EXPLORING CAUSAL VARIABILITY IN PHYTOPLANKTON IOPS IN THE SOUTHERN OCEAN

OR, HOW I LOST MY FAITH IN PHYTOPLANKTON BACKSCATTER

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CSIR

Touching lives through innovation

SOCCO

Southern Ocean Carbon and Climate Observatory

SOUTHERN OCEAN: WHAT WE KNOW

- **S. Ocean phytoplankton optics are distinct from other oceans** (Robinson et al, 2021)
- The Southern Ocean is a significant **carbon sink.** But it is **changing** wrt ocean warming, acidification, stratification, light & nutrient regimes and hence **phytoplankton physiology** & community structure.

DO THESE CHANGES IMPACT UPON THE TRAJECTORY OF THE BIOLOGICAL CARBON PUMP?

- This is a **highly dynamic environment** in time (seasonal, interannual) & space (zonal, regional). Extremely undersampled. Empirical relationships are not robust for a changing ocean. We need a **causal understanding of phytoplankton optics** to be able to fully exploit remote sensing over the large time and spatial scales we need.

JKravitz presentation at Ocean Sciences 2022 in coastal and inland observing systems coming up!

PHYTOPLANKTON OPTICAL MODELLING

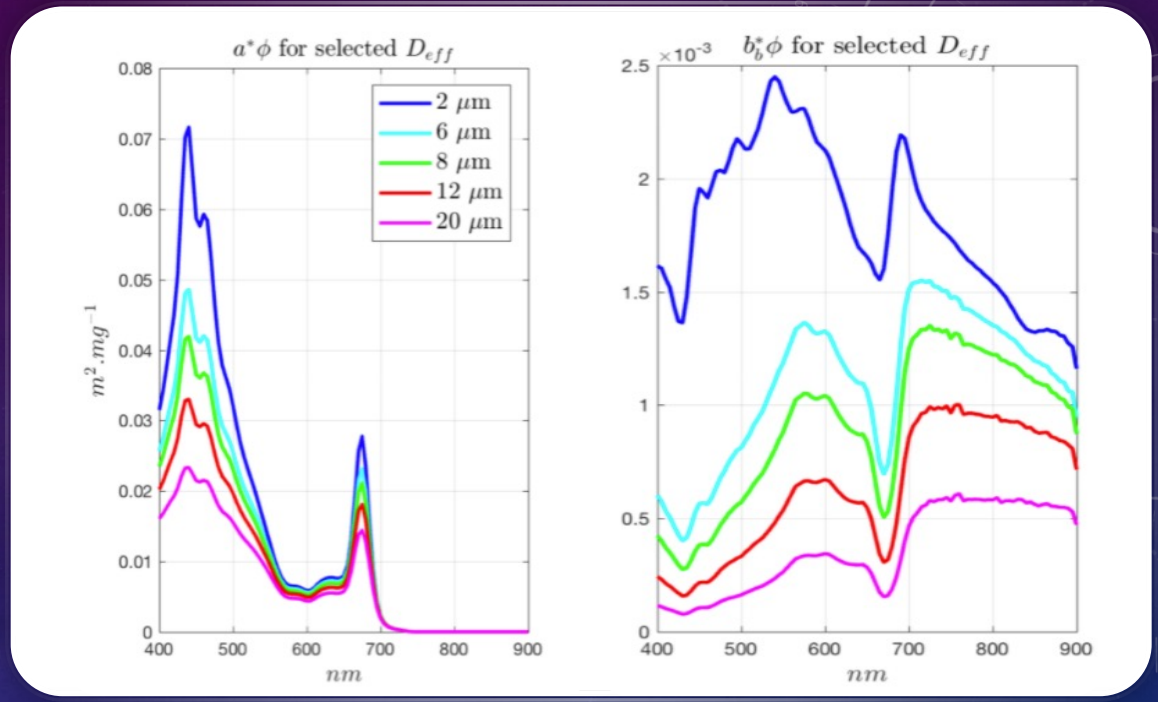
Coated sphere representation now understood to be appropriate for phyto IOPs (Scattnlay nested Mie code is often used)

outer sphere: chloroplast, imaginary RI, absorption by pigments, relationship with chlorophyll

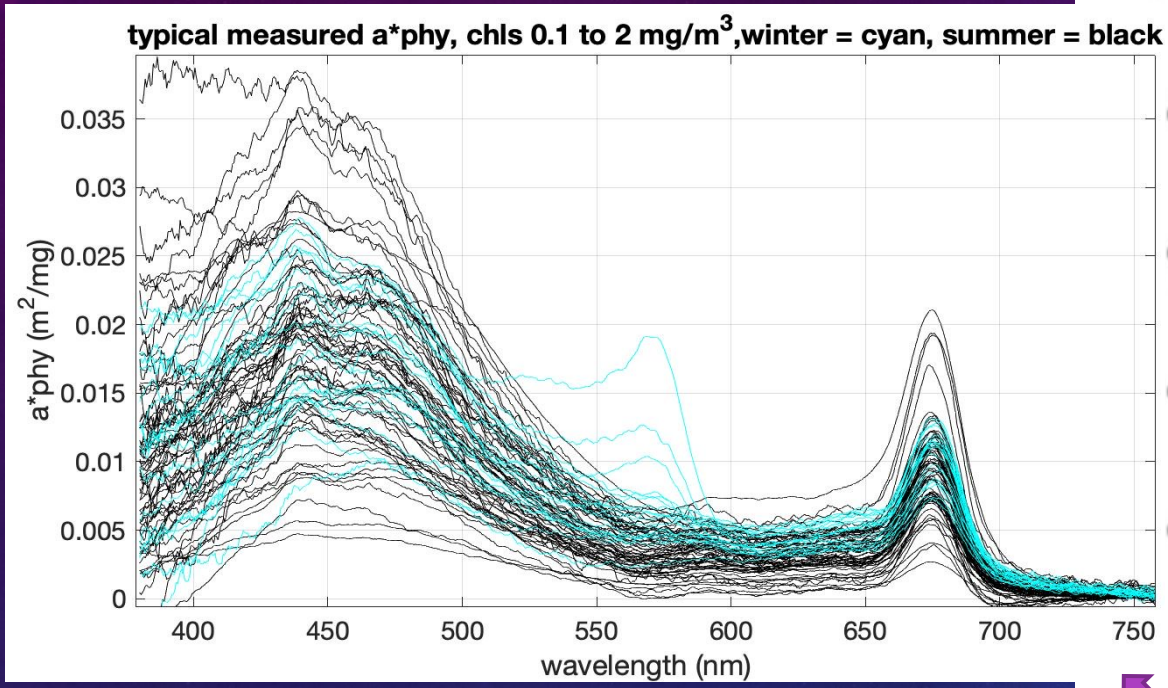
Inner sphere: cytoplasm, real RI, scattering characteristics, relationship with carbon

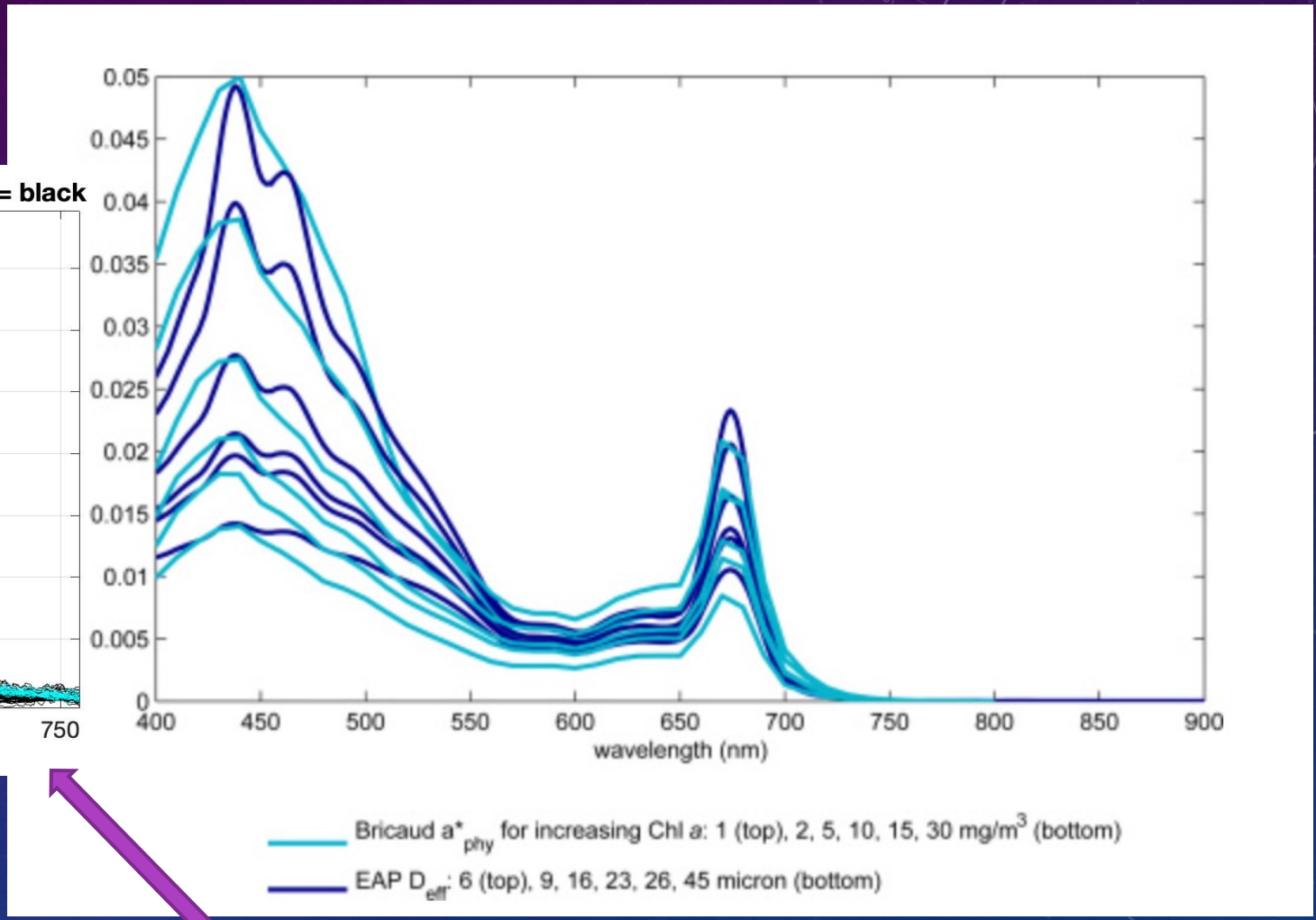
Equivalent Algal Populations (EAP) model: www.thecoatedsphere.com (in progress)

Real & imaginary parts of a particle's spectral RI are not independent: Kramers Kronig relations, implemented mathematically via Hilbert transform.



IOPS DIFFERENT HOW?





DEPRESSED ABSORPTION ☹

1. chl specific absorption spectra can be depressed wrt comparable chl a from other oceans. Suggest large size or physiological stress resulting in increased ci
2. Variability is observed seasonally, regionally, zonally. Not consistent from year to year either.

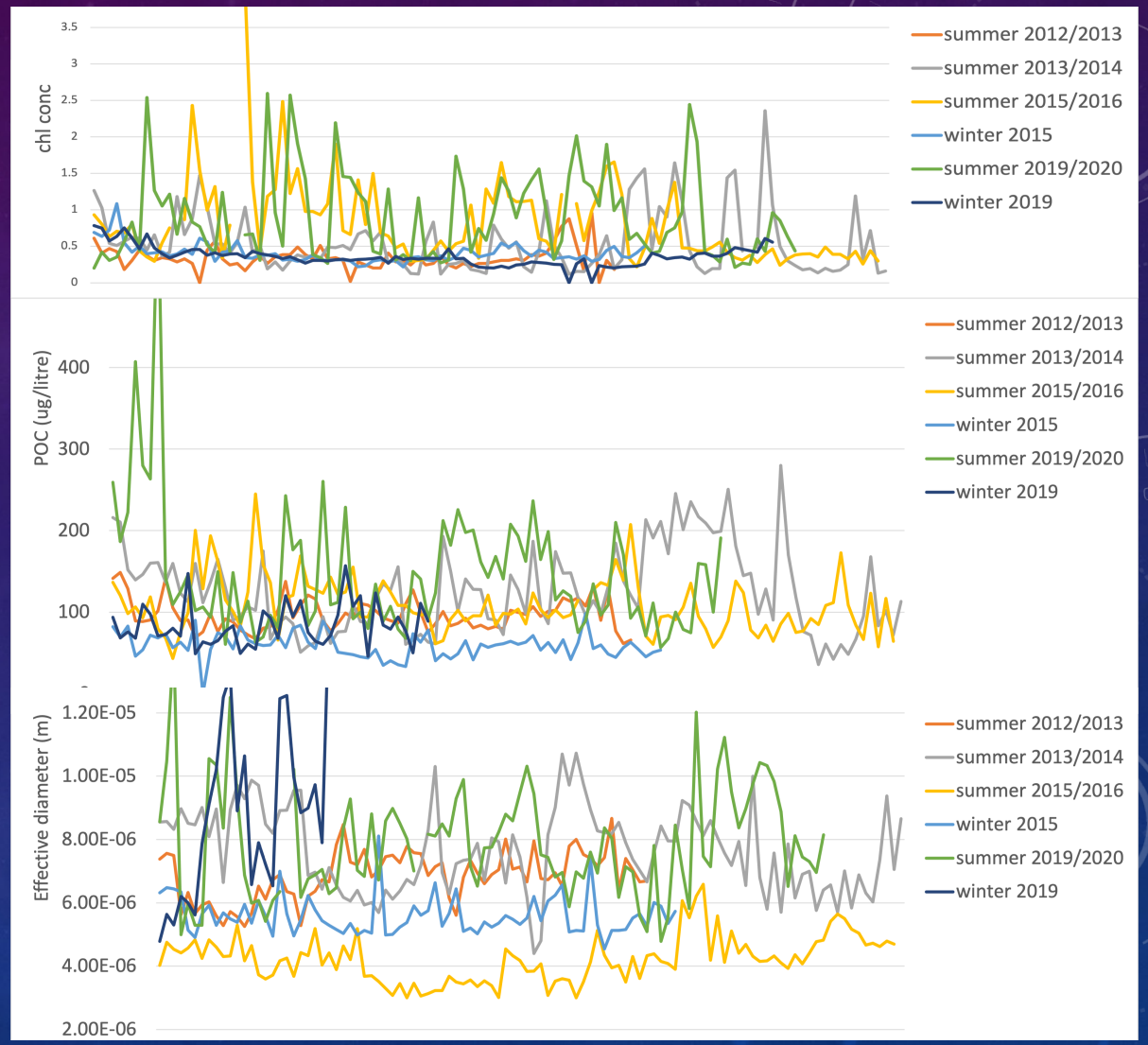
*Not entire dataset, esp in summer not all are depressed

CHL A, POC, DEFF … ALL LOOK NORMAL

Data from 6 cruises, spanning seasons, latitudes from 40 to 80 degrees, mostly along Good Hope Line.
These measurements, over 8 years, are remarkably well constrained within their seasonal and latitudinal ranges.

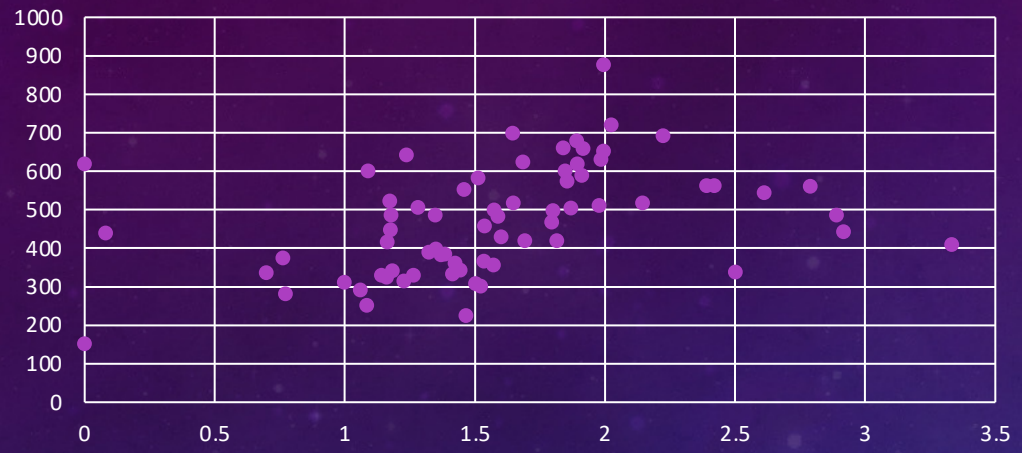
Modelling study: using these measurements, can we reproduce modelled absorption to match the measured?

One key parameter for model input is the chl ci, intracellular chlorophyll density. Each phyto species has its own ci, lower when unstressed and increases under physiological stress to maximise photosynthetic capacity

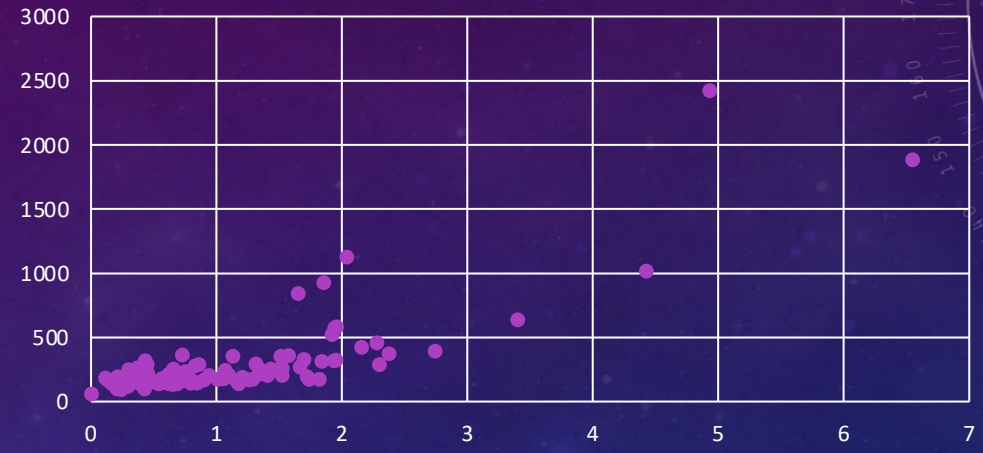


INTRACELLULAR CHLOROPHYLL DENSITY IN THE S.O.

ci vs Ci SOSCEX1, summer 2013



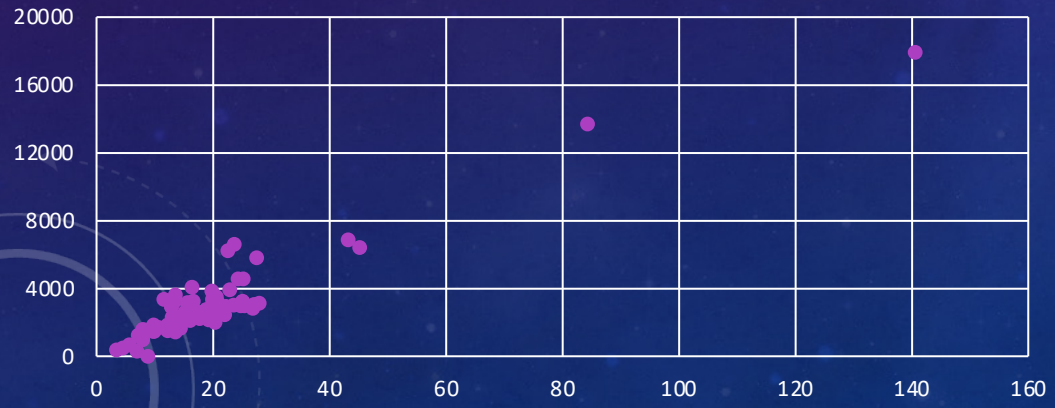
SANAE53 – summer 2014: ci vs Ci



* can we please not talk about the carbon Ci – it's big, no detrital particles accounted for

Published ci's vary from 1 kg/m^3 to 16 kg/m^3, with most lab-grown cells with ci from 2.5 to 7.
Literature Ci varies from 150 to 300 kg/m^3.

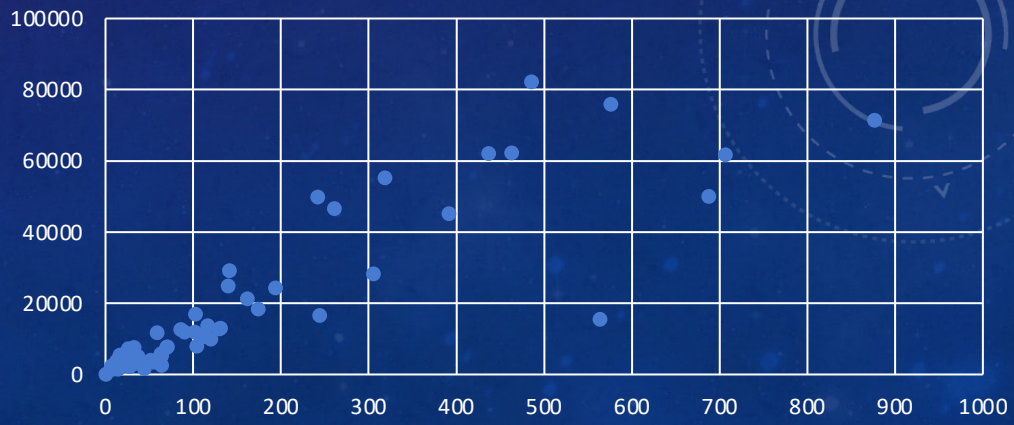
Winter 2015 ci vs Ci



We expect elevated ci in winter. But 30?

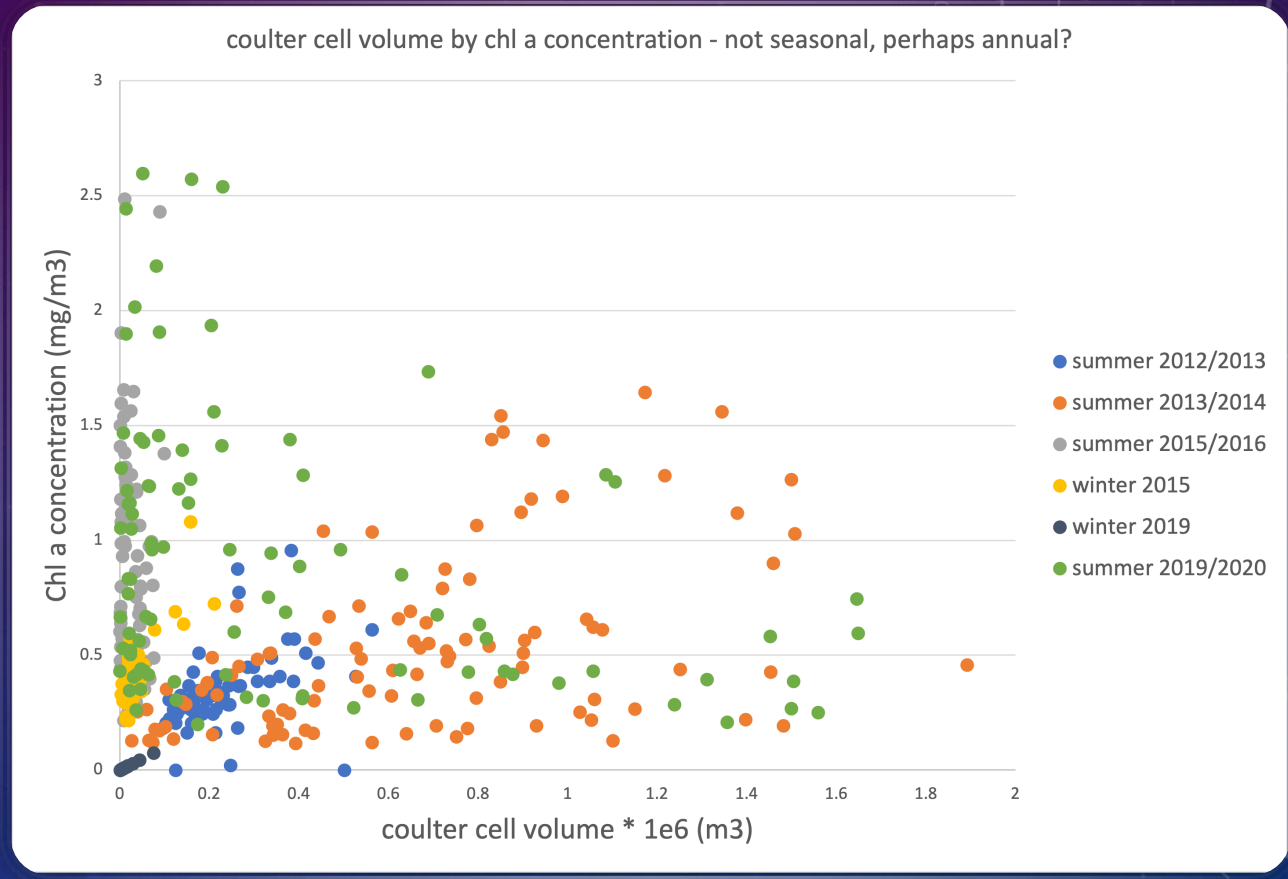
AND WHAT IS THIS?

SANAE55 - summer 2015/2016: ci vs Ci



SOMETIMES, THE COULTER CELL VOLUME IS SMALL

- If we were catching all cells by coulter, there would be an identifiable relationship between coulter volume and chl concentration. Seasonal assemblage changes would then also be more evident
- Are we ‘missing’ an entire population of small photosynthesizing cells?
- When we look carefully at the hplc this info was there all along ;)



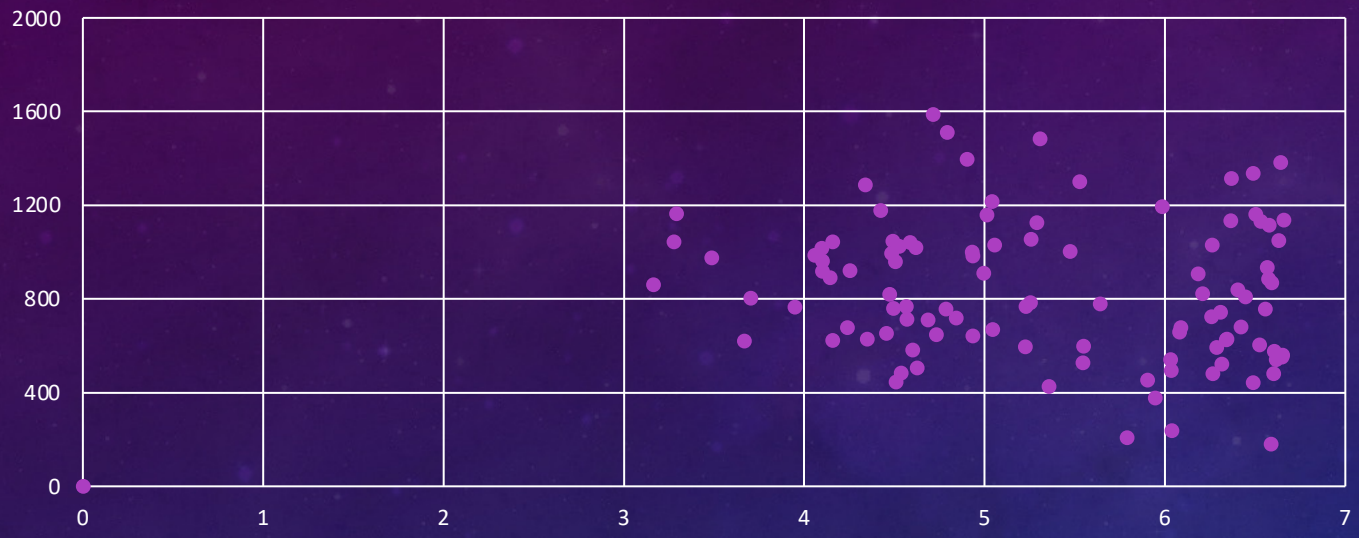
… BUT NOT ALWAYS

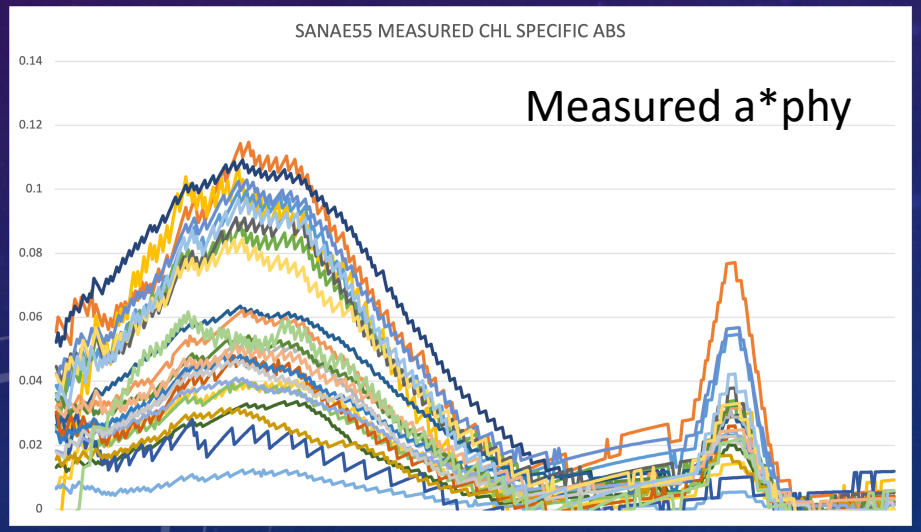
SUMMER ABSORPTION SPECTRA

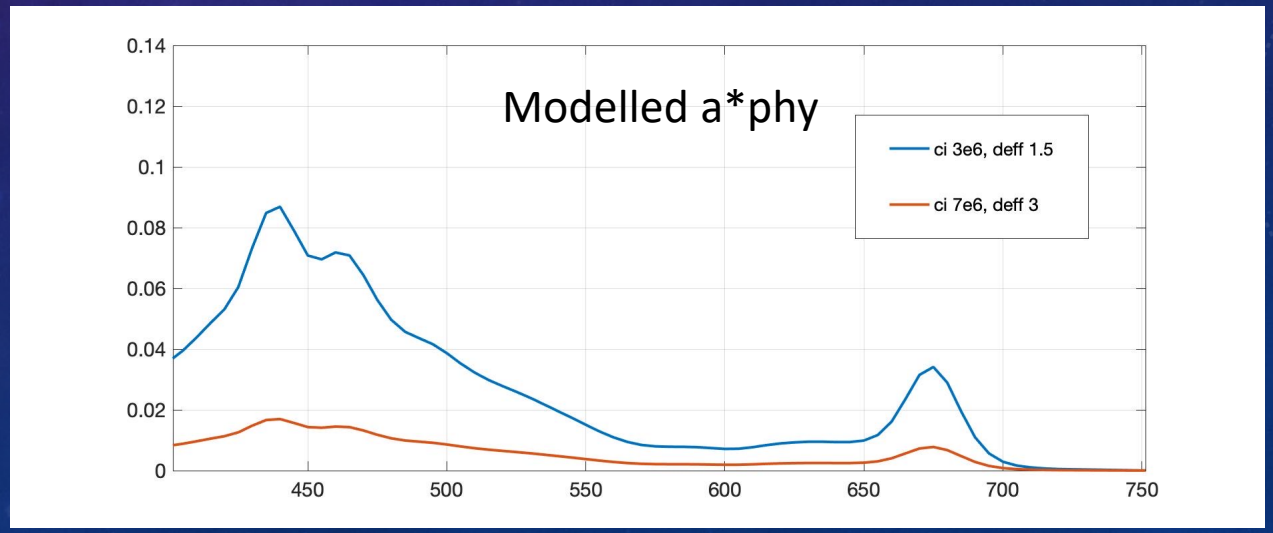
HPLC says 0.2 - 0.7 of chl a is due to pico. Here we model 50% of the measured chl with (guessed!) deff 1.5 micron, and add it to the coulter cell volume, we get ci within expected range of 3 to 7.

BUT small phytos should ***elevate*** a*phy. How can adding a large population of small cells give you a "depressed" a*phy?

We don't expect light limitation in summer. Upper range of absorption is reproduced with deff 1.5, ci 3.
But lower range of abs is reproduced by larger deff, with higher ci. Within this range, we just don't know.

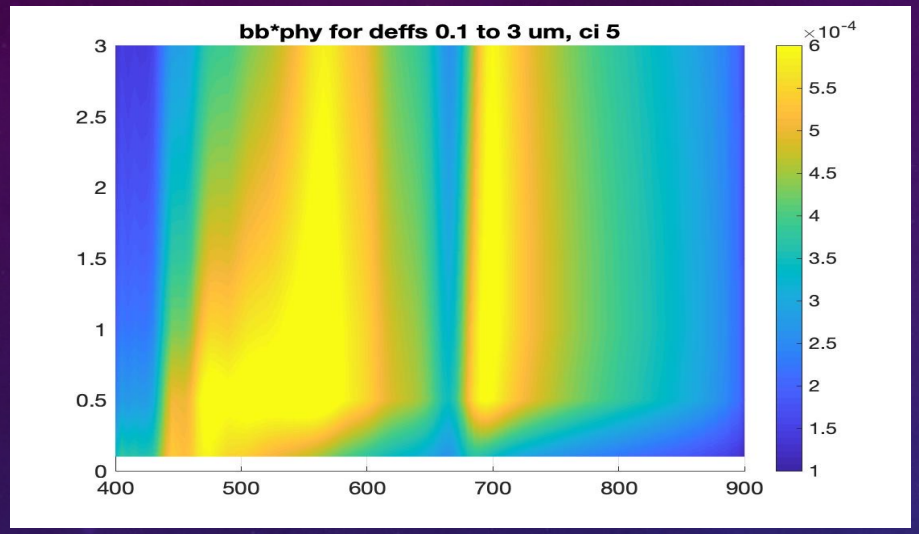


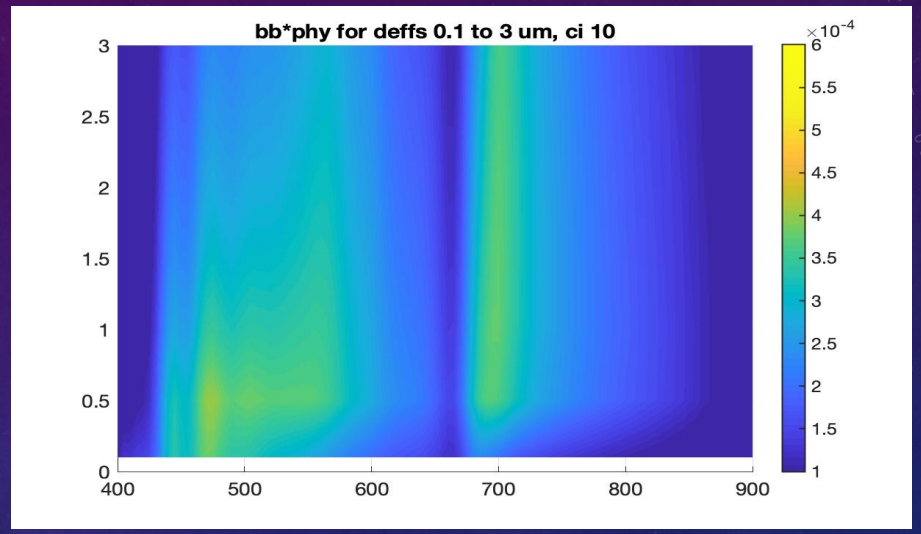




Modelled vs measured a*phy: ci is 3 – 7, deff between 1 and 3 um.

THE (SOMETIMES) PRESENCE OF SMALL PHYTOS IS A GAME CHANGER FOR UNDERSTANDING THE OPTICS

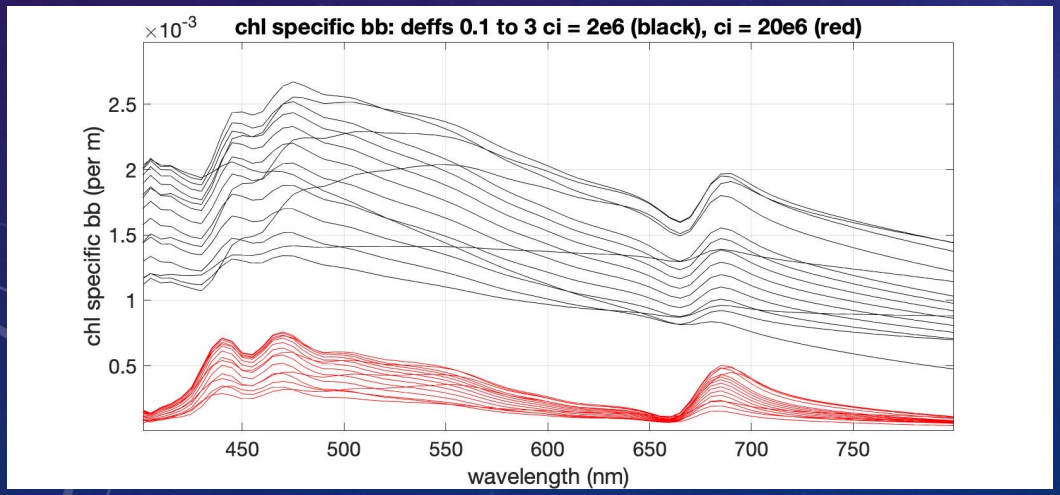


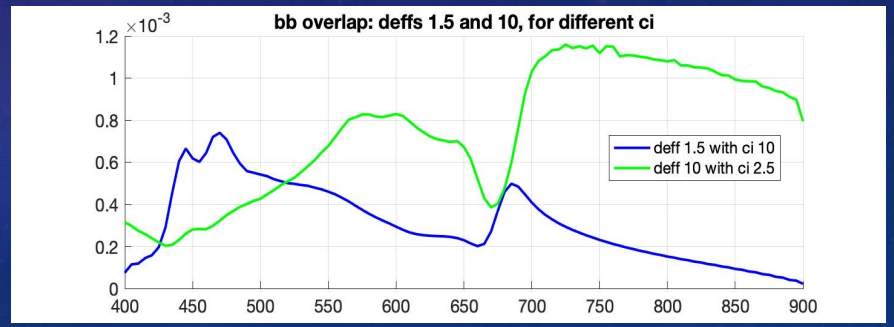


Colour scale
Is bb*phy

1 x 10-4 to
6 x 10-4

Bb for deff 3 >>> bb deff 1 for different ci. Increasing ci introduces significant ambiguity in bb/size relationship.
Feature around 0.5 micron is an artefact – cell geometry and arrangement becomes important as chl ci increases in v. small cells



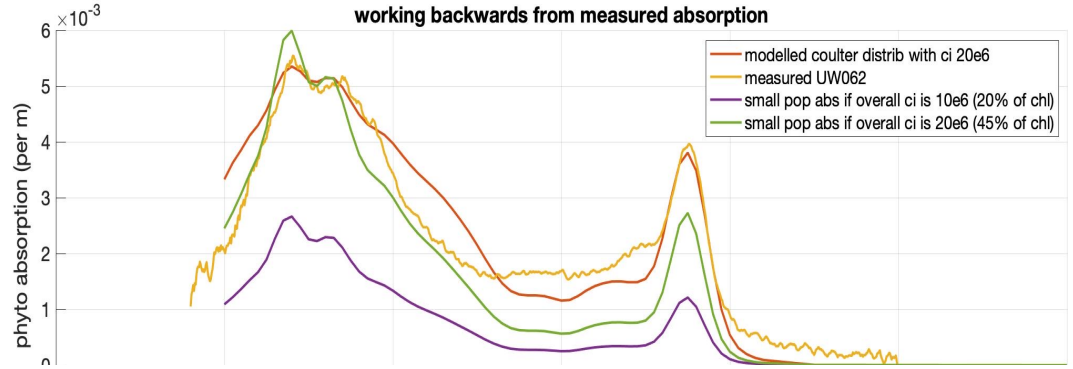


Takehome: We can't model <1um yet, but it is clear that even for very small cells, high ci means very reduced bb

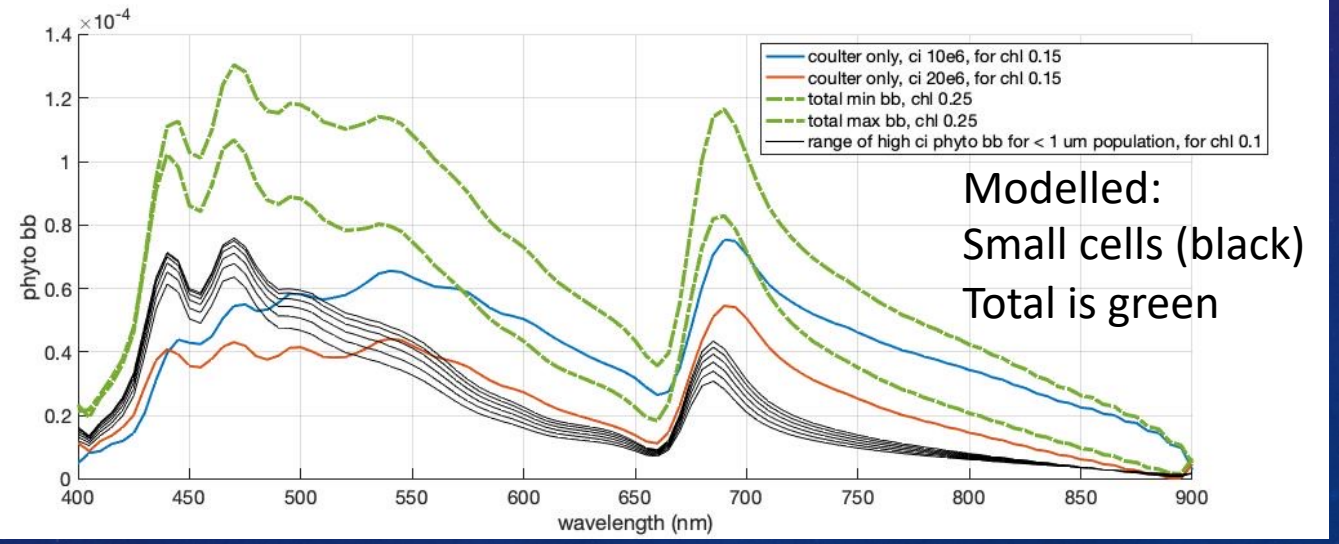
SUMMARY SO FAR …

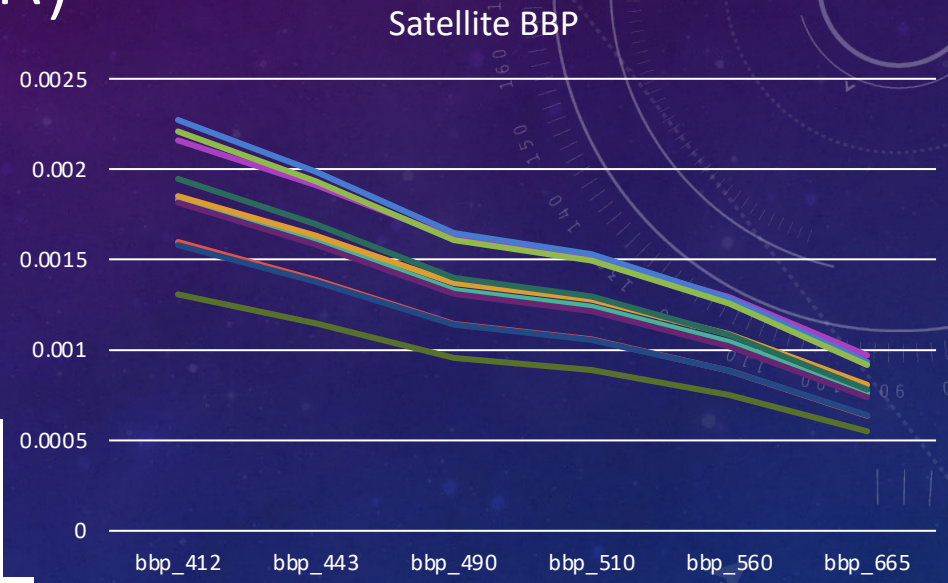
- We need to rethink our dataset due to these small phytos
- In the model, **changes in ci have a direct impact on bb** as well as absorption. This becomes less predictable at very small cell sizes.
- Bb size relationship does not hold when changing physiology
- Physiological AND assemblage effects can be observed in phyto absorption measurements, and can be quantified using ancillary measurements (size distribution, chl conc, ci) inputted into inverse model
- we can then calculate phyto backscatter from *the same assemblage*, incorporating those physiological changes
- (Then we can observe the relationships between chl and carbon via the absorption and backscatter)
- We need to rethink our methodologies due to these small phytos

PROPORTIONAL CONTRIBUTION OF PHYTOS TO TOTAL PARTICULATE BACKSCATTER (WINTER)



Yellow is measured. Red is modelled with measured coulter, given the overall ci of 20. Very little abs is coming from the small pop, implying small contrib to chl, and/or high ci, probably both.





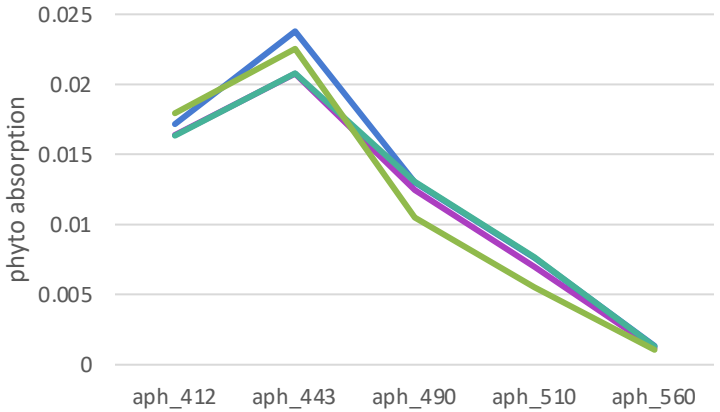
We can work out approx. the contribution of pico to total (size fract chl f, hplc, flow cyto).
But we don't know what the ci really is. And it matters.
Tension between % contribution to chl conc, and the implied ci.
Bb phyto is still dwarfed by the detrital bb.

WINTER:

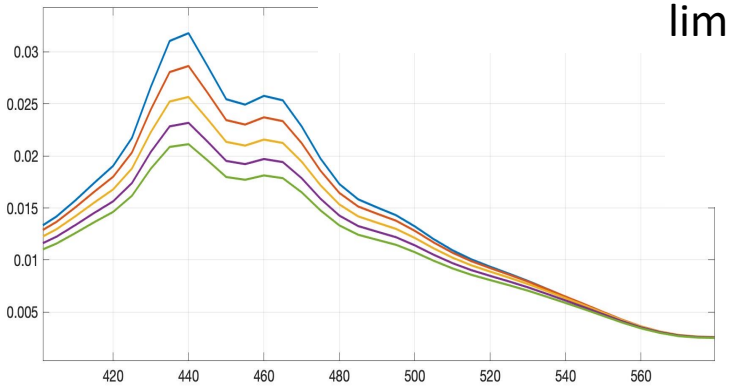
CCI BBP CORRESPONDS WELL WITH BB3

CCI PHYTO ABS OVERESTIMATES

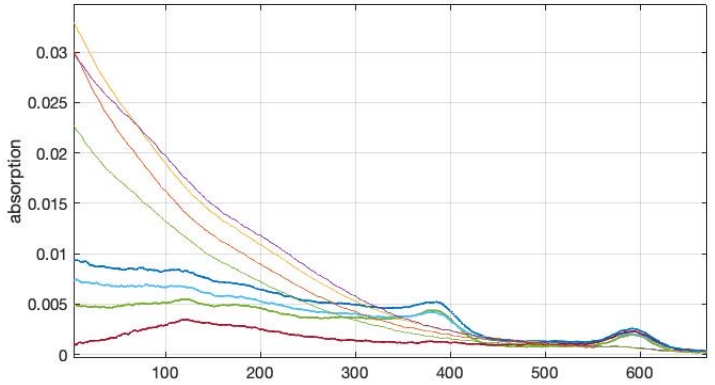
Satellite phyto abs (winter)



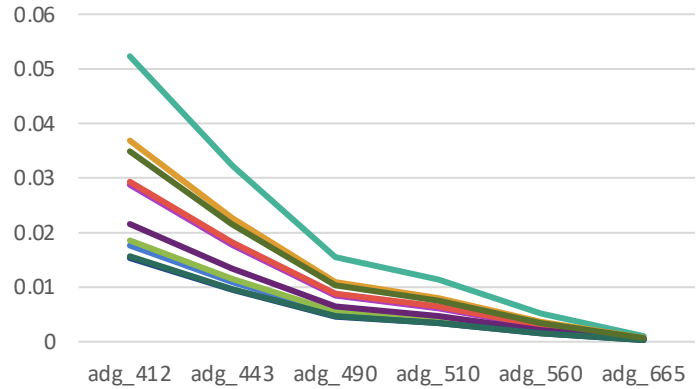
modelled phyto abs, not accounting for light limit



measured depig (top lines)
phyto abs (bottom lines)



Satellite detrital & cdom absorption



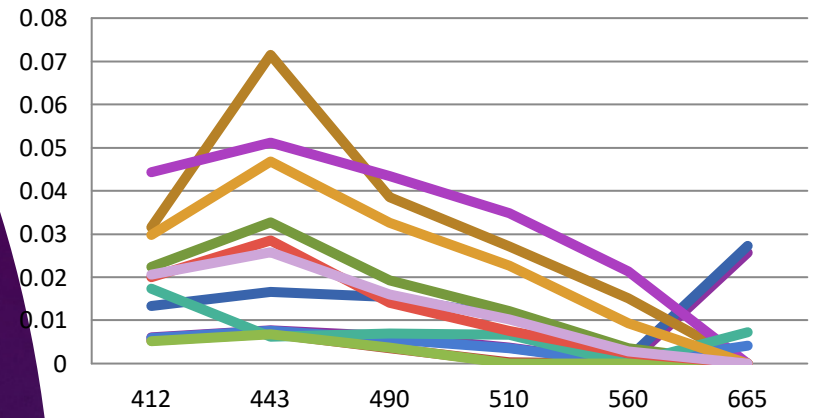
… by the same amount as the non-light limited model

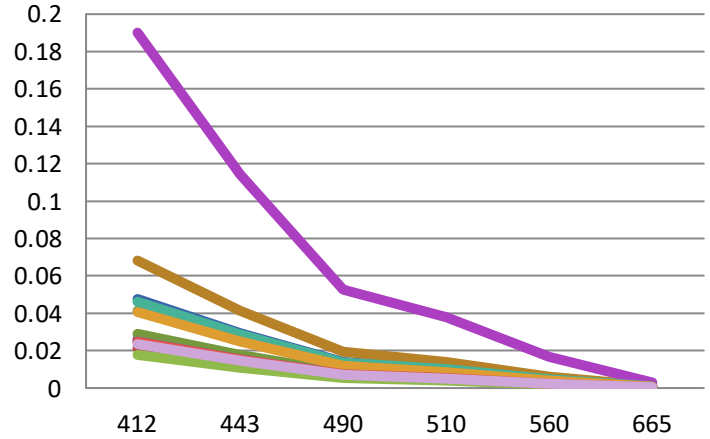
… agd looks like small overestimate, but measurement has no cdom.

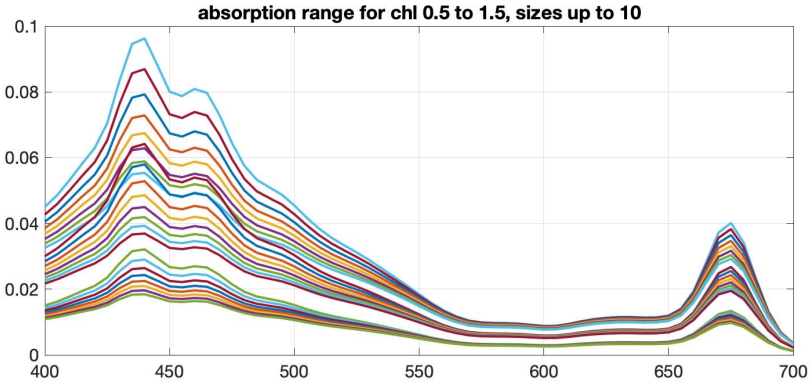
SUMMER:

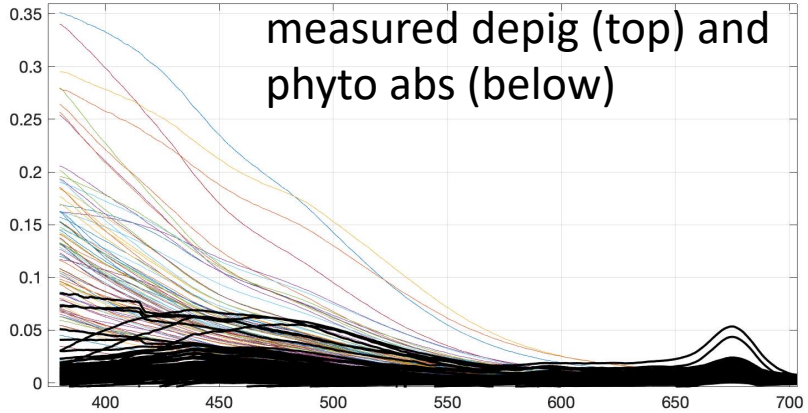
CCI BBP LOOKS PLAUSIBLE. OUR BB3 ALSO V VARIABLE.

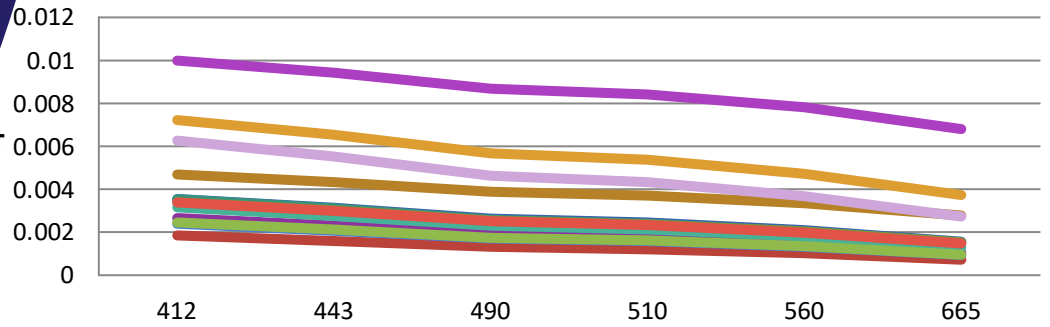
CCI PHYTO ABS LOOKS GOOD

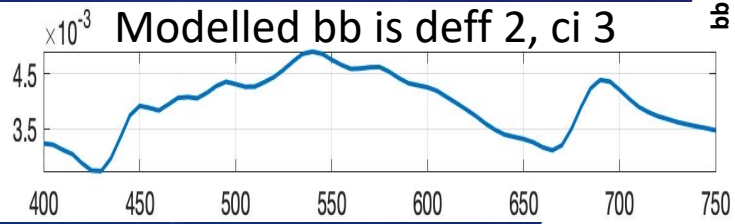






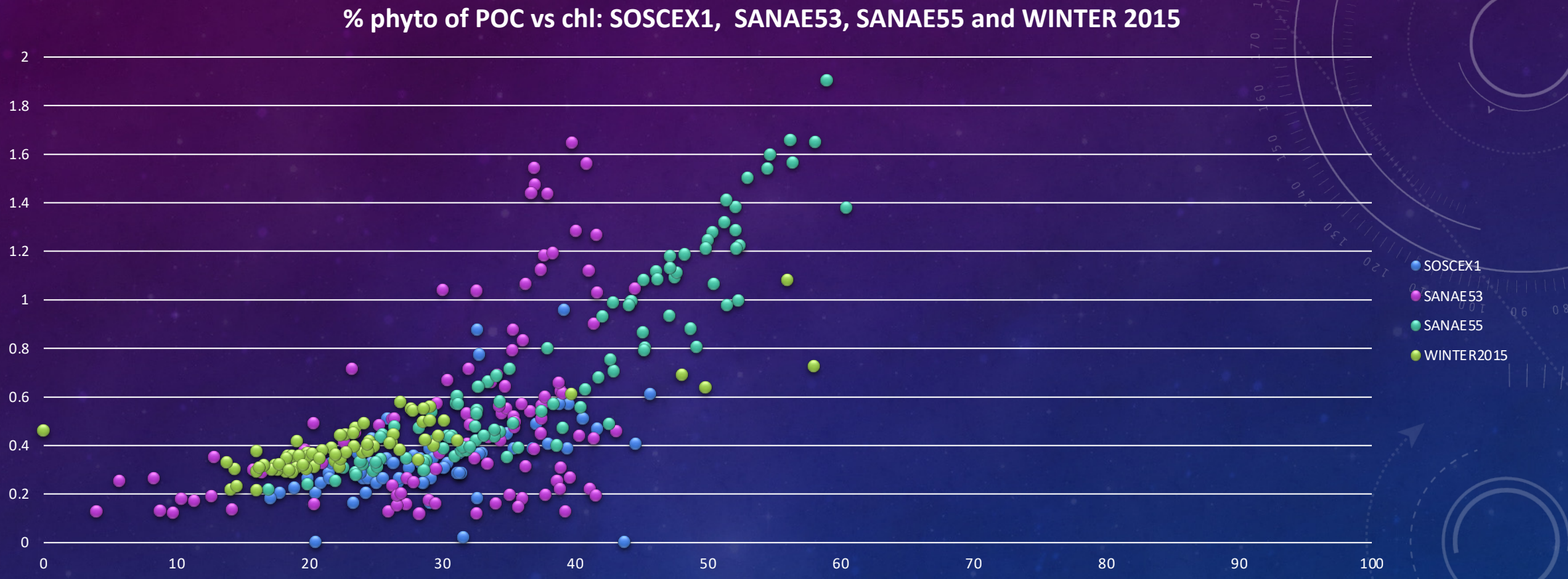






… phyto abs within range
… agd looks like it could be underestimating this time, need a closer look

WHAT ARE THE IMPLICATIONS AND CAN ANY OF THIS BE USEFUL?



Plot initial ci vs Ci. Add population of small particles at <2um, until total cell volume is right for ci range 3-7 (summer) and appropriate proportion of chl a. [Winter ci? We don't know, allowed max of 16.] Add detrital volume until the and Ci is within 150 to 300, cross check with total abs. Calculate % of POC attributable to phyto. Can be greatly improved with better ci and size parameterizations.

Wide range in purple is from cruise with very LOW coulter ci, ie probably more large detrital. Not yet accounted for.

THE REST OF THE SUMMARY:

1) We have some sneaky small phytos. Sometimes.
2) They don't affect the absorption much. But the total phyto absorption tells us that all the phytos are quite high ci.
3) This is not good news for being able to detect or understand their backscatter in situ, despite being small and scattery

In winter, phyto bb is very small and the bbp signal is overwhelmed by non-algal particles. Summer satellite bbp is hugely variable … is the phyto bb large enough to be retrieved with confidence? Only at very high biomass.

Backscatter under 1.5 micron is complex to model well, but we will try. These sizes are important in the S. Ocean. Chl ci is a major driver of bb at these sizes. It looks likely that high ci results in low backscatter. This corresponds to idea of variable chl:carbon ratios under physiological stress.

We do not have information on ci variability. Using backscatter to identify phyto size without ci information is going to be difficult even if you know the chl biomass.

Using size as a known (measured) constraint and overall ci and Ci as tentative ones, we can model phyto populations to match the measured phyto absorption, then adding an attendant detrital population to match the measured depigmented abs and the total bbp. This gives a complete set of IOPs together with the physiological properties of an assemblage (deff or distribution, chl ci, carbon Ci).

We can see that the contribution of phyto to total POC is highly variable, and it looks like there are discernible relationships there. Further constraining the ci will improve these results.

THE WAY FORWARD

Can we observe the biological carbon pump via absorption?
What would we need to be able to do this?

1. Excellent satellite **phytoplankton absorption retrievals**
2. Measured **constraints** for true population **size distribution** (flow cyto plus Coulter), ci, Ci (via POC and detrital model).
3. An **understanding of ci variability**, due to light stress in the first instance:
    A. Using Fluorescence Light Curve (FLC) data gives Ek, **relative measure of light levels** the phytos are adapted to. Sigma_PSII gives the effective absorption cross section of PS2.
    B. At sea, **stress experiments** to test the systematic **progression of physiological changes** forced by light and nutrient limitations.
4. A **better small phyto IOP model**. Links to phytoplankton cellular models.

Thanks for listening!

Comments, criticism, contributions and collaborations all welcome

☺