

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL  
INSTITUTO DE FÍSICA  
DEPARTAMENTO DE ASTRONOMIA

**Os primeiros 62 AGNs observados  
com o SDSS-IV MaNGA:  
Populações Estelares Espacialmente Resolvidas\***

Nícolás Dullius Mallmann

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# Resumo

Uma das vertentes de estudo da evolução de galáxias se concentra nos processos de alimentação (*feeding*) e de retroalimentação (*feedback*) do núcleo ativo de galáxias (*active galactic nucleus*; AGN). AGNs são fenômenos muito energéticos, podendo alterar a distribuição de matéria (estelar e gasosa) no seu entorno. Neste trabalho apresentamos mapas de populações estelares espacialmente resolvidos, perfis radiais médios e gradientes destes para as primeiras 62 galáxias com núcleo ativo, observadas no *Mapping Nearby Galaxies at APO* do *Sloan Digital Sky Survey IV*, para estudar os efeitos de AGNs no histórico de formação estelar das galáxias hospedeiras. Esses resultados, derivados com síntese de populações estelares (utilizando o código STARLIGHT), são comparados com os derivados para uma amostra de galáxias inativas cujas propriedades foram pareadas com as ativas. A fração de populações estelares jovens ( $t < 40.1 \text{ Myr}$ ) em AGNs de alta luminosidade é maior nas regiões mais internas ( $R \leq 0.5 R_e$ ) quando comparadas com a amostra de controle; AGNs de baixa luminosidade, por outro lado, apresentam frações muito similares de estrelas jovens às das galáxias de controle para toda a região estudada ( $1R_e$ ). A fração de populações estelares de idade intermediária ( $40.1 \text{ Myr} < t \leq 2.6 \text{ Gyr}$ ) em galáxias ativas aumenta radialmente, com um aumento significativo se comparadas com as galáxias de controle. As regiões centrais das galáxias (tanto ativas quanto inativas) são dominadas por populações velhas ( $t > 2.6 \text{ Gyr}$ ), cuja fração diminui com o raio. Também comparamos os resultados (diferenças entre AGNs e controles) de galáxias hospedeiras *early* e *late-type* e não encontramos nenhuma diferença significativa. Em resumo, nossos resultados sugerem que a atividade dos AGNs mais luminosas seja alimentada por um suprimento recente de gás, que, por sua vez, também ativou formação estelar recente ( $t \leq 40 \text{ Myr}$ ) nas regiões centrais.

# Abstract

One of the main open problems in galaxy evolution's studies concentrates on the feeding and feedback processes generated by the active galactic nuclei (AGN). AGN are very energetic phenomena that can alter their surrounding environment (stellar or gaseous). In this work, we present spatially resolved stellar population age maps, average radial profiles and gradients for the first 62 Active Galactic Nuclei observed with SDSS-IV's Mapping Nearby Galaxies at APO survey (MaNGA) to study the effects of the active nuclei on the star formation history of the host galaxies. These results, derived with stellar population synthesis (using the STARLIGHT code), are compared with a control sample of non-active galaxies matching the properties of the AGN hosts. We find that the fraction of young stellar populations ( $t < 40.1 \text{ Myr}$ ) in high-luminosity AGN is higher in the inner ( $R \leq 0.5 R_e$ ) regions when compared with the control sample; low-luminosity AGN, on the other hand, present very similar fractions of young stars to the control sample hosts for the entire studied range ( $1 R_e$ ). The fraction of intermediate age stellar populations ( $40.1 \text{ Myr} < t \leq 2.6 \text{ Gyr}$ ) of the AGN hosts increases outwards, with a clear enhancement when compared with the control sample. The inner region of the galaxies (AGN and control galaxies) presents a dominant old stellar population ( $t > 2.6 \text{ Gyr}$ ), whose fraction decreases outwards. We also compare our results (differences between AGN and control galaxies) for the early and late-type hosts and find no significant differences. In summary, our results suggest that the most luminous AGN seems to have been triggered by a recent supply of gas that has also triggered recent star formation ( $t \leq 40 \text{ Myr}$ ) in the central region.

# Abreviaturas

AGN: Núcleo Ativo de Galáxia (*Active Galactic Nucleus*).

APO: Apache Point Observatory.

IFU: Unidade de campo integral (*Integral Field Unit*).

MaNGA: Mapping Nearby Galaxies at APO.

MNRAS: Monthly Notes of the Royal Astronomical Society.

SDSS: Sloan Digital Sky Survey.

SFH: Histórico de Formação Estelar (*Star Formation History*).

SMBH: Buraco Negro Supermassivo (*Supermassive Black Hole*).

SSP: População estelar simples (*Simple Stellar Population*).

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# Capítulo 1

## Introdução

### 1.1 Galáxias de Núcleo Ativo

Uma fração<sup>1</sup> das galáxias observáveis no universo emite alta luminosidade, se comparadas com galáxias de mesmas características, proveniente de regiões centrais extremamente compactas. Essas regiões, denominadas de núcleos ativos de galáxias (*Active Galactic Nucleus*; AGN), são caracterizadas por luminosidades bolométricas da ordem de  $10^{42}$  a  $10^{48}$  ergs/s, volumes compactos de  $1 \text{ pc}^3$  e altas taxas de variação da luminosidade com o tempo (Beckmann & Shrader, 2012). A energia luminosa destes objetos, quando comparada com a energia emitida pelas estrelas da galáxia hospedeira, não pode ser explicada via processos de fusão termonuclear, como acontece no interior estelar. A hipótese mais aceita para explicar o fenômeno de AGNs envolve a conversão de energia potencial em energia radiativa através da acreção de matéria a um buraco negro supermassivo (*supermassive black hole*; SMBH). A matéria, ao se aproximar do SMBH, espirala e forma um disco de acreção que, devido à viscosidade, fricção e emite energia (Krolik, 1999). O disco de acreção é composto por uma camada interna mais quente e, por isso, mais espessa e uma camada externa mais fria e estreita, cuja espessura aumenta com a distância ao SMBH (Carroll & Ostlie, 2006). AGNs também apresentam jatos relativísticos de partículas, possivelmente carregadas pelo campo magnético, que, ao entrar em contato com o meio interestelar, transferem sua energia e geram lóbulos de emissão em rádio. Além disso, estes objetos apresentam intensas linhas de emissão que por vezes podem ser muito alargadas (podendo chegar a  $10\,000 \text{ km/s}$  em casos extremos). Os AGNs são classificados de acordo com a sua luminosidade e com a presença ou não de

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<sup>1</sup>Se considerarmos objetos de baixa luminosidade, como os LINERs (*Low Ionization Emission Line Regions*), essa fração pode chegar a 50% (Ho, 2008).



uma componente alargada nas linhas de emissão, oriundas de transições permitidas.

A fase de núcleo ativo caracteriza um estágio crítico da evolução de galáxias. Uma vez que o disco de acreção é formado no entorno do SMBH, processos de *feedback* começam a acontecer, como: jatos de partículas relativísticas emitidos da parte interna do disco de acreção, ventos emanando da região externa deste e radiação emitida pelo plasma quente do disco ou de sua coroa (Elvis, 2000, Ciotti et al., 2010). Acredita-se que os processos de *feeding* (alimentação do AGN) e *feedback* (resposta do AGN) conectam o crescimento do SMBH com o crescimento de suas galáxias hospedeiras (figura 1.1), e são reivindicados como responsáveis pela correlação entre a massa do SMBH e a massa do bojo da galáxia (Somerville et al., 2008, Kormendy & Ho, 2013). Em outras palavras, há um cenário de co-evolução, onde o fluxo de gás (*feeding*) no kiloparsec central de galáxias, quando na fase ativa, resulta no crescimento do bojo<sup>2</sup> da galáxia em consonância com o crescimento do SMBH (Ferrarese & Merritt, 2000, Gebhardt et al., 2000). Desde os estudos pioneiros de Terlevich e seus colaboradores (Terlevich et al., 1990) sugere-se que o excesso observado no azul e a diluição das linhas em absorção no espectro nuclear de AGNs é devido as estrelas massivas jovens. Estudos posteriores utilizando espectroscopia de fenda longa (Kauffmann et al., 2003, Cid Fernandes et al., 2004, Riffel et al., 2009) encontraram um excesso nas contribuições de populações jovens das galáxias ativas quando comparadas com as não ativas. Esse resultado levou à proposição de um cenário evolutivo onde o fluxo de gás para a região nuclear da galáxia dispara a formação estelar na região circumnuclear que é, então, seguida pela ignição do processo de atividade nuclear (Storchi-Bergmann et al., 2001, Hopkins, 2012). Neste cenário o chamado *feedback* positivo do AGN poderia atuar como um catalisador e induzir a formação estelar na galáxia hospedeira, pois este aumenta a turbulência no meio interestelar como previsto por simulações (Gaibler et al., 2012, Ishibashi & Fabian, 2012, Wagner et al., 2012, Zubovas et al., 2013, Bieri et al., 2015, Zubovas & Bourne, 2017) e detectado em poucos objetos (Cresci et al., 2015, Maiolino et al., 2017).

Modelos e simulações modernas de *inflows* de gás em torno da região nuclear de galáxias predizem episódios de formação estelar circumnuclear (Kormendy & Ho, 2013, Heckman & Best, 2014, Zubovas & Bourne, 2017). Contudo, a partir de estudos observacionais, não há um consenso se a alimentação do AGN e a formação estelar ocorrem simultaneamente (Kawakatu & Wada, 2008), ou se essa alimentação acontece em uma fase posterior ao surto de formação estelar (Cid Fernandes et al.,

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<sup>2</sup>Somente bojo clássico.

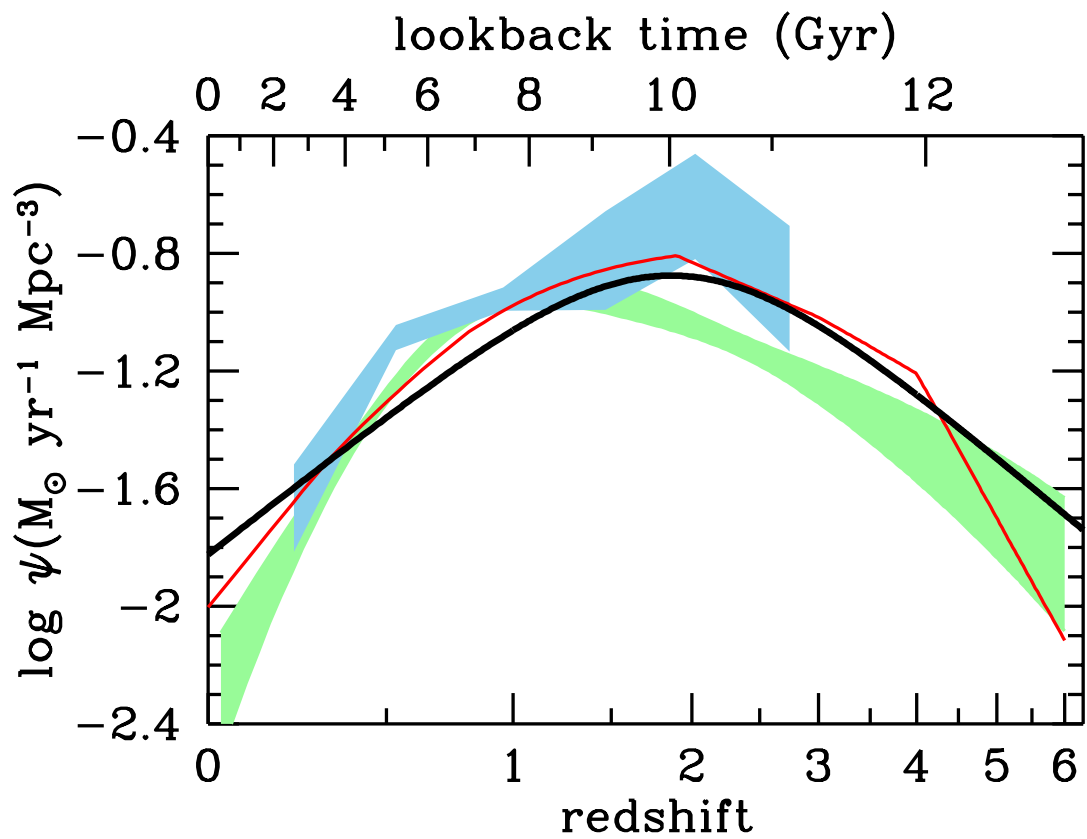


Figura 1.1: Histórico de formação estelar (linha preta) e diferentes medidas da taxa de crescimento de SMBH: Shankar et al. (2009) em vermelho, Aird et al. (2010) em verde e Delvecchio et al. (2014) em azul. Figura retirada de Madau & Dickinson (2014).

2005, Davies et al., 2007, 2009) ou se essa não está relacionada com nenhuma formação estelar recente (Sarzi et al., 2007, Hicks et al., 2013). Neste contexto, é fundamental para esse debate investigar se há alguma associação entre a formação estelar e a atividade nuclear levando em consideração, particularmente, diferentes regimes de luminosidade do AGN. Alguns resultados da literatura (Kauffmann et al., 2003, Davies et al., 2007, Esquej et al., 2014, Ruschel-Dutra et al., 2017) sugerem que estrelas jovens nas vizinhanças do AGN são apenas encontradas em Seyferts com  $L_{AGN} \gtrsim 10^{43}$  erg/s (i.e. taxas de acreção acima de  $\sim 10^{-3} M_{\odot}/yr$ ). Portanto, outros processos de *feeding* menos eficientes podem ser suficientes para fornecer material ao SMBH em taxas de acreção menores. De fato, muitos dos resultados inconclusivos em AGNs do Universo local podem ser atribuídos à luminosidade como sendo um “parâmetro oculto”, já que as análises anteriores, de AGN do universo local, foram focadas em objetos de baixa luminosidade (e.g. Davies et al., 2007).

Durante os últimos anos um grande esforço observacional vem sendo feito para tentar compreender essa co-evolução através do estudo do histórico de formação estelar e da cinemática estelar, ambos, espacialmente resolvidos nas dezenas de parsecs centrais das AGNs. O nosso grupo, até o presente momento, estudou poucas galáxias Seyfert do universo local utilizando cubos de dados na região do infravermelho próximo. Um dos principais resultados é que existe uma correlação espacial entre estrelas com baixa dispersão de velocidades e populações estelares de idade intermediária (Riffel et al., 2010, 2011, Storchi-Bergmann et al., 2012, Schönell et al., 2017, Diniz et al., 2017). Vale ressaltar que, apesar de inúmeros estudos do histórico de formação estelar (*Star Formation History*; SFH) em galáxias terem utilizado cubos de dados (e.g. de Amorim et al., 2017, Goddard et al., 2017a,b, Zheng et al., 2017, Sanchez et al., 2017, e referências), até onde sabemos, não existe nenhum estudo focado em AGNs explorando, por exemplo, os efeitos da luminosidade do AGN no SFH das galáxias hospedeiras.

## 1.2 Motivação e Objetivos

Um importante avanço na compreensão do AGN e seu papel na distribuição das populações estelares pode ser alcançado através de uma investigação da presença ou não de estrelas jovens ou de idades intermediárias nas poucas centenas de  $pc$  do núcleo ativo. Neste contexto: (i) se estrelas jovens dominam a contribuição luminosa, a alimentação do AGN e a formação estelar ocorrem concomitantemente; (ii) se estrelas de idade intermediárias dominarem a população estelar, a alimentação

do AGN seria devida a massa ejetada pelas estrelas evoluídas, assim a fase de AGN seria posterior à fase de formação estelar (*post-starburst phase*); (iii) se apenas encontrarmos populações estelares velhas o *inflow* de gás para o AGN é eficiente e a formação estelar não ocorre. Pelo dito acima fica evidente que para o avanço na compreensão dos processos envolvidos na alimentação do SMBH é necessário mapear as populações estelares nas regiões centrais de uma amostra de AGNs e compará-la com uma amostra de galáxias inativas com mesmas características.

Nosso objetivo aqui é fazer um estudo piloto e mapear espacialmente o histórico de formação estelar em AGNs e compará-lo com o de galáxias inativas com as mesmas propriedades das galáxias hospedeiras de AGNs (ex. luminosidade, massa estelar, tipo de Hubble, etc), e estudar os efeitos da luminosidade do AGN na formação estelar. Para tal, selecionamos os primeiros 62 AGNs observados no survey Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) e criamos uma amostra de controle composta por galáxias inativas para comparação. O MaNGA e a seleção da amostra são descritos no Cap. 2.

## Capítulo 2

# Os primeiros 62 AGNs do MaNGA

### 2.1 MaNGA

MaNGA é um dos três principais programas do Sloan Digital Sky Survey de quarta geração (SDSS-IV). O projeto, liderado por Kevin Bundy (Bundy et al., 2015), tem como objetivo investigar a estrutura cinemática e composição química do gás e estrelas e, com isso, entender a evolução das galáxias e os processos que regulam a formação de suas componentes. Para tal, o MaNGA irá mapear o fluxo de  $\sim 10\,000$  galáxias próximas ( $\langle z \rangle \approx 0.03$ ) com massas estelares  $M_\star > 10^9 M_\odot$  até o final do projeto (em 2020).

O MaNGA utiliza um telescópio de 2,5 metros do Sloan, dedicado ao SDSS, no Apache Point Observatory (APO). As observações são feitas com unidades de campo integral (*Integral Field Unit*; IFU) compostos por um conjunto de 19 a 127 fibras ópticas agrupados em estruturas hexagonais, cobrindo campos de  $12''$  a  $32''$ . Uma

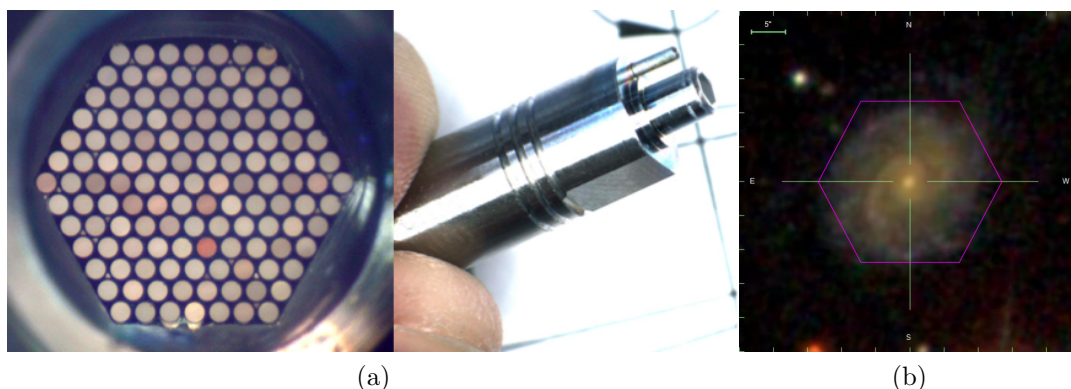


Figura 2.1: Exemplo (a) de um conjunto de fibras do IFU do MaNGA, composto por 127 fibras, e (b) do campo de observação para a galáxia MaNGA ID 1-114306.

imagem do IFU pode ser vista na figura 2.1a e um exemplo do campo observado na figura 2.1b. Cada fibra alimenta um dos dois espectrógrafos BOSS, desenvolvidos anteriormente para o SDSS-III (Smee et al., 2013), que são capazes de fornecer uma cobertura espectral de 3600 Å à 10300 Å, com um poder de resolução médio de  $R \sim 2000$ . Para uma leitura mais técnica do design do IFU e estratégias de observação, recomenda-se ler Drory et al. (2015) e Law et al. (2015).

## 2.2 Nossa Amostra

A amostra de 62 AGNs utilizada nesse trabalho é uma subamostra das 2778 galáxias do MaNGA Public Launch 5 (MPL-5), selecionada por Rembold et al. (2017). Dados espectrais dessas galáxias, obtidas no Data Release 12 (DR12) do SDSS-III, foram utilizados para calcular tanto fluxos de linhas quanto larguras equivalentes ( $H\beta$ ,  $H\alpha$ ,  $[\text{OIII}]\lambda 5007$ ,  $[\text{NII}]\lambda 6584$ ). Com os valores de fluxos e larguras equivalentes, a identificação das galáxias ativas foi realizada empregando dois diagramas diagnóstico, BPT (Baldwin et al., 1981) que envolve as razões de linhas  $[\text{NII}]\lambda 6584/H\alpha \times [\text{OIII}]\lambda 5007/H\beta$  e WHAN (Cid Fernandes et al., 2010, 2011) que usa a razão  $[\text{NII}]\lambda 6584/H\alpha \times \text{EW}(H\alpha)$ . Esses diagramas foram desenvolvidos para identificar o mecanismo de ionização do gás que produz as linhas de emissão observadas. Para que uma galáxia observada pelo MaNGA fosse classificada como AGN e, consequentemente, adicionada à nossa amostra, ela deve ser classificada como AGN em ambos os diagramas citados – ver figura 2.2. A necessidade de utilizar ambos os diagramas se dá pelo fato do diagrama BPT não diferenciar AGNs com baixa ionização de galáxias com linhas de emissão geradas por estrelas evoluídas de baixa massa, caracterizadas por  $\text{EW}(H\alpha) < 3 \text{ \AA}$  (Cid Fernandes et al., 2010).

Uma segunda amostra, contendo galáxias inativas do MPL-5, foi selecionada através do pareamento de propriedades físicas dos AGNs desse trabalho. Para construir essa amostra, foram selecionadas diversas galáxias inativas, para cada AGN, cujo *redshift*  $z$  e massa estelar  $M_*$  não diferissem por 30% dos respectivos valores da galáxia ativa. Através da análise morfológica (razão dos eixos, tipo de Hubble, presença de barras, etc.), o número de candidatas à controle foi reduzido, chegando em alguns casos à duas galáxias por AGN. Para manter a amostra de controle mais homogênea, foram escolhidas apenas as 2 melhores galáxias de controle para cada galáxia ativa. A seleção resultou em uma amostra de controle com 109 objetos (ao invés de 124) pois 12 objetos da amostra de controle foram pareados com mais de um AGN. A figura 2.3 mostra a distribuição das amostras desse trabalho para qua-

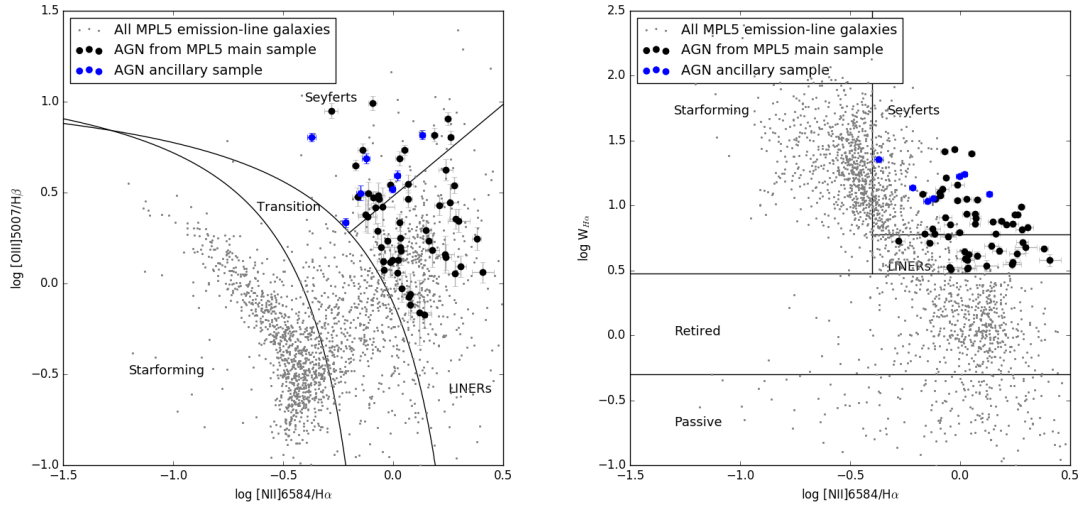


Figura 2.2: Diagramas BPT e WHAN gerados para a amostra do MPL-5 do MaNGA. Pontos cinzas são todas as galáxias com linhas de emissão do MPL-5, pontos pretos (azuis) são os AGNs confirmadas da amostra principal (amostra auxiliar – galáxias não pertencentes ao plano original de observação do MaNGA) do MPL-5. Figura retirada de Rembold et al. (2017).

tro propriedades. Para mais detalhes da seleção das amostras, ver Rembold et al. (2017).

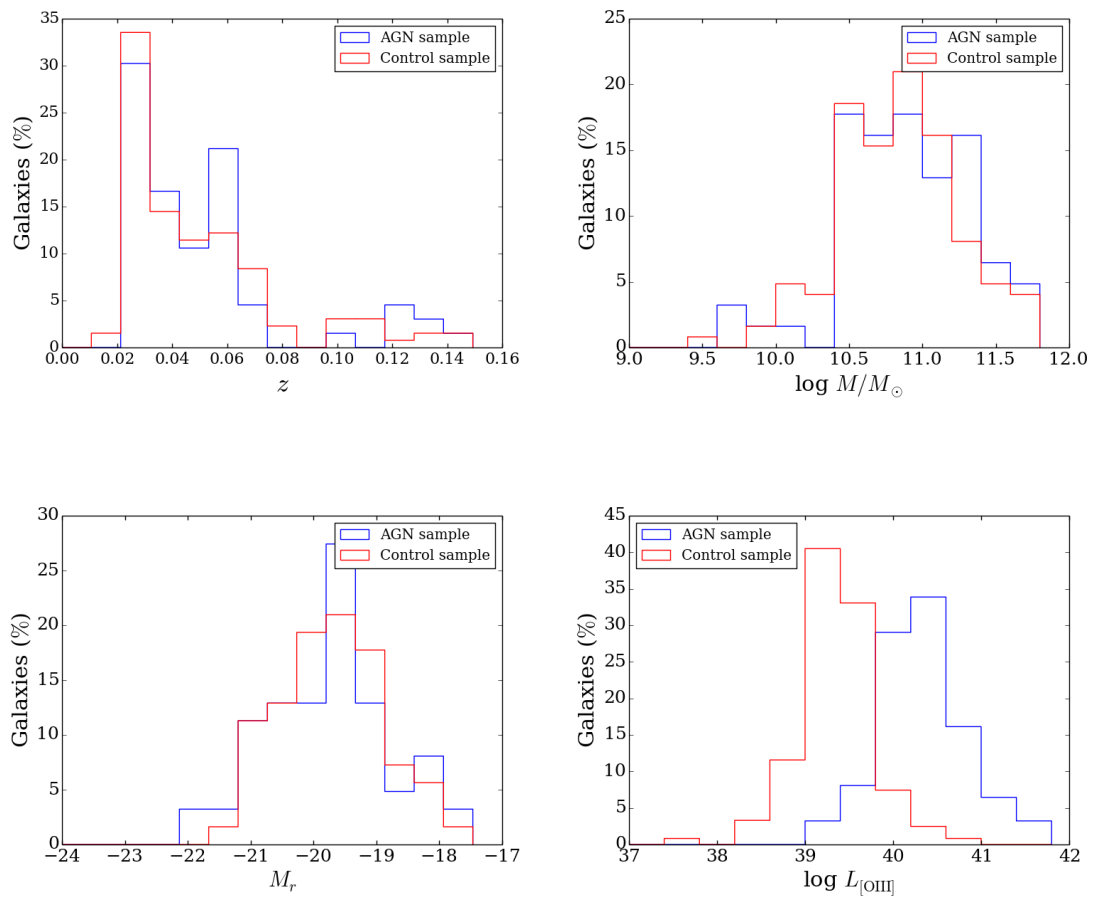


Figura 2.3: Distribuição das duas amostras, AGNs e galáxias de controle, para quatro propriedades. Para o *redshift*, massa estelar e magnitudes na banda  $r$  as duas amostras são semelhantes. Já para a luminosidade  $L_{[\text{O III}]}$ , a distribuição de galáxias ativas está deslocada em relação a das controles pois  $L_{[\text{O III}]}$  é um indicador da intensidade do AGN. Figura retirada de Rembold et al. (2017).



# Capítulo 3

## O *Software* MEGACUBE

Um *software*, chamado MEGACUBE, foi desenvolvido para realizar a síntese de populações estelares de mais de 150 cubos de dados, cada qual com centenas de espectros. Esse *software* foi projetado para trabalhar com diversos cubos de dados em paralelo, utilizando processos filhos independentes. As figuras 3.1 e 3.2 apresentam os fluxogramas do MEGACUBE e de um processo filho, respectivamente.

O primeiro passo realizado pelo MEGACUBE é carregar um arquivo de configuração geral, responsável pelo controle do fluxo de operações dos processos filhos. Após a leitura, o programa importa os módulos e funções necessários, além de obter a lista de cubos de dados, indicados no arquivo de configuração. O programa, então, distribui as funções e cubos de dados para processos filhos que, por sua vez, são executados em paralelo (o número de processos filhos simultâneos é indicado por um parâmetro). Quando todos os cubos de dados foram processados, o programa termina.

Uma das preocupações com a criação do MEGACUBE foi desenvolver uma ferramenta que pudesse ser rapidamente adaptada para: (i) trabalhar com cubos de dados de diferentes *surveys*, (ii) executar diferentes códigos de síntese de populações estelares (ou até mesmo outras funções computacionais, como algoritmos para medidas de fluxos de linhas) e (iii) gerar diferentes resultados conforme o objetivo do trabalho. Com isso em mente, desenvolvemos esse código com capacidade modular, ou seja, pedaços do código são carregados dinamicamente através dos parâmetros do arquivo de configuração. Além disso, para que a comunicação entre os diferentes módulos possa acontecer, a passagem de parâmetros é feita através da atualização do arquivo de configuração.

Nesse trabalho, desenvolvemos três módulos: extração, síntese e análise. A figura 3.2 esquematiza a execução dos três módulos pelos processos filhos do MEGACUBE.

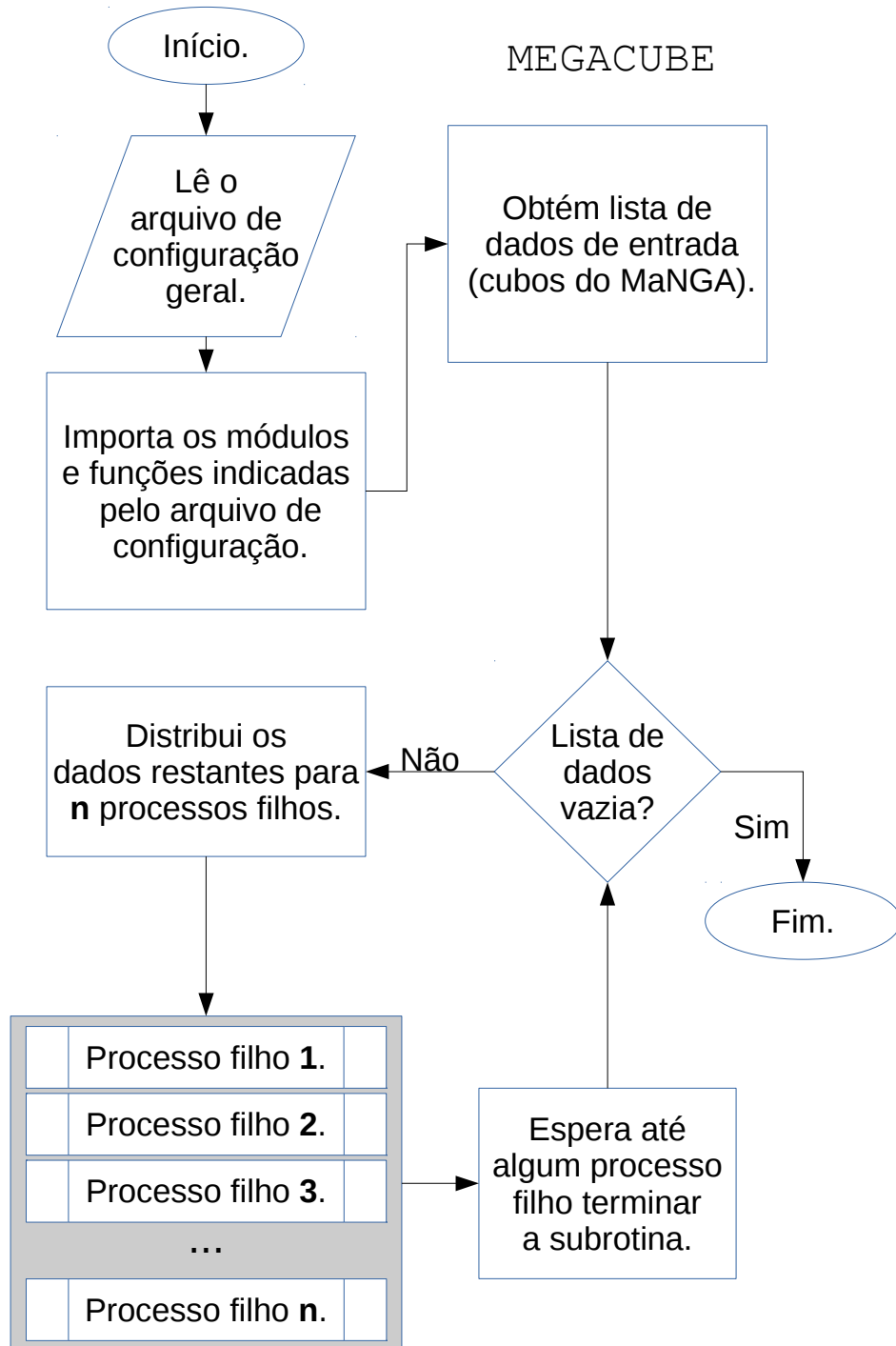


Figura 3.1: Fluxograma esquematisando o programa MEGACUBE.

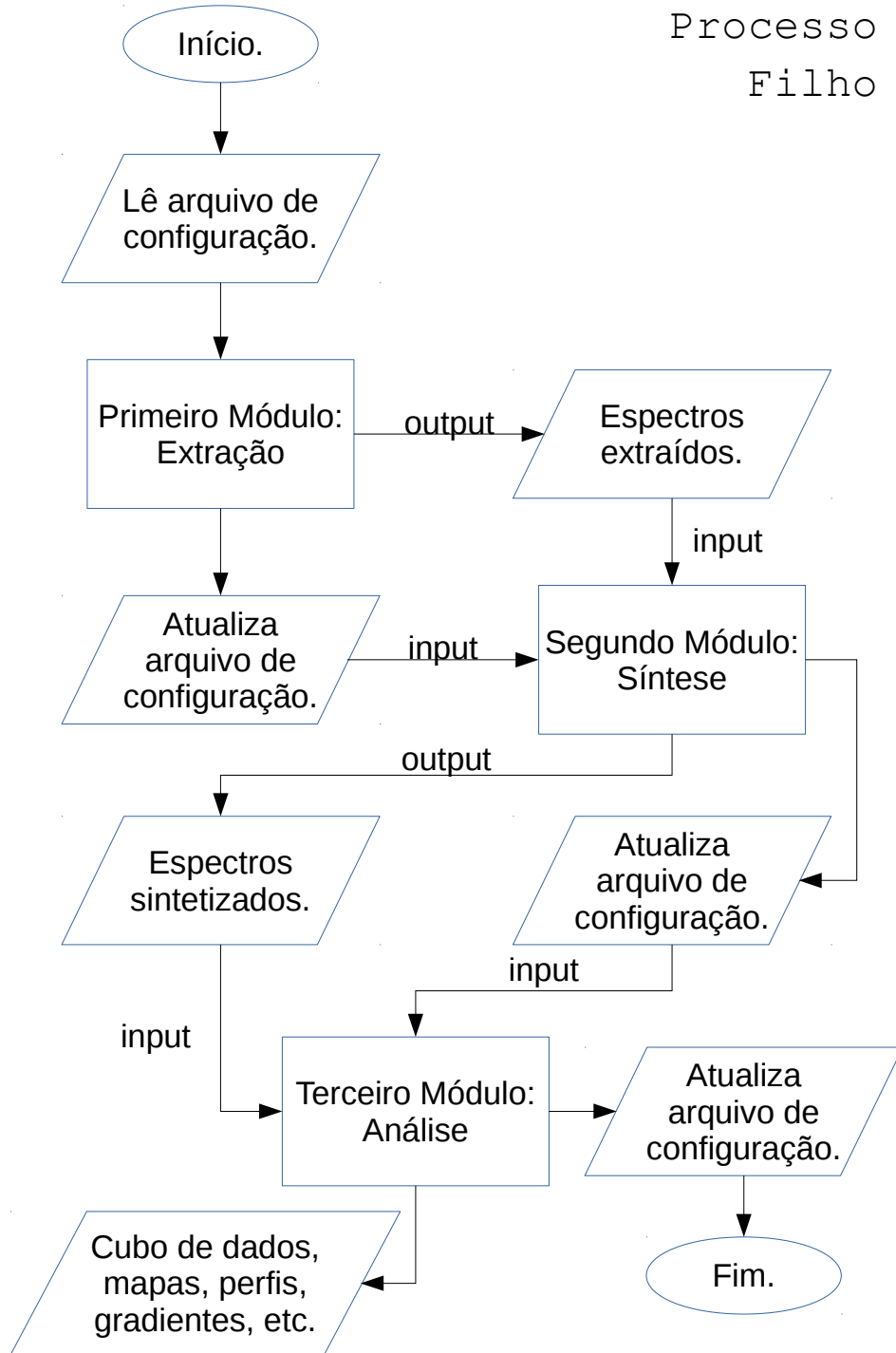


Figura 3.2: Fluxograma esquematisando a sub-rotina do MEGACUBE.

Descrevemos as funções dos três módulos nas seções 3.1, 3.2, 3.3.

### 3.1 Extração de Dados

O módulo de extração foi desenvolvido para converter os espectros dos cubos de dados do MaNGA para um formato aceito pelo programa de síntese de populações estelares (nesse trabalho, STARLIGHT, seç. 3.2.1). Os espectros são preparados, antes da extração, conforme as seguintes etapas:

- Aplicação do filtro *Butterworth* bidimensional para remover dados espúrios (sem a necessidade de combinar spaxels do cubo, como no método *Voronoi binning*). Essa filtragem permite uma exploração dos parâmetros espaciais sem grandes perdas de resolução;
- Aplicação da correção por avermelhamento galático usando os mapas de Schlegel (Schlegel et al., 1998) e da lei de avermelhamento CCM (Cardelli et al., 1989);
- Correção do deslocamento *redshift* usando os parâmetros fornecidos pelas tabelas de dados do MaNGA (*drpall*), valores do SDSS-III;
- Espectros com sinal ruído  $\text{SNR} < 10$ , calculados dentro dos limites 5650-5750 Å, foram excluídos da síntese.

Após as correções, arquivos ASCII foram criados para cada spaxel contendo quatro parâmetros: comprimento de onda  $\lambda$ , fluxo  $f_\lambda$ , incerteza  $e_\lambda$  e a máscara  $m_\lambda$  (indicando se os dados contém problemas).

### 3.2 Síntese de Populações Estelares

A função principal desse módulo é executar o código de síntese de populações estelares STARLIGHT (Cid Fernandes et al., 2004, 2005). Para tal, são gerados arquivos de configuração necessários para realizar a síntese. Além disso, esse módulo pode subdividir a lista dos espectros para que mais de uma instância do código STARLIGHT possa rodar em paralelo e, assim, acelerar o processo de síntese do cubo inteiro. Um exemplo de espectro sintetizado pode ser visto na figura 3.3.

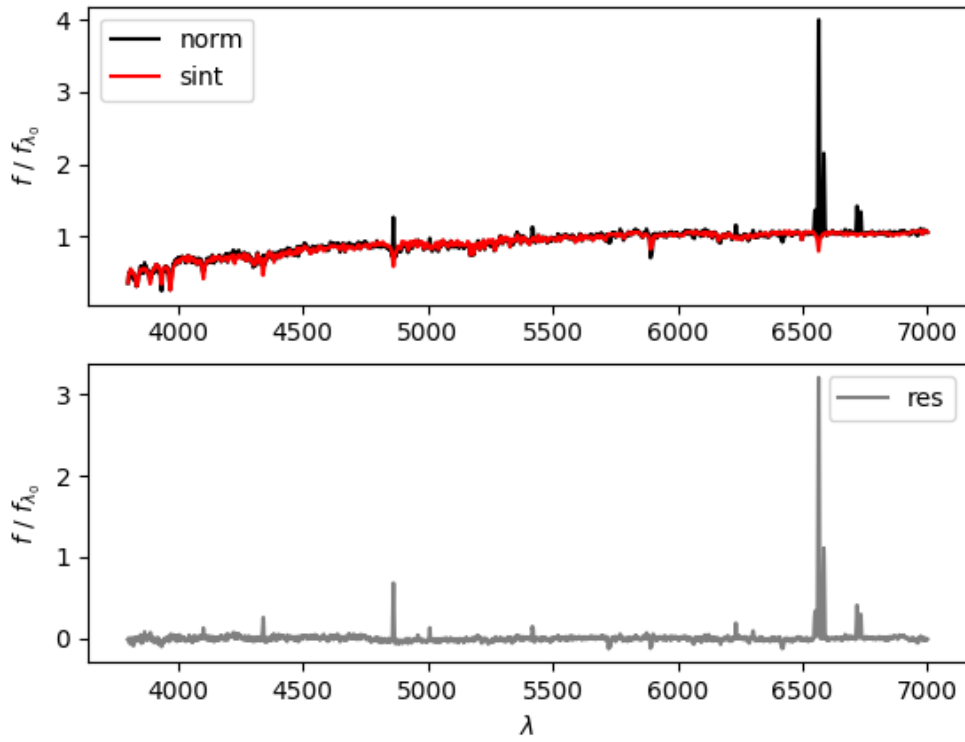


Figura 3.3: Exemplo de síntese espectral para o spaxel central da galáxia MaNGA ID 1-635503. O primeiro painel mostra o espectro observado em preto e o sintetizado em vermelho, ambos normalizados em  $\lambda_0 = 5700 \text{ \AA}$ . O segundo painel mostra o resíduo da síntese. Linhas em emissão não são ajustadas pela síntese de populações estelares.

### 3.2.1 O Código STARLIGHT

STARLIGHT é uma ferramenta de síntese de populações estelares cuja função é buscar o melhor espectro sintetizado a partir de um espectro observado. Para tal finalidade, o programa utiliza um conjunto base de  $N_*$  modelos – nesse trabalho, modelos de populações estelares simples (*simple stellar populations*; SSPs), ou seja, populações de estrelas com mesma idade e mesma metalicidade. São utilizados SSPs calculadas por Bruzual & Charlot (2003), cujos parâmetros variam entre 3 metalicidades ( $Z = 0.002, 0.04$  e  $0.05$ ) e 15 idades ( $10 \text{ Myr} \leq t \leq 13 \text{ Gyr}$ ), por serem amplamente utilizados na literatura. Uma lei de potência do tipo  $F_\nu \propto \nu^{-1.5}$  foi utilizada em conjunto com as SSPs para dar conta do contínuo do espectro gerado pelo núcleo ativo. O programa trabalha com a seguinte equação para o espectro modelo:

$$M_\lambda = M_{\lambda_0} \left[ \sum_{n=1}^{N_*} x_j b_{j,\lambda} r_\lambda \right] \otimes G(v_*, \sigma_*) \quad (3.1)$$

na qual  $M_{\lambda_0}$  é o fluxo sintético no comprimento de onda normalizado em  $\lambda_0$ ,  $j$  representa cada uma das SSPs da base utilizada,  $b_{j,\lambda}$  é o espectro da SSP,  $r_\lambda$  é a componente de avermelhado da SSP e  $x_j$  é o vetor de população. A soma é convoluída com uma distribuição gaussiana representada por  $G(v_*, \sigma_*)$ , onde  $v_*$  é a velocidade central da distribuição e  $\sigma_*$  é a dispersão de velocidades. Para obter os melhores resultados, o STARLIGHT busca minimizar uma função que represente o afastamento do espectro sintetizado com relação ao observado – quanto maior o valor, pior é a síntese. A função utilizada é o  $\chi^2$ :

$$\chi^2 = \sum_{\lambda_i}^{\lambda_f} [(O_\lambda - M_\lambda)\omega_\lambda]^2 \quad (3.2)$$

onde  $O_\lambda$  é o espectro medido,  $M_\lambda$  é o espectro sintetizado,  $w_\lambda$  é o peso correspondente ao comprimento de onda  $\lambda$  (cujo valor pode ser nulo a fim de mascarar, por exemplo, as linhas de emissão de AGNs ou dados espúrios) e  $\lambda$  percorre todo o intervalo de comprimentos de onda escolhido para a síntese.

## 3.3 Análise dos Dados

O terceiro módulo desenvolvido para o MEGACUBE utiliza os cubos de dados estendidos criados pelo módulo da síntese para gerar os seguintes resultados:

- Mapas RGB: mapa representando, de modo qualitativo, a distribuição relativa

de populações com diferentes idades. O cálculo dos mapas é feito relacionando as cores vermelha, verde e azul aos mapas de populações velhas, de idade intermediária e jovens, respectivamente;

- Perfis radiais médios: para cada mapa estudado neste trabalho, foram gerados 30 perfis radiais igualmente espaçados, com um deslocamento angular máximo de  $\theta_{max} = \tan^{-1}[b/a]$  (relativo ao semieixo maior), onde  $a$  é o comprimento do semieixo maior e  $b$  do semieixo menor (ver figura 3.4). Optamos por não gerar perfis próximos ao semieixo menor devido à inclinação da galáxia, que implica em perfis mais distorcidos, obscurecidos e ruidosos. Calculamos, então, os perfis radiais médio e do desvio padrão.
- Gradientes radiais: com os perfis médios, foram calculados gradientes utilizando regressão linear para três limites de distância radial (em unidades de raio efetivo  $R_e$ ; 0.0-0.5  $R_e$ , 0.5-1.0  $R_e$  e 0.0-1.0  $R_e$ )
- Figuras comparativas: para cada trio de galáxias, isto é, AGN e suas duas galáxias controle, foram geradas figuras comparando mapas, perfis médios e gradientes;
- Perfis agrupados em luminosidade de [O III] $\lambda$ 5007: para comparar os efeitos dos AGNs no histórico de formação estelar, agrupamos as galáxias ativas conforme a luminosidade da linha de emissão do [OIII] $\lambda$ 5007, subdividindo em cinco intervalos de  $\log L_{[\text{O III}]}$  [ergs/s]: 39-39.75, 39.75-40.25, 40.25-40.75, 40.75-41.25 e 41.25-42. Para cada grupo, geramos o perfil médio das galáxias ativas, das respectivas galáxias de controle e das diferenças dos perfis das AGNs e controles.

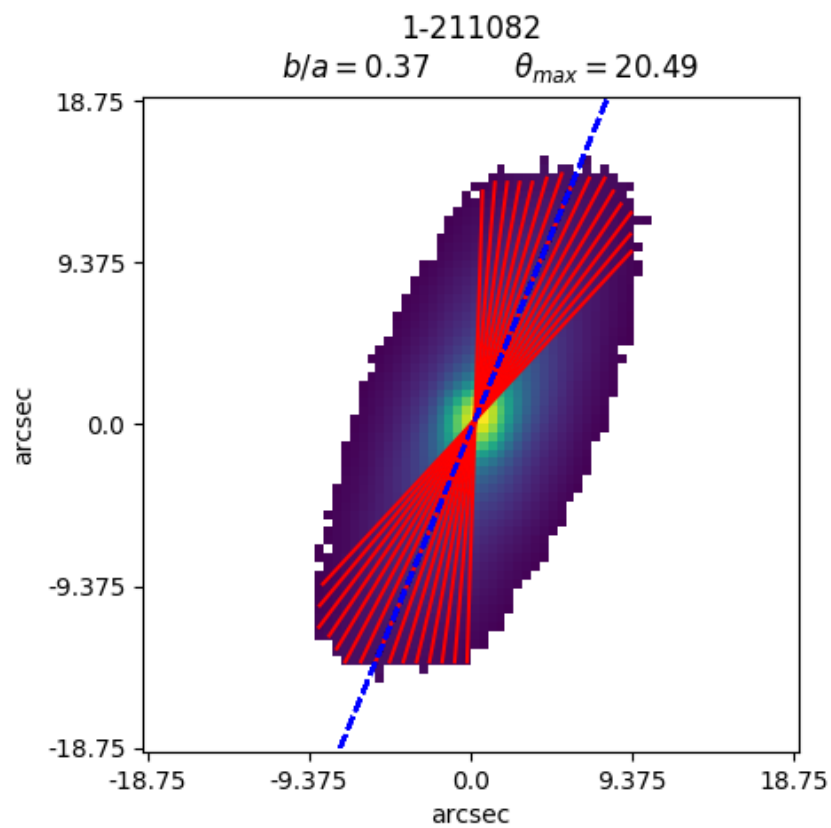


Figura 3.4: Exemplo de perfis obtidos para a galáxia MaNGA-ID 1-211082. A direção do eixo maior é indicada pela linha azul tracejada. As semi-retas em vermelho representam as direções dos perfis calculados para a galáxia. O ângulo máximo entre o eixo maior e um perfil qualquer é de  $\theta_{max} \approx 20.5$  para essa galáxia.



# Capítulo 4

## Artigo

Neste capítulo apresentamos os resultados da síntese de população estelar dos primeiros 62 AGNs e uma comparação destes com os objetos de controle. Tais resultados são apresentados em formato de artigo, publicado no Monthly Notices of the Royal Astronomical Society (MNRAS), Mallmann et al. (2018). Por questões estéticas, optamos por colocar neste capítulo apenas as páginas do corpo do artigo. O apêndice do artigo foi colocado em anexo a essa dissertação (apêndice A).

# The first 62 AGN observed with SDSS-IV MaNGA - II: resolved stellar populations

Nícolas Dullius Mallmann<sup>1,2,\*</sup>, Rogério Riffel<sup>1,2</sup>, Thaisa Storchi-Bergmann<sup>1,2</sup>, Sandro Barboza Rembold<sup>2,3</sup>, Rogemar A. Riffel<sup>2,3</sup>, Jaderson Schimoia<sup>1,2,3</sup>, Luiz Nicolaci da Costa<sup>2</sup>, Vladimir Ávila-Reese<sup>4</sup>, Sebastian F. Sanchez<sup>4</sup>, Alice D. Machado<sup>2,3</sup>, Rafael Cirolini<sup>2,3</sup>, Gabriele S. Ilha<sup>2,3</sup>, Janaína C. do Nascimento<sup>1,2</sup>

<sup>1</sup>*Departamento de Astronomia, Universidade Federal do Rio Grande do Sul - Av. Bento Gonçalves 9500, Porto Alegre, RS, Brazil.*

<sup>2</sup>*Laboratório Interinstitucional de e-Astronomia, Rua General José Cristino, 77 Vasco da Gama, Rio de Janeiro, Brazil, 20921-400*

<sup>3</sup>*Departamento de Física, Centro de Ciências Naturais e Exatas, Universidade Federal de Santa Maria, 97105-900, Santa Maria, RS, Brazil*

<sup>4</sup>*Instituto de Astronomía, Universidad Nacional Autónoma de México, A. P. 70-264, C.P. 04510, México, D.F., Mexico*

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## ABSTRACT

We present spatially resolved stellar population age maps, average radial profiles and gradients for the first 62 Active Galactic Nuclei (AGN) observed with SDSS-IV MaNGA to study the effects of the active nuclei on the star formation history of the host galaxies. These results, derived using the STARLIGHT code, are compared with a control sample of non-active galaxies matching the properties of the AGN hosts. We find that the fraction of young stellar populations (SP) in high-luminosity AGN is higher in the inner ( $R \leq 0.5 R_e$ ) regions when compared with the control sample; low-luminosity AGN, on the other hand, present very similar fractions of young stars to the control sample hosts for the entire studied range ( $1 R_e$ ). The fraction of intermediate age SP of the AGN hosts increases outwards, with a clear enhancement when compared with the control sample. The inner region of the galaxies (AGN and control galaxies) presents a dominant old SP, whose fraction decreases outwards. We also compare our results (differences between AGN and control galaxies) for the early and late-type hosts and find no significant differences. In summary, our results suggest that the most luminous AGN seems to have been triggered by a recent supply of gas that has also triggered recent star formation ( $t \leq 40$  Myrs) in the central region.

**Key words:** galaxies: active – galaxies: stellar content – galaxies: star formation

## 1 INTRODUCTION

An important galaxy evolution stage is characterized by the Active Galactic Nuclei (AGN), a phenomenon that occurs when the galaxy’s supermassive black hole (SMBH) is accreting matter from its surroundings, i.e., the accretion disk. Subsequent feedback processes start to happen, comprising radiation emitted by the hot gas in the accretion disc or by its corona, jets of relativistic particles, and winds emanating from outer regions of the disk.

Current models and simulations of gas inflows on tens to hundreds of parsec (pc) scales around galaxy nuclei lead to episodes of circumnuclear star formation (Kormendy & Ho 2013; Heckman & Best 2014; Zubovas & Bourne 2017). Zubovas & Bourne (2017) suggests that there is a critical

AGN luminosity in which the feedback of the nuclear activity increases the fragmentation of the gas clouds. Above this luminosity threshold, the feedback is powerful enough to remove the gas efficiently and stop fragmentation; for AGN luminosities under this threshold, however, the feedback is not efficient to compress the gas to high densities and enhance fragmentation. However, there is no consensus on whether AGN fueling occurs at the same time as the star formation (Kawakatu & Wada 2008), or follows it during a post-starburst phase (Cid Fernandes et al. 2005; Davies et al. 2007, 2009) or if it is not associated with any recent star formation (Sarzi et al. 2007; Hicks et al. 2013).

A breakthrough in understanding the relation between the AGN and the surrounding stellar population can be reached by a simple, but thorough, investigation of whether young or intermediate age stars are present within few hundred pc of the AGN. If the youngest stellar types are present,

\* E-mail: nicolas.mallmann@ufrgs.br

AGN fueling is coeval with star formation; if instead intermediate age stars dominate the stellar population, fueling would be driven by a post-starburst and, thus the AGN phase would follow the starburst phase; finding only old stars would imply that gas inflow to the AGN is not necessarily linked to star formation.

Over the last few years, major observational effort to understand this co-evolution between AGN and the circumnuclear stellar population is being made using spatially resolved stellar population studies in large samples of galaxies (Goddard et al. 2017; Zheng et al. 2017). These studies, however, are not focused on comparing AGN hosts with non-active galaxies. One recent effort focusing on such kind of comparison was made by Sanchez et al. (2017) who found that AGN hosts are mostly morphologically early-type or early-spirals and that for a given morphology, AGN hosts are more massive, more compact, more centrally peaked, and rather pressure than rotationally-supported systems when compared to the non-active galaxies. However, these studies did not use a selected control sample of galaxies to match the fundamental properties of the AGN sample, nor considered the dependence on the AGN luminosities.

This is the second paper of a series in which we aim at studying the resolved stellar population as well as the gas emission properties of the AGN host galaxies observed with MaNGA and compare them with those of a control sample of non-active galaxies. In Paper I (Rembold et al. 2017), we have presented the AGN sample so far observed with MaNGA (available through the MPL-5) and have defined a control sample matching the AGN host galaxies in terms of galaxy masses, morphology, distance and inclination. In Paper I we have also characterized the stellar population properties of the AGN hosts as compared with those of the control sample for the single aperture SDSS-III spectrum that covers the inner 3" diameter nuclear region, using spectral synthesis via the STARLIGHT program (Cid Fernandes et al. 2005).

Aimed at investigating the relation between the nuclear activity and the hosts' star formation history (SFH), in the present paper (Paper II), we use the MaNGA datacubes of the AGN and control sample defined in Paper I to obtain the resolved SFH and stellar population properties for these objects. These properties were compared between the AGN hosts and inactive galaxies in different luminosity ranges. This paper is organized as follows: brief description of the MaNGA subsample chosen for this work (Section 2); the method of stellar population synthesis as well as the base set of simple stellar populations (Section 3); the results of the synthesis for the AGN and control sample (Section 4); a discussion comparing the stellar populations of AGN and control galaxies (Section 5); and a conclusion in Section 6.

## 2 DATA

The study of spatially resolved properties in galaxies were always undermined by the small sample size of past integral field spectroscopy surveys, not to mention the less numerous AGN. To address this problem, the Mapping Nearby Galaxies at Apache Point Observatory (MaNGA) survey (Bundy et al. 2015) was developed to observe a large sample of nearby galaxies with integral field spectroscopy.

MaNGA is part of the fourth generation Sloan Digital Sky Survey (SDSS IV) along with APOGEE-2 (Majewski et al. 2017) and eBOSS (Dawson et al. 2016). The survey aims to provide optical spectroscopy (3600 Å–10400 Å) of  $\sim 10,000$  nearby galaxies (with  $\langle z \rangle \approx 0.03$ ). The observations are carried with fiber bundles of different sizes (19–127 fibers) covering a field of 12" to 32" in diameter. The selected sample is divided into "primary" and "secondary" targets, the former are observed up to 1.5 effective radius ( $R_e$ ) whilst the latter is observed up to  $2.5 R_e$ . For more details, see Drory et al. (2015); Law et al. (2015); Yan et al. (2015); Yan et al. (2016).

The data used in the present work is a sub-sample of MaNGA data (Law et al. 2016, MPL-5's Data Reduction Pipeline, DRP) selected in Paper I. In short, the AGN were selected from the MaNGA sample by crossmatching them with SDSS-III data products, using then the BPT diagram [O III]/H $\beta$  vs. [N II]/H $\alpha$  (Baldwin et al. 1981) to select the AGN. In addition, we have used the WHAN diagram (Cid Fernandes et al. 2010; Cid Fernandes et al. 2011) to eliminate from the AGN sample the "LIERS", or "fake AGN". The resulting AGN sample contains 62 objects. To study the relationship between AGN and the stellar populations of the host, we have chosen two control galaxies to match each of the selected AGN hosts. The matching was done according to the morphology (using concentration and asymmetry indices), axial ratios, redshifts, galaxy inclination, and total stellar masses. For more details regarding the AGN and control sample selection, see Rembold et al. (2017).

## 3 STELLAR POPULATION SYNTHESIS

We have used stellar population synthesis technique in order to derive the SFH of the galaxies of the AGN and control samples. We first briefly describe of the fitting code used. We then present a summary of the data preparation and processing pipeline we have developed to manage the fitting process.

### 3.1 Fitting code

To disentangle the contribution of each stellar population to the integrated spectra of each spaxel in the datacubes we employed the STARLIGHT code (Cid Fernandes et al. 2005). In summary, this code combines the spectra of a base set of  $N_\star$  template spectra  $b_{j,\lambda}$  – usually, simple stellar population (SSP) covering a range of ages and metallicities – in order to reproduce the observed spectra  $O_\lambda$ . To generate the modeled spectra  $M_\lambda$ , the SSPs are normalized at an arbitrary  $\lambda_0$  wavelength, reddened by the term  $r_\lambda = 10^{-0.4(A_\lambda - A_{\lambda_0})}$ , weighted by the population vector  $x_j$  (which represents the fractional contribution of the  $j$ th SSP to the light at the normalization wavelength  $\lambda_0$ ), and convolved with a Gaussian distribution  $G(v_\star, \sigma_\star)$  to account for the effects of velocity shifts in the central velocity  $v_\star$  and velocity dispersion  $\sigma_\star$ . The model spectrum can be expressed as:

$$M_\lambda = M_{\lambda_0} \left[ \sum_{n=1}^{N_\star} x_j b_{j,\lambda} r_\lambda \right] \otimes G(v_\star, \sigma_\star) \quad (1)$$

where  $M_{\lambda_0}$  is the synthetic flux at the wavelength  $\lambda_0$ . To

find the best parameters for the fit, the code searches for the minimum of  $\chi^2 = \sum_{\lambda_i}^{N_f} [(O_{\lambda} - M_{\lambda})\omega_{\lambda}]^2$ , where  $\omega_{\lambda}$  is the inverse of the error, using a simulated annealing plus Metropolis scheme. Further details on the code can be found in [Cid Fernandes et al. \(2005\)](#).

The base set used in the spectral synthesis is a reduced number of the SSPs calculated by [Bruzual & Charlot \(2003\)](#). It comprises  $N_{\star} = 46$  elements (45 SSPs + 1 featureless continuum – FC – function of the form  $F_{\nu} \propto \nu^{-1.5}$  to represent the AGN emission), spanning 15 ages (0.001, 0.003, 0.005, 0.010, 0.025, 0.040, 0.101, 0.286, 0.640, 0.905, 1.43, 2.50, 5.00, 11.00 and 13.00 Gyrs) and 3 metallicities (0.1, 1 and 2.5  $Z_{\odot}$ ). The addition of a power law is necessary to account for the AGN continuum ([Cid Fernandes et al. 2004](#); [Riffel et al. 2009](#)). For the foreground extinction, we used the [Cardelli et al. \(1989, CCM\)](#) law, with  $R_V = 3.1$ . The adopted normalization wavelength was  $\lambda_0 = 5700 \text{ \AA}$  and the synthesis was performed for the spectral range from 3800  $\text{\AA}$  to 7000  $\text{\AA}$ .

### 3.2 Data Management

In order to improve the management of the data which includes STARLIGHT inputs and outputs, the compilation of the results and the analysis, we developed a software called MEGACUBE. This software is designed to work with three main modules set up by a general configuration file. The modular approach was chosen with adaptability in mind, e.g., if a module was programmed to work with MaNGA datacubes' extraction, we could replace it with one that extracts another survey's datacubes. The modules used in this work are (in order of execution):

**i) Data preparation:** This module is used to process and convert the MaNGA datacubes to a data format suitable for the chosen stellar population fitting code (STARLIGHT). The main steps are as follows:

- Filtering of the spectra using a two-dimensional but-terworth filter to remove spurious data (e.g., spiked values) and increase the signal to noise ratio, without combining adjacent spaxel, thus allowing to a better exploration of the spatial resolution. A better description of this technique can be found in [Riffel et al. \(2016\)](#);
- Galactic reddening correction of each spaxel using the Schlegel extinction maps ([Schlegel et al. 1998](#)) and the CCM reddening law;
- Redshift correction using the SDSS-III redshift provided in the *drpall* tables of the MaNGA database;
- Estimation of the signal to noise ratio (SNR) in the wavelength range 5650-5750  $\text{\AA}$  for every spaxel;
- Spaxels with  $\text{SNR} < 10$  were excluded when performing the fitting. This was done in order to have a good compromise between the spatial coverage and the reliability of the fitting results (see [Cid Fernandes et al. 2004](#), for details).

**ii) Spectral Fitting:** This module is used to invoke the fitting code and compile its results as described below:

- Setting up all the configuration files needed for the fits;
- Fitting each individual spaxel with STARLIGHT;
- Derivation of mean ages and metallicities, as well as star formation rates, from the starlight output;
- Inclusion of both standard starlight output and derived

parameters to the original datacubes as additional extensions.

**iii) Analysis:** This module uses the fitting results to produce maps and radial plots (see Section 4 for a better description):

- RGB maps: Qualitative representation of the spatially resolved stellar population age distribution for each galaxy, where the colors (red, green, and blue) represent three main age bins (see Sect. 4);
- Comparison figures: for each trio of galaxies (AGN and its two controls), panels showing the relevant properties (maps of stellar population properties derived from starlight and/or SDSS-III combined *ugriz* images);
- Radial profiles and gradients: for each galaxy and property, a mean profile (as well as its mean gradient value – calculated as a function of R,  $dX/dR$ ) is calculated to use for quantitative comparisons;
- Gradients table: as result of the analysis, we have also generated a Table showing the gradients of the profiles for three different bins in terms of effective radius  $R_e$ ;
- [O III]  $\lambda 5007$  luminosity  $L_{[\text{O III}]}$  binned radial profiles: Radial profiles of the stellar population properties where the profiles for the AGN (and corresponding controls) are binned in groups according to the AGN luminosity. These profiles are shown also for AGN subsamples binned according to the host galaxy type: early and late-type.

It is worth mentioning that a similar organizer tool was developed by [de Amorim et al. \(2017\)](#) for the Calar Alto Legacy Integral Field Area (CALIFA) survey, which is a pioneer project of integral field spectroscopy legacy surveys.

## 4 RESULTS

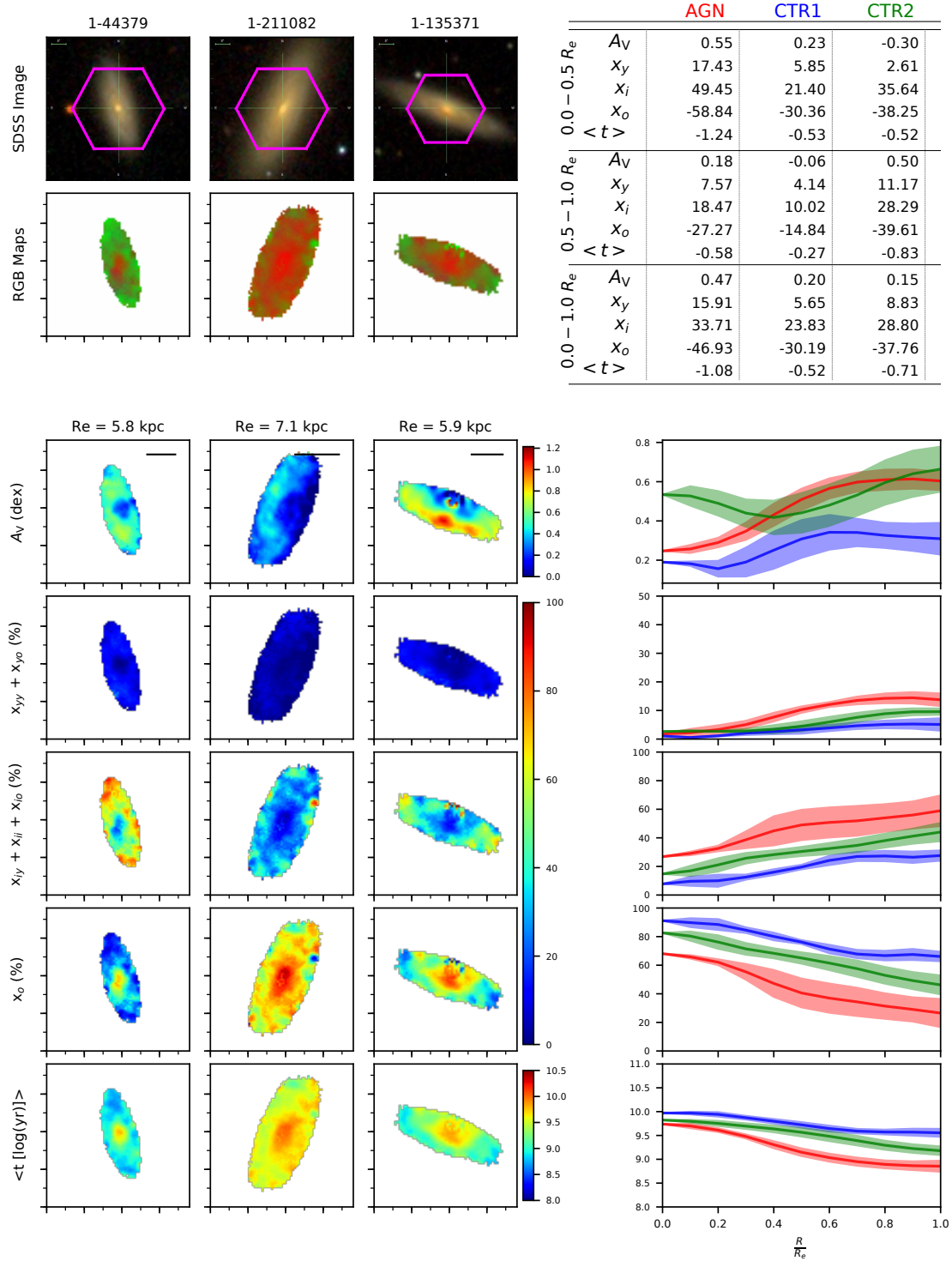
The spectral synthesis gives as results, a number of output parameters, but we are mostly interested in  $x_j$  – the fractional contribution of each SSP to the total light at the normalization wavelength  $\lambda_0$ , that gives the SFH of each spaxel, and from which we also obtain the mean age for each spaxel, representing the age of the stellar populations as a single parameter. In addition, a valuable byproduct of the fitting is the amount of extinction in the line of sight, parameterized by the visual extinction  $A_V$ . In Figs. 1 and 2 we illustrate the derived data products (maps, radial profiles and gradients) for two AGN and their respective control sample galaxies; the equivalent plots for the remaining of the sample is available in the Appendix.

In order to represent the galaxies' ages distribution with a single parameter at each spaxel, we calculated their light weighted mean age ([Cid Fernandes et al. 2005](#)), as follows:

$$\langle \log t_L \rangle = \frac{\sum_{j=1}^{N_{\star}} x_j \log(t_j)}{\sum_{j=1}^{N_{\star}} x_j}, \quad (2)$$

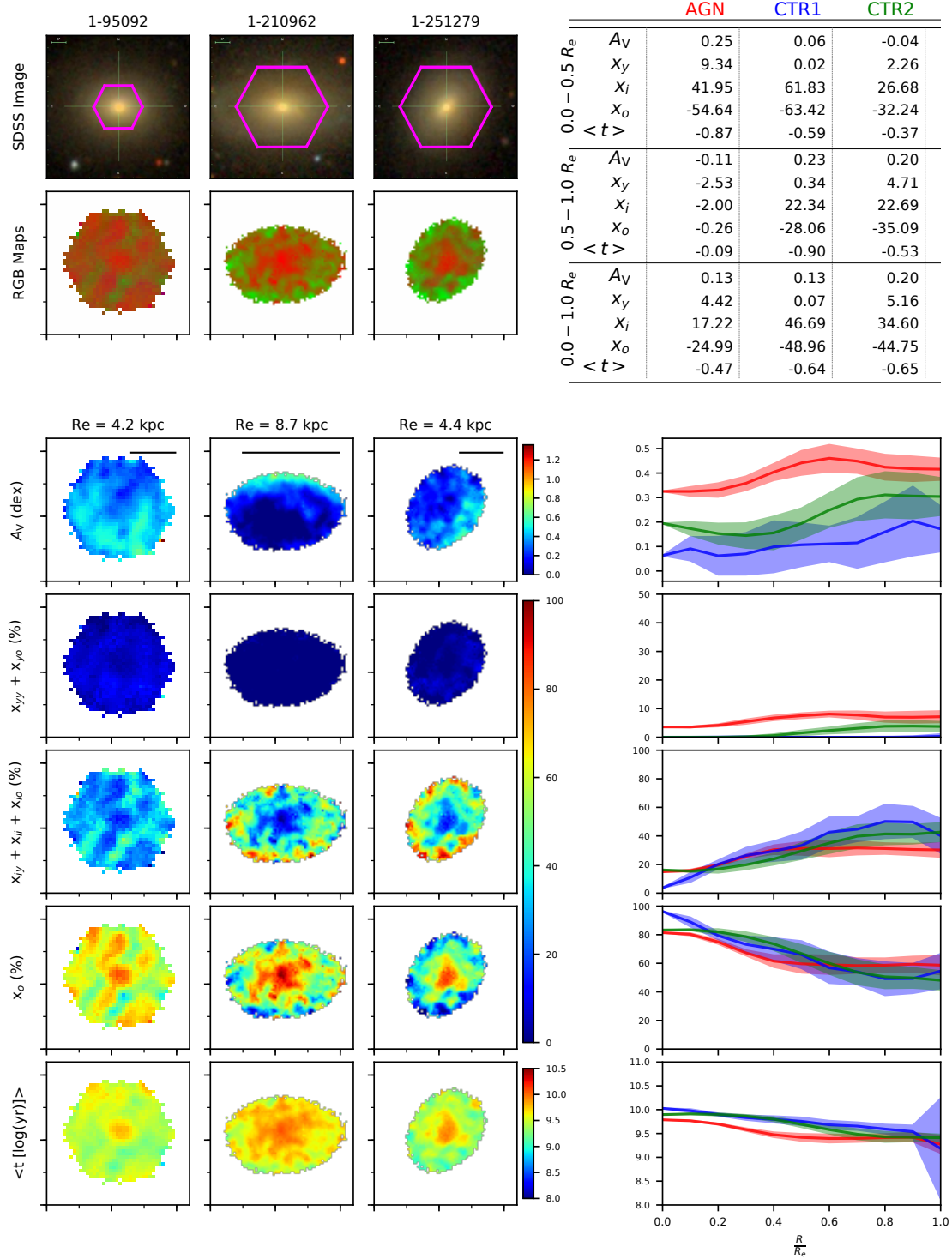
where  $t_j$  is the age of the template  $j$ . The distributions of mean age are shown in the bottom row of the bottom left panels of Figs. 1 and 2.

As stated by [Cid Fernandes et al. \(2005\)](#), small differences in ages of individual SSPs are washed away in real data by noise effects. We therefore rebinned the population vectors in six stellar population components (SPCs):  $x_{yy}$  (1 Myr



**Figure 1.** Comparison between a late-type AGN and its control galaxies. **Left side panels** - *Top set of panels*: SDSS image (the MaNGA field is indicated in magenta). Second row: composed RGB image using the binned population vectors [blue: young ( $X_Y$ :  $t \leq 40$  Myr); green: intermediate age ( $X_I$ :  $40 \ll t \ll 2.5$  Gyr); red: old ( $X_O$ :  $t > 2.5$  Gyr)]. *Bottom set of panels*: From top to bottom: visual extinction ( $A_V$ ),  $X_Y$ ,  $X_I$ ,  $X_O$  and mean age ( $\langle t \rangle$ ) maps. For display purposes we used tick marks separated by  $5''$ . The solid horizontal line in the  $A_V$  maps represent  $1 R_e$ . **Right side panels** - *Top*: summary table with the mean gradient values for each property in 3 different  $R_e$  ranges. *Bottom*: average radial profiles, up to  $1 R_e$ , for AGN (red color) and control (blue and green colors). Shaded area represents  $1 \sigma$  standard deviation. For profiles smaller than  $1 R_e$  the gradients were calculated using extrapolated values.





**Figure 2.** Comparison between an early-type AGN and its control galaxies. See Fig. 1 for description.

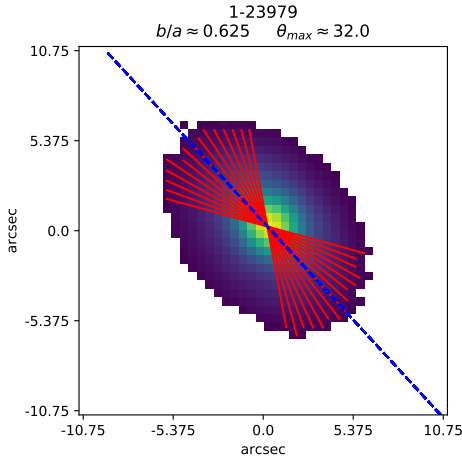
$\leq t \leq 10$  Myr),  $x_{yo}$  ( $10$  Myr  $< t \leq 40$  Myr),  $x_{iy}$  ( $40$  Myr  $< t \leq 286$  Myr),  $x_{ii}$  ( $286$  Myr  $< t \leq 905$  Myr),  $x_{io}$  ( $905$  Myr  $< t \leq 2.5$  Gyr), and  $x_o$  ( $2.5$  Gyr  $< t \leq 13$  Gyr).

We have also grouped the stellar population vector in three major age bins, described as follows:

- Young Age:  $X_Y = x_{yy} + x_{yo}$

- Intermediate Age:  $X_I = x_{iy} + x_{ij} + x_{io}$
- Old Age:  $X_O = x_o$

In order to visualize the spatial distribution of the populations' relative contributions in a qualitative way, RGB images of the galaxies were created by assigning the 3 colors (red, green, blue) to the binned population vectors: Red



**Figure 3.** Example of radial profile cuts on the normalization flux map of a galaxy (MaNGA ID: 1-23979) with  $\approx 32$  degrees of angle displacement from the major-axis (indicated with a blue dashed line). Red line segments are the radial profile cuts used to calculate the mean radial profile. Profiles closer to the minor axis were excluded to reduce any effects of projection (the more edge-on the galaxy is, the greater the projection distortion).

represents the old  $X_O$  ( $2.5 \text{ Gyr} < t \leq 13 \text{ Gyr}$ ), green the intermediate age  $X_I$  ( $40 \text{ Myr} < t \leq 2.6 \text{ Gyr}$ ), and blue the young stellar populations  $X_Y$  ( $1 \text{ Myr} \leq t \leq 40 \text{ Myr}$ ).

In the bottom right of Figs. 1 and 2 we show mean radial profiles, up to  $1.0 R_e$ , for each galaxy and property, derived using a nearest neighbor interpolation method to generate continuous values between pixel transitions and to remove abrupt changes due to spatially discrete maps. We opted for 30 equally spaced radial profiles in the galaxy plane limited to angular distances from the major axis of  $\theta_{max} = \tan^{-1}(b/a)$  degrees, where  $a$  and  $b$  are, respectively, the semi-major and semi-minor axis of the SDSS galaxy image, obtained from the MaNGA’s *drpall* table (calculated using Sérsic profiles), as illustrated in Fig. 3. The reason for this choice of maximum displacement from the major axis was the fact that profiles closer to the minor axis, when projected, resulted too noisy, possibly due to obscuration effects when the galaxies are too inclined relative to the line of sight. Mean profiles were then calculated for each property map by averaging all these profiles.

We have also calculated the mean gradients of each property (using the mean radial profiles) for 3 different regions: from 0.0 to  $0.5 R_e$ ,  $0.5$  to  $1.0 R_e$ , and 0.0 to  $1.0 R_e$ . Since we are comparing relatively low luminosity active galaxies with a matched control sample of non-active galaxies, the major differences should be detected in their nuclear regions. Thus, the division we used was decided based on qualitative observation of the average radial profiles, which revealed, in most galaxies, a trend of slope changes close to  $0.5 R_e$ . Some values had to be extrapolated to a constant slope since the radial profiles could not reach  $1.0 R_e$  due to poor signal to noise ratio. These gradients for  $A_V$ ,  $X_Y$ ,  $X_I$  and  $X_O$ , together with the gradients in mean age, are shown in a Table in the top right corner of Figs. 1 and 2.

#### 4.1 AGN hosts versus control galaxies

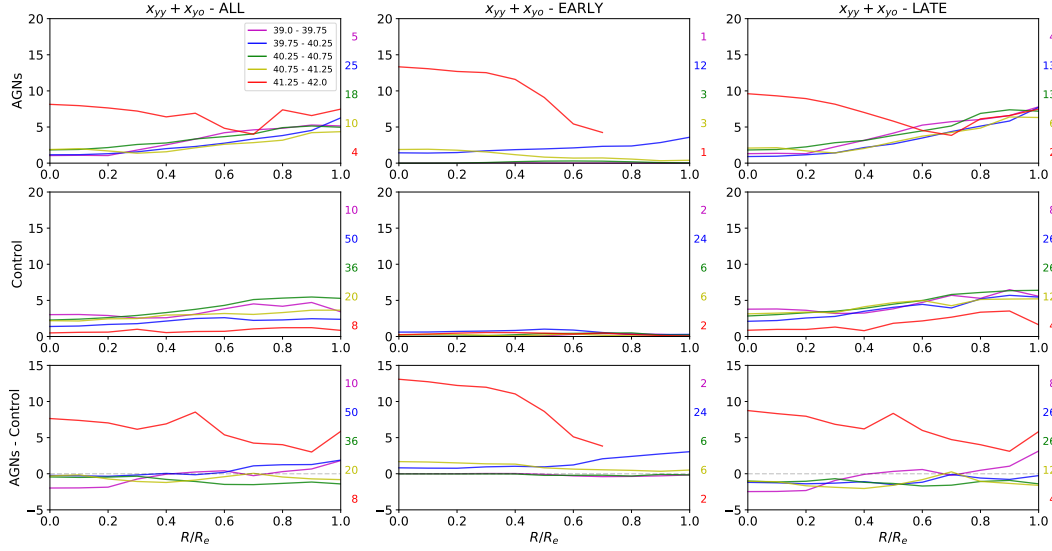
For each one of the AGN we show the radial variation of the derived properties compared to the two control galaxies in the Appendix. As an example, we have selected to show two typical sets of results in Figs. 1 and 2, the results for one “late-type” AGN (MaNGA ID 1-44379) and one “early-type” AGN (MaNGA ID 1-95092) and their control galaxies.

In the case of the late-type AGN of Fig. 1, it shows that the RGB maps are dominated by the contribution of old populations in the centers for both the AGN hosts and the control galaxies. Just outward of the nucleus, younger populations dominate the AGN and the control galaxy CRT2 a bit further out, while the control galaxy CRT1 shows larger contribution of older age components also outside the nucleus. The extinction at the nucleus is stronger for the second control than the AGN while outwards they reach similar values that are higher than those of the first control. Regarding the contribution of the different stellar population age bins to the light at  $5700 \text{ \AA}$ , there is no difference between the AGN and the controls for the youngest age bins, while for the intermediate age one, its contribution in the AGN is larger than in its control galaxies at all radii. There is also a difference for the old age bin  $X_O$ , that is lower in the AGN than in the control galaxies everywhere inside  $R_e$ . These results also reflect in the mean age  $\langle t \rangle$ : the mean age of the stellar population is lower everywhere in the galaxy for the AGN than for the control galaxies. The table listing the gradients also show differences between the AGN and control galaxies: for the inner radial bin ( $0-0.5 R_e$ ) and for the full radial range ( $0-1.0 R_e$ ), the AGN host galaxy shows steeper gradients than the controls for all properties.

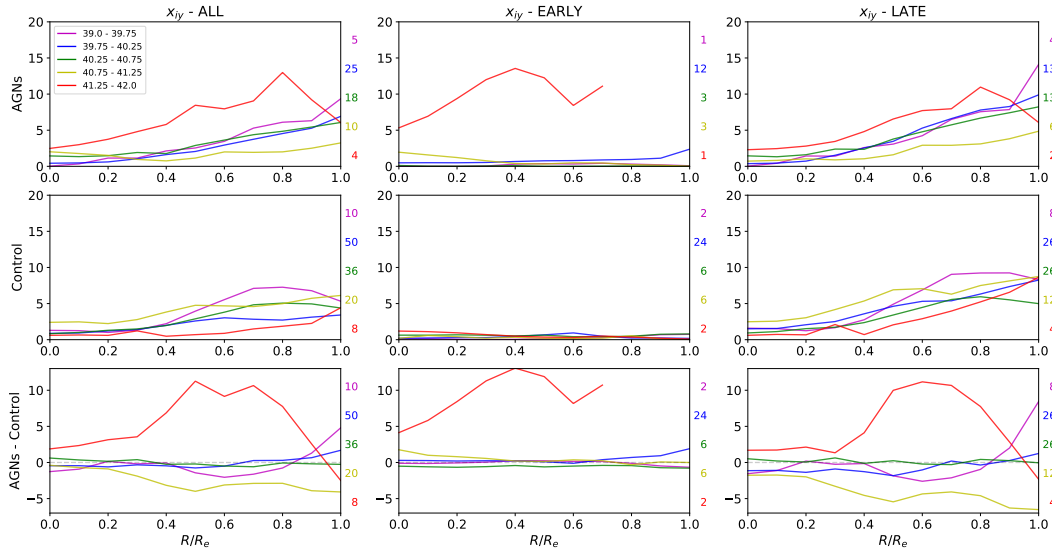
The early-type AGN case of Fig. 2 shows higher contribution of the old component in the central regions of the galaxies for the AGN and its controls. In this case, however, the AGN’s RGB map shows a more homogeneous population throughout the galaxy, whilst the control galaxies’ RGB maps show an older central region surrounded by a younger population outwards. The extinction for the AGN is larger compared with its control galaxies as can be seen in the  $A_V$  profiles. Although the  $A_V$  maps show higher values for the control galaxies, they are concentrated closer to the limits of  $SNR \leq 10$ , thus less reliable. The population profiles show a more constant distribution of ages for the AGN inside the  $R \leq 1.0 R_e$ , specially between  $0.5$  and  $1.0 R_e$ . This behavior is reflected in the low gradient values of the  $0.5 - 1.0 R_e$  bin compared to the control galaxies. The mean age  $\langle t \rangle$  profile of the AGN shows a younger population over almost all of the  $0 - 1.0 R_e$  range, similar to the late-type case (Fig. 1). The gradients table shows that the outer region ( $0.5 - 1.0 R_e$ ) has a different behavior for the AGN compared to the control galaxies (which, in turn, behave similarly).

## 5 DISCUSSION

In order to test for a possible relation between the AGN luminosity and the star formation history, we compare the stellar population profiles derived for the AGN and controls building average profiles for each of five  $L([\text{O III}])$  bins. We grouped them in bins of  $\log_{10} L_{[\text{O III}]}$  as follows: 39 to 39.75, 39.75 to 40.25, 40.25 to 40.75, 40.75 to 41.25, and 41.25 to 42, using the values for  $L_{[\text{O III}]}$  listed in Paper I.



**Figure 4.**  $L_{[\text{O III}]}$  binned mean radial profiles for the  $x_{yy}$  ( $1 \text{ Myr} \leq t \leq 10 \text{ Myr}$ ) and  $x_{yo}$  ( $10 \text{ Myr} < t \leq 40 \text{ Myr}$ ) components combined. Each color pertains to the same  $L_{[\text{O III}]}$  range for every plot. The columns represent the groups of AGN used to calculate the average profiles for the AGN, its control galaxies, and their differences. The groups are, from left to right: all AGN, early-type AGN, late-type AGN. The rows, from top to bottom, show the average profiles for the AGN, the control galaxies (of the respective AGN group), and the differences. The colored numbers to the right of every plot are the quantity of galaxies used to calculate the mean profile of the same color.

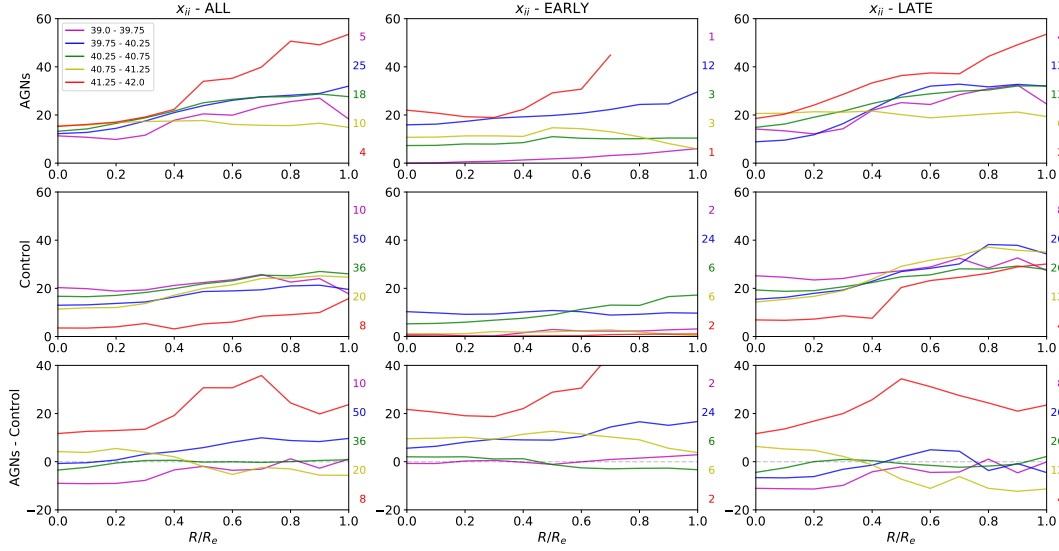


**Figure 5.**  $L_{[\text{O III}]}$  binned mean radial profiles for the  $x_{ij}$  components ( $40 \text{ Myr} < t \leq 286 \text{ Myr}$ ). See figure 4 for the description.

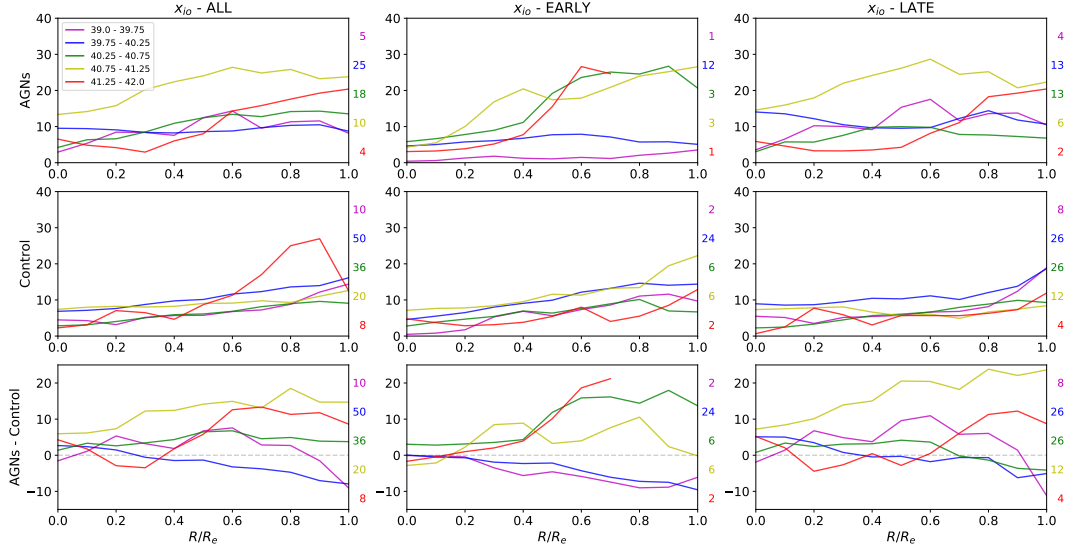
In Figures 4 to 9 we show the mean radial profiles for the different age bins (see § 4 as well as for the mean ages). In order to see if there are differences in these profiles for early and late type galaxies, we show the results both for all the galaxies grouped together and also separated in early and late-type hosts. In the top panels we show the results for

the AGN hosts, in the middle panel for the corresponding controls and in the bottom panels the difference between AGN and controls. In each panel we show the five ranges of  $L_{[\text{O III}]}$  color coded and the respective number of objects (colored numbers) included in the average calculation. It is important to note that some of the AGN are not classified as





**Figure 6.**  $L_{[\text{O III}]}$  binned mean radial profiles for the  $x_{II}$  components ( $286 \text{ Myr} < t \leq 905 \text{ Myr}$ ). See figure 4 for the description.



**Figure 7.**  $L_{[\text{O III}]}$  binned mean radial profiles for the  $x_{I0}$  components ( $905 \text{ Myr} < t \leq 2.5 \text{ Gyr}$ ). See figure 4 for the description.

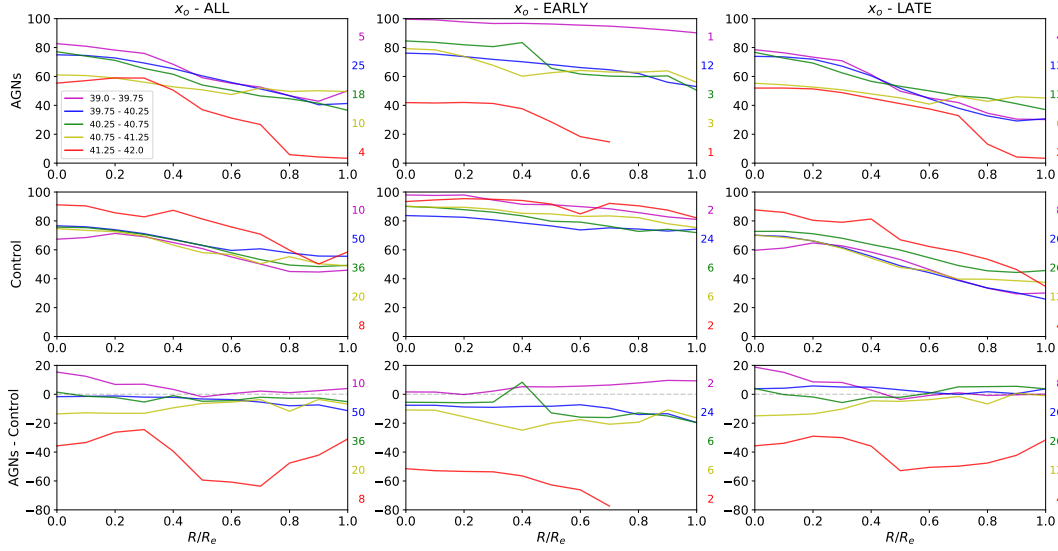
early or late-type (because they could not be clearly classified, e.g. could be the result of mergers), so the sum of early and late-type galaxies may not represent the total number of objects (left column).

As can be seen in Fig. 4, the clearest difference in the profiles occurs for the highest  $[\text{O III}]$  luminosity AGN, that show higher contribution of the young age component than the controls along the whole galaxy<sup>1</sup>. In addition, the be-

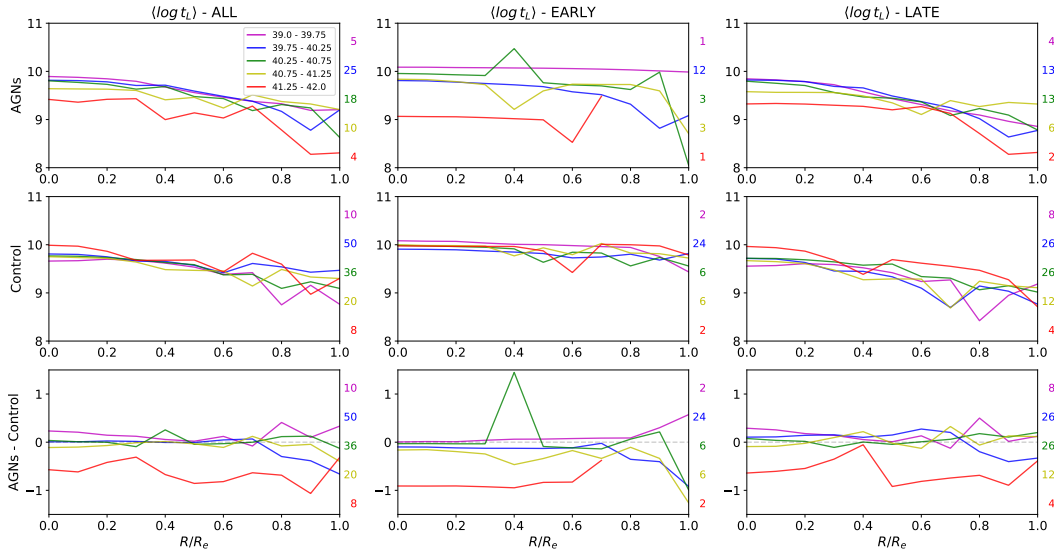
havior seems not to depend on the type of host galaxy (early or late-type), at least up to  $0.6R_e$ . We note that this bin has only 4 galaxies, but if we look at the profiles individually, we find the same behavior in each one of them. Comparing with the non-active galaxies, the corresponding profiles are similar to the other luminosity bins. For the late-type sources,

for the highest luminosity AGN, where differences in the young population were detected, and no problems with the synthesis quality were found.

<sup>1</sup> It is worth mentioning that we have inspected carefully the fits



**Figure 8.**  $L_{[\text{O III}]}$  binned mean radial profiles for the  $x_o$  components ( $2.5 \text{ Gyr} < t \leq 13 \text{ Gyr}$ ). See figure 4 for the description.

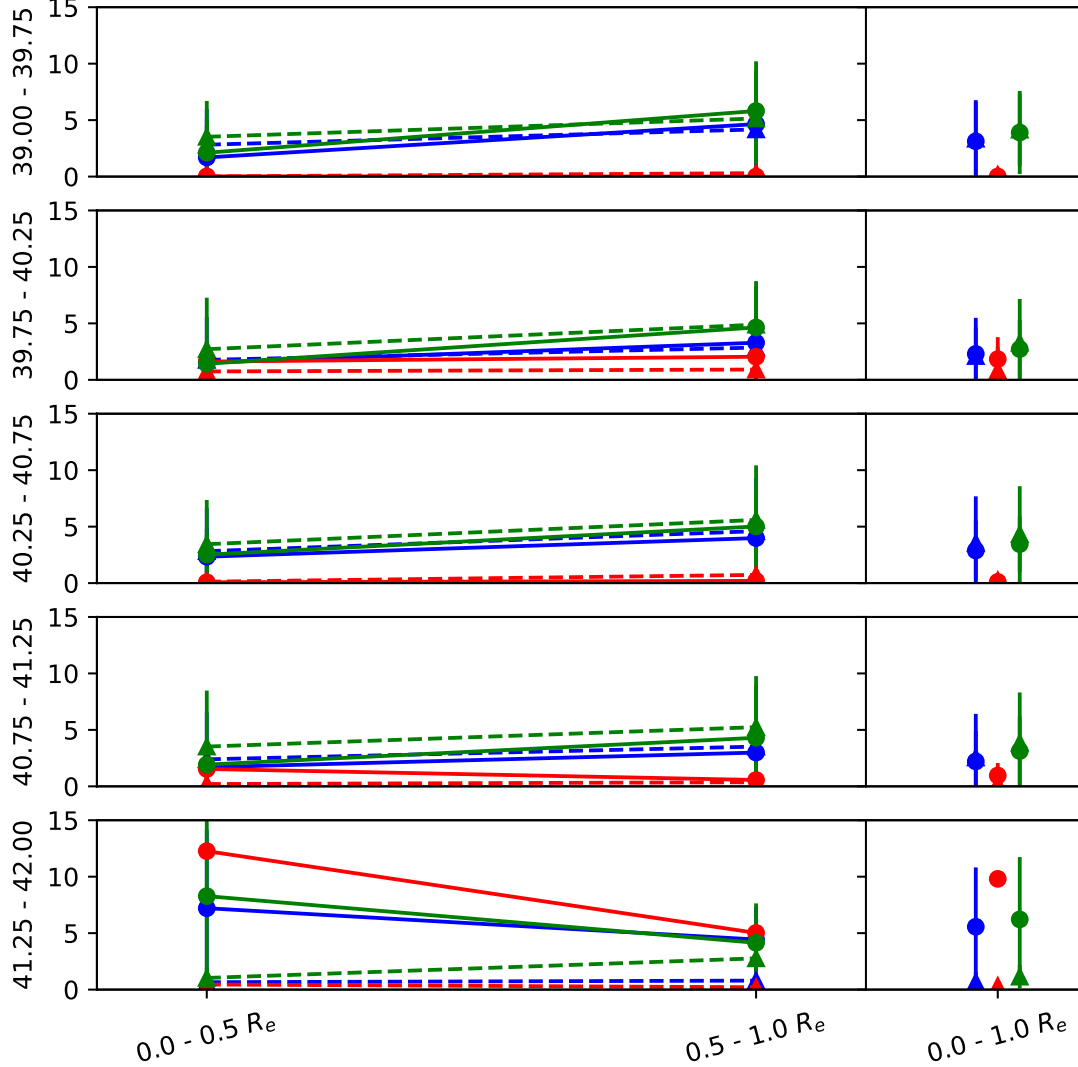


**Figure 9.**  $L_{[\text{O III}]}$  binned mean radial profiles for the mean age ( $\langle \log t \rangle$ ). See figure 4 for the description.

there is a clear shift in the slope at  $\sim 0.7R_e$ , for larger values of  $R_e$  it follows the other luminosity ranges. This, and the fact that the differences have a slightly negative slope in all morphology groups, suggests that the AGN may enhance the star formation process in the nuclear region ( $R_e \lesssim 0.6$ ).

A similar excess in the AGN as compared to controls is also observed in the intermediate age bins  $x_{iy}$  and  $x_{ii}$  shown in Figs. 5 and 6, although the excess seems to occur farther from the center. A comparison between Figs. 4, 5 and 6 suggests an age stratification with radius for the highest luminosity sources, showing a larger fraction of younger

stars in the central region, with the intermediate age stars contributing more to the light in the outer regions. Regarding the old component, Fig. 7 shows that, as expected, the high-luminosity AGN has less contribution of this component than the controls, with differences ranging from  $\sim 20\%$  to  $60\%$ . A small trend can be observed also in this figure, in the sense that a similar although smaller difference is also observed for the second luminosity bin, with the third and fourth bins showing almost no difference when compared with the controls, while the lowest luminosity bin showing



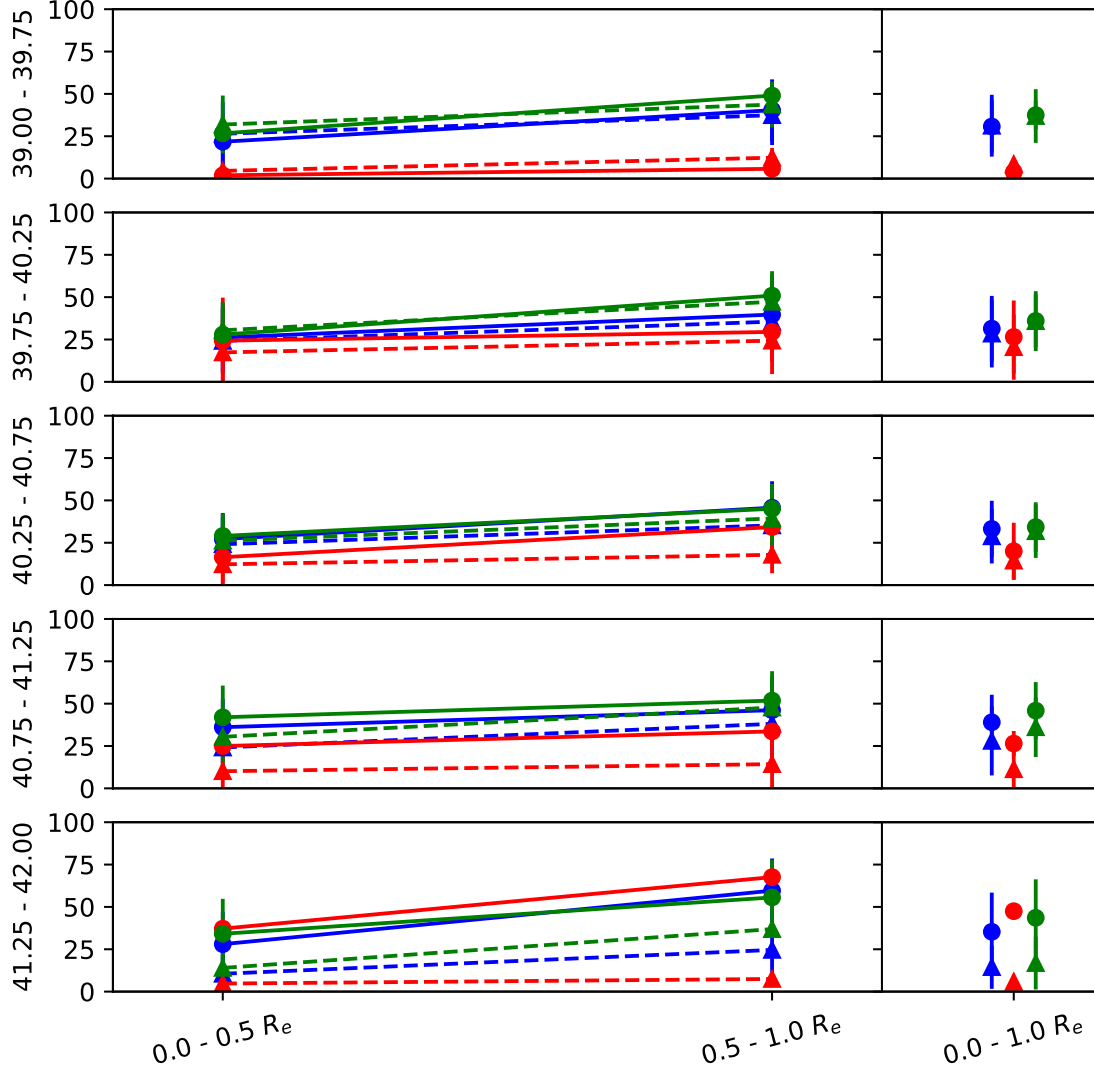
**Figure 10.** Young stellar population  $x_y$  contribution for five different bins of luminosity (39-39.75, 39.75-40.25, 40.25-40.75, 40.75-41.25, 41.25-42), calculated for three different regions ( $0.0-0.5 R_e$ ,  $0.5-1.0 R_e$ ,  $0.0-1.0 R_e$ ). Each color represents a different AGN grouping: green for the late-type AGN, red for the early-type AGN, and blue for all the AGN sample. Solid lines correspond to the active galaxies and dashed lines to the control galaxies.

the opposite: the controls having less contribution of the old component than the AGN.

In order to compare the galaxies using a single parameter we plot the radial profiles of their mean ages (see §4) in Fig. 9. It is clear from this figure that the higher luminosity AGN hosts are younger than the control galaxies in the entire studied region ( $1R_e$ ). We interpret these results as due to the fact that AGN hosts do prefer the “outside-in” scenario for the recent star formation, while the galaxy’s global stellar formation history (SFH) is better described by an inside out scenario. This may reflect the idea that the active nuclei

can drive the star formation process in the circumnuclear region.

Although the differences in the stellar population of the strongest AGN, when compared with the controls, were evident, a problem arises when trying to analyze other luminosity bins: the differences between the radial profiles are too noisy. In order to circumvent this problem, we binned the profiles into three regions ( $0.0-0.5 R_e$ ,  $0.5-1.0 R_e$ , and  $0.0-1.0 R_e$ ) and the stellar populations into  $X_Y$ ,  $X_I$ ,  $x_O$ . We also plotted the contribution of the FC using these radial bins to inspect the light contribution of the AGN continuum. Fig-



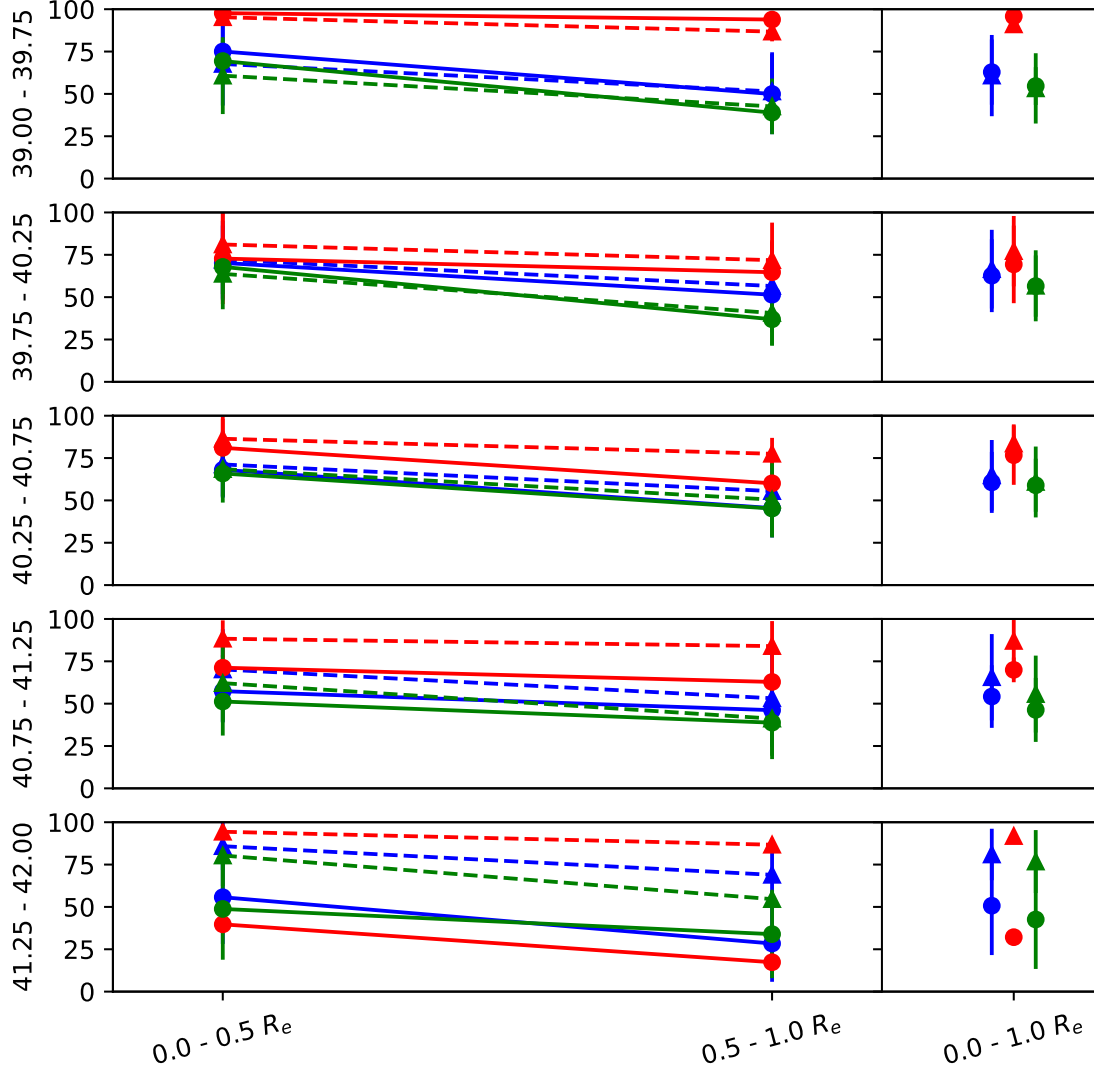
**Figure 11.** Intermediate age stellar population  $x_i$  for different bins of luminosity, calculated for three different regions. See Fig. 10.

ures 10-14 show the results of this exercise<sup>2</sup>. What clearly emerges from this test is that the youngest SPs are concentrated in the inner  $0.5 R_e$  of the most luminous AGN hosts (Fig. 10) – where the FC signature is the strongest (Fig. 14) – and intermediate age ones are located in regions with radius  $R \gtrsim 0.5 R_e$  (see Fig. 11) for all AGN luminosities. In addition, the contribution of these stellar population components are much larger in the AGN hosts (circles) than that in the control galaxies (triangles) in the case of the highest luminosity AGN. Another result shown by these plots

is that the youngest age contributions increase outwards for late-type galaxies (both controls and AGN – except the most luminous AGN).

Figs. 12 and 13 show that the strongest (highest luminosity) AGN present, in general, younger SPs than their control objects. In addition these plots do allow us to better analyze the other luminosity bins. For  $\log(L[\text{O III}])$  between 40.75 and 41.25 (the second most luminous bin) no significant differences can be seen for the younger populations, while the intermediate age contributions are higher for the AGN, being slightly more concentrated at the outer region ( $R \gtrsim 0.5 R_e$ ). For the remaining luminosity bins a similar behavior is observed, however, when looking to the overall

<sup>2</sup> Some galaxies have limited  $R_e$  coverage, meaning that the statistics gets weaker with radial distance. We addressed this problem by using radial intervals ( $0.5 R_e$ ).



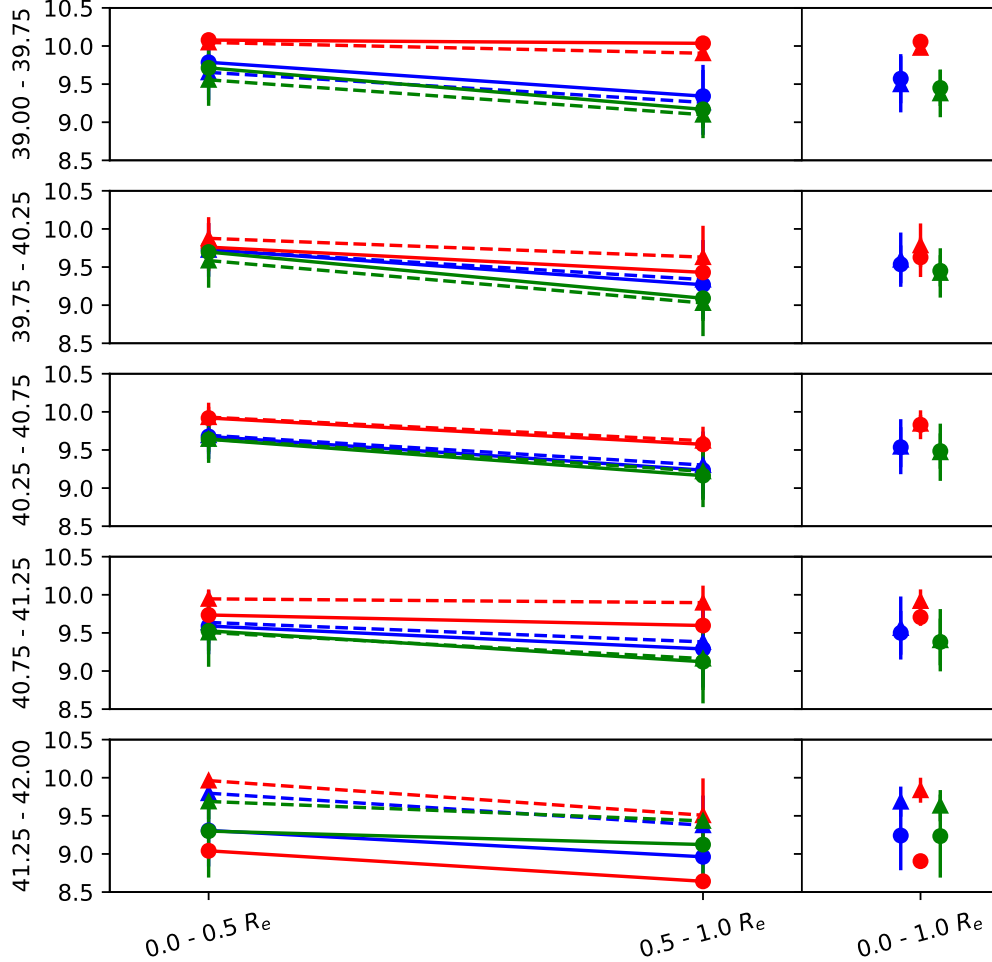
**Figure 12.** Old stellar population  $x_o$  for different bins of luminosity, calculated for three different regions. See Fig. 10.

mean values (right side of Fig. 11) it is clear that the difference vanishes with luminosity decrease.

In the case of the old stellar population bin, the contribution of this population in the AGN hosts is lower than that observed in the control objects, and a decrease is observed from the center outwards. A significant difference between active and non-active sources is seen for the two highest luminosity bins, specially when using the overall mean values (right side plot). We also separate the objects according to their Hubble types (color coded) and no clear difference is observed between early and late-type galaxies when comparing active and non-active hosts.

The above results reinforce literature results (Rembold et al. 2017; Kauffmann et al. 2003), in the sense that when

comparing low and high luminosity AGN, the contribution of old stellar populations decreases, while that of the younger stellar populations increases in the latter. However, our results do additionally show that this is specially enhanced in the circumnuclear regions ( $R \leq 0.5 R_e$ ) indicating that the the inflow of material feeding the AGN is partially being used to form stars. In addition, we suggest that these nuclear starbursts could at least be partially related to a positive AGN feedback, which may be inducing star formation in the host galaxy through enhancing the gas turbulence in the interstellar medium. Such a positive feedback is predicted by simulations (Gaibler et al. 2012; Ishibashi & Fabian 2012; Wagner et al. 2012; Zubovas et al. 2013; Bieri et al. 2015; Zubovas & Bourne 2017) and was already de-



**Figure 13.** Mean age ( $\log t$ ) for different bins of luminosity, calculated for three different regions. See Fig. 10.

tected in a few objects (Cresci et al. 2015; Maiolino et al. 2017).

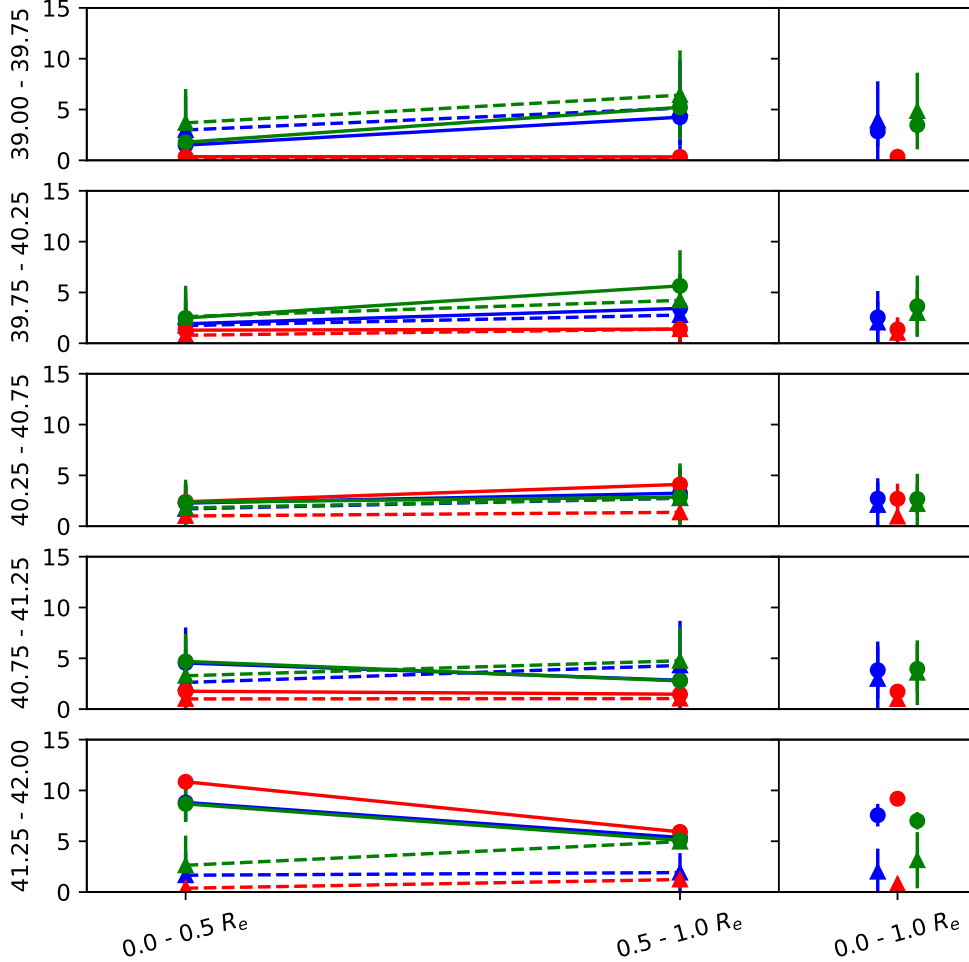
As can be seen from Figs. 10 to 13 in general we observe that the fraction of young and intermediate age stellar populations increases with the radius, while in the case of the old population, it decreases. These results support the previous findings reported by Sánchez et al. (2013), Ibarra-Medel et al. (2016) and Goddard et al. (2017) favoring an inside-out scenario for the formation of galaxies. However, when considering the most luminous AGN, it no longer applies, and it seems that these AGN have been triggered by a recent supply of gas that has also triggered a recent star formation in their central regions. Our findings are opposite to the results of Goddard et al. (2017) in the case of early-type sources, we derive a slightly negative gradient while they de-

rived a slightly positive one for this Hubble class<sup>3</sup>. On the other hand, our findings seem to agree with those of Ibarra-Medel et al. (2016), who showed that the radial stellar mass growth histories of early-type galaxies are on average nearly inside-out, though with a trend much less pronounced than that of the late-type galaxies.

## 6 CONCLUSIONS

We studied the stellar content of the first 62 AGN observed with SDSS-IV MaNGA and compared them with a matched sample of inactive galaxies presented in Paper I. We constructed spatially resolved stellar population age maps, corresponding average radial profiles and gradients for these sources using the STARLIGHT code, aimed at studying the

<sup>3</sup> Note, however, that we are studying the inner  $1 R_e$  (they used  $1.5 R_e$ ) and a smaller sample than that studied by these authors.



**Figure 14.** Featureless continuum for different bins of luminosity, calculated for three different regions. See Fig. 10.

effects of the AGN on the star formation history of the host galaxies.

We found that the fraction of the young stellar population ( $t \lesssim 40$  Myr) is related with the AGN luminosity. For high-luminosity AGN ( $L_{[\text{O III}]} \gtrsim 10^{41.25}$  ergs/s) it increases in the inner ( $R \leq 0.5R_e$ ) regions when compared with the objects in the control sample. In the case of the low-luminosity AGN, both AGN and control sample hosts, present very similar fractions of young stars. This result indicates that the inflow of material, besides feeding the nuclear engine, is being used to form new stars, thus rejuvenating the stellar content of the nuclear region of the AGN hosts. In addition, this very young starburst could also be enhanced by a positive AGN feedback produced by the high-luminosity AGN.

The fraction of the intermediate age,  $X_I$  ( $40 \text{ Myr} < t \leq 2.6 \text{ Gyr}$ ), SP of the AGN hosts slightly increase outwards, with a clear enhancement over the entire galaxy when compared with the control sample. In addition, our results show

that the inner region of the galaxies are dominated by an old SP, whose fraction decreases outwards. These results support the previous findings of the CALIFA team (Sánchez et al. 2013), supporting an inside-out scenario for the galaxies' star formation history.

We also investigated for differences on the star formation histories between the different Hubble types. No significant differences were found between early and late-type hosts galaxies.

From our results we suggest that an outside in scenario better describes the recent star formation in the AGN hosts, while an inside out scenario represents better the older generations of stars.

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## APPENDIX A: AGN - CONTROL GALAXIES COMPARISON IMAGES

All the comparisons between AGN and its control galaxies will be available online.

This paper has been typeset from a  $\text{\TeX}/\text{\LaTeX}$  file prepared by the author.



# Capítulo 5

## Considerações Finais

Apresentamos aqui um estudo do histórico de formação estelar espacialmente resolvido dos primeiros 62 AGNs observados no projeto MaNGA em comparação com os resultados de galáxias de controle. Nosso principais resultados estão listados abaixo.

- A contribuição de estrelas jovens está relacionada com a luminosidade do AGN: Há um aumento considerável na fração de populações estelares jovens nas regiões internas ( $R \leq 0.5R_e$ ) dos AGNs mais luminosas da amostra quando comparadas com as frações das respectivas galáxias de controle. Para o caso de AGNs de baixa luminosidade, essa fração se assemelha à das inativas;
- O resultado acima indica que o fluxo de material para as regiões nucleares, além de alimentar o AGN, está sendo usado para formar novas estrelas e, por isso, rejuvenescendo o conteúdo estelar das regiões centrais das galáxias ativas. Sugerimos que o *feedback* positivo produzido por AGNs de alta luminosidade pode ser um possível candidato para deflagrar a formação estelar;
- Há indícios de formação estelar de dentro para fora (cenário *inside-out*): A fração de populações intermediárias em AGNs aumenta radialmente e, quando comparadas com as galáxias inativas, apresentam aumento considerável sobre toda região estudada ( $1R_e$ ). Além disso, as galáxias são dominadas por populações velhas nas regiões centrais, mas apresentam decréscimo da contribuição de estrelas velhas com o raio.
- Não observamos diferenças entre galáxias *early-* e *late-type* do ponto de vista do nosso estudo.

Com esses resultados, sugerimos que a formação estelar em galáxias ativas de alta luminosidade é melhor descrita por um cenário de formação *outside-in*, enquanto

que um cenário *inside-out* melhor representa a distribuição das populações estelares mais velhas da galáxias.

Como subproduto desenvolvemos um código capaz de manipular cubos de dados do MaNGA, realizar síntese de populações estelares e gerar resultados de forma automatizada e paralelizada. Além disso, o código possui capacidade modular e, por isso, possibilita uma fácil implementação de diferentes funções de extração, análise e geração de resultados.

## 5.1 Perspectivas

Com a crescente amostra de galáxias observadas pelo MaNGA, a quantidade de AGNs deverá crescer (com um valor estimado de  $\sim 300$  até 2020). Propomos utilizar os métodos desenvolvidos para esse trabalho em uma amostra mais completa de AGNs e galáxias controle (já sendo construída) melhorando a estatística para AGNs mais luminosos. Também iremos aprimorar o método utilizando diferentes modelos de populações estelares para fins de comparação, como os de Maraston (2005) e Vazdekis et al. (2010). Além disso, o software MEGACUBE desenvolvido nesse trabalho será documentado e disponibilizado em uma versão pública.

# Capítulo 6

## Participação em Outros Trabalhos

O desenvolvimento da ferramenta MEGACUBE possibilitou ao autor participar de outros artigos, listados abaixo, onde sua principal contribuição foi gerar os mapas de populações estelares dos cubos de dados (ou espectros de fenda longa) bem como gerar mapas de diferentes propriedades, permitindo sua rápida análise.

- SDSS-IV MaNGA: stellar population gradients as a function of galaxy environment. GODDARD, D., THOMAS, D., MARASTON, C., WESTFALL, K., ETHERINGTON, J., RIFFEL, R., **Mallmann, N. D.**, ZHENG, Z., ARGUDO-FERNÁNDEZ, M., BERSHADY, M., BUNDY, K., DRORY, N., LAW, D., YAN, R., WAKE, D., WEIJMANS, A., BIZYAEV, D., BROWNSTEIN, J., LANE, R. R., MAIOLINO, R., MASTERS, K., MERRIFIELD, M., NITSCHHELM, C., PAN, K., ROMAN-LOPES, A., STORCHI-BERGMANN, T.. DOI: "10.1093/mnras/stw2719".
- SDSS-IV MaNGA: Spatially resolved star formation histories in galaxies as a function of galaxy mass and type. GODDARD, D., THOMAS, D., MARASTON, C., WESTFALL, K., ETHERINGTON, J., RIFFEL, R., **Mallmann, N. D.**, ZHENG, Z., ARGUDO-FERNÁNDEZ, M., LIAN, J., BERSHADY, M., BUNDY, K., DRORY, N., LAW, D., YAN, R., WAKE, D., WEIJMANS, A., BIZYAEV, D., BROWNSTEIN, J., LANE, R. R., MAIOLINO, R., MASTERS, K., MERRIFIELD, M., NITSCHHELM, C., PAN, K., ROMAN-LOPES, A., STORCHI-BERGMANN, T., SCHNEIDER, D. P.. DOI: "10.1093/mnras/stw3371".
- The first 62 AGNs observed with SDSS-IV MaNGA - I. Their characterization and definition of a control sample. REMBOLD, S. B., SHIMOIA, J. S., STORCHI-BERGMANN, T., RIFFEL, R., RIFFEL, R. A., **Mallmann, N. D.**,

DO NASCIMENTO, J. C., MOREIRA, T. N., ILHA, G. S., MACHADO, A. D., CIROLINI, R., DA COSTA, L. N., MAIA, M. A. G., SANTIAGO, B. X., SCHNEIDER, D. P., WYLEZALEK, D., BIZYAEV, D., PAN, K., MÜLLER-SÁNCHEZ, F.. DOI: "10.1093/mnras/stx2264".

O autor também contribuiu com um artigo (em preparação) utilizando o parte do código MEGACUBE.

- The first 62 AGN observed with SDSS-IV MaNGA - IV: gas excitation and surface mass density distribution. JANAÍNA C. DO NASCIMENTO, THAISA STORCHI-BERGMANN, **Nícolás D. Mallmann**, ROGÉRIO RIFFEL, GABRIELE S. ILHA, ROGEMAR A. RIFFEL, SANDRO B. REMBOLD, JÁDERSON SHIMOIA, LUIZ NICOLACI DA COSTA, MARCIO A.G. MAIA.

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# **Apêndice A: Comparações AGN-Controles**

Aqui, colocamos as imagens do apêndice do artigo apresentado no capítulo 4.

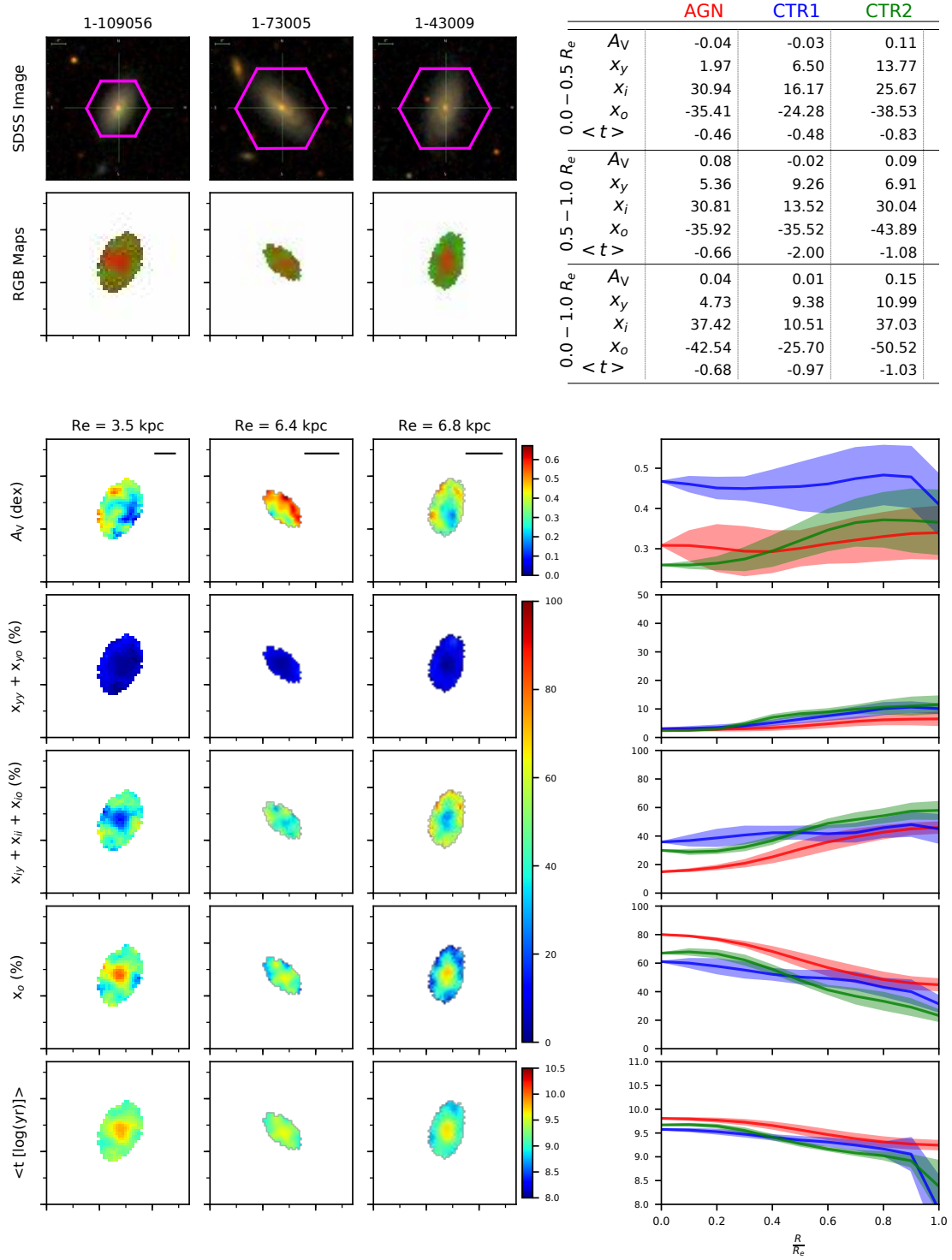


Figure A1. Comparison of the AGN with MaNGA ID 1-109056 and its control galaxies.

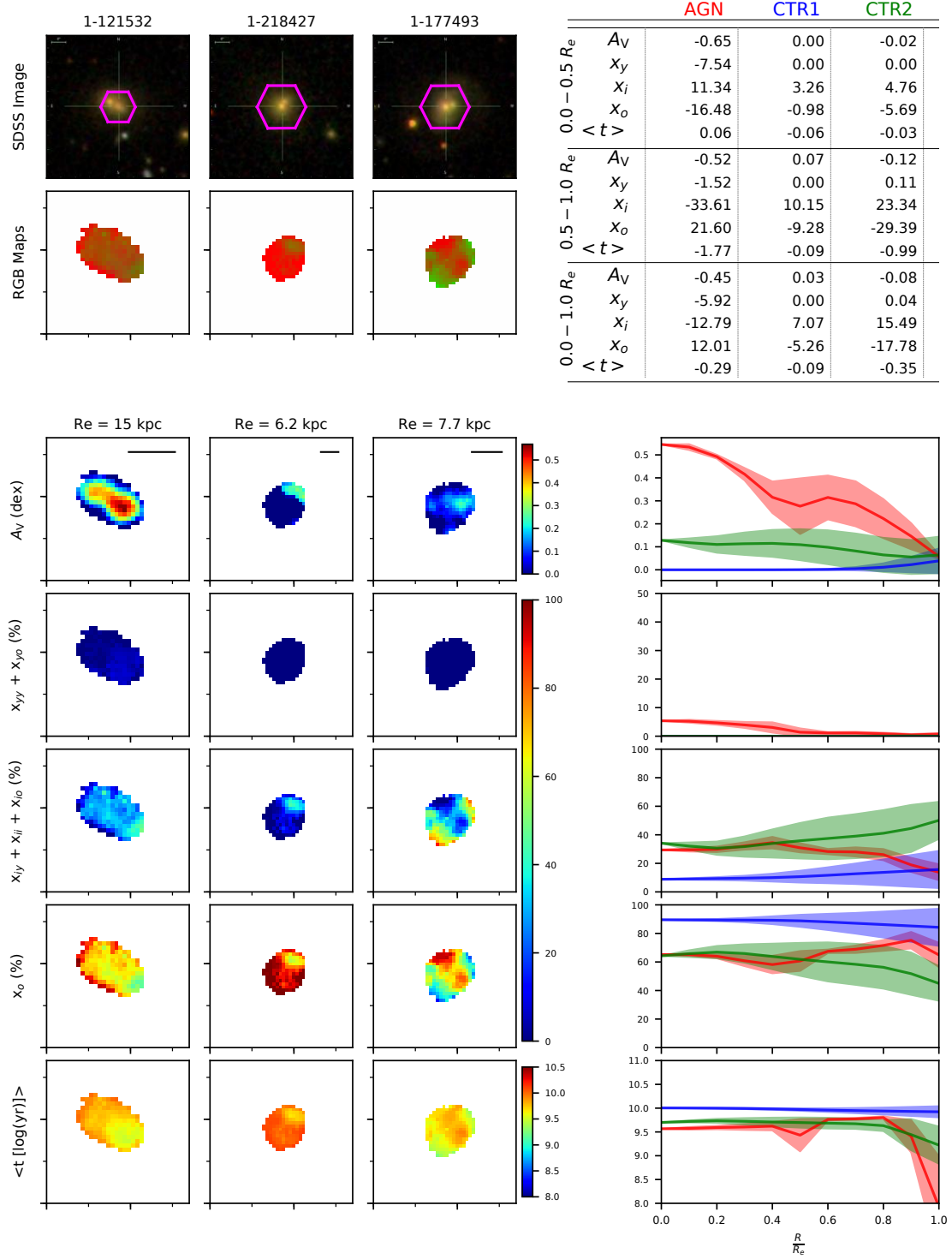
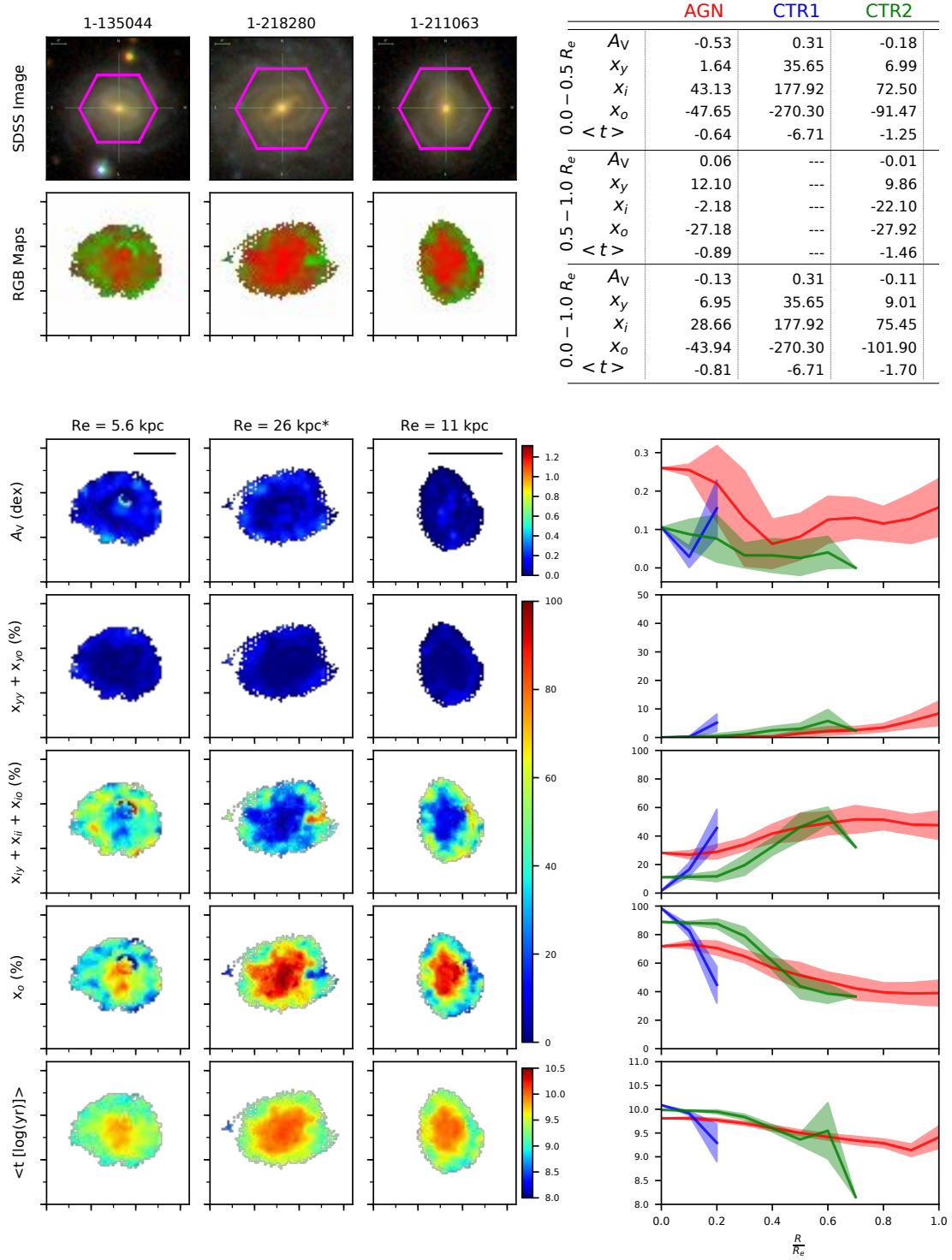


Figure A2. Comparison of the AGN with MaNGA ID 1-121532 and its control galaxies.





**Figure A3.** Comparison of the AGN with MaNGA ID 1-135044 and its control galaxies. \*The effective radius of this galaxy is too large to fit in the panel ( $R_e = 51''$ ).

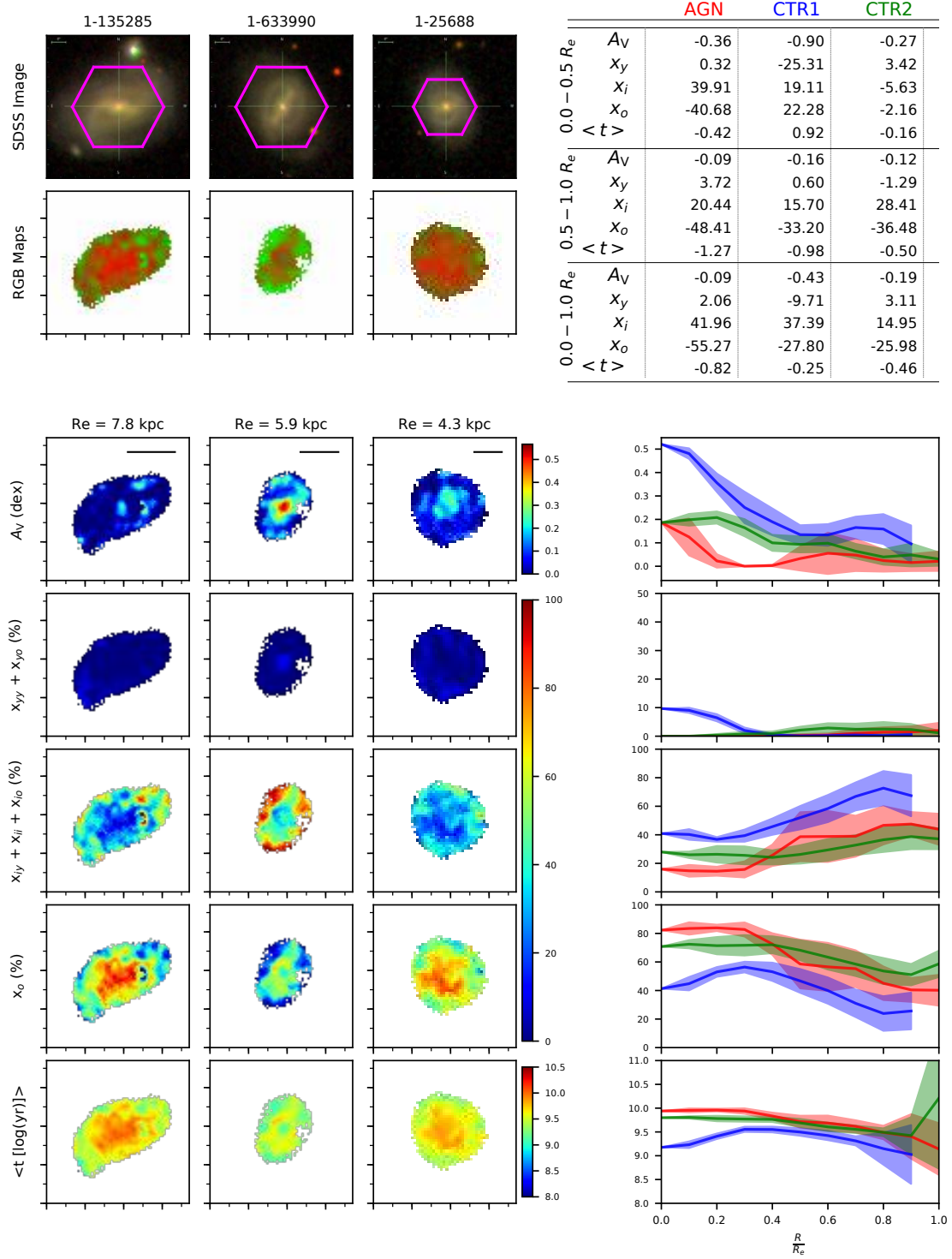
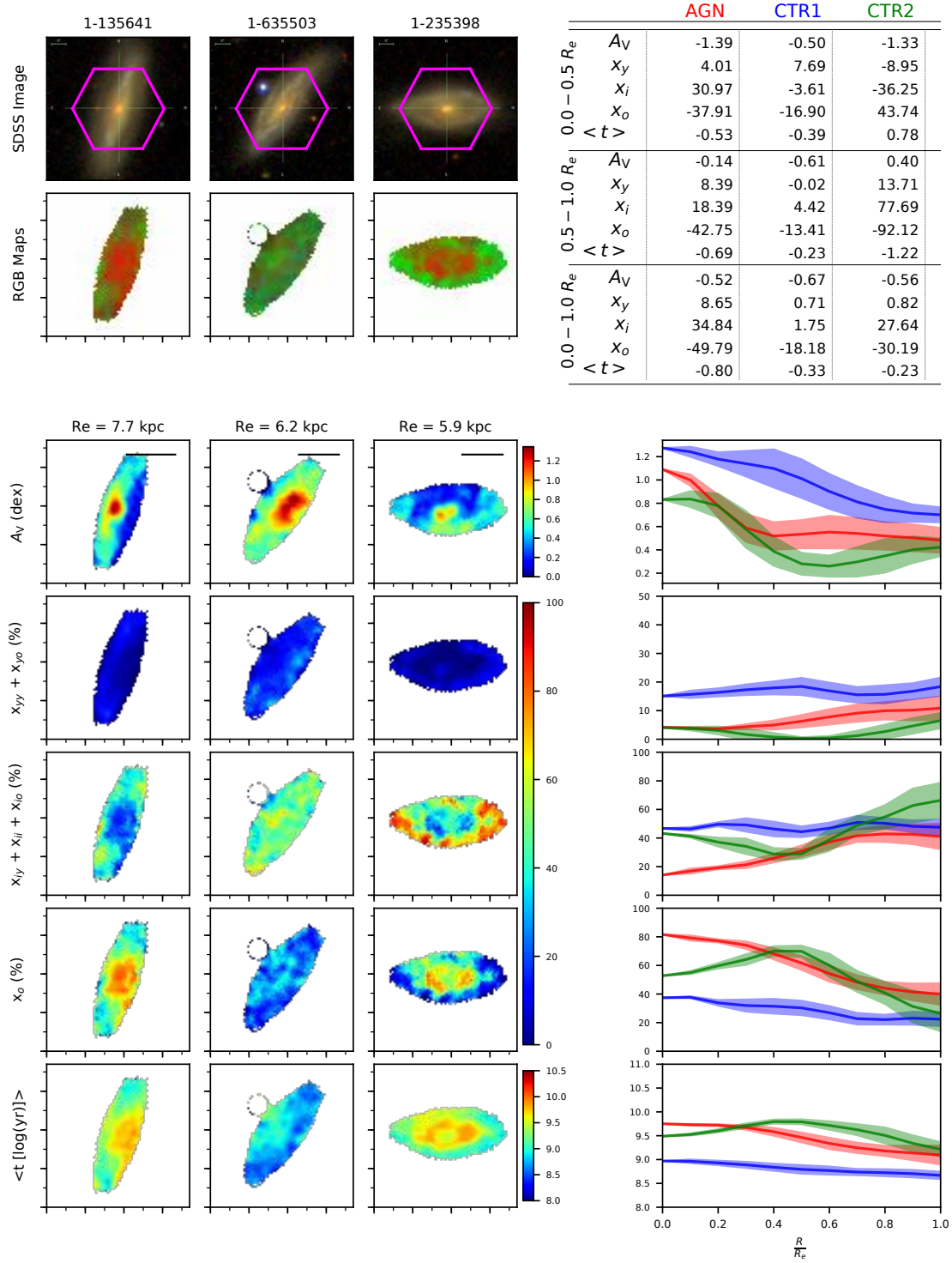


Figure A4. Comparison of the AGN with MaNGA ID 1-135285 and its control galaxies.



**Figure A5.** Comparison of the AGN with MaNGA ID 1-135641 and its control galaxies. It is important to note that the artifact present on the galaxy 1-635503 (the ring on the maps) is just the result of the spaxels' exclusion mask we used (MaNGA bit signaling a foreground star and S/N cutoff) and have no effect on our results. A similar situation occurs in other results, such as in Figs. A7 and A12.

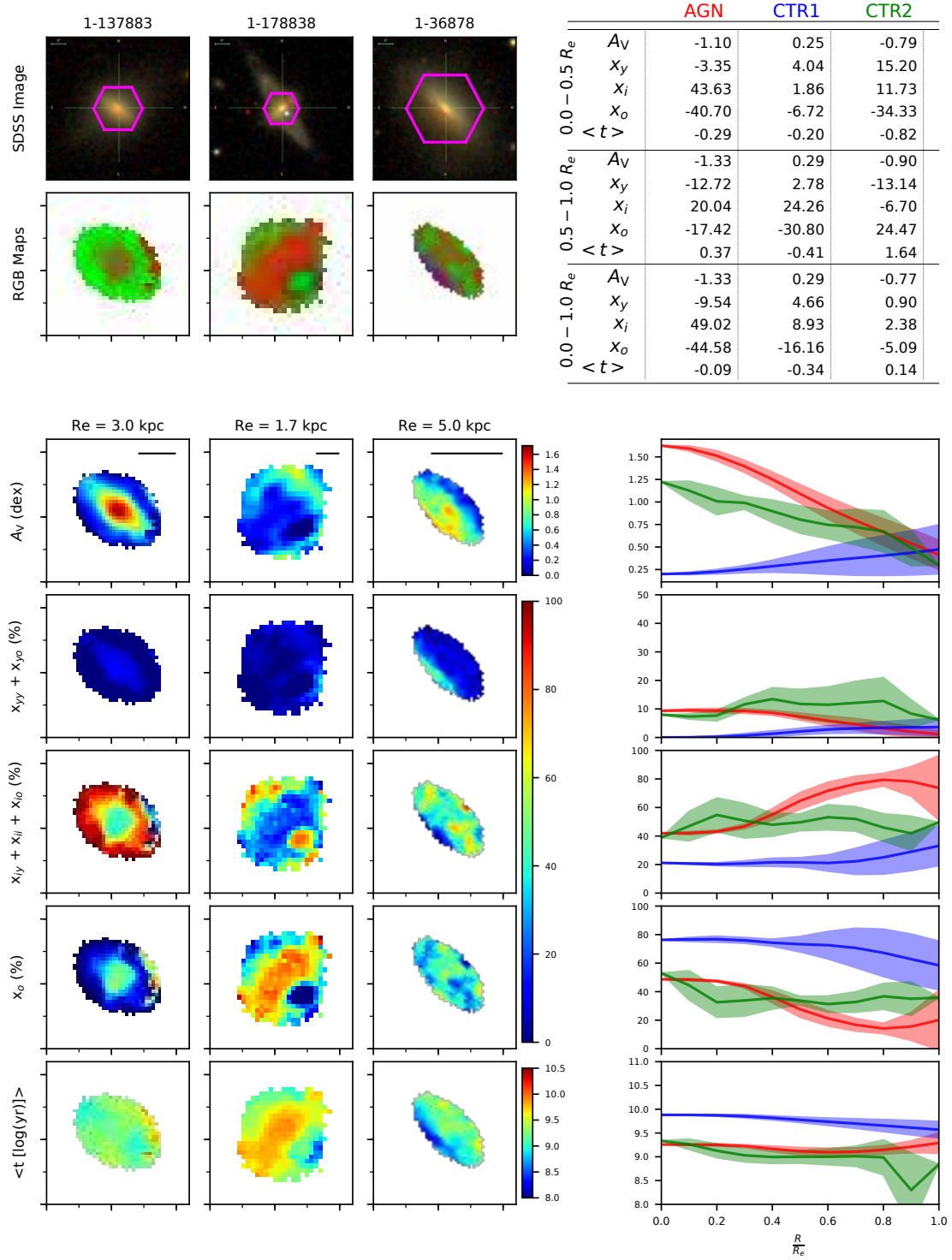


Figure A6. Comparison of the AGN with MaNGA ID 1-137883 and its control galaxies.

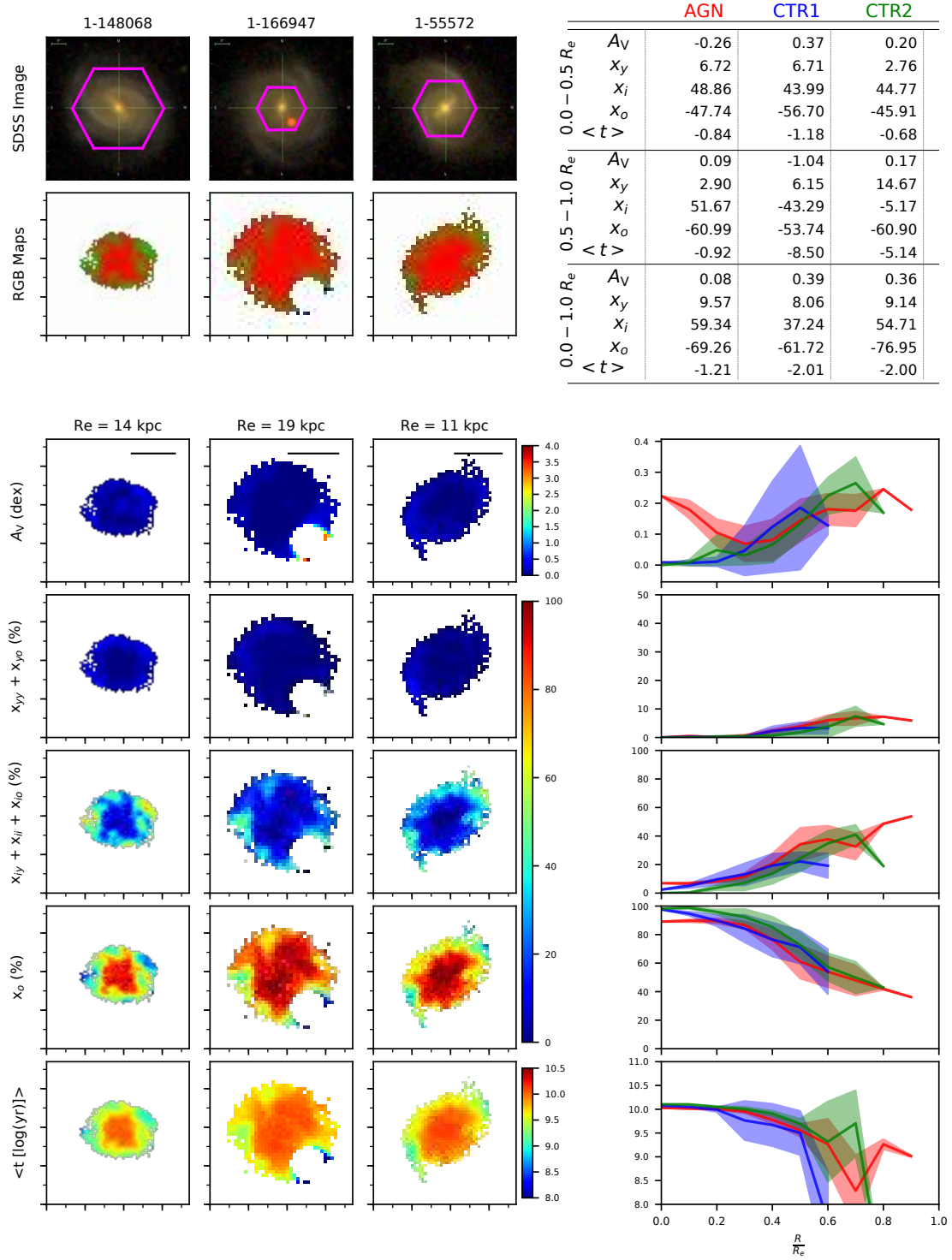


Figure A7. Comparison of the AGN with MaNGA ID 1-148068 and its control galaxies.

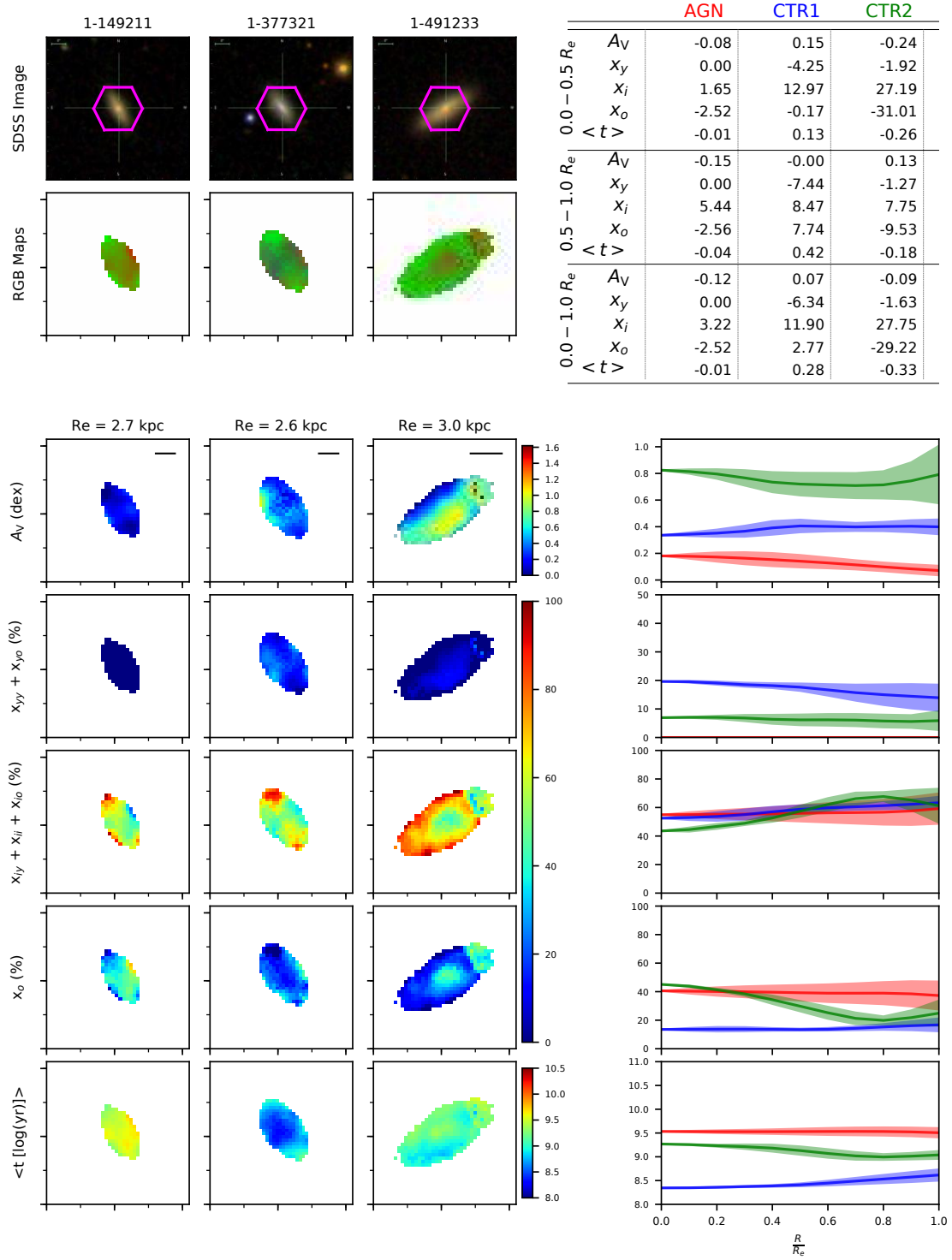


Figure A8. Comparison of the AGN with MaNGA ID 1-149211 and its control galaxies.

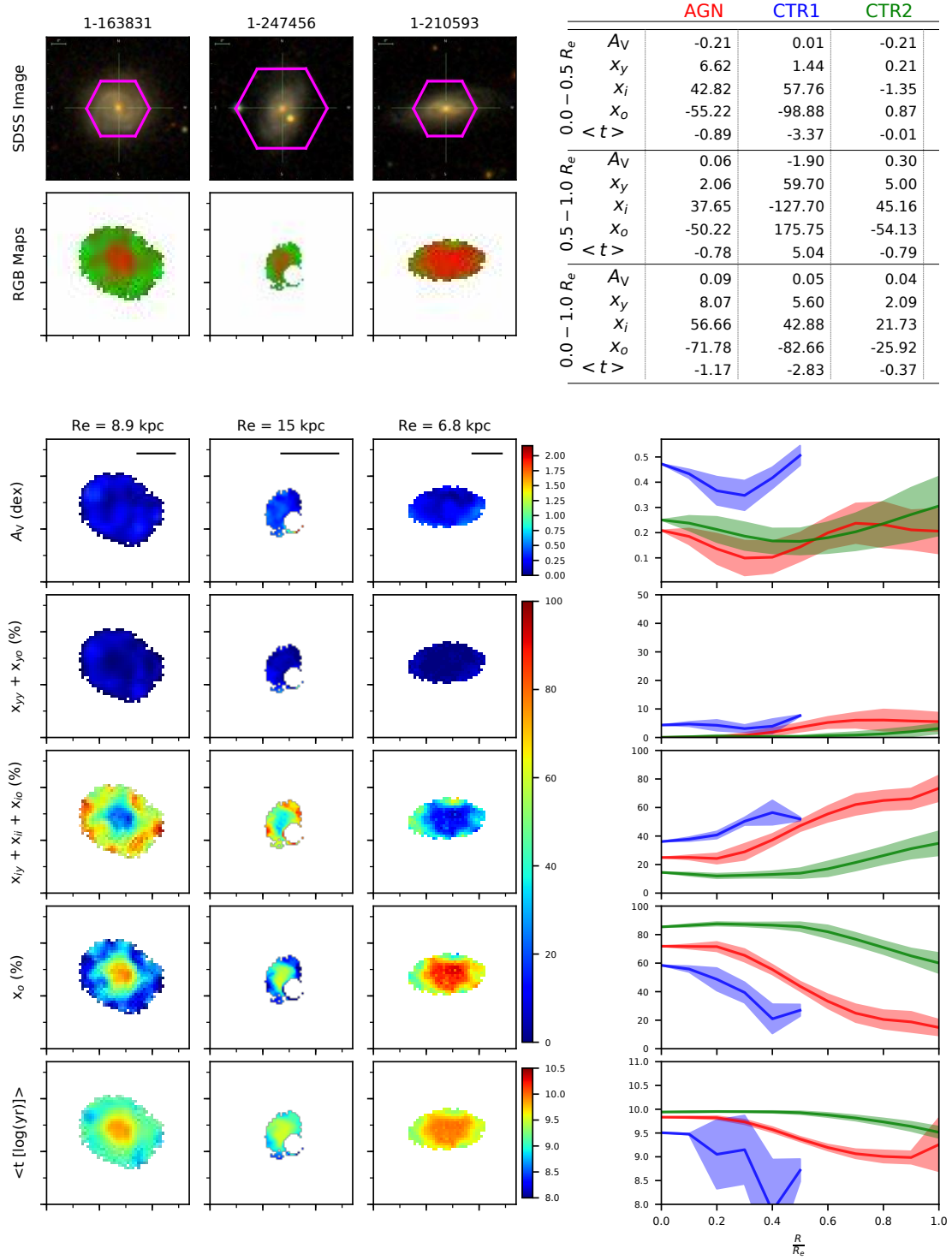


Figure A9. Comparison of the AGN with MaNGA ID 1-163831 and its control galaxies.

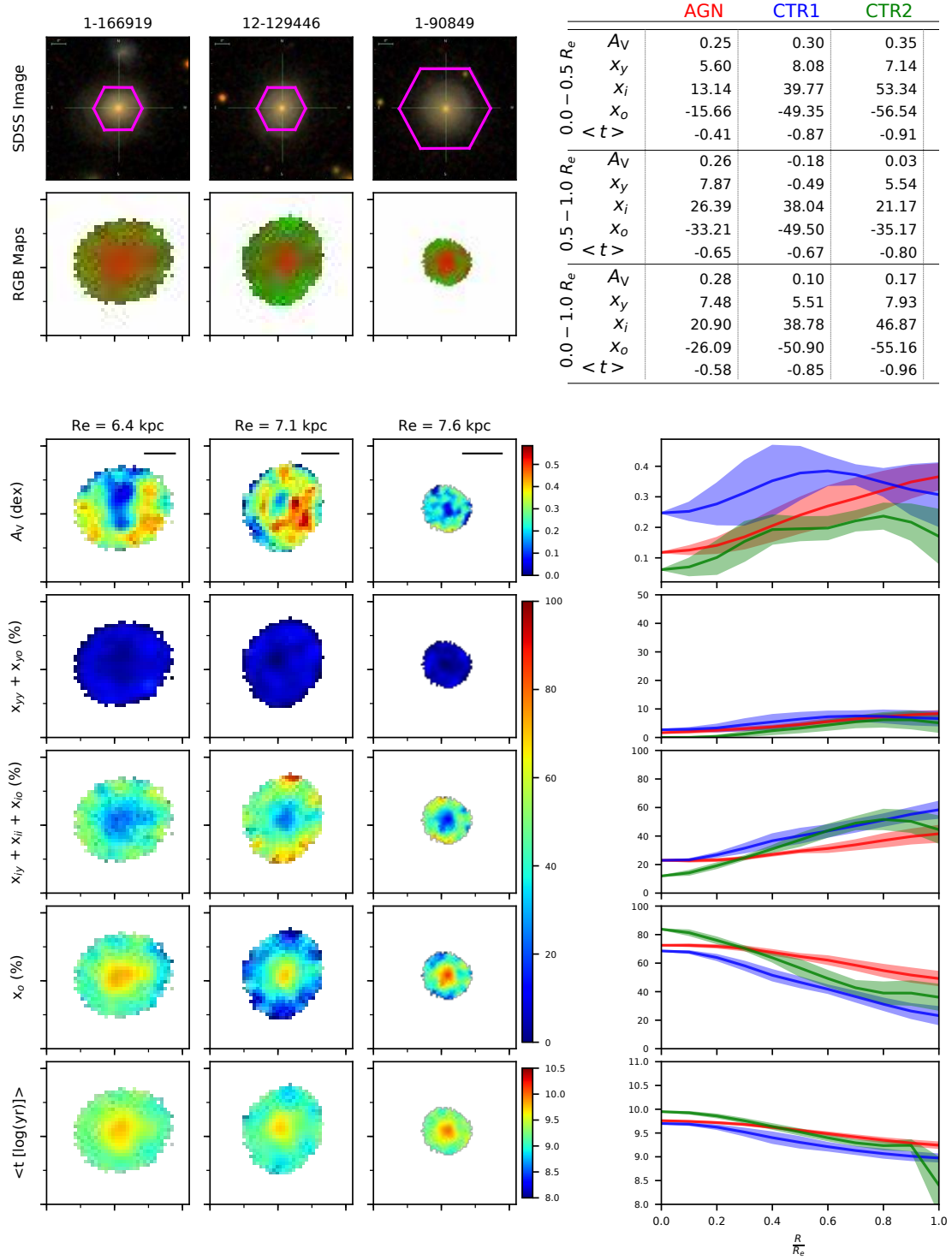


Figure A10. Comparison of the AGN with MaNGA ID 1-166919 and its control galaxies.



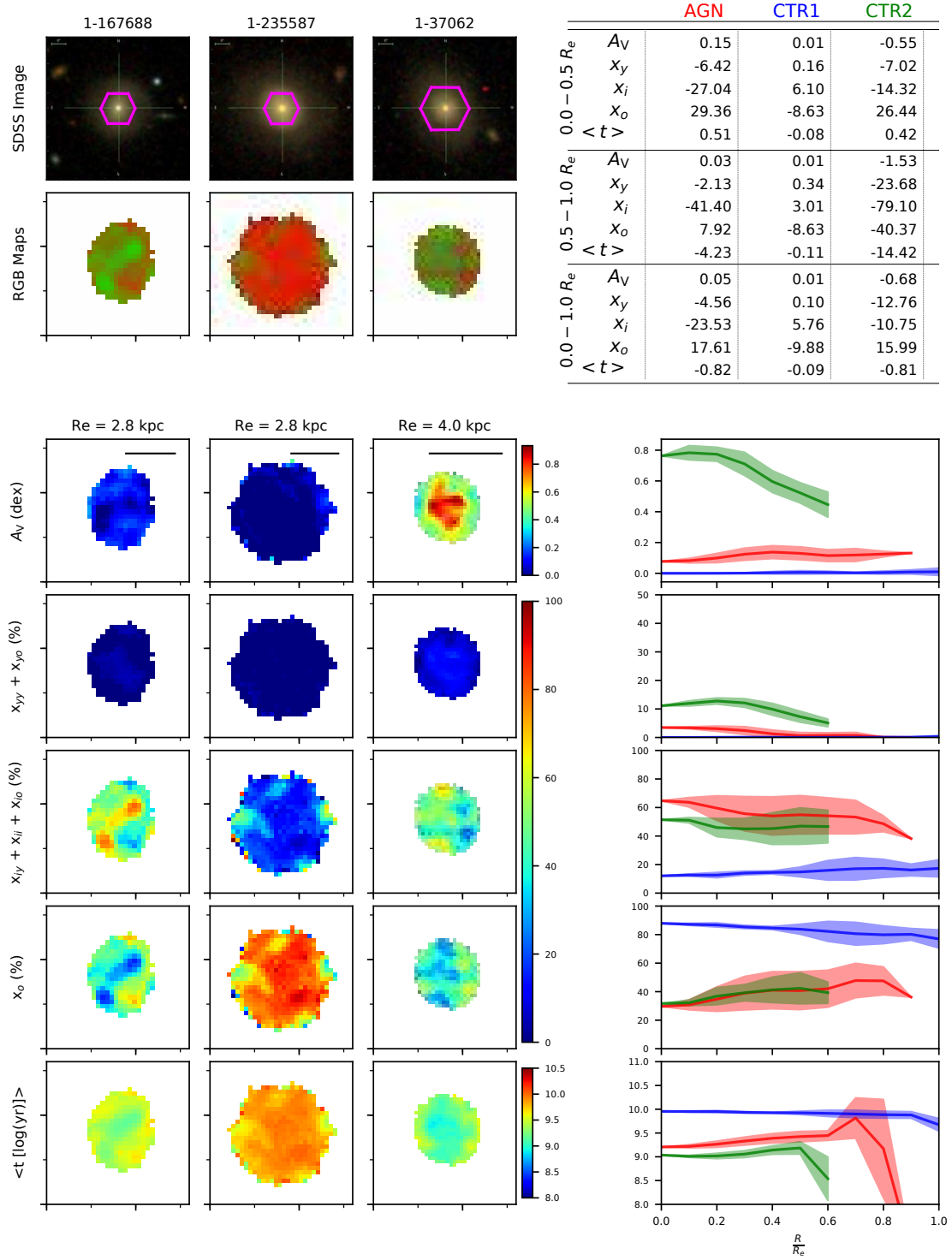


Figure A11. Comparison of the AGN with MaNGA ID 1-167688 and its control galaxies.

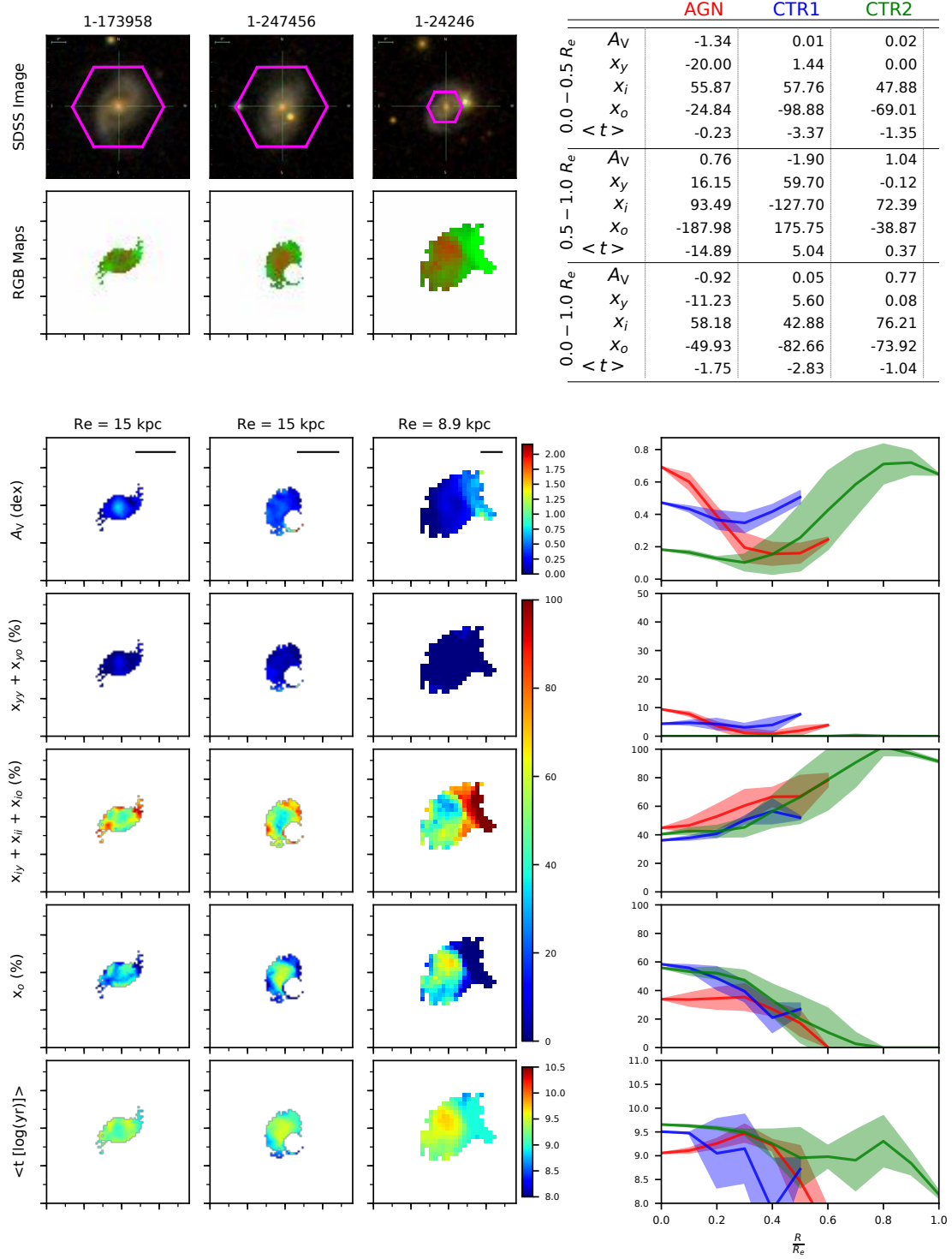


Figure A12. Comparison of the AGN with MaNGA ID 1-173958 and its control galaxies.

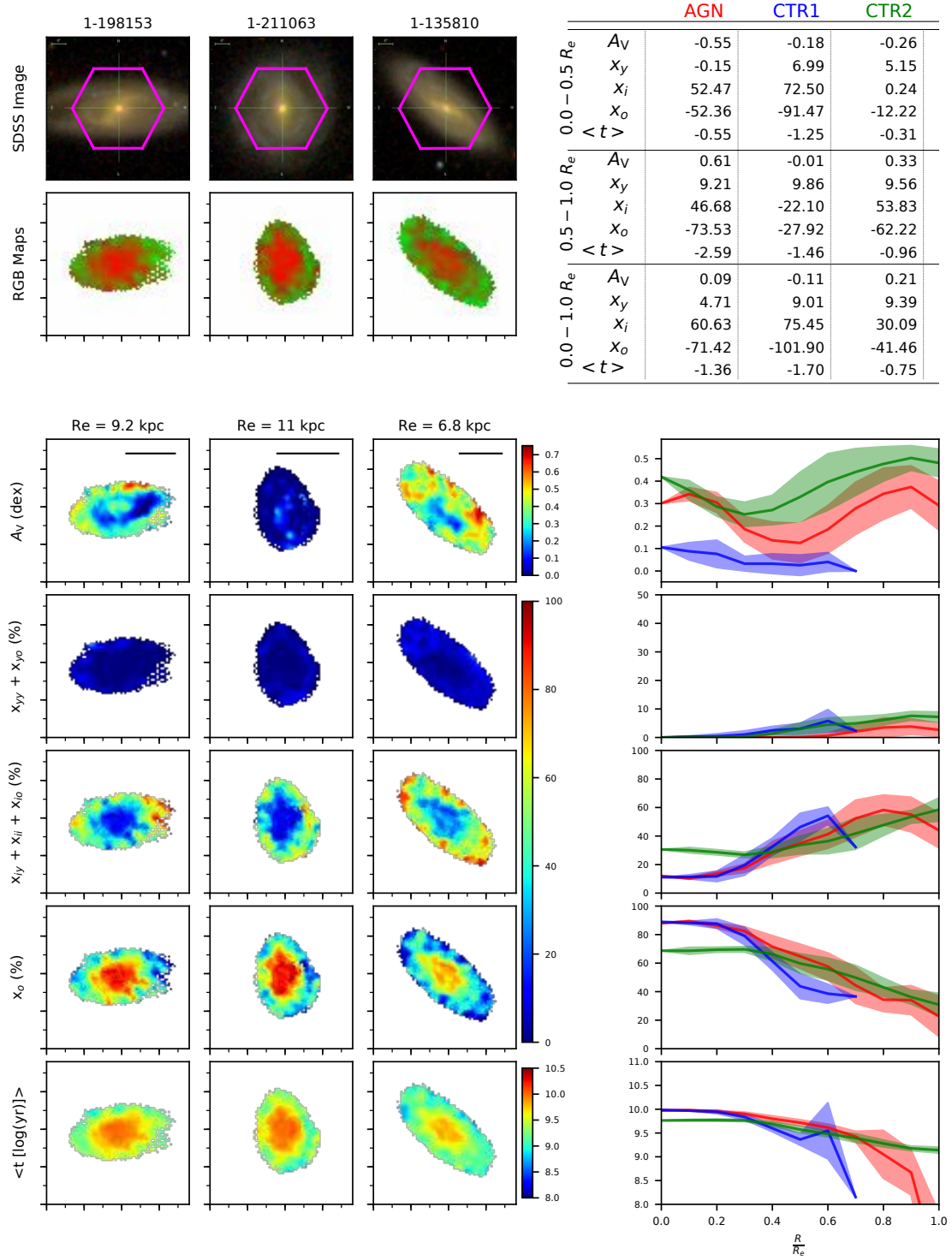


Figure A13. Comparison of the AGN with MaNGA ID 1-198153 and its control galaxies.

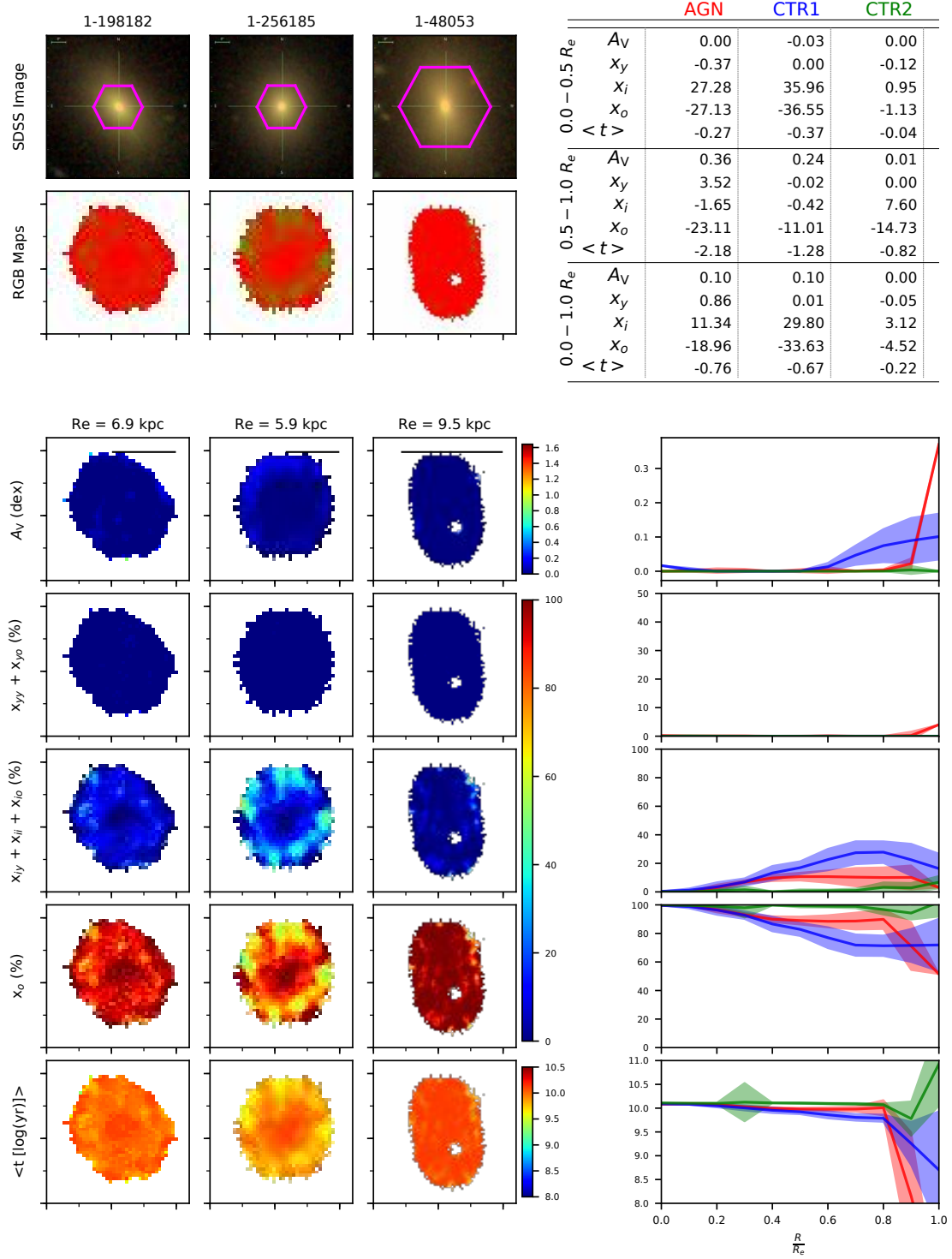


Figure A14. Comparison of the AGN with MaNGA ID 1-198182 and its control galaxies.

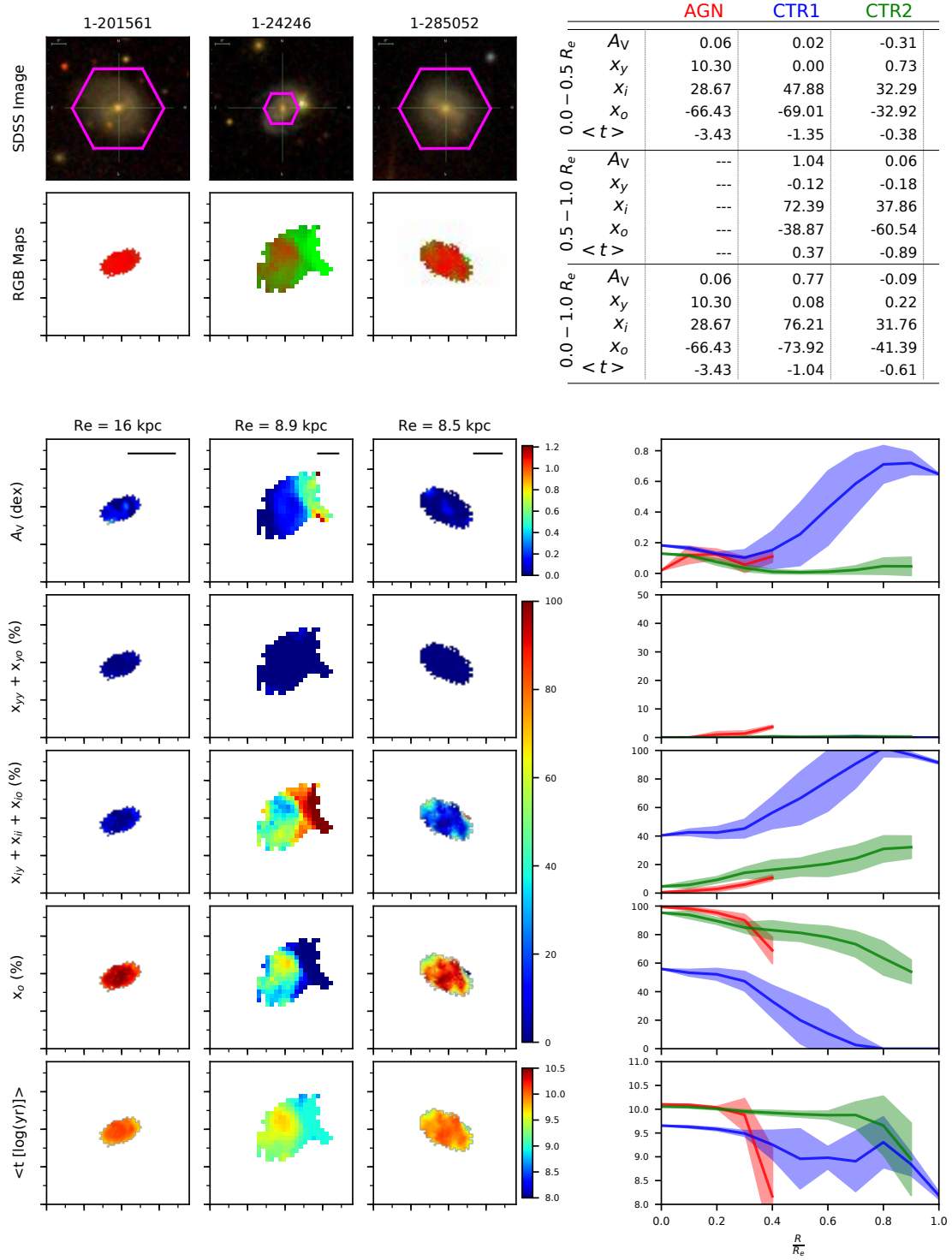


Figure A15. Comparison of the AGN with MaNGA ID 1-201561 and its control galaxies.

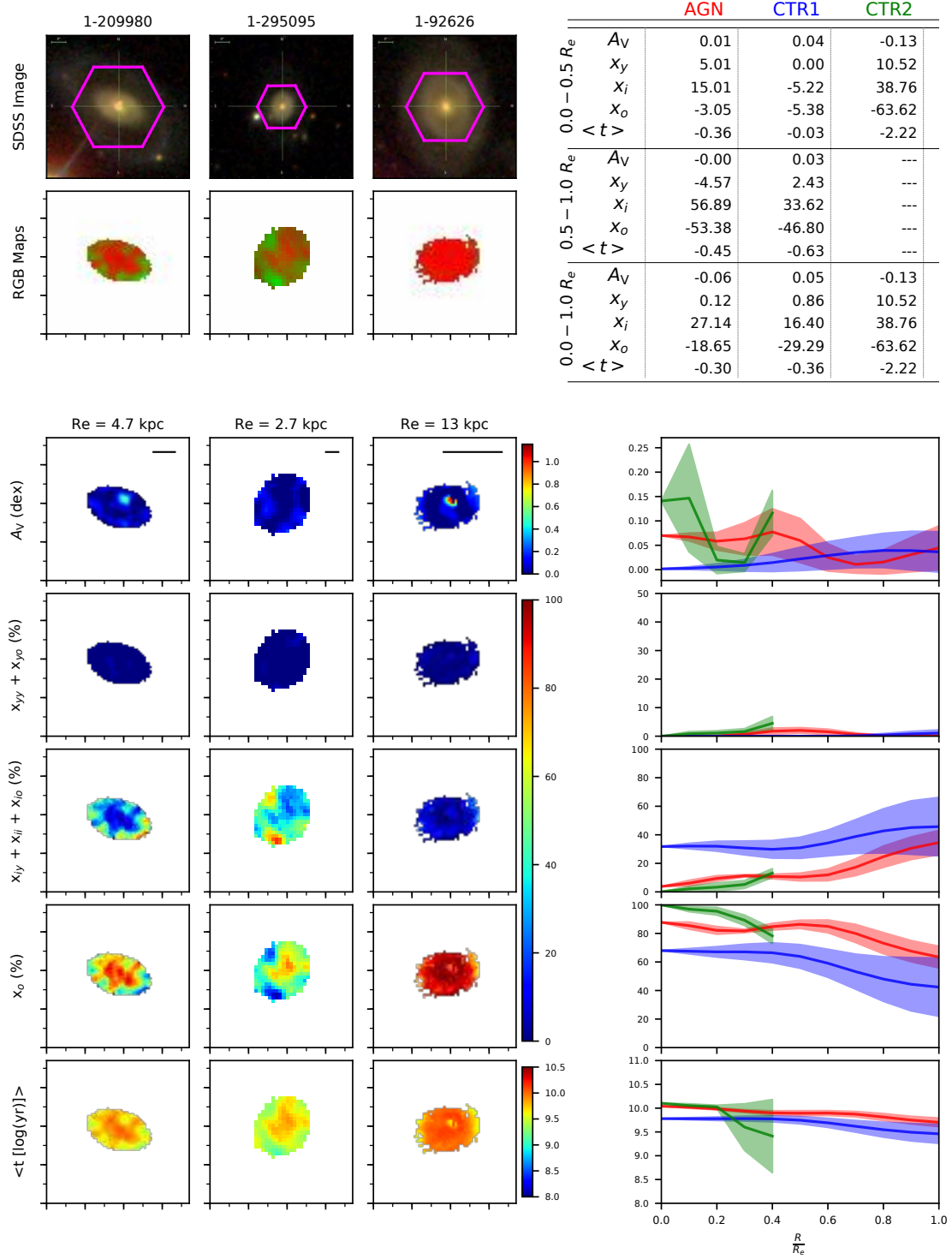


Figure A16. Comparison of the AGN with MaNGA ID 1-209980 and its control galaxies.

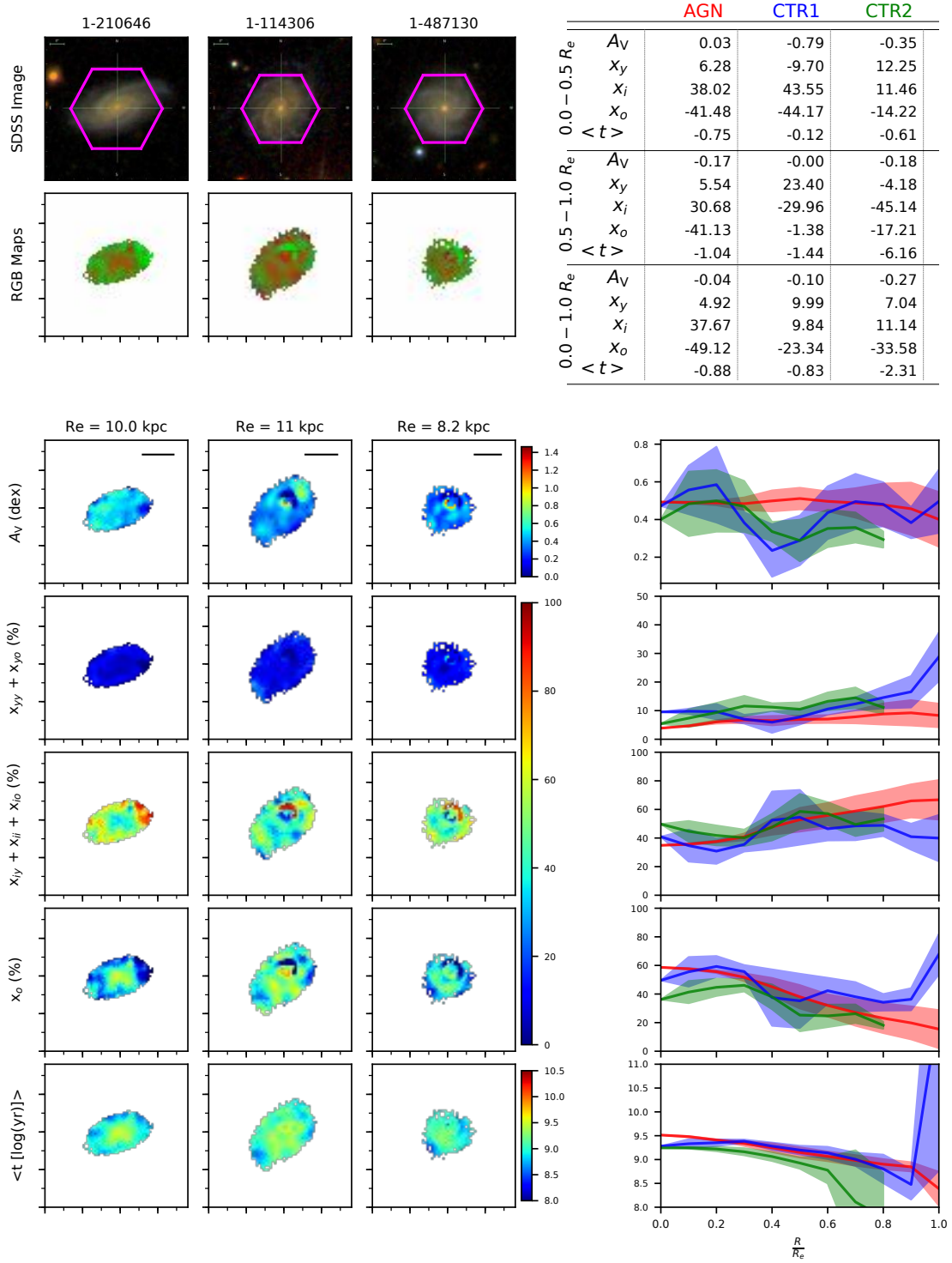


Figure A17. Comparison of the AGN with MaNGA ID 1-210646 and its control galaxies.

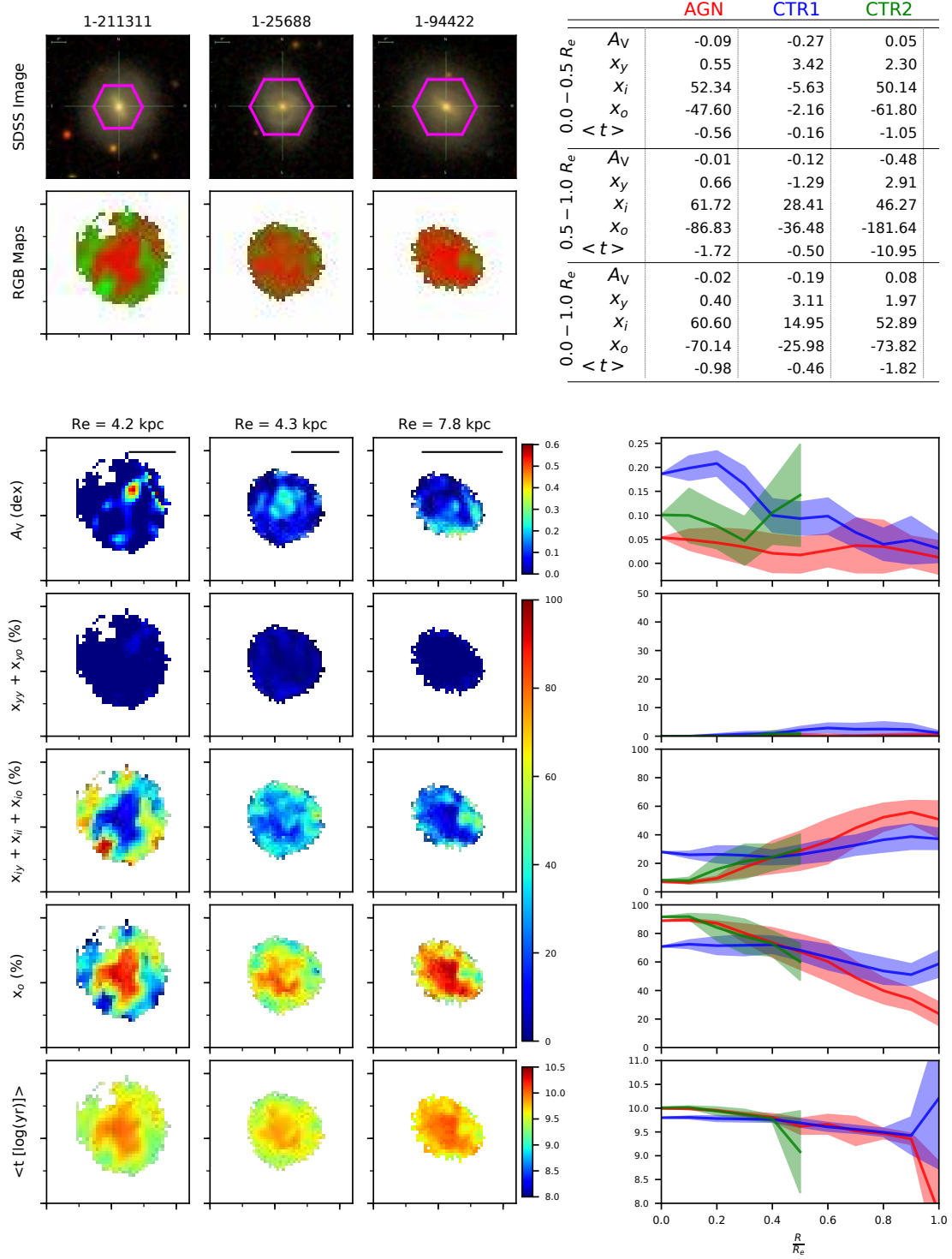


Figure A18. Comparison of the AGN with MaNGA ID 1-211311 and its control galaxies.



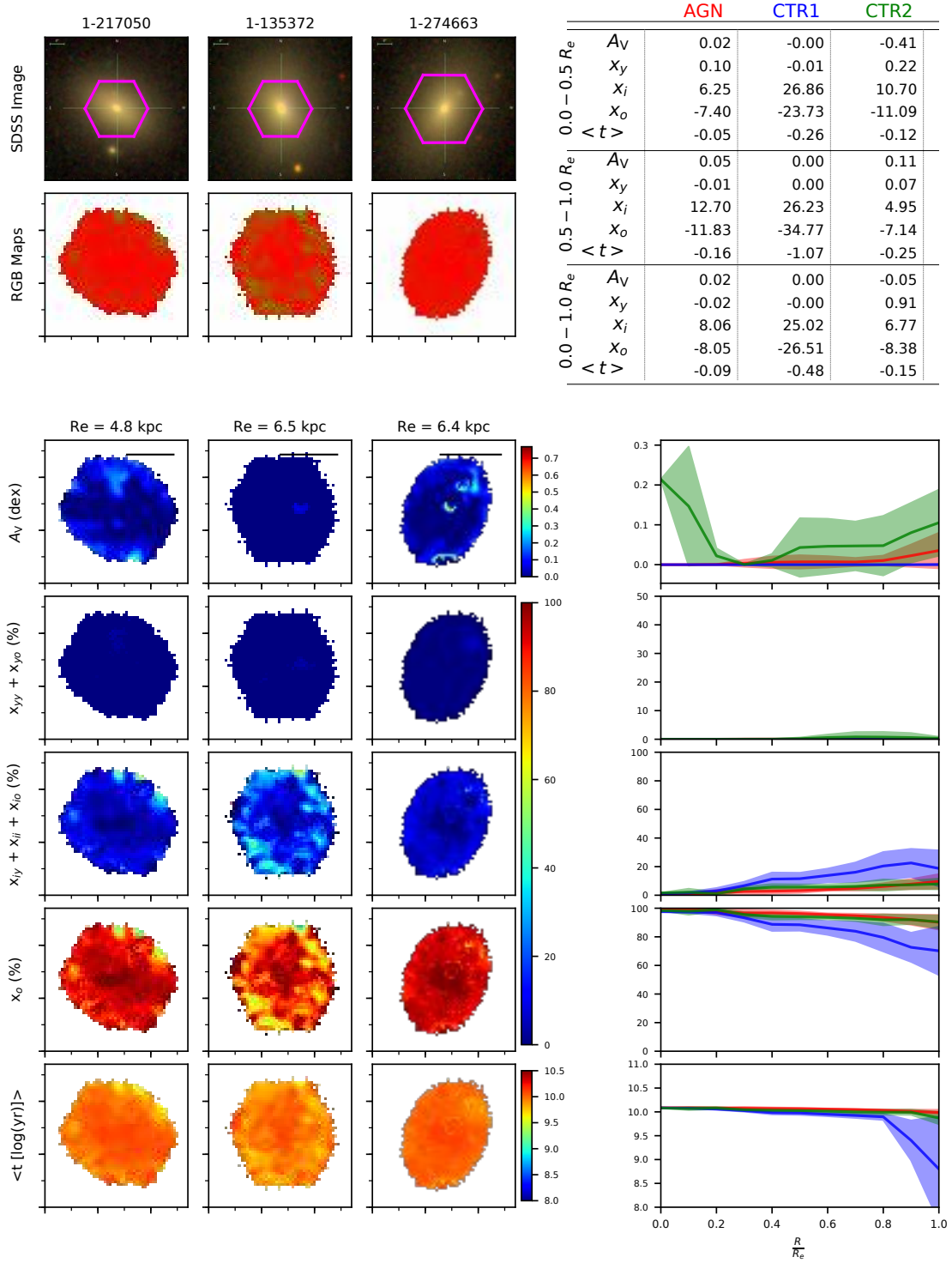


Figure A19. Comparison of the AGN with MaNGA ID 1-217050 and its control galaxies.

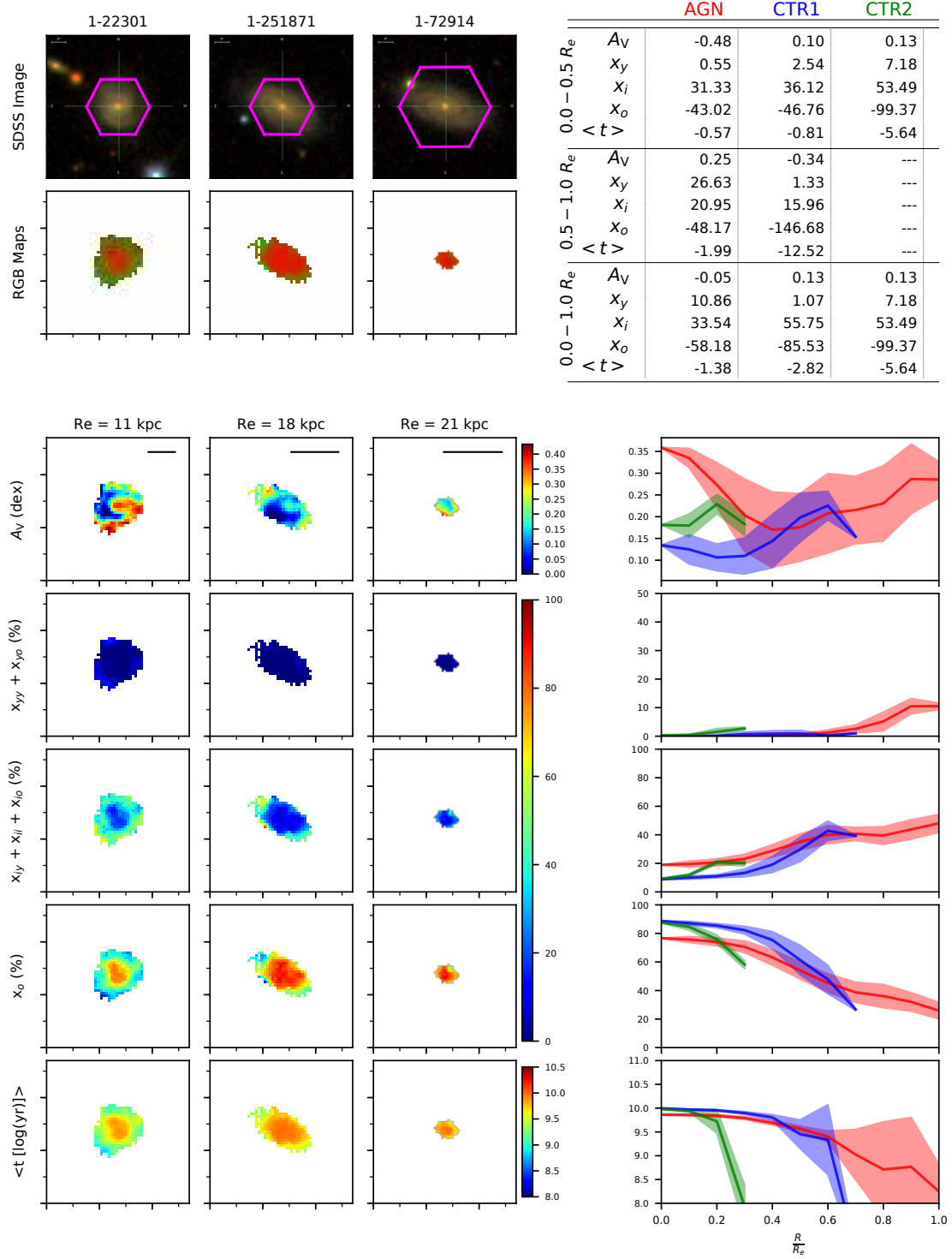


Figure A20. Comparison of the AGN with MaNGA ID 1-22301 and its control galaxies.

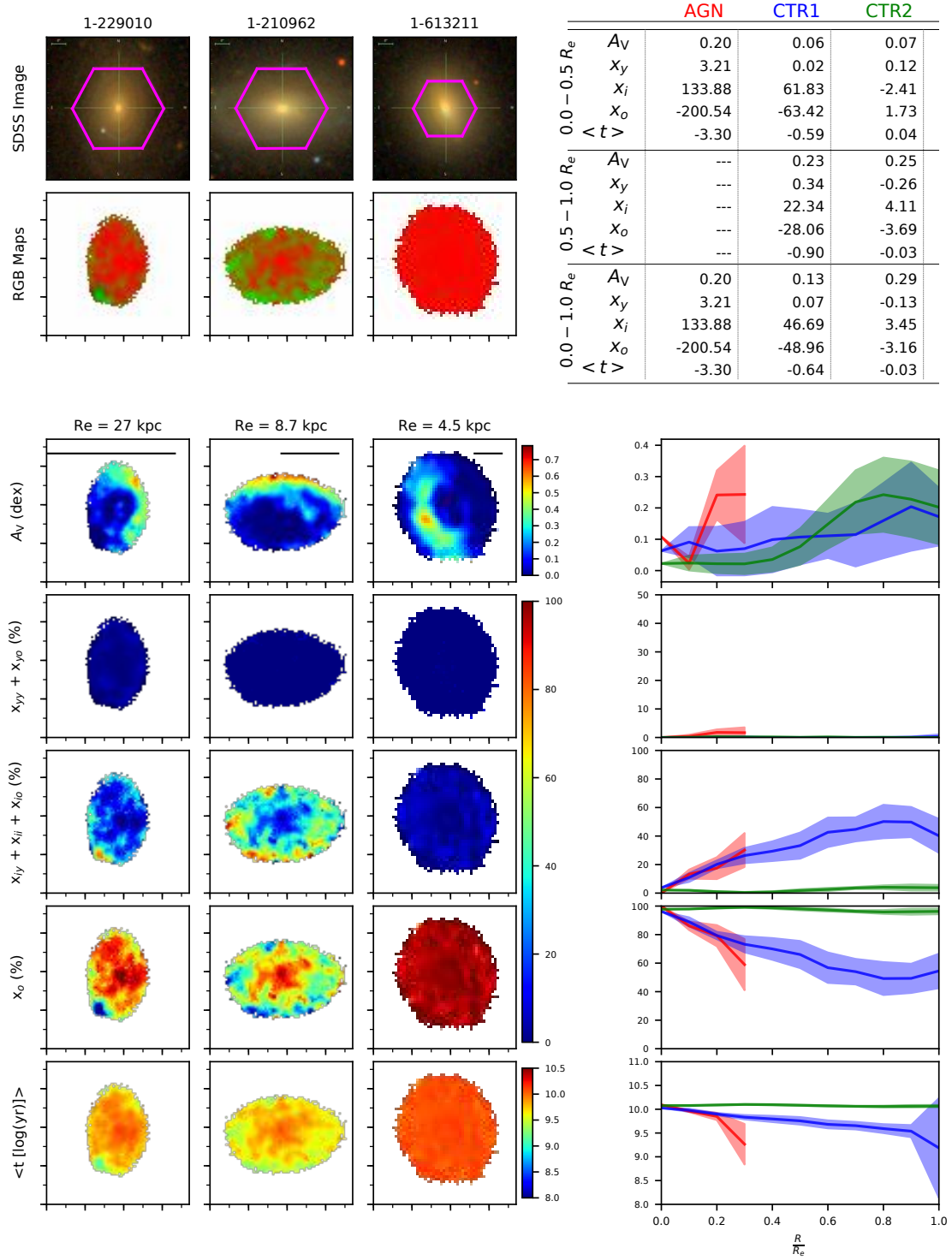


Figure A21. Comparison of the AGN with MaNGA ID 1-229010 and its control galaxies.

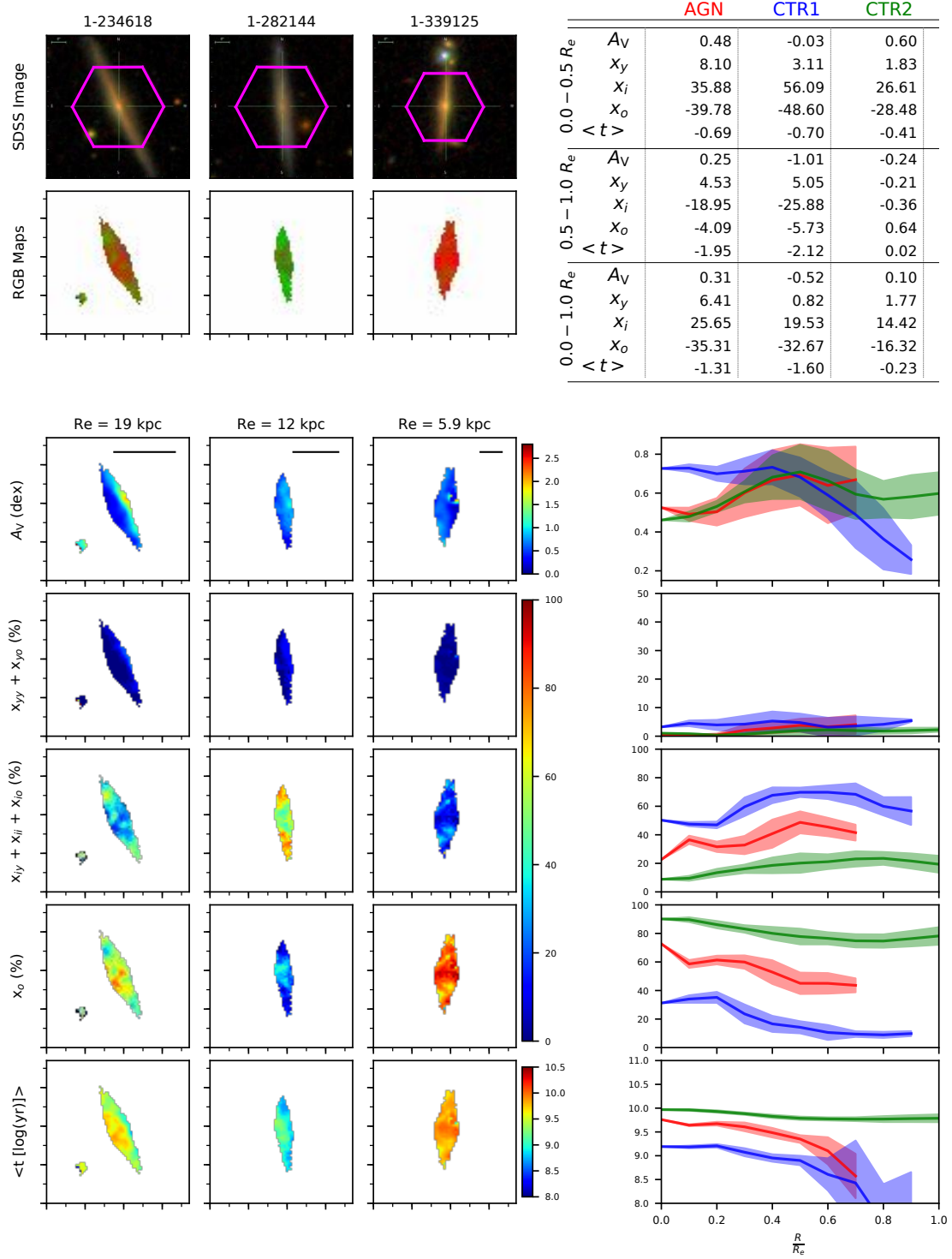


Figure A22. Comparison of the AGN with MaNGA ID 1-234618 and its control galaxies.

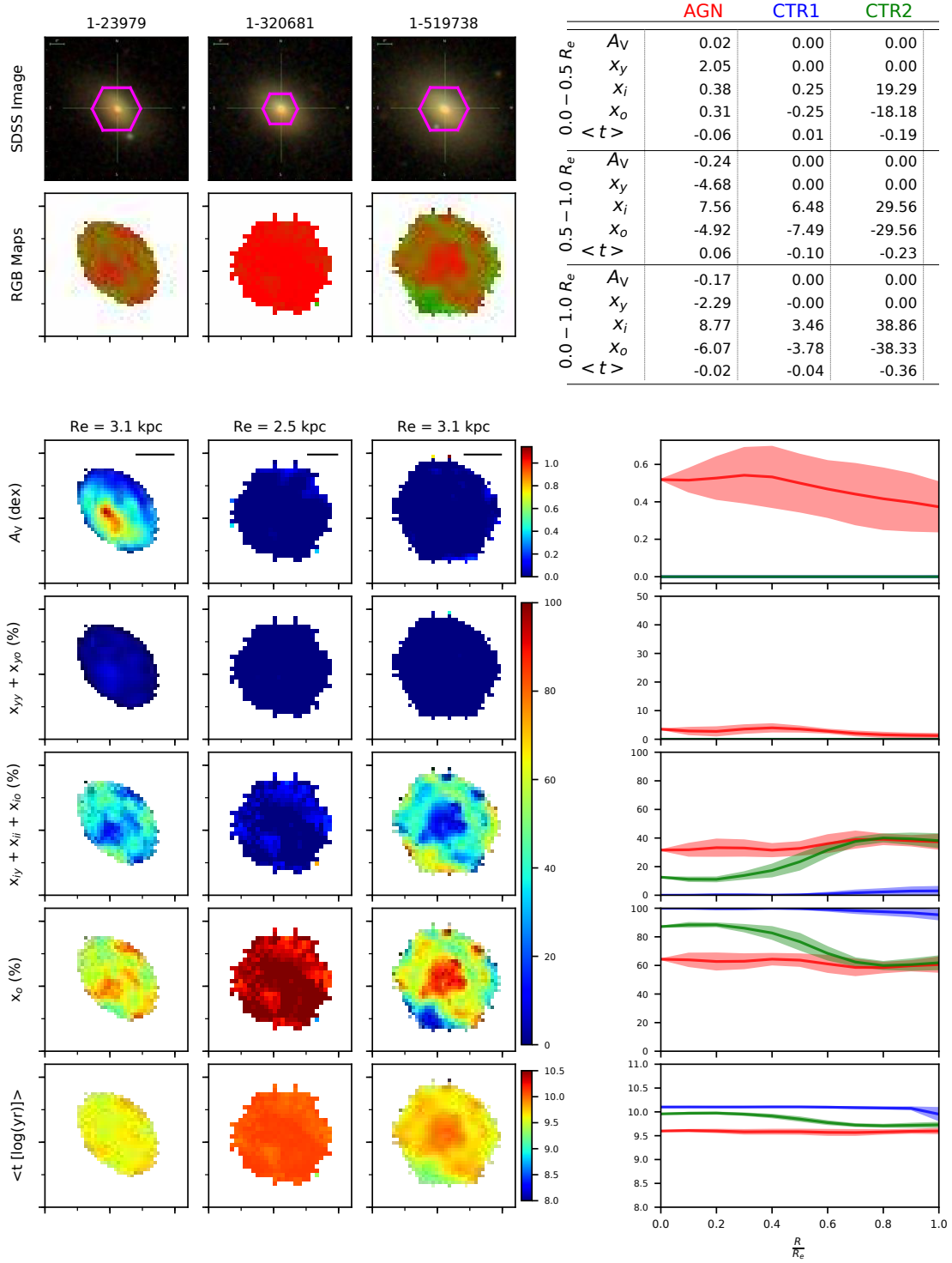


Figure A23. Comparison of the AGN with MaNGA ID 1-23979 and its control galaxies.

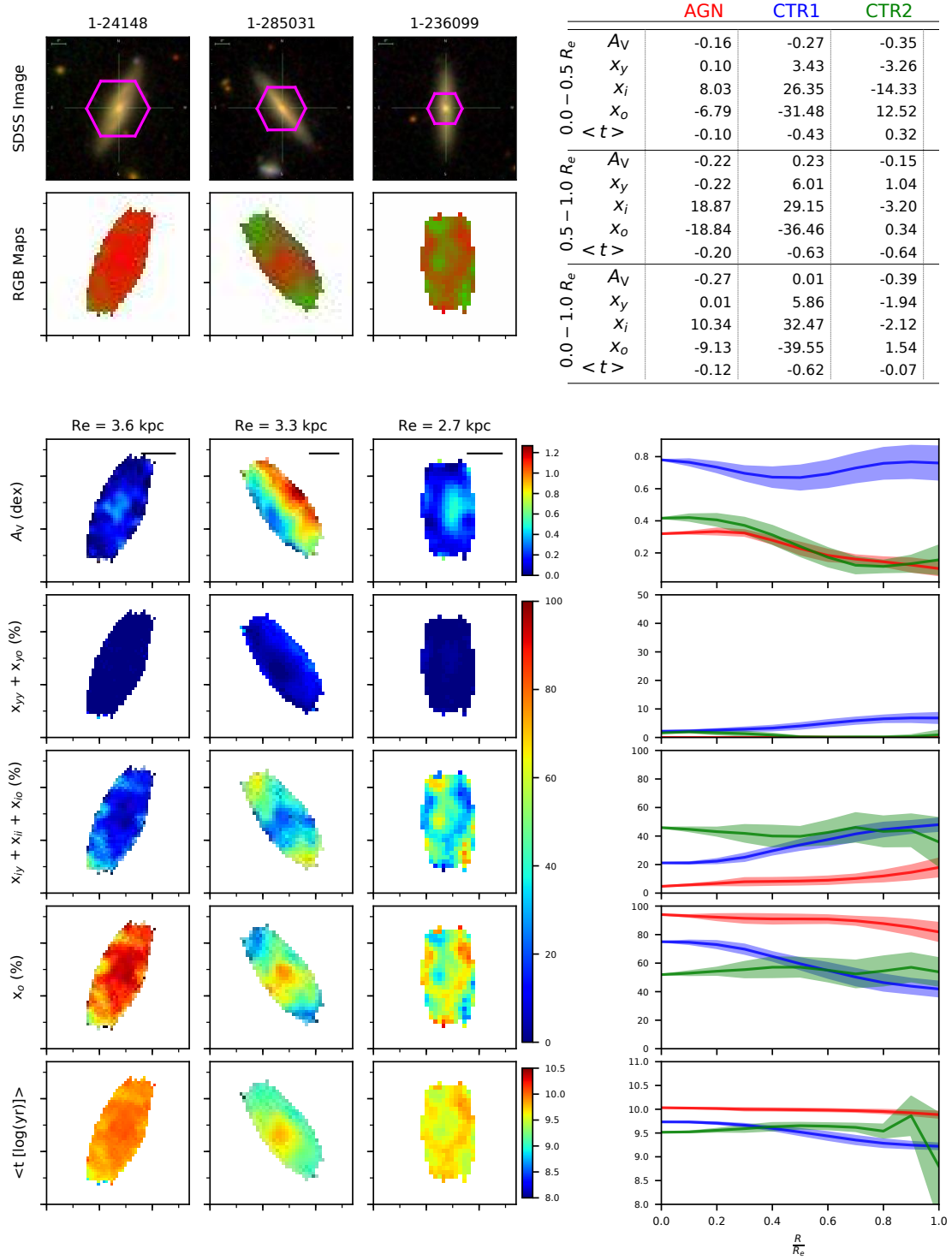


Figure A24. Comparison of the AGN with MaNGA ID 1-24148 and its control galaxies.

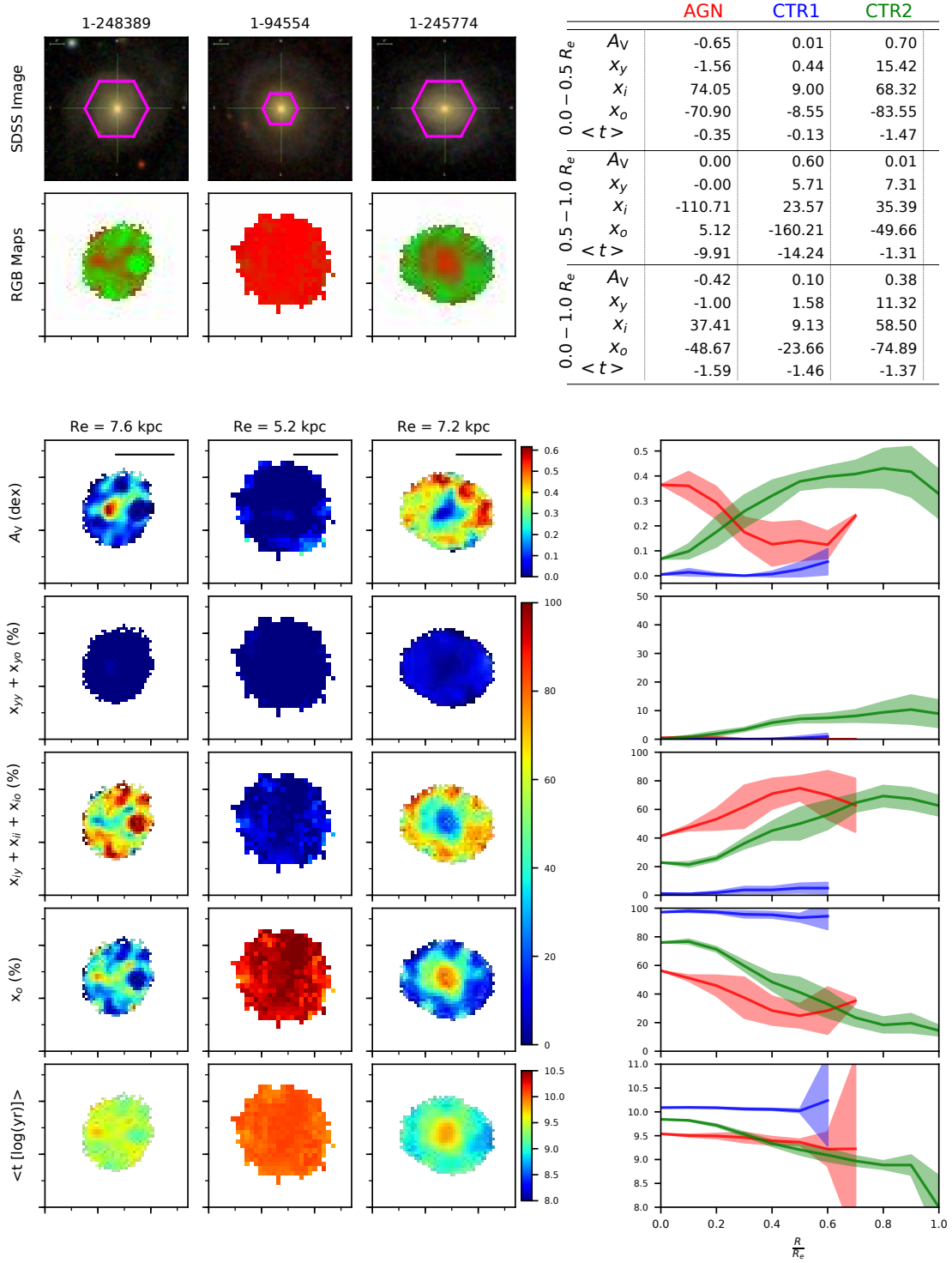


Figure A25. Comparison of the AGN with MaNGA ID 1-248389 and its control galaxies.

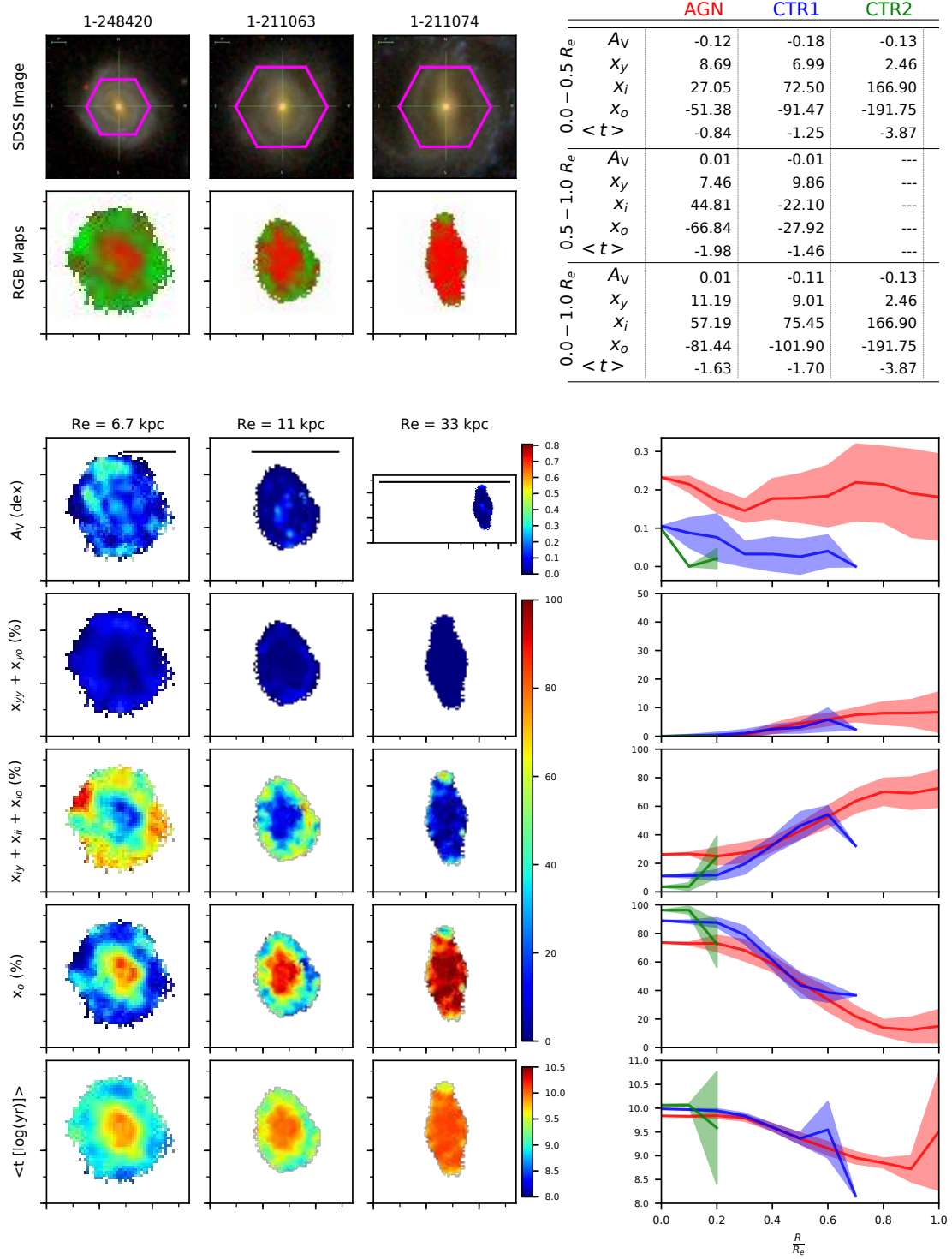


Figure A26. Comparison of the AGN with MaNGA ID 1-248420 and its control galaxies.



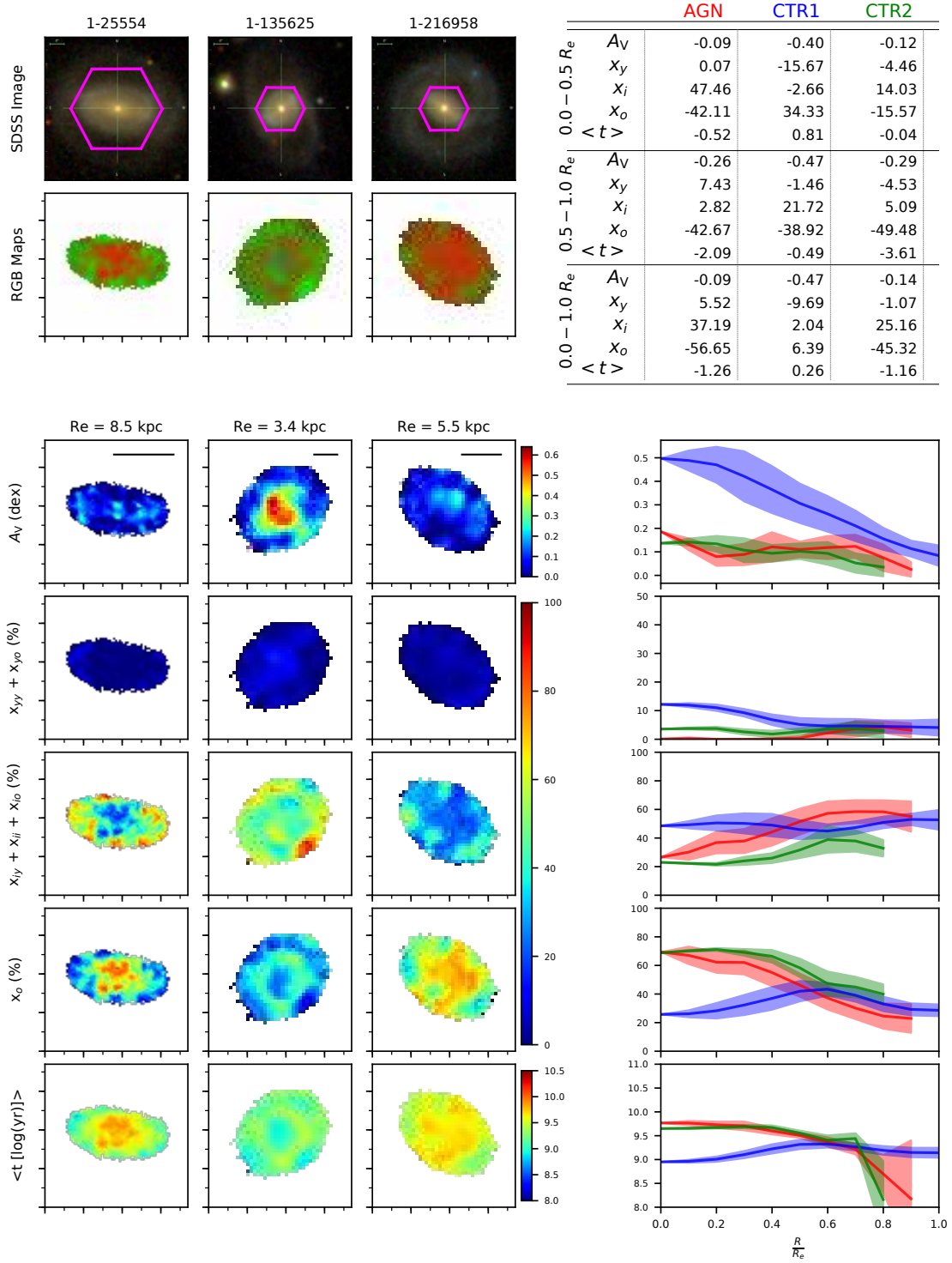


Figure A27. Comparison of the AGN with MaNGA ID 1-25554 and its control galaxies.

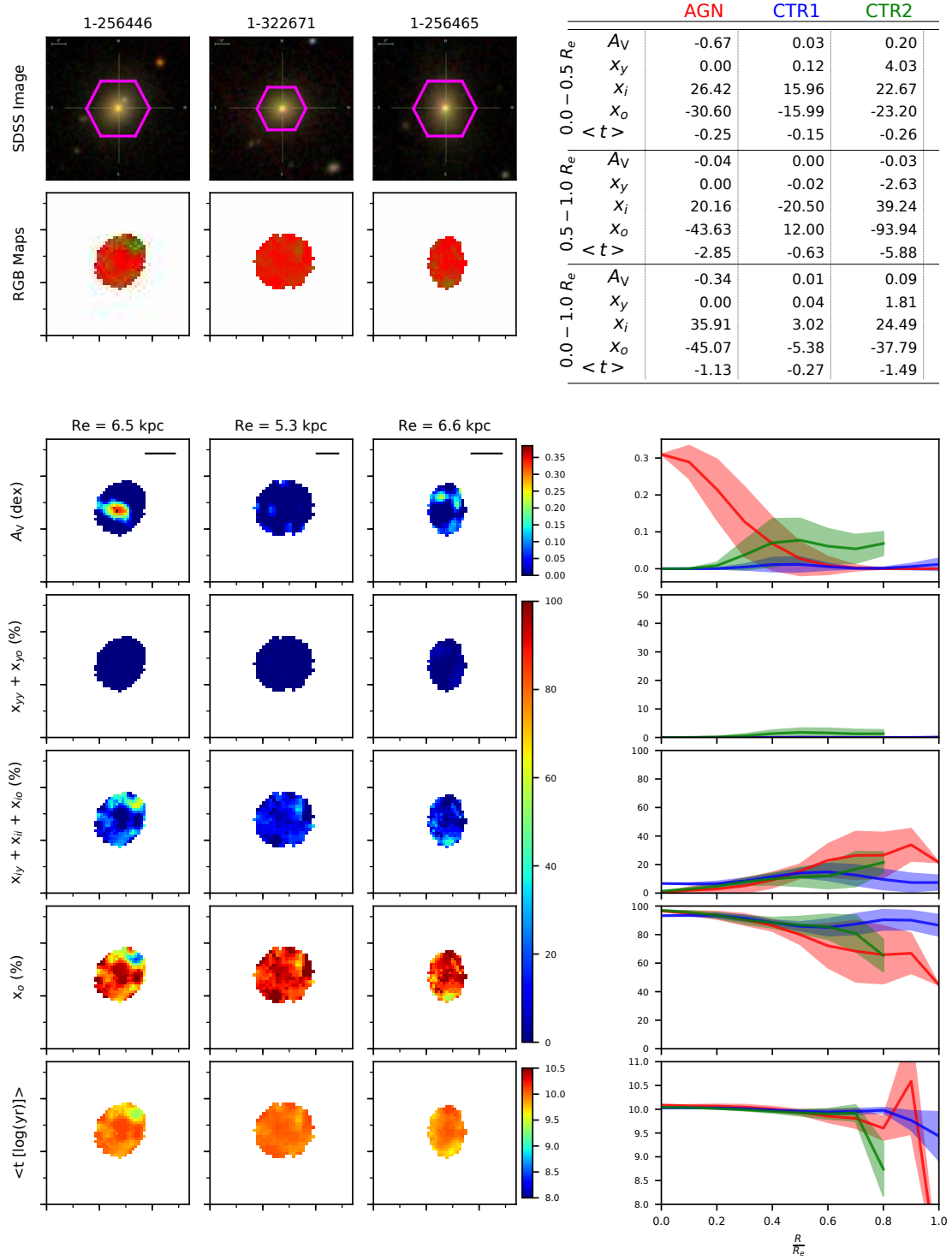


Figure A28. Comparison of the AGN with MaNGA ID 1-256446 and its control galaxies.

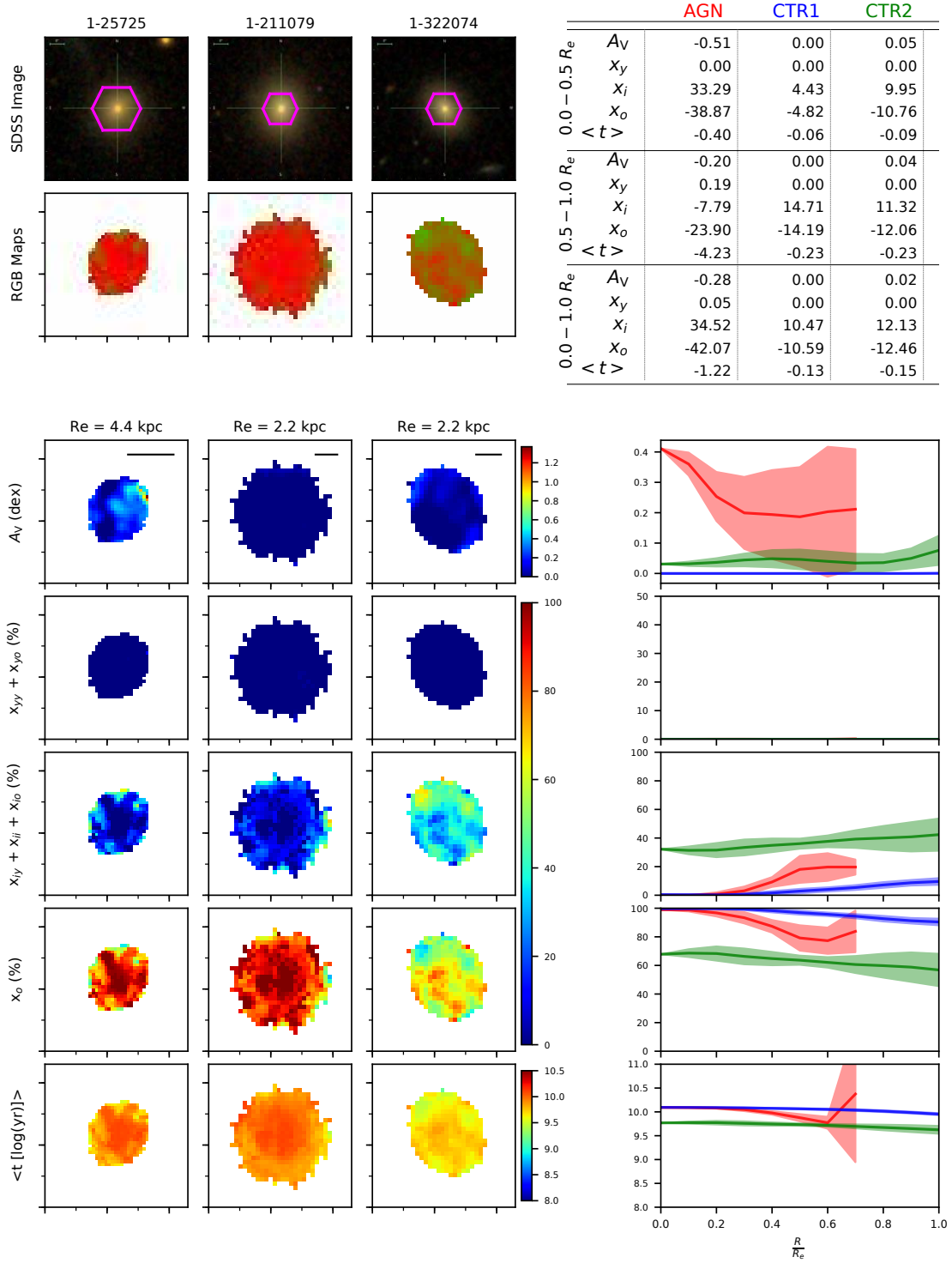


Figure A29. Comparison of the AGN with MaNGA ID 1-25725 and its control galaxies.

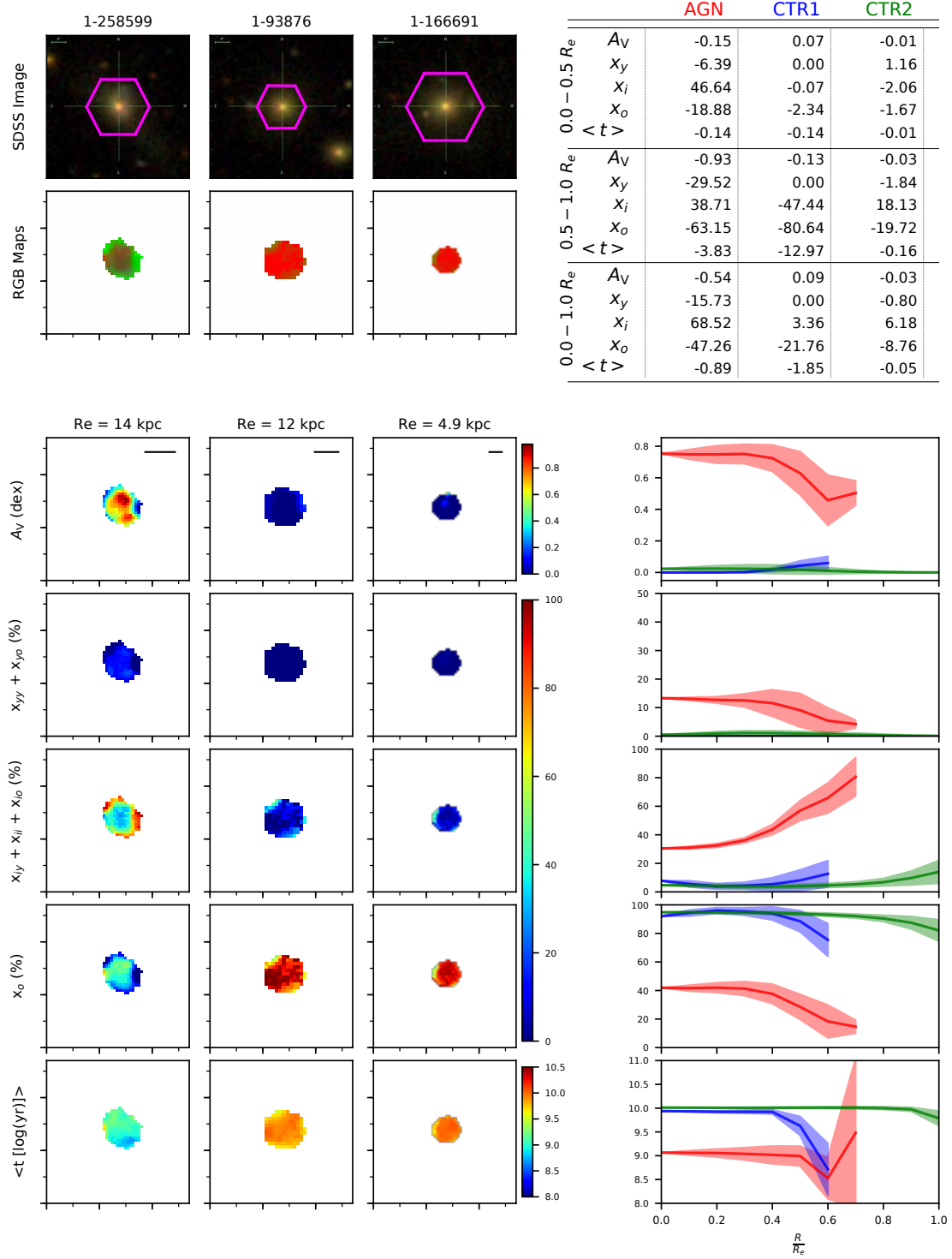


Figure A30. Comparison of the AGN with MaNGA ID 1-258599 and its control galaxies.

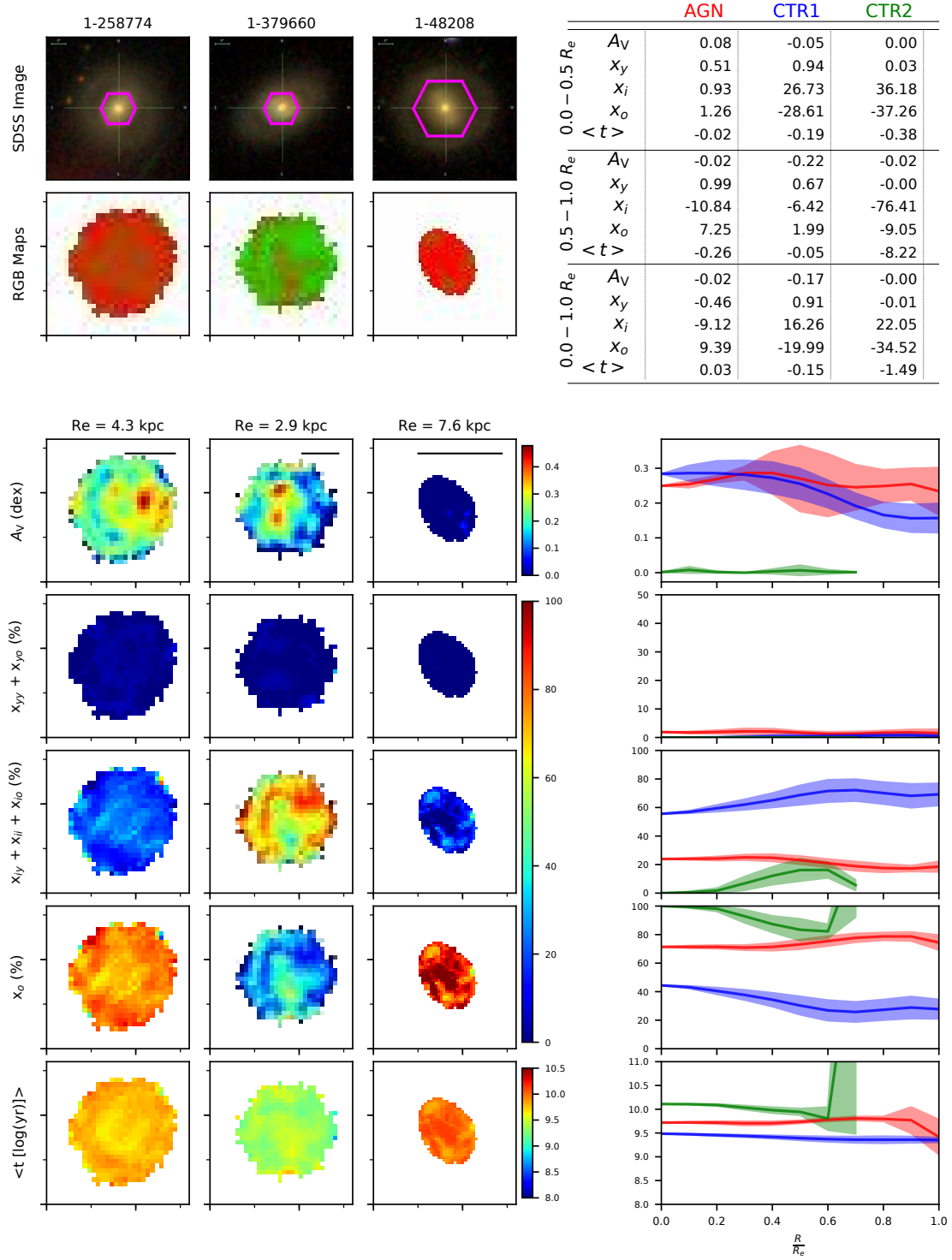


Figure A31. Comparison of the AGN with MaNGA ID 1-258774 and its control galaxies.

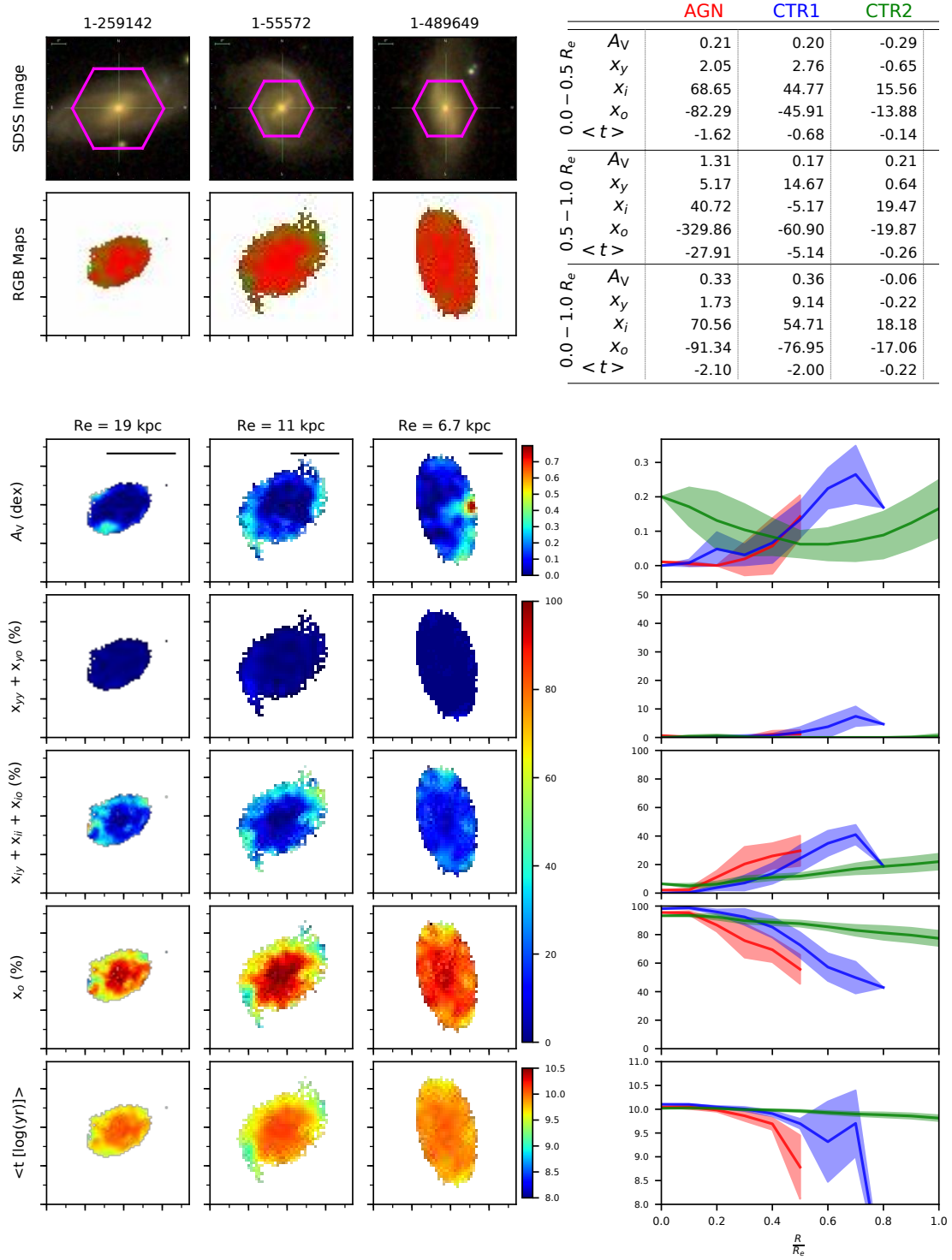
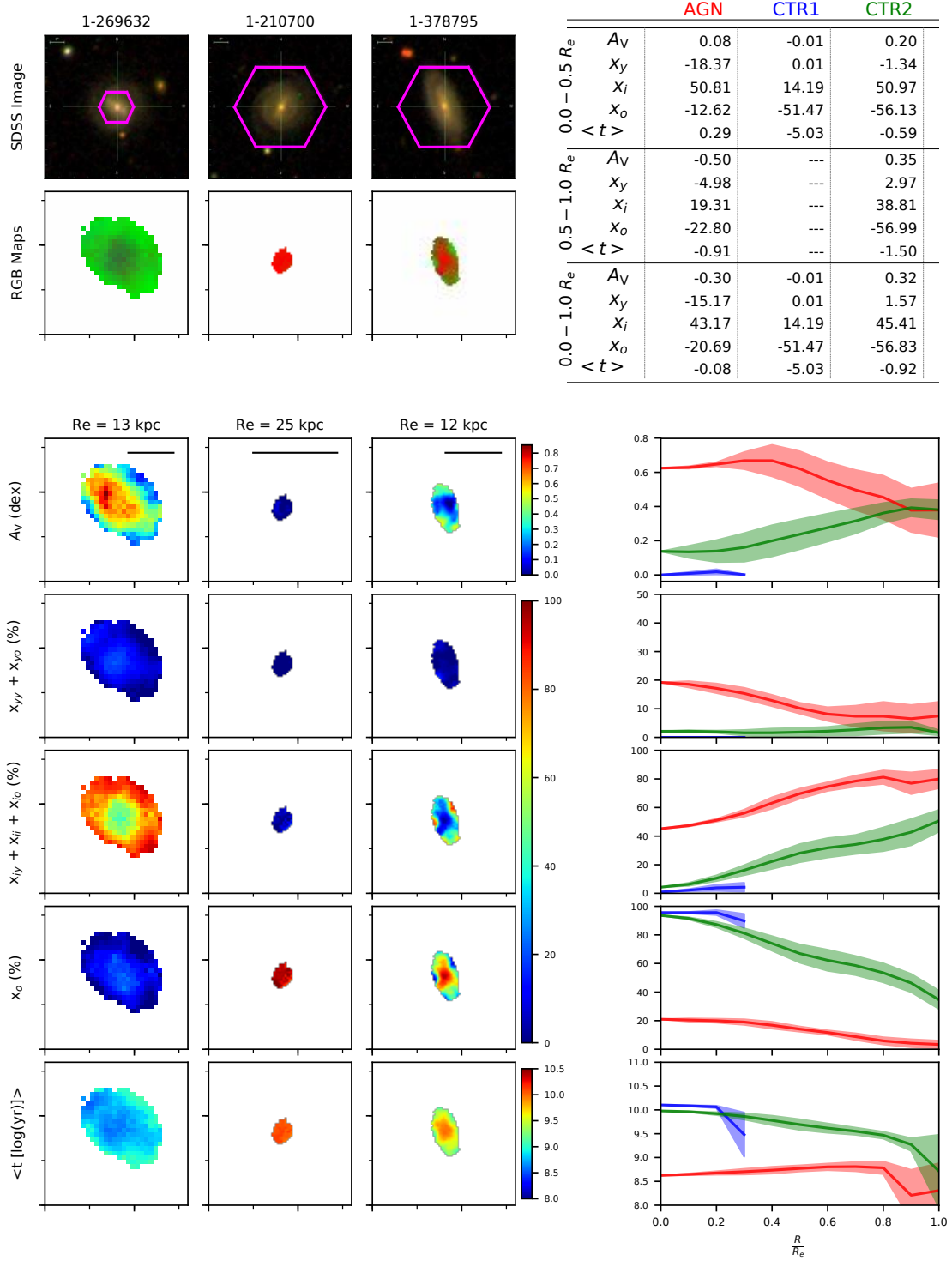


Figure A32. Comparison of the AGN with MaNGA ID 1-259142 and its control galaxies.



**Figure A33.** Comparison of the AGN with MaNGA ID 1-269632 and its control galaxies.

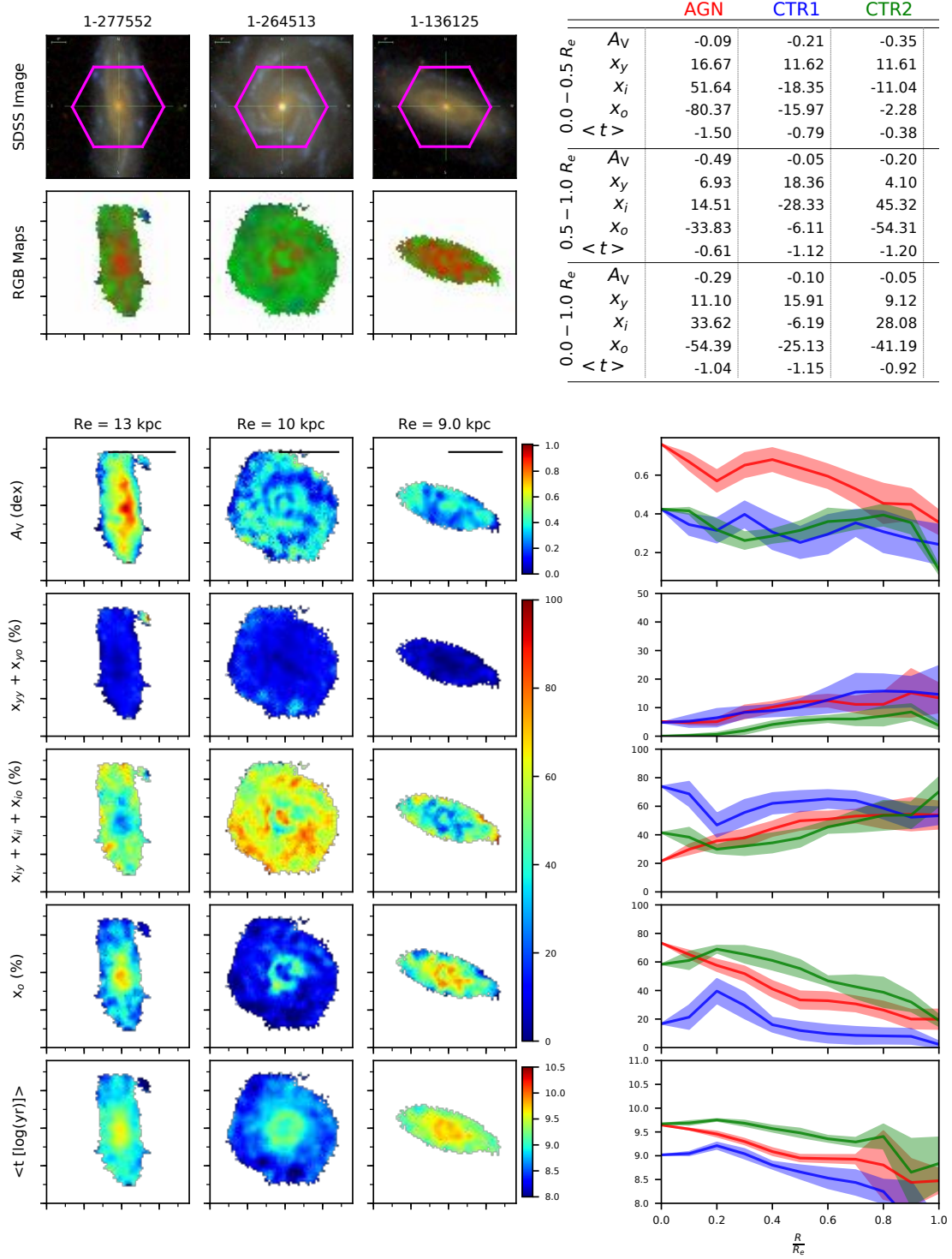


Figure A34. Comparison of the AGN with MaNGA ID 1-277552 and its control galaxies.



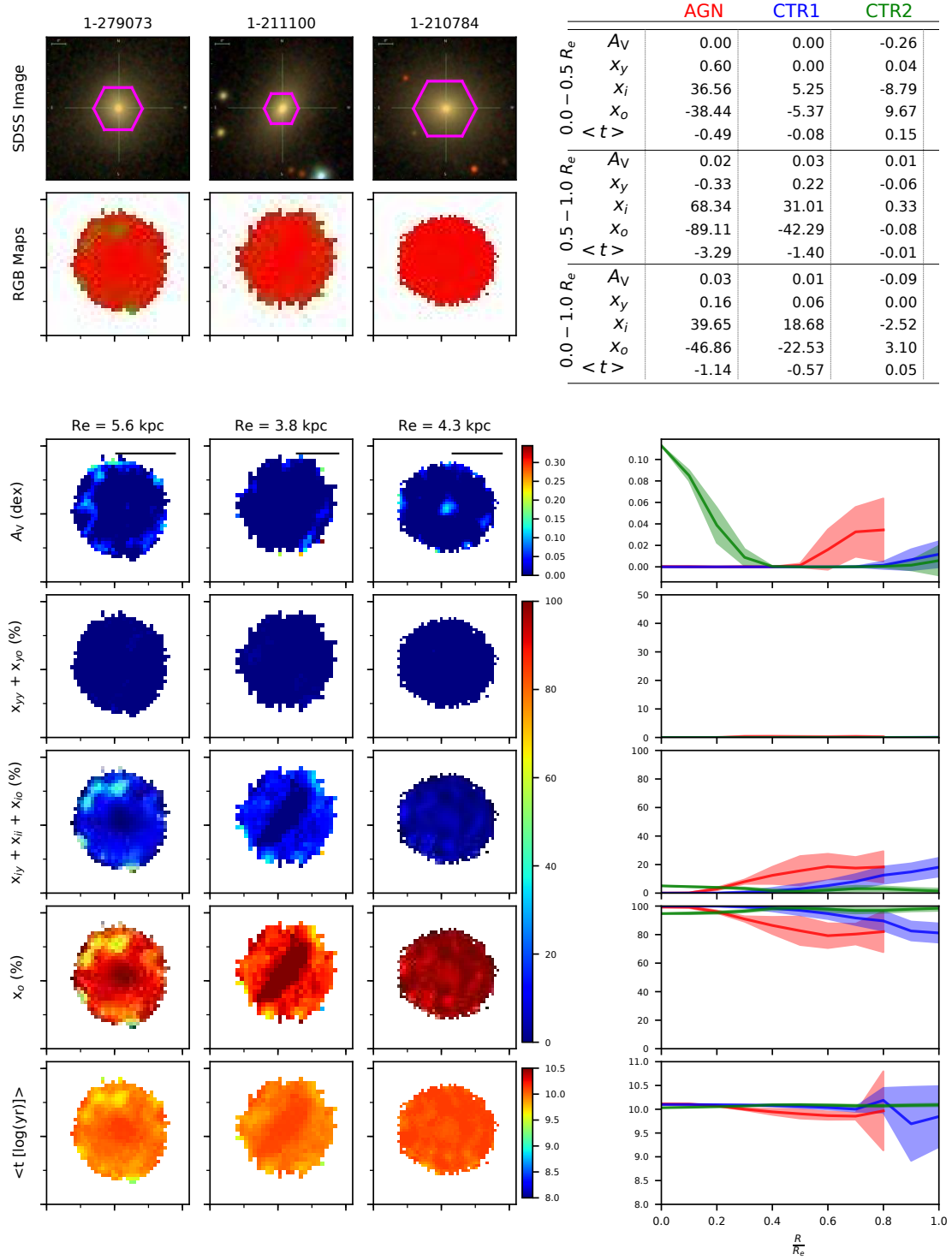
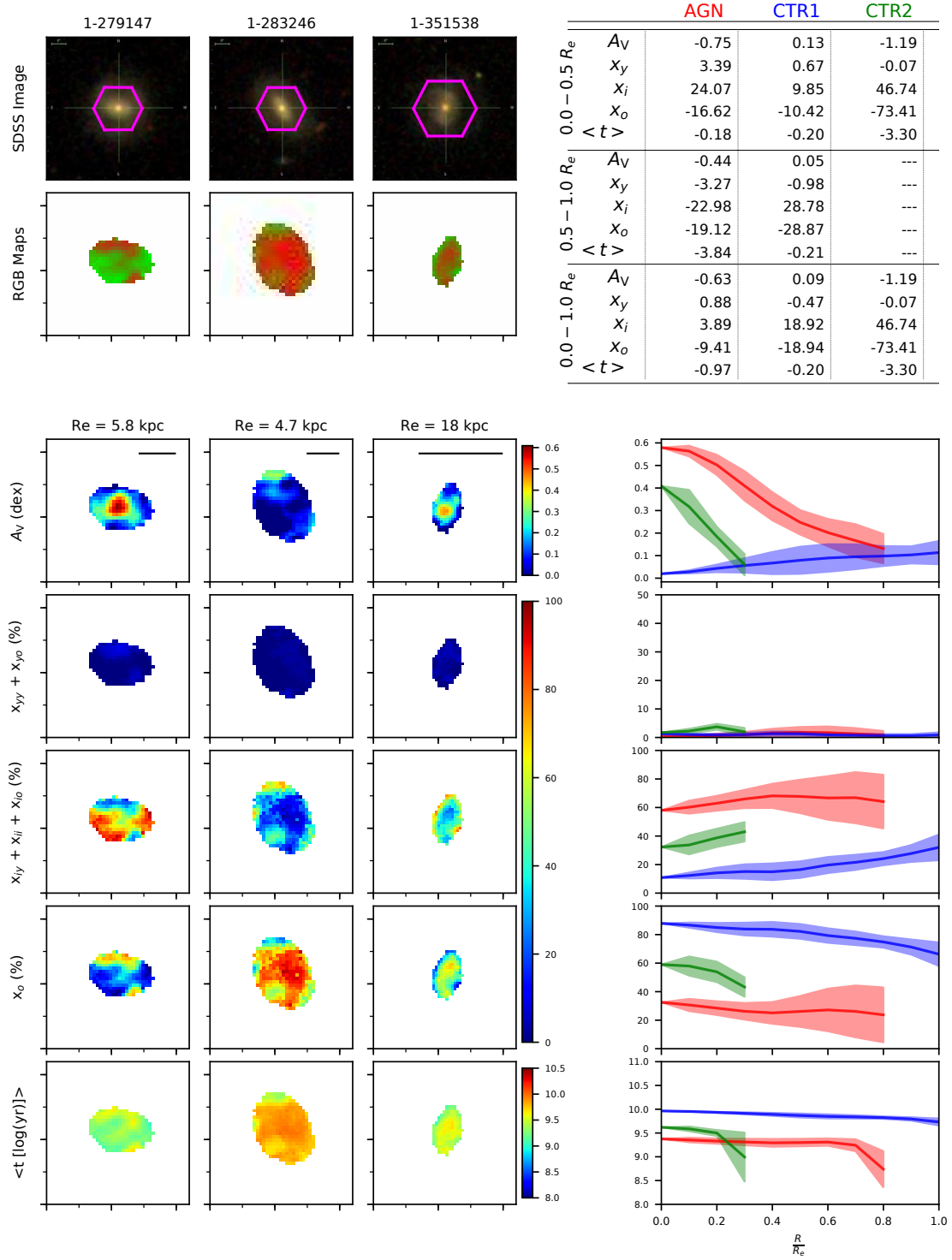
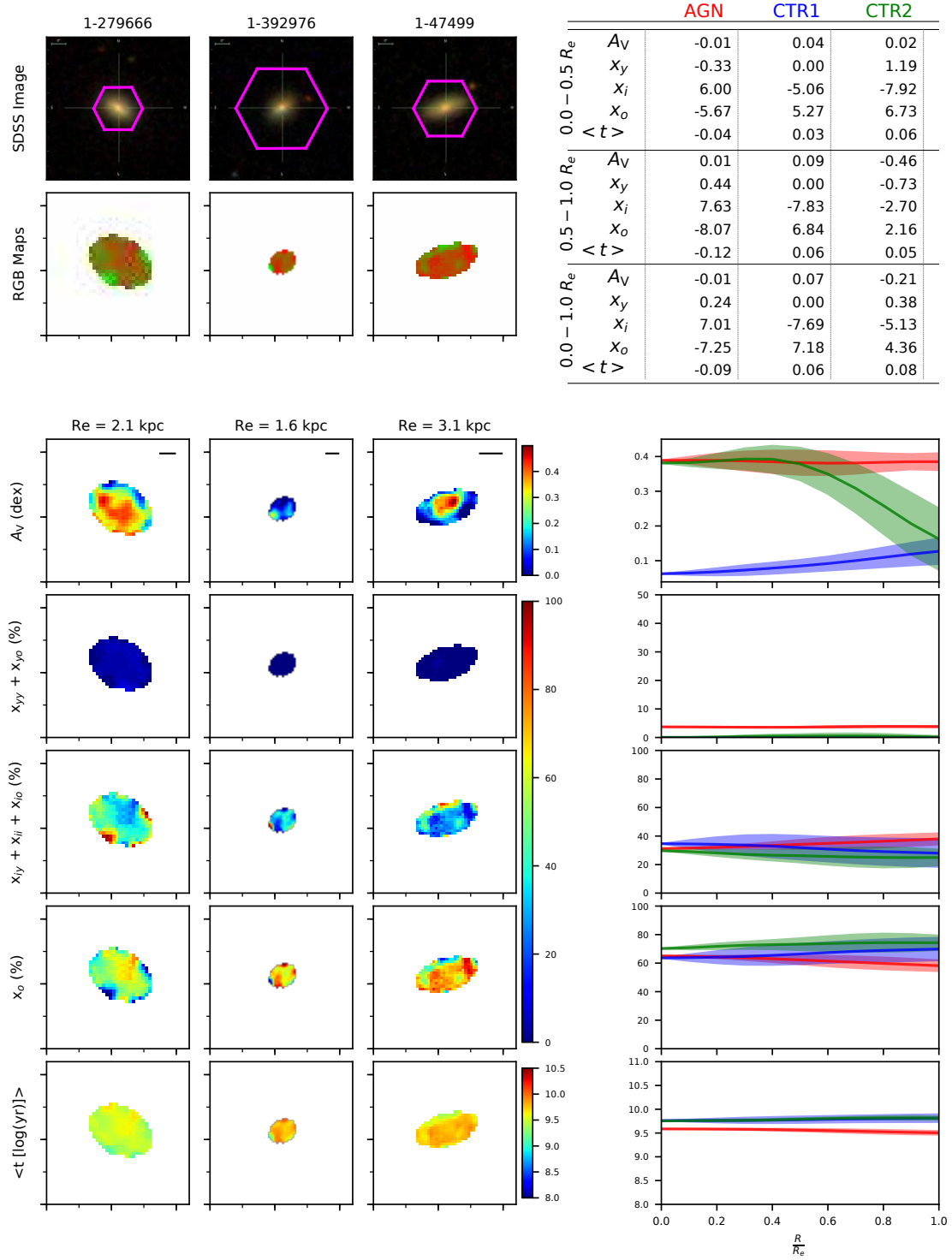


Figure A35. Comparison of the AGN with MaNGA ID 1-279073 and its control galaxies.



**Figure A36.** Comparison of the AGN with MaNGA ID 1-279147 and its control galaxies.



**Figure A37.** Comparison of the AGN with MaNGA ID 1-279666 and its control galaxies.

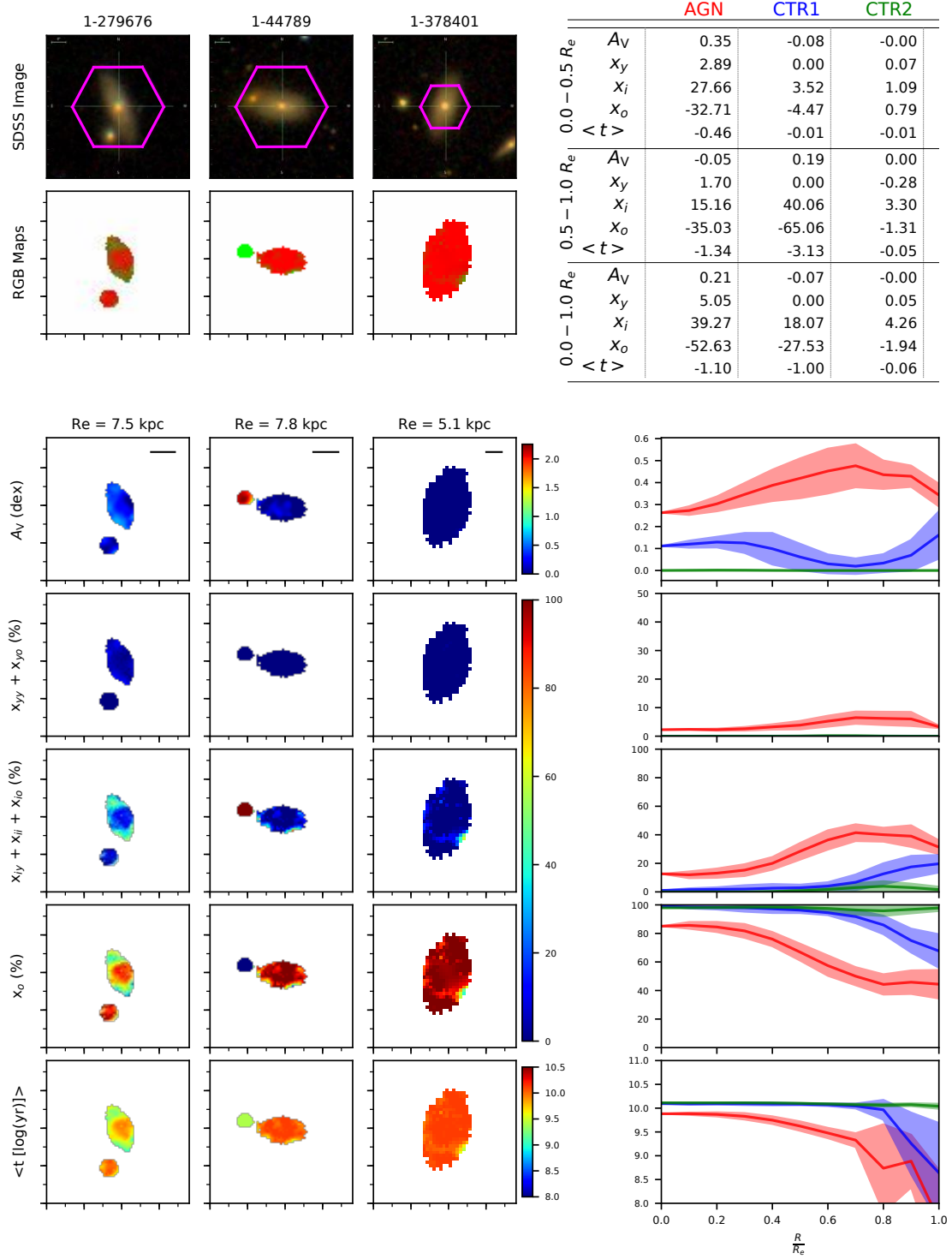
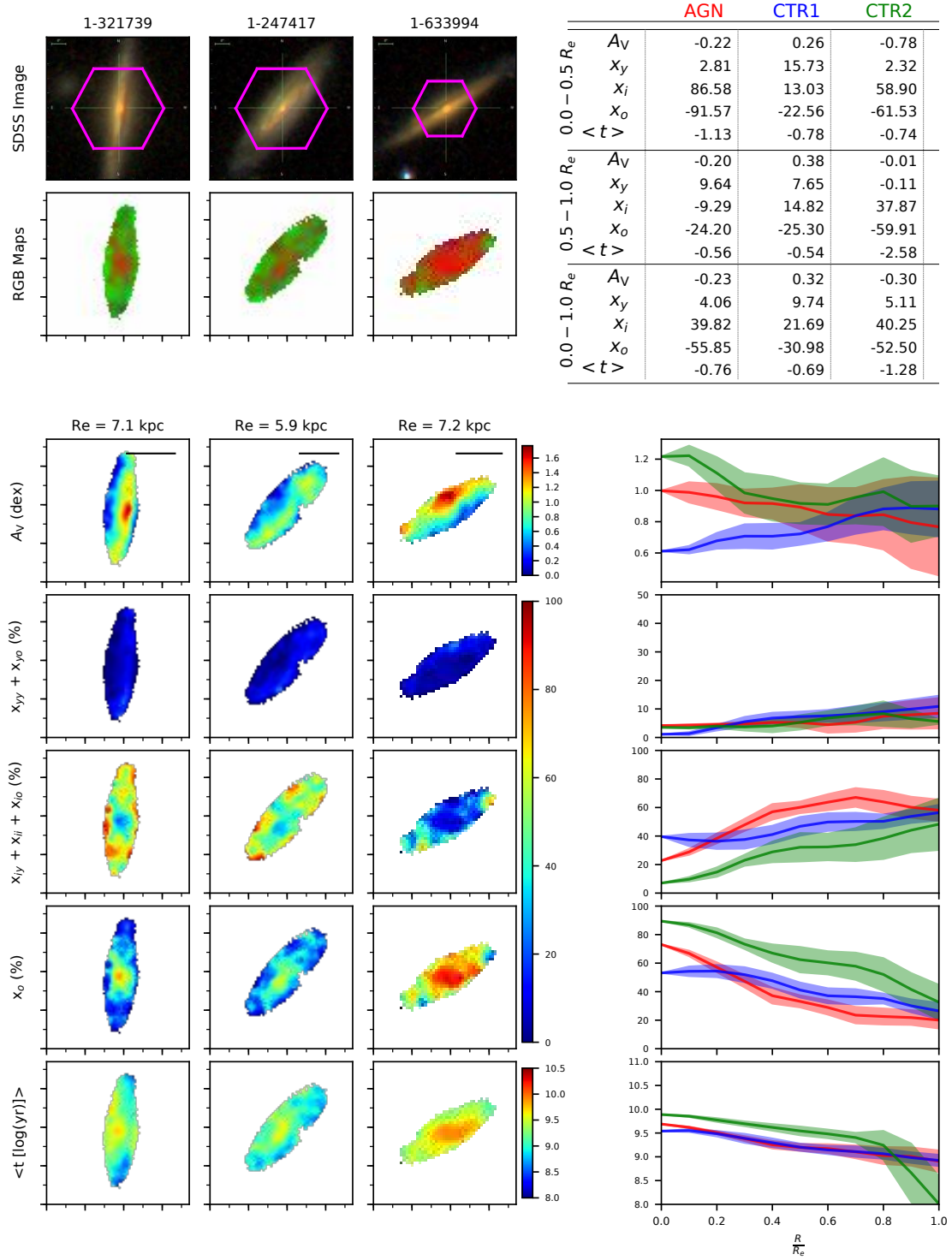


Figure A38. Comparison of the AGN with MaNGA ID 1-279676 and its control galaxies.



**Figure A39.** Comparison of the AGN with MaNGA ID 1-321739 and its control galaxies.

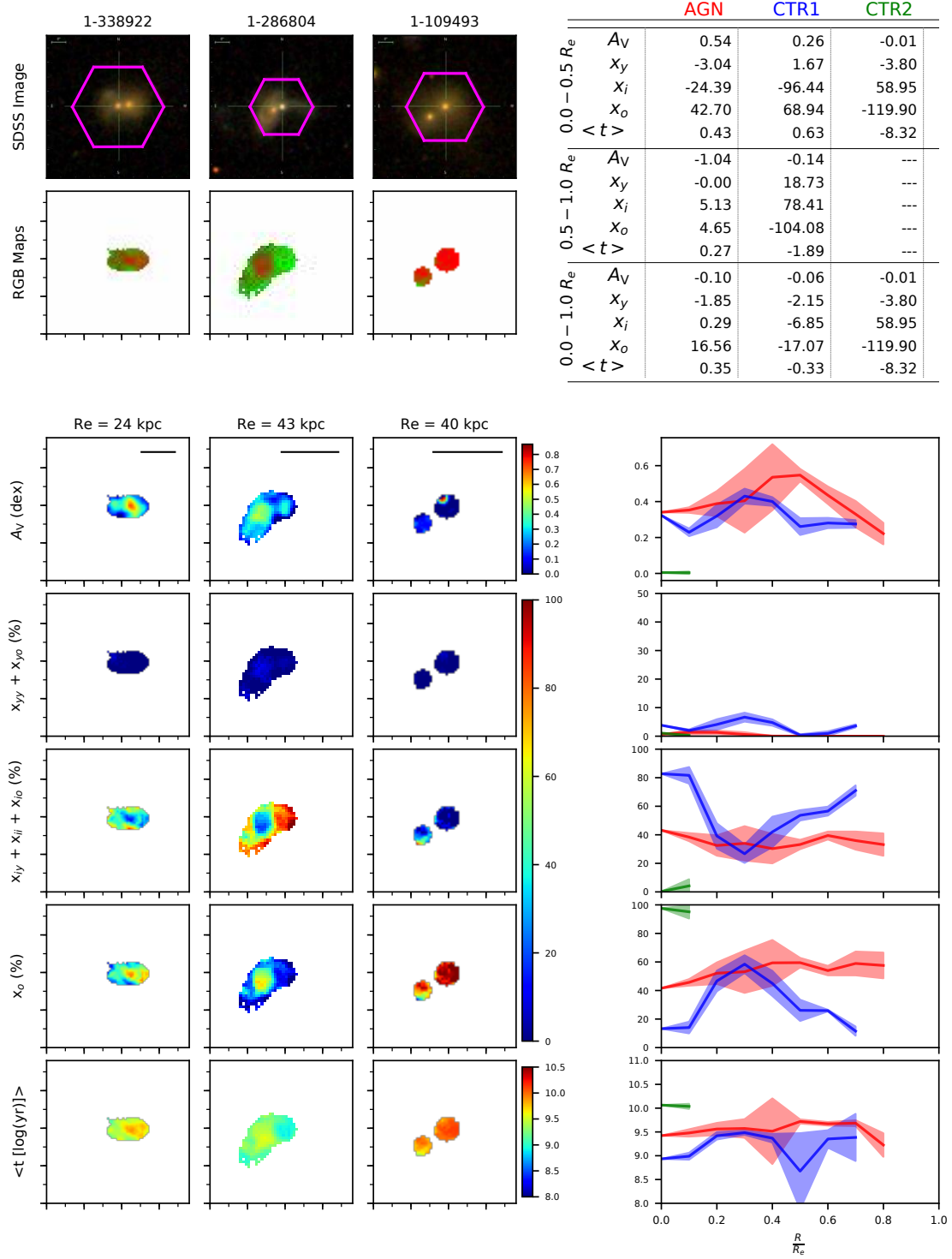


Figure A40. Comparison of the AGN with MaNGA ID 1-338922 and its control galaxies.

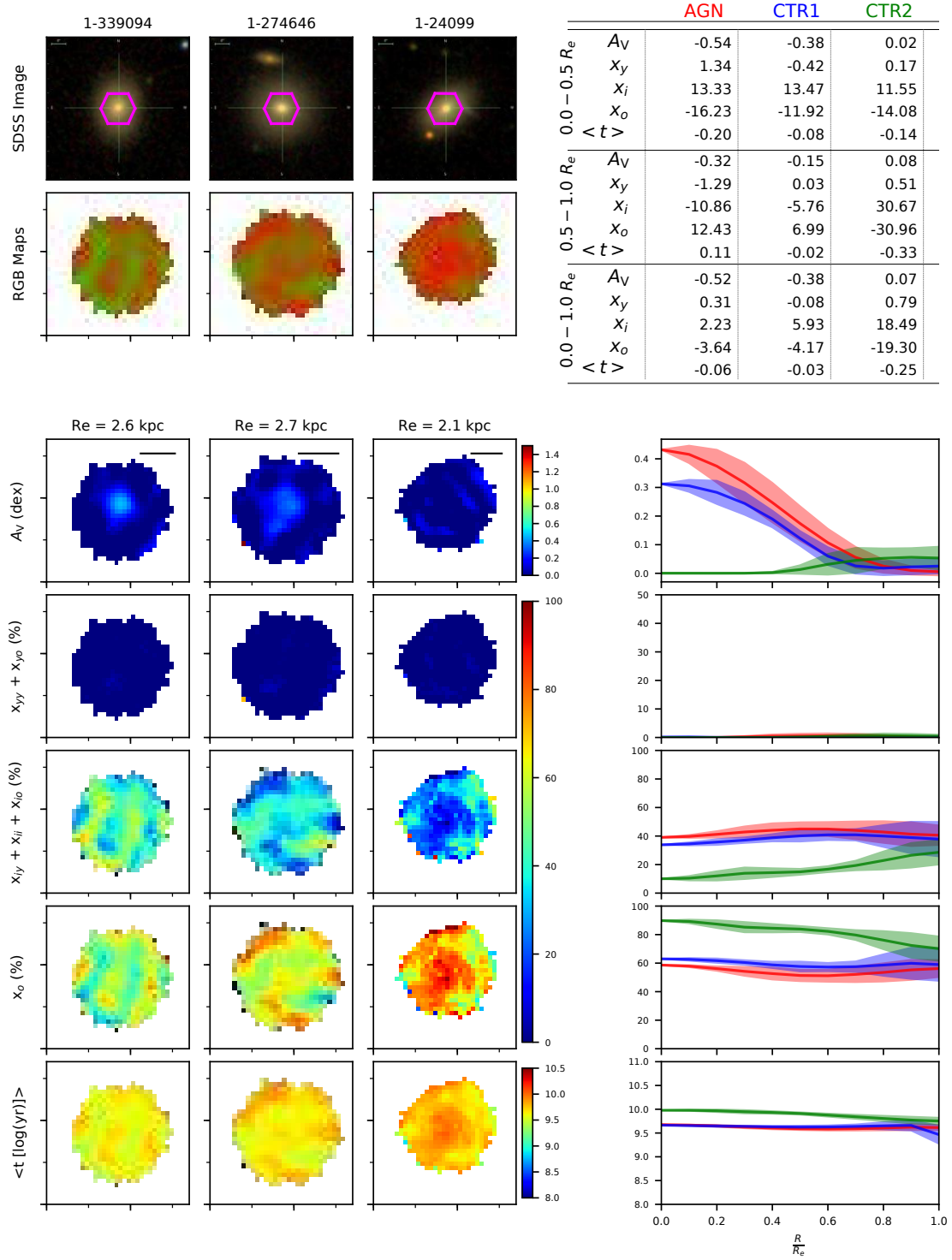


Figure A41. Comparison of the AGN with MaNGA ID 1-339094 and its control galaxies.

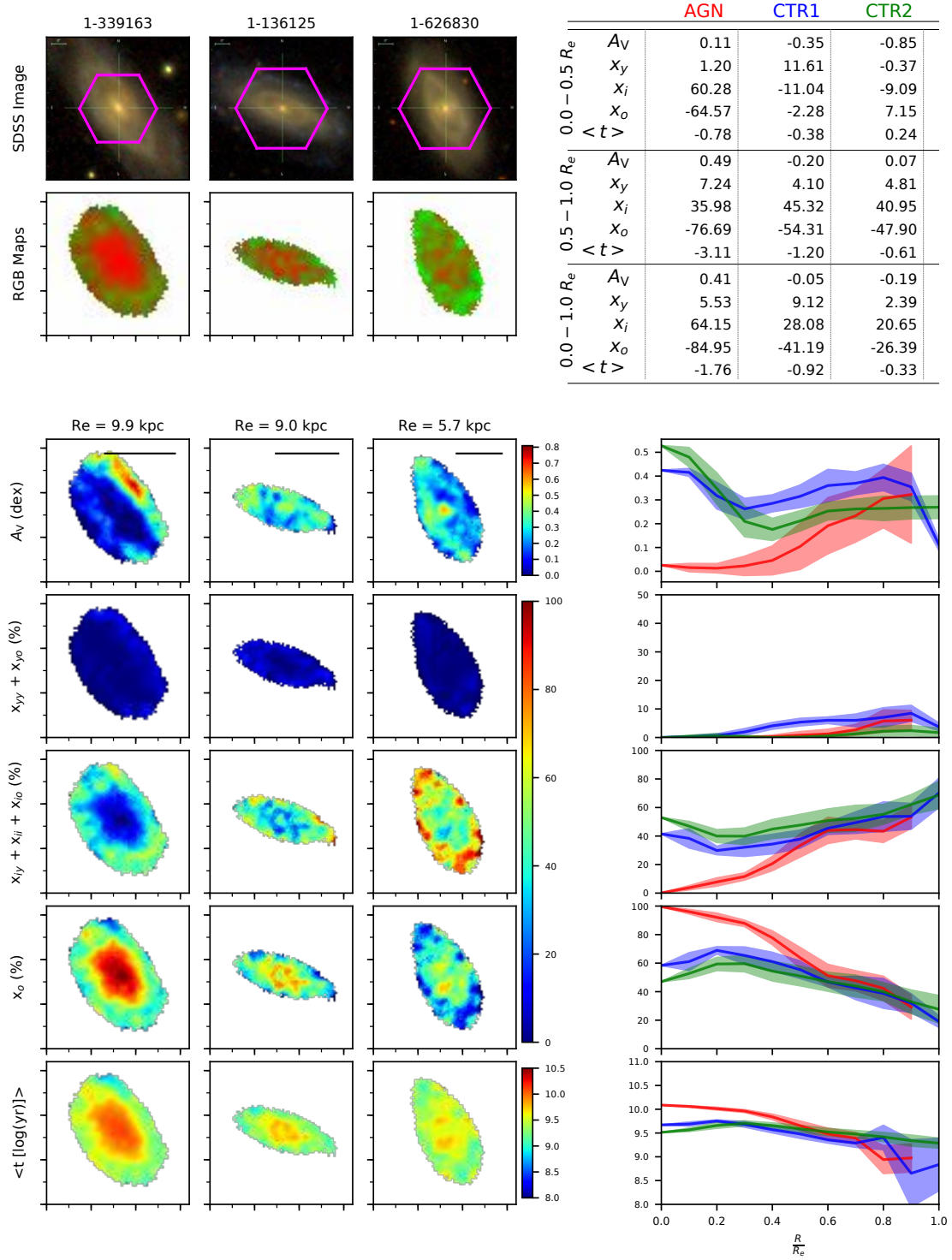


Figure A42. Comparison of the AGN with MaNGA ID 1-339163 and its control galaxies.



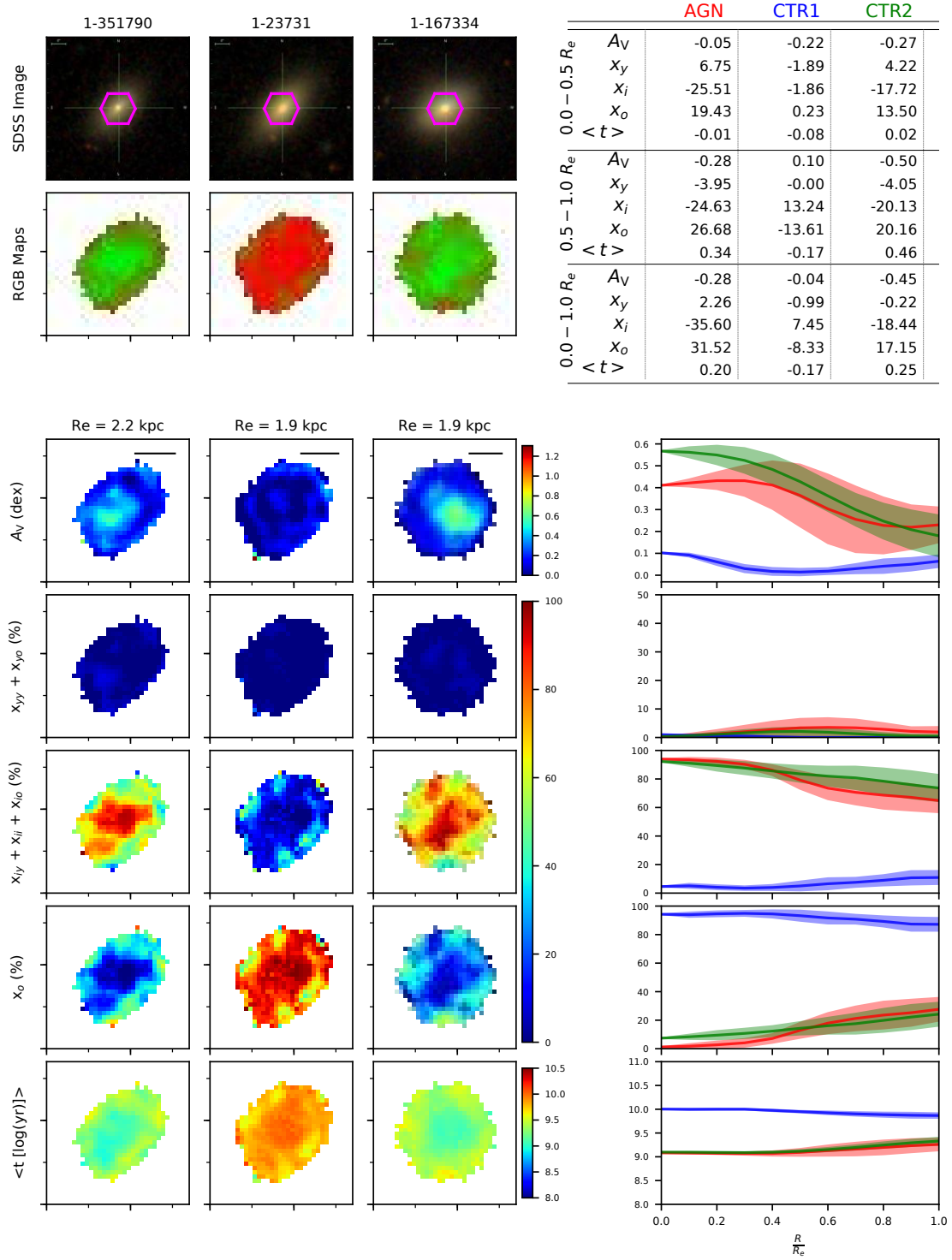


Figure A43. Comparison of the AGN with MaNGA ID 1-351790 and its control galaxies.

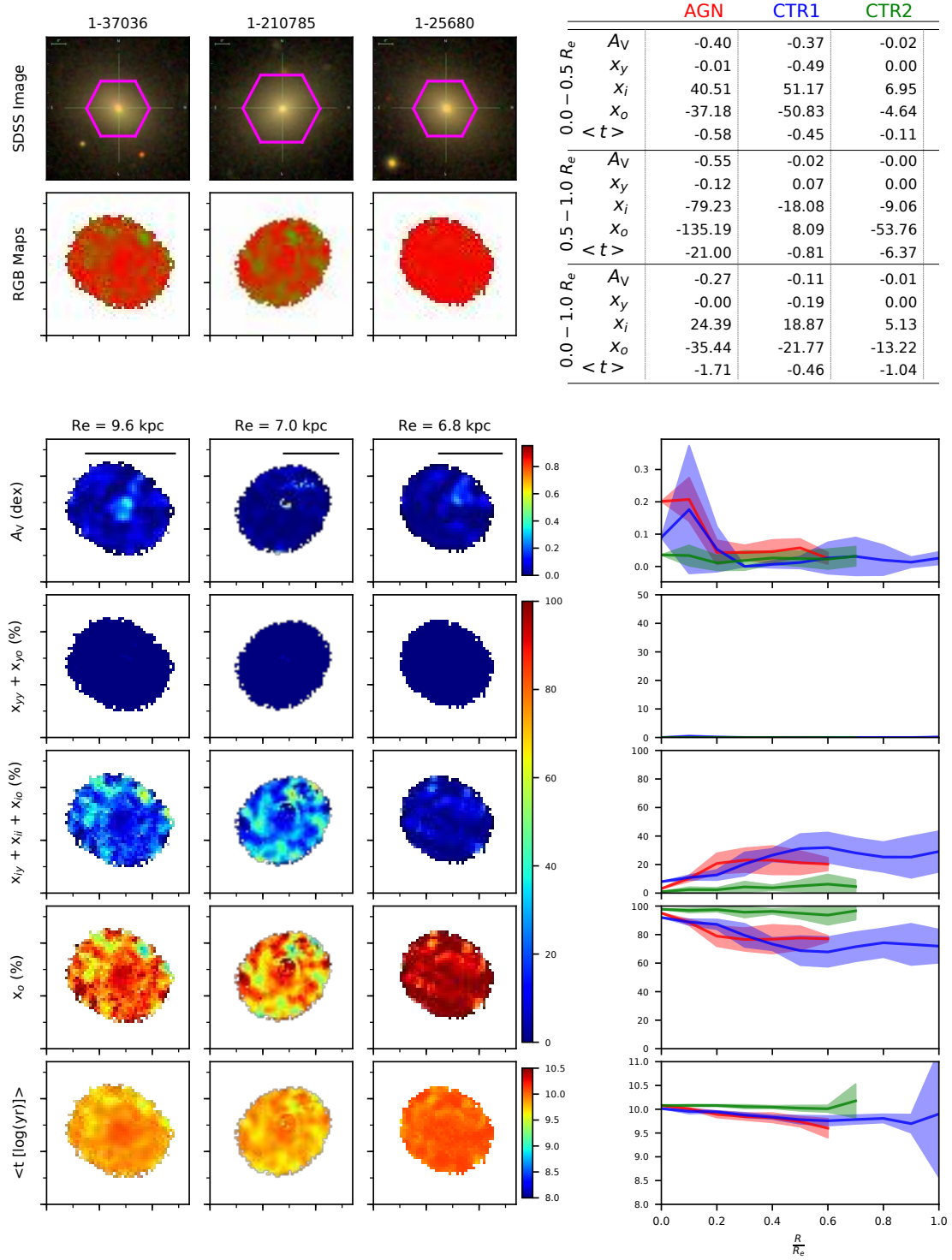


Figure A44. Comparison of the AGN with MaNGA ID 1-37036 and its control galaxies.

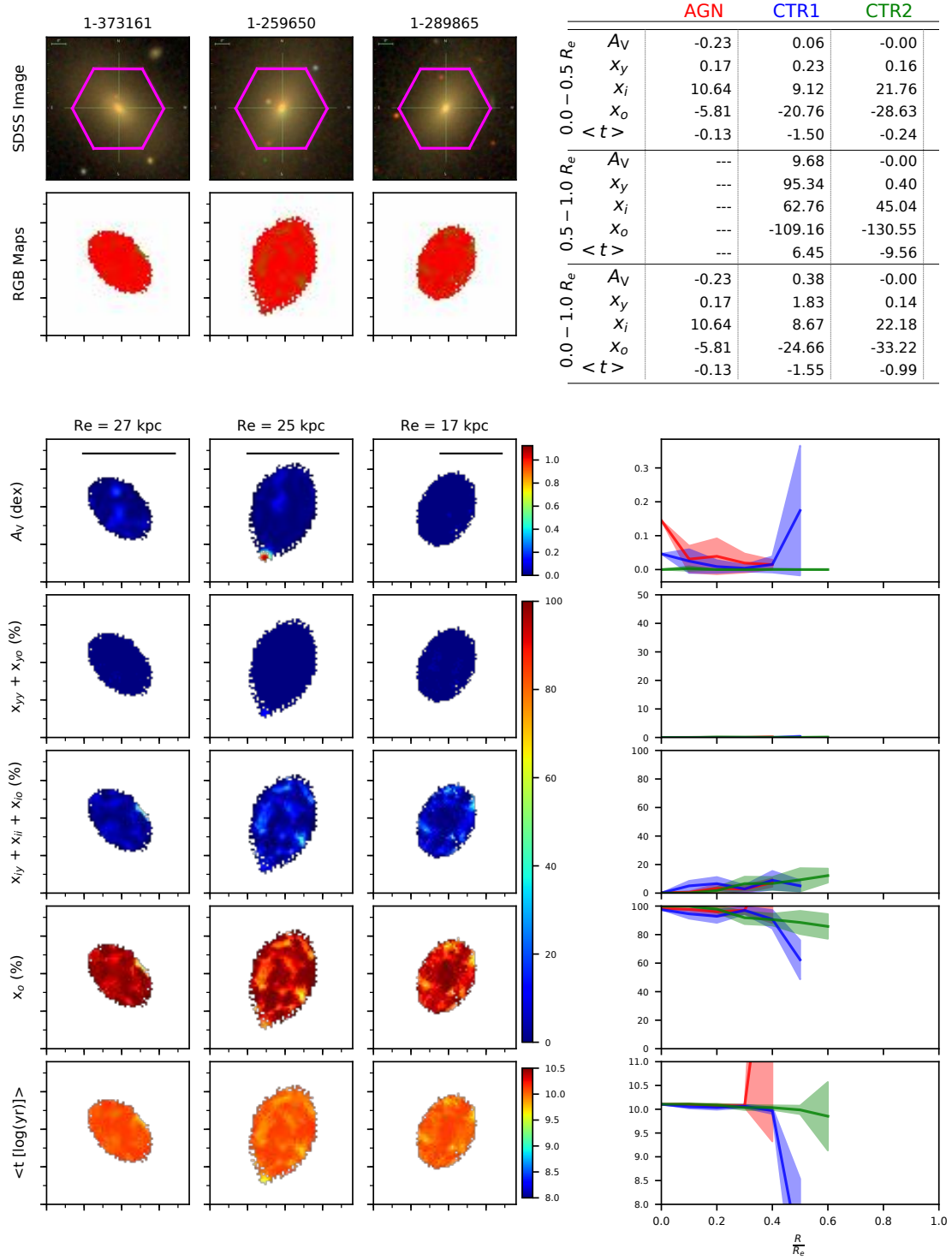


Figure A45. Comparison of the AGN with MaNGA ID 1-373161 and its control galaxies.

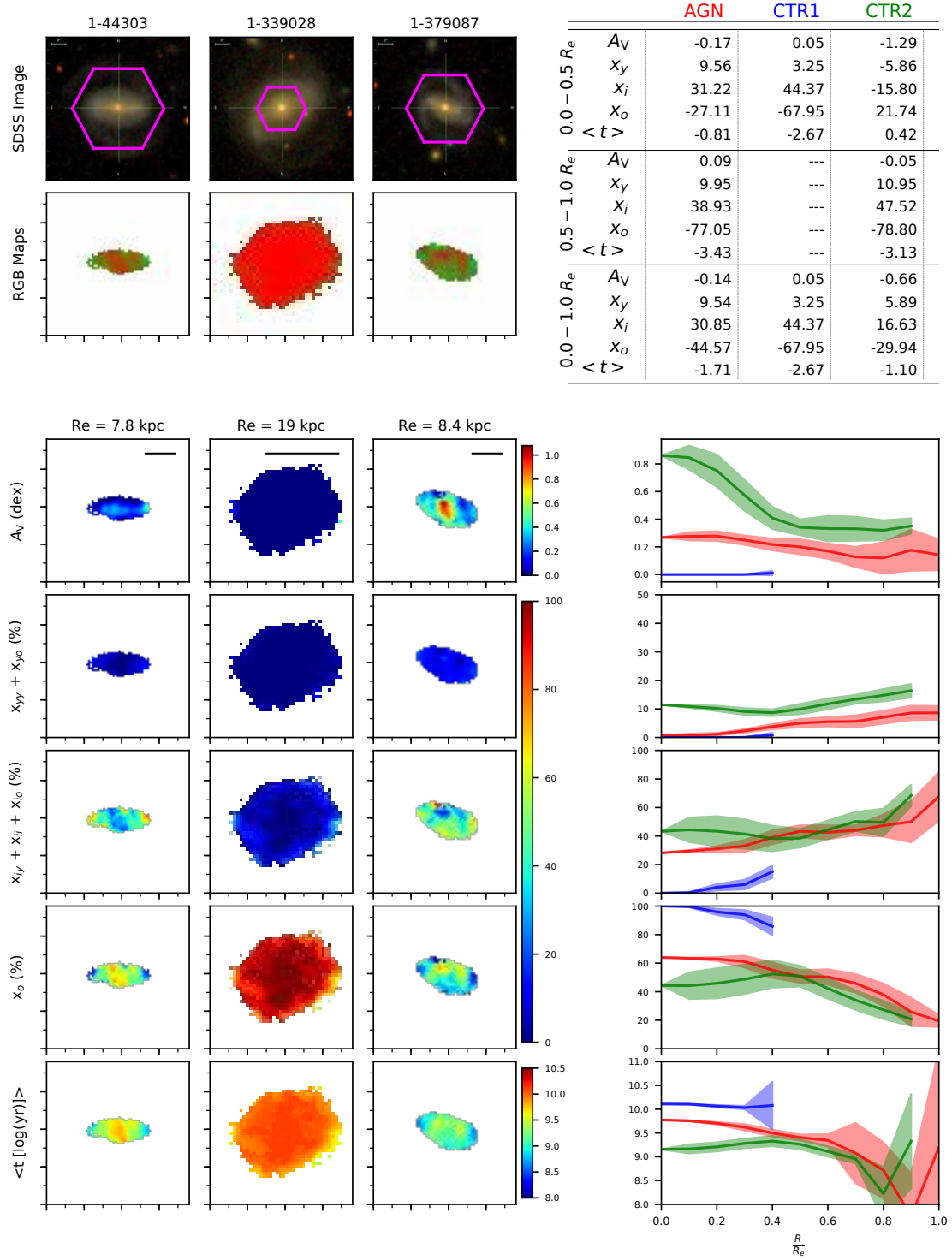


Figure A46. Comparison of the AGN with MaNGA ID 1-44303 and its control galaxies.

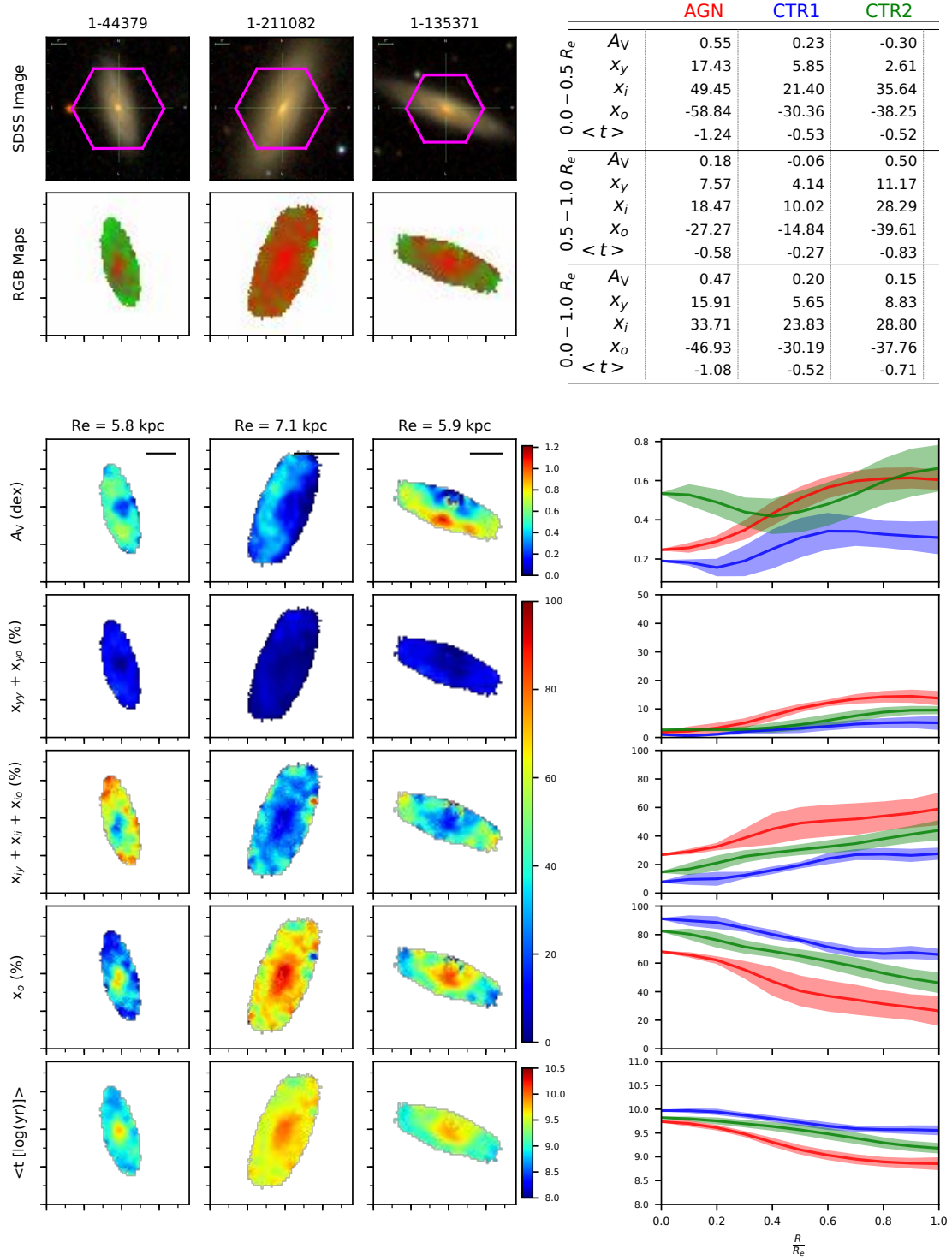


Figure A47. Comparison of the AGN with MaNGA ID 1-44379 and its control galaxies.

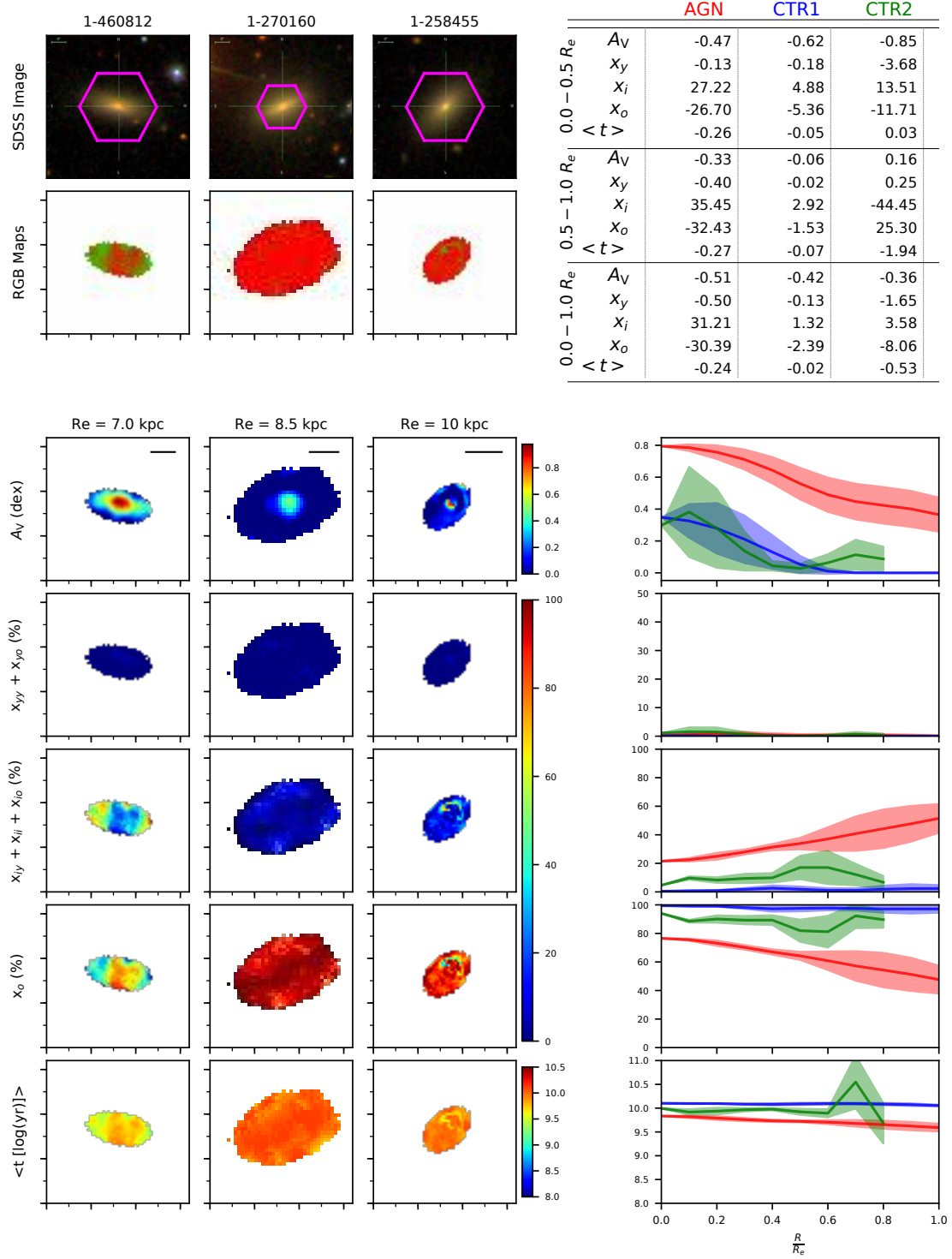


Figure A48. Comparison of the AGN with MaNGA ID 1-460812 and its control galaxies.

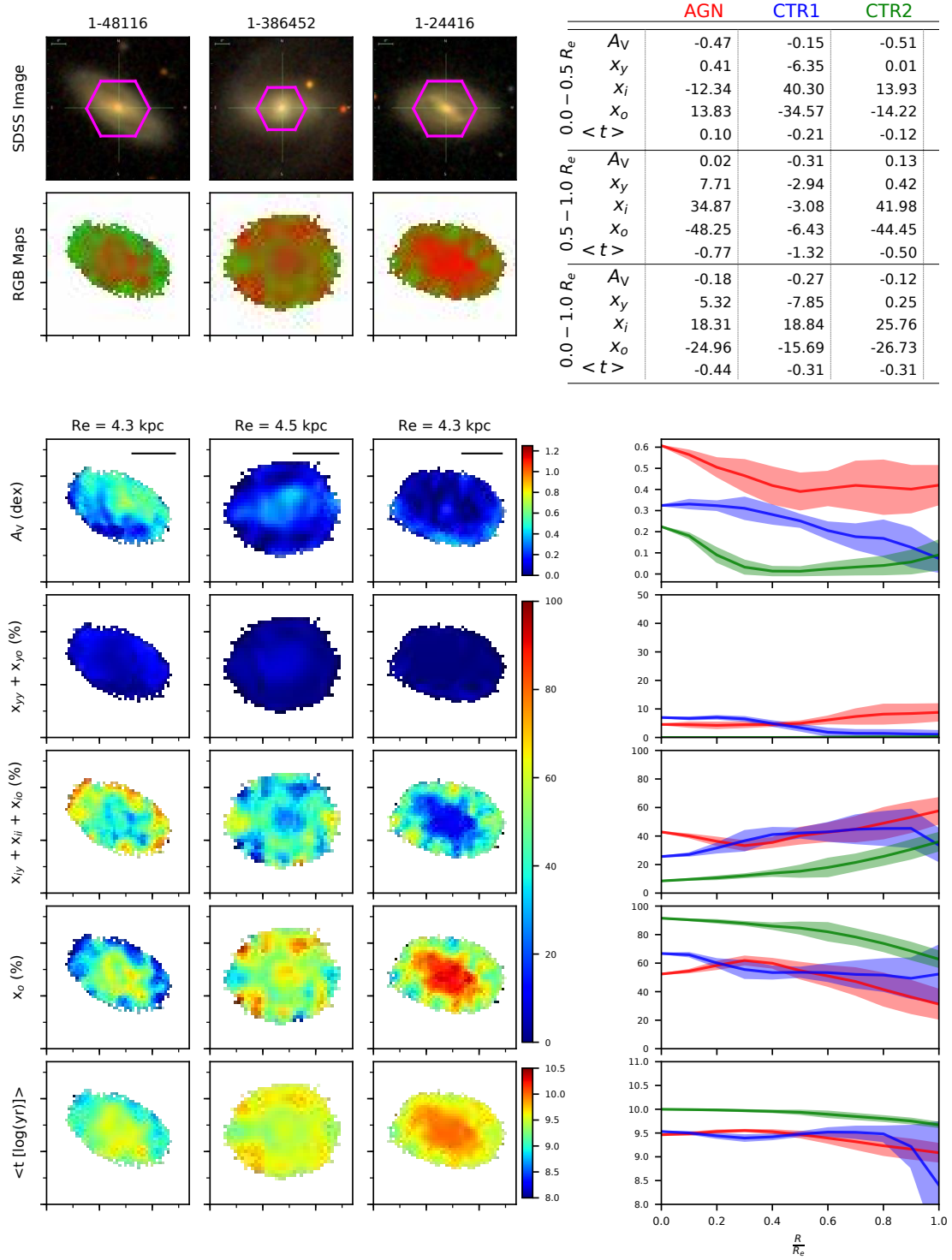


Figure A49. Comparison of the AGN with MaNGA ID 1-48116 and its control galaxies.

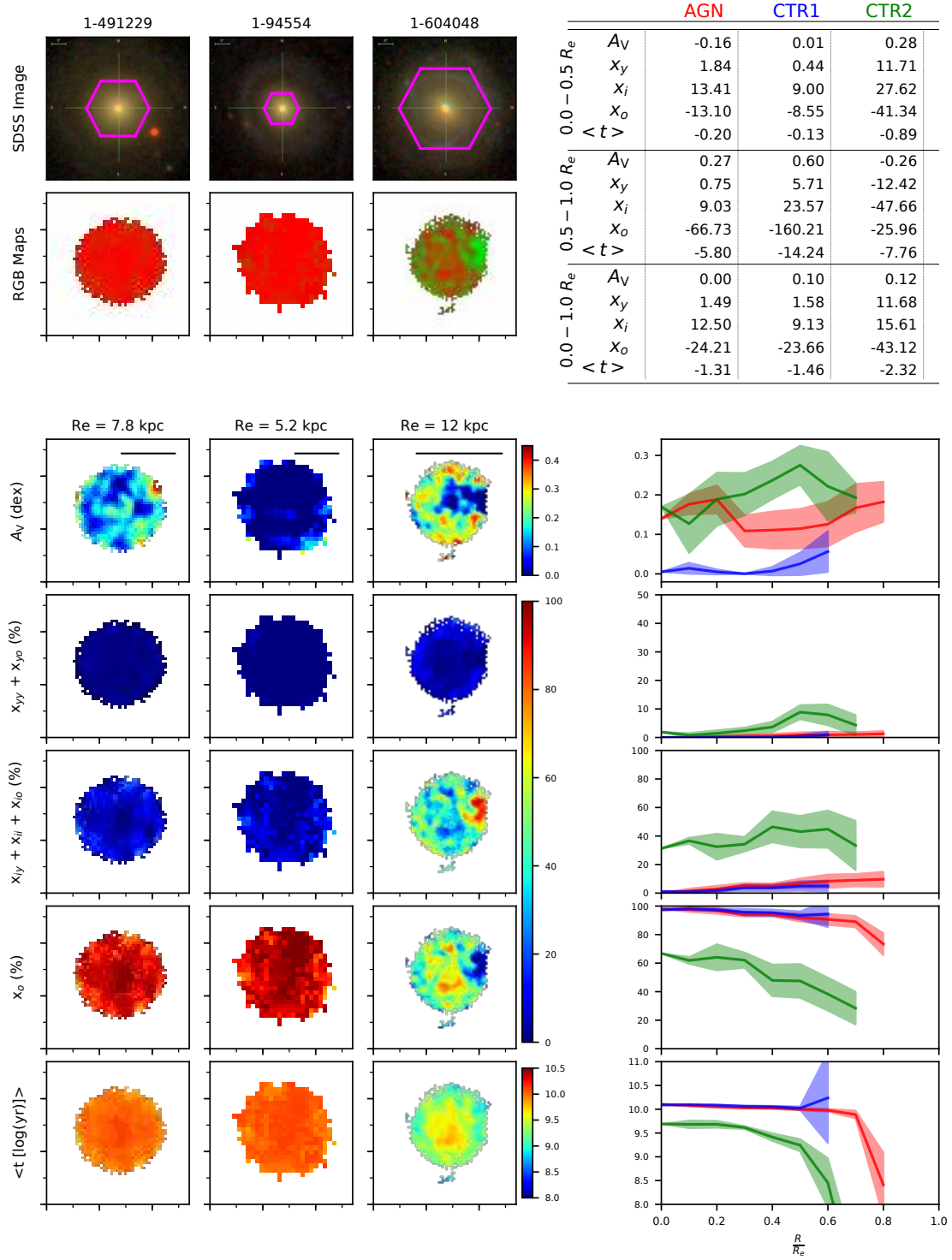


Figure A50. Comparison of the AGN with MaNGA ID 1-491229 and its control galaxies.



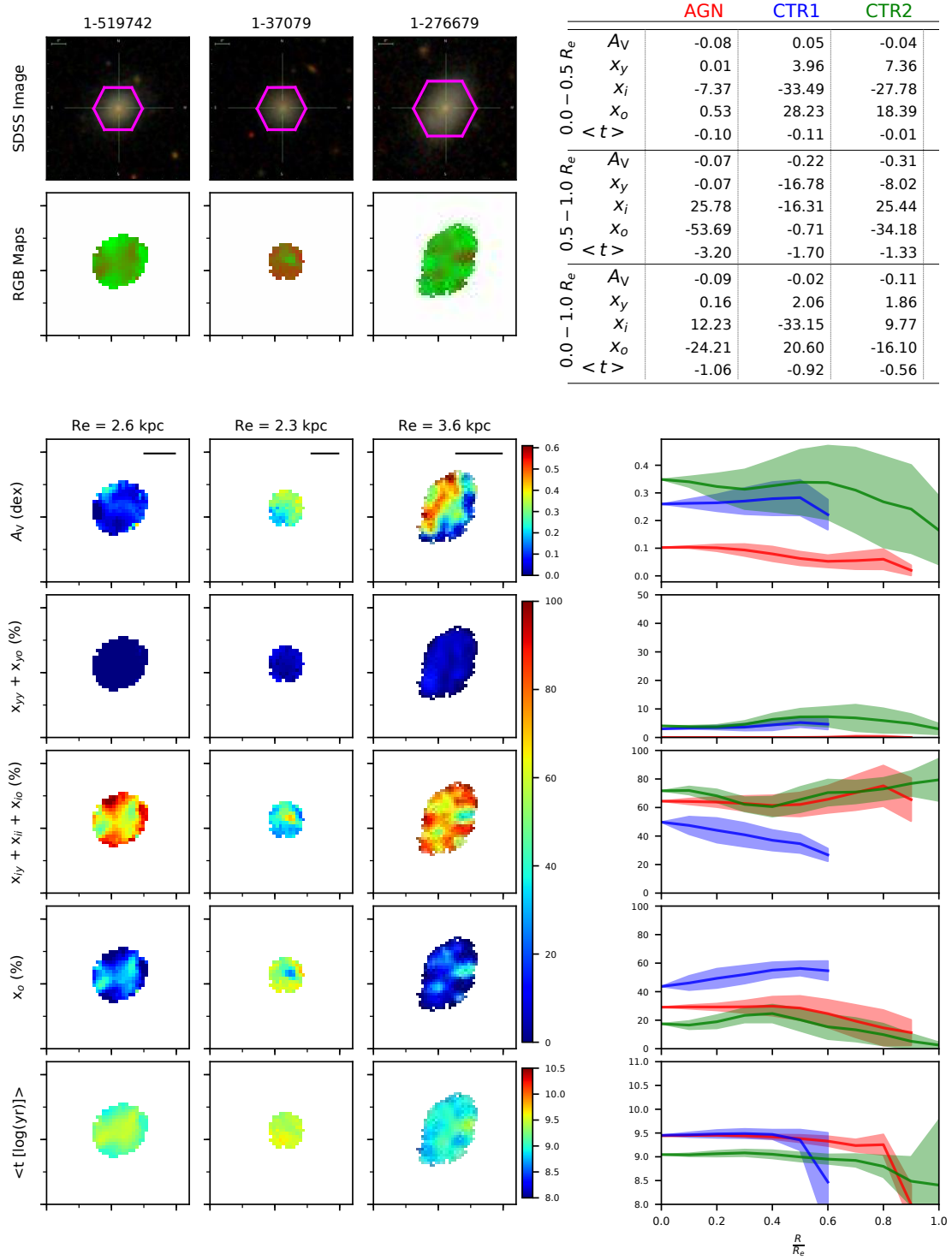
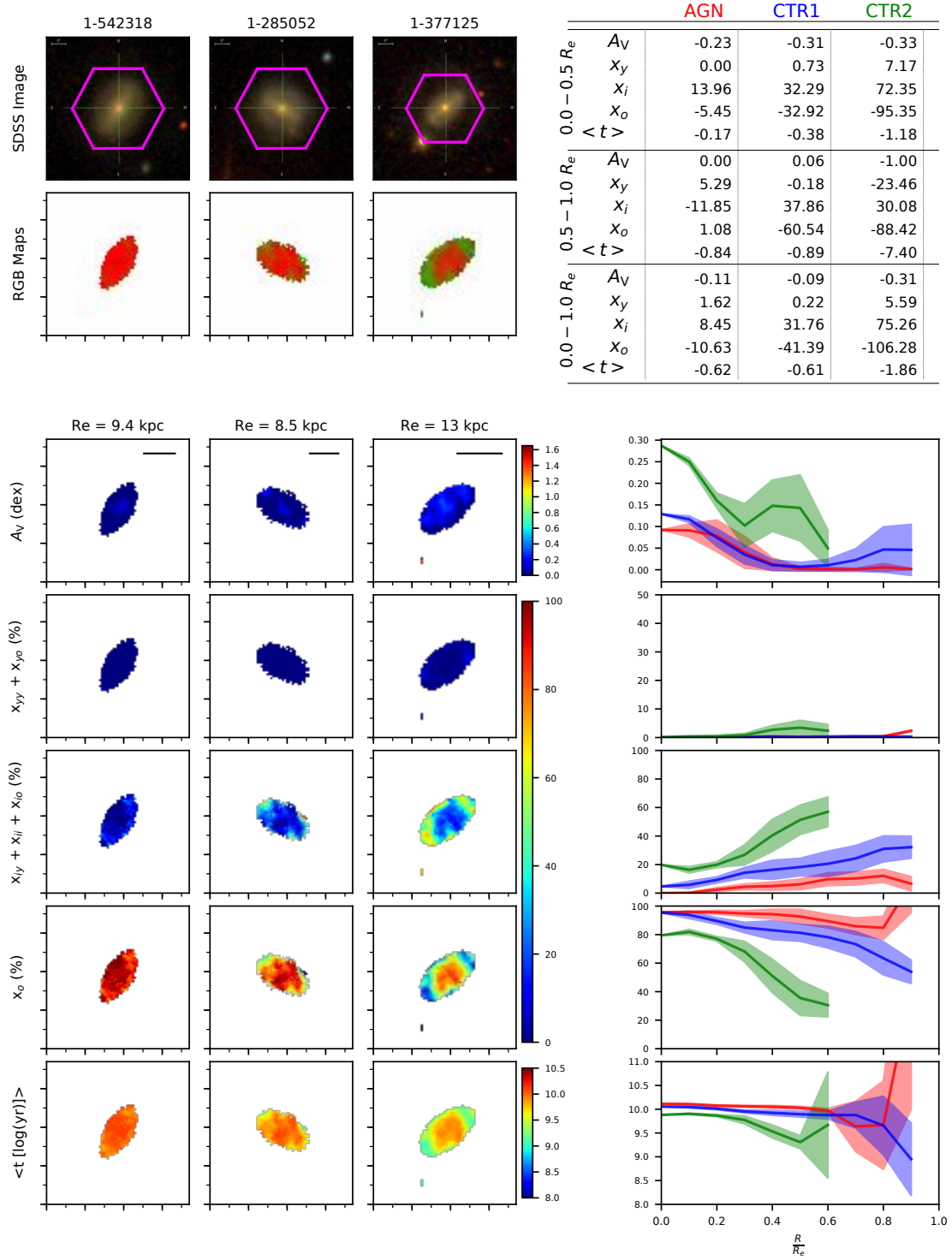


Figure A51. Comparison of the AGN with MaNGA ID 1-519742 and its control galaxies.



**Figure A52.** Comparison of the AGN with MaNGA ID 1-542318 and its control galaxies.

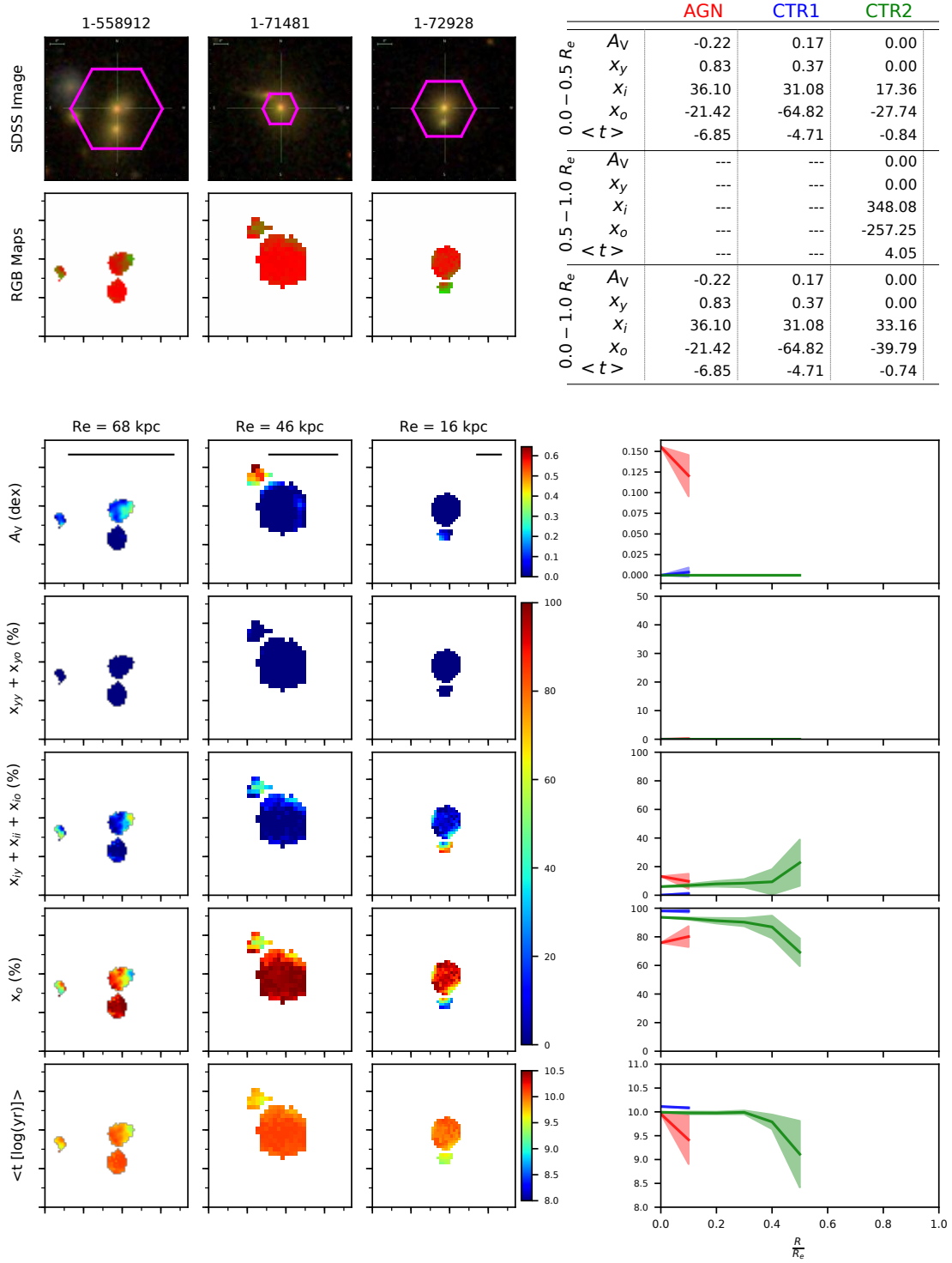


Figure A53. Comparison of the AGN with MaNGA ID 1-558912 and its control galaxies.

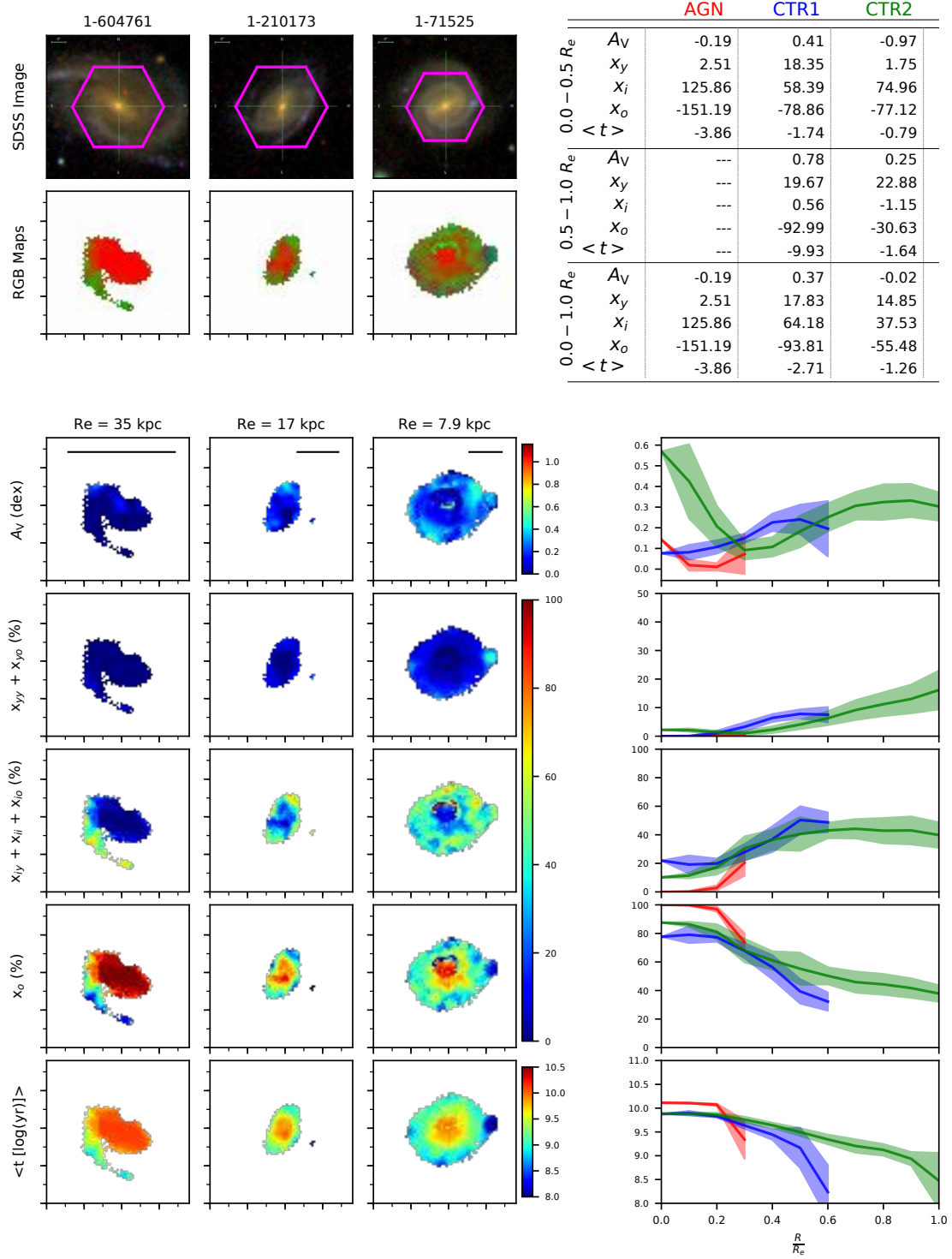


Figure A54. Comparison of the AGN with MaNGA ID 1-604761 and its control galaxies.

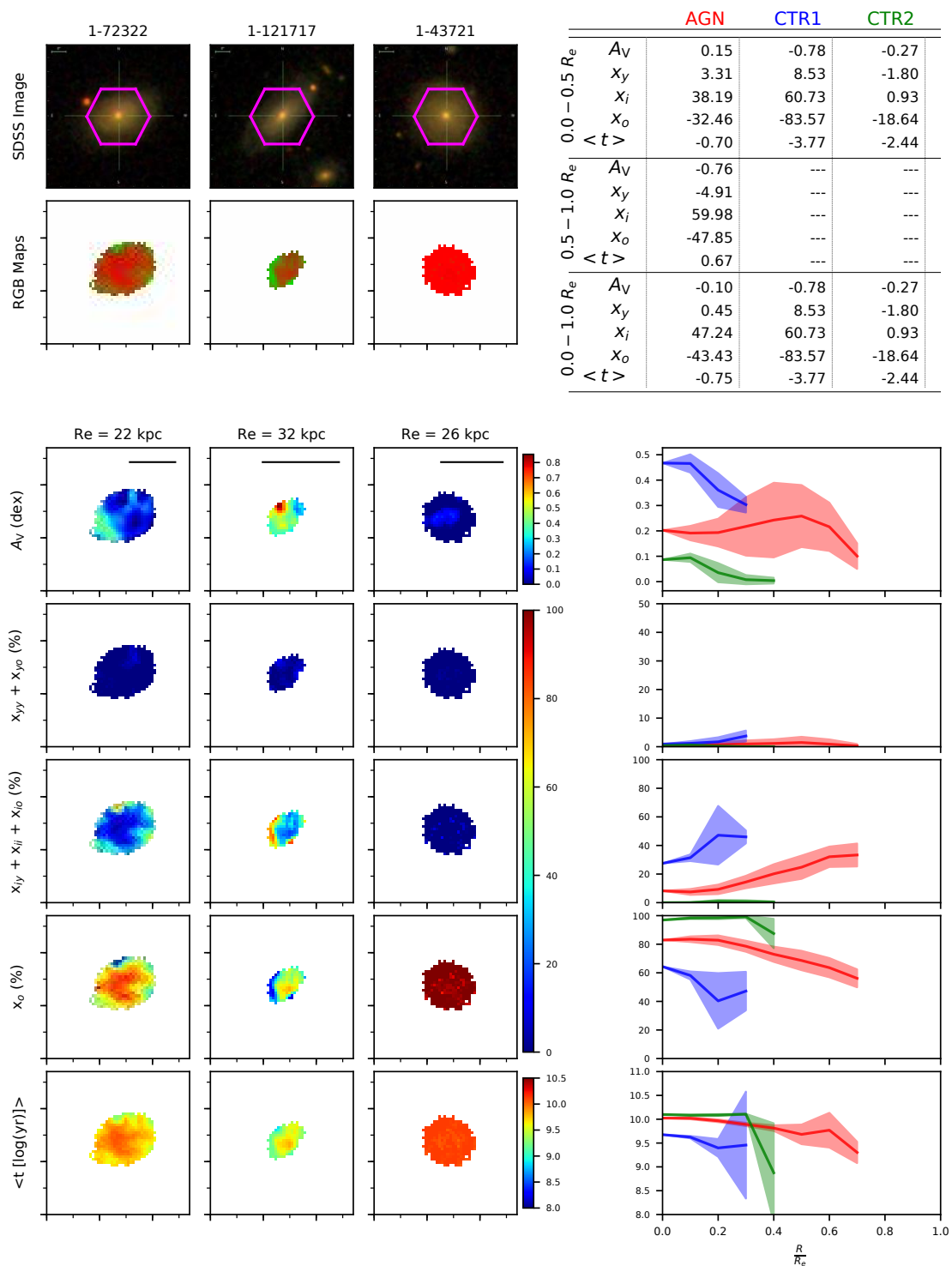


Figure A55. Comparison of the AGN with MaNGA ID 1-72322 and its control galaxies.

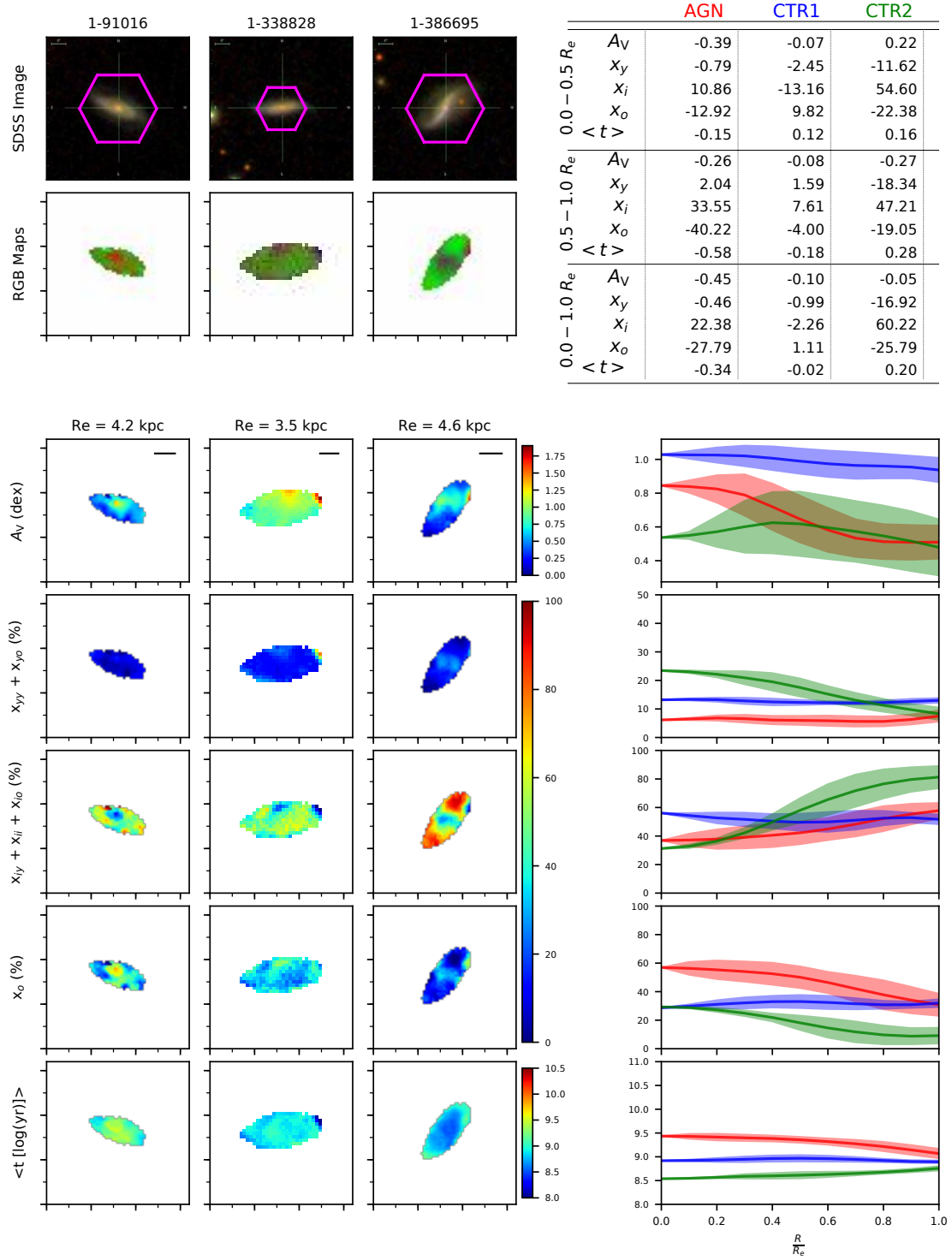


Figure A56. Comparison of the AGN with MaNGA ID 1-91016 and its control galaxies.

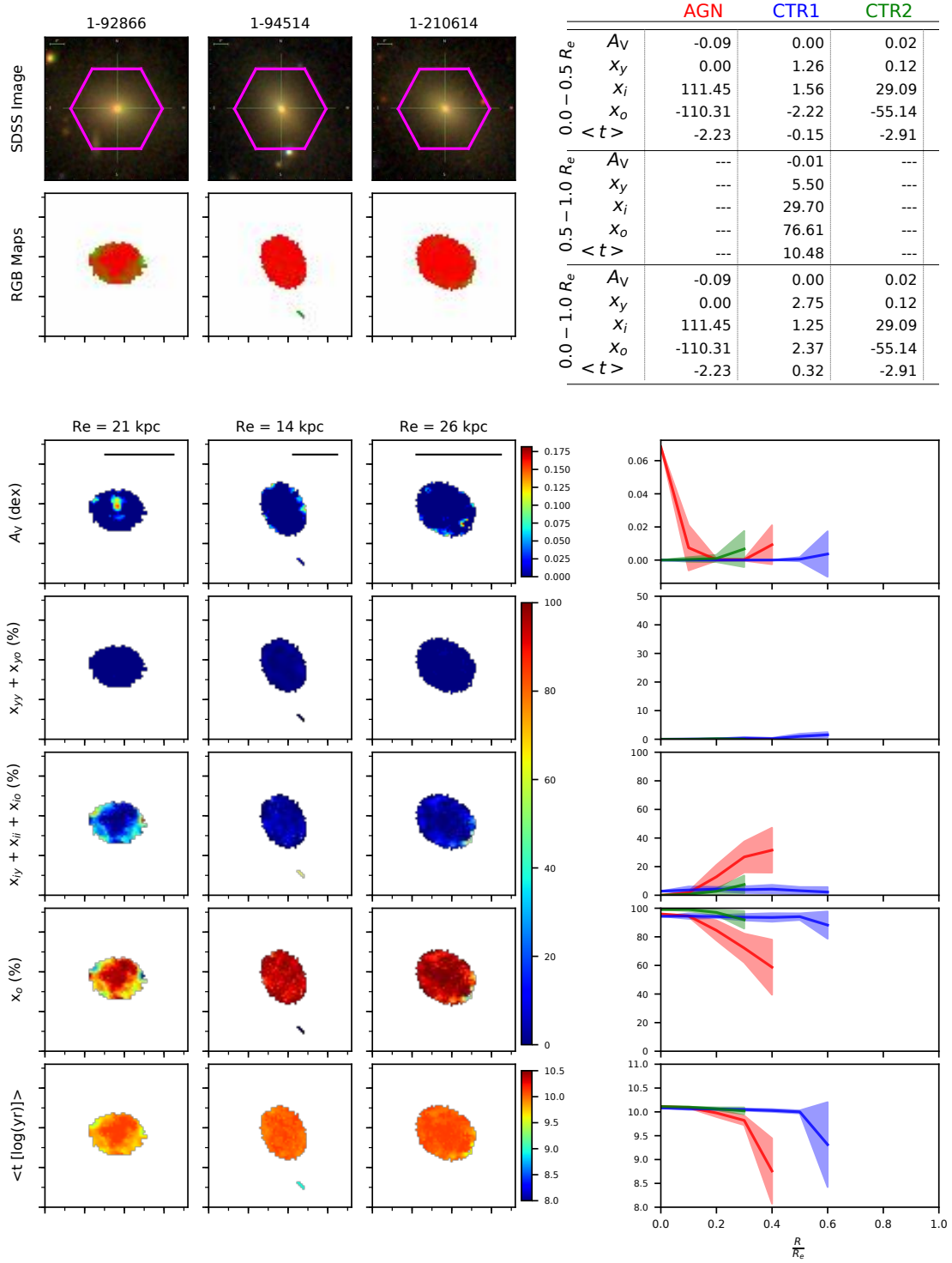


Figure A57. Comparison of the AGN with MaNGA ID 1-92866 and its control galaxies.

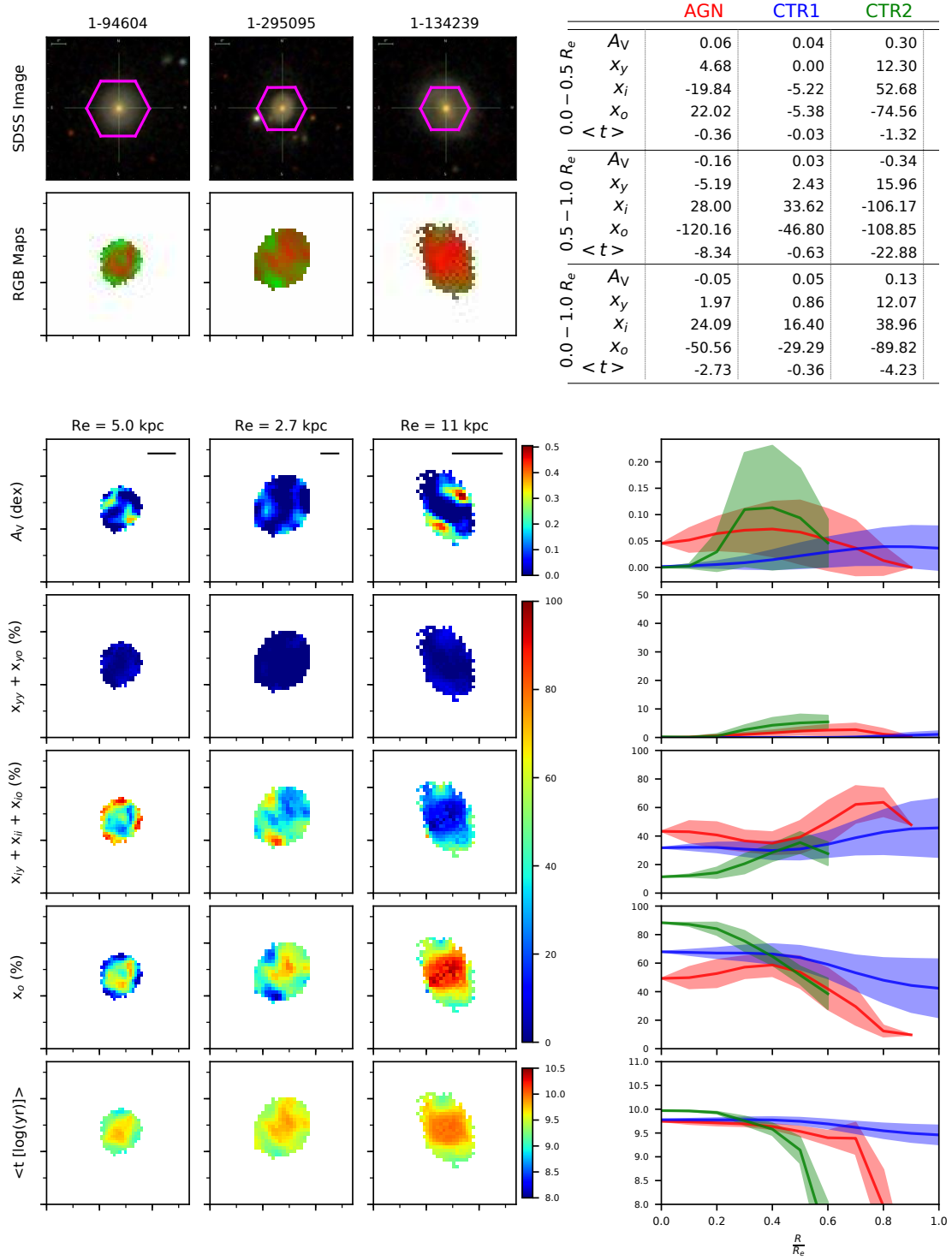


Figure A58. Comparison of the AGN with MaNGA ID 1-94604 and its control galaxies.



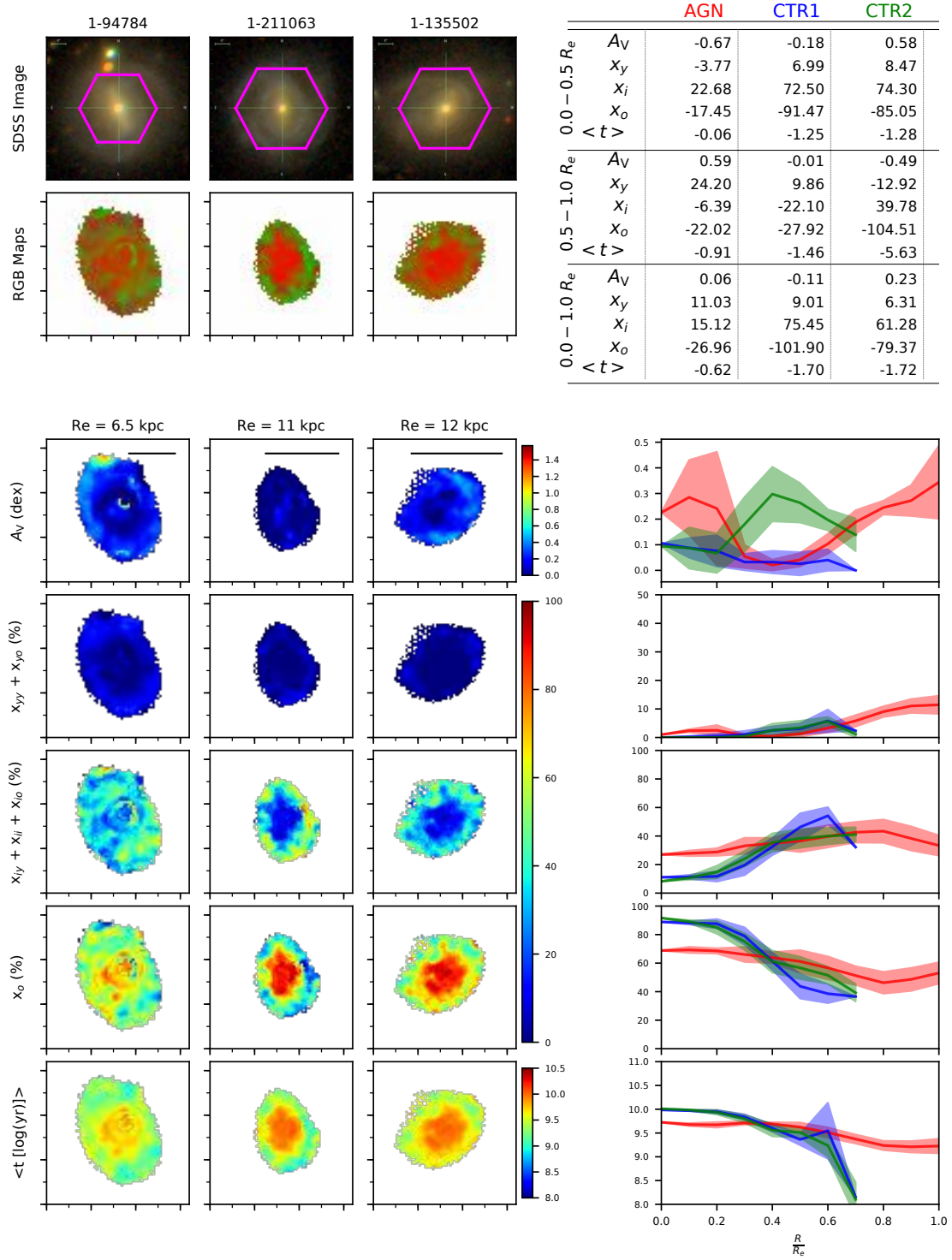


Figure A59. Comparison of the AGN with MaNGA ID 1-94784 and its control galaxies.

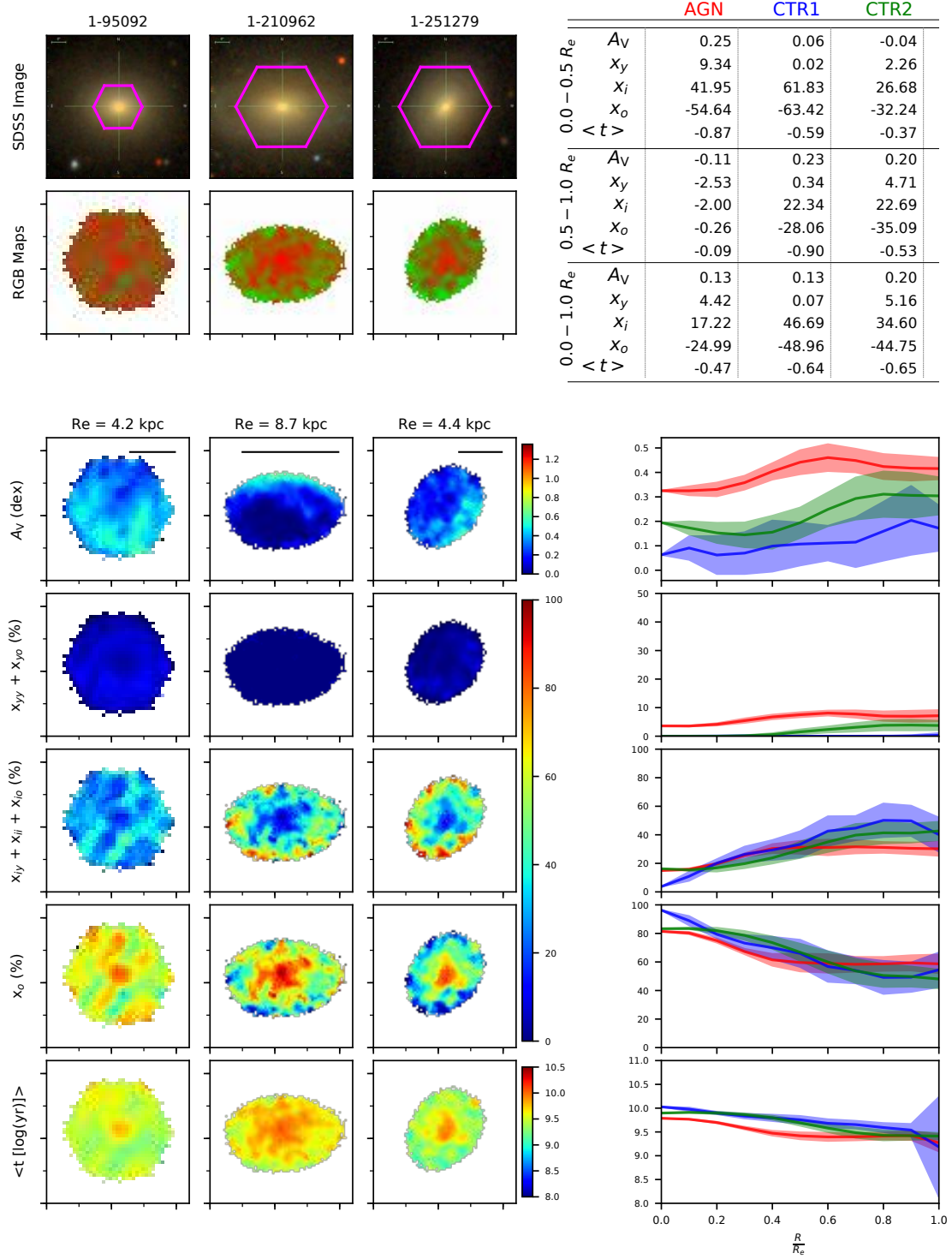


Figure A60. Comparison of the AGN with MaNGA ID 1-95092 and its control galaxies.

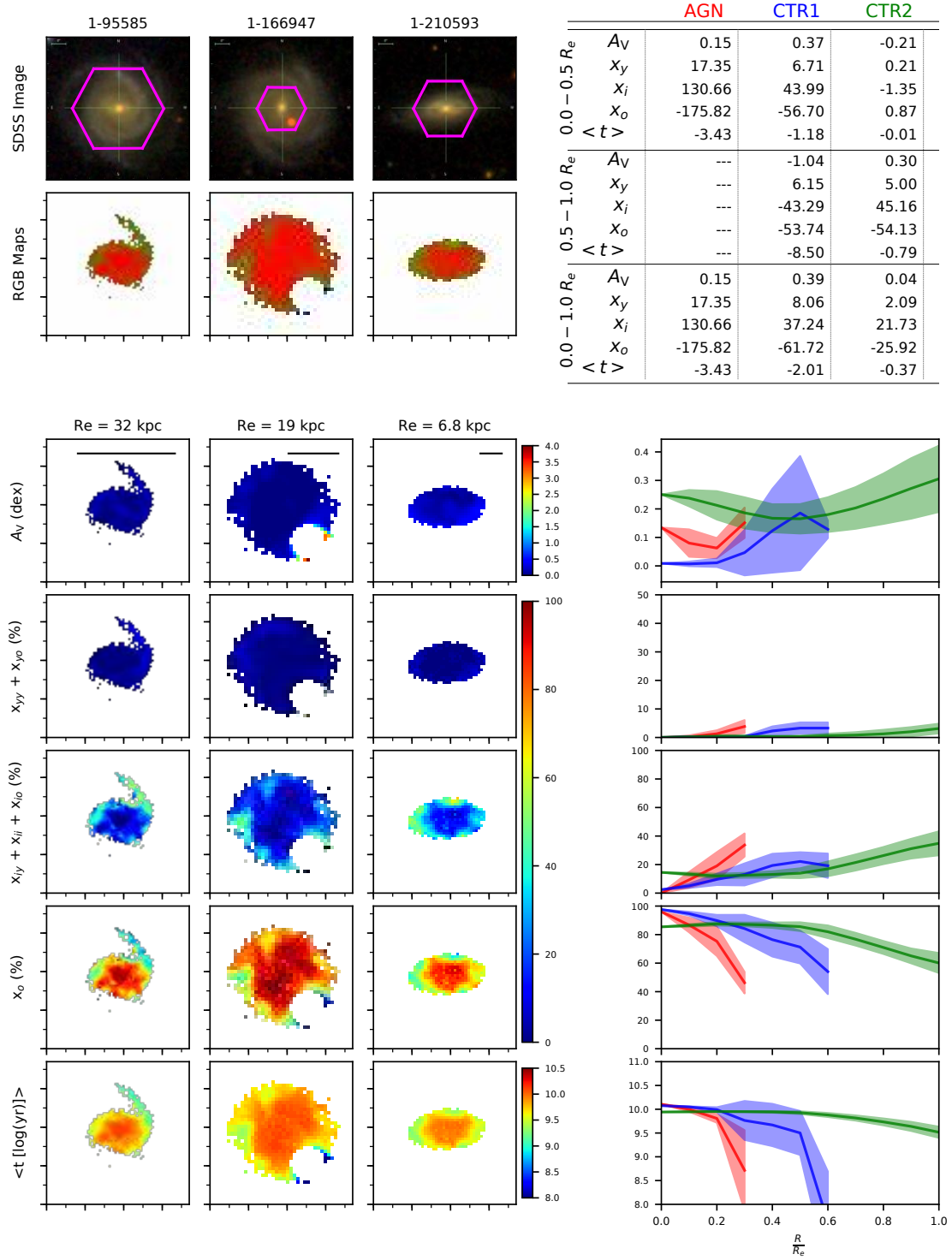


Figure A61. Comparison of the AGN with MaNGA ID 1-95585 and its control galaxies.

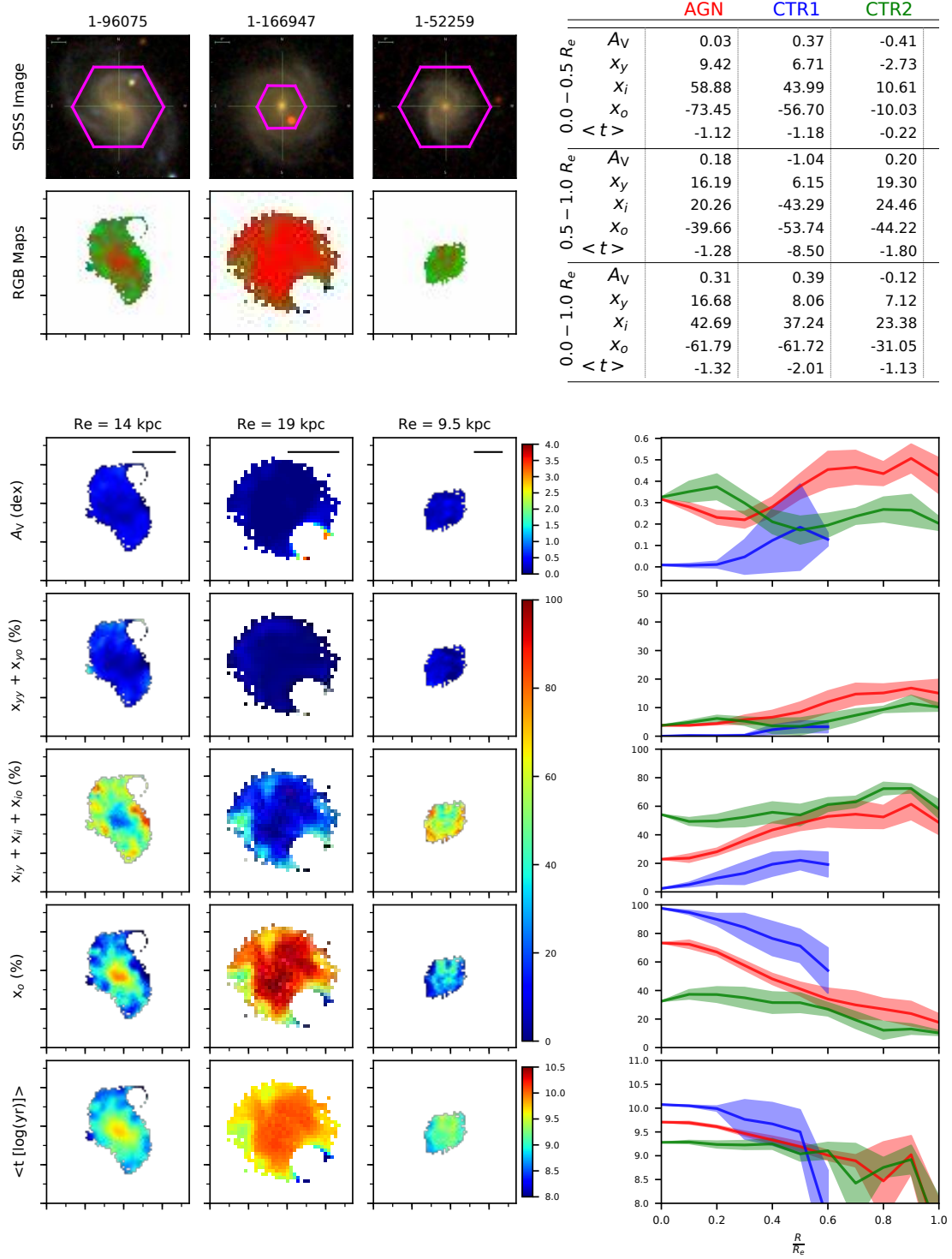


Figure A62. Comparison of the AGN with MaNGA ID 1-96075 and its control galaxies.