Maximizing detection probabilities in targeted transient surveys

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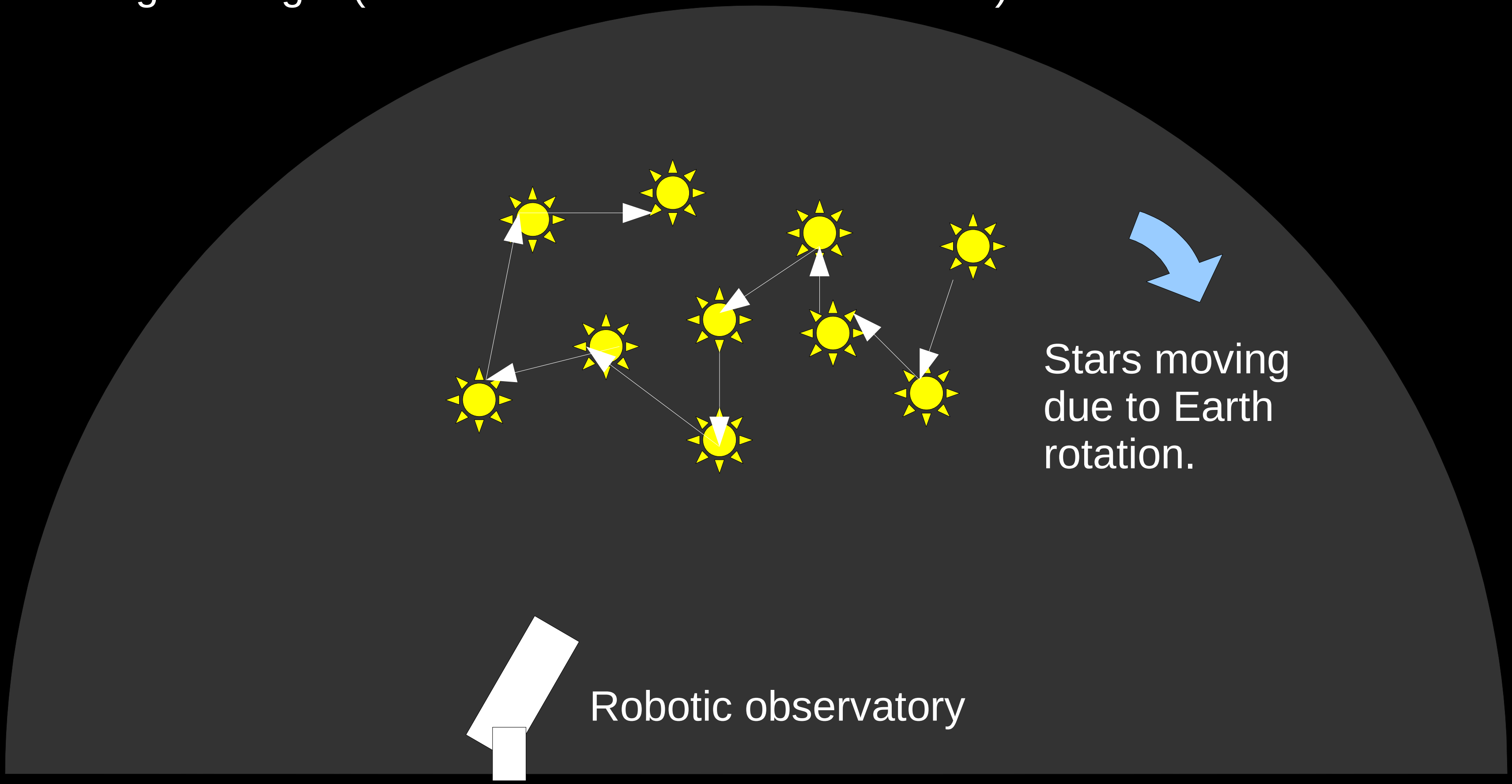
Problem

To find the optimal schedule, or sequence of observations, that maximizes the scientific output for an arbitrary scientific goal.

E.g.

- The sequence of observations that surveys the most stars near the zenith in a given night (see Petr Kubánek's master thesis).



What is (are) our scientific goal(s)?

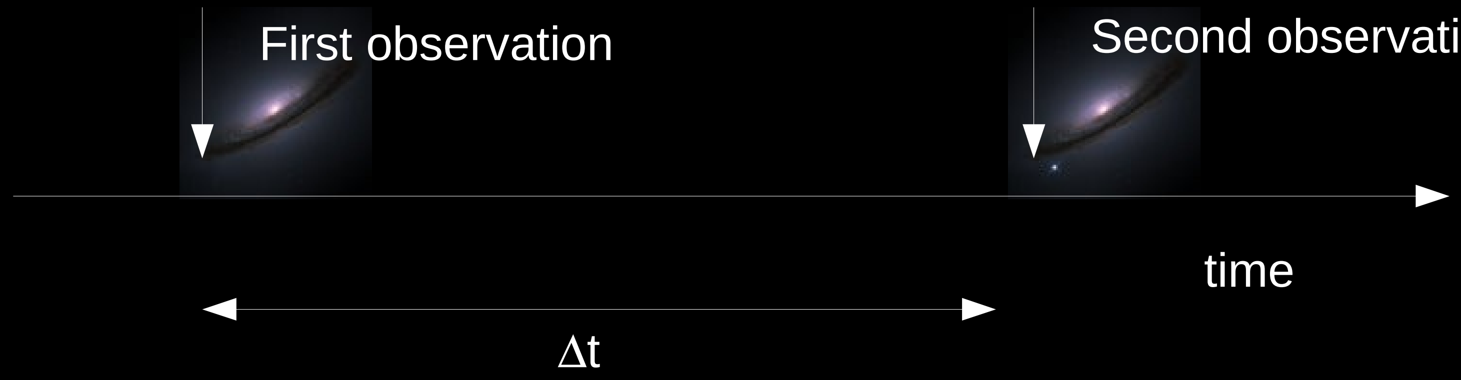
- We would like to find many nearby supernovae.

- We want young events, which give information on supernova progenitors

- We would like to find interesting events, new types of supernova.

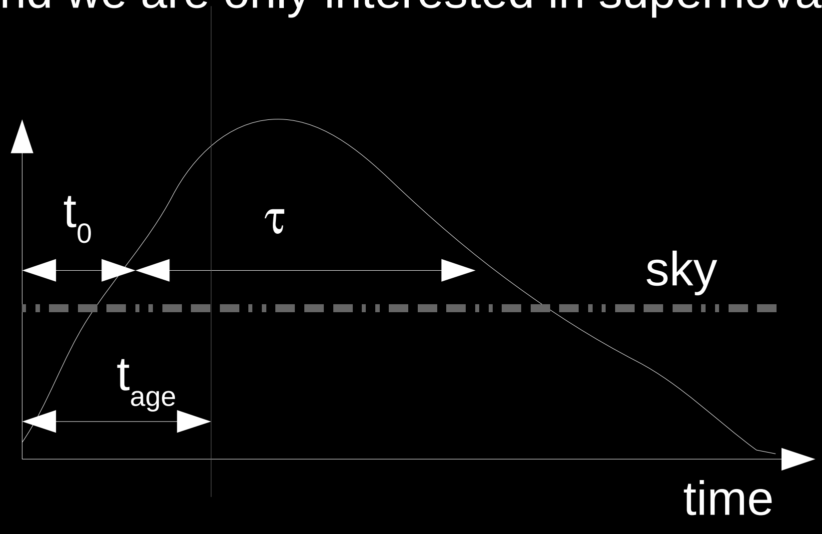
Detection probabilities

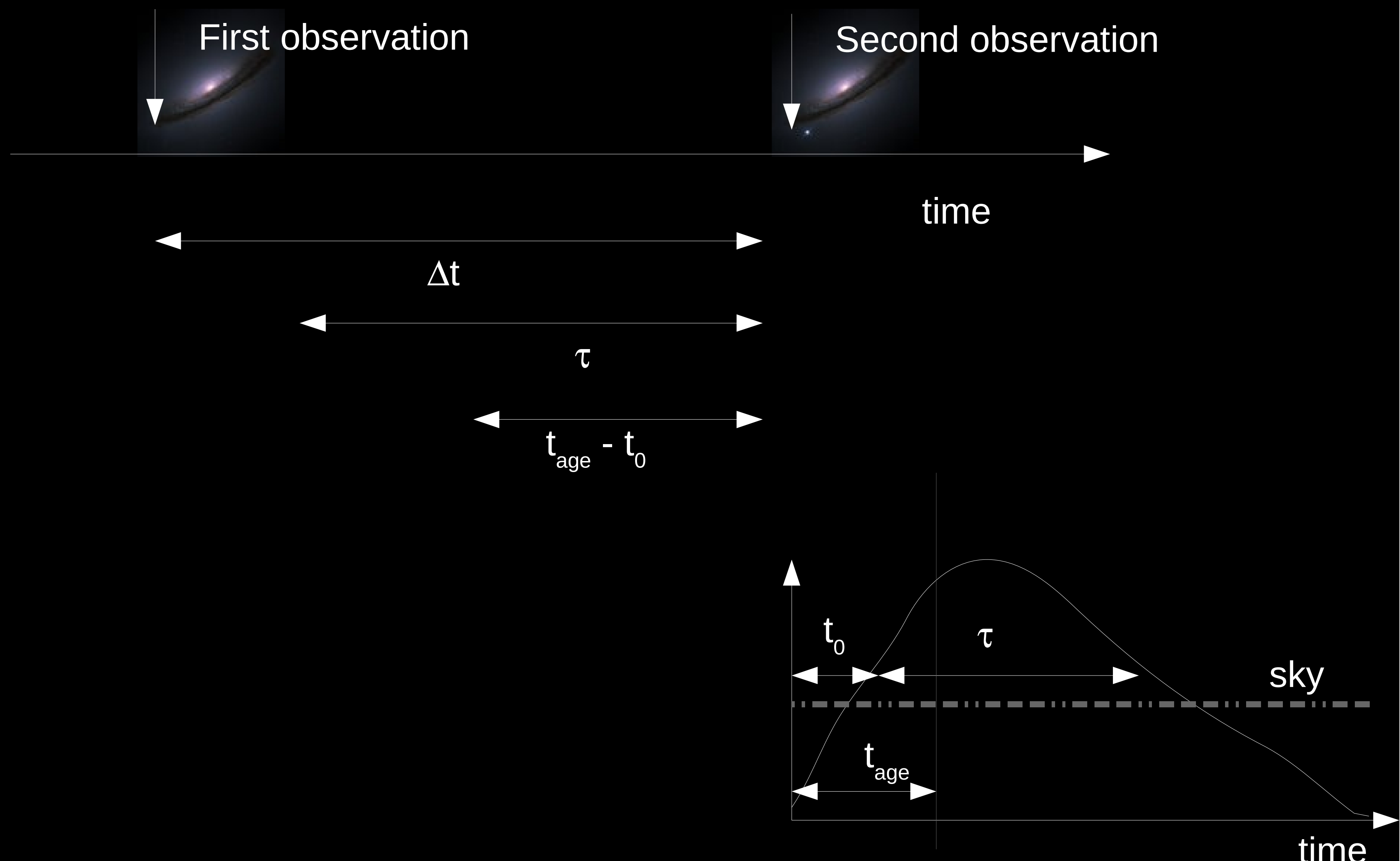
- We repeat observations for difference imaging with a cadence Δt.

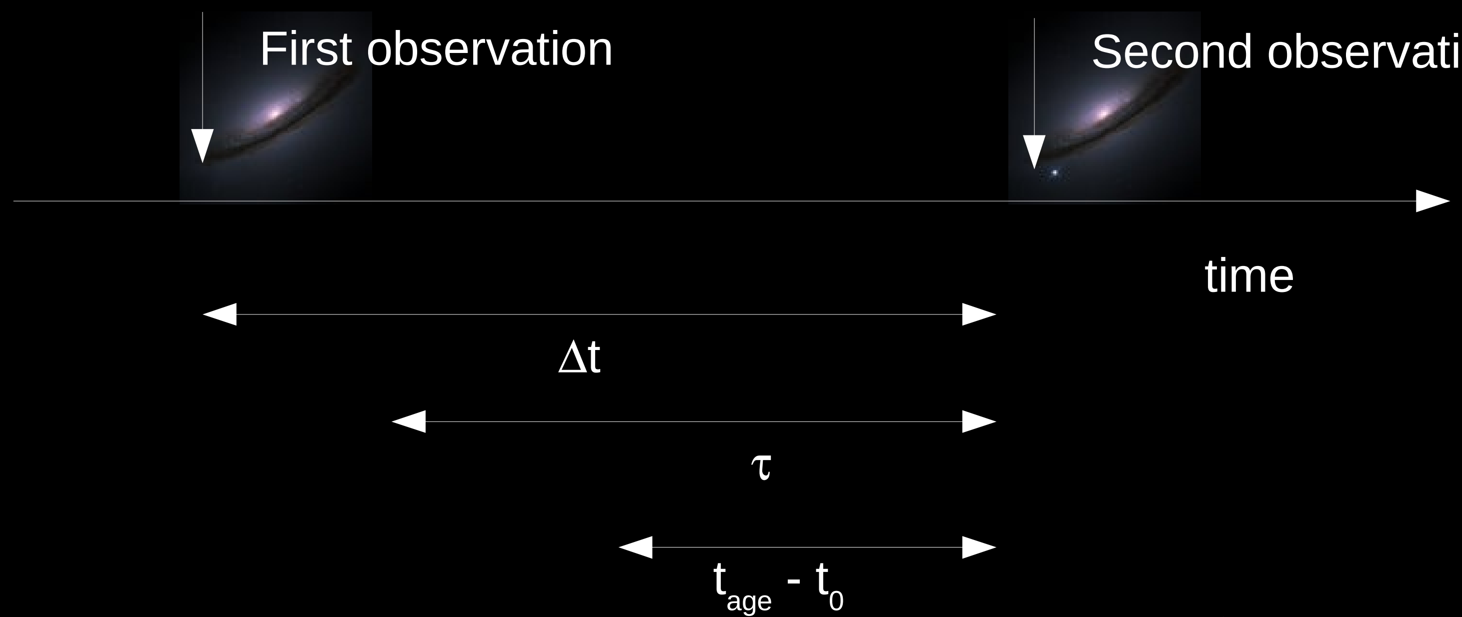


- The rate of supernovae explosions in the target is R

- A supernova would take t_0 days to become visible at the distance of the target, it would remain visible for τ days, and we are only interested in supernova younger than t_{age} days.

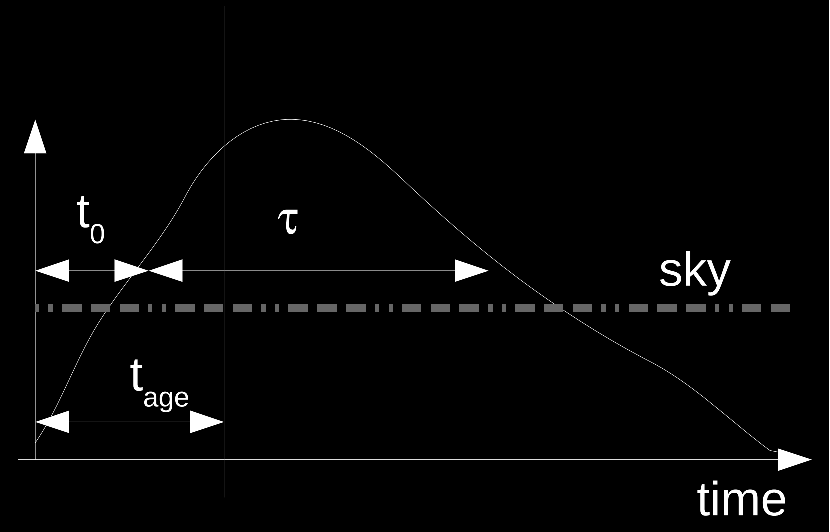



First observation
Second observation
time
Δt
τ
$t_{age} - t_0$
t_0
τ
sky
t_{age}
time



The number of supernova not seen in the first observation and detected in the second observation younger than t_{age} would be:

$$n = R \times \max[0, \min(t_{age} - t_0, \tau, \Delta t)]$$



Expected number of supernova

$$n = R \times \max[0, \min(t_{age} - t_0, \tau, \Delta t)]$$

The probability of not detecting any supernova would be exp(-n).

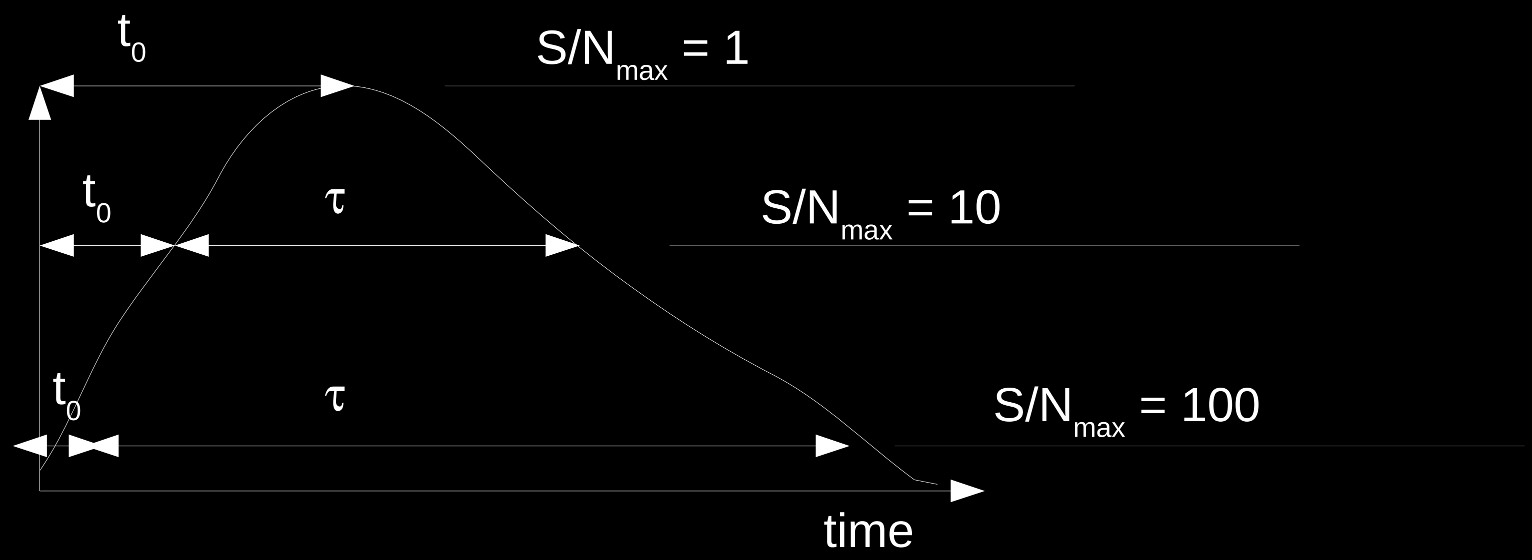
The probability of detecting supernovae in a given night would be:

$$P^{\rm age}_{\rm D,\ Total} = 1 - \exp\left[-\Sigma_i\ R^i\ \min\{\Delta t^i,\ \max(\tau^i_{\rm age} - t^i_0,\ 0),\ \tau^i\} \right].$$

Thus, if we can compute t_0 and τ for every target, we have a way of measuring the fitness of every schedule.

We use modified version of RTS2 (Kubanek et al 2003), which uses a multi-objective non-dominated sorting genetic algorithm (NSGAII, Deb et al. 2002) to find the optimal schedule or the Pareto front of optimal schedules.

Calculation of t_0 and τ



We compute them as a function of the signal to noise at maximum light, which is computed for a given supernova, at a given position in the sky and at a given distance

Calculation of the signal to noise at maximum

$S/N = \gamma_{SN} / (\gamma_{sky} + \gamma_{RN}{}^2)^{1/2} \sim \gamma_{SN} / (\gamma_{sky})^{1/2}$

$\gamma_{SN} \;\alpha\; D^{-2}\, T$

$\gamma_{sky} \;\alpha\; \sin h^{-1}\, T$

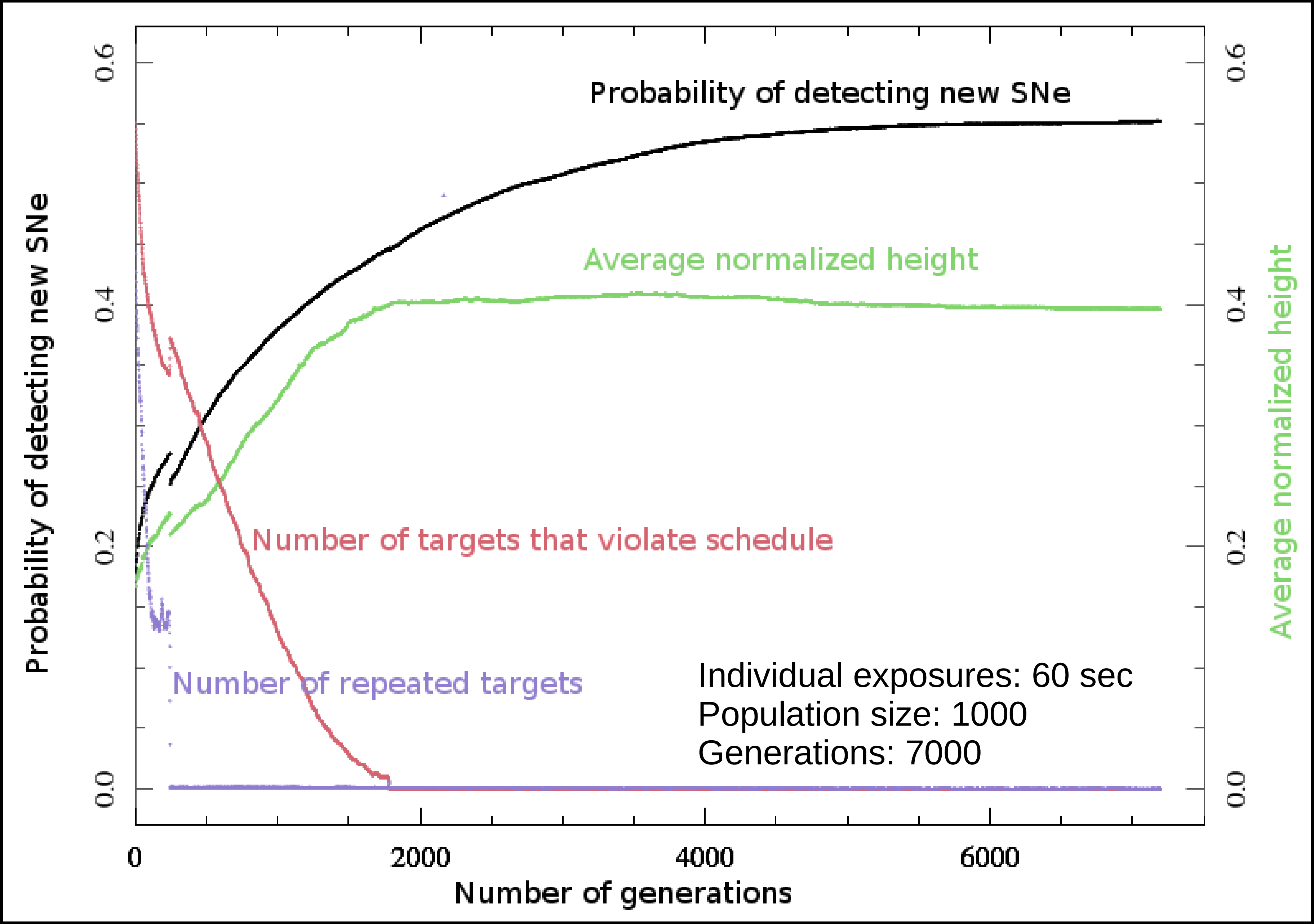
➡

$S/N \;\alpha\; D^{-2} \; (\sin h \;\; T)^{½}$

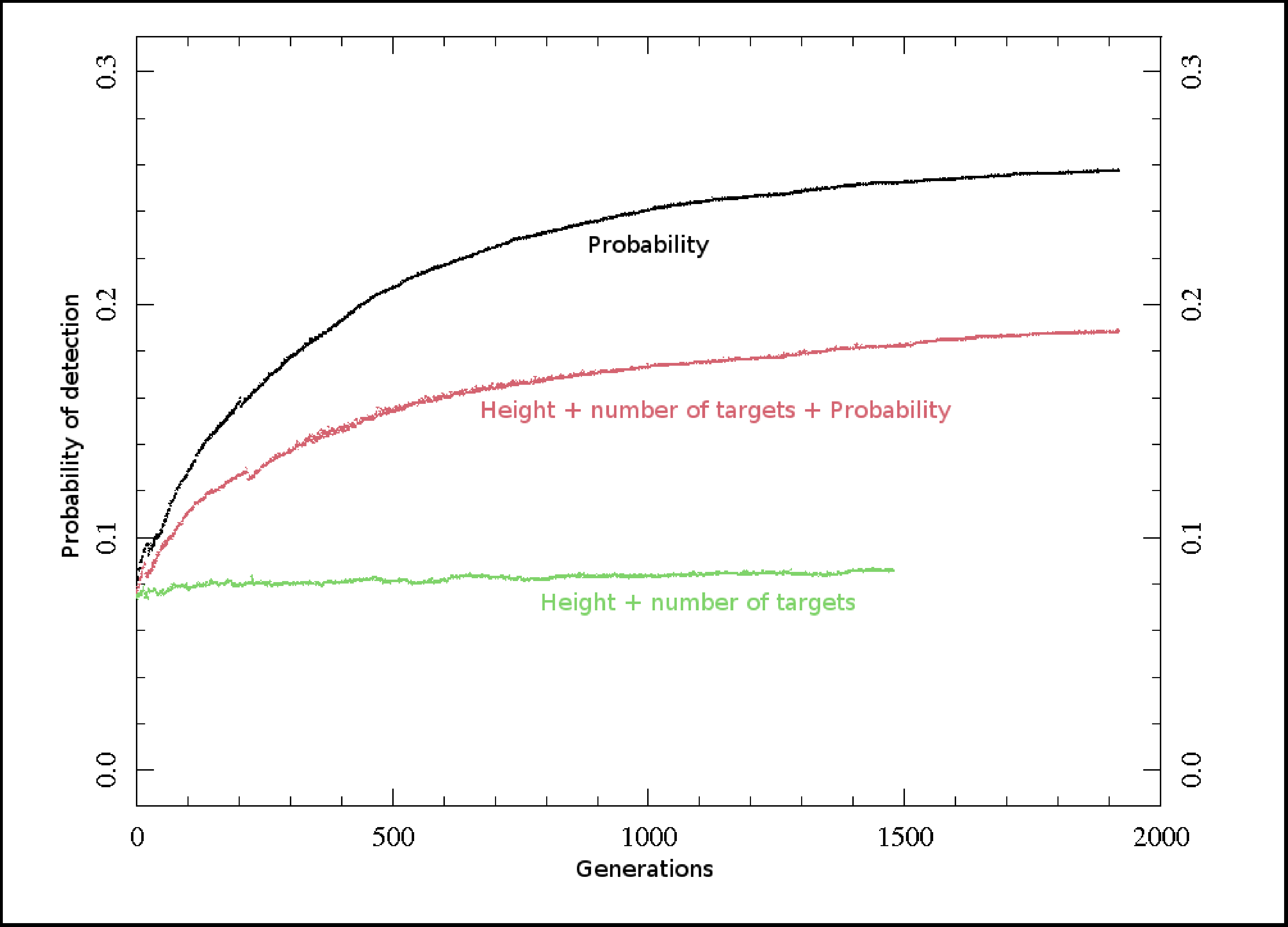
$S/N_{max} = S/N_{max}(D_0, h_0, T_0) * (D/D_0)^{-2} \; (\sin h / \sin h_0)^{½} \; (T / T_0)^{½}$

S/N : signal to noise, γ_{sky}: photons from the supernova, γ_{sky}: photons from the sky, D: distance, T: exposure time, γ_{RN}: readout noise

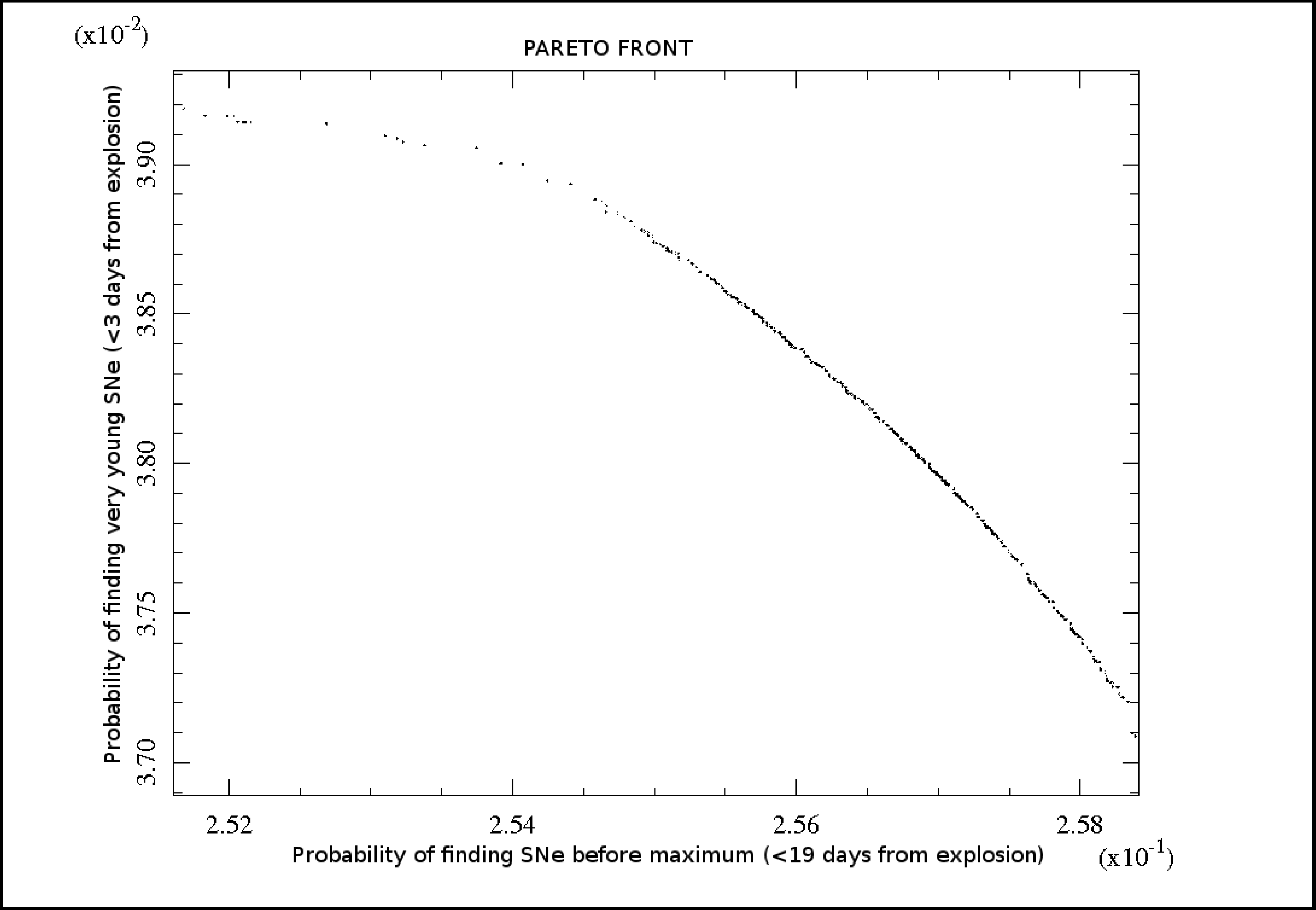
Example: probability of detecting SNe before maximum



Comparison of probabilities using different objectives



Multiple objectives Pareto front
(SNe younger than 3 or 19 days after explosion)



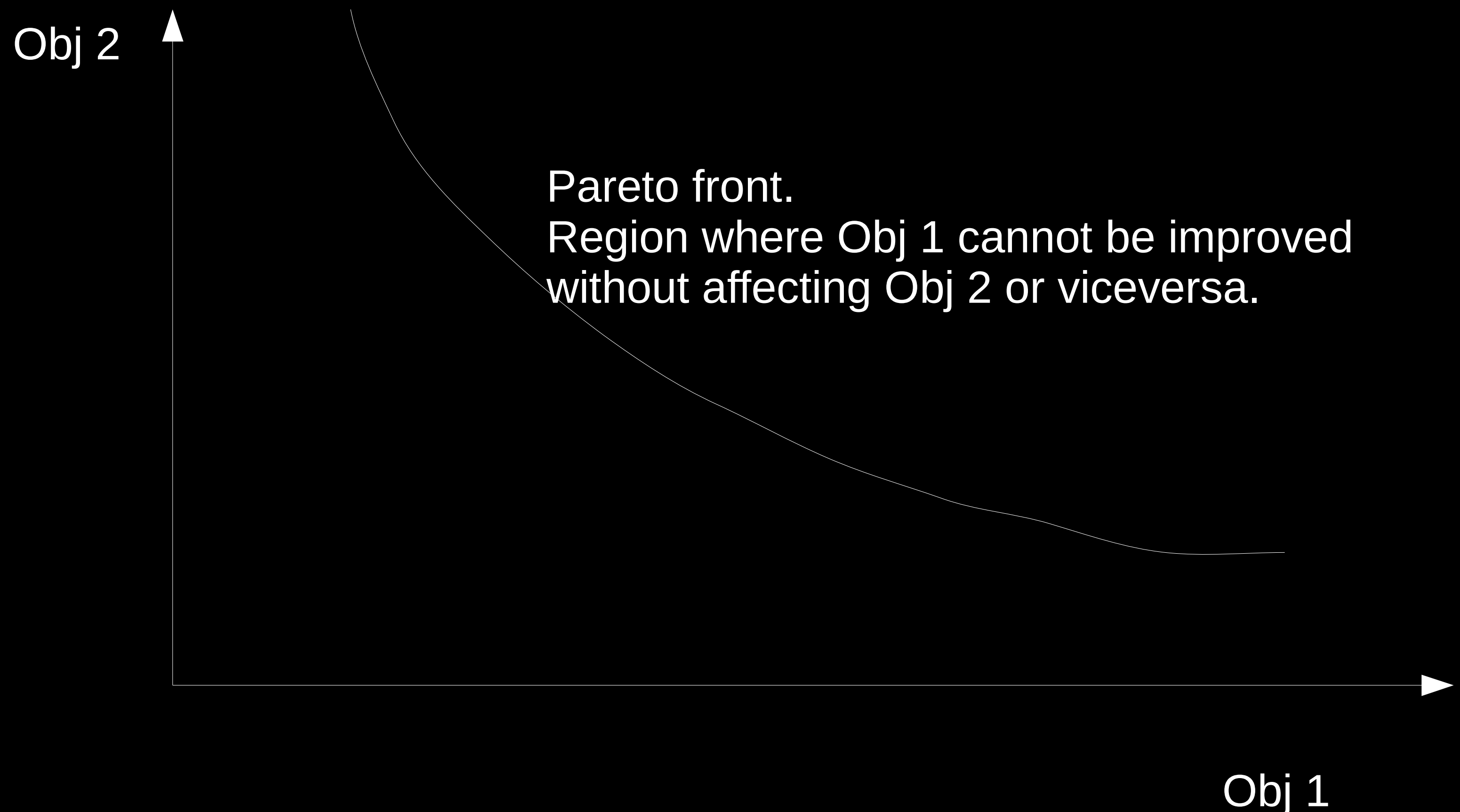
Conclusions

- Scheduling for specific transient events can increase finding rates significantly
- RTS2 showed to be a good tool for testing scheduling strategies
- Detailed description of individual targets important component of scheduler
- Rate analysis difficult, but any targeted survey has the same problem.

Things to do:

- Real time scheduler for unexpected plan changes
- Fast scheduler for longer time-scales to avoid short-sightedness
- Any ideas welcomed!

Pareto front



e.g.

Obj 1: Number of Supernova before maximum

Obj 2: Number of Supernova younger than two days after explosion

Some numbers

- There are typically one supernova every 100 years in every galaxy

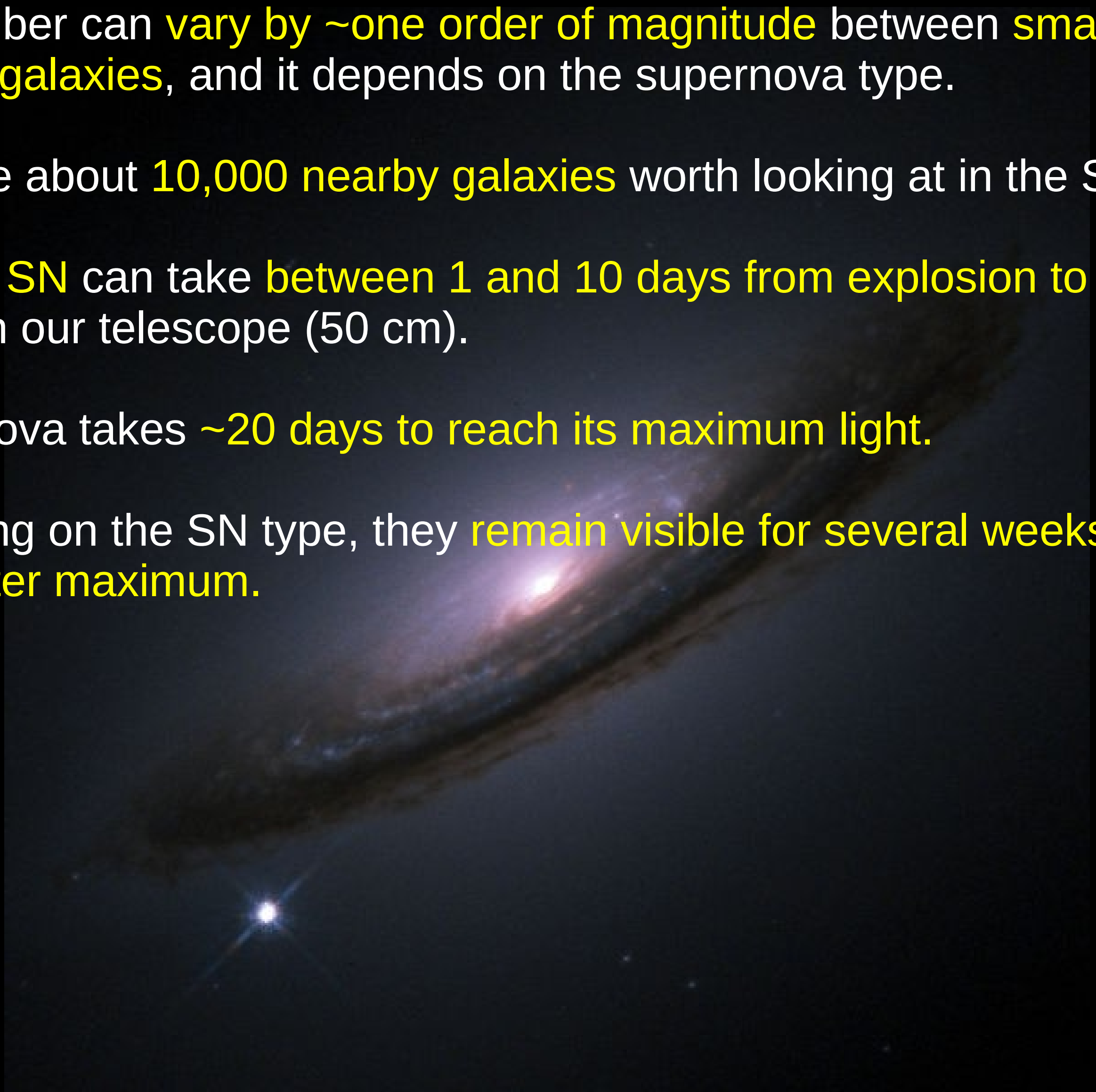
- This number can vary by ~one order of magnitude between small/big, or young/old galaxies, and it depends on the supernova type.

- There are about 10,000 nearby galaxies worth looking at in the Southern sky.

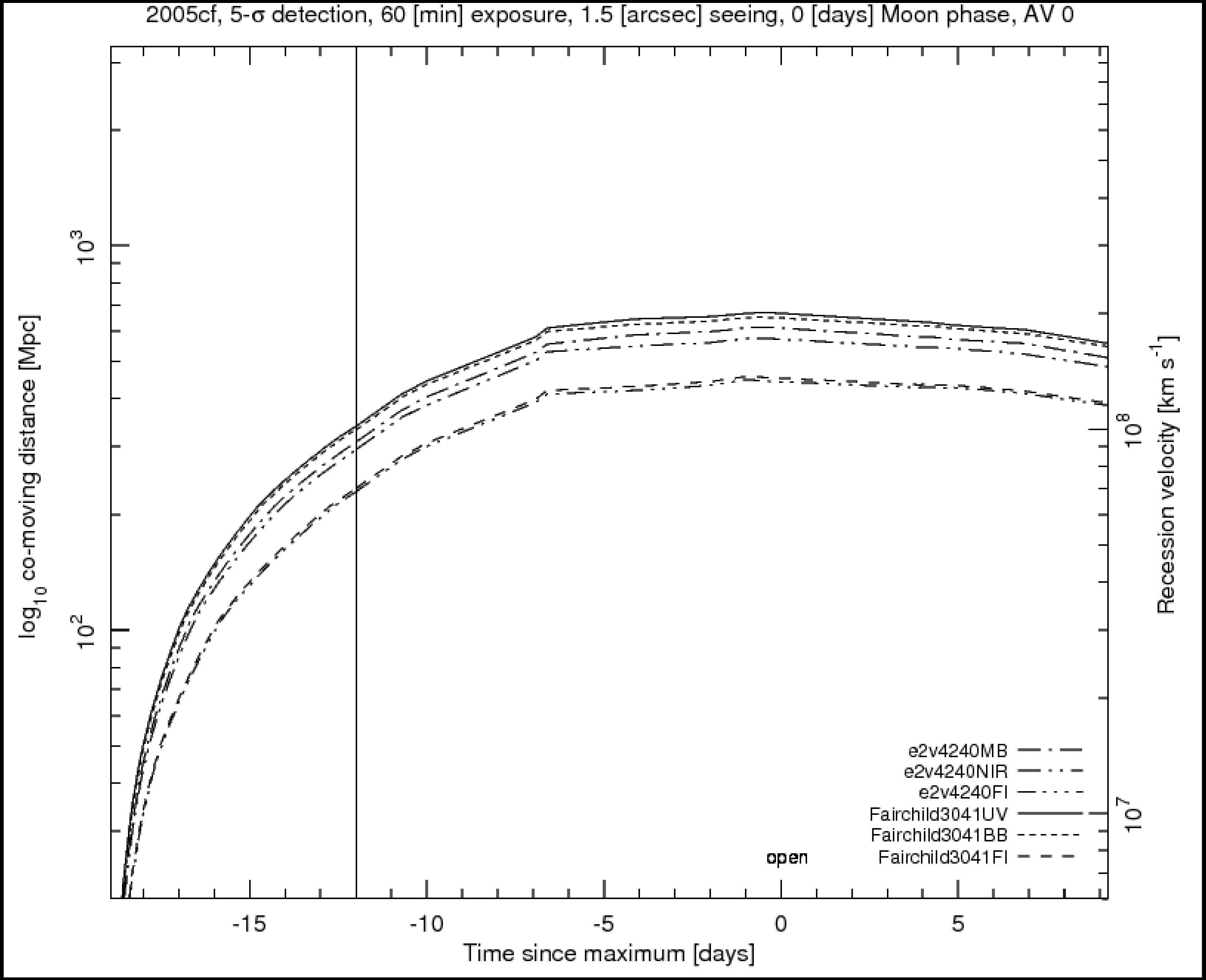
- A nearby SN can take between 1 and 10 days from explosion to become visible with our telescope (50 cm).

- A supernova takes ~20 days to reach its maximum light.

- Depending on the SN type, they remain visible for several weeks or even months after maximum.



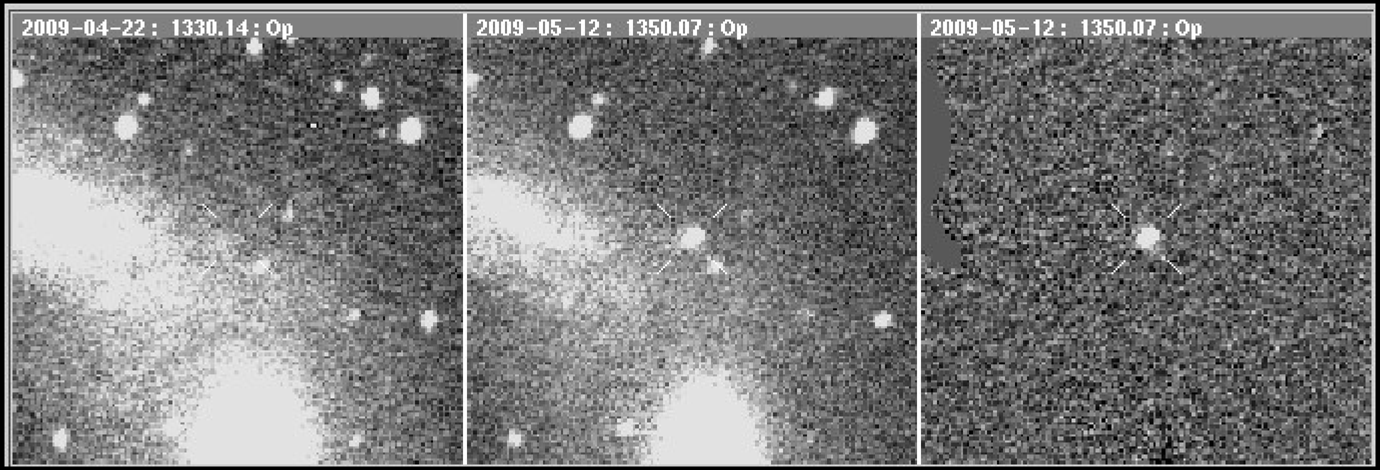
Supernova Ia early phase detection distances



Expected number of supernova

- The time between two observations for difference imaging is known as the cadence of the survey

- In a targeted survey, the cadence varies between targets because of the scheduling, changes in atmospheric conditions and other problems



Example of a good candidate from CHASE