Using HAWC+ to Find A Cold Quasar's Place in AGN Feedback

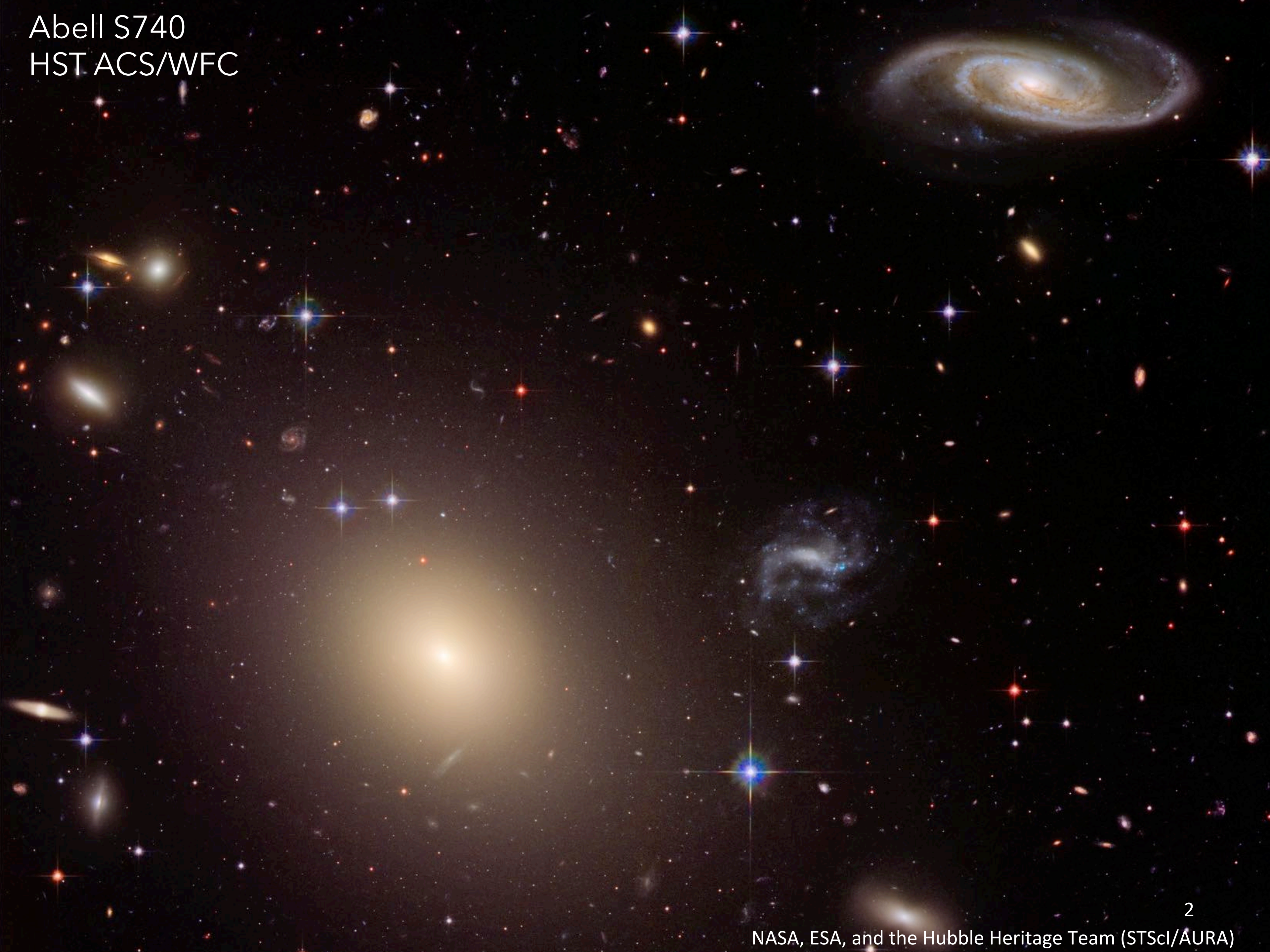
Dr. Kevin C. Cooke
University of Kansas

Allison Kirkpatrick, Michael Estrada, Hugo Messias, Alessandro Peca, Nico Cappelluti, Tonima Tasnim Ananna, Jason Brewster, Eilat Glikman, Stephanie LaMassa, T.K. Daisy Leung, Jonathan R. Trump, Tracey Jane Turner, Meg Urry

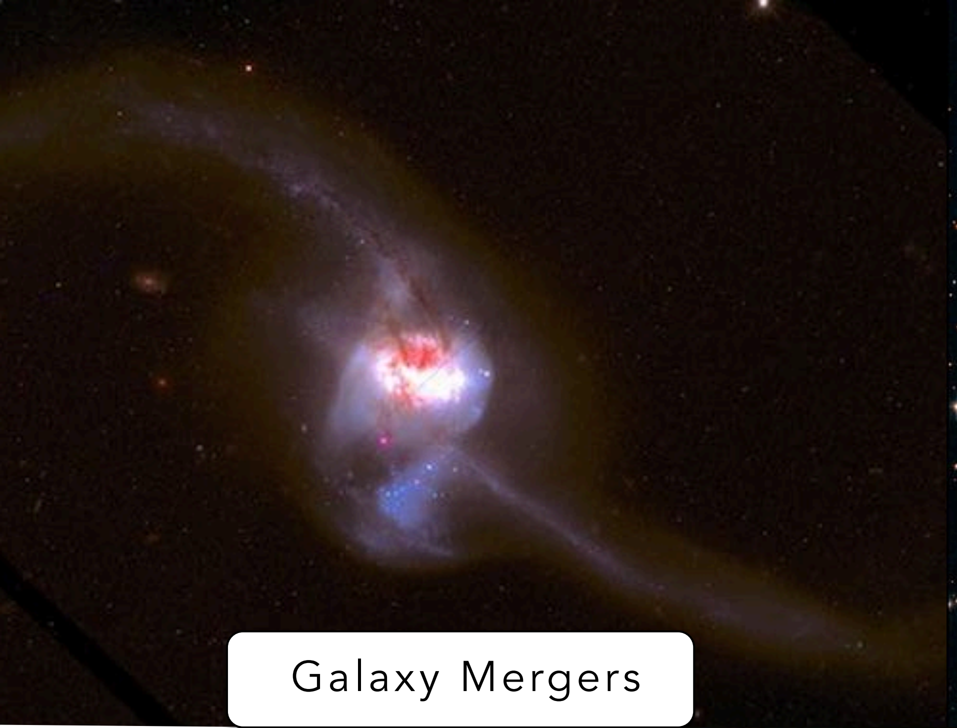
SOFIA tele-talk 1-20-21

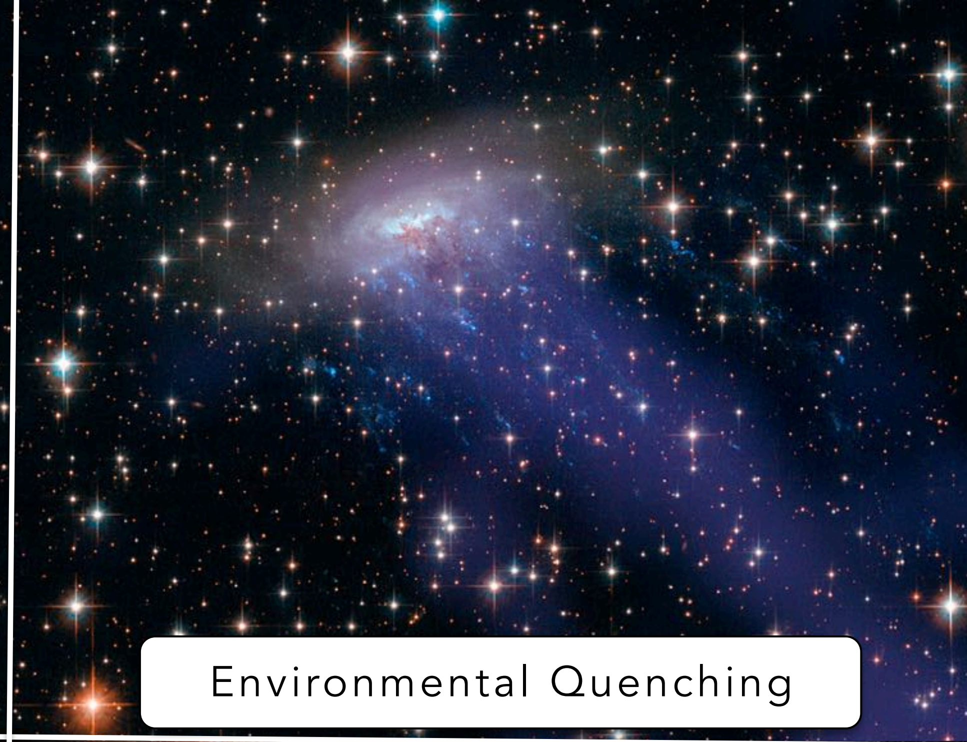
Stratospheric Observatory for Infrared Astronomy

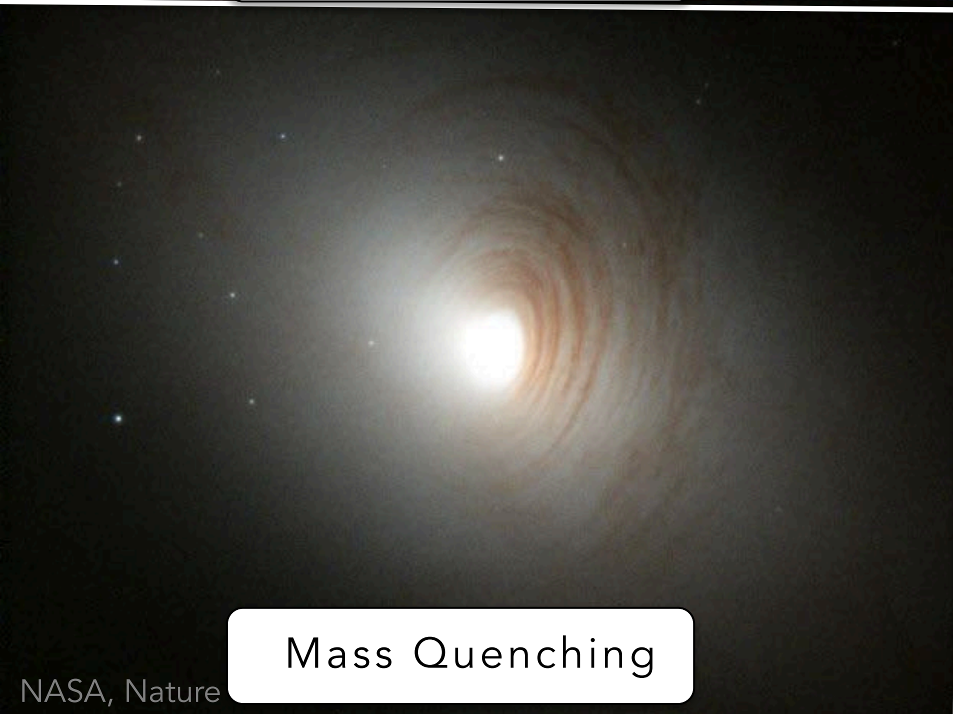
Artist Conception Credit: NASA/ Daniel Rutter



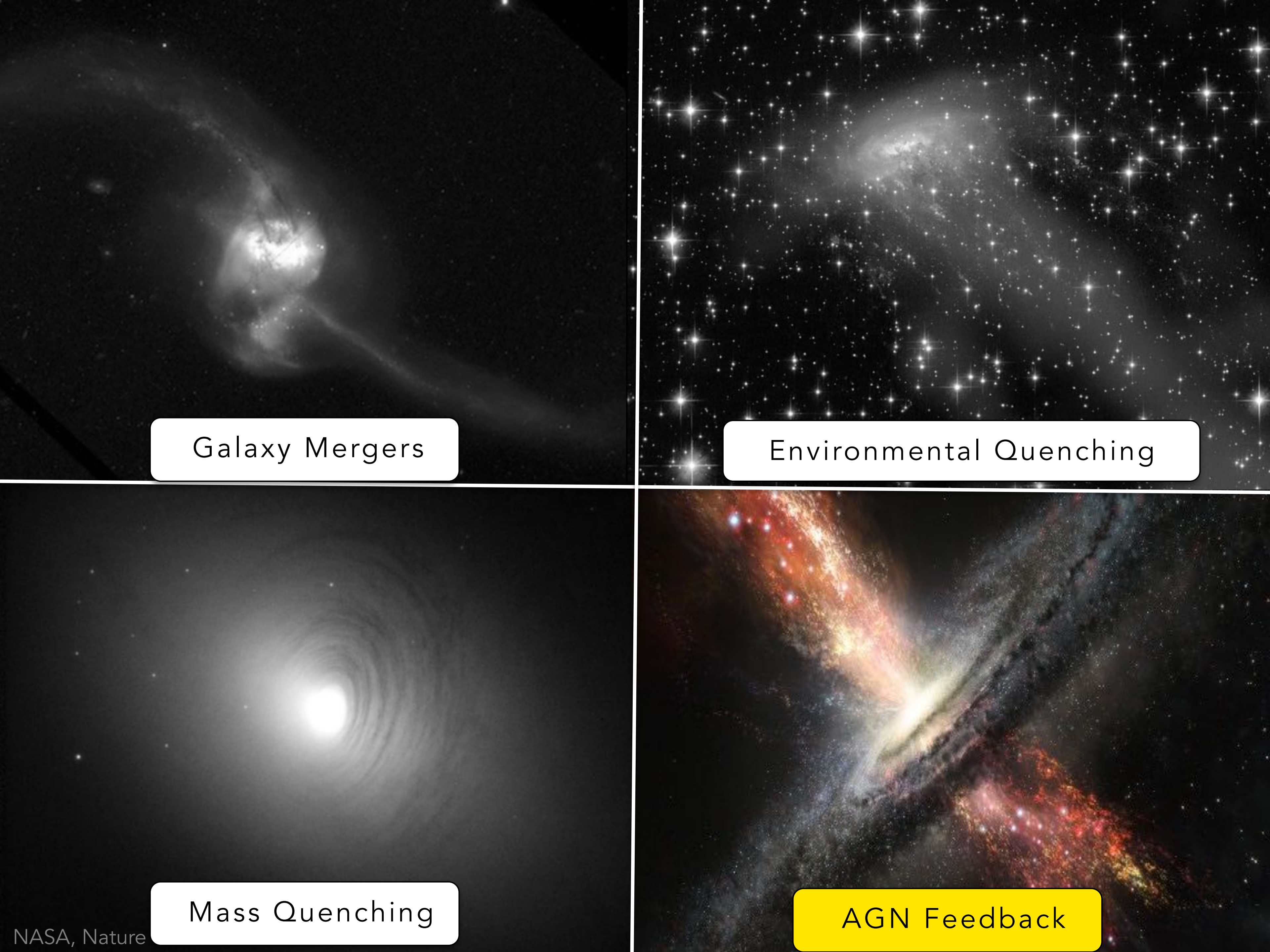
NASA, ESA, and the Hubble Heritage Team (STScI/AURA)


Galaxy Mergers

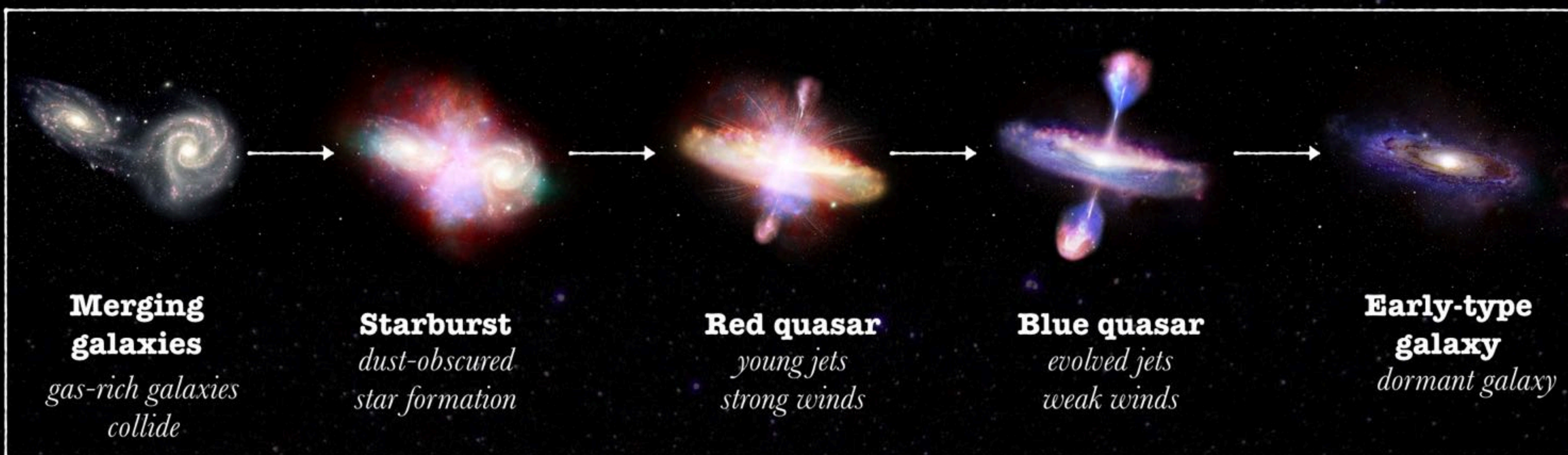

Environmental Quenching


Mass Quenching
NASA, Nature


AGN Feedback

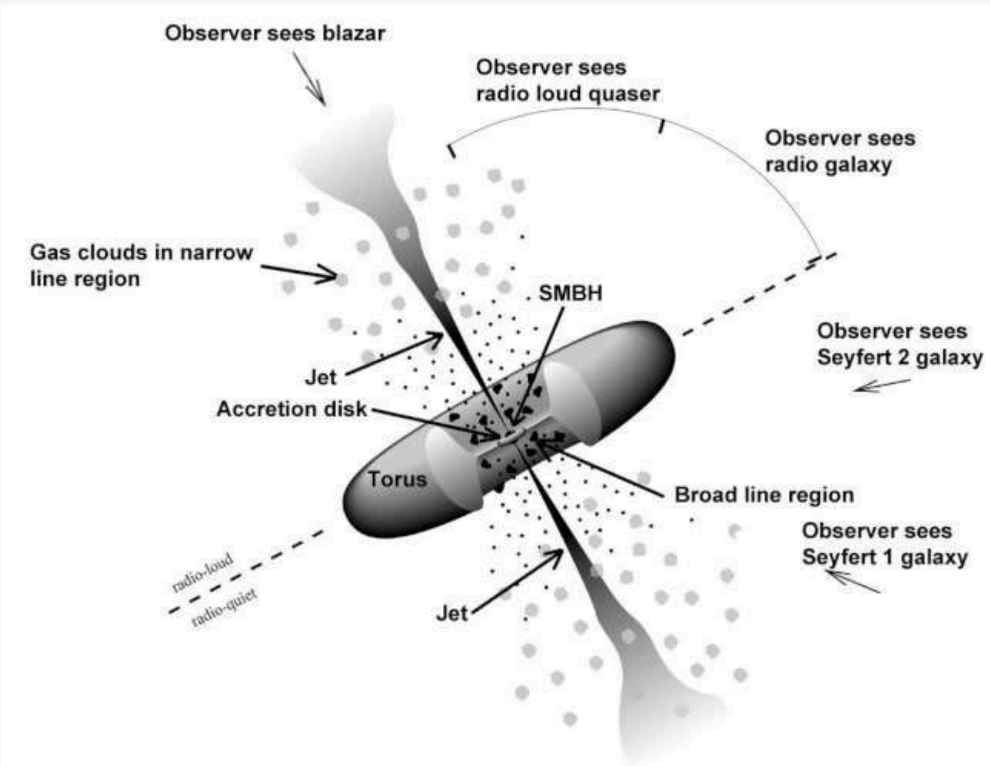

Galaxy Mergers
Environmental Quenching
Mass Quenching
AGN Feedback
NASA, Nature

SF SHUTDOWN DUE TO AGN



Gemini Observatory, GMOS-South, NSF, S. Munro

WHAT MAKES THIS DIFFICULT TO OBSERVE?



AGN Unified Model
Urry & Padovani (1995)
https://fermi.gsfc.nasa.gov/science/eteu/agn/

- AGN get many names for the same object.
- Identifying active AGN requires seeing the emission directly from the central engine.
- Optical emission lines can be used to map the broad line region.
- X-ray can be used to estimate the accretion rate.

SF SHUTDOWN DUE TO AGN

- The radiant energy from an actively accreting SMBH can heat and unbind the cold gas component of the host galaxy (e.g. Hopkins et al. 2006).
  - However some targets remain star-forming while X-ray bright (e.g. Salome et al. 2015; Mahoro et al. 2017, Perna et al. 2018).

- Goal: Understand how AGN shut down star-formation
  - Find the rare objects where the cold gas remains while an AGN is active.
    - Far-infrared
  - Find the rare objects where we can estimate how bright the central engine is (a.k.a., how much is the SMBH accreting material?)
    - X-ray, optical

Nature

STRIPE82X SURVEY

- A wide field X-ray survey (16.5 deg^2 XMM Newton coverage)
  - Designed to probe the high-z, high luminosity parameter space (LaMassa et al. 2013).
- Utilizes the Stripe 82 region of SDSS as a bedrock to guarantee optical/NIR photometry and limited spectroscopic coverage.
- Field found the first changing look quasar, which changed from unobscured to obscured (LaMassa 2015)
- Component of the Accretion History of AGN (AHA) survey.

STRIPE82X SURVEY - FIR

- Out of the X-ray-optical coverage, 15.6 deg^2 is also contiguously covered by the *Herschel Space Observatory*.
  - Herschel Stripe82 Survey (HerS; Viero et al. 2014)

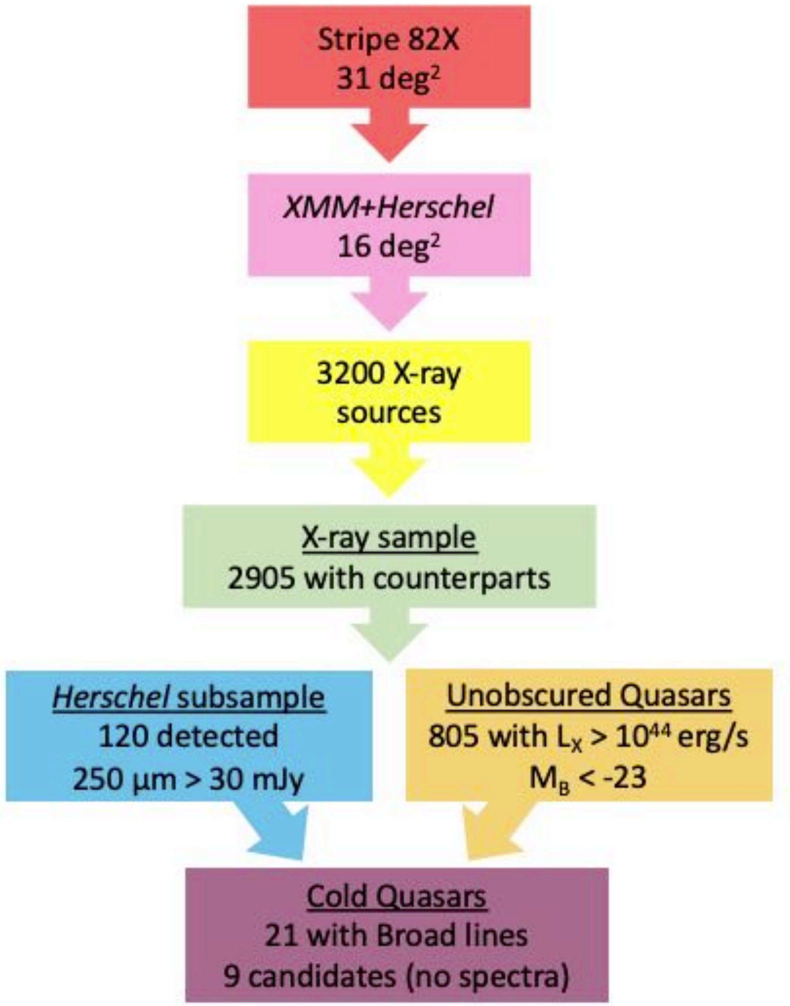
- Observed using SPIRE at 250, 350, and 500 microns.

- AHA team combined this coverage to form the multi-wavelength AHA survey catalog (Ananna et al. 2016)

https://www.herschel.caltech.edu/

IDENTIFICATION OF COLD QUASARS

- Goal of AHA was to identify host characteristics of the brightest AGN.
- When investigating the highest luminosity cases in Stripe82X, 4% of unobscured quasars were detected in the FIR.
- Classified as: "Cold Quasars"



Kirkpatrick et al. (2020)

COLD QUASARS

- Cold quasars are a population of unobscured, IR-detected quasar.
  - $L_x > 10^{44}$ ergs/s
  - $S_{250} > 30$ mJy
  - Combination of X-ray and IR detection selects for the narrow timeframe where the AGN has not cleared the gas.

- Due to the 4% FIR detection rate of X-ray and optically selected quasars, we can loosely constrain their stage to ~10^6 yrs.

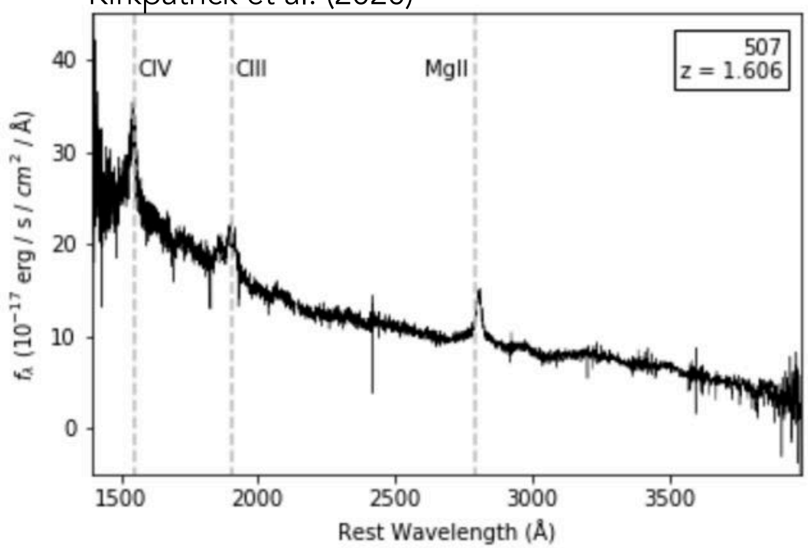
- Span a wide range of host properties and epochs:
  - SFR ~ 200-1000 M/yr
  - $\log_{10}(M_*/M_{sol})$ ~ 10.5-11.2
  - $1 < z <$ ~2.5

COLD QUASAR OPTICAL CHARACTERISTICS

- Feature a compact bright source in SDSS color-composite images, determination of host properties requires looking to longer wavelengths.

- Broad optical emission lines confirm the unobscured classification.

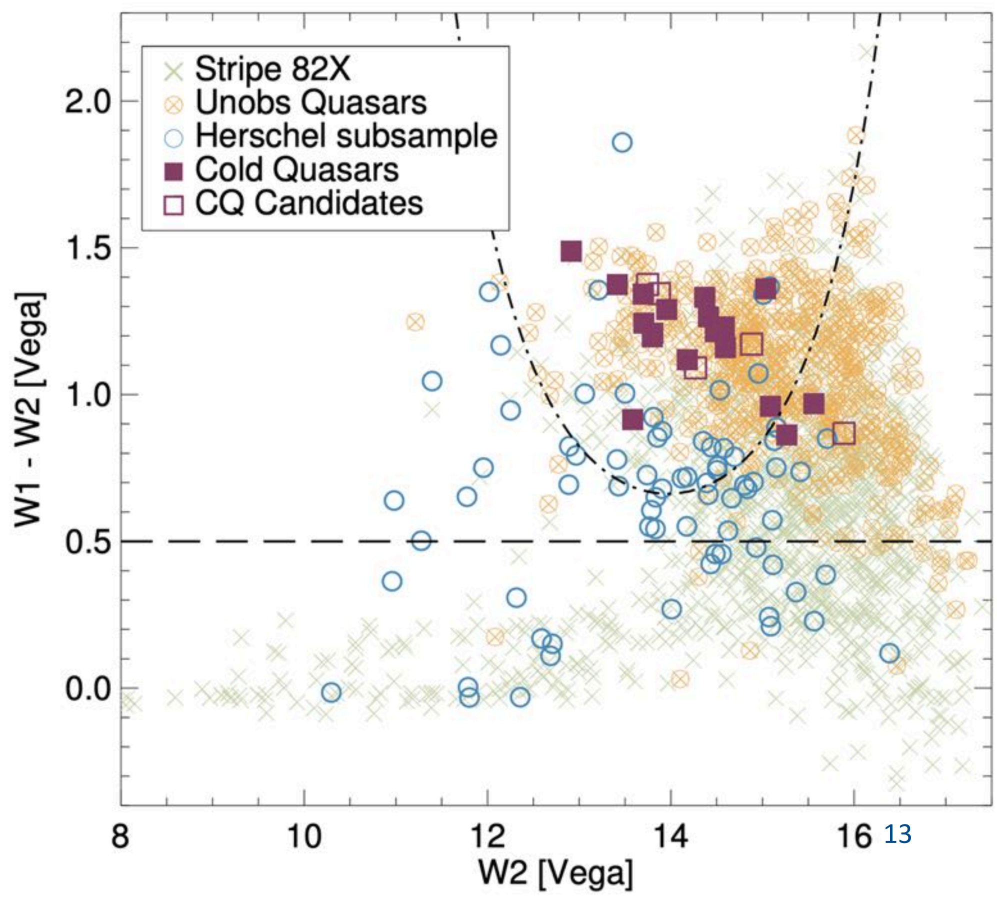
CQ 507, z = 1.6
DECam grz
Kirkpatrick et al. (2020)



COLD QUASAR NIR CHARACTERISTICS

- Cold quasars satisfy NIR AGN classification, such the WISE color criteria of Assef et al. (2018).

- Generally redder and brighter than the unobscured sample (orange) or full Stripe82X sample (green).

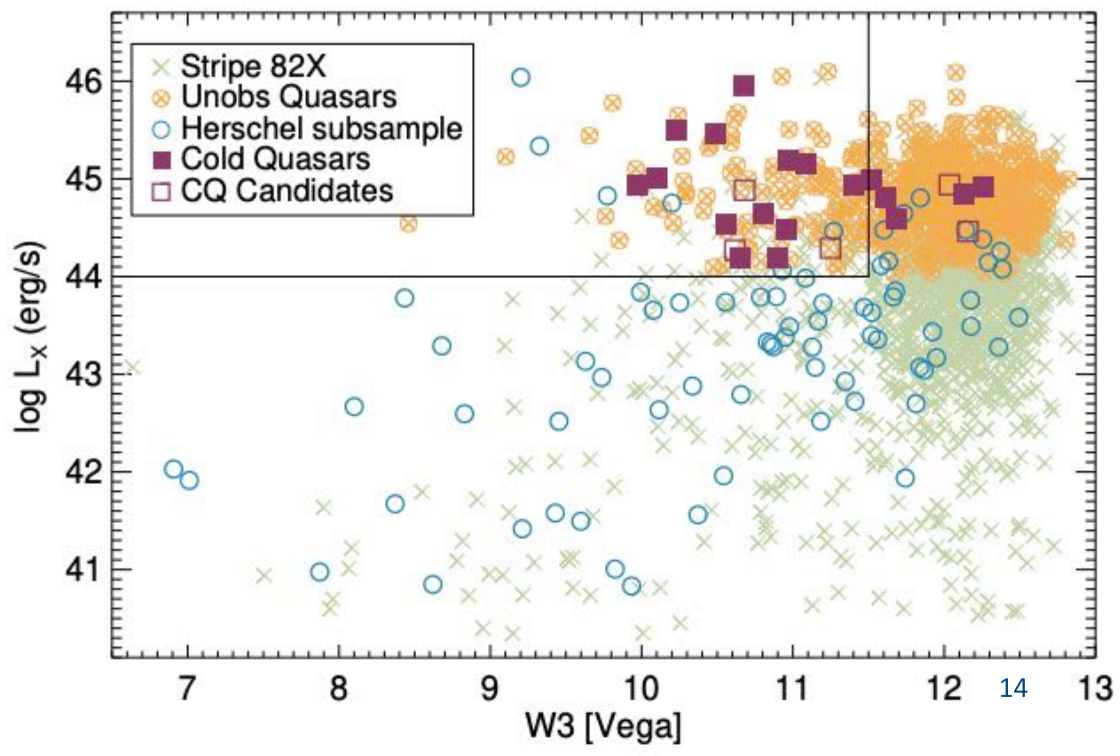


Kirkpatrick et al. (2020)

COLD QUASAR NIR CHARACTERISTICS

- Higher brightness in the longer wavelengths (W3 – 12 microns), sets them apart from the unobscured sample.

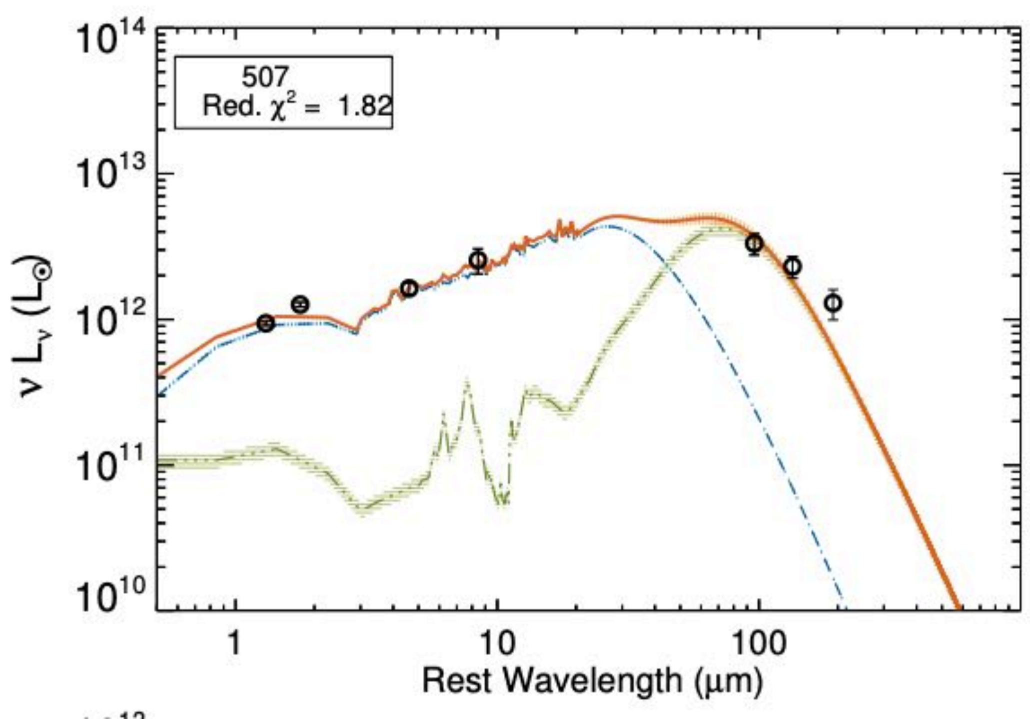
- Interpreted as evidence for a lower optical depth or covering fraction.



Kirkpatrick et al. (2020)

COLD QUASAR SFR ESTIMATION

- SED fitting was performed using the WISE and Herschel photometry using a featureless AGN template (Kirkpatrick 2012) and submillimeter template (Pope 2008).
- Derived SFRs from 300-1300 M/yr!
- However, peak of FIR is loosely constrained



CQ 507, z = 1.6
SFR = 835
Kirkpatrick et al. (2020)

COLD QUASAR SOFIA FOLLOW UP

- Kirkpatrick et al. followed up on a sample of lower X-ray luminosity targets in Stripe82X.
  - Included targets 0.5x the original X-ray cutoff
  - PI: Kirkpatrick: 07-0096

- Proposal targeted cold quasar candidates predicted to be bright in SOFIA HAWC+ FIR bands.
  - Detection would constrain the FIR peak location → Dust Temperature and accurate SFR!

- SOFIA HAWC+ chosen to enable a choice in imaging band to optimize the FIR peak detection for each target.

SOFIA FOLLOW UP

- Guest observing met with technical difficulties at first....
- Engine maintenance meant no flights while I was in California.

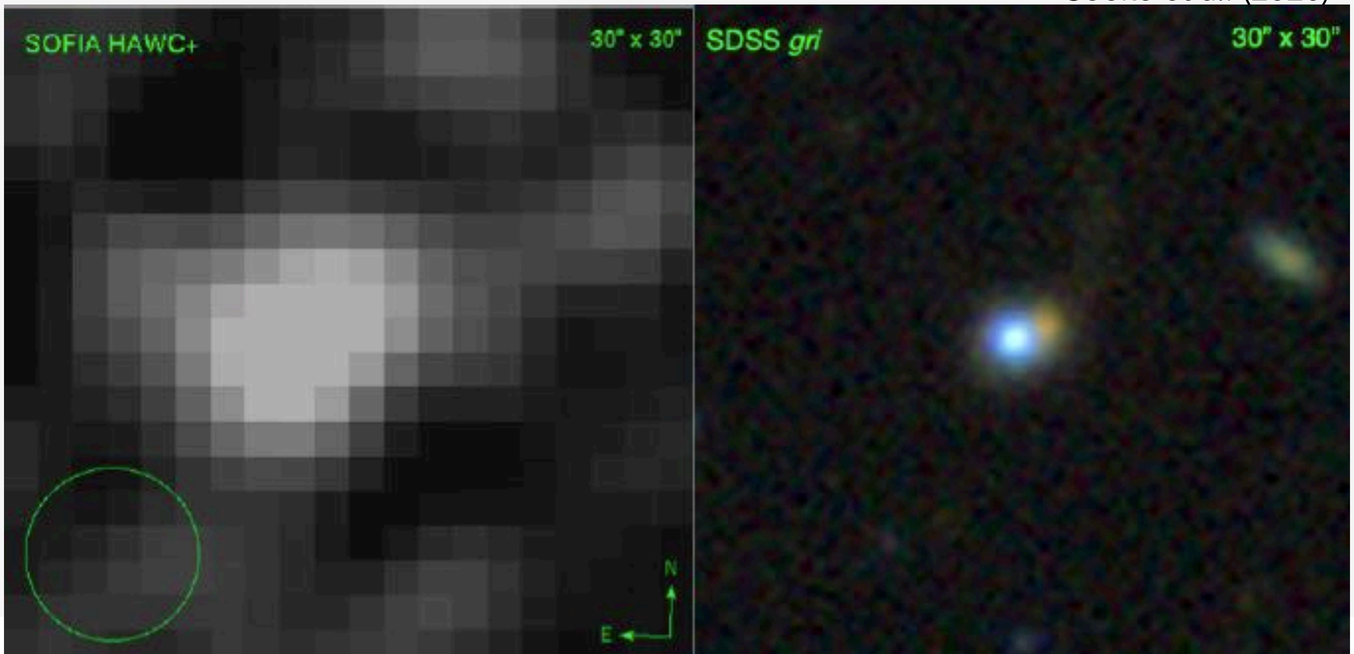
SOFIA FOLLOW UP

- Reduced the images using the CRUSH pipeline in faint mode with help from the SOFIA team.

- 1 strong detection!
  CQ 4479: 75.42 +/-14.2 mJy (SNR = 5.31) at 89um
  z = 0.405

CQ4479

Cooke et al. (2020)



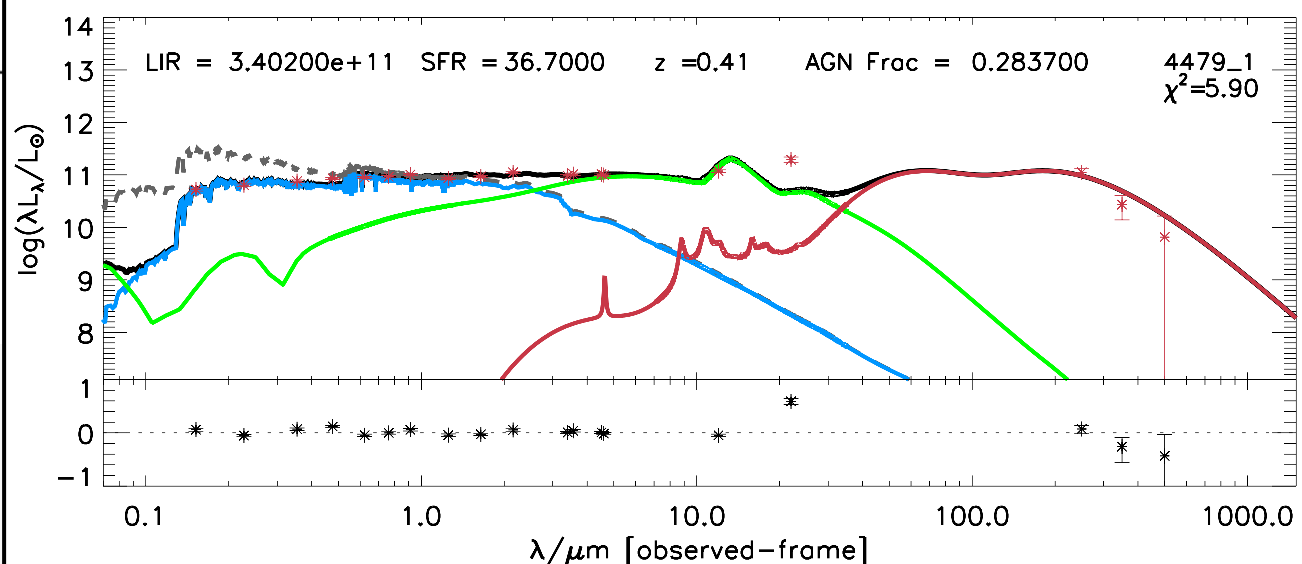
SOFIA'S CRITICAL ROLE

- We use spectral energy distribution (SED) fitting codes with stellar, dust, and AGN components to determine the energy output from each one.
- CIGALE for model customization, SED3FIT for dust temp.

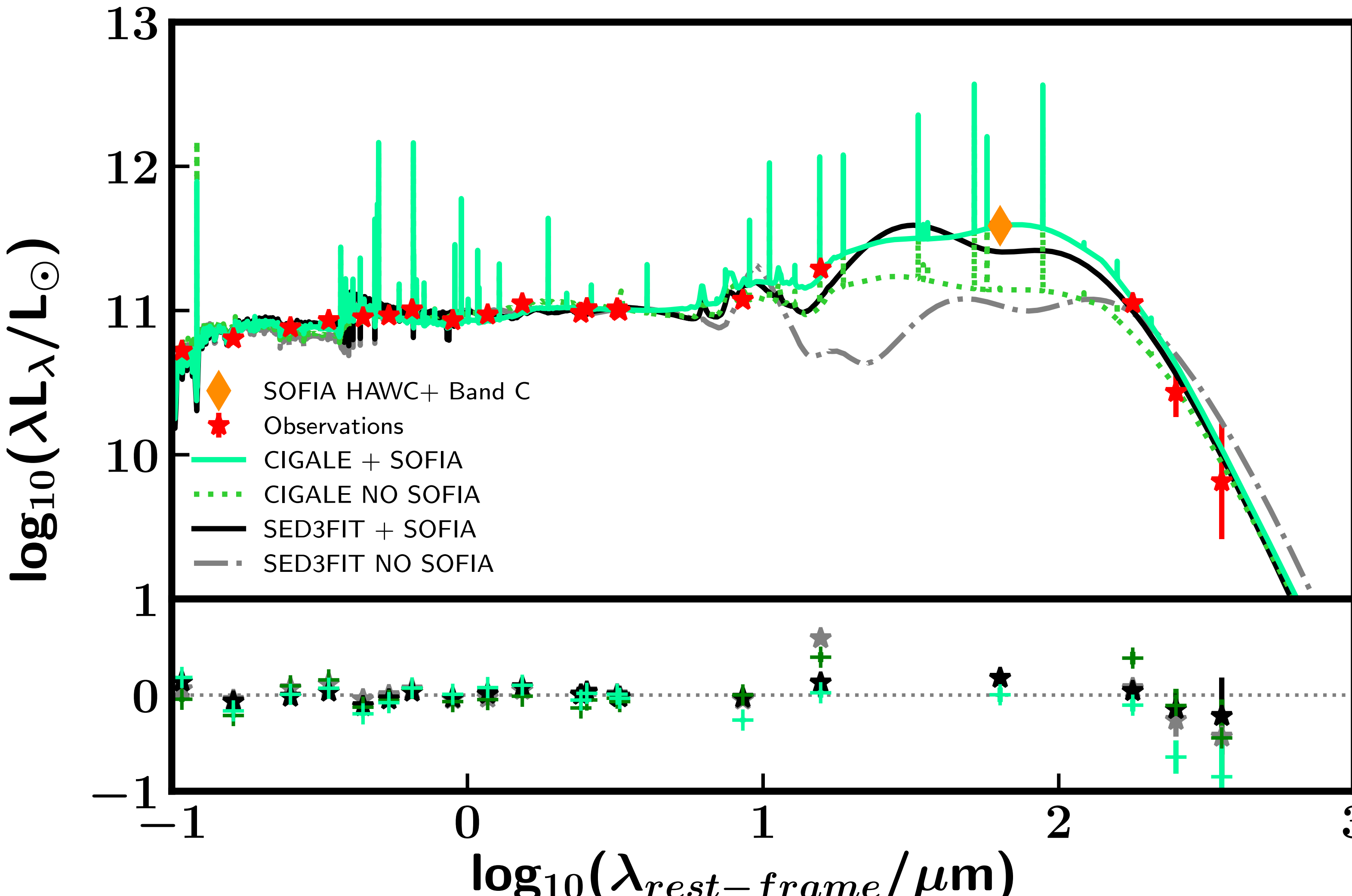
Cooke et al. (2020)

CIGALE w/ SOFIA
Bruzual & Charlot (2003)
Draine et al. (2014)[a]
Fritz et al. (2006)
Chabrier (2003)

SED3FIT w/ SOFIA
Bruzual & Charlot (2003)
da Cunha et al. (2008)
Feltre et al. (2012)
Chabrier (2003)

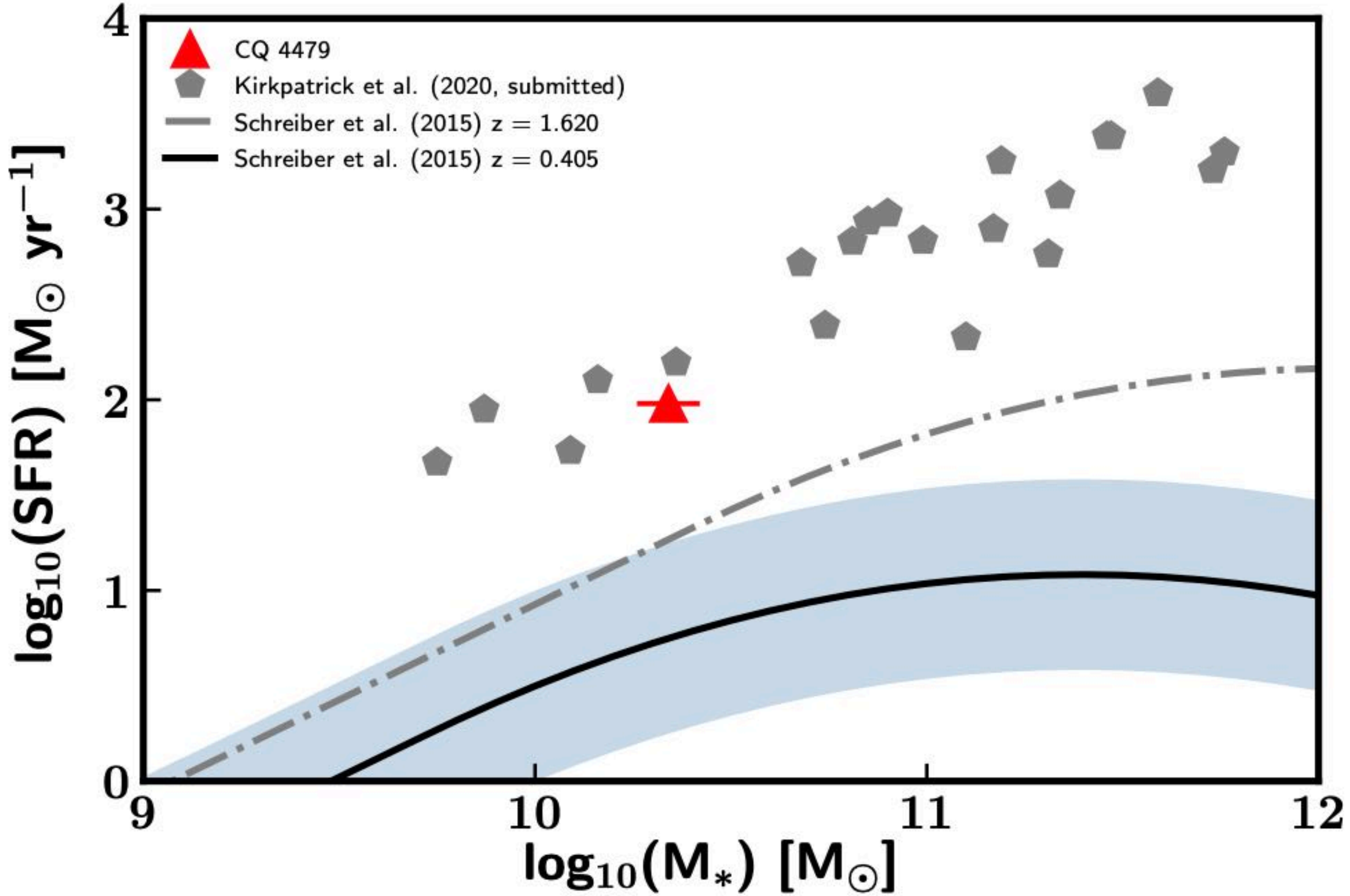


SOFIA'S CRITICAL ROLE



Cooke et al. (2020)

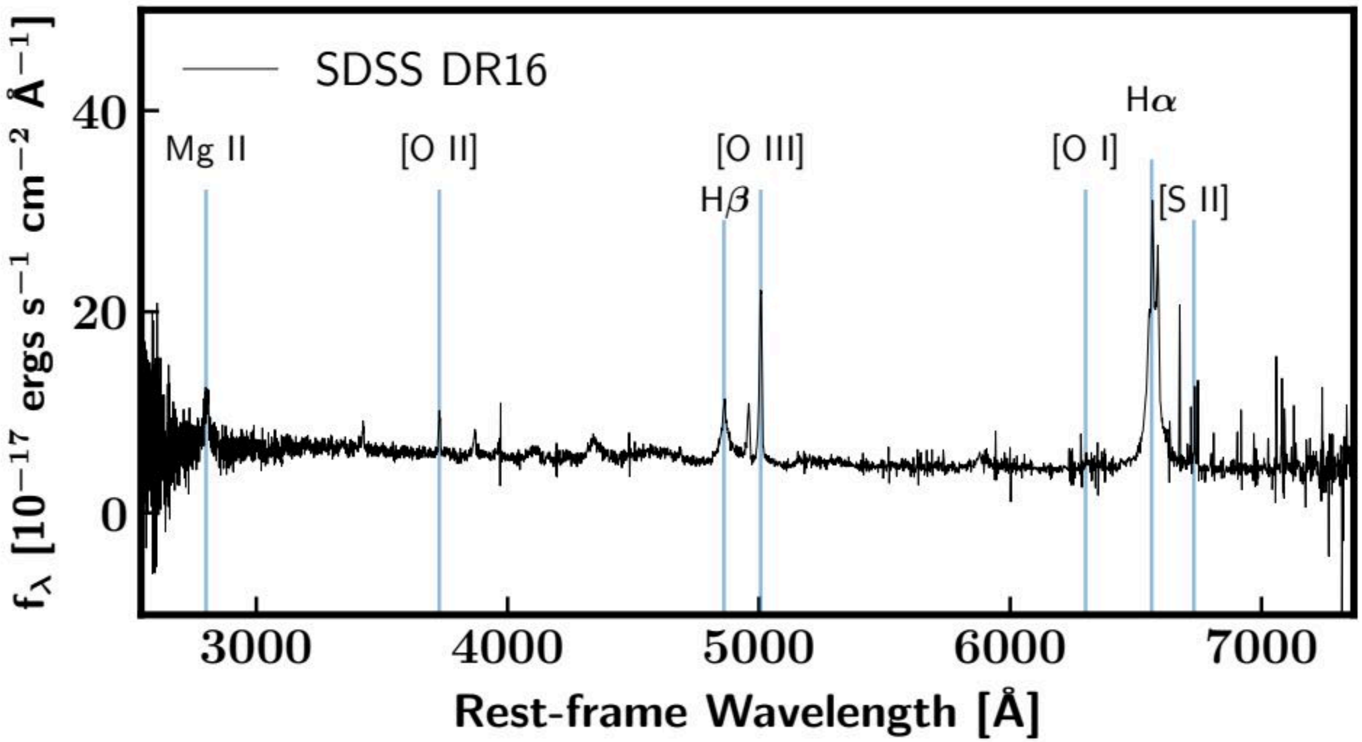
CQ 4479 IS STARBURSTING!



Cooke et al. (2020)

EMISSION LINE DIAGNOSTICS

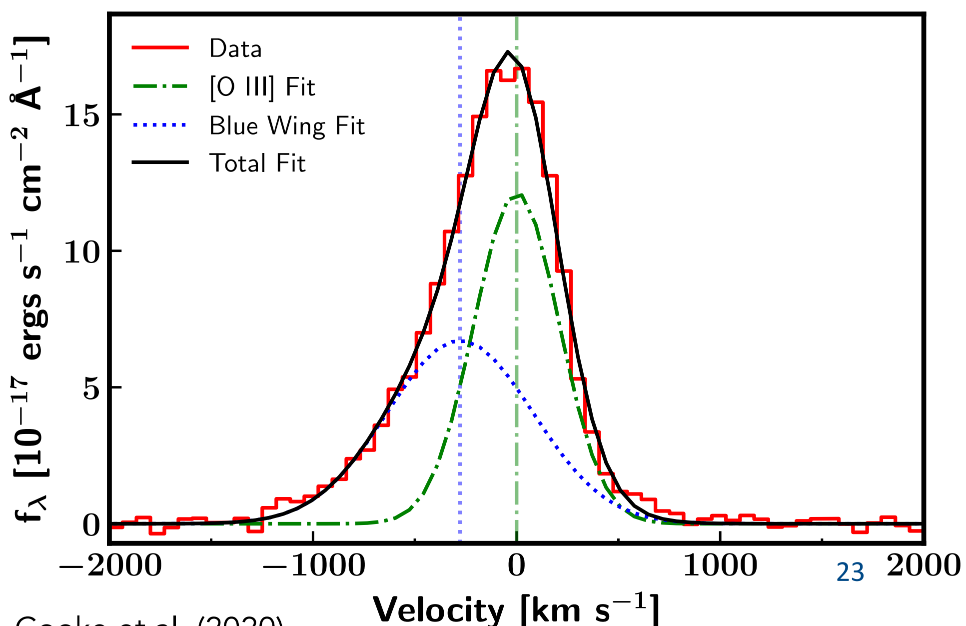
- SDSS DR16 spectra exhibit broad MgII, Hβ, and Hα emission lines consistent with Type-1 AGN.



Cooke et al. (2020)

OPTICALLY ESTIMATING SMBH MASS AND ACCRETION RATE

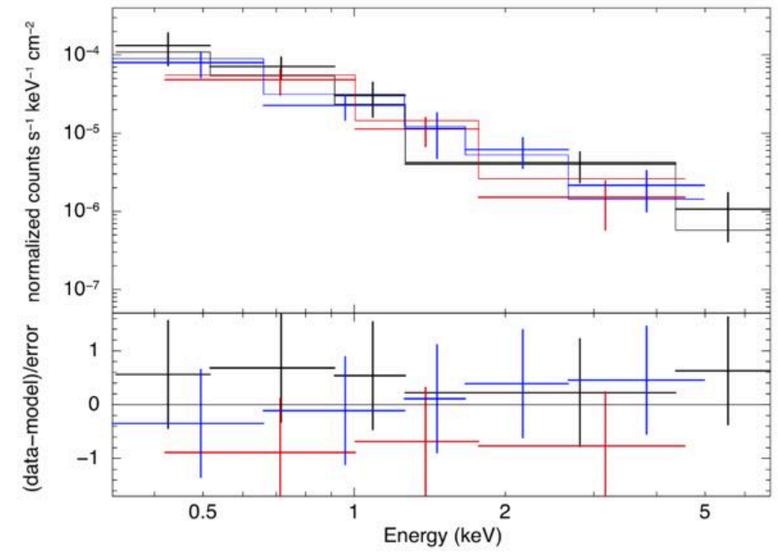
- Sloan Digital Sky Survey provides spectra for optical emission lines [OIII], Hα.
- We normalize and fit each line with a narrow and broad Gaussian component to find FWHM and flux from the broad component.
  - Used to estimate M_{SMBH}
  - M_{sol} / yr [O III]: 0.30
- The [O III] line is asymmetric, requiring a second Gaussian component.
  - -202 km/s from systematic



Cooke et al. (2020)

X-RAY ESTIMATES OF SMBH MASS AND ACCRETION RATE

- The X-ray luminosity directly traces the regions of the accretion disk closest to the central engine.
  - L(2-10 keV) = 3.4 {+0.15} {-0.19} x 10^43 erg s^{1}



(Cooke et al. 2020)

- Use bolometric luminosity derived from [OIII] and X-ray emission from *XMM-Newton* to estimate accretion rate.
  - M_{sol} / yr [X-ray]: 0.11
  - M_{sol} / yr [OIII]: 0.30

$$\dot{M}_\bullet = \frac{(1-\eta)L_{\rm bol}}{\eta c^2}$$

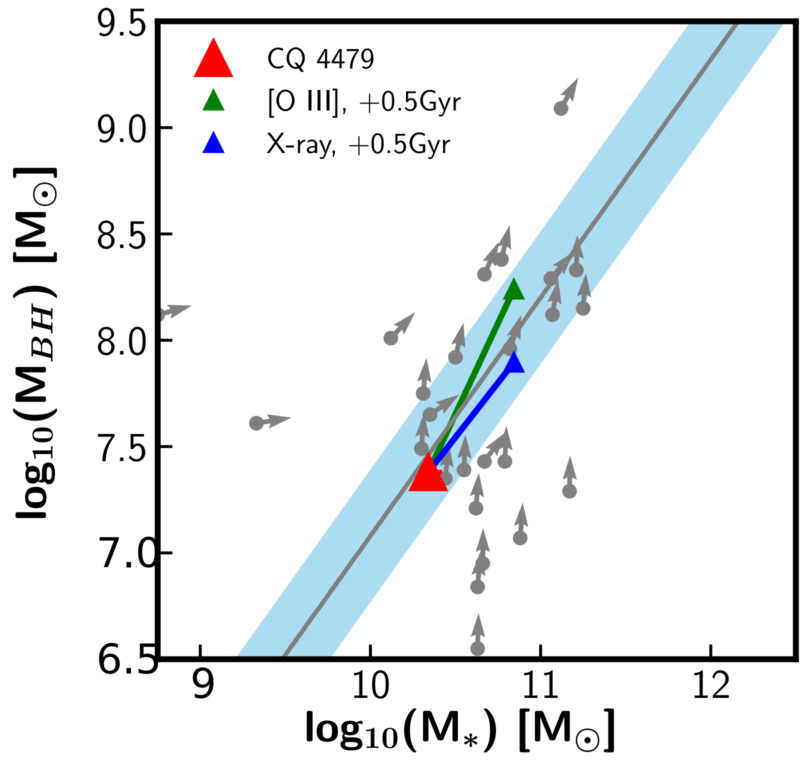
(e.g., Shakura & Sunyaev 1973)

COOKE ET AL. (2020) RESULTS

- We find that cold quasars behave similarly to previously observed samples of Herschel-detected broad-line AGN at z < 1 (Sun+2015).

- Stellar mass and black hole mass grow at different scales, but at correlated rates that teach us the SMBH `knows' of the gas available in the galaxy.

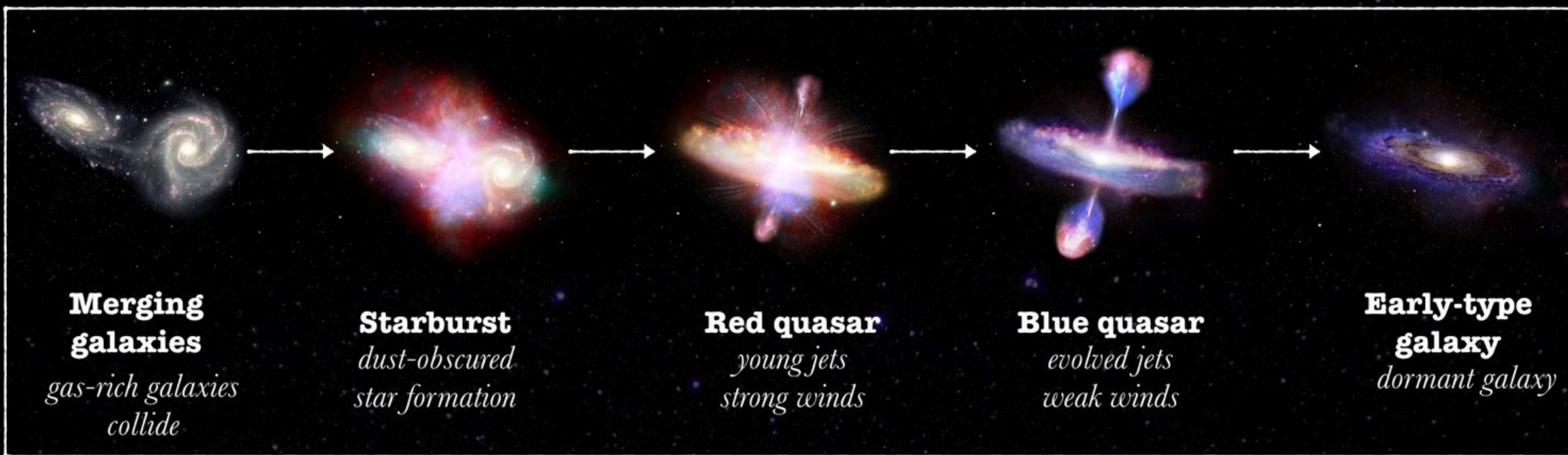
- SMBH and stellar component are growing in lock-step, indicating this is truly an early stage where SFR is not shutting down.



Cooke et al. (2020)

WHAT ARE COLD QUASARS?

Gemini Observatory, GMOS-South, NSF, S. Munro

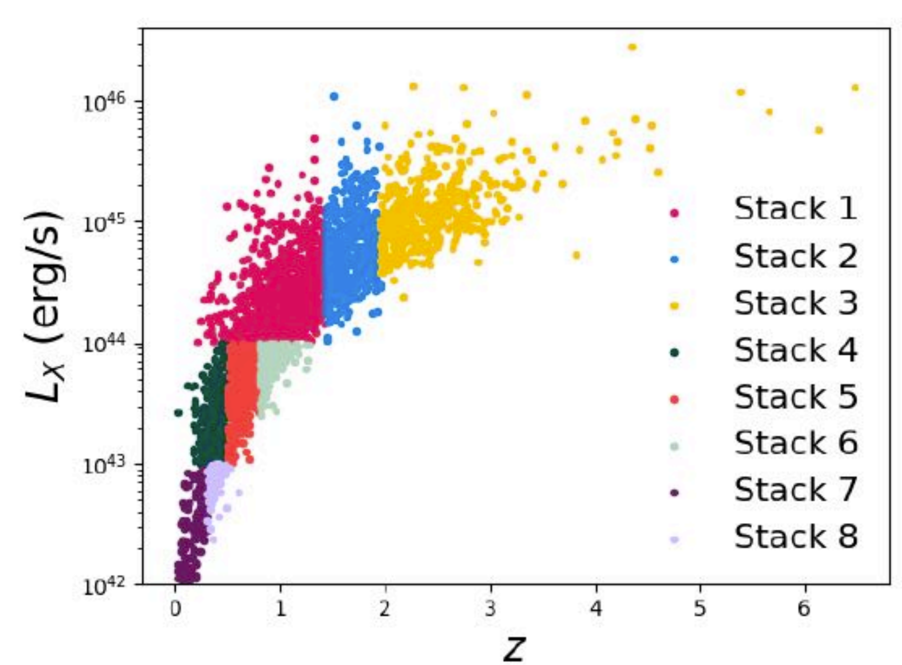


CQ 4479

Luminous FIR	Luminous B-band
Ongoing star formation	Luminous X-ray
Medium winds	Medium winds

COMPARISON TO IR-DIM SAMPLE

- Select targets from Stripe82X that have optical detections but no counterpart detected at 250 microns.
  - 2785 sources
- Stack the FIR image at each location for targets in bins of X-ray luminosity.
  - X-ray chosen to characterize the state of the AGN, and whatever the stacks result in teach us of the median star-forming behavior of the sample.



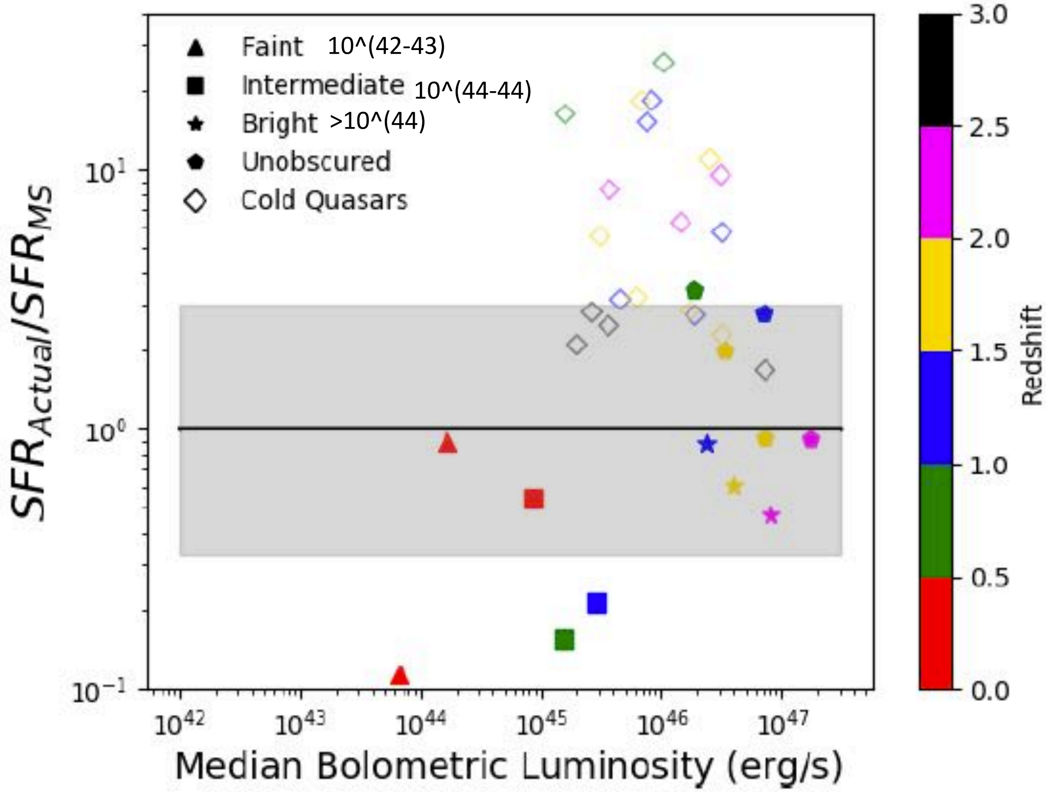
Coleman et al. (Submitted)

COMPARISON TO IR-DIM SAMPLE

- Stacking of unobscured quasars in Stripe82X that have not been detected in the FIR show a population that is growing both components slower than cold quasars.

- Median SEDs of the stacked FIR targets exhibit lower SFR and L_{bol}.

- Being below the main sequence is commonly associated with post-starburst, quiescent galaxies.



Coleman et al. (Submitted)

FUTURE FOLLOW-UPS

- HST-resolution optical images are highly desired to determine the state of the host galaxy.
- Due to the improved SFRs, more SOFIA measurements will continue to be applied for.
- Currently discussing the availability and feasibility of radio observations to determine the kinematics of the host gas.
- Long-term: Roman surveys will provide enormous optical imaging catalogs along fields with FIR coverage, enabling the examination of far more cold quasars.

CONCLUSIONS

- Cold quasars represent a rare phase between red and blue quasars where we can observe the co-evolution of an active supermassive black hole and ongoing star-formation.

- SOFIA is the only facility that can deliver new observations to constrain the gas temperature and SFR without contamination from the AGN.

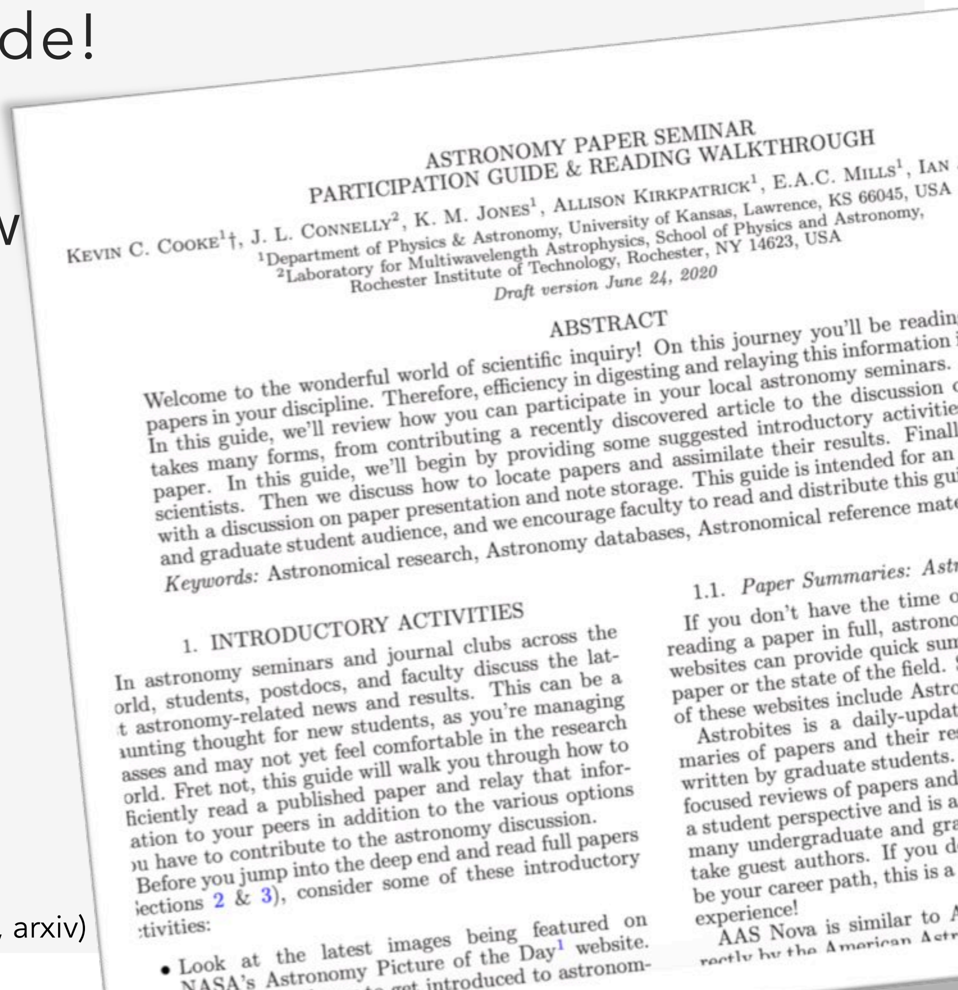
Thank you!

people.ku.edu/~k739c541
kcooke@ku.edu
@astrokevincooke

Artist Conception Credit: NASA/ Daniel Rutter

NEED TO GET YOUR STUDENTS UP TO SPEED?

- Try our astronomy paper research and reading guide!
- Built for getting your new undergraduate and graduate students going into the world of paper reading!
- arXiv: 2006.12566


ASTRONOMY PAPER SEMINAR
PARTICIPATION GUIDE & READING WALKTHROUGH

Kevin C. Cooke[1]†, J. L. Connelly[2], K. M. Jones[1], Allison Kirkpatrick[1], E.A.C. Mills[1], Ian
[1]Department of Physics & Astronomy, University of Kansas, Lawrence, KS 66045, USA
[2]Laboratory for Multiwavelength Astrophysics, School of Physics and Astronomy,
Rochester Institute of Technology, Rochester, NY 14623, USA

Draft version June 24, 2020

ABSTRACT

Welcome to the wonderful world of scientific inquiry! On this journey you'll be readin papers in your discipline. Therefore, efficiency in digesting and relaying this information i In this guide, we'll review how you can participate in your local astronomy seminars. takes many forms, from contributing a recently discovered article to the discussion c paper. In this guide, we'll begin by providing some suggested introductory activitie scientists. Then we discuss how to locate papers and assimilate their results. Finall with a discussion on paper presentation and note storage. This guide is intended for an and graduate student audience, and we encourage faculty to read and distribute this gui

Keywords: Astronomical research, Astronomy databases, Astronomical reference mate

1. INTRODUCTORY ACTIVITIES

In astronomy seminars and journal clubs across the orld, students, postdocs, and faculty discuss the lat- t astronomy-related news and results. This can be a unting thought for new students, as you're managing asses and may not yet feel comfortable in the research orld. Fret not, this guide will walk you through how to ficiently read a published paper and relay that infor- ation to your peers in addition to the various options ou have to contribute to the astronomy discussion. Before you jump into the deep end and read full papers ections 2 & 3), consider some of these introductory tivities:

- Look at the latest images being featured on NASA's Astronomy Picture of the Day[1] website.

1.1. *Paper Summaries: Ast*

If you don't have the time o reading a paper in full, astron websites can provide quick sun paper or the state of the field. of these websites include Astro Astrobites is a daily-updat maries of papers and their re written by graduate students. focused reviews of papers and a student perspective and is a many undergraduate and gra take guest authors. If you d be your career path, this is a experience!

AAS Nova is similar to A

Cooke et al. (2020, arxiv)