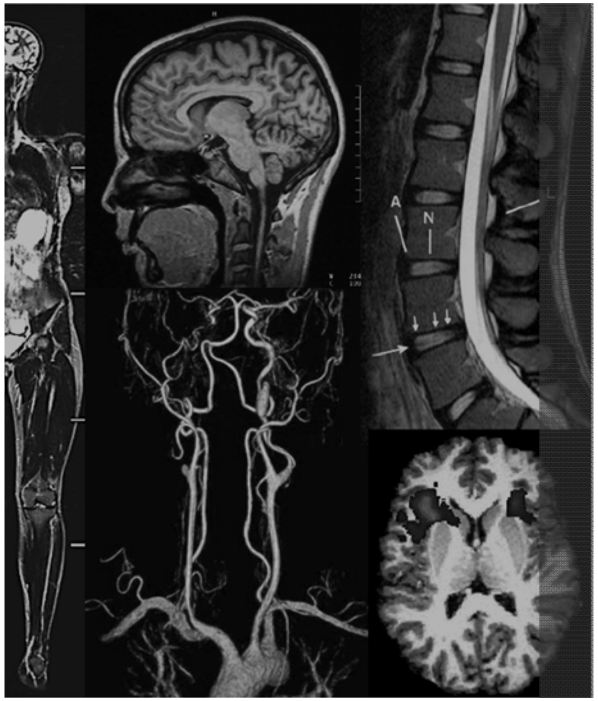

快速脈衝程序I
A Course of MRI

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本週課程內容

- Fast spin echo, FSE
- Gradient-recalled echo, GRE

Fast Spin Echo

FSE

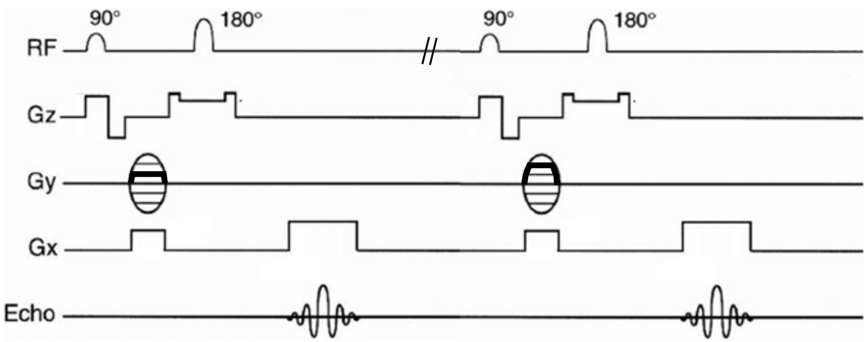
Fast Spin Echo, FSE

- **RARE**: raped acquisition with relaxation enhancement
- **FSE**: fast spin echo (for GE, Hitachi, Toshiba)
- **TSE**: turbo spin echo (for Siemens, Philips)

- **SSFSE**: single shot fast spin echo (ETL = phase encoding number)
- **HASTE**: half-Fourier acquisition single-shot turbo spin-echo

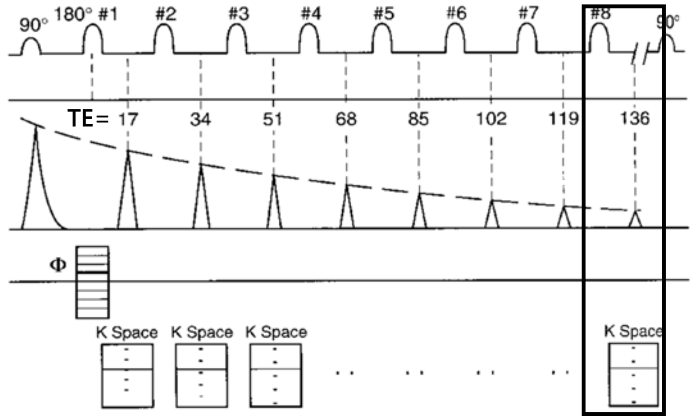
Conventional Spin Echo, CSE or SE

- Scan time = (TR)(number of phase encodes)(NEX)



Multiple Echo CSE

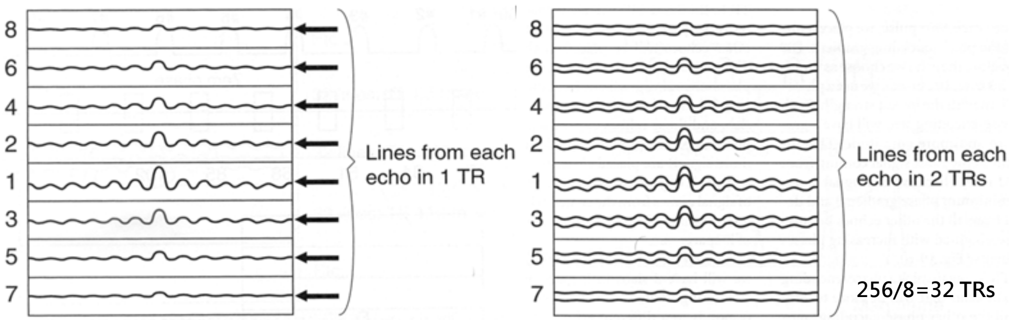
- Only a single phase encoding step in each TR.



Each echo has its own k-space with different T2 contrasts.

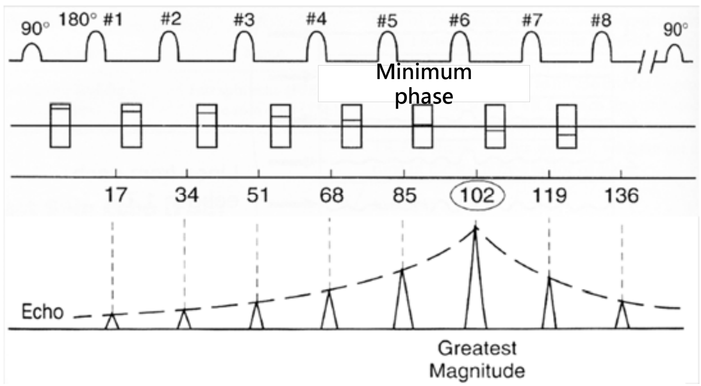
Fast Spin Echo, FSE

- Echo train length (ETL): the number of echoes used in FSE.
- With ETL = 8, we can fill one k-space eight lines in a TR.
- Before each 180° pulse, we place a different value of the phase-encoding gradient.



Fast Spin Echo, FSE

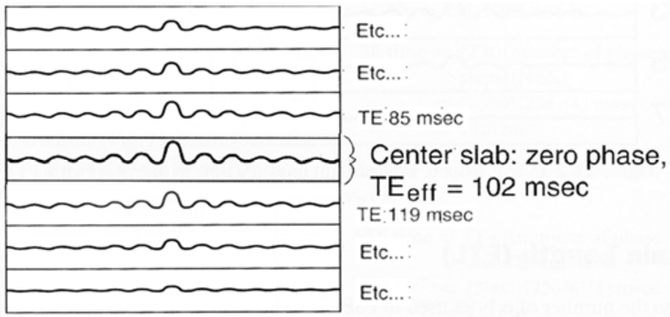
- Echo spacing (ESP): the time interval between successive echoes (or between 180° pulses).
- Effective TE (TE_{eff}): the minimum phase gradient and the maximum signal.



TE_{eff}=102 ms

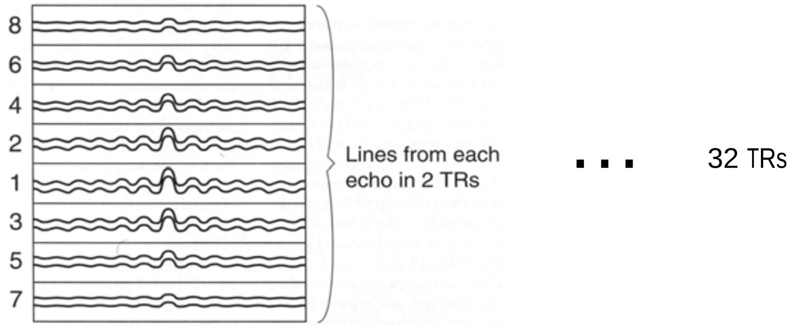
Filling K space by FSE

- Recall that the center of k space has maximum signal, and there are weaker signals near edges.
- We always put signals with the minimum phase gradient in the center slab.



Filling K space by FSE

- With ETL = 8, we divide the rows of k space into 8 slabs.
- Considering a 256-row k space, each slab contains 32 lines, from 32 shots (TRs)



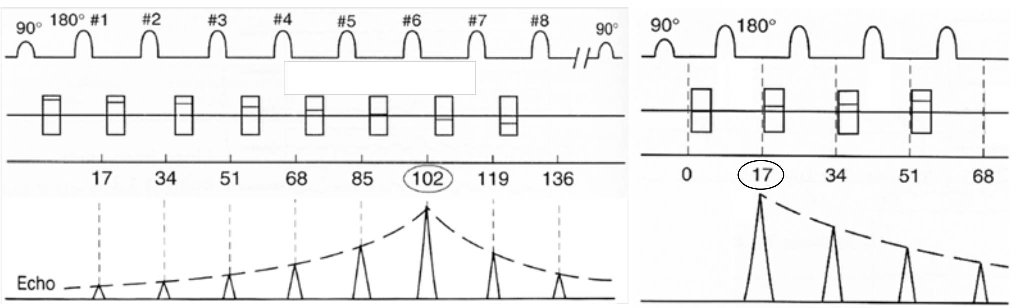
K space from FSE

- We put signals from different TEs in the same k space.
- The image contrast mainly comes from the center of the k space, namely the echoes at TE_{eff}.
- In this way, we put most of the weight on the echo corresponding to TE_{eff} and less weight on the other echoes.

T1 and T2 weighted in FSE

Long ETL/ long TR/ long TE_{eff}
T2-weighted image

Short ETL/ short TR/ short TE_{eff}
T1-weighted image



Shorter ETL ➔ fewer lines can be filled in one TR.

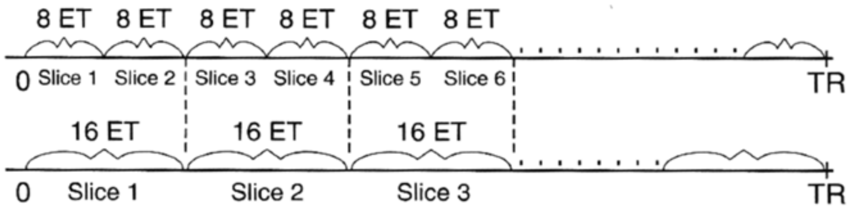
Scan time

- CSE: $\boldsymbol{Scan\ time} = (\boldsymbol{TR})(\boldsymbol{Ny})(\boldsymbol{NEX})$
- FSE: $\boldsymbol{Scan\ time} = \frac{(\boldsymbol{TR})(\boldsymbol{Ny})(\boldsymbol{NEX})}{\boldsymbol{ETL}}$

- A T2W study, TR = 3000 ms, Ny = 256, NEX = 1, ETL = 8
  - Scan time (CSE) = 3s x 256 x 1 = 768 s = 12.8 min
  - Scan time (FSE) = $\frac{3s \times 256 \times 1}{8}$ = 96 s = 1.6 min
- A T1W study, TR = 500 ms, Ny = 256, NEX =1, ETL = 4
  - Scan time (CSE) = 0.5s x 256 x 1 = 128 s = 2.1 min
  - Scan time (FSE) = $\frac{0.5s \times 256 \times 1}{4}$ = 32 s

Trade-off of FSE

- Slice coverage
- ETL ↑ → slice coverage ↓ (# slices ↓)

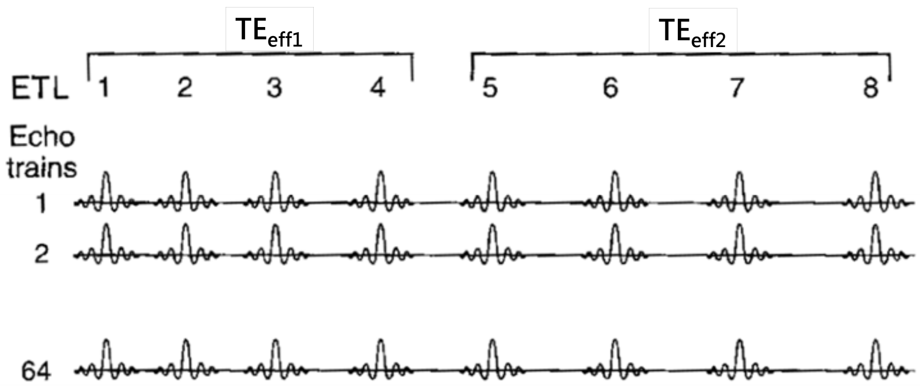


Multi-Echo/ Multi-TE_{eff} FSE

- Full echo train

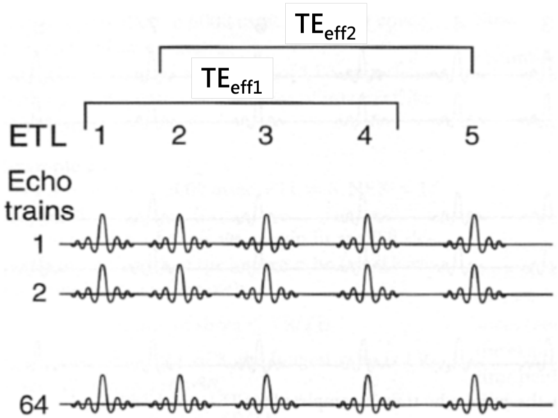
Multi-Echo/ Multi-TE_{eff} FSE

- Split echo train (TE_{eff2} should be long and larger than TE_{eff1})



Multi-Echo/ Multi-TE_{eff} FSE

- Shared echo train: shorter ETL compared with a full or split echo train approach (therefore increase slice coverage).



Keyhole imaging

- K-space is covered completely on the first image, but only the central portion (e.g. 20%) of k-space is covered on subsequent images.
- This approach has a disadvantage in that the high spatial frequency outer portion (e.g. 80%) of k-space is shared information.
- It has the advantage of speeding up the subsequent imaging by a factor of 5 (100%/20%=5).
- Fast repetitive imaging of the same slice, e.g., perfusion imaging.

Advantages of FSE

- Fast scanning
- Increased speed allows for high-resolution imaging in a reasonable amount of time.
- Less motion artifact
  - Even-echo rephasing effect: the 180^{o} pulses are evenly spaced.
- Less distortion in metallic objects
- More tolerant of a poorly shimmed magnet

Disadvantages of FSE

- Reduced slice coverage
- Contrast averaging (k-space averaging)
  - CSF is brighter on PDW FSE image (T2 effects from long TE echoes).
- Normal intervertebral discs are not as bright on T2W FSE images compared with CSE.
  - Reduced contrast between desiccated and normal discs
- Magnetic susceptibility effects will be less than with CSE.
  - Less sensitve to detect hemorrhage
- Fat is bright on T2-weighted FSE images.

Gradient-Recalled Echo

GRE

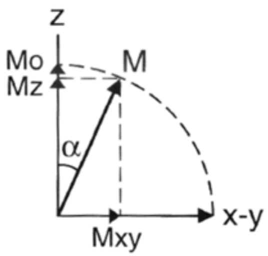
Gradient-Recalled Echo, GRE

- Partial (small) flip angle technique
- Short TR ➔ fast scanning
- Three-dimensional imaging

- Scan time (GRE) = (TR)(Ny)(NEX)(# of slice)
  - When TR of GRE is too short to perform multi-slice imaging.
  - One slice in one TR

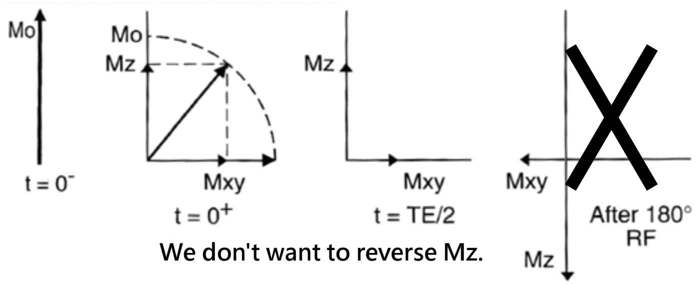
TR in GRE

- The longitudinal magnetization M_z needs sufficient TR to recover to a reasonable value.
- The 90° RF pulse used in SE ➔ long TR is needed to recover M_z.
- A RF pulse yielding a smaller flip angle α ➔ short TR is sufficient to recover M_z.



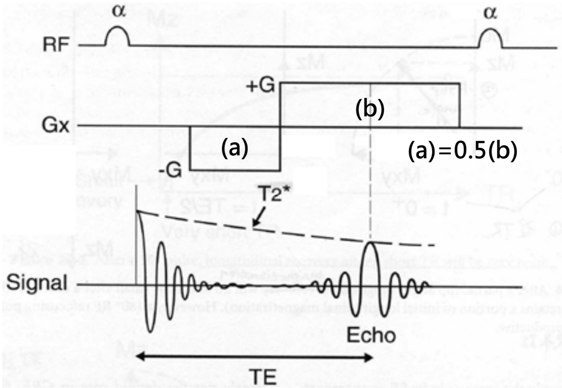
Rephasing in GRE

- A 180° refocusing RF pulse is not used in GRE.



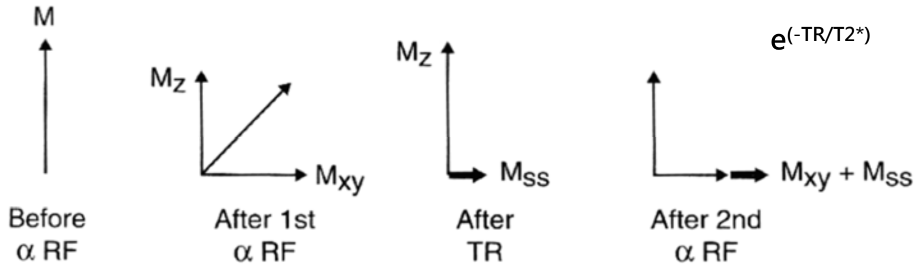
Rephasing in GRE

- Refocusing gradient in the x direction
- The rate of decay between echoes is given by T2* (instead of T2).



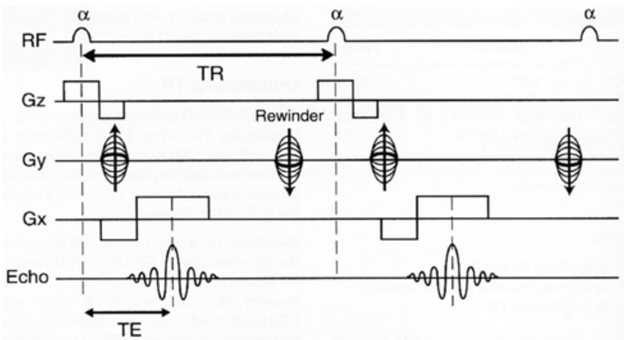
Steady state magnetization, M_{ss}

- GRE may have residual transverse magnetization M_{xy} due to short TR (M_{xy} is not complete dephasing).
- After a few cycles, the residual transverse magnetization reaches a steady state, referred to as M_{ss}.



Rewinder gradient

- A rewinder gradient is applied in the G_y at the end of the cycle to unwind the effects of the phase encodes (hence preserve M_{ss}).
- **GRASS**: gradient-recalled acquisition in the steady-state (GE)
- **FISP**: fast imaging with steady-state precession (Siemens)



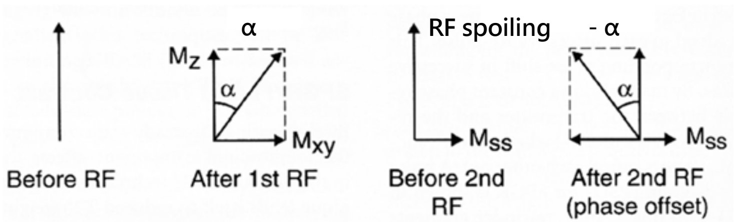
More T2* weighting

Tissue Contrast of GRE with M_{ss}

- Flip angle α
  - Flip angle ↓ ➔T1 weighting ↓, proton-density weighting ↑
  - Flip angle ↑ ➔T1 weighting ↑,T2* weighting ↑ (larger M_{ss})
- TR (with a small α)
  - TR ↓ (TR<3T2*)➔ T2* weighting ↑ (larger M_{ss}), T1 weighting ↓
  - TR ↑ (in several hundred milliseconds)➔ T1 weighting ↑,T2* weighting ↓
- TE
  - TE ↓ ➔ T2* weighting ↓, proton-density or T1 weighting ↑
  - TE ↑ ➔ T2* weighting ↑

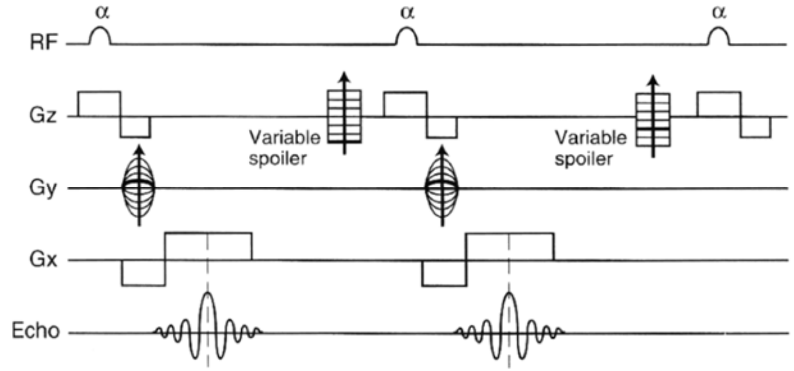
Spoiling of M_{ss}

- RF spoiling (phase offset)
- Gradient spoiler
- **SPGR**: spoiled GRASS (GE)
- **FLASH**: fast low-angle shot (Siemens)



Gradient spoiler

- Introduce an additional gradient with variable strengths from cycle to cycle.



Tissue Contrast of GRE without M_{ss}

- Flip angle α
  - Flip angle ↓ ➔T1 weighting ↓ , proton-density weighting ↑
  - Flip angle ↑ ➔T1 weighting ↑ ,~~T2* weighting ↑ (larger M_{ss})~~
- TR (with a small α)
  - TR ↓ (TR<3T2*)➔ ~~T2* weighting ↑ (larger M_{ss}),~~ T1 weighting ↓
  - TR ↑ (in several hundred milliseconds)➔ T1 weighting ↑ ,~~T2* weighting ↓~~
- TE (a lager TR and a small α)
  - TE ↓ ➔ T2* weighting ↓ , proton-density weighting ↑
  - TE ↑ ➔ T2* weighting ↑

Magnetic susceptibility effects

- The lack of a 180^o refocusing pulse results in greater dephasing of spins.
- This in turn results in greater sensitivity to magnetic susceptibility effects.
- Increased artifact at the air/tissue interfaces
- Increased detection of subtle hemorrhage

Advantages of GRE

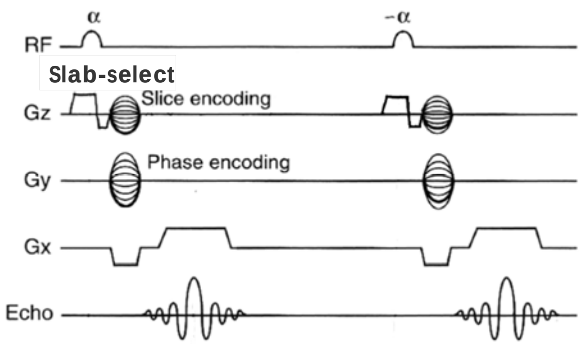
- Increased speed
- Increased sensitivity to magnetic susceptibility effects of hemorrhage
- 3D imaging in a reasonable time
- Imaging of flowing blood

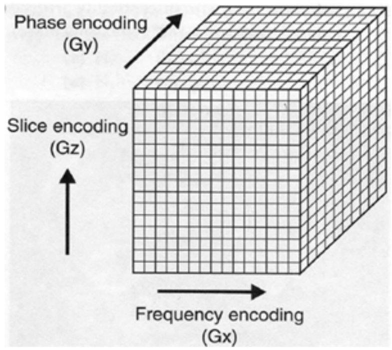
Disadvantages of GRE

- Decreased SNR per echo (however GRE can obtained more echoes to compensate this effect).
- Increased magnetic susceptibility artifacts
- T2* decay ➔ more sensitive to magnetic field inhomogeneities
- Chemical shift effects of the second kind
  - Dark band around organs with water fat interfaces, such as the kidneys, liver, spleen, etc.

3D GRE/ 3D FSE

- A phase-encoding step (N_Z) in the slice-select direction (z axis).
- Scan time (3D GRE) = (TR)(Ny)(NEX)(Nz)
- Scan time (3D FSE) = (TR)(Ny)(NEX)(Nz)/ETL (need high performance gradients)





THE END

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