Searching for (feedback in) obscured and reddened quasars at the peak of galaxy formation

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(soon to be CITA/Dunlap!)

Elusive AGN
George Mason University
June 14, 2017

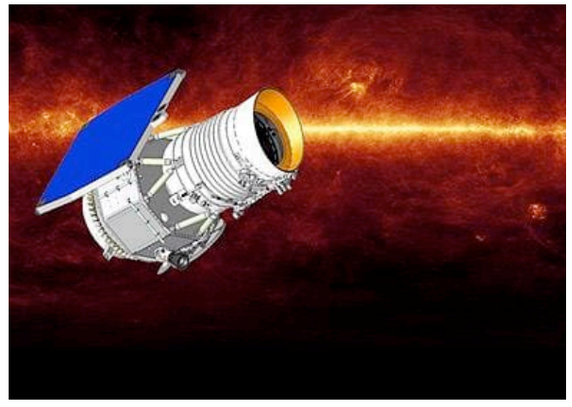
Image credit: David A. Hardy (UK ATC)

Special Thanks To:

Nadia Zakamska (JHU), Fred Hamann (UCR), Jenny Greene (Princeton), Michael Strauss (Princeton), Nic Ross (Univ. Edinburgh), Niel Brandt (Penn State), ...

Outline

1. How do we identify “elusive” AGN at high redshift?

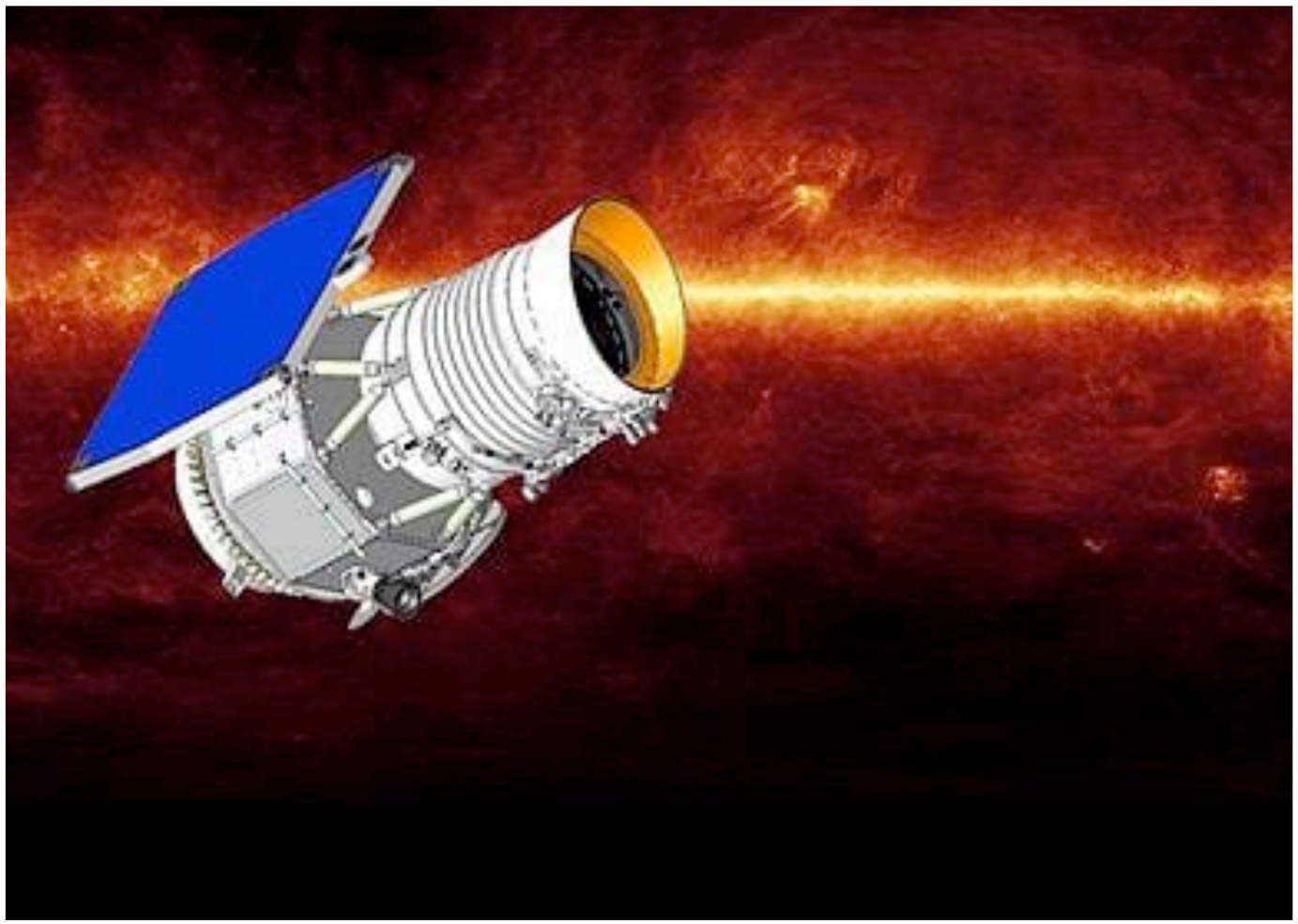


2. How can we use multi-wavelength studies to probe quasar winds (feedback) at

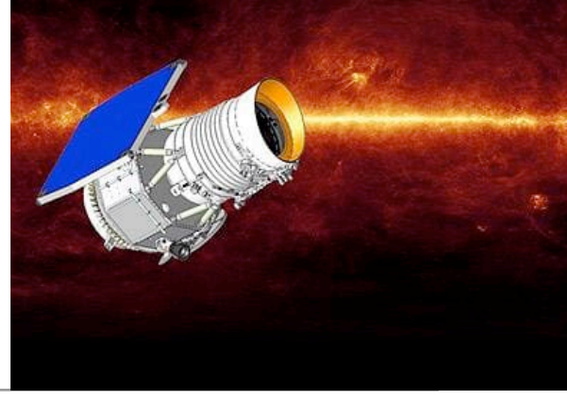
   a) small and

   b) large scales?

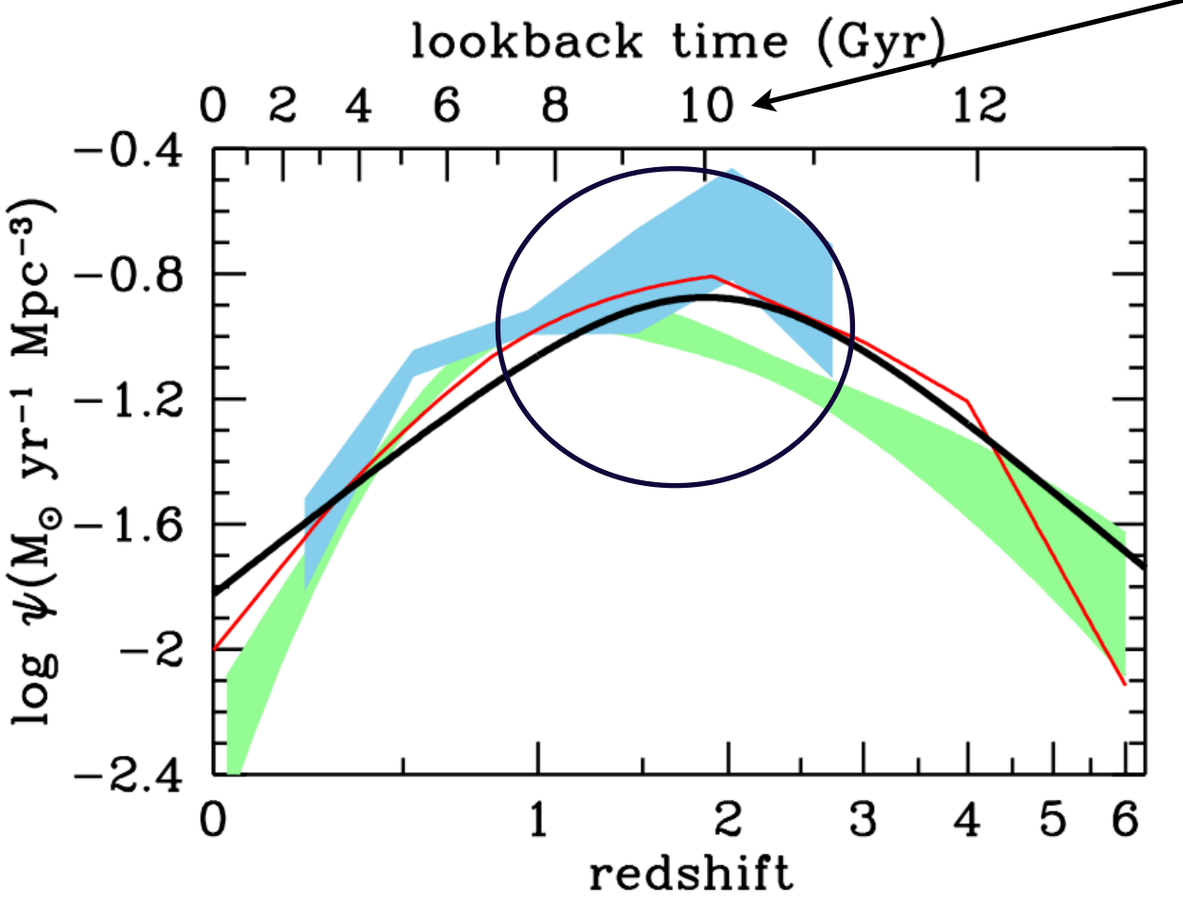
1. How do we identify “elusive” AGN in the early universe?



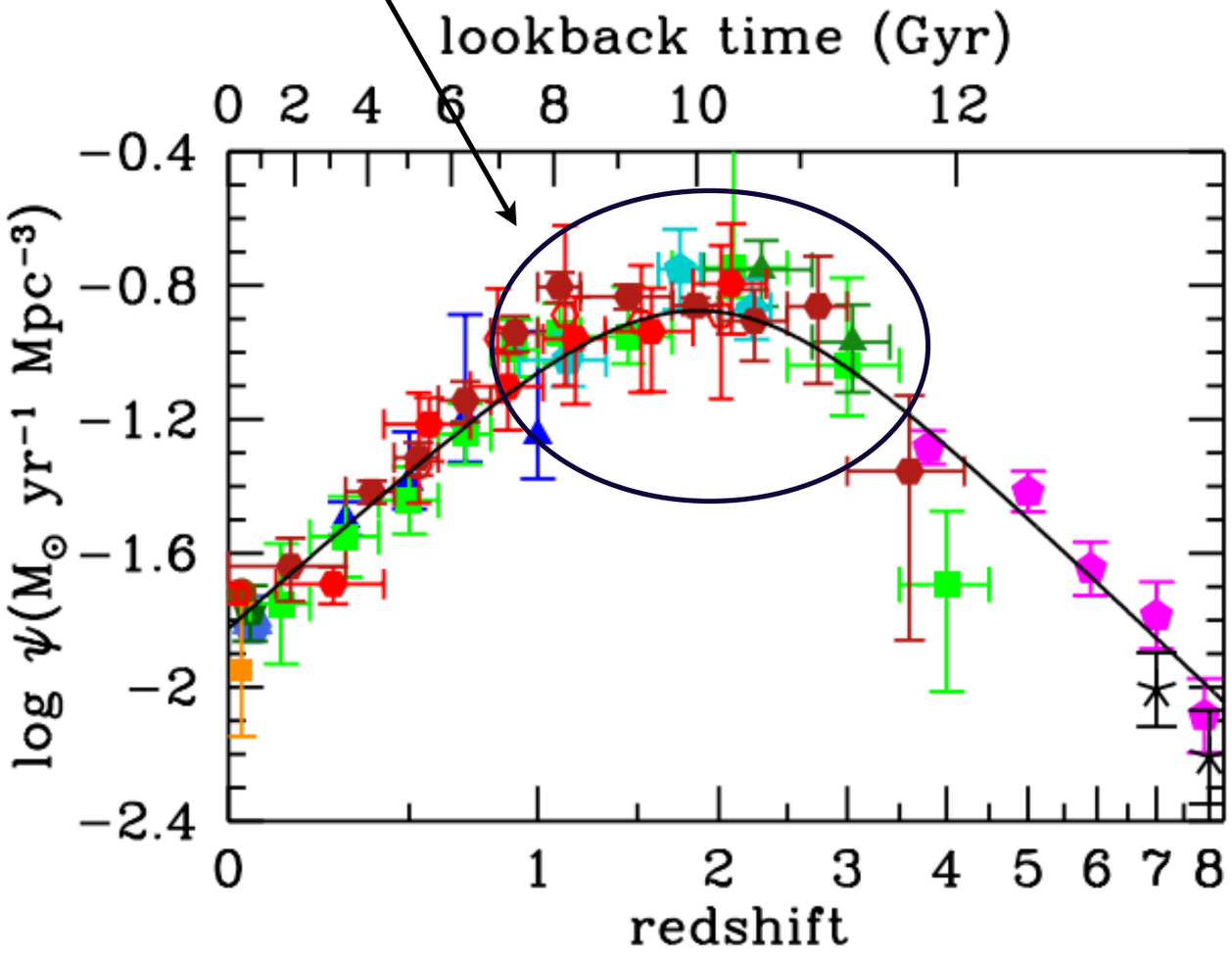
Why is the “early universe” so important?



Peak in quasar density & star formation rate 10 billion years ago

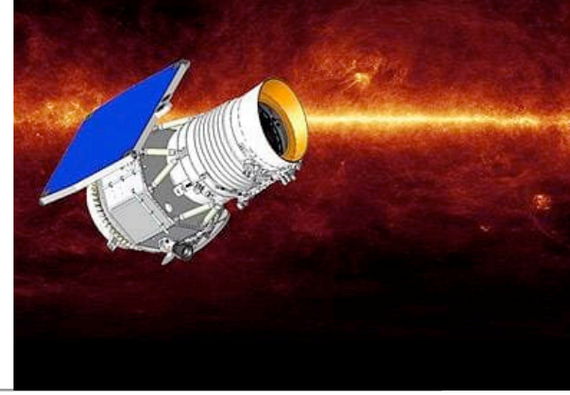


Madau & Dickinson 2014



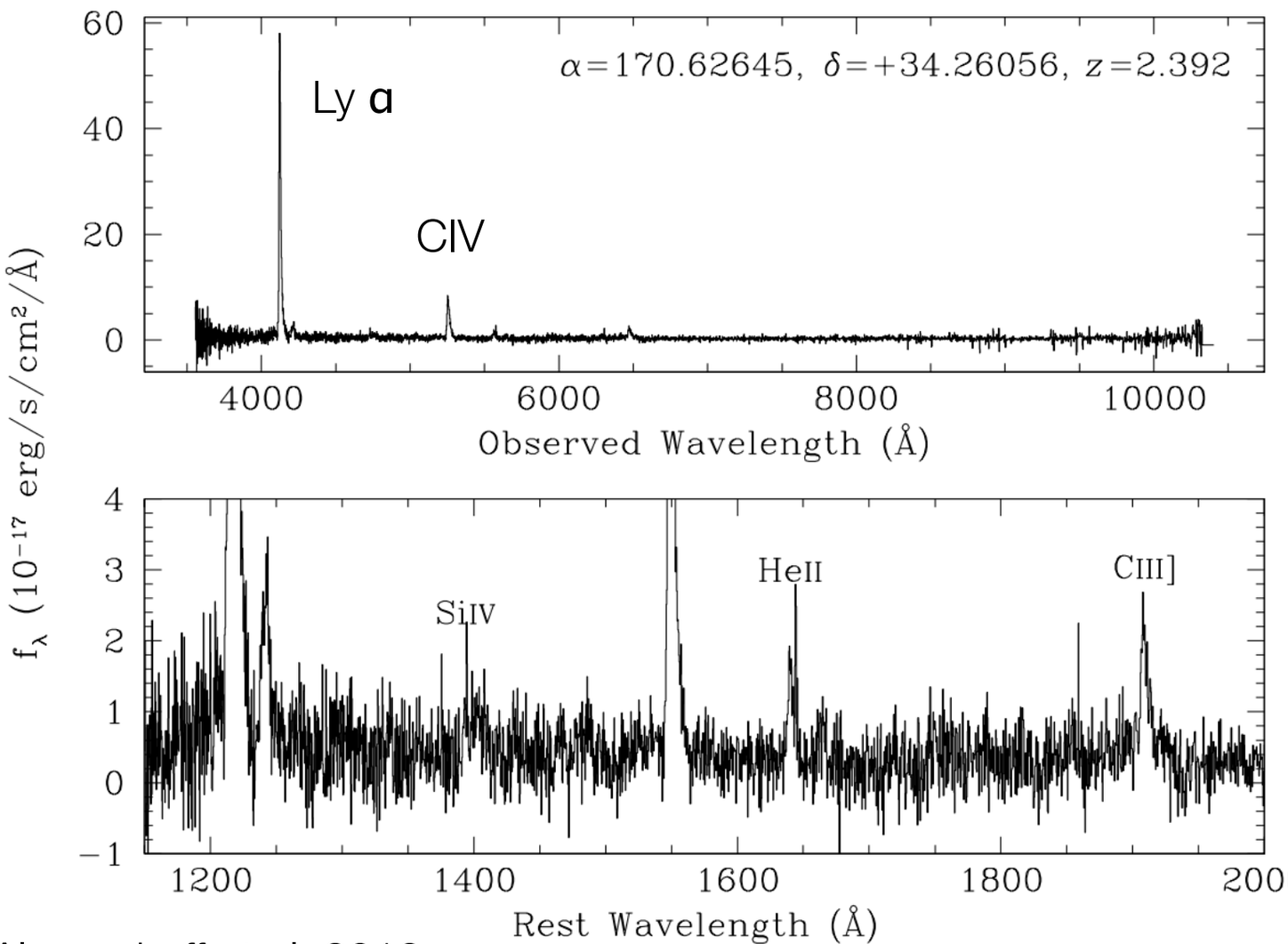
- If we want to understand the bulk of BH growth we need to be at $1 \lesssim z \lesssim 3$

Obscured Quasar Candidates



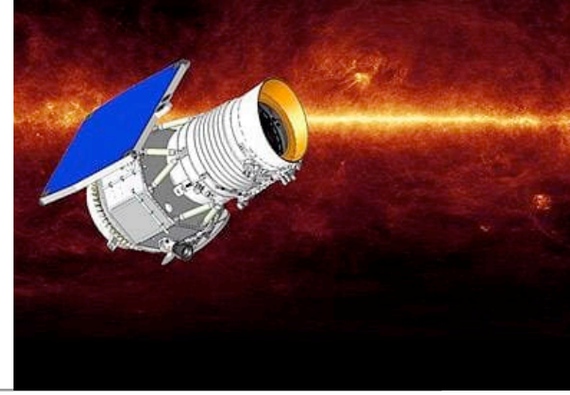
- selected using optical (SDSS-III) BOSS spectroscopy
- ~150 candidate obscured quasars from SDSS III, 2 < z < 4
  - “traditional” narrow emission lines (FWHM < 2000 km/s)
  - mostly obscured continuum

One of the largest samples of optically-selected obscured quasars in the early universe



Alexandroff et al. 2013

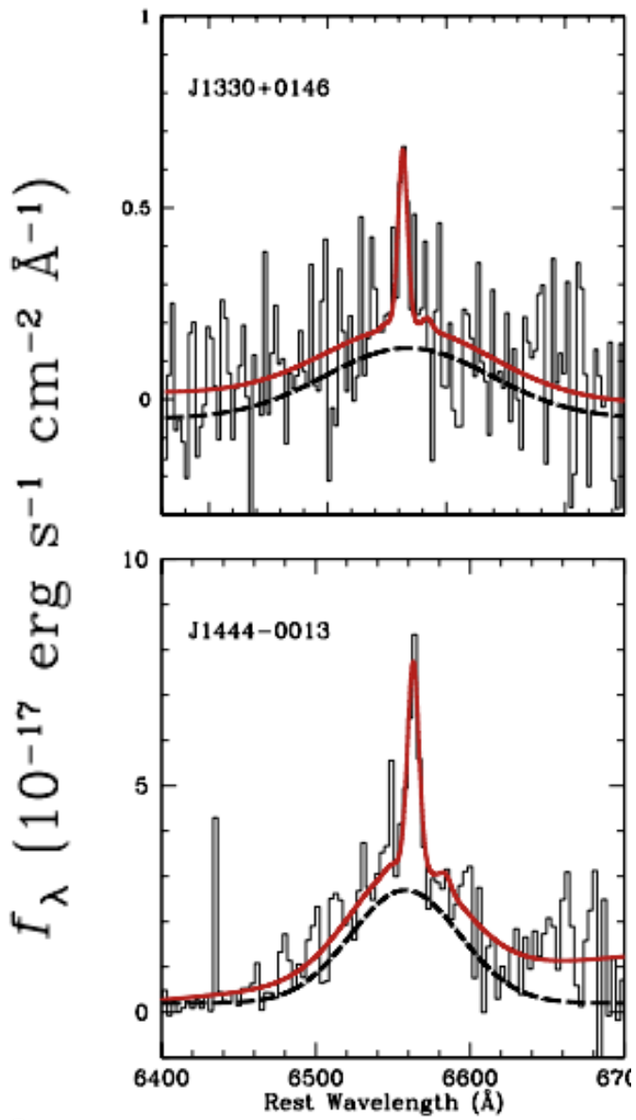
Obscured Quasar Candidates



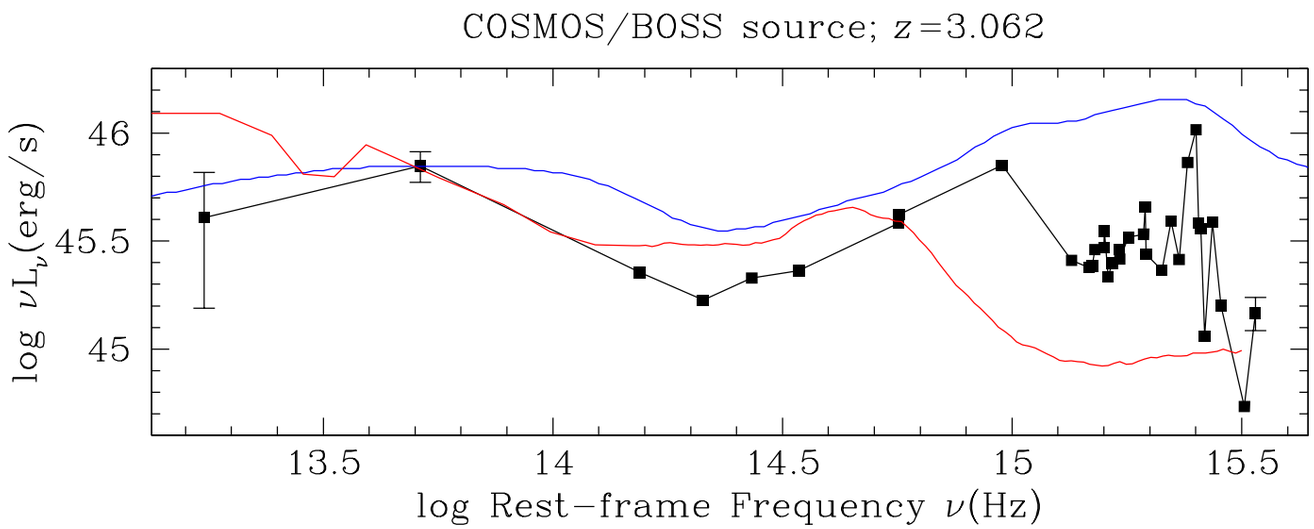
14/16 show broad Hα in optical spectroscopy

0.05 < Av < 2.2

SEDs intermediate between Type 1 & Type 2



Greene, Alexandroff et al. 2014

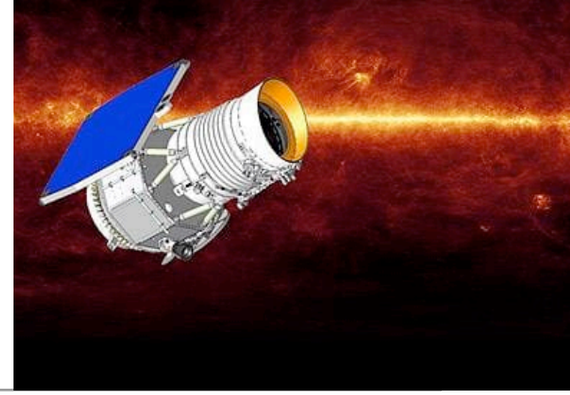


—Type I quasar SED (Richards et al. 2006)

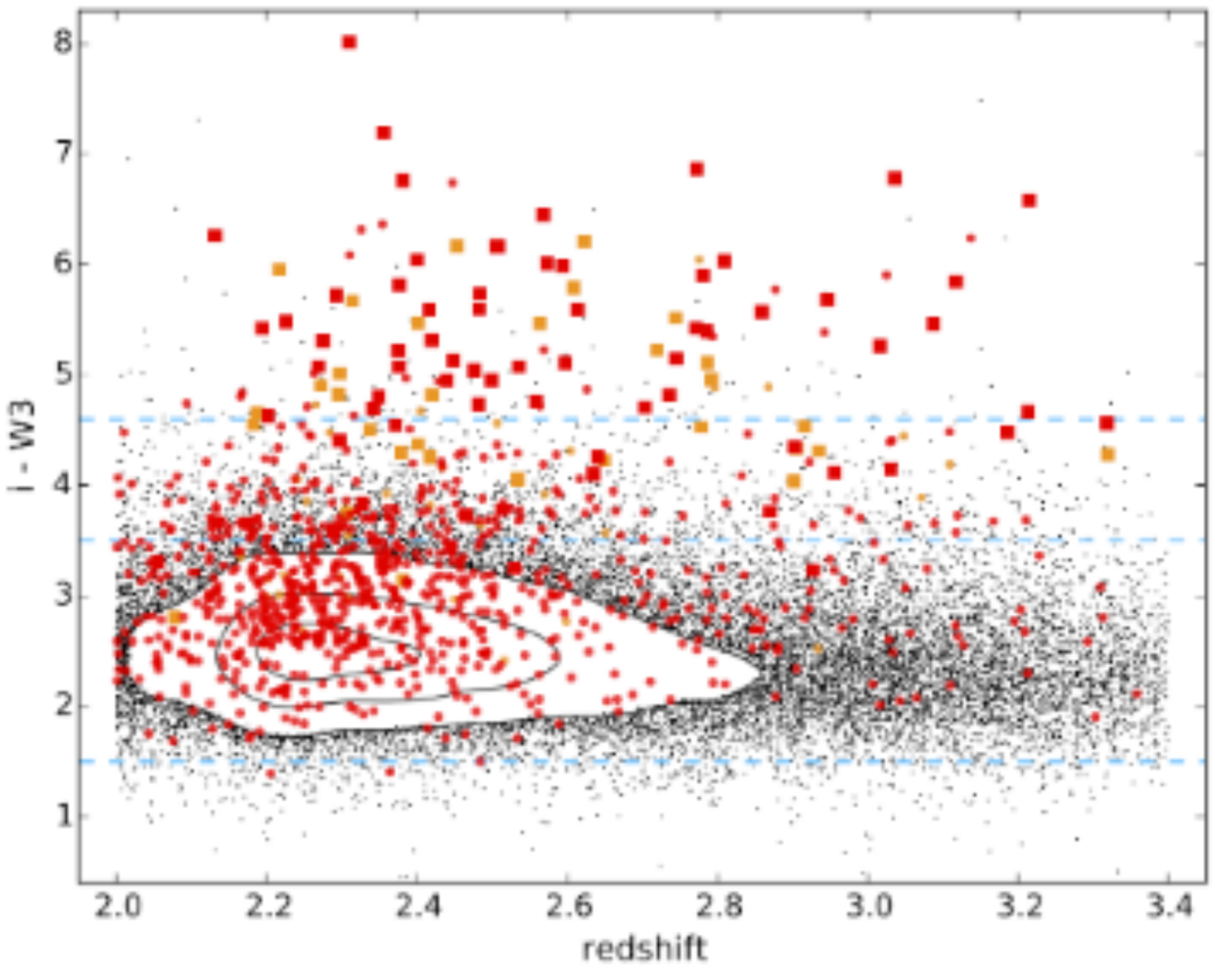
—Type II quasar SED (Zakamska et al. 2003)

Alexandroff et al. 2013

Extremely Red Quasars



- 95 quasars selected using a combination of MIR (WISE) & optical (SDSS-III)
  - **i-w3 > 4.6 (AB mag)**
  - picks out heavily dust-enshrouded objects re-radiating in the MIR
  - we noticed something strange....



Ross et al. 2015
Hamann et al. 2017

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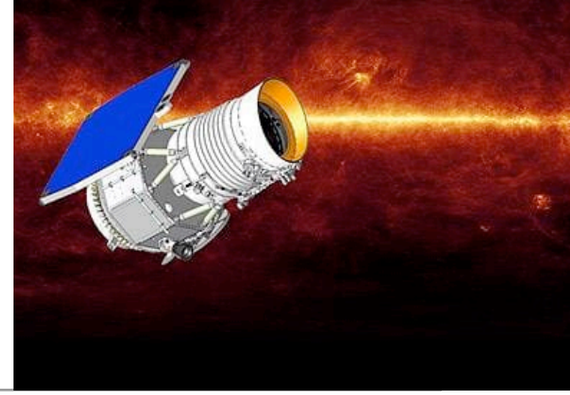
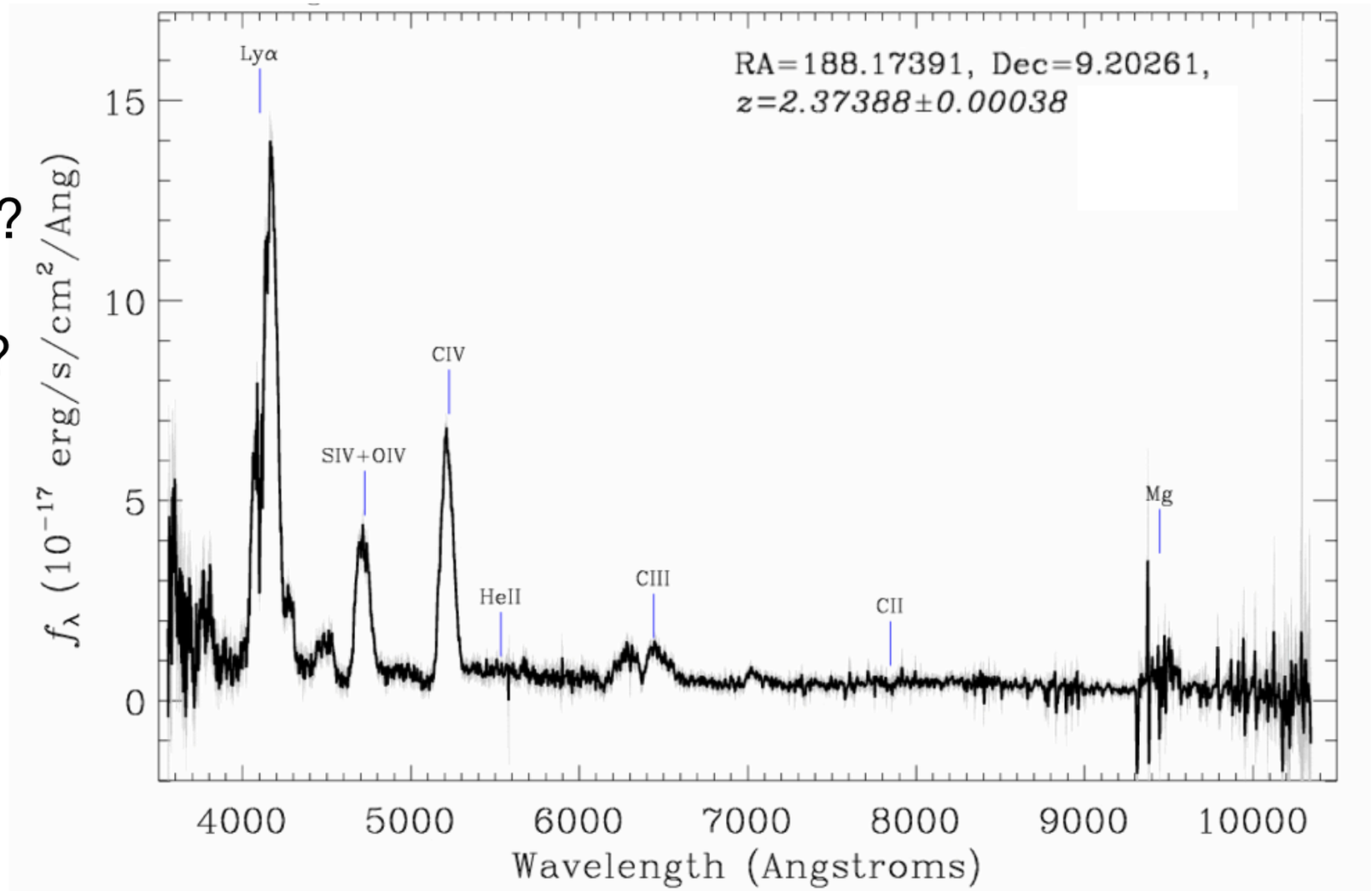
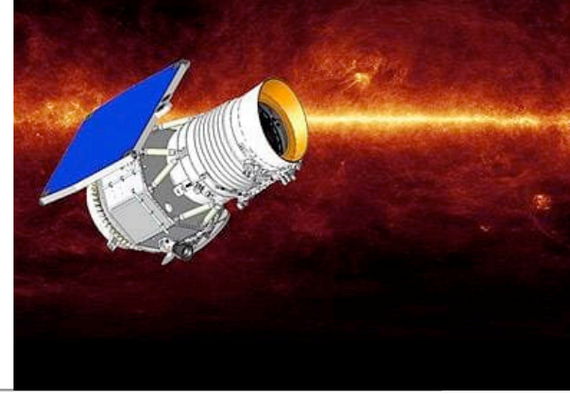


- 95 quasars selected using a combination of MIR (WISE) & optical (SDSS-III)
  - **REW CIV > 100 Å**
  - Hypothesis-
    - suppressing quasar continuum but not emission line region? Dusty outflow with patchy obscuration?



Ross et al. 2015
Hamann et al. 2017

Introducing: Extremely Red Quasars



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Av ~ 5

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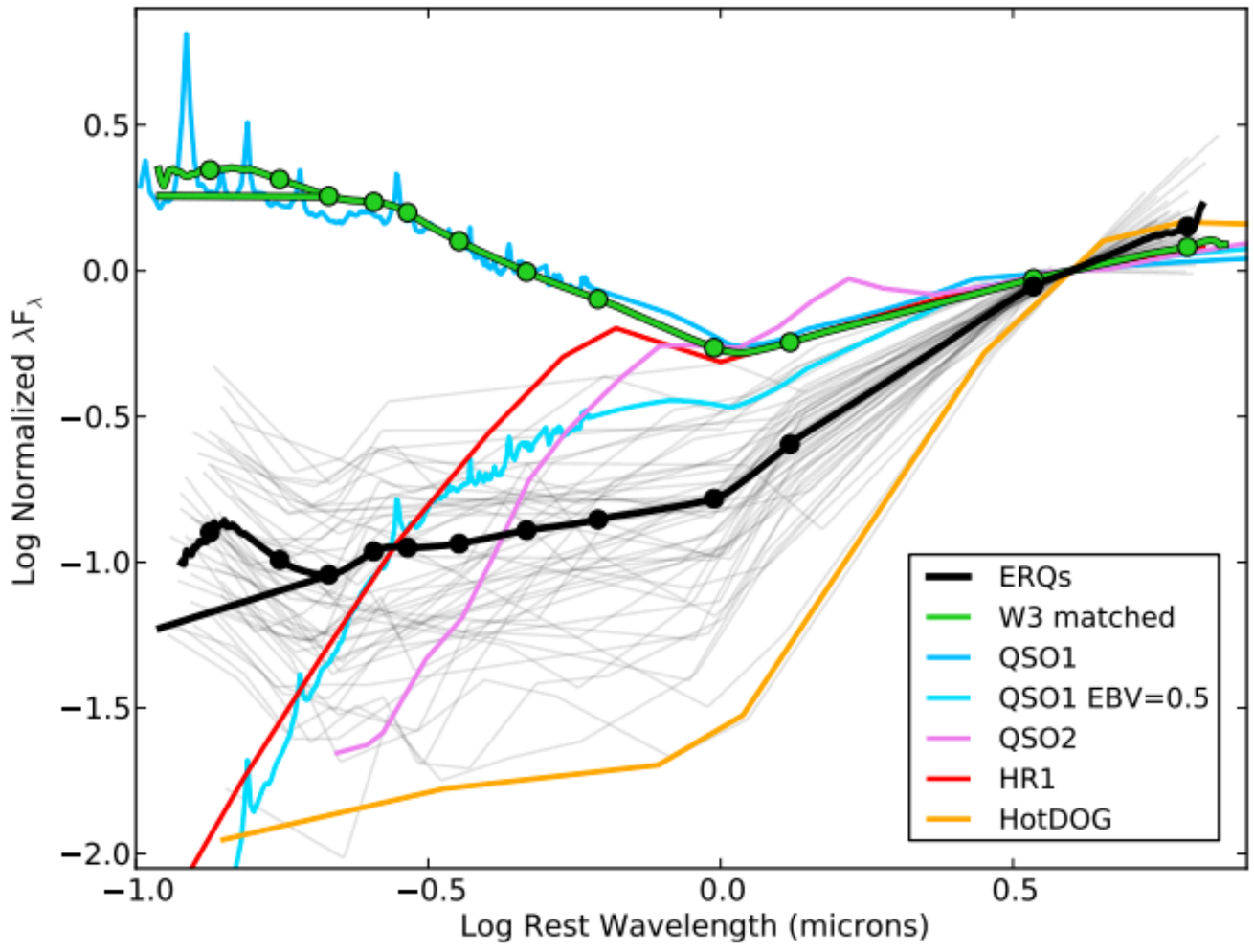


Ross et al. 2015
Hamann et al. 2017

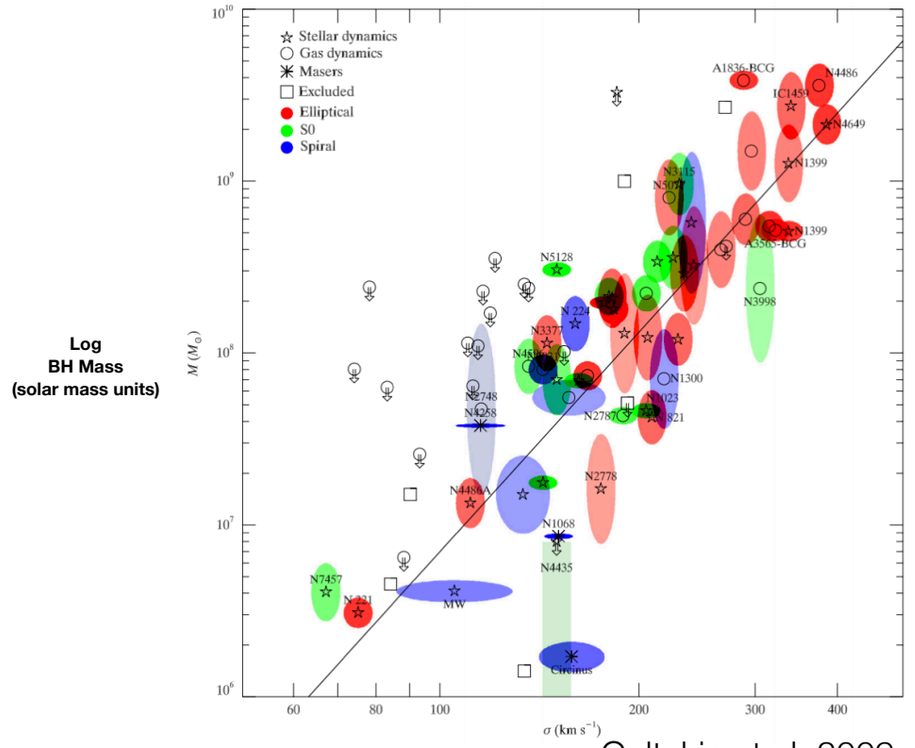
Why study “elusive” AGN?

1. These powerful sources may be the sites of **quasar feedback**:

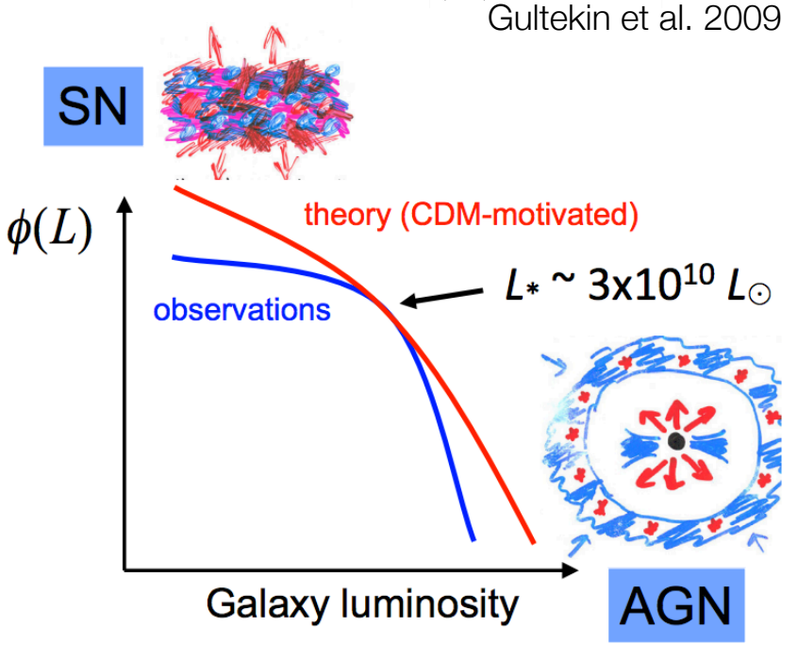
   a) creation of BH-bulge correlations

   b) regulate size of massive galaxies

...mediated by quasar winds



Gultekin et al. 2009



Silk & Mamon, 2012

2. What evidence do we see for outflows launched by the quasar on small scales?

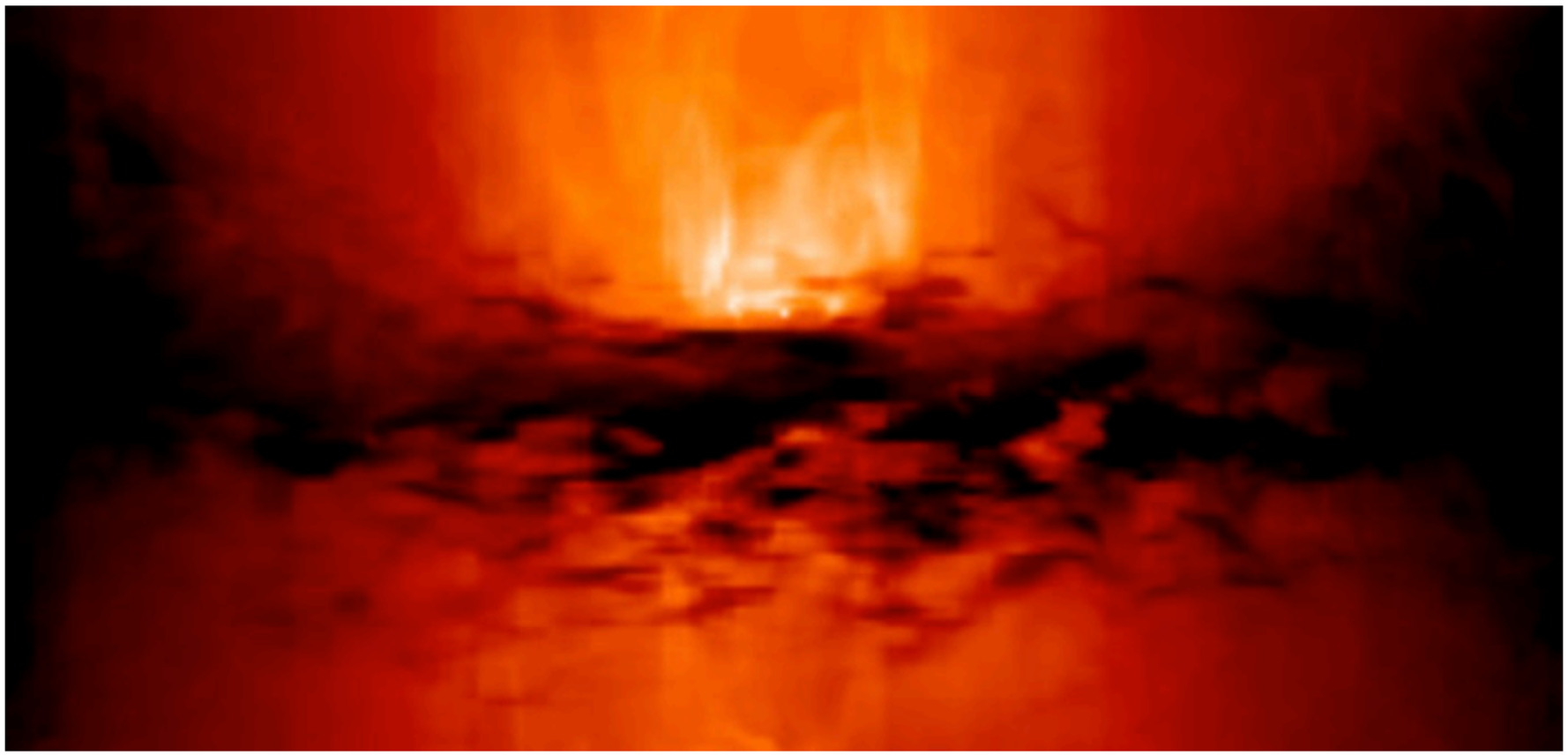
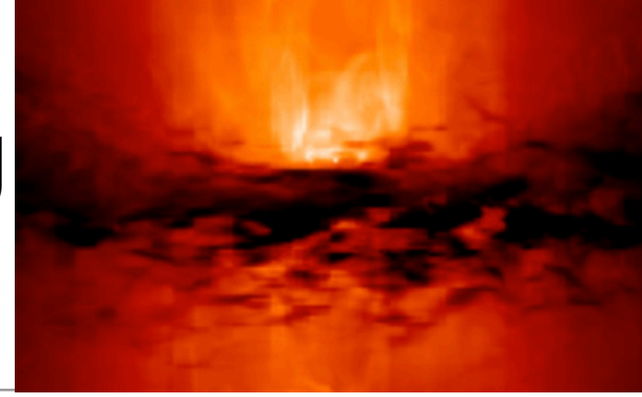
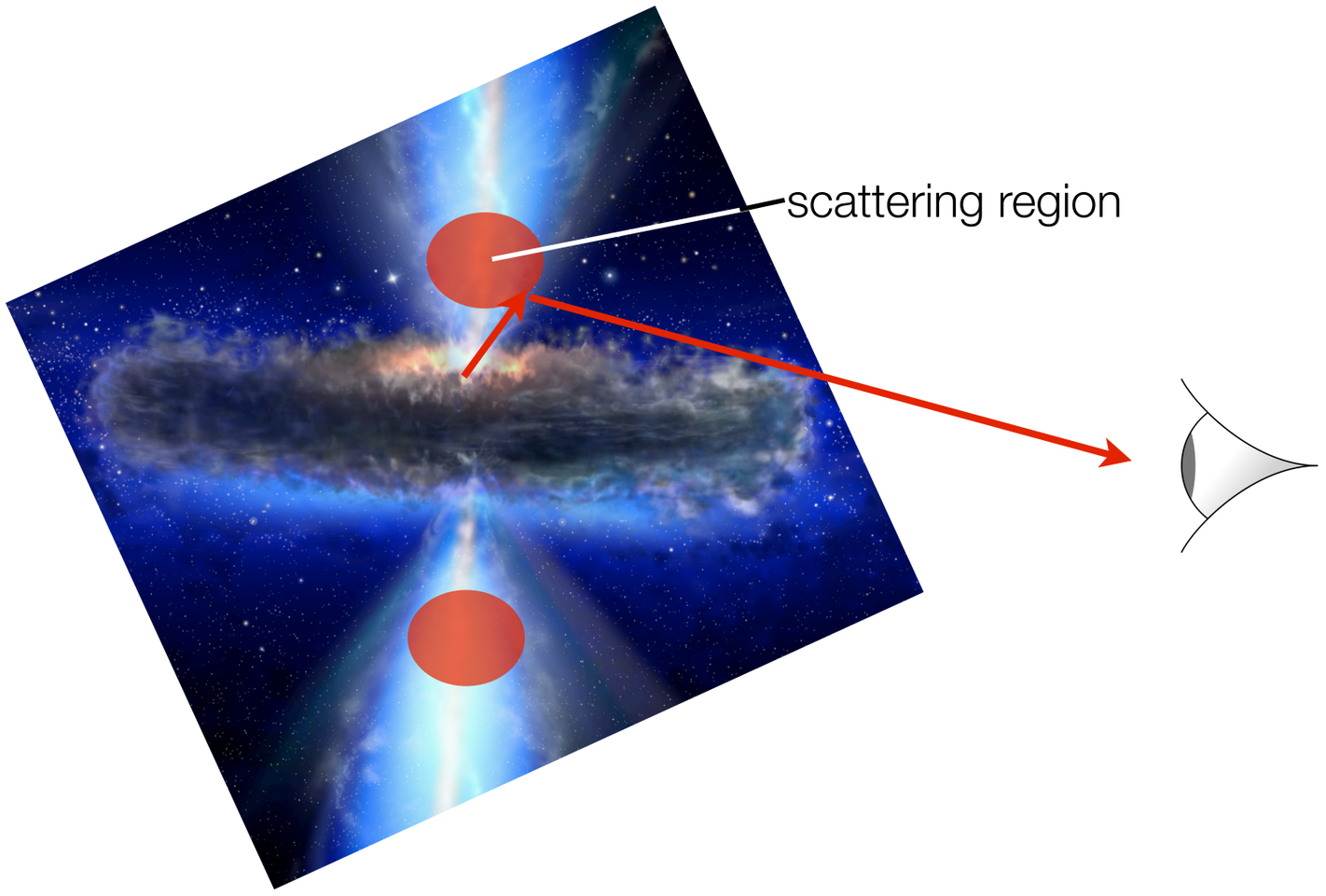


Image credit: Wada et al. 2016

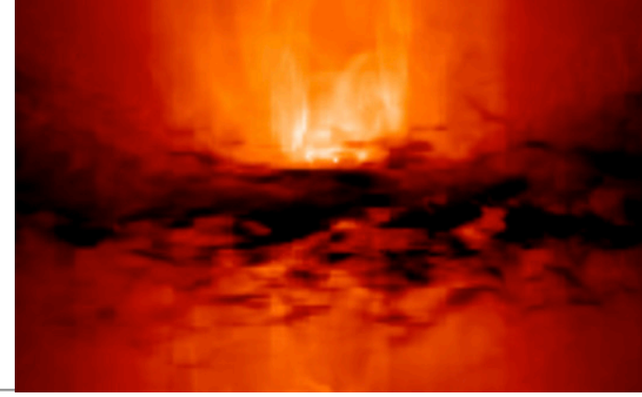
Spectropolarimetry can reveal scattering geometry & kinematics



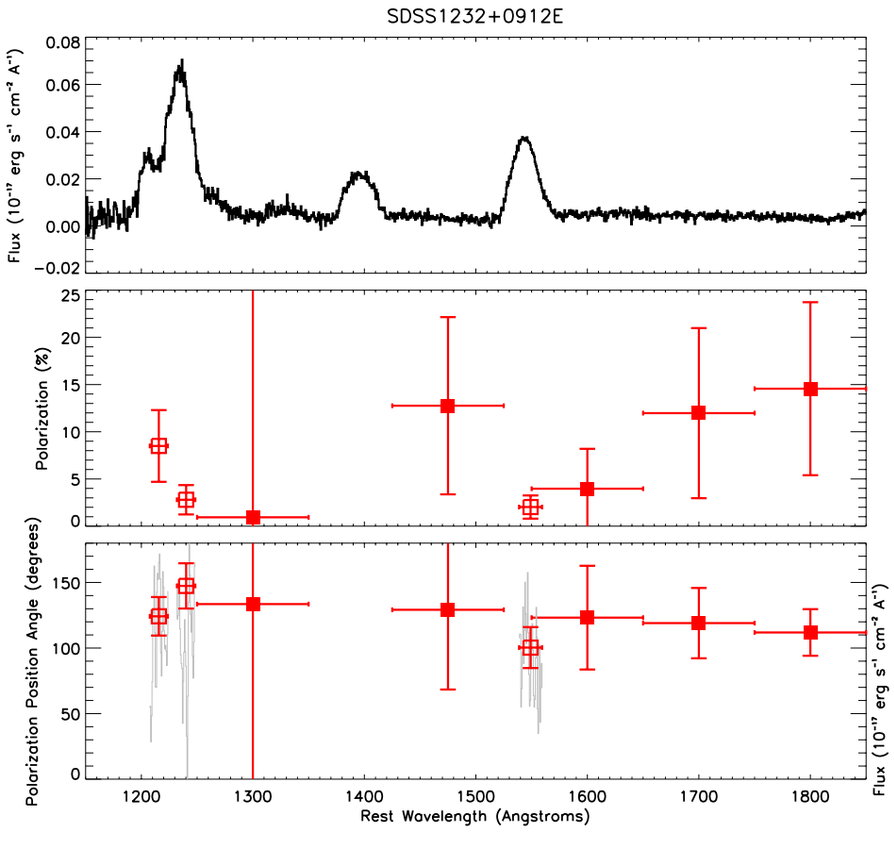
- quasar light may be scattered in to our line of sight from dust or free electrons
- the light becomes linearly polarized in the process
- traditional obscured quasars have optical polarization of a few %

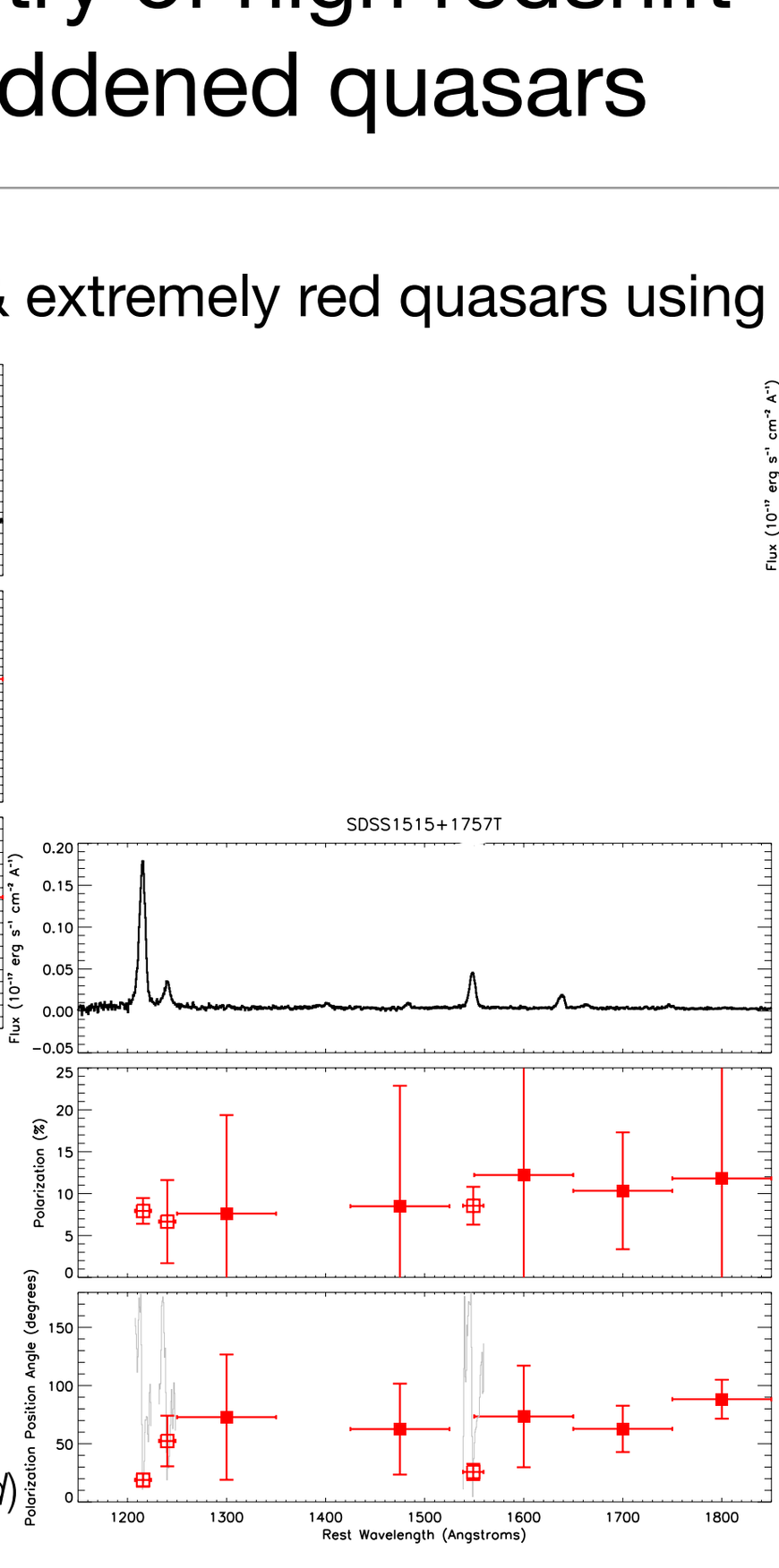


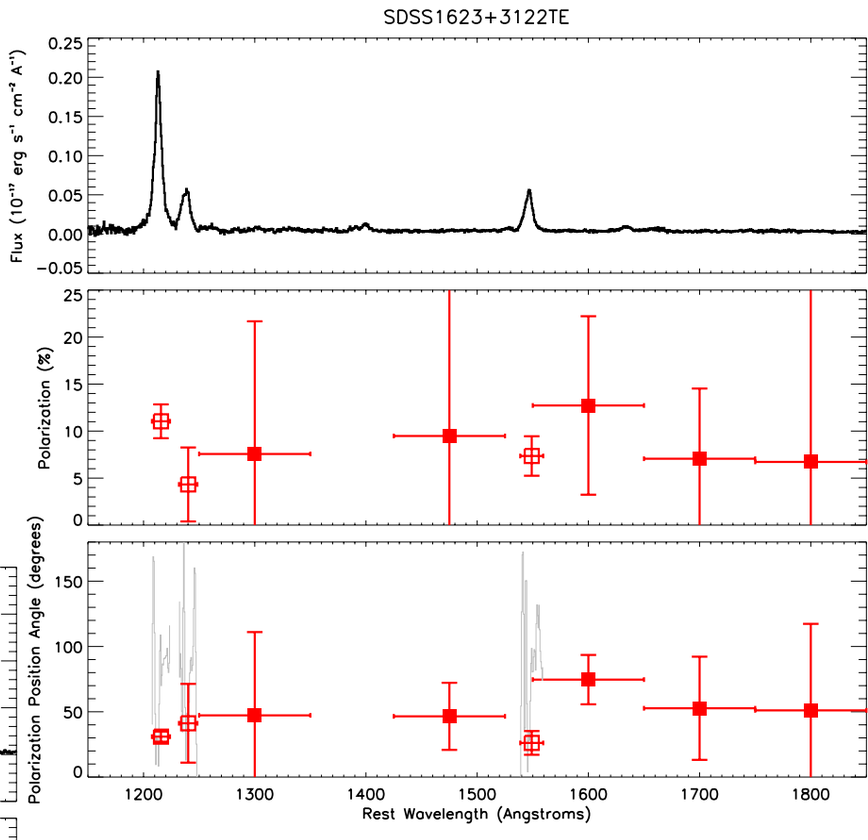
Spectropolarimetry of high redshift obscured and reddened quasars



- Observed 5 obscured & extremely red quasars using LRISp on Keck







Alexandroff et al. 2017 (*being submitted*)

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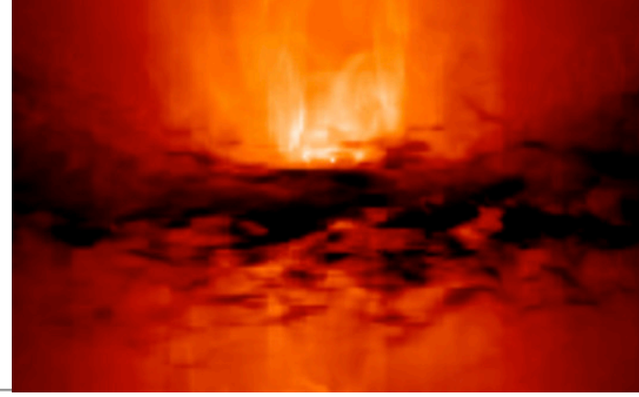

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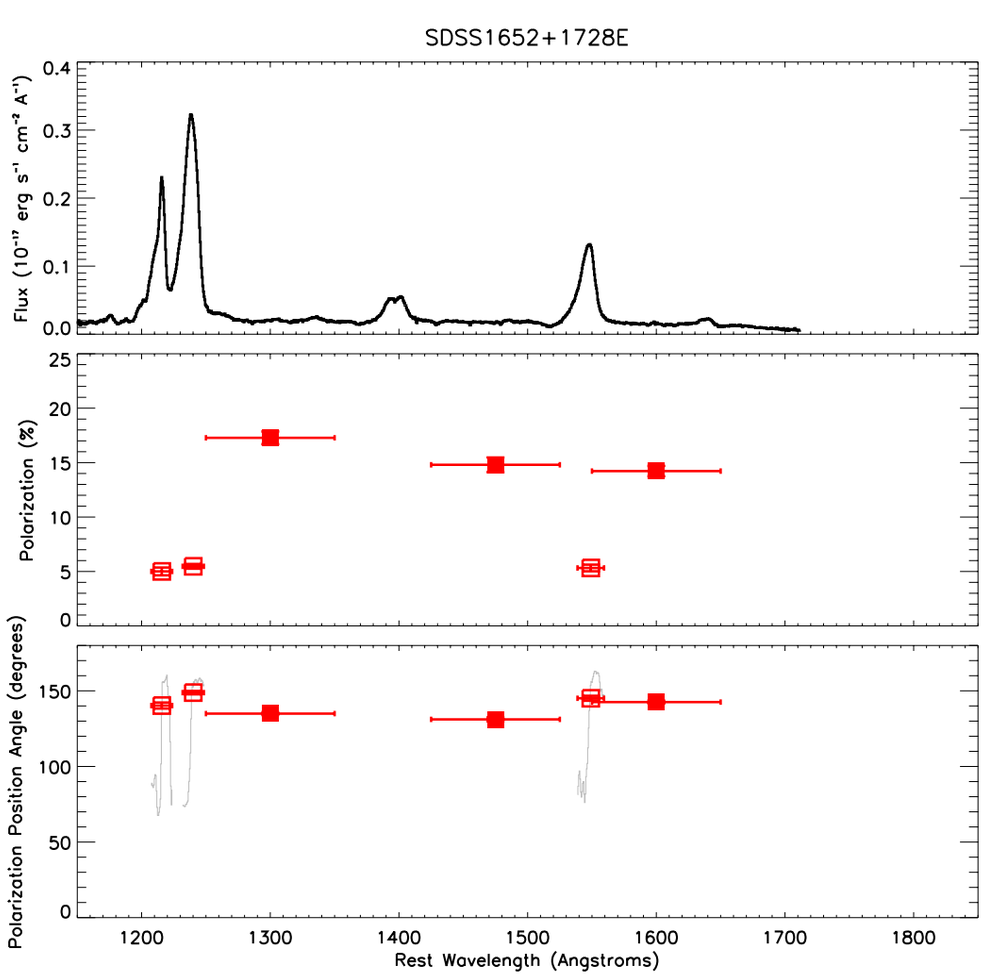

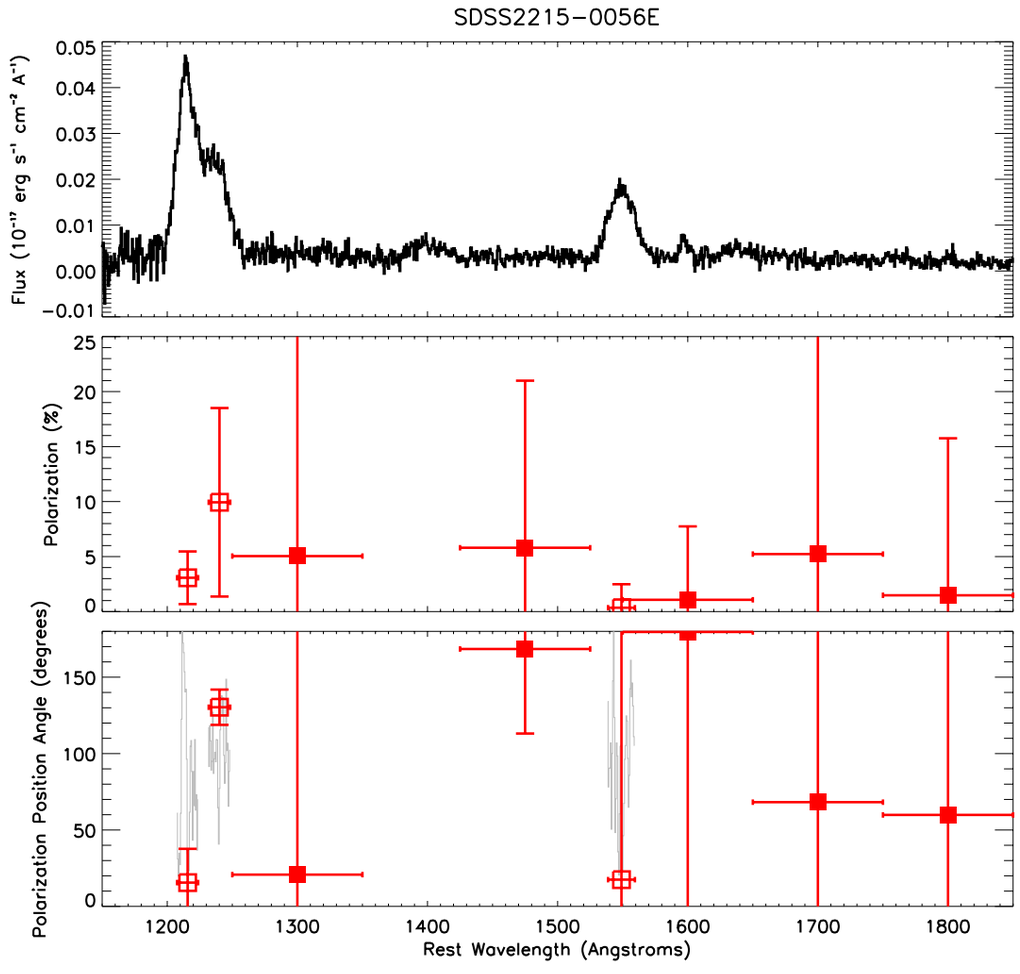

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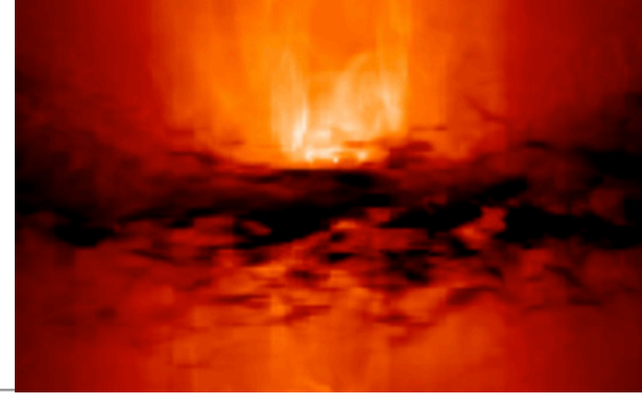
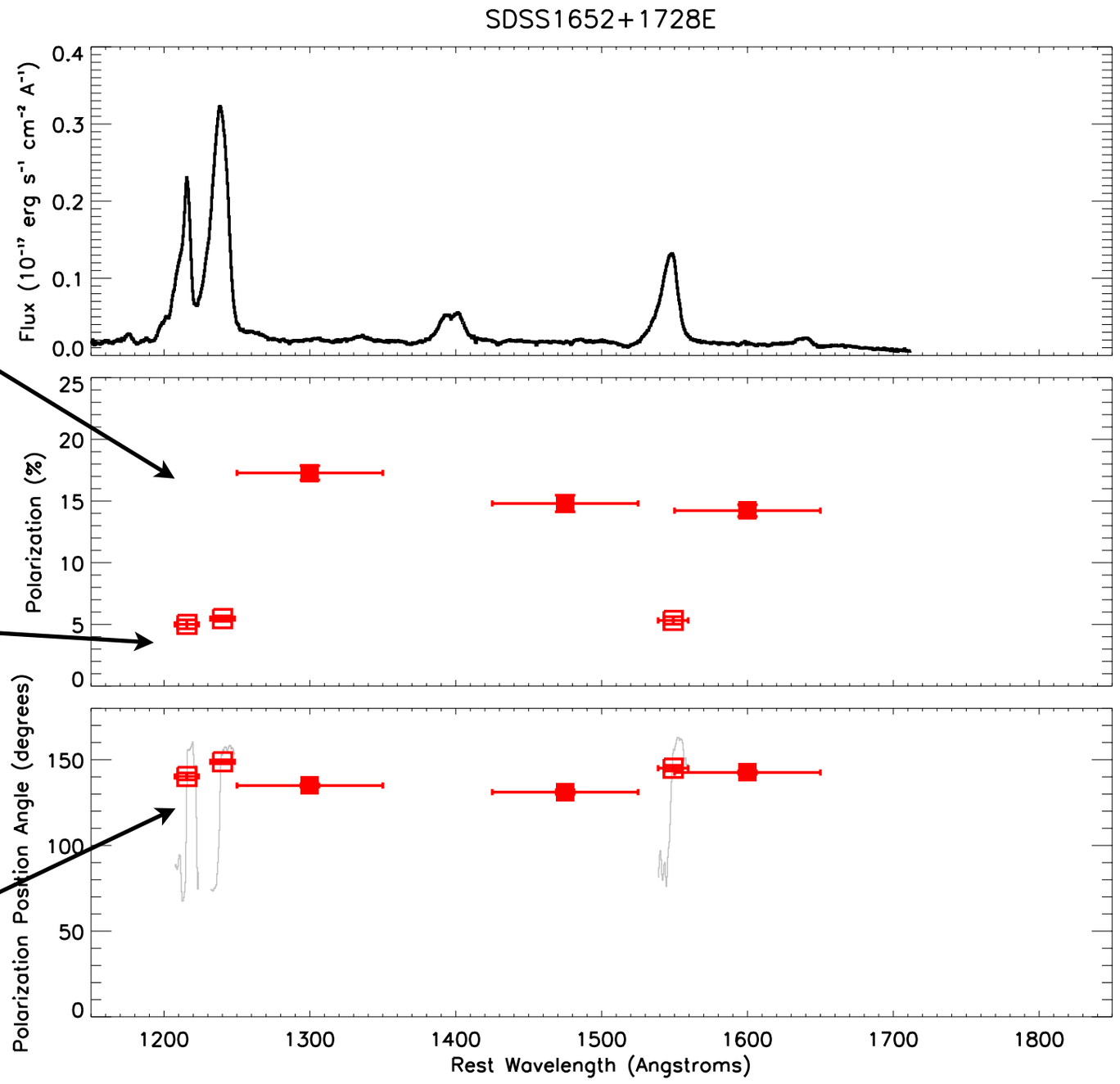


- Main observational signatures:
  - high levels of continuum polarization (>15% in 3 objects)
  - lower levels of polarization in emission lines than the continuum
  - rotation of the polarization position angle as a function of wavelength in the emission lines



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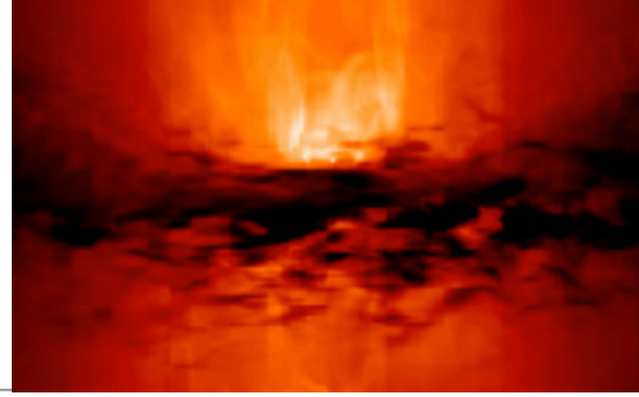

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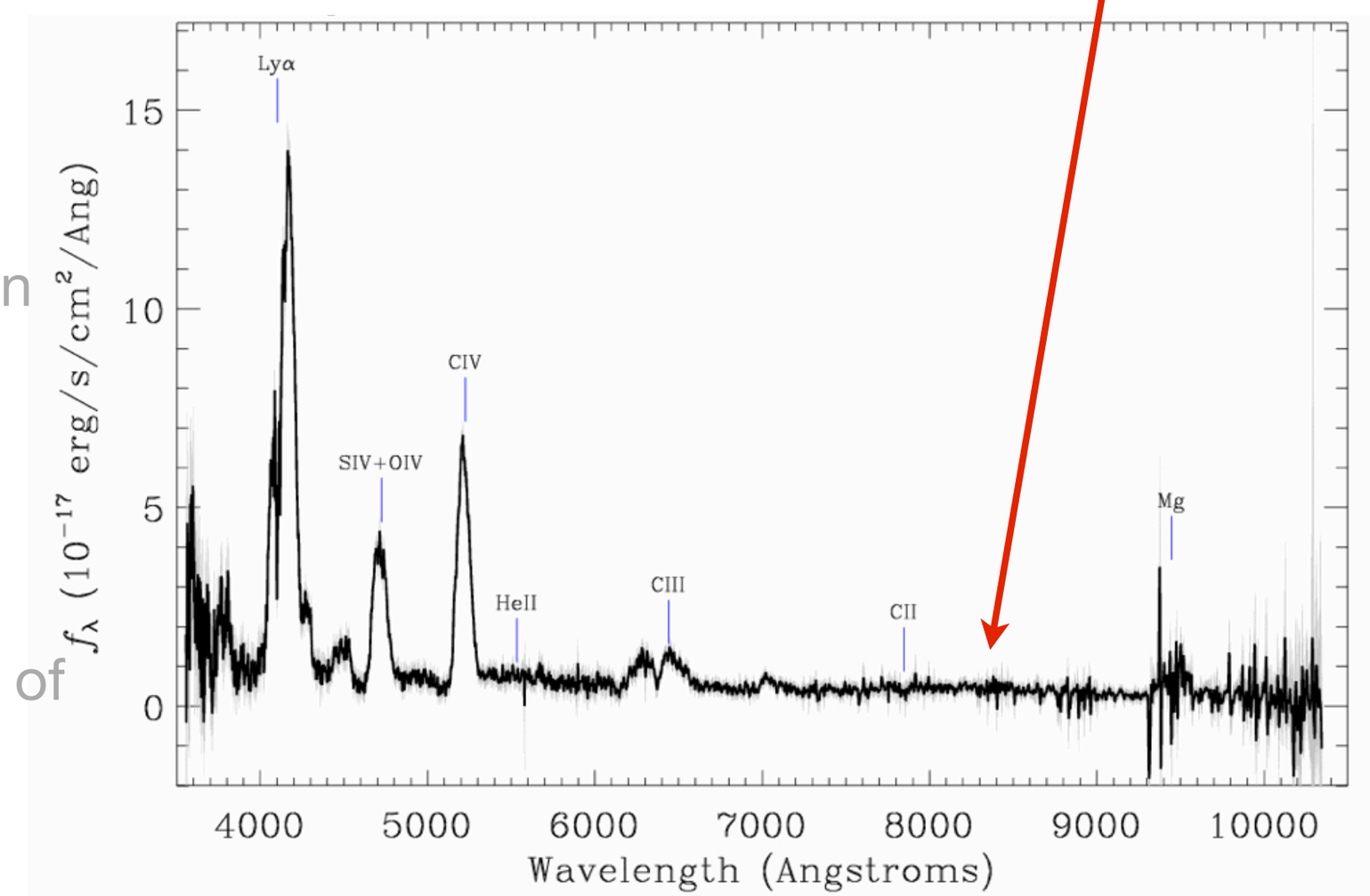
- Most of the observed continuum must be scattered light
- scattering efficiency a few percent



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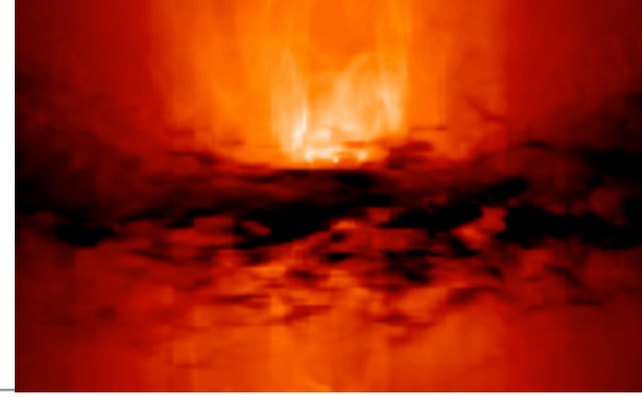

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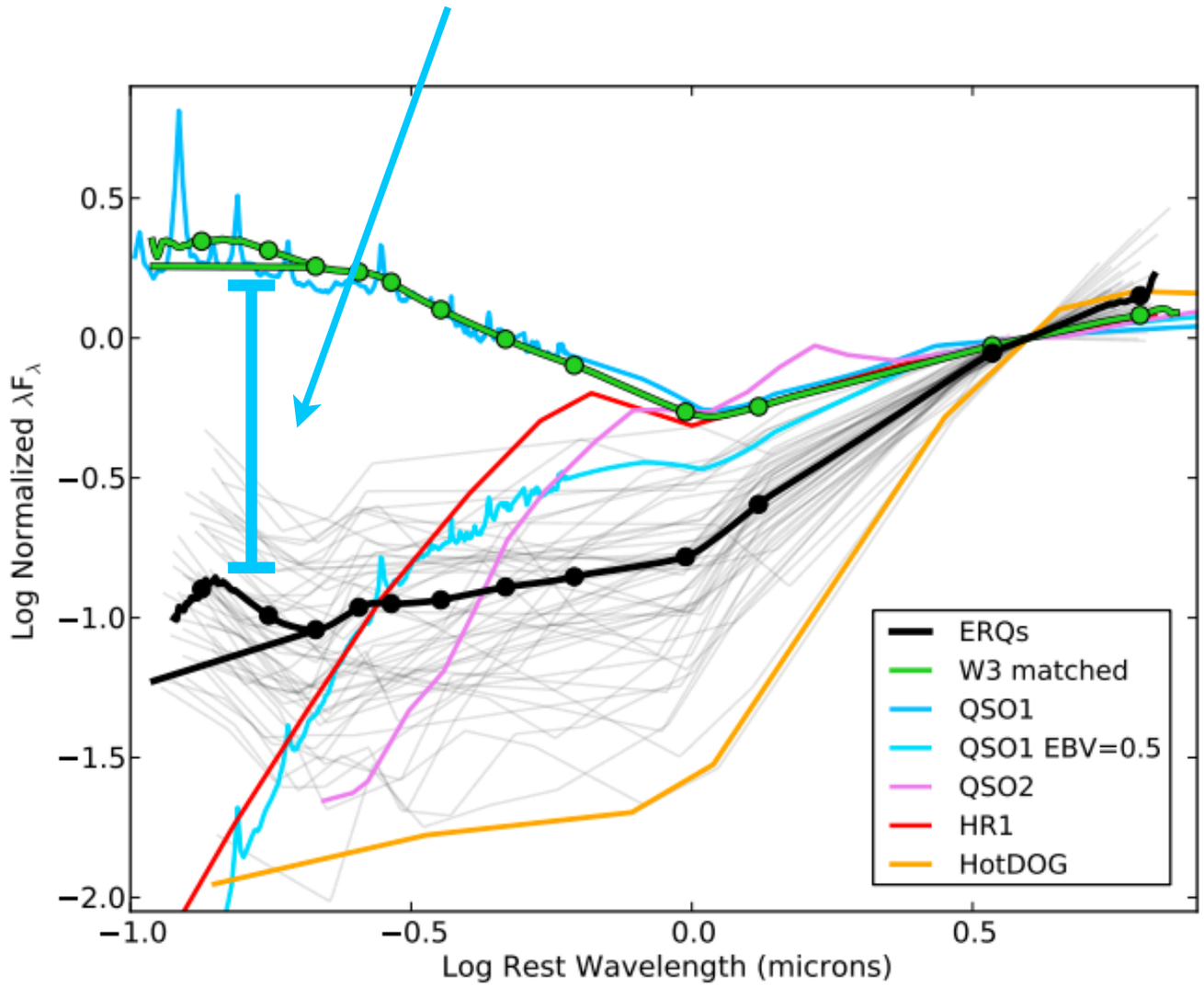

Hamann et al. 2017

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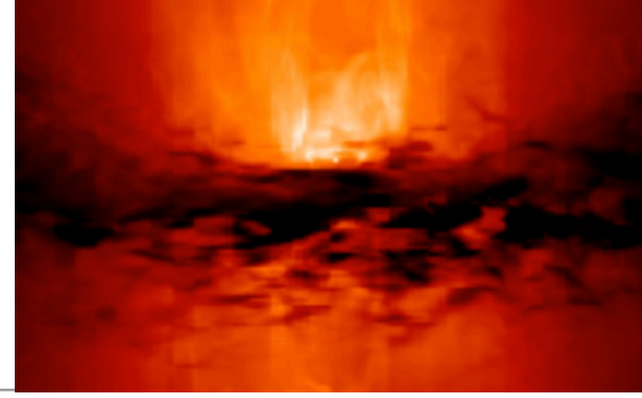

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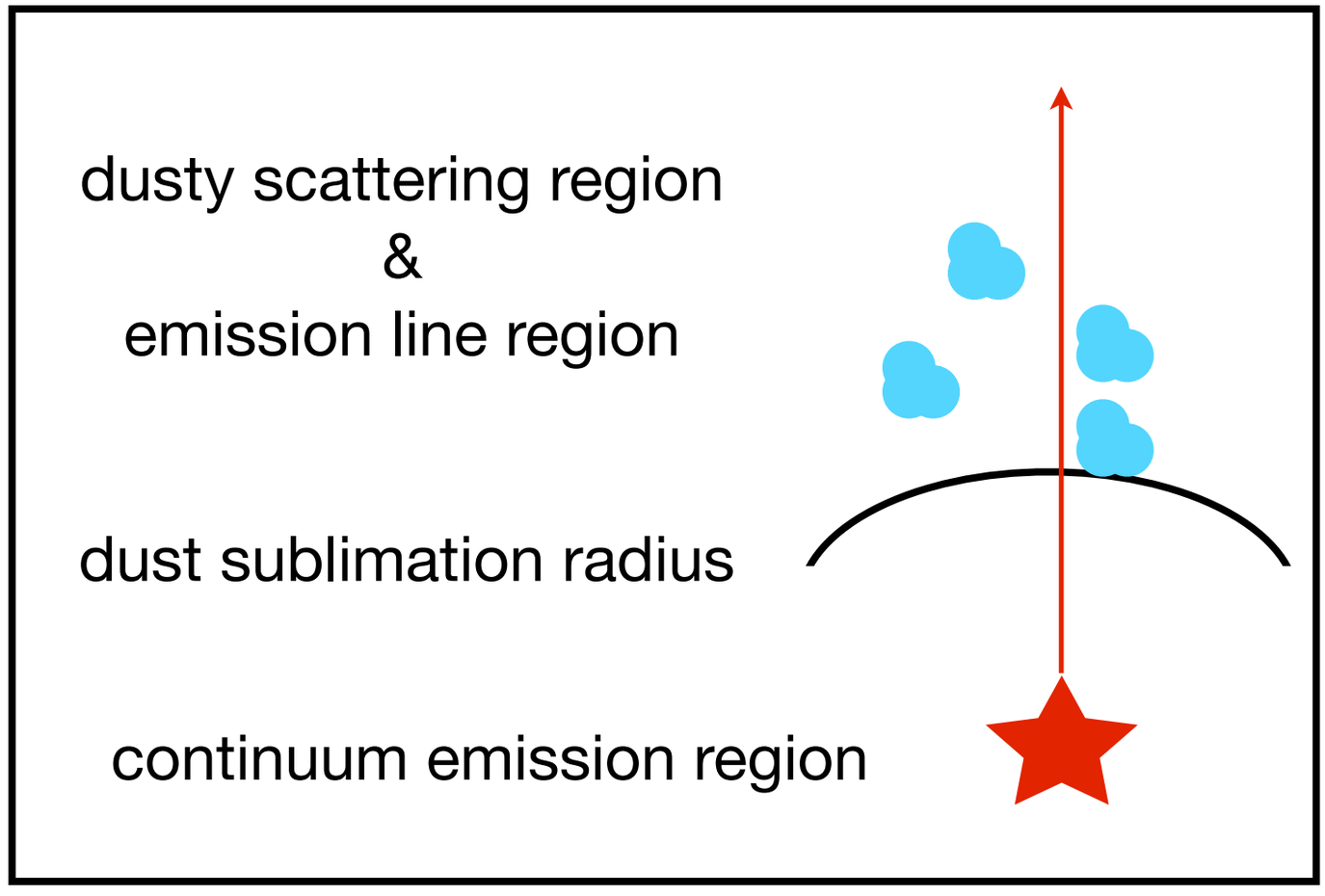
- Scattering region ~ scale of the emission line region (~10 pc)
- lots of dust on these scales (obscured objects!) and therefore dust scattering, more efficient than e^- scattering, dominates



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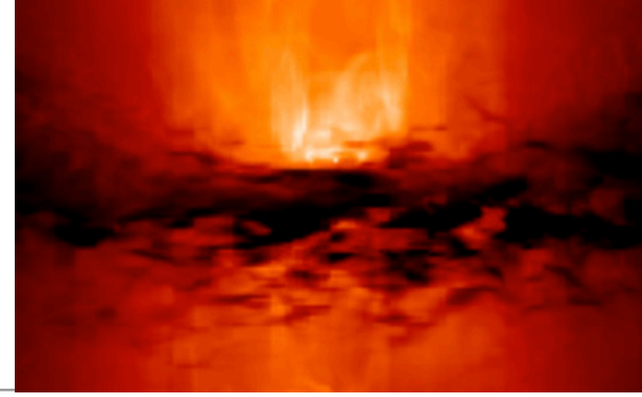
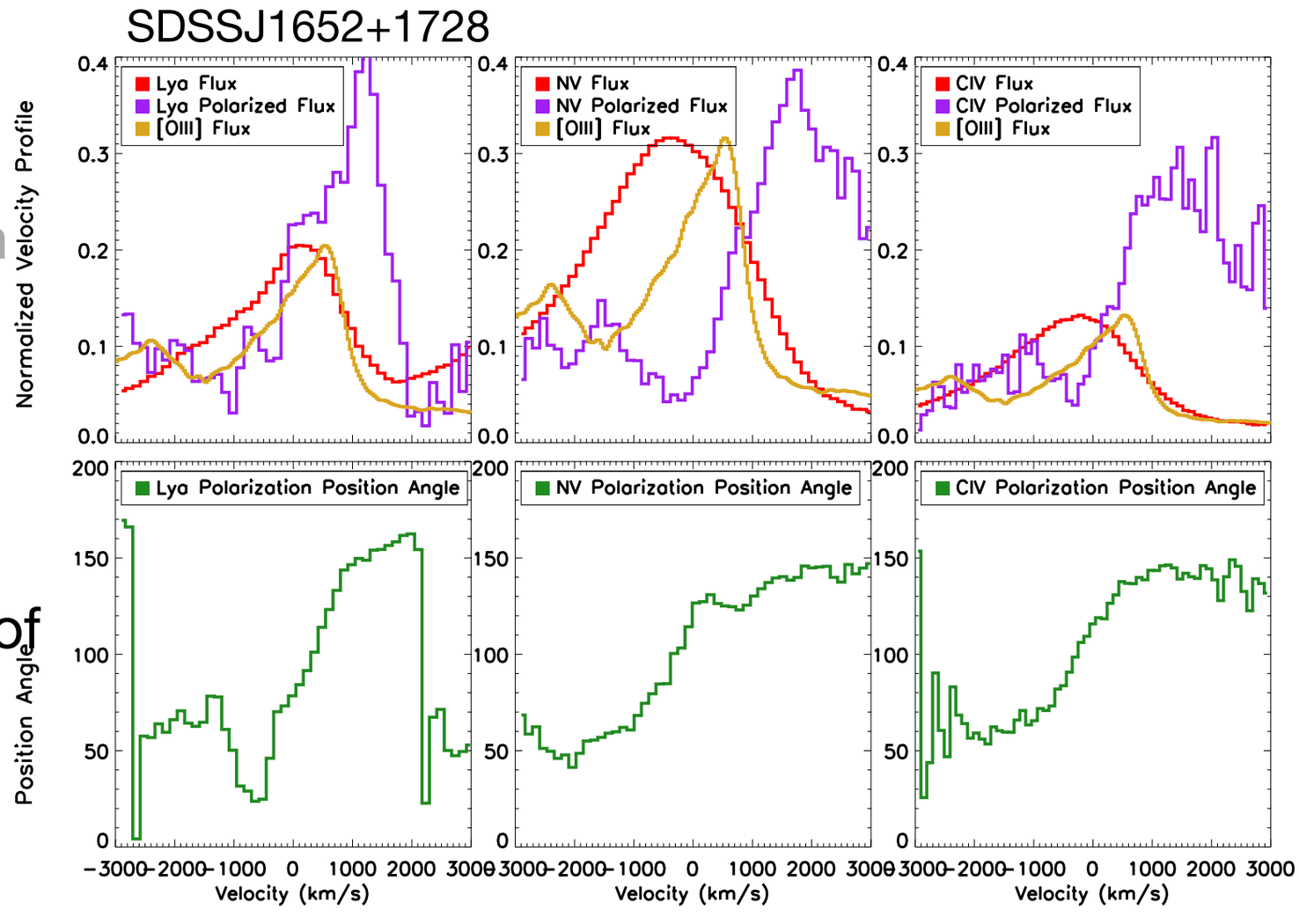


- Main observational signatures:
  - high levels of continuum polarization (>15% in 3 objects)
  - lower levels of polarization in emission lines than the continuum
  - rotation of the polarization position angle as a function of wavelength in the emission lines
- Need different structures to produce polarized emission at different velocities



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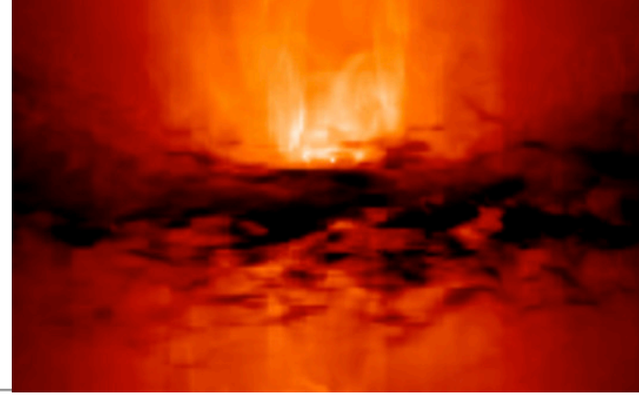
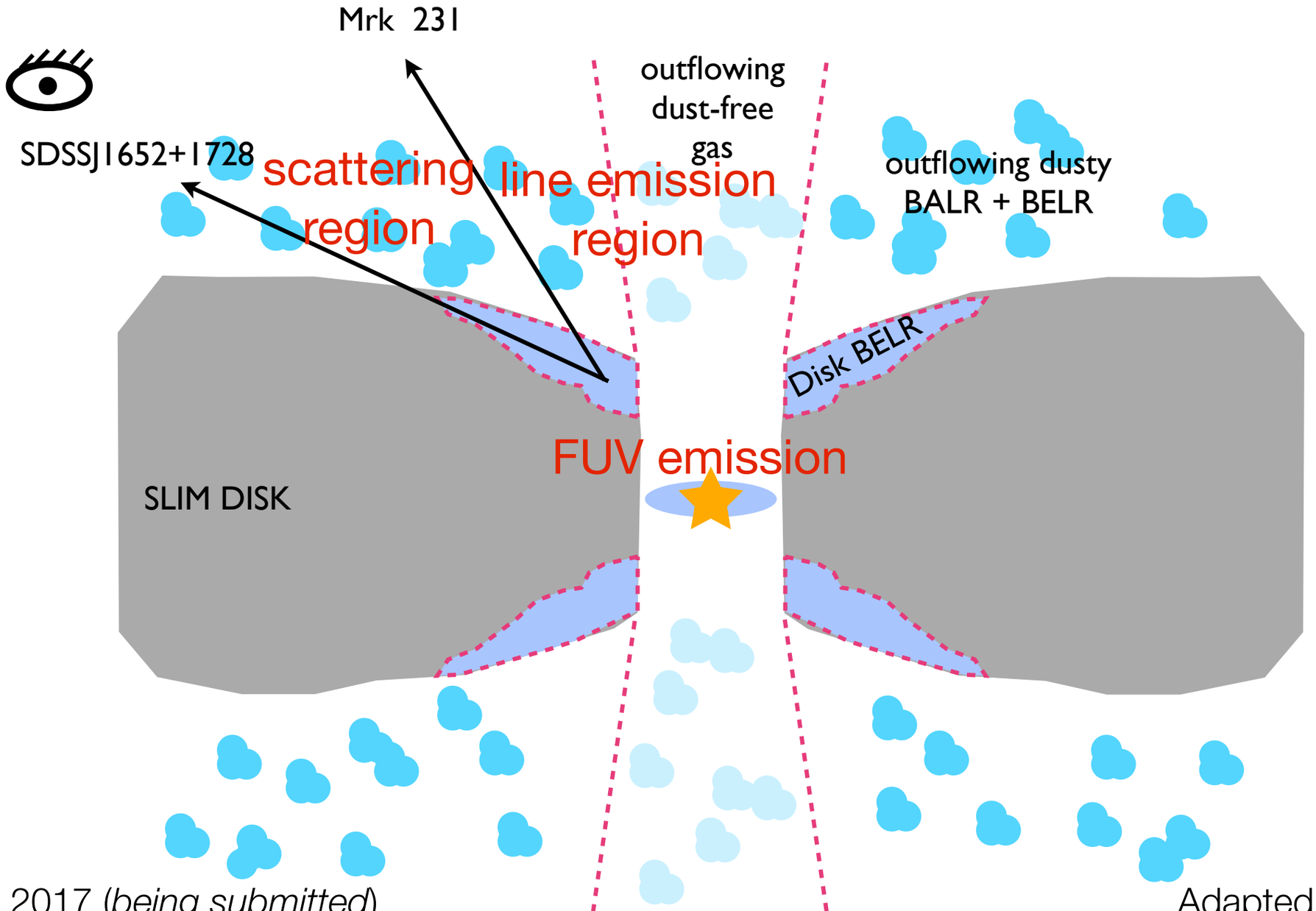


- Physically-motivated “slim disk” model



Alexandroff et al. 2017 (*being submitted*)
Zakamska & Alexandroff 2017 (in prep)

Adapted with permission from Veilleux et al. 2016

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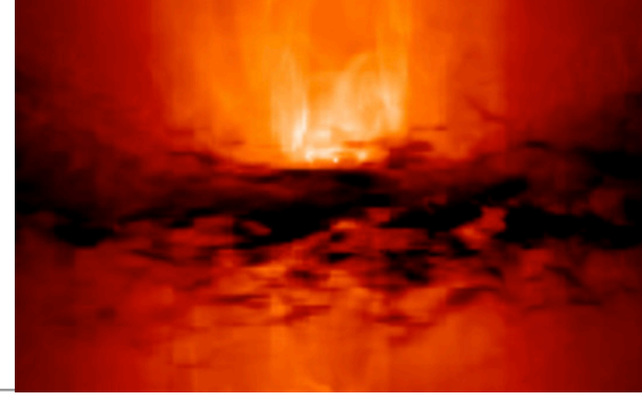
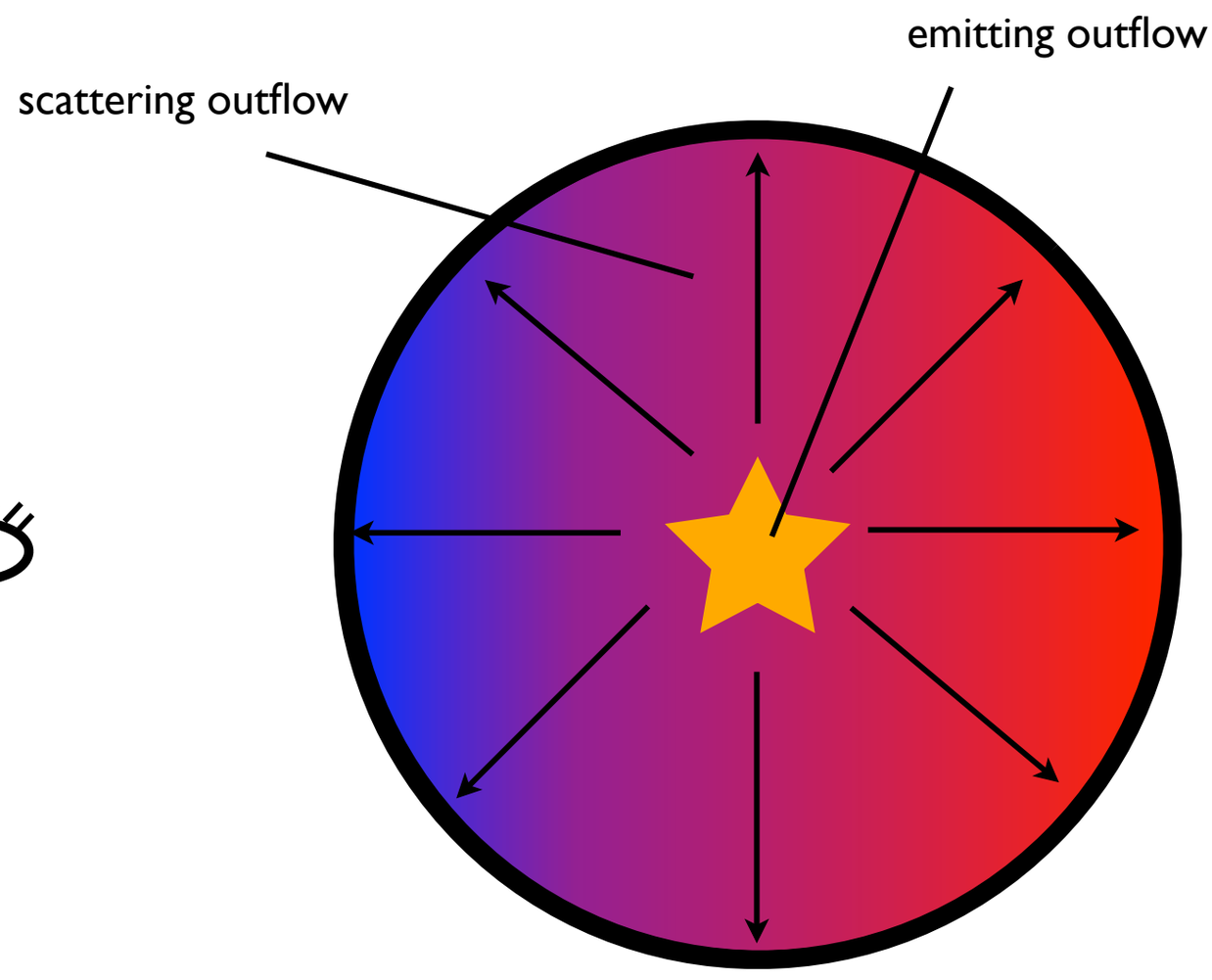


- Physically-motivated “slim disk” model
- Naturally reproduces polarization position angle variation as a function of emission line velocity
- Implies these quasars are driving outflows near the central engine



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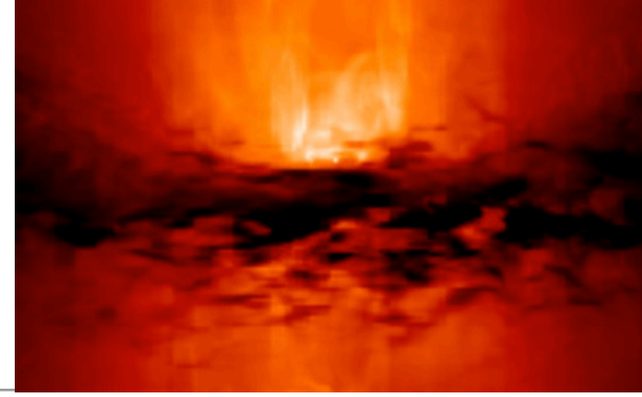

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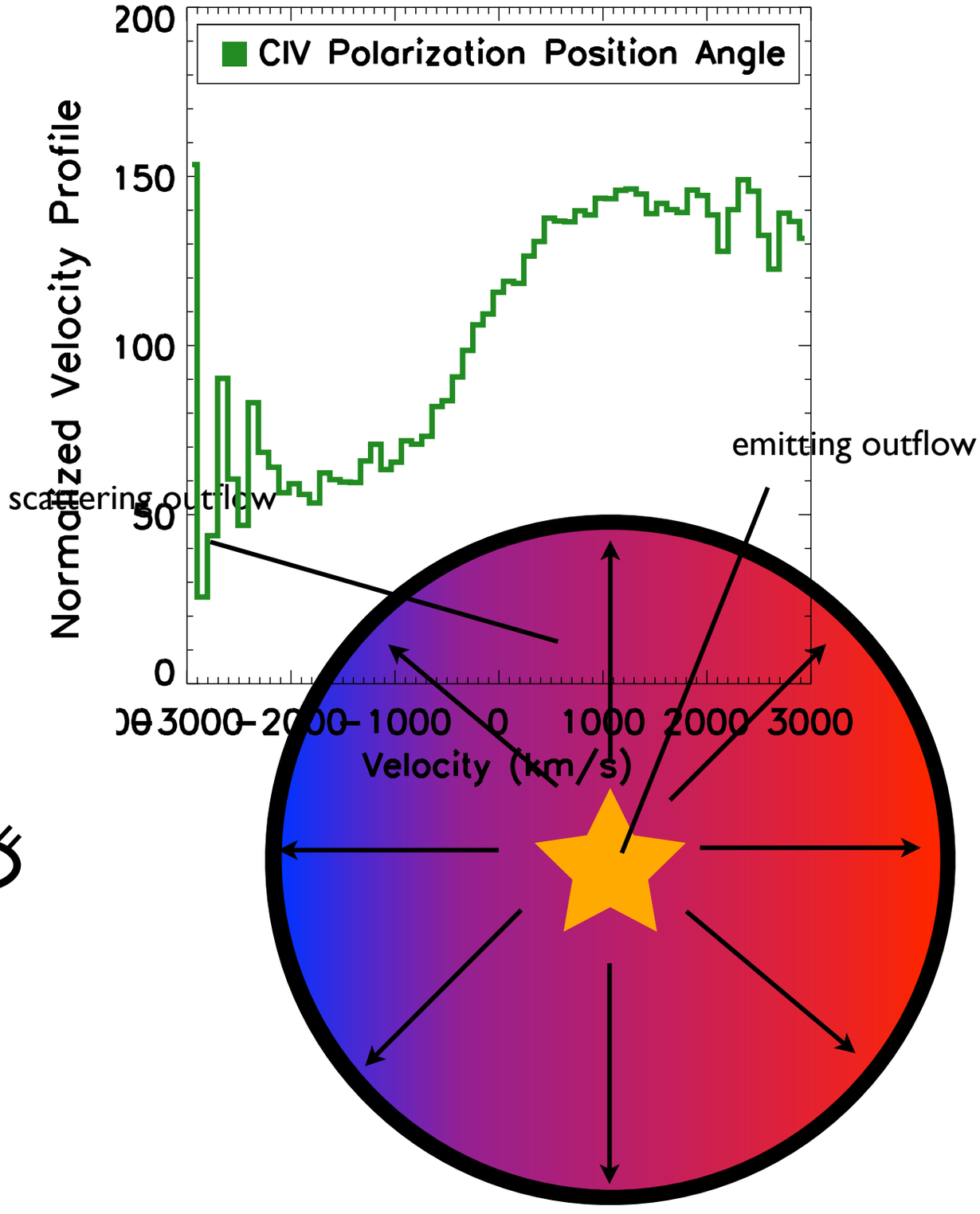

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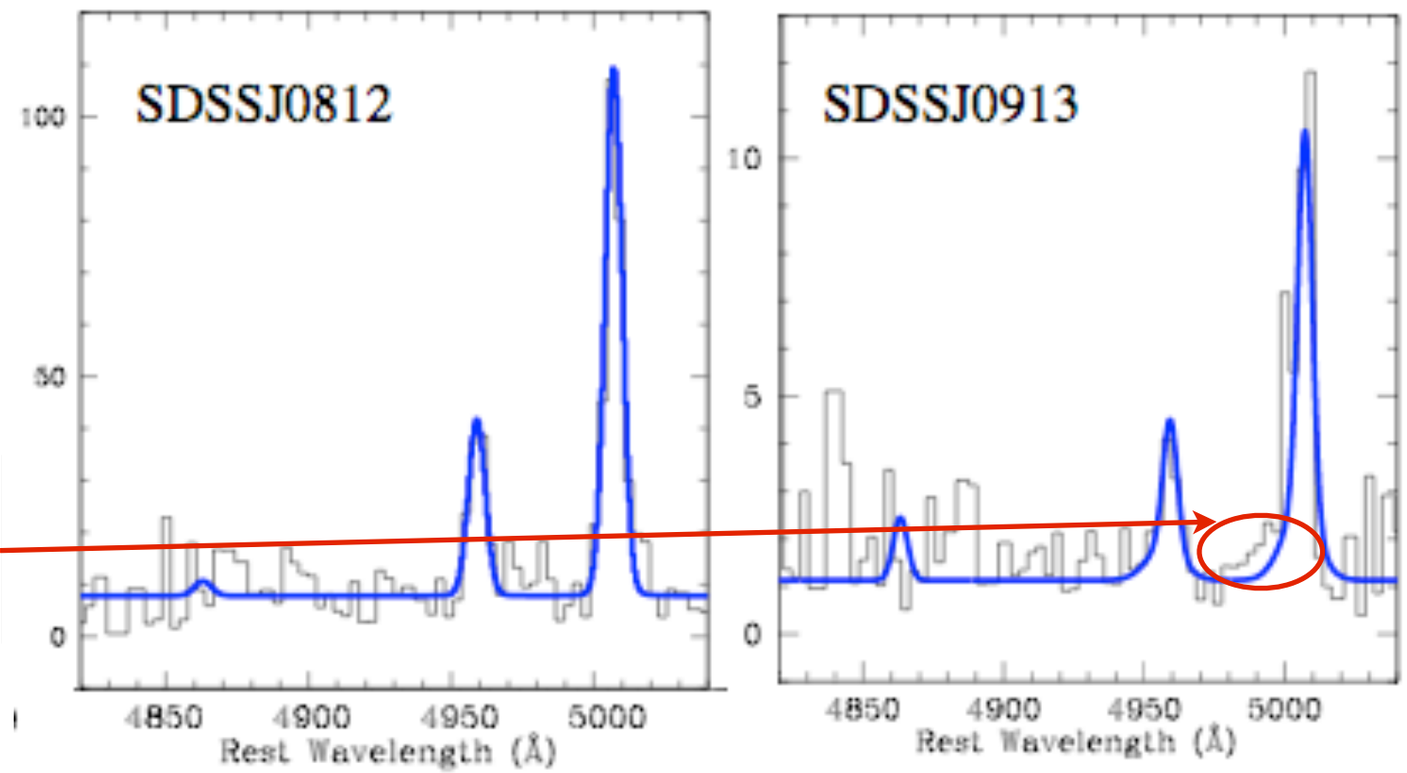
2. What evidence do we see for outflows launched by the quasar effecting the host galaxy on large scales?

Tracing ionized outflows using [OIII] gas

- Ionized outflows can be traced by forbidden emission line [OIII]
- Without IFU observations (pending), rely on kinematics

“Type 2” objects show hints of blueshifted emission



Greene, Alexandroff et al. 2014

Tracing ionized outflows using [OIII] gas

- Ionized outflows can be traced by forbidden emission line [OIII]
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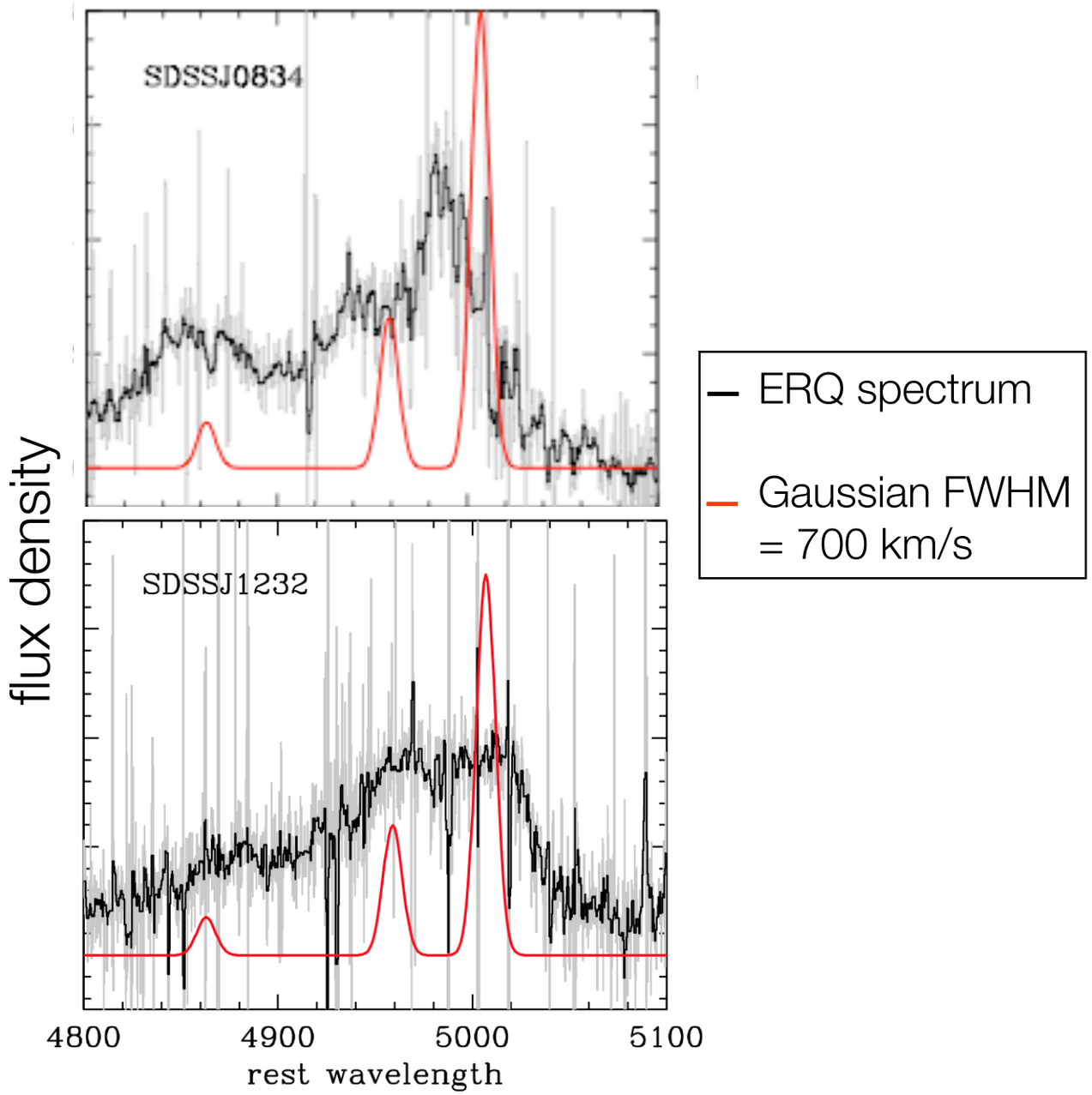
most extreme ERQs show [OIII] FWHM > 3000 km/s

this is to large to be contained by any reasonable galaxy potential



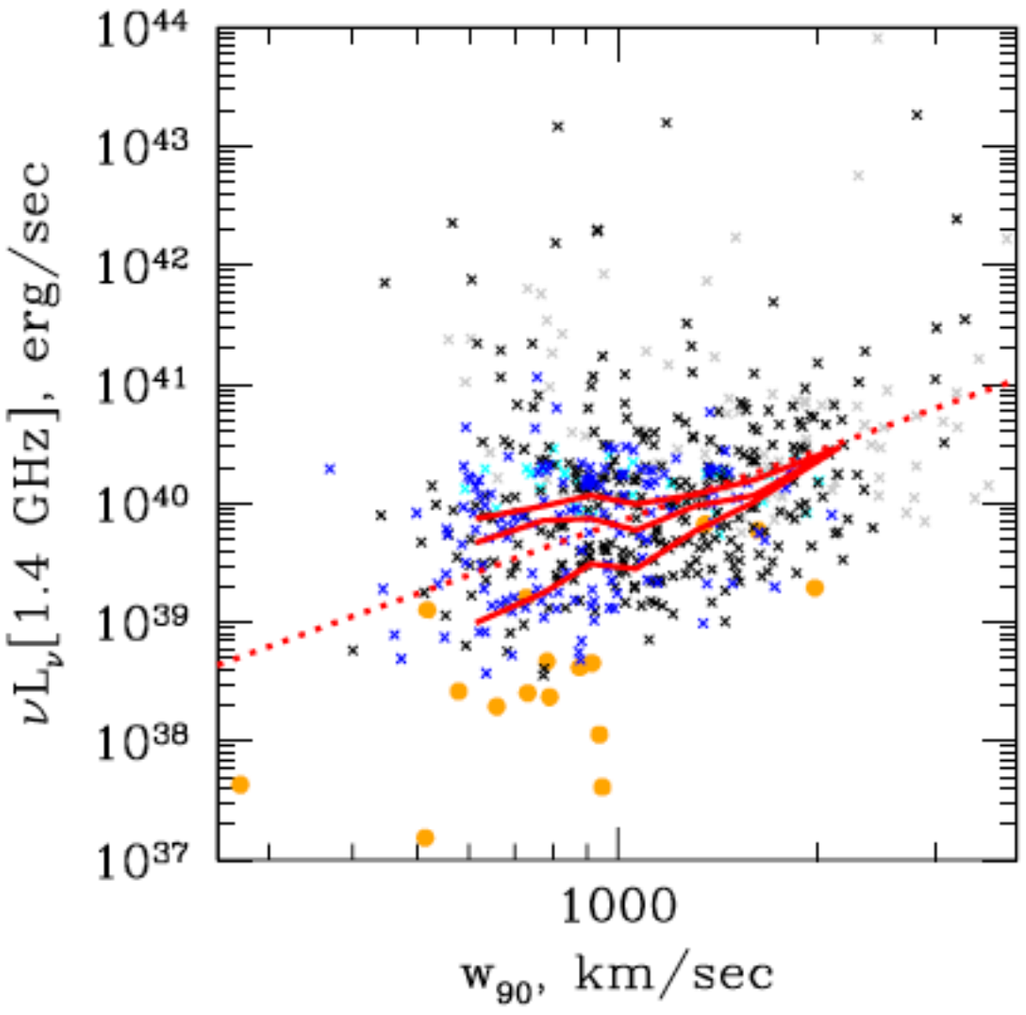
Zakamska et al. 2016

Origin of Radio Emission in Radio-Quiet Quasars

- $z < 0.8$ observed correlation between line width & radio luminosity

- Could the quasar-driven shocks also accelerate particles and produce the observed radio emission?

- How to differentiate from young/weak radio jets?

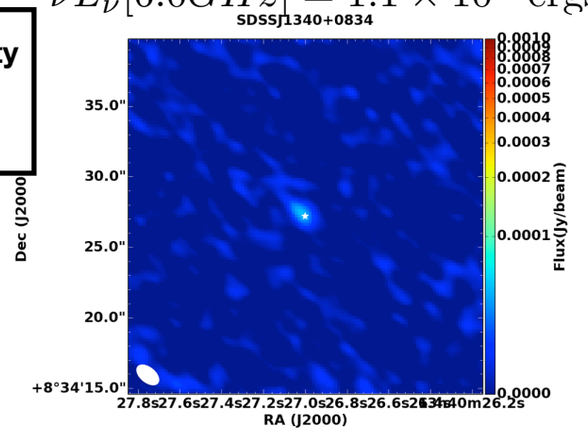


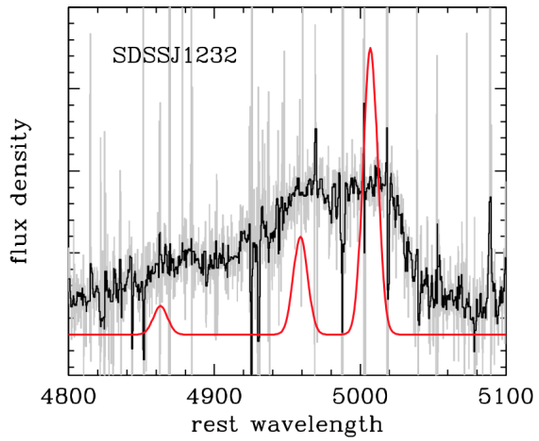
Zakamska & Greene 2014

Origin of Radio Emission in Radio-Quiet Quasars

median radio luminosity of all ERQs at 6.0GHz from FIRST & VLA

$$\nu L_\nu[6.0GHz] = 1.1 \times 10^{41} \mathrm{ergs}^{-1}$$





Hwang et al. 2017, in prep

mean stack of 11 obscured quasars at z ~ 2.5 at 6.0GHz from the VLA

$$\nu L_\nu[6.0GHz] = 6.0 \times 10^{40} \mathrm{ergs}^{-1}$$

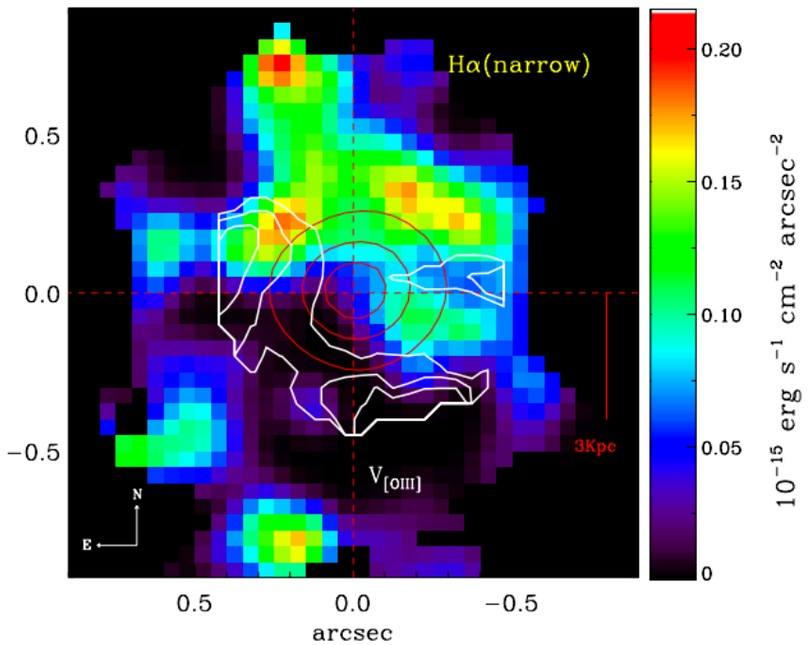
Alexandroff et al. 2016, arXiv:1603.07325

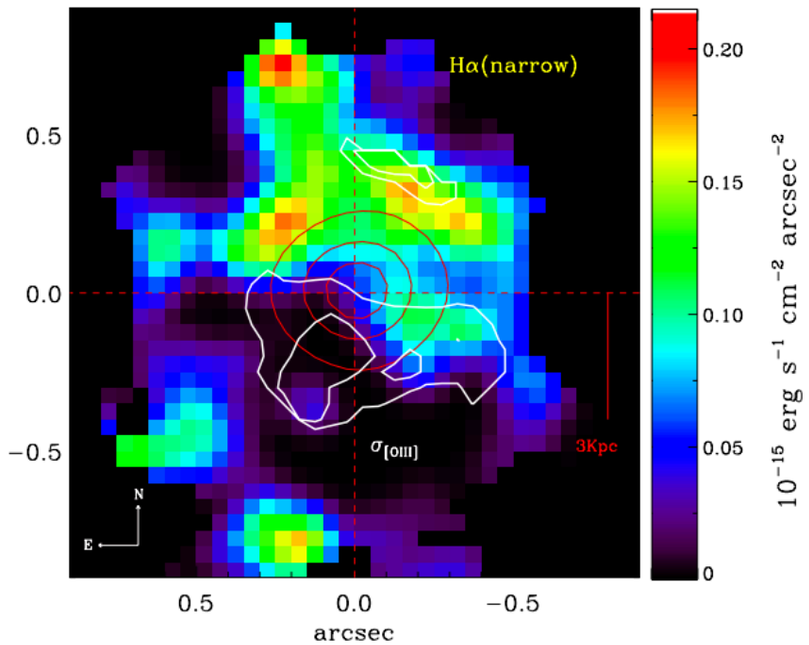
2. What evidence do we see for outflows effecting the molecular material on galaxy scales?

Warning: Results still preliminary
Proceed with caution

Tracing molecular outflows using CO(1-0)

- Tracing molecular gas is the only way to ascertain if the quasar is removing star-forming material from its host galaxy
- Look for molecular gas by tracing CO emission with VLA (ALMA in future)

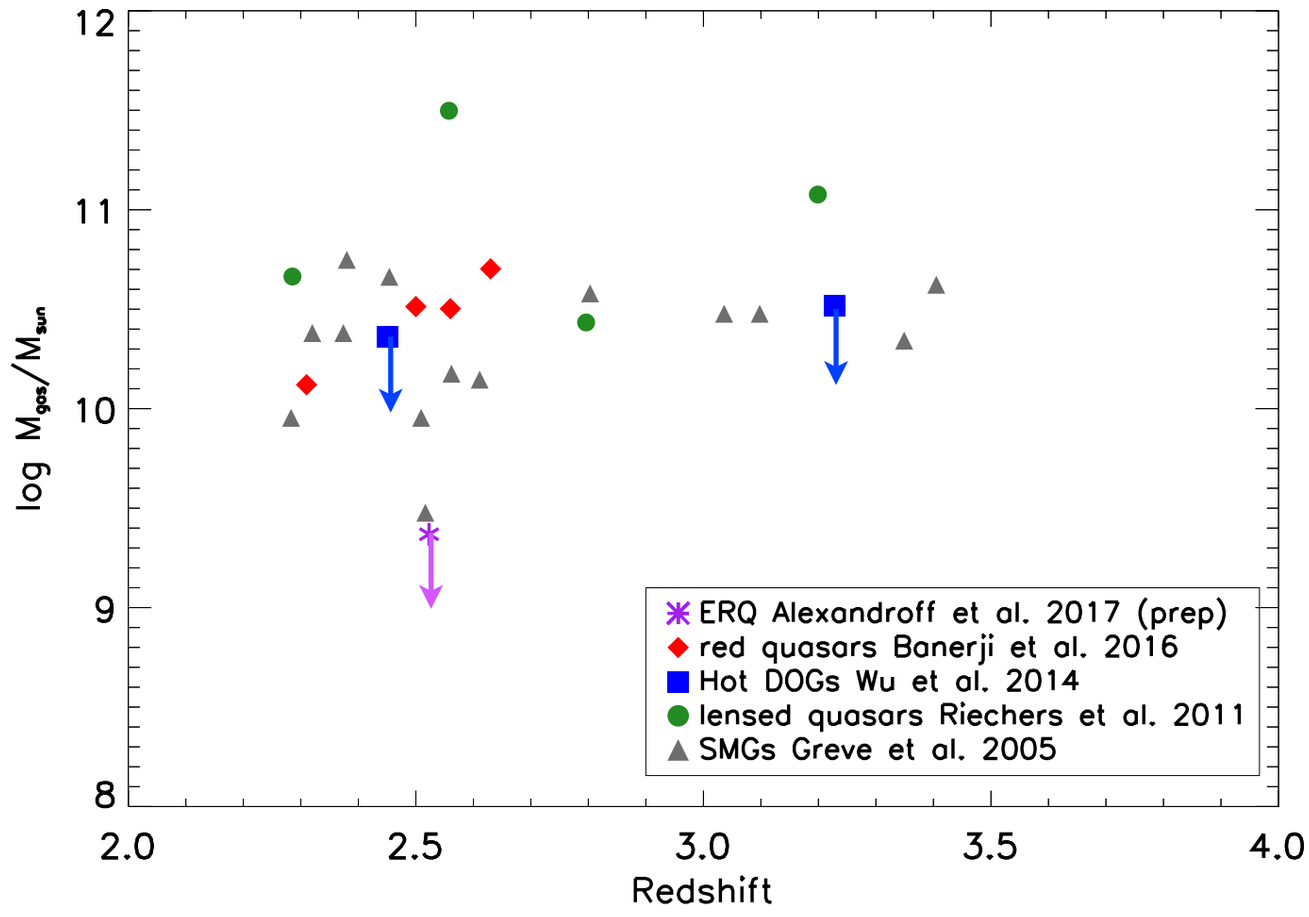




Cano-Diaz et al. 2012

Tracing molecular outflows using CO(1-0)

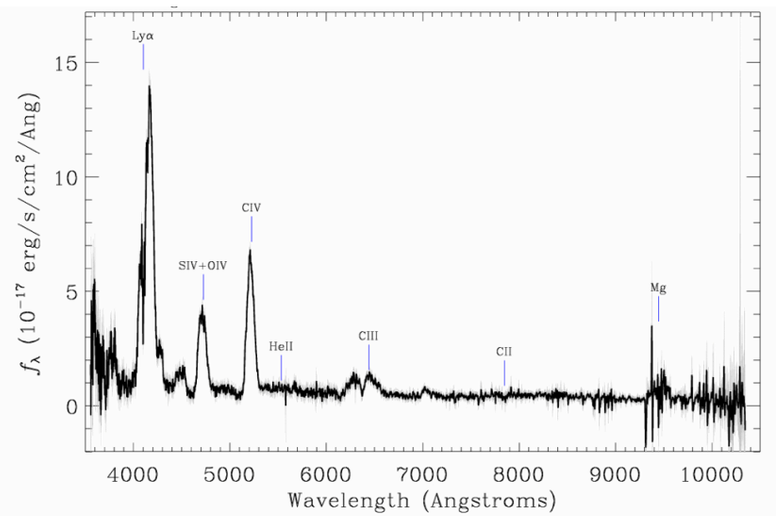
- Non-detection of CO (1-0) in a stack of 11 quasars observed for a total of 14 hours with the VLA in 2016
  - CO line luminosity < 2.4 x 10^9 K km/s pc^2
  - implies gas mass < 9.6-1.9 x 10^9 $M_\odot$ (depending on α_{CO})
- Evidence that quasars have little low excitation gas compared to SMGs?
- Evidence that powerful quasar is clearing its host galaxy of molecular gas?



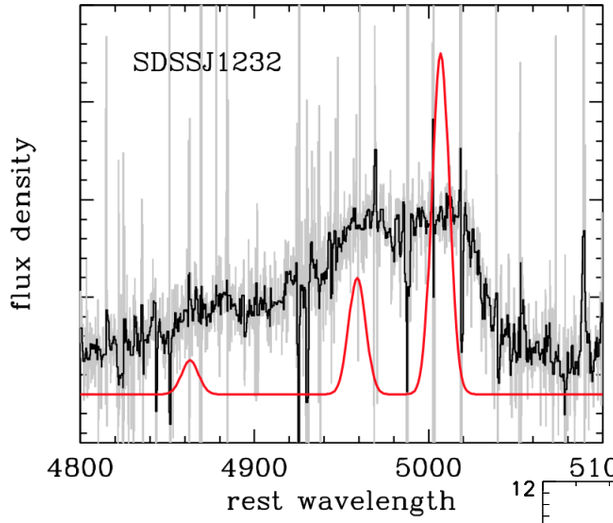
Alexandroff et al. 2017b (*in prep*)

Conclusions

1. A combination of optical & MIR selection reveals “elusive” quasars at high redshift that may shed some light on important open questions



2. ERQs especially display tantalizing evidence of quasar feedback



3. Multi-wavelength observations and new techniques allow us to probe gas at small & large scales, in various ionization states