ACCURATE CHEMICAL ABUNDANCE MEASUREMENTS FROM SOFIA, HERSCHEL AND KECK

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Galactic Ecosystem, Lake Arrowhead
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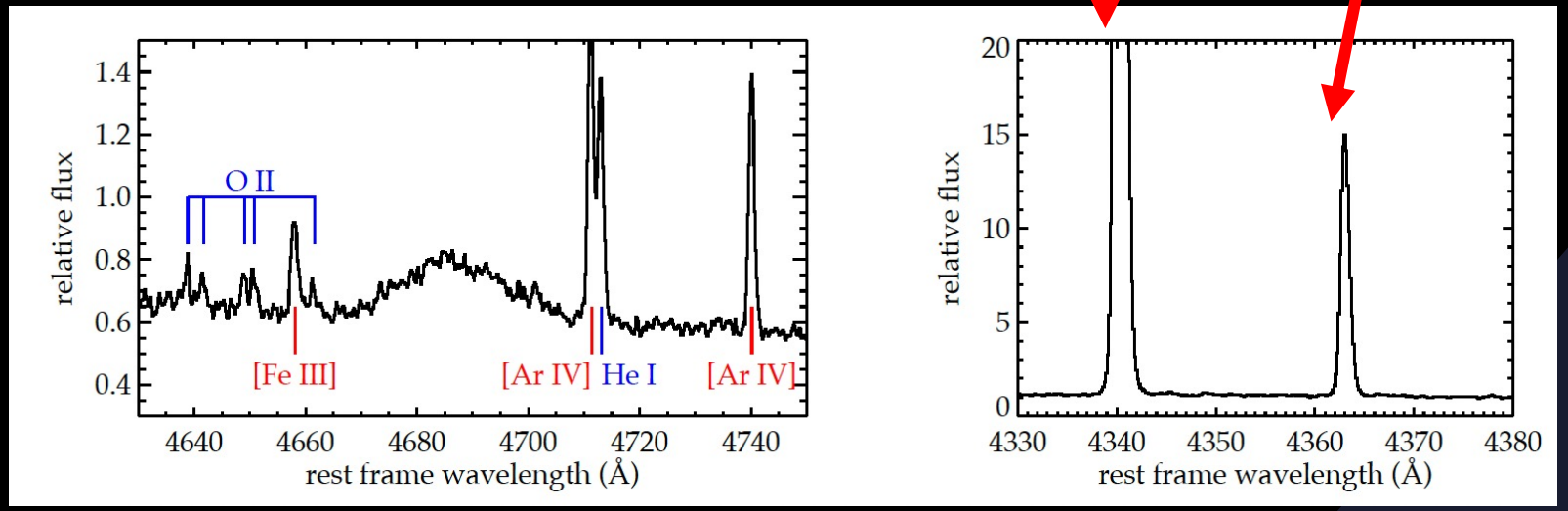
On behalf of Tucker Jones (UCD), Ryan Sanders (UCD), Erin Huntzinger (UCD), Guido Roberts-Borsani (UCLA), Peter Senchyna (Carnegie), Justin Spilker (Texas A&M), Daniel Stark (UA), Robert Minchin (SOFIA), Benjamin Weine (UA)

BACKGROUND

Measuring Metallicity in Optical

- Collisionally excited forbidden transition
  - [O III] 4363, 4959, 5007
  - Bright, dominant in optical spectra
- Recombination lines
  - >100 times fainter

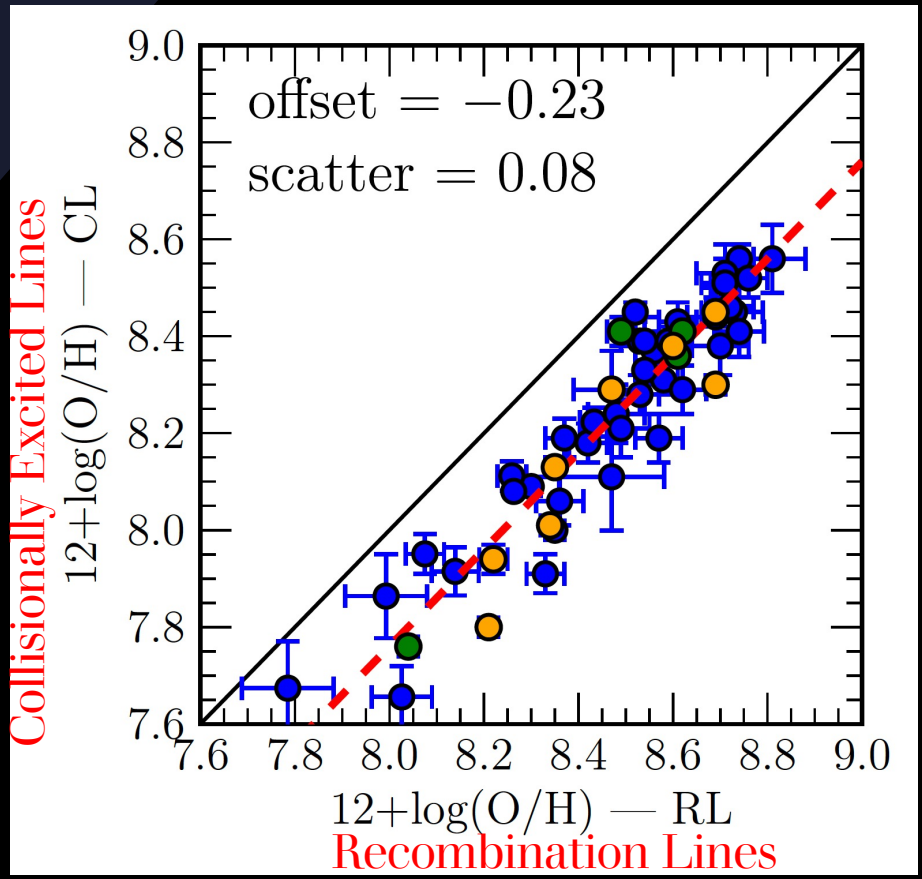


Esteban+14

The Abundance Discrepancy

- Potential systematic uncertainty of O/H ~ factor of 2.

Oxygen Abundance



Credit: R. Sanders

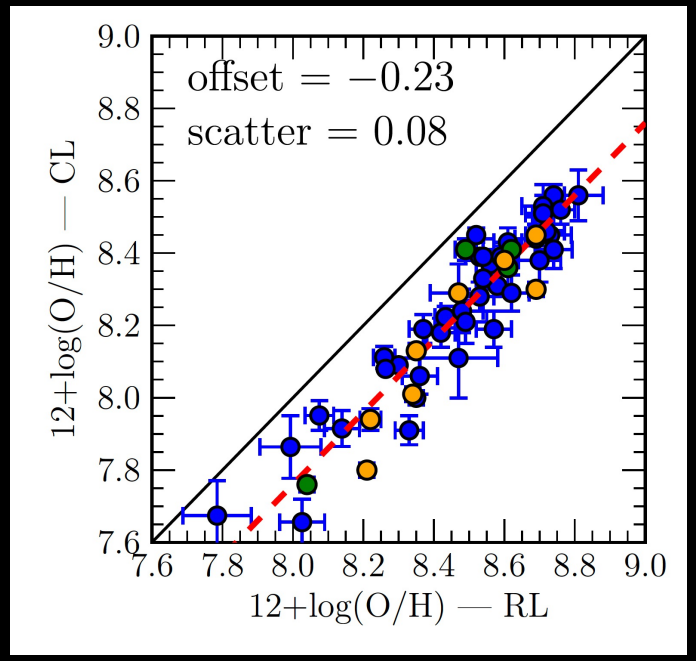
Temperature Fluctuation

Gaussian temperature distribution

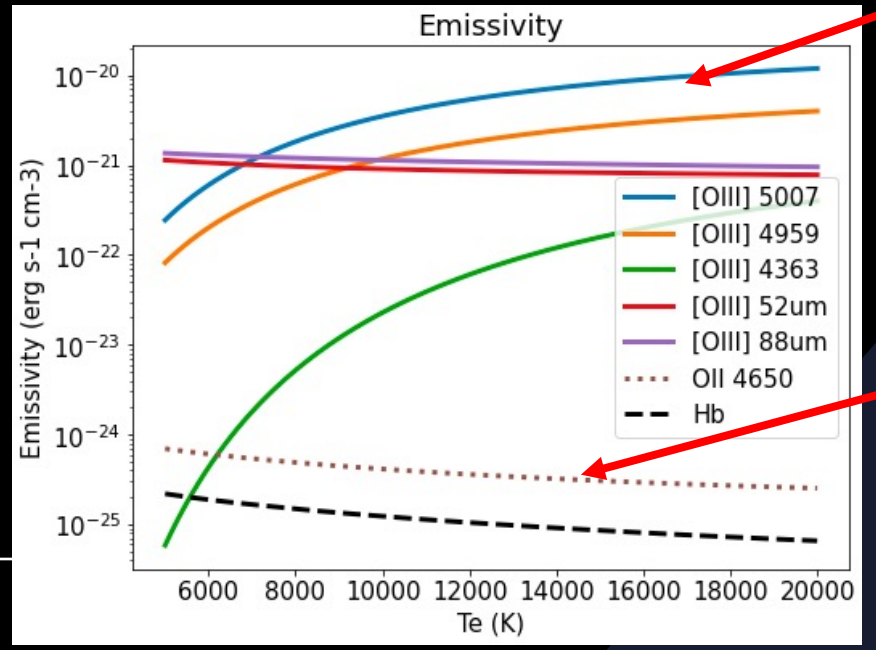
- Optical CELs are sensitive to Te
- Line intensity skewed toward high Te phase.

- RLs independent of Te
- O/H from RL lines -> Unbiased

ADF = t^2 = variance / mean^2 ~ 0.01 -- 0.1



Optical CEL

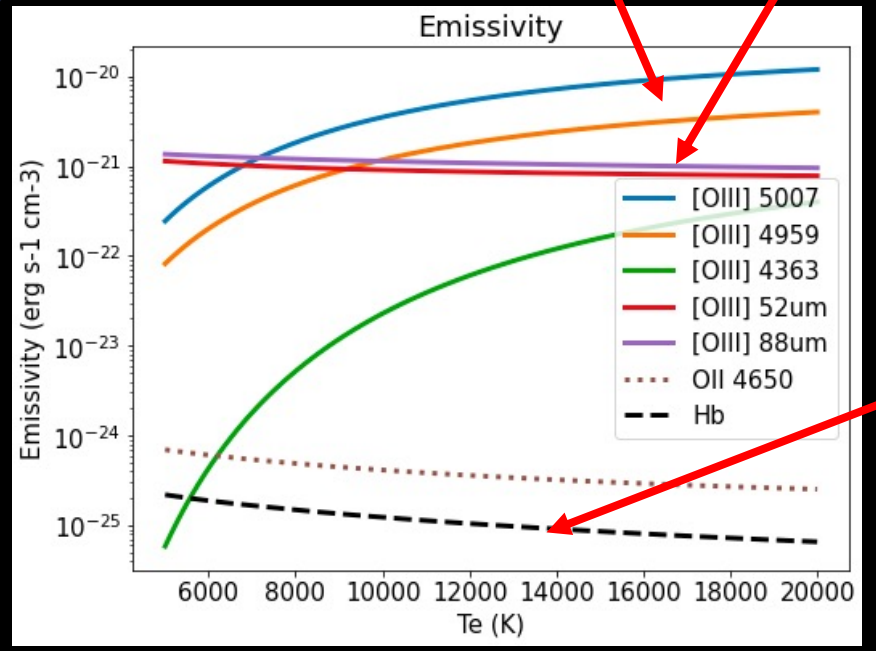


RL

Temperature Fluctuation

- FIR CELs (52 um, 88 um) insensitive to Te
- The O/H measured from FIR lines should be close to RL.

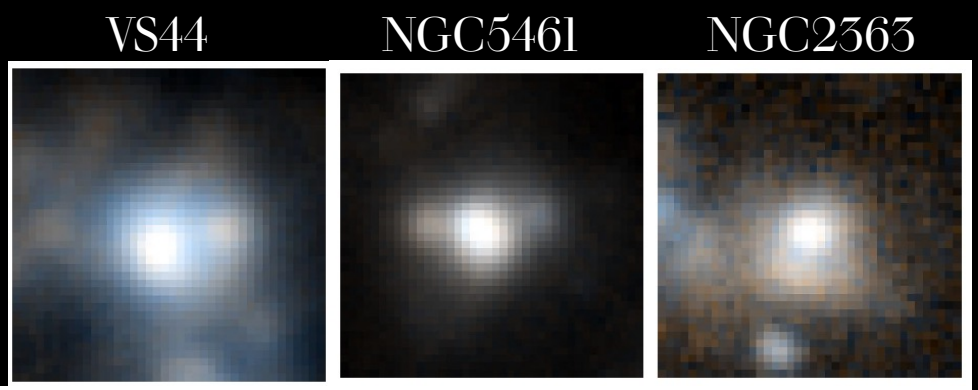
Direct Test with SOFIA

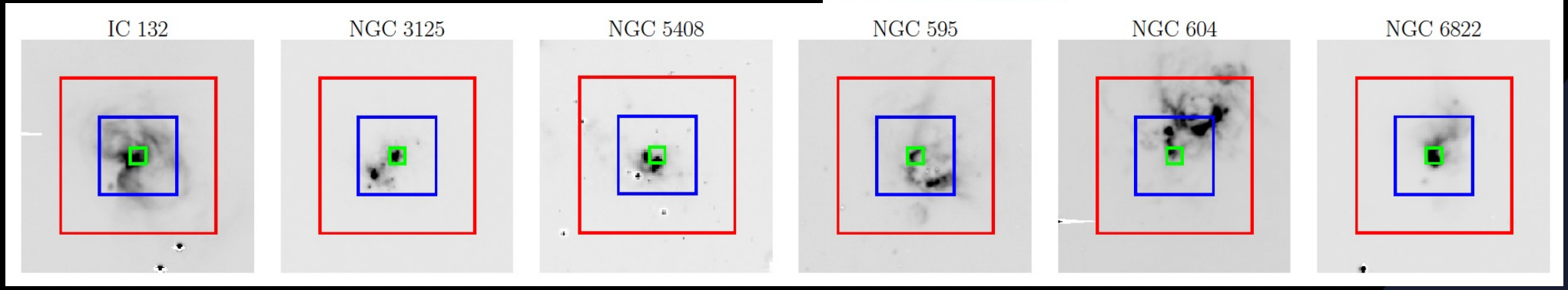


OBSERVATION

Target Selection

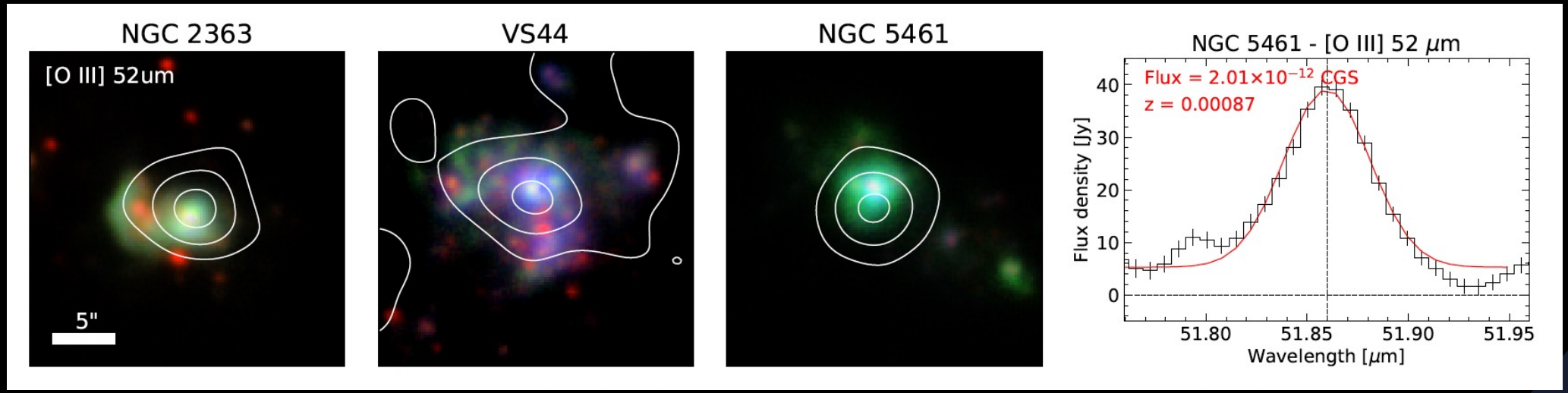
- Nearby bright HII regions
- Relatively compact (FIFI-LS, KCWI FoV)
- Wide range of O/H metallicity





SOFIA FIFI-LS Cycles 8+9

- Well detected [OIII] 52 um



Keck KCWI IFU

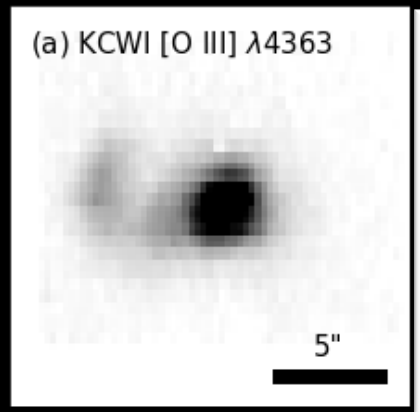
- Spectra coverage: 3500A – 5500A
- R~2000, FoV ~ 16” x 20”
  - *Short snapshots (<15s)*

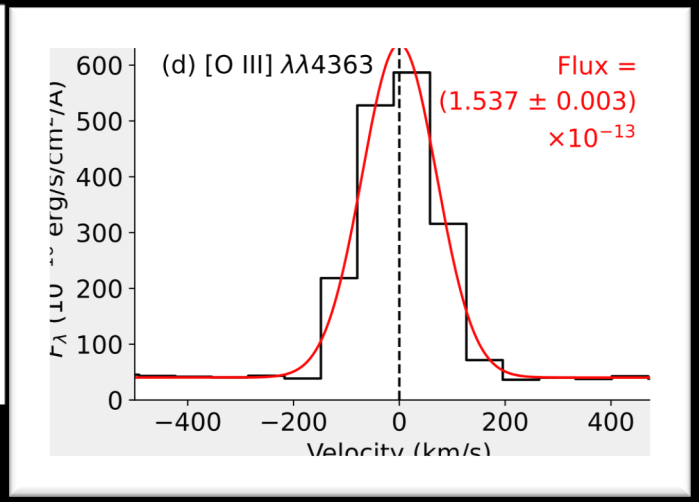
    [OIII] 4363, 4959, 5007 for CEL metallicity

    Balmer series: Hβ, Hγ, Hδ... for extinction correction
  - *Long exposures (>2 hours, pending)*

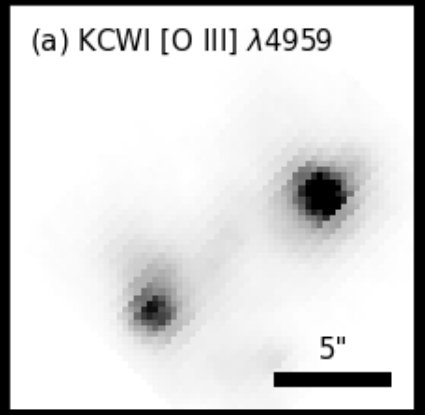
    OII RLs

NGC2363

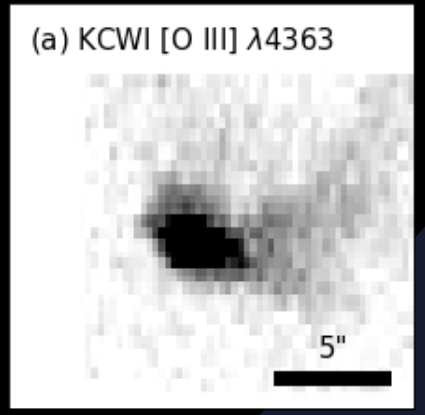




NGC3125

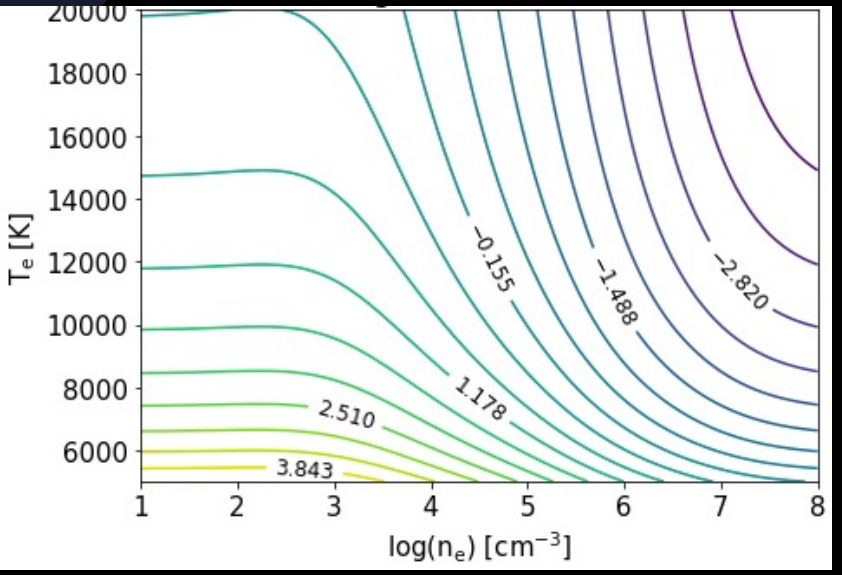


NGC6822

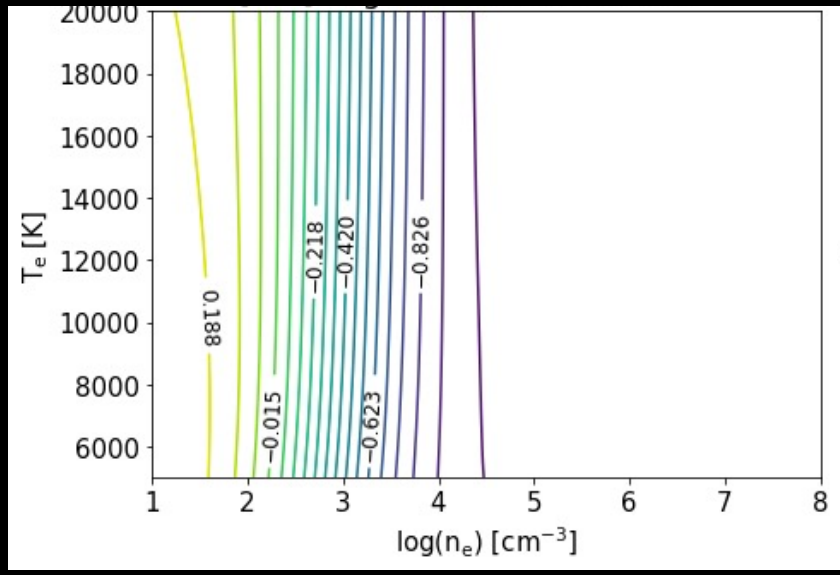


Roadmap

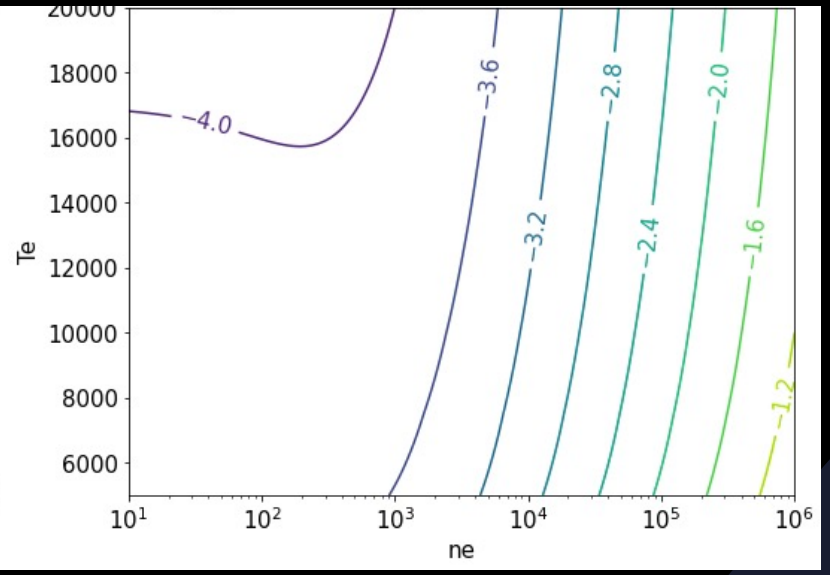
[O III] 52 um / 5007



[O III] 88 um / 52 um



Hb / [O III] 52 um



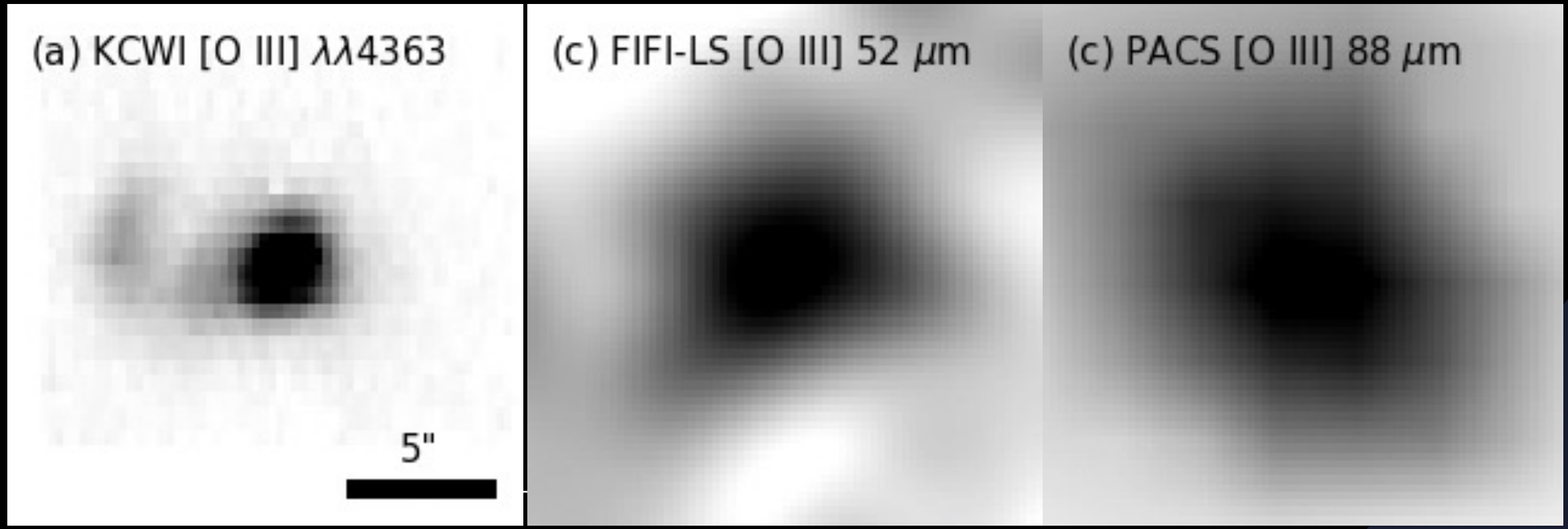
Te as a function of ne → ne → O/H from FIR

An example: NGC 2363

Keck KCWI

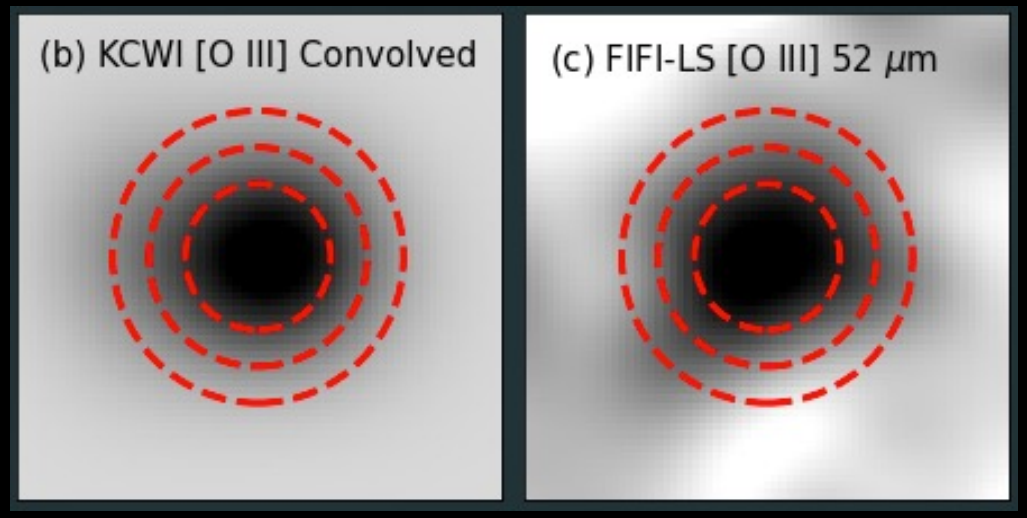
SOFIA FIFI-LS

Herschel PACS

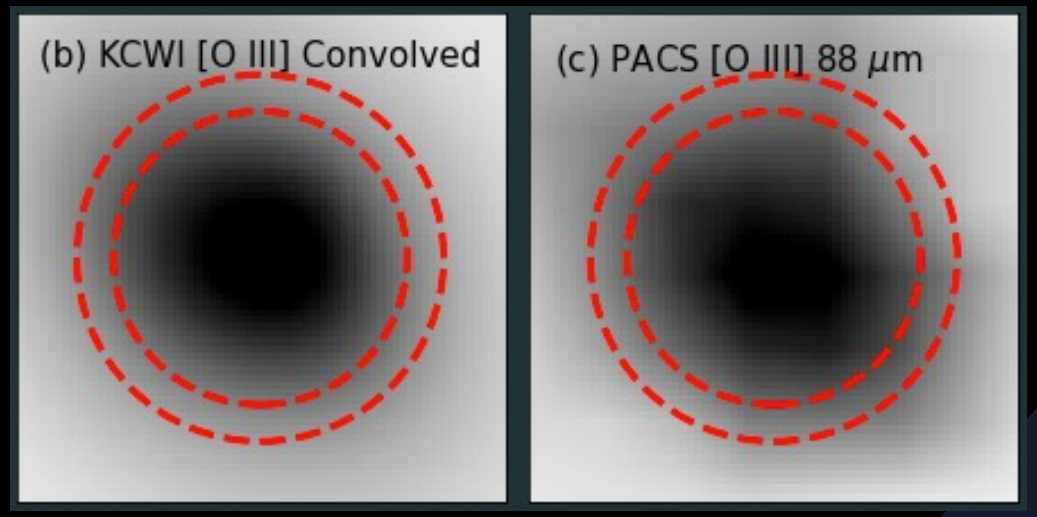


PSF Matching

KCWI -> FIFI-LS



KCWI -> Herschel PACS



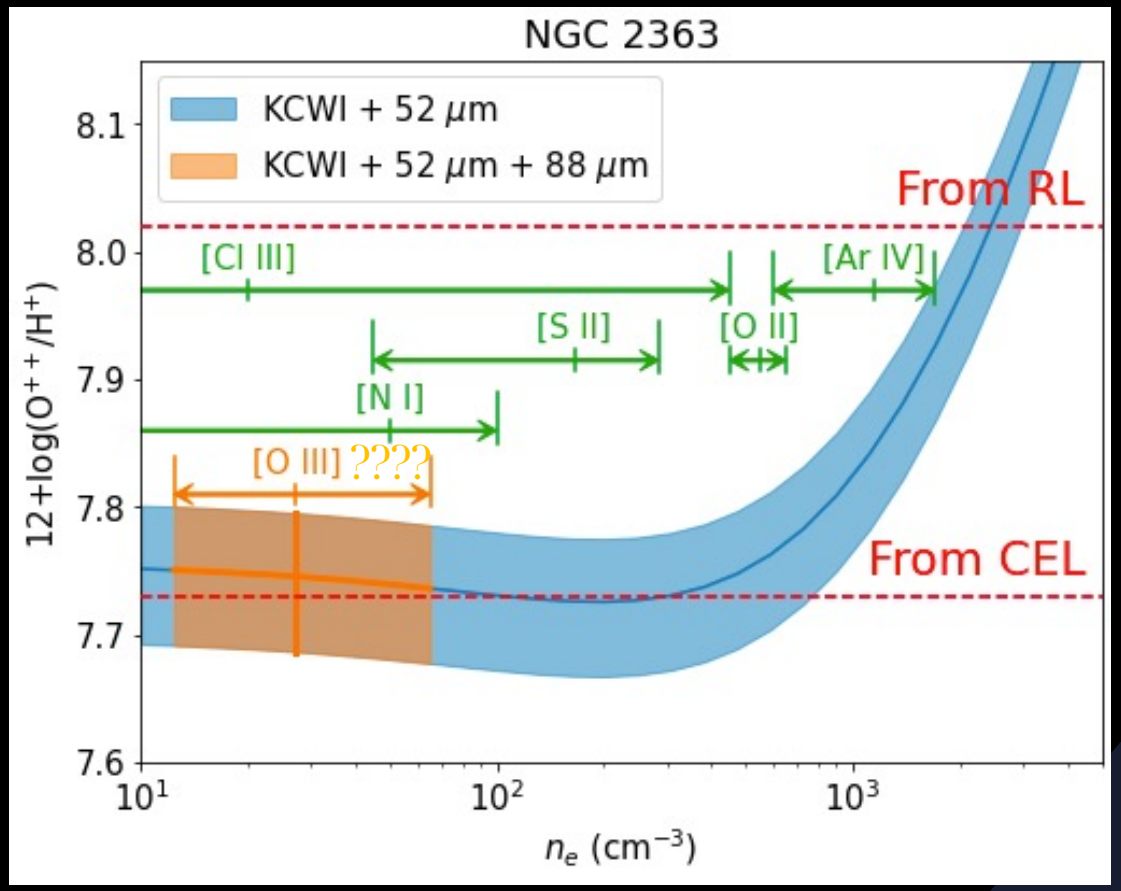
Work in progress!

Results

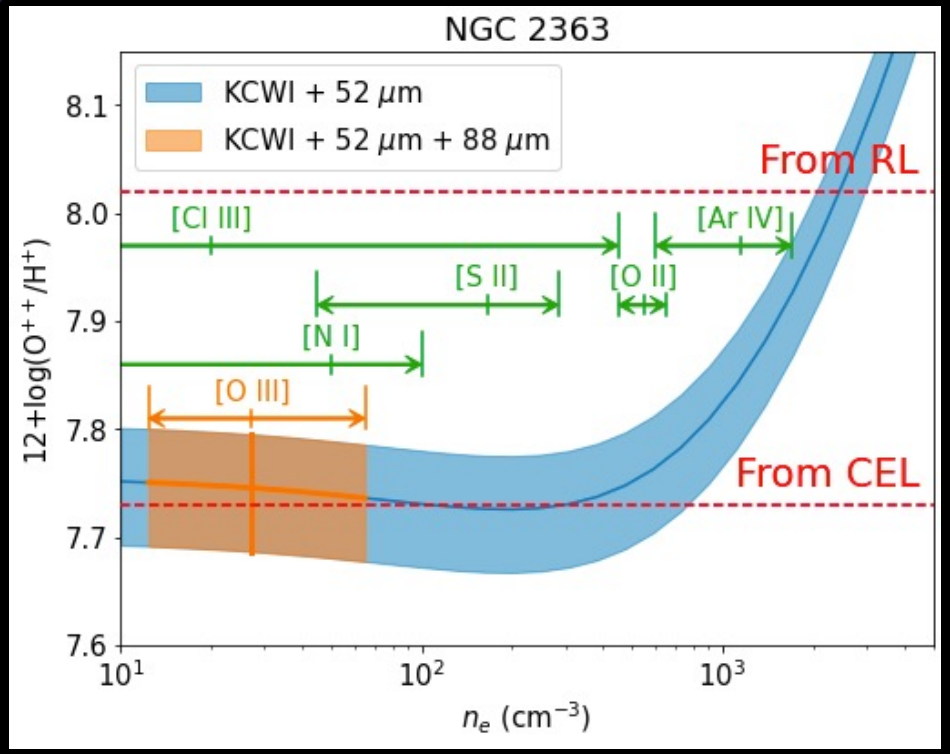
- NGC 2363

  Inconsistent with temperature fluctuation

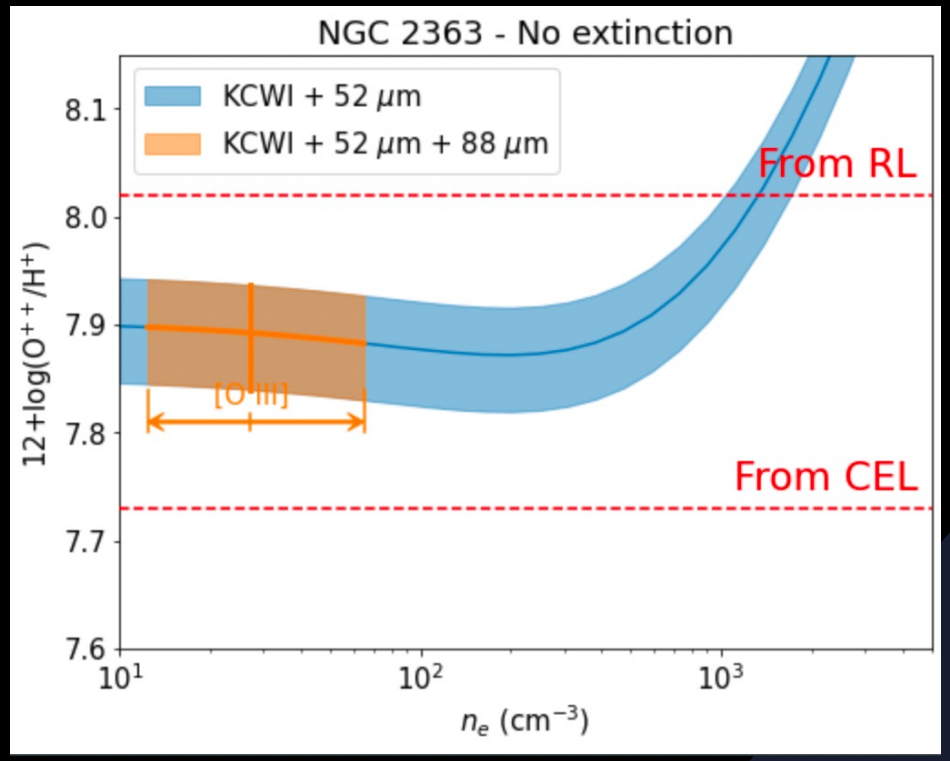
- Caveats:
  - *Herschel PACS flux for unchopped data, significant correction required. (looking for your expertise!!)*
  - *Dust extinction*



Extinction

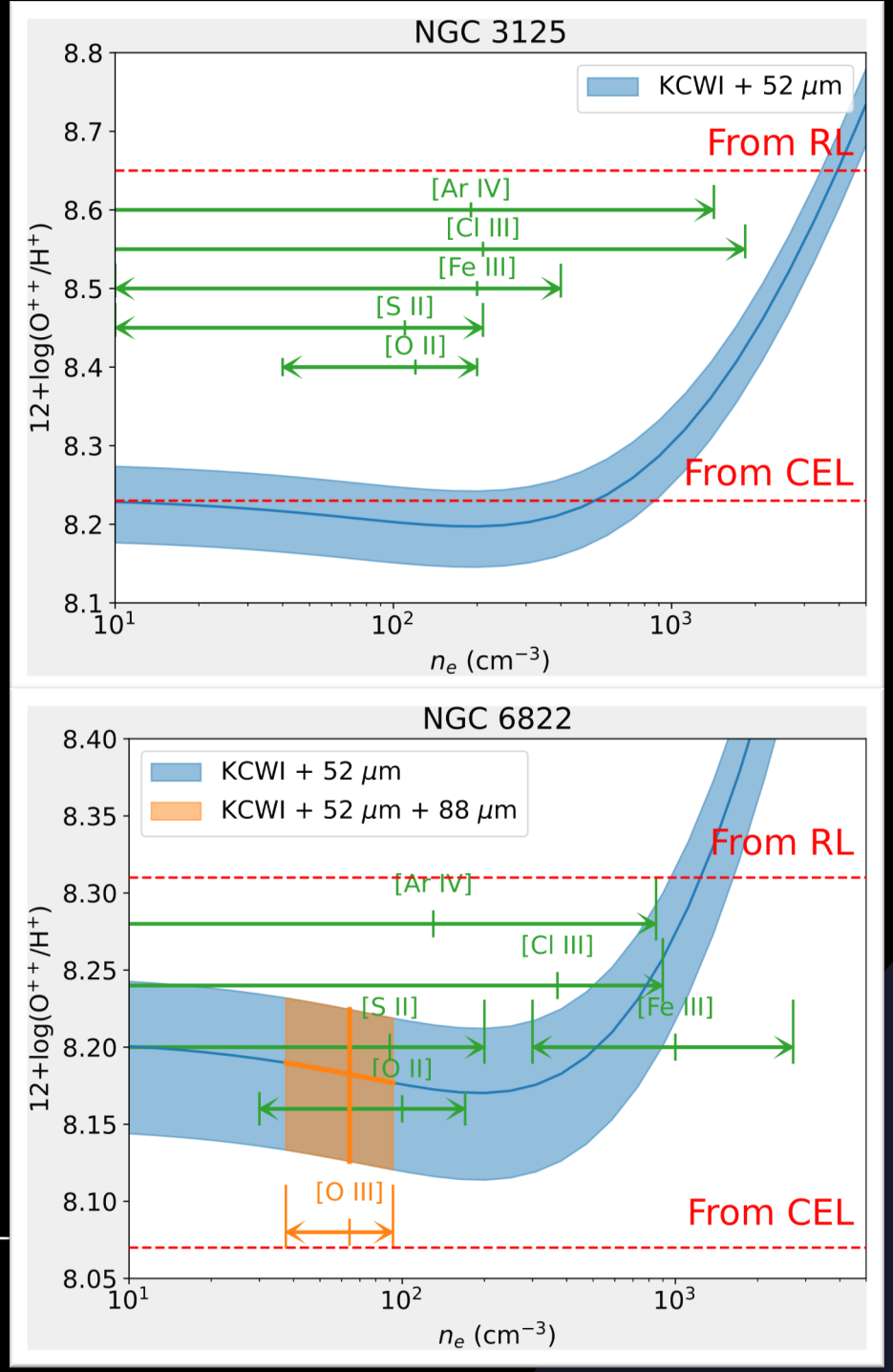


No extinction



Results

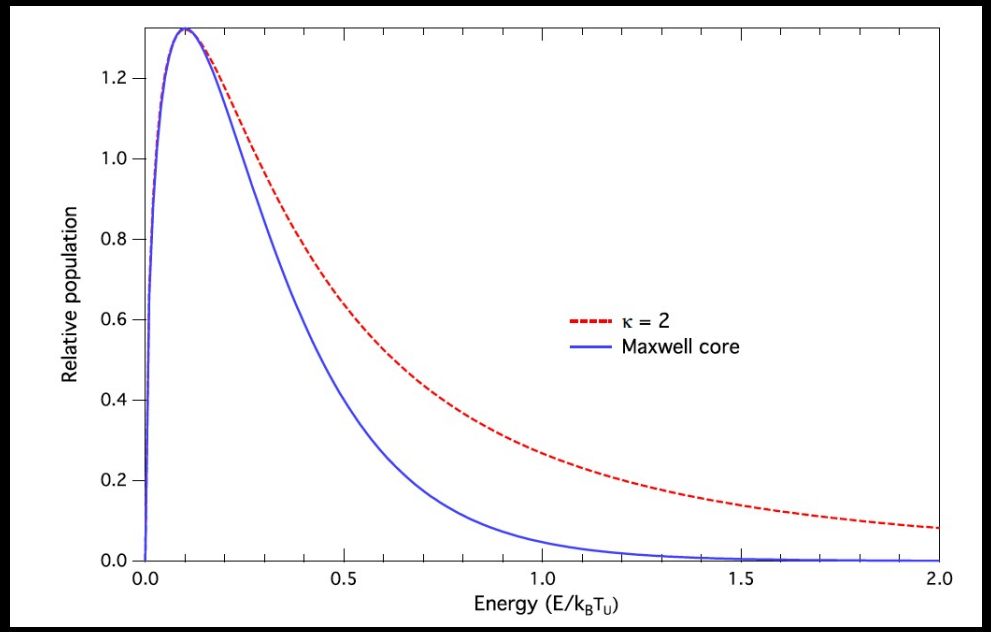
- Not all objects have O/H consistent with CEL.
- But temperature fluctuation may not be enough to explain ADF



- If not t^2, then what?

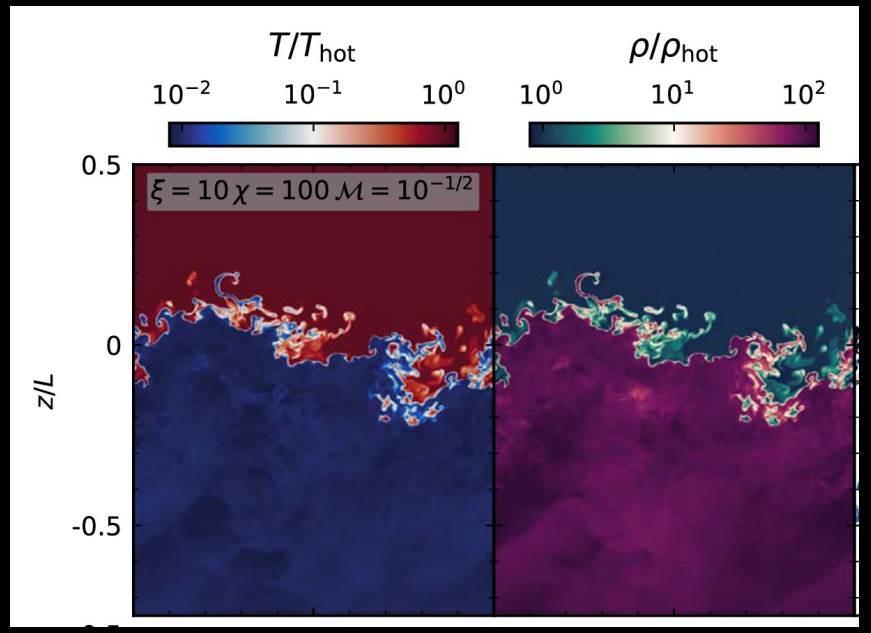
Other pure Te modifications ✗

e.g., κ distribution



Nicholls+2012

+ ne or O/H distribution ?



Fielding+2020

Revised abundance measurements

Future

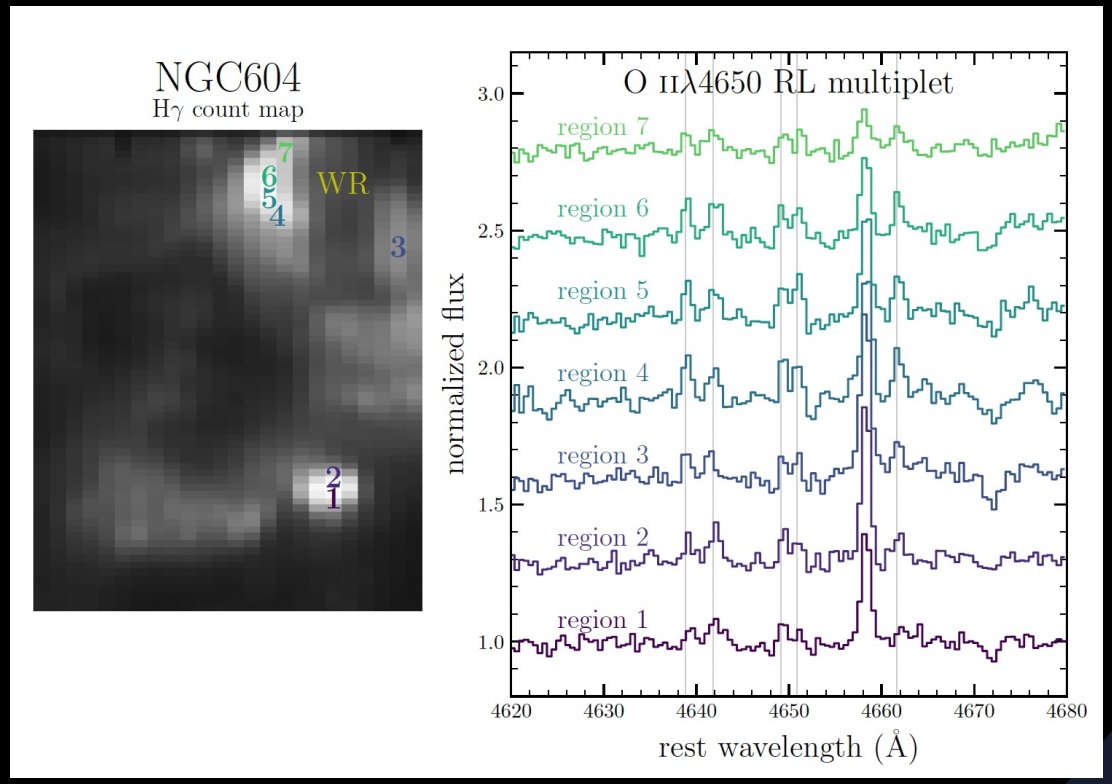
- Pending SOFIA cycle 10 proposals:

  [OIII] 88um – double sample size, reliable flux

- Pending KCWI observations:

  Deep map of recombination lines

15 min KCWI



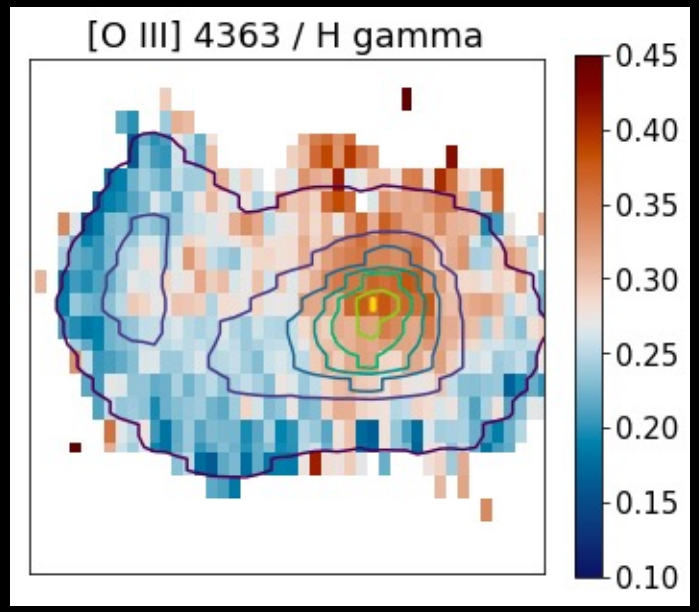
Summary

- Preliminary [OIII] 52 um flux from FIFI-LS provide direct evidence inconsistent with temperature fluctuation paradigm, suggesting revised O/H abundance

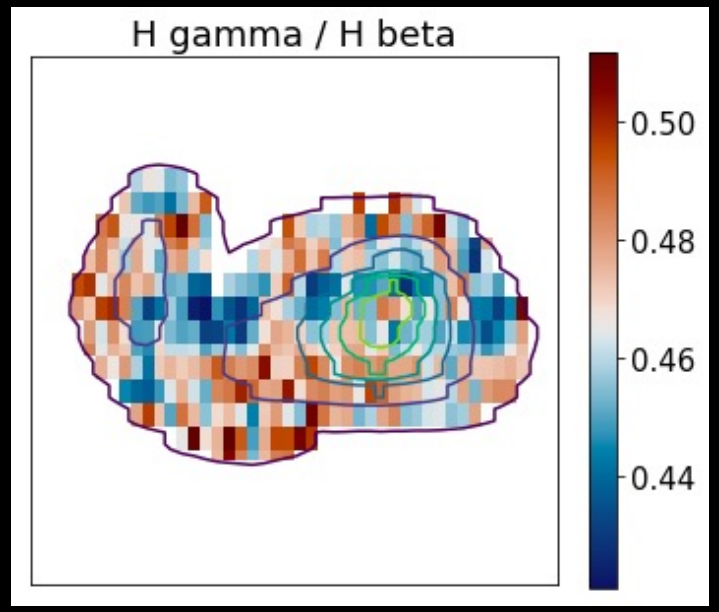
- Future FIFI-LS [OIII] 88 um and KCWI observations will improve the sample

Backup

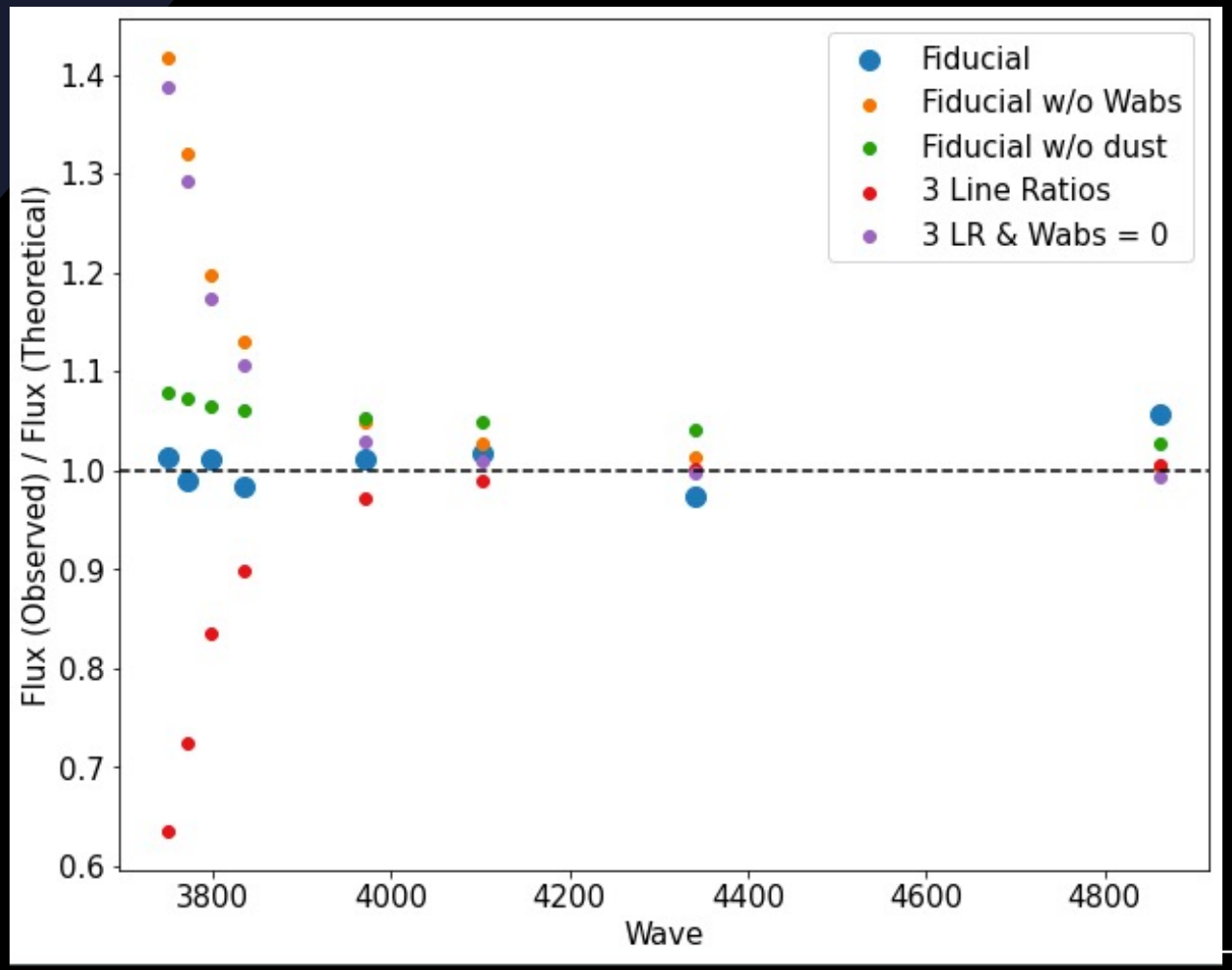
O III Metallicity



Balmer Decrement



All extinction systematics



idx	Rv	Type	cHb
0	2.6	fiducial	0.03380927277433697
1	2.6	low	0.02405293959700428 5
2	2.6	high	0.047287254915730964
3	3.1	fiducial	0.0381544504957304
4	3.1	low	0.025404438766235 73
5	3.1	high	0.053271471375235 96
6	3.6	fiducial	0.04223662376942135
7	3.6	low	0.026404603208188 37
8	3.6	high	0.058875643815689 93
9	3.1	e09	0.12
10	3.1	zero	0.0