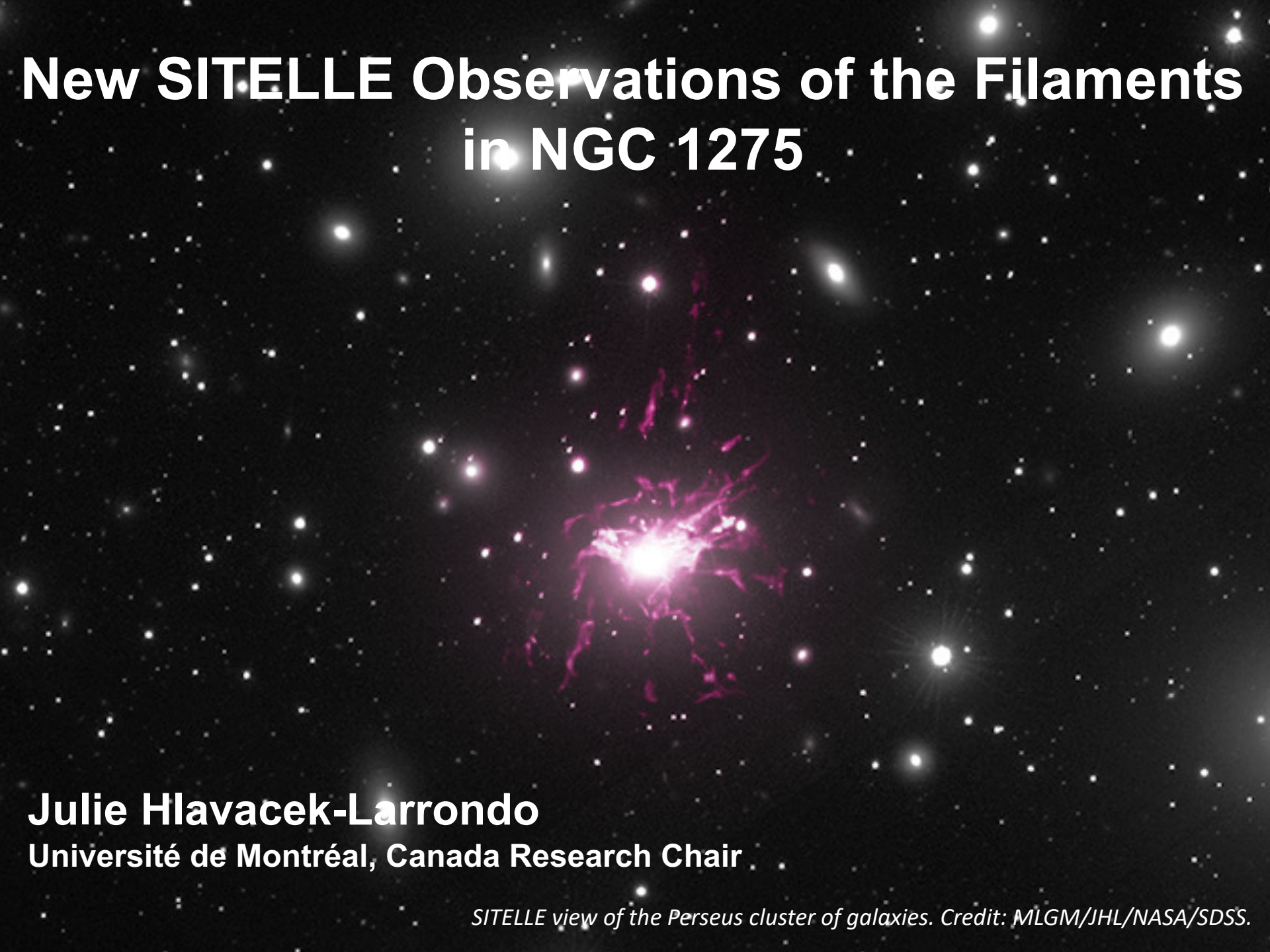
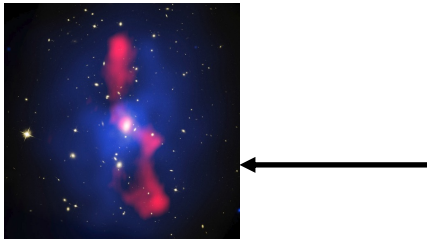
# New SITELLE Observations of the Filaments in NGC 1275

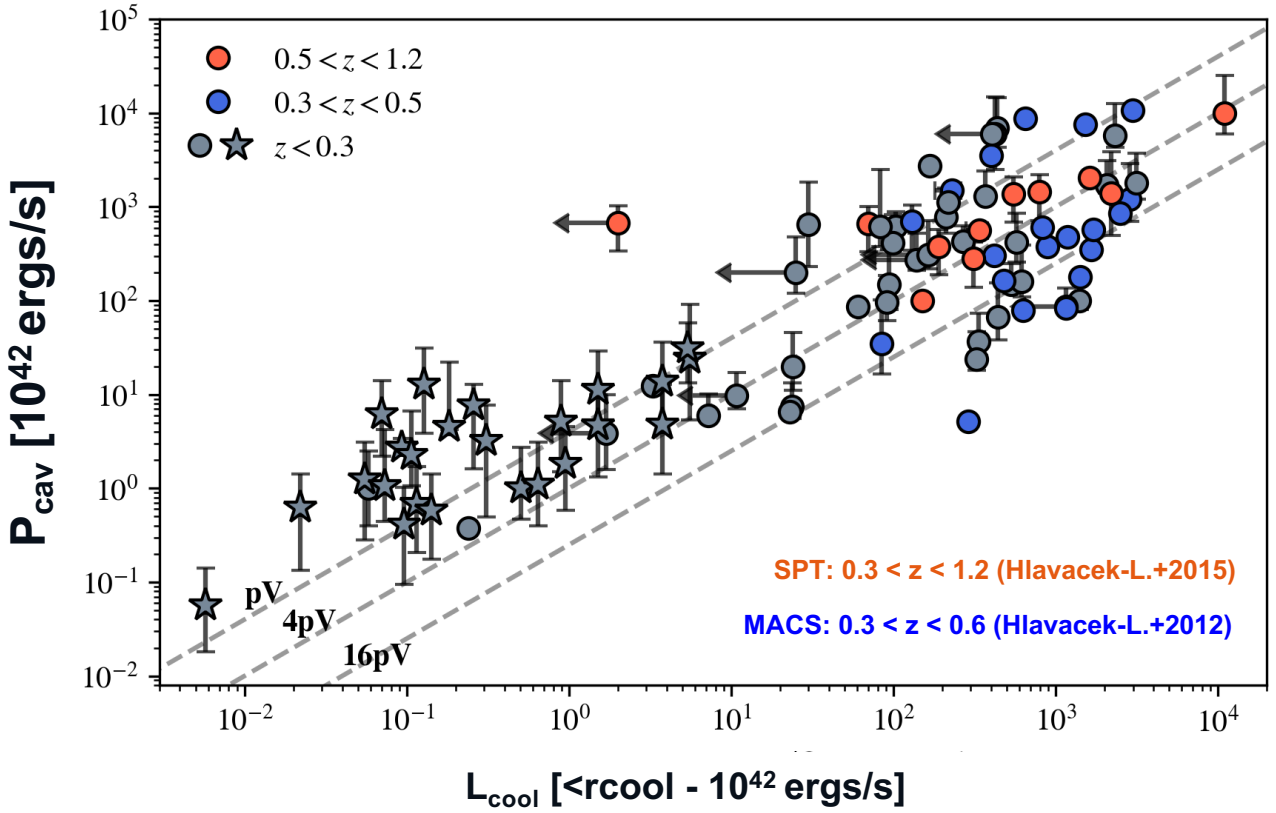


**Julie Hlavacek-Larrondo**
**Université de Montréal, Canada Research Chair**

*SITELLE view of the Perseus cluster of galaxies. Credit: MLGM/JHL/NASA/SDSS.*

# AGN Feedback in High-z Clusters of Galaxies

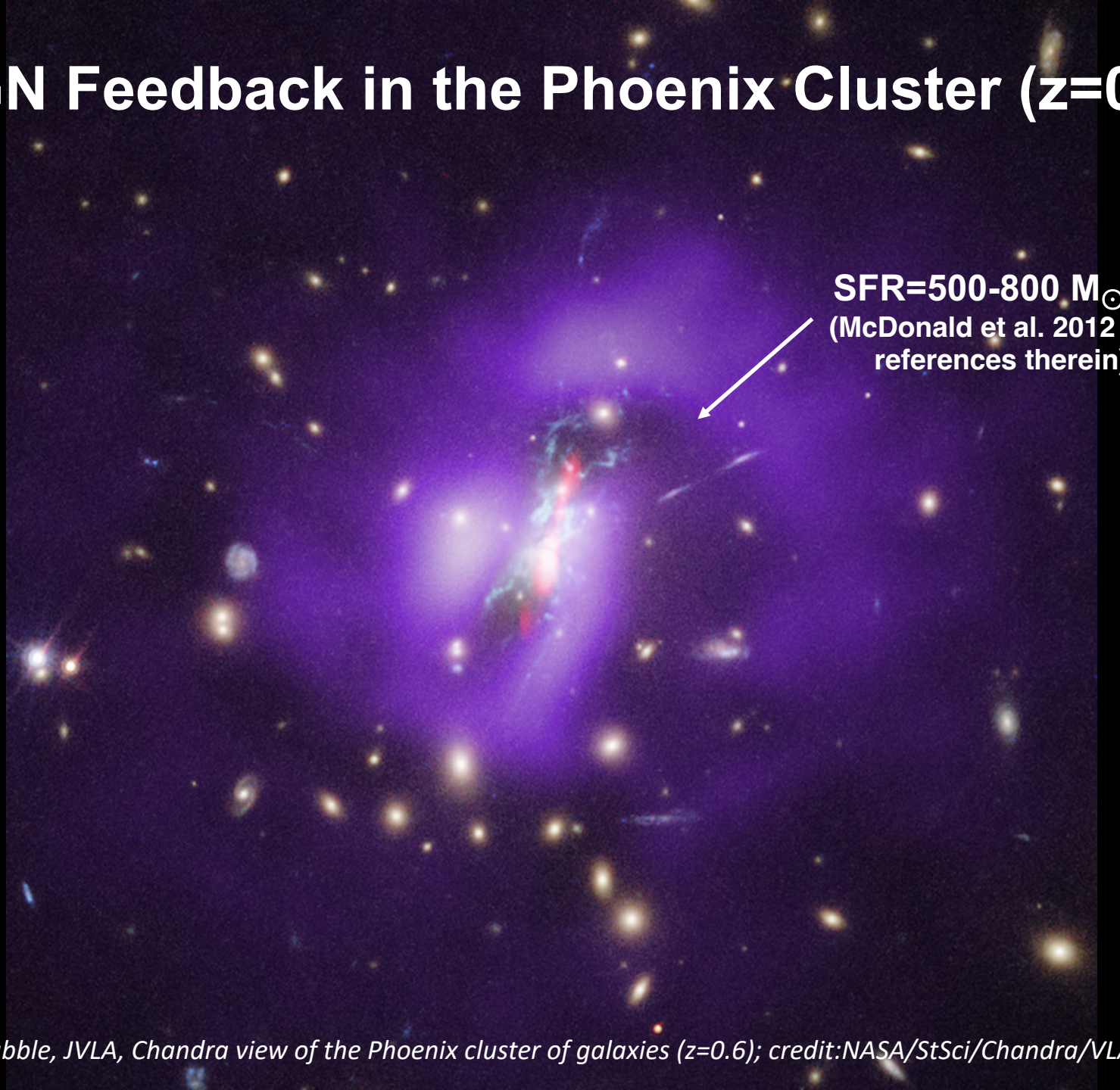





→ **Black hole feedback has been operating in clusters of galaxies for > 8 Gyrs, i.e. over half of the age of the Universe (based on work with the clusters discovered by the South Pole Telescope).**

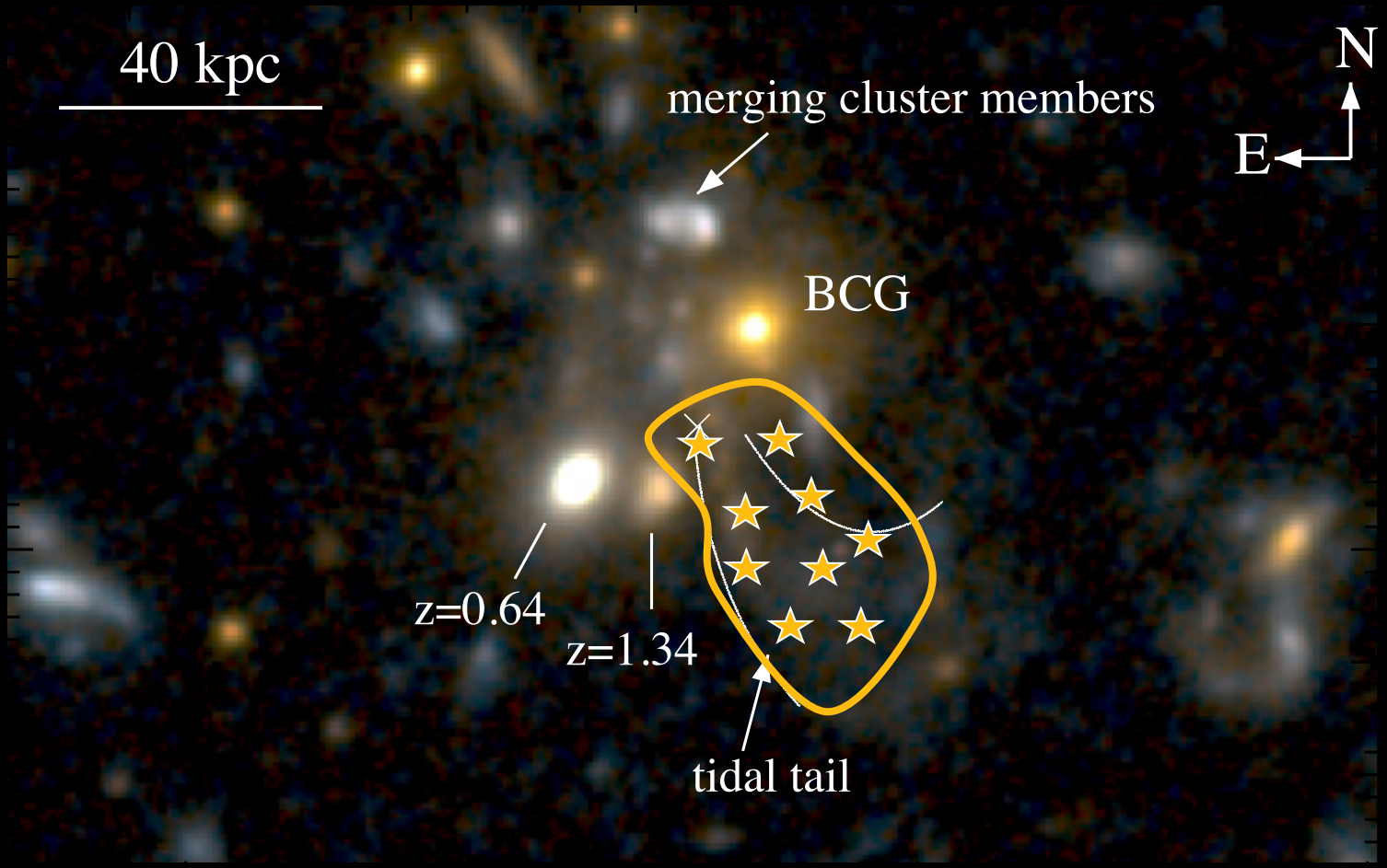
*Hlavacek-Larrondo et al. 2012, Hlavacek-Larrondo et al. 2015 and references therein.*

# AGN Feedback in the Phoenix Cluster (z=0.6)




*Hubble, JVLA, Chandra view of the Phoenix cluster of galaxies (z=0.6); credit:NASA/StSci/Chandra/VLA/Mcdonald.*

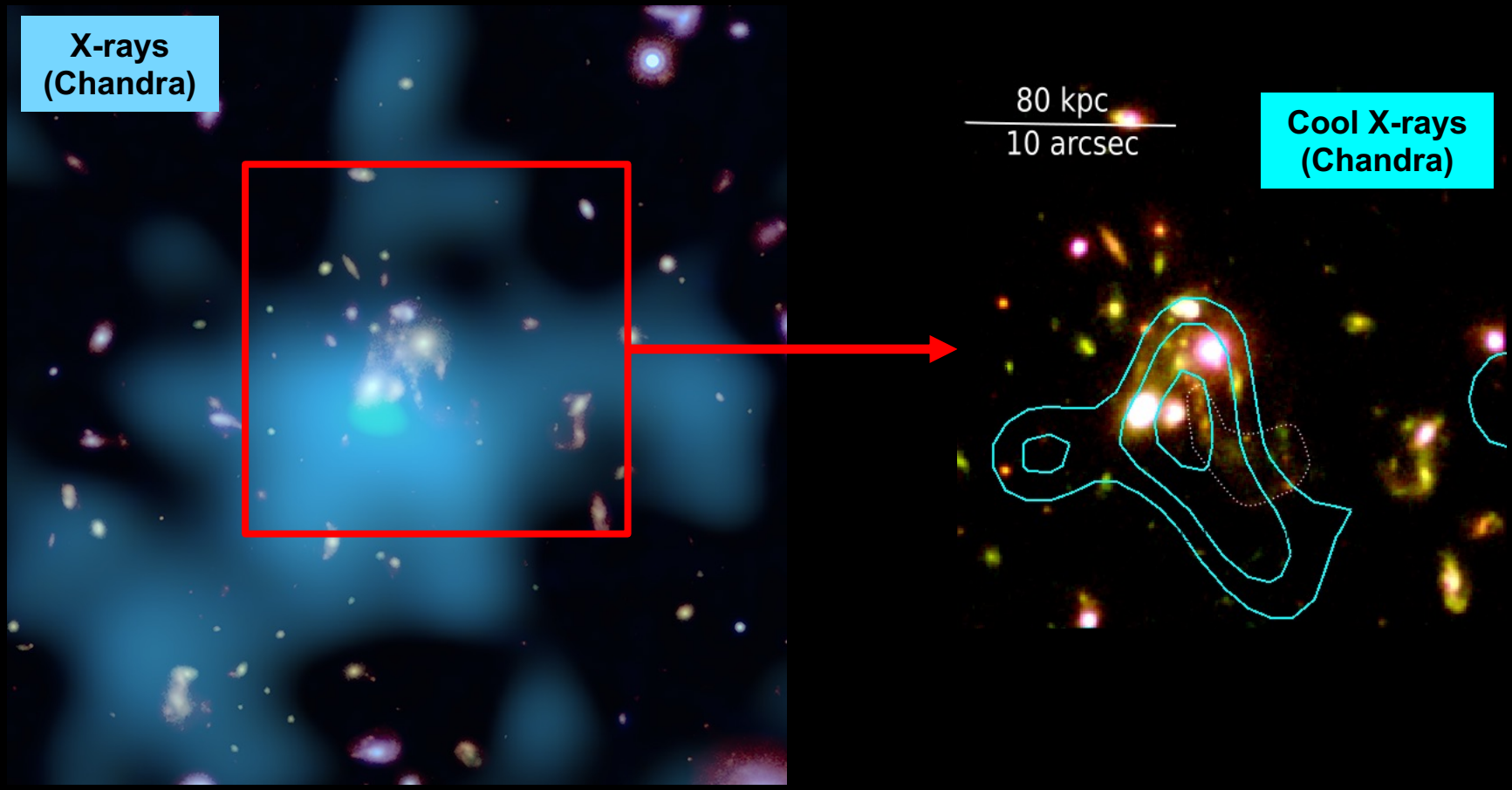
# SpARCS104922.6+564032.5 (z=1.7;≈ $3.5\times10^{14}$ $M_\odot$)




→ **A massive starburst (SFR = 900 $M_\odot$ / year; CO ≈ $10^{11}$ $M_\odot$ ). The stars are forming offset (25 kpc) from the central galaxy (BCG) and extended (Webb et al. 2015a, 2015b, 2018).**

*Hlavacek-Larrondo, Rhea et al. 2020; arXiv 2007.15660*

# SpARCS104922.6+564032.5 (z=1.7;≈ $3.5\times10^{14}$ $M_{\odot}$)

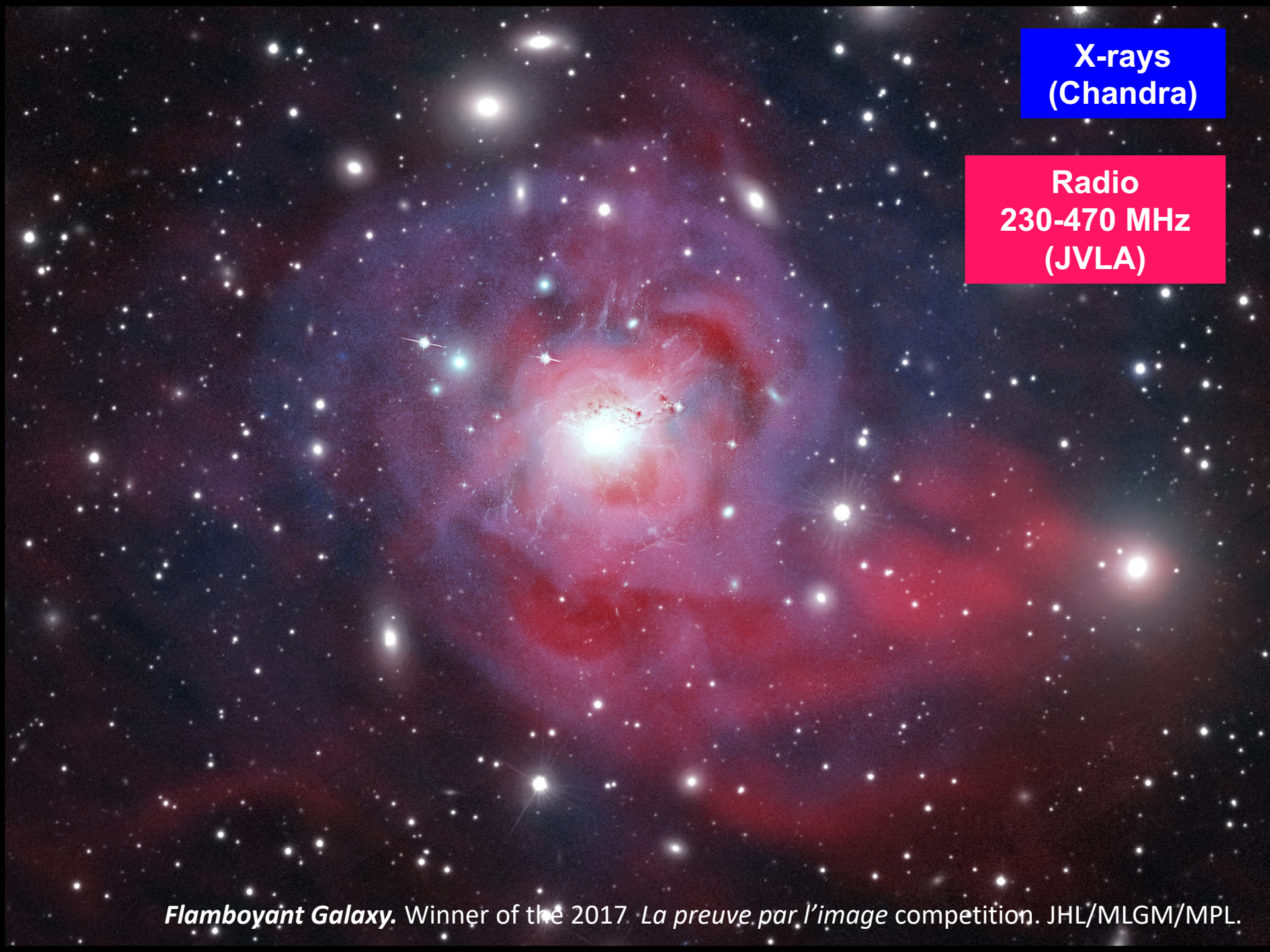



→ Strong cool core, offset from BCG.

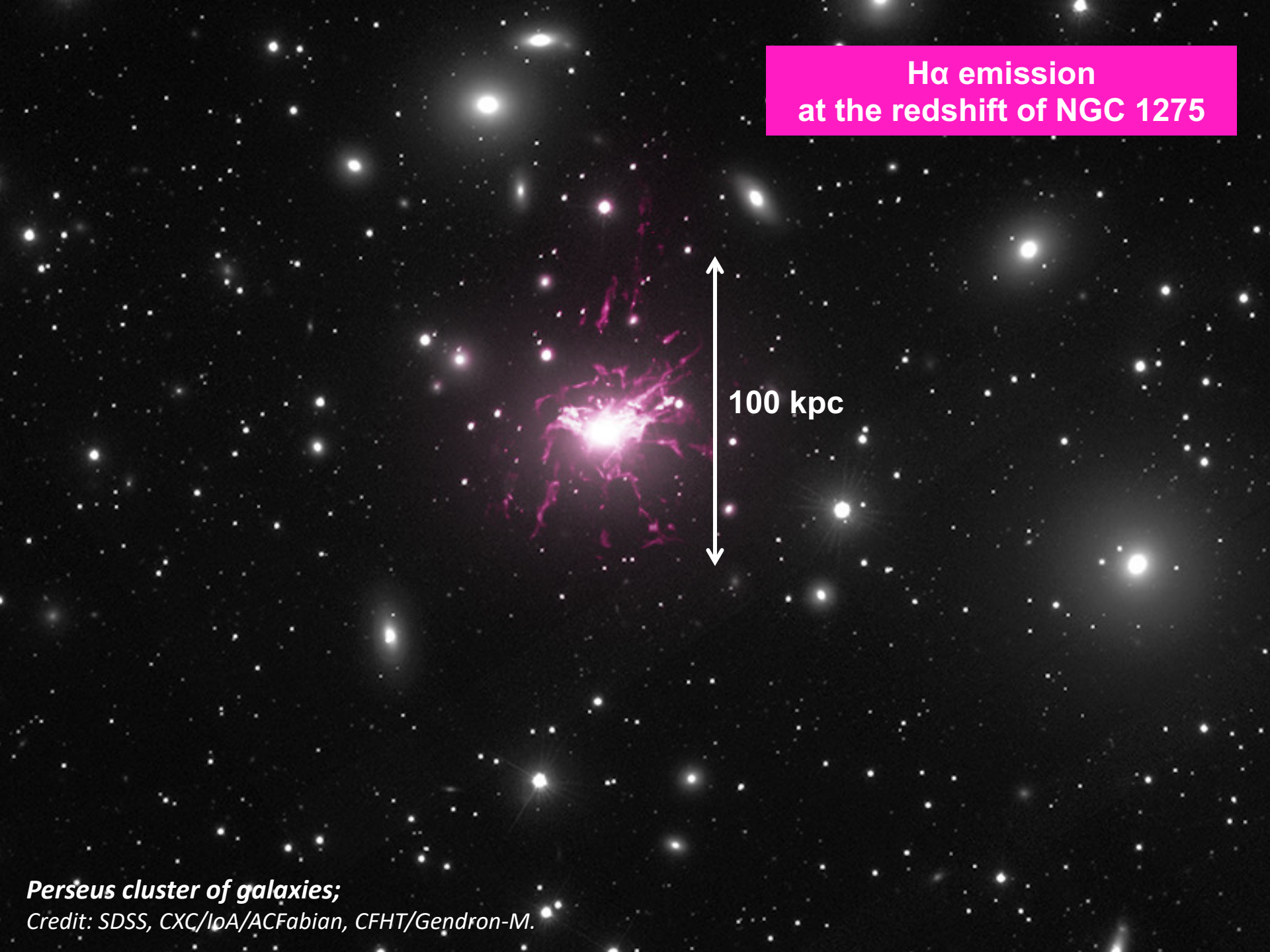
→ NO AGN feedback (Trudeau+2019)– starburst is from a pure cooling flow.

→ New way to form intracluster stars (build Milky way in 10^8 years).

*Hlavacek-Larrondo, Rhea et al. 2020; arXiv 2007.15660*

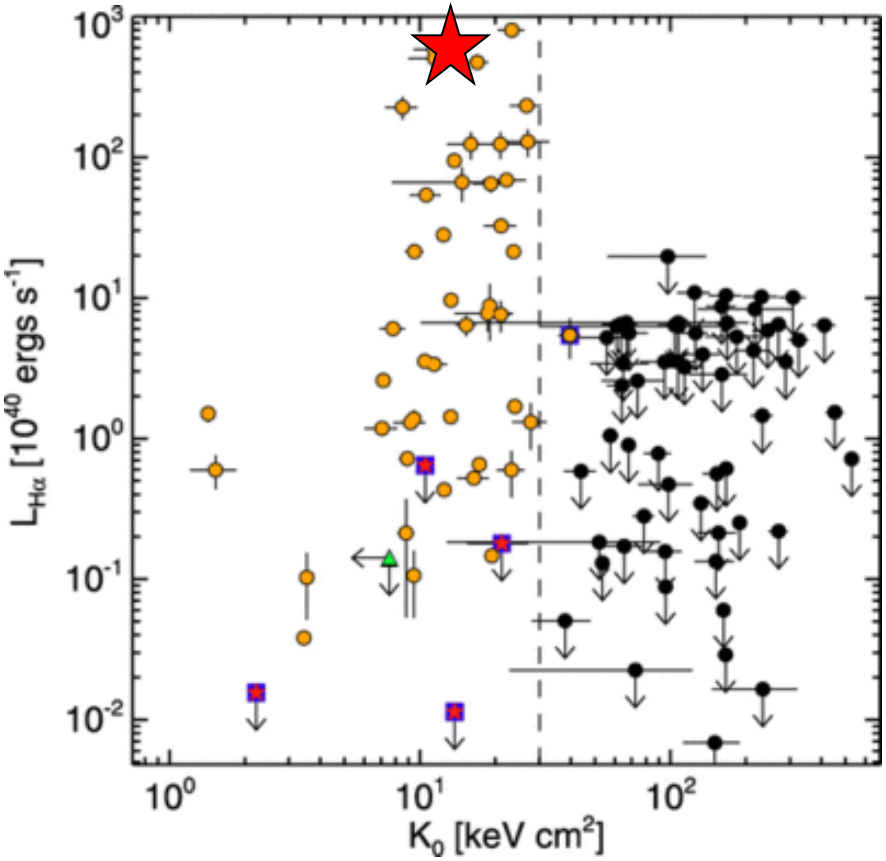


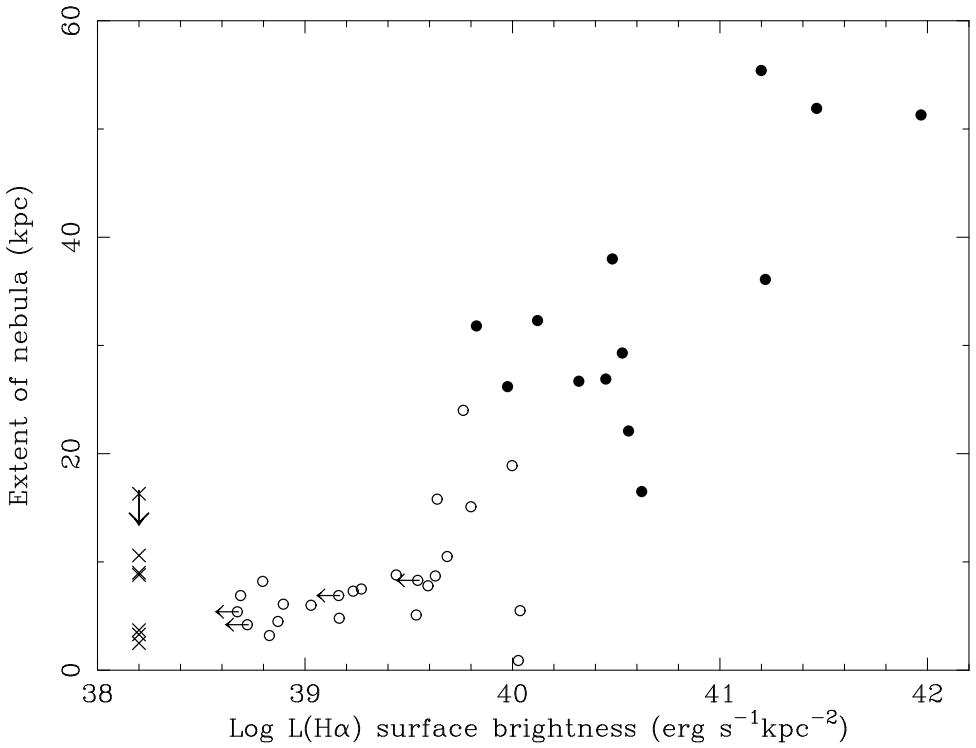

***Flamboyant Galaxy.*** Winner of the 2017 *La preuve par l'image* competition. JHL/MLGM/MPL.




***Perseus cluster of galaxies;***
*Credit: SDSS, CXC/IoA/ACFabian, CFHT/Gendron-M.*

# The Filaments of NGC 1275



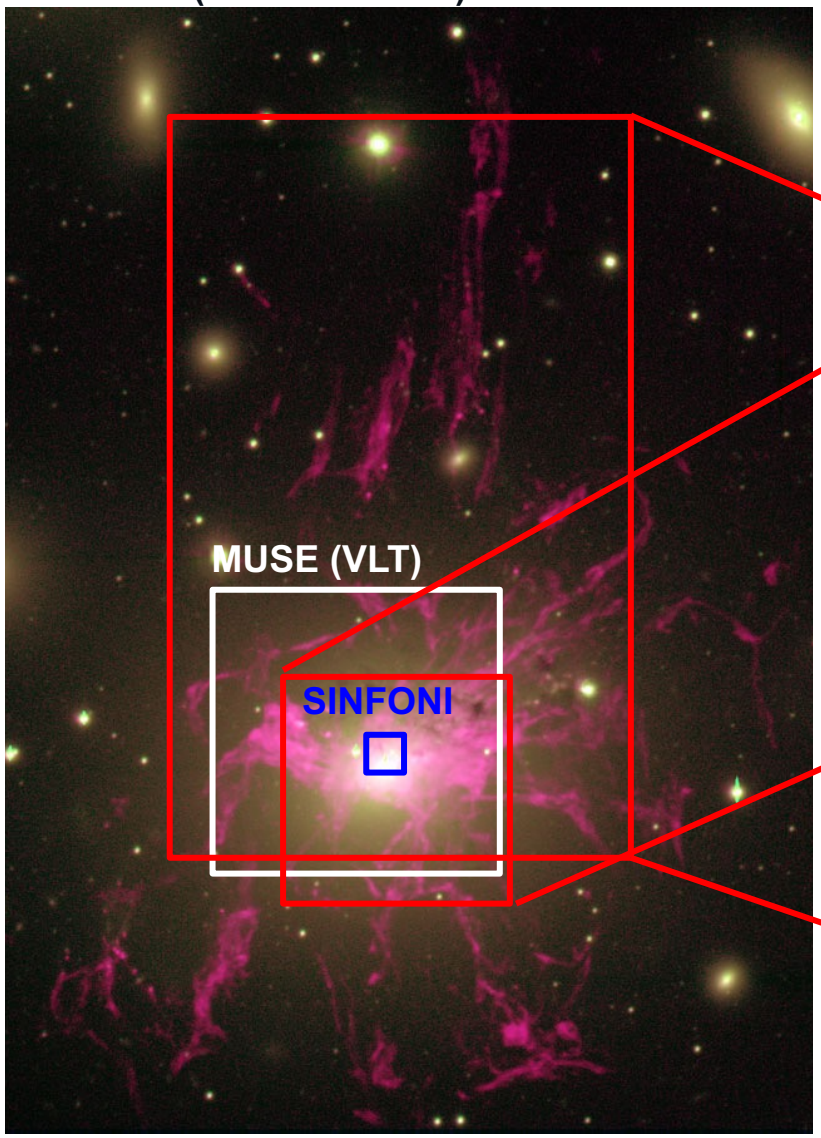




Cavagnolo et al. 2008.

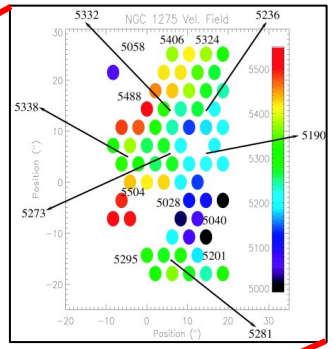
Crawford et al. 1999.

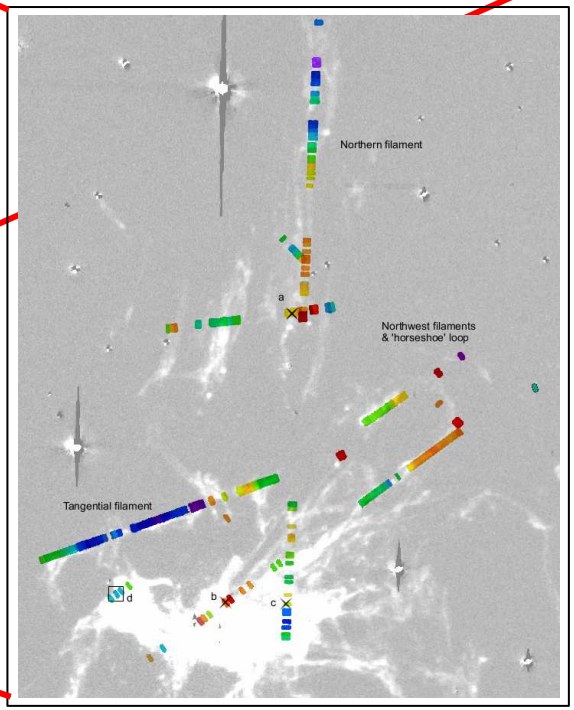
# The “Problem” with the filaments in NGC 1275

NGC 1275 (Hα continuum)




90 kpc
4.2 arcmin

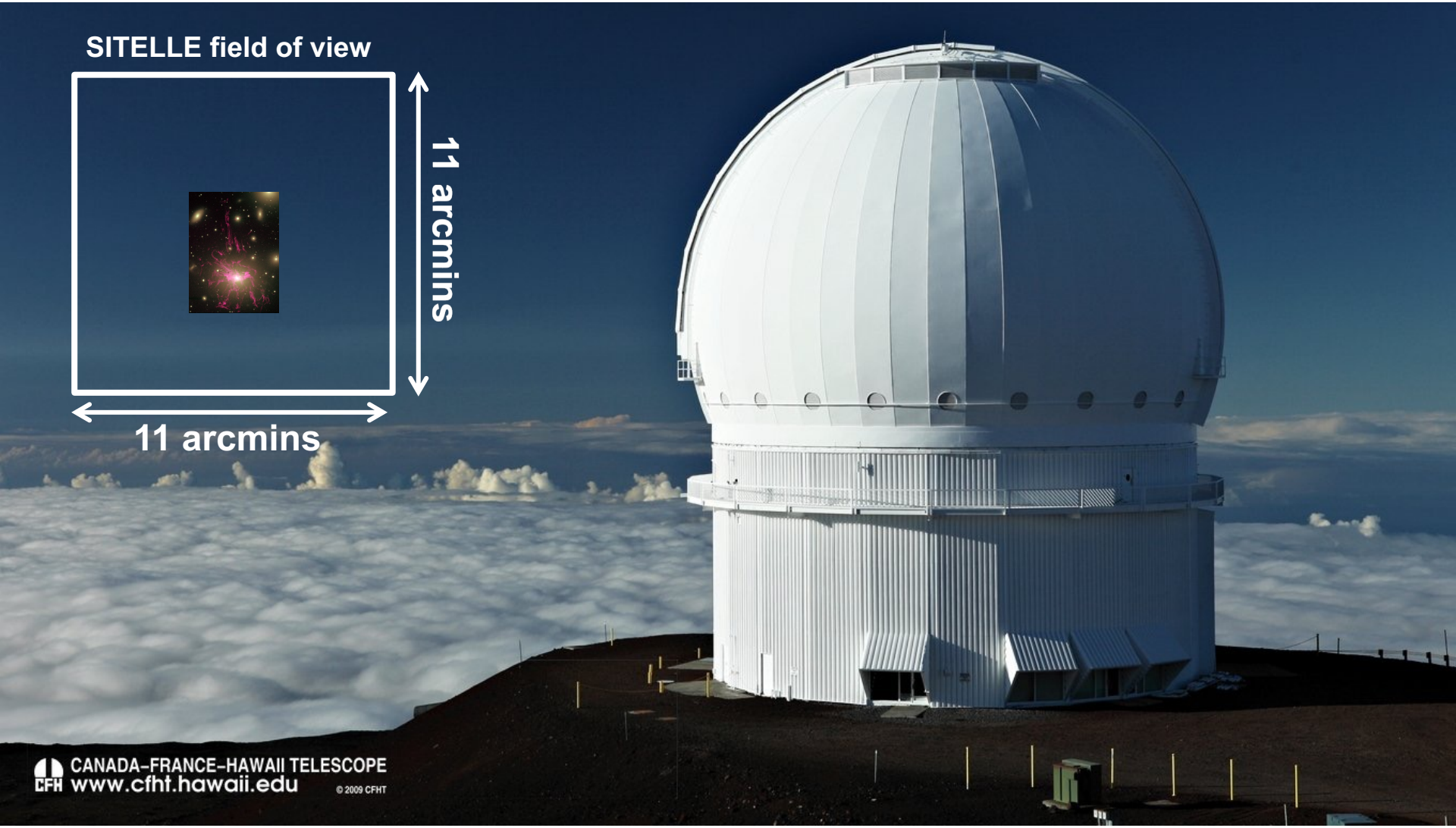


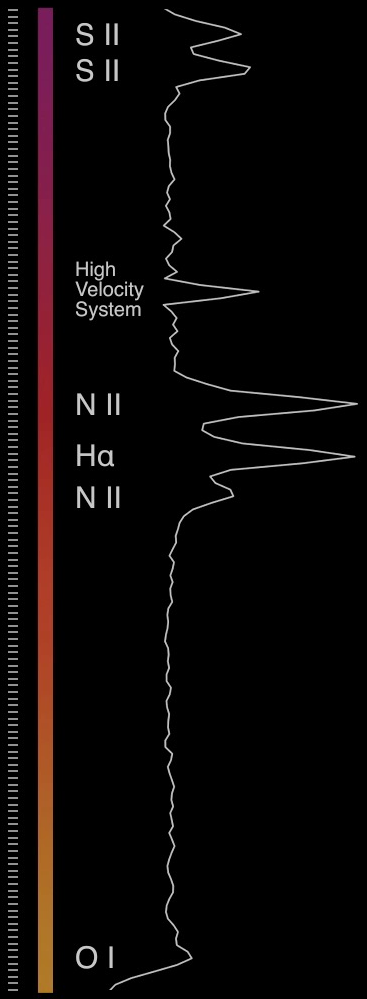

Hatch et al. 2006

Conselice et al. 2001, see also Salomé’s work on CO observations of NGC 1275.

# SITELLE at the CFHT




**Science verification observations (2018):** NGC 1275 observed for 2.1 hours with the 647-685 nm filter (SN3) and $R$ = 1800 (covering Hα, NII, SII, OI).




NGC 1275

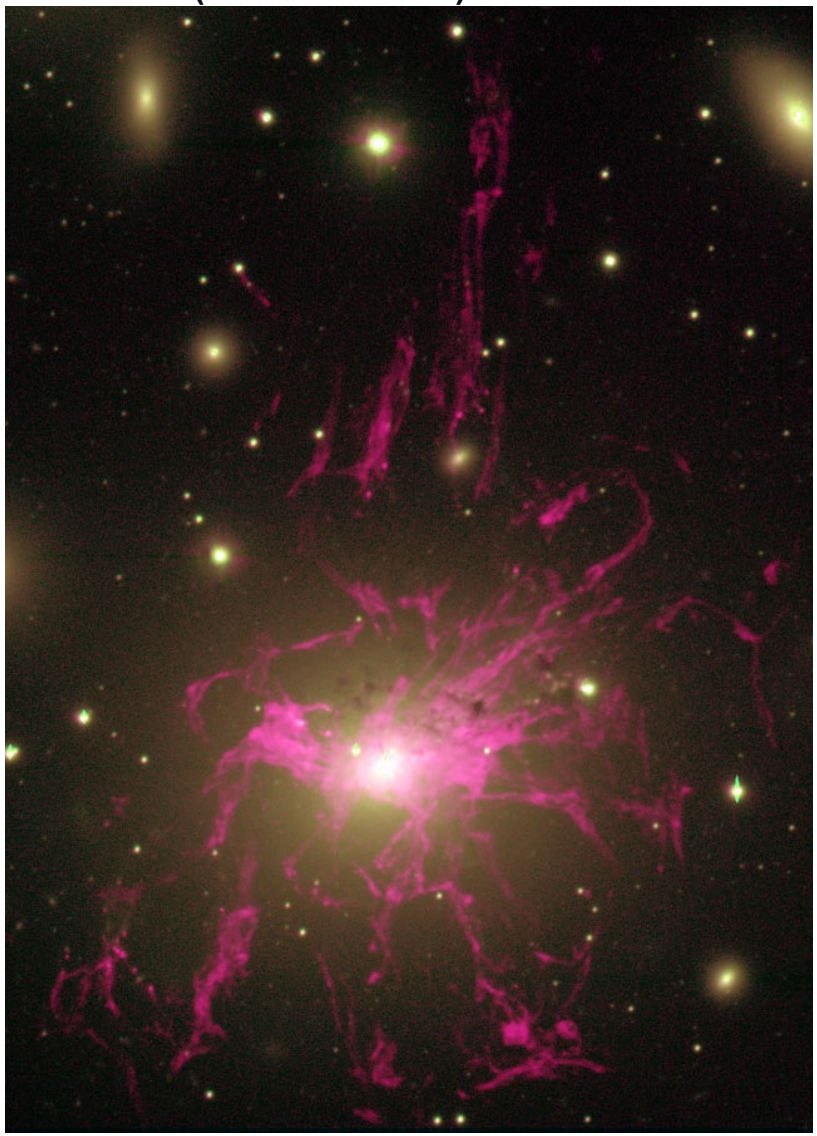
Observations with
SITELLE at CFHT
SN3 (647-685 nm)
2.14h (16BQ12)
R=1800

Université de Montréal

**Credit: JHL/MLGM/ML.**

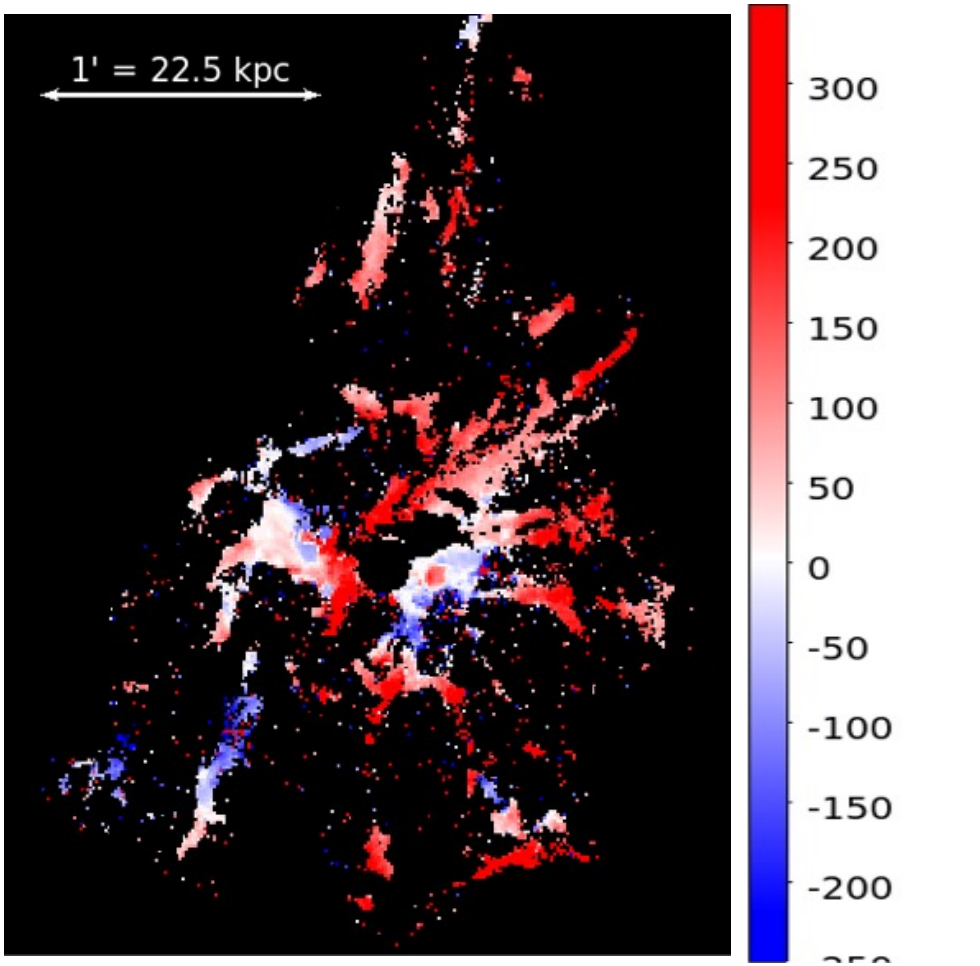
# SITELLE Observations of NGC 1275

NGC 1275 (Hα continuum)



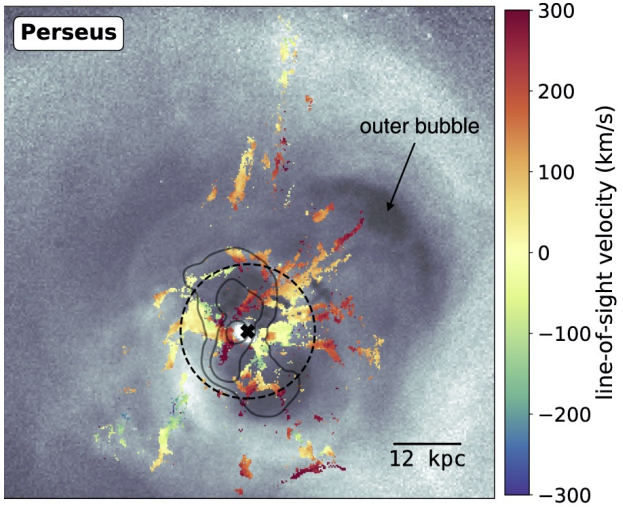
Conselice et al. 2001.

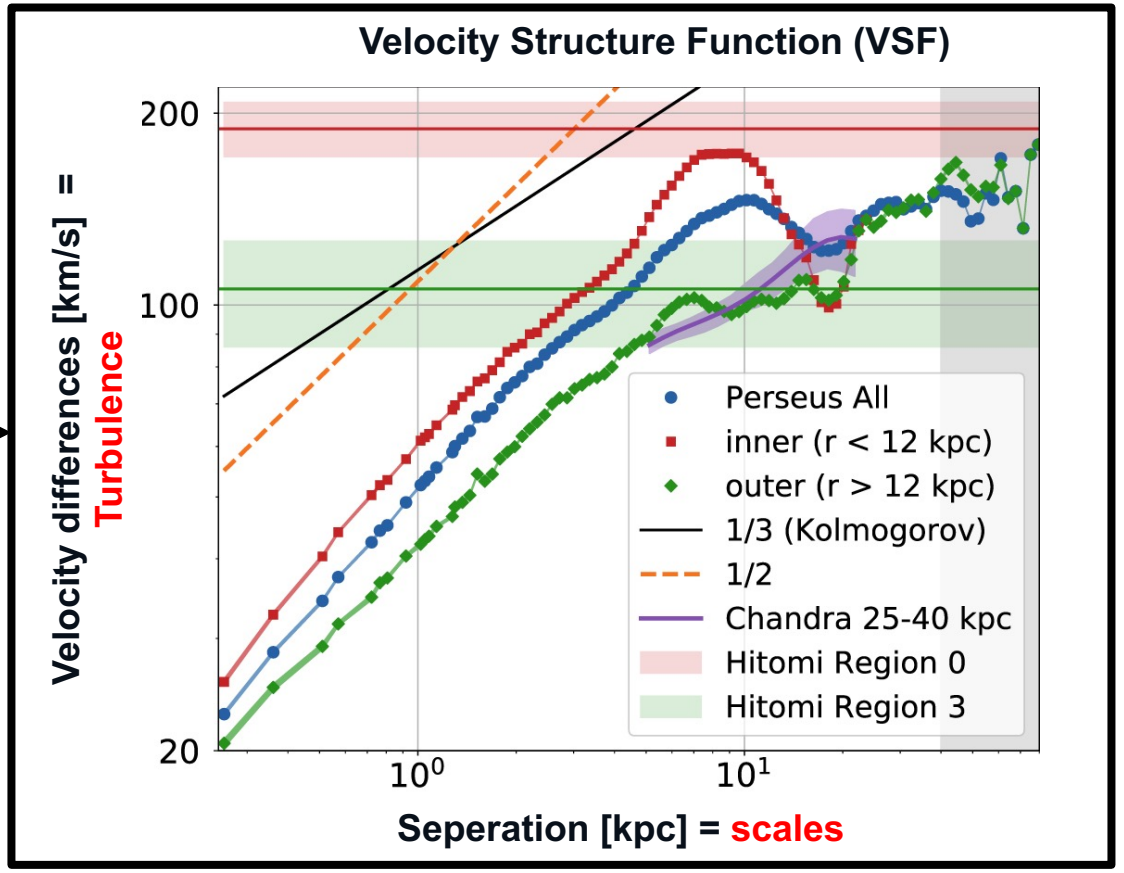
NGC 1275 (R=1800; Hα velocity)




Gendron-Marsolais, Hlavacek-L. et al. 2018

# Black Hole-driven Turbulence in Clusters




→ **Li et al. 2020 show that for Perseus, Virgo and A2597:**

1) **Motions of filaments are turbulent**
2) **Features in the VSF correlate directly with AGN jet features**
3) **Motions of filaments (10,000K) = motions of X-ray gas (10,000,000K).**

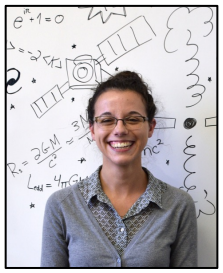
→ **Evidence that central AGN (BCG) drives turbulence in cluster cores.**

*Li et al. 2020, ApJ Letters*

# SITELLE Observations of NGC 1275

## 2018

- 2.1 hours
- SN3 (647-685 nm): Hα, NII, SII, OI.
- **R = $\lambda/\Delta\lambda$ = 1800**
- **R = 3.7Å (~80 km/s)**
- Gendron-Marsolais et al. 2018



*M.-L. Gendron-M. (ESO fellow)*

## 2022

- 4 hours
- SN3 (647-685 nm: Hα, NII, SII, OI.
- **R = $\lambda/\Delta\lambda = 7000$**
- **R = 0.9 Å (~15 km/s)**
- **Vigneron et al. in prep**

*Benjamin Vigneron, M. Sc.*

## 2022

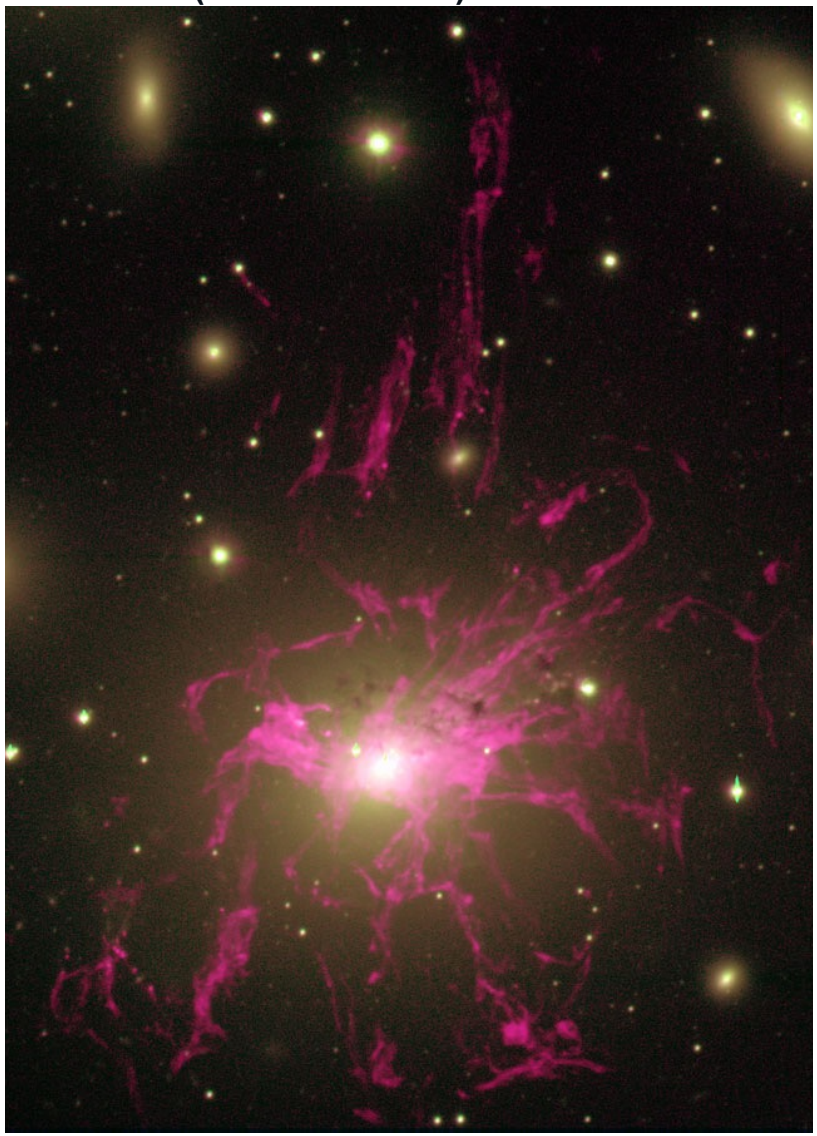
- 3 hours each filter
- SN1 (365-385 nm): OII
- SN2 (480-520 nm): H$\beta$
- R = $\lambda/\Delta\lambda = 1800$
- R = 2.1/2.7 Å (~80 km/s)
- Thilloy et al. in prep

*Auriane Thilloy, B. Sc.*

*Carter Rhea. (Ph. D. IVADO scholar)*
*See https://github.com/crhea93/LUCI*

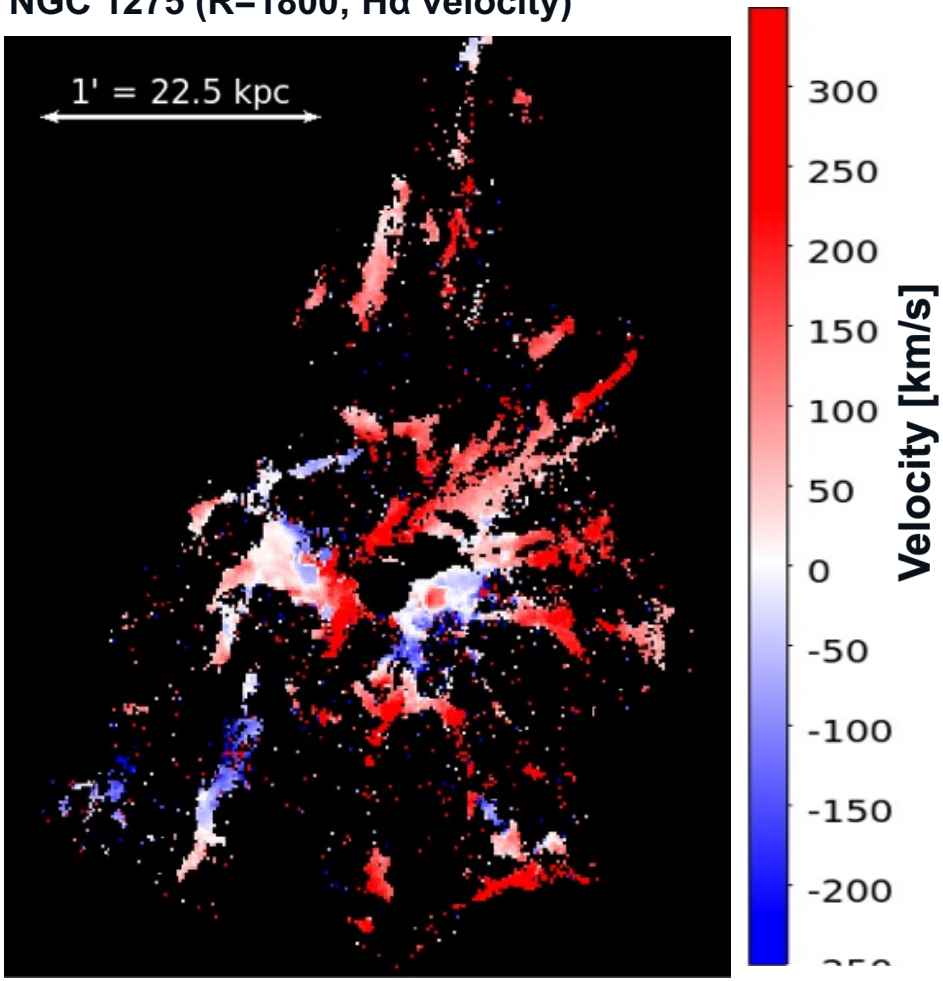
# New SITELLE Observations of NGC 1275

NGC 1275 (Hα continuum)



Conselice et al. 2001.

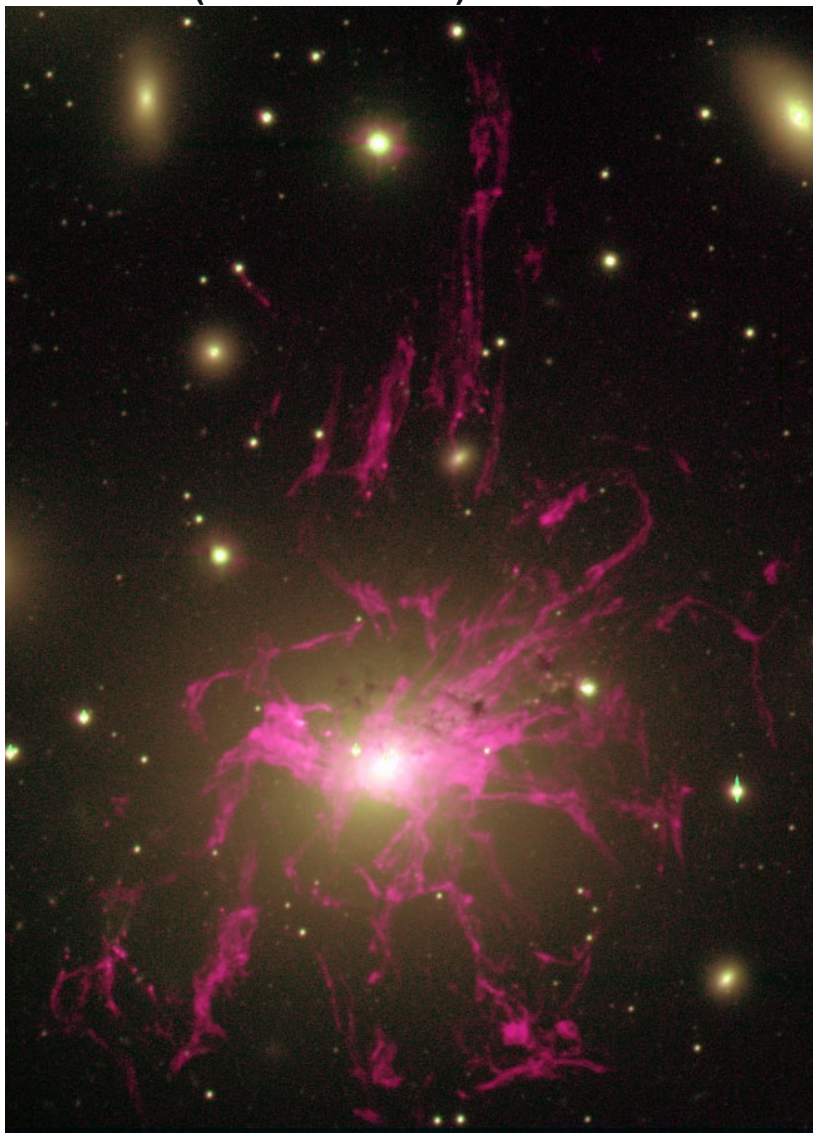
NGC 1275 (R=1800; Hα velocity)




Gendron-Marsolais, Hlavacek-L. et al. 2018

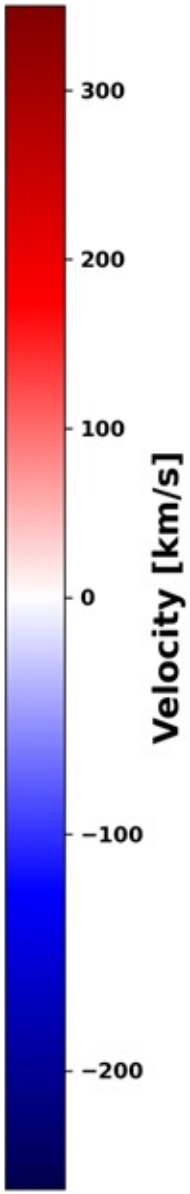
# New SITELLE Observations of NGC 1275

NGC 1275 (Hα continuum)



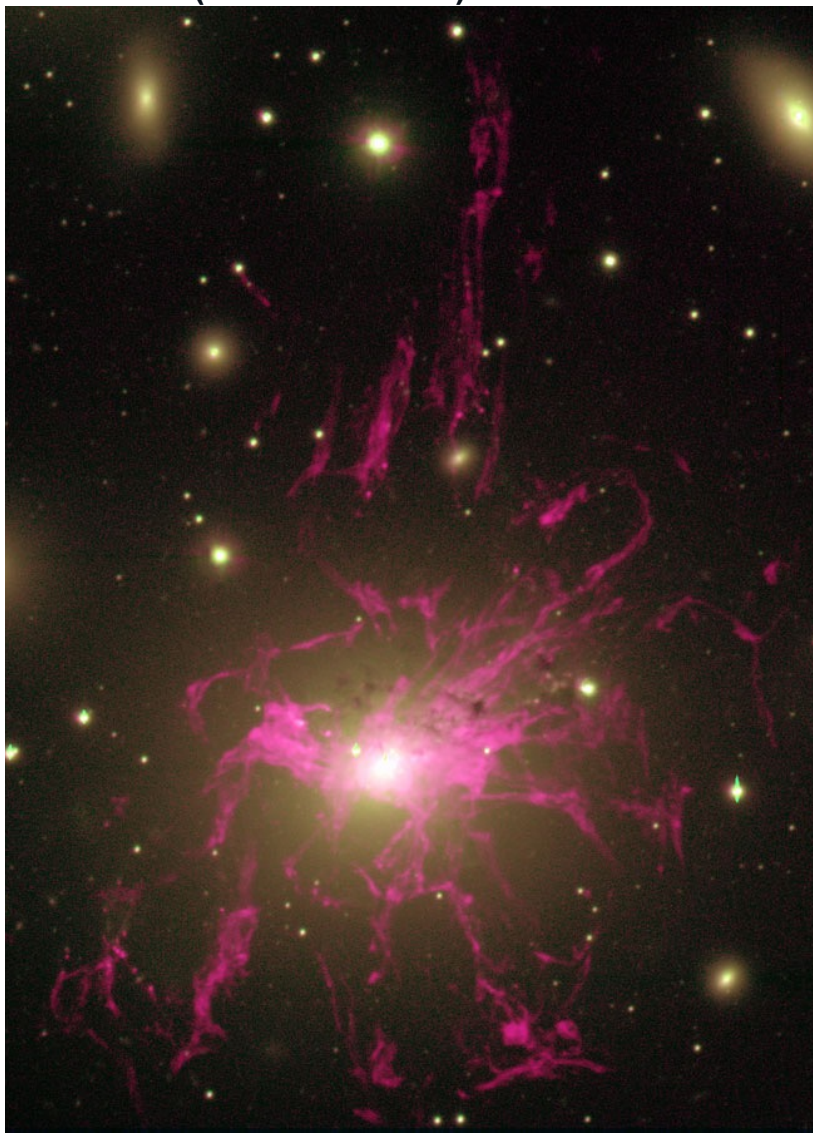
Conselice et al. 2001.

Vigneron, Hlavacek-L. et al. 2022, in prep



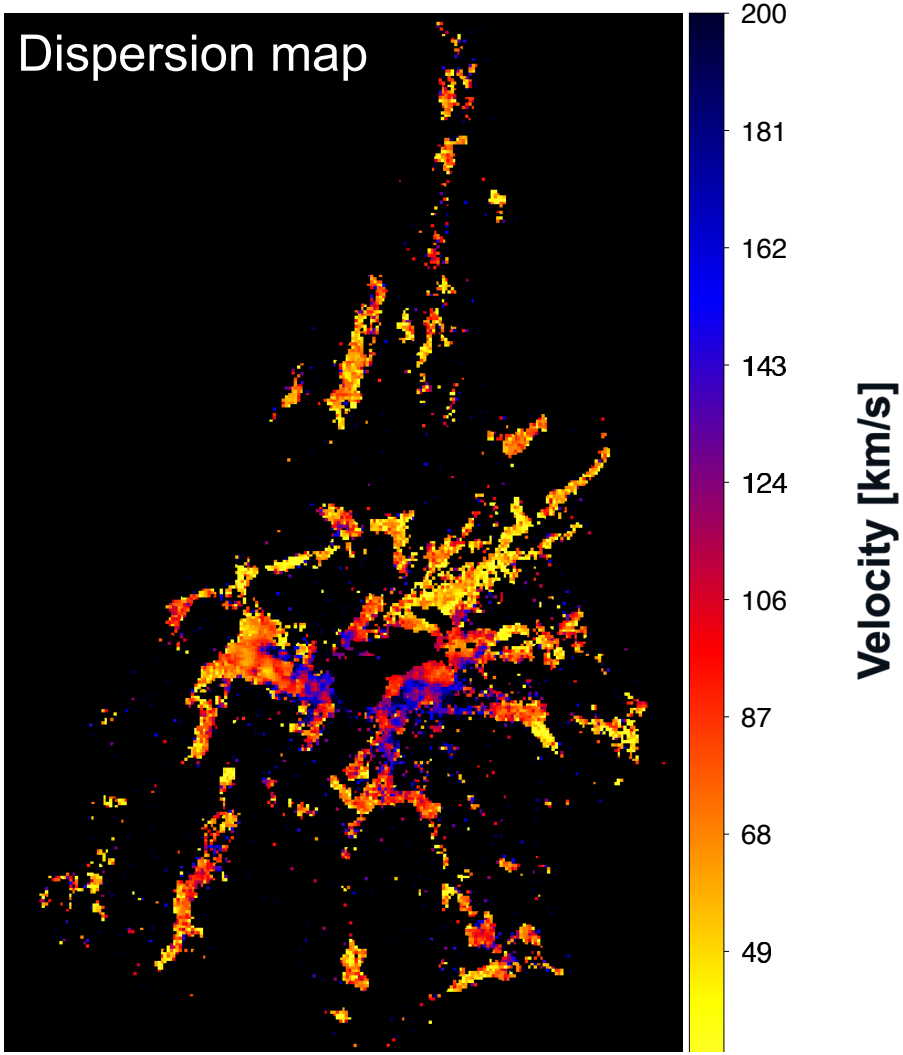
# New SITELLE Observations of NGC 1275

NGC 1275 (Hα continuum)



Conselice et al. 2001.

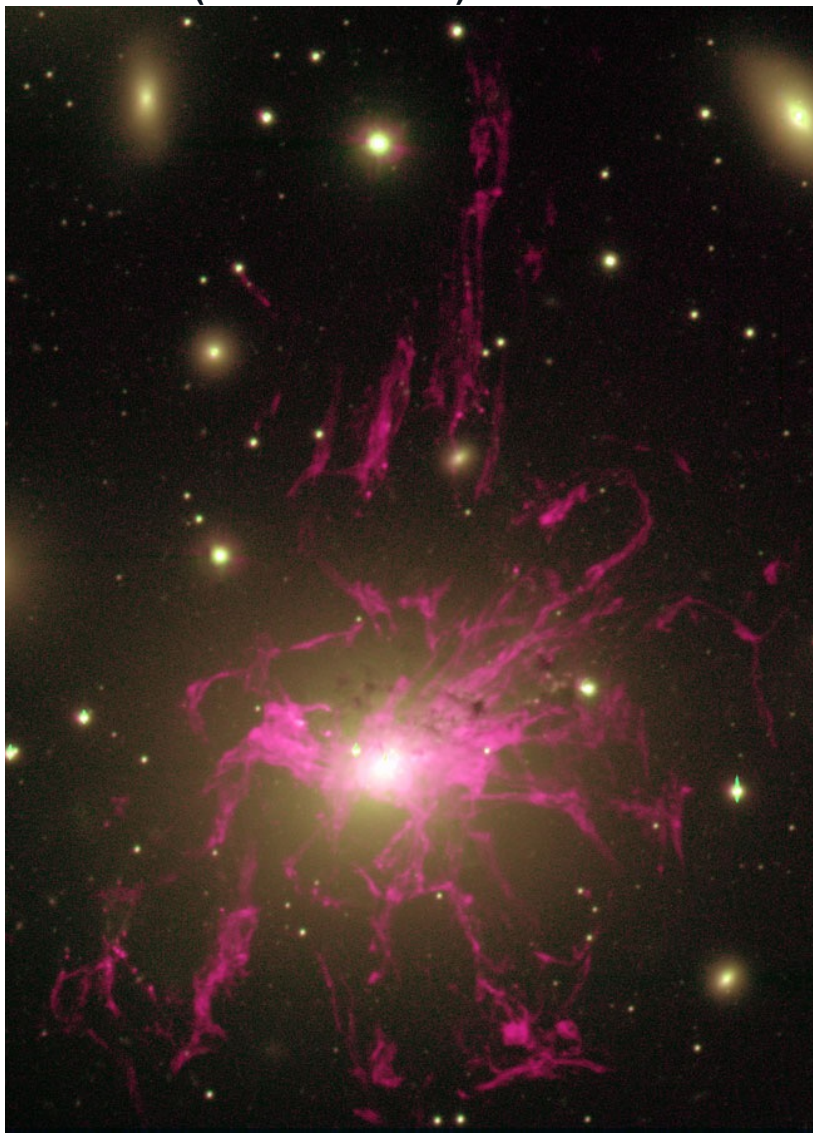
NGC 1275 (R=1800; Hα dispersion)




Gendron-Marsolais, Hlavacek-L. et al. 2018

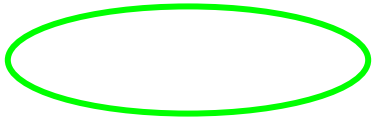
# New SITELLE Observations of NGC 1275

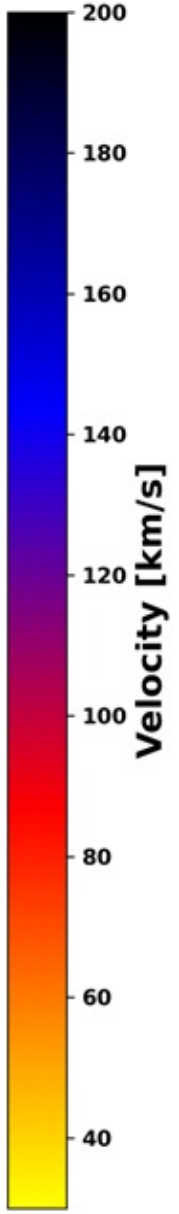
NGC 1275 (Hα continuum)



Conselice et al. 2001.

Vigneron, Hlavacek-L. et al. 2022, in prep





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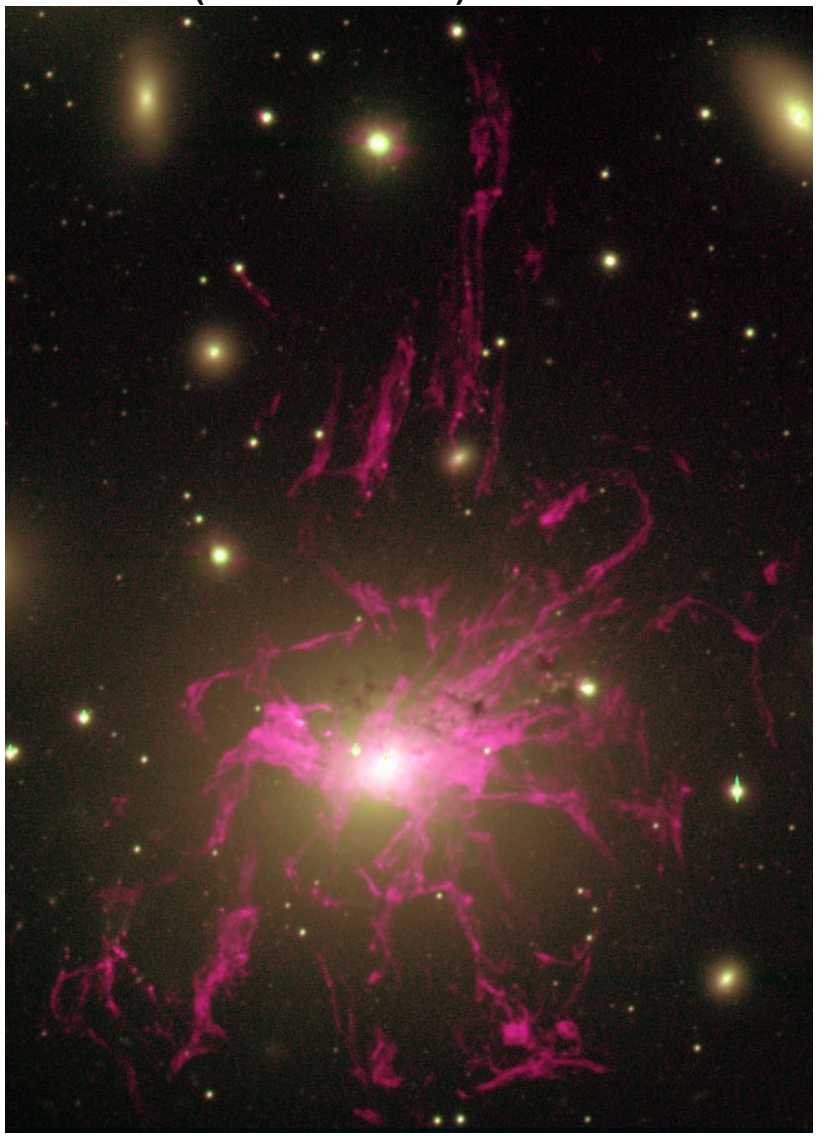
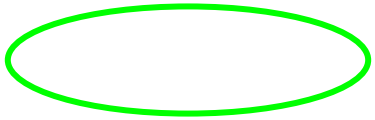
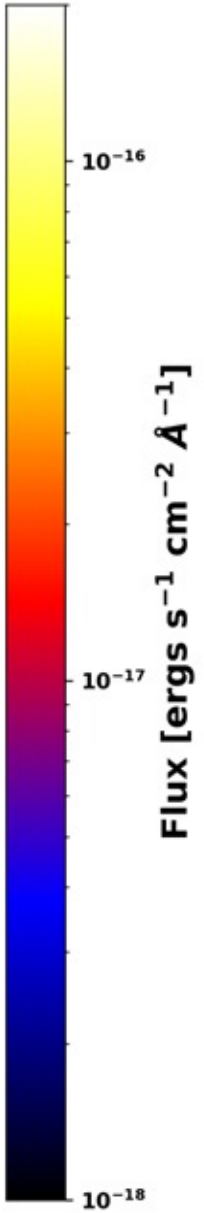
NGC 1275 (Hα continuum)



Conselice et al. 2001.

Vigneron, Hlavacek-L. et al. 2022, in prep





# New SITELLE Observations of NGC 1275

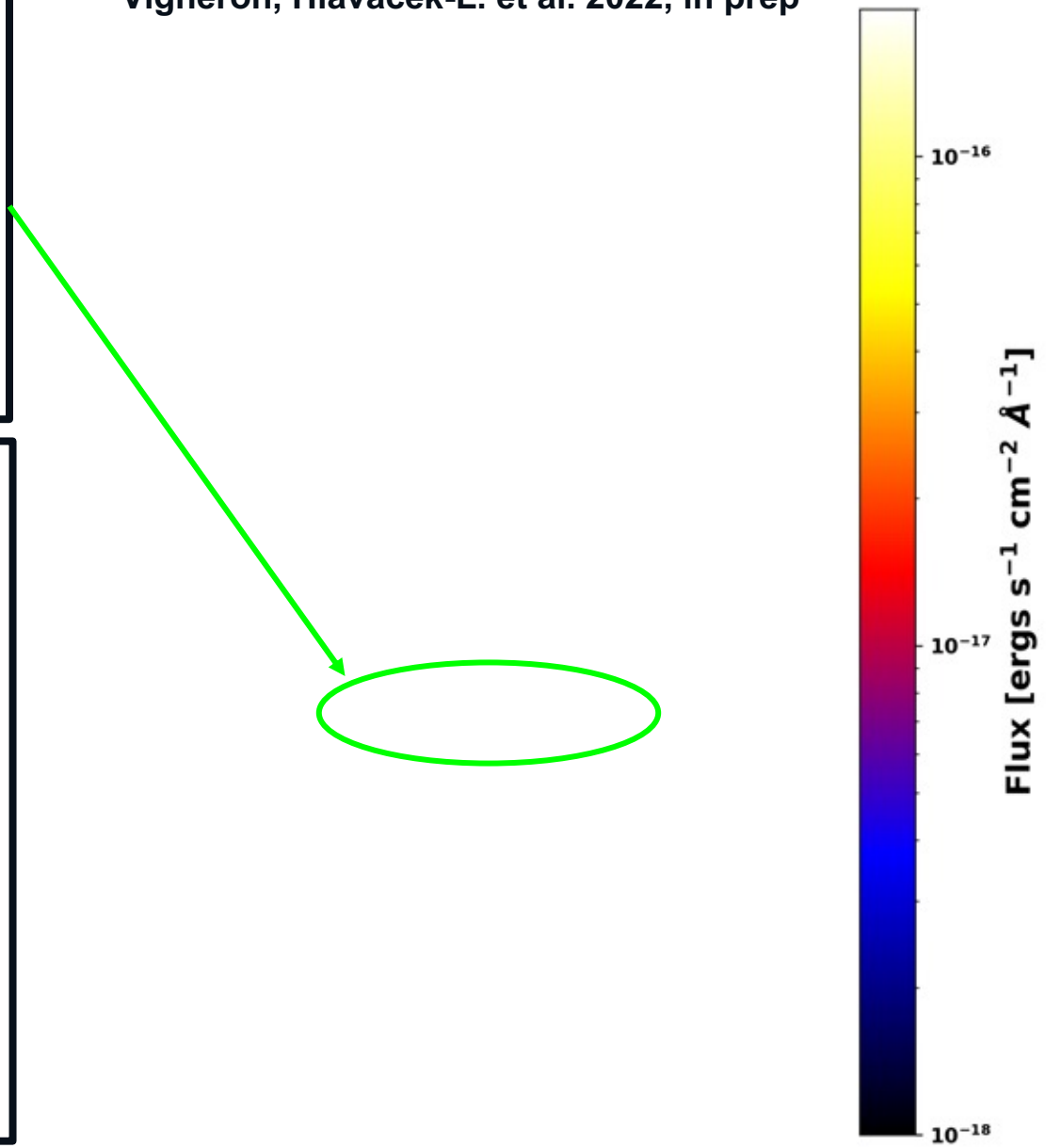
Vigneron, Hlavacek-L. et al. 2022, in prep

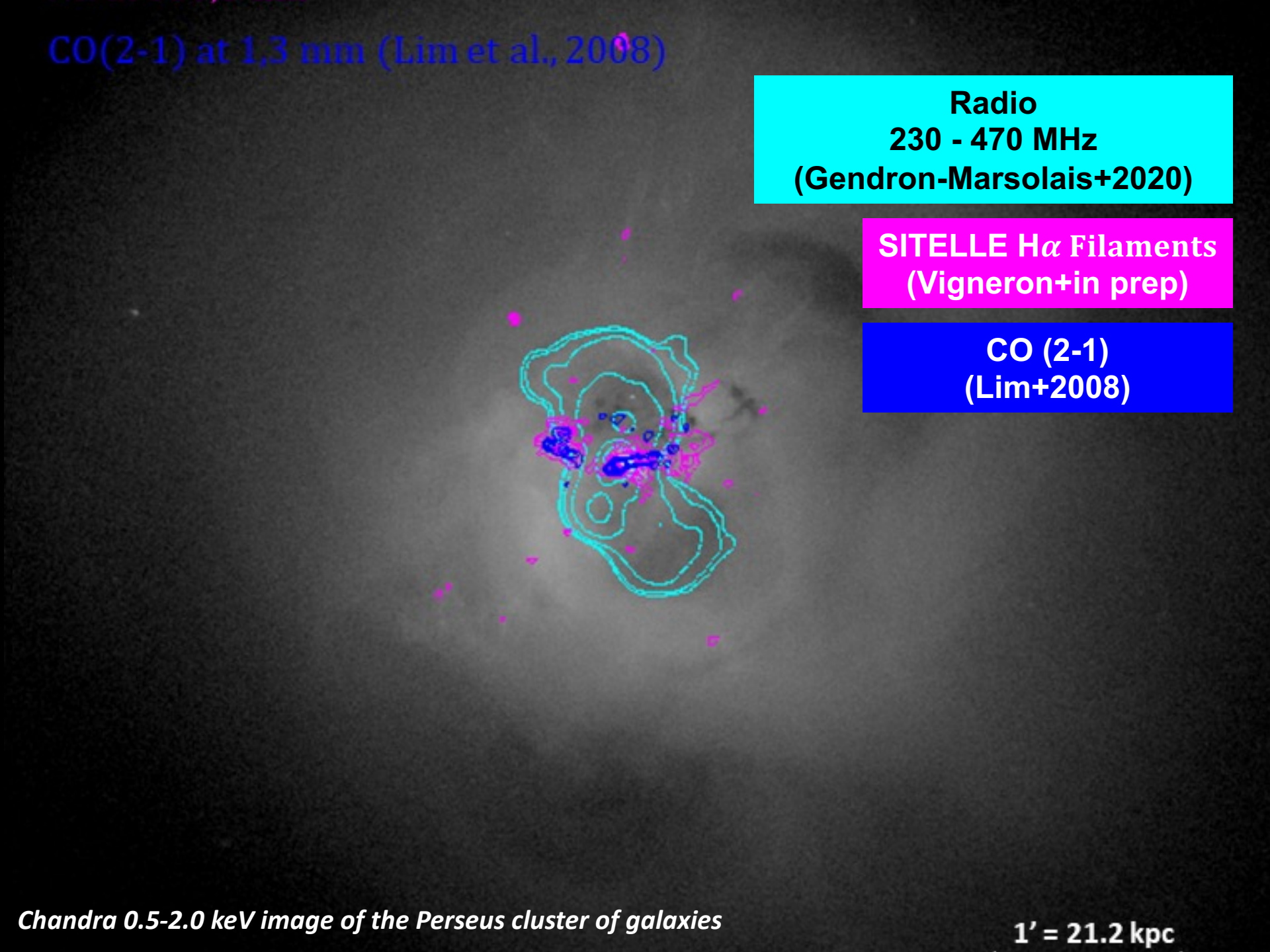
## Disk-like Structure

- 25 kpc by 10 kpc
- High flux at Hα, NII, SII
- $\sigma \cong$ 160 km/s
- No rotation

## Extended Filaments

- 90 kpc by 60 kpc
- Low flux (10 times fainter) at Hα, NII, SII – that is remarkably uniform.
  *Also 10 times fainter in CO (Salome+2011).
- **$\sigma \cong$ 50 km/s – that is remarkably uniform.**
- Chaotic velocity structure




CO(2-1) at 1,3 mm (Lim et al., 2008)
Radio
230 - 470 MHz
(Gendron-Marsolais+2020)
SITELLE Hα Filaments
(Vigneron+in prep)
CO (2-1)
(Lim+2008)
Chandra 0.5-2.0 keV image of the Perseus cluster of galaxies
1' = 21.2 kpc

# Implications: 2 mechanisms form filaments

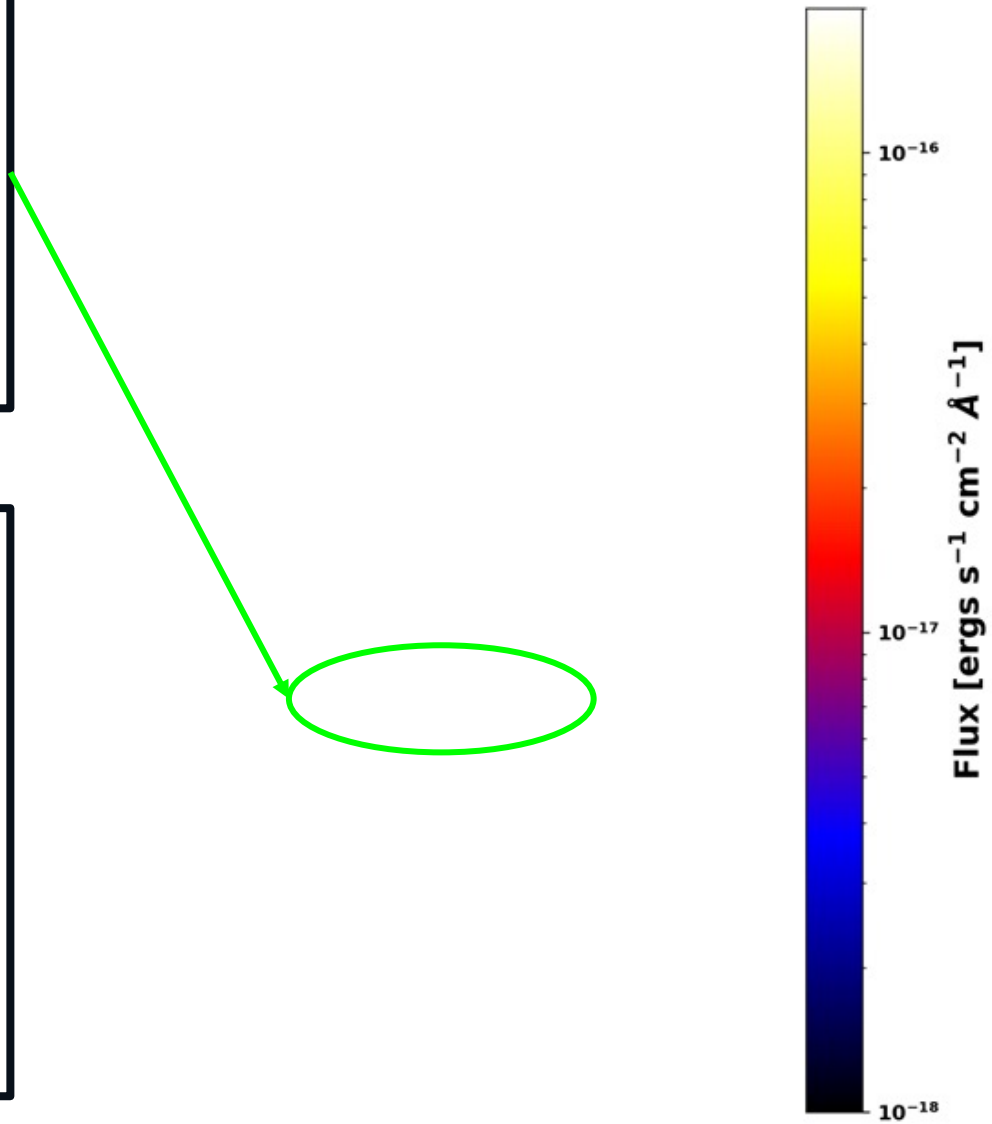
**Mechanism 1:**
**Instabilities in the wake of bubbles**

→ **Localised** to the wake of bubbles.
→ Leads to brighter and more turbulent ($\sigma \cong$ 160 km/s) H$\alpha$ filaments.
→ **Mechanism that is more turbulent.**

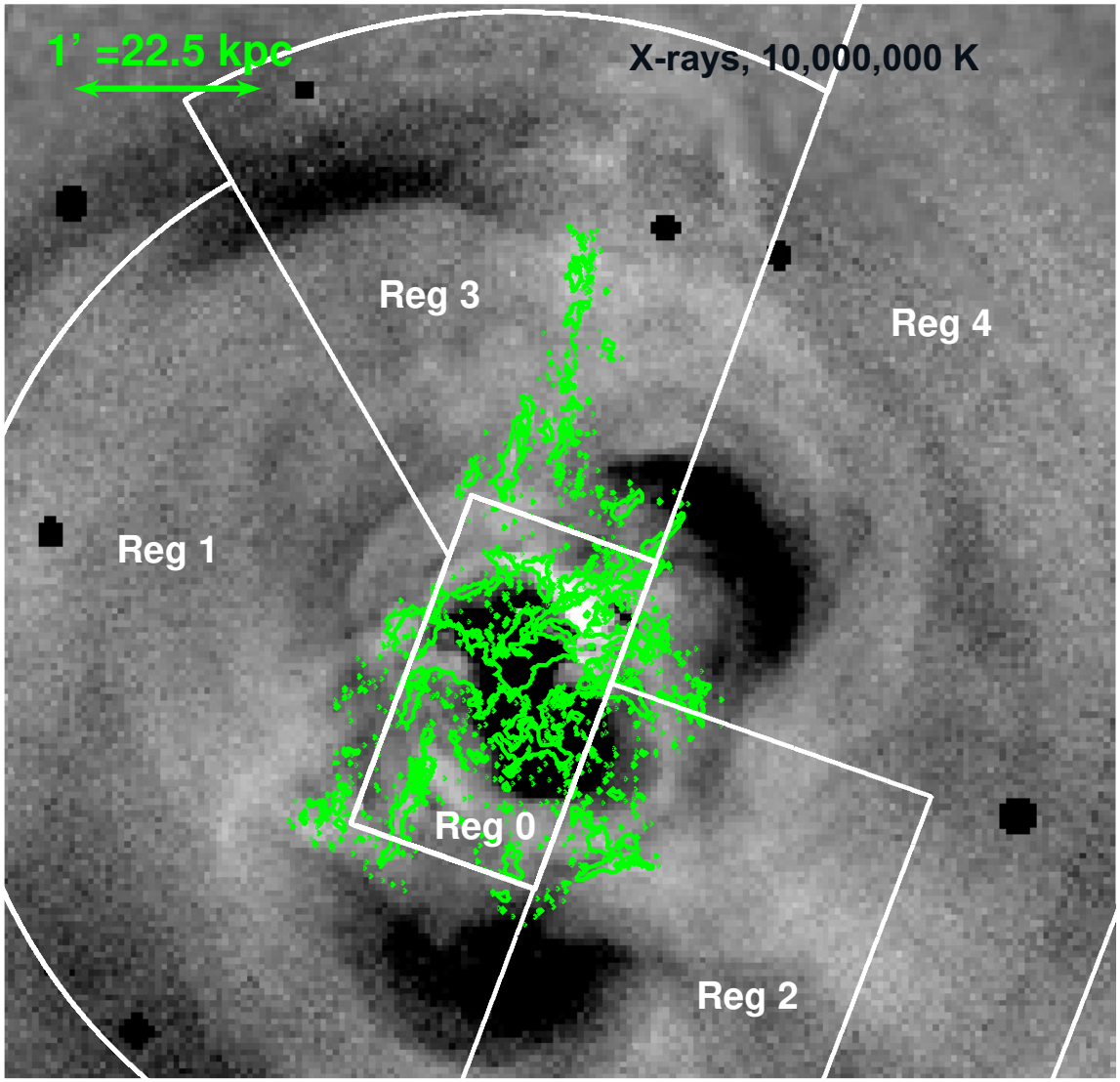
**Mechanism 2:**
**Instabilities throughout the cool core**

→ **Spread out uniformly** throughout the cool core.
→ Leads to a web of filaments that are faint and quiescent ($\sigma \cong$ 50 km/s).
→ **Mechanism is more gentle and isotropic.**

Vigneron, Hlavacek-L. et al. 2022, in prep



# SITELLEObservations of NGC 1275




**Take Home Point**

→ **Reg 0:**

$\sigma_{v,Hitomi} = 189^{+19}_{-18}$ km/s

$\sigma_{v,H\alpha} = 184$ km/s

→ **Reg 3:**

$\sigma_{v,Hitomi} = 106^{+20}_{-20}$km/s

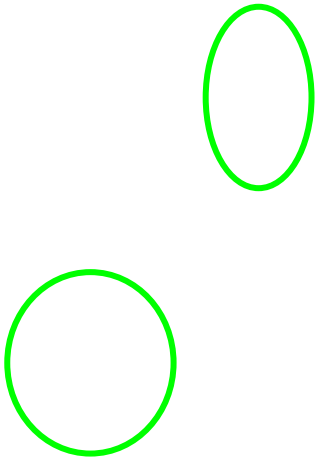
$\sigma_{v,H\alpha} = 82$ km/s

→ **Velocity dispersion of the 10,000 K gas similar to the hot X-ray gas (Hitomi collab 2017), i.e. they might be subject to the same turbulence/mouvements.**

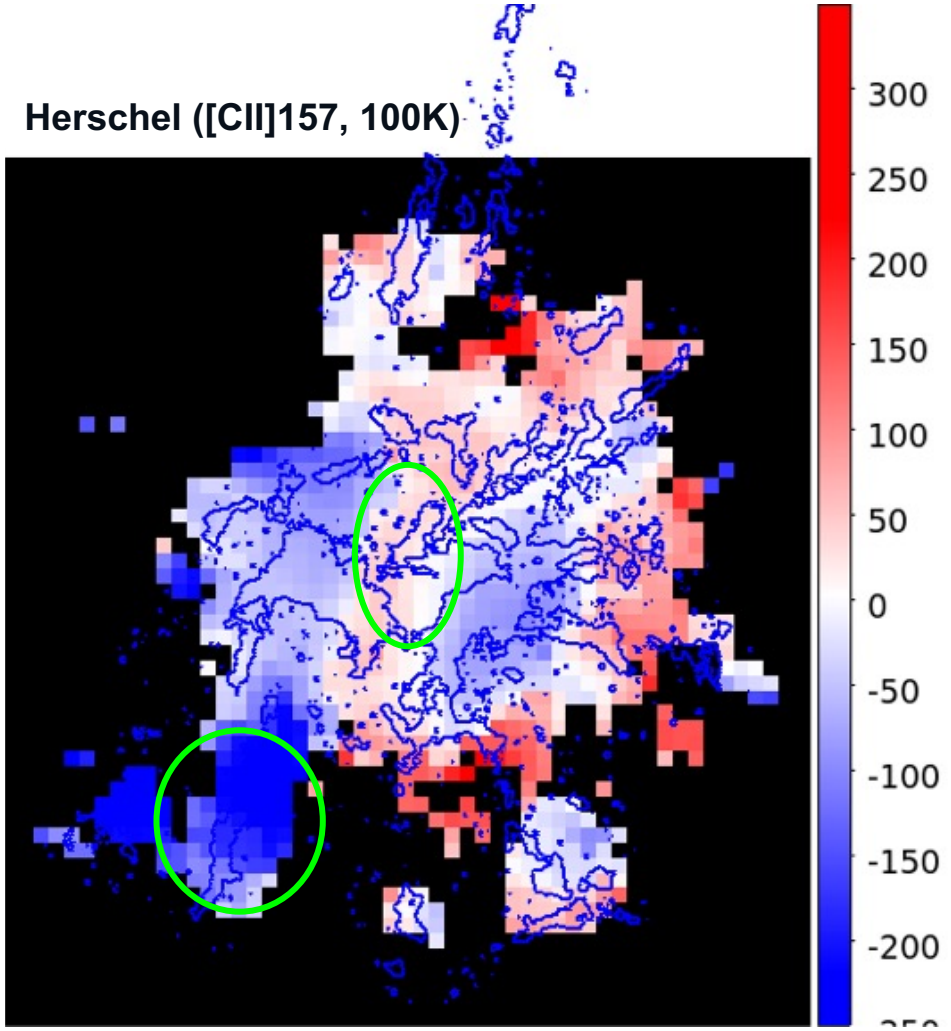
Gendron-Marsolais, JHL et al. 2018; Vigneron, Hlavacek-Larrondo et al. in prep.

# SITELLE Observations of NGC 1275

SITELLE (Hα, 10,000K)



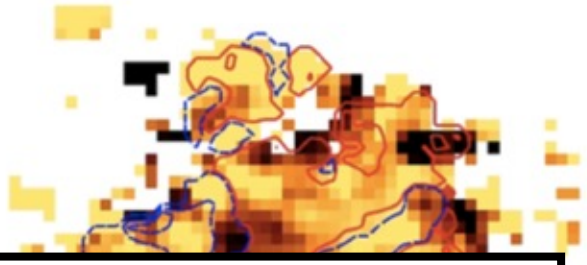
Herschel ([CII]157, 100K)




Vigneron, Hlavacek-Larrondo et al. in prep.

Mittal et al. 2012

# SITELLE Observations of NGC 1275



**Take Home Point**

→ **Warm (10,000 K) and cold gas (< 100 K) are co-spatial AND have SAME kinematics in NGC 1275.**

→ **However….cold gas is more chaotic/turbulent...agrees with idea that hot particles can excite/heat cold gas and prevent it from forming stars (e.g. Canning et al. 2016).**

600

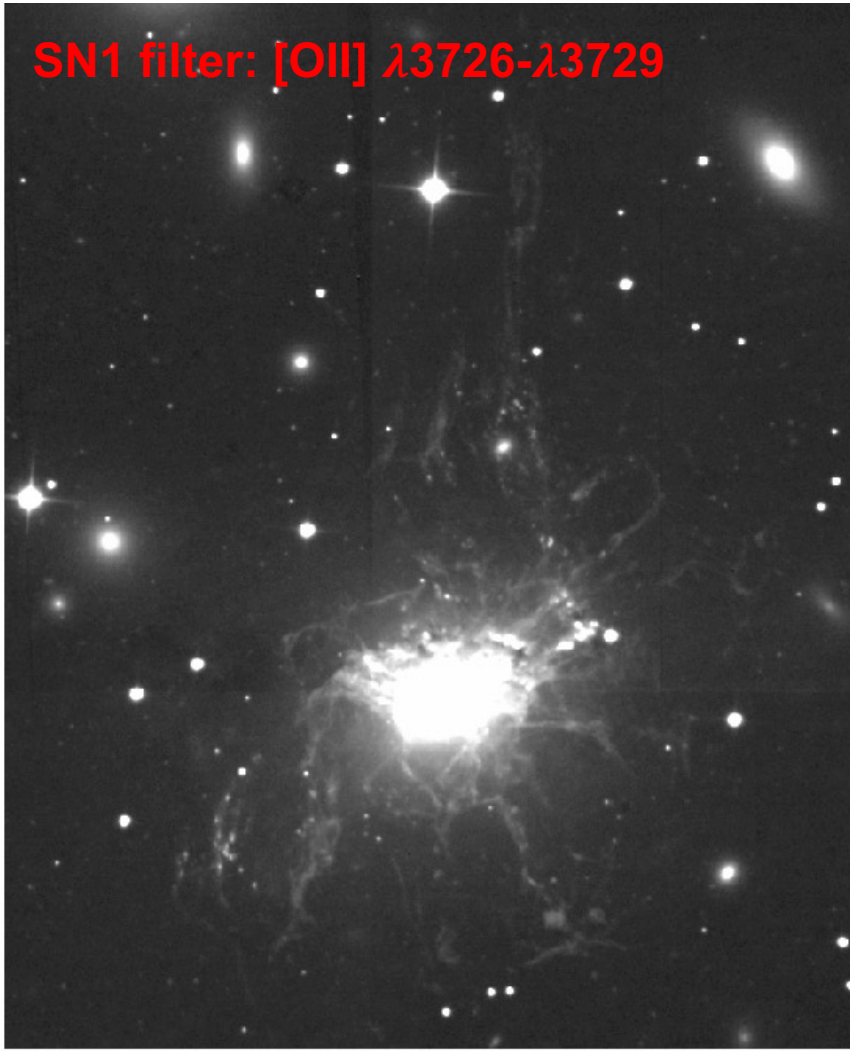
urs corre-
l contours
the upper

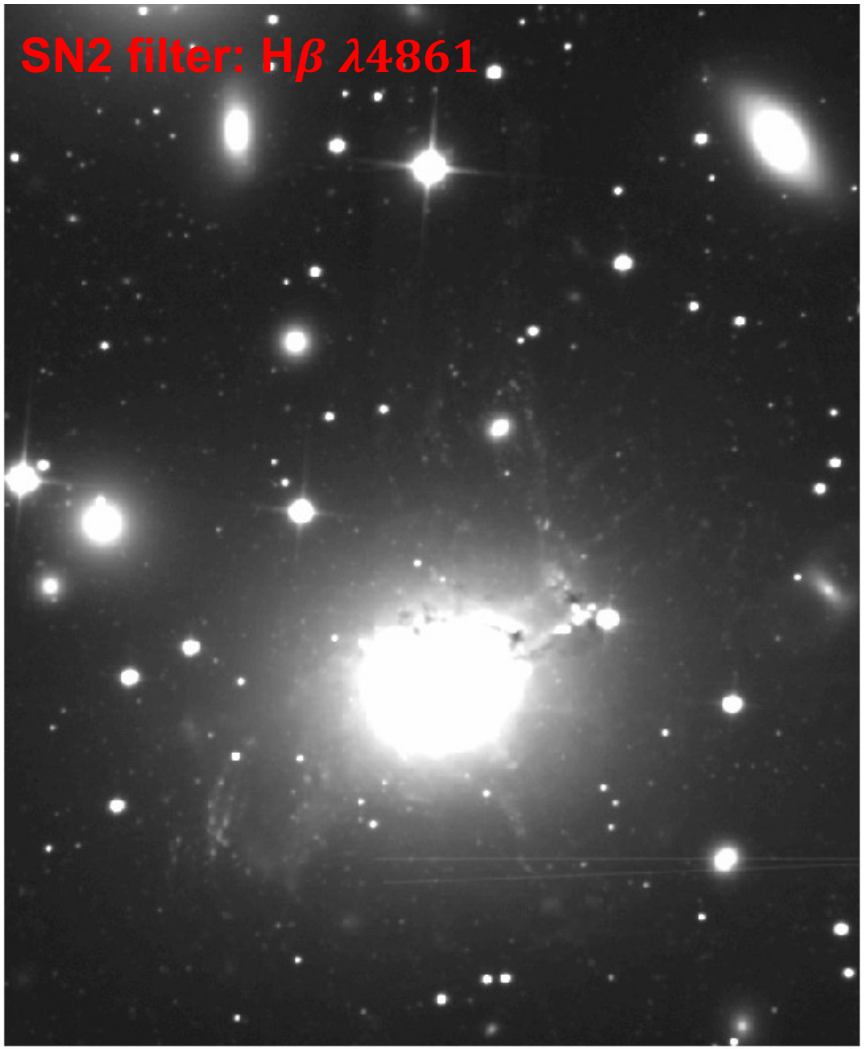
right panel of Fig. 5).

**Mittal et al. 2012**

**Vigneron, Hlavacek-Larrondo et al. in prep.**

# SITELLE Observations of NGC 1275




Thilloy, Hlavacek-Larrondo et al. in prep.

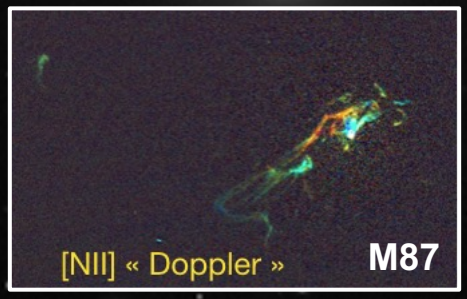
# Take Home Points

→ New SITELLE Observations of the filaments in the Perseus cluster at high-spectral resolution (R=7000).

→ Two mechanisms that lead to filaments:

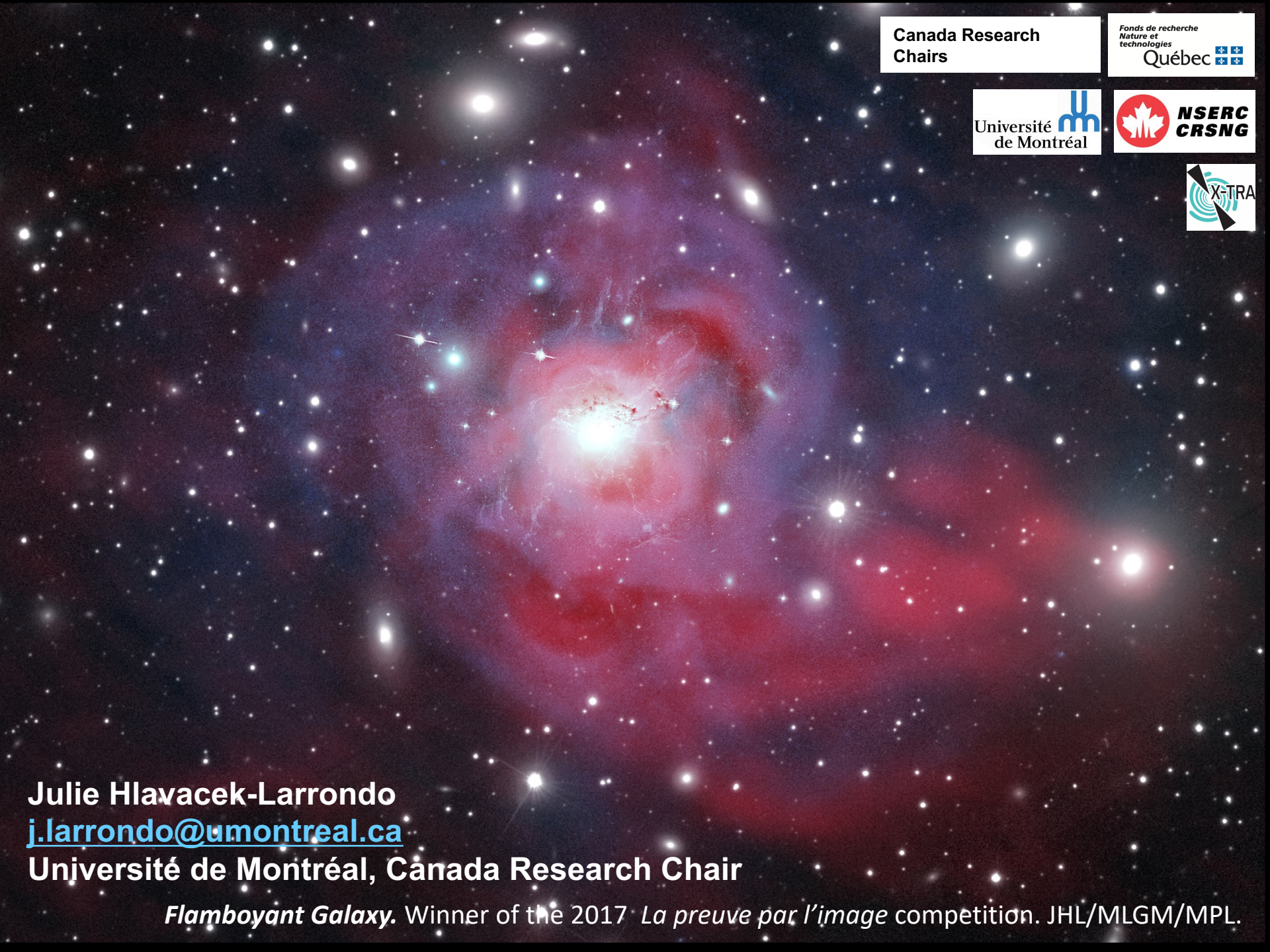
1) Turbulence generated in the wake of bubbles leads to brighter, more turbulent filaments (high $\sigma$).
2) Largely spread turbulence that leads to a uniform web of filaments that are faint and quiescent (lower $\sigma$).

See Vingeron, Hlavacek-Larrondo et al. in prep




# Future with SITELLE

→ NGC1275: Hβ and [OII] (Thilloy+in prep).
→ M87: Hα, [NII], [SII], Hβ and [OII] (Guité+in prep)
→ NGC 5813: Hα, [NII], [SII], Hβ and [OII] (PI Hlavacek-L.).



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***Flamboyant Galaxy.*** Winner of the 2017 *La preuve par l'image* competition. JHL/MLGM/MPL.