Constraining the acceleration mechanism of quasar-driven winds using emission and absorption line ratios

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Max Planck Institute for Astronomy

AGN-Driven Winds workshop, Technion, May 2017

Papers:

- Stern, Faucher-Giguère, et al. (2016)
- RPC I–IV: Stern et al. (2014a,b), Baskin et al. (2014a,b)

Outline

1. Extended vs. local density gradients
   (1 slide)

2. Radiation Pressure Confinement (RPC) in a hydro-simulation
   (1 slide)

3. Constraining the acceleration mechanism of quasar-driven winds from observations
   (7 slides)

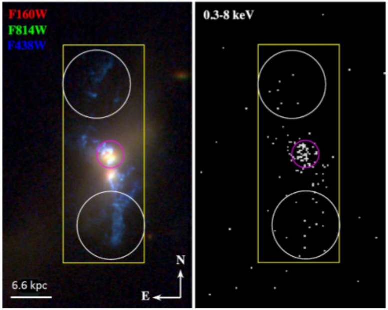
4. RPC in ~~Warm Absorbers~~ outflows observed in X-ray
   (1 slide)

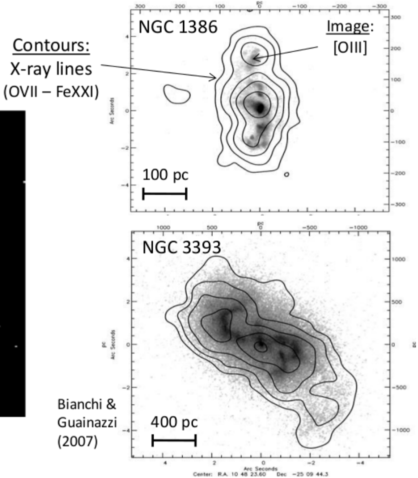
Spatial overlap of [O III] and X-ray line emission

Ehud's talk: large range of ξ in absorption.
Is it due to an *extended* or *local* density gradient?

A hint from resolved emission:

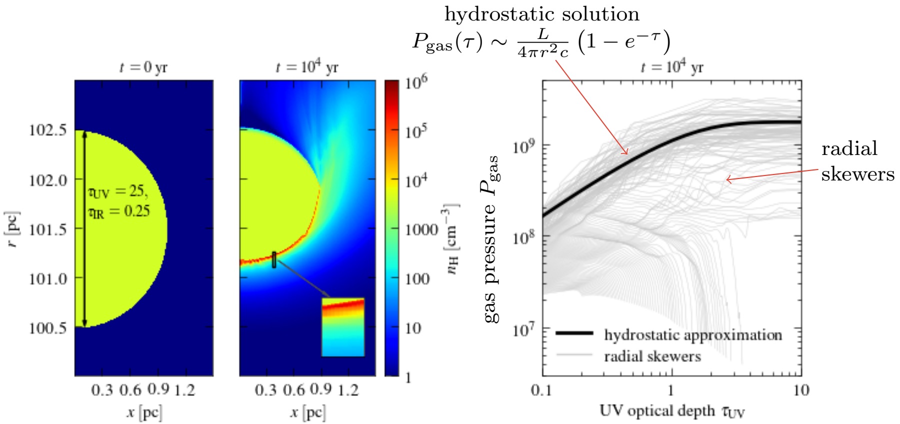
Greene et al. (2014)





Radiation Pressure Confinement

RHD simulation of NLR cloud (PLUTO+):



Stern, Oñorbe & Kuiper, PRELIMINARY

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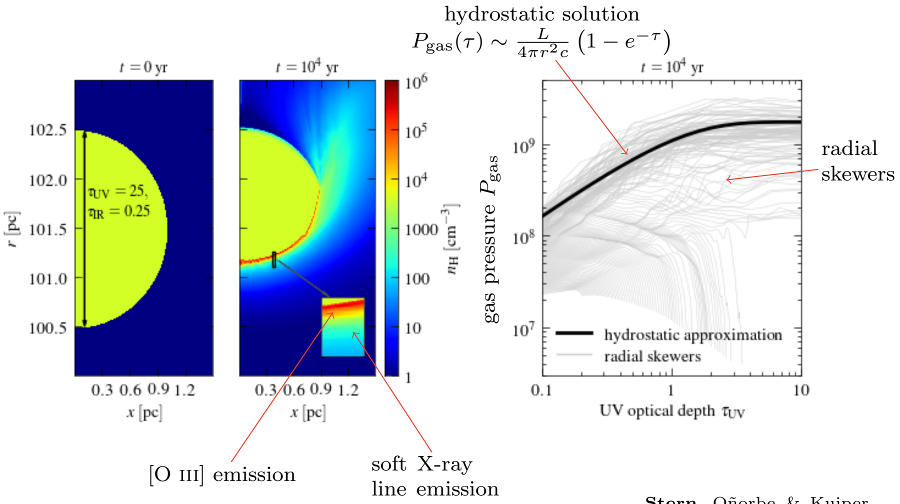


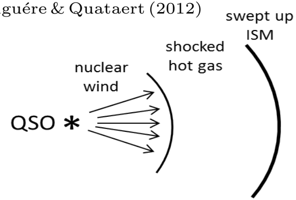
Stern, Oñorbe & Kuiper, PRELIMINARY

Acceleration of quasar-driven galaxy-scale winds

Potential mechanisms

1. Shocked Wind:

e.g. Faucher-Giguére & Quataert (2012)



2. Radiation Pressure:

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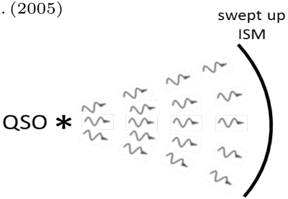

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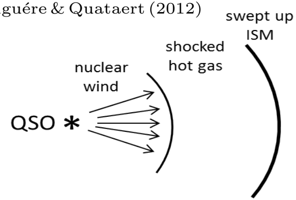

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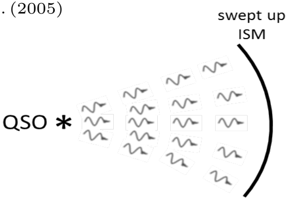

Expected pressure of cool ($\gtrsim 10^4$ K) emission line gas

$$P_{\rm cool} \sim P_{\rm hot}$$

$$P_{\rm cool} \sim P_{\rm rad}\left(1 - e^{-\tau}\right) \equiv \frac{L}{4\pi r^2 c}\left(1 - e^{-\tau}\right)$$

(Pier & Voit 1995, Dopita+02, Różańska+06, Draine 2011, **Stern**+14a,b, Baskin+14a,b)

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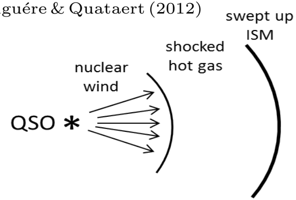

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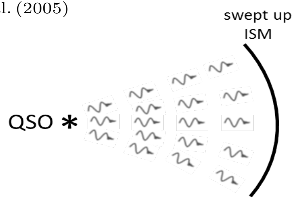
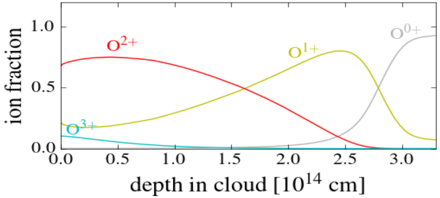


Hydrostatic Photoionization Calculations

$P_{\rm cool} \sim P_{\rm hot} \gg P_{\rm rad} \rightarrow$ low ionization



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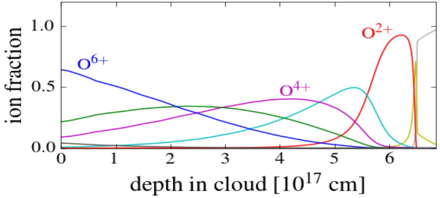
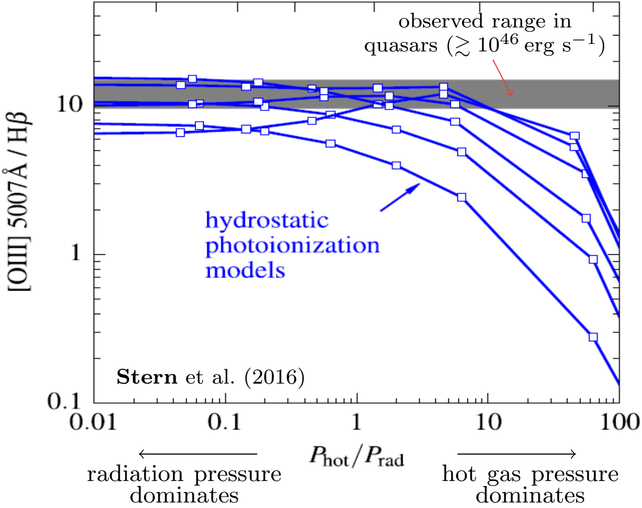


Hydrostatic photoionization solutions vs. observations



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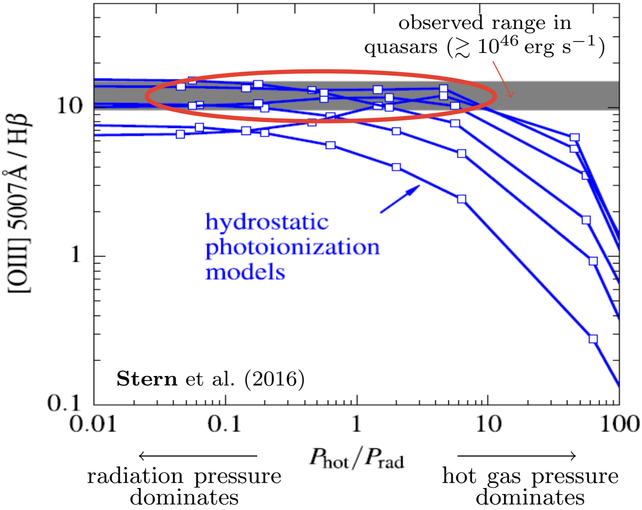

$P_{\rm hot} > 10P_{\rm rad}$
ruled out

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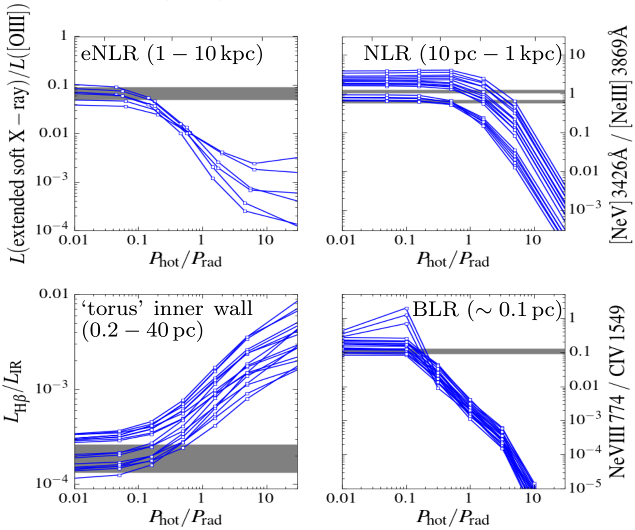

Stern et al. (2016)

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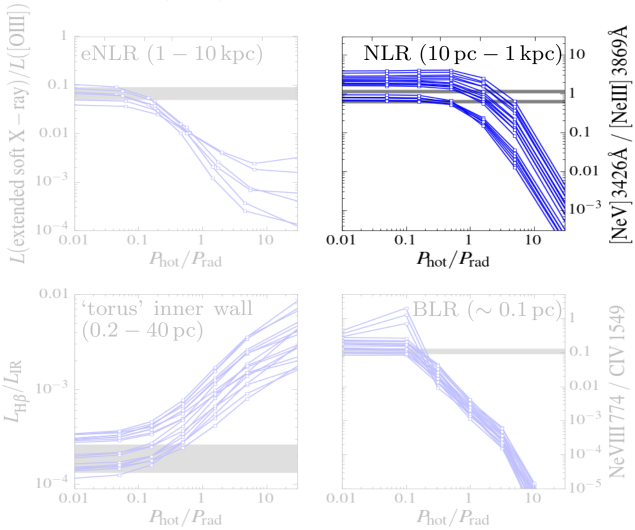


Region: **NLR**

Distance:
10 pc – 1 kpc

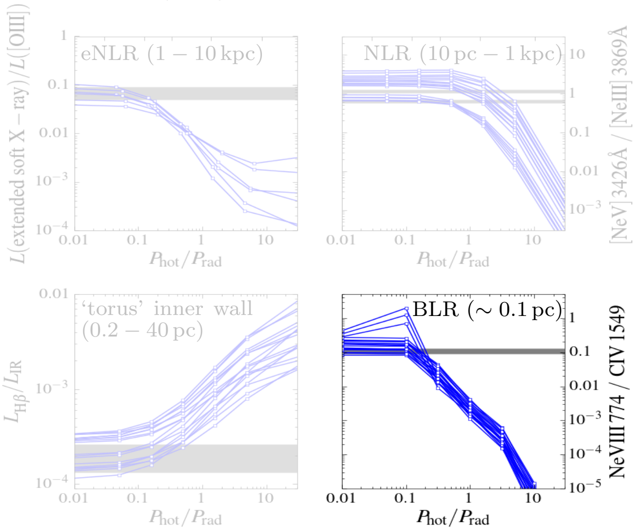
Object:
Average type 1,
average type 2

Telescope:
SDSS

Reference:
Vanden Berk et al. (2001),
Zakamska et al. (2003)

Stern et al. (2016)

Hydrostatic photoionization solutions vs. observations



Region: **BLR**

Distance:
~ 0.1 pc

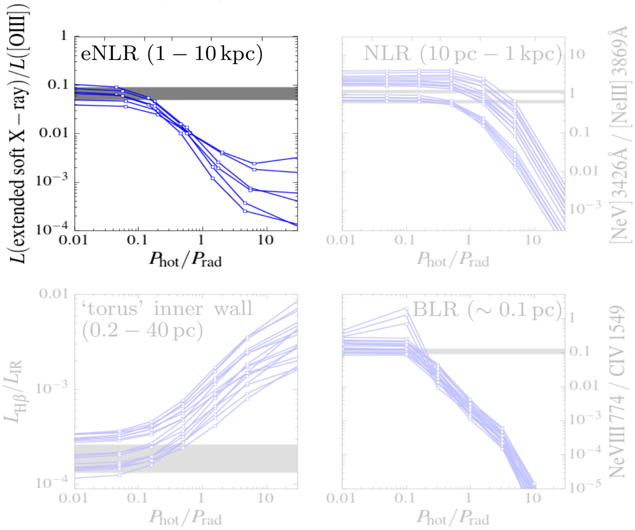
Object:
Average type 1

Telescope:
HST

Reference:
Telfer et al. (2002)

Stern et al. (2016)

Hydrostatic photoionization solutions vs. observations



Region:
Extended NLR

Distance:
1 – 10 kpc

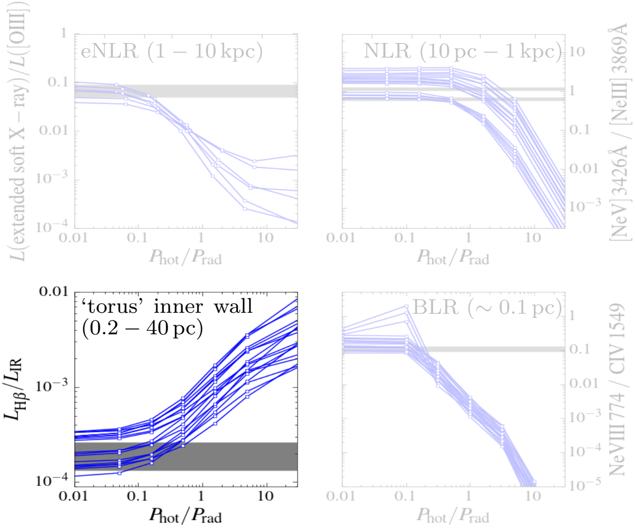
Object:
J1356+1026

Telescope:
Chandra, Magellan

Reference:
Greene et al. (2014)

Stern et al. (2016)

Hydrostatic photoionization solutions vs. observations



Region: **Torus**

Distance:
0.2 – 40 pc

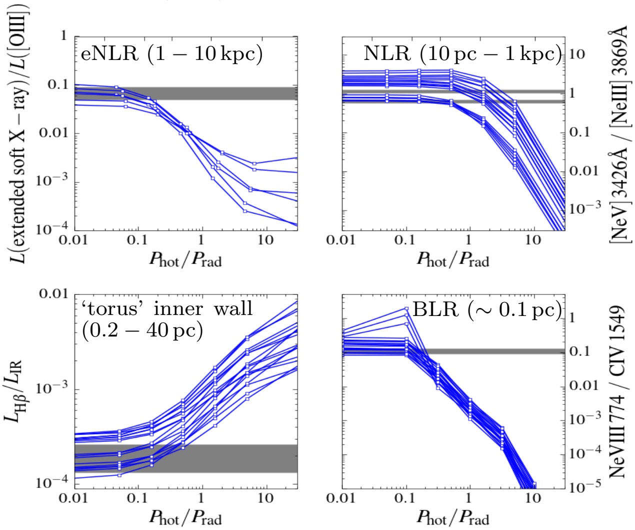
Object:
Average type 1

Telescope:
SDSS, WISE

Reference:
Shen et al. (2011)

Stern et al. (2016)

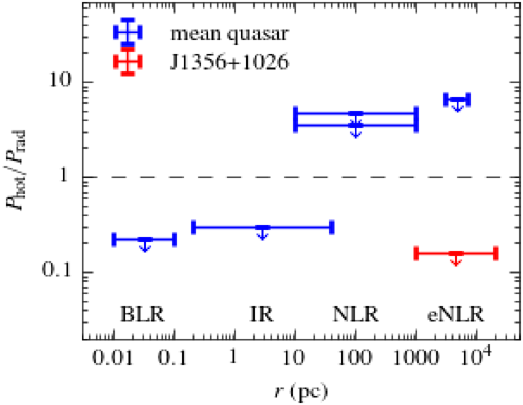
Hydrostatic photoionization solutions vs. observations



$P_{\mathrm{hot}} \gg P_{\mathrm{rad}}$
at all distances

Stern et al. (2016)

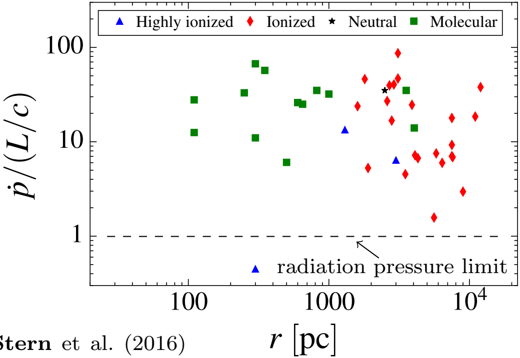
Hydrostatic photoionization solutions vs. observations



- *At all distances*, observations consistent with radiation pressure
- Significant hot gas pressure *ruled out*

Comparison to momentum outflow rate measurements

- Line ratios suggest acceleration via *radiation pressure*
- However, radiation pressure *insufficient* to explain $\dot{p} \equiv \frac{M_{\rm outflow} \times v_{\rm r}}{t_{\rm flow}}$



Stern et al. (2016)

$\dot{p}$ measurements: Arav+13, Bautista+10, Borguet+13, Liu+13, Harrison+14, Greene+14, Feruglio+15, Sturm+11, Cicone+14, Tombesi+15 (however, see Villar-Martin+16, Husemann+16)

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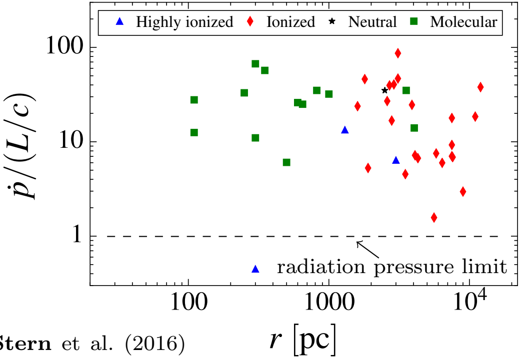

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Is the acceleration time-dependent?

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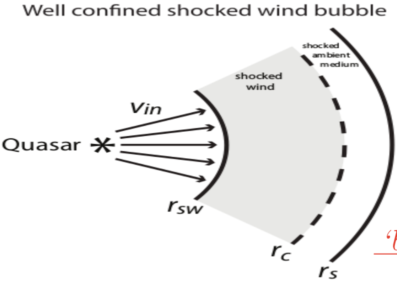
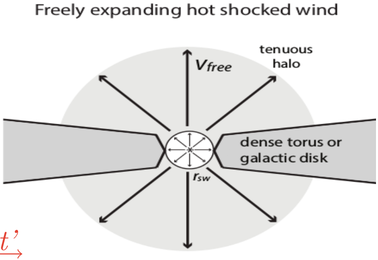
Wind acceleration in a 'buried' accretion phase?



'blow out' →



- Observable as ULIRG
- large shocked-gas pressure
- strong wind acceleration, large $\dot{p}$ reached

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- weak acceleration by radiation pressure, explains line ratios

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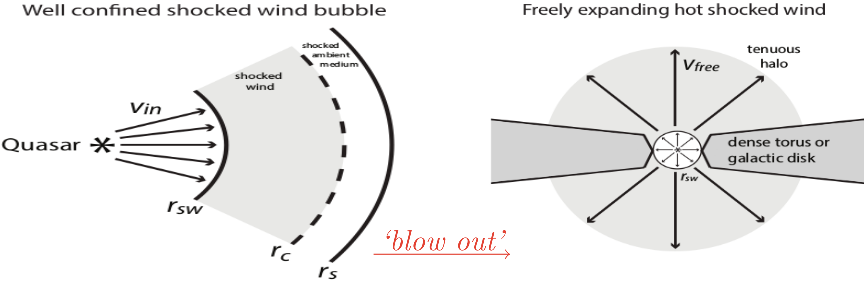

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Predictions:

1. Blow out occured in the last $\sim$ Myr
2. Mid-IR line ratios of ULIRGs

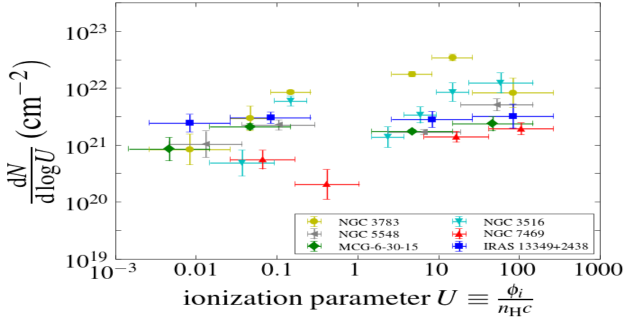
Quasar outflows: Summary

1. The dominant force accelerating outflows can be *constrained from line ratios*
2. Narrow and broad line ratios suggest that *radiation pressure* is the dominant force at 0.1 pc – 10 kpc from the BH
3. Radiation pressure is *insufficient* to explain large observed momentum outflow rates ($\dot{p} \gg L/c$)
   $\longrightarrow$ acceleration in 'buried' accretion phase?

Future

- Measure mid-IR line ratios in 'buried' accreting BHs

Additional observational signatures of RPC



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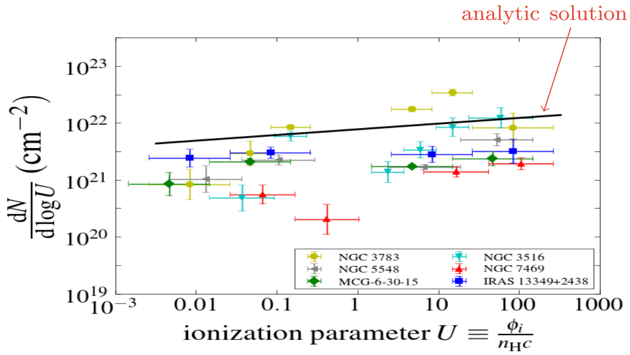

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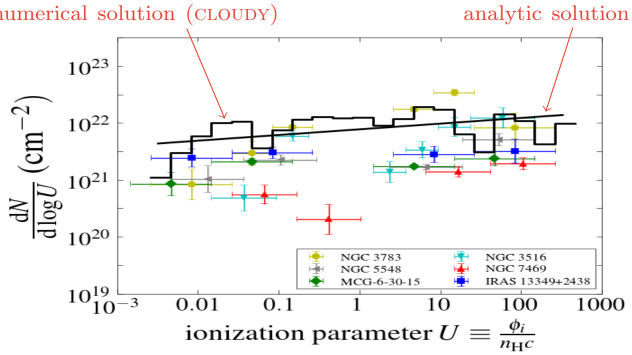

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