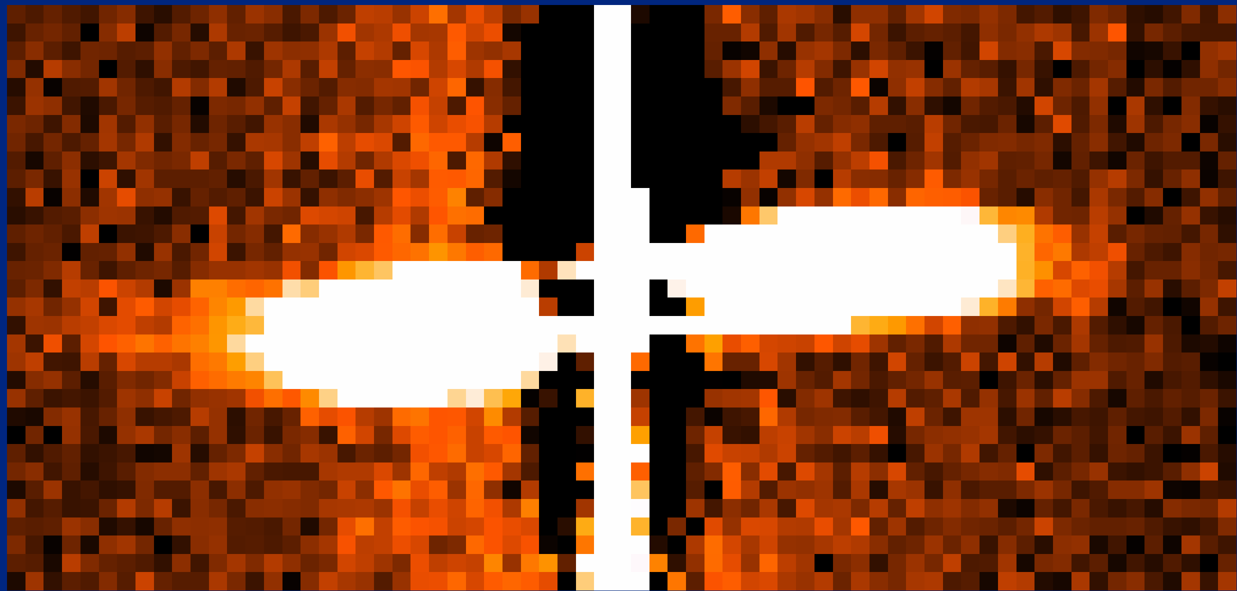


HE 1009–0702: 53% 0.7 Gyr + 47% 1 Gyr (elliptical!)

Modelling results

- EFOSC
  - successful: 3
  - successful (after modification): 4
  - S/N too low: 1
- FORS
  - successful: 2
  - successful (after modification): 5
  - S/N too low: 3

Rotation: emission lines

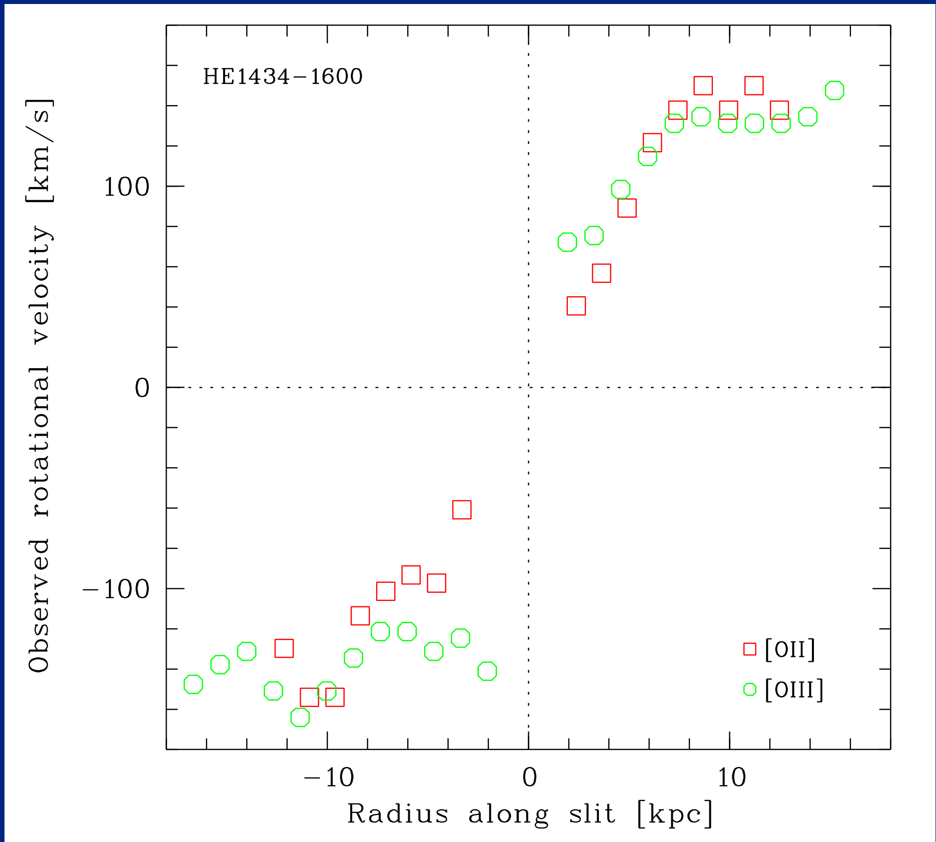


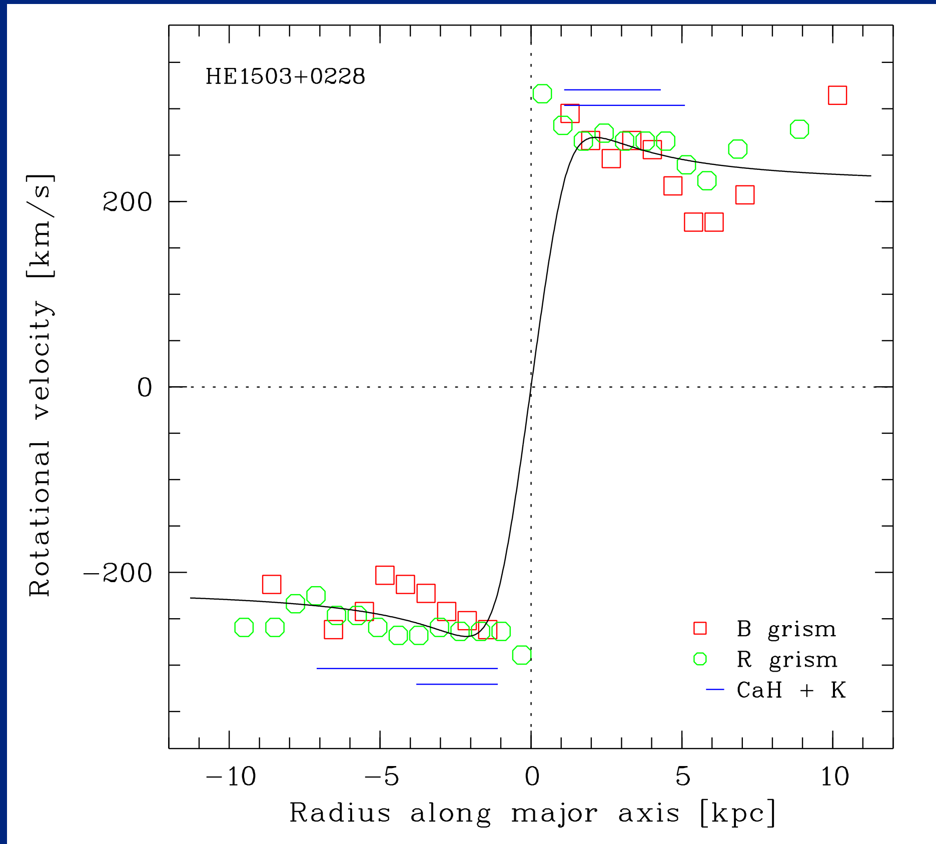
Rotation

- EFOSC
  - gas rotation for 2 disks, 1 elliptical
  - clearly no gas rotation for 1 elliptical
  - stellar rotation for 2 disks
  - clearly no stellar rotation for 1 elliptical
- rotation velocities
  - gas: 200–470 km/s (observed)
  - stars: 215–325 km/s (observed)

Rotation

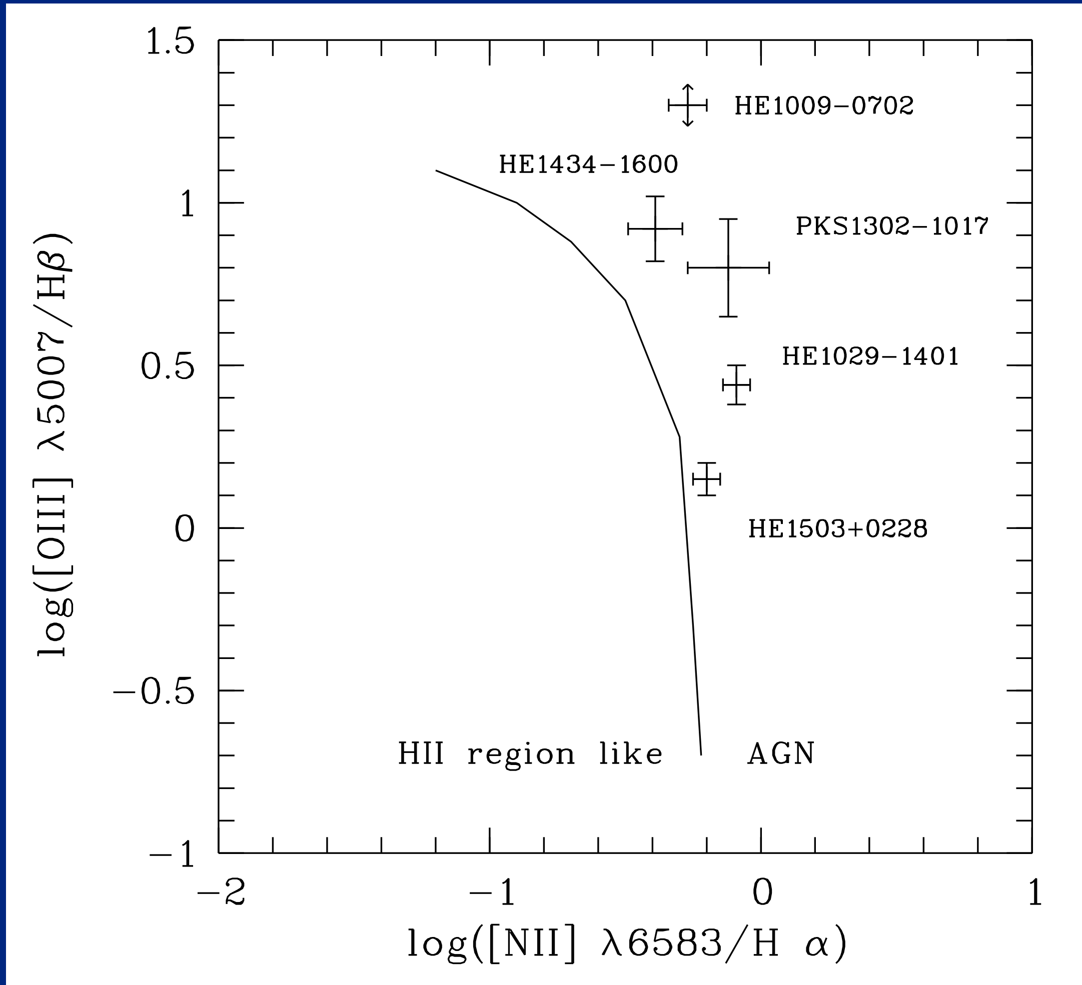
- FORS
  - gas rotation for 7 of 8 (of these 3 ellipticals)
  - clearly no gas rotation for 1 elliptical
  - stellar rotation for 2 disks
  - clearly no stellar rotation for 1 elliptical
- rotation velocities
  - gas: 75–180 km/s (observed)
  - stars: 40–150 km/s (observed)
- spatially resolved for 4 objects ⟶ rotation curves


HE1434−1600
Observed rotational velocity [km/s]
100
0
−100
−10
0
10
Radius along slit [kpc]
[OII]
[OIII]


HE1503+0228
Rotational velocity [km/s]
200
0
−200
−10
−5
0
5
10
Radius along major axis [kpc]
B grism
R grism
CaH + K

Line ratios

- determine ionisation source, hot stars vs. AGN (Veilleux & Osterbrock 1987):
  - [O III] 5007/Hβ vs. [N II] 6583/Hα
  - [O III] 5007/Hβ vs. [S II] (6716+6731)/Hα
  - [O III] 5007/Hβ vs. [O I] 6300/Hα
- temperature: [O III] (4959+5007)/4363
- electron densities: [S II] 6716/6731


log([OIII] λ5007/Hβ)
1.5
1
0.5
0
−0.5
−1
−2
−1
0
1
log([NII] λ6583/H α)
HE1009−0702
HE1434−1600
PKS1302−1017
HE1029−1401
HE1503+0228
HII region like
AGN

On-nucleus spectroscopy: summary

- separation working, multicolour imaging fluxes reproduced
- spatial resolution achievable
- emission and absorption lines detectable
- quality depending on PSF quality, S/N, nucleus-to-host ratio

On-nucleus spectroscopy: summary

- disks:
  - no signs of strong starbursts
  - gas ionised by hot stars and/or nucleus
  - in total very similar to inactive spirals
- ellipticals:
  - young populations consistent with multicolour imaging
  - no signs of old evolved populations
  - excluded: only added starburst
  - (massive) rotating gas disks in several objects
  - ionised by nucleus

Discussion

Discussion

- Nolan et al. 2001:
  - higher luminosity quasars
  - only ellipticals with red, evolved population
  - weak or absent gas emission
  - no bias from off-nucleus position expected
- Boroson et al. 1985:
  - luminous quasars: red spectra + weak gas lines or blue spectra + strong gas lines
  - less luminous quasars: weak or strong gas lines

$\longrightarrow$ contradictory results?

Proposal: scenario supporting/supported by hierarchical merging

- intermediately luminous ($L < 2L^*$) elliptical host galaxies:
  - created in major merger of two disks
  - merger induces nuclear activity
  - dynamically transformed in merger $\rightarrow$ elliptical morphology
  - stellar populations as in progenitor galaxies $\rightarrow$ colours, spectra
  - (re-)creation of gas disk after merger? $\rightarrow$ timescale problem?
  - surface density of gas disk low $\rightarrow$ no strong starburst
  - passive evolution to “red” elliptical within 1 Gyr

- luminous elliptical host galaxies:
  - activity created by $\leq$ minor merger
  - more massive $\rightarrow$ later in mass evolution
- disk host galaxies:
  - activity created by minor merger events $\rightarrow$ distortions, companions
  - (slightly) enhanced SFR

$\longrightarrow$ direct sign for hierarchical clustering?

$\longrightarrow$ creation of luminous ellipticals caught in the act?

Open questions

- special initial conditions required for merger? → gas disk creation
- what happens with other merger geometries? → ULIRGs? radio galaxies?
- why is the gas/ionisation geometry so different in disks and ellipticals?
  → obscuring material close to nucleus? the dust torus itself?

Outlook

- techniques:
  - more detailed emission line modelling
  - improved PSF determination
  - extention to integral field spectroscopy data
  - absorption line diagnostics $\rightarrow$ ages/metallicities/dust
  - velocity dispersions $\rightarrow$ central masses
- more data:
  - second half of FORS sample, integration times doubled
  - “multicolour-north”, second sample from Palomar-Green
  - 3d spectroscopy: PMAS, VIMOS
  - luminosity dependence of spectral properties
  - correlation broad-line shape and host properties
  - with VIMOS host galaxy spectra available to $z \sim 0.5$

More on quasar host galaxies:

Tuesday, January 28, 16:00
Extragalactic Science Club

Björn Kuhlbrodt (Hamburg)
“The luminosity function of QSO host galaxies”