4MOST – 4m Multi-Object Spectroscopic Telescope

Survey Strategy and 4FS

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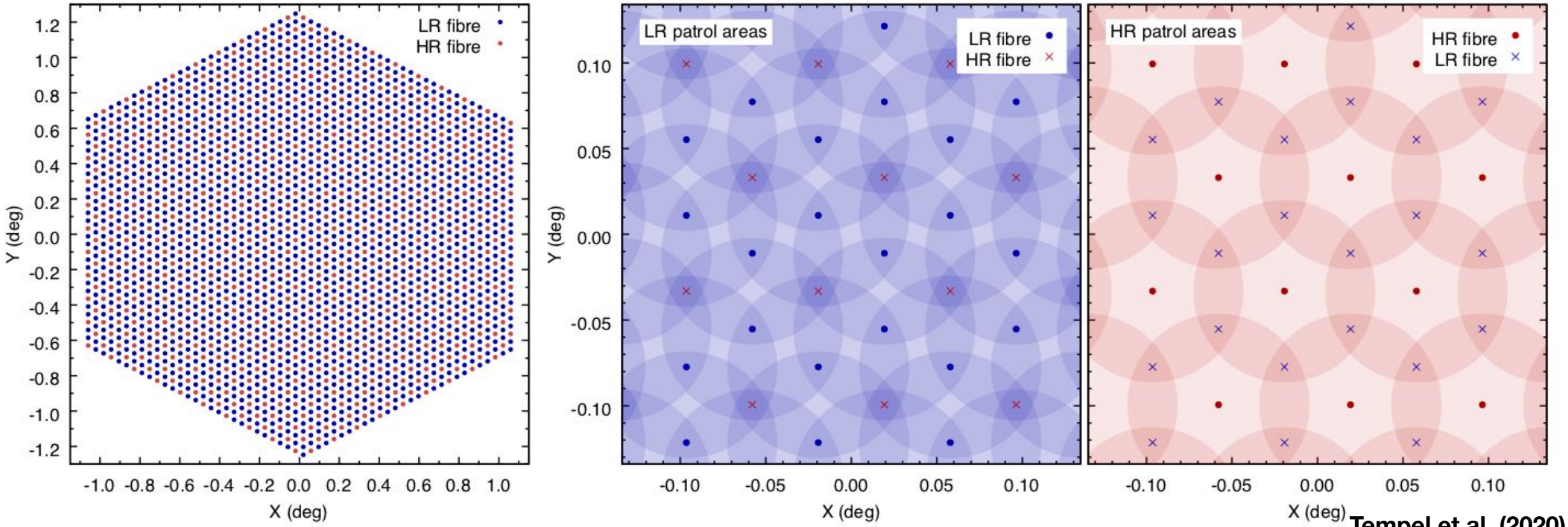
www.4MOST.eu

Overview

- Basic concepts
  - 4MOST Field layout (LR and HR fibres)
  - Exposures, overheads, S/N
  - Observing conditions
  - Survey duration, feedback loops, catalogue changes
- 4MOST Facility Simulator (4FS):
  - 4FS WI (input): (consortium + community) survey catalogues + 4FS-ETC + 4FS-SoS
  - 4FS OpSim (sim): Visit Planner + Scheduler (long/short term) + Probabilistic Fibre-to-Target Assignment
  - 4FS Output (results)
- Area coverage and target densities, special areas
- Exposure times, conditions
- Cadence, variables and transients
- Supplementary Targets and Poor Observing Conditions programmes
- Summary

4MOST Field layout



Tempel et al. (2020)

- 1624 Low-Resolution Spectrographs fibres (LR) $\Rightarrow$ ~400 / deg^2
- 812 High-Resolution Spectrograph fibres (HR) $\Rightarrow$ ~200 / deg^2
- Number density of targets x exposure time must match between HR/LR

Exposures, overheads, S/N

- Typical exposure times expected to be 5–30 mins
  - Longest ~30 mins limited by differential atmospheric refraction
  - Shortest possible 10s (but see overhead below!)
- After repointing of telescope, one or more exposures for total visit duration of 1.25h
- Each target can be exposed one or multiple times in a visit, each fibre can be repositioned between exposures
- Repeat exposures allows increased exposure time / S/N for each target individually
- Overheads:
  - Initial telescope slew, acquisition, fibre positioning: 3.5 min
  - Each exposure (readout, calibrations, fibre repositioning): 4.4 min
    - Extra calibrations needed because of tilting spines, may not be needed after initial calibration
  - Ongoing activities to reduce overheads

Observing conditions

- Exposure times depend on:
  - Sky condition (bright/grey/dark)
  - Seeing
  - Airmass
  - Atmospheric transparency
  - S/N requested
- *4MOST users cannot choose observing conditions!*
- Exposure times will be estimated for standard conditions
  (see ETC talk by Genoveva Micheva and OpSys talk by Wing-Fai Thi)
- Exposure times adjusted as needed during simulations/operations (TBC)

Survey duration, feedback loops, catalogue changes

- The first 4MOST survey will last 5 years
  - More 5-year surveys are foreseen to follow
- S/N success of all targets checked on ~weekly basis and return to the pool if not completed
- Progress at Survey level monitored on yearly timescale
  - Algorithms adjusted if needed when a Survey falls behind
- To ensure understandable selection function, catalogue changes will be kept to a minimum during the 5 years
  - A small number of Transients will be allowed per field (<2% of fibres)

4MOST Facility Simulator: Input

- Input to 4FS (4FS WI):
  - Target and Spectral catalogue package:
    - Coordinates, magnitudes,... and associated spectral templates
  - Spectral Success Criteria (SSC):
    - Rules and Rulesets defining spectral requirements
  - “FoM” package:
    - Small Scale Merit (SSM) function: encodes completeness requirements on scales of ~ 4MOST FoV
    - Large Scale Merit (LSM) map: encodes priority sky areas for each Survey
    - Required Area and Tmax: encodes requested area and maximum exposure time
- Survey can consist of multiple sub-surveys:
  - each with its individual target and spectral package, SSC and FoM package
  - Typically sub-surveys contain objects with similar selection criterion -> *sub-survey selection function*
- Minimal cadence input (in progress: expects to be delivered when 4FS WI goes online)

4MOST Facility Simulator: Input

See Wing-Fai Thi's OpSys talk on Friday and Jake Laas 4FS WI tutorial on Tuesday

- Input to 4FS (4FS WI):
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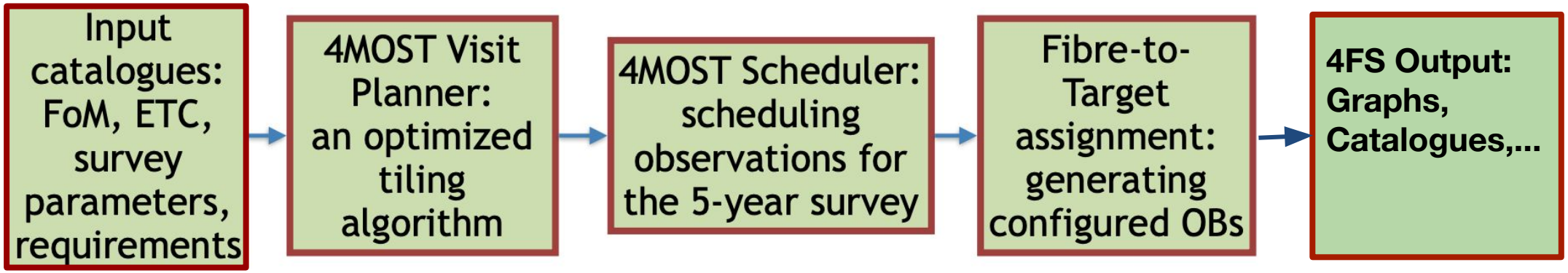
4MOST Facility Simulator

- Take ETC estimate on each target (see talk by GM & WFT)
- Decide tiling, observing conditions, fibre-target assignment
- Run 5-year survey strategy with all surveys
  - Observing conditions: seeing, wind, clouds, down-time, ...
- Verify survey success



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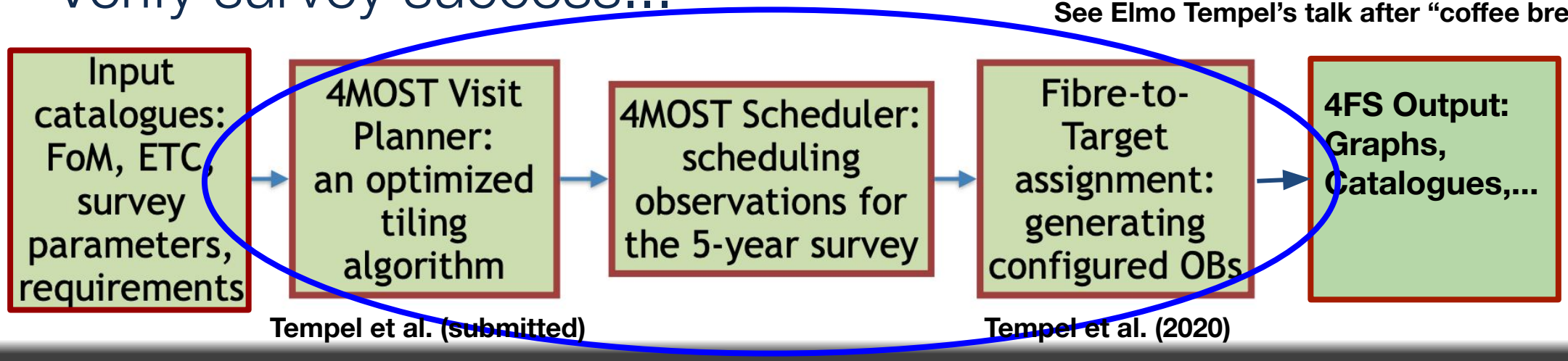
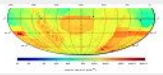
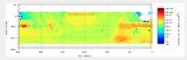
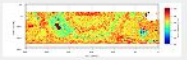
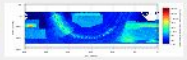
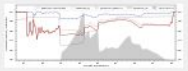
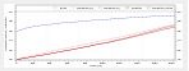
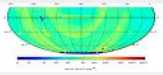
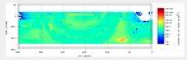
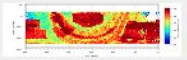
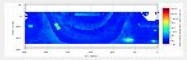
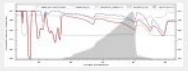
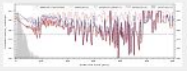
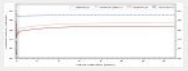
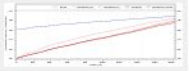
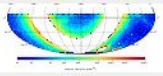
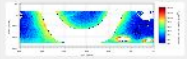
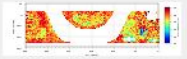
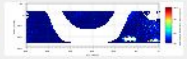
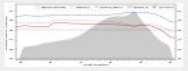
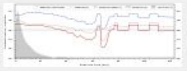
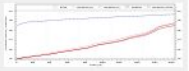
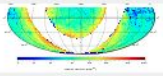
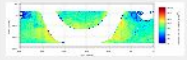
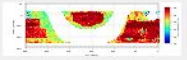
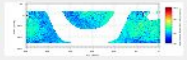
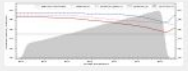
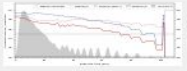
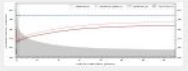
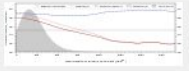
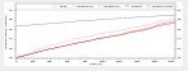
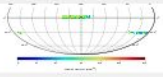
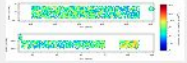
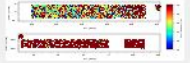
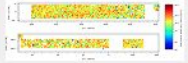
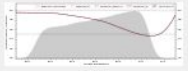
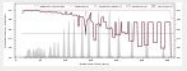
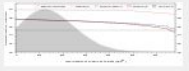
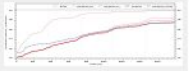
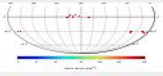
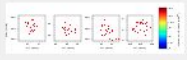
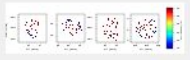
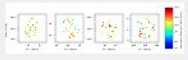
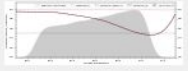
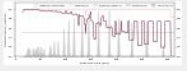
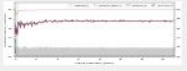
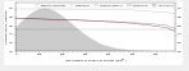
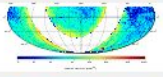
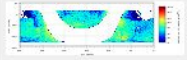
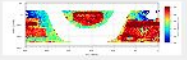
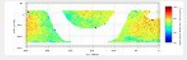
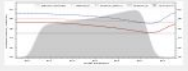
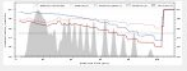
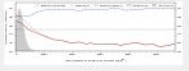
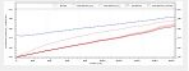
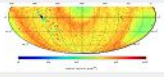
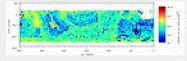
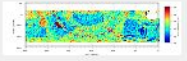
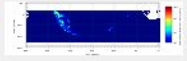
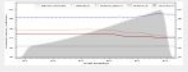
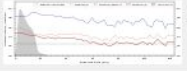
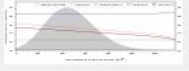
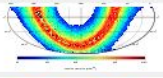
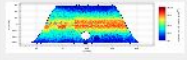
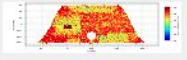
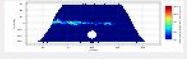
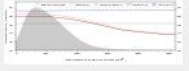
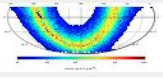
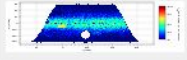
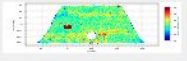
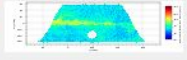
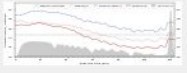
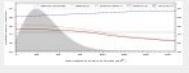


4MOST Facility Simulator output: single run

4MOST Selection Functions Pipeline: Plot collections

R15: Year 1 | R15: Year 2 | R15: Year 3 | R15: Year 4 | R15: Full Survey

R15: Full Survey

ID	Res	Collection	Count	All targets	Successful	Successful / all	Exp. time (dark)	Magnitude	Exp. time (dark)	Ang. sep. (small)	Loc. den. (512)	Survey progress
1	LR	All LR targets	40633868									
2	HR	All HR targets	10502491									
101	LR	S1 MW halo LR	2479224									
201	HR	S2 MW halo HR bright	1526979									
202	HR	S2 MW halo HR deep (wide view)	47929									
202	HR	S2 MW halo HR deep (deep fields)	47929									
203	HR	S2 MW halo HR faint	983503									
301	LR	S3 4MIDABLE-LR sub 1	10431215									
302	LR	S3 4MIDABLE-LR sub 2	5503684									
303	LR	S3 4MIDABLE-LR sub 3	3233310									

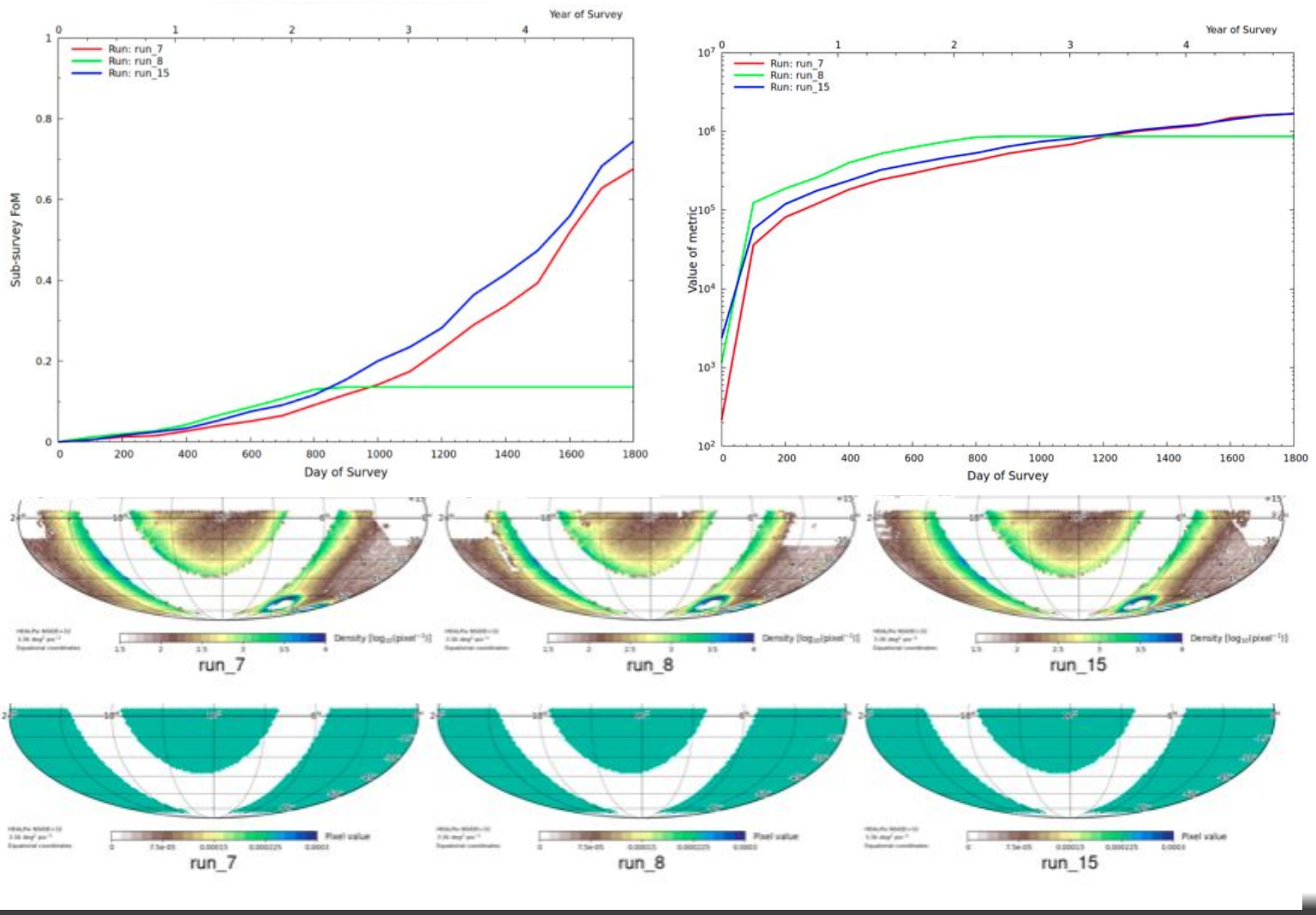
4MOST Facility Simulator output: multiple runs

sim_202005/compare_7-8-15

OpSim pages for this sub-survey, for each run compared

Table of contents

- Metrics computed from input catalogues
  - 1. Map of the Large Scale Merit (LSM) function
  - 2. Sky density of all targets
  - 3. Sky density of fibre-hours requested
- Metrics computed from output catalogues
  - 4. SoS Figure of Merit (SoS FoM)
  - 5. Alternative merit measure
  - 6. Fraction of sky pixels that reached the required completeness level
  - 7. Number of targets that have been completed
  - 8. Number of targets that have been observed at least once but not completed
  - 9. Number of targets that have been observed at least once
  - 10. Contiguous sky area that reached the required completeness level
  - 11. Sky area that reached the required completeness level
  - 12. Sky area touched by observations
  - 13. Sum of the Small Scale Merit (SSM)
- Glossary of terms
- Explanation of metrics



4MOST Facility Simulator output

- For surveys, sub-surveys and total:
  - Statistics of input catalogues
  - Output statistics of runs: observed/completed/unobserved total & fractions
  - 1D distributions: B/G/D exposure times, magnitudes, ...
  - 2D sky distributions: completeness, …
  - Progress reports: FoMs, (contiguous) sky coverage, …
- For multiple simulation runs:
  - Comparisons between runs for the same survey

Scientific and SoS Figure of Merit (FoM)

- Two important concepts to capture actual survey progress:
  - SoS Figure of Merit (SoS FoM): encodes overall success of a sub-survey via a fixed metric depending on SSM, LSM and area_requested and sub-survey progress.
  - Scientific Figure of Merit: encodes overall success of a sub-survey via a survey defined metric and sub-survey progress. *The scientific FoM needs to be defined in the Survey proposals.*
- *Scientific FoM* and *SoS FoM* are defined for each sub-survey and overall for a survey.
- Both Scientific FoM and SoS FoM are key ingredients to measure survey progress.

What area can 4MOST cover in 5 years?

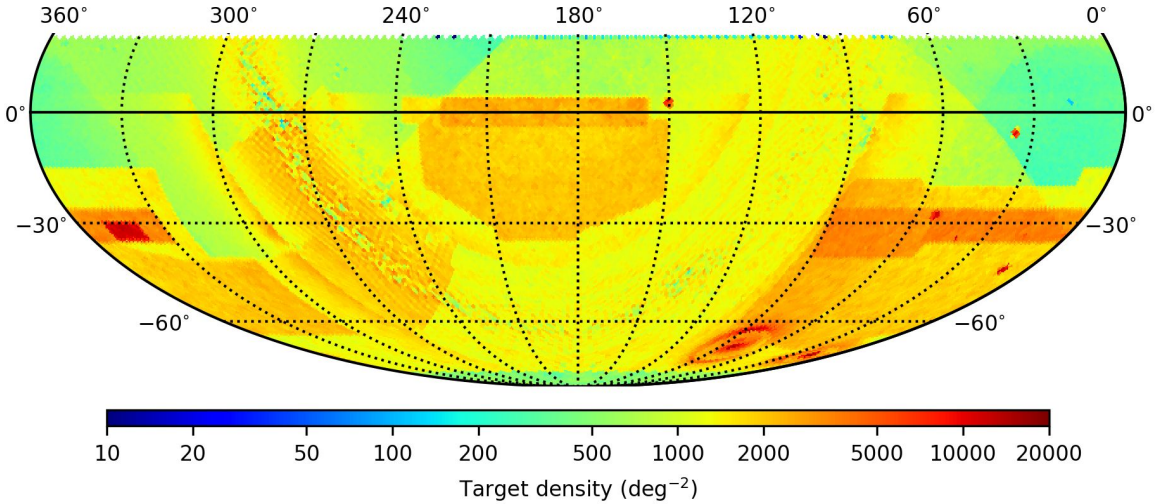
- 5 years x 300 nights/year x 9h/night x 4.2 degree^2 FoV
- Assume 0.75 open shutter fraction and 2h per pointing
- This allows you to cover ~21000 degree^2

- Area roughly equivalent to a nominal survey area of -70° < Dec < 5°

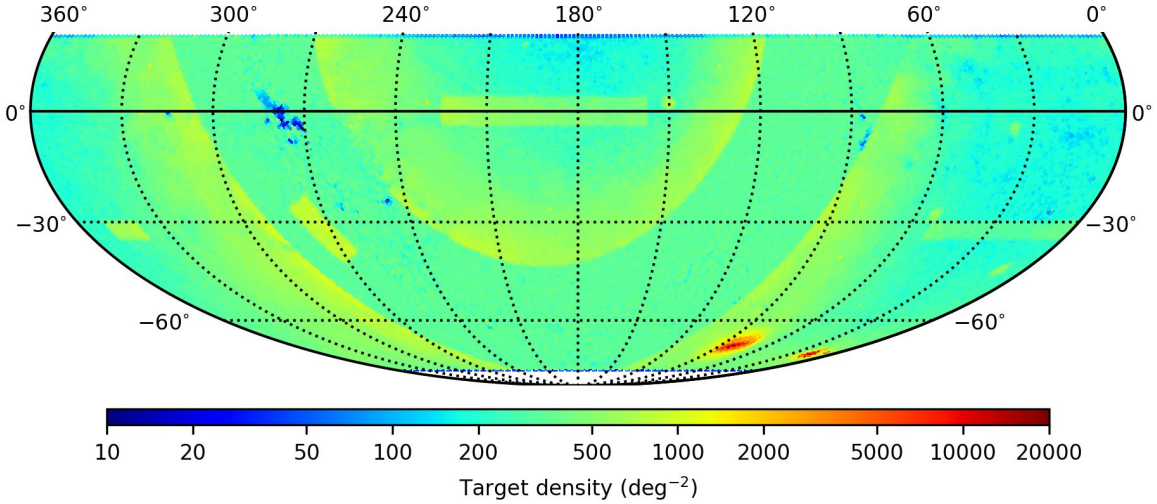
  (to be visited twice with 3x20 min exposures reaching 2h total)
- Observing outside this area or exposing longer than 2h in certain areas means:
  1. reducing exposure time somewhere else in this nominal area or
  2. not covering certain areas at all in this nominal range

Area coverage and target densities for consortium surveys

Low Resolution

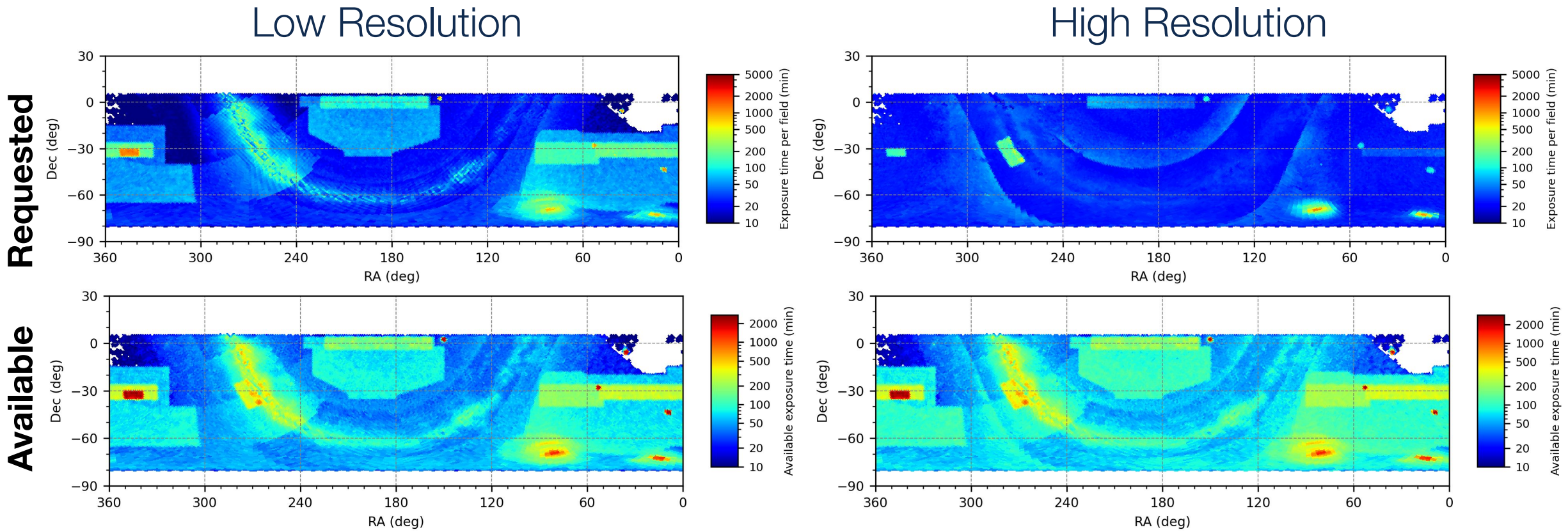


High Resolution



- Catalogues have more targets than needed: requested completeness sets the number of targets each survey is interested in.
- *Catalogues are still being worked on in the details.*
- *Hereafter: simulation results assume catalogues limited to -80° < Dec < 5°*

Requested dark exposure time and available exposure time for consortium surveys in an example OpSim run

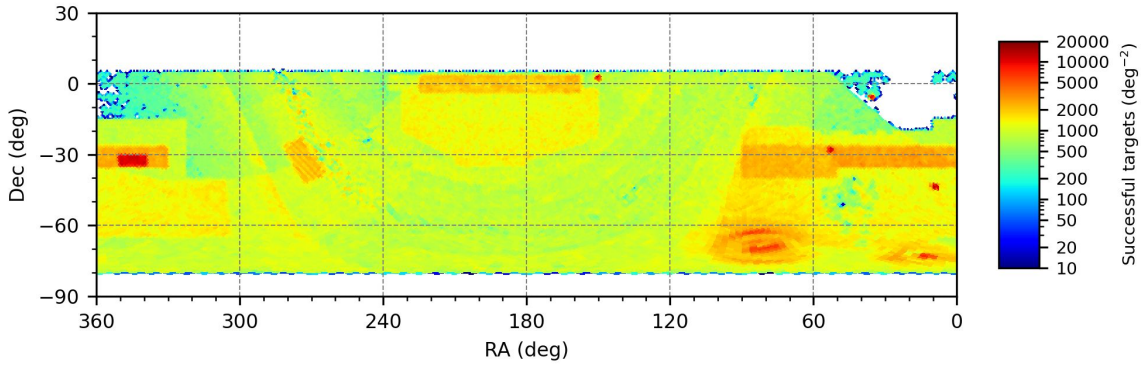


- *Catalogues are still being worked on in the details.*

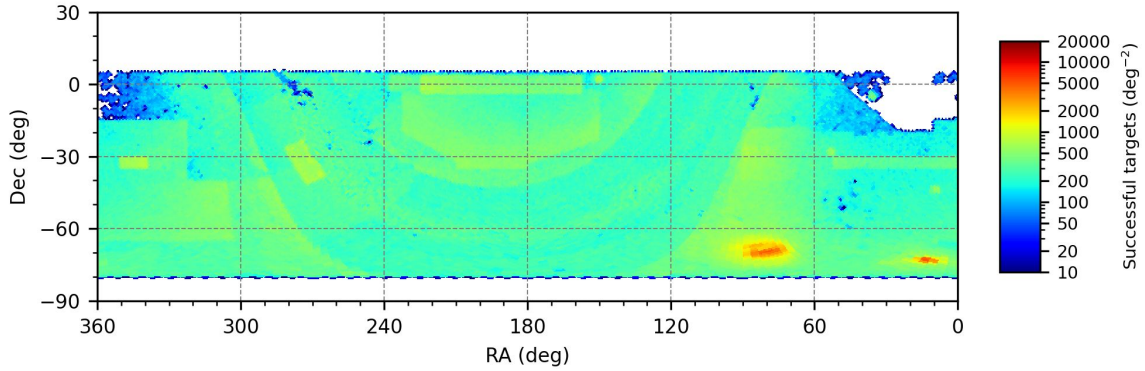
Corresponding observing success rates...

Number of successful spectra

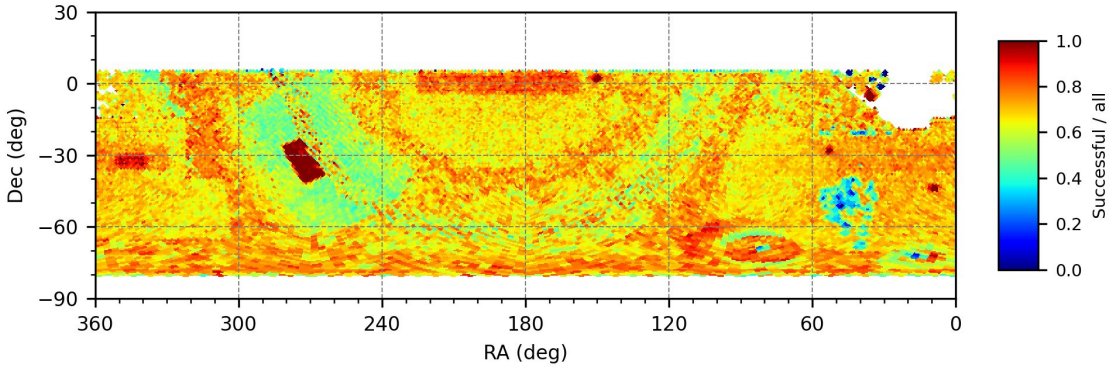
Low Resolution

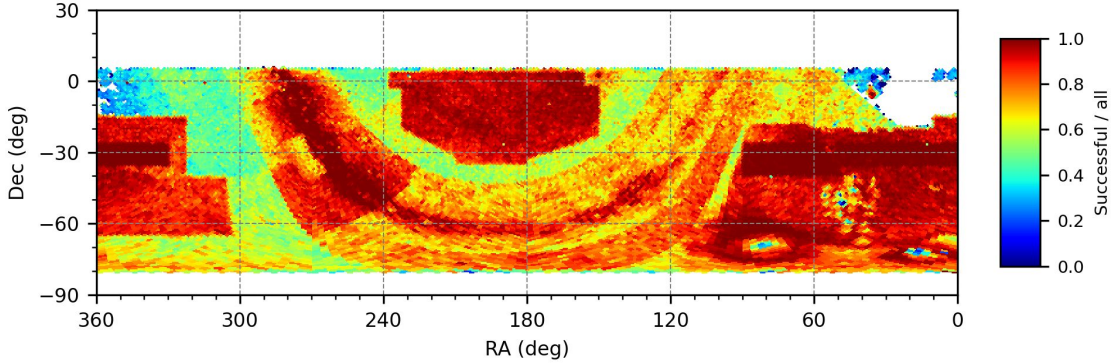


High Resolution



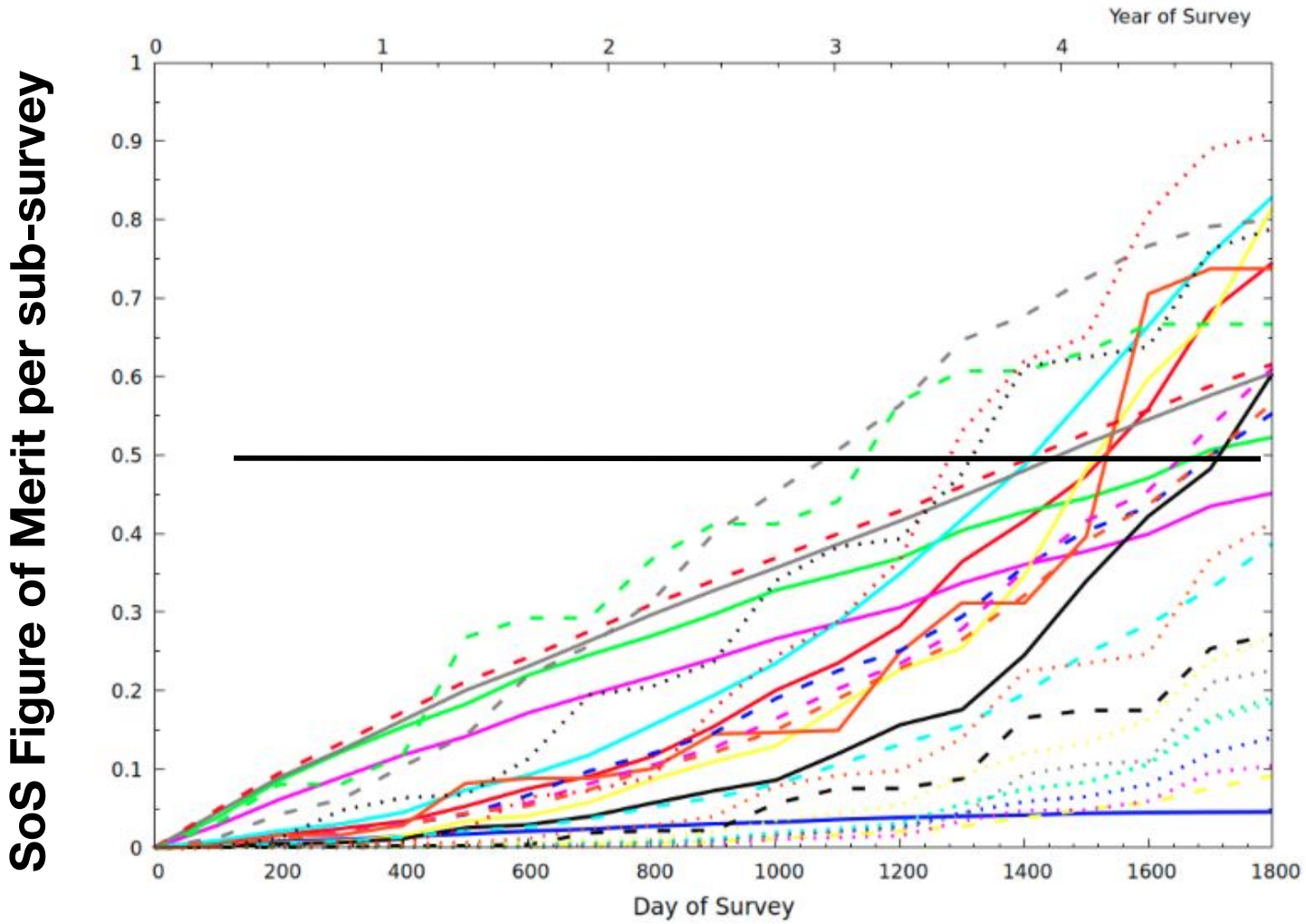
Observing success rate





- *Catalogues are still being worked on in the details.*

Corresponding SoS Figure-of-Merit progress



From this example OpSim run, some sub-surveys do not reach their nominal SoS FoM.

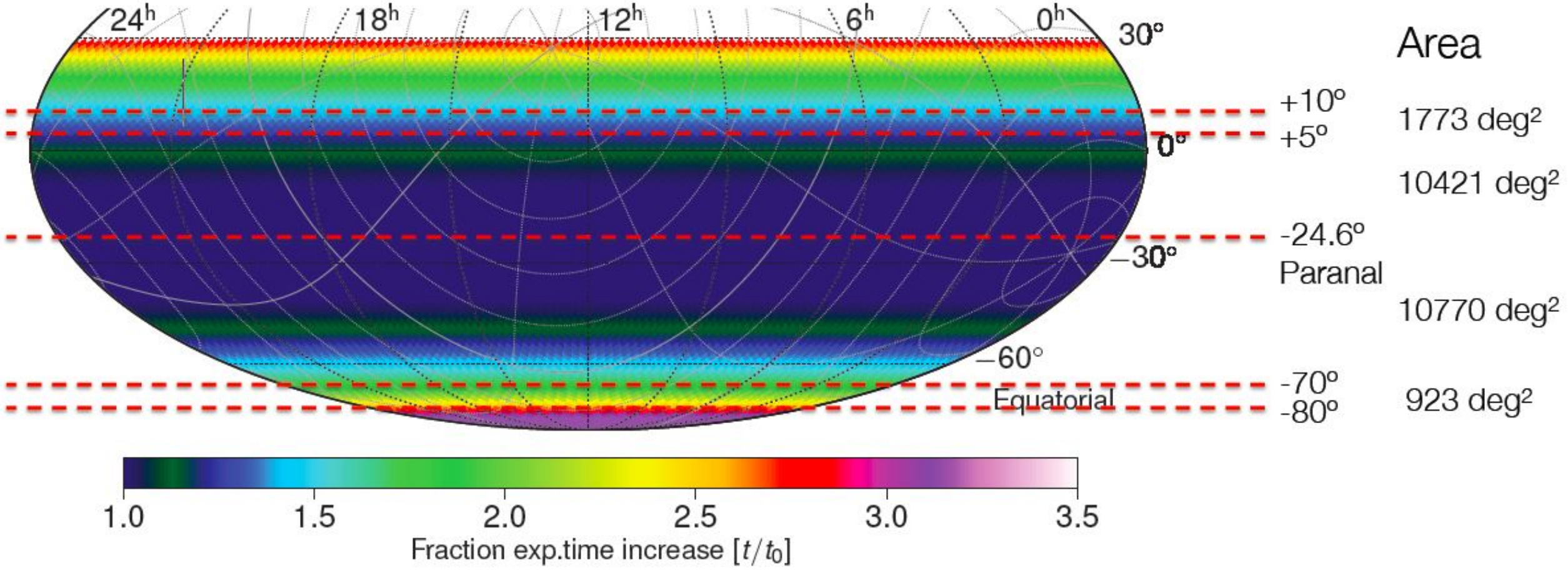
This is *not yet* a concern:

- surveys working on catalogues
- first OpSim run including a model mimicking 30% community time.

SoS FoM has a fixed format, defined by 4FS WI input (LSM, SSM, area_requested) and survey progress.

Plots with scientific FoM in progress.

Where to point, when accounting for overall 4MOST observing efficiency?



Atmospheric Dispersion Compensator limit (55° ZD) => -80° to +30° are “instrument” limits

Sky transparency suggests -70° ≤ Dec ≤ 20°

1a. Observing efficiency rapidly decreases at higher airmasses due to decreasing sky transparency:

- $m(\lambda)=m_0(\lambda) + \kappa(\lambda)\, X(z)$
- Atmospheric extinction effects worst in the blue

passband	mag/airmass
U	0.6
B	0.4
V	0.2
R	0.1
I	0.08

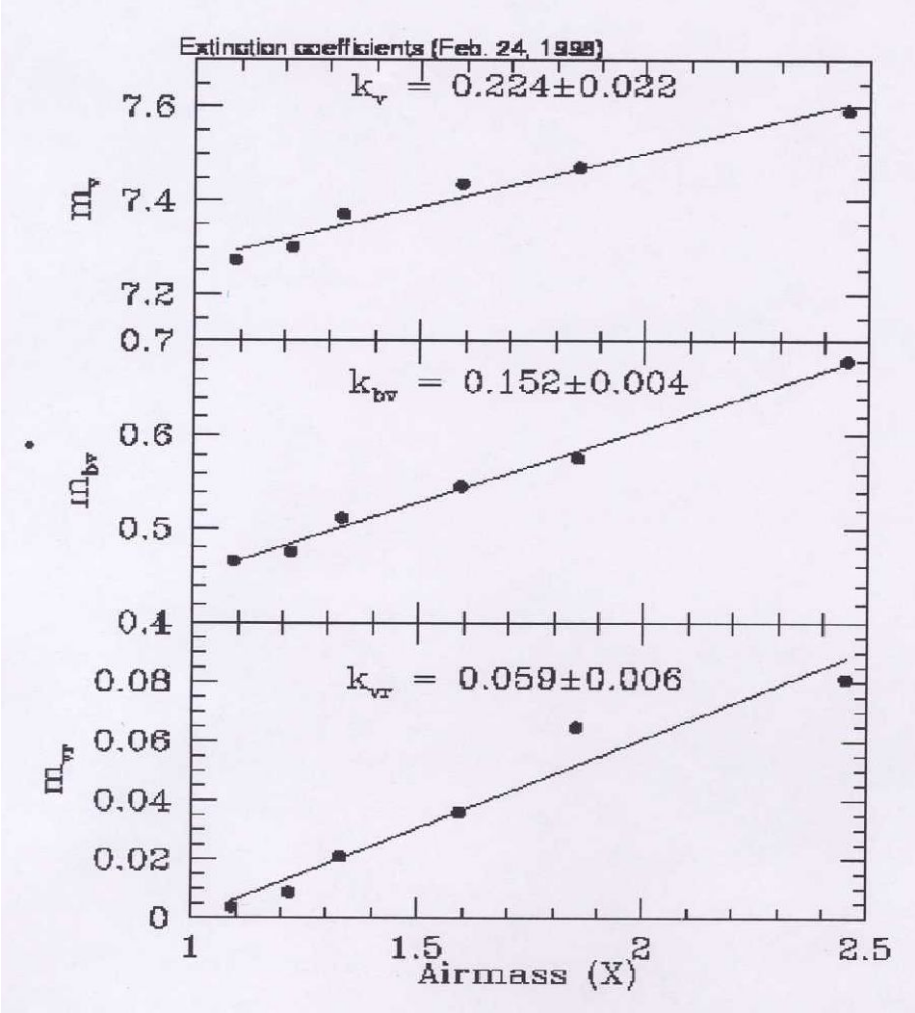
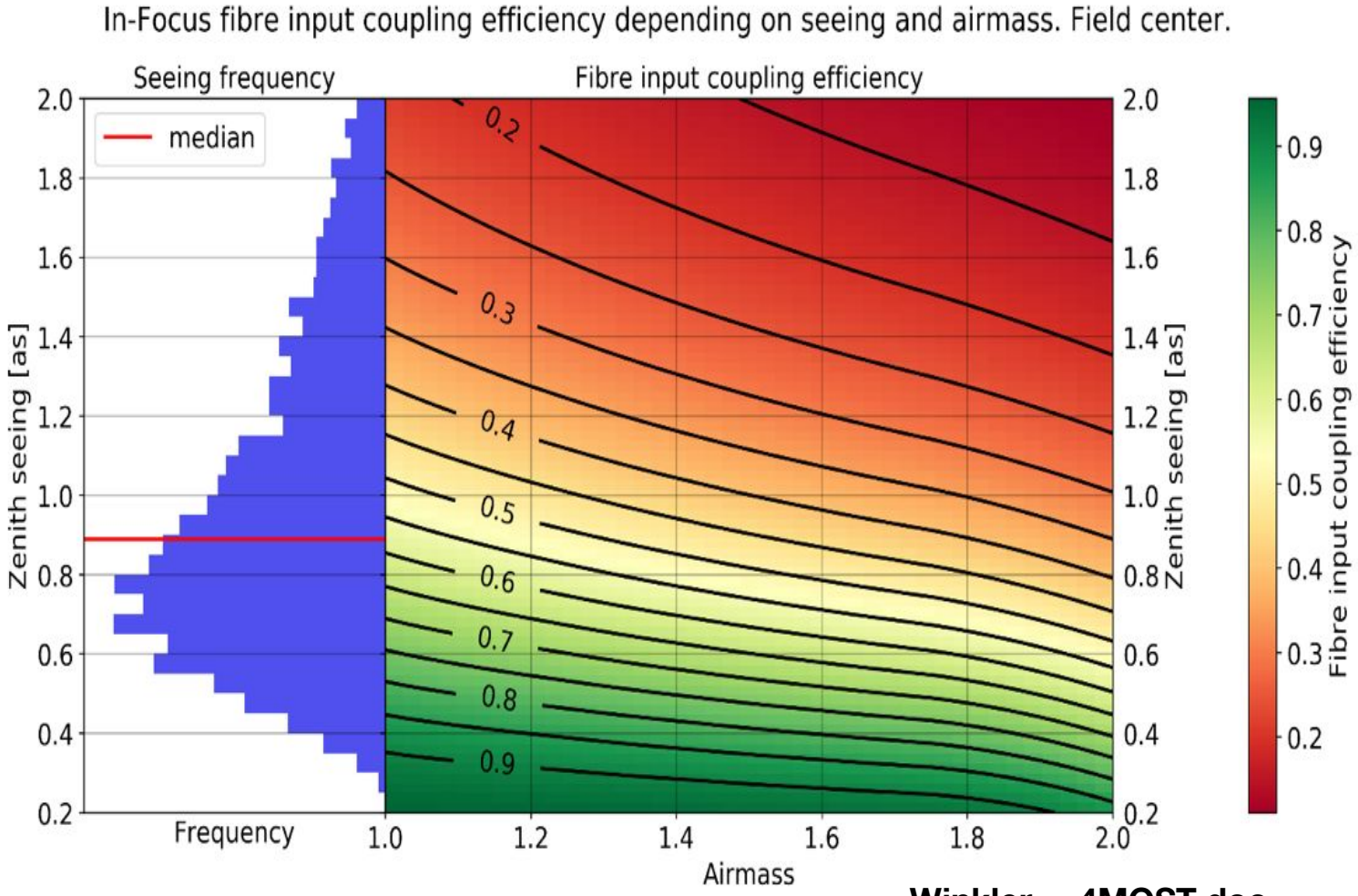


Image quality suggest -70° ≤ Dec ≤ 20°

1b. Worsening image quality

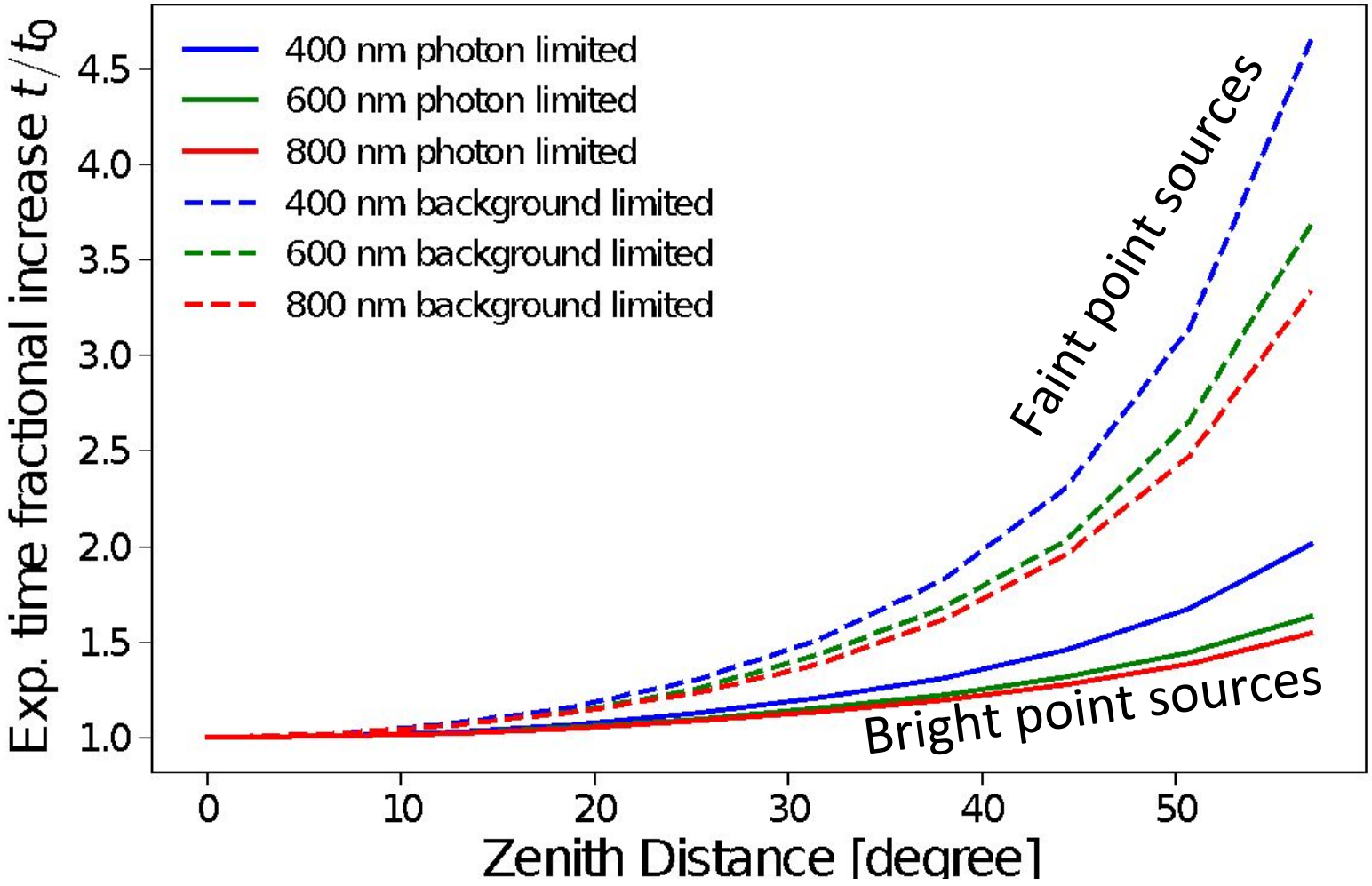
Image quality and hence light coupling in fibre depends on wavelength and airmass:

$$FWHM(\lambda) \propto AM^{\frac{3}{5}} \cdot \lambda^{-\frac{1}{5}}$$



Winkler -- 4MOST doc

Observing Efficiency suggests -70° ≤ Dec ≤ 20°



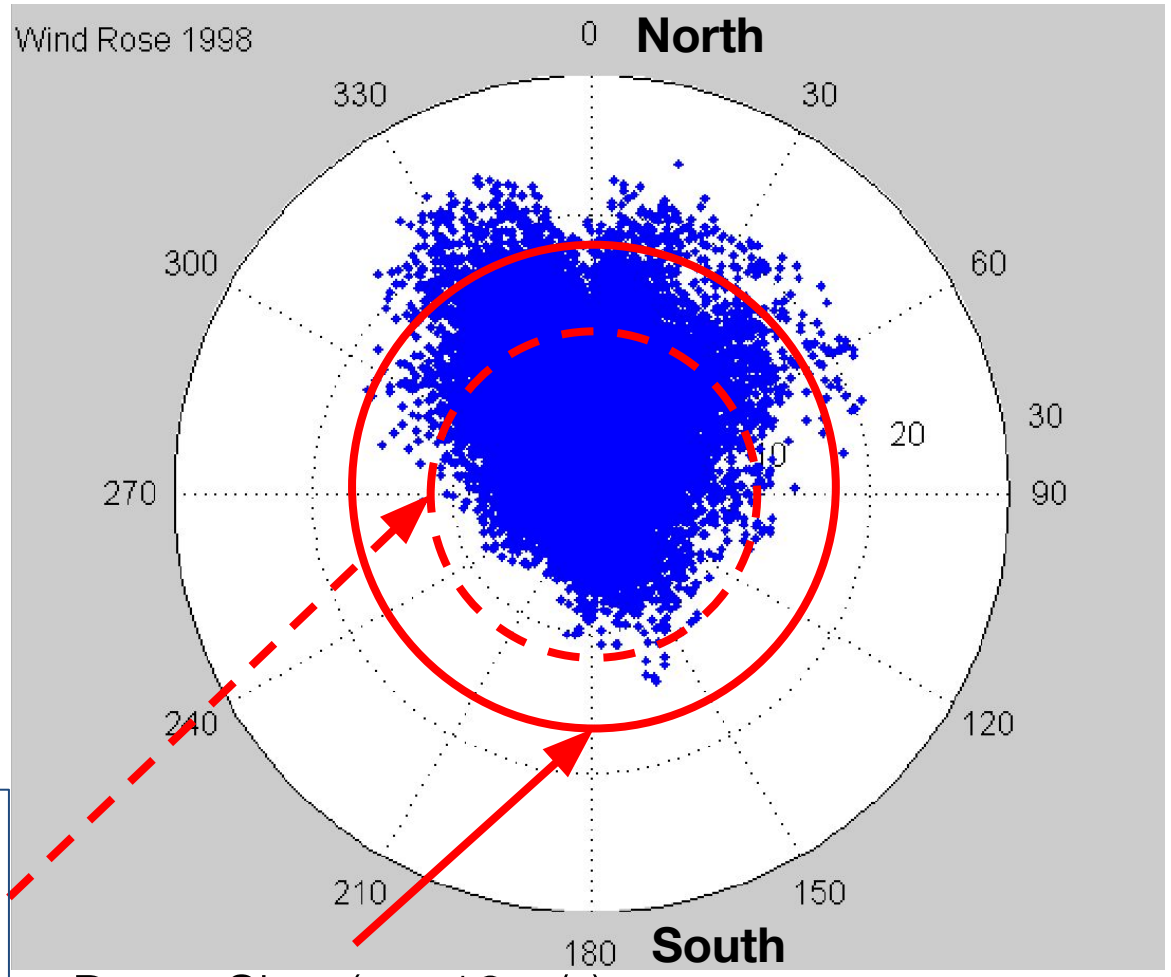
- Exposure time increases with airmass to get same S/N
- Extended sources somewhat less affected

Prevailing northern winds suggests Dec ≤ 5°

2. Northern winds

Prevailing strong northern winds results in northern regions (dec>-24.6) harder to schedule.

Together with worsening observing efficiency at higher airmasses, regions north of dec=5° are not recommended.



Telescope can't point towards wind direction (v >12m/s)

Dome Shut (v >18m/s)

Prevailing northern winds suggests Dec ≤ 5°

2. Northern winds

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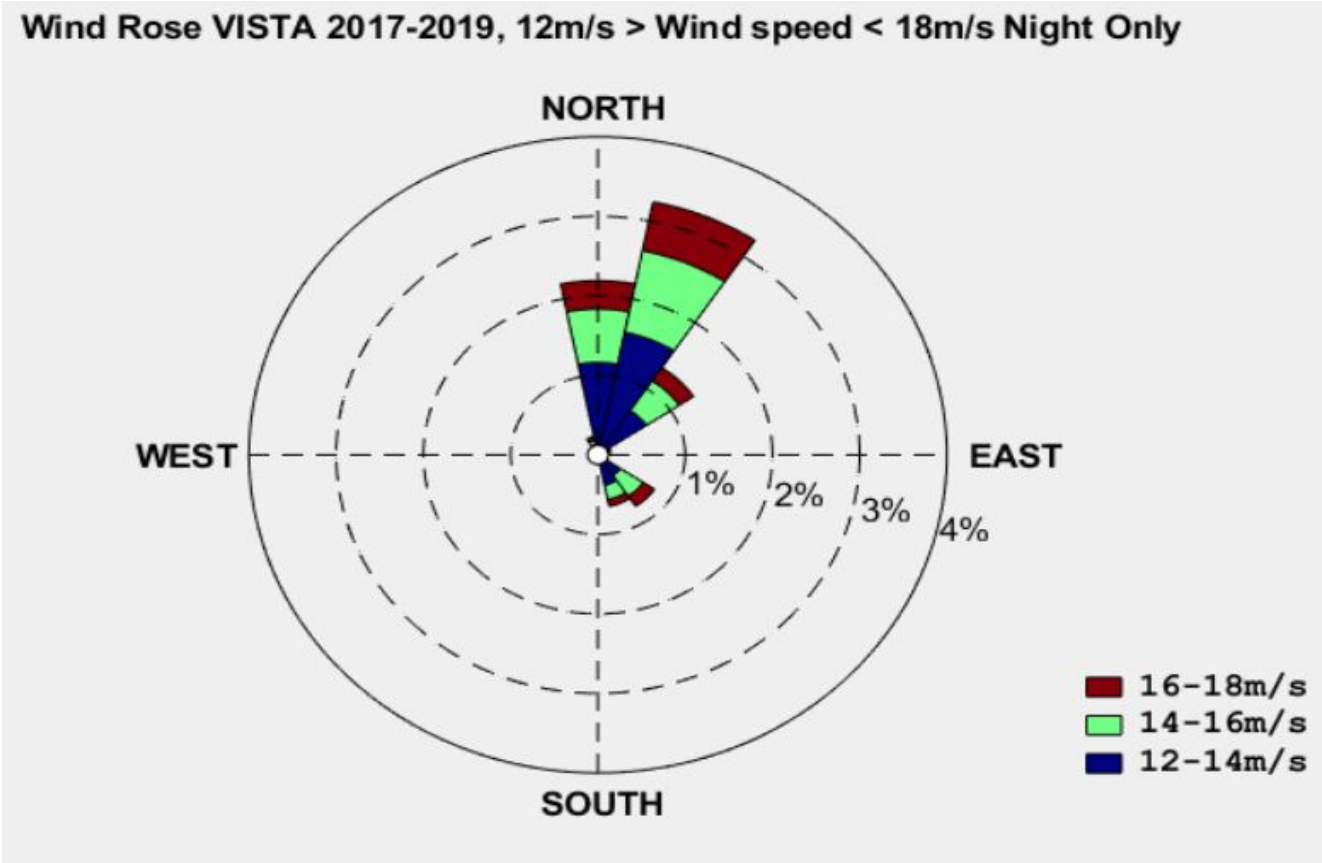
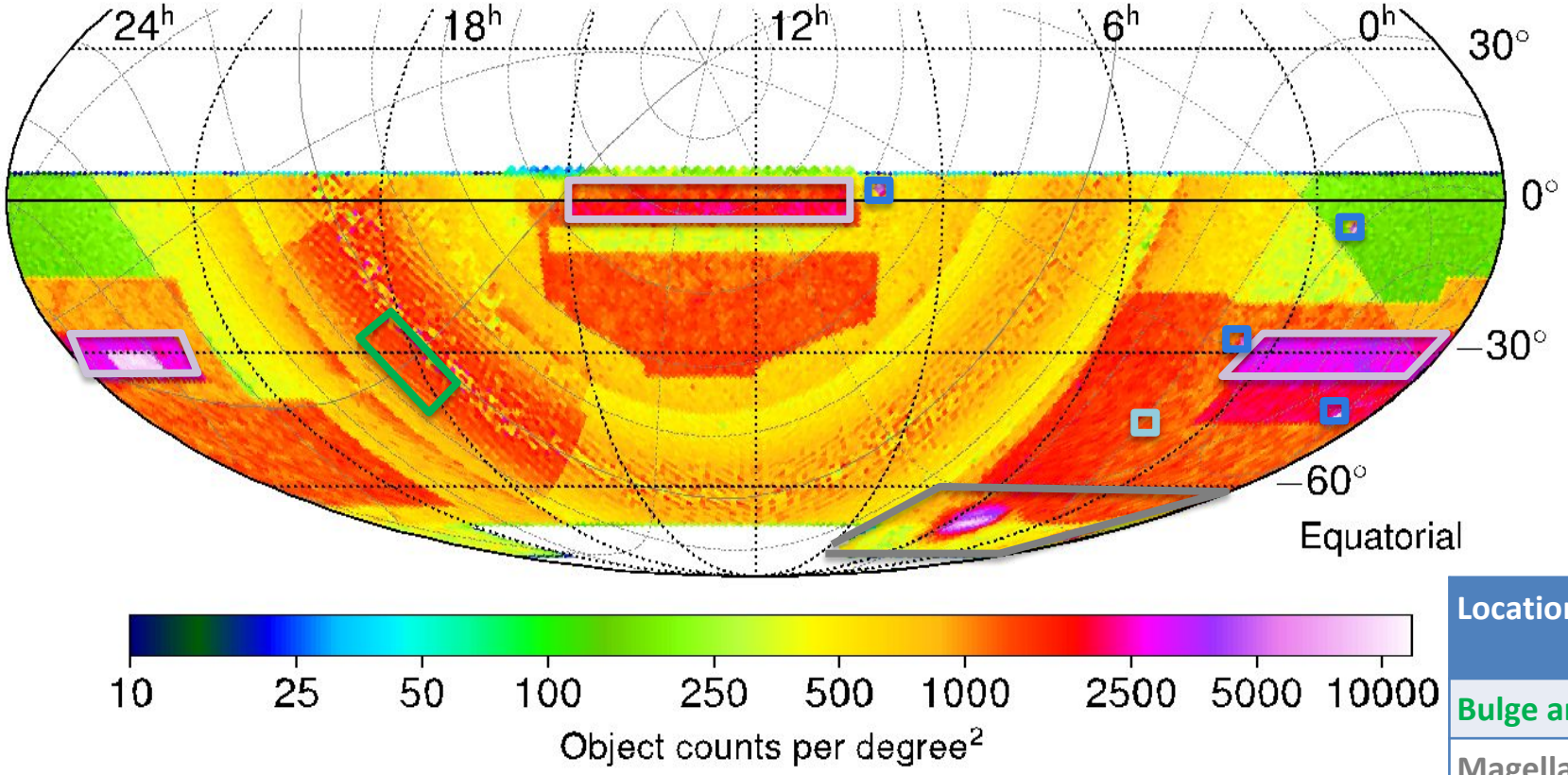


Three reasons to recommend -70° ≤ Dec ≤ 5°:

1. Observing efficiency
2. Northern winds
3. Other facilities in the North
   - WEAVE
   - DESI
   - PFS
   - (but need to coordinate overlap)

- Preference:
  - stay within -70° ≤ Dec ≤ 5° or even narrower
  - Add time/targets Dec < -24.6°

Special areas in use by consortium surveys



- Preference: use special areas if you
  - want to go very faint or high S/N
  - want repeats to study objects with a certain cadence for variability

Location	Area (deg²)	Average t_{exp} (hours)
Bulge and Inner Galaxy	500	4–6
Magellanic Clouds	200–300	2–10
WAVES-Wide	1300	3–4
WAVES-Deep	50	7
LSST Deep Drilling Fields	4x 4.2	4x 60
South Ecliptic Pole area	300	4

Cadence, variables, transients

- *4MOST does not allow for timed observations!*
  - The survey nature clashes with individual target needs
- Limited set of deep/repeat fields that will be observed with a certain cadence (~once every 2 weeks)
- Some areas may be re-observed on purpose with a minimum amount of time in between (~12 months) to check for variability (e.g., radial velocity binaries)
- Contiguous areas will be completed as quickly as possible to measure large scale spatial structures
- 4MOST may adapt some of the cadence strategy to mimic/follow LSST (e.g., rolling Dec cadence)
- A small fraction of transients may be added on ~weekly time scale to be observed in the coming weeks
  - This will not drive the pointing of the telescope significantly; transients will be observed wherever observations are scheduled

Supplementary target programme
Poor observing condition programme

- Consortium Surveys designed to have an over-abundance of targets from Surveys not requiring high local spatial completeness
- Empty fibres expected still after all targets from main Surveys have been allocated
- Need for a “Supplementary Targets Programme” with following properties:
  - No requirements on any completeness (spatial, magnitude, redshift)
  - No requirements on total and/or fraction of completed targets
- Not to be used statistically, but may be ideal for serendipitous rare object discovery
- All participating surveys will be requested, after proposal selection, to provide input targets for this “Supplementary Target Programme”.
- Poor observing condition programme: quick (~2 min exposures) survey of most bright stars, e.g. $5 < G < \sim 11.5$ mag (HRS) & $11 < G < \sim 13$ mag (LRS), within 4MOST footprint.
- Opportunities of science cross calibrations with other instruments/surveys

Summary of Survey Strategy (I)

- Survey strategy of 4MOST will consists in combining the requests of:
  - 10 consortium surveys with a total of ~40 sub-surveys
  - A large number of participating surveys and sub-surveys (at most 17 surveys)

  => Not an easy task :) , but...

- 4MOST has:
  - 4FS WI: survey input ingestion portal with ETC (Genoveva, Thi and Laas' talks)
  - 4FS OpSim: a comprehensive survey simulation pipeline (Tempel's talk)
  - 4FS Output: a pipeline of survey progress monitoring

  => So it is possible, while still not easily done :)

Summary of Survey Strategy (II)

- Key messages for survey strategy to work:

  – *Vital that input catalogues and spectral requests are reasonable*:
  => *SoS Fibre Hour (SoS FH) estimate is a lower limit of actual needs* (ignores most complications only possible to estimate through full simulation work).
  => Do not expect to use less Fibre Hours than estimated by SoS.

  – *Nearly all survey cross talk with each other* to some more or large extent:
  => understanding how other surveys target similar areas can be extremely helpful and informative for every survey
  => *issues with one survey can impact all surveys*, as 4MOST tiling depends on all survey inputs and requests.

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