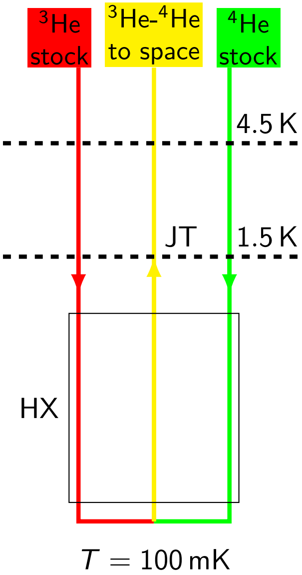
Towards a ^3He-^4He closed cycle dilution refrigerator for space

Angela Volpe[1,2] Gerard Vermeulen[1]

[1]Néel Institute (CNRS) [2]Agenzia Spaziale Italiana

ICEC25-ICMC2014, 2014-07-10

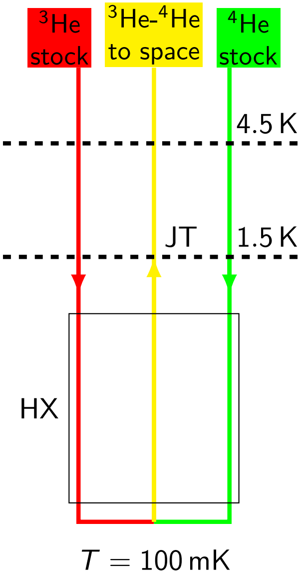
Planck: Open Cycle Dilution Refrigerator (OCDR)



2009: Planck (CMB)

- ^{3}He and ^{4}He stocked on satellite
- space plays role of pump
- capillary forces play the role of gravity
- requires 10 mW at 4.5 K
- intrinsic 1.5 K Joule-Thompson cooler

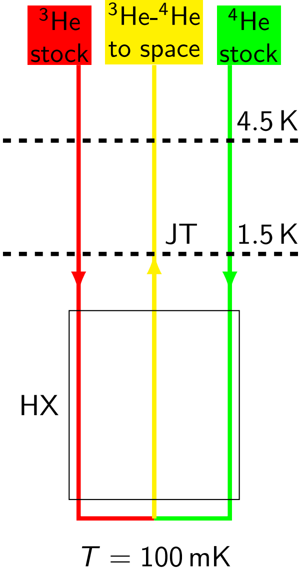
Planck: Open Cycle Dilution Refrigerator (OCDR)



2009: Planck (CMB)

- temperature: 100 mK
- cooling power: 200 nW
- lifetime: 2 years
- helium flowrates:
  ^{3}He 6 µmol s^{-1}
  ^{4}He 18 µmol s^{-1}
- high pressure storage on satellite:
  ^{3}He 12 m^3 stp
  ^{4}He 36 m^3 stp

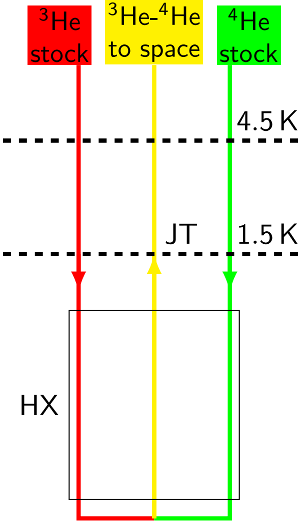
Planck: Open Cycle Dilution Refrigerator (OCDR)



2020–2025: Future missions

- temperature: 50 mK
- cooling power: 1 μW
- lifetime: 5 years
- helium flowrates:
  - ^{3}He 18 μmol s^{-1}
  - ^{4}He 360 μmol s^{-1}
- high pressure storage on satellite:
  - ^{3}He 90 m^3 stp
  - ^{4}He 1800 m^3 stp

Planck: Open Cycle Dilution Refrigerator (OCDR)



$T = 100\,\mathrm{mK}$

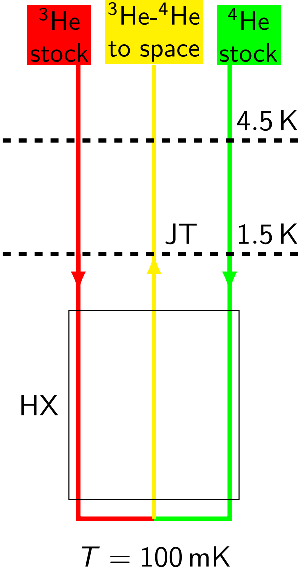
2020–2025: Future missions

- temperature: 50 mK
- cooling power: 1 μW
- lifetime: 5 years
- helium flowrates:
  ^{3}He 18 μmol s^{-1}
  ^{4}He 360 μmol s^{-1}
- high pressure storage on satellite:
  ^{3}He 90 m^3 stp
  ^{4}He 1800 m^3 stp

Too heavy and too costly . . .

- $\Longrightarrow$ closed cycle is required

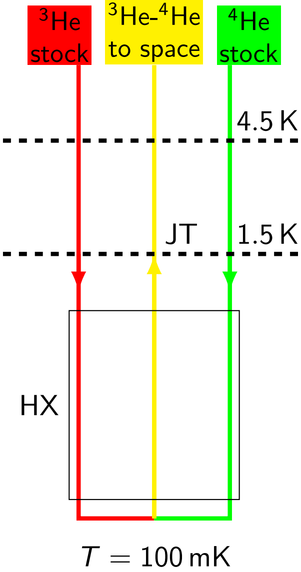
Planck: Open Cycle Dilution Refrigerator (OCDR)



Too heavy and too costly $\Longrightarrow$ CCDR

Tested Closed Cycle Dilution Refrigerator

Planck: Open Cycle Dilution Refrigerator (OCDR)



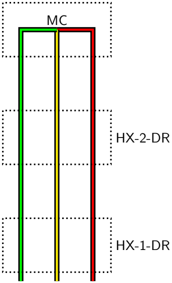
Too heavy and too costly $\Longrightarrow$ CCDR

Tested Closed Cycle Dilution Refrigerator

Zero Gravity?

Testing No, but Negative Gravity Closed Cycle Dilution Refrigerator (NG-CCDR)

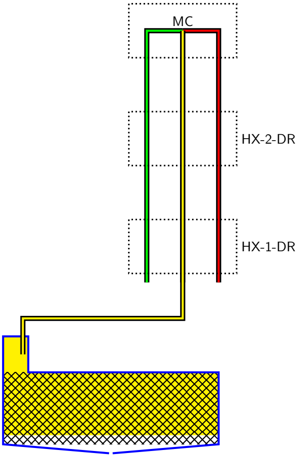
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is . . .

- upside-down OCDR with . . .

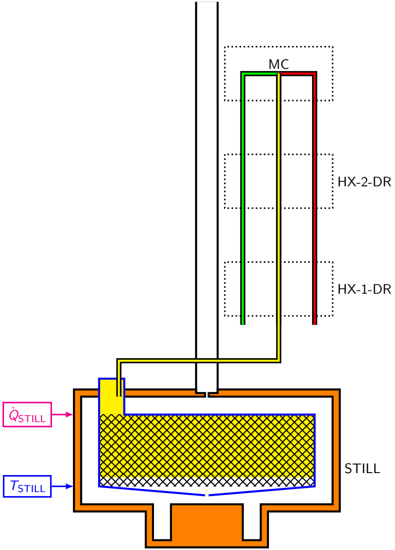
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid

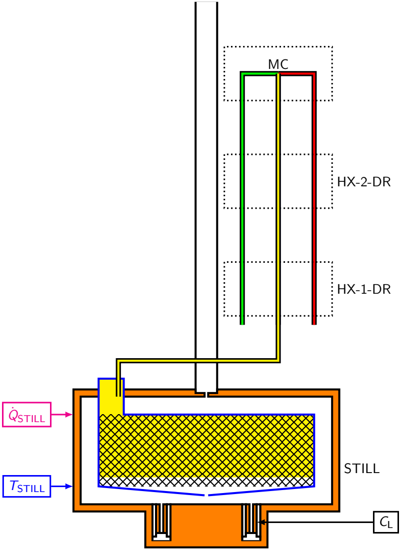
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line

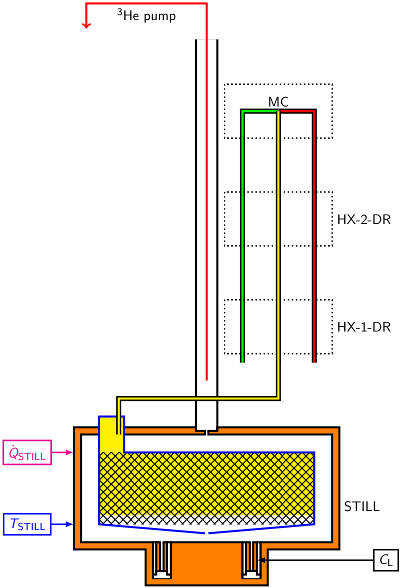
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge

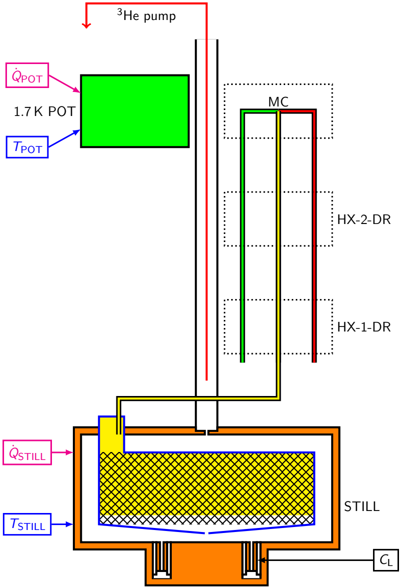
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge
- ^{3}He out from sponge

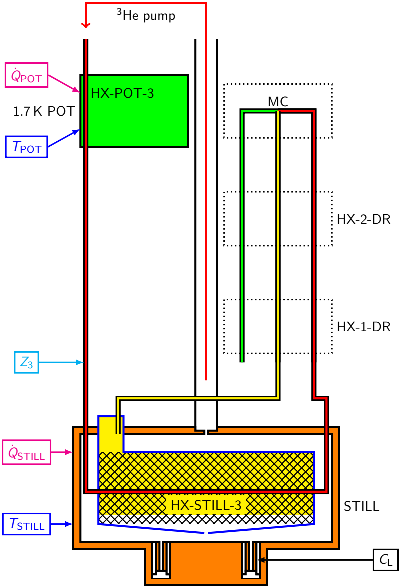
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge
- ^{3}He out from sponge
- 1.7 K pot (e.g. SPICA)

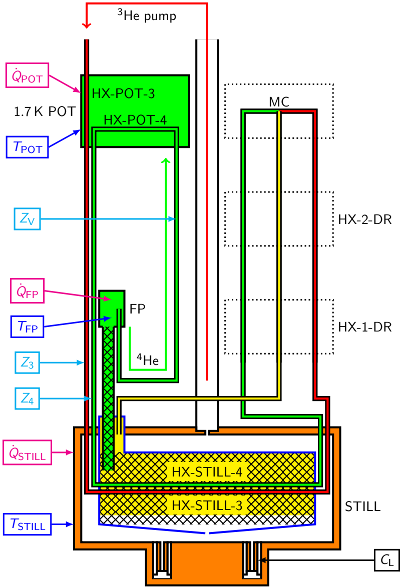
Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is ...

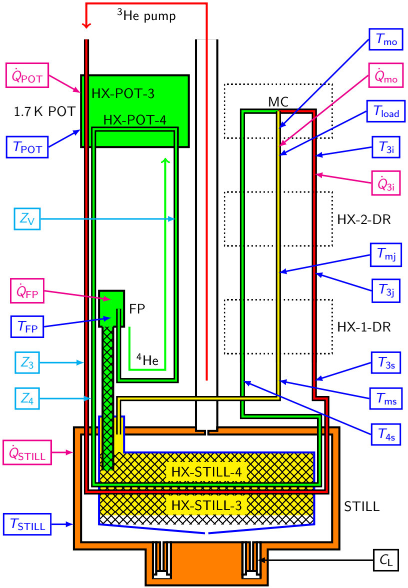
- upside-down OCDR with ...
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge
- ^{3}He out from sponge
- 1.7 K pot (e.g. SPICA)
- ^{3}He in, 2 HX, 1 Z

Negative Gravity Closed Cycle Dilution Refrigerator



NG-CCDR setup is . . .

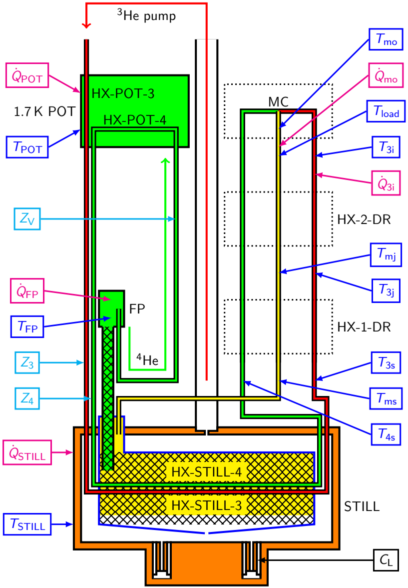
- upside-down OCDR with . . .
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge
- ^{3}He out from sponge
- 1.7 K pot (e.g. SPICA)
- ^{3}He in, 2 HX, 1 Z
- ^{4}He pump, 2 HX, 2 Z

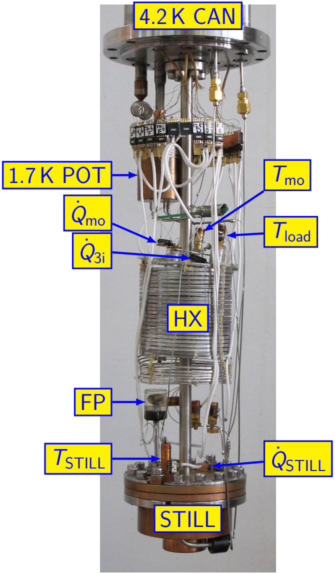


NG-CCDR setup is . . .

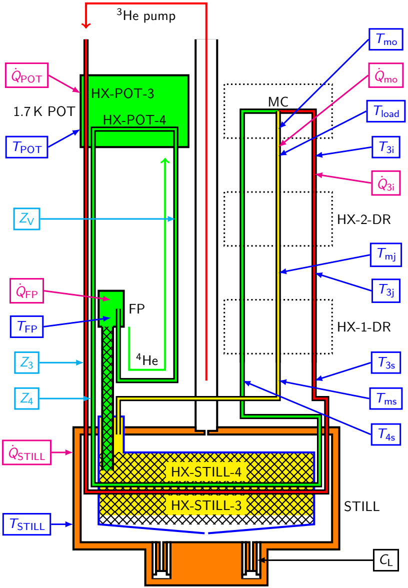
- upside-down OCDR with . . .
- mixture return capillary to still with sponge to confine liquid
- still pot with pumping line
- capacitive liquid level gauge
- ^{3}He out from sponge
- 1.7 K pot (e.g. SPICA)
- ^{3}He in, 2 HX, 1 Z
- ^{4}He pump, 2 HX, 2 Z
- remaining Ts and $\dot{Q}$s

Negative Gravity Closed Cycle Dilution Refrigerator





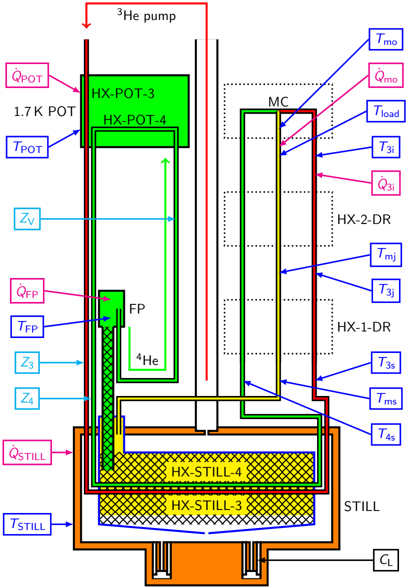
Negative Gravity Closed Cycle Dilution Refrigerator



Objectives from CCDR

- shown $\dot{Q}_{CCDR} = 1\,\mu W$ at $T = 52\,mK$ possible when:
  - $p_{STILL} = 5\,mbar$
  - $x_{STILL,\ LIQUID} = 0.1$ and $T_{STILL} = 1\,K$
  - $\dot{n}_4 = 0.35\,mmol\,s^{-1}$
  - $\dot{n}_3 = 18.5\,\mu mol\,s^{-1}$

Negative Gravity Closed Cycle Dilution Refrigerator



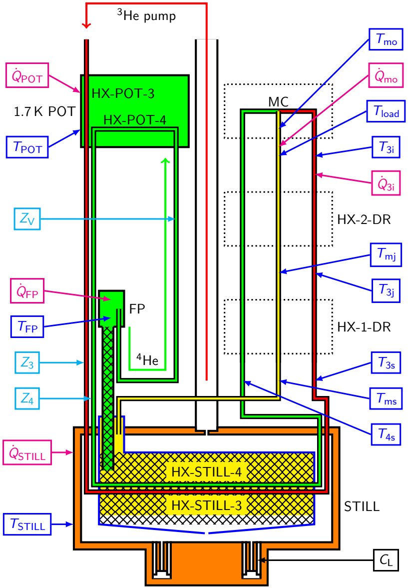
Objectives from CCDR

- shown $\dot{Q}_{CCDR} = 1\,\mu W$ at $T = 52\,mK$ possible when:
  - $p_{STILL} = 5\,mbar$
  - $x_{STILL,\ LIQUID} = 0.1$ and $T_{STILL} = 1\,K$
  - $\dot{n}_4 = 0.35\,mmol\,s^{-1}$
  - $\dot{n}_3 = 18.5\,\mu mol\,s^{-1}$

Pumps under development

JAXA	based on SPICA 1.7 K
Twente	adsorption at 15 K
Grenoble	Holweck (drag)

Negative Gravity Closed Cycle Dilution Refrigerator



Tests

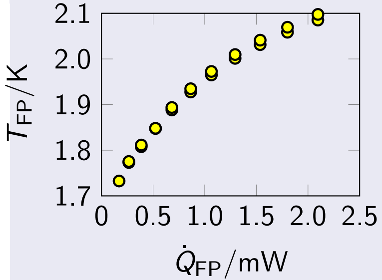
- amounts of ^{3}He and ^{4}He
- circulate ^{3}He and ^{4}He
- cooling performance
- no liquid in detector below

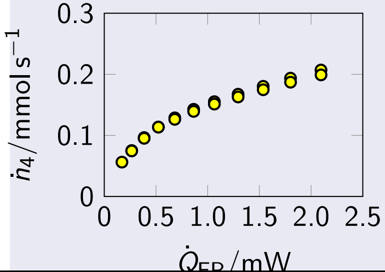
Objectives

- $p_{STILL} = 5\,\text{mbar}$
- $x_{STILL,\ LIQUID} = 0.1$ and $T_{STILL} = 1\,\text{K}$
- $\dot{n}_4 = 0.35\,\text{mmol}\,\text{s}^{-1}$
- $\dot{n}_3 = 18.5\,\mu\text{mol}\,\text{s}^{-1}$

Results for $p_{\mathrm{STILL}} \approx 0.35\,\mathrm{mbar}$ and $T_{\mathrm{POT}} = 1.32\,\mathrm{K}$

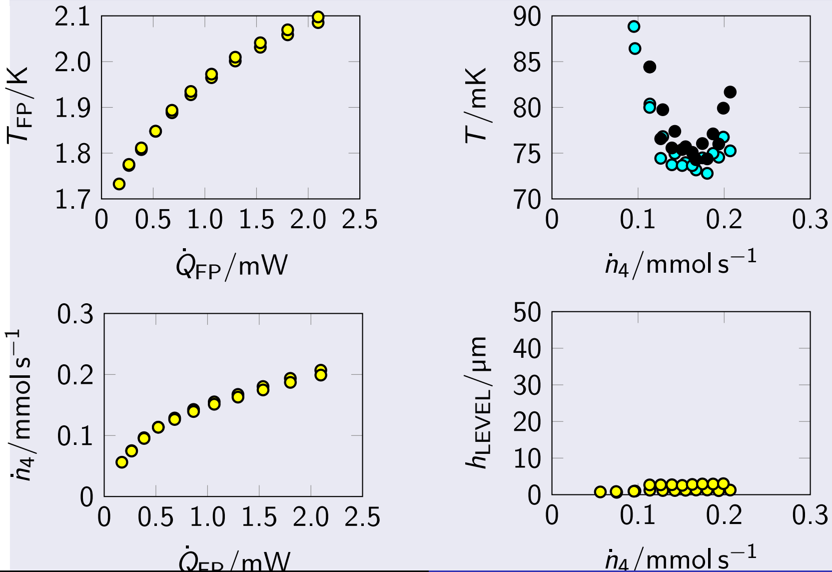
$\dot{Q}_{\mathrm{STILL}} = 0$ and $4.3\,\mu\mathrm{mol\,s^{-1}} < \dot{n}_3 < 14.7\,\mu\mathrm{mol\,s^{-1}}$





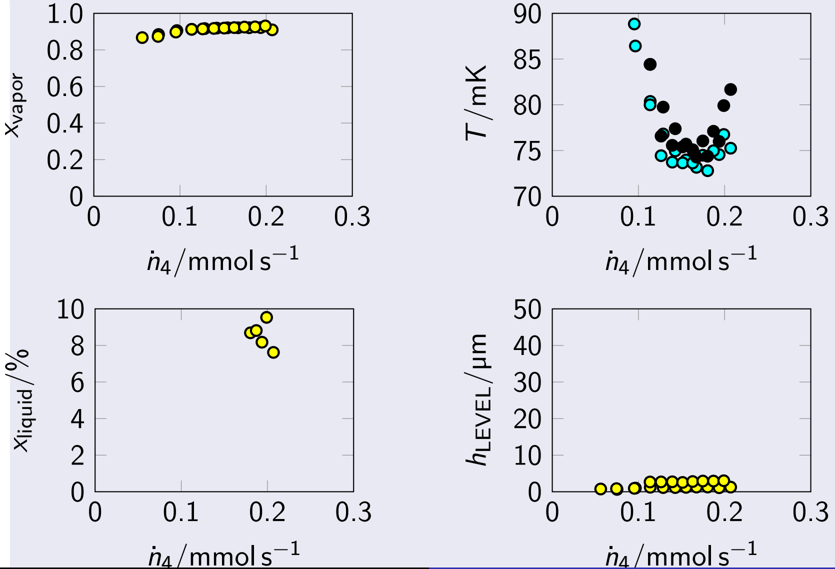
Results for $p_{STILL} \approx 0.35$ mbar and $T_{POT} = 1.32$ K

$\dot{Q}_{STILL} = 0$ and $4.3\,\mu mol\,s^{-1} < \dot{n}_3 < 14.7\,\mu mol\,s^{-1}$



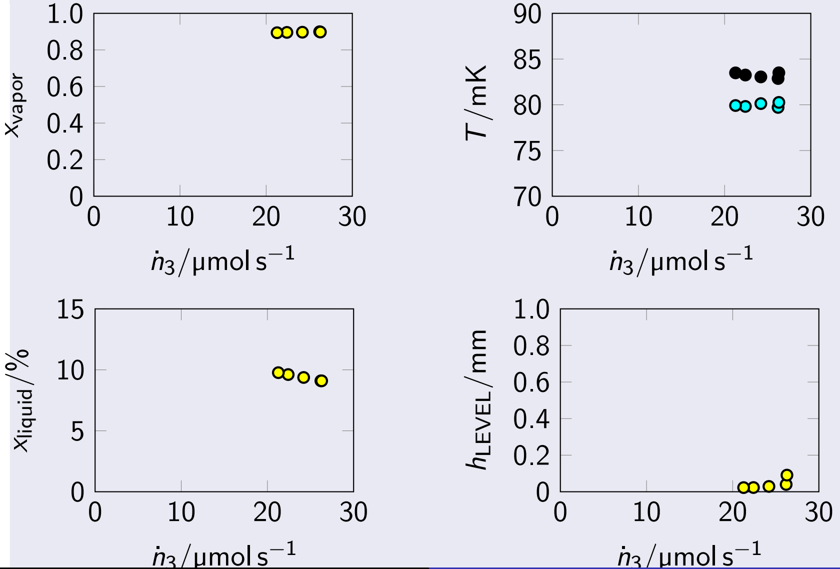
Results for $p_{\mathrm{STILL}} \approx 0.35\,\mathrm{mbar}$ and $T_{\mathrm{POT}} = 1.32\,\mathrm{K}$

$\dot{Q}_{\mathrm{STILL}} = 0$ and $4.3\,\mu\mathrm{mol\,s^{-1}} < \dot{n}_3 < 14.7\,\mu\mathrm{mol\,s^{-1}}$



Results for $p_{STILL} = 4.94\,\text{mbar}$ and $T_{POT} = 1.64\,\text{K}$

$\dot{Q}_{FP} = 1.54\,\text{mW}$ and $\dot{n}_4 = 1.60\,\mu\text{mol}\,\text{s}^{-1}$



Conclusion

NG-CCDR is working, but not yet as it should

- T minimum ≈ 70 mK to 80 mK
- $\dot{n}_4$ maximum ≈ $200\,\mu\mathrm{mol\,s^{-1}}$ instead of ≈ $400\,\mu\mathrm{mol\,s^{-1}}$
  - too much flow impedance downstream of the fountain pump?
- mixing chamber heaters broken

More data are needed

- $\dot{n}_4 \approx 400\,\mu\mathrm{mol\,s^{-1}}$
- cooling power data